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Newfoundland and Labrador Region

Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2015

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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 2015 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 Northwest Atlantic, remained in a positive phase in 2015, reaching a record high resulting in a 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 winter 2014 with the first positive anomaly (higher-than-normal extent) observed in 16 years and in 2015 the total extent was about normal except for March and April when it was above normal. Annual sea-surface temperatures (SST) based on infrared satellite imagery across the Newfoundland and Labrador (NL) Shelves ranged from near-normal to below normal in some areas. The cold-intermediate layer (CIL; volume of <0°C) in 2015 was at its highest level on record (since 1970) on the Grand Bank during the spring. The annual bottom (176 m) water temperature at the inshore monitoring station (Station 27) was below normal in 2015 by -0.7 standard deviations (SD), a significant decrease from the record high in 2011. Spring bottom temperatures in 3Ps remained above normal by about 0.5°C (0.8 SD) and were about normal on the Grand Banks. Fall bottom temperatures in 2J, 3K and 3LNO decreased from 2, 2.7, and 1.8 SD above normal in 2011 to 0.2 and 0.8 SD above normal in 2J and 3K and to -0.4 SD below normal in 3LNO in 2015, a significant decrease in the past four years. A standardized climate index derived from 28 meteorological, ice and ocean temperature and salinity time series declined for the 4th consecutive year, reaching the 7th lowest in 66 years and the lowest value since 1993.

Évaluation de l’environnement océanographique physique sur la plateforme continentale de Terre-Neuve-et-Labrador en 2015

RÉSUMÉ

Un aperçu des conditions océanographiques physiques dans la région de Terre-Neuve-et-Labrador en 2015 est présenté dans le cadre du Programme de monitorage de la zone Atlantique (PMZA). L'indice d'oscillation nord-atlantique, un indicateur de la direction et de l'intensité des patrons de vents dominants au-dessus de l'Atlantique Nord, est demeurée en 2015 dans la phase positive et a atteint un record de série, résultant en 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 avait grandement augmenté au cours de l'hiver 2014 avec la première anomalie positive (étendue plus grande que la normale) observée depuis 16 ans. En 2015, l’étendue de glace était près de la normale, excepté des mois de mars et avril durant lesquels la glace était au-dessus de la normale. Les moyennes annuelles des températures de la surface, basées sur l'imagerie satellitaire infrarouge, étaient généralement près de la normale, mais sous la normale à quelques endroits. La couche intermédiaire froide (CIF; volume avec température inférieure à 0°C) était à son plus haut niveau de la série (depuis 1970) sur les Grands Bancs au printemps, et le plus haut depuis 1991 au large de l'est de Terre-Neuve en été. En 2015, la température de l'eau près du fond (176 m) à la station de monitorage (station 27) était sous la normale de - 0,7 écart-type, une diminution importante par rapport à un niveau record enregistré en 2011.Les températures au fond au printemps dans la sous-division 3Ps étaient au-dessus de la normale d’approximativement + 0,5°C (+ 0,8 écart-type) et étaient près de la normale sur les Grands Bancs. Les températures au fond à l'automne dans les divisions 2J et 3K et 3LNO ont diminué; elles sont passées d'anomalies de + 2, + 2,7 et + 1,8 écart-type au-dessus de la normale en 2011 à des anomalies de + 0,2, + 0,8 et – 0,4 écart-type en 2015, respectivement, ce qui représente une diminution importante au cours des quatre dernières années. Un indice climatique normalisé dérivé de 28 séries chronologiques pour la météorologie, la glace, la salinité et la température océanique a diminué pour la quatrième année consécutive pour atteindre le septième plus bas niveau en 66 ans, le plus bas niveau depuis 1993.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Figure 1) during 2015 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. 2016; Hebert et al. 2016[1]). 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 2015 is derived from four 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);
3. oceanographic observations made during spring and fall multi-species resource assessment surveys (Figure 2); and
4. SST data based on infrared satellite imagery of the Northwest Atlantic.

Historical data from other research surveys and ships of opportunity were also used to help define the long-term mean conditions.

These data are available from archives at the Ocean Science Branch (OSB) of Fisheries and Oceans Canada 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 2014 was presented in Colbourne et al. (2015).

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 2015. 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 two for example indicates that the index was two standard deviations (SD) 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 2015 are presented in coloured boxes as figures with gradations of 0.5 SD. Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions (Figure 3). 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.

[1] Hebert, D., R. Pettipas, D, Brickman and M. Dever. (2016) Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2015. DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

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 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).

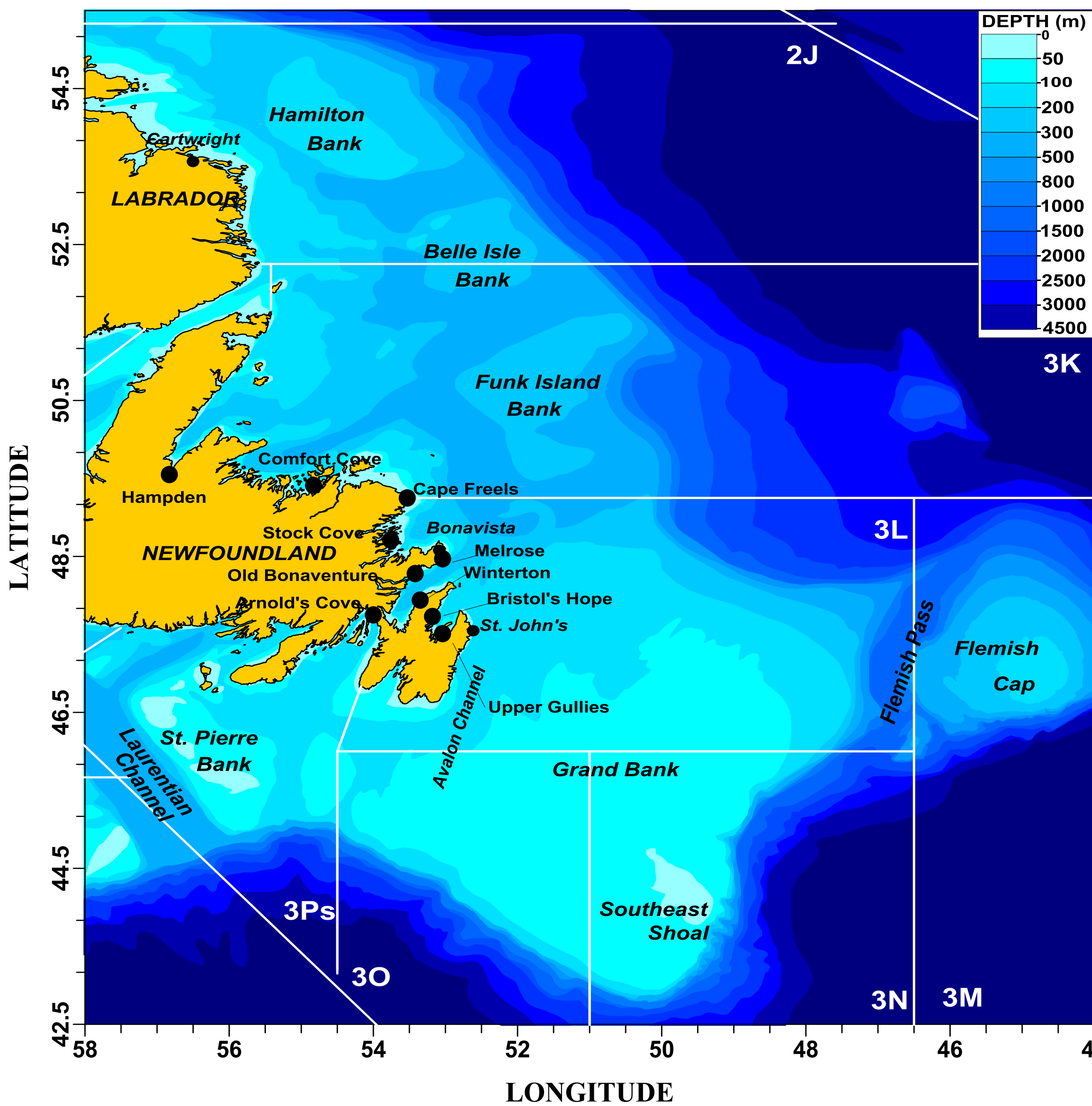

Figure 1. Map showing NAFO Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

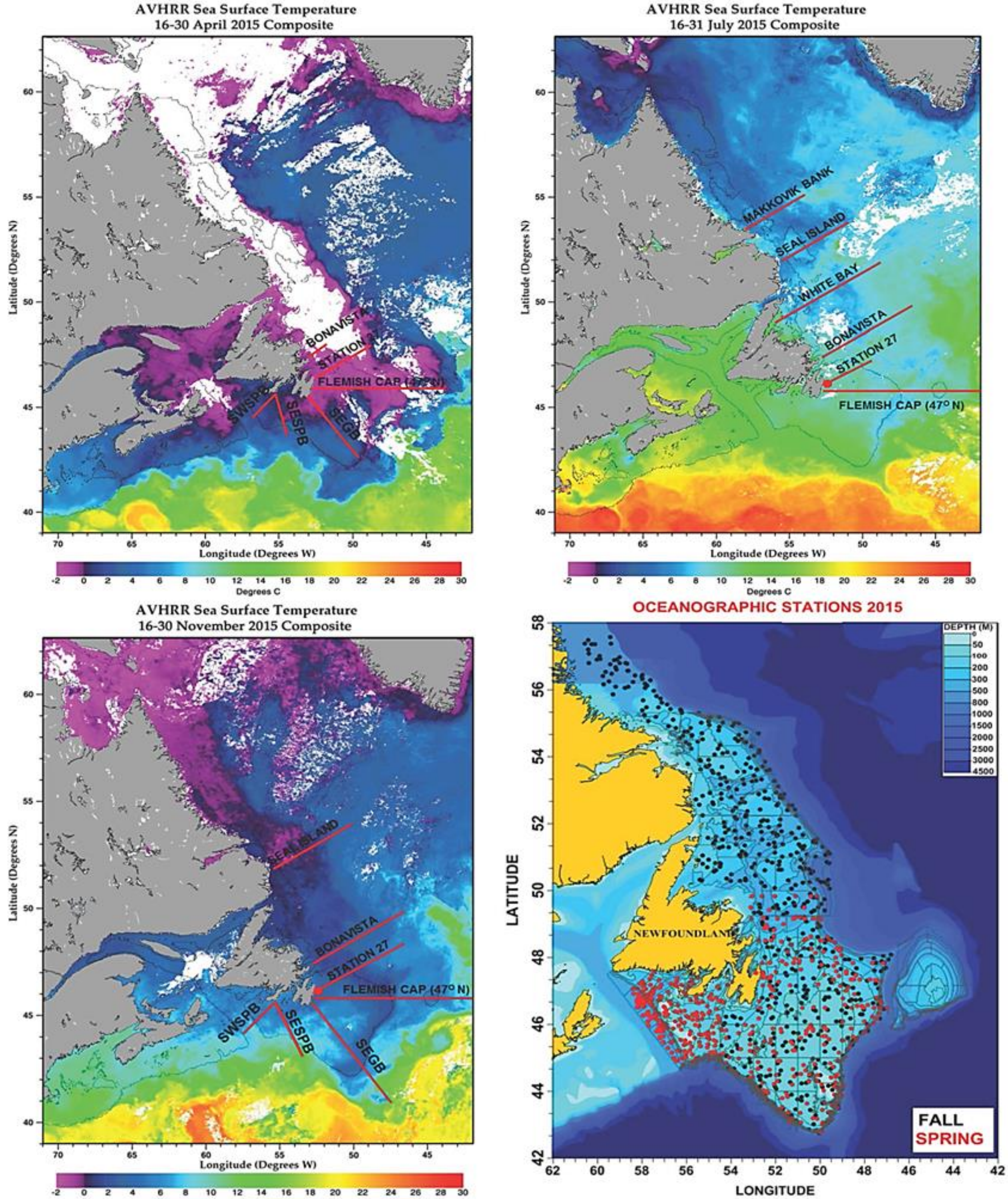

Figure 2. Map showing spring, summer and fall AZMP section occupations along with Sea-Surface-Temperature (SST) during 2015. The lower right panel shows the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2015. (SST map courtesy of the Marine Ecosystem Section, BIO).

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 over the 2014 value to 2 SD above normal, the highest in the 120 year record. In 2010 it was at a record low of 2.9 SD below normal. The similar, but larger scale Arctic Oscillation also increased over the 2014 values to +0.6 SD. As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2015 increased over the previous year causing a significant decrease in winter air temperatures over much of the Newfoundland and Labrador region and adjacent shelves (Figure 4).

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 4 in as standardized values and in Figure 5 as monthly anomalies. The air temperature data, where available, are from the second generation of the Adjusted and Homogenized Canadian Climate Data (AHCCD), which accounts for shifts in the location of stations and changes in observing methods (Vincent et al. 2012).

Annual values in 2015 decreased over the previous year with all sites reporting below normal values ranging from -0.5 to -1.3 SD. The predominance of warmer-than-normal annual and seasonal air temperatures at all sites from the mid-1990s to 2013 is evident, with the exception of 2008. There was a significant increase at all sites in 2010 with air temperatures at Cartwright on the mid-Labrador Coast and at Iqaluit on southern Baffin Island reaching 2.5 and 2.7 SD above normal, setting 77 and 65 year records, respectively. The cumulative annual air temperature index for the five sites was below normal in 2015 reaching the lowest value since 1993 (Figure 6).

Data on the spatial extent and concentration of sea ice are available from the daily ice charts published by the Canadian Ice Service of Environment Canada. The annual average sea-ice extent (defined by 1/10 coverage) on the NL Shelf (between 45°-55°N) derived from these charts show slightly above normal sea ice extent in 2014, the first time in 19 years and about normal in 2015 (Figure 4). In 2011 sea ice extent decreased to 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. (2016[1]).

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 1,165 (0.6 SD above normal) icebergs drifted south of 48°N onto the Northern Grand Bank during 2015, the 12th 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 485 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 (increased melting from wave action) and warmer than normal ocean temperatures on the NL Shelf.

A composite index derived from the meteorological and sea-ice data presented in Figure 4 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 with a significant decline during the past four years with 2015 showing below normal conditions similar to 1994 (Figure 7).

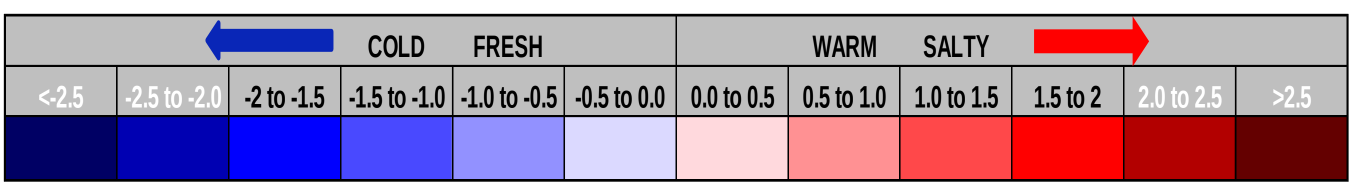

Figure 3. Standardized anomaly colour coding scale in units of 0.5 standard deviations.

LOCATION/INDEX	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
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
(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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

LOCATION/INDEX	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	MEAN	SD
ARCTIC OSCILLATION (AO)	-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	0.6	N/A	N/A
(ICELAND-AZORES) NAO	-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	2.0	20.44	8.77
NA SST (AMO)	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	0.1	N/A	N/A
NUUK WINTER AIR T	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	-0.9	-8.41	3.16
IQALUIT WINTER AIR T	-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	-1.3	-25.68	3.05
CARTWRIGHT WINTER AIR T	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	-1.7	-12.13	2.56
BONAVISTA WINTER AIR T	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	-0.5	-3.96	1.47
ST. JOHN'S WINTER AIR T	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	-0.6	-4.00	1.43
NUUK ANNUAL AIR T	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	-1.0	-1.37	1.53
IQALUIT ANNUAL AIR T	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	-1.3	-9.07	1.76
CARTWRIGHT ANNUAL AIR T	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	-1.2	0.05	1.32
BONAVISTA ANNUAL AIR T	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	-0.5	4.71	0.89
ST. JOHN'S ANNUAL AIR T	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	-1.0	5.03	0.84
NL SEA-ICE EXTENT (Annual)	-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	-0.1	74179	33578
NL SEA-ICE EXTENT (Winter)	-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	0.0	196477	81320
NL SEA-ICE EXTENT (Spring)	-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	-0.1	92547	52253
ICEBERG COUNT	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	0.6	767	649

Figure 4. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1980 to 2015.

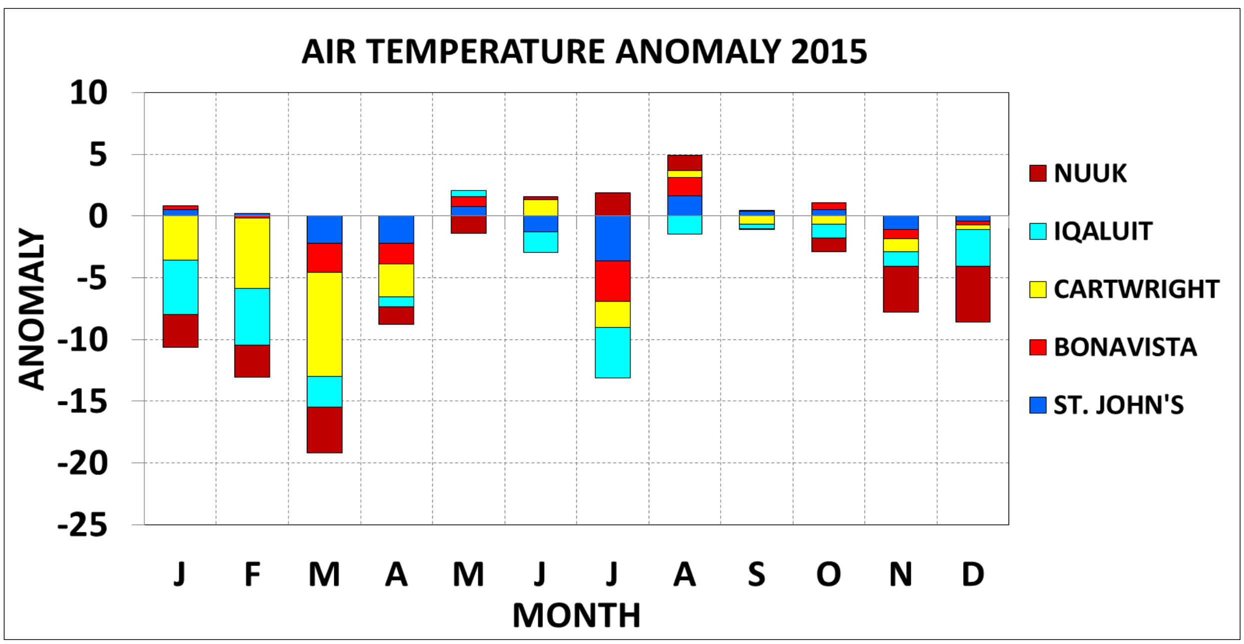

Figure 5. Standardized monthly air temperature anomalies for 2015 at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

The 4 km resolution Pathfinder 5.2 monthly 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 November 1981 to 2012. Updated values were taken from NOAA and EUMETSAT satellite data provided by the remote sensing group in the Marine Ecosystem Section at BIO. A least squares fit of the Pathfinder and

NOAA temperatures during the period 2001-2010 is given by SST (Pathfinder) = 0.989*SST (NOAA) - 0.02 with an r^2=0.98 (Hebert et al. 2012). The 2011-15 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. The NOAA data were available as bi-weekly values which were averaged to produce the monthly mean. The monthly anomalies were then computed from the 1982-2010 monthly climatology. Annual anomalies were then computed and standardized by the standard deviation of the annual anomalies over the same base period. Data were not available for every month in some of the northern areas due to sea ice cover.

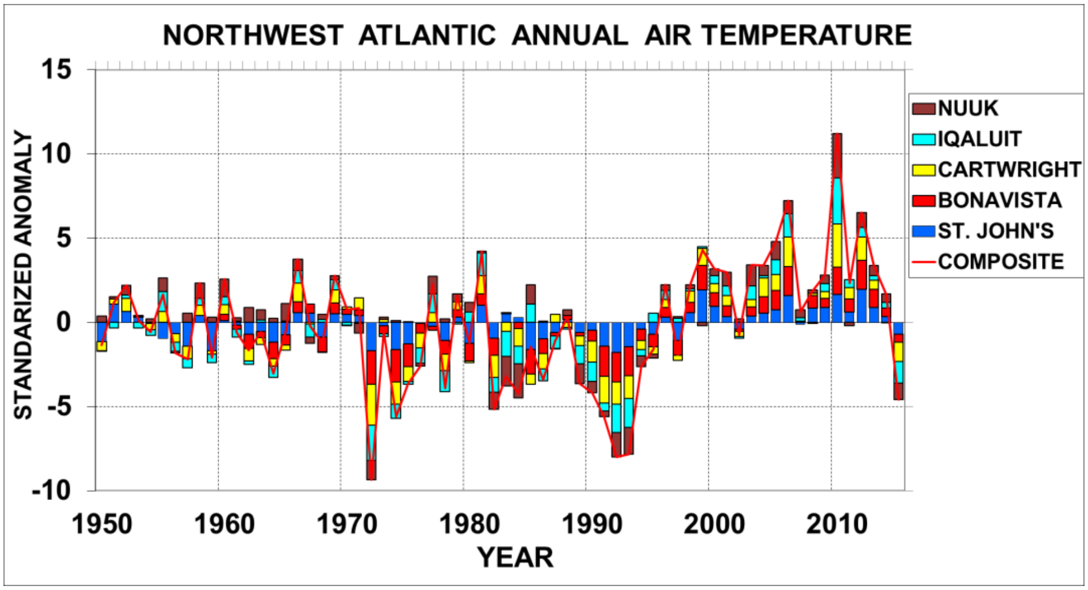

Figure 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

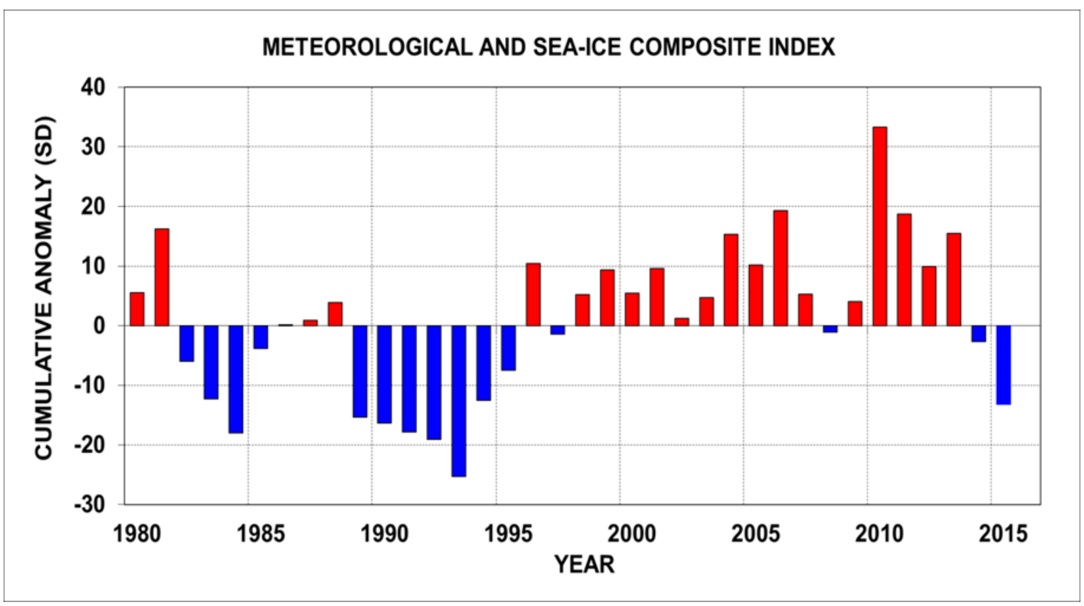

Figure 7. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 4.

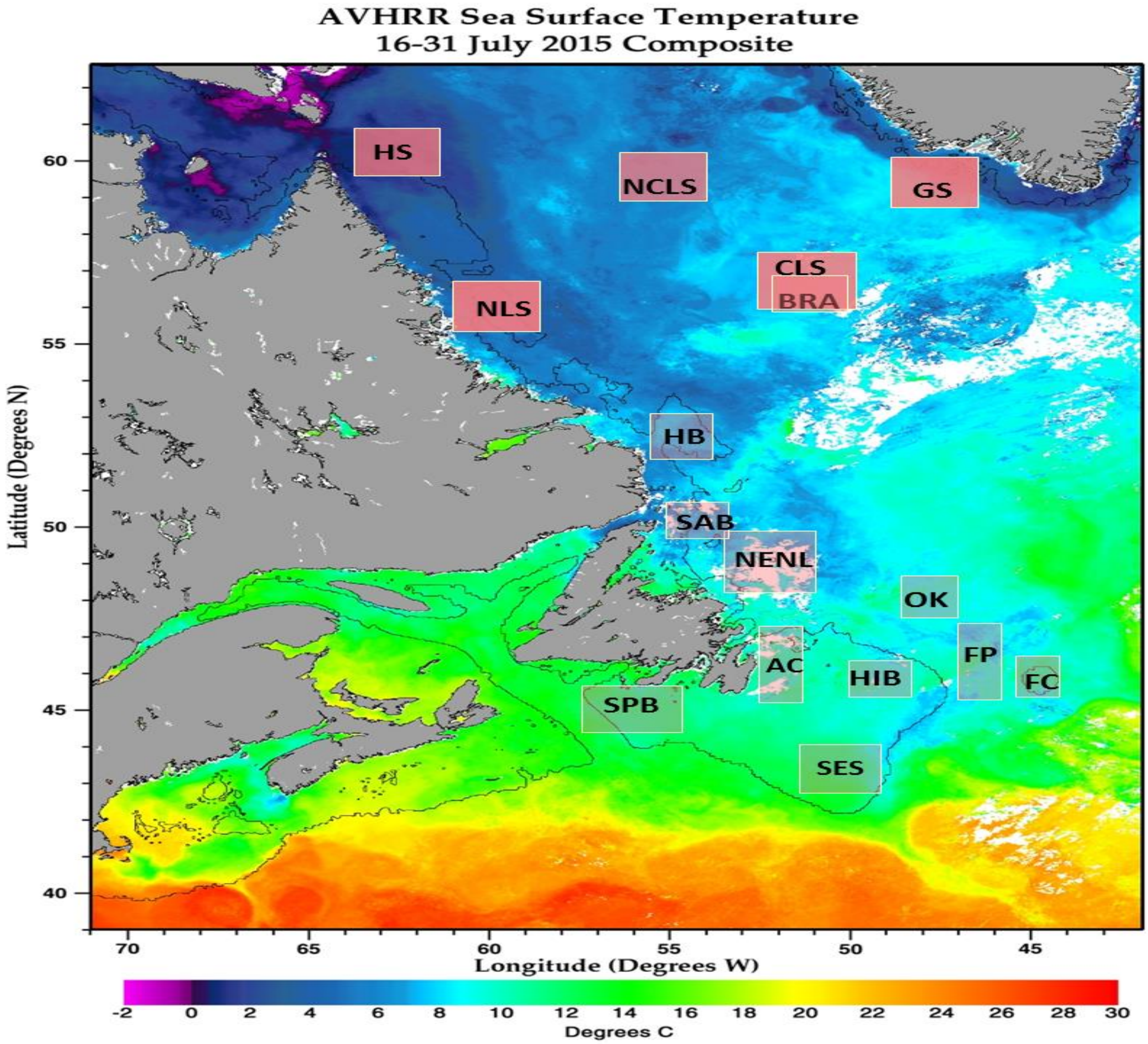

Figure 8. Map showing the subareas where SST time series were constructed for the Northwest Atlantic. (SST map courtesy of the Marine Ecosystem Section, BIO).

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 Figure 10 as monthly anomalies and in Figure 11 as standardized annual values. Most areas had below normal monthly values that reached a minimum in July when SSTs reached 2-3 SD below normal. Annual values were either near-normal or below normal in most areas during 2015. The most significant annual anomalies occurred offshore in the Flemish Pass, Flemish Cap and Orphan Knoll areas where they were as low as -1.6 SD below normal. These values represent a significant decrease over recent record highs set in 2010 in some of the southern regions.

A composite index together with individual series shows an increasing trend in SSTs since the early part of the time series with near-decadal oscillations superimposed (Figure 12). Overall 2012 was the 2nd highest in the series after 2006 and the five warmest years in the series have occurred in the past decade. Since 2012 however, the composite index show a significant decreasing trend with the 2015 value the coldest since 1993.

REGION	J	F	M	A	M	J	J	A	S	O	N	D
WEST GREENLAND SHELF (GS)	-0.3	-0.7	-0.7	0.0	-1.1	-0.5	0.3	-0.3	-0.5	-0.1	-0.5	-0.3
NORTH CENTRAL LAB SEA (NCLS)	-0.8	-0.1	-1.1	-1.8	-2.0	-1.5	-0.8	0.3	0.3	-0.7	-1.6	-1.5
CENTRAL LAB SEA (CLS)	-0.2	0.1	0.0	-0.3	0.0	0.1	0.7	0.6	0.0	0.1	-0.9	-1.8
BRAVO (BRA)	0.2	0.0	0.3	-0.1	0.2	0.3	0.8	0.5	-0.1	0.0	-0.8	-1.8
HUDSON STRAIT (HS)	0.9	-0.3	-0.1	-0.4	-0.7	-0.2	-1.0	-0.5	-0.1	0.0	-0.2	-0.7
NORTHERN LAB SHELF (NLS)	-0.3	1.8	0.0	-0.1	-0.3	0.2	-0.8	-0.4	0.1	0.5	0.1	-0.4
HAMILTON BANK (HB)	-0.4	-0.2	-0.4	-0.4	-0.3	0.6	0.6	0.7	-0.4	0.6	-0.4	-0.1
ST ANTHONY BASIN (SAB)	-0.6	-0.6	0.1	-0.7	-0.1	0.5	-0.9	-0.6	-1.2	-0.5	-0.1	-0.3
NE NF SHELF (NENS)	-0.2	-0.4	-0.4	-0.9	-1.1	-0.6	-1.2	-0.6	-0.3	0.0	-0.3	-0.2
ORPHAN KNOLL (OK)	0.3	-0.5	-1.0	-1.8	-1.3	-1.6	-2.0	-1.5	-0.6	0.6	-0.2	-0.5
FLEMISH CAP (FCAP)	0.8	0.1	-1.4	-2.7	-2.9	-2.8	-3.5	-1.6	-0.8	0.2	-1.6	-1.2
FLEMISH PASS (FP)	0.4	-0.7	-1.4	-2.4	-2.3	-2.5	-2.8	-0.9	-0.1	0.4	-0.9	-0.7
SE SHOAL (SES)	1.5	2.1	1.1	0.0	-0.5	-0.7	-3.2	-1.7	0.7	0.6	-0.6	-0.4
HIBERNIA (HIB)	2.5	1.8	0.6	-0.6	-0.5	-0.6	-2.4	-1.5	0.2	1.0	-0.9	-0.1
AVALON CHANNEL (AC)	1.3	0.3	-0.5	-1.1	-0.7	-0.6	-1.7	-0.7	0.9	1.1	0.3	1.0
GREEN-ST PIERRE BANK (SPB)	0.9	1.3	0.2	-0.5	-0.7	-1.2	-2.3	-1.2	1.5	1.7	0.5	1.2

Figure 9. Monthly SST anomalies derived from the data within the boxes shown in Figure 8. The anomalies are referenced to the 1981-2010 base period.

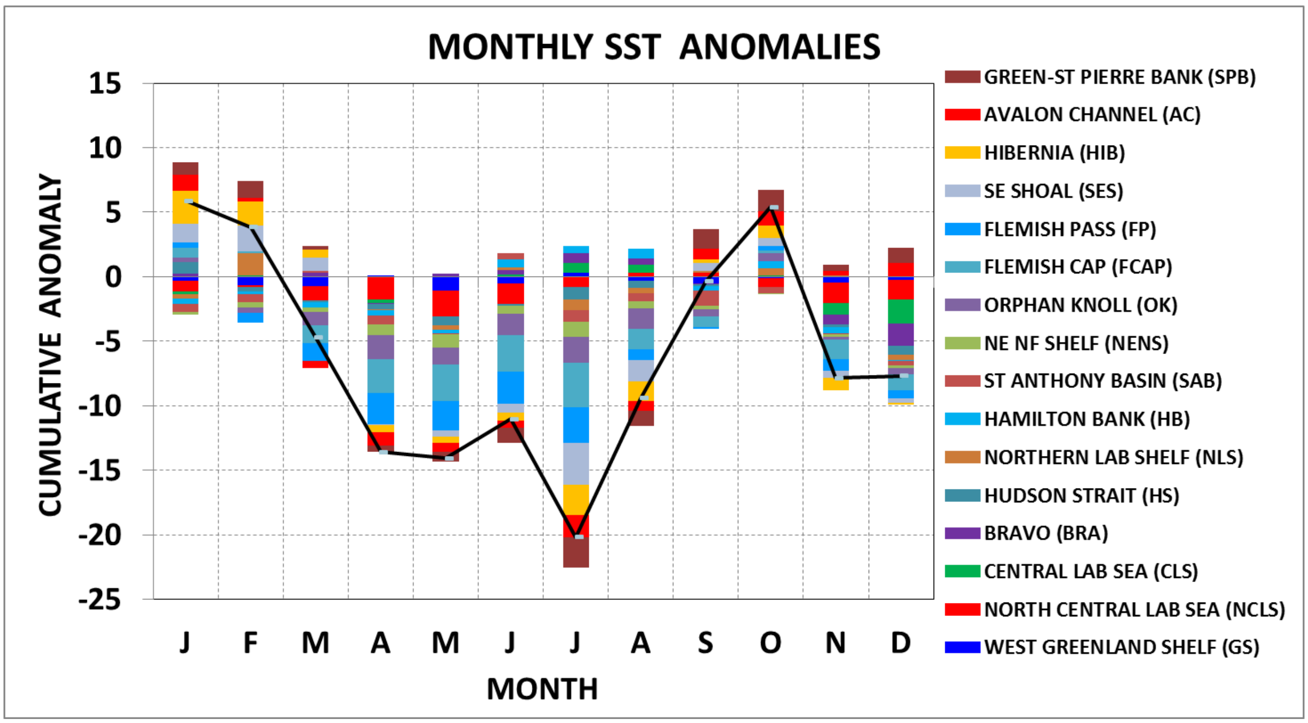

Figure 10. Cumulative SST anomalies for 2015 derived from the data within the boxes shown in Figure 8 and displayed in Figure 9. The anomalies are referenced to the 1981-2010 base period.

REGION	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	15	MEAN	SD
WEST GREENLAND SHELF (GS)			-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	-0.5	6.16	0.79
NORTH CENTRAL LAB SEA (NCLS)			-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	-0.8	2.85	1.16
CENTRAL LAB SEA (CLS)			-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	-0.1	4.26	0.85
BRAVO (BRA)			-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	0.0	4.33	0.79
HUDSON STRAIT (HS)			-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	-0.7	-0.17	0.36
NORTHERN LAB SHELF (NLS)			-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	0.1	0.46	0.48
HAMILTON BANK (HB)			-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	0.0	1.44	0.51
ST ANTHONY BASIN (SAB)			-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	-0.7	2.61	0.58
NE NF SHELF (NENS)			-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	-0.8	3.49	0.61
ORPHAN KNOLL (OK)			-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	-1.1	6.15	0.78
FLEMISH CAP (FCAP)			-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	-1.6	7.20	0.91
FLEMISH PASS (FP)			-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	-1.4	5.76	0.81
SE SHOAL (SES)			-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	-0.1	7.42	0.98
HIBERNIA (HIB)			-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	0.0	5.79	0.84
AVALON CHANNEL (AC)			-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	-0.1	5.01	0.69
GREEN-ST PIERRE BANK (SPB)			-0.4	1.0	0.4	-2.1	-1.2	-0.1	-0.2	-0.4	-0.8	-1.3	-1.1	-0.4	1.1	-1.0	0.0	-1.2	0.7	1.5	1.2	0.1	-0.6	0.3	0.4	1.4	1.3	-0.5	0.7	0.4	0.9	0.1	2.1	1.1	0.6	0.2	6.16	0.75

Figure 11. 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.

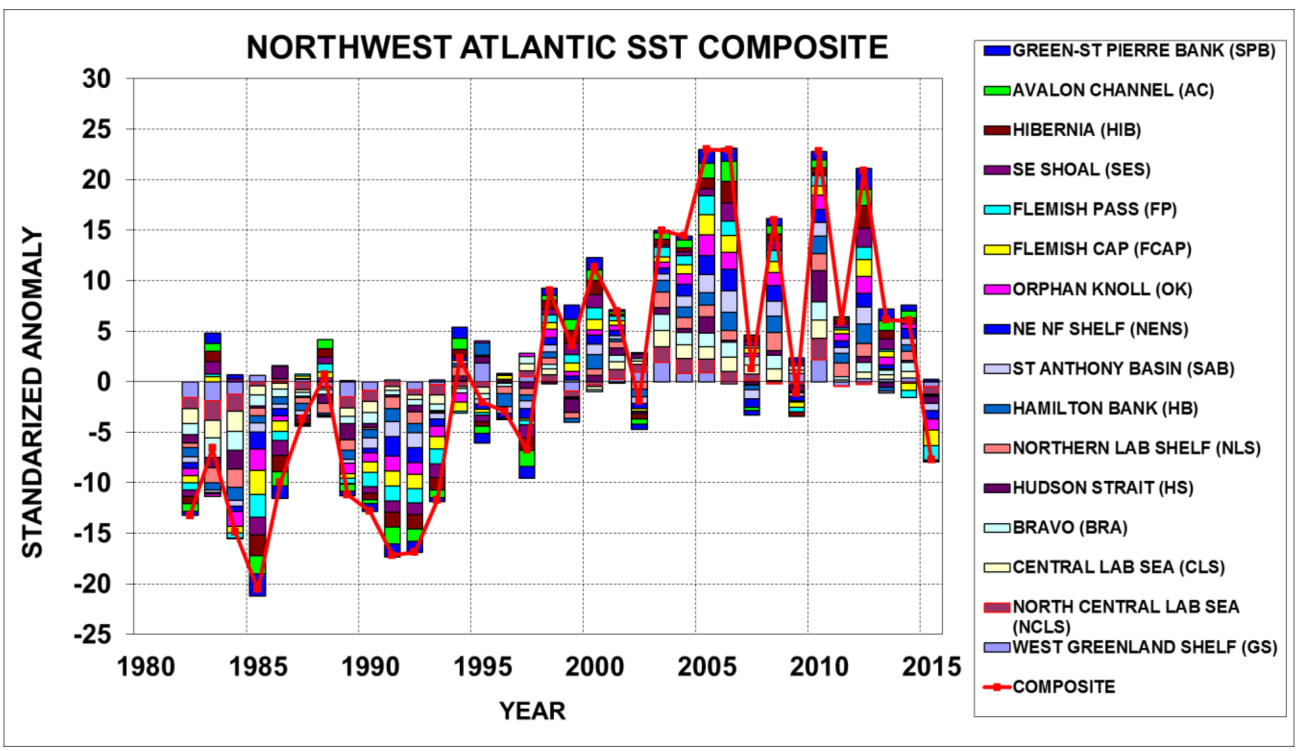

Figure 12. Standardized annual SST anomalies from the subareas on the NL shelf presented in Figure 8. The solid red line represents the composite sum.

TRENDS IN TEMPERATURE AND SALINITY

Long-Term Inshore Temperature Monitoring

Temperature data obtained from thermographs deployed at 10 inshore monitoring sites during the May to October (July-Sept.) along the coast of Newfoundland (see Figure 1 for locations) at nominal water depths of 10 and 15 m are shown in Figure 13 as monthly anomalies, in Figure 14 as standardized annual anomalies and repeated in Figure 15 as cumulative annual sums. Note that some sites are missing data, particularly before 1998; hence the composite plot (Figure 15) only included data from 1998 onwards.

The data from individual sites show considerable monthly and inter-annual variability, due largely to highly variable local wind driven effects near the coast including upwelling and local summer air temperatures. The monthly variability is reasonably coherent among different sites with some exceptions. In 2015, monthly anomalies ranged from near-normal to above normal, with July being the warmest month. The most significant negative anomalies occurred in August when values reached more than 5°C below normal on the northeast coast at Comfort Cove (Figure 13).

LOCATION	MAY	JUNE	JULY	AUG	SEPT	OCT
HAMPDEN (10 m)		1.6	2.7	-2.8	2.1	0.3
COMFORT COVE (10 m)	-0.7	-0.6	-1.5	-5.3	-1.8	0.3
CAPE FREELS (15 m)		1.0	-0.6	-1.9	-1.0	0.5
STOCK COVE		1.9	2.6	0.3	0.0	0.6
MELROSE (15 m)		1.2	1.1	-1.1	-0.4	0.9
OLD BONAVENTURE (10 m)		2.4	2.7	-0.2	0.4	0.0
WINTERTON (10 m)	0.3	-0.8	-0.4	0.6	-0.4	-0.1
BRISTOL'S HOPE (10 m)	-0.7	0.3	1.4	0.2	0.7	0.3
UPPER GULLIES (10 m)	-0.6	0.1	0.7	2.0	0.5	1.0
ARNOLDS COVE (10 m)	2.4	1.1	-1.7	-0.7	0.6	2.5

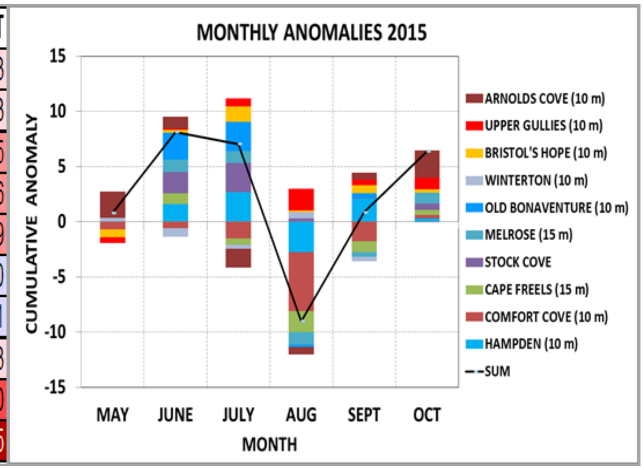

Figure 13. Monthly temperature anomalies displayed as color coded values (in °C, left panel) and as cumulative sums (right panel) from data collected with thermographs along the coast of Newfoundland (Figure 1). The anomalies are referenced to the standard base period if the data exist, otherwise over the length of the series.

Mean temperatures during the summer (July-September) generally exhibit a north to south gradient with the warmest values occurring at Arnolds Cove (13.4°C) and the coldest at Hampden on the northeast coast with a mean summer temperature of 7.9°C. Exceptions are Melrose and Old Bonaventure, two sites in Trinity Bay that are prone to strong summer upwelling (Figure 14).

Near-shore temperatures trends (Figure 15) indicate below normal during most of the 1990s but increased to above normal conditions in 1999 that continued for several years, peaking in 2006 when all sites were either normal or above normal. In 2007, there was a sharp decrease with values not seen since the early 1990s with eight of nine sites reporting below normal (-0.8 to -2.3 SD) summer temperature. In 2008-2010 temperatures varied about the mean with no clear pattern. In 2011 however, eight of nine sites with data again reported below normal summer coastal temperatures with anomalies ranging from ~1-2 SD below normal. This occurred in spite of the fact that 2011 was a record warm year in most areas. The only exception was at Hampden, White Bay where temperatures were 0.7 SD above normal.

In 2012, there was an overall increase over the previous year with record highs at Hampden, White Bay (+1.4 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 2015 near-shore temperatures were below normal at three sites (Comfort Cove, Cape Freels and Arnolds Cove), normal at Melrose, Winterton and above normal at Hampden, Stock Cove Bristol's Hope and Upper Gullies.

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	2015	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	0.5	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	-1.5	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	-1.0	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	0.6	0.7	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	-0.1	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	0.6	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	-0.1	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	0.6	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	0.9	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	-0.5	13.40	1.21

Figure 14. Standardized temperature anomalies derived from data collected with thermographs along the coast of Newfoundland (Figure 1). 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.

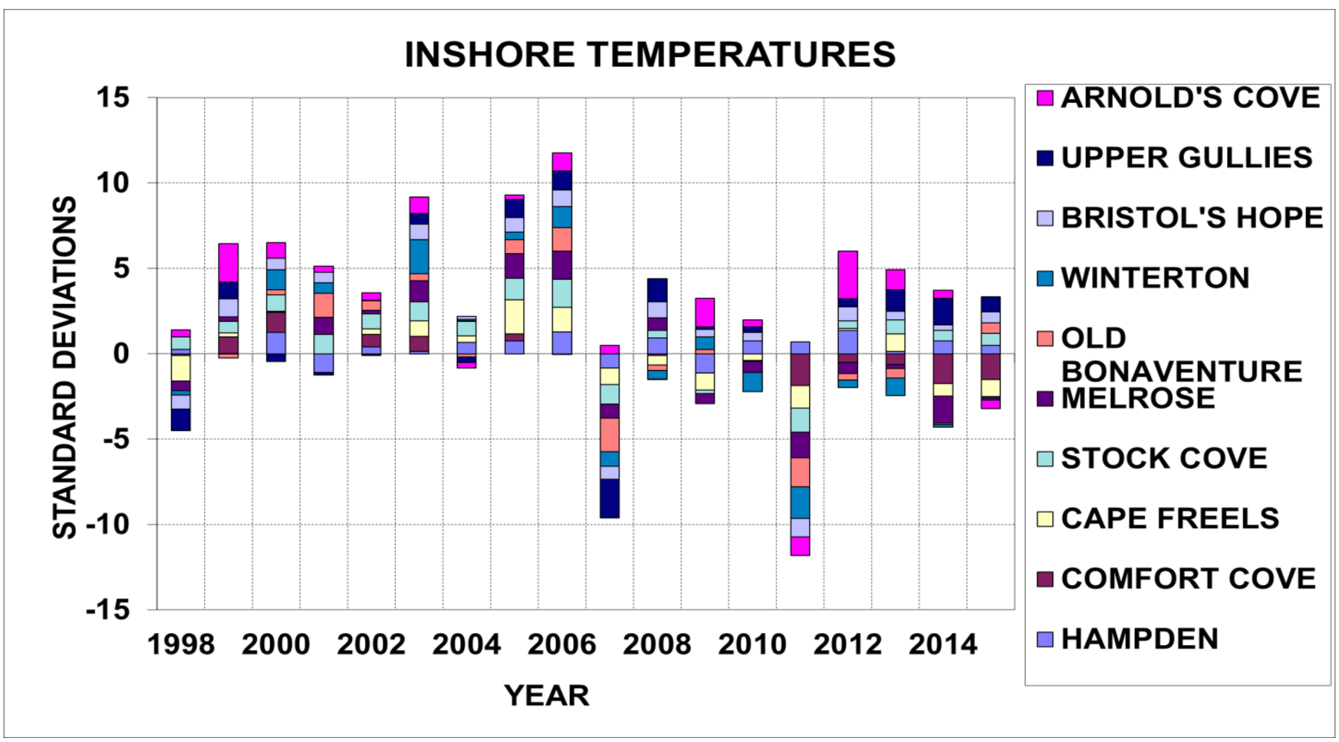

Figure 15. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland (Figure 1). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the duration of the time series.

Station 27

Station 27 (47° 32.8’ N, 52° 35.2’ W), located in the Avalon Channel off Cape Spear NL (Figure 2), was sampled 39 times (34 CTD profiles, 5 XBT profiles) during 2015. Observations were available for all months although only one profile was available in February, March, June and August. In addition Hourly T/S mooring data were available from January-July at 20, 25, 30, 40, 50, 75, 100, 125, 150, 160 and 170 m for temperature and at 20, 50, 100 and 170 m for salinity. Station 27 has been designated as the only high frequency AZMP monitoring site in the NL Region

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2015 are displayed in Figures 16 and 17. The temperature cycle includes daily averaged values from the mooring deployment at the depths mention above. The water column at Station 27 was near-isothermal ranging in temperature from -1.7° to -1.0°C during February to April. These values persisted throughout the year below 150 m as the cold intermediate layer (CIL) extended to the bottom. Upper layer temperatures warmed to >3°C by late-May and to 12°C by late-August to early September, after which the fall cooling commenced with temperatures decreasing to <4°C by late December.

Temperatures were above normal during early winter months over most of the water column and below normal during March and into April. Values were below normal throughout most of the year near in the bottom zone. Temperature anomalies varied considerably in the upper water column with a strong positive anomaly in the near-surface layer during May to early July. These strong positive anomalies penetrated deeper into the water column reaching 150 m by November. Intense negative anomalies with temperatures reaching more than 2°C below normal near the surface occurred from July into early September.

Upper layer (0-30 m) salinities (Figure 17) were <32 in January and from 32 to 32.4 from February to May then decreased to 31.2 by early August and to 31 by mid-September. Below 50 m, salinities ranged from 32.4 to >33 throughout most of the year, except for late fall when fresher water reached to >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. Salinities were below normal throughout the water column during the winter months and except for a strong positive anomaly in the upper layer during late fall and a weaker positive anomaly from May to August at roughly 50-150 m depth they were predominately below normal during the remainder of the year over most of the water column (Figure 17).

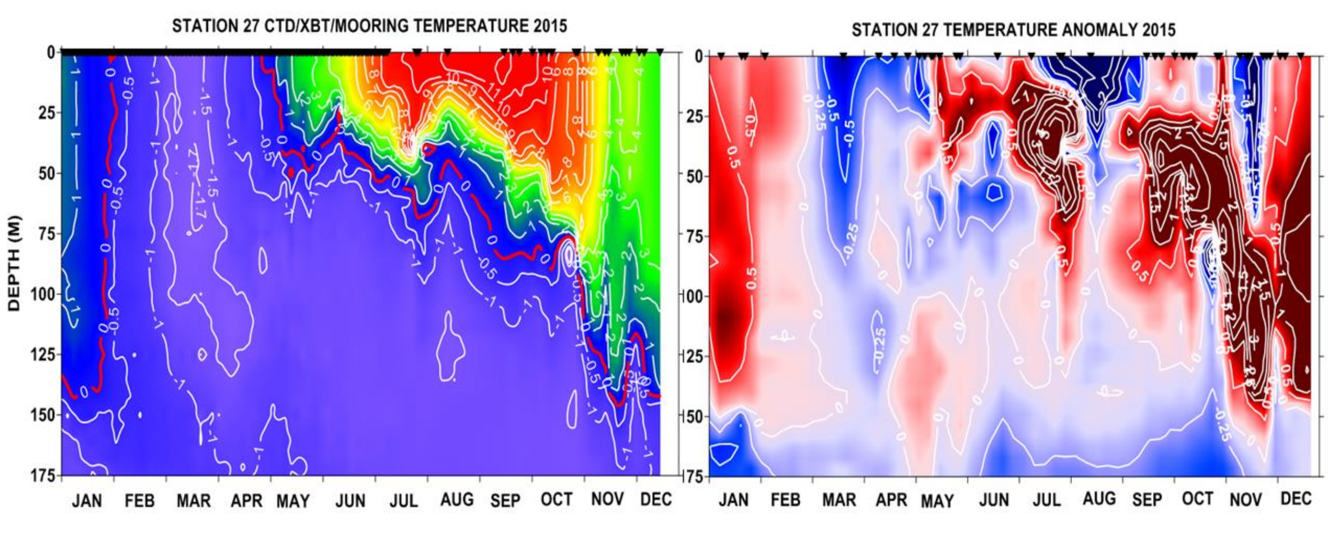

Figure 16. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2015. The symbols at the top indicate sampling times.

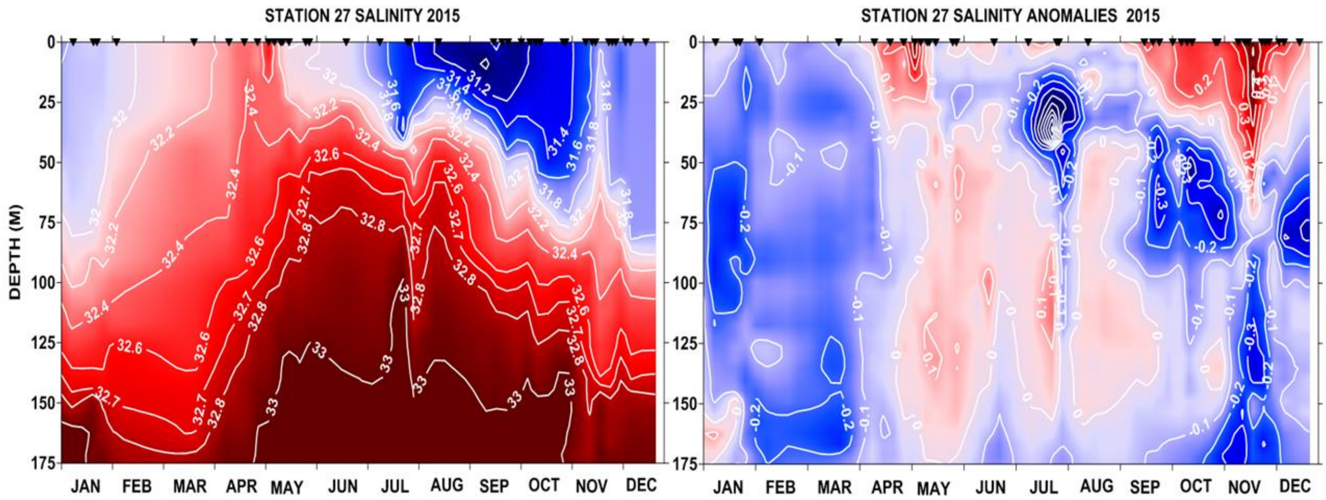

Figure 17. Contours of salinity and salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2015. The symbols at the top indicate sampling times.

The annual surface temperatures at Station 27 reached a 61-year high of +1.5°C(+2.2 SD) above their long-term mean in 2006, have been above normal since 2010 but decreased to slightly below normal in 2015 (Figure 18 and 24). 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°C) above normal and to -0.7 SD (-0.2°C) below normal in 2015, the lowest since 1995 (Figure 18 and 24). Vertically averaged temperatures (0-50 and 0-176 m), which also set record highs (0-176) in 2011 at +2.7 SD, decreased to about normal in 2014 but increased to 0.7 SD above normal in 2015 (Figure 19 and 24). Recent temperatures at Station 27 contrasted sharply to values observed from 1990 to 1997 when values were often 1-2 SD below normal (Figure 24).

The layer of cold water with temperatures <0°C on most of the NL shelf, commonly referred as the cold intermediate layer (CIL) described in a later section, extends to the surface during the winter months and in shallow areas such as the northern Grand Banks and near-shore, including at Station 27, extends to the bottom throughout the year. The vertical extent of water with temperatures <-1.0°C, <-0.5°C, <0.0°C, <0.5°C and <1.0°C are shown in Figure 20, 21 and 24. The average ±1 SD annual thickness of the Station 27 vertical extent of water with temperatures <-1.0°C, <-0.5°C, <0.0°C, <0.5°C and <1.0°C is 74 ± 32, 102 ± 25, 118 ± 18, 128 ± 11 and 135 ± 8 m, respectively.

The vertical thickness of the layer <0°C reached a remarkably low anomaly of 58 m (-4.3 SD) below normal in 2011 but increased to seven m (0.5 SD) above normal in 2014 and returned to 10 m (-0.8 SD) below normal in 2015 (Figure 21 and 24). The CIL layers defined by other temperature thresholds show similar trends that reached a minimum in 2011 and have since increased to above normal in 2014 but were either near-normal or below normal in 2015. Since the CIL intersects the bottom at Station 27, bottom temperatures are always <1.0°C and indeed only reaches above 0.0°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 slightly above normal in 2015 while bottom values were below normal and water column averaged values were close to normal in the 0-50 m range and below normal over the full water column (0-176 m). 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 22, 23 and 24).

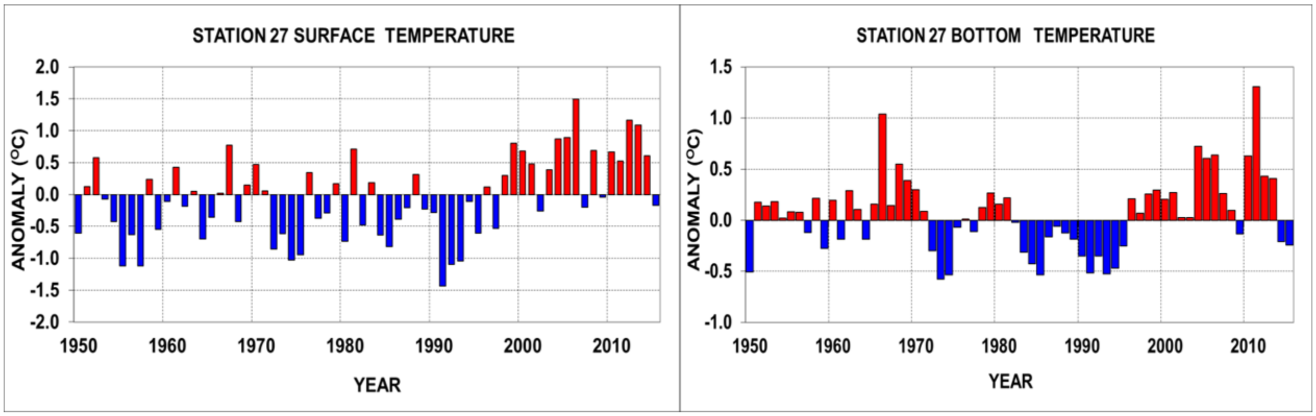

Figure 18. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

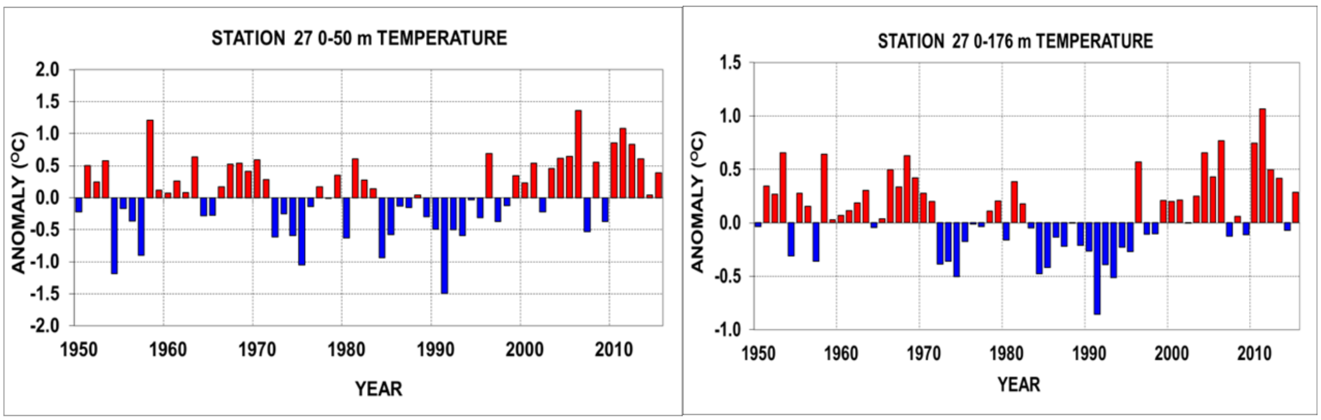

Figure 19. Annual Station 27 vertically averaged (0-50 m, 0-176 m) temperature anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

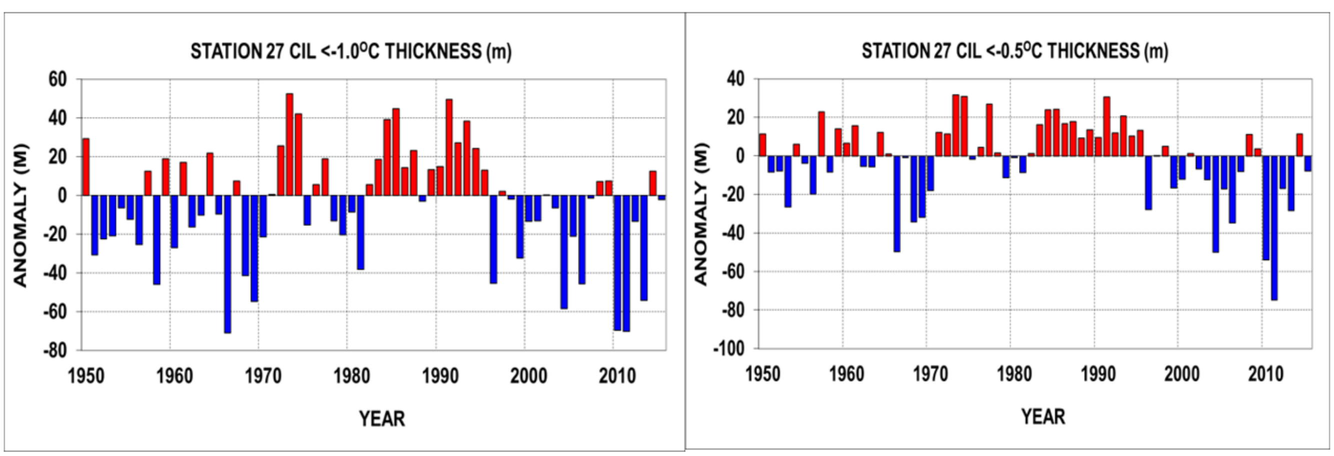

Figure 20. Annual Station 27 CIL (<-1.0°C and <-0.5°C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

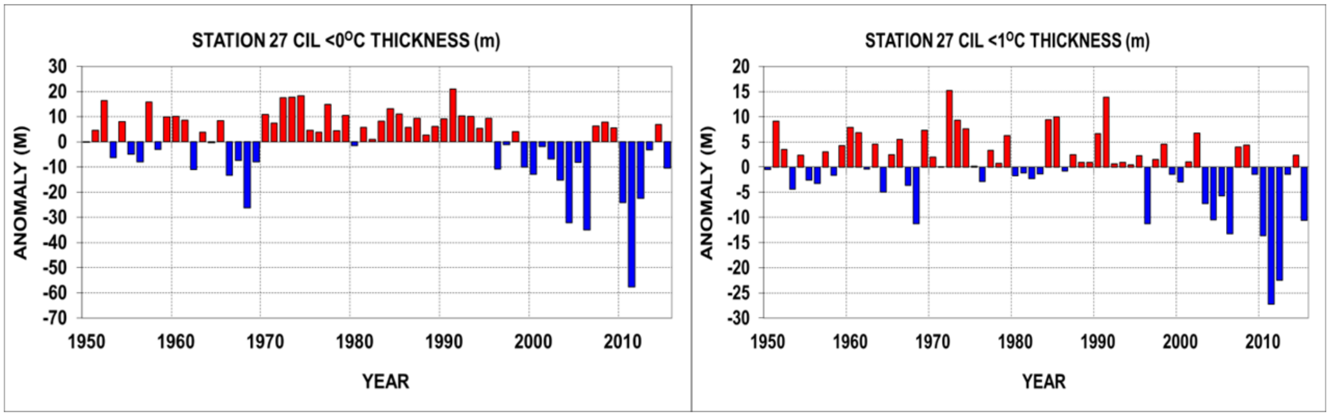

Figure 21. Annual Station 27 CIL (<0°C and <1°C) thickness anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

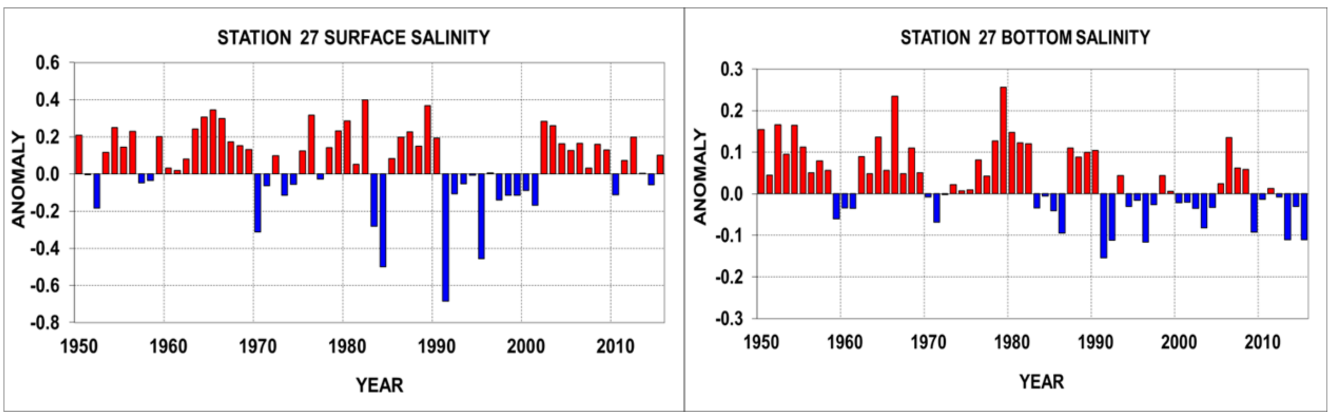

Figure 22. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

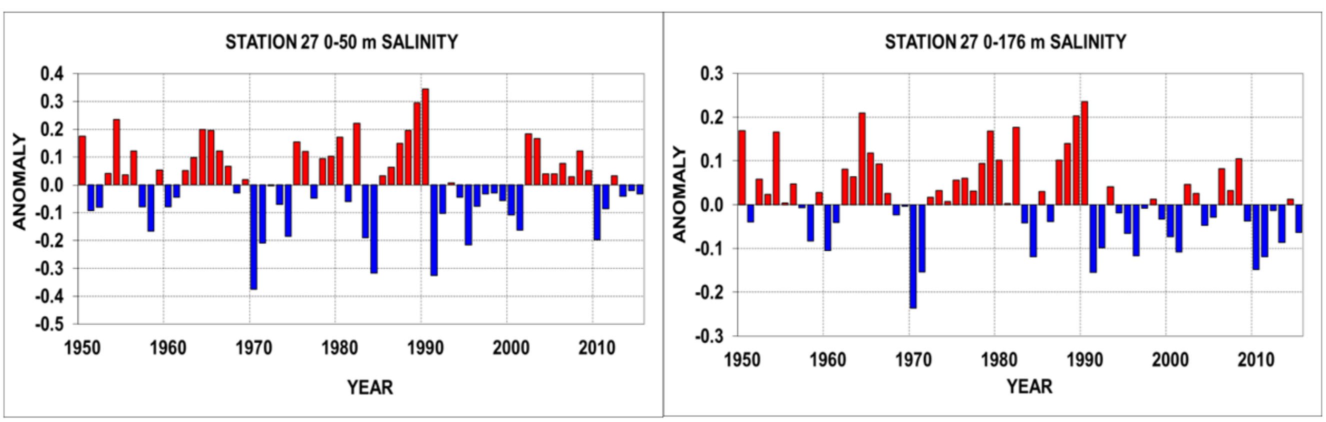

Figure 23. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean. The mean and SD are shown in Figure 24.

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	15	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	-0.2	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	-0.7	-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	0.7	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	0.7	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	-0.1	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	-0.4	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	-0.8	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	-1.0	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	-1.6	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	0.4	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	-1.4	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	-0.2	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	-0.6	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	1.4	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	1.5	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	-0.7	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	0.6	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	0.7	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	-1.6	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	-0.4	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	-0.6	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	-1.9	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	-1.0	13.85	6.45

Figure 24. Standardized temperature and salinity anomalies, CIL thickness, MLD and stratification at Station 27 from 1980 to 2015. The anomalies are normalized with respect to their standard deviations over the standard base period. Grey cells indicate no data available.

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 five 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 2015 monthly values are shown in Figure 25. On average the water column is very weakly stratified during the winter months, stratification increases during the spring (typically May or June) reaching its maximum by August then decreases to winter time values by December. In 2015, the stratification was very weak until May when it increased to near-normal values. During the summer and fall period the stratification was significantly below normal (Figure 25).

The annual averaged stratification from 1950 to 2015 at Station 27 is shown in Figure 26. The annual and seasonal values are shown in Figure 24 as standardized anomalies. The annual index was generally below the mean prior to the 1980s after which it began to increase with large fluctuations about the mean. In general, stratification on the inshore Newfoundland Shelf at Station 27 shows a long-term increasing trend from about the mid-1960s until about 2000. Since then it has been decreasing until about 2012. During the past couple of years the stratification has decreased from 1.1 SD above normal in 2014 to -1.6 SD below normal in 2015 (Figure 26).

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 high resolution data profiles available prior to 1990 to compute reliable annual means. The monthly, seasonal and annual values of the MLD are shown in Figures 24, 27 and 28.

The average monthly values range from about 120-170 m in the winter to <25 m in summer and up to 80 m by late fall (Figure 27). In 2015 winter values were deeper than normal while during the remainder of the year values were near-normal to above normal (Figure 27). In general, there appears to be a slight increasing trend since 1995 of about 0.7 m/year in the annual mean which was +1.4 SD (Figure 24) deeper than normal in 2015 (Figure 28).

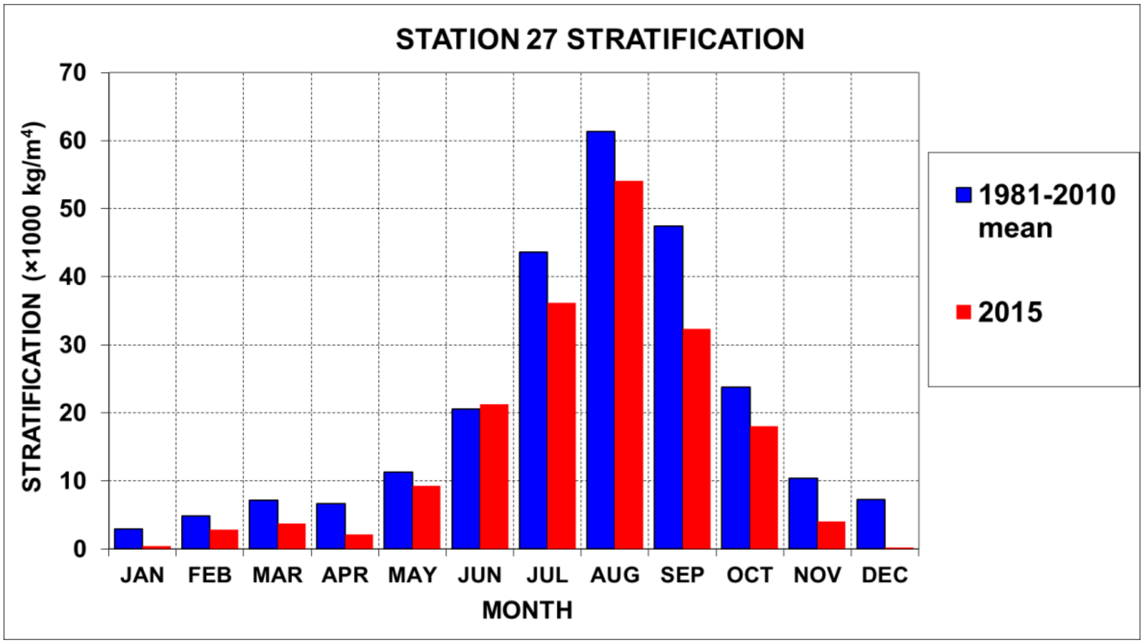

Figure 25. The 1981-2010 monthly average and the 2015 monthly average stratification values at Station 27.

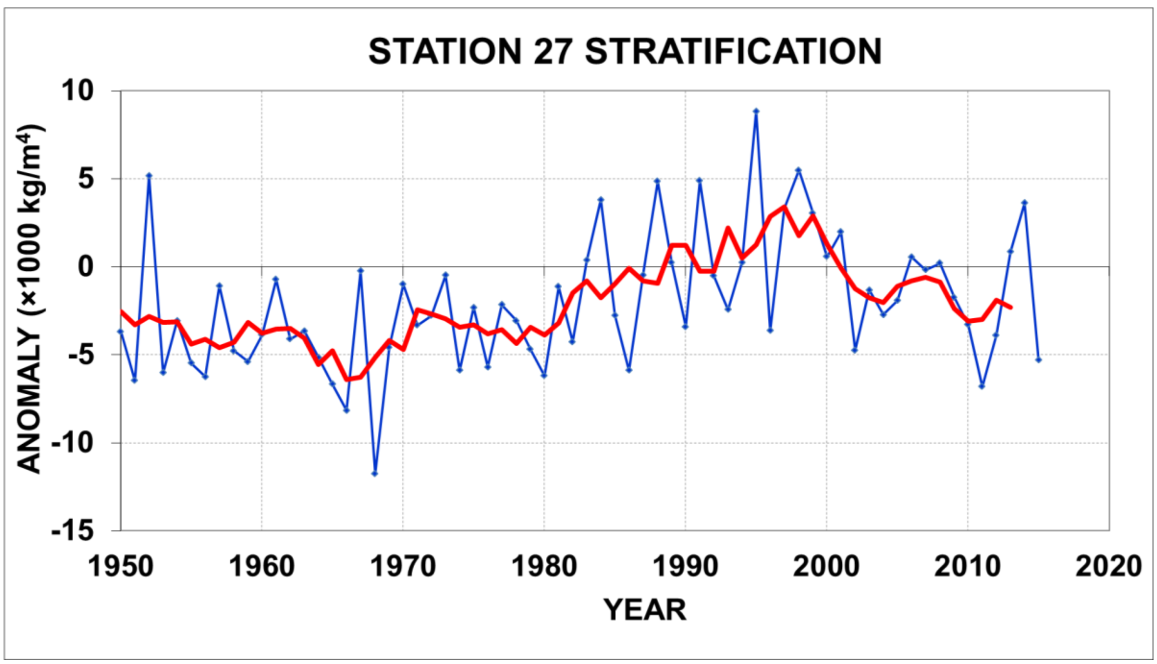

Figure 26. Annual stratification index anomalies at Station 27 referenced to the 198--2010 mean. The red line is a 5-year running mean.

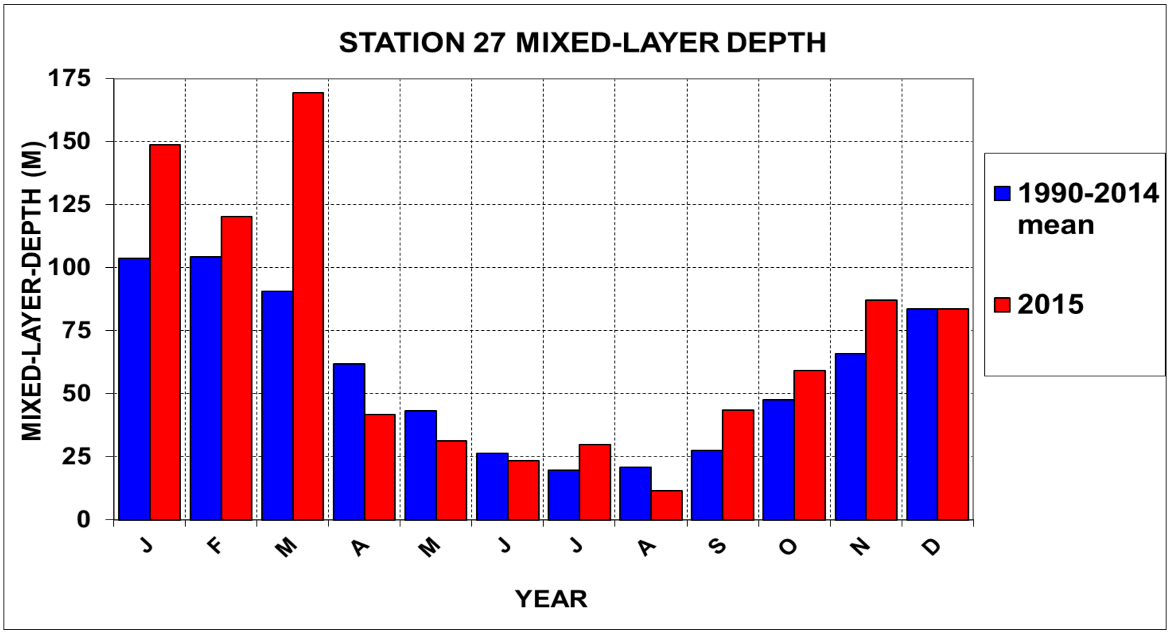

Figure 27. The 1990-2010 average and the 2015 monthly mean Mixed Layer Depths at Station 27.

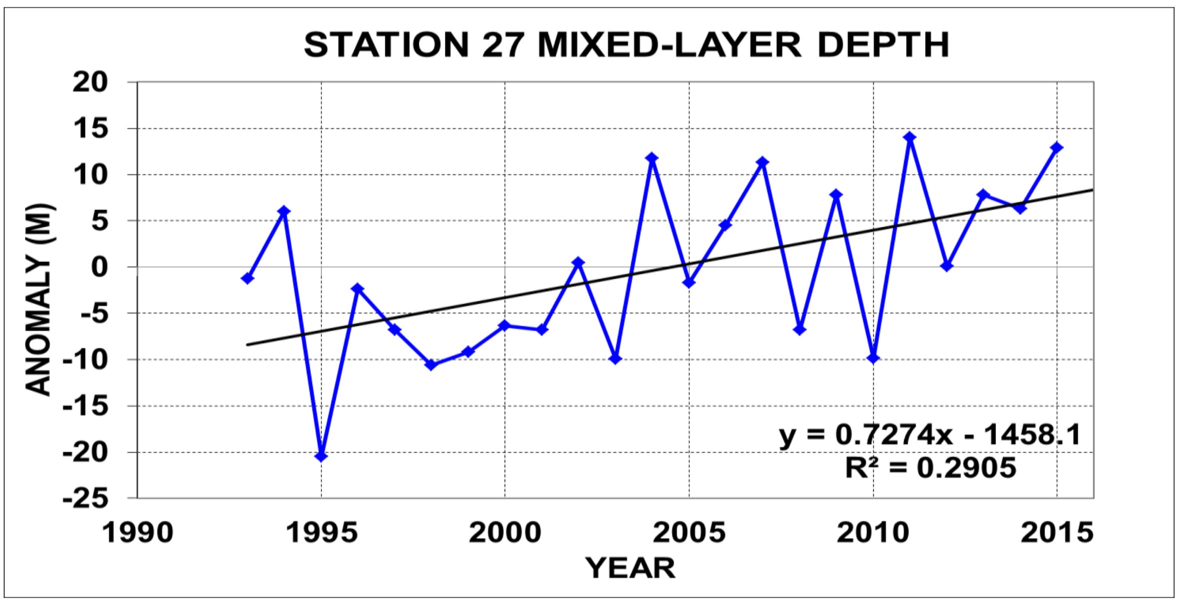

Figure 28. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2015 mean.

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 29) and 40 on the Newfoundland Shelf (Figure 32).

Bottom of the temperature profiles were selected as near-bottom values if it was within 20% of the water depth at the location, otherwise rejected. The selected 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 three 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.

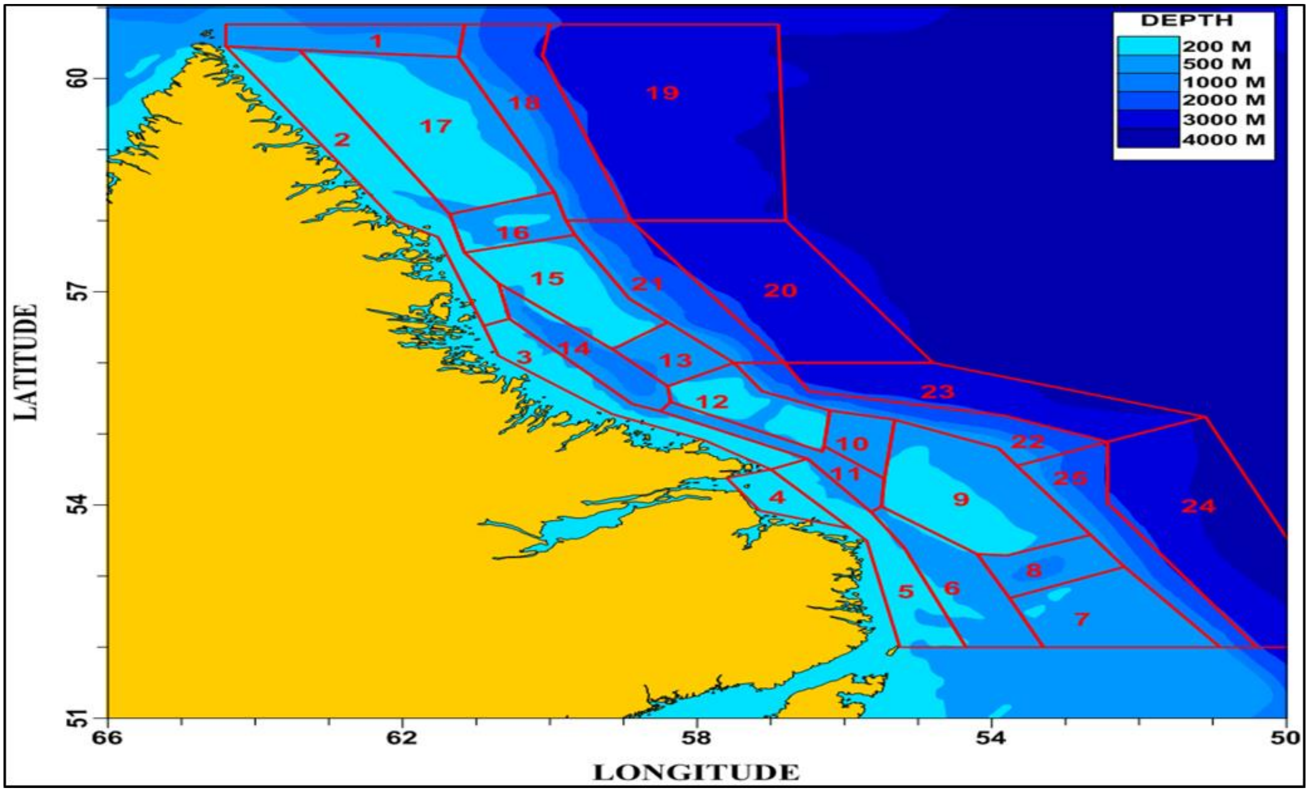

Figure 29. Areas on the Labrador Shelf where bottom temperatures were analyzed. The numbers within each area correspond to the areas listed below in Figure 30.

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 30 and repeated in Figure 31 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 2015, 14 out of the 21 areas with sufficient data reported near-normal (anomalies within ±0.5 SD) values compared to 2011 when 19 out of 21 areas had temperatures significantly above normal (positive anomalies >0.5 SD). 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 31). Since the peak in 2011 bottom temperatures on the Labrador Shelf have decreased with 2015 remaining above normal overall, similar to the previous two years.

Similarly, standardized annual near-bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 33 and repeated in Figure 34 as a cumulative time series. The results are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999. In 2015, 14 out of 35 areas has temperatures that were near-normal (anomalies within ±0.5 SD) compared to 2011 when 31 out of 35 areas had values significantly above normal (positive anomalies >0.5 SD). The composite plot (Figure 34) shows an increasing trend since the early 1990s reaching a series record high in 2011 when 20/35 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. The 2014 and 2015 values have decreased but have remained above the long term mean with a slight warming in 2015.

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	15	MEAN	SD
02 N Labrador Shelf	-0.4	0.3	0.8	-2.4				-0.1				-1.0		-1.5			-0.4	1.4	-0.4	0.4	-1.3	-0.9		-1.5	0.2	0.7	-0.1	0.2	1.7	-0.6	0.3	2.8	1.1	-0.4	1.0	0.7	3.45	0.41
03 Central Labrador Inshore	-0.8	-0.1	-0.3	-0.7	-0.8	-1.6	-0.8							-1.0			0.2	0.2	0.3	0.7	-0.1	0.7	-0.8	2.1	-0.5	0.1	0.7		2.8	-0.8	-0.3	2.0	0.2	0.1	-0.5	0.2	-0.06	0.45
05 Labrador Inshore	-0.1	1.1	0.4	-1.3	-1.4	-1.6	0.5	-1.2	-0.1	-0.5	-1.0	-0.9	-1.3	-1.1	-0.8	1.0	-0.4	0.3	1.9	0.3	0.2	0.3	0.1	0.2	1.9	1.2	0.0	0.8	0.9	1.4	1.2	2.2	0.1	1.2	-0.7	0.1	-0.61	0.52
06 Labrador Trough	0.2	0.4	-1.1	-0.9	-0.8	-1.6	0.0	-0.8	0.9	-0.4	-1.1	0.0	-0.9	-2.4	-0.5	-0.5	0.0	1.2	1.5	1.4	0.1	0.4	1.2	0.6	1.0	0.3	0.4	2.0	-0.4	-0.9	1.0	1.8	0.2	1.6	0.5	-0.2	1.02	0.57
07 Belle Isle Bank	-0.1	0.4	-0.6	-0.1	-2.1	-2.6	-0.5	-0.7	0.5	-0.6	-0.7	0.3	0.2	-0.7	-0.6	-0.4	0.4	0.8	0.8	1.2	0.9	0.7	-0.1	0.8	1.4	0.9	0.1	0.9	1.0	2.0	-1.5	2.1	1.3	0.4	-0.3	0.3	2.79	0.56
08 Hawke Saddle	0.7	0.4	-0.1	0.5	1.0	-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	1.8	0.7	1.5	0.9	0.2	0.2	0.6	0.5	1.3	1.0	1.3	1.6	-1.0	2.8	1.8	1.7	1.4	-0.2	3.22	0.31
09 Hamilton Bank	-0.4	0.7	-1.3	-1.8	-1.0	-1.2	0.7	-1.1	0.9	1.4	-1.0	0.2	-0.5	-1.6	-0.9	-0.3	0.0	1.3	0.8	0.2	-0.6	0.9	-0.1	0.4	1.6	1.4	0.4	1.2	0.3	-0.3	1.9	2.0	0.0	0.7	-0.2	0.6	1.36	0.64
10 Cartwright Saddle	0.7	0.0	-0.7	-1.0	-1.5	-1.2	0.6	-0.5	-0.2	0.6	-0.9	-0.7	-0.3	-1.2	-1.0		0.2	1.4	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	1.8	0.6	-0.6	0.7	2.14	0.78
11 Central Labrador Trough	-0.4	-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	1.4	1.2	0.0	-0.9	-1.8	-1.6	0.4	0.7	-0.2	2.5	1.9	1.1	0.1	1.2	0.7	0.4	0.0	-1.2	0.0	0.92	0.59
12 Makkovik Bank	-0.2	1.0	-0.1	-1.5	-2.6	-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	1.9	1.3	-0.2	0.7	0.6	-0.1	0.7	2.4	0.0	-0.2	-0.2	0.1	0.78	0.71
13 Hopedale Saddle	0.6	1.0	-0.4	-0.6	-0.5	-0.5	-0.2	-0.9	0.7		-2.1	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	1.0	-0.6	-0.4	2.60	0.45
14 N Labrador Trough	0.7	0.4	0.0	0.0	0.1	-1.4	0.5	0.0	0.3	-0.4	0.3	-0.7		-2.4			0.3	0.5	0.7	-0.1	-1.0	0.1	-1.8	0.1	1.2	1.1	0.6	-2.4	0.6	1.7	1.1	1.4	0.8	1.1	1.2	0.9	2.73	1.01
15 Nain Bank	1.2	0.6	-1.2	-2.2	-1.9	-0.4	2.3	-0.9	0.0		-0.1	-0.7	1.3	-0.4			1.4	0.4	0.3	0.4	0.3	0.4	0.4	0.5	1.5	-0.3	-0.6	0.0	-0.4	-0.7	1.5	2.6	0.1	-1.4	3.6	2.3	0.02	0.58
16 Okak Bank	0.5	0.4	-1.0	-1.7		-0.3		0.6	0.3			-1.2	-1.9				0.4	-0.1	1.7	0.3						0.8	-1.7	0.7	1.1	0.0	0.3	0.9	0.9	-1.1	-1.0	-0.1	1.66	1.03
17 Saglek Bank	0.1	1.6	-1.0	-2.3		1.4	0.4	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	1.8	0.1	-0.7	1.2	1.4	0.72	0.66
18 Saglek Slope	-2.3	0.4	-1.1	-0.1	-1.4	-0.7	-2.2	0.0	-0.1		-0.3	-0.6	-0.6				-0.8	0.7	0.3	2.1	2.0		-1.3		0.3	-0.6	-0.1	1.1	1.1	0.4	0.5	2.0	1.0	-0.8	0.7	-0.4	3.71	0.30
21 Nain Slope	-0.2	-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	1.9	0.7	1.4	1.5	1.0	-0.2	1.0	3.49	0.32
22 Makkovik Slope	-0.8	0.0	-1.5	0.5	-1.3	-0.3	0.4	0.2	-0.4	-0.5	-0.7	0.2	-0.8	-3.9	-0.5	-1.3	0.1	0.3	0.4	1.2	0.2	0.3	0.4	0.8	0.9	0.7	0.5	0.3	0.5	1.2	0.7	1.2	1.1	1.3	0.8	0.0	3.39	0.30
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	-1.0	-3.2	1.2	0.1	0.5		0.1	-0.2	1.8	1.1	0.3	0.2	0.4	-0.4	-0.9	-0.2	-0.3	0.4	-1.1	-0.7	-1.0	-0.6	-0.6	0.0	3.19	0.35
24 Hamilton Offshore	-0.1	0.8	-5.2	-0.5	0.1	0.5	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	0.0	-0.1	0.2	0.1	0.0	-0.1	3.07	0.65
25 Hamilton Slope	-1.4	0.9	-0.9	0.8	-1.4	-0.8	-0.3	-1.1	-0.1	-0.8	-0.1	-0.4	-0.1	-0.3	-0.3	-0.2	-0.8	0.1	0.4	0.0	0.0	0.3	-0.5	0.6	1.1	0.8	1.2	1.9	3.3	2.2	0.3	1.2	1.4	0.6	0.7	-0.4	3.45	0.25

Figure 30. Standardized bottom temperature anomalies for the Labrador Shelf derived from data within most of the areas displayed in Figure 29. The anomalies are normalized with respect to their standard deviations over the standard base period 1981-2010 and color-coded accordingly to Figure 3. The grey shaded cells indicate years for which there were no observations.

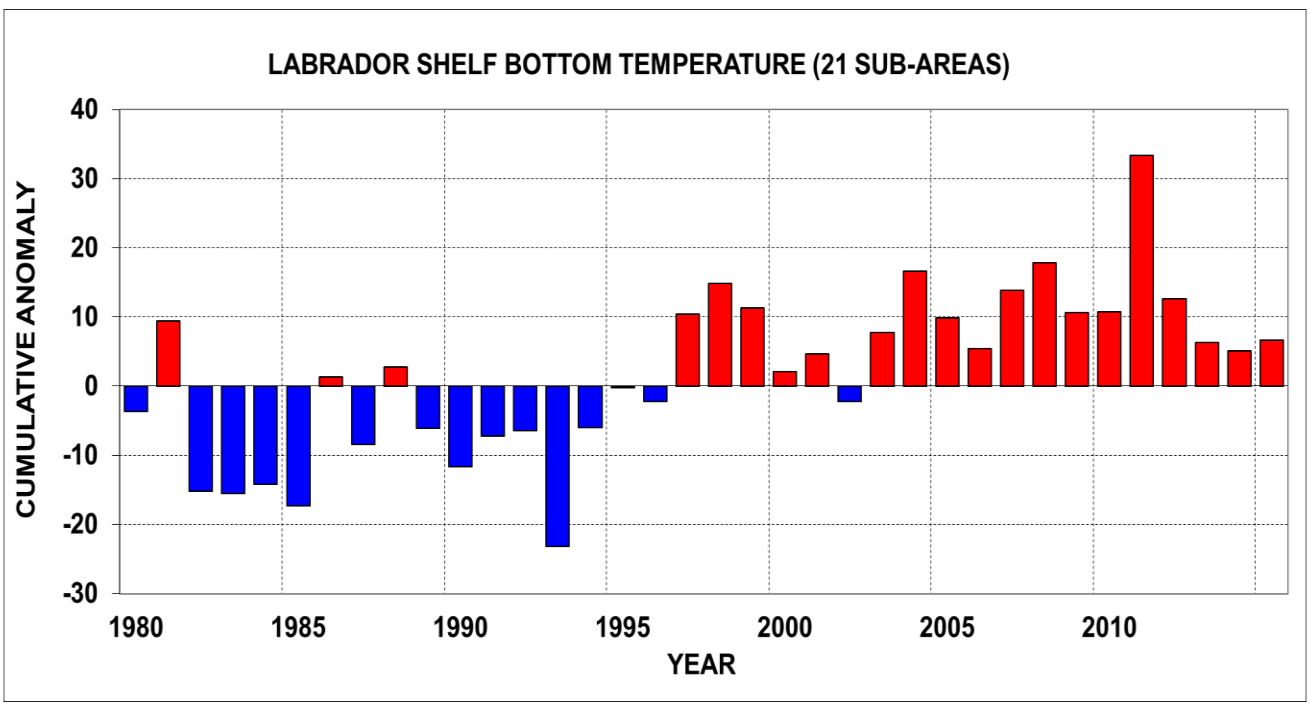

Figure 31. Cumulative bottom temperature anomalies based on the values presented in Figure 30 for the Labrador Shelf.

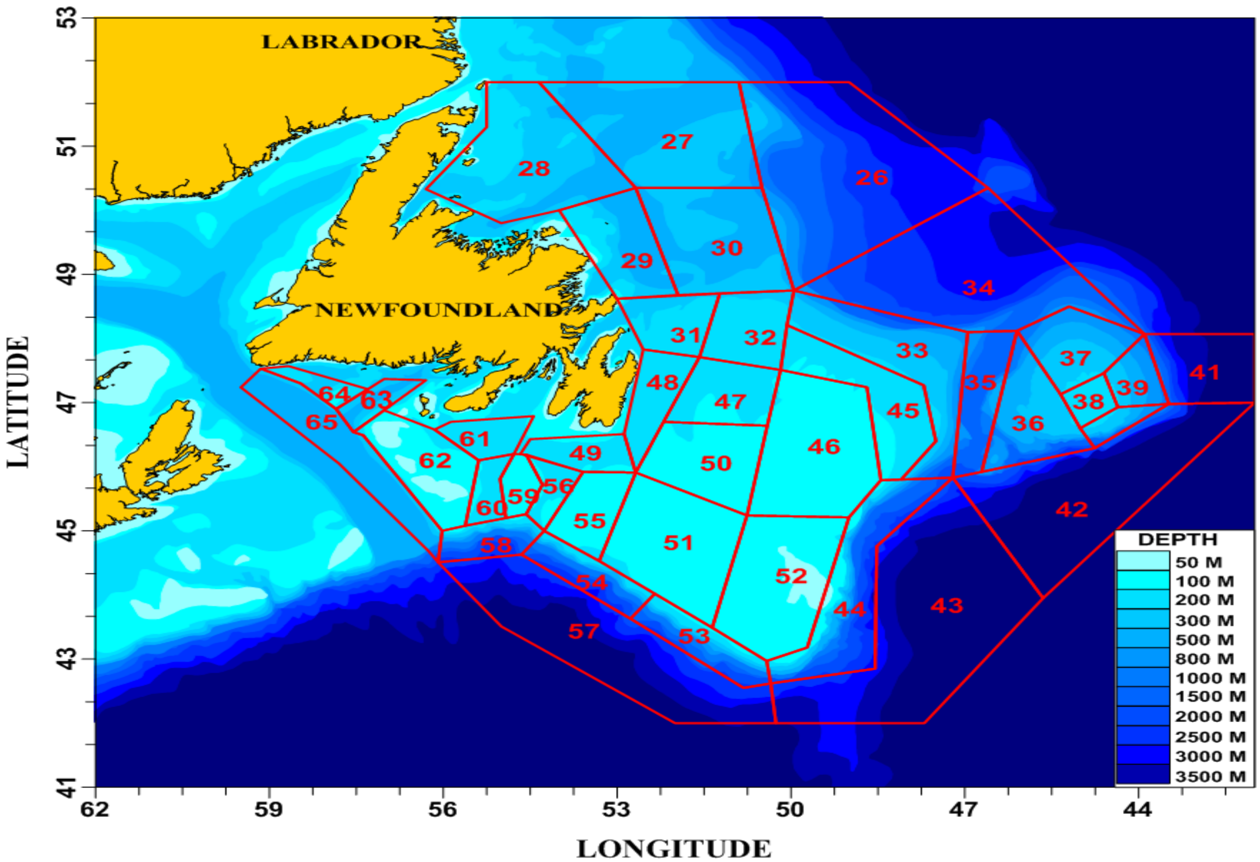

Figure 32. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed below in Figure 33.

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	15	MEAN	SD
26 Funk Slope	-0.1	0.0	-0.5	1.1	-0.5	-2.1	-1.0	-0.4	-0.9	-1.8	0.0	0.1	-0.9	0.2	0.8	-1.0	-0.8	-0.1	0.2	3.3	0.3	-0.4	-0.8	-0.3	0.9	1.0	0.5	0.8	0.9	-0.1	0.5	1.3	0.3	0.8	0.4	0.8	3.41	0.23
27 Funk Island	0.7	0.4	0.3	-0.9	-0.7	-1.9	-1.8	-0.3	0.1	-0.9	-1.1	-0.2	-0.6	1.4	-1.2	-0.4	-1.0	0.5	0.6	0.9	1.1	1.0	0.3	1.2	2.6	0.9	0.4	0.8	1.2	-0.3	-0.2	2.5	0.7	1.4	0.9	0.8	2.82	0.41
28 White Bay	0.5	1.4	0.3	-0.2	-0.3	-0.7	1.5	-0.7	-0.2	-0.5	-1.2	-0.7	-1.9	-0.8	-0.8	-1.1	-0.9	0.0	0.6	1.2	-1.7	-0.5	-0.5	0.4	0.8	2.3	1.1	1.3	0.7	-0.9	-0.5	3.0	0.1	1.5	-0.4	0.1	0.76	0.46
29 Bonavista	1.5	1.4	0.5	-1.3	1.6	-0.9	-0.4	1.1	0.4	-1.8	-1.0	-1.0	-0.9	-2.0	-1.2	-0.9	-0.2	0.5	-0.4	0.7	0.2	0.2	0.7	-0.4	1.1	0.1	1.0	2.0	0.0	0.5	0.6	2.7	0.6	0.1	-0.5	0.0	0.91	0.50
30 NE Nfld Shelf	0.6	-0.4	-0.1	-0.2	-2.0	-1.9	-1.4	-0.3	-0.6	-0.4	-1.1	0.0	-0.5	-0.9	-1.3	-0.1	0.2	0.7	1.1	1.2	0.7	0.9	0.6	0.3	1.7	1.2	1.2	1.2	1.7	-0.6	0.7	2.5	1.4	0.7	-0.3	0.4	2.54	0.52
31 Baccaliu	1.2	0.7	-0.1	-0.9	-1.0	-0.9	0.0	-0.3	-0.2	-1.1	-1.2	-1.4	-1.0	-1.2	-1.0	-0.4	2.1	1.7	1.4	1.1	0.9	0.0	0.3	-0.2	1.1	0.8	1.2	0.9	-0.4	-0.8	1.5	2.1	1.1	0.3	-1.0	-0.6	-0.32	0.61
32 N Slope	0.2	1.4	0.0	-0.7	-1.1	-1.2	0.1	-0.7	1.0	-1.0	-1.3	-0.8	-0.9	-1.3	-0.6	-0.7	0.6	0.9	1.0	1.4	0.4	0.0	0.4	-0.4	1.3	1.6	2.0	0.5	1.0	-1.1	1.3	2.6	0.8	0.3	-0.6	-1.1	-0.17	0.51
33 NE Slope	0.4	-0.5	-0.1	-1.0	-1.5	-2.4	-1.0	0.3	-1.1	-0.1	-0.9	-0.9	-0.8	-0.9	-0.2	0.7	0.0	1.0	0.9	1.0	0.9	0.7	0.6	0.6	1.6	1.2	1.4	0.9	1.2	0.9	1.1	2.1	1.4	0.3	0.3	0.2	2.51	0.65
34 Funk Offshore	-0.3	0.4	-0.1	0.7	0.3	-0.1	-0.4	0.1	-0.2	-0.5	-1.3	0.2	-0.4	0.2	0.0	-0.5	-0.5	-0.1	-0.3	2.5	-0.2	-0.5	-0.2	4.4	0.0	-0.6	-0.1	-0.1	-0.3	0.0	-0.2	0.0	1.6	0.0	-0.4	-0.1	3.48	0.55
35 Flemish Pass	0.2	0.2	0.0	0.5	0.6	0.9	-2.0	-0.3	0.2	-2.5	-1.1	0.3	-0.5	0.1	0.3	-1.6	-0.5	-0.6	0.3	0.6	0.7	0.1	0.2	-0.3	0.0	0.8	1.4	1.5	1.2	2.0	1.6	1.3	1.4	1.4	1.5	0.6	3.54	0.27
36 Flemish Cap (W Slope)	0.5	0.0	-0.4	1.1	1.7	0.5	-0.2	-0.6	0.0	-0.6	-2.4	0.5	-1.4	-0.5	-0.8	-1.5	-1.0	-0.8	0.2	0.8	1.1	-0.1	-0.3	-0.5	0.4	0.3	0.6	0.2	1.6	2.5	0.5	6.6	2.4	2.5	0.7	2.0	3.75	0.28
37 Flemish Cap (N Slope)	0.5	0.3	-0.2	1.1	1.5	-0.3	-0.1	-0.3	0.5	-1.4	-1.1	-0.8	-1.7	-0.8	-0.2	-0.7	-0.8	-0.4	-0.4	2.0	0.8	0.2	-0.1	-0.7	-0.1	0.1	0.8	0.4	1.9	1.7	2.2	2.6	1.6	1.2	1.2	0.9	3.65	0.31
38 Central Flemish Cap	0.4	0.3	-0.2	0.3	0.1	-0.2	-1.1	-0.4	0.4	-2.2	-1.6	-1.3	-1.0	-0.4	-1.9	-0.8	-0.3	-0.1	0.7	1.4	0.2	-0.2	-0.1	0.0	0.9	1.7	0.8	0.0	1.1	0.7	2.2	1.0	0.3	0.6	-1.2	-1.2	3.34	0.62
39 Flemish Cap (E Slope)	-0.2	-0.6	-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	2.2	1.2	1.4	1.5	0.9	1.1	3.71	0.37
44 E Slope	1.5	0.7	0.8	1.1	-0.1	-2.0	-1.0	-0.4	-1.2	-0.1	-2.5	-0.7	-0.8	0.6	-1.0	0.1	-0.7	0.0	1.5	0.5	1.0	0.9	0.6	1.0	1.4	1.4	-0.1	0.5	0.9	0.8	1.0	1.6	0.4	0.5	1.1	0.8	2.44	0.62
45 NE Edge	-0.3	0.2	0.2	-0.9	-1.0	-1.2	1.3	0.3	-0.3	-0.6	-1.3	-1.1	-1.1	-1.6	-1.0	-0.8	0.5	1.4	0.8	1.2	0.0	0.6	-0.4	-0.1	1.7	0.6	1.8	0.8	0.3	-0.8	1.8	3.4	1.0	0.7	-0.6	-0.8	-0.28	0.51
46 NE Grand Bank	0.1	0.6	0.7	0.0	-1.0	-0.4	-0.7	-0.2	0.0	-0.4	-0.1	-0.8	-0.7	-1.1	-1.0	-0.3	0.2	-0.5	0.2	1.2	-0.3	-0.1	0.3	-0.1	4.4	0.0	0.8	-0.4	-0.2	0.9	1.0	1.2	0.3	0.8	-0.1	0.3	0.16	0.87
47 NE Avalon Channel	0.5	1.2	0.5	-0.4	-0.8	-0.7	-0.7	0.5	-0.1	-0.9	-1.4	-1.4	-1.2	-1.7	-1.2	-0.7	0.5	0.7	0.9	1.3	0.4	0.2	-0.1	-0.4	2.1	1.0	1.8	0.3	0.3	-0.3	1.8	2.9	1.9	1.0	-1.0	-0.7	-0.65	0.43
48 N Avalon Channel	0.1	0.8	-0.3	-0.8	-1.0	-1.5	-0.6	0.1	-0.4	-0.7	-1.1	-1.4	-1.1	-1.5	-1.4	-0.5	0.4	0.8	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	1.0	-0.7	-0.7	-0.82	0.38
49 S Avalon Channel	0.1	-0.1	0.6	-1.5	-0.8	-1.0	-0.8	-0.8	0.8	-1.2	-0.8	-1.1	-1.1	-1.2	-1.3	0.1	1.3	-0.3	1.1	-0.5	0.7	0.6	-0.3	-0.6	1.5	1.4	2.5	-0.7	-0.1	0.3	1.0	3.1	2.1	1.3	-0.5	0.3	-0.76	0.45
50 NW Grand Bank	0.5	1.8	0.1	1.5	-0.8	-0.3	0.7	0.1	-0.2	-0.5	-0.5	-1.7	-1.5	-2.0	-1.5	0.4	0.3	-0.8	1.0	1.6	0.0	0.5	0.1	-0.8	1.3	1.2	1.1	-0.1	-0.7	0.2	1.0	2.0	0.8	1.5	-0.4	0.6	0.16	0.50
51 SW Grand Bank	0.3	0.1	0.1	3.5	-0.1	-0.8	-0.2	0.0	-0.2	-0.5	-1.0	-0.7	-1.1	-0.6	-0.9	0.4	0.2	-0.8	0.0	0.8	0.4	0.0	-0.4	-0.4	3.3	0.0	0.3	0.4	-0.2	0.1	0.6	0.8	0.8	0.7	0.3	0.0	2.15	1.46
52 SE Grand Bank	0.6	1.1	0.1	2.1	0.1	-0.6	-0.3	-0.4	-0.9	0.7	-0.9	-0.5	-1.7	-1.7	-0.5	-0.2	0.1	-0.3	1.1	2.1	0.2	-0.4	-0.8	-1.0	1.4	-0.3	0.7	0.3	-1.2	1.6	1.2	2.1	0.6	0.6	-0.7	0.2	2.11	0.63
53 S Slope	0.5	0.8	-0.8	3.0	-0.8	-0.2	0.7	0.0	-0.1	0.4	-1.6	-1.7	-1.8	0.3	0.5	0.1	-0.6	-0.9	1.2	0.8	1.6	0.0	-0.3	0.5	0.6	1.0	-0.1	-0.1	-0.6	1.1	0.3	1.7	1.3	0.6	0.8	1.5	3.69	1.05
54 SW Slope	-0.3	-0.1	-1.8	0.0	1.0	-1.1	0.9	0.2	1.4	-0.4	-1.4	-2.5	-0.9	1.6	-0.1	1.3	0.9	-0.6	-0.3	1.4	0.4	0.6	0.0	0.0	-0.5	0.9	1.2	-0.6	-0.8	1.3	0.3	2.5	1.7	3.0	0.5	1.5	4.92	0.85
55 Whale Bank	-0.1	1.7	0.0	3.5	1.1	-0.7	1.4	-1.0	1.6	-0.6	-0.6	-0.8	-0.8	-0.3	-1.5	-0.6	0.3	-0.5	0.3	1.2	0.0	-0.2	0.0	-0.6	0.3	0.3	-0.4	-0.5	-0.4	-0.1	0.2	1.7	1.8	0.7	-0.5	-0.4	0.39	0.83
56 Haddock Channel	-1.0	-0.1	0.1	0.1	-0.1	-1.4	1.0	-0.5	0.5	0.5	-1.2	-0.5	-0.9	0.6	-1.7	0.5	-0.5	0.3	-0.2	1.2	-0.5	2.0	-0.7	0.2	3.4	-0.4	0.3	-1.0	-0.1	0.8	0.8	6.1	3.4	2.0	-2.3	0.6	-0.36	0.56
58 Halibut Channel Slope	-2.9	0.8	-0.8	0.4	1.0	-0.4	0.1	-0.5	0.0	-0.4	-1.3	-0.6	0.3	-0.9	-0.4	-0.7	0.7	-0.1	0.6	1.7	0.7	3.6	-0.1	-0.9	-1.1	0.8	-1.7	-0.1	-0.4	0.2	0.1	0.9	0.9	1.3	0.4	0.0	4.61	1.20
59 Green Bank	1.1	2.7	0.0	0.2	1.8	-1.4	-1.1	-0.3	-0.3	-0.7	-1.5	-1.1	-0.8	-1.2	-1.6	0.2	0.4	-0.3	0.6	0.5	1.5	0.8	0.0	-0.5	0.9	0.5	1.2	0.6	-0.2	0.2	1.1	5.5	1.2	1.8	-0.4	0.9	-0.64	0.54
60 Halibut Channel	-0.9	0.7	-0.8	0.5	0.5	0.2	-0.1	-0.9	-0.1	-0.1	-1.0	-0.5	-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	2.0	0.92	1.41
61 St. Pierre Channel	-0.5	-0.2	-1.2	0.6	0.0	-0.7	-1.0	-0.7	0.8	-0.2	-1.2	-0.9	-0.2	-1.2	-1.2	-1.5	0.3	3.3	-0.5	0.4	0.8	-0.5	-0.2	-1.3	0.6	0.4	0.5	0.4	0.7	0.8	1.3	2.1	1.5	0.7	1.4	-0.2	-0.57	0.43
62 St. Pierre Bank	-1.6	-0.1	-0.9	0.0	1.5	-0.8	-1.3	-1.0	0.7	-0.5	-0.3	0.0	0.0	-0.6	-0.4	-0.3	0.0	-2.0	-1.2	1.5	0.1	-0.6	0.5	-1.6	-0.5	1.5	1.6	-0.8	-0.1	0.4	2.4	1.5	-1.7	-0.5	-0.1	-0.3	1.62	0.66
63 Hermitage Channel	-2.3	2.6	-0.3	-0.3	0.6	1.4	1.7	0.3	-2.1	-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	0.4	1.1	0.0	2.1	1.3	5.25	0.79
64 Burgeo Bank	-5.0	0.6	1.0	0.3	0.4	1.7	1.8	-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	-1.6	0.0	-2.8	-0.9	0.4	1.2	0.1	0.0	0.9	-0.1	2.1	1.6	1.1	0.9	-0.2	3.59	0.71
65 Laurentian Channel	-1.0	1.6	-2.9	0.5	1.8	-0.3	-1.3	-0.3	0.4	-0.9	-1.3	-0.3	-0.1	0.3	-1.3	1.0	1.3	-0.6	0.5	-0.4	1.1	0.6	-0.1	-0.5	-1.3	-0.3	0.8	-1.4	-0.4	0.5	0.1	-0.2	2.8	4.0	1.7	2.5	4.95	0.44

Figure 33. Standardized bottom temperature anomalies for the Newfoundland Shelf referenced to 1981-2010.

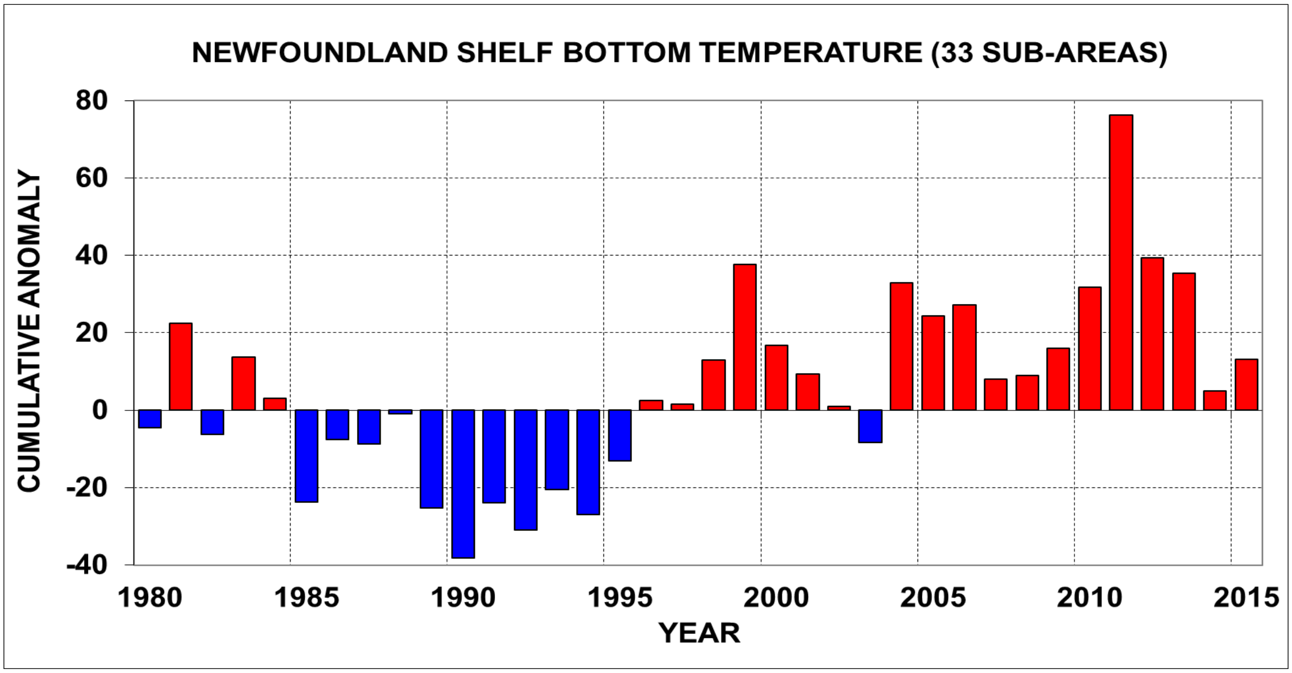

Figure 34. Cumulative bottom temperature anomalies based on the values presented in Figure 33 for the areas on the Newfoundland Shelf shown in Figure 32.

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°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 section established by ICNAF/NAFO.

Two ICNAF 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 2015, 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 2015 due to limited ship time. Also only five inshore stations were completed in April on the BB section due to heavy ice conditions. 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 NL Shelf during 2015.

Temperature and Salinity Structure

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 -1.5°C-2°C 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°C and salinities in the range of 34-34.75. Surface temperatures normally warm to 10°-12°C during late summer, while bottom temperatures remain <0°C over much of the Grand Banks but increase to 1°-3.5°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°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 temperature and salinity changes are highlighted in Figures 35 and 36 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 a relatively fresh upper layer shelf water with sources from arctic outflow and the Labrador Shelf with values <33 contrasting to the saltier Labrador Slope water further offshore with values >34 (Figure 36). During 2015 temperatures along the Bonavista section were predominately below normal on the shelf during spring at mid-depth during summer and in the off slope areas during fall. The near-surface layer temperature values during the summer and over most of the shelf during the fall were above normal with values exceeding 2°C above normal (Figure 35, 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 higher than normal by up to 0.4 over the offshore shelf areas (Figure 36, 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 35 and 36). 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°C isotherm is generally regarded as a robust index of ocean climate conditions on the eastern Canadian Continental Shelf.

The Cold Intermediate Layer (CIL)

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 0°C CIL was 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 was 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 was 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 was 55.3 ± 14.2 km^2 and 27.3 ± 7.5 km^2, respectively.

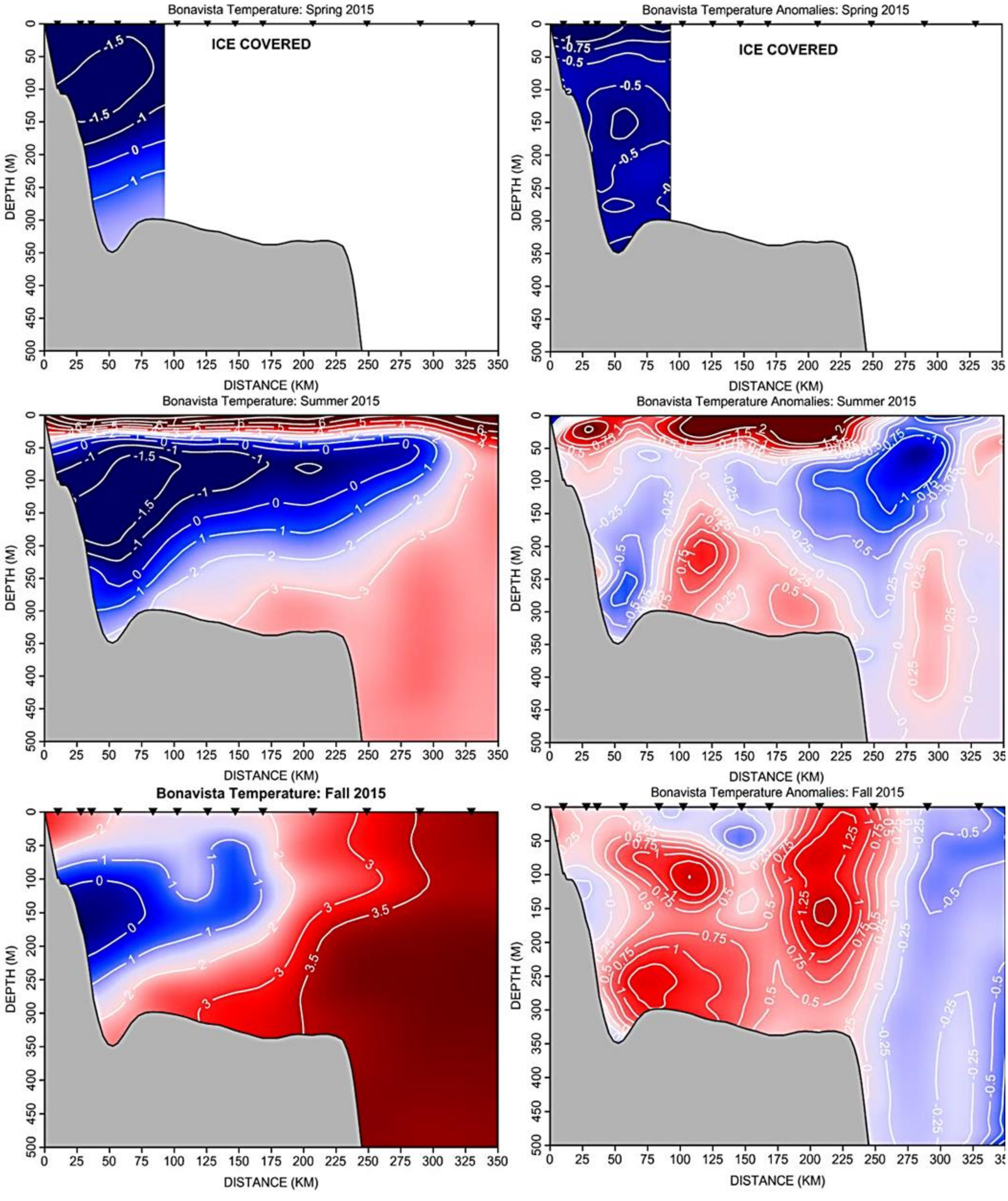

Figure 35. Contours of temperature (°C) and temperature anomalies along the Bonavista section (Figure 2) during the spring, summer and fall of 2015. Station locations along the section are indicated by the symbols on the top of each panel.

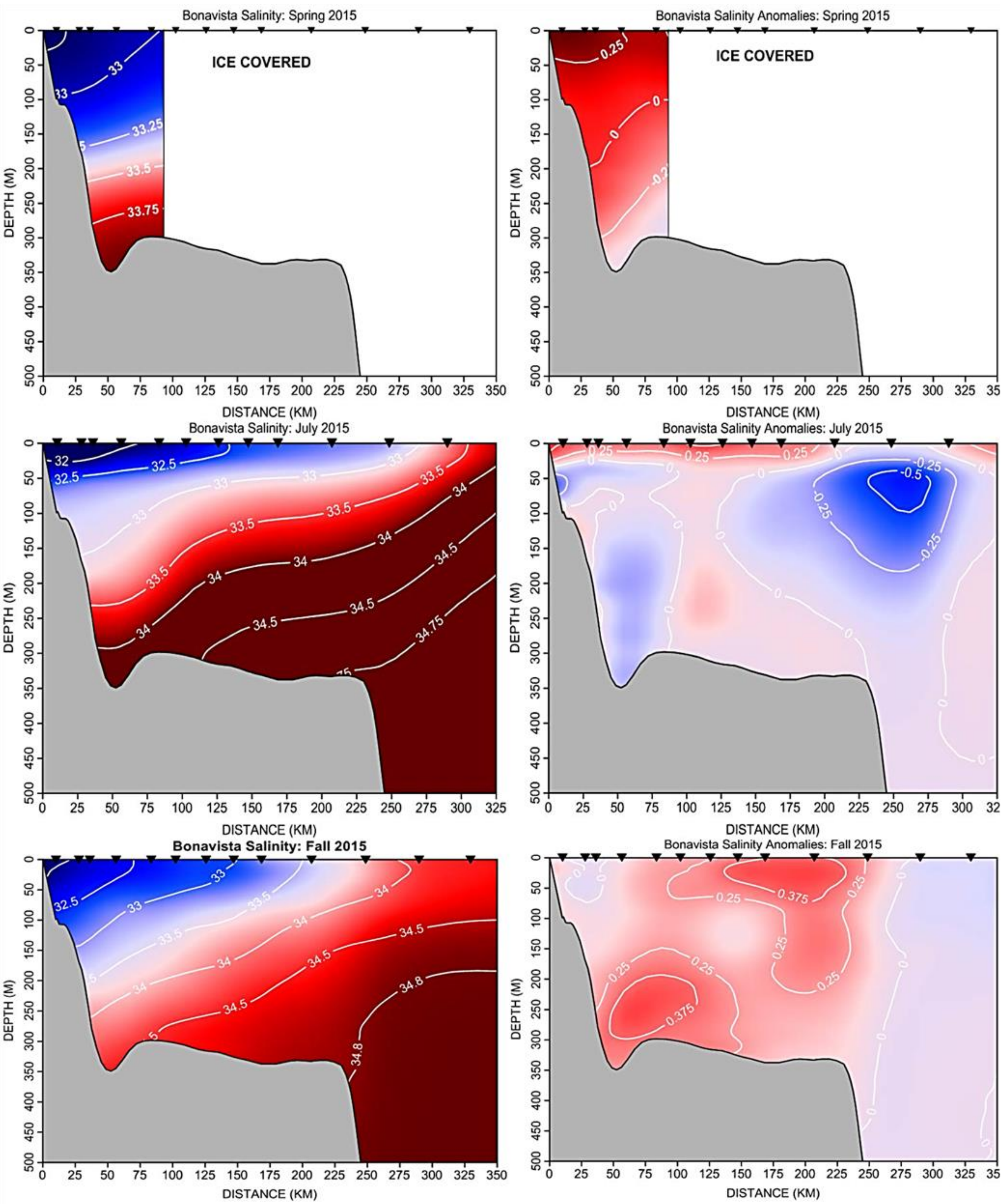

Figure 36. Contours of salinity and salinity anomalies along the Bonavista section (Figure 2) during the spring, summer and fall of 2015. Station locations along the section are indicated by the symbols on the top of each panel.

Time series of 0°C CIL cross-sectional area anomalies along sections from southern Labrador to the Grand Banks are displayed in Figures 37, 38 and 39 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. In addition, the spring CIL value along the BB section was estimated from a least-squares fit (r=0.7) with the Grand Bank CIL. The CIL area anomalies during the spring and summer of 2015 were above normal (implying colder-than-normal shelf water conditions) along most sections, except for the SEGB during spring and the FC section during the summer and in fact it was at the highest level in the series on the Grand Bank (FC) during the spring. By late fall the CIL had eroded significantly to below normal areas along the SEGB, FC and BB sections and was completely eroded along the SI section (not shown) possibly due to reduced stratification (Figures 25 and 26) and more intense vertical mixing during late fall.

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 40 as standardized values and in Figure 41and Figure 42 as composite temperature and salinity indices. Most of temperature and salinity indices shown were either near-normal or below normal by up to a maximum of -1.7 SD, with the strongest anomalies in salinity. This is in contrast to most of the 2000s when conditions were mostly warmer and saltier than normal. The composite temperature index (Figure 41) shows coldest conditions since 1995 during the past two years compared to a record high in 2011. The composite salinity index (Figure 42) shows fresher-than-normal conditions during the past seven years.

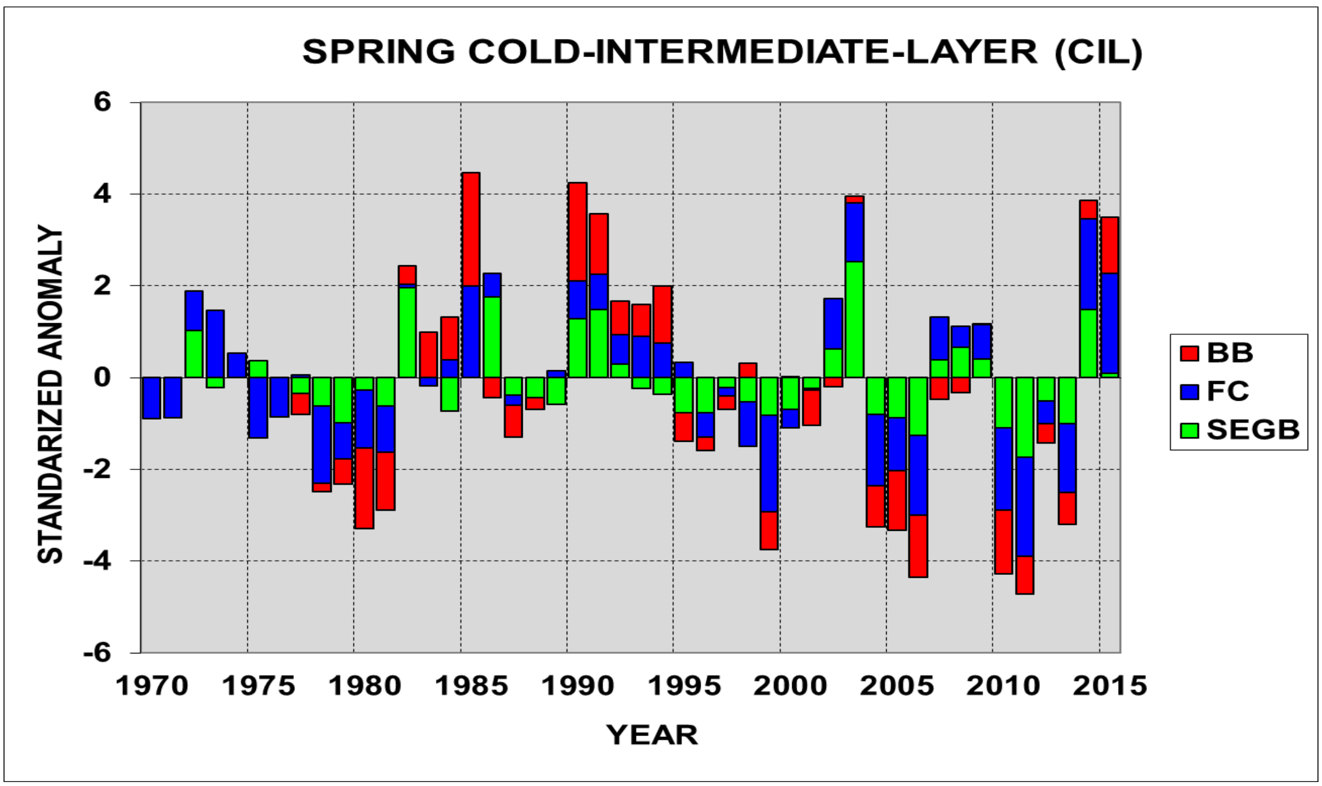

Figure 37. Cold-Intermediate-Layer areas during the spring along the Bonavista (BB), Flemish Cap (FC) and the South East Grand Bank (SEGB) sections displayed as cumulative standardized anomalies relative to 1981-2010.

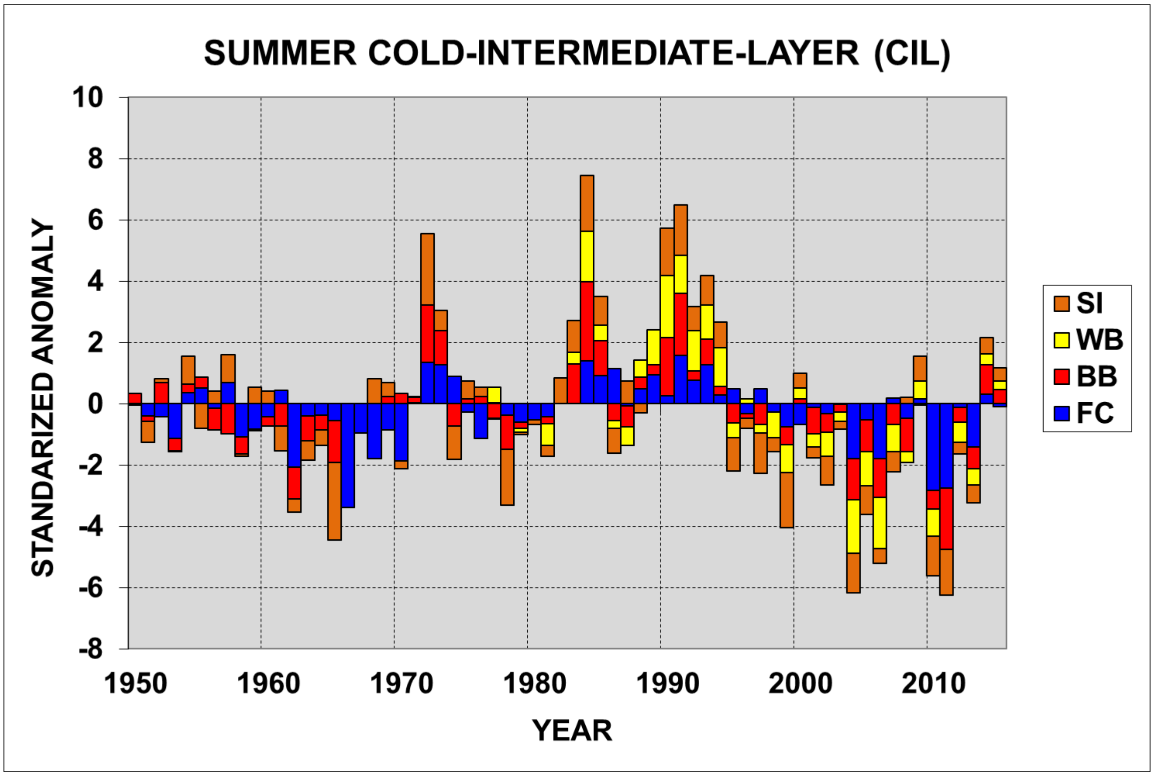

Figure 38. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

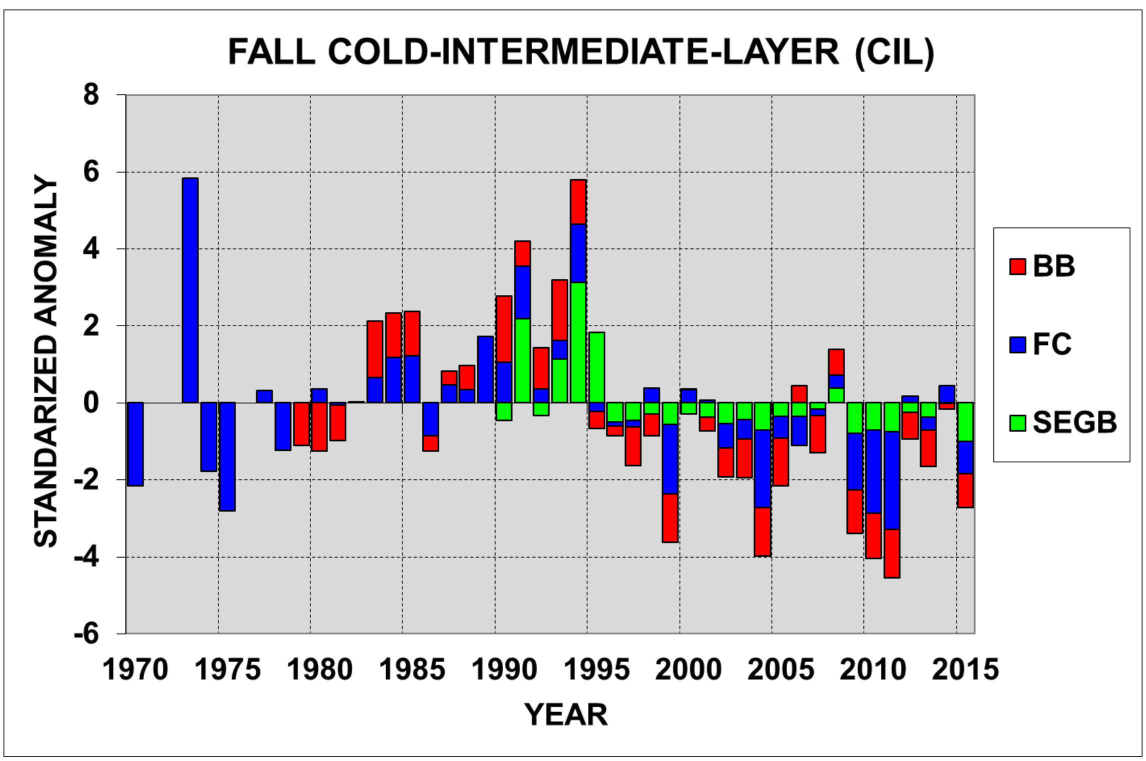

Figure 39. Cold-Intermediate-Layer areas during the fall along the Bonavista (BB), Flemish Cap (FC) and the South East Grand Bank (SEGB) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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	15	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	0.4	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	0.0	-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	0.1	-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	-0.7	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	-0.9	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	0.6	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	0.5	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	-0.3	-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	-0.9	-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	-0.6	-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	-1.0	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	-0.8	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	-0.1	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	-0.2	-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	-1.0	-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	-1.0	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	-1.7	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	-0.3	32.69	0.16

Figure 40. 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.

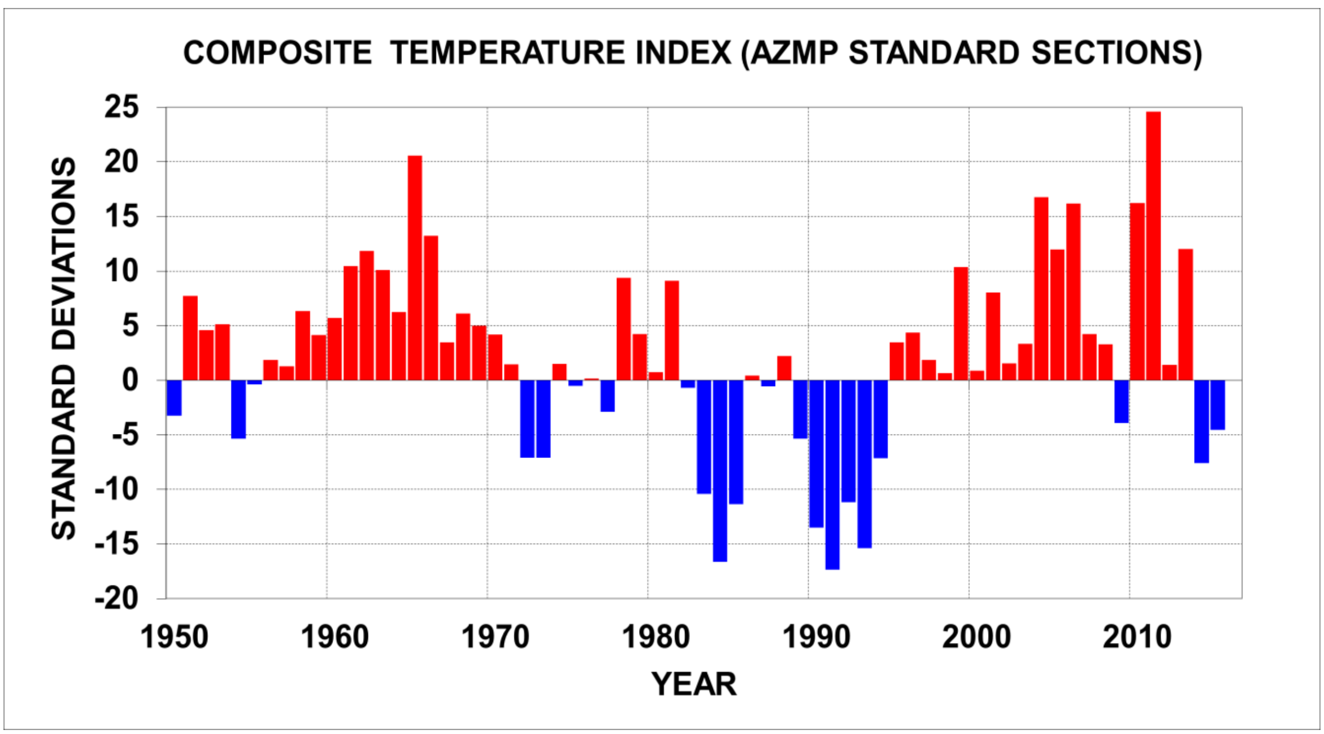

Figure 41. Composite temperature index derived from data collected along standard cross-shelf sections shown in Figure 40.

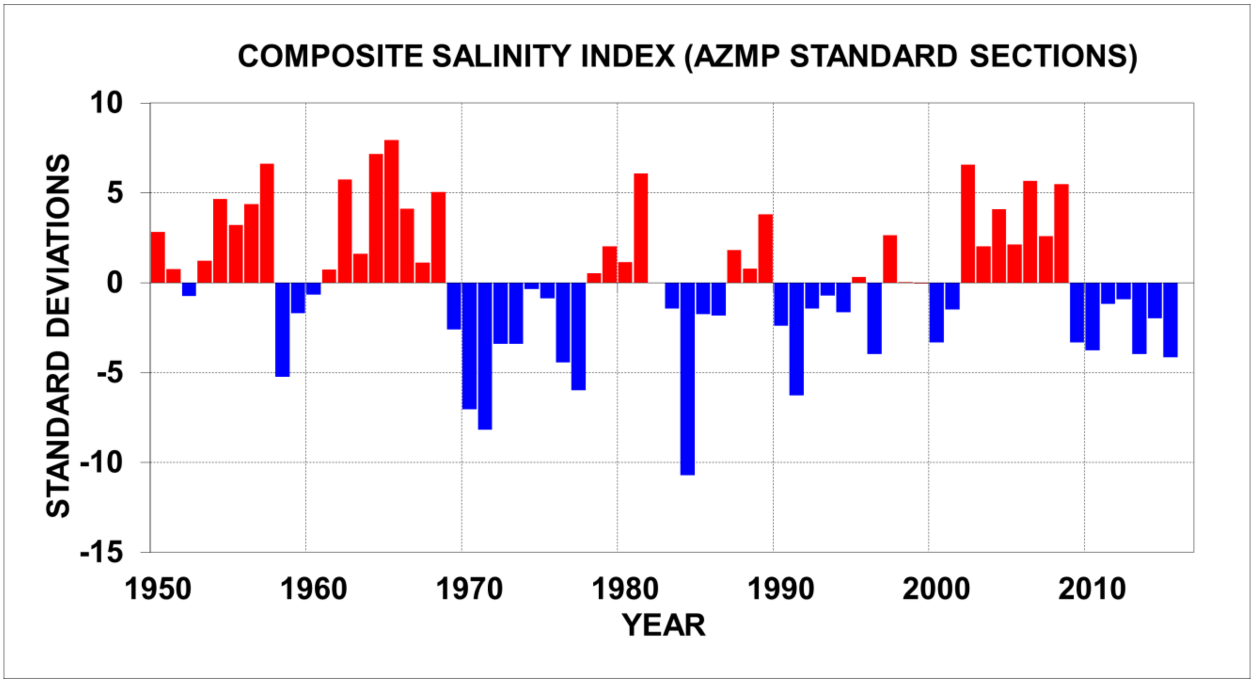

Figure 42. Composite salinity index derived from data collected along standard cross-shelf sections shown in Figure 40.

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, usually from April to early June, NAFO Subdivision 3Ps on the Newfoundland south coast and Divisions 3LNO on the Grand Banks are surveyed and in the fall, usually from October to December, Division 2HJ off Labrador in the north, 3KL off eastern Newfoundland and 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, spatial variability in the volume of the cold intermediate layer and water-column stratification and mixed-layer depth spatial maps. In addition, species specific ‘thermal habitat’ indices are often used in marine resource assessments for snow crab and northern shrimp.

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 2015.

Spring Conditions

Maps of the climatological mean bottom temperature and salinity together with the spring 2015 bottom temperature and salinity, their anomalies and difference from the previous year are displayed in Figure 43 and 44 for NAFO Divisions 3PLNO (See Figure 2 bottom right panel for station occupation coverage). Bottom temperatures in Division 3L generally range from -1° to 0°C in most areas and from 2° to 3°C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 1° to 5°C. In the northern areas of Divisions 3NO bottom temperatures generally ranged from -0.5° to 1°C. Bottom temperature anomalies were below normal (up to -0.5°C) over most of the northern areas and above normal (up to +1°C) on the southwestern Grand bank.

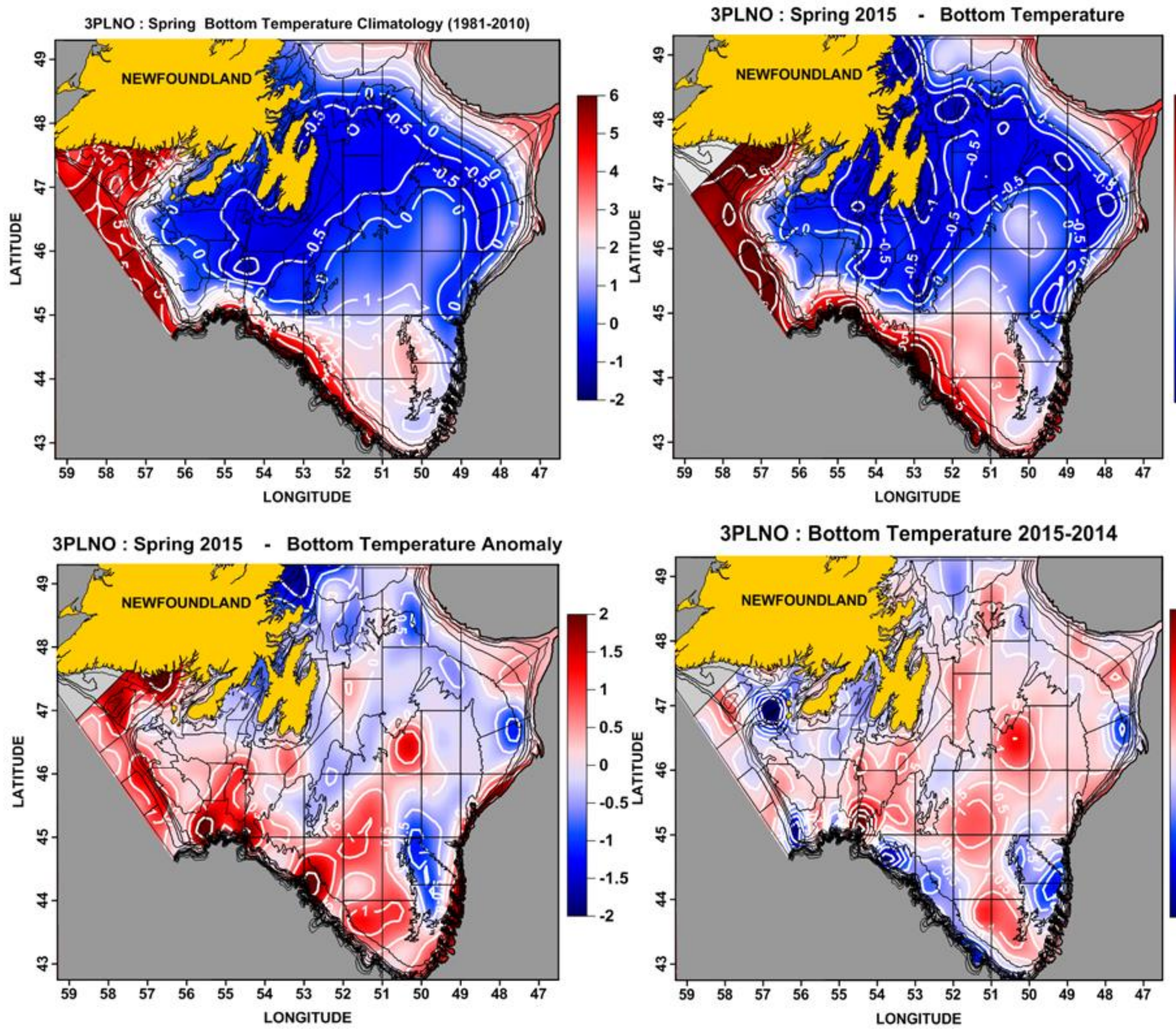

Figure 43. Maps of the mean 1981-2010 bottom temperature, bottom temperature and anomalies during spring 2015 and the difference from 2014 (in °C) in NAFO Divisions 3PLNO.

On St. Pierre Bank temperatures ranged from 0°-3°C on St. Pierre Bank and up to 5°-6°C in the Laurentian Channel and areas to the west. Bottom temperature anomalies ranged from near-normal to 1°C above normal on St. Pierre Bank and above normal (up to 1°C) in the deeper channels and areas to the west of St. Pierre Bank. The bottom right panel of Figure 43 shows, except for isolated areas, a slight warming over 2014 values.

Bottom salinities in Div. 3L generally range from 32.5-33 over most areas and from 33 to 35 at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom salinities ranged from 32 to 32.5, with the lowest values on the southeast shoal of the Grand Bank. Bottom salinity anomalies were below normal (up to -0.5) over most of the region, except for along the deeper slope and Laurentian Channel areas (Figure 44).

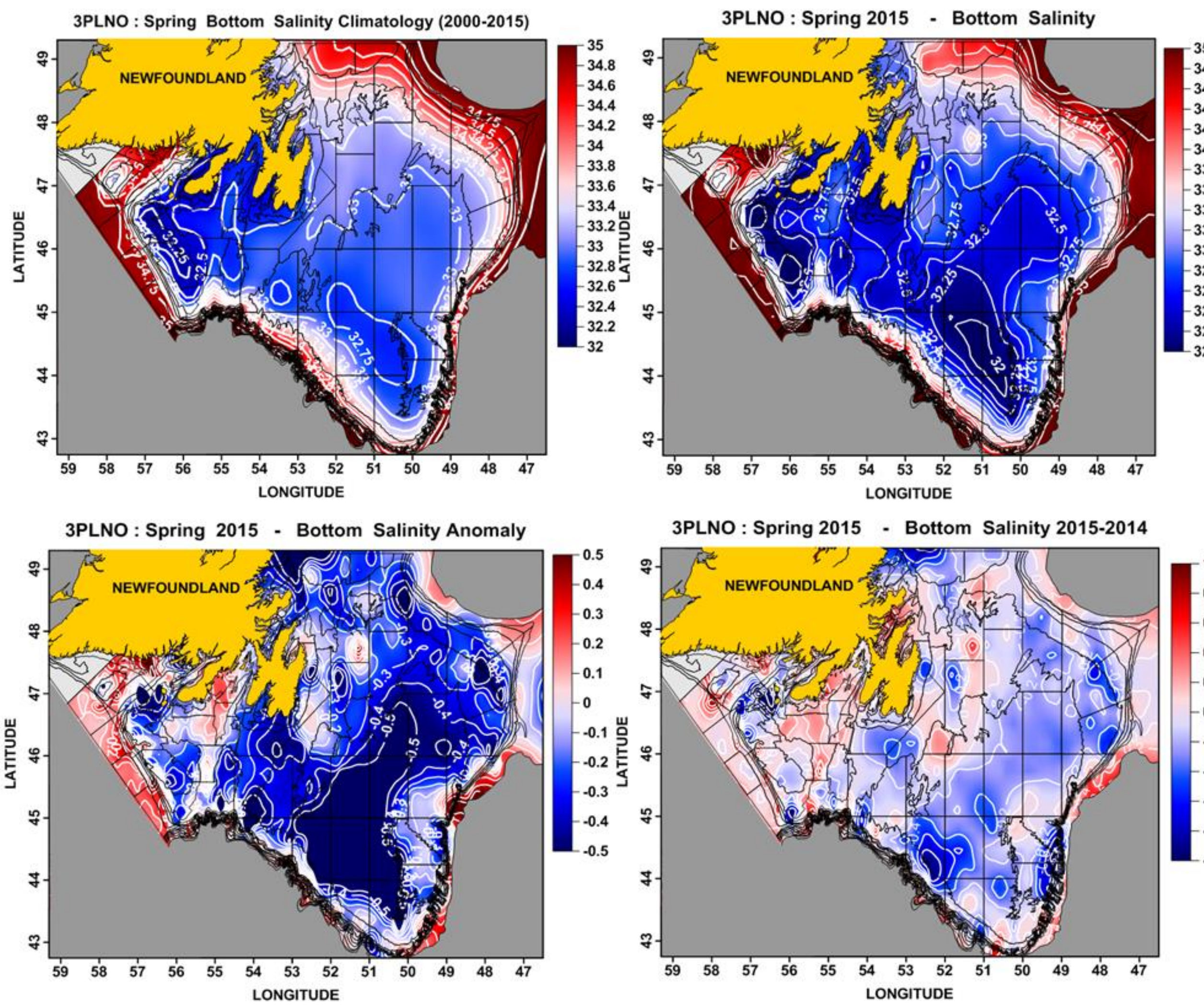

Figure 44. Maps of the mean 2000-2015 bottom salinity, bottom salinity and anomalies during spring 2015 and the difference from 2014 in NAFO Divisions 3PLNO.

Climate indices based on the temperature data collected during the spring survey for the years 1990-2015 are displayed in Figure 45 as normalized anomalies. During the spring of 2011 in Divisions 3LNO, none of the bottom area was covered by <0°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 and in 2015 it was about normal (Figure 45).

In 3LNO spring bottom temperatures were generally lower than normal from 1989 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 have decreased to near-normal values by 2015 (Figure 45).

In Division 3P bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000, near record cold conditions in 2003 (-1.4 SD). A notable exception occurred in 2007-08 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 2015. The spring of 2011 had the lowest area of <0°C bottom water since 1981 at 1.9 SD below normal, also corresponding to little or no bottom waters with temperatures of <0°C. This area has increased somewhat in recent years and was just slightly below normal in 2015 (Figure 45).

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	2015	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	-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	0.1	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	0.7	26.72	10.86
THERMAL HABITAT AREA <0°C	-0.4	-1.0	0.0	-0.5	0.8	1.1	1.1	0.8	0.5	0.9	1.1	1.5	1.1	1.2	0.8	0.5	-0.3	0.7	-1.0	-1.5	-0.7	-0.5	-0.3	0.5	-2.0	-1.2	-1.7	-0.1	-0.2	0.2	-1.7	-2.2	-1.3	-1.5	0.5	0.2	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	0.8	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	0.0	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	0.0	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	-0.4	22.13	11.78

Figure 45. 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.

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 46 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 to near-normal values in 2015, except for 3Ps which remained above normal.

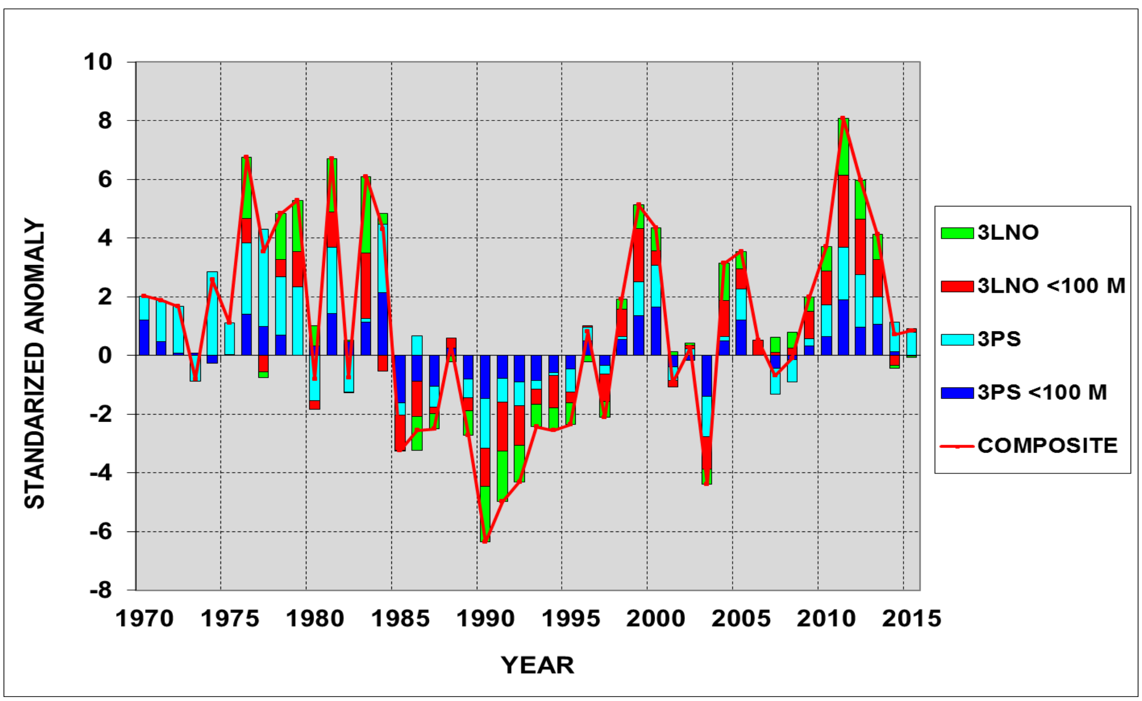

Figure 46. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divisions 3LNOP.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from the fall of 2015 multi-species survey (Figure 2) in NAFO Division 2J, 3KL are displayed in Figure 47. 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° and 4°C. Bottom temperature anomalies ranged from 0.5° to 1°C below normal on areas of Hamilton Bank and along the southern Labrador coast and along the northeast coast of Newfoundland. In the offshore areas temperatures were near-normal to slightly below normal in 2J and 3K by up to -0.25°C.

Bottom temperatures in Divs. 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 in the southern areas of 3L. Temperatures were below normal over most of 3L and in the southern area of 3NO. Over the central area of the Grand Bank they were up to 0.5°C above normal (Figure 47).

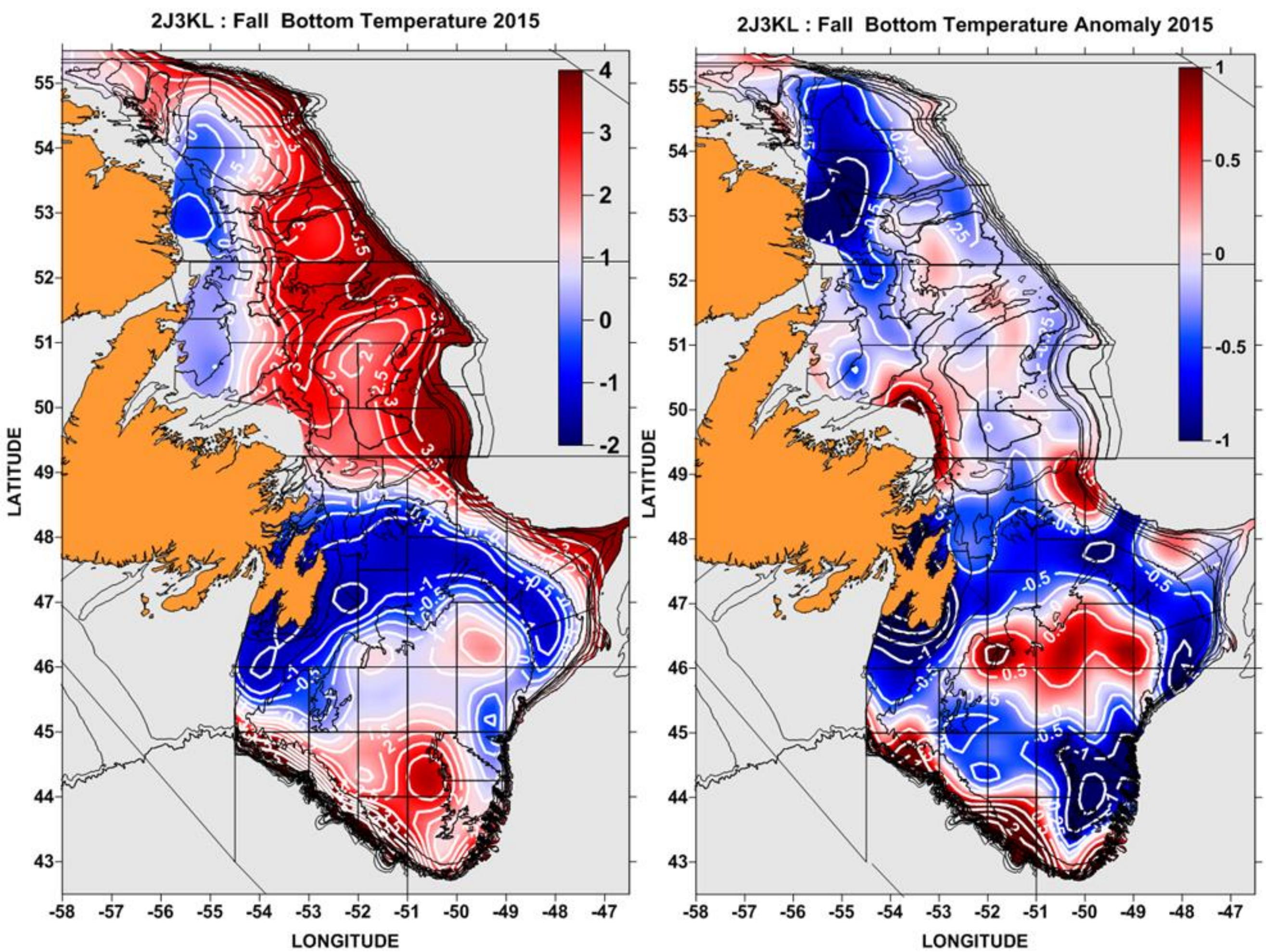

Figure 47. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2015 in NAFO Divisions 2J3KL.

Bottom salinities in Division 2J generally range from 32.75-34 over most areas and from 34 to 35 at the shelf edge. In 3K salinities ranged from 34 to 35 and on the Grand Banks bottom salinities ranged from 32.5 to 33.5, with the lowest values on the southeast shoal of the Grand Bank. Bottom salinity anomalies were below normal (up to -0.5) over northern regions and on the Grand Banks and near-normal on the northeast Newfoundland Shelf (Figure 48).

Bottom temperature anomalies and derived indices are displayed in Figure 49 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 to 2.2 SD above normal and in 2015 they decreased to near-normal values. The area of the bottom with temperatures <1°C was about normal in 2015. In Division 3K, bottom temperatures were at a record high in 2011 (+2.7 SD) but have decreased in recent years and were about 0.8 SD above normal in 2015.

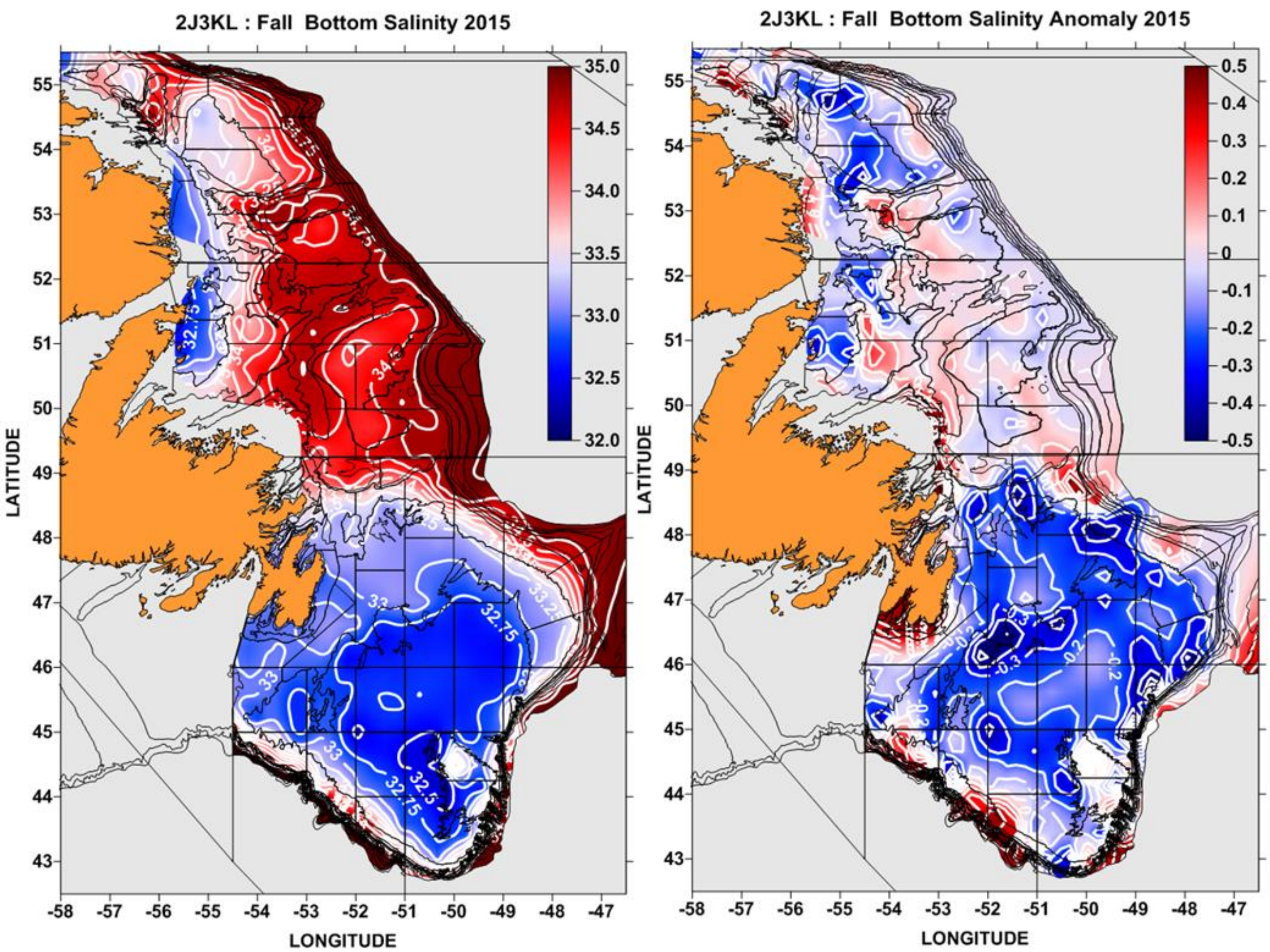

Figure 48. Contour maps of bottom salinity and bottom salinity anomalies (referenced to 2000-15) during the fall of 2015 in NAFO Divisions 2J3KL.

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 50. 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 a recent decreasing trend is noted with conditions in 2015 varying slightly about the mean depending on the area.

Composite indices derived by summing the standardized values presented in Figures 45 and 49 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 both 2014 and 2015 (Figure 51).

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	2015	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	0.2	2.35	0.47
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	-0.3	0.79	0.71
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	-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	0.0	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	0.8	2.13	0.53
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	0.7	1.46	0.62
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	1.0	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	0.4	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		-0.4	1.78	0.39
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		-0.5	1.22	0.64
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		-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		0.0	30.33	12.93
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	-0.5	1.65	0.95

Figure 49. 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.

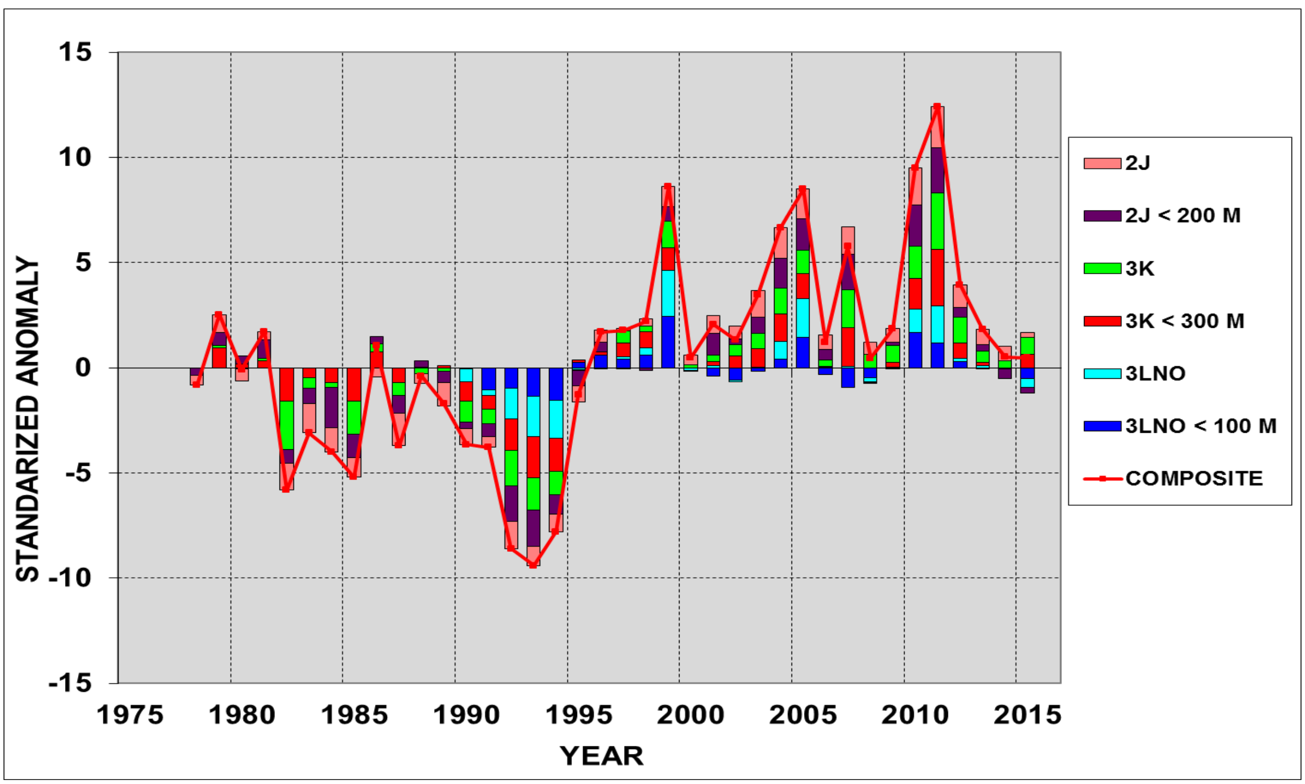

Figure 50. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divisions 2J3KLNO.

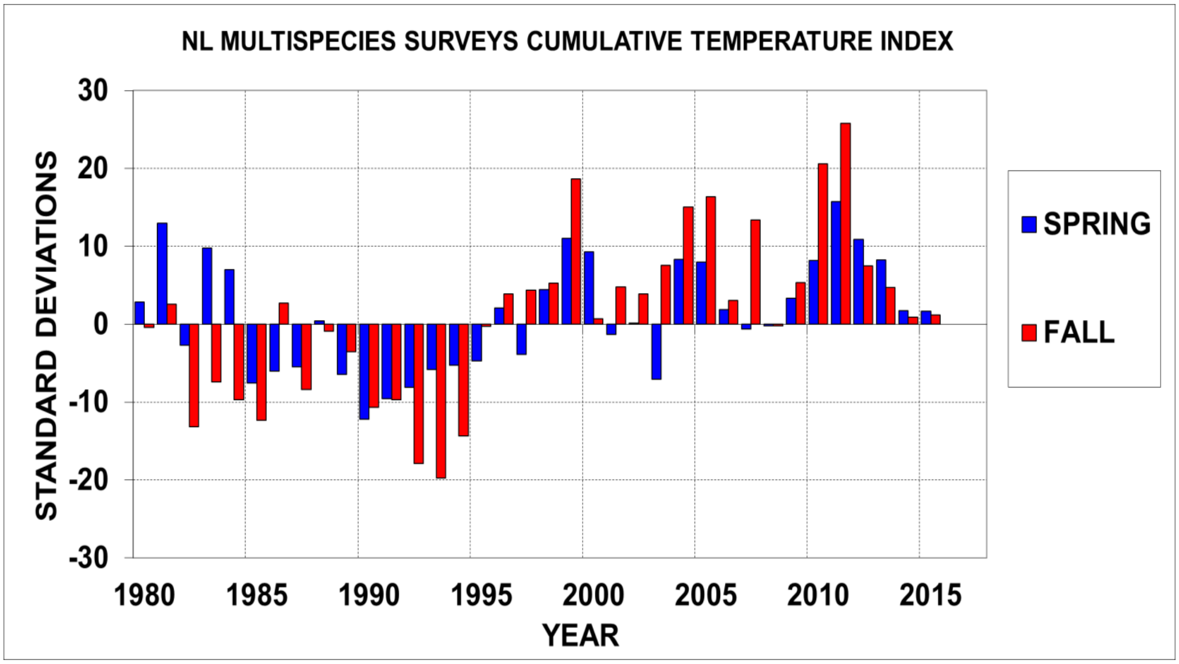

Figure 51. Spring and fall composite temperature index derived by summing the standardized anomalies displayed in Figures 45 and 49.

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 (Figure 52).

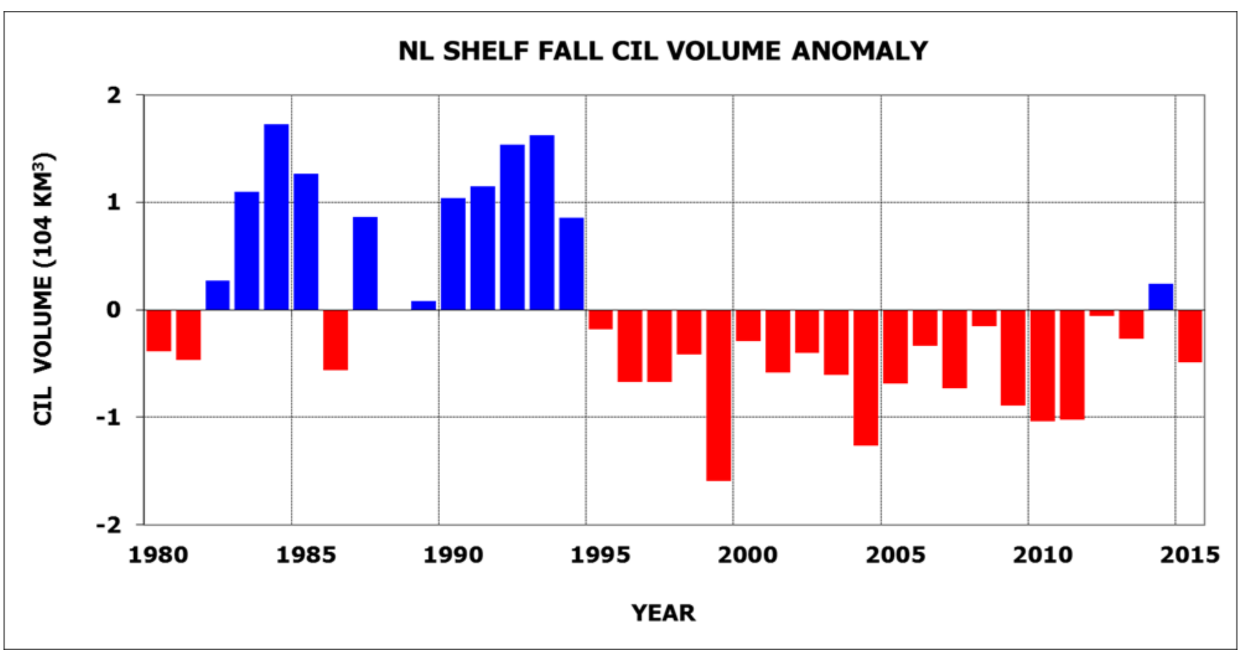

Figure 52. Time series of the CIL (<0°C) volume anomaly on the NL shelf bounded by NAFO Divisions 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

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 also shown in Figure 49 as standardized anomalies. 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 but in 2015 it had returned to a negative value, implying less volume of CIL waters remaining on the shelf by autumn.

SUMMARY

A summary of selected temperature and salinity time series and other climate indices for the years 1950-2015 are displayed in Figure 53 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, the warming trend from late 1990s to 2013 and the recent cooling in 2014 and 2015.

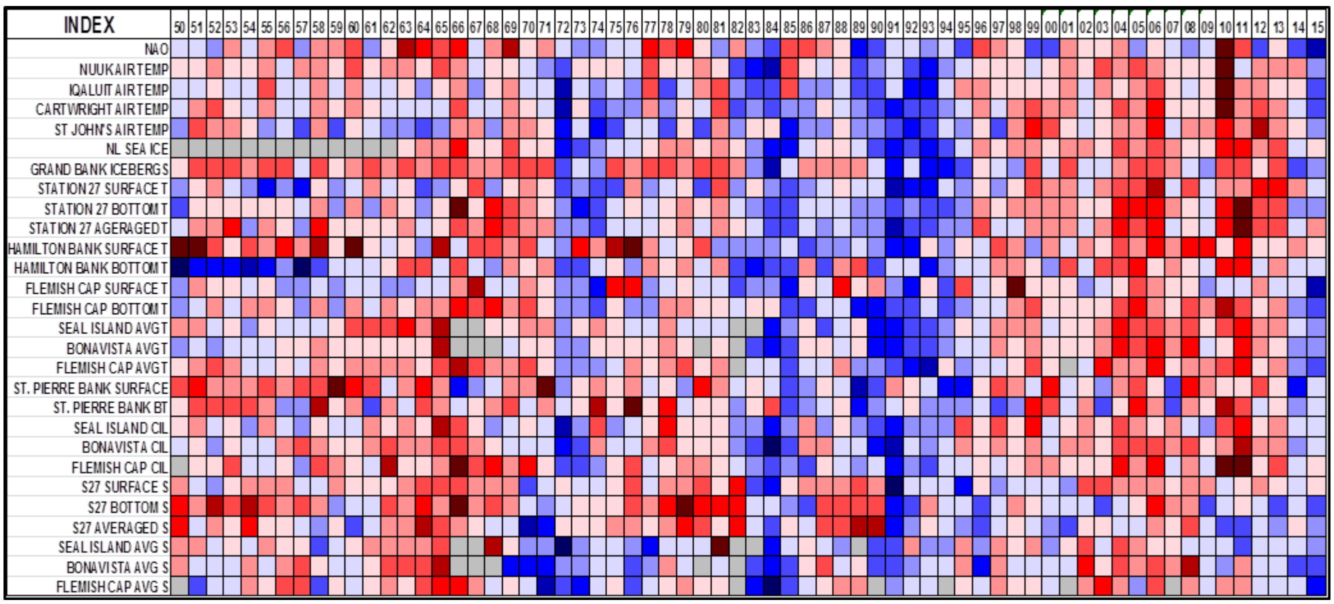

Figure 53. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Figure 3. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells indicate missing data.

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 54).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 with less sea-ice and conversely 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.

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 66-year time series. In 2011 it was very similar to 2010, the 4th highest in 66 years but in 2012 it had decreased to the 8th highest and has continued a trend of decreasing values reaching the 7th lowest in 2015, the lowest (coldest) value since 1993.

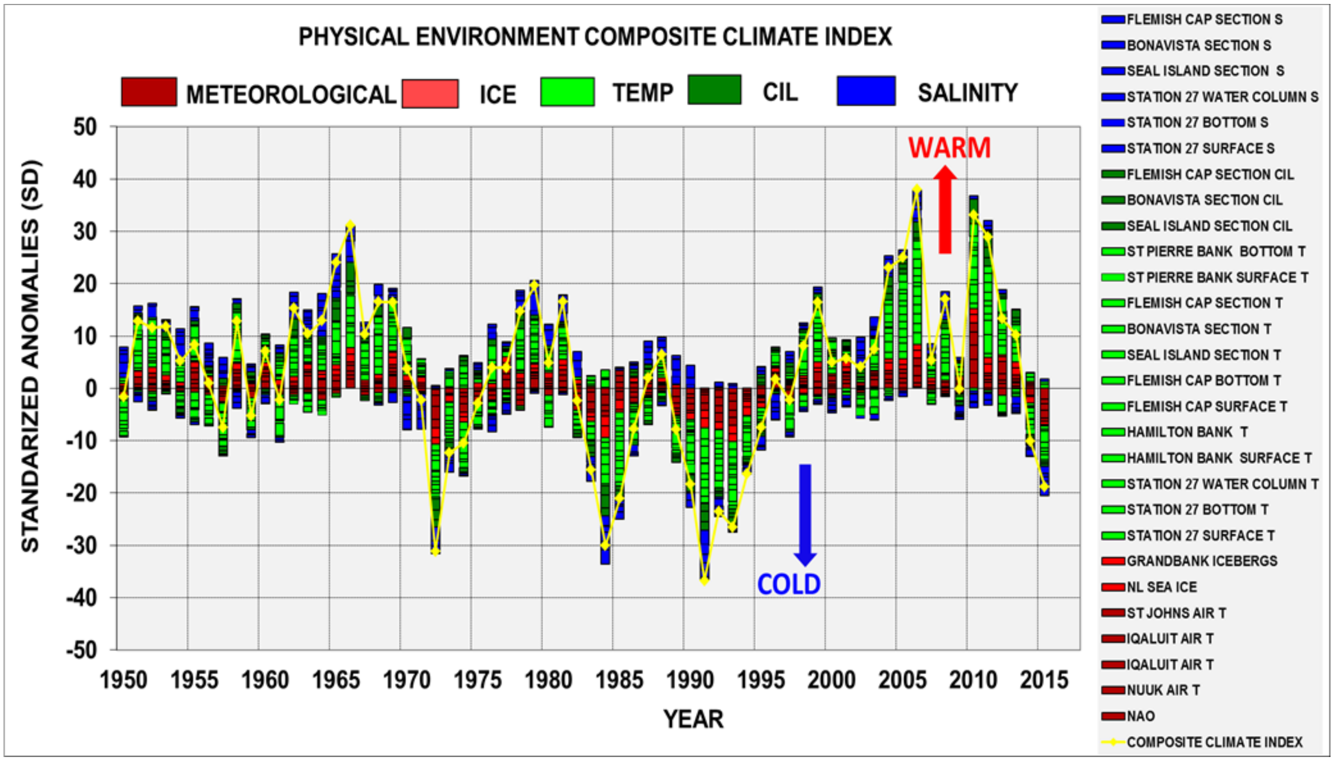

Figure 54. Composite climate index (yellow line) derived by summing the standardized anomalies from Figure 53 together with their individual components.

SUMMARY POINTS FOR 2015

- The NAO Index, a key indicator of climate conditions on the NL Shelf, remained in a positive phase in 2015 at 2 SD above normal, a 120-year record.
- Arctic air outflow during the winter increased over the previous year causing a significant decrease in air temperatures (-0.7 to -1.5 SD below normal) over much of the NL region.
- Sea ice extent on the NL Shelf returned to slightly above normal conditions in 2014 and about normal in 2015 after nearly two decades of lighter than normal conditions.
- 1,165 icebergs were detected south of 48°N on the Northern Grand Bank (0.6 SD above the 1981-2010 mean of 767).
- Annual SST ranged from about normal to as much as 1 SD below normal in some areas of the Northwest Atlantic.
- Annual bottom temperatures (176 m) at Station 27 were -0.2°C (0.7 SD) below normal, the lowest since 1995.
- Annual bottom salinity at Station 27 was -0.1 (1.4 SD) below the long-term mean.
- The area of the CIL (<0°°C) on the Grand Banks during the spring was at its highest level on record (+2.2 SD) but warmed to near-normal by summer and below normal by late fall.

- Spatially averaged spring bottom temperatures in NAFO Division 3P remained above normal by about 0.5°C (0.8 SD).
- Spring bottom temperatures in NAFO Divisions 3LNO were about normal.
- Fall bottom temperatures in 2J and 3K were slightly above normal by 0.2 and 0.7 SD, respectively, but slightly below normal (-0.4 SD) in 3LNO.
- A composite climate index for the NL region decreased to the 7th lowest in 66 years the lowest since 1993.

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