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Newfoundland & Labrador Region | **Région de Terre-Neuve et Labrador**

An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2010

Évaluation de l'environnement océanographique physique sur la plate-forme continentale de Terre-Neuve et du Labrador en 2010

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ABSTRACT

The North Atlantic Oscillation (NAO) index, a key indicator of climate conditions in the Northwest Atlantic, was at a record low in 2010 and as a consequence, outflow of arctic air masses to the Northwest Atlantic was much weaker than normal. This resulted in a broad-scale warming throughout the Northwest Atlantic from West Greenland to Baffin Island to Newfoundland relative to 2009. Air temperatures were above normal by 2-3 standard deviations (SD) and at a record high at some northern sites on Baffin Island and the Labrador Coast. Sea-ice extent and duration on the Newfoundland and Labrador Shelf decreased in 2010 for the 15th consecutive year, with the annual average reaching a record low. As a result of these and other factors, local water temperatures on the Newfoundland and Labrador Shelf increased compared to 2009 and were above normal in most 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 in 2010. At Station 27 off St. John's, the annual depth-averaged water temperature increased to 2 SD above normal, the second highest on record. Annual surface and bottom temperatures at Station 27 were also above normal by 0.6°C (1 SD) and 0.64 °C (1.7 SD) respectively. Bottom temperatures at Station 27 were slightly below normal in 2009. The area of the Cold-Intermediate-Layer (CIL) water mass with temperatures <0 °C on the eastern Newfoundland Shelf during 2010 was below normal by 0.6 SD off Bonavista and 1 SD off Seal Island Labrador. Average temperatures conditions along sections off eastern Newfoundland and southern Labrador were above normal while salinities were generally below normal. Spring bottom temperatures in NAFO Divs. 3Ps and 3LNO during 2010 were above normal by up to 1 SD and as a result the area of the bottom habitat covered by water <0 °C was significantly below normal. During the fall, bottom temperatures in 2J were at record high values, almost 2 SD above normal and in Divisions 3K and 3LNO they were >1 SD above normal. The volume of CIL water on the NL shelf during the fall was below normal (3rd lowest since 1980) for the 16th consecutive year. A composite climate index derived from 26 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 to the 2nd highest in 61 years, indicating warmer than normal conditions throughout the area.

RÉSUMÉ

En 2010, l'indice d'oscillation nord-atlantique, un indicateur clé des conditions climatiques dans l'Atlantique Nord-Ouest, a été à un niveau record bas et, par conséquent, le courant d'air arctique vers l'Atlantique Nord-Ouest a été beaucoup plus faible que la normale. Cela a entraîné un réchauffement à grande échelle dans l'ensemble de l'Atlantique Nord-Ouest par rapport à 2009, de l'ouest du Groenland jusqu'à l'île de Baffin et à Terre-Neuve. La température de l'air a été supérieure à la normale de 2 à 3 écarts-types et à un sommet record à certains sites du nord de l'île de Baffin et de la côte du Labrador. L'étendue et la durée des glaces de mer sur le plateau de Terre-Neuve et du Labrador ont diminué en 2010, pour la 15^{e} année consécutive, la moyenne annuelle atteignant un niveau record bas. En raison de ces facteurs et autres, la température locale de l'eau sur le plateau de Terre-Neuve et du Labrador a augmenté par rapport à 2009 et a été au-dessus de la normale dans la plupart des régions. La salinité sur le plateau de Terre-Neuve a été inférieure à la normale pendant presque toutes les années 1990, a augmenté au-dessus de la normale pendant presque toute la dernière décennie, mais a diminué jusqu'à des conditions plus fraîches que la normale dans plusieurs régions en 2010. À la station 27, au large de St. John's, la température annuelle moyenne par rapport à la profondeur a augmenté, se situant à 2 écarts-types au-dessus de la normale, soit le deuxième niveau record le plus élevé. La température annuelle en surface et de fond à la station 27 a également été supérieure à la normale de 0,6 °C (1 écart-type) et de 0,64 °C (1,7 écart-type), respectivement. La température de fond à la station 27 était légèrement inférieure à la normale en 2009. La température de la masse d'eau de l'aire de la couche intermédiaire froide (CIF), inférieure à 0 °C dans la partie est du plateau continental de Terre-Neuve en 2010, était inférieure à la normale de 0,6 écart-type au large de Bonavista et de 1 écart-type au large de l'île Seal, au Labrador. Les conditions de température moyenne le long des sections au large de l'est de Terre-Neuve et du sud du Labrador étaient supérieures à la normale, tandis que la salinité était généralement inférieure à la normale. La température de fond au printemps dans les div. 3Ps et 3LNO de l'OPANO a été en 2010 supérieure à la normale jusqu'à 1 écart-type et, par conséquent, la superficie de l'habitat de fond ayant de l'eau d'une température inférieure à 0 °C était considérablement inférieure à la normale. Durant l'automne, la température de fond dans la div. 2J a atteint des valeurs élevées record, soit près de 2 écarts-types au-dessus de la normale, et, dans les divisions 3K et 3LNO, elle a été supérieure à 1 écart-type au-dessus de la normale. Le volume d'eau de la CIF sur le plateau de Terre-Neuve durant l'automne a été inférieur à la normale (3^{e} plus bas depuis 1980) pour la 16^{e} année consécutive. Un indice climatique composite obtenu à partir de 26 séries chronologiques météorologiques, de glace, de température océanographique et de salinité indique un sommet en 2006, une tendance à la baisse de 2007 à 2009, puis une hausse abrupte en 2010, se situant au 2^{e} rang le plus élevé en 61 ans, ce qui indique des conditions plus chaudes que la normale pour l'ensemble de la région.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region (Fig. 1) during 2010 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 1981 to 2010 in accordance with the recommendations of the World Meteorological Organization. The information presented for 2010 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 2010. 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 2009 was presented in Colbourne et al. 2010.

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. Bottom temperature anomaly maps are still referenced to the 1971-2000 mean. 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 2010 are presented as colored 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 colored 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 north westerly 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). 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. As a consequence, outflow of arctic air masses to the Northwest Atlantic was much weaker than normal resulting in a broad-scale warming throughout the Northwest Atlantic from West Greenland to Baffin Island to Newfoundland relative to 2009 (Table 2).

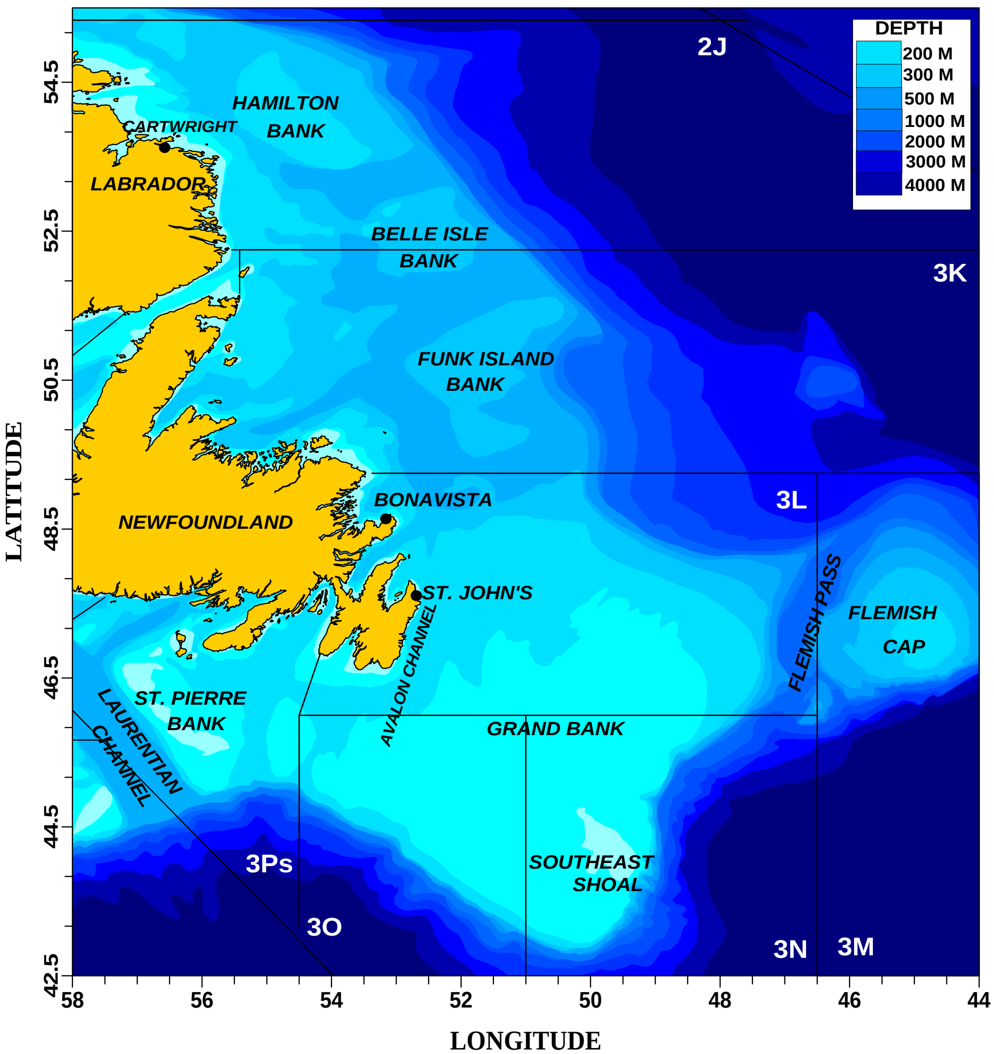

Figure 1. Map showing NAFO Divisions and bathymetric features of the Newfoundland and southern Labrador Shelf.

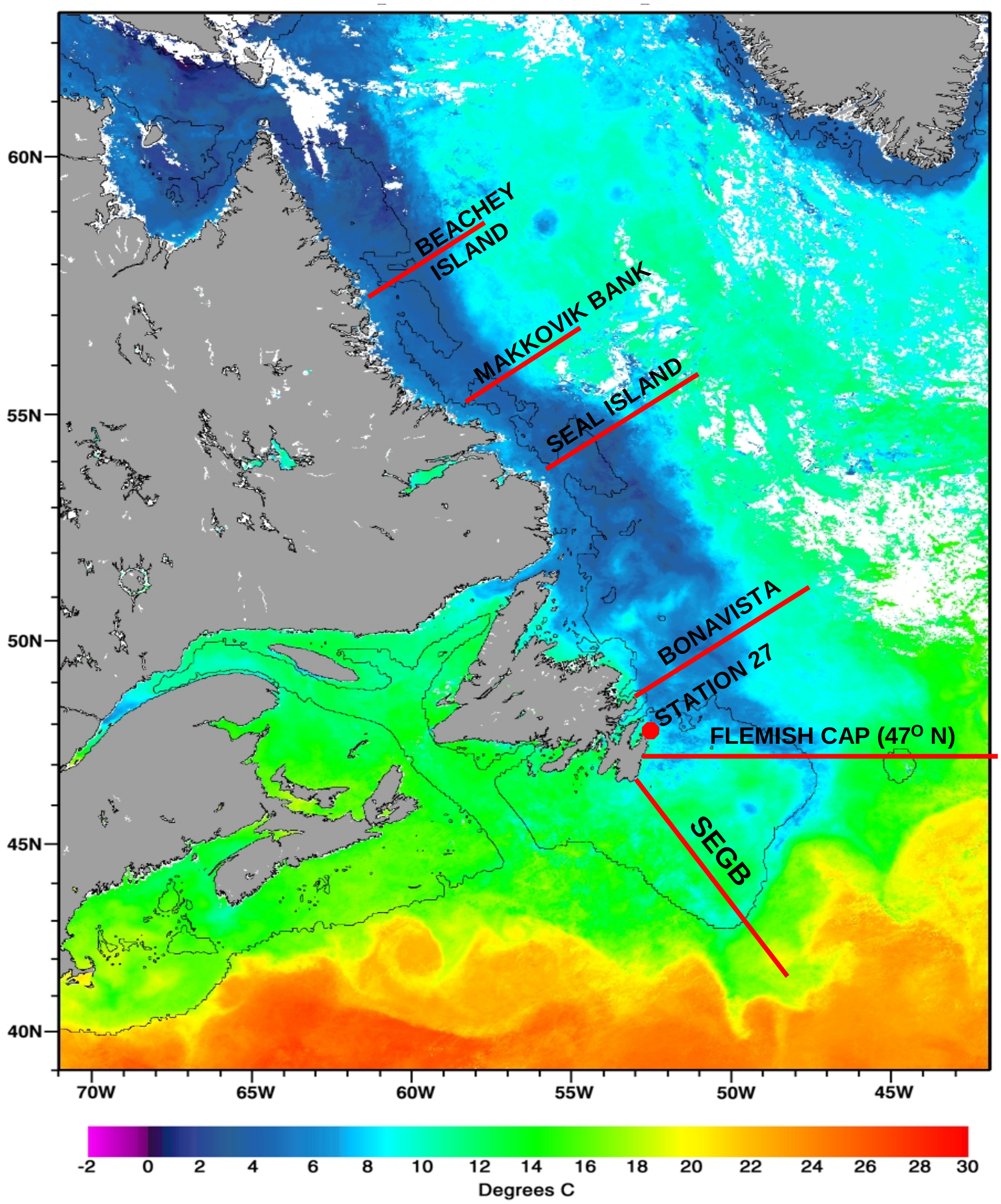

Figure 2a. Map showing summer SST during September 2010, Station 27 and the standard sections sampled during 2010 (SST map courtesy of the Ocean Research and Monitoring Section, BIO).

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 (January-March) 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). Annual temperature at Cartwright on the mid-Labrador Coast broke a 77-year record at 2.5 SD above normal in 2010 while Iqaluit broke a 65 year record at 2.7 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 8 years with a record high set in 2010 (Fig. 3).

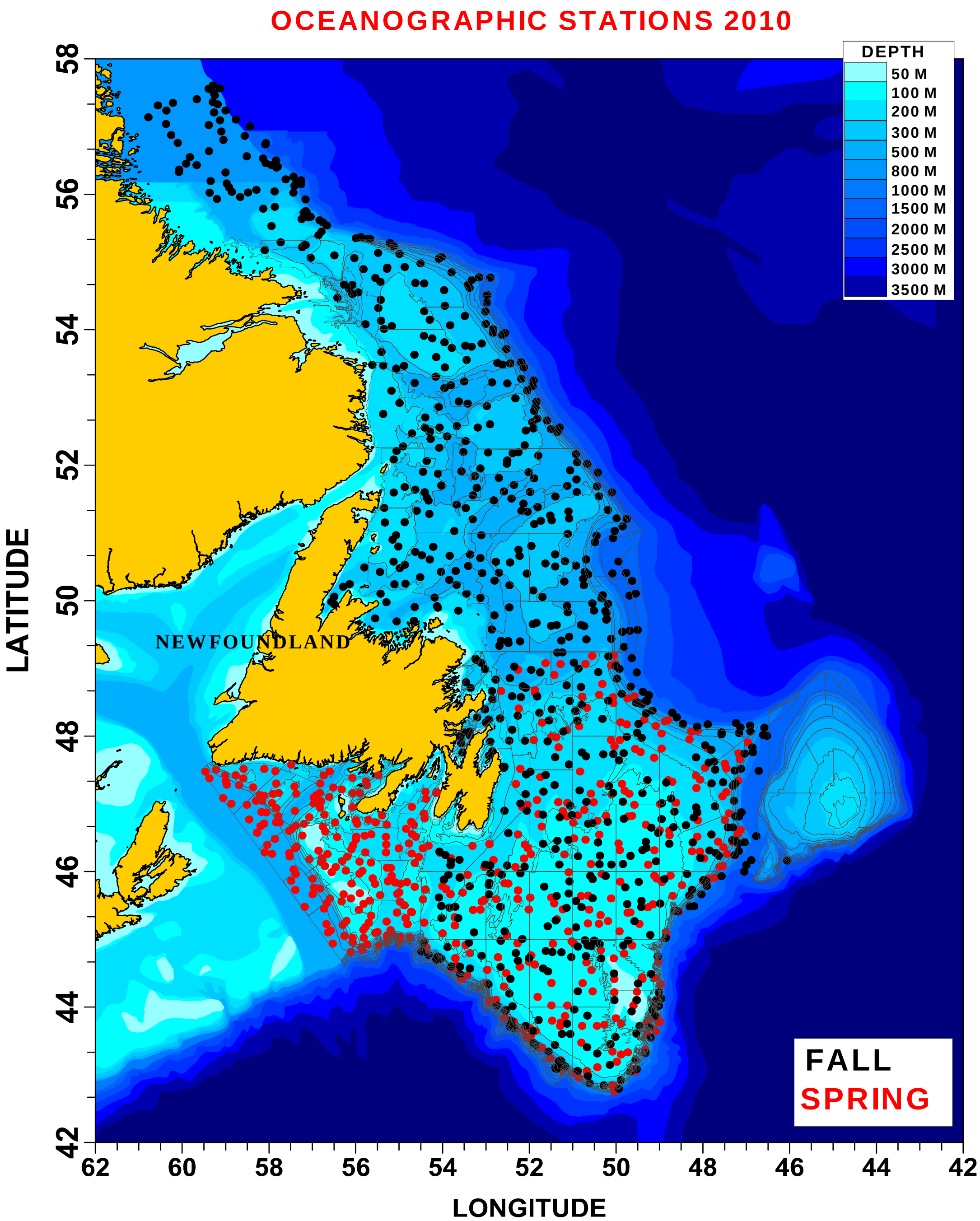

Figure 2b. Map showing the positions of trawl-mounted CTD profiles obtained from spring (red dots) and fall (black dots) multi-species assessment surveys during 2010.

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°-55°N) (Fig. 4a) continued to be below normal for the 15th consecutive year and was at a 48 year record low during the winter of 2010 (Fig. 4b) while the spring extent was the 5th lowest (Fig. 4c, Table 2). 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 one iceberg drifted south of 48°N onto the Northern Grand Bank during 2010 compared with 1204 in 2009. The 111-year average is 478 and that for 1981-2010 is 761. 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 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 15 years of the past 2 decades were either near-normal or warmer than normal with 2010 showing the warmest in the time series (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. (2011).

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

INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
ARCTIC OSCILLATION	1.02	0.20	0.44	0.08	0.53	-0.27	-0.46	-0.04	-0.27	0.11	-0.05	-0.16	0.07	0.15	-0.19	-0.38	0.14	0.27	0.18	-0.33	-1.04
(ICELAND-AZORES) NAO	1.08	0.37	0.27	0.90	0.42	1.30	-1.35	-0.58	-0.29	1.21	1.12	-0.91	-0.32	-0.34	-0.99	0.51	-0.34	0.33	0.53	0.17	-2.86
ATLANTIC MULTIDECADAL OSCILLATION	-0.12	-0.65	-1.14	-1.08	-0.86	0.83	-0.24	0.37	2.14	0.78	0.27	0.79	0.49	1.39	1.25	1.72	1.59	0.94	0.89	0.36	2.07
NUUK WINTER AIR TEMP	-0.56	-0.20	-0.81	-1.84	-0.40	-0.85	0.68	-0.19	-0.03	-0.18	0.05	0.54	-0.18	0.90	0.66	1.17	0.93	1.01	-0.69	0.60	1.81
NUUK ANNUAL AIR TEMP	-0.69	-0.35	-1.44	-1.61	-0.64	-0.24	0.35	0.08	0.22	-0.21	0.39	0.80	0.19	1.27	0.62	1.07	0.75	0.50	0.19	0.50	2.62
IQALUIT WINTER AIR TEMP	-0.81	-1.39	-0.62	-1.72	-0.51	0.01	0.32	0.25	-0.47	0.01	0.32	0.47	0.05	0.46	0.88	-0.33	0.58	1.21	-0.72	0.11	2.21
IQALUIT ANNUAL AIR TEMP	-1.16	-0.49	-1.67	-1.72	-0.35	0.55	0.53	0.28	0.16	0.11	0.44	0.56	-0.10	0.80	0.12	0.88	1.39	0.15	-0.11	0.49	2.73
CARTWRIGHT WINTER AIR TEMP	-1.22	-1.39	-1.55	-1.47	-1.02	-0.76	0.62	0.23	0.79	0.41	0.30	-0.01	0.37	0.21	1.75	-0.01	0.70	0.88	-0.84	0.17	2.82
CARTWRIGHT ANNUAL AIR TEMP	-1.26	-1.57	-1.35	-1.31	-0.59	-0.27	0.53	-0.34	0.62	1.13	0.53	0.61	-0.29	0.43	1.10	0.93	1.77	0.05	0.15	0.40	2.54
BONAVISTA WINTER AIR TEMP	-1.74	-0.81	-1.07	-1.71	-1.70	-0.43	0.96	-0.85	0.61	1.90	1.18	0.27	0.06	-1.07	0.77	0.32	1.52	0.22	-0.07	0.41	1.47
BONAVISTA ANNUAL AIR TEMP	-0.62	-1.80	-1.76	-1.75	-0.66	-0.73	0.58	-0.86	0.60	1.45	0.83	0.63	-0.14	0.53	0.97	1.16	1.72	0.01	0.74	0.54	1.63
ST. JOHN'S WINTER AIR TEMP	-2.12	-1.12	-1.66	-1.50	-1.20	-0.85	0.37	0.16	0.21	1.24	1.43	-0.60	0.24	-0.63	0.91	0.67	1.62	0.24	-0.09	1.05	1.24
ST. JOHN'S ANNUAL AIR TEMP	-0.50	-1.38	-1.72	-1.49	-0.46	-0.74	0.28	-1.07	0.61	1.89	1.00	0.28	-0.37	0.38	0.59	0.73	1.59	-0.07	0.81	0.88	1.71
NL SEA-ICE EXTENT (Annual)	1.20	1.59	1.32	1.61	1.13	0.10	-0.85	-0.16	-0.53	-0.73	-0.43	-0.91	-0.55	-0.19	-1.42	-0.90	-1.38	-0.60	-0.35	-0.09	-1.63
NL SEA-ICE EXTENT (Winter)	1.12	1.13	1.26	1.68	1.26	0.35	-0.52	0.08	-0.74	-0.53	-0.26	-0.87	-0.57	-0.21	-1.69	-0.67	-1.26	-0.91	-0.15	-0.40	-1.93
NL SEA-ICE EXTENT (Spring)	0.93	1.87	1.15	1.51	0.95	-0.17	-1.23	-0.42	-0.14	-0.94	-0.59	-0.84	-0.48	-0.03	-0.88	-1.20	-1.46	-0.06	-0.59	0.53	-1.15
ICEBERG COUNT GRAND BANKS	0.04	1.86	0.17	1.52	1.54	1.02	-0.24	0.38	0.95	-1.15	0.12	-1.04	0.17	0.25	-0.78	-1.16	-1.18	-0.68	0.32	0.67	-1.18

TIME TRENDS IN TEMPERATURE AND SALINITY

Station 27 (47°32.8'N, 52°35.2'W), located in the Avalon Channel off Cape Spear NL (Fig. 1), was sampled 41 times (34 CTD profiles, 7 XBT profiles) during 2010 a significant decrease over previous years. There was no sampling in January or February. Depth versus time contours of the annual temperature and salinity cycles and the corresponding anomalies for 2010 are displayed in Figs. 6 and 7. The cold, near-isothermal water column during March to late April has temperatures ranging from near 0 °C to –0.5 °C. These temperature persisted throughout the year below 150 m. Upper layer temperatures warmed to >2 °C by late April and to >14 °C by August, after which the fall cooling commenced with temperatures decreasing to 4 °C by early December. Temperatures were above normal throughout the year over the entire water column except for the upper layer negative anomaly during late September and early October centered at about 30 m depth.

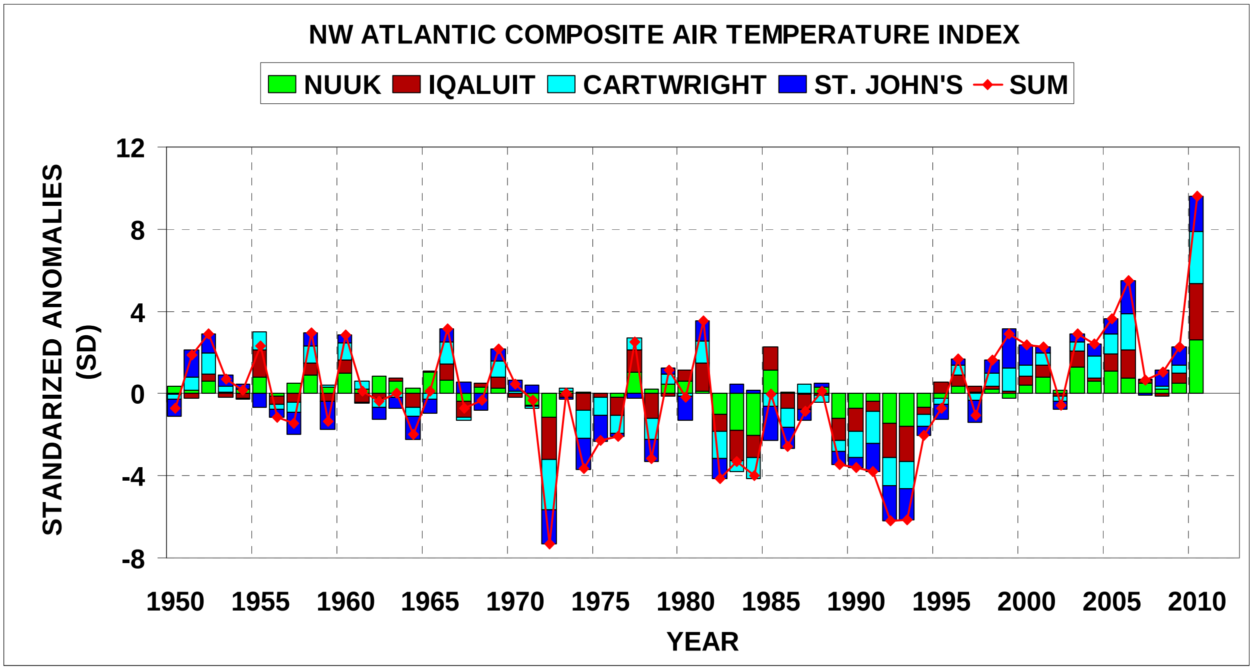

Figure 3. Standardized annual air temperature anomalies at Nuuk, Iqaluit, Cartwright and at St. John's relative to the 1981-2010 means.

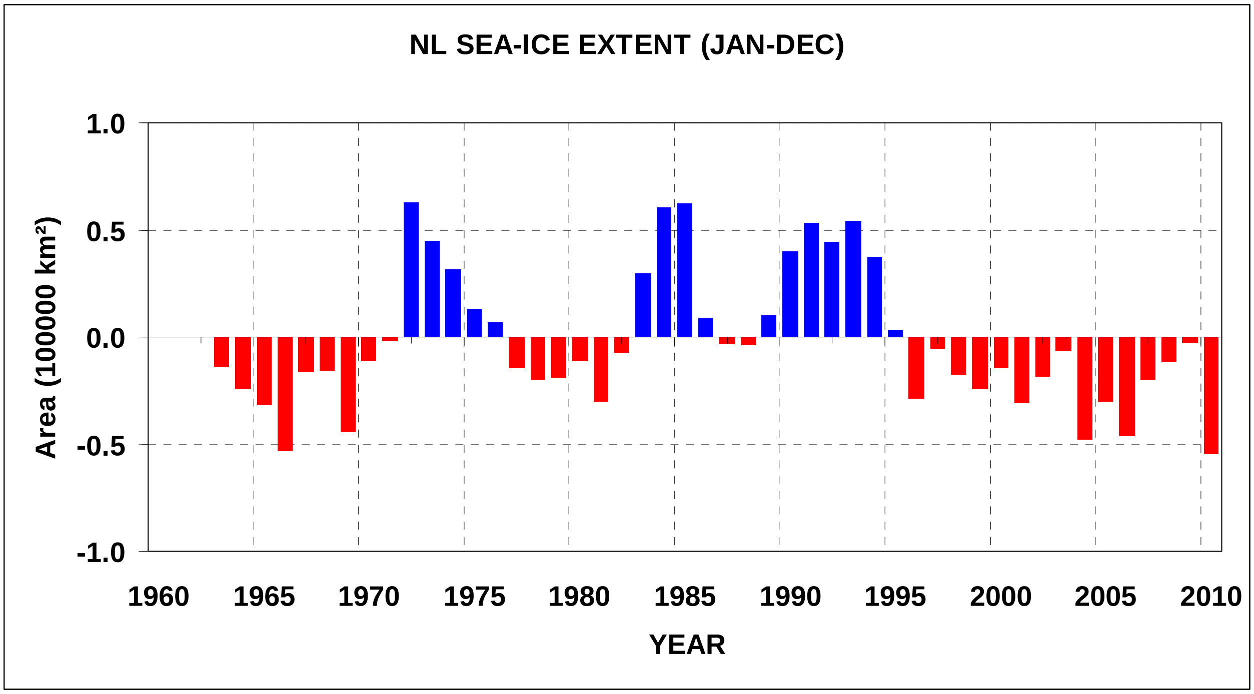

Figure 4a. The annual sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf relative to the 1981-2010 means.

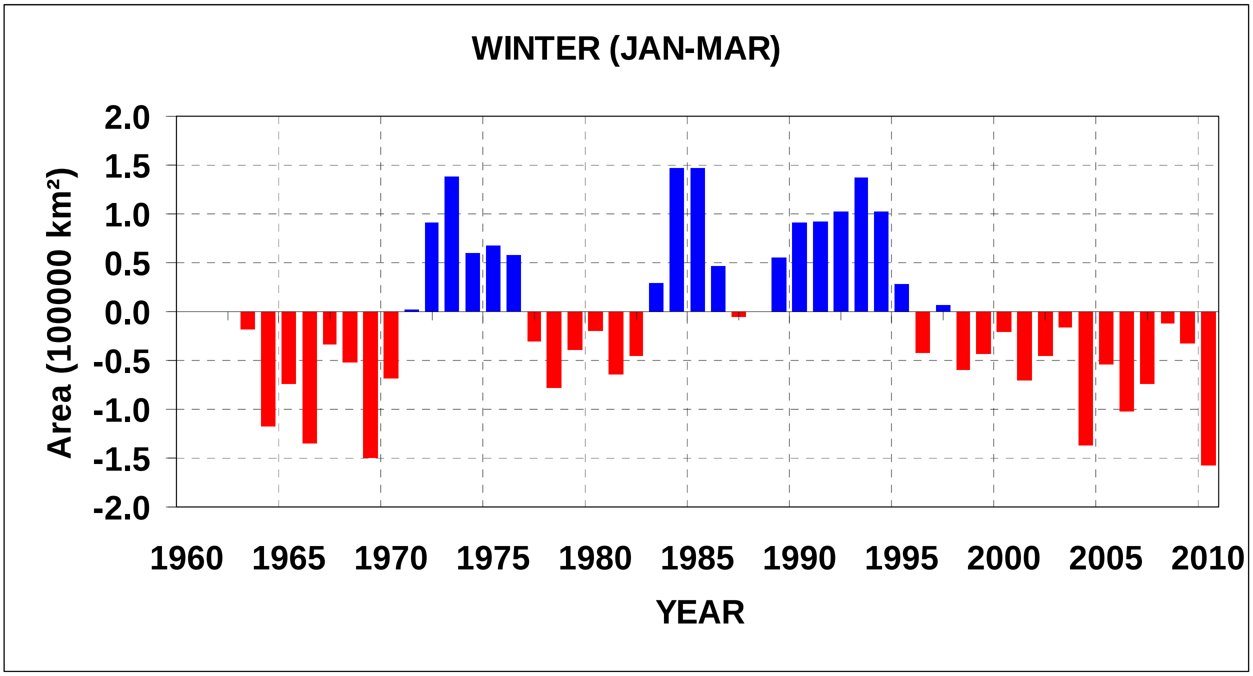

Figure 4b. Sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf during winter (January-March) relative to the 1981-2010 means.

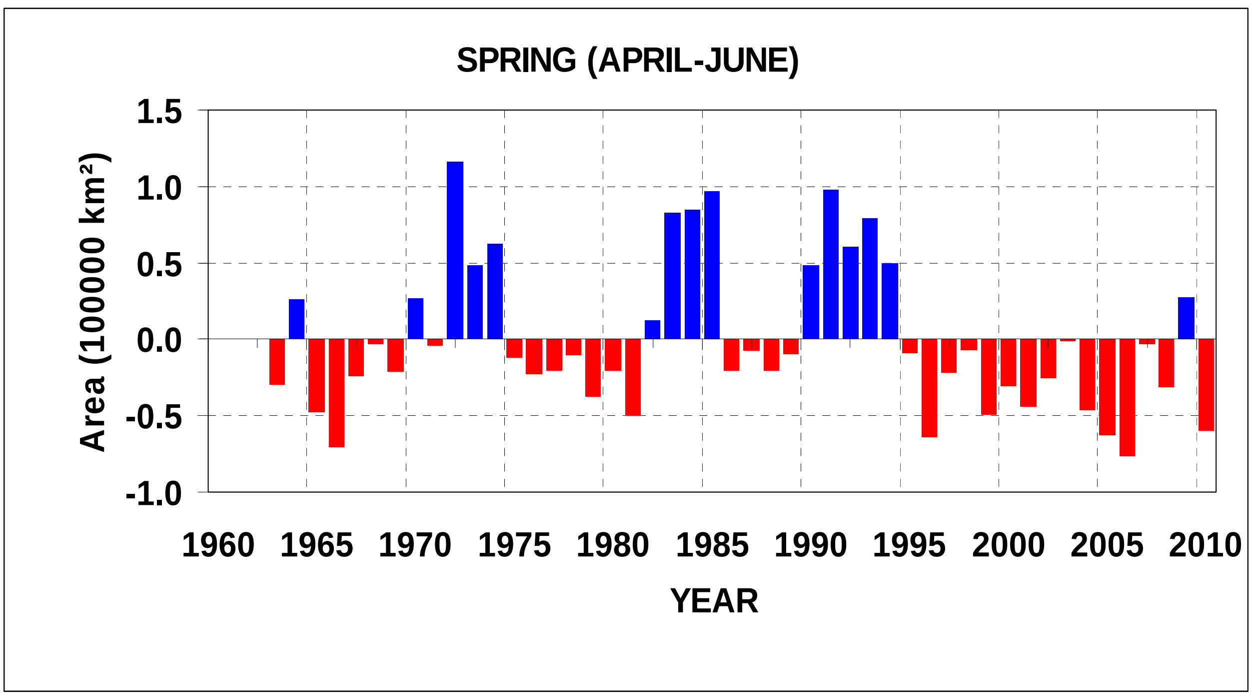

Figure 4c. Sea-ice areal extent anomalies on the Newfoundland and southern Labrador Shelf during the spring (April-June) relative to the 1981-2010 means.

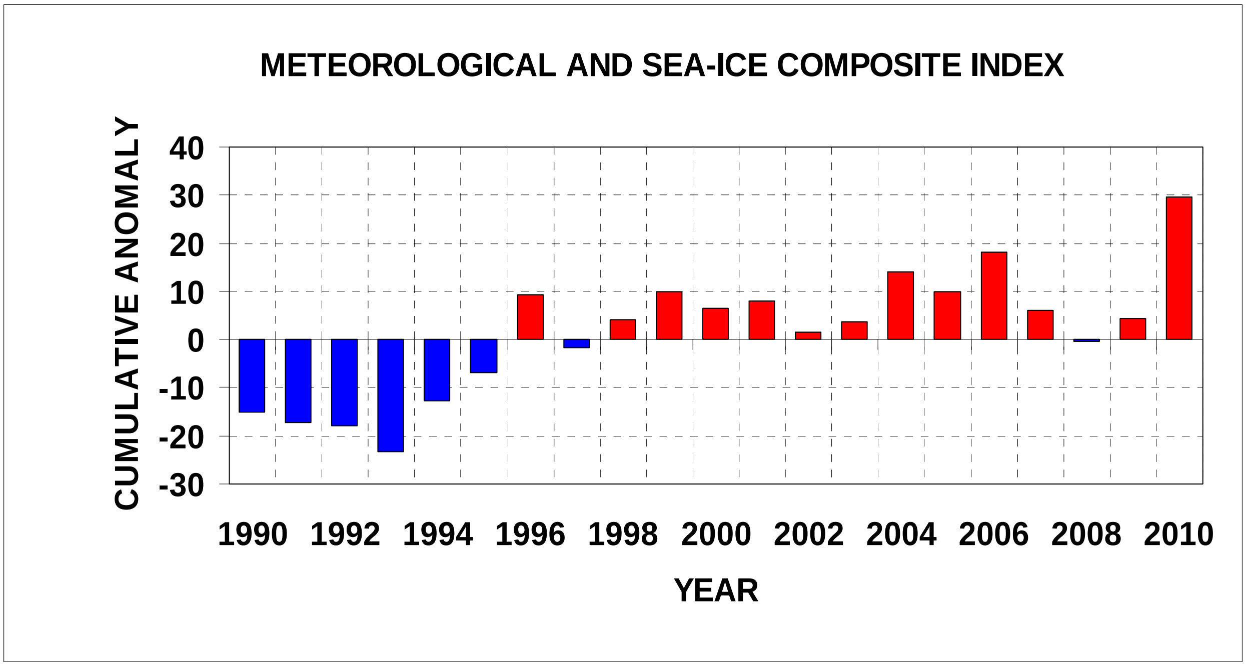

Figure 5. Meteorological and sea-ice composite index derived by summing the standardized anomalies from Table 2.

Upper layer salinities reached maximum values in late winter and early spring (~32.2) and decreased to <30.8 by late September. Except during mid-summer these values were generally below normal. Below 100 m, salinities ranged from 32.6 to 33 throughout the year, slightly below normal except during April. 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 2010 a colder and saltier than normal anomaly appeared in late August lasting until early October centered at approximately 30 m depth. This was possibly due to local upwelling of colder and saltier water.

In general, Station 27 temperatures were below normal from 1990 to 1997, reaching minimum values in 1991 when they dipped to less than 1-2 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 near 1 SD above normal in 2010. 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 (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) (Fig. 9a, Table 3). Annual surface salinities at Station 27 decreased from +0.2 SD in 2009 to about -0.7 SD in 2010, the freshest since 1995. In 2010 the water column average salinity was the lowest since the early 1990s. Upper-layer salinities during the previous several 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 (Fig. 9b, Table 3).

On Hamilton and St. Pierre banks surface temperatures increased from 2009 values to near 1 SD above normal whereas on Flemish Cap they were slightly below normal in 2009 and just above normal in 2010. On St. Pierre Bank, Flemish Cap and Hamilton Bank, near-bottom temperatures were above normal values by 1-2 SD in 2010. Temperature data obtained from thermographs deployed at inshore sites during the summer months (July-September) at 5-10 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 2008-10 temperatures varied about the mean with no clear pattern (Table 3). On the Flemish Cap surface salinities were slightly above normal compared to Hamilton Bank and at Station 27.

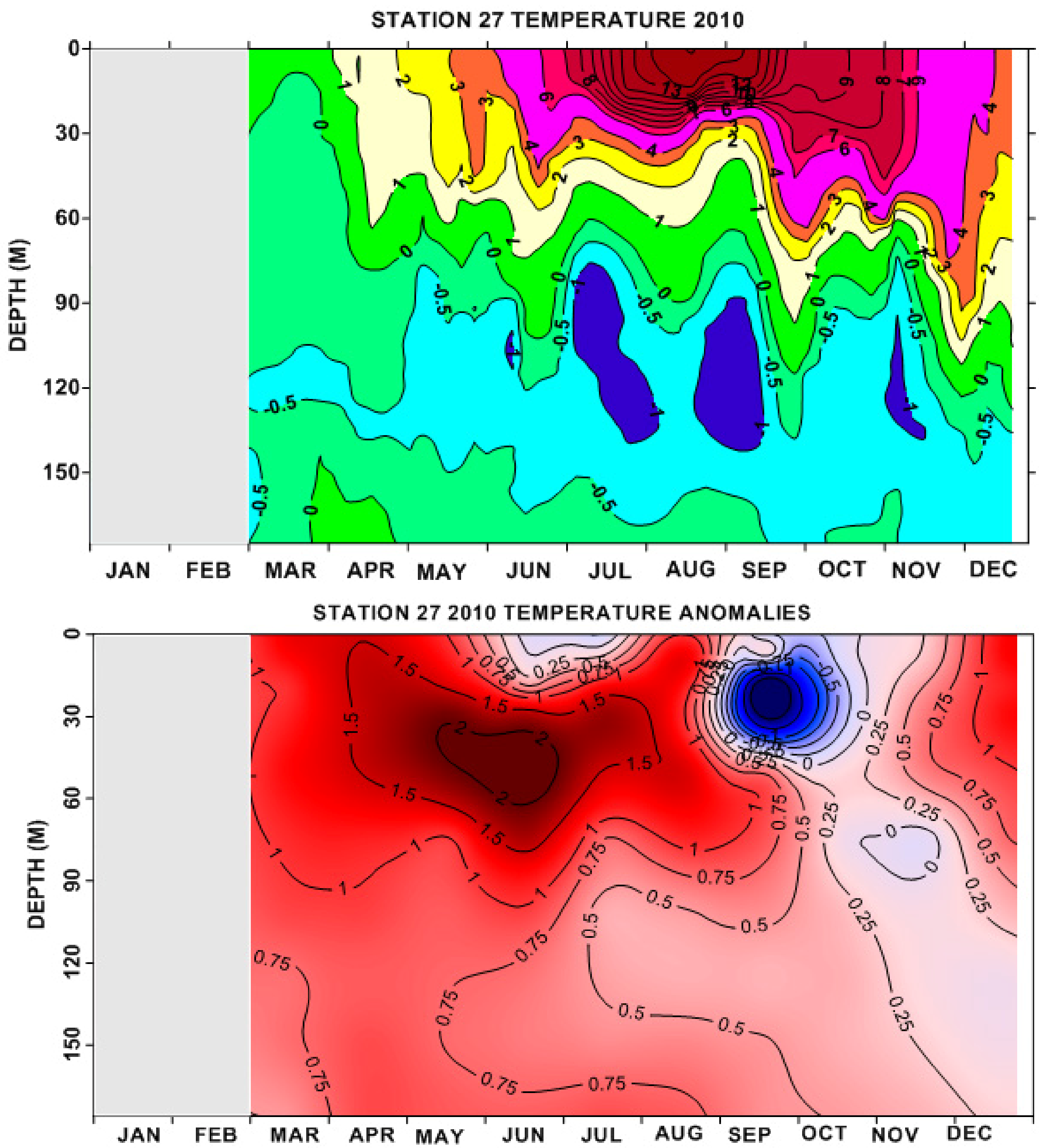

Figure 6. Contours of temperature (°C) and temperature anomalies as a function of depth at Station 27 during 2010.

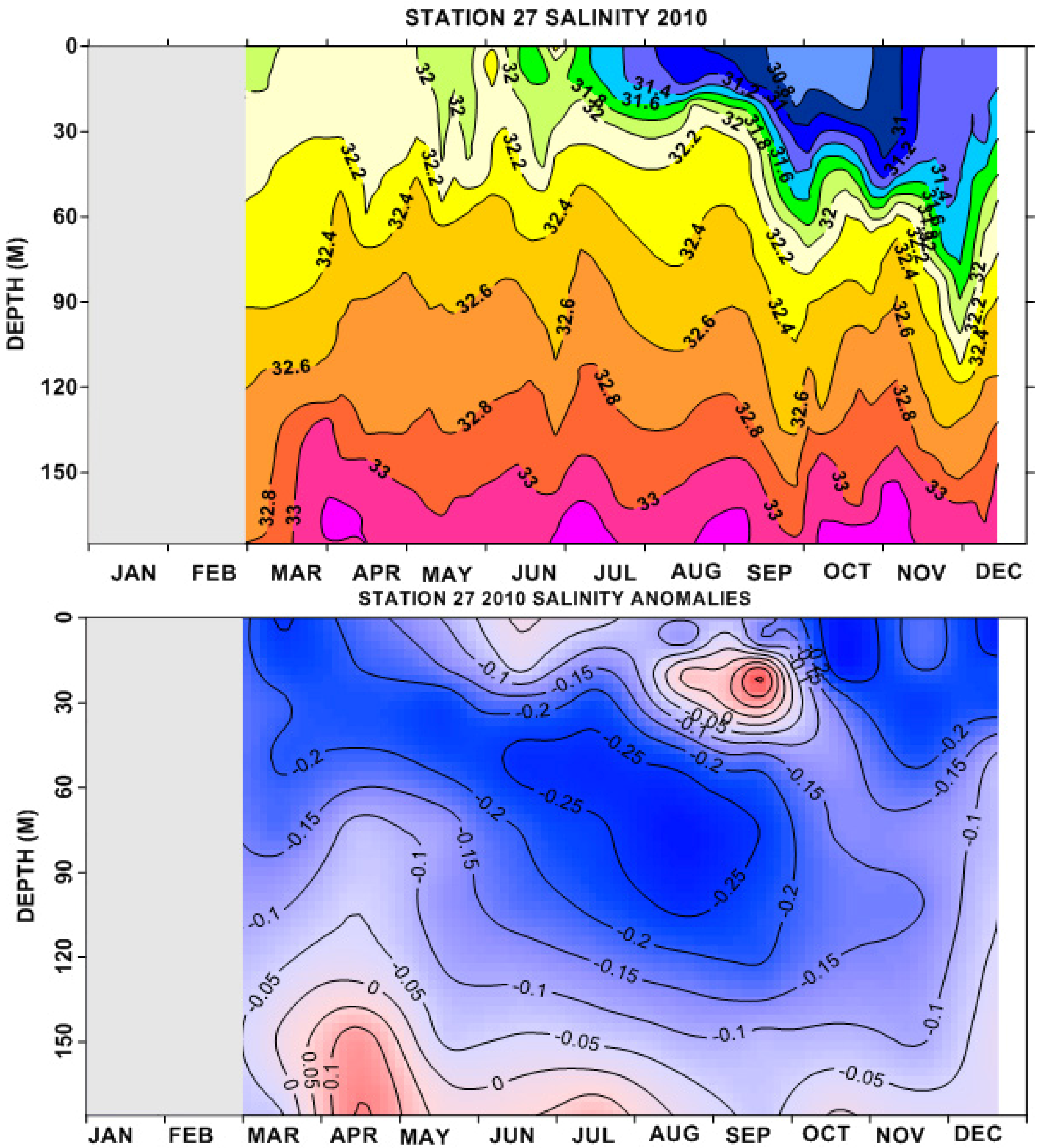

Figure 7. Contours of salinity and salinity anomalies as a function of depth at Station 27 for 2010.

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 to 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. The spring values show similar patterns with the 2010 values at 0.7 SD below normal. 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

2010 the annual averaged MLD and the winter (March only) values were shallower than normal while the spring value was deeper than normal (Table 3).

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.

	STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (FIXED SITES)																					
INDEX	LOCATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	HAMILTON BANK	0.02	-0.85	-0.63	-0.30	-0.16	-0.47	-0.41	-0.63	1.79	-0.20	1.17	-0.12	-0.43	1.64	1.25	1.64	0.80	0.23	2.05	0.10	0.94
SURFACE	FLEMISH CAP	-0.61	-1.42	-1.25	-1.63	-0.76	-0.21	0.05	0.24	2.51	0.01	0.59	0.07	-0.88	-0.05	0.27	1.38	1.96	0.20	0.96	-0.38	0.16
TEMPERATURE	STATION 27	-0.34	-2.40	-1.53	-1.49	-0.12	-0.87	-0.12	-0.73	0.31	1.09	0.57	0.38	-0.46	0.70	1.25	1.26	2.19	-0.04	1.16	0.17	0.88
	ST. PIERRE BANK	-1.61	-0.09	-1.24	-0.58	-0.67	0.56	0.22	-0.56	0.71	0.88	1.17	-0.90	-0.08	-0.65	0.11	2.21	2.19	-0.16	-0.01	0.15	1.18
	HAMILTON BANK	-0.62	-0.04	-0.44	-1.43	-1.35	0.80	0.79	1.08	-0.47	-0.69	-0.24	0.17	-0.49	-0.42	0.29	0.88	0.35	-1.23	-1.14	-0.30	-0.47
SURFACE	FLEMISH CAP	0.29	0.54		-0.35	-2.53	0.58	0.29	0.98	-0.72	0.21	-1.06	0.76	1.07	1.99	1.03	0.90	0.10	0.87	-0.25	-0.68	0.38
SALINITY	STATION 27	1.45	-1.95	-1.07	-0.12	-0.42	-1.94	0.16	-0.37	-0.36	-0.44	-0.31	-0.64	1.01	0.94	0.53	0.36	0.56	-0.07	0.52	0.17	-0.65
	STATION 27	-0.98	-1.46	-1.13	-1.45	-1.29	-0.69	0.58	0.24	0.69	0.73	0.63	0.78	0.06	0.09	1.90	1.67	1.69	0.57	0.24	-0.44	1.71
BOTTOM	FLEMISH CAP	-2.11	-0.98	-0.26	-0.68	-2.41	-0.61	-0.51	-0.18	0.33	1.40	0.09	-0.29	-0.14	0.53	0.76	1.34	0.70	-0.07	1.23	0.82	1.03
TEMPERATURE	HAMILTON BANK	-1.21	-0.60	-0.96	-1.23	-0.74	0.20	0.33	1.40	0.49	1.12	-0.06	1.12	0.99	0.72	1.69	1.26	0.40	1.33	-0.25	-0.44	1.98
	ST. PIERRE BANK	-1.32	-0.09	-0.68	-0.67	-1.46	-0.86	-0.18	-0.64	-0.33	0.75	0.74	-0.38	-0.47	-0.93	0.73	2.36	1.55	-0.63	-0.97	0.23	1.66
S27 TEMPERATURE	STATION 27 (0-175 M)	-0.49	-2.24	-0.93	-1.19	-0.28	-0.70	1.48	-0.41	-0.41	0.51	0.48	0.55	0.12	0.49	1.84	1.11	2.07	-0.35	0.21	-0.08	1.93
S27 SALINITY	STATION 27 (0-175 M)	1.75	-1.37	-1.57	0.23	-0.58	-0.60	-1.02	0.14	0.24	-0.28	-0.44	-0.85	0.59	0.39	-0.43	-0.04	0.84	0.40	1.00	-0.45	-1.23
MIXED-LAYER	STATION 27 (WINTER)	-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	-2.53
MIXED-LAYER	STATION 27 (ANNUAL)	-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	-1.16
MIXED-LAYER	STATION 27 (SPRING)	-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	0.56
STRATIFICATION	STATION 27 (ANNUAL)	-1.46	-0.36	-0.50	-1.19	-0.46	1.45	-1.61	0.21	1.01	1.27	0.41	1.28	-0.59	-0.36	-0.77	-0.09	1.12	0.42	0.81	0.02	-0.42
STRATIFICATION	STATION 27 (SPRING)	-1.52	-0.83	-1.09	-0.28	-0.60	1.79	-0.89	-0.01	1.02	0.81	-0.28	0.00	-1.06	-1.04	-0.34	0.21	0.59	0.07	-0.40	0.41	-0.70
9 M TEMPERATURE	HAMPDEN WB			-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	0.86
10 M TEMPERATURE	COMFORT COVE NDB	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									-1.61	-0.02	-0.16		0.08	0.63	0.14	1.67	1.15	-1.13	-0.74	-1.16	-0.59
10 M TEMPERATURE	STOCK COVE BB	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	0.21
10 M TEMPERATURE	MELROSE									-1.31	-0.29		0.58	-0.36	0.85	-0.57	1.08	1.37	-1.6	0.26	-1.32	-1.38
10 M TEMPERATURE	OLD BONAVENTURE		-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	-0.15
10 M TEMPERATURE	WINTERTON									-0.72		0.89	0.23	-0.53	1.84	-0.34	0.07	0.96	-1.39	-1.01	0.38	-1.71
5 M TEMPERATURE	BRISTOL'S HOPE	-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	0.55
10 M TEMPERATURE	UPPER GULLIES CB	-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	0.50
10 M TEMPERATURE	ARNOLDS COVE PB	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	0.51

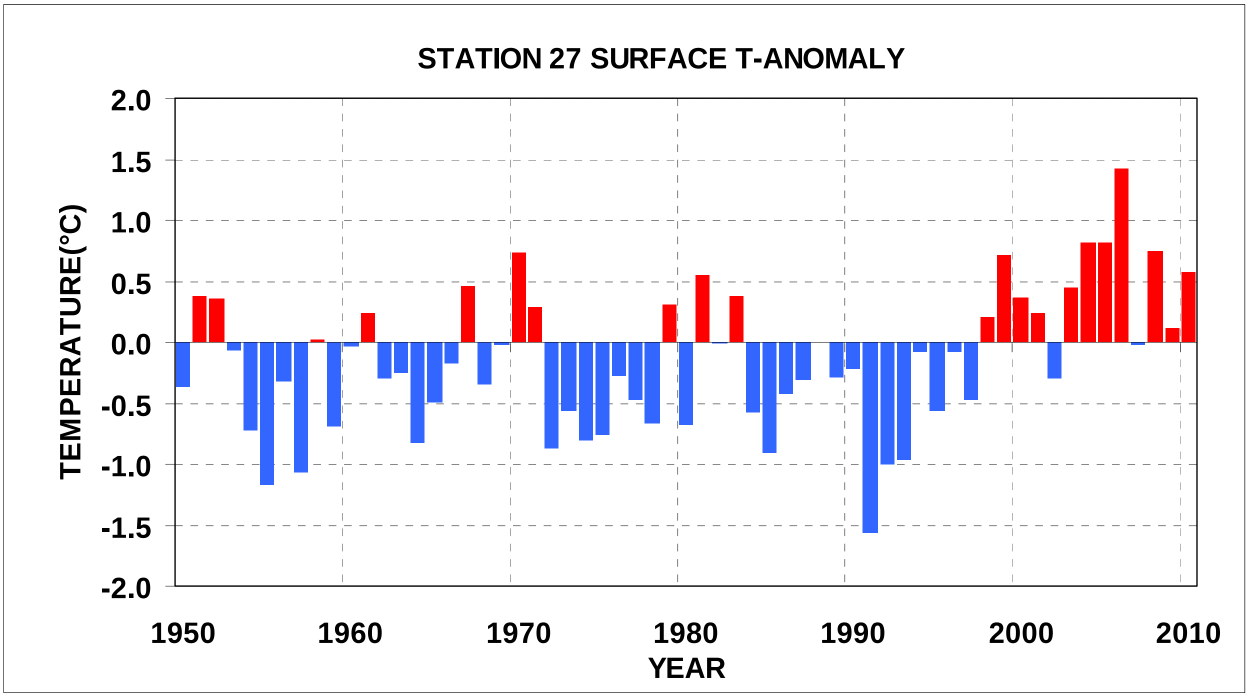

Figure 8a. Annual near surface temperature anomalies at Station 27 referenced to the 1981-2010 mean.

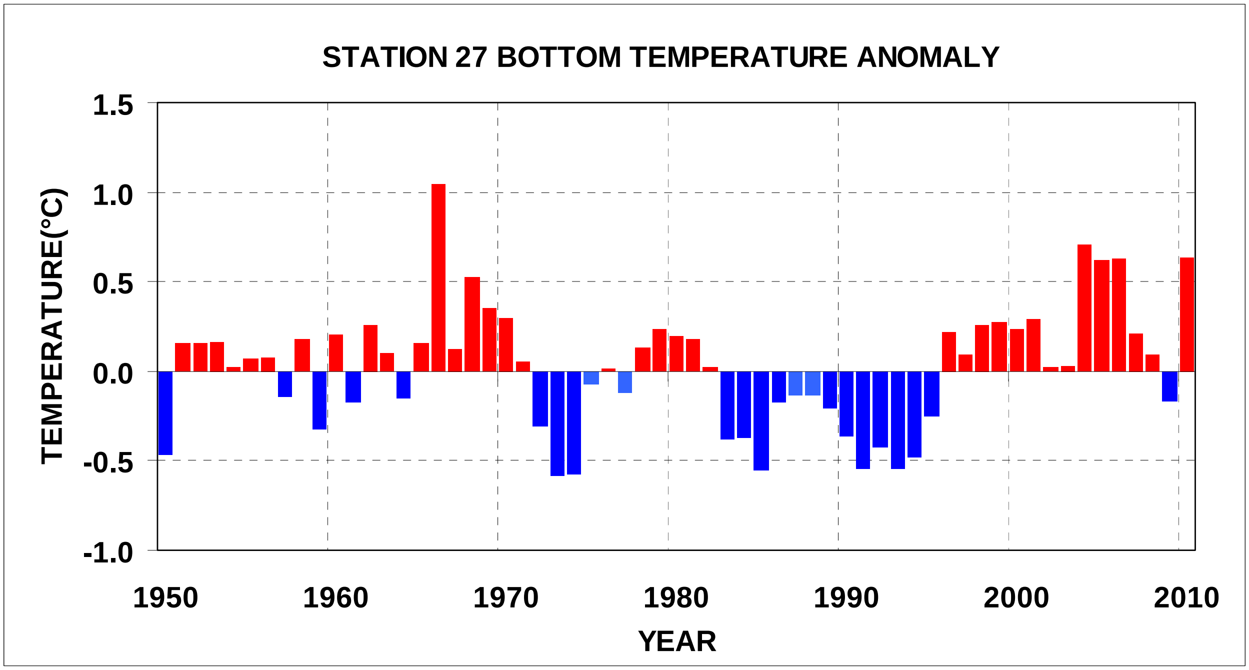

Figure 8b. Annual near bottom (176 m) temperature anomalies at Station 27 referenced to the 1981-2010 mean.

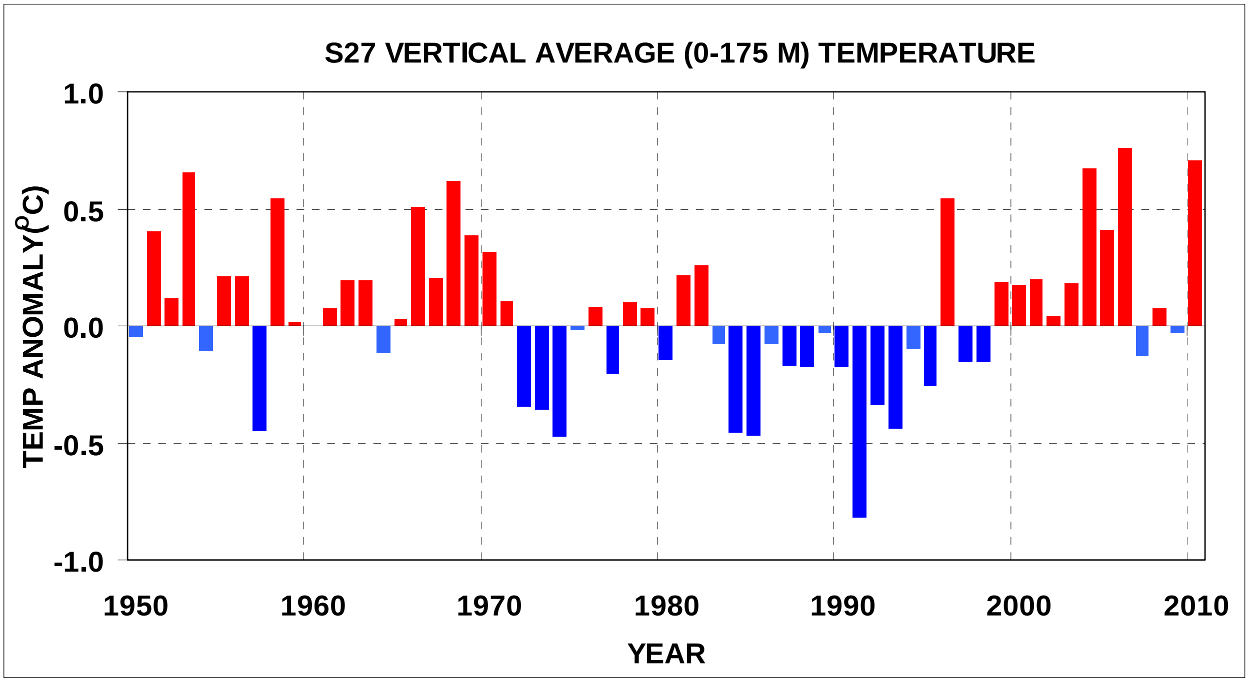

Figure 9a. Annual vertically averaged temperature (0-176 m) anomalies at Station 27 referenced to the 1981-2010 mean.

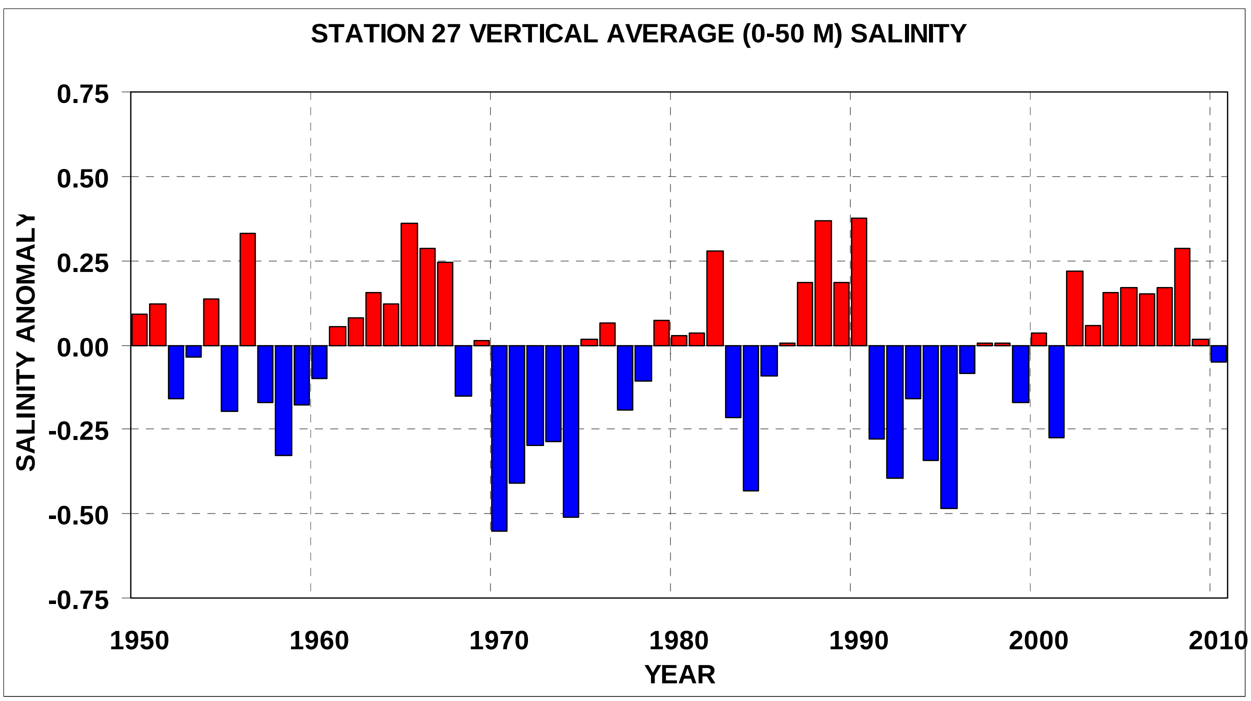

Figure 9b. Annual vertically averaged salinity (0-50 m) anomalies at Station 27 referenced to the 1981-2010 mean.

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 was added to the survey.

In 2010, the southeast Grand Bank section was sampled during April 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. 2a).

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 -1.5─2 °C 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°C to 4 °C.

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 ice formation and melt. These 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 (Figs. 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.

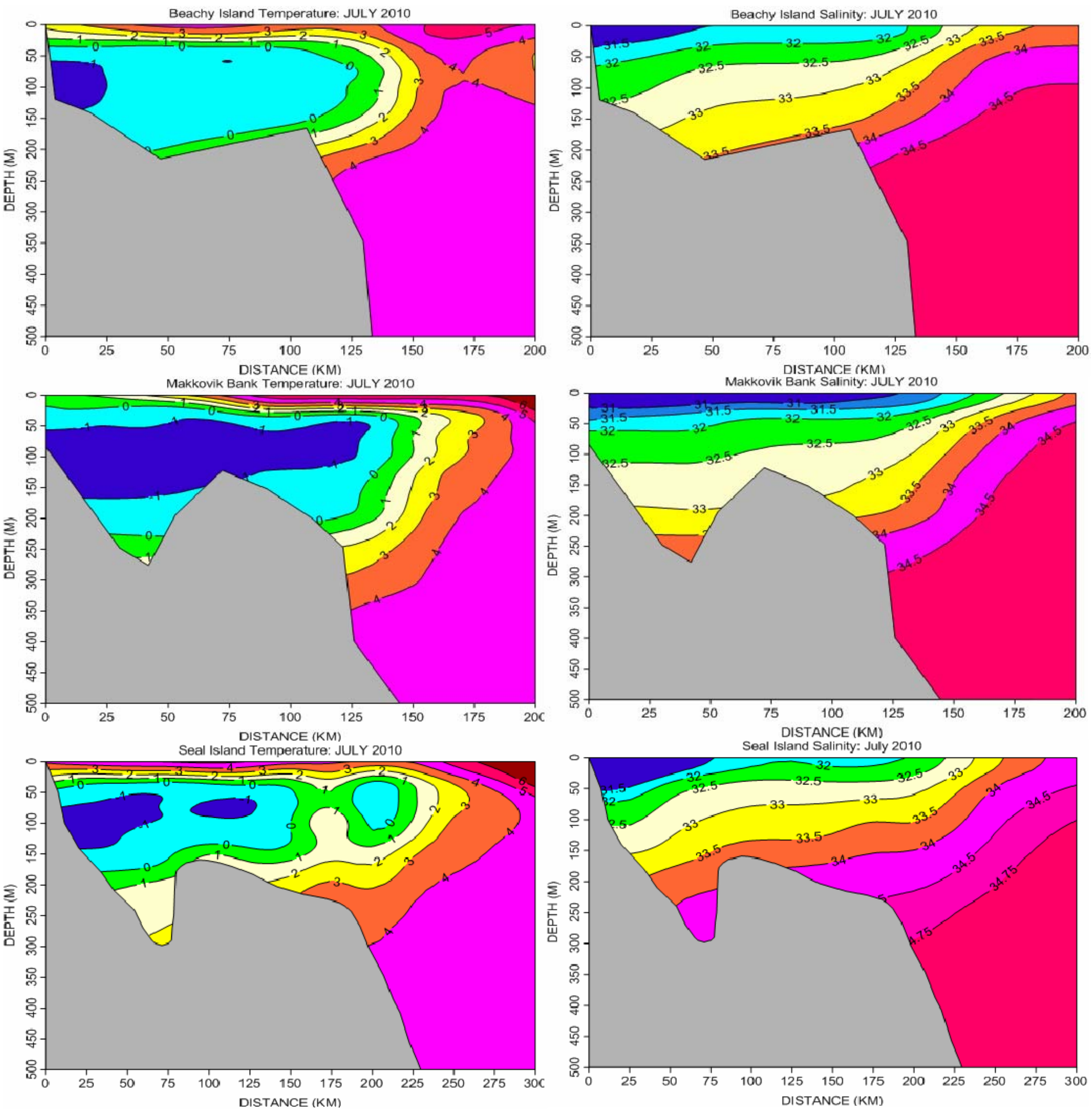

Figure 10. Contours of temperature (^oC) and salinity across the Labrador Shelf along the Beachy Island (Nain Bank), Makkovik Bank and Seal Island (Hamilton Bank) sections (Fig. 2a) during the summer of 2010.

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 for the two northern sections, the first time in almost a decade (Figs. 12a and 12b). In 2010 temperatures again increased significantly while salinities remained generally lower than normal. From 1990 to 1994, temperatures and salinities were significantly below normal in these areas. Farther south on the Southeast Grand Bank and St. Pierre Bank, conditions have been more variable with cold conditions observed during 1990-94 and during the spring of 2003. During 2004-06 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 conditions varied about the mean and between sections and in 2010 they again increased to above normal values.

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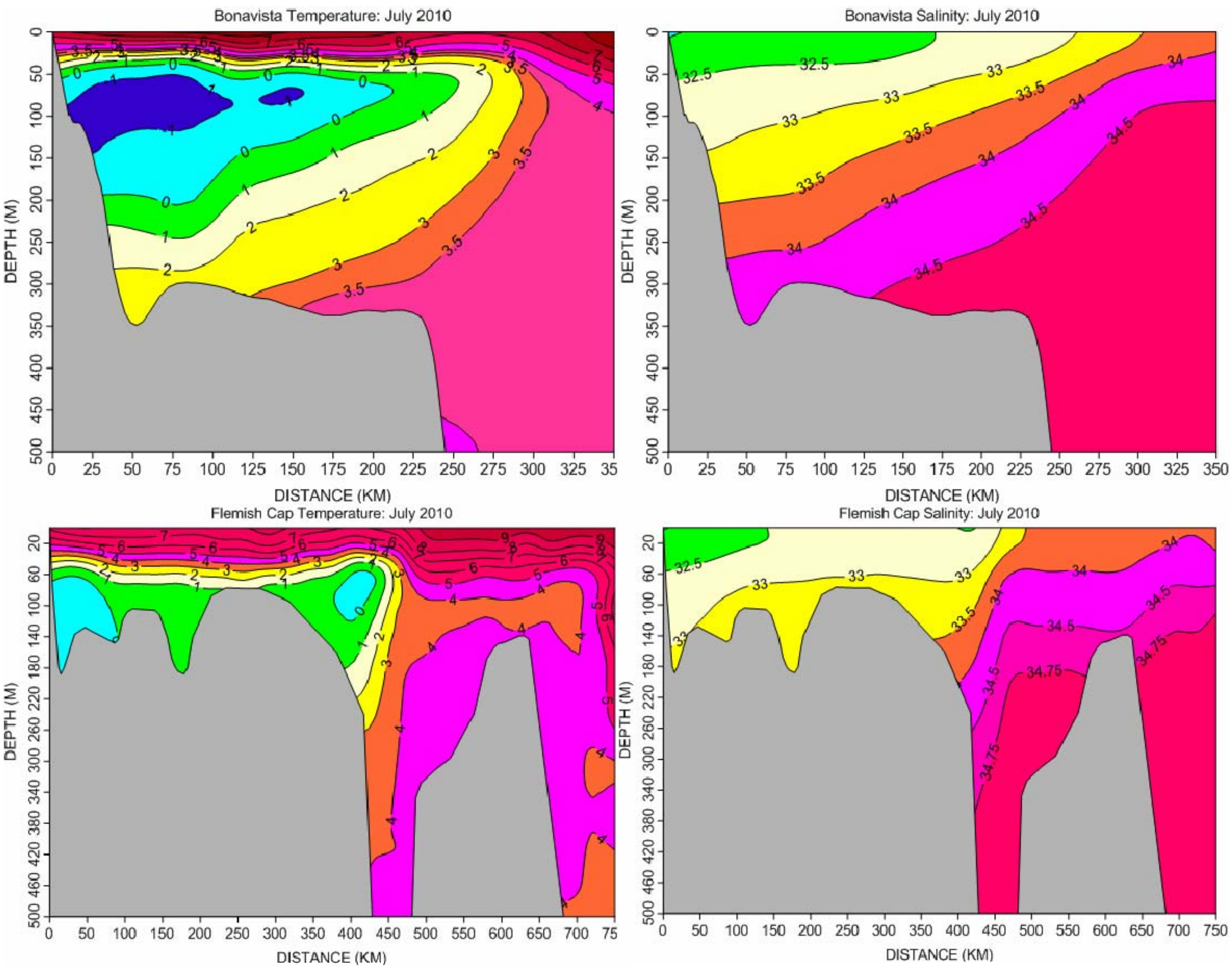
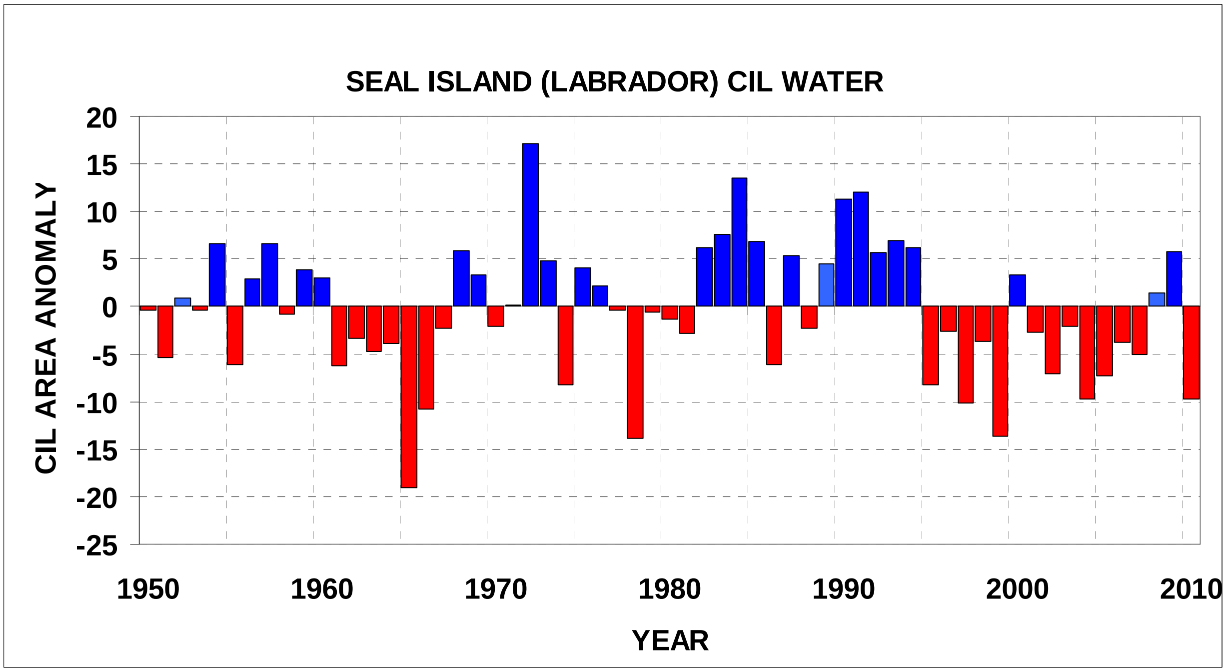


Figure 11. Contours of temperature (^oC) and salinity across the Newfoundland Shelf along the Bonavista and Flemish Cap sections (Fig. 2a) during the summer of 2010.

The CIL cross sectional area anomalies during the spring of 2010 were below normal along all sections from off Cape Bonavista to St. Pierre Bank. Below normal CIL areas generally implies warmer-than-normal water temperatures on the continental shelf. Summer sections are common to four areas. Along the Bonavista section, the CIL area was below normal during spring, summer and fall (~1 SD) for the 10th consecutive year during the summer. The overall average temperature along the Bonavista section decreased from 1.8 SD above normal in 2008 to below normal (-0.2 SD) in 2009 but increased to +0.4 SD in 2010. 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 2009-10. 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.



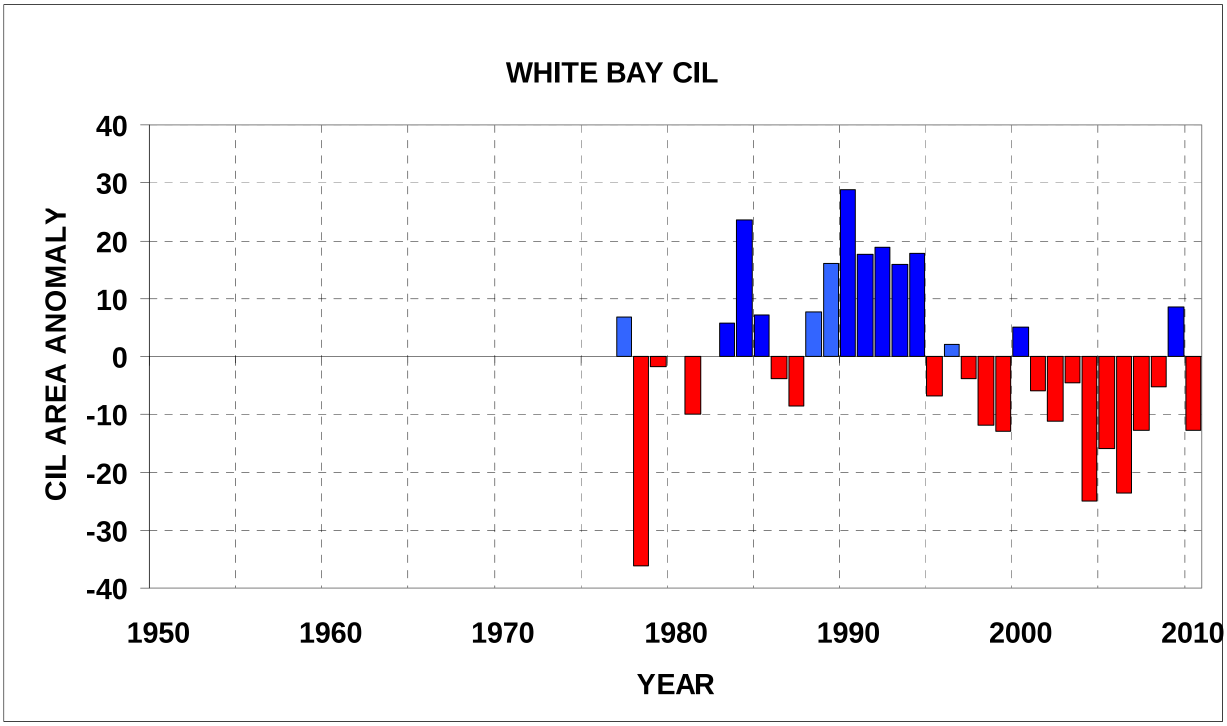
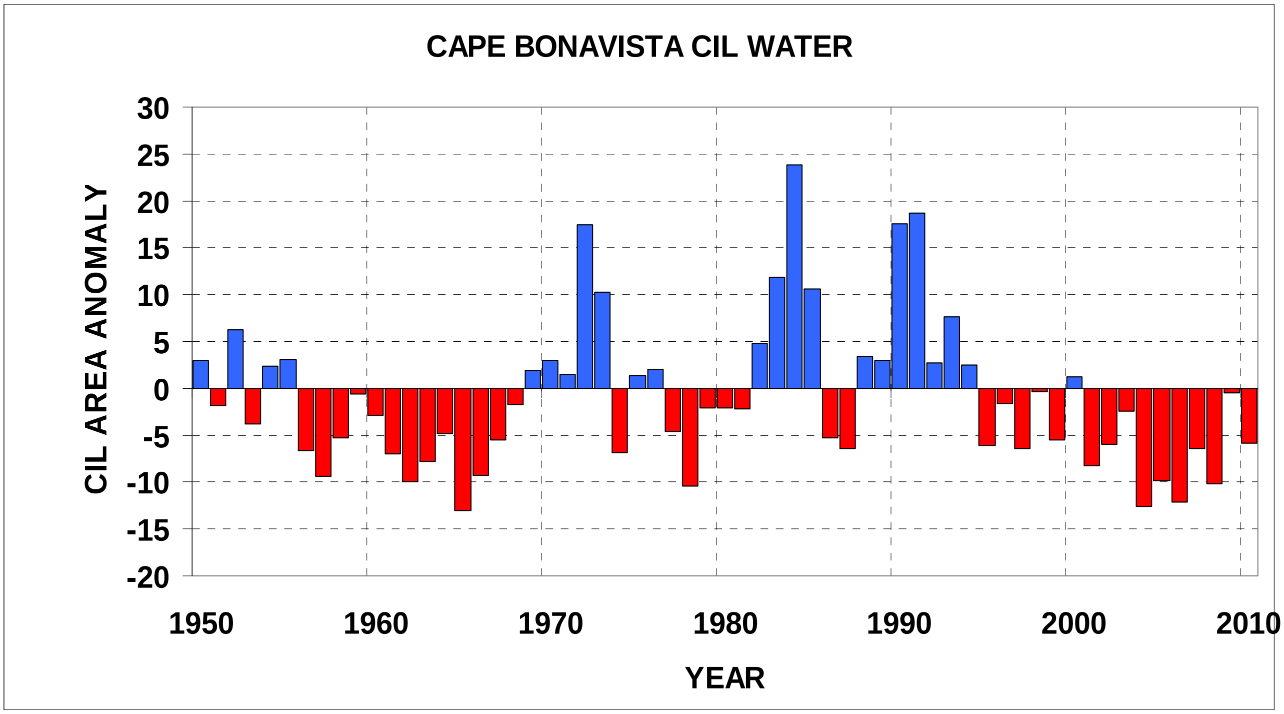


Figure 12a. Summer CIL (T<0 °C) area anomalies (km^2) along the Seal Island and White Bay sections referenced to the 1981-2010 mean.



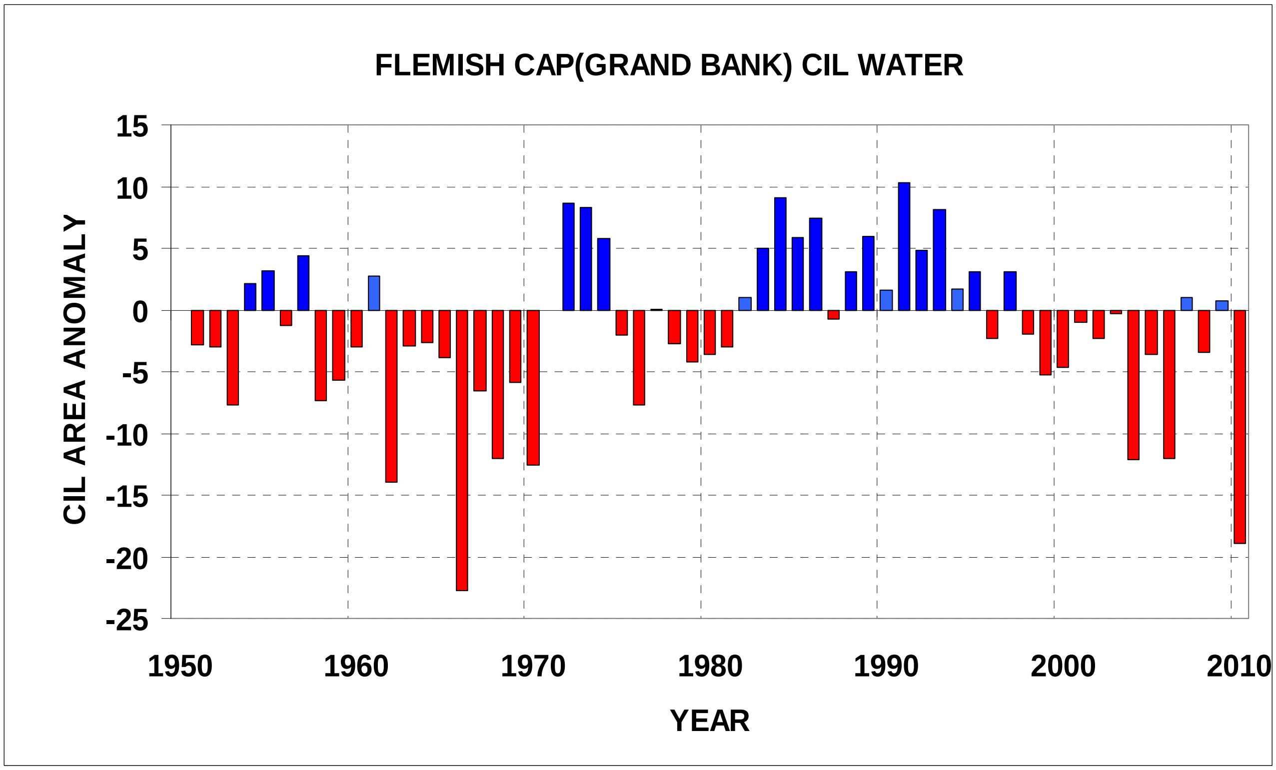


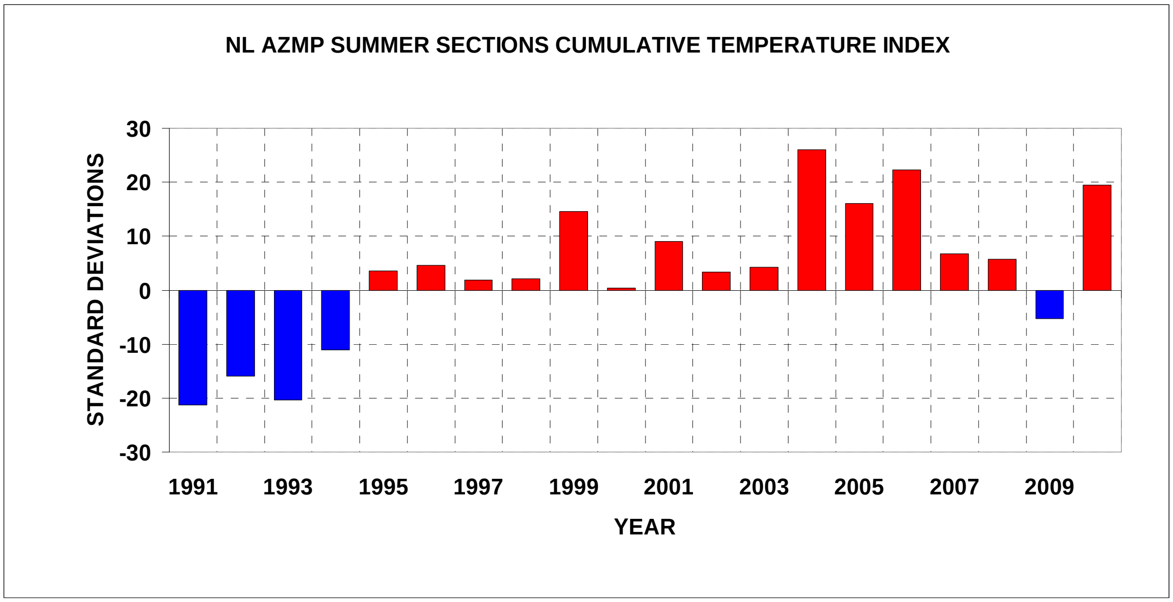
Figure 12b. Summer CIL (T<0 °C) area anomalies (km²) along the Bonavista and Flemish Cap sections referenced to the 1981-2010 mean.

Temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections (Fig. 2a) were used to compute geostrophic transports estimates of the near-surface component (referenced 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 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 4) was near normal during 2008 but increased significantly in 2009 and remained above normal in 2010. Further south off the Grand Bank through the Flemish Pass the transport increased from >2 SD below normal in 2008 and varied above and below the mean in 2009-10 by about 0.8 SD. 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 while 2009 and 2010 were close to normal (Table 4).

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.

	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	2010
	COLD-INTERMEDIATE-LAYER AREA	1.51	1.62	0.76	0.93	0.83	-1.10	-0.35	-1.36	-0.49	-1.83	0.45	-0.37	-0.94	-0.27	-1.30	-0.97	-0.50	-0.67	0.20	0.77	-1.30
SOUTHERN	MEAN CIL TEMPERATURE	-1.53	-0.86	-1.15	-1.38	-0.76	1.71	0.52	0.57	0.33	1.57	-0.38	0.95	0.85	0.09	0.90	1.42	0.71	0.28	-0.43	-0.96	0.76
LABRADOR	MINIMUM CIL TEMPERATURE	-0.94	-1.20	-0.95	-1.31	-0.67	1.92	-0.37	-0.64	-0.43	1.00	-0.55	0.94	-0.62	0.60	2.21	0.94	1.06	-0.15	-0.67	-0.33	1.06
SEAL ISLAND	MEAN SECTION TEMPERATURE	-1.69	-1.61	-1.41	-1.35	-0.89	0.27	-0.01	0.64	0.52	0.88	-0.03	0.17	0.43	0.74	1.64	1.04	1.16	0.80	1.08	0.17	1.24
SECTION	MEAN SECTION SALINITY	-1.32	-1.46	0.85	-0.69	-0.97	0.57	-0.69	0.64	0.08	0.71	-0.97	0.08	1.06	-0.13	1.27	0.57	0.36	0.01	-0.20	-0.27	-0.20
(SUMMER)	INSHORE SHELF SALINITY	-0.14	-1.06	0.87	0.95	-0.80	0.57	-0.80	0.53	0.32	0.95	-1.43	0.11	0.53	-0.01	0.03	1.12	0.16	0.07	0.41	-0.51	-2.35
	LABRADOR CURRENT TRANSPORT	0.08	0.28	0.73	-2.00	-1.03	-0.11	0.28	-0.05	0.60	-0.64	0.41	0.60	0.99	0.86	0.47	0.99	0.41	-0.11	-0.44	1.58	0.80
	COLD-INTERMEDIATE-LAYER AREA	2.03	1.25	1.32	1.13	1.26	-0.48	0.15	-0.28	-0.83	-0.91	0.36	-0.42	-0.78	-0.33	-1.76	-1.11	-1.66	-0.90	-0.37	0.60	-0.90
NORTHEAST	MEAN CIL TEMPERATURE	-1.37	-0.76	-0.88	-1.31	-0.64	0.23	0.23	-0.45	0.23	1.40	-0.39	0.47	0.78	-0.14	2.32	0.97	1.09	0.29	0.72	-0.27	0.72
NEWFOUNDLAND	MINIMUM CIL TEMPERATURE	-0.56	-0.79	-0.78	-1.02	-0.50	-0.35	0.48	-0.42	-0.39	0.82	0.04	-0.08	-0.02	0.11	3.80	0.43	1.73	0.24	0.18	-0.02	0.63
WHITE BAY SECTION	MEAN SECTION TEMPERATURE	-1.62	-1.07	-1.79	-1.47	-1.49	-0.30	-0.40	0.60	0.79	1.05	0.19	0.17	0.24	0.60	1.43	1.50	1.6	1.03	1.13	-0.47	0.92
(SUMMER)	MEAN SECTION SALINITY	-1.10	-0.82	-0.72	-0.25	-0.82	0.42	-1.39	1.27	0.61	-0.34	-0.53	0.23	1.27	0.32	1.37	0.80	1.08	0.99	0.80	-0.91	-1.96
	MEAN SHELF SALINITY	0.09	-0.79	-1.39	0.97	-0.90	0.09	-1.06	1.63	-0.02	-1.89	-0.73	-0.02	1.19	-0.46	0.86	-0.18	0.92	0.75	0.97	-0.46	-1.06
	CIL AREA (SPRING)	2.14	1.31	0.73	0.70	1.25	-0.61	-0.29	-0.30	0.31	-0.82	0.01	-0.78	-0.20	0.14	-0.90	-1.31	-1.34	-0.48	-0.32	0.02	-1.40
	CIL AREA (SUMMER)	1.90	2.02	0.30	0.84	0.28	-0.63	-0.16	-0.67	-0.02	-0.57	0.15	-0.86	-0.62	-0.24	-1.32	-1.03	-1.28	-0.67	-1.07	-0.04	-0.61
	CIL AREA (FALL)	1.73	0.67	1.09	1.60	1.17	-0.44	-0.26	-1.01	-0.58	-1.28	0.01	-0.34	-0.76	-1.01	-1.28	-1.25	0.46	-0.98	0.69	-1.14	-1.19
EASTERN																						
NEWFOUNDLAND	MEAN CIL TEMPERATURE (SUMMER)	-1.08	-1.62	-0.54	-1.21	-0.60	0.55	1.22	-0.54	-1.15	-0.33	-0.06	1.15	-0.40	-0.40	1.43	1.29	1.70	0.75	-0.27	-0.40	1.36
BONAVISTA	MINIMUM CIL TEMPERATURE (SUMMER)	-0.77	-1.10	-0.63	-1.09	-0.83	-0.24	0.37	-0.46	-0.48	0.14	-0.11	0.67	0.07	-0.16	2.05	1.12	2.25	0.07	-0.16	-0.54	1.04
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-1.61	-1.56	-1.31	-1.05	-0.94	-0.03	-0.35	0.53	0.42	0.85	0.32	0.17	0.25	0.51	1.69	1.36	1.58	0.77	1.62	-0.15	0.42
	MEAN SECTION SALINITY (SUMMER)	-1.32	-1.32	-0.67	-0.39	-0.02	0.81	-1.60	0.72	-0.39	-0.11	-0.11	-0.21	1.55	0.44	1.46	0.72	1.46	0.81	2.11	-0.30	-0.95
	INSHORE SHELF SALINITY (SUMMER)	0.39	-1.46	-1.38	-0.03	0.22	-1.46	-0.20	-0.20	-0.62	-2.05	0.39	-0.71	1.91	-0.28	0.64	0.73	1.40	0.98	1.65	-1.30	-0.12
	LABRADOR CURRENT TRANSPORT (SUMMER)	-0.18	1.89	1.89	0.51	-0.28	-0.28	0.61	0.12	-0.38	2.18	0.80	-1.26	0.51	0.90	-0.18	0.31	-1.16	-0.47	-1.85	-0.08	0.02
	CIL AREA (SPRING)	0.82	0.78	0.66	0.89	0.75	0.33	-0.54	-0.17	-0.96	-2.12	-0.41	-0.02	1.08	1.29	-1.55	-1.15	-1.74	0.95	0.44	0.74	-1.79
GRAND BANK	CIL AREA (SUMMER)	0.24	1.59	0.75	1.26	0.26	0.47	-0.36	0.47	-0.30	-0.81	-0.72	-0.16	-0.36	-0.05	-1.88	-0.56	-1.86	0.15	-0.53	0.12	-2.92
FLEMISH PASS	CIL AREA (FALL)	1.05	1.36	0.36	0.48	1.51	-0.23	-0.10	-0.18	0.39	-1.80	0.35	0.06	-0.64	-0.51	-2.01	-0.55	-0.74	-0.16	0.32	-1.47	-2.15
FLEMISH CAP																						
	MEAN CIL TEMPERATURE (SUMMER)	-1.00	-1.75	-1.22	-1.62	-0.17	-0.79	0.87	0.31	0.61	1.40	1.00	0.92	0.17	-0.35	1.31	0.87	1.62	0.31	0.17	-0.66	1.70
47 ^{O}N	MINIMUM CIL TEMPERATURE (SUMMER)	-0.49	-1.15	-0.61	-1.09	-0.88	-0.44	1.32	0.20	-0.46	0.53	0.42	1.65	-0.76	-0.05	0.18	0.59	0.77	0.24	-0.17	-0.88	2.83
SECTION	MEAN SECTION TEMPERATURE (SUMMER)	-0.73	-1.29	-1.52	-2.26		-0.76	-0.06	-0.30	0.48	1.11	0.17		-0.37	1.79	0.87	0.79	1.73		0.72	0.66	1.01
	MEAN SECTION SALINITY (SUMMER)		-0.52	-0.33	-0.23		0.15	-0.04	0.71	0.34	0.43	-0.42		0.90	1.85	0.71	-0.80	1.19		0.90	-0.42	0.62
	INSHORE SHELF SALINITY (SUMMER)		-0.45	-0.76	-0.33	-0.08	-0.33	-0.64	0.23	0.30	0.05	-0.76	-0.76	0.61	0.17	-0.02	-0.20	1.11	0.73	0.61	-0.51	-0.76
	LABRADOR CURRENT TRANSPORT (SUMMER)		-0.23	0.92	0.35		0.63	-0.32	-0.04	0.73	-0.52	0.63	0.73	0.92	1.88	0.63	0.63	-0.23	0.44	-2.34	0.63	-0.80
	CIL AREA (SPRING)	1.28	1.48	0.29	-0.24	-0.37	-0.77	-0.76	-0.22	-0.53	-0.81	-0.69	-0.24	0.63	2.52	-0.79	-0.87	-1.26	0.38	0.67	0.41	-1.09
	MEAN CIL TEMPERATURE (SPRING)	-0.17	-0.43	-0.43	-1.63	-0.90	-1.38	0.23	-0.03	0.45	-0.61	0.49	1.07	0.52	-0.03	1.91	0.56	2.35	0.05	-0.68	-1.52	1.84
SOUTHEAST	MEAN TEMPERATURE (SPRING)	-1.52	-1.14	-0.60	-0.19	0.01	-0.18	0.34	0.13	0.61	1.81	0.52	-0.94	-1.34	-2.09	0.24	0.04	0.24	-0.69	-0.88	0.18	-0.21
GRAND BANK																						
SECTION	CIL AREA (FALL)	-0.48	1.97	-0.37	0.99	2.86	1.65	-0.52	-0.48	-0.33	-0.58	-0.33	-0.42	-0.56	-0.47	-0.72	-0.40	-0.39	-0.21	0.30	-0.80	-0.72
	MEAN CIL TEMPERATURE (FALL)	-1.48	0.40	-1.01	0.07	-0.47	1.48	0.27	-1.35	-1.21	0.20	-0.13	-0.27	-1.28	-1.48	1.55	0.94	0.94	0.67	0.07	1.08	1.01
	MEAN SECTION TEMPERATURE (FALL)	-1.08	-0.49	-1.46	-0.46	-0.74	1.14	-0.71	-0.06	1.76	1.86	1.23	0.46	-0.48	-0.52	0.32	-0.42	1.16	-0.70	-0.01	-1.56	0.76
	CIL AREA				1.35	1.13	0.55	-0.97	1.28	-0.77	-1.11	-1.11	0.71	0.03	1.39	-1.03	-1.11		0.82	0.37	-0.43	-1.11
ST. PIERRE	MEAN TEMPERATURE (< 100 M)				-1.24	-1.05	-0.44	0.08	-1.19	0.60	1.62	1.26	-0.66	-0.38	-1.55	0.34	0.96		-0.71	0.05	1.29	1.01
BANK	MEAN SECTION TEMPERATURE				-0.73	-1.24	0.31	0.06	-0.68	0.36	1.44	1.08	-0.73	0.01	-0.85	0.08	1.03		-1.17	-1.64	1.48	1.19
SECTION	MEAN SALINITY < 100 M				1.04	-1.80	0.48	-0.76	-0.48	1.17	0.62	-1.80	1.17	-0.83	0.48	0.35	-0.62		1.45	-0.76	-0.14	0.41
(SPRING)	MEAN SECTION SALINITY				1.47	-1.72	0.92	-0.76	-0.36	0.44	1.07	-0.36	-0.04	-0.52	0.04	0.52	0.12		0.60	-2.52	0.52	0.60

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 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 to the 3rd highest since 1991 (Fig. 13). The salinity composite shows mostly below normal values from 1991 to 2001, except 1997, then higher than normal from 2002-2008 with below normal conditions during the past 2 years. 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 and 2010 rebounding to warmer but fresher than normal conditions.



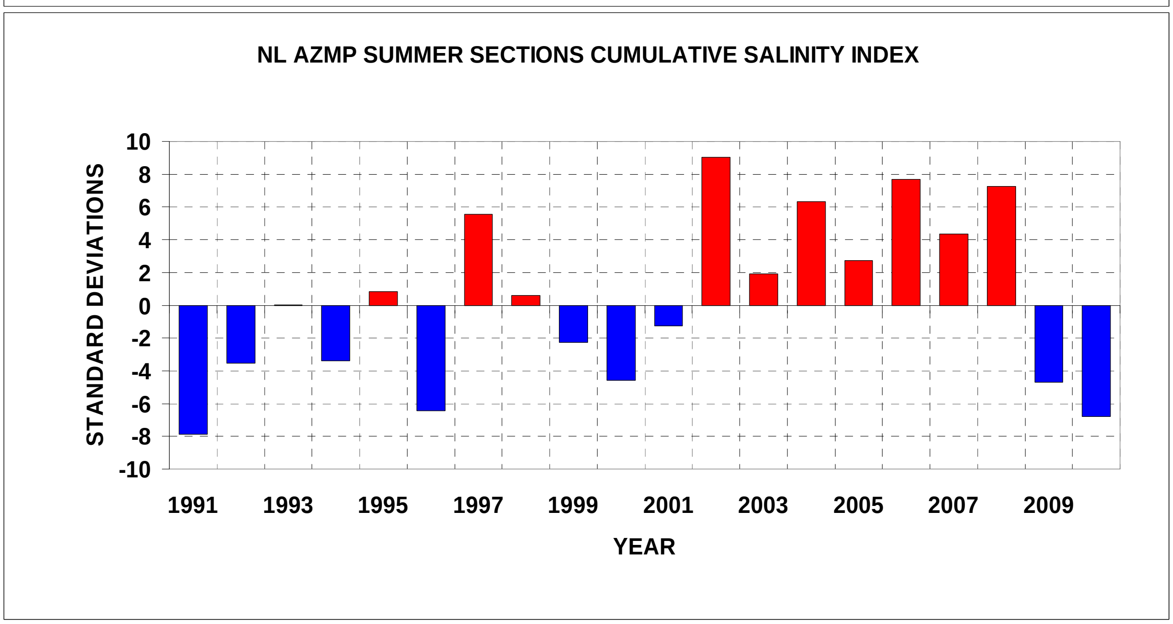


Figure 13. Standard summer section composite index derived by summing the standardized temperature and salinity anomalies from Table 4.

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 Subdiv. 3Ps and Div. 3LNO on the Grand Bank and 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 2010.

SPRING CONDITIONS

Maps of bottom temperatures and their anomalies derived from the spring of 2010 multi-species survey (Fig. 2b) are displayed in Fig. 14 for NAFO Div. 3PLNO. Bottom temperatures in Div. 3L were generally <0 °C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 0 °C to >3 °C at the shelf edge. Over the central and southern areas of the Grand Bank (3NO) bottom temperatures ranged from 1 °C to 5 °C. In the northern areas of Divs. 3NO bottom temperatures generally ranged from 0.5 °C to 1 °C. On St. Pierre Bank temperatures ranged from 0.5 °C to 3 °C and up to 5-6 °C in the Laurentian Channel and areas to the west. Bottom temperature anomalies were highly variable with values generally above normal by up to 1.5 °C over most of 3L and along the slope region they were above normal by up to 2 °C. In southern areas of 3NO bottom temperatures were up to 2 °C above normal. In western areas of Div. 3P, some isolated areas of negative anomalies were present, particularly in the deeper areas while on St. Pierre Bank they were above normal. It should be noted that some of the inshore areas have limited or no sampling resulting in unreliable temperature estimates in these areas.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990-2010 are displayed in Table 5 and Fig. 15 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 2010, 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 Div. 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 it decreased significantly to 1.7 SD below normal (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 (1.2 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 (Table 5).

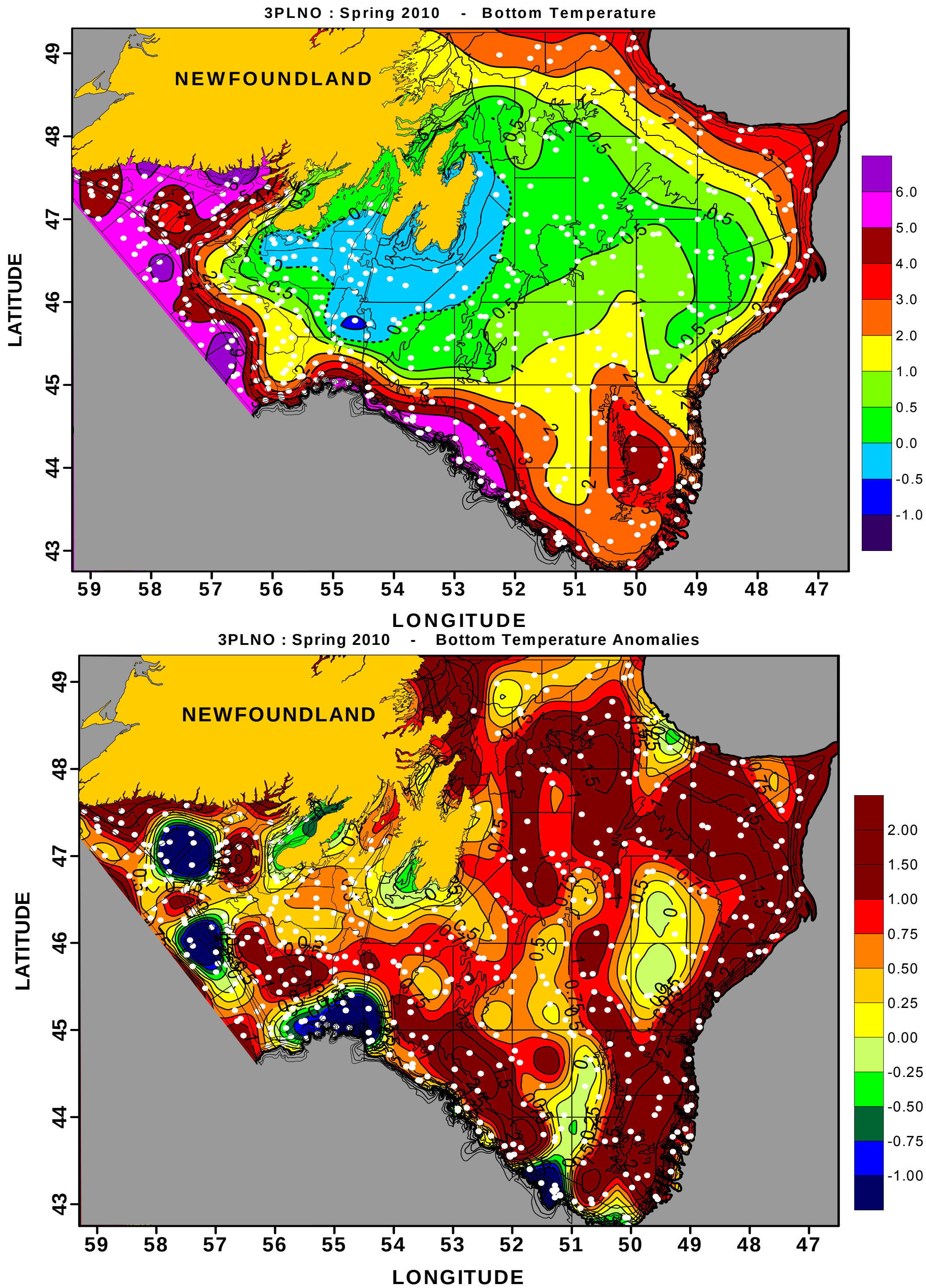


Figure 14. Contour maps of bottom temperature and their anomalies (°C) relative to the 1971-2000 mean for the same period of the year, during the spring of 2010 in NAFO Division 3PLNO. The white dots indicate sampling locations.

A composite index derived by summing the standardized indices presented in Table 5 show overall temperature conditions during the spring of 2009 and 2010 above normal after 2 years (2007-08) of slightly below normal conditions (Fig. 16). In fact, 2010 was comparable to the warm years of 1999-2000 and 2004-05.

FALL CONDITIONS

Bottom temperature and temperature anomaly maps derived from the fall of 2010 multi-species survey (Fig. 2b) in NAFO Div. 2J, 3KLNO are displayed in Figs. 15a and 15b. Bottom temperatures in all of Div. 2J were above normal, ranging from <2 °C inshore to >4 °C at the shelf break and between 2 °C and 3 °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 °C and 4 °C, which were also above normal.

Bottom temperatures in Div. 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 2 °C to 8 °C with the warmest bottom waters found on the Southeast Shoal and along the edge of the Grand Bank in Div. 3O. Temperature anomalies were above normal over the entire survey area from Hamilton Bank to the southeast Grand Bank where anomalies reached 3-4 °C above the long term mean (Fig. 16b).

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990-2010 are displayed in Table 5 and Fig. 16. 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 (1.7 SD) but decreased to about normal on the bank during 2008. In 2009 temperatures increased slightly over 2008 values but in 2010 they reached a record high of 2 SD above normal. From 1996 to 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 (1.9 SD) values in 2007 and again, a slight warming in 2009 and a further increase in 2010 to the second highest in the series. In Div. 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 showed a slight cooling trend from 2006 to 2009 but increased sharply in 2010 (Table 5). The composite time series derived from the normalized anomalies (Table 5) show overall temperature conditions reaching a record high during the fall of 2010 (Fig. 16).

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 °C temperature ranges are presented in Fig. 17. The increasing trend in bottom temperatures is 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 this water mass varies considerably inter-annually and seasonally, 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 (1.7 SD below normal) and remaining significantly below normal (1.1 SD) in 2010, the 3rd lowest since 1980 (Fig. 18).

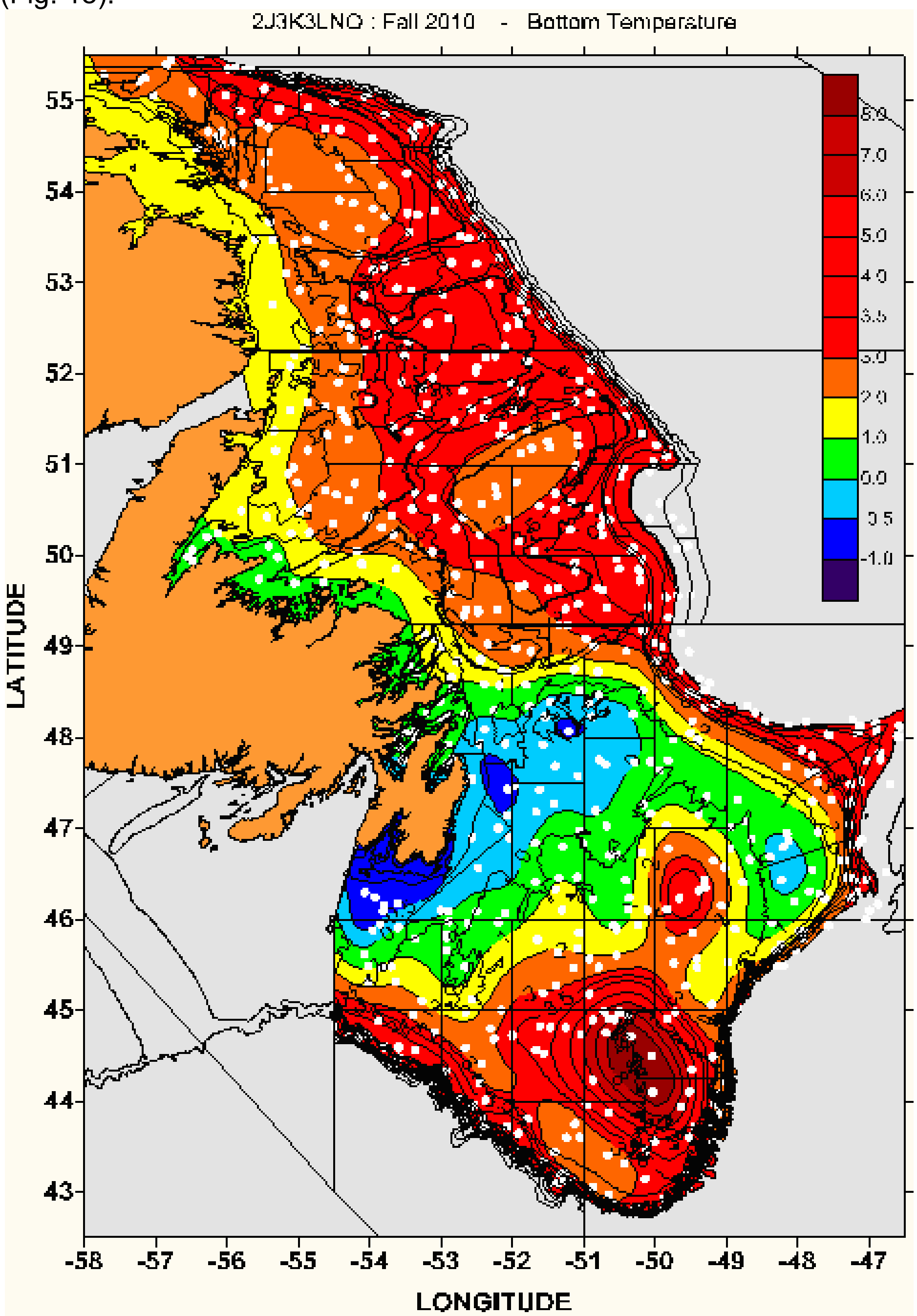


Figure 15a. Contour maps of bottom temperature (in °C) during the fall of 2010 in NAFO Division 2J3KLNO. The white dots indicate sampling locations.

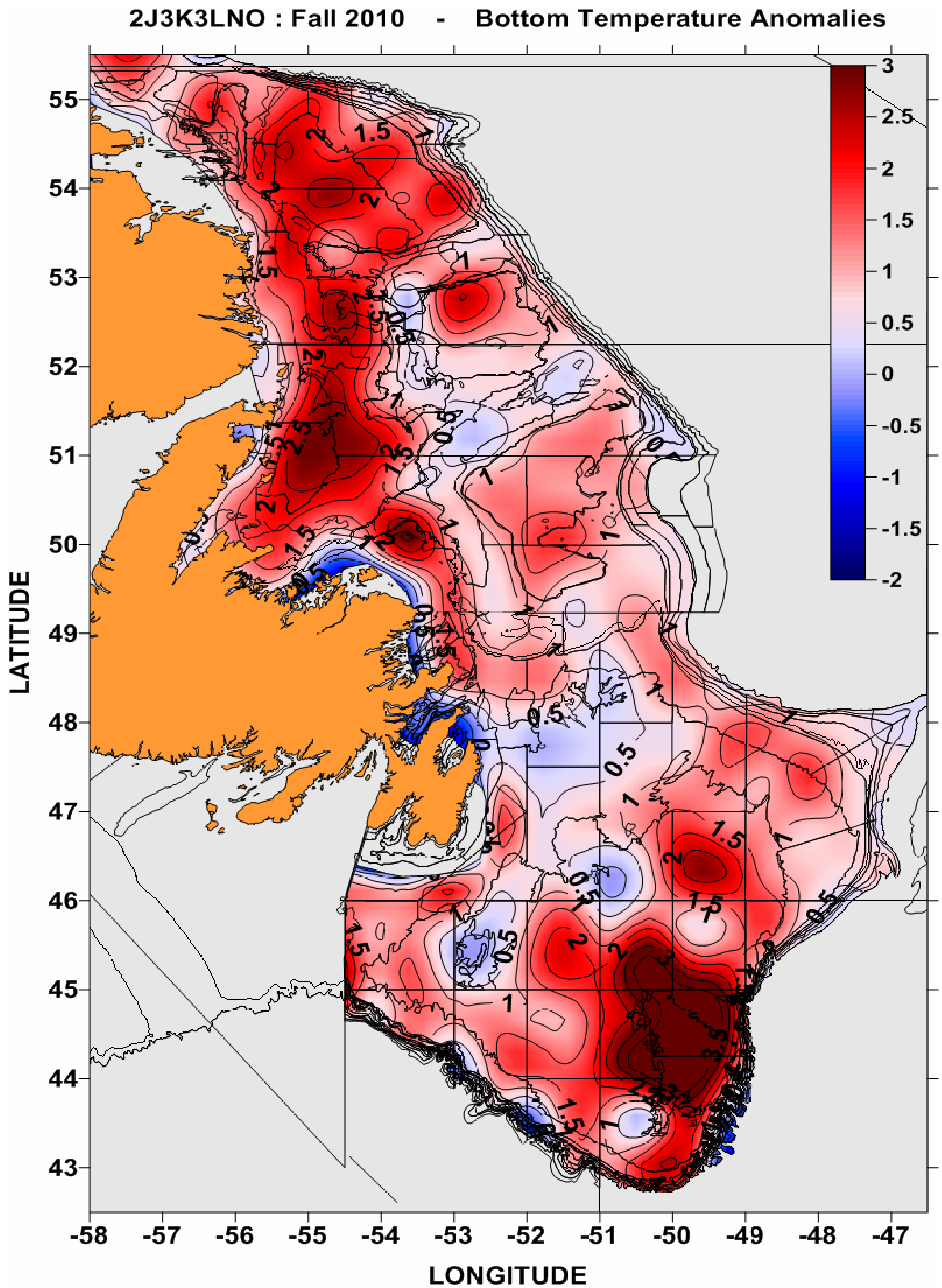


Figure 15b. Contour maps of bottom temperature anomalies (in °C) relative to the 1971-2000 mean for the same period of the year, during the fall of 2010 in NAFO Division 2J3KLNO.

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.

	STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (MULTI-SPECIES SURVEYS)																						
REGION	INDEX	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	BOTTOM TEMPERATURES	1981-2010	-0.76	-0.50	-1.30	-0.93	-0.82	-0.76	0.57	0.09	0.32	0.97	0.48	0.84	0.61	1.25	1.46	1.42	0.69	1.33	0.54	0.67	1.74
NAFO DIV. 2J	BOTTOM TEMPERATURES < 200 M	1981-2010	-0.31	-0.62	-1.70	-1.72	-0.93	-0.72	0.43	-0.07	-0.12	0.70	0.00	1.03	0.27	0.76	1.43	1.48	0.49	1.65	-0.05	0.15	1.98
FALL	THERMAL HABITAT AREA >2°C	1981-2010	-0.98	-0.67	-1.14	-0.77	-0.60	-0.02	0.34	0.42	0.19	0.62	0.05	0.82	0.52	0.86	1.33	1.75	0.13	1.95	-0.17	0.30	2.41
	THERMAL HABITAT AREA <0°C	1981-2010	0.21	-0.19	1.38	1.01	0.01	0.78		-0.46									-0.39				
	BOTTOM TEMPERATURES	1981-2010	-0.97	-0.70	-1.68	-1.52	-1.11	-0.04	0.03	0.58	0.26	1.24	0.13	0.32	0.52	0.73	1.21	1.13	0.32	1.81	0.66	0.81	1.53
NAFO DIV. 3K	BOTTOM TEMPERATURES < 300 M	1981-2010	-0.94	-0.66	-1.48	-1.97	-1.59	0.09	0.13	0.67	0.78	1.07	0.00	0.17	0.58	0.91	1.31	1.19	0.05	1.86	-0.03	0.24	1.44
FALL	THERMAL HABITAT >2°C	1981-2010	-1.43	-0.55	-1.56	-1.49	-1.06	-0.01	0.14	0.73	0.66	1.36	0.37	0.22	0.76	0.83	0.85	1.17	0.33	1.71	0.45	0.28	1.60
	THERMAL HABITAT AREA <0°C	1981-2010	0.66	1.02	1.61	1.25	0.88	-0.80	-0.76	-0.83	-0.07	-0.83	-0.47	-0.68	-0.83	-0.73	-0.83	-0.83	-0.78	-0.83	-0.13	-0.60	-0.83
	BOTTOM TEMPERATURES	1990-2010	-0.58	-0.27	-1.48	-1.92	-1.81	-0.10	-0.07	0.12	0.33	2.19	-0.12	0.11	-0.07	0.01	0.85	1.85	0.01	0.06	-0.20	-0.02	1.13
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	1990-2010	-0.07	-1.04	-0.96	-1.36	-1.54	0.27	0.61	0.40	0.61	2.45	0.00	-0.40	-0.58	-0.18	0.40	1.44	-0.33	-0.95	-0.46	0.01	1.67
FALL	THERMAL HABITAT AREA >2°C	1990-2010	-1.24	-0.51	-1.00	-1.88	-0.95	-0.18	0.23	0.15	0.71	2.77	0.06	0.13	-0.49	-0.14	0.43	0.41	-0.16	-0.19	-0.62	0.76	1.69
	THERMAL HABITAT AREA <0°C	1990-2010	0.42	1.39	1.46	1.81	1.72	-0.73	-0.13	0.35	-0.51	-1.32	0.56	-0.08	-0.56	0.02	-1.36	-1.09	-1.29	-0.06	0.60	-0.11	-1.08
NAFO DIV 2J3KL	CIL VOLUME (FALL)	1981-2010	1.12	1.23	1.65	1.74	0.92	-0.19	-0.72	-0.72	-0.44	-1.70	-0.31	-0.62	-0.43	-0.64	-1.35	-0.73	-0.36	-0.78	-0.16	-0.95	-1.11
	BOTTOM TEMPERATURES	1981-2010	-1.91	-1.71	-1.25	-0.78	-0.77	-0.76	-0.21	-0.56	0.36	0.80	0.78	0.14	0.07	-0.52	1.26	0.59		0.51	0.54	0.51	0.84
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	1981-2010	-1.29	-1.68	-1.34	-0.52	-1.11	-0.35	0.05	-0.92	0.94	1.82	0.51	-0.22	0.13	-1.09	1.23	0.70	0.53	0.11	0.25	0.91	1.16
SPRING	THERMAL HABITAT AREA >2°C	1981-2010	-1.73	-1.58	-1.32	-0.64	-0.66	-0.47	-0.15	-0.37	0.60	1.77	0.68	-0.29	-0.17	-0.31	1.81	0.96	-0.33	0.69	0.46	0.90	1.11
	THERMAL HABITAT AREA <0°C	1981-2010	1.09	1.52	1.08	1.17	0.84	0.52	-0.33	0.66	-0.97	-1.50	-0.68	-0.54	-0.29	0.52	-1.97	-1.24	-1.66	-0.06	-0.21	0.20	-1.70
	BOTTOM TEMPERATURES	1981-2010	-1.69	-0.80	-0.81	-0.28	-0.09	-0.80	0.47	-0.31	0.08	1.15	1.42	-0.46	0.23	-1.38	0.15	1.04		-0.88	-0.74	0.26	1.06
NAFO DIV. 3PS	BOTTOM TEMPERATURES <100 M	1981-2010	-1.47	-0.79	-0.90	-0.85	-0.58	-0.45	0.51	-0.32	0.55	1.36	1.64	-0.39	-0.17	-1.39	0.51	1.22		-0.43	-0.15	0.32	0.66
SPRING	THERMAL HABITAT AREA >2°C	1981-2010	-1.53	-0.85	-0.42	-0.52	-0.76	-0.62	0.30	-0.26	0.52	1.69	2.23	-0.28	-0.11	-0.62	-0.08	0.85		-0.30	-0.41	0.48	0.59
	THERMAL HABITAT AREA <0°C	1981-2010	1.45	0.66	0.94	1.02	0.47	0.74	-0.81	0.44	-0.42	-0.96	-1.35	0.35	0.14	1.25	-1.46	-1.35		0.39	0.39	-0.14	-1.07

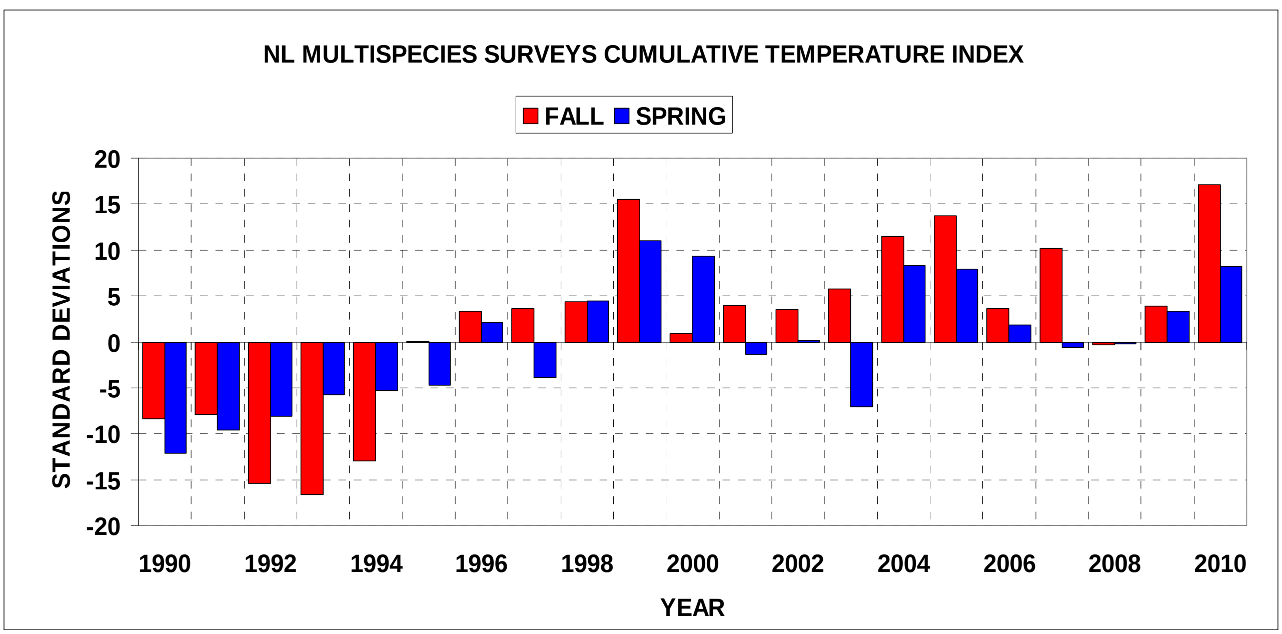


Figure 16. Composite bottom temperature index derived by summing the standardized anomalies from Table 5 for the spring and fall multi-species surveys.

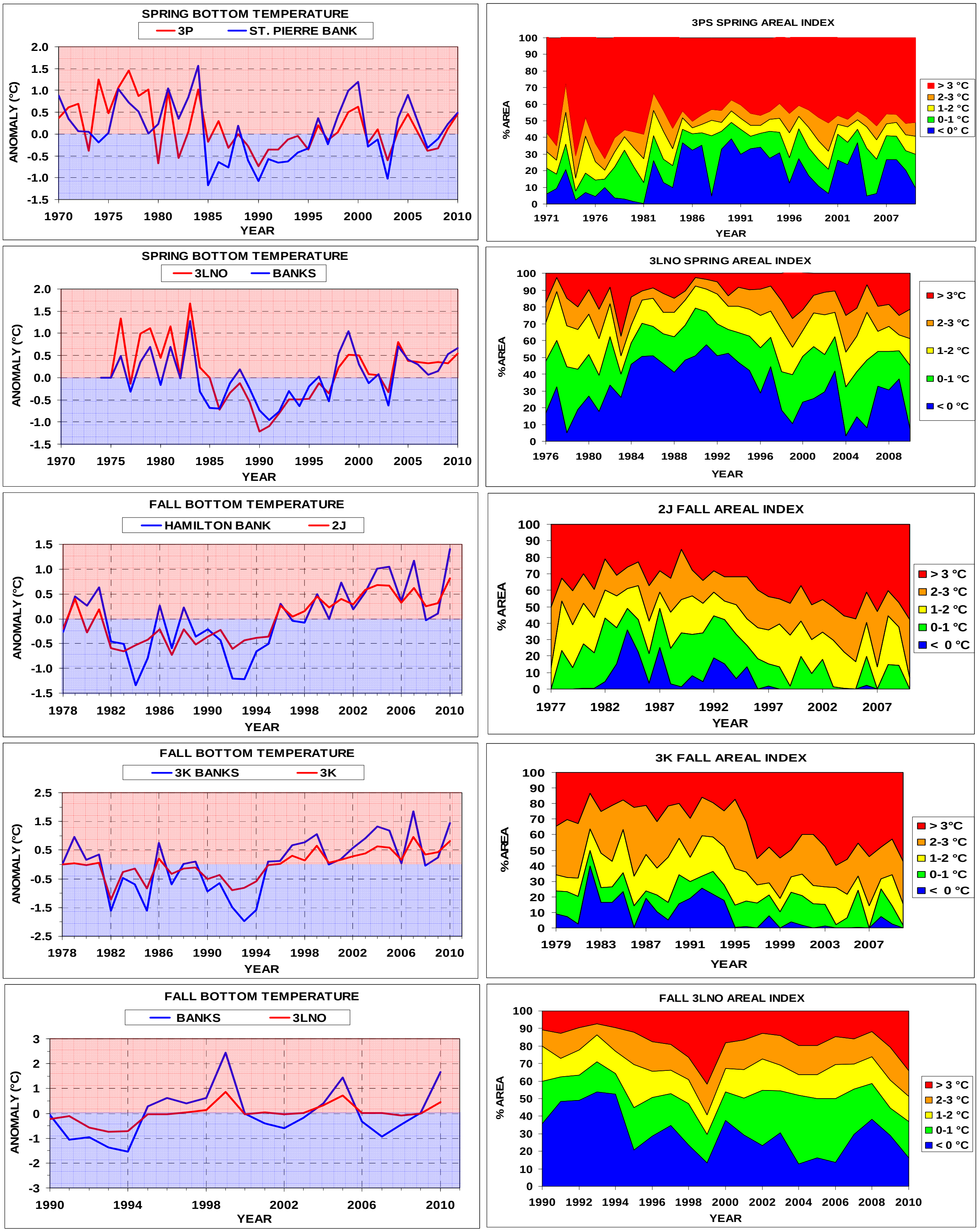


Figure 17. Bottom temperature anomalies (left panels) and the area of the bottom covered with water in different temperature bins (right panels) for the spring and fall multi-species surveys in NAFO Division 2J, 3KLNOP.

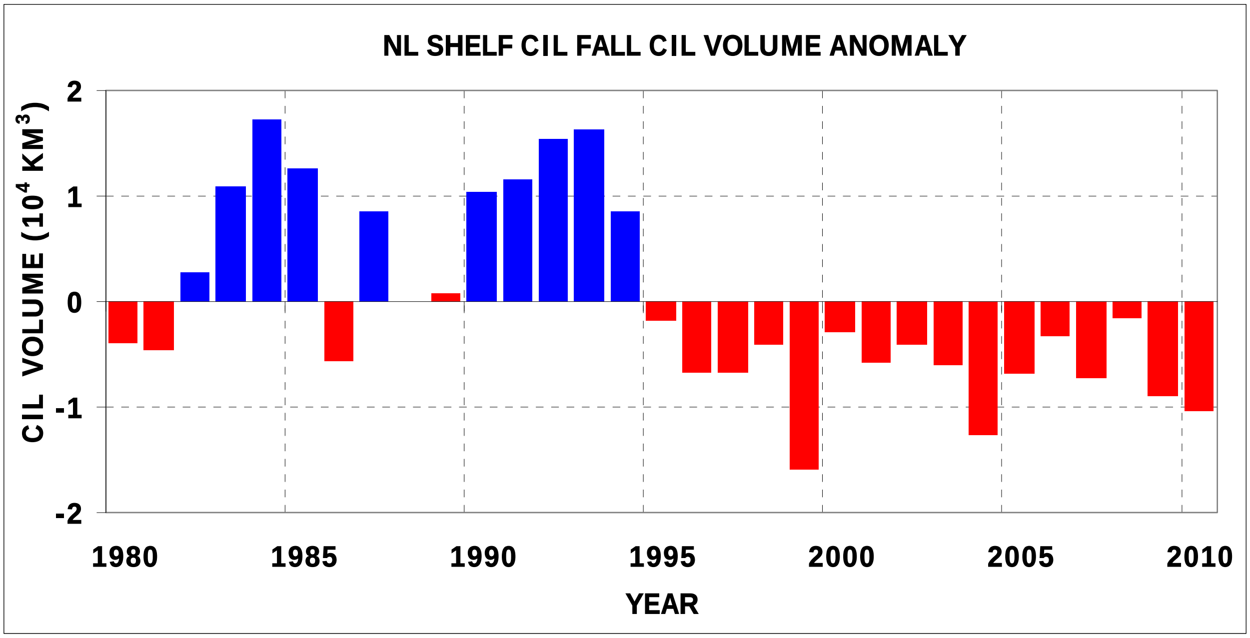


Figure 18. The extent of CIL (< 0°C) volume anomaly on the NL shelf bounded by NAFO Division 2J3KL based on the fall multi-species temperature data profiles.

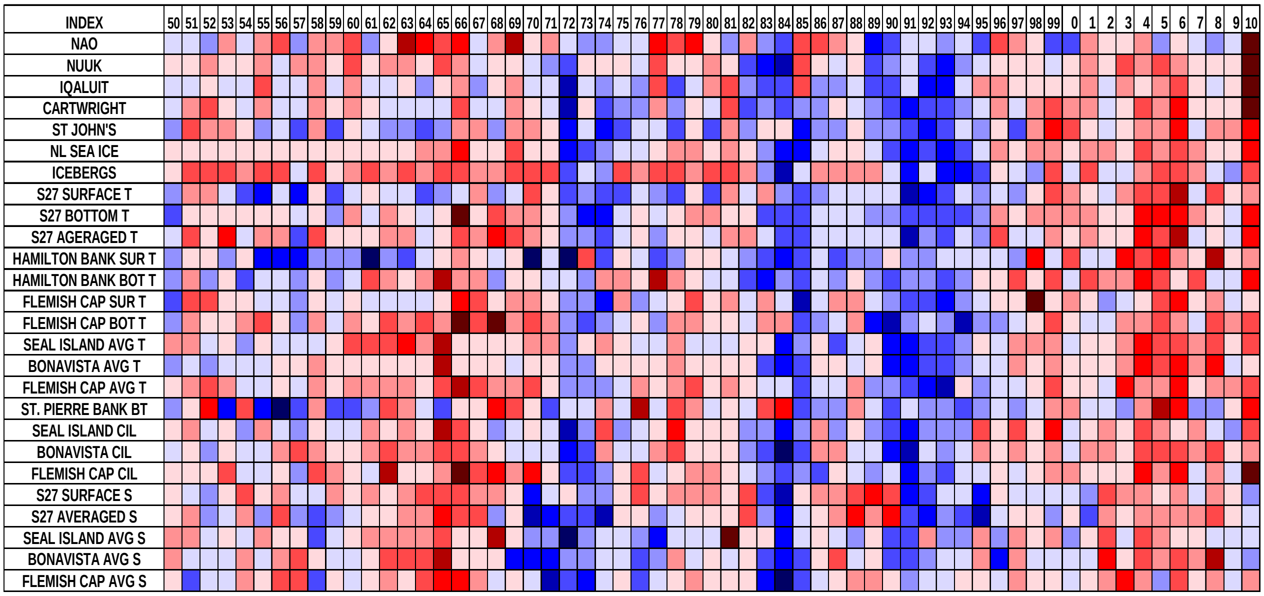
SUMMARY

A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2010 are displayed in Table 6 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. 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 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. During 2010, 85/106 environmental time series presented in Tables 2-5 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. In fact only 12/106 indices were within ±0.5 SD of the mean during 2010.

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 1981 to 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

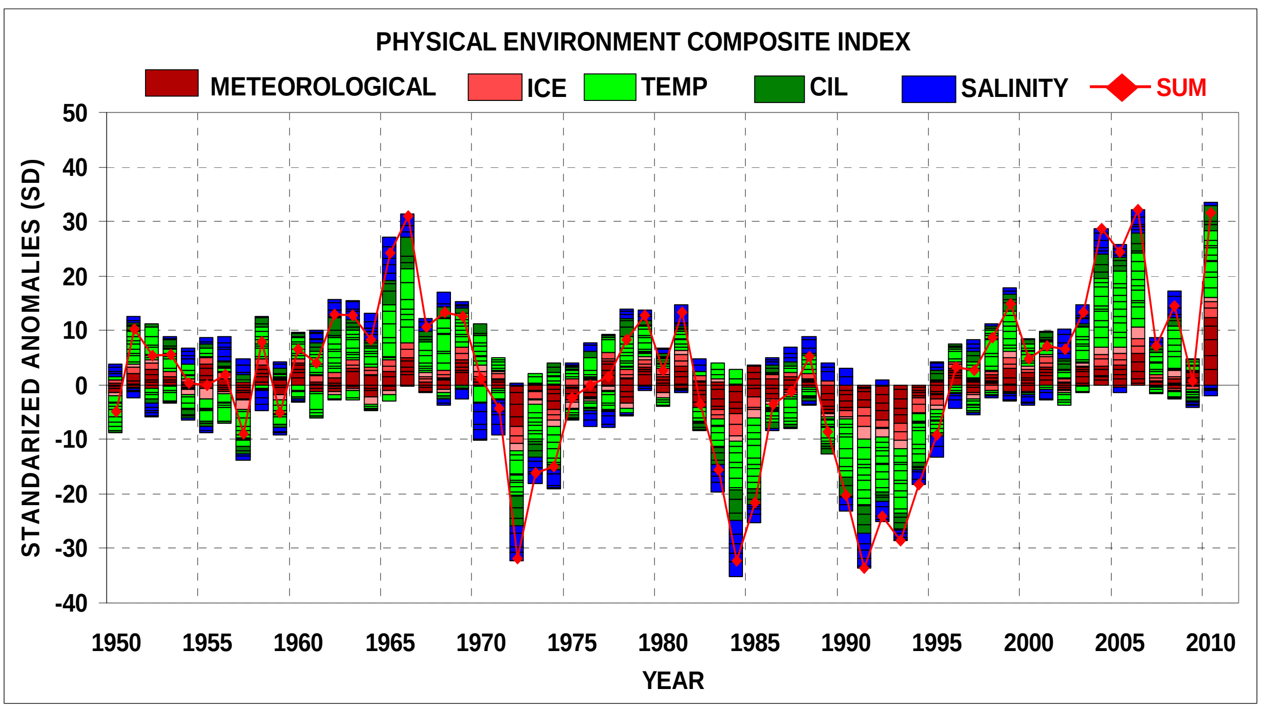


Figure 19. Composite climate index derived by summing the standardized anomalies from Table 6 together with their individual components.

Highlights for 2010:

- 85/106 environmental indices indicated warmer temperatures, saltier water, less CIL and sea-ice, and only 5 of these were not considered significant.

- Out of the 106 environmental time series analyzed, only 12 were within ±0.5 SD and are not considered significantly different from normal.

- Air temperatures were above normal by 2-3 standard deviations (SD) throughout much of the NW Atlantic and at record highs at some northern sites on Baffin Island and the Labrador Coast.

- The annual sea ice extent on the NL Shelf remained below normal for the 15^{th} consecutive year reaching a 48-year record low during the winter.

- Only one iceberg was detected south of 48°N on the Northern Grand Bank, down from 1204 in 2009.

- Annual surface temperature at Station 27 was 1 SD above normal while the water column average was at ~2 SD above normal, the 2^{nd} highest on record.

- The annual bottom temperature at Station 27 was at 1.7 SD above normal, the 3^{rd} highest on record.

- The cross sectional area of the <0 °C (CIL) water mass remained below normal along all sections with the 47°N section displaying the 2^{nd} lowest on record.

- A composite bottom temperature index for the spring multi-species surveys (3PLNO) was the 4^{th} warmest in the past 2 decades, while that from the fall surveys (2J3KLNO) was the warmest.

- The composite climate index for the NL region ranked 2^{nd} highest after 2006 in 61 years of observations.

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REFERENCES

Colbourne, E.B., Craig, J., Fitzpatrick, C, Senciall, D., Stead, P., and Bailey, W. 2010. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2009. NAFO SCR. Doc. 2010/6. Serial No. 5770. 25 p.

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., Narayanan, S., and Prinsenberg, S. 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 Colbourne. E.B. 2002. Trends in stratification on the inner Newfoundland Shelf. DFO Can. Sci. Advis. Sec. 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.

Hebert, D., Pettipas, R. and Petrie, B. 2011. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2009 and 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/094. iv + 31 p.

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

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

Petrie, B., Akenhead, S. Lazier, J. and Loder, J. 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.