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Newfoundland and Labrador Region

Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2016

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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 2016 is presented as part of the Atlantic Zone Monitoring Program (AZMP). The North Atlantic Oscillation (NAO) Index, a key indicator of the direction and intensity of the winter wind field patterns over the Northwest Atlantic, remained in a positive phase during 2016; however, it was lower than in 2015. In addition, the spatial patterns of the associated atmospheric pressure fields resulted in a reduced arctic air outflow in the northwest Atlantic during the winter months. This resulted in higher than normal winter air temperatures in many areas. Sea ice extent, although above normal during March and April, was below normal overall during 2016. Annual sea-surface temperature trends on the northeast Newfoundland Shelf while showing an increase of about 1oC since the early 1980s were mostly below normal during 2016. The annual bottom (176 m) temperature/salinity at the inshore monitoring site (Station 27) was below normal at -0.7/-1.4 standard deviations (SD), respectively in 2016. Station 27 stratification was slightly below normal by -0.3 SD and the mixed-layer depth was deeper than normal by 0.5 SD. The cold-intermediate layer (CIL; volume of <0°C) during 2016 was below normal off southern Labrador (2J) but near normal on the northeast Newfoundland Shelf and Grand Bank (3KL). The volume of CIL water during the fall in the Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J3KL from multi-species net-mounted CTD deployments was below normal. The spatially averaged spring bottom temperature in 3Ps was about 1°C (2 SD) above normal, a 33-year record, while in 3LNO it was about normal. The spatially averaged bottom temperature during the fall in 2J and 3K show an increasing trend since the early 1990s of about 1°C, reaching a peak of >2 SD above normal in 2011 and remaining above normal in 2016 by 0.5 and 0.3°C, respectively. A standardized composite climate index for the Northwest Atlantic derived from meteorological, ice and ocean temperature and salinity time series since 1950 reached a record low value in 1991. Since then it shows an increasing trend with mostly above normal values except for 2014 and 2015, the latter being the 7^{th} lowest in 67 years and the lowest value since 1993. During 2016, the composite climate index returned to above normal conditions.

Évaluation de l’environnement océanographique physique sur la plateforme continentale de Terre-Neuve-et-Labrador en 2016

RÉSUMÉ

Un survol des conditions océanographiques physiques pour la région de Terre-Neuve et Labrador en 2016 sont présentés dans le cadre du Programme de Monitorage de la Zone Atlantique (PMZA). L'indice de l'oscillation Nord-Atlantique (NAO), un indicateur clé pour la direction et l'intensité des champs de vents hivernaux au-dessus de l'Atlantique nord-ouest, est demeuré positif en 2016, bien que plus faible qu'en 2015. Les champs de pression atmosphérique associés à l'indice NAO ont causé une réduction des vents circulant de l'Arctique vers l'Atlantique Nord-Ouest en hiver, causant des températures hivernales au-dessus des normales sur plusieurs régions. L'étendue des glaces, bien qu'au-dessus des normales en mars et avril, a été au-dessous des normales sur l'ensemble de 2016. Malgré la hausse observée de 1oC depuis le début des années 1980, la température de surface de l'eau au nord-est du plateau Terre-Neuvien a été sous les normales en 2016. Au site d'observation côtier Station 27, la température et la salinité de fond (176m) ont été sous la normale en 2016, respectivement de -0,7 et -1,4 écart-type (É.T.). La stratification à la Station 27 a été quelque peu sous la normale de -0,3 É.T., et la couche mélangée de surface plus profonde de 0,5 É.T. Le volume de la couche intermédiaire froide (CIF; définie par des température <0°C) en 2016 a été sous la normale au large de la partie sud du Labrador (zone NAFO 2J), mais près des normales sur les Grands Bancs et la partie nord-est du plateau Terre-Neuvien (zones 3KL). Le volume de la CIF tel que mesuré en automne lors des relevés multi-espèces dans les zones 2J3KL a été sous la normale. Alors que les moyennes spatiales des températures de fond au printemps dans les zones 3LNO étaient à peu près normales, elles ont été près de 1oC (2 É.T.) au-dessus de la normale dans les zones 3Ps, un record des 33 dernières années. À l'automne, ces mêmes températures de fond dans les zones 2J et 3K se sont réchauffées d'environ 1°C depuis 1990, atteignant un sommet de 2 É.T. au-dessus des normales en 2011. En 2016, elles étaient au-dessus des normales respectivement par 0,5 et 0,3oC. L'indice-composite standardisé du climat de l'Atlantique nord-ouest est calculé à partir des données météorologiques, de glace et de température et de salinité de l'océan depuis 1950. Depuis son niveau le plus bas en 1991, cet indice a affiché une tendance à la hausse, avec presque toujours des valeurs au-dessus des normales, sauf en 2014 et 2015 (7e valeur la plus basse en 67 ans et la plus basse depuis 1993). En 2016, cet indice-composite est retourné à des valeurs normales.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Figure 1) during 2016 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. 2017; Hebert et al. 2017[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.

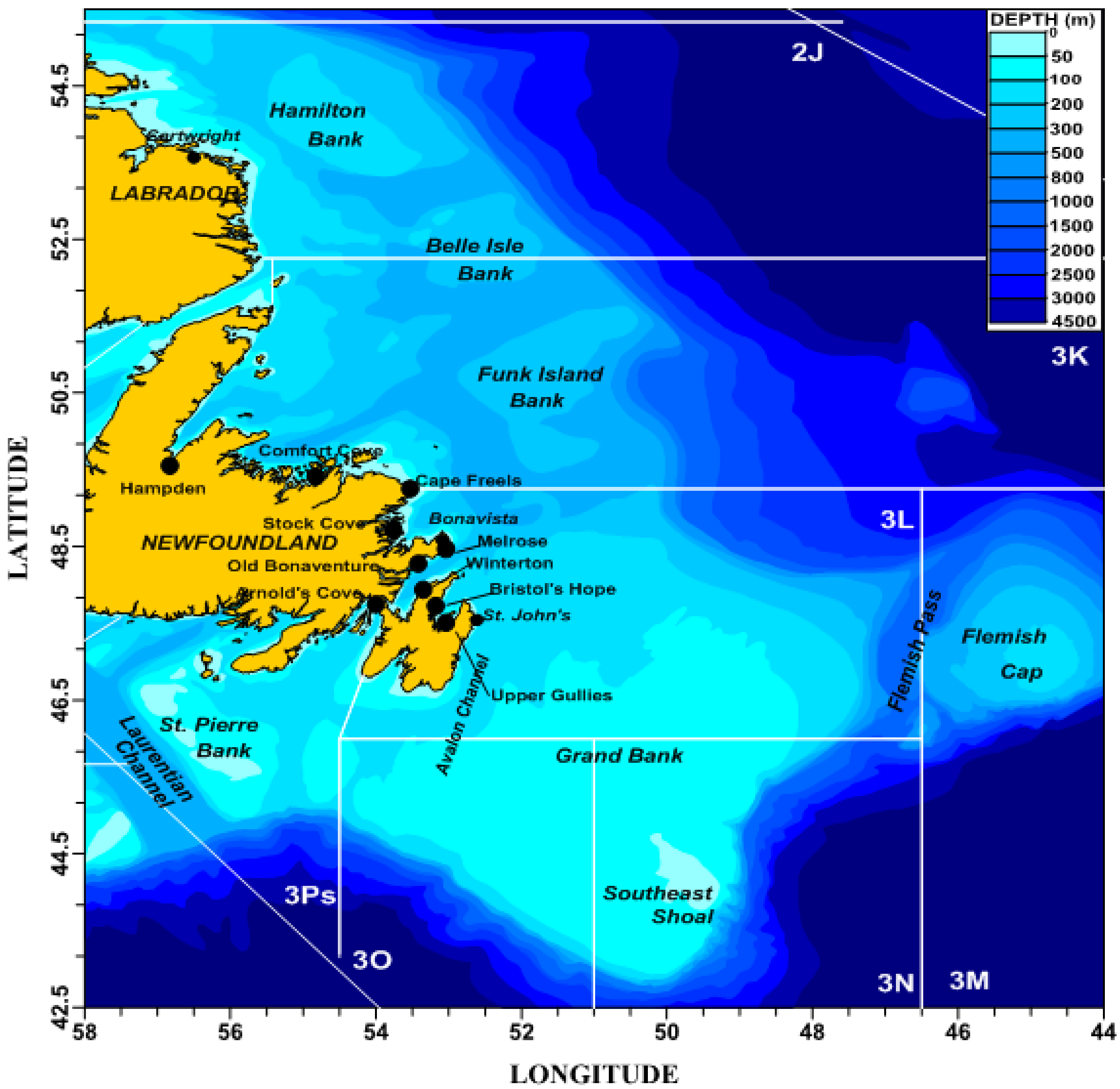

Figure 1. Map showing Northwest Atlantic Fisheries Organization (NAFO) Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

[1]Hebert, D., Pettipas, R., Brickman, D., and Dever, M. 2017. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2016. DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

The information presented for 2016 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.

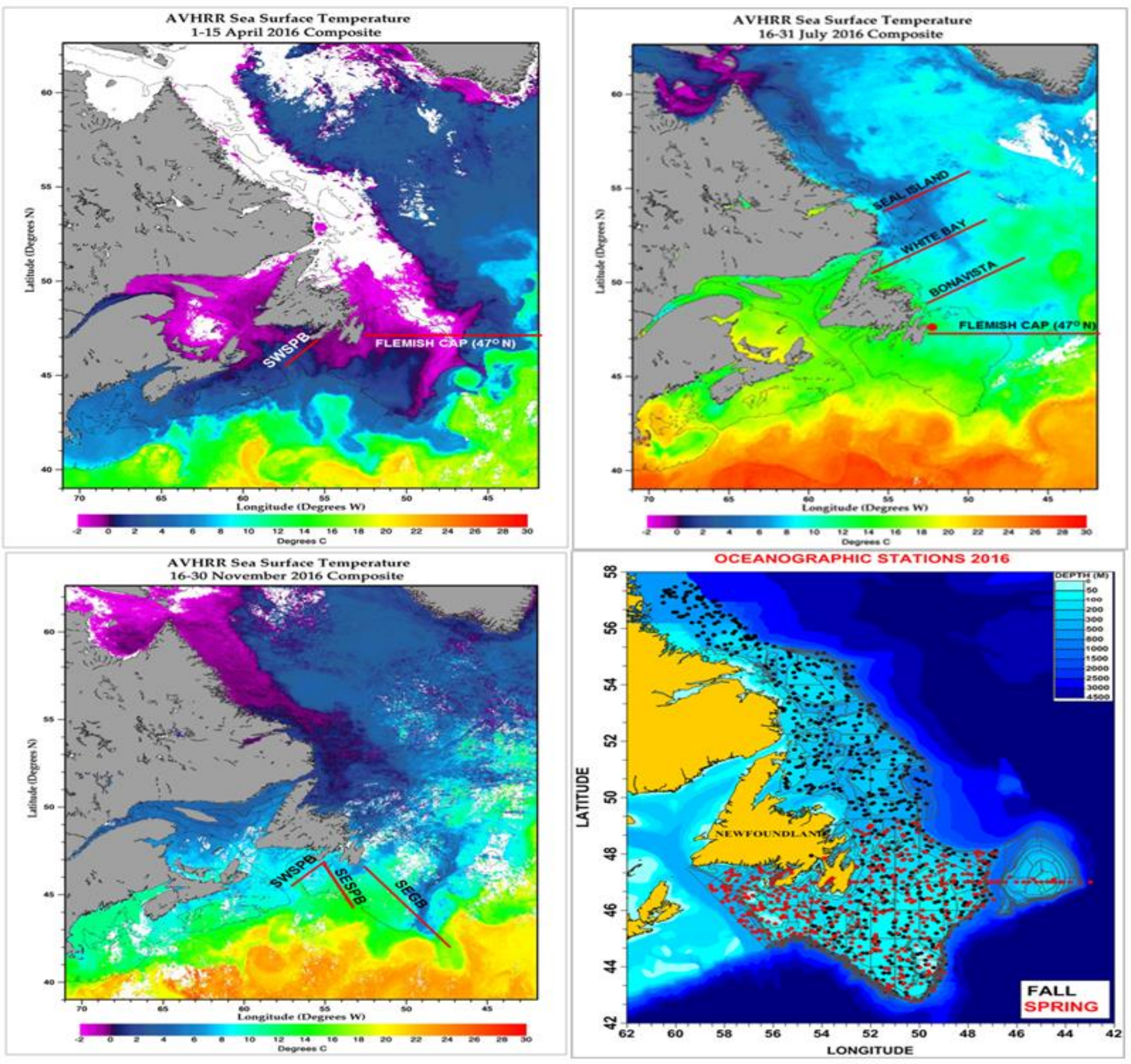

Figure 2. Map showing spring, summer, and fall AZMP section occupations along with Sea-Surface-Temperature (SST) during 2016. The lower right panel shows the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2016. (SST map courtesy of the Marine Ecosystem Section, Bedford Institute of Oceanography [BIO]).

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 2015 was presented in Colbourne et al. (2016).

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 2016. It is recognized that monthly and annual estimates of anomalies that are based on a varying number of observations may only approximate actual conditions; therefore, caution 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. For example, a value of 2 indicates that the index was 2 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 2016 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.

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

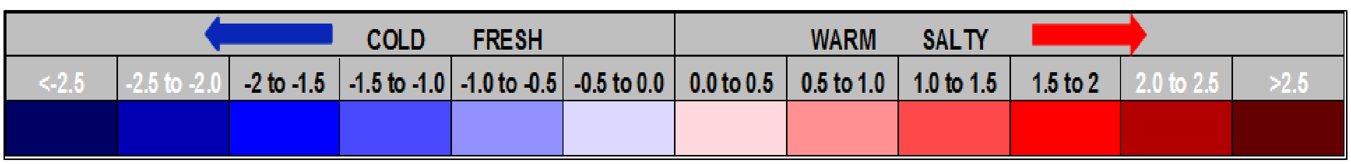

Figure. 3. Standardized anomaly colour coding scale in units of 0.5 SD.

METEOROLOGICAL AND SEA-ICE CONDITIONS

The North Atlantic Oscillation (NAO) index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is often a measure of the strength of the winter westerly and north westerly winds over the Northwest Atlantic. A high (positive phase) NAO index occurs from an intensification of the Icelandic Low and Azores High. This favours strong northwest winds, cold air and sea temperatures and heavy ice conditions on the NL Shelf regions (Colbourne et al. 1994; Drinkwater 1996, Petrie et al. 2007).

However, there are exceptions to this response pattern (e.g. 1999 and 2000) due to shifting locations in the sea level pressure (SLP) features. In 2016 the NAO value was 0.5 SD above normal, a significant decrease over the 120 year record high set in 2015 at 2 SD above normal. In 2010 it was at a record low of 2.9 SD below normal. The similar, but larger scale Arctic Oscillation also decreased over the 2015 value to about normal. As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2016 decreased over the previous year, resulting in higher winter air temperatures over much of the Newfoundland and Labrador and adjacent shelf regions.

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 as winter and annual 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 2016 increased over the previous year with all sites except Cartwright reporting above normal values ranging from 0.5 to 1.3 SD above normal. The predominance of warmer-than-normal air temperatures at all sites from the mid-1990s to 2013 are evident with values in 2010 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 above normal in 2016 after decreasing to the lowest value since 1994 in 2015 (Figure 6).

LOCATION/INDEX	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MEAN	SD
ARCTIC OSCILLATION (AO)	-0.6	-0.2	-0.4	0.2	0.3	-1.3	-1.8	-0.9	-0.4	2.7	1.3	0.4	1.1	1.8	-0.4	0.7	-1.1	-0.1	-0.8	0.6	1.1	-1.3	0.5	-0.6	-1.0	0.1	-0.8	1.0	0.9	0.3	-3.4	-0.9	0.7	-1.1	0.2	0.6	-0.1	N/A	N/A
(ICELAND-AZORES) NAO	-0.4	0.6	-0.6	0.8	1.2	-1.2	-1.1	-1.0	-0.5	1.6	1.1	0.4	0.3	0.9	0.4	1.3	-1.4	-0.6	-0.3	1.2	1.1	-0.9	-0.3	-0.3	-1.0	0.5	-0.3	0.3	0.5	0.2	-2.9	-1.2	1.3	-0.4	1.3	2.0	0.5	20.44	8.77
NA SST (AMO)	0.0	-0.1	-0.2	-0.1	-0.2	-0.3	-0.3	0.1	**0.0**	-0.1	0.0	-0.1	-0.2	-0.2	-0.2	0.1	-0.1	0.1	0.4	0.1	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.1	0.0	0.4	0.1	0.2	0.2	0.1	0.1	0.3	N/A	N/A
NUUK WINTER AIR T	1.2	0.5	-0.2	-2.0	-2.3	1.1	1.0	0.0	0.8	-1.3	-0.6	-0.2	-0.8	-1.8	-0.4	-0.9	0.7	-0.2	0.0	-0.2	0.0	0.5	-0.2	0.9	0.7	1.2	0.9	1.0	-0.7	0.6	1.8	0.3	-0.1	1.1	0.3	-0.9	1.0	-8.41	3.16
IQALUIT WINTER AIR T	1.3	2.3	0.2	-1.6	-1.2	1.1	0.6	-0.6	0.1	-1.5	-0.8	-1.4	-0.6	-1.7	-0.5	0.0	0.3	0.2	-0.5	0.0	0.3	0.5	0.0	0.5	0.9	-0.3	0.6	1.2	-0.7	0.1	2.2	2.1	0.2	1.2	0.8	-1.3	0.6	-25.68	3.05
CARTWRIGHT WINTER AIR T	0.8	1.9	-0.6	-0.6	-0.8	0.4	-0.1	0.5	-0.2	-1.0	-1.2	-1.4	-1.5	-1.5	-1.0	-0.8	0.6	0.2	0.8	0.4	0.3	0.0	0.4	0.2	1.7	0.0	0.7	0.9	-0.8	0.2	2.8	2.1	**0.0**	1.2	-0.6	-1.7	0.0	-12.13	2.56
BONAVISTA WINTER AIR T	0.2	1.4	-0.6	0.4	0.3	-0.8	-0.1	-0.1	0.4	-1.1	-1.7	-0.8	-1.1	-1.7	-1.7	-0.4	1.0	-0.8	0.6	1.9	1.2	0.3	0.1	-1.1	0.8	0.3	1.5	0.2	-0.1	0.4	1.5	1.2	0.7	1.0	-1.0	-0.5	0.7	-3.96	1.47
ST. JOHN'S WINTER AIR T	-0.1	1.3	-0.8	0.9	0.7	-1.0	0.0	-0.4	0.3	-1.4	-2.1	-1.1	-1.7	-1.5	-1.2	-0.8	0.4	0.2	0.2	1.2	1.4	-0.6	0.2	-0.6	0.9	0.7	1.6	0.2	-0.1	1.1	1.2	2.4	1.2	0.9	-0.6	-0.6	0.8	-4.00	1.43
NUUK ANNUAL AIR T	0.6	0.1	-1.0	-1.8	-2.0	1.2	0.1	0.0	0.3	-1.2	-0.7	-0.4	-1.4	-1.6	-0.6	-0.2	0.4	0.1	0.2	-0.2	0.4	0.8	0.2	1.3	0.6	1.1	0.7	0.5	0.2	0.5	2.6	-0.3	0.9	0.6	0.5	-1.0	1.3	-1.37	1.53
IQALUIT ANNUAL AIR T	1.0	2.4	-1.5	-2.6	-1.9	1.9	-1.3	-1.3	-0.2	-1.9	-1.2	-0.5	-1.7	-1.7	-0.4	0.5	0.5	0.3	0.2	0.1	0.4	0.6	-0.1	0.8	0.1	0.9	1.4	0.2	-0.1	0.5	2.7	0.5	0.6	0.2	0.4	-1.3	0.5	-9.07	1.76
CARTWRIGHT ANNUAL AIR T	-0.2	1.4	-1.7	-0.7	-1.4	-0.8	-1.2	0.6	-0.4	-0.8	-1.3	-1.6	-1.4	-1.3	-0.6	-0.3	0.5	-0.3	0.6	1.1	0.5	0.6	-0.3	0.4	1.1	0.9	1.8	0.1	0.1	0.4	2.5	0.7	1.4	0.5	0.0	-1.2	-0.3	0.05	1.32
BONAVISTA ANNUAL AIR T	-1.0	0.7	-1.0	0.1	-0.4	-1.4	-0.9	-0.2	0.2	-0.2	-0.6	-1.8	-1.8	-1.8	-0.7	-0.7	0.6	-0.9	0.6	1.5	0.8	0.6	-0.1	0.5	1.0	1.2	1.7	0.0	0.7	0.5	1.6	0.8	1.7	1.1	0.5	-0.5	0.6	4.71	0.89
ST. JOHN'S ANNUAL AIR T	-1.2	1.0	-1.0	0.5	0.2	-1.7	-1.0	-0.5	0.2	-0.6	-0.5	-1.4	-1.7	-1.5	-0.5	-0.7	0.3	-1.1	0.6	1.9	1.0	0.3	-0.4	0.4	0.6	0.7	1.6	-0.1	0.8	0.9	1.7	0.6	2.3	0.8	0.4	-1.0	0.7	5.03	0.84
NL SEA-ICE EXTENT (Annual)	-0.3	-0.9	-0.2	0.9	1.8	1.9	0.3	-0.1	-0.1	0.3	1.2	1.6	1.3	1.6	1.1	0.1	-0.9	-0.2	-0.5	-0.7	-0.4	-0.9	-0.5	-0.2	-1.4	-0.9	-1.4	-0.6	-0.3	-0.1	-1.6	-1.7	-0.9	-1.4	0.2	-0.1	-0.4	74179	33578
NL SEA-ICE EXTENT (Winter)	-0.2	-0.8	-0.6	0.4	1.8	1.8	0.6	-0.1	**0.0**	0.7	1.1	1.1	1.3	1.7	1.3	0.4	-0.5	0.1	-0.7	-0.5	-0.3	-0.9	-0.6	-0.2	-1.7	-0.7	-1.3	-0.9	-0.1	-0.4	-1.9	-1.9	-0.9	-1.5	0.4	0.0	-0.4	196477	81320
NL SEA-ICE EXTENT (Spring)	-0.4	-1.0	0.2	1.6	1.6	1.9	-0.4	-0.1	-0.4	-0.2	0.9	1.9	1.2	1.5	1.0	-0.2	-1.2	-0.4	-0.1	-0.9	-0.6	-0.8	-0.5	0.0	-0.9	-1.2	-1.5	-0.1	-0.6	0.5	-1.1	-1.4	-0.7	-1.1	0.1	-0.1	-0.1	92547	52253
ICEBERG COUNT	-1.1	-1.1	-0.9	0.9	2.2	0.5	-0.9	-0.7	-0.9	-0.7	0.0	1.9	0.2	1.5	1.5	1.0	-0.2	0.4	1.0	-1.1	0.1	-1.0	0.2	0.2	-0.8	-1.2	-1.2	-0.7	0.3	0.7	-1.2	-1.2	-0.4	-1.2	1.2	0.6	-0.1	767	649

Figure. 4. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1980 to 2016.

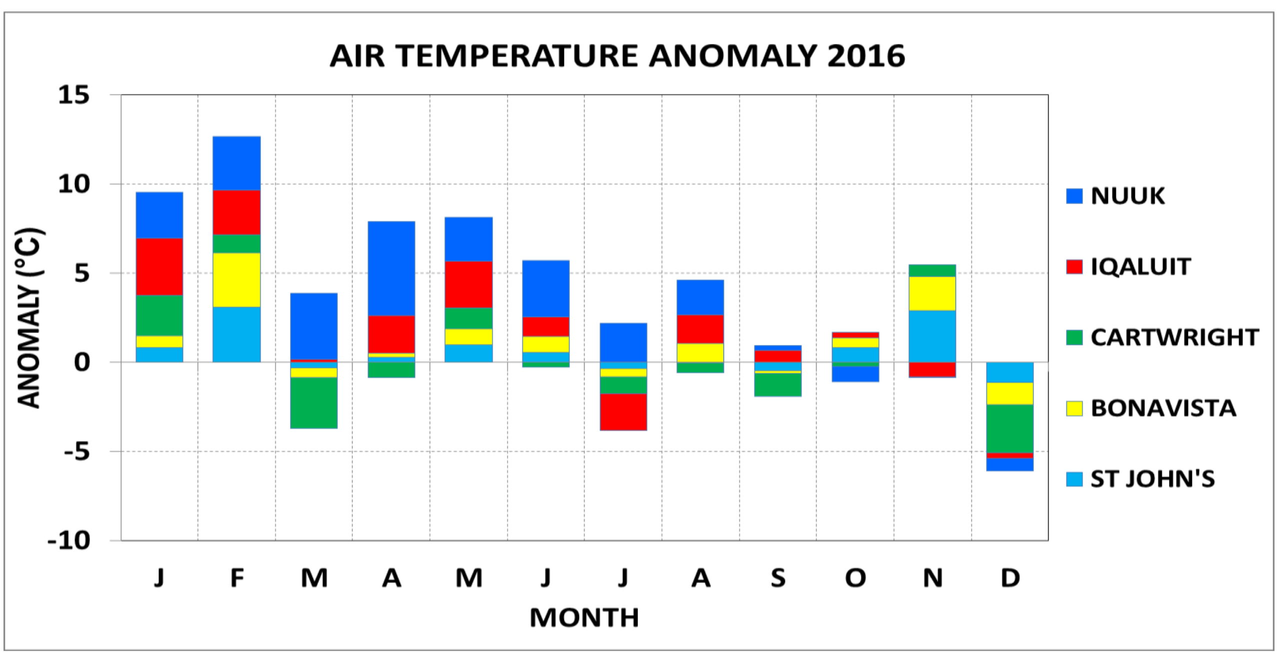

Figure. 5. Cumulative monthly air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's for 2016.

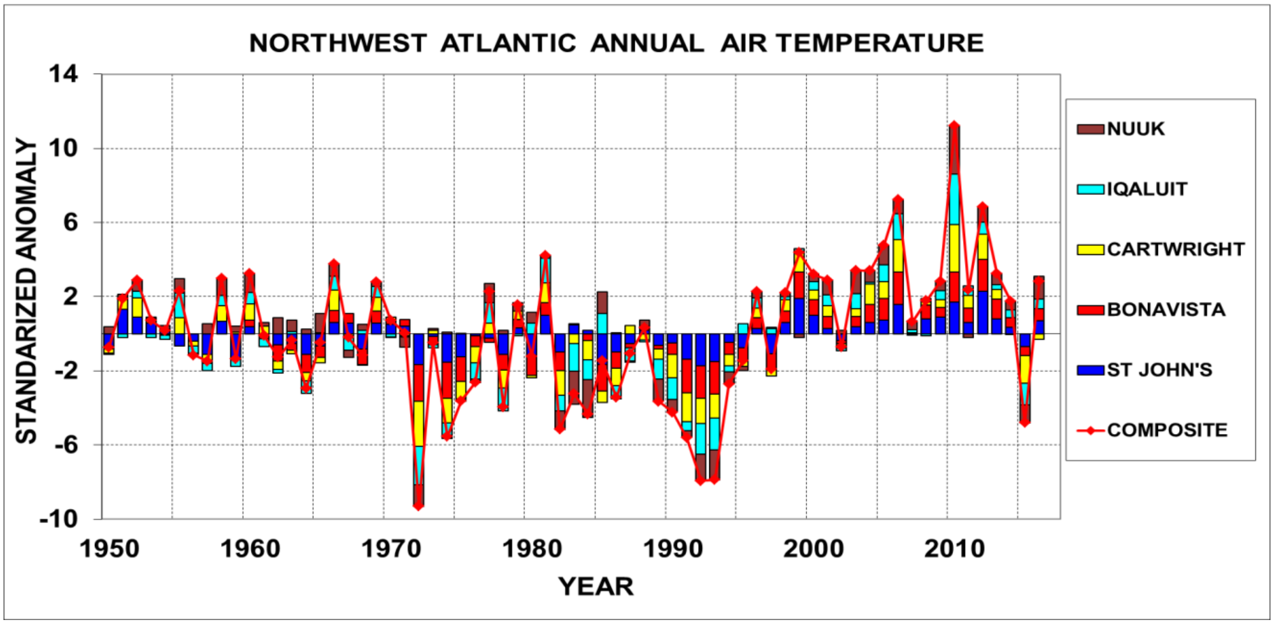

Figure. 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

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, about normal in 2015 but slightly below normal again in 2016 (Figures 4 and 7). However, it is noted that the sea ice extend during the past 3-years have all been within ±0.5 SD and not considered significant in the long term. In 2011 sea ice extent decreased to a 49-year record low of -1.7 SD. Monthly values during 2016 show below normal conditions during January and February but about normal during the remainder of the ice season (Figure 8). More information on the spatial extent and duration of sea ice on the NL shelf is presented in Hebert et al. (2017) [1].

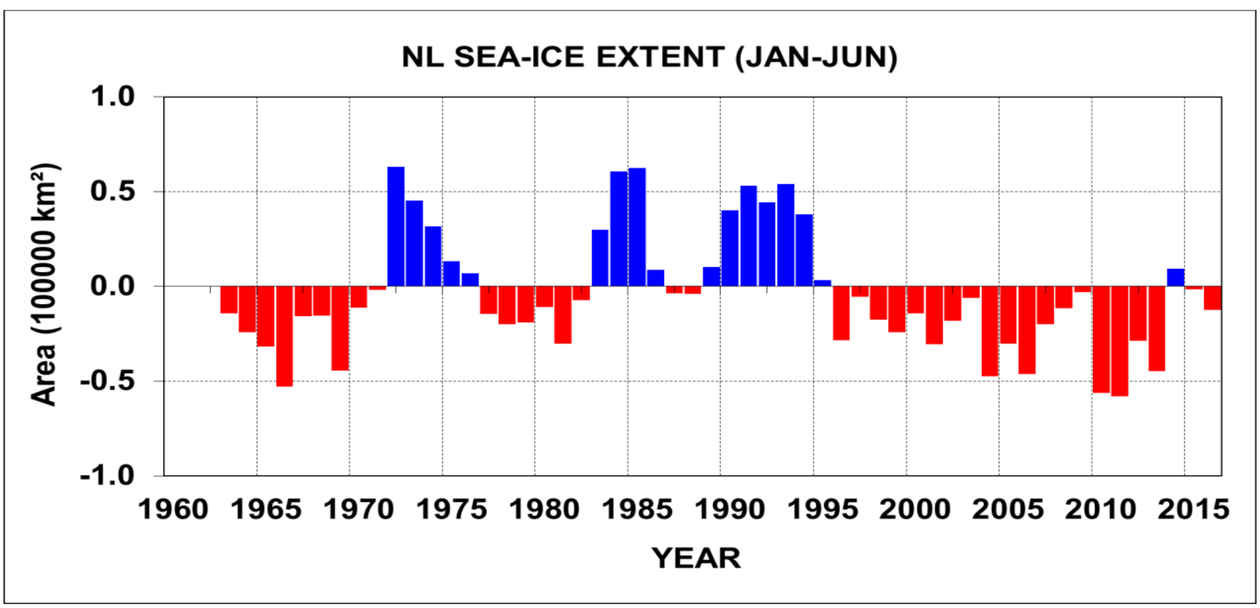

Figure. 7. Seasonal (January-June) sea ice extent (defined by 1/10 coverage) anomalies on the NL Shelf between 45-55ºN latitude.

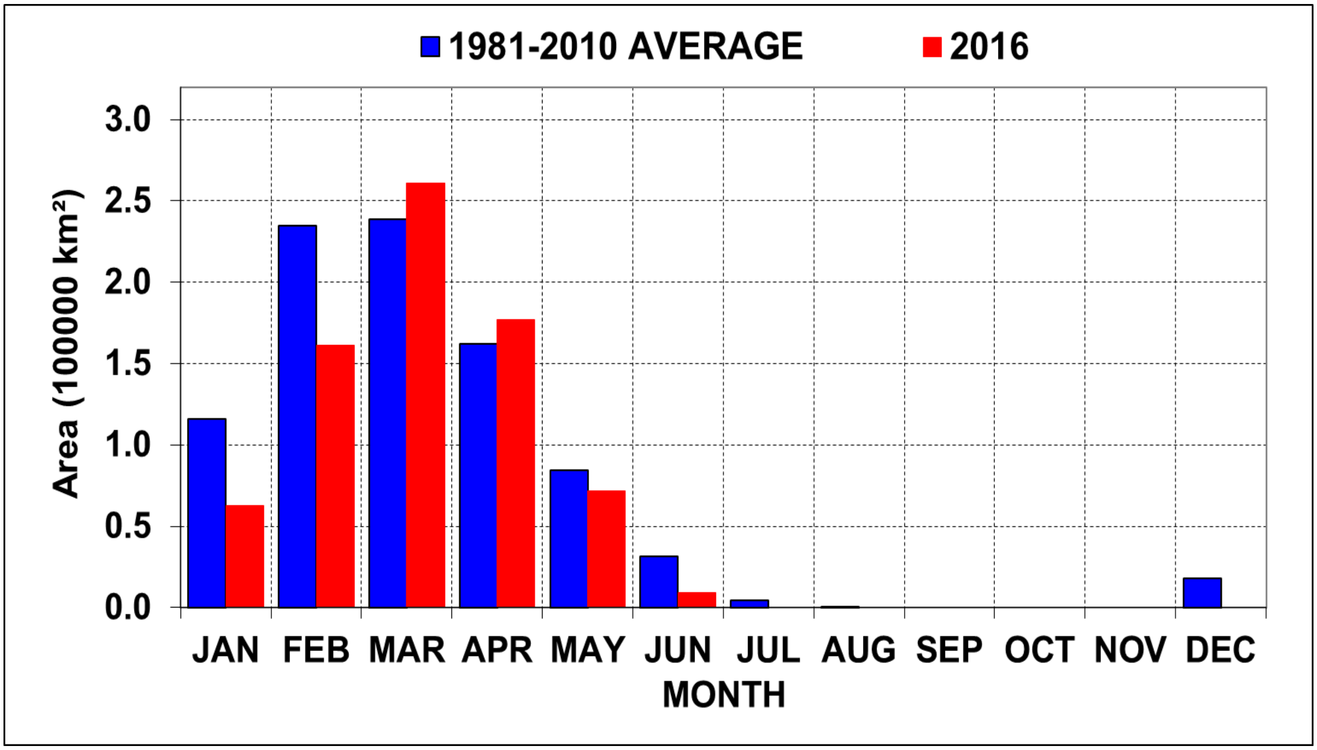

Figure. 8. Monthly sea ice extent (defined by 1/10 coverage) on the NL Shelf between 45-55ºN latitude.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 687 (-0.1 SD) icebergs drifted south of 48°N onto the Northern Grand Bank during 2016, down from 1165 in 2015. There were only 13 in 2013, 499 in 2012 and only 3 in 2011 and one in 2010. The 117 year average is 487 and that for the 1981-2010 is 767.

In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48°N with an all-time record of 2202 in 1984. Only 2 years (1966 and 2006) in the 117 year time series reported no icebergs having drifted south of 48°N.

Years with low iceberg numbers on the Grand Banks generally correspond to higher than normal air temperatures, lighter than normal sea-ice conditions and warmer than normal ocean temperatures on the NL Shelf (Figure 9). Monthly iceberg numbers during 2016 show mostly below normal counts except for March when there were 64 more than average in that month (Figure 10).

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 as the warmest in the time series. There was a significant decline in recent years with 2015 showing colder than normal conditions similar to 1994 but conditions returned to above normal again during 2016 (Figure 11).

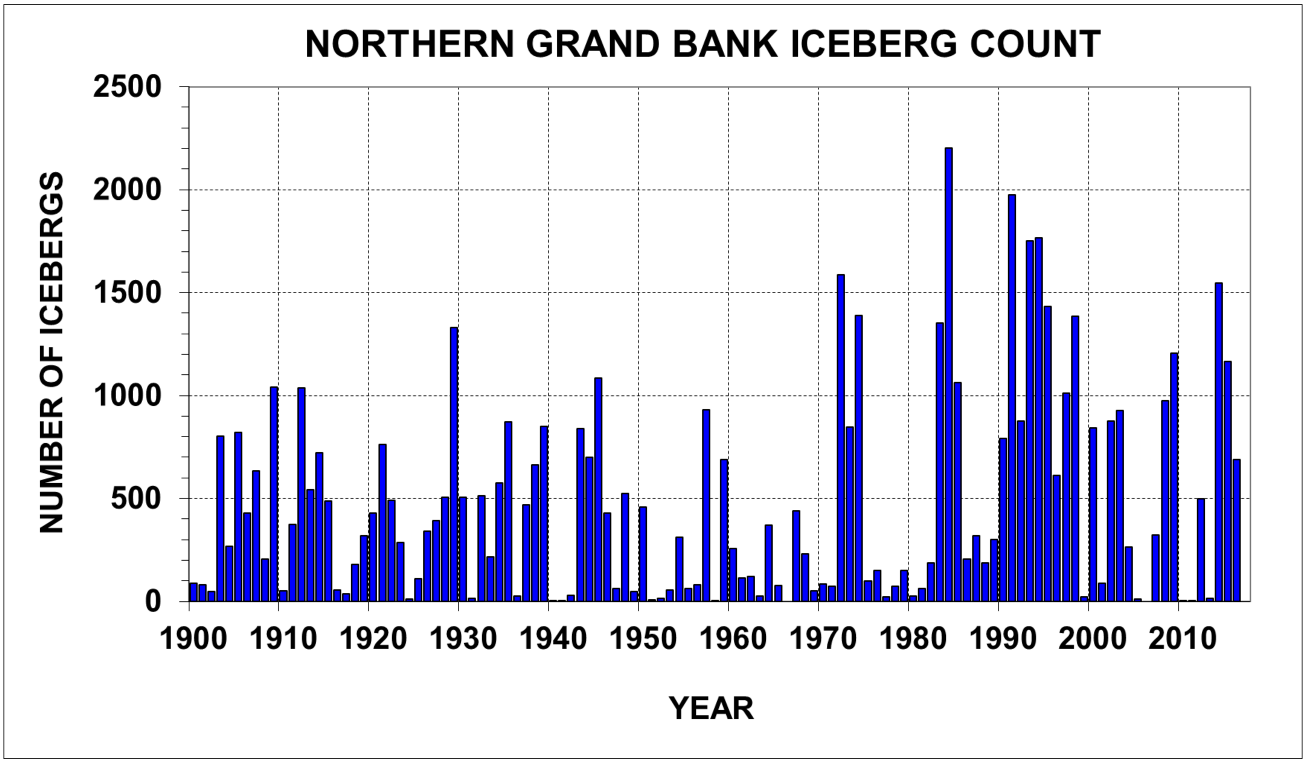

Figure. 9. Annual iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP of the USCG).

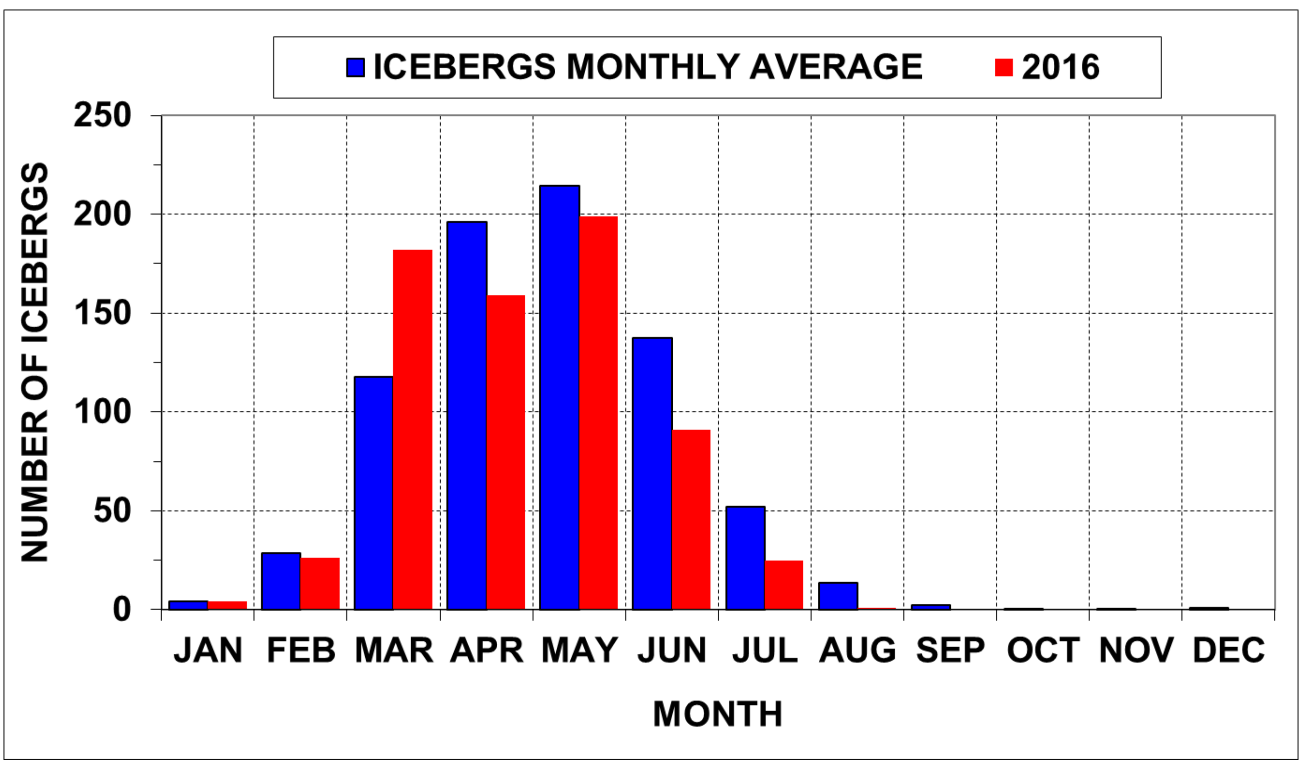

Figure. 10. Monthly iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP if the USCG).

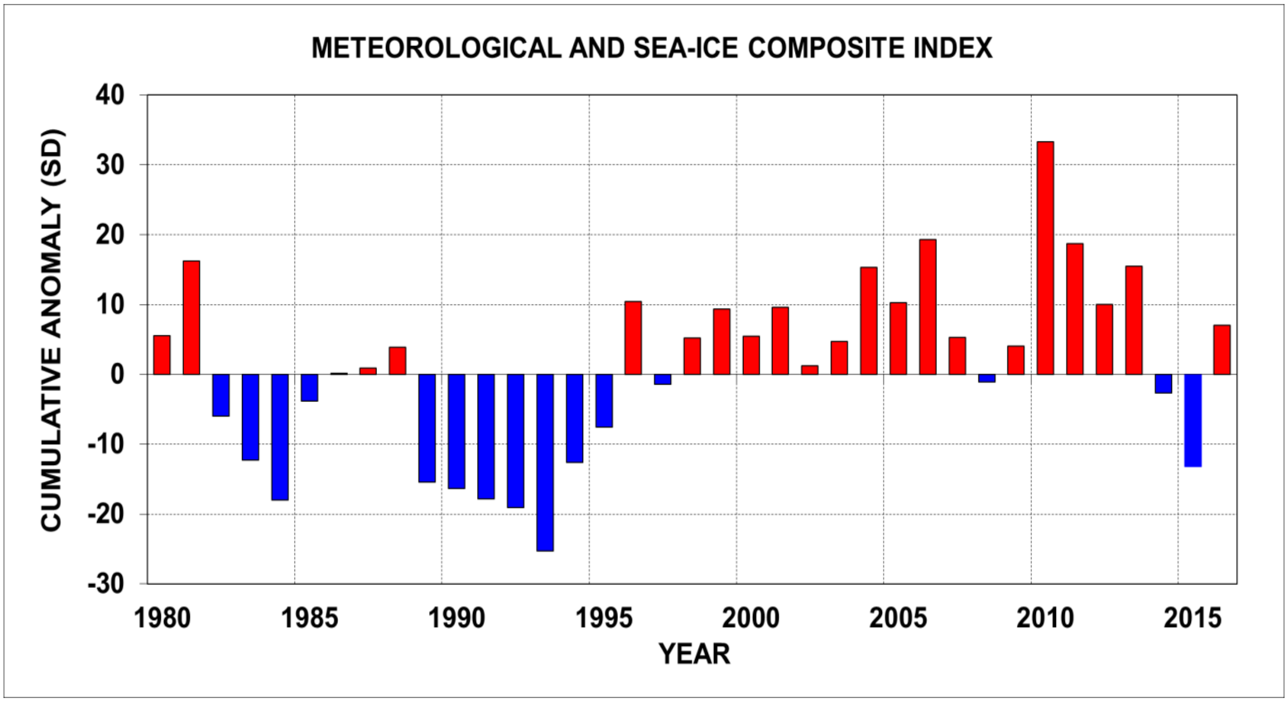

Figure. 11. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 4.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

The 4 km resolution Pathfinder 5.2 sea SST database (Casey et al. 2010) was used to provide annual estimates of the SST within defined sub-areas (Figure 12) in the Northwest Atlantic from southern Newfoundland to Hudson Strait. We used this data set from 1981 to 2010 and in more recent years (2011-16) we use data from NOAA and EUMETSAT satellite provided by the remote sensing group in the Marine Ecosystem Section at the BIO.

A least squares fit of the Pathfinder and NOAA temperatures during the period (1997-2012) is given by SST (Pathfinder) = 0.989*SST (NOAA) -0.02 with an r^2=0.98 (Hebert et al. (2017) [1]. The recent 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. Data were not available for every month in some of the northern areas due to sea ice cover.

Monthly SST anomalies for 16 areas from West Greenland to Hudson Strait to Green and St. Pierre Banks off southern Newfoundland are presented in Figures 13 and 14 and in Figures 15 and 16 as standardized annual values. Monthly values varied about the mean in most areas with the most significant negative anomalies occurring offshore in the Flemish Cap area during May to July, while the largest and most widespread positive anomalies occurred on the Grand Banks during November. Annual values were mostly above normal in northern areas, and either near normal or below normal in other areas. The exception was St. Pierre Bank where they were about 0.8 SD above normal.

A composite index together with individual series shows an increasing trend (~2°C) in SSTs since the early part of the time series with near-decadal oscillations superimposed (Figure 16). Overall, 2012 was the 2nd highest in the series after 2006 and the 5 warmest years in the series have occurred in the past 12 years. However, since 2012 the composite index shows a significant decreasing trend with the 2015 value the coldest since 1993. Overall SST conditions recovered slightly in 2016 but remained below normal in many areas (Figure 16).

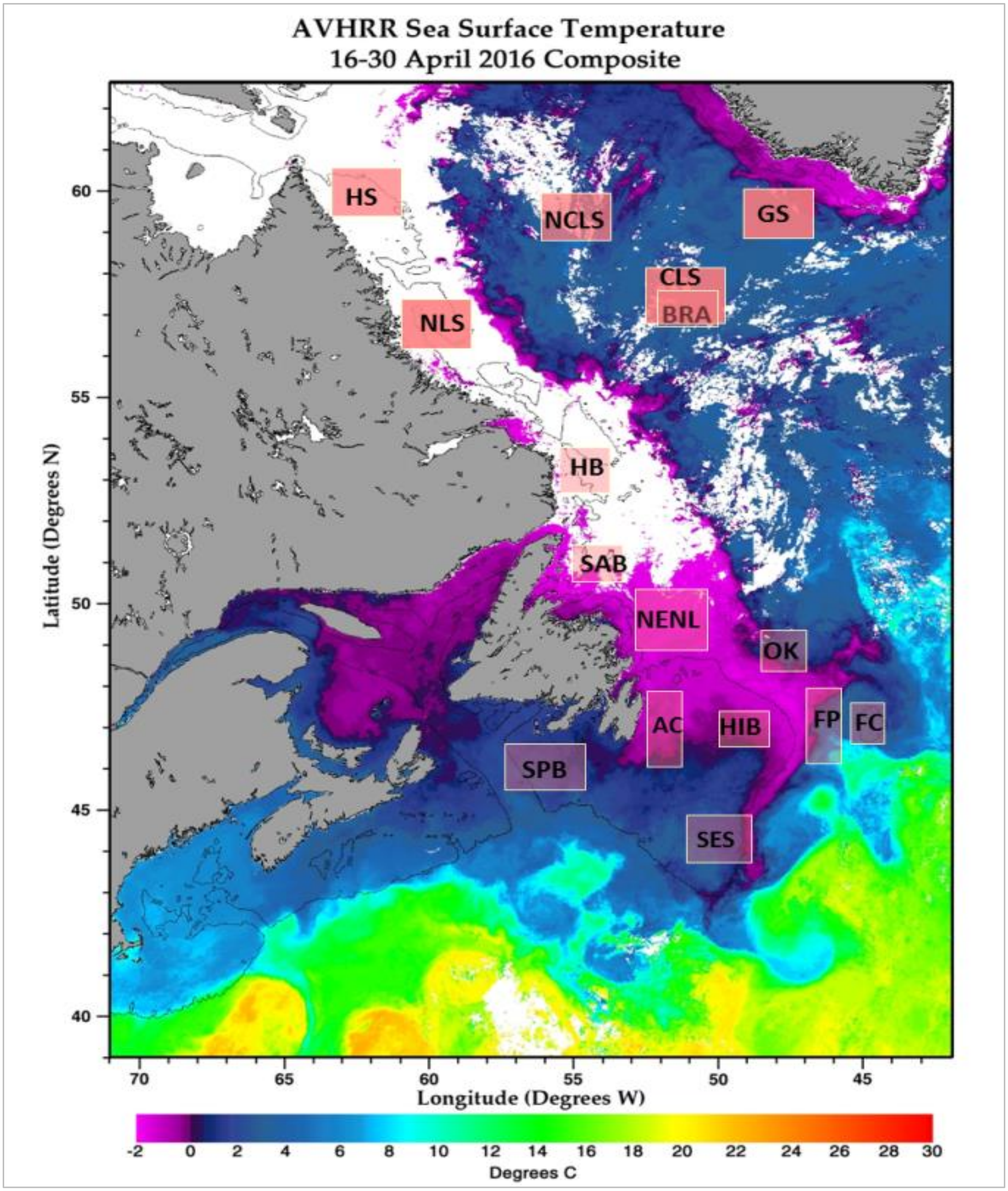

Figure. 12. Map showing the April 16-30 SST and sea-ice extent and the subareas where SST time series were constructed for the Northwest Atlantic. (SST map courtesy of the Marine Ecosystem Section, BIO).

REGION	J	F	M	A	M	J	J	A	S	O	N	D
WEST GREENLAND SHELF (GS)	-0.4	0.6	-0.3	0.6	0.4	0.7	0.2	3.0	1.8	2.2	1.1	0.4
NORTH CENTRAL LAB SEA (NCLS)	-1.5	-1.4	-0.5	0.6	1.1	1.6	1.1	2.4	1.2	0.8	-0.4	-0.9
CENTRAL LAB SEA (CLS)	-0.6	-0.1	0.4	0.4	0.5	1.8	1.4	1.4	0.1	0.2	-0.2	-0.7
BRAVO (BRA)	-0.2	-0.6	0.5	0.5	0.4	1.8	1.6	1.2	-0.3	0.1	-0.3	-0.4
HUDSON STRAIT (HS)	-0.9				-0.5	1.0	-1.1	0.0	0.1	0.6	-0.1	-0.7
NORTHERN LAB SHELF (NLS)	-0.3			-0.2	-0.4	0.5	0.7	1.2	-0.3	0.1	0.4	-0.2
HAMILTON BANK (HB)	-0.4		-0.4	-0.7	0.3	0.8	-0.3	-0.4	-0.8	-0.3	0.3	-0.2
ST ANTHONY BASIN (SAB)	-0.4	-0.6	-0.3	-0.6	-0.3	-0.8	-0.6	0.8	-0.6	0.1	0.6	0.2
NE NF SHELF (NENS)	0.1	-0.3	-0.4	-0.5	-0.7	-1.1	-1.2	0.6	-0.9	0.1	1.4	0.0
ORPHAN KNOLL (OK)	0.5	0.1	-0.2	-1.1	-1.2	-1.0	-1.1	0.3	0.0	0.6	1.8	0.3
FLEMISH CAP (FCAP)	-0.7	-1.3	-0.4	-1.1	-2.0	-1.6	-1.8	-0.3	-1.2	-1.4	0.9	-0.1
FLEMISH PASS (FP)	-0.3	-1.1	-0.5	-1.1	-1.5	-2.0	-1.9	0.2	-1.1	-0.6	0.8	0.4
SE SHOAL (SES)	-1.1	-0.6	-0.1	-0.5	-0.8	-0.7	-0.5	0.1	0.5	0.4	2.8	0.7
HIBERNIA (HIB)	-0.4	-0.6	-0.1	-0.6	-1.1	-1.3	-1.5	0.5	0.0	-0.7	2.8	0.6
AVALON CHANNEL (AC)	0.9	0.2	0.0	-0.4	-0.8	-0.7	-1.0	0.7	-0.5	0.2	2.9	0.8
GREEN-ST PIERRE BANK (SPB)	1.1	0.5	0.9	0.1	-0.2	0.2	0.3	1.4	0.1	0.6	3.2	0.7

Figure. 13. Monthly SST anomalies (in °C) for 2016 derived from the data within the boxes shown in Figure 12. The anomalies are referenced to the 1981-2010 base period.

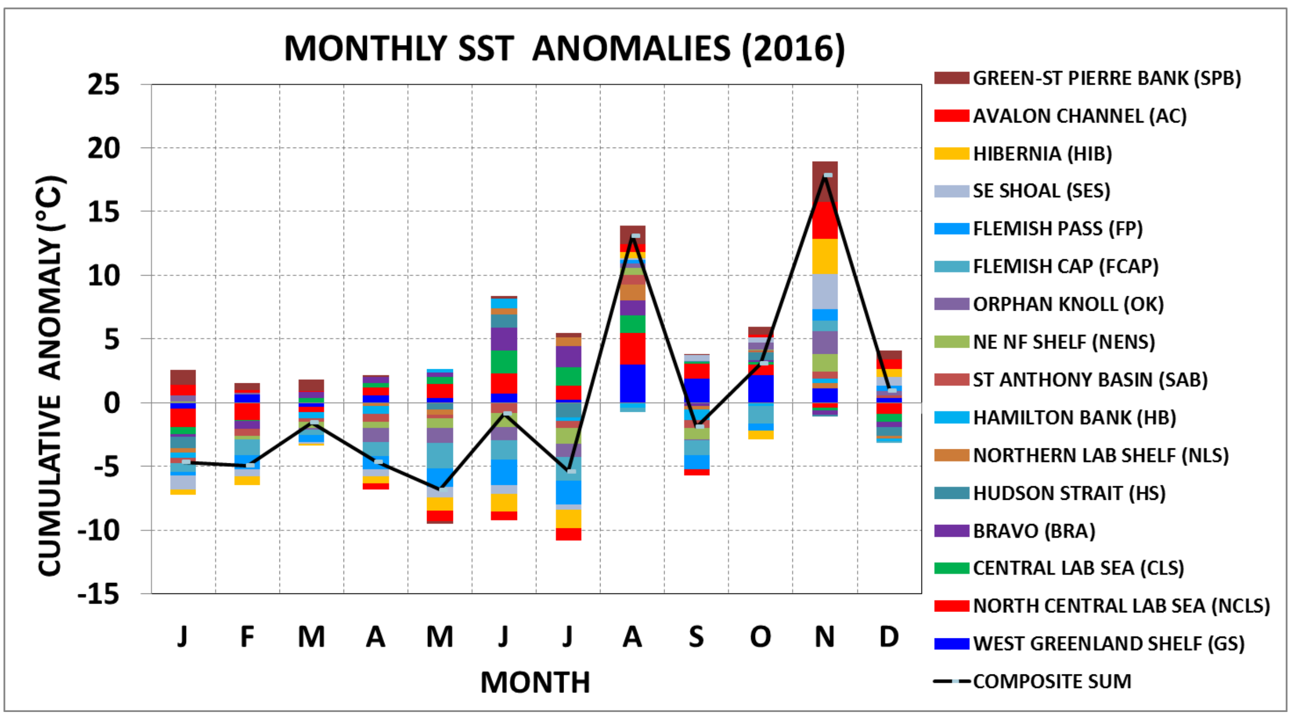

Figure. 14. Cumulative SST anomalies derived from the data within the boxes shown in Figure 12 and displayed in Figure 13. The anomalies are referenced to the 1981-2010 base period.

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	16	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	0.9	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	0.5	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	0.8	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	0.8	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	-0.6	-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	0.4	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	-0.4	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	-0.6	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	-0.7	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	-0.4	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	-1.2	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	-1.1	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	-0.3	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	-0.6	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	-0.2	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	0.8	6.16	0.75

Figure. 15. Standardized SST anomalies derived from the data within the boxes shown in Figure 12. The anomalies are normalized with respect to their standard deviations over the period 1981-2010.

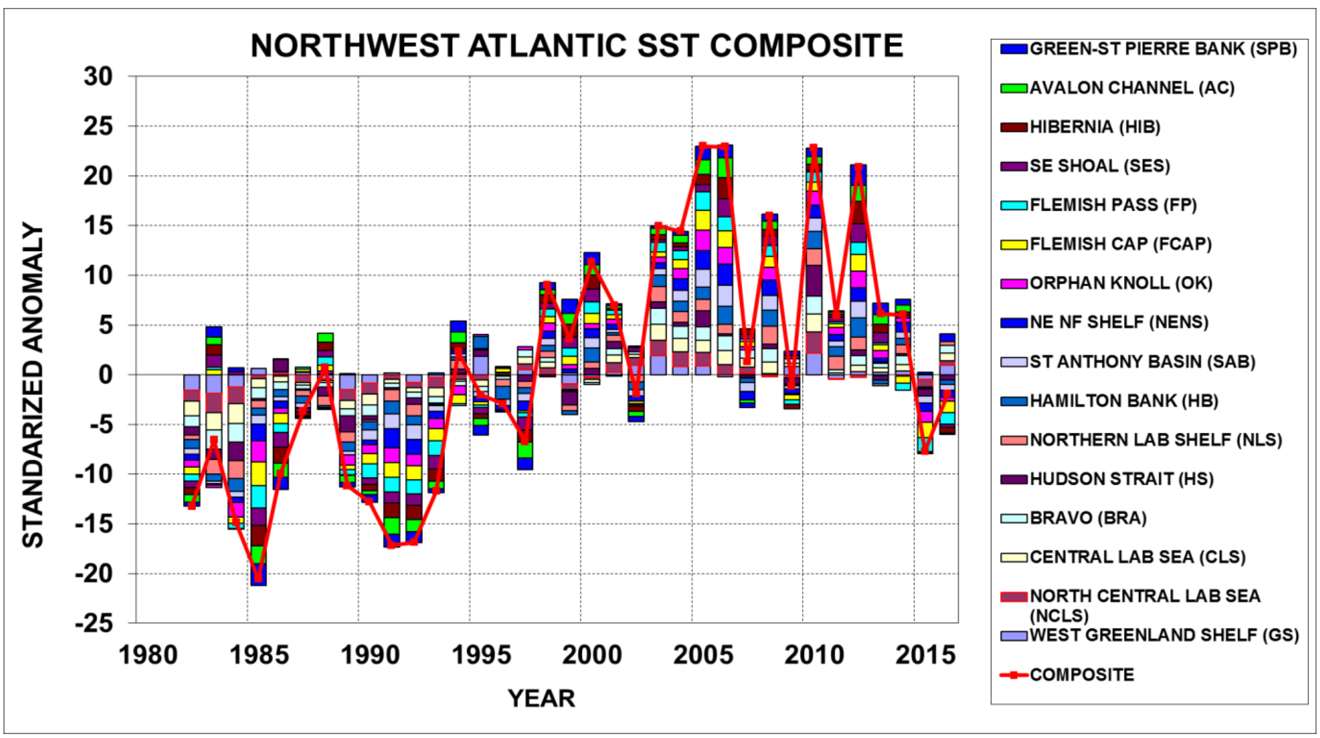

Figure. 16. Standardized annual SST anomalies from the subareas on the NL shelf presented in Figure 15. The solid red line represents the composite sum.

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 period along the coast of Newfoundland (see Figure 1 for locations) at nominal water depths of 10 and 15 m are shown in Figure 17 as monthly anomalies, in Figure 18 as standardized July-September anomalies and repeated in Figure 19 as cumulative anomaly sums. Note that some sites are missing data, particularly before 1998; hence the composite plot (Figure 19) 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 2016, monthly anomalies ranged from 5°C below normal at Bristol's Hope (the strongest negative anomaly of 2016) in June to 3.8°C above normal at Comfort Cove in August. The warmest month with observations was August when all 10 sites reported positive anomalies with some sites showing anomalies >3°C (Figure 17).

LOCATION	MAY	JUNE	JULY	AUG	SEPT	OCT
HAMPDEN (10 m)		-1.8	2.7	1.4	1.1	-0.2
COMFORT COVE (10 m)	0.9	2.9	3.2	3.8	0.4	
CAPE FREELS (15 m)		0.0	1.7	3.2	0.4	0.0
STOCK COVE		0.7	1.3	2.2	0.8	1.4
MELROSE (15 m)		-0.6	1.0	1.8	0.2	0.5
OLD BONAVENTURE (10 m)		-0.6	1.9	2.0	0.6	2.3
WINTERTON (10 m)	-0.5	0.0	-1.2	1.2	0.3	-0.8
BRISTOL'S HOPE (10 m)	-3.1	-5.0	1.4	1.4	0.9	0.8
UPPER GULLIES (10 m)	0.8	0.7	1.2	3.2	0.3	0.3
ARNOLDS COVE (10 m)	2.4	0.9	-1.8	1.4	1.5	1.4

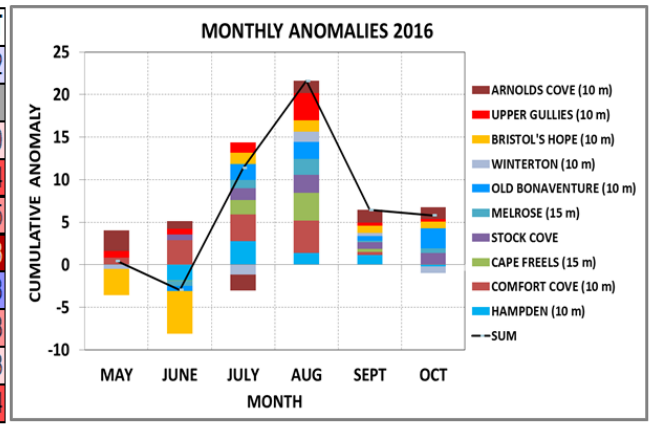

Figure 17. Monthly temperature anomalies displayed as color-coded values (in °C, left panel) and as cumulative sums (right panel) from data collected with thermographs along the coast of Newfoundland (Figure 1). The anomalies (in °C) shown are referenced to the standard base period if the data exist, 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 18).

Near-shore temperatures trends (Figure 19) indicate below normal conditions during most of the 1990s with an increase 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 8 of 9 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, 8 of 9 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, 4 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 varies about the mean and in 2016 near-shore temperatures were either near-normal or above normal at all sites and the warmest since 2006.

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	2016	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	1.2	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	1.3	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	1.4	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	1.0	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	0.8	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	0.9	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	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	1.0	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	1.2	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	0.3	13.40	1.21

Figure 18. Standardized temperature anomalies derived from data collected with thermographs along the coast of Newfoundland from July to September of each year (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.

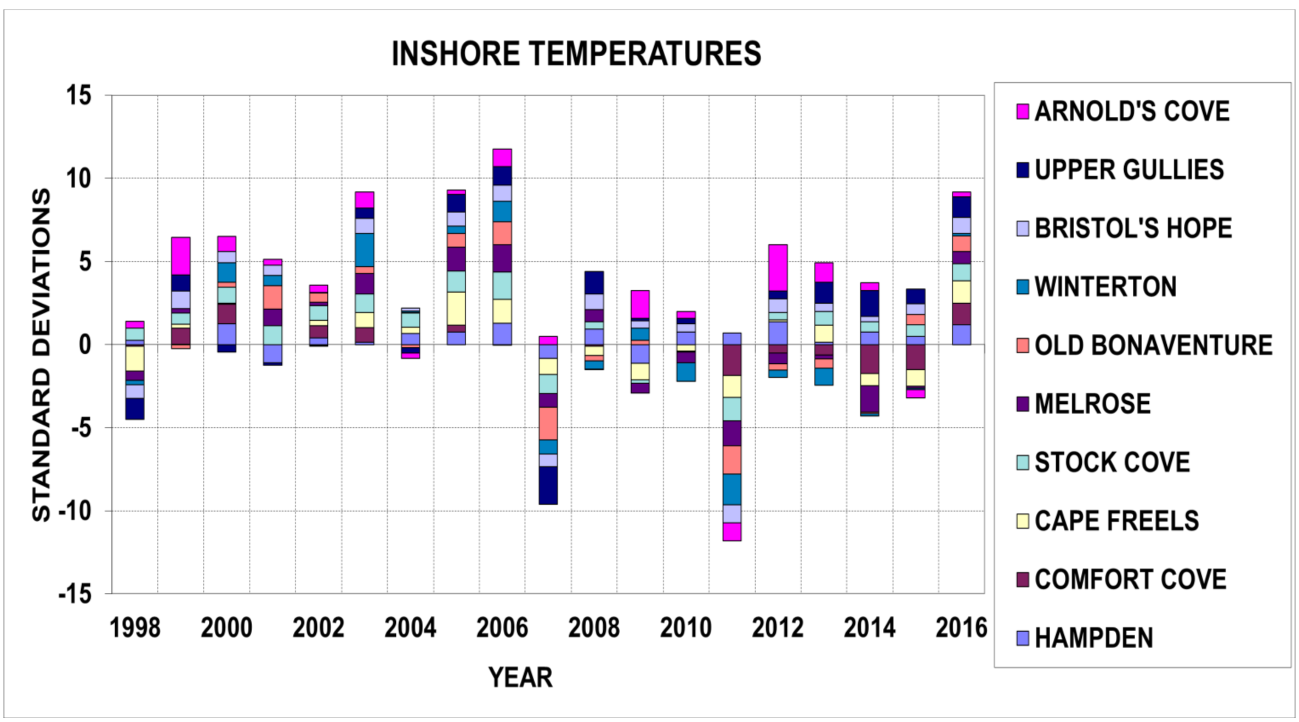

Figure 19. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland from July to September of each year (Figure 1). The anomalies were normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the duration of the time series.

AZMP FIXED MONITORING SITE (STATION 27)

Station 27 (47° 32.8’ N, 52° 35.2’ W), located in the Avalon Channel off Cape Spear NL (Figure 1), was sampled 45 times (43 CTD profiles, 2 XBT profiles) during 2016. Observations were available for all months except March, although only one profile was available in January and February. In addition, hourly T/S mooring data were available from January-November at 20, 25, 30, 40, 50, 75, 100, 125, 150, 160 and 170 m for temperature and at 20, 50, 75, 100 and 170 m for salinity.

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2016 are displayed in Figures 20 to 23. The temperature data from the mooring deployment are incorporated in the annual temperature cycle in Figure 20. The anomaly maps of temperature and salinity are based on full water column profiles (CTD/XBT) only, therefore some of the high frequency structure evident in these maps may be due to under sampling of tidal influences and other oceanographic effects such as internal waves.

The water column at Station 27 was near-isothermal ranging in temperature from -1.5°C to 0.0°C during February to April. These values persisted throughout the year below about 90 m as the CIL extended to the bottom. In fact, the largest volume of water with temperatures <1.4°C occurred during the summer (>100 m) as the winter chilled CIL water was continuously advected onto the northern Grand Banks. Upper layer temperatures warmed to >3°C by late-May and to 15°C by mid-August, after which the fall cooling commenced with temperatures decreasing to <3°C by late December.

Temperatures were above normal during early winter months over most of the water column. Anomalies varied considerably in the upper water column throughout the remainder of the year with strong positive values in the top 100 m of the water column reaching >2°C above normal, particularly in September at depths of 25-75 m. Values were slightly below normal throughout most of the year in the near bottom zone with an intense negative anomaly in October-November at intermediate depths.

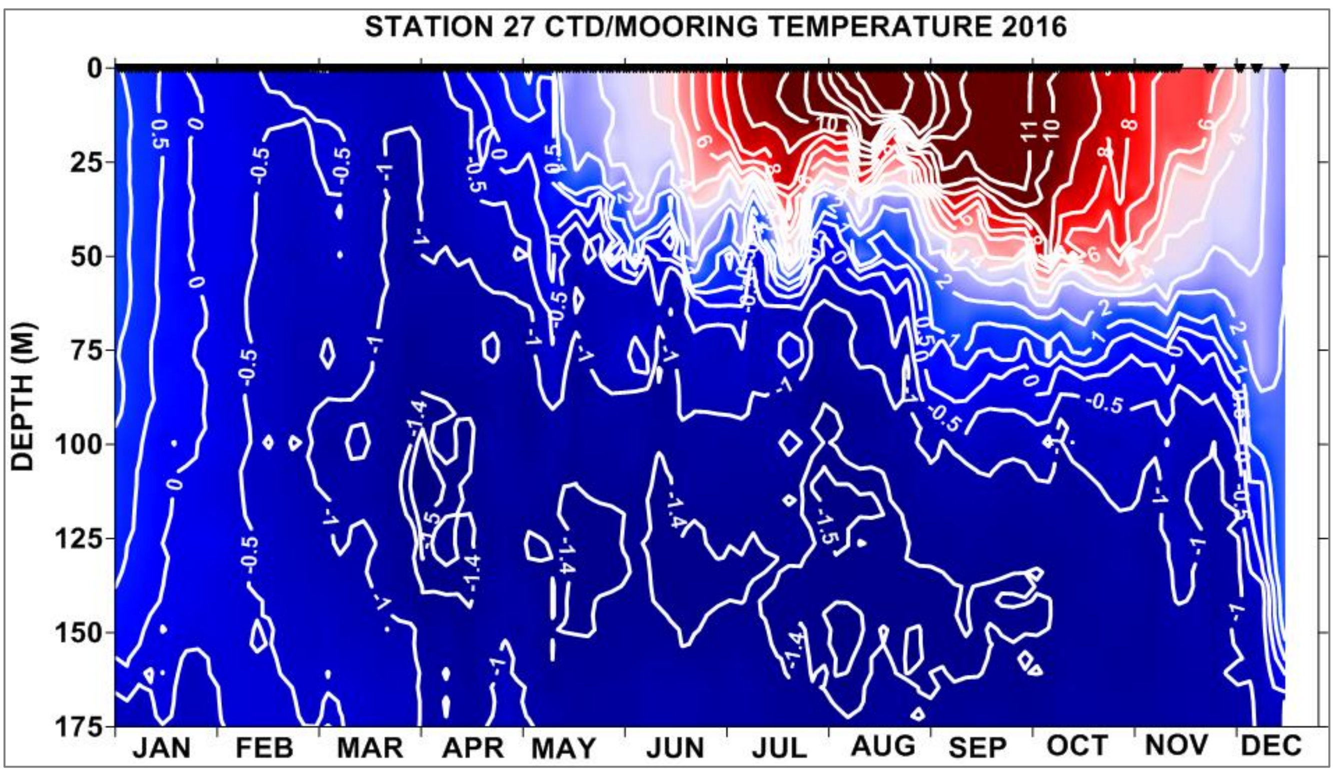

Figure. 20. Contours of temperature (°C) as a function of depth at Station 27 during 2016. The symbols at the top indicate sampling times.

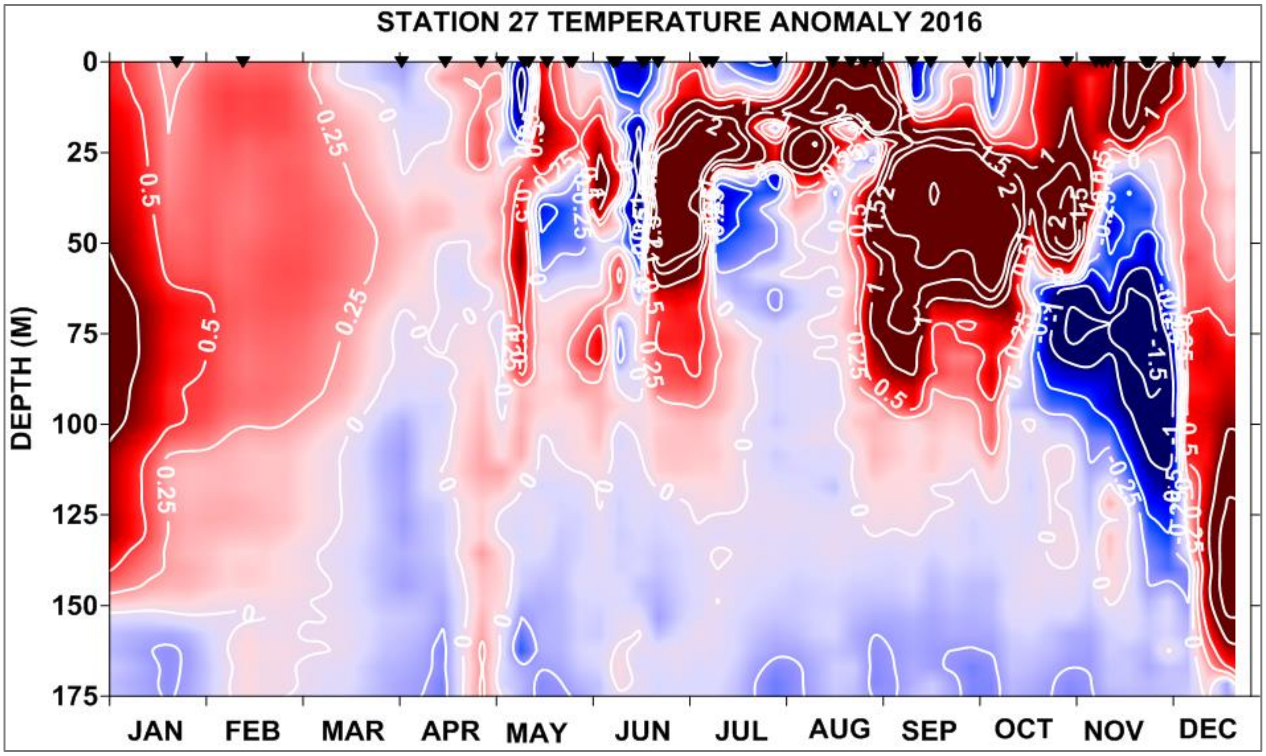

Figure. 21. Contours of temperature anomalies (°C) as a function of depth at Station 27during 2016. The symbols at the top indicate sampling times.

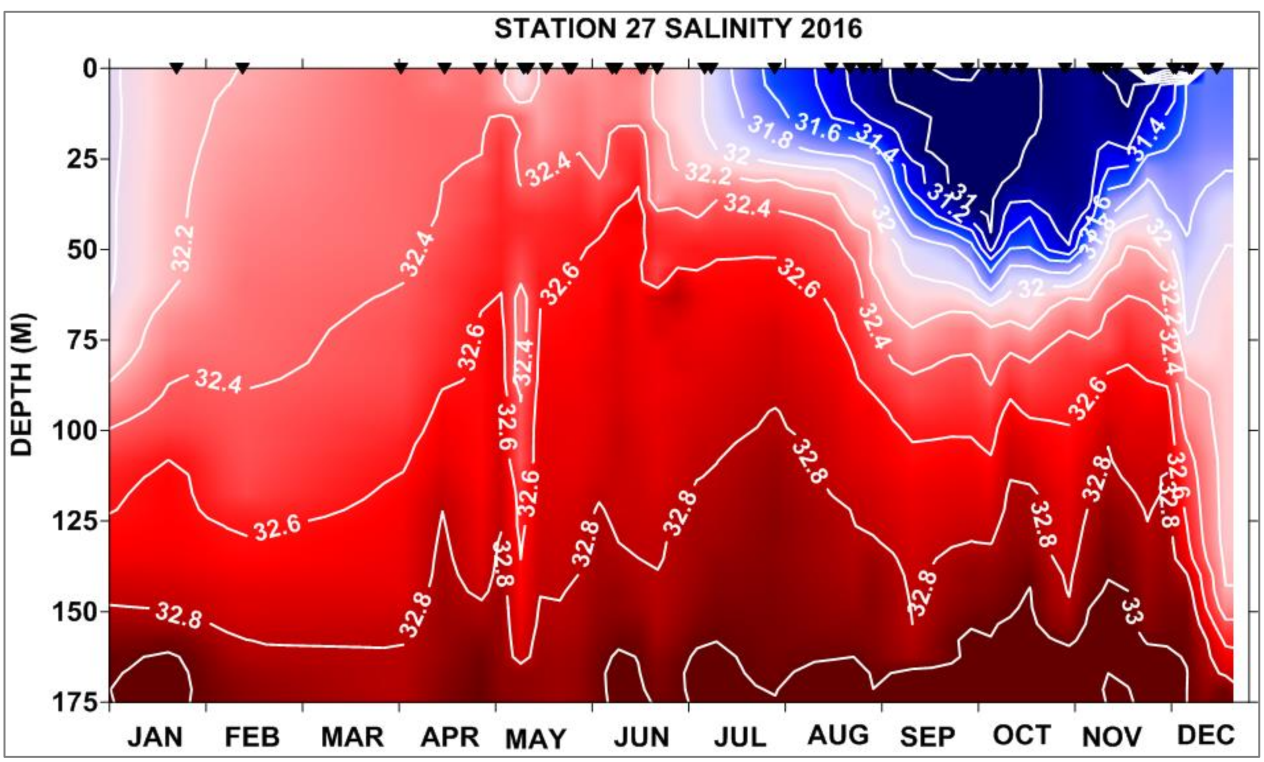

Figure. 22. Contours of salinity (PSU) as a function of depth at Station 27 for 2016. The symbols at the top indicate sampling times.

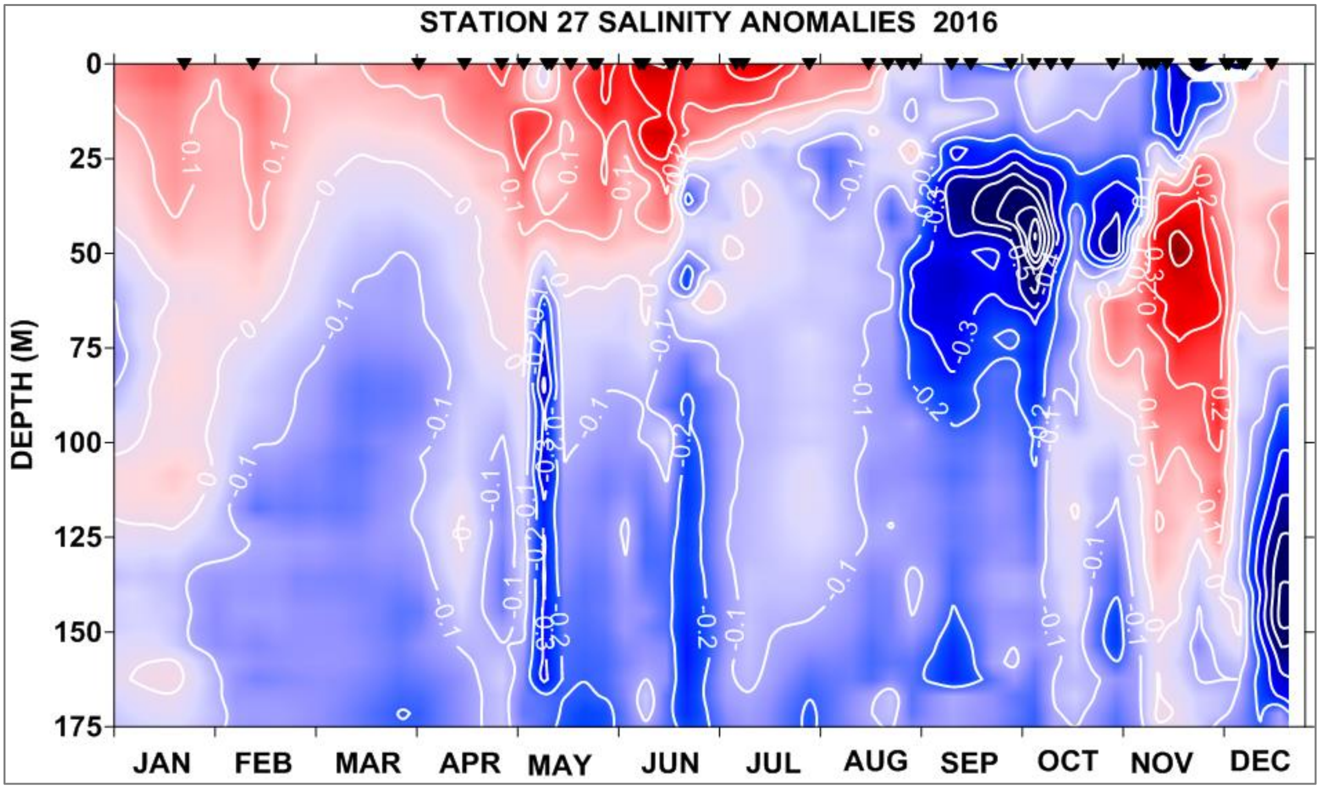

Figure. 23. Contours of salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2016. The symbols at the top indicate sampling times.

Upper layer salinities (Figure 22) ranged from <32.2 to 32.4 during the first half of the year and from 32.4 to 33 throughout the year from about 75 to 175 m depth. 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 in this layer ranged from <31 to 32, with minimum values occurring in late-September. Salinities were above normal in the near-surface layer from January to July and again at intermediate depths in November, otherwise values were below normal during 2016 (Figure 23).

The annual surface temperature at Station 27 was 0.4°C (0.5 SD) above normal representing an increase over the slightly below normal value in 2015. In 2006 the surface temperature reached a 67-year high of +1.5°C (+2.2 SD) above the long-term mean and has been mostly above normal since that time (Figure 24). Annual bottom temperature anomalies at Station 27 were the highest on record in 2011 at 3.6 SD above normal. Since then bottom temperatures have experienced a decreasing trend and have been below normal (~0.5 SD) during the past three years (Figure 24). Vertically averaged temperatures (0-176 m), which also set record highs in 2011 at +2.7 SD above normal, decreased to about normal in 2014 but increased to 0.7 SD above normal in 2015 and 2016 (Figure 25, left panel, Figure 28).

The layer of cold water with temperatures <0°C on most of the NL shelf, commonly referred as the CIL elaborated on in the next 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 <0.0°C reached a remarkably low anomaly of 58 m below normal (-4.3 SD, normal of 118 m and SD of 17 m) in 2011 but increased to 7 m (+0.5 SD) above normal in 2014 and have since decreased to 16 m (-1.3 SD) below normal in 2016 (Figure 25, right panel, Figure 28).

Annual surface salinities at Station 27 were near normal in 2016 while bottom values were below normal by 1.4 SD, similar to 2015 (Figure 26). Depth layer averaged values were close to normal in the 0-50 m range and below normal (0.5 SD) over the full water column (0-176 m) (Figure 27, 28). In general, water column averaged salinities have varied slightly about the mean in some years but have been predominately below the long term average since the early 1990s.

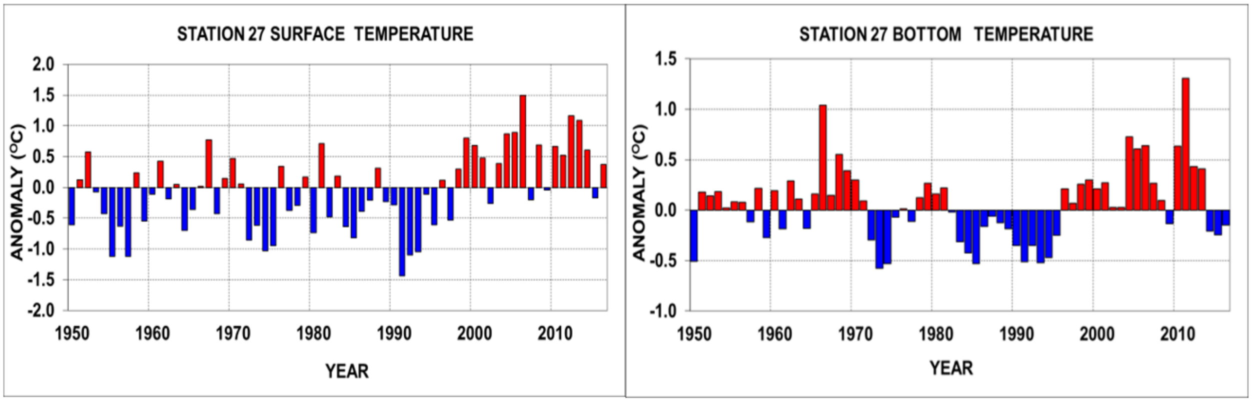

Figure. 24. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean.

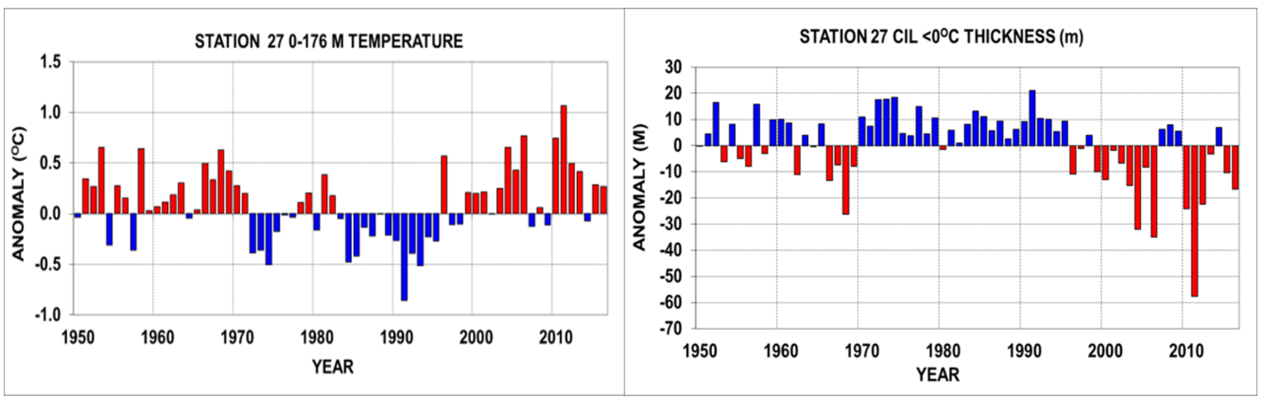

Figure. 25. Annual Station 27 vertically averaged (0-176 m) temperature and CIL (<0°C) thickness anomalies referenced to the 1981-2010 mean.

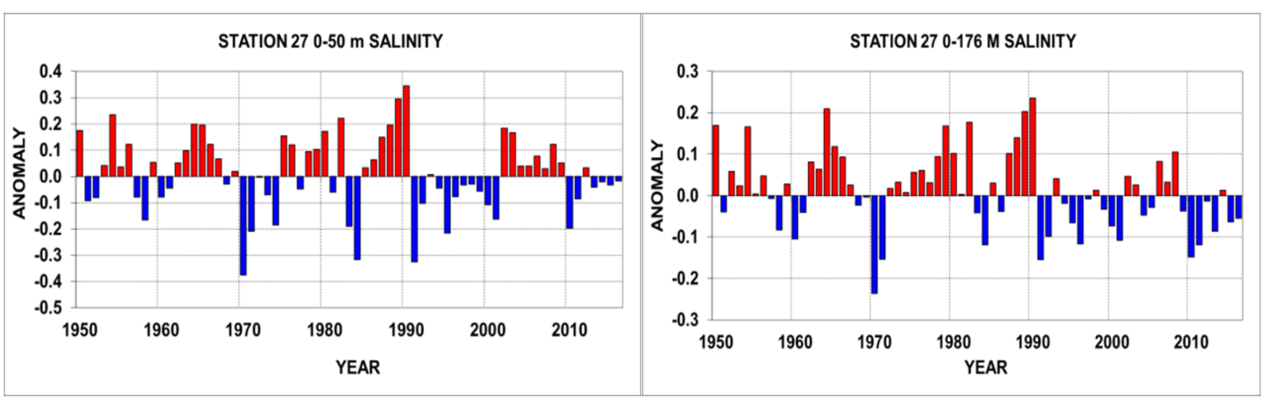

Figure. 26. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean.

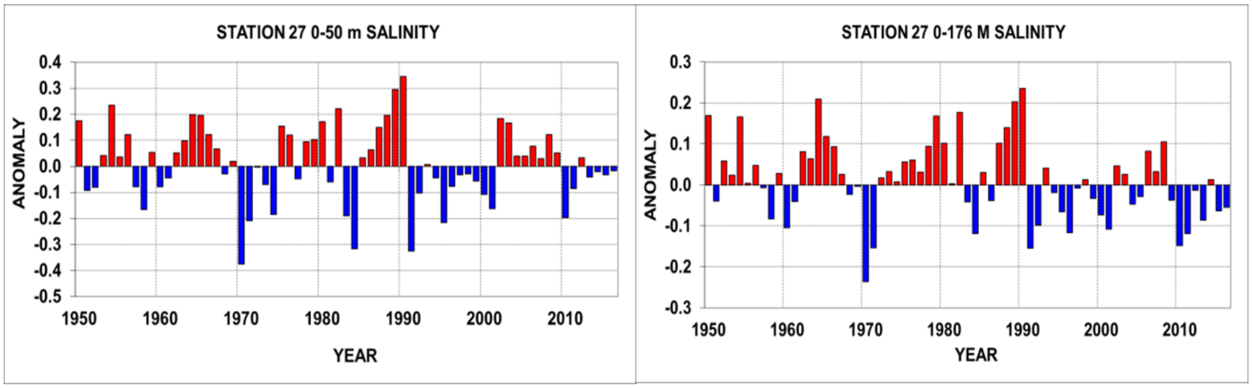

Figure. 27. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean.

INDEX	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	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	0.5	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	-0.4	-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	1.2	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	0.7	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	-0.3	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	-0.2	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	-1.2	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	-1.6	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	-0.4	135.09	8.23
Surface S	1.1	0.2	1.6	-1.1	-2.0	0.3	0.8	0.9	0.6	1.5	0.8	-2.7	-0.4	-0.2	0.0	-1.8	0.0	-0.6	-0.5	-0.5	-0.4	-0.7	1.1	1.0	0.6	0.5	0.7	0.1	0.6	0.5	-0.4	0.3	0.8	0.0	-0.2	0.4	-0.1	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	-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	-0.1	31.94	0.17
0-176 m S	1.0	0.0	1.7	-0.4	-1.2	0.3	-0.4	1.0	1.4	2.0	2.3	-1.5	-1.0	0.4	-0.2	-0.6	-1.2	-0.1	0.1	-0.3	-0.7	-1.1	0.5	0.3	-0.5	-0.3	0.8	0.3	1.0	-0.4	-1.5	-1.2	-0.1	-0.9	0.1	-0.6	-0.5	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	0.5	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	1.9	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	-0.2	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	0.0	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	-1.3	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	-0.3	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	-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	-0.9	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	-1.0	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	1.2	13.85	6.45

Figure 28. Standardized temperature and salinity anomalies, CIL thickness, MLD and stratification at Station 27 from 1980 to 2016. 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 5 and 50 m for each density profile (i.e. $\Delta\rho/\Delta z$). These values were then averaged by month and the annual anomalies computed from the available monthly averages (Craig and Colbourne 2002). The annual and seasonal values are shown in Figure 28 as standardized anomalies.The 1981-2010 monthly mean and the 2016 monthly values are shown in Figure 29. 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 2016, the stratification was below the long-term mean until August when it increased to near-normal values. During September to October it again returned to below normal values but was significantly above normal in November to December (Figure 29).

The annual averaged stratification from 1950 to 2016 at Station 27 is shown in Figure 30. 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 had been decreasing until about 2011. 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 28). In 2016, it increased over 2015 but remained slightly below normal (Figure 30).

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 28, 31 and 32.

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 31). In 2016, winter values were deeper than normal (no data in March), about normal from April to October and shallower than normal in November and December (Figure 31). In general, there appears to be a slight increasing trend since 1995 of about 0.7 m/year in the annual mean which was +0.5 SD (Figure 28) deeper than normal in 2016 (Figure 32).

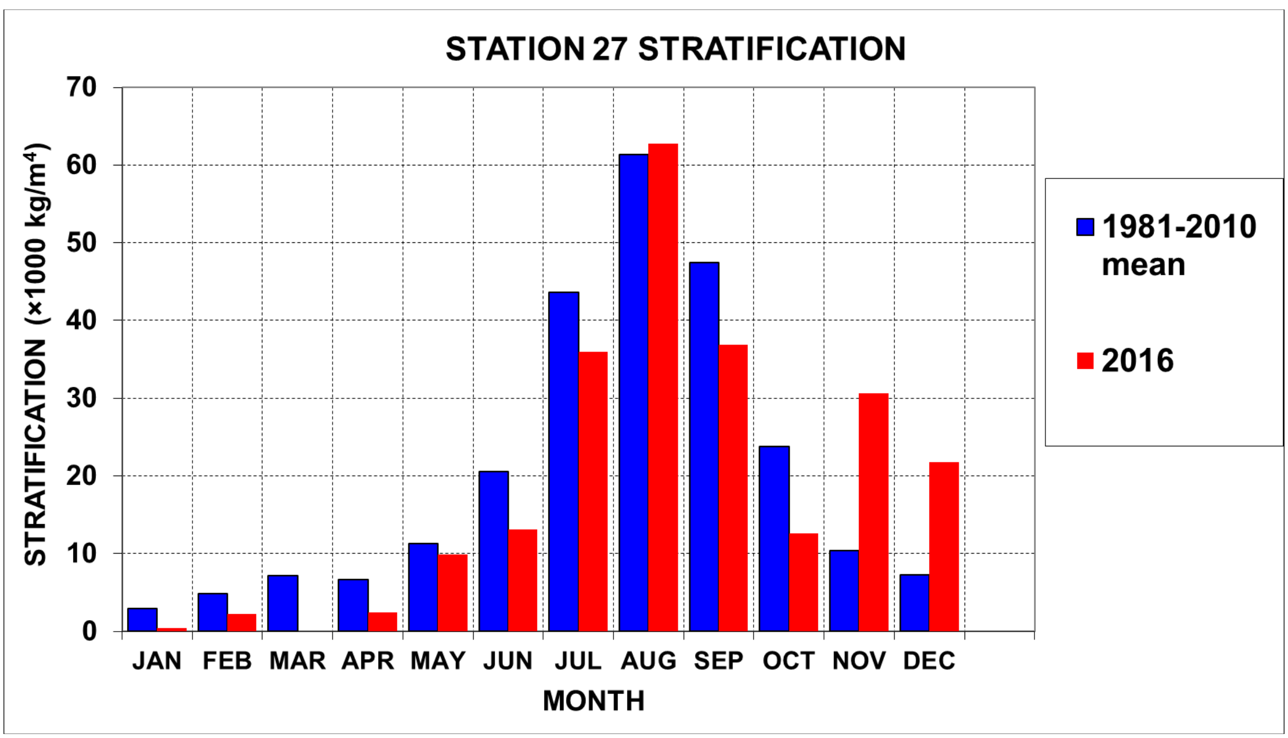

Figure 29. The 1981-2010 monthly average and the 2016 monthly average stratification values at Station 27.

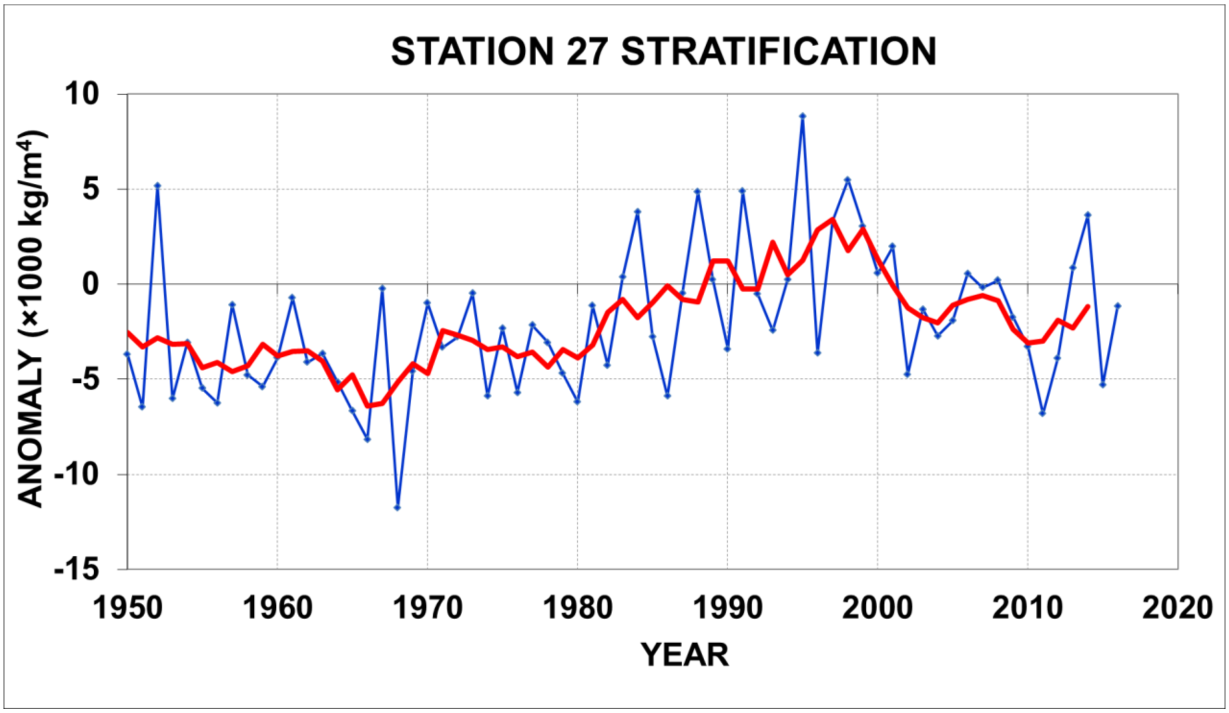

Figure 30. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean. The red line is a 5-year running mean.

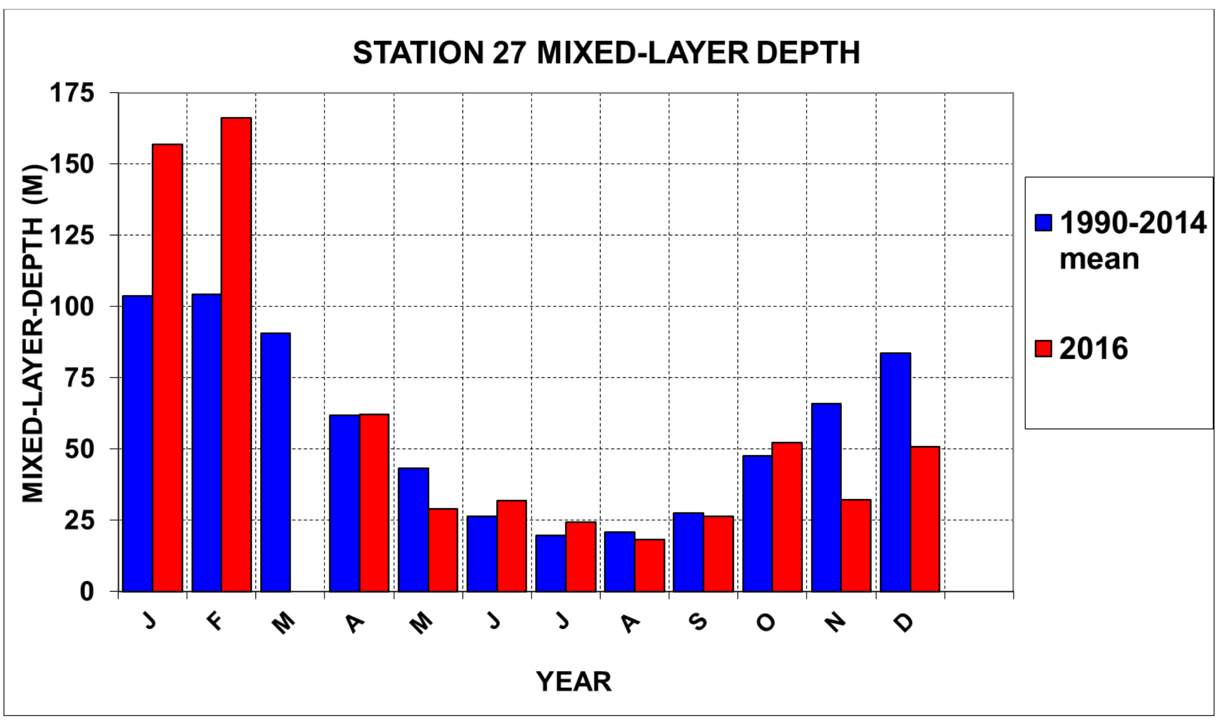

Figure 31. The 1990-2010 average and the 2016 monthly mean Mixed Layer Depths at Station 27.

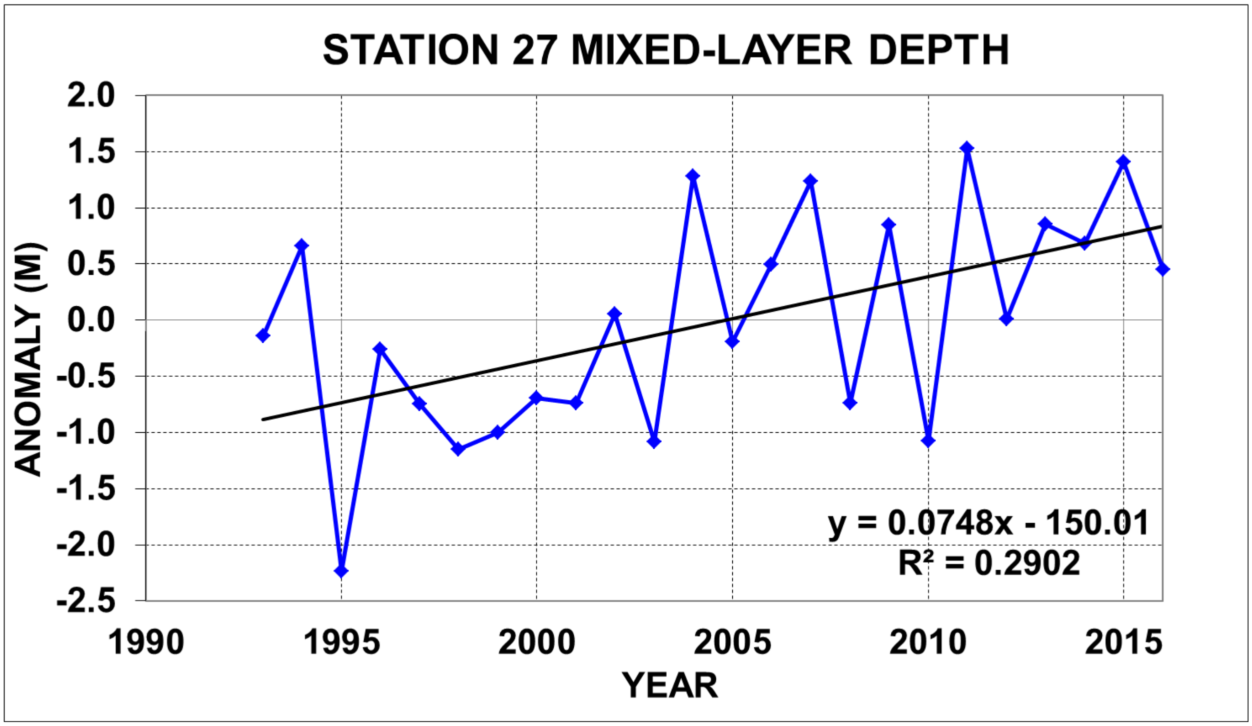

Figure 32. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2015 mean.

NL SHELF BOTTOM TEMPERATURES, CIL AND MIXED-LAYER-DEPTH

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 33) and 40 on the Newfoundland Shelf (Figure 36).

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 3 monthly values. As a result the time series can show spikes that correspond to high frequency temporal or spatial variability and may poorly represent annual means in any given year.

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 34 and repeated in Figure 35 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 2016, 9 out of 21 areas with sufficient data reported above normal values (anomalies >0.5 SD) while 8 out of 21 reported near-normal values (anomalies within ±0.5 SD), 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 35). Since the peak in 2011 bottom temperatures on the Labrador Shelf have decreased with 2016 remaining above normal overall, similar to the previous 3 years.

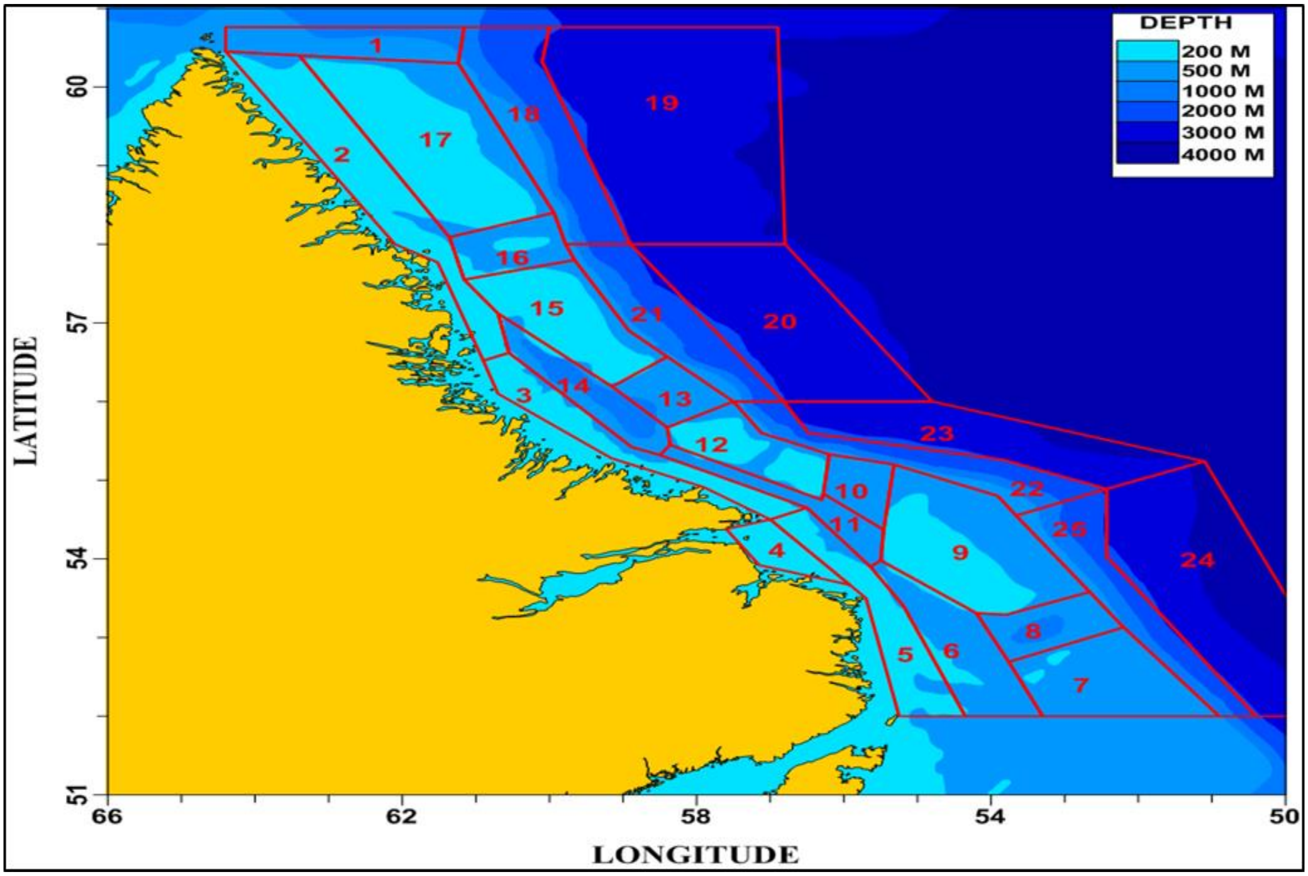

Figure 33. Areas on the Labrador Shelf where bottom temperatures were analysed. The numbers within each area correspond to the areas listed below in Figure 30.

Similarly, standardized annual near-bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 37 and repeated in Figure 38 as a cumulative time series. The results are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999. In 2016, 13 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 38) 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 second highest since 1980 in 2012 and the fourth highest in 2013. The 2014-16 values have decreased but have remained above the long term mean.

The available temperature and density profiles for each sub-area were also used were to compute the vertical extent of the CIL and the MLD. The thickness of the CIL water mass was estimated from the depth of the top and bottom of the water mass with temperatures <0°C. In some cases there were multiple 0°C crossings which were included in the total thickness estimate. The MLD was estimated from the density profiles as the depth of maximum density gradient similar to the Station 27 estimates. Similar to bottom temperature, values within each area were averaged by month and the annual anomalies then computed from the monthly values and standardized by the standard deviation of the annual anomalies over the same base period. The time series of CIL values shown in Figure 39 shows a decreasing trend in the amount of CIL water since the early 1990s with mostly below normal values since 1996.The MLD shows an increasing trend in the depth of the maximum density gradient since 2000. In both cases these trends are similar to that observed at Station 27 (Figure 25 and 32) indicating broad-scale forcing over the Newfoundland Shelf.

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	16	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	-0.1	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	0.9	-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	0.1	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	-0.1	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	0.7	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	1.0	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	0.2	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	1.1	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	0.8	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	-1.9	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	0.8	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	3.0	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	-0.7	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	1.5	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	-0.3	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	-0.1	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	0.1	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	-0.5	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	-0.2	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	1.1	3.45	0.25

Figure 34. 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.

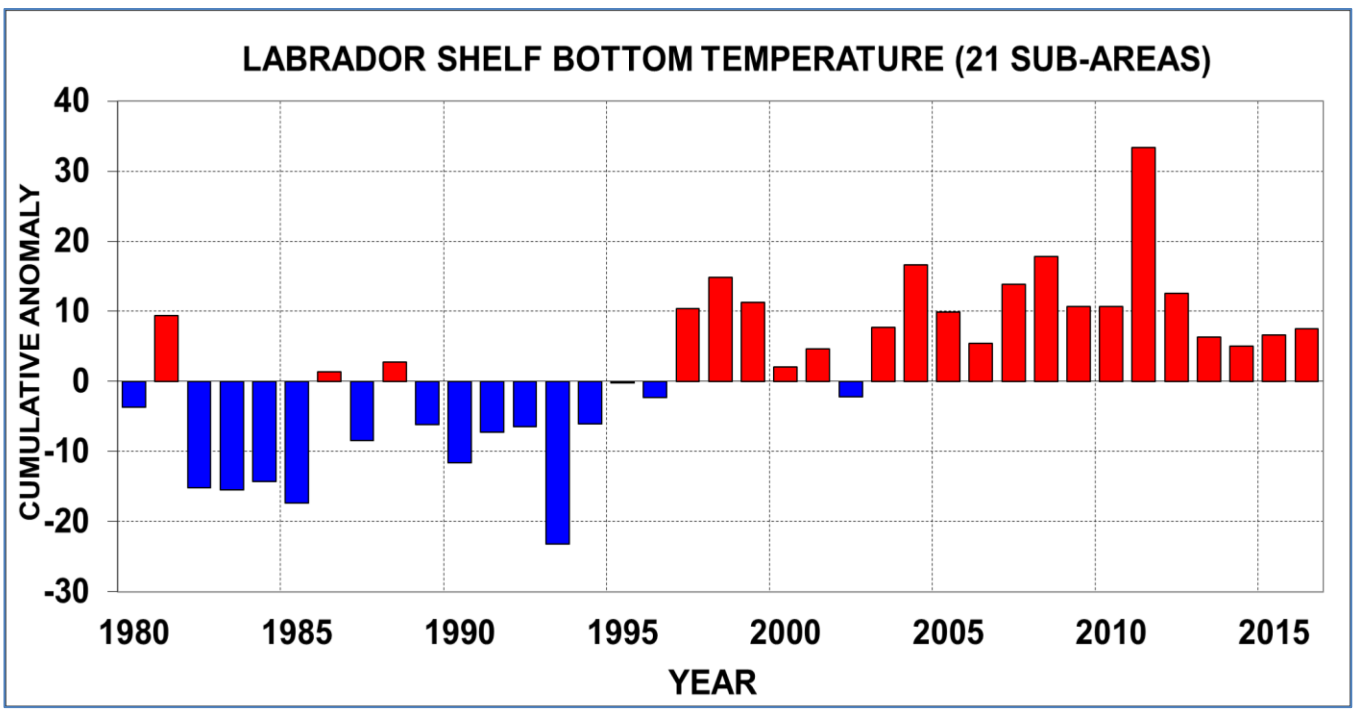

Figure 35. Cumulative bottom temperature anomalies based on the values presented in Figure 30 for the Labrador Shelf.

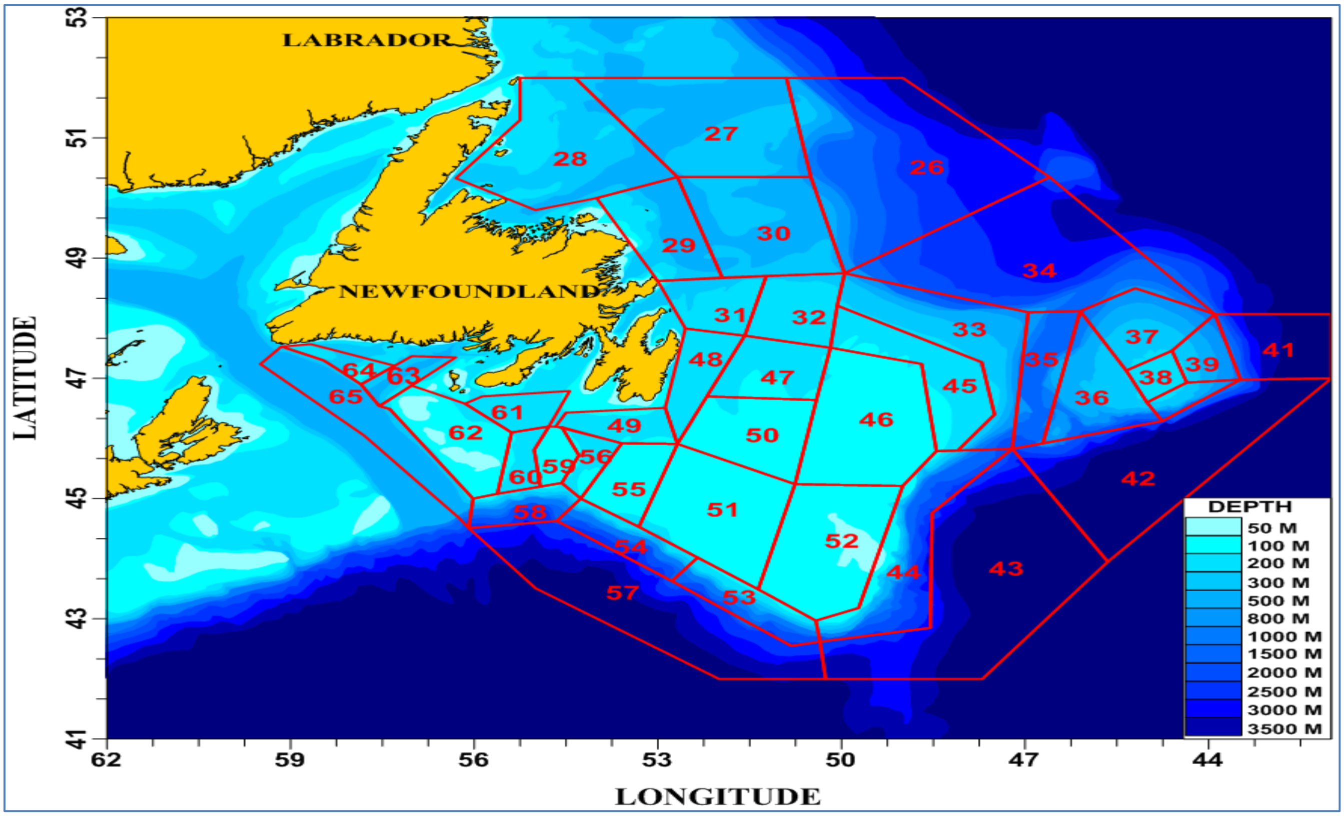

Figure 36. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed below in Figure 33.

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	16	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	-0.4	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	0.1	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	-1.0	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	-1.2	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	-0.7	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	-0.9	-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	-1.2	-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	0.4	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	0.0	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	0.5	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	1.8	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	0.6	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	-0.3	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	0.6	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	1.5	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	-1.0	-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	1.3	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	-0.5	-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	-0.2	-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	0.4	-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	1.4	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	0.3	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	-0.7	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	-0.5	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	0.0	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	0.4	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	0.3	-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	0.7	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	0.9	-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	0.5	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	4.5	0.0	-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	0.6	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	1.8	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	0.0	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	1.2	4.95	0.44

Figure 37. Standardized bottom temperature anomalies for the Newfoundland Shelf referenced to 1981-2010.

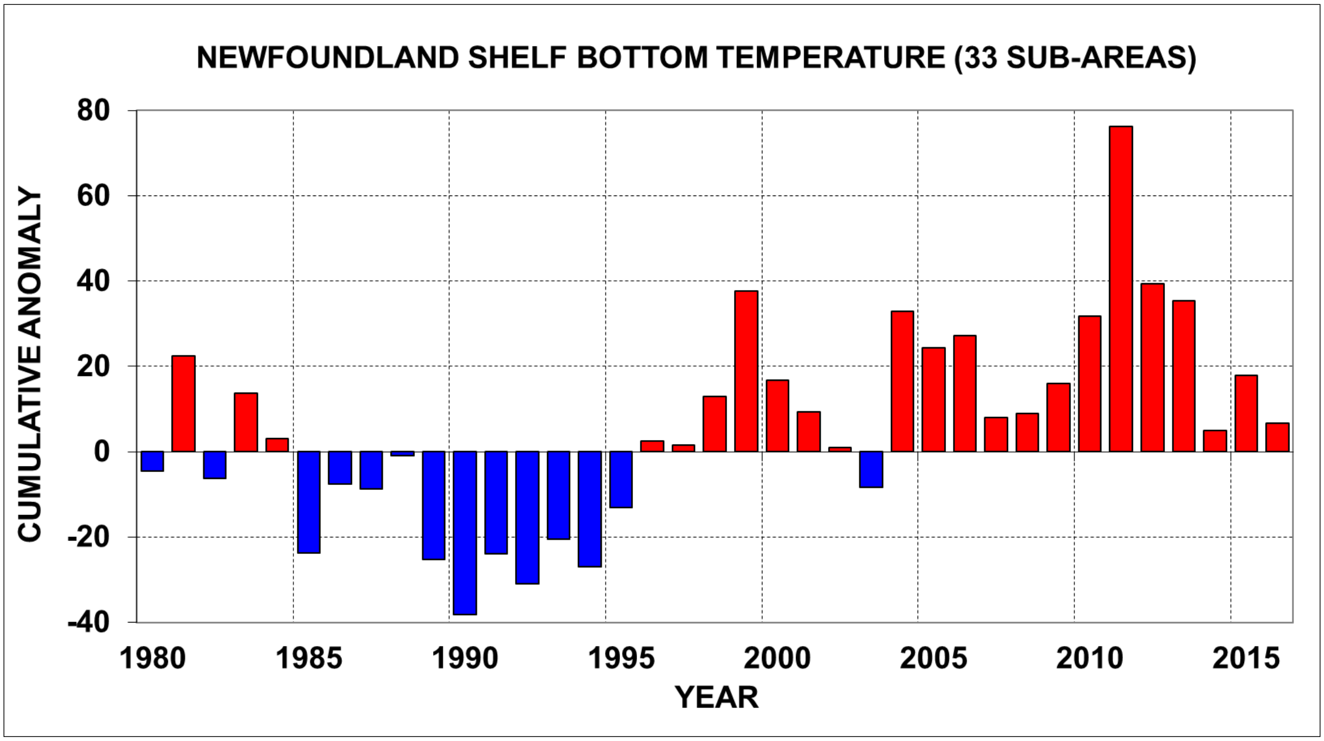

Figure 38. Cumulative bottom temperature anomalies based on the values presented in Figure 33 for the areas on the Newfoundland Shelf shown in Figure 32.

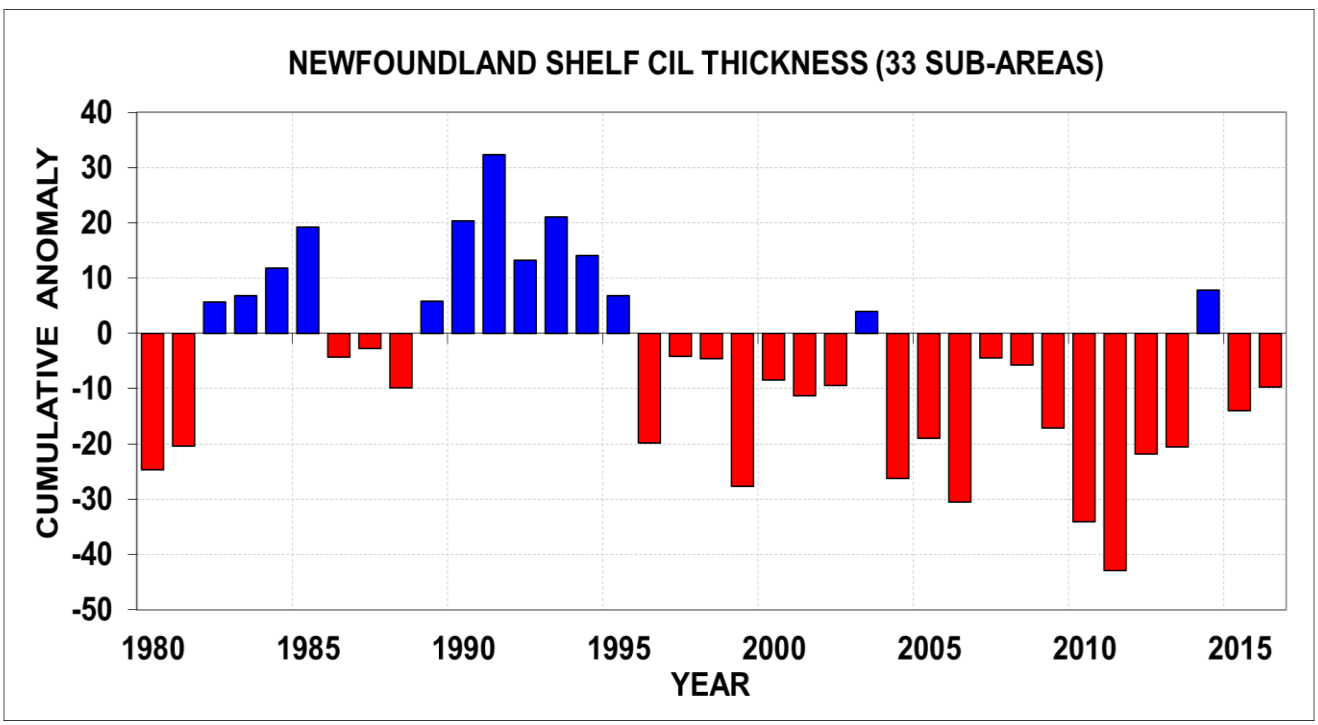

Figure 39. Cumulative CIL thickness anomalies based on available temperature profiles for the areas on the Newfoundland Shelf shown in Figure 36. Red bars indicate thinner than normal CIL water.

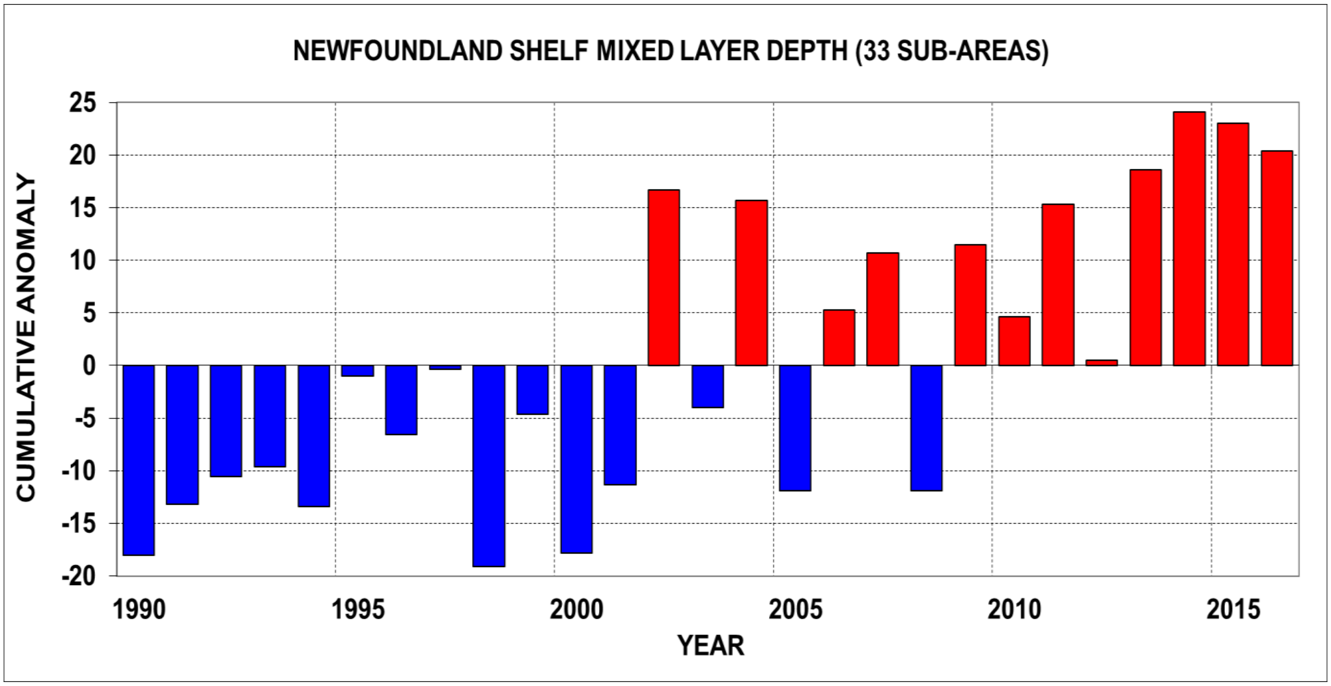

Figure 40. Cumulative MLD anomalies based on available temperature profiles for the areas on the Newfoundland Shelf shown in Figure 36. Red bars indicate deeper than normal maximum density gradients.

STANDARD AZMP SECTIONS

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

In 1998 under the AZMP program, the Seal Island (SI), Bonavista Bay (BB), Flemish Cap (47^{o}N) (FC) and Southeast Grand Bank (SEGB) historical stations were selected as core monitoring sections. The White Bay section (WB) was continued to be sampled during the summer as a long time series ICNAF/NAFO section. In addition, two ICNAF sections on the mid-Labrador Shelf, the Beachy Island (BI) and the Makkovik Bank (MB) sections were selected to be sampled during the summer if survey time permitted and 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.

In 2016, the SWSPB section was sampled in April and November, the SESPB and SEGB sections were sampled in November, the FC section during May and July and the BB, WB and SI sections during July (Figure 2). Most spring and fall sections normally sampled were not during 2016 due to limited available ship time. In this manuscript we present the summer cross sections of temperature and salinity and their anomalies along the Flemish Cap, Bonavista and Seal Island sections to represent the vertical temperature and salinity structure across the Newfoundland and Labrador Shelf during the summer of 2016. The seasonal changes in the temperature and salinity fields off eastern Newfoundland along with time series of spring and fall CIL values are presented in Colbourne et al. 2015, and earlier similar reports.

TEMPERATURE AND SALINITY VARIABILITY

The water mass characteristics observed along the standard sections crossing the NL Shelf (Figure 2) are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1.5°C to 2°C and salinities of 31.5 to 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° to 4°C and salinities in the range of 34 to 34.75. Surface temperatures normally warm to 10° to 12°C during late summer, while bottom temperatures remain <0°C over much of the Grand Banks but increase to 1° to 3.5°C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper (>1,000 m) waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3° to 4°C.

In general, the near-surface water mass characteristics along the standard sections undergo seasonal modification from annual 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 summer temperature structure along the Flemish Cap (47ºN), Bonavista and Seal Island sections (Figure 2) during 2016 are highlighted in Figures 41, 42 and 43. The dominate thermal feature along these sections is the mass of cold relatively fresh water overlying the shelf separated from the warmer higher density water of the continental slope region by strong temperature and salinity (density) fronts. This winter chilled water mass is commonly referred to as the cold intermediate layer (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.

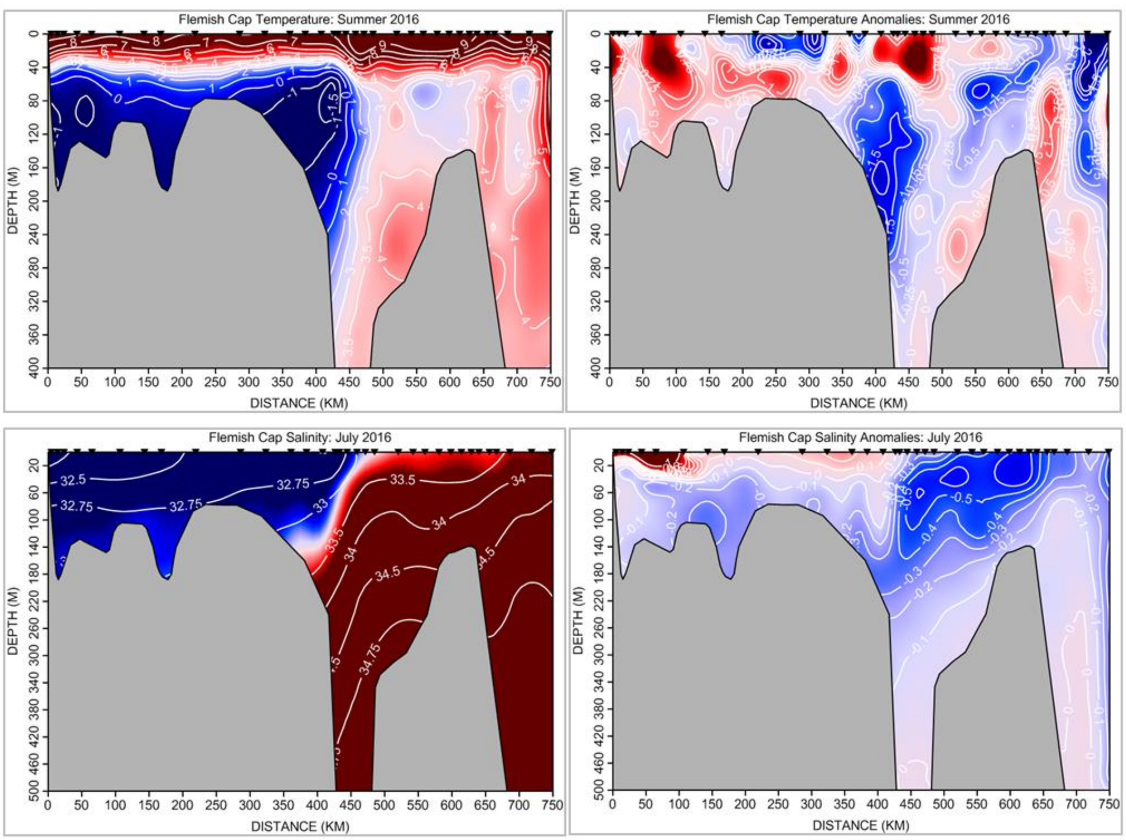

Figure 41. Contours of temperature (°C), salinity, and their anomalies along the Flemish Cap (47ºN) section (Figure 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

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.

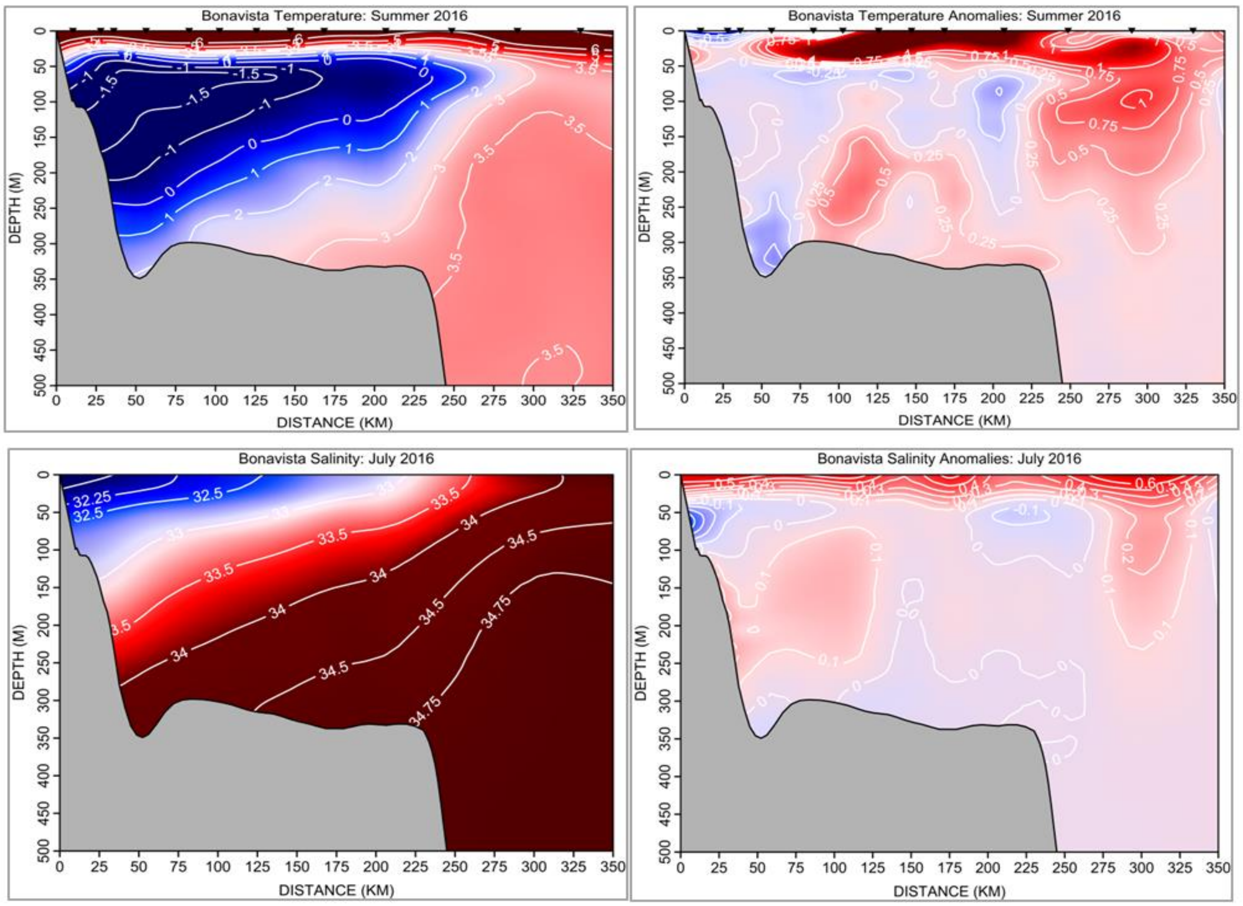

Figure 42. Contours of temperature (°C), salinity, and their anomalies along the Bonavista section (Figure 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

During 2016 temperatures along the Flemish Cap section were mostly above normal across the Grand Bank, near surface in the Flemish Pass and the deeper waters around the Flemish Cap. In other areas, at the edge of the Grand Bank and waters above the Flemish Cap temperatures ranged from 0.5° to 2°C below normal (Figure 41, top right panel). Temperatures along the Bonavista section were predominately above normal (>1°C in the near-surface layer) except at CIL depths on the shelf where they were near normal or slightly below normal (Figure 42, top right panel). Along the Seal Island section, temperatures were below normal in the near surface layer, particularly in the inshore region. Elsewhere they were above normal with a significant offshore positive anomaly where temperature were >2.5°C above normal (Figure 43, top right panel).

The corresponding salinity cross-sections show 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 (Figures 41, 42 and 43, bottom panels). In 2016, salinities were above normal in the surface layer across the Grand Bank, but below normal elsewhere, reaching 0.6 below normal over the Flemish Cap and Pass areas (Figure 41, bottom right panel). Along the

Bonavista section salinity anomalies were generally near normal at depth with a significant upper layer positive anomaly with values >0.5 above normal (Figure 42, bottom right panel). Along the Seal Island section near-surface salinities varied about the mean with a significant offshore anomaly where values exceeded 0.5 above normal between 50-100 m depth (Figure 43, bottom right panel).

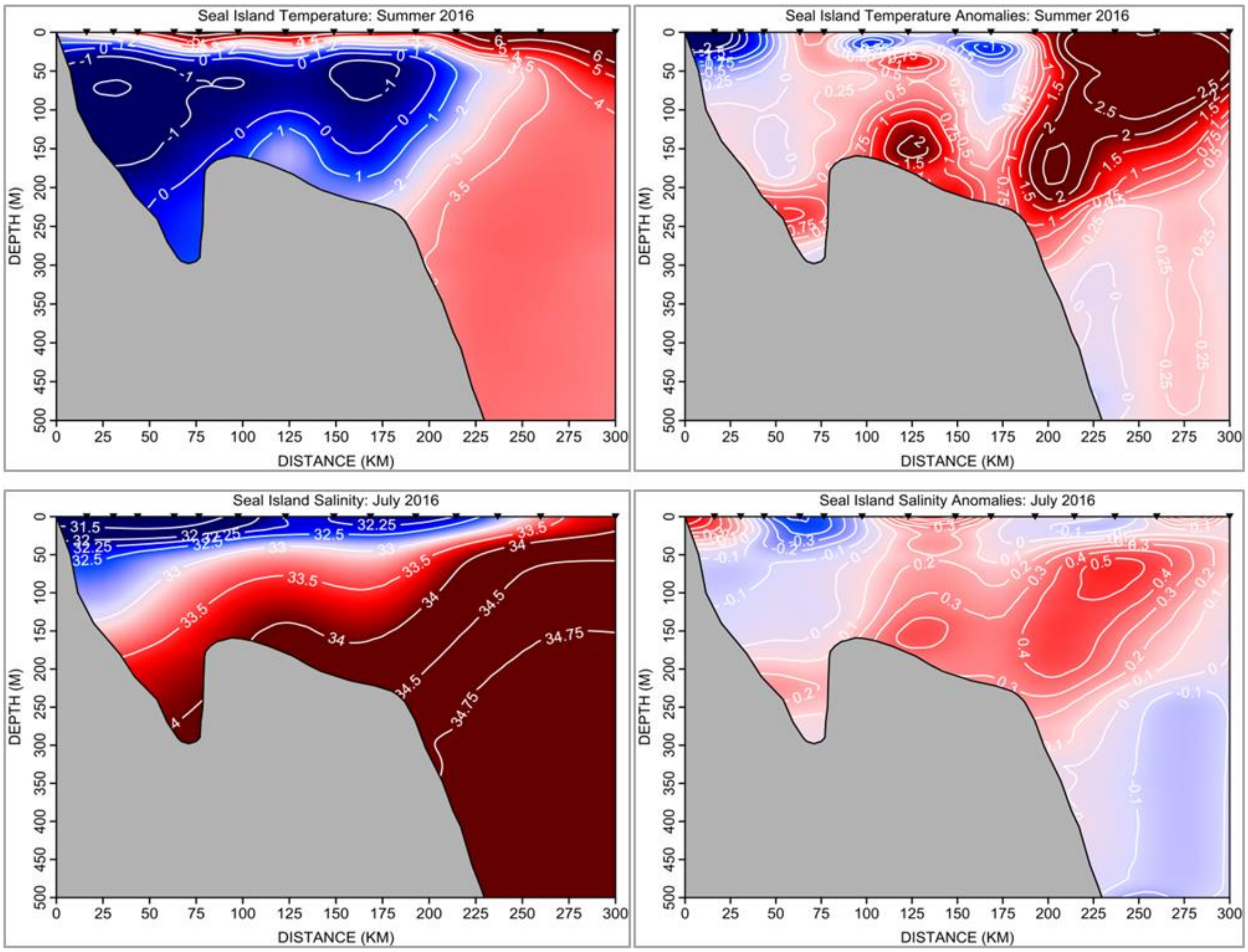

Figure 43. Contours of temperature (°C) and salinity and their anomalies along the Seal Island section (Figure 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

COLD-INTERMEDIATE-LAYER VARIABILITY

Time series of the summer CIL (<0°C) cross-sectional area anomalies along sections from southern Labrador to the Grand Banks are displayed in Figure 44. Along the FC section the average cross-sectional area of the CIL is 26.5 ± 6.6 km^2 during the summer, along the BB section the average cross-sectional area is 25.6 ± 9.3 km^2 and along the WB and SI sections the average summer cross-sectional area of the CIL are 55.3 ± 14.2 km^2 and 27.3 ± 7.5 km^2, respectively. In general, summer CIL values have been below normal during most years of the past 2 decades. Note also that not all sections were sampled in the early years of each series. The CIL area anomalies during the summer of 2016 were above normal along the WB section (implying colder shelf water conditions) but below normal off southern Labrador along the SI section. Along the BB and FC sections the CIL area was near normal.

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 45 as standardized values and in Figures 46 and 47 as composite temperature and salinity indices. Most temperature and salinity indices shown, except along the SI section, were either near-normal or slightly below normal by up to a maximum of -0.9 SD in salinity on the Grand Banks. This is in contrast to most of the 2000s when conditions were mostly warmer and saltier than normal. The composite temperature index (Figure 46) shows the coldest conditions since 1995 during 2014 and 2015 but closer to normal in 2016 compared to a record high in 2011. The composite salinity index (Figure 47) shows fresher-than-normal conditions during the previous 7-years but normal conditions in 2016.

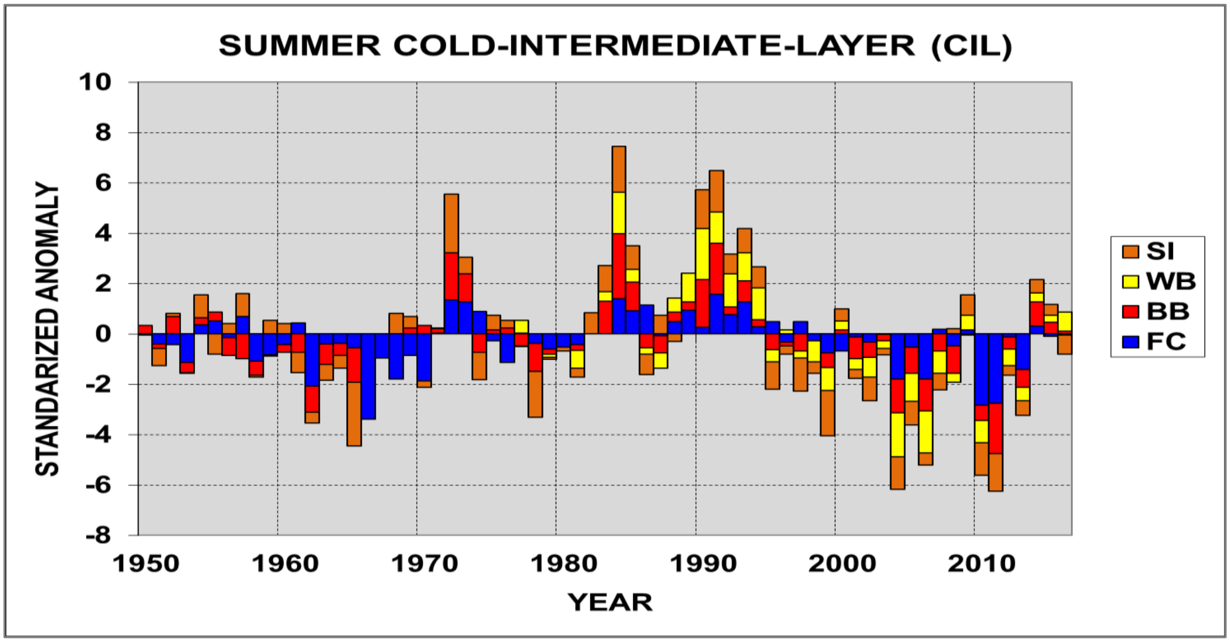

Figure 44. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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	16	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	-0.8	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	0.2	-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	-0.5	-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	0.8	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	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	0.2	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	0.1	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	-0.4	-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	-0.5	-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	-0.2	-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	0.3	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	-0.1	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	-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	0.0	-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	-0.1	-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	-0.4	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	-0.9	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	-0.4	32.69	0.16

Figure 45. 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.

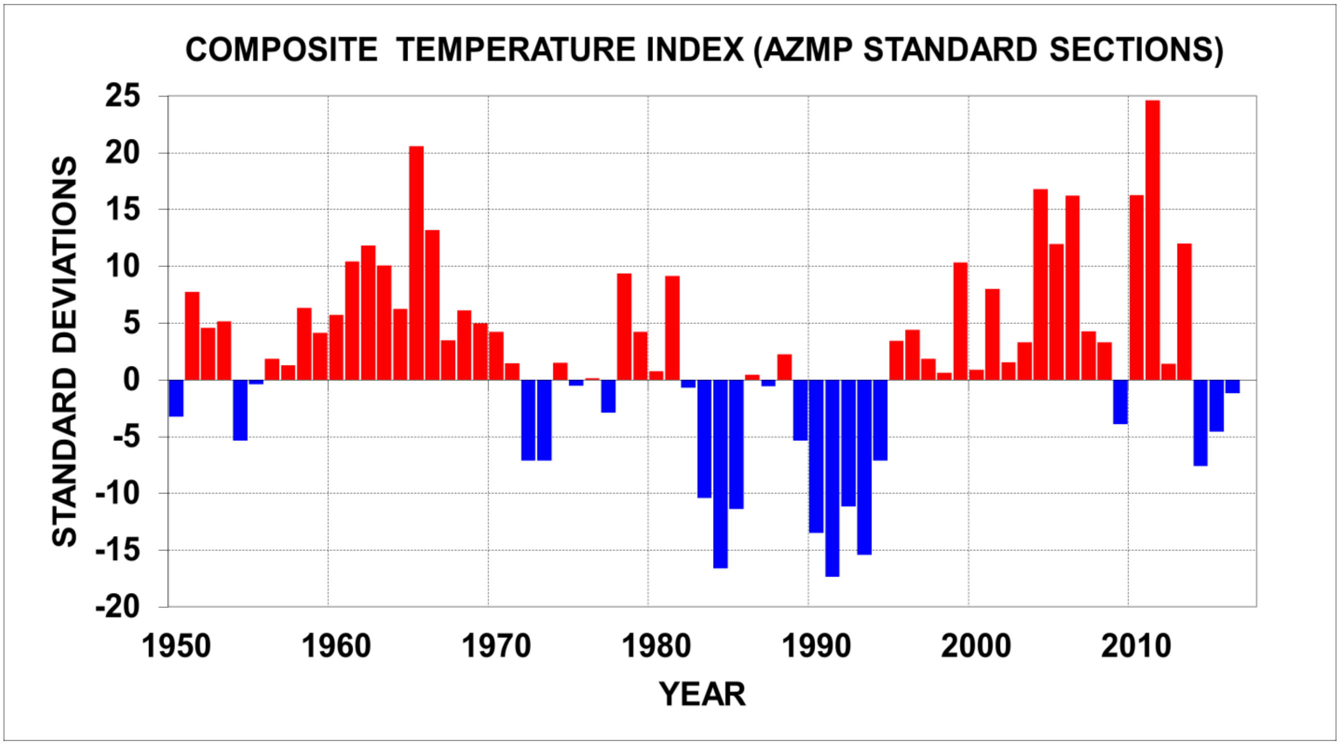

Figure 46. Composite temperature index derived from data collected along standard cross-shelf sections shown in Figure 45.

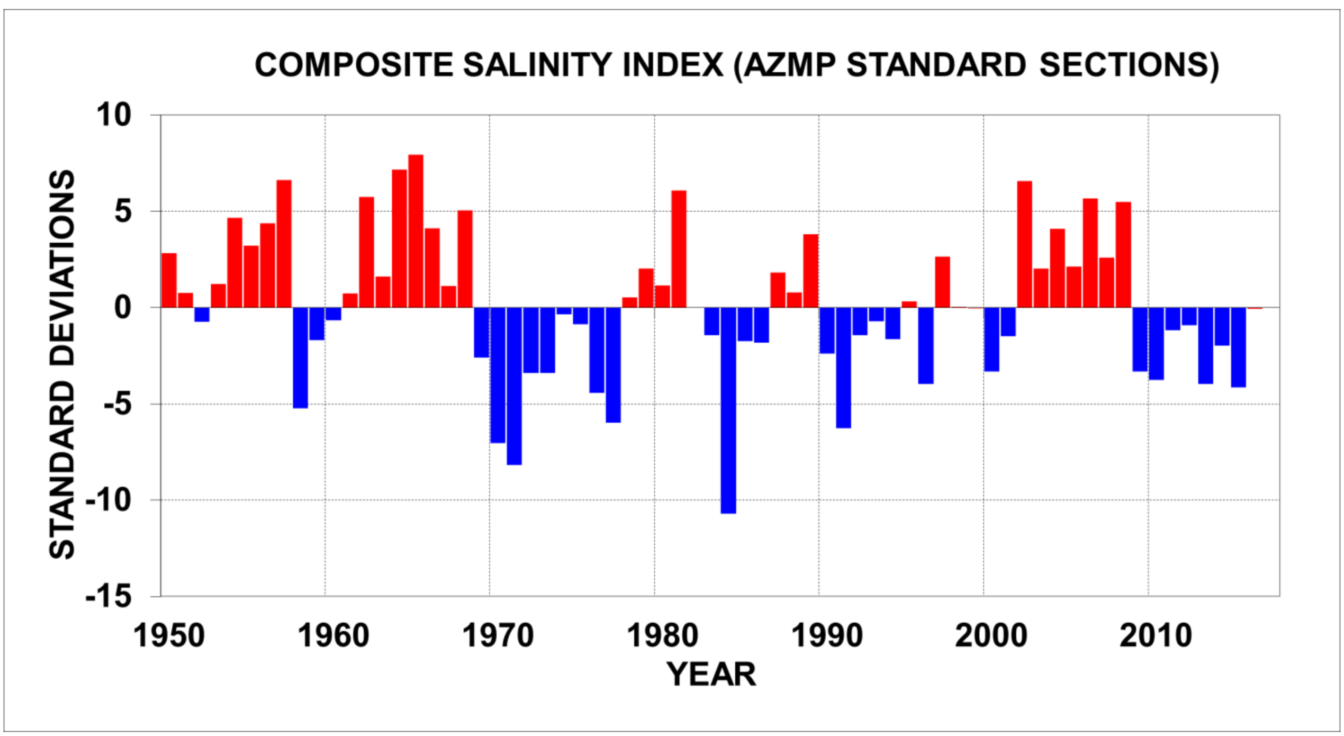

Figure 47. Composite salinity index derived from data collected along standard cross-shelf sections shown in Figure 45.

CIRCULATION IN THE AZMP AREA

The circulation pattern through most of the standard AZMP sections in the Newfoundland and Labrador area is dominated by the south-eastward flowing Labrador Current, which floods the eastern shelf areas with cold, relatively fresh sub-polar water. This flow can significantly affect physical and biological environments off Atlantic Canada on seasonal and interannual time scales. The current originates near the northern tip of Labrador where outflow through Hudson Strait combines with the east Baffin Island Current and flows southeastward along the Labrador coast as a strong western boundary current. The flow over the shelf is strongly influenced by the seabed topography, following the various cross shelf saddles and inshore troughs. A well-defined inshore branch has formed by the time the flow reaches the mid-Labrador Shelf. Further south, near the northern Grand Bank, the inshore branch becomes broader and less defined. In this region, most of the inshore flow combines with the offshore branch and flows eastward a portion of which follows the bathymetry southward around the southeast Grand Bank, the remainder continues eastward and then southward around the Flemish Cap.

The smaller inshore branch flows through the Avalon Channel, around the Avalon Peninsula, and then westward along the Newfoundland south coast. Off the southern Grand Bank the offshore branch flows westward along the continental slope some of which flows into the Laurentian Channel and eventually onto the Scotian Shelf. Additionally, part of the flow combines with the North Atlantic Current and forms the southern section of the sub-polar gyre. Further east, the Flemish Cap is located in the confluence zone of sub-polar and sub-tropical western boundary currents of the North Atlantic. Labrador Current water flows to the east along the northern slopes of the Cap and south around the eastern slopes of the Cap. In the eastern Flemish Pass area, warmer high salinity North Atlantic Current water flows northward contributing to a topographically induced anticyclonic gyre over the central portion of the Cap.

LABRADOR CURRENT TRANSPORT INDEX

In this section we use satellite altimetry data over a large spatial area to calculate the annual-mean anomalies of the Labrador Current transport (Han et al. 2014). A total of nine cross-slope satellite altimetry tracks are used to cover the Labrador and northeast Newfoundland Slopes from approximately 47 to 58^{o}N latitude. On the Scotian Slope we use five tracks from approximately 55 to 65^{o}W longitude. The nominal cross-slope depth ranges used for calculating the transport are from 200 -3,000 m isobaths over the Labrador and northeast Newfoundland Slopes and from 200-2,000 m isobaths over the Scotian Slope, with the nominal depth range from 0 m to 500 m for the former and from 0 m to 100 m for the latter.

An empirical orthogonal function (EOF) analysis of the annual-mean Labrador Current transport anomalies was carried out. The index was developed from the time series of the first EOF mode, standardized by dividing the time series by its standard deviation. The mean transport values are provided based on ocean circulation model output over the Labrador and northeast Newfoundland Slopes (Han et al. 2008) and over the Scotian Slope (Han et al.1997). The mean transport on the Labrador and NE Newfoundland Slope is 13 Sv with a standard deviation of 1.4 Sv and on the Scotian Slope it is 0.6 Sv with a standard deviation of 0.3 Sv. The mean transport values will be updated as new model output becomes available. The standard deviation values will be updated as knowledge on nominal depth improves.

The annual-mean Labrador Current transport index shows that the Labrador Current transport over the Labrador and northeast Newfoundland Slope was out of phase with that over the Scotian Slope for most of the years over 1993-2016 (Figures 48 and 49). The transport was strongest in the early-1990s and weakest in the mid-2000s over the Labrador and northeast Newfoundland Slope, and opposite over the Scotian Slope. The Labrador Current transport index was positively and negatively correlated with the winter North Atlantic Oscillation index over the Labrador and northeast Newfoundland Slopes and over the Scotian Slope, respectively. In the past three years the Labrador Current was close to its normal strength. In 2016 its annual-mean transport was above normal by about 1.3 SD over the Labrador and northeast Newfoundland Slopes and below normal by about 1.0 over the Scotian Slope.

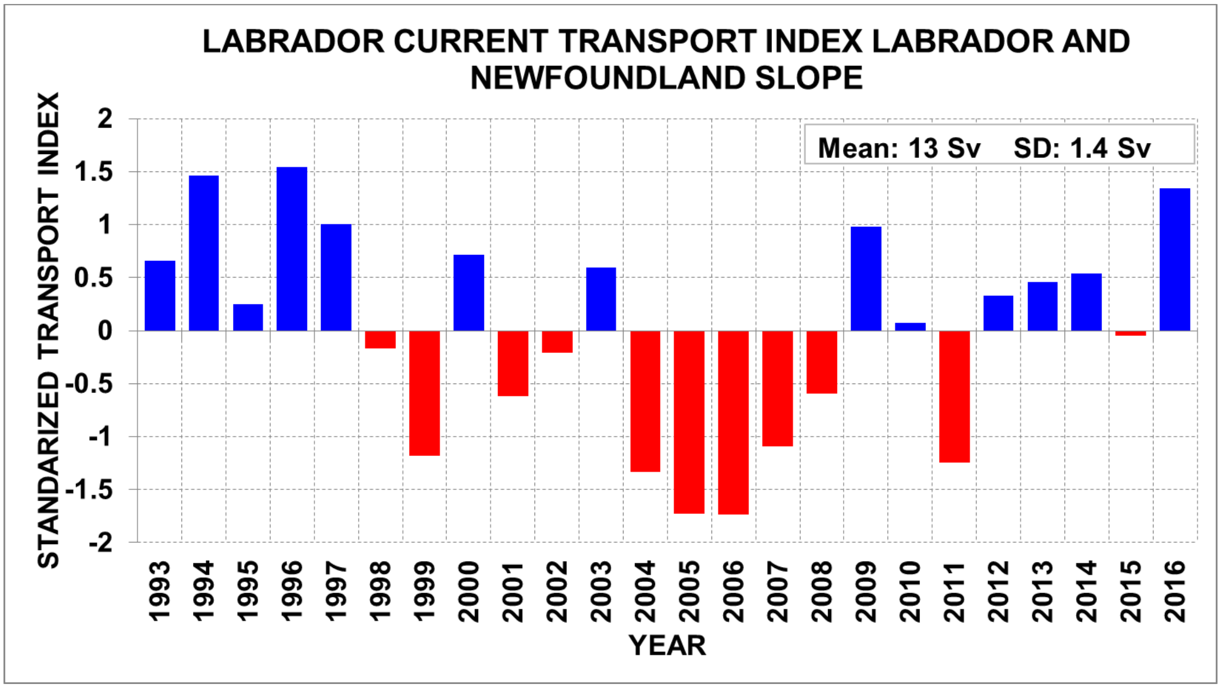

Figure 48. Standardized index of the annual mean Labrador Current transport for the Labrador and northeast Newfoundland Slope. The blue bars indicate higher than average southward transport values.

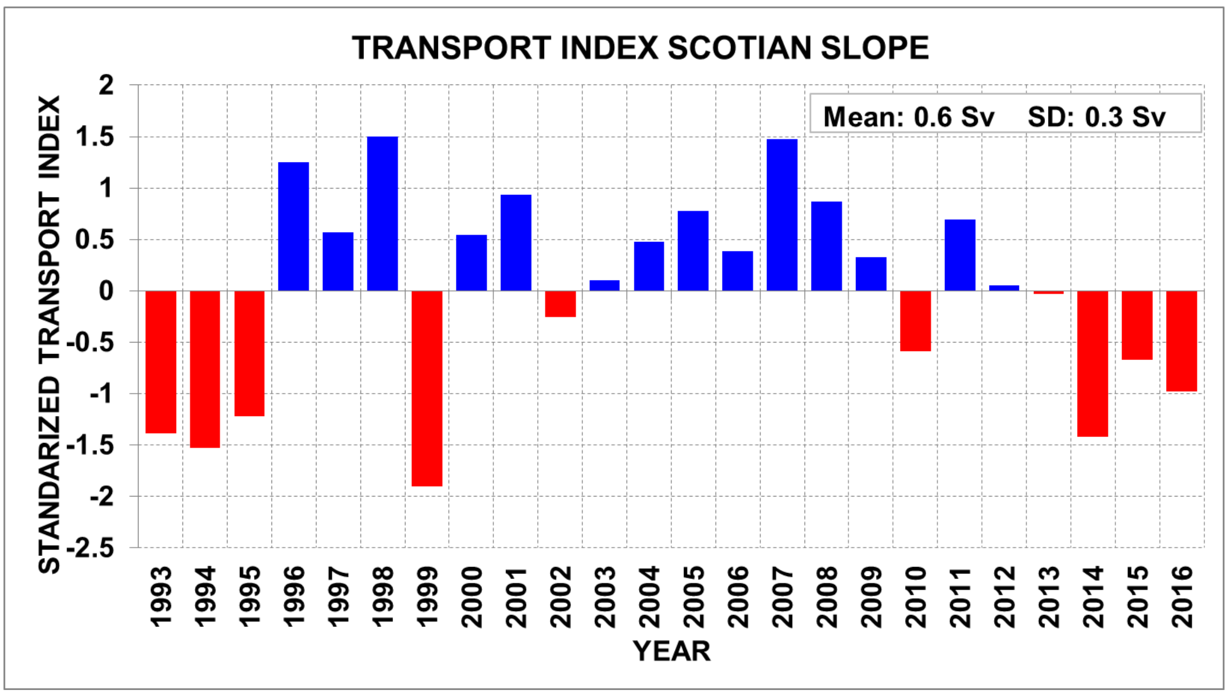

Figure 49. Standardized index of the annual mean transport for the Scotian Slope. The blue bars indicate higher than average southward transport values.

LABRADOR CURRENT VARIABILITY

In this section, we present an analysis of the circulation and transport through the Flemish Cap section (Figure 2) based on direct current measurements using a vessel mounted 75 kHz Acoustic Doppler Current Profiler (ADCP) at 10 m resolution with an effective range of about 620 m. All archived data were used to compute currents and transport along the standard Flemish Cap (47^{o}N) section for the years 2008-16 for the spring and summer period and 2007-15 for the fall period. The ADCP data were collected using Teledyne RDI VmDas and processed using the CODAS3 software suite developed by the University of Hawaii. The data were quality controlled with a percent good threshold of 70-80%. Absolute currents were determined by subtracting ship motion as determined by the ship's 3D DGPS system. Currents were then de-tided using tidal predictions obtained from a high-resolution numerical 2-dimensional tidal model. Averaged data from multiple surveys are used to construct seasonal cross-sections of the mean current field and transport estimates.

The Labrador Current through 47°N, which exhibits considerable annual and seasonal variability, varies spatially from about 50-100 km wide at shelf break of the Grand Bank and east of Flemish Cap (Figure 50). During spring, the main branch of the Labrador Current is about 100 km wide, centred over the 400 m isobath with mean southward currents of about 20 cm/s and peak values >40 cm/s. Currents are weak and highly variable over most of the Grand Banks. During the spring of 2016 southward currents were generally stronger than average along the entire section (Figure 50, top right panel).

During the summer, the Labrador Current on average was generally weaker and narrowed over the shelf break at about 60 km wide with mean speeds <15 cm/s and peak values of about 35 cm/s. In 2016 the current system appears stronger than the average with the appearance of an enhanced anticyclonic circulation around the Flemish Cap (Figure 50, middle panels). The fall data shows current values similar to the spring at the shelf break but a weaker flow east of the Flemish Cap, with the 2015 data showing a significantly enhanced current system (Figure 50, bottom panels). No data were available for the fall of 2016.

LABRADOR CURRENT TRANSPORT

Labrador Current transport values for each survey were computed for various components of the circulation along the Flemish Cap section. Transport values are presented for the Avalon Channel (0-100 km), Grand Bank Slope (300-450 km) and the eastern Flemish Cap area (625-750 km) of the section (Figure 51). Currents in the top 15 m of the water column were extrapolated from the values in the first 10 m data bin (15-25 m). Transport values were then calculated by integrating from the surface to the near bottom bin or to the maximum range of 620 m along the various parts of the section.

Annual transport values for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the spring, summer and fall are shown in Figures 52 to 54. The Avalon Channel transports show maximum values during the spring of about 1 Sv (10^6 m^3/s) and about 2 Sv during the summer and fall. In the offshore branch at the Grand Bank slope area transport values ranged from about 4 Sv in 2009, up to 10 Sv in 2010 and about 8 Sv during 2015 and 2016. During the summer transports were weaker, with values ranging from less than 4 Sv in 2009 to about 7 Sv in 2015. East of the Flemish Cap, spring transport values were highly variable ranging from just over 2 Sv in 2009 to 16 Sv in 2015, a similar pattern was observed during the summer. In the fall they ranged from about 1 Sv in 2007-08 to about 9 Sv in 2013 and 2015.

The average seasonal transport values based on the data presented in Figures 52 to 54 are shown in Figure 55 for the spring, summer and fall periods. In the Avalon channel the seasonal transport is about 1 SV with no significant difference between seasons. On the Grand Bank Slope-Flemish Pass area the transport is weakest during the summer and strongest during the spring ranging from 5.2 to 7.4 Sv and in the offshore branch east of the Flemish Cap transport values range from 3.8 in the fall to 8.1 Sv in spring.

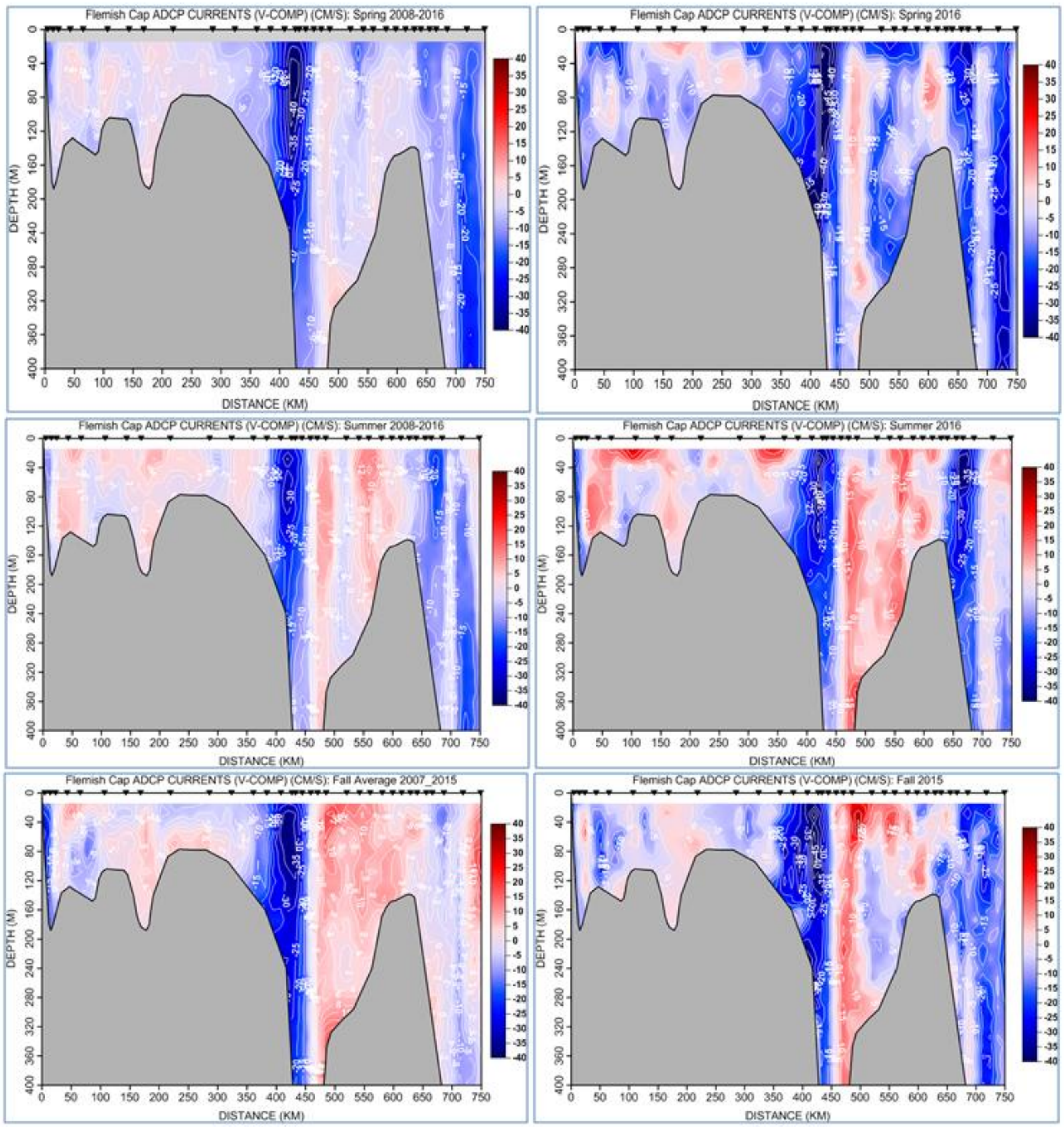

Figure 50. Average current speeds (cm/s) during the spring, summer and fall (left panels) along the Flemish Cap section (Figure 2) and during the spring and summer of 2016 and during the fall of 2015 (right panels). Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

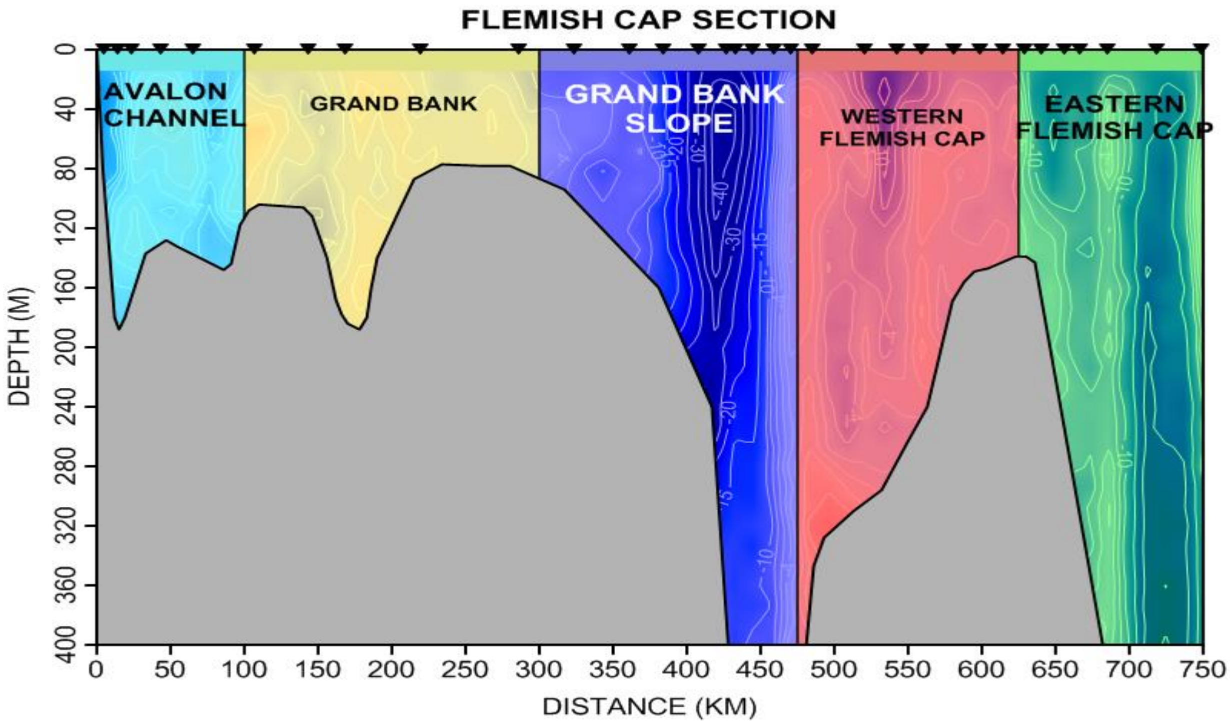

Figure 51. The Flemish Cap section showing areas along the section where Labrador Current transport values were computed. The symbols along the top of the panels are the standard AZMP stations.

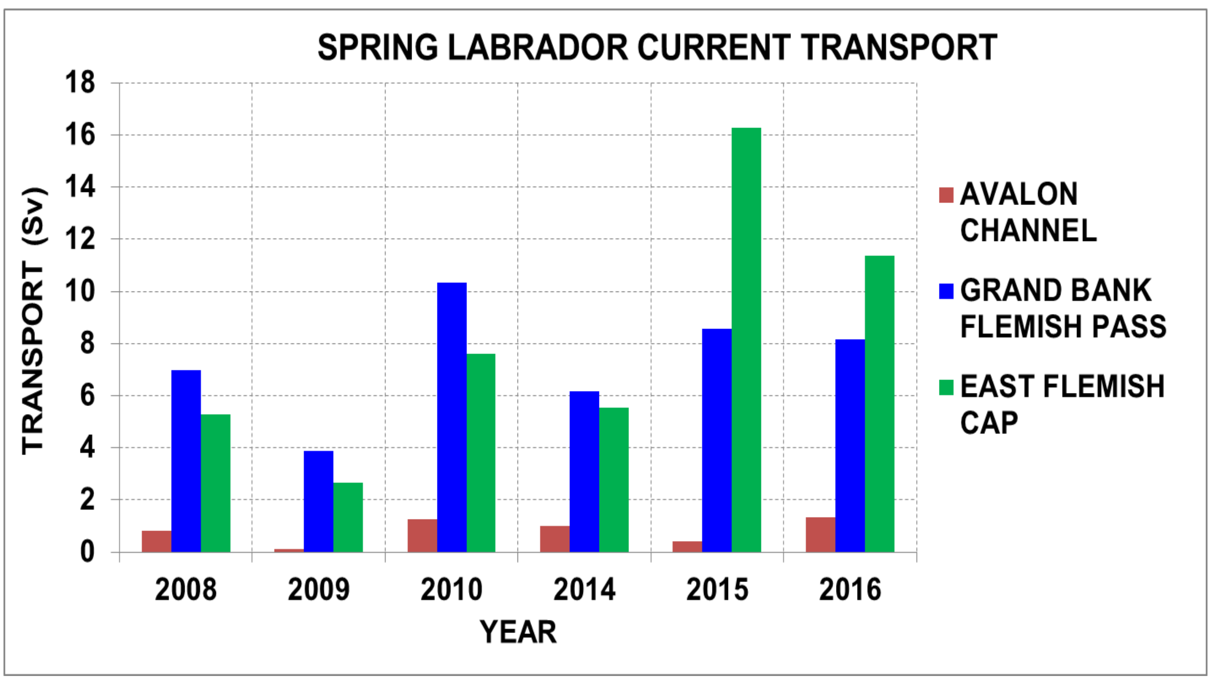

Figure 52. Annual transport values (Sv, 10^6 m^3/s), for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the spring based on all available ADCP data.

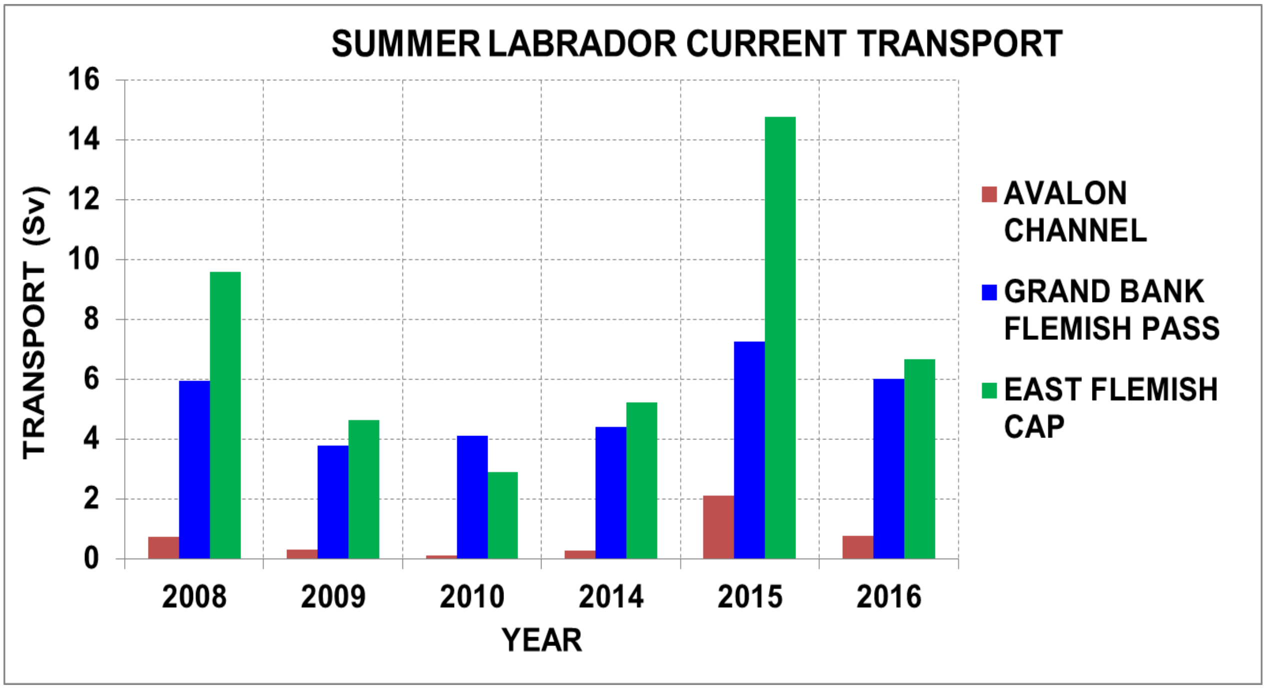

Figure 53. Annual transport values (Sv, 10^6 m^3/s), for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the summer based on all available ADCP data.

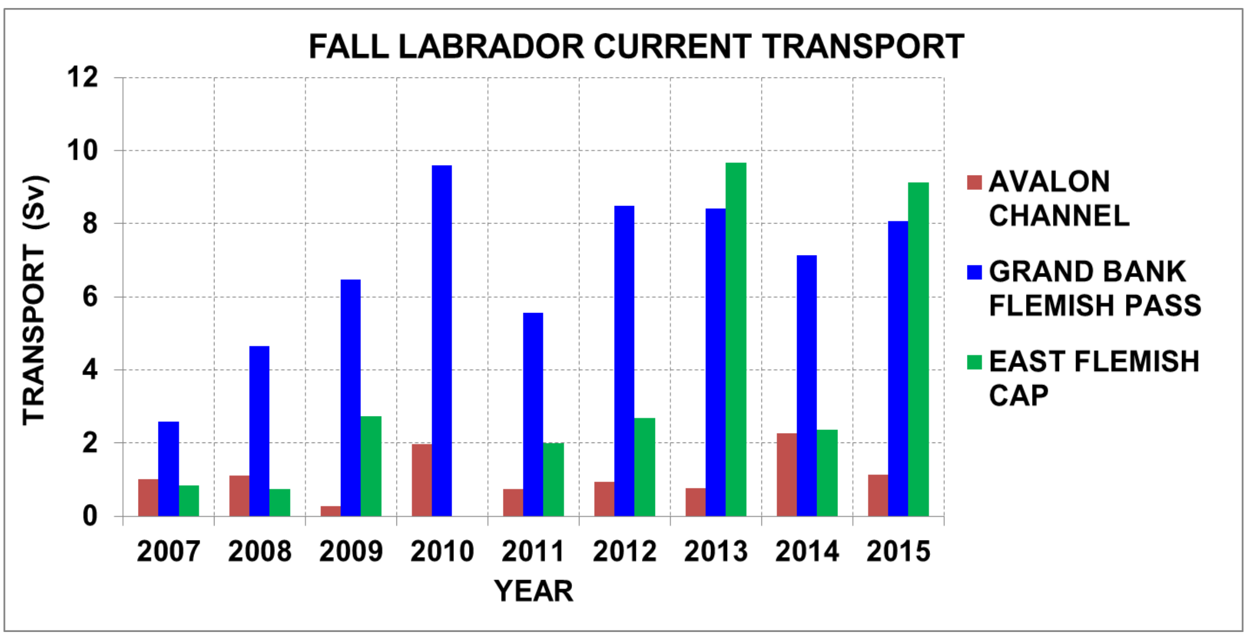

Figure 54. Annual transport values (Sv, 10^6 m^3/s), for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the fall based on all available ADCP data.

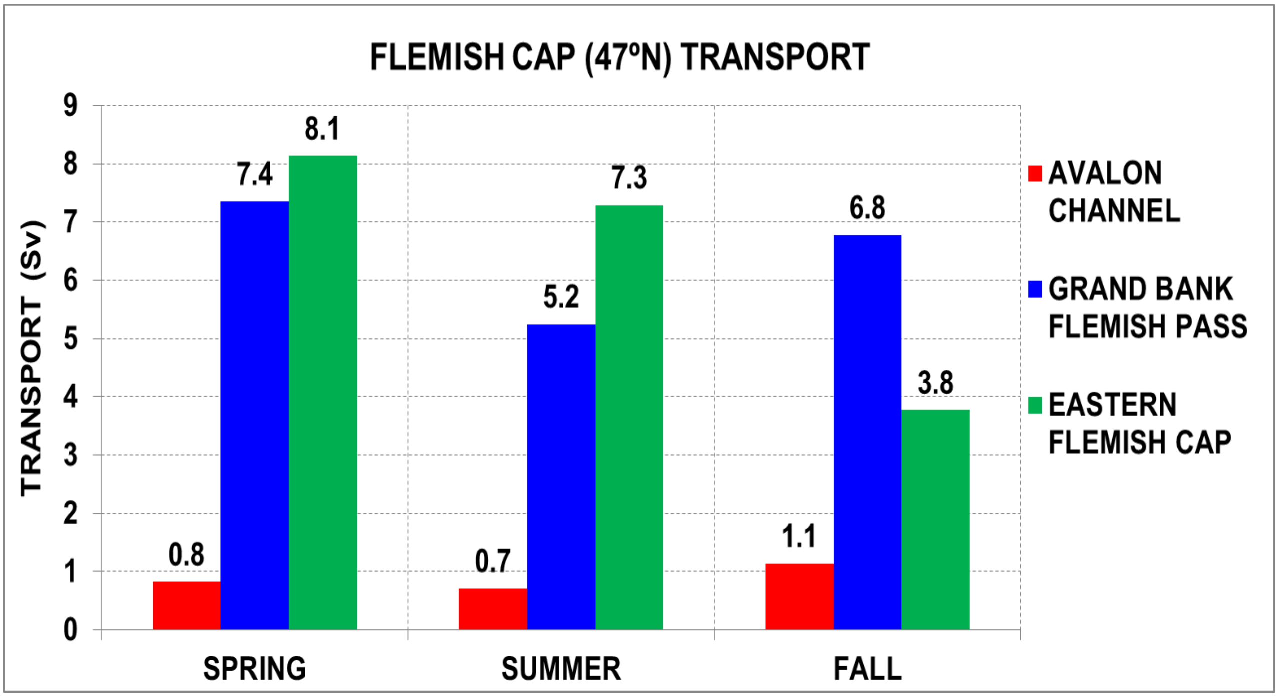

Figure 55. Seasonal transport values (Sv, 10^6 m^3/s), for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the spring, summer and fall based on the average for all years with available ADCP data.

MULTI-SPECIES SURVEY BOTTOM TEMPERATURES

Canada has been conducting stratified random bottom trawl surveys in NAFO Subareas 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 from either a trawl mounted CTD or an XBT profile.

These surveys provide large spatial-scale oceanographic data sets for the Newfoundland and Labrador Shelf. During the spring NAFO Subdiv. 3Ps on the Newfoundland south coast and Divs. 3LNO on the Grand Banks are surveyed and in the fall 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 2016.

SPRING CONDITIONS

Maps of the climatological mean bottom temperature and salinity together with the spring 2016 bottom temperature and salinity, their anomalies and difference from the previous year are displayed in Figures 56 and 57 for NAFO Divs. 3PLNO (See Figure 2 right panel for station occupation coverage)

Bottom temperatures in Div. 3L generally range from -0.5°C to 0°C in most areas and from 1° to 3°C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 1° to 6°C. Bottom temperature anomalies were below normal (up to -0.5°C) over northern areas of 3L and above normal (up to +1°C) on the southern Grand bank in Divs. 3NO.

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 +0.5°C to more than 1°C above normal in almost all areas of 3Ps. The bottom right panel of Figure 56 shows, except for isolated areas, a slight warming over 2015 values.

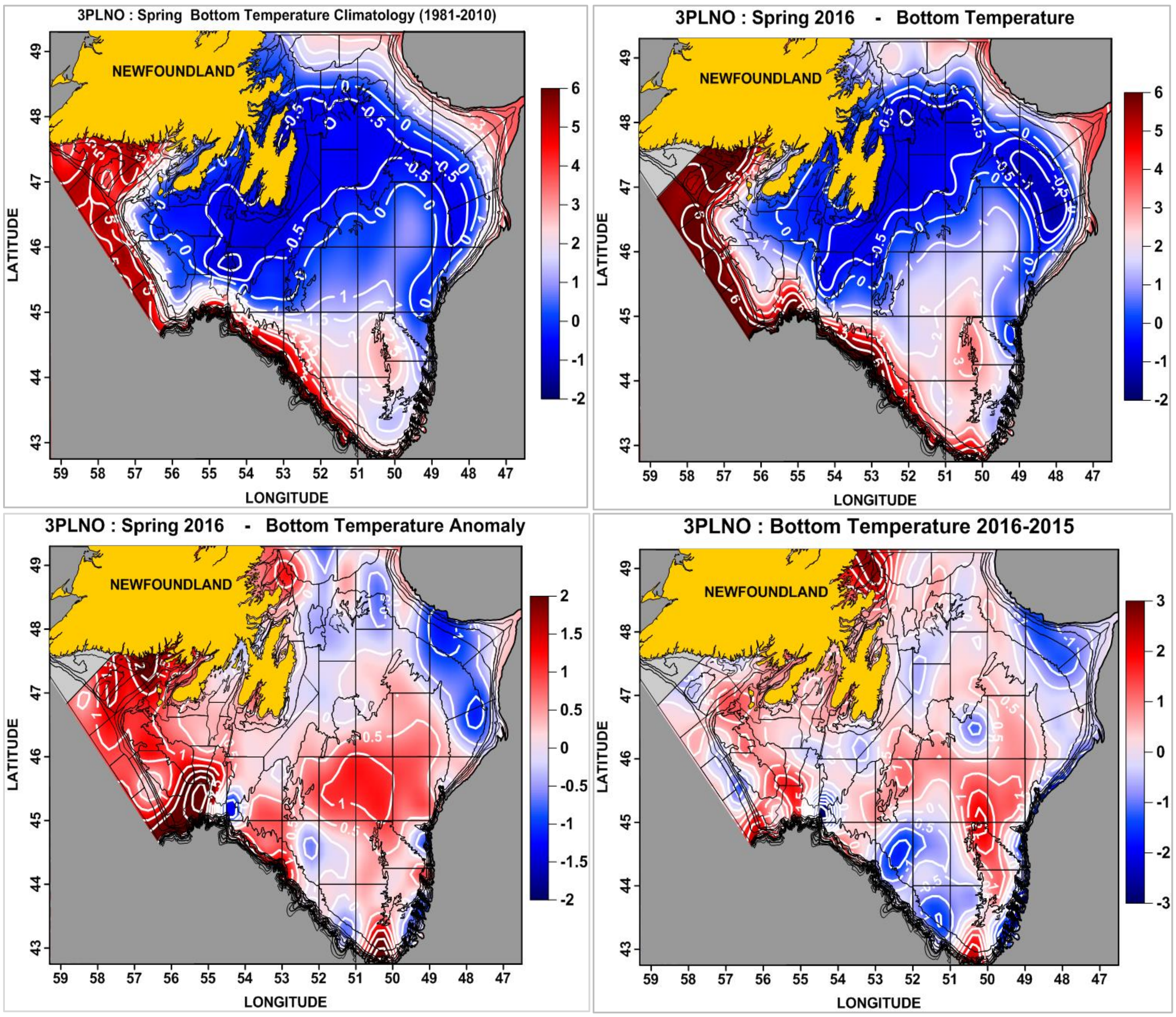

Figure 56. Maps of the mean 1981-2010 bottom temperature, bottom temperature and anomalies during spring 2016 and the difference from 2015 (in °C) in NAFO Divs. 3PLNO.

Bottom salinities in Div. 3L generally range from 32.75-33 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 32.5 to 33.25, 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 57).

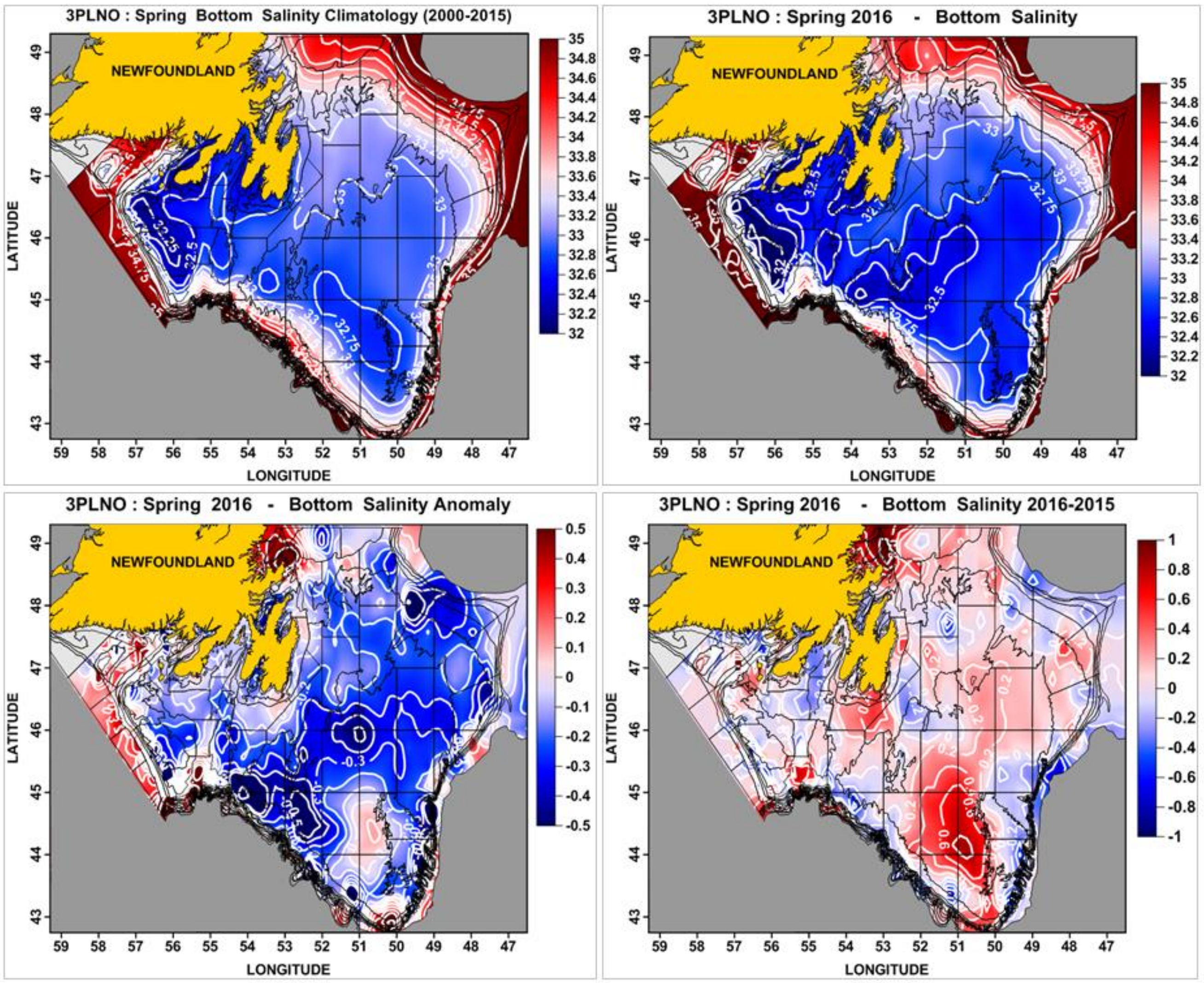

Figure 57. Maps of the mean (2000-15) bottom salinity, bottom salinity and anomalies during spring 2016 and the difference from 2015 in NAFO Divs. 3PLNO.

Climate indices based on the temperature data collected during the spring survey for the years 1990-2016 are displayed in Figure 58 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 and 2016 it was about normal (Figure 58).

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 has decreased to near-normal values by 2015 and 2016 (Figure 58).

In Div. 3P bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000, near record cold conditions in 2003 (-1.4 SD). A notable exception occurred in 2007-08 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 almost 2 SD in 2011-12 and then again in 2016. 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. The area of <0°C water increased somewhat in recent years but remained at 1 SD below normal in 2016 (Figure 58).

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	2016	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	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	0.3	0.69	0.57
THERMAL HABITAT AREA >2°C	-0.2	1.1	-0.8	2.0	0.4	-1.0	-1.1	-0.3	-0.3	-1.0	-1.7	-1.6	-1.3	-0.6	-0.7	-0.5	-0.2	-0.4	0.6	1.8	0.7	-0.3	-0.2	-0.3	1.8	1.0	-0.3	0.7	0.5	0.9	1.1	2.5	1.4	0.7	0.4	0.7	0.3	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	-0.1	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	2.0	2.53	0.44
BOTTOM TEMPERATURES <100 M	0.3	1.4	0.5	1.1	2.1	-1.6	-0.9	-1.0	0.3	-0.8	-1.5	-0.8	-0.9	-0.9	-0.6	-0.5	0.5	-0.3	0.6	1.4	1.6	-0.4	-0.2	-1.4	0.5	1.2		-0.4	-0.1	0.3	0.7	1.9	1.0	1.1	0.1	0.0	1.2	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	1.2	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	-1.0	22.13	11.78

Figure 58. 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 59 as stacked bar graphs. The increasing trend since the early 1990s is evident with some cooling events, one occurring in 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 and in 2016 increased even further to 2 SD above normal, the highest since 1984.

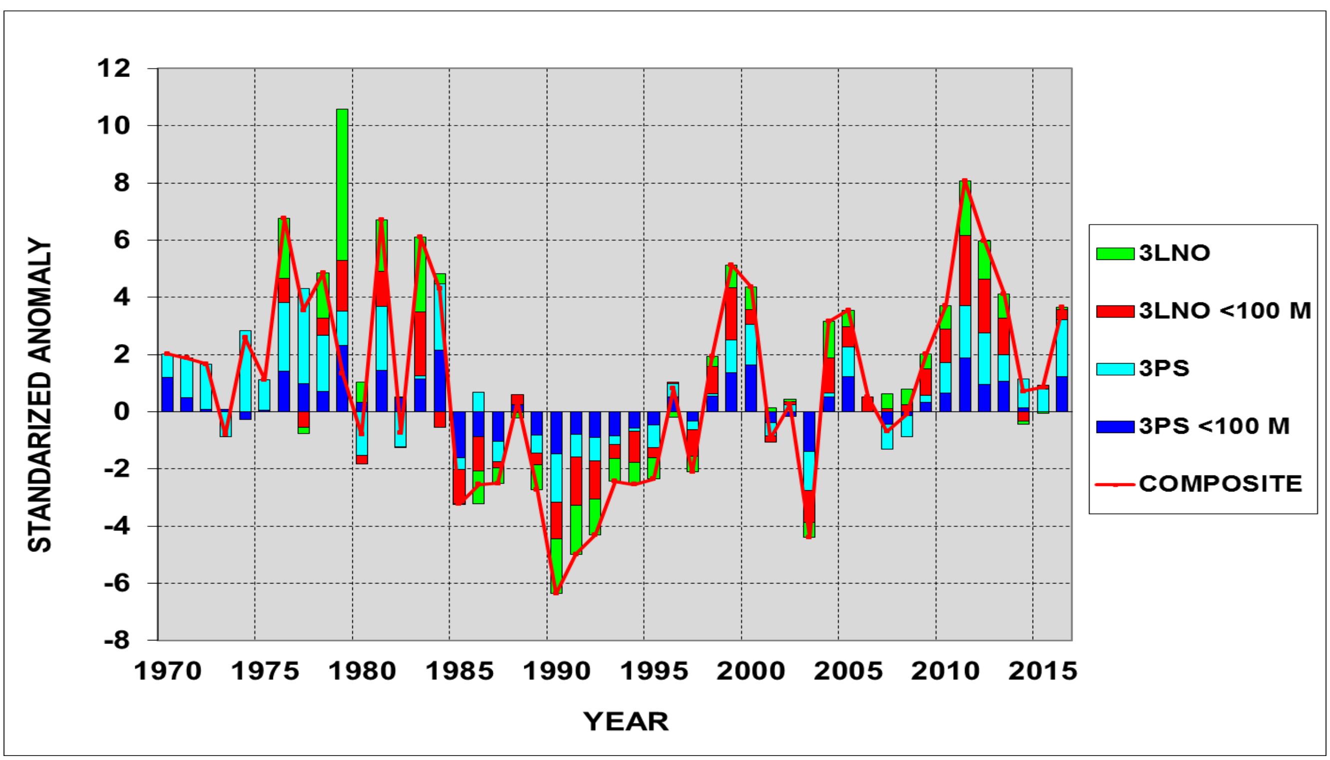

Figure 59. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divs. 3LNOP.

FALL CONDITIONS

Bottom temperature and temperature anomaly maps derived from data collected during the fall of 2016 multi-species survey (Figure 2) in NAFO Divs. 2J, 3KL are displayed in Figure 60. Bottom temperatures in Div. 2J ranged from 1°-2.5°C on Hamilton Bank and the inshore areas of the Labrador coast to >3.5°C at the shelf break.

Most of the 3K region is deeper than 200 m. As a result, relatively warm Labrador Slope water (2°-3°C) 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 Funk Island Bank ranged between 1° to 2.5°C and from 2.5° to 3°C on Belle Isle Bank. Bottom temperature anomalies were up to 1°C above normal on Hamilton Bank and along the southern Labrador coast and along the northeast coast of Newfoundland. In the offshore areas temperatures were below normal by up to -0.5°C in both 2J and 3K.

Bottom temperatures in NAFO Div. 3L generally ranged from -1°-0°C on the northern Grand Bank and in the Avalon Channel to 3°-4°C along the shelf edge and >1°C in the southern areas of 3L. Temperatures were below normal over most of 3L and in parts of 3NO whereas over the central area of the Grand Bank bottom temperatures were up to >1°C above normal (Figure 60).

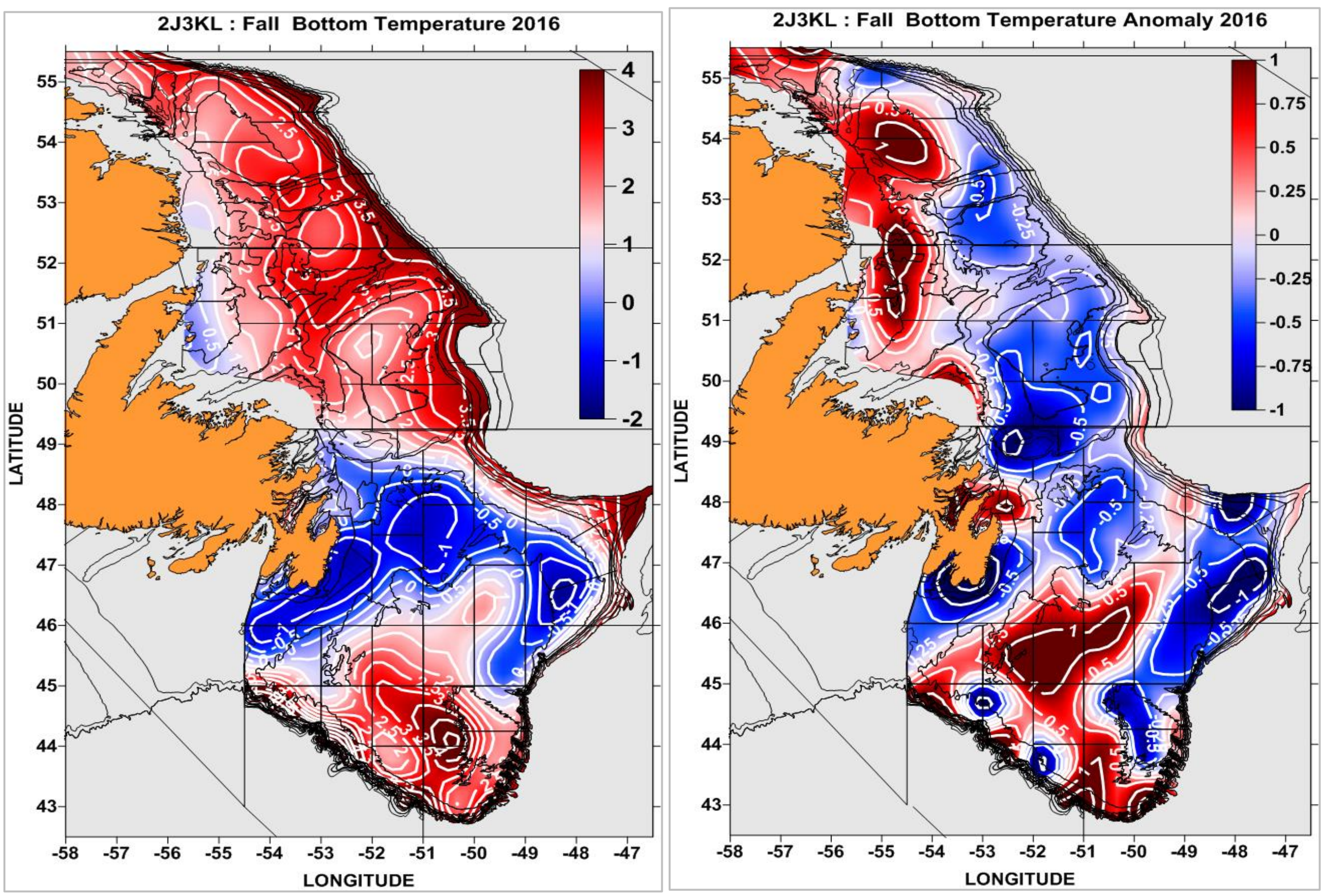

Figure 60. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2016 in NAFO Divs. 2J3KL.

Bottom salinities in Div. 2J generally range from 32.75-34.5 over most areas and from 34.5 to 35 at the shelf edge. In 3K salinities ranged from 33.5 to 34.75 and on the Grand Banks bottom salinities ranged from 32.75 to >34.5, with the lowest values on the southeast shoal of the Grand Bank. Except for isolated areas bottom salinities were generally below normal (up to -0.3) over most regions (Figure 61).

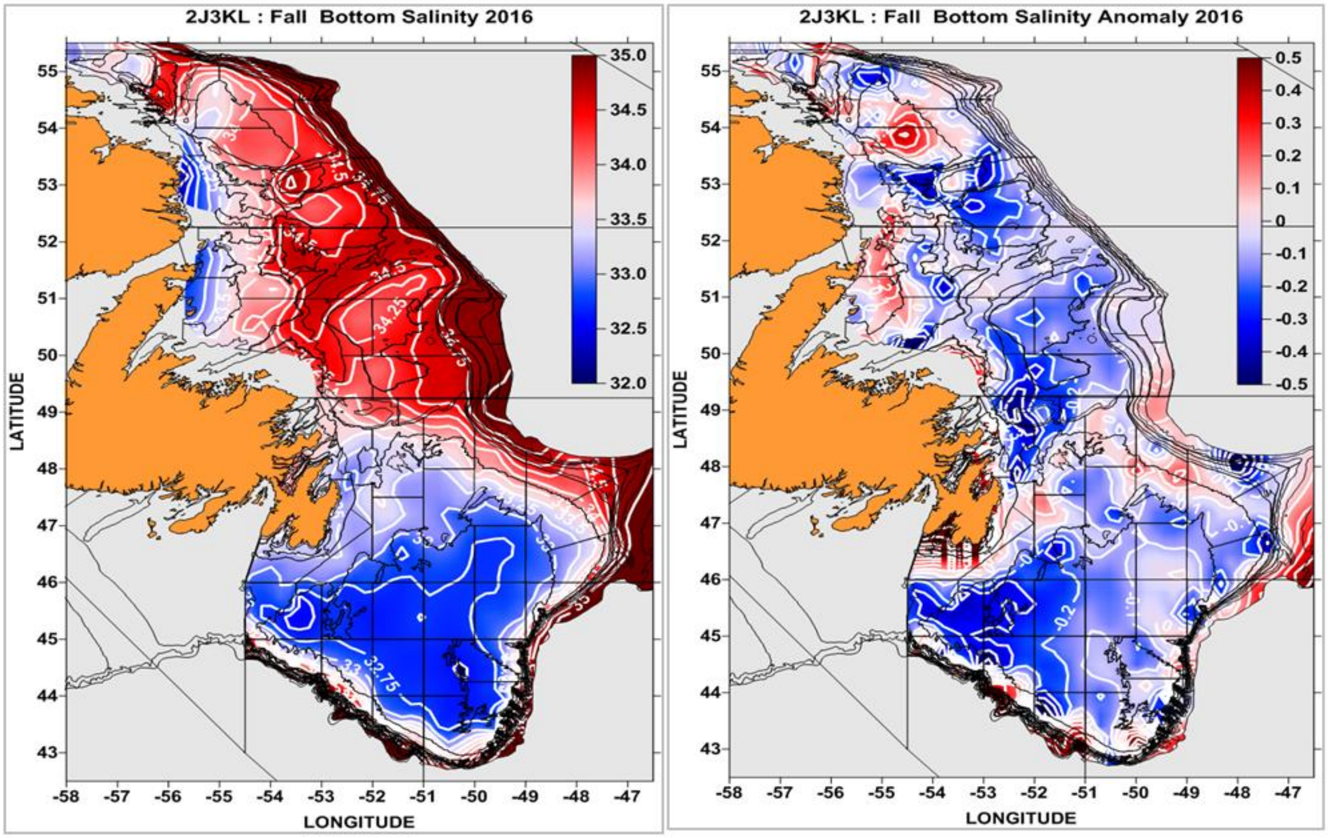

Figure 61. Contour maps of bottom salinity and bottom salinity anomalies (referenced to 2000-15) during the fall of 2016 in NAFO Divs. 2J3KL.

Bottom temperature anomalies and derived indices are displayed in Figure 62 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 2.0-2.2 SD above normal and in 2015 they decreased to near-normal values but increased again in 2016 to near 1 SD above normal. The area of the bottom covered by water with temperatures <1°C was near normal in 2015 but 1.5 SD below normal in 2016. In Div. 3K, bottom temperatures were at a record high in 2011 (+2.7 SD) but have decreased in recent years to about 0.5 SD above normal in 2016.

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 63. 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. Conditions in 2016 warmed somewhat over the previous year, particularly in 2J.

Composite indices derived by summing the standardized values presented in Figures 58 and 62 compare the overall temperature conditions during the spring and fall since 1980. Since the record high in 2011 temperature conditions have decreased significantly to near-normal values in both 2014 and 2015 but warmed somewhat in 2016 (Figure 64).

NAFO DIV. 2J	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
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
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
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
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
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
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
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
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
NAFO DIV. 3LNO																			
BOTTOM TEMPERATURES											-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3
BOTTOM TEMPERATURES <100 M											-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6
THERMAL HABITAT AREA >2°C											-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7
THERMAL HABITAT AREA <0°C											0.4	1.4	1.5	1.8	1.7	-0.7	-0.1	0.3	-0.5
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

NAFO DIV. 2J	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MEAN	SD
BOTTOM TEMPERATURES	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	1.0	2.35	0.47
BOTTOM TEMPERATURES < 200 M	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	1.1	0.79	0.71
THERMAL HABITAT AREA >2°C	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	1.2	57.94	14.65
THERMAL HABITAT AREA <1°C	-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	-1.5	22.72	15.71
NAFO DIV. 3K																				
BOTTOM TEMPERATURES	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	0.5	2.13	0.53
BOTTOM TEMPERATURES < 300 M	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	0.6	1.46	0.62
THERMAL HABITAT >2°C	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	0.3	62.16	13.74
THERMAL HABITAT AREA <1°C	-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	-1.0	20.76	11.06
NAFO DIV. 3LNO																				
BOTTOM TEMPERATURES	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	0.0	1.78	0.39
BOTTOM TEMPERATURES <100 M	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	0.0	1.22	0.64
THERMAL HABITAT AREA >2°C	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	0.3	32.18	9.83
THERMAL HABITAT AREA <0°C	-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	-0.2	30.33	12.93
CIL VOLUME (FALL) 2J3KL	-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	-0.7	1.65	0.95

Figure 62. 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.

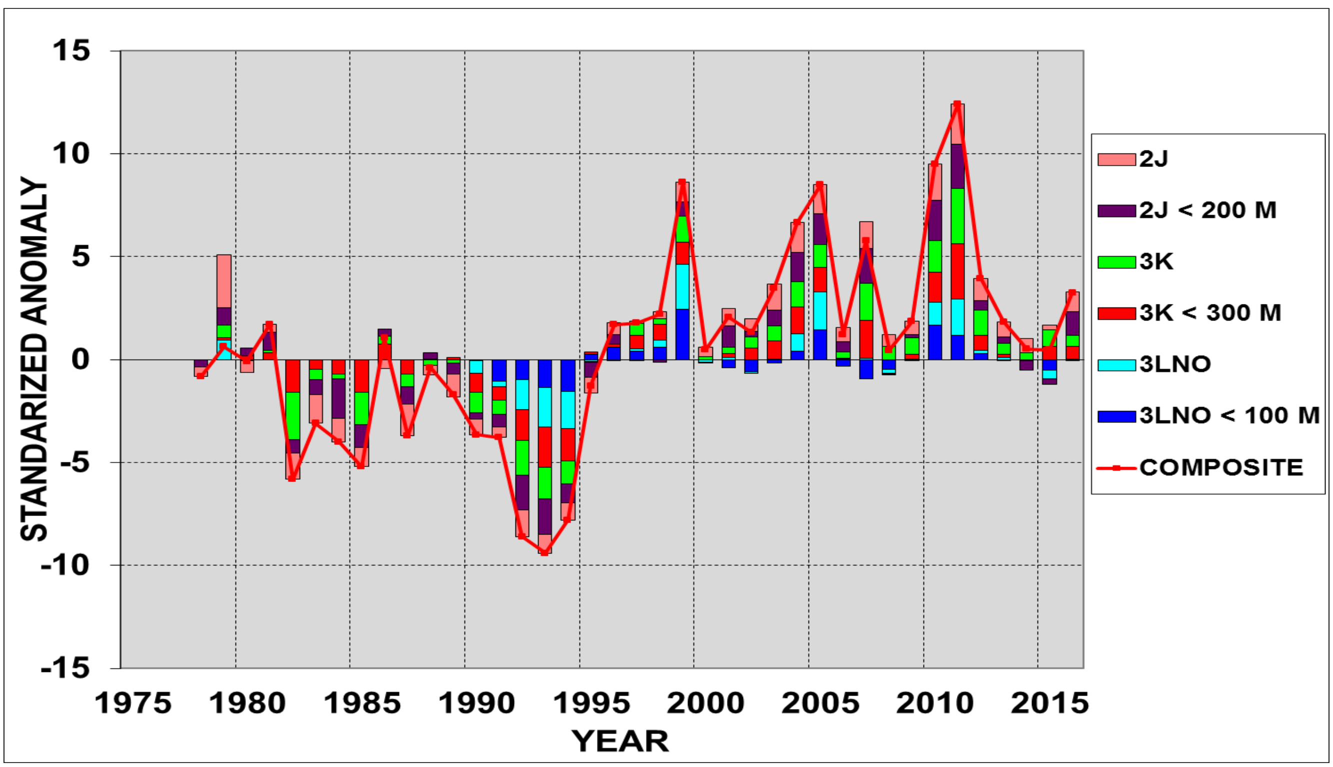

Figure 63. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divs. 2J3KLNO.

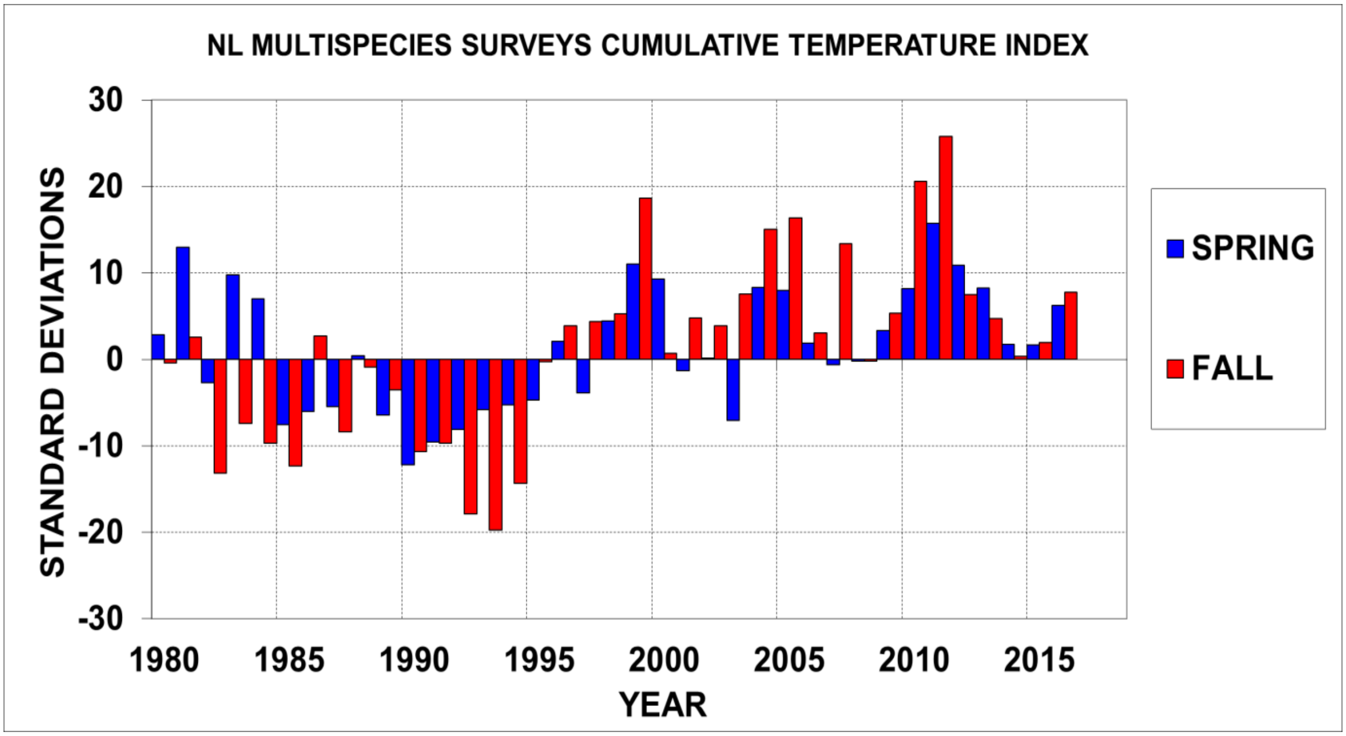

Figure 64. Spring and fall composite temperature index derived by summing the standardized anomalies displayed in Figures 50 and 54.

FALL CIL VOLUME

The spatial extent of the CIL water mass (T <0°C) 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 by the fall in warm years. The total volume of CIL water remaining on the shelf in NAFO Divisions 2J3KL after the summer warming and early fall mixing was calculated from the vertical temperature profiles collected during the fall multi-species survey (October to mid-December).

The average volume of the CIL on the NL Shelf is (1.65± 0.95) × 10^4 km^3. The annual values are shown in Figure 62 as standardized anomalies and in Figure 65 as a volume anomaly time series. The high volumes associated with the cold periods of the mid 1980s and early 1990s are evident as well as the decreasing trend since 1993. The CIL volume was the lowest in the 34-year record during 1999 (1.7 SD below normal) with 2010 and 2011 tied for 3rd lowest at 1.1 SD below normal. During 2014 the CIL volume increased to 1.90 × 10^4 km^3 or 0.3 SD above normal, the first positive anomaly since 1994 but it had returned to a negative value in 2015 and in 2016 it stood at 0.7 SD below normal.

SUMMARY

A summary of selected temperature and salinity time series and other climate indices for the years 1950-2016 are displayed in Figure 66 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 particularly the early 1990s stands out as the coldest period in the time series. The warming trend from the late 1990s that lasted to 2013 was followed by recent cooling in 2014 and 2015 but appears to have reversed somewhat in 2016 with 16/28 indices showing either near-normal or positive values compared to only 6/28 in 2015. The cold years of 2014 and 2015 corresponded to a high positive phase of the NAO, with the 2015 value at 2 SD above normal, a 120-year record high.

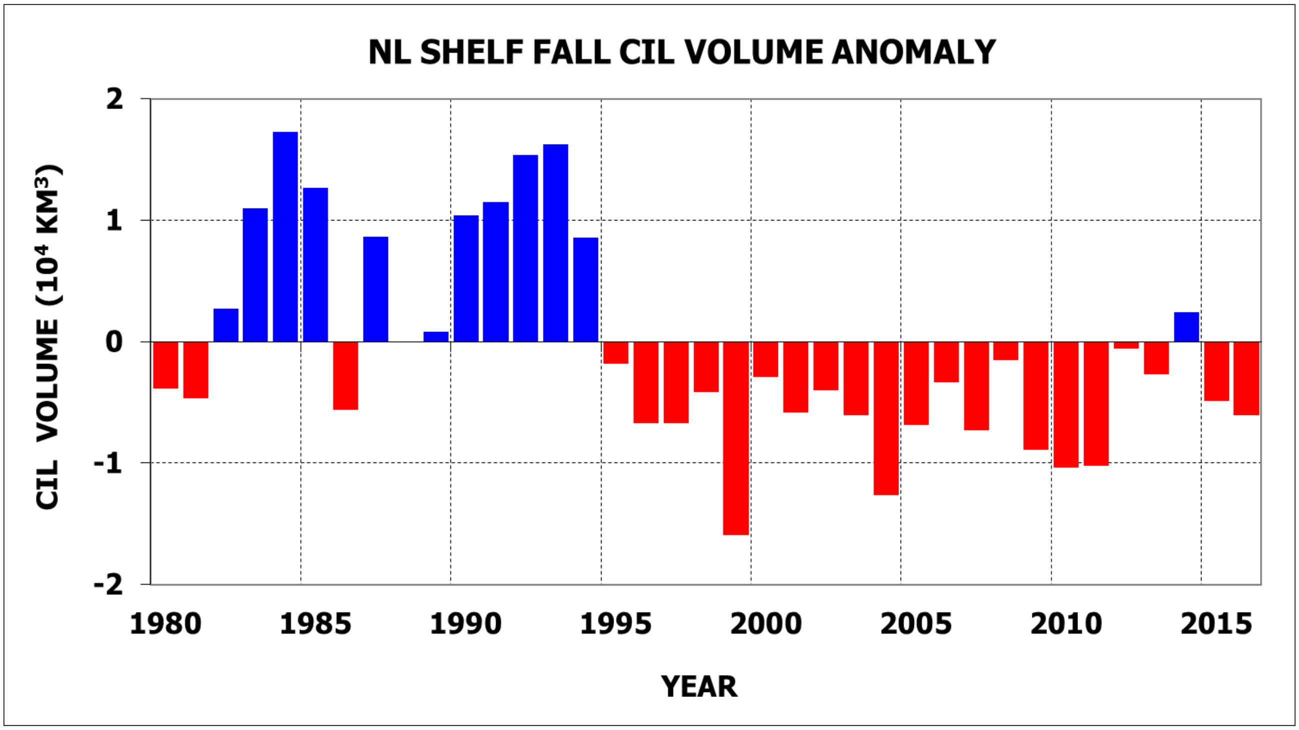

Figure 65. Time series of the CIL (<0°C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

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 67). 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 can be interpreted as 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.

Similar to the standardized values shown in Figure 66, 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 second highest in the 67-year time series.

In 2011 it was very similar to 2010, the 4th highest, but in 2012 it had decreased to the 8th highest and has continued a trend of decreasing values reaching the seventh lowest in 2015, the lowest (coldest) value since 1993. In 2016 the composite climate index recovered to a positive value, similar to conditions observed in 2007.

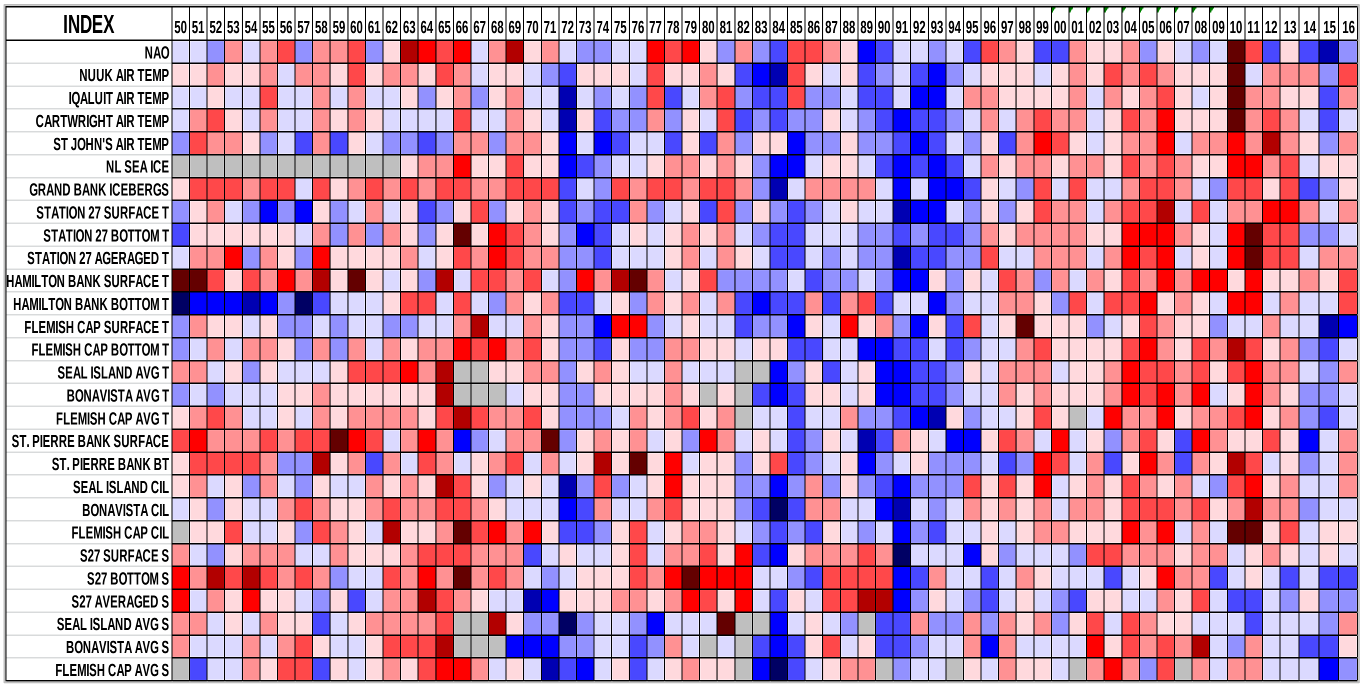

Figure 66. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Figure 3. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells indicate missing data.

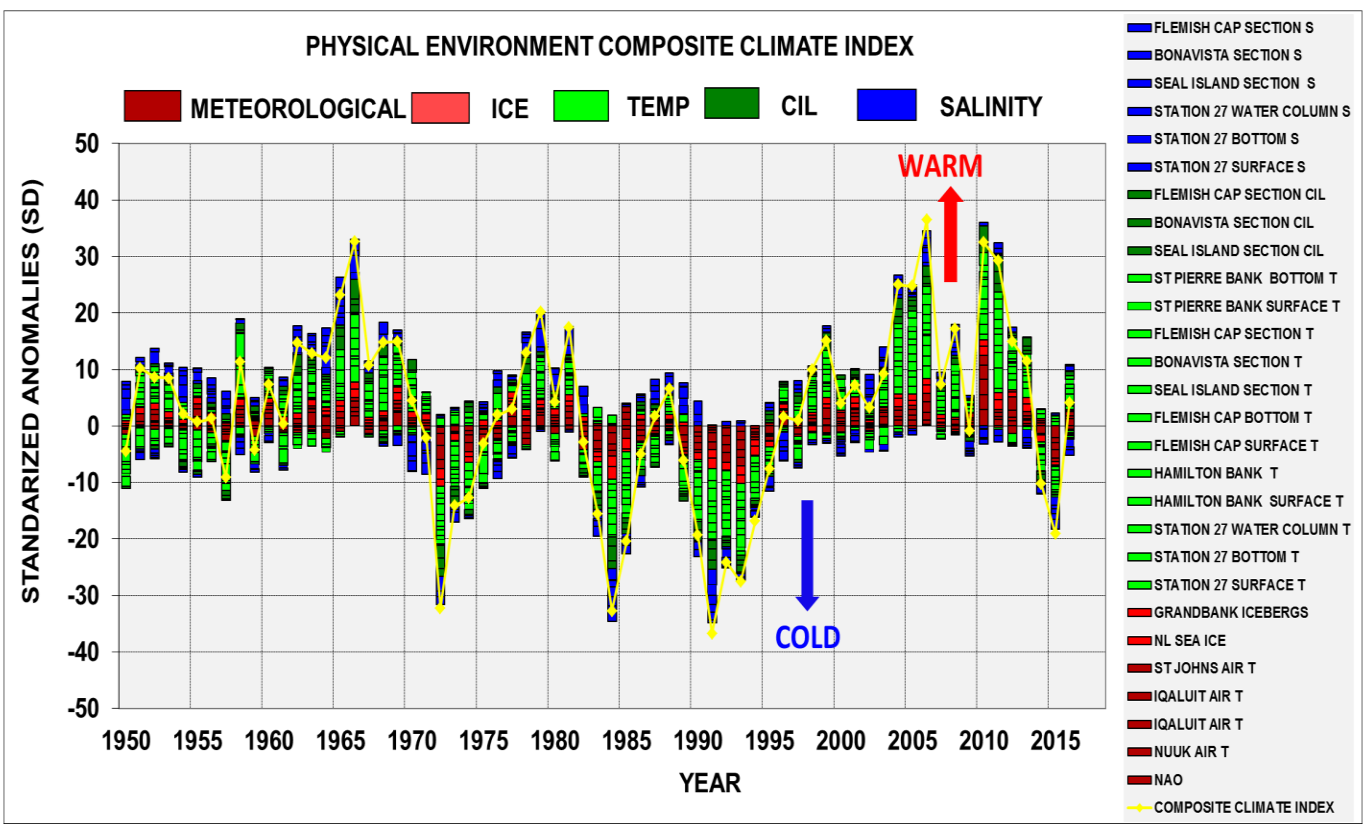

Figure 67. Composite climate index (yellow line) derived by summing the standardized anomalies from Figure 58 together with their individual components.

SUMMARY POINTS FOR 2016

- The North Atlantic Oscillation Index, a key indicator of climate conditions on the NL Shelf, remained in a positive phase in 2016 at 0.5 SD above normal.
- Arctic air outflow during the winter decreased over the previous year causing a significant increase in air temperatures with most sites reporting positive anomalies, except Cartwright where values remained at 0.3 SD below normal.
- Sea ice extent on the NL Shelf returned to slightly below normal conditions in 2016 at 0.4 SD below the long term mean.
- 687 icebergs were detected south of 48ºN on the Northern Grand Bank (0.1 SD below the 1981-2010 average of 767).
- Annual sea surface temperatures (SST) were mostly below normal over the eastern Newfoundland Shelf, Flemish Cap and Grand Banks, except for St. Pierre and Green Banks where they were 0.8 SD above normal.
- The annual surface temperature anomaly at Station 27 was +0.4°C or 0.5 SD above normal.
- The annual bottom (176 m) temperature anomaly at Station 27 was -0.2°C or 0.4 SD below normal.
- The annual surface salinity anomaly at Station 27 was -0.02 or -0.1 SD below normal.
- The annual bottom (176 m) salinity anomaly at Station 27 was -0.1 or -1.4 SD below normal.
- The annual water column average (0-176 m) temperature and salinity anomaly at Station 27 was +0.3°C and -0.05 or +0.7 and -0.5 SD different from normal, respectively.
- The summer area of CIL (<0°C) water on the Grand Banks (FC), eastern Newfoundland (BB) and southern Labrador (SI) was 26.2, 26.6 and 21.7 km^2 or -0.1, 0.1, -0.7 SD different from normal, respectively.
- Labrador Current transport through the Flemish Section on the slope of the Grand Bank and Flemish Pass was similar to the 2015 value, about 6 and 8 Sv during summer and fall, respectively. East of the Flemish Cap the transport was lower than the extremely high value observed in 2015 of 14-16 Sv.
- The averaged spring bottom temperature in NAFO Div. 3P was about 3.4°C, almost 1°C (2 SD) above normal, the highest since 1984.
- The spatial averaged spring and fall bottom temperature in NAFO Divs. 3LNO was about normal at 1.5° and 1.8°C, respectively.
- The averaged fall bottom temperature in 2J was 2.8°C which was 1 SD above normal.
- In 3K the averaged fall bottom temperature was 2.4°C or 0.5 SD above normal.
- A composite climate index for the NL region returned to slightly above normal from the seventh lowest in 67 years and the lowest since 1993 in 2015.

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