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An Assessment of the Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2008

by

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ABSTRACT

The North Atlantic Oscillation index, a key indicator of climate conditions in the Northwest Atlantic, for both 2007 and 2008 was slightly above normal (<0.5 standard deviations) and as a consequence, outflow of arctic air masses to the Northwest Atlantic was stronger than in 2006. This resulted in a broad-scale cooling of air temperatures throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland relative to 2006. Sea-ice extent and duration on the Newfoundland and Labrador Shelf increased in 2008 but remained below average for the 14th consecutive year. As a result of these factors, water temperatures on the Newfoundland and Labrador Shelf generally cooled compared to 2006 but remained above normal in most areas in 2008, continuing the warmer than normal conditions experienced since the mid-to-late 1990s. Salinities in general on the NL Shelf, which were lower than normal throughout most of the 1990s, increased to the highest observed since the early 1990s during 2002 and have remained mostly above normal during the past 7 years. In particular, at Station 27 off St. John's, the depth-averaged annual water temperature decreased from the record high observed in 2006 to about normal in 2007 and to about 1 SD above normal in 2008. Annual surface temperatures at Station 27 also decreased from the 61-year record of 1.7°C (3 SD) above normal in 2006 to about normal in 2007 and to 1 SD (1°C) above normal in 2008. Bottom temperatures at Station 27 remained above normal for the 13th consecutive year. From 2004-06, they were >2.5 SD above normal but decreased to about 1 SD above normal during 2007-08. Upper-layer salinities at Station 27 were above normal for the 7th consecutive year. Annual surface temperatures on Hamilton Bank were 1.8 SD above normal, 1.3 SD above normal on the Flemish Cap and near normal on St. Pierre Bank. Bottom temperatures on Hamilton Bank were normal, ~2 SD above normal on the Flemish Cap and ~1 SD below normal on St. Pierre Bank. The area of the Cold-Intermediate-Layer (CIL) water mass on the eastern Newfoundland Shelf during 2008 was below normal for the 14th consecutive year and the 5th lowest since 1948. The average temperature and salinity during the summer of 2008 along the Bonavista section has remained significantly above normal by 2.4 and 3.3 SD, respectively. Bottom temperatures during the spring of 2008 remained slightly above normal on the Grand Banks (3LNO) but were below normal on St. Pierre Bank (3Ps). During the fall they were above normal in NAFO Div. 2J and 3K and slightly below normal in 3LNO. The area of the bottom on the Grand Banks covered by <0°C water during the spring decreased from near 60% in 1991 to <5% in 2004 but increased to near-normal at about 30% in 2007-08. A composite climate index derived from several meteorological, ice and oceanographic time series indicate a continuation of warm-salty conditions with 2008 ranking 6th warmest in 59 years of observations.

INTRODUCTION

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region during 2008 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 2008 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. 1). Data from other research surveys and ships of opportunity are also used to help define the long-term means and conditions during 2008. 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 2007. 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 ocean climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2008 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

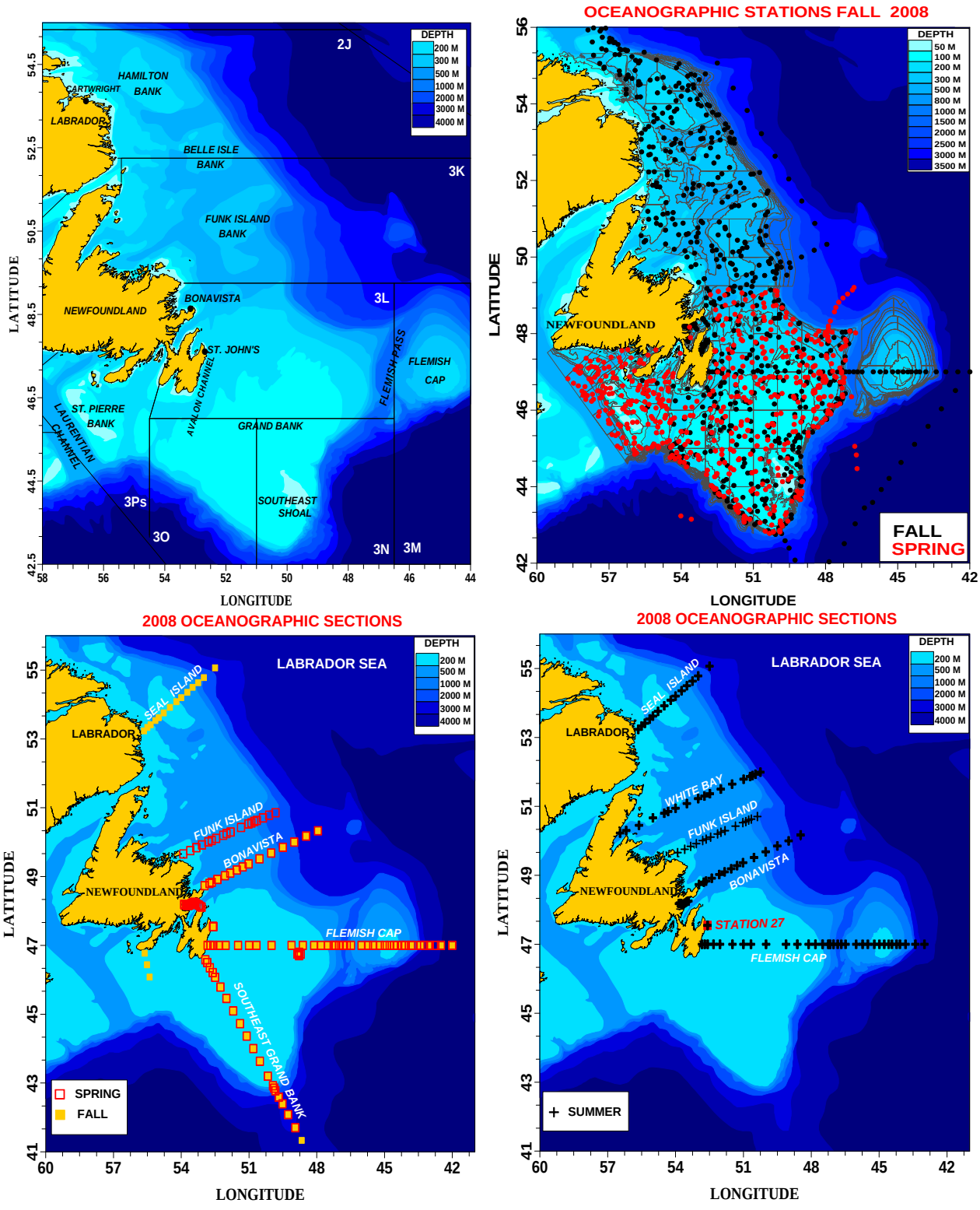

Figure 1. Maps showing bathymetric features, Station 27, the positions of trawl-mounted CTD profiles obtained from multi-species assessment surveys and standard sections sampled during 2008 on the NL Shelf.

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 and 2008 the index returned to slightly above normal, indicating cooling conditions relative to 2006. 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 2008 with some sites reporting below normal winter (Jan.-Mar.) values. 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. 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 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^{o}-55^{o}N) show lower than normal areas covered by ice during 2008 for the 14th consecutive year (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. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. For 2007 in contrast, it extended into June, particularly in the inshore areas. Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 976 icebergs drifted south of 48^{o}N onto the Northern Grand Bank during 2008, 324 in 2007 and 0 in 2006 compared with the 106-year average of 477. In some years during the cold periods of the early 1980s and 1990s, over 1500 icebergs were observed south of 48^{o}N with an all time record of 2202 in 1984. Years with low iceberg numbers on the Grand Banks generally correspond to warmer than normal meteorological and oceanographic conditions on the NL Shelf.

Table 2. Standardized anomalies from atmospheric and ice data from several locations in the Northwest Atlantic during 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	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
SEA-LEVEL	SLP (ICELAND-AZORES) NAO	1971-2000	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
PRESSURE	SLP (GREENLAND-GANDER)	1971-2000	0.49	1.45	0.79	0.98	0.04	-1.26	-0.83	0.57	-0.24	0.57	0.74	-1.90	-0.30	-1.07	-1.60	0.25	-1.35	-0.39	
AIR TEMPERATURES	NUUK (WINTER)	1971-2000	-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
	NUUK (ANNUAL)	1971-2000	-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
	IQALUIT (WINTER)	1971-2000	-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
	IQALUIT (ANNUAL)	1971-2000	-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
	CARTWRIGHT (WINTER)	1971-2000	-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
	CARTWRIGHT (ANNUAL)	1971-2000	-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
	BONAVISTA (WINTER)	1971-2000	-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
	BONAVISTA (ANNUAL)	1971-2000	-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
	ST. JOHN'S (WINTER)	1971-2000	-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
	ST. JOHN'S (ANNUAL)	1971-2000	-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
SEA ICE COVERAGE	NL SEA-ICE EXTENT (Annual)	1971-2000	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	-0.82
	NL SEA-ICE EXTENT (Winter)	1971-2000	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
	NL SEA-ICE EXTENT (Spring)	1971-2000	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
ICE BERG COUNT	GRAND BANKS	1971-2000	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	0.39

A more extensive analysis of meteorological, sea ice and sea-surface temperature data in the Northwest Atlantic, including the Newfoundland and Labrador Shelf, are presented by Petrie et al. (2009).

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 51 times (38 CTD profiles, 13 XBT profiles) during 2008. Depth versus time contours of the annual temperature cycle and the corresponding anomalies for 2008 are displayed in Figure 2. 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 90 m. Upper layer temperatures warmed to >1^{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 5^{o}C by early December. The seasonally heated upper-layer was constrained to the upper 30 m during the early summer resulting in a sub-surface cold anomaly with temperatures about 0.5^{o}C below normal. During the fall the rate of cooling of the seasonally heated upper-layer was slower than normal resulting in above normal temperature during November and early 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). Bottom temperatures have remained above normal for the past 13 years but have decreased from the 3rd highest rank in 2006 (2.7 SD) to 30/62 highest (+0.8 SD) in 2008. The annual surface temperatures at Station 27 have been above normal since 2002, 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 and increased to 1.9 SD above normal in 2008. Vertically averaged values over various depths also set record highs >3 SD above normal in 2006, decreased significantly in 2007, but increased again in 2008 to 0.8-2 SD above normal (Table 3).

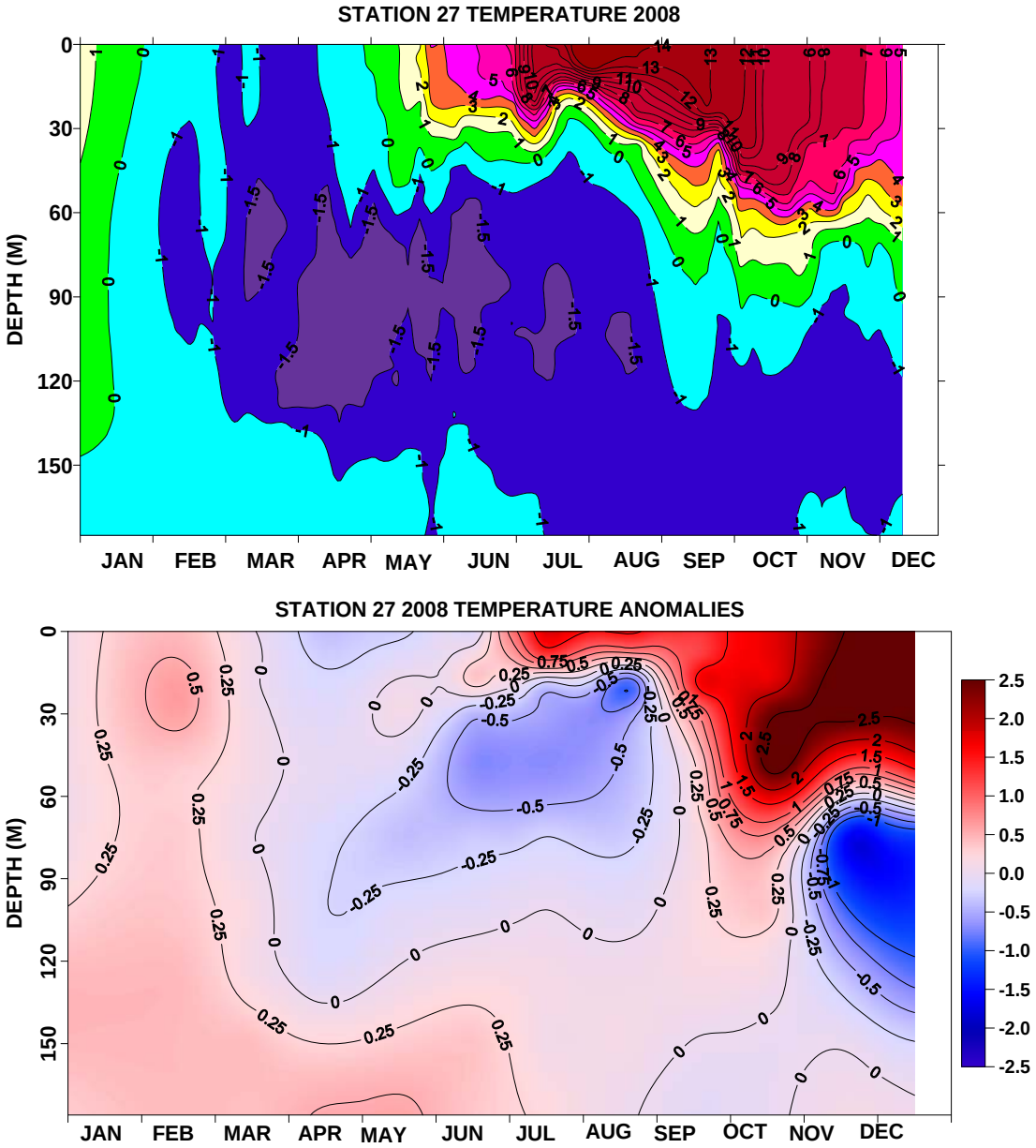

Figure 2. Contours of temperature and temperature anomalies (in °C) as a function of depth at Station 27 for 2008.

Depth versus time contours of the annual salinity cycle for Station 27 and the corresponding anomalies for 2008 are displayed in Figure 3. Surface salinities reached maximum values in late winter and early spring (>32.2) and decreased to <31.4 by early August. Below 100 m, salinities ranged from 32.8 - 33.2 throughout the year. 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 2008 this effect was slightly diminished as indicated by the positive salinity anomalies in the upper water column from August to December. Annual surface salinities at Station 27 in 2008 increased from the near normal values in 2007 to about 0.6 SD above normal. The depth averaged values were all above normal in 2008 and increased over 2007 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 (Table 3).

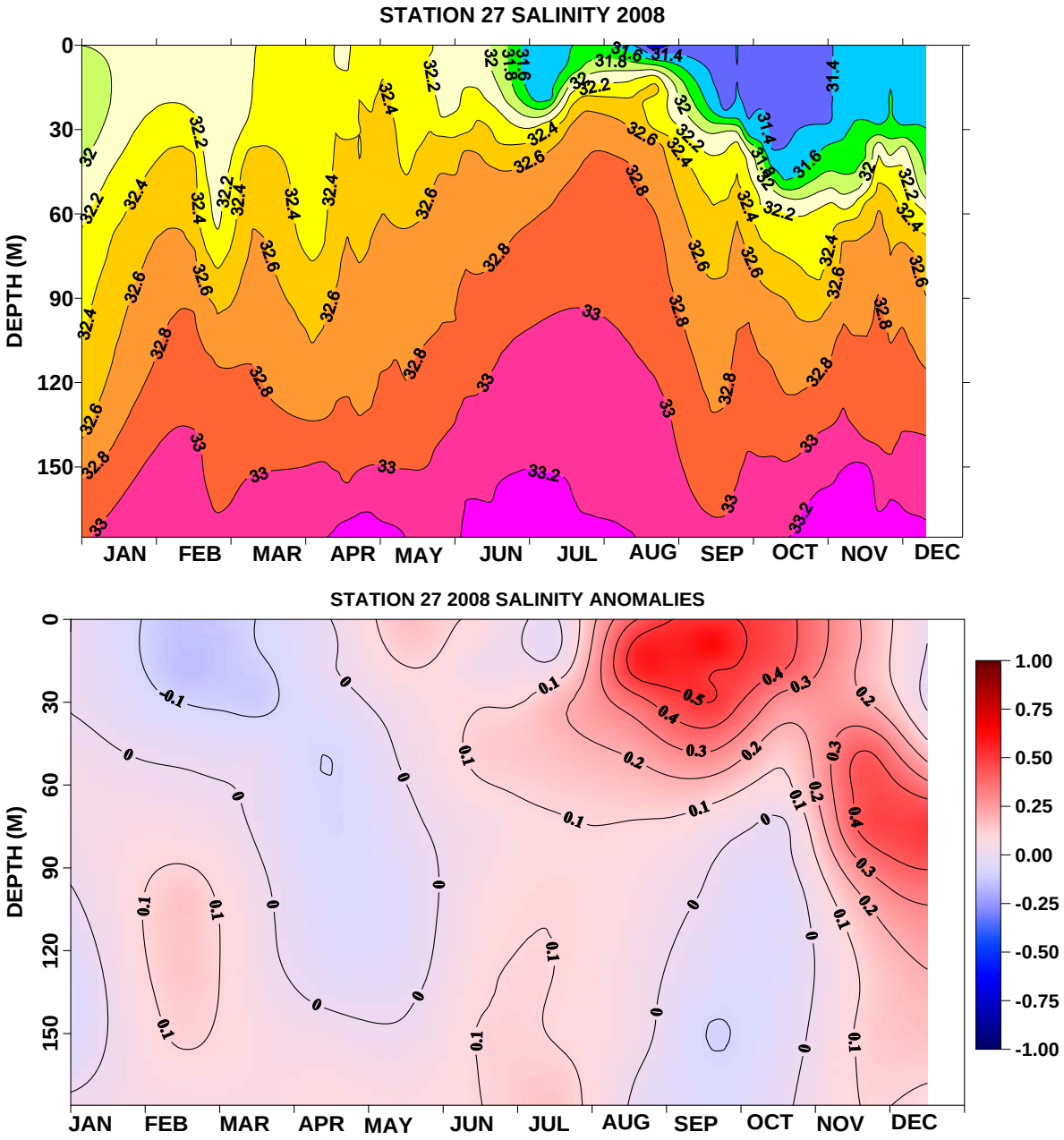

Figure 3. Contours of salinities and salinity anomalies as a function of depth at Station 27 for 2008.

At other locations, (Hamilton Bank, Flemish Cap and St. Pierre Bank) surface temperatures also increased over 2007 values and were up to 1.8 SD above normal in some areas. On St. Pierre Bank, near-bottom temperatures decreased to below normal values by 0.7 and 0.8 SD in 2007 and 2008 respectively. Temperature data obtained from thermographs deployed at inshore sites 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 up to 2006. In 2007, 5/6 sites with data reported significant negative anomalies whereas in 2008 5/7 sites reported either near normal or above normal values (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 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
SURFACE TEMPERATURE	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
	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	1.97	2.29	0.44	1.25
	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
	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	0.18
SURFACE SALINITY	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
	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
	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
BOTTOM TEMPERATURE	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
	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	2.12	1.40	0.18	1.81
	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
	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
VERTICALLY AVERAGED TEMPERATURE	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
	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
	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
	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
	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	0.03
VERTICALLY AVERAGED SALINITY	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
	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
	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
	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
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
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
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
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
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
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
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
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
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	ARNOLDS COVE PB	1981-2007	0.74	-2.00	-1.36	-1.55	0.48	-0.78	0.65	-0.36	0.48	2.30	0.96	0.44	0.51	1.03	-0.22	0.35	1.11	0.56	0.08
5 M TEMPERATURE	BRISTOL'S HOPE	1989-2007	-0.68	-2.96		-0.62	0.57	0.06	0.14	-0.03	-0.64	1.09	0.76	0.71	0.10	0.96	0.29	0.92	1.01	-0.59	1.00
9 M TEMPERATURE	HAMPDEN WB	1992-2007			-0.37	0.22	-1.42	-2.09	-0.33	-0.84	0.45	0.22	1.43	-0.85	0.59	0.35	0.86	0.95	1.45	-0.60	1.11
10 M TEMPERATURE	OLD BONAVENTURE	1991-2007		-1.76	-1.10	-0.97	2.10	0.20	0.65	0.01	-5.60	-0.45	0.12	1.29	0.39	0.23	-0.39	0.67	1.24	-2.23	-0.51
10 M TEMPERATURE	UPPER GULLIES CB	1990-2007	-1.18	-1.28	0.83	-0.35	0.25	0.34	-0.86	-0.05	-1.02	1.34	-0.17	0.12	0.34	0.94	-0.04	1.39	1.46	-2.07	1.72

On the Flemish Cap, surface salinities were slightly higher than normal during 2008, while on Hamilton Bank they were below normal by >1 SD. Salinities on the Flemish Cap have been above normal from 2001 to 2008. During the past several decades, cold ocean temperatures and fresher-than-normal waters were associated with strong positive NAO anomalies, colder-than-normal winter air temperatures, and heavy sea-ice conditions on the continental shelf (Colbourne et al. 1994, Drinkwater 1996). The magnitude of negative salinity anomalies (up to 1.8 SD) on the inner Newfoundland Shelf during most of the early 1990s is comparable to that experienced during the 'Great Salinity Anomaly' of the early 1970s (Dickson et al. 1988), however, the spatial extent of the fresh water was mainly restricted to the inner Newfoundland Shelf.

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. The spring values show similar patterns, however they were significantly below normal in 2002 and 2003 and slightly below normal in 2008. 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. 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 values was deeper than normal, while the annual average was about normal (Table 3).

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.

In 2008, 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 April, July and November, the White Bay in July, the Funk Island section in May and Seal Island section during July and November (Fig. 1).

The water mass characteristics observed along the standard sections crossing the Newfoundland and Labrador Shelf (Fig. 1) are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1ºC ─ 2ºC and salinities of 32 ─ 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^{o} - 4^{o}C and salinities in the range of 34 ─ 34.75. Surface temperatures normally warm to 10^{o} ─ 12^{o}C during late summer, while bottom temperatures remain <0^{o}C over much of the Grand Banks but increase to 1^{o} ─ 3.5^{o}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^{o} ─ 4^{o}C.

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 leads to intense vertical and horizontal temperature and salinity gradients, particularly along the frontal boundaries separating the shelf and slope water masses.

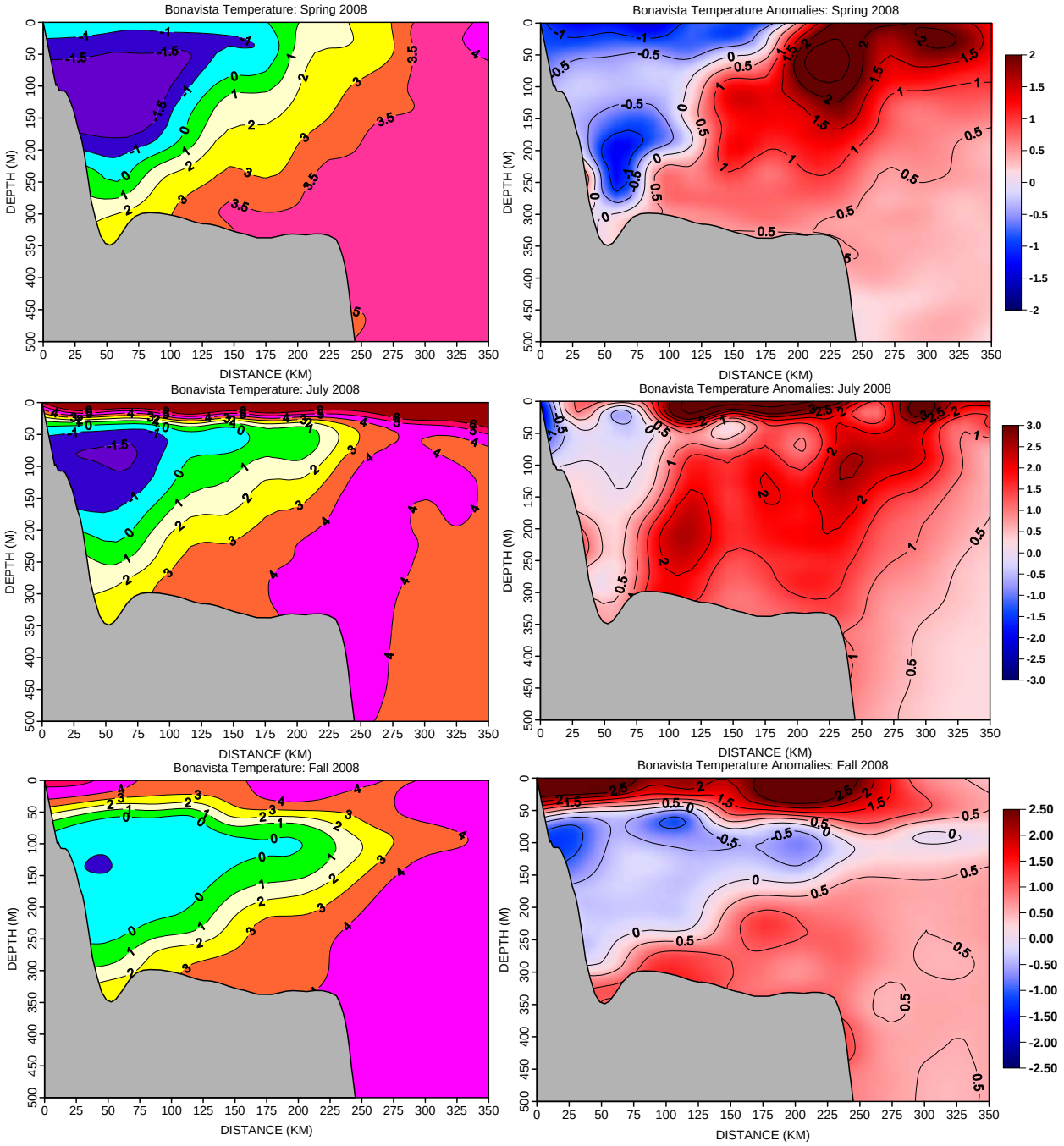

Figure 4a. Contours of temperature and temperature anomalies (^{o}C) across the Newfoundland Shelf along the Bonavista Section (Fig. 1) during the spring, summer and fall of 2008.

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 a strong temperature and density front (Fig. 4a). This winter formed shelf 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^{o}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. This shelf water mass remains present throughout most of the year as summer heating and salinity changes increases the

stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although CIL heat content continues to undergo a gradual decay during late summer reaching a minimum in late fall, due mainly to wind forced mixing. The seasonal variation in the cross-sectional area of this winter-chilled water mass is evident in the contour plots of the temperature along the Bonavista section in 2008 (Fig. 4a). The cross sectional area of the cold water extended to the surface during April, was below normal in the summer and was still present in late November. Seasonal cross sections of salinity along the Bonavista section for 2008 show remarkable similarities from spring to fall with saltier than normal conditions during the spring and summer, whereas fall conditions were fresher than normal in the upper water column (Fig. 4b).

Climate indices based on temperature and salinity data collected along sections from southern Labrador to southern Newfoundland are displayed in Table 4 for the years 1990-2008. On the southern Labrador Shelf and south to eastern Newfoundland, temperature and salinity have been increasing since 2000, reaching near-record high 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 this trend continued during 2008. From 1990 to 1994, temperature and salinity conditions were significantly below normal in these areas. Farther south on the 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 particularly along the southeast Grand Bank and St. Pierre Bank sections.

In 2008, the CIL cross sectional area anomalies varied by season and location with above normal areas observed along the three southern sections during the spring. 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 was below normal for the 14th consecutive year (1995-2008) ranking 5th lowest in the 60 year time series. The summer CIL area during the fall however expanded compared to 2007 to ~0.5 SD above normal. The overall average temperature along the Bonavista section increased to >2 SD above normal in 2008, similar to 2004-06. Average salinities along the Bonavista section have been significantly above normal since 2002, with 2008 at 3.3 SD higher than normal.

On the Grand Bank along the 47^{o}N section, the summer CIL area was below normal for the 11th consecutive year (1998-2008) and along the southeast Grand Bank section the spring CIL area was above normal, similar to 2007. On St. Pierre Bank the spring CIL area decreased sharply during 2004 and 2005 from the record high value during the cold spring of 2003. No data were available for 2006 and by 2007-08 the CIL area was once again above normal, although the 2008 value was <0.5 SD above normal.

Average salinities along each section were above normal in 2006-08. The baroclinic transport in the offshore branch of the Labrador Current was near normal during 2008 off southern Labrador but decreased significantly off the Grand Bank through the Flemish Pass. 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 a below normal estimate.

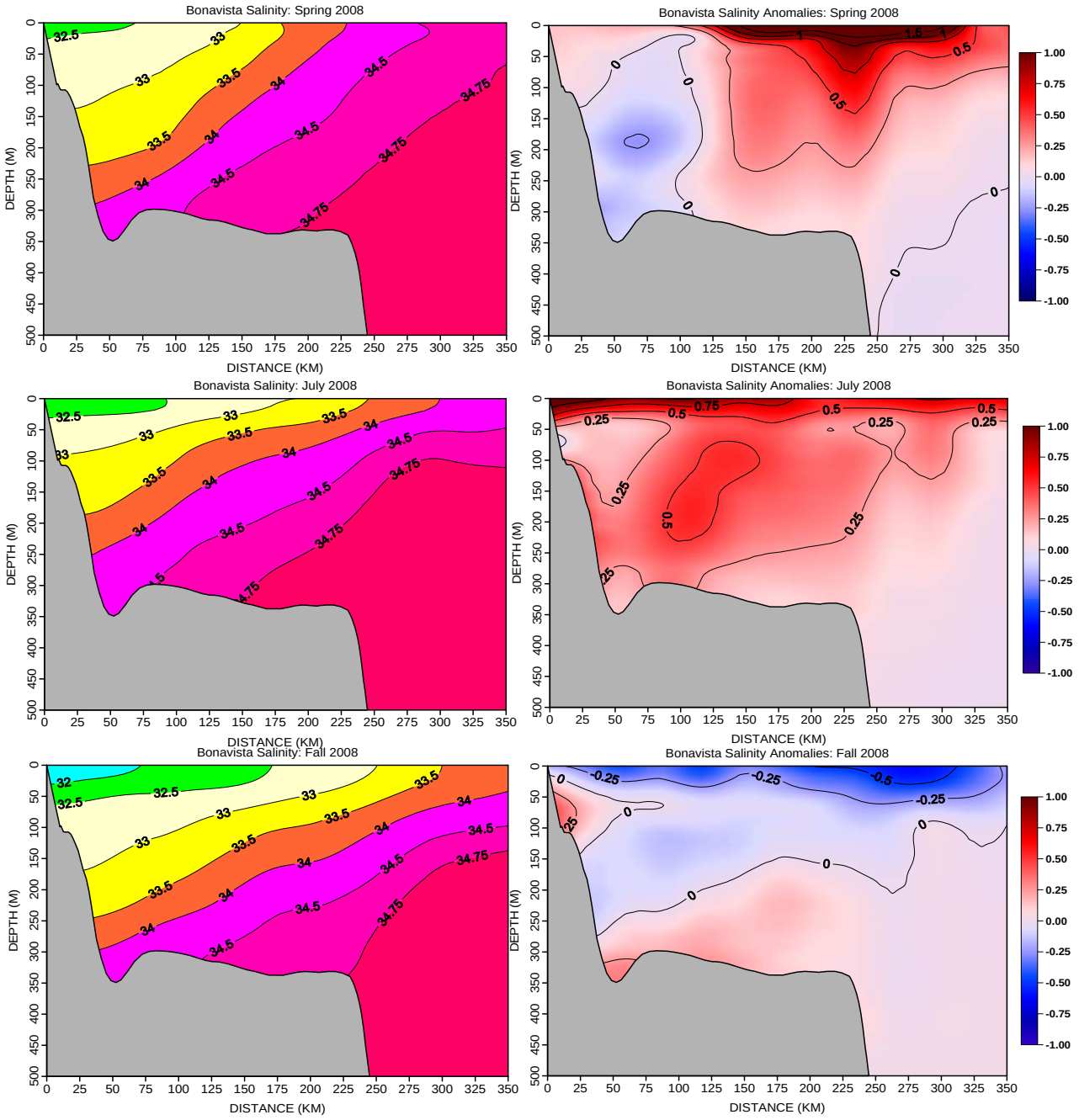

Figure 4b. Contours of salinity and salinity anomalies across the Newfoundland Shelf along the Bonavista Section (Fig. 1) during the spring, summer and fall of 2008.

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 3Pn in the west to 3LNO on the Grand Bank and one during the fall from 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 2008.

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	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
SOUTHERN LABRADOR SEAL ISLAND SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1971-2000	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
	MEAN CIL TEMPERATURE	1971-2000	-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	0.42	0.07	-0.52
	MINIMUM CIL TEMPERATURE	1971-2000	-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	1.53	0.33	-0.18
	MEAN SECTION TEMPERATURE	1971-2000	-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	1.74	1.30	1.64
	MEAN SECTION SALINITY	1971-2000	-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	0.66	0.34	0.14
	INSHORE SHELF SALINITY	1971-2000	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	0.33	0.26	0.56
	LABRADOR CURRENT TRANSPORT	1971-2000	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	0.98	0.43	0.09
NORTHEAST WHITE BAY SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1977-2000	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
	MEAN CIL TEMPERATURE	1977-2000	-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	1.25	0.48	0.89
	MINIMUM CIL TEMPERATURE	1977-2000	-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	2.25	0.52	0.45
	MEAN SECTION TEMPERATURE	1977-2000	-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	2.11	1.48	1.59
	MEAN SECTION SALINITY	1977-2000	-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	1.28	1.18	0.98
	MEAN SHELF SALINITY	1977-2000	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	0.93	0.78	0.98
EASTERN NEWFOUNDLAND BONAVISTA SECTION	CIL AREA (SPRING)	1977-2000	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
	CIL AREA (SUMMER)	1971-2000	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
	CIL AREA (FALL)	1979-2000	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
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-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
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-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
	MEAN SECTION TEMPERATURE (SUMMER)	1971-2000	-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
	MEAN SECTION SALINITY (SUMMER)	1971-2000	-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
	INSHORE SHELF SALINITY (SUMMER)	1971-2000	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
	LABRADOR CURRENT TRANSPORT (SUMMER)	1971-2000	-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
GRAND BANK FLEMISH PASS FLEMISH CAP 47 °N SECTION	CIL AREA (SPRING)	1971-2000	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
	CIL AREA (SUMMER)	1971-2000	-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
	CIL AREA (FALL)	1973-2000	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
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-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
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-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
	MEAN SECTION TEMPERATURE (SUMMER)	1971-2000	-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
	MEAN SECTION SALINITY (SUMMER)	1971-2000		-0.15	0.05	0.15		0.54	0.34	1.12	0.73	0.83	-0.05		1.32	2.29	1.12	-0.44	1.61		1.32
	INSHORE SHELF SALINITY (SUMMER)	1971-2000		-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
	LABRADOR CURRENT TRANSPORT (SUMMER)	1971-2000		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
SOUTHEAST GRAND BANK SECTION	CIL AREA (SPRING)	1972-2000	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
	MEAN CIL TEMPERATURE (SPRING)	1972-2000	-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
	MEAN TEMPERATURE (SPRING)	1972-2000	-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
	CIL AREA (FALL)	1990-2007	-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
	MEAN CIL TEMPERATURE (FALL)	1990-2007	-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	1.38	1.09	0.42
	MEAN SECTION TEMPERATURE (FALL)	1990-2007	-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	0.93	-0.63	-0.05
ST. PIERRE BANK SECTION (SPRING)	CIL AREA	1993-2007				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
	MEAN TEMPERATURE (< 100 M)	1993-2007				-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
	MEAN SECTION TEMPERATURE	1993-2007				-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
	MEAN SALINITY < 100 M	1993-2007				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
	MEAN SECTION SALINITY	1993-2007				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

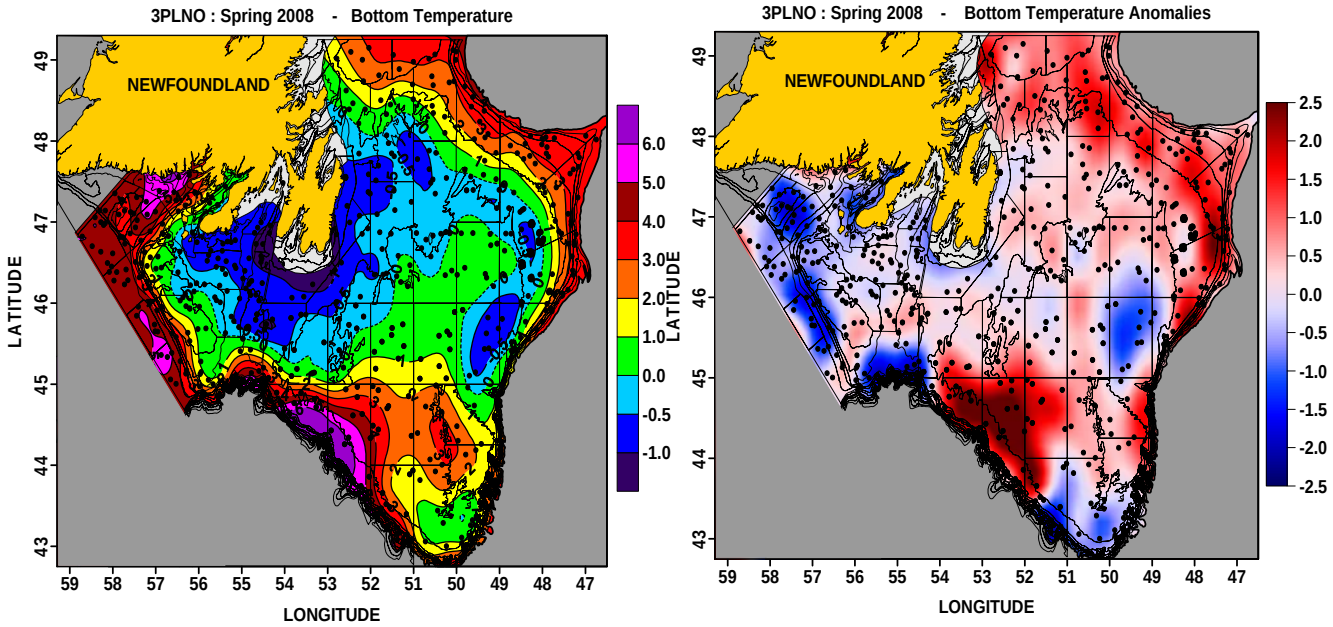

Figure 5. Contour maps of bottom temperature and their anomalies (in °C) relative to the 1971-2000 mean for the same period of the year, during the spring of 2008 in NAFO Div. 3PLNO. The black dots indicate sampling locations.

Spring Conditions

Maps of bottom temperatures and their anomalies during the spring of 2008 are displayed in Figure 5 for NAFO Div. 3LNO. 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 1° to >3°C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1°C - 5°C. There was a significant increase in the area of St. Pierre Bank and the Grand Banks covered by water with temperatures <0°C during the spring of 2007-08 compared with the previous three years (Fig. 5 and Table 5). Bottom temperature anomalies were highly variable with values >1° above normal over most of northern 3L, along the slope region and in southern areas of 3O. In western areas of Div. 3Ps, negative anomalies dominated, particularly in the deeper areas of the Laurentian Channel. It should be noted that areas of the inshore have limited or no sampling and as such the temperature estimates for these regions are not reliable.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990-2008 are displayed in Table 5 as normalized anomalies. In both 3Ps and 3LNO, 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 2008, with the exception of 2003, with 1999 and 2004 among the warmest years 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 0.3 SD below normal (Table 5).

In 3P bottom temperatures were below normal from 1990 to 1995, moderated in 1996, decreased again in 1997 but increased to above normal values by 1999 and 2000. Beginning in 2001 temperatures again decreased, reaching near-record cold conditions in 2003 with bottom temperatures on St. Pierre Bank (depths <100 m) reaching 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 and by 2007-08 spring temperatures across the 3P area returned to below normal conditions at near 1 SD (Table 5).

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
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
	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
	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
	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
	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
	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
	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
NAFO DIV. 3LNO FALL	BOTTOM TEMPERATURES	1990-2007	-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
	BOTTOM TEMPERATURES <100 M	1990-2007	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
	THERMAL HABITAT AREA >2°C	1990-2007	-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
	THERMAL HABITAT AREA <0°C	1990-2007	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
NAFO DIV 2J3KL	CIL VOLUME (SUMMER)	1980-1999	1.90	1.16		0.74	0.32	-1.23	-0.61	-0.81	-0.70	-1.28									
	CIL VOLUME (FALL)	1980-2007	1.06	1.18	1.59	1.68	0.86	-0.25	-0.78	-0.78	-0.50	-1.77	-0.37	-0.68	-0.49	-0.70	-1.41	-0.79	-0.42	-0.84	-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
	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
	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
	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
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
	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
	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
	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

Fall Conditions

Bottom temperature and temperature anomaly maps for the fall of 2008 in NAFO Div. 2J, 3K and 3LNO are displayed in Figure 6. Bottom temperatures in Div. 2J ranged from <2°C inshore to >3.5°C offshore at the shelf break. Over most areas of Hamilton Bank, temperatures were <1°C, a significant decrease from 2007. 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° - 3.5°C.

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 1° to 3.5°C and to >3.5°C along the edge of the Grand Bank. The area of the bottom covered by <0°C water have been increasing during the past couple of years with about 40% coverage. Bottom temperatures were still predominately above normal from Hamilton Bank to the northern Grand Bank although the magnitude of the anomalies have decreased over the previous 2 years particularly over northern areas. Over southern areas of the Grand Banks, bottom temperatures were generally below normal (Fig. 6).

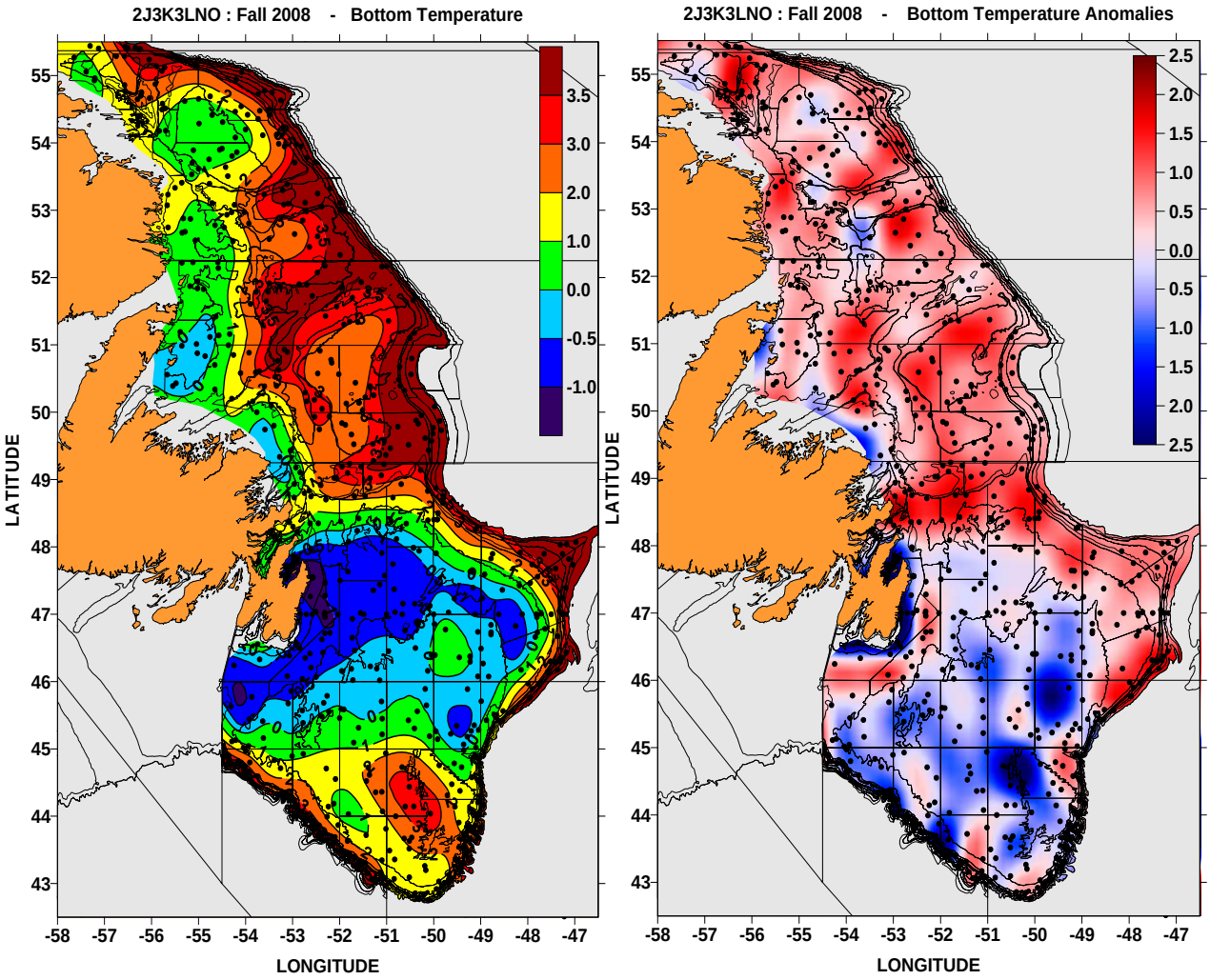

Figure 6. Contour maps of bottom temperature and temperature anomalies (in °C) during the fall of 2008 in NAFO Div. 2J, 3KLNO. The black dots indicate sampling locations.

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990-2008 are displayed in 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. From 1996-2008 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 cooling in 2008.

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 and slight cooling trend from in 2006-08. The total volume of CIL water remaining on the shelf was the lowest in the 27-year record during 1999 (1.8 SD below normal), followed by 2004 (1.4 SD below normal) and 2007 (0.8 SD below normal). In 2008, the volume of CIL water increased to near-normal (Table 5).

SUMMARY

The North Atlantic Oscillation index for 2007 and 2008 was slightly above normal (<0.5 SD) and as a consequence, outflow of arctic air masses to the Northwest Atlantic was stronger than in 2006 resulting in a broad-scale cooling of air temperatures throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland. Sea-ice extent and duration on the Newfoundland and Labrador Shelf increased slightly but remained below average for the 14th consecutive year. As a result of these factors water temperatures on the Newfoundland and Labrador Shelf generally cooled compared to 2006 but remained above normal in most areas in 2008, continuing the warmer than normal conditions experienced since the mid-to-late 1990s. Salinities on the NL Shelf, which were lower than normal throughout most of the 1990s, increased to the highest observed since the early 1990s during 2002 and have remained mostly above normal during the past 7 years.

A summary of selected temperature and salinity time series and other derived climate indices for the years 1950-2008 are displayed in Figure 7 (top panel) 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. 7 bottom panel).

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 results show that 2006 was the warmest in the 59 years of data collection, followed by 2004 and 1966. These were also the only years when all of the time series contributed positively to the overall index. The coldest year in the record occurred in 1991 followed by 1984 and 1972. In 2007, it appears that climate conditions cooled significantly over the previous 3-years with 2007 ranking 22nd warmest in 59 years. In 2008 overall climate conditions rebounded over 2007 to rank 6th warmest. In general, during 2008, 72/112 environmental time series presented in Tables 1-5 indicated a warming climate with saltier water and less sea-ice compared to 92/101 in 2006.

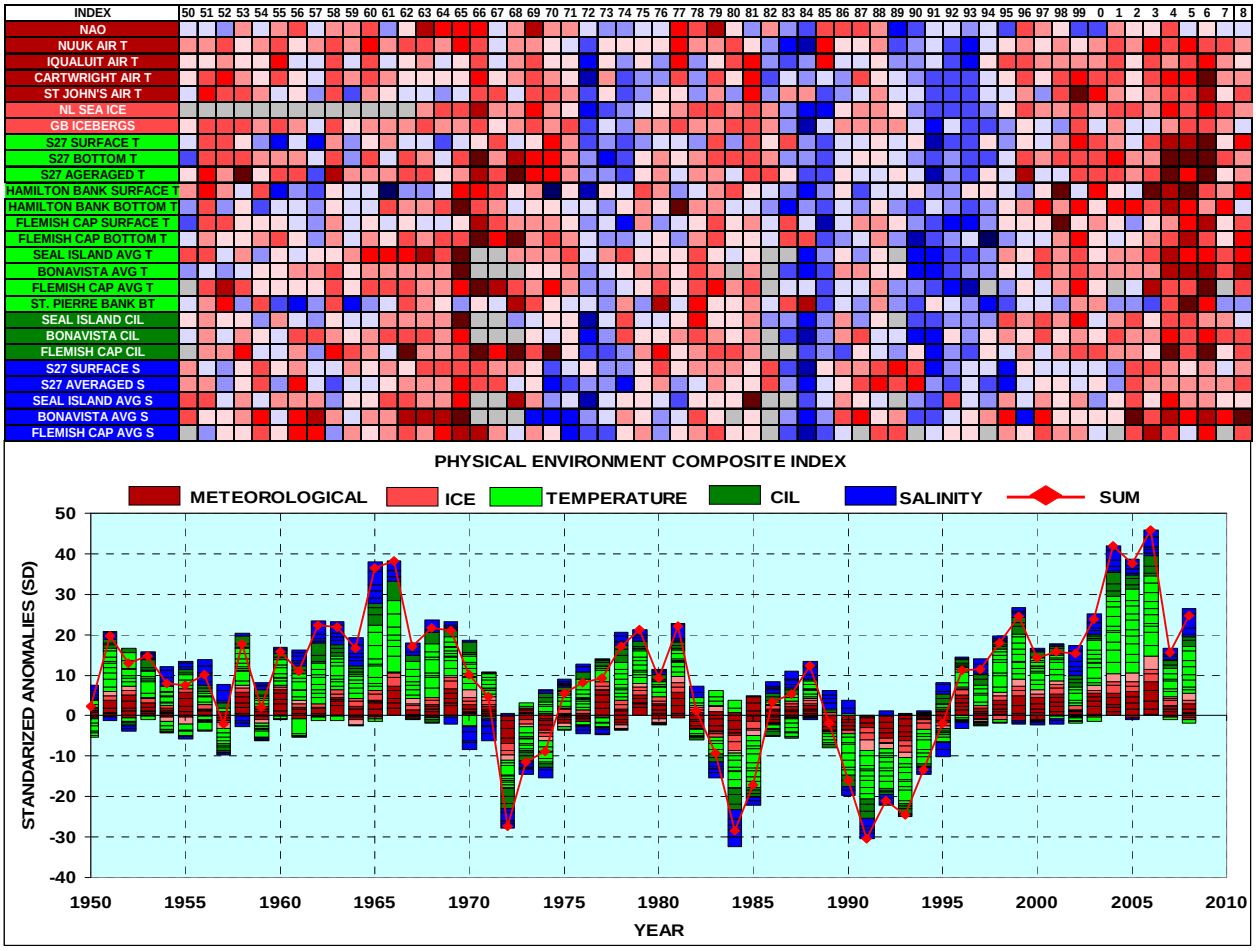

Figure. 7. Standardized anomalies of NAO, air temperature, ice, water temperature and salinity and CIL areas from several locations in the Northwest Atlantic colour-coded according to Table 1. The anomalies are normalized with respect to their standard deviations over a base period from 1971-2000 (top panel). The sum of the anomalies is shown in the bottom panel together with the individual components.

Highlights for 2008:

- The North Atlantic oscillation index, during both 2007-08, was slightly positive (<0.5 SD), which likely contributed to a cooling of air and ocean temperatures relative to 2006.

- Annual air temperatures were above normal in Newfoundland and Labrador by 0.8°C (0.7 SD) at Cartwright, 1°C (1.4 SD) at Bonavista and by 1°C (1.4 SD) at St. John's, a significant decrease over the record highs of 2006 but warmer than in 2007.

- The annual sea ice extent on the NL Shelf remained below normal for the 14th consecutive year. The winter ice extent was the highest since 1997 whereas the spring extent ranked 11th lowest since 1963.

- 976 icebergs were detected south of 48^{o}N on the Northern Grand Bank, up from 324 in 2007 and 0 in 2006.

- The Station 27 depth-averaged annual water temperature increased slightly over 2007 to above normal by nearly 1 SD (0.2°C).

- Annual surface temperatures at Station 27 also increased over 2007 values to 2 SD (1°C) above normal.

- Near surface (0-50 m) summer salinities at Station 27 were above normal for the 7th consecutive year, by 0.35 (1.5 SD) in 2008.

- Bottom temperatures at Station 27 remained above normal for the 13th consecutive year. From 2004-06, they were >2.5 SD (0.8°C) above normal but decreased to about 0.8 SD (<0.5°C) above normal in 2007-08.

- Annual surface temperatures on Hamilton Bank were 1.8 SD (1.3°C) above normal, 1.3 SD (1.4°C) above normal on the Flemish Cap and near normal on St. Pierre Bank.

- Bottom temperatures on Hamilton Bank were normal, 1.8 SD (1.1°C) above normal on the Flemish Cap and 0.8 SD (-0.5°C) below normal on St. Pierre Bank

- The cross sectional area of <0°C (CIL) water mass on the eastern Newfoundland Shelf was below normal for the 14th consecutive year and the 5th lowest since 1948.

- The average temperature and salinity along the Bonavista section has remained significantly above normal by 2.4 (2.8°C) and 3.3 SD (0.3), respectively.

- The upper layer baroclinic transport of the shelf-slope component of the Labrador Current off southern Labrador showed an increasing trend from 2000-05 but has been decreasing during 2006-08 period.

- Averaged spring bottom temperatures remained slightly above normal by 0.4 SD (0.3°C) in Divs. 3LNO but were below normal by 0.9 SD (-0.6°C) in Sub-Div. 3Ps.

- Averaged fall bottom temperatures were above normal by 1.3 SD (0.6°C) in Div. 3K, by 1.3 SD (0.5°C) in 2J and slightly below normal in Divs. 3LNO.

- The area of bottom on the Grand Banks covered by <0°C water during the spring decreased from near 60% in 1991 to <5% in 2004 but increased to near-normal at about 30% in 2007-08.

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