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Physical Oceanographic Conditions on the Scotian Shelf and in the eastern Gulf of Maine (NAFO areas 4V,W,X) during 2012

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Abstract

A review of the 2012 physical oceanographic conditions on the Scotian Shelf and in the eastern Gulf of Maine and adjacent offshore areas indicates that above normal conditions prevailed. The climate index, a composite of 18 selected, normalized time series, averaged +2.8 standard deviations (SD) with 16 of the 18 variables more than 1.0 SD above normal making 2012 as the warmest year in the last 43 years. The anomalies did not show a strong spatial variation. Bottom temperatures were above normal with anomalies for NAFO areas 4Vn, 4Vs, 4W, 4X of +0.5°C (+1.2 SD), +1.2°C (+1.8 SD), +1.7°C (+2.3 SD), and +2.1°C (+3.0 SD) respectively. Compared to 2011, bottom temperatures increased in areas 4Vs, 4W and 4X by 0.4, 1.5 and 1.7°C. The exception was area 4Vn where temperature decreased by 0.2°C.

Introduction

This document describes air temperature, ice area and volume, and ocean temperature variability of Scotian Shelf and Gulf of Maine waters during 2012 (see Fig. 1 for the study area and Fig. 2 for area names of time series presented in document). The results are derived from data obtained at coastal and long-term monitoring stations, on annual ecosystem surveys and the Atlantic Zone Monitoring Program (AZMP) missions and from ships-of-opportunity and other research cruises. 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 (http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html). The products available include sections from the AZMP spring and fall surveys, time series of physical properties from fixed stations, climate indices such as coastal temperature series, frontal positions, and bottom temperatures from ecosystem surveys.

In order to detect interannual variability and long-term trends of the time series presented, 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 present the standardized anomaly (anomaly divided by the standard deviation). When possible, long-term monthly and annual means, and standard deviations (SD) are based on 1981-2010 averaging period.

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 (see inset, Fig. 1). 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 properties of shelf waters are modified by mixing with offshore waters from the continental slope. These offshore waters are generally of two 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).

Air Temperatures

Annual air temperature anomalies for six sites in the Scotian Shelf-Gulf of Maine region are shown in Fig. 3 and Table 1. In 2012, annual air temperature anomalies were positive at all sites and ranged from +1.3°C (Saint John) to +1.7°C (Sydney, Sable Island and Halifax). These values represent an increase from 2011 observations and all are approximately 2 standard deviations above the long-term mean; furthermore, the time series of annual anomalies indicates that all sites feature increasing temperatures over the long term with decadal scale variability superimposed. Over shorter periods, there are times when this is no trend or a decreasing trend in the temperature (Fig. 3). Linear trends from 1900 to present from Boston, Shearwater, Sydney and Sable Island correspond to changes of +1.8°C, +1.5°C, 1.1°C and 1.0°C/century respectively; the trends from Yarmouth and Saint John are smaller, at 0.7 and 0.4°C/century.

The anomalies for all 6 sites are displayed in Fig. 4 as a composite sum and illustrates three points. 1) In the 113 year time series shown, 2012 was the warmest year for the region as a whole. 2) For most years the anomalies have the same sign. Since 1900, 91 of the 113 years had 5 or more stations with the annual anomalies having the same signs; for 63 years, all 6 stations had anomalies with the same sign. This indicates that the spatial scale of the air temperature patterns is greater than the largest spacing among sites. In fact, plotting the correlation between annual anomalies against station separations yields an e-folding scale of 1800 km (Petrie et al. 2009). The e-folding scale (=1/k) is determined from a least squares fit of an exponential function 1*exp(-kx) to the correlations among the six time series; it represents the distance at which the correlation equals 1/e, where e is the base of natural logarithms. 3) The time scale of the dominant variability has been changing from longer periods for 1900-1954 to shorter periods for 1955-2010. For the earlier period, a lagged autocorrelation analysis gives an e-folding scale of 3 years; whereas, for the later period, the scale was 0.6 years, i.e. less than the sampling interval of the series. In this case, the e-folding scale is based on the autocorrelation of the average annual temperature anomaly for the 6 sites (Petrie et al., 2009).

Table 1. The 2012 annual mean air temperature anomaly in degrees and standardize anomaly (relative to the 1981-2010 climatology) and standard deviation of the monthly anomalies for Scotian Shelf and Gulf of Maine.

Site	Annual Anomaly 2012		Monthly SD 2012 (°C)	1981-2010 Climatology	
	Observed (°C)	Normalized		Mean (°C)	SD (°C)
Sydney	+1.7	+2.1	0.9	5.87	0.81
Sable I.	+1.7	+2.4	0.7	7.88	0.68
Shearwater (Halifax)	+1.7	+2.3	1.0	6.99	0.74
Yarmouth	+1.6	+2.5	0.9	7.16	0.62
Saint John	+1.3	+1.8	1.0	5.19	0.74
Boston	+1.4	+2.4	1.7	10.91	0.60

Sea Ice

The greater part of sea ice on the Scotian Shelf originates in the Gulf of St. Lawrence and is transported through Cabot Strait by northwesterly winds and ocean currents. Sydney Bight and the southern coast of Cape Breton are typically the only areas heavily affected by ice in the region and in 2012 it was present for only a short period, lasting about 1 week (Fig. 5). Regions of duration less than 1 week are not shown in the duration maps.

There has been essentially no ice on the Scotian Shelf from April 2009 (Fig. 6). The ice areas and volumes for the 2011-2012 season are compiled in Tables 2 and 3. Months with the heaviest ice coverage, January to April, featured below normal coverage and volumes. Overall, the January to April 2012 coverage and ice volume were the fourth lowest in the 51 year long record. Only 1969, 2010 and 2011 had lesser coverage and volume; the difference between these 3 years is within the uncertainty of the observations.

Table 2. Ice area statistics, Scotian Shelf

Month	2011-2012 Ice Year (km^2)	1981-2010 Mean (km^2)	Anomaly (km^2)	Normalized
Jan	1.5	1200	-1200	-0.5
Feb	432	11300	-10900	-1.1
Mar	752	15700	-15500	-1.1
Apr	<0.1	4600	-4600	-1.0

Table 3. Ice volume statistics, Scotian Shelf

Month	2011-2012 Ice Year (km^3)	1981-2000 Mean (km^3)	Anomaly (km^3)	Normalized
Jan	<0.01	0.2	-0.2	-0.7
Feb	0.08	2.8	-2.7	-1.0
Mar	0.16	6.9	-6.7	-1.0
Apr	<0.01	3.0	-3.0	-1.0

Remotely-Sensed Sea Surface Temperature

A 4 km resolution Pathfinder 5.2 (Casey et al., 2010) sea surface temperature database is kept at the Bedford Institue of Ooceanography. The Pathfinder dataset runs from November 1981 to December 2010; to provide data for 2011 and 2012, we used the Advanced Very High Resolution Radiometer (AVHRR) sea surface temperature data downloaded from the NOAA satellites by the remote sensing group in the Ocean Research & Monitoring Section (ORMS). Comparison of the Pathfinder and ORMS temperatures during the common time period led to a conversion equation SST(Pathfinder) = 0.989*SST(ORMS)-0.02 with an r^2=0.98. We adjusted the 2011-2012 NOAA observations to bring them in line with the longer Pathfinder series. Anomalies were based on 1981-2010 averages.

Annual anomalies were calculated from monthly averaged temperatures for 8 subareas in the Scotian Shelf-Gulf of Maine region (Fig. 7, Table 4). The annual anomalies during 2012 ranged from +1.7°C (+1.4 SD) over Western Bank to +2.5°C (+3.2 SD) in the Bay of Fundy. All eight areas had positive anomalies; all but one was greater than +1.5 SD. Over the lengths of the records all areas show increasing temperature trends, based on a linear least squares fit, corresponding to temperature changes from a lowest value 0.9°C (Lurcher Shoals) to a highest value of 2.0°C (Bay of Fundy). A similar trend in SST from AVHRR measurements was found in the Gulf of St. Lawrence (Galbraith et al., 2012). The large increase in the observed SST over this period has likely been enhanced by the cold period at the beginning of the AVHRR period and a rapid temperature increase from 2011 to 2012 (Fig. 3).

The overall coherent variability of the annual temperature anomalies in the eight regions suggested a principal component analysis might be revealing. The leading mode, PCA1, captured 83% of the variance and all loadings had similar amplitudes, meaning roughly equal contributions from each series; PCA2 accounted for an additional 8% of the variance with negative loadings in the eastern half of the region, changing to positive values roughly to the west of the central Scotian Shelf (Fig. 8).

Table 4. 2012 SST annual anomalies and long-term SST statistics including 1982-2012 temperature change based on linear trend.

Site	2012 SST Anomaly (^oC)	2012 SST Anomaly Normalized	1981-2010 Mean Annual SST (^oC)	1981-2010 SST Annual Anomaly Std. Dev. (^oC)	ΔT (^oC) 1982-2012
Cabot Strait	+1.7	+1.6	5.9	1.0	1.2
Eastern Scotian Shelf (ESS)	+1.9	+1.7	7.1	1.1	1.2
Central Scotian Shelf (CSS)	+2.3	+2.1	8.5	1.1	1.5
Western Bank	+1.7	+1.4	8.9	1.2	1.2
Western Scotian Shelf (WSS)	+2.5	+2.3	8.1	1.1	1.3
Lurcher Shoal	+2.4	+2.2	7.2	1.1	0.9
Bay of Fundy	+2.5	+3.2	7.2	0.8	2.0
Georges Bank	+2.0	+2.1	10.0	1.0	1.0

Coastal Temperatures and Salinities

Coastal sea surface temperatures have been collected at Halifax (Nova Scotia) and St. Andrews (New Brunswick) since the 1920s (Fig. 9). In 2012, the SST anomalies were +1.0^{o}C (+1.4 SD) for Halifax, an increase of 0.4^{o}C from 2011 and +1.8^{o}C (+3.2 SD) for St. Andrews, an increase of 0.9^{o}C from 2011.

Temperature and salinity measurements through the water column, 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, salinity and density anomaly time series are shown in Fig. 9(C-E). In 2012, the annual temperature anomaly was +1.9^{o}C (+3.5 SD) and the salinity anomaly was +0.2 (+1.1 SD). These represent changes of +0.9^{o}C and +0.6 from the 2011 values. The density anomaly is largely accounted for by the temperature anomaly and secondarily by the salinity anomaly.

Scotian Shelf and Gulf of Maine Temperatures from Long-term Stations

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 correspond 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. We present time series of annual mean and filtered (5 year running means) temperature anomalies at selected depths for five areas (Fig. 10). The Cabot Strait temperatures represent a mix of Labrador Sea Water and Slope Water (e.g., Gilbert et al., 2005) entering the Gulf of St. Lawrence along Laurentian Channel; the Misaine Bank series characterizes the colder near bottom temperatures on the eastern Scotian Shelf; the deep Emerald Basin anomalies represent the slope water intrusions onto the Shelf that are subsequently trapped in the deep inner basins (note the large anomaly "events" in Fig. 10C); the Lurcher Shoals observations define the ocean climate in SW Nova Scotia and the shallow waters entering the Gulf of Maine via the Nova Scotia Current; finally, the Georges Basin series indicates the slope waters entering the Gulf of Maine through the Northeast Channel. Annual anomalies are based on the averages of monthly values; however, observations may not be available for each month in each area. For Cabot Strait, Misaine Bank, Emerald Basin, Lurcher Shoals and Georges Basin, 2012 annual anomalies are based on observations from only 4, 4, 5, 2 and 5 months, respectively.

In 2012, the annual anomalies were +0.9^{o}C (+2.7 SD) for Cabot Strait 200-300 m (the warmest and 2nd saltiest year in 61 years; 2011 was the 3rd warmest year), +1.3^{o}C (+2.0 SD) for Misaine Bank 100 m (2nd warmest year), +0.7^{o}C (+0.9 SD) for Emerald Basin 250 m, +3.4^{o}C (+4.3 SD) for Lurcher Shoals 50 m (warmest year), and +0.5^{o}C (+0.9 SD) for Georges Basin 200 m (2010 was the warmest year and 2011 was the 3rd warmest year). These values correspond to changes of +0.4^{o}C, +0.5^{o}C, -0.2^{o}C, +2.1^{o}C and -0.3^{o}C, respectively over 2011 values. The 2010 and 2011 North Atlantic

Oscillation anomalies were well below normal and based on similar atmospheric forcing in the past, notably in the mid-1060s, cooler deep water temperatures might have been expected in this region for 2012 (Petrie, 2007).

Temperatures during the Summer Groundfish Surveys

The broadest spatial temperature 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, at the outer Scotian Shelf, and at the Northeast Channel into the Gulf of Maine towards the Bay of Fundy. A total of 219 CTD stations were sampled during the 2012 survey and an additional 181 bottom temperature stations were obtained using Vemco Minilog temperature recorders as part of the ITQ (Individual Transferable Quota) fleet survey. The groundfish survey takes one 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 40 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 at the standard depths (e.g. 0 m, 10m, 20m, …) and for near the bottom.

Bottom temperatures ranged from an average of 4.5°C in NAFO area 4Vs and 4Vn to 9.4°C in 4X during 2012, illustrating the difference in the environmental conditions across the Shelf (Fig. 11). The anomalies were positive for these NAFO areas in 2012: +0.5°C (+1.2 SD) in 4Vn; +1.2°C (+1.8 SD) in 4Vs; +1.7°C (+2.3 SD) in 4W; and +2.1°C (+3.0 SD) in 4X (Fig. 12 A-D). Compared to 2011, bottom temperatures increased in areas 4Vs, 4W and 4X by 0.4, 1.5 and 1.7°C; temperature decreased by 0.2°C in area 4Vn.

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. 12E). 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 1981-2010 data in Fig. 12E) 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 from 1998 until 2009 (Fig. 12E). In 2012, the observed volume of 2900 km^3 was 2.3 SD less than the 1981-2010 mean value of 5500 km^3 and the smallest volume in the 43 years of surveys.

Density Stratification

Stratification of the near surface layer influences physical and biological processes in the ocean such as vertical mixing, the ocean's response to wind forcing, the timing of the spring bloom, vertical nutrient fluxes and plankton distribution. 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. 2. The long-term monthly mean density gradients for 1981-2010 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 occurred when stratification was strong. However, initial results, using normalized monthly anomalies, 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. 2, 13). 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 period from about 1950 to 1990 which featured generally below average stratification in contrast to the past 20 years which is characterized by above normal values. Stratification on the Scotian

Shelf in 2012 strengthened significantly compared to 2011; obtaining a value near that seen in 2010 and the fourth strongest stratification of the series. Since 1950, there has been an increase in stratification on the Scotian Shelf, resulting in a change in the 0-50 m density difference of 0.36 kg m^{-3} over 50 years. The density difference due to the decrease in surface salinity accounted for 48% of the change in stratification. Changes in density to surface warming, changes in temperature and salinity at 50 m accounted for 20%, 16% and 16%, respectively, of the stratification change.

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, 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. The PGR rates for Yarmouth (-10.3 cm/century), Halifax (-14.7 cm/century) and North Sydney (-16.8 cm/century) have been obtained from NRCan's gridded GPS-based vertical velocities (Philip MacAulay, pers. comm., 2012; Craymer et al., 2011).

Relative sea level at Halifax (1920-2012) is plotted as monthly means and as a filtered series using a 5-year running-mean filter (Fig. 14). The linear trend of the monthly mean data has a positive slope of 32.9 cm/century, slightly lower than the value of 36.7 cm/century (1897-1980) given by Barnett (1984). In 2012, relative sea level at Halifax decreased from the 2011 level although sea level rise appears to have increased rapidly in 2009/2010. An interesting feature of the data is the long-term variation that has occurred since the 1920s. In Fig. 14 we show the differences of the annual sea level from the 1981-2010 long-term trend for Yarmouth, Halifax and North Sydney. .It is apparent that from the 1920s to the early 1970s, the trend at Halifax was greater than the trend for the 1981-2010 period. The residual sea level data for the common period 1970-2012 shows that the variability has a large spatial structure given the coherence between these sites. Several potential causes of this decadal scale variability have been examined; however, we still do not understand the cause of these changes. Further south, near Delaware, USA, variations in the wind stress in the subtropical gyre appears to be responsible for the low frequency variation in sea level (Hong et al., 2000)

Summary

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 and 2010-2012 were warmer than normal (Fig. 15). The period 1979-1986 also tends to be warmer than normal. In this figure, annual anomalies based on the 1981-2010 means have been normalized by dividing by the 1981-2010 standard deviations for each variable. The results are displayed as the number of standard deviations above (red) and below (blue) normal. In 2012, all 22 series shown had positive anomalies; only 2 variables were less than 1 SD above their normal values and were in the deep basin waters. Of the 20 remaining series, 14 were more than 2 SD above normal and 4 of these were more than 4 SD above normal. In 2012, the average (median) normalized anomaly was 2.7 (2.4), the highest in the 43 year series. The standard deviation of the normalized anomalies was 1.2. These statistics indicate that 2012 was an exceptionally warm year with a fairly uniform distribution of anomalies throughout the region.

Eighteen selected variables of the mosaic plot are summarized as a stacked bar plot in Fig. 16. 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, 4Vs, 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 anomalies did not show a strong spatial distribution in 2012. The leading mode of a principal component analysis of the 18 series captured 50% of the variance with all loadings having the same sign. The loadings of 17 of the 18 variables were strong (0.16 to 0.29) with weak contributions only from the Emerald Basin 250 m (0.05) series.

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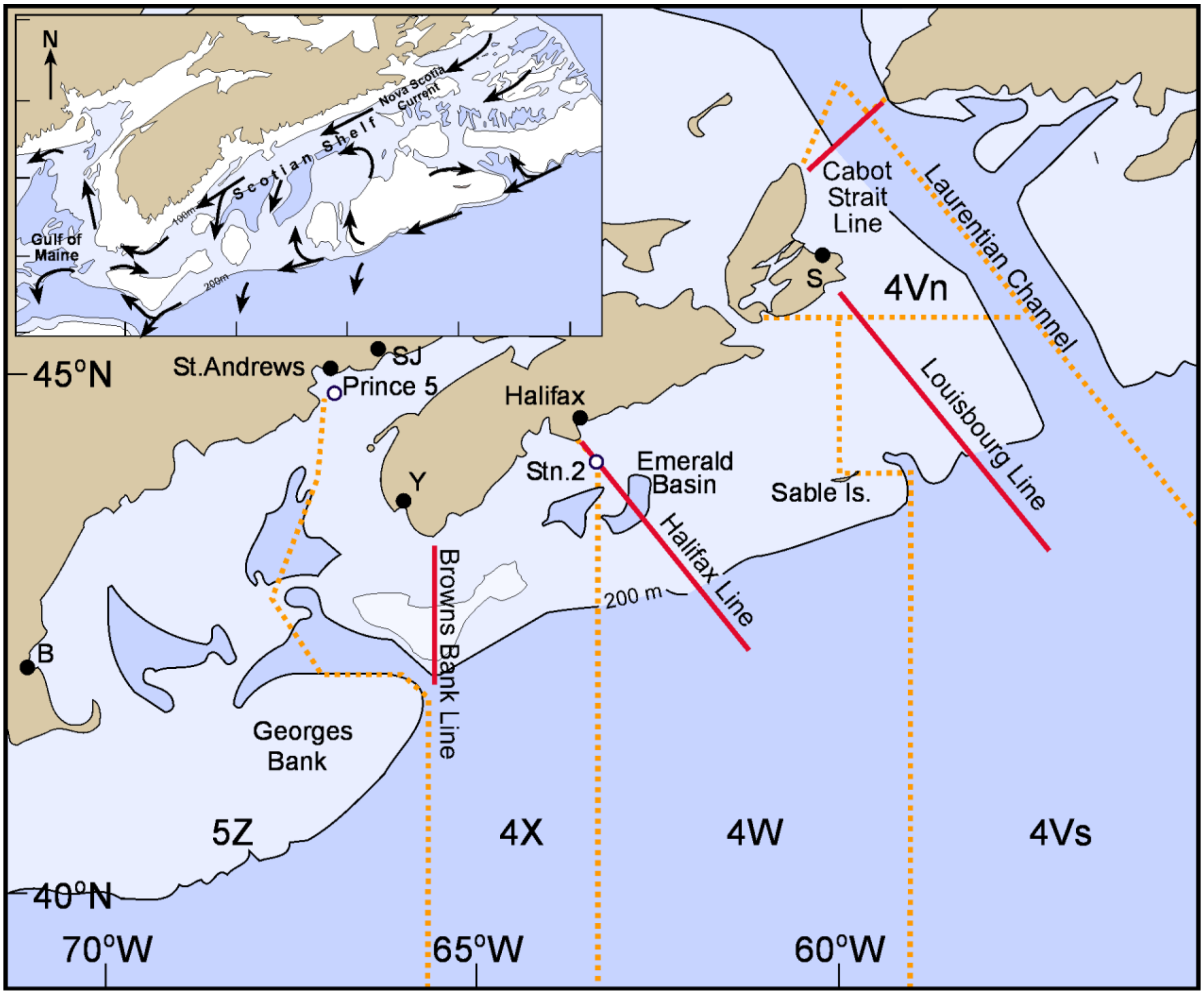
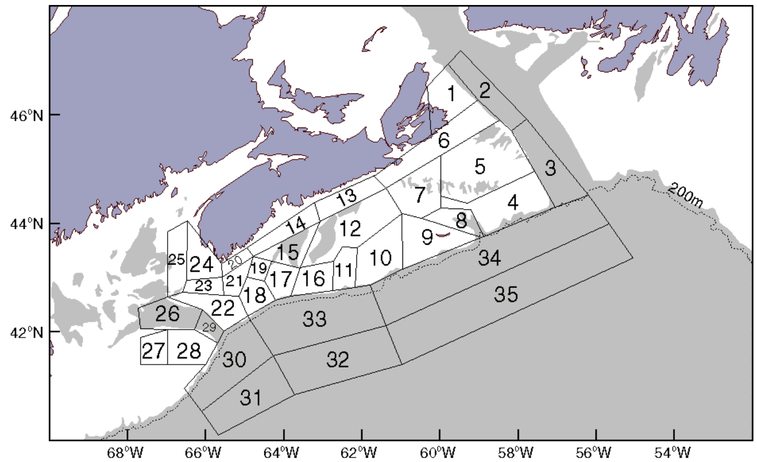


Fig. 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the NAFO Subareas. Inset depicts major circulation features. Air temperature stations at Sydney (S), Yarmouth (Y), Saint John (SJ), and Boston (B) are designated by a letter.



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

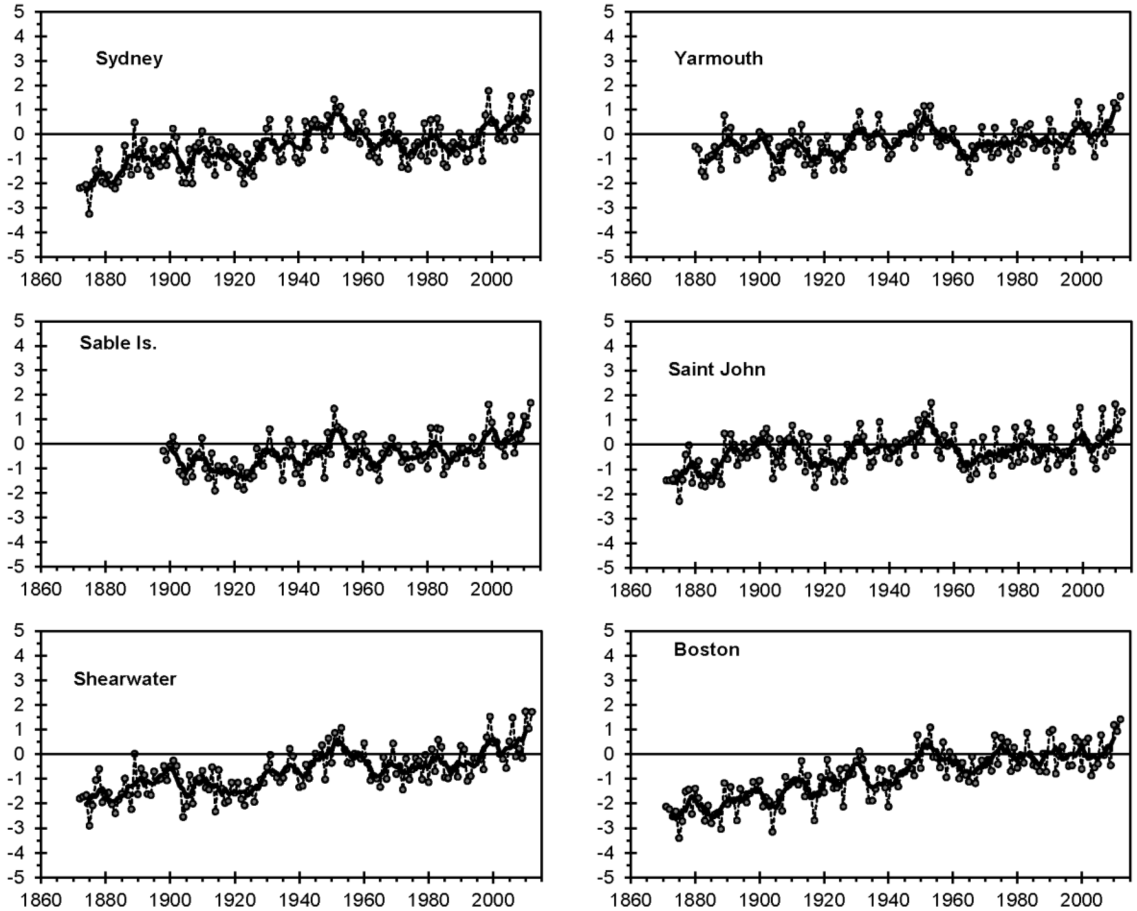


Fig. 3. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites in Scotian Shelf-Gulf of Maine region.

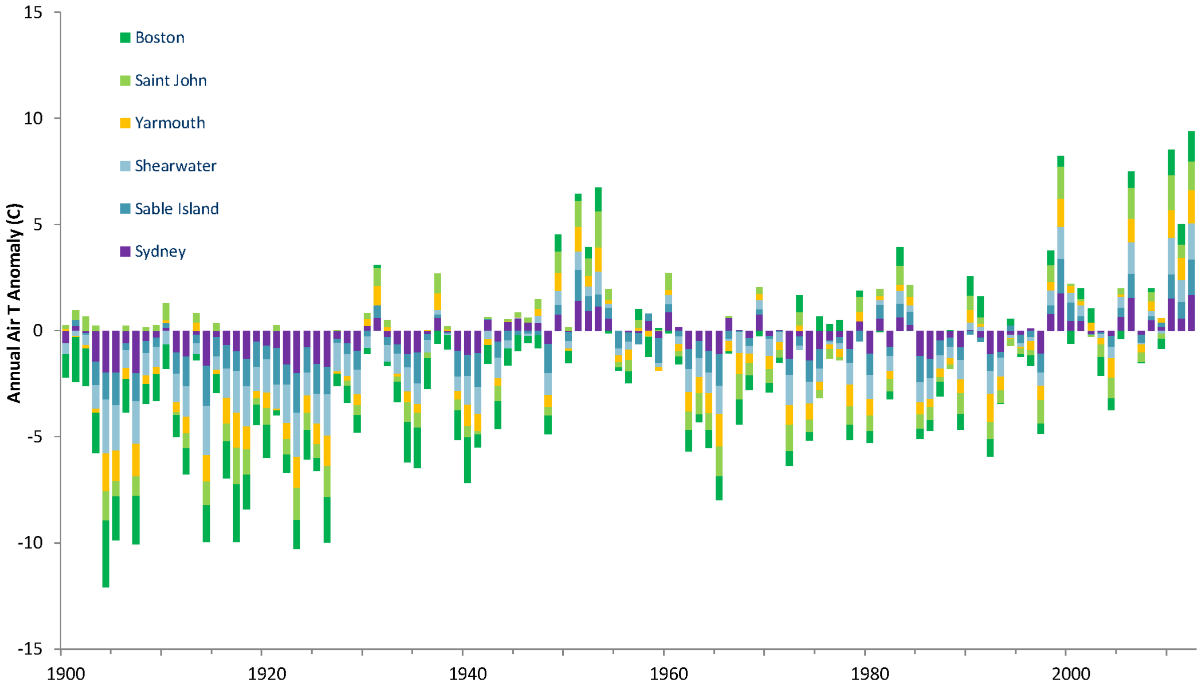


Fig. 4. The contributions of each of the annual temperature anomalies for 6 Scotian Shelf-Gulf of Maine sites are shown as a stacked bar chart.

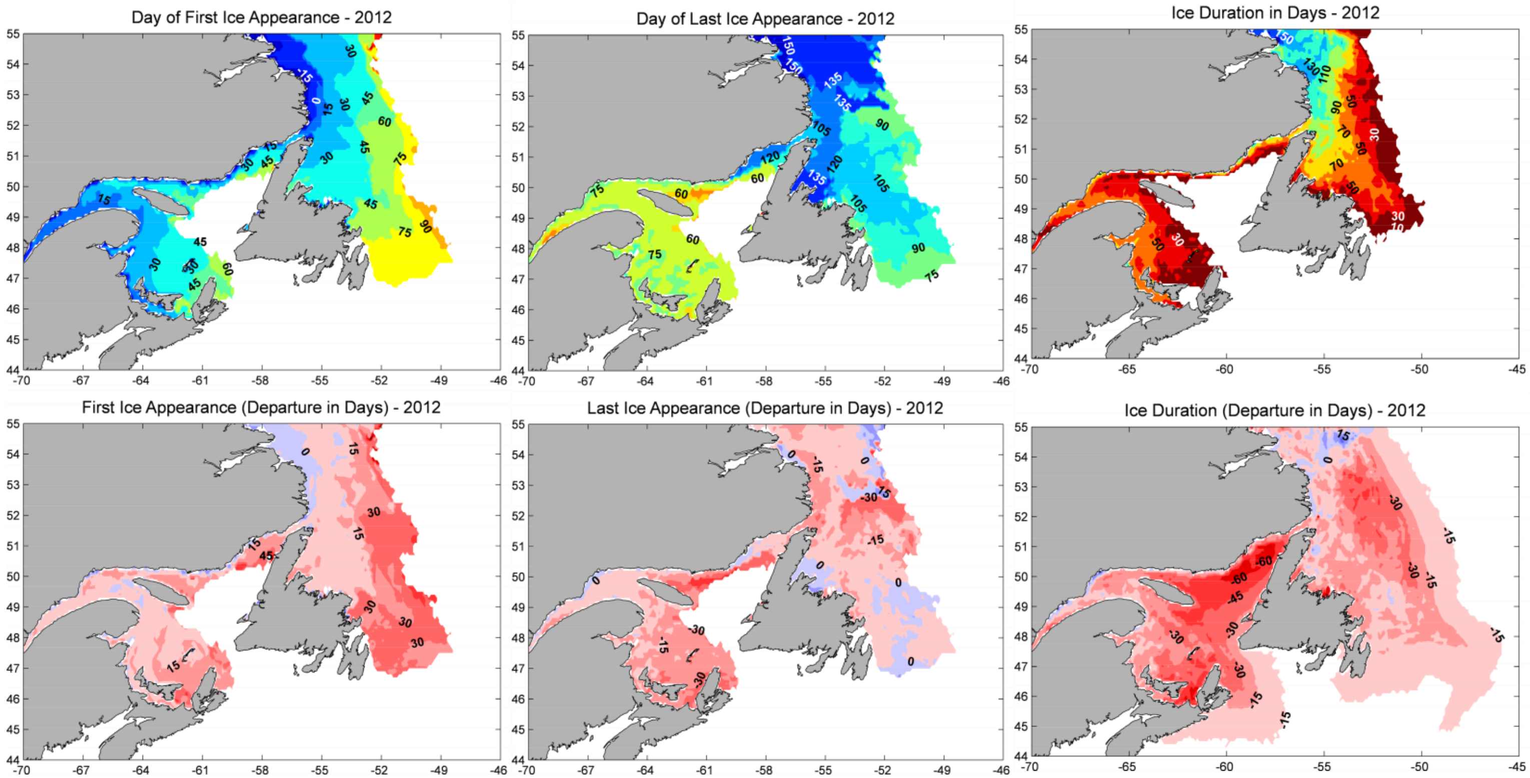


Fig. 5. The time when ice first appeared during 2012 in days from the beginning of the year (left, top panel) and its anomaly from the 1981-2010 mean in days (left, bottom panel). Negative (positive) anomalies indicate earlier (later) than normal appearance. The time when ice was last seen in 2012 in days from the beginning of the year (centre, top panel) and its anomaly from the 1981-2010 mean in days (centre, bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance. The duration of ice in days (right, top panel) during 2012 and the anomalies from the 1981-2010 mean in days (right, bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

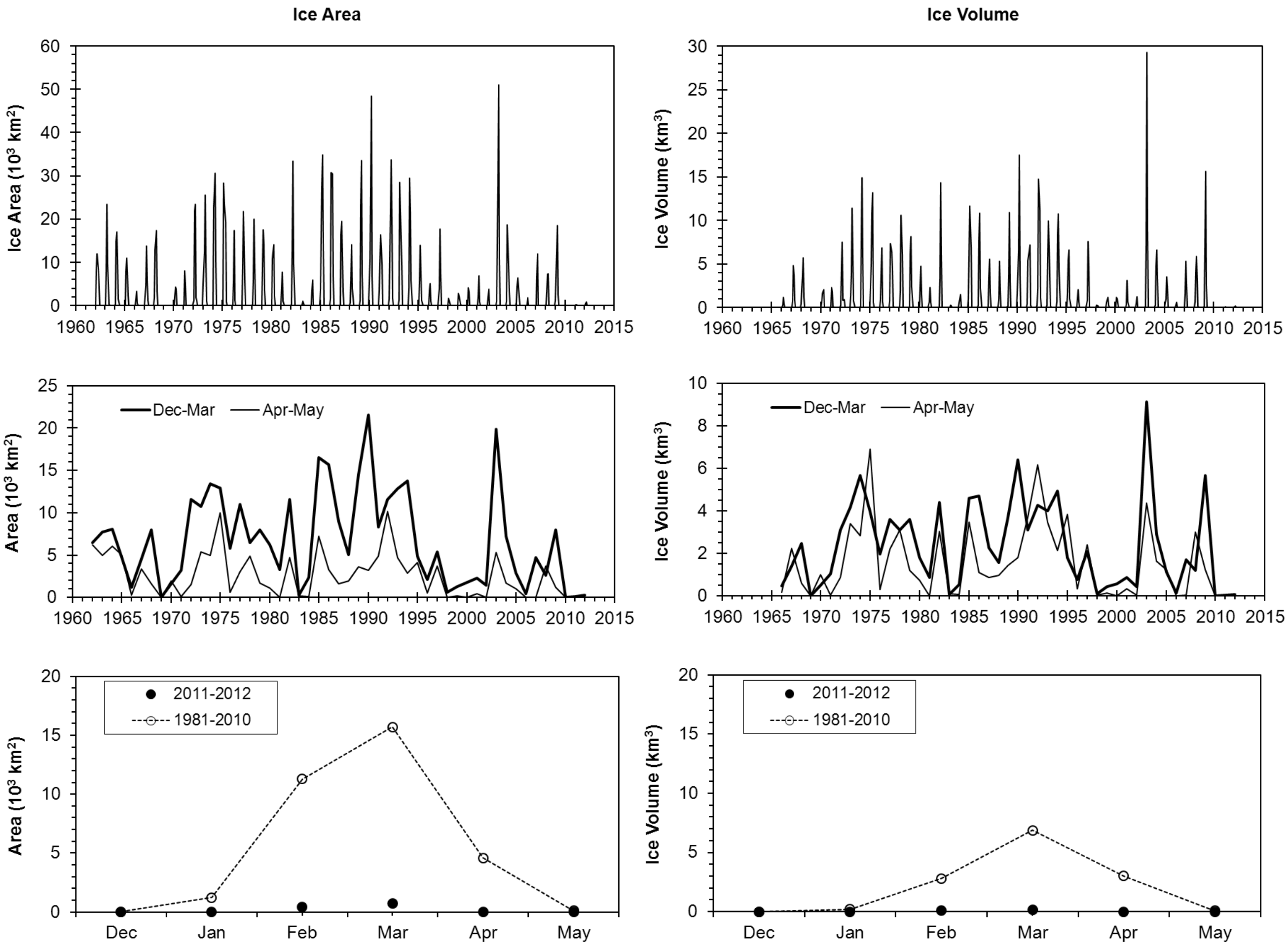


Fig. 6. Time series of the monthly mean ice area and volume for the Scotian Shelf (top panels), the average ice area during the usual periods of advancement (January-March) and retreat (April-May) (middle panels) and the comparison of the monthly areas and volumes to the 1981-2010 means (bottom panels)

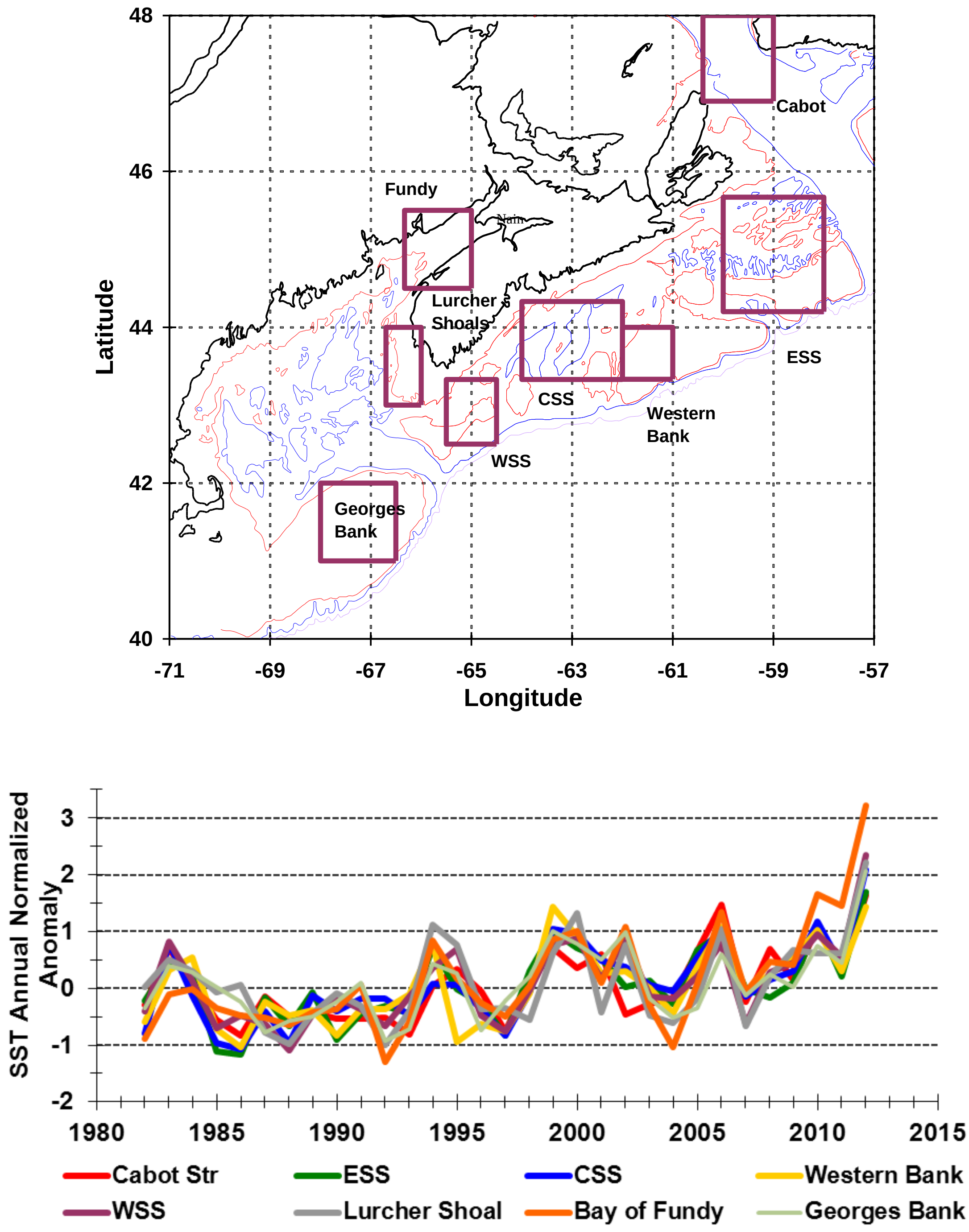


Fig. 7 Scotian Shelf-Gulf of Maine areas used for extraction of sea-surface temperature (upper panel). The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means (lower panel).

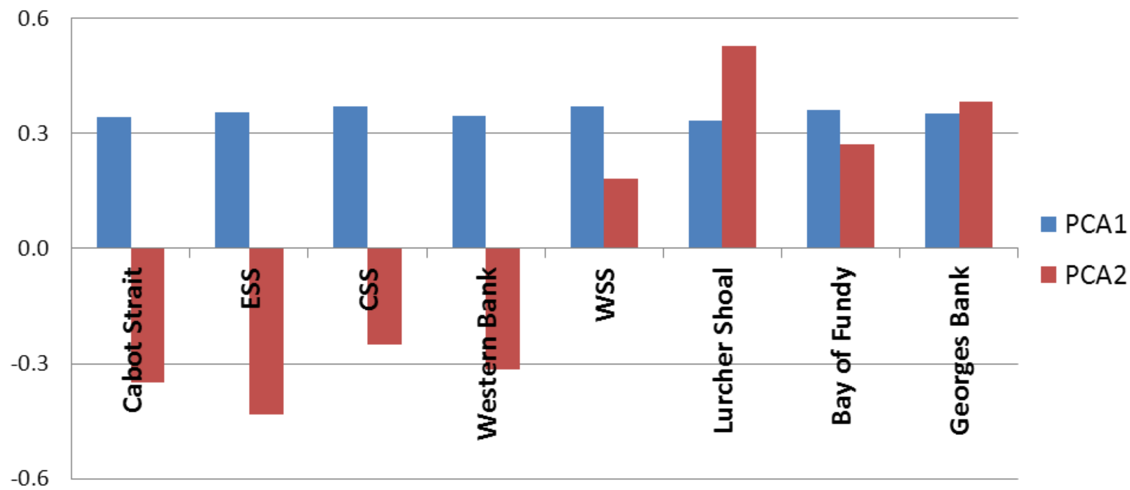


Fig. 8. PCA 1 (83% of variance) and PCA2 (8%) loadings from a principal components analysis of the annual mean temperature anomalies (Fig. 7, lower panel) for the eight Scotian Shelf and Gulf of Maine regions (Fig. 7, upper panel).

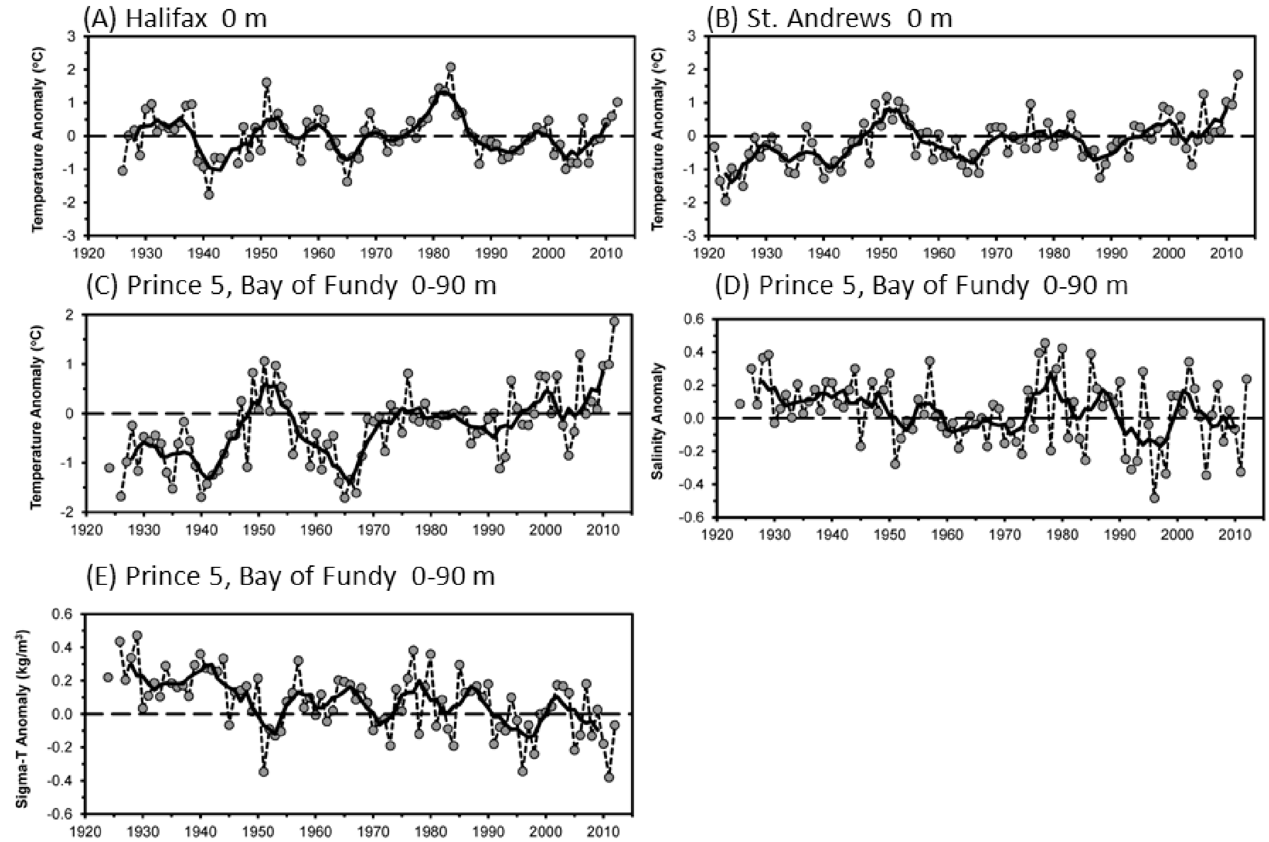


Fig. 9. The annual surface temperature anomalies (dotted line with circles) and their 5-year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews; annual depth-averaged (0-90 m) (C) temperature, (D) salinity and (E) density anomalies for the Prince 5 monitoring station at the mouth of the Bay of Fundy.

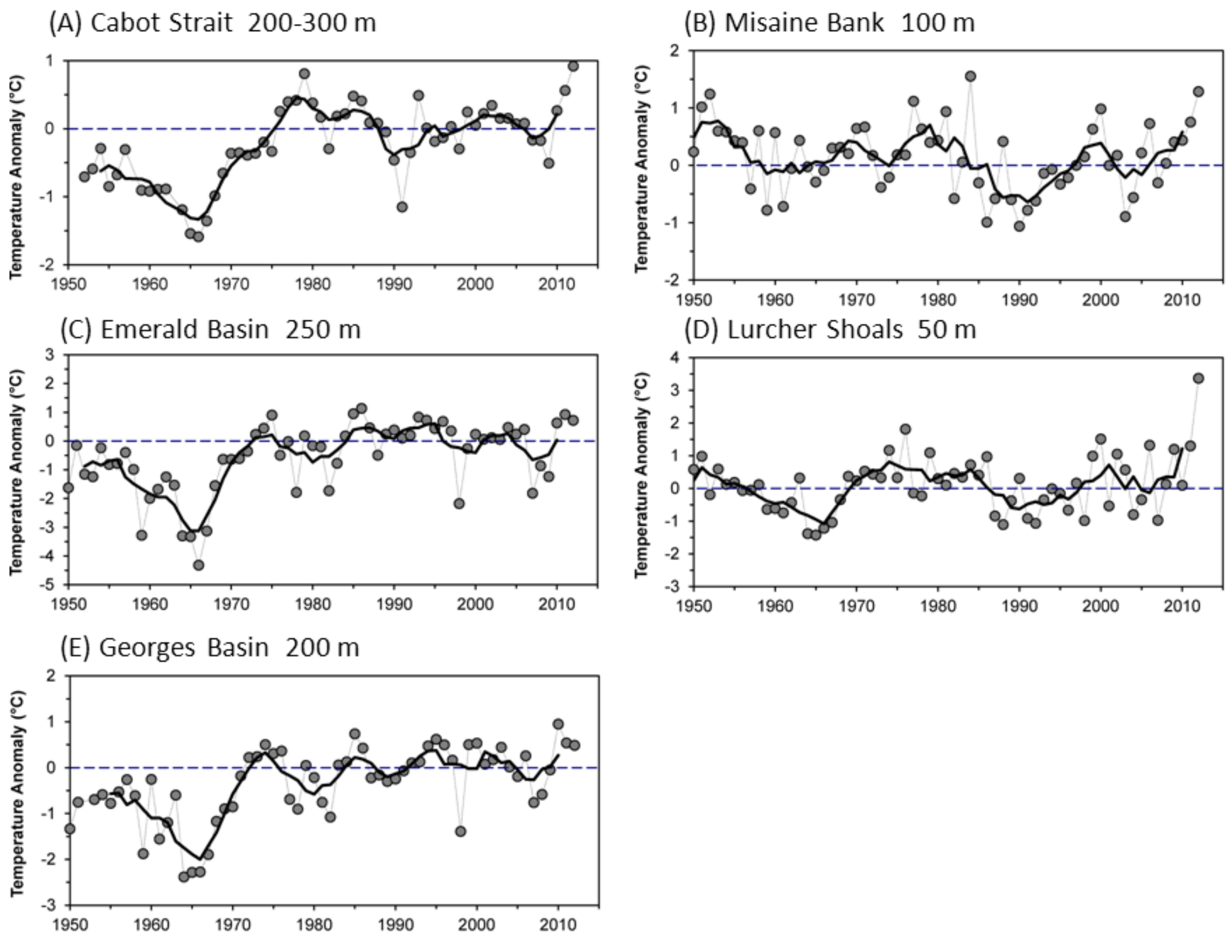


Fig. 10. The annual mean temperature anomaly time series (dotted line with circles) and the 5 year running mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at (A) Cabot Strait 200-300 m; (B) Misaine Bank 100 m; (C) Emerald Basin 250 m; (D) Lurcher Shoals 50 m; and Georges Basin (200 m) (see Fig. 2).

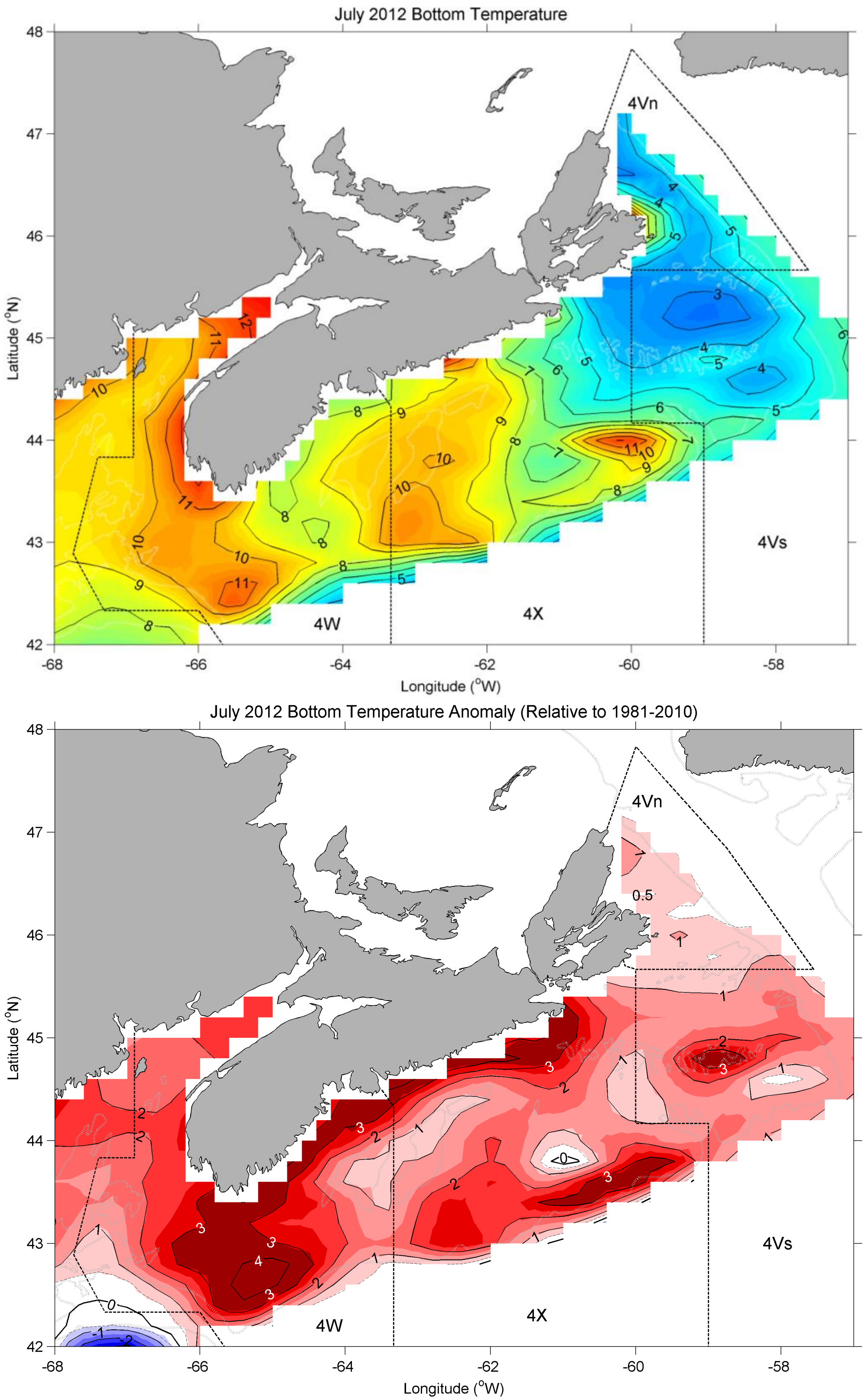


Fig. 11. July bottom temperature (upper panel) and anomaly (lower panel) maps for 2012. NAFO areas 4Vn, 4Vs, 4X and 4W are shown.

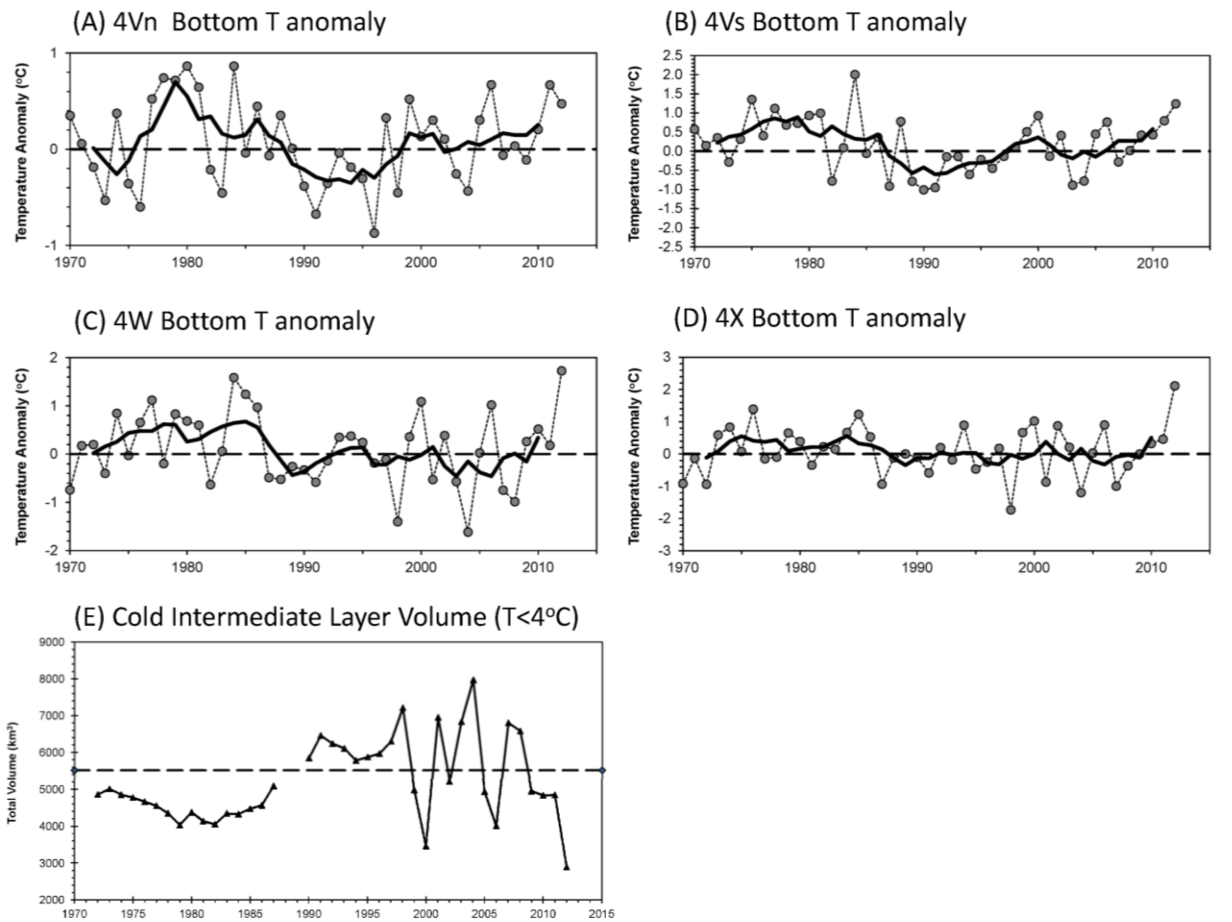


Fig. 12. Time series of July bottom temperature anomalies (dashed lines with circles) and 5 year running mean filtered series (heavy line) for areas (A) 4Vn, (B) 4Vs, (C) 4W and (D) 4X. (E) Time series of the Cold Intermediate Layer (CIL, defined as waters with T<4°C) volume on the Scotian Shelf based on the July ecosystem survey. The dashed horizontal line is the long-term mean.

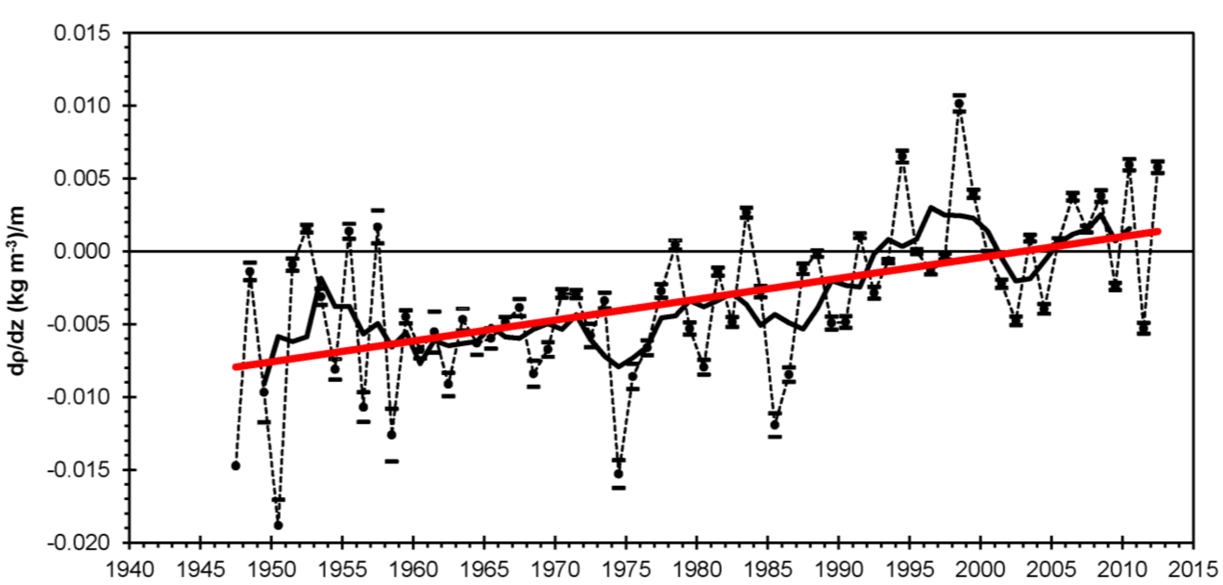
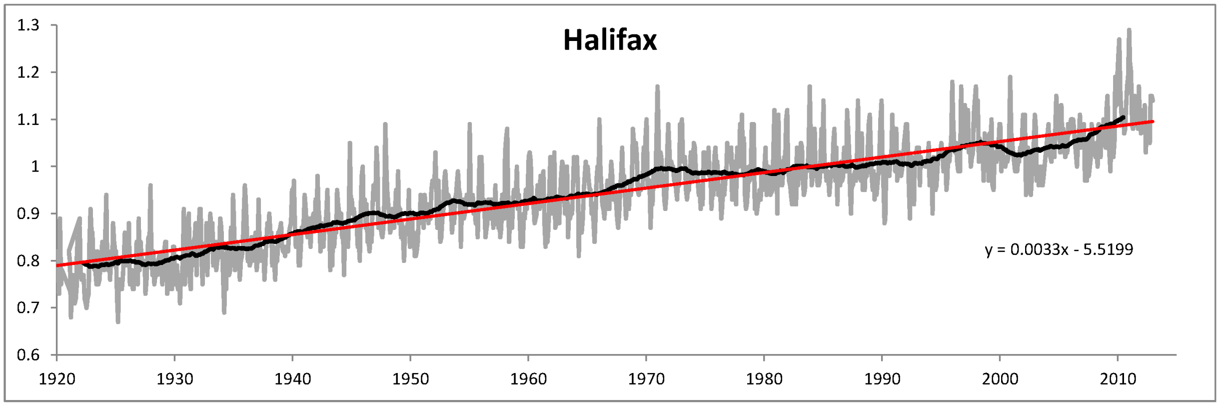


Fig. 13. The mean annual anomaly (dashed line with circles) and 5-yr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive, see Fig. 2). Standard error estimates for each annual anomaly value are also shown. The linear trend (red line) shows a change in the 0-50 m density difference of 0.36 kg m^{-3} over 50 years.



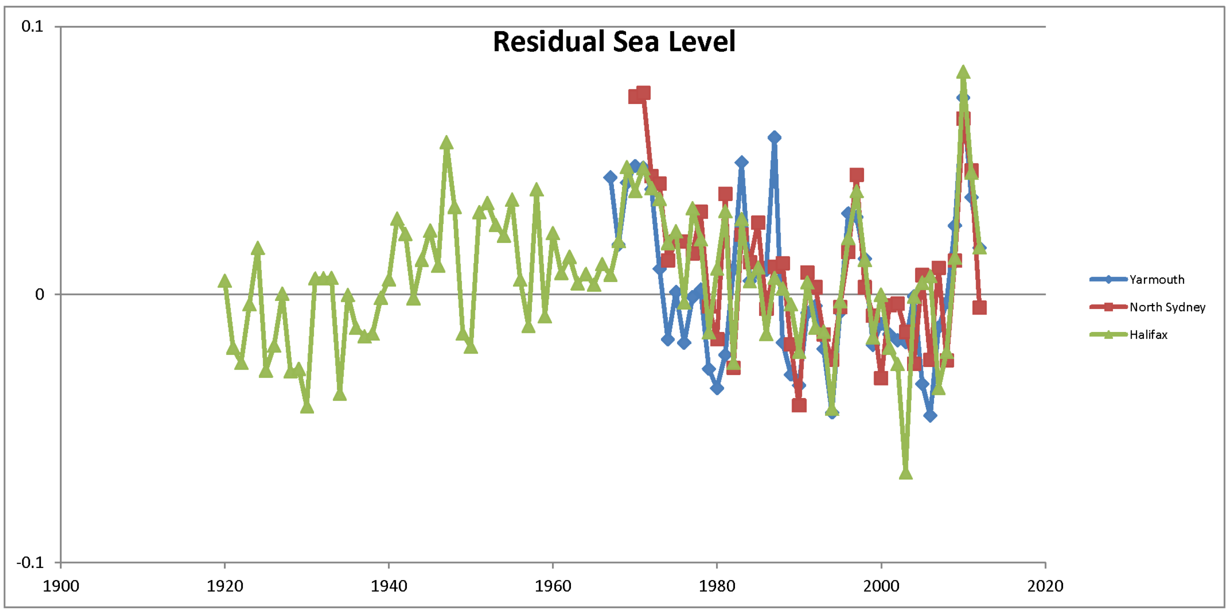


Fig. 14. The time series of the monthly means (gray) and a 5 year running mean (black) of the relative sea level elevations at Halifax, along with the linear trend (red) over 1920-2011 (upper panel). Residual relative sea level (monthly observed values – (1981-2010) linear trend, averaged to annual estimates) for Halifax (green), Yarmouth (blue) and North Sydney (red).

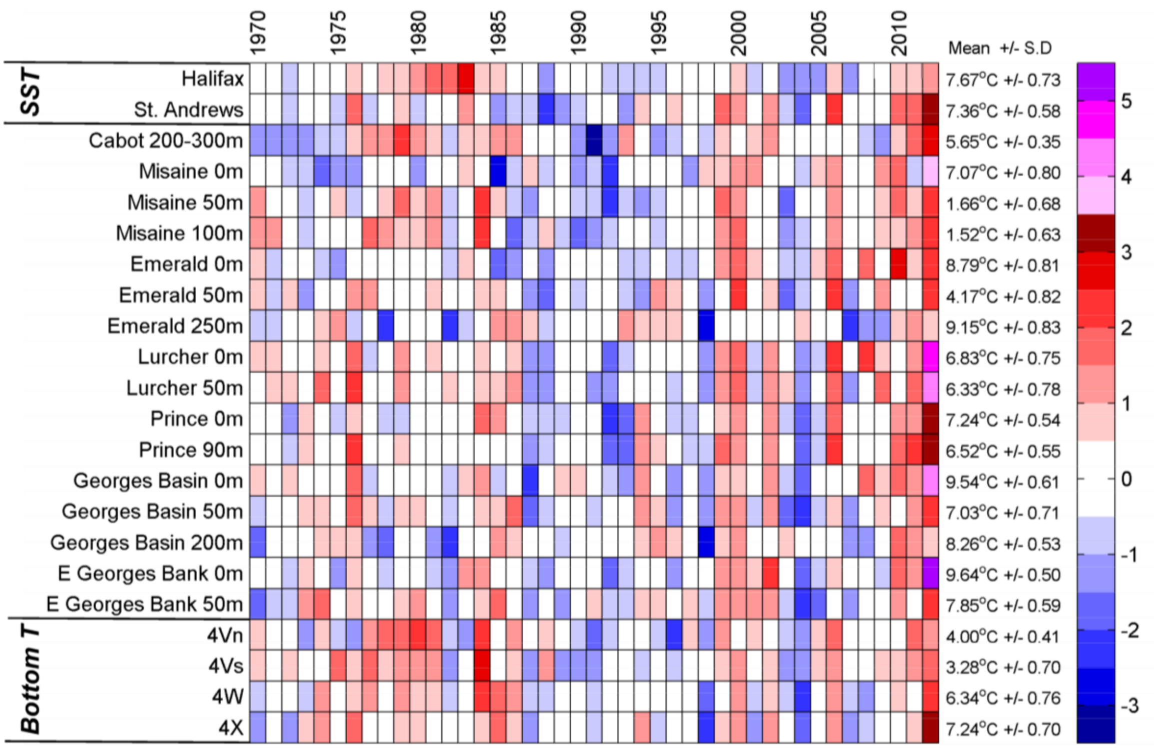


Fig. 15. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf-Gulf of Maine region. These normalized, annual anomalies are based on the 1981-2010 means, divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal. (For this year, the colour scale had to be increased above +3.5 SD and shaded in purple.)

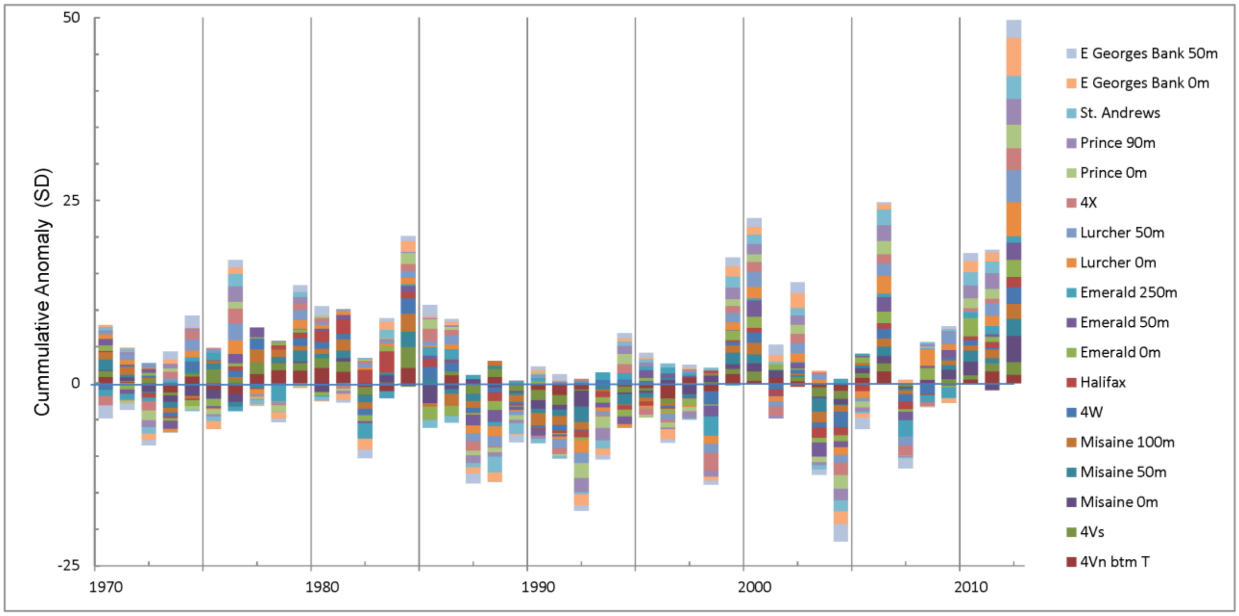


Fig. 16. The contributions of each of the normalized anomalies are shown as a stacked bar chart.