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Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2016

by

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ABSTRACT

Oceanographic and meteorological observations in NAFO Sub-areas 2 and 3 during 2016 are presented referenced to their long-term (1981-2010) means. 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 (SST based on infrared satellite imagery) trends on the northeast Newfoundland Shelf while showing an increase of about 1°C 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 by -0.7/-1.4 SD, respectively in 2016. 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 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°C 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 7th lowest in 67 years and the lowest value since 1993. Data from 2016 show a return to above normal conditions.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in in NAFO sub-areas 2 and 3 on 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 environmental conditions on the Scotian Shelf, the Flemish Cap, Northeast US Shelf, the Labrador Sea and West Greenland Waters as part of the Scientific Council's annual review of environmental conditions in the NAFO Convention Area. 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 2016 is derived from four main sources: (1) observations made at a monitoring location in NAFO Sub-area 3 off St. John's, NL (Station 27) throughout the year; (2) measurements made during the summer along standard NAFO and Atlantic Zone Monitoring Program (AZMP) (Therriault et al. 1998) cross-shelf sections (Figure 2, left panel); (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Figure 2, right panel); and(4) SST data based on infrared satellite imagery of the Northwest Atlantic (Figure 12).

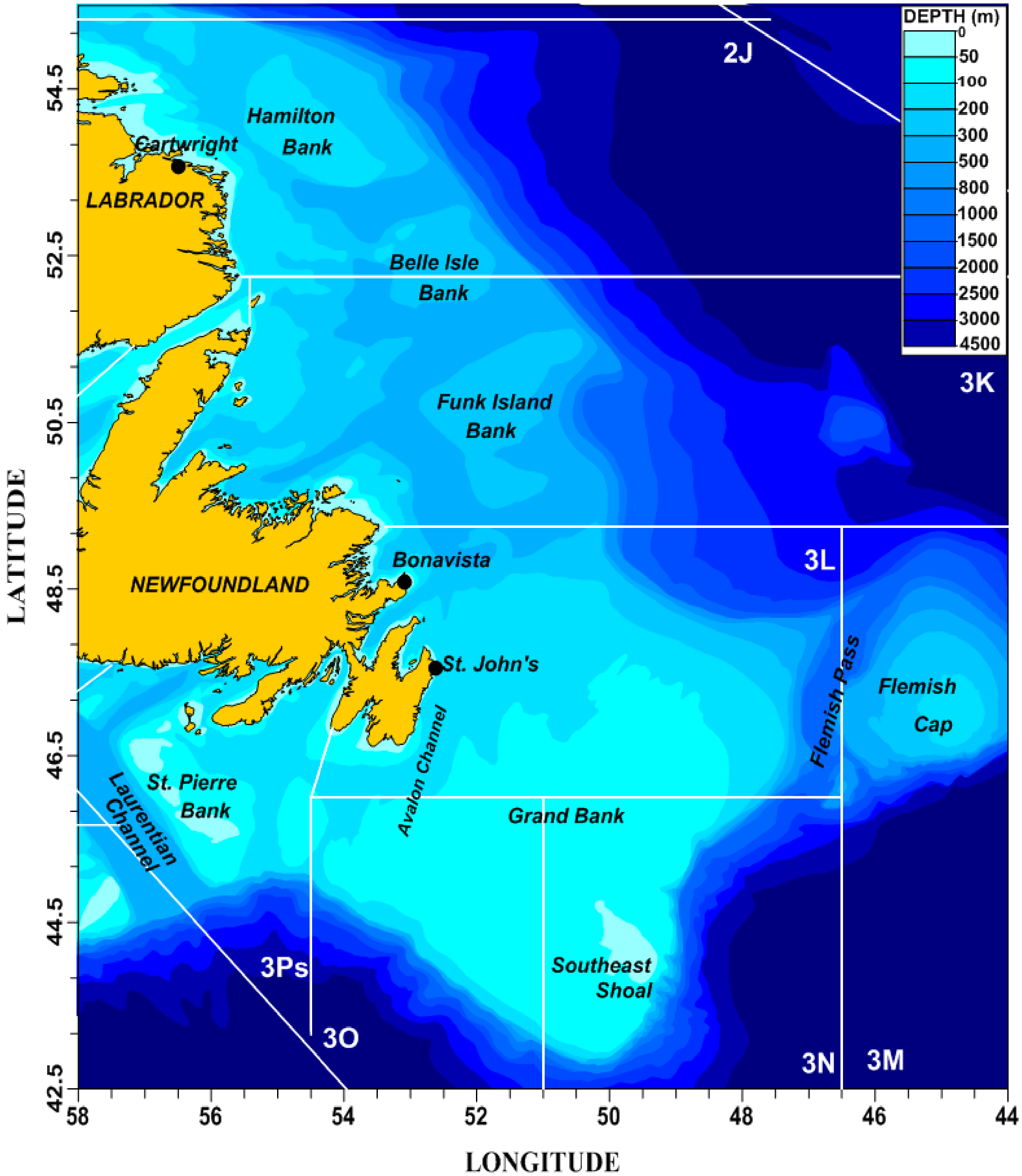


Fig. 1. Map showing NAFO Divisions and main bathymetric features of the Newfoundland and southern Labrador Shelf.

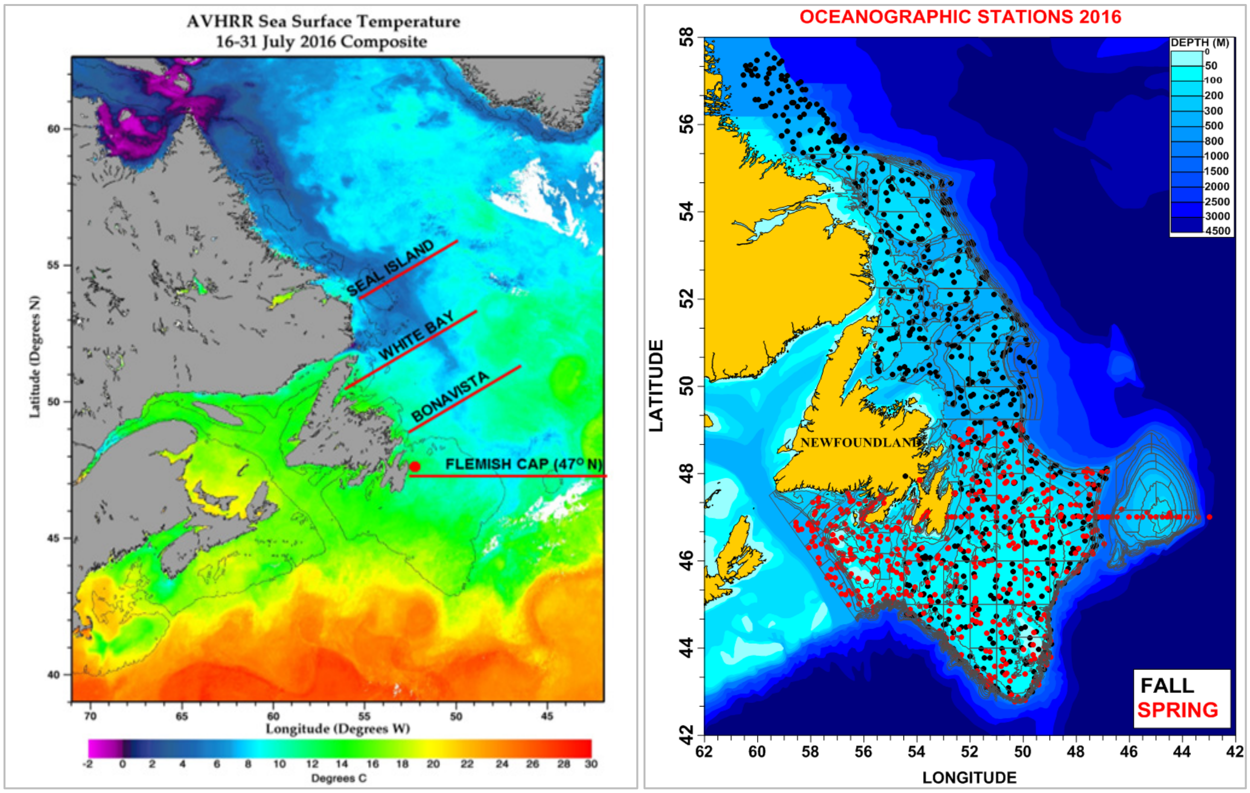


Fig. 2. Map showing summer NAFO/AZMP section occupations along with Sea-Surface-Temperature (SST) during 2016. The right panel shows the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during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

These data are available from archives at the Fisheries and Oceans Ocean Science Branch (OSB) Branch in Ottawa and maintained in a regional data archive at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL.

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

The normalized values of water properties and derived climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2016 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 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. 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.

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

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

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 in 2015. 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 NAFO convention area in 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 in terms of 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

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

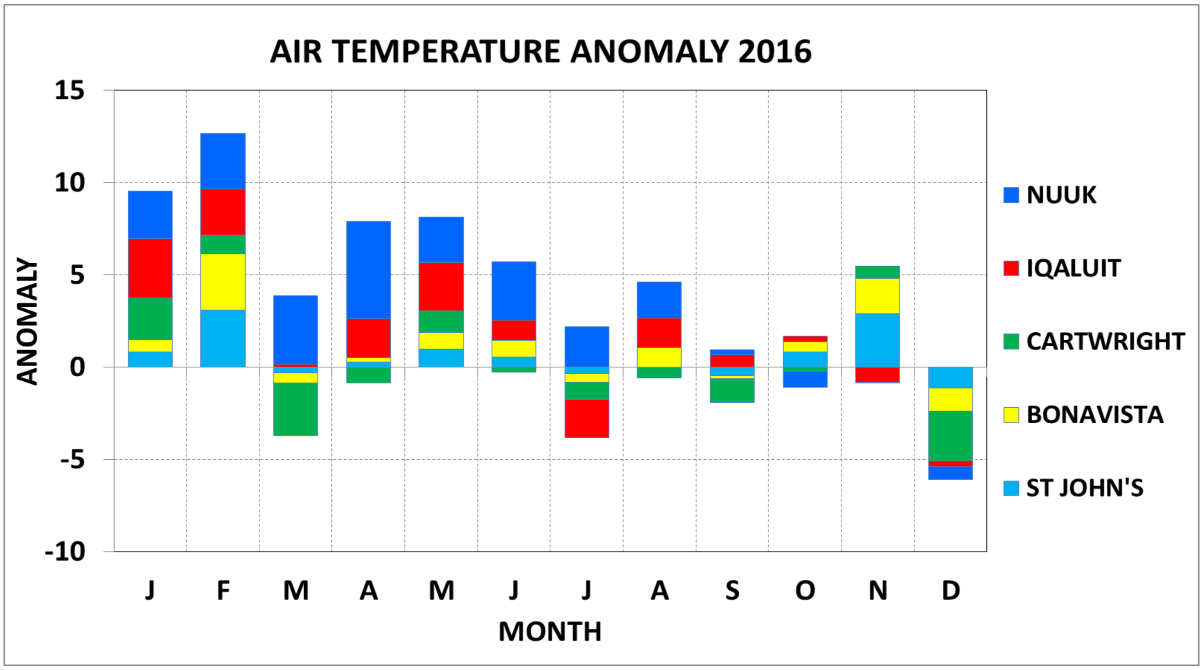


Fig. 5. Cumulative monthly air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's for 2016.

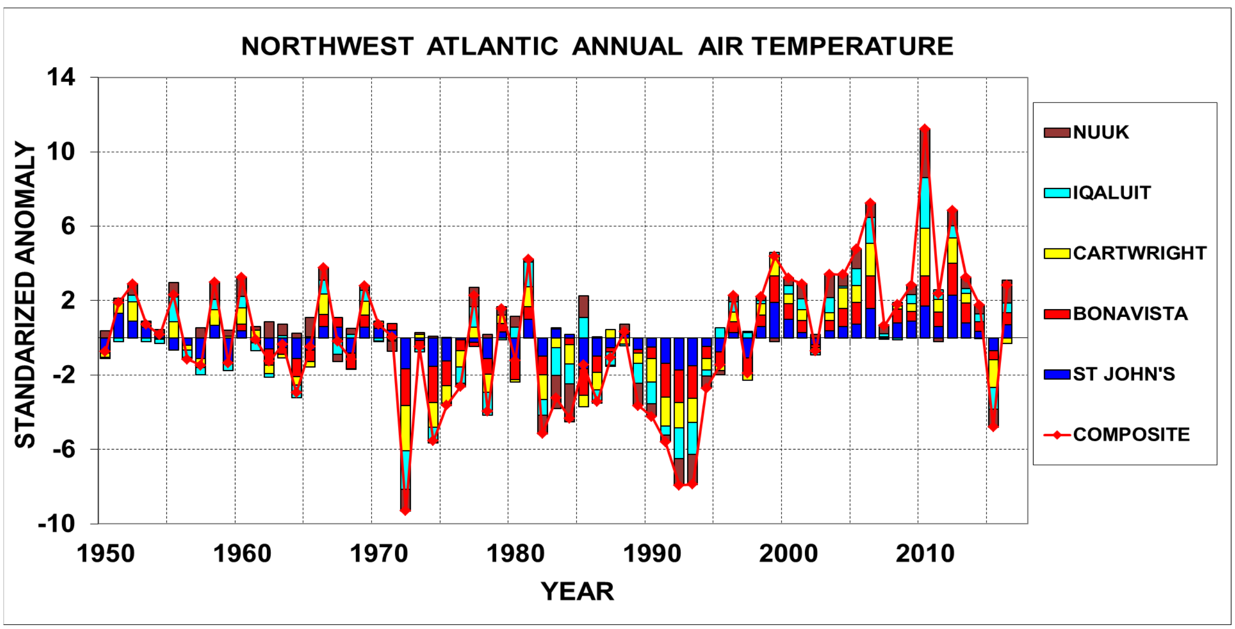


Fig. 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

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 below normal again in 2016 (Figures 4 and 7). In 2011 sea ice extent decreased to 49-year record low of -1.7 SD. Monthly values during 2016 shows below normal conditions during January and February but about normal during the remainder of the ice season (Figure 8).

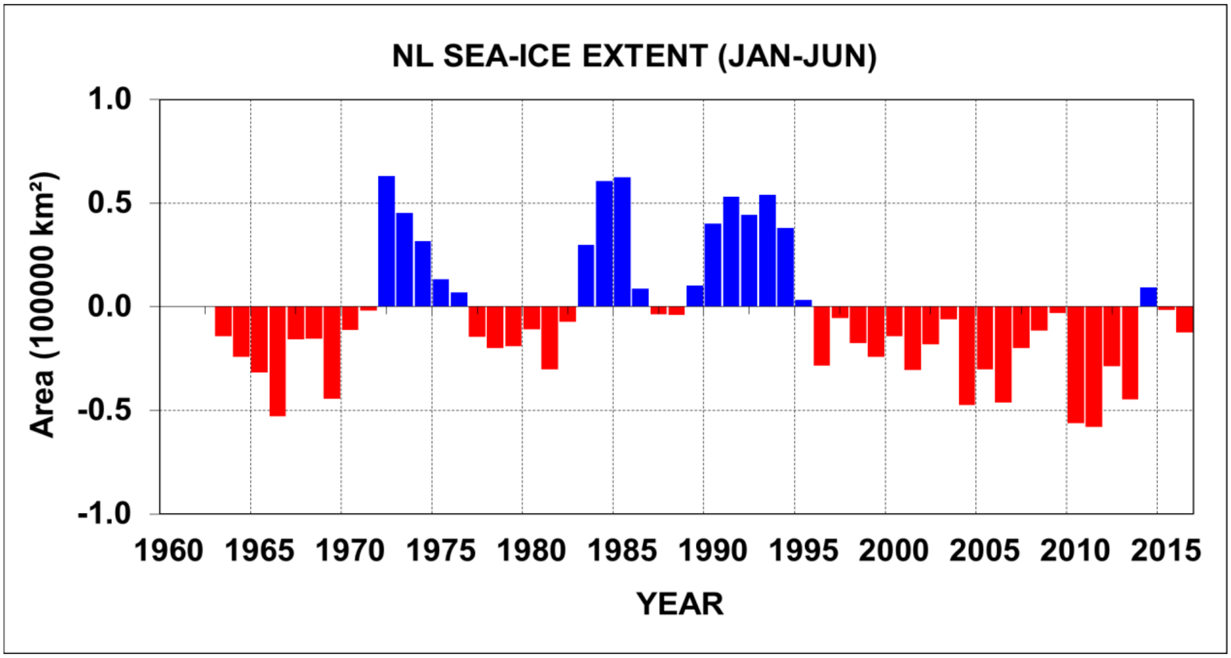


Fig. 7. Annual sea ice extent (defined by 1/10 coverage) anomalies on the NL Shelf between 45-55°N latitude.

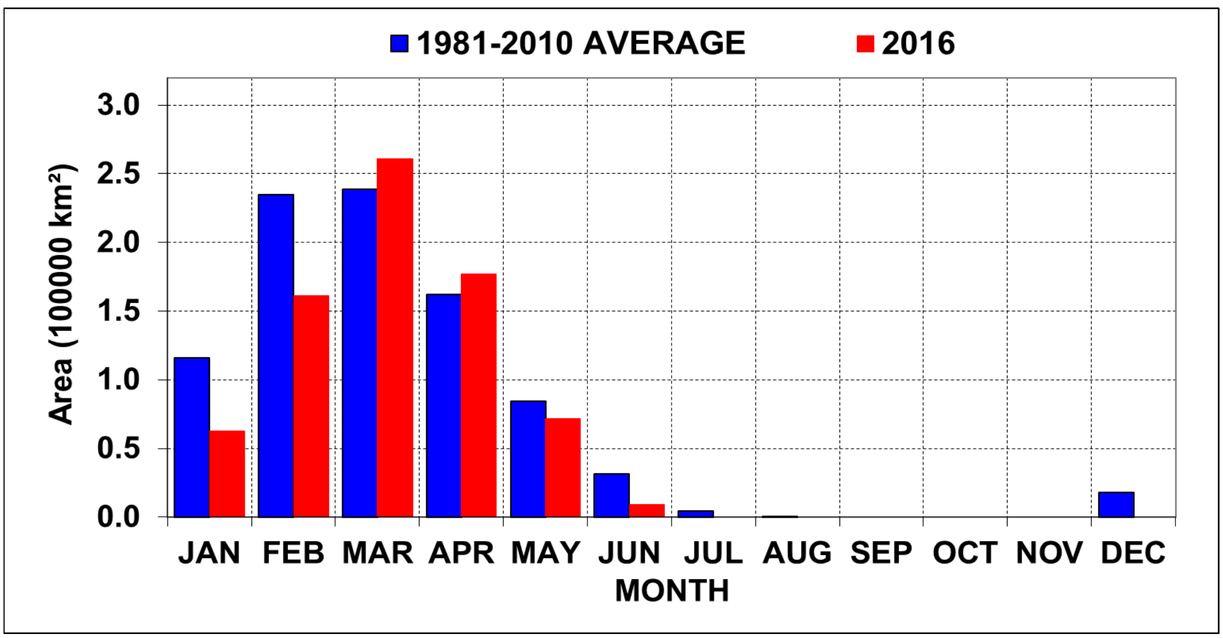


Fig. 8. Monthly sea ice extent (defined by 1/10 coverage) on the NL Shelf between 45-55°N latitude.

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 the 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 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 shows 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 below normal conditions similar to 1994 but conditions returned to above normal again during 2016 (Figure 11).

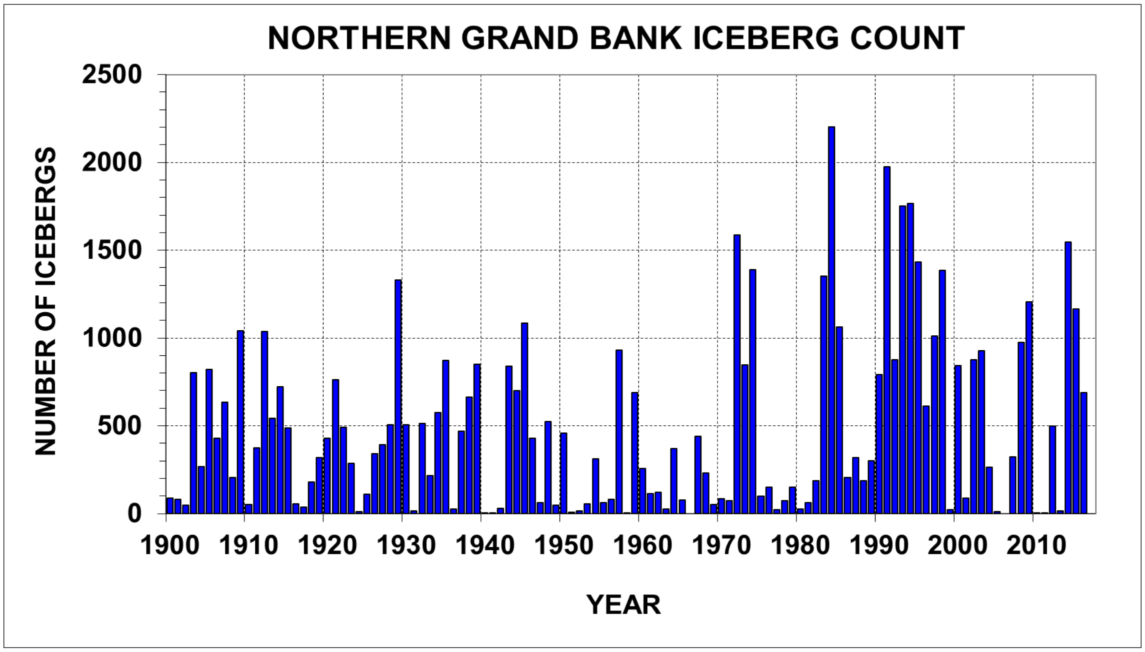


Fig. 9. Annual iceberg count crossing south of 48°N on the northern Grand Bank (data courtesy of IIP of the USCG).

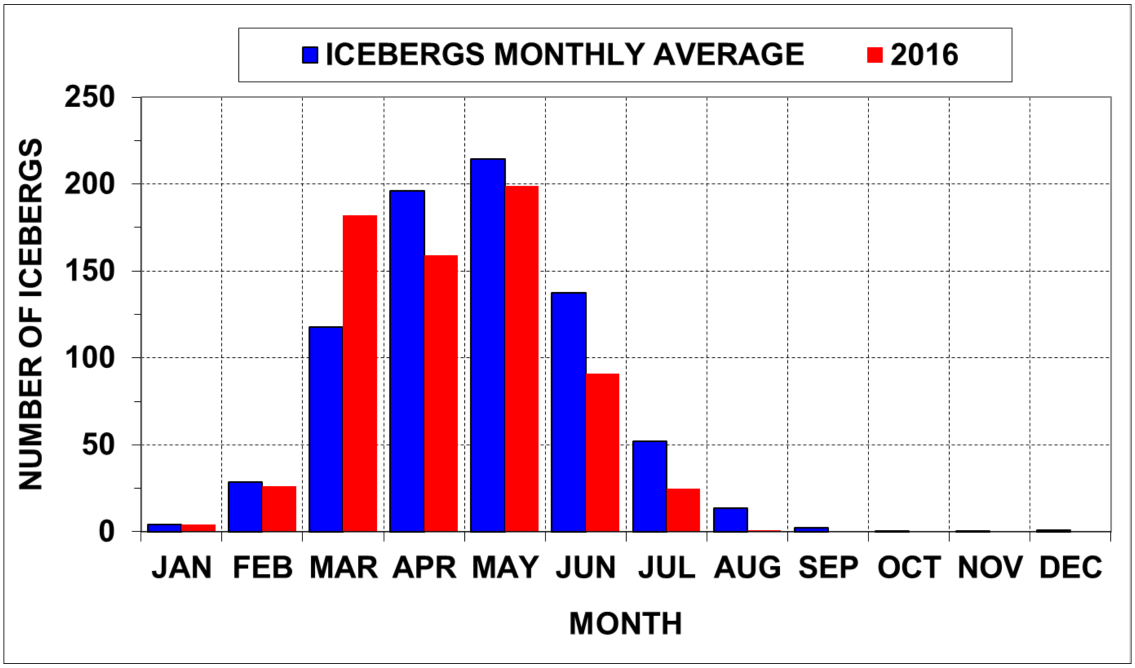


Fig. 10. Monthly iceberg count crossing south of 48°N on the northern Grand Bank (data courtesy of IIP if the USCG).

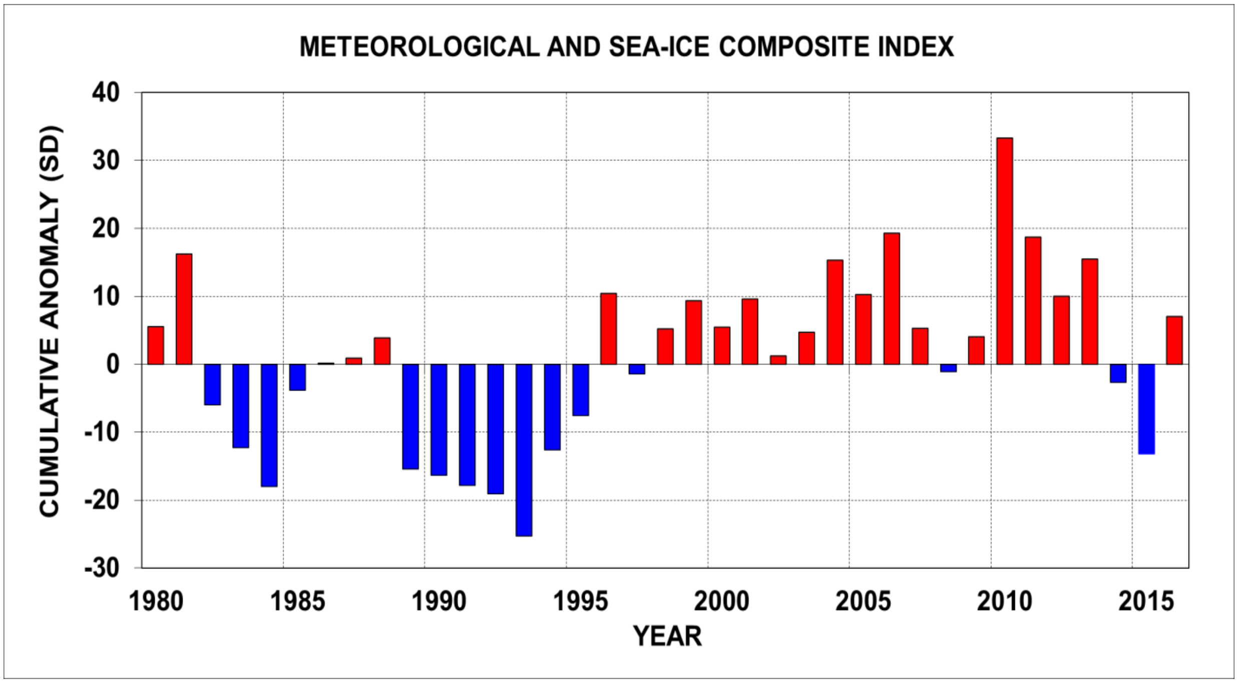


Fig. 11 Meteorological and sea-ice composite index derived by summing the standardized anomalies from Fig. 4.

Satellite Sea-Surface Temperature Conditions

The 4 km resolution Pathfinder 5.2 sea surface temperature (SST) database (Casey et al., 2010) was used to provide annual estimates of the SST within defined 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 (2011-2016) we use data from NOAA and EUMETSAT satellite provided by the remote sensing group in the Marine Ecosystem Section at the Bedford Institute of Oceanography (BIO).

A least squares fit of the Pathfinder and NOAA temperatures during the period (1997-2010) is given by SST (Pathfinder) = 0.989*SST (NOAA) -0.02 with an r^2=0.98 (Hebert et al. 2012). 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 most significant 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 decade. 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).

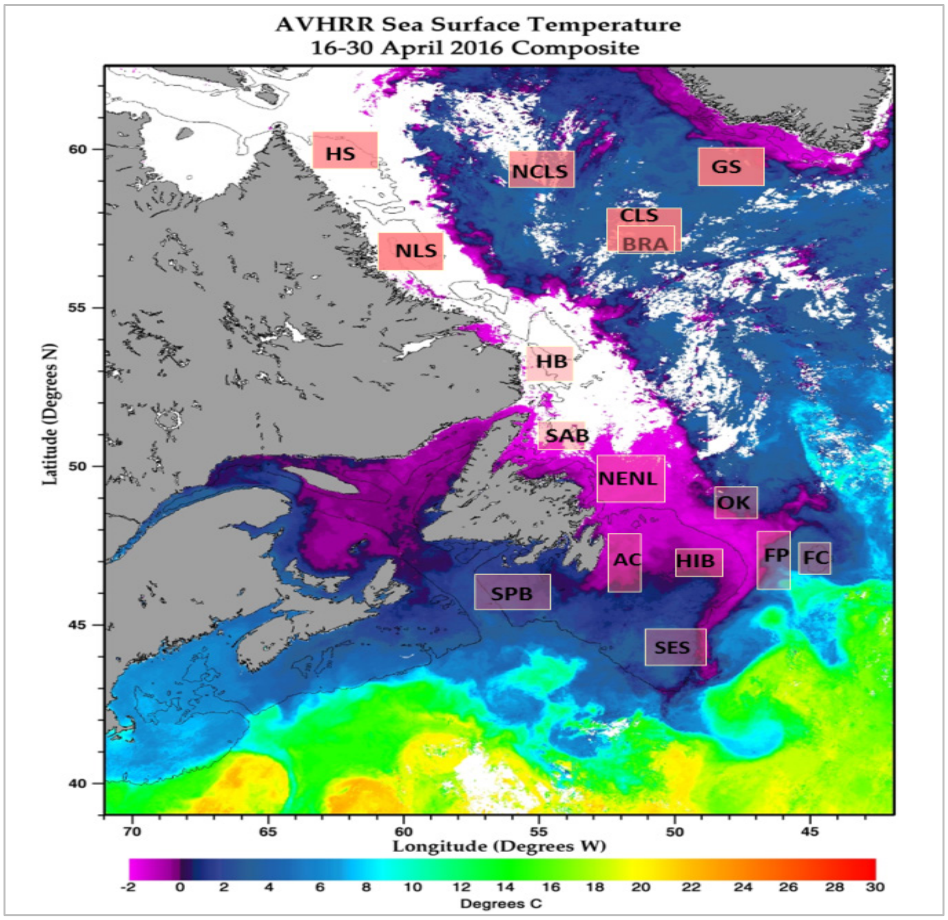


Fig. 12. Map showing the April 16-30 SST and sea-ice extent and the subareas where SST time series were constructed for the Northwest Atlantic. (SST map courtesy of the Marine Ecosystem Section, BIO).

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

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

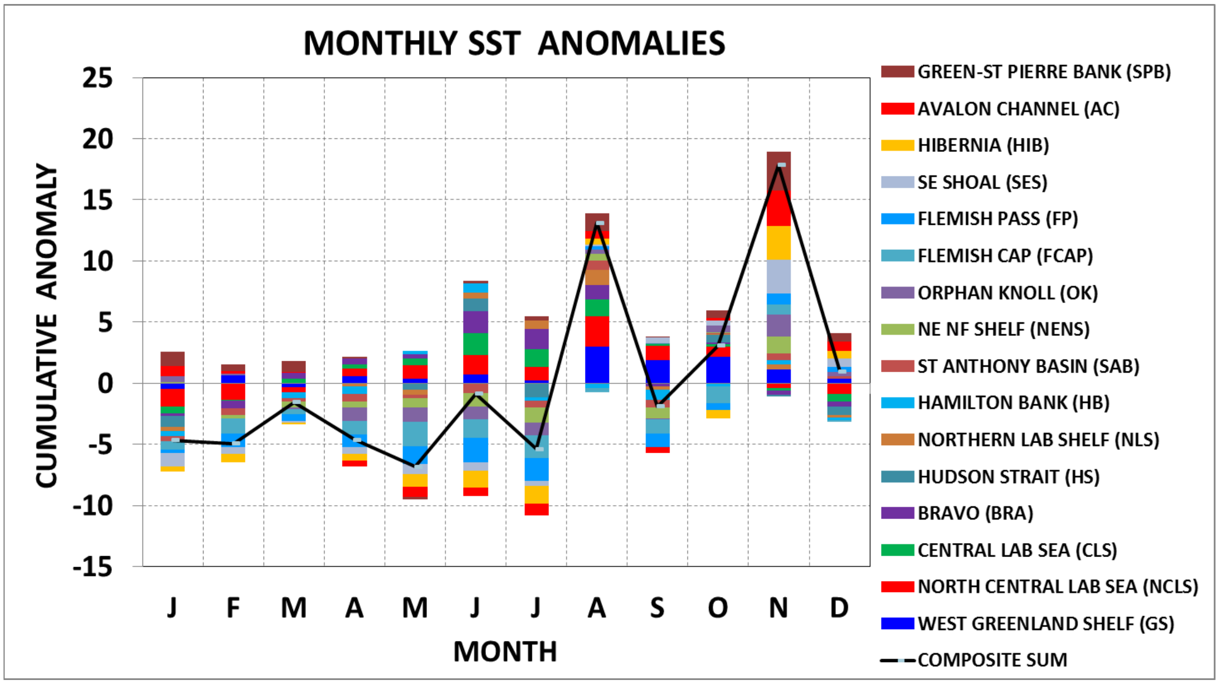


Fig. 14. Cumulative SST anomalies derived from the data within the boxes shown in Fig. 12 and displayed in Fig. 13. The anomalies are referenced to the 1981-2010 base period.

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

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

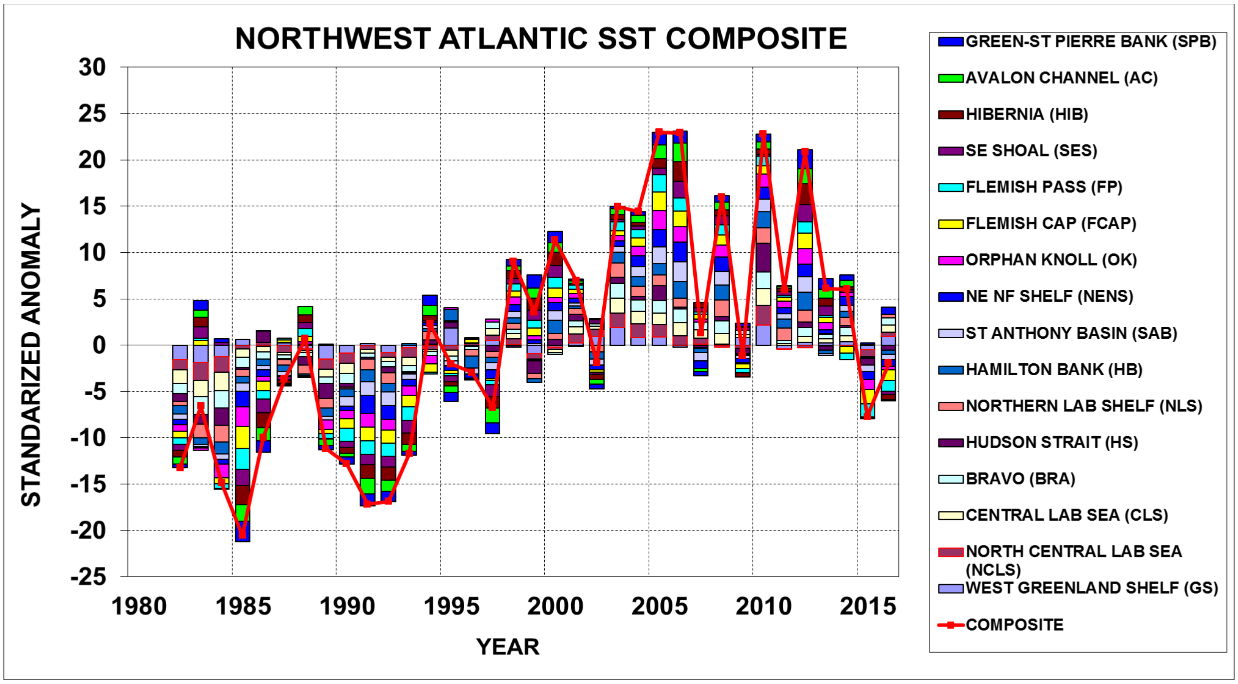


Fig. 16. Standardized annual SST anomalies from the subareas on the NL shelf presented in Fig. 15. The solid red line represents the composite sum.

TRENDS IN TEMPERATURE AND SALINITY AT 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 17 and 18. The temperature data from the mooring deployment are incorporated in the annual cycle in Figure 17.

The water column at Station 27 was near-isothermal ranging in temperature from -1°C to 0.0°C during February to April. These values persisted throughout the year below about 90 m as the cold intermediate layer (CIL) extended to the bottom. 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.

Upper layer salinities (Figure 18) 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 18, bottom panel).

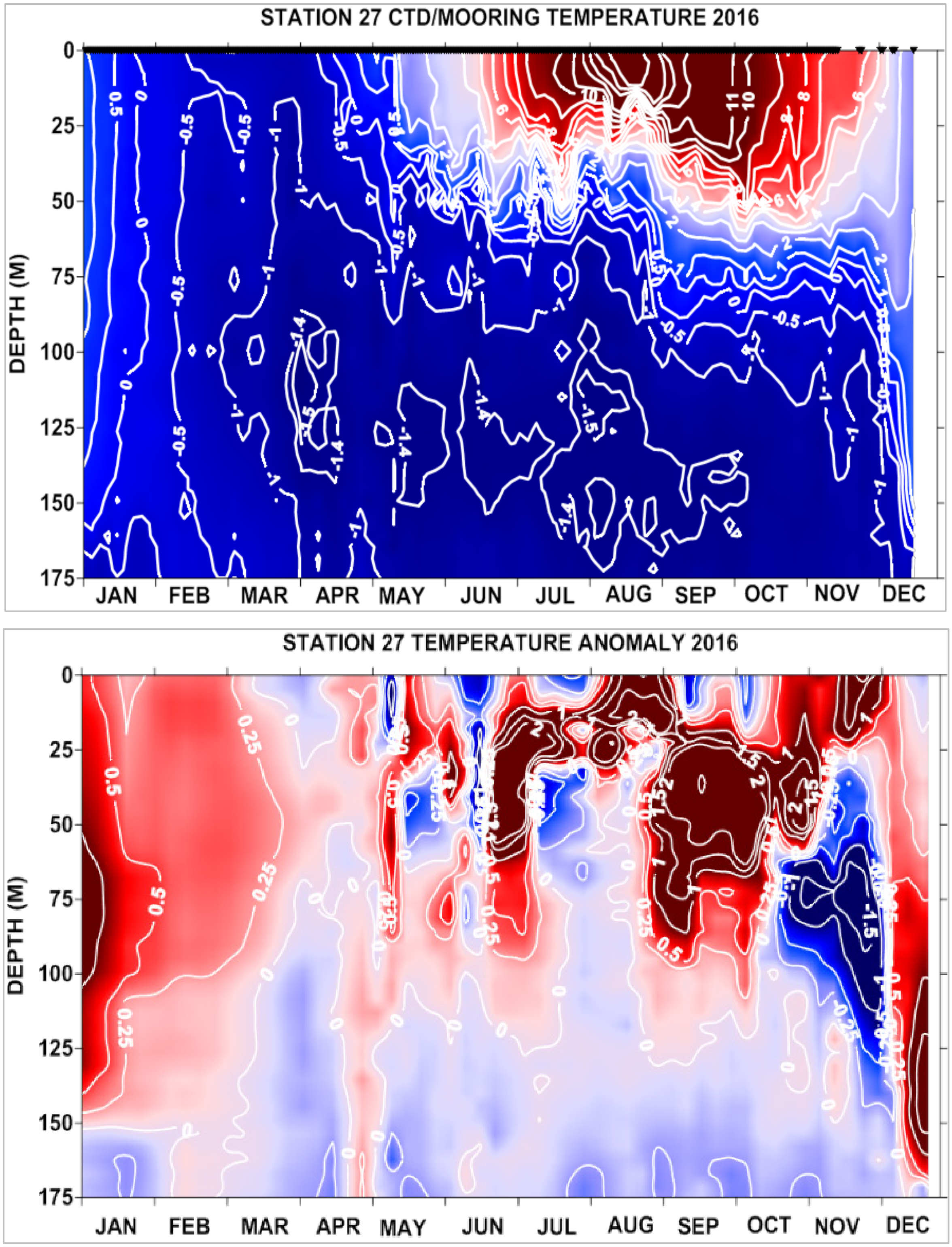
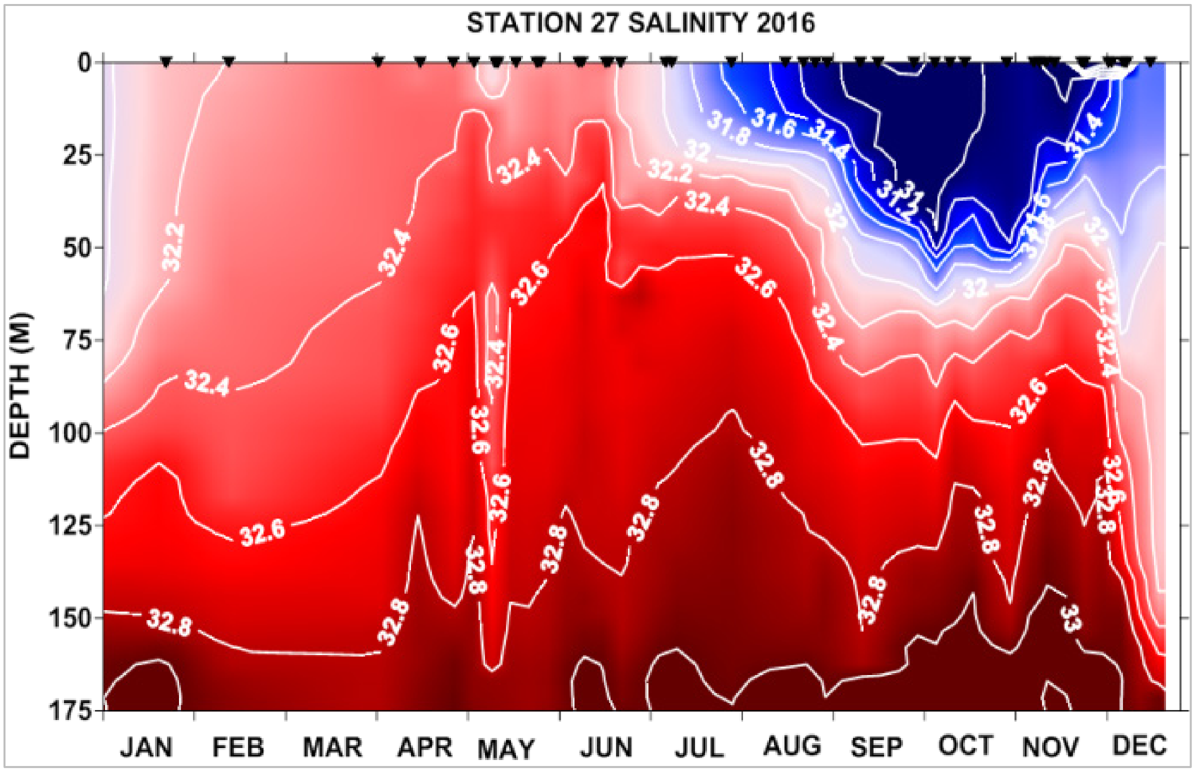


Fig. 17. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2016. The symbols at the top indicate sampling times.



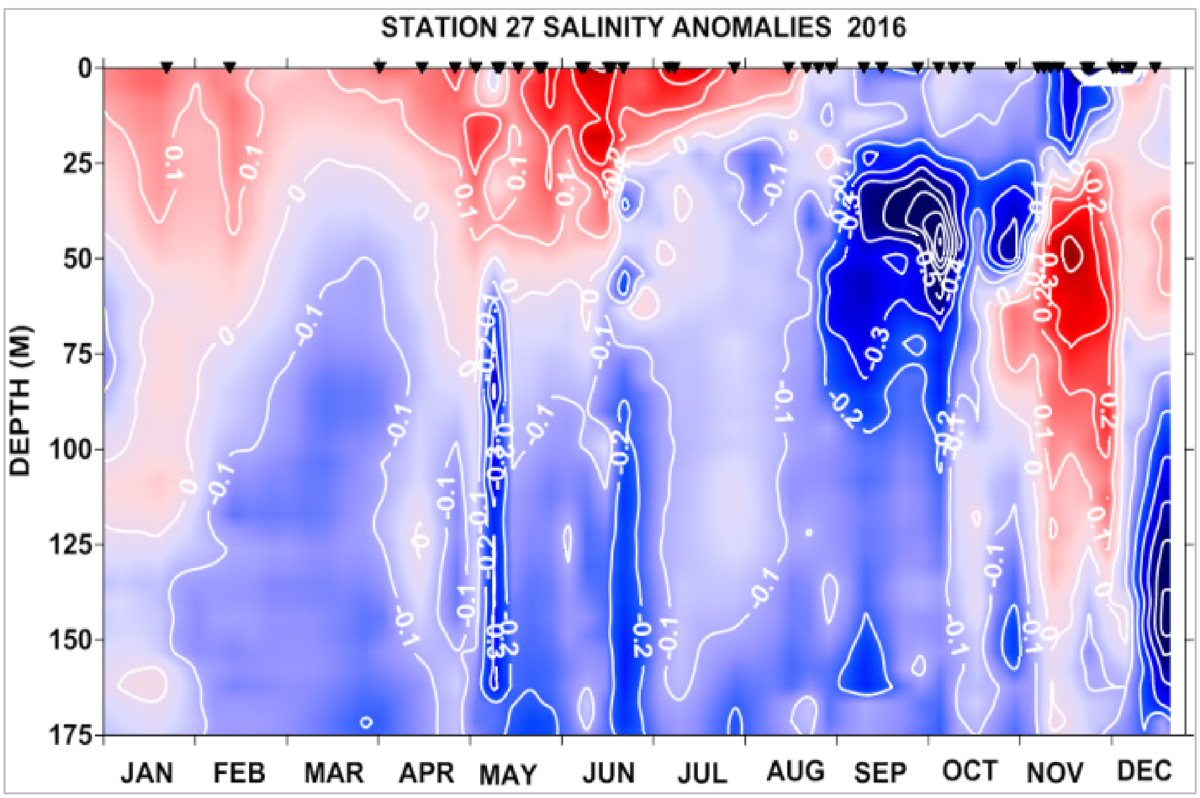


Fig. 18. Contours of salinity and salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2016. The symbols at the top indicate sampling times.

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 19). 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 19). 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 20).

The layer of cold water with temperatures <0°C on most of the NL shelf, commonly referred as the cold intermediate layer (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 20).

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 21). Water column 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 22). 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.

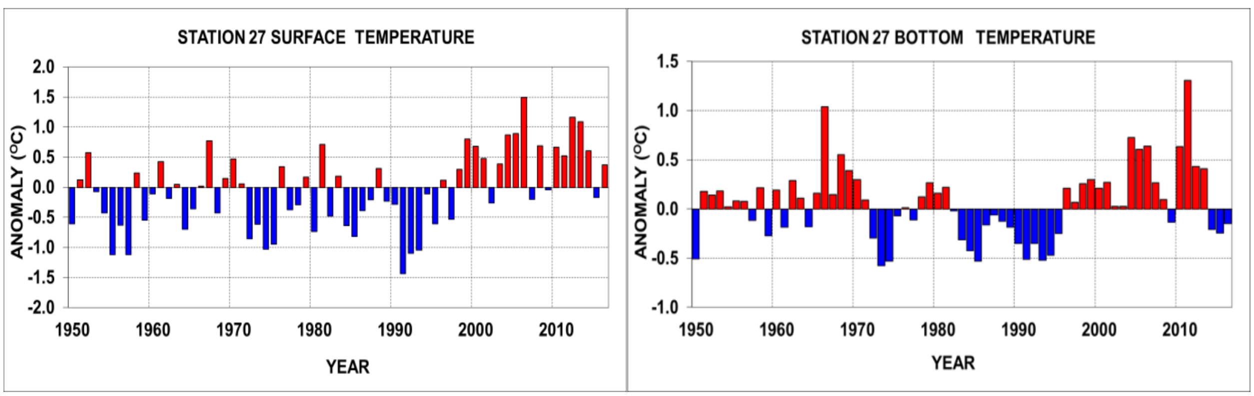


Fig. 19. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean.

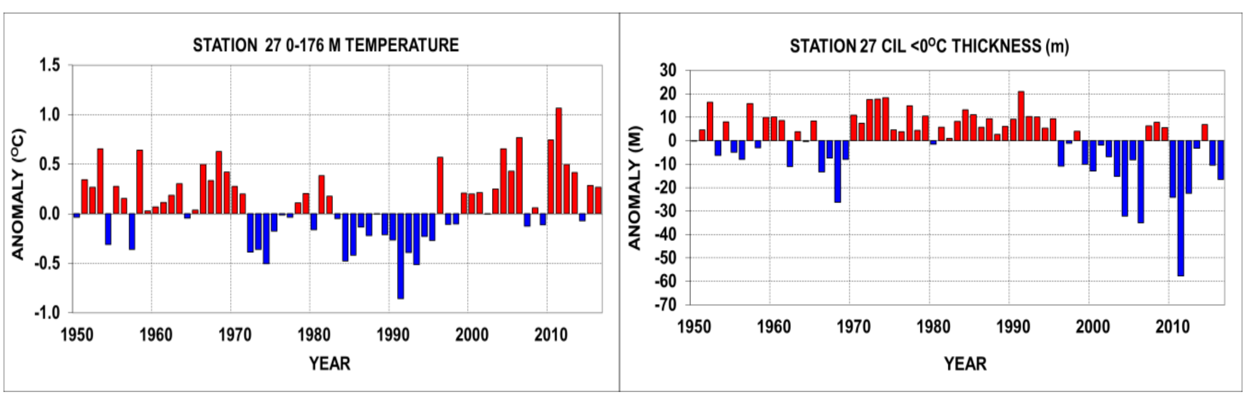


Fig. 20. Annual Station 27 vertically averaged (0-176 m) temperature and CIL (<0°C) thickness anomalies referenced to the 1981-2010 mean.

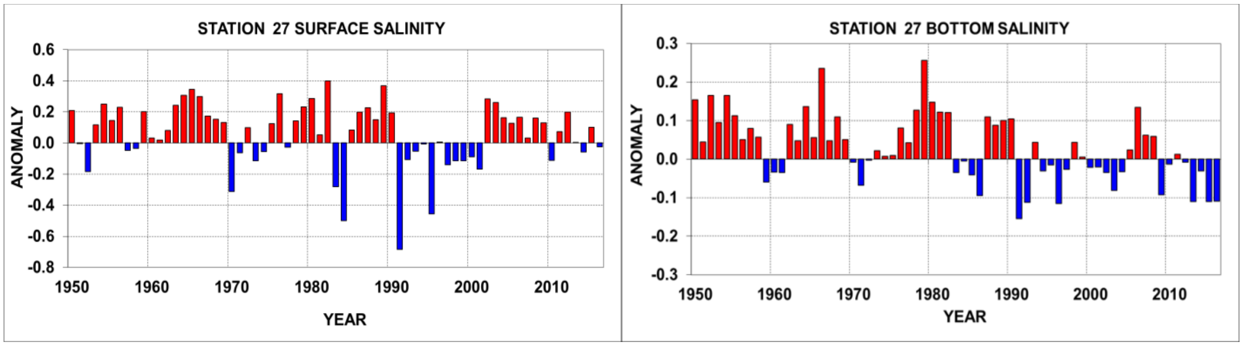


Fig. 21. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean.

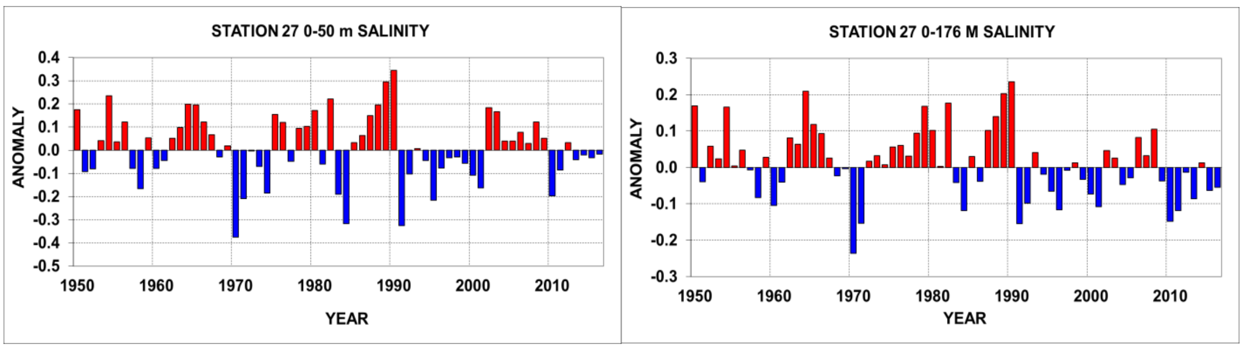


Fig. 22. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean.

STANDARD SECTIONS

In the early 1950s several countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic monitoring along sections in Newfoundland and Labrador waters. In 1976, ICNAF standardized a suite of oceanographic monitoring stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF 1978). In 1998 under the AZMP program, the Seal Island (SI), Bonavista Bay (BB), Flemish Cap (47°N) (FC) and Southeast Grand Bank (SEGB) historical stations were selected as core monitoring sections. The White Bay section (WB) was continued to be sampled during the summer as a long time series ICNAF/NAFO section.

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. 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 the 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 ship time. In this manuscript we present the summer cross sections of temperature and salinity and their anomalies along the Bonavista and Seal Island sections to represent the vertical temperature and salinity structure across the Newfoundland and Labrador Shelf during 2016.

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 - 2°C and salinities of 31.5 - 33.5. Labrador Slope water flows southward along the shelf edge and into the Flemish Pass and Flemish Cap regions. This water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3° - 4°C and salinities in the range of 34 - 34.75. Surface temperatures normally warm to 10° - 12°C during late summer, while bottom temperatures remain <0°C over much of the Grand Banks but increase to 1° - 3.5°C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper (>1000 m) waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3° - 4°C. In general, the near-surface water mass characteristics along the standard sections undergo seasonal modification from 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 seasonal changes in the temperature and salinity fields along the Bonavista section are presented in Colbourne et al. 2015.

The summer temperature structure along the Flemish Cap (47ºN), Bonavista and Seal Island sections (Figure 2) during 2016 are highlighted in Figures 23, 24 and 25. 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 or CIL (Petrie et al. 1988) and its cross sectional area or volume bounded by the 0°C isotherm is generally regarded as a robust index of ocean climate conditions on the eastern Canadian Continental Shelf.

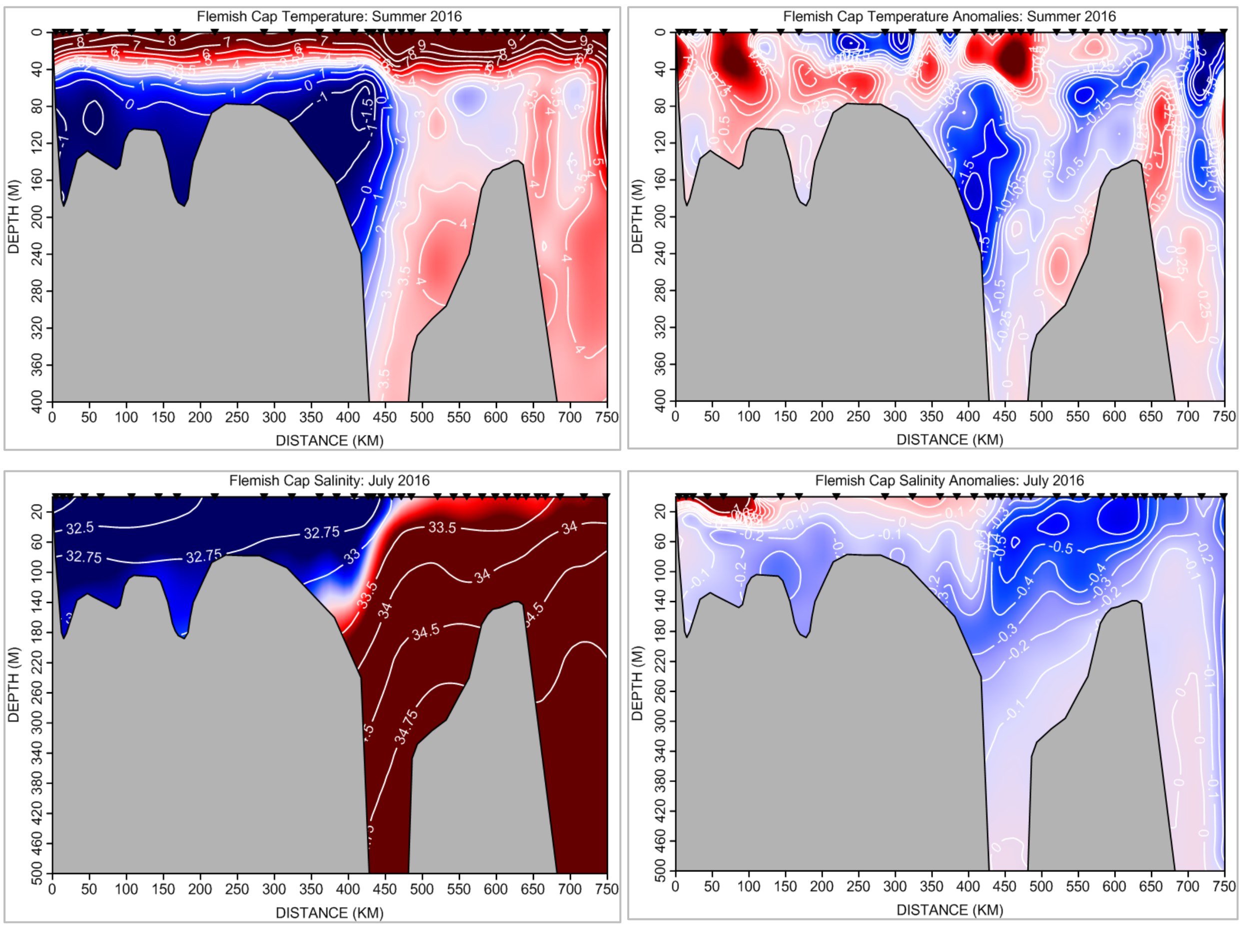


Fig. 23. Contours of temperature (°C) and salinity and their anomalies along the Flemish Cap (47ºN) section (Fig. 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

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.

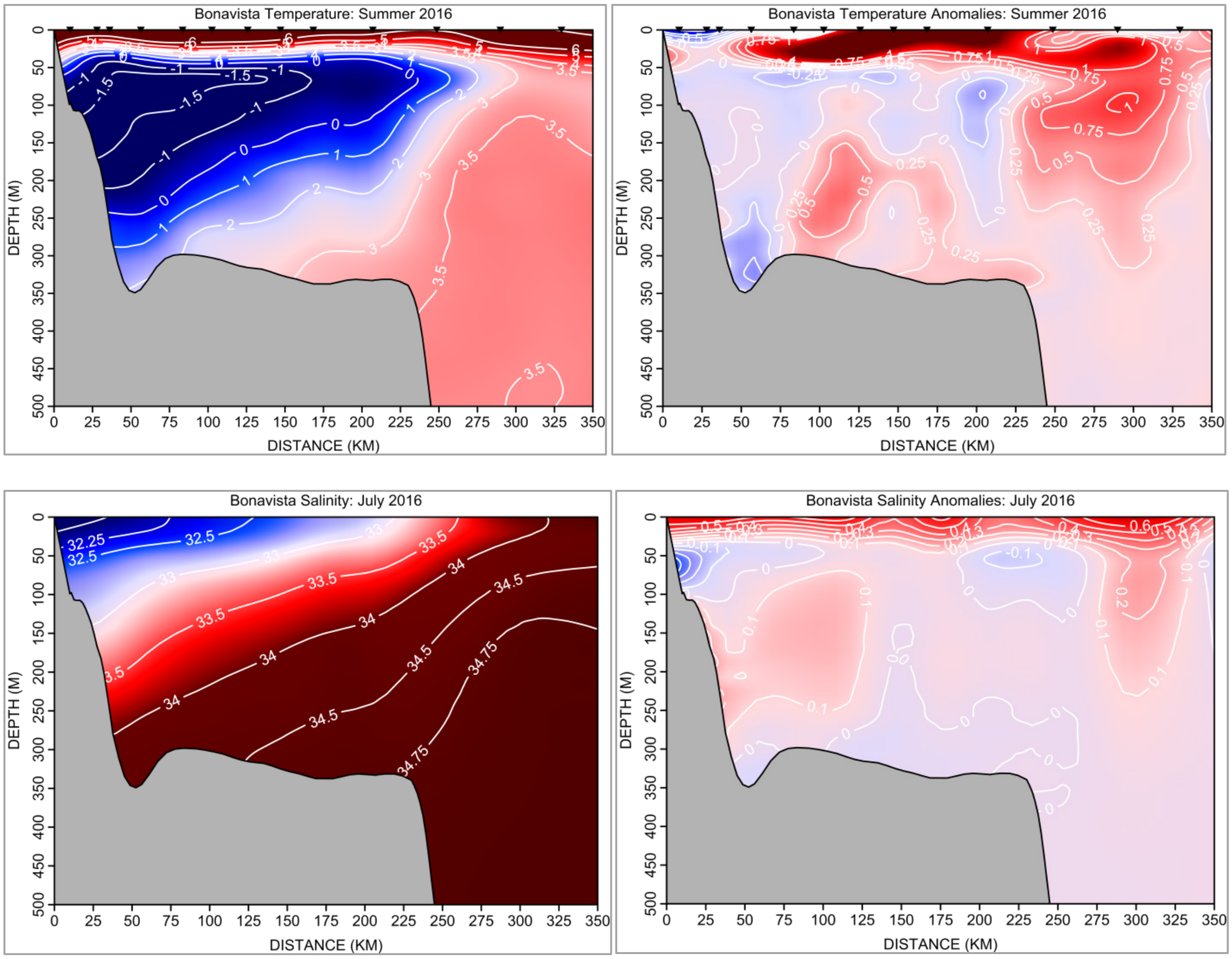


Fig. 24. Contours of temperature (°C) and salinity and their anomalies along the Bonavista section (Fig. 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

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 23, 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 24, 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 25, 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 23, 24 and 25, 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 23, 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 24, 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 25, bottom right panel).

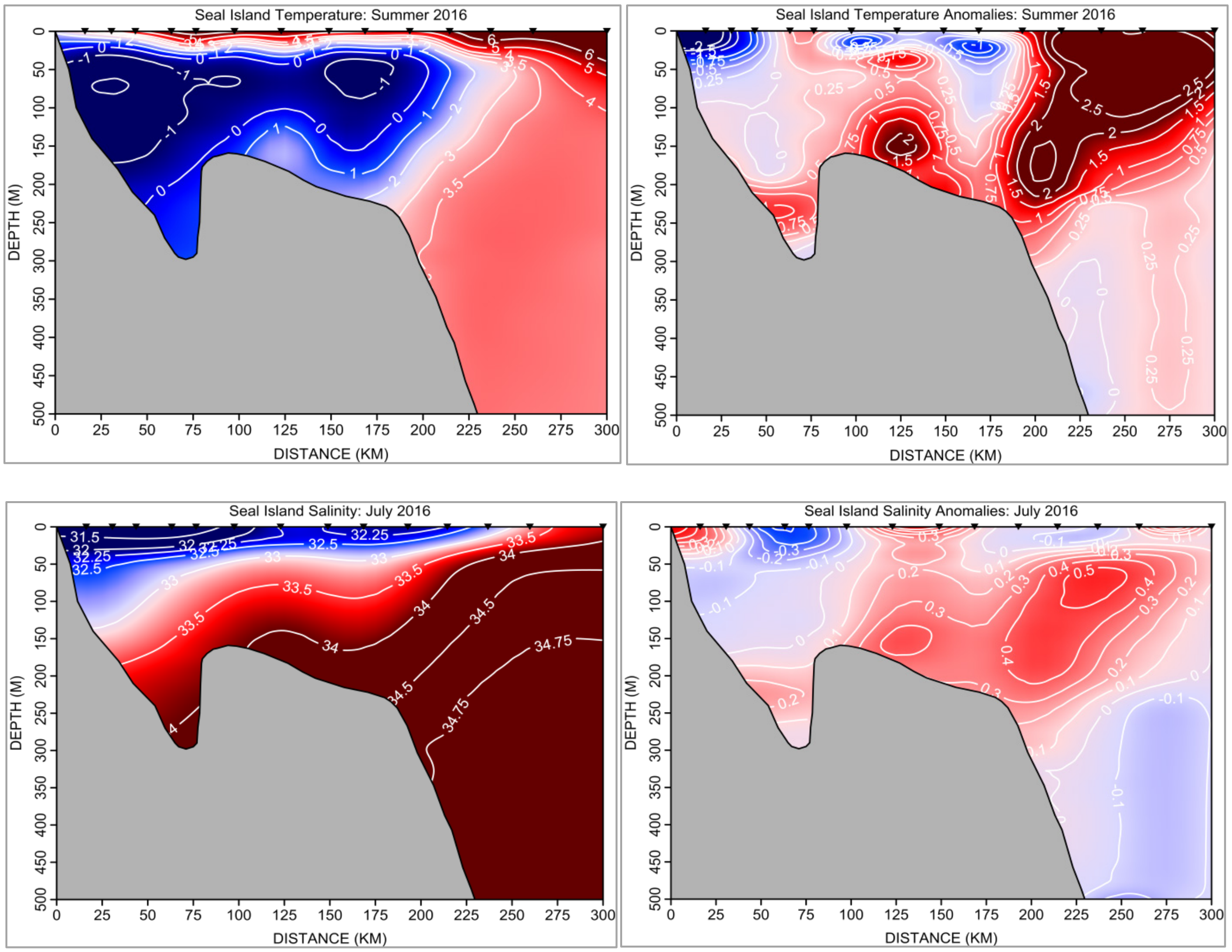


Fig. 25. Contours of temperature (°C) and salinity and their anomalies along the Seal Island section (Fig. 2) during the summer of 2016. Station locations along the section are indicated by the symbols on the top panels.

Time series of summer CIL (<0°C) cross-sectional area anomalies along sections from southern Labrador to the Grand Banks are displayed in Figure 26. 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 27 as standardized values and in Figures 28 and 29 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 28) 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 29) shows fresher-than-normal conditions during the previous 7-years but normal conditions in 2016.

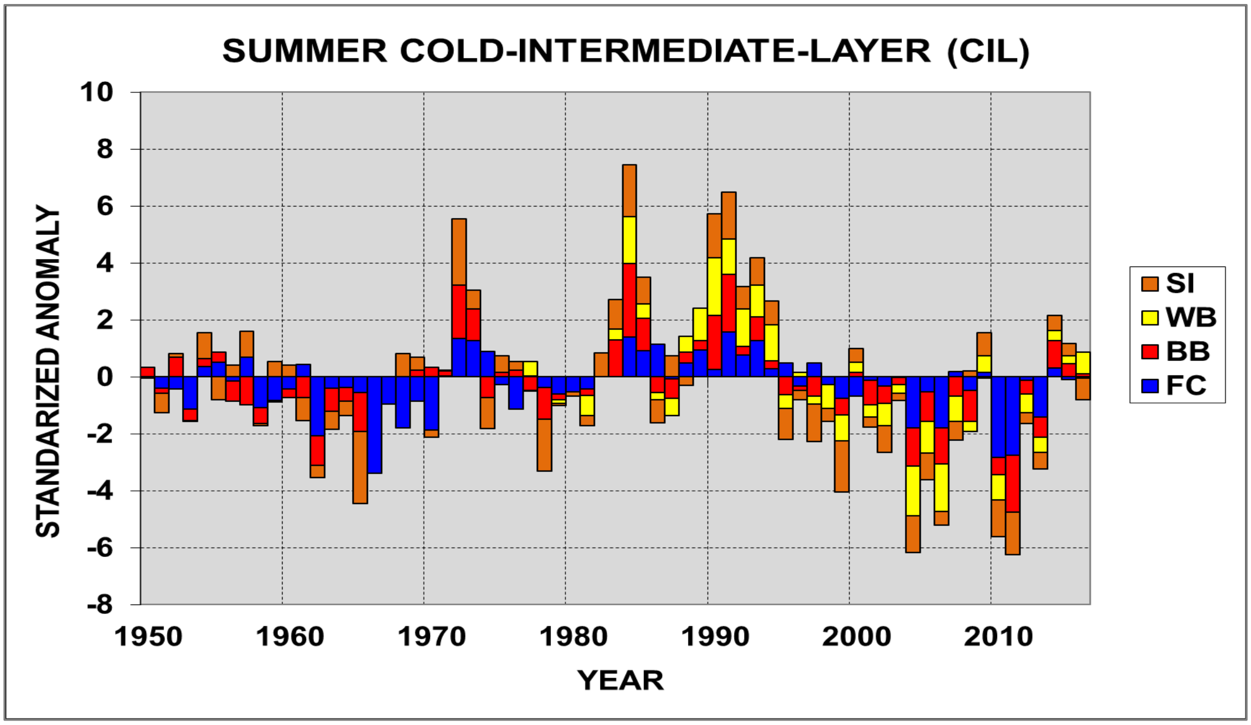


Fig. 26. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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

Fig. 27. Standardized temperature and salinity anomalies derived from data collected along standard cross-shelf sections during the summer (Fig. 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.

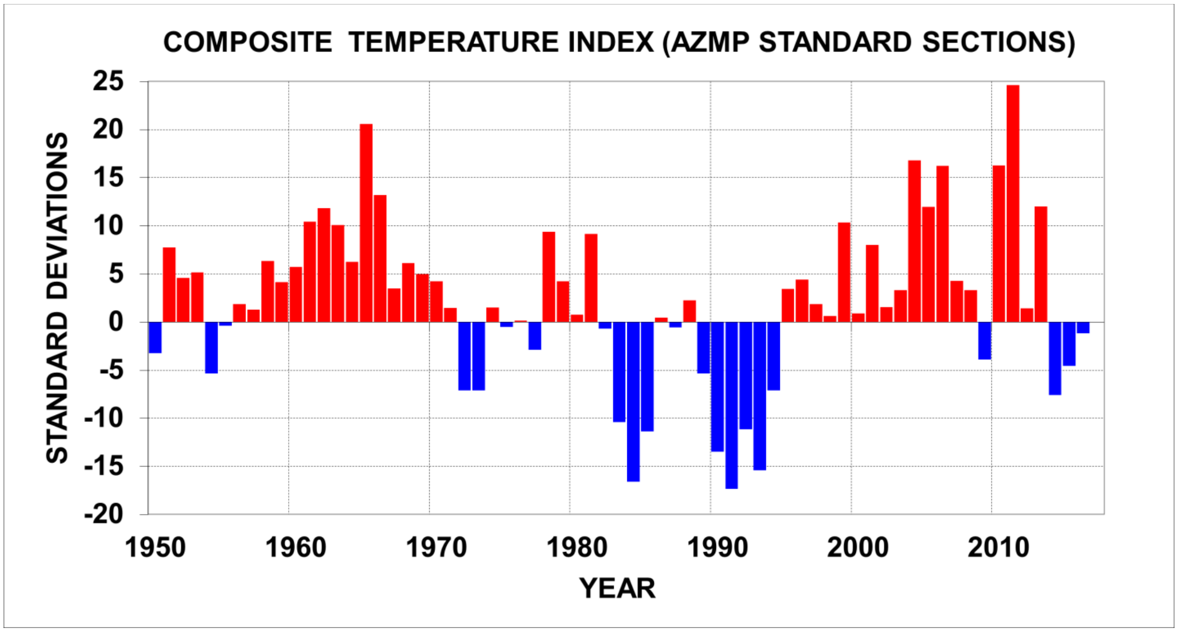


Fig. 28. Composite temperature index derived from data collected along standard cross-shelf sections shown in Fig. 27.

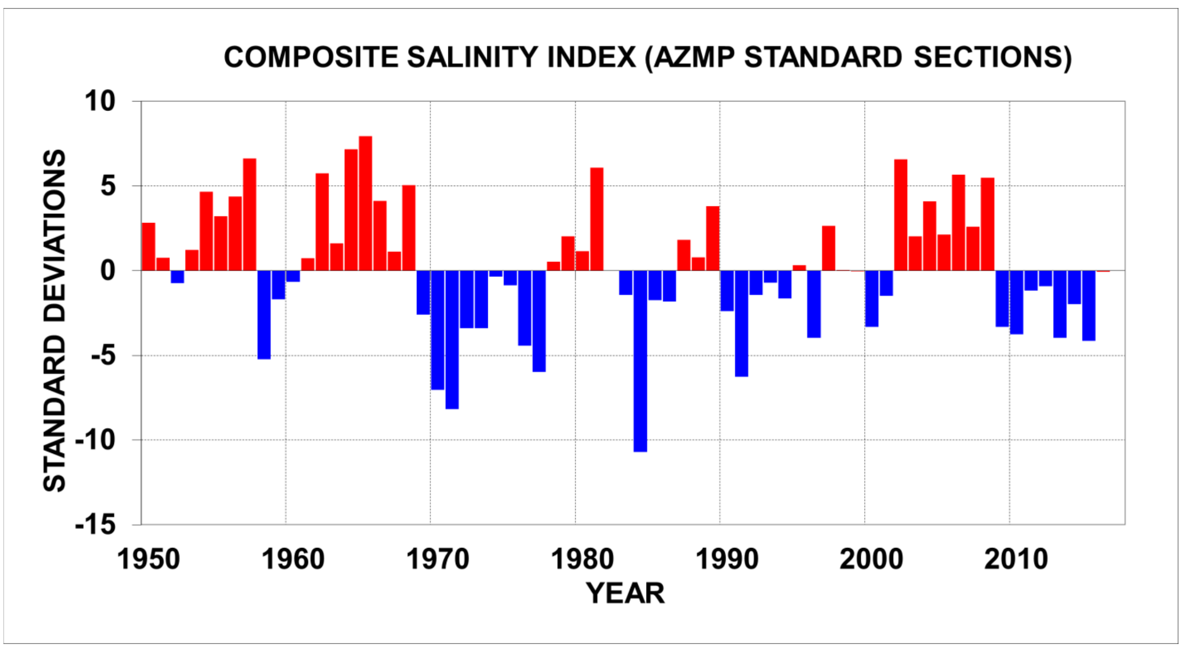


Fig. 29. Composite salinity index derived from data collected along standard cross-shelf sections shown in Fig. 27.

MULTI-SPECIES SURVEY BOTTOM TEMPERATURES

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday 1981). Temperature profiles (and salinity since 1990) are available for most fishing sets in each stratum.

These surveys provide large spatial-scale oceanographic data sets for the Newfoundland and Labrador Shelf. During the spring NAFO Subdivision 3Ps on the Newfoundland south coast and Divisions 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 30 and 31 for NAFO Div. 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.

On St. Pierre Bank temperatures ranged from 0° - 3°C on St. Pierre Bank and up to 5°-6°C in the Laurentian Channel and areas to the west. Bottom temperature anomalies ranged from +0.5°C to more than 1°C above normal in almost all areas of 3Ps. The bottom right panel of Figure 30 shows, except for isolated areas, a slight warming over 2015 values.

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 31).

Climate indices based on the temperature data collected during the spring survey for the years 1990-2016 are displayed in Figure 32 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 32).

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 32).

In Div. 3P bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000, near record cold conditions in 2003 (-1.4 SD). A notable exception occurred in 2007-2008 when bottom temperatures were colder than normal, by almost 1 SD in 2007. Temperatures began to moderate in 2009 with a further increase in 2010, reaching almost 2 SD in 2011-2012 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 32).

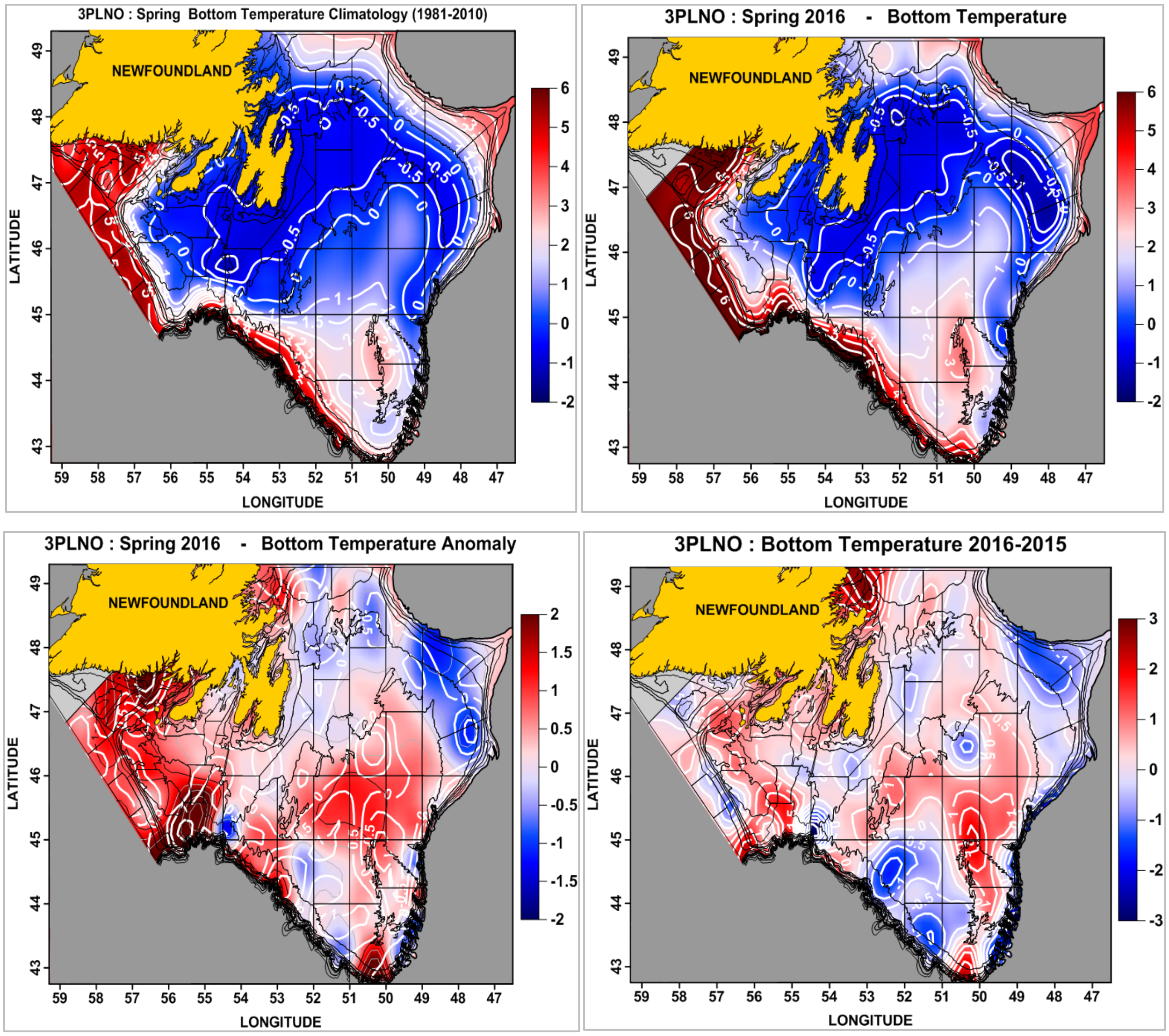


Fig. 30. Maps of the mean 1981-2010 bottom temperature, bottom temperature and anomalies during spring 2016 and the difference from 2015 (in °C) in NAFO Divs. 3PLNO.

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 33 as stacked bar graphs. The increasing trend since the early 1990s is evident with some cooling observed in individual years, 2003 being the most significant. Bottom temperatures reached record high values in 2011 but have experienced a decreasing trend to near-normal values in 2015, except for 3Ps which remained above normal and in 2016 increased even further to 2.0 SD above normal, the highest since 1984.

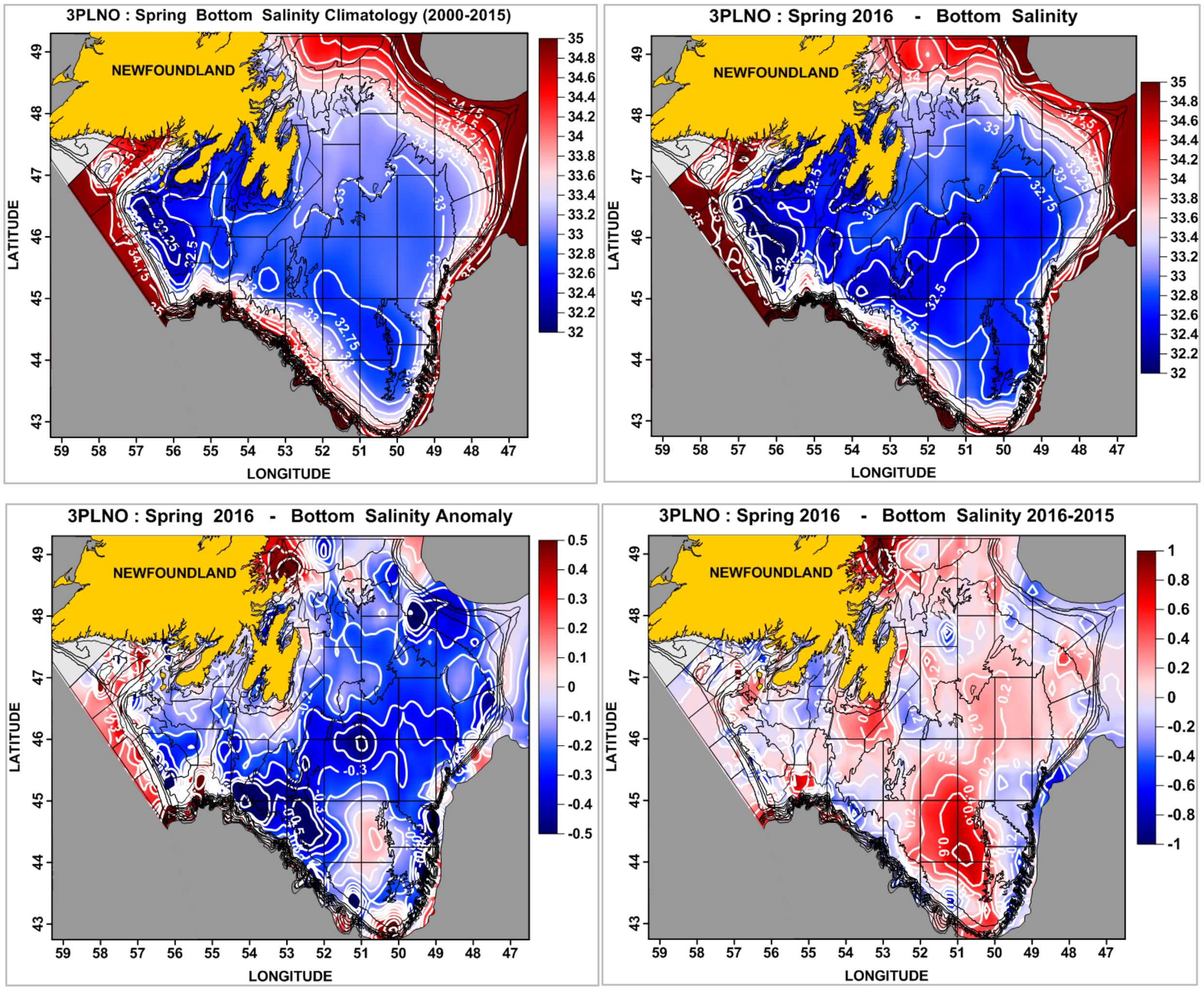


Fig. 31. Maps of the mean 2000-2015 bottom salinity, bottom salinity and anomalies during spring 2016 and the difference from 2015 in NAFO Divs. 3PLNO.

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

Fig. 32. 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.

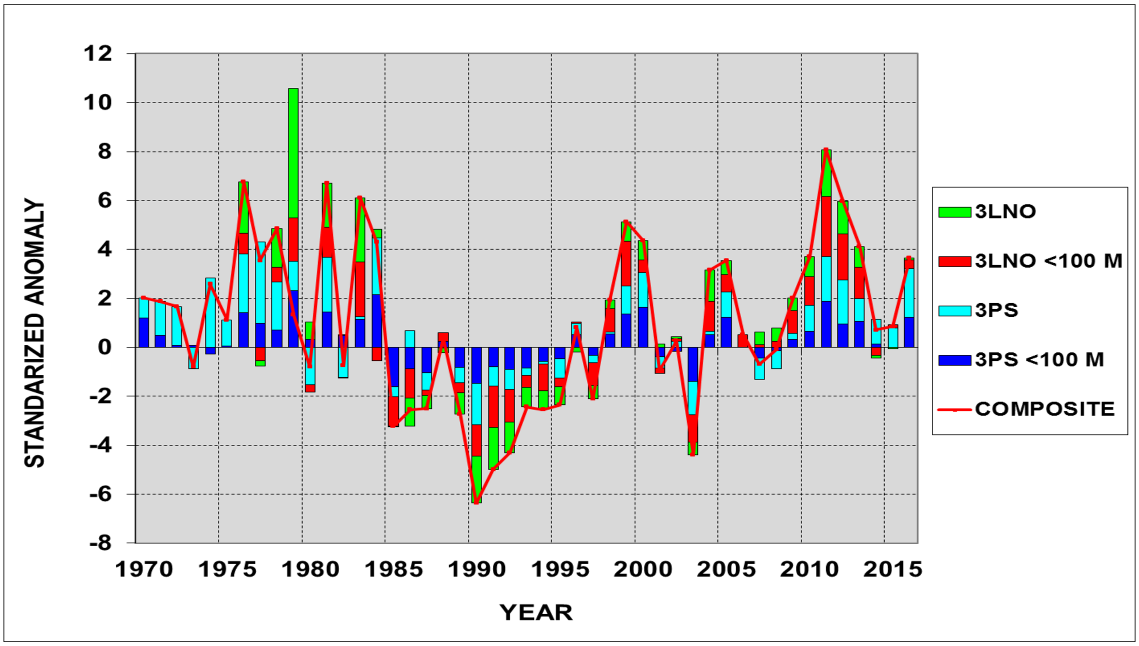


Fig. 33. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divs. 3LNOP.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from data collected during the fall of 2016 multi-species survey (Figure 2) in NAFO Div. 2J, 3KL are displayed in Figure 34. 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 34).

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 35).

Bottom temperature anomalies and derived indices are displayed in Figure 36 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.

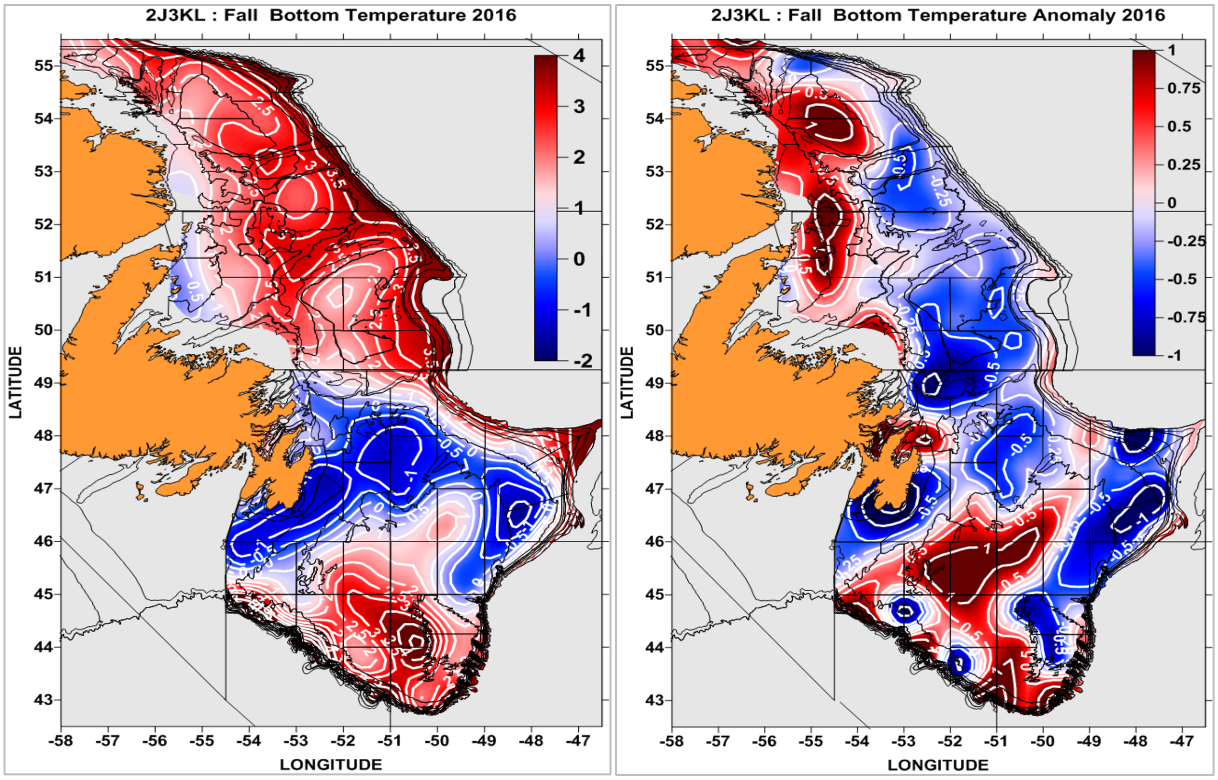


Fig. 34. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1981-2010) during the fall of 2016 in NAFO Divs. 2J3KL.

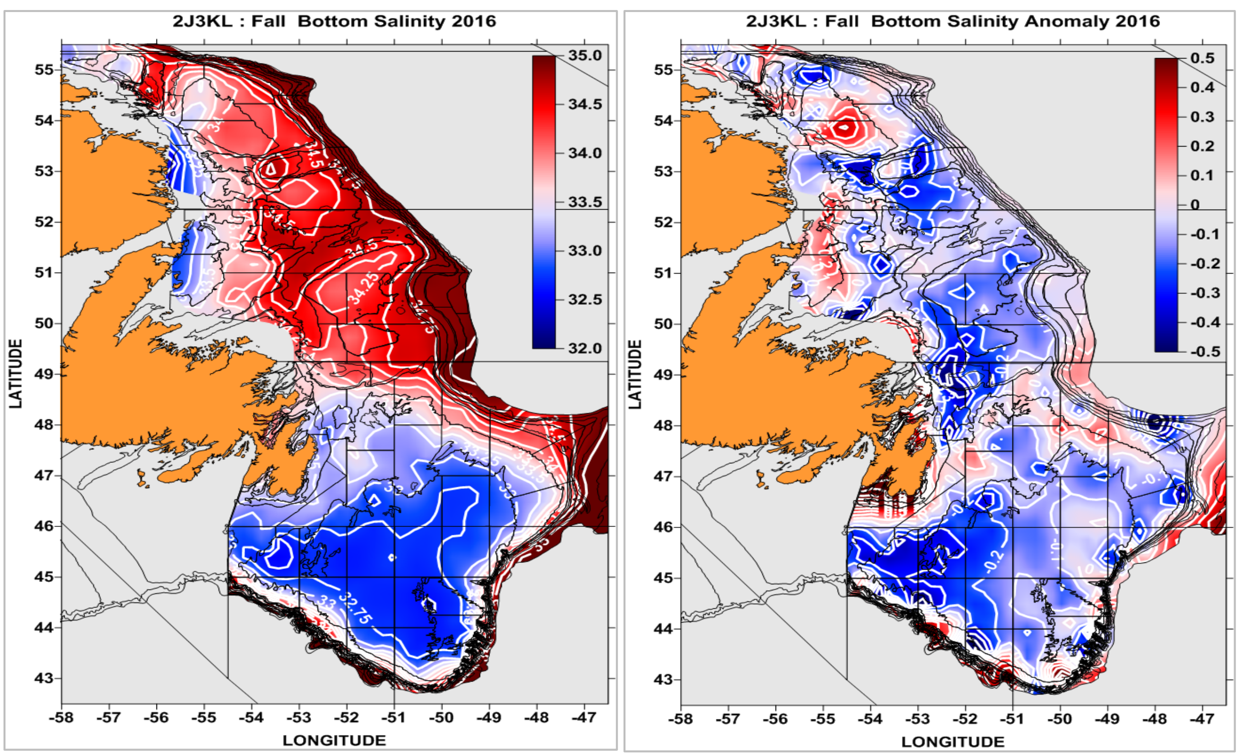


Fig.35. Contour maps of bottom salinity and bottom salinity anomalies (referenced to 2000-2015) during the fall of 2016 in NAFO Divs. 2J3KL.

Temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area based on the fall survey are presented in Figure 37. 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 32 and 36 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 38).

NAFO DIV. 2J	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MEAN	SD
BOTTOM TEMPERATURES	-0.6	0.4	-1.3	-1.4	-1.1	-0.9	-0.4	-1.5	-0.5	-1.1	-0.8	-0.5	-1.3	-0.9	-0.8	-0.8	0.6	0.1	0.3	1.0	0.5	0.8	0.6	1.2	1.5	1.4	0.7	1.3	0.5	0.7	1.7	2.0	1.1	0.8	0.7	0.2	1.0	2.35	0.47
BOTTOM TEMPERATURES < 200 M	0.4	0.9	-0.6	-0.7	-1.9	-1.1	0.4	-0.8	0.3	-0.5	-0.3	-0.6	-1.7	-1.7	-0.9	-0.7	0.4	-0.1	-0.1	0.7	0.0	1.0	0.3	0.8	1.4	1.5	0.5	1.7	0.0	0.2	2.0	2.2	0.4	0.3	-0.4	-0.3	1.1	0.79	0.71
THERMAL HABITAT AREA >2°C	-0.7	-0.1	-1.2	-1.0	-1.3	-1.4	0.0	-1.1	-0.3	-0.8	-1.0	-0.7	-1.1	-0.8	-0.6	0.0	0.3	0.4	0.2	0.6	0.0	0.8	0.5	0.9	1.3	1.7	0.1	2.0	-0.2	0.3	2.4	2.8	0.4	0.4	0.2	-0.2	1.2	57.94	14.65
THERMAL HABITAT AREA <1°C	0.3	0.0	1.3	0.9	1.7	1.2	-0.1	1.7	0.1	0.7	0.7	0.7	1.4	1.2	0.7	0.2	-0.3	-0.5	-0.6	-1.3	-0.2	-0.9	-0.3	-1.4	-1.4	-1.4	-0.2	-1.4	-0.5	-0.5	-1.4	-1.4	-0.9	-0.8	0.3	0.0	-1.5	22.72	15.71
NAFO DIV. 3K																																							
BOTTOM TEMPERATURES	0.0	0.1	-2.3	-0.5	-0.3	-1.6	0.4	-0.6	-0.3	-0.2	-1.0	-0.7	-1.7	-1.5	-1.1	0.0	0.0	0.6	0.3	1.2	0.1	0.3	0.5	0.7	1.2	1.1	0.3	1.8	0.7	0.8	1.5	2.7	1.2	0.5	0.3	0.8	0.5	2.13	0.53
BOTTOM TEMPERATURES < 300 M	0.2	0.3	-1.6	-0.5	-0.7	-1.6	0.7	-0.7	0.0	0.1	-0.9	-0.7	-1.5	-2.0	-1.6	0.1	0.1	0.7	0.8	1.1	0.0	0.2	0.6	0.9	1.3	1.2	0.0	1.9	0.0	0.2	1.4	2.7	0.7	0.2	-0.1	0.7	0.6	1.46	0.62
THERMAL HABITAT >2°C	0.4	0.4	-1.9	-0.7	-0.4	-1.8	0.3	-0.7	0.0	-0.6	-1.4	-0.5	-1.6	-1.5	-1.1	0.0	0.1	0.7	0.7	1.4	0.4	0.2	0.8	0.8	0.9	1.2	0.3	1.7	0.4	0.3	1.6	2.3	0.8	0.7	0.2	1.0	0.3	62.16	13.74
THERMAL HABITAT AREA <1°C	0.2	0.0	2.6	0.5	0.5	1.3	-0.6	0.3	0.0	-0.4	1.2	0.8	1.1	1.4	0.6	-0.5	-0.3	-0.4	0.0	-0.9	0.2	0.0	-0.5	-0.5	-1.7	-1.3	0.3	-1.9	0.4	-0.6	-1.7	-1.9	-0.8	-0.1	0.0	-0.4	-1.0	20.76	11.06
NAFO DIV. 3LNO																																							
BOTTOM TEMPERATURES											-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3	2.2	-0.1	0.1	-0.1	0.0	0.8	1.8	0.0	0.1	-0.2	0.0	1.1	1.8	0.2	0.1		-0.4	0.0	1.78	0.39
BOTTOM TEMPERATURES <100 M											-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6	2.4	0.0	-0.4	-0.6	-0.2	0.4	1.4	-0.3	-0.9	-0.5	0.0	1.7	1.2	0.3	0.0		-0.5	0.0	1.22	0.64
THERMAL HABITAT AREA >2°C											-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5	0.4	0.2		-0.2	0.3	32.18	9.83
THERMAL HABITAT AREA <0°C											0.4	1.4	1.5	1.8	1.7	-0.7	-0.1	0.3	-0.5	-1.3	0.6	-0.1	-0.6	0.0	-1.4	-1.1	-1.3	-0.1	0.6	-0.1	-1.1	-2.3	-0.1	-0.3		0.0	-0.2	30.33	12.93
CIL VOLUME (FALL) 2J3KL	-0.4	-0.5	0.3	1.2	1.8	1.4	-0.6	0.9		0.1	1.1	1.2	1.6	1.7	0.9	-0.2	-0.7	-0.7	-0.4	-1.7	-0.3	-0.6	-0.4	-0.6	-1.4	-0.7	-0.4	-0.8	-0.2	-1.0	-1.1	-1.1	-0.1	-0.3	0.3	-0.5	-0.7	1.65	0.95

Fig. 36. 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.

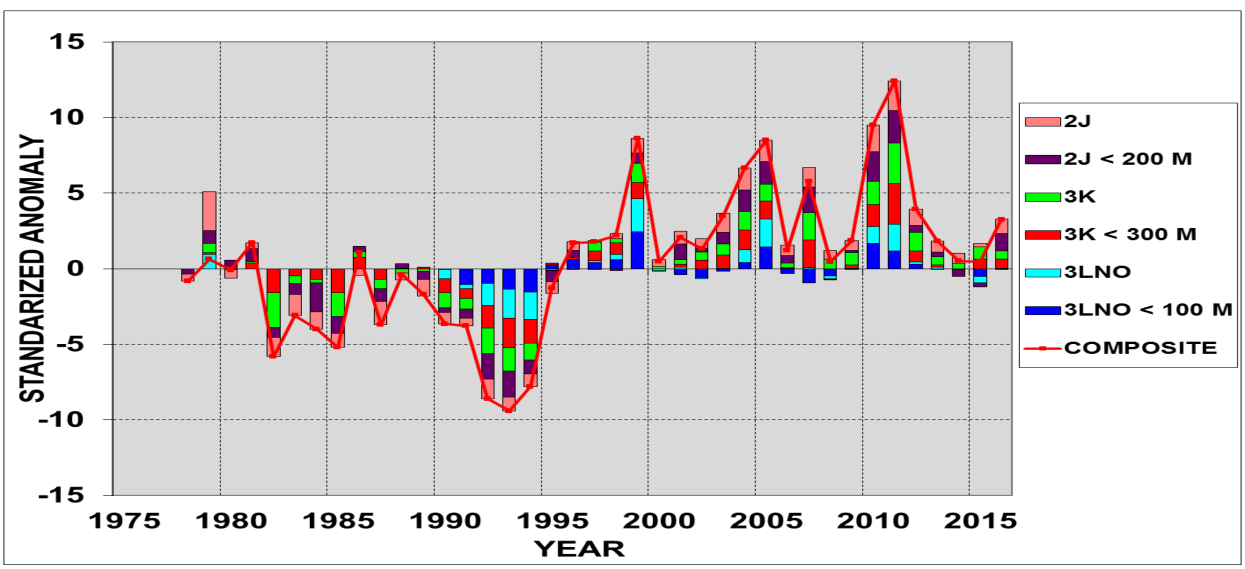


Fig. 37. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divs. 2J3KLNO.

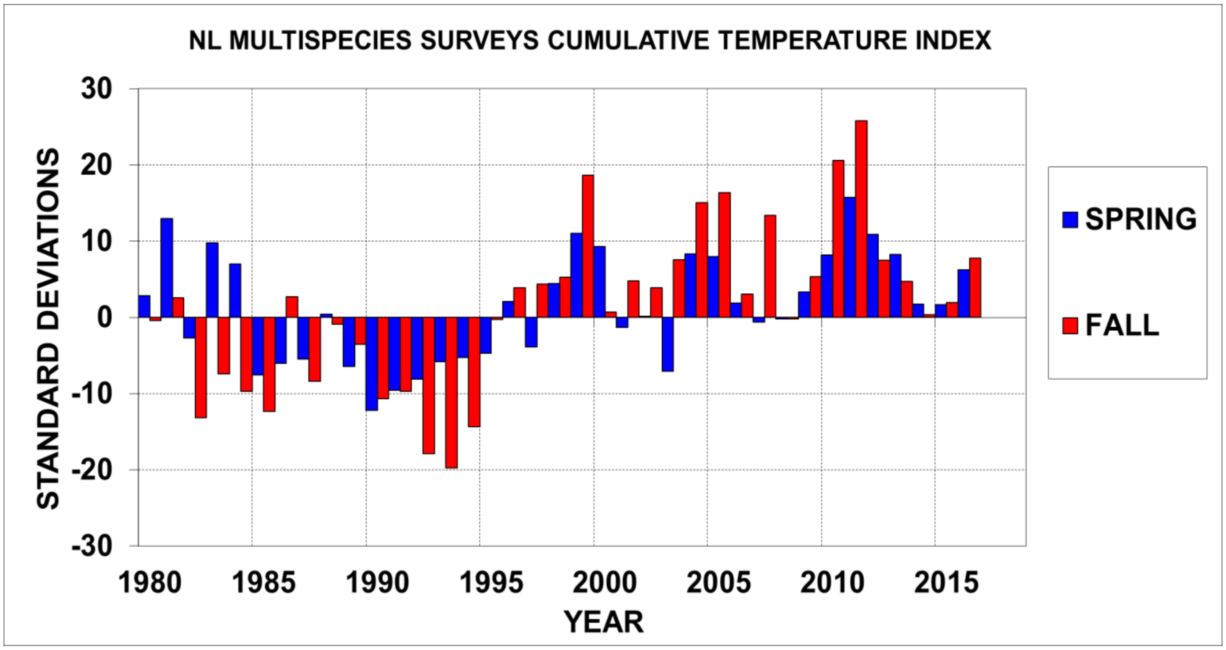


Fig. 38. Spring and fall composite temperature index derived by summing the standardized anomalies displayed in Figs. 32 and 36.

Fall CIL Volume

The spatial extent of the CIL water mass overlying the NL shelf during the fall exhibits considerable inter-annual and seasonal variability. It usually covers most of the NL Shelf (except for parts of 3NO) during cold years and is almost completely eroded in warm years. The total volume of CIL water remaining on the shelf 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 $(1.65 \pm 0.95) \times 10^4$ km^3. The annual values are shown in Figure 36 as standardized anomalies and in Figure 39 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 40 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.

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 41). 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.

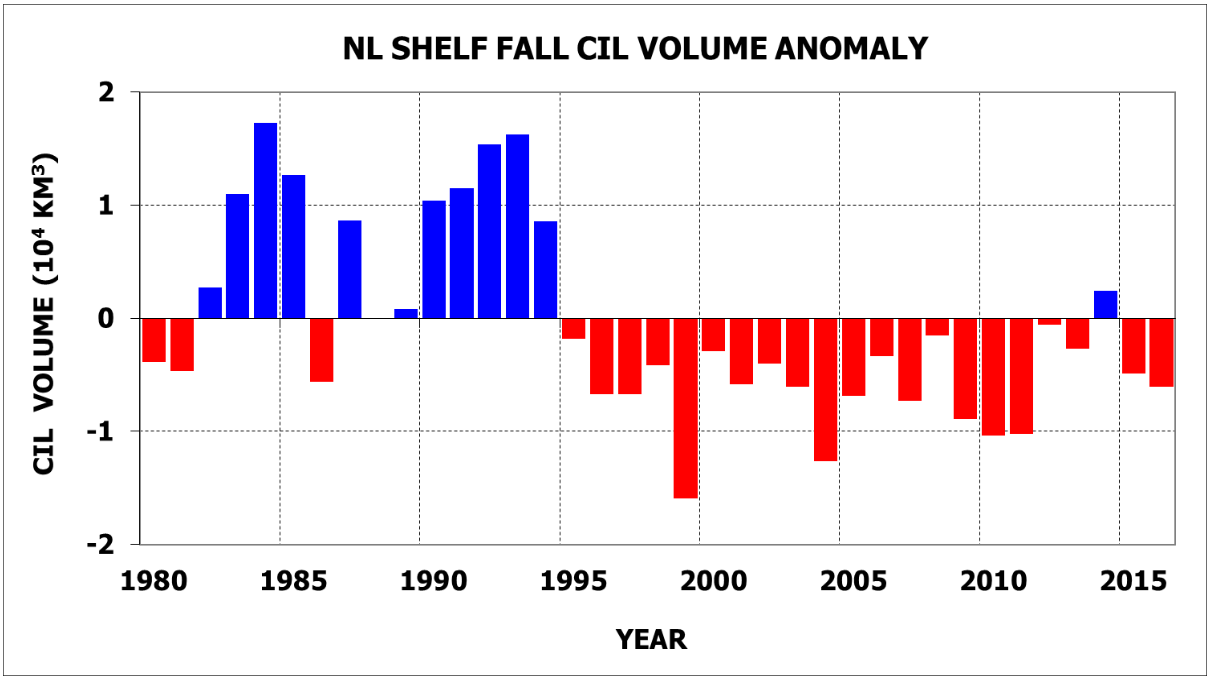


Fig. 39. Time series of the CIL (<0⁰C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

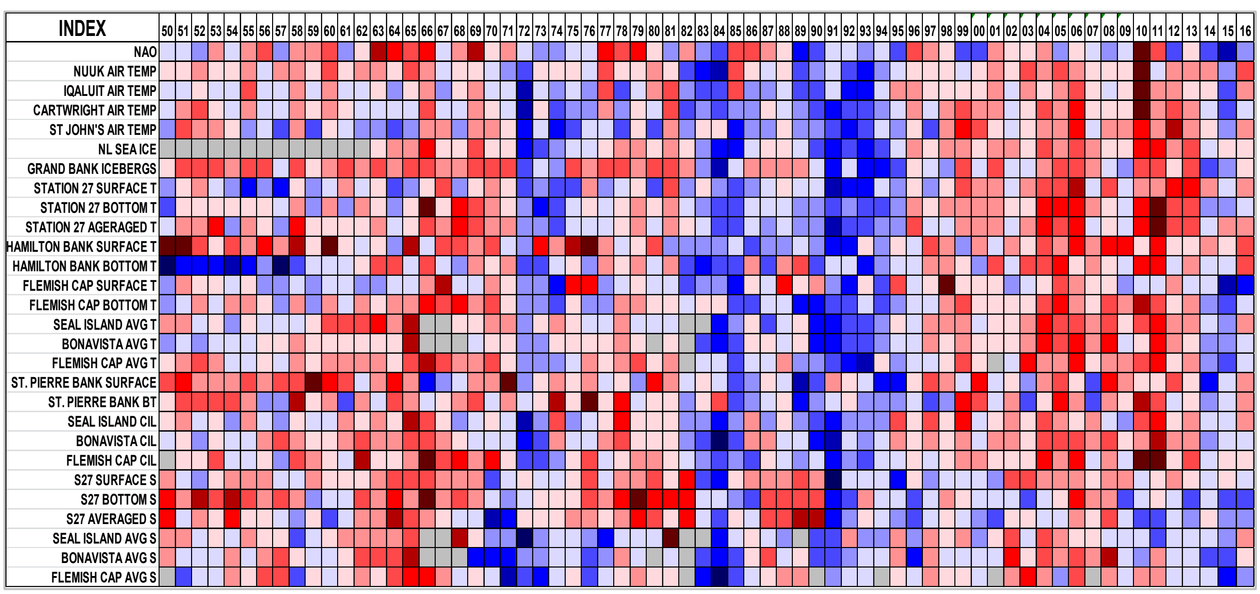


Fig. 40. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Fig. 3. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells indicate missing data.

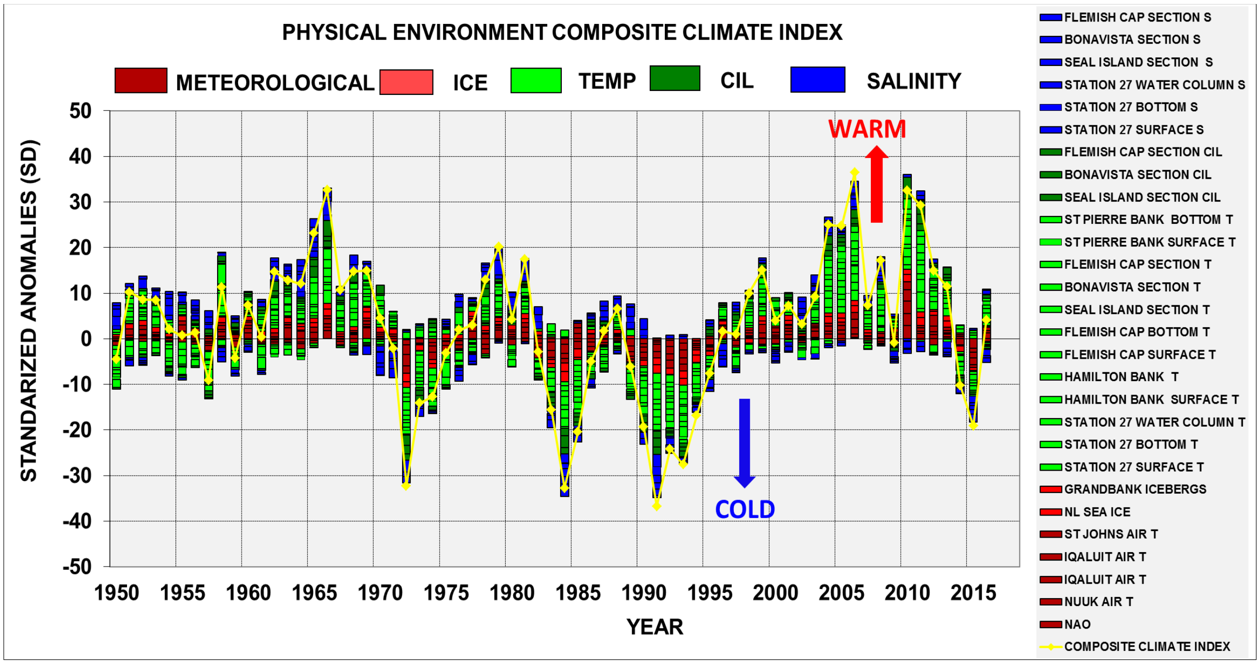


Fig. 41. Composite climate index (yellow line) derived by summing the standardized anomalies from Fig. 40 together with their individual components.

Similar to the standardized values shown in Figure 40, the overall composite index clearly defines the cold/fresh conditions of the 1970s, 1980s and early 1990s, the recent increasing trend that reached a record high in 2006 and the three years of relatively cooler conditions of 2007-2009. In 2010, the composite index increased sharply over the near-normal year of 2009 to the 2nd highest in the 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 7th 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.

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 48°N 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.
- 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 7th lowest in 67 years and the lowest since 1993 in 2015.

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