Fisheries and Oceans Canada / Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/052

Newfoundland and Labrador Region

An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2012

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September 2013

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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Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Colbourne, E., Craig, J., Fitzpatrick, C., Senciall, D., Stead, P., and Bailey, W. 2013. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/052. v + 35 p.

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ABSTRACT

A key indicator of climate conditions on the Newfoundland and Labrador (NL) Shelf, the North Atlantic Oscillation (NAO) index, increased to 1.3 Standard Deviations (SD) above normal in 2012, the highest since 1989. As a result, arctic air outflow to the Northwest Atlantic during the winter increased over the previous year causing a significant decrease in winter air temperatures over much of the Labrador Sea area. Annually however, air temperatures remained above the long-term mean at Labrador by 1.4 SD (1.8 °C at Cartwright) and Newfoundland by 2.3 SD (1.9 °C at St. John's, a record high). The annual sea ice extent on the NL Shelf remained below normal (0.7 SD) for the 17th consecutive year, but increased by 1 SD over the record low in 2011. As a result of these and other factors, local water temperatures on the NL Shelf remained above normal in most areas but decreased significantly over 2011 values. Sea surface temperatures attained record highs (>2 SD) in some areas of the Grand Banks. At a standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature decreased to 1 SD (0.4 °C) above normal from the record high of 3 SD (1 °C) in 2011. Annual surface temperatures at Station 27 increased to 1.5 SD (1 °C, 2nd highest on record) above normal while bottom temperatures (176 m) decreased to 1.1 SD (0.4 °C), down from the record high of 3.4 SD (1.3 °C) in 2011. The annual depth-averaged salinities at Station 27 were near the long-term average. The area of the cold intermediate layer (CIL) water mass with temperatures <0°C on the eastern Newfoundland and southern Labrador Shelf during 2012 was about 0.5 SD below normal compared to the record low value of 2 SD below normal in 2011, implying a continuation of less cold shelf water than normal. Spring bottom temperatures in NAFO Divs. 3Ps and 3LNO during 2012 were above normal by an average of about 1 °C, a moderate decrease over 2011 conditions. During the fall, bottom temperatures in 2J, 3K and 3LNO decreased from 2, 2.7 and 1.8 SD above normal in 2011 to 1.1, 1.2 and 0.2 SD above normal in 2012 respectively, a significant decrease. The volume of CIL (<0 °C) water on the NL shelf during the fall was close to normal. A composite climate index derived from 27 meteorological, ice and ocean temperature and salinity time series declined from 2nd and 4th highest in 2010 and 2011 to the 8th highest in the 63 year time series in 2012.

Évaluation de l'environnement océanographique physique sur la plate-forme continentale de Terre-Neuve-et-Labrador en 2012

RÉSUMÉ

L'un des indicateurs clés des conditions météorologiques sur la plate-forme continentale de Terre-Neuve-et-Labrador (T.-N.-L.), l'indice d'oscillation nord-atlantique, a augmenté à 1,3 écarts-types (ÉT) au-dessus de la normale en 2012, un sommet depuis 1989. En conséquence, le courant d'air arctique vers l'Atlantique Nord-Ouest en hiver a augmenté l'année dernière, entraînant une diminution considérable des températures de l'air en hiver au-dessus de presque toute la zone de la mer du Labrador. Cependant, les températures annuelles de l'air sont demeurées supérieures de 1,4 ÉT au Labrador (1,8 °C à Cartwright) et de 2,3 ÉT à Terre-Neuve (1,9 °C à St. John's, un record de température élevée) par rapport à la moyenne à long terme. L'étendue de la couverture de glace de mer annuelle sur la plate-forme continentale de T.-N.-L. est restée sous la normale (0,7 ÉT) pour la 17^{e} année consécutive, mais elle s'est élevée de 1 ÉT au-dessus du creux record observé en 2011. Du fait de ces facteurs et d'autres, les températures locales de l'eau sur la plate-forme continentale de T.-N.-L. sont demeurées au-dessus de la normale dans la plupart des zones, mais elles ont diminué considérablement par rapport à celles de 2011. Les températures à la surface de la mer ont atteint des sommets records (> 2 ÉT) dans certaines zones des Grands Bancs. À la station 27, un site de surveillance standard situé au large à l'est de Terre-Neuve, la température moyenne annuelle établie en fonction de la profondeur a diminué à 1 ÉT (0,4 °C) au-dessus de la normale par rapport au niveau élevé record de 3 ÉT (1 °C) relevé en 2011. Les températures moyennes annuelles à la surface de la mer à la station 27 ont augmenté à 1,5 ÉT (1 °C, 2^{e} en termes de niveaux records) au-dessus de la normale, tandis que les températures au fond (176 m) ont diminué à 1,1 ÉT (0,4 °C), une baisse par rapport au sommet record de 3,4 ÉT (1,3 °C) observé en 2011. Les salinités moyennes annuelles établies en fonction de la profondeur à la station 27 se situaient près de la moyenne à long terme. La masse d'eau de la zone de la couche intermédiaire froide (CIF) avec des températures de < 0 °C, à l'est de la plate-forme continentale de Terre-Neuve et au sud de la plate-forme continentale du Labrador, était en 2012 sous la normale de 0,5 ÉT environ par rapport au creux record de 2 ÉT sous la normale en 2011, ce qui signifie que l'eau sur la plate-forme continentale est toujours moins froide que la normale. Les températures au fond au printemps 2012 dans les divisions 3Ps et 3LNO de l'OPANO étaient supérieures à la normale d'environ 1 °C en moyenne, ce qui représente une diminution modérée par rapport aux conditions de 2011. À l'automne, les températures au fond dans les divisions 2J, 3K et 3LNO ont considérablement diminué, passant respectivement d'un ÉT de 2, 2,7 et 1,8 au-dessus de la normale en 2011 à un ÉT de 1,1, 1,2 et 0,2 au-dessus de la normale en 2012. Le volume d'eau de la CIF (< 0 °C) sur la plate-forme continentale de Terre-Neuve-et-Labrador à l'automne se situait près de la normale. Un indice climatique composite obtenu à partir de 27 séries chronologiques répertoriant les conditions météorologiques , celle de la glace et celle de l'océan ainsi que la salinité a décliné, passant en 2012 des 2^{e} et 4^{e} rangs les plus élevés en 2010 et en 2011 au 8^{e} rang le plus élevé parmi les 63 années des séries chronologiques.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Fig.1) during 2012 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. 2013; Hebert et al. 2013). When possible, the long-term averages were standardized to a 'normal' base period from 1981 to 2010 in accordance with the recommendations of the World Meteorological Organization.

The information presented for 2012 is derived from three main sources: (1) observations made at the fixed (Station 27) throughout the year from all sources; (2) measurements made along standard NAFO and AZMP cross-shelf sections from seasonal oceanographic surveys (Fig. 2); and, (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Fig. 3). Data from other research surveys and ships of opportunity were also used to help define the long-term means and the conditions during 2012. These data are available from archives at the Fisheries and Oceans Integrated Scientific Data Management (ISDM) Branch in Ottawa and maintained in regional a database at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL. An overview of the physical oceanographic conditions for 2011 was presented in Colbourne et al. (2012).

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 here as the average over the base period. For shorter time series, the base period included all data up to 2012. It is recognized that monthly and annual estimates of anomalies that are based on a varying number of observations may only approximate actual conditions; caution therefore should be used when interpreting short time scale features of many of these indices.

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

Normalized water property time series and derived climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2012 are presented in coloured boxes as figures with gradations of 0.5 standard deviations (SD). Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions (Figure 4). If the magnitude of the anomaly is ≥2 SD it is typeset in white. In some instances (NAO, ice and water mass areas or volumes for example) negative anomalies may indicate warm conditions and hence are coloured red.

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

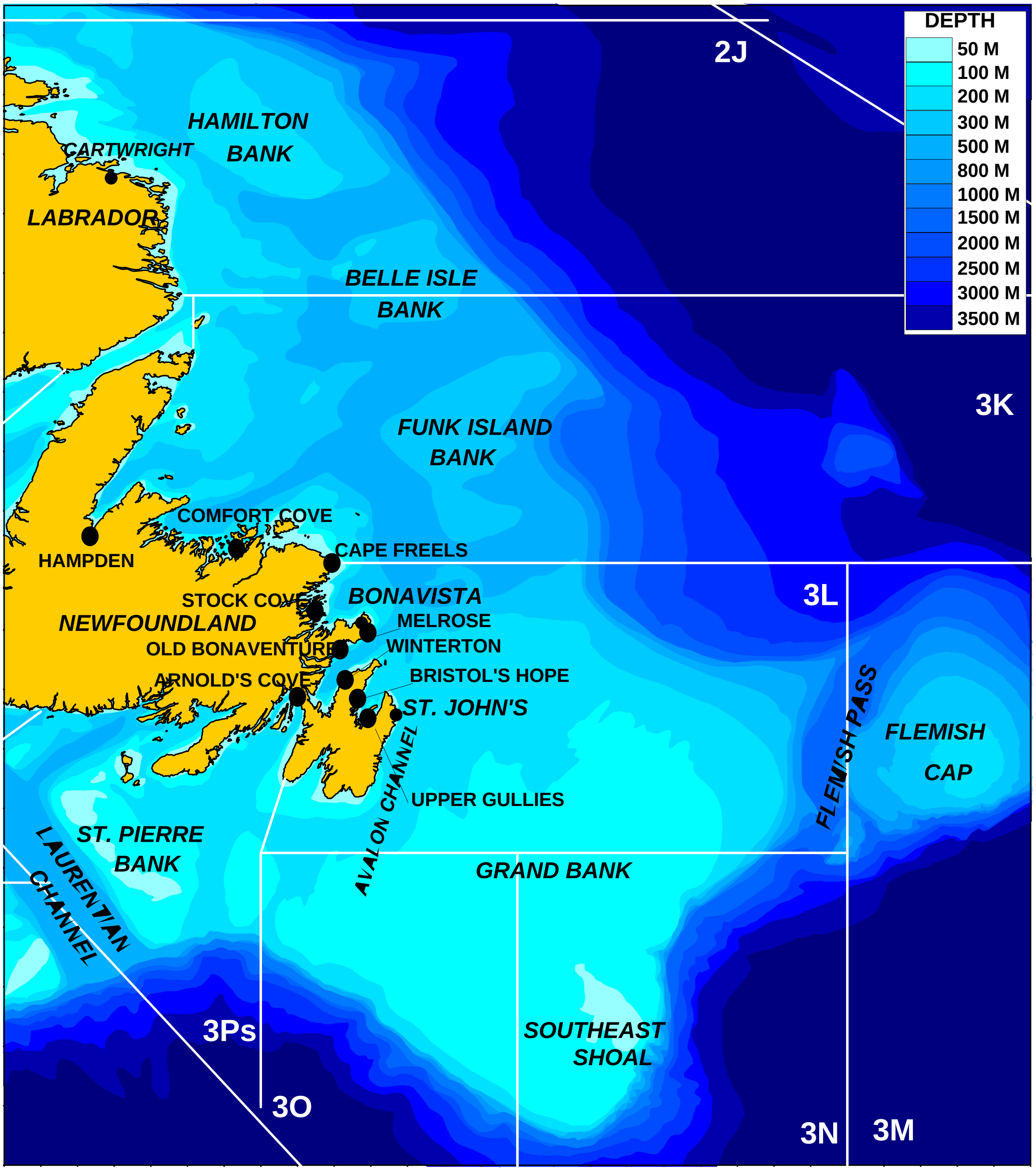

Figure 1. Map showing NAFO Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

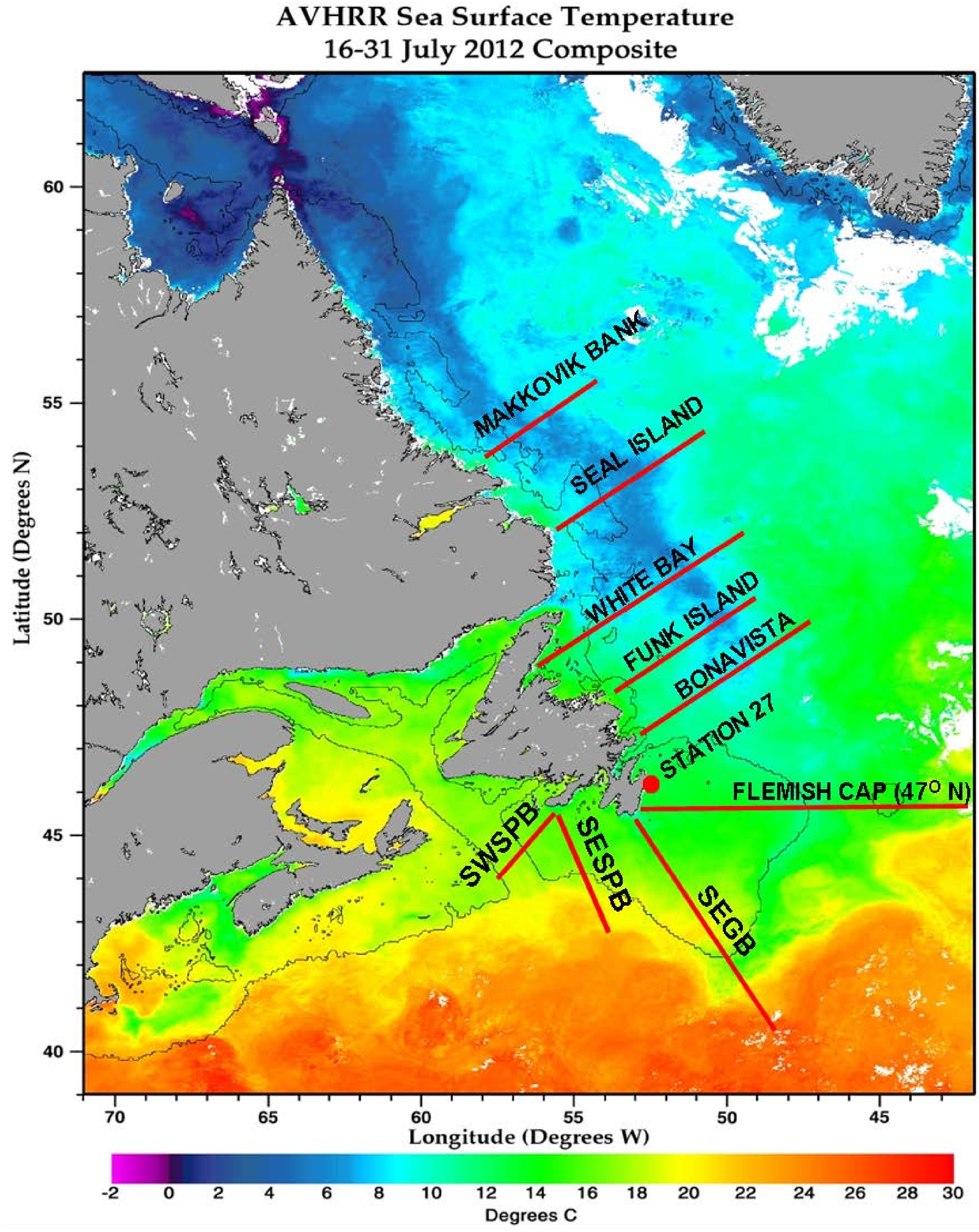

Figure 2. Map showing summer Sea-Surface-Temperature (SST) during July 16-31, 2012, Station 27 and standard sections sampled during 2012 (SST map courtesy of the Ocean Research and Monitoring Section, BIO).

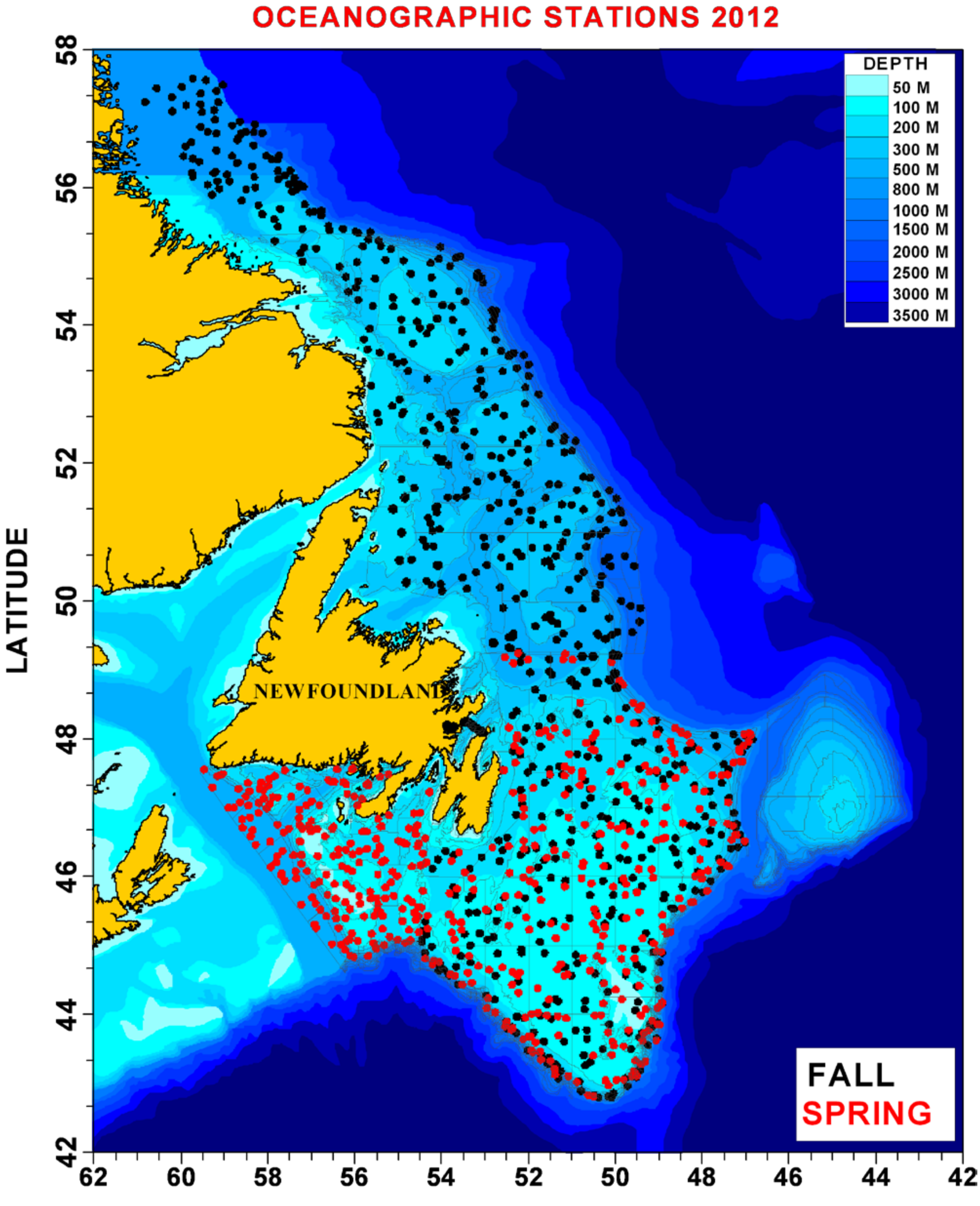

Figure 3. Map showing the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2012.

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 a measure of the strength of the winter westerly and north westerly winds over the Northwest Atlantic. A high NAO index results 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 2007). However, there are exceptions to this response pattern (e.g. 1999 and 2000) due to shifting locations in the sea level pressure (SLP) features. The NAO increased to 1.3 SD above normal in 2012, the highest since 1989. It was at a record low of 2.9 SD below normal in 2010 and increased to 1.2 SD below normal in 2011. The similar, but larger scale Arctic Oscillation was also in the positive phase at 0.7 SD in 2012. As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2012 increased over the previous year causing a significant decrease in winter air temperatures over much of the Labrador Sea and adjacent shelves.

Air temperature anomalies at five sites in the Northwest Atlantic (Nuuk Greenland, Iqaluit Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland) are shown in Figure 5. In 2012 winter values decrease over the previous year whereas annual values increased slightly. The predominance of warmer-than-normal annual and seasonal air temperatures at all sites from the mid-1990s to 2007 is evident, with 2006 values ranging from 1-2 SD above normal. There was a slight increase in the annual air temperatures in 2009 at 4/5 sites and a significant increase at all sites in 2010 with air temperatures reaching record highs at northern sites with values 2-3 SD above normal. At Cartwright on the mid-Labrador Coast and at Iqaluit on southern Baffin Island, annual air temperatures were 2.5 and 2.7 SD above normal in 2010, setting 77 and 65 year records, respectively. There was a decrease at all sites in 2011 from the record highs in 2010 with annual values at Nuuk in West Greenland decreasing to 0.3 SD below normal. The cumulative winter air temperature index remained above normal in 2012 but has experienced a decreased trend since the record high set in 2010 (Fig. 6). These conditions contrasted strongly with the cold conditions experienced in the early 1990s when annual anomalies often exceeded 1 SD below normal (Fig. 6).

The spatial extent and concentration of sea ice are available from the daily ice charts published by the Canadian Ice Service of Environment Canada. The annual average sea-ice extent (defined by 1/10 coverage) on the NL Shelf (between 45^{o}-55^{o}N) continued to be below normal (0.7 SD) in 2012 for the 17^{th} consecutive year. This was however a significant increase over the 49-year record low during 2011 (Fig. 5). In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. Exceptions were 2007 and 2009 when it extended into June, particularly in the inshore areas.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 499 (-0.4 SD) icebergs drifted south of 48^{o}N onto the Northern Grand Bank during 2012, up from only 3 in 2011 and one in 2010. The 113-year average is 475 and that for the 1981-2010 is 767. In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48^{o}N with an all-time record of 2202 in 1984. Years with low iceberg numbers on the Grand Banks generally correspond to higher than normal air temperatures, lighter than normal sea-ice conditions and warmer than normal ocean temperatures on the NL Shelf.

A composite index derived from the meteorological and sea-ice data presented in Figure 5 indicate that annual values for the past decade were either near-normal or warmer than normal with 2010 showing the warmest in the time series with a significant decline during the past 2 years (Fig. 7). Hebert et al. (2013) elaborated on meteorological and sea ice conditions in the Northwest Atlantic, including the Newfoundland and Labrador Shelf.

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

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

INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ARCTIC OSCILLATION	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
NAO (ICELAND-AZORES)	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
NUUK AIR T (WINTER)	-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	0.4	-0.1
NUUK AIR T (ANNUAL)	-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	-0.2	0.9
IQALUIT AIR T (WINTER)	-0.8	-0.7	-1.0	-1.8	-0.3	0.0	0.5	0.0	-0.9	0.2	0.0	0.3	-0.8	0.1	0.2	0.7	1.3	1.2	-0.4	0.7	2.0	0.9	0.2
IQALUIT AIR T (ANNUAL)	-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
CARTWRIGHT AIR T (WINTER)	-1.6	-0.7	-0.8	-1.6	-1.2	-1.1	0.7	-0.6	0.7	1.3	0.4	0.3	-0.3	-0.4	1.3	0.2	1.2	0.7	-0.7	0.3	2.4	1.1	0.0
CARTWRIGHT AIR T(ANNUAL)	-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
BONAVISTA AIR T (WINTER)	-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
BONAVISTA AIR T (ANNUAL)	-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
ST. JOHN'S AIR T (WINTER)	-1.6	-0.8	-1.1	-1.2	-1.3	-0.4	0.7	-1.0	0.6	2.2	1.6	-0.3	-0.3	-1.0	0.3	0.2	1.1	0.2	0.3	0.8	1.5	1.1	1.2
ST. JOHN'S AIR T (ANNUAL)	-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
NL SEA-ICE EXTENT (Annual)	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	-0.7
NL SEA-ICE EXTENT (Winter)	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
NL SEA-ICE EXTENT (Spring)	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
ICEBERGS GRAND BANKS	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

Figure 5. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1990 to 2012. The anomalies are normalized with respect to their standard deviations over the 1981-2010 base period.

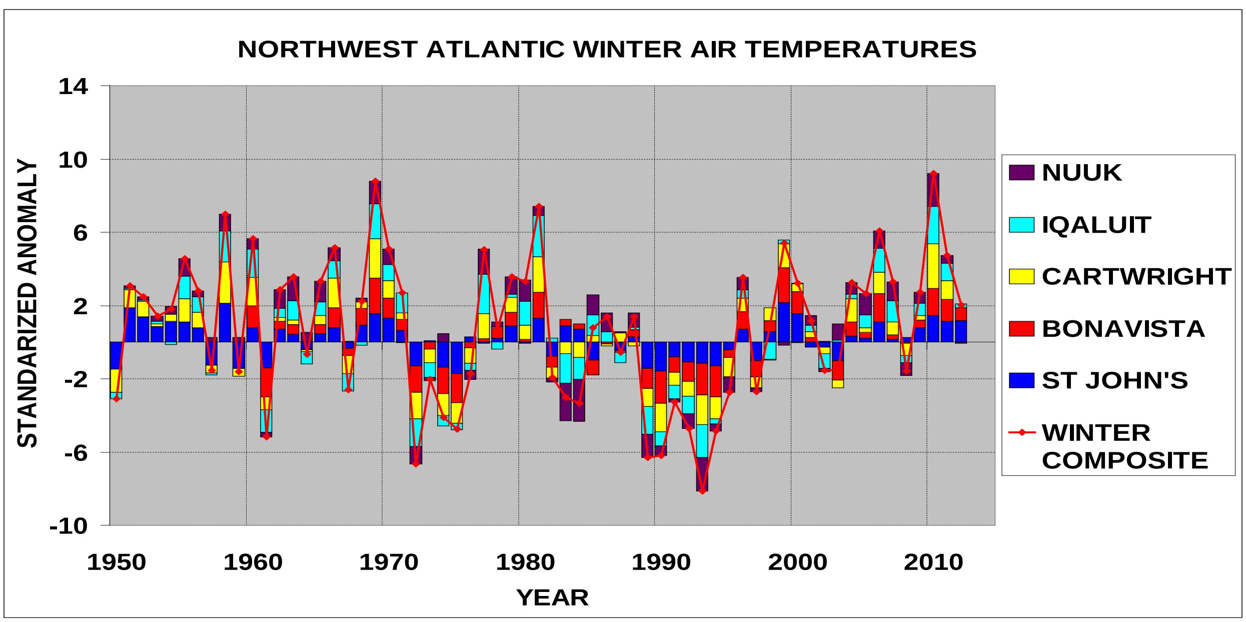

Figure 6. Standardized winter air temperature anomalies at Nuuk, Iqaluit, Cartwright and at St. John's relative to the 1981-2010 means.

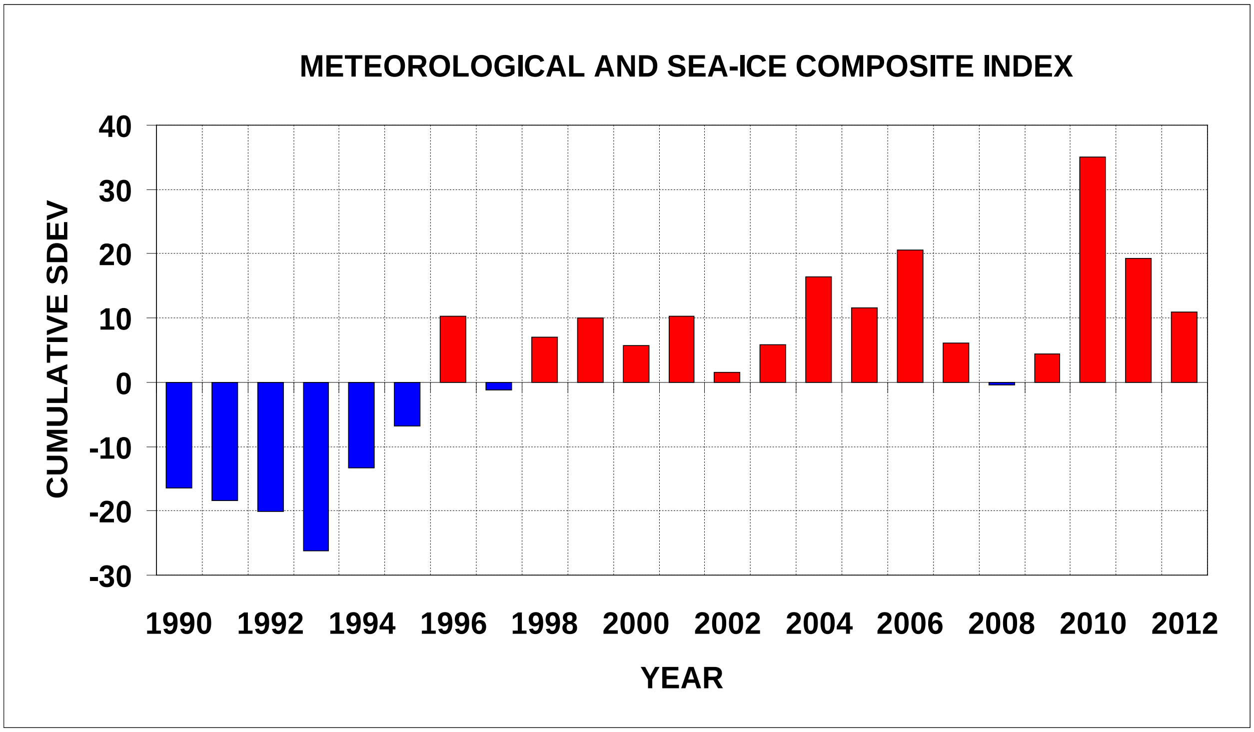

Figure 7. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 5.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

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

Annual anomalies for 16 areas from West Greenland to southern Newfoundland are presented in Figure 9 and in Figure 10 for Hudson Strait to St. Pierre Bank. All areas had positive anomalies during 2012 except for West Greenland where they were slightly below average. The magnitude of the anomalies increased from north to south with record high values set at 4/16 areas. These values represent a significant increase over the previous year and contrasts to 2010 when SST anomalies were higher in the north and decreased towards the south.

A composite index together with individual series shows an increasing trend in SSTs since the early 1990s (Fig. 9). Overall 2012 was the 2nd highest in the series after 2006. Since 1981, 5 of the 8 warmest years have occurred since 2005. To focus on our principal area of interest, the Labrador Sea and West Greenland boxes were excluded from the composite SST index.

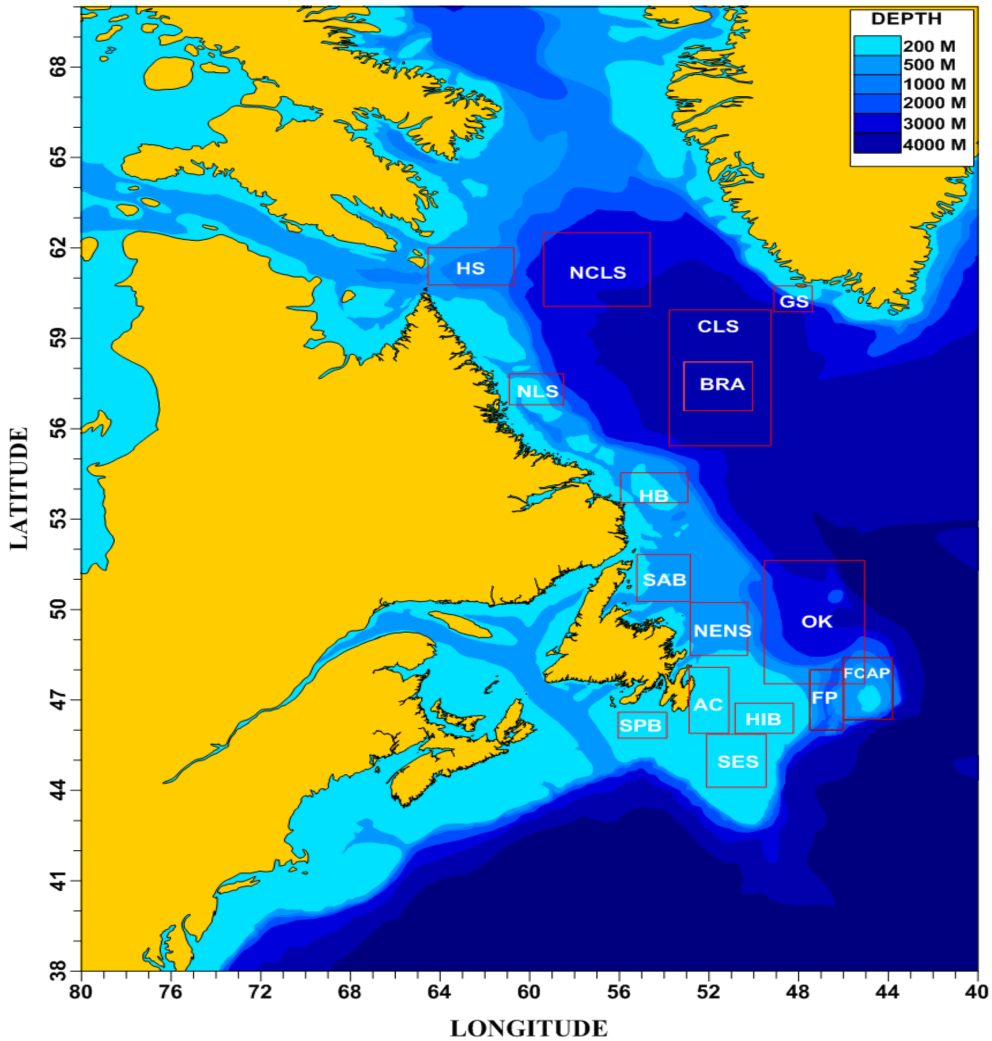

Figure 8. Map showing the subareas where SST time series were constructed for the Northwest Atlantic.

PETRIE BOX	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
WEST GREENLAND SHELF (GS)		-1.0	-1.6	-1.9	-1.3	0.6	-0.2	0.3	-0.4	-1.5	-0.8	0.2	-0.8	-0.3	0.1	1.9	-0.1	0.5	0.0	-0.9	-0.2	0.3	0.9	1.9	0.8	0.9	-0.2	0.1	0.1	0.8	2.1	-0.4	0.3
NORTH CENTRAL LAB SHELF (NCLS)		-0.7	-1.1	-1.9	-1.7	-0.4	0.3	-0.8	-0.2	-1.1	-1.1	-0.5	-0.5	-1.0	-0.5	-0.6	0.2	0.6	0.7	-0.6	-0.3	0.9	0.8	1.5	1.5	1.4	1.0	0.7	-0.2	-0.3	2.2	-0.1	-0.3
CENTRAL LAB SEA (CLS)		0.1	-1.5	-1.8	-2.0	-0.9	-0.5	-0.3	-0.2	-0.8	-1.1	-0.4	-0.5	-0.9	-0.2	-0.6	0.0	0.7	0.6	-0.1	-0.4	0.8	0.3	1.6	1.3	1.2	1.4	0.9	1.2	0.4	1.8	0.2	0.6
BRAVO (BRA)		0.1	-1.1	-1.9	-1.9	-1.1	-0.8	-0.4	-0.4	-0.7	-1.1	-0.4	-0.5	-0.7	-0.4	-0.5	-0.3	0.7	0.4	-0.1	-0.1	0.6	0.3	1.6	1.2	1.4	1.5	0.8	1.4	0.4	1.7	0.3	1.0
HUDSON STRAIT (HS)		0.8	-0.8	-1.0	-1.9	-0.2	1.2	-0.1	-0.9	-1.6	-0.4	-0.2	-0.7	-0.1	0.4	0.6	0.0	-0.7	-0.2	-1.4	0.6	0.7	0.4	0.7	0.4	1.6	0.2	-0.3	0.4	-0.6	3.1	0.0	0.5
NORTHERN LAB SHELF (NLS)		1.4	-0.5	-1.5	-1.8	-0.8	0.0	-0.6	-1.0	-1.0	-0.2	-1.1	-1.2	-0.1	1.0	0.1	-0.7	-0.7	0.7	-0.6	0.7	0.6	-0.8	1.5	1.1	1.1	0.9	-0.1	1.8	-0.1	1.7	1.3	1.3
HAMILTON BANK (HB)		1.1	-0.9	-0.7	-1.3	-0.7	-0.7	-0.7	-0.2	-0.9	-0.8	-1.3	-0.9	0.2	0.3	1.2	-1.3	-0.6	0.6	-0.4	1.4	0.3	-0.7	1.1	1.0	1.2	1.8	-0.4	1.6	-0.1	1.7	1.0	1.9
ST ANTHONY BASIN (SAB)		1.6	-0.6	-0.3	-0.6	-0.9	-0.5	-0.4	0.0	-0.4	-1.1	-1.5	-1.5	-0.6	0.3	-0.5	-0.6	-0.8	0.7	0.2	1.0	0.3	-0.7	0.7	1.1	1.8	2.1	-0.9	1.5	-0.3	1.4	0.6	1.7
NE NF SHELF (NENS)		0.7	-0.6	-0.1	-0.5	-1.6	-0.6	-0.1	0.1	0.0	-0.4	-1.9	-1.5	-0.7	0.3	-0.5	-0.5	-1.0	0.7	0.4	0.9	0.5	-0.5	0.6	1.1	1.9	2.2	-0.8	1.5	-0.4	1.3	0.6	1.3
ORPHAN KNOLL (OK)		-0.1	-0.7	-0.3	-1.5	-2.2	-0.5	0.1	0.2	-1.0	-0.9	-1.5	-1.2	-1.0	-0.9	0.2	0.0	0.3	0.9	0.4	0.6	0.6	0.1	0.6	1.1	2.0	1.7	0.3	1.3	-0.2	1.4	0.7	1.7
FLEMISH CAP (FCAP)		0.3	-0.7	0.5	-0.6	-2.4	-1.0	0.3	0.6	-0.5	-1.0	-1.4	-1.4	-1.2	-0.9	-0.3	0.4	-0.2	0.6	0.8	1.0	0.4	-0.3	0.5	0.9	2.0	1.7	0.5	1.1	-0.5	0.9	0.4	1.7
FLEMISH PASS (FP)		0.2	-0.7	0.3	-0.5	-2.2	-0.9	0.2	0.8	-0.5	-1.4	-1.5	-1.4	-1.5	-0.2	-0.2	-0.1	-0.5	0.8	0.9	1.1	0.5	0.0	1.0	0.9	1.9	1.4	0.3	1.1	-0.5	1.0	0.2	1.3
SE SHOAL (SES)		2.3	-0.7	1.2	0.3	-1.8	-1.5	-0.4	0.7	0.0	-0.7	-1.1	-1.2	-1.3	0.2	-0.7	0.1	-1.3	0.6	1.1	1.3	-0.1	-0.2	0.2	0.3	0.7	1.8	0.5	1.0	0.3	0.2	0.4	1.9
HIBERNIA (HIB)		0.4	-0.7	1.0	0.0	-2.0	-1.6	-0.4	0.8	0.1	-0.6	-1.5	-1.4	-1.2	0.6	-0.4	0.1	-1.2	0.8	1.3	1.4	0.2	-0.5	0.6	0.4	1.1	2.1	0.5	0.6	-0.5	0.6	0.3	2.3
AVALON CHANNEL (AC)		0.5	-0.8	0.8	-0.1	-1.9	-1.4	-0.1	0.9	-0.8	-0.4	-1.7	-1.3	-0.8	1.1	-0.7	-0.1	-1.6	0.6	1.0	1.0	0.3	-0.5	0.6	0.7	1.4	2.0	-0.3	0.9	0.1	0.8	0.2	1.6
GREEN-ST PIERRE BANK (SPB)		2.1	-0.4	1.0	0.4	-2.2	-1.2	-0.1	-0.2	-0.4	-0.8	-1.3	-1.1	-0.5	1.1	-1.0	0.0	-1.2	0.7	1.4	1.2	0.1	-0.6	0.2	0.4	1.4	1.3	-0.5	0.7	0.4	0.9	0.1	2.1

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

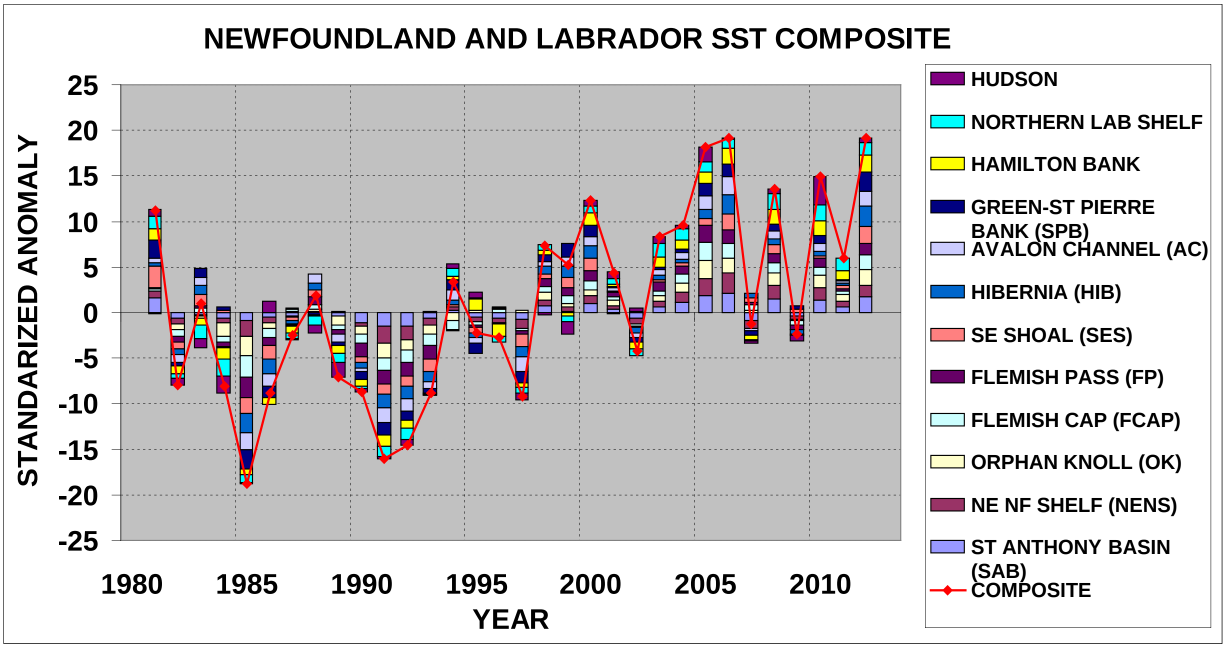

Figure 10. Standardized annual SST anomalies from the subareas presented above except for the Labrador Sea and the West Greenland Boxes. The solid red line represents the composite sum.

TRENDS IN TEMPERATURE AND SALINITY

LONG-TERM INSHORE TEMPERATURE MONITORING

Temperature data obtained from thermographs deployed at 10 inshore monitoring sites during the summer months (July-Sept.) along the coast of Newfoundland (see Fig. 1 for locations) at nominal water depths of 10 and 15-m are shown in Fig. 11 as standardized anomalies and repeated in Fig. 12 as cumulative sums. The data show considerable variability about the mean, due mostly to highly variable local wind driven effects near the coast including upwelling and local summer air temperatures.

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

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

It is noteworthy that some sites are missing data, particularly before 1998. This no doubt reduces the accuracy of anomalies hence the composite plot only included data from 1998 when most sites have data.

LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
HAMPDEN (10 m)			-0.4	0.2	-1.5	-2.2	-0.4	-0.9	0.4	0.2	1.4	-0.9	0.5	0.3	0.8	0.9	1.4	-0.7	1.1	-1.0	0.9	0.8	1.5
COMFORT COVE (10 m)	1.2	-2.1	-0.8	-1.9	0.1	-1.1	0.8	-0.7	-0.1	1.0	1.2		0.8	0.9	0.0	0.4	0.0		-0.1			-1.9	-0.5
CAPE FREELS (15 m)									-1.4	0.2	0.1		0.3	0.9	0.4	2.0	1.4	-0.9	-0.5	-0.9	-0.4	-1.2	0.1
MELROSE (15 m)	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
MELROSE (15 m)									-0.8	0.1		0.8	0.0	1.1	-0.2	1.3	1.5	-1.0	0.6	-0.8	-0.8	-1.7	-0.9
OLD BONAVENTURE (10 m)		-1.5	-0.9	-0.8	2.0	0.3	0.7	0.1		-0.3	0.2	1.3	0.5	0.3	-0.2	0.7	1.2	-1.9	-0.3	0.2	-0.1	-1.7	-0.4
WINTERTON (10 m)									-0.4		1.0	0.5	-0.2	1.8	0.0	0.3	1.1	-0.9	-0.6	0.6	-1.2	-1.9	-0.5
BRISTOL'S HOPE (10 m)	-0.8	-3.1		-0.7	0.5	0.0	0.1	-0.1	-0.7	1.1	0.7	0.7	0.0	0.9	0.2	0.9	1.0	-0.7	1.0	0.5	0.6	-1.0	0.8
UPPER GULLIES (10 m)	-1.2	-1.3	0.7	-0.4	0.2	0.2	-0.9	-0.1	-1.1	1.2	-0.2	0.0	0.2	0.8	-0.1	1.2	1.3	-2.1	1.6	0.3	0.5		0.7
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

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

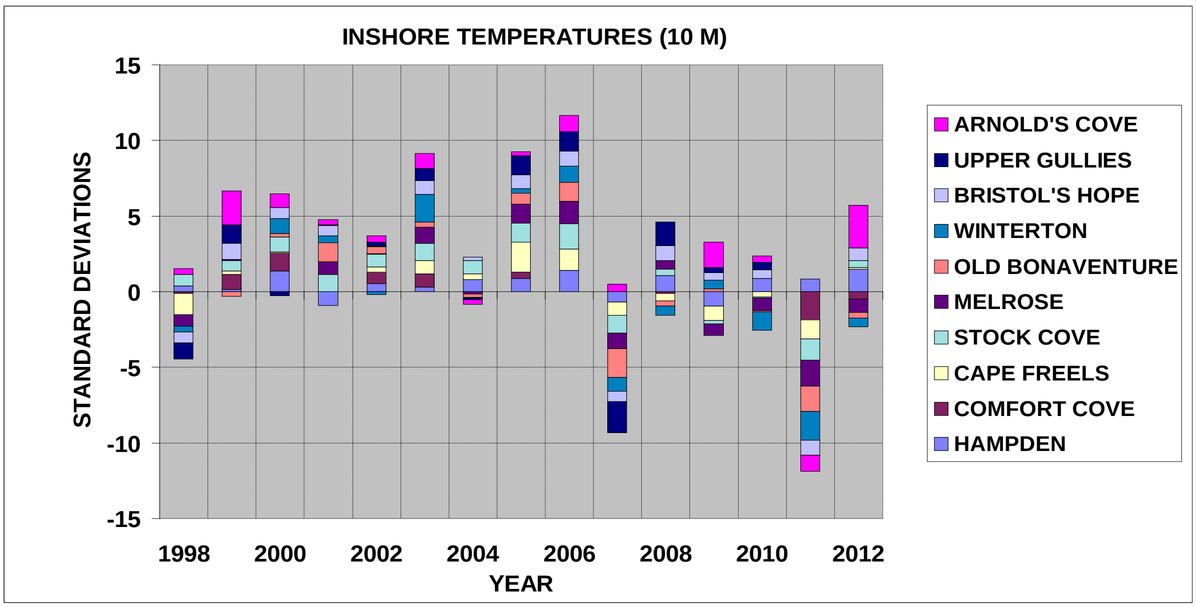

Figure 12. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland (Fig. 2). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the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

AZMP FIXED SITE (STATION 27)

Station 27 (47^o 32.8' N, 52^o 35.2' W), located in the Avalon Channel off Cape Spear NL (Fig. 2), was sampled 66 times (61 CTD profiles, 5 XBT profiles) during 2012, including 30 CTD profiles that were collected in July as part of a diel high frequency variability study. Observations were available for all months except February.

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2012 are displayed in Figs 13 and 14. The cold, near-isothermal water column during February to April had temperatures ranging from near 0^o to –1.5^{o}C. These values persisted throughout the year below 120 m as the cold intermediate layer (CIL) extended to the bottom. Upper layer temperatures warmed to >2°C by early May and to >15°C by mid-August, after which the fall cooling commenced with temperatures decreasing to 4°C by early December.

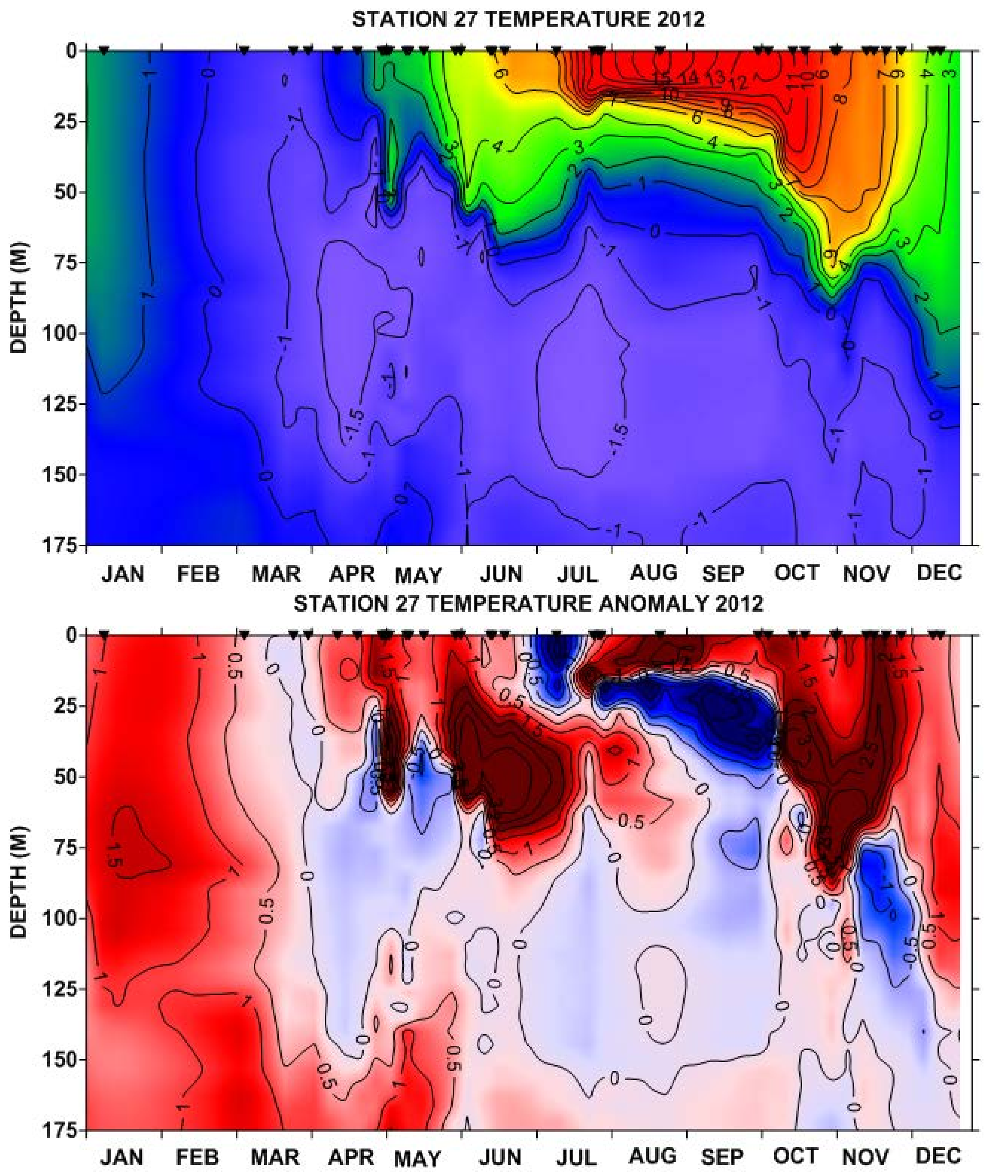

Figure 13. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2012.

Temperatures were above normal during the winter months over the entire water column and mostly below normal the remainder of the year below 90 m. Temperature anomalies varied considerably in the upper water column with strong positive values from 40-30 m in June to strong negative values at the surface in early July and at thermocline depths in August and September indicating a shallower than normal mixed layer depth. A strong positive anomaly developed in the surface layer in late July that penetrated into the water column reaching to >100 m by late December.

Upper layer (0-30 m) salinities (Fig. 14) were about 32.2 from January to June then decreased to 31.8 by late July and to a minimum of 31.2 by October. Below 30 m, salinities ranged from 32.2 – 33.2 throughout most of the year, except for late fall when fresher water reached to near 100 m. The period of low, near-surface salinity values evident from early summer to late fall is a prominent feature of the salinity cycle on the Newfoundland Shelf and is due largely to the melting of sea-ice off the coast of Labrador earlier in the year followed by advection southward onto the Grand Banks.

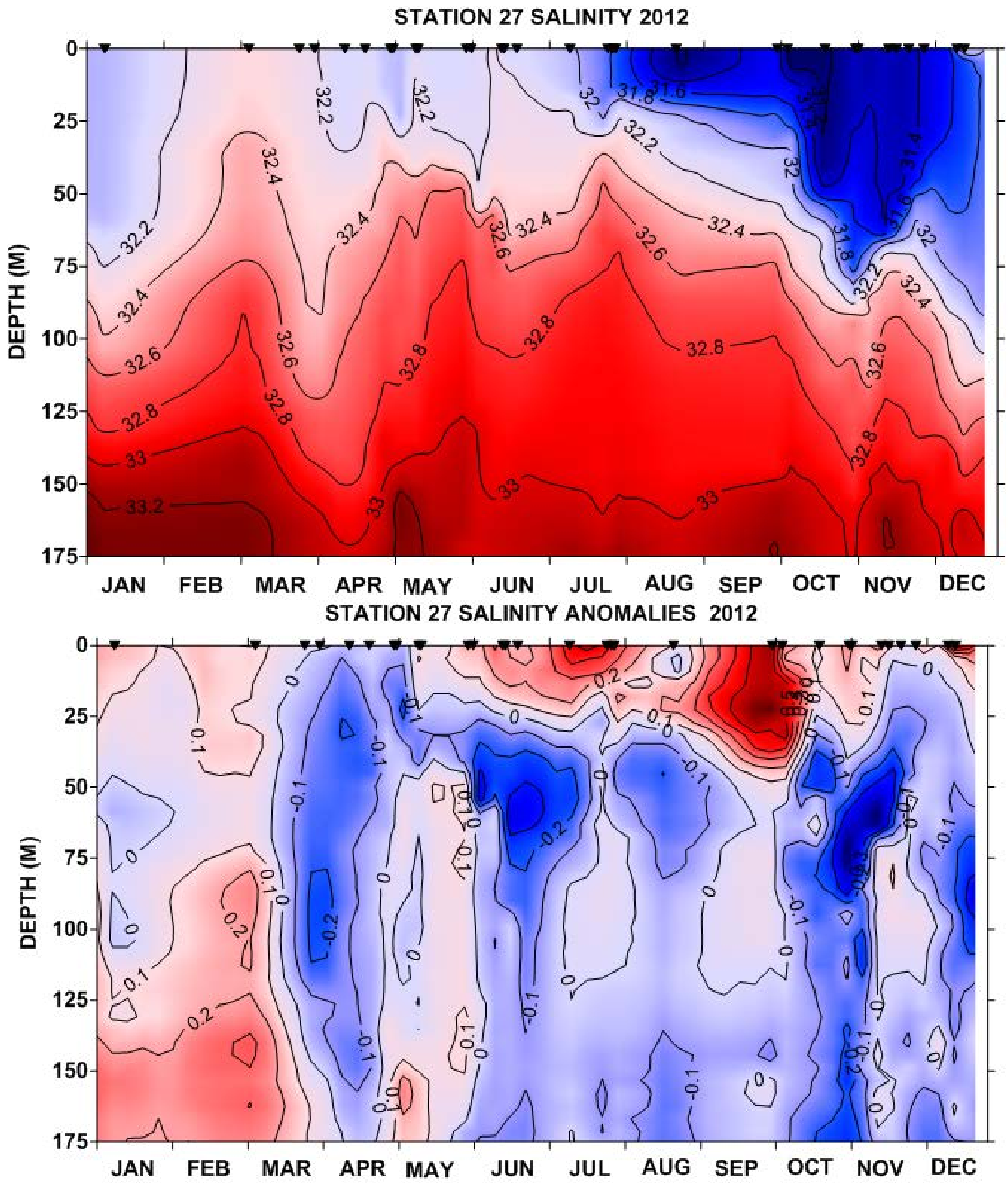

Figure 14. Contours of salinity and salinity anomalies as a function of depth at Station 27 for 2012.

Except for the winter and near surface during the summer, salinities were generally below normal during 2012. The strongest positive anomaly was centered at 25 m during September and early October, partially resulting from a shallower than normal halocline during late summer.

Temperatures at Station 27 were below normal from 1990 to 1997, reaching minima in 1991 when surface, bottom and integrated values were 1-2 SD below normal (Fig. 15). The annual surface temperatures at Station 27 having been near-normal or above normal since 2003, reached a 61-year high of 2.2 SD above their long-term mean in 2006, varied about the mean from 2007-2009 and increased to above normal since then reaching +1.6 SD (~1^{O}C) in 2012 (Fig 15).

Bottom temperature anomalies at Station 27 were the 3rd highest in 2010 at +1.7 SD and the highest on record in 2011 at 3.3 SD above normal. In 2012 they decreased to +1.2 SD (0.4^{O}C) (Figs. 15 and 16). Vertically averaged temperatures which also set record highs in 2011 at +2.7 SD decreased to +1.3 SD in 2012. Salinities at Station 27 were near the long temp mean in 2012 except at the surface where it was 0.8 SD above normal.

The vertical thickness of the layer of cold <0^{O}C water (commonly referred as the cold-intermediate-layer or CIL on the shelf) at Station 27 reached a remarkably low value of 4.8 SD below normal in 2011 but increased to 1.7 SD below normal in 2012.

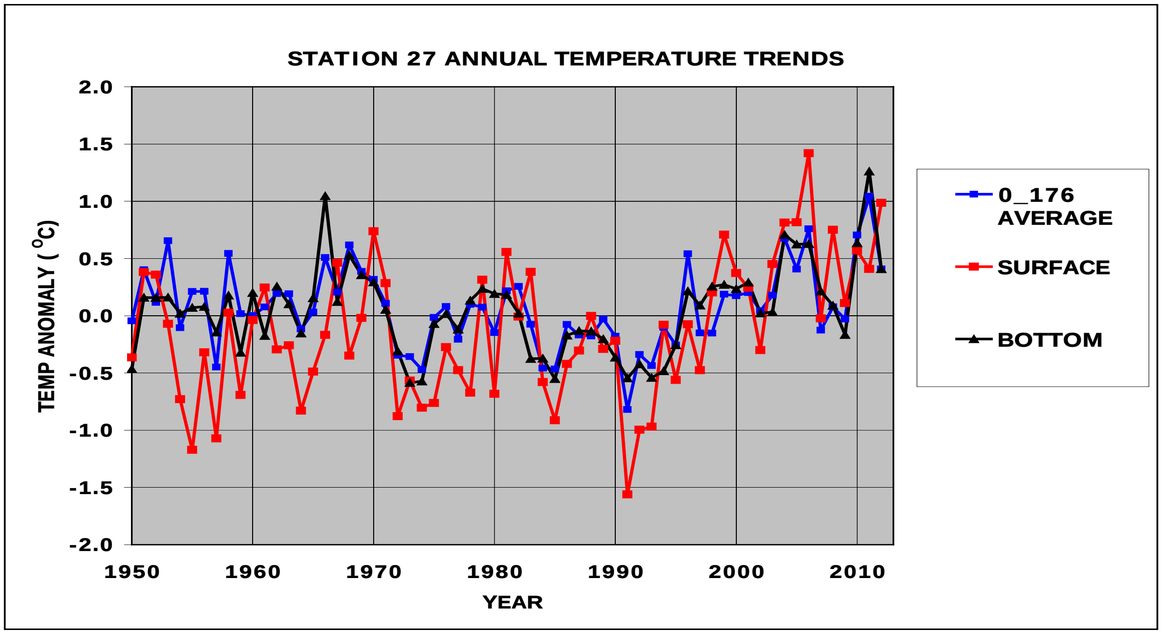

Figure 15. Annual Station 27 vertically averaged (0-175 m), surface and bottom temperature anomalies referenced to the 1981-2010 mean.

INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
SURFACE TEMPERATURE	-0.4	-2.1	-1.6	-1.5	-0.2	-0.9	0.2	-0.8	0.4	1.2	1.0	0.7	-0.3	0.6	1.3	1.3	2.2	-0.3	1.0	-0.1	1.0	0.8	1.6
BOTTOM TEMPERATURE	-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
0-50 M TEMPERATURE	-0.8	-2.5	-0.8	-1.0	-0.1	-0.5	1.1	-0.6	-0.2	0.6	0.4	0.9	-0.3	0.8	1.0	1.1	2.3	-0.9	0.9	-0.6	1.4	1.9	1.4
0-176 M TEMPERATURE	-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
CIL M (<0^{O}C)	0.8	1.5	0.9	0.9	0.6	0.9	-0.7	0.0	0.4	-0.7	-0.9	0.0	-1.0	-1.1	-2.4	-0.5	-2.6	0.6	0.5	0.6	-1.9	-4.8	-1.7
SURFACE SALINITY	1.4	-1.9	-1.1	-0.1	-0.4	-1.9	0.2	-0.4	-0.4	-0.4	-0.3	-0.6	1.0	0.9	0.5	0.4	0.6	-0.1	0.5	0.2	-0.7	0.2	0.8
BOTTOM SALINITY	1.3	-1.9	-1.4	0.6	-0.4	-0.2	-1.5	-0.3	0.6	0.1	-0.3	-0.3	-0.4	-1.0	-0.4	0.3	1.7	0.8	0.7	-1.2	-0.2	0.2	-0.1
0-50 M SALINITY	2.1	-2.0	-0.6	0.0	-0.3	-1.3	-0.5	-0.2	-0.2	-0.3	-0.6	-1.0	0.9	1.0	0.2	0.2	0.5	0.2	0.7	0.3	-1.2	-0.5	0.2
0-176 M SALINITY	1.6	-1.2	-1.7	-0.7	-1.4	-2.0	-0.4	0.0	0.0	-0.7	0.2	-1.2	0.9	0.2	0.7	0.7	0.6	0.7	1.2	0.1	-0.2	-1.0	-0.1

Figure 16. Standardized temperature and salinity anomalies and CIL thickness at Station 27 from 1990 to 2012. The anomalies are normalized with respect to their standard deviations over the standard base period.

NEWFOUNDLAND AND LABRADOR SHELF BOTTOM TEMPERATURES

Drinkwater and Trites (1986) examined monthly mean temperatures and salinities from historical data in irregularly shaped areas on the Newfoundland Shelf that generally corresponded to topographic features such as banks, basins and slope regions. These areas were further refined and extended to the Labrador Shelf by BIO as part of the ocean climate database. There are 25 areas defined on the Labrador Shelf (Fig. 17) and 40 on the Newfoundland Shelf (Fig. 20). All data within each area were averaged by month and compare with the long-term averages (1981-2010). The annual anomalies were then computed from the monthly values and standardized by the standard deviation of the annual anomalies over the same base period. Data were not available for every month in each area and some areas had insufficient data to construct a time series. In fact, some annual estimates are based on as few as 3 monthly values. As a result the time series can show spikes that correspond to high frequency temporal or spatial variability and may poorly represent annual means.

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 18 and repeated in Fig. 19 as cumulative plots. During the past decade most of the areas had positive anomalies with 15 areas out of 21 with sufficient data reporting positive values in 2012 down from 20 out of 21 in 2011. In general bottom temperatures on the Labrador Shelf have shown an increasing trend since the early 1990s from the coldest in 1993 to the warmest in 2011 (Fig. 19).

Similarly, standardized annual bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 21 and repeated in Fig. 22 as cumulative plots. The results are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999 with 33 areas out of 35 with sufficient data areas reporting positive anomalies. The composite plot shows an increasing trend since the early 1990s reaching an all-time record in 2011 and decreasing to the 2nd highest in 2012. In 2012 5 of 35 areas had anomalies greater than 2 SD above normal, down from 17 areas in 2011.

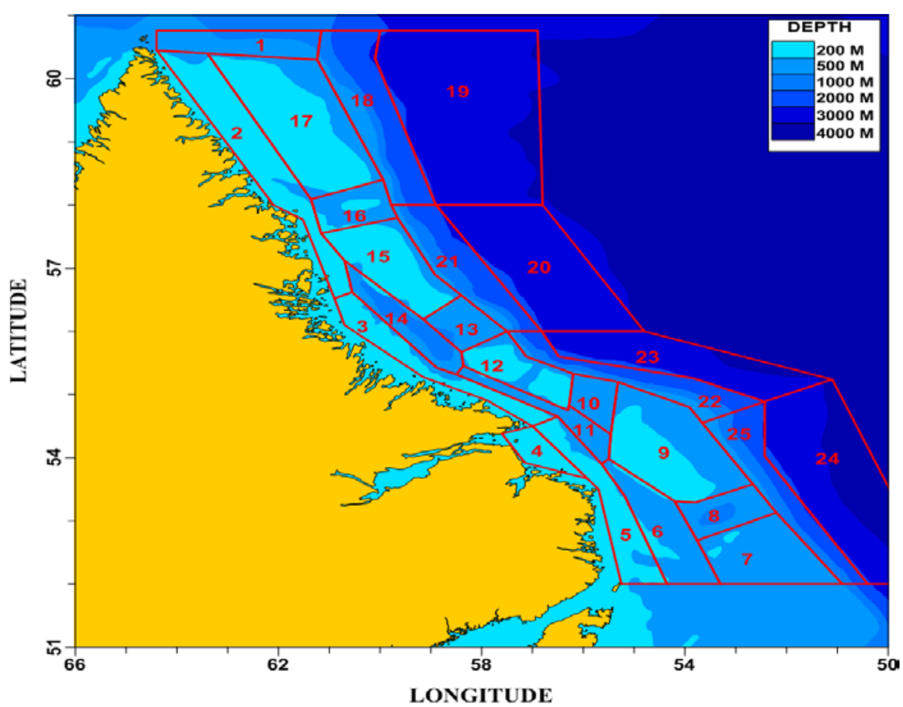

Figure 17. Areas on the Labrador Shelf where bottom temperatures were analysed. The numbers within each area correspond to the areas listed below in Figure 18.

SUB-AREA	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12
02 N Labrador Shelf		0.3		-1.7			0.8	1.7	0.9	1.3	-1.6	-1.4		-1.0	-0.2	0.1	-0.6	-0.2	1.3	-1.2	0.1	0.8	0.5
03 Central Labrador Inshore				-1.4			0.6	0.0	1.4	0.4	-0.1	0.2	-0.7	0.8	0.9	0.0	0.5		2.8	-0.5	0.0	0.4	-0.6
05 Labrador Inshore	-0.6	-1.4	-1.2	-1.5	-1.3	1.0	-0.6	0.3	1.4	0.7	-0.6	0.6	-0.1	0.0	2.0	0.9	-0.2	1.0	0.7	1.2	0.6	1.8	0.0
06 Labrador Trough	-1.0	-0.1	-1.3	-2.1	-0.9	-0.3	0.0	1.2	1.1	1.4	0.3	0.7	1.4	0.9	1.4	0.2	0.0	2.1	-0.7	-0.6	0.2	0.9	-0.4
07 Belle Isle Bank	-0.7	0.1	-0.1	-0.5	0.0	-0.5	0.2	0.8	0.6	0.9	0.8	0.8	0.0	0.9	1.5	0.8	0.1	0.9	0.9	1.7	-2.1	1.9	1.3
08 Hawke Saddle	0.1	-0.7	0.0	-1.9	-1.4	-0.2	-0.8	0.3	0.7	0.6	1.1	0.7	0.1	0.4	0.9	1.1	0.7	0.7	1.4	1.7	-1.7	2.5	1.5
09 Hamilton Bank	-1.2	-0.1	-0.5	-1.7	-1.0	-0.3	-0.1	0.9	0.8	0.4	-0.5	1.1	-0.1	1.0	1.3	1.6	0.0	0.8	0.3	-0.4	1.6	1.7	-0.2
10 Cartwright Saddle	-0.9	-0.6	-0.4	-1.7	-0.9		0.1	1.1	1.0	0.6	0.7	1.2	-0.4	1.3	1.9	1.0	0.4	0.6	0.2	0.2	1.0	1.1	1.5
11 Central Labrador Trough	-0.1	0.1	-1.7	-0.6	-1.9	-2.4	-0.7	1.3	1.2	0.1	-0.6	-0.7	-0.6	0.7	0.8	0.3	1.9	1.7	0.9	0.1	1.0	0.5	0.4
12 Makkovik Bank	-0.9	1.2	-0.4	-1.9	-0.6		-0.6	1.3	0.7	0.2	-0.1	-0.5	1.5	-0.3	2.2	1.6	0.3	0.0	0.3	-0.6	0.4	1.6	-0.1
13 Hopedale Saddle	-1.1	0.2		1.2			-0.2	0.2	0.6	0.2	-1.2	-1.0	0.2		0.5		0.7		1.6	1.0	1.5	1.3	0.5
14 N Labrador Trough	0.3	-0.4		-2.1			0.1	0.3	0.8	0.0	-0.8	0.5	-1.8	-0.1	1.2	0.5	0.7	-2.5	1.3	1.5	1.0	1.3	0.9
15 Nain Bank	-1.2	0.5	1.3	-1.4			0.8	-0.1	0.7	0.3	-0.9	0.0	-0.9	-0.2	2.0	-0.2	0.8	-0.8	0.9	-1.6	0.9	1.4	1.2
16 Okak Bank		-0.9	-2.0				0.3	0.0	1.8	0.4						1.0	-1.3	0.7	1.0	0.2	0.5	1.1	1.1
17 Saglek Bank		-0.9	-2.0				-0.4	1.2	1.4	0.5						0.1	-0.6	0.5	0.8	-0.8	0.0	1.3	-0.2
18 Saglek Slope	-0.3	-1.0	-0.8				-1.3	0.0	-0.2	1.4	1.2		-0.8		1.2	0.5	0.9	0.8	1.4	1.1	1.5	2.8	1.1
21 Nain Slope	-1.6	-0.4	-0.2	0.9			-0.3	0.1	0.4	0.8	0.2	0.1	-1.0	0.3	1.4	0.8	0.7	1.1	0.4	2.2	1.0	1.8	1.9
22 Makkovik Slope	-0.3	0.3	-0.8	-4.0	-0.4	-1.3	0.0	0.0	0.7	1.1	0.3	0.3	0.2	0.5	1.3	0.6	0.7	0.3	0.6	1.2	0.5	1.3	1.0
23 Makkovik Offshore	-0.4	-0.2	-1.3	-3.5	0.7	0.2	0.6		-0.2	0.3	1.2	0.7	0.2	0.1	0.5	-0.1	-0.6	-0.4	-0.3	0.4	-1.0	-0.5	-1.3
24 Hamilton Offshore	0.0	-0.2	-0.2	-0.5		-0.1	0.3	0.0	0.2	0.3	0.4	0.6	-0.1	0.1	0.2	0.2	0.4	0.0	0.3	0.3	0.3	0.2	0.3
25 Hamilton Slope	-0.3	-0.4	-0.6	-0.4	-0.2	-1.3	-0.8	-0.5	0.3	-0.2	0.1	0.4	-0.2	0.5	0.7	0.6	0.9	1.6	2.9	2.0	-1.0	1.2	1.1

Figure 18. Standardized bottom temperature anomalies for the Labrador Shelf derived from data within most of the areas displayed in Figure 17. The anomalies are normalized with respect to their standard deviations over the standard base period 1981-2010 and color-coded accordingly to Figure 4. The grey shaded cells indicate years for which there were no observations.

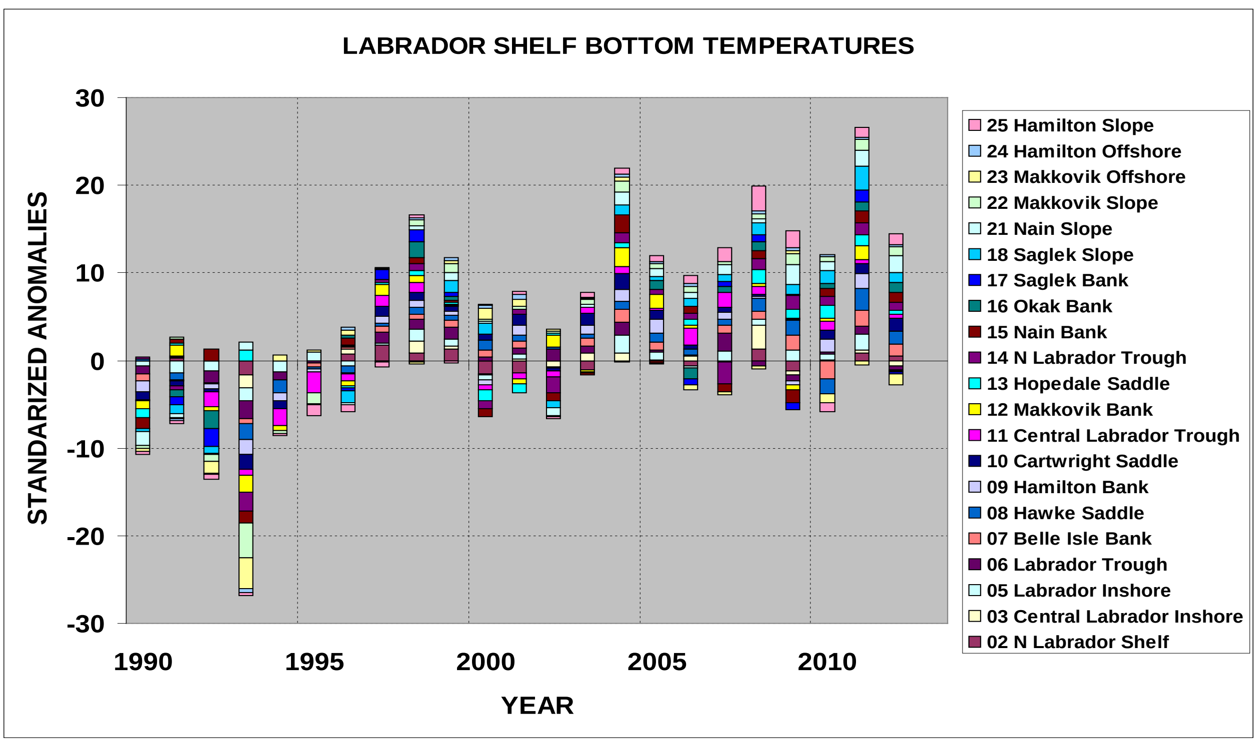

Figure 19. Cumulative bottom temperature anomalies based on the values presented in Figure 18 for the Labrador Shelf.

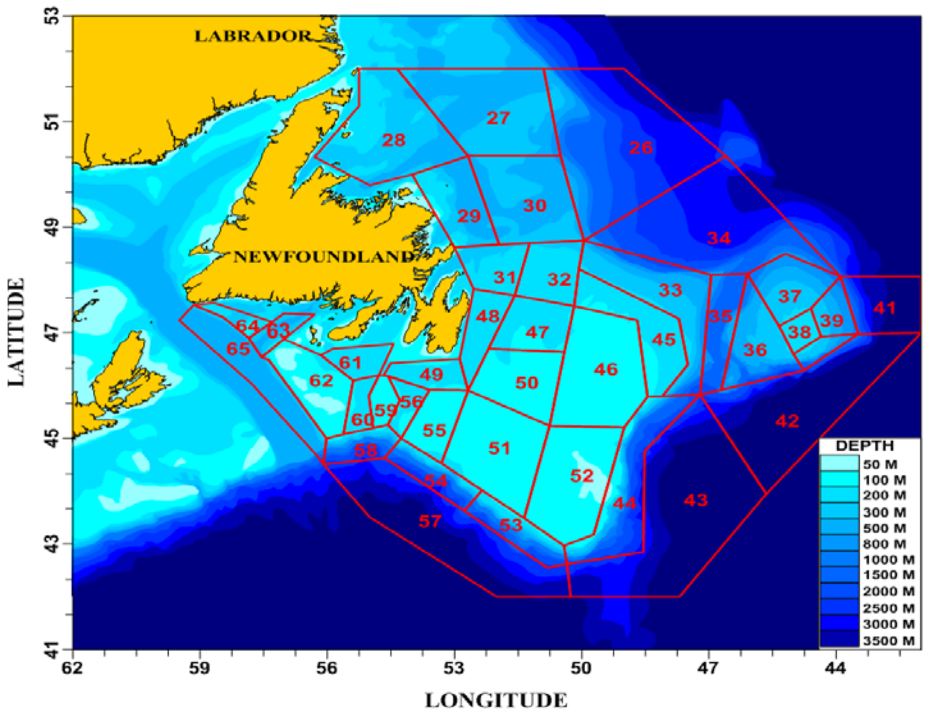

Figure 20. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed in Figure 21.

AREA	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12
26 Funk Slope	0.1	0.2	-0.8	0.6	0.1	-0.9	-0.8	0.0	0.1	2.2	0.6	-0.1	-0.7	-0.1	1.2	1.3	0.7	0.9	1.0	-0.2	0.8	0.9	0.4
27 Funk Island	-1.2	-0.3	-0.8	1.2	-1.5	-0.6	-0.7	0.8	1.0	1.1	0.9	0.7	-0.1	1.0	2.5	1.0	0.2	0.6	1.1	-0.2	-0.3	2.4	0.6
28 White Bay	-0.9	-0.7	-1.6	-0.6	-0.7	-0.2	-0.6	0.3	0.6	1.5	-1.6	-0.1	-0.3	-0.8	0.9	2.3	1.5	1.9	0.5	-0.3	-0.1	2.8	0.2
29 Bonavista	-1.1	-1.0	-0.9	-1.8	-1.0	-0.8	-0.2	0.5	-0.5	0.6	0.2	0.1	0.7	-0.4	1.1	0.2	1.1	1.8	-0.1	0.3	0.5	2.5	0.7
30 NE Nfld Shelf	-1.1	-0.1	-0.5	-1.0	-1.3	-0.2	-0.1	0.7	1.0	1.2	0.8	0.9	0.4	0.4	1.6	1.0	1.1	1.2	1.6	-0.6	0.7	2.3	1.4
31 Baccaliu	-1.1	-1.3	-1.0	-1.1	-1.0	-0.6	1.9	1.8	1.5	1.1	0.8	-0.1	0.2	-0.4	1.0	0.8	1.1	0.8	-0.4	-0.8	1.4	1.9	0.9
32 N Slope	-1.3	-0.9	-1.1	-1.6	-0.8	-0.7	0.7	1.0	0.7	1.5	0.6	0.0	0.3	-0.5	1.1	1.3	1.8	0.3	0.9	-1.1	1.1	2.2	0.6
33 NE Slope	-0.9	-0.9	-0.9	-1.0	-0.5	0.1	-0.1	0.9	0.9	1.0	0.5	0.6	0.6	0.7	1.5	1.1	1.4	0.8	1.1	0.7	1.0	1.9	1.3
34 Funk Offshore	-1.7	0.4	-0.6	-0.1	-0.4	-0.6	-0.4	-0.1	-0.2	2.3	0.3	-0.5	0.6	3.7	-0.1	-0.7	0.1	0.1	-0.2	-0.2	-0.5	0.1	2.4
35 Flemish Pass	-1.1	0.2	-0.6	0.1	0.0	-1.9	-0.8	-0.8	0.2	0.5	0.7	-0.2	0.1	-0.3	0.1	0.5	1.4	1.2	0.8	1.7	1.4	1.2	1.3
36 Flemish Cap (W Slope)	-2.2	0.6	-1.5	-0.6	-0.7	-1.7	-0.9	-0.9	-0.5	0.9	1.0	-0.3	-0.4	-0.7	0.5	0.7	0.6	0.2	1.5	2.3	0.6	6.2	2.3
37 Flemish Cap (N Slope)	-1.2	-0.4	-1.9	-0.8	-0.4	-0.7	-0.9	-0.7	-0.7	2.1	0.6	0.3	-0.4	-0.9	-0.1	0.5	0.4	0.3	1.3	1.8	2.0	2.2	1.6
38 Central Flemish Cap	-1.8	-1.4	-1.1	-0.5	-1.4	-0.8	-0.3	-0.1	0.6	1.5	0.5	0.1	0.2	0.0	1.1	1.6	0.9	0.3	1.2	0.9	2.1	1.1	0.5
39 Flemish Cap (E Slope)	-1.4	3.3	-0.7	-0.8	-1.0	-0.9	-1.2	-0.6	-0.2	0.0	0.4	0.0	-0.1	-0.6	0.0	0.2	0.5	0.5	0.8	1.2	2.1	1.1	1.2
44 E Slope	-2.6	-0.9	-1.2	0.0	-1.1	0.0	-0.8	0.0	0.7	0.6	1.1	0.7	0.5	0.2	1.1	1.5	0.0	0.5	0.9	0.9	1.0	1.7	0.4
45 NE Edge	-1.3	-1.1	-1.2	-1.8	-1.2	-0.7	0.4	1.2	0.8	1.3	0.0	0.4	-0.5	0.0	1.6	0.5	1.8	0.8	0.3	-0.9	1.6	3.3	0.9
46 NE Grand Bank	0.0	-1.2	-1.3	-1.9	-1.3	-0.3	0.3	-0.7	0.6	1.8	-0.5	-0.2	0.3	-0.1	1.8	0.3	1.3	-0.4	-0.3	1.4	1.7	2.0	0.6
47 NE Avalon Channel	-1.3	-1.4	-1.2	-1.7	-1.2	-0.8	0.4	0.6	0.8	1.2	0.4	0.2	-0.1	-0.4	2.0	1.0	1.7	0.3	0.3	-0.3	1.8	2.8	1.7
48 N Avalon Channel	-1.1	-1.5	-1.0	-1.5	-1.3	-0.5	0.5	0.4	0.6	0.9	0.6	0.6	-0.1	0.1	1.9	1.5	2.1	0.6	0.0	-0.3	1.3	3.3	1.2
49 S Avalon Channel	-0.8	-1.2	-1.0	-1.3	-1.2	0.0	1.2	-0.5	1.4	0.3	0.5	0.5	-0.3	-0.6	1.7	1.5	2.4	-0.2	-0.2	0.0	0.9	3.0	2.4
50 NW Grand Bank	-0.5	-1.6	-1.4	-1.8	-1.6	0.2	0.4	-0.7	0.9	1.7	0.1	0.3	0.1	-0.7	0.9	1.3	1.1	0.1	-0.5	0.4	1.1	2.0	0.9
51 SW Grand Bank	-1.0	-0.6	-1.3	-0.6	-1.2	0.7	0.2	-0.8	0.2	1.1	0.4	-0.1	-0.6	-0.5	0.1	0.2	0.2	0.5	-0.2	0.3	0.6	1.0	0.9
52 SE Grand Bank	-1.0	-0.5	-1.8	-1.7	-0.4	-0.6	0.0	-0.4	0.9	2.0	0.0	-0.5	-0.8	-0.8	1.0	-0.2	0.8	0.2	-1.0	1.9	1.0	2.2	0.8
53 S Slope	-1.9	-1.8	-1.9	0.2	0.0	0.0	-0.7	-0.9	0.5	0.2	1.7	0.0	0.0	0.0	0.4	0.9	-0.1	-0.2	-0.1	1.4	0.5	1.7	1.1
54 SW Slope	-1.7	-2.4	-1.1	1.0	-0.2	0.6	0.6	-0.7	-0.4	1.2	0.7	0.2	0.5	-0.6	-0.4	0.3	0.8	-0.6	-0.6	1.2	0.4	1.8	1.5
55 Whale Bank	-1.0	-0.9	-1.2	-0.2	-1.4	-0.9	0.3	-0.5	0.3	1.3	0.2	-0.1	-0.2	-0.7	0.3	0.1	0.1	-0.6	-0.5	0.1	0.3	1.4	1.5
56 Haddock Channel	-1.4	-1.1	-1.3	0.2	-1.6	0.6	-0.5	-0.5	0.2	1.0	-0.9	1.2	-0.7	-0.3	3.3	-0.3	0.9	-0.7	-0.2	0.2	0.2	4.7	2.3
58 Halibut Channel Slope	-1.9	-0.8	0.3	-1.1	-0.5	-1.0	1.1	0.1	0.7	0.7	0.7	0.9	0.2	-1.0	-1.3	1.3	-2.2	0.0	-0.3	0.6	0.7	1.2	1.0
59 Green Bank	0.0	-0.9	-0.8	-1.2	-1.5	-0.1	0.1	-0.8	0.1	0.3	1.4	0.8	0.1	-0.7	0.9	0.5	1.2	0.5	-0.8	0.2	0.9	4.8	1.2
60 Halibut Channel	-1.1	-0.9	-0.7	-1.1	-1.3	-1.0	1.8	-0.7	-0.1	0.7	2.3	1.1	1.9	-0.6	-0.3	-0.2	0.2	-0.7	-0.9	2.2	-0.4	-0.1	-0.6
61 St. Pierre Channel	-0.7	-1.1	0.0	-1.0	-2.0	-1.0	0.0	3.5	-0.4	0.4	1.1	-0.4	-0.2	-1.1	0.5	0.5	0.4	0.5	-0.2	1.0	1.1	2.2	1.4
62 St. Pierre Bank	-0.8	-0.1	0.3	-0.5	-0.9	-0.7	0.0	-1.1	-0.7	1.9	1.1	-0.3	0.6	-1.1	0.2	1.7	0.9	-1.1	0.6	0.3	2.3	1.2	-0.3
63 HERMITAGE CHANNEL	-0.9	-1.8	-0.1	0.7	1.0	0.5	0.2	0.9	-0.8	0.8	1.1	-0.7	0.9	-1.2	0.2	-0.1	0.6	-0.1	0.3	-0.2	1.2	0.6	1.6
64 Burgeo Bank	0.1	-1.8	-2.2	0.3	1.2	0.3	0.2	-0.3	-0.4	1.5	0.2	-0.3	0.9	-2.3	-0.8	0.2	0.8	0.3	-0.1	-0.4	-0.2	1.4	1.8
65 Laurentian Channel	-0.7	-0.2	-0.1	0.5	-0.8	1.0	1.3	-0.3	0.3	-0.1	1.4	0.9	0.2	-0.8	-1.4	-0.1	0.4	-1.3	-0.3	0.4	0.4	-0.3	2.0

Figure 21. Standardized bottom temperature anomalies for the Newfoundland Shelf derived from data within the areas displayed in Figure 20. The anomalies are normalized with respect to their standard deviations over the standard base period 1981-2010 and colour-coded accordingly to Figure 4.

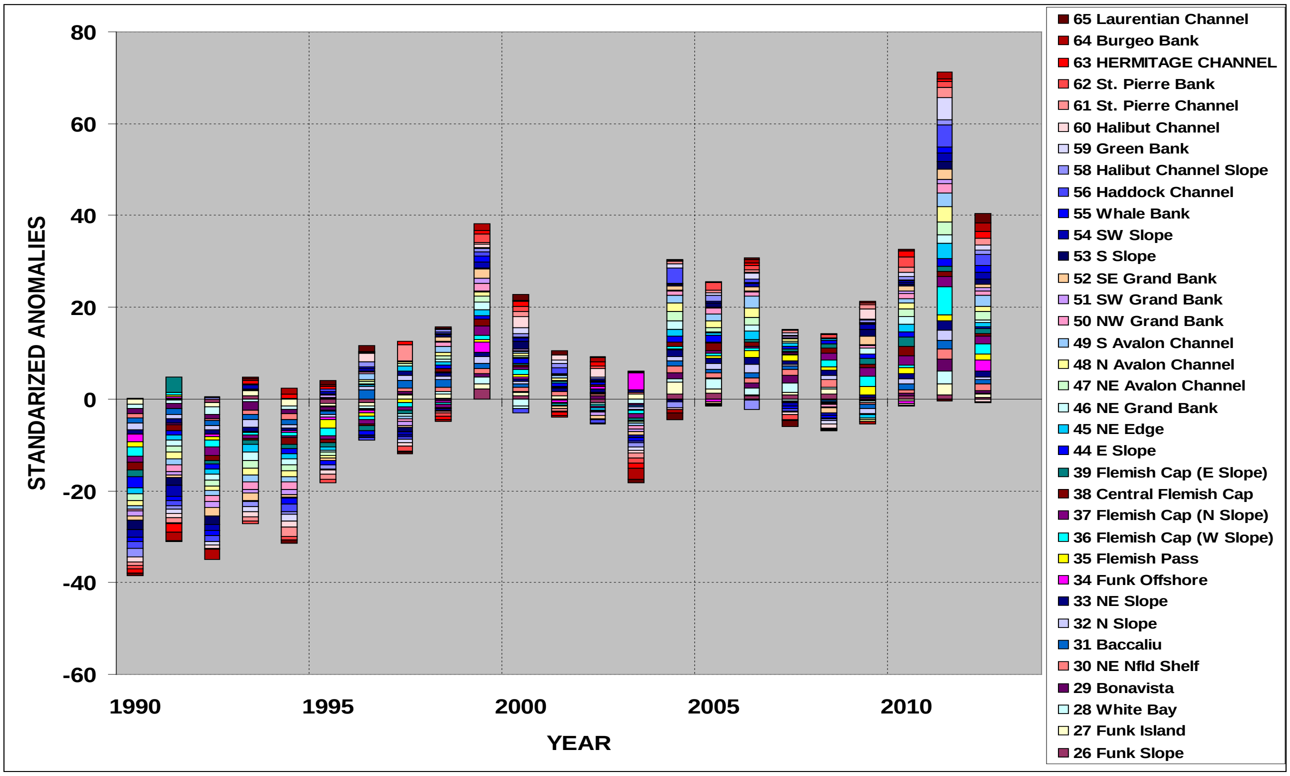

Figure 22. Cumulative bottom temperature anomalies based on the values presented in Figure 21 for areas on the Newfoundland Shelf.

STRATIFICATION AND MIXED-LAYER DEPTH

Stratification is an important characteristic of the water column influencing vertical mixing rates and extent, the transfer of solar heat to lower layers and important biochemical processes. It is one of the most important parameters influencing the formation and evolution of the cold-intermediate-layer on the shelf regions of Atlantic Canada during the summer when the lower water column becomes essentially isolated from the upper layers thus slowing vertical heat flux from the seasonally heated surface layer.

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

The 1981-2010 monthly mean and the 2012 monthly values are shown in Figure 23. On average the water column is essentially unstratified during the winter months, stratification increases during the spring reaching its maximum by August then decrease to winter time values by December. In 2012, the stratification was near 0 in January, below normal in March, above normal in April and near normal in May. In June, stratification was below normal but increased to stronger than normal in July and August and then was weaker than normal during the remainder of the year. There were no data in February.

In 2012, the annual averaged stratification increased over the previous year but remained below the long-term mean (Fig. 24). The seasonal standardized anomalies are summarized in Fig. 27. 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 recent years it has decreased from about 1 SD above normal in 2006 to the lowest since 1980 at 2 SD below normal in 2011 (Fig. 27). A similar large decrease in stratification was also observed in 2011 on the Scotian Shelf (Hebert et al. 2012). In general, both on the Scotian and Newfoundland shelves there is a long-term trend of increasing stratification since 1950.

The monthly mean mixed layer depths (MLD) at Station 27 were also estimated from the density profiles as the depth of maximum density gradient. There were insufficient data available prior to 1990 to compute reliable annual means. The MLDs are highly variable, particularly during the winter months. The average monthly values range from >80 m in the winter to <20 m in summer. In 2012 the winter values appear to be deeper than normal while summer values were near normal (Fig. 25). In general, there appears to be an increasing trend since 1990 of about 10 cm/year (Fig. 26). During 2011 the annual averaged MLD was 1.6 SD deeper than normal and <1 SD deeper than normal in 2012 (Fig. 27).

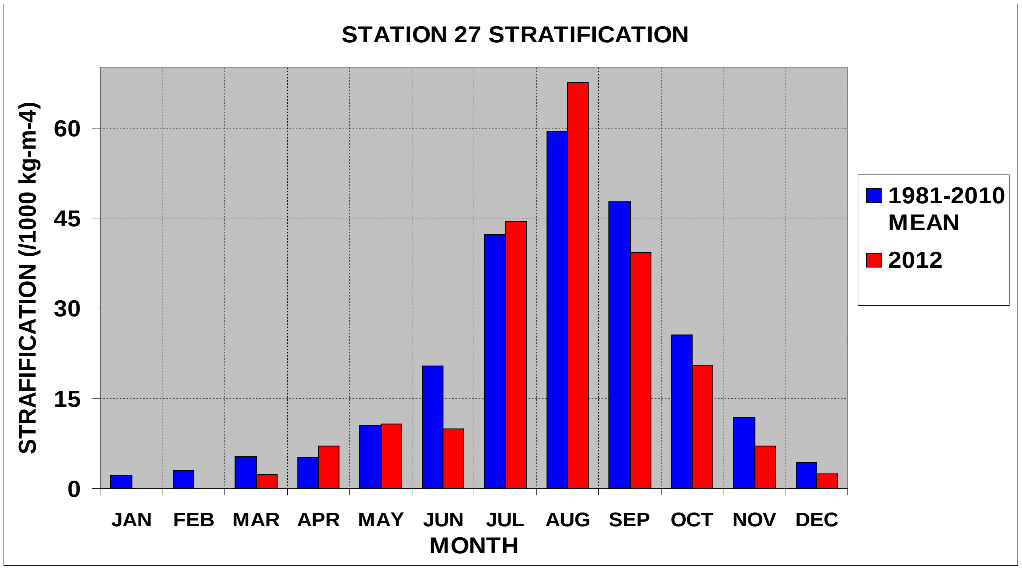

Figure 23. The 1981-2010 monthly average and the 2012 monthly average stratification values at Station 27. No data were available in February.

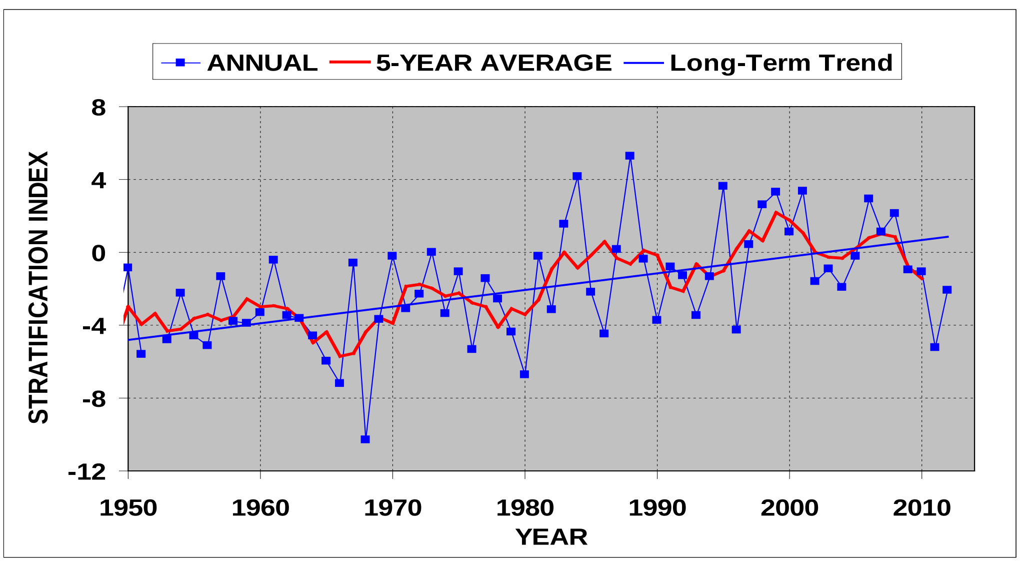

Figure 24. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean.

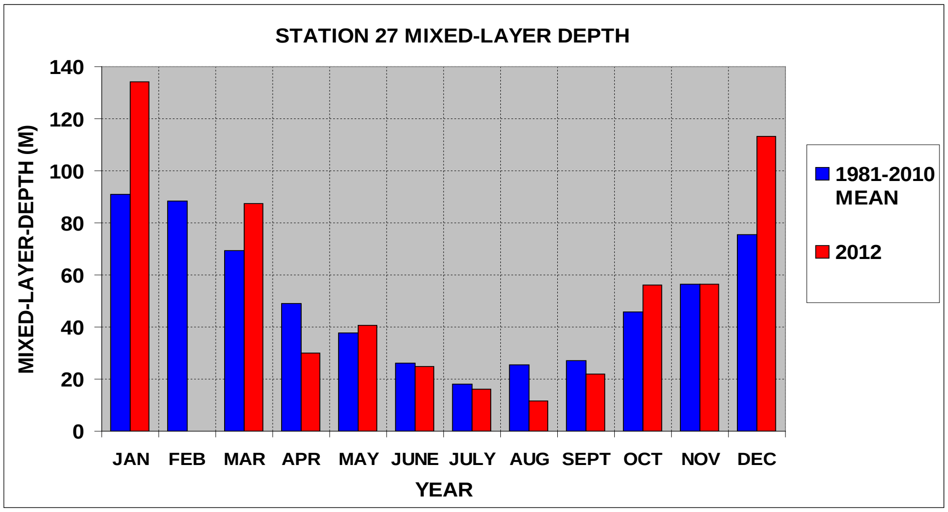

Figure 25. The 1990-2010 average and the 2012 monthly average Mixed Layer Depth at Station 27.

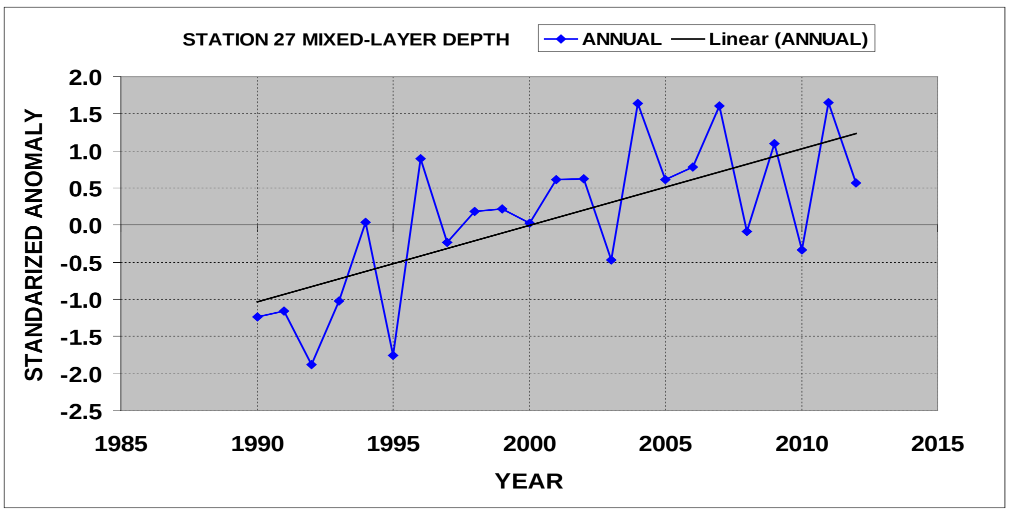

Figure 26. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2010 mean.

INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ANNUAL MLD	-1.2	-1.2	-1.9	-1.0	0.0	-1.8	0.9	-0.2	0.2	0.2	0.0	0.6	0.6	-0.5	1.6	0.6	0.8	1.6	-0.1	1.1	-0.3	1.6	0.6
WINTER MLD	-2.0	-0.1	-1.6	-0.9	-0.8	-0.8	0.5	0.6	-0.3	0.5	0.3	0.9	-0.5	-0.3	1.4	1.0	1.4	1.1	-0.7	1.0	-1.2	1.0	0.7
SPRING MLD	-1.4	-1.4	-1.0	-0.4	-0.1	-1.1	1.2	-0.6	1.3	-1.2	0.2	1.1	1.0	-0.3	0.8	-0.7	-0.6	0.9	1.8	-1.0	0.4	1.3	-0.4
SUMMER MLD	4.3	-0.6	0.5	-0.1	0.0	0.0	0.2	-0.3	-0.3	-0.2	-0.4	0.0	-0.3	-0.3	-0.3	-0.2	0.0	-0.3	-0.3	-0.3	-0.2	0.2	-0.3
FALL MLD	-2.1	-0.7	-0.6	-0.1	1.1	-1.7	-0.1	-0.1	0.1	1.0	-0.2	-1.3	1.5	0.0	0.5	0.6	0.0	0.9	-0.3	1.9	0.1	0.5	0.8
ANNUAL STRATIFICATION	-1.4	-0.3	-0.5	-1.3	-0.5	1.4	-1.6	0.2	1.0	1.3	0.4	1.3	-0.6	-0.3	-0.7	-0.1	1.1	0.4	0.8	-0.4	-0.4	-2.0	-0.8
SPRING STRATIFICATION	-1.5	-0.8	-1.1	-0.3	-0.6	1.8	-0.9	0.0	1.0	0.8	-0.3	0.0	-1.1	-1.0	-0.3	0.2	0.6	0.1	-0.4	0.4	-0.7	-0.3	-0.6
SUMMER STRATIFICATION	-1.6	-0.4	-1.6	-1.3	0.8	1.1	-1.5	-0.3	1.6	1.4	-0.5	0.7	0.4	-0.8	-0.4	0.3	0.7	1.2	0.2	0.5	-0.8	-2.2	0.0
FALL STRATIFICATION	0.3	0.8	1.1	-1.1	-0.9	0.8	-0.9	0.7	0.1	0.4	1.3	1.8	-1.0	0.6	-0.7	-0.4	1.1	-0.1	1.3	-1.4	0.3	-1.5	-1.3

Figure 27. Standardized mixed-layer-depth and stratification anomalies derived from data collected at Station 27. The anomalies are normalized with respect to their standard deviations over the same base period.

STANDARD SECTIONS

Beginning 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). Beginning in 1998 under the AZMP program, the Bonavista and Flemish Cap sections are occupied during the spring, summer and fall and a section crossing the Southeast Grand Bank was added to the spring and fall monitoring surveys. Starting in the spring of 2009 two sections crossing St. Pierre Bank were added to the survey (Fig. 2).

In 2012, St. Pierre Bank and the Southeast Grand Bank sections were sampled in April and December, the Flemish Cap section during April, July and November/December, the Bonavista section during April, July and November, the Seal Island in July and November, and the Makkovik Bank and White Bay sections during July (Fig. 2).

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

In general, the near-surface water mass characteristics along the standard sections undergo seasonal modification from seasonal cycles of air-sea heat flux; wind forced mixing, and the formation and melting of sea ice. These mechanisms cause intense vertical and horizontal temperature and salinity gradients, particularly along the frontal boundaries separating the shelf and slope water masses.

Throughout most of the year, the cold relatively fresh water overlying the shelf is separated from the warmer higher density water of the continental slope region by strong temperature and salinity (density) fronts (Fig. 28 and 29). This winter formed water mass is commonly referred to as the cold intermediate layer or CIL (Petrie et al. 1988) and its cross sectional area or volume bounded by the 0^{o}C isotherm is generally regarded as a robust index of ocean climate conditions on the eastern Canadian continental shelf. While the cross sectional area of the CIL water mass undergoes significant annual variability, the changes are highly coherent from the Labrador Shelf to the Grand Banks. The shelf water mass remains present throughout most of the year as summer heating and salinity changes increase the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although CIL areal extent continues to undergo a gradual decay during late summer reaching a minimum in late fall as the seasonally heated upper layers penetrates the water column.

During the summer of 2012 the temperature cross section was highlighted by the CIL with temperatures near to slightly below the long term average. At the surface and deeper layers however temperatures were significantly above normal with anomalies ranging from 1^O to 4^{O}C over most of the shelf (Fig. 28). The salinity cross section clearly shows the freshwater outflow from the arctic and the Labrador Shelf with near-shore surface values <32 increasing to > 34.8 offshore in the deeper Labrador Slope water. Salinities were lower than normal at mid-depths corresponding to the CIL water mass but generally above normal elsewhere over the water column (Fig. 29).

The CIL areas and other indices based on temperature and salinity data collected along sections from southern Labrador to the Grand Banks are displayed in Figs. 30 and 31. The CIL cross sectional area anomalies during the summer of 2012 were below normal along all 4 sections from southern Labrador to the Grand Banks (implying warmer-than-normal shelf water), however there was a significant increase over the previous 2 years (Fig. 30). In general the CIL area has experienced a downward trend since the mid-1990s. The overall average summer temperature along the Bonavista section decreased from 1.6 SD above normal in 2008, fluctuated slightly in 2009-10, then increased substantially in 2011 to +1.9 SD before decreasing to +1 SD in 2012 (Fig. 31).

A composite index derived from the temperature indices presented in Fig. 31 for the Seal Island, Bonavista and Flemish Cap sections sampled during the summer is shown in Fig. 32. An increasing trend in temperature since the early 1990s is clearly evident, peaking during the mid-2000s, and then declining to slightly below normal in 2009 but increasing again in 2010 reaching the highest value since 1991 in 2011 but then declined to near normal in 2012 (Fig. 32).

Similarly the salinity composite shows mostly below normal values from 1991-2001, except 1997, then higher than normal from 2002-2008 with below normal conditions during the past 4 years (Fig. 33).

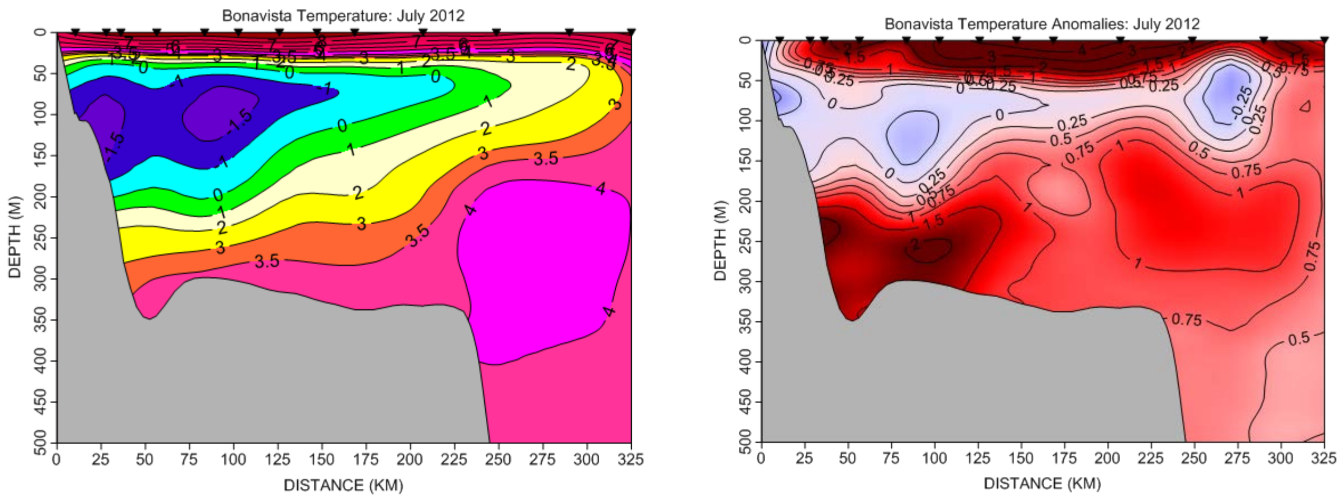

Figure 28. Contours of temperature (^{o}C) and temperature anomalies along the Bonavista section (Fig. 3) during the summer of 2012.

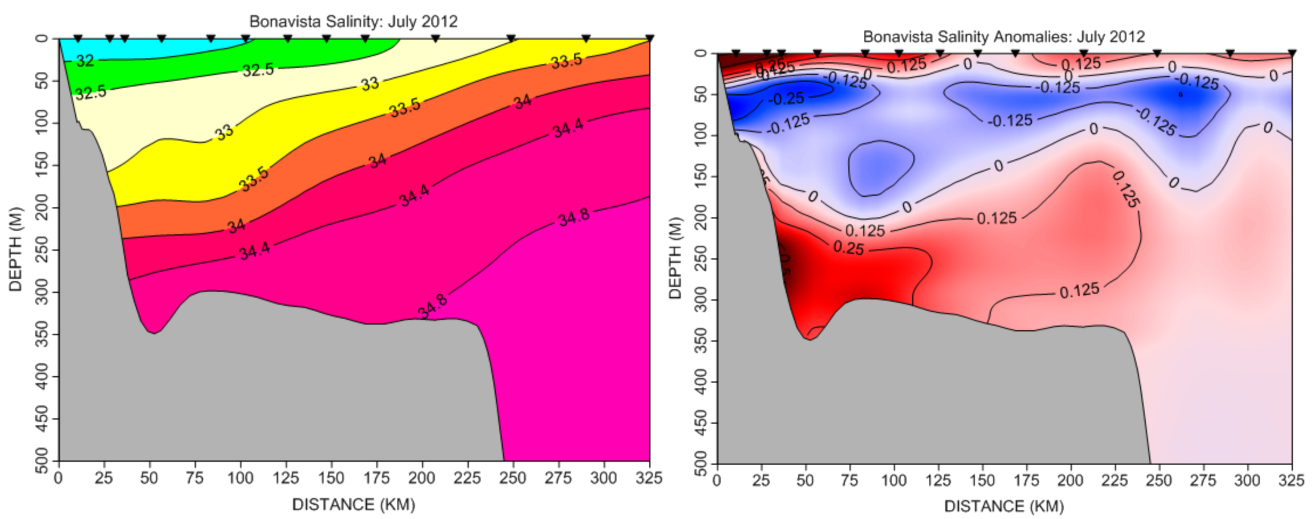

Figure 29. Contours of salinity and salinity anomalies along the Bonavista section (Fig. 3) during the summer of 2012.

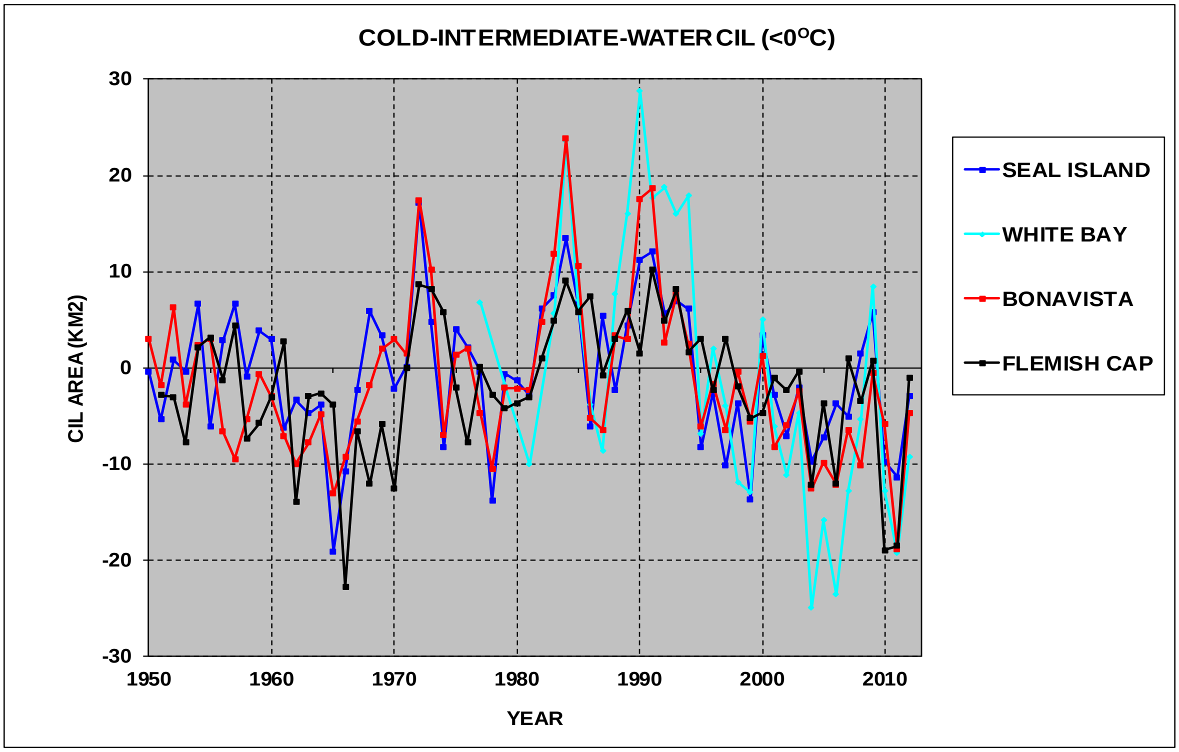

Figure 30. Summer CIL ($T<0^{O}C$) area anomalies along the Seal Island, White Bay, Bonavista and Flemish Cap Sections referenced to the 1981-2010 mean.

REGION/SECTION	INDEX	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12
	CIL AREA	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
SOUTHERN	MEAN CIL TEMPERATURE	-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	1.9
LABRADOR	MINIMUM CIL TEMPERATURE	-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
SEAL ISLAND	MEAN SECTION TEMPERATURE	-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	2.7
SECTION	MEAN SECTION SALINITY	-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
	INSHORE SHELF SALINITY	-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
	CIL AREA	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
EASTERN	MEAN CIL TEMPERATURE	-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
NEWFOUNDLAND	MINIMUM CIL TEMPERATURE	-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
BONAVISTA	MEAN SECTION TEMPERATURE	-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
SECTION	MEAN SECTION SALINITY	-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
	INSHORE SHELF SALINITY	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
GRAND BANK	CIL AREA	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
	MEAN CIL TEMPERATURE	-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
47 °N	MINIMUM CIL TEMPERATURE	-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
SECTION	MEAN SECTION TEMPERATURE	-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
	MEAN SECTION SALINITY		-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
	INSHORE SHELF SALINITY		-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

Figure 31. Standardized temperature and salinity anomalies derived from data collected along standard cross-shelf sections during the summer (Fig. 3). 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.

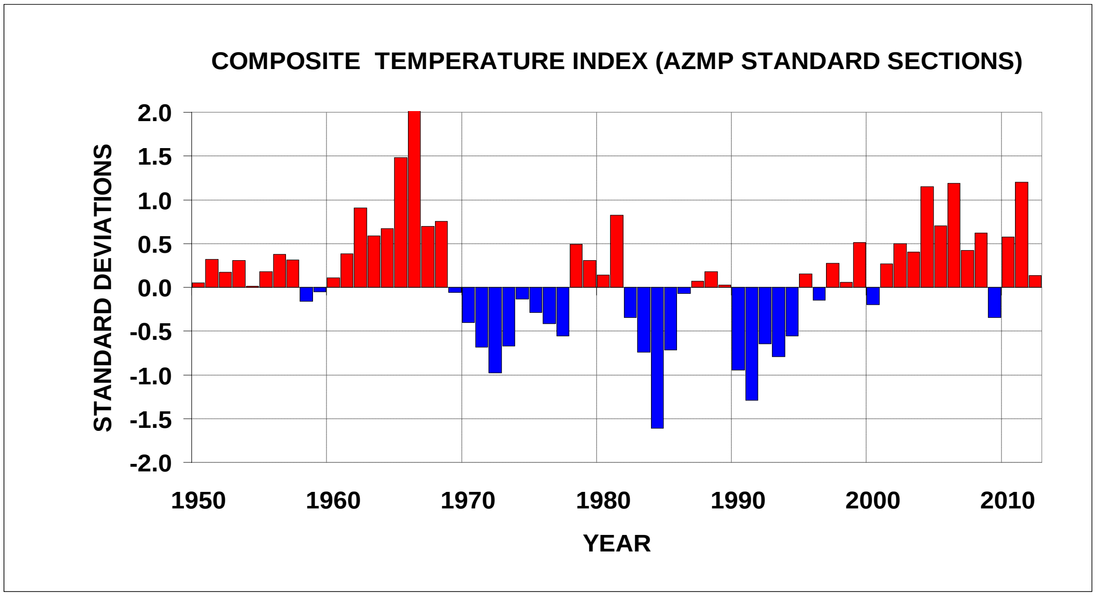

Figure 32. Standard summer section composite temperature index derived by summing the standardized anomalies from Figure 30.

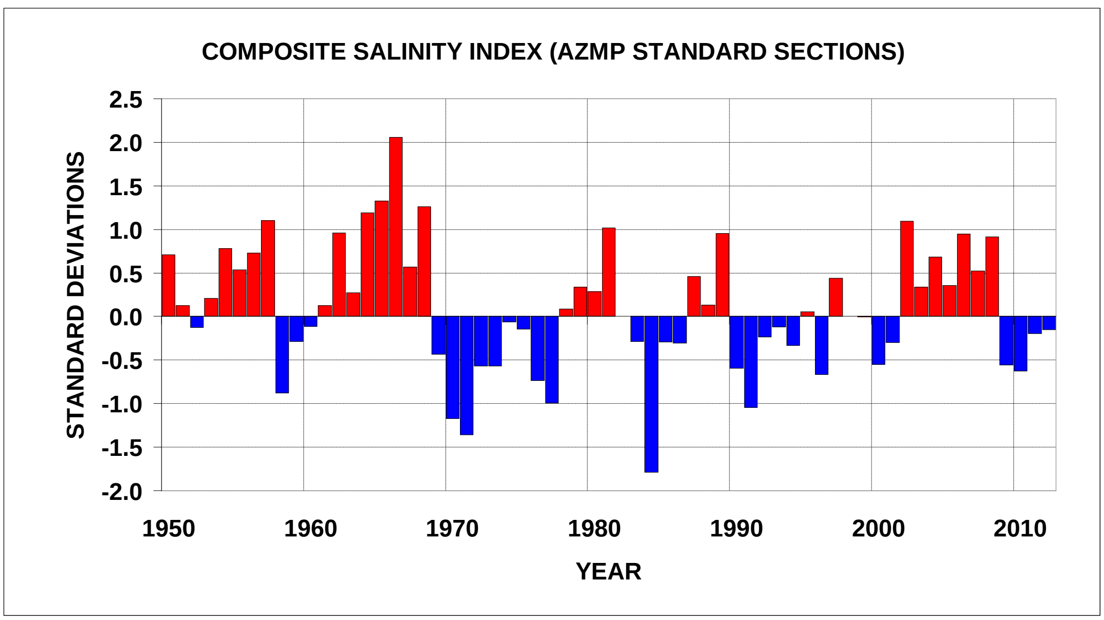

Figure 33. Standard summer section composite salinity index derived by summing the standardized anomalies from Figure 30.

MULTI-SPECIES SURVEY BOTTOM TEMPERATURES

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday 1981). Temperature profiles are available for fishing sets in each stratum and trawl-mounted CTDs have provided profiles of salinity since 1989.

These surveys provide large spatial-scale oceanographic data sets for the Newfoundland Shelf. During the spring NAFO Subdivision 3Ps and Divisions 3LNO on the Grand Bank are surveyed while in the fall Division 2HJ in the north to 3NO in the south are surveyed. The hydrographic data collected are now routinely used to assess the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of data products based on these data are used to characterize the oceanographic habitat. Among these are contoured maps of the bottom temperatures and their anomalies, the area of the bottom covered by water in various temperature ranges as a 'thermal habitat' index, spatial variability in the volume of the cold intermediate layer and water-column stratification and mixed-layer depth spatial maps. In this section, an analysis of the near-bottom temperature fields and their anomalies based on these data sets are presented for the spring and fall surveys of 2012.

SPRING CONDITIONS

Maps of bottom temperatures and their anomalies derived from the spring of 2012 multi-species survey (Fig. 3) are displayed in Figure 34 for NAFO Div. 3PLNO. Bottom temperatures in Div. 3L were generally <1^{o}C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 2^{o} to >3^{o}C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 1^{o}C – 7^{o}C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from 1^{o} -2^{o}C. On St. Pierre Bank temperatures ranged from 1^{o}C to 3^{o}C and up to 5^{o}C in the Laurentian Channel and areas to the west. Bottom temperature anomalies were above normal by 0.5^{o} to 1^{o}C over most of the region except for southern 3NO where they were >3^{o}C above normal.

Temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area are presented in Fig. 35. The increasing trend in bottom temperatures is seen in almost all areas with record high values in 2011 that decreased moderately in 2012.

Climate indices based on the temperature data collected during the spring multi-species survey for the years 1990-2012 are displayed in Fig. 36 as normalized anomalies. The spring of 2011 had the lowest area of <0^{o}C water in Division 3L since the surveys began in the early 1970s at 2.2 SD units below normal. In 2012 it increased over the previous 2 years but remained at 1.3 SD below the long term mean (Fig. 36).

In both 3LNO and 3Ps, spring bottom temperatures were generally lower than normal from 1990 to 1995 with anomalies often exceeding 1.5 SD below the mean. By 1996, conditions had moderated to near-normal values but decreased again in the spring of 1997 to colder than normal in both 3Ps and 3LNO. In 3LNO temperatures were above normal from 1998 to 2012, with the exception of 2003.The spring of 2011 had the warmest bottom temperatures on record.

In Div. 3P bottom temperatures increased to above normal values by 1999 and 2000, decreased again in 2001 reaching near-record cold conditions in 2003 with bottom temperatures on St. Pierre Bank (depths <100 m) at 1.4 SD below normal, the coldest since 1990. During 2004 and 2005 temperatures again increased to above normal values with 2005 the highest on St. Pierre Bank since 2000 (1.2 SD). No data were available for 2006 but by 2007-08 spring temperatures across the 3P area returned to below normal conditions that moderated somewhat to near-normal values in 2009 with a further increase in 2010-12 to >1.5 SD above normal, although there was a slight decrease on the banks in water depths <100 m (Fig. 36).

A composite index derived by summing the standardized indices presented in Fig. 36 shows overall temperature conditions during the spring since 1990. In 2012 this index decreased moderately over the record high value in 2011 (Fig. 37).

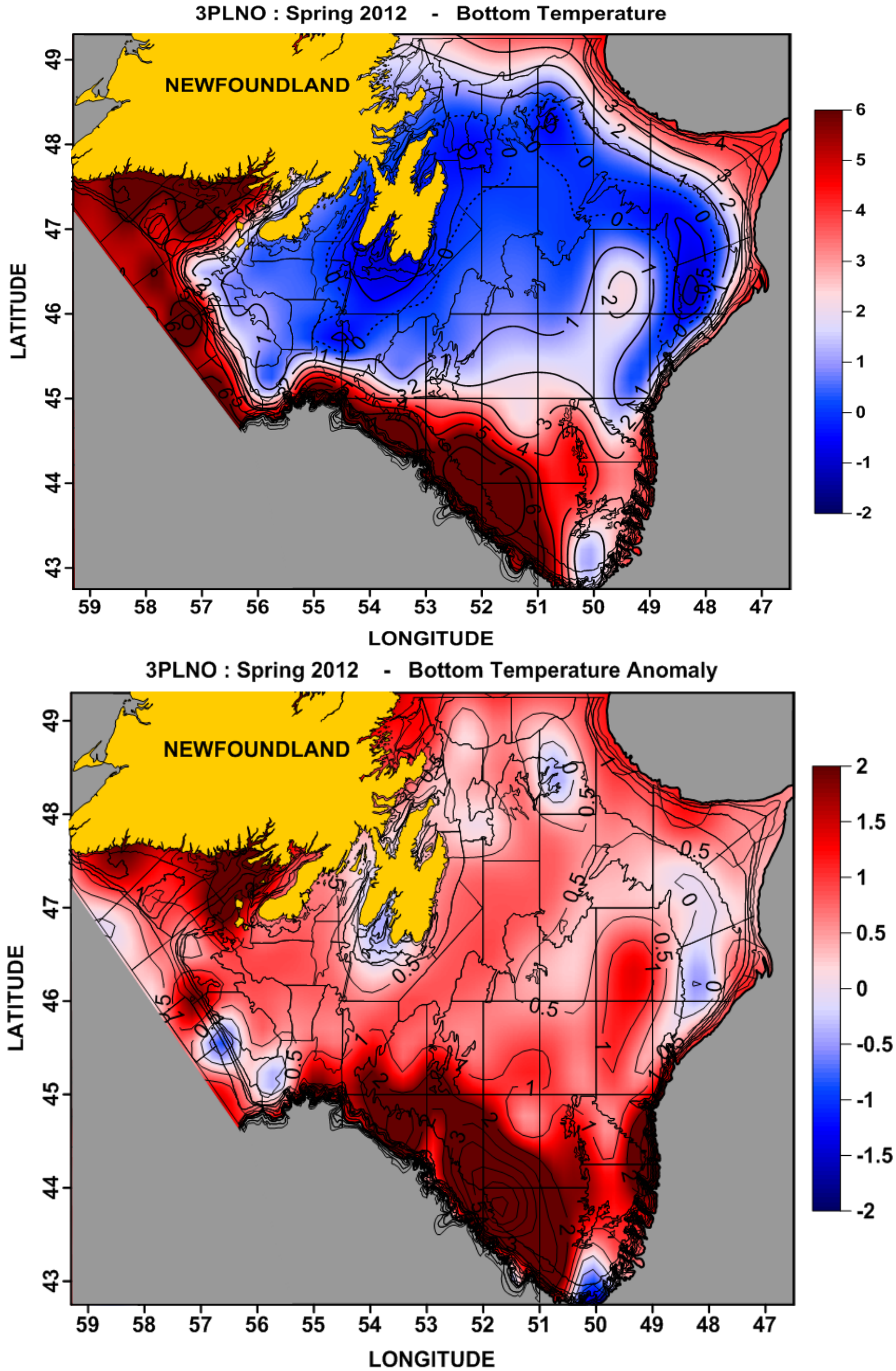

Figure 34. Contour maps of bottom temperature (top panel) and bottom temperature anomalies (bottom panel) (°C) during the spring of 2012 in NAFO Divisions 3PLNO. The anomalies are referenced to the period 1981-2010.

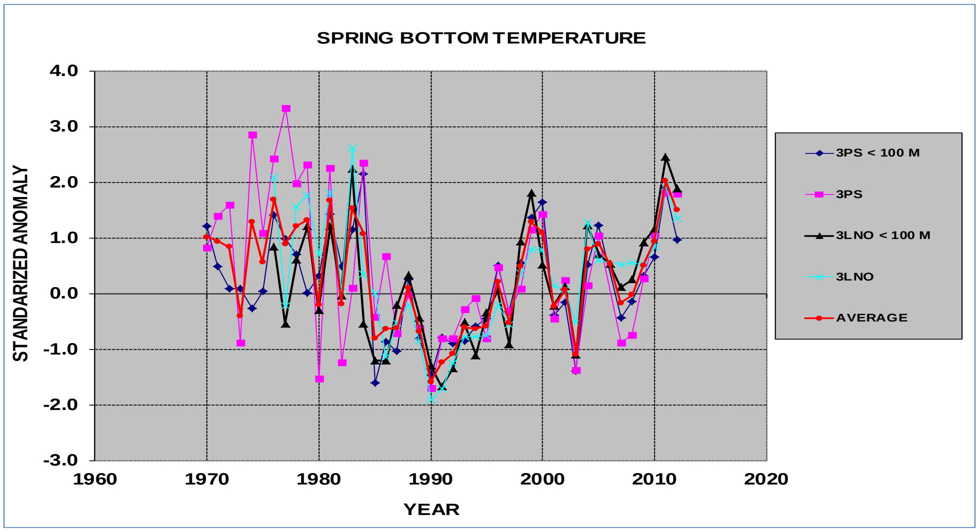

Figure 35. Bottom temperature anomalies from the spring multi-species surveys in NAFO Divisions 3LNOP.

REGION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	BOTTOM TEMPERATURES	-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
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-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
SPRING	THERMAL HABITAT AREA >2°C	-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
	THERMAL HABITAT AREA <0°C	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
	BOTTOM TEMPERATURES	-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
NAFO DIV. 3PS	BOTTOM TEMPERATURES <100 M	-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
SPRING	THERMAL HABITAT AREA >2°C	-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
	THERMAL HABITAT AREA <0°C	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

Figure 36. Temperature indices derived from data collected during spring multi-species surveys. The anomalies are normalized with respect to their standard deviations. The grey shaded cells indicate years without observations.

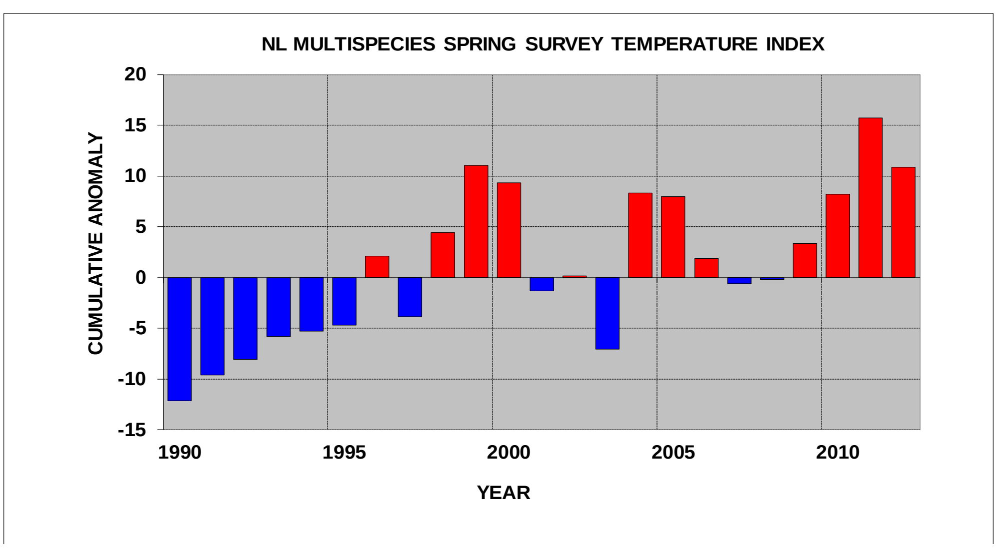

Figure 37. Composite temperature index derived by summing the standardized anomalies from Figure 36.

FALL CONDITIONS

Bottom temperature and temperature anomaly maps derived from the fall of 2012 multi-species survey (Fig. 3) in NAFO Div. 2J, 3KLNO are displayed in Fig. 38. Bottom temperatures in Div. 2J ranged from <0.5^{o}C on Hamilton Bank and the inshore areas to >3^{o}C at the shelf break. Most of the 3K region is deeper than 200 m. As a result relatively warm slope water floods through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. Bottom temperatures on these Banks and in the offshore slope regions ranged between 2^o - 4^{o}C. Bottom temperature anomalies ranged from 0.5^{o}C below normal on Hamilton Bank to 0.5^{o}C above normal in the deep troughs.

Bottom temperatures in Divs. 3LNO generally ranged from <0^{o}C on the northern Grand Bank and in the Avalon Channel to 3^o - 4^{o}C along the shelf edge. Over the southern areas, bottom temperatures ranged from 2^o to 6^{o}C with the warmest bottom waters found on the Southeast Shoal and along the edge of the Grand Bank in Div. 3O (Fig. 38). Except for a few isolated areas, temperatures were slightly below normal over most of 3L and above normal over 3NO where anomalies were up to 2^{o}C above the long-term mean (Fig. 38).

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 Fig. 39. For all areas, the 2012 values were significantly reduced from the record highs of the previous year. Similar to the spring survey results an overall increasing trend in bottom temperatures is evident with record high values in 2011.

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species survey for the years 1990-2012 are displayed in Fig. 40. In 2J, bottom temperatures were generally below normal from 1990 to 1995, with the coldest anomalies observed in 1993 when they declined to more than 1.7 SD units below normal on Hamilton Bank (<200 m depth). From 1996 to 2012 bottom temperatures experienced an increasing trend, reaching a record high of 2 SD above normal in 2011, but decreased significantly in 2012. From 1996-2012 near-bottom water with temperatures <1^{o}C has been decreasing with a corresponding increase in the area covered by water >2^{o}C.

In Div. 3K, conditions were very similar to 2J with an increasing trend since 1996, reaching a record high in 2011 (+2.7 SD) and decreasing again in 2012 to +1.2 SD. In Divs. 3LNO bottom temperatures were somewhat cooler than farther north in 2J and 3K, with record high values in 1999, warm conditions in 2010-2011 and a sharp decrease to near normal values in 2012 (Fig. 40).

A composite index derived by summing the standardized indices presented in Fig. 40 shows overall temperature conditions during the fall since 1990. In 2012 this index decreased significantly over the record high value in 2011 (Fig. 41).

CIL VOLUME

The spatial extent of the CIL water mass overlying the NL shelf is shown in Fig. 42 and Fig 43 for the cold year of 1993 and for 2012. The CIL water mass exhibits considerable inter-annual and seasonal variability. It usually covers most of the NL Shelf (except for parts of 3NO) during cold years (e.g. 1993) in contrast with near-normal years (e.g. 2012) when most of the CIL has been eroded by summer heating and wind forced mixing during the fall (Fig. 43). The CIL water mass was restricted to the slope of the Grand Banks in the Flemish Pass region even during cold years. In 1993, the CIL extended northward to the southern Labrador Shelf but is completely eroded there during warm years. In 2012 there were still some remnants of the CIL in the inshore regions of NAFO Div. 3K.

The total volume of CIL water remaining on the shelf after the summer heating season was calculated from the vertical temperature profiles in 2J3KL from October to mid-December (Fig. 44). The high volumes associated with the cold periods of the mid 1980s and early 1990s are evident as well as the decreasing trend since 1995. The CIL volume was the lowest in the 33-year record during 1999 (1.7 SD below normal) with 2010 and 2011 tied for 3rd lowest at 1.1 SD below normal. During 2012 the CIL volume increased to near-normal conditions, similar to that observed in 2008.

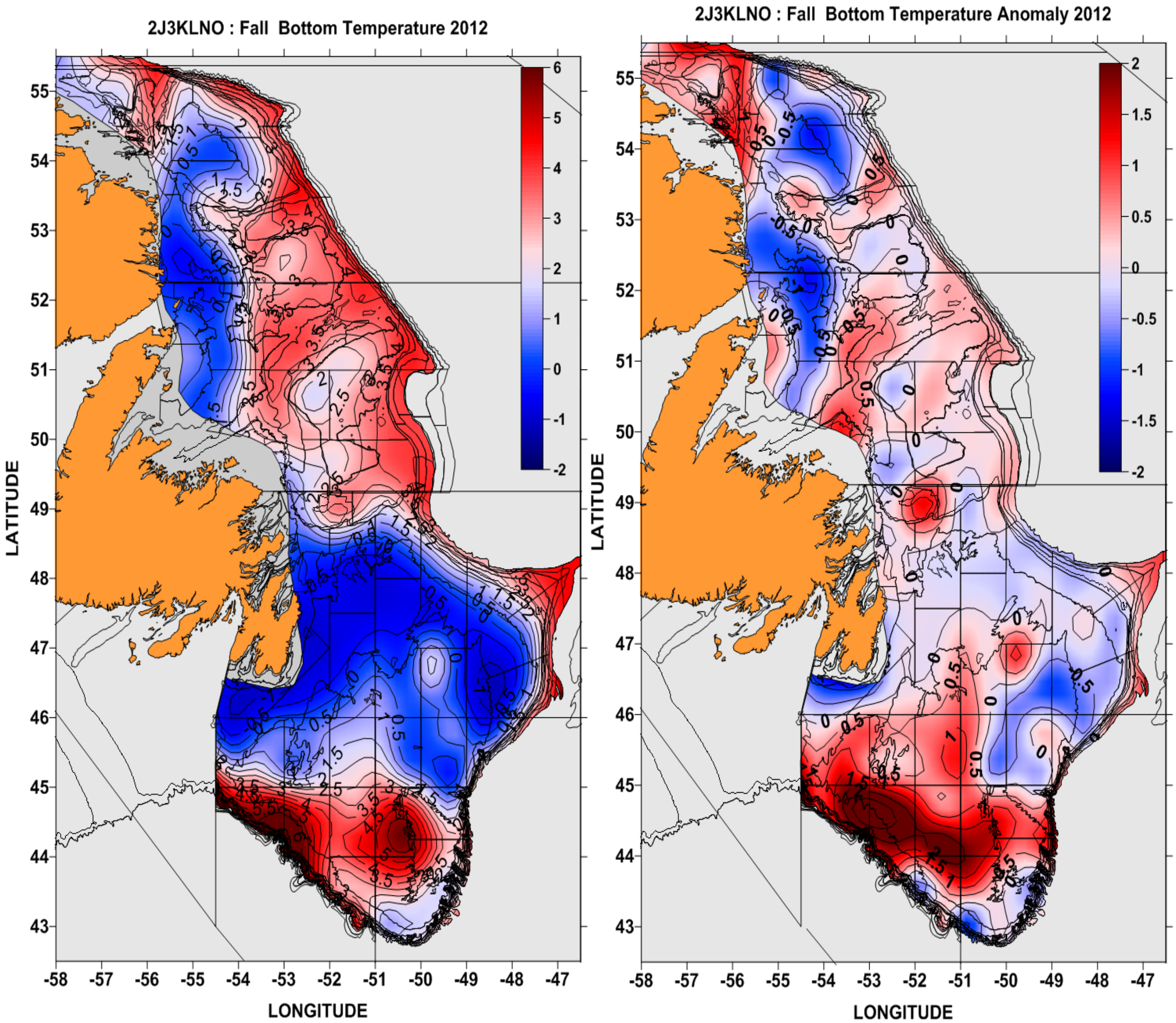

Figure 38. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2012 in NAFO Divisions 2J3KLNO.

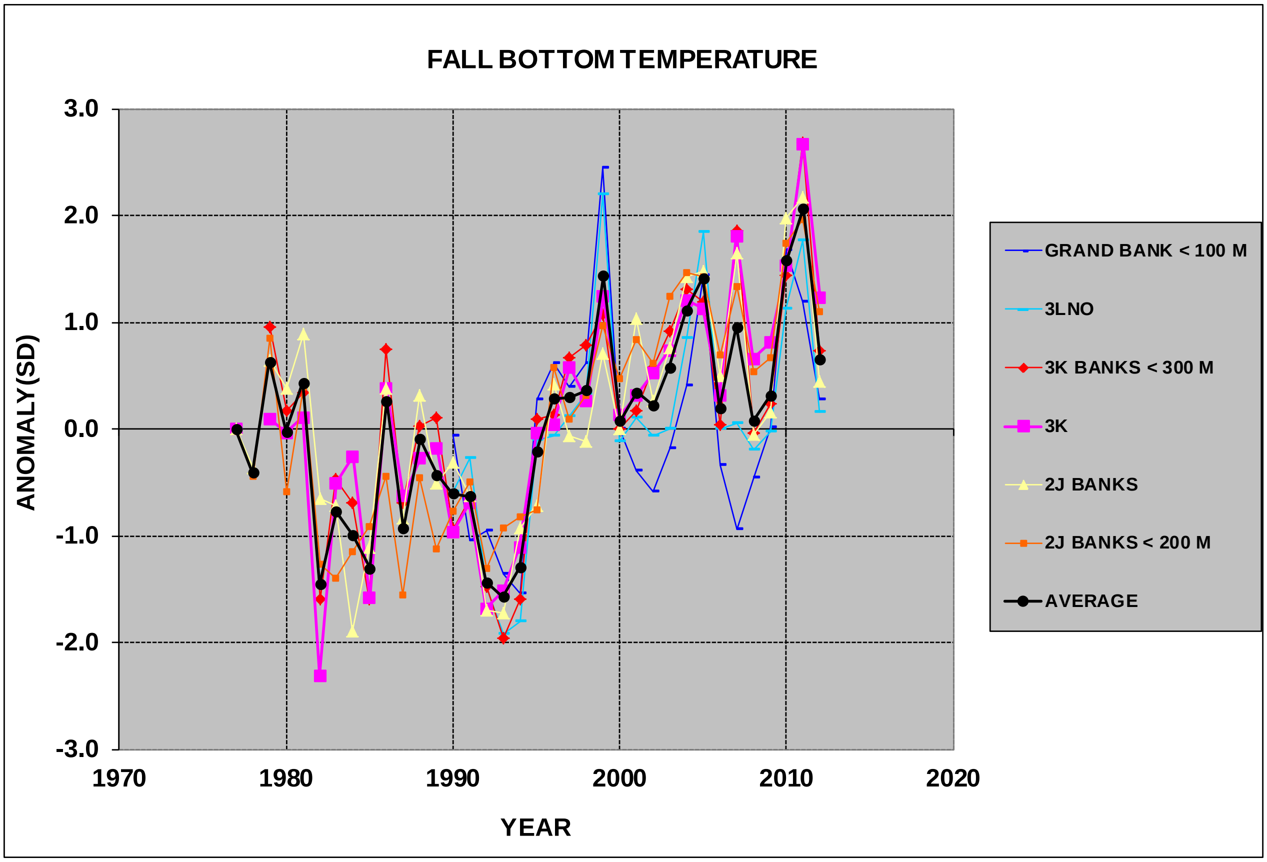

Figure 39. Bottom temperature anomalies from the fall multi-species surveys in NAFO Divisions 2J3KLNO.

REGION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	BOTTOM TEMPERATURES	-0.8	-0.5	-1.3	-0.9	-0.8	-0.8	0.6	0.1	0.3	1.0	0.5	0.8	0.6	1.2	1.5	1.4	0.7	1.3	0.5	0.7	1.7	2.0	1.1
NAFO DIV. 2J	BOTTOM TEMPERATURES < 200 M	-0.3	-0.6	-1.7	-1.7	-0.9	-0.7	0.4	-0.1	-0.1	0.7	0.0	1.0	0.3	0.8	1.4	1.5	0.5	1.7	0.0	0.2	2.0	2.2	0.4
FALL	THERMAL HABITAT AREA >2°C	-1.0	-0.7	-1.1	-0.8	-0.6	0.0	0.3	0.4	0.2	0.6	0.0	0.8	0.5	0.9	1.3	1.7	0.1	2.0	-0.2	0.3	2.4	2.8	0.4
	THERMAL HABITAT AREA <1°C	0.7	0.7	1.4	1.2	0.7	0.2	-0.3	-0.5	-0.6	-1.3	-0.2	-0.9	-0.3	-1.4	-1.4	-1.4	-0.2	-1.4	-0.5	-0.5	-1.4	-1.4	-0.9
	BOTTOM TEMPERATURES	-1.0	-0.7	-1.7	-1.5	-1.1	0.0	0.0	0.6	0.3	1.2	0.1	0.3	0.5	0.7	1.2	1.1	0.3	1.8	0.7	0.8	1.5	2.7	1.2
NAFO DIV. 3K	BOTTOM TEMPERATURES < 300 M	-0.9	-0.7	-1.5	-2.0	-1.6	0.1	0.1	0.7	0.8	1.1	0.0	0.2	0.6	0.9	1.3	1.2	0.0	1.9	0.0	0.2	1.4	2.7	0.7
FALL	THERMAL HABITAT >2°C	-1.4	-0.5	-1.6	-1.5	-1.1	0.0	0.1	0.7	0.7	1.4	0.4	0.2	0.8	0.8	0.9	1.2	0.3	1.7	0.4	0.3	1.6	2.3	0.8
	THERMAL HABITAT AREA <1°C	1.2	0.8	1.1	1.4	0.6	-0.5	-0.3	-0.4	0.0	-0.9	0.2	0.0	-0.5	-0.5	-1.7	-1.3	0.3	-1.9	0.4	-0.6	-1.7	-1.9	-0.8
	BOTTOM TEMPERATURES	-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3	2.2	-0.1	0.1	-0.1	0.0	0.8	1.8	0.0	0.1	-0.2	0.0	1.1	1.8	0.2
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6	2.4	0.0	-0.4	-0.6	-0.2	0.4	1.4	-0.3	-0.9	-0.5	0.0	1.7	1.2	0.3
FALL	THERMAL HABITAT AREA >2°C	-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5	0.4
	THERMAL HABITAT AREA <0°C	0.4	1.4	1.5	1.8	1.7	-0.7	-0.1	0.3	-0.5	-1.3	0.6	-0.1	-0.6	0.0	-1.4	-1.1	-1.3	-0.1	0.6	-0.1	-1.1	-2.3	-0.1
NAFO DIV 2J3KL	CIL VOLUME (FALL)	1.1	1.2	1.6	1.7	0.9	-0.2	-0.7	-0.7	-0.4	-1.7	-0.3	-0.6	-0.4	-0.6	-1.4	-0.7	-0.4	-0.8	-0.2	-1.0	-1.1	-1.1	-0.1

Figure 40. Temperature indices derived from data collected during fall multi-species survey. The anomalies are normalized with respect to their standard deviations.

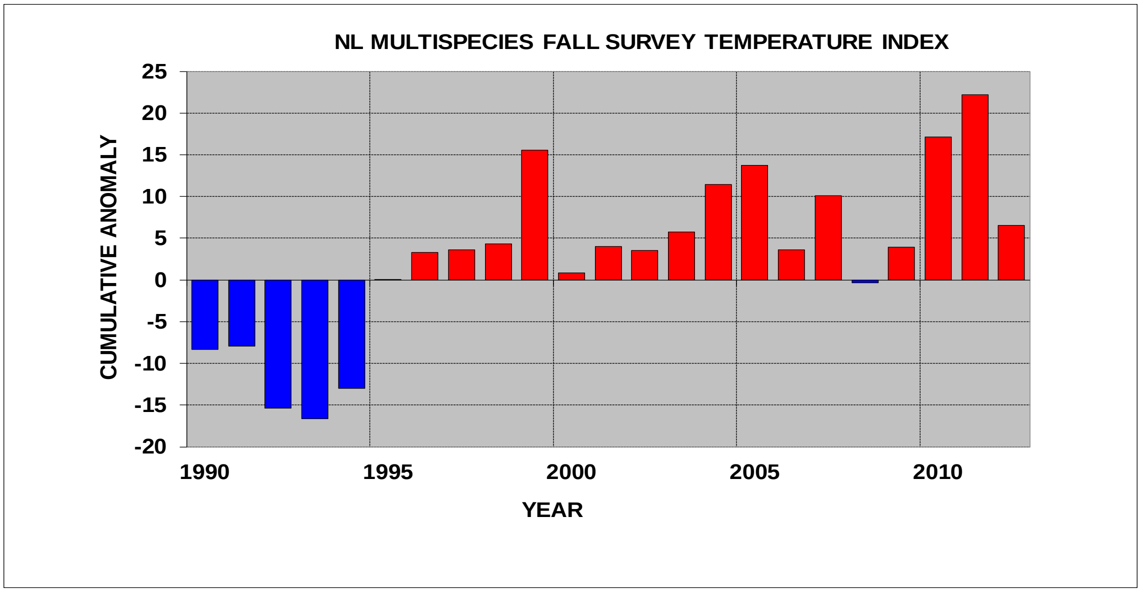

Figure 41. Composite temperature index derived by summing the standardized anomalies from Figure 40.

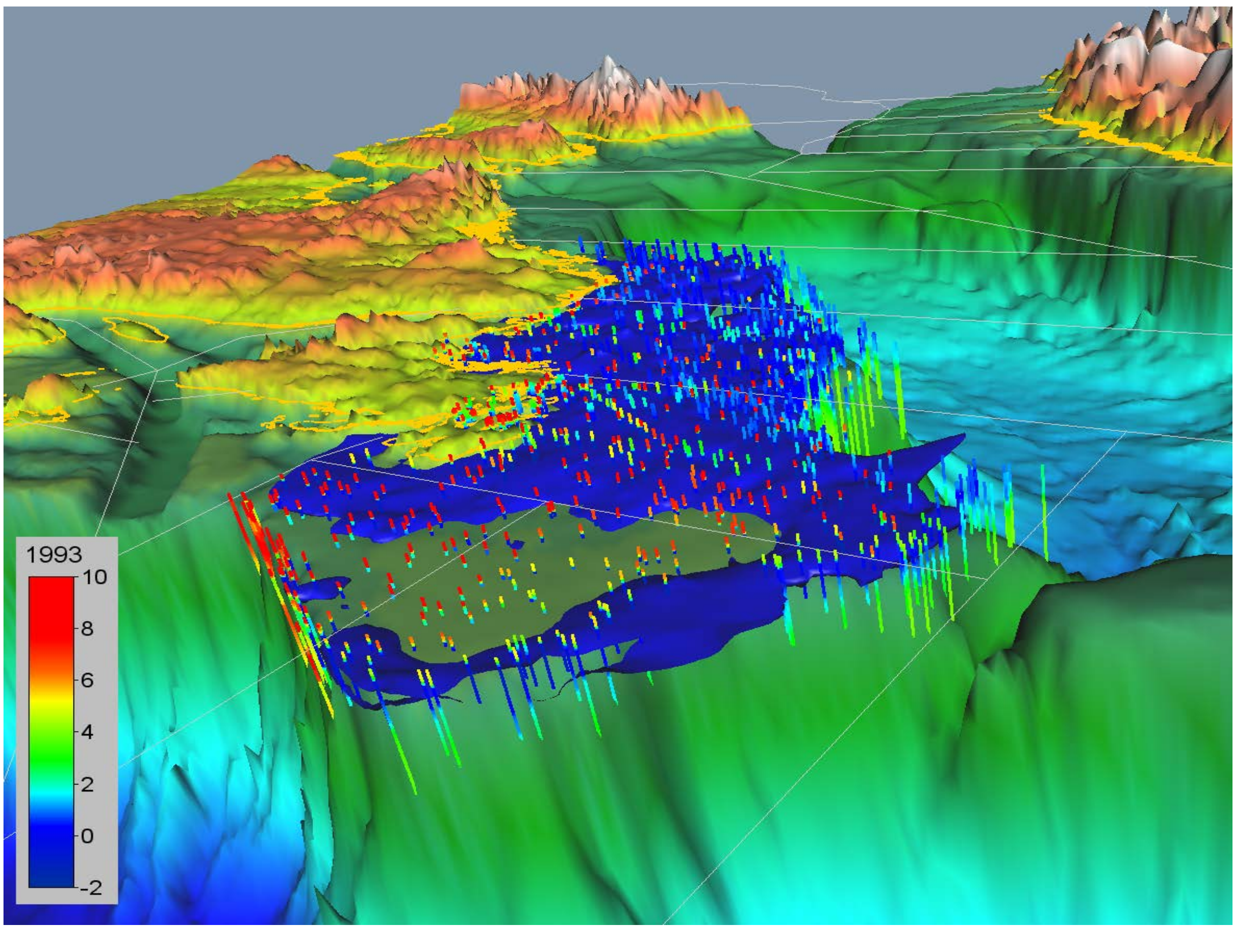

Figure 42. A 3D rendering of the CIL (<0^{O}C) water mass on the NL shelf during 1993 (a cold year) derived from the fall multi-species trawl-mounted CTD data. The vertical lines are the colour-coded temperature profile data. The outline of NAFO sub-areas (Figure 1) are shown by the white lines.

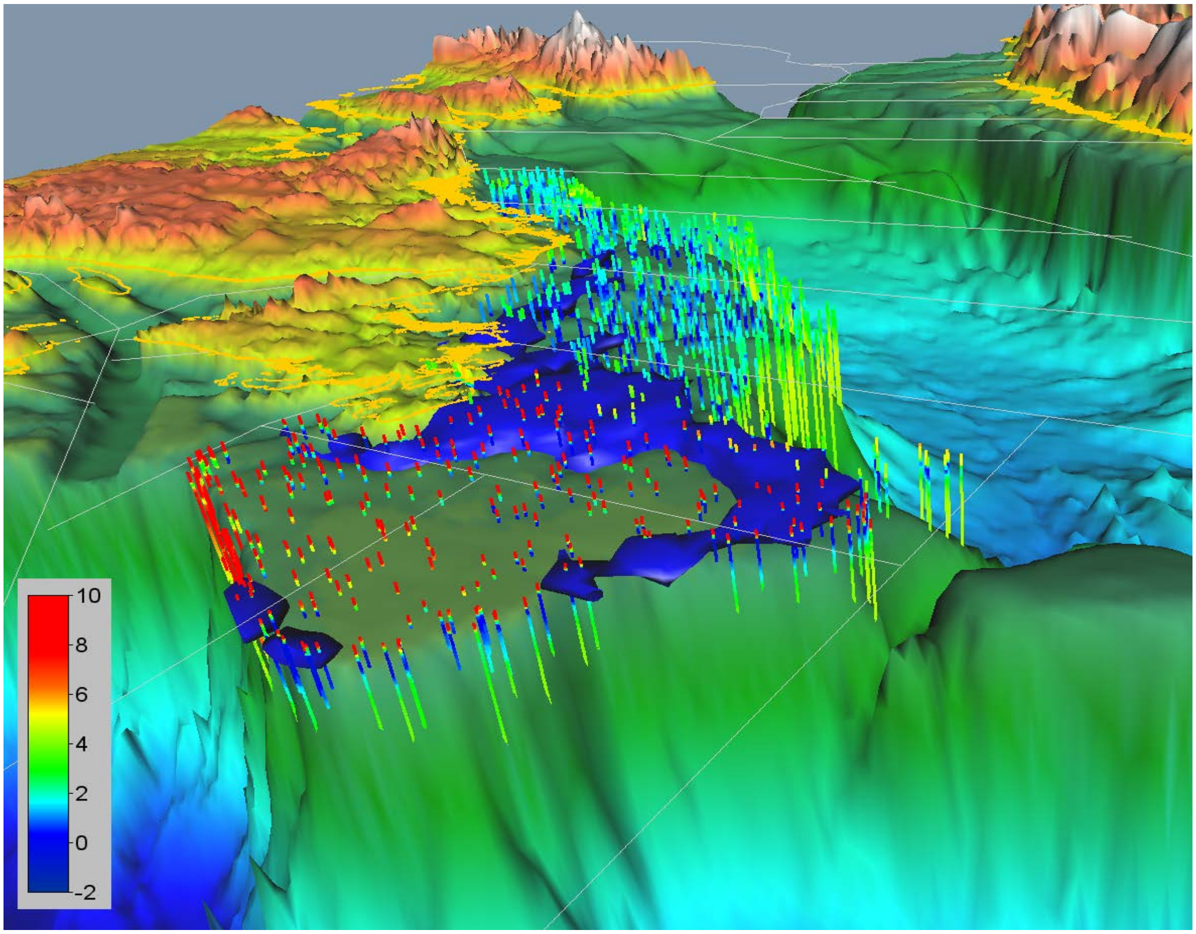

Figure 43. A 3D rendering of the CIL (<0^{O}C) water mass on the NL shelf during 2012 (a normal year) derived from the fall multi-species trawl-mounted CTD data. The vertical lines are the colour-coded temperature profile data. The outline of NAFO sub-areas (Figure 1) are shown by the white lines.

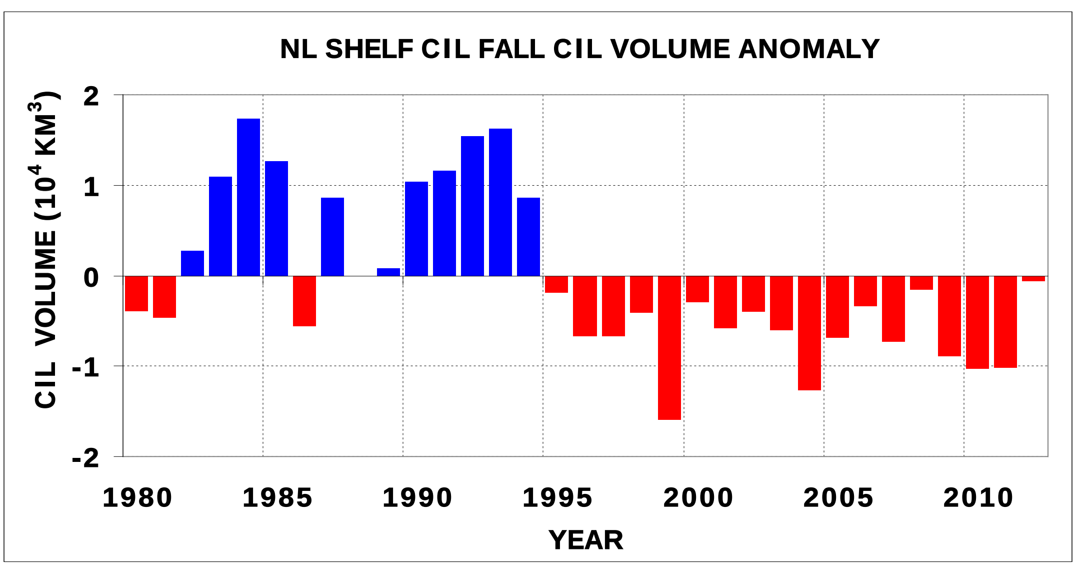

Figure 44. Time series of the CIL (<0^{O}C) volume anomaly on the NL shelf bounded by NAFO Divisions 2J3KL based on the fall multi-species temperature data profiles.

SUMMARY

A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2012 are displayed in Figure 45 as colour-coded normalized anomalies. Different climatic conditions are readily apparent from the warm and salty 1960s and early 2000s to the cold-fresh early 1970s, mid-1980s and early 1990s.

Following Petrie et al. (2007) a mosaic or composite climate index was constructed from the 26 time series as the sum of the standardized anomalies with each time series contribution shown as stacked bars (Fig. 46).

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

The overall composite index clearly defines the cold/fresh conditions of the 1970s, 1980s and early 1990s, the recent increasing trend that peaked in 2006 and the 3 years of relatively cooler conditions of 2007-09. In 2010 the composite index increased sharply to the 2nd highest in the 63-year time series. In 2011 it was very similar to 2010, the 4th highest in 63 years but in 2012 it had decreased to the 8th highest.

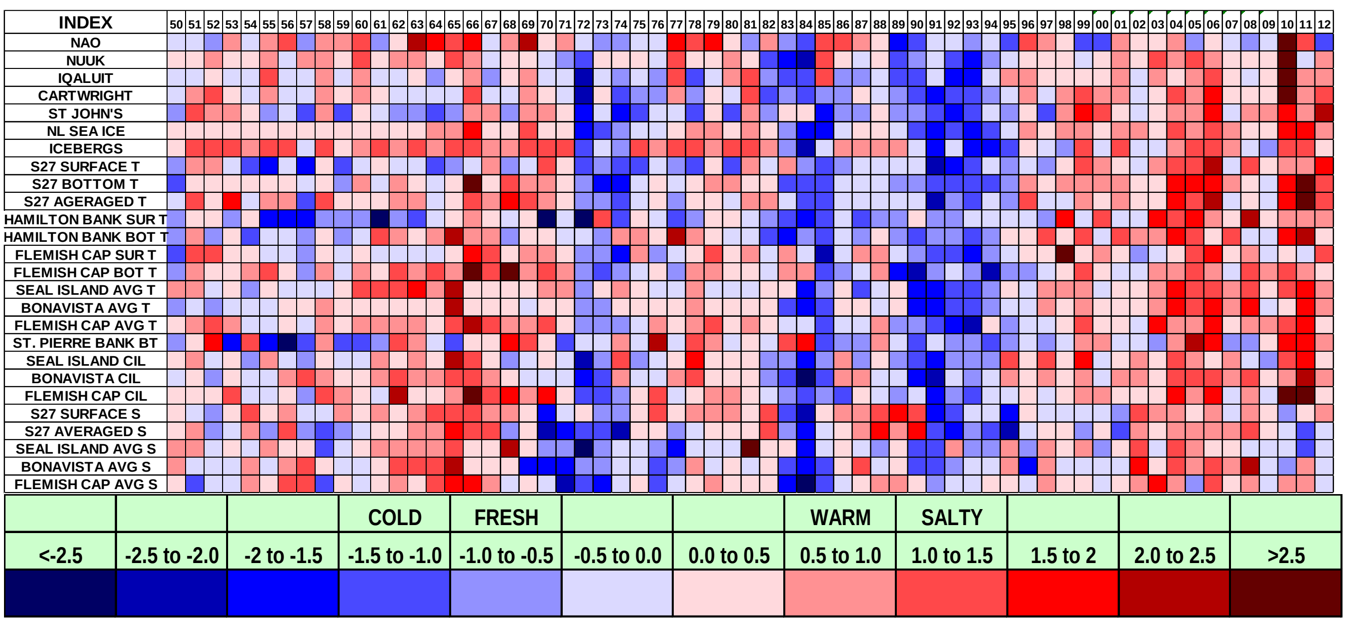

Figure 45. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Figure 4. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010.

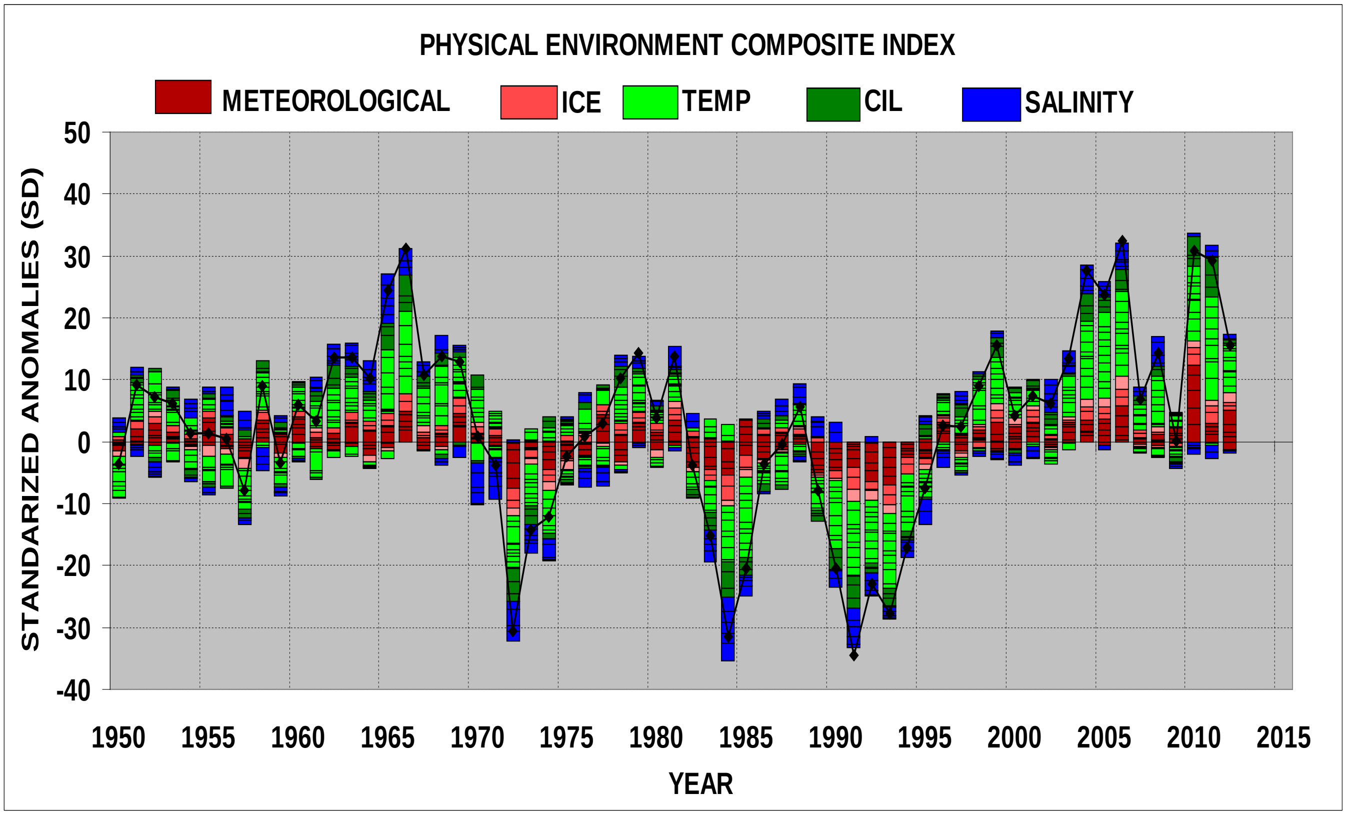

Figure 46. Composite climate index derived by summing the standardized anomalies from Figure 45 together with their individual components.

SUMMARY POINTS FOR 2012

- The North Atlantic Oscillation index, a key indicator of climate conditions on the Newfoundland and Labrador Shelf, increased to 1.3 SD above normal in 2012, the highest since 1989.
- Arctic air outflow during the winter increased over the previous year causing a significant decrease in winter air temperatures over much of the Labrador Sea and adjacent areas.
- Annual air temperatures however remained above normal at Labrador by 1.4 SD (1.8 °C at Cartwright) and Newfoundland by 2.3 SD (1.9 °C at St. John's).
- The annual sea ice extent on the NL Shelf remained below normal (0.7 SD) for the 17th consecutive year, an increase of 1 SD over the record low in 2011.
- 499 icebergs were detected south of 48^{o}N on the Northern Grand Bank, compared with 3 in 2011, still substantially fewer than the 1981-2010 mean of 767.
- Sea surface temperatures (SST) attained record highs in many areas throughout the region reaching 2 SD above normal in some areas.
- Annual surface temperatures at Station 27 increased to 1.5 SD (1 °C) above normal the 2nd highest on record.
- Bottom temperatures (176 m) at Station 27 however decreased to 1.1 SD (0.4 °C) down from the record high of 3.4 SD (1.3 °C) in 2011.

- At Station 27, the depth-averaged annual water temperature decreased to 1 SD (0.4 °C) above normal from the record high of 3 SD (1 °C) in 2011.
- The annual depth-averaged salinities at Station 27 were near the long-term mean.
- The area of the CIL (<0 °C) on the eastern Newfoundland Shelf (Bonavista Section) during 2012 increased to 0.5 SD below normal from the record low value at 2 SD below normal in 2011.
- Spring bottom temperatures in NAFO Divs. 3Ps and 3LNO during 2012 were above normal by an average of about 1 °C, a moderate decreased over 2011 conditions.
- During the fall, bottom temperatures in 2J, 3K and 3LNO decreased from 2, 2.7 and 1.8 SD above normal in 2011 to 1.1, 1.2 and 0.2 SD above normal in 2012 respectively, a significant decrease.
- The volume of CIL (<0 °C) water on the NL shelf during the fall was close to normal.
- A composite climate index decreased to the 8^{th} highest in the 63 year time series from the 4^{th} highest in 2011.

ACKNOWLEDGMENTS

We thank the many scientists and technicians at the Northwest Atlantic Fisheries Centre for collecting and providing much of the data contained in this analysis and to the national Integrated Scientific Data Management (ISDM) branch in Ottawa for providing most of the historical data and Environment Canada for meteorological data. We thank Ingrid Peterson at the Bedford Institute of Oceanography for providing the NL Shelf monthly sea ice data. We also thank the captains and crews of the CCGS Teleost and Hudson for three successful oceanographic surveys during 2012. We also thank David Hebert and Peter Galbraith for reviewing the document.

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