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An Assessment of the Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2009

by

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ABSTRACT

The North Atlantic Oscillation index for 2009 was about normal (+0.1 SD) and as a consequence, outflow of arctic air masses to the Northwest Atlantic during the winter (Dec.-Feb.) return to normal conditions. This resulted in a slight increase in air temperatures throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland relative to 2008. Sea-ice extent and duration on the Newfoundland and Labrador Shelf increased in 2009 but remained below average for the 15th consecutive year, although it was the most extensive since 1994 during the spring. Local water temperatures on the Newfoundland and Labrador Shelf continued a slight cooling trend but remained above normal in some areas in 2009. Salinities, which were lower than normal throughout most of the 1990s, have experienced a general increasing trend during the past 8 years. At Station 27, the depth-averaged annual water temperature decreased from the record high observed in 2006 to about 0.4 SD above normal in 2009. Annual surface temperatures at Station 27 also decreased from the 64-year record of 1.7°C (3 SD) above normal in 2006 to about 0.4°C (0.7 SD) above normal in 2009. Bottom temperatures at Station 27 were slightly below normal in 2009 the first time since 1995. The area of the Cold-Intermediate-Layer (CIL) water mass with temperatures <0°C on the eastern Newfoundland Shelf was below normal (0.4 SD) for the 15th consecutive year while off southern Labrador it was above normal by 0.6 SD, the largest since 1994. Bottom temperatures on the Grand Banks (3LNO) during the spring were above normal by <1 SD. During the fall bottom temperatures in 2J and 3K were above normal by up to 1.5 SD while in 3LNO they were about normal. A total of 112 environmental time series were analyzed and 54 were within ±0.5 SD and are not considered significantly different from normal, 72 indicated warmer temperatures, saltier water with less CIL and sea-ice, but only 42 of these were considered significantly different than normal. A composite climate index derived from selected annual and seasonal time series ranked 34th in 60 years of observations, which represents a decreasing trend since the record high in 2006.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Fig.1) during 2009 in relation to long-term average conditions based on archived data. When possible, the long-term averages were standardized to a ‘normal’ base period from 1971 to 2000 in accordance with the recommendations of the World Meteorological Organization. The information presented for 2009 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; and, (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Fig. 2). Data from other research surveys and ships of opportunity are also used to help define the long-term means and the conditions during 2009. 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.

Time series of temperature and salinity anomalies and other derived climate indices were constructed by removing the annual cycle computed over the standard base period. 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. ‘Normal’ is defined here as the average over the base period. For shorter time series the base period included data up to 2008. Annual or seasonal anomalies were normalized by dividing the values by the standard deviation of the data time series over the indicated base periods, usually 1971–2000 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 2009 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. 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. During both 1999 and 2000 the NAO was well above normal. However, the colder-than-normal winter conditions 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 index for 2001 to 2004 was below normal indicating a reduced Arctic outflow to the Northwest Atlantic during the winter months. In 2005, the index was slightly above normal whereas in 2006, it was slightly below normal and in both cases, the spatial patterns in the SLP fields during the winter months resulted in very weak northwesterly winds over the Newfoundland and Labrador area. In 2007 to 2008 the index returned to above normal values but less than 0.5 SD, nevertheless it resulted in a slight cooling trend in air temperatures relative to 2006. In 2009 the index was about normal. The difference in SLP between Nuuk in West Greenland and Gander NL show similar patterns and correlation with local ocean conditions on the NL Shelf (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 (Fig. 3). Annual temperature at Cartwright on the mid-Labrador Coast broke a 73-year record at 2.6 SD above normal in 2006, but was only slightly above 0.7 SD in 2008 and 1 SD above normal in 2009. Other recent extremes included 1999 which saw the second highest air temperatures at Cartwright (1.8 SD above normal) and a 126 year record at St. John’s (2.5 SD above normal). The coldest overall air temperatures in the Northwest Atlantic since the early 1990s occurred in 1993, when the annual anomalies were all at least 1 SD below normal. The cumulative air temperature index was above normal over the past 15 years with a record high in 2006 (Fig. 3).

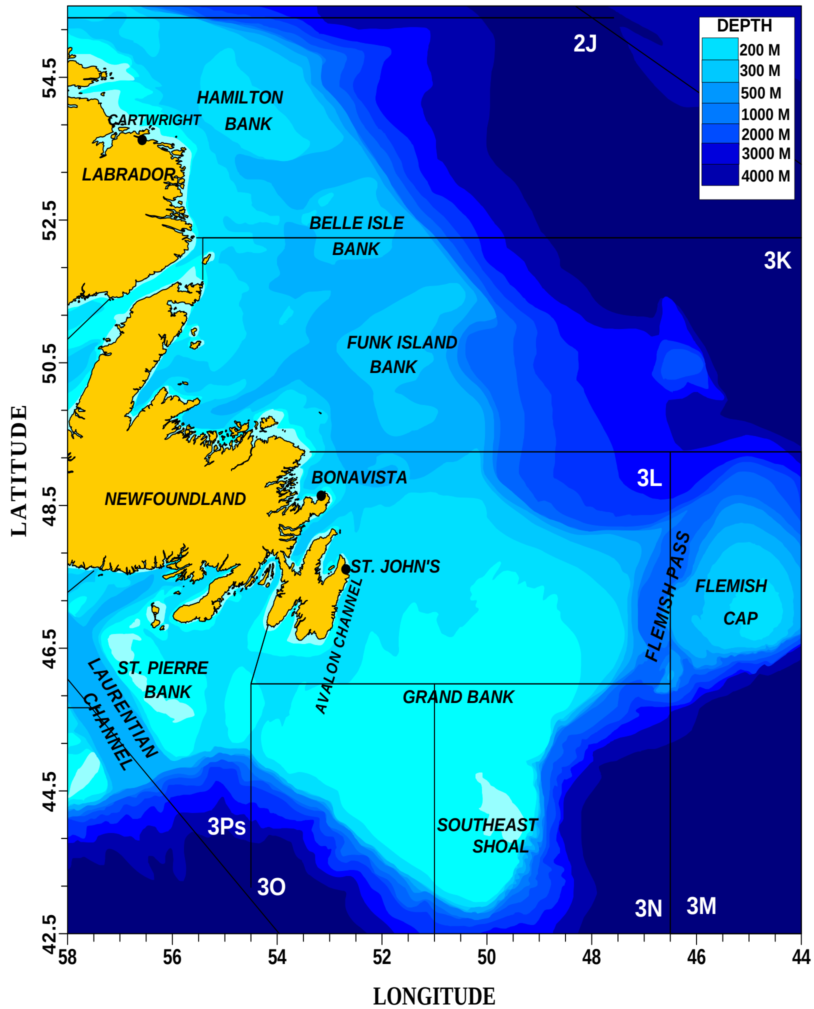


Figure 1. Maps showing NAFO Divisions and bathymetric features of the Newfoundland and southern Labrador Shelf.

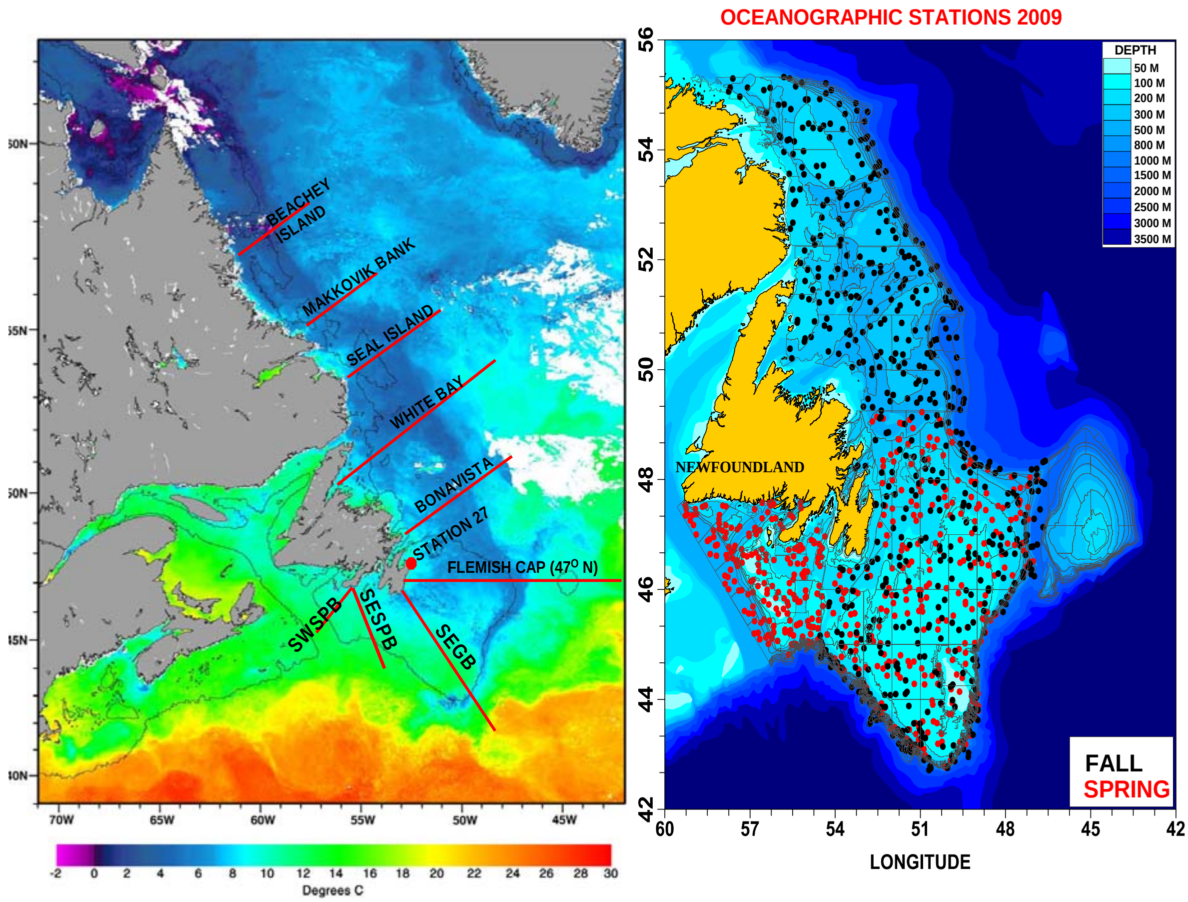


Figure 2. Maps showing summer SST, standard sections sampled during 2009, Station 27 and the positions of trawl-mounted CTD profiles obtained from spring (red dots) and fall (black dots) multi-species assessment surveys during 2009.

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 sea-ice extent (defined by at least 1/10 coverage) on the NL Shelf (between 45°-55°N) show lower than normal areas covered by ice during the winter of 2009 for the 15th consecutive year (Fig. 4, Table 2). The spring of 2006 had the lowest extent of sea-ice on the NL Shelf since record keeping began in 1963, whereas the 2007 spring value was only slightly below the long-term mean but decreased again in 2008 to near 1 SD below normal. 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 1204 icebergs drifted south of 48°N onto the Northern Grand Bank during 2009, 976 in 2008, 324 in 2007 and 0 in 2006 compared with the 110-year average of 483 and the 1971-2000 average of 759. In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48°N with an all time record of 2202 in 1984. Years with low iceberg numbers on the Grand Banks generally correspond to warmer than normal meteorological and oceanographic conditions on the NL Shelf.

A composite index derived from the meteorological and sea-ice time series presented in Table 2 indicate that 14 years of the past 2 decades were warmer than normal with less sea-ice on the NL shelf (Fig. 5).

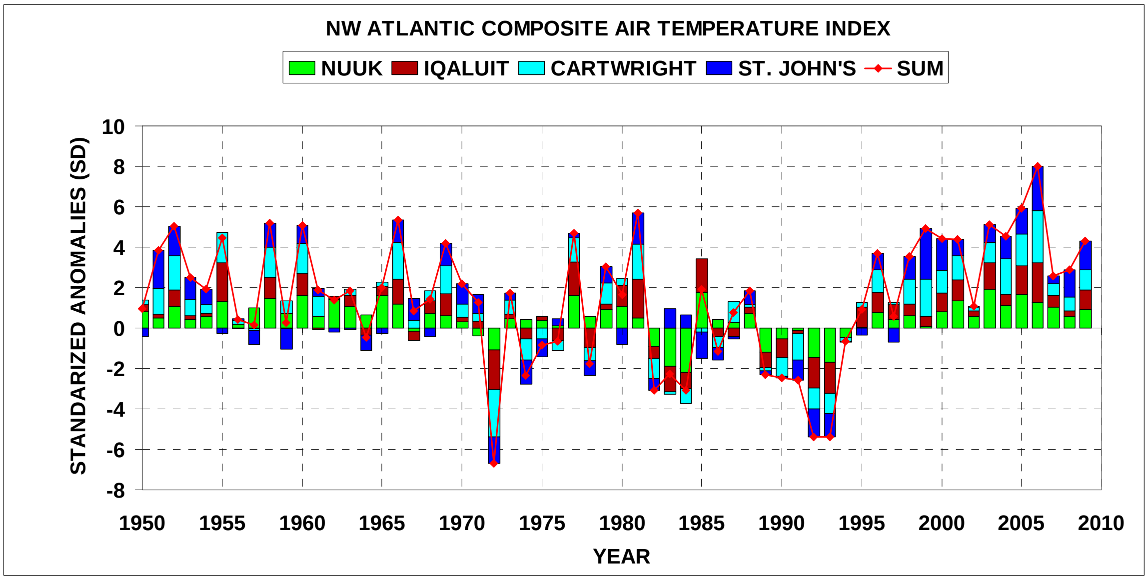


Figure 3. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright and at St. John's relative to the 1971-2000 means.

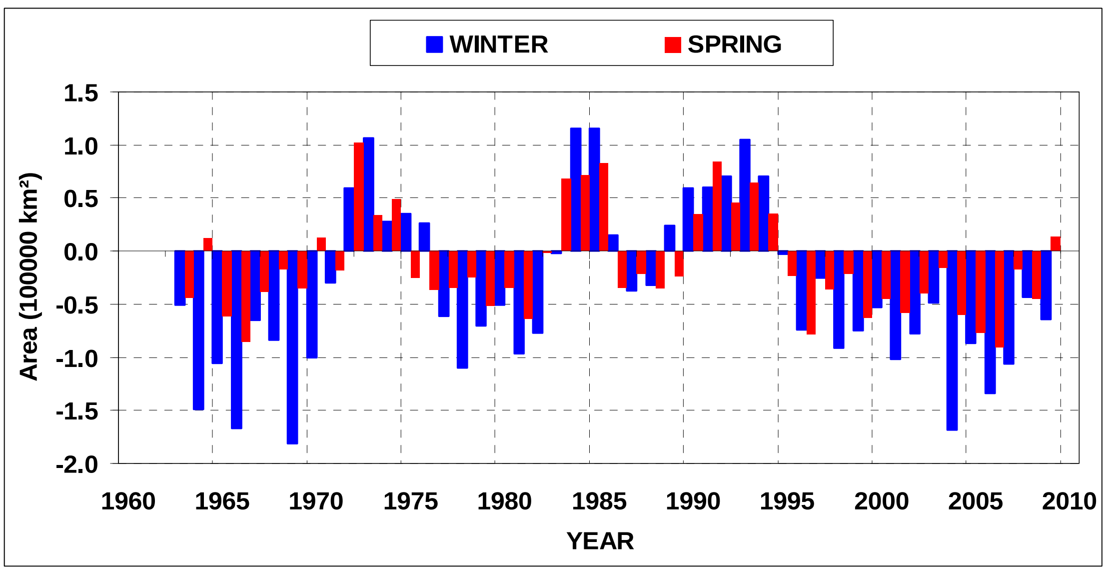


Figure 4. Sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf during winter (Jan.-Mar.) and spring (Apr.-Jun.) relative to the 1971-2000 means.

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 59 times (47 CTD profiles, 12 XBT profiles) during 2009. None were in March. Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2009 are displayed in Figure 6 and 7. The cold, near-isothermal water column during late January to late April has temperatures ranging from near 0^{o} to –1.5^{o}C. These temperature persisted throughout the year below 150 m. Upper layer temperatures warmed to >2^{o}C by mid-May and to >14^{o}C by late July and August, after which the fall cooling commenced with temperatures decreasing to 3^{o}C by early December. Temperatures were above normal in the upper water column during early winter and summer and below 60 m depth during the fall. A cold sub-surface anomaly developed during late summer and near surface during the fall.

Table 2. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic from 1990 to 2008. The anomalies are normalized with respect to their standard deviations over the indicated base period

	STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (METEOROLOGICAL AND SEA-ICE)																				
INDEX	LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SLP	(ICELAND-AZORES) NAO	1.05	0.33	0.23	0.87	0.38	1.27	-1.42	-0.64	-0.34	1.18	1.10	-0.96	-0.37	-0.39	-1.05	0.47	-0.39	0.29	0.49	0.12
	NUUK (WINTER)	-0.45	-0.06	-0.72	-1.84	-0.28	-0.77	0.88	-0.05	0.12	-0.04	0.20	0.73	-0.04	1.11	0.86	1.40	1.15	1.23	-0.60	0.79
	NUUK (ANNUAL)	-0.54	-0.11	-1.47	-1.68	-0.47	0.03	0.77	0.42	0.61	0.06	0.82	1.33	0.56	1.91	1.10	1.67	1.26	1.04	0.57	0.93
	IQALUIT (WINTER)	-0.60	-0.55	-0.80	-1.59	-0.12	0.14	0.62	0.13	-0.76	0.36	0.12	0.49	-0.65	0.25	0.37	0.84	1.45	1.31	-0.25	0.82
AIR	IQALUIT (ANNUAL)	-0.91	-0.15	-1.48	-1.54	0.01	1.02	1.00	0.72	0.58	0.53	0.91	1.05	0.29	1.31	0.54	1.40	1.98	0.58	0.28	0.96
TEMPERATURES	CARTWRIGHT (WINTER)	-1.38	-0.52	-0.59	-1.46	-1.00	-0.86	0.99	-0.40	0.97	1.61	0.70	0.55	-0.10	-0.20	1.59	0.50	1.46	0.97	-0.44	0.51
	CARTWRIGHT (ANNUAL)	-0.94	-1.30	-1.05	-1.01	-0.17	0.20	1.12	0.12	1.23	1.82	1.13	1.22	0.18	1.01	1.79	1.59	2.56	0.57	0.68	0.98
	BONAVISTA (WINTER)	-1.51	-0.58	-0.84	-1.48	-1.46	-0.20	1.19	-0.62	0.84	2.12	1.41	0.50	0.29	-0.84	1.00	0.55	1.75	0.45	0.16	0.64
	BONAVISTA (ANNUAL)	-0.12	-1.42	-1.37	-1.37	-0.16	-0.25	1.21	-0.39	1.23	2.17	1.49	1.26	0.41	1.15	1.64	1.84	2.47	0.58	1.38	1.17
	ST. JOHN'S (WINTER)	-1.38	-0.63	-0.88	-0.97	-1.11	-0.22	0.87	-0.84	0.73	2.28	1.69	-0.11	-0.11	-0.81	0.48	0.39	1.26	0.32	0.42	0.94
	ST. JOHN'S (ANNUAL)	-0.07	-1.02	-1.39	-1.14	-0.03	-0.33	0.78	-0.69	1.13	2.51	1.55	0.78	0.07	0.88	1.11	1.26	2.19	0.40	1.35	1.42
SEA ICE	NL SEA-ICE EXTENT (Annual)	0.93	1.36	1.07	1.39	0.85	-0.29	-1.35	-0.58	-0.99	-1.21	-0.88	-1.41	-1.01	-0.61	-1.98	-1.40	-1.94	-1.06	-0.78	-0.50
COVERAGE	NL SEA-ICE EXTENT (Winter)	0.86	0.87	1.02	1.52	1.02	-0.05	-1.08	-0.37	-1.33	-1.09	-0.77	-1.48	-1.13	-0.70	-2.45	-1.25	-1.95	-1.54	-0.63	-0.93
	NL SEA-ICE EXTENT (Spring)	0.67	1.63	0.90	1.27	0.70	-0.45	-1.53	-0.70	-0.42	-1.23	-0.87	-1.13	-0.77	-0.30	-1.17	-1.50	-1.77	-0.33	-0.88	0.27
ICEBERG COUNT	GRAND BANKS	0.05	1.77	0.17	1.45	1.47	0.98	-0.22	0.37	0.91	-1.07	0.12	-0.98	0.17	0.25	-0.72	-1.09	-1.11	-0.63	0.32	0.65

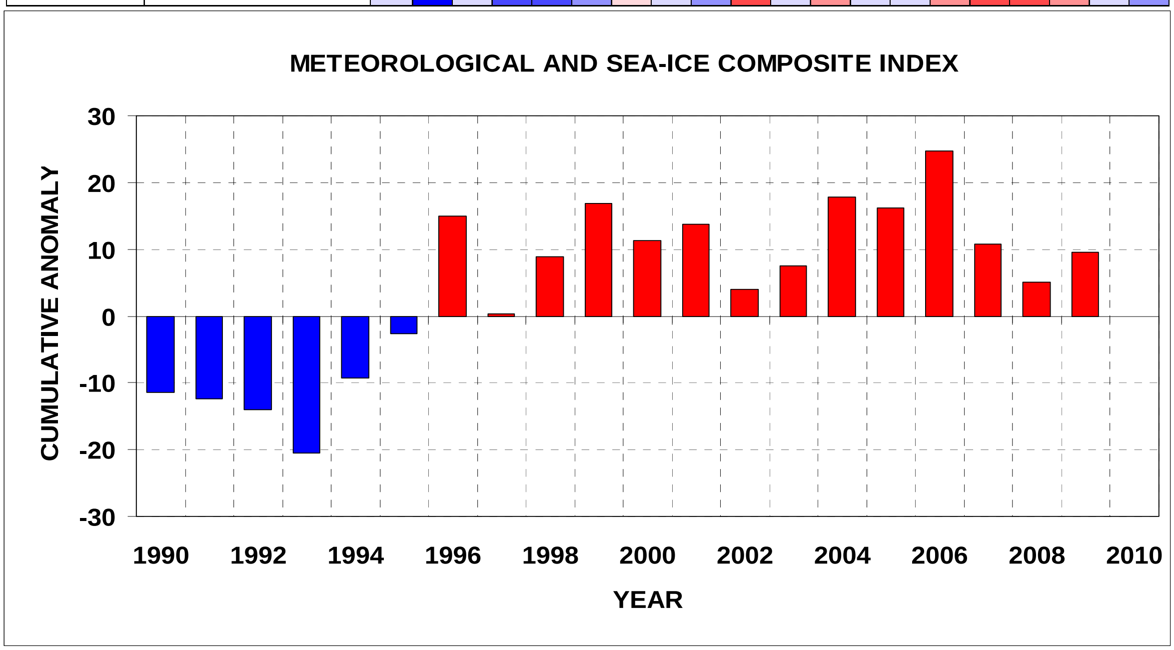


Figure 5. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Table 2.

Upper layer salinities reached maximum values in late winter and early spring (>32.2) and decreased to <31.2 by early August. These were below normal during late March to early May. Below 100 m, salinities ranged from 32.4 - 33 throughout the year, slightly below normal. 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 2009 this effect was slightly diminished as indicated by the positive salinity anomalies at shallow depths from August to December.

In general, Station 27 temperatures were below normal from 1990 to 1995, reaching minimum values in 1991 when they dipped to 2-3 SD below normal (Table 3). The annual surface temperatures at Station 27 have been above normal since 2002 (Figure 8), reaching a 61-year high of 3.2 SD above their long-term mean in 2006, decreased to <0.5 SD above normal in 2007, 1.9 SD above normal in 2008 and decreasing to +0.7 SD in 2009. Bottom temperatures at Station 27 were above normal from 1996-2008 but have decreased from the 3rd highest rank in 2006 (+2.7 SD) to slightly below normal in 2009. Vertically averaged temperatures over various depth ranges also set record highs >3 SD above normal in 2006, decreased significantly in 2007, but remained above normal in 2008-09 but only slightly in 2009 (Figure 9, Table 3). Annual surface salinities at Station 27 decreased from +0.6 SD in 2008 to about 0.3 SD above normal in 2009. In 2009 the averaged values over various depth ranges decreased compared to 2008 values. Upper-layer salinities during the past 7 years have ranged from near-normal to saltier-than-normal in contrast to the mainly fresher-than-normal values that dominated most of the 1990s (Figure 9, Table 3).

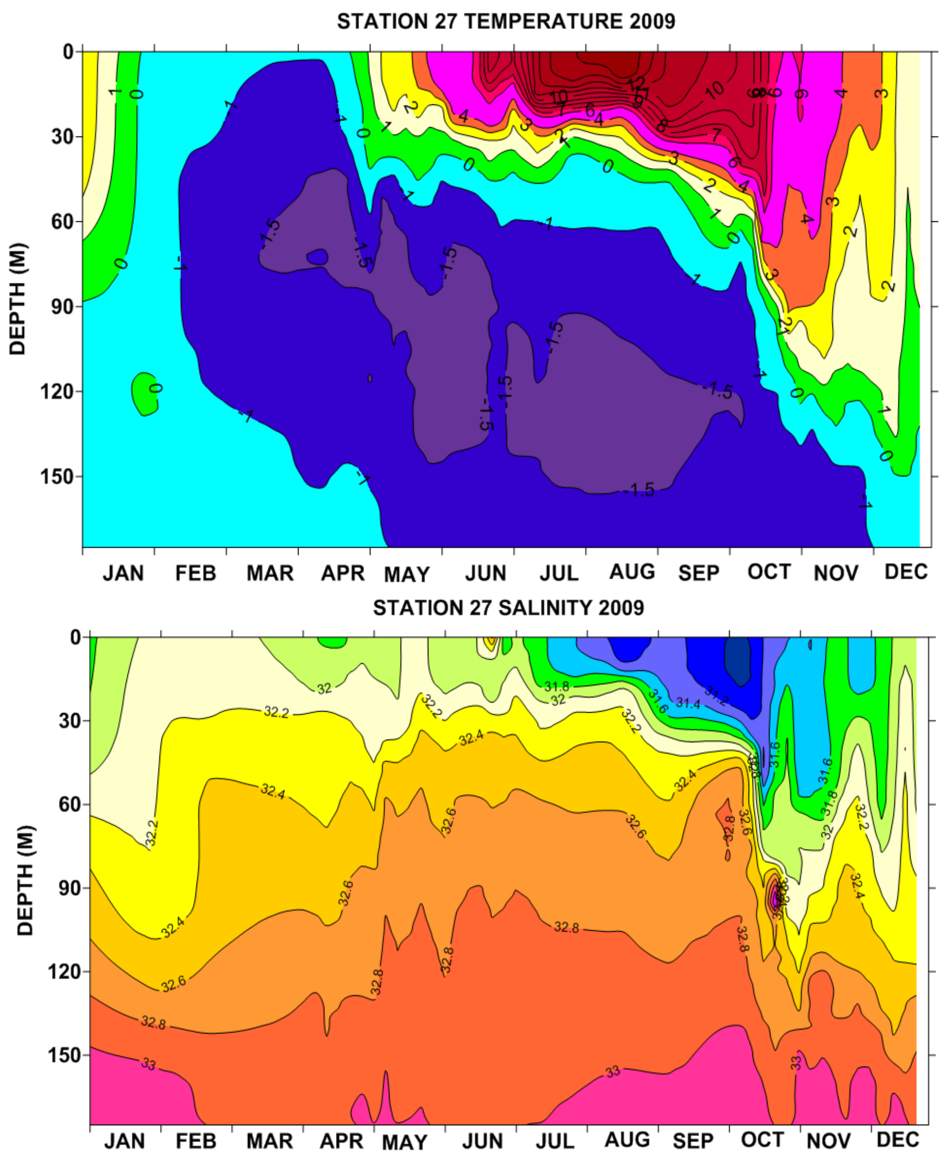


Figure 6. Contours of temperature (°C) and salinity as a function of depth at Station 27 for 2009.

On Hamilton and St. Pierre Banks surface temperatures decreased over 2008 values to only slightly above normal (<0.5 SD) whereas on Flemish Cap they were slightly below normal. On St. Pierre Bank and Flemish Cap near-bottom temperatures remained above normal values by 0.8 and 1.5 SD. Temperature data obtained from thermographs deployed at inshore sites during the summer months (July-Sept.) at 10-m depth show considerable variability about the mean due to local wind driven effects. In general however, they show similar patterns, with mostly below normal anomalies during the first half of the 1990s and above normal during the latter half to 2006. In 2007, 8/9 sites reported below normal summer temperature while in 2008-09 temperatures varied about the mean with no clear pattern (Table 3). On the Flemish Cap and Hamilton Bank surface salinities were slightly lower than normal during 2009. Salinities on the Flemish Cap were above normal from 2001 to 2008.

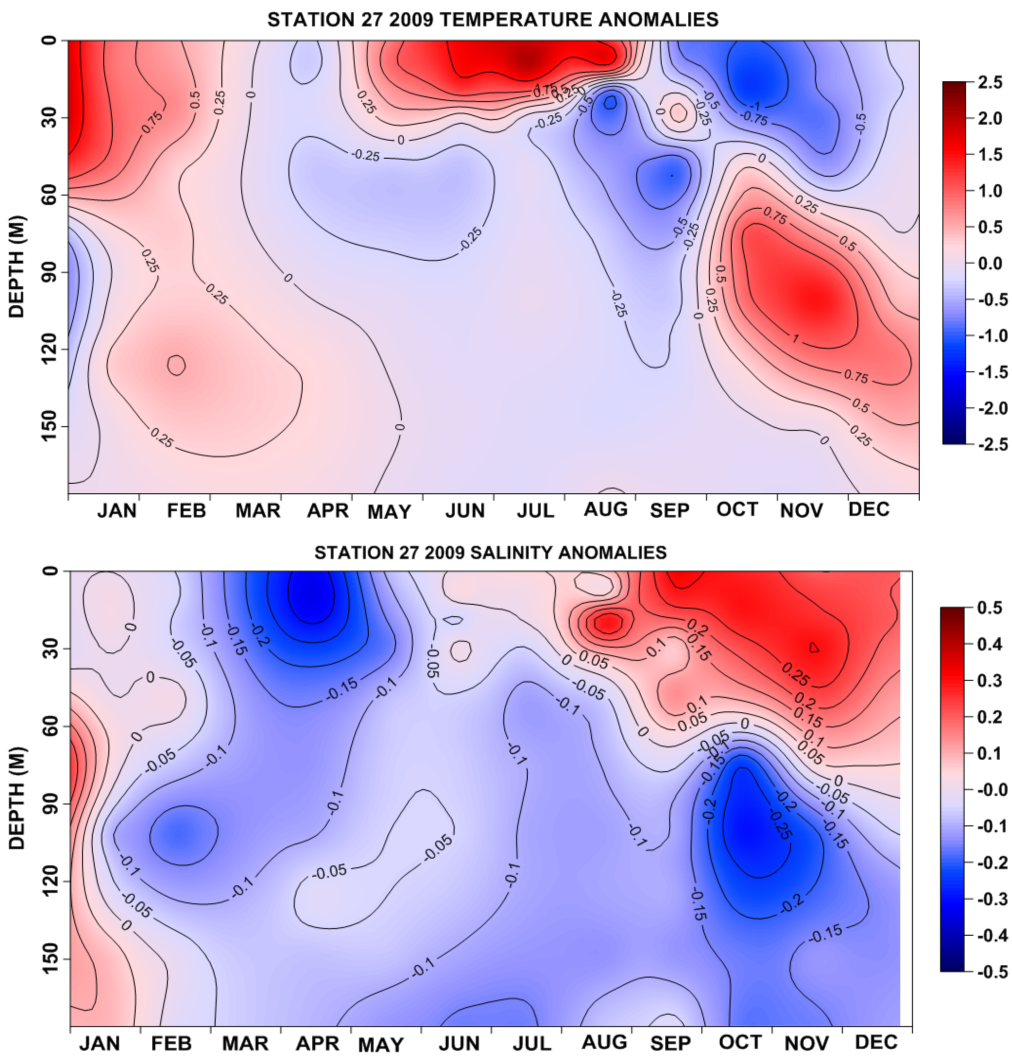
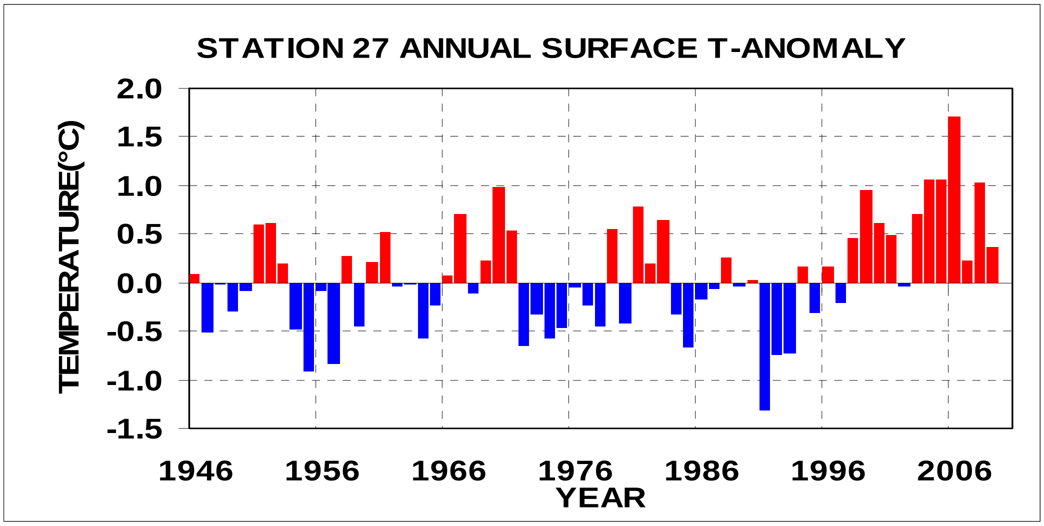


Figure 7. Contours of temperature (°C) and salinity anomalies as a function of depth at Station 27 for 2009.

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. The annual average stratification index was generally below normal in the early 1990s, increased to above normal from 1997-2001, varied about the mean from 2002 to 2005 increased to 1.4 SD above normal in 2006 and continued >1 SD above normal in 2008. In 2009 it decreased to about normal. The spring values show similar patterns, however they were significantly below normal in 2002 and 2003, slightly below normal in 2008 and 0.4 SD above normal in 2009. Both the time of the spring onset of stratification and of its maximum amplitude were slightly later than normal from 2000 to 2006, earlier than normal in 2007 and within 0.5 SD in 2008 and 2009. 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 2004 the annual averaged MLD was significantly (>2 SD) deeper than normal but shoaled to near normal depths during 2005 and deepened again in 2006 and 2007. In 2008 the winter MLD was shallower than normal, the spring value was deeper than normal, while the annual average was about normal and in 2009 the winter and annual values were deeper than normal while the spring value was shallower than normal (Table 3).



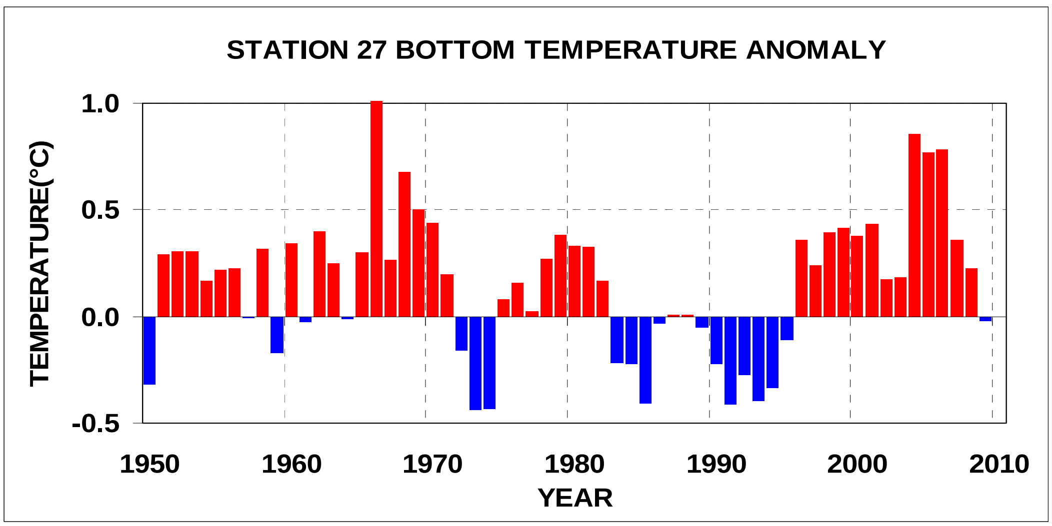


Figure 8. Annual surface and bottom (176 m) temperature anomalies at Station 27 referenced to the 1971-2000 mean.

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.

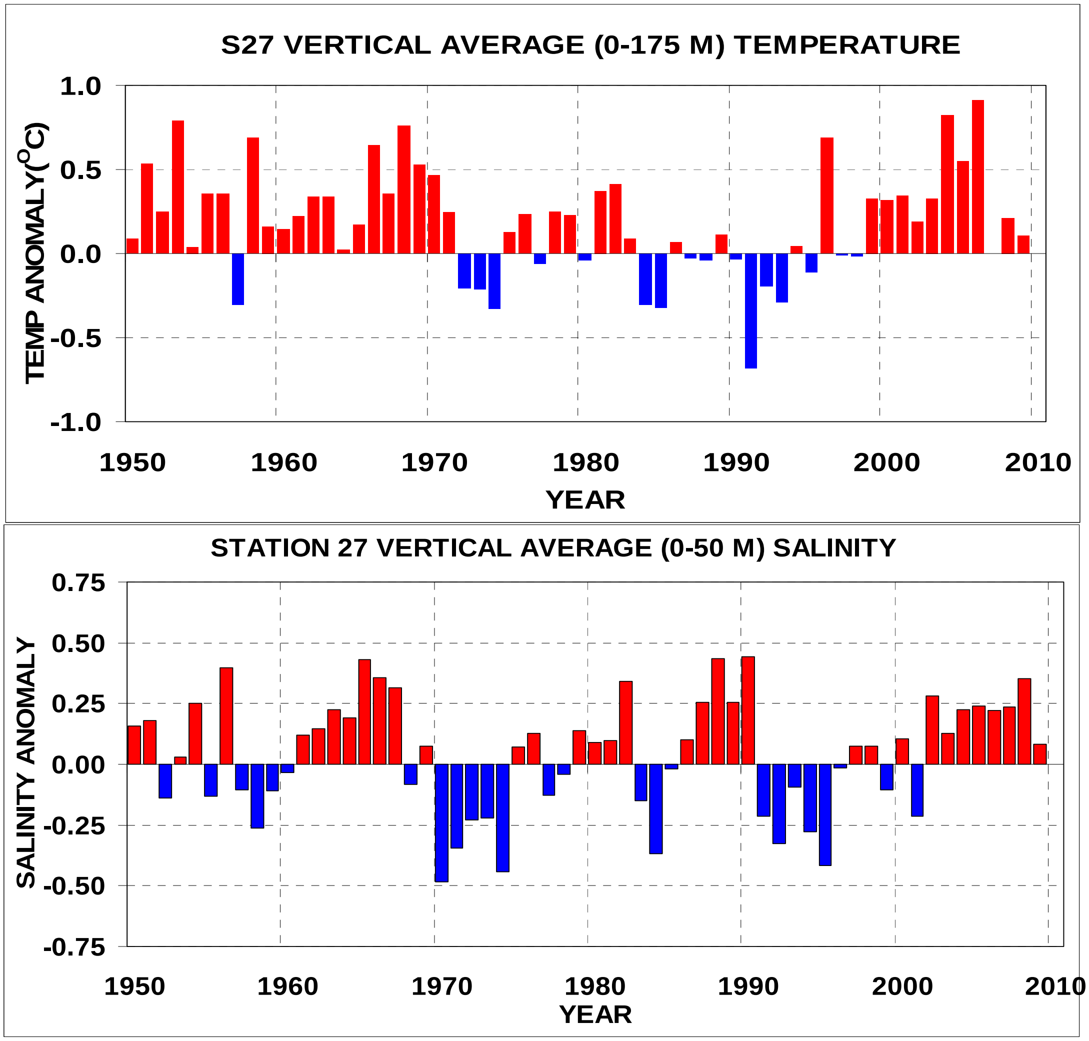


Figure 9. Annual vertically averaged temperature (0-176 m) and salinity (0-50 m) anomalies at Station 27 referenced to the 1971-2000 mean.

In 2009, the Southeast Grand Bank section was sampled during May and December, the Flemish Cap section during April, July and November/December, the Bonavista section during May, July and November, the White Bay in July, the Seal Island in July and November, the Makkovik Bank and Beachy Island sections during July (Fig. 2).

The water mass characteristics observed along the standard sections crossing the Newfoundland and Labrador Shelf (Fig. 2) 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 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.

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 indicated base period. The grey shaded cells indicate no data. Negative stratification onset and phase indicate earlier in the spring.

	STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (FIXED SITES)																					
INDEX	LOCATION	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	HAMILTON BANK	1971-2000	0.38	-0.87	-0.56	0.34	0.15	-0.19	-0.52	0.12	2.82	-0.01	1.75	0.05	-0.23	2.50	2.03	2.73	1.43	0.67	1.76	0.43
SURFACE	FLEMISH CAP	1971-2000	-0.51	-1.30	-1.54	-1.66	-0.73	0.01	0.17	0.32	2.50	0.13	0.85	0.48	-0.66	0.20	0.53	1.57	2.29	0.46	1.26	-0.12
TEMPERATURE	STATION 27	1971-2000	0.05	-2.49	-1.40	-1.37	0.32	-0.60	0.32	-0.39	0.86	1.81	1.15	0.92	-0.08	1.34	2.00	2.00	3.22	0.43	1.93	0.70
	ST. PIERRE BANK	1971-2000	-1.81	-0.01	-1.24	-0.40	-0.72	0.74	0.39	-0.41	1.13	1.21	1.51	-0.82	-0.08	-0.43	0.44	2.85	2.79	0.09	0.22	0.40
	HAMILTON BANK	1971-2000	-0.40	0.07	-0.29	-1.06	-1.01	0.74	0.56	1.04	-0.21	-0.46	-0.06	0.13	-0.51	-0.35	-0.09	0.73	0.02	-1.40	-1.29	-0.13
SURFACE	FLEMISH CAP	1971-2000	0.75	0.47		0.00	-1.38	0.80	0.60	1.14	-0.06	0.82	-0.29	1.26	1.49	2.27	1.46	1.20	0.56	1.36	0.27	-0.09
SALINITY	STATION 27	1971-2000	1.48	-1.85	-0.96	-0.04	-0.33	-1.82	0.22	-0.26	-0.29	-0.37	-0.23	-0.56	1.06	1.01	0.58	0.44	0.65	0.00	0.57	0.26
	STATION 27	1971-2000	-0.76	-1.42	-0.95	-1.37	-1.16	-0.38	1.24	0.83	1.36	1.43	1.31	1.50	0.60	0.63	2.95	2.65	2.70	1.23	0.77	-0.08
BOTTOM	FLEMISH CAP	1971-2000	-2.30	-1.02	-0.66	-0.41	-2.59	-0.51	-0.48	-0.11	0.82	1.78	0.36	-0.16	0.11	0.84	1.08	2.28	1.40	0.18	1.97	1.52
TEMPERATURE	HAMILTON BANK	1971-2000	-1.19	-0.45	-0.96	-1.29	-0.64	0.49	0.67	1.71	0.65	1.56	0.28	1.79	1.72	1.19	2.25	1.86	0.66	1.82	-0.04	-0.29
	ST. PIERRE BANK	1971-2000	-1.26	0.20	-0.47	-0.69	-1.78	-1.07	-0.21	-0.21	-0.61	0.67	0.70	-0.53	-0.62	-1.11	1.29	2.91	1.70	-0.70	-0.84	0.83
	STATION 27 (0-20 M)	1971-2000	0.26	-2.40	-1.10	-1.22	0.62	-0.31	0.67	-0.10	1.00	2.10	1.00	1.25	0.18	1.53	2.11	1.97	3.46	0.52	1.95	0.95
VERTICALLY	STATION 27 (0-50 M)	1971-2000	-0.18	-3.04	-0.57	-0.54	0.63	-0.13	1.62	0.03	0.18	1.26	0.95	1.73	-0.11	1.48	1.96	1.94	3.91	-0.88	1.87	0.28
AVERAGED	STATION 27 (0-100 M)	1971-2000	0.20	-2.71	-0.59	-0.89	0.59	-0.34	2.24	-0.33	-0.28	1.23	0.87	1.12	0.56	1.30	2.61	1.89	3.21	-0.38	0.88	0.10
TEMPERATURE	STATION 27 (0-175 M)	1971-2000	-0.13	-2.46	-0.69	-1.04	0.16	-0.40	2.47	-0.05	-0.05	1.18	1.14	1.25	0.68	1.18	2.95	1.98	3.27	0.01	0.75	0.38
	ST. PIERRE BANK (0-75 M)	1971-2000	-2.46	0.45	-0.26	-0.87	-1.47	-1.27	-0.49	-1.01	-0.36	1.94	0.75	-0.65	-0.14	-0.59	0.31	2.66	1.33	-0.44	-0.59	1.05
VERTICALLY	STATION 27 (0-20 M)	1971-2000	1.57	-1.81	-0.95	0.02	-0.26	-1.77	0.17	-0.31	-0.24	-0.35	-0.19	-0.62	1.10	1.08	0.61	0.48	0.66	0.08	0.68	0.28
AVERAGED	STATION 27 (0-50 M)	1971-2000	1.82	-0.88	-1.34	-0.38	-1.14	-1.72	-0.07	0.32	0.32	-0.44	0.43	-0.88	1.15	0.52	0.93	0.99	0.91	0.97	1.45	0.34
SALINITY	STATION 27 (0-100 M)	1971-2000	1.91	-1.37	-1.57	-0.07	-0.63	-1.00	-0.74	0.16	0.08	-0.32	-0.71	-0.78	0.77	0.85	-0.31	0.01	0.77	0.44	0.94	0.05
	STATION 27 (0-175 M)	1971-2000	1.61	-1.41	-1.54	0.15	-0.63	-0.65	-1.07	0.08	0.16	-0.32	-0.50	-0.90	0.49	0.29	-0.49	-0.10	0.77	0.36	0.89	-0.44
MIXED-LAYER	STATION 27 (WINTER)	1990-2007	-0.89	-1.22	-0.96	-1.04	1.16	-0.99	0.68	0.49	-0.91	-0.29	-1.02	0.52	0.73	-0.44	1.69	0.58	1.88	0.04	-1.56	1.42
MIXED-LAYER	STATION 27 (ANNUAL)	1990-2007	-1.09	-1.50	0.01	-0.14	1.08	-1.77	0.53	-0.72	-0.38	-0.27	-0.63	0.37	1.14	-0.39	2.18	-0.01	0.50	1.10	0.00	1.12
MIXED-LAYER	STATION 27 (SPRING)	1990-2007	-0.77	-0.85	-0.17	-0.17	0.35	-1.27	-0.50	-1.26	1.53	-1.18	-0.17	0.96	0.89	-0.02	2.03	-0.69	-0.11	1.41	3.09	-1.01
STRATIFICATION	STATION 27 (ANNUAL)	1971-2000	-0.92	0.07	-0.11	-0.79	-0.12	1.55	-1.09	0.56	1.22	1.44	0.68	1.44	-0.17	0.03	-0.35	0.27	1.36	0.69	1.06	0.01
STRATIFICATION	STATION 27 (SPRING)	1971-2000	-1.31	-0.63	-0.93	-0.22	-0.51	1.60	-0.75	0.05	0.92	0.73	-0.22	0.02	-0.91	-0.89	-0.28	0.21	0.57	0.09	-0.33	0.39
STRAT ONSET	ONSET (25% OF MAX)	1993-2007				-0.49	0.89	-2.33	0.58	-1.10	-1.10	-0.49	0.74	0.28	1.04	1.04	1.25	0.07	0.07	-0.44	-0.44	-0.03
STRAT PHASE	TIME OF MAX AMPLITUDE	1993-2007				0.48	0.23	-1.39	1.76	-0.45	-1.14	-1.39	0.57	-0.63	0.40	1.42	0.06	0.65	0.65	-1.22	0.40	0.06
9 M TEMPERATURE	HAMPDEN WB	1992-2007			-0.44	0.16	-1.48	-2.15	-0.40	-0.90	0.38	0.16	1.36	-0.91	0.52	0.28	0.79	0.88	1.38	-0.66	1.04	-0.95
10 M TEMPERATURE	COMFORT COVE NDB	1982-2007	1.20	-2.07	-0.76	-1.83	0.12	-1.12	0.80	-0.65	-0.11	0.96	1.13		0.74	0.85		0.40	-0.02		-0.11	
10 M TEMPERATURE	CAPE FREELS	1998-2007									-1.61	-0.02	-0.16		0.08	0.63	0.14	1.67	1.15	-1.13	-0.74	-1.16
10 M TEMPERATURE	STOCK COVE BB	1971-2000	0.44	-1.73	-0.36	-1.76	0.98	0.09	0.53	-0.70	0.96	0.90	1.18	1.33	1.08	1.32	1.05	1.44	1.81	-0.80	0.68	0.06
10 M TEMPERATURE	MELROSE	1998-2007									-1.31	-0.29		0.58	-0.36	0.85	-0.57	1.08	1.37	-1.6	0.26	-1.32
10 M TEMPERATURE	OLD BONAVENTURE	1991-2007		-1.56	-0.97	-0.85	1.93	0.21	0.61	0.04		-0.38	0.14	1.19	0.38	0.23	-0.32	0.63	1.15	-1.99	-0.43	0.10
10 M TEMPERATURE	WINTERTON	1998-2007									-0.72		0.89	0.23	-0.53	1.84	-0.34	0.07	0.96	-1.39	-1.01	0.38
5 M TEMPERATURE	BRISTOL'S HOPE	1989-2007	-0.73	-3.02		-0.67	0.52	0.00	0.09	-0.08	-0.70	1.04	0.71	0.65	0.04	0.91	0.24	0.87	0.95	-0.65	0.95	0.48
10 M TEMPERATURE	UPPER GULLIES CB	1990-2007	-1.21	-1.31	0.71	-0.42	0.16	0.24	-0.91	-0.14	-1.06	1.19	-0.25	0.03	0.24	0.81	-0.12	1.24	1.31	-2.06	1.55	0.35
10 M TEMPERATURE	ARNOLDS COVE PB	1981-2007	0.75	-2.04	-1.39	-1.59	0.49	-0.80	0.66	-0.37	0.49	2.34	0.98	0.44	0.52	1.05	-0.22	0.36	1.13	0.57	0.07	1.76

In general, the water mass characteristics encountered along the standard sections undergo seasonal modification due to the seasonal cycles of air-sea heat flux, wind forced mixing, and ice formation and melt which lead to 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. 10 and 11). This winter formed water mass is commonly referred to as the cold intermediate layer or CIL (Petrie et al. 1988) and its cross sectional area or volume bounded by the 0°C isotherm is generally regarded as a robust index of ocean climate conditions off 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, due mainly to wind forced vertical mixing of the seasonally heated upper layers.

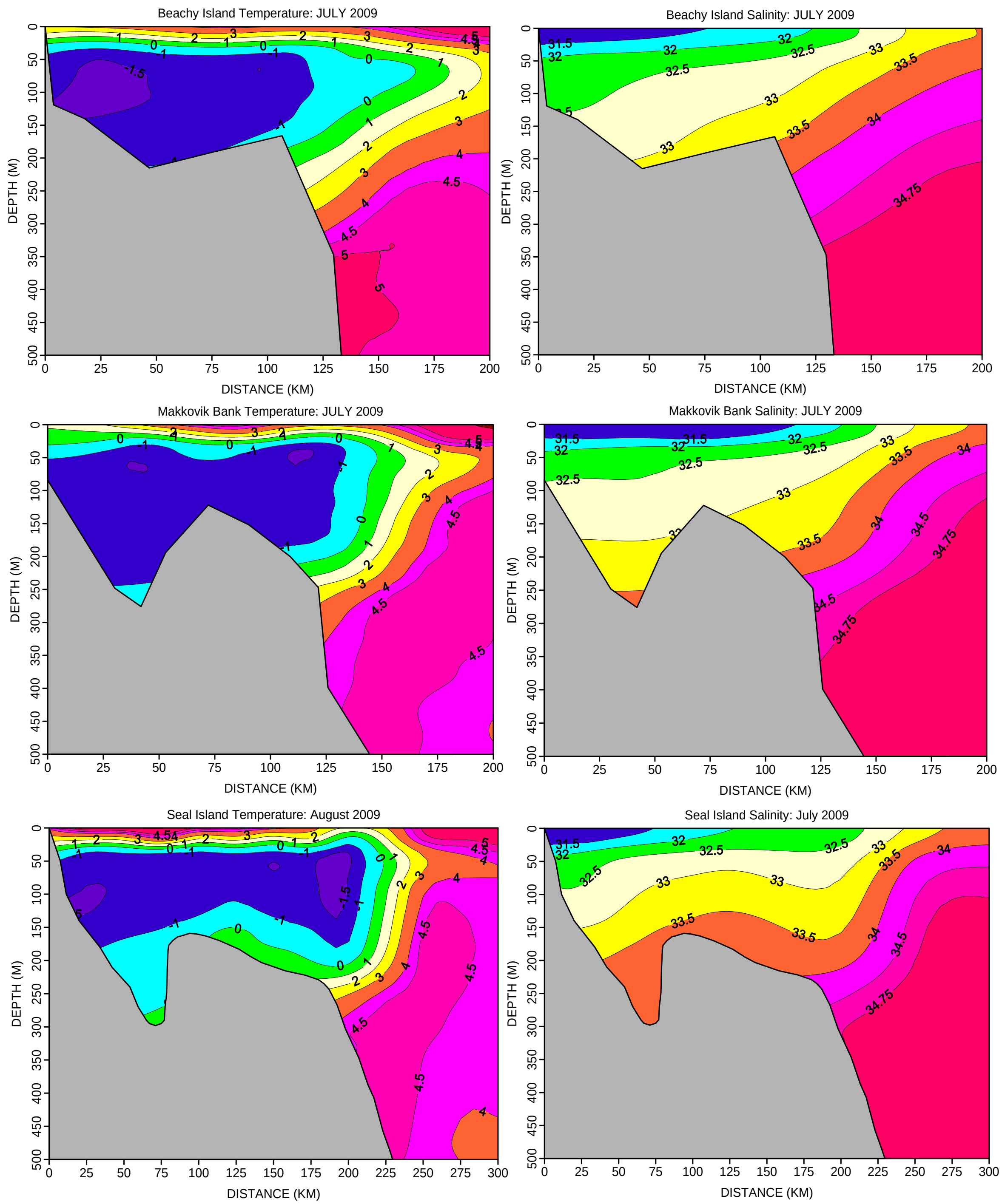


Figure 10. Contours of temperature (°C) and salinity across the Labrador Shelf along the Beachy Island (Nain Bank), Makkovik Bank and Seal Island (Hamilton Bank) Sections (Fig. 2) during the summer of 2009.

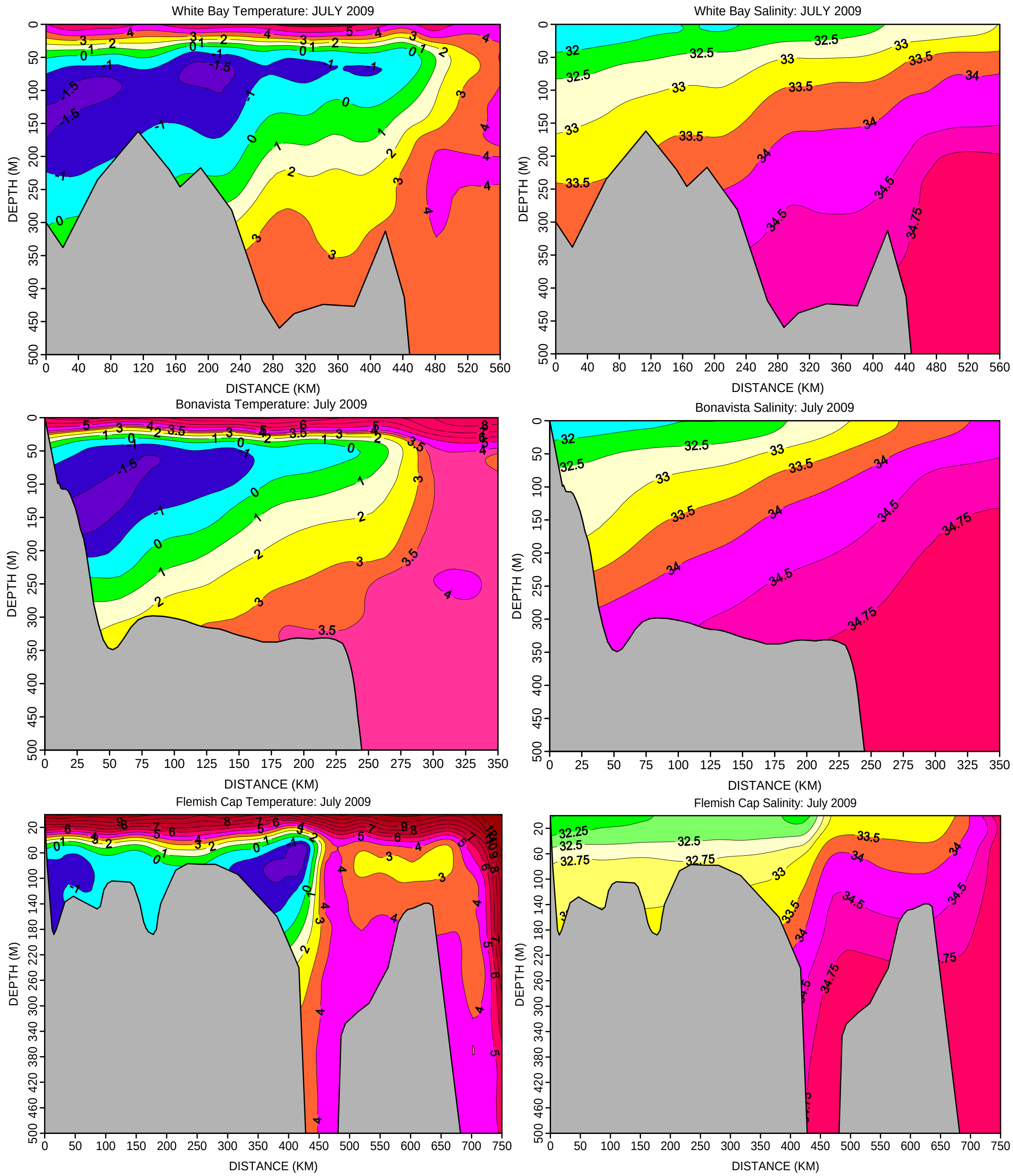
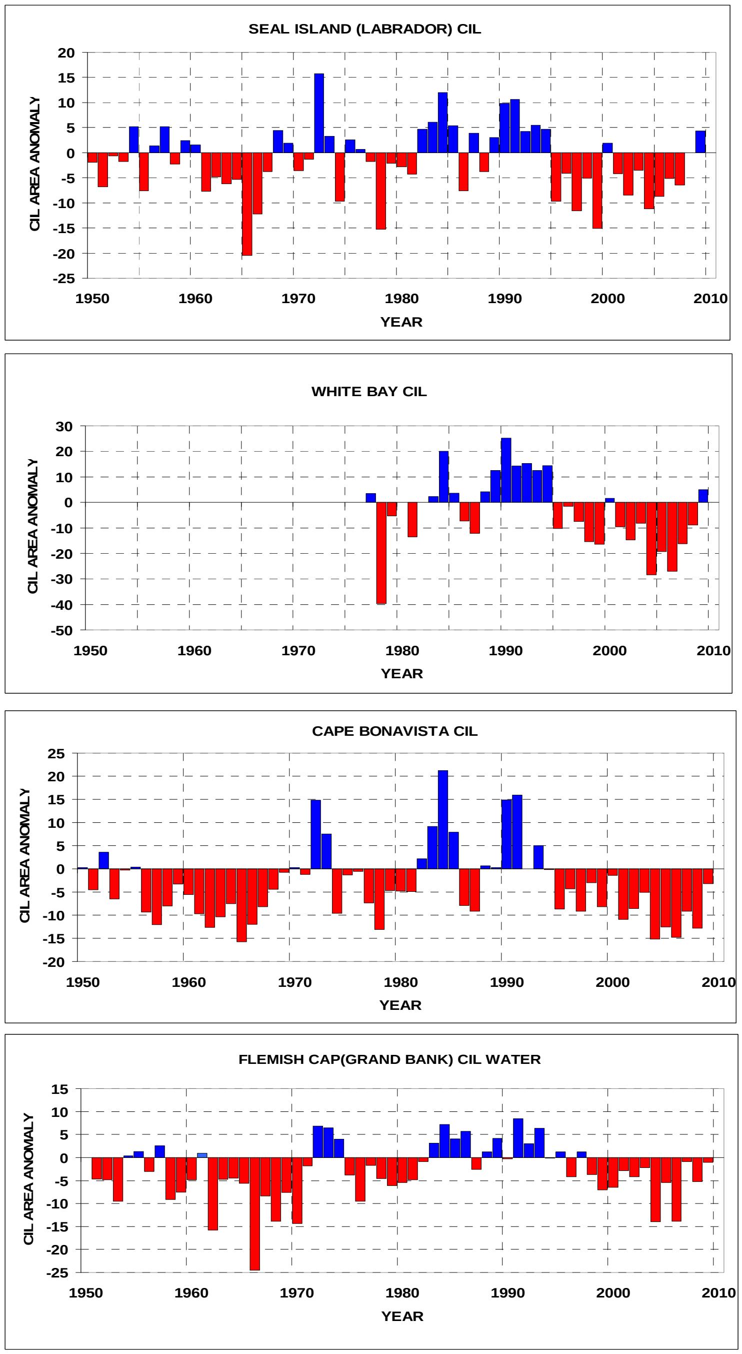


Figure 11. Contours of temperature (°C) and salinity across the Newfoundland Shelf along the White Bay, Bonavista and Flemish Cap Sections (Fig. 1) during the summer of 2009.

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. 12 and Table 4. 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 increased along all sections from the Seal Island to Flemish Cap, with positive anomalies (colder conditions) reported for the two northern sections, the first time in almost a decade (Fig. 12). From

1990 to 1994, temperatures and salinites were significantly below normal in these areas. Farther south on the Southeast Grand Bank and St. Pierre Bank, conditions have been more variable with near-record cold conditions 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. In 2007-08, some cooling was evident along the southeast Grand Bank and St. Pierre Bank sections and in 2009 this trend continued on the Southeast Grand Bank but reversed on St. Pierre Bank.

Figure 12. Summer CIL ($T<0^{O}C$) area anomalies along the Seal Island, White Bay, Bonavista and Flemish Cap



Sections referenced to the 1971-2000 mean.

Table 4. 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 over the indicated base period.

	STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (AZMP STANDARD SECTIONS)																				
REGION/SECTION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	COLD-INTERMEDIATE-LAYER AREA	1.26	1.36	0.55	0.71	0.61	-1.22	-0.51	-1.46	-0.63	-1.91	0.26	-0.52	-1.07	-0.43	-1.41	-1.09	-0.65	-0.81	0.01	0.56
SOUTHERN	MEAN CIL TEMPERATURE	-1.42	-0.87	-1.11	-1.30	-0.79	1.25	0.27	0.31	0.11	1.13	-0.48	0.62	0.54	-0.09	0.58	1.01	0.4229	0.07	-0.52	-0.95
LABRADOR	MINIMUM CIL TEMPERATURE	-0.45	-0.71	-0.46	-0.82	-0.18	2.39	0.11	-0.16	0.06	1.48	-0.06	1.42	-0.13	1.08	2.68	1.42	1.5344	0.33	-0.18	0.16
SEAL ISLAND	MEAN SECTION TEMPERATURE	-1.74	-1.64	-1.39	-1.32	-0.76	0.66	0.32	1.10	0.95	1.39	0.29	0.54	0.86	1.22	2.32	1.59	1.7367	1.30	1.64	0.54
SECTION	MEAN SECTION SALINITY	-0.90	-1.03	1.12	-0.32	-0.58	0.86	-0.32	0.92	0.40	0.99	-0.58	0.40	1.31	0.21	1.51	0.86	0.6613	0.34	0.14	0.07
(SUMMER)	INSHORE SHELF SALINITY	0.07	-0.77	0.98	1.05	-0.54	0.71	-0.54	0.67	0.48	1.05	-1.11	0.29	0.67	0.18	0.22	1.21	0.3316	0.26	0.56	-0.28
	LABRADOR CURRENT TRANSPORT	0.64	0.84	1.32	-1.54	-0.52	0.43	0.84	0.50	1.18	-0.11	0.98	1.18	1.59	1.46	1.05	1.59	0.9785	0.43	0.09	2.21
	COLD-INTERMEDIATE-LAYER AREA	1.69	0.95	1.02	0.83	0.96	-0.69	-0.10	-0.50	-1.03	-1.10	0.10	-0.64	-0.98	-0.54	-1.90	-1.29	-1.81	-1.09	-0.59	0.33
NORTHEAST	MEAN CIL TEMPERATURE	-1.14	-0.54	-0.66	-1.08	-0.42	0.42	0.42	-0.24	0.42	1.55	-0.18	0.66	0.95	0.06	2.45	1.13	1.2535	0.48	0.89	-0.06
NEWFOUNDLAND	MINIMUM CIL TEMPERATURE	-0.41	-0.68	-0.66	-0.94	-0.34	-0.16	0.80	-0.24	-0.20	1.20	0.29	0.15	0.22	0.37	4.65	0.75	2.2489	0.52	0.45	0.22
WHITE BAY SECTION	MEAN SECTION TEMPERATURE	-1.46	-0.84	-1.65	-1.29	-1.31	0.01	-0.11	1.00	1.22	1.50	0.55	0.53	0.60	1.00	1.92	2.00	2.114	1.48	1.59	-0.18
(SUMMER)	MEAN SECTION SALINITY	-1.07	-0.77	-0.66	-0.15	-0.77	0.57	-1.38	1.49	0.77	-0.25	-0.46	0.36	1.49	0.46	1.59	0.98	1.2825	1.18	0.98	-0.87
	MEAN SHELF SALINITY	0.17	-0.65	-1.21	0.98	-0.75	0.17	-0.90	1.59	0.07	-1.67	-0.60	0.07	1.19	-0.34	0.88	-0.09	0.932	0.78	0.98	-0.34
	CIL AREA (SPRING)	1.90	1.11	0.55	0.53	1.05	-0.74	-0.44	-0.44	0.14	-0.94	-0.14	-0.90	-0.34	-0.01	-1.02	-1.41	-1.44	-0.61	-0.46	-0.14
	CIL AREA (SUMMER)	1.66	1.78	-0.01	0.55	-0.03	-0.99	-0.49	-1.03	-0.35	-0.93	-0.17	-1.24	-0.98	-0.58	-1.72	-1.41	-1.67	-1.03	-1.45	-0.37
	CIL AREA (FALL)	1.46	0.45	0.84	1.33	0.92	-0.63	-0.45	-1.17	-0.76	-1.43	-0.19	-0.53	-0.93	-1.17	-1.43	-1.40	0.24	-1.15	0.46	-1.30
EASTERN																					
NEWFOUNDLAND	MEAN CIL TEMPERATURE (SUMMER)	-0.95	-1.51	-0.40	-1.09	-0.47	0.71	1.41	-0.40	-1.02	-0.19	0.09	1.34	-0.26	-0.26	1.62	1.48	1.89	0.92	-0.12	-0.26
BONAVISTA	MINIMUM CIL TEMPERATURE (SUMMER)	-0.41	-0.79	-0.25	-0.78	-0.48	0.19	0.88	-0.06	-0.09	0.62	0.34	1.22	0.54	0.28	2.78	1.73	3.02	0.54	0.28	-0.15
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-1.68	-1.61	-1.30	-0.97	-0.83	0.30	-0.10	1.01	0.87	1.41	0.75	0.56	0.66	0.99	2.48	2.05	2.33	1.32	2.38	0.16
	MEAN SECTION SALINITY (SUMMER)	-1.18	-1.18	-0.32	0.04	0.53	1.63	-1.54	1.51	0.04	0.41	0.41	0.29	2.61	1.14	2.49	1.51	2.49	1.63	3.34	0.17
	INSHORE SHELF SALINITY (SUMMER)	0.74	-1.19	-1.10	0.30	0.56	-1.19	0.13	0.13	-0.31	-1.81	0.74	-0.40	2.32	0.04	1.00	1.09	1.80	1.36	2.06	-1.02
	LABRADOR CURRENT TRANSPORT (SUMMER)	-0.16	1.49	1.49	0.39	-0.24	-0.24	0.47	0.08	-0.32	1.73	0.63	-1.02	0.39	0.70	-0.16	0.23	-0.95	-0.40	-1.50	-0.08
	CIL AREA (SPRING)	0.95	0.90	0.77	1.02	0.87	0.42	-0.50	-0.10	-0.94	-2.17	-0.36	0.05	1.22	1.44	-1.57	-1.14	-1.77	1.08	0.54	0.86
GRAND BANK	CIL AREA (SUMMER)	-0.03	1.68	0.62	1.26	-0.01	0.26	-0.80	0.26	-0.72	-1.37	-1.25	-0.54	-0.80	-0.41	-2.72	-1.06	-2.70	-0.15	-1.01	-0.19
FLEMISH PASS	CIL AREA (FALL)	0.47	0.66	0.02	0.09	0.76	-0.36	-0.28	-0.33	0.04	-1.37	0.01	-0.17	-0.62	-0.54	-1.50	-0.57	-0.69	-0.31	-0.01	-1.16
FLEMISH CAP																					
	MEAN CIL TEMPERATURE (SUMMER)	-1.07	-1.83	-1.30	-1.70	-0.22	-0.85	0.86	0.27	0.59	1.39	0.99	0.90	0.14	-0.40	1.30	0.86	1.62	0.27	0.14	-0.71
47 °N	MINIMUM CIL TEMPERATURE (SUMMER)	-0.11	-0.86	-0.25	-0.79	-0.55	-0.05	1.97	0.69	-0.08	1.06	0.93	2.34	-0.42	0.39	0.66	1.13	1.33	0.73	0.25	-0.554
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-0.64	-1.31	-1.58	-2.47		-0.67	0.18	-0.12	0.82	1.59	0.45		-0.20	2.41	1.29	1.19	2.33		1.12	1.04
	MEAN SECTION SALINITY (SUMMER)		-0.15	0.05	0.15		0.54	0.35	1.14	0.74	0.84	-0.05		1.34	2.33	1.14	-0.45	1.63		1.34	-0.05
	INSHORE SHELF SALINITY (SUMMER)		-0.54	-0.83	-0.42	-0.18	-0.42	-0.71	0.12	0.18	-0.06	-0.83	-0.83	0.47	0.06	-0.12	-0.30	0.95	0.59	0.47	-0.59
	LABRADOR CURRENT TRANSPORT (SUMMER)		0.18	1.45	0.81		1.13	0.07	0.39	1.24	-0.14	1.13	1.24	1.45	2.51	1.13	1.13	0.18	0.92	-2.16	1.13
	CIL AREA (SPRING)	1.54	1.78	0.40	-0.21	-0.36	-0.83	-0.81	-0.19	-0.55	-0.87	-0.73	-0.21	0.79	2.98	-0.85	-0.94	-1.40	0.51	0.84	0.54
	MEAN CIL TEMPERATURE (SPRING)	-0.08	-0.38	-0.38	-1.81	-0.94	-1.50	0.40	0.09	0.65	-0.60	0.70	1.39	0.74	0.09	2.38	0.78	2.90	0.18	-0.68	-1.68
SOUTHEAST	MEAN TEMPERATURE (SPRING)	-1.77	-1.40	-0.89	-0.48	-0.29	-0.47	0.03	-0.17	0.29	1.46	0.20	-1.21	-1.61	-2.34	-0.07	-0.26	-0.07	-0.97	-1.16	-0.13
GRAND BANK																					
SECTION	CIL AREA (FALL)	-0.51	1.47	-0.41	0.68	2.18	1.21	-0.54	-0.50	-0.38	-0.59	-0.38	-0.45	-0.57	-0.50	-0.70	-0.44	-0.44	-0.29	0.12	-0.77
	MEAN CIL TEMPERATURE (FALL)	-1.28	0.79	-0.77	0.42	-0.17	1.98	0.64	-1.14	-0.99	0.57	0.20	0.05	-1.06	-1.28	2.05	1.38	1.3827	1.09	0.42	1.53
	MEAN SECTION TEMPERATURE (FALL)	-0.95	-0.46	-1.27	-0.43	-0.67	0.92	-0.64	-0.10	1.44	1.52	0.99	0.35	-0.44	-0.48	0.22	-0.39	0.9304	-0.63	-0.05	-1.36
	CIL AREA				1.16	0.95	0.40	-1.03	1.09	-0.84	-1.16	-1.16	0.55	-0.09	1.20	-1.09	-1.16		0.65	0.23	-0.52
ST. PIERRE	MEAN TEMPERATURE (< 100 M)				-1.00	-0.82	-0.22	0.29	-0.96	0.80	1.81	1.45	-0.43	-0.16	-1.31	0.55	1.16		-0.49	0.26	1.49
BANK	MEAN SECTION TEMPERATURE				-0.81	-1.45	0.47	0.16	-0.74	0.54	1.88	1.42	-0.81	0.10	-0.96	0.19	1.36		-1.35	-1.93	1.92
SECTION	MEAN SALINITY < 100 M				0.99	-1.64	0.48	-0.68	-0.42	1.12	0.60	-1.64	1.12	-0.74	0.48	0.35	-0.55		1.37	-0.68	-0.10
(SPRING)	MEAN SECTION SALINITY				1.60	-2.00	0.97	-0.92	-0.47	0.43	1.15	-0.47	-0.11	-0.65	-0.02	0.52	0.07		0.61	-2.90	0.52

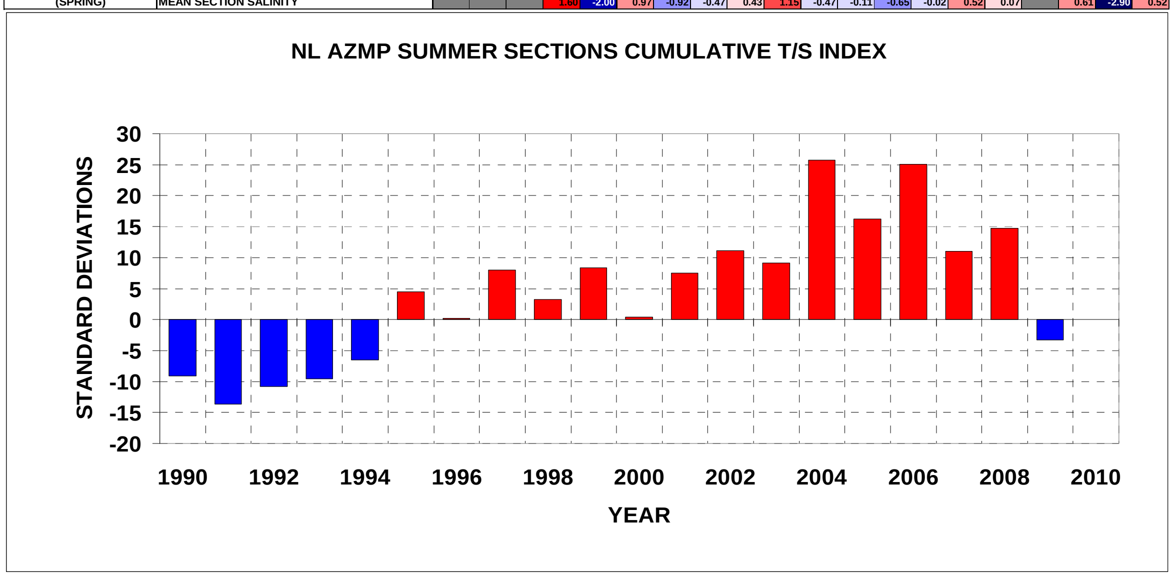


Figure 13. Standard summer section composite index derived by summing the standardized temperature and salinity anomalies from Table 4.

The CIL cross sectional area anomalies during the spring of 2009 varied by season and location with above normal areas for example on St. Pierre Bank and below normal areas on the Southeast Grand Bank. Above normal CIL areas generally implies colder-than-normal water temperatures on the continental shelf. Summer sections are common to four areas. Along the Bonavista section, the summer CIL area remained below normal (<0.5 SD) for the 15th consecutive year (1995-2009). The summer CIL area during the fall of 2009 however decreased compared to 2007-08 to 1.3 SD above normal. The overall average temperature along the Bonavista section decreased to >2 SD above normal in 2008 to near normal (+0.2 SD) in 2009. Average salinities along the Bonavista section have been significantly above normal since 2002, with 2008 at 3.3 SD higher than normal and 2009 at +0.2 SD. In 2009 along the 47°N section, the summer CIL area was below normal for the 12th consecutive year (1998-2009), the average temperature about 1 SD above normal and the average salinity was about normal.

Temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections (Fig. 2) were used to compute geostrophic transports estimates of the near-surface component (reference to 130 m) of the offshore branch of the Labrador Current. Variations in the volume transport are likely due to changes in the upper layer shelf stratification due 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 4) was near normal during 2008 but increased significantly to >2 SD above normal in 2009. Further south off the Grand Bank through the Flemish Pass the transport also increased from 2 SD below normal in 2008 to >1 SD above normal in 2009. 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 2006-09 showing a below normal estimate.

A composite index derived from the temperature and salinity indices presented in Table 4 for the sections sampled during the summer (Seal Island, White Bay, Bonavista and Flemish Cap) clearly show an increasing trend since the early 1990s, peaking during the mid-2000s, and then declining in the past three years to slightly below normal in 2009 (Fig. 13). These results together with the individual time series in Table 4 indicate generally warmer and saltier conditions in recent years with 2009 slightly below normal the first time since 1994.

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 two large spatial-scale oceanographic data sets annually for the Newfoundland Shelf, one during the spring from Subdiv. 3Ps and Divs. 3LNO on the Grand Bank and one during the fall from Div. 2J 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 2009.

Spring Conditions

Maps of bottom temperatures and their anomalies during the spring of 2009 are displayed in Figure 14 for NAFO Div. 3PLNO. Bottom temperatures in Div. 3L were generally -1 -0°C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 0° to >3°C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO) bottom temperatures ranged from 1°C – 6.5°C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from 0° -1°C. There was a significant increase in the area of St. Pierre Bank and the Grand Bank covered by water with temperatures <0°C during the spring of 2007-09 compared with the previous three years (Fig. 16 and Table 5). Bottom temperature anomalies were highly variable with values generally within ±0.5°C over most of 3L, along the slope region they were generally above normal. In most of the southern areas of 3NO bottom temperatures were up to 2.5°C above normal. In western areas of Div. 3P, negative anomalies dominated, particularly in the deeper areas of the Laurentian Channel while on St. Pierre Bank and the southeastern areas they were above normal. It should be noted that even though areas of the inshore that have limited or no sampling were blanked out there still could be some smaller areas that have unreliable temperature estimates.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990-2009 are displayed in Fig. 16 and Table 5 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 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 2009, with the exception of 2003, with 1999 and 2004 among the warmest springs on record. The spring of 2004 had the lowest area of <0°C water in Division 3L since the surveys began in the early 1970s at 2.1 SD units below normal. In 2008, this area increased to only slightly below normal (0.3 SD) and to near-normal conditions in 2009 (Table 5). 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 1.6 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 (1.1 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 (Table 5). A composite index derived from the indices presented in Table 5 show overall conditions during the spring of 2009 slightly above normal after 2 years of slightly below normal conditions (Fig. 17).

Fall Conditions

Bottom temperature and temperature anomaly maps for the fall of 2009 in NAFO Div. 2J, 3KLNO are displayed in Figure 15. Bottom temperatures in Div. 2J were generally above normal, ranging from <2°C inshore to >3.5°C at the shelf break and between 1° -2°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 2° - 3.5°C, which were near-normal to slightly above normal. Bottom temperatures in Divs. 3LNO generally ranged from <0°C on the northern Grand Bank and in the Avalon Channel to 3.5°C along the shelf edge. Over the southern areas, bottom temperatures ranged from 1° to 4°C with the warmest bottom waters found on the Southeast Shoal and along the edge of the Grand Bank in Div. 3O. Temperature anomalies over the Grand Banks generally varied about the mean with mostly positive values in the offshore slope areas (Fig. 15).

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990-2009 are displayed in Fig. 16 and Table 5. In 2J, bottom temperatures were generally colder than normal from 1990 to 1995, with the coldest anomalies observed in 1993 when they reached >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 (2.6 SD) but decreased to <0.5 SD above normal on the banks during 2008. In 2009 temperatures increased over 2008 values reaching 1.5 SD above normal. From 1996-2009 near-bottom water with temperatures <0°C have been largely absent from Hamilton Bank with a corresponding increase in the area covered by water >2°C. In Div. 3K, conditions were very similar to 2J with above normal temperatures since 1996, a slight cooling in 2006, record high (>2 SD) values in 2007 and again, a slight warming in 2009 compared to 2008. 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. Bottom temperatures experienced a slight cooling trend from 2006-08 before recovering slightly in 2009 (Table 5). Composite indices derived from the normalized anomalies (Table 5) show overall conditions during the fall of 2009 continued the above normal trend for the 15th consecutive year although the magnitude of the anomalies have decreased during the past 2 years compared to 2007 (Fig. 17).

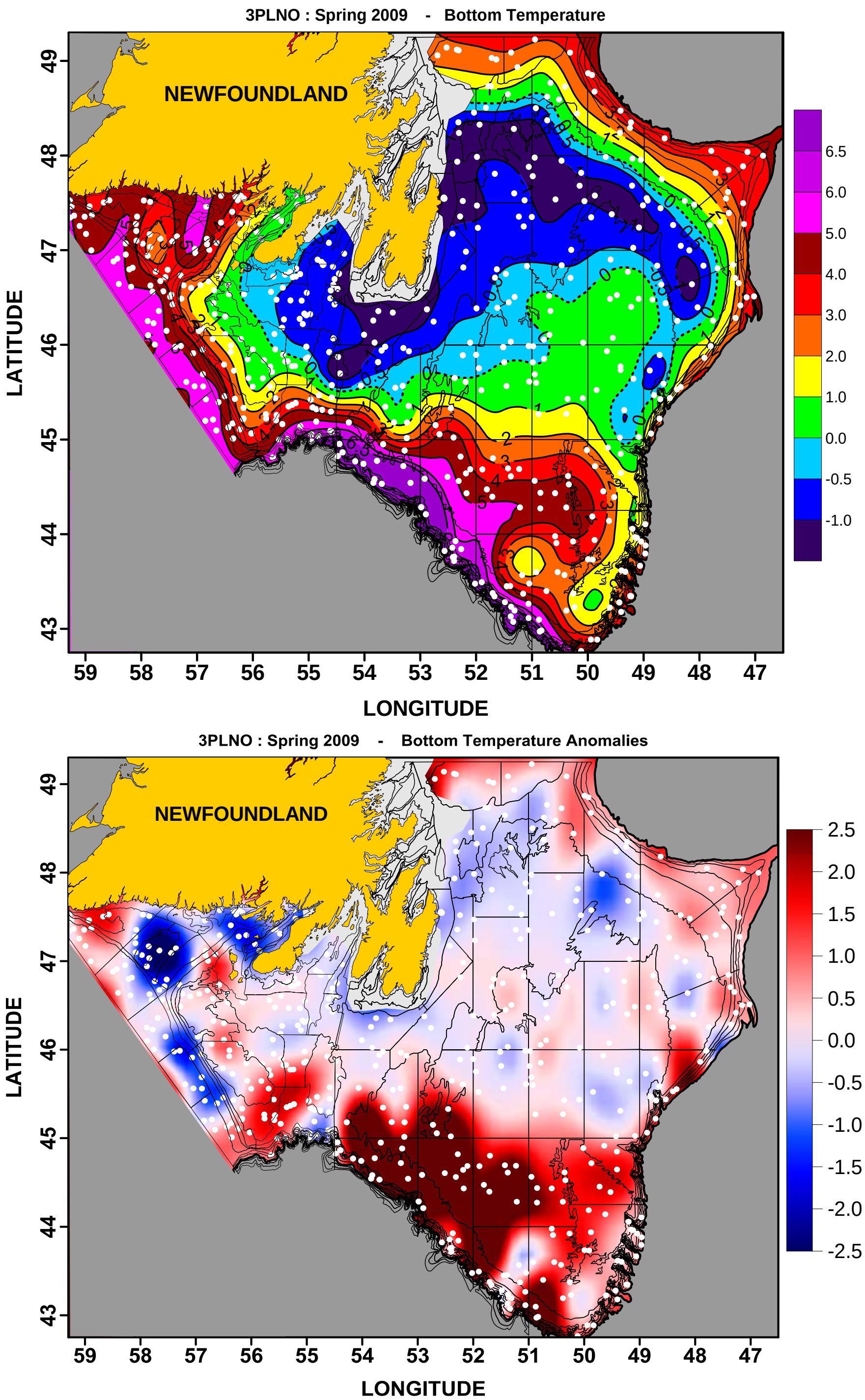


Figure 14. Contour maps of bottom temperature and their anomalies (°C) relative to the 1971-2000 mean for the same period of the year, during the spring of 2009 in NAFO Divs. 3PLNO. The white dots indicate sampling locations.

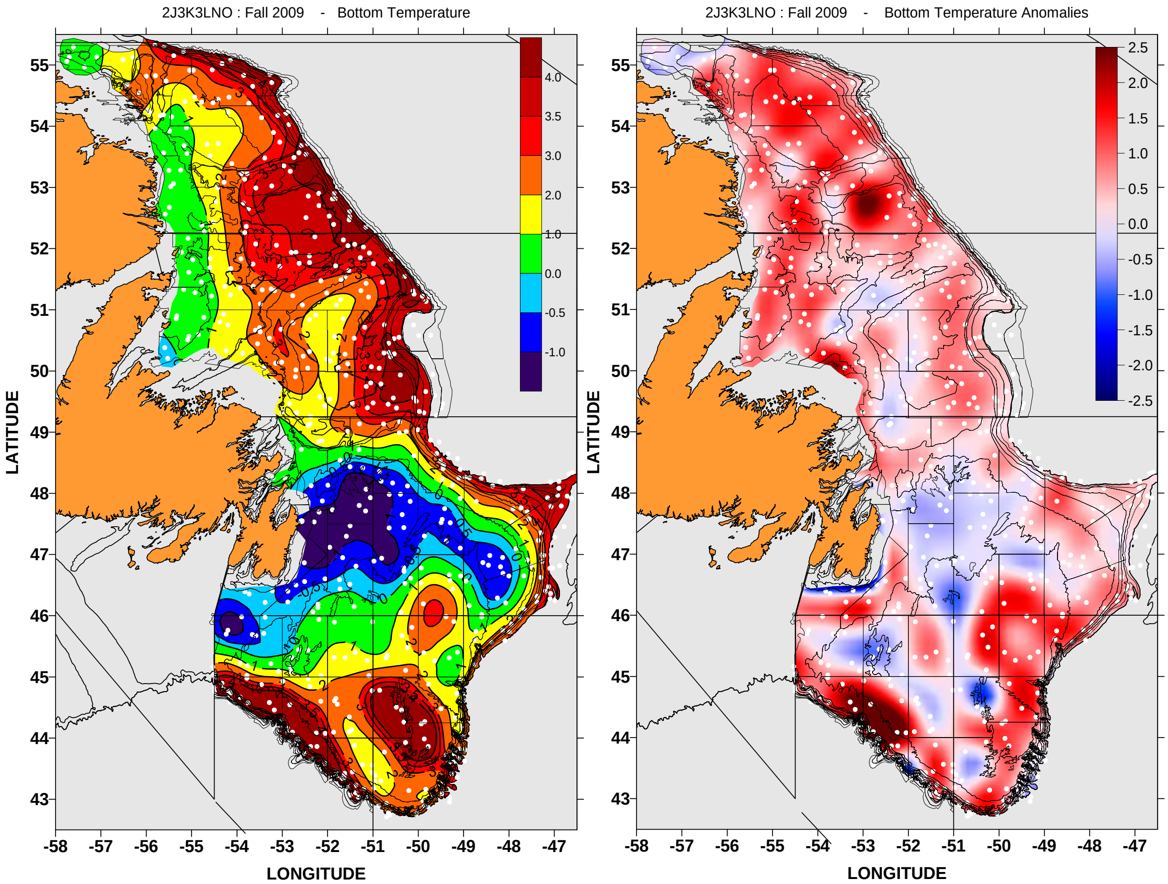


Figure 15. Contour maps of bottom temperature and their anomalies (in °C) relative to the 1971-2000 mean for the same period of the year, during the fall of 2009 in NAFO Divs. 2J3KLNO. The white dots indicate sampling locations.

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 this water mass varies considerably by year and season usually covering 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 (1.8 SD below normal) and remaining significantly below normal (1 SD) in 2009 (Fig. 18).

SUMMARY

The North Atlantic Oscillation index for 2009 was about normal (+0.1 SD) and as a consequence, outflow of arctic air masses to the Northwest Atlantic during the winter (Dec.-Feb.) return to more like normal conditions. This resulted in a slight increase in air temperatures throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland relative to 2008. Sea-ice extent and duration on the Newfoundland and Labrador Shelf increased in 2009 but remained below average for the 15th consecutive year, although it was the most extensive since 1994 during the spring. Local water temperatures on the Newfoundland and Labrador Shelf continued a slight cooling trend but remained above normal in some areas in 2009. Salinities which were lower than normal throughout most of the 1990s have experienced a general increasing trend during the past 8 years.

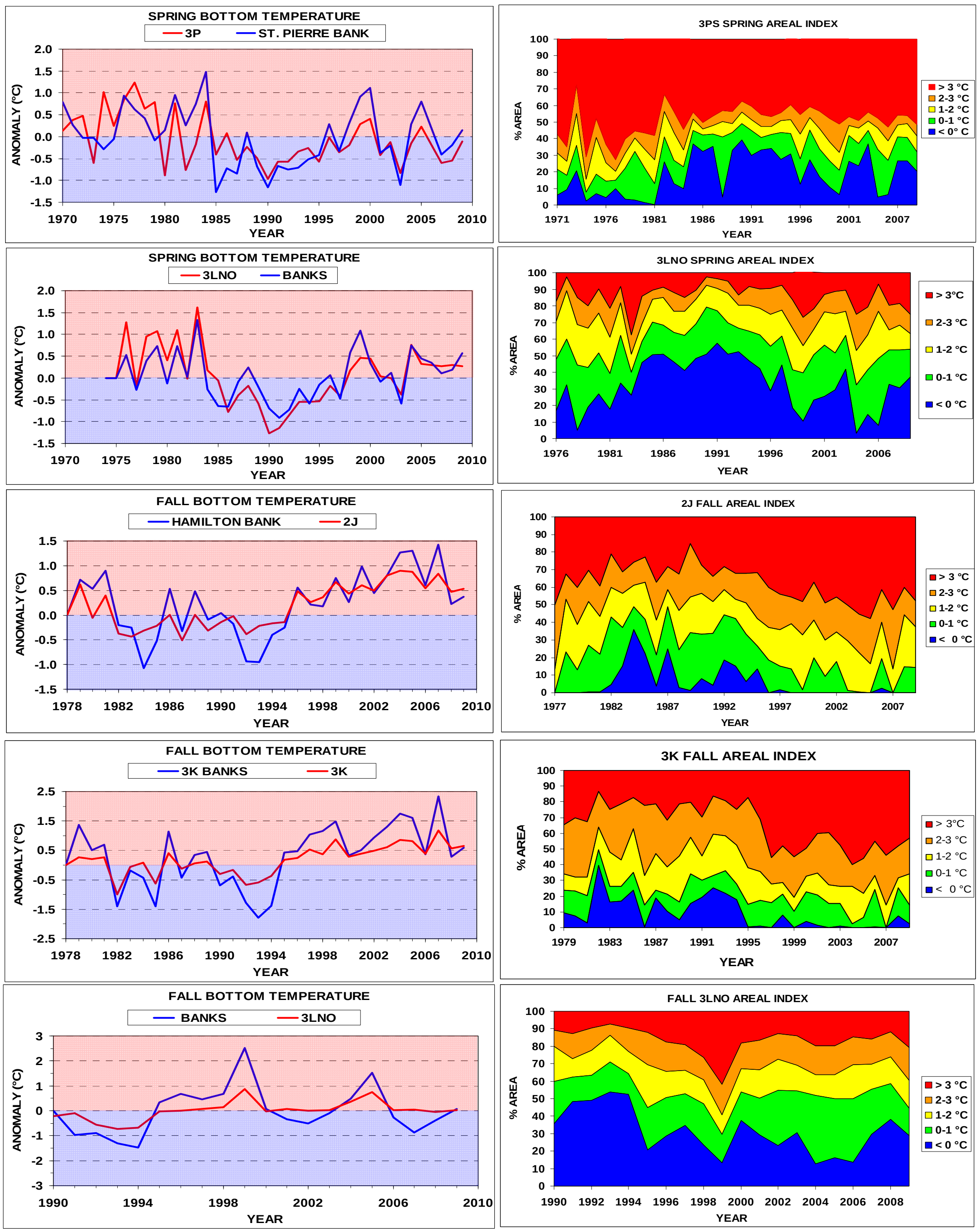


Figure 16. Bottom temperature anomalies (left panels) and the area of the bottom covered with water in different temperature bins (right panels) for the spring and fall multi-species surveys in NAFO Dovs. 2J, 3KLNOP.

Table 5. Temperature anomalies and derived indices from data collected during spring and fall multi-species surveys on the Newfoundland and Labrador Shelf. The anomalies are normalized with respect to their standard deviations over the indicated base period. The deep red cells without numbers indicate the absence of <0°C water in these years.

REGION	INDEX	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
NAFO DIV. 3PS SPRING	BOTTOM TEMPERATURES	1971-2000	-1.56	-0.93	-0.94	-0.56	-0.42	-0.93	-0.03	-0.58	-0.30	0.46	0.65	-0.69	-0.19	-1.34	-0.25	0.38		-0.98	-0.89	-0.17
	BOTTOM TEMPERATURES <100 M	1971-2000	-1.65	-0.94	-1.07	-1.01	-0.73	-0.60	0.40	-0.46	0.45	1.29	1.58	-0.53	-0.30	-1.57	0.40	1.14		-0.58	-0.28	0.20
	THERMAL HABITAT AREA >2°C	1971-2000	-1.49	-1.02	-0.72	-0.79	-0.96	-0.86	-0.21	-0.61	-0.06	0.77	1.15	-0.62	-0.50	-0.85	-0.48	0.17		-0.63	-0.71	-0.09
	THERMAL HABITAT AREA <0°C	1971-2000	1.66	0.95	1.20	1.27	0.77	1.02	-0.38	0.75	-0.03	-0.52	-0.88	0.67	0.47	1.48	-0.98	-0.88		0.70	0.70	0.22
NAFO DIV. 3LNO SPRING	BOTTOM TEMPERATURES	1976-2000	-1.66	-1.49	-1.11	-0.72	-0.71	-0.70	-0.24	-0.53	0.23	0.60	0.58	0.05	0.00	-0.50	0.99	0.43		0.36	0.39	0.36
	BOTTOM TEMPERATURES <100 M	1976-2000	-1.17	-1.54	-1.22	-0.42	-0.99	-0.26	0.12	-0.81	0.98	1.82	0.57	-0.14	0.20	-0.98	1.25	0.75	0.58	0.18	0.31	0.95
	THERMAL HABITAT AREA >2°C	1976-2000	-1.54	-1.39	-1.13	-0.44	-0.46	-0.27	0.06	-0.17	0.82	2.00	0.90	-0.08	0.04	-0.10	2.05	1.18		0.91	0.68	1.12
	THERMAL HABITAT AREA <0°C	1976-2000	1.02	1.46	1.01	1.11	0.76	0.44	-0.44	0.58	-1.10	-1.65	-0.80	-0.66	-0.41	0.43	-2.13	-1.38	-1.81	-0.17	-0.32	0.10
NAFO DIV. 2J FALL	BOTTOM TEMPERATURES	1978-2000	-0.40	-0.04	-1.11	-0.61	-0.47	-0.39	1.38	0.74	1.05	1.91	1.25	1.74	1.43	2.28	2.56	2.51	1.54	2.39	1.34	1.51
	BOTTOM TEMPERATURES < 200 M	1978-2000	0.08	-0.32	-1.68	-1.71	-0.71	-0.45	1.01	0.39	0.32	1.36	0.47	1.78	0.81	1.44	2.28	2.35	1.09	2.57	0.41	0.66
	THERMAL HABITAT AREA >2°C	1978-2000	-0.76	-0.37	-0.96	-0.50	-0.28	0.45	0.92	1.01	0.73	1.28	0.54	1.53	1.14	1.57	2.17	2.70	0.65	2.96	0.27	0.86
	THERMAL HABITAT AREA <0°C	1978-2000	0.05	-0.32	1.15	0.80	-0.14	0.59		-0.58									-0.51			
NAFO DIV. 3K FALL	BOTTOM TEMPERATURES	1979-2000	-0.67	-0.34	-1.51	-1.32	-0.83	0.43	0.52	1.17	0.80	1.96	0.64	0.86	1.11	1.35	1.91	1.82	0.86	2.63	1.26	1.44
	BOTTOM TEMPERATURES < 300 M	1979-2000	-0.69	-0.38	-1.27	-1.80	-1.39	0.42	0.46	1.04	1.17	1.47	0.32	0.51	0.94	1.31	1.74	1.60	0.37	2.33	0.29	0.58
	THERMAL HABITAT >2°C	1979-2000	-1.19	-0.23	-1.34	-1.26	-0.79	0.37	0.53	1.17	1.10	1.87	0.79	0.62	1.21	1.29	1.32	1.67	0.74	2.25	0.87	0.68
	THERMAL HABITAT AREA <0°C	1979-2000	0.33	0.70	1.28	0.93	0.56	-1.11	-1.07		-0.38		-0.78	-0.99		-1.04			-1.09	-1.14	-0.44	0.91
NAFO DIV. 3LNO FALL	BOTTOM TEMPERATURES	1990-2008	-0.51	-0.21	-1.37	-1.79	-1.68	-0.05	-0.02	0.16	0.37	2.14	-0.07	0.15	-0.02	0.05	0.86	1.81	0.05	0.10	-0.14	0.03
	BOTTOM TEMPERATURES <100 M	1990-2008	0.00	-0.98	-0.89	-1.30	-1.47	0.34	0.68	0.47	0.68	2.52	0.06	-0.33	-0.52	-0.11	0.47	1.51	-0.27	-0.88	-0.39	0.08
	THERMAL HABITAT AREA >2°C	1990-2008	-1.18	-0.42	-0.92	-1.83	-0.87	-0.08	0.35	0.26	0.84	2.96	0.17	0.24	-0.40	-0.04	0.55	0.53	-0.06	-0.09	-0.53	0.88
	THERMAL HABITAT AREA <0°C	1990-2008	0.37	1.31	1.37	1.70	1.62	-0.74	-0.15	0.30	-0.52	-1.30	0.51	-0.11	-0.57	-0.01	-1.34	-1.08	-1.27	-0.09	0.55	0.14

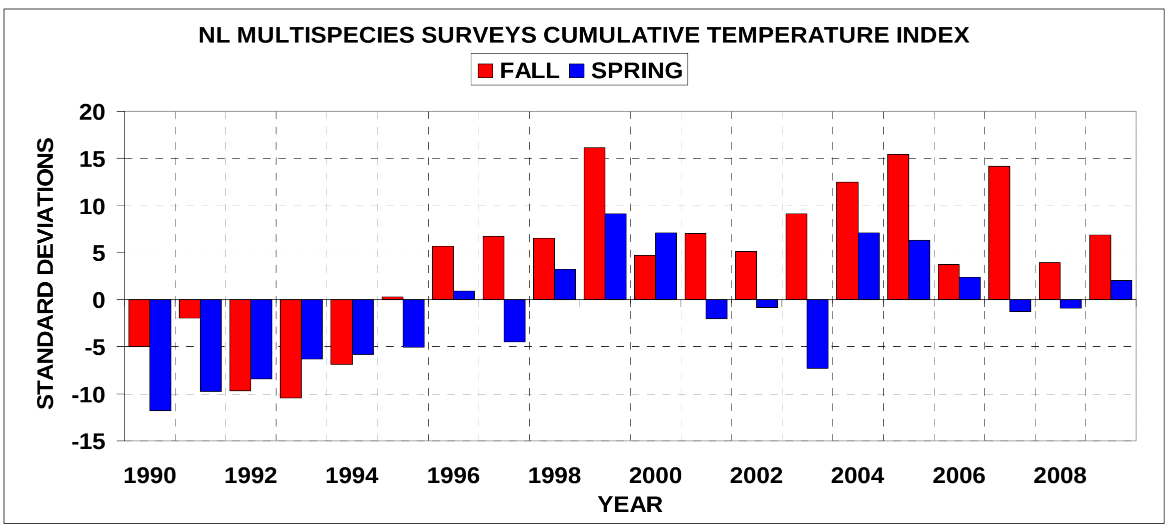


Figure 17. Composite index derived by summing the standardized anomalies from Table 5 for the spring and fall multi-species surveys.

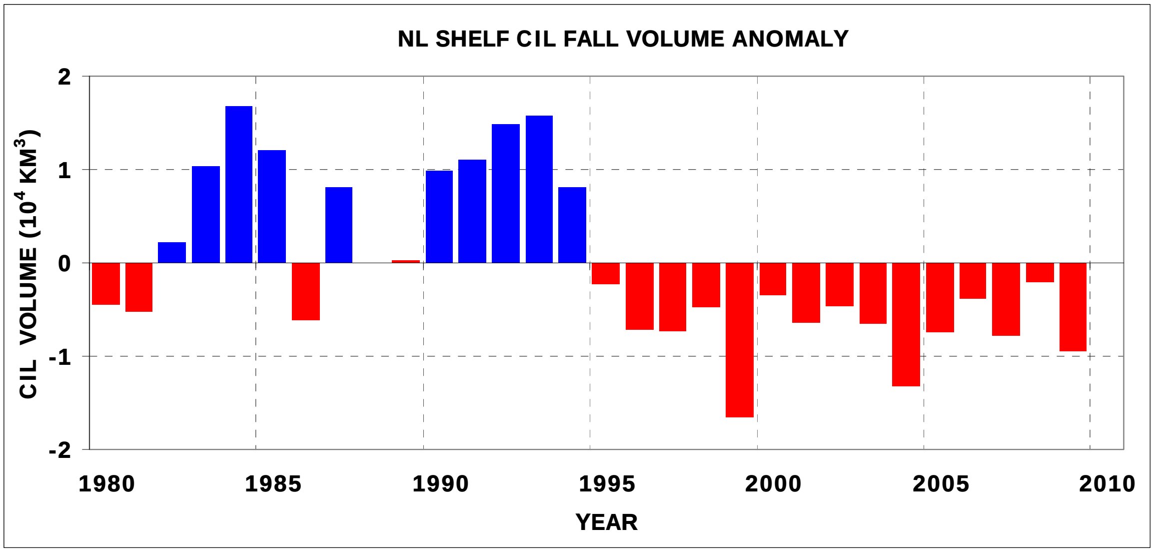
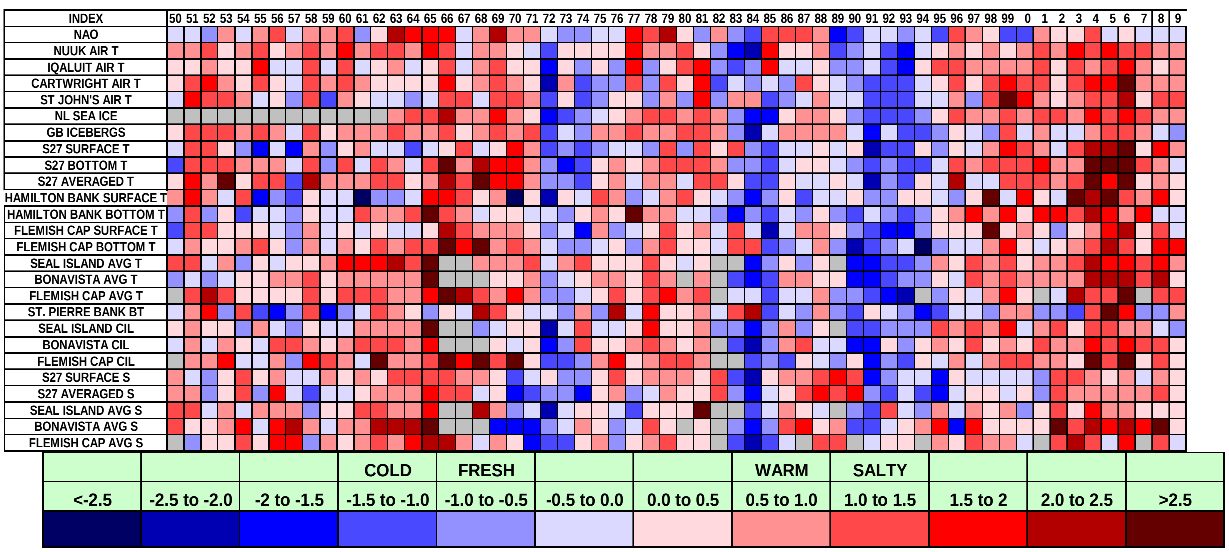


Figure 18. The extent of CIL (<0^{O}C) volume anomaly on the NL shelf bounded by NAFO Divs. 2J3KL based on the fall multi-species temperature data profiles.

Table. 6. 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 1971-2000.



A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2009 are displayed in Table 6 as color-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. 19).

To further visualize the components, each time series was then grouped according to the type of measurement; meteorological, 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 indicates a decreasing trend during the past three years with the 2009 value ranking 34th in the 60-year record. During 2009, 72/112 environmental time series presented in Tables 2-5 indicates a warming climate with saltier water and less CIL and sea-ice, however 30 of these were not significant and were within ±0.5 SD of normal. In fact 54/112 indices were within ±0.5 SD of the mean during 2009.

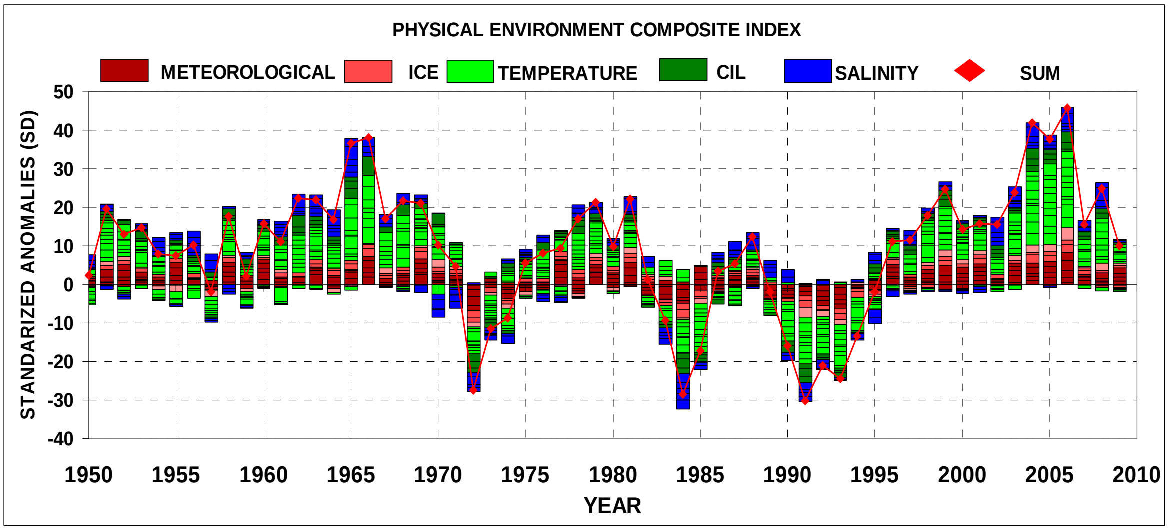


Figure 19. Composite climate index derived by summing the standardized anomalies from Table 6 together with their individual components.

Highlights for 2009:

- Out of the 112 environmental time series analyzed, 54 were within ±0.5 SD and are not considered significantly different from normal.

- 72/112 indices indicated warmer temperatures, saltier water, less CIL and sea-ice, but only 42 were considered significant at greater than +0.5 SD or less than -0.5 SD.

- Annual air temperatures were above normal in Newfoundland and Labrador by 1°C (1 SD) at Cartwright, and by 1°C (1.4 SD) at St. John's, a significant decrease over the record highs of 2006 (2.6 SD).

- The annual sea ice extent on the NL Shelf remained below normal (0.5 SD) for the 15th consecutive year, winter extent was below normal by 0.9 SD, spring extent slightly below normal (0.3 SD) however it was the most extensive since 1994.

- 1204 icebergs were detected south of 48°N on the Northern Grand Bank, up from 976 in 2008 and well above (0.7 SD) the long term mean of 759.

- Annual surface temperatures at Station 27 were 0.4°C (0.7 SD) above normal.

- After 13th consecutive years of above normal values, bottom temperatures at Station 27 were slightly below normal, albeit by only -0.02°C (0.1 SD).

- The cross sectional area of <0°C (CIL) water mass, while slightly below normal (0.4 SD) on the eastern Newfoundland Shelf for the 15th consecutive year, it was above normal (0.6 SD) on the southern Labrador Shelf, the most extensive since 1994.

- The upper layer baroclinic transport of the shelf-slope component of the Labrador Current off southern Labrador increased significantly to the highest in the time series at 2.2 SD above normal and through the Flemish Pass it increased to 1 SD above normal.

- Averaged fall bottom temperatures were above normal by 0.6°C (1.4 SD) in Div. 3K, by 0.5°C (1.5 SD) in 2J and about normal in Divs. 3LNO.

- The volume of CIL water (<0°C) on the NL shelf during the fall remained below normal (1 SD) for the 15th consecutive year.

- The composite climate index for the NL region ranked 34th in 60 years of observations which represents a decreasing trend since the record high in 2006.

ACKNOWLEDGMENTS

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REFERENCES

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.

Dickson, R. R., Meincke, J., Malmberg, S. A. and Lee, A. J. 1988. The "Great Salinity Anomaly” in the northern North Atlantic 1968-82. Progr. Oceanogr. 20: 103-151.

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.

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

Petrie, B., R. G. Pettipas, and W. M. Petrie. 2009. An overview of meteorological, sea ice and sea surface temperature conditions off eastern Canada during 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/In Prep.

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.