Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2019/051

Newfoundland and Labrador Region

Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2017

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September 2019

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

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

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

ISSN 1919-5044

Correct citation for this publication:

Cyr, F., Colbourne, E., Holden, J., Snook, S., Han, G., Chen, N., Bailey, W., Higdon, J., Lewis, S., Pye, B. and D. Senciall. 2019. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/051. iv + 58 p.

Aussi disponible en français :

Cyr, F., Colbourne, E., Holden, J., Snook, S., Han, G., Chen, N., Bailey, W., Higdon, J., Lewis, S., Pye, B. et D. Senciall. 2019. Conditions océanographiques physiques sur le plateau continental de Terre-Neuve-et-Labrador en 2017. Secr. can. de consult. sci. du MPO. Doc. de rech. 2019/051. iv + 62 p.

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ABSTRACT

An overview of physical oceanographic conditions in the Newfoundland and Labrador Region during 2017 is presented as part of the Atlantic Zone Monitoring Program (AZMP). The North Atlantic Oscillation (NAO) Index, a key indicator of the direction and intensity of the winter wind field patterns over the Northwest Atlantic 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 is 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 SD 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 NAFO Division 3Ps remained slightly above normal, a significant decrease over the 37-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 >1.8 SD above normal in 2011 before returning to near normal values, including in 2017. Oceanographic data from the fall 2017 3LNO indicate that bottom temperatures were about 1 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 document presents an overview of the physical oceanographic environment in 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 the environmental conditions in the Gulf of St. Lawrence and the Scotian Shelf and Gulf of Maine as part of the Atlantic Zone Monitoring Program (AZMP; Therriault et al. 1998; Galbraith et al. 2018; Hebert et al. 2018). When possible, the long-term averages were standardized to a 'normal' base period from 1981 to 2010 in accordance with the recommendations of the World Meteorological Organization.

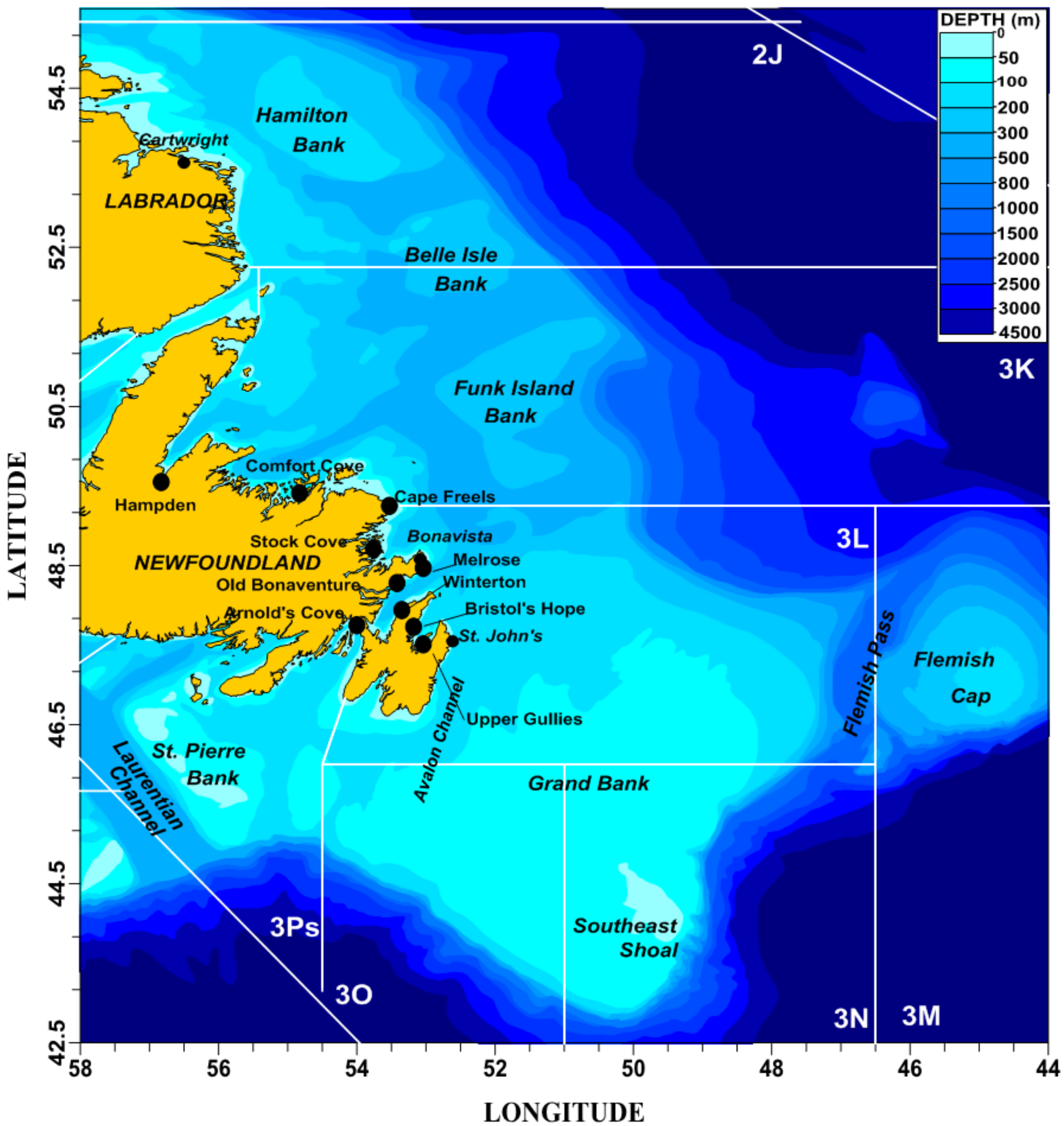

Figure 1. Map showing Northwest Atlantic Fisheries Organization (NAFO) Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments sites (black solid circles).

The information presented for 2017 is derived from different sources:

1. Observations made at a monitoring location off St. John's, NL (Station 27) throughout the year from all sources;
2. Measurements made along standard NAFO and AZMP cross-shelf sections from seasonal oceanographic surveys (Figure 2);
3. Oceanographic observations made during spring and fall multi-species resource assessment surveys (Figure 2);
4. SST data based on infrared satellite imagery of the Northwest Atlantic; and
5. Other multi-source historical data (ships of opportunity, international campaign, other DFO regions surveys, Argo program, etc.) made available by DFO's Marine Environment Data Section (MEDS) are also considered.

These data are available from MEDS archives and maintained in a regional data archive at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL. An overview of the physical oceanographic conditions for 2016 was presented in Colbourne et al. (2017).

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. Standardized anomalies were obtained by dividing the anomalies by the standard deviation of the data time series over the same base period. For example, a value of 2 indicates that the index was 2 standard deviations (SD) higher than its long-term average. As a general guide, anomalies within ±0.5 SD in most cases are not considered to be significantly different from the long-term mean. For shorter time series, the base period included all data up to 2016 (i.e., excluding the present year). 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.

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 colored boxes as figures with gradations of 0.5 SD. Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions (Figure 3). If the magnitude of the anomaly is ≥1.5 SD it is typeset in white. In some instances (NAO, ice and water mass areas or volumes for example) negative anomalies may indicate warm conditions and hence are colored red. Note that for the section on Bottom Conditions, a new color code is introduced where anomalies within ±0.5 SD are colored white.

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

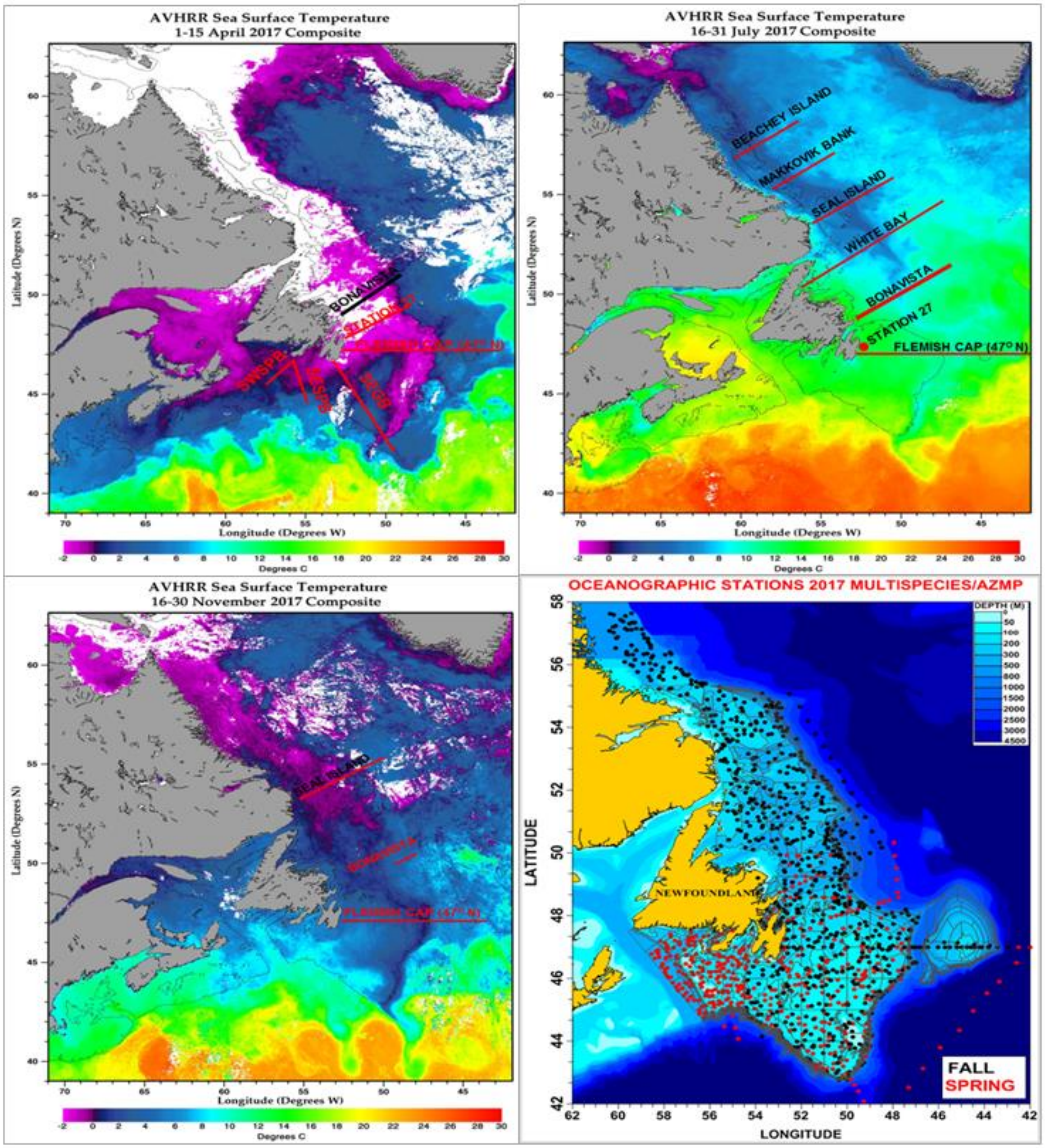

Figure 2. Maps showing DFO-NL 2017 monitoring effort. Spring (top left), summer (top right), and fall (lower left) AZMP section occupations along with Sea-Surface-Temperature (SST) are presented. The lower right panel shows the positions of trawl-mounted CTD profiles obtained from spring (red dots, April-June) and fall (black dots, October-December) multi-species assessment surveys during 2017. SST maps are a courtesy of the Marine Ecosystem Section, Bedford Institute of Oceanography (BIO).

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

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

METEOROLOGICAL AND SEA-ICE CONDITIONS

The North Atlantic Oscillation (NAO) index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is often a measure of the strength of the winter westerly and north westerly winds over the Northwest Atlantic. A high (positive phase) NAO index occurs from an intensification of the Icelandic Low and Azores High. This favors strong northwest winds, cold air and sea temperatures and heavy ice conditions on the NL shelves (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 normal value 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 NL 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 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 anomalies decreased in 2017 over the previous year, except at Iqaluit and Cartwright, 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 at 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 and at Iqaluit 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
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
(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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

LOCATION/INDEX	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	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	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)	0.1	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	-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	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	0.4	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	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	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	-0.2	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	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	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	1.5	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	1.9	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)	-0.7	-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)	-0.5	-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)	-0.9	-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	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

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

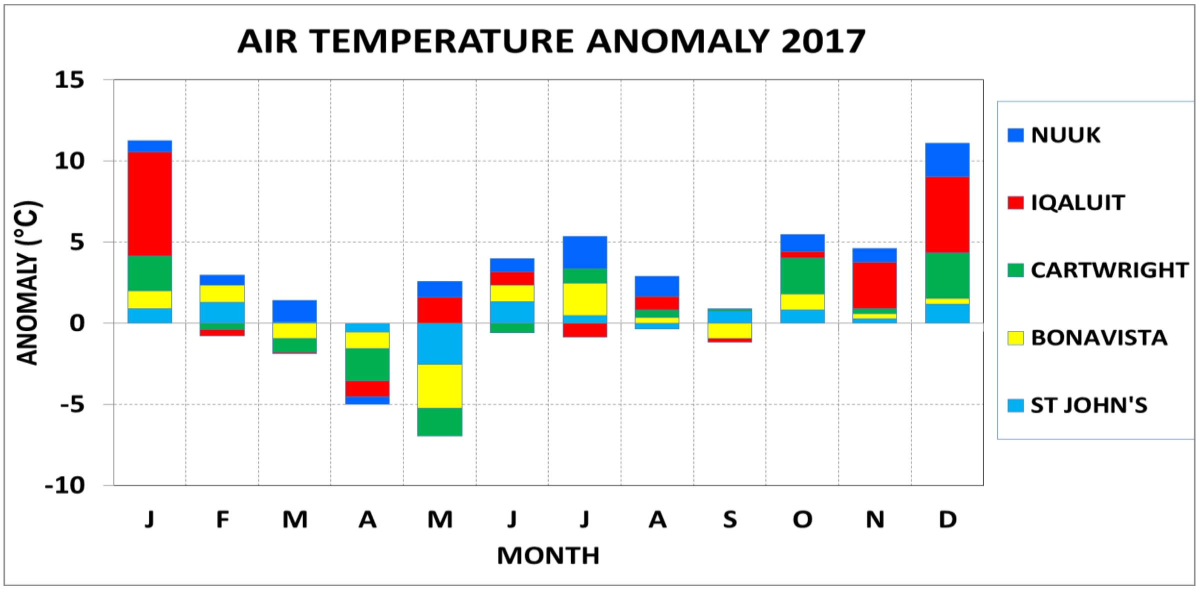

Figure 5. Cumulative monthly air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's for 2017.

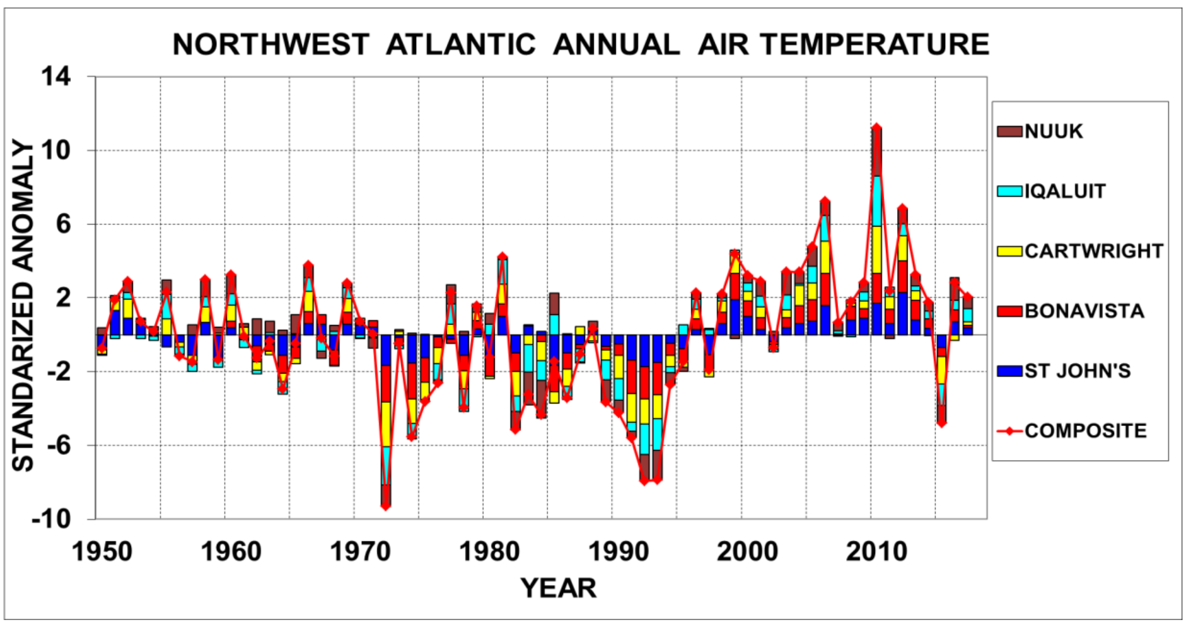

Figure 6. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

Data on the spatial extent and concentration of sea ice are available from the daily ice charts published by the Canadian Ice Service of Environment Canada. The annual average sea-ice extent (defined by 1/10 coverage) on the NL Shelf (between 45°-55°N) derived from these charts is presented in Figure 4 and Figure 7. Between 2014 and 2017, the annual sea ice extent returned close to normal after a long period of below normal conditions between 1997 and 2013 (with some close-to-normal exceptions). In 2011 sea ice extent decreased to 49-year record low of -1.7 SD (Figure 4). Monthly values of sea ice extent for 2017 as well as their climatological values are presented in Figure 8. For 2017, the only month with values above the average was May. 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 is 15-45 days later than normal depending on the area. More information on the spatial extent and duration of sea ice on the NL shelf is presented in Hebert et al. (2018).

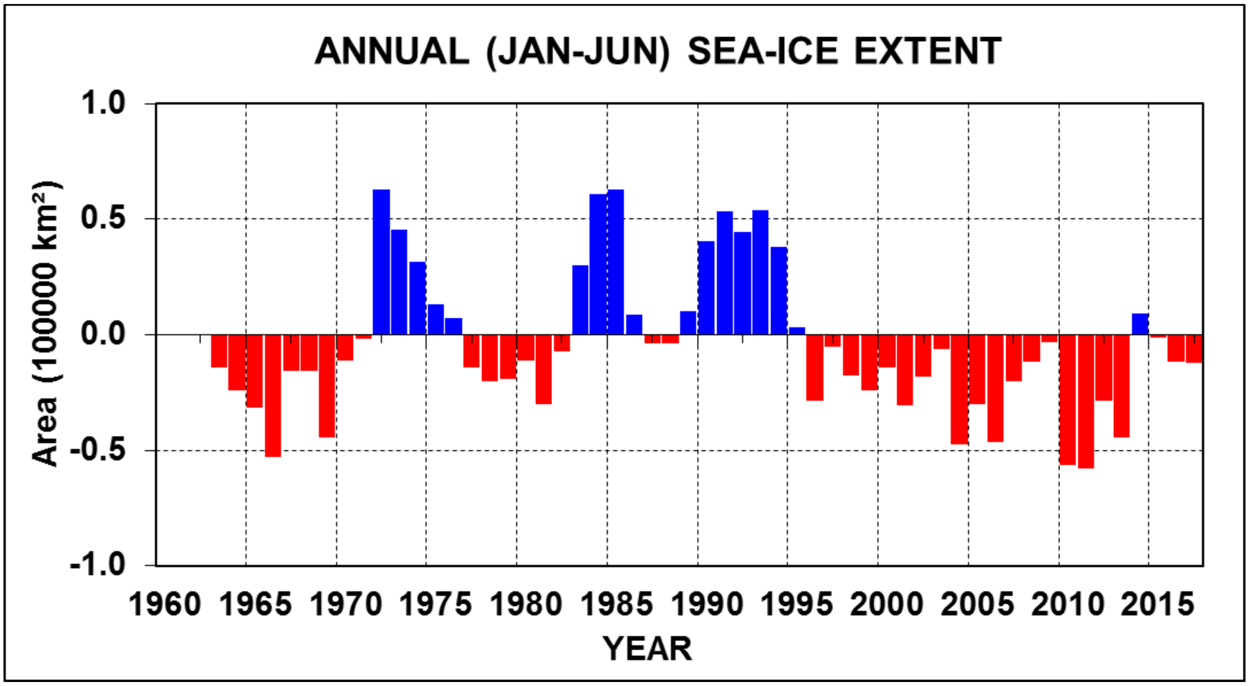

Figure 7. Seasonal (January-June) sea ice extent (defined by 1/10 coverage) anomalies on the NL Shelf between 45-55ºN latitude.

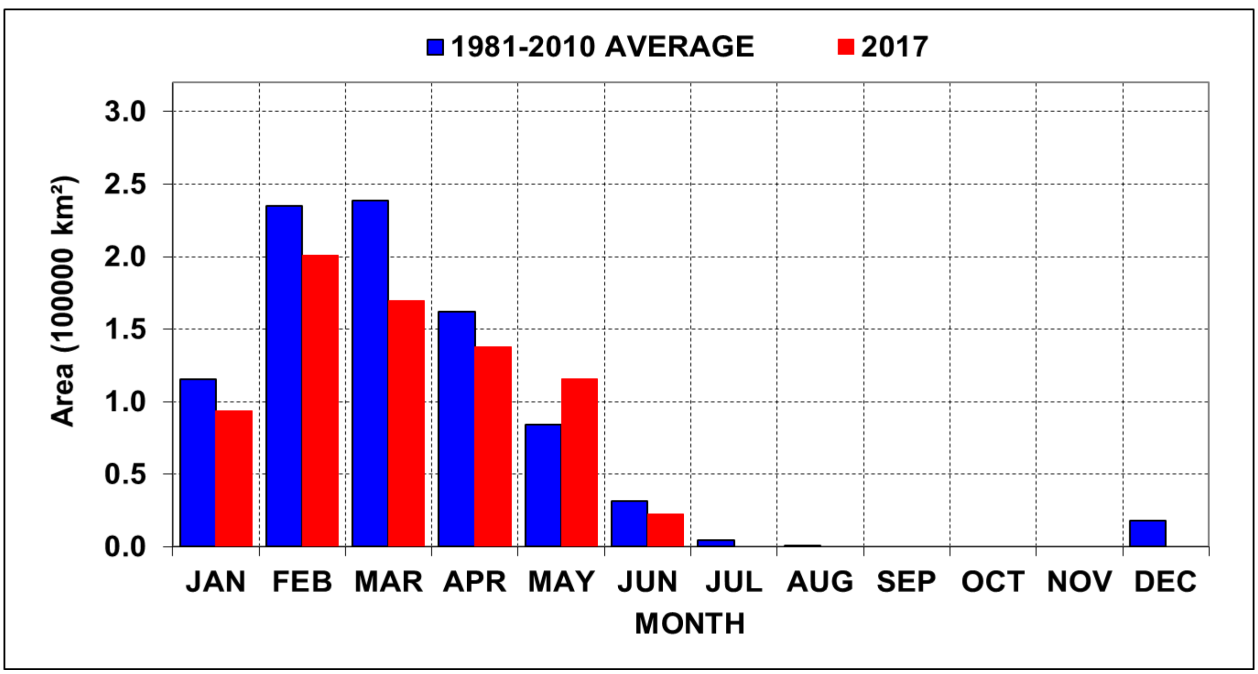

Figure 8. Monthly sea ice extent (defined by 1/10 coverage) on the NL Shelf between 45-55ºN latitude.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 1008 (+0.4 SD) icebergs drifted south of 48ºN 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 48ºN 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).

Figure 11 presents 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 near normal in 2017.

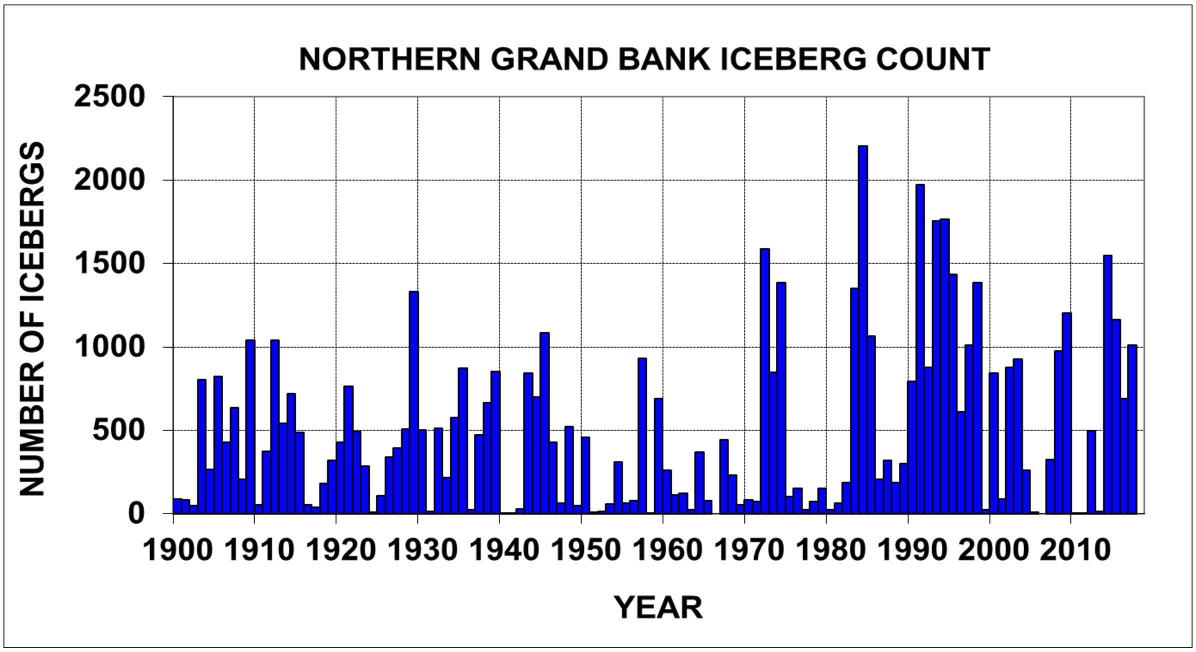

Figure 9. Annual iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP of the USCG).

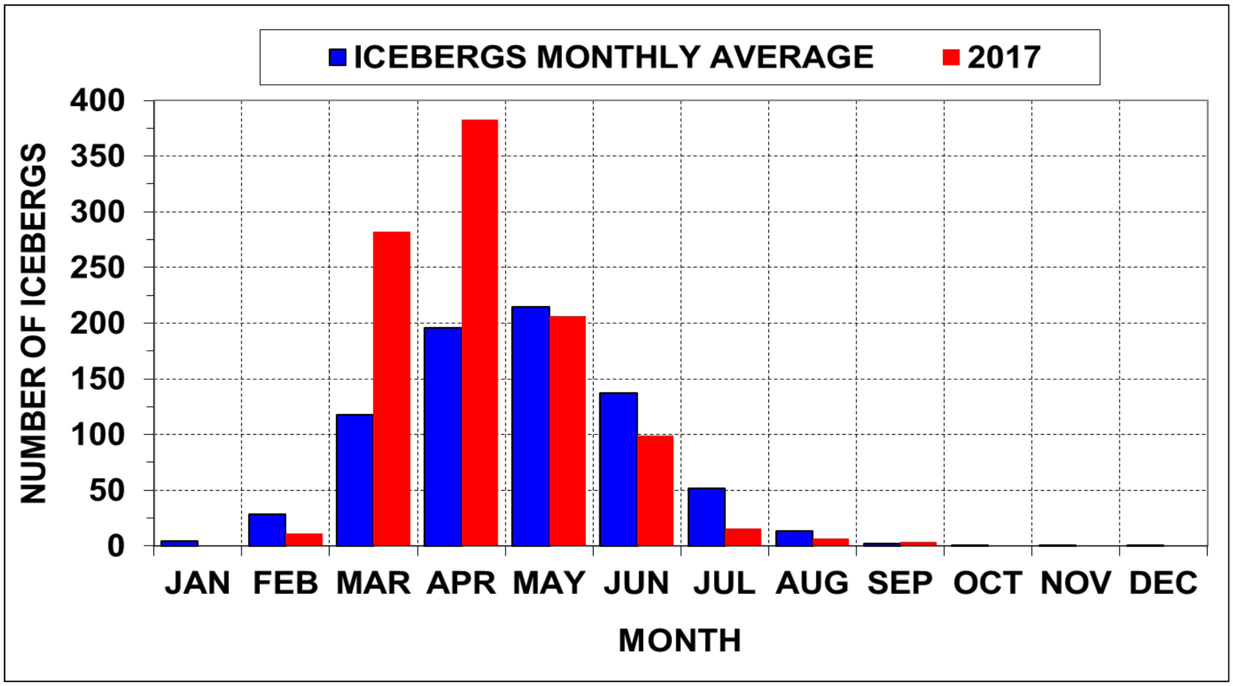

Figure 10. Monthly iceberg count crossing south of 48ºN on the northern Grand Bank (data courtesy of IIP if the USCG).

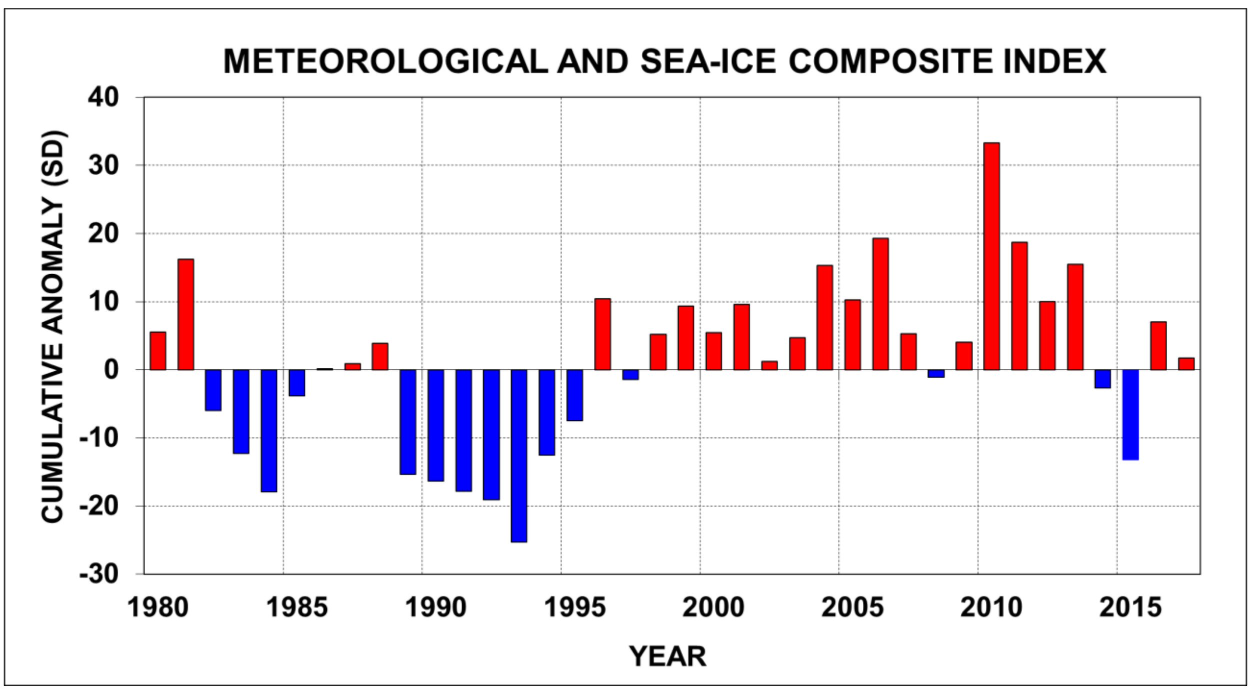

Figure 11. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Figure 4.

SATELLITE SEA-SURFACE TEMPERATURE CONDITIONS

The 4 km resolution Pathfinder 5.2 sea 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 (2011-17) we use data from NOAA and EUMETSAT satellite data provided by the remote sensing group in the Ocean Monitoring and Observations Section, Ocean Sciences Division 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 $SST_{Pathfinder} = 0.989xSST_{NOAA} - 0.02$ 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 Figure 13 and Figure 14, and as standardized annual values in Figure 15 and Figure 16. 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 2017 occurred 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 were near normal in most areas, with 14/16 sub-areas with reporting values within ±0.5 SD (Figure 15). Only Hudson Strait (-1.5 SD) and Flemish Pass (+1.1 SD) were respectively colder and warmer than normal. 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). 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).

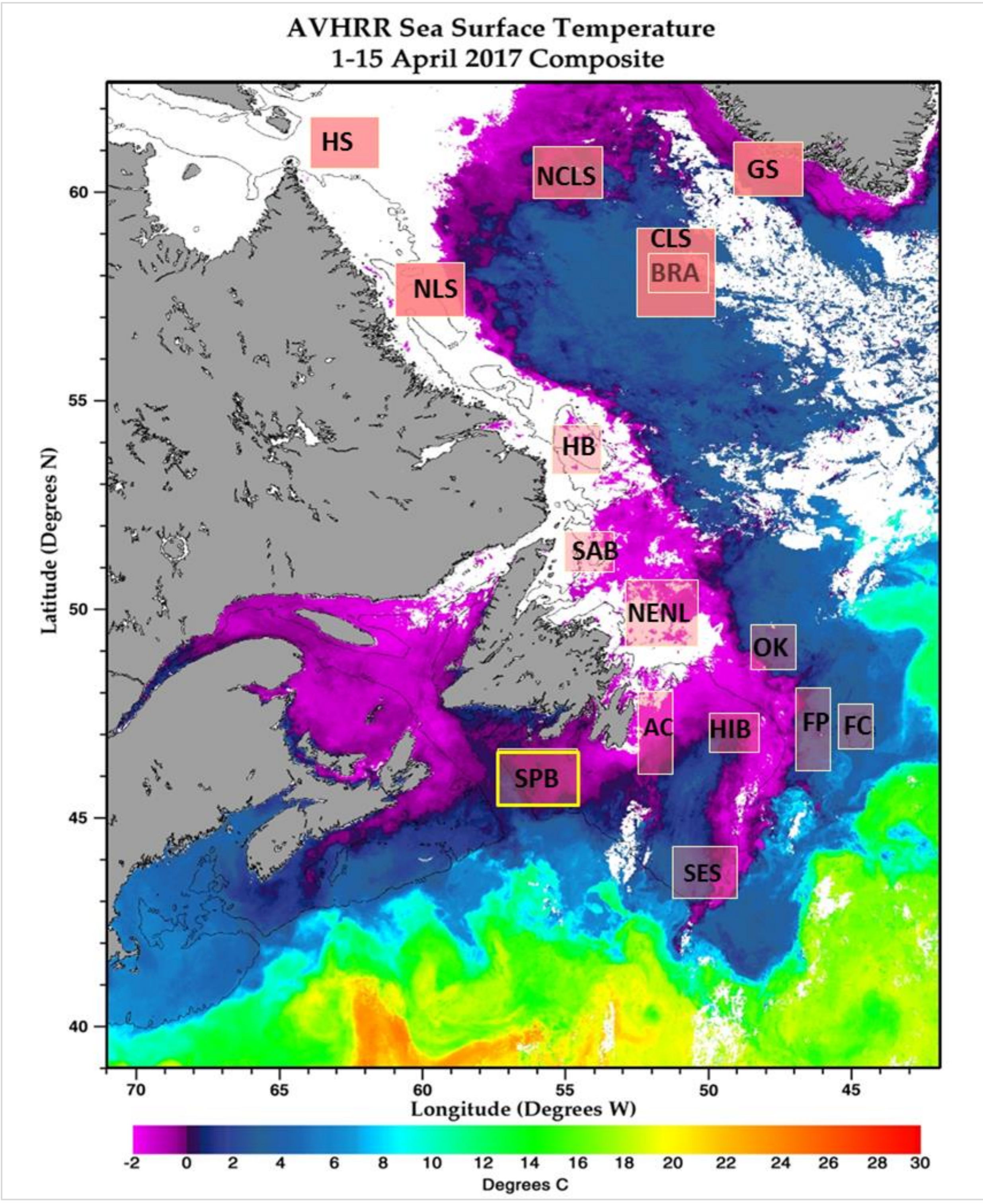

Figure 12. Map showing the April 16-30 SST and sea-ice extent and the subareas where SST time series were constructed for the Northwest Atlantic. (SST map courtesy of the Marine Ecosystem Section, BIO).

REGION	J	F	M	A	M	J	J	A	S	O	N	D
WEST GREENLAND SHELF (GS)	0.0	-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

Figure 13. Monthly SST anomalies (in °C) for 2017 derived from the data within the boxes shown in Figure 12. The anomalies are referenced to the 1981-2010 base period and color-coded according to their anomaly (Figure 3).

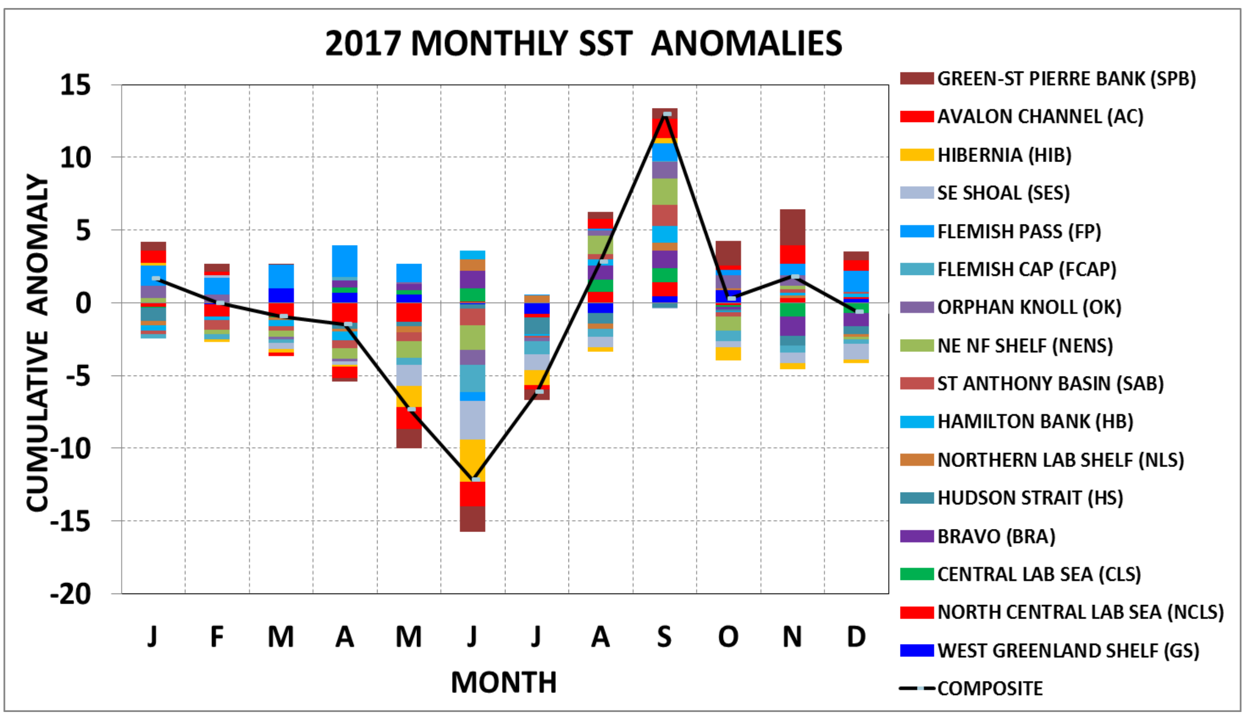

Figure 14. Cumulative SST anomalies derived from the data within the boxes shown in Figure 12 and displayed in Figure 13. The anomalies are referenced to the 1981-2010 base period.

REGION	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

REGION	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	MEAN	SD
WEST GREENLAND SHELF (GS)	-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)	-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)	-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)	-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)	0.6	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)	0.7	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)	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)	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)	0.9	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)	0.6	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)	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)	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)	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)	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)	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)	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

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

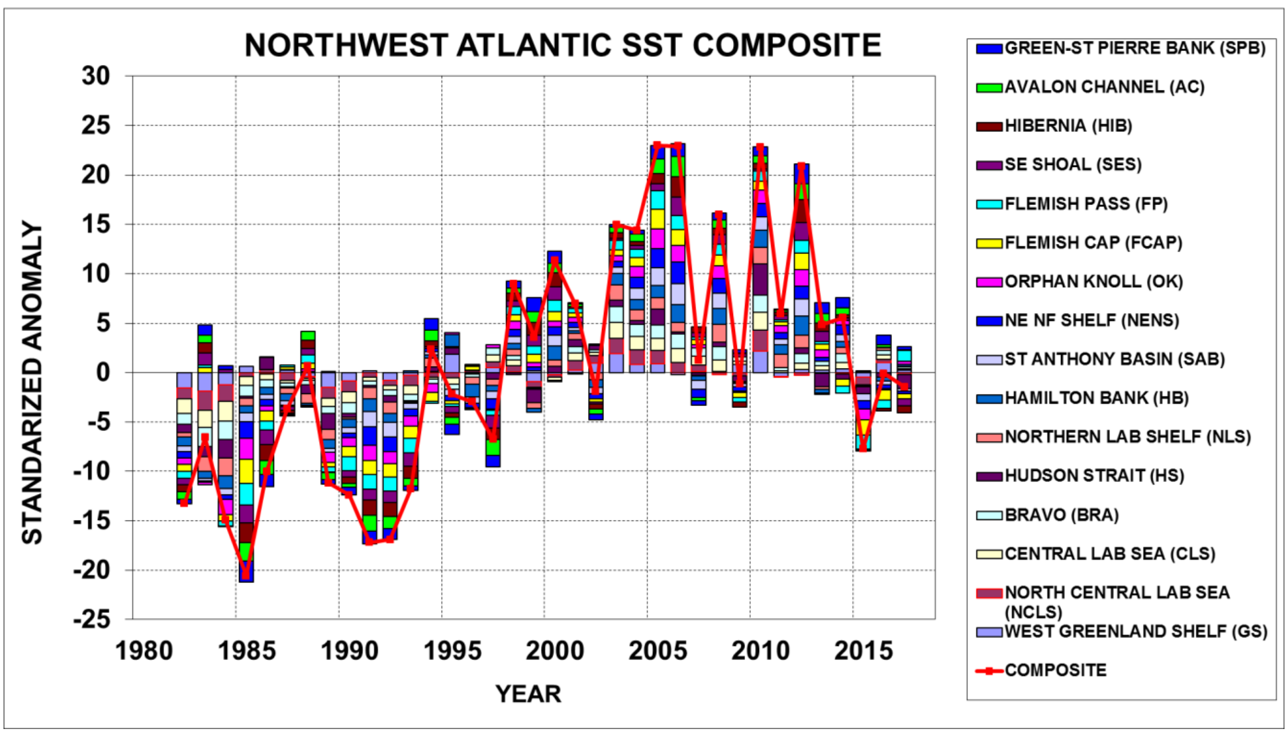

Figure 16. Standardized annual SST anomalies from the subareas on the NL shelf presented in Figure 15. The solid red line represents the composite sum.

LONG-TERM INSHORE TEMPERATURE MONITORING

Temperature data obtained from thermographs deployed at 10 inshore monitoring sites during the May to October period along the coast of Newfoundland (see Figure 1 for locations) at nominal water depths of 10 and 15 m are shown in Figure 17 as monthly anomalies, in Figure 18 as standardized July-September anomalies and repeated in Figure 19 as cumulative anomaly sums.

The data from individual sites show considerable monthly and inter-annual variability, due largely to highly variable local wind driven effects near the coast including upwelling and local summer air temperatures. The monthly variability is reasonably coherent among different sites with some exceptions. In 2017, monthly anomalies ranged from -3.7°C below normal at Comfort Cove (the strongest negative anomaly of 2017) in July to 2.1°C above normal at Upper Gullies in Conception Bay in August. The warmest month with observations was September when all 10 sites reported either near-normal or positive anomalies reaching 1.6°C above normal at Stock Cove in Bonavista Bay. The coldest month was July (Figure 17).

LOCATION	JUNE	JULY	AUG	SEPT	OCT
HAMPDEN (10 m)		-1.9	1.4	1.1	-0.8
COMFORT COVE (10 m)		-3.7	-2.2	0.4	0.8
CAPE FREELS (15 m)		-1.9	0.4	0.6	0.2
STOCK COVE		-0.3	-0.4	1.6	0.5
MELROSE (15 m)	-1.3	-2.4	0.1	0.7	0.4
OLD BONAVENTURE (10 m)	-2.8	-2.2	0.6	0.8	0.3
WINTERTON (10 m)	-0.9	-1.8	0.7	-0.2	-0.6
BRISTOL'S HOPE (10 m)	-0.1	-1.4	0.8	1.5	0.2
UPPER GULLIES (10 m)	1.5	1.1	2.1	1.4	0.3
ARNOLDS COVE (10 m)	0.5	0.1	0.1	-0.2	0.3

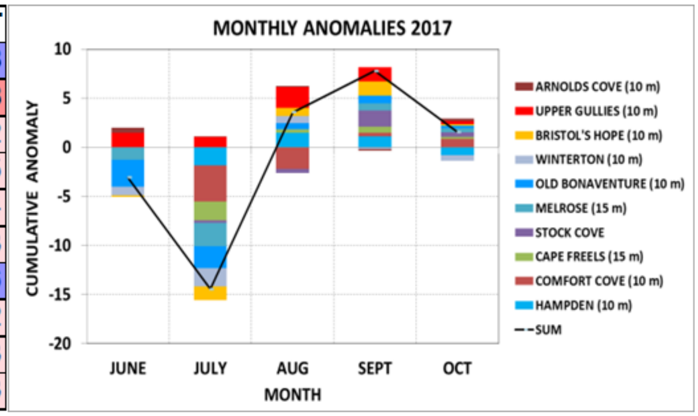

Figure 17. Monthly temperature anomalies (left panel) and cumulative sums (right panel) from data collected with thermographs along the coast of Newfoundland (Figure 1). The anomalies (in °C) are referenced to the standard base period if the data exist, otherwise over the length of the series, and are color-coded according their standard deviation (Figure 3).

Mean temperatures during the summer (July-September, Figure 18) generally exhibit a north to south gradient with the coldest values occurring at Hampden on the northeast coast with a mean summer temperature of 7.9°C and the warmest at Arnolds Cove (13.4°C). Exceptions are Melrose and Old Bonaventure, two sites in Trinity Bay that are prone to strong summer upwelling.

Near-shore temperatures trends (Figure 19) indicate below normal conditions during most of the 1990s with an increase to above normal conditions in 1999 that continued for several years, peaking in 2006 when all sites were either normal or above normal. In 2007, there was a sharp decrease with values not seen since the early 1990s with 8 of 9 sites reporting below normal (-0.8 to -2.3 SD) summer temperature. In 2008-10 temperatures varied about the mean with no clear pattern. In 2011 however, 8 of 9 sites with data again reported below normal summer coastal temperatures with anomalies ranging from ~1-2 SD below normal. The only exception was at Hampden, White Bay where temperatures were 0.7 SD above normal.

In 2012, there was an overall increase over the previous year with record highs at Hampden, White Bay (+1.4 SD) and at Arnold's Cove Placentia Bay (+2.8 SD). However, 4 of the 10 sites reported below normal temperature conditions in spite of widespread warmer than normal SST throughout the Atlantic region. In 2016, near-shore temperatures were either near-normal or above normal at all sites and the warmest since 2006 but in 2017 conditions cooled significantly (Figure 18 and Figure 19).

LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	MEAN	SD
HAMPDEN (10 m)			-0.6	0.0	-1.7	-2.4	-0.6	-1.1	0.2	0.0	1.2	-1.1	0.4	0.1	0.7	0.7	1.3	-0.8	0.9	-1.1	0.7	0.7	1.4	0.1	0.8	0.5	1.2	0.2	7.92	1.55
COMFORT COVE (10 m)	1.2	-2.1	-0.8	-1.9	0.1	-1.1	0.8	-0.7	-0.1	1.0	1.2		0.8	0.9		0.4	0.0		-0.1			-1.9	-0.5	-0.6	-1.7	-1.5	1.3	-1.0	10.54	1.76
CAPE FREELS (15 m)									-1.5	0.2	0.1		0.3	0.9	0.4	2.0	1.4	-1.0	-0.5	-1.0	-0.4	-1.3	0.1	1.0	-0.7	-1.0	1.4	-0.3	10.09	1.25
STOCK COVE	0.2	-2.2	-0.7	-2.2	0.8	-0.2	0.3	-1.0	0.7	0.7	1.0	1.1	0.9	1.1	0.8	1.3	1.7	-1.1	0.4	-0.2	-0.1	-1.4	0.5	0.8	0.6	0.7	1.0	0.2	10.72	1.40
MELROSE (15 m)									-0.6	0.3		1.0	0.2	1.2	0.0	1.4	1.7	-0.8	0.7	-0.6	-0.6	-1.5	-0.7	-0.2	-1.6	-0.1	0.8	-0.4	9.38	1.32
OLD BONAVENTURE (10 m)		-1.5	-0.9	-0.8	2.2	0.4	0.8	0.2		-0.3	0.3	1.4	0.5	0.4	-0.2	0.8	1.4	-2.0	-0.3	0.3	0.0	-1.7	-0.4	-0.6	-0.1	0.6	0.9	-0.1	8.64	1.65
WINTERTON (10 m)									-0.2		1.2	0.6	-0.1	2.0	0.1	0.4	1.2	-0.8	-0.5	0.7	-1.1	-1.8	-0.4	-1.0	-0.2	-0.1	0.1	-0.5	11.56	0.90
BRISTOL'S HOPE (10 m)	-0.9	-3.4		-0.8	0.5	-0.1	0.0	-0.2	-0.8	1.0	0.7	0.6	0.0	0.9	0.2	0.9	1.0	-0.8	1.0	0.4	0.5	-1.1	0.8	0.5	0.3	0.6	1.0	0.3	10.04	1.38
UPPER GULLIES (10 m)	-1.4	-1.5	0.5	-0.6	0.0	0.0	-1.1	-0.3	-1.2	1.0	-0.4	-0.2	0.0	0.6	-0.3	1.0	1.1	-2.3	1.3	0.1	0.3		0.5	1.3	1.6	0.9	1.2	1.2	12.12	1.32
ARNOLDS COVE (10 m)	0.7	-2.1	-1.5	-1.7	0.4	-0.9	0.6	-0.5	0.4	2.3	0.9	0.4	0.4	1.0	-0.3	0.3	1.1	0.5	0.0	1.7	0.4	-1.1	2.8	1.2	0.5	-0.5	0.3	0.0	13.40	1.21

Figure 18. Standardized temperature anomalies derived from data collected with thermographs along the coast of Newfoundland from July to September of each year (Figure 1). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise over the length of the time series. The grey shaded cells indicate no data.

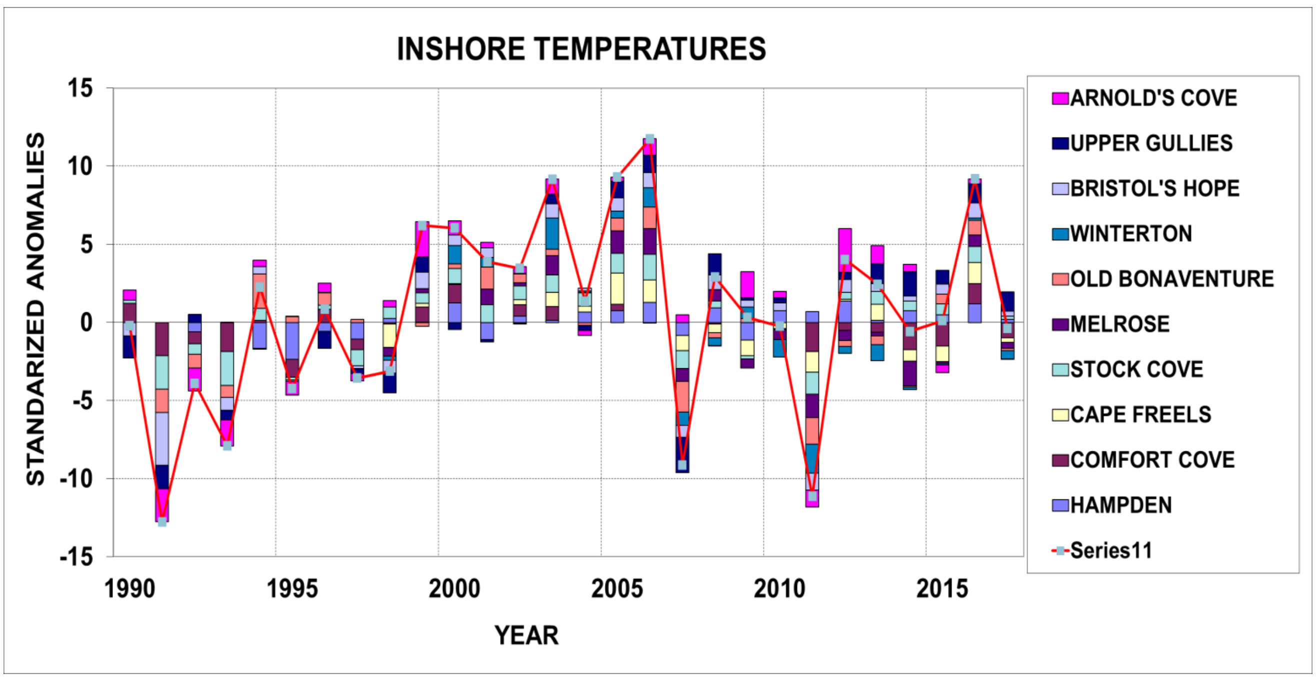

Figure 19. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland from July to September of each year (Figure 1). The anomalies were normalized with respect to their standard deviations over the standard base period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

AZMP FIXED MONITORING SITE (STATION 27)

Station 27 (47° 32.8' N, 52° 35.2' W), located in the Avalon Channel off Cape Spear NL (Figure 1), was sampled 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. These data are presented in the next sub-section.

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 Figure 20 and in Figure 21. 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.

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), a layer usually found at mid-depth elsewhere in the region, extended here down 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 were also seen to occur 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.

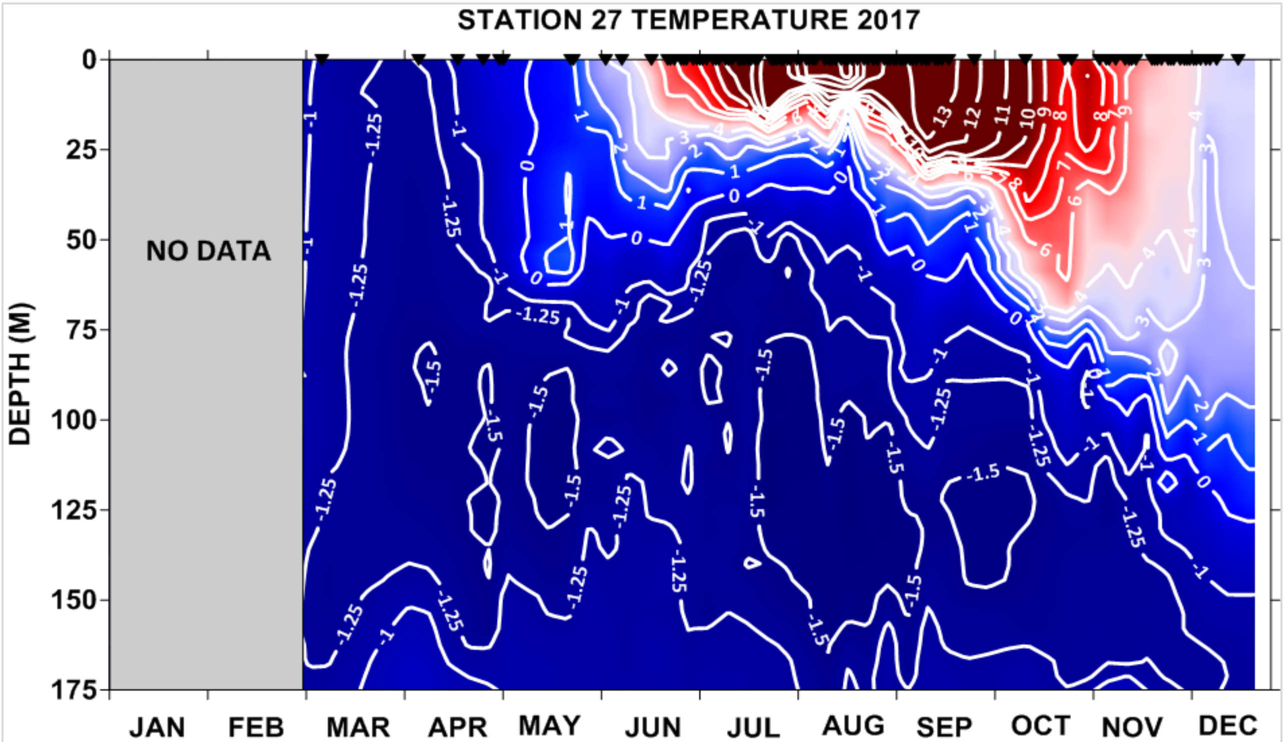

Figure 20. Contours of temperature (°C) as a function of depth at Station 27 during 2017. The symbols at the top indicate sampling times.

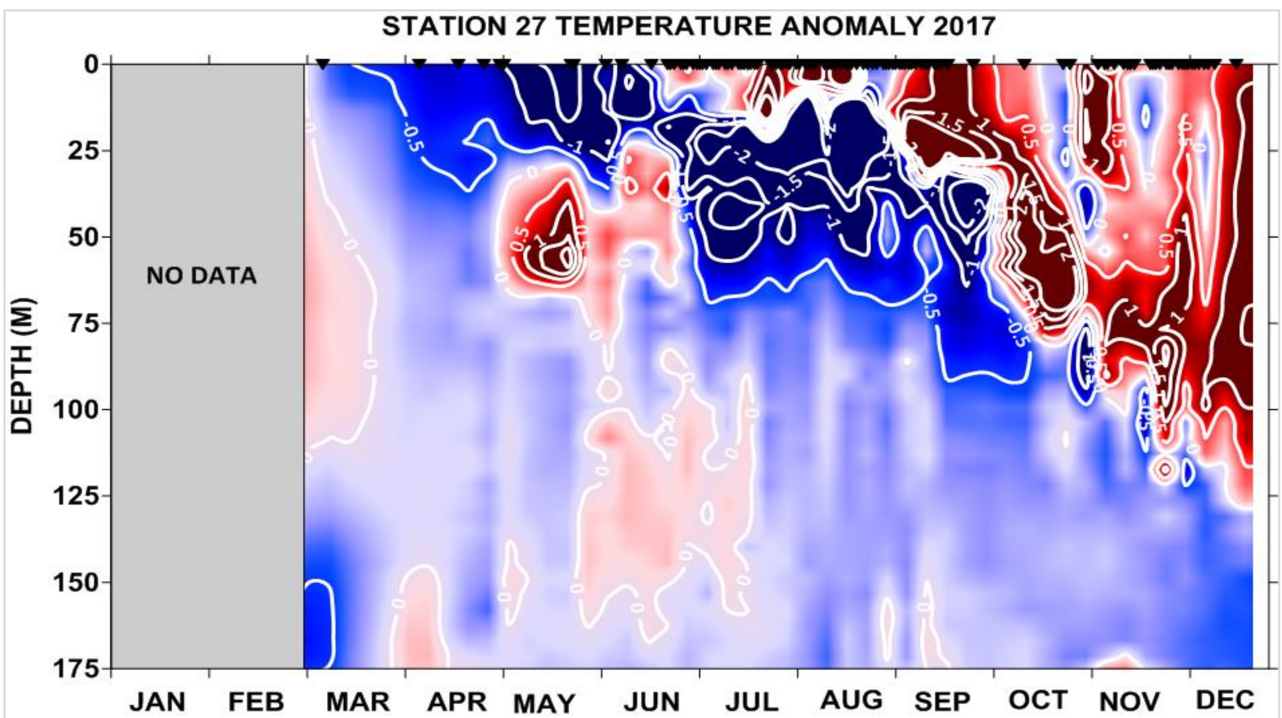

Figure 21. Contours of temperature anomalies (°C) as a function of depth at Station 27during 2017. The symbols at the top indicate sampling times.

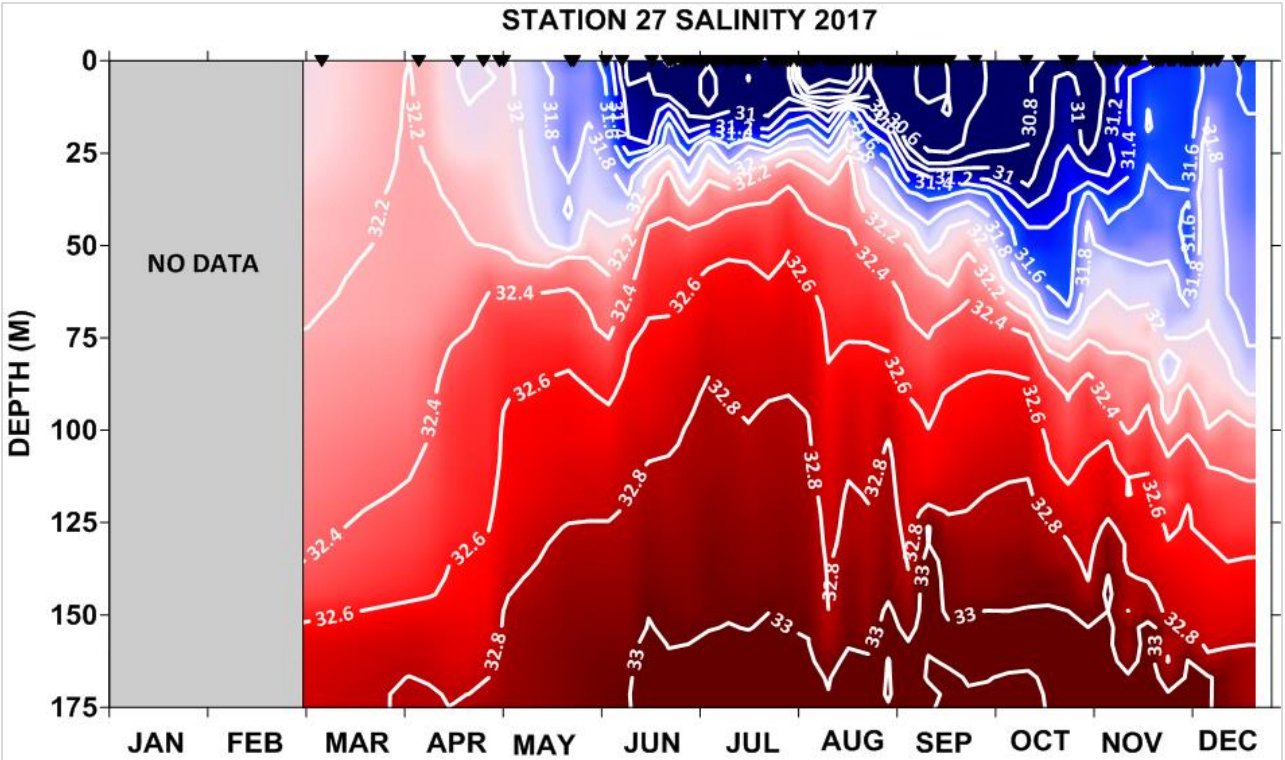

Figure 22. Contours of salinity (PSU) as a function of depth at Station 27 for 2017. The symbols at the top indicate sampling times.

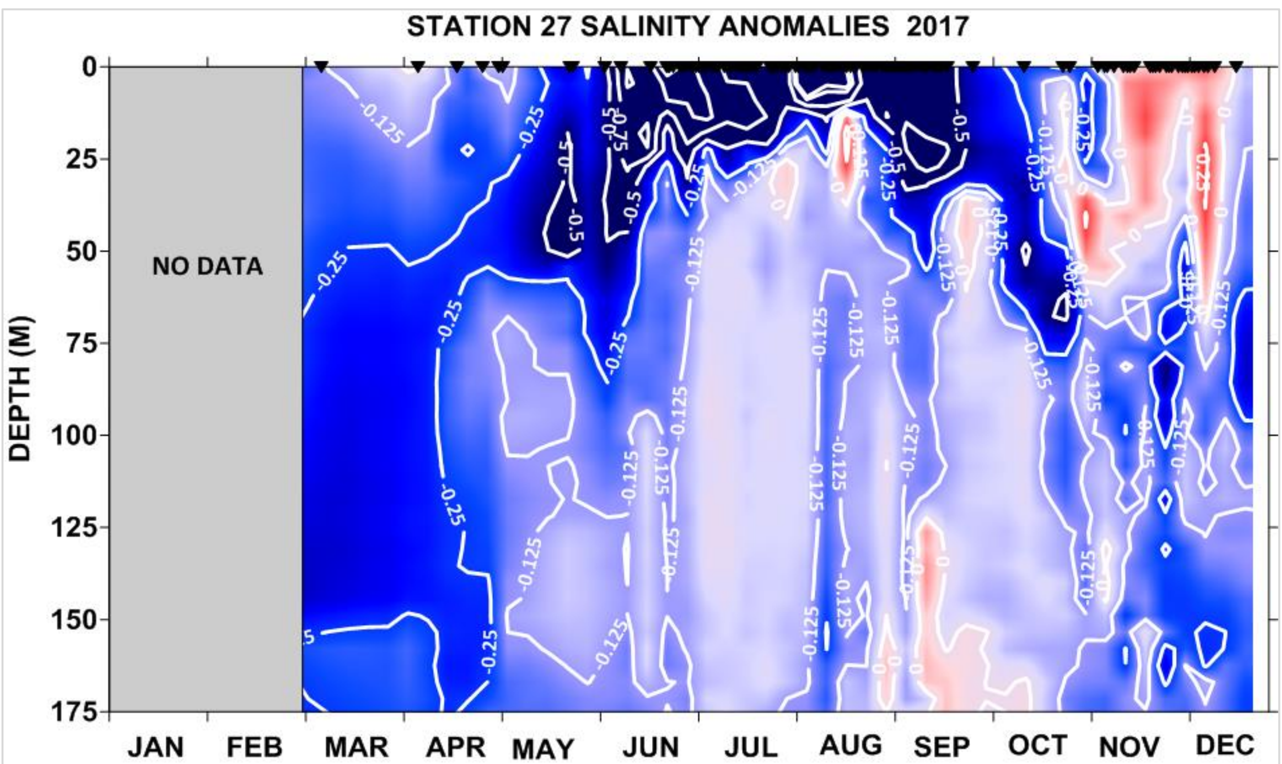

Figure 23. Contours of salinity anomalies (0.1 PSU intervals) as a function of depth at Station 27 for 2017. The symbols at the top indicate sampling times.

Upper layer salinities (Figure 22) ranged from <32.2 to 32.4 during the first half of the year and from 32.4 to 33 throughout the year from about 75 to 175 m depth. The period of low, near-surface salinity values evident from early summer to late fall is a prominent feature of the salinity cycle on the Newfoundland Shelf and is due largely to the melting of sea-ice off the coast of Labrador earlier in the year followed by advection southward onto the Grand Banks. 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 23).

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 24). Annual bottom temperature anomalies at Station 27 were the highest on record in 2011 at 3.6 SD above normal. Since then bottom temperatures have experienced a decreasing trend and have been below normal (~0.5 SD) during the past four years (Figure 24). Vertically averaged temperatures (0-176 m), which also set record highs in 2011 at +2.7 SD above normal, decreased to about normal in 2014, increased to 0.7 SD above normal in 2015 and 2016 and were about normal in 2017(Figure 25).

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 25).

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 26). 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 27). In general, water column averaged salinities have varied slightly about the mean in some years but have been predominately below the long term average since the early 1990s.

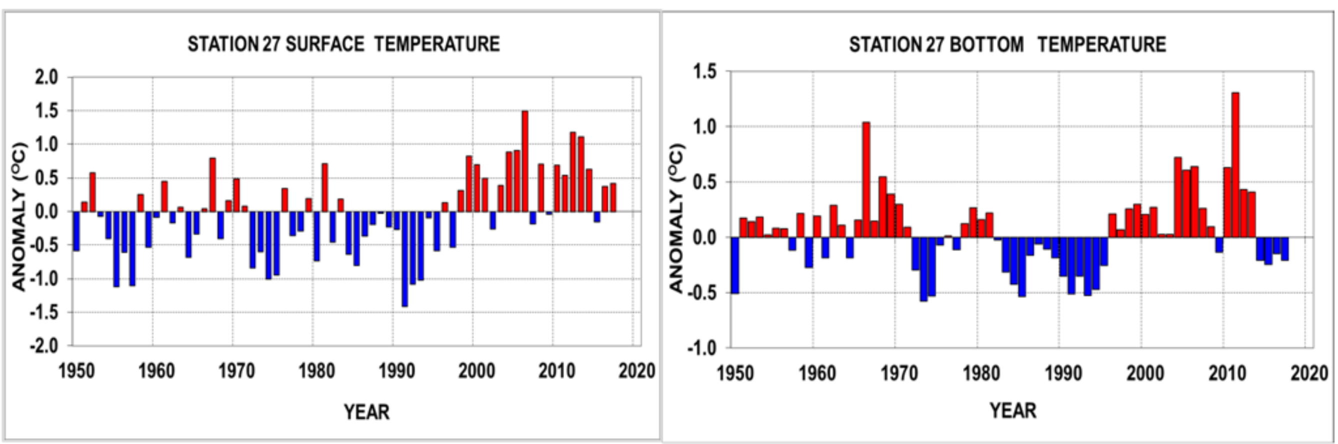

Figure 24. Annual Station 27 near-surface and near-bottom temperature anomalies referenced to the 1981-2010 mean.

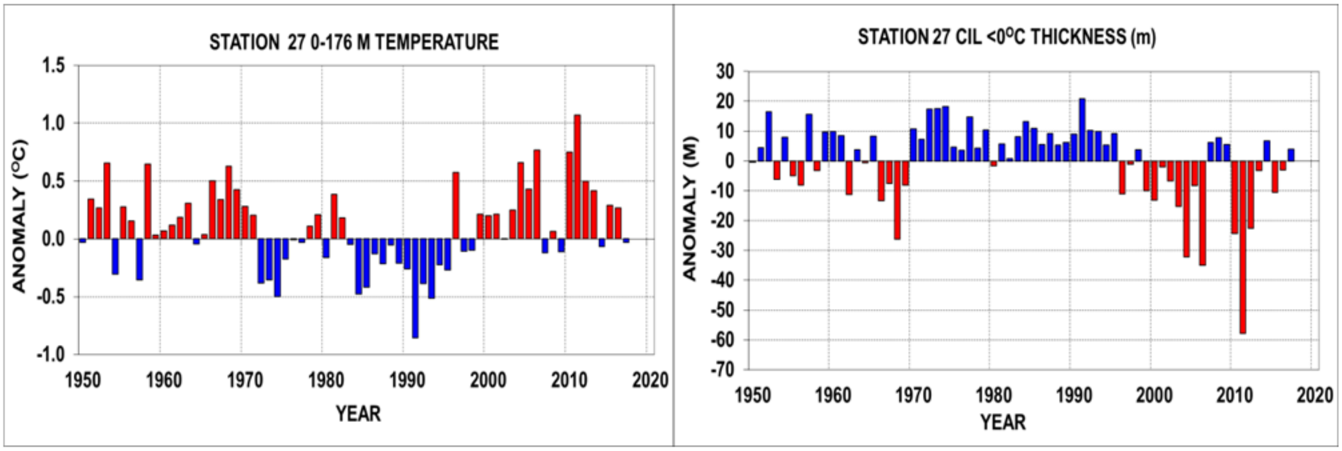

Figure 25. Annual Station 27 vertically averaged (0-176 m) temperature and CIL (<0°C) thickness anomalies referenced to the 1981-2010 mean.

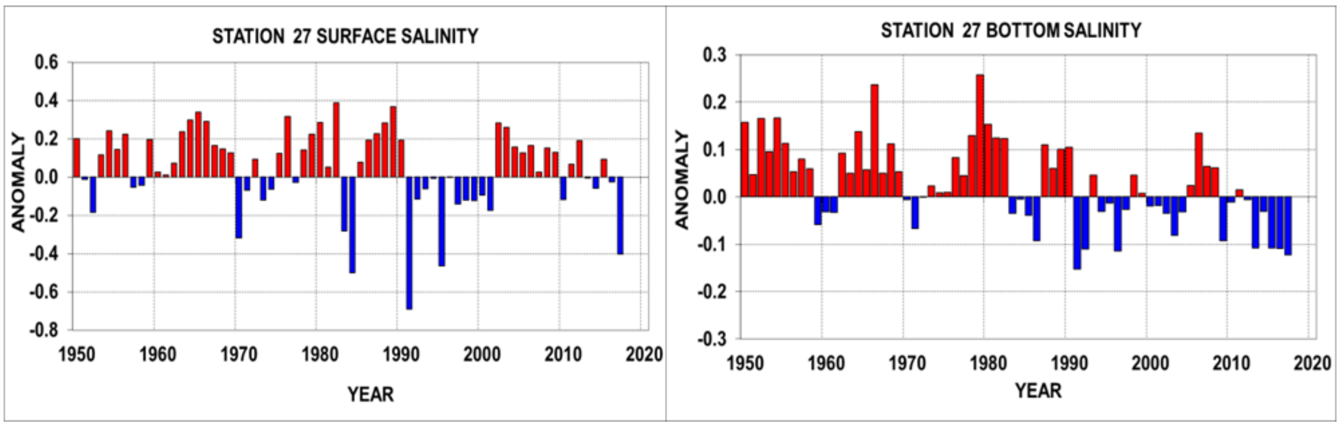

Figure 26. Annual Station 27 near-surface and near-bottom salinity anomalies referenced to the 1981-2010 mean.

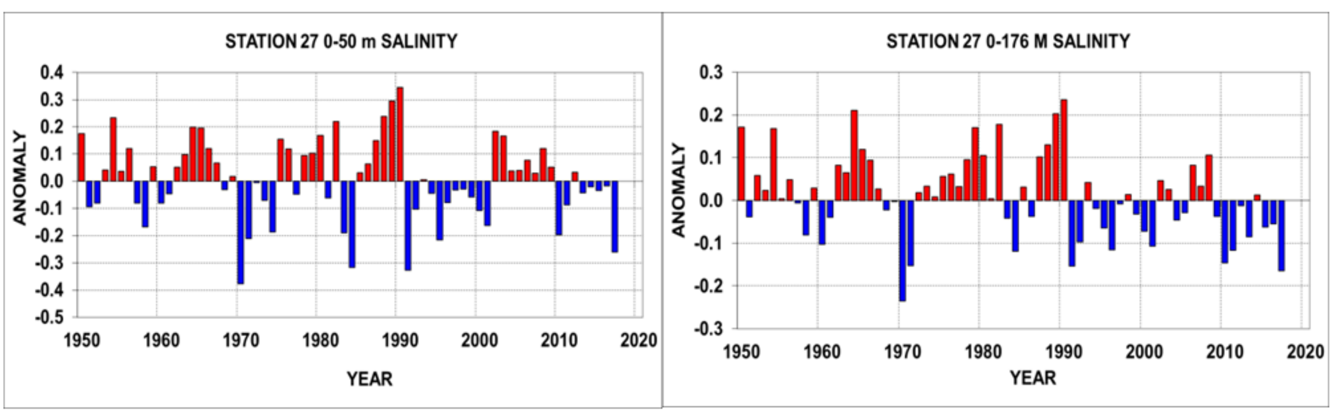

Figure 27. Annual Station 27 vertically averaged (0-50 m, 0-176 m) salinity anomalies referenced to the 1981-2010 mean.

INDEX	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	MEAN	SD
Surface T	-1.1	1.0	-0.7	0.3	-0.9	-1.2	-0.6	-0.3	0.5	-0.3	-0.4	-2.1	-1.6	-1.5	-0.2	-0.9	0.2	-0.8	0.4	1.2	1.0	0.7	-0.4	0.6	1.3	1.3	2.2	-0.3	1.0	-0.1	1.0	0.8	1.7	1.6	0.9	-0.2	0.5	0.6	4.88	0.68
Bottom T	0.4	0.6	-0.1	-0.9	-1.2	-1.5	-0.4	-0.2	-0.3	-0.5	-1.0	-1.4	-1.0	-1.4	-1.3	-0.7	0.6	0.2	0.7	0.8	0.6	0.7	0.1	0.1	2.0	1.7	1.7	0.7	0.3	-0.4	1.7	3.6	1.2	1.1	-0.6	-0.7	-0.4	-0.6	-0.89	0.44
0-50 m T	-1.0	1.0	0.5	0.2	-1.6	-1.0	-0.2	-0.3	0.1	-0.5	-0.8	-2.5	-0.8	-1.0	-0.1	-0.5	1.1	-0.6	-0.2	0.6	0.4	0.9	-0.4	0.8	1.0	1.1	2.3	-0.9	0.9	-0.6	1.4	1.8	1.4	1.0	0.1	0.7	1.2	-0.1	2.86	0.62
0-176 m T	-0.4	1.0	0.5	-0.1	-1.2	-1.1	-0.3	-0.6	0.0	-0.5	-0.7	-2.2	-1.0	-1.3	-0.6	-0.7	1.5	-0.3	-0.3	0.5	0.5	0.5	0.0	0.6	1.7	1.1	2.0	-0.3	0.2	-0.3	1.9	2.7	1.3	1.1	-0.2	0.7	0.7	-0.1	0.32	0.43
CIL (<-1.0°C)	-0.3	-1.3	0.2	0.6	1.3	1.5	0.5	0.8	-0.1	0.4	0.5	1.6	0.9	1.3	0.8	0.4	-1.5	0.1	-0.1	-1.1	-0.4	-0.4	0.0	-0.2	-1.9	-0.7	-1.5	0.0	0.2	0.2	-2.3	-2.3	-0.4	-1.8	0.4	-0.1	-0.3	0.8	73.52	32.03
CIL (<-0.5°C)	0.0	-0.4	0.1	0.8	1.1	1.2	0.8	0.9	0.4	0.6	0.4	1.5	0.6	1.0	0.5	0.6	-1.3	0.0	0.2	-0.8	-0.6	0.1	-0.3	-0.6	-2.4	-0.8	-1.7	-0.4	0.5	0.2	-2.6	-3.6	-0.8	-1.3	0.5	-0.4	-0.2	0.5	101.77	25.00
CIL (<0°C)	-0.1	0.4	0.1	0.6	1.0	0.8	0.4	0.7	0.2	0.5	0.7	1.6	0.8	0.8	0.4	0.7	-0.8	-0.1	0.3	-0.7	-1.0	-0.1	-0.5	-1.1	-2.4	-0.6	-2.6	0.5	0.6	0.4	-1.8	-4.3	-1.7	-0.2	0.5	-0.8	-0.2	0.3	118.26	16.88
CIL (<0.5°C)	-0.4	0.2	0.3	0.3	1.4	0.7	0.0	0.4	0.2	0.4	0.8	2.1	0.5	0.4	0.4	0.7	-1.3	0.2	0.3	0.0	-0.9	0.0	-0.8	-0.8	-1.4	-0.9	-2.9	0.8	0.7	0.0	-2.0	-4.7	-2.6	-0.1	0.5	-1.0	0.2	0.2	128.39	10.95
CIL (<1°C)	-0.3	-0.2	-0.4	-0.2	1.4	1.5	-0.1	0.4	0.1	0.1	1.0	2.1	0.1	0.1	0.1	0.3	-1.7	0.2	0.7	-0.2	-0.4	0.1	1.0	-1.1	-1.6	-0.9	-2.0	0.6	0.7	-0.2	-2.1	-4.1	-3.4	-0.2	0.4	-1.6	-0.4	-0.2	135.09	8.23
Surface S	1.1	0.2	1.6	-1.1	-2.0	0.3	0.8	0.9	0.6	1.5	0.8	-2.7	-0.4	-0.2	0.0	-1.8	0.0	-0.6	-0.5	-0.5	-0.4	-0.7	1.1	1.0	0.6	0.5	0.7	0.1	0.6	0.5	-0.4	0.3	0.8	0.0	-0.2	0.4	-0.1	-1.6	31.64	0.25
Bottom S	1.9	1.5	1.5	-0.4	-0.1	-0.5	-1.2	1.4	1.1	1.3	1.3	-2.0	-1.4	0.6	-0.4	-0.2	-1.5	-0.3	0.5	0.1	-0.3	-0.3	-0.4	-1.0	-0.4	0.3	1.7	0.8	0.7	-1.2	-0.2	0.2	-0.1	-1.4	-0.4	-1.4	-1.4	-1.6	33.13	0.08
0-50 m S	1.0	-0.4	1.3	-1.1	-1.9	0.2	0.4	0.9	1.2	1.8	2.1	-2.0	-0.6	0.0	-0.3	-1.3	-0.5	-0.2	-0.2	-0.3	-0.6	-1.0	1.1	1.0	0.2	0.2	0.5	0.2	0.7	0.3	-1.2	-0.5	0.2	-0.2	-0.1	-0.2	-0.1	-1.5	31.94	0.17
0-176 m S	1.0	0.0	1.7	-0.4	-1.2	0.3	-0.4	1.0	1.4	2.0	2.3	-1.5	-1.0	0.4	-0.2	-0.6	-1.2	-0.1	0.1	-0.3	-0.7	-1.1	0.5	0.3	-0.5	-0.3	0.8	0.3	1.0	-0.4	-1.5	-1.2	-0.1	-0.9	0.1	-0.6	-0.5	-1.6	32.50	0.10
Annual MLD											1.0	0.5	1.7	-0.1	0.7	-2.2	-0.3	-0.7	-1.2	-1.0	-0.7	-0.7	0.1	-1.1	1.3	-0.2	0.5	1.2	-0.7	0.8	-1.1	1.5	0.0	0.9	0.7	1.4	0.5	0.2	58.19	9.16
Winter MLD											0.3	-0.8	-0.1	-0.6	0.5	-1.1	-0.2	0.4	-1.0	-0.5	-0.2	-0.2	-1.2	-0.9	1.3	0.6	1.3	1.0	-1.5	0.9	-2.3	0.7	0.4	1.9	-0.5	1.5	1.9		97.41	30.74
Spring MLD											-0.3	1.8	-0.1	0.2	-0.5	-1.6	0.1	-1.5	0.0	-1.6	-0.1	0.7	0.3	-0.4	0.4	-1.1	-0.6	0.5	1.4	-1.2	0.0	1.5	-0.8	1.4	1.4	-0.7	-0.2	0.9	43.87	15.16
Summer MLD											2.1	1.9	2.8	0.3	0.4	0.4	0.4	-0.5	-0.3	-0.4	-0.7	0.1	-0.5	-0.6	-0.5	-0.4	0.0	-0.5	-0.5	-0.5	-0.3	0.5	-0.7	-0.3	-0.4	0.6	0.0	-0.4	23.40	8.72
Fall MLD											0.8	-0.6	1.7	0.2	1.0	-1.9	-0.6	0.0	-0.9	0.3	-0.7	-2.0	1.5	-0.4	0.2	0.1	-0.4	0.8	-0.8	2.0	-0.4	0.3	0.6	-0.8	0.5	0.7	-1.3	-0.2	66.01	16.27
Annual Stratification	-1.8	-0.3	-1.2	0.1	1.1	-0.8	-1.7	-0.1	1.4	0.1	-1.0	1.4	-0.2	-0.7	0.1	2.6	-1.1	1.0	1.6	0.9	0.2	0.6	-1.4	-0.4	-0.8	-0.6	0.2	-0.1	0.1	-0.5	-1.0	-2.0	-1.1	0.2	1.1	-1.6	-0.3	1.6	20.71	3.62
Winter Stratification			-0.3		0.0	-0.6	-0.6	-1.0		-0.3	1.3	-0.8	3.0	0.8	-1.0	1.9	0.6	-0.2	-0.8	0.7	1.6	-0.3	-0.1	-0.4	-0.9	-0.9	-0.7	-1.0	0.2	-0.4	-0.4	-0.6	-1.0	-1.6	-1.4	-0.7	-1.0		5.54	6.92
Spring Stratification	-1.0	-0.1	-0.7	2.2	1.7	-1.0	-0.4	1.4	-0.2	-0.7	-1.6	1.9	0.1	-0.2	-0.7	1.8	-0.5	1.0	0.4	0.9	-0.7	-0.2	-1.1	-1.1	-0.5	-0.2	0.4	-0.2	-0.6	0.2	-1.2	-0.5	-0.7	-0.2	-1.0	-0.4	-0.9	0.6	12.86	4.87
Summer Stratification	-1.3	0.1	-2.0	-0.4	1.8	-0.1	-1.4	-1.3	0.4	0.6	-1.0	-0.3	-1.4	-0.9	1.2	0.8	-1.5	0.2	1.0	1.7	0.1	0.5	-1.1	-0.5	-0.1	0.5	0.0	1.3	0.5	0.2	-0.9	-2.9	-0.4	1.3	4.1	-1.9	-1.0	2.7	50.50	5.84
Fall Stratification		-0.6		-1.2	-0.6	-0.6	-1.5	0.0	0.5	0.2	0.4	1.9	-0.4	-0.8	-0.2	2.2	-0.8	0.9	2.4	-0.4	0.4	1.2	-1.0	0.6	-0.7	-1.1	0.3	-0.5	0.3	-1.2	0.1	-1.1	-0.9	-0.1	-0.5	-1.0	1.2	-0.2	13.85	6.45

Figure 28. Standardized temperature and salinity anomalies, CIL thickness, MLD and stratification at Station 27 from 1980 to 2017. The anomalies are normalized with respect to their standard deviations over the standard base period. Grey cells indicate no data available.

STATION 27 VIKING BUOY

In June 2017, a new buoy (type Viking) was deployed at Station 27. In addition to air and ocean surface sensors (wind speed, wave height, air temperature and humidity, sea surface temperature and salinity, pH, etc.), this buoy profiles automatically the water column with a CTD when the conditions are favorable (wave heights below a certain threshold and air temperature above freezing). Data from this buoy were already included in previous section plots. Since these data will gradually appear in AZMP reporting throughout the zone, an emphasis for 2017 on temperature and salinity fields is presented here. Figure 29 shows the temperature field resulting from daily averages of the 334 automatic profiles realized in 2017. Unfortunately, mechanical problems prevent the buoy from profiling between mid-September to early November. Shortly after reparation, the cable became tangled and prevented the CTD from profiling deeper than about 40 m. Nevertheless, the high-resolution sampling presented here offers a new synoptic view of the conditions at Station 27, including the resolution of internal isotherm heaving, especially during the stratified period (before mid-September's breakdown). The largest of these isotherm heaving is found in the first days of September between depths of 20-50 m.

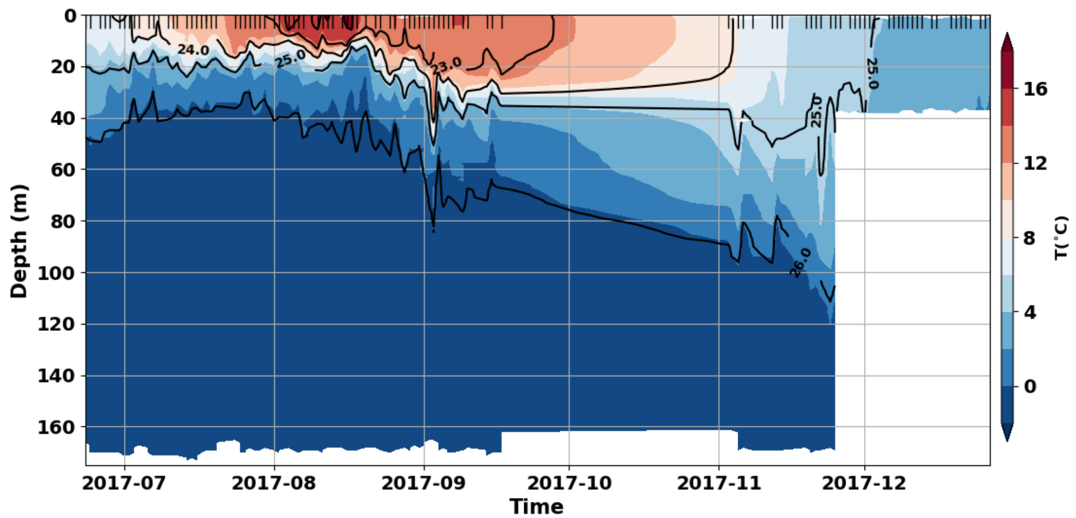

Figure 29. Temperature field (colored contours) as measured by the Viking buoy automatic profiling system. Isopycnals (σ_t, black lines) are identified on figure. All casts have been averaged in daily mean profiles (marked as black tick marks on the top of the Figure) before being linearly interpolated in time.

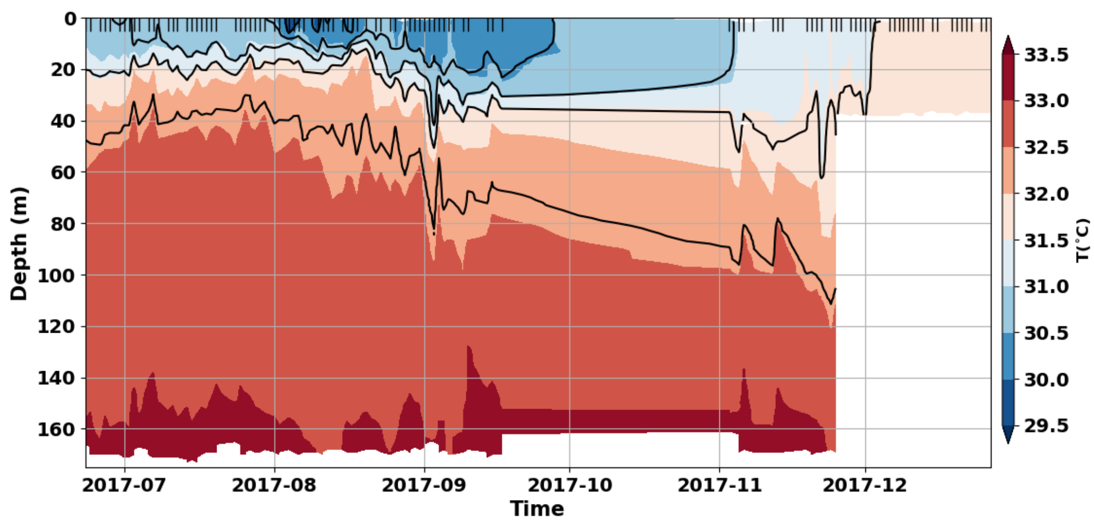

Figure 30. Salinity field (colored contours) as measured by the Viking buoy automatic profiling system. Isopycnals (σ_t) are the same as in Figure 29 (see Figure for identification). All casts have been averaged in daily mean profiles (marked as black tick marks on the top of the Figure) before being linearly interpolated in time.

STATION 27 STRATIFICATION AND MIXED-LAYER DEPTH

Stratification is an important characteristic of the water column influencing vertical mixing rates, the transfer of solar heat to lower layers and important biochemical processes. The seasonal development of stratification is an important process influencing the formation and evolution of the cold intermediate layer on the shelf regions of Atlantic Canada. It essentially insulates the lower water column from the upper layers, thus slowing vertical heat flux from the seasonally heated surface layer.

Stratification index at Station 27 is computed from the density (sigma-t) difference between 5 and 50 m for each density profile (i.e. $\Delta\rho/\Delta z$). These values are then averaged by month and the annual anomalies are computed from the available monthly averages (Craig and Colbourne 2002). The annual and seasonal values are shown in Figure 28 as standardized anomalies. The 1981-2010 monthly mean and the 2017 monthly values are shown in Figure 31. On average the water column is very weakly stratified during the winter months, stratification increases during the spring (typically May or June) reaching its maximum by August then decreases to winter time values by December. In 2017, the stratification was below the long-term mean in April and May, above normal during the summer months and near-normal towards the end of the year (Figure 31).

The annual averaged stratification from 1950 to 2017 at Station 27 is shown in Figure 32. The annual index was generally below the mean prior to the 1980s after which it began to increase with large fluctuations about the mean. In general, stratification on the inshore Newfoundland Shelf at Station 27 shows a long-term increasing trend from about the mid-1960s until the late 1990s. After a decrease of the low-pass anomaly between about 2000 and 2011, the stratification is increasing again with 2017 being the highest since positive anomaly since 1998 (Figure 32).

The monthly mean mixed layer depths (MLD) at Station 27 were also estimated from the density profiles as the depth of maximum density gradient. There were insufficient high resolution data profiles available prior to 1990 to compute reliable annual means. The monthly, seasonal and annual values of the MLD are shown in Figure 33, Figure 28 and Figure 34, respectively. The average monthly values range from about 120-170 m in the winter to <25 m in summer and up to 80 m by late fall (Figure 33). In 2017, April values were deeper than normal (no data in January to March), near normal from June to September, above normal in October but shallower than normal in November and December (Figure 33). In general, there appears to be a slight increasing trend since 1995 of about 0.7 m/year in the annual mean, although the 2017 value was near-normal at +0.2 SD (Figure 28 and Figure 34).

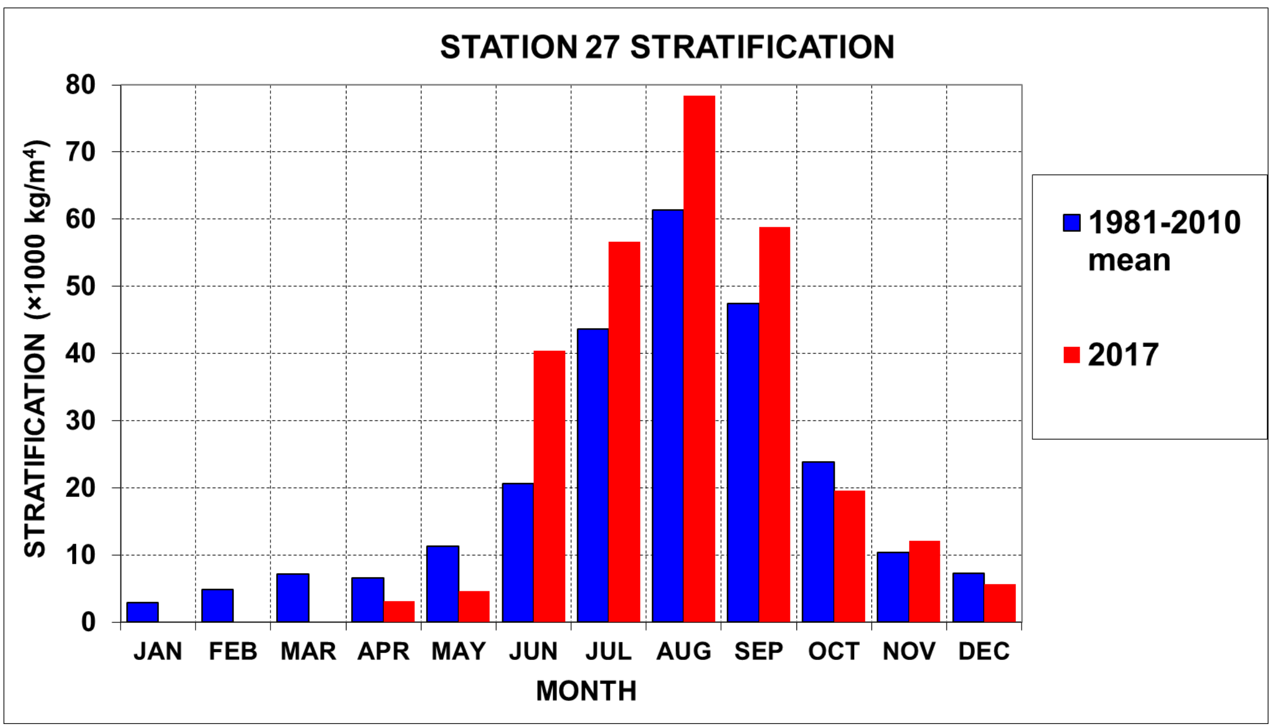

Figure 31. The 1981-2010 monthly average and the 2017 monthly average stratification values at Station 27.

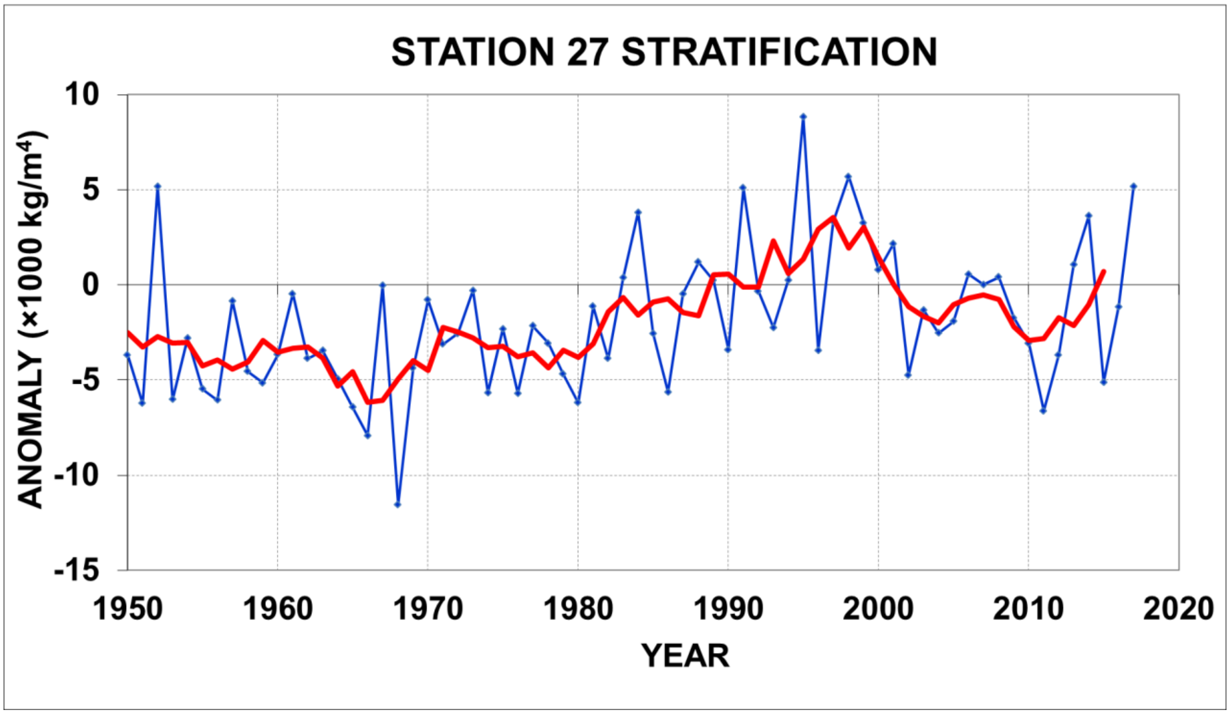

Figure 32. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean. The red line is a 5-year running mean.

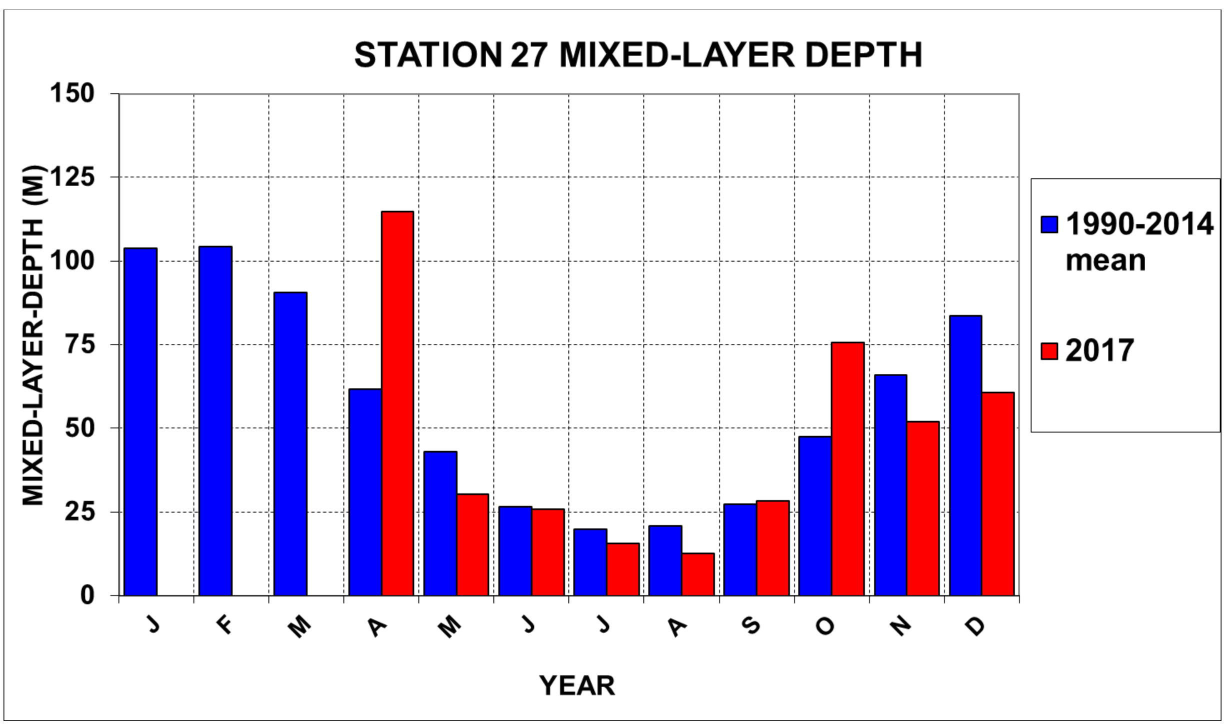

Figure 33. The 1990-2010 average and the 2017 monthly mean Mixed Layer Depths at Station 27.

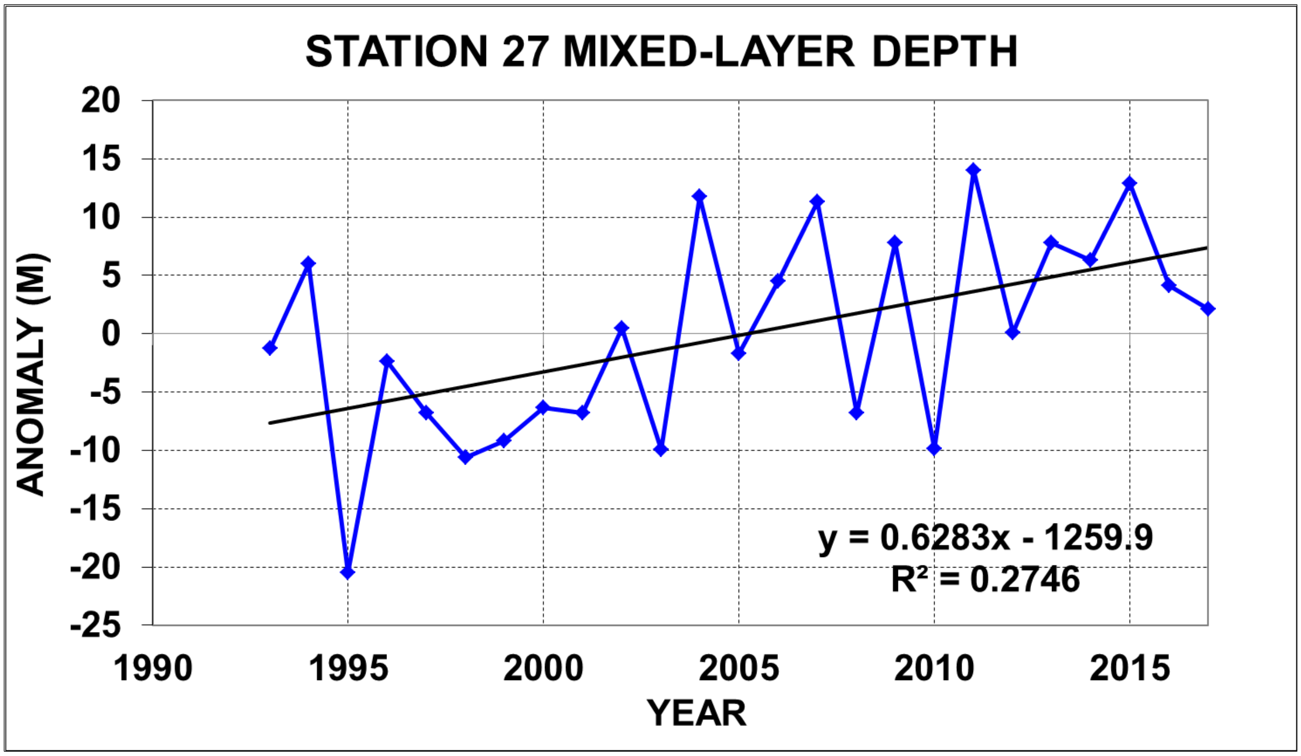

Figure 34. Annual mixed-layer-depth anomalies at Station 27 referenced to the 1990-2015 mean.

STANDARD AZMP SECTIONS

In the early 1950s, several countries under the auspices of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic hydrographic 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 DFO's 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 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 occupied 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 (see Figure 2 for location).

TEMPERATURE AND SALINITY VARIABILITY

The water mass characteristics observed along the standard sections crossing the NL Shelf are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1.5°C to 2°C and salinities of

31.5 to 33.5. Labrador Slope water flows southward along the shelf edge and into the Flemish Pass and Flemish Cap regions. This water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3°-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 gradient of temperature and salinity, particularly along the frontal boundaries separating the shelf and slope water masses.

The summer temperature and salinity structures along the Flemish Cap (47ºN), Bonavista and Seal Island sections during 2017 are highlighted in Figure 35, Figure 36. Contours of temperature (°C), salinity, and their anomalies along the Bonavista section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels. and Figure 37, respectively. The dominant thermal feature along these sections is the mass of cold and 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.

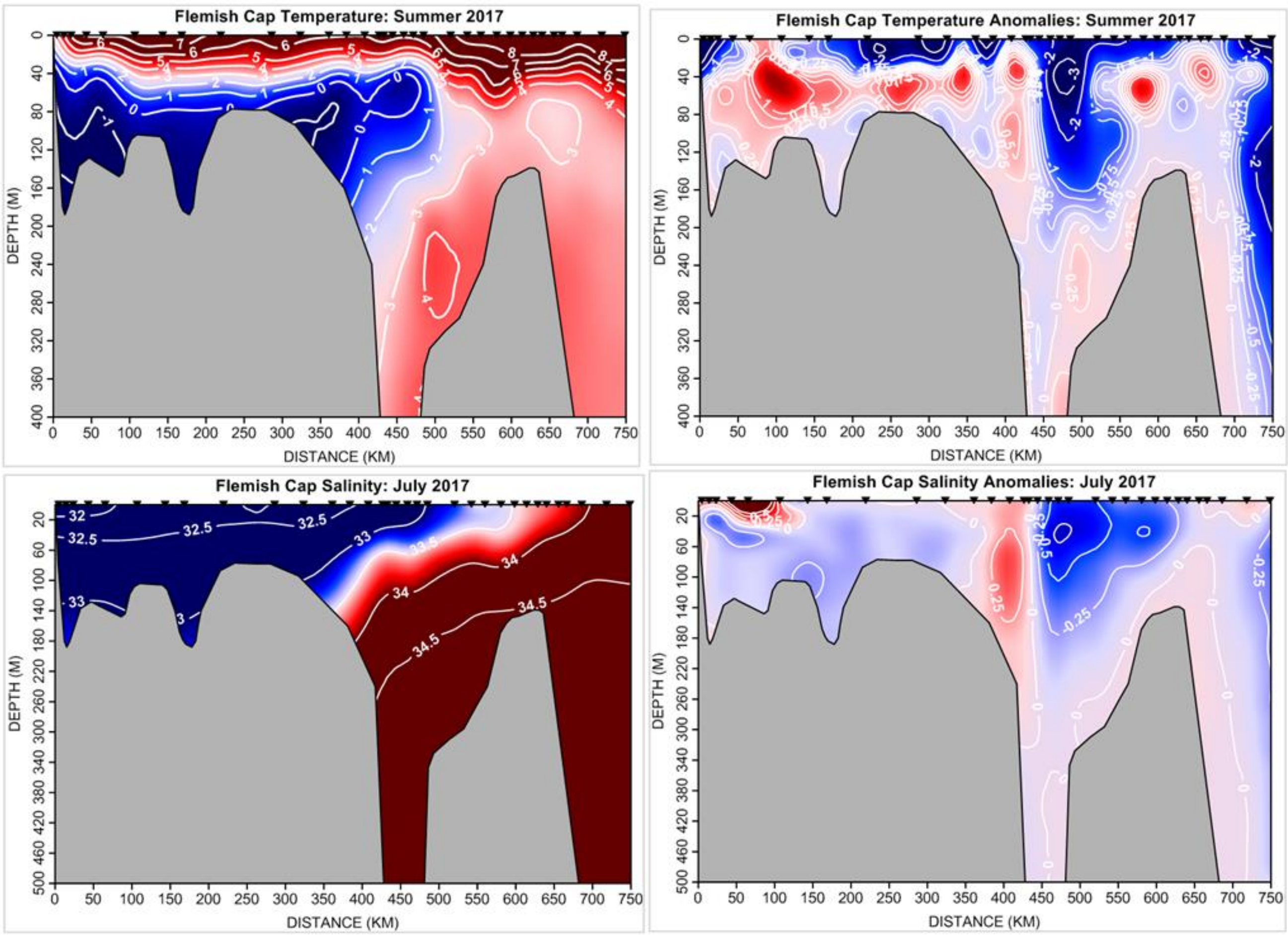

Figure 35. Contours of temperature (°C), salinity, and their anomalies along the Flemish Cap (47ºN) section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels.

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. After its formation, the CIL remains present throughout most of the year until its complete mixing the following winter.

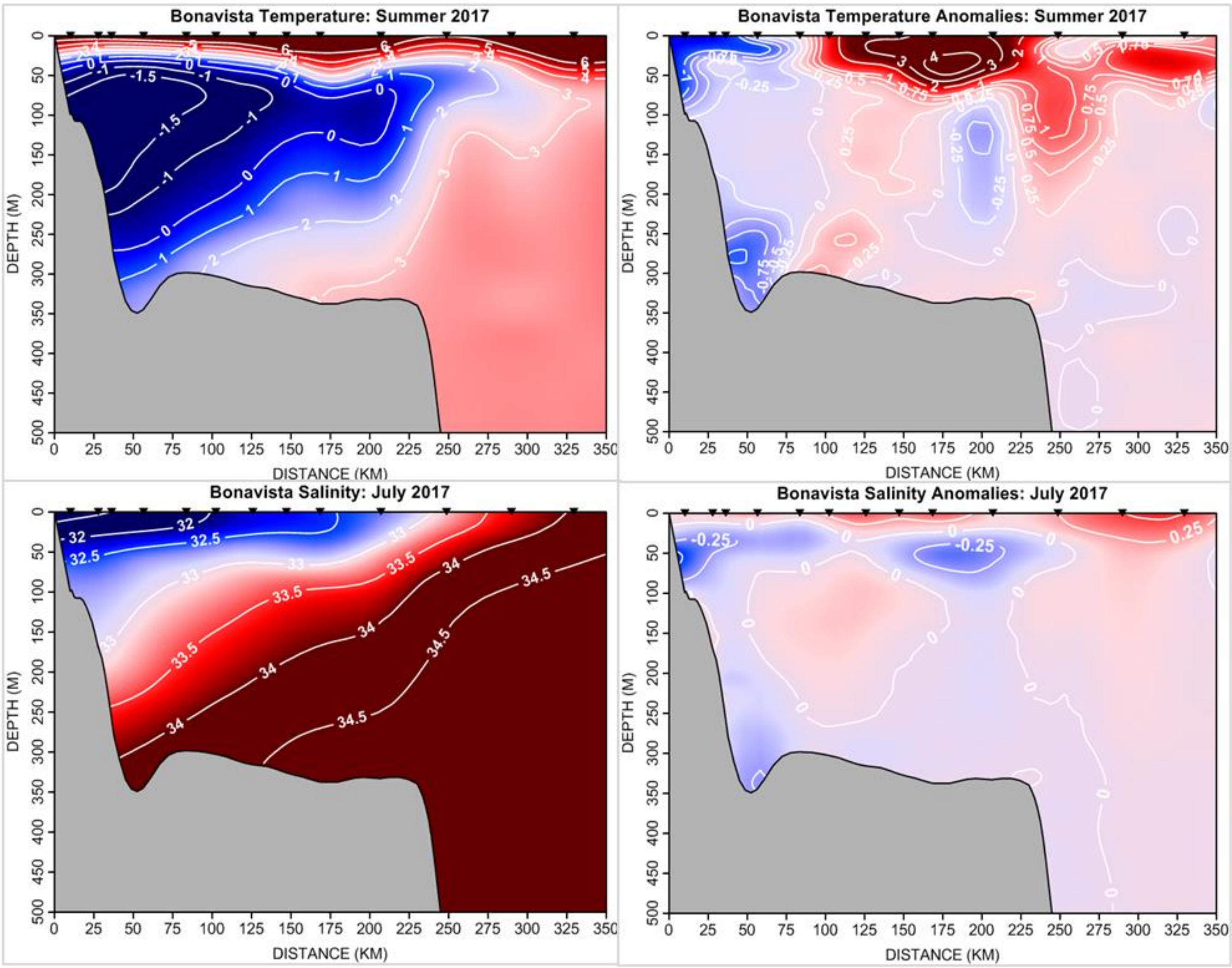

Figure 36. Contours of temperature (°C), salinity, and their anomalies along the Bonavista section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels.

In summer 2017, along the Flemish Cap section, temperature anomalies of up to 2°C below normal are found at the surface as well as deep into the water column in the east of the Cap and in the Flemish Pass region (Figure 35, top right panel). Intermediate water temperatures over the Grand Banks were above normal while bottom temperatures were near normal along the section. Temperatures along the Bonavista Bay 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 near normal (Figure 36. Contours of temperature (°C), salinity, and their anomalies along the Bonavista section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels., top right panel). Along the SI 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° to 2°C below normal. In the offshore slope water temperatures were above normal by up to 2°C near the surface (Figure 37, top right).

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. In 2017, salinities along the Flemish Cap section varied about the mean with below normal values reaching 0.5 below normal over the Flemish Cap and Pass areas (Figure 35, bottom right panel). Along the Bonavista Bay section salinity anomalies were generally near normal at depth with some isolated areas of above and below values in the near surface layer (Figure 36. Contours of temperature (°C), salinity, and their anomalies along the Bonavista section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels., 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 37, bottom right panel).

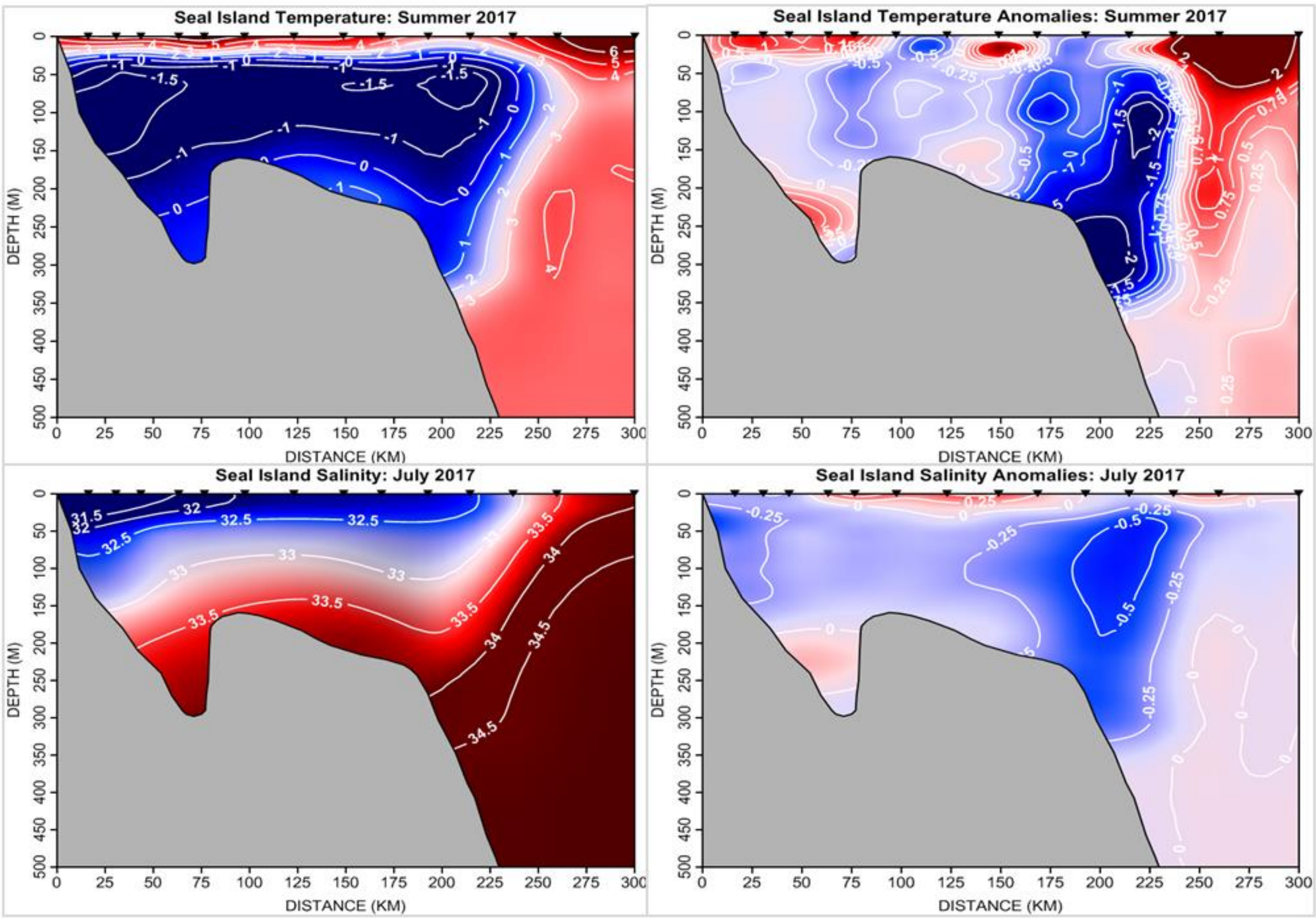

Figure 37. Contours of temperature (°C) and salinity and their anomalies along the Seal Island section (Figure 2) during the summer of 2017. Station locations along the section are indicated by the symbols on the top panels.

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 38. Along the Flemish Cap section the average cross-sectional area of the CIL is 26.5 ± 6.6 km^2 during the summer, along the Bonavista Bay section the average cross-sectional area is 25.6 ± 9.3 km^2 and along the White Bay and Seal Island 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 White Bay and Seal Island sections (implying colder shelf water conditions), near normal along the Bonavista Bay section but below normal on the Grand Banks along the Flemish Cap section.

Indices derived from the temperature and salinity data for the Seal Island, Bonavista Bay and Flemish Cap sections sampled during the summer are shown in Figure 39 as standardized values and in Figure 40 and Figure 41 as composite temperature and salinity time series. Most temperature and salinity indices shown, except along the Flemish Cap section, were either near-normal or below normal by as much as -1.6 SD in salinity on the Bonavista Bay section. This is in contrast to most of the 2000s when conditions were mostly warmer and saltier than normal. The composite temperature index (Figure 40) 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 41) shows, except for 2016, fresher-than-normal conditions during the previous 8-years with the 2017 value the lowest since 1991.

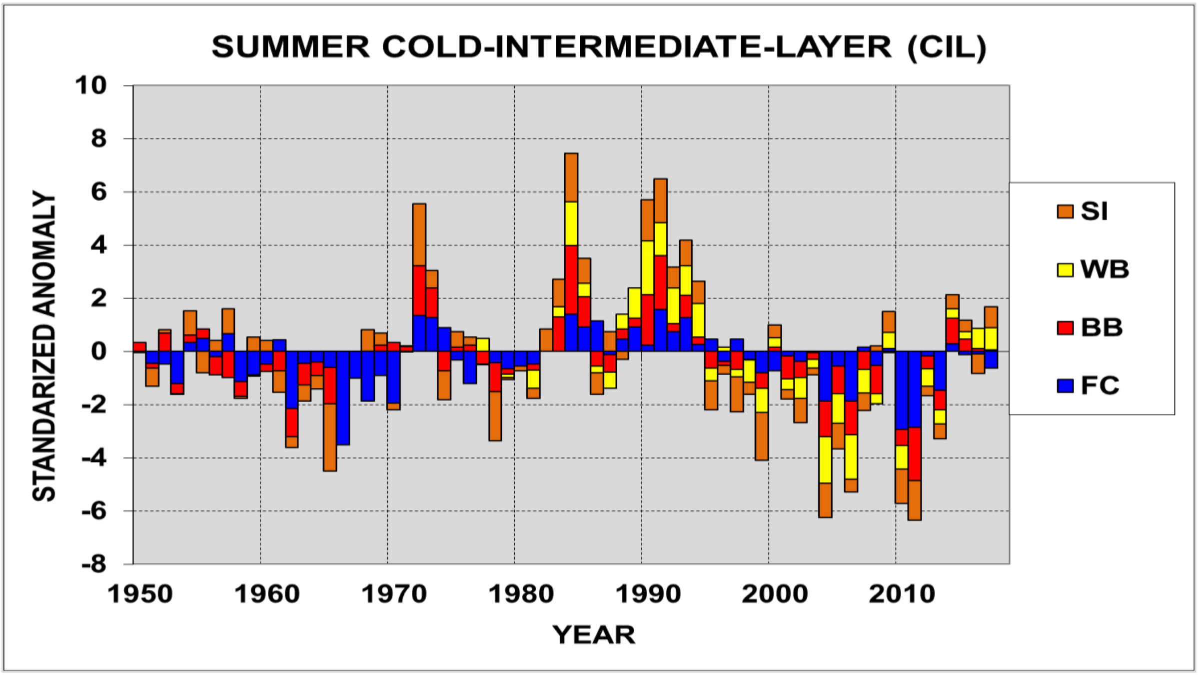

Figure 38. Cold-Intermediate-Layer areas during the summer along the Seal Island (SI), White Bay (WB), Bonavista (BB) and Flemish Cap (FC) sections displayed as cumulative standardized anomalies relative to 1981-2010.

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

Figure 39. Standardized temperature and salinity anomalies derived from data collected along standard cross-shelf sections during the summer (Figure 2). The anomalies are normalized with respect to their standard deviations over the standard base period. The grey shaded cells indicate years for which no observations were available.

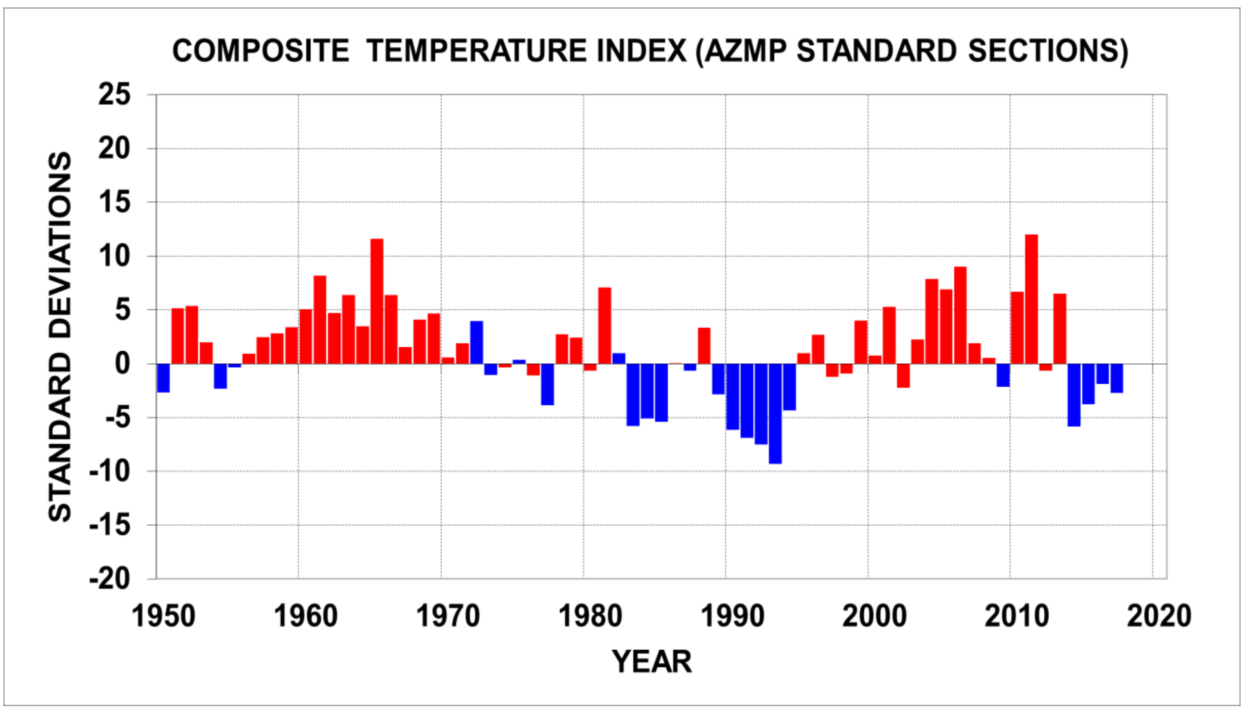

Figure 40. Composite temperature index derived from data collected along standard cross-shelf sections shown in Figure 39. All rows with temperature anomalies are taken into account and the signs for CIL areas were reversed.

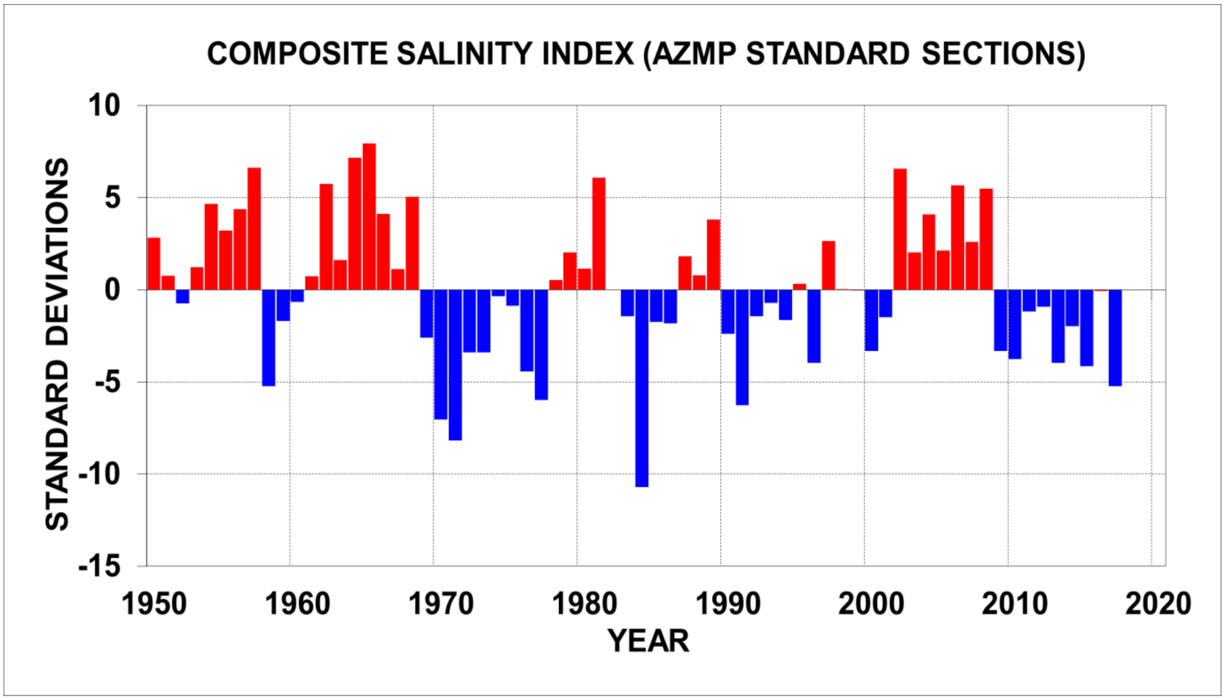

Figure 41. Composite salinity index derived from data collected along standard cross-shelf sections shown in Figure 39. All rows with salinity anomalies are taken into account.

BOTTOM OBSERVATIONS IN NAFO SUB-AREAS

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 previous CSAS research documents (e.g., Colbourne et al. 2017), these data were combined with AZMP hydrographic surveys to derive bottom temperature and salinity. A new method for calculating these parameters is introduced here. While most of the data used here also use also acquired by DFO-NL during multi-species surveys and AZMP hydrographic campaigns, observations are completed with data from other origins made available by MEDS (surveys from other DFO regions, international oceanographic campaigns, Argo program, etc.)

Moreover, the calculation method of the bottom conditions also slightly differs. While previous calculation consisted on a flat 2D interpolation of the closest observations to the bottom, this new method now consider the bathymetry during the determination of the bottom conditions of the observed fields (e.g., a trough or seamount would likely have different conditions than the surroundings). For consistency, historical time series presented in this section have been re-calculated using the same methodology. Small discrepancies may thus exist between the results presented here and the same quantities from previous year's reports.

This new method is similar to the approach in the annual physical oceanographic conditions for the Gulf of St. Lawrence (e.g., Galbraith et al. 2018) and details are given here. First, all available annual profiles of temperature and salinity are vertically averaged in 5m bins and vertically interpolated to fill missing bins. Then, for each season (April-June for spring and October-December for fall) all data are averaged on a regular 0.1° x 0.1° (latitudinal x longitudinal) grid to obtain one seasonal profile per grid cell. Since this grid has missing data in many cells, each depth level is horizontally linearly interpolated to fill missing data. For each grid point, the bottom observation is considered as the data at the closest depth to the GEBCO_2014 Grid bathymetry (version 20150318, Website), to a maximum of 50 m difference. In the following, bottom observations deeper than 1000 m are clipped. This method is applied for all years between 1980 and 2017 from which the 1981-2010 climatology is derived. Anomalies for 2017 are calculated as the difference between annual observations and the climatology.

SPRING CONDITIONS

Spring climatological bottom temperature and salinity maps, together with 2017 observations and anomalies for NAFO divisions 3LNOPs are presented in Figure 42 and Figure 43, respectively (see center panel for station occupation coverage). In 2017, bottom temperatures in 3L are generally below 0°C except in the northern part and near the shelf edge where they range from 2° to 4°C. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures ranged from 0° to 6°C. Bottom temperature anomalies were generally weak on the Grand Banks, except for 3O where anomalies of 1.5 to 3.5°C are observed. On St. Pierre Bank (eastern 3Ps) temperatures were generally below 0° and above 5°C in the Laurentian Channel. Bottom temperature anomalies were generally low, except in the Laurentian channel (0.5 to 1.5°C above normal).

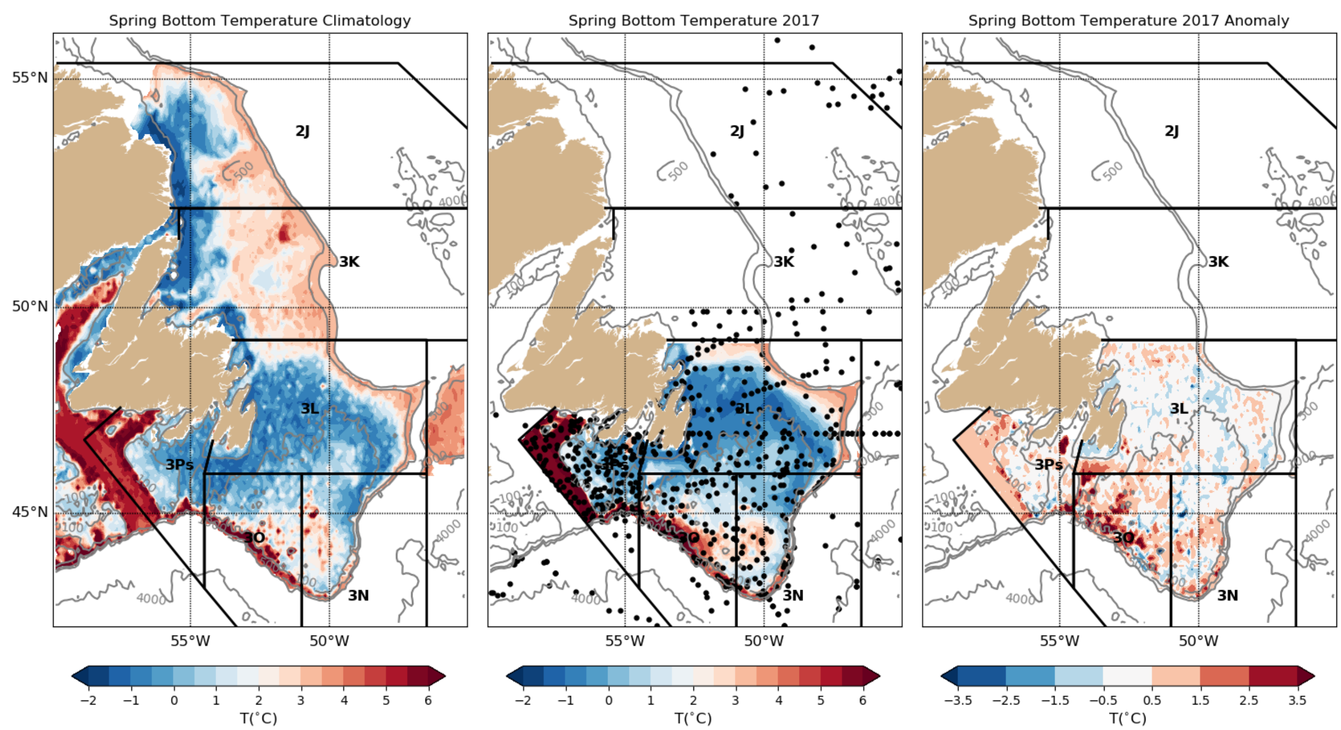

Figure 42. Maps of the mean 1981-2010 spring bottom temperature (left), and spring 2017 bottom temperature (center) and anomalies (right) for NAFO Divisions 3LNOPs only. The location of observations used to derive the temperature field is shown as black dots in center panel.

Spring bottom salinities are presented in Figure 43. In 3LNO they generally range from 32-33 over the central Grand Bank, and from 33-35 closer to the shelf edge. In 3Ps, salinities are between 32 and 33 over shallower areas and above 34.5 in the Laurentian channel. Bottom salinity anomalies were generally less than ±0.4 in the entire zone.

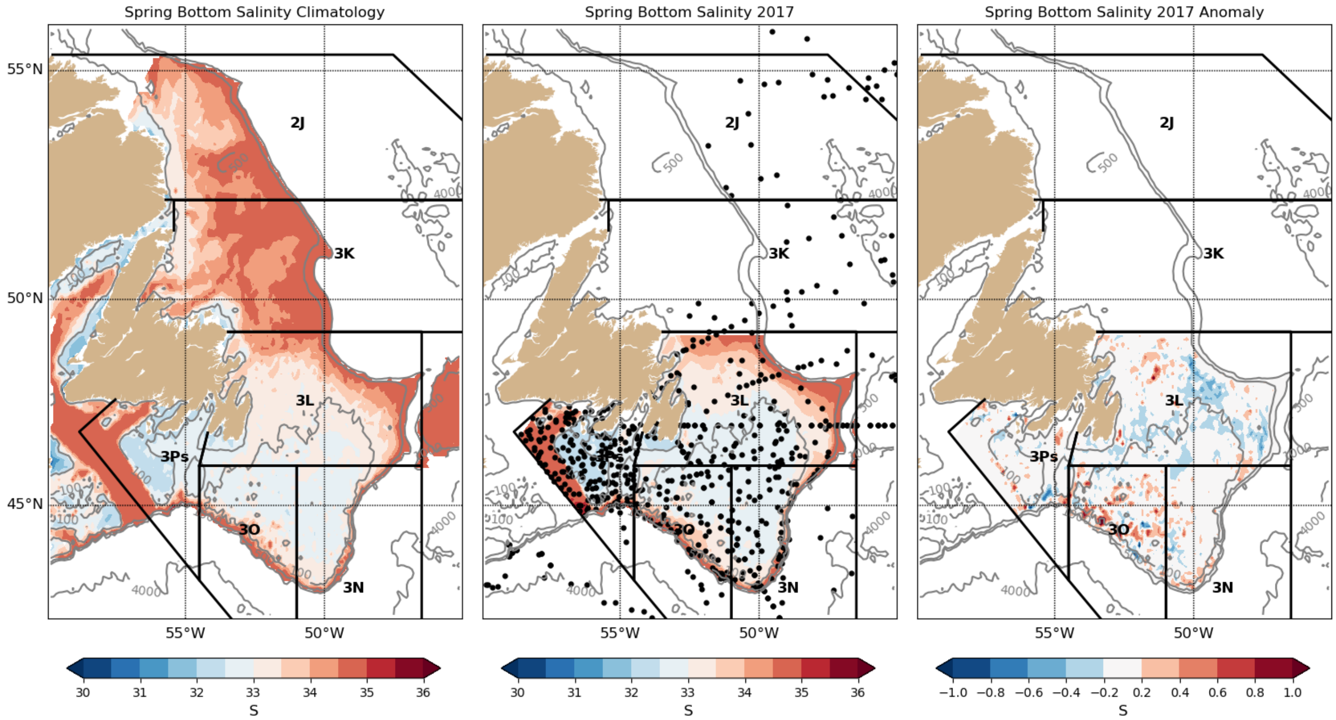

Figure 43. Maps of the mean 1981-2010 spring bottom salinity (left), and spring 2017 bottom salinity (center) and anomalies (right) for NAFO Divisions 2J3KLNO only. The location of observations used to derive the salinity field is shown as black dots in center panel.

Climate indices based on normalized spring temperature anomalies between 1980 and 2017 are shown in a color-coded scorecard in Figure 44. Overall, the table colors visually highlight two main periods of this time series that are the cold period of the late 80's / early 90's (mostly blue cells) and the warm period of the early 2010's (mostly red cells). 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 (statistics not shown). This corresponded to 3.4 SD below normal for the surface area with water below 1°C, the largest warm anomaly of Figure 44. This warm period lasted between 2010 and 2013 before returning towards to normal values: between 2015 and 2017 the bottom area that was covered by <0°C was only 0 to 0.2 SD above normal.

Spring bottom temperatures in 3LNO were generally lower than normal from 1989 to 1995 with anomalies reaching more than 1.5 SD below the mean. Between 1996 and 2010, conditions alternated between near-normal (1996 and 2001-2003) to moderately above normal bottom temperature (1998-2000 and 2004-2006). This warming trend peaked in the spring of 2011 (2.3 SD above normal) before decreasing to near-normal values between 2014 and 2017 (all years within ±0.4 SD of normal).

In Div. 3Ps bottom temperatures exhibit some similarities to 3LNO with warm years of 1999-2000 and 2005-2006 separated by a colder period between 2001-2004 (2003 is the coldest year on record since 1991 at -1.1 SD). With the exception of 2007 (cold at -0.7 SD) and 2008 (normal), all years between 2005-17 were warmer than normal with the warmest year being 2016 at 1.6 SD above normal. 2017 was slightly above normal at +0.4 SD. The spring of 2011 had the lowest area of <0°C bottom water since 1981 at 1.5 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 was near normal in 2017 (+0.4 SD).

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
-- NAFO division 3LNO --																			
T_{bot}	0.2	1.7	-0.4	0.7	-0.6	-1.1	-0.9	-0.2	0.3	-1.0	-1.7	-1.7	-1.4	-0.9	-1.2	-0.5	0.3	-0.5	0.8
$T_{bot<200m}$	0.1	1.8	-0.3	1.0	-0.5	-1.1	-1.0	-0.1	0.3	-0.8	-1.7	-1.7	-1.4	-0.9	-1.2	-0.5	0.3	-0.7	0.9
$Area_{>2°C}$	0.1	1.5	-1.1	0.8	-0.4	-1.2	-0.9	-0.1	0.2	-1.1	-1.7	-1.4	-1.5	-0.8	-1.0	-0.1	0.2	-0.5	0.6
$Area_{<1°C}$	-0.7	-1.9	0.4	-0.6	0.5	1.1	0.8	0.2	-0.3	0.8	1.6	1.6	1.3	1.0	0.9	0.4	-0.1	0.7	-1.2
-- NAFO division 3Ps --																			
T_{bot}	-0.1	2.7	0.0	0.5	0.5	-1.3	-0.2	-2.2	0.3	-0.7	-1.7	-1.6	-0.1	-0.5	-0.6	-0.2	0.3	-0.4	0.2
$T_{bot<200m}$	0.3	3.2	0.2	0.4	0.8	-0.6	-0.2	-1.3	1.1	-0.3	-1.0	-0.9	1.0	-1.4	-1.1	-0.7	0.0	-1.0	0.2
$Area_{>2°C}$	-0.8	3.0	0.3	0.8	-0.4	-1.9	-0.4	-2.0	0.1	-0.4	-1.7	-1.6	-0.4	0.0	-0.2	0.4	-0.1	-0.2	0.3
$Area_{<1°C}$	-0.4	-2.8	-0.3	-0.7	-0.8	0.0	-0.3	0.9	-1.6	0.2	0.8	0.9	-1.0	1.0	1.1	0.8	0.5	1.2	0.0

	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	$\bar{x}$	sd
-- NAFO division 3LNO --																					
T_{bot}	1.5	0.9	0.4	0.2	-0.7	1.6	0.9	0.9	0.5	0.5	0.6	1.2	2.4	1.7	1.4	-0.2	0.3	0.0	0.2	0.9	0.6
$T_{bot<200m}$	1.7	1.0	0.3	0.1	-0.9	1.5	0.8	0.7	0.4	0.3	0.5	1.1	2.4	1.6	1.4	-0.3	0.2	0.0	0.1	0.5	0.6
$Area_{>2°C}$	1.7	0.7	-0.1	0.2	-0.7	2.0	0.9	0.8	0.6	0.9	0.9	0.6	2.8	1.7	0.8	-0.2	0.8	-0.1	0.3	64.8	22.8
$Area_{<1°C}$	-1.5	-0.4	-0.2	-0.1	1.0	-2.0	-1.2	-0.9	-0.4	-0.3	-0.2	-1.0	-3.1	-1.2	-1.6	0.4	-0.3	-0.4	0.0	161.2	27.9
-- NAFO division 3Ps --																					
T_{bot}	1.0	1.3	-0.4	0.1	-1.0	0.3	1.0	1.0	-0.5	0.3	0.8	0.9	1.5	1.3	1.1	0.9	1.0	1.8	0.7	2.1	0.6
$T_{bot<200m}$	0.9	1.1	-0.7	-0.4	-1.5	0.1	0.9	0.7	-0.7	0.1	0.5	0.4	1.2	0.8	0.7	0.3	0.4	1.0	-0.2	0.8	0.8
$Area_{>2°C}$	1.3	1.2	-0.3	0.0	-0.3	0.0	0.5	0.8	-0.2	0.6	0.4	0.4	1.2	0.2	0.5	0.5	0.5	0.8	0.1	26.3	6.5
$Area_{<1°C}$	-0.9	-1.3	1.2	0.8	1.3	0.1	-1.0	-0.7	1.2	-0.1	-0.3	-0.1	-1.5	-0.7	-1.0	0.0	0.5	-1.5	0.5	27.9	8.3

Figure 44. Temperature indices derived from data collected in 3LNO (top) and 3Ps (bottom). Anomalies for T_{bot} (mean the bottom temperature), $T_{bot<200}$ (mean bottom temperature in area shallower than 200m), $Area_{>2°C}$ (surface of the bottom covered by water above 2°C) and $Area_{<1°C}$ (surface of the bottom covered by water below 1°C) are presented. The anomalies are normalized with respect to their standard deviations. Note that unlike color code of Figure 3, anomalies within ±0.5 SD are shown in white background indicating normal conditions. Below or above ±0.5 SD, the colors are set to be darker blue (negative) or red (positive) every 1 SD increment.

The mean standardized anomaly derived from Figure 44 is presented in Figure 45 as a bar plot integrating the average bottom temperature rows of the scorecards (i.e., not considering the thermal surface areas). An overall bottom temperature increasing trend since the early 1990s to 2011 is observed, although with important inter-annual variability (e.g. 2003 being the most significant cooling in the last two decades). Bottom temperatures reached record high values in 2011 but have experienced a decreasing trend to near-normal values by 2015. On average, 2017 was about 0.1 SD above normal for the entire 3LNOPs.

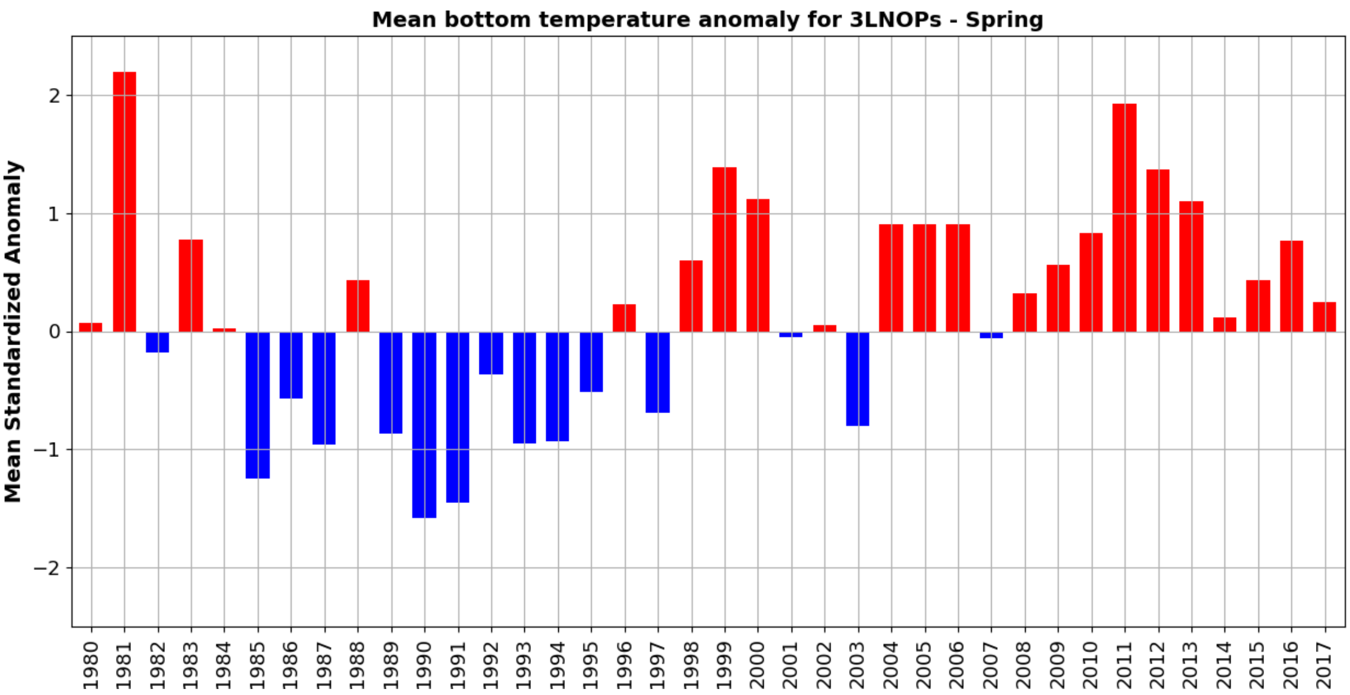

Figure 45. Mean standardized spring bottom temperature anomalies in NAFO Divisions 3LNOPs.The values are the average of bottom temperature rows in Figure 44 (thermal habitat area are ignored).

FALL CONDITIONS

Fall climatological bottom temperature and salinity maps, together with 2017 observations and anomalies for NAFO divisions 2J3KLNO are presented in Figure 46 and Figure 47, respectively (see center panel for station occupation coverage). While bottom temperature are mostly near the average in 2017 for 3K and 3L, observations shows slightly warm temperature in 2J and 3O (+ 2.5°C anomaly for this last region) and a slightly cold anomaly for the eastern Grand Bank (3N) and the eastern part of

3L. Bottom salinities are presented in Figure 47. In divisions 2J and 3K there is generally an inshore-offshore salinity gradient between <33 in inshore to 34 to 35 at the shelf edge. The Grand Banks bottom salinities ranged from <33 to 35, with the lowest values on the southeast shoal. Bottom salinity anomalies were generally below normal in 2J3KL (low salinity anomaly exceeding -0.6 units in some areas), and above normal in 3NO, especially at the tip and the southwest part of the Grand Bank.

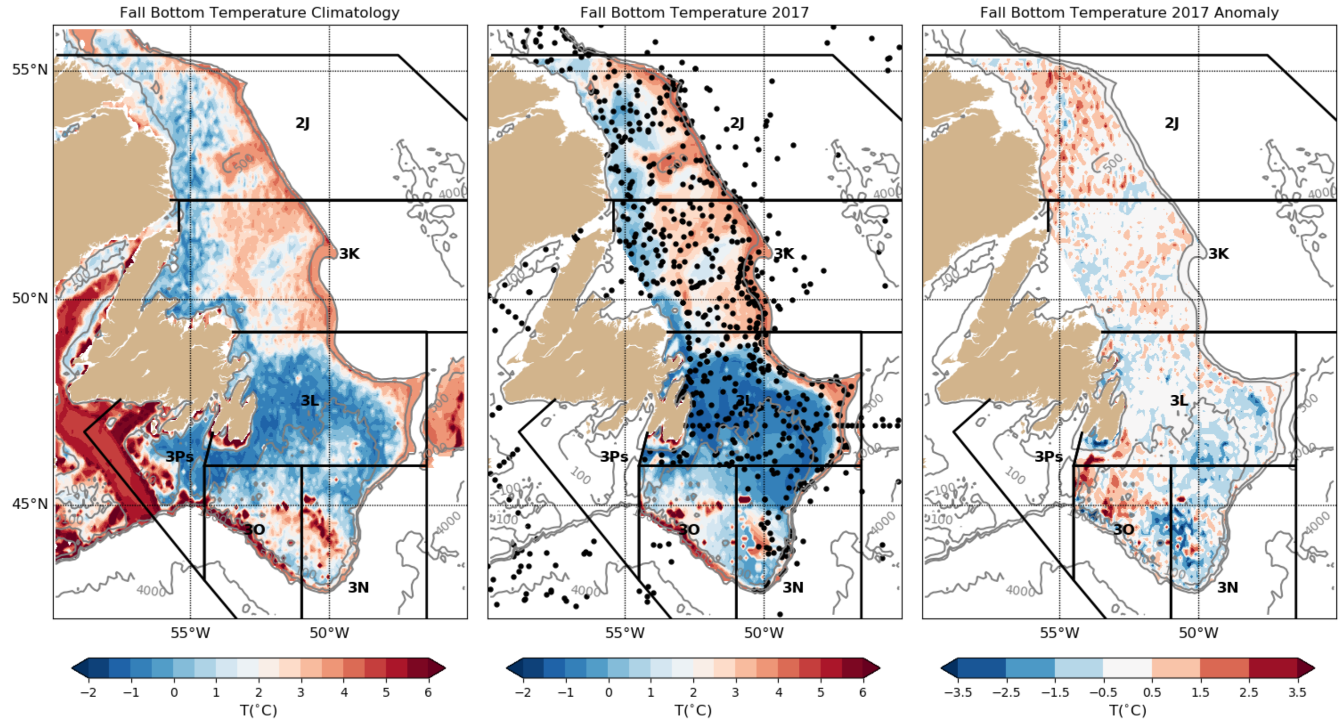

Figure 46. Maps of the mean 1981-2010 fall bottom temperature (left), and fall 2017 bottom temperature (center) and anomalies (right) for NAFO Divisions 2J3KLNO only. The location of observations used to derive the temperature field is shown as black dots in center panel.

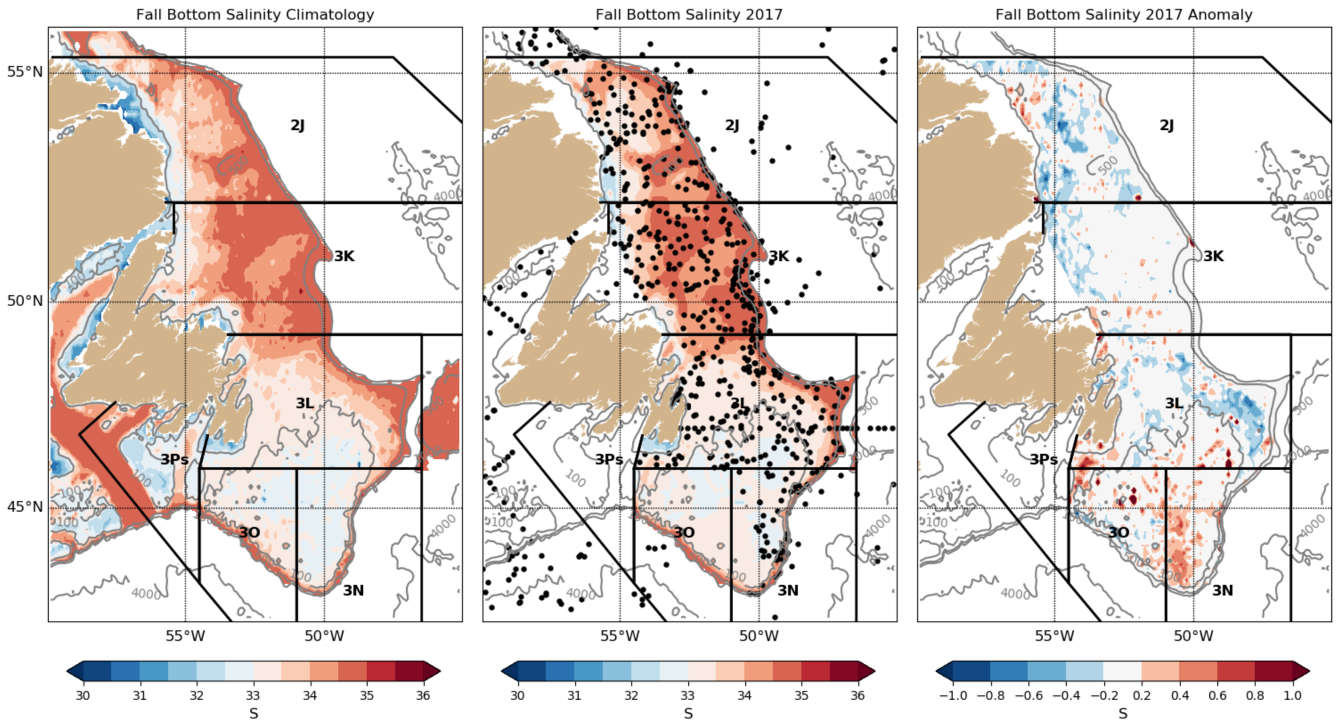

Figure 47. Maps of the mean 1981-2010 fall bottom salinity (left), and fall 2017 bottom salinity (center) and anomalies (right) for NAFO Divisions 2J3KLNO only. The location of observations used to derive the salinity field is shown as black dots in center panel.

Standardized bottom temperature and other derived indices anomalies are presented in Figure 48. Low frequency patterns are generally consistent between the regions with some difference on certain years. In 2J, bottom temperatures were generally below normal from 1980 to 1995, with the coldest anomalies observed in 1984-85 (-2.1 to -1.7 SD) and 1992-93 (-1.6SD). The warmest anomaly occurred in 2010-11 with values reaching a record high of 1.8 SD above normal. In 2016 bottom temperatures were 0.6 SD above normal but decreased to normal in 2017. In 3K, bottom temperatures were at a record high in 2011 (+2.3 SD) but have decreased in recent years to about -0.4 SD below normal in 2017. For 2017, bottom temperatures were slightly cold in 3LNO (-1.1 SD), which is the coldest conditions seen since 1994.

	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	x̄	sd
-- NAFO division 2J --																																								
T_{bot}	-0.2	0.3	-1.1	-0.9	-1.9	-1.5	0.3	-1.2	0.1	-0.4	-1.1	-0.7	-1.4	-1.4	-0.8	0.0	0.7	0.4	0.4	0.7	0.1	0.9	0.6	1.0	1.3	1.4	0.1	1.5	0.4	0.5	1.8	1.8	0.4	0.4	-0.1	-0.1	0.6	0.2	2.0	0.6
$T_{bot<200m}$	0.1	0.4	-0.8	-1.2	-1.8	-1.2	0.4	-1.2	0.1	-0.4	-0.9	-0.9	-1.5	-1.4	-0.8	0.0	0.8	0.3	0.2	0.8	0.0	1.0	0.7	1.0	1.1	1.5	-0.3	1.5	0.2	0.5	1.8	2.0	0.2	0.1	-0.5	-0.3	1.1	0.1	0.7	0.8
$Area_{>2°C}$	0.0	0.2	-1.4	-0.5	-1.4	-1.3	0.3	-0.9	0.0	-0.7	-1.0	-0.6	-1.0	-1.1	-0.7	-1.6	1.0	0.6	0.3	0.2	0.2	0.9	0.7	1.0	1.2	1.6	0.2	1.8	-0.1	0.1	2.0	2.2	0.0	0.2	-0.1	0.0	0.6	0.1	46.4	16.3
$Area_{<1°C}$	0.1	-0.4	1.2	1.1	1.5	1.3	-0.5	1.4	-0.5	0.5	1.2	1.0	1.2	1.4	0.9	-1.0	-0.7	-0.4	-0.2	-1.1	0.1	-1.0	-0.7	-1.1	-0.9	-1.5	0.3	-1.4	0.1	-0.4	-1.5	-1.5	0.1	0.0	0.4	0.3	-1.4	0.0	26.1	17.0
-- NAFO division 3K --																																								
T_{bot}	0.1	0.1	-0.2	-0.5	-1.1	-2.0	-0.1	-0.9	-0.3	-0.2	-1.6	-0.7	-1.6	-1.6	-1.1	-0.6	0.1	0.7	0.6	1.0	0.6	0.3	0.8	1.0	1.6	1.1	0.4	1.2	0.9	0.5	1.7	2.3	0.6	0.7	0.0	0.3	0.0	-0.3	2.4	0.5
$T_{bot<200m}$	0.3	0.1	-1.4	-1.2	-1.4	-1.3	0.4	-1.1	-0.5	-0.3	-1.1	-1.0	-1.1	-1.3	-0.9	0.5	0.9	0.2	0.0	0.8	0.0	0.7	0.9	1.1	1.5	1.2	0.2	1.4	0.2	0.3	2.2	2.0	0.5	0.1	-0.3	0.3	1.3	0.1	0.2	0.8
$Area_{>2°C}$	0.1	0.4	-0.1	-0.7	-0.9	-2.1	0.2	-0.9	-0.3	-0.4	-1.5	-0.5	-1.4	-1.5	-1.2	-0.9	0.0	0.9	0.8	0.9	0.7	0.2	1.1	0.8	1.3	1.2	0.4	1.1	0.9	-0.2	1.8	1.6	0.4	0.8	-0.2	0.3	-0.3	-0.4	73.4	14.9
$Area_{<1°C}$	-0.1	-0.2	0.1	0.7	0.9	2.0	-0.8	0.3	-0.2	-0.1	2.1	0.9	1.4	1.9	1.3	-0.2	-0.8	-0.3	-0.2	-0.6	0.0	-0.4	-0.9	-1.0	-1.4	-1.2	0.0	-1.2	-0.2	-0.1	-1.6	-1.6	-0.2	-0.5	0.1	-0.3	-1.0	0.3	17.5	10.3
-- NAFO division 3LNO --																																								
T_{bot}	0.5	0.0	1.3	0.3	-0.4	-1.1	0.2	-0.7	-1.1	0.4	-1.0	-1.5	-1.4	-2.2	-1.4	-0.2	0.2	0.1	1.0	2.2	-0.2	0.3	0.2	-0.1	1.2	0.5	0.8	0.1	-0.4	0.8	1.8	3.1	0.7	0.9	0.5	0.1	0.7	-1.0	1.1	0.4
$T_{bot<200m}$	0.8	0.1	1.6	0.4	-0.3	-0.9	0.4	-0.7	-1.0	0.4	-0.7	-1.4	-1.1	-2.2	-1.4	0.0	0.4	-0.1	0.9	2.3	-0.5	0.2	0.0	-0.3	1.0	0.4	0.8	-0.1	-0.8	0.8	1.8	3.1	0.6	0.9	0.6	-0.2	0.7	-1.1	0.7	0.5
$Area_{>2°C}$	0.2	-0.1	0.6	0.7	0.3	-1.4	0.3	-0.6	-1.6	0.9	-1.0	-1.0	-1.4	-1.9	-1.3	-0.4	0.0	0.0	1.3	2.6	0.1	0.2	-0.1	-0.2	1.0	0.4	0.4	0.1	-0.5	0.8	1.5	2.9	1.0	1.1	0.9	0.3	0.8	-0.7	71.2	20.0
$Area_{<1°C}$	-1.3	0.5	-0.8	-0.2	0.2	1.1	-0.8	0.5	1.0	-0.6	0.8	1.0	1.1	2.2	1.6	-0.3	-0.2	-0.1	-1.0	-2.5	0.5	-0.1	-0.3	0.4	-1.4	-0.4	-0.7	0.3	0.8	-0.7	-1.7	-3.4	-0.4	-0.7	-0.8	-0.2	-0.5	1.0	155.8	21.8

Figure 48. Temperature indices derived from data collected in 2J (top), 3K (middle) and 3LNO (bottom). The anomalies are normalized with respect to their standard deviations. Note that unlike color code of Figure 3, anomalies within ±0.5 SD are shown in white background indicating normal conditions. Color code is similar to Figure 44.

The mean standardized anomaly derived from Figure 48 is presented in Figure 49 as a bar plot integrating all rows of the scorecards, except the thermal habitat >2°C. Presented this way, the figure shows the low frequency patterns (~15 year half-cycle) with colder temperature between the early 80's to the mid-90's, followed by a warmer period until the late 2010's). Since the record high in 2011 temperature conditions have decreased significantly to near-normal values in both 2014 and 2015, somewhat warm in 2016 but decreased to normal conditions in the spring and to below normal during the fall of 2017 (coldest since 1994, as mentioned above). It will be interesting to monitor if the return towards cold anomalies after the peak of 2010 and 2011 will be continued over the following years.

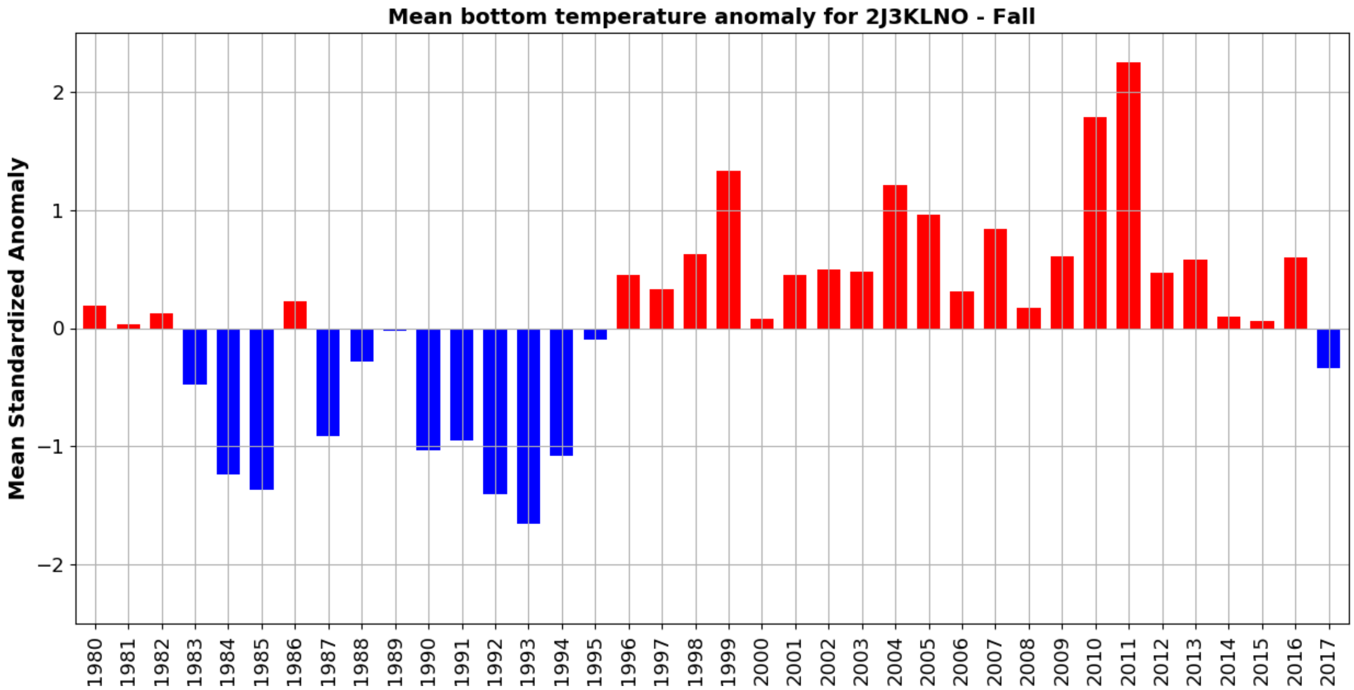

Figure 49. Mean standardized fall bottom temperature anomalies in NAFO Divisions 3LNOPs.The values are the average of all rows in Figure 47, except for the thermal habitat >2°C.

NL SHELVES SUB-AREAS

Drinkwater and Trites (1986) examined monthly mean temperatures and salinities from historical data in irregularly shaped areas on the Newfoundland Shelf that generally corresponded to topographic features such as banks, basins and slope regions. These areas were further refined and extended to the Labrador Shelf by BIO as part of the ocean climate database. There are 25 areas defined on the Labrador Shelf (Figure 50) and 40 on the Newfoundland Shelf (Figure 51).

Using a similar approach as in previous section, e.g. using all available data in the MEDS database, bottom temperature from each profile are calculated as near-bottom values if it was within 20% of the water depth at the location, otherwise rejected. Unlike in the previous section, this method does not use the GEBCO bathymetry, but rather the depth measured by the ship echo-sounder and manually entered in the data files. The selected data within each area were averaged by month and the annual anomalies were then computed from the monthly values and standardized by the standard deviation of the annual anomalies over the same base period. Data were not available for every month in each area and some areas had insufficient data to construct a time series. In fact, some annual estimates are based on as few as 3 monthly values. As a result the time series can show spikes that correspond to high frequency temporal or spatial variability and may poorly represent annual means in any given year.

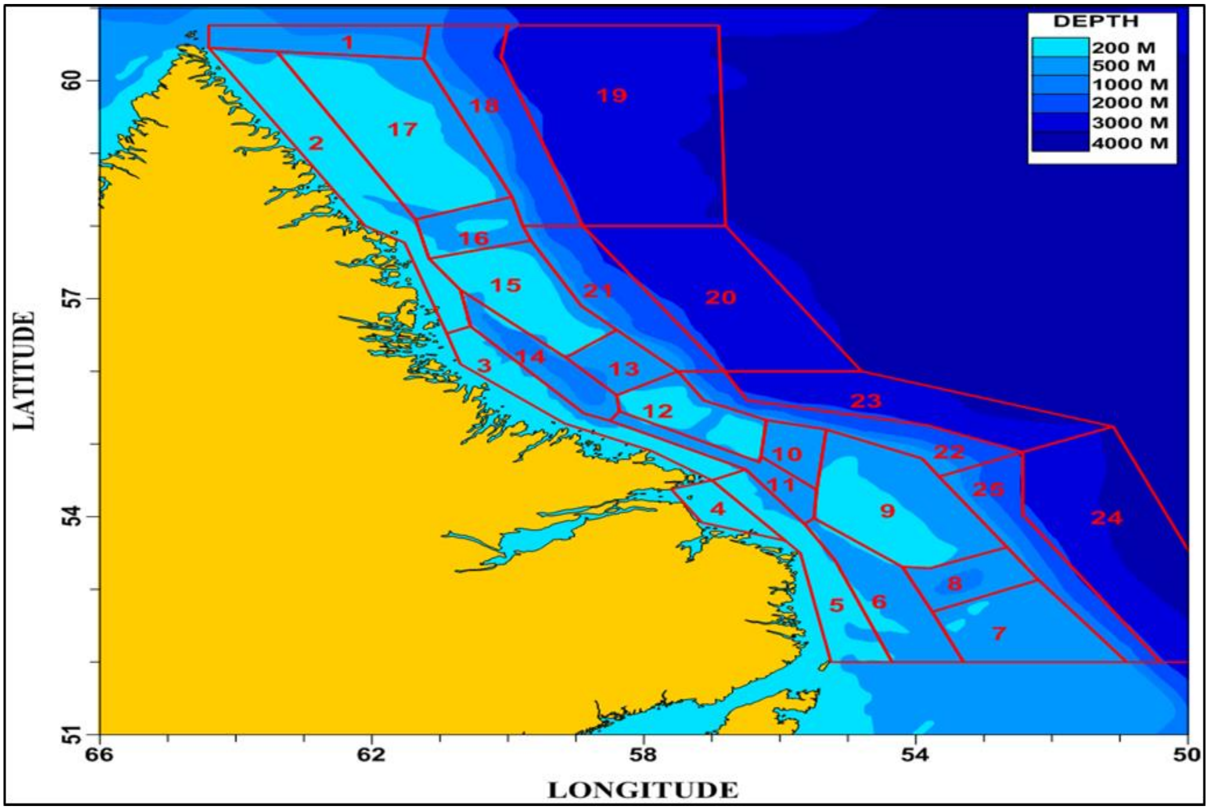

Figure 50. Areas on the Labrador Shelf where bottom temperatures were analysed. The numbers within each area correspond to the areas listed below in Figure 32.

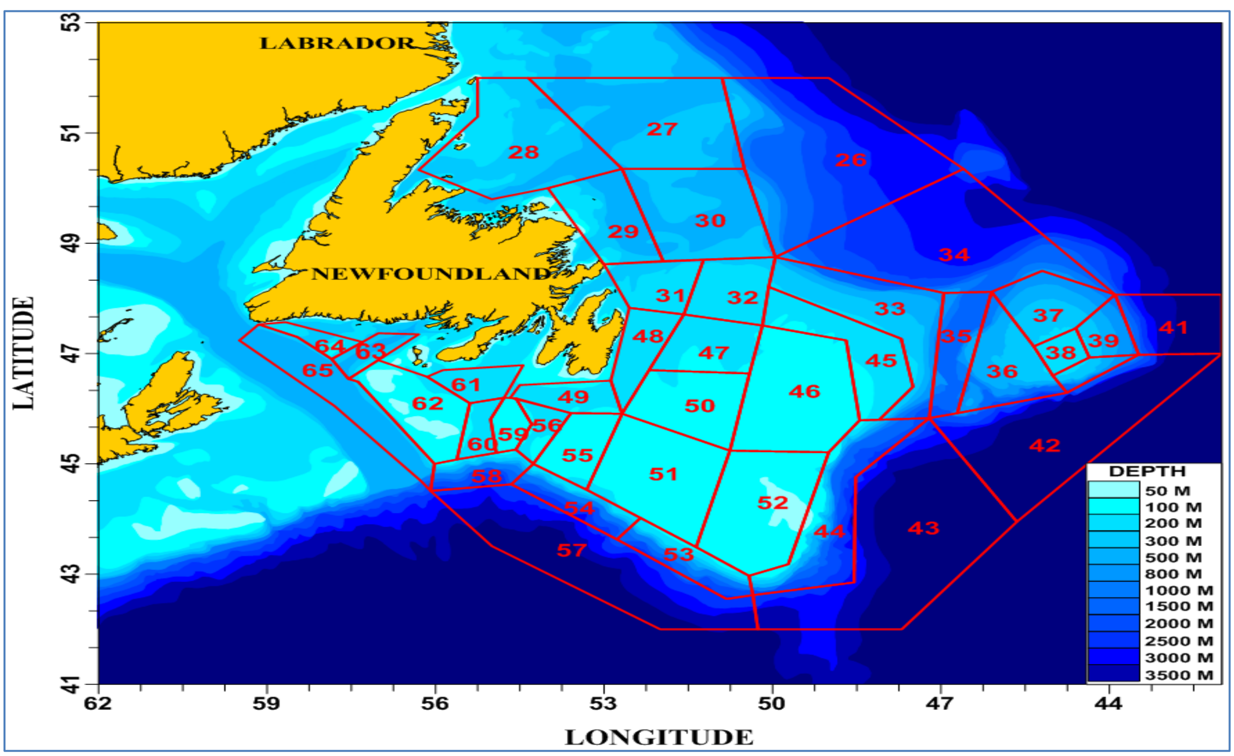

Figure 51. Areas on the Newfoundland Shelf where bottom temperatures were examined. The numbers correspond to the areas listed below in Figure 50.

LABRADOR SHELF BOTTOM TEMPERATURES

Time series of standardized annual bottom temperature anomalies for areas on the Labrador Shelf are shown in Figure 52 and repeated in Figure 53 as a cumulative plot for all areas. During the past decade most of the areas had positive anomalies compared to mostly negative anomalies in the previous decade. In 2017, only 3 out of 21 areas with sufficient data reported above normal values (anomalies >0.5 SD) while 11 out of 21 reported near-normal values (anomalies within ±0.5 SD), compared to 2011 when 19 out of 21 areas had temperatures significantly above normal (positive anomalies >0.5 SD). In general bottom temperatures on the Labrador Shelf have shown an increasing trend since the early 1990s from the coldest in 1993 to the warmest in 2011 with most years since 1997 showing above normal cumulative values (Figure 53). Since the peak in 2011 bottom temperatures on the Labrador Shelf have decreased with 2017 showing below normal conditions, the first time since 2003.

SUB-AREA	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	MEAN	SD
02 N Labrador Shelf	-0.4	0.3	0.8	-2.4				-0.1				-1.0		-1.5			-0.4	1.4	-0.4	0.4	-1.3	-0.9		-1.5	0.2	0.7	-0.1	0.2	1.7	-0.6	0.3	2.8	1.1	-0.4	1.0	0.7	-0.1	0.7	3.45	0.41
03 Central Labrador Inshor	-0.8	-0.1	-0.3	-0.7	-0.8	-1.6	-0.8							-1.0			0.2	0.2	0.3	0.7	-0.1	0.7	-0.8	2.1	-0.5	0.1	0.7		2.8	-0.8	-0.3	2.0	0.2	0.1	-0.5	0.2		-1.1	-0.06	0.45
05 Labrador Inshore	-0.1	1.1	0.4	-1.3	-1.4	-1.6	0.5	-1.2	-0.1	-0.5	-1.0	-0.9	-1.3	-1.1	-0.8	1.0	-0.4	0.3	1.9	0.3	0.2	0.3	0.1	0.2	1.9	1.2	0.0	0.8	0.9	1.4	1.2	2.2	0.1	1.2	-0.7	0.1	0.9	0.8	-0.61	0.52
06 Labrador Trough	0.2	0.4	-1.1	-0.9	-0.8	-1.6	0.0	-0.8	0.9	-0.4	-1.1	0.0	-0.9	-2.4	-0.5	-0.5	0.0	1.2	1.5	1.4	0.1	0.4	1.2	0.6	1.0	0.3	0.4	2.0	-0.4	-0.9	1.0	1.8	0.2	1.6	0.5	-0.2	0.1	-0.3	1.02	0.57
07 Belle Isle Bank	-0.1	0.4	-0.6	-0.1	-2.1	-2.6	-0.5	-0.7	0.5	-0.6	-0.7	0.3	0.2	-0.7	-0.6	-0.4	0.4	0.8	0.8	1.2	0.9	0.7	-0.1	0.8	1.4	0.9	0.1	0.9	1.0	2.0	-1.5	2.1	1.3	0.4	-0.3	0.3	-0.1	-0.2	2.79	0.56
08 Hawke Saddle	0.7	0.4	-0.1	0.5	1.0	-1.5	-0.8	-1.6	0.1	-0.9	-0.1	-0.7	0.7	-1.9	-1.5	0.3	-0.2	0.7	1.8	0.7	1.5	0.9	0.2	0.2	0.6	0.5	1.3	1.0	1.3	1.6	-1.0	2.8	1.8	1.7	1.4	-0.2	0.7	0.2	3.22	0.31
09 Hamilton Bank	-0.4	0.7	-1.3	-1.8	-1.0	-1.2	0.7	-1.1	0.9	1.4	-1.0	0.2	-0.5	-1.6	-0.9	-0.3	0.0	1.3	0.8	0.2	-0.6	0.9	-0.1	0.4	1.6	1.4	0.4	1.2	0.3	-0.3	1.9	2.0	0.0	0.7	-0.2	0.6	1.0	-0.7	1.36	0.64
10 Cartwright Saddle	0.7	0.0	-0.7	-1.0	-1.5	-1.2	0.6	-0.5	-0.2	0.6	-0.9	-0.7	-0.3	-1.2	-1.0		0.2	1.4	0.9	0.8	1.0	1.2	-1.0	1.4	2.2	0.9	1.1	1.6	0.3	0.2	1.2	2.3	1.8	0.6	-0.6	0.7	0.2	-0.6	2.14	0.78
11 Central Labrador Trough	-0.4	-0.3	0.3	-0.2	-0.2	-1.9	0.3	0.2	0.1	-0.4	-0.2	-0.4	-0.1	-0.9	-0.5	1.3	-0.1	1.4	1.2	0.0	-0.9	-1.8	-1.6	0.4	0.7	-0.2	2.5	1.9	1.1	0.1	1.2	0.7	0.4	0.0	-1.2	0.0	1.1	-0.6	0.92	0.59
12 Makkovik Bank	-0.2	1.0	-0.1	-1.5	-2.6	-0.4	0.3	-0.4	0.1	-0.2	-0.5	0.9	-0.6	-1.6	-0.7		-1.1	0.8	0.1	0.7	0.4	-0.5	2.2	-0.2	1.9	1.3	-0.2	0.7	0.6	-0.1	0.7	2.4	0.0	-0.2	-0.2	0.1	0.8	-0.1	0.78	0.71
13 Hopedale Saddle	0.6	1.0	-0.4	-0.6	-0.5	-0.5	-0.2	-0.9	0.7		-2.1	0.9		1.5			-0.2	-1.0	-0.4	-0.1	-2.2	-0.3	0.9		-0.6		-0.2		0.6	1.3	1.5	0.7	-0.6	1.0	-0.6	-0.4	-1.9	-0.4	2.60	0.45
14 N Labrador Trough	0.7	0.4	0.0	0.0	0.1	-1.4	0.5	0.0	0.3	-0.4	0.3	-0.7		-2.4			0.3	0.5	0.7	-0.1	-1.0	0.1	-1.8	0.1	1.2	1.1	0.6	-2.4	0.6	1.7	1.1	1.4	0.8	1.1	1.2	0.9	0.8	0.8	2.73	1.01
15 Nain Bank	1.2	0.6	-1.2	-2.2	-1.9	-0.4	2.3	-0.9	0.0		-0.1	-0.7	1.3	-0.4			1.4	0.4	0.3	0.4	0.3	0.4	0.4	0.5	1.5	-0.3	-0.6	0.0	-0.4	-0.7	1.5	2.6	0.1	-1.4	3.6	2.3	3.0	0.2	0.02	0.58
16 Okak Bank	0.5	0.4	-1.0	-1.7		-0.3		0.6	0.3			-1.2	-1.9				0.4	-0.1	1.7	0.3						0.8	-1.7	0.7	1.1	0.0	0.3	0.9	0.9	-1.1	-1.0	-0.1	-0.7	-1.2	1.66	1.03
17 Saglek Bank	0.1	1.6	-1.0	-2.3		1.4	0.4	0.3	0.1			-1.1	-1.3				-0.8	0.9	1.2	0.1						0.3	-0.4	0.8	1.1	-0.4	0.4	1.8	0.1	-0.7	1.2	1.4	1.5	-0.8	0.72	0.66
18 Saglek Slope	-2.3	0.4	-1.1	-0.1	-1.4	-0.7	-2.2	0.0	-0.1		-0.3	-0.6	-0.6				-0.8	0.7	0.3	2.1	2.0		-1.3		0.3	-0.6	-0.1	1.1	1.1	0.4	0.5	2.0	1.0	-0.8	0.7	-0.4	-0.3	-1.8	3.71	0.30
21 Nain Slope	-0.2	-0.7	-1.3	-0.6	0.2	-1.7	-0.1	-0.5	-0.5	-1.1	-2.7	-0.7	0.9	0.2			-0.5	-0.6	1.0	1.0	-0.2	0.2	-0.4	0.9	0.9	0.2	0.8	1.4	0.6	1.9	0.7	1.4	1.5	1.0	-0.2	1.0	-0.1	-0.3	3.49	0.32
22 Makkovik Slope	-0.8	0.0	-1.5	0.5	-1.3	-0.3	0.4	0.2	-0.4	-0.5	-0.7	0.2	-0.8	-3.9	-0.5	-1.3	0.1	0.3	0.4	1.2	0.2	0.3	0.4	0.8	0.9	0.7	0.5	0.3	0.5	1.2	0.7	1.2	1.1	1.3	0.8	0.0	0.1	0.3	3.39	0.30
23 Makkovik Offshore	-1.1	0.2	1.1	0.7	1.3	0.4	0.1	0.2	0.0	-2.3	-0.1	-0.3	-1.0	-3.2	1.2	0.1	0.5		0.1	-0.2	1.8	1.1	0.3	0.2	0.4	-0.4	-0.9	-0.2	-0.3	0.4	-1.1	-0.7	-1.0	-0.6	-0.6	0.0	-0.5	0.0	3.19	0.35
24 Hamilton Offshore	-0.1	0.8	-5.2	-0.5	0.1	0.5	0.2	0.0	0.4	0.0	-0.2	-0.4	-0.4	-0.7		-0.3	-0.2	0.0	0.1	-0.1	0.0	0.6	-0.3	0.2	-0.1	0.2	0.1	-0.2	0.1	0.1	0.0	-0.1	0.2	0.1	0.0	-0.1	-0.2	0.3	3.07	0.65
25 Hamilton Slope	-1.4	0.9	-0.9	0.8	-1.4	-0.8	-0.3	-1.1	-0.1	-0.8	-0.1	-0.4	-0.1	-0.3	-0.3	-0.2	-0.8	0.1	0.4	0.0	0.0	0.3	-0.5	0.6	1.1	0.8	1.2	1.9	3.3	2.2	0.3	1.2	1.4	0.6	0.7	-0.4	1.1	0.2	3.45	0.25

Figure 52. Standardized bottom temperature anomalies for the Labrador Shelf derived from data within most of the areas displayed in Figure 31. The anomalies are normalized with respect to their standard deviations over the standard base period 1981-2010 and color-coded accordingly to Figure 3. The grey shaded cells indicate years for which there were no observations.

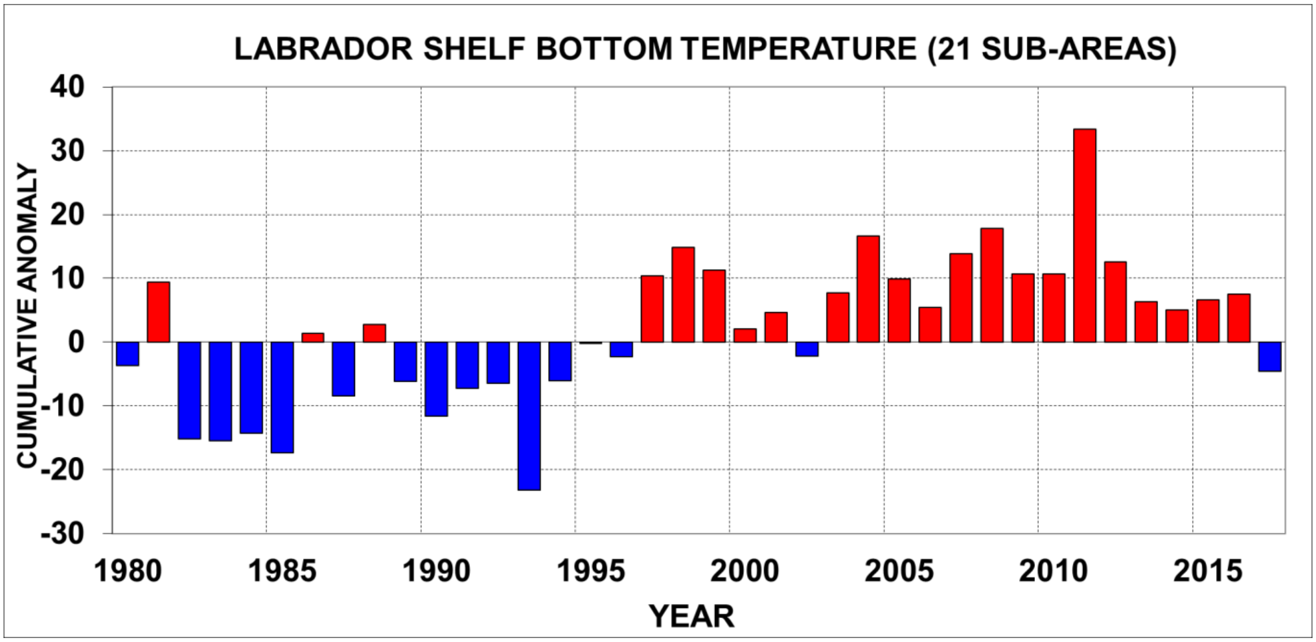

Figure 53. Cumulative bottom temperature anomalies based on the values presented in Figure 32 for the Labrador Shelf.

NEWFOUNDLAND SHELF BOTTOM TEMPERATURES

Similarly, standardized annual near-bottom temperature anomalies for areas on the Newfoundland Shelf are shown in Figure 54 and repeated in Figure 55 as a cumulative time series. The trends are similar to the Labrador Shelf with mostly above normal bottom temperatures since 1999. In 2017, 17 out of 35 areas has temperatures that were near-normal (anomalies within ±0.5 SD) compared to 2011 when 31 out of 35 areas had values significantly above normal (positive anomalies >0.5 SD). The composite plot (Figure 55) shows an increasing trend since the early 1990s reaching a series record high in 2011 when 20/35 areas were above normal by more than 2 SD. Bottom temperatures on the Newfoundland Shelf were the second highest since 1980 in 2012 and the fourth highest in 2013. The 2014-17 values have decreased but have remained slightly above the long term mean.

SUB-AREA	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
26 Funk Slope	-0.1	0.0	-0.5	1.1	-0.5	-2.1	-1.0	-0.4	-0.9	-1.8	0.0	0.1	-0.9	0.2	0.8	-1.0	-0.8	-0.1	0.2	3.3
27 Funk Island	0.7	0.4	0.3	-0.9	-0.7	-1.9	-1.8	-0.3	0.1	-0.9	-1.1	-0.2	-0.6	1.4	-1.2	-0.4	-1.0	0.5	0.6	0.9
28 White Bay	0.5	1.4	0.3	-0.2	-0.3	-0.7	1.5	-0.7	-0.2	-0.5	-1.2	-0.7	-1.9	-0.8	-0.8	-1.1	-0.9	0.0	0.6	1.2
29 Bonavista	1.5	1.4	0.5	-1.3	1.6	-0.9	-0.4	1.1	0.4	-1.8	-1.0	-1.0	-0.9	-2.0	-1.2	-0.9	-0.2	0.5	-0.4	0.7
30 NE Nfld Shelf	0.6	-0.4	-0.1	-0.2	-2.0	-1.9	-1.4	-0.3	-0.6	-0.4	-1.1	0.0	-0.5	-0.9	-1.3	-0.1	0.2	0.7	1.1	1.2
31 Baccaliu	1.2	0.7	-0.1	-0.9	-1.0	-0.9	0.0	-0.3	-0.2	-1.1	-1.2	-1.4	-1.0	-1.2	-1.0	-0.4	2.1	1.7	1.4	1.1
32 N Slope	0.2	1.4	0.0	-0.7	-1.1	-1.2	0.1	-0.7	1.0	-1.0	-1.3	-0.8	-0.9	-1.3	-0.6	-0.7	0.6	0.9	1.0	1.4
33 NE Slope	0.4	-0.5	-0.1	-1.0	-1.5	-2.4	-1.0	0.3	-1.1	-0.1	-0.9	-0.9	-0.8	-0.9	-0.2	0.7	0.0	1.0	0.9	1.0
34 Funk Offshore	-0.3	0.4	-0.1	0.7	0.3	-0.1	-0.4	0.1	-0.2	-0.5	-1.3	0.2	-0.4	0.2	0.0	-0.5	-0.5	-0.1	-0.3	2.5
35 Flemish Pass	0.2	0.2	0.0	0.5	0.6	0.9	-2.0	-0.3	0.2	-2.5	-1.1	0.3	-0.5	0.1	0.3	-1.6	-0.5	-0.6	0.3	0.6
36 Flemish Cap (W Slope)	0.5	0.0	-0.4	1.1	1.7	0.5	-0.2	-0.6	0.0	-0.6	-2.4	0.5	-1.4	-0.5	-0.8	-1.5	-1.0	-0.8	0.2	0.8
37 Flemish Cap (N Slope)	0.5	0.3	-0.2	1.1	1.5	-0.3	-0.1	-0.3	0.5	-1.4	-1.1	-0.8	-1.7	-0.8	-0.2	-0.7	-0.8	-0.4	-0.4	2.0
38 Central Flemish Cap	0.4	0.3	-0.2	0.3	0.1	-0.2	-1.1	-0.4	0.4	-2.2	-1.6	-1.3	-1.0	-0.4	-1.9	-0.8	-0.3	-0.1	0.7	1.4
39 Flemish Cap (E Slope)	-0.2	-0.6	-0.1	0.5	1.2	-0.5	-0.2	-0.6	-0.5	-0.6	-1.4	3.2	-0.5	-0.7	-1.3	-0.9	-1.3	-0.8	-0.2	0.2
44 E Slope	1.5	0.7	0.8	1.1	-0.1	-2.0	-1.0	-0.4	-1.2	-0.1	-2.5	-0.7	-0.8	0.6	-1.0	0.1	-0.7	0.0	1.5	0.5
45 NE Edge	-0.3	0.2	0.2	-0.9	-1.0	-1.2	1.3	0.3	-0.3	-0.6	-1.3	-1.1	-1.1	-1.6	-1.0	-0.8	0.5	1.4	0.8	1.2
46 NE Grand Bank	0.1	0.6	0.7	0.0	-1.0	-0.4	-0.7	-0.2	0.0	-0.4	-0.1	-0.8	-0.7	-1.1	-1.0	-0.3	0.2	-0.5	0.2	1.2
47 NE Avalon Channel	0.5	1.2	0.5	-0.4	-0.8	-0.7	-0.7	0.5	-0.1	-0.9	-1.4	-1.4	-1.2	-1.7	-1.2	-0.7	0.5	0.7	0.9	1.3
48 N Avalon Channel	0.1	0.8	-0.3	-0.8	-1.0	-1.5	-0.6	0.1	-0.4	-0.7	-1.1	-1.4	-1.1	-1.5	-1.4	-0.5	0.4	0.8	0.7	1.0
49 S Avalon Channel	0.1	-0.1	0.6	-1.5	-0.8	-1.0	-0.8	-0.8	0.8	-1.2	-0.8	-1.1	-1.1	-1.2	-1.3	0.1	1.3	-0.3	1.1	-0.5
50 NW Grand Bank	0.5	1.8	0.1	1.5	-0.8	-0.3	0.7	0.1	-0.2	-0.5	-0.5	-1.7	-1.5	-2.0	-1.5	0.4	0.3	-0.8	1.0	1.6
51 SW Grand Bank	0.3	0.1	0.1	3.5	-0.1	-0.8	-0.2	0.0	-0.2	-0.5	-1.0	-0.7	-1.1	-0.6	-0.9	0.4	0.2	-0.8	0.0	0.8
52 SE Grand Bank	0.6	1.1	0.1	2.1	0.1	-0.6	-0.3	-0.4	-0.9	0.7	-0.9	-0.5	-1.7	-1.7	-0.5	-0.2	0.1	-0.3	1.1	2.1
53 S Slope	0.5	0.8	-0.8	3.0	-0.8	-0.2	0.7	0.0	-0.1	0.4	-1.6	-1.7	-1.8	0.3	0.5	0.1	-0.6	-0.9	1.2	0.8
54 SW Slope	-0.3	-0.1	-1.8	0.0	1.0	-1.1	0.9	0.2	1.4	-0.4	-1.4	-2.5	-0.9	1.6	-0.1	1.3	0.9	-0.6	-0.3	1.4
55 Whale Bank	-0.1	1.7	0.0	3.5	1.1	-0.7	1.4	-1.0	1.6	-0.6	-0.6	-0.8	-0.8	-0.3	-1.5	-0.6	0.3	-0.5	0.3	1.2
56 Haddock Channel	-1.0	-0.1	0.1	0.1	-0.1	-1.4	1.0	-0.5	0.5	0.5	-1.2	-0.5	-0.9	0.6	-1.7	0.5	-0.5	0.3	-0.2	1.2
58 Halibut Channel Slope	-2.9	0.8	-0.8	0.4	1.0	-0.4	0.1	-0.5	0.0	-0.4	-1.3	-0.6	0.3	-0.9	-0.4	-0.7	0.7	-0.1	0.6	1.7
59 Green Bank	1.1	2.7	0.0	0.2	1.8	-1.4	-1.1	-0.3	-0.3	-0.7	-1.5	-1.1	-0.8	-1.2	-1.6	0.2	0.4	-0.3	0.6	0.5
60 Halibut Channel	-0.9	0.7	-0.8	0.5	0.5	0.2	-0.1	-0.9	-0.1	-0.1	-1.0	-0.5	-0.4	-0.9	-1.5	-1.1	2.0	0.0	0.0	0.9
61 St. Pierre Channel	-0.5	-0.2	-1.2	0.6	0.0	-0.7	-1.0	-0.7	0.8	-0.2	-1.2	-0.9	-0.2	-1.2	-1.2	-1.5	0.3	3.3	-0.5	0.4
62 St. Pierre Bank	-1.6	-0.1	-0.9	0.0	1.5	-0.8	-1.3	-1.0	0.7	-0.5	-0.3	0.0	0.0	-0.6	-0.4	-0.3	0.0	-2.0	-1.2	1.5
63 Hermitage Channel	-2.3	2.6	-0.3	-0.3	0.6	1.4	1.7	0.3	-2.1	-1.7	-0.6	-1.6	-0.3	0.6	0.7	0.1	-0.1	0.6	-0.8	0.3
64 Burgeo Bank	-5.0	0.6	1.0	0.3	0.4	1.7	1.8	-0.2	-0.4	-1.1	-0.1	-1.4	-1.9	-0.3	0.6	-0.6	-0.5	-0.3	-0.2	0.8
65 Laurentian Channel	-1.0	1.6	-2.9	0.5	1.8	-0.3	-1.3	-0.3	0.4	-0.9	-1.3	-0.3	-0.1	0.3	-1.3	1.0	1.3	-0.6	0.5	-0.4

SUB-AREA	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	MEAN	SD
26 Funk Slope	0.3	-0.4	-0.8	-0.3	0.9	1.0	0.5	0.8	0.9	-0.1	0.5	1.3	0.3	0.8	0.4	0.8	-0.4	0.0	3.41	0.23
27 Funk Island	1.1	1.0	0.3	1.2	2.6	0.9	0.4	0.8	1.2	-0.3	-0.2	2.5	0.7	1.4	0.9	0.8	0.1	-0.5	2.82	0.41
28 White Bay	-1.7	-0.5	-0.5	0.4	0.8	2.3	1.1	1.3	0.7	-0.9	-0.5	3.0	0.1	1.5	-0.4	0.1	-1.0	-0.7	0.76	0.46
29 Bonavista	0.2	0.2	0.7	-0.4	1.1	0.1	1.0	2.0	0.0	0.5	0.6	2.7	0.6	0.1	-0.5	0.0	-1.2	0.3	0.91	0.50
30 NE Nfld Shelf	0.7	0.9	0.6	0.3	1.7	1.2	1.2	1.2	1.7	-0.6	0.7	2.5	1.4	0.7	-0.3	0.4	-0.7	0.1	2.54	0.52
31 Baccaliu	0.9	0.0	0.3	-0.2	1.1	0.8	1.2	0.9	-0.4	-0.8	1.5	2.1	1.1	0.3	-1.0	-0.6	-0.9	-0.3	-0.32	0.61
32 N Slope	0.4	0.0	0.4	-0.4	1.3	1.6	2.0	0.5	1.0	-1.1	1.3	2.6	0.8	0.3	-0.6	-1.1	-1.2	-0.3	-0.17	0.51
33 NE Slope	0.9	0.7	0.6	0.6	1.6	1.2	1.4	0.9	1.2	0.9	1.1	2.1	1.4	0.3	0.3	0.2	0.4	-0.2	2.51	0.65
34 Funk Offshore	-0.2	-0.5	-0.2	4.4	0.0	-0.6	-0.1	-0.1	-0.3	0.0	-0.2	0.0	1.6	0.0	-0.4	-0.1	0.0	-0.5	3.48	0.55
35 Flemish Pass	0.7	0.1	0.2	-0.3	0.0	0.8	1.4	1.5	1.2	2.0	1.6	1.3	1.4	1.4	1.5	0.6	0.5	1.0	3.54	0.27
36 Flemish Cap (W Slope)	1.1	-0.1	-0.3	-0.5	0.4	0.3	0.6	0.2	1.6	2.5	0.5	6.6	2.4	2.5	0.7	2.0	1.8	0.8	3.75	0.28
37 Flemish Cap (N Slope)	0.8	0.2	-0.1	-0.7	-0.1	0.1	0.8	0.4	1.9	1.7	2.2	2.6	1.6	1.2	1.2	0.9	0.6	0.3	3.65	0.31
38 Central Flemish Cap	0.2	-0.2	-0.1	0.0	0.9	1.7	0.8	0.0	1.1	0.7	2.2	1.0	0.3	0.6	-1.2	-1.2	-0.3	-0.3	3.34	0.62
39 Flemish Cap (E Slope)	0.3	0.2	-0.1	-0.5	0.0	0.5	0.6	0.6	0.9	1.3	2.2	1.2	1.4	1.5	0.9	1.1	0.6	0.5	3.71	0.37
44 E Slope	1.0	0.9	0.6	1.0	1.4	1.4	-0.1	0.5	0.9	0.8	1.0	1.6	0.4	0.5	1.1	0.8	1.5	1.0	2.44	0.62
45 NE Edge	0.0	0.6	-0.4	-0.1	1.7	0.6	1.8	0.8	0.3	-0.8	1.8	3.4	1.0	0.7	-0.6	-0.8	-1.0	-0.7	-0.28	0.51
46 NE Grand Bank	-0.3	-0.1	0.3	-0.1	4.4	0.0	0.8	-0.4	-0.2	0.9	1.0	1.2	0.3	0.8	-0.1	0.3	1.3	-0.9	0.16	0.87
47 NE Avalon Channel	0.4	0.2	-0.1	-0.4	2.1	1.0	1.8	0.3	0.3	-0.3	1.8	2.9	1.9	1.0	-1.0	-0.7	-0.5	-0.3	-0.65	0.43
48 N Avalon Channel	0.5	0.6	-0.1	0.2	1.9	1.5	2.1	0.6	0.1	-0.3	1.5	3.3	1.2	1.0	-0.7	-0.7	-0.2	-0.7	-0.82	0.38
49 S Avalon Channel	0.7	0.6	-0.3	-0.6	1.5	1.4	2.5	-0.7	-0.1	0.3	1.0	3.1	2.1	1.3	-0.5	0.3	0.4	-0.4	-0.76	0.45
50 NW Grand Bank	0.0	0.5	0.1	-0.8	1.3	1.2	1.1	-0.1	-0.7	0.2	1.0	2.0	0.8	1.5	-0.4	0.6	1.4	0.4	0.16	0.50
51 SW Grand Bank	0.4	0.0	-0.4	-0.4	3.3	0.0	0.3	0.4	-0.2	0.1	0.6	0.8	0.8	0.7	0.3	0.0	0.3	0.0	2.15	1.46
52 SE Grand Bank	0.2	-0.4	-0.8	-1.0	1.4	-0.3	0.7	0.3	-1.2	1.6	1.2	2.1	0.6	0.6	-0.7	0.2	-0.7	0.0	2.11	0.63
53 S Slope	1.6	0.0	-0.3	0.5	0.6	1.0	-0.1	-0.1	-0.6	1.1	0.3	1.7	1.3	0.6	0.8	1.5	-0.5	0.8	3.69	1.05
54 SW Slope	0.4	0.6	0.0	0.0	-0.5	0.9	1.2	-0.6	-0.8	1.3	0.3	2.5	1.7	3.0	0.5	1.5	0.0	1.1	4.92	0.85
55 Whale Bank	0.0	-0.2	0.0	-0.6	0.3	0.3	-0.4	-0.5	-0.4	-0.1	0.2	1.7	1.8	0.7	-0.5	-0.4	0.4	0.5	0.39	0.83
56 Haddock Channel	-0.5	2.0	-0.7	0.2	3.4	-0.4	0.3	-1.0	-0.1	0.8	0.8	6.1	3.4	2.0	-2.3	0.6	0.3	-0.1	-0.36	0.56
58 Halibut Channel Slope	0.7	3.6	-0.1	-0.9	-1.1	0.8	-1.7	-0.1	-0.4	0.2	0.1	0.9	0.9	1.3	0.4	0.0	0.7	2.1	4.61	1.20
59 Green Bank	1.5	0.8	0.0	-0.5	0.9	0.5	1.2	0.6	-0.2	0.2	1.1	5.5	1.2	1.8	-0.4	0.9	0.9	0.5	-0.64	0.54
60 Halibut Channel	2.3	1.3	1.2	-0.7	-0.2	0.5	-1.5	-0.9	-1.0	1.8	-0.3	0.0	-0.3	0.2	1.4	2.0	0.5	-0.3	0.92	1.41
61 St. Pierre Channel	0.8	-0.5	-0.2	-1.3	0.6	0.4	0.5	0.4	0.7	0.8	1.3	2.1	1.5	0.7	1.4	4.5	0.0	-0.1	-0.57	0.43
62 St. Pierre Bank	0.1	-0.6	0.5	-1.6	-0.5	1.5	1.6	-0.8	-0.1	0.4	2.4	1.5	-1.7	-0.5	-0.1	-0.3	0.6	-0.4	1.62	0.66
63 Hermitage Channel	0.8	-1.0	0.6	-1.4	0.2	0.1	0.4	-0.4	0.5	0.0	1.0	0.4	1.1	0.0	2.1	1.3	1.8	1.8	5.25	0.79
64 Burgeo Bank	-0.8	-1.6	0.0	-2.8	-0.9	0.4	1.2	0.1	0.0	0.9	-0.1	2.1	1.6	1.1	0.9	-0.2	0.0	-1.4	3.59	0.71
65 Laurentian Channel	1.1	0.6	-0.1	-0.5	-1.3	-0.3	0.8	-1.4	-0.4	0.5	0.1	-0.2	2.8	4.0	1.7	2.5	1.2	2.4	4.95	0.44

Figure 54. Standardized bottom temperature anomalies for the Newfoundland Shelf referenced to 1981-2010.

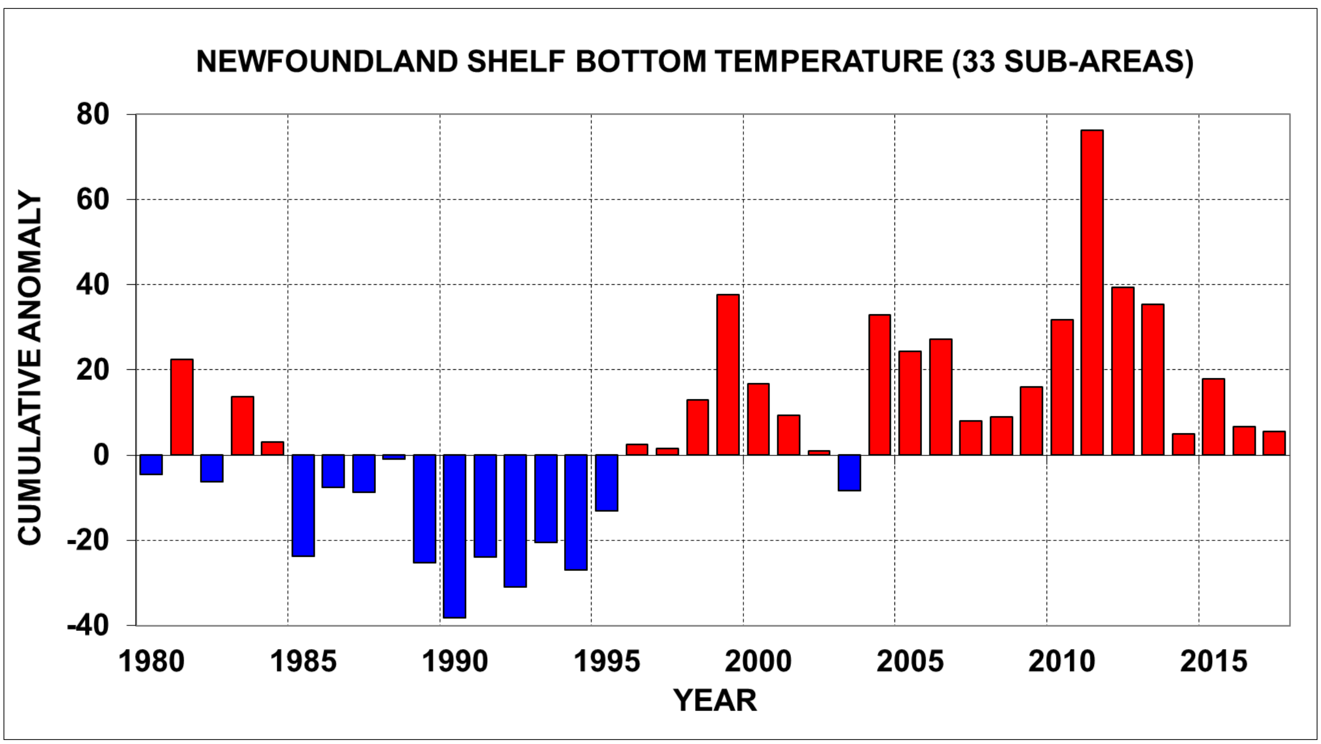

Figure 55. Cumulative bottom temperature anomalies based on the values presented in Figure 50 for the areas on the Newfoundland Shelf shown in Figure 34.

NEWFOUNDLAND SHELF CIL AND MIXED LAYER DEPTH

The available temperature and density profiles for each sub-area were also used were to compute the vertical extent of the CIL and the MLD. The thickness of the CIL water mass was estimated from the depth of the top and bottom of the water mass with temperatures <0°C. In some cases there were multiple 0°C crossings which were included in the total thickness estimate. The MLD was estimated from the density profiles as the depth of maximum density gradient similar to the Station 27 estimates. Similar to bottom temperature, values within each area were averaged by month and the annual anomalies then computed from the monthly values and standardized by the standard deviation of the annual anomalies over the same base period. The time series of CIL values shown in Figure 56 shows a decreasing trend in the amount of CIL water since the early 1990s with mostly below normal values since 1996.The MLD shows an increasing trend in the depth of the maximum density gradient since 2000. In both cases these trends are similar to that observed at Station 27 (Figure 25 and Figure 34) indicating broad-scale forcing over the Newfoundland Shelf.

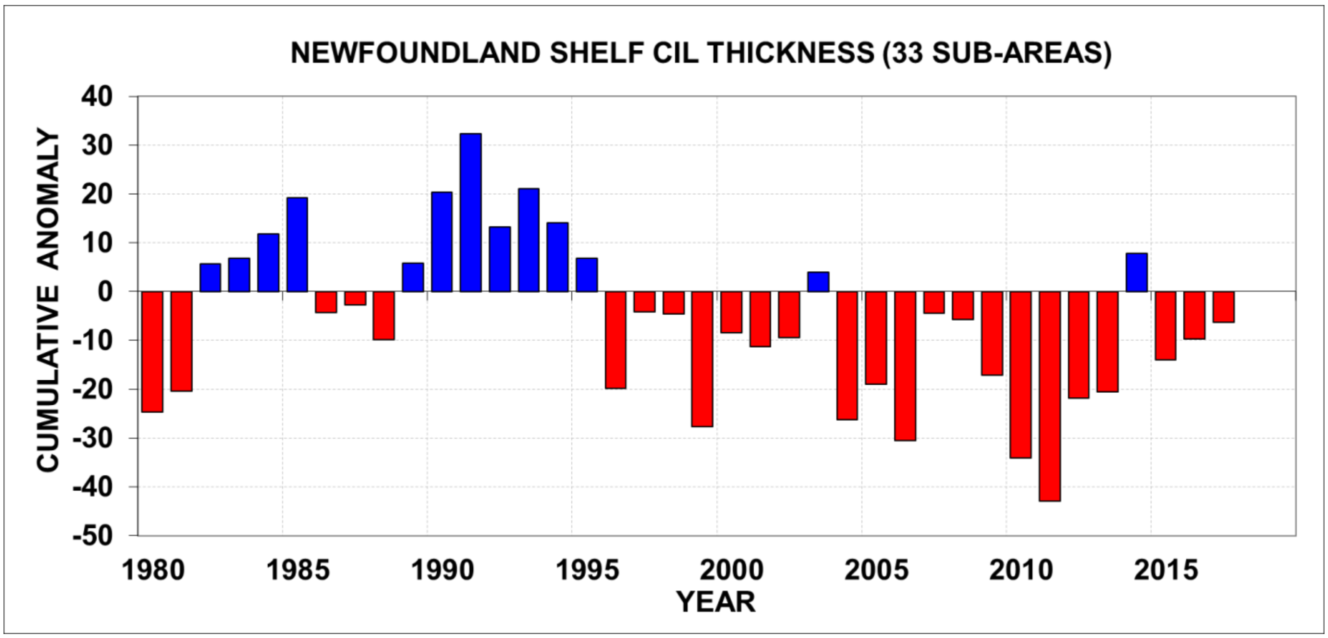

Figure 56. Cumulative CIL thickness anomalies based on available temperature profiles for the areas on the Newfoundland Shelf shown in Figure 51. Red bars indicate thinner than normal CIL water.

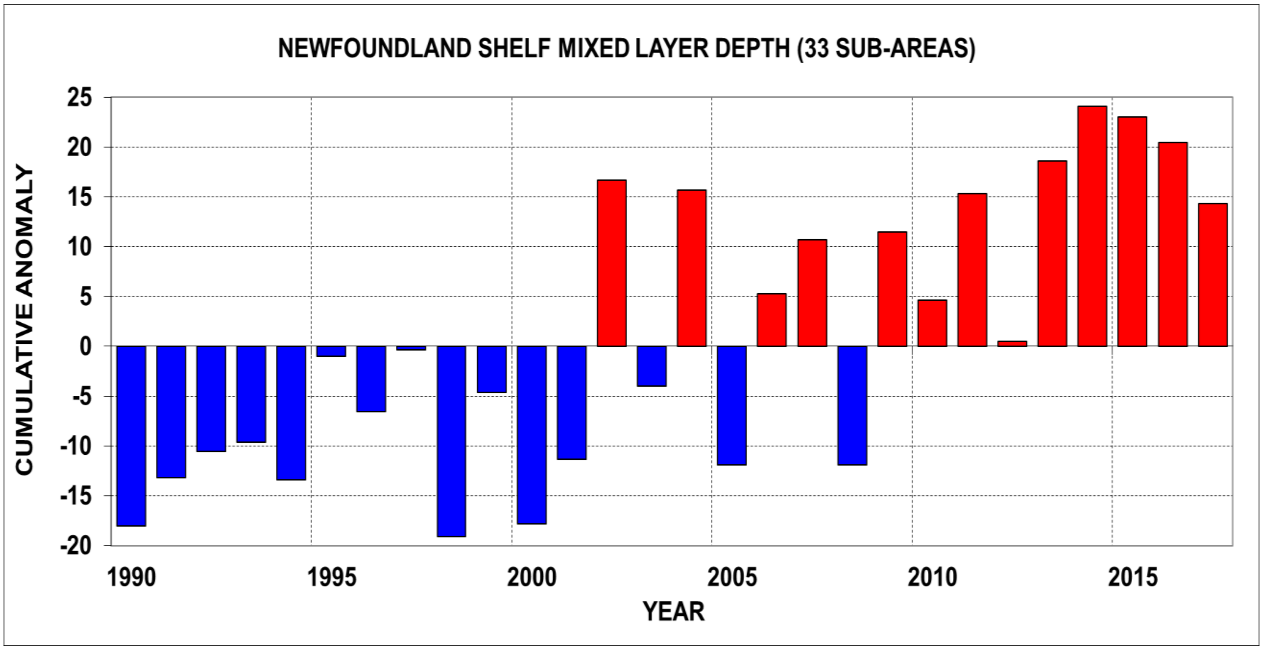

Figure 57. Cumulative MLD anomalies based on available temperature profiles for the areas on the Newfoundland Shelf shown in Figure 51. Red bars indicate deeper than normal maximum density gradients.

CIRCULATION IN THE AZMP AREA

The circulation pattern through most of the standard AZMP sections in the NL 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 south eastward 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.

LABRADOR CURRENT TRANSPORT INDEX

Satellite altimetry data are used over a large spatial area to calculate the annual-mean anomalies of the Labrador Current transport (Han et al. 2014). A total of nine cross-slope satellite altimetry tracks are used to cover the Labrador and northeast Newfoundland Slopes from approximately 47 to 58ºN latitude (Figure 58). On the Scotian Slope we use five tracks from approximately 55 to 65ºW longitude. The nominal cross-slope depth ranges used for calculating the transport are from 200 to 3,000 m isobaths over the Labrador and northeast Newfoundland Slopes and from 200-2,000 m isobaths over the Scotian Slope.

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

The annual-mean Labrador Current transport index shows that the Labrador Current transport over the Labrador and northeast Newfoundland Slope was out of phase with that over the Scotian Slope for most of the years over 1993-2017 (Figure 59 and Figure 60). The transport was strongest in the early-1990s and weakest in the mid-2000s over the Labrador and northeast Newfoundland Slope, and opposite over the Scotian Slope. The Labrador Current transport index was positively and negatively correlated with the winter North Atlantic Oscillation index over the Labrador and northeast Newfoundland Slopes and over the Scotian Slope, respectively. In the past two years the annual mean transport of the Labrador Current was above normal by about approximately 1 SD over the Labrador and northeast Newfoundland Slopes while on the Scotian Shelf the transport has been below normal for the past four years with values near -1 SD in 2016 and 2017.

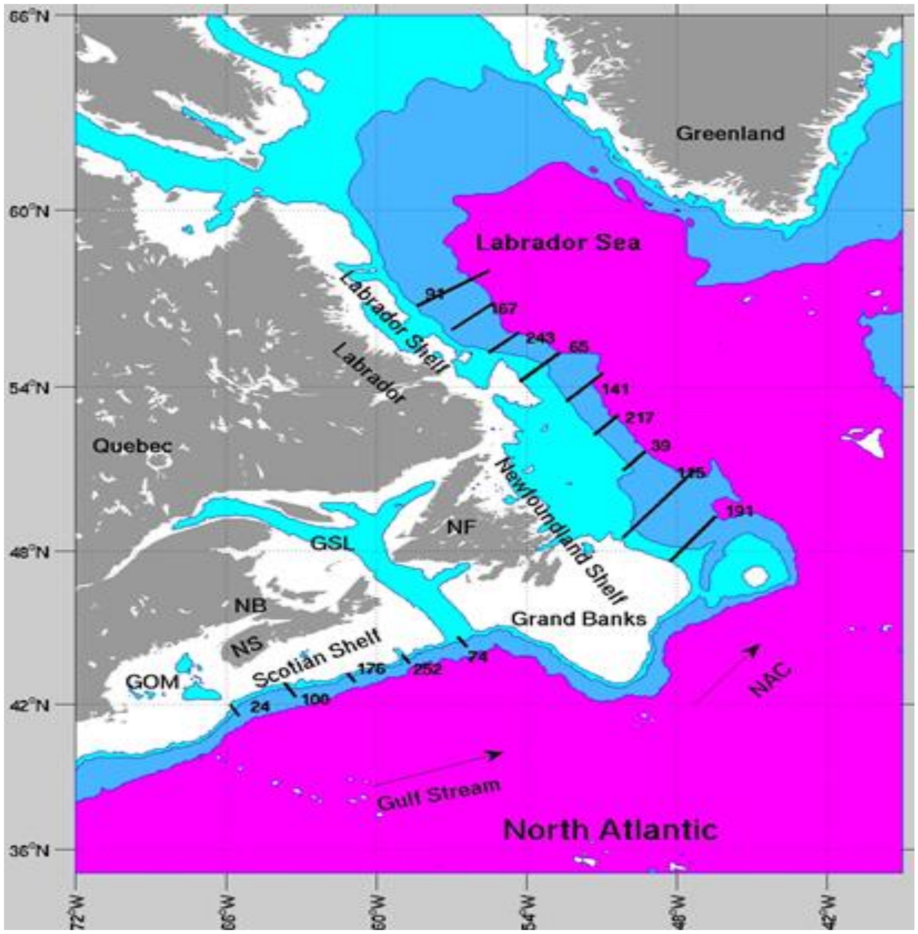

Figure 58. Map showing the Northwest Atlantic bottom topography, with the blue lines depicting 200, 1000, and 3000 m isobaths. The Labrador Current transport is calculated across the cross-slope sections (black) identified by the number of satellite ground tracks. GSL: Gulf of St. Lawrence; GOM: Gulf of Maine; NAC: North Atlantic Current; NB: New Brunswick; NF: Newfoundland; and NS: Nova Scotia.

LABRADOR CURRENT VARIABILITY

The analysis of the circulation and transport through Seal Island and Flemish Cap sections (Figure 2) is presented here. It is 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 2008-17 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 the 2D numerical model WebTide.

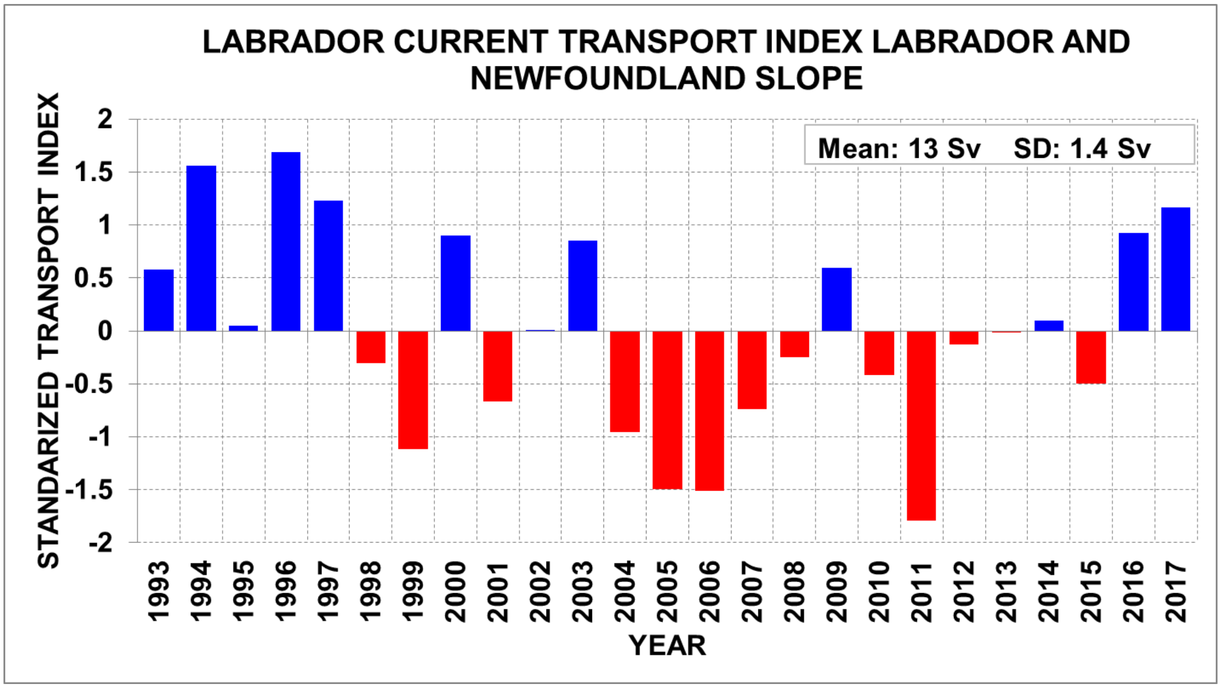

Figure 59. Standardized index of the annual mean Labrador Current transport for the Labrador and northeast Newfoundland Slope. The blue bars indicate higher than average southward transport values.

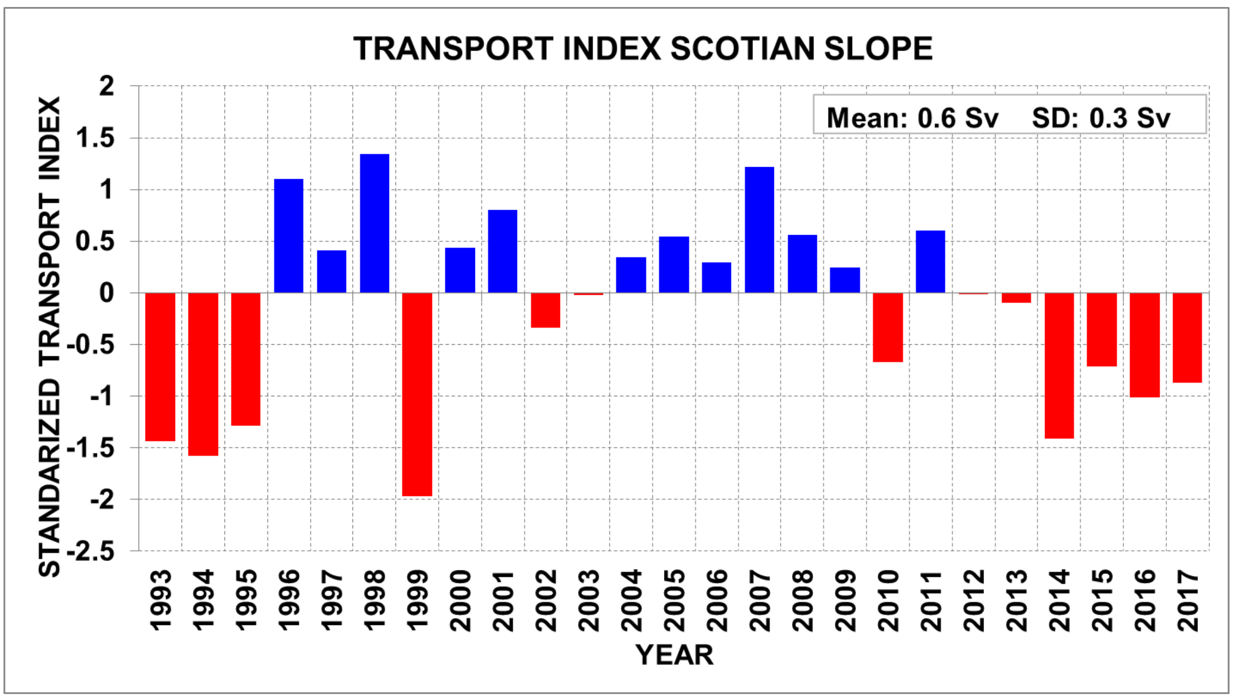

Figure 60. Standardized index of the annual mean transport for the Scotian Slope. The blue bars indicate higher than average southward transport values.

The Labrador Current crossing 47°N, which exhibits considerable annual and seasonal variability, is about 50-100 km wide between the 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, centered over the 400 m isobath, with mean southward currents of about 20 cm/s and peak values >40 cm/s (Figure 61).

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 2008-16 average (Figure 61, 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 62, top panel). It was generally weaker than the 2008-16 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 62, bottom panel).

The average (2008-17) 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 centered 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 63, 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 centered over the 500 m isobath (Figure 63, bottom panel).

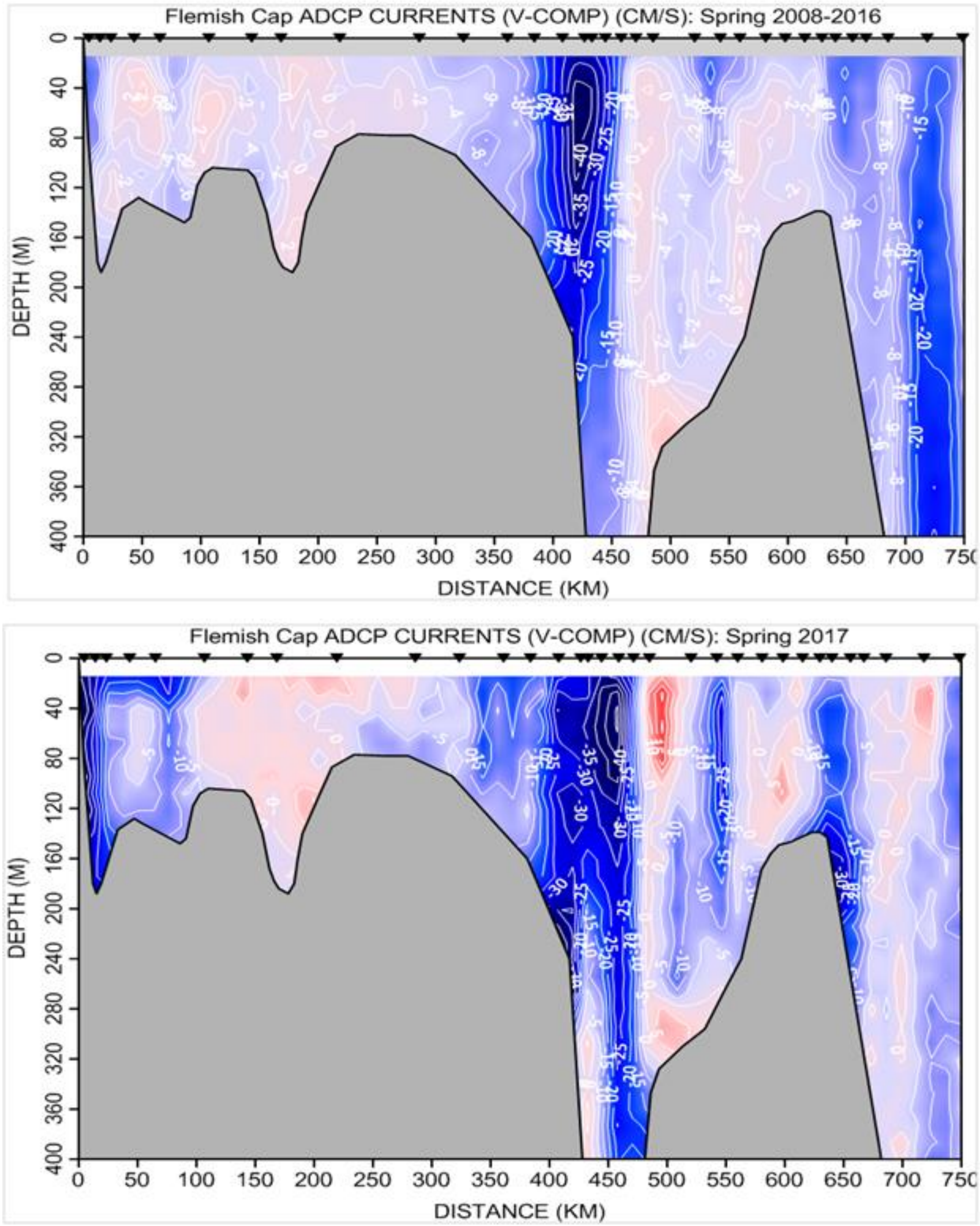

Figure 61. Average current speeds (cm/s) during the spring 2008-16 (top panel) and for the spring of 2017 (bottom panel) along the Flemish Cap section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

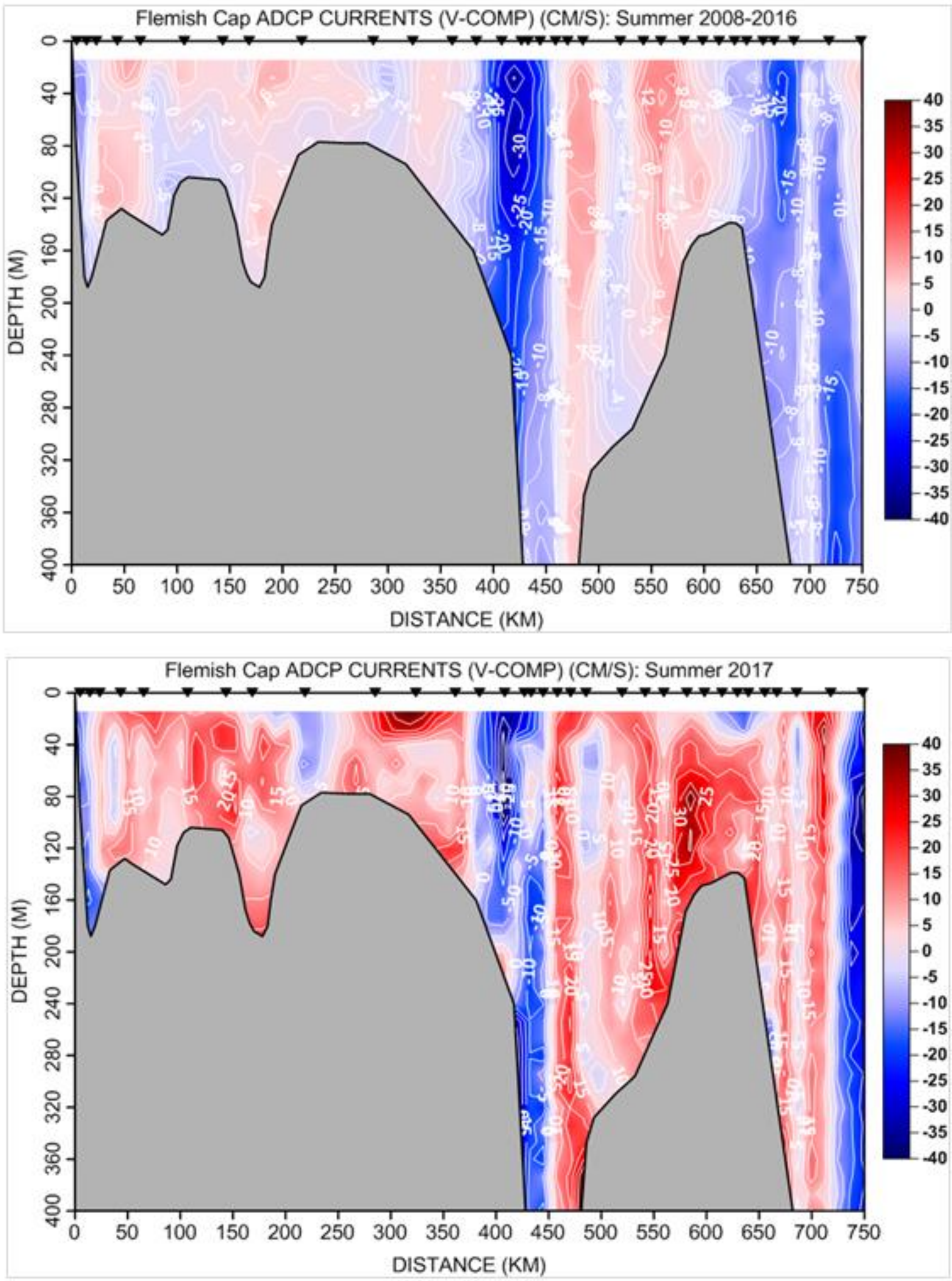

Figure 62. Average current speeds (cm/s) during the summer 2008-16 (top panel) and for the summer of 2017 (bottom panel) along the Flemish Cap section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

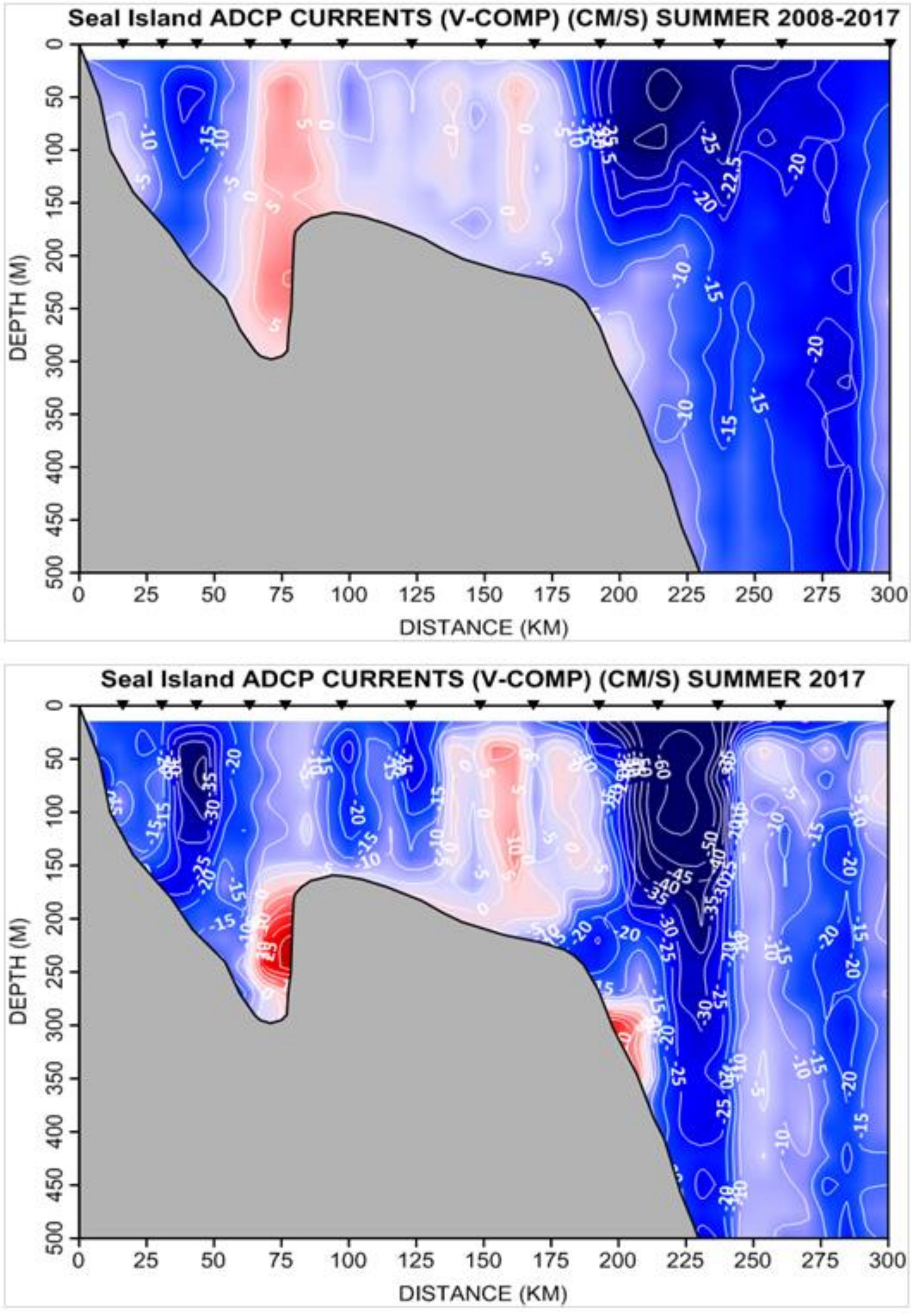

Figure 63. Average current speeds (cm/s) during the summer (top panel) and for the summer of 2017 (bottom panel) along the Seal Island section. Southward flowing water is colored blue and northward red. The symbols along the top of the panels are the standard AZMP stations.

LABRADOR CURRENT TRANSPORT

Volume transport of the Labrador Current computed using vessel mounted ADCP velocities are given here for 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 64). For the Seal Island section transport values were computed within the shaded areas of Figure 65 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 Figure 66, Figure 67 and Figure 68. The maximum values for transport in Avalon Channel was reached in spring 2017 at about 1.5 Sv (1 Sv = 10^6 m^3/s) and in summer 2015 at about 1.7 Sv. In 2017 the spring transport increased over 2016 to the maximum value in the series while the summer value was among the lowest (Figure 66). 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 67). 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 68). 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.

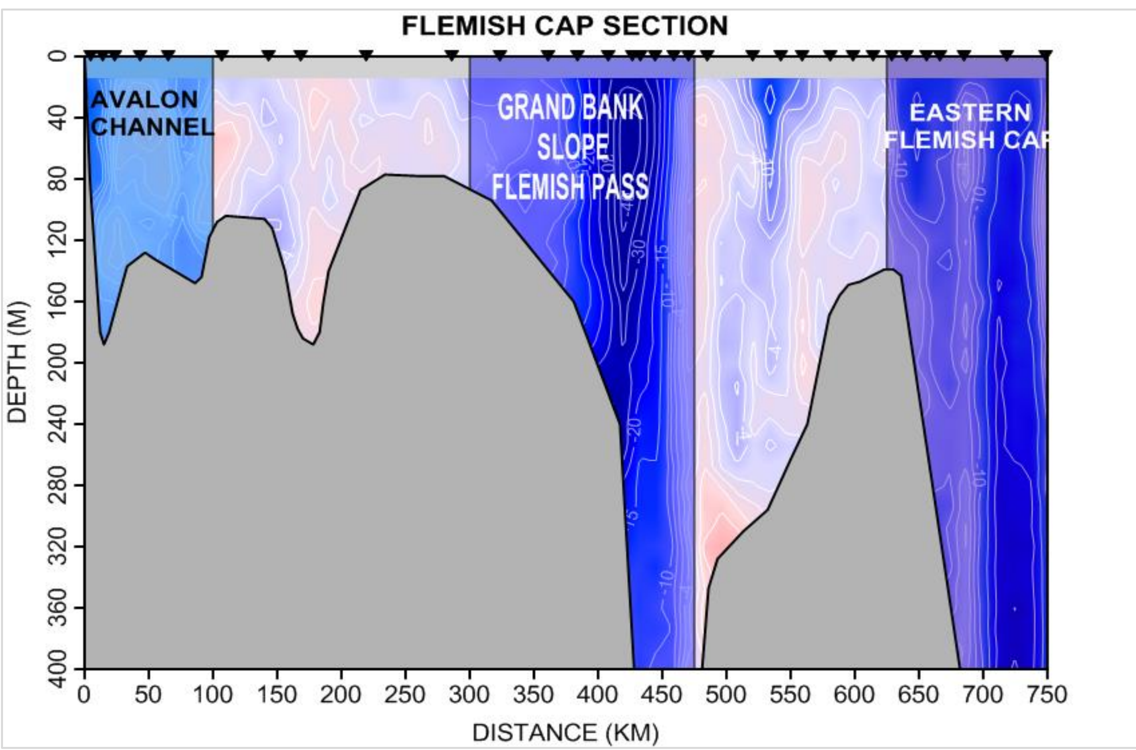

Figure 64. The Flemish Cap section showing the areas where the Labrador Current transport values were computed. The symbols along the top of the panels are the standard AZMP stations.

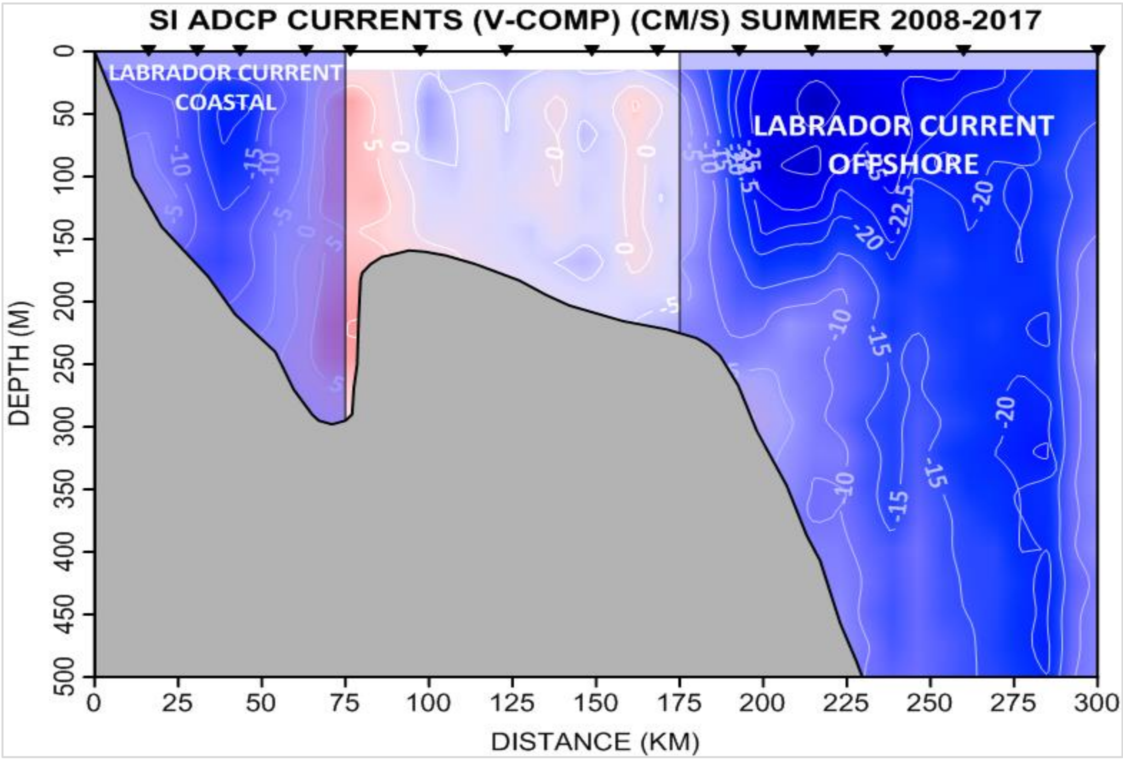

Figure 65. The Seal Island section showing the areas where the Labrador Current transport values were computed. The symbols along the top of the panels are the standard AZMP stations.

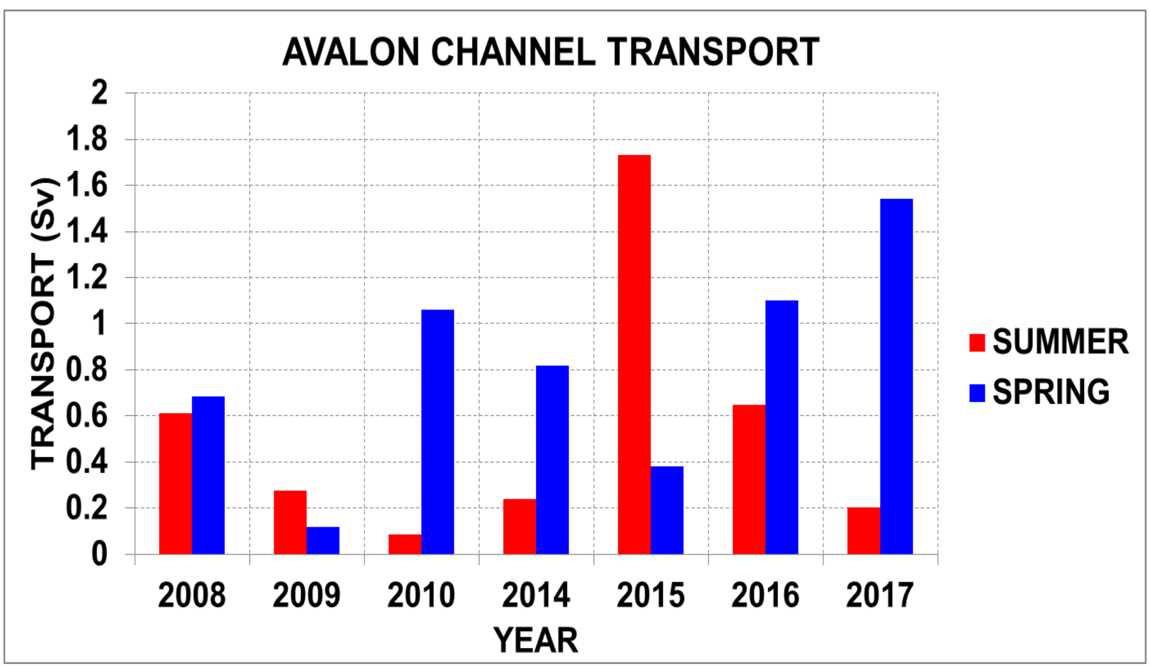

Figure 66. Transport values (1 Sv = 10^6 m^3/s) for the Avalon Channel for the spring and summer based on available ADCP data.

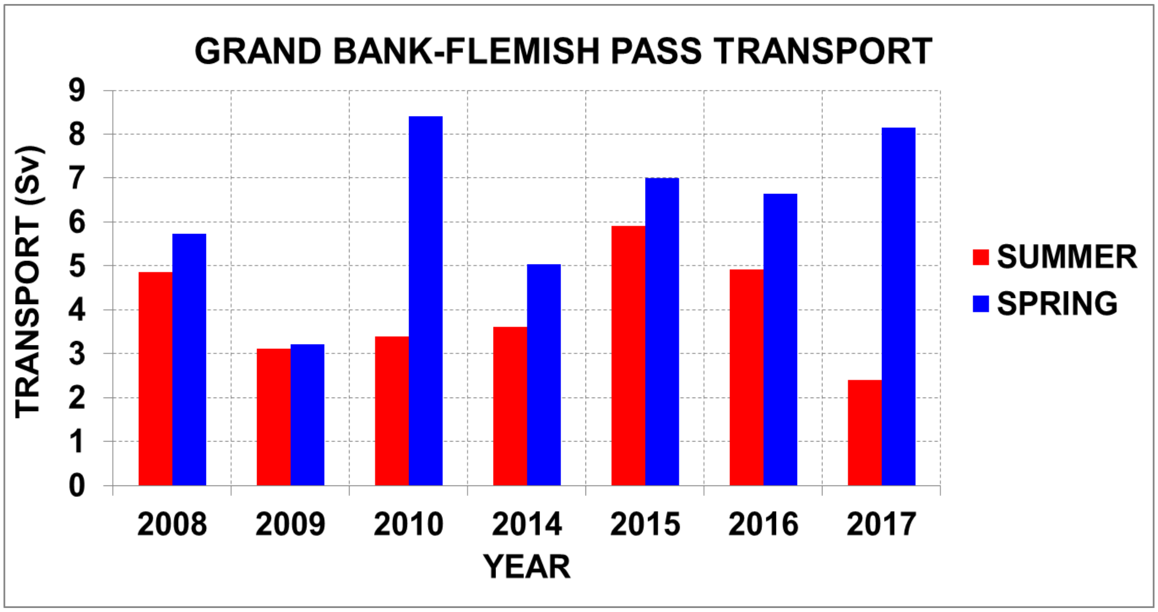

Figure 67. Transport values for the Grand Bank Slope-Flemish Pass for the spring and summer based on available ADCP data.

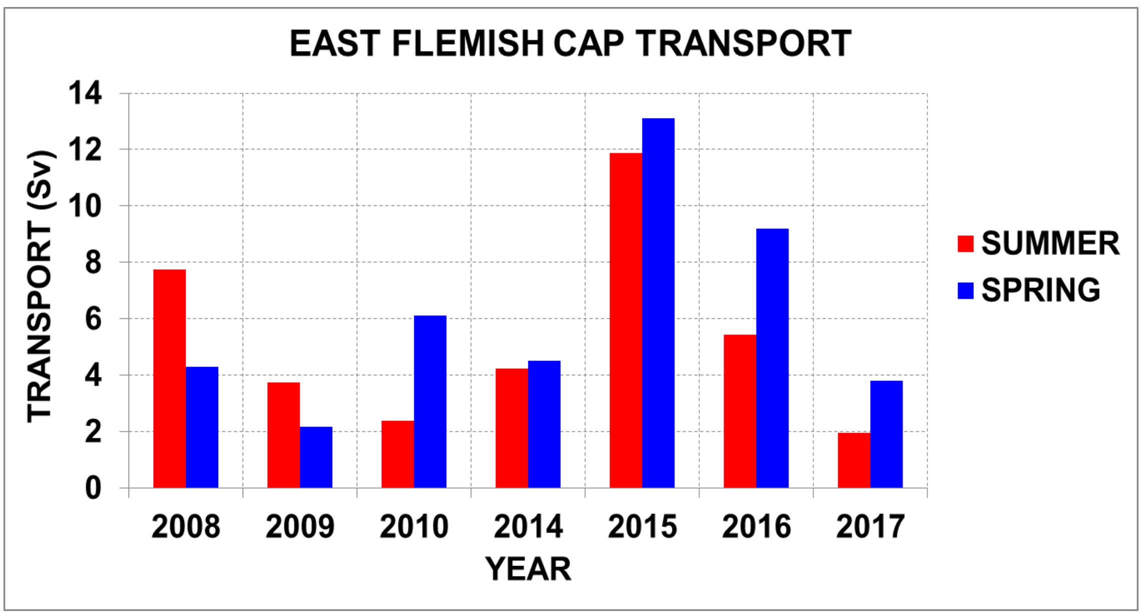

Figure 68. Transport values for east of the Flemish Cap for the spring and summer based on available ADCP data.

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 Figure 69 and Figure 70. 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 2014-15 was significantly less that that the other years. No data were available for 2011-13.

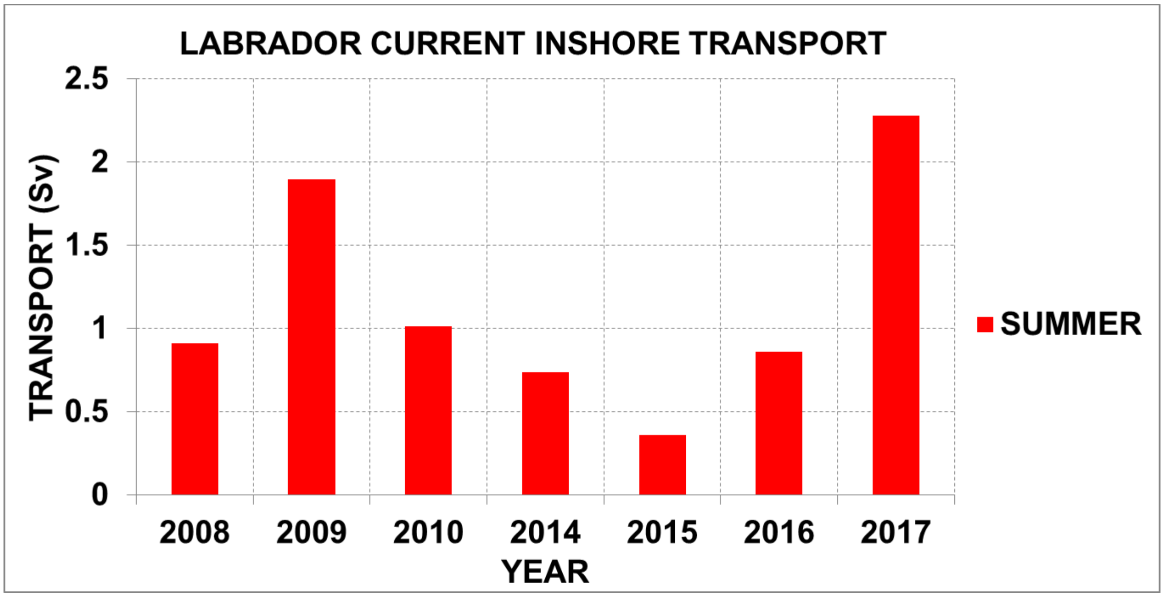

Figure 69. Transport values for the inshore Labrador Current off southern Labrador for the summer period based on ADCP data.

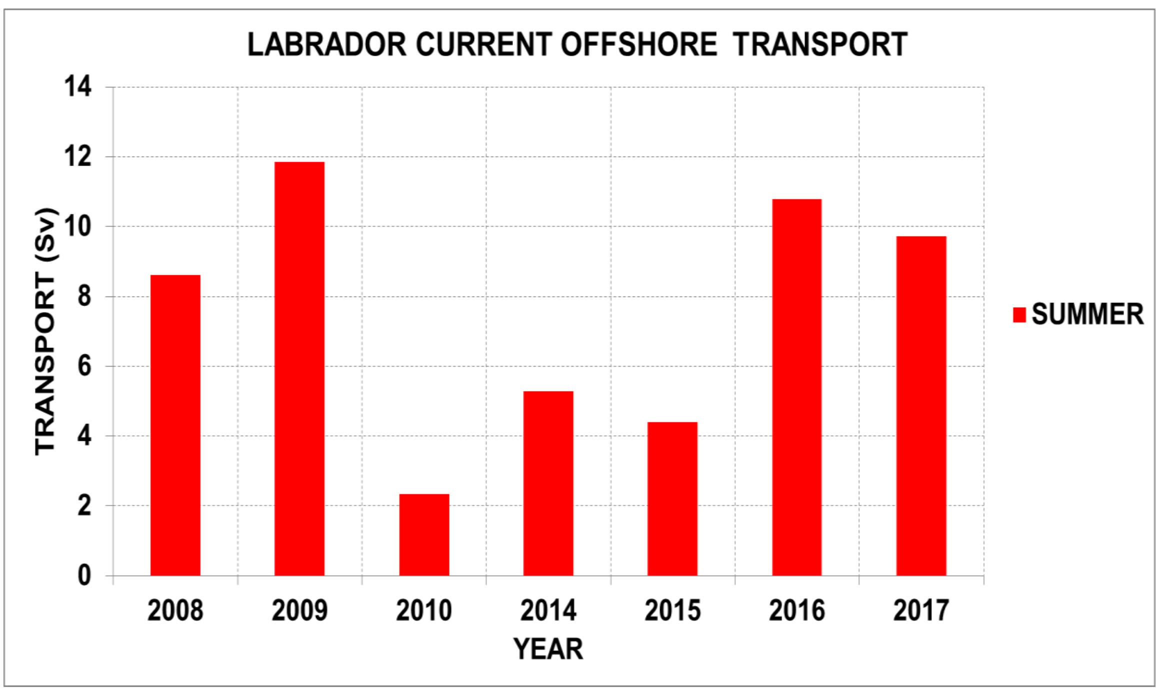

Figure 70. Transport values for the offshore Labrador Current for the summer based on available ADCP data.

SUMMARY

A summary of selected temperature and salinity time series and other climate indices for the years 1950-2017 are displayed in Figure 71 as color-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 72). To further visualize the components, each time series was then grouped according to the type of measurement; meteorological, sea ice, water temperature, CIL area and salinity. The composite index can be interpreted as a measure of the overall state of the climate system with positive values representing warm-salty conditions with less sea-ice and conversely negative values representing cold-fresh conditions.

The plot also indicates the degree of correlation between the various measures of the environment. In general, most time series are correlated, but there are some exceptions as indicated by the negative contributions during a given year with an overall positive composite index and conversely during a year with a negative composite index.

Similar to the standardized values shown in Figure 71, 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 72).

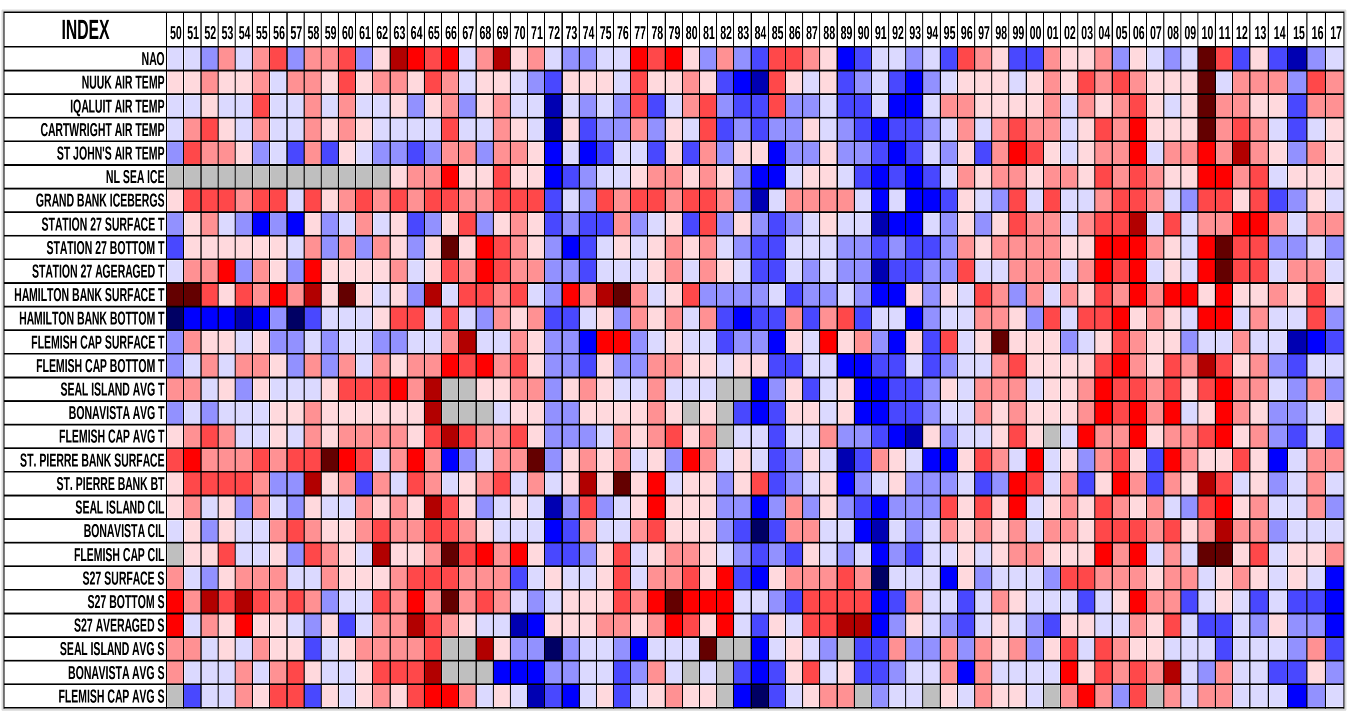

Figure 71. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic color-coded according to Figure 3. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010. Grey cells indicate missing data.

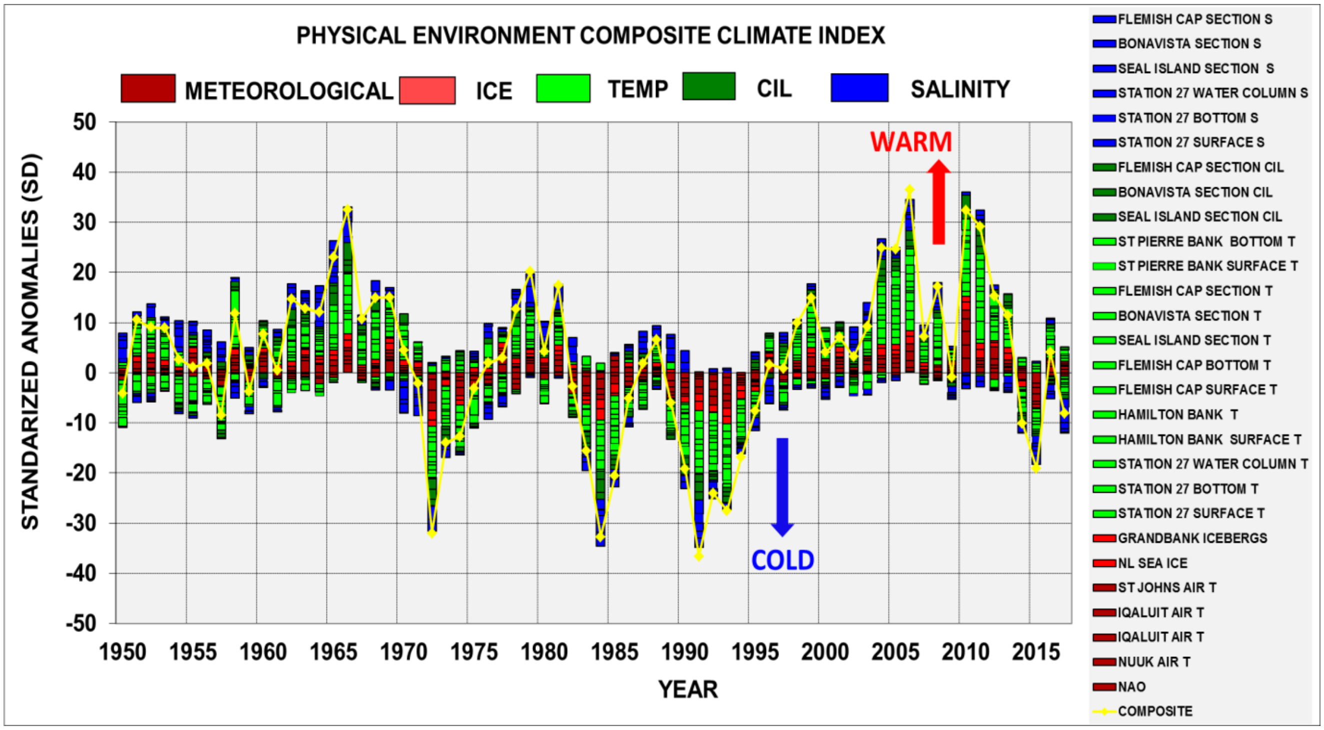

Figure 72. Composite climate index (yellow line) derived by summing the standardized anomalies from Figure 42 together with their individual components.

SUMMARY POINTS FOR 2017

- The winter NAO Index, a key indicator of climate conditions on the NL Shelf, was normal in 2017 at +0.3 SD. The Arctic air outflow in the region was weak and the winter and annual air temperatures at several sites in the region were slightly above normal on average.
- Sea ice extent on the NL Shelf was slightly below normal conditions at -0.4 SD. 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. The number of icebergs detected south of 48ºN on the Northern Grand Bank (1008) was slightly above average at +0.4 SD.
- Annual sea-surface temperatures (SST) were mostly below normal during 2017, driven largely by very cold spring conditions. This pattern is coherent with a cooling of the northern North Atlantic observed since about 2014.
- At station 27, the annual SST was +0.4°C (0.6 SD) above normal and the annual surface salinity anomaly was -0.4 (-1.58 SD) below normal. The annual bottom temperature and salinity anomalies were below normal at -0.2°C (0.6 SD) and -0.12 (-1.57 SD), respectively. The annual water column average temperature and salinity anomaly at Station 27 were +0.03°C (-0.1 SD) and -0.16°C (-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 (see Figure 2)) was -0.4, 0.7, -0.2, 1.0 and -0.3 SD different from normal, respectively. Positive/negative anomalies indicate colder/warmer conditions. During the summer the CIL area 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 Cap 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 averaged spring bottom temperature in NAFO Div. 3Ps was about 2.6°C, or 0.4°C (0.7 SD) above normal, a significant decrease from 1.8 SD above normal in 2016. In 3LNO the bottom temperature was 1.0°C, or 0.1°C (0.2 SD) above normal, about the same compare to 2016.
- The averaged fall bottom temperature in NAFO Divs. 3LNO was 0.7°C, or -0.4°C (-1 SD) below normal, a significant decrease from 2016. In 3K and 2J, the bottom temperature were 2.2°C, or -0.2°C (-0.3 SD) below normal and 2.1°C, or 0.1°C (0.2 SD) above normal, respectively.
- A composite climate index for the NL region returned to slightly below normal (15th lowest) compared to slightly above normal in 2016.

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 Marine Environment Data Section of Fisheries and Oceans Canada 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 captains and crews of the CCGS Teleost, CCGS Needler and Fugro Discovery for oceanographic data collection during 2017. We thank David Hebert and Peter Galbraith for reviewing the document.

REFERENCES CITED

Casey, K.S., Brandon, T.B., Cornillon, P., 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. pp 273-287.

Colbourne, E., Holden, J., Snook, S., Han, G., Lewis, S., Senciall, D., Bailey, W., Higdon, J., and N. Chen . 2017. Physical oceanographic conditions on the Newfoundland and Labrador Shelf during 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/079. v + 50 p.

Colbourne, E. B., Narayanan, S., 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.

Craig, J. D. C., and E. B. Colbourne. 2002. Trends in stratification on the inner Newfoundland Shelf. DFO RES DOC. 2002/071.

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.

Drinkwater, K. F., and R. W. Trites. 1986. Monthly means of temperature and salinity in the Grand Banks region. Can. Tech. Rep. Fish. Aquat. Sci. 1450: iv+111 p.

Galbraith, P.S., Chassé, J., Caverhill, C., Nicot, P., Gilbert, D., Lefaivre, D. and C., Lafleur. 2018. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/050. v + 79 p.

Han, G., Chen, N., and Z. Ma. 2014. Is there a north-south phase shift in the surface Labrador Current transport on the interannual-to-decadal scale? Geophys. Res. 119: 276-287.

Han, G., Lu, Z., Wang, Z., Helbig, J., Chen, N., and B. deYoung. 2008. Seasonal variability of the Labrador Current and shelf circulation off Newfoundland. Geophys. Res. 113.

Han, G., Hannah, C.G., Smith, P.C., and J.W. Loder. 1997. Seasonal variation of the three-dimensional circulation over the Scotian Shelf. Geophys. Res. 102:1011-1025.

Hebert, D., Pettipas, R., 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.

Hebert, D., Pettipas, R., and D. Brickman. 2018. Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/016. v + 53 p.

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

Petrie, B., Pettipas, R. G., 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., Akenhead, S., Lazier, J.,and J. Loder. 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978-1986. NAFO Sci. Coun. Studies 12: 5769.

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 D. Sameoto. 1998. Proposal for a northwest Atlantic zonal monitoring program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57 pp.

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