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Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf During 2013

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

A key indicator of ocean climate conditions on the Newfoundland and Labrador (NL) Shelf, the North Atlantic Oscillation (NAO) index, returned to a weak negative phase in 2013 and as a result arctic air outflow to the Northwest Atlantic during the winter decreased over the previous year. This appears to have resulted in an increase in winter air temperatures over much of the Labrador Sea area causing a continuation of less sea-ice than normal on the NL Shelf. Annually however, air temperatures decreased over 2012 but remained above the long-term mean in southern Labrador by 0.5 SD (0.7°C at Cartwright) and Newfoundland by 0.8 SD (0.7°C at St. John's). The annual sea ice extent on the NL Shelf remained below normal (-1.4 SD) for the 18th consecutive year, a decrease of 0.5 SD over 2012. As a result of these and other factors, local water temperatures remained above normal in most areas in 2013 but showed a decrease over 2011-2012 values. Average sea surface temperatures on the NL Shelf decreased from 1.6 SD above normal in 2012 to about 0.4 SD above normal in 2013 and near shore at Station 27 they were 1.1OC (1.6 SD) above normal, similar to 2012. Bottom temperatures at Station 27 were 1 SD (0.4°C) above normal, nearly identical to 2012 values. Spring bottom temperatures in NAFO Div. 3P ranged from 0.4 to 1.1 SD above normal in 2013 down from near +2 SD in 2011 and in 3LNO they ranged from 0.8 to 1.3 SD above normal, a moderate decrease over the previous two years. Fall bottom temperatures in 2J, 3K and 3LNO decreased from 2, 2.7 and 1.8 SD above normal in 2011 to 1.1, 1.2 and 0.2 SD above normal in 2012 and to 0.8, 0.5 and 0.1 above normal in 2013, respectively, a significant decrease in the past 2 years. The area of the cold intermediate layer (CIL) water mass with temperatures <0°C along standard AZMP sections on the NL Shelf during the spring, summer and fall were below normal ranging from 0.7 to 1.5, 0.5 to 1.4 and 0.3 to 0.9 SD, respectively, implying a continuation of less cold shelf water than normal. In general, most environmental indices show a continuation of a warmer than normal trend throughout the area. During the past 2 years however, temperatures have decreased from the record warm conditions of 2011. A composite climate index derived from 27 meteorological, ice and ocean temperature and salinity time series declined from 8th highest in 2012 to the 18th highest in the 64 year time series in 2013.

Évaluation de l’environnement océanographique physique sur la plateforme continentale de Terre-Neuve-et-Labrador en 2013

RÉSUMÉ

Un indicateur clé des conditions climatiques de l’océan sur la plateforme continentale de Terre-Neuve-et-Labrador (T.-N.-L.), l'indice d'oscillation de l'Atlantique Nord, est revenu à une faible phase négative en 2013 et, par conséquent, le courant d'air arctique vers l'Atlantique Nord-Ouest en hiver a diminué pendant l'année dernière. Cela semble avoir donné lieu à une augmentation des températures de l'air hivernales sur la majeure partie de la zone de la mer du Labrador, prolongeant la période de glaces en quantités inférieures à la normale sur la plateforme de Terre-Neuve. Cependant, les températures annuelles de l'air ont diminué au cours de 2012, mais sont demeurées au-dessus de la moyenne à long terme dans le sud du Labrador par 0,5 écart-type (ÉT) (0,7 °C à Cartwright) et à Terre-Neuve par 0,8 ÉT (0,7 °C à St. John’s). L'étendue de la couverture de glace de mer annuelle sur la plateforme continentale de T.-N. est restée sous la normale (-1,4 ÉT) pour la 18e année consécutive, une réduction de 0,5 ÉT par rapport à 2012. Du fait de ces facteurs, entre autres, les températures de l'eau locales sont restées au-dessus de la normale dans la plupart des zones en 2013, mais ont affiché une diminution par rapport aux valeurs de 2011-2012. La moyenne des températures de la surface de la mer sur la plateforme de Terre-Neuve a diminué de 1,6 ÉT au-dessus de la normale en 2012 pour atteindre 0,4 ÉT au-dessus de la normale en 2013; près de la côte, à la station 27, elles étaient de 1,1 °C (1,6 ÉT) supérieures à la normale, une situation semblable à celle de 2012. À la station 27, les températures du fond étaient de 1 ÉT (0,4 °C) supérieures à la normale, presque identiques aux valeurs de 2012. Au printemps, les températures du fond dans la division 3P de l'OPANO variaient de 0,4 à 1,1 ÉT au-dessus de la normale en 2013, une baisse par rapport à la valeur de près de +2 ÉT en 2011; dans les divisions 3LNO, elles allaient de 0,8 à 1,3 ÉT au-dessus de la normale, ce qui représente une diminution modérée au cours des deux dernières années. À l'automne, les températures du fond dans les divisions 2J, 3K et 3LNO ont diminué, passant respectivement d'un ÉT de 2, 2,7 et 1,8 au-dessus de la normale en 2011 à un ÉT de 1,1, 1,2 et 0,2 au-dessus de la normale en 2012, puis à un ÉT de 0,8, 0,5 et 0,1 au-dessus de la normale en 2013. Il s'agit d'une diminution importante ces deux dernières années. Au cours du printemps, de l'été et de l'automne, la zone de la masse d'eau de la couche intermédiaire froide (CIF), dont les températures sont inférieures à 0 °C, le long des secteurs normaux du PMZA sur la plateforme de Terre-Neuve, était sous la normale, variant de 0,7 à 1,5, de 0,5 à 1,4 et de 0,3 à 0,9 ÉT, respectivement. Cela laisse entendre que l'eau de la plateforme continentale continue d'être moins froide que la normale. En général, la plupart des indices environnementaux montrent une poursuite de la tendance des températures supérieures à la normale dans l'ensemble de la région. Cependant, au cours des deux dernières années, les températures ont diminué depuis les conditions chaudes records de 2011. Un indice climatique composite obtenu à partir de 27 séries chronologiques répertoriant la température ambiante, celle de la glace et celle de l'océan ainsi que la salinité a décliné, passant du 8e rang le plus élevé en 2012 au 18e rang le plus élevé de toute la série chronologique de 64 ans en 2013.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Figure 1) during 2013 in relation to long-term average conditions based on archived data. It complements similar reviews of the environmental conditions in the Gulf of St. Lawrence and the Scotian Shelf and Gulf of Maine as part of the Atlantic Zone Monitoring Program (AZMP; Therriault et al. 1998; Galbraith et al. 2014; Hebert et al. 2014). When possible, the long-term averages were standardized to a ‘normal’ base period from 1981 to 2010 in accordance with the recommendations of the World Meteorological Organization.

The information presented for 2013 is derived from three main sources: (1) observations made at a monitoring location off St. John’s, NL (Station 27) throughout the year from all sources; (2) measurements made along standard NAFO and AZMP cross-shelf sections from seasonal oceanographic surveys (Figure 2); and, (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Figure 3). Data from other research surveys and ships of opportunity were also used to help define the long-term means and the conditions during 2013.

These data are available from archives at the Fisheries and Oceans Integrated Scientific Data Management (ISDM) Branch in Ottawa and maintained in a regional data archive at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL. An overview of the physical oceanographic conditions for 2012 was presented in Colbourne et al. (2013).

Time series of temperature and salinity anomalies and other derived climate indices were constructed by removing the annual cycle computed over a standard base period from 1981 to 2010. ‘Normal’ is defined in this document as the average over the base period. For shorter time series, the base period included all data up to 2013. It is recognized that monthly and annual estimates of anomalies that are based on a varying number of observations may only approximate actual conditions; caution therefore should be used when interpreting short time scale features of many of these indices.

Annual or seasonal anomalies were normalized by dividing the values by the standard deviation of the data time series over the base period, usually 1981–2010 if the data permit. A value of 2 for example indicates that the index was 2 standard deviations higher than its long-term average. As a general guide, anomalies within ±0.5 standard deviations in most cases are not considered to be significantly different from the long-term mean.

Normalized water property time series and derived climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2013 are presented in coloured boxes as figures with gradations of 0.5 standard deviations (SD). Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions (Figure 4). If the magnitude of the anomaly is ≥1.5 SD it is typeset in white. In some instances (NAO, ice and water mass areas or volumes for example) negative anomalies may indicate warm conditions and hence are coloured red.

Positive stratification and mixed-layer-depth anomalies (deeper than normal values) are colored red. Composite indices are derived by summing the standardized values for each year, reversing the sign when negative anomalies denote warmer than normal conditions such as ice or cold water mass areas.

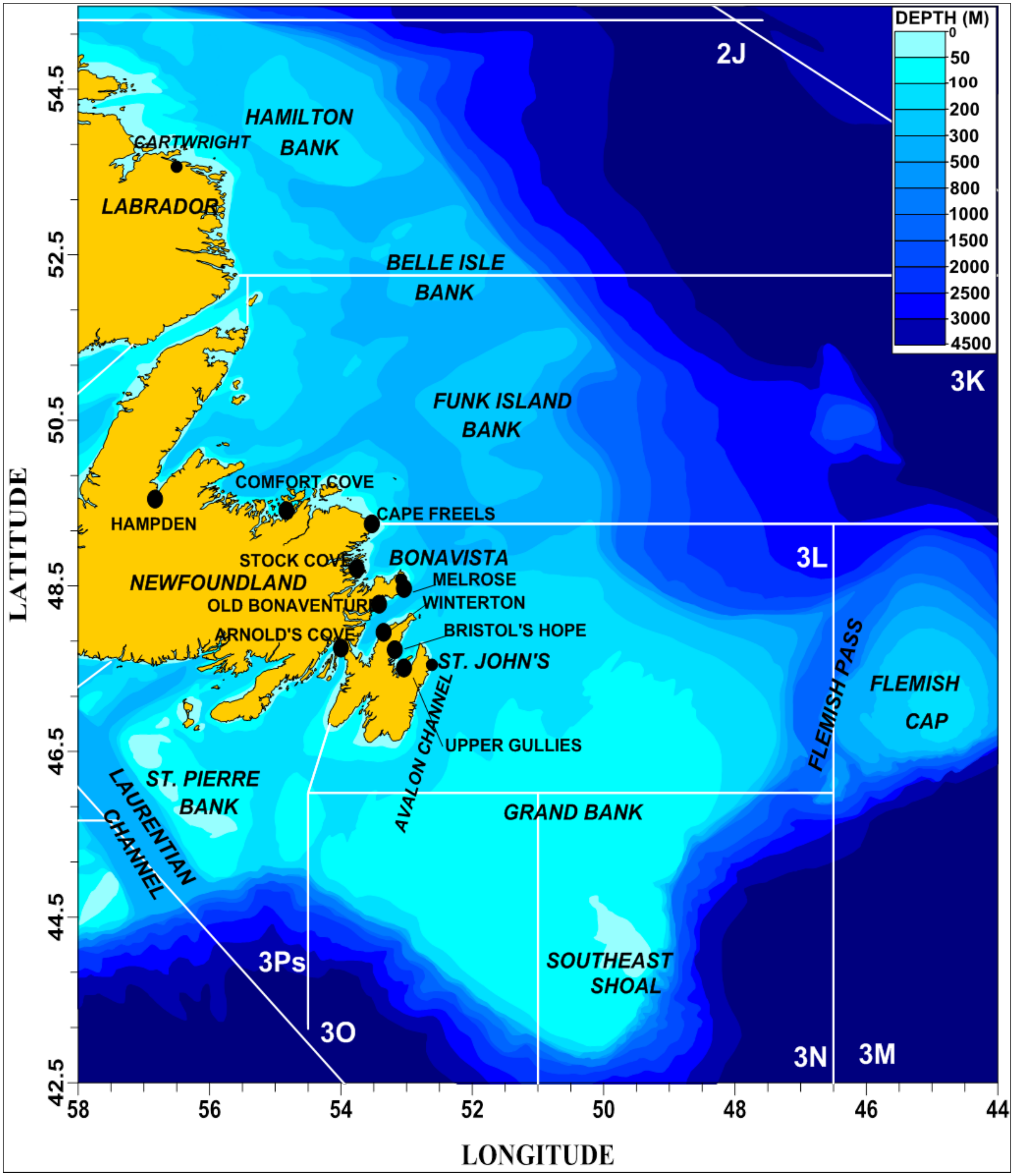

Figure 1. Map showing NAFO Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

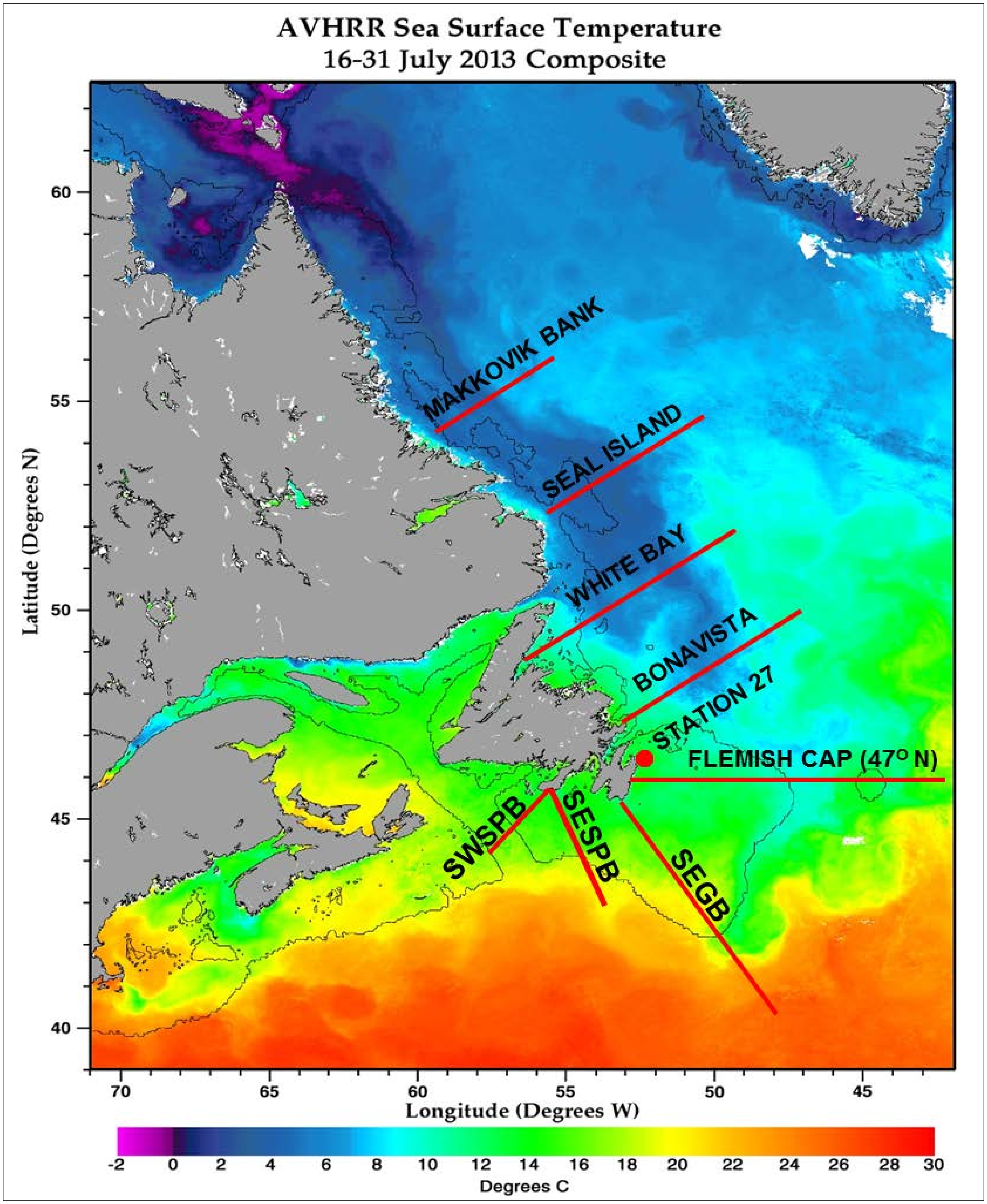

Figure 2. Map showing summer Sea-Surface-Temperature (SST) during July 16-31, 2013, Station 27 and the Makkovik Bank, Seal Island, White Bay, Bonavista, Flemish Cap, Southeast Grand Bank (SEGB), Southeast St. Pierre Bank (SESPB) and Southwest St. Pierre Bank (SWSPB) sections sampled during 2013 (SST map courtesy of the Ocean Research and Monitoring Section, BIO).

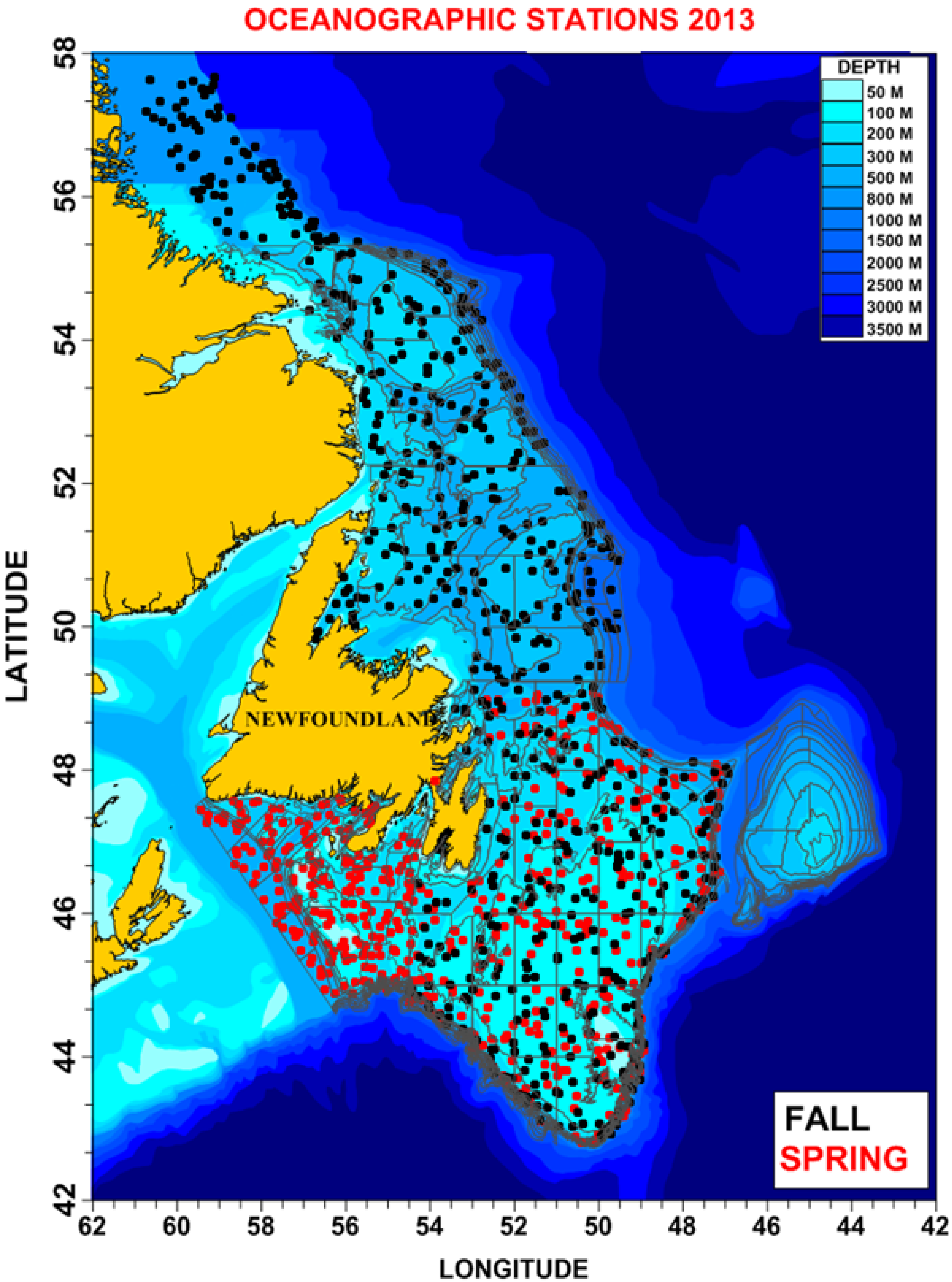

Figure 3. Map showing the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2013.

METEOROLOGICAL AND SEA-ICE CONDITIONS

The North Atlantic Oscillation (NAO) index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is often a measure of the strength of the winter westerly and north westerly winds over the Northwest Atlantic. A high (positive phase) NAO index occurs from an intensification of the Icelandic Low and Azores High. This favours strong northwest winds, cold air and sea temperatures and heavy ice conditions on the NL Shelf regions (Colbourne et al. 1994; Drinkwater 1996, Petrie et al. 2007). However, there are exceptions to this response pattern (e.g. 1999 and 2000) due to shifting locations in the sea level pressure (SLP) features. The NAO decreased to slightly negative at 0.4 SD below normal in 2013 down from 1.3 SD above normal in 2012. It was at a record low of 2.9 SD below normal in 2010 and increased to 1.2 SD below normal in 2011. The similar, but larger scale Arctic Oscillation also returned to a negative phase in 2013 at 1.1 SD below normal (Figure 5). As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2013 decreased over the previous year causing a significant increase in winter air temperatures over much of the Labrador Sea and adjacent shelves.

Air temperature anomalies at five sites in the Northwest Atlantic (Nuuk Greenland, Iqaluit Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland) are shown in Figure 5 as a table of standardized values. Annual values in 2013 decreased over the previous year but remained above normal at all five sites while winter values increased. The predominance of warmer-than-normal annual and seasonal air temperatures at all sites from the mid-1990s to 2007 is evident, with 2006 values ranging from 0.7-1.8 SD above normal. There was a slight increase in the annual air temperatures in 2009 at 4/5 sites and a significant increase at all sites in 2010 with air temperatures reaching record highs at northern sites with values 2-3 SD above normal. At Cartwright on the mid-Labrador Coast and at Iqaluit on southern Baffin Island, annual air temperatures were 2.5 and 2.7 SD above normal in 2010, setting 77 and 65 year records, respectively. There was a decrease at all sites in 2011 from the record highs in 2010 with annual values at Nuuk in West Greenland decreasing to 0.2 SD below normal. The cumulative annual air temperature index remained above normal in 2013 but is showing a decreasing trend since the record high set in 2010 (Figure 6). These conditions contrasted sharply with the cold conditions experienced in the early 1990s when annual anomalies often exceeded 1 SD below normal (Figure 6).

Data on the spatial extent and concentration of sea ice are available from the daily ice charts published by the Canadian Ice Service of Environment Canada. The annual average sea-ice extent (defined by 1/10 coverage) on the NL Shelf (between 45^{o}-55^{o}N) derived from these charts show below normal (-1.4 SD) sea ice extent in 2013 for the 18th consecutive year (Figure 5). It decreased by 0.5 SD from the 2012 value and reached close to the 49-year record low of 2011 of -1.7 SD. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. Exceptions were 2007 and 2009 when it extended into June, particularly in the inshore areas.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that only 13 (-1.2 SD) icebergs drifted south of 48^{o}N onto the Northern Grand Bank during 2013, down from 499 in 2012. In the two years previous there were only 3 in 2011 and one in 2010. The 114-year average is 470 and that for the 1981-2010 is 767. In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48^{o}N with an all-time record of 2202 in 1984. Years with low iceberg numbers on the Grand Banks generally correspond to higher than normal air temperatures, lighter than normal sea-ice conditions and warmer than normal ocean temperatures on the NL Shelf.

A composite index derived from the meteorological and sea-ice data presented in Figure 5 indicate that annual values for the past decade were either near-normal or warmer than normal with 2010 showing the warmest in the time series with a significant decline during the past 3 years (Figure 7). Hebert et al.

(2014) elaborated on meteorological and sea ice conditions in the Northwest Atlantic, including the Newfoundland and Labrador Shelf.

COLD		FRESH				WARM	SALTY				
<-2.5	-2.5 to -2.0	-2 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2	2.0 to 2.5	>2.5

Figure 4. Standardized anomaly colour coding scale in units of 0.5 standard deviations.

LOCATION	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	MEAN	SD
ARCTIC OSCILLATION (AO)	-0.6	-0.2	-0.4	0.2	0.3	-1.3	-1.8	-0.9	-0.4	2.7	1.3	0.4	1.1	1.8	-0.4	0.7	-1.1	-0.1	-0.8	0.6	1.1	-1.3	0.5	-0.6	-1.0	0.1	-0.8	1.0	0.9	0.3	-3.4	-0.9	0.7	-1.1	N/A	N/A
(ICELAND-AZORES) NAO	-0.4	0.6	-0.6	0.8	1.2	-1.2	-1.1	-1.0	-0.5	1.6	1.1	0.4	0.3	0.9	0.4	1.3	-1.4	-0.6	-0.3	1.2	1.1	-0.9	-0.3	-0.3	-1.0	0.5	-0.3	0.3	0.5	0.2	-2.9	-1.2	1.3	-0.4	20.44	8.77
NA SST (AMO)	0.0	-0.1	-0.2	-0.1	-0.2	-0.3	-0.3	0.1	0.0	-0.1	0.0	-0.1	-0.2	-0.2	-0.2	0.1	-0.1	0.1	0.4	0.1	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.1	0.0	0.4	0.1	0.2	0.2	N/A	N/A
NUUK WINTER AIR T	1.2	0.5	-0.2	-2.0	-2.3	1.1	1.0	0.0	0.8	-1.3	-0.6	-0.2	-0.8	-1.8	-0.4	-0.9	0.7	-0.2	0.0	-0.2	0.0	0.5	-0.2	0.9	0.7	1.2	0.9	1.0	-0.7	0.6	1.8	0.3	-0.1	1.1	-8.41	3.16
NUUK ANNUAL AIR T	0.6	0.1	-1.0	-1.8	-2.0	1.2	0.1	0.0	0.3	-1.2	-0.7	-0.4	-1.4	-1.6	-0.6	-0.2	0.4	0.1	0.2	-0.2	0.4	0.8	0.2	1.3	0.6	1.1	0.7	0.5	0.2	0.5	2.6	-0.3	0.9	0.6	-1.37	1.53
IQALUIT WINTER AIR T	1.3	2.3	0.2	-1.6	-1.2	1.1	0.6	-0.6	0.1	-1.5	-0.8	-1.4	-0.6	-1.7	-0.5	0.0	0.3	0.2	-0.5	0.0	0.3	0.5	0.0	0.5	0.9	-0.3	0.6	1.2	-0.7	0.1	2.2	2.1	0.2	1.2	-25.68	3.05
IQALUIT ANNUAL AIR T	1.0	2.4	-1.5	-2.6	-1.9	1.9	-1.3	-1.3	-0.2	-1.9	-1.2	-0.5	-1.7	-1.7	-0.4	0.5	0.5	0.3	0.2	0.1	0.4	0.6	-0.1	0.8	0.1	0.9	1.4	0.2	-0.1	0.5	2.7	0.5	0.6	0.2	-9.07	1.76
CARTWRIGHT WINTER AIR T	0.8	1.9	-0.6	-0.6	-0.8	0.4	-0.1	0.5	-0.2	-1.0	-1.2	-1.4	-1.5	-1.5	-1.0	-0.8	0.6	0.2	0.8	0.4	0.3	0.0	0.4	0.2	1.7	0.0	0.7	0.9	-0.8	0.2	2.8	2.1	0.0	1.2	-12.13	2.56
CARTWRIGHT ANNUAL AIR T	-0.2	1.4	-1.7	-0.7	-1.4	-0.8	-1.2	0.6	-0.4	-0.8	-1.3	-1.6	-1.4	-1.3	-0.6	-0.3	0.5	-0.3	0.6	1.1	0.5	0.6	-0.3	0.4	1.1	0.9	1.8	0.1	0.1	0.4	2.5	0.7	1.4	0.5	0.05	1.32
BONAVISTA WINTER AIR T	0.2	1.4	-0.6	0.4	0.3	-0.8	-0.1	-0.1	0.4	-1.1	-1.7	-0.8	-1.1	-1.7	-1.7	-0.4	1.0	-0.8	0.6	1.9	1.2	0.3	0.1	-1.1	0.8	0.3	1.5	0.2	-0.1	0.4	1.5	1.2	0.7	1.0	-3.96	1.47
BONAVISTA ANNUAL AIR T	-1.0	0.7	-1.0	0.1	-0.4	-1.4	-0.9	-0.2	0.2	-0.2	-0.6	-1.8	-1.8	-1.8	-0.7	-0.7	0.6	-0.9	0.6	1.5	0.8	0.6	-0.1	0.5	1.0	1.2	1.7	0.0	0.7	0.5	1.6	0.8	1.7	1.1	4.71	0.89
ST. JOHN'S WINTER AIR T	-0.1	1.3	-0.8	0.9	0.7	-1.0	0.0	-0.4	0.3	-1.4	-2.1	-1.1	-1.7	-1.5	-1.2	-0.8	0.4	0.2	0.2	1.2	1.4	-0.6	0.2	-0.6	0.9	0.7	1.6	0.2	-0.1	1.1	1.2	2.4	1.2	0.9	-4.00	1.43
ST. JOHN'S ANNUAL AIR T	-1.2	1.0	-1.0	0.5	0.2	-1.7	-1.0	-0.5	0.2	-0.6	-0.5	-1.4	-1.7	-1.5	-0.5	-0.7	0.3	-1.1	0.6	1.9	1.0	0.3	-0.4	0.4	0.6	0.7	1.6	-0.1	0.8	0.9	1.7	0.6	2.3	0.8	5.03	0.84
NL SEA-ICE EXTENT (Annual)	-0.3	-0.9	-0.2	0.9	1.8	1.9	0.3	-0.1	-0.1	0.3	1.2	1.6	1.3	1.6	1.1	0.1	-0.9	-0.2	-0.5	-0.7	-0.4	-0.9	-0.5	-0.2	-1.4	-0.9	-1.4	-0.6	-0.3	-0.1	-1.6	-1.7	-0.9	-1.4	74179	33578
NL SEA-ICE EXTENT (Winter)	-0.2	-0.8	-0.6	0.4	1.8	1.8	0.6	-0.1	0.0	0.7	1.1	1.1	1.3	1.7	1.3	0.4	-0.5	0.1	-0.7	-0.5	-0.3	-0.9	-0.6	-0.2	-1.7	-0.7	-1.3	-0.9	-0.1	-0.4	-1.9	-1.9	-0.9	-1.5	196477	81320
NL SEA-ICE EXTENT (Spring)	-0.4	-1.0	0.2	1.6	1.6	1.9	-0.4	-0.1	-0.4	-0.2	0.9	1.9	1.2	1.5	1.0	-0.2	-1.2	-0.4	-0.1	-0.9	-0.6	-0.8	-0.5	0.0	-0.9	-1.2	-1.5	-0.1	-0.6	0.5	-1.1	-1.4	-0.7	-1.1	92546.7	52253
ICEBERG COUNT	-1.1	-1.1	-0.9	0.9	2.2	0.5	-0.9	-0.7	-0.9	-0.7	0.0	1.9	0.2	1.5	1.5	1.0	-0.2	0.4	1.0	-1.1	0.1	-1.0	0.2	0.2	-0.8	-1.2	-1.2	-0.7	0.3	0.7	-1.2	-1.2	-0.4	-1.2	767	649

Figure 5. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1980 to 2013.

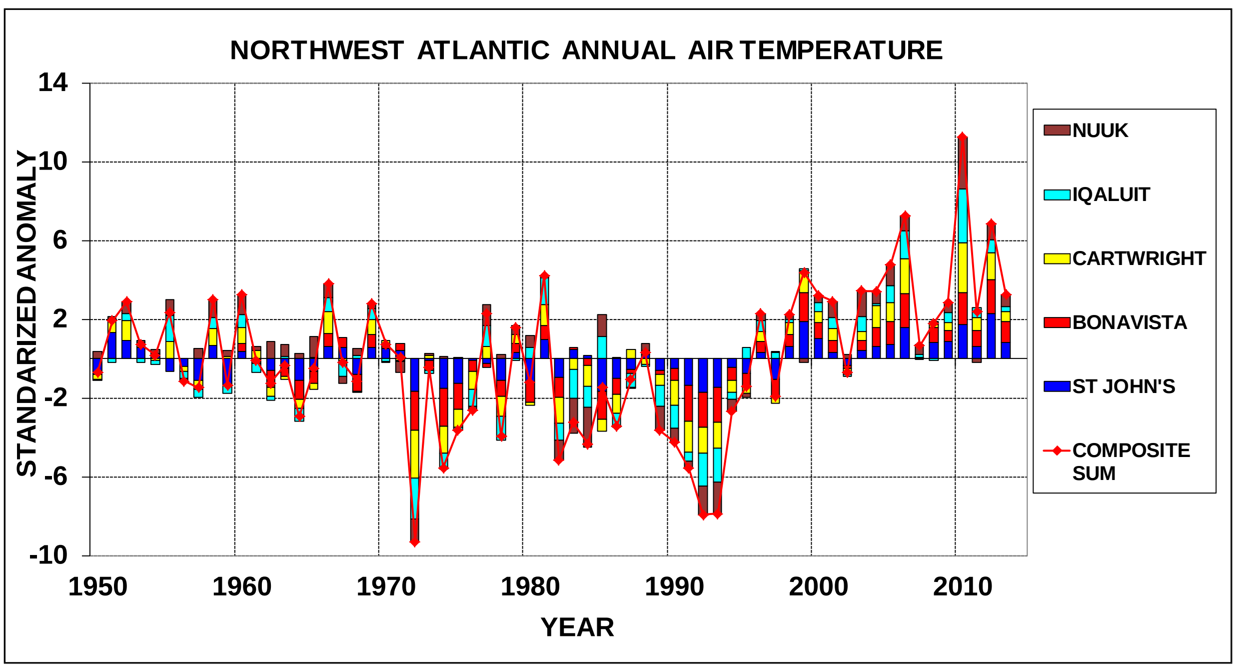

Figure 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

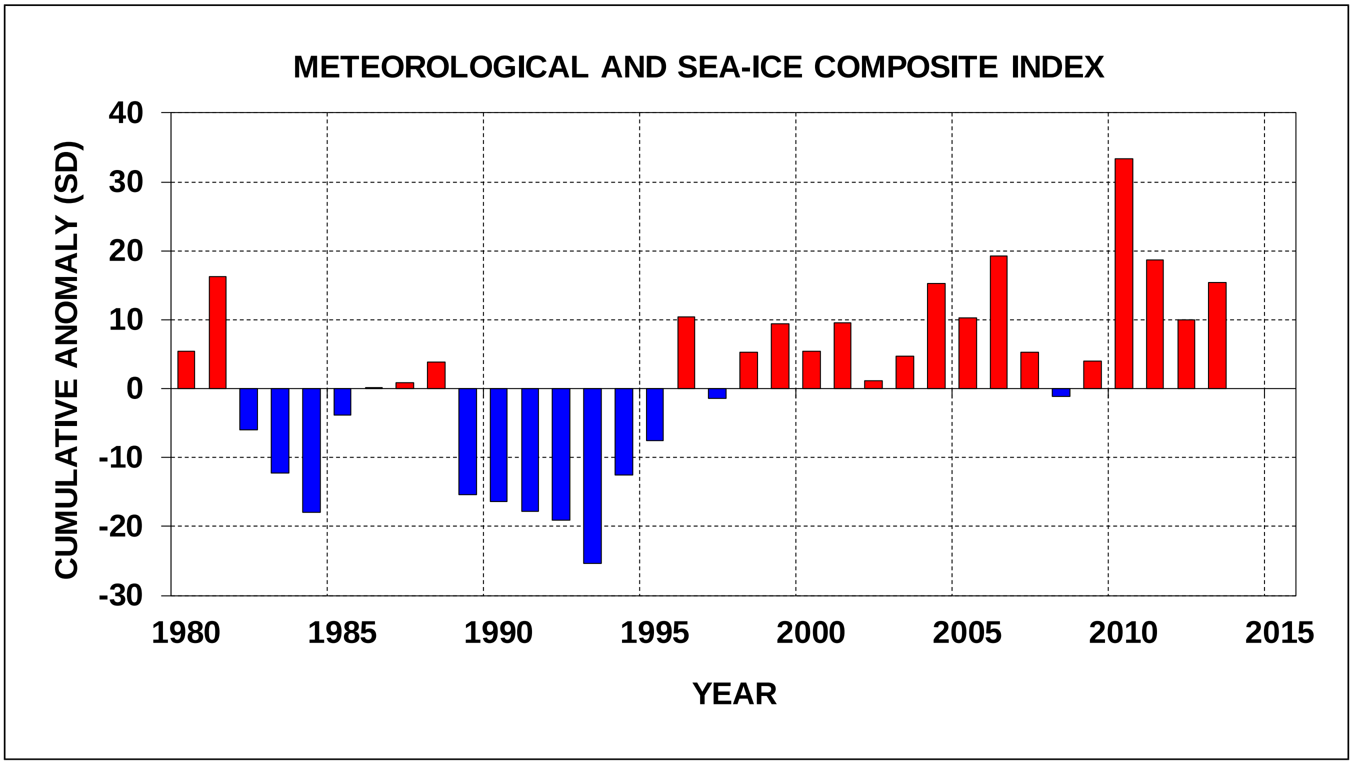

Figure 7. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 5.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

The 4 km resolution Pathfinder 5.2 sea surface temperature (SST) database (Casey et al., 2010) archived at BIO was used to provide annual estimates of the SST within defined subareas (Figure 8) in the Northwest Atlantic from southern Newfoundland to Hudson Strait. This dataset runs from 1981 to 2010. Updated values for 2011 to 2013 were taken from NOAA satellite data provided by the remote sensing group in the Ocean Research and Monitoring Section at BIO. A least squares fit of the Pathfinder and NOAA temperatures during the common period (2001-2010) is given by SST (Pathfinder) = 0.989*SST (NOAA) -0.02 with an r^2=0.98 (Hebert et al. 2014). The 2011, 2012 and 2013 NOAA SST data were then adjusted accordingly and anomalies computed based on 1981-2010 averages. A comparison of the Pathfinder data with near-surface measurements indicate that SST derived from night satellite passes provided the best fit with *in situ* data.

Annual anomalies for 12 areas from Hudson Strait to Green and St. Pierre Banks off southern Newfoundland are presented in Figure 9 and in Figure 10. Most (9/12) areas had positive anomalies during 2013 except for Hudson Strait, Hamilton Bank and St. Anthony Basin, where they were slightly below average. Similar to 2012 the magnitude of the anomalies increased from north to south with the negative anomalies occurring in the northern regions. These values represent a significant decrease over the previous year when record highs were set in some of the southern regions.

A composite index together with individual series shows an increasing trend (~2^{o}C) in SSTs since the early part of the time series with near-decadal oscillations superimposed (Figure 10). Overall 2012 was the 2nd highest in the series after 2006 with 2013 showing a significant decrease. Since 1981, 5 of the warmest years have occurred since 2005.

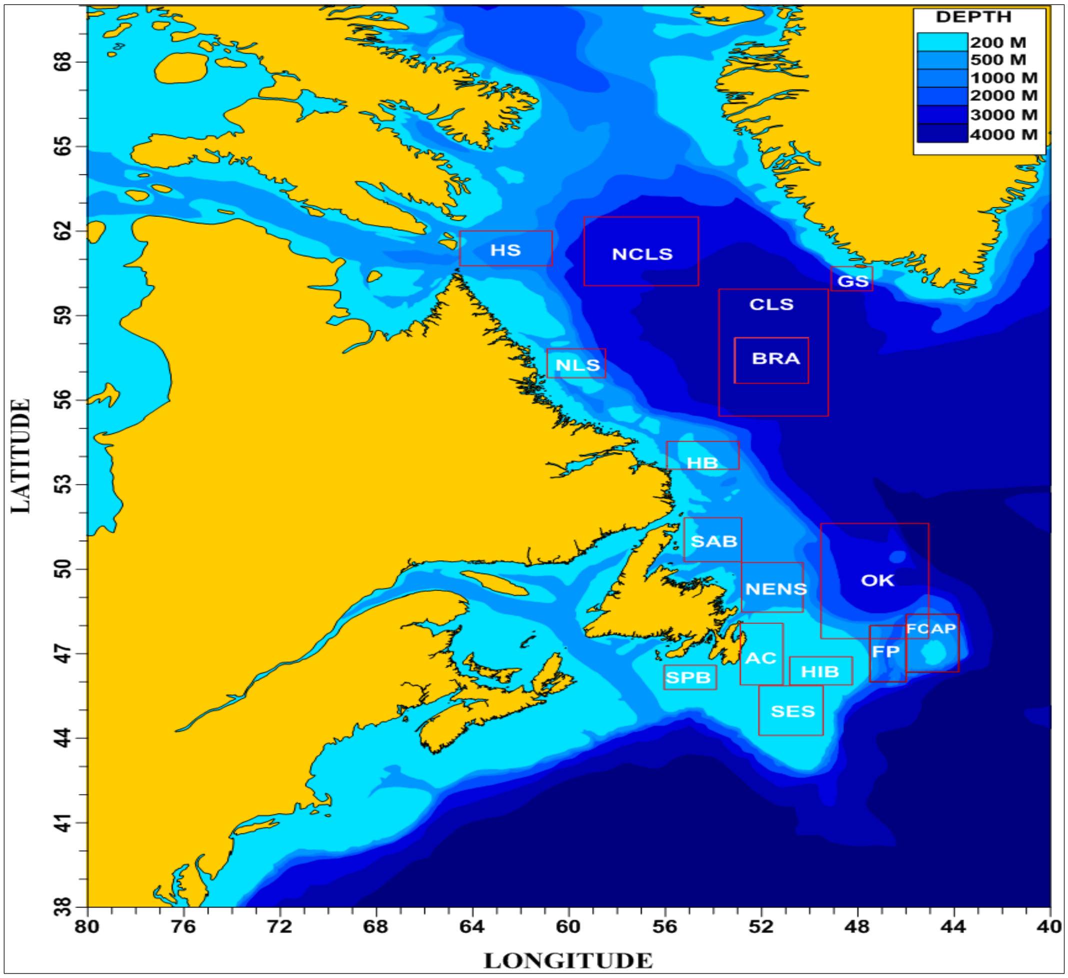

Figure 8. Map showing the subareas where SST time series were constructed for the Northwest Atlantic.

REGION	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
WEST GREENLAND SHELF (GS)	-1.0	-1.6	-1.9	-1.3	0.6	-0.2	0.3	-0.4	-1.5	-0.8	0.2	-0.8	-0.3	0.1	1.9	-0.1	0.5	0.0	-0.9	-0.2	0.3	0.9	1.9	0.8	0.9	-0.2	0.1	0.1	0.8	2.1	-0.4	0.3	0.2	1.61	0.79
NORTH CENTRAL LAB SHELF (NCLS)	-0.7	-1.1	-1.9	-1.7	-0.4	0.3	-0.8	-0.2	-1.1	-1.1	-0.5	-0.5	-1.0	-0.5	-0.6	0.2	0.6	0.7	-0.6	-0.3	0.9	0.8	1.5	1.5	1.4	1.0	0.7	-0.2	-0.3	2.2	-0.1	-0.3	-0.1	2.85	1.16
CENTRAL LAB SEA (CLS)	0.1	-1.5	-1.8	-2.0	-0.9	-0.5	-0.3	-0.2	-0.8	-1.1	-0.4	-0.5	-0.9	-0.2	-0.6	0.0	0.7	0.6	-0.1	-0.4	0.8	0.3	1.6	1.3	1.2	1.4	0.9	1.2	0.4	1.8	0.2	0.6	0.5	4.26	0.85
BRAVO (BRA)	0.1	-1.1	-1.9	-1.9	-1.1	-0.8	-0.4	-0.4	-0.7	-1.1	-0.4	-0.5	-0.7	-0.4	-0.5	-0.3	0.7	0.4	-0.1	-0.1	0.6	0.3	1.6	1.2	1.4	1.5	0.8	1.4	0.4	1.7	0.3	1.0	0.4	4.33	0.79
HUDSON STRAIT (HS)	0.8	-0.8	-1.0	-1.9	-0.2	1.2	-0.1	-0.9	-1.6	-0.4	-0.2	-0.7	-0.1	0.4	0.6	0.0	-0.7	-0.2	-1.4	0.6	0.7	0.4	0.7	0.4	1.6	0.2	-0.3	0.4	-0.6	3.1	0.0	0.5	-0.5	-0.17	0.36
NORTHERN LAB SHELF (NLS)	1.4	-0.5	-1.5	-1.8	-0.8	0.0	-0.6	-1.0	-1.0	-0.2	-1.1	-1.2	-0.1	1.0	0.1	-0.7	-0.7	0.7	-0.6	0.7	0.6	-0.8	1.5	1.1	1.1	0.9	-0.1	1.8	-0.1	1.7	1.3	1.3	0.1	0.46	0.48
HAMILTON BANK (HB)	1.1	-0.9	-0.7	-1.3	-0.7	-0.7	-0.7	-0.2	-0.9	-0.8	-1.3	-0.9	0.2	0.3	1.2	-1.3	-0.6	0.6	-0.4	1.4	0.3	-0.7	1.1	1.0	1.2	1.8	-0.4	1.6	-0.1	1.7	1.0	1.9	-0.4	1.44	0.51
ST ANTHONY BASIN (SAB)	1.6	-0.6	-0.3	-0.6	-0.9	-0.5	-0.4	0.0	-0.4	-1.1	-1.5	-1.5	-0.6	0.3	-0.5	-0.6	-0.8	0.7	0.2	1.0	0.3	-0.7	0.7	1.1	1.8	2.1	-0.9	1.5	-0.3	1.4	0.6	1.7	-0.2	2.61	0.58
NE NF SHELF (NENS)	0.7	-0.6	-0.1	-0.5	-1.6	-0.6	-0.1	0.1	0.0	-0.4	-1.9	-1.5	-0.7	0.3	-0.5	-0.5	-1.0	0.7	0.4	0.9	0.5	-0.5	0.6	1.1	1.9	2.2	-0.8	1.5	-0.4	1.3	0.6	1.3	0.4	3.49	0.61
ORPHAN KNOLL (OK)	-0.1	-0.7	-0.3	-1.5	-2.2	-0.5	0.1	0.2	-1.0	-0.9	-1.5	-1.2	-1.0	-0.9	0.2	0.0	0.3	0.9	0.4	0.6	0.6	0.1	0.6	1.1	2.0	1.7	0.3	1.3	-0.2	1.4	0.7	1.7	0.8	6.15	0.78
FLEMISH CAP (FCAP)	0.3	-0.7	0.5	-0.6	-2.4	-1.0	0.3	0.6	-0.5	-1.0	-1.4	-1.4	-1.2	-0.9	-0.3	0.4	-0.2	0.6	0.8	1.0	0.4	-0.3	0.5	0.9	2.0	1.7	0.5	1.1	-0.5	0.9	0.4	1.7	0.6	7.20	0.91
FLEMISH PASS (FP)	0.2	-0.7	0.3	-0.5	-2.2	-0.9	0.2	0.8	-0.5	-1.4	-1.5	-1.4	-1.5	-0.2	-0.2	-0.1	-0.5	0.8	0.9	1.1	0.5	0.0	1.0	0.9	1.9	1.4	0.3	1.1	-0.5	1.0	0.2	1.3	0.2	5.76	0.81
SE SHOAL (SES)	2.3	-0.7	1.2	0.3	-1.8	-1.5	-0.4	0.7	0.0	-0.7	-1.1	-1.2	-1.3	0.2	-0.7	0.1	-1.3	0.6	1.1	1.3	-0.1	-0.2	0.2	0.3	0.7	1.8	0.5	1.0	0.3	0.2	0.4	1.9	1.0	7.42	0.98
HIBERNIA (HIB)	0.4	-0.7	1.0	0.0	-2.0	-1.6	-0.4	0.8	0.1	-0.6	-1.5	-1.4	-1.2	0.6	-0.4	0.1	-1.2	0.8	1.3	1.4	0.2	-0.5	0.6	0.4	1.1	2.1	0.5	0.6	-0.5	0.6	0.3	2.3	0.9	5.79	0.84
AVALON CHANNEL (AC)	0.5	-0.8	0.8	-0.1	-1.9	-1.4	-0.1	0.9	-0.8	-0.4	-1.7	-1.3	-0.8	1.1	-0.7	-0.1	-1.6	0.6	1.0	1.0	0.3	-0.5	0.6	0.7	1.4	2.0	-0.3	0.9	0.1	0.8	0.2	1.6	1.0	5.01	0.69
GREEN-ST PIERRE BANK (SPB)	2.1	-0.4	1.0	0.4	-2.2	-1.2	-0.1	-0.2	-0.4	-0.8	-1.3	-1.1	-0.5	1.1	-1.0	0.0	-1.2	0.7	1.4	1.2	0.1	-0.6	0.2	0.4	1.4	1.3	-0.5	0.7	0.4	0.9	0.1	2.1	1.1	6.16	0.75

Figure 9. Standardized SST anomalies derived from the data within the boxes shown in Figure 8. The anomalies are normalized with respect to their standard deviations over the period 1981-2010.

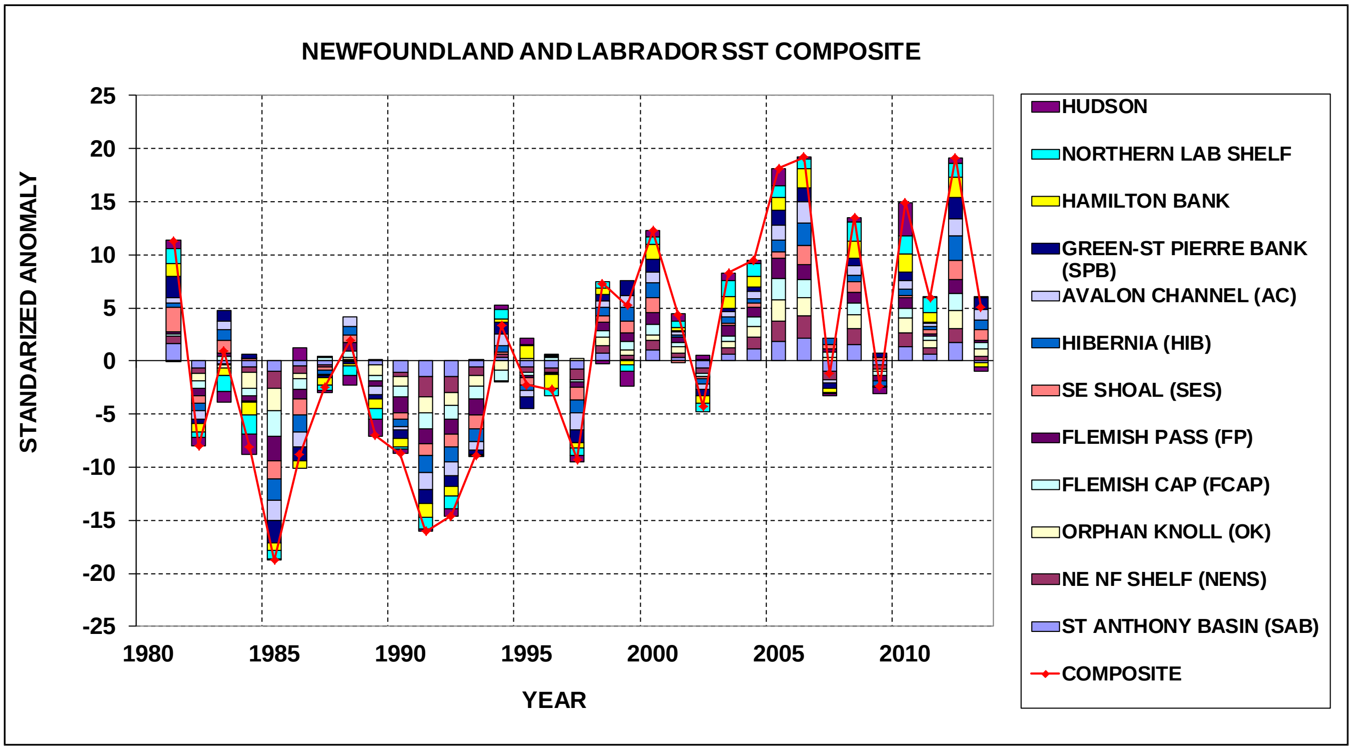

Figure 10. Standardized annual SST anomalies from the subareas presented in Figure 9. The solid red line represents the composite sum.

TRENDS IN TEMPERATURE AND SALINITY

Long-Term Inshore Temperature Monitoring

Temperature data obtained from thermographs deployed at 10 inshore monitoring sites during the summer months (July-Sept.) along the coast of Newfoundland (see Figure 1 for locations) at nominal water depths of 10 and 15 m are shown in Figure 11 as standardized anomalies and repeated in Figure 12 as cumulative sums. It is noteworthy that some sites are missing data, particularly before 1998. This no doubt reduces the accuracy of anomalies hence the composite plot only included data from 1998 when most sites have data. The data show considerable variability about the mean, due mostly to highly variable local wind driven effects near the coast including upwelling and local summer air temperatures.

Near-shore temperatures were generally below normal during most of the 1990s but increased to above normal conditions in 1999 and continued above normal for several years peaking in 2006. In 2007 there was a sharp decrease with values not seen since the early 1990s with 8 of 9 sites reporting below normal (-0.7 to -2.1 SD) summer temperature. In 2008-2010 temperatures varied about the mean with no clear pattern. In 2011 however, 8 of 9 sites with data again reported below normal summer coastal temperatures with anomalies ranging from ~1-2 SD below normal. The only exception was at Hampden, White Bay where temperatures were close to 1 SD above normal.

In 2012, there was an overall increase over the previous year with record highs at Hampden, White Bay (+1.5 SD) and at Arnold's Cove Placentia Bay (+2.8 SD). However, 4 of the 10 sites reported below normal temperature conditions in spite of widespread warmer than normal SST throughout the Atlantic region. In 2013 near-shore temperatures were similar to 2012 values with 4/10 sites reporting below normal values. Again this may be related to local upwelling along the east coast in response to prevailing offshore winds.

LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	MEAN	SD
HAMPDEN (10 m)			-0.4	0.2	-1.5	-2.2	-0.4	-0.9	0.4	0.2	1.4	-0.9	0.5	0.3	0.8	0.9	1.4	-0.7	1.1	-1.0	0.9	0.8	1.5	**0.3**	7.87	1.55
COMFORT COVE (10 m)	1.2	-2.1	-0.8	-1.9	0.1	-1.1	0.8	-0.7	-0.1	1.0	1.2		0.8	0.9	0.0	0.4	0.0		-0.1			-1.9	-0.5	**-0.6**	10.54	1.76
CAPE FREELS (15 m)									-1.4	0.2	0.1		0.3	0.9	0.4	2.0	1.4	-0.9	-0.5	-0.9	-0.4	-1.2	0.1	**1.0**	10.15	1.27
STOCK COVE	0.2	-2.2	-0.7	-2.2	0.8	-0.2	0.3	-1.0	0.7	0.7	1.0	1.1	0.9	1.1	0.8	1.3	1.7	-1.1	0.4	-0.2	-0.1	-1.4	0.5	**0.8**	10.72	1.40
MELROSE (15 m)									-0.8	0.1		0.8	0.0	1.1	-0.2	1.3	1.5	-1.0	0.6	-0.8	-0.8	-1.7	-0.9	**-0.4**	9.52	1.24
OLD BONAVENTURE (10 m)		-1.5	-0.9	-0.8	2.0	0.3	0.7	0.1		-0.3	0.2	1.3	0.5	0.3	-0.2	0.7	1.2	-1.9	-0.3	0.2	-0.1	-1.7	-0.4	**-0.6**	8.64	1.69
WINTERTON (10 m)									-0.4		1.0	0.5	-0.2	1.8	0.0	0.3	1.1	-0.9	-0.6	0.6	-1.2	-1.9	-0.5	**-1.1**	11.56	0.90
BRISTOL'S HOPE (10 m)	-0.8	-3.1		-0.7	0.5	0.0	0.1	-0.1	-0.7	1.1	0.7	0.7	0.0	0.9	0.2	0.9	1.0	-0.7	1.0	0.5	0.6	-1.0	0.8	**0.6**	10.02	1.41
UPPER GULLIES (10 m)	-1.2	-1.3	0.7	-0.4	0.2	0.2	-0.9	-0.1	-1.1	1.2	-0.2	0.0	0.2	0.8	-0.1	1.2	1.3	-2.1	1.6	0.3	0.5		0.7	**1.5**	12.03	1.26
ARNOLDS COVE (10 m)	0.7	-2.1	-1.5	-1.7	0.4	-0.9	0.6	-0.5	0.4	2.3	0.9	0.4	0.4	1.0	-0.3	0.3	1.1	0.5	0.0	1.7	0.4	-1.1	2.8	**1.2**	13.40	1.21

Figure 11. Standardized temperature anomalies derived from data collected with thermographs along the coast of Newfoundland (Figure 2). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the length of the time series. The grey shaded cells indicate no data.

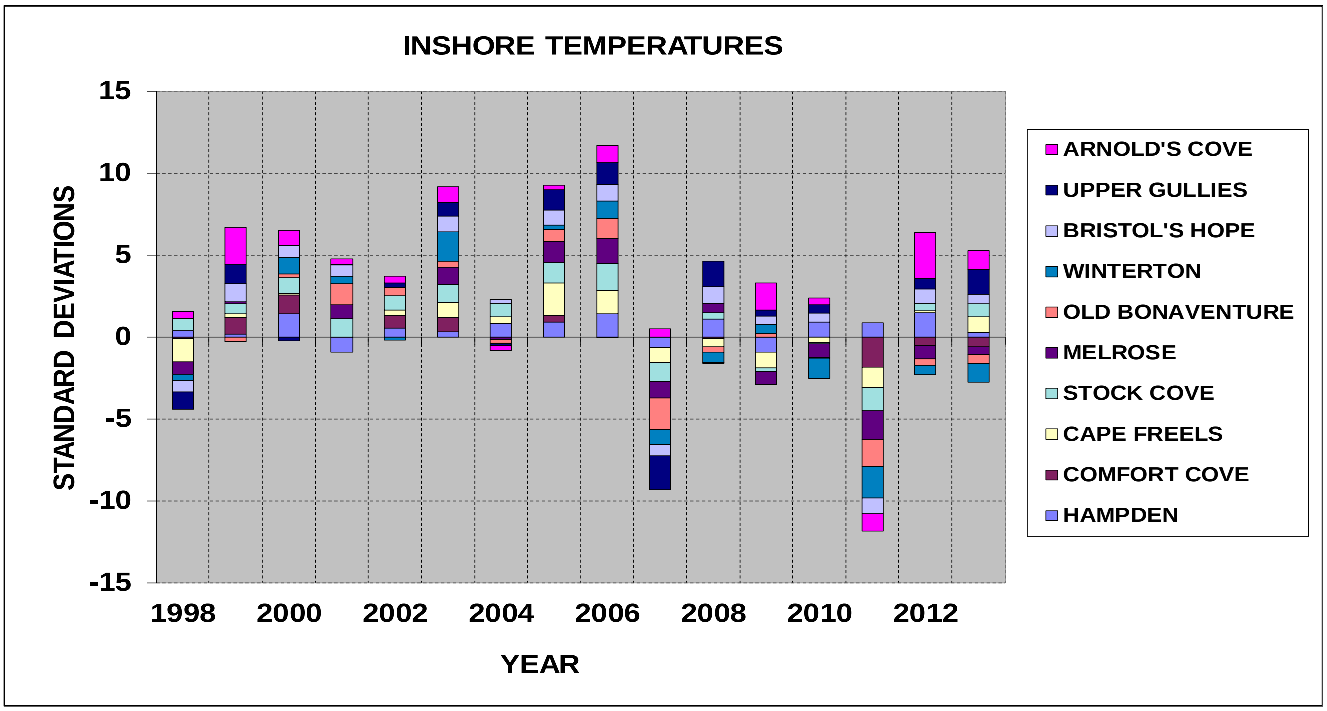

Figure 12. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland (Fig. 2). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the duration of the time series.

Station 27

Station 27 (47^o 32.8' N, 52^o 35.2' W), located in the Avalon Channel off Cape Spear NL (Figure 2), was sampled 43 times (39 CTD profiles, 4 XBT profiles) during 2013. Observations were available for all months except January and February.

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2013 are displayed in Figure 13 and 14. The water column at Station 27 was near-isothermal ranging in temperature from -0.5^o to 0^{o}C during March and most of April. These values persisted throughout the year below 100 m as the cold intermediate layer (CIL) extended to the bottom. Upper layer temperatures warmed to >2°C by mid-May and to >15°C by mid-August, after which the fall cooling commenced with temperatures decreasing to <4°C by early December.

Temperatures were above normal during late winter over the entire water column and above normal throughout the year in the bottom layer. Temperature anomalies varied considerably in the upper water column with strong negative values in the near-surface layer during late-May to early July and a strong positive anomaly from late July to early December that penetrated to about 75 m depth. An intense negative anomaly with values reaching 4°C below normal in a depth range of 25-75 m occurred in August and September.

Upper layer (0-30 m) salinities (Figure 14 upper panel) were about 32.2 from March to May then decreased to 31.8 by early July and to a minimum of 31 by September. Below 30 m, salinities ranged from 32.2 – 33 throughout most of the year, except for late fall when fresher water reached to near 75 m. The period of low, near-surface salinity values evident from early summer to late fall is a prominent feature of the salinity cycle on the Newfoundland Shelf and is due largely to the melting of sea-ice off the coast of Labrador earlier in the year followed by advection southward onto the Grand Banks.

Upper layer salinities were slightly above normal from March to late summer and significantly above normal during late summer in the 20-70 m depth range with salinity values reaching 0.5 above normal. Upper layer values during October to early December were significantly below normal (by 0.3-0.4). At depth (generally >50 m) salinities were generally below the long term average (Figure 14 bottom panel).

The annual surface temperatures at Station 27 having been near-normal or above normal since 2003, reached a 61-year high of 2.2 SD above their long-term mean in 2006, varied about the mean from 2007-2009 and increased to above normal since then, reaching +1.6 SD (~1°C) in 2012 and 2013 (Figure 15 and 20). Annual bottom temperature anomalies at Station 27 were the highest on record in 2011 at 3.6 SD above normal. In 2012 they decreased to +1.2 SD (0.4°C) and remained nearly identical in 2013 (Figure 15 and 20).

Vertically averaged temperatures (0-176 m) which also set record highs in 2011 at +2.7 SD decreased to +1.3 SD in 2012 and to +1.1 SD in 2013 (Figure 16 and 20). Recent temperatures at Station 27 contrasted sharply to values observed 1990 to 1997 when values were often 1-2 SD below normal (Figure 20).

The layer of cold water on most of the NL shelf extends to the surface during the winter months but remains partially isolated during the remainder of the year between warmer bottom water and the seasonally heated near-surface layer. This water mass is commonly referred as the cold intermediate layer or CIL (Petrie et al. 1988) and is usually defined as water with temperatures <0°C. In shallow areas, such as the northern Grand Banks and near-shore, including at Station 27 the cold water mass extends to the bottom throughout the year. The vertical extent of water with temperatures <-1.0°C, <-0.5°C, <0.0°C, <0.5°C and <1.0°C are shown in Figure 17 and 20.The vertical thickness of the layer <0°C reached a remarkably low value of 60 m (4.8 SD) below normal (116±17 m) in 2011 but increased to 1.7 SD below normal in 2012 and to near-normal in 2013 (Figure 17 and 20). The CIL layer defined by other temperature thresholds show similar trends that reached a minimum in 2011 and has since returned to near-normal values in 2013.

Annual surface salinities at Station 27 were about normal in 2013 while bottom and water column averaged values were below normal by up to 1 SD. In general, water column averaged salinities have varied slightly about the mean in some years but have been predominately below the long term average since the early 1990s (Figure 18-20).

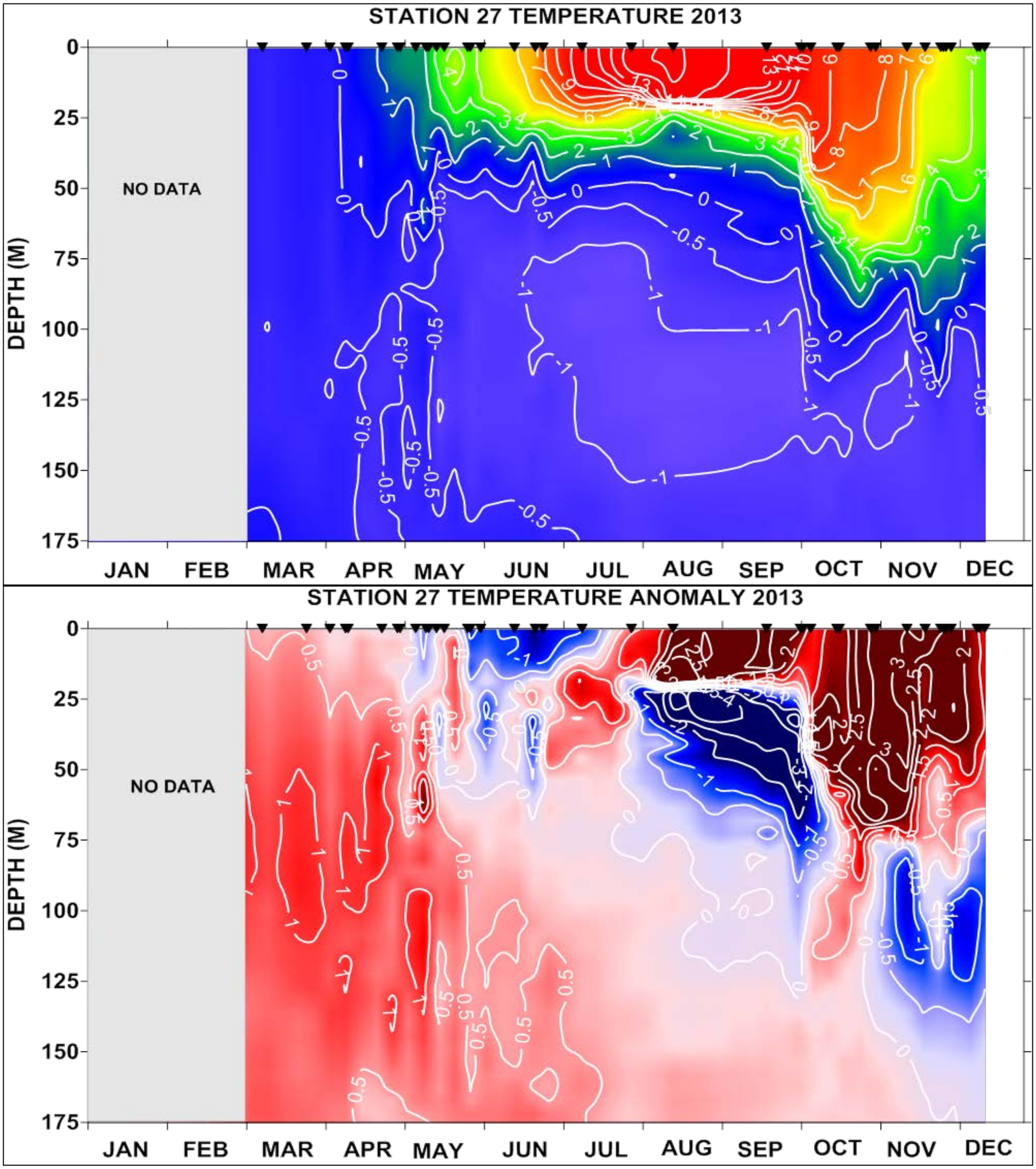

Figure 13. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2013. The symbols at the top indicate sampling times.

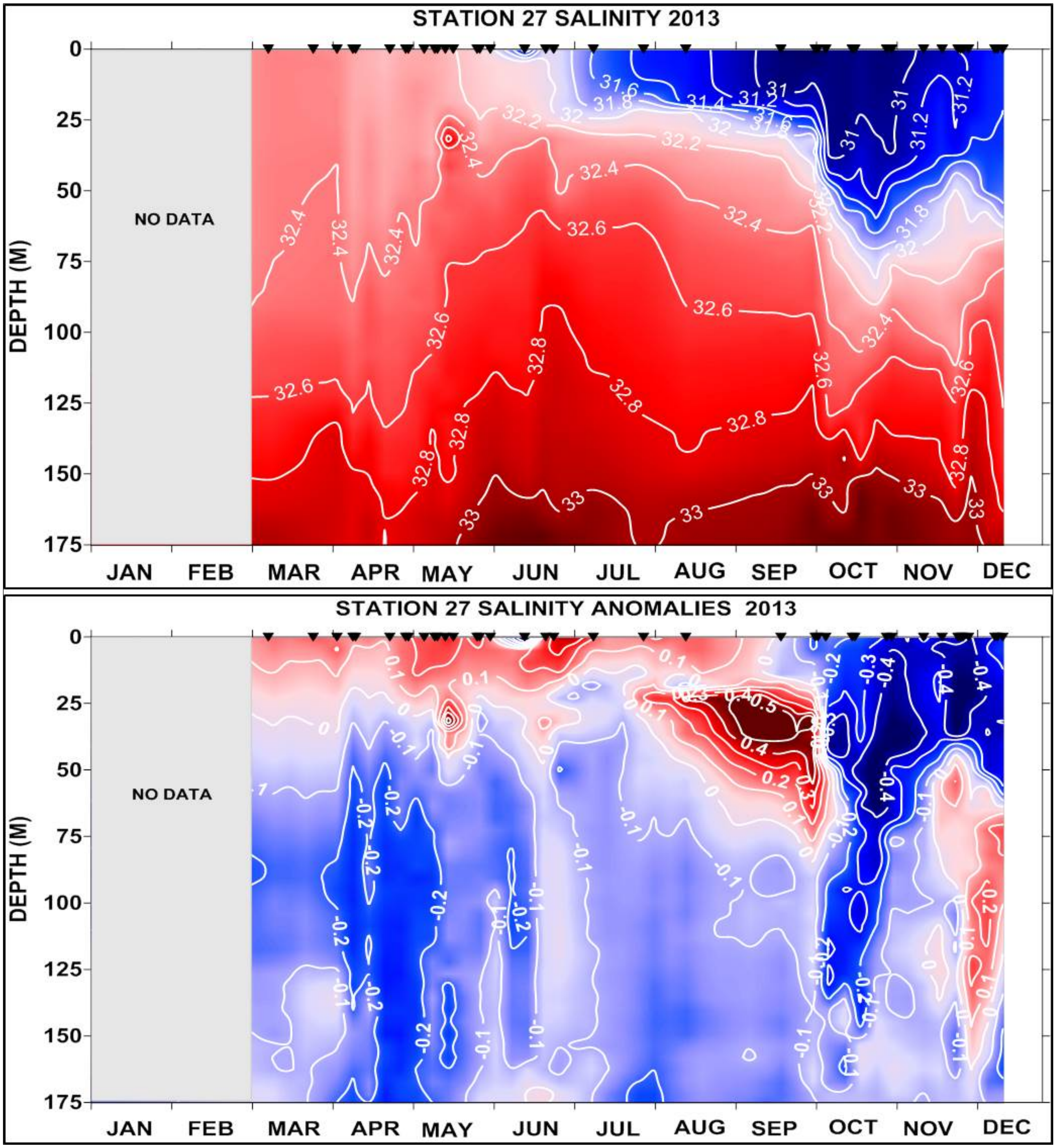

Figure 14. Contours of salinity and salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2013. The symbols at the top indicate sampling times.

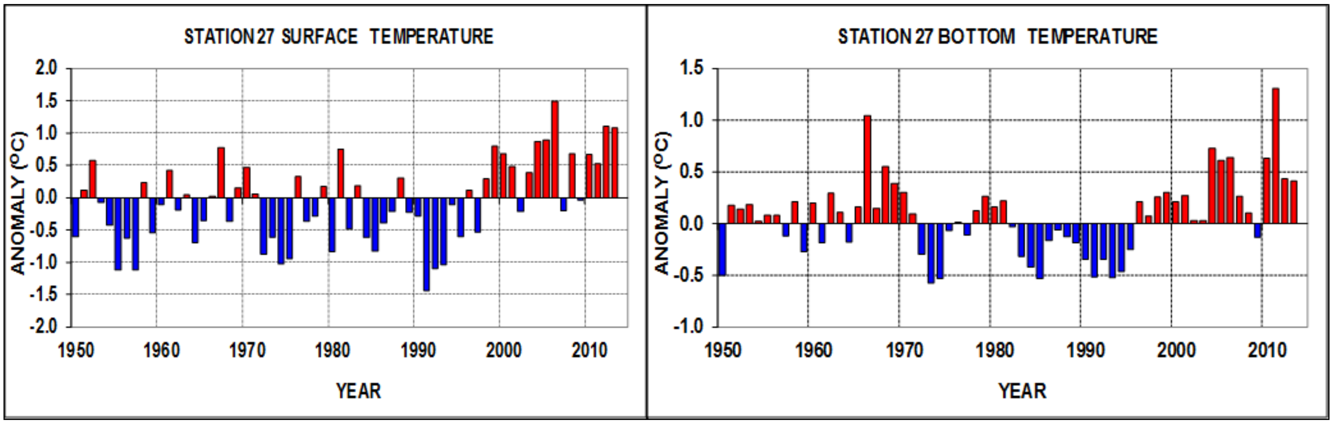

Figure 15. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean.

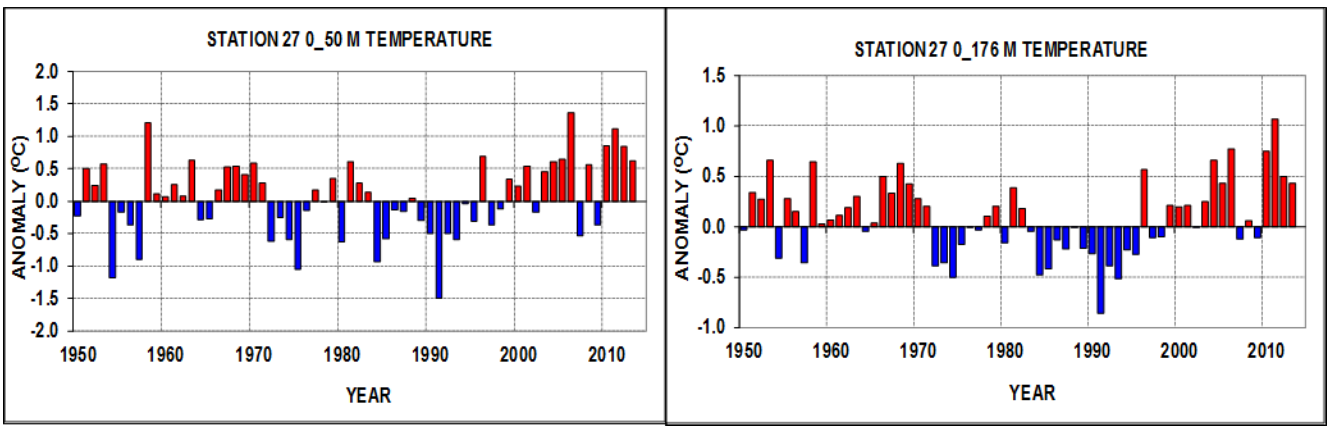

Figure 16. Annual Station 27 vertically averaged (0-50 m, 0-176 m) temperature anomalies referenced to the 1981-2010 mean.

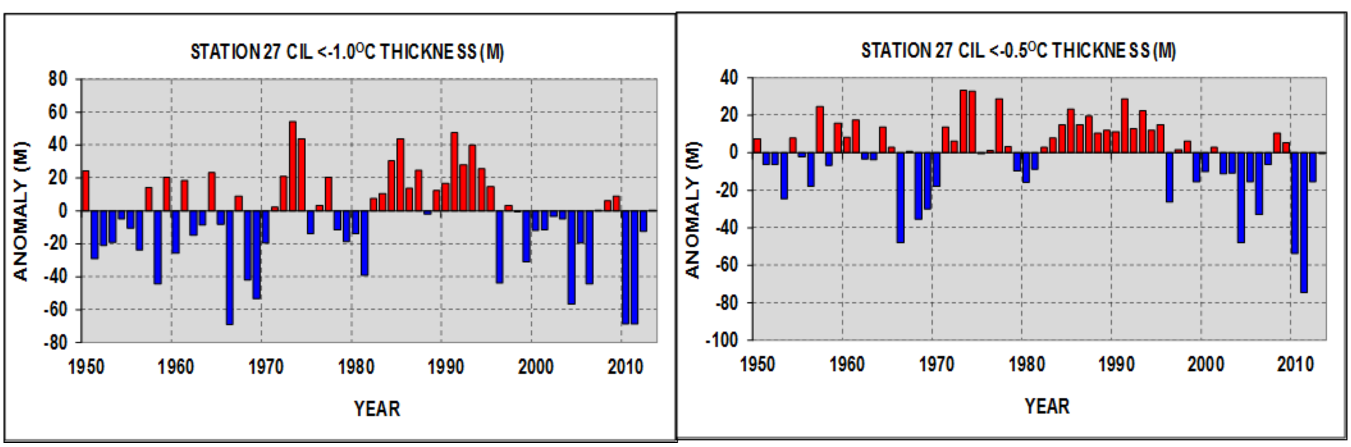

Figure 17a. Annual Station 27 CIL (<-1.0^{O}C and <-0.5^{O}C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Fig. 20.

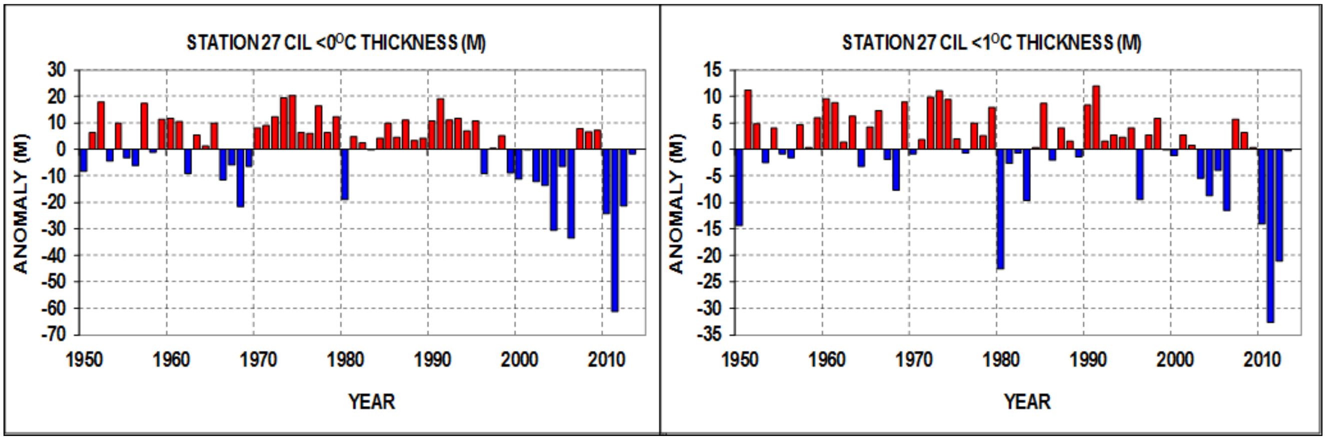

Figure 17b. Annual Station 27 CIL (<0^{O}C and <1 ^{O}C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Fig. 20.

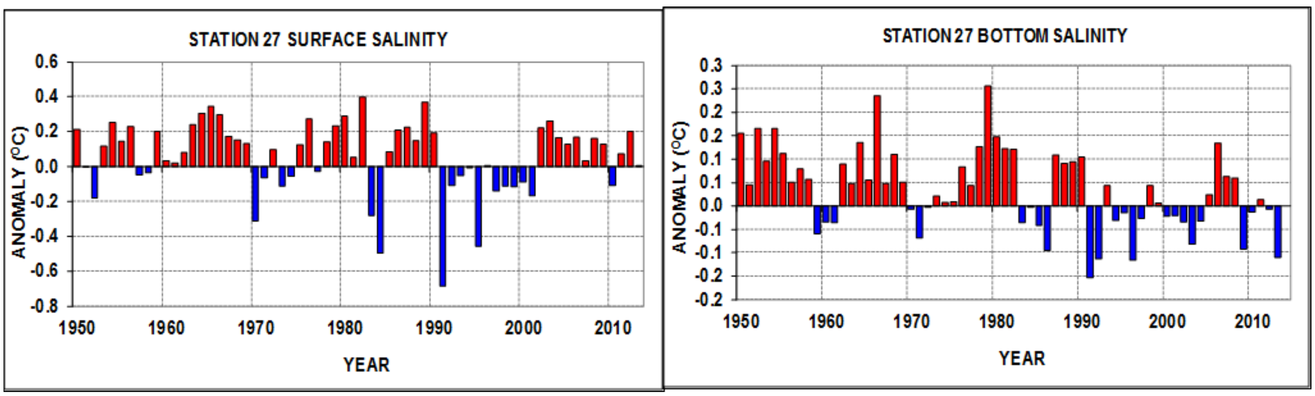

Figure 18. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean.

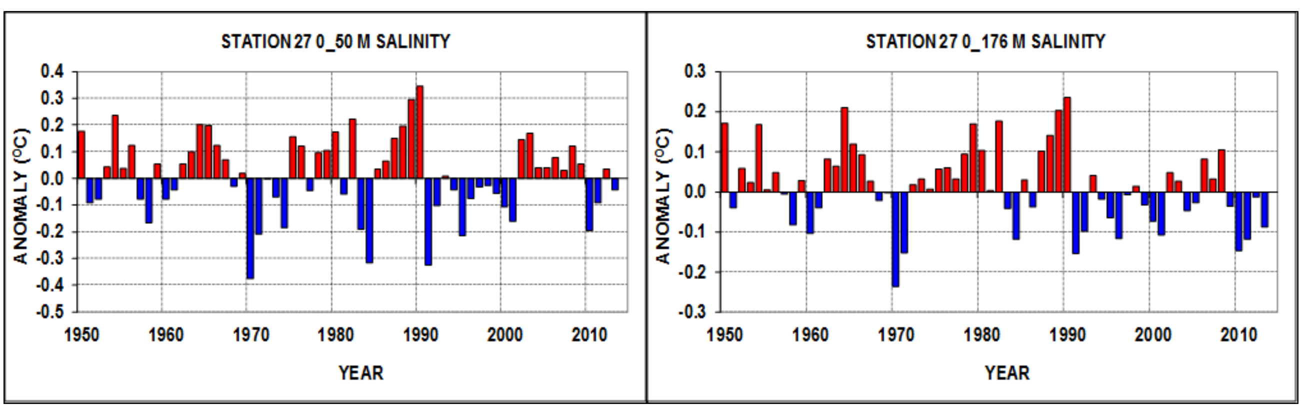

Figure 19. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean.

INDEX	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
SURFACE T	-1.2	1.1	-0.7	0.3	-0.9	-1.2	-0.6	-0.3	0.4	-0.3	-0.4	-2.1	-1.6	-1.5	-0.2	-0.9	0.2	-0.8	0.4	1.2	1.0	0.7	-0.3	0.6	1.3	1.3	2.2	-0.3	1.0	-0.1	1.0	0.8	1.6	1.6	4.89	0.68
BOTTOM T	0.4	0.6	-0.1	-0.9	-1.2	-1.5	-0.4	-0.2	-0.3	-0.5	-1.0	-1.4	-1.0	-1.4	-1.3	-0.7	0.6	0.2	0.7	0.8	0.6	0.7	0.1	0.1	2.0	1.7	1.7	0.7	0.3	-0.4	1.7	3.6	1.2	1.1	-0.89	0.44
0-50 M T	-1.0	1.0	0.5	0.2	-1.6	-1.0	-0.2	-0.3	0.1	-0.5	-0.8	-2.5	-0.8	-1.0	-0.1	-0.5	1.1	-0.6	-0.2	0.6	0.4	0.9	-0.3	0.8	1.0	1.1	2.3	-0.9	0.9	-0.6	1.4	1.9	1.4	1.0	2.86	0.62
0-176 M T	-0.4	1.0	0.5	-0.1	-1.2	-1.1	-0.3	-0.6	0.0	-0.5	-0.7	-2.2	-1.0	-1.3	-0.6	-0.7	1.5	-0.3	-0.3	0.5	0.5	0.5	0.0	0.6	1.7	1.1	2.0	-0.3	0.2	-0.3	1.9	2.7	1.3	1.1	0.32	0.43
CIL (<-1.0°C)	-0.5	-1.3	0.3	0.3	1.0	1.5	0.5	0.8	-0.1	0.4	0.6	1.6	1.0	1.4	0.9	0.5	-1.5	0.1	0.0	-1.1	-0.4	-0.4	-0.1	-0.2	-2.0	-0.7	-1.5	0.0	0.2	0.3	-2.3	-2.4	-0.4	0.0	71.83	31.08
CIL (<-0.5°C)	-0.8	-0.4	0.1	0.4	0.7	1.1	0.7	1.0	0.5	0.6	0.5	1.4	0.6	1.1	0.6	0.7	-1.3	0.1	0.3	-0.8	-0.5	0.1	-0.6	-0.5	-2.4	-0.8	-1.7	-0.3	0.5	0.3	-2.7	-3.7	-0.8	0.0	99.88	24.32
CIL (<0°C)	-1.5	0.4	0.2	0.0	0.3	0.8	0.3	0.9	0.3	0.3	0.9	1.5	0.9	0.9	0.6	0.9	-0.7	0.0	0.4	-0.7	-0.9	0.0	-1.0	-1.1	-2.4	-0.5	-2.6	0.6	0.5	0.6	-1.9	-4.8	-1.7	0.0	116.31	16.84
CIL (<0.5°C)	-2.9	0.0	0.5	-0.7	0.3	0.5	-0.2	0.7	0.3	0.2	1.1	1.9	0.6	0.6	0.6	0.9	-1.2	0.3	0.5	0.2	-0.7	0.2	-1.5	-0.6	-1.3	-0.7	-2.8	1.0	0.6	0.2	-2.1	-5.5	-2.5	0.0	126.51	11.35
CIL (<1°C)	-3.7	-0.4	-0.1	-1.6	0.1	1.4	-0.5	0.7	0.3	-0.2	1.4	2.0	0.2	0.4	0.4	0.7	-1.5	0.5	1.0	0.0	-0.2	0.4	0.1	-0.9	-1.4	-0.6	-1.9	0.9	0.5	0.1	-2.3	-5.3	-3.4	-0.2	133.18	8.54
SURFACE S	1.2	0.2	1.6	-1.1	-2.0	0.3	0.8	0.9	0.6	1.5	1.4	-1.9	-1.1	-0.1	-0.4	-1.9	0.2	-0.4	-0.4	-0.4	-0.3	-0.6	1.0	0.9	0.5	0.4	0.6	-0.1	0.5	0.2	-0.7	0.2	0.8	0.0	31.64	0.25
BOTTOM S	1.9	1.6	1.5	-0.4	0.0	-0.5	-1.2	1.4	1.1	1.2	1.3	-1.9	-1.4	0.6	-0.4	-0.2	-1.5	-0.3	0.6	0.1	-0.3	-0.3	-0.4	-1.0	-0.4	0.3	1.7	0.8	0.7	-1.2	-0.2	0.2	-0.1	-1.4	33.13	0.08
0-50 M S	1.1	-0.4	1.3	-1.2	-1.9	0.2	0.4	0.9	1.2	1.8	2.1	-2.0	-0.6	0.0	-0.3	-1.3	-0.5	-0.2	-0.2	-0.3	-0.6	-1.0	0.9	1.0	0.2	0.2	0.5	0.2	0.7	0.3	-1.2	-0.5	0.2	-0.3	31.94	0.17
0-176 M S	1.0	0.0	1.7	-0.4	-1.2	0.3	-0.4	1.0	1.4	2.0	1.6	-1.2	-1.7	-0.7	-1.4	-2.0	-0.4	0.0	0.0	-0.7	0.2	-1.2	0.9	0.2	0.7	0.7	0.6	0.7	1.2	0.1	-0.2	-1.0	-0.1	-0.9	32.50	0.10

Figure 20. Standardized temperature and salinity anomalies and CIL thickness at Station 27 from 1980 to 2013. The anomalies are normalized with respect to their standard deviations over the standard base period.

STRATIFICATION AND MIXED-LAYER DEPTH

Stratification is an important characteristic of the water column influencing vertical mixing rates, the transfer of solar heat to lower layers and important biochemical processes. The seasonal development of stratification is an important process influencing the formation and evolution of the cold-intermediate-layer on the shelf regions of Atlantic Canada. It essentially insulates the lower water column from the upper layers, thus slowing vertical heat flux from the seasonally heated surface layer.

We examined the variability in stratification at Station 27 by computing the density (sigma-t) difference between 5 and 50 m for each density profile (i.e. $\Delta\rho/\Delta z$). These values were then averaged by month and the annual anomalies computed from the available monthly averages (Craig and Colbourne 2002).

The 1981-2010 monthly mean and the 2012 and 2013 monthly values are shown in Figure 21. On average the water column is essentially unstratified during the winter months, stratification increases during the spring reaching its maximum by August then decreases to winter time values by December. In 2013, the stratification was near 0 in March, below normal in April and May and above normal from June-September. During the remainder of the year it was near normal decreasing to below normal in December.

In 2013, the annual averaged stratification increased significantly over the previous two years to near the long-term mean (Figure 22). The seasonal standardized anomalies are summarized in Figure 25. The annual index was generally below the mean prior to the 1980s after which it began to increase with large fluctuations about the mean (Figure 22). In recent years it has decreased from about 0.2 SD above normal in 2006 to the lowest since 1980 at 2.1 SD below normal in 2011 (Figure 25). A similar large decrease in stratification was also observed in 2011 on the Scotian Shelf (Hebert et al. 2012). In general, both on the Scotian and Newfoundland shelves there is a long-term trend of increasing stratification since 1950.

The monthly mean mixed layer depths (MLD) at Station 27 were also estimated from the density profiles as the depth of maximum density gradient. There were insufficient data available prior to 1990 to compute reliable annual means. The MLDs are highly variable, particularly during the winter months. The average monthly values range from about 90 m in the winter to <20 m in summer (Figure 23). In

2013 the late-winter and spring values were deeper than normal while during the remainder of the year values were near normal (Figure 23). In general, there appears to be an increasing trend since 1990 of about 1 m/year in the annual mean (Figure 24). During 2011 the annual averaged MLD was +1.6 SD (deeper-than-normal), +0.6 SD in 2012 and +1.2 SD in 2013 (Figure 25). The seasonal values ranged from +2 SD to +1.8 SD above normal during the winter and spring, while the summer and fall values were slightly below normal by 0.2-0.3 SD. In this case the winter value was based on one density profile in early March.

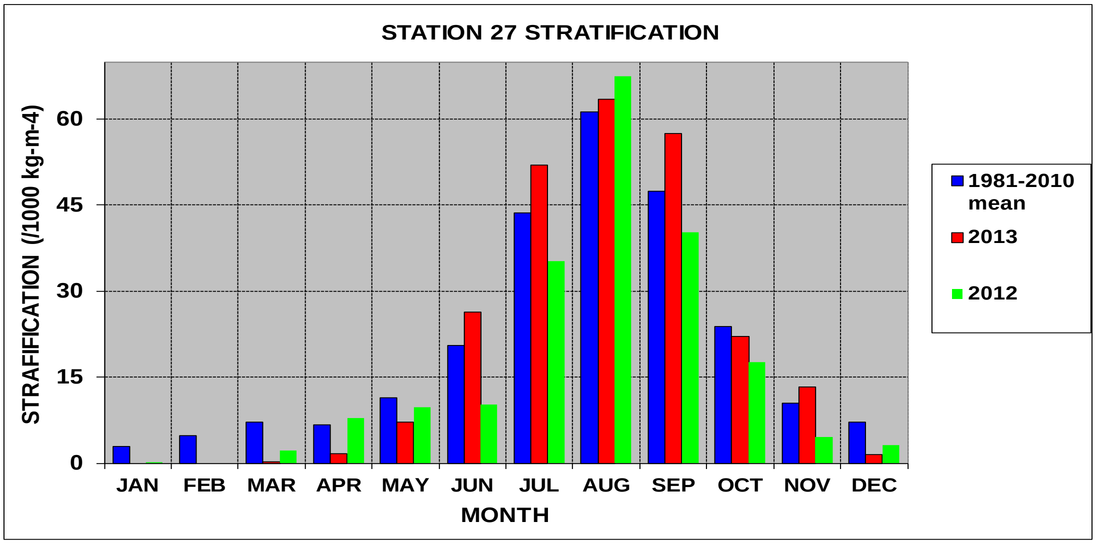

Figure 21. The 1981-2010 monthly average and the 2012 and 2013 monthly average stratification values at Station 27. No data were available in January and February.

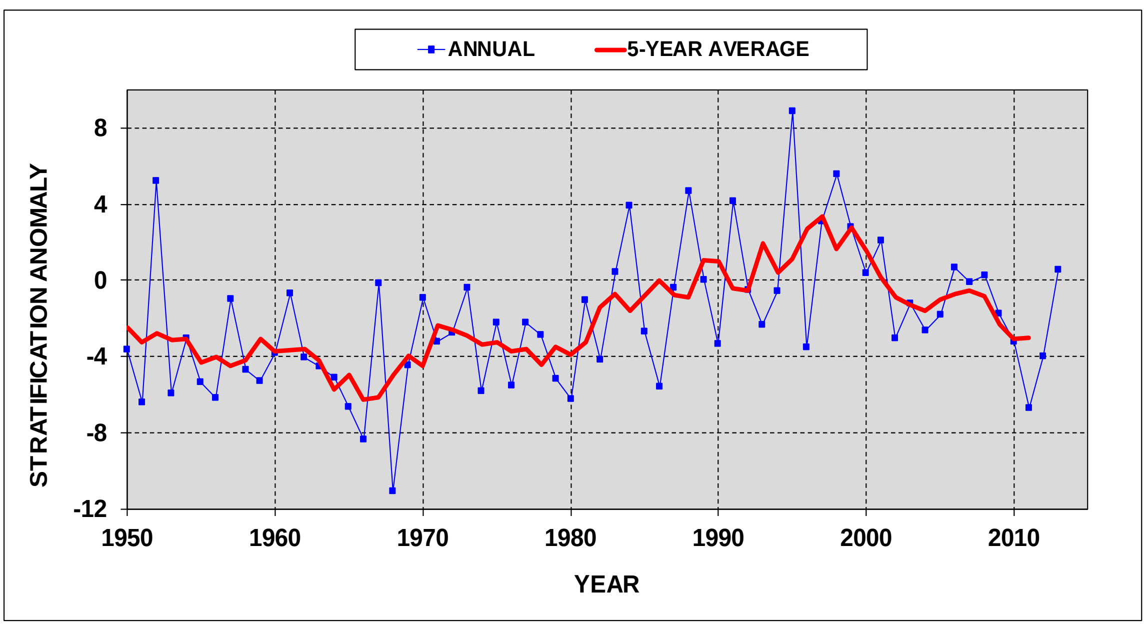

Figure 22. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean.

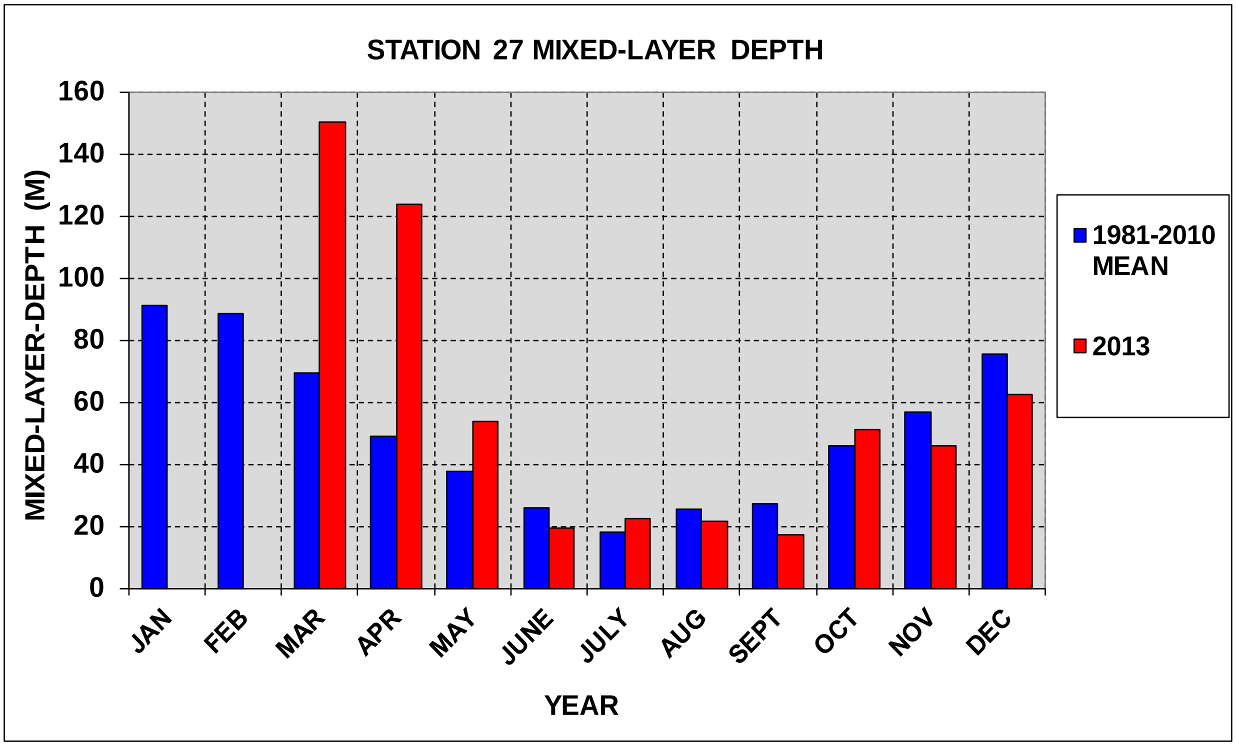

Figure 23. The 1990-2010 average and the 2013 monthly mean Mixed Layer Depths at Station 27.

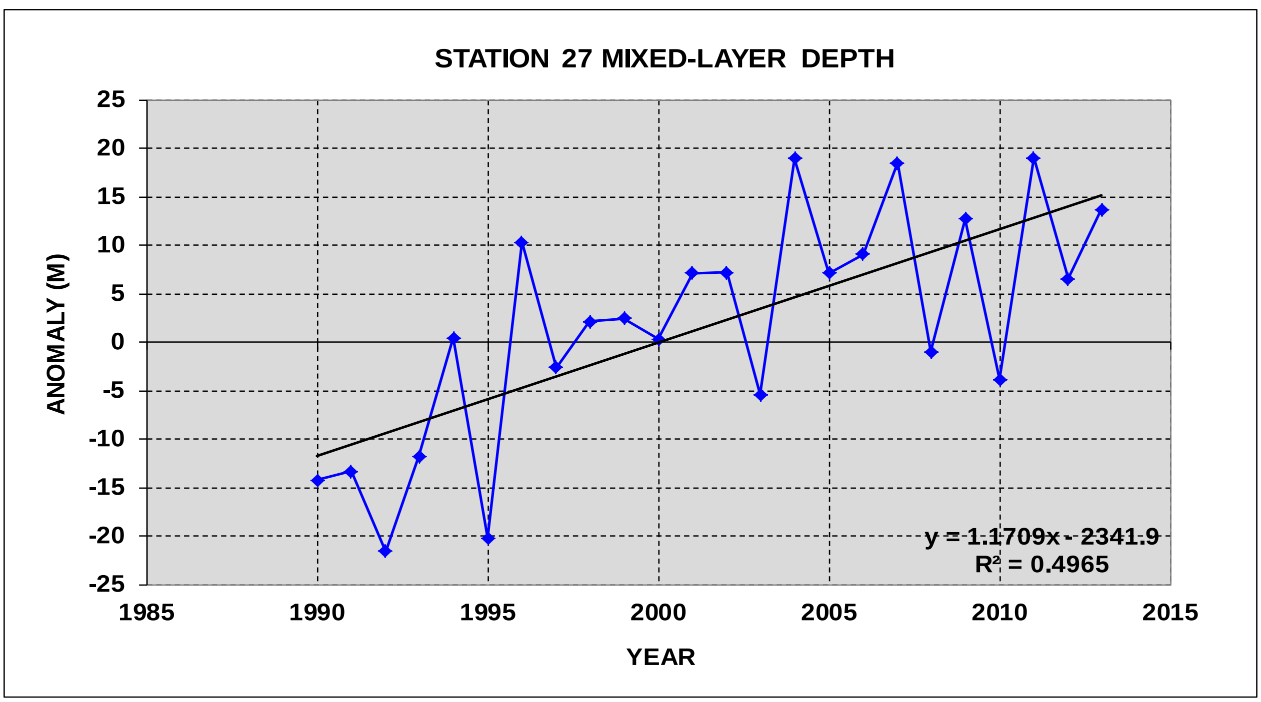

Figure 24. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2010 mean.

INDEX	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
ANNUAL MLD											-1.2	-1.2	-1.9	-1.0	0.0	-1.8	0.9	-0.2	0.2	0.2	0.0	0.6	0.6	-0.5	1.6	0.6	0.8	1.6	-0.1	1.1	-0.3	1.6	0.6	1.2	50.89	11.95
WINTER MLD											-2.0	-0.1	-1.6	-0.9	-0.8	-0.8	0.5	0.6	-0.3	0.5	0.3	0.9	-0.5	-0.3	1.4	1.0	1.4	1.1	-0.7	1.0	-1.2	1.0	0.7	2.0	81.72	41.26
SPRING MLD											-1.4	-1.4	-1.0	-0.4	-0.1	-1.1	1.2	-0.6	1.3	-1.2	0.2	1.1	1.0	-0.3	0.8	-0.7	-0.6	0.9	1.8	-1.0	0.4	1.3	-0.4	1.8	36.85	16.06
SUMMER MLD											4.3	-0.6	0.5	-0.1	0.0	0.0	0.2	-0.3	-0.3	-0.2	-0.4	0.0	-0.3	-0.3	-0.3	-0.2	0.0	-0.3	-0.3	-0.3	-0.2	0.2	-0.3	-0.2	24.36	19.59
FALL MLD											-2.1	-0.7	-0.6	-0.1	1.1	-1.7	-0.1	-0.1	0.1	1.0	-0.2	-1.3	1.5	0.0	0.5	0.6	0.0	0.9	-0.3	1.9	0.1	0.5	0.8	-0.3	59.86	19.91
ANNUAL STRATIFICATION	-1.9	-0.3	-1.3	0.1	1.2	-0.8	-1.7	-0.1	1.4	0.0	-1.0	1.3	-0.2	-0.7	-0.2	2.7	-1.1	0.9	1.7	0.8	0.1	0.6	-0.9	-0.4	-0.8	-0.6	0.2	0.0	0.1	-0.5	-1.0	-2.1	-1.2	0.2	20.58	3.48
WINTER STRATIFICATION			-0.3		0.0	-0.3	-0.4	-0.4	4.8	-0.1	0.6	-0.5	1.1	0.2	-0.4	0.8	0.2	0.0	-0.5	-0.1	0.2	-0.2	0.0	-0.1	-0.4	-0.3	-0.2	-0.5	-0.1	-0.1	-0.5	-0.3	-0.5	-1.0	5.54	6.92
SPRING STRATIFICATION	-1.0	0.0	-0.7	2.3	1.7	-1.0	-0.4	1.5	-0.3	-0.7	-1.7	1.4	0.1	-0.2	-0.7	1.8	-0.5	1.0	0.4	0.9	-0.7	-0.2	-1.1	-1.1	-0.5	-0.1	0.4	-0.2	-0.6	0.1	-1.2	-0.4	-0.7	-0.2	12.86	4.87
SUMMER STRATIFICATION	-1.3	0.1	-2.1	-0.4	1.8	-0.1	-1.5	-1.4	0.3	0.6	-1.1	-0.3	-1.5	-1.0	1.2	0.8	-1.6	0.1	1.0	1.7	0.1	0.5	0.0	-0.5	-0.1	0.5	0.0	1.3	0.4	0.2	-1.0	-3.0	-0.6	1.3	50.50	5.84
FALL STRATIFICATION	-6.8	-0.2	-3.2	1.5	4.1	-2.2	-4.5	0.2	5.3	-0.4	0.4	1.9	-0.5	-0.8	-0.6	2.3	-0.7	0.7	2.4	-0.4	0.5	1.2	-0.9	0.7	-0.7	-1.0	0.3	-0.4	0.3	-1.2	0.2	-1.1	-0.8	-0.2	13.85	6.45

Figure 25. Standardized mixed-layer-depth (MLD) and stratification anomalies derived from data collected at Station 27. The anomalies are normalized with respect to their standard deviations over the same base period. Insufficient data were available before 1990 to compute annual estimates of MLD.

NEWFOUNDLAND AND LABRADOR SHELF BOTTOM TEMPERATURES

Drinkwater and Trites (1986) examined monthly mean temperatures and salinities from historical data in irregularly shaped areas on the Newfoundland Shelf that generally corresponded to topographic features such as banks, basins and slope regions. These areas were further refined and extended to the Labrador Shelf by BIO as part of the ocean climate database. There are 25 areas defined on the Labrador Shelf (Figure 26) and 40 on the Newfoundland Shelf (Figure 29). All data within each area were averaged by month and the annual anomalies were then computed from the monthly values and standardized by the standard deviation of the annual anomalies over the same base period. Data were not available for every month in each area and some areas had insufficient data to construct a time series. In fact, some annual estimates are based on as few as 3 monthly values. As a result the time series can show spikes that correspond to high frequency temporal or spatial variability and may poorly represent annual means.

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 27 and repeated in Figure 28 as a cumulative plot for all areas. During the past decade most of the areas had positive anomalies with 13 areas out of the 21 with sufficient data reporting positive values in 2013 down from 20 out of 21 in 2011. In general bottom temperatures on the Labrador Shelf have shown an increasing trend since the early 1990s from the coldest in 1993 to the warmest in 2011 with most years since 1997 showing above normal cumulative values (Figure 28). Since the peak in 2011 bottom temperatures on the Labrador Shelf have been decreasing with 2013 showing the lowest value since 2001.

Similarly, standardized annual bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 30 and repeated in Figure 31 as a cumulative time series. The results are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999 with 32 areas out of 35 with sufficient data reporting positive anomalies in 2013. The composite plot shows an increasing trend since the early 1990s reaching an all-time record in 2011 when 17/35 areas were above normal by more than 2 SD. Bottom temperatures on the Newfoundland Shelf decreased to the 2^{nd} highest since 1990 in 2012 and the 4^{th} highest in 2013. In 2013 only 3 of 35 areas had anomalies greater than 2 SD above normal.

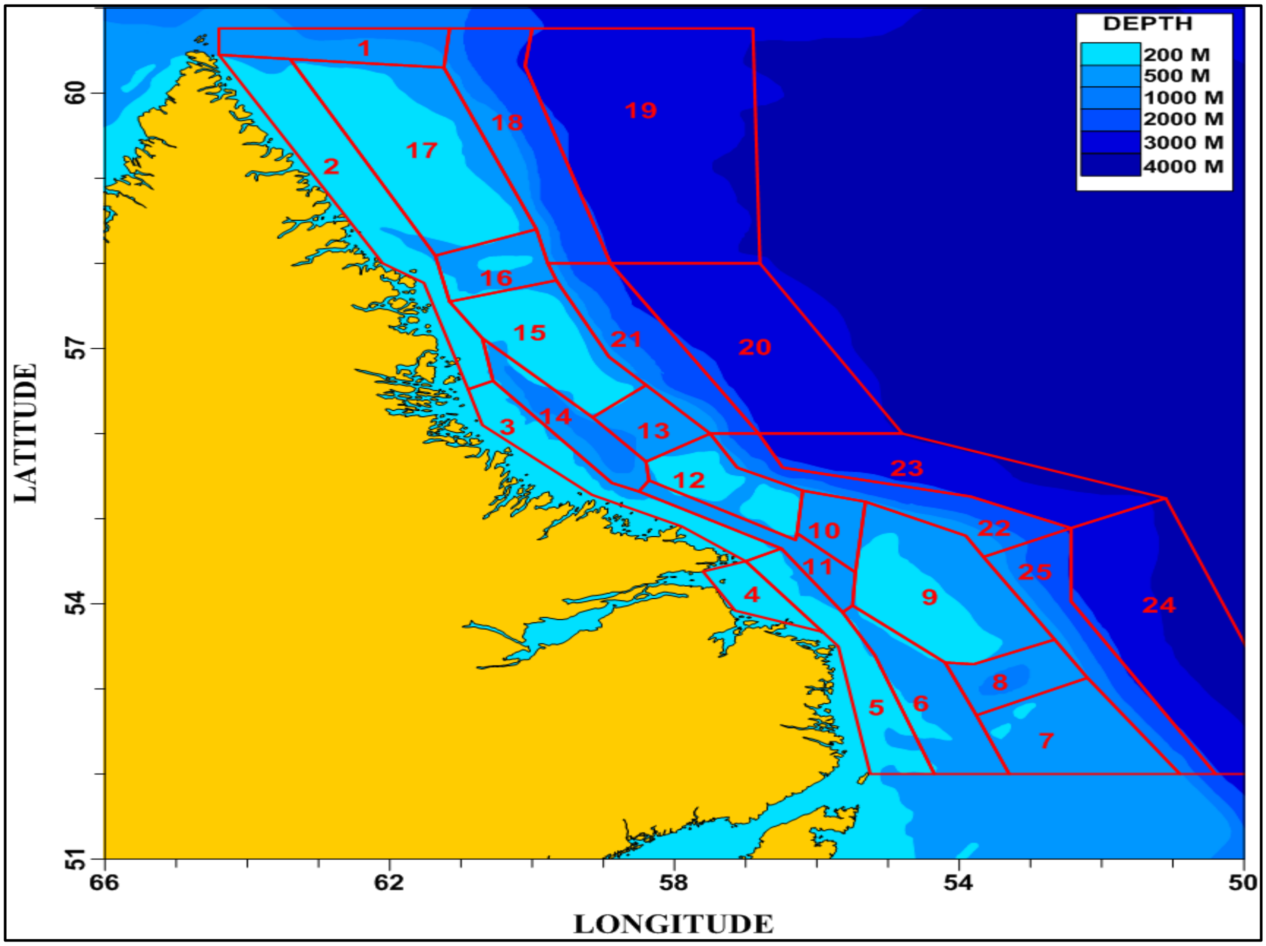

Figure 26. Areas on the Labrador Shelf where bottom temperatures were analysed. The numbers within each area correspond to the areas listed below in Figure 27.

SUB-AREA	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
02 N Labrador Shelf	-0.4	0.3	0.8	-2.3				-0.1				-1.0		-1.5			-0.3	1.3	-0.4	0.4	-1.3	-0.9		-1.4	0.2	0.7	-0.1	0.2	1.7	-0.6	0.3	2.8	1.1	-0.4	-0.03	0.37
03 Central Labrador Inshore	-0.8	-0.1	-0.3	-0.7	-0.8	-1.6	-0.8							-1.0			0.1	0.2	0.3	0.7	-0.2	0.6	-0.7	2.0	-0.5	0.1	0.8		2.7	-0.8	-0.3	1.8	0.2	0.0	0.23	0.70
05 Labrador Inshore	-0.1	1.1	0.4	-1.3	-1.4	-1.5	0.4	-1.2	-0.3	-0.5	-1.0	-0.9	-1.2	-1.1	-0.8	1.0	-0.4	0.3	1.9	0.3	0.2	0.3	0.2	0.2	1.8	1.2	0.0	0.8	0.9	1.4	1.2	2.2	0.1	1.2	-0.61	0.52
06 Labrador Trough	0.2	0.4	-1.1	-0.9	-1.0	-1.5	0.0	-0.8	0.9	-0.3	-1.1	0.0	-0.9	-2.3	-0.5	-0.5	0.0	1.2	1.4	1.5	0.1	0.4	1.1	0.5	0.9	0.3	0.4	2.0	-0.4	-0.9	0.9	1.6	0.2	1.6	1.02	0.58
07 Belle Isle Bank	-0.1	0.4	-0.6	-0.1	-2.1	-2.5	-0.5	-0.7	0.4	-0.5	-0.7	0.3	0.2	-0.7	0.1	-0.6	0.4	0.8	0.8	1.1	0.9	0.7	-0.1	0.8	1.4	0.9	0.0	0.9	0.9	2.0	-1.5	2.1	1.3	0.4	2.81	0.55
08 Hawke Saddle	0.7	0.4	-0.1	0.4	1.5	-1.5	-0.8	-1.6	0.1	-0.9	-0.1	-0.7	0.7	-1.9	-1.5	0.3	-0.2	0.7	1.7	0.7	1.4	0.8	0.2	0.2	0.6	0.5	1.2	1.0	1.2	1.5	-1.0	2.7	1.8	1.6	3.23	0.32
09 Hamilton Bank	-0.3	0.7	-1.3	-1.7	-1.0	-1.3	0.7	-1.1	0.9	1.4	-1.0	0.2	-0.4	-1.5	-0.8	-0.3	0.0	1.3	0.7	0.2	-0.6	0.9	-0.1	0.4	1.5	1.4	0.4	1.2	0.3	-0.3	1.8	2.0	0.0	0.7	1.35	0.65
10 Cartwright Saddle	0.7	0.0	-0.7	-1.0	-1.4	-1.2	0.6	-0.5	-0.2	0.6	-0.9	-0.7	-0.3	-1.2	-1.0		0.2	1.3	0.9	0.8	1.0	1.2	-1.0	1.4	2.2	0.9	1.1	1.6	0.3	0.2	1.2	2.3	1.7	0.6	2.14	0.77
11 Central Labrador Trough	-0.2	-0.3	0.3	-0.2	-0.2	-1.9	0.3	0.2	0.1	-0.4	-0.2	-0.4	-0.1	-0.9	-0.5	1.3	-0.1	1.3	1.2	0.0	-0.9	-1.7	-1.6	0.4	0.6	-0.2	2.5	1.9	1.0	0.1	1.2	0.7	0.4	0.0	0.92	0.58
12 Makkovik Bank	0.0	1.0	-0.1	-1.4	-2.5	-0.4	0.3	-0.4	0.1	-0.2	-0.5	0.9	-0.6	-1.6	-0.7		-1.1	0.8	0.1	0.7	0.4	-0.5	2.2	-0.2	1.8	1.3	-0.2	0.7	0.6	-0.1	0.7	2.4	0.0	-0.2	0.78	0.70
13 Hopedale Saddle	0.6	1.0	-0.3	-0.8	-0.4	-0.5	-0.2	-0.9	0.7		-1.9	0.9		1.5			-0.2	-1.0	-0.4	-0.1	-2.2	-0.3	0.9		-0.6		-0.2		0.6	1.3	1.5	0.7	-0.6	1.1	2.61	0.39
14 N Labrador Trough	0.7	0.4	0.0	-0.2	0.1	-1.4	0.5	0.0	0.2	-0.4	0.3	-0.7		-2.4			0.2	0.5	0.7	-0.2	-0.9	0.2	-1.7	0.1	1.2	1.1	0.7	-2.3	0.6	1.7	1.0	1.3	0.8	1.1	2.71	0.96
15 Nain Bank	1.2	0.6	-1.2	-2.2	-1.9	-0.3	2.2	-0.9	0.0		-0.1	-0.7	1.3	-0.4			1.3	0.3	0.3	0.4	0.3	0.4	0.4	0.5	1.4	-0.3	-0.6	0.0	-0.4	-0.7	1.5	2.5	0.1	-1.1	0.01	0.55
16 Okak Bank	0.5	0.4	-0.9	-1.6		-0.3		0.6	0.2			-1.1	-1.9				0.4	-0.1	1.7	0.3						0.8	-1.6	0.6	1.1	-0.1	0.3	0.8	0.8	-1.1	1.69	0.78
17 Saglek Bank	0.1	1.5	-0.9	-2.2		1.4	0.3	0.3	0.1			-1.1	-1.3				-0.8	0.9	1.2	0.1						0.3	-0.4	0.8	1.1	-0.4	0.4	1.7	0.1	-0.6	0.70	0.52
18 Saglek Slope	-2.3	0.4	-1.1	-0.1	-1.4	-0.7	-2.1	0.0	-0.1		-0.3	-0.6	-0.6				-0.8	0.7	0.3	2.0	2.0		-1.2		0.3	-0.6	-0.1	1.1	1.1	0.4	0.5	1.9	3.8	5.1	3.71	0.27
21 Nain Slope	-0.3	-0.7	-1.3	-0.6	0.2	-1.7	-0.1	-0.5	-0.5	-1.1	-2.7	-0.7	0.9	0.2			-0.5	-0.6	1.0	1.0	-0.2	0.2	-0.4	0.9	0.9	0.2	0.8	1.4	0.6	1.8	0.7	1.3	1.5	1.0	3.49	0.31
22 Makkovik Slope	-0.9	0.0	-1.4	0.4	-1.2	-0.2	0.4	0.2	-0.3	-0.4	-0.6	0.2	-0.7	-4.1	-0.4	-1.1	0.1	0.3	0.4	1.1	0.3	0.4	0.4	0.7	0.9	0.7	0.5	0.2	0.5	1.2	0.7	1.2	1.0	0.9	3.39	0.32
23 Makkovik Offshore	-1.1	0.2	1.1	0.7	1.3	0.4	0.1	0.2	0.0	-2.3	-0.1	-0.3	-0.9	-3.1	1.2	0.1	0.4		0.1	-0.2	1.7	1.1	0.3	0.2	0.4	-0.4	-0.9	-0.2	-0.2	0.4	-1.0	-0.7	-1.0	-0.6	3.19	0.35
24 Hamilton Offshore	-0.1	0.8	-5.1	-0.5	0.1	0.4	0.2	0.0	0.4	0.0	-0.2	-0.4	-0.4	-0.7		-0.3	-0.2	0.0	0.1	-0.1	0.0	0.6	-0.3	0.2	-0.1	0.2	0.1	-0.2	0.1	0.1	-0.1	-0.1	0.2	0.1	3.07	0.64
25 Hamilton Slope	-1.4	1.2	-0.9	0.7	-1.4	-0.8	-0.3	-1.1	-0.1	-0.7	-0.2	-0.3	0.1	-0.3	-0.3	0.0	-0.8	0.0	0.4	0.0	0.0	0.3	-0.5	0.5	1.1	0.7	1.1	1.8	3.2	2.2	0.0	1.2	1.4	0.6	3.44	0.25

Figure 27. Standardized bottom temperature anomalies for the Labrador Shelf derived from data within most of the areas displayed in Figure 26. The anomalies are normalized with respect to their standard deviations over the standard base period 1981-2010 and color-coded accordingly to Figure 4. The grey shaded cells indicate years for which there were no observations.

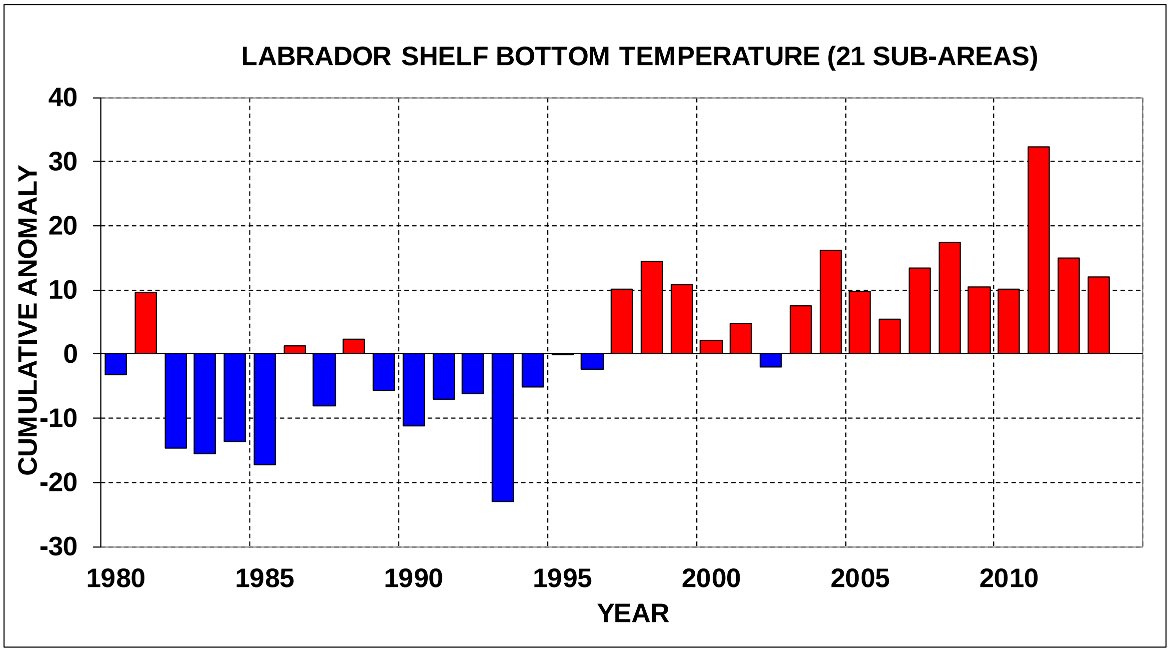

Figure 28. Cumulative bottom temperature anomalies based on the values presented in Figure 27 for the Labrador Shelf.

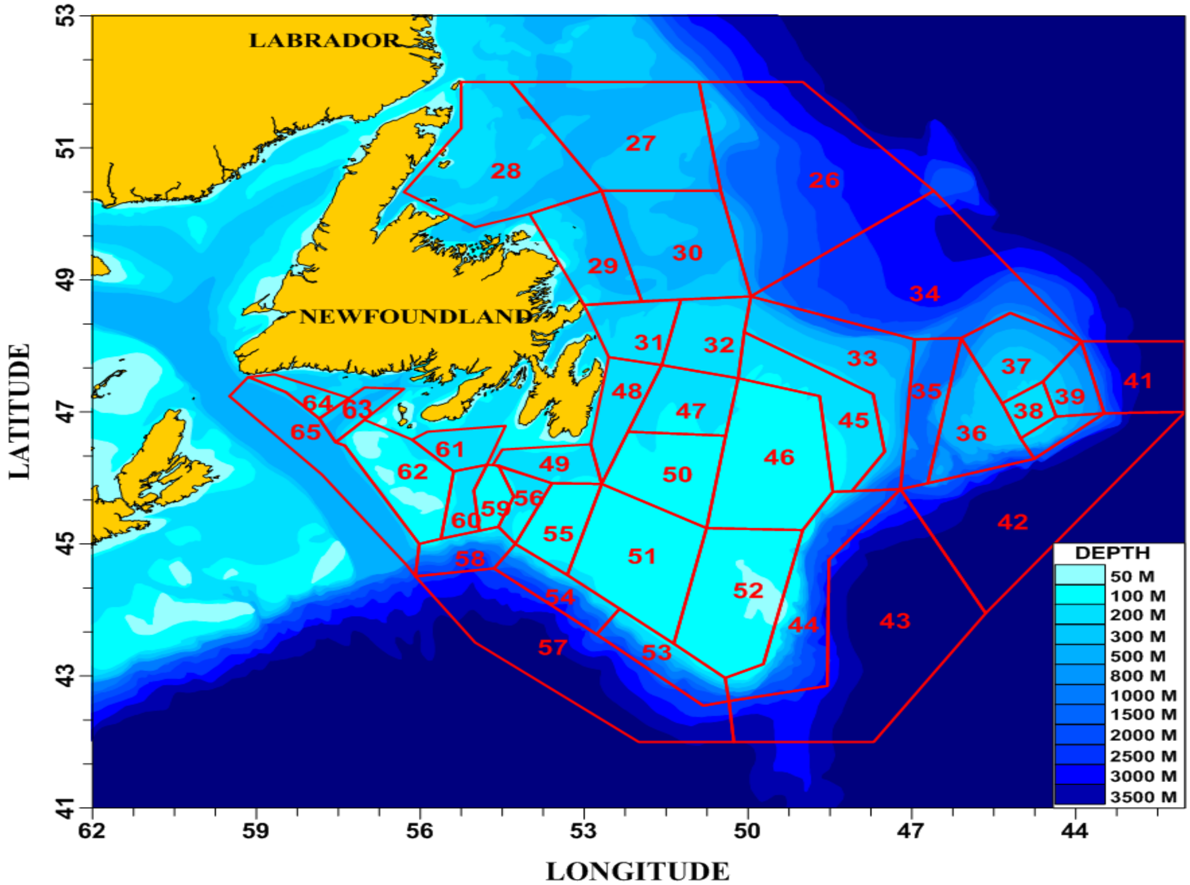

Figure 29. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed in Figure 30.

SUB-AREA	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
26 Funk Slope	0.1	0.1	-0.3	1.3	-0.5	-2.1	-1.6	-0.4	-1.2	-1.9	0.1	0.3	-0.9	0.4	0.1	-0.9	-0.7	0.0	0.1	2.3	0.6	-0.2	-0.8	-0.2	1.1	1.2	0.6	1.0	1.1	-0.1	0.8	0.9	0.4	1.0	3.39	0.20
27 Funk Island	0.7	0.4	0.3	-0.8	-0.7	-1.8	-1.8	-0.2	0.1	-0.9	-1.1	-0.1	-0.6	1.4	-1.2	-0.3	-1.0	0.5	0.6	0.9	1.0	1.0	0.3	1.2	2.5	0.9	0.4	0.8	1.1	-0.3	-0.2	2.4	0.7	1.4	2.82	0.41
28 White Bay	0.5	1.4	0.2	-0.1	-1.2	-0.7	1.4	-0.7	-0.2	0.0	-1.1	-0.7	-1.7	-0.7	-0.7	-1.0	-0.8	0.0	0.7	1.2	-1.6	-0.5	-0.4	0.4	0.8	2.3	1.1	1.5	0.6	-0.9	-0.4	2.8	0.2	1.4	0.69	0.48
29 Bonavista	1.4	1.3	0.5	-1.2	1.6	-0.9	-0.4	1.1	0.4	-1.8	-1.1	-1.0	-0.9	-1.9	-1.2	-0.8	-0.2	0.5	-0.4	0.7	0.2	0.2	0.8	-0.4	1.1	0.1	1.0	2.0	0.0	0.5	0.6	2.7	0.6	0.1	0.91	0.50
30 NE Nfld Shelf	0.6	-0.3	-0.1	-0.2	-2.0	-1.8	-1.3	-0.3	-0.5	-0.4	-1.1	0.0	-0.5	-0.9	-1.2	-0.1	0.1	0.7	1.1	1.2	0.7	0.9	0.6	0.3	1.7	1.2	1.2	1.2	1.6	-0.6	0.6	2.5	1.4	0.7	2.54	0.52
31 Baccaliu	1.4	0.7	-0.1	-0.9	-1.0	-0.9	0.0	-0.3	-0.3	-1.1	-1.1	-1.4	-1.0	-1.1	-1.0	-0.4	2.0	1.7	1.5	1.0	0.9	-0.1	0.3	-0.2	1.0	0.8	1.1	0.8	-0.4	-0.8	1.5	2.0	1.1	0.3	-0.32	0.63
32 N Slope	0.2	1.4	-0.1	-0.7	-1.1	-1.1	0.1	-0.3	1.0	-1.0	-1.3	-0.8	-0.9	-1.4	-0.6	-0.7	0.6	0.9	0.9	1.4	0.4	0.0	0.4	-0.5	1.2	1.6	2.0	0.5	1.0	-1.1	1.3	2.5	0.7	0.3	-0.16	0.51
33 NE Slope	0.4	-0.5	0.0	-1.0	-1.4	-2.3	-1.0	-0.1	-1.0	-0.1	-0.8	-0.8	-0.8	-0.8	-0.4	0.2	0.0	1.0	1.0	1.1	0.6	0.7	0.7	0.7	1.7	1.2	1.5	0.9	1.3	0.8	1.1	2.1	1.4	0.4	2.47	0.64
34 Funk Offshore	-0.4	0.8	-0.3	1.2	0.6	-0.1	-0.6	0.0	-0.2	-0.8	-1.8	0.4	-0.5	0.2	0.0	-0.6	-0.6	0.0	-0.3	2.2	0.0	-0.7	0.5	3.8	0.0	-0.9	0.0	0.0	-0.3	0.2	-0.2	0.1	2.3	0.1	3.42	0.34
35 Flemish Pass	0.2	0.2	0.1	0.6	0.6	0.8	-2.0	-0.3	0.3	-2.5	-1.1	0.3	-0.5	0.1	0.3	-1.6	-0.5	-0.5	0.3	0.6	0.7	0.1	0.2	-0.3	0.0	0.8	1.4	1.5	1.2	1.9	1.6	1.3	1.3	1.4	3.54	0.27
36 Flemish Cap (W Slope)	0.5	0.0	-0.3	1.1	1.7	0.3	-0.2	-0.6	0.0	-0.6	-2.4	0.5	-1.4	-0.5	-0.8	-1.5	-1.0	-0.7	-0.3	0.8	1.1	-0.1	-0.3	-0.5	0.4	0.3	0.6	0.2	1.6	2.4	0.5	6.6	2.4	2.5	3.74	0.28
37 Flemish Cap (N Slope)	0.5	0.3	-0.2	1.1	1.5	-0.4	-0.1	-0.3	0.5	-1.4	-1.1	-0.6	-1.7	-0.8	-0.1	-0.7	-0.8	-0.4	-0.3	2.0	0.8	0.2	-0.1	-0.7	-0.1	0.1	0.8	0.4	1.9	1.7	2.1	2.6	1.6	1.2	3.65	0.31
38 Central Flemish Cap	1.1	0.3	-0.1	0.3	0.2	-1.1	-0.9	-0.4	0.3	-2.1	-1.5	-1.1	-0.9	-0.4	-1.9	-0.7	-0.2	0.0	0.7	1.4	0.3	-0.1	0.0	0.0	0.9	1.6	0.8	0.1	1.1	0.8	2.2	1.0	0.3	0.6	3.33	0.64
39 Flemish Cap (E Slope)	-0.2	-0.5	-0.1	0.5	1.2	-0.5	-0.2	-0.6	-0.5	-0.6	-1.4	3.2	-0.5	-0.7	-1.3	-0.9	-1.3	-0.8	-0.2	0.2	0.3	0.2	-0.1	-0.5	0.0	0.5	0.6	0.6	0.9	1.3	2.1	1.2	1.3	1.5	3.71	0.37
44 E Slope	1.6	0.8	0.7	1.0	0.0	-2.0	-1.0	-0.3	-1.2	0.0	-2.5	-0.6	-0.9	0.3	-1.0	0.3	-0.6	0.1	1.0	0.5	1.1	1.0	0.6	0.4	1.6	1.5	-0.1	0.5	1.0	0.9	1.1	1.7	0.4	0.4	2.38	0.59
45 NE Edge	-0.3	0.2	0.2	-0.9	-1.1	-1.1	1.1	0.3	-0.3	-0.6	-1.3	-1.0	-1.1	-1.6	-1.0	-0.8	0.5	1.4	0.8	1.3	0.0	0.6	-0.3	-0.1	1.7	0.6	1.8	0.8	0.3	-0.8	1.8	3.4	1.0	0.7	-0.28	0.50
46 NE Grand Bank	0.4	1.1	1.2	0.2	-1.3	-0.7	-1.0	-0.2	0.1	-0.4	0.2	-1.1	-1.1	-1.8	-1.3	-0.3	0.5	-0.6	0.6	1.9	-0.5	-0.2	0.4	-0.2	1.9	0.2	1.3	-0.4	-0.3	1.4	1.7	1.9	0.6	1.3	0.04	0.53
47 NE Avalon Channel	0.5	1.2	0.5	-0.4	-0.8	-0.9	-0.7	0.5	0.0	-0.9	-1.2	-1.3	-1.1	-1.7	-1.2	-0.6	0.5	0.6	0.8	1.2	0.4	0.2	-0.1	-0.4	2.1	1.0	1.7	0.3	0.3	-0.3	1.8	2.9	1.8	1.0	-0.65	0.43
48 N Avalon Channel	0.1	0.8	-0.3	-0.8	-1.0	-1.5	-0.6	0.1	-0.3	-0.7	-1.1	-1.4	-1.1	-1.5	-1.3	-0.5	0.4	0.5	0.7	1.0	0.5	0.6	-0.1	0.2	1.9	1.5	2.1	0.6	0.1	-0.3	1.5	3.3	1.2	1.3	-0.82	0.38
49 S Avalon Channel	0.0	-0.1	0.6	-1.5	-0.9	-0.4	-0.8	-0.8	0.8	-1.3	-0.8	-1.1	-1.1	-1.3	-1.3	0.0	1.3	-0.4	1.1	-0.5	0.7	0.6	-0.3	-0.6	1.5	1.3	2.5	-0.5	-0.1	0.3	0.9	3.1	2.1	1.2	-0.75	0.45
50 NW Grand Bank	0.5	1.8	0.2	1.5	-0.7	-0.9	0.4	0.1	-0.2	-0.5	-0.4	-1.6	-1.4	-1.9	-1.6	0.5	0.4	-0.7	1.0	1.6	0.0	0.5	0.2	-0.7	1.3	1.2	1.1	0.0	-0.6	0.3	1.0	2.0	0.8	1.5	0.16	0.51
51 SW Grand Bank	0.4	0.6	0.1	4.3	-0.2	-1.0	-0.1	0.0	0.0	-0.4	-1.0	-0.5	-1.2	-0.4	-1.1	0.9	0.3	-0.7	0.5	1.3	0.6	0.0	-0.5	-0.5	0.1	0.3	0.3	0.6	-0.2	0.1	0.7	1.1	1.0	0.9	1.92	1.14
52 SE Grand Bank	0.7	1.1	0.1	2.0	0.1	-0.7	-0.2	-0.3	-0.9	0.7	-0.8	-0.4	-1.6	-1.7	-0.4	-0.1	0.1	-0.3	1.2	2.0	0.2	-0.4	-0.7	-1.1	1.4	-0.2	0.7	0.0	-1.1	1.6	1.1	2.2	0.6	0.7	2.08	0.63
53 S Slope	0.5	0.8	-0.8	2.7	-0.8	-0.2	0.7	0.0	-0.1	0.4	-1.6	-1.8	-1.9	0.4	0.1	0.1	-0.6	-0.9	1.2	0.8	1.7	0.0	-0.3	0.5	0.7	1.0	0.0	-0.1	-0.5	1.2	0.3	1.6	0.9	0.5	3.66	1.00
54 SW Slope	-0.3	-0.1	-1.8	0.0	1.0	-1.1	0.9	0.2	1.4	-0.3	-1.4	-2.4	-0.9	1.5	-0.1	1.2	0.9	-0.6	-0.3	1.3	0.4	0.6	0.0	0.0	-0.5	1.0	1.1	-0.6	-0.8	1.3	0.3	2.5	1.6	2.7	4.92	0.83
55 Whale Bank	-0.1	1.8	0.0	3.5	1.1	-0.7	0.7	-0.9	1.8	-0.5	-0.5	-0.7	-0.8	-0.3	-1.4	-0.6	0.3	-0.4	0.3	1.2	0.0	-0.2	0.0	-0.6	0.3	0.4	-0.4	-0.5	-0.4	-0.1	0.4	1.8	2.0	1.0	0.38	0.81
56 Haddock Channel	-0.9	-0.1	0.1	0.1	-0.1	-1.3	1.0	-0.5	0.5	0.5	-1.3	-0.5	-0.8	0.6	-1.7	0.5	-0.5	0.3	-0.2	1.2	-0.5	2.0	-0.6	0.2	3.3	-0.4	0.3	-0.9	-0.1	0.8	0.8	6.0	3.3	2.0	-0.37	0.56
58 Halibut Channel Slope	-4.0	1.9	-0.5	1.1	1.6	0.2	0.6	-0.3	0.2	-0.6	-1.8	-0.8	0.3	-1.0	-0.6	-0.9	1.2	0.0	1.0	0.9	0.9	0.6	0.0	-1.0	-1.3	1.0	-2.3	-0.2	-0.6	0.3	0.4	1.4	1.2	1.7	4.42	0.88
59 Green Bank	1.1	2.7	0.0	0.2	1.8	-1.4	-1.1	-0.3	-0.4	-0.8	-0.3	-1.2	-0.9	-1.4	-1.6	0.2	0.4	-0.3	0.5	0.6	1.5	0.8	0.0	-0.5	0.9	0.5	1.2	0.6	-0.2	0.2	1.1	5.6	1.2	1.8	-0.62	0.53
60 Halibut Channel	-0.8	0.7	-0.8	0.5	0.5	0.2	-0.1	-0.9	-0.1	-0.1	-1.0	-0.4	-0.4	-0.9	-1.5	-1.1	2.0	0.0	0.0	0.9	2.3	1.3	1.2	-0.7	-0.2	0.5	-1.5	-0.9	-1.0	1.8	-0.3	0.0	-0.3	0.2	0.92	1.41
61 St. Pierre Channel	-0.5	-0.2	-1.2	0.7	0.1	-0.7	-1.0	-0.7	0.8	-0.2	-1.2	-0.9	-0.2	-1.1	-1.1	-1.4	0.3	3.4	-0.4	0.4	0.9	-0.3	-0.1	-1.2	0.6	0.4	0.6	0.5	-0.3	0.9	1.3	2.1	1.6	0.7	-0.56	0.43
62 St. Pierre Bank	-1.6	0.0	-0.9	0.0	1.5	-0.8	-1.3	-1.0	0.7	-0.5	-0.3	-0.1	0.0	-0.6	-0.4	-0.3	0.0	-2.0	-1.2	1.5	0.1	-0.6	0.5	-1.4	-0.5	1.5	1.6	-0.8	-0.1	0.2	2.3	1.4	-1.6	-0.5	1.62	0.65
63 Hermitage Channel	-2.3	2.6	-0.3	-0.3	0.6	1.3	1.7	0.3	-2.0	-1.7	-0.6	-1.6	-0.3	0.6	0.7	0.1	-0.1	0.6	-0.8	0.3	0.8	-1.0	0.6	-1.4	0.2	0.1	0.4	-0.4	0.5	0.0	1.0	0.3	1.1	0.0	5.25	0.79
64 Burgeo Bank	-4.9	0.6	1.0	0.3	0.4	1.7	1.7	-0.2	-0.4	-1.1	-0.1	-1.4	-1.9	-0.3	0.6	-0.6	-0.5	-0.3	-0.2	0.8	-0.8	-1.5	0.0	-2.7	-0.9	0.4	1.1	0.1	0.0	0.9	-0.1	2.1	1.6	1.1	3.59	0.71
65 Laurentian Channel	-1.0	1.6	-2.8	0.5	1.8	-0.3	-1.2	-0.2	0.5	-1.1	-1.4	-0.3	-0.1	0.3	-1.2	1.0	1.3	-0.6	0.5	-0.4	1.1	0.7	-0.1	-0.5	-1.3	-0.2	0.0	-1.3	-0.4	0.6	0.3	-0.1	2.7	3.9	4.94	0.45

Figure 30. Standardized bottom temperature anomalies for the Newfoundland Shelf referenced to 1981-2010.

STANDARD SECTIONS

In the early 1950s several countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic monitoring along sections in Newfoundland and Labrador Waters. In 1976, ICNAF standardized a suite of oceanographic monitoring stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF 1978).

In 1998 under the AZMP program, the Seal Island (SI), Bonavista Bay (BB), Flemish Cap (47^{o}N) (FC) and Southeast Grand Bank (SEGB) historical stations were selected as core monitoring sections. The White Bay section (WB) was continued to be sampled during the summer as a long time series NAFO section. Two sections on the mid-Labrador Shelf, the Beachy Island (BI) section and the Makkovik Bank (MB) section were selected to be sampled during the summer if survey time permitted. Starting in the spring of 2009 a section crossing to the southwest of St. Pierre Bank (SWSPB) and one crossing to the southeast of St. Pierre Bank (SESPB) was added to the AZMP surveys (Figure 2). In addition since 2008 the Seal Island section, normally only sampled during the summer, was also sampled during the fall.

In 2013, the SWSPB, SESPB and the SEGB sections were sampled in April and December, the FC section during April, July and November/December, the BB section during April, July and November, the SI section in July and November, and the MB and WB sections during July (Figure 2).

The water mass characteristics observed along the standard sections crossing the NL Shelf (Figure 2) are typical sub-polar waters with a sub-surface temperature range on the shelf of -1.5ºC ─ 2ºC and salinities of 31.5 ─ 33.5. Labrador Slope Water flows southward along the shelf edge and into the Flemish Pass and Cap regions. This water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3^o - 4^{o}C and salinities in the range of 34 ─ 34.75. Surface temperatures normally warm to 10^o ─ 12^{o}C during late summer, while bottom temperatures remain <0^{o}C over much of the Grand Banks but increase to 1^o ─ 3.5^{o}C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper (>1000 m) waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3^o ─ 4^{o}C.

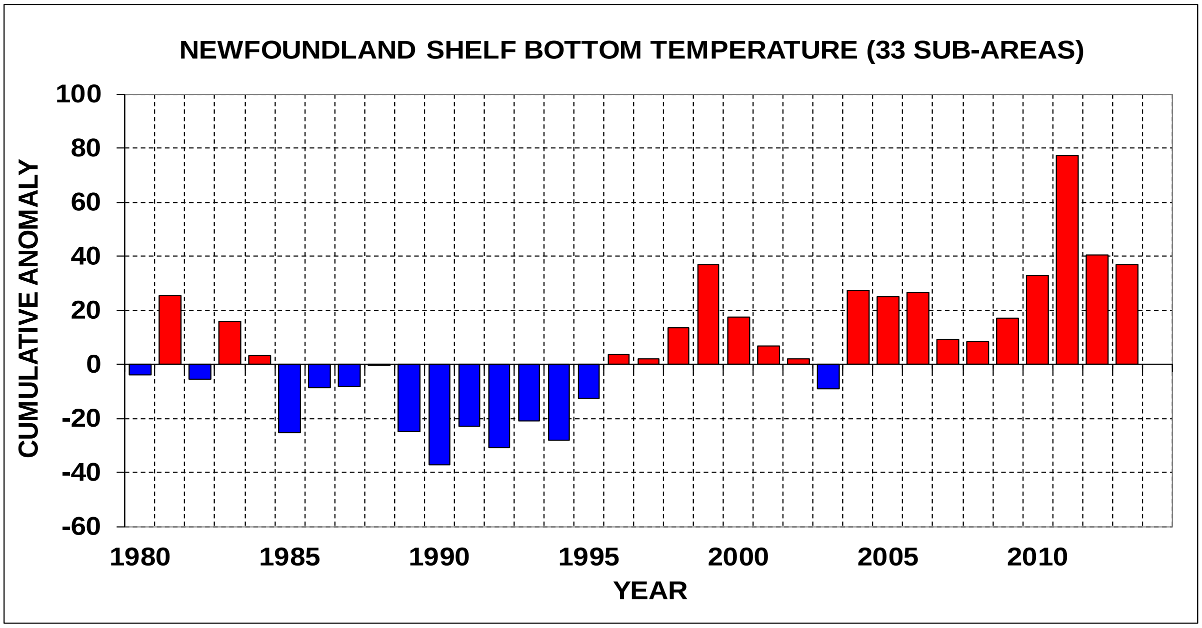

Figure 31. Cumulative bottom temperature anomalies based on the values presented in Figure 30 for the areas on the Newfoundland Shelf shown in Figure 29.

In general, the near-surface water mass characteristics along the standard sections undergo seasonal modification from seasonal cycles of air-sea heat flux; wind forced mixing, and the formation and melting of sea ice. These mechanisms cause intense vertical and horizontal temperature and salinity gradients, particularly along the frontal boundaries separating the shelf and slope water masses. These seasonal changes are highlighted in Figure 32 along the Bonavista Section with the cold shelf water mass as the dominate feature. The corresponding salinity cross-sections show remarkable seasonal similarities with the relatively fresh outflow from the arctic and the Labrador Shelf with values <33 contrasting to the saltier Labrador Slope water further offshore with values >34 (Figure 33).

Throughout most of the year, the cold relatively fresh water overlying the shelf is separated from the warmer higher density water of the continental slope region by strong temperature and salinity (density) fronts (Figure 32 and 33). This winter chilled water mass is commonly referred to as the cold intermediate layer or CIL (Petrie et al. 1988) and its cross sectional area or volume bounded by the 0^oC isotherm is generally regarded as a robust index of ocean climate conditions on the eastern Canadian Continental Shelf. While the cross sectional area of the CIL water mass undergoes significant annual variability, the changes are highly coherent from the Labrador Shelf to the Grand Banks. The shelf water mass remains present throughout most of the year as summer heating and salinity changes increase the stratification in the upper layers to a point where heat transfer to the lower layers is reduced. The CIL areal extent continues to undergo a gradual decay during the fall however as the seasonally heated upper layers penetrate the water column.

During 2013 temperatures along the Bonavista section were predominately above normal with a few isolated areas with below normal values, particularly during the spring. The most significant anomalies occurred during the summer in the near-surface layer when values exceeded 3^oC above normal over the shelf areas (Figure 32, right panels). Salinity anomalies were highly variable but generally weak with maximum values <0.5. The most significant anomaly occurred during the spring in offshore waters when values were lower than normal and during the summer when values were higher than normal in the near-surface layer (Figure 33, right panels).

Time series of CIL cross-sectional area anomalies along sections from southern Labrador to the Grand Banks are displayed in Figures 34, 35 and 36 for the spring, summer and fall. The CIL area anomalies during the spring, summer and fall of 2013 were below normal along all sections sampled (implying warmer-than-normal shelf water conditions) and in fact they decreased compared to the previous year. With the exception of the Bonavista section in 2012 the CIL areas have been below normal during the past four years and have experienced a general downward trend since the early-1990s. Note also that not all sections were sampled in the early years of each series.

Standardized indices derived from the temperature and salinity data for the Seal Island, Bonavista and Flemish Cap sections sampled during the summer are shown in Figure 37. All temperature indices shown were either near-normal or above normal by up to a maximum of 2.7 SD, with the strongest anomalies on the Grand Bank along the Flemish Cap (47°N) section. In contrast the salinity indices were either near-normal or below normal (fresher water) by up 1.4 SD.

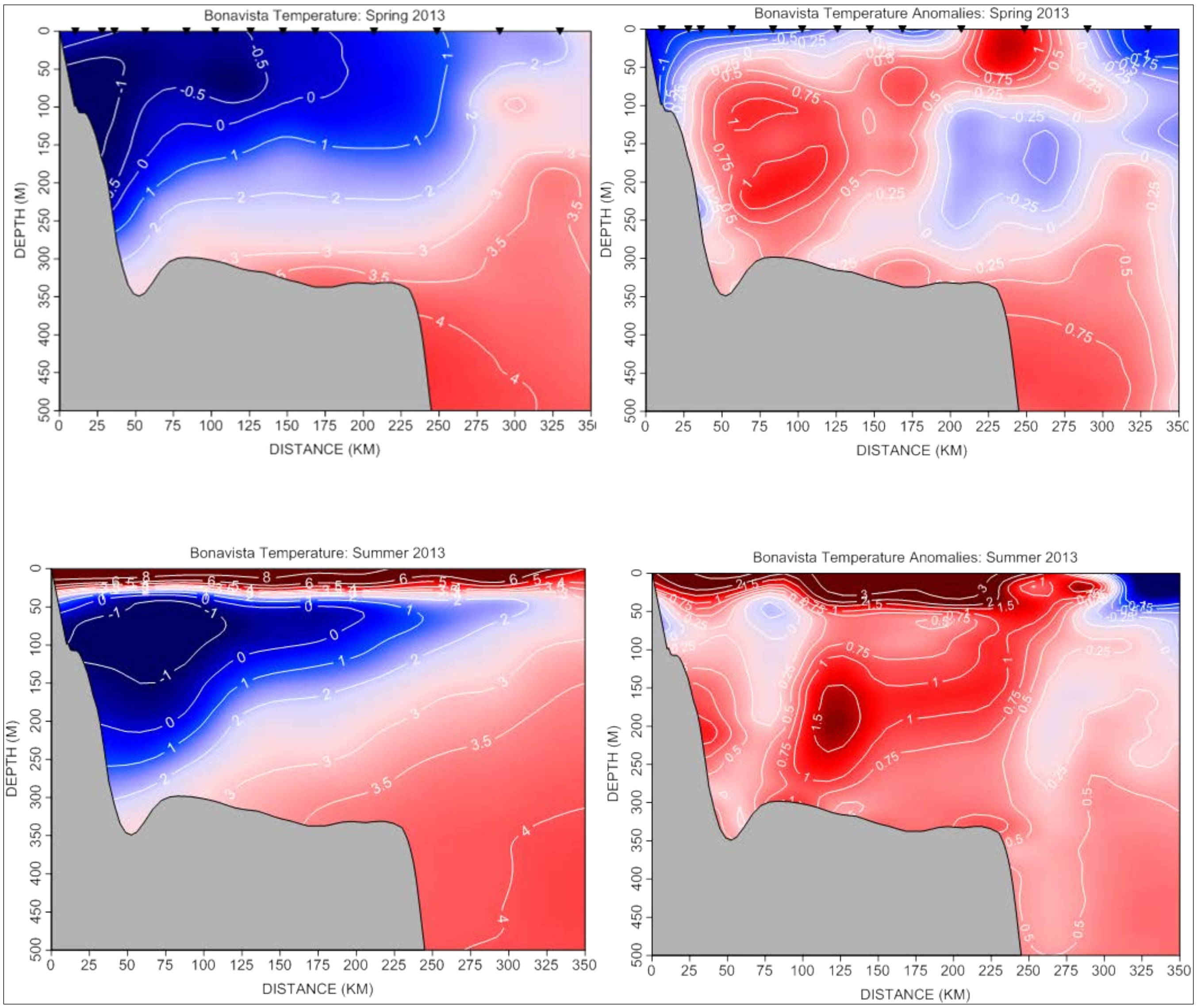

Figure 32a. Contours of temperature (°C) and temperature anomalies along the Bonavista section (Figure 2) during the spring and summer of 2013. Station locations along the section are indicated by the symbols on the top panels.

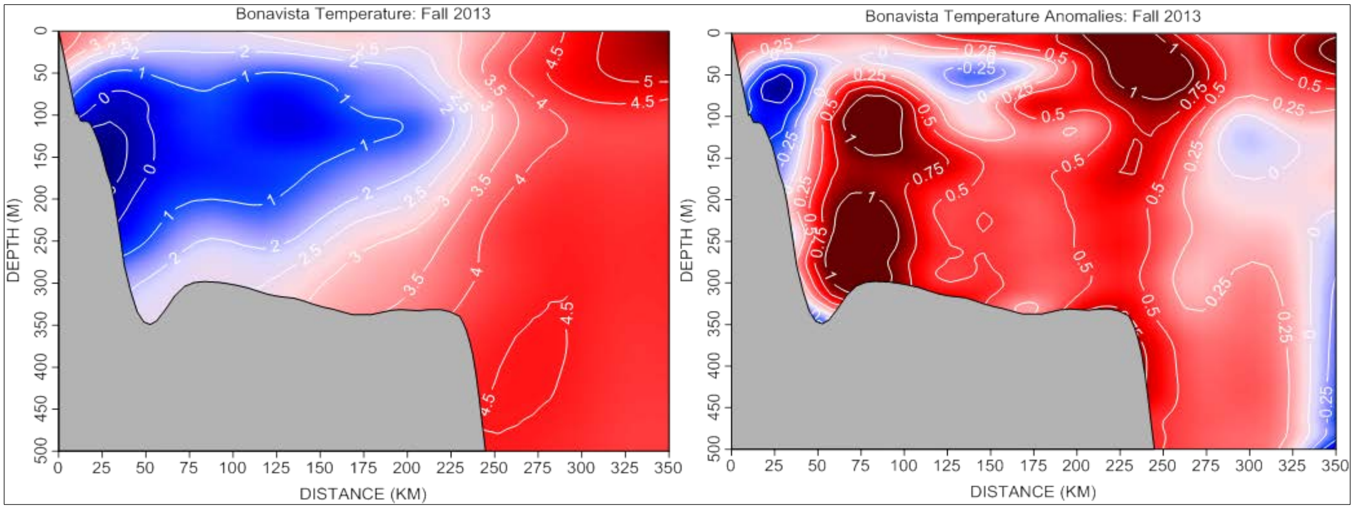

Figure 32b. Contours of temperature (^oC) and temperature anomalies along the Bonavista section (Figure 2) during the fall of 2013. Station locations along the section are indicated by the symbols on the top panels.

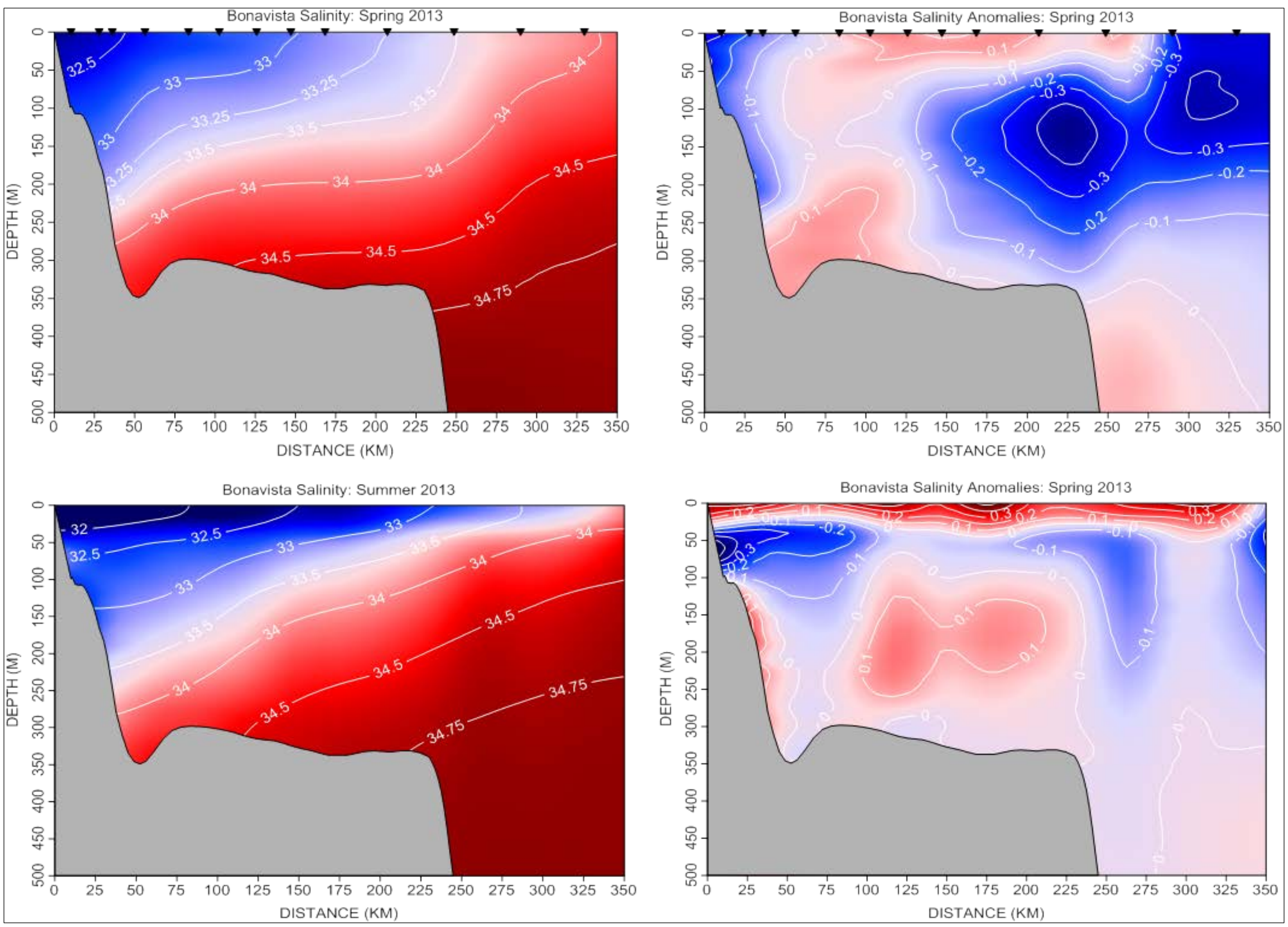

Figure 33a. Contours of salinity and salinity anomalies along the Bonavista section (Figure 2) during the spring and summer of 2013. Station locations along the section are indicated by the symbols on the top panels.

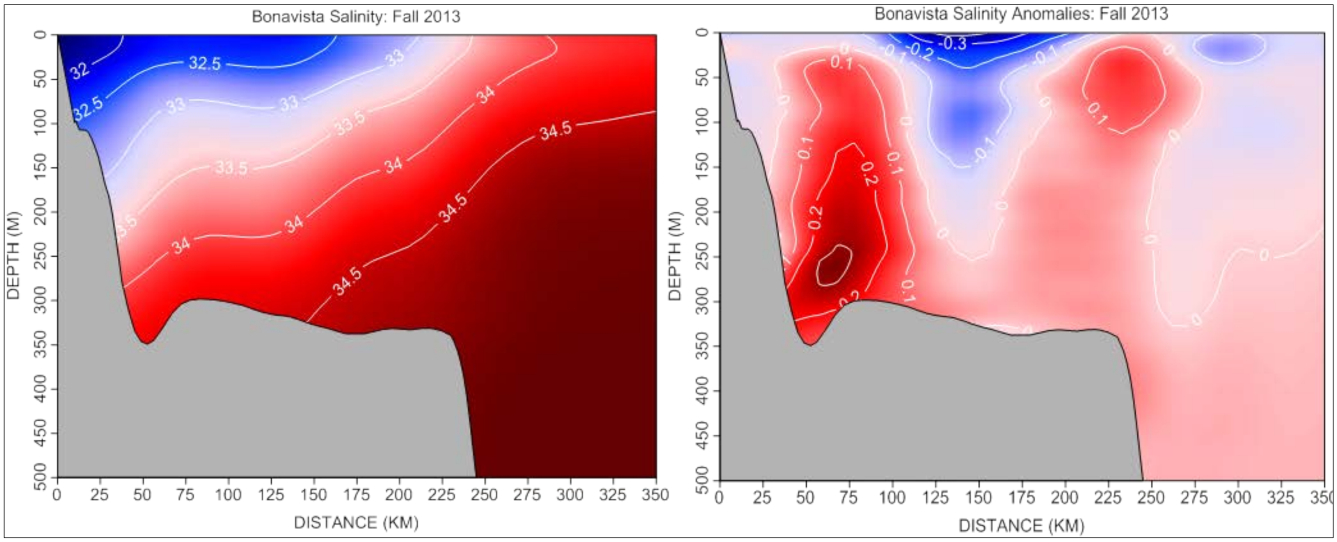

Figure 33b. Contours of salinity and salinity anomalies along the Bonavista section (Figure 2) during the fall of 2013. Station locations along the section are indicated by the symbols on the top panels.

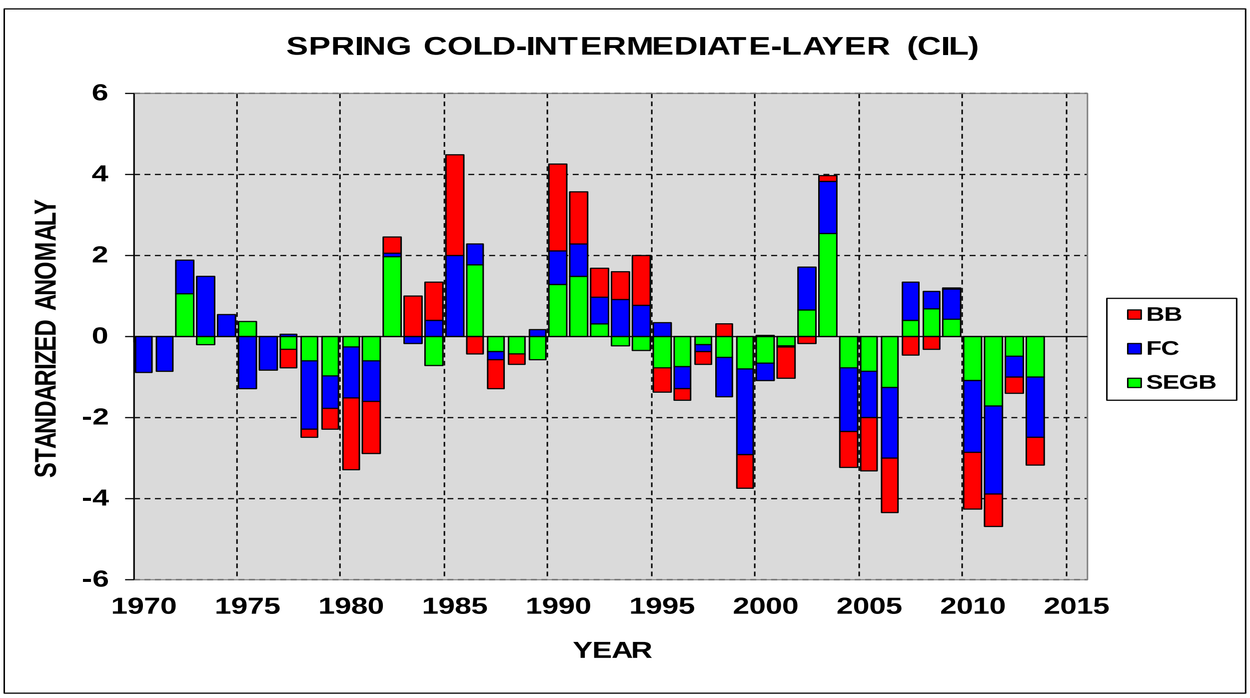

Figure 34. Cold-Intermediate-Layer areas during the spring along the Bonavista, Flemish Cap and the south east Grand Bank sections displayed as cumulative standardized anomalies relative to 1981-2010.

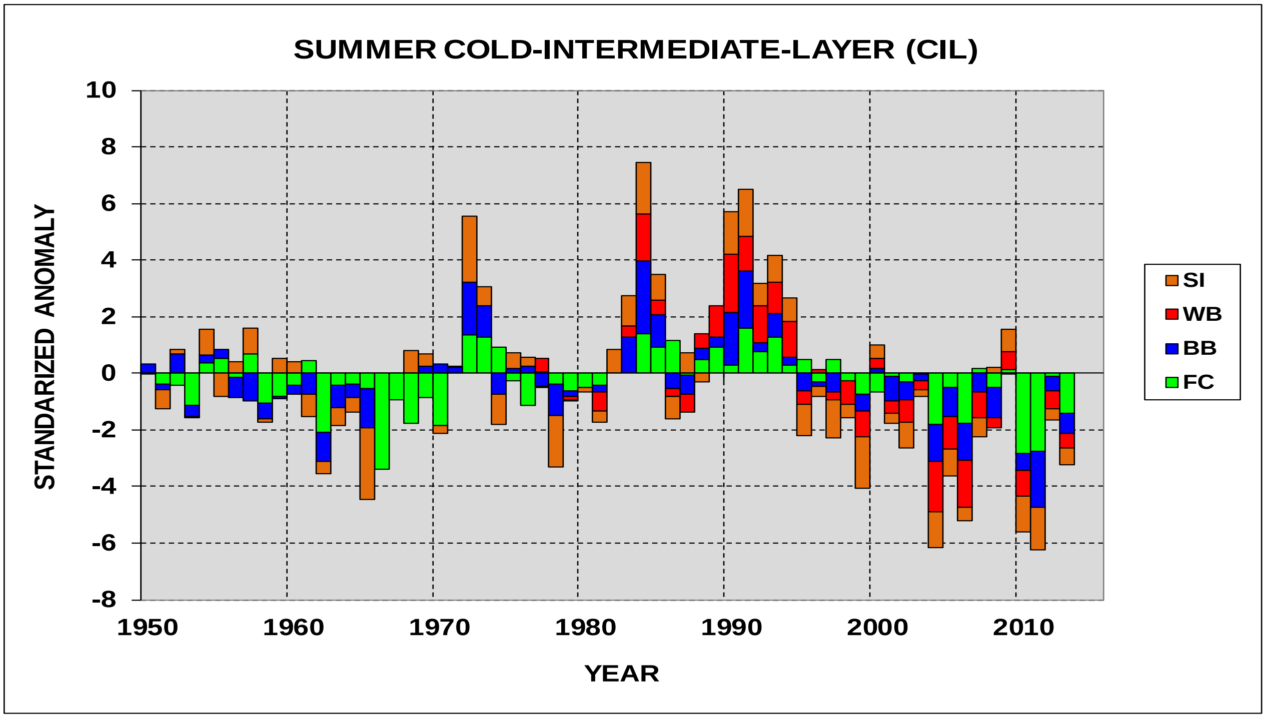

Figure 35. Cold-Intermediate-Layer areas during the summer along the Seal Island, White Bay, Bonavista and Flemish Cap sections displayed as cumulative standardized anomalies relative to 1981-2010.

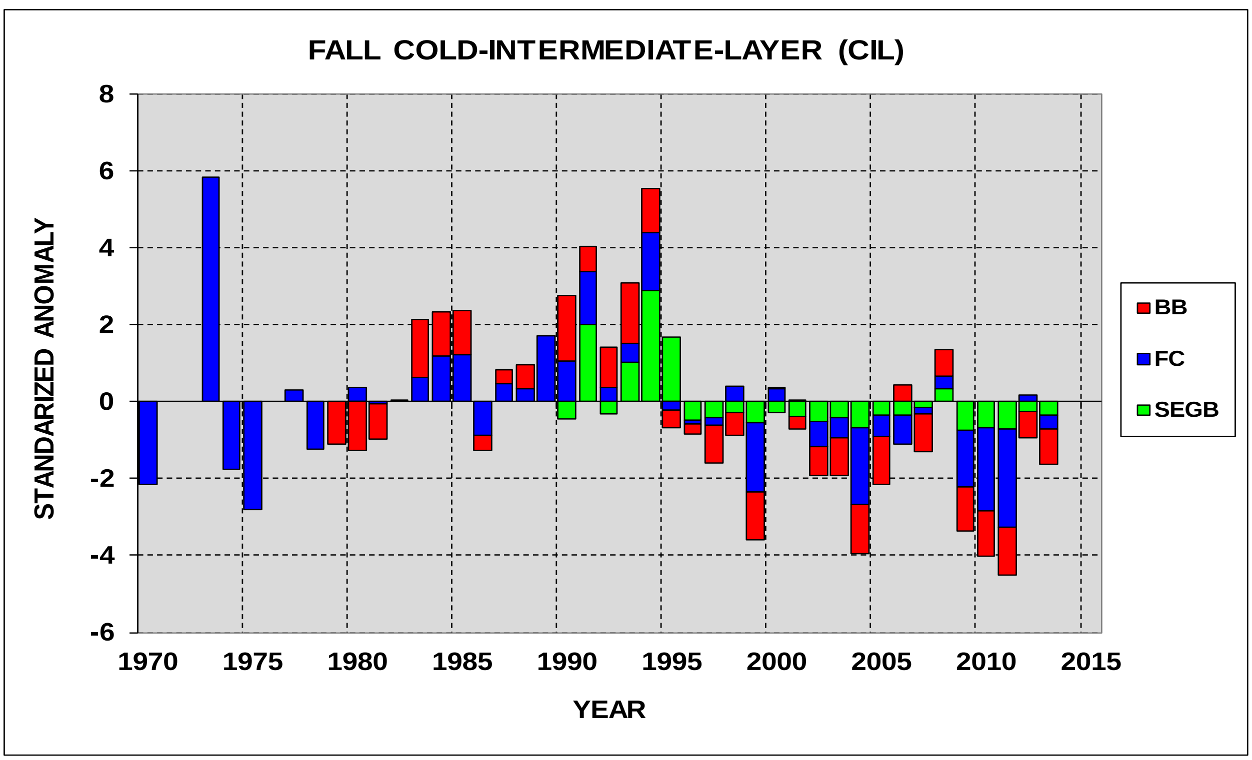

Figure 36. Cold-Intermediate-Layer areas during the fall along the Bonavista, Flemish Cap and the south east Grand Bank sections displayed as cumulative standardized anomalies relative to 1981-2010.

INDEX	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	MEAN	SD
CIL AREA	-0.2	-0.4	0.8	1.0	1.8	0.9	-0.8	0.7	-0.3		1.5	1.6	0.8	0.9	0.8	-1.1	-0.4	-1.4	-0.5	-1.8	0.5	-0.4	-0.9	-0.3	-1.3	-1.0	-0.5	-0.7	0.2	0.8	-1.3	-1.5	-0.4	-0.6	27.27	7.46
MEAN CIL TEMPERATURE	-0.4	0.9		-1.4	-1.1	-1.6	0.6	-0.5	-0.2		-1.5	-0.9	-1.1	-1.4	-0.8	1.7	0.5	0.6	0.3	1.6	-0.4	0.9	0.9	0.1	0.9	1.4	0.7	0.3	-0.4	-1.0	0.8	1.6	0.2	0.9	-0.88	0.21
MINIMUM CIL TEMPERATURE	0.0	1.3	0.1	-1.3	-1.2	-1.0	0.8	0.2	0.1		-0.9	-1.2	-0.9	-1.3	-0.7	1.9	-0.4	-0.6	-0.4	1.0	-0.6	0.9	-0.6	0.6	2.2	0.9	1.1	-0.2	-0.7	-0.3	1.1	2.6	-0.5	0.3	-1.50	0.17
MEAN SECTION TEMPERATURE	-0.5	-0.1			-1.9	-0.8	0.1	-1.0	-0.1		-1.7	-1.6	-1.4	-1.4	-0.9	0.3	0.0	0.6	0.5	0.9	0.0	0.2	0.4	0.7	1.6	1.0	1.2	0.8	1.1	0.2	1.2	1.6	0.6	0.6	1.81	0.50
MEAN SECTION SALINITY	-0.1	3.2			-1.7	-0.4	0.3	-0.1	-0.7		-1.3	-1.5	0.9	-0.7	-1.0	0.6	-0.7	0.6	0.1	0.7	-1.0	0.1	1.1	-0.1	1.3	0.6	0.4	0.0	-0.2	-0.3	-0.2	-1.0	-0.3	-0.5	33.87	0.14
INSHORE SHELF SALINITY	0.4	2.9		-0.7	-0.6	0.3	-0.5	0.4	-1.4		-0.1	-1.1	0.9	1.0	-0.8	0.6	-0.8	0.5	0.3	1.0	-1.4	0.1	0.5	0.0	0.0	1.1	0.2	0.1	0.4	-0.5	-2.4	-0.8	-0.4	-1.4	32.54	0.24
CIL AREA		-0.2		1.3	2.6	1.1	-0.5	-0.7	0.4	0.3	1.9	2.0	0.3	0.8	0.3	-0.6	-0.2	-0.7	0.0	-0.6	0.2	-0.9	-0.6	-0.2	-1.3	-1.0	-1.3	-0.7	-1.1	0.0	-0.6	-2.0	-0.5	-0.7	25.56	9.35
MEAN CIL TEMPERATURE		0.7		-1.4	-1.3	-0.3	0.4	1.0	1.0	-1.0	-1.1	-1.6	-0.5	-1.2	-0.6	0.5	1.2	-0.5	-1.1	-0.3	-0.1	1.2	-0.4	-0.4	1.4	1.3	1.7	0.7	-0.3	-0.4	1.4	1.6	-0.5	1.8	-0.93	0.15
MINIMUM CIL TEMPERATURE		1.5		-1.8	-1.5	-0.8	0.7	0.7	0.8	-0.9	-0.8	-1.1	-0.6	-1.1	-0.8	-0.2	0.4	-0.5	-0.5	0.1	-0.1	0.7	0.1	-0.2	2.0	1.1	2.2	0.1	-0.2	-0.5	1.0	2.8	-0.7	0.6	-0.93	0.15
MEAN SECTION TEMPERATURE		0.2		-1.1	-1.8	-1.4	0.1	0.5	0.0	0.1	-1.6	-1.6	-1.3	-1.0	-0.9	0.0	-0.4	0.5	0.4	0.8	0.3	0.2	0.2	0.5	1.7	1.4	1.6	0.8	1.6	-0.1	0.4	1.9	1.0	0.0	-1.60	0.13
MEAN SECTION SALINITY		-0.4		-1.0	-1.7	-1.0	0.3	1.1	-0.1	0.2	-1.3	-1.3	-0.7	-0.4	0.0	0.8	-1.6	0.7	-0.4	-0.1	-0.1	-0.2	1.6	0.4	1.5	0.7	1.5	0.8	2.1	-0.3	-0.9	0.8	0.0	-0.4	33.94	0.11
INSHORE SHELF SALINITY		-0.2		0.7	-0.8	0.2	-0.9	0.4	1.1	1.0	0.4	-1.5	-1.4	0.0	0.2	-1.5	-0.2	-0.2	-0.6	-2.1	0.4	-0.7	1.9	-0.3	0.6	0.7	1.4	1.0	1.7	-1.3	-0.1	-0.3	-0.1	-1.3	32.97	0.12
CIL AREA	-0.5	-0.5			1.4	0.9	1.1	-0.1	0.5	0.9	0.2	1.6	0.8	1.3	0.3	0.5	-0.4	0.5	-0.3	-0.8	-0.7	-0.2	-0.4	-0.1	-1.9	-0.6	-1.9	0.1	-0.5	0.1	-2.9	-2.9	-0.2	-1.5	26.52	6.63
MEAN CIL TEMPERATURE	0.9	1.1		-0.9	-0.7	-0.5	-1.4	-0.2	-0.4	-0.8	-1.0	-1.7	-1.2	-1.6	-0.2	-0.8	0.9	0.3	0.6	1.4	1.0	0.9	0.2	-0.3	1.3	0.9	1.6	0.3	0.2	-0.7	1.7	2.3	0.8	1.6	-0.79	0.23
MINIMUM CIL TEMPERATURE	-0.4	1.6			-0.9	-0.9	-0.8	-0.9	1.0	-0.8	-0.5	-1.2	-0.6	-1.1	-0.9	-0.4	1.3	0.2	-0.5	0.5	0.4	1.7	-0.8	-0.1	0.2	0.6	0.8	0.2	-0.2	-0.9	2.8	2.2	-1.0	2.7	-1.54	0.17
MEAN SECTION TEMPERATURE	0.4	0.8		-0.2	-0.4	-1.2	-0.5	-0.5	0.6	-0.7	-0.7	-1.3	-1.5	-2.3		-0.8	-0.1	-0.3	0.5	1.1	0.2		-0.4	1.8	0.9	0.8	1.7		0.7	0.7	1.0	1.7	0.4	0.7	3.49	0.49
MEAN SECTION SALINITY	0.1	0.1		-1.7	-2.7	-1.5	-0.4		0.6	0.6		-0.5	-0.3	-0.2		0.1	0.0	0.7	0.3	0.4	-0.4		0.9	1.8	0.7	-0.8	1.2		0.9	-0.4	0.6	1.0	0.0	0.0	33.93	0.11
INSHORE SHELF SALINITY	0.8	0.5		1.4	-3.3	0.7	-0.7		1.3	2.0		-0.5	-0.8	-0.3	-0.1	-0.3	-0.6	0.2	0.3	0.0	-0.8	-0.8	0.6	0.2	0.0	-0.2	1.1	0.7	0.6	-0.5	-0.8	-0.9	-0.1	-0.3	32.69	0.16

Figure 37. Standardized temperature and salinity anomalies derived from data collected along standard cross-shelf sections during the summer (Figure 2). The anomalies are normalized with respect to their standard deviations over the standard base period. The grey shaded cells indicate years for which no observations were available.

MULTI-SPECIES SURVEY BOTTOM TEMPERATURES

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday 1981). Temperature profiles (and salinity since 1990) are available for fishing sets in each stratum. These surveys provide large spatial-scale oceanographic data sets for the Newfoundland Shelf. During the spring NAFO Subdivision 3Ps and Divisions 3LNO on the Grand Bank are surveyed while in the fall Division 2HJ in the north to 3NO in the south are surveyed. The hydrographic data collected are routinely used to assess the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of data products based on these data are used to characterize the oceanographic habitat. Among these are contoured maps of the bottom temperatures and their anomalies, the area of the bottom covered by water in various temperature ranges as a 'thermal habitat' index, spatial variability in the volume of the cold intermediate layer and water-column stratification and mixed-layer depth spatial maps. In this section, an analysis of the near-bottom temperature fields and their anomalies based on these data sets are presented for the spring (April-May) and fall (October-December) surveys of 2013.

Spring Conditions

Maps of bottom temperatures and their anomalies derived from the spring of 2013 survey (Figure 3) are displayed in Figure 38 for NAFO Div. 3PLNO. Bottom temperatures in Div. 3L were generally <1°C in the inshore regions of the Avalon Channel and parts of the northern Grand Bank and from 2° to >3°C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 1°C – 6°C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from 1° -2°C. On St. Pierre Bank temperatures ranged from 1°C - 3°C and up to 5°C in the Laurentian Channel and areas to the west. Bottom temperature anomalies were above normal by 0.5° to 1°C over most of the region except for isolated areas of 3NO and to the west of St. Pierre Bank where they were slightly below normal.

Standardized temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area are presented in Figure 39 as stacked bar graphs. The increasing trend since the early 1990s is evident with some cooling observed in individual years, 2003 being the most significant. Bottom temperatures reached record high values in 2011 but decreased moderately in 2012 and 2013.

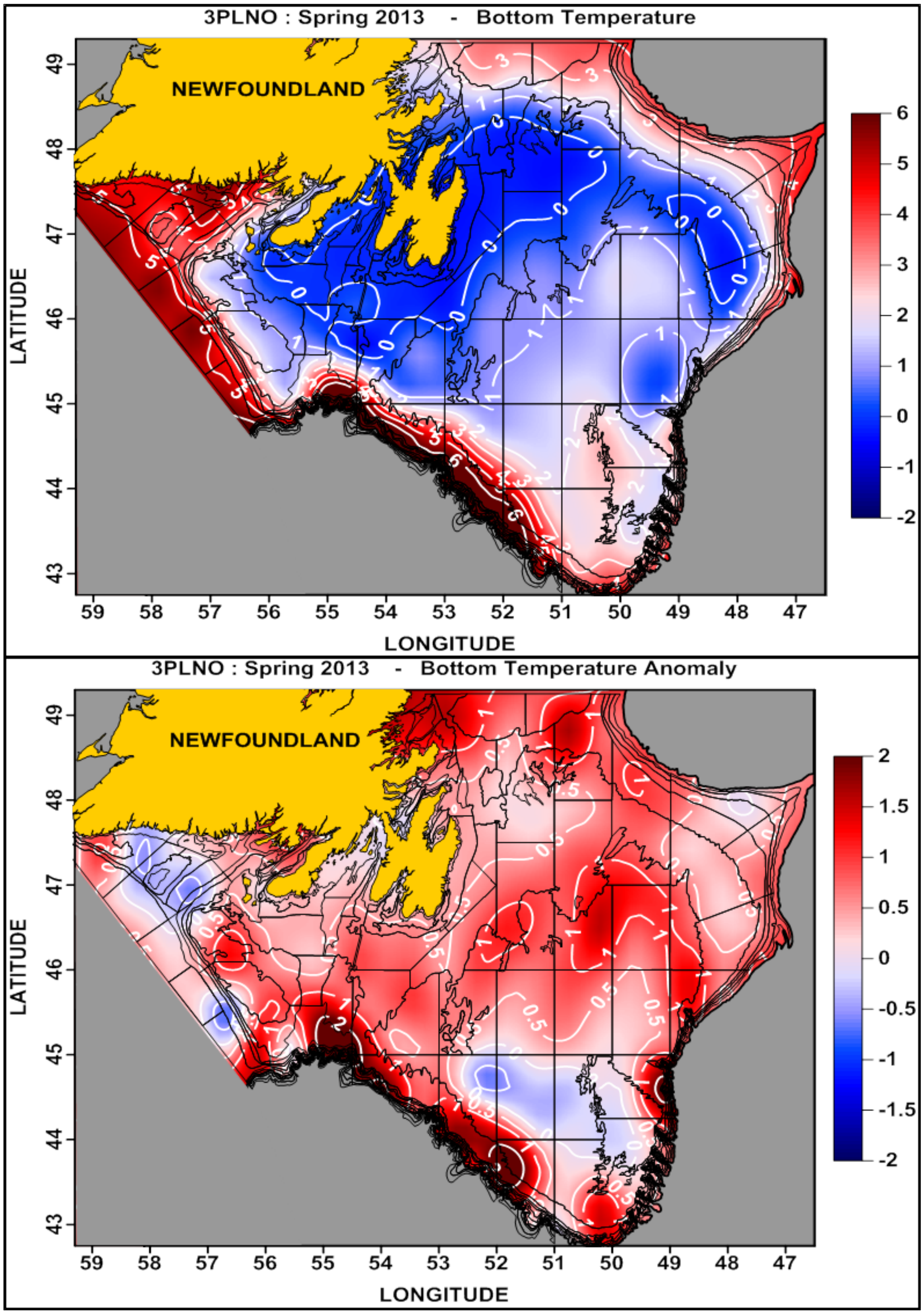

Figure 38. Contour maps of bottom temperature (top panel) and bottom temperature anomalies (bottom panel) (°C) during the spring of 2013 in NAFO Divs. 3PLNO. The anomalies are referenced to the period 1981-2010.

Climate indices based on the temperature data collected during the spring survey for the years 1990-2013 are displayed in Figure 40 as normalized anomalies. The spring of 2011 had the lowest bottom area of <0°C water in Division 3LNO since the surveys began in the early 1970s at 2.2 SD units below normal. In 2013 it remained at 1.5 SD below the long term mean (Figure 40).

In 3LNO spring bottom temperatures were generally lower than normal from 1990 to 1995 with anomalies sometimes exceeding 1.5 SD below the mean. By 1996, conditions had moderated to near-normal values but decreased again in the spring of 1997 before increasing to above normal values from 1998 to 2013, with the exception of 2003.The spring of 2011 had the warmest bottom temperatures on record which remained above normal in 2013 by 0.8-1.3 SD (Figure 40).

In Div. 3P bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000, near record cold conditions in 2003 (-1.4 SD). A notable exception occurred in 2007-2008 when bottom temperatures were colder than normal, by almost 1 SD in 2007. Temperatures began to moderate in 2009 with a further increase in 2010, reaching 1.8 SD in 2011-2012 and then decreasing to 0.4 SD in 2013. Similar to 3LNO, the spring of 2011 had the lowest area of <0°C bottom water since 1990 at 1.9 SD below normal. This area has remained below normal (by 1.5 SD) in 2012-2013 (Figure 40).

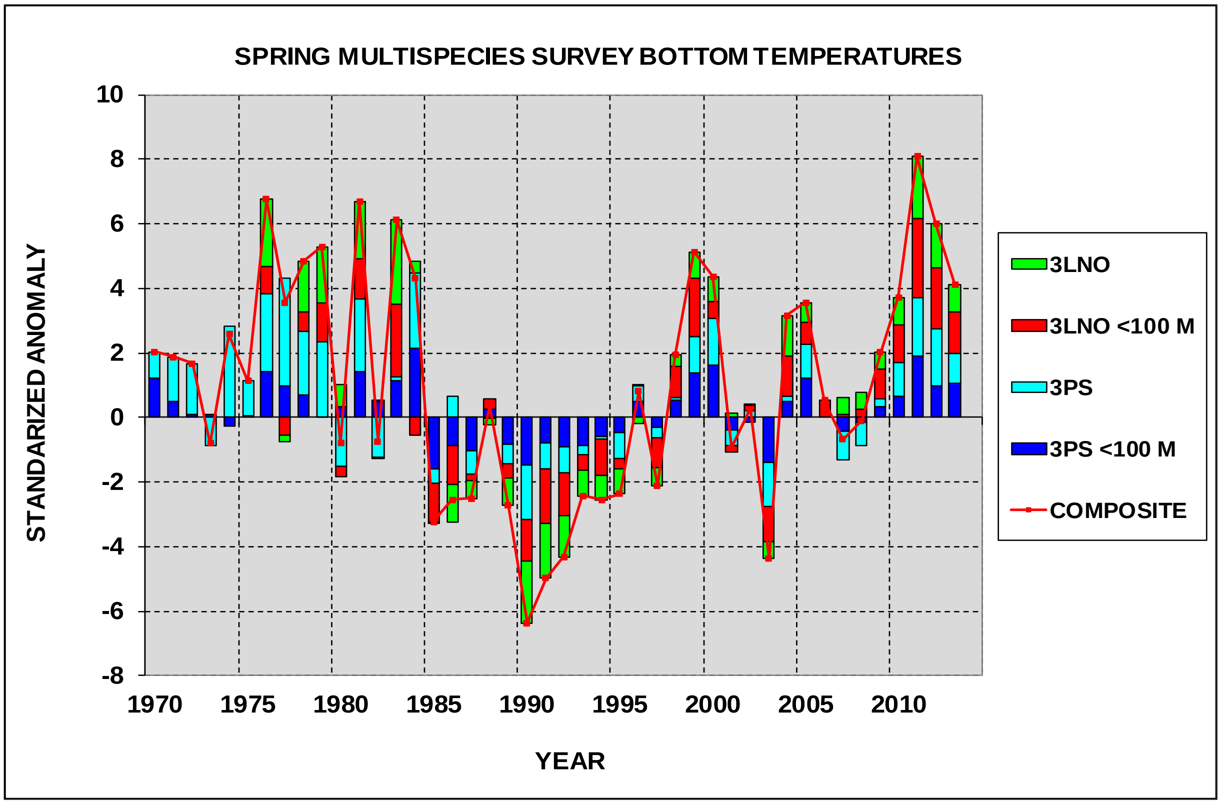

Figure 39. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divs. 3LNOP.

REGION	INDEX	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	MEAN	SD
	BOTTOM TEMPERATURES	0.7	1.8	0.0	2.6	0.4	0.0	-1.1	-0.5	-0.2	-0.9	-1.9	-1.7	-1.3	-0.8	-0.8	-0.8	-0.2	-0.6	0.4	0.8	0.8	0.1	0.1	-0.5	1.3	0.6		0.5	0.5	0.5	0.8	1.9	1.3	0.8	1.48	0.64
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-0.3	1.2	0.0	2.2	-0.5	-1.2	-1.2	-0.2	0.3	-0.4	-1.3	-1.7	-1.3	-0.5	-1.1	-0.3	0.0	-0.9	0.9	1.8	0.5	-0.2	0.1	-1.1	1.2	0.7	0.5	0.1	0.3	0.9	1.2	2.4	1.9	1.3	0.69	0.57
SPRING	THERMAL HABITAT AREA >2°C	-0.2	1.1	-0.8	2.0	0.4	-1.0	-1.1	-0.3	-0.3	-1.0	-1.7	-1.6	-1.3	-0.6	-0.7	-0.5	-0.2	-0.4	0.6	1.8	0.7	-0.3	-0.2	-0.3	1.8	1.0	-0.3	0.7	0.5	0.9	1.1	2.5	1.4	0.7	26.72	10.86
	THERMAL HABITAT AREA <0°C	-0.4	-1.0	0.0	-0.5	0.8	1.1	1.1	0.8	0.5	0.9	1.1	1.5	1.1	1.2	0.8	0.5	-0.3	0.7	-1.0	-1.5	-0.7	-0.5	-0.3	0.5	-2.0	-1.2	-1.7	-0.1	-0.2	0.2	-1.7	-2.2	-1.3	-1.5	33.65	15.38
	BOTTOM TEMPERATURES	-1.5	2.3	-1.2	0.1	2.3	-0.4	0.7	-0.7	0.0	-0.6	-1.7	-0.8	-0.8	-0.3	-0.1	-0.8	0.5	-0.3	0.1	1.2	1.4	-0.5	0.2	-1.4	0.1	1.0		-0.9	-0.7	0.3	1.1	1.8	1.8	0.9	2.53	0.44
NAFO DIV. 3PS	BOTTOM TEMPERATURES <100 M	0.3	1.4	0.5	1.1	2.1	-1.6	-0.9	-1.0	0.3	-0.8	-1.5	-0.8	-0.9	-0.9	-0.6	-0.5	0.5	-0.3	0.6	1.4	1.6	-0.4	-0.2	-1.4	0.5	1.2		-0.4	-0.1	0.3	0.7	1.9	1.0	1.1	0.29	0.73
SPRING	THERMAL HABITAT AREA >2°C	1.6	2.3	-0.9	0.4	2.1	-1.0	-0.4	-0.7	-0.6	-0.9	-1.5	-0.8	-0.4	-0.5	-0.8	-0.6	0.3	-0.3	0.5	1.7	2.2	-0.3	-0.1	-0.6	-0.1	0.8	-0.3	-0.4	0.5	0.6	1.1	0.7	0.6	0.6	54.39	8.19
	THERMAL HABITAT AREA <0°C	-1.7	-1.9	0.3	-0.8	-1.0	1.2	0.9	1.1	-1.5	0.9	1.4	0.7	0.9	1.0	0.5	0.7	-0.8	0.4	-0.4	-1.0	-1.4	0.4	0.1	1.3	-1.5	-1.4	0.4	0.4	-0.1	-1.1	-1.9	-1.5	-1.5	-1.5	22.13	11.78

Figure 40. Temperature indices derived from data collected during spring multi-species surveys. The anomalies are normalized with respect to their standard deviations. The grey shaded cells indicate years without observations.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from the fall of 2013 multi-species survey (Figure 3) in NAFO Div. 2J, 3KLNO are displayed in Figure 41. Bottom temperatures in Div. 2J ranged from <0.5°C on portions of Hamilton Bank and the inshore areas of the Labrador coast to >3°C at the shelf break. Most of the 3K region is deeper than 200 m. As a result relatively warm Labrador Slope Water from offshore floods in through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. Bottom temperatures on these Banks and in the offshore slope regions ranged between 2° - 4°C. Bottom temperature anomalies ranged from 0.5°C below normal on northern areas of Hamilton Bank and along the Labrador coast and along the northeast coast of Newfoundland. In the offshore areas temperatures were near-normal to slightly above normal in 2J and up to 0.5°C above normal in 3K. Bottom temperatures in Divs. 3LNO generally ranged from <0°C on the northern Grand Bank and in the Avalon Channel to 3° - 4°C along the shelf edge. Over the southern areas they ranged from 2° - 5°C, with the warmest waters found on the Southeast Shoal and along the southern edge of the Grand Bank in Div. 3O. Except for a few isolated areas, temperatures were near normal over most of 3L and in 3NO they were up to 1°C above the long-term mean, with an area of below normal values in southern regions (Figure 41).

Temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area based on the fall survey are presented in Figure 42. For all areas, the 2012 and 2013 values decreased significantly over 2011. Similar to the spring survey results, an overall increasing trend in bottom temperatures since the early 1990s is evident with record high values in 2011.

Bottom temperature anomalies and derived indices are displayed in Figure 43 as standardized values. In 2J, bottom temperatures were generally below normal from 1990 to 1995, with the coldest anomalies observed in 1993 when they declined to 0.9 - 1.7 SD units below normal. From 1996 to 2011 bottom temperatures experienced an increasing trend, reaching a record high of 2 – 2.2 SD above normal in 2011, but decreased significantly in 2012-2013 to +0.3 to +0.8 SD. From 1996-2013 near-bottom area with temperatures <1°C has been below the long-term average, 0.8 SD in 2013. In Div. 3K, conditions were very similar to 2J with an increasing trend since 1996, reaching a record high in 2011 (+2.7 SD) and decreasing to 0.2 – 0.5 SD above normal in 2013. In Divs. 3LNO bottom temperatures were somewhat cooler than farther north in 2J and 3K, with record high values in 1999 (+2.2 – 2.4 SD), warm conditions in 2010-2011 and a sharp decrease to near normal values in 2012-2013 (Figure 43).

Composite indices derived by summing the standardized values presented in Figures 20 and 43 show the overall temperature conditions during the spring and fall since 1990. Since the record high in 2011 this index has decreased significantly during the past two years during both the spring and fall (Figure 44).

Fall CIL Volume

The spatial extent of the CIL water mass overlying the NL shelf during the fall exhibits considerable inter-annual and seasonal variability. It usually covers most of the NL Shelf (except for parts of 3NO) during cold years and is almost completely eroded in warm years. The total volume of CIL water remaining on the shelf after the summer warming season was calculated from the vertical temperature profiles in 2J3KL from October to mid-December. The values are shown in Figure 43 as standardized anomalies and in Figure 45 as a volume anomaly time series. The high volumes associated with the cold periods of the mid 1980s and early 1990s are evident as well as the decreasing trend since 1995. The CIL volume was the lowest in the 34-year record during 1999 (1.7 SD below normal) with 2010 and 2011 tied for 3^{rd} lowest at 1.1 SD below normal. During 2012 the CIL volume increased to near-normal conditions but decreased again in 2013 to 0.3 SD below normal.

SUMMARY

A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2013 are displayed in Figure 46 as colour-coded normalized anomalies. Different climatic conditions are readily apparent from the warm and salty 1960s, the cold-fresh early 1970s, mid-1980s and early 1990s and the warming conditions from late 1990s to the present. Following Petrie et al. (2007) a mosaic or composite climate index was constructed from the 26 time series as the sum (yellow line) of the standardized anomalies with each series contribution shown as stacked bars (Figure 47).

To further visualize the components, each time series was then grouped according to the type of measurement; meteorological, sea ice, water temperature, CIL area and salinity. The composite index is therefore a measure of the overall state of the climate system with positive values representing warm-salty conditions and negative values representing cold-fresh conditions. The plot also indicates the degree of correlation between the various measures of the environment. In general, most time series are correlated, but there are some exceptions as indicated by the negative contributions during a year with an overall positive composite index and conversely during a year with a negative composite index.

The overall composite index clearly defines the cold/fresh conditions of the 1970s, 1980s and early 1990s, the recent increasing trend that reached a record high in 2006 and the 3 years of relatively cooler conditions of 2007-2009. In 2010 the composite index increased sharply over the near-normal year of 2009 to the 2^{nd} highest in the 64-year time series. In 2011 it was very similar to 2010, the 4^{th} highest in 64 years but in 2012 it had decreased to the 8^{th} highest and to the 18^{th} highest in 2013, a notable decrease.

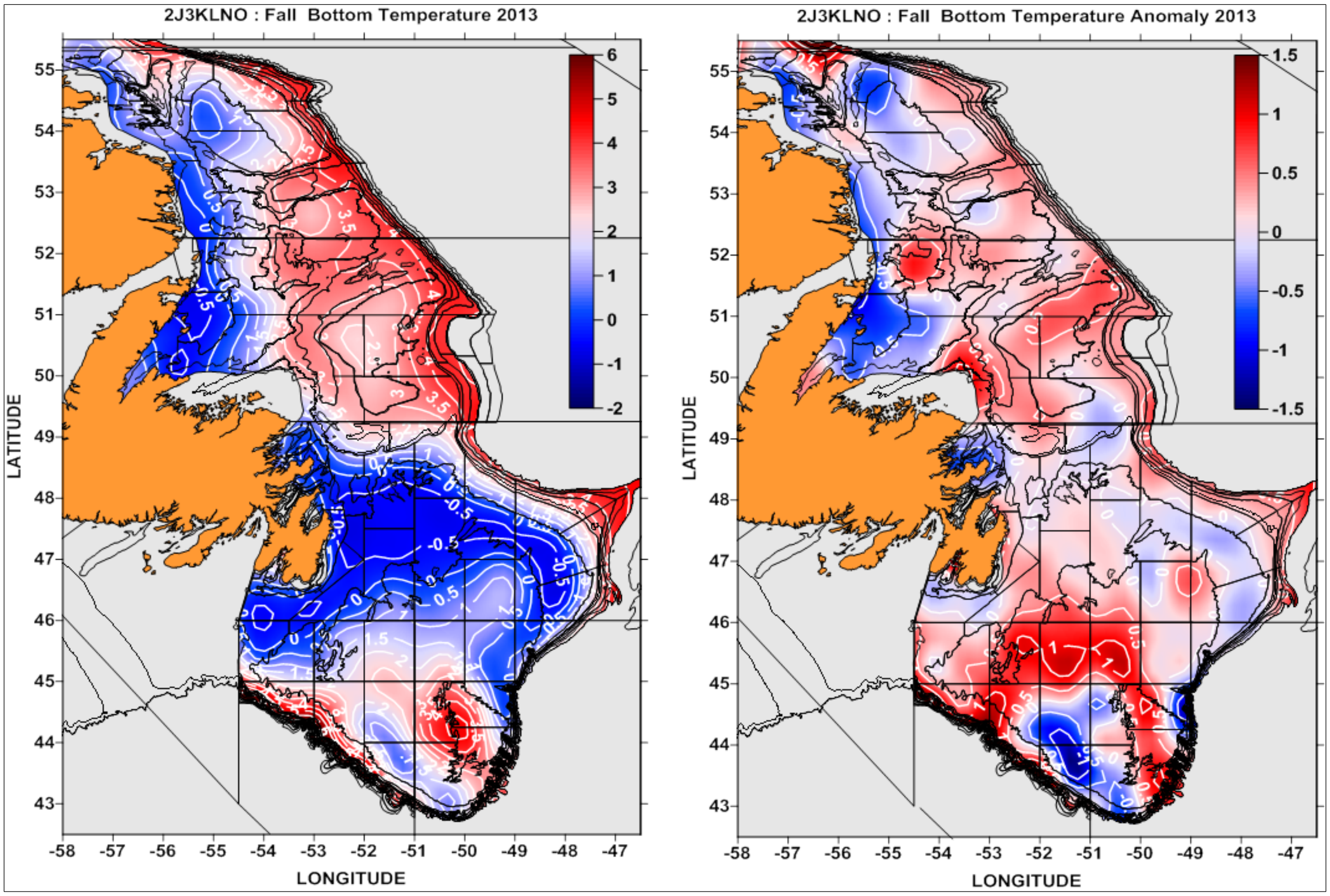

Figure 41. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2013 in NAFO Divs. 2J3KLNO.

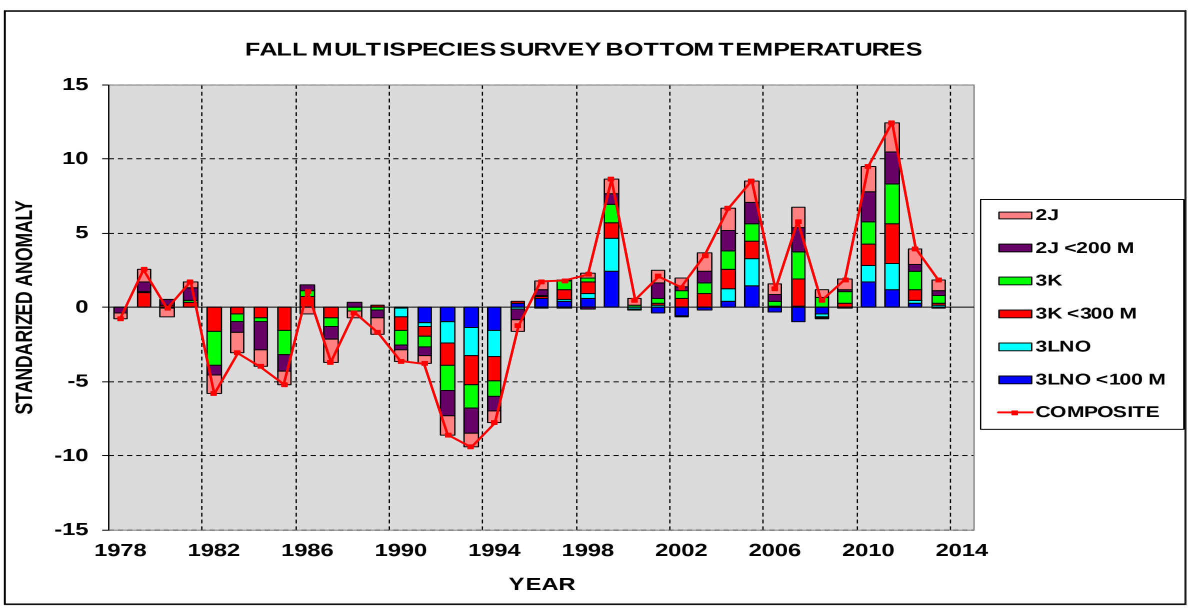

Figure 42. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divs. 2J3KLNO.

REGION	INDEX	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	MEAN	SD
	BOTTOM TEMPERATURES	-0.6	0.4	-1.3	-1.4	-1.1	-0.9	-0.4	-1.5	-0.5	-1.1	-0.8	-0.5	-1.3	-0.9	-0.8	-0.8	0.6	0.1	0.3	1.0	0.5	0.8	0.6	1.2	1.5	1.4	0.7	1.3	0.5	0.7	1.7	2.0	1.1	0.8	2.35	0.47
NAFO DIV. 2J	BOTTOM TEMPERATURES < 200 M	0.4	0.9	-0.6	-0.7	-1.9	-1.1	0.4	-0.8	0.3	-0.5	-0.3	-0.6	-1.7	-1.7	-0.9	-0.7	0.4	-0.1	-0.1	0.7	0.0	1.0	0.3	0.8	1.4	1.5	0.5	1.7	0.0	0.2	2.0	2.2	0.4	0.3	0.79	0.71
FALL	THERMAL HABITAT AREA >2°C	-0.7	-0.1	-1.2	-1.0	-1.3	-1.4	0.0	-1.1	-0.3	-0.8	-1.0	-0.7	-1.1	-0.8	-0.6	0.0	0.3	0.4	0.2	0.6	0.0	0.8	0.5	0.9	1.3	1.7	0.1	2.0	-0.2	0.3	2.4	2.8	0.4	0.4	57.94	14.65
	THERMAL HABITAT AREA <1°C	0.3	0.0	1.3	0.9	1.7	1.2	-0.1	1.7	0.1	0.7	0.7	0.7	1.4	1.2	0.7	0.2	-0.3	-0.5	-0.6	-1.3	-0.2	-0.9	-0.3	-1.4	-1.4	-1.4	-0.2	-1.4	-0.5	-0.5	-1.4	-1.4	-0.9	-0.8	22.72	15.71
	BOTTOM TEMPERATURES	0.0	0.1	-2.3	-0.5	-0.3	-1.6	0.4	-0.6	-0.3	-0.2	-1.0	-0.7	-1.7	-1.5	-1.1	0.0	0.0	0.6	0.3	1.2	0.1	0.3	0.5	0.7	1.2	1.1	0.3	1.8	0.7	0.8	1.5	2.7	1.2	0.5	2.13	0.53
NAFO DIV. 3K	BOTTOM TEMPERATURES < 300 M	0.2	0.3	-1.6	-0.5	-0.7	-1.6	0.7	-0.7	0.0	0.1	-0.9	-0.7	-1.5	-2.0	-1.6	0.1	0.1	0.7	0.8	1.1	0.0	0.2	0.6	0.9	1.3	1.2	0.0	1.9	0.0	0.2	1.4	2.7	0.7	0.2	1.46	0.62
FALL	THERMAL HABITAT >2°C	0.4	0.4	-1.9	-0.7	-0.4	-1.8	0.3	-0.7	0.0	-0.6	-1.4	-0.5	-1.6	-1.5	-1.1	0.0	0.1	0.7	0.7	1.4	0.4	0.2	0.8	0.8	0.9	1.2	0.3	1.7	0.4	0.3	1.6	2.3	0.8	0.7	62.16	13.74
	THERMAL HABITAT AREA <1°C	0.2	0.0	2.6	0.5	0.5	1.3	-0.6	0.3	0.0	-0.4	1.2	0.8	1.1	1.4	0.6	-0.5	-0.3	-0.4	0.0	-0.9	0.2	0.0	-0.5	-0.5	-1.7	-1.3	0.3	-1.9	0.4	-0.6	-1.7	-1.9	-0.8	-0.1	20.76	11.06
	BOTTOM TEMPERATURES											-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3	2.2	-0.1	0.1	-0.1	0.0	0.8	1.8	0.0	0.1	-0.2	0.0	1.1	1.8	0.2	0.1	1.78	0.39
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M											-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6	2.4	0.0	-0.4	-0.6	-0.2	0.4	1.4	-0.3	-0.9	-0.5	0.0	1.7	1.2	0.3	0.0	1.22	0.64
FALL	THERMAL HABITAT AREA >2°C											-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5	0.4	0.2	32.18	9.83
	THERMAL HABITAT AREA <0°C											0.4	1.4	1.5	1.8	1.7	-0.7	-0.1	0.3	-0.5	-1.3	0.6	-0.1	-0.6	0.0	-1.4	-1.1	-1.3	-0.1	0.6	-0.1	-1.1	-2.3	-0.1	-0.3	30.33	12.93
NAFO DIV 2J3KL	CIL VOLUME (FALL)	-0.4	-0.5	0.3	1.2	1.8	1.4	-0.6	0.9		0.1	1.1	1.2	1.6	1.7	0.9	-0.2	-0.7	-0.7	-0.4	-1.7	-0.3	-0.6	-0.4	-0.6	-1.4	-0.7	-0.4	-0.8	-0.2	-1.0	-1.1	-1.1	-0.1	-0.3	1.65	0.95

Figure 43. Temperature indices derived from data collected during fall multi-species survey. The anomalies are normalized with respect to their standard deviations.

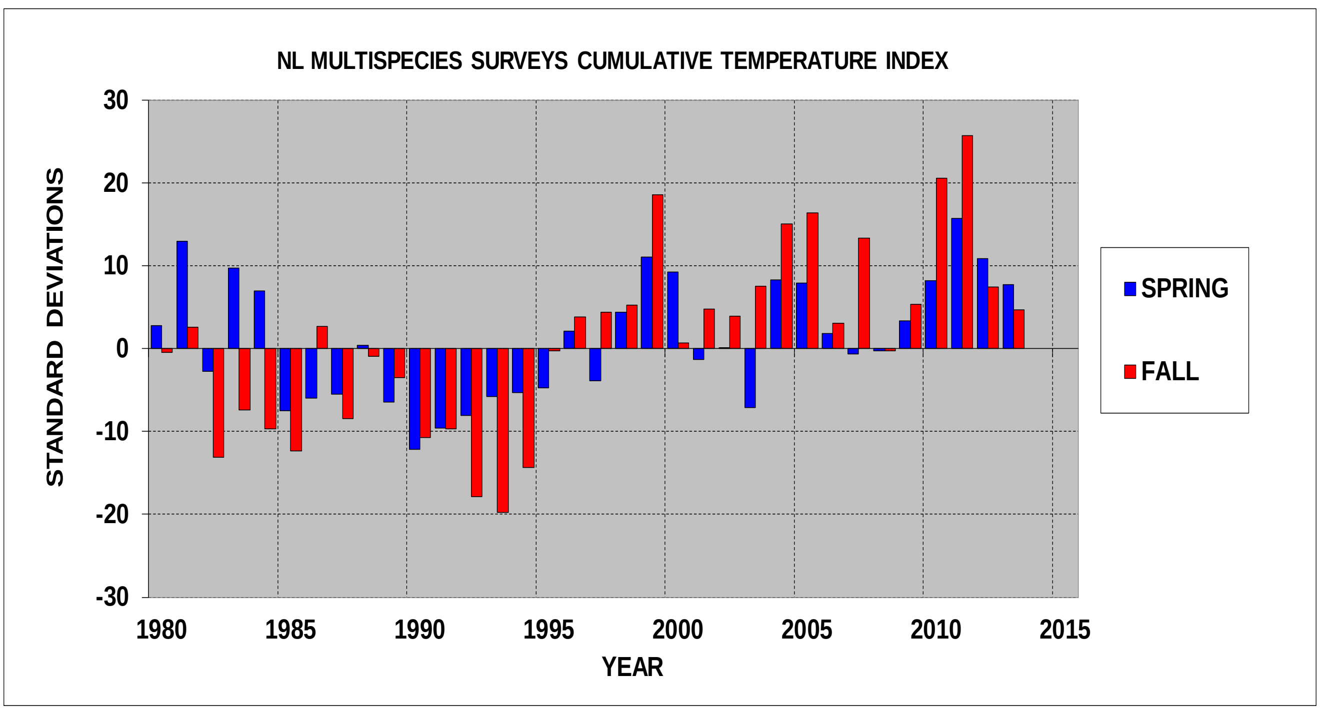

Figure 44. Spring and fall composite temperature index derived by summing the standardized anomalies from Figure 43.

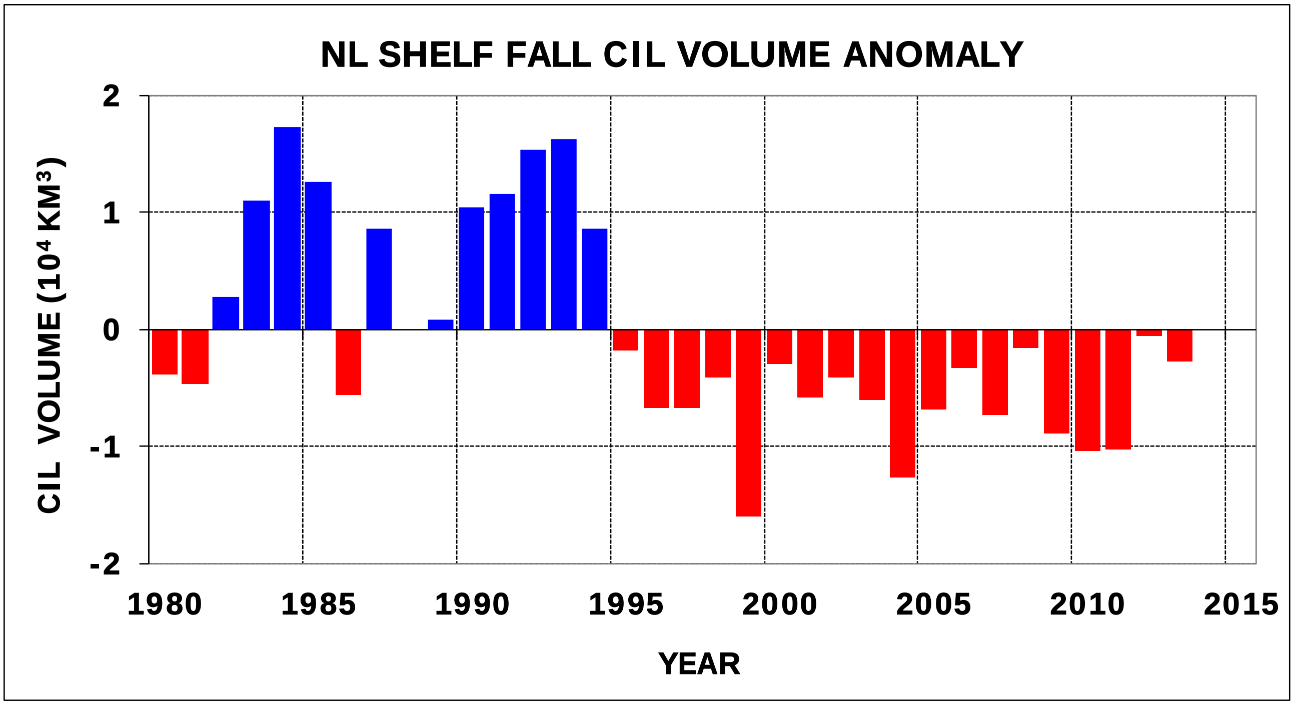

Figure 45. Time series of the CIL (<0^{O}C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

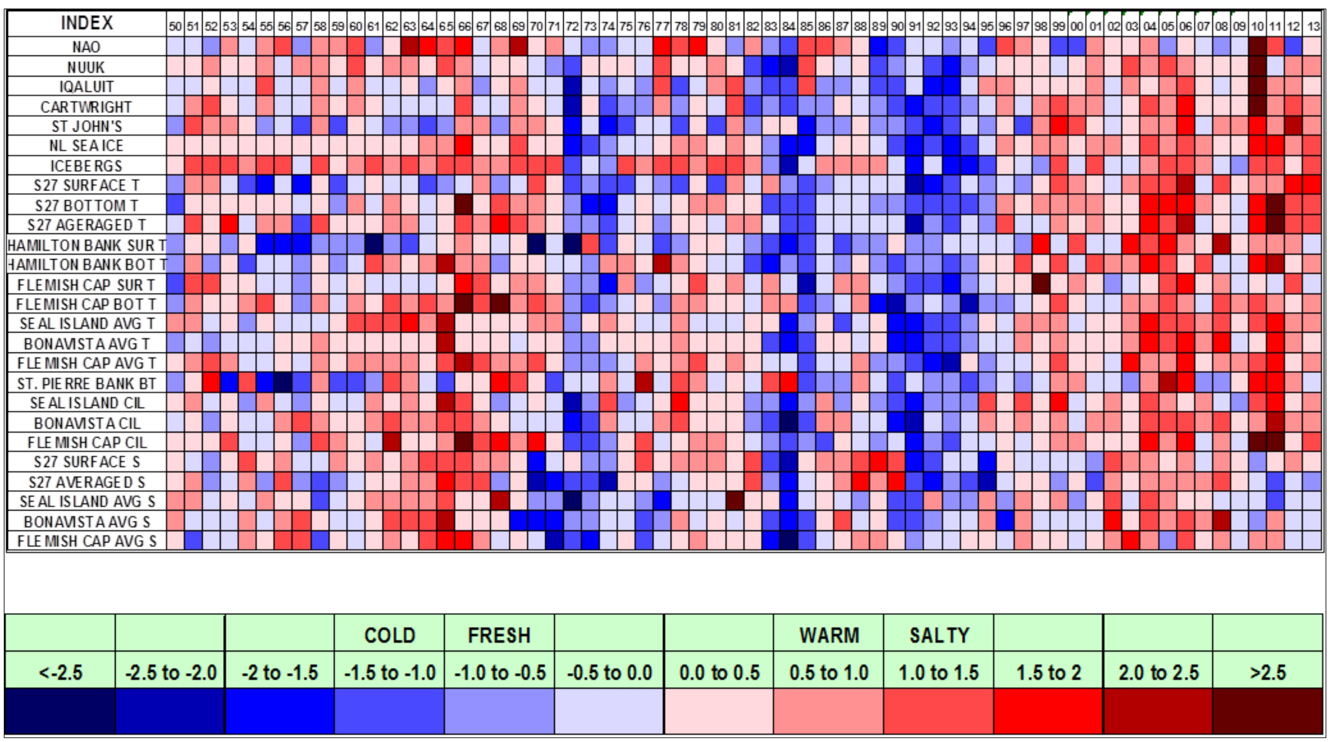

Figure 46. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Figure 4. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010.

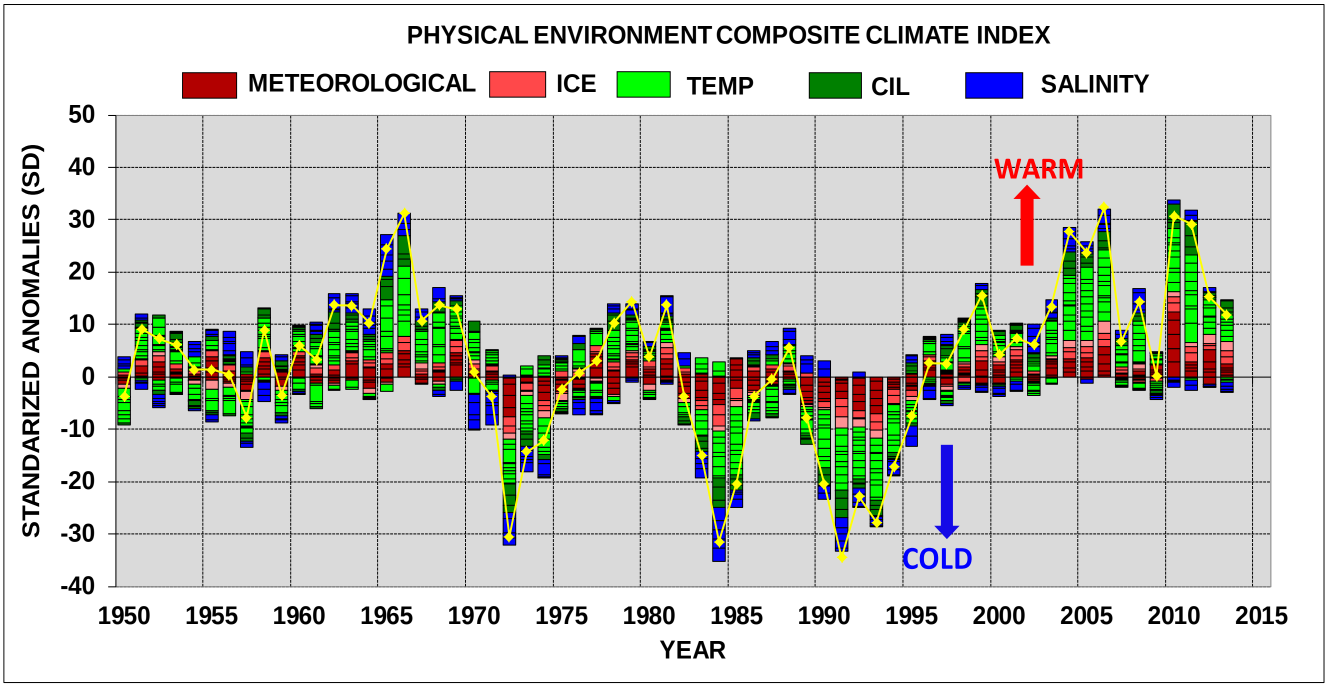

Figure 47. Composite climate index (yellow line) derived by summing the standardized anomalies from Figure 45 together with their individual components.

SUMMARY POINTS FOR 2013

- The North Atlantic Oscillation index, a key indicator of climate conditions on the Newfoundland and Labrador Shelf, returned to a weak negative phase in 2013 at 0.4 SD below normal.
- Arctic air outflow during the winter decreased over the previous year causing a significant increase in winter air temperatures (+1 SD above normal) over much of the Labrador Sea and adjacent areas.
- Annual air temperatures however remained above normal at Labrador by 0.5 SD (0.7°C at Cartwright) and Newfoundland by 0.8 SD (0.7°C at St. John's).
- The annual sea ice extent on the NL Shelf remained below normal (1.4 SD) for the 18^{th} consecutive year.
- 13 icebergs were detected south of 48°N on the Northern Grand Bank, compared with 499 in 2012, substantially fewer than the 1981-2010 mean of 767.
- Sea surface temperatures (SST) after attaining record highs in many areas during 2012 decreased to near-normal values in northern areas and to about 1 SD above normal on the Grand Banks.
- Annual surface temperatures at Station 27 were 1.1°C (1.6 SD) above normal, similar to 2012.
- Bottom temperatures (176 m) at Station 27 were 0.4°C (1.1 SD) above normal, nearly identical to 2012 values.
- At Station 27, the depth-averaged annual water temperature was 1.1 SD (0.4°C) above normal compared to the record high of 2.7 SD (1°C) in 2011.
- The annual depth-averaged salinity at Station 27 was 0.1 (-0.9 SD) below the long-term mean.

- The area of the CIL (<0°C) along standard AZMP sections on the NL Shelf during the spring, summer and fall were below normal ranging from 0.7 to 1.5, 0.5 to 1.4 and 0.3 to 0.9 SD, respectively.
- Spring bottom temperatures in NAFO Div. 3P ranged from 0.4 to 1.1 SD above normal in 2013.
- Spring bottom temperatures in NAFO Divs. 3LNO ranged from 0.8 to 1.3 SD above normal in 2013, a moderate decrease over 2012 conditions.
- Fall bottom temperatures in 2J, 3K and 3LNO were above normal by 2, 2.7 and 1.8 SD in 2011, 1.1, 1.2 and 0.2 SD in 2012 and 0.8, 0.5 and 0.1 SD in 2013, respectively, a significant decrease in the past 2 years.
- A composite climate index for the NL region decreased to the 18th highest in the 64 year time series from the 8th highest in 2012.

ACKNOWLEDGMENTS

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