Northwest Atlantic Fisheries Organization

Serial No. N6033 **NAFO SCR Doc. 12/009**

SCIENTIFIC COUNCIL MEETING – JUNE 2012

An Assessment of the Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2011

by

E. B. Colbourne, J. Craig, C. Fitzpatrick, D. Senciall, P. Stead and W. Bailey

Fisheries and Oceans, Canada, P. O. Box 5667, St. John's Newfoundland, Canada A1C 5X1

ABSTRACT

The North Atlantic Oscillation index, is a key indicator of climate conditions on the Newfoundland and Labrador Shelf, and after reaching a record low in 2010 it remained in the negative phase at 1.2 Standard Deviation (SD) below normal. As a result, arctic air outflow to the Northwest Atlantic remained weak in most areas in 2011. Annual air temperatures remained above normal at Labrador by 0.7 SD (0.9°C at Cartwright) and at Newfoundland by 0.6 SD (0.5°C at St. John's) but declined significantly from the record highs of 2010. The annual sea ice extent on the NL Shelf remained below normal for the 16th consecutive year reaching a record low in 2011. As a result of these and other factors, local water temperatures on the Newfoundland and Labrador Shelf remained above normal, setting new record highs in some areas. Salinities on the NL Shelf were lower than normal throughout most of the 1990s, increased to above normal during most of the past decade but decreased to fresher-than-normal conditions in many areas from 2009-2011. At a standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature increased to a record high in 2011 at 3 SD above the long-term mean. Annual surface temperatures at Station 27 were above normal by 0.6 SD (0.4°C) while bottom temperatures (176 m) were at a record high at 3.4 SD (1.3°C) above normal. The annual depth-averaged salinities at Station 27 were below normal for the 3rd consecutive year. The annual stratification index at Station 27 decreased to 2 SD below normal, the lowest since 1980. The area of the cold intermediate layer (CIL) water mass with temperatures <0°C on the eastern Newfoundland Shelf (Bonavista Section) during the summer of 2011 was at a record low value at 2 SD below normal, implying warm conditions, while off southern Labrador it was the 4th lowest at 1.5 SD below normal. On the Grand Bank the CIL area was the second lowest on record. The volume of CIL (<0°C) water on the NL shelf during the fall was below normal (4th lowest since 1980) for the 17th consecutive year. Average temperatures along sections off eastern Newfoundland and southern Labrador were above normal while salinities were generally below normal. All spring bottom temperature measurements in NAFO Divs. 3Ps and 3LNO during 2011 were above 0°C and up to 1°-2°C higher than normal. The gridded average bottom temperature across the 3Ps-3LNO region was at a record high. During the fall, bottom temperatures in 2J and 3K were also at a record high value, at 2 and 2.7 SD above normal, respectively, and in 3LNO they were 1.8 SD above normal. Generally, bottom temperatures were about 1°-2°C above normal in most regions, with very limited areas of the bottom covered by <0°C water. A composite climate index derived from 27 meteorological, ice and ocean temperature and salinity time series show a peak in 2006, a declining trend in 2007-09 and a sharp increase in 2010 and 2011 to the 2nd and 4th highest, respectively, indicating warmer than normal conditions throughout the region.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Fig.1) during 2011 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; see Therriault et. al., 1998; Galbraith et al., 2012; Hebert et al., 2012). When possible, the long-term averages were standardized to a 'normal' base period from 1981 to 2010 in accordance with the recommendations of the World Meteorological Organization. The information presented for 2011 is derived from three principal sources: (1) observations made at the fixed Atlantic Zone Monitoring Program (AZMP) site (Station 27) throughout the year from all research and assessment surveys; (2) measurements made along standard NAFO and AZMP cross-shelf sections from seasonal oceanographic surveys (Fig. 2a); and, (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Fig. 2b). Data from other research surveys and ships of opportunity are also used to help define the long-term means and the conditions during 2011. These data are available from archives at the Fisheries and Oceans Integrated Scientific Data Management (ISDM) Branch in Ottawa and maintained in regional databases at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL. An overview of the physical oceanographic conditions for 2010 was presented in Colbourne et al. (2011).

Time series of temperature and salinity anomalies and other derived climate indices were constructed by removing the annual cycle computed over a standard base period from 1981 to 2010. 'Normal' is defined here as the average over the base period. For shorter time series, the base period included all data up to 2010. It is recognized that monthly and annual estimates of anomalies that are based on a varying number of observations may only approximate actual conditions; caution therefore should be used when interpreting short time scale features of many of these indices. Annual or seasonal anomalies were normalized by dividing the values by the standard deviation of the data time series over the base period, usually 1981–2010 if the data permit. A value of 2 for example indicates that the index was 2 standard deviations higher than its long-term average. As a general guide, anomalies within ±0.5 standard deviations in most cases are not considered to be significantly different from the long-term mean.

Normalized water property time series and derived climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2011 are presented as coloured cells with gradations of 0.5 standard deviations (SD) and summarized in tables. Blues represent cold-fresh environmental conditions and reds warm-salty conditions (Table 1). In some instances (NAO, ice and water mass areas or volumes for example) negative anomalies indicate warm conditions and hence are coloured red. Positive current transport values are colored blue. Composite indices are derived by summing the standardized values for each year, reversing the sign when negative anomalies denote warmer than normal conditions. More details on oceanographic monitoring programs, data analysis and long-term trends in the environment are presented in Colbourne et al. (2005).

Table 1. Standardized anomalies colour coding scale in units of 0.5 standard deviations.

			←	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

METEOROLOGICAL AND SEA-ICE CONDITIONS

The North Atlantic Oscillation (NAO) Index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly and northwesterly winds over the Northwest Atlantic. A high NAO index results from an intensification of the Icelandic Low and Azores High. This favours strong northwest winds, cold air and sea temperatures and heavy ice conditions on the NL Shelf regions (Colbourne et al. 1994; Drinkwater 1996, Petrie 2007). However, this relationship did not prevail in 1999 and 2000 when the NAO was well above normal and the colder-than-normal winter conditions which are usually associated with high NAO values did not extend into Atlantic Canada due to shifting locations in the sea level pressure (SLP) features. The

NAO was below normal for the past 6/10 years reaching a record low of 2.9 SD below normal in 2010 but increased to -1.2 SD in 2011. The similar, but larger scale Arctic Oscillation was also in the negative phase at -0.9 SD in 2011. As a consequence, outflow of arctic air masses to the Northwest Atlantic during the winter remained weaker than normal resulting in a continuation of warmer than normal conditions throughout much of the Northwest Atlantic (Table 2).

Air temperature anomalies at five sites in the Northwest Atlantic (Nuuk Greenland, Iqaluit Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland) are shown in Table 2. The predominance of warmer-than-normal annual and seasonal air temperatures at all sites from the mid-1990s to 2007 is evident, with 2006 values ranging from 1-2 SD above normal. Some cooling was noted for 2007 that continued into the winter of 2008 with some sites reporting below normal winter (Jan.-Mar.) values. There was a slight increase in the annual air temperatures in 2009 at 4/5 sites and a significant increase at all sites in 2010 with air temperatures reaching record highs at northern sites with values 2-3 SD above normal (Fig. 3). At Cartwright on the mid-Labrador Coast and at Iqaluit on southern Baffin Island, annual air temperatures were 2.5 and 2.7 SD above normal in 2010, setting 77 and 65 year records, respectively. There was a decrease at all sites in 2011 from the record highs in 2010 with annual values at Nuuk in West Greenland decreasing to 0.3 SD below normal. The cumulative air temperature index remained above normal in 2011 but decreased sharply from the record high set in 2010 (Fig. 3). These conditions contrasted strongly with the cold conditions experienced in the early 1990s when annual anomalies often exceeded 1 SD below normal (Table 2).

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 time series of the annual sea-ice extent (defined by at least 1/10 coverage) on the NL Shelf (between 45^o-55^{o}N) continued to be below normal for the 16th consecutive year and was at a 49 year record low during 2011 (Fig. 4a) while the winter and spring extents were the 2nd lowest (Fig. 4b and 4c). During the spring of 2009 sea-ice extent was slightly above normal, the first time since 1994. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. Exceptions were 2007 and 2009 when it extended into June, particularly in the inshore areas.

Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that only three icebergs drifted south of 48^{o}N onto the Northern Grand Bank during 2011, one in 2010 and 1204 in 2009. The 112-year average is 474 and that for the 1981-2010 period is 767. In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48^{o}N with an all time record of 2202 in 1984. Years with low iceberg numbers on the Grand Banks generally correspond to higher than normal air temperatures, lighter than normal sea-ice conditions and warmer than normal ocean temperatures on the NL Shelf.

A composite index derived from the meteorological and sea-ice data presented in Table 2 indicate that annual values for the past decade were either near-normal or warmer than normal with 2010 showing the warmest in the time series followed by 2006 and 2011 (Fig. 5). More information on meteorological and sea ice conditions in the Northwest Atlantic, including the Newfoundland and Labrador Shelf, are presented by Hebert et al. (2012).

TIME TRENDS IN TEMPERATURE AND SALINITY

Station 27 (47^o 32.8' N, 52^o 35.2' W), located in the Avalon Channel off Cape Spear NL (Fig. 1), was sampled 40 times (37 CTD profiles, 3 XBT profiles) during 2011 from January to December. Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2011 are displayed in Figures 6a-b and 7a-b. The cold, near-isothermal water column during March to late April has temperatures ranging from near 1^o to –0.5^{o}C. These temperatures persisted throughout the year below 120 m as the cold-intermediate-layer (CIL). Upper layer temperatures warmed to >2^{o}C by early May and to >12^{o}C by late August, after which the fall cooling commenced with temperatures decreasing to 4^{o}C by early December. Temperatures were above normal throughout the year over the entire water column except for the upper layer negative anomaly during July to early October, however it only extended to about 25 m depth with values at 30 m depth reaching 1.5^{o}C above normal.

Upper layer (0-30 m) salinities reached maximum values in late winter and early spring (~32.2) and decreased to <31.2 by October. These values were below normal from January to June and above normal for the remainder of the year. Below 30 m, salinities ranged from 32.2 – 33.2 throughout the year, generally below normal except during December. 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. During 2011 a colder and saltier than normal anomaly dominated the summer and early fall months. This was possibly due to a combination of local upwelling of colder and saltier water and colder than normal summer air temperatures.

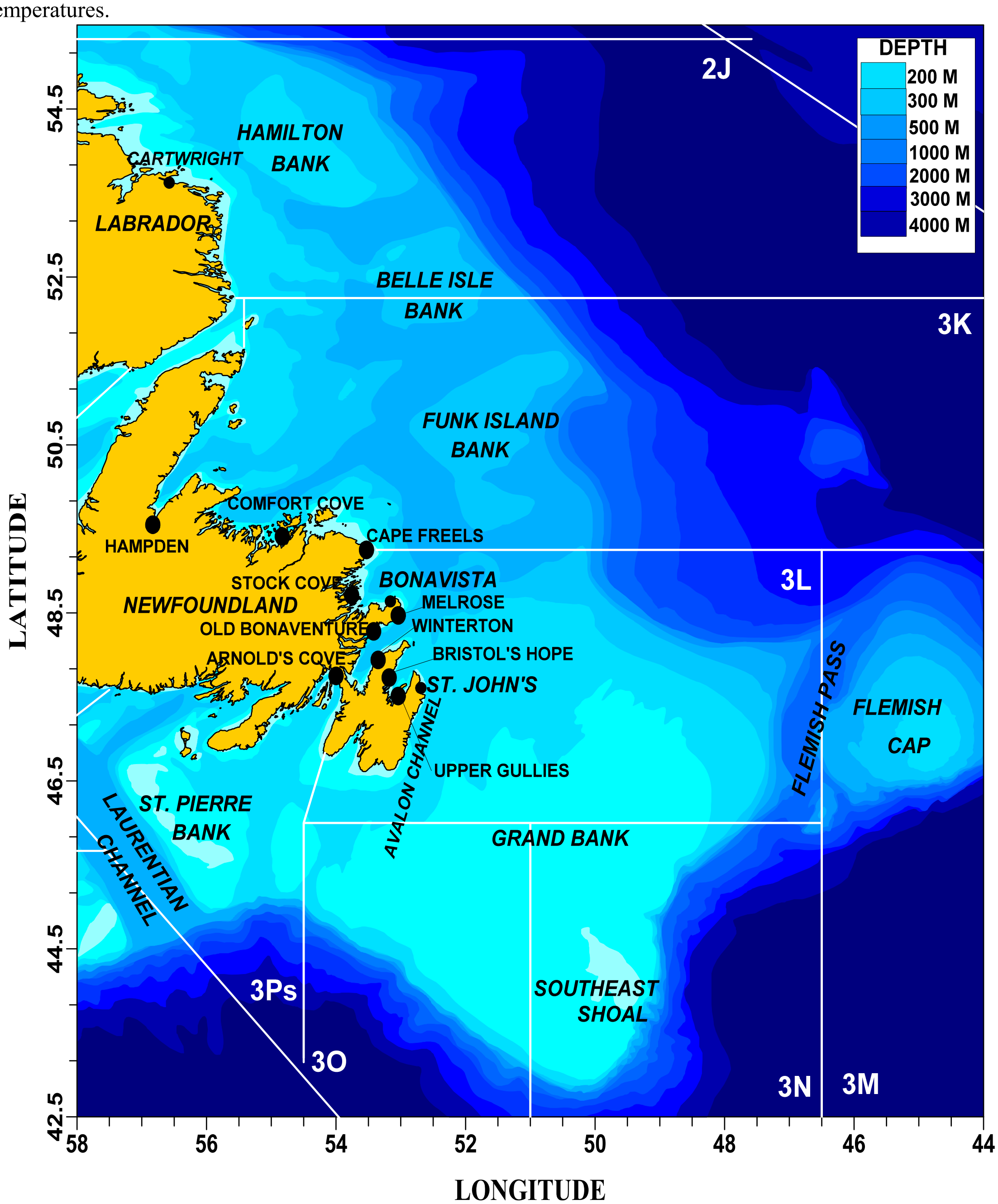


Figure 1. Map showing NAFO Divisions, bathymetric features of the Newfoundland and southern Labrador Shelf and the locations of the near-shore thermograph deployments (black solid circles).

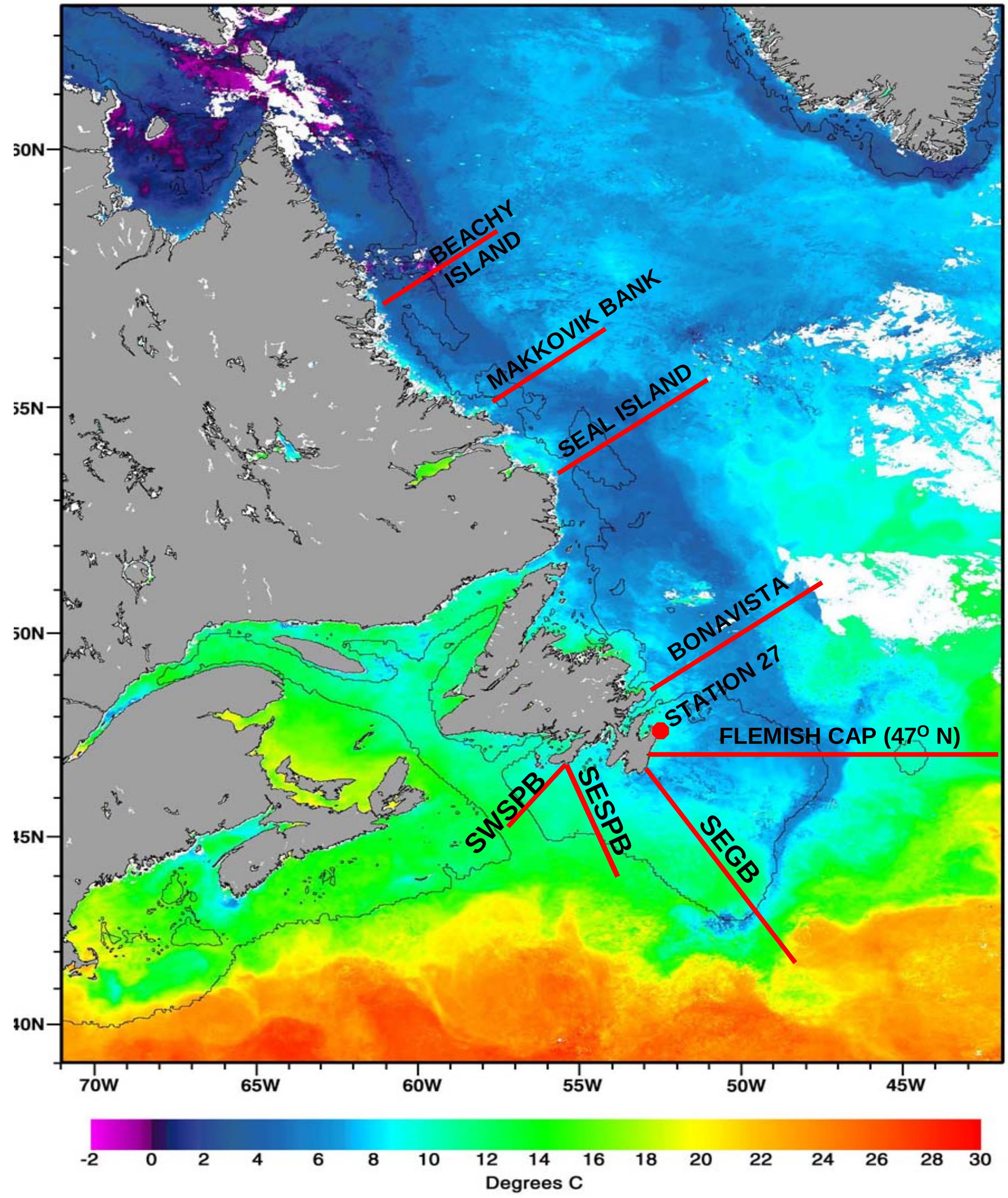


Figure 2a. Map showing summer Sea-Surface-Temperature (SST) during July 15-31, 2011, Station 27 and the standard sections sampled during 2011 (SST map courtesy of the Ocean Research and Monitoring Section, Bedford Institute of Oceanography , BIO).

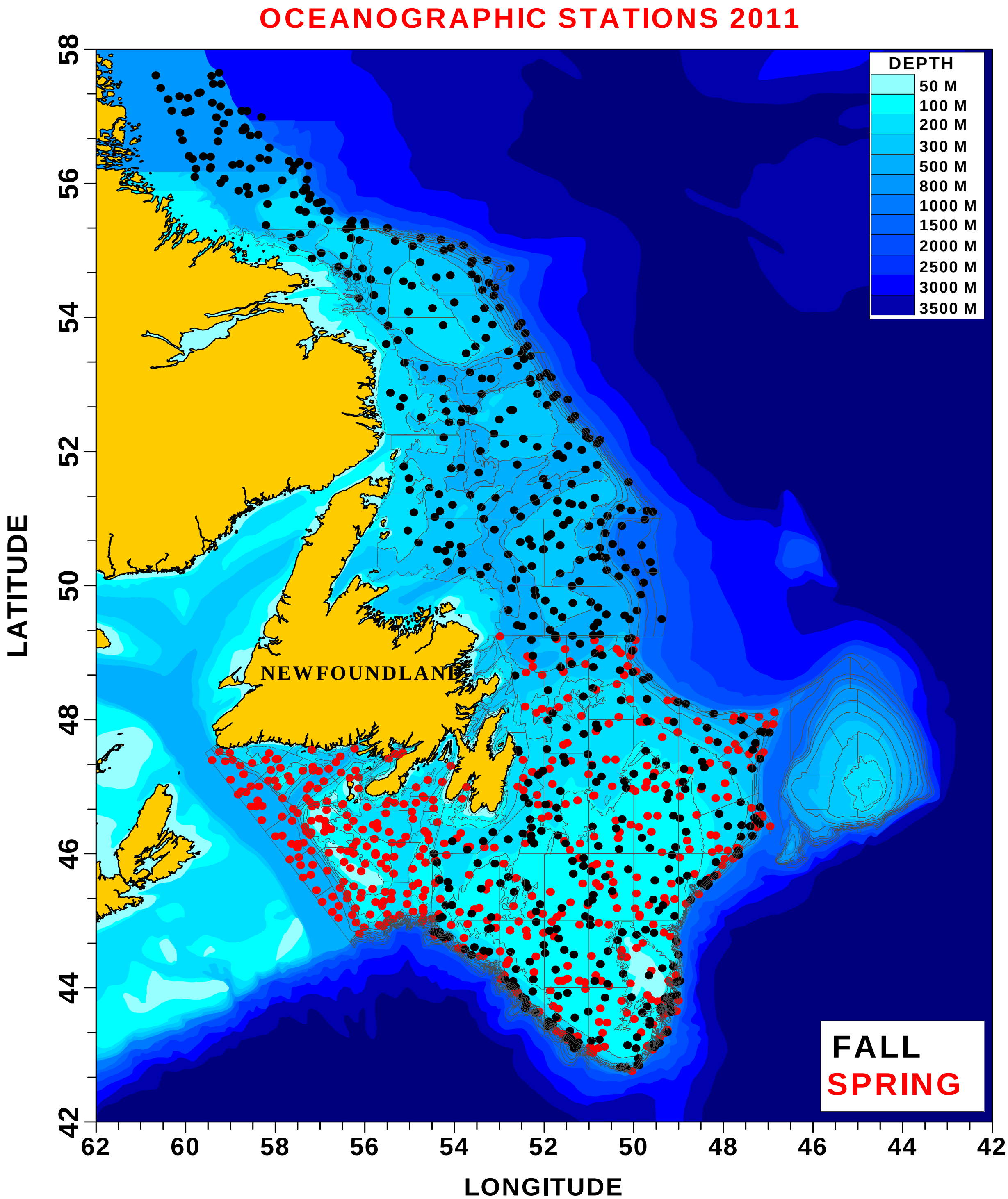


Figure 2b. Map showing the positions of trawl-mounted CTD profiles obtained from spring (red dots) and fall (black dots) multi-species assessment surveys during 2011.

Table 2. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1990 to 2011. The anomalies are normalized with respect to their standard deviations over the 1981-2010 base period.

INDEX	LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
SLP (NAO)	ICELAND-AZORES	1.1	0.4	0.3	0.9	0.4	1.3	-1.4	-0.6	-0.3	1.2	1.1	-0.9	-0.3	-0.3	-1.0	0.5	-0.3	0.3	0.5	0.2	-2.9	-1.2
	NUUK (WINTER)	-0.6	-0.2	-0.8	-1.8	-0.4	-0.9	0.7	-0.2	0.0	-0.2	0.0	0.5	-0.2	0.9	0.7	1.2	0.9	1.0	-0.7	0.6	1.8	0.3
	NUUK (ANNUAL)	-0.7	-0.4	-1.4	-1.6	-0.6	-0.2	0.4	0.1	0.2	-0.2	0.4	0.8	0.2	1.3	0.6	1.1	0.7	0.5	0.2	0.5	2.6	-0.3
	IQALUIT (WINTER)	-0.8	-1.4	-0.6	-1.7	-0.5	0.0	0.3	0.2	-0.5	0.0	0.3	0.5	0.0	0.5	0.9	-0.3	0.6	1.2	-0.7	0.1	2.2	2.1
AIR	IQALUIT (ANNUAL)	-1.2	-0.5	-1.7	-1.7	-0.4	0.5	0.5	0.3	0.2	0.1	0.4	0.6	-0.1	0.8	0.1	0.9	1.4	0.2	-0.1	0.5	2.7	0.5
TEMPERATURES	CARTWRIGHT (WINTER)	-1.2	-1.4	-1.5	-1.5	-1.0	-0.8	0.6	0.2	0.8	0.4	0.3	0.0	0.4	0.2	1.7	0.0	0.7	0.9	-0.8	0.2	2.8	2.1
	CARTWRIGHT (ANNUAL)	-1.3	-1.6	-1.4	-1.3	-0.6	-0.3	0.5	-0.3	0.6	1.1	0.5	0.6	-0.3	0.4	1.1	0.9	1.8	0.1	0.1	0.4	2.5	0.7
	BONAVISTA (WINTER)	-1.7	-0.8	-1.1	-1.7	-1.7	-0.4	1.0	-0.8	0.6	1.9	1.2	0.3	0.1	-1.1	0.8	0.3	1.5	0.2	-0.1	0.4	1.5	1.2
	BONAVISTA (ANNUAL)	-0.6	-1.8	-1.8	-1.8	-0.7	-0.7	0.6	-0.9	0.6	1.5	0.8	0.6	-0.1	0.5	1.0	1.2	1.7	0.0	0.7	0.5	1.6	0.8
	ST. JOHN'S (WINTER)	-2.1	-1.1	-1.7	-1.5	-1.2	-0.8	0.4	0.2	0.2	1.2	1.4	-0.6	0.2	-0.6	0.9	0.7	1.6	0.2	-0.1	1.1	1.2	2.4
	ST. JOHN'S (ANNUAL)	-0.5	-1.4	-1.7	-1.5	-0.5	-0.7	0.3	-1.1	0.6	1.9	1.0	0.3	-0.4	0.4	0.6	0.7	1.6	-0.1	0.8	0.9	1.7	0.6
SEA ICE	NL SEA-ICE EXTENT (Annual)	1.2	1.6	1.3	1.6	1.1	0.1	-0.9	-0.2	-0.5	-0.7	-0.4	-0.9	-0.5	-0.2	-1.4	-0.9	-1.4	-0.6	-0.3	-0.1	-1.6	-1.8
COVERAGE	NL SEA-ICE EXTENT (Winter)	1.1	1.1	1.3	1.7	1.3	0.4	-0.5	0.1	-0.7	-0.5	-0.3	-0.9	-0.6	-0.2	-1.7	-0.7	-1.3	-0.9	-0.1	-0.4	-1.9	-1.9
	NL SEA-ICE EXTENT (Spring)	0.9	1.9	1.2	1.5	1.0	-0.2	-1.2	-0.4	-0.1	-0.9	-0.6	-0.8	-0.5	0.0	-0.9	-1.2	-1.5	-0.1	-0.6	0.5	-1.1	-1.4
ICEBERG COUNT	GRAND BANKS	0.0	1.9	0.2	1.5	1.5	1.0	-0.2	0.4	1.0	-1.1	0.1	-1.0	0.2	0.2	-0.8	-1.2	-1.2	-0.7	0.3	0.7	-1.2	-1.2

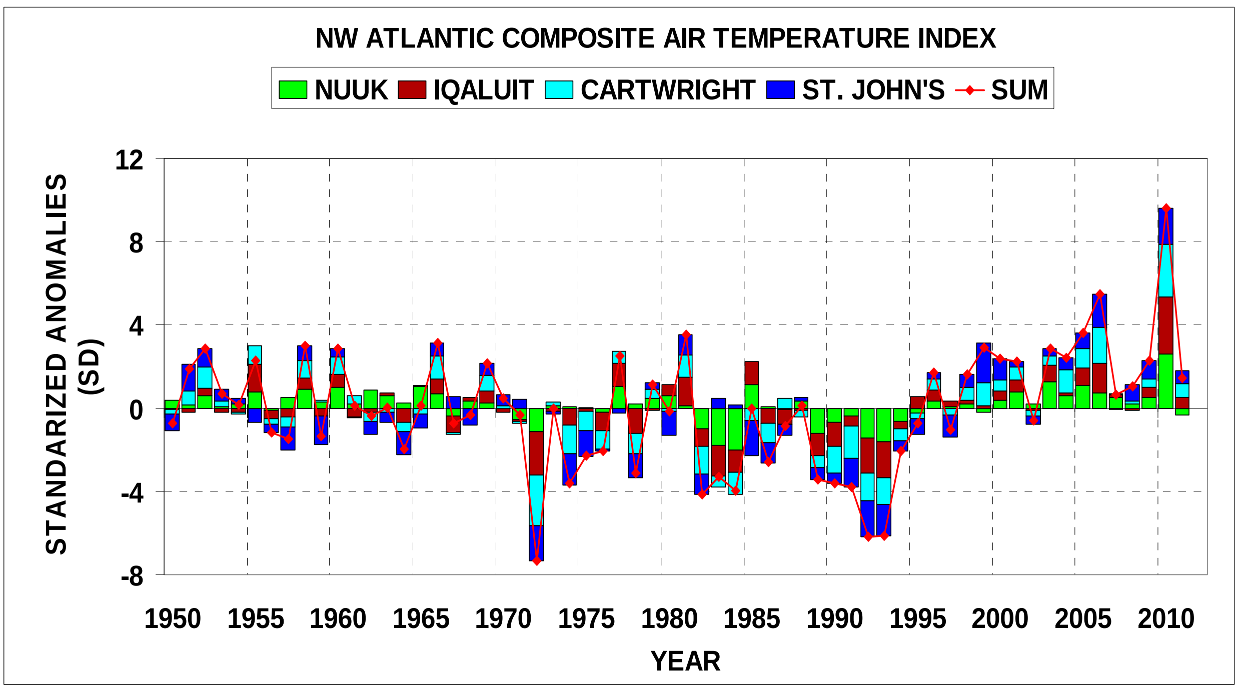


Figure 3. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright and at St. John's relative to the 1981-2010 means.

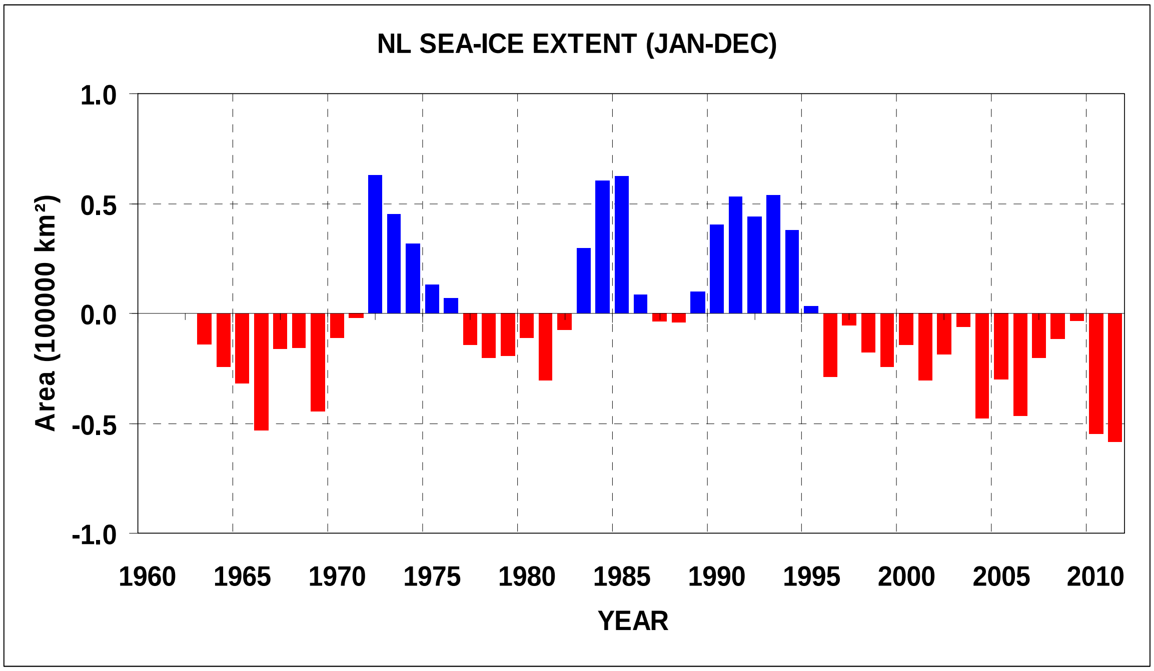


Figure 4a. The annual sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf relative to the 1981-2010 means.

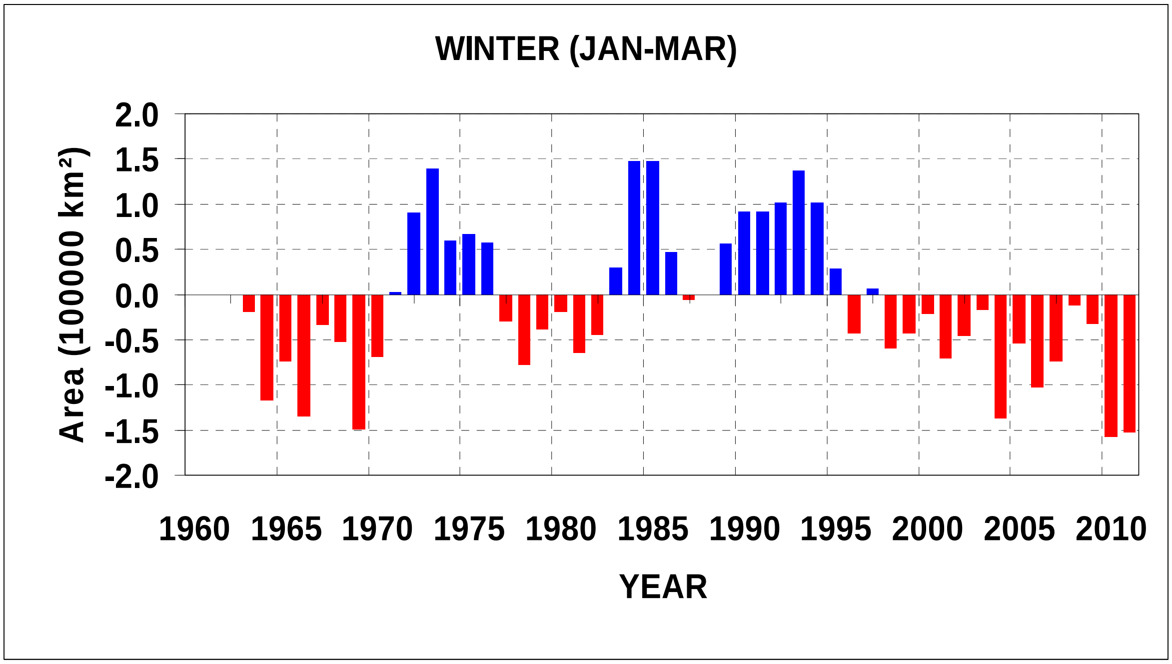


Figure 4b. Sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf during winter (Jan.-Mar.) relative to the 1981-2010 means.

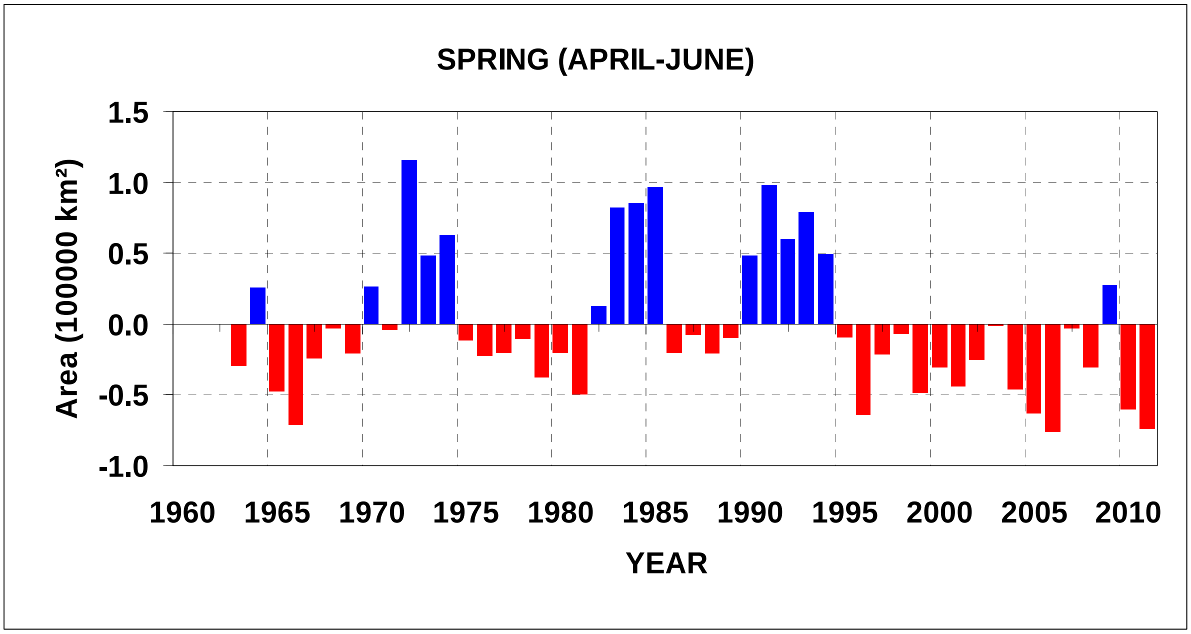


Figure 4c. Sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf during the spring (Apr.-Jun.) relative to the 1981-2010 means.

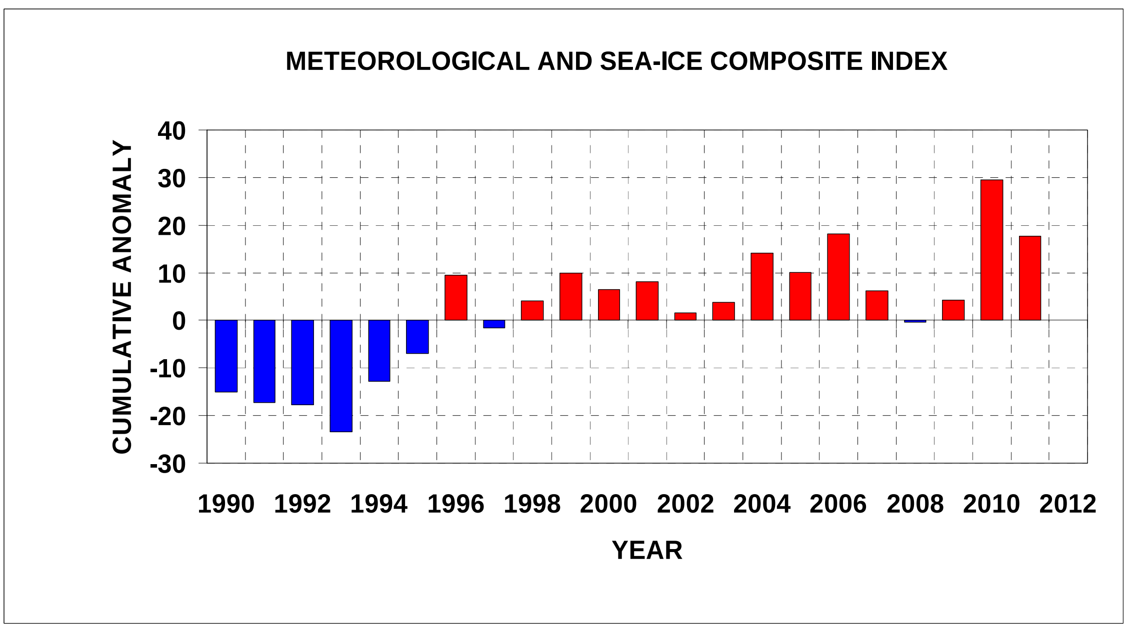


Figure 5. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Table 2.

In general, Station 27 temperatures were below normal from 1990 to 1997, reaching minima in 1991 when surface, bottom and integrated values were in excess of 1 SD below normal (Table 3). The annual surface temperatures at Station 27 having been near-normal or above normal since 2003 (Fig. 8a), reached a 61-year high of 2.2 SD above their long-term mean in 2006, decreased to near normal in 2007 and increased to above normal since then.

Bottom temperatures at Station 27 were above normal from 1996-2008, decreased to slightly below normal in 2009 but increased to the 3rd highest in 2010 at +1.7 SD and to the highest on record in 2011 at 3.3

SD (Table 3, Fig. 8b). Vertically averaged temperatures also set record highs >2 SD above normal in 2006, decreased significantly in 2007, but have increased to the 2nd highest on record in 2010 (+1.9 SD) and to the highest on record in 2011 at 2.9 SD (Fig. 9a, Table 3). Annual vertically averaged salinities at Station 27 decreased from +1.0 SD in 2008 to about >1.0 SD below normal in 2010 and 2011, the freshest conditions since 1995 (Fig. 9b, Table 3).

On Hamilton Bank surface temperatures decreased from 2010 values to about 0.5 SD above normal whereas on St. Pierre Bank and Flemish Cap they were slightly below normal in 2011 (Table 3). On St. Pierre Bank, Flemish Cap and Hamilton Bank, near-bottom temperatures were above normal values by 1-2 SD in 2011, the highest since 1990s on Hamilton Bank. On the Hamilton Bank, Flemish Cap and at Station 27 surface salinities were above normal.

The stratification index, defined as the density gradient between 0 and 50 m, i.e. $\Delta\rho/\Delta z$, was computed from temperature and salinity data collected at Station 27 (Craig and Colbourne 2002). The annual average stratification index was generally below normal in the early 1990s, increased to above normal from 1997-2001, below normal from 2002 to 2005 increased to 1.1 SD above normal in 2006 and continued above normal until 2010 when it fell to 0.4 SD below the long term mean. In 2011 the annual mean stratification decreased to the lowest since 1980 at 2.0 SD below normal (Fig. 10). A similar large decrease in stratification was also observed in 2011 on the Scotian Shelf (Hebert et al, 2012). The spring values show similar patterns with the 2011 values at 0.3 SD below normal (Table 3). The mixed layer depth (MLD), estimated as the depth of maximum density gradient is highly variable on the inner NL Shelf, particularly during the winter months. During 2011 the annual averaged MLD was 1.6 SD deeper than normal. The winter and spring values were deeper than normal by 1 and 1.4 SD, respectively (Table 3).

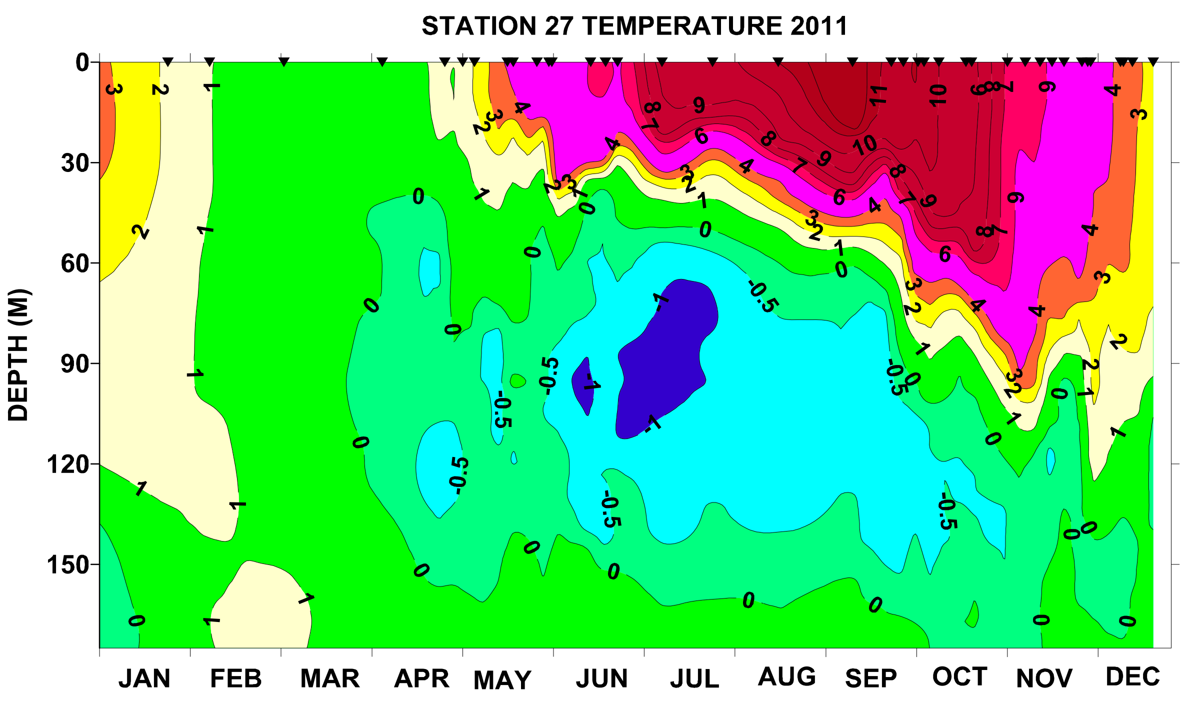


Figure 6a. Contours of temperature (°C) as a function of depth at Station 27 during 2011. Observation times are indicated by the top black triangles.

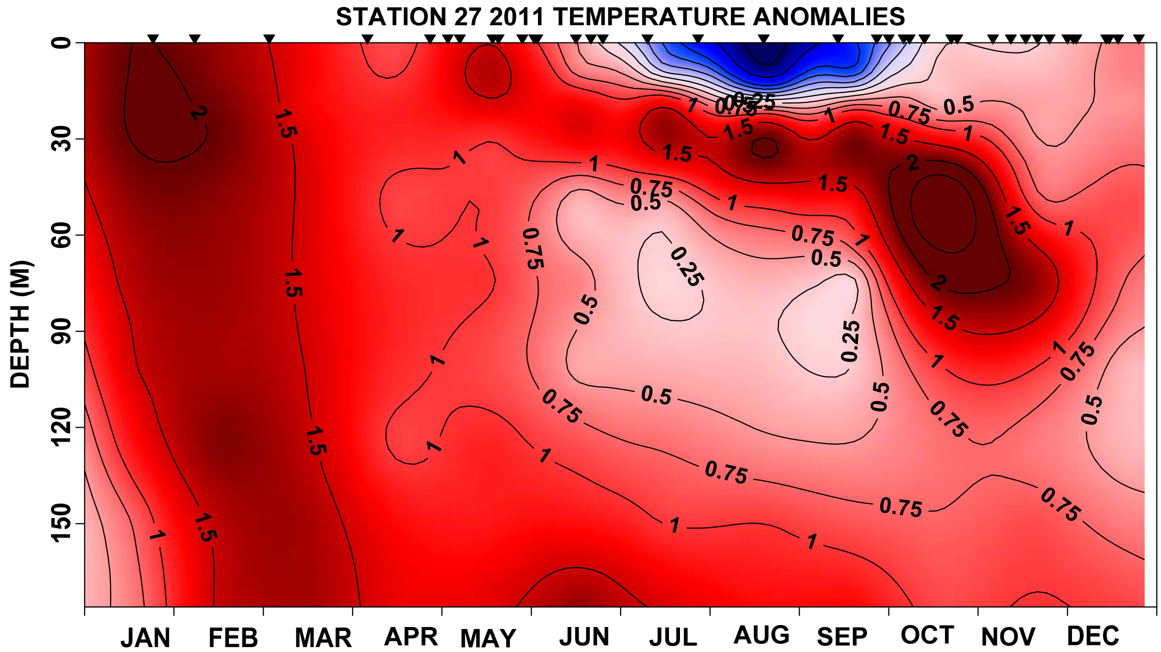


Figure 6b. Contours of temperature anomalies (°C) as a function of depth at Station 27 during 2011. Observation times are indicated by the top black triangles.

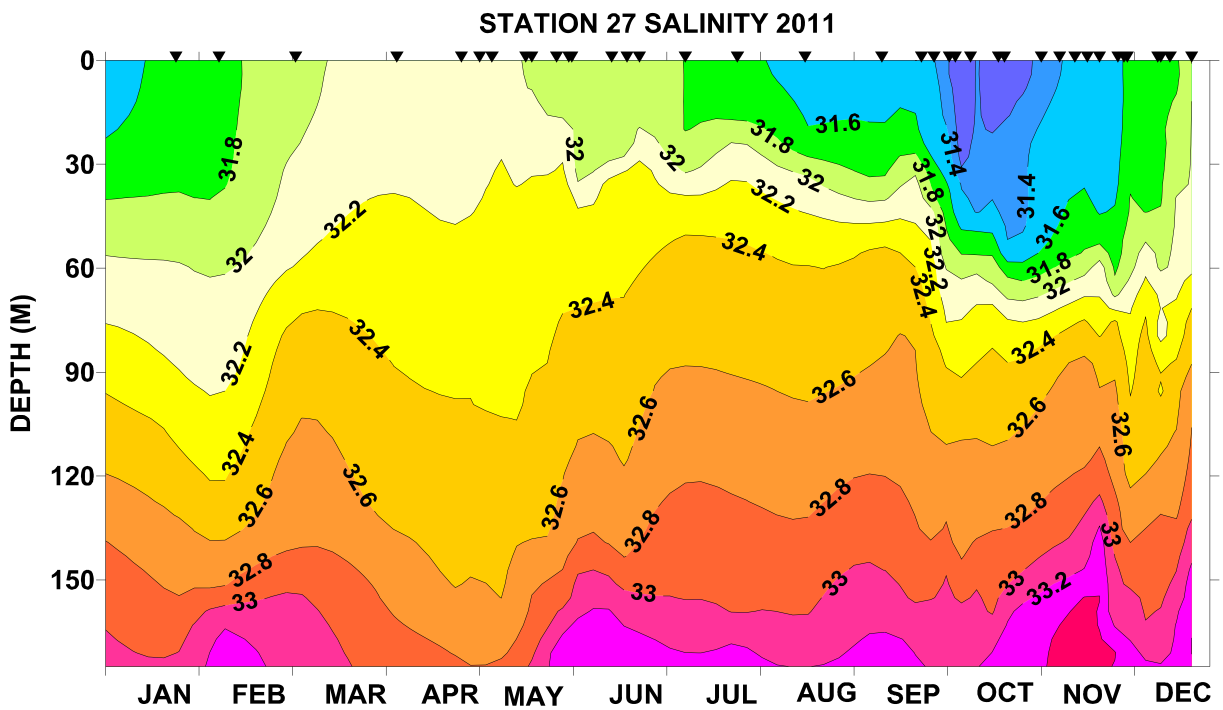


Figure 7a. Contours of salinity as a function of depth at Station 27 for 2011. Observation times are indicated by the top black triangles.

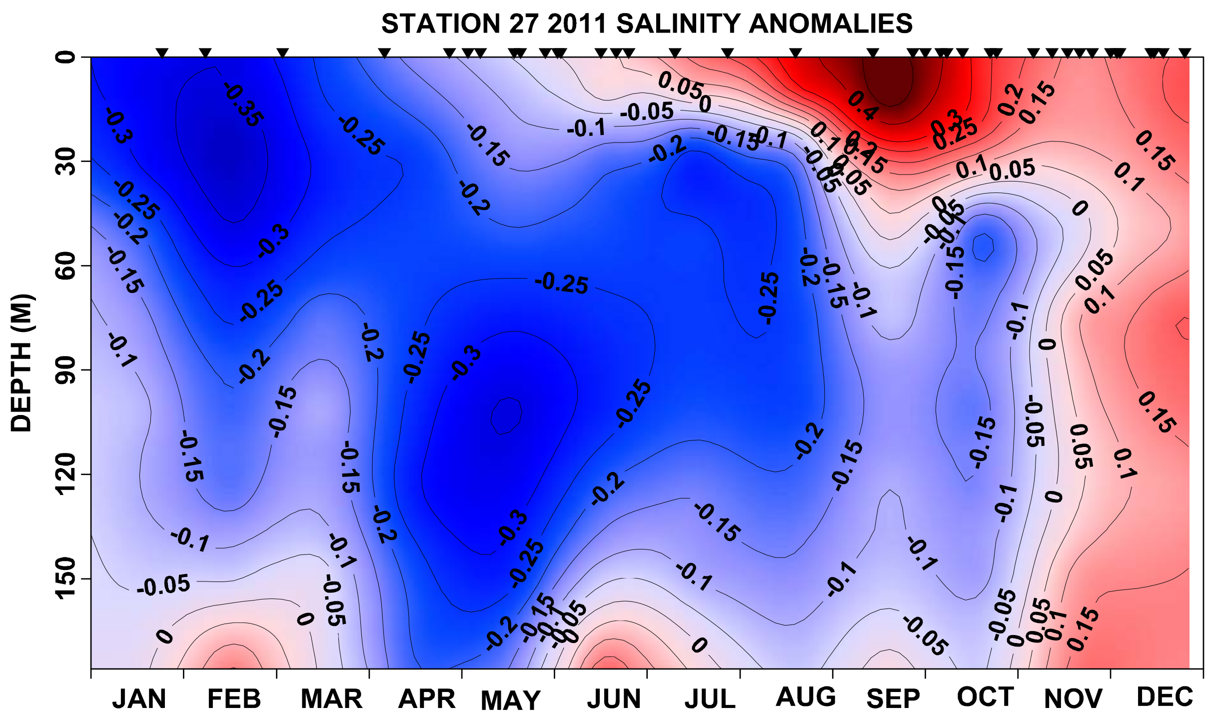


Figure 7b. Contours of salinity anomalies as a function of depth at Station 27 for 2011. Observation times are indicated by the top black triangles.

Table 3. Water property anomalies and ocean climate indices derived from temperature and salinity data collected on the Newfoundland and Labrador Shelf. The anomalies are normalized with respect to their standard deviations over the standard base period. The grey shaded cells indicate no data.

INDEX	LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	HAMILTON BANK	0.0	-0.9	-0.6	-0.3	-0.2	-0.5	-0.4	-0.6	1.8	-0.2	1.2	-0.1	-0.4	1.6	1.3	1.6	0.8	0.2	2.1	0.1	0.9	0.5
SURFACE	FLEMISH CAP	-0.6	-1.4	-1.3	-1.6	-0.8	-0.2	0.1	0.2	2.5	0.0	0.6	0.1	-0.9	0.0	0.3	1.4	2.0	0.2	1.0	-0.4	0.2	-0.3
TEMPERATURE	STATION 27	-0.3	-2.4	-1.5	-1.5	-0.1	-0.9	-0.1	-0.7	0.3	1.1	0.6	0.4	-0.5	0.7	1.3	1.3	2.2	0.0	1.2	0.2	0.9	0.6
	ST. PIERRE BANK	-1.6	-0.1	-1.2	-0.6	-0.7	0.6	0.2	-0.6	0.7	0.9	1.2	-0.9	-0.1	-0.6	0.1	2.2	2.2	-0.2	0.0	0.2	1.2	0.0
	HAMILTON BANK	-0.6	0.0	-0.4	-1.4	-1.3	0.8	0.8	1.1	-0.5	-0.7	-0.2	0.2	-0.5	-0.4	0.3	0.9	0.4	-1.2	-1.1	-0.3	-0.5	1.2
SURFACE	FLEMISH CAP	0.3	0.5		-0.3	-2.5	0.6	0.3	1.0	-0.7	0.2	-1.1	0.8	1.1	2.0	1.0	0.9	0.1	0.9	-0.2	-0.7	0.4	0.4
SALINITY	STATION 27	1.4	-1.9	-1.1	-0.1	-0.4	-1.9	0.2	-0.4	-0.4	-0.4	-0.3	-0.6	1.0	0.9	0.5	0.4	0.6	-0.1	0.5	0.2	-0.7	0.2
	STATION 27	-1.0	-1.5	-1.1	-1.5	-1.3	-0.7	0.6	0.2	0.7	0.7	0.6	0.8	0.1	0.1	1.9	1.7	1.7	0.6	0.2	-0.4	1.7	3.4
BOTTOM	FLEMISH CAP	-2.1	-1.0	-0.3	-0.7	-2.4	-0.6	-0.5	-0.2	0.3	1.4	0.1	-0.3	-0.1	0.5	0.8	1.3	0.7	-0.1	1.2	0.8	1.0	0.9
TEMPERATURE	HAMILTON BANK	-1.2	-0.6	-1.0	-1.2	-0.7	0.2	0.3	1.4	0.5	1.1	-0.1	1.1	1.0	0.7	1.7	1.3	0.4	1.3	-0.2	-0.4	2.0	2.1
	ST. PIERRE BANK	-1.3	-0.1	-0.7	-0.7	-1.5	-0.9	-0.2	-0.6	-0.3	0.8	0.7	-0.4	-0.5	-0.9	0.7	2.4	1.5	-0.6	-1.0	0.2	1.7	1.6
S27 TEMPERATURE	STATION 27 (0-175 M)	-0.5	-2.2	-0.9	-1.2	-0.3	-0.7	1.5	-0.4	-0.4	0.5	0.5	0.6	0.1	0.5	1.8	1.1	2.1	-0.3	0.2	-0.1	1.9	2.8
S27 SALINITY	STATION 27 (0-175 M)	1.8	-1.4	-1.6	0.2	-0.6	-0.6	-1.0	0.1	0.2	-0.3	-0.4	-0.8	0.6	0.4	-0.4	0.0	0.8	0.4	1.0	-0.4	-1.2	-1.0
MIXED-LAYER	STATION 27 (WINTER)	-0.9	-1.2	-1.0	-1.0	1.2	-1.0	0.7	0.5	-0.9	-0.3	-1.0	0.5	0.7	-0.4	1.7	0.6	1.9	0.0	-1.6	1.4	-2.5	1.0
MIXED-LAYER	STATION 27 (ANNUAL)	-1.1	-1.5	0.0	-0.1	1.1	-1.8	0.5	-0.7	-0.4	-0.3	-0.6	0.4	1.1	-0.4	2.2	0.0	0.5	1.1	0.0	1.1	-1.2	1.6
MIXED-LAYER	STATION 27 (SPRING)	-0.8	-0.8	-0.2	-0.2	0.3	-1.3	-0.5	-1.3	1.5	-1.2	-0.2	1.0	0.9	0.0	2.0	-0.7	-0.1	1.4	3.1	-1.0	0.6	1.4
STRATIFICATION	STATION 27 (ANNUAL)	-1.5	-0.4	-0.5	-1.2	-0.5	1.4	-1.6	0.2	1.0	1.3	0.4	1.3	-0.6	-0.4	-0.8	-0.1	1.1	0.4	0.8	0.0	-0.4	-2.0
STRATIFICATION	STATION 27 (SPRING)	-1.5	-0.8	-1.1	-0.3	-0.6	1.8	-0.9	0.0	1.0	0.8	-0.3	0.0	-1.1	-1.0	-0.3	0.2	0.6	0.1	-0.4	0.4	-0.7	-0.3

Temperature data obtained from thermographs deployed at 10 inshore monitoring sites during the summer months (July-Sept.) along the coast of Newfoundland (see Fig. 1 for locations) at nominal water depths of 5-10-m are shown in Table 4 as standardized anomalies and repeated in Fig. 11 as cumulative sums. The data show considerable variability about the mean, due mostly to local wind driven effects near the coast including upwelling and local summer air temperatures.

Near-shore temperatures were generally below normal during most of the 1990s, although there was considerable variability and missing data at some sites. Temperatures increased to above normal conditions in 1999 and continued above normal for several years peaking in 2006. In 2007 there was a sharp decrease with values not seen since the early 1990s with 8/9 sites reporting below normal (-0.7 to -2.1 SD) summer temperature. In 2008-10 temperatures varied about the mean with no clear pattern. In 2011 however, 8/9 sites with data again reported below normal summer upper-layer temperatures with anomalies ranging from 1-2 SD below normal. The only exception was at Hampden, White Bay where temperatures were close to 1 SD above normal.

The colder than normal conditions observed in 2011 from the thermograph deployments were consistent with the observations at Station 27 where upper layer (0-20 m) temperatures were below normal from July to September (Fig. 6b).

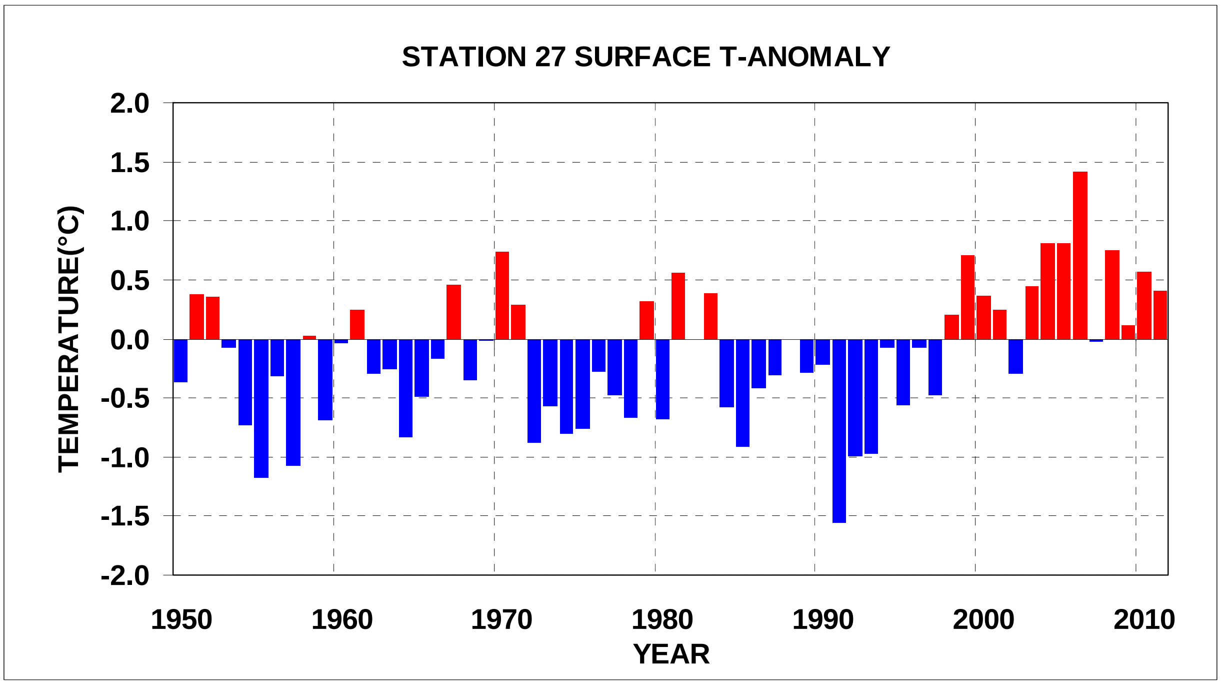


Figure 8a. Annual near surface temperature anomalies at Station 27 referenced to the 1981-2010 mean.

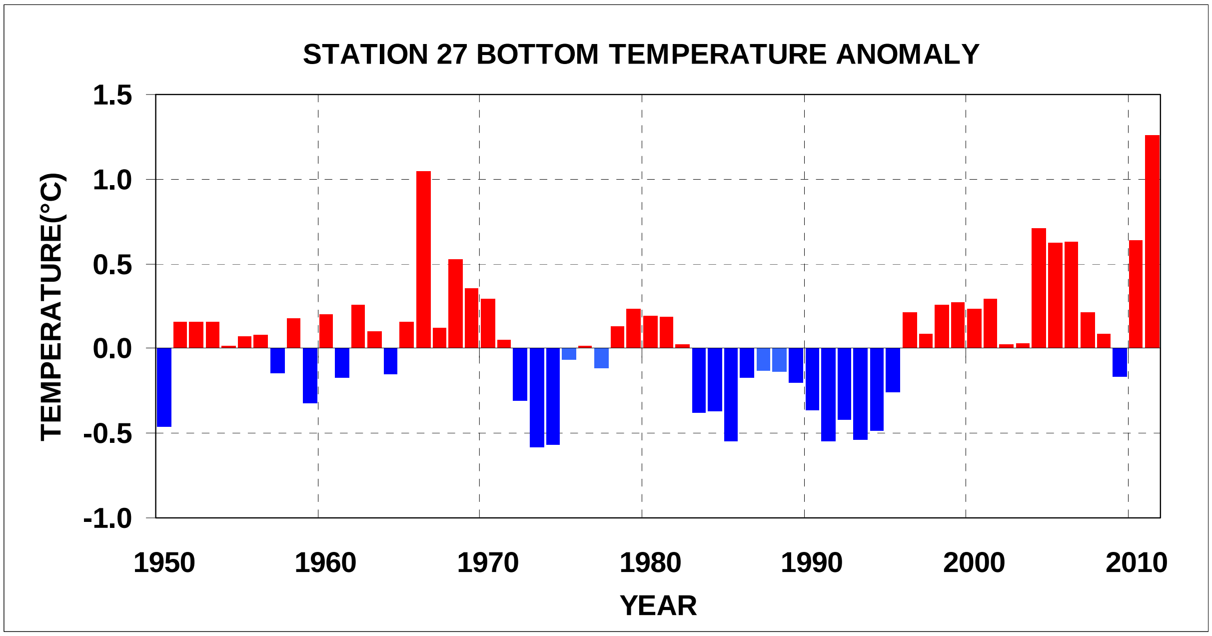


Figure 8b. Annual near bottom (176 m) temperature anomalies at Station 27 referenced to the 1981-2010 mean.

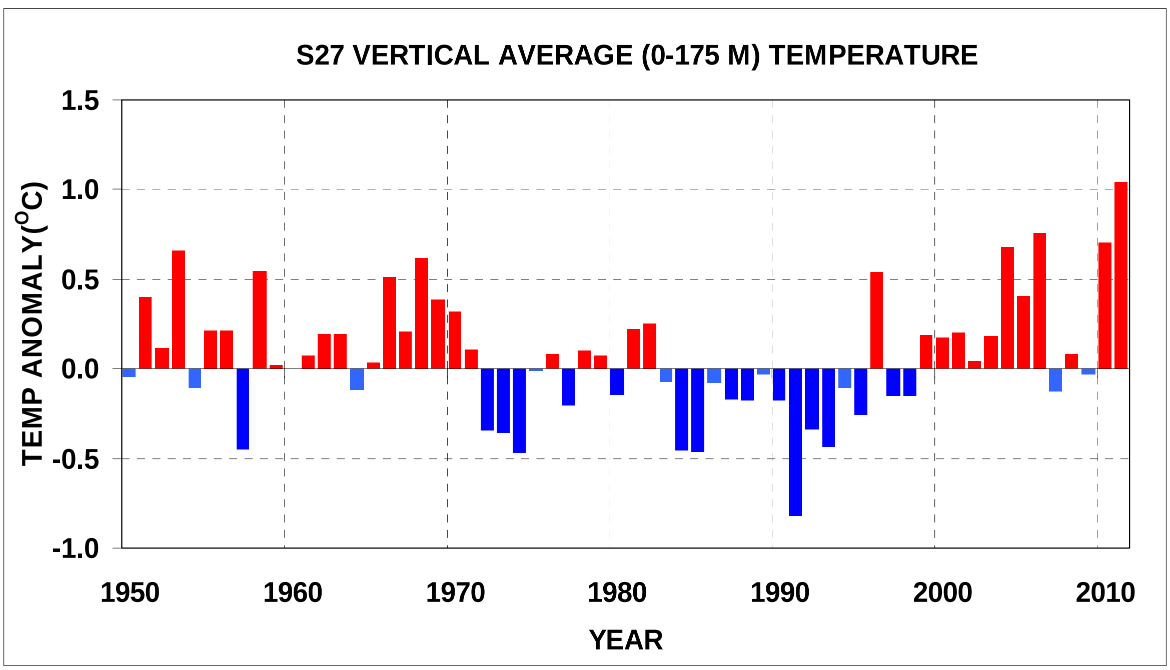


Figure 9a. Annual vertically averaged (0-175 m) temperature anomalies at Station 27 referenced to the 1981-2010 mean.

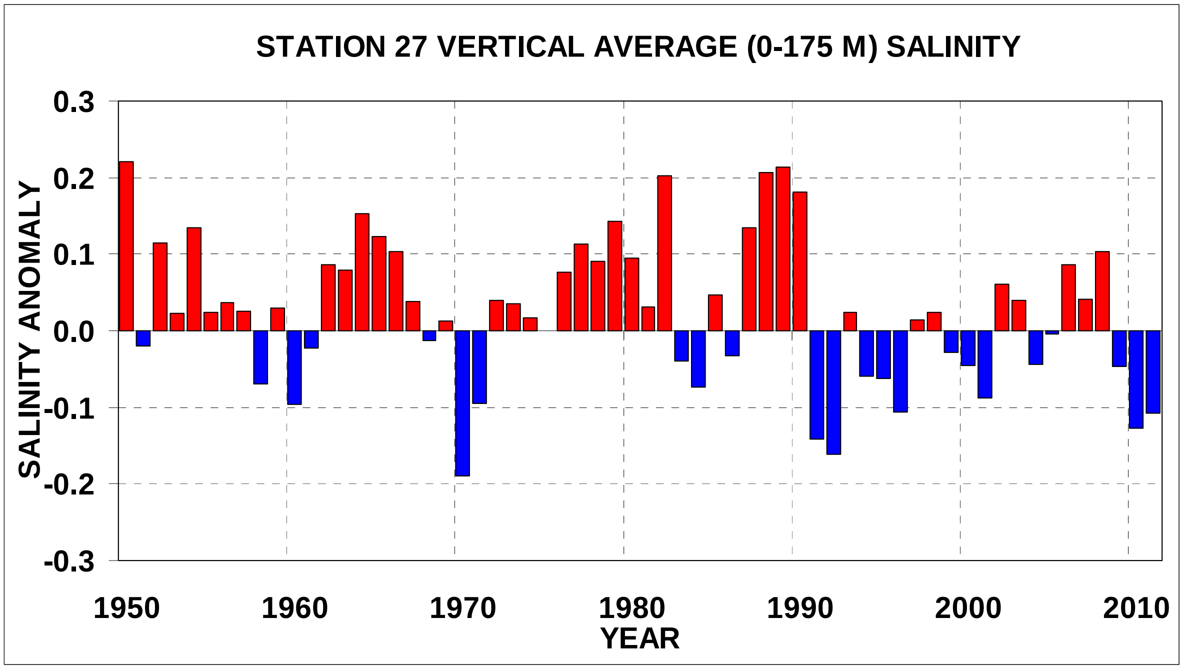


Figure 9b. Annual vertically averaged (0-175 m) salinity anomalies at Station 27 referenced to the 1981-2010 mean.

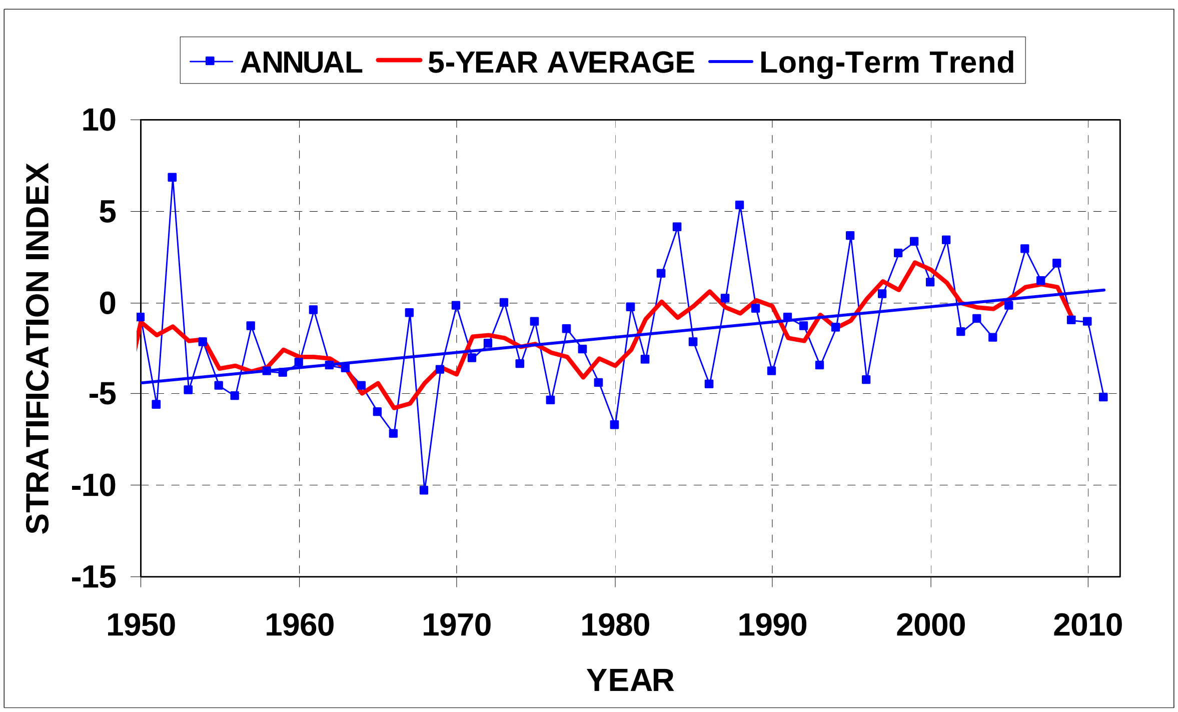


Figure 10. Annual stratification index anomalies at Station 27 referenced to the 1981-2010 mean.

Table 4. Standardized temperature anomalies derived from data collected with thermographs along the coast of Newfoundland (Fig. 1). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise the length of the time series. The grey shaded cells indicate no data.

INDEX	LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
9 M TEMPERATURE	HAMPDEN WB			-0.4	0.2	-1.5	-2.2	-0.4	-0.9	0.4	0.2	1.4	-0.9	0.5	0.3	0.8	0.9	1.4	-0.7	1.1	-1.0	0.9	0.8
10 M TEMPERATURE	COMFORT COVE NDB	1.2	-2.1	-0.8	-1.9	0.1	-1.1	0.8	-0.7	-0.1	1.0	1.2		0.8	0.9	0.0	0.4	0.0		-0.1			-1.9
10 M TEMPERATURE	CAPE FREELS									-1.4	0.2	0.1		0.3	0.9	0.4	2.0	1.4	-0.9	-0.5	-0.9	-0.4	-1.2
10 M TEMPERATURE	STOCK COVE BB	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
10 M TEMPERATURE	MELROSE									-1.0	-0.1		0.8	-0.1	1.0	-0.3	1.3	1.5	-1.3	0.5	-1.0	-1.1	-2.1
10 M TEMPERATURE	OLD BONAVENTURE		-1.7	-1.0	-0.9	2.0	0.2	0.7	0.0		-0.4	0.1	1.3	0.4	0.3	-0.3	0.7	1.2	-2.1	-0.5	0.1	-0.2	-1.8
10 M TEMPERATURE	WINTERTON									-0.6		1.0	0.3	-0.4	1.9	-0.2	0.2	1.0	-1.2	-0.9	0.5	-1.5	-2.3
5 M TEMPERATURE	BRISTOL'S HOPE	-0.8	-3.2		-0.8	0.5	0.0	0.0	-0.1	-0.8	1.0	0.7	0.6	0.0	0.9	0.2	0.9	0.9	-0.7	0.9	0.4	0.5	-1.0
10 M TEMPERATURE	UPPER GULLIES CB	-1.2	-1.3	0.7	-0.4	0.2	0.2	-0.9	-0.1	-1.1	1.2	-0.2	0.0	0.2	0.8	-0.1	1.2	1.3	-2.1	1.6	0.3	0.5	
10 M TEMPERATURE	ARNOLDS COVE PB	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

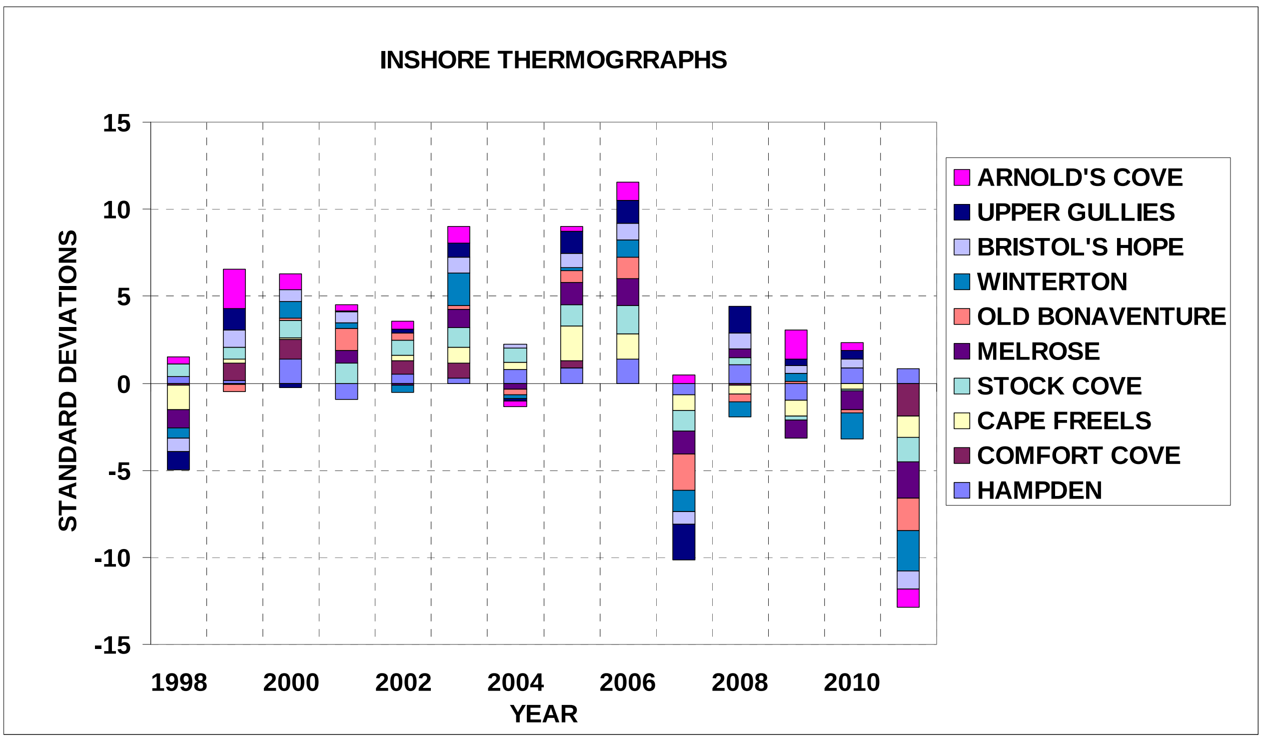


Figure 11. Standardized temperature anomalies presented as cumulative sums derived from data collected with thermographs along the coast of Newfoundland (Fig. 1). The anomalies are normalized with respect to their standard deviations over the standard base period if the data exist, otherwise the length of the time series.

STANDARD SECTIONS

Beginning in the early 1950s several countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic monitoring along sections in Newfoundland and Labrador Waters. In 1976, ICNAF standardized a suite of oceanographic monitoring stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF 1978). Beginning in 1998 under the AZMP program, the Bonavista and Flemish Cap sections are occupied during the spring, summer and fall and a section crossing the Southeast Grand Bank was added to the spring and fall monitoring surveys. Starting in the spring of 2009 two sections crossing St. Pierre Bank were added to the survey (Fig. 2a).

In 2011, St. Pierre Bank Sections were sampled in December, the Southeast Grand Bank section was sampled during April and December, the Flemish Cap section during May, July and November/December, the Bonavista section during May, July and November, the Seal Island in July and November, and the Makkovik Bank and Beachy Island sections during July (Fig. 2a). The White Bay section was not sampled during 2011.

The water mass characteristics observed along the standard sections crossing the Newfoundland and Labrador Shelf (Fig. 2a) are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1.5ºC ─ 2ºC and salinities of 31.5 ─ 33.5. Labrador Slope Water flows southward along the shelf edge and into the Flemish Pass region. This water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3º - 4ºC and salinities in the range of 34 ─ 34.75. Surface temperatures normally warm to 10º ─ 12ºC during late summer, while bottom temperatures remain <0ºC over much of the Grand Banks but increase to 1º ─ 3.5ºC 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 3º ─ 4ºC.

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

Throughout most of the year, the cold relatively fresh water overlying the shelf is separated from the warmer higher density water of the continental slope region by strong temperature and salinity (density) fronts (Fig. 12 and 13). This winter formed water mass is commonly referred to as the cold intermediate layer or CIL (Petrie et al. 1988) and its cross sectional area or volume bounded by the 0ºC isotherm is generally regarded as a robust index of ocean climate conditions on the eastern Canadian continental shelf. While the cross sectional area of the CIL water mass undergoes significant annual variability, the changes are highly coherent from the Labrador Shelf to the Grand Banks. The shelf water mass remains present throughout most of the year as summer heating and salinity changes increase the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although CIL areal extent continues to undergo a gradual decay during late summer reaching a minimum in late fall as the seasonally heated upper layers penetrates the water column.

The CIL areas and other indices based on temperature and salinity data collected along sections from southern Labrador to southern Newfoundland are displayed in Fig. 14a-c and Table 5. On the southern Labrador Shelf and south to eastern Newfoundland, temperature and salinity have been increasing since 2000, reaching near-record values in 2004 and continuing warm and salty during 2005-07. Except for the decrease in CIL temperature and the increase in its area on Hamilton Bank along the Seal Island section, this trend continued during 2008 but generally reversed in 2009. In fact, the CIL areas during the summer of 2009 increased along all sections from the Seal Island to Flemish Cap, with positive anomalies (colder conditions) reported at some sections, the first time in almost a decade (Fig. 14a-c). In 2010 and 2011 temperatures again increased significantly while salinities remained generally lower than normal. From 1990 to 1994, temperatures and salinities were significantly below normal. Farther south on the Southeast Grand Bank and St. Pierre Bank, conditions have been more variable with cold conditions observed during 1990-1994 and during the spring of 2003. During 2004 to 2006 however, ocean conditions in this area have also become generally warmer and saltier than normal, although the magnitude of the anomalies are lower than those observed farther north. During 2007-09 these conditions varied about the mean and between sections but were again above normal in 2010-11.

The CIL cross sectional area anomalies during the spring of 2011 were below normal along all sections from off Cape Bonavista to St. Pierre Bank (Table 5). Below normal CIL areas generally implies warmer-than-normal water temperatures on the continental shelf. Along the Bonavista section, the CIL area was below normal during spring, summer and fall (~1-2 SD) for the 11th consecutive year during the summer and at a record low (Fig. 14b). The overall average summer temperature along the Bonavista section decreased from 1.6 SD above normal in 2008, fluctuated slightly in 2009-10, then increased substantially (by 1.9 SD) in 2011. Average salinities along the Bonavista section have been significantly above normal since 2002, with 2008 at 2.1 SD higher than normal but decreased to below normal in 2009-11. Along the 47°N section, the summer CIL area was above normal in 2009 but in 2010 it had decreased to the 2nd lowest value in the 61-year record after 1966 and remained nearly identical in 2011.

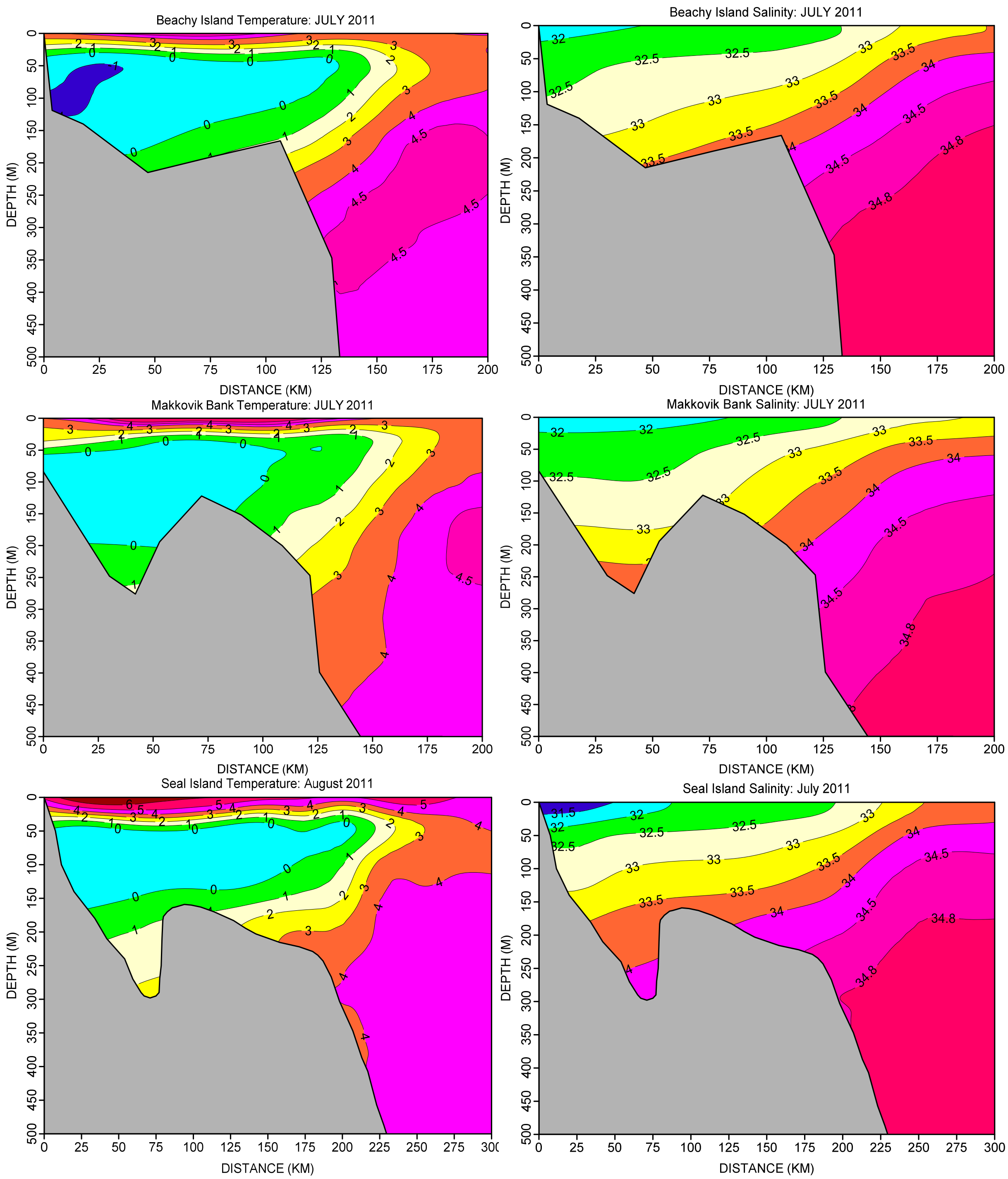


Figure 12. Contours of temperature (^{o}C) and salinity across the Labrador Shelf along the Beachy Island (Nain Bank), Makkovik Bank and Seal Island (Hamilton Bank) Sections (Fig. 2a) during the summer of 2011.

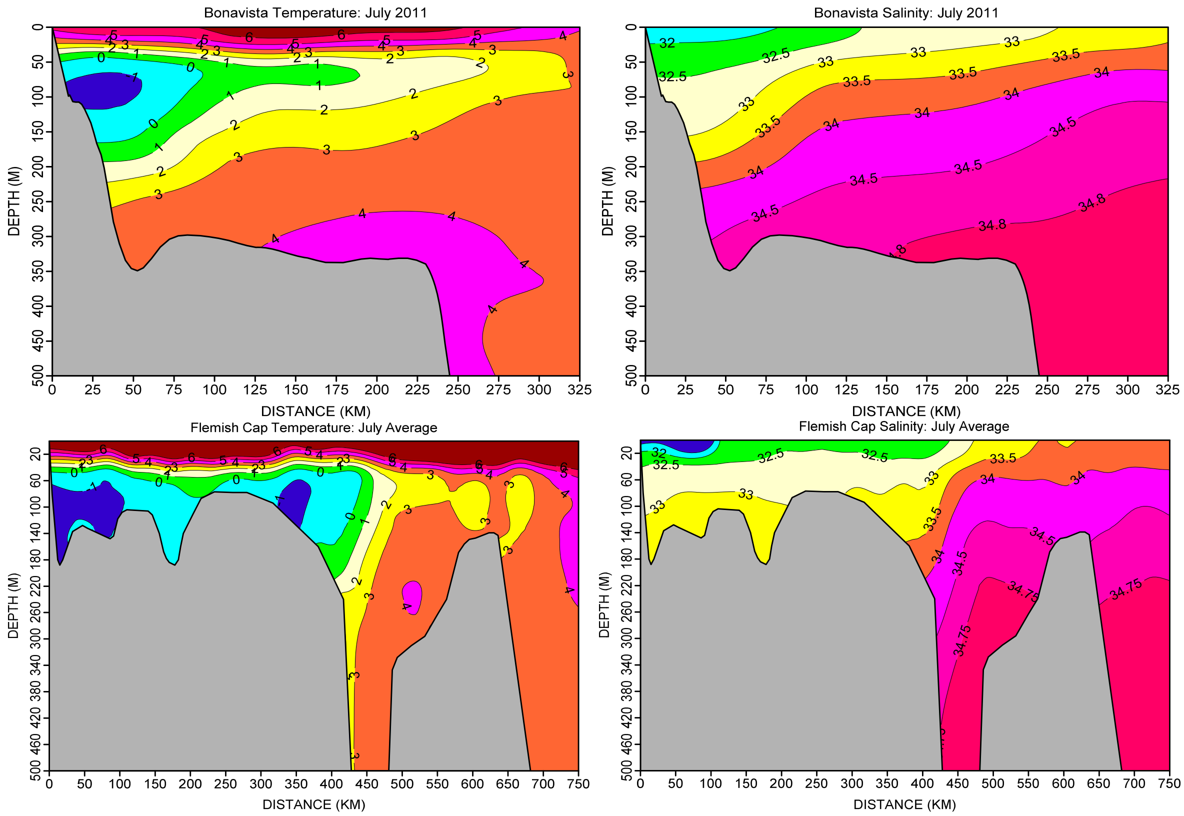


Figure 13. Contours of temperature (^{o}C) and salinity across the Newfoundland Shelf along the Bonavista and Flemish Cap Sections (Fig. 2a) during the summer of 2011.

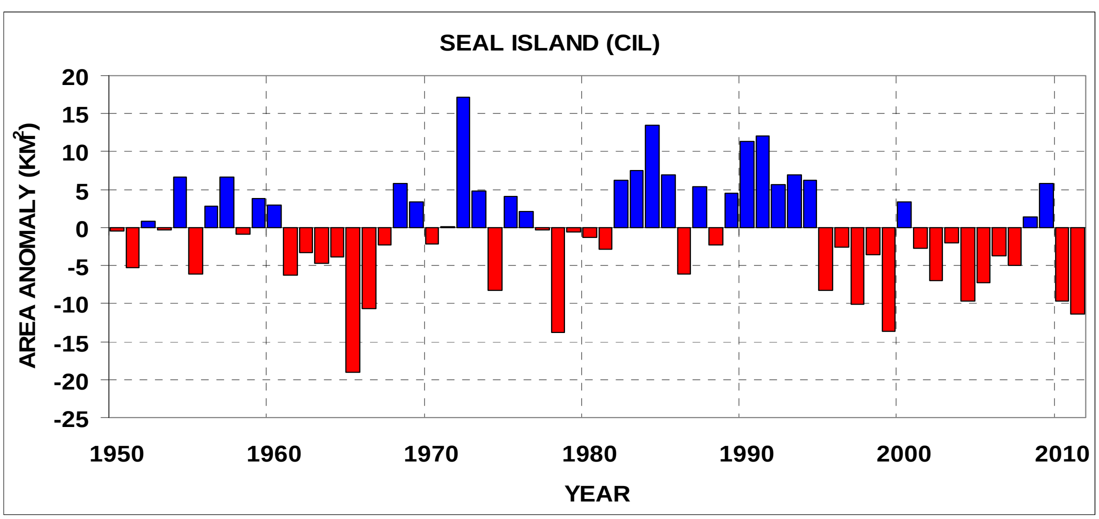


Figure 14a. Summer CIL (T<0^{O}C) area anomalies (km^2) along the Seal Island Section referenced to the 1981-2010 mean.

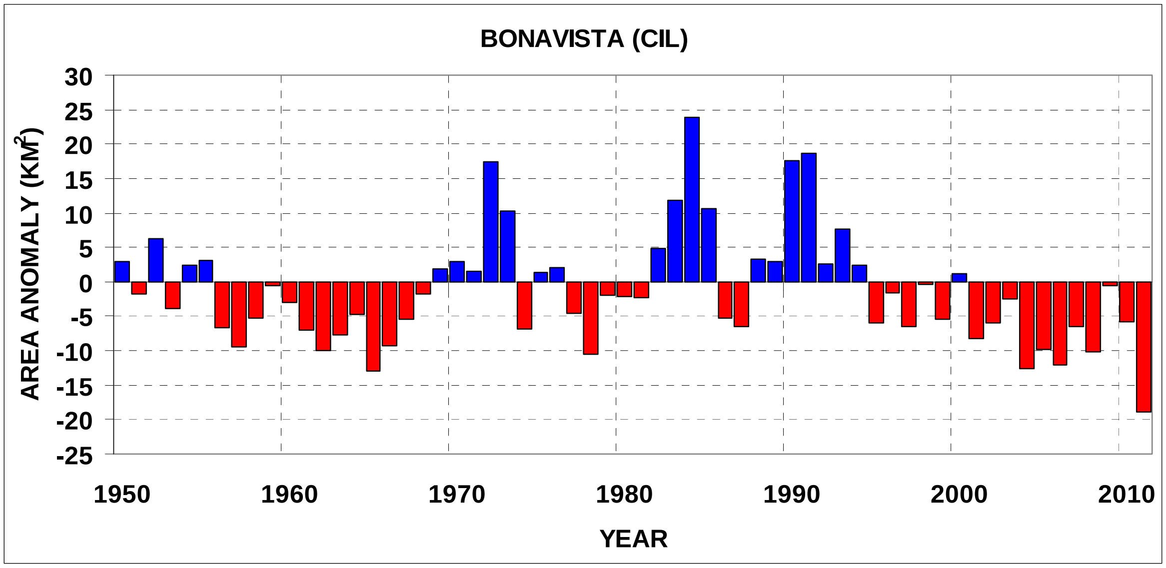


Figure 14b. Summer CIL (T<0^{O}C) area anomalies (km^2) along the Bonavista Section referenced to the 1981-2010 mean.

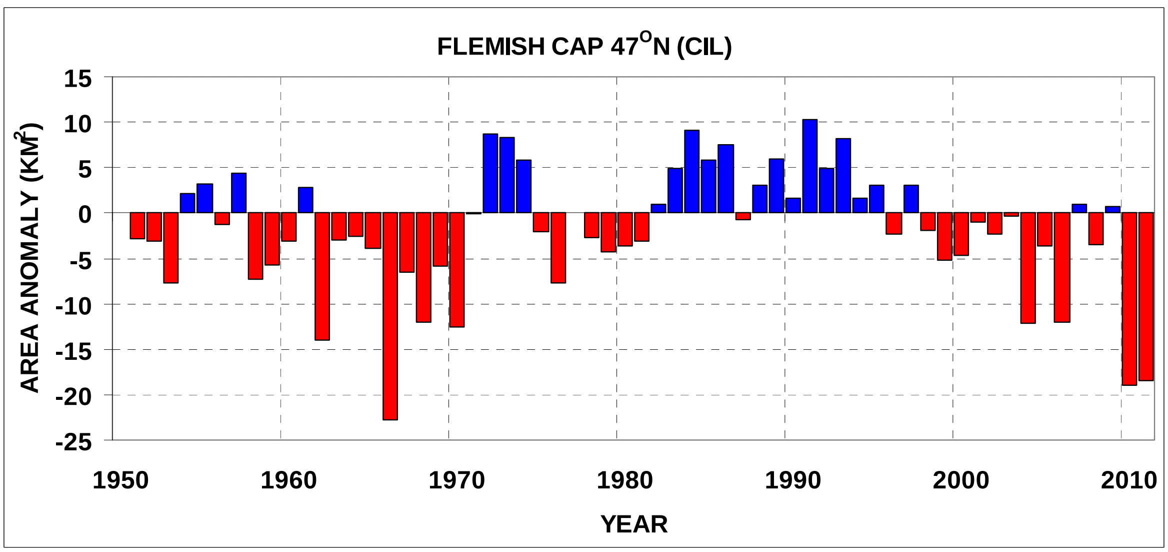


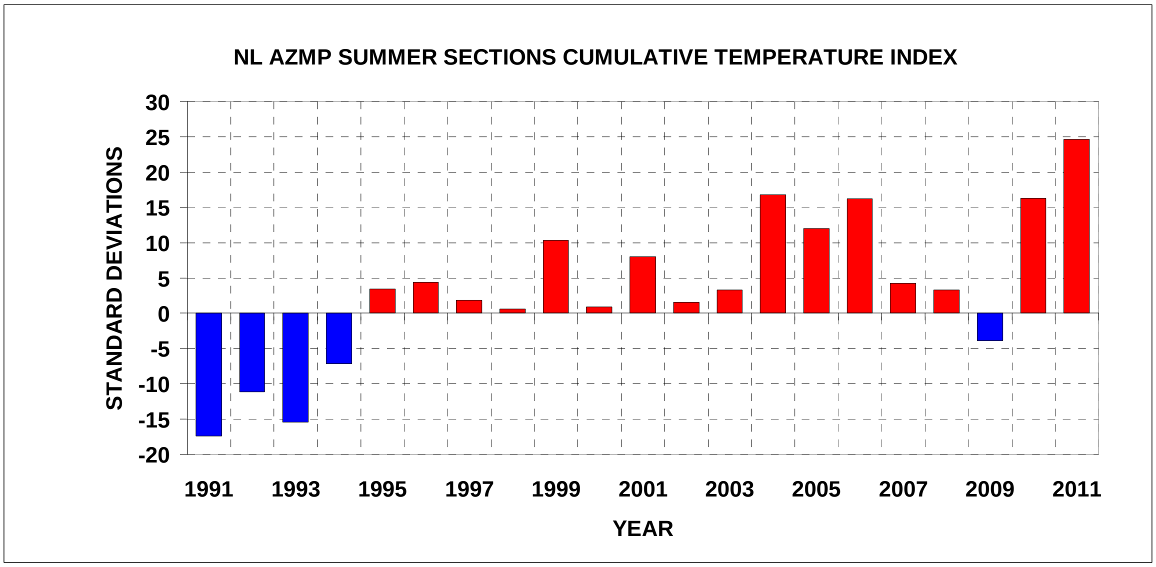
Figure 14c. Summer CIL (T<0^{O}C) area anomalies (km^2) along the Flemish Cap Section referenced to the 1981-2010 mean.

Geostrophic transports estimates of the near-surface component (referenced to 130 m) of the offshore branch of the Labrador Current were computed from temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections (Fig. 2a). Variations in the volume transport are likely due to changes in the upper layer shelf stratification as a result of changes to temperature and salinity gradients along the sections. The baroclinic transport in the offshore branch of the Labrador Current off southern Labrador (Seal Island section, Table 5) was slightly below normal during 2008 but increased significantly to above normal in 2009-11. Further south off the Grand Bank through the Flemish Pass the transport increased from >2 SD below normal in 2008, varied about the mean for 2009 and 2010 and was near the long term mean in 2011. Along the Bonavista Section however, where a significant component of the flow is in the offshore direction, there are no apparent long-term patterns in the estimates of upper layer transport in recent years with 2006-08 showing below normal values, 2009 and 2010 close to normal and 2011 was again strongly below normal (Table 5).

Table 5. Temperature and salinity anomalies and ocean climate indices derived from data collected along standard sections from southern Labrador to southern Newfoundland. The anomalies are normalized with respect to their standard deviations. The grey shaded cells indicate no data.

REGION/SECTION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	COLD-INTERMEDIATE-LAYER AREA	1.5	1.6	0.8	0.9	0.8	-1.1	-0.4	-1.4	-0.5	-1.8	0.5	-0.4	-0.9	-0.3	-1.3	-1.0	-0.5	-0.7	0.2	0.8	-1.3	-1.5
SOUTHERN	MEAN CIL TEMPERATURE	-1.5	-0.9	-1.1	-1.4	-0.8	1.7	0.5	0.6	0.3	1.6	-0.4	0.9	0.9	0.1	0.9	1.4	0.7	0.3	-0.4	-1.0	0.8	1.6
LABRADOR	MINIMUM CIL TEMPERATURE	-0.9	-1.2	-0.9	-1.3	-0.7	1.9	-0.4	-0.6	-0.4	1.0	-0.6	0.9	-0.6	0.6	2.2	0.9	1.1	-0.2	-0.7	-0.3	1.1	2.6
SEAL ISLAND	MEAN SECTION TEMPERATURE	-1.7	-1.6	-1.4	-1.4	-0.9	0.3	0.0	0.6	0.5	0.9	0.0	0.2	0.4	0.7	1.6	1.0	1.2	0.8	1.1	0.2	1.2	1.6
SECTION	MEAN SECTION SALINITY	-1.3	-1.5	0.9	-0.7	-1.0	0.6	-0.7	0.6	0.1	0.7	-1.0	0.1	1.1	-0.1	1.3	0.6	0.4	0.0	-0.2	-0.3	-0.2	-1.0
(SUMMER)	INSHORE SHELF SALINITY	-0.1	-1.1	0.9	1.0	-0.8	0.6	-0.8	0.5	0.3	1.0	-1.4	0.1	0.5	0.0	0.0	1.1	0.2	0.1	0.4	-0.5	-2.4	-0.8
	LABRADOR CURRENT TRANSPORT	0.1	0.3	0.7	-2.0	-1.0	-0.1	0.3	0.0	0.6	-0.6	0.4	0.6	1.0	0.9	0.5	1.0	0.4	-0.1	-0.4	1.6	0.8	0.7
	COLD-INTERMEDIATE-LAYER AREA	2.0	1.2	1.3	1.1	1.3	-0.5	0.1	-0.3	-0.8	-0.9	0.4	-0.4	-0.8	-0.3	-1.8	-1.1	-1.7	-0.9	-0.4	0.6	-0.9	
NORTHEAST	MEAN CIL TEMPERATURE	-1.4	-0.8	-0.9	-1.3	-0.6	0.2	0.2	-0.5	0.2	1.4	-0.4	0.5	0.8	-0.1	2.3	1.0	1.1	0.3	0.7	-0.3	0.7	
NEWFOUNDLAND	MINIMUM CIL TEMPERATURE	-0.6	-0.8	-0.8	-1.0	-0.5	-0.3	0.5	-0.4	-0.4	0.8	0.0	-0.1	0.0	0.1	3.8	0.4	1.7	0.2	0.2	0.0	0.6	
WHITE BAY	MEAN SECTION TEMPERATURE	-1.6	-1.1	-1.8	-1.5	-1.5	-0.3	-0.4	0.6	0.8	1.0	0.2	0.2	0.2	0.6	1.4	1.5	1.6	1.0	1.1	-0.5	0.9	
(SUMMER)	MEAN SECTION SALINITY	-1.1	-0.8	-0.7	-0.2	-0.8	0.4	-1.4	1.3	0.6	-0.3	-0.5	0.2	1.3	0.3	1.4	0.8	1.1	1.0	0.8	-0.9	-2.0	
	MEAN SHELF SALINITY	0.1	-0.8	-1.4	1.0	-0.9	0.1	-1.1	1.6	0.0	-1.9	-0.7	0.0	1.2	-0.5	0.9	-0.2	0.9	0.8	1.0	-0.5	-1.1	
	CIL AREA (SPRING)	2.1	1.3	0.7	0.7	1.2	-0.6	-0.3	-0.3	0.3	-0.8	0.0	-0.8	-0.2	0.1	-0.9	-1.3	-1.3	-0.5	-0.3	0.0	-1.4	-0.8
	CIL AREA (SUMMER)	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
	CIL AREA (FALL)	1.7	0.7	1.1	1.6	1.2	-0.4	-0.3	-1.0	-0.6	-1.3	0.0	-0.3	-0.8	-1.0	-1.3	-1.2	0.5	-1.0	0.7	-1.1	-1.2	-1.3
EASTERN																							
NEWFOUNDLAND	MEAN CIL TEMPERATURE (SUMMER)	-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
BONAVISTA	MINIMUM CIL TEMPERATURE (SUMMER)	-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
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-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
	MEAN SECTION SALINITY (SUMMER)	-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	-0.9
	INSHORE SHELF SALINITY (SUMMER)	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
	LABRADOR CURRENT TRANSPORT (SUMMER)	-0.2	1.9	1.9	0.5	-0.3	-0.3	0.6	0.1	-0.4	2.2	0.8	-1.3	0.5	0.9	-0.2	0.3	-1.2	-0.5	-1.9	-0.1	0.0	-2.4
	CIL AREA (SPRING)	0.8	0.8	0.7	0.9	0.7	0.3	-0.5	-0.2	-1.0	-2.1	-0.4	0.0	1.1	1.3	-1.6	-1.1	-1.7	0.9	0.4	0.7	-1.8	-2.2
GRAND BANK	CIL AREA (SUMMER)	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
FLEMISH PASS	CIL AREA (FALL)	1.1	1.4	0.4	0.5	1.5	-0.2	-0.1	-0.2	0.4	-1.8	0.3	0.1	-0.6	-0.5	-2.0	-0.6	-0.7	-0.2	0.3	-1.5	-2.2	-2.5
FLEMISH CAP																							
	MEAN CIL TEMPERATURE (SUMMER)	-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
47 ^{O}N	MINIMUM CIL TEMPERATURE (SUMMER)	-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
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-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
	MEAN SECTION SALINITY (SUMMER)		-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
	INSHORE SHELF SALINITY (SUMMER)		-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
	LABRADOR CURRENT TRANSPORT (SUMMER)		-0.2	0.9	0.3		0.6	-0.3	0.0	0.7	-0.5	0.6	0.7	0.9	1.9	0.6	0.6	-0.2	0.4	-2.3	0.6	-0.8	-0.1
	CIL AREA (SPRING)	1.3	1.5	0.3	-0.2	-0.4	-0.8	-0.8	-0.2	-0.5	-0.8	-0.7	-0.2	0.6	2.5	-0.8	-0.9	-1.3	0.4	0.7	0.4	-1.1	-1.7
	MEAN CIL TEMPERATURE (SPRING)	-0.2	-0.4	-0.4	-1.6	-0.9	-1.4	0.2	0.0	0.4	-0.6	0.5	1.1	0.5	0.0	1.9	0.6	2.3	0.0	-0.7	-1.5	1.8	
SOUTHEAST	MEAN TEMPERATURE (SPRING)	-1.5	-1.1	-0.6	-0.2	0.0	-0.2	0.3	0.1	0.6	1.8	0.5	-0.9	-1.3	-2.1	0.2	0.0	0.2	-0.7	-0.9	0.2	-0.2	
GRAND BANK																							
SECTION	CIL AREA (FALL)	-0.5	2.0	-0.4	1.0	2.9	1.6	-0.5	-0.5	-0.3	-0.6	-0.3	-0.4	-0.6	-0.5	-0.7	-0.4	-0.4	-0.2	0.3	-0.8	-0.7	0.8
		-1.5	0.4	-1.0	0.1	-0.5	1.5	0.3	-1.3	-1.2	0.2	-0.1	-0.3	-1.3	-1.5	1.6	0.9	0.9	0.7	0.1	1.1	1.0	3.9
		-1.1	-0.5	-1.5	-0.5	-0.7	1.1	-0.7	-0.1	1.8	1.9	1.2	0.5	-0.5	-0.5	0.3	-0.4	1.2	-0.7	0.0	-1.6	0.8	0.3
	CIL AREA				1.4	1.1	0.5	-1.0	1.3	-0.8	-1.1	-1.1	0.7	0.0	1.4	-1.0	-1.1		0.8	0.4	-0.4	-1.1	-1.1
ST. PIERRE	MEAN TEMPERATURE (< 100 M)				-1.2	-1.0	-0.4	0.1	-1.2	0.6	1.6	1.3	-0.7	-0.4	-1.5	0.3	1.0		-0.7	0.1	1.3	1.0	1.2
BANK	MEAN SECTION TEMPERATURE				-0.7	-1.2	0.3	0.1	-0.7	0.4	1.4	1.1	-0.7	0.0	-0.9	0.1	1.0		-1.2	-1.6	1.5	1.2	1.5
SECTION	MEAN SALINITY < 100 M				1.0	-1.8	0.5	-0.8	-0.5	1.2	0.6	-1.8	1.2	-0.8	0.5	0.3	-0.6		1.5	-0.8	-0.1	0.4	-0.2
(SPRING)	MEAN SECTION SALINITY				1.5	-1.7	0.9	-0.8	-0.4	0.4	1.1	-0.4	0.0	-0.5	0.0	0.5	0.1		0.6	-2.5	0.5	0.6	0.2

A composite index derived from the temperature and salinity indices presented in Table 5 for the Seal Island, Bonavista and Flemish Cap sections sampled during the summer clearly show an increasing trend in temperature since the early 1990s, peaking during the mid-2000s, and then declining to slightly below normal in 2009 but increasing again in 2010 reaching the highest value since 1991 in 2011 (Fig. 15). The salinity composite shows mostly below normal values from 1991-2001, except 1997, then higher than normal from 2002-2008 with below normal conditions during the past 3 years. These results together with the individual time series in Table 4 indicate generally warmer and saltier conditions up to 2009. In 2009 temperature and salinity decreased to below normal the first time in several years.



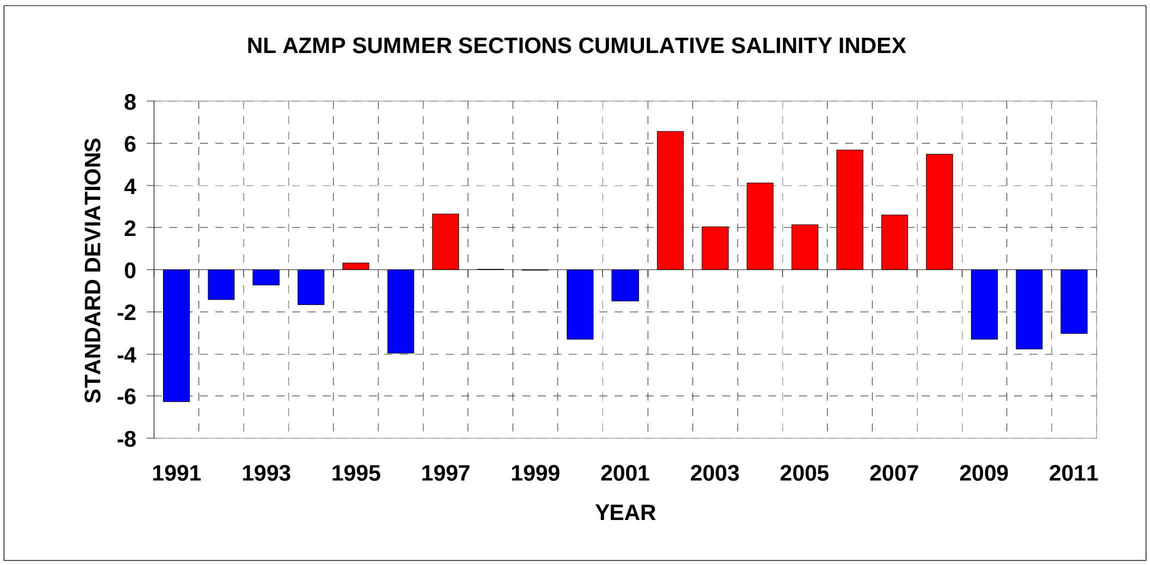


Figure 15. Standard summer section temperature (top panel) and salinity (bottom panel) composite index derived by summing the standardized temperature and salinity anomalies from Table 5.

MULTI-SPECIES SURVEY RESULTS

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday 1981). Temperature profiles are available for fishing sets in each stratum and trawl-mounted CTDs have provided profiles of salinity since 1989. These surveys provide large spatial-scale oceanographic data sets annually for the Newfoundland Shelf, during the spring from NAFO Subdivision 3Ps and Divisions 3LNO on the Grand Bank and the fall from Division 2HJ in the north to 3NO in the south. The hydrographic data collected on the surveys are now routinely used to assess the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of data products based on these data are used to characterize the oceanographic habitat. Among these are contoured maps of the bottom temperatures and their anomalies, the area of the bottom covered by water in various temperature ranges as a ‘thermal habitat’ index, spatial variability in the volume of the cold intermediate layer and water-column stratification and mixed-layer depth spatial maps. In this section, an analysis of the near-bottom temperature fields and their anomalies based on these data sets are presented for the spring and fall surveys of 2011.

Spring Conditions

Maps of bottom temperatures and their anomalies derived from the spring of 2011 multi-species survey (Fig. 2b) are displayed in Figure 16 for NAFO Div. 3PLNO. Bottom temperatures in Div. 3L were generally <1^{o}C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 2^o to >3^{o}C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO) bottom temperatures ranged from 1^{o}C – 6^{o}C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from 1^o -2^{o}C. On St. Pierre Bank temperatures ranged from 1^{o}C to 3^{o}C and up to 5^{o}C in the Laurentian Channel and areas to the west. Bottom temperature anomalies were above normal by 1^o to 1.5^{o}C over most of the region except for the Laurentian Channel where they were near normal.

Temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area together with time series of the bottom area covered by water in 1^{o}C temperature ranges are presented in Fig. 17. The increasing trend in bottom temperatures is seen in almost all areas along with the corresponding decrease in the area of the bottom covered by colder water.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990-2011 are displayed in Table 6 and Fig. 18 as normalized anomalies. In both 3Ps and 3LNO, spring bottom temperatures were generally lower than normal from 1990 to 1995 with anomalies often exceeding 1.5 SD below the mean. By 1996, conditions had moderated to near-normal values but decreased again in the spring of 1997 to colder than normal in both 3Ps and 3LNO. In 3LNO temperatures were above normal from 1998 to 2011, with the exception of 2003, with 1999, 2004 and 2011 among the warmest springs on record. The spring of 2004 had the lowest area of <0^{o}C water in Division 3L since the surveys began in the early 1970s at nearly 2 SD units below normal. In 2008-09 this area varied about the mean by 0.2 SD but in 2010 and 2011 it decreased significantly to 1.7 and 2.2 SD below normal, respectively, breaking the 2004 record (Table 6).

In Div. 3P bottom temperatures increased to above normal values by 1999 and 2000, decreased again in 2001 reaching near-record cold conditions in 2003 with bottom temperatures on St. Pierre Bank (depths <100 m) at 1.4 SD below normal, the coldest since 1990. During 2004 and 2005 temperatures again increased to above normal values with 2005 the highest on St. Pierre Bank since 2000 (1.2 SD). No data were available for 2006 but by 2007-08 spring temperatures across the 3P area returned to below normal conditions that moderated somewhat to near-normal values in 2009 with a further increase in 2010 and 2011 to >1.5 SD above normal (Table 6).

A composite index derived by summing the standardized indices presented in Table 6 shows overall temperature conditions during the spring of 2009-11 above normal after 2 years (2007-08) of near normal conditions (Fig. 18). In fact, 2011 showed a record high value since 1990.

Fall Conditions

Bottom temperature and temperature anomaly maps derived from the fall of 2011 multi-species survey (Fig. 2b) in NAFO Div. 2J, 3KLNO are displayed in Figs. 19a and 19b. Bottom temperatures in all of Div. 2J were above normal, ranging from <2^{o}C inshore to >4^{o}C at the shelf break and between 2^o -3^{o}C over most areas of Hamilton Bank. Most of the 3K region is deeper than 200 m. As a result relatively warm slope water floods through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. Bottom temperatures on these Banks and in the offshore slope regions ranged between 3.5^o - 4^{o}C, which were also above normal. Bottom temperature anomalies range from 0.5^o -1.5^o C over all of 2J and 3K in 2011.

Bottom temperatures in Divs. 3LNO generally ranged from <0.5^{o}C on the northern Grand Bank and in the Avalon Channel to 3.5^o - 4^{o}C along the shelf edge. Over the southern areas, bottom temperatures ranged from 2^o to 6^{o}C with the warmest bottom waters found on the Southeast Shoal and along the edge of the Grand Bank in Div. 3O (Fig 19a). Except for a few isolated areas temperatures were above normal over the entire 3LNO area with anomalies at 0.5^o - 2^{o}C above the long term mean (Fig. 19b).

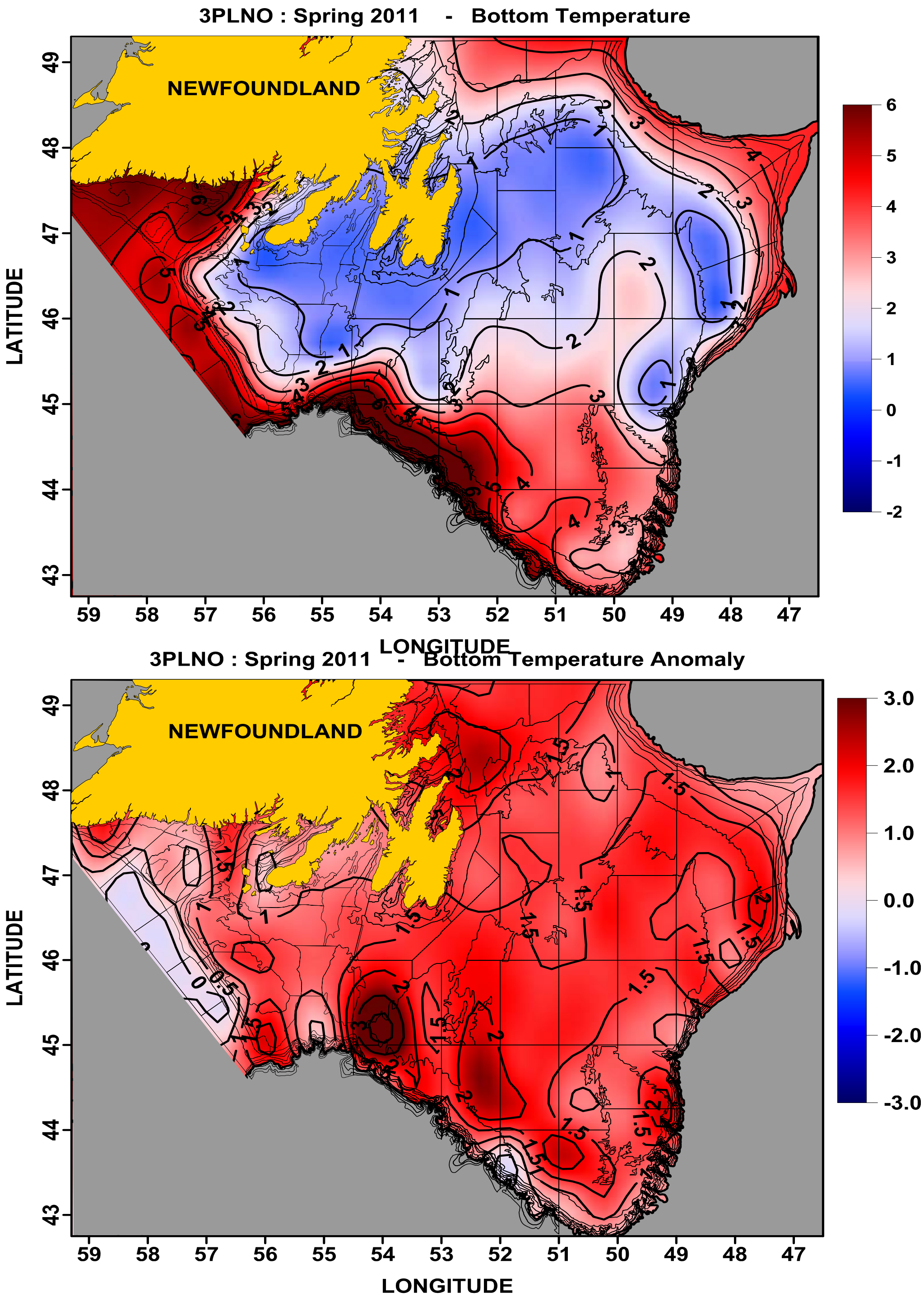


Figure 16. Contour maps of bottom temperature (top panel) and bottom temperature anomalies (bottom panel) (°C) during the spring of 2011 in NAFO Divs. 3PLNO. The anomalies are referenced to the period 1981-2010.

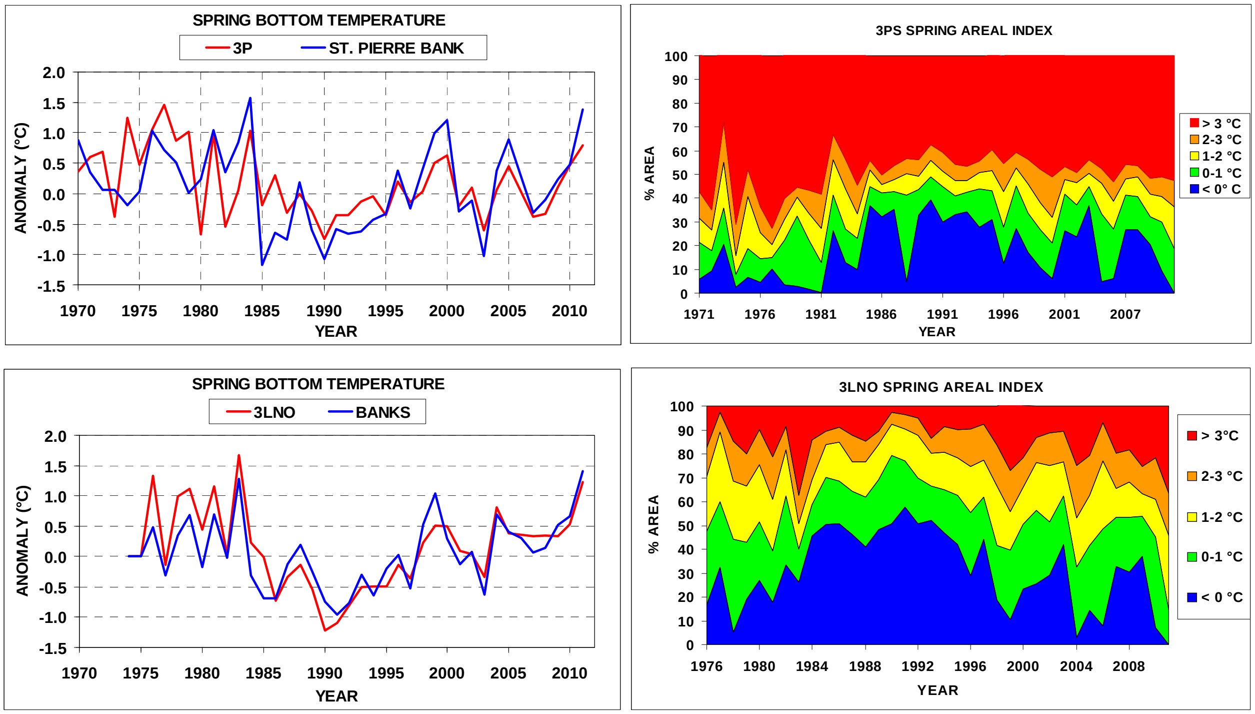


Figure 17. Bottom temperature anomalies (left panels) and the area of the bottom covered with water in different temperature bins (right panels) for the spring multi-species surveys in NAFO Divs. 3LNOP.

Table 6. Temperature indices derived from data collected during spring and fall multi-species surveys. The anomalies are normalized with respect to their standard deviations. The deep red cells without numbers indicate the absence of <0°C water in these years. The grey shaded cells indicate no data.

REGION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	BOTTOM TEMPERATURES	-0.8	-0.5	-1.3	-0.9	-0.8	-0.8	0.6	0.1	0.3	1.0	0.5	0.8	0.6	1.2	1.5	1.4	0.7	1.3	0.5	0.7	1.7	2.0
NAFO DIV. 2J	BOTTOM TEMPERATURES < 200 M	-0.3	-0.6	-1.7	-1.7	-0.9	-0.7	0.4	-0.1	-0.1	0.7	0.0	1.0	0.3	0.8	1.4	1.5	0.5	1.7	0.0	0.2	2.0	2.2
FALL	THERMAL HABITAT AREA >2°C	-1.0	-0.7	-1.1	-0.8	-0.6	0.0	0.3	0.4	0.2	0.6	0.0	0.8	0.5	0.9	1.3	1.7	0.1	2.0	-0.2	0.3	2.4	2.8
	THERMAL HABITAT AREA <0°C	0.2	-0.2	1.4	1.0	0.0	0.8		-0.5									-0.4					
	BOTTOM TEMPERATURES	-1.0	-0.7	-1.7	-1.5	-1.1	0.0	0.0	0.6	0.3	1.2	0.1	0.3	0.5	0.7	1.2	1.1	0.3	1.8	0.7	0.8	1.5	2.7
NAFO DIV. 3K	BOTTOM TEMPERATURES < 300 M	-0.9	-0.7	-1.5	-2.0	-1.6	0.1	0.1	0.7	0.8	1.1	0.0	0.2	0.6	0.9	1.3	1.2	0.0	1.9	0.0	0.2	1.4	2.7
FALL	THERMAL HABITAT >2°C	-1.4	-0.5	-1.6	-1.5	-1.1	0.0	0.1	0.7	0.7	1.4	0.4	0.2	0.8	0.8	0.9	1.2	0.3	1.7	0.4	0.3	1.6	2.3
	THERMAL HABITAT AREA <0°C	0.7	1.0	1.6	1.3	0.9	-0.8	-0.8	-0.8	-0.1	-0.8	-0.5	-0.7	-0.8	-0.7	-0.8	-0.8	-0.8	-0.8	-0.1	-0.6	-0.8	-0.8
	BOTTOM TEMPERATURES	-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3	2.2	-0.1	0.1	-0.1	0.0	0.8	1.8	0.0	0.1	-0.2	0.0	1.1	1.8
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6	2.4	0.0	-0.4	-0.6	-0.2	0.4	1.4	-0.3	-0.9	-0.5	0.0	1.7	1.2
FALL	THERMAL HABITAT AREA >2°C	-1.2	-0.5	-1.0	-1.9	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5
	THERMAL HABITAT AREA <0°C	0.4	1.4	1.5	1.8	1.7	-0.7	-0.1	0.3	-0.5	-1.3	0.6	-0.1	-0.6	0.0	-1.4	-1.1	-1.3	-0.1	0.6	-0.1	-1.1	-2.3
NAFO DIV 2J3KL	CIL VOLUME (FALL)	1.1	1.2	1.6	1.7	0.9	-0.2	-0.7	-0.7	-0.4	-1.7	-0.3	-0.6	-0.4	-0.6	-1.4	-0.7	-0.4	-0.8	-0.2	-1.0	-1.1	-1.1
	BOTTOM TEMPERATURES	-1.9	-1.7	-1.3	-0.8	-0.8	-0.8	-0.2	-0.6	0.4	0.8	0.8	0.1	0.1	-0.5	1.3	0.6		0.5	0.5	0.5	0.8	1.9
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-1.3	-1.7	-1.3	-0.5	-1.1	-0.3	0.0	-0.9	0.9	1.8	0.5	-0.2	0.1	-1.1	1.2	0.7	0.5	0.1	0.3	0.9	1.2	2.4
SPRING	THERMAL HABITAT AREA >2°C	-1.7	-1.6	-1.3	-0.6	-0.7	-0.5	-0.2	-0.4	0.6	1.8	0.7	-0.3	-0.2	-0.3	1.8	1.0	-0.3	0.7	0.5	0.9	1.1	2.5
	THERMAL HABITAT AREA <0°C	1.1	1.5	1.1	1.2	0.8	0.5	-0.3	0.7	-1.0	-1.5	-0.7	-0.5	-0.3	0.5	-2.0	-1.2	-1.7	-0.1	-0.2	0.2	-1.7	-2.2
	BOTTOM TEMPERATURES	-1.7	-0.8	-0.8	-0.3	-0.1	-0.8	0.5	-0.3	0.1	1.2	1.4	-0.5	0.2	-1.4	0.1	1.0		-0.9	-0.7	0.3	1.1	1.8
NAFO DIV. 3PS	BOTTOM TEMPERATURES <100 M	-1.5	-0.8	-0.9	-0.9	-0.6	-0.5	0.5	-0.3	0.6	1.4	1.6	-0.4	-0.2	-1.4	0.5	1.2		-0.4	-0.1	0.3	0.7	1.9
SPRING	THERMAL HABITAT AREA >2°C	-1.5	-0.8	-0.4	-0.5	-0.8	-0.6	0.3	-0.3	0.5	1.7	2.2	-0.3	-0.1	-0.6	-0.1	0.8		-0.3	-0.4	0.5	0.6	1.1
	THERMAL HABITAT AREA <0°C	1.4	0.7	0.9	1.0	0.5	0.7	-0.8	0.4	-0.4	-1.0	-1.4	0.4	0.1	1.3	-1.5	-1.4		0.4	0.4	-0.1	-1.1	-1.9

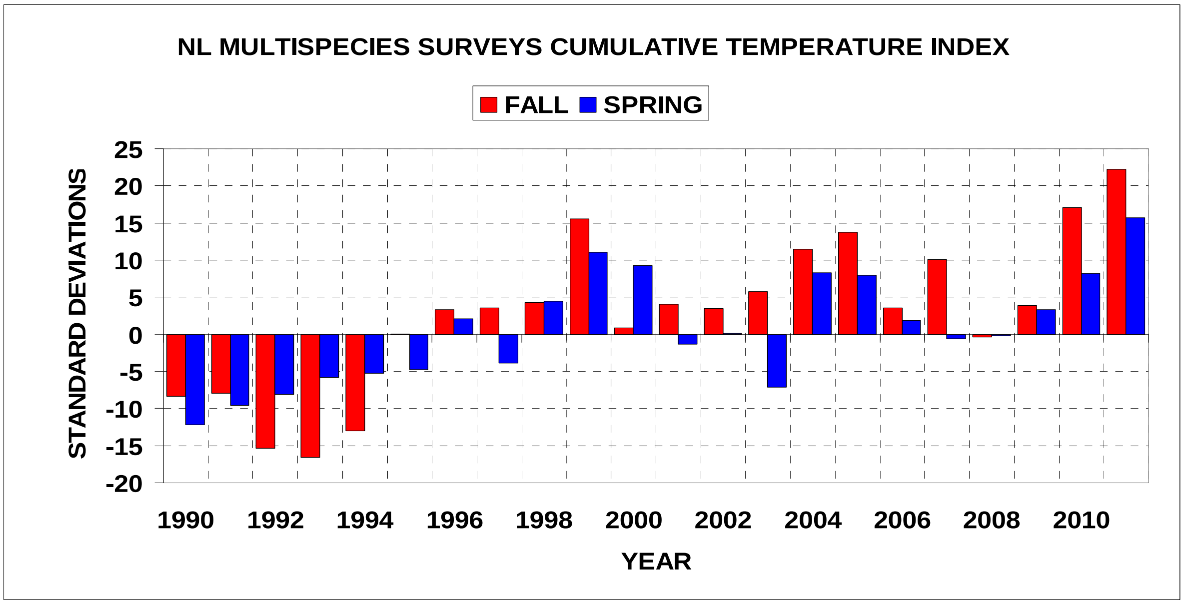


Figure 18. Composite bottom temperature index derived by summing the standardized anomalies from Table 6 for the spring and fall multi-species surveys.

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990-2011 are displayed in Table 6 and Fig. 18. In 2J, bottom temperatures were generally colder than normal from 1990 to 1995, with the coldest anomalies observed in 1993 when they declined to more than 1.7 SD units below normal on Hamilton Bank (<200 m depth). From 1996 to 2007 bottom temperatures were above normal reaching record high values in 2007 (1.7 SD) but decreased to about normal on the bank during 2008. In 2009 temperatures increased slightly over 2008 values and by 2011 they reached a new record high of 2 SD above normal. From 1996-2011 near-bottom water with temperatures <0^{o}C have been largely absent from Hamilton Bank with a corresponding increase in the area covered by water >2^{o}C.

In Div. 3K, conditions were very similar to 2J with above normal temperatures since 1996, a slight cooling in 2006, high (1.9 SD) values in 2007 and again, a slight warming in 2009 and a further increase in 2010 and 2011 to the highest in the series (+2.7 SD). In Divs. 3LNO bottom temperatures were somewhat cooler than farther north in 2J and 3K, with record high values in 1999, near normal values in 2000-03 and above normal temperatures during 2004-05. A slight cooling trend from 2006-09 was followed by a sharp increase in 2010 and 2011 (Table 6). The composite time series derived from the normalized anomalies (Table 6) show overall temperature conditions reaching a record high during the fall of 2011 (Fig. 18).

Temperature anomaly time series based on the gridded fields used to contour the bottom temperature maps for each NAFO sub-area together with time series of the bottom area covered by water in 1^{o}C temperature ranges based on the fall surveys are presented in Fig. 20. Consistent with the spring survey the increasing trend in bottom temperatures in almost all areas and the corresponding decrease in the area of the bottom covered by colder waters are readily apparent.

Finally, the total volume of CIL water remaining on the shelf after the summer heating season was calculated from the vertical temperature profiles collected during the fall multi-species surveys, usually from October to mid-December. The spatial extent of the CIL water mass exhibits considerable inter-annual and seasonal variability. It usually covers most of the NL Shelf (except for parts of 3NO) during cold years (e.g. 1993) in contrast to warm years (e.g. 2009) when most of the CIL has been eroded by summer heating and early fall wind forced mixing. This has been the case since 1995 with the CIL volume the lowest in the 30-year record during 1999 (1.7 SD below normal) and remaining significantly below normal (1 SD) in 2011, the 4th lowest since 1980 (Fig. 21).

SUMMARY

A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2011 are displayed in Table 7 as colour-coded normalized anomalies. Different climatic conditions are readily apparent from the warm and salty 1960s and early 2000s to the cold-fresh early 1970s, mid-1980s and early 1990s. Following Petrie et al. (2007) a mosaic or composite climate index was constructed from the 26 time series as the sum of the standardized anomalies with each time series contribution shown as stacked bars (Fig. 22).

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

The overall composite index clearly defines the cold/fresh conditions of the 1970s, 1980s and early 1990s, the recent increasing trend that peaked in 2006 and the 3 years of relatively cooler conditions of 2007-09. In 2010 the composite index increased sharply to the 2nd highest in the 61-year time series. In 2011 it was very similar to 2010, the 4th highest in 62 years. During 2011, 73/85 environmental time series presented in Tables 2-6 indicate a warming climate with saltier water and less CIL and sea-ice, only 5 of these were not significant and were within 0.5 SD of normal.

Highlights for 2011:

- 73/85 environmental indices analysed indicated warmer temperatures, saltier water, less CIL and sea-ice, and only 5 of these were not considered significant (within ±0.5 SD).
- The above normal air temperatures experienced over the Northwest Atlantic in 2010 decreased significantly in 2011, but remained above normal by <1 SD
- The annual sea ice extent on the NL Shelf remained below normal for the 16th consecutive year reaching a record low.
- Only three icebergs were detected south of 48°N on the Northern Grand Bank, compared to one in 2010, substantially fewer than the 1981-2010 mean of 767.
- Annual water column averaged temperature at Station 27 increased to a record high in 2011 at 3 SD above the long-term mean.
- Station 27 annual bottom temperatures (176 m) were also at a record high at 3.4 SD (1.3°C) above normal.
- Near-surface summer temperatures in the inshore regions along the east coast of Newfoundland were 1-2 SD below normal.
- The annual stratification index at Station 27 decreased to 2 SD below normal, the lowest since 1980.
- The area of the cold intermediate layer (CIL) water mass (<0°C) on the eastern Newfoundland Shelf was at a record low value at 2 SD below normal.
- Spring bottom temperatures across the 3Ps-3LNO region were at a record high in 2011 at about 2 SD above normal.
- Fall bottom temperatures in 2J and 3K were also at a record high value, at 2 and 2.7 SD above normal, respectively.

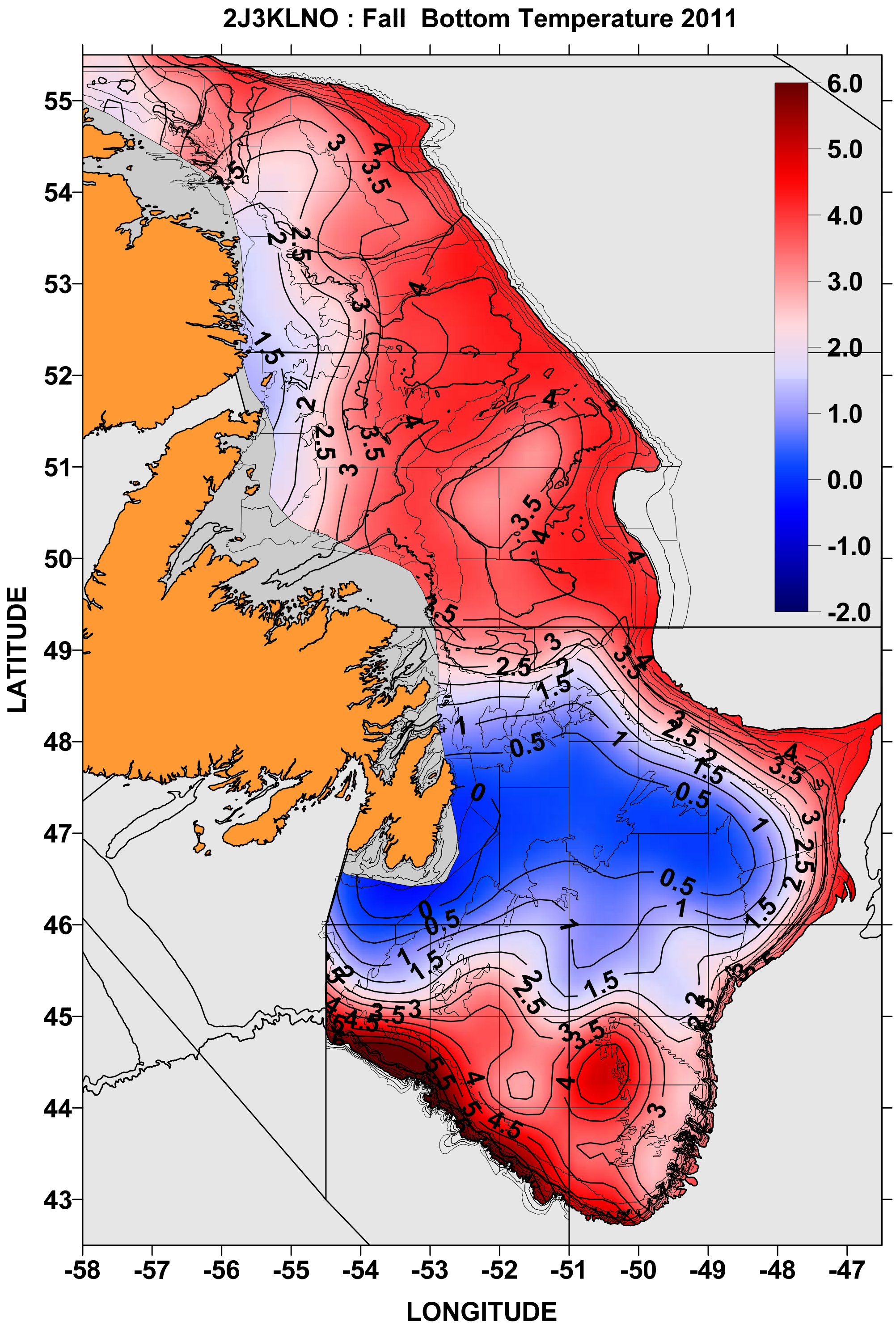


Figure 19a. Contour maps of bottom temperature (in °C) during the fall of 2011 in NAFO Divs. 2J3KLNO.

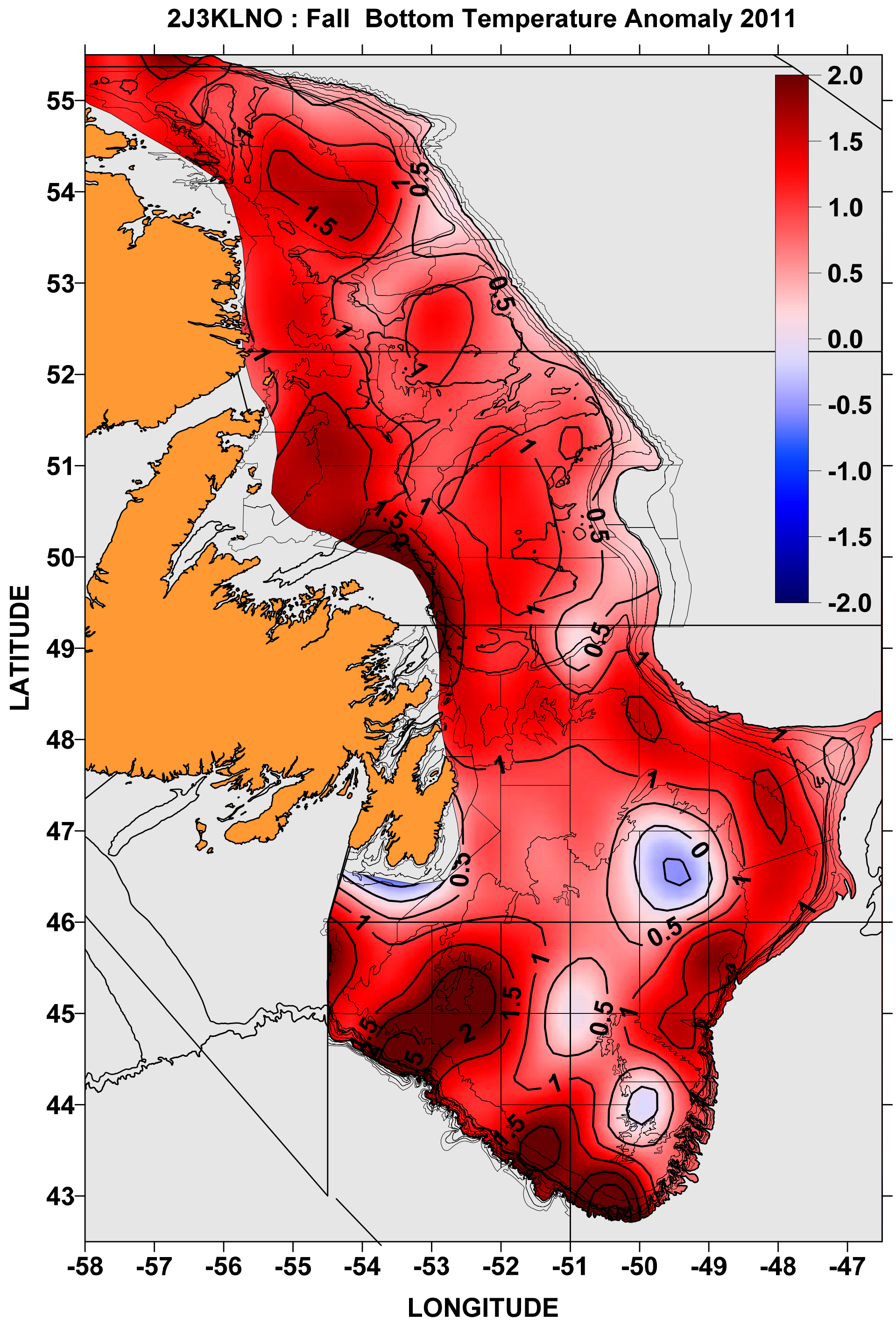


Figure 19b. Contour maps of bottom temperature anomalies (in °C) relative to the 1990-2010 mean during the fall of 2011 in NAFO Divs. 2J3KLNO.

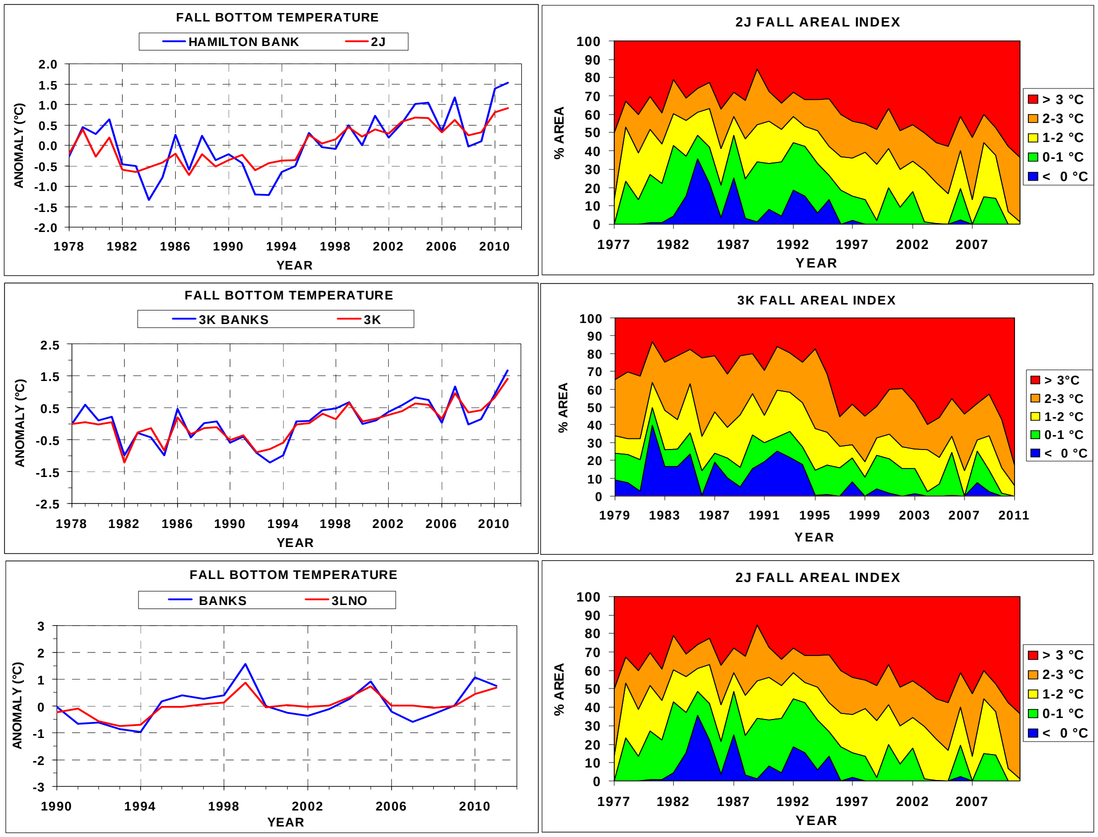


Figure 20. Bottom temperature anomalies (left panels) and the area of the bottom covered with water in different temperature bins (right panels) for the fall multi-species surveys in NAFO Divs. 2J, 3KLNO.

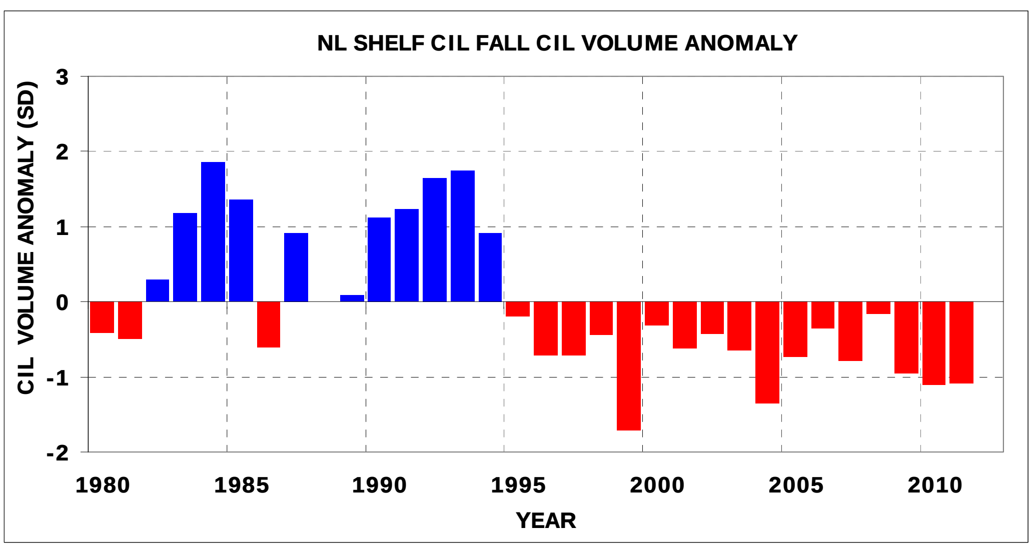
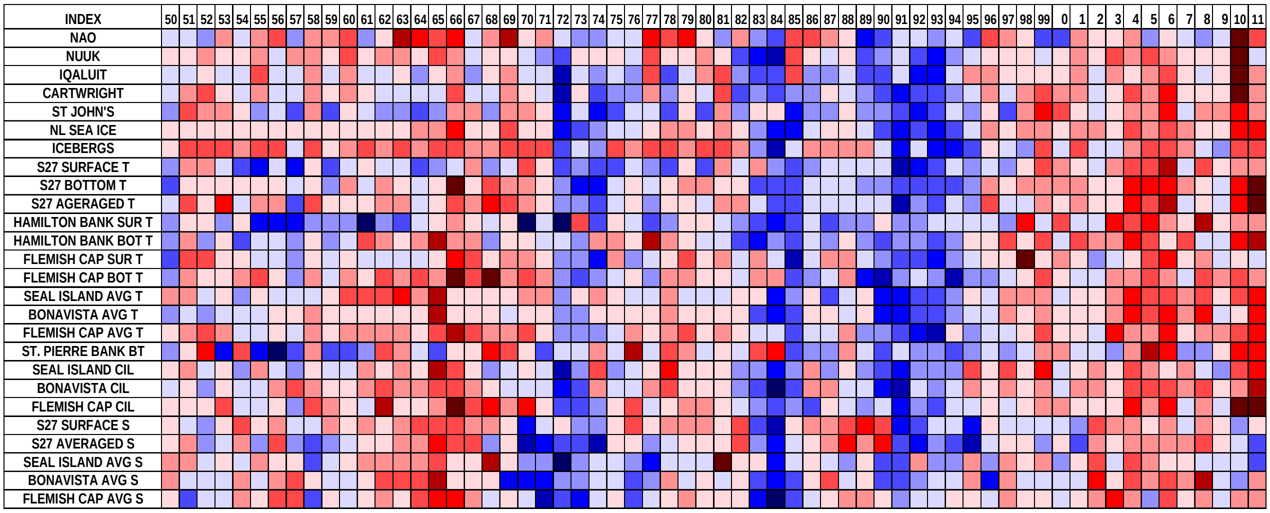


Figure 21. Time series of the CIL (<0^{O}C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species temperature data profiles.

Table. 7. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Table 1. The anomalies are normalized with respect to their standard deviations over a base period from 1981-2010.



			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

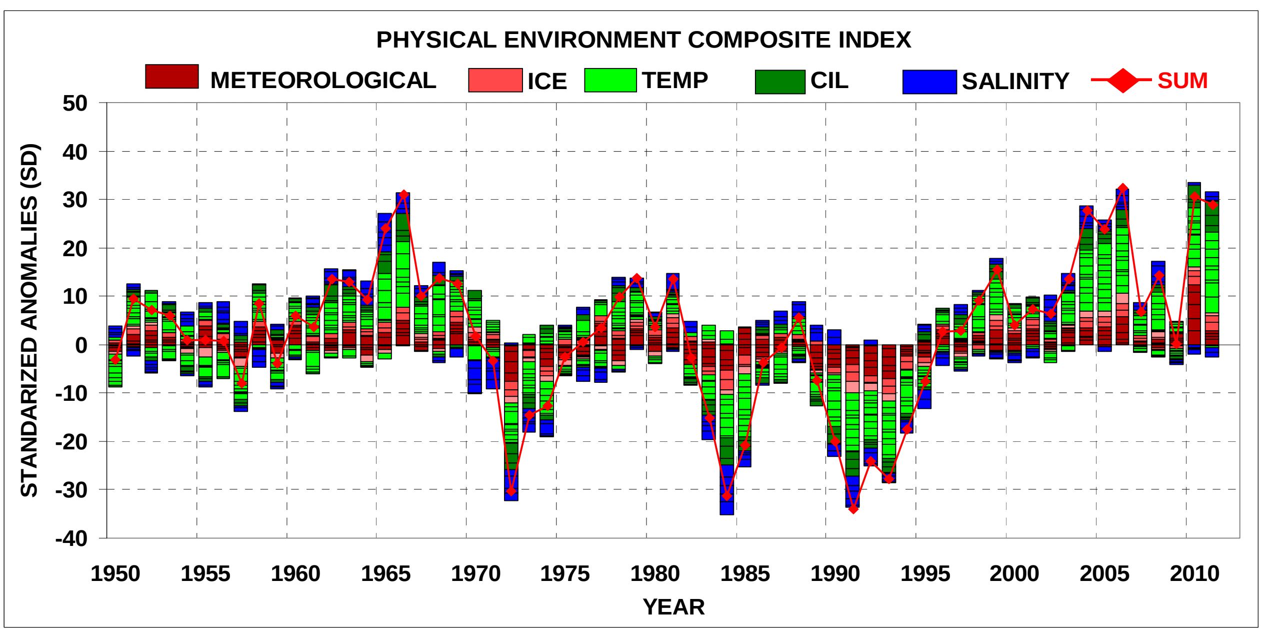


Figure 22. Composite climate index derived by summing the standardized anomalies from Table 7 together with their individual components.

ACKNOWLEDGMENTS

We thank the many scientists and technicians at the Northwest Atlantic Fisheries Centre for collecting and providing much of the data contained in this analysis and to the national Integrated Scientific Data Management (ISDM) branch in Ottawa for providing most of the historical data and Environment Canada for meteorological data. We thank Ingrid Peterson at the Bedford Institute of Oceanography for providing the NL Shelf monthly sea ice data. Special thanks are extended to Fran Mowbray for completing the Flemish Cap and Bonavista Sections after major ship related issues on the spring AZMP survey. We also thank the captains and crews of the CCGS Teleost and Hudson for two successful oceanographic surveys during 2011. We also thank David Hebert and Peter Galbraith for reviewing the document.

REFERENCES

Colbourne, E., Craig, J., Fitzpatrick, C., Senciall, D., Stead, P., and Bailey, W. 2011. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/089. iv + 31p.

Colbourne, E. B., Fitzpatrick, C., Senciall, D., Stead, P., Bailey, W., Craig, J. and Bromley, C. 2005. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/014, 36 p.

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

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.

Galbraith, P.S., Chassé, J., Gilbert, D., Larouche, P., Brickman, D., Pettigrew, B., Devine, L., Gosselin, A., Pettipas, R.G. and Lafleur, C., 2012. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/023. iii + 85 p.

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

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

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

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

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

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