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Newfoundland and Labrador Region

Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2014

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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

An overview of physical oceanographic conditions in the Newfoundland and Labrador Region during 2014 is presented as part of the Atlantic Zone Monitoring Program (AZMP). The North Atlantic Oscillation (NAO) index, an indicator of the direction and intensity of the winter wind field patterns over the North Atlantic, returned to a positive phase in 2014 that was associated with strong arctic air outflow in the northwest Atlantic during the winter months and consequently, lower than normal winter air temperatures. Sea ice extent increased substantially during the winter of 2014 with the first positive anomaly (higher-than-normal extent) observed in 16 years. Annual sea-surface temperatures (SST) based on infrared satellite imagery remained above normal in most areas across the Newfoundland and Labrador (NL) Shelves in 2014, however, values have declined from record-highs observed in 2012. The annual bottom (176 m) water temperature at the inshore monitoring station (Station 27) was below normal in 2014 by-0.6 standard deviations (SD), a significant decrease from the record high in 2011. The cold-intermediate layer (CIL; volume of < 0°C) in 2014 was at its highest level since 1985 on the Grand Bank during the spring and the highest since 1991 off eastern Newfoundland during the summer. Spring bottom temperatures in 3Ps remained above normal by about +0.5 SD but were slightly below normal on the Grand Banks by - 0.3 SD. Fall bottom temperatures in 2J and 3K decreased from 2 and 2.7 SD above normal in 2011 to 0.7 and 0.3 above normal in 2014, respectively, a significant decrease in the past three years. As a result the area of bottom habitat covered by water < 2^{o}C increased to near-normal values in 2014 during both spring and fall. A standardized climate index derived from 28 meteorological, ice and ocean temperature and salinity time series declined for the 3rd consecutive year, reaching the 11th lowest in 65 years the lowest since 1994 and the first negative index since 1995.

Conditions océanographiques physiques sur la plateforme continentale de Terre-Neuve-et-Labrador en 2014

RÉSUMÉ

Un aperçu des conditions océanographiques physiques dans la région de Terre-Neuve-et-Labrador en 2014 est présenté dans le cadre du Programme de monitorage de la zone Atlantique. L'indice d'oscillation nord-atlantique, un indicateur de la direction et de l'intensité des configurations du champ de vent glacial au-dessus de l'Atlantique Nord, est revenu en 2014 à une phase positive qui a été associée à un fort courant d'air arctique dans l'Atlantique Nord-Ouest pendant les mois d'hiver et, par conséquent, à des températures de l'air inférieures à la normale en hiver. L'étendue des glaces de mer a grandement augmenté au cours de l'hiver 2014; la première anomalie positive (étendue plus grande que la normale) depuis 16 ans a été observée. Les températures de la surface de la mer annuelles, basées sur l'imagerie satellitaire infrarouge, sont demeurées au-dessus de la normale dans la plupart des zones des plateaux de Terre-Neuve-et-Labrador en 2014; toutefois, les valeurs ont diminué par rapport aux records observés en 2012. En 2014, la température de l'eau au fond (176 m) à la station de surveillance côtière (station 27) était sous la normale (écart-type de -0,6), une diminution importante par rapport à un niveau record enregistré en 2011. En 2014, la couche intermédiaire froide (volume inférieur à 0 °C) était à son plus haut niveau depuis 1985 sur les Grands Bancs au printemps, et le plus haut depuis 1991 au large de l'est de Terre-Neuve en été. Les températures au fond au printemps dans la sous-division 3Ps sont demeurées au-dessus de la normale (écart-type d'environ +0,5), mais elles étaient légèrement sous la normale sur les Grands Bancs (écart-type de -0,3). Les températures au fond à l'automne dans les divisions 2J et 3K ont diminué; elles sont passées d'un écart-type de 2 et 2,7 au-dessus de la normale en 2011 à un écart-type de 0,7 et 0,3 au-dessus de la normale en 2014, respectivement, ce qui représente une diminution importante au cours des trois dernières années. Par conséquent, la zone d'habitat de fond couverte d'eau d'une température inférieure à 2 °C a augmenté à des valeurs près de la normale en 2014, et ce, au printemps et à l'automne. Un indice climatique normalisé dérivé de 28 séries chronologiques pour la météorologie, la glace, la salinité et la température océanique a diminué pour la troisième année consécutive pour atteindre le onzième plus bas niveau en 65 ans, le plus bas niveau depuis 1994 et le premier indice négatif depuis 1995.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Figure 1) during 2014 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. 2015; Hebert et al. 2015). 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 2014 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 2014.

These data are available from archives at the [Fisheries and Oceans Oceanography and Scientific Data (OSD) 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 2013 was presented in Colbourne et al. (2014).

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 2014. 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.

The normalized values of water properties and derived climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2014 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.

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).

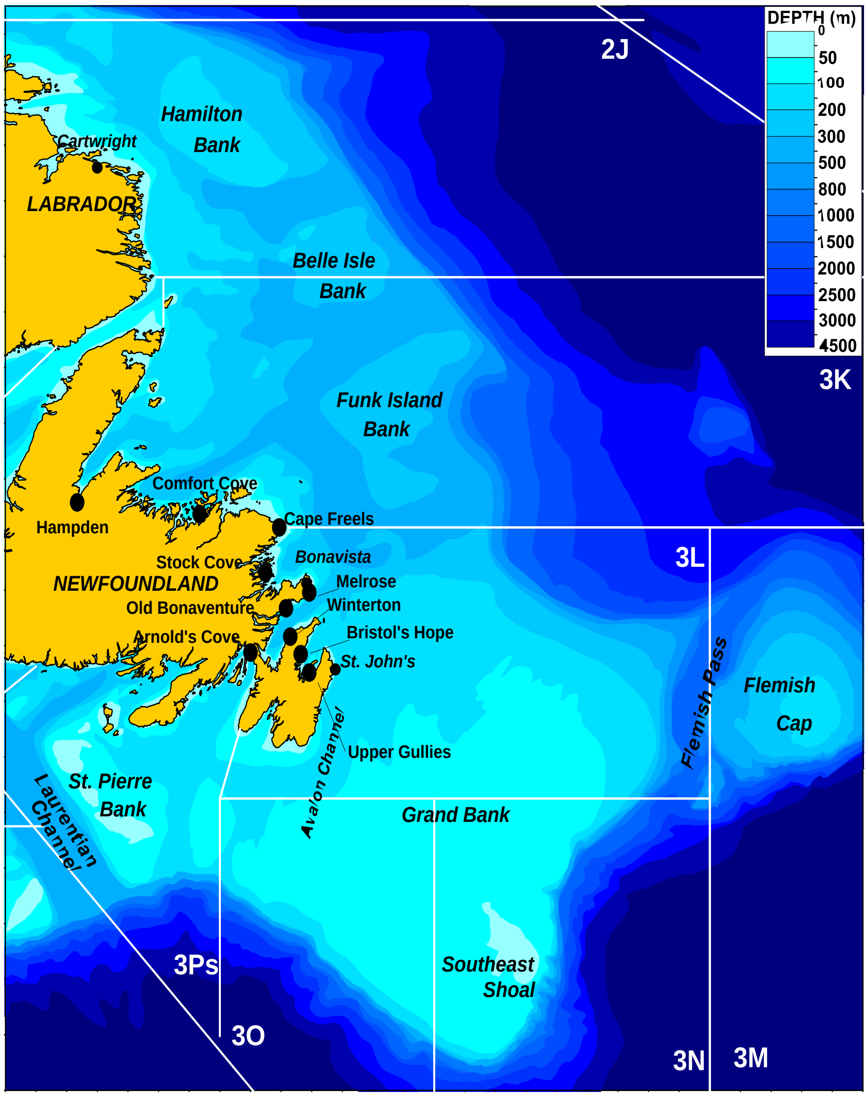

Figure 1. Map showing NAFO Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

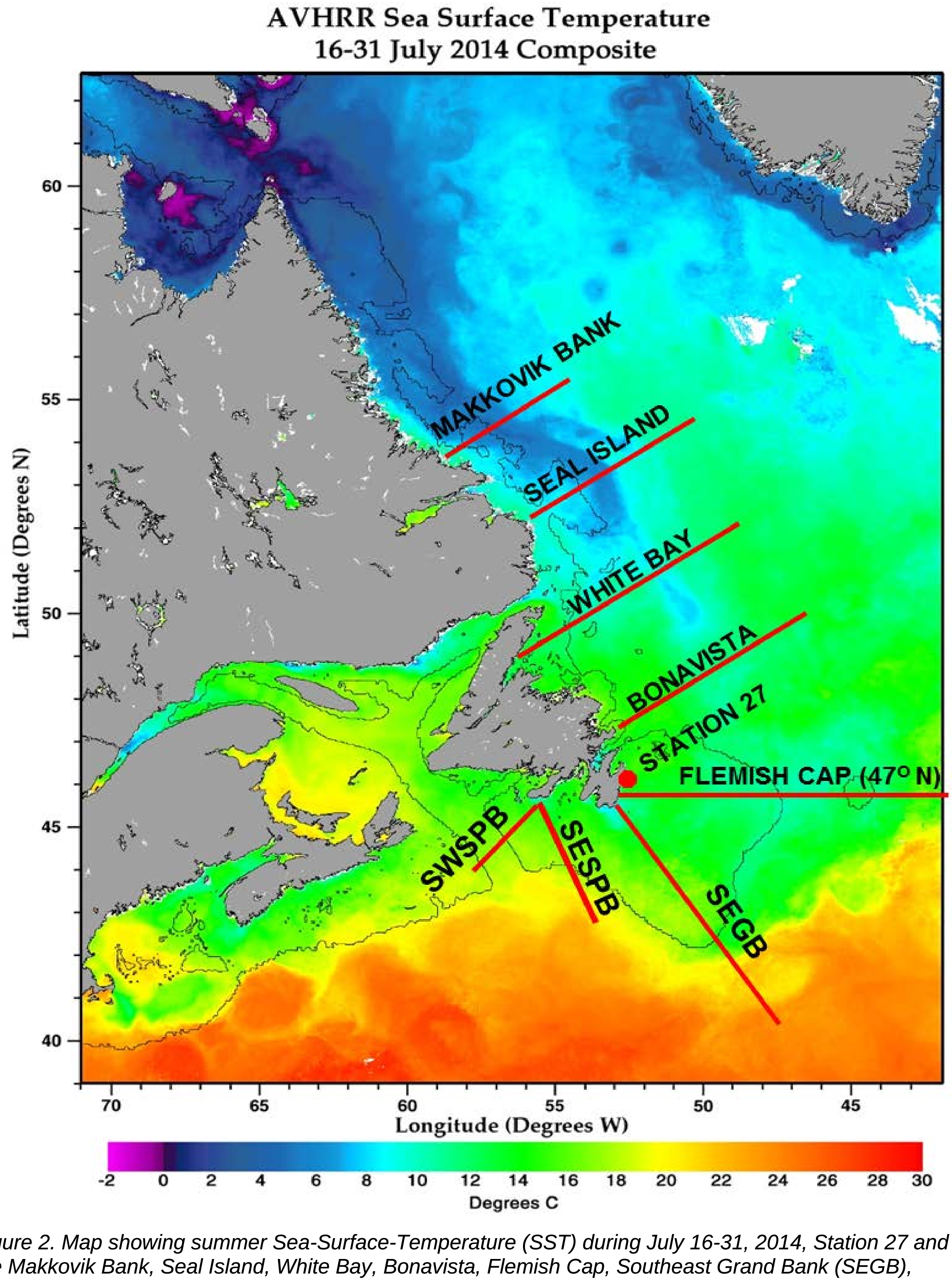

Figure 2. Map showing summer Sea-Surface-Temperature (SST) during July 16-31, 2014, Station 27 and the Makkovik Bank, Seal Island, White Bay, Bonavista, Flemish Cap, Southeast Grand Bank (SEGB), Southeast St. Pierre Bank (SESPB) and Southwest St. Pierre Bank (SWSPB) sections sampled during 2014 (SST map courtesy of the Ocean Research and Monitoring Section, BIO).

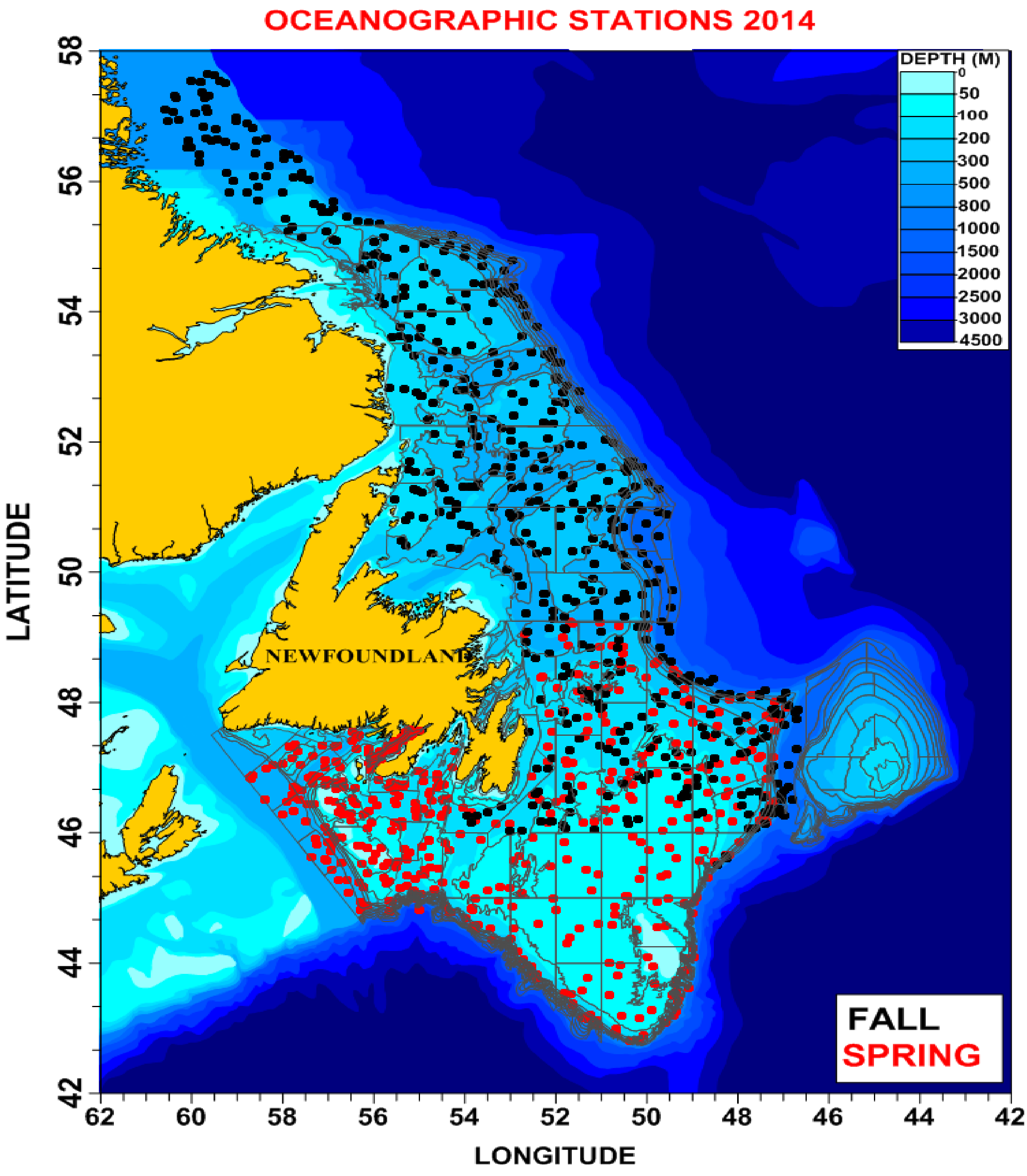

Figure 3. Map showing the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2014. Note the absence of coverage in on the southern Grand Banks during the fall.

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 increased significantly over the 2013 value to 1.3 SD above normal, similar to the 2012 value. In 2010 it was at a record low of 2.9 SD below normal. The similar, but larger scale Arctic Oscillation also returned to a positive phase in 2014, although only slightly above normal at +0.2 SD (Figure 5). As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2014 increased over the previous year causing a significant decrease in winter air temperatures over much of the Newfoundland and Labrador region 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 in terms of standardized values. Annual values in 2014 decreased over the previous year at all sites but remained above normal at three of five sites while winter values were below normal at Cartwright, Bonavista and St. John’s. The predominance of warmer-than-normal annual and seasonal air temperatures at all sites from the mid-1990s to 2007 is evident. There was 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. The cumulative annual air temperature index remained above normal in 2014 but continues to show 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). Hebert et al. (2015) elaborated on meteorological conditions in the Northwest Atlantic in 2014.

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°-55°N) derived from these charts show slightly above normal sea ice extent in 2014, the first time in 19 years (Figure 5). In 2011 sea ice extent decreased to a 49-year record low 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, 2009 and 2014 when it extended into June, particularly in the inshore areas. More details on the spatial extent of sea ice across Atlantic Canada are presented in Hebert et al. (2015).

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 1,546 (1.2 SD above normal) icebergs drifted south of 48°N onto the Northern Grand Bank during 2014, the 6^{th} highest since 1900. There were only 13 in 2013, 499 in 2012 and only three in 2011 and one in 2010. The 115-year average is 480 and that for the 1981-2010 is 767. In some years during the cold periods of the early 1980s and 1990s, over 1,500 icebergs were observed south of 48°N with an all-time record of 2,202 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 indicates that annual values for the past decade were either near-normal or warmer than normal, with 2010 showing the warmest in the time series and a significant decline during the past four years, with 2014 showing slightly below normal conditions (Figure 7).

			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/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	2014	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	0.2	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	1.3	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	0.1	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	0.3	-8.41	3.16
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	0.8	-25.68	3.05
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	-0.6	-12.13	2.56
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	-1.0	-3.96	1.47
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	-0.6	-4.00	1.43
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	0.5	-1.37	1.53
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	0.4	-9.07	1.76
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	0.0	0.05	1.32
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	0.5	4.71	0.89
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	0.4	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	0.2	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	0.4	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	0.1	92547	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	1.2	767	649

Figure 5. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1980 to 2014.

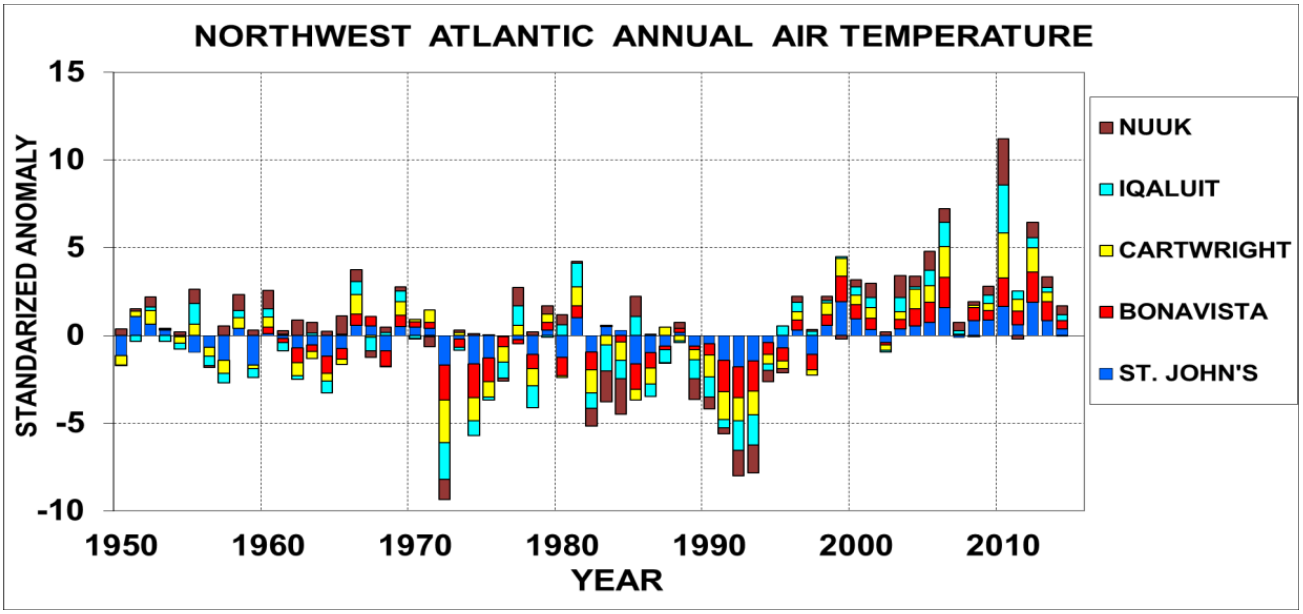

Figure 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

The 4 km resolution Pathfinder 5.2 sea surface temperature (SST) database (Casey et al. 2010) 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 2014 were taken from NOAA and EUMETSAT 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 (2001-10) is given by SST (Pathfinder) = 0.989*SST (NOAA) -0.02 with an r^2=0.98 (Hebert et al. 2012). The 2011-14 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.

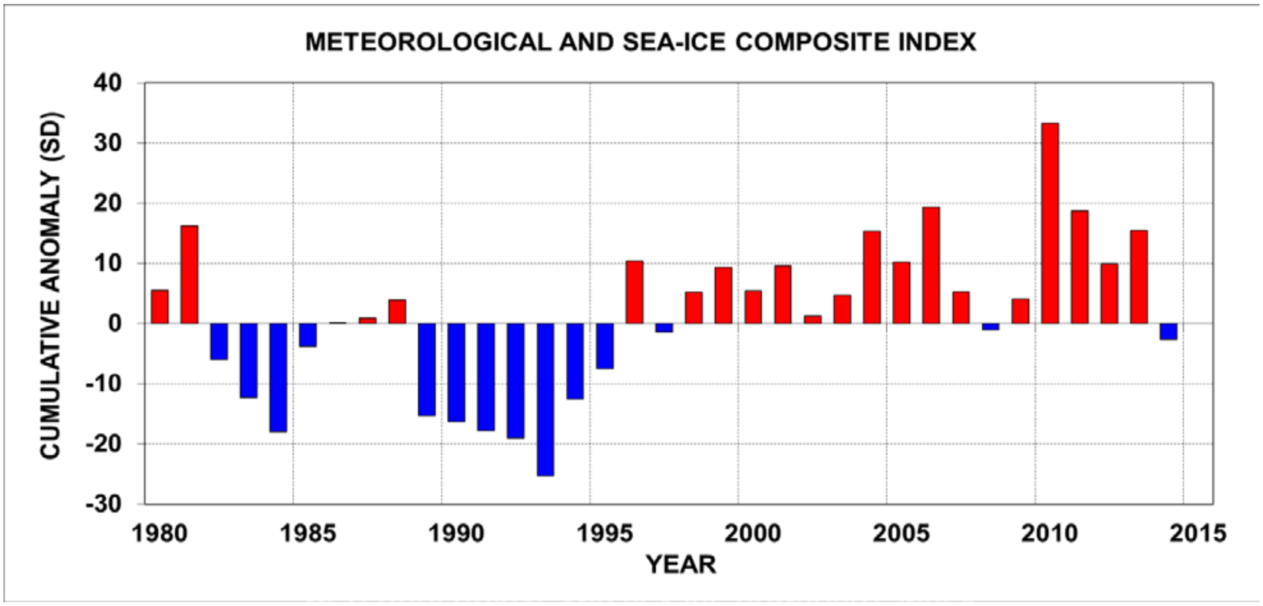

Figure 7. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 5.

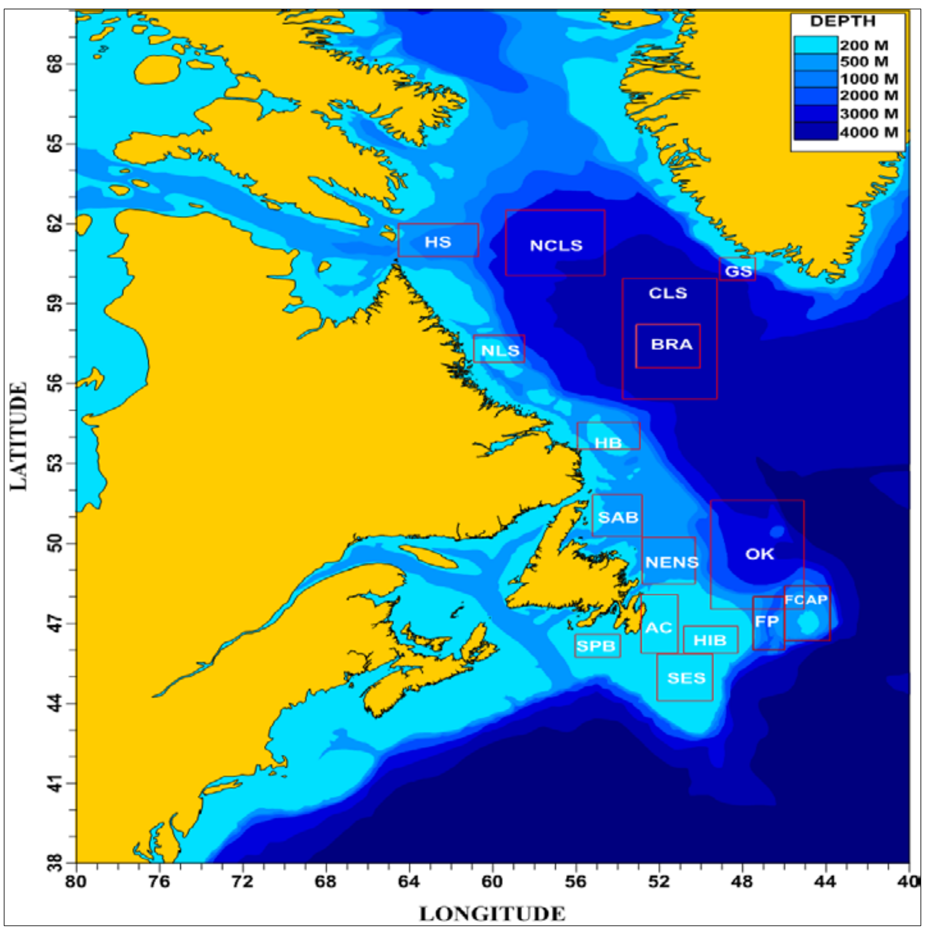

Figure 8. Map showing the subareas where SST time series were constructed for the Northwest Atlantic.

Annual anomalies for 16 areas from West Greenland to Hudson Strait to Green and St. Pierre Banks off southern Newfoundland are presented in Figure 9 and in Figure 10. Most (13 of 15) areas had positive anomalies during 2014 except for North Central Labrador Sea, the Flemish Pass and Flemish Cap, where they were below average. These values represent a significant decrease over 2012 when record highs were set in some of the southern regions.

A composite index together with individual series shows an increasing trend (~2°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 and 2014 showing a significant decrease. The five warmest years in the series have occurred in the past decade.

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	14	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	0.4	6.16	0.79
NORTH CENTRAL LAB SEA (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	-0.2	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	0.7	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	0.9	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	0.2	-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	0.9	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	0.6	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	0.7	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	1.0	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	0.5	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	-0.7	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	-0.7	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	0.3	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	0.3	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	0.7	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	0.6	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.

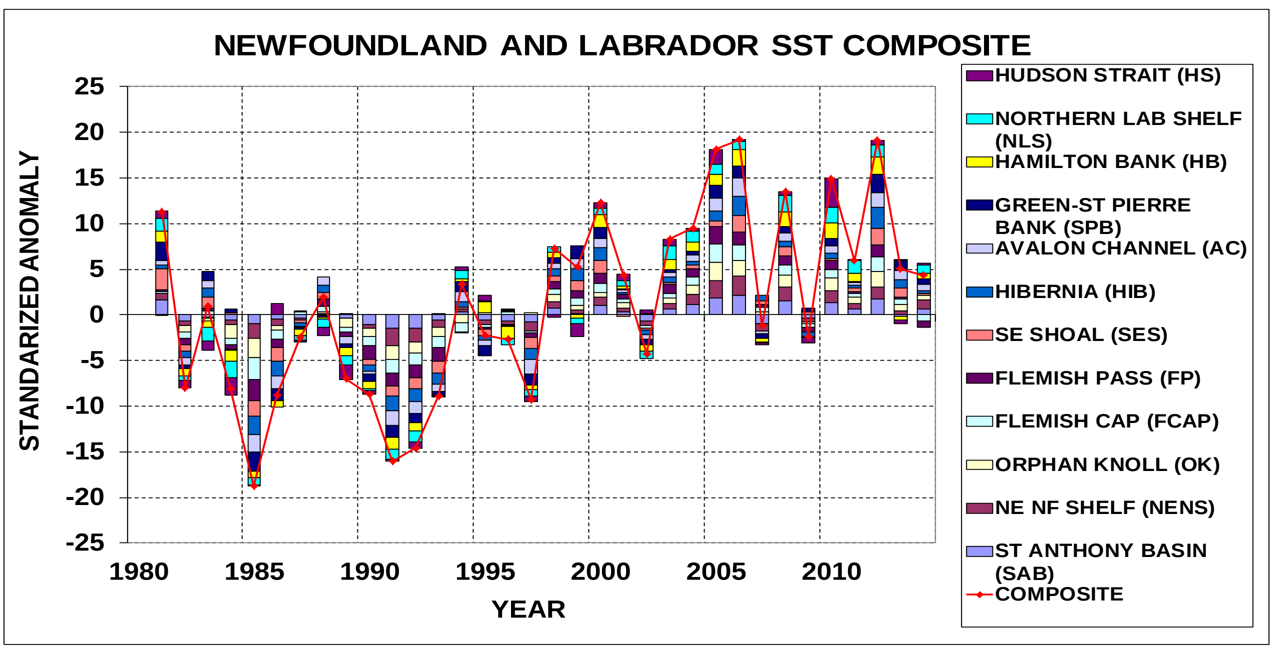

Figure 10. Standardized annual SST anomalies from the subareas on the NL shelf presented in Figure 9. The solid red line represents the composite sum.

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-September) 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 largely 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 eight of nine sites reporting below normal (-0.7 to -2.1 SD) summer temperature. In 2008-10 temperatures varied about the mean with no clear pattern. In 2011 however, right of nine 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, four of the 10 sites reported below normal temperature conditions in spite of widespread warmer than normal SST throughout the Atlantic region. In 2014 near-shore temperatures decreased at some sites over 2013 values with five of nine sites reporting below normal values. Again this may be related to local upwelling along the east coast in response to prevailing 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	2014	MEAN	SD
HAMPDEN (10 m)			-0.6	0.0	-1.7	-2.4	-0.6	-1.1	0.2	0.0	1.2	-1.1	0.4	0.1	0.7	0.7	1.3	-0.8	0.9	-1.1	0.7	0.7	1.4	0.1	0.8	7.92	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		0.4	0.0		-0.1			-1.9	-0.5	-0.6	-1.7	10.54	1.76
CAPE FREELS (15 m)									-1.5	0.2	0.1		0.3	0.9	0.4	2.0	1.4	-1.0	-0.5	-1.0	-0.4	-1.3	0.1	1.0	-0.7	10.09	1.25
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)									-0.6	0.3		1.0	0.2	1.2	0.0	1.4	1.7	-0.8	0.7	-0.6	-0.6	-1.5	-0.7	-0.2	-1.6	9.38	1.32
OLD BONAVENTURE (10 m)		-1.5	-0.9	-0.8	2.2	0.4	0.8	0.2		-0.3	0.3	1.4	0.5	0.4	-0.2	0.8	1.4	-2.0	-0.3	0.3	0.0	-1.7	-0.4	-0.6	-0.1	8.64	1.65
WINTERTON (10 m)									-0.2		1.2	0.6	-0.1	2.0	0.1	0.4	1.2	-0.8	-0.5	0.7	-1.1	-1.8	-0.4	-1.0	-0.2	11.56	0.90
BRISTOL'S HOPE (10 m)	-0.9	-3.4		-0.8	0.5	-0.1	0.0	-0.2	-0.8	1.0	0.7	0.6	0.0	0.9	0.2	0.9	1.0	-0.8	1.0	0.4	0.5	-1.1	0.8	0.5	0.3	10.04	1.38
UPPER GULLIES (10 m)	-1.4	-1.5	0.5	-0.6	0.0	0.0	-1.1	-0.3	-1.2	1.0	-0.4	-0.2	0.0	0.6	-0.3	1.0	1.1	-2.3	1.3	0.1	0.3		0.5	1.3	1.6	12.12	1.32
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	0.5	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.

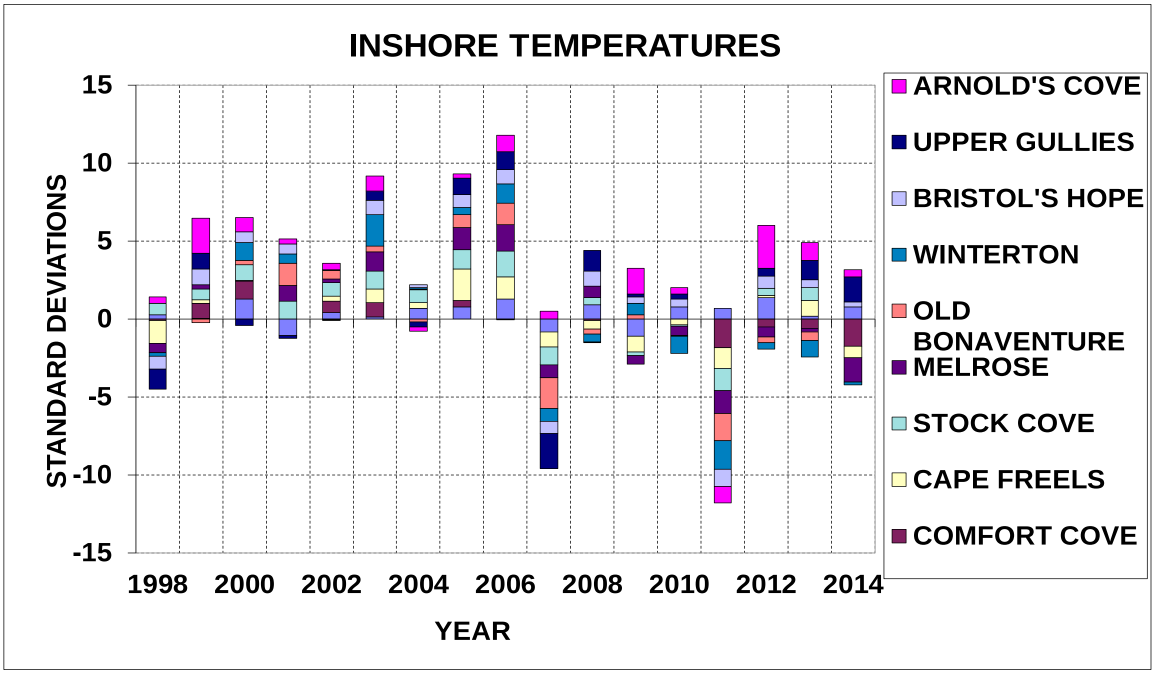

Figure 12. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland (Figure 2). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the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

Station 27 (Standard AZMP fixed site)

Station 27 (47° 32.8' N, 52° 35.2' W), located in the Avalon Channel off Cape Spear NL (Figure 2), was sampled 30 times (28 CTD profiles, 2 XBT profiles) during 2014. While this represents a marked decrease in sampling from previous years (43 profiles in 2013), observations were available for all months except January.

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2014 are displayed in Figure 13 and 14. The water column at Station 27 was near-isothermal ranging in temperature from -1.7°C to 0°C during February to 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 late-July, after which the fall cooling commenced with temperatures decreasing to <3°C by late December.

Temperatures were below normal during the winter months over most of the water column and below normal throughout most of the year near the bottom. Temperature anomalies varied considerably in the upper water column with a strong negative anomaly in the near-surface layer during late-May to early June and strong positive anomalies thereafter until late November. Intense negative anomalies with values reaching 2°C below normal at intermediate depths occurred from July to December indicating limited heat penetration during most of the heating season resulting in a shallower-than-normal thermocline.

Upper layer (0-30 m) salinities (Figure 14 upper panel) ranged from 32 to 32.4 from February to May then decreased to 31.4 by early July and to a minimum of <30.6 by August. Below 50 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 near normal in February, above normal from March to May (by 0.1-0.3) and below normal from June to October (by 0.1-0.4). At depth (generally > 50 m) salinities varied weakly about the mean (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^{o}C) in 2012 and 2013 and 0.9 SD (0.6^{o}C) in 2014 (Figures 15 and 20). Annual bottom temperature anomalies at Station 27 were the highest on record in 2011 at 3.6 SD above normal. In 2012-13 they decreased to ~1 SD (0.4^{o}C) above normal and to 0.6 SD (-0.2^{o}C) below normal in 2014, the lowest since 1995 (Figures 15 and 20). Vertically averaged temperatures (0-176 m), which also set record highs in 2011 at +2.7 SD, decreased to about +1 SD in 2012/13 and to near normal in 2014 (Figures 16 and 20). Recent temperatures at Station 27 contrasted sharply to values observed during 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 (on the NL Shelf) as water with temperatures < 0^{o}C. In shallow areas, such as the northern Grand Banks and near-shore, including at Station 27 where topography limits intrusions of warmer Labrador Slope water, the cold water mass extends to the bottom throughout the year. The vertical extent of water with temperatures < -1.0^{o}C, < -0.5^{o}C, < 0.0^{o}C, < 0.5^{o}C and < 1.0^{o}C are shown in Figures 17 and 20. The vertical thickness of the layer < 0^{o}C reached a remarkably low value of 58 m (4.3 SD) below normal (118 m and SD of 17 m) in 2011 but increased to 22 m (1.7 SD) below normal in 2012, near-normal in 2013 and 7 m (0.5 SD) above normal in 2014 (Figures 17 and 20). The CIL layer defined by other temperature thresholds show similar trends that reached a minimum in 2011 and have since increased to above normal in 2014, indicating colder climate conditions during the year. Since the CIL intersects the bottom at Station 27, bottom temperatures are always < 1.0^{o}C and indeed only reach above 0.0^{o}C during late fall-early winter of the warmest years, therefore these indices are measures of the extent of heat penetration (thermocline depth) into the water column during the year.

Annual surface salinities at Station 27 were about normal in 2013-14 while bottom values were slightly below normal and water column averaged values were close to normal values. 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 (Figures 18-20).

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.

Stratification values at Station 27 were computed from 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 2014 monthly values are shown in Figure 21. On average the water column is essentially unstratified during the winter months, stratification increases during the spring (typically June) reaching its maximum by August, then decreases to winter time values by December. In 2014, the stratification was near 0 until June when it had increased to normal values. During the summer (July-September) the stratification was significantly above normal (by 4 SD, Figure 20), about normal in October and very weak during the remainder of the year.

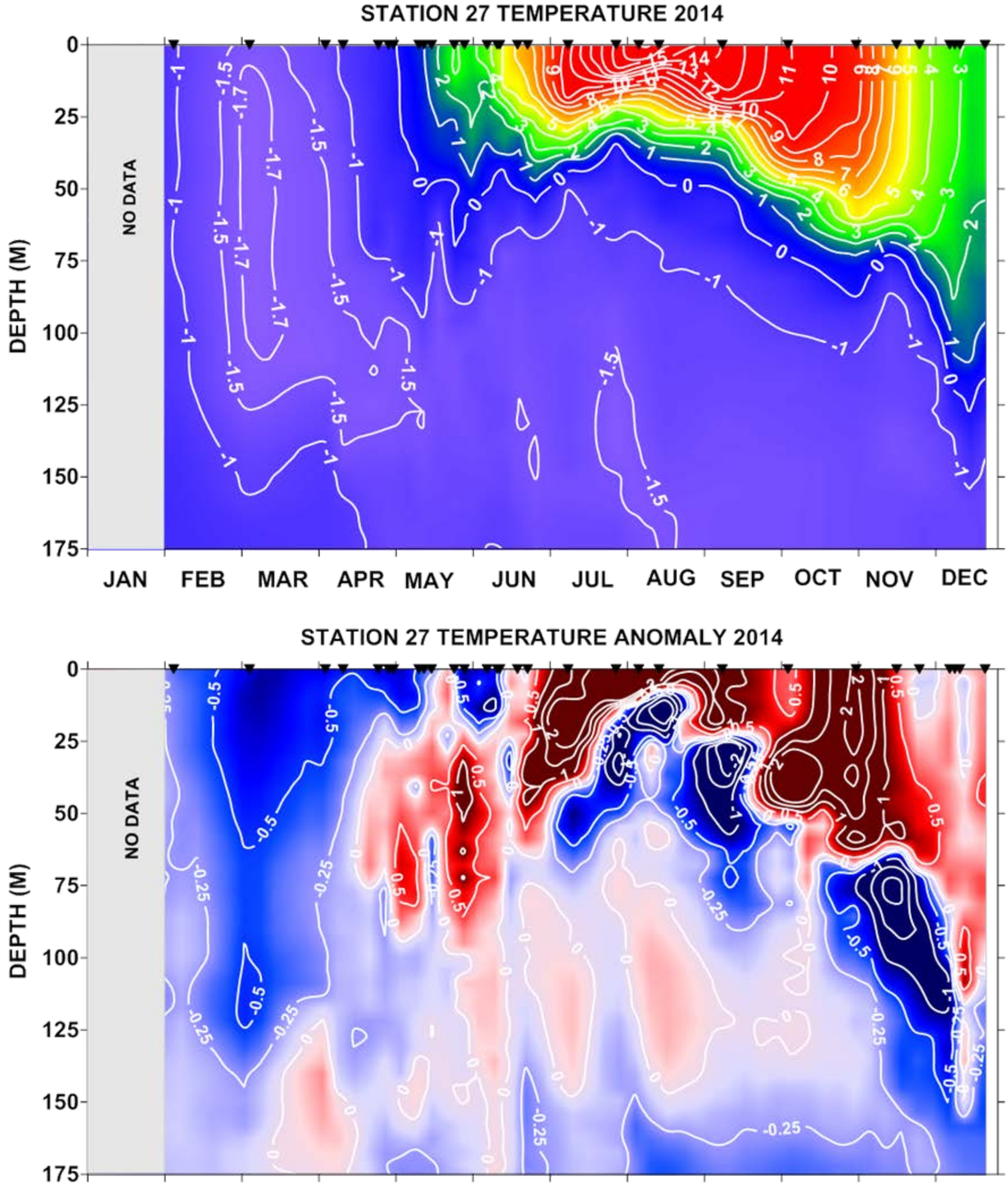

Figure 13. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2014. The symbols at the top indicate sampling times.

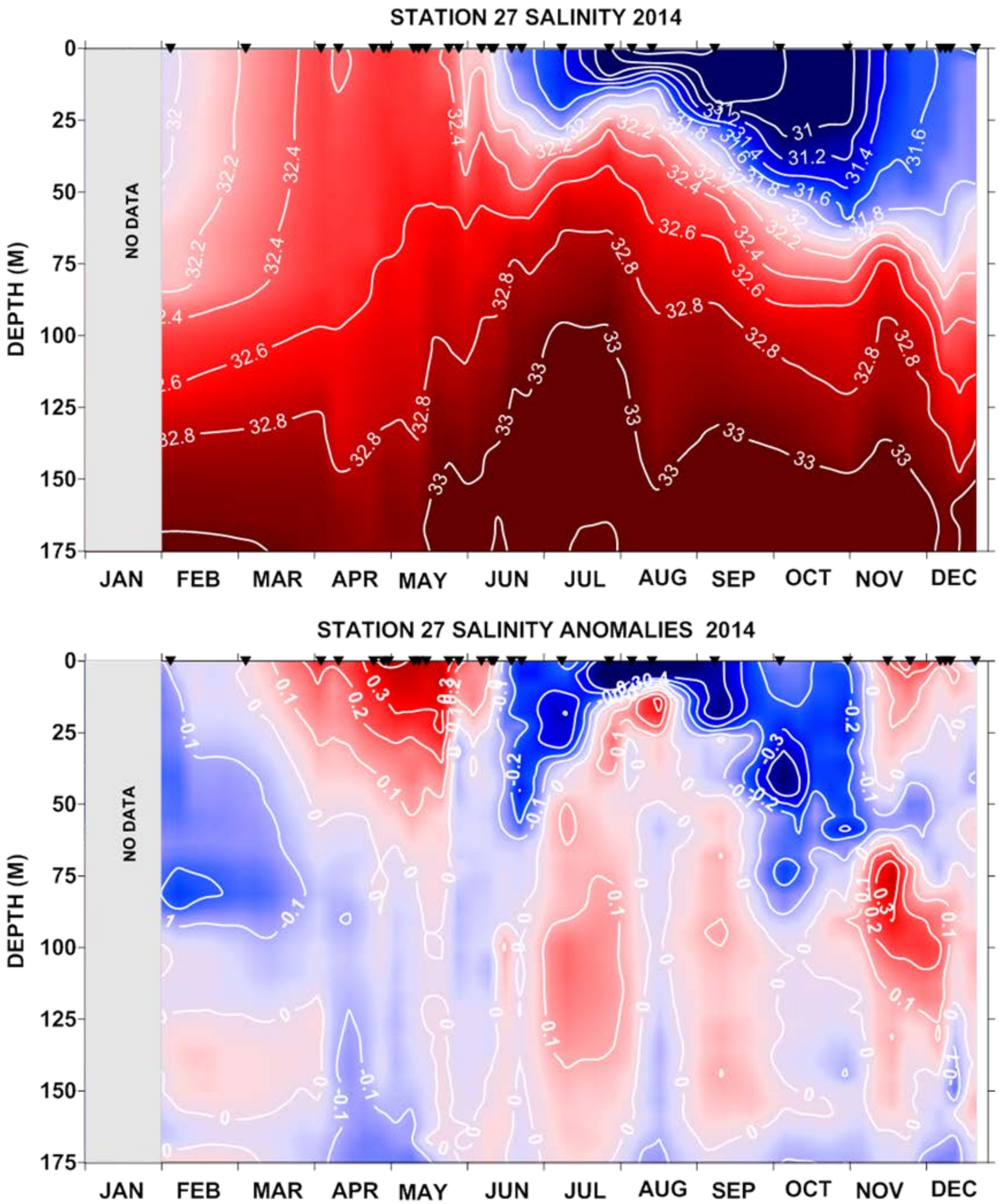

Figure 14. Contours of salinity and salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2014. The symbols at the top indicate sampling times.

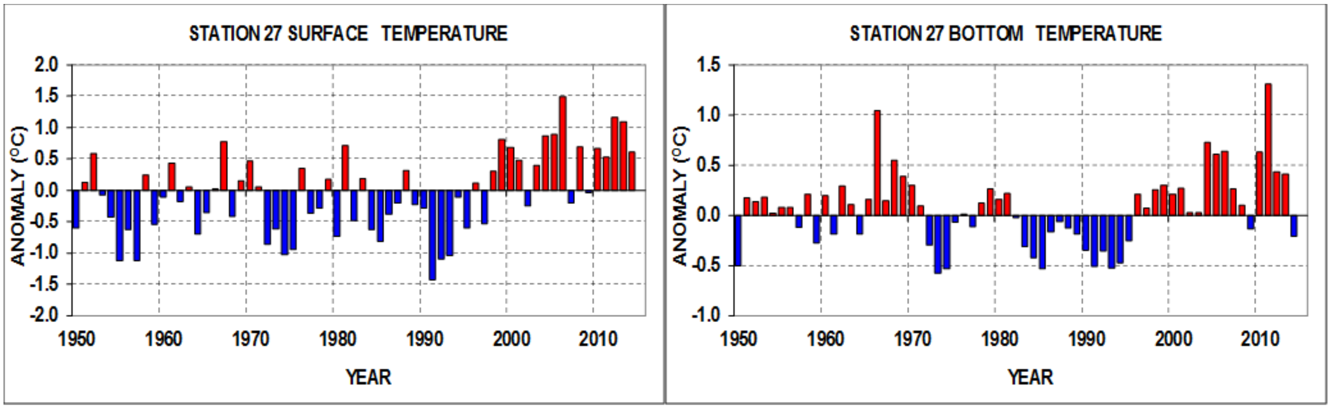

Figure 15. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

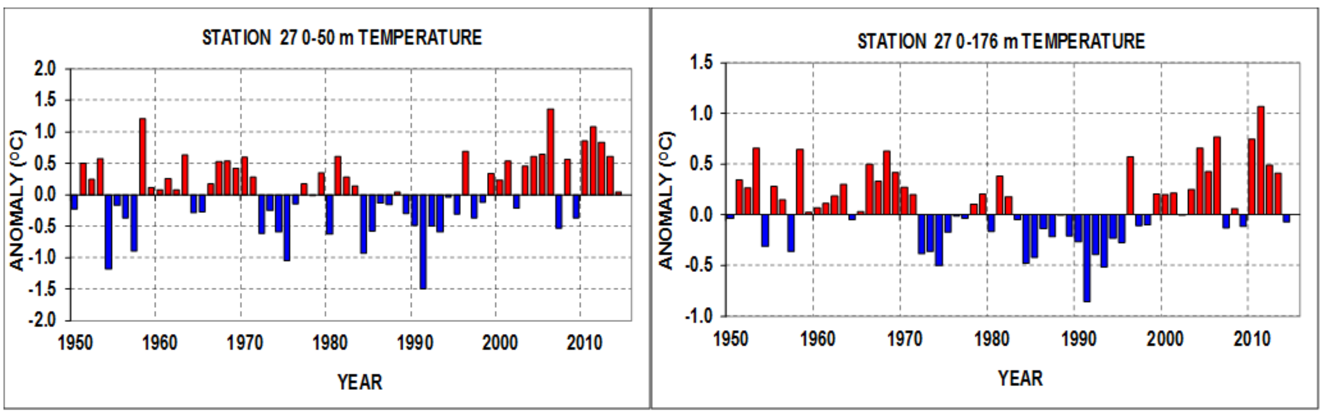

Figure 16. Annual Station 27 vertically averaged (0-50 m, 0-176 m) temperature anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

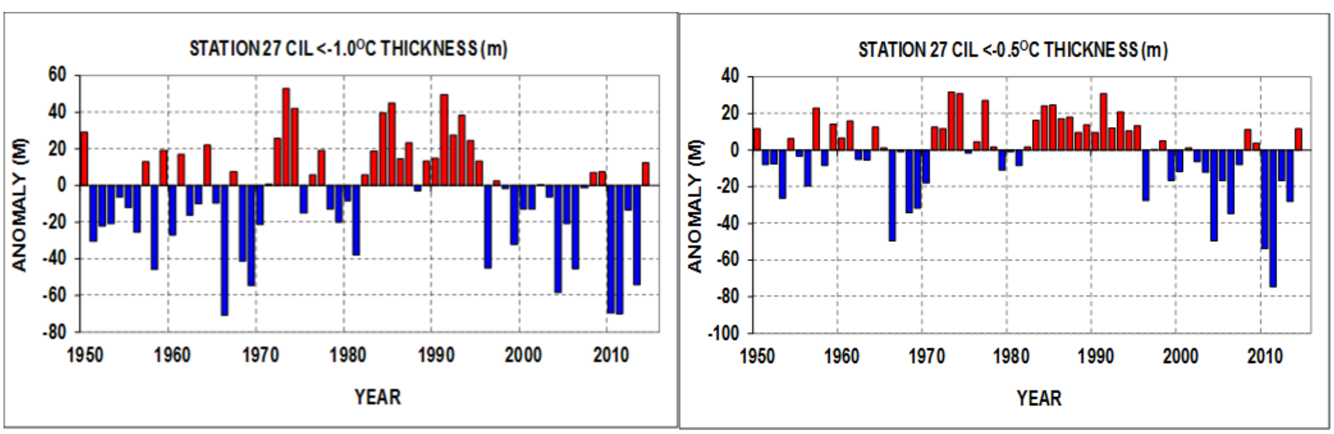

Figure 17a. Annual Station 27 CIL (<-1.0°C and <-0.5°C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

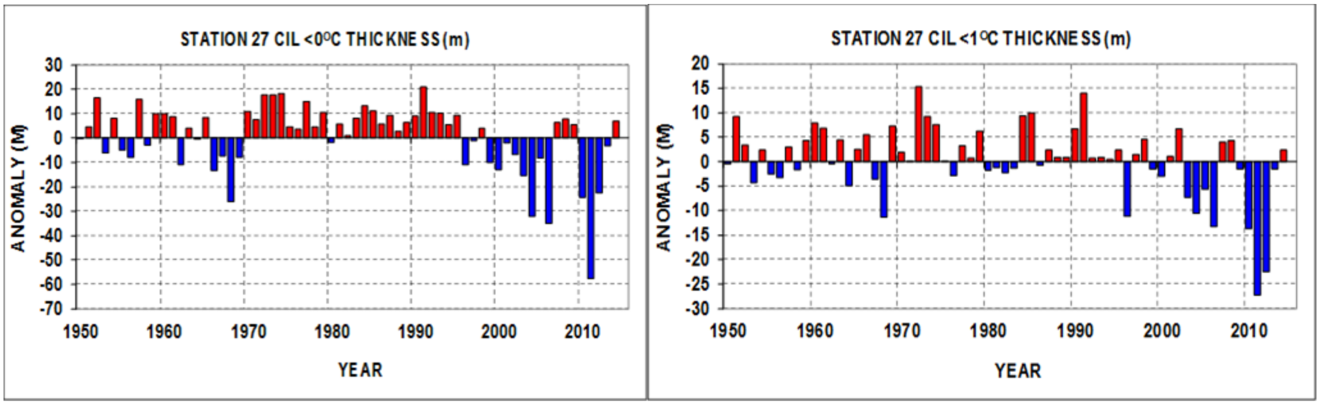

Figure 17b. Annual Station 27 CIL (<0^{o}C and <1^{o}C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

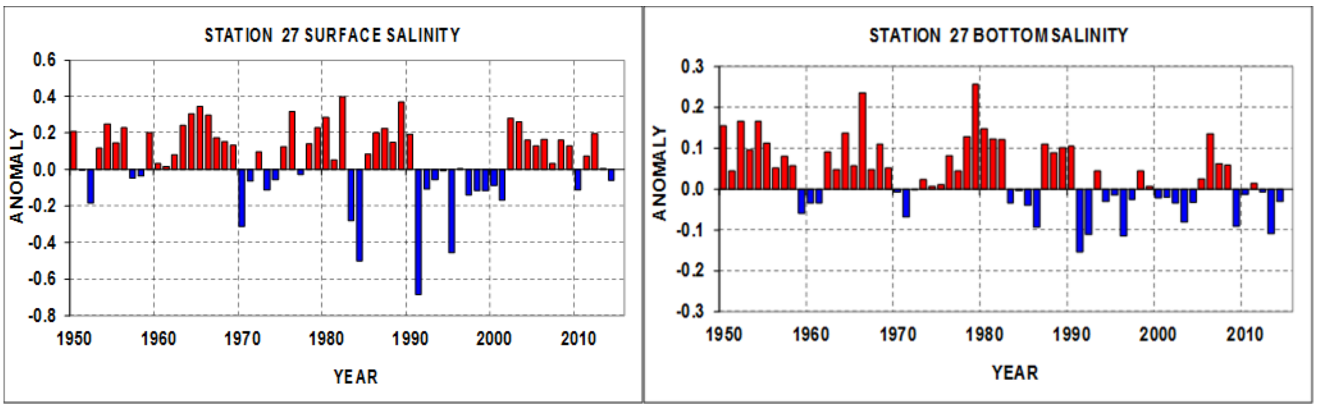

Figure 18. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

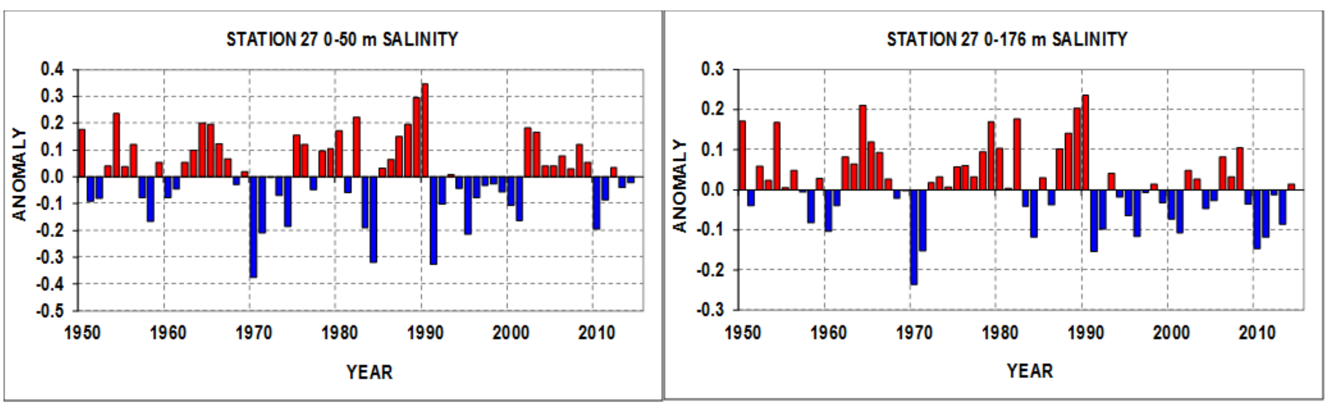

Figure 19. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 20.

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	14	MEAN	SD
Surface T	-1.1	1.0	-0.7	0.3	-0.9	-1.2	-0.6	-0.3	0.5	-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	-0.4	0.6	1.3	1.3	2.2	-0.3	1.0	-0.1	1.0	0.8	1.7	1.6	0.9	4.88	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	-0.6	-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	-0.4	0.8	1.0	1.1	2.3	-0.9	0.9	-0.6	1.4	1.8	1.4	1.0	0.1	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	-0.2	0.32	0.43
CIL (<-1.0°C)	-0.3	-1.3	0.2	0.6	1.3	1.5	0.5	0.8	-0.1	0.4	0.5	1.6	0.9	1.3	0.8	0.4	-1.5	0.1	-0.1	-1.1	-0.4	-0.4	0.0	-0.2	-1.9	-0.7	-1.5	0.0	0.2	0.2	-2.3	-2.3	-0.4	-1.8	0.4	73.52	32.03
CIL (<-0.5°C)	0.0	-0.4	0.1	0.8	1.1	1.2	0.8	0.9	0.4	0.6	0.4	1.5	0.6	1.0	0.5	0.6	-1.3	0.0	0.2	-0.8	-0.6	0.1	-0.3	-0.6	-2.4	-0.8	-1.7	-0.4	0.5	0.2	-2.6	-3.6	-0.8	-1.3	0.5	101.77	25.00
CIL (<0°C)	-0.1	0.4	0.1	0.6	1.0	0.8	0.4	0.7	0.2	0.5	0.7	1.6	0.8	0.8	0.4	0.7	-0.8	-0.1	0.3	-0.7	-1.0	-0.1	-0.5	-1.1	-2.4	-0.6	-2.6	0.5	0.6	0.4	-1.8	-4.3	-1.7	-0.2	0.5	118.26	16.88
CIL (<0.5°C)	-0.4	0.2	0.3	0.3	1.4	0.7	0.0	0.4	0.2	0.4	0.8	2.1	0.5	0.4	0.4	0.7	-1.3	0.2	0.3	0.0	-0.9	0.0	-0.8	-0.8	-1.4	-0.9	-2.9	0.8	0.7	0.0	-2.0	-4.7	-2.6	-0.1	0.5	128.39	10.95
CIL (<1°C)	-0.3	-0.2	-0.4	-0.2	1.4	1.5	-0.1	0.4	0.1	0.1	1.0	2.1	0.1	0.1	0.1	0.3	-1.7	0.2	0.7	-0.2	-0.4	0.1	1.0	-1.1	-1.6	-0.9	-2.0	0.6	0.7	-0.2	-2.1	-4.1	-3.4	-0.2	0.4	135.09	8.23
Surface S	1.1	0.2	1.6	-1.1	-2.0	0.3	0.8	0.9	0.6	1.5	0.8	-2.7	-0.4	-0.2	0.0	-1.8	0.0	-0.6	-0.5	-0.5	-0.4	-0.7	1.1	1.0	0.6	0.5	0.7	0.1	0.6	0.5	-0.4	0.3	0.8	0.0	-0.2	31.64	0.25
Bottom S	1.9	1.5	1.5	-0.4	-0.1	-0.5	-1.2	1.4	1.1	1.3	1.3	-2.0	-1.4	0.6	-0.4	-0.2	-1.5	-0.3	0.5	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	-0.4	33.13	0.08
0-50 m S	1.0	-0.4	1.3	-1.1	-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	1.1	1.0	0.2	0.2	0.5	0.2	0.7	0.3	-1.2	-0.5	0.2	-0.2	-0.1	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	2.3	-1.5	-1.0	0.4	-0.2	-0.6	-1.2	-0.1	0.1	-0.3	-0.7	-1.1	0.5	0.3	-0.5	-0.3	0.8	0.3	1.0	-0.4	-1.5	-1.2	-0.1	-0.9	0.1	32.50	0.10
Annual MLD											1.0	0.5	1.7	-0.1	0.7	-2.2	-0.3	-0.7	-1.2	-1.0	-0.7	-0.7	0.1	-1.1	1.3	-0.2	0.5	1.2	-0.7	0.8	-1.1	1.5	0.0	0.9	0.7	58.19	9.16
Winter MLD											0.3	-0.8	-0.1	-0.6	0.5	-1.1	-0.2	0.4	-1.0	-0.5	-0.2	-0.2	-1.2	-0.9	1.3	0.6	1.3	1.0	-1.5	0.9	-2.3	0.7	0.4	1.9	-0.5	97.41	30.74
Spring MLD											-0.3	1.8	-0.1	0.2	-0.5	-1.6	0.1	-1.5	0.0	-1.6	-0.1	0.7	0.3	-0.4	0.4	-1.1	-0.6	0.5	1.4	-1.2	0.0	1.5	-0.8	1.4	1.4	43.87	15.16
Summer MLD											2.1	1.9	2.8	0.3	0.4	0.4	0.4	-0.5	-0.3	-0.4	-0.7	0.1	-0.5	-0.6	-0.5	-0.4	0.0	-0.5	-0.5	-0.5	-0.3	0.5	-0.7	-0.3	-0.4	23.40	8.72
Fall MLD											0.8	-0.6	1.7	0.2	1.0	-1.9	-0.6	0.0	-0.9	0.3	-0.7	-2.0	1.5	-0.4	0.2	0.1	-0.4	0.8	-0.8	2.0	-0.4	0.3	0.6	-0.8	0.5	66.01	16.27
Annual Stratification	-1.8	-0.3	-1.2	0.1	1.1	-0.8	-1.7	-0.1	1.4	0.1	-1.0	1.4	-0.2	-0.7	0.1	2.6	-1.1	1.0	1.6	0.9	0.2	0.6	-1.4	-0.4	-0.8	-0.6	0.2	-0.1	0.1	-0.5	-1.0	-2.0	-1.1	0.2	1.1	20.71	3.62
Winter Stratification			-0.3	0.0	0.0	-0.4	-0.4	-0.4	4.8	-0.1	0.5	-0.5	1.1	0.2	-0.4	0.8	0.1	-0.1	-0.5	0.1	0.5	-0.2	-0.1	-0.2	-0.5	-0.4	-0.3	-0.5	-0.1	-0.1	-0.5	-0.4	-0.6	-1.0	-0.6	5.54	6.92
Spring Stratification	-1.0	-0.1	-0.7	2.2	1.7	-1.0	-0.4	1.4	-0.2	-0.7	-1.6	1.9	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	-0.2	0.4	-0.2	-0.6	0.2	-1.2	-0.5	-0.7	-0.2	-1.0	12.86	4.87
Summer Stratification	-1.3	0.1	-2.0	-0.4	1.8	-0.1	-1.4	-1.3	0.4	0.6	-1.0	-0.3	-1.4	-0.9	1.2	0.8	-1.5	0.2	1.0	1.7	0.1	0.5	-1.1	-0.5	-0.1	0.5	0.0	1.3	0.5	0.2	-0.9	-2.9	-0.4	1.3	4.1	50.50	5.84
Fall Stratification		-0.6		-1.2	-0.6	-0.6	-1.5	0.0	0.5	0.2	0.4	1.9	-0.4	-0.8	-0.2	2.2	-0.8	0.9	2.4	-0.4	0.4	1.2	-1.0	0.6	-0.7	-1.1	0.3	-0.5	0.3	-1.2	0.1	-1.1	-0.9	-0.1	-0.5	13.85	6.45

Figure 20. Standardized temperature and salinity anomalies, CIL thickness, Mixed Layer Depths (MLD) and stratification at Station 27 from 1980 to 2014. The anomalies are normalized with respect to their standard deviations over the standard base period. Grey cells represent missing data.

In 2013 and 2014, the annual averaged stratification increased significantly over the previous two years (Figure 22). Seasonal standardized stratification values are shown in Figure 20. 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 stratification has increased from 2 SD below normal in 2011 to 1.1 SD above normal in 2014 (Figure 20). 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. During 2011 the annual averaged MLD was +1.5 SD (deeper-than-normal), but had decreased to < 1 SD above normal in 2013-14 (Figure 20).The average monthly values range from about 90-100 m in the winter to < 20 m in summer (Figure 23). In 2014 spring values were deeper than normal while during the remainder of the year values were near normal, except August which was shallower than normal (Figure 23). In general, there appears to be a slight increasing trend since 1995 of about 0.7 m/year in the annual mean (Figure 24).

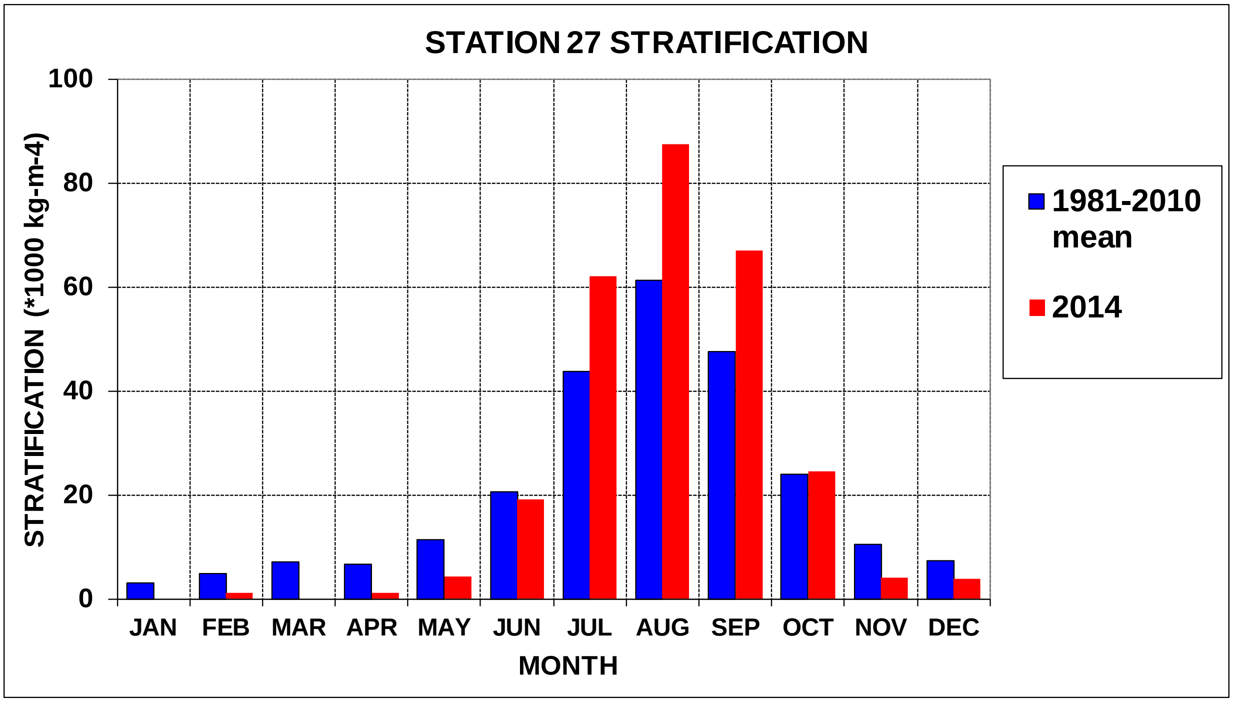

Figure 21. The 1981-2010 monthly average and the 2014 monthly average stratification values at Station 27. No data were available in January and March.

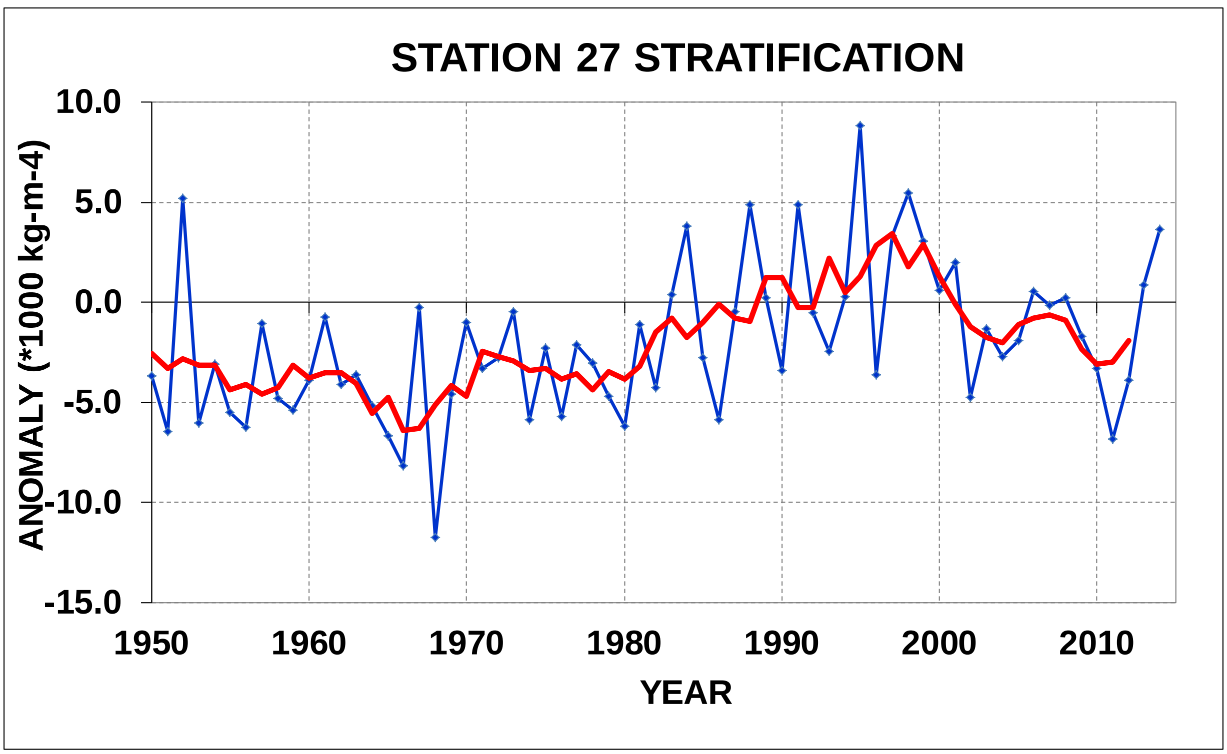

Figure 22. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean. The red line is the 5-year running mean.

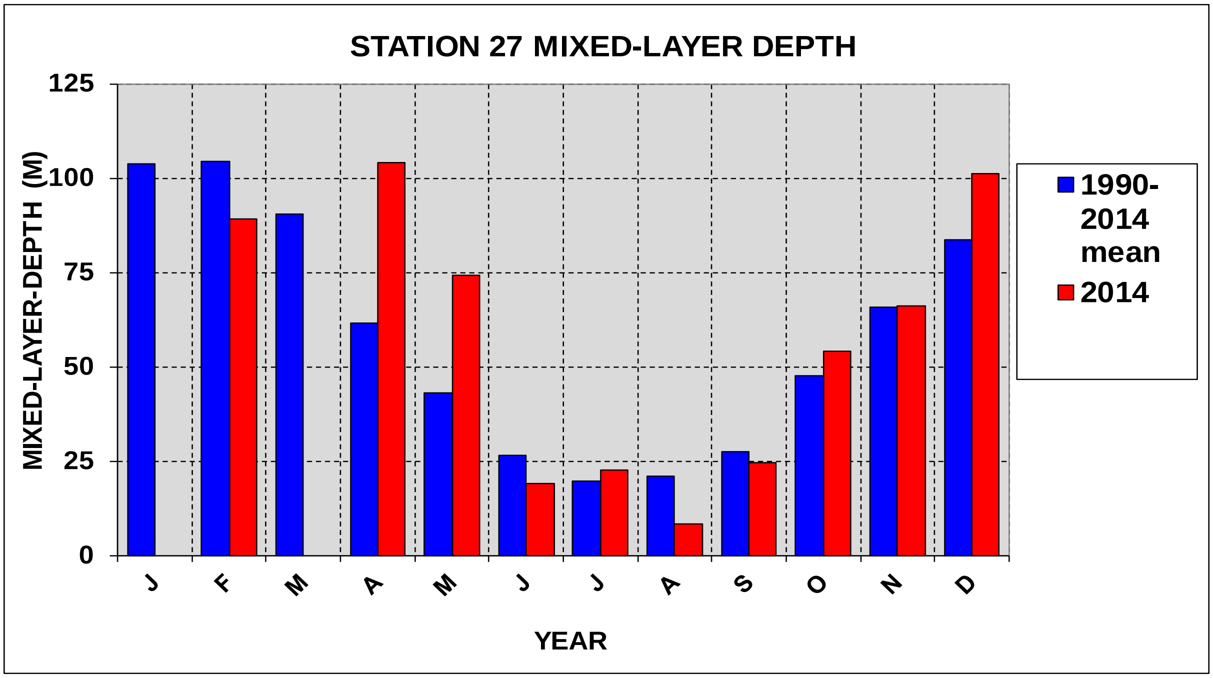

Figure 23. The 1990-2010 average and the 2014 monthly mean Mixed Layer Depths at Station 27.

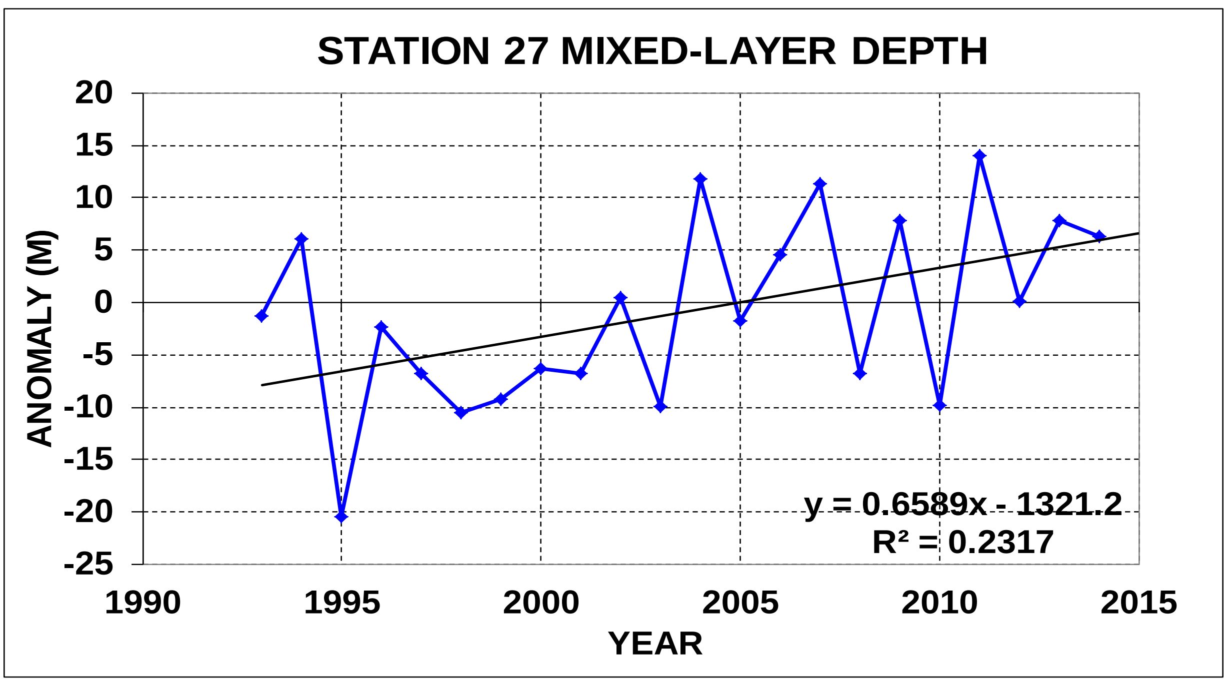

Figure 24. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2014 mean.

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 25) and 40 on the

Newfoundland Shelf (Figure 28). 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 in any given year.

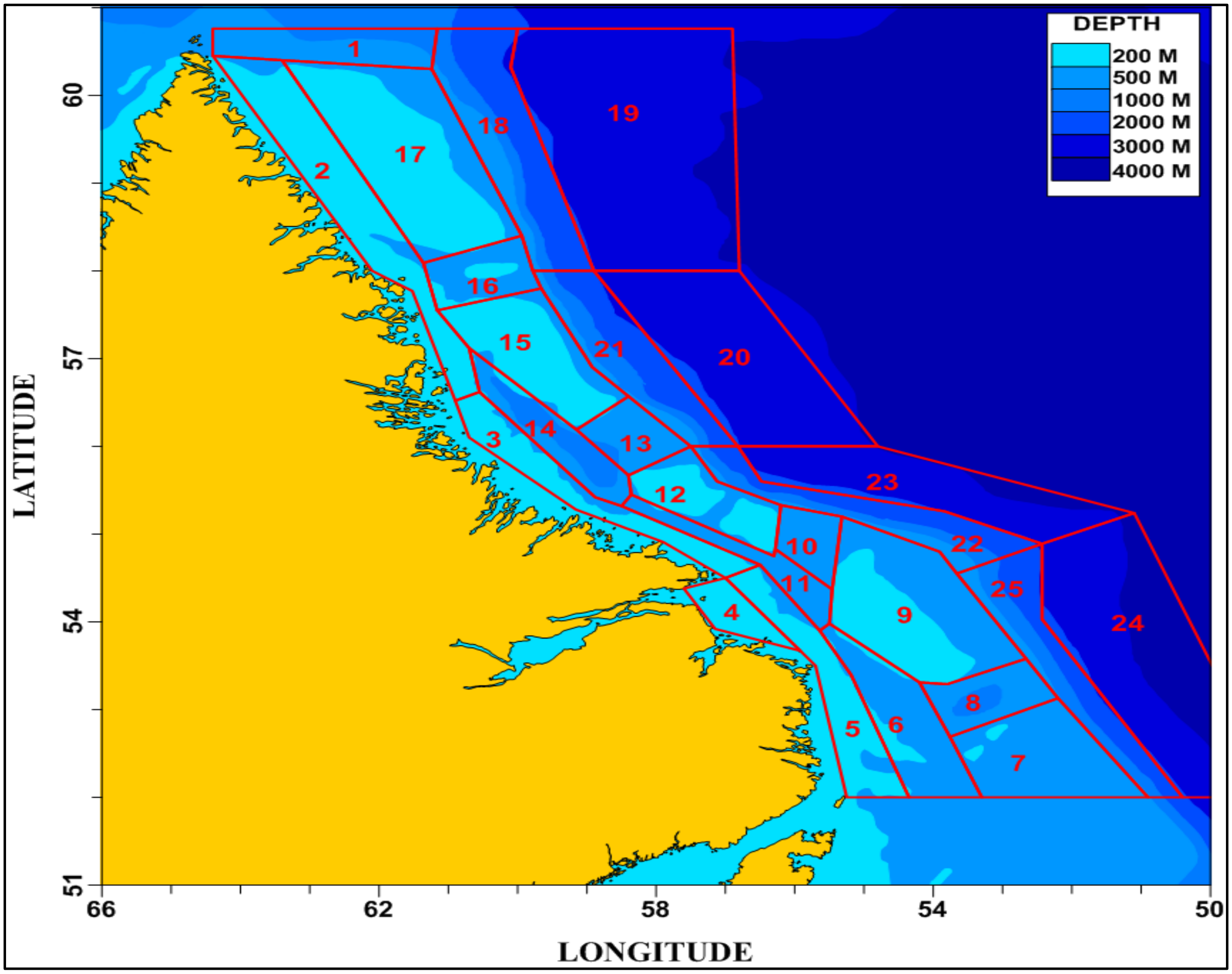

Figure 25. Areas on the Labrador Shelf where bottom temperatures were analysed. The numbers within each area correspond to the areas listed below in Figure 26.

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 26 and repeated in Figure 27 as a cumulative plot for all areas. During the past decade most of the areas had positive anomalies compared to mostly negative anomalies in the previous decade. In 2014, 11 areas out of the 21 with sufficient data reported positive values 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 27). Since the peak in 2011 bottom temperatures on the Labrador Shelf have been decreasing with 2014 showing the lowest cumulative value since 2002.

Similarly, standardized annual bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 29 and repeated in Figure 30 as a cumulative time series. The results are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999. In 2014, 17 of the 35 areas were positive down from 32 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 of 35 areas were above normal by more than 2 SD. Bottom temperatures on the Newfoundland Shelf were the 2nd highest since 1980 in 2012 and the 4th highest in 2013. In 2014 the cumulative temperature index decreased significantly and was similar to the 2008 value.

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	14	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	1.0	-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	-0.5	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	-0.7	-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	0.5	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	-0.3	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	1.3	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	-0.2	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	-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	-1.2	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	-0.2	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	-0.6	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	1.2	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	3.5	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	-1.0	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	1.2	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	0.7	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	-0.2	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	0.7	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	-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	-0.4	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	0.0	3.44	0.25

Figure 26. Standardized bottom temperature anomalies for the Labrador Shelf derived from data within most of the areas displayed in Figure 25. 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.

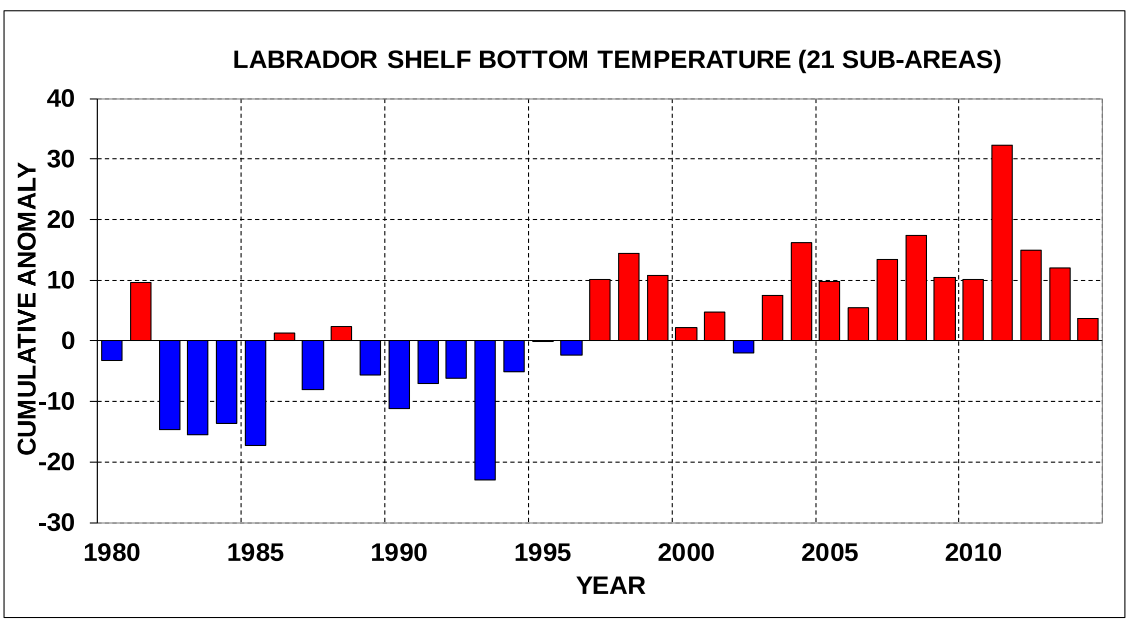

Figure 27. Cumulative bottom temperature anomalies based on the values presented in Figure 26 for the Labrador Shelf.

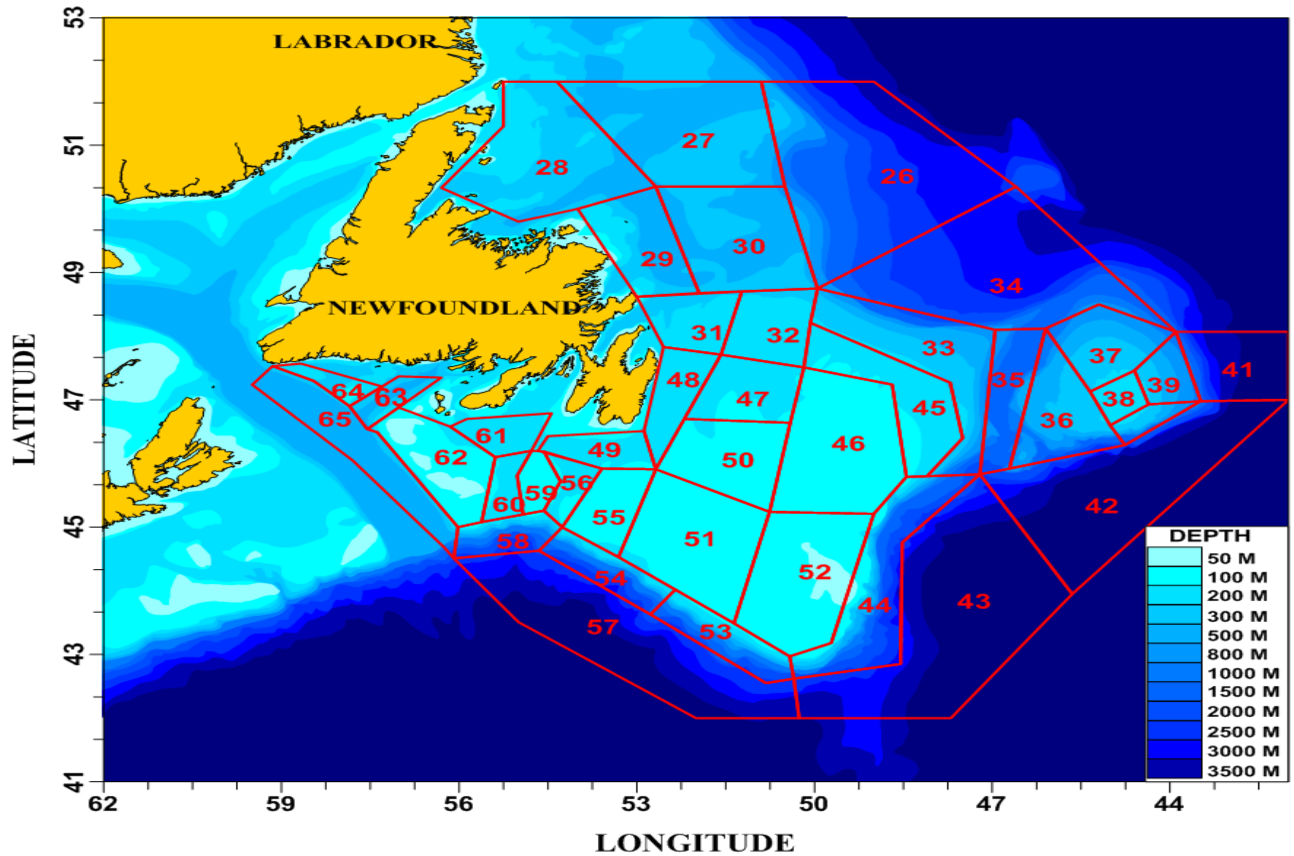

Figure 28. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed in Figure 29.

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	14	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	0.6	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	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	-0.4	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	-0.5	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	-0.3	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	-1.0	-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	-0.6	-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	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	-0.3	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	1.5	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	0.7	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	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	-1.0	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	0.9	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	1.1	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	-0.6	-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	-0.1	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	-0.1	-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	-0.7	-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	-0.5	-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	-0.4	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	0.4	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	-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	1.0	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	0.5	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	-0.5	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	-2.2	-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	1.0	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	-0.4	-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	1.4	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	1.5	-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	-0.1	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	2.2	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	0.9	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	1.8	4.94	0.45

Figure 29. Standardized bottom temperature anomalies for the Newfoundland Shelf referenced to 1981-2010.

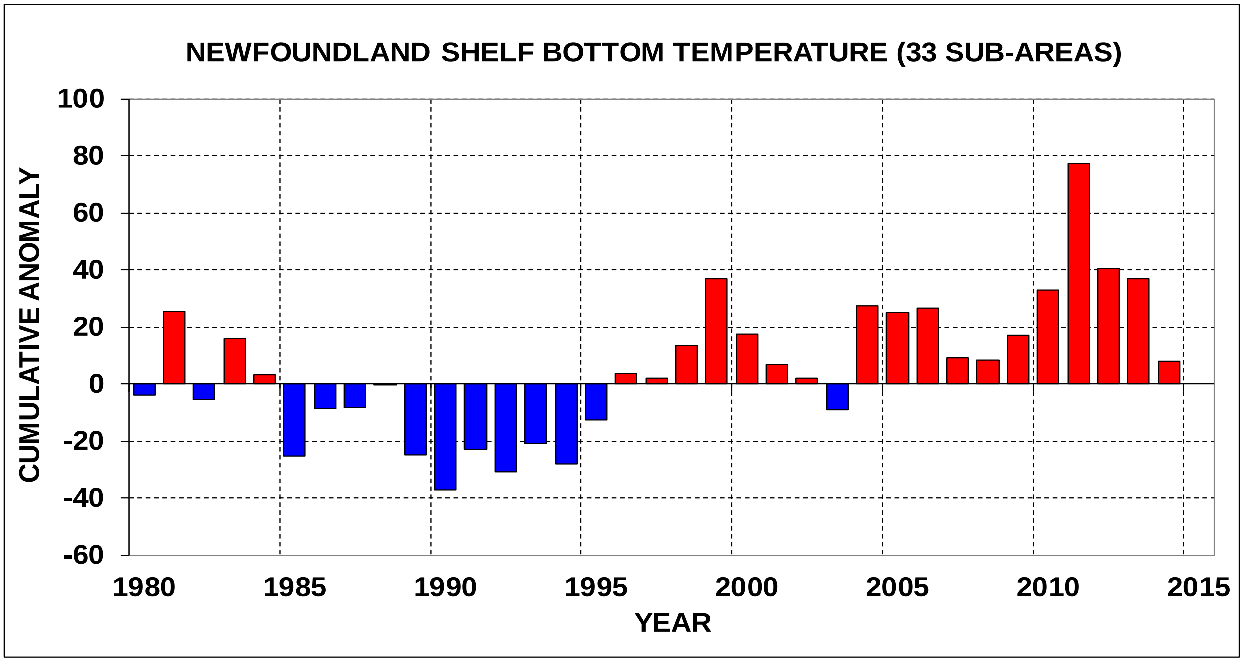

Figure 30. Cumulative bottom temperature anomalies based on the values presented in Figure 29 for the areas on the Newfoundland Shelf shown in Figure 28.

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 ICNAF/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 2014, the SWSPB, SESPB sections were sampled in April, the SEGB section was sampled in April and December, the FC section during April, July and November, 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 BI section on the mid-Labrador Shelf was not sampled in 2012 due to limited ship time. In this manuscript we present seasonal cross sections of temperature and salinity and their anomalies along the Bonavista section to represent the vertical temperature and salinity structure across the Newfoundland and Labrador Shelf during 2014.

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 Flemish Cap regions. This water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3-4^{o}C and salinities in the range of 34 - 34.75. Surface temperatures normally warm to 10-12^{o}C during late summer, while bottom temperatures remain <0^{o}C over much of the Grand Banks but increase to 1-3.5^{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 3-4^{o}C.

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.

The seasonal changes are highlighted in Figures 31 and 32 along the Bonavista Section (Figure 2) with the cold shelf water mass as the dominate thermal feature. The corresponding salinity cross-sections show remarkable seasonal similarities with the relatively fresh upper layer shelf water having sources from arctic outflow and the Labrador Shelf with values < 33, contrasting to the saltier Labrador Slope water further offshore with values > 34 (Figure 32).

During 2014 temperatures along the Bonavista section were predominately below normal on the shelf and above normal in the deeper water off the shelf edge. There were some exceptions, for example in the near-surface layer during the summer when values exceeded 5^{o}C above normal (Figure 31, right panels). Salinity anomalies were weak during the spring and summer with anomalies generally < 0.25 with a tendency towards lower than normal in the offshore. The most significant anomaly occurred during the fall when values were lower than normal by up to 0.4 over the shelf (Figure 32, right panels).

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 (Figures 31 and 32). 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^{o}C 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 slowed. The CIL areal extent continues to undergo a gradual decay during the fall however as increasing wind stress mixes the seasonally heated upper layers deeper into the water column. Along the SEGB section the average cross-sectional area of the CIL is 10.8 ± 6.2 km^2 and 7.6 ± 7.0 km^2, during the spring and fall, respectively. Along the FC section the average cross-sectional area of the CIL is 30.8 ± 12.9 km^2, 26.5 ± 6.6 km^2 and 18.4 ± 5.4 km^2 during the spring, summer and fall, respectively. Along the BB section the average cross-sectional area of the CIL is 32.0 ± 13.5 km^2, 25.6 ± 9.3 km^2 and 13.2 ± 10.3 km^2 during the spring, summer and fall, respectively. Along the WB and SI sections the average summer cross-sectional area of the CIL is 55.3 ± 14.2 km^2 and 27.3 ± 7.5 km^2, respectively.

Time series of CIL cross-sectional area anomalies along sections from southern Labrador to the Grand Banks are displayed in Figures 33, 34 and 35 for the spring, summer and fall. In general, summer CIL values have been below normal during most years of the past two decades. Note also that not all sections were sampled in the early years of each series.The CIL area anomalies during the spring and summer of 2014 were all above normal (implying colder-than-normal shelf water conditions) and in fact it was at the highest level since 1985 on the Grand Bank (FC) during the spring and the highest since 1991 off eastern Newfoundland (BB) during the summer. By late fall the CIL was only slightly above normal on the Grand Bank (FC) and had eroded to normal values along the BB and SEGB sections.

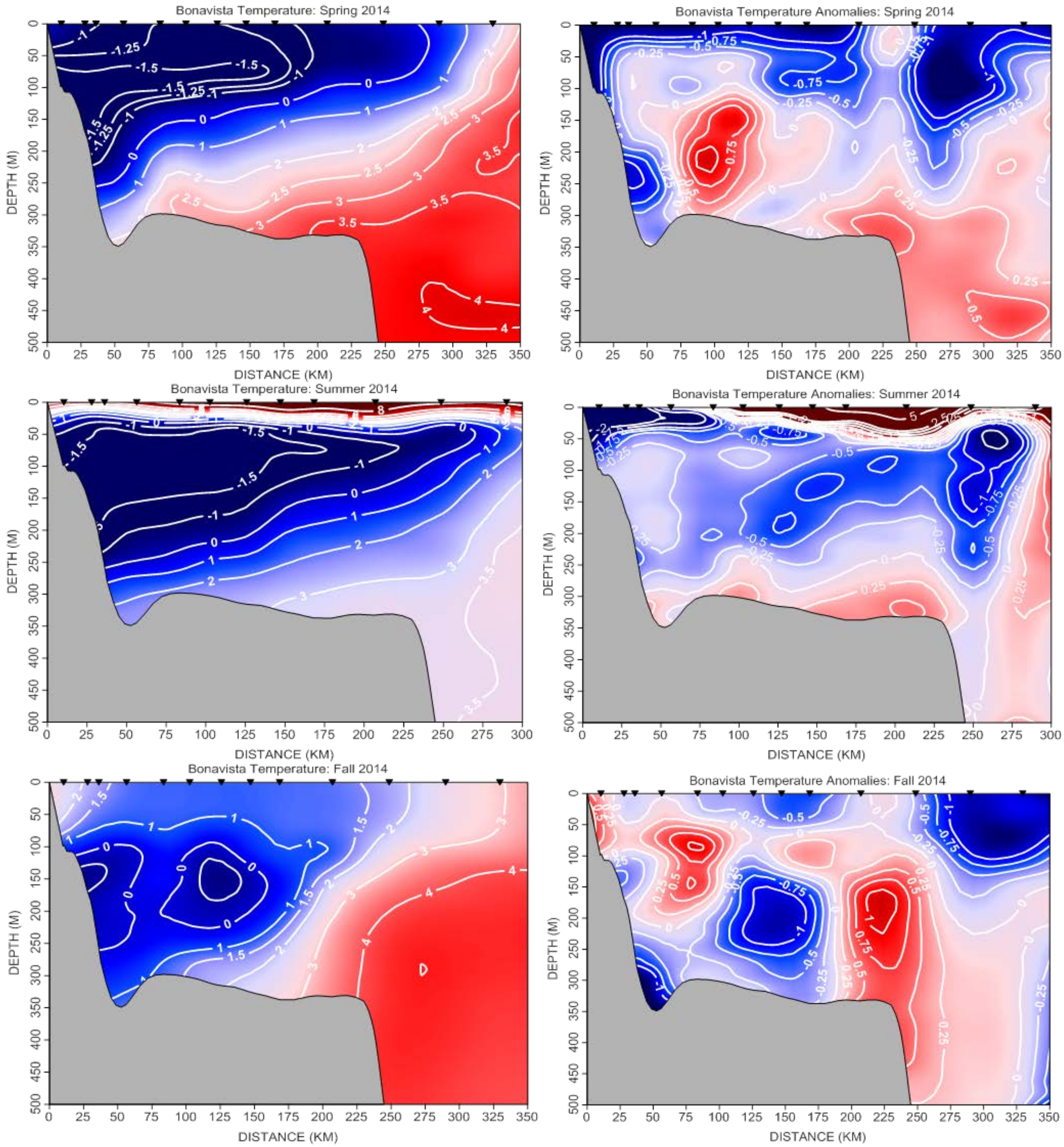

Figure 31. Contours of temperature (^oC) and temperature anomalies along the Bonavista section (Figure 2) during the spring, summer and fall of 2014. Station locations along the section are indicated by the symbols on the top of each panel.

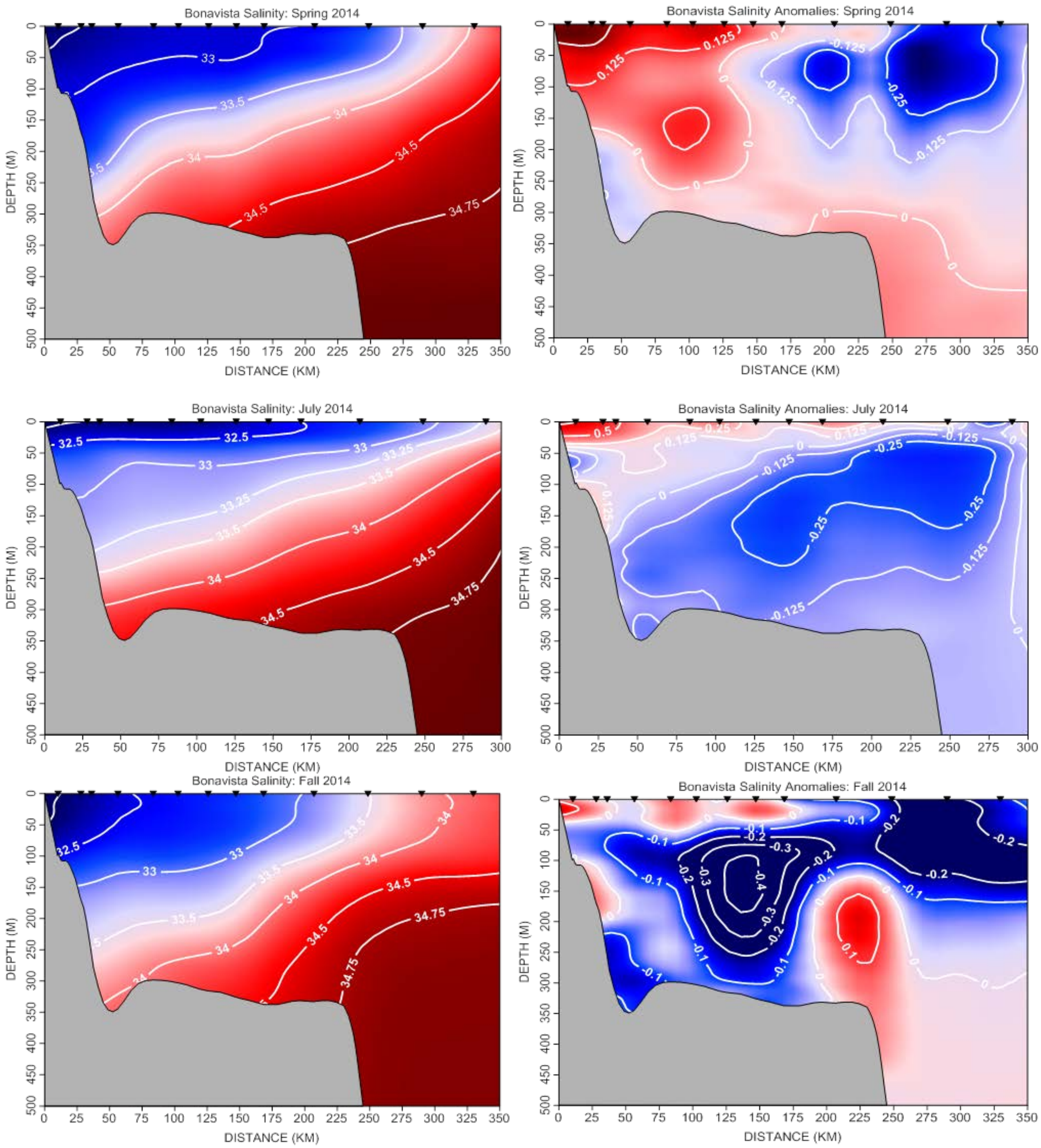

Figure 32. Contours of salinity and salinity anomalies along the Bonavista section (Figure 2) during the spring, summer and fall of 2014. Station locations along the section are indicated by the symbols on the top of each panel.

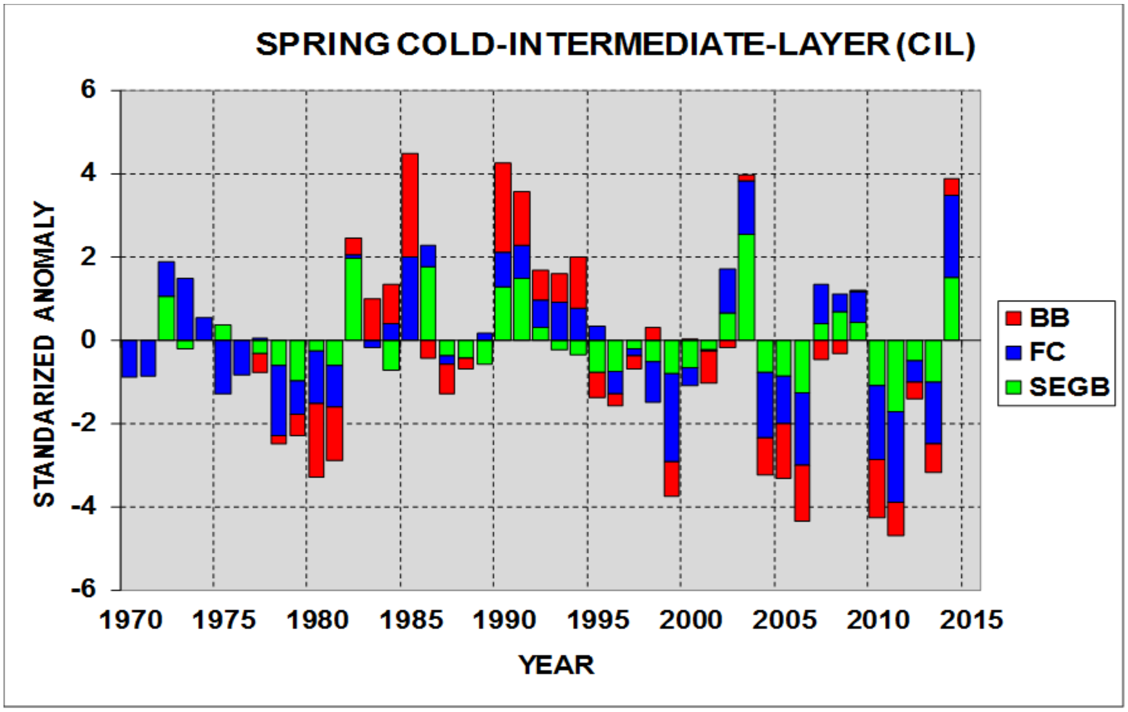

Figure 33. Cold-Intermediate-Layer areas during the spring along the Bonavista (BB), Flemish Cap (FC) and the South East Grand Bank (SEGB) sections displayed as cumulative standardized anomalies relative to 1981-2010.

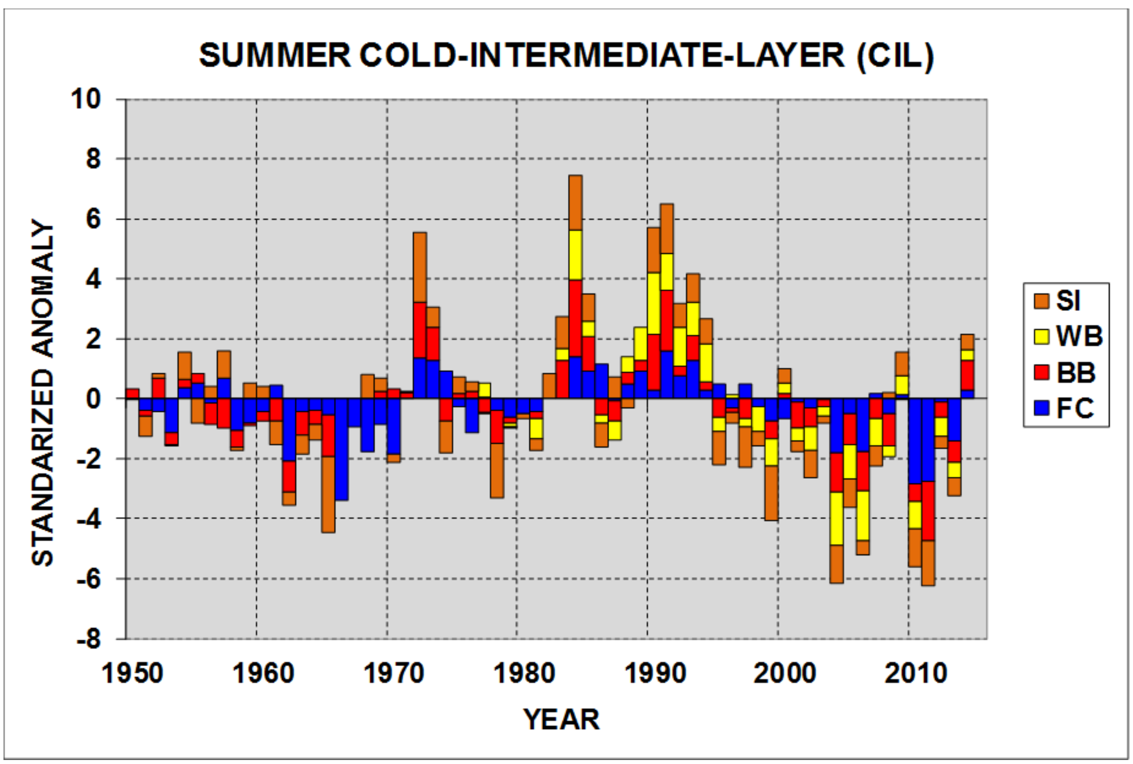

Figure 34. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

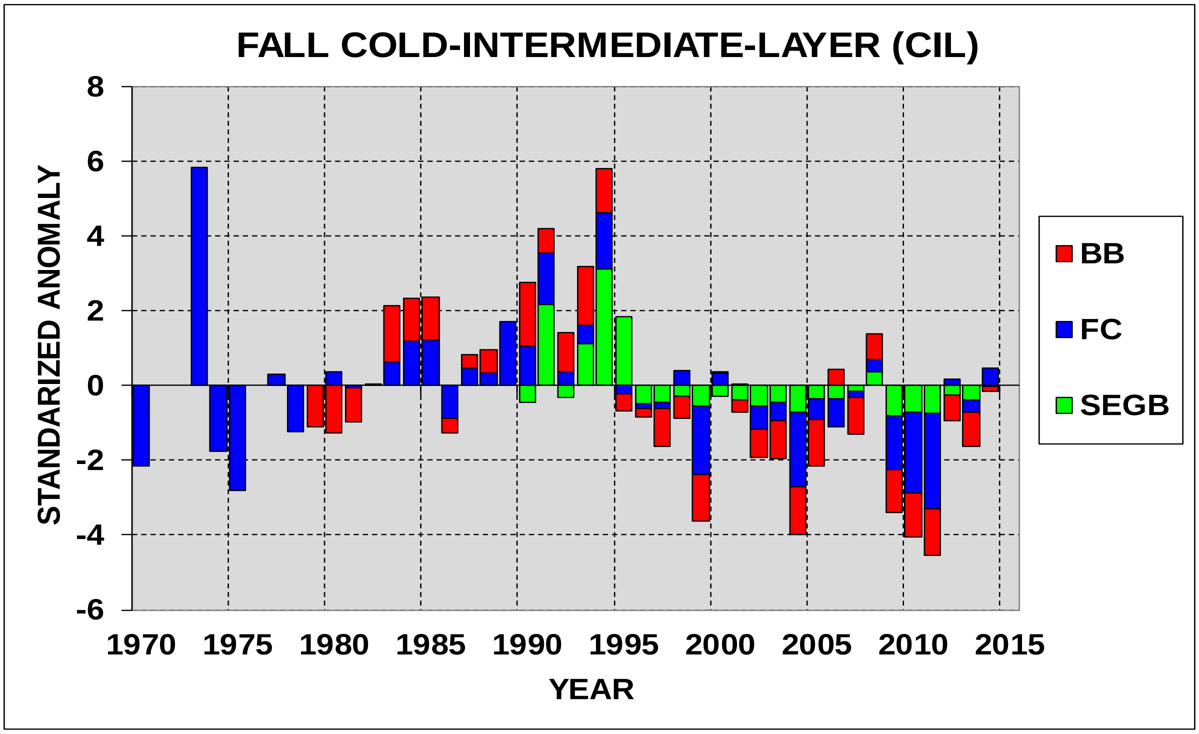

Figure 35. Cold-Intermediate-Layer areas during the fall along the Bonavista (BB), Flemish Cap (FC) and the South East Grand Bank (SEGB) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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 36. All temperature indices shown were either near or below normal by up to a maximum of -1.5 SD, with the strongest anomalies along the Bonavista section. This is in contrast to the previous 4 years when conditions were mostly warmer than normal. Salinity on the other hand was either near-normal or below normal (fresher water) by up 1.2 SD, continuing the trend since 2009.

SEAL ISLAND SECTION	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	14	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	0.5	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	-1.1	-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	1.4	-1.0	-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	-0.2	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	-0.3	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	-0.4	32.54	0.24
BONAVISTA SECTION																																					
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	1.0	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	-1.5	-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	-0.8	-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	-0.9	-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	-1.2	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	0.3	32.97	0.12
FLEMISH CAP SECTION																																					
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	0.3	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	-0.4	-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	-0.7	-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	-0.9	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	-0.1	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	-0.1	32.69	0.16

Figure 36. 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 most fishing sets in each stratum.

These surveys provide large spatial-scale oceanographic data sets for the Newfoundland Shelf. During the spring NAFO Subdiv. 3Ps on the Newfoundland south coast and Divs. 3LNO on the Grand Banks are surveyed while in the fall, Divs. 2HJ off Labrador in the north to 3NO on the southern Grand Bank are surveyed.

The hydrographic data collected on these surveys are routinely used to assess the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of products based on the data are used to characterize the oceanographic bottom 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 2014. Note that there was no coverage in Divs. 3NO during the fall of 2014 and furthermore, some of the data from Divs.3L was actually collected in January, 2015.

Spring Conditions

Maps of the climatological mean bottom temperatures and spring 2014 bottom temperature, their anomalies and difference from the previous year, are displayed in Figure 37 for NAFO Divs. 3PLNO (See Figure 3 for station occupation coverage). Bottom temperatures in Divs. 3L were generally < -1^{o}C in the inshore regions of the Avalon Channel and parts of the northern Grand Bank and from 2^{o} to 3^{o}C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 2^{o} to 5^{o}C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from -1^{o} to 0^{o}C. Bottom temperature anomalies were below normal (up to 0.5^{o}C) over most of the region except for the slope and southwestern 3O where there were areas with above normal values.

On St. Pierre Bank temperatures ranged from 0-3^{o}C and up to $5^{-}6^{o}$C in the Laurentian Channel and areas to the west. Bottom temperature anomalies in this region were near normal on St. Pierre Bank and above normal (up to 2^{o}C) in the deeper channels and areas to the west of St. Pierre Bank. The bottom right panel of Figure 37 shows a significant decrease in bottom temperatures on the Grand Banks and an increase in values west of St. Pierre Bank compared to 2013.

Climate indices based on the temperature data collected during the spring survey for the years 1990-2014 are displayed in Figure 38 as normalized anomalies. During the spring of 2011 in Divs. 3LNO, none of the bottom area was covered by <0^{o}C water, the only such occurrence since the surveys began in the early 1970s, corresponding to 2.2 SD units below normal. In 2013 it remained at 1.5 SD below the long term mean but increased to 0.5 SD above normal in 2014 (Figure 38).

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 at 1.9 SD above normal but these have decreased to near-normal values by 2014 (Figure 38).

In Div. 3P bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000, and near record cold conditions in 2003 (-1.4 SD). A notable exception occurred in 2007-08 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 2011-12 and then decreasing to near 1 SD in 2013-14. The spring of 2011 had the lowest area of <0^{o}C bottom water since 1981 at 1.9 SD below normal, also corresponding to little or no bottom waters with temperatures of <0^{o}C. This area has remained below normal (by 0.8-1.5 SD) in 2012-14 (Figure 38).

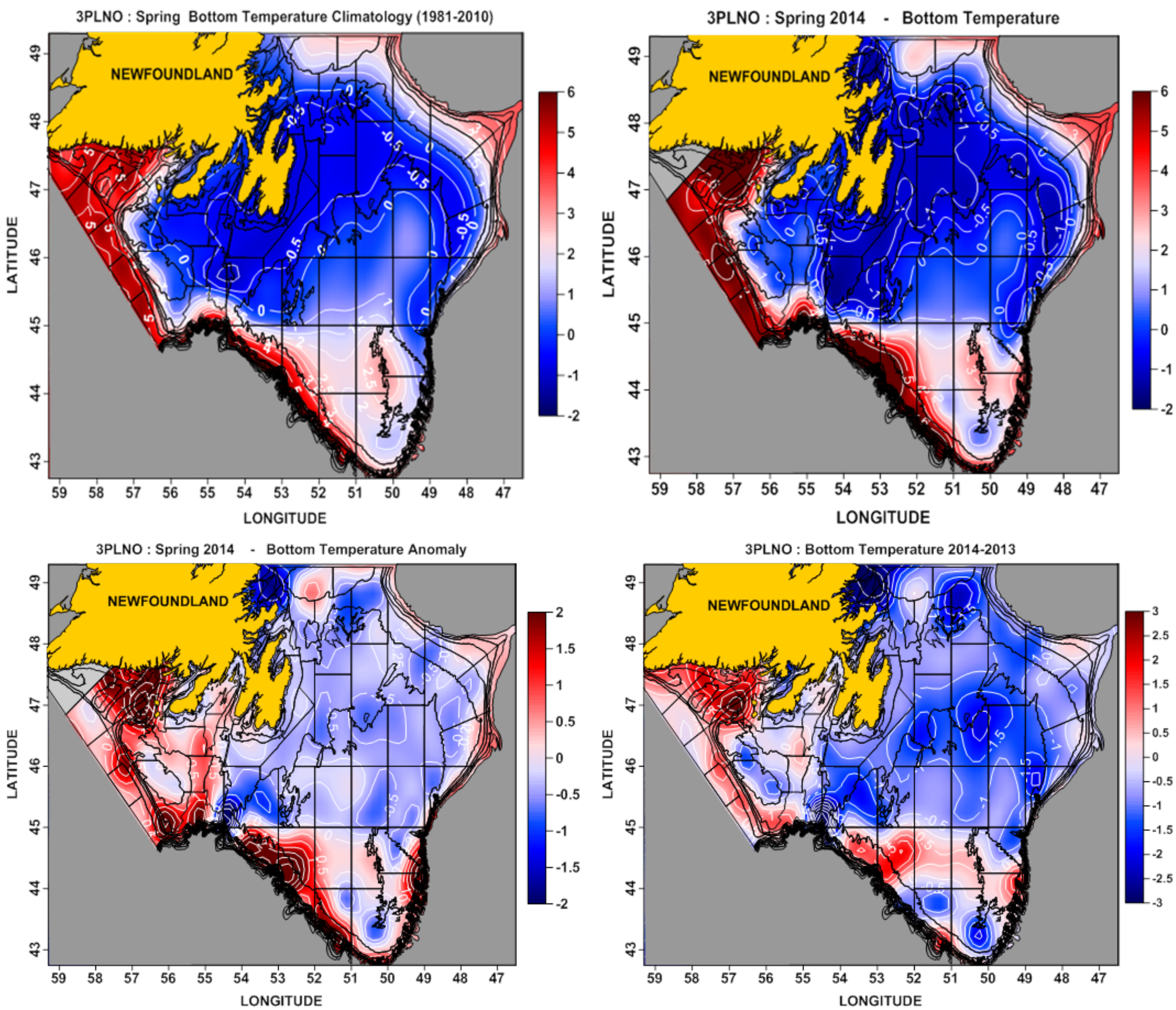

Figure 37. Maps of the mean 1981-2010 bottom temperature, bottom temperature and anomalies during spring 2014 and the difference from 2013 (in °C) in NAFO Divs. 3PLNO.

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 have experienced a decreasing trend since then reaching slightly below normal on the Grand Banks in 2014.

NAFO DIV. 3LNO	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	2014	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	-0.1	1.48	0.64
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	-0.3	0.69	0.57
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	0.4	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	0.5	33.65	15.38
NAFO DIV. 3PS																																					
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	1.0	2.53	0.44
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	0.1	0.29	0.73
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	0.3	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	-0.8	22.13	11.78

Figure 38. 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 data.

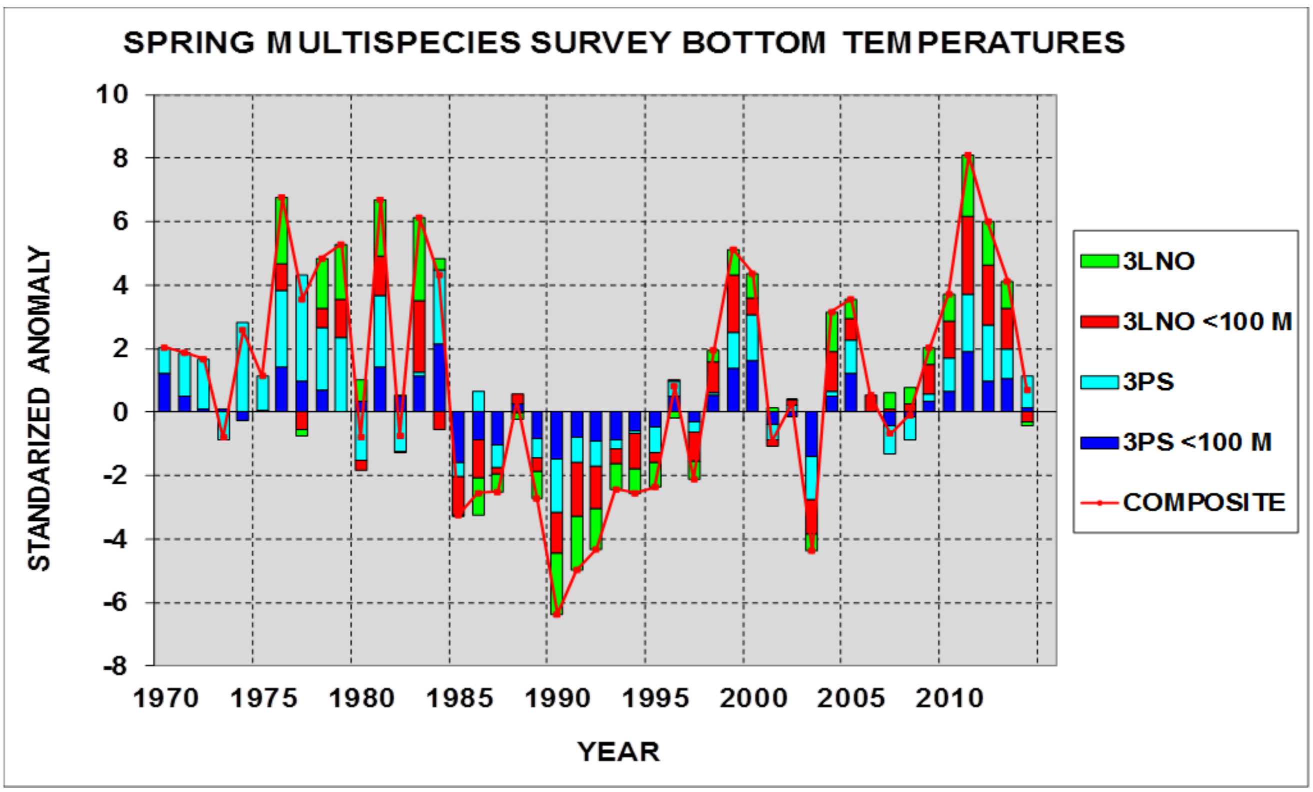

Figure 39. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divs. 3LNOP.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from the fall of 2014 multi-species survey (Figure 3) in NAFO Divs. 2J and 3KL are displayed in Figure 40. Bottom temperatures in Div. 2J ranged from <0°C on portions of Hamilton Bank and the inshore areas of the Labrador coast to >4°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 the northeast coast of Newfoundland. In the offshore areas temperatures were near-normal to slightly above normal in 2J and up to 0.25°C above normal in 3K.

Bottom temperatures in Div. 3L generally ranged from -1-0°C on the northern Grand Bank and in the Avalon Channel to 3-4°C along the shelf edge and > 2°C over the southern areas of 3L. Temperatures were below normal over most of 3L except along the slope edge and in the southern central area where they appeared up to 1.5°C above normal (Figure 40).

Bottom temperature anomalies and derived indices are displayed in Figure 41 as standardized values. In 2J, bottom temperatures were generally below normal from 1980 to 1995, with the coldest anomalies observed in 1993 when they declined to 0.9-1.7 SD below normal. The warmest anomaly occurred in 2011 with values reaching a record high of 2-2.2 SD above normal and in 2014 they decreased to 0.7 SD above normal and slightly below normal on Hamilton Bank (< 200 m). The area of the bottom with temperatures <1°C increased to slightly above normal (0.3 SD) in 2014, the highest since 1995. In Div. 3K, bottom temperatures were at a record high in 2011 (+ 2.7 SD) but have decreased to near-normal conditions in 2014.

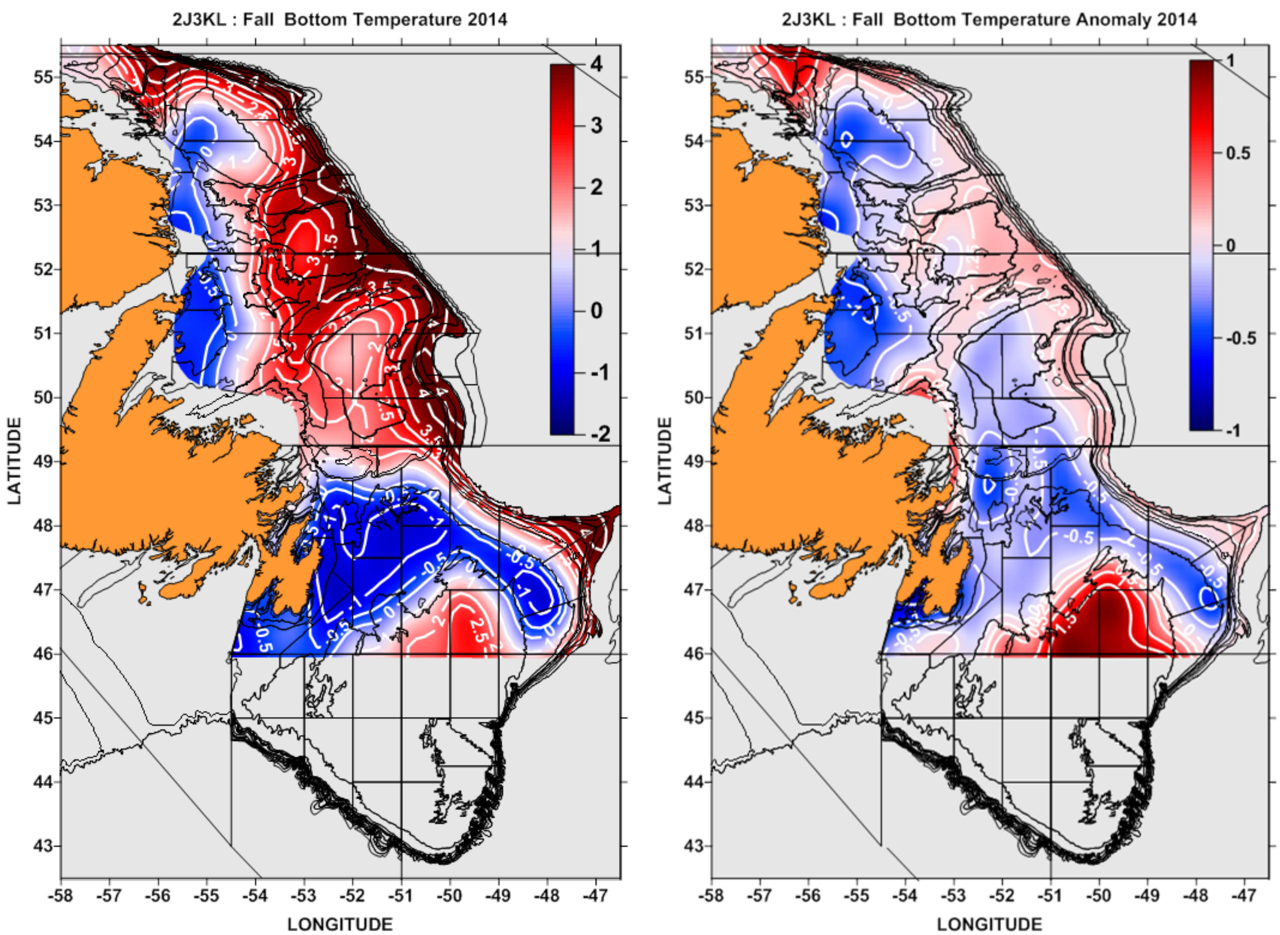

Figure 40. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2014 in NAFO Divs. 2J3KL.

REGION	NAFO DIV. 2J	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	2014	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	0.7	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	-0.4	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	0.2	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	0.3	22.72	15.71
	NAFO DIV. 3K																																					
	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	0.3	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	-0.1	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	0.2	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	0.0	20.76	11.06
	NAFO DIV. 3LNO																																					
	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) 2J3KL	-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	0.3	1.65	0.95

Figure 41. Temperature indices derived from data collected during fall multi-species survey. The anomalies are normalized with respect to their standard deviations. Grey cells represent missing data.

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. 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. For all areas, the 2012 and 2014 values decreased significantly over 2011. The 2014 value for 3LNO was not available.

Composite indices derived by summing the standardized values presented in Figures 38 and 41 compare the overall temperature conditions during the spring and fall since 1980. Since the record high in 2011 this index has decreased significantly to near-normal values in 2014 (Figure 43).

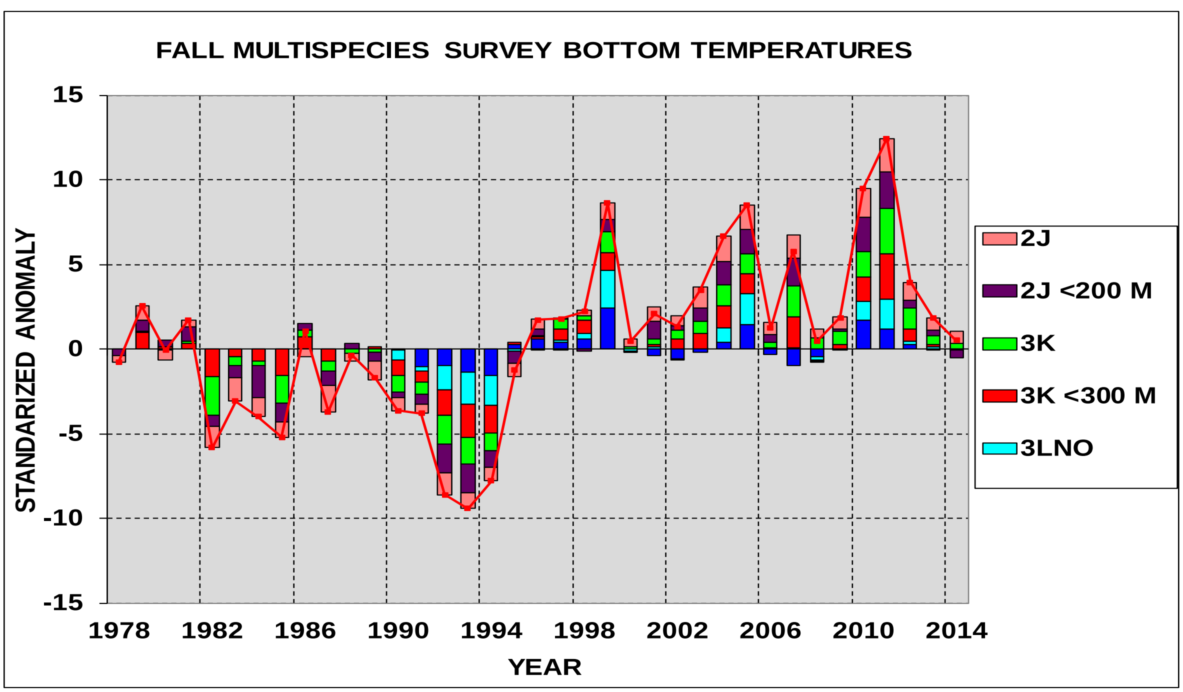

Figure 42. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divs. 2J3KLNO.

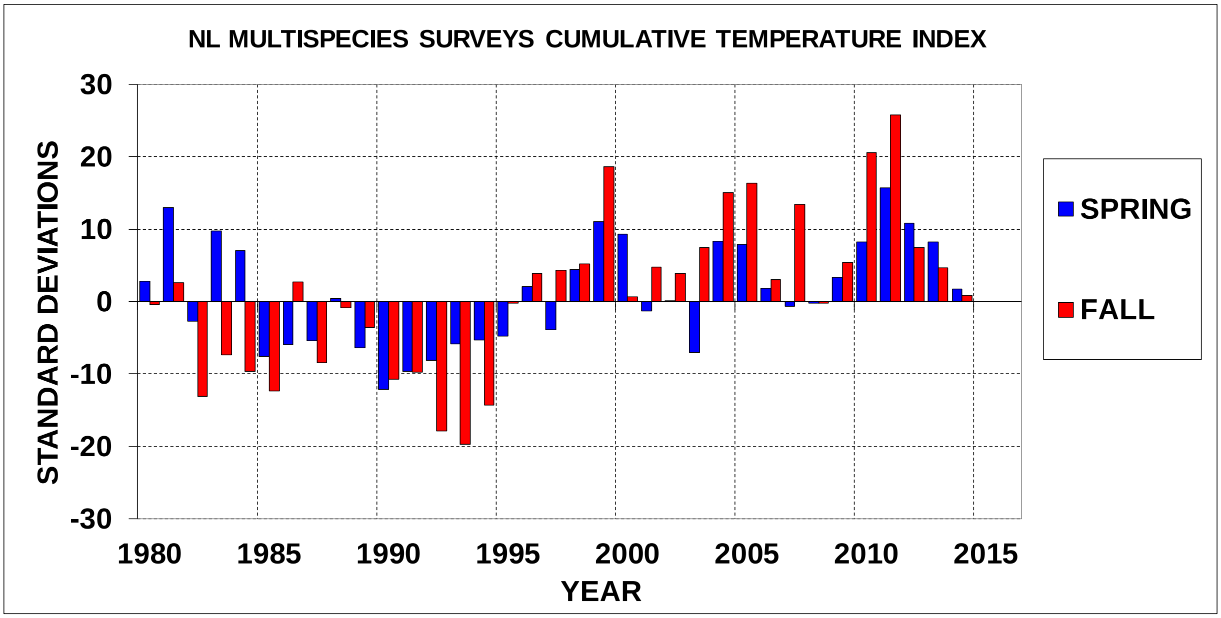

Figure 43. Spring and fall composite temperature index derived by summing the standardized anomalies from Figures 38 and 41.

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 and early fall mixing was calculated from the vertical temperature profiles in 2J3KL collected during the fall multi-species survey (October to mid-December).

The average volume of the CIL on the NL Shelf is $1.65 \pm 0.95 \times 10^4$ km^3.The annual values are shown in Figure 41 as standardized anomalies and in Figure 44 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 1993. The CIL volume was the lowest in the 34-year record during 1999 (1.7 SD below normal) with 2010 and 2011 tied for 3rd lowest at 1.1 SD below normal. During 2014 the CIL volume increased to 1.90×10^4 km^3 or 0.3 SD above normal, the first positive anomaly since 1994.

SUMMARY

A summary of selected temperature and salinity time series and other climate indices for the years 1950-2014 are displayed in Figure 45 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 2013. Following Petrie et al. (2007) a mosaic or composite climate index was constructed from the 28 time series as the sum (yellow line) of the standardized anomalies with each series contribution shown as stacked bars (Figure 46).

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 given year with an overall positive composite index and conversely during a year with a negative composite index.

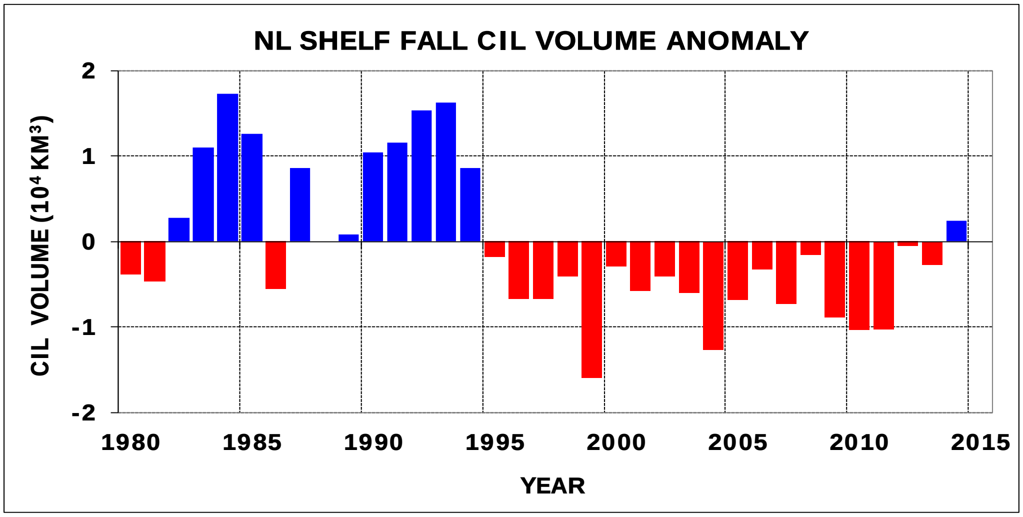

Figure 44. Time series of the CIL (< 0^{o}C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

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 three years of relatively cooler conditions of 2007-2009. In 2010 the composite index increased sharply over the near-normal year of 2009 to the 2nd highest in the 64-year time series. In 2011 it was very similar to 2010, the 4th highest in 64 years but in 2012 it had decreased to the 8th highest and has continued a trend of decreasing values reaching the 11th lowest in 2014 the lowest (coldest) value since 1994.

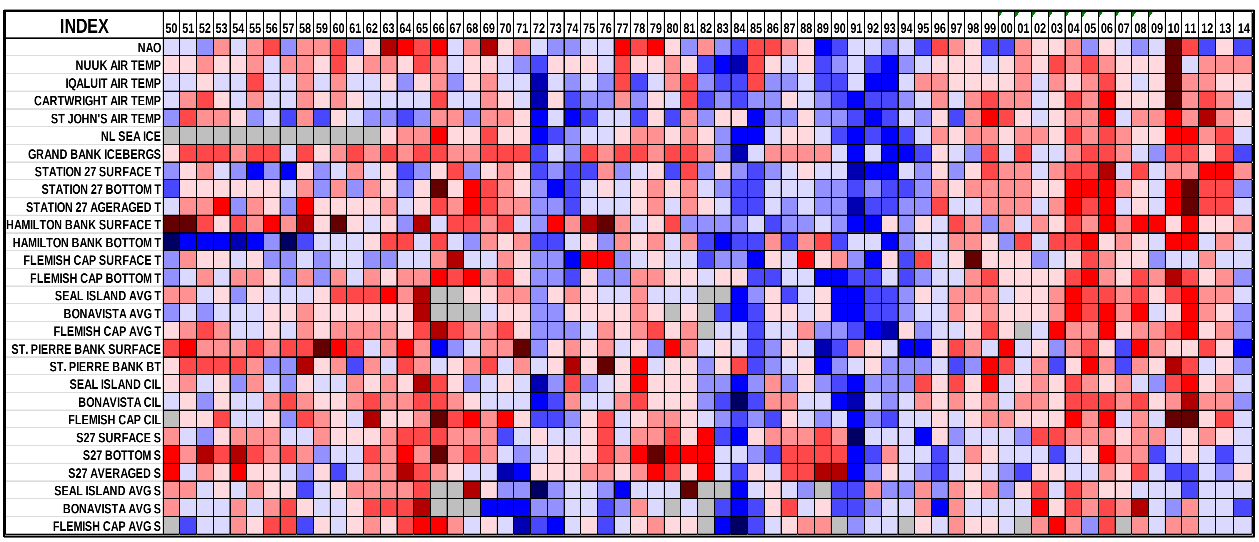

Figure 45. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Figure 4. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells represent missing data.

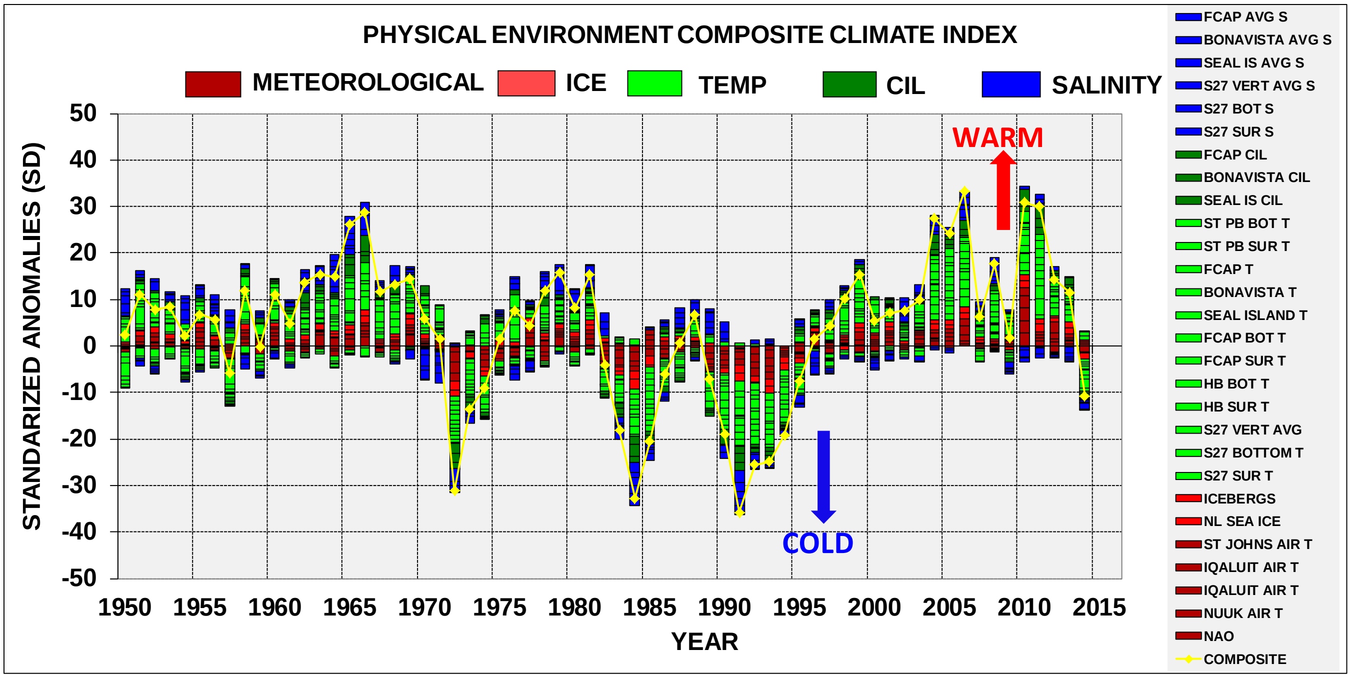

Figure 46. Composite climate index (yellow line) derived by summing the standardized anomalies from Figure 45 together with their individual components.

SUMMARY POINTS FOR 2014

- The NAO index, a key indicator of climate conditions on the Newfoundland and Labrador Shelf, returned to a strong positive phase in 2014 at 1.3 SD above normal.
- Arctic air outflow during the winter increased over the previous year causing a significant decrease in winter air temperatures (- 0.6 to - 1.0 SD below normal) over much of the NL region.
- Annual air temperatures however were near normal over Labrador (at Cartwright) and slightly above normal by 0.4 SD over Newfoundland (at St. John's).
- Sea ice extent on the NL Shelf returned to slightly above normal conditions (0.4 SD during winter), the first positive anomaly in 19 years.
- 1,546 icebergs were detected south of 48°N on the Northern Grand Bank (1.2 SD above the 1981-2010 mean of 767), compared to only 13 in 2013.
- Annual SST were above normal throughout most of the Northwest Atlantic, similar to 2013 values.
- At Station 27 annual surface temperatures were 0.6°C (0.9 SD) above normal.
- Annual bottom temperatures (176 m) at Station 27 were -0.2°C (0.6 SD) below normal, the lowest since 1995.
- Annual bottom salinity at Station 27 was -0.03 (- 0.4 SD) below the long-term mean, otherwise near normal.
- The area of the CIL (< 0°C) on the Grand Banks during the spring was at its highest level since 1985 (+ 2 SD).

- Off eastern Newfoundland during the summer, the CIL was the highest since 1991 (+ 1 SD).
- Spring bottom temperatures in NAFO Div. 3P remained above normal by about + 0.5 SD.
- Spring bottom temperatures in NAFO Divs. 3LNO were slightly below normal by -0.3 SD.
- Fall bottom temperatures in 2J and 3K decreased from 2 and 2.7 SD above normal in 2011 to 0.7 and 0.3 above normal in 2014, respectively, a significant decrease in the past three years.
- A composite climate index for the NL region decreased to the 11th lowest in 65 years the lowest since 1994 and the first negative index since 1995.

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