Northwest Atlantic Fisheries Organization

Serial No. N6793 **NAFO SCR Doc. 18/009**

SCIENTIFIC COUNCIL MEETING – JUNE 2018

Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2017

by

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ABSTRACT

Oceanographic and meteorological observations in NAFO Sub-areas 2 and 3 during 2017 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 was weakly positive during 2017. The associated atmospheric pressure fields resulted in a reduced arctic air outflow in the northwest Atlantic during the winter months resulting in near-normal winter air temperatures, however air temperatures were below normal during the spring. Sea ice extent across the Newfoundland and Labrador Shelf between 45-55°N, although above normal during late spring, was below the long-term mean in 2017. In the inshore regions along the east and northeast coast of Newfoundland sea ice duration was up to 15-60 days longer than normal. Sea ice in these regions disappeared by mid-June which ranged from 15-45 days later than normal depending on the area. Annual sea-surface temperature (SST based on infrared satellite imagery) trends on the Newfoundland and Labrador Shelf, while showing an increase of about 1°C since the early 1980s, were mostly below normal during 2017, driven largely by very cold spring conditions. In 2017, the annual bottom (176 m) temperature/salinity at the inshore monitoring site (Station 27) was below normal by -0.6/-1.5 standard deviations (SD), respectively. Observations from the summer AZMP oceanographic survey indicated that the area of cold-intermediate-layer (CIL <0°C) water overlying the northeast Newfoundland and southern Labrador shelf increased over 2016 to about 1 standard deviation above normal, implying more extensive cold winter chilled water throughout the region. Labrador Current transport through the Flemish Section remained high during the spring (13.5 Sv) but decreased to lower than normal during the summer (4.6 Sv). Summer transport through the Seal Island section was higher than normal in 2017 at 12 Sv. The spatially averaged bottom temperature during the spring in 3Ps remained slightly above normal, a significant decrease over the 33-year record high in 2016. In Divs. 3LNO spring bottom temperatures were 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. Oceanographic data from the fall 2017 multi-species surveys in NAFO Divisions 3LNO indicate bottom temperatures were about 1.2 standard deviations (SD) below normal. In Divisions 2J and 3K fall bottom temperatures continued to decrease from the record high in 2011 to about normal conditions in 2017. A standardized composite climate index for the Northwest Atlantic derived from 28 time series of meteorological, ice, water mass areas and ocean temperature and salinity conditions since 1950 reached a record low (cold) value in 1991. Since then it shows a warming trend that reached a peak in 2010 and thereafter decreased to mostly below normal conditions (cold/fresh) during the past 4 years. The 2015 value was the 7th lowest in 68 years of observations and the lowest value since 1993, while the 2017 value was the 15th lowest.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in NAFO sub-areas 2 and 3 on the Newfoundland and Labrador (NL) Region (Figure 1) during 2017 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 2017 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).

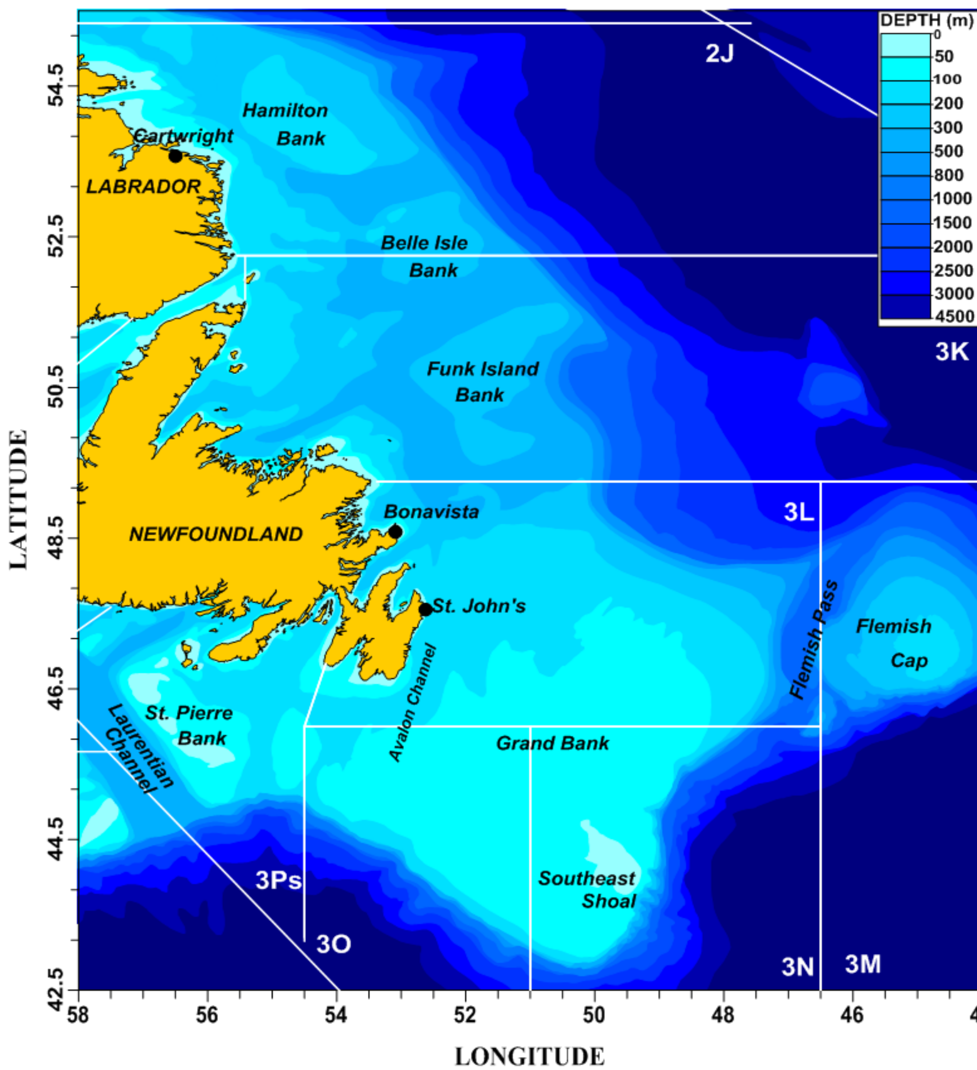

Fig. 1. Map showing NAFO Divisions and main bathymetric features of the Newfoundland and southern Labrador Shelf.

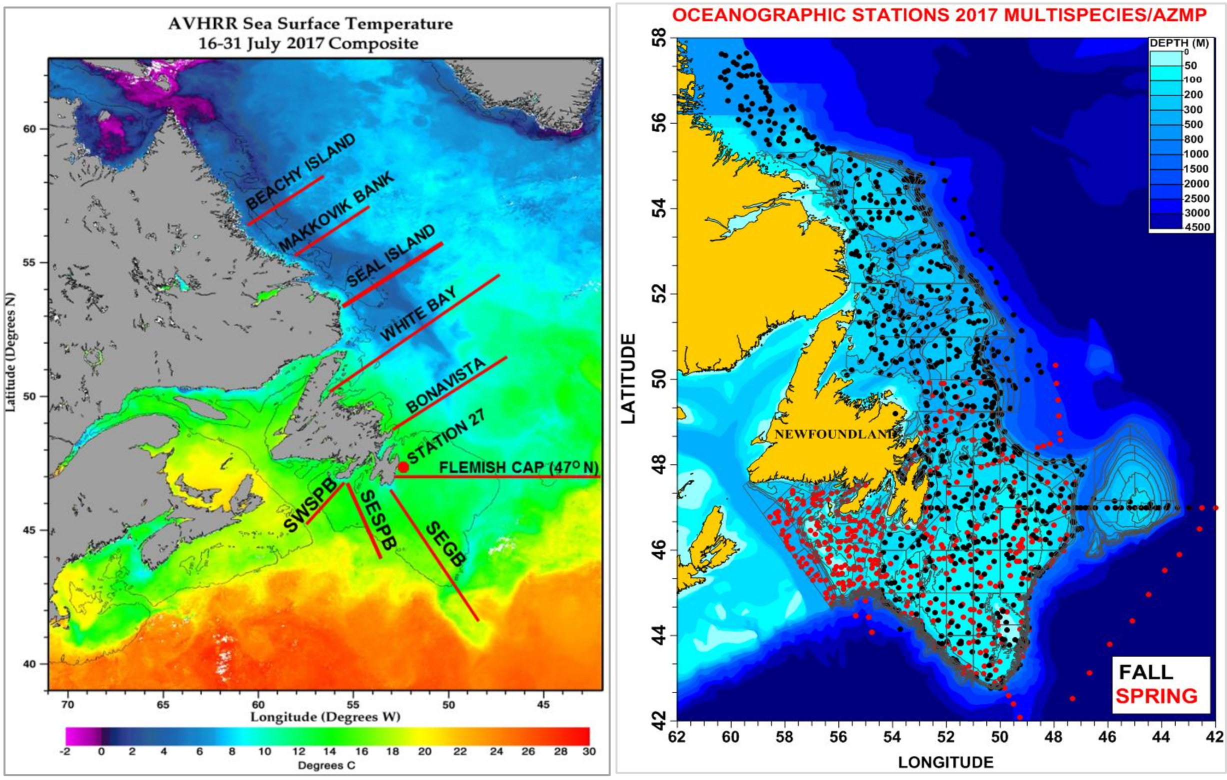

Fig. 2. Map showing summer NAFO/AZMP section occupations along with Sea-Surface-Temperature (SST) during 2017. The right panel shows the positions of trawl-mounted and CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment and AZMP surveys during 2017. (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 and at the Bedford Institute of Oceanography in Dartmouth, NS.

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 2017. 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 (SD) 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 SD higher than its long-term average. As a general guide, anomalies within ±0.5 SD 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 2017 are presented in coloured boxes as figures with gradations of 0.5 SD. Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions (Figure 3). If the magnitude of the anomaly is ≥1.5 SD it is typeset in white to highlight exceptional values. 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 2017, the NAO continued its decreasing trend from the 120 year record high in 2015 to just slightly above normal at +0.3 SD. In 2010 it was at a record low of 2.9 SD below normal. The similar, but larger scale Arctic Oscillation was also close to normal in 2017. As a consequence, arctic air outflow to the Northwest Atlantic during the winter months of 2017 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 (winter and annual values) 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). Winter values in 2017, except at Iqaluit and Cartwright, decreased over the previous year with all sites reporting near normal values ranging from 0.1 to 0.5 SD above normal. The annual values were +0.6 SD at Nuuk and Iqaluit and near normal the other 3 stations. 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 remained above normal in 2017 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	2017	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	0.3	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	0.3	20.44	8.77
NA SST (AMO)	0.0	-0.1	-0.2	-0.1	-0.2	-0.3	-0.3	0.1	0.0	-0.1	0.0	-0.1	-0.2	-0.2	-0.2	0.1	-0.1	0.1	0.4	0.1	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.1	0.0	0.4	0.1	0.2	0.2	0.1	0.1	0.3	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	0.3	-8.41	3.16
IQALUIT WINTER AIR T	1.3	2.3	0.2	-1.6	-1.2	1.1	0.6	-0.6	0.1	-1.5	-0.8	-1.4	-0.6	-1.7	-0.5	0.0	0.3	0.2	-0.5	0.0	0.3	0.5	0.0	0.5	0.9	-0.3	0.6	1.2	-0.7	0.1	2.2	2.1	0.2	1.2	0.8	-1.3	0.5	0.5	-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	0.1	0.1	-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	0.3	-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	0.9	0.3	-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	0.6	-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	0.3	0.6	-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	0.2	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	0.1	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	0.1	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	-0.3	-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	-0.5	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	0.0	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	0.4	767	649

Fig. 4. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1980 to 2017.

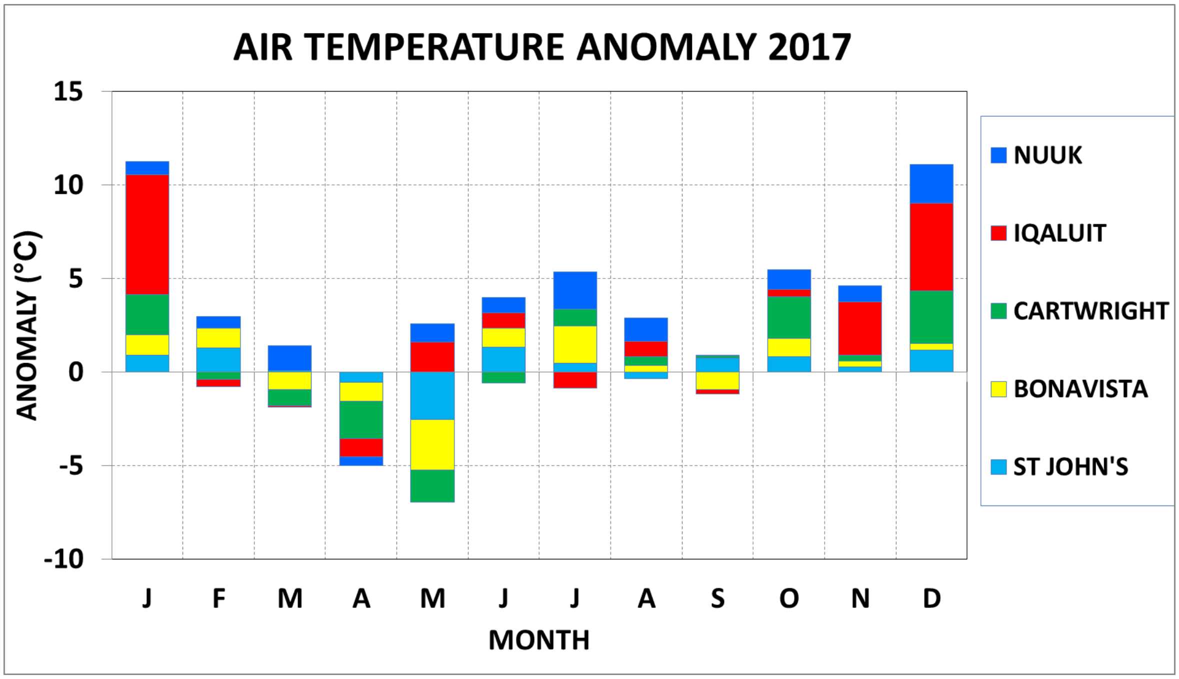

Fig. 5. Cumulative monthly air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's for 2017.

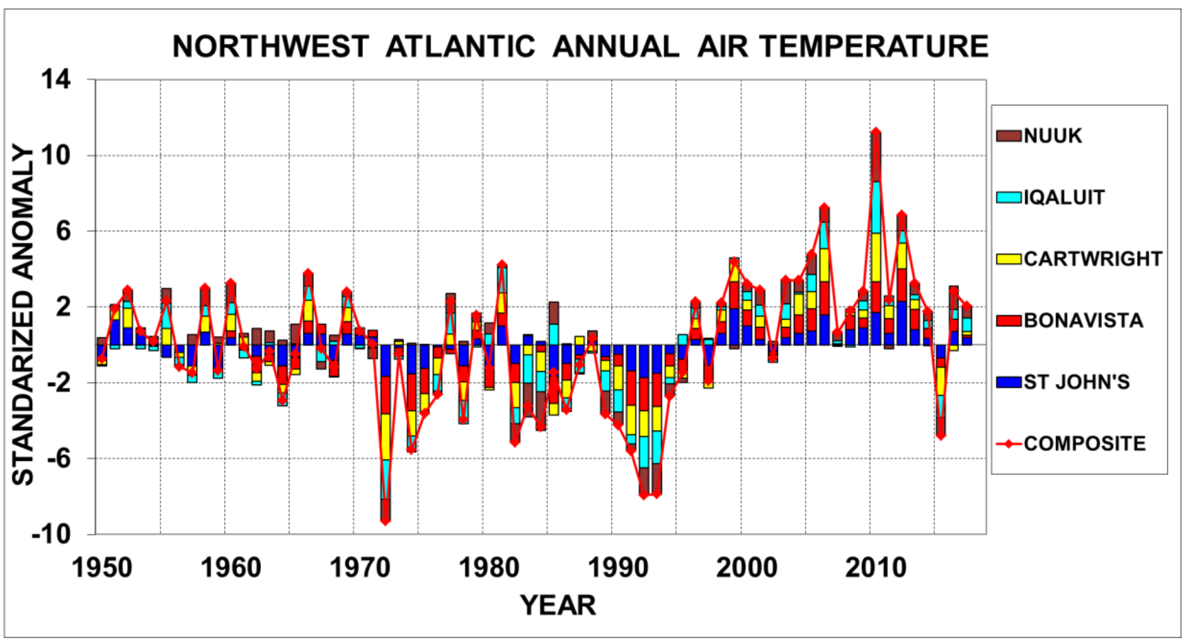

Fig. 6. Standardized annual air temperature anomalies time series at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

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 and 2017 (Figures 4 and 7). In 2011 sea ice extent decreased to 49-year record low of -1.7 SD (Figure 4). Monthly values of sea ice extent were below normal during most of the ice season (January to April) but above normal (more extensive than normal) in May (Figure 8). In the inshore regions along the east and northeast coast of Newfoundland sea ice duration was up to 15-60 days longer than normal. Sea ice in these regions disappeared by mid-June which ranged from 15-45 days later than normal depending on the area.

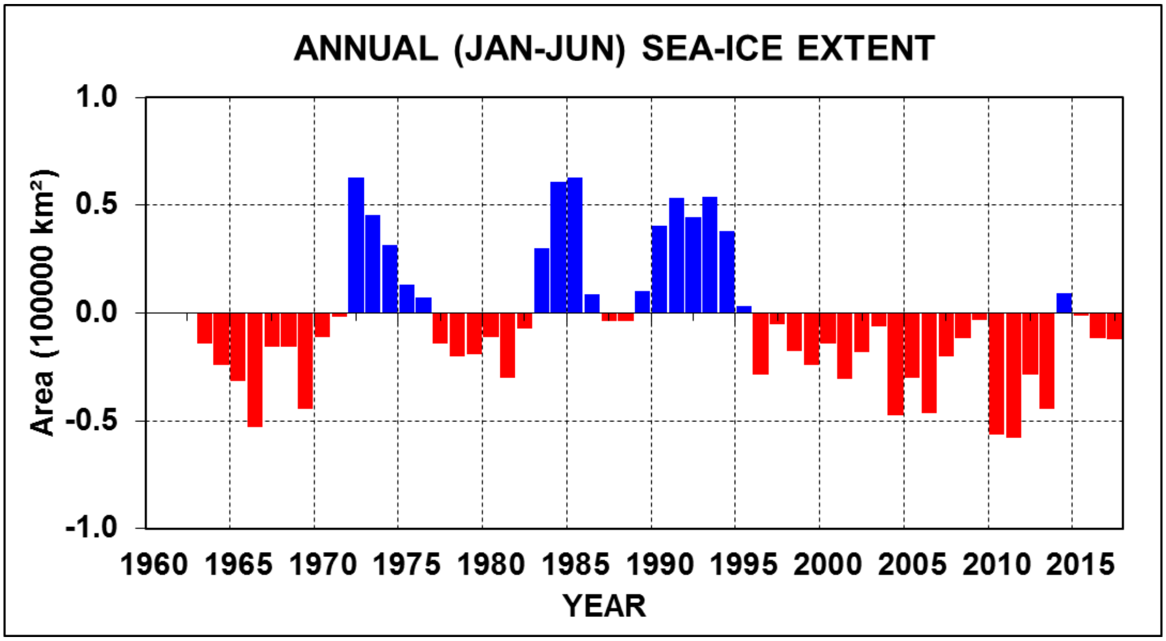

Fig. 7. Time series of annual sea ice extent (defined by 1/10 coverage) anomalies on the NL Shelf between 45-55°N latitude.

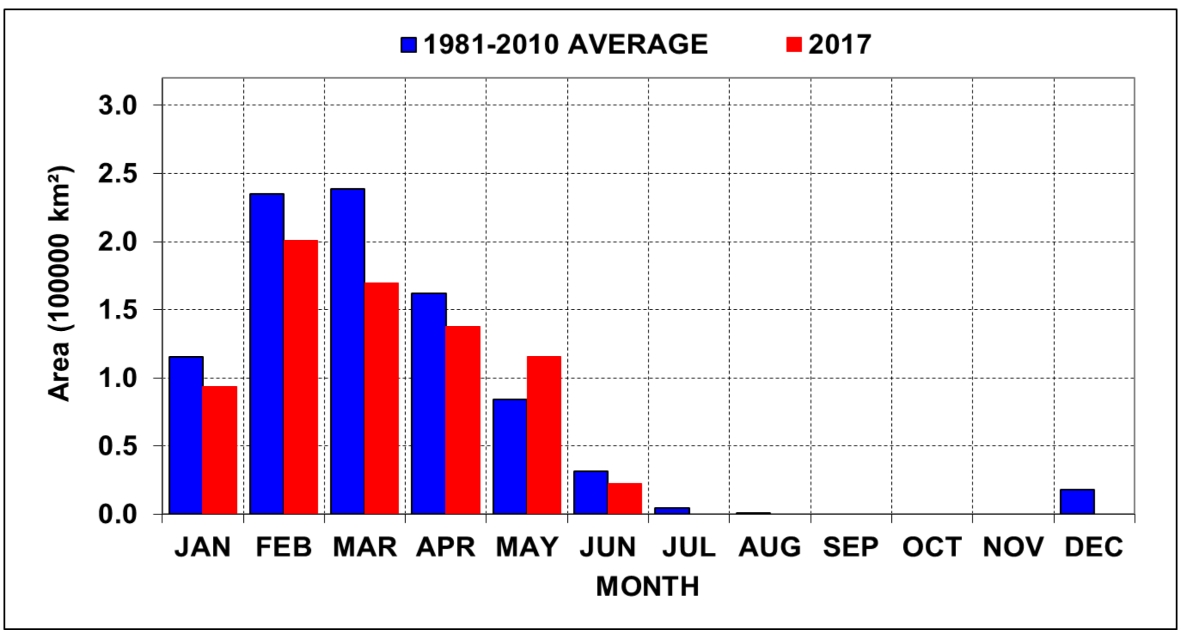

Fig. 8. Monthly sea ice extent (defined by 1/10 coverage) on the NL Shelf between 45-55°N latitude.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 1008 (+0.4 SD) icebergs drifted south of 48°N onto the Northern Grand Bank during 2017, up from the 687 in 2016. There were only 13 in 2013, 499 in 2012 and only 3 in 2011 and one in 2010. The 118-year average is 492 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 118 year time series reported no icebergs drifted south of 48ºN. 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 2017 shows mostly near normal counts except for March and April when there were 665 out of the 1008 observed (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 and about normal in 2017 (Figure 11).

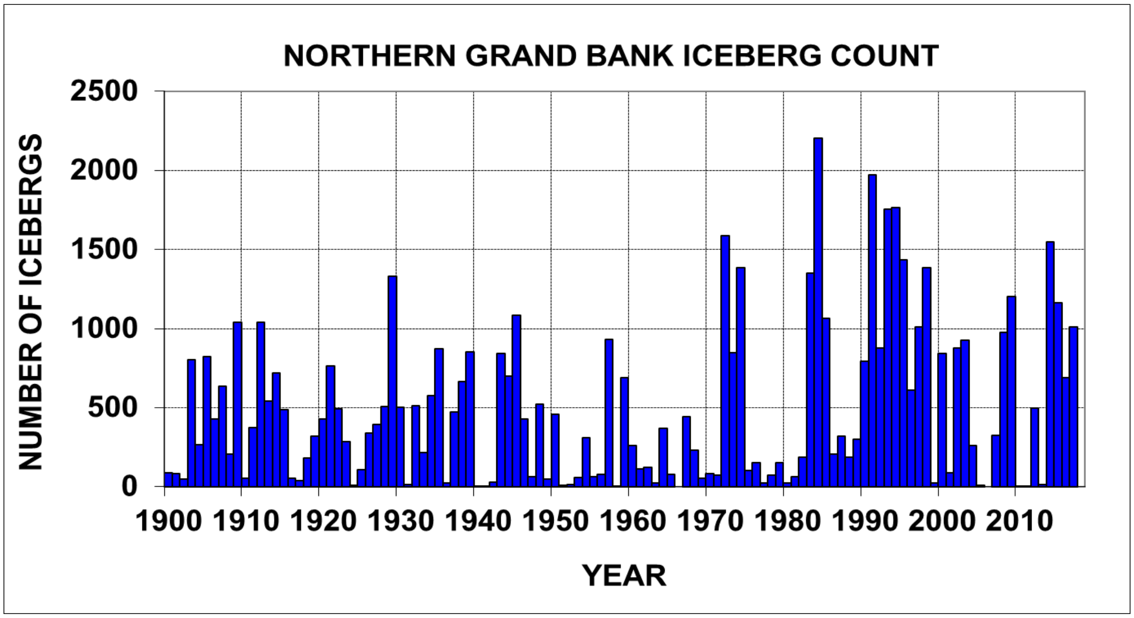

Fig. 9. Annual iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP of the USCG).

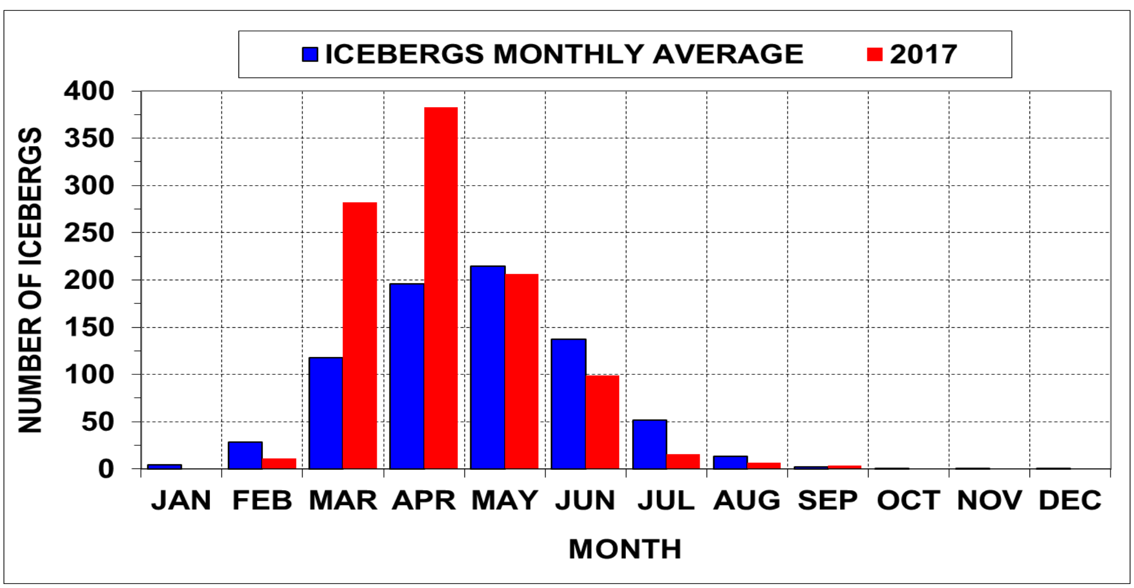

Fig. 10. Monthly iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP of the USCG).

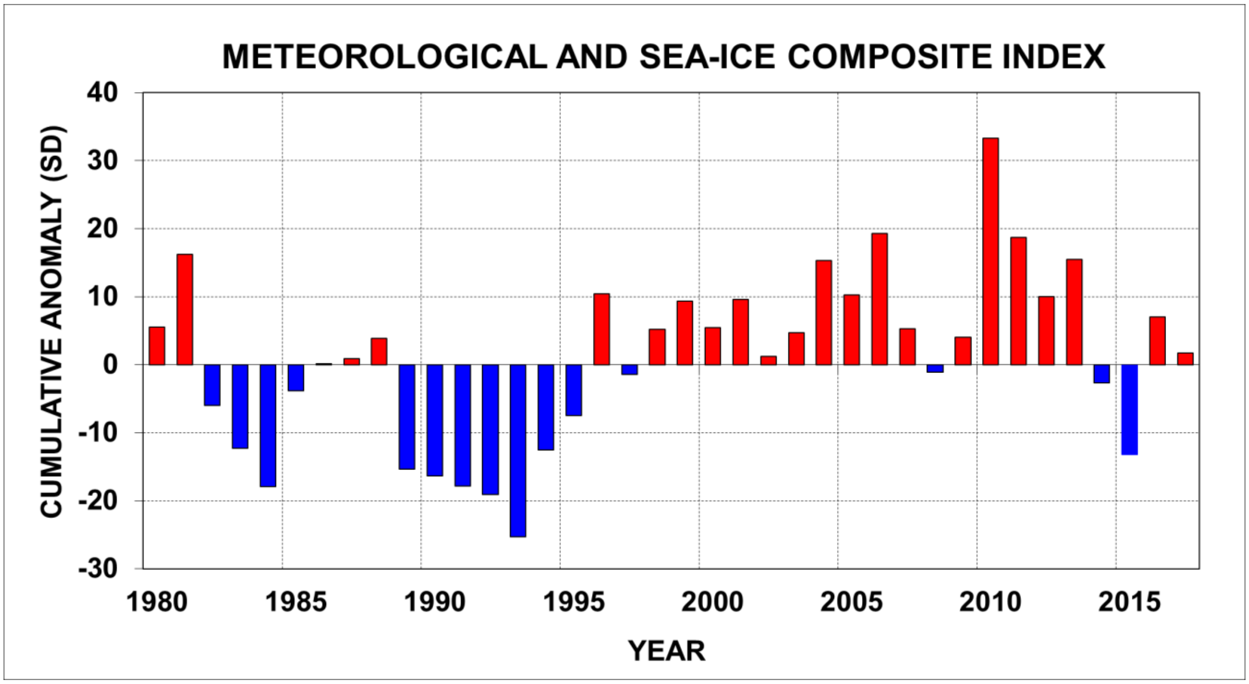

Fig. 11 Meteorological and sea-ice composite index derived by summing the standardized anomalies from Fig. 4.

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, the Labrador Sea and West Greenland. We used this data set from 1981 to 2010 and in more recent years (2011-2017) we use data from NOAA and EUMETSAT satellite data 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 (1997-2012) 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 south of Hamilton Bank in May and June when values ranged from 1-3°C below normal in some areas. The most significant positive anomaly in 2017occurred in September when values were either near normal to as high as 1.9°C above normal on the Northeast Newfoundland Shelf.

Annual SST anomalies varied about the mean in most areas, with 11/16 sub-areas with reporting values within ±0.5 SD, with no overall pattern. The most significant negative/positive anomaly occurred in Hudson Strait/Flemish Pass where values were -1.5/1.2 SD from the mean, respectively (Figure 15). A composite index together with individual series of annual values shows an increasing trend 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 and 2017 but remained below normal in many areas (Figure 16).

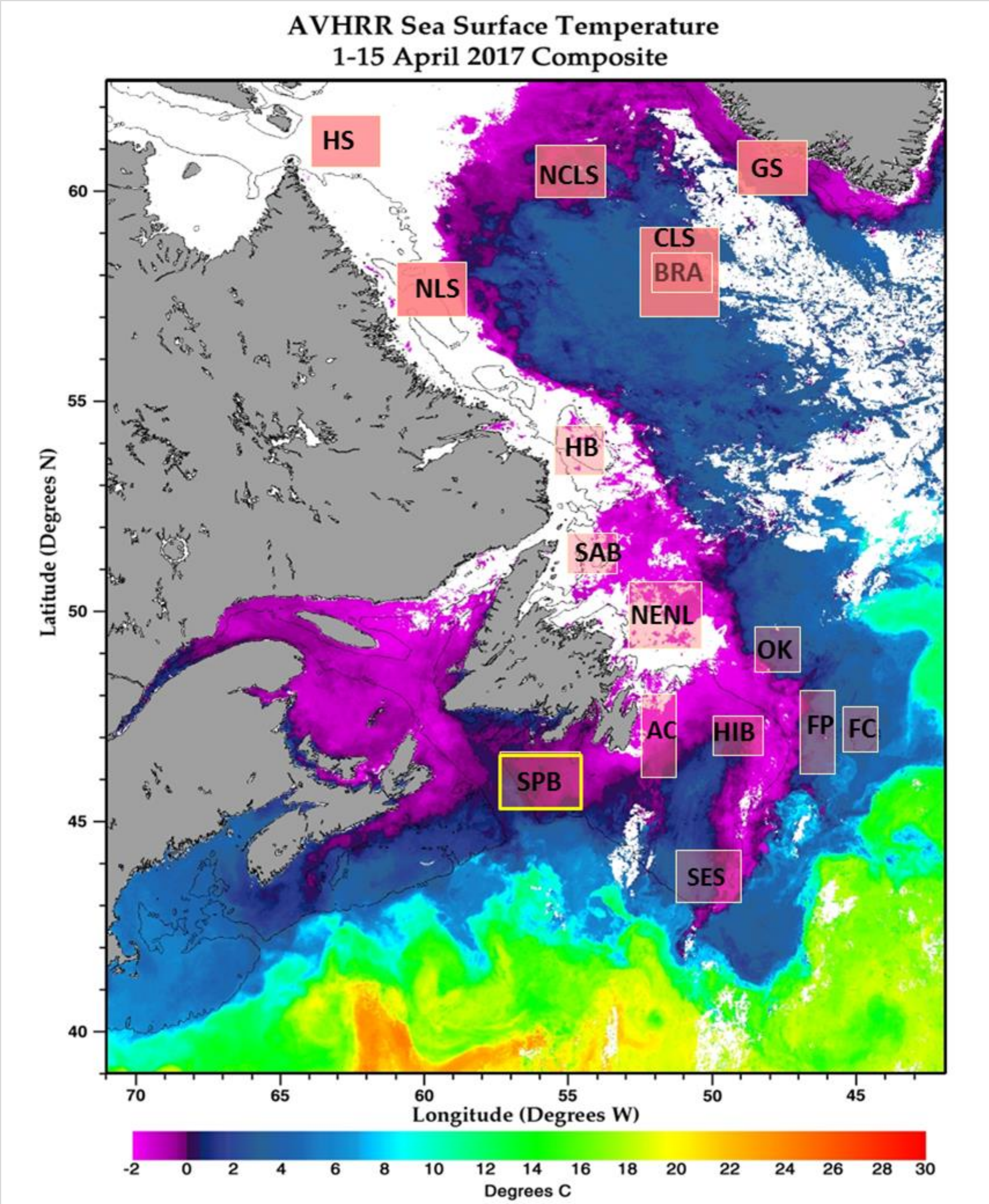

Fig. 12. Map showing the April 1-15 SST and sea-ice extent for 2017 and the subareas where SST time series were constructed for the Northwest Atlantic. (SST map courtesy of the Marine Ecosystem Section, BIO).

REGION	J	F	M	A	M	J	J	A	S	O	N	D
WEST GREENLAND SHELF (GS)	0.0	-0.1	1.0	0.7	0.6	-0.1	-0.8	-0.7	0.5	0.9	0.0	0.3
NORTH CENTRAL LAB SEA (NCLS)	-0.3	-0.9	-1.0	-1.4	-1.3	0.1	-0.2	0.7	1.0	-0.2	0.3	0.1
CENTRAL LAB SEA (CLS)	0.0	0.0	0.0	0.4	0.3	0.9	0.0	0.8	1.0	-0.1	-1.0	-0.7
BRAVO (BRA)	0.0	0.0	0.0	0.5	0.4	1.2	0.0	1.0	1.2	-0.2	-1.3	-0.9
HUDSON STRAIT (HS)	-0.9			-0.4	-0.3	-0.3	-1.2	-0.7	-0.4	-0.2	-0.7	-0.6
NORTHERN LAB SHELF (NLS)	-0.3	0.0	-0.2	-0.2	-0.4	0.8	0.4	-0.4	0.6	0.1	0.2	-0.2
HAMILTON BANK (HB)	-0.4	-0.2	-0.4	-0.6		0.6	-0.1	0.5	1.2	0.0	0.2	0.2
ST ANTHONY BASIN (SAB)	-0.2	-0.6	-0.3	-0.5	-0.6	-1.1	-0.1	0.4	1.4	-0.3	0.2	0.2
NE NF SHELF (NENS)	0.3	-0.3	-0.4	-0.7	-1.2	-1.7	0.0	1.2	1.9	-1.0	0.3	-0.2
ORPHAN KNOLL (OK)	0.8	0.5	-0.2	-0.2	0.1	-1.1	-0.2	0.4	1.2	0.9	0.7	0.0
FLEMISH CAP (FCAP)	-0.3	-0.4	-0.3	0.2	-0.4	-1.9	-0.9	-0.5	0.1	-0.7	-0.5	-0.3
FLEMISH PASS (FP)	1.4	1.1	1.6	2.2	1.3	-0.6	0.1	0.2	1.2	0.4	0.8	1.4
SE SHOAL (SES)	0.0	0.2	-0.4	-0.3	-1.5	-2.6	-1.1	-0.8	0.0	-0.4	-0.7	-1.1
HIBERNIA (HIB)	0.2	-0.2	-0.3	-0.1	-1.4	-2.9	-1.0	-0.3	0.3	-0.9	-0.4	-0.2
AVALON CHANNEL (AC)	0.8	0.3	-0.2	-0.8	-1.5	-1.7	-0.3	0.6	1.3	0.3	1.3	0.7
GREEN-ST PIERRE BANK (SPB)	0.6	0.5	0.1	-0.3	-1.3	-1.7	-0.8	0.4	0.7	1.7	2.4	0.6

Fig. 13. Monthly SST anomalies for 2017 derived from the data within the boxes shown in Figure 12. The anomalies are referenced to the 1981-2010 base period.

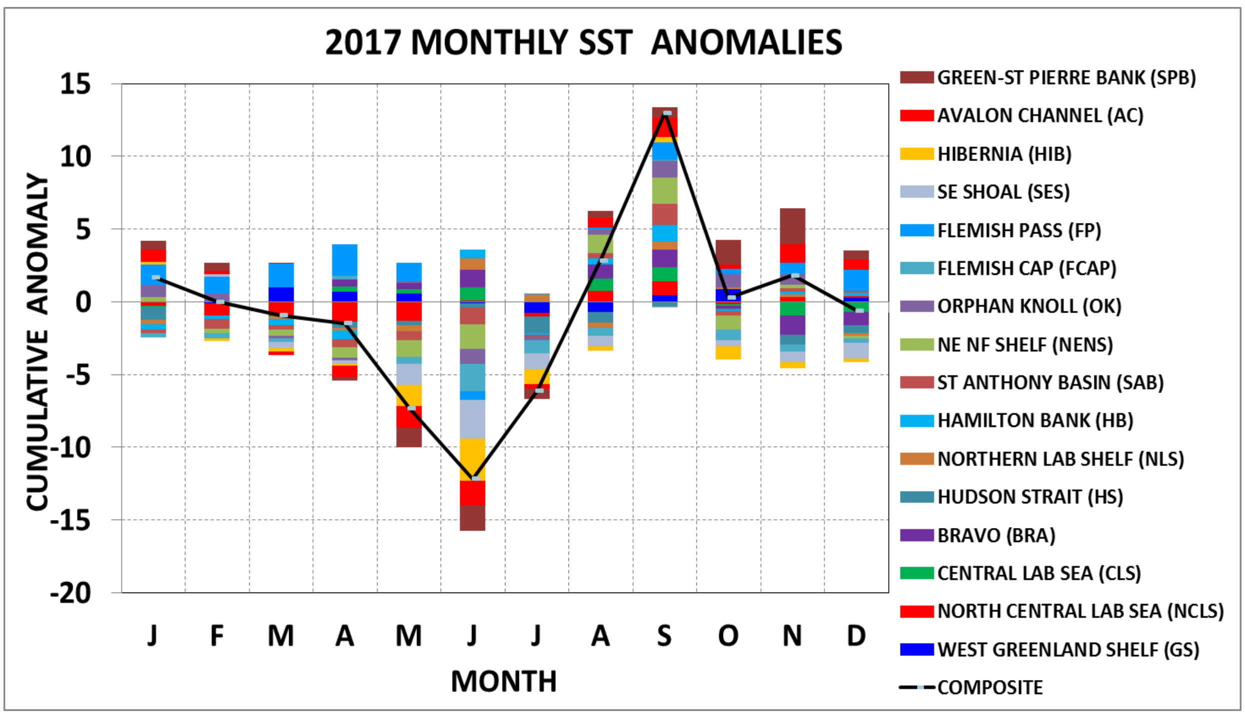

Fig. 14. Cumulative SST anomalies for 2017 derived from the data within the boxes shown in Fig. 12 and displayed in Fig. 13. The anomalies are referenced to the 1981-2010 base period.

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	17	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	1.0	0.2	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	0.3	-0.2	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	-0.3	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	0.4	0.2	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	0.5	0.2	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	-1.4	-0.5	-0.7	-0.5	-1.5	-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	-0.2	0.7	0.1	0.3	0.1	0.46	0.48
HAMILTON BANK (HB)			-0.9	-0.7	-1.3	-0.7	-0.7	-0.7	-0.2	-0.9	-0.8	-1.3	-0.9	0.2	0.3	1.2	-1.3	-0.6	0.6	-0.4	1.4	0.3	-0.7	1.1	1.0	1.2	1.8	-0.4	1.6	-0.1	1.7	1.0	1.9	-0.4	0.6	0.0	-0.4	0.1	1.44	0.51
ST ANTHONY BASIN (SAB)			-0.6	-0.3	-0.6	-0.9	-0.5	-0.4	0.0	-0.4	-0.6	-1.5	-1.5	-0.6	0.3	-0.7	-0.7	-0.8	0.7	0.2	1.1	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	-0.4	-0.2	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	-0.4	-0.2	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	-0.1	0.3	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	-1.0	-0.5	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	-0.8	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	0.0	-0.7	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	-0.2	-0.7	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	0.3	0.1	5.01	0.69
GREEN-ST PIERRE BANK (SPB)			-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	2.0	1.1	1.0	0.1	0.9	0.3	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.

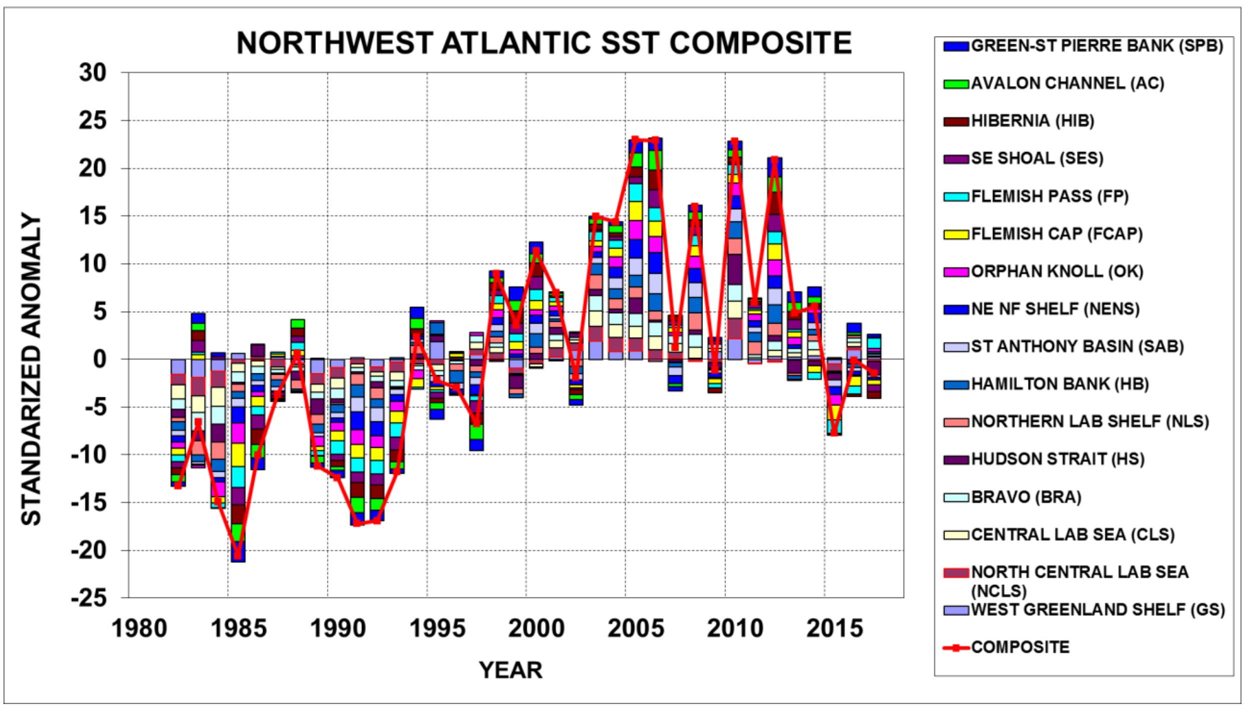

Fig. 16. Standardized annual SST anomalies from the subareas on the NL shelf presented in Fig. 15. The solid red line represents the composite sum.

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 35 times (31 CTD profiles, 4 XBT profiles) during 2017. No observations were available for January and February and only one XBT temperature profile was available for March. In addition, a total of 29, 93, 83, 20, 63 and 12 CTD profiles were collected from a Viking buoy deployment in June, July, August, September, October, November and December, respectively. Although 31 of these only profiled to 40 m depth in late November and early December.

Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies based on all CTD and XBT temperature and salinity data available for 2017 are displayed in Figures 17 and 18. The temperature and salinity anomalies are based on water column profile data collected at a temporal resolution ranging from daily to monthly, therefore some of the high frequency structure evident in these maps may be due to under sampling of tidal influences and other oceanographic effects such as internal waves.

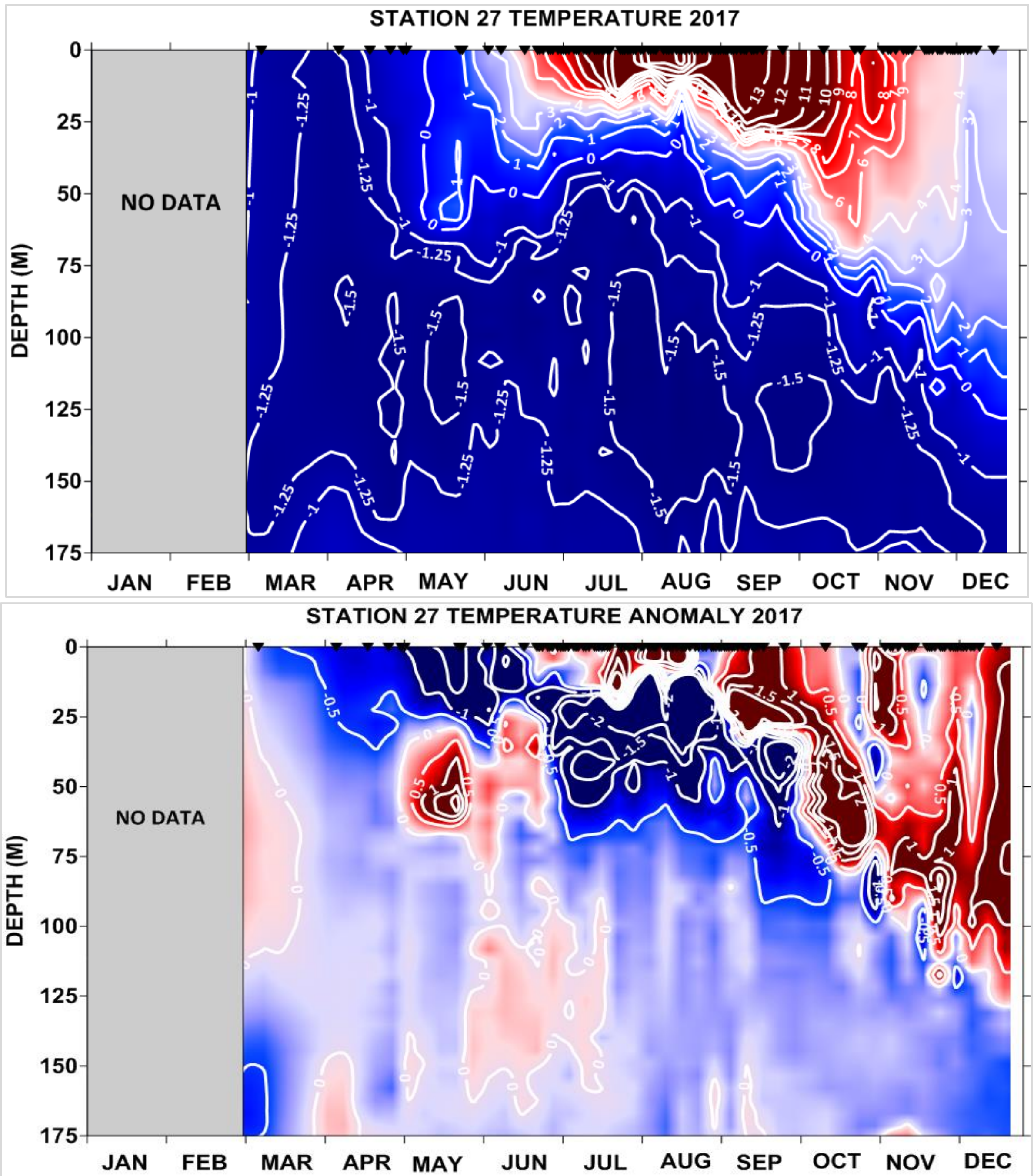

Fig. 17. Contours of temperature (°C) and temperature anomalies (°C) as a function of depth at Station 27 during 2017. The symbols at the top indicate sampling times.

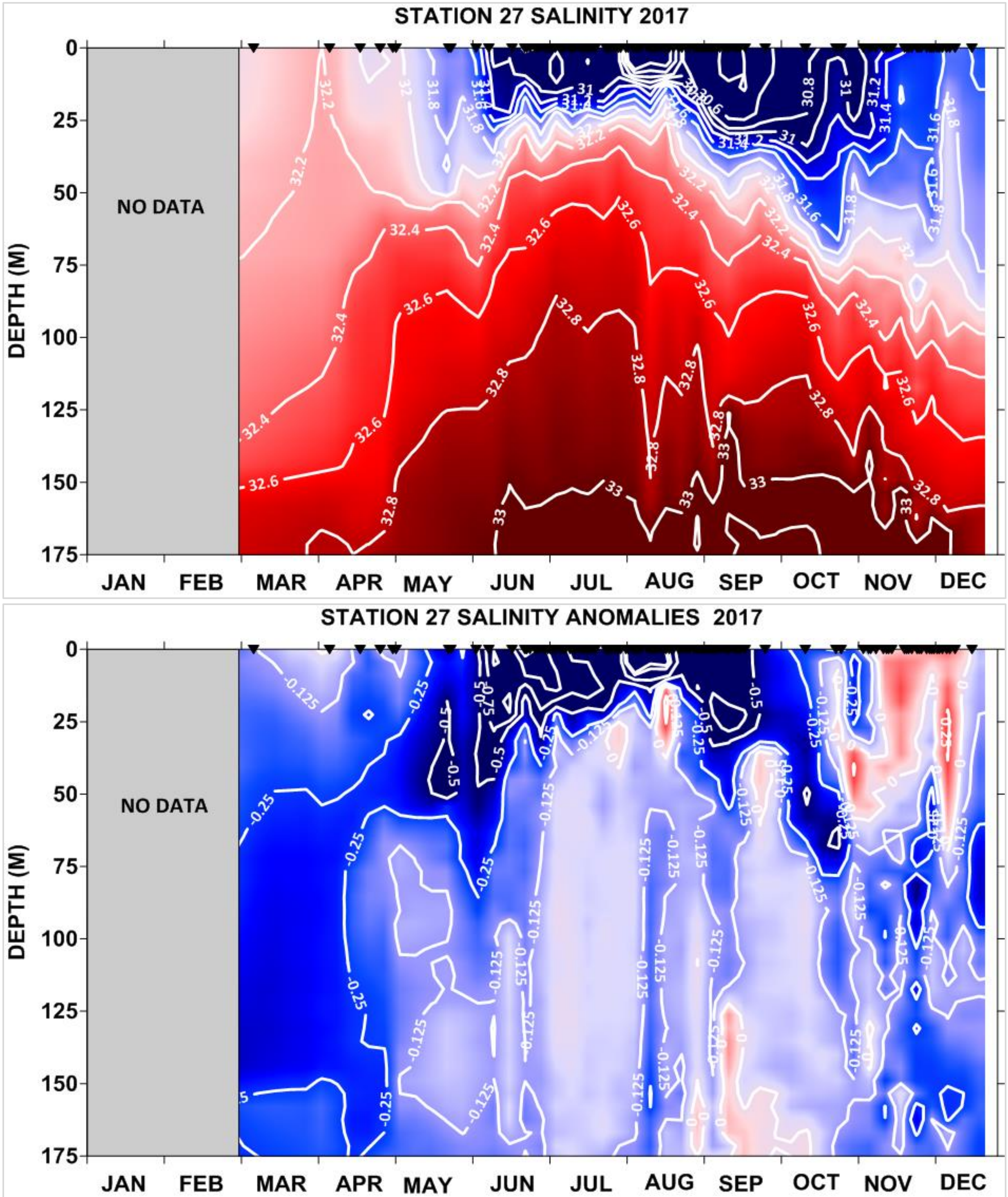

Fig. 18. Contours of salinity and salinity anomalies as a function of depth at Station 27 for 2017. The symbols at the top indicate sampling times.

The water column at Station 27 was near-isothermal during March and April with temperatures <-1°C. These values persisted throughout the year below about 100 m as the cold intermediate layer (CIL) extended to the bottom. Upper layer temperatures warmed to about 3°C by late-May and to about 15°C by early-August, after which the fall cooling commenced with temperatures decreasing to <4°C by December.

The below normal surface temperatures observed during spring propagated deeper into the water column during the summer reaching near 100 m depth by early fall. These values resulted from the shallow heat penetration during the same period. However, temperature anomalies in the seasonally heated upper water column during late summer and throughout the remainder of the year were strongly positive with values in the top 100 m of the water column reaching >1°C above normal. Temperature values in deeper water >100 m ranged from near-normal to below normal particularly during the fall months.

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. In 2017 this feature was particularly intense and occurring much earlier in the year resulting in intense negative salinity anomalies ranging from 0.5 to 1 below normal during the summer months when minimum salinities of about 30 were observed. In general, salinities were below normal over most of the water column in 2017 with the exception of the upper layer late in the year (Figure 18, bottom panel).

The annual surface temperature at Station 27 was 0.4°C (0.6 SD) above normal similar to the 2016 value. 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 four 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, increased to 0.7 SD above normal in 2015 and 2016 and were about normal in 2017(Figure 20).

The layer of cold water with temperatures <0°C on most of the NL shelf, commonly referred to as the cold intermediate layer (CIL) which is 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 the water column 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 varied slightly about the mean (+0.3 SD in 2017) (Figure 20).

Annual surface and bottom salinities at Station 27 were below normal in 2017 by 1.6 SD the lowest values since the early 1990s (Figure 21). Water column averaged values were also below normal by about 1.5 SD over both the 0-50 m range and 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.

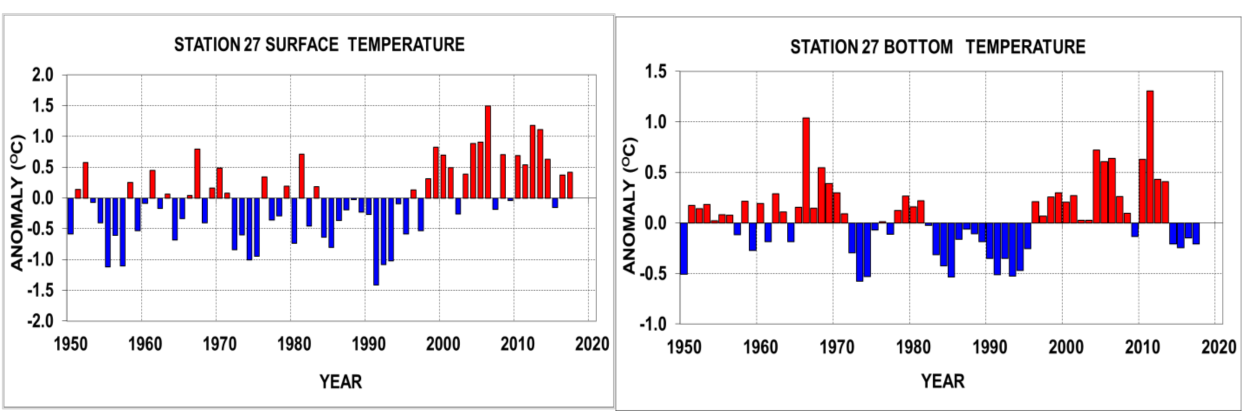

Fig. 19. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean.

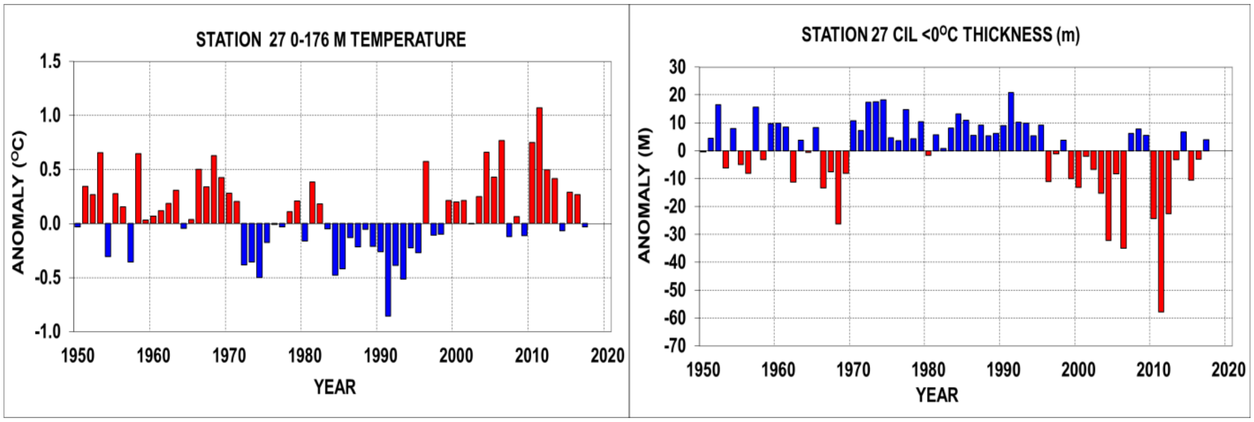

Fig. 20. Annual Station 27 vertically averaged (0-176 m) temperature and CIL (<0°C) thickness anomalies referenced to the 1981-2010 mean.

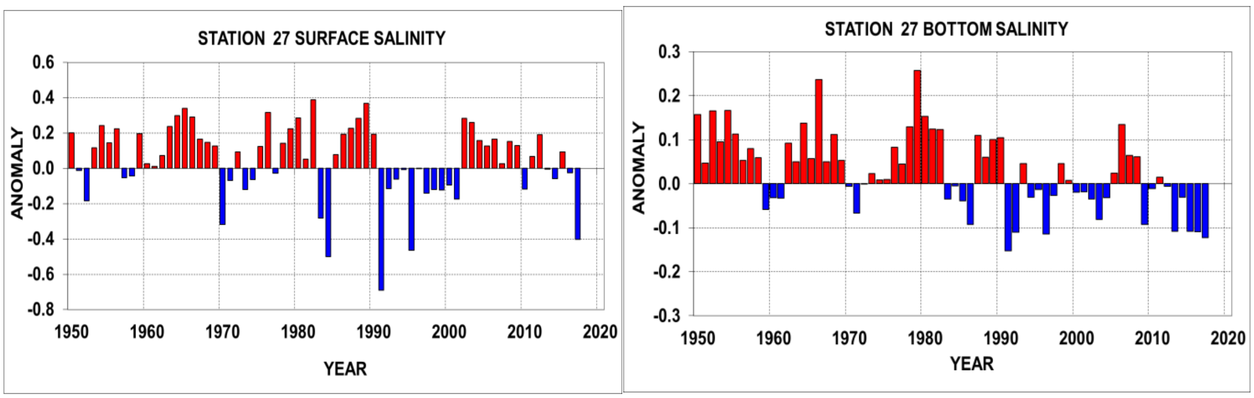

Fig. 21. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean.

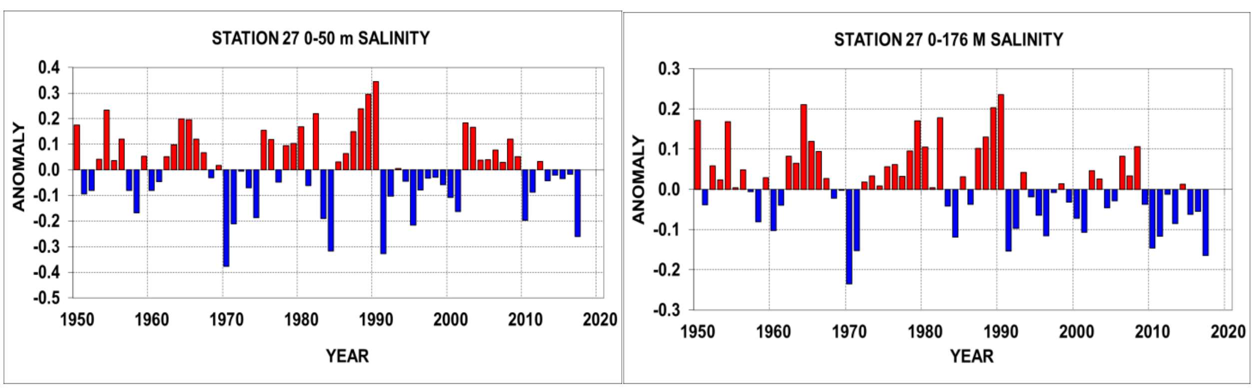

Fig. 22. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean.

STANDARD SECTIONS

In the early 1950s, several countries under the auspices 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 of Fisheries and Oceans Canada, 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 2017, the SWSPB, SESPB and SEGB sections were sampled in April, the FC and BB sections during April, July and November/December, the WB section in July and the SI section during July and November. Most fall sections, including part of the BB section, normally sampled were not during 2017 due to limited ship time. In this manuscript we present the summer cross sections of temperature and salinity and their anomalies along the FC, BB and SI sections to represent the vertical temperature and salinity structure across the Newfoundland and Labrador Shelf during 2017.

Temperature and Salinity Variability

The water mass characteristics observed along the standard sections crossing the NL Shelf (Figure 2) are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1.5°C - 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 2017 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.

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.

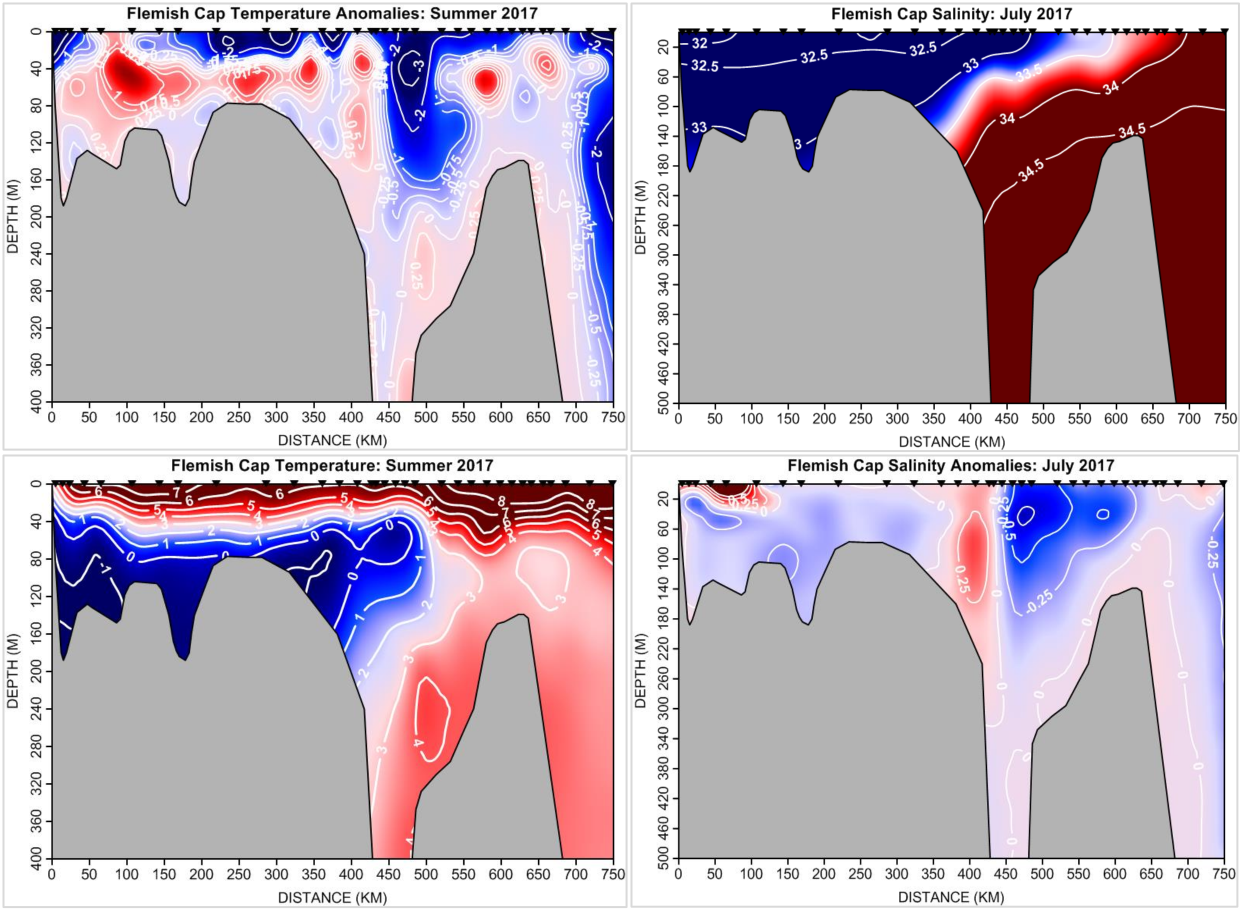

Fig. 23. Contours of temperature (°C) and salinity and their anomalies along the Flemish Cap (47°N) section (Fig. 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top of each panel.

During 2017 the below normal near-surface temperatures along the Flemish Cap section penetrated deeper in to the water column in the Flemish Pass and regions to the east of the Cap with values up to 2°C below normal (Figure 23, top right panel). Intermediate waters over the Grand Banks were above normal while bottom temperatures were near normal along the section. Temperatures along the Bonavista section were predominately below normal in the inshore regions. Offshore upper layer temperatures were warmer than normal (>3°C in some areas) while deeper waters were about normal (Figure 24, top right panel). Along the Seal Island section temperatures were below normal in the intermediate waters over the shelf and in the offshore Labrador Current at the shelf break where they were 1° -2°C below normal. In the offshore slope water temperatures were above normal by up to 2°C near the surface.

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 2017, salinities along the FC section varied about the mean with below normal values reaching 0.5 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 some isolated areas of above and below values in the near surface layer (Figure 24, bottom right panel). Along the Seal Island section near-surface salinities varied about the mean with a significant negative anomaly at the shelf break in the offshore branch of the Labrador Current (Figure 25, bottom right panel).

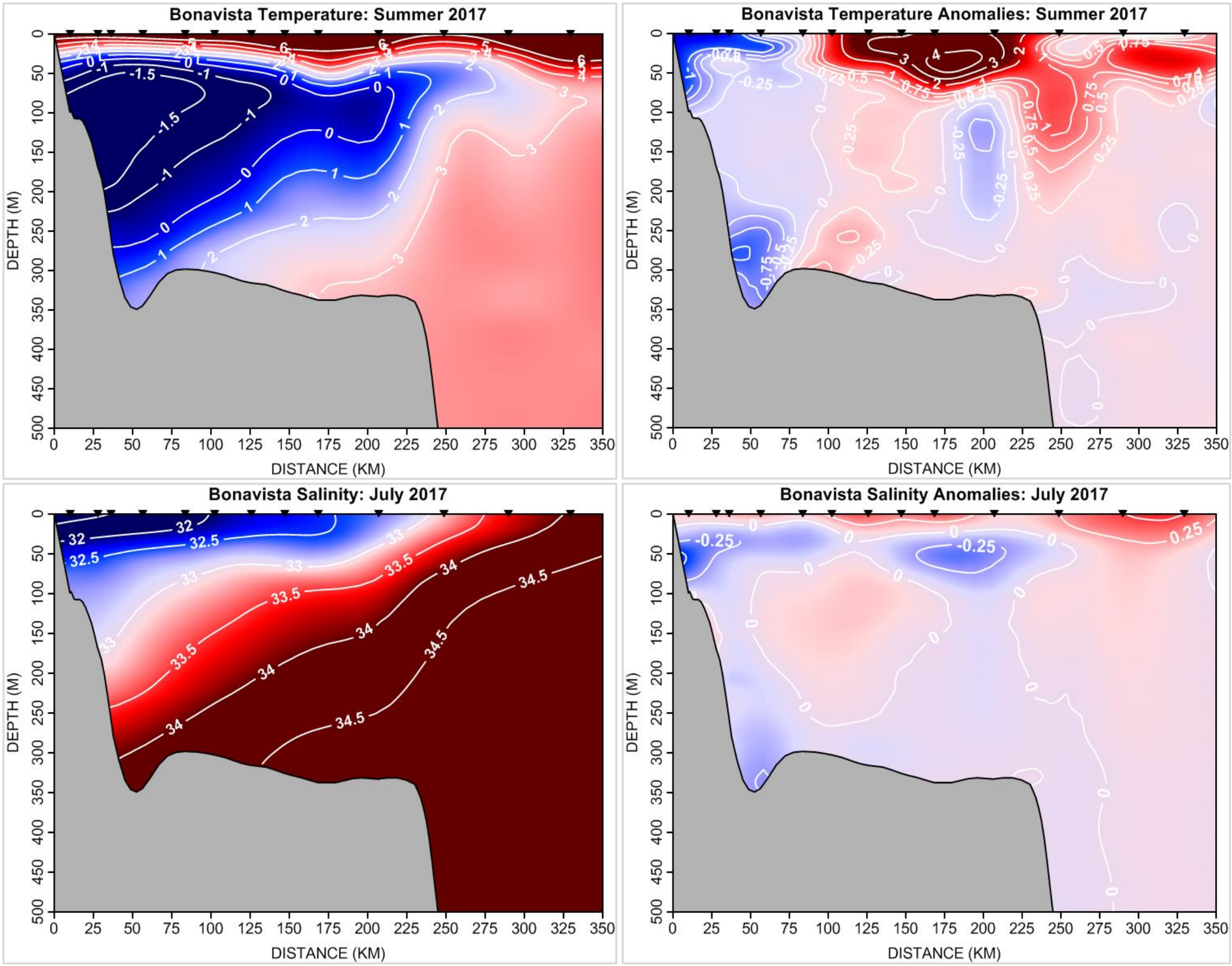

Fig. 24. Contours of temperature (°C) and salinity and their anomalies along the Bonavista section (Fig. 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top of each panel.

Cold-Intermediate-Layer Variability

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. The CIL area anomalies during the summer of 2017 were above normal along the WB and SI sections (implying colder shelf water conditions), about normal along the BB section but below normal on the Grand Banks along the FC section.

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 time series. Most temperature and salinity indices shown, except along the FC section, were either near-normal or below normal by up to a maximum of -1.6 SD in salinity on the BB section. 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 with the index remaining below normal up to 2017 in contrast to the record high value in 2011. The composite salinity index (Figure 29) shows, except for 2016, fresher-than-normal conditions during the previous 8-years with the 2017 value the lowest since 1991.

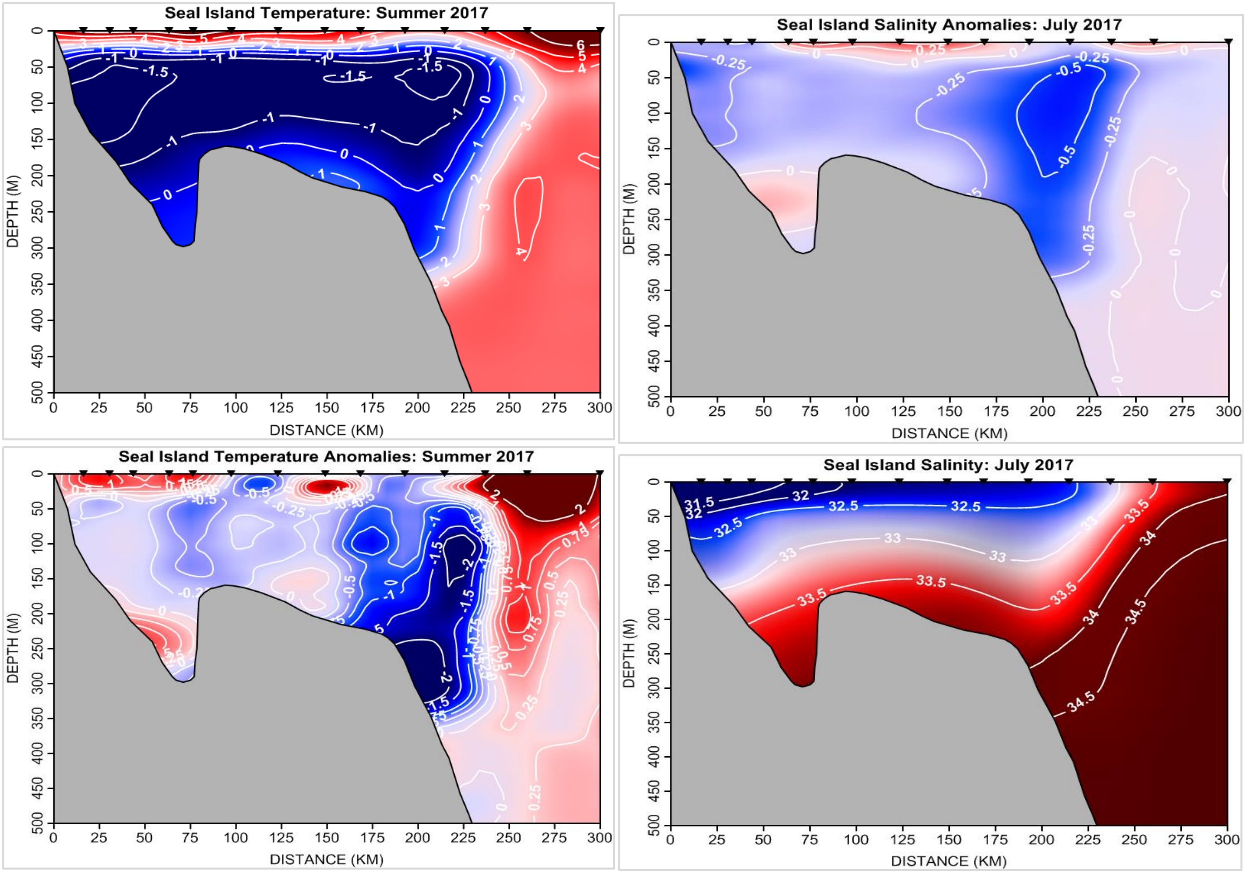

Fig. 25. Contours of temperature (°C) and salinity and their anomalies along the Seal Island section (Fig. 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top of each panel.

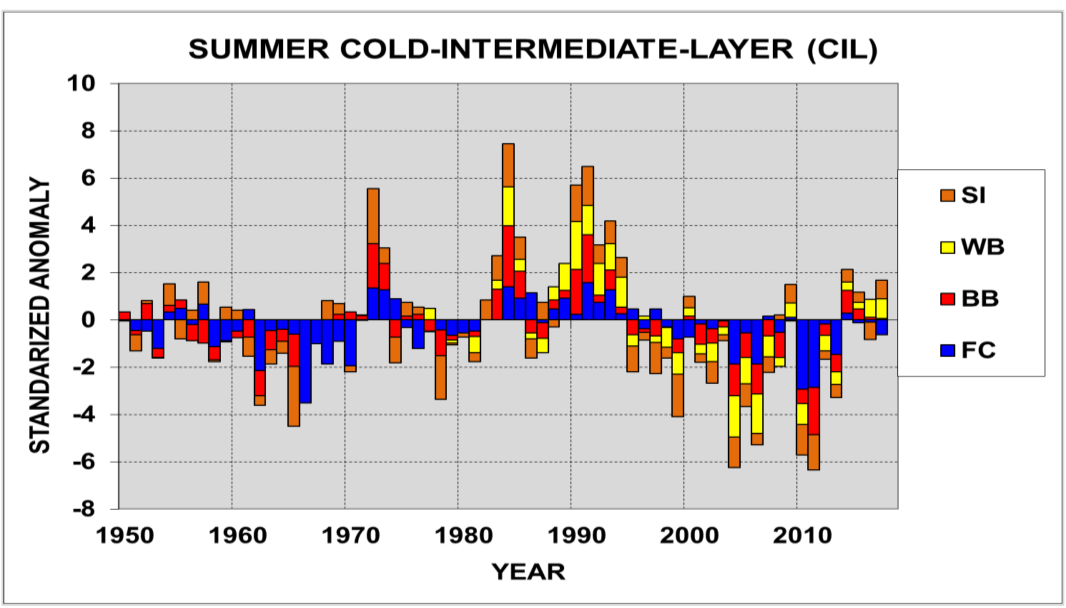

Fig. 26. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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	17	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	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	-1.0	-0.88	0.21
MINIMUM CIL TEMPERATURE	0.0	1.3	0.1	-1.3	-1.2	-1.0	0.8	0.2	0.1		-0.9	-1.2	-0.9	-1.3	-0.7	1.9	-0.4	-0.6	-0.4	1.0	-0.6	0.9	-0.6	0.6	2.2	0.9	1.1	-0.2	-0.7	-0.3	1.1	2.6	-0.5	1.4	-1.0	0.1	-0.5	-0.7	-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	-0.5	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	-1.2	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	-0.8	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	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	-0.3	-0.93	0.15
MINIMUM CIL TEMPERATURE		1.5		-1.8	-1.5	-0.8	0.7	0.7	0.8	-0.9	-0.8	-1.1	-0.6	-1.1	-0.8	-0.2	0.4	-0.5	-0.5	0.1	-0.1	0.7	0.1	-0.2	2.0	1.1	2.2	0.1	-0.2	-0.5	1.0	2.8	-0.7	0.6	-0.8	-0.9	-0.5	-0.8	-0.93	0.15
MEAN SECTION TEMPERATURE		0.2		-1.1	-1.8	-1.4	0.1	0.5	0.0	0.1	-1.6	-1.6	-1.3	-1.0	-0.9	0.0	-0.4	0.5	0.4	0.8	0.3	0.2	0.2	0.5	1.7	1.4	1.6	0.8	1.6	-0.1	0.4	1.9	1.0	0.0	-0.9	-0.6	-0.2	0.4	-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	-0.7	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	-1.6	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	-0.6	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	0.6	-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	0.4	-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	-1.1	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	-0.2	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	-0.7	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.

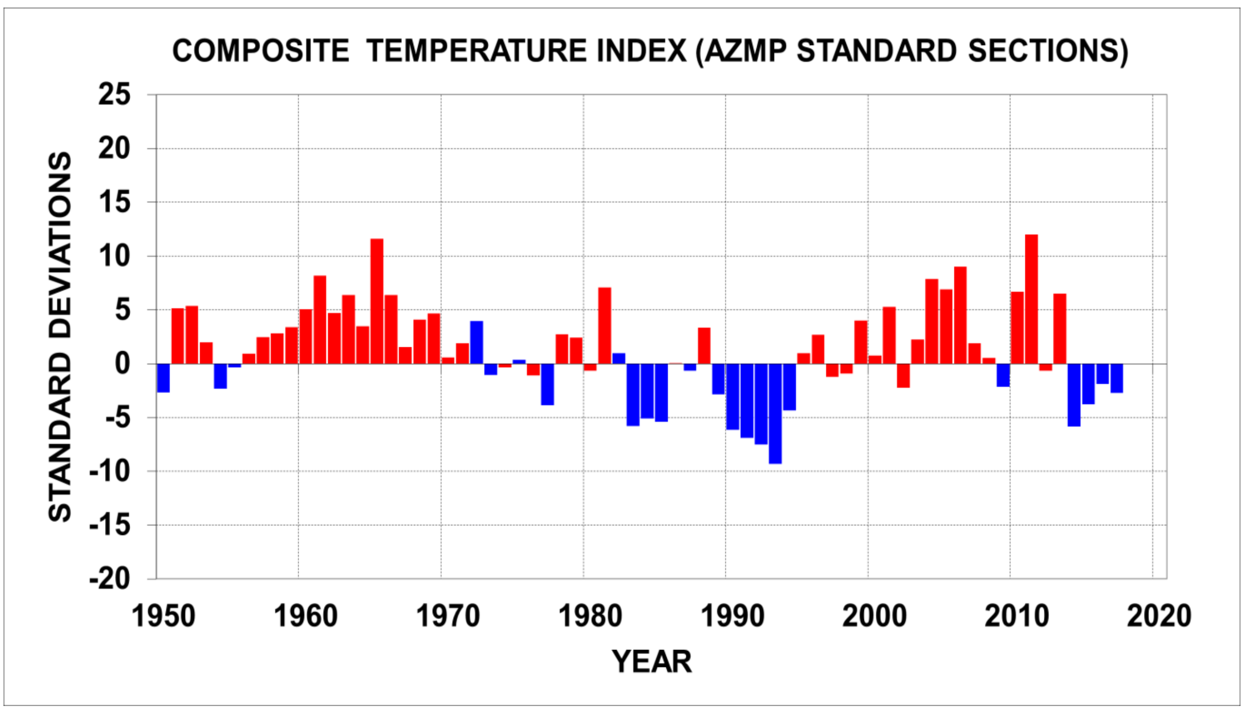

Fig. 28. Composite temperature index derived from data collected along standard cross-shelf sections shown in Fig. 27.

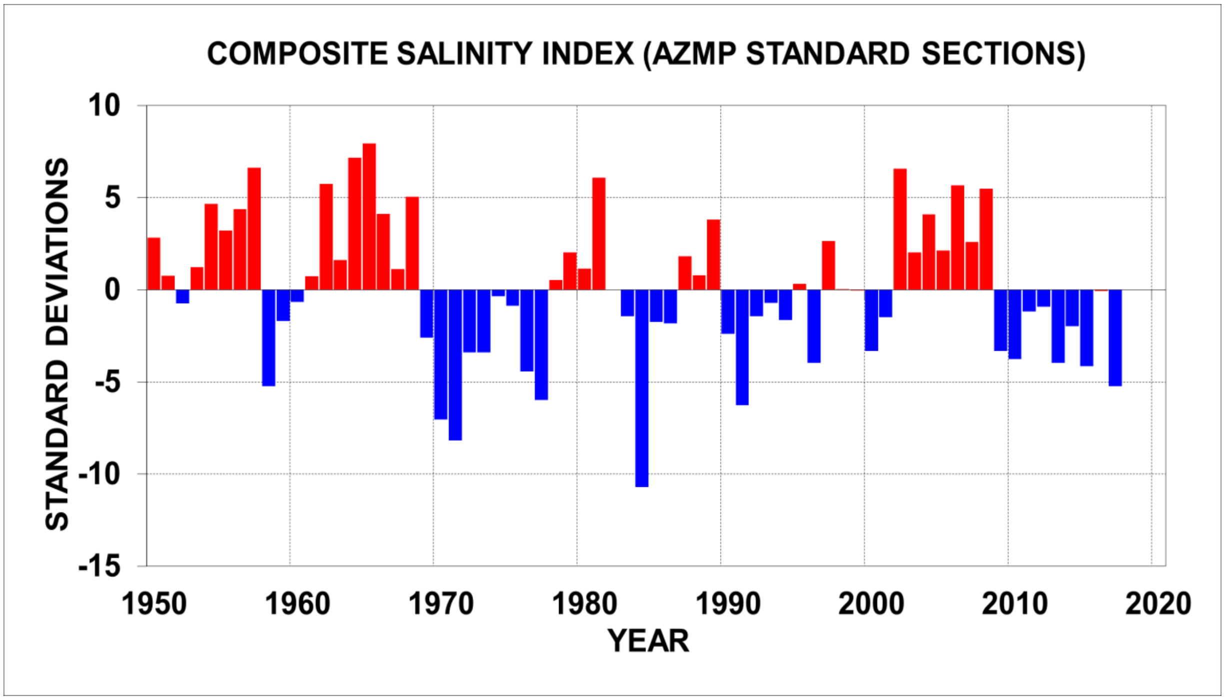

Fig. 29. Composite salinity index derived from data collected along standard cross-shelf sections shown in Fig. 27.

Labrador Current Variability

The circulation pattern through most of the standard NAFO/AZMP sections in the Newfoundland and Labrador area is dominated by the south-eastward flowing Labrador Current, which floods the eastern shelf areas with cold, relatively fresh sub-polar water. This flow can significantly affect physical and biological environments off Atlantic Canada on seasonal and annual time scales. The shelf current originates near the northern tip of Labrador where outflow through Hudson Strait combines with the east Baffin Island Current and flows southeastward along the Labrador coast and is strongly influenced by the seabed topography, following the various cross shelf saddles and inshore troughs. A separate offshore branch flows south eastward along the western boundary of the Labrador Sea. This current is part of the large-scale Northwest Atlantic circulation consisting of the West Greenland Current that flows northward along the West Coast of Greenland, a branch of which turns westward and crosses the northern Labrador Sea forming the northern section of the northwest Atlantic sub-polar gyre.

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

In this section, we present an analysis of the circulation and transport through the Seal Island and Flemish Cap sections (Figure 2) based on direct current measurements using vessel mounted 75 kHz Acoustic Doppler Current Profilers (ADCP) at 8 m resolution with an effective range of about 620 m. All archived data were used to compute currents and transport along the standard Flemish Cap (47°N) section for the years 2008-2017 for the spring and summer period and for the summer period along the Seal Island Section. The current measurements were rotated by 30° along the Seal Island section to align with the axis of the Labrador Current. The ADCP data were collected using Teledyne RDI VmDas and processed using the CODAS3 software suite developed by the University of Hawaii. The data were quality controlled with a percent good threshold of 70-80%. Absolute currents were determined by subtracting ship motion as determined by the ship's 3D DGPS system. Currents were then de-tided using tidal predictions obtained from a high-resolution numerical 2-dimensional tidal model.

The Labrador Current through 47°N, which exhibits considerable annual and seasonal variability, varies spatially from about 50-100 km wide at shelf break of the Grand Bank and east of Flemish Cap. During spring, the main branch of the Labrador Current is about 100 km wide, centred over the 400 m isobath with mean southward currents of about 20 cm/s and peak values >40 cm/s (Figure 30). Average currents are weak and highly variable over most of the Grand Banks and in the Flemish Pass regions. During the spring of 2017 southward currents were generally stronger than average in the Avalon Channel area. At the shelf break and Flemish Pass regions peak currents were in the 30-45 cm/s range however the width of the shelf break jet appeared wider than average at approximately 150 km. Current speeds east of the Flemish Cap were weaker than the 2008-2016 average (Figure 30, bottom panel).

During the summer of 2017, the Labrador Current on average was generally weaker and narrowed compared to spring over the shelf break at about 60 km wide with mean speeds <15 cm/s and peak values of about 35 cm/s (Figure 31, top panel). It was generally weaker than the 2008-2016 average with a narrow jet over the shelf break of about 50 km wide with mean speeds <15 cm/s and peak values of about 30 cm/s. In 2017, the current system appears weaker than the average with the Labrador Current restricted to a narrow jet at the edge of the Grand Bank and at the extreme eastern edge of the section. In general northward flowing water during the summer of 2017 was more prominent over the Grand Banks and particularly over the Flemish Cap area (Figure 31, bottom panel).

The average (2008-2017) summer current through Seal Island section consists of a well-defined coastal branch with peak speeds ranging from 15-20 cm/s extending to 60 km offshore. Over Hamilton Bank average currents are weak and variable. At the shelf break a strong baroclinic component of the Labrador Current is centred at about 225 km offshore over the 500 m isobath with peak upper layer speeds of 30 cm/s. Further offshore the current extends seaward of the 2500 m isobath with typical speeds of around 20 cm/s extending deeper than 500 m (Figure 32, top panel). During the summer of 2017 southward currents were generally stronger than average along most of the section with peak inshore speeds of around 35 cm/s at 50 km offshore. At the shelf break a strong baroclinic jet of about 50 km wide with peak upper layer speeds >60 cm/s was centred over the 500 m isobath (Figure 32, bottom panel).

Labrador Current Transport

Volume transport values were computed for the Labrador Current through the Flemish Cap section during spring and summer and through the Seal Island section during the summer. Transport values are presented for the Avalon Channel (0-100 km), Grand Bank Slope (300-450 km) and the eastern Flemish Cap area (625-750 km) of the Flemish Cap section (Figure 33). For the Seal Island section transport values were computed within the shaded areas of Figure 37 for the inshore Labrador Current (0-75 km) and for the offshore current (175-300 km). Currents in the top 15 m of the water column were extrapolated from the values in the first 8 m data bin (16-24 m). Transport values were then calculated by integrating from the surface to the near bottom bin or to the maximum range of 620 m along the section.

Transport values for the Avalon Channel, Grand Bank Slope and east of the Flemish Cap for the spring, and summer are shown in Figures 34 to 36. The Avalon Channel transports show maximum values during the spring of about 1.5 Sv (10^6 m^3/s) and about 1.7 Sv during the summer. In 2017 the spring transport increased over 2016 to the maximum value in the series while the summer value was among the lowest (Figure 34). In the offshore branch at the Grand Bank Slope-Flemish Pass area spring transport values ranged from about 3 Sv in 2009 to 8.4 Sv in 2010, with summer values somewhat lower, ranging from 2.4 to 5.9 Sv. In 2017 spring transport increased over 2016 to 8 Sv while the summer transport decreased to the lowest in the series at 2.4 Sv (Figure 35). In the offshore branch east of the Flemish Cap spring transport values ranged from 2.2 to 13 Sv with summer values ranging from 2 to 11.9 Sv. Both the spring and summer maximum transports occurred in 2015. In 2017, spring transport decreased over 2015 and 2016 values to 3.8 Sv while the summer transport decreased to the lowest in the series at 2 Sv (Figure 36). The total southward transport through the Flemish Cap section in all three regions during the spring and summer of 2017 was 13.5 and 4.6 Sv, respectively.

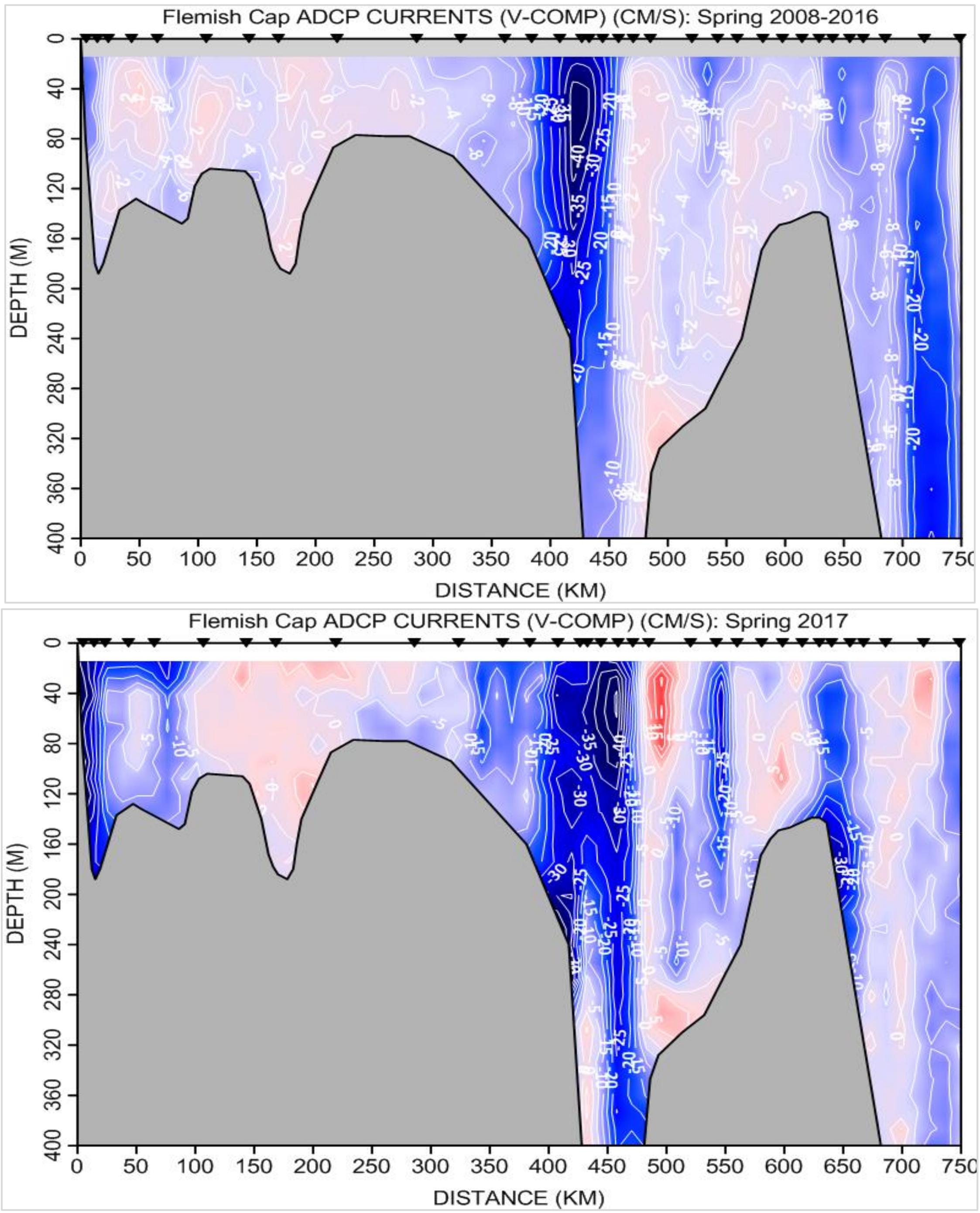

Fig. 30. Average current speeds (cm/s) during the spring (top panel) and for the spring of 2017 (bottom panel) along the Flemish Cap section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

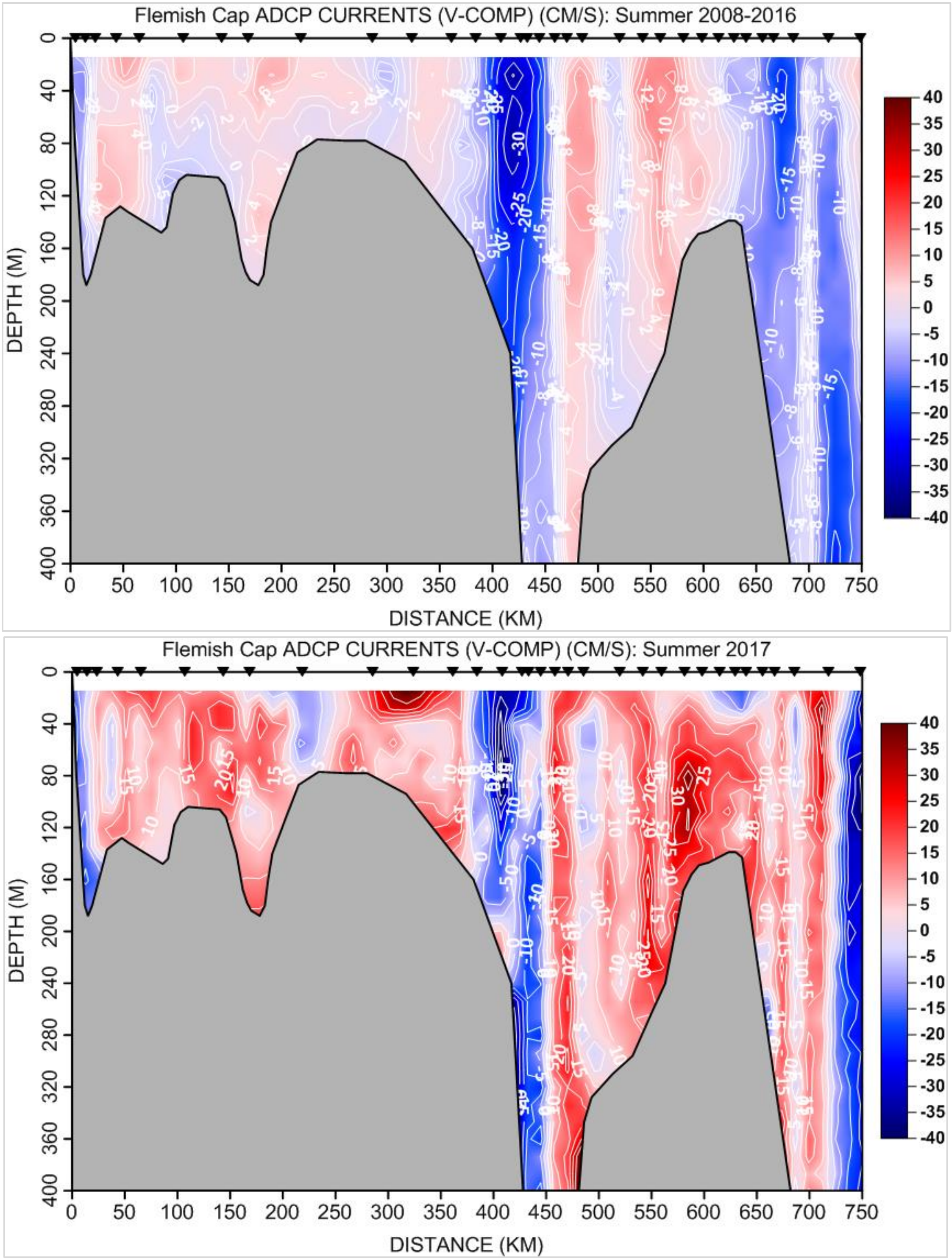

Fig. 31. Average current speeds (cm/s) during the summer (top panel) and for the summer of 2017 (bottom panel) along the Flemish Cap section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

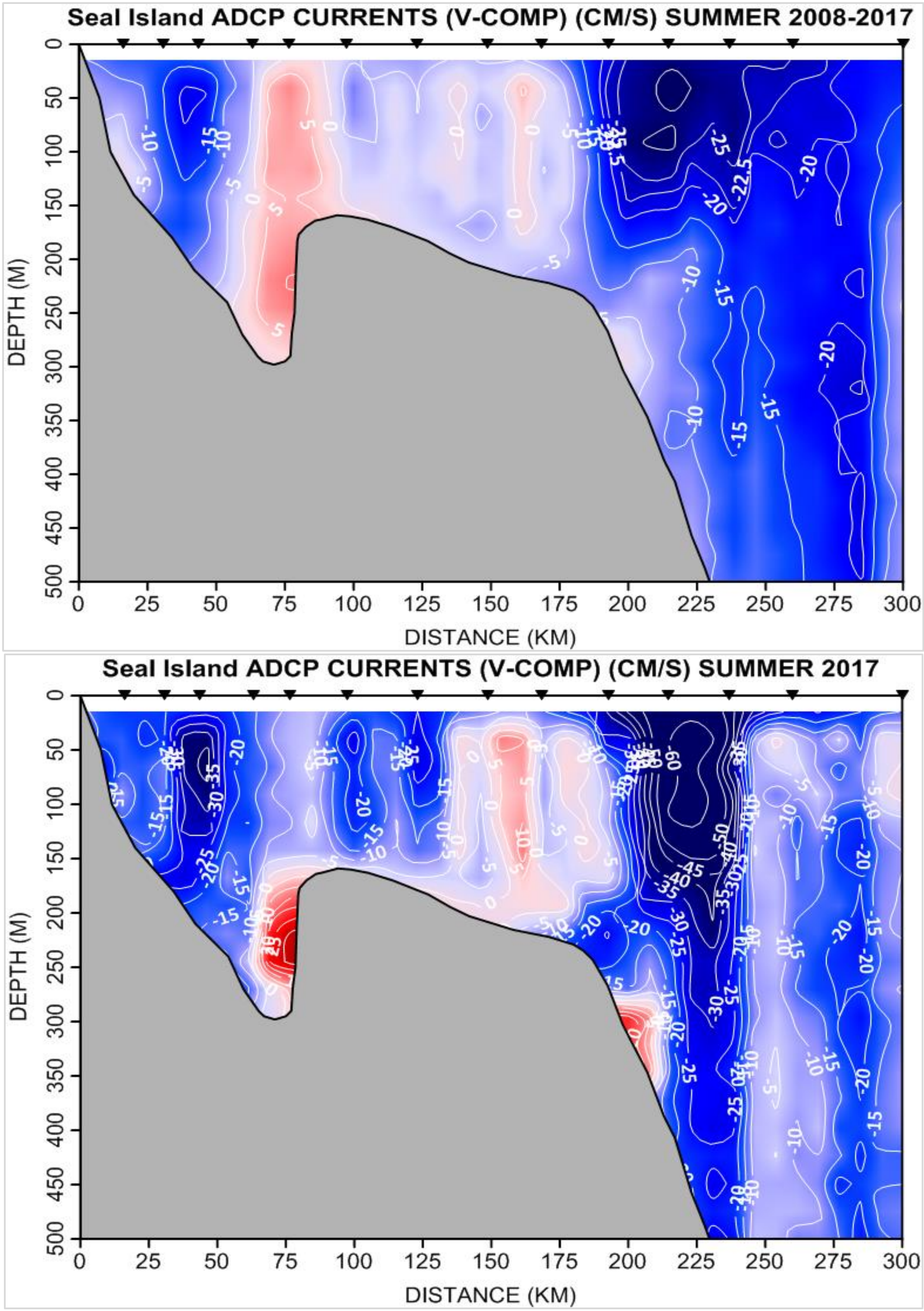

Fig. 32. Average current speeds (cm/s) during the summer (top panel) and for the summer of 2017 (bottom panel) along the Seal Island section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

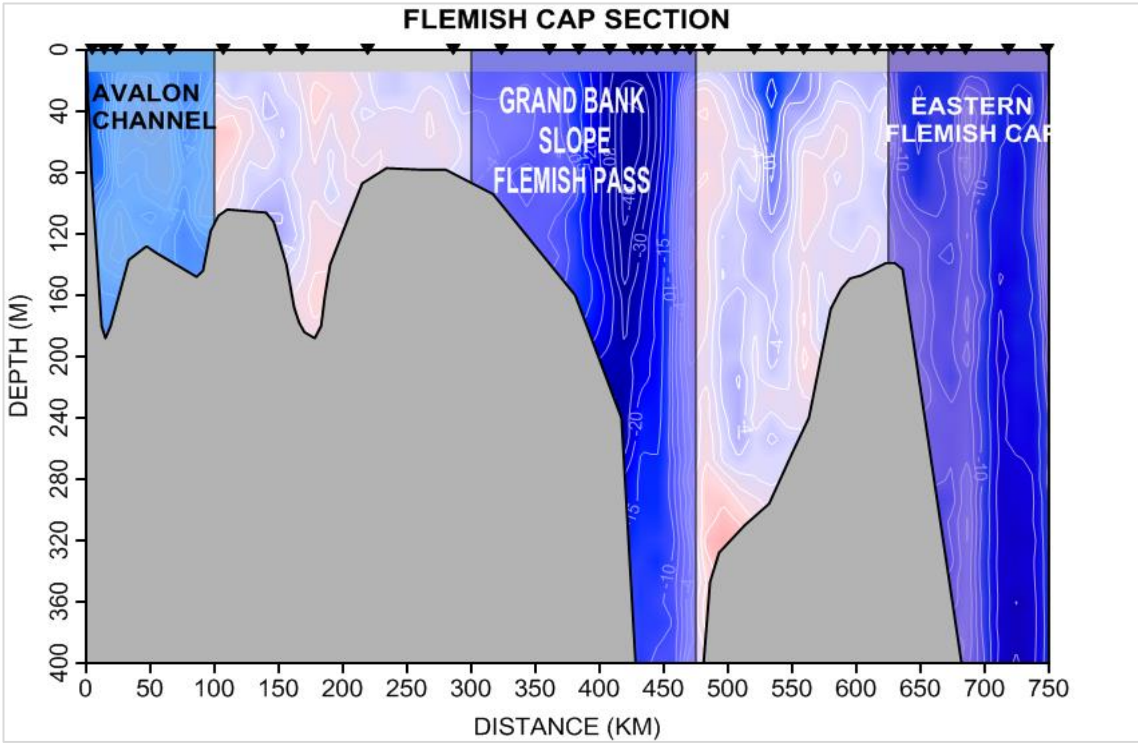

Fig. 33. The Flemish Cap section showing the areas where the Labrador Current transport values were computed. The symbols along the top of the panels are the standard AZMP stations.

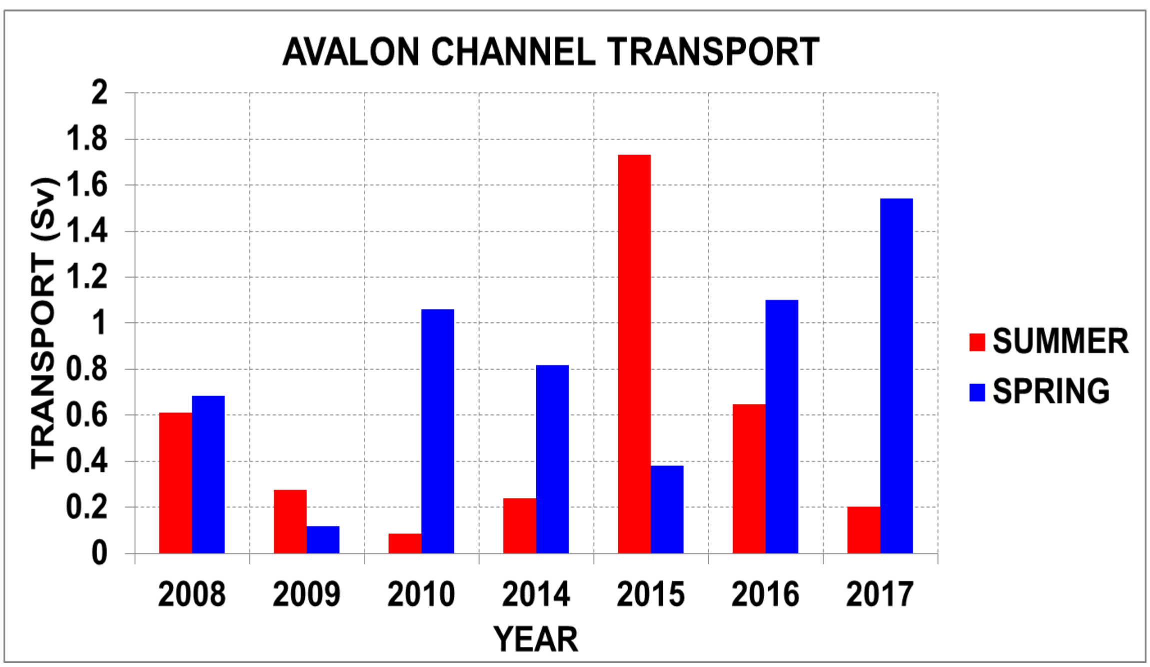

Fig. 34. Transport values (Sv, 10^6 m^3/s) for the Avalon Channel for the spring and summer based on available ADCP data.

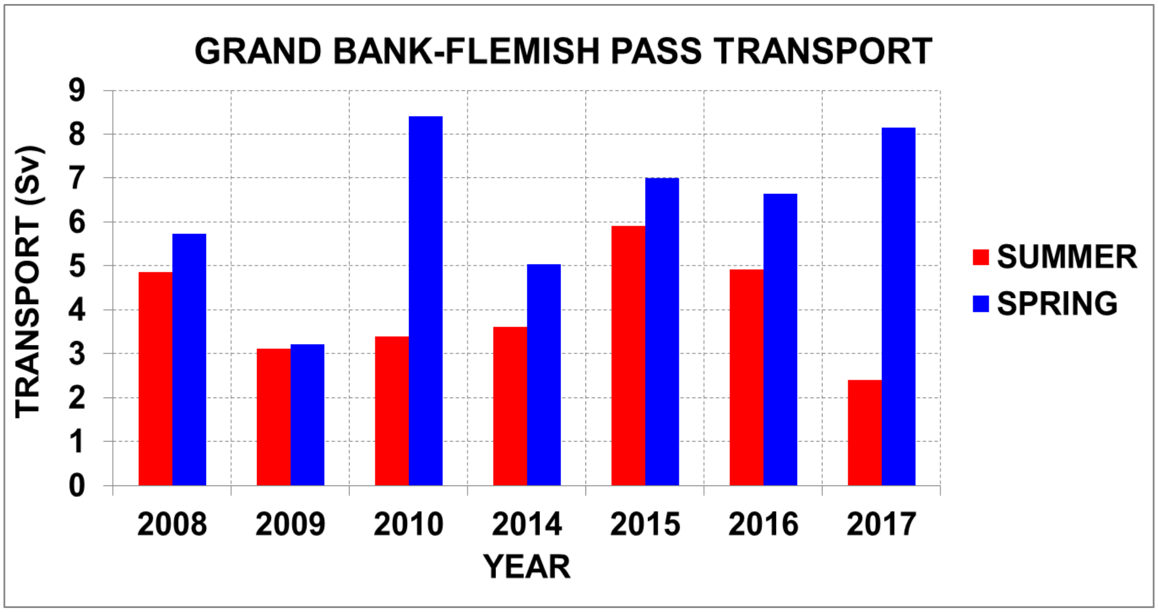

Fig. 35. Transport values (Sv, 10^6 m^3/s) for the Grand Bank Slope-Flemish Pass for the spring and summer based on available ADCP data.

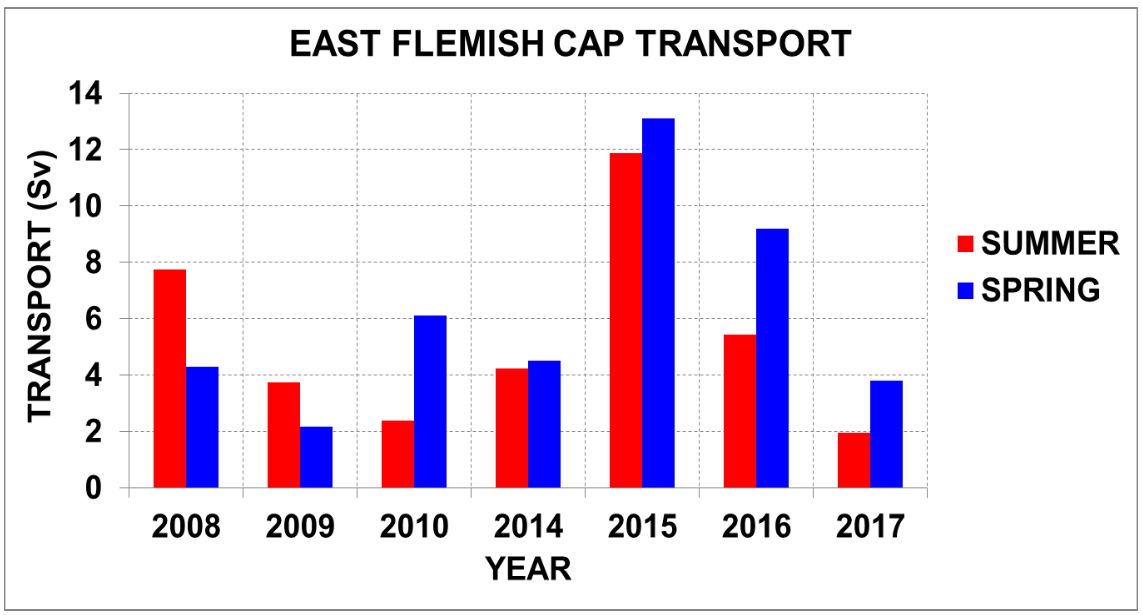

Fig. 36. Transport values (Sv, 10^6 m^3/s) for east of the Flemish Cap for the spring and summer based on available ADCP data.

Transport values for the inshore and offshore components of the Labrador Current through the Seal Island section off southern Labrador for the summer surveys are shown in Figures 38 and 39. The inshore transport was at a minimum in 2015 at <0.5 Sv in contrast to further south in the Avalon Channel where it was at a maximum in 2015 at 1.7 Sv. Similarly, the inshore Labrador Current showed a maximum transport of 2.3 Sv in 2017 while further south in the Avalon Channel the 2017 value was at a minimum. In the offshore branch off southern Labrador summer transport values ranged from about 2.3 Sv in 2010 to 11.8 Sv in 2009. In 2017, summer transport was similar to 2016 at 9.7 Sv. The total southward transport through the Seal Island section in 2017 was about 12 Sv. In general, the transport estimates for the years 2010 and 2014-2015 was significantly less that that the other years. No data were available for 2011-2013.

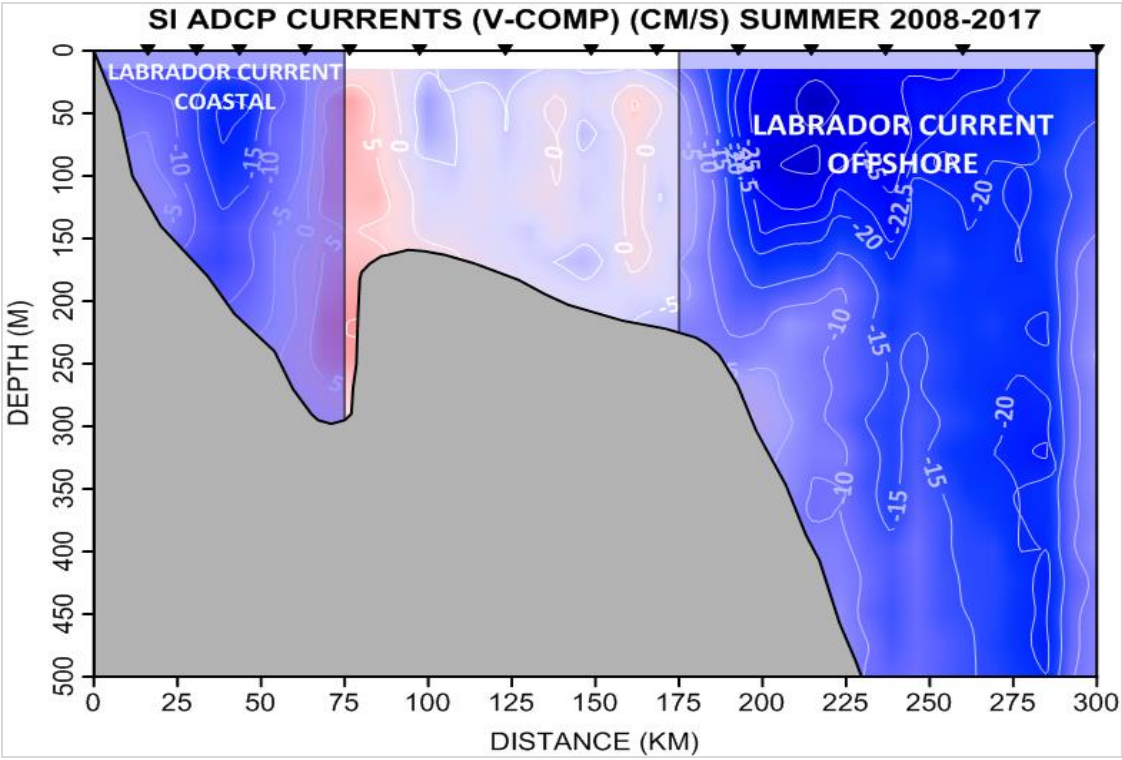

Fig. 37. The Seal Island section showing the areas where the Labrador Current transport values were computed. The symbols along the top of the panels are the standard AZMP stations.

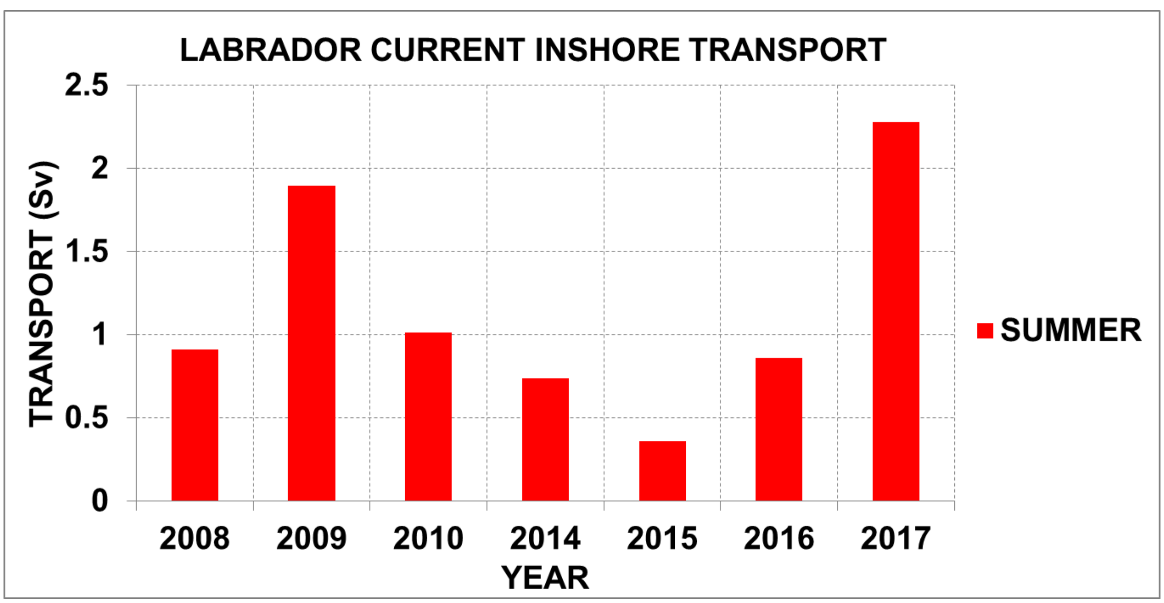

Fig. 38. Transport values (Sv, 10^6 m^3/s) for the inshore Labrador Current off southern Labrador for the summer period based on ADCP data.

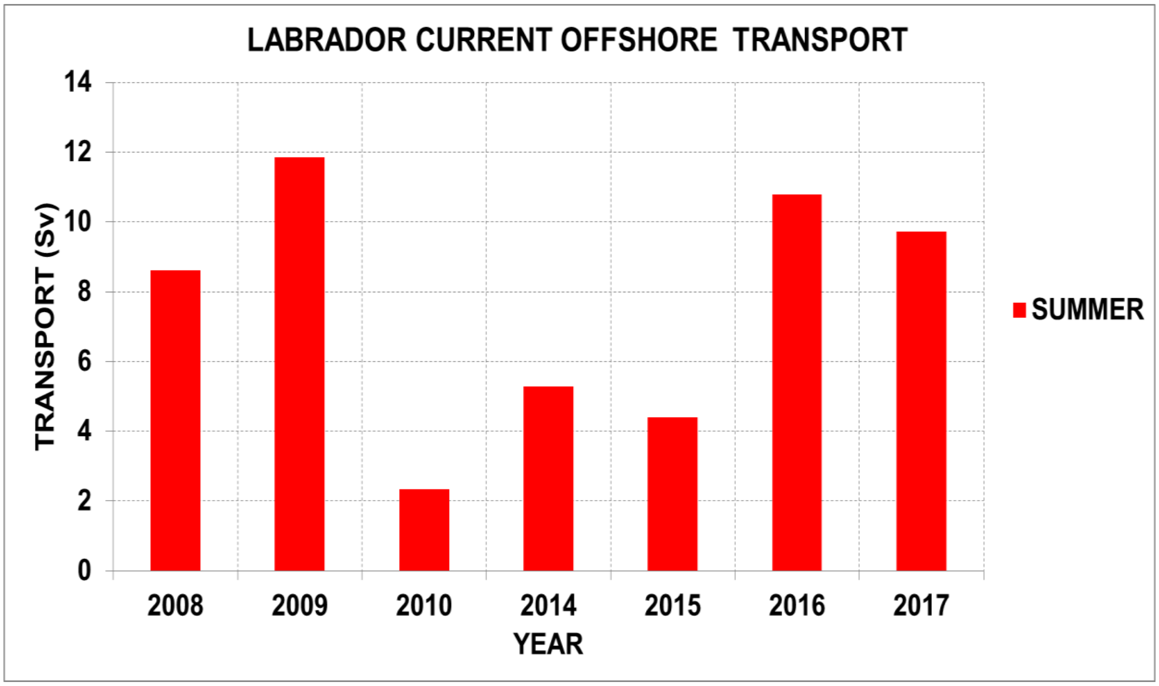

Fig. 39. Transport values (Sv, 10^6 m^3/s) for the offshore Labrador Current for the summer based on available ADCP data.

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 2017.

Spring Conditions

Maps of the climatological mean bottom temperature and salinity together with the spring 2017 bottom temperature and salinity, their anomalies and difference from the previous year are displayed in Figures 40 and 41 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 over the banks 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 generally weak on the Grand Banks varying about the mean with no consistent pattern.

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 some areas particularly in the deep channels of 3Ps. The bottom right panel of Figure 38 shows, except for isolated areas, a slight cooling over 2016 values.

Bottom salinities in Div. 3L generally range from 33 – 33.5 over most areas and from 33.5 to 35 at the shelf edge. Over the central and southern areas of the Grand Bank (3NO), bottom salinities ranged from 32.75 to >34 at the shelf edge, 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 41). The bottom right panel of Figure 39 shows, except for isolated areas, a general increase in spring bottom salinity over 2016 values.

Climate indices based on the temperature data collected during the spring survey for the years 1990-2017 are displayed in Figure 42 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 2017 it was near normal at -0.3 SD (Figure 42).

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 from 2014 to 2017 (Figure 42).

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 before decreasing to slightly above normal in 2017 at +0.4 SD. 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 to +0.3 SD above normal in 2017 (Figure 42).

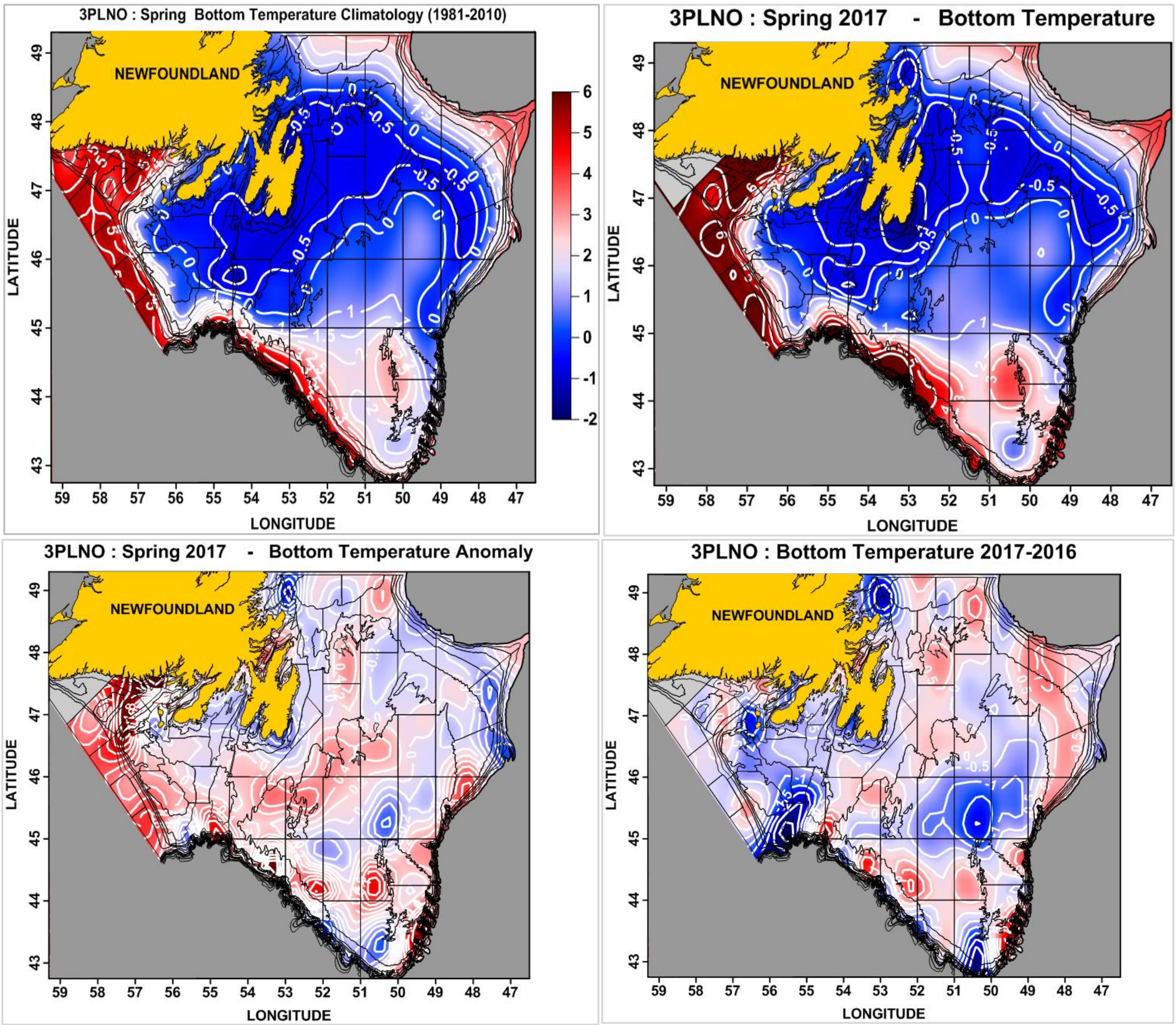

Fig. 40. Maps of the mean (1981-2010) bottom temperature, bottom temperature and anomalies during spring 2017 and the difference from 2016 (in °C) in NAFO Divs. 3PLNO.

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 43 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 by 2015. In 3Ps during 2016 bottom temperatures increased to 2 SD above normal, the highest since 1984 but again returned to near-normal conditions in 2017.

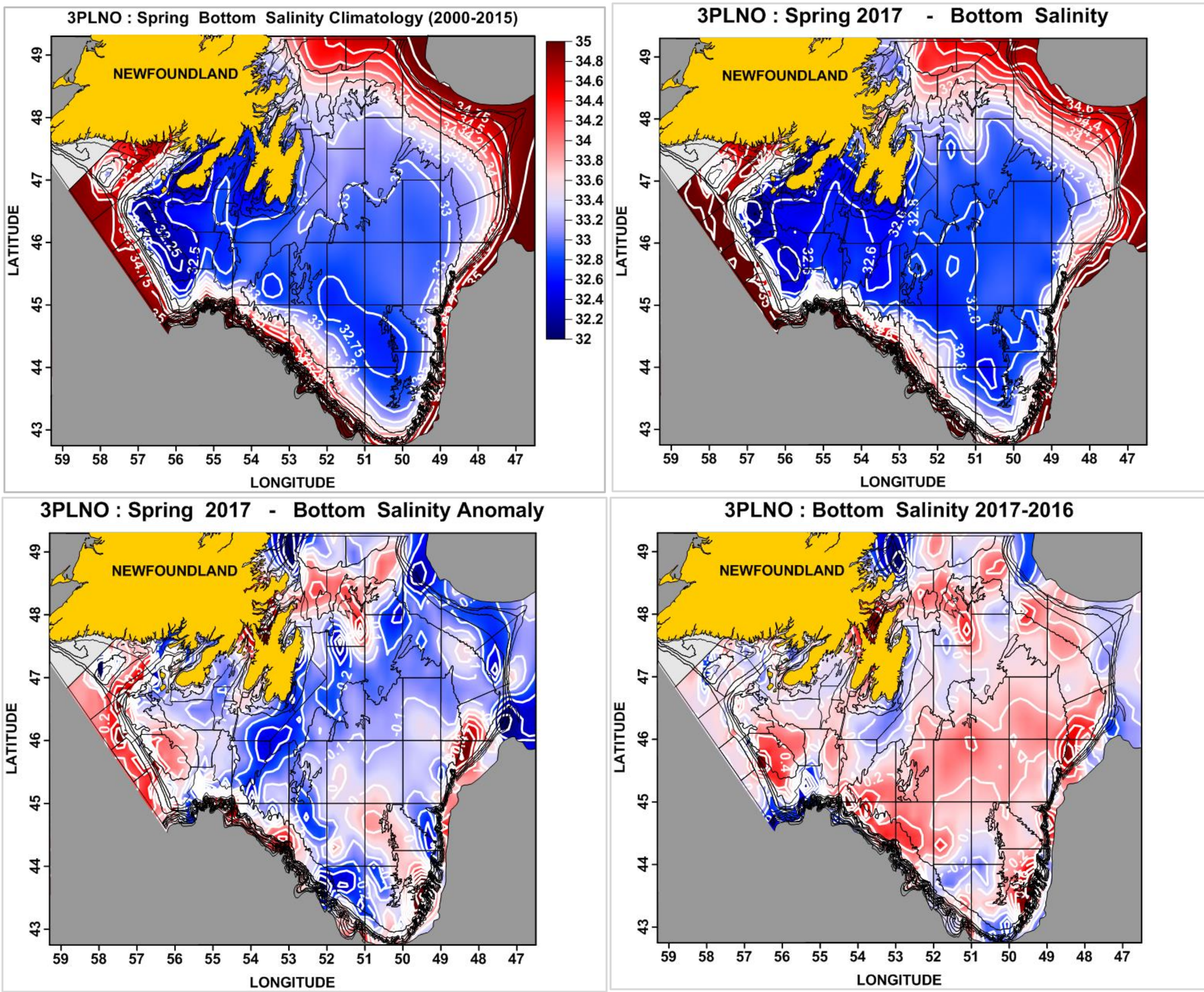

Fig. 41. Maps of the mean (2000-2015) bottom salinity, bottom salinity and anomalies during spring 2017 and the difference from 2016 in NAFO Divs. 3PLNO.

NAFO DIV. 3LNO	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	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	-0.2	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	0.0	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	0.1	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	-0.3	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	0.4	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	-0.1	0.29	0.73
THERMAL HABITAT AREA >2°C	1.6	2.3	-0.9	0.4	2.1	-1.0	-0.4	-0.7	-0.6	-0.9	-1.5	-0.8	-0.4	-0.5	-0.8	-0.6	0.3	-0.3	0.5	1.7	2.2	-0.3	-0.1	-0.6	-0.1	0.8		-0.3	-0.4	0.5	0.6	1.1	0.7	0.6	0.3	0.0	1.2	-0.3	54.39	8.19
THERMAL HABITAT AREA <0°C	-1.7	-1.9	0.3	-0.8	-1.0	1.2	0.9	1.1	-1.5	0.9	1.4	0.7	0.9	1.0	0.5	0.7	-0.8	0.4	-0.4	-1.0	-1.4	0.4	0.1	1.3	-1.5	-1.4		0.4	0.4	-0.1	-1.1	-1.9	-1.5	-1.5	-0.8	-0.4	-1.0	0.3	22.13	11.78

Fig. 42. 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.

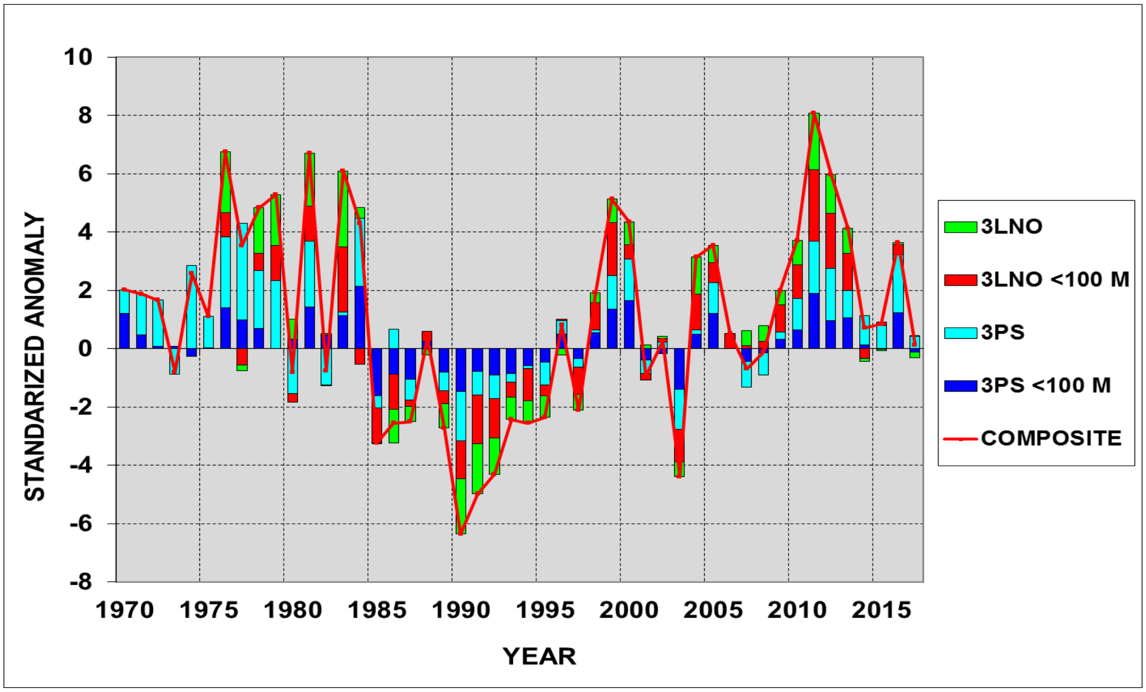

Fig. 43. Standardized bottom temperature anomalies from the spring multi-species surveys in NAFO Divs. 3LNOP.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from data collected during the fall of 2017 multi-species survey (Figure 2) in NAFO Div. 2J, 3KL are displayed in Figure 44. Bottom temperatures in Div. 2J ranged from 0.5° - 2°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. Except for some isolated areas of positive anomalies, bottom temperature generally below normal in most of 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. Temperatures were below normal over most of 3L and in 3N with values >°C below normal (Figure 44).

Bottom salinities in Div. 2J generally range from <32 in the inshore areas to 34 over the offshore areas of Hamilton Bank and from 34 to near 35 at the shelf edge. In 3K salinities ranged from <33 inshore to 34.75 offshore and on the Grand Banks bottom salinities ranged from <33 to >35, with the lowest values on the southeast shoal of the Grand Bank. Except for isolated areas in the south bottom salinities were generally below normal (up to -0.3) over most regions (Figure 45).

Bottom temperature anomalies and derived indices are displayed in Figure 46 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. In 2016 bottom temperatures were near 1 SD above normal but decreased to -0.5 SD below normal in water depths <200 m in 2017. The area of the bottom covered by water with temperatures <1°C was 0.5 SD below normal in 2017. In Div. 3K, bottom temperatures were at a record high in 2011 (+2.5 SD) but have decreased in recent years to about -0.3 SD below normal in 2017.

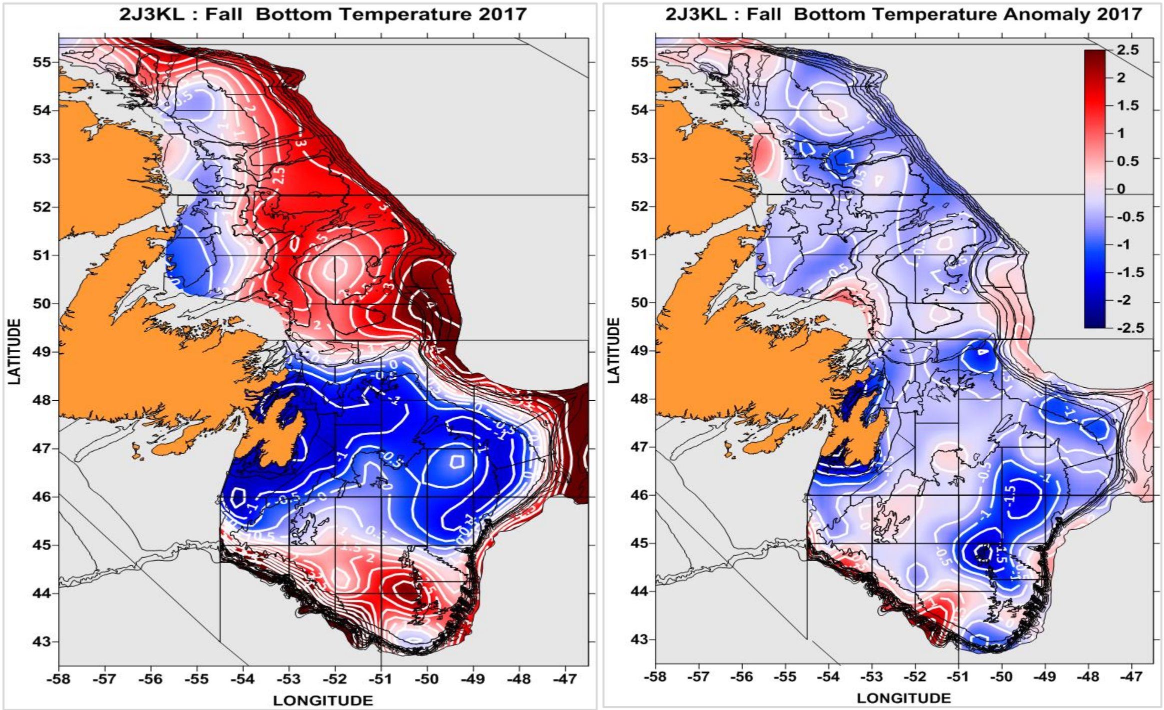

Fig. 44. Contour maps of bottom temperature (in °C) and bottom temperature anomalies (referenced to 1990-2010) during the fall of 2017 in NAFO Divs. 2J3KL.

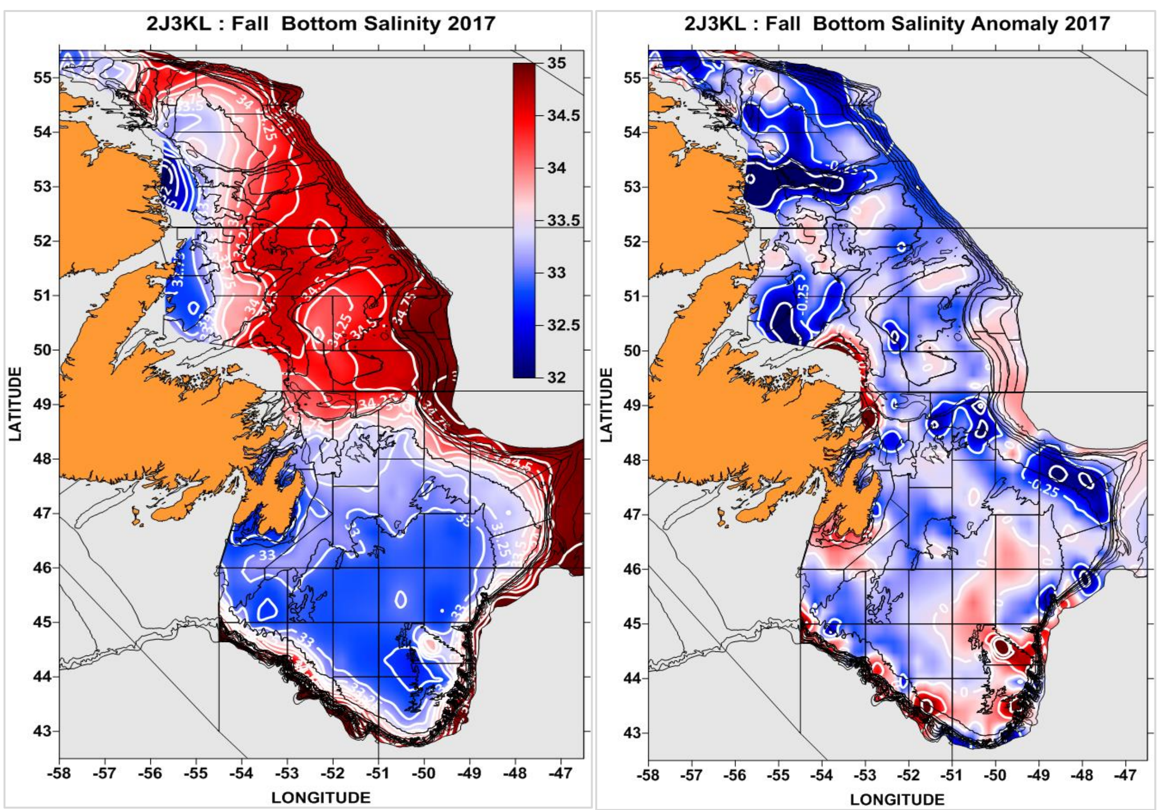

Fig.45. Contour maps of bottom salinity and bottom salinity anomalies (referenced to 2000-2015) during the fall of 2017 in NAFO Divs. 2J3KL.

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 47. 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, but decreased again in 2017, particularly on the Grand Banks in 3LNO.

Composite indices derived by summing the standardized values presented in Figures 42 and 46 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, warmed somewhat in 2016 but decreased to normal conditions in the spring and to below normal in the fall (Figure 48).

NAFO DIV. 2J	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	MEAN	SD
BOTTOM TEMPERATURES	-1.1	0.0	-1.8	-2.0	-1.7	-1.4	-0.9	-2.1	-0.9	-1.7	-1.3	-1.0	-1.9	-1.5	-1.3	-1.3	0.2	-0.3	-0.1	0.7	0.1	0.5	0.3	1.0	1.2	1.2	0.3	1.1	0.2	0.3	1.5	1.8	0.8	0.4	0.3	-0.2	0.7	0.1	2.35	0.47
BOTTOM TEMPERATURES < 200 M	0.2	0.7	-0.8	-0.9	-2.1	-1.3	0.2	-1.0	0.1	-0.7	-0.5	-0.8	-1.9	-1.9	-1.1	-0.9	0.2	-0.3	-0.3	0.5	-0.2	0.8	0.1	0.6	1.2	1.3	0.3	1.4	-0.2	0.0	1.8	2.0	0.3	0.1	-0.6	-0.5	0.9	-0.5	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	0.2	57.94	14.65
THERMAL HABITAT AREA <1°C	0.3	0.0	1.3	0.9	1.7	1.2	-0.1	1.7	0.1	0.7	0.7	0.7	1.4	1.2	0.7	0.2	-0.3	-0.5	-0.6	-1.3	-0.2	-0.9	-0.3	-1.4	-1.4	-1.4	-0.2	-1.4	-0.5	-0.5	-1.4	-1.4	-0.9	-0.8	0.3	0.0	-1.5	-0.5	22.72	15.71
NAFO DIV. 3K																																								
BOTTOM TEMPERATURES	-0.3	-0.1	-2.6	-0.8	-0.5	-1.9	0.1	-0.9	-0.5	-0.4	-1.3	-1.0	-2.0	-1.8	-1.4	-0.3	-0.2	0.3	0.0	1.0	-0.1	0.1	0.3	0.5	1.0	0.9	0.1	1.6	0.4	0.6	1.3	2.5	1.0	0.3	0.1	0.6	0.3	0.0	2.13	0.53
BOTTOM TEMPERATURES < 300 M	0.0	0.2	-1.7	-0.6	-0.8	-1.7	0.5	-0.8	-0.1	-0.1	-1.1	-0.8	-1.6	-2.1	-1.7	-0.1	-0.1	0.5	0.6	0.9	-0.2	0.0	0.4	0.7	1.1	1.0	-0.1	1.6	-0.2	0.1	1.2	2.4	0.5	0.0	-0.2	0.5	0.4	-0.3	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	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	-0.1	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	-1.2	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	-1.5	1.22	0.64
THERMAL HABITAT AREA >2°C											-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5	0.4	0.2		-0.2	0.3	-0.4	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	1.2	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	0.0	1.65	0.95

Fig. 46. 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.

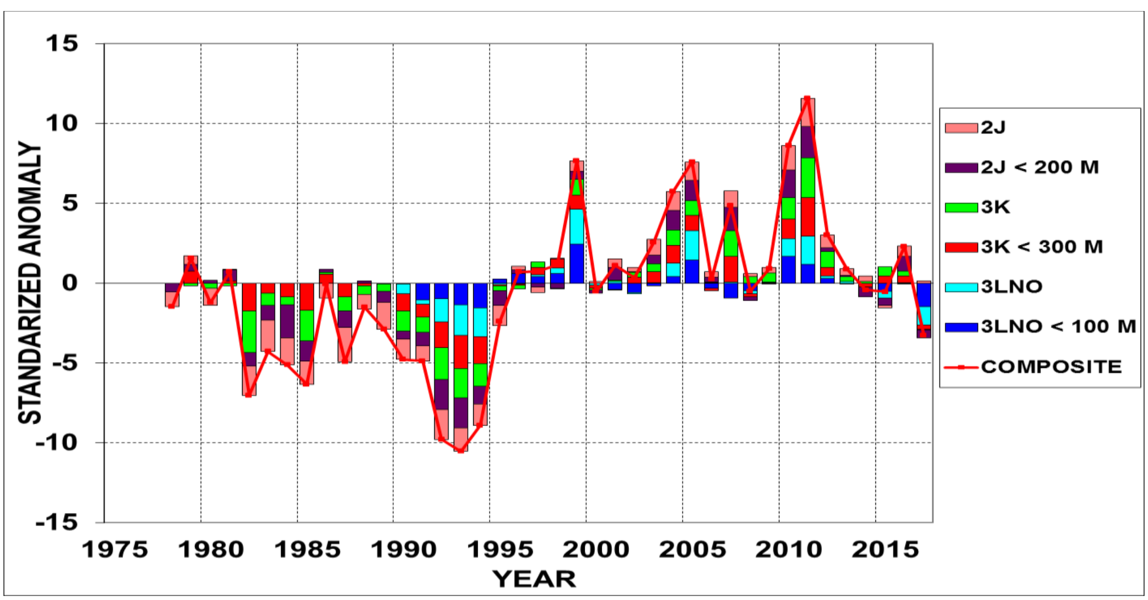

Fig. 47. Standardized bottom temperature anomalies from the fall multi-species surveys in NAFO Divs. 2J3KLNO.

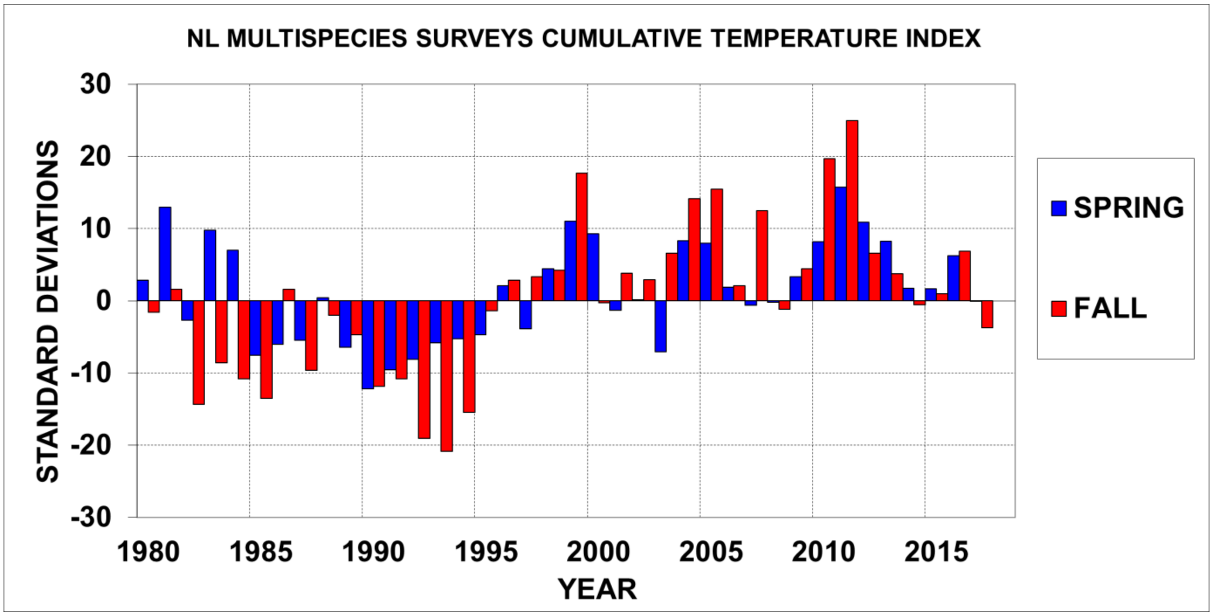

Fig. 48. Spring and fall composite temperature index derived by summing the standardized anomalies displayed in Figs. 40 and 44.

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 46 as standardized anomalies and in Figure 49 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 2016 (-0.7 SD) and normal in 2017.

SUMMARY

A summary of selected temperature and salinity time series and other climate indices for the years 1950-2017 are displayed in Figure 50 as colour-coded (Figure 3) 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. In 2017, 17/28 indices were negative with the most significant negative anomalies occurring in salinity.

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 51). 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.

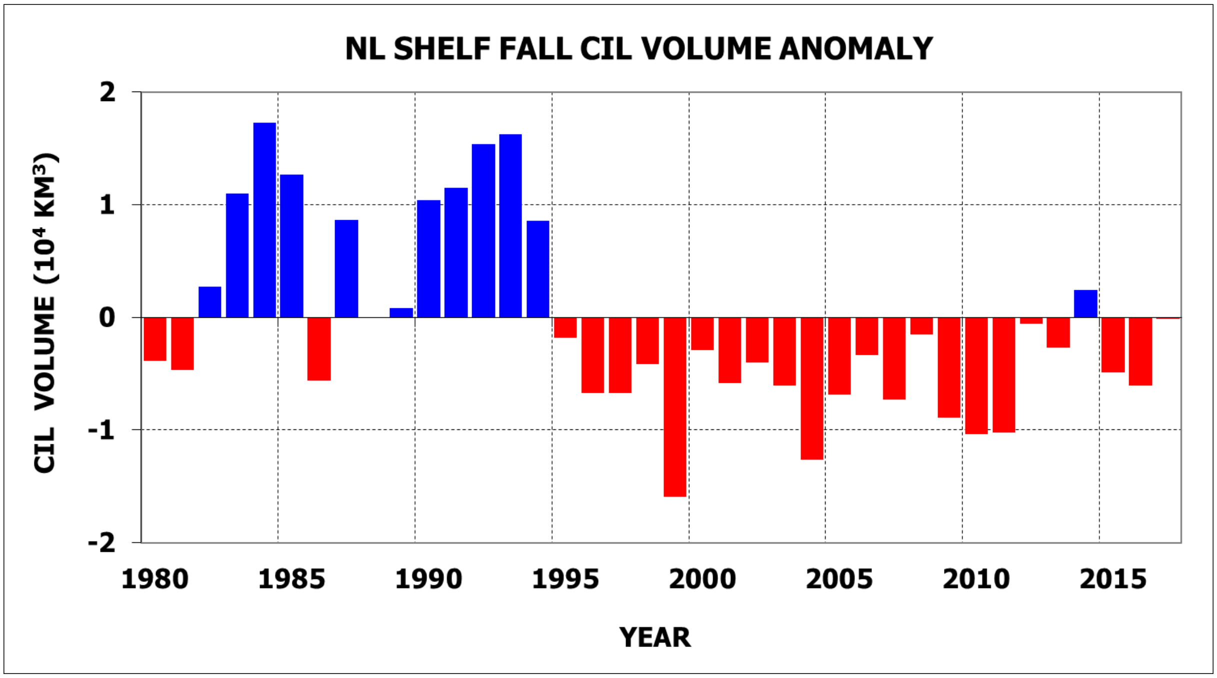

Fig. 49. Time series of the CIL (<0⁰C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species survey temperature data profiles. No data were available in 1988.

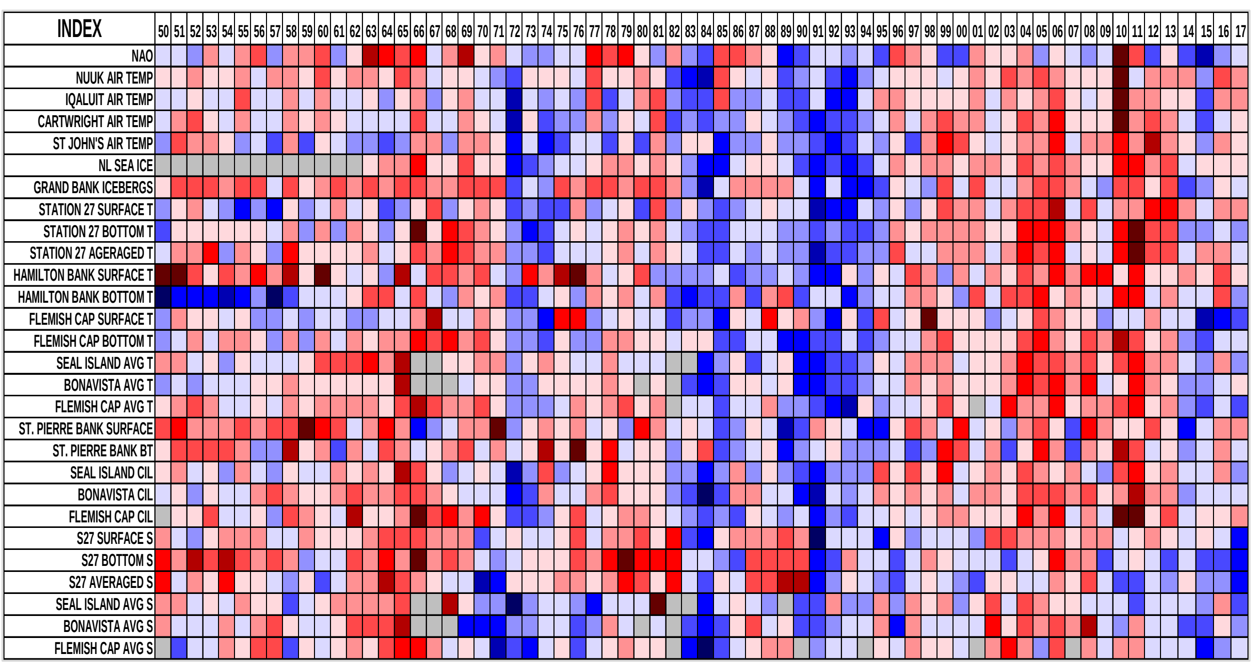

Fig. 50. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Fig. 3. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells indicate missing data.

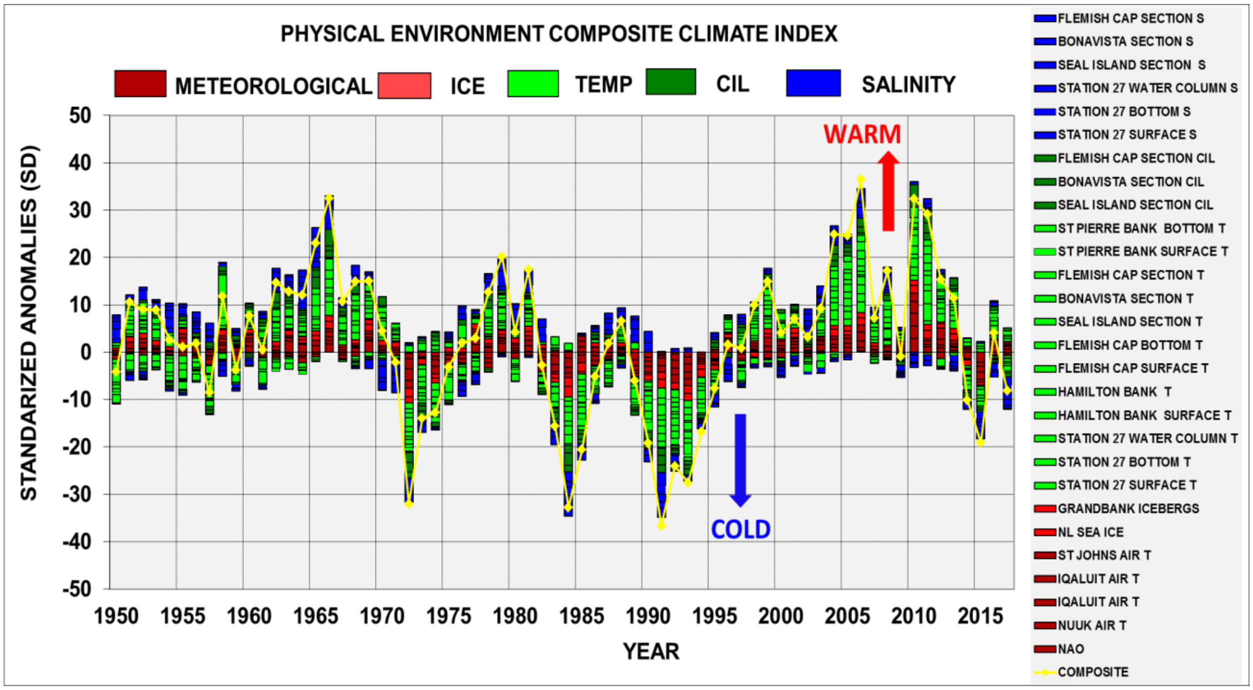

Fig. 51. Composite climate index (yellow line) derived by summing the standardized anomalies from Fig. 50 together with their individual components.

Similar to the standardized values shown in Figure 50, 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 68-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 but in 2017 it returned to a negative state (Figure 51).

Summary Points for 2017

- The North Atlantic Oscillation Index, a key indicator of climate conditions on the NL Shelf, weakly positive in 2017 at 0.3 SD above normal.
- Arctic air outflow during the winter was also weak with both winter and annual air temperatures at several sites in the region reporting slightly positive anomalies.
- Sea ice extent on the NL Shelf was slightly below normal conditions in 2017 at 0.4 SD below the long term mean.
- Sea ice duration was up to 60 days longer than normal with departure up to 45 days later than normal in the inshore areas along the east and northeast coast of Newfoundland and southern Labrador.
- 1008 icebergs were detected south of 48ºN on the Northern Grand Bank (0.4 SD above the 1981-2010 average of 767).
- Annual sea-surface temperatures (SST) were mostly below normal during 2017, driven largely by very cold spring conditions.
- The annual surface temperature anomaly at Station 27 was +0.4°C or 0.6 SD above normal.
- The annual bottom (176 m) temperature anomaly at Station 27 was -0.2°C or 0.6 SD below normal.

- The annual surface salinity anomaly at Station 27 was -0.40 or -1.58 SD below normal.
- The annual bottom (176 m) salinity anomaly at Station 27 was -0.12 or -1.57 SD below normal.
- The annual water column average (0-176 m) temperature and salinity anomaly at Station 27 was +0.03°C and -0.16 or -0.1 and -1.6 SD different from normal, respectively.
- The area of the CIL (<0°C) water during the spring on the SWSPB, SESPB, SEGB, FC and BB sections was -0.4, 0.7, -0.2, 1.0 and -0.3 SD different from normal, respectively. Positive/negative anomalies indicate colder/warmer conditions.
- The area of CIL (<0°C) water during the summer on the FC, BB, WB and SI sections was -0.6, 0.1, 0.8 and 0.8 SD different from normal, respectively.
- Labrador Current transport through the Flemish Section remained high during the spring (13.5 Sv) but decreased to lower than normal during the summer (4.6 Sv). Summer transport through the Seal Island section was higher than normal in 2017 at 12 Sv.
- The volume of CIL on the Newfoundland and Labrador Shelf during the fall was about normal compared to 0.7 SD below normal in 2016.
- The averaged spring bottom temperature in NAFO Div. 3P was about 2.7°C, or 0.2°C (0.4 SD) above normal, a significant decrease from 2 SD above normal in 2016.
- The averaged spring bottom temperature in NAFO Divs. 3LNO was 1.4°C, or -0.1°C (-0.2 SD) below normal, a slight decrease from 2016.
- The averaged fall bottom temperature in NAFO Divs. 3LNO was 1.3°C, or -0.5°C (-1.2 SD) below normal, a significant decrease from 2016.
- The averaged fall bottom temperature in NAFO Divs. 3K was 2.3°C, or -0.01°C (-0.03 SD) below normal, a slight decrease from 2016.
- The averaged fall bottom temperature in NAFO Divs. 2J was 2.6°C, or 0.1°C (0.1 SD) above normal.
- A composite climate index for the NL region returned to slightly below normal (15th lowest) compared to slightly above normal in 2016.
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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 Ocean Science Branch of Fisheries and Oceans in Ottawa for providing most of the historical data. Environment Canada provided the meteorological data. We thank Ingrid Peterson at the Bedford Institute of Oceanography for providing the NL Shelf monthly sea ice data. We thank Michael Hicks of the USCG International Ice Patrol for providing monthly iceberg data for the Grand Banks. We also thank the captain and crew of the CCGS Teleost for successful oceanographic survey during the spring and summer of 2017.

REFERENCES

Casey, K.S., T.B. Brandon, P. Cornillon, and R. Evans. 2010. The past, present and future of the AVHRR Pathfinder SST Program. *In* Oceanography from space: Revisited. Edited by V. Barale, J.F.R. Gower, and L. Alberotanza. Springer, Dordrecht, The Netherlands. 273-287 p. DOI: 10.1007/978-90-481-8681-5_16.

Colbourne, E. B., J. Holden, D. Senciall, W. Bailey, J. Craig and S. Snook. 2015. Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2014. NAFO SCR. Doc. 2015/011. Serial No. N6431.

Colbourne, E. B., S. Narayanan and S. Prinsenberg. 1994. Climatic change and environmental conditions in the Northwest Atlantic during the period 1970-1993. ICES Mar. Sci. Symp., 198:311-322.

Doubleday, W. G., Editor. 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFC. Sco. Coun. Studies, 2: 56p.

Drinkwater, K. F. 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early-1990s. J. Northw. Atl. Fish. Sci., 18: 77-97.

Hebert, D., R. Pettipas, and B. Petrie. 2012. Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/055. iv + 42 p.

ICNAF. 1978. List of ICNAF standard oceanographic sections and stations. ICNAF selected papers #3.

Petrie, B., R. G. Pettipas and W. M. Petrie. 2007. An overview of meteorological, sea ice and sea surface temperature conditions off eastern Canada during 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/022.

Petrie, B., S. Akenhead, J. Lazier and J. Loder. 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978-1986. NAFO Sci. Coun. Studies 12: 57-69.

Rogers, J. C. 1984. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. Mon. Wea. Rev. 112: 1999-2015.

Therriault, J.-C., Petrie, B., Pepin, P., Gagnon, J., Gregory, D., Helbig, J., Herman, A., Lefaivre, D., Mitchell, M., Pelchat, B., Runge, J., and Sameoto, D. 1998. Proposal for a northwest Atlantic zonal monitoring program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57 pp.

Vincent, L. A., X. L. Wang, E. J. Milewska, H. Wan, F. Yang, and V. Swail. 2012. A second generation of homogenized Canadian monthly surface air temperature for climate trend analysis. *J. Geophys. Res.* 117, D18110, doi:10.1029/2012JD017859.