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Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2011

Conditions météorologiques, de la glace de mer et océanographiques physiques sur le plateau néo-écossais et dans le golfe du Maine en 2011

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ABSTRACT

In 2011, the North Atlantic Oscillation (NAO) index remained below the 1981-2010 mean (-10.2 mb, -1.2 SD [standard deviation]). In 2010, the NAO index was at its lowest value in the entire record analyzed, -25.1 mb, 2.9 SD below normal. Mean annual air temperatures were from 0.6 ^{o}C (Sydney, Nova Scotia, and Saint John, New Brunswick) to 1.1^{o}C (Yarmouth, Nova Scotia), approximately 1 to 2 SD, above normal in 2011 but lower than those found in 2010. There has been essentially no ice on the Scotian Shelf from December 2009 until the end of the season in May 2011. The ice volume during 2011 was the third lowest since 1969 and not significantly different from the lowest volume of the 43 year record. Positive sea surface temperature (SST) anomalies prevailed throughout the region during 2011, with representative values of about +0.1 to 0.8^{o}C (+0.1 to +0.7 SD). Long-term coastal monitoring sites at St. Andrews (New Brunswick) and Halifax (Nova Scotia) recorded positive annual SST anomalies, 0.9^{o}C (+1.6 SD) and 0.6^{o}C (+0.8 SD) in 2011 and were similar to those observed in 2010. At selected sites across the region, annual water temperature anomalies were positive in 2011: +0.6^{o}C (+1.6 SD) for Cabot Strait 200-300 m (the 2nd warmest in 60 years), +0.8^{o}C (+1.2 SD) for Misaine Bank 100 m, +0.9^{o}C (+1.1 SD) for Emerald Basin 250 m, +1.3^{o}C (+1.7 SD) for Lurcher Shoals 50 m, and +0.8^{o}C (+1.5 SD) for Georges Basin 200 m (the 2nd highest anomaly with last year being the highest). Bottom temperature anomalies in Northwest Atlantic Fisheries Organization areas 4VWX were all positive in 2011 and ranged from +0.2^{o}C (+0.3 SD) in 4W to +0.8^{o}C in 4Vn (+1.6 SD). Average stratification on the Scotian Shelf weakened significantly compared to 2010, reaching a low value not seen since 2002. This decrease in stratification from 2010 to 2011 was due mainly to a decrease in surface temperature. Surface salinity was also the lowest in more than a decade. Since 1950, the stratification has slowly been increasing on the Scotian Shelf due mainly to a freshening of the surface waters. A composite index consisting of ocean temperatures from surface to bottom across the region indicated that 2011 was the 6th warmest of 42 years, with an averaged normalized anomaly of +0.9 SD relative to the 1981-2010 period.

RÉSUMÉ

En 2011, l'indice d'oscillation nord-atlantique est demeuré en dessous de la moyenne de 1981-2010 (- 10,2 hPa, - 1,2 ÉT [écart-type]). En 2010, l'indice d'oscillation nord-atlantique se situait à la valeur la plus faible du jeu de données analysé (- 25,1 hPa, 2,9 ÉT sous la normale). Les températures moyennes annuelles de l’air allaient de 0,6°C (Sydney**,** Nouvelle-Écosse, et Saint John, Nouveau-Brunswick) à 1,1 °C (Yarmouth, Nouvelle-Écosse), approximativement 1 à 2 ÉT, au-dessus de la normale en 2011, mais elles étaient inférieures à celles relevées en 2010. Il n'y a pratiquement pas eu de glace sur le plateau néo-écossais à partir du mois de décembre 2009, jusqu'à la fin de la saison en mai 2011. En 2011, le volume de glace était le troisième moins élevé depuis 1969 et n’était pas significativement différent du volume le plus faible enregistré en 43 ans. Des anomalies de température positive de la surface de la mer (SST) ont prévalu dans toute la région en 2011, avec des valeurs représentatives d'environ + 0,1 à 0,8 °C (+ 0,1 à 0,7 ÉT). Aux sites de surveillance côtière à long terme de St. Andrews (Nouveau-Brunswick) et de Halifax (Nouvelle-Écosse), de faibles anomalies de SST annuelle de 0,9 °C (+ 1,6 ÉT) et de 0,6 °C (+ 0,8 ÉT) en 2011 et étaient semblables à celles observées en 2010. À des endroits choisis à l’échelle de la région, les anomalies annuelles de température étaient positives en 2011 : + 0,6 °C (+ 1,6 ÉT) entre 200 et 300 m dans le détroit de Cabot (le 2^e^ plus chaud en 60 ans), + 0,8 °C (+ 1,2 ÉT) dans la strate de 100 m du banc de Misaine, + 0,9 °C (+ 1,1 ÉT) dans la strate de 250 m du bassin Émeraude 250 m, + 1,3 °C (+ 1,7 ÉT) dans la strate de 50 m du haut-fond Lurcher et + 0,8 °C (+ 1,5 ÉT) dans la strate de 200 m du bassin Georges, (la deuxième anomalie la plus élevée, celle de l'année dernière étant la plus élevée). Les anomalies de température au fond dans les divisions 4VWX de l’Organisation des pêches de l’Atlantique Nord-Ouest étaient toutes positives en 2011 et allaient de + 0,2 °C (+ 0,3 ÉT) dans la division 4W à + 0,8 °C dans la zone 4Vn (+ 1,6 ÉT). La stratification moyenne sur le plateau néo-écossais a baissé de manière significative par rapport à 2010, atteignant une faible valeur qui n'a pas été enregistrée depuis 2002. Cette diminution de la stratification de 2010 à 2011 s'explique principalement par la baisse de la température de la surface. La salinité de surface était à son niveau le plus bas depuis plus de dix ans. Depuis 1950, la stratification a lentement augmenté sur le plateau néo-écossais principalement en raison d'une dessalure des eaux superficielles. Un indice composite composé des températures de la mer de la surface au fond à l’échelle de la région révèle que 2011 était la 6^e^ année la plus chaude en 42 ans, avec une anomalie normalisée de + 0,9 ÉT par rapport à la période allant de 1981-2010.

INTRODUCTION

This research document discusses air temperature trends, winds, ice cover, sea surface temperatures (SST) and physical oceanographic variability during 2011 on the Scotian Shelf and the Gulf of Maine (Fig. 1). It complements similar reviews of the conditions in the Gulf of St. Lawrence and the Newfoundland-Labrador regions for the Atlantic Zone Monitoring Program (AZMP; see Galbraith et al., 2012b; Colbourne et al., 2012). Environmental conditions are compared with the long-term monthly and annual means. These comparisons are often expressed as anomalies, which are the deviations from the long-term means, or as standardized anomalies, i.e. the anomaly divided by the standard deviation (SD). If the data permit, the long-term means and standard deviations are calculated for the 30-year base period, 1981-2010. The use of standardized anomalies and the same base period allow direct comparison of anomalies among sites and variables. Note that last year's report (Hebert et al., 2011) marked the change from the 1971-2000 (Petrie et al., 2009a, 2009b) to the 1981-2010 reference period.

Temperature and salinity conditions on the Scotian Shelf, in the 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 (Fig. 1). This 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 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, along- and across-shelf gradients, and vary with depth (Petrie et al., 1996).

METEOROLOGICAL OBSERVATIONS

NORTH ATLANTIC OSCILLATION (NAO) INDEX

The NAO index used here is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland (Rogers, 1984), and is a measure of the strength of the winter westerly winds over the northern North Atlantic. It represents the dominant, large scale meteorological forcing over the North Atlantic Ocean. Specifically, the index was calculated using observed monthly sea level pressures at Ponta Delgada (up to 1997, 2009-2011), Santa Maria (1998-2005), and Lajes (2006-2008) in the Azores, and at Akureyri in Iceland. The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1981-2010 mean.

A high NAO index corresponds to a deepening of the Icelandic Low and a strengthening of the Azores High. Strong northwest winds, cold air and sea temperatures, and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index (Colbourne et al., 1994; Drinkwater, 1996). The opposite response occurs during years with a negative NAO index.

The NAO has been shown to strongly affect bottom temperature distributions throughout the region from the Labrador Shelf to the Gulf of Maine (Petrie, 2007). The response is bimodal, the product of direct and advective effects, with positive (negative) NAO generally corresponding to colder (warmer) than normal bottom temperatures over the Labrador-Newfoundland Shelf, the Gulf of St. Lawrence, and the eastern Scotian Shelf, and warmer (colder) than normal conditions on the central and western Scotian Shelf and in the Gulf of Maine.

In 2011, the winter NAO index remained low; 10.2 mb (1.2 SD) below the 1981-2010 mean (Fig. 2, upper panel). The lower panels of Fig. 2 show the sea level pressure conditions during the winter of 2011 compared to the 1981-2010 mean. The Icelandic low was near its typical value while the Azores high as slightly weaker. The warmer air temperatures experienced in the Maritimes region are likely related to this NAO sea level pressure distribution.

AIR TEMPERATURES

Monthly surface air temperature anomalies relative to the 1981-2010 means for the North Atlantic Region are available from the US National Oceanic and Atmospheric Administration (NOAA, 2011) interactive website at http://www.cdc.noaa.gov/cgi-bin/data/getpage.pl. The annual anomalies are above normal by up to 0.75°C over the Scotian Shelf and by up to 1.25°C in the Gulf of Maine in 2011 (Fig. 3). The positive annual anomaly of these regions appears to be due to slightly warmer winter and fall periods (Fig. 4).

Monthly air temperature anomalies for 2010 and 2011 relative to their 1981-2010 means at six sites in the Scotian Shelf-Gulf of Maine region are shown in Fig. 5. The anomalies are presented in two ways: the heights of the bars represent the anomalies in °C; the colours of the bars represent the number of standard deviations the anomalies differ from their long-term means. Data for the Canadian sites were from the Environment Canada website http://climate.weatheroffice.gc.ca/prods_servs/cdn_climate_summary_e.html and from the *Monthly Climatic Data for the World* (NOAA, 2011) for Boston. The observed and normalized annual anomalies for these stations are listed in Table 1. In 2011, the annual anomalies were positive at all sites, ranging from +0.6 to +1.1°C, approximately 1-2 standard deviations above normal at all sites but lower than found in 2010. These anomalies are all smaller than the within year monthly SD (Table 1). The time series of annual anomalies indicates that all sites feature increasing temperatures over the long-term with decadal scale variability superimposed. For shorter periods, this can lead to no trend or decreasing temperatures (Fig. 6). Linear trends from 1900 to present for Sydney, Sable Island, Shearwater, Yarmouth, Saint John, and Boston correspond to changes of +1.0°C, +1.0°C, +1.5°C, +0.6°C, +0.3°C, and +1.8°C per century, respectively (Fig. 6).

Table 1. Air temperature anomaly statistics (Standard Deviation (SD)).

Site	Annual Anomaly (°C)		SD of Monthly Anomalies(°C)	1981-2010 Annual	
	Observed	Normalized		Mean (°C)	SD (°C)
Sydney	+0.6	+0.7	1.2	5.87	0.81
Sable I.	+0.8	+1.1	1.0	7.88	0.68
Shearwater (Halifax)	+1.0	+1.4	1.1	6.99	0.74
Yarmouth	+1.1	+1.7	0.9	7.16	0.62
Saint John	+0.6	+0.8	1.1	5.19	0.74
Boston	+0.9	+1.6	1.3	10.91	0.60

The air temperature anomalies for the six Scotian Shelf-Gulf of Maine sites, summarized in Fig. 7 as a composite sum, illustrate two points: for most years the anomalies have the same sign; i.e. the stacked bars coincide. Since 1900, when all sites were operating, 90 of the 112 years had five or more stations with the annual anomalies having the same signs; for 62 years, all six stations had anomalies with the same sign. This indicates that the spatial scale of the air temperature patterns is greater than the largest spacing between sites. Previous analyses yielded an e-folding scale of 1800 km (Petrie et al., 2009a). In addition, the time scale of the dominant variability has been changing from longer periods for the first half of the record to shorter periods for the second half. The summed anomaly in 2011 was +5.0°C, the 6th warmest year but a decrease from 2010.

For the 13-year period of AZMP sampling, all of the sites except Saint John were ranked as the warmest 13-year period from 1900 to 2011 (Table 2). The next warmest 13-year period was the previous overlapping 13-year period (offset by a single year). The second warmest period not overlapping the AZMP period was in the late 1940s and 1950s.

Table 2. Average air temperature anomaly for the period of the AZMP sampling, its ranking compared to the 100 13-year overlapping periods between 1900 and 2011.

	AZMP 1999-2011		Warmest/next warmest 13-year period		Next warmest non-overlapping period		
Site	T anom	Rank	T anom	Years	T anom	Years	Rank
Sydney	0.45	1	0.42	1998-2010	0.41	1946-58	3
Sable Island	0.34	1	0.27	1998-2010	-0.04	1946-58	10
Shearwater	0.44	1	0.36	1998-2010	0.10	1948-60	6
Yarmouth	0.31	1	0.21	1998-2010	0.17	1946-58	3
Saint John	0.23	12	0.40	1948-1960	Ranks 1-11 span years 1941-63		
Boston	0.13	1	0.09	1998-2010	0.00	1972-84	8

WINDS

For an indication of the winds on the Scotian Shelf for 2011, daily mean Sable Island wind speed and stress (which is proportional to the square of the wind speed) are presented (Fig. 8) as the along and cross-shore components. The variability of the wind speed and stress is dominated by the high-frequency component which is related to storms. There is an annual cycle in the across-shore wind speed with an offshore wind during the winter and a weaker on-shore wind during the summer. There is no obvious annual cycle in the along-shore component of the wind. Most of the wind observations in 2011 were within ±1 SD of the long term means. For the along-shore component, there were 4 strong events around early April. The across-shore component had energetic storm events in mid-February and late October

SEA ICE OBSERVATIONS

Ice areas, volumes and extents were computed using the Canadian Ice Service (CIS) of Environment Canada weekly composite GIS formatted charts available from the CIS website http://ice-glaces.ec.gc.ca/ for the period 1969-2011. In the current analysis, ice concentrations of ≥1 tenth were obtained for a grid with 0.1 degree latitude and 0.1 degree longitude intervals from these ice charts. A climatology (1981-2010) of first and last appearance and duration was generated for each grid point and was subtracted from the values determined for 2011 to generate anomaly maps. Previous reports had used an earlier (1971-2000) period for the reference period. Grid points for which the climatology had less than five years with data or where the duration was less than ten days were excluded from further analysis. The duration of sea ice is the number of days that ice, with a minimum concentration of 10%, is present. It is not simply the date of the first presence minus the last presence, because the ice may disappear from an area for a time and then reappear.

Ice cover provides an index that can be related to the initiation and maintenance of the spring phytoplankton bloom. On the other hand, identical ice cover but differing thickness, leading to different ice volumes, could distinguish a winter with above or below normal heat losses. Since observations of ice thickness are not available, ice volumes have been estimated for the region using a look up table that assigns characteristic thicknesses to particular ice types. While this is not an ideal way to estimate ice volumes, it does provide a basic assessment that can be used as an additional climate index and a reference point for testing ice models. The Canadian Ice Service does not generally compute ice volume estimates for Canadian waters. They give two main reasons for this (S. McCourt, Environment Canada, pers. comm.): “1. Ice types are reported in terms of "stage of development", which have an associated range of thickness. For example, "first-year ice" has an associated range of thickness of 30 cm to 120 cm. It is, therefore, difficult to assign a "typical" thickness and in the case of first-year ice, the value assigned will vary from area to area (i.e. first-year ice in the Gulf would have a different thickness than first-year ice in the Arctic). 2. Old ice in particular is extremely difficult to estimate thickness and subsequent volume; however, for the Gulf of St. Lawrence this should not be a limiting factor.”

ATLANTIC REGION

Ice appeared off Labrador, northern Newfoundland and in the Gulf of St. Lawrence in mid- to late February in 2011 (Fig. 9); over much of the region, the day of first appearance of ice was more than 15 to 45 days later than normal. In general, the day of last appearance of ice was earlier than usual off Labrador and Newfoundland by 15 to 30 days (Fig. 10). Overall, ice duration was shorter than normal over most of the region with the duration off Labrador and in the central Gulf of St. Lawrence where there was no ice in 2011, being 90 days shorter than the long-term average (Fig. 11).

SCOTIAN SHELF

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 northeastern coast of Cape Breton are typically the only areas heavily affected by ice in the region and, in 2011, it was present there for only a short period, lasting about 1 week. In 2011, there was no ice on the Scotian Shelf from December 2010 until the end of the ice season in May 2011 (Fig. 9).

The ice areas and volumes are shown in Fig. 12 and compiled in Tables 3 and 4. There is an overall decrease in the mean ice areas and volumes for the 1981-2011 reference period compared to the earlier reference period of 1971-2000 (Table 3). The January to April 2011 ice coverage and volume was the third lowest in the 43 year long record. Only 1969 and 2010 had lower coverage and volume; the differences between these three years are within the uncertainty of the observations.

Table 3. Ice area and volume 30-year mean statistics, Scotian Shelf.

Month	1971-2000 Mean Area (km^2)	1981-2010 Mean Area (km^2)	Change in Area (km^2)	Change in Area (SD)	1971-2000 Mean Volume (km^3)	1981-2010 Mean Volume (km^3)	Change in Volume (km^3)	Change in Volume (SD)
Jan	1700	1200	-500	-0.2	0.2	0.2	0.0	0.0
Feb	13900	11300	-2600	-0.2	3.5	2.8	-0.7	-0.2
Mar	18000	15700	-2300	-0.2	7.4	6.9	-0.5	-0.1
Apr	5800	4600	-1200	-0.2	3.6	3.0	-0.6	-0.2

Table 4. Ice area and volume statistics, Scotian Shelf.

Month	2011 Ice Area (km^2)	2011 Area Anomaly (km^2)	2011 Normalized Area Anomaly	2011 Ice Volume (km^3)	2011 Volume Anomaly (km^3)	2011 Normalized Volume Anomaly
Jan	4.8	-1200	-0.5	<0.01	-0.2	-0.7
Feb	95	-11200	-1.1	0.01	-2.8	-1.0
Mar	204	-15500	-1.1	0.06	-6.8	-1.0
Apr	4.3	-4600	-1.0	<0.01	-3.0	-1.0

REMOTELY-SENSED SEA SURFACE TEMPERATURE

A 4 km resolution Pathfinder 5.0 (Casey et al., 2010) sea surface temperature database is maintained at the Bedford Institute of Oceanography (Dartmouth, Nova Scotia). The Pathfinder dataset runs from January 1985 to December 2009; to provide data for 2010 and 2011, we used the sea surface temperature data downloaded from the 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) = 0.976*SST(ORMS)+0.46 with an r^2=0.98. We adjusted the ORMS observations to bring them in line with the longer Pathfinder series. Anomalies were based on 1985-2011 averages.

Annual anomalies for eight subareas in the Scotian Shelf-Gulf of Maine region were determined from the averages of monthly anomalies (Fig. 13, Table 5). On average, periods of one year and longer accounted for 38% of the overall variance determined from the monthly anomalies. The annual anomalies during 2011 ranged from +0.1°C (+0.1 SD) over Georges Bank to +0.8°C (+0.7 SD) in the Bay of Fundy. All 8 areas had positive anomalies; only 1 was greater than +0.5 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 +0.4°C (Georges Bank) to a highest value of +1.4°C (eastern and central Scotian Shelf). A similar trend in SST from Advanced Very High Resolution Radiometer (AVHRR) measurements was found in the Gulf of St. Lawrence (Galbraith et al., 2012a). The large increase in the observed SST over this period could have been enhanced by the cold period at the beginning of the AVHRR period (Fig. 6).

The overall coherent variability of the annual SST temperature anomalies in the 8 regions suggested that a principal component analysis might be revealing. The leading mode, PCA1, captured 71% of the variance, all loadings had similar amplitudes, meaning roughly equal contributions from each series, and all had the same sign, indicating in-phase heating or cooling in the eight regions for this mode. PCA2 accounted for an additional 18% 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. 14).

Table 5. 2011 SST anomalies and long-term SST statistics.

Site	2011 SST Anomaly (°C)	2011 SST Anomaly Normalized	1985-2011 Mean Annual SST (°C)	1985-2011 Monthly SST Anomaly Std. Dev. (°C)	ΔT (ºC) 1985-2011
Cabot Strait.	+0.5	+0.4	6.2	1.0	1.2
Eastern Scotian Shelf (ESS)	+0.3	+0.3	8.8	1.2	1.4
Central Scotian Shelf (CSS)	+0.5	+0.4	7.4	1.0	1.4
Western Bank	+0.3	+0.3	10.7	1.1	1.2
Western Scotian Shelf (WSS)	+0.3	+0.3	7.9	1.0	0.9
Lurcher Shoal	+0.3	+0.3	8.8	1.0	0.5
Bay of Fundy	+0.8	+0.7	9.3	0.8	1.0
Georges Bank	+0.1	+0.1	7.9	0.8	0.4

COASTAL TEMPERATURES AND SALINITIES

Coastal SSTs have been collected at St. Andrews (New Brunswick) and Halifax (Nova Scotia) since the 1920s (Fig. 15). In 2011, the SST anomalies were +0.9°C (+1.6 SD) for St. Andrews, a decrease of 0.1°C from 2010 and 0.6°C (+0.8 SD) for Halifax, an increase of 0.2 °C from 2010. Interestingly, the sea surface temperature at Halifax, located in the harbour, had no significant change from 1985 to 2011, due to a warmer 1985 (Fig. 15), whereas the satellite-based SST showed an increase (Table 5; Fig. 13). Slight changes in timing of warming and cooling events can affect estimates of trends over short periods. For example, the trend in the Halifax temperature between 1987 and 2011 was the equivalent of an increase of 0.4°C for that period.

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, salinity and density time series are shown in Fig. 15. In 2011, the annual temperature anomaly was +1.0°C (+1.8 SD) and the salinity anomaly was -0.3 (-1.4 SD). These represent changes of +0.0°C and -0.2 from the 2010 values. The density anomaly is largely accounted for by the salinity anomaly (63%) and secondarily by the temperature anomaly (37%).

The 2011 annual cycle at Prince 5 shows warmer than normal temperatures throughout the year with no real depth dependence in the anomaly (Fig. 16). The largest temperature anomaly occurred in the winter. The salinity anomaly observed at Prince 5 is due to the arrival of fresh water in the upper ocean with the Saint John River a nearby source. It is not surprising that the time of arrival of fresh water varies from one year to another. The 0-90 m average density indicates that 2011 had the least dense water on record (Fig. 15).

The 2011 annual cycle at Halifax 2 shows the standard seasonal cycle in temperature (Fig. 17). The observed temperature anomaly is due to variability of the vertical extent of the summer mixed layer. The salinity anomaly at the surface in June is probably due to mixing of saltier water from below the mixed layer. A pulse of fresh water in the upper 25 m was observed in the

October/November period. The deeper variability of the salinity is likely due to the vertical motion of the isohalines.

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. 18). 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 (five year running means) temperature anomalies at selected depths for five areas (Fig. 19). The Cabot Strait (see Fig.1) temperatures represent the a mix of Labrador Water and Slope Water entering the Gulf of St. Lawrence along the Laurentian Channel (Gilbert et al., 2005); the Misaine Bank (region 5; Fig. 18) series characterizes the colder near bottom temperatures on the eastern Scotian Shelf; the deep Emerald Basin (region 12) anomalies represent the slope water intrusions onto the Shelf that are subsequently trapped in the inner deep basins; 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 all months in each area. For Cabot Strait, Misaine Bank, Emerald Basin, Lurcher Shoals and Georges Basin, 2011 annual anomalies are based on observations from only 5, 4, 4, 1 and 4 months.

In 2011, the annual anomalies were +0.6°C (+1.6 SD) for Cabot Strait 200-300 m (the 2nd warmest year in 60 years), +0.8°C (+1.2 SD) for Misaine Bank 100 m, +0.9°C (+1.1 SD) for Emerald Basin 250 m, +1.3°C (+1.7 SD) for Lurcher Shoals 50 m, and +0.8°C (+1.5 SD) for Georges Basin 200 m (the 2nd highest anomaly with last year being the highest). These values correspond to changes of +0.3°C, +0.4°C, +0.3°C, +1.2°C and -0.1°C, respectively, over the 2010 values. The 2010 and 2011 NAO anomalies were well below normal and based on similar atmospheric forcing in the past, notably in the mid-1960s, cooler deep water temperatures might have been expected in this region for 2011 (Petrie, 2007).

TEMPERATURES DURING THE SUMMER GROUNDFISH SURVEYS

The broadest spatial temperature and salinity coverage of the Scotian Shelf is obtained during the annual July Department of Fisheries and Oceans (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 257 Conductivity-Temperature-Depth (CTD) stations were taken during the 2011 survey and an additional 121 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 (for details, see Petrie et al., 1996). 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 0, 50, 100 m, and near bottom. The reference period for the anomalies has been changed to the standard period (1981-2010) this year. For example, the new bottom temperature reference field shows a slight decrease from the previous reference period (1971-2000) over the Scotian Shelf (Fig. 20). Near bottom temperature anomalies for 2011 showed considerable spatial variability (Fig. 21). The July surface temperature anomalies also show significant spatial variability as well with cooler waters on the central Scotian Shelf and warmer waters in the Bay of Fundy (Fig. 22).

Bottom temperatures ranged from 4.1°C in Northwest Atlantic Fisheries Organization (NAFO) area 4Vs to 7.7°C in 4X during 2011, illustrating the substantial difference in the environmental conditions across the Shelf (see Fig. 1 for locations of the NAFO regions). The anomalies were positive for these NAFO areas in 2011: +0.7°C (+1.6 SD) in 4Vn; +0.8°C (+1.1 SD) in 4Vs; +0.2°C (+0.3 SD) in 4W; and +0.5°C (+0.6 SD) in 4X (Fig. 23 A-D). Compared to 2010, bottom temperatures increased in areas 4Vn, 4Vs and 4X by 0.5, 0.4 and 0.1°C; temperature decreased by 0.3°C in area 4W.

The volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures less than 4°C, was estimated from the full depth CTD profiles for the region from Cabot Strait to Cape Sable (panel E of Fig. 23). For the period 1970 to 1989, the number of CTD profiles per year was limited; therefore, five 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 one 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. 23-E) 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. 23E). In 2011, the observed volume of 4800 km^3 was 0.6 SD less than the 1981-2010 mean value of 5500 km^3 and similar to that observed in the previous two years.

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 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. 18. 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. 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, using normalized monthly anomalies obtained by dividing the anomalies by their monthly standard deviations, were qualitatively similar to the plots presented here. The annual anomalies and their five year running means were then calculated for an area-weighted combination of subareas 4-23 on the Scotian Shelf (Fig. 18, 24). 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 with generally below average stratification in contrast to the past 20 years which is characterized by above normal values

(Fig. 24). Stratification on the Scotian Shelf in 2011 weakened significantly compared to 2010; obtaining a value near that seen in 2002 and a record low since 1986. Since 1950, there has been a slow increase in the mean 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. This change in mean stratification is due mainly to a freshening of the surface waters (Fig. 25). The density difference due to the change in the 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. However, the change in stratification from 2010 to 2011 was mainly the result of a decrease in the surface temperature in 2011 although surface salinity was the lowest in a decade.

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, Halifax, and North Sydney have been obtained from Natural Resource Canada's gridded GPS-based vertical velocities (Phillip MacAulay, DFO, pers. comm., 2012; Craymer et al., 2011).

Relative sea level at Yarmouth (1967-2011), Halifax (1920-2011) and North Sydney (1970-2011) are plotted as monthly means and as a filtered series using a 12-month running-mean filter (Fig. 26). The linear trend of the monthly mean data has a positive slope of 34.5 cm/ century (Yarmouth), 32.8 cm/century (Halifax) and 36.9 cm/century (North Sydney). Barnett (1984) found a slightly higher sea level rise for Halifax (36.7 cm/century) for the period 1897-1980. This is due to the decrease in sea level rise after 1980 as discussed below. With the removal of the PGR for Yarmouth (-10.3 cm/century), Halifax (-14.7 cm/century) and North Sydney (-16.8 cm/century), sea level rise is 24.2 cm/century, 18.1 cm/century and 20.1 cm/century, respectively. In 2011, the relative sea level at Yarmouth, Halifax and North Sydney decreased from the 2010 level although sea level rise appears to have increased rapidly in 2009-10. An interesting feature of the data is the long-term variation that has occurred since the 1920s. In Fig. 27 we show the differences of the annual sea level from the 1971-2011 sea level rise trend. It is apparent that from the 1920s to the early 1970s, the sea level rise trend at Halifax was greater than the 1971-2011 trend. The residual sea level data for the common period 1970-2011 shows that the variability has a large spatial structure given the coherence between the three sites. Several potential causes of this decadal scale variability have been examined; however, we still do not understand the cause of these changes. Farther 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).

CALCULATIONS FROM NUMERICAL CIRCULATION MODEL

Currents and transports are derived from a numerical model of the Gulf of St. Lawrence, Scotian Shelf, and Gulf of Maine. The model is prognostic, i.e. allows for evolving temperature and salinity fields, and includes the five principal tidal constituents and 78 river inputs. It has a spatial resolution of 1/12° with 46 z-levels in the vertical. Atmospheric forcing is derived from the Global Environmental Multiscale Model (GEM) model run at the Canadian Meteorological

Center (CMC). Freshwater runoff is taken from observed data and the hydrological model (for details see Galbraith et al., 2012b).

A simulation was run for the AZMP years 1999-2011 using a version of the circulation model that incorporated a simple scheme to assimilate the AZMP temperature and salinity data for these years. We present some calculations that may help interpret some of the other data collected by the AZMP, and of potential interest to ecosystem studies in the region. Note that the model, at this time, uses climatological open boundary conditions so changes in interior flows related to interannual variability at the open boundaries are not captured. The reader is cautioned that the results outlined below are not measurements but simulations and improvements in the model may lead to changes in them.

PARTITIONING OF VOLUME FLUXES INTO THE GULF OF MAINE: 1999-2011

Flow into the Gulf of Maine occurs through two principal locations: via the Nova Scotian Current flowing through the Cape Sable Island (CSI) section (or Browns Bank section) and via the shelf-break current: flowing into the Gulf of Maine at Northeast Channel (NEC). These two current streams bring on-shelf and off-shelf water properties into the Gulf of Maine and the partitioning of the transports is potentially important to processes occurring in the Gulf of Maine. From the inflows through the CSI and NEC sections the annual average fraction, CSI / (CSI + NEC) was computed (Fig. 28). Over the 13-year simulation, the average fractional volume flux through CSI is 0.27 with a peak of 0.45 in 2004. The average fractional volume flux for 2011 was at the 13-year average.

COMPARISON OF NEARSHORE (INSIDE OF THE 100 M ISOBATH) CURRENTS

The general circulation on the shelf seas of Maritime Canada can be characterized as a general northeast-to-southwest flow through from the Strait of Belle Isle, through Cabot Strait, and along the Scotian Shelf toward the Gulf of Maine. Part of the water that flows out of the Gulf of St. Lawrence through the western side of Cabot Strait follows the Nova Scotian coastline as the Nova Scotian Current, which ultimately feeds into the Gulf of Maine. Variations in this coastal current may influence the distributions of various fish and invertebrate larvae (e.g. southern Gulf and eastern Scotian Shelf snow crab).

Model simulation of flow through the four Maritime AZMP sections (Cabot Strait, Louisbourg, Halifax and Browns Bank/Cape Sable Island) was analyzed to produce the expected seasonal cycle plus variability. We show plots of the results for 2011 compared to the 1999-2011 average value (Fig. 29). For 2011, the nearshore transport through Cabot Strait was within 1 SD of the mean except for the last few weeks of the year. At Louisbourg the transport showed more variability with about seven weeks where it was an extreme of the 13-year time series. The coastal transport through the Halifax section was less extreme than at Louisbourg, and exhibited a two month period during early summer where it was consistently approximately 1 SD above the mean. At Cape Sable Island, where the nearshore transport is typically more variable than at upstream locations, 2011 was a normal year.

Coastal transports through sections are correlated in the downstream direction with correlation coefficients decaying with distance downstream. For 2011, the strongest correlations were between Cabot Strait and Louisbourg (0.69) and between Halifax and Cape Sable Island (0.73). The correlation between Louisbourg and Halifax was weaker (0.52) but still significant. This indicates that longer period (subtidal) transport anomalies propagate downstream along the Nova Scotia coastline, but the region between Louisbourg and Halifax may act as a partial barrier to transport anomalies.

SUMMARY

In 2011, the NAO index remained low (10.2 mb, 1.2 SD below the 1981-2010 mean). In 2010, the NAO index was at its lowest value (-25.1 mb, -2.5 SD) since records were started in 1895. Mean annual air temperatures for 2011 were 0.6 to 1.1°C above normal across the whole region. In 2011, there was basically no ice on the Scotian Shelf; the areal coverage and volume was the 3rd lowest in the 42 year record and not significantly different from the lowest value of zero. The analysis of satellite data indicates that positive SST anomalies prevailed throughout the Scotian Shelf and Gulf of Maine region in 2011 with a values from +0.1 to +0.8°C (+0.1 to +0.7 SD) above the 1985-2011 mean values.

A graphical summary of selected 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. 30). The period 1979-1986 also tends to be warmer than normal. It is apparent that 2011 was an exceptional year based on these series. In 2011, 20 of the 22 series shown had positive anomalies; 4 variables were within 0.5 SD of their normal values and were concentrated in the western end of the region. Of the 18 remaining series, all except Misaine 0 m temperature (which was below normal) were more than 0.5 SD greater than normal. In 2011, the average (median) normalized anomaly was 0.9 (0.7), the 6th (3rd) highest in the 42 year series. The standard deviation of the normalized anomalies was 0.7. These statistics indicate that 2011 was another exceptionally warm year with a fairly uniform distribution of anomalies throughout the region.

Eighteen selected variables of the mosaic plot are summarized as a combination bar plot in Fig. 31. This plot represents 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 2011. The leading mode of a principal component analysis of the 18 series captured 43% of the variance with all loadings having the same sign. The loadings of 16 of the 18 variables were strong (0.19 to 0.30) with weak contributions from the Emerald Basin 250 m (0.04) and Misaine Bank 0 m (0.09) series.

ACKNOWLEDGEMENTS

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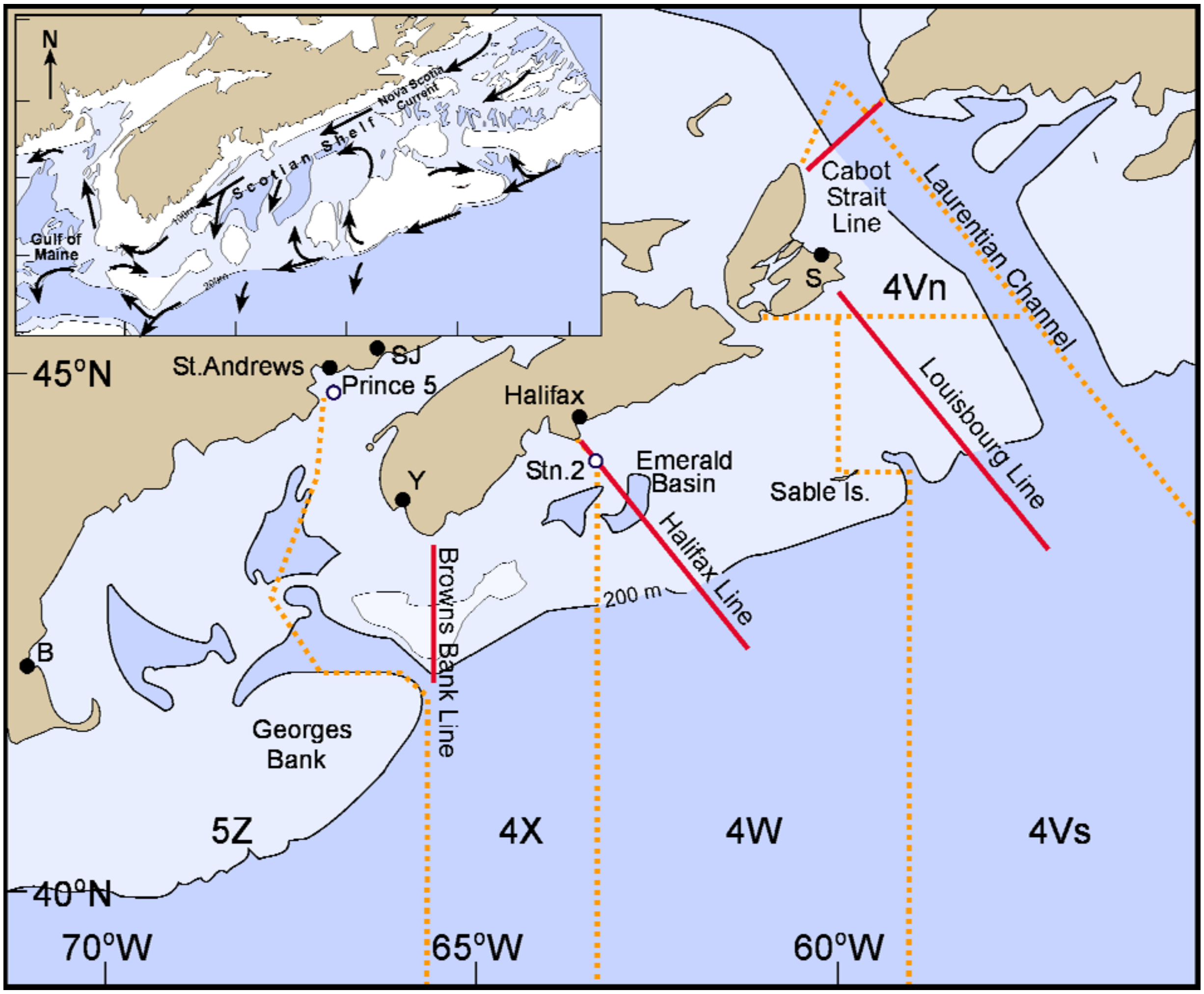

Figure 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the Northwest Atlantic Fisheries Organization (NAFO) Subareas. Inset depicts major circulation features. Air temperature stations at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

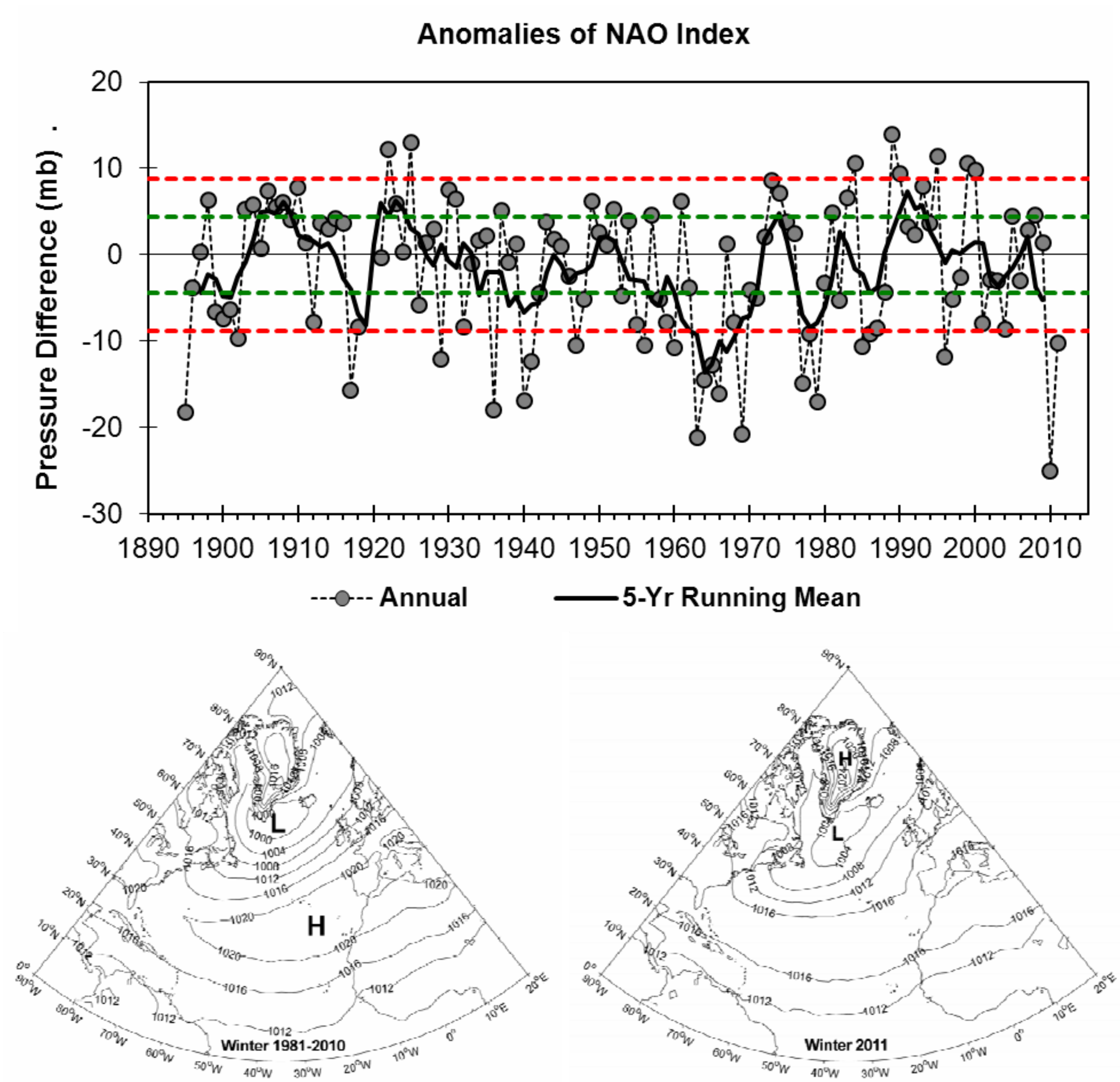

Figure 2. Anomalies of the North Atlantic Oscillation (NAO) index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1981-2010 mean. The 0.5 (green broken lines) and 1.0 (red) standard deviations are shown (upper panel). The lower panels show the 1981-2010 December-Februrary mean (left) and December 2010-February 2011 mean (right) sea level pressure over the North Atlantic.

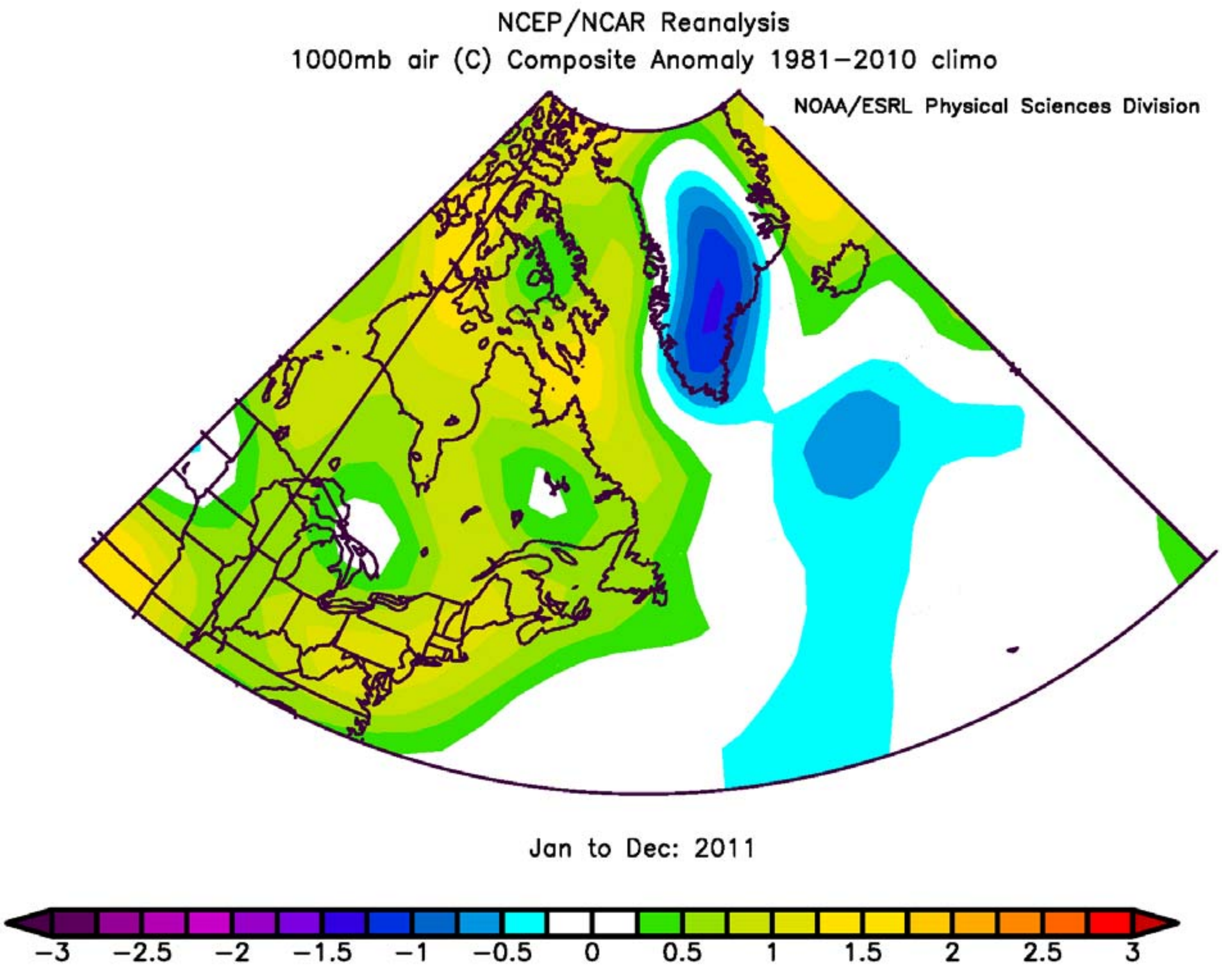

Figure 3. Annual air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981-2010 means; data were obtained from http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl (accessed 15 June 2012).

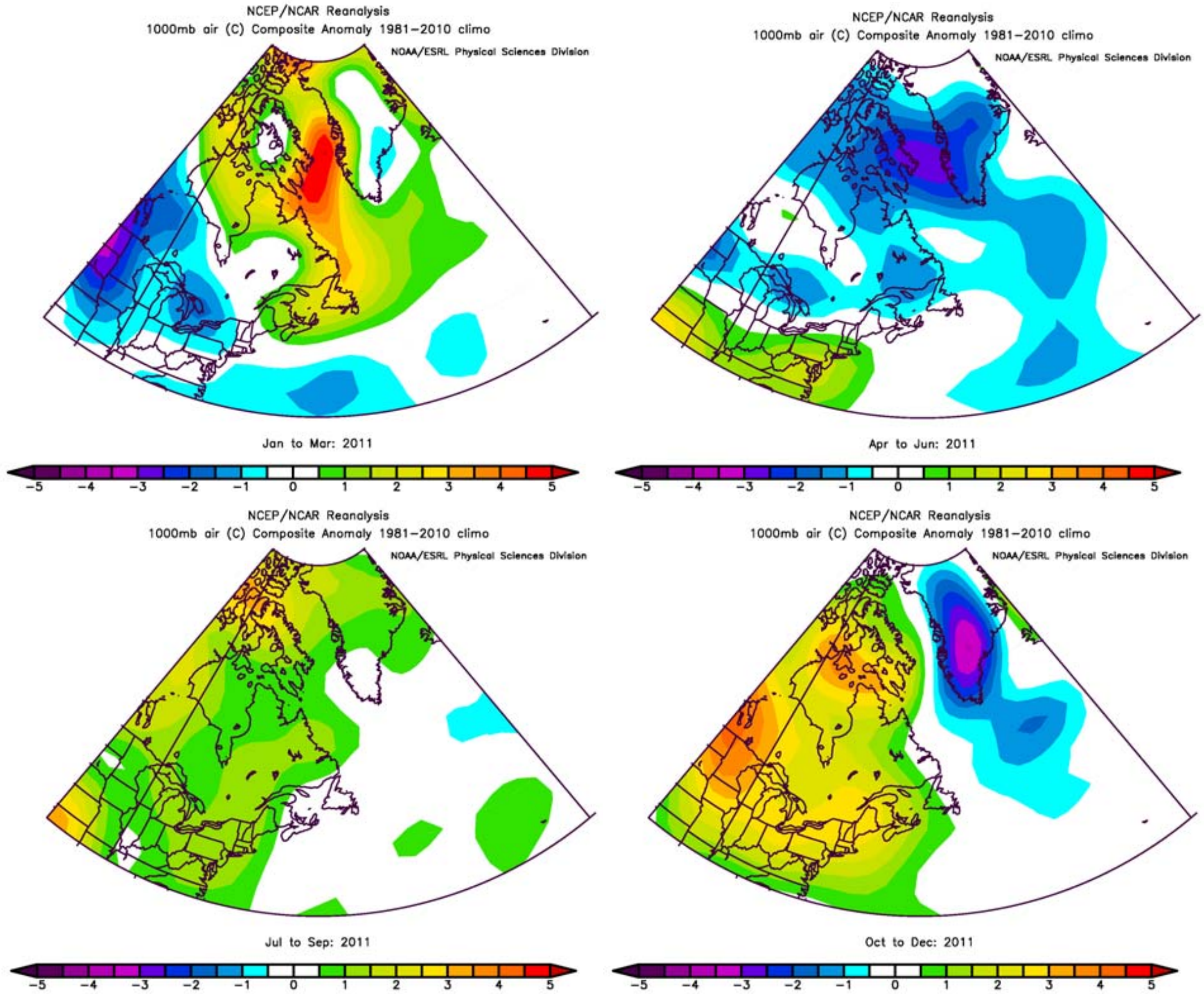

Figure 4. Seasonal air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981-2010 means; data were obtained from http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl (accessed 15 June 2012).

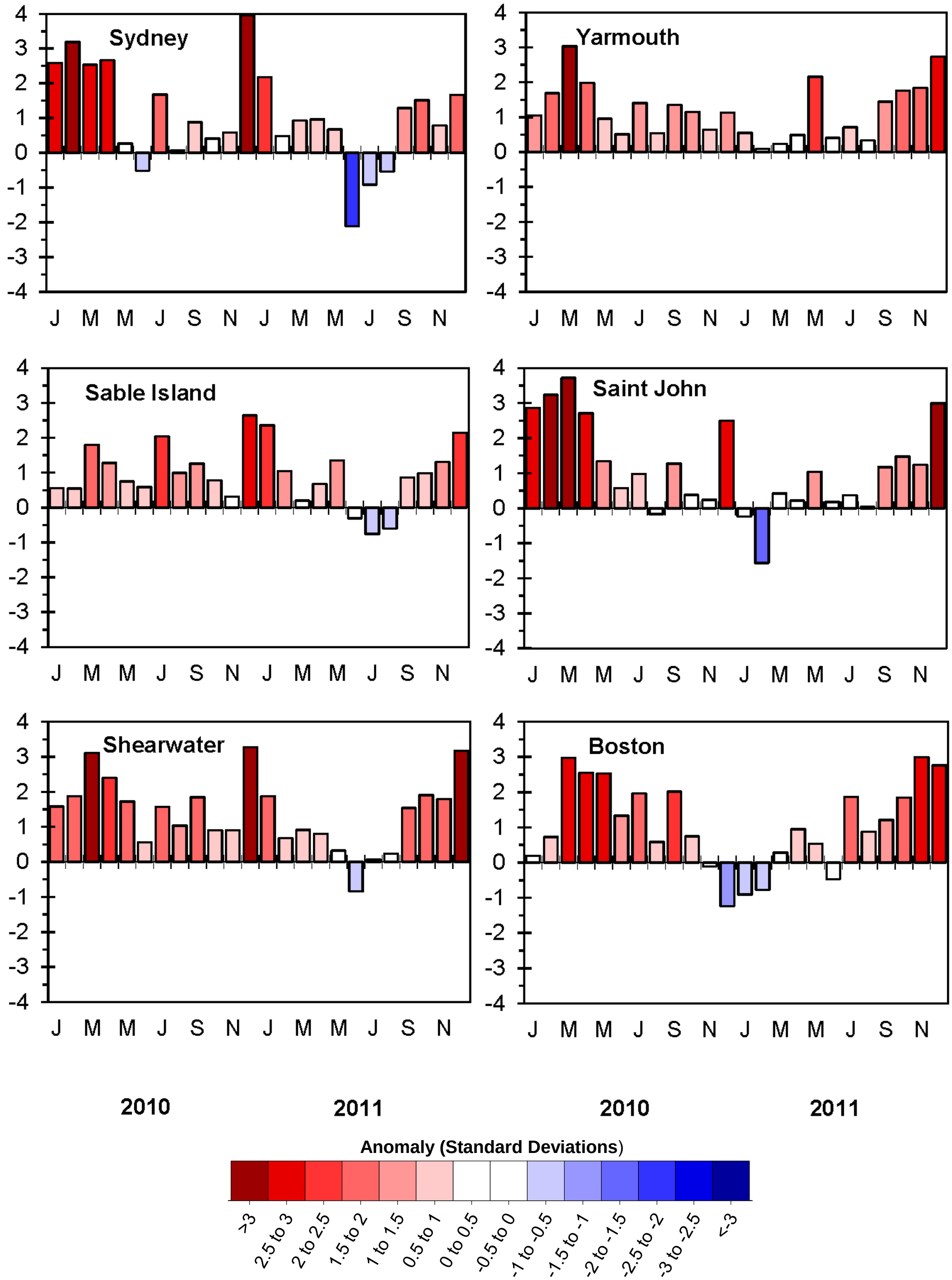

Figure 5. Monthly air temperature anomalies in 2010 and 2011 at coastal sites in Scotian Shelf-Gulf of Maine region (see Figure 1 for locations). Anomalies are colour coded in terms of the numbers of Standard Deviations (SD) above or below normal.

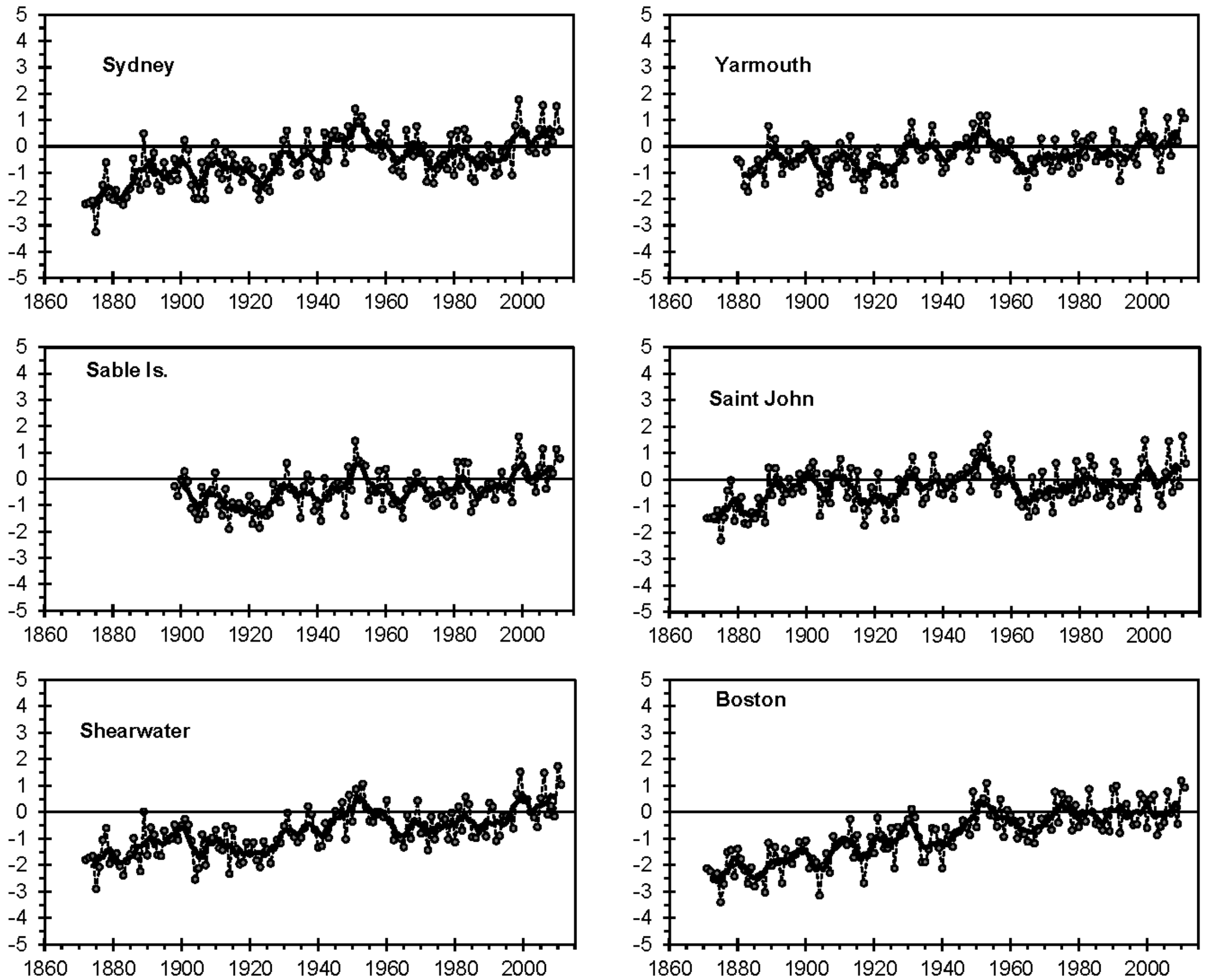

Figure 6. Annual air temperature anomalies (dashed line, dots) and five year running means (solid line) at selected sites in Scotian Shelf-Gulf of Maine region.

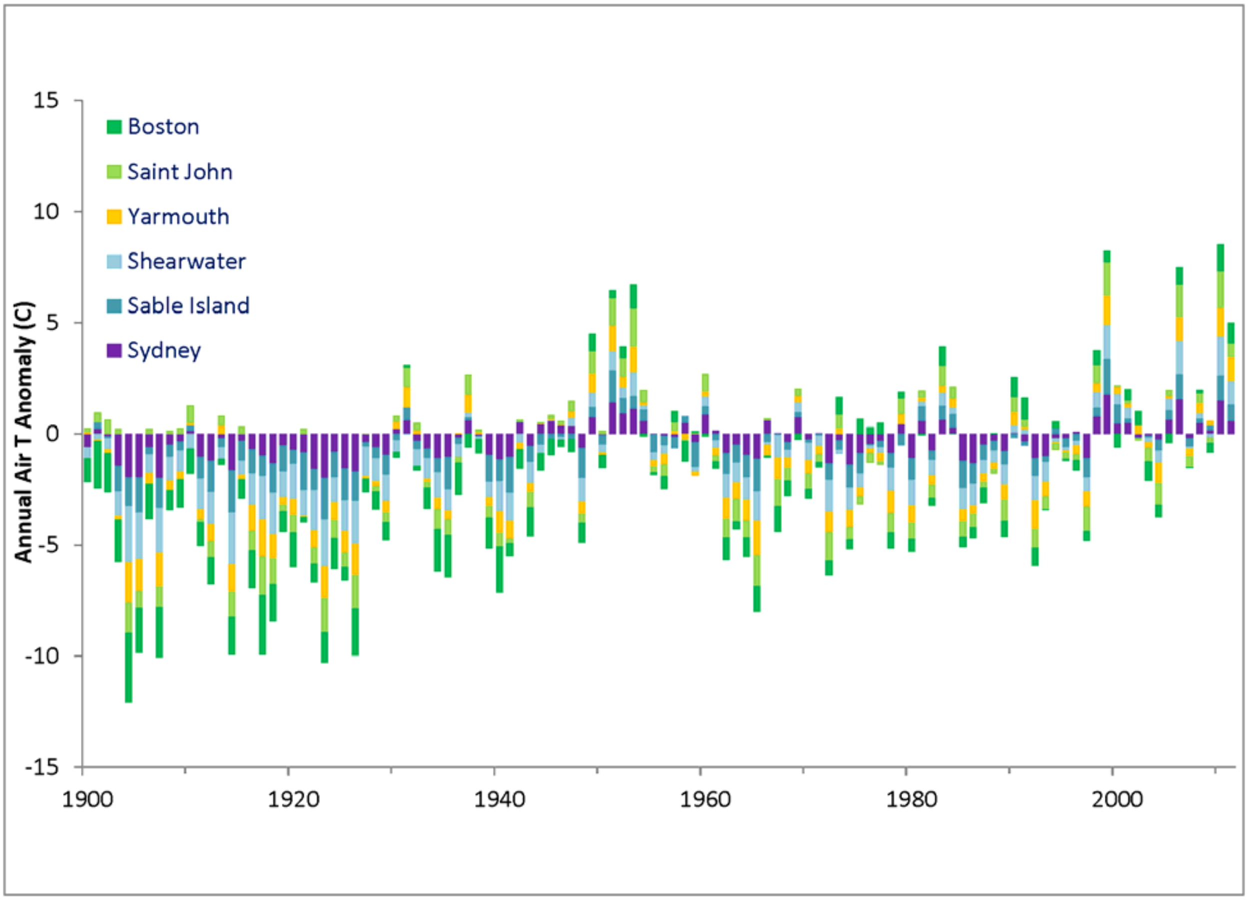

Figure 7. The contributions of each of the annual air temperature anomalies for six Scotian Shelf-Gulf of Maine sites are shown as a stacked bar chart. Anomalies referenced to 1981-2010.

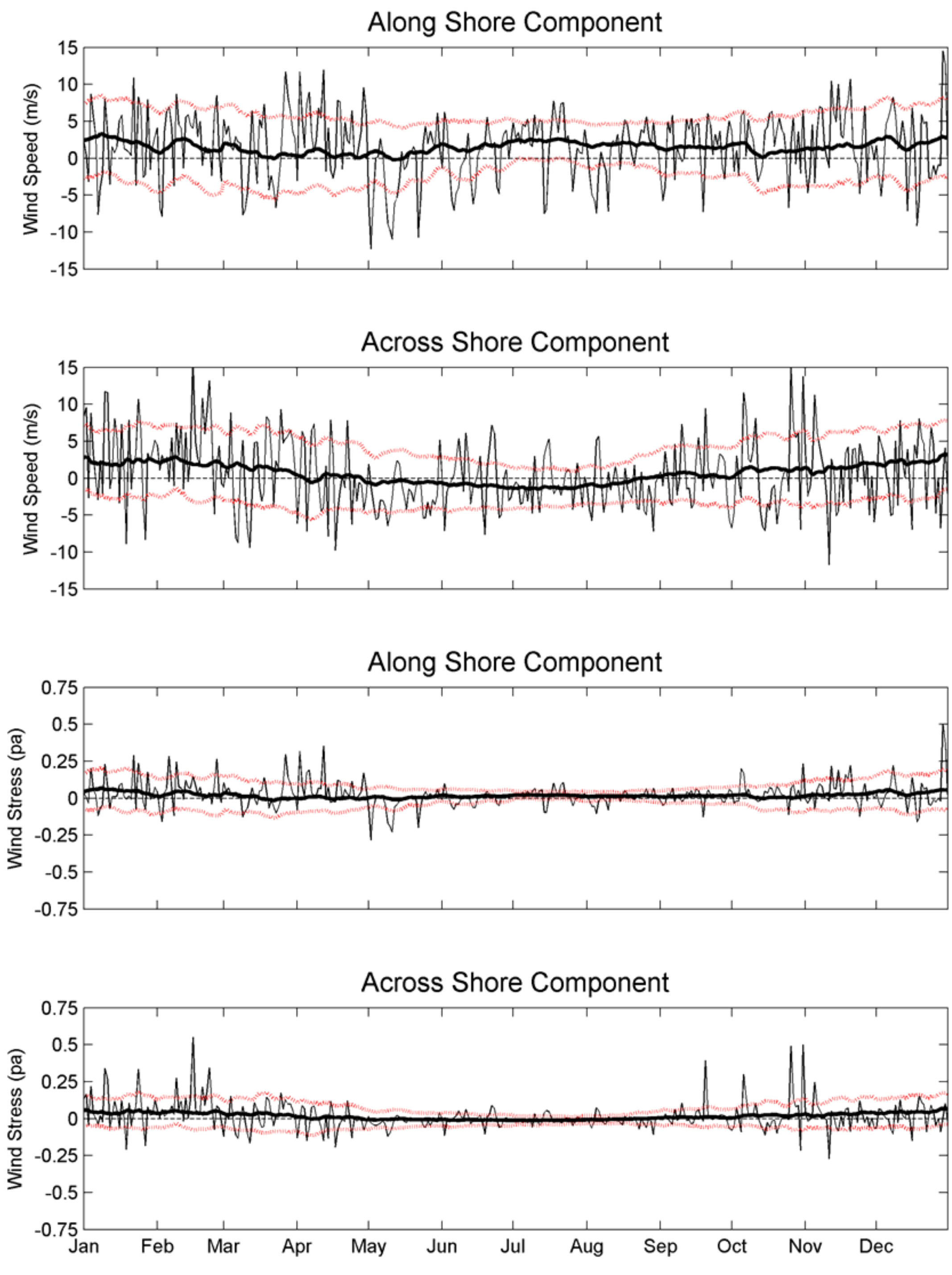

Figure 8. The Sable Island wind speed (top panels) and wind stress (lower panels) for 2011 (thin black line) and 30-year (1981-2010) average values smoothed with seven day running mean (thick black line) and ±1 SD (red lines).

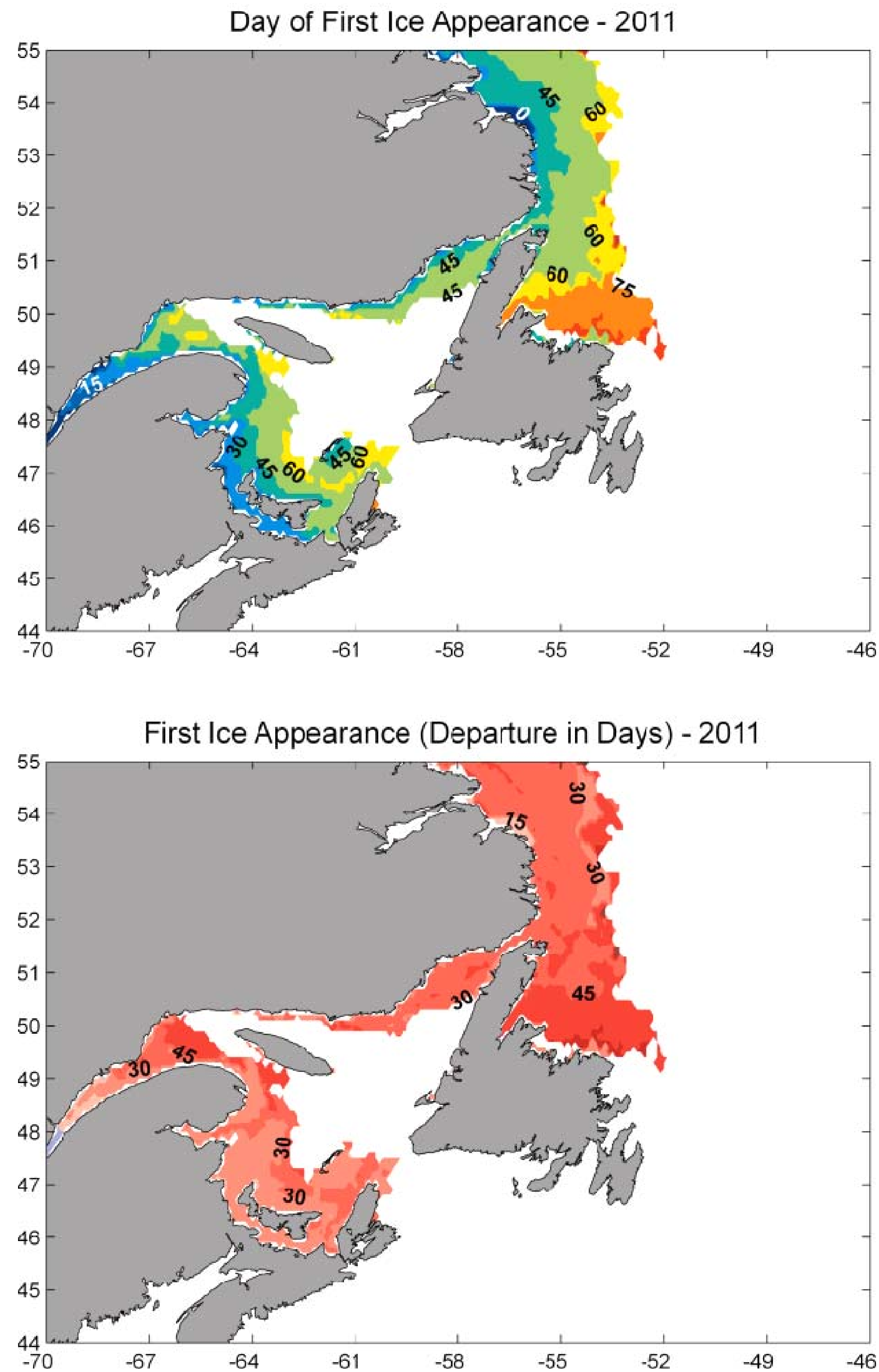

Figure 9. The time when ice first appeared during 2011 in days from the beginning of the year (top panel) and its anomaly from the 1981-2010 mean in days (bottom panel). Negative (positive) anomalies in blue (red) indicate earlier (later) than normal appearance.

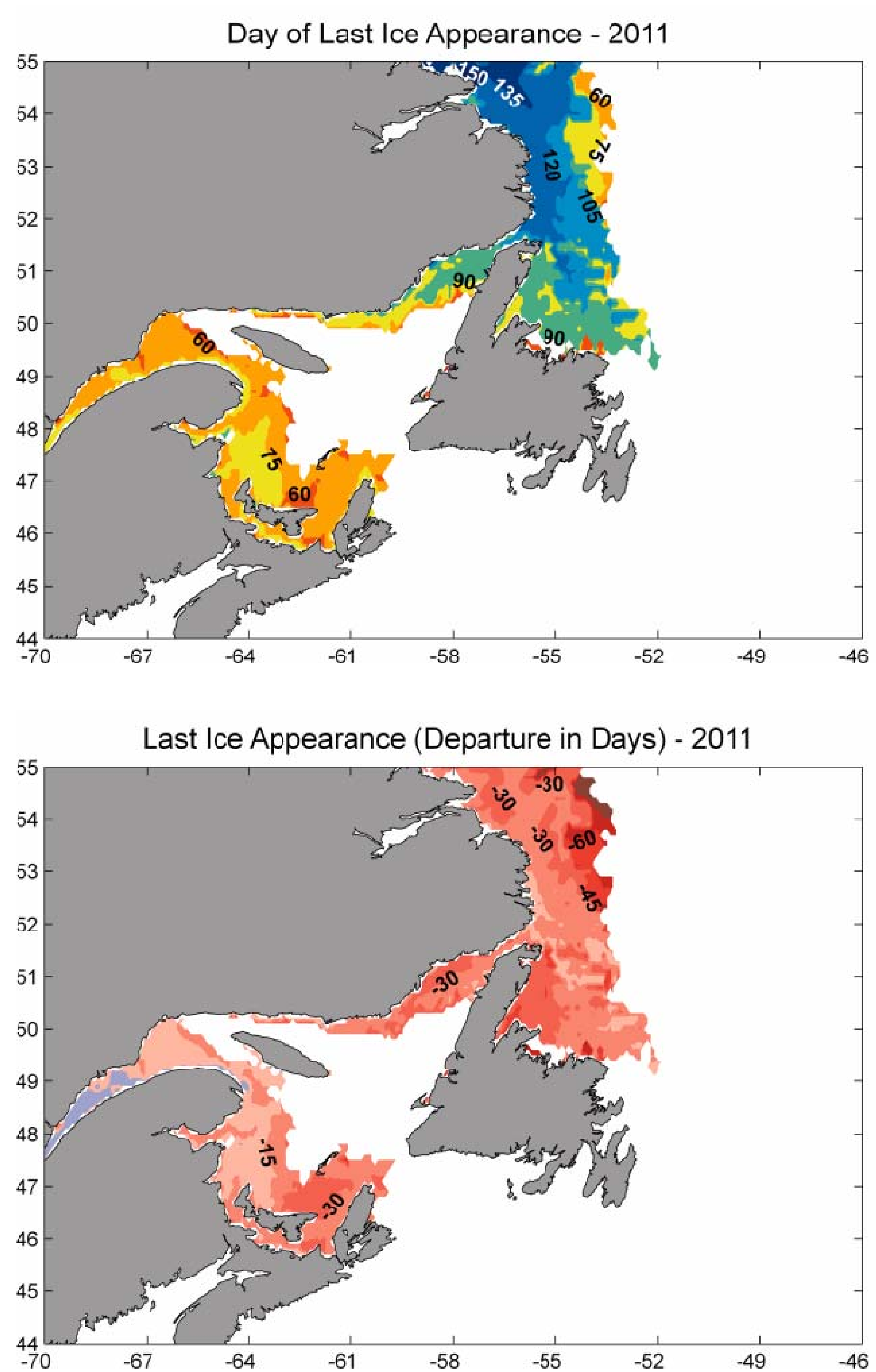

Figure 10. The time when ice was last seen in 2011 in days from the beginning of the year (top panel) and its anomaly from the 1981-2010 mean in days (bottom panel). Negative (positive) anomalies in red (blue) indicate earlier (later) than normal disappearance.

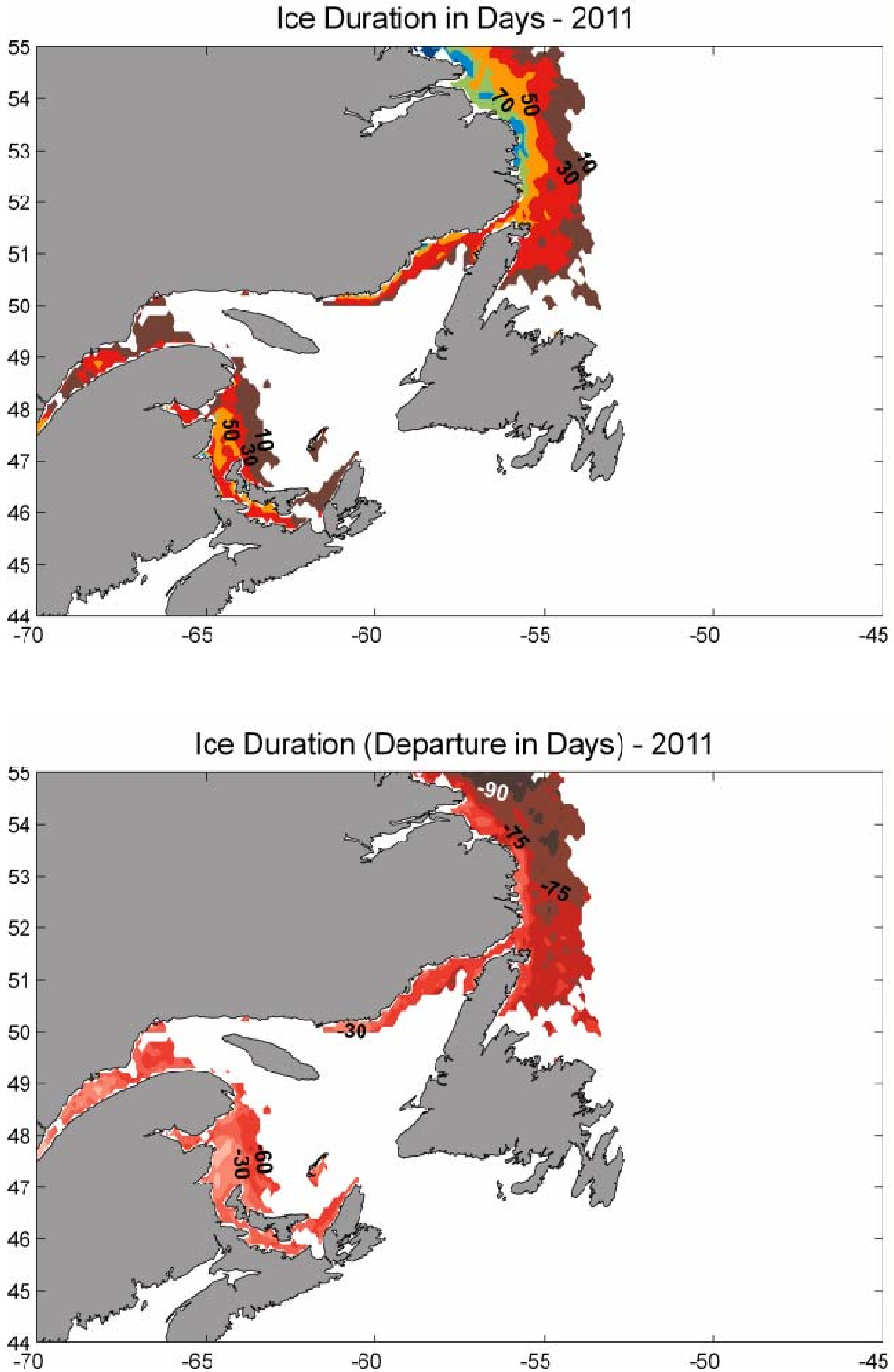

Figure 11. The duration of ice in days (top panel) during 2011 and the anomalies from the 1981-2010 mean in days (bottom panel). Positive (negative) anomalies in blue (red) indicate durations longer (shorter) than the mean. Note that areas of duration approximately ten days are not displayed.

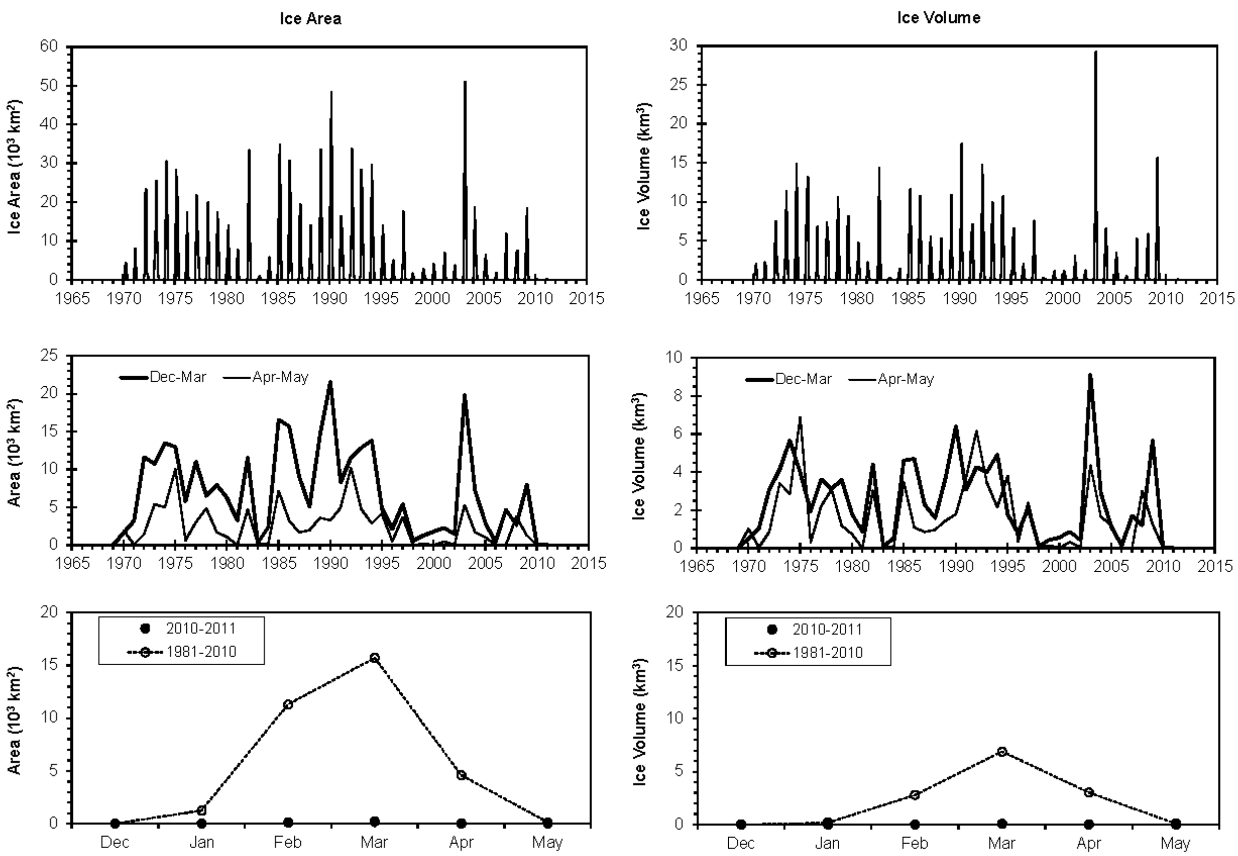

Figure 12. Time series of the monthly mean ice area and volume for the Scotian Shelf (top panels), the average ice area and volume during the usual periods of advancement (January-March) and retreat (April-May) (middle panels), and the comparison of the 2010-2011 monthly areas and volumes to the 1981-2010 means (bottom two panels). Note that the 2010-2011 ice area and volume is basically zero.

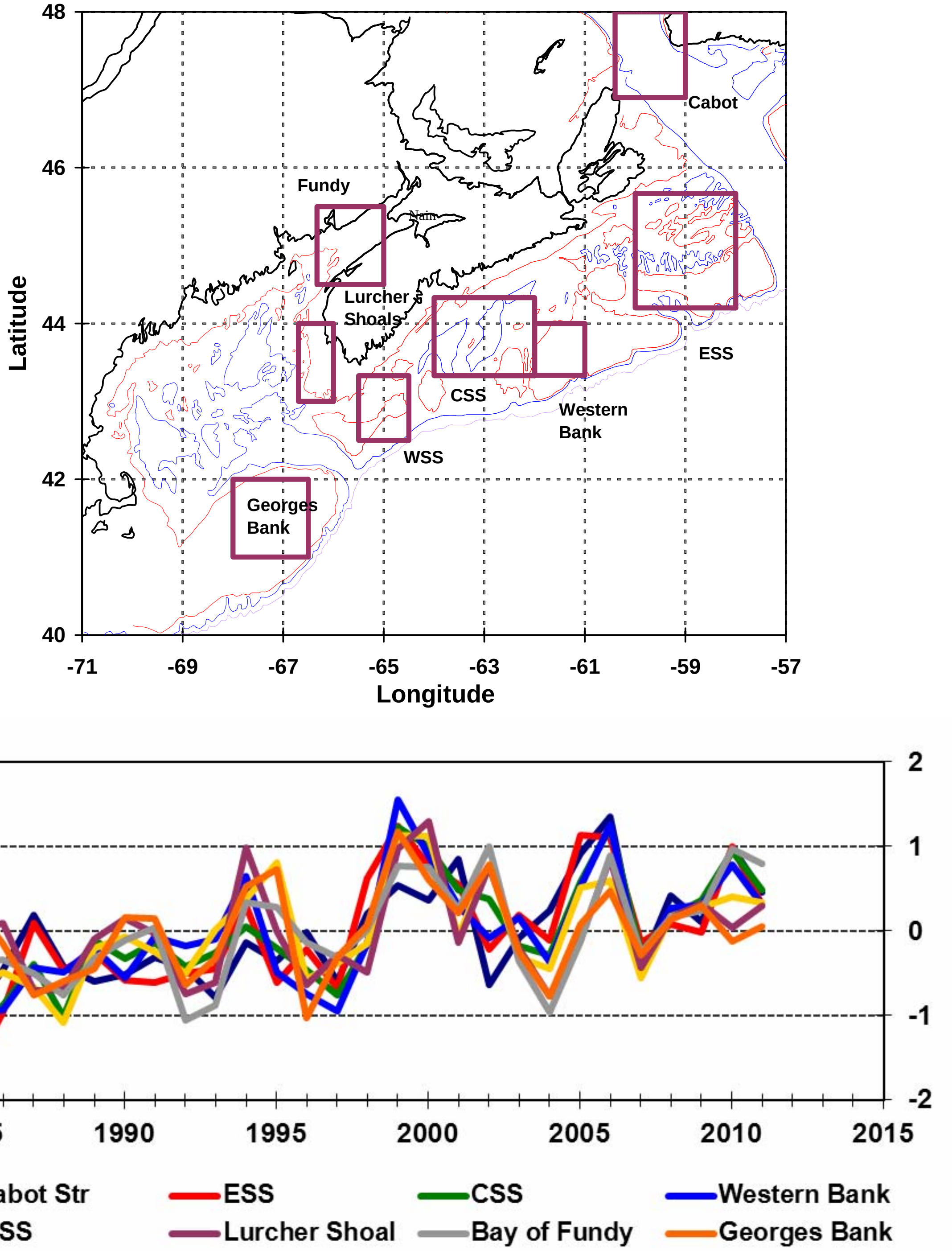

Figure 13. Scotian Shelf-Gulf of Maine areas used for extraction of sea-surface temperature (upper panel). The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term monthly means (lower panel).

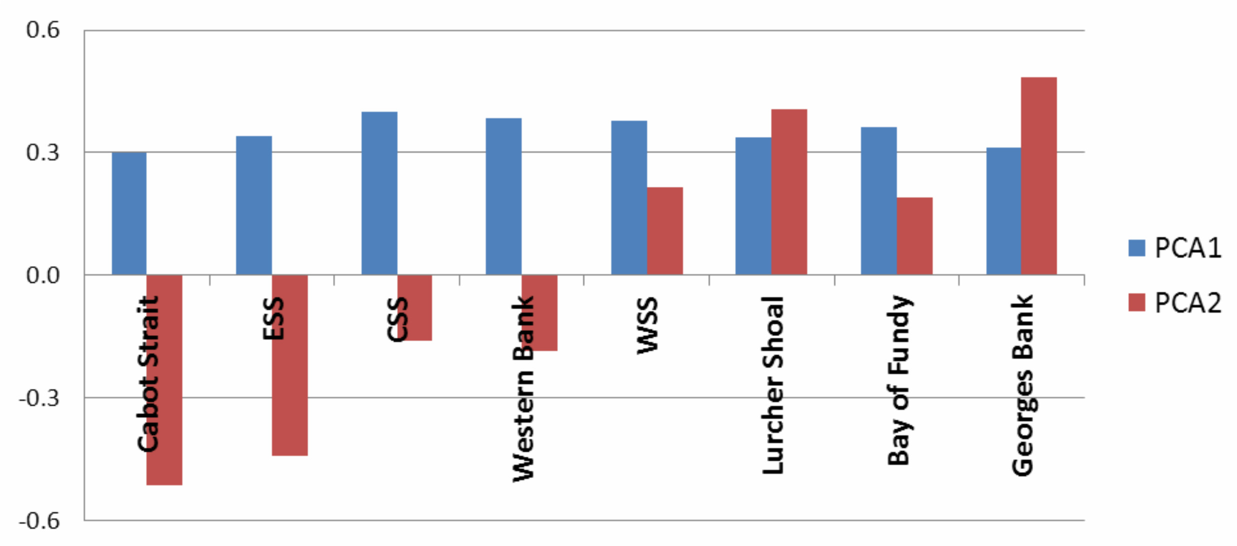

Figure 14. PCA1 (71% of variance) and PCA2 (18%) loadings from a principal components analysis of the annual mean temperature anomalies (Figure 13, lower panel) for the eight Scotian Shelf and Gulf of Maine regions (Figure 13, upper panel).

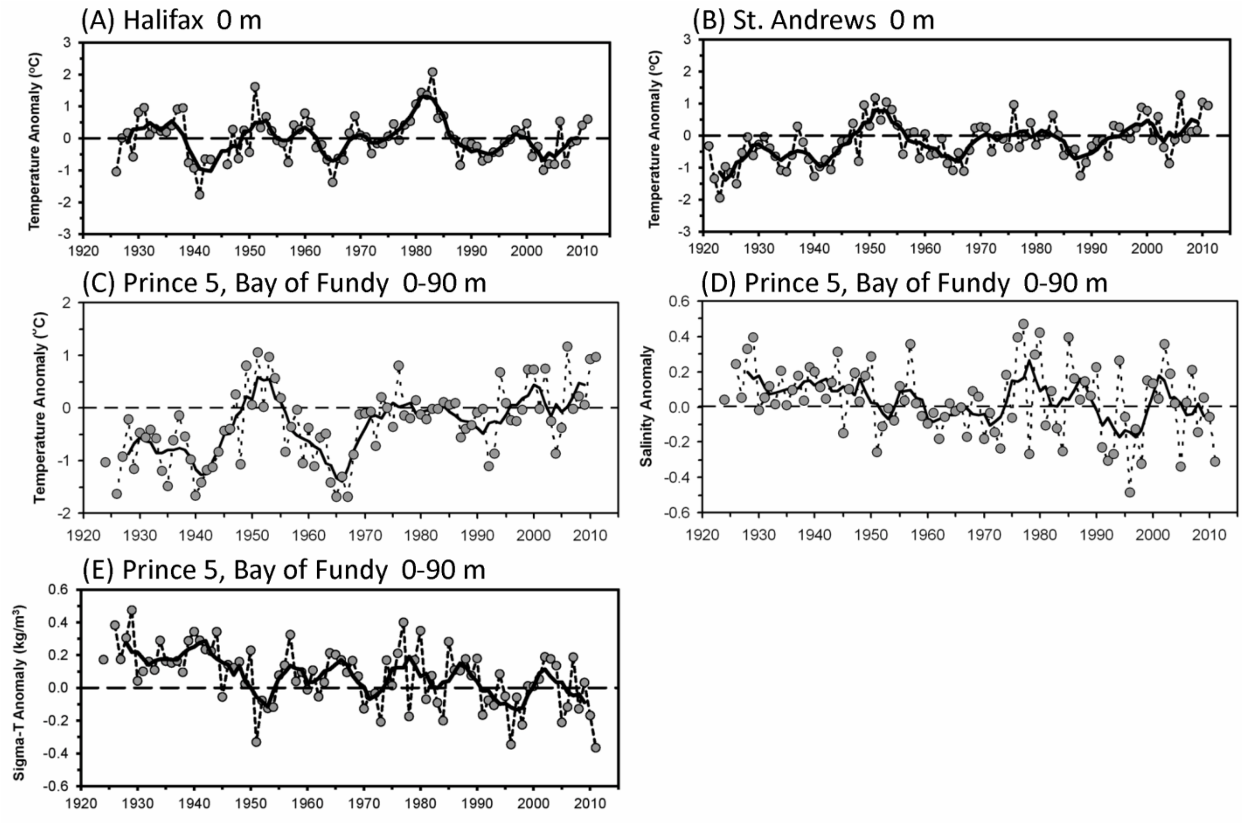

Figure 15. The annual surface temperature anomalies (dotted line with circles) and their five year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews; annual depth-averaged (0-90 m) (C) temperature, (D) salinity, and (E) density anomalies for the Prince 5 monitoring station at the mouth of the Bay of Fundy.

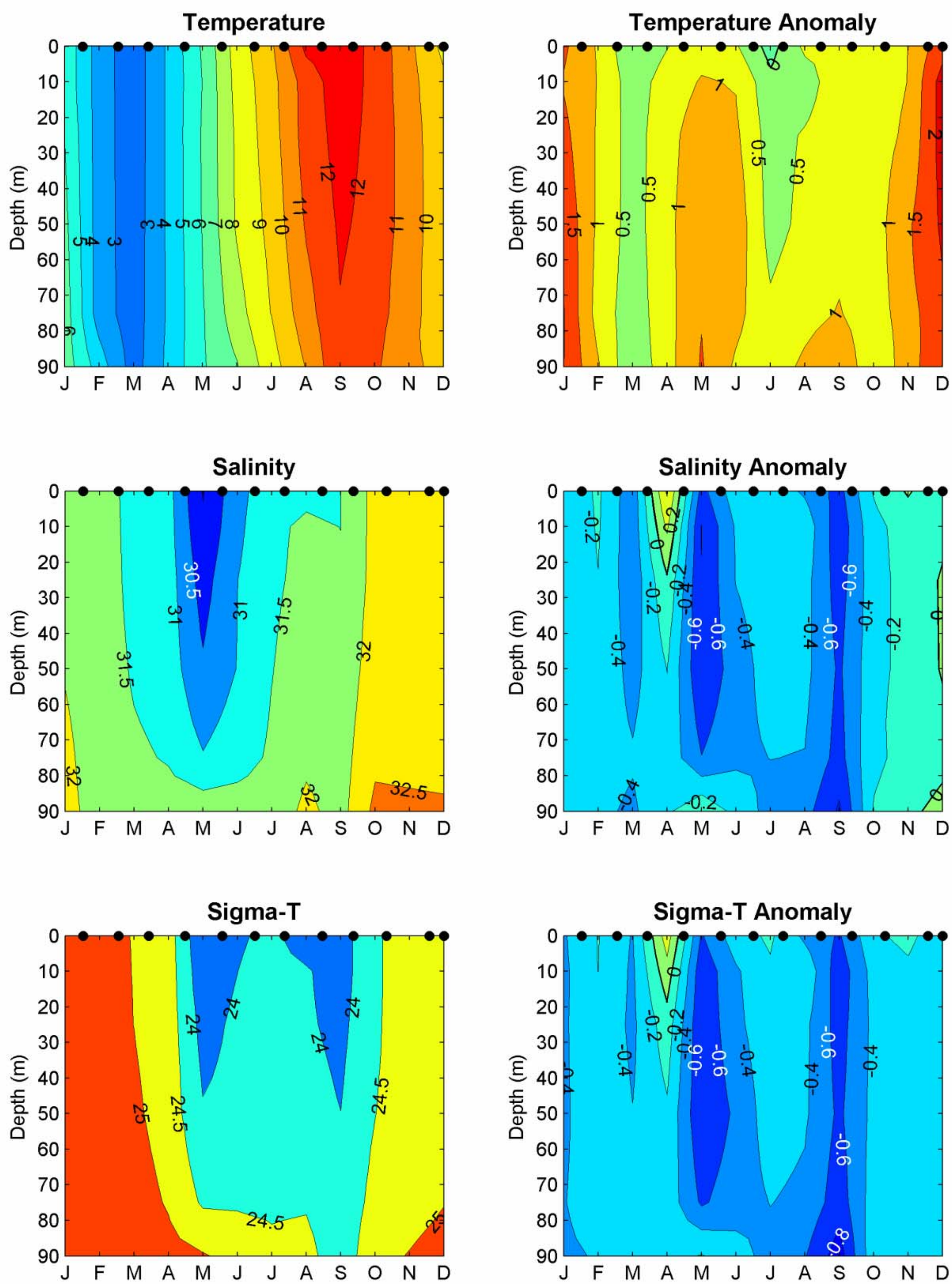

Figure 16. The 2011 annual cycle of temperature (top panel), salinity (middle panel) and density (lower panel) and their anomalies with respect to 1981-2010 monthly means (right panels) for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Bullets indicate periods of sampling.

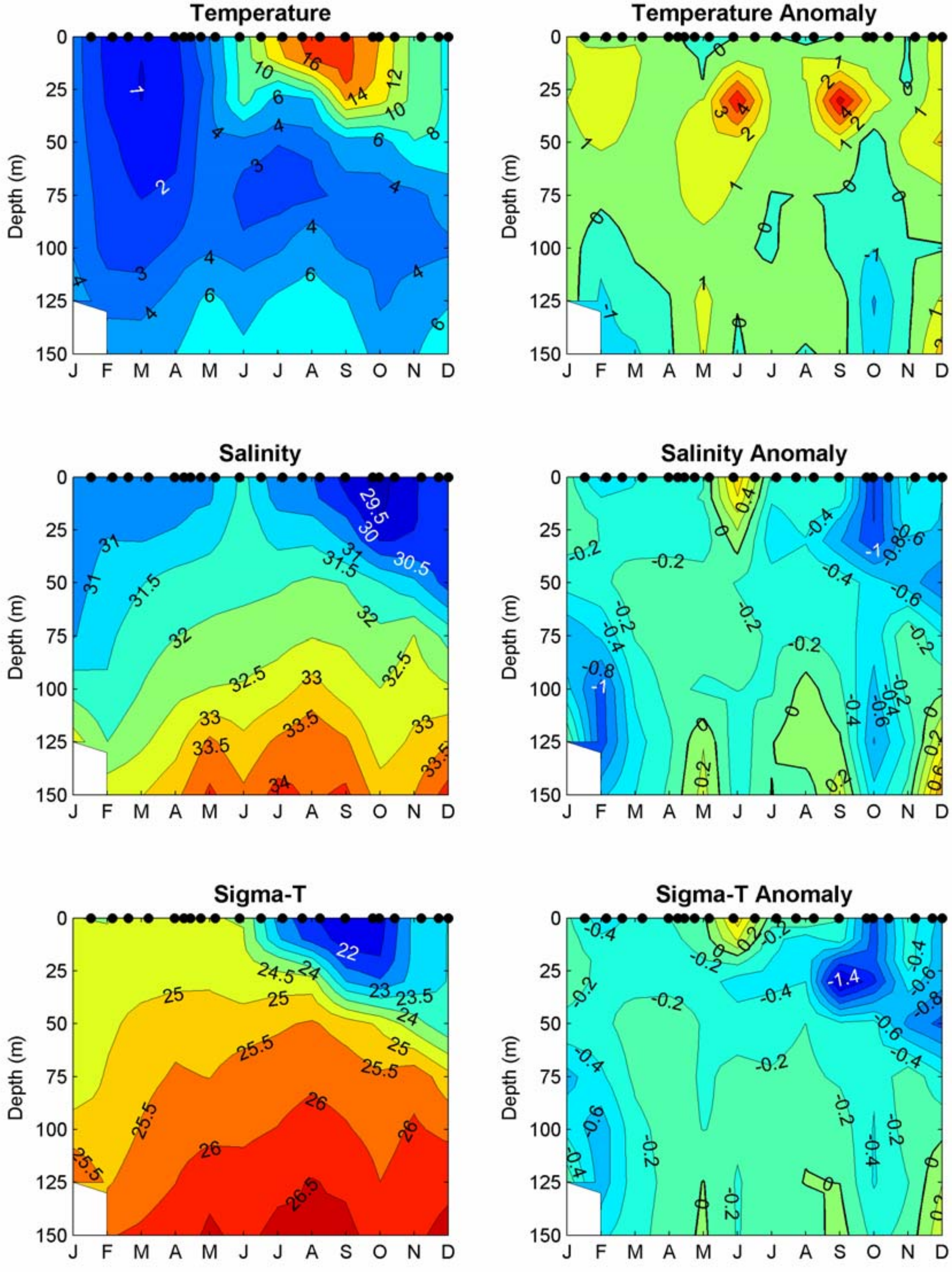

Figure 17. The 2011 annual cycle of temperature (top panel), salinity (middle panel) and density (lower panel) and their anomalies with respect to 1981-2011 monthly means (right panels) for Halifax station 2. Bullets indicate periods of sampling.

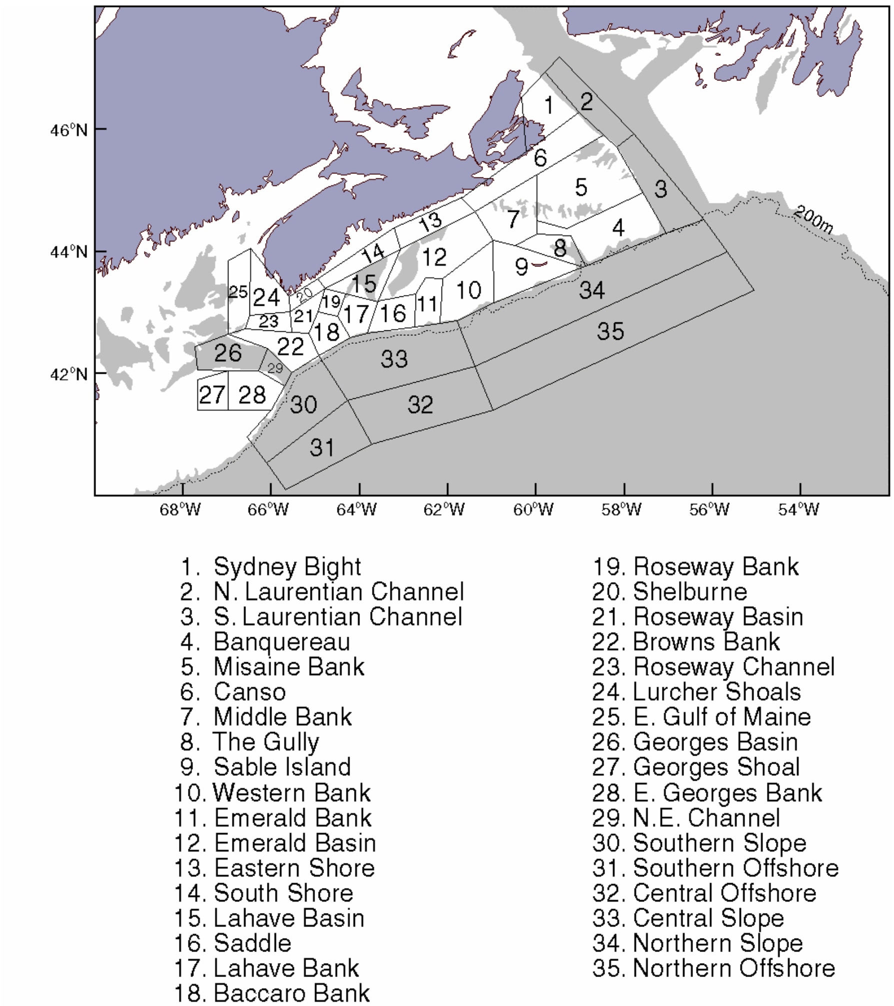

Figure 18. Areas on the Scotian Shelf and eastern Gulf of Maine from Drinkwater and Trites (1987).

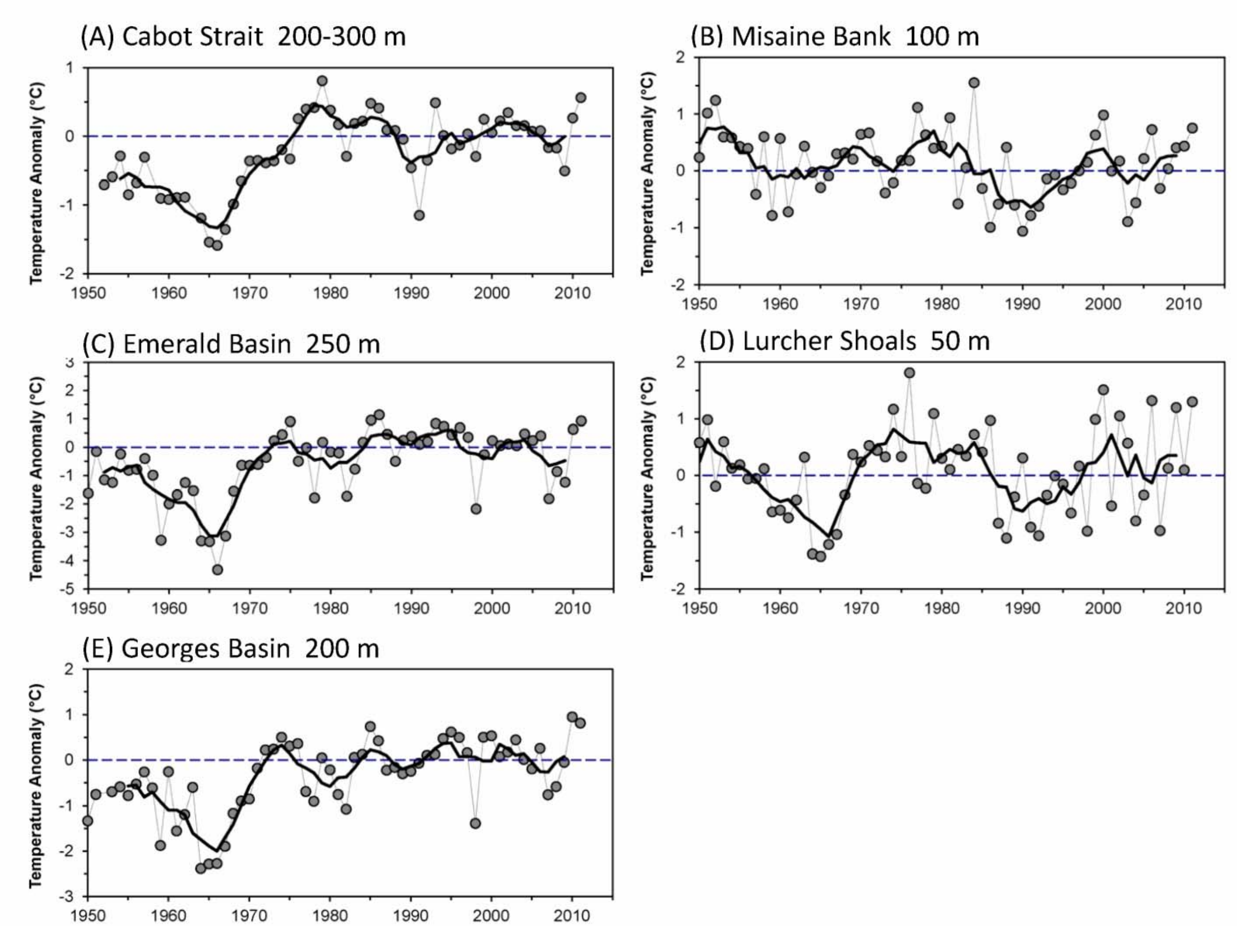

Figure 19. The annual mean temperature anomaly time series (dotted line with circles) and the five year running mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at (A) Cabot Strait 200-300 m; (B) Misaine Bank 100 m; (C) Emerald Basin 250 m; (D) Lurcher Shoals 50 m; and Georges Basin (200 m) (see Figure 18).

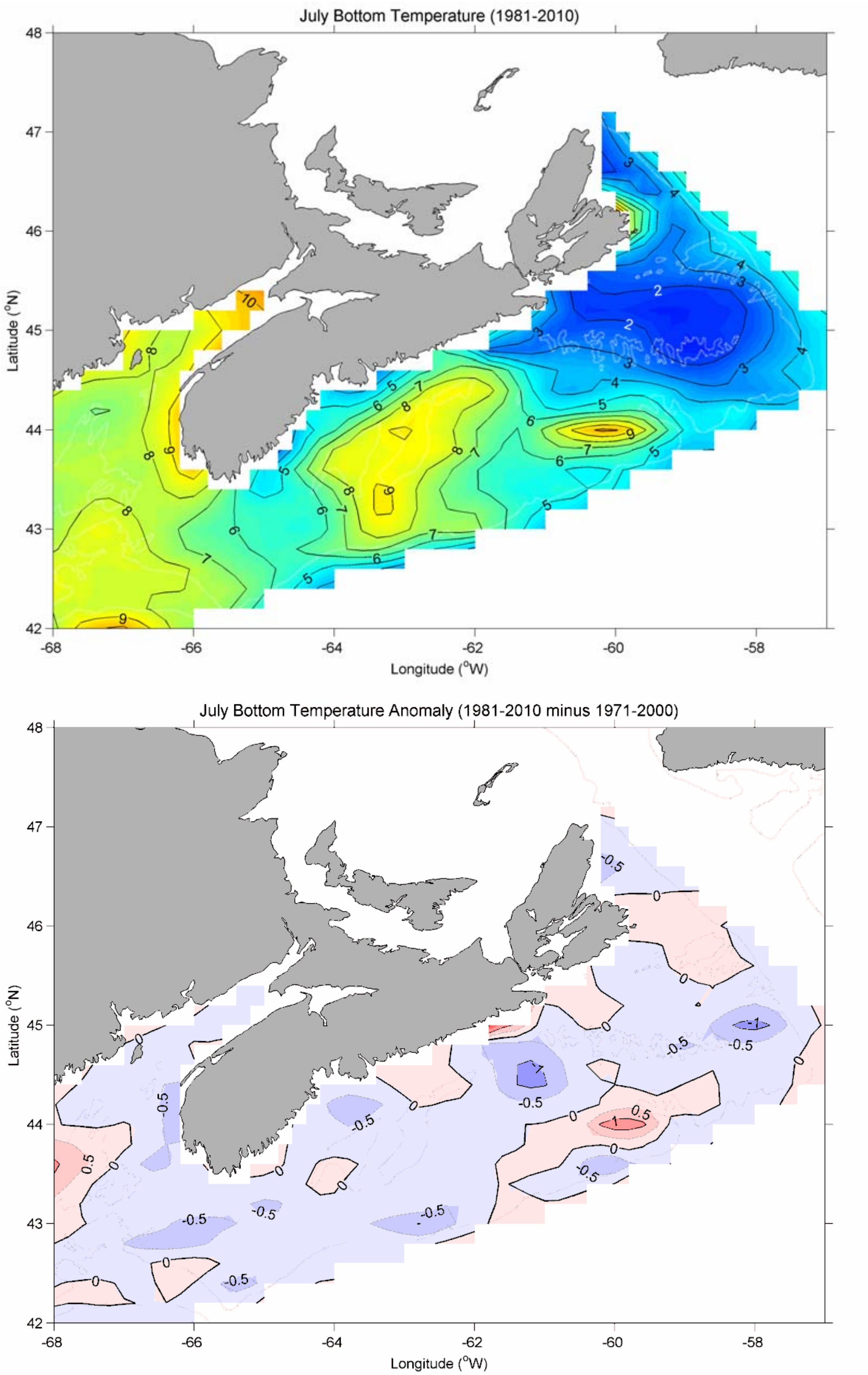

Figure 20. 1981-2010 Mean July bottom temperature (upper panel) and anomaly from the previously used 1971-2000 Mean July bottom temperature (lower panel) maps.

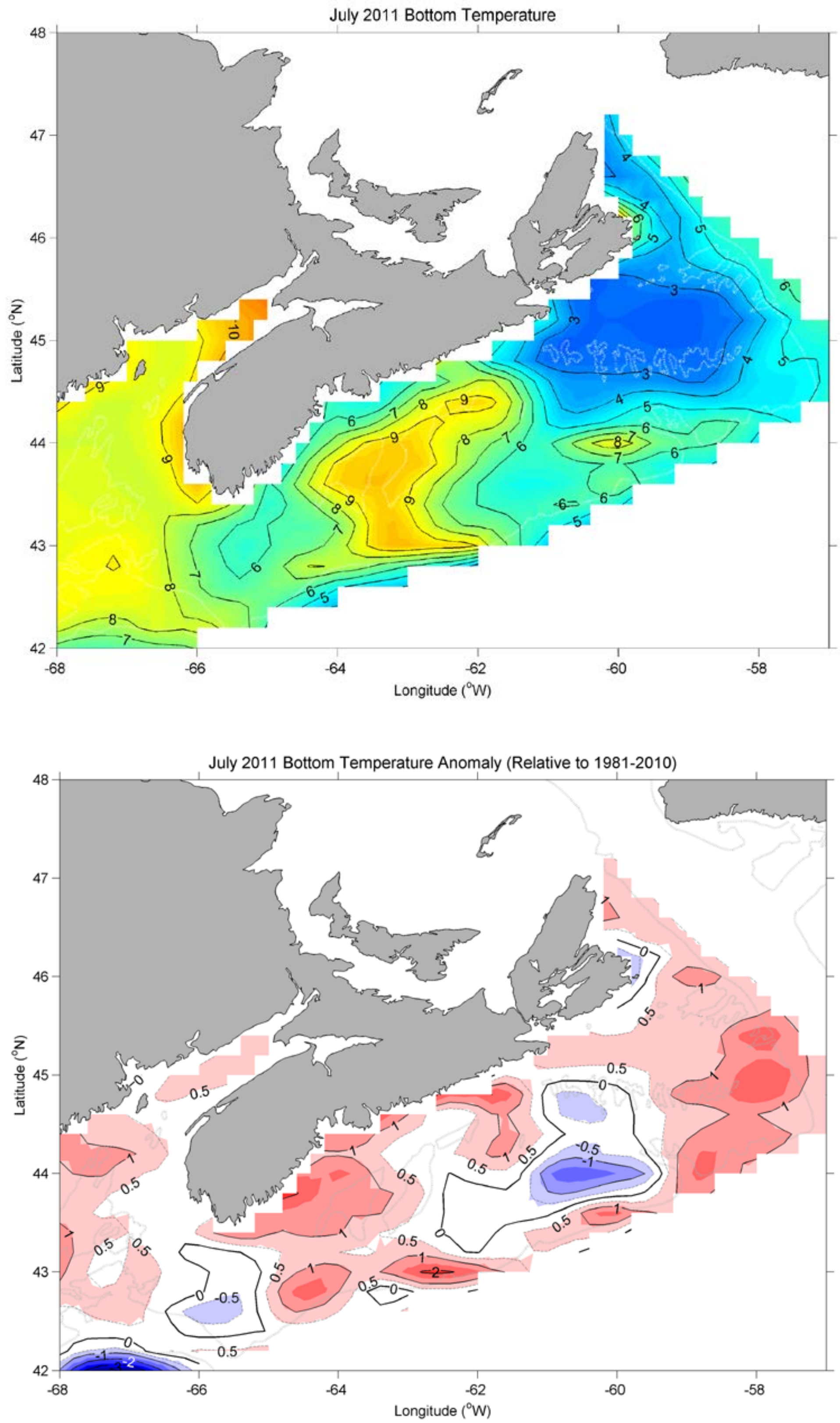

Fig. 21. *July bottom temperature (upper panel) and anomaly (lower panel) maps for 2011.*

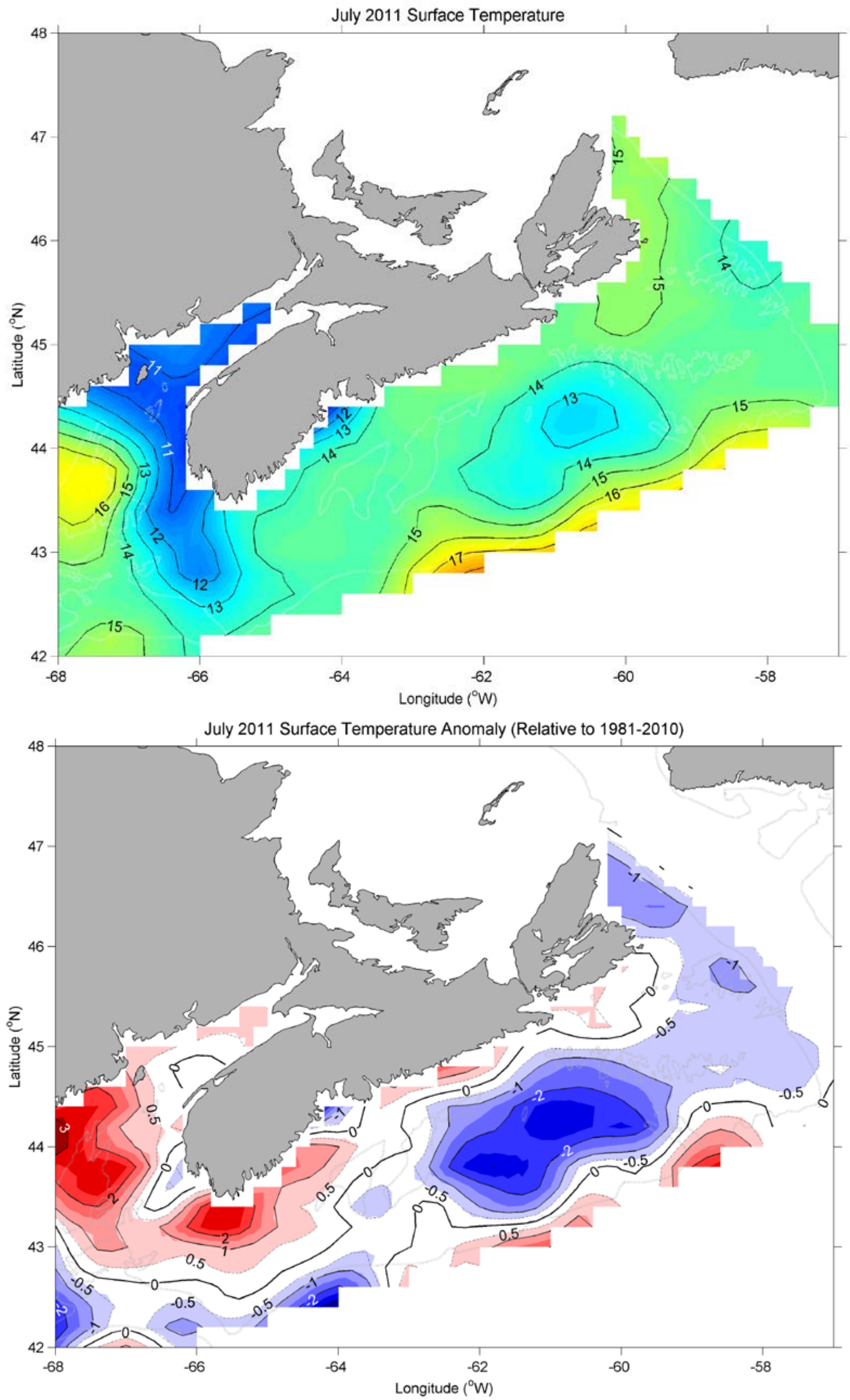

***Fig. 22.** July surface temperature (upper panel) and anomaly (lower panel) maps for 2011.*

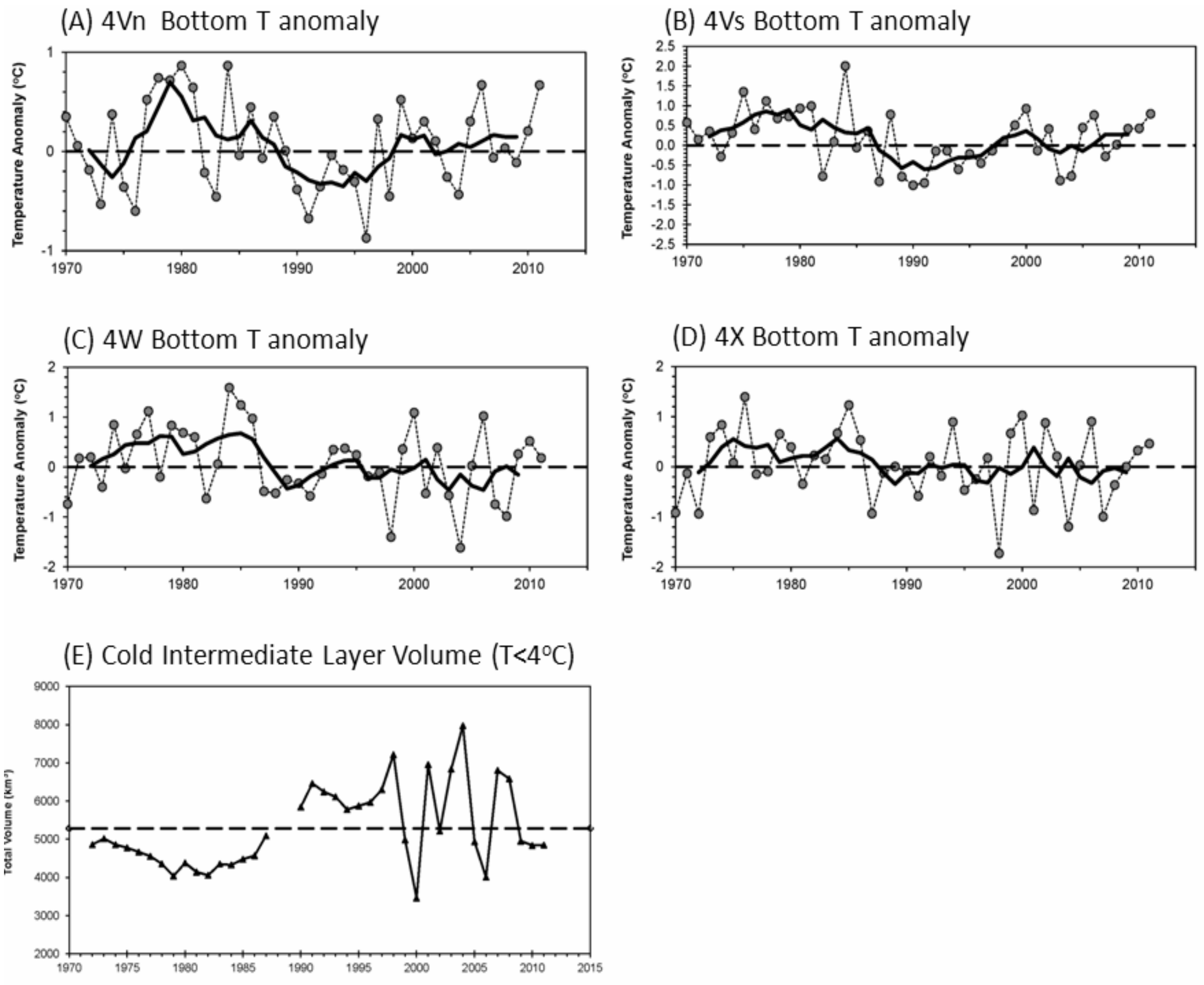

Figure 23. Time series of July bottom temperature anomalies (dashed lines with circles) and five year running mean filtered series (heavy line) for areas (A) 4Vn, (B) 4Vs, (C) 4W, and (D) 4X. (E) Time series of the Cold Intermediate Layer (defined as waters with temperature (T)<4^{o}C) volume on the Scotian Shelf based on the July ecosystem survey. The dashed horizontal line is the long-term mean.

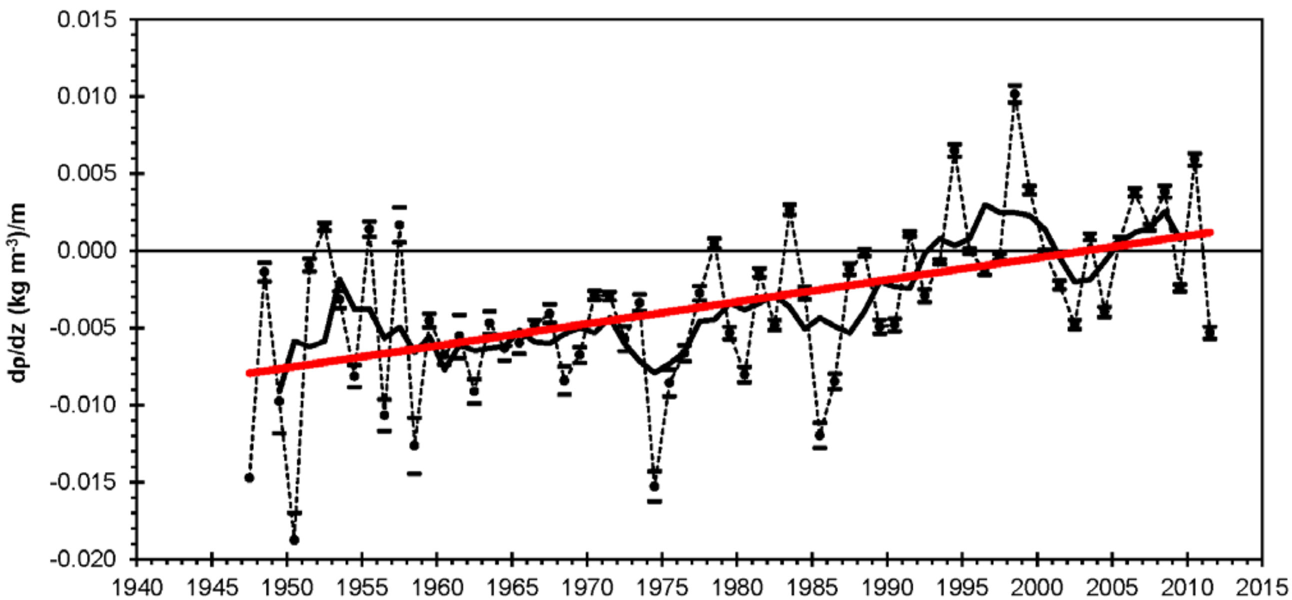

Figure 24. The mean annual anomaly (dashed line with circles) and five year running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive, see Figure 18). Standard error estimates for each annual anomaly value are also shown. The linear trend (red line) shows a change in the 0-50 m density difference of 0.36 kg m^{-3} over 50 years.

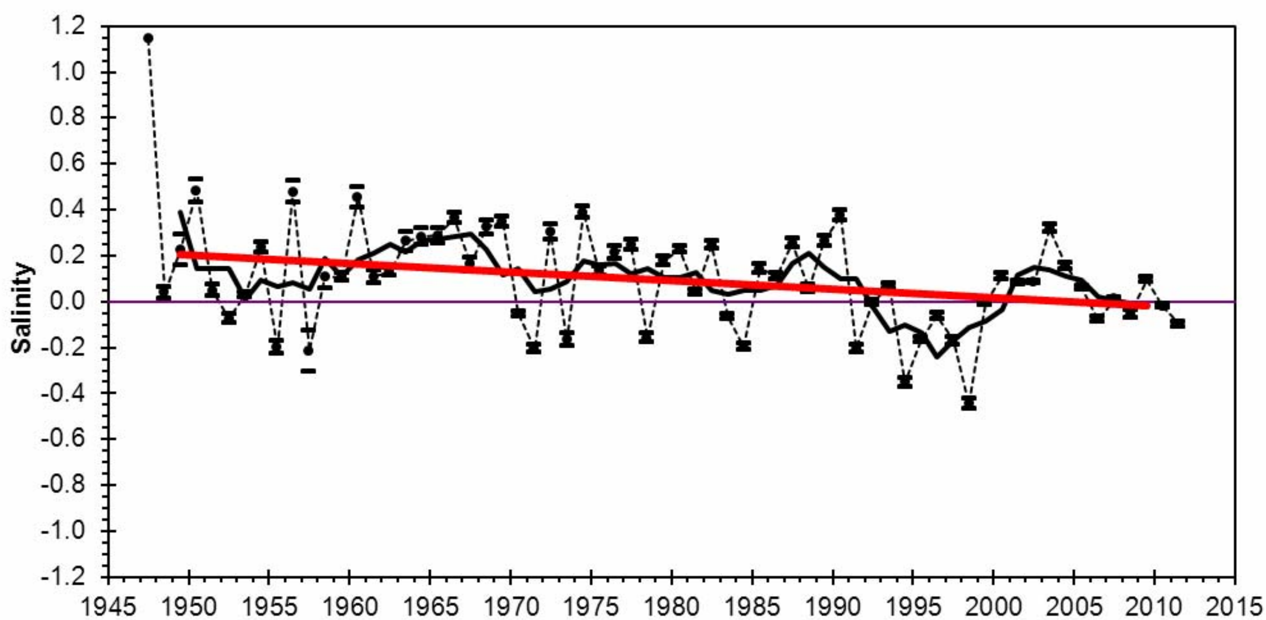

Figure 25. The mean annual surface salinity anomaly (dashed line with circles) and five year running mean (heavy solid line) averaged over the Scotian Shelf (areas 4-23 inclusive, see Fig. 18). Standard error estimates for each annual anomaly value are also shown. The linear trend (red line) shows a freshening of 0.18 over a 50 year period.

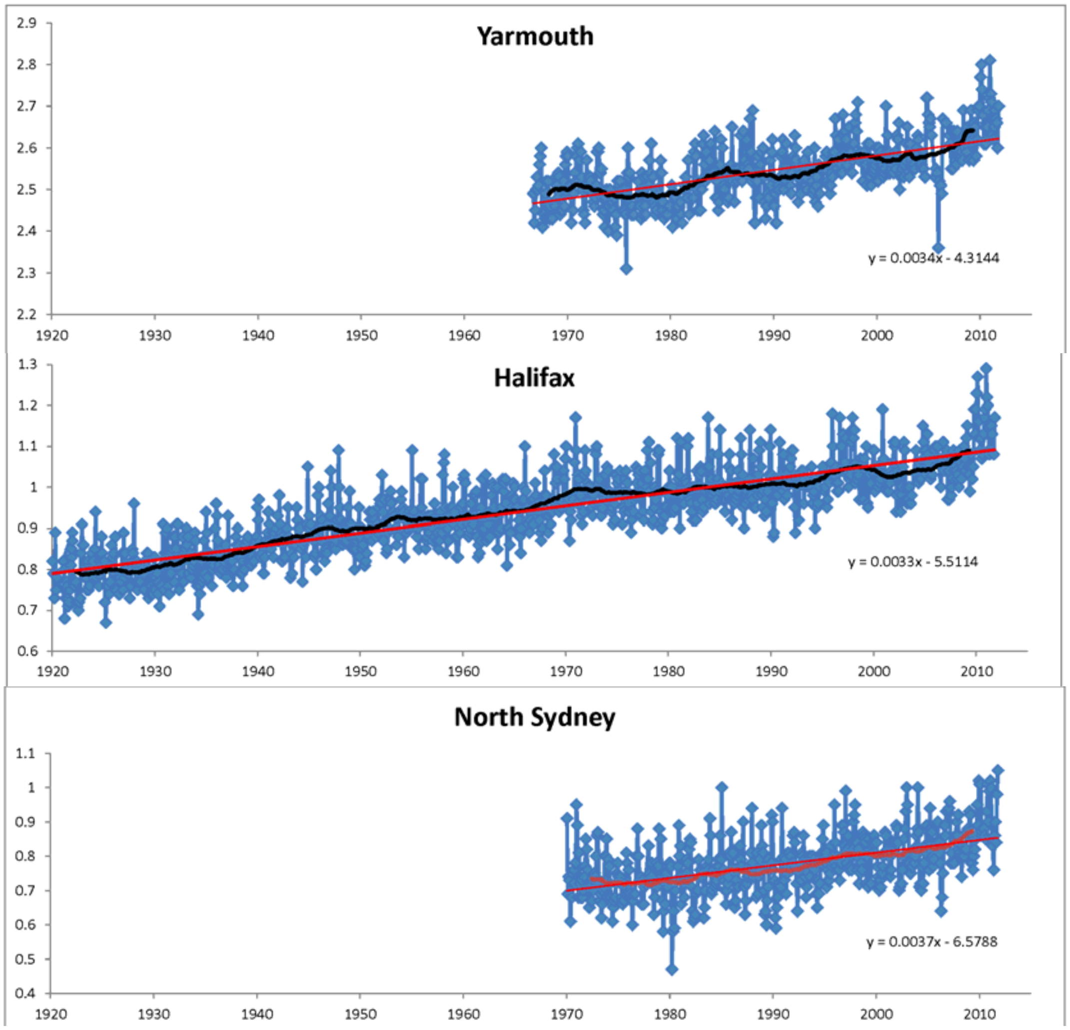

Figure 26. The time series of the monthly means (grey) and a five year running mean (black) of the relative sea level elevations at Yarmouth, Halifax, and North Sydney, along with the linear trend (red) over the observation period.

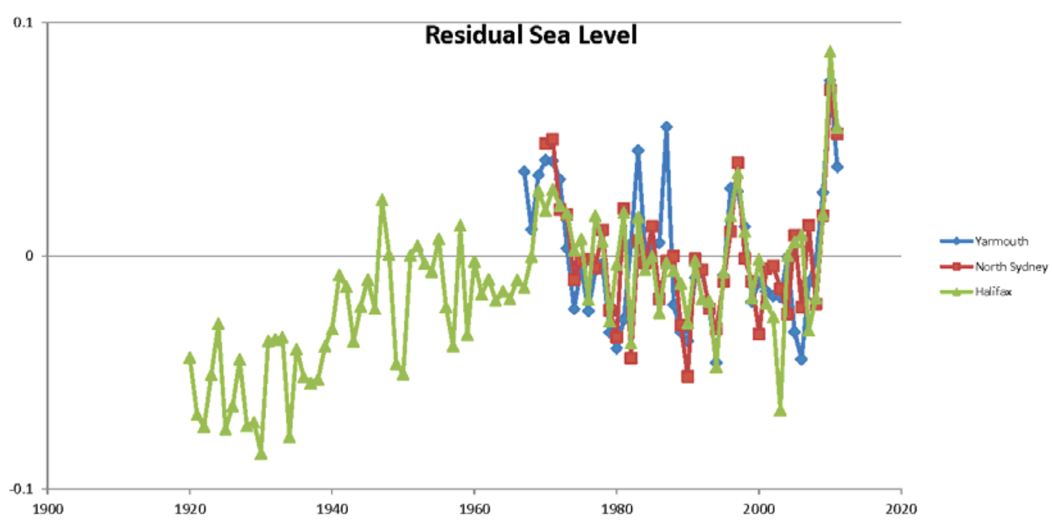

Figure 27. Residual relative sea level (monthly observed values – (1971-2011) linear trend, averaged to annual estimates).

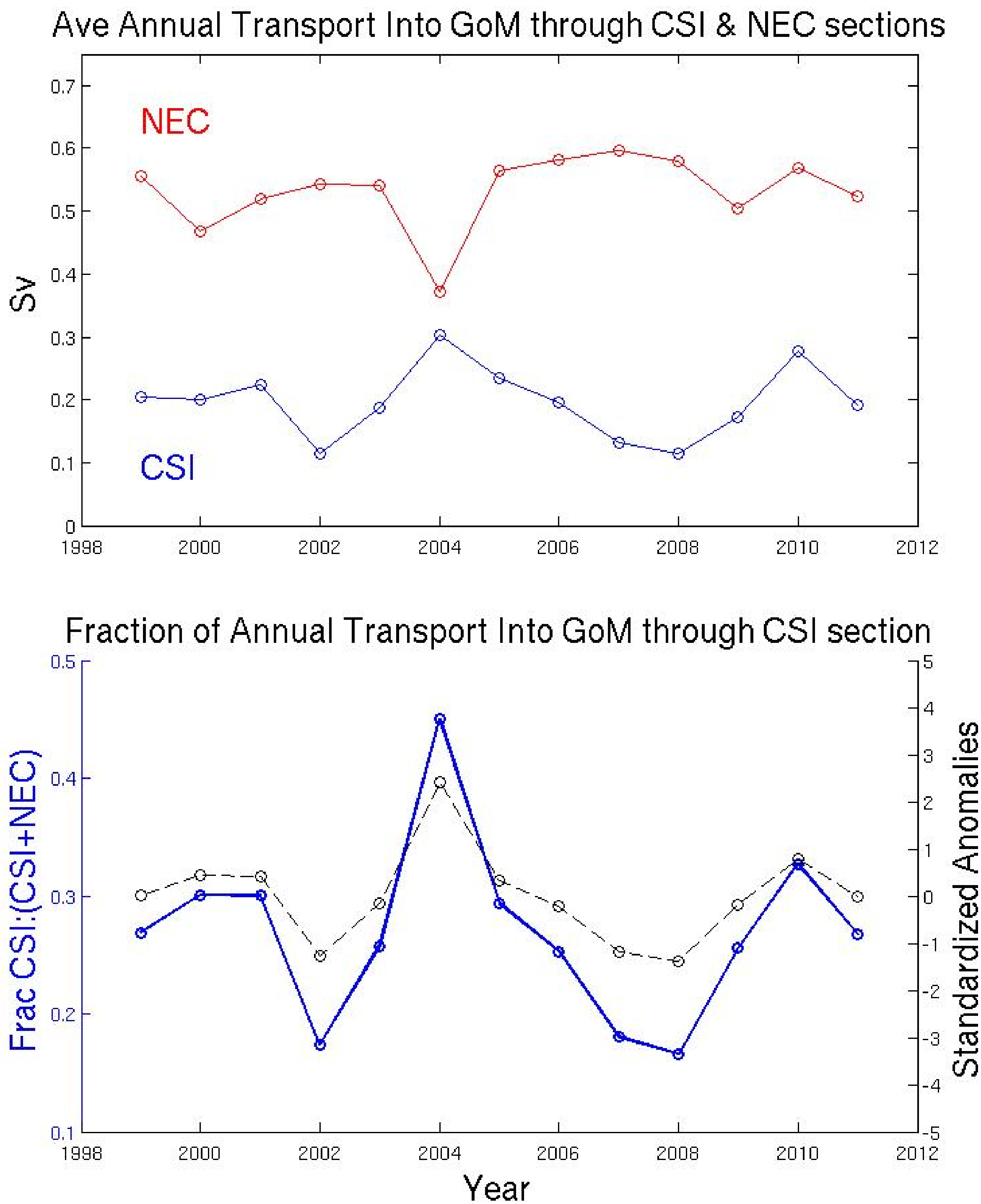

Figure 28. The annual transport into the Gulf of Maine (GoM) through the Cape Sable Island (CSI)/Browns Bank section and through the Northeast Channel (NEC) for 1999-2011 (top panel). The lower panel shows the fraction of the transport that comes through the on-shelf (CSI) pathway.

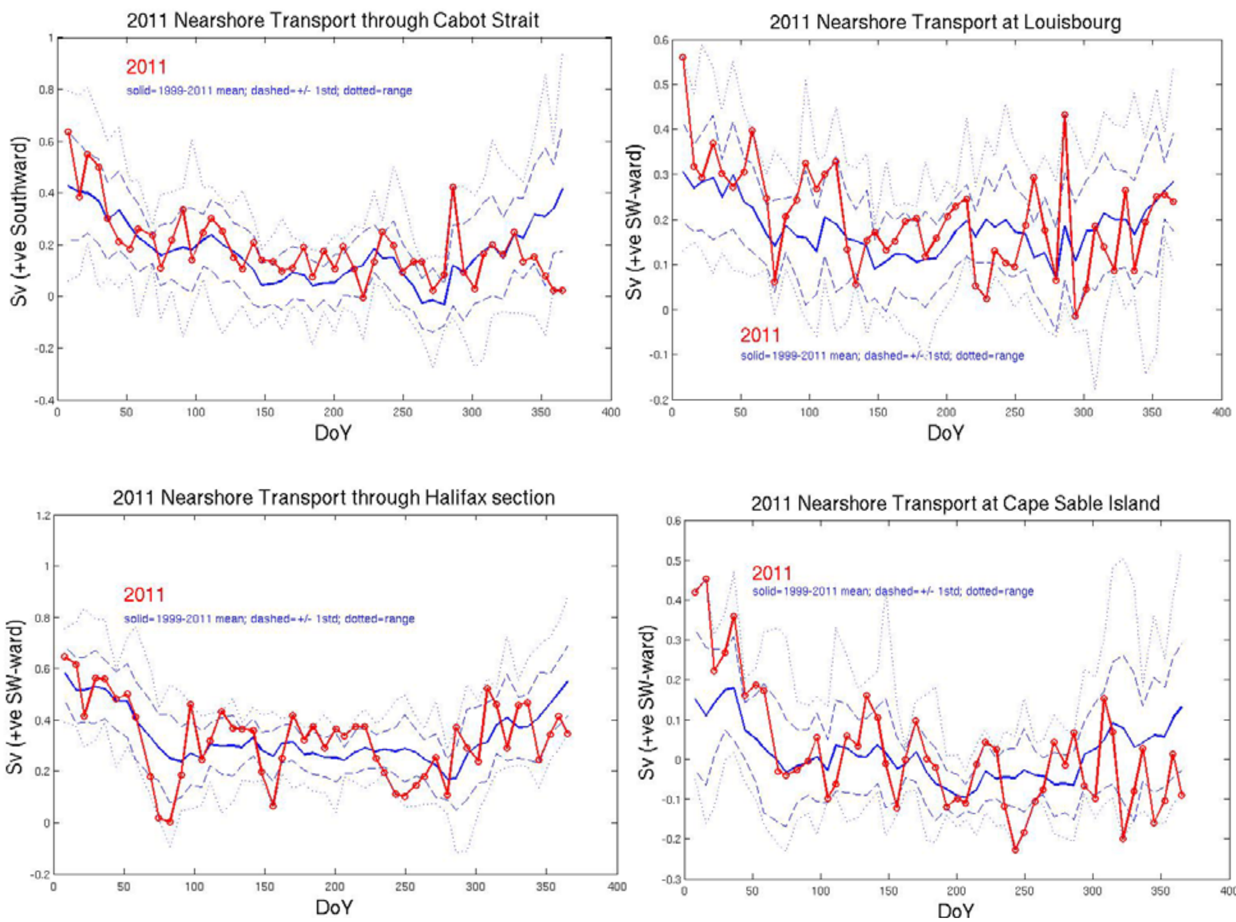

Figure 29. Nearshore (shoreward of the 100 m isobaths) for the four Maritime AZMP sections (Cabot Strait, Louisbourg, Halifax, Browns Bank/Cape Sable Island). Roughly weekly transport (50 outputs-per-year) for 2011 (red line) and the average transport (blue line), ±1 SD (dashed blue line) and range (dotted blue line) for the 1999-2011 period.

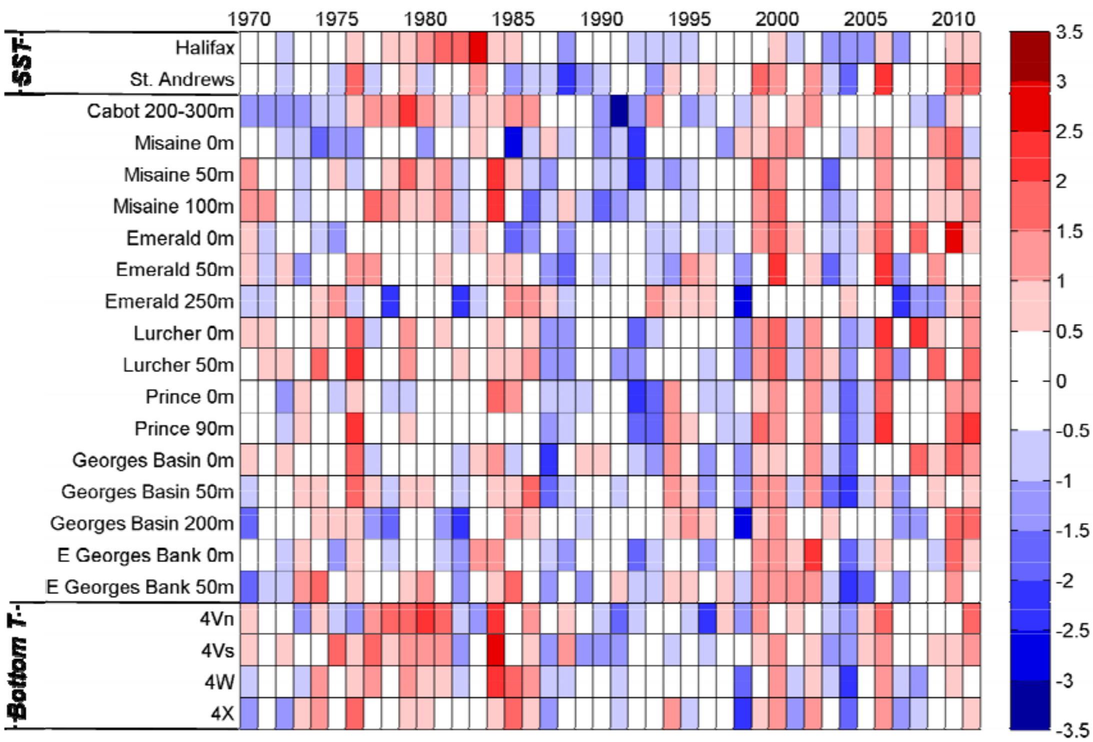

Figure 30. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf-Gulf of Maine region. These normalized, annual anomalies are based on the 1981-2010 means, divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal.

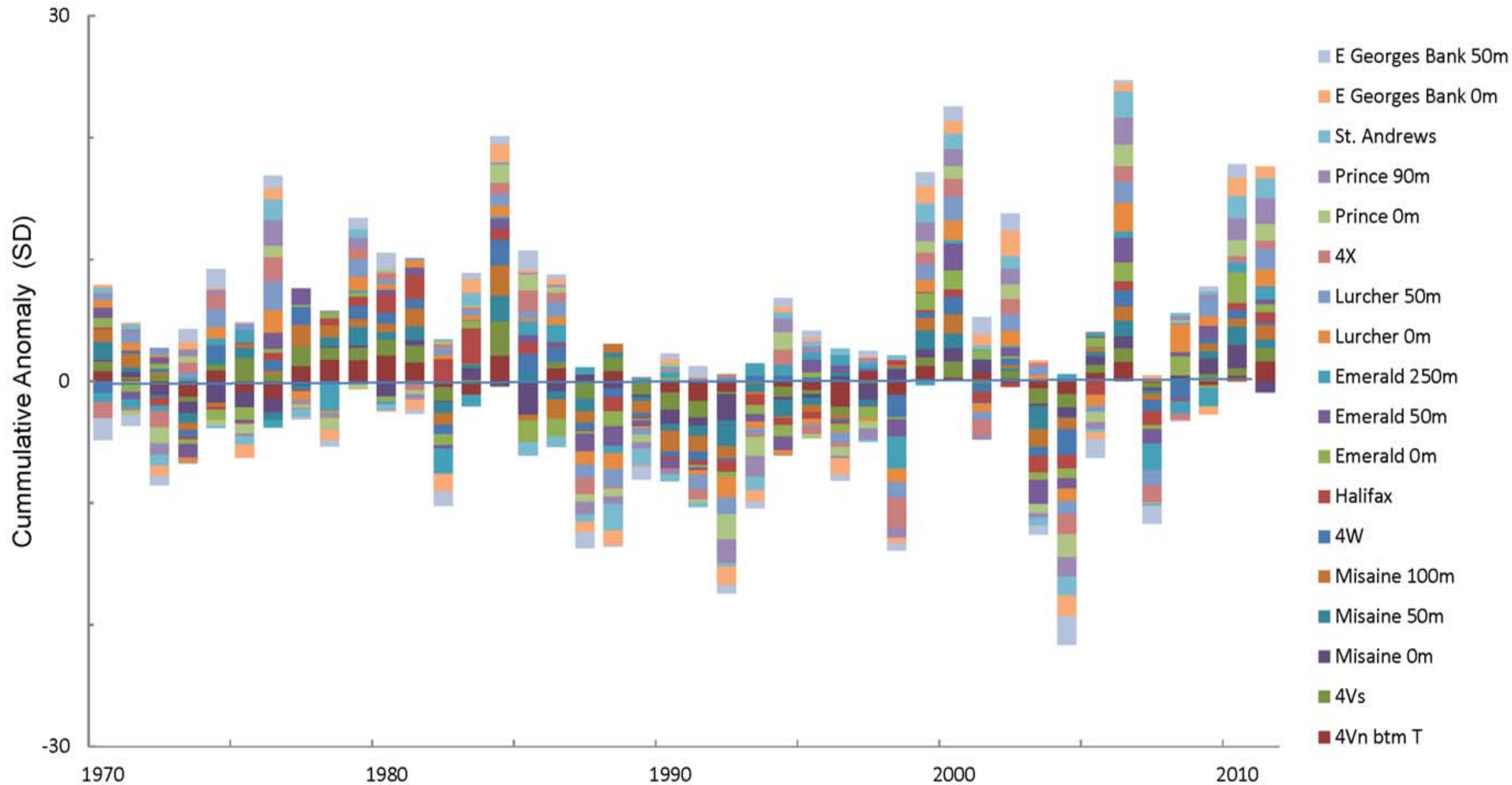

Figure 31. The contributions of each of the normalized anomalies are shown as a stacked bar chart.