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# An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2005

# Évaluation de l'environment océanographique physique sur la plate-forme continentale de Terre-Neuve et du Labrador en 2005

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## ABSTRACT

Oceanographic observations on the Newfoundland and Labrador Shelf during 2005 are presented in relation to their long-term (1971-2000) means. At Station 27 off St. John's, the depth-averaged annual water temperature decreased slightly from the record high of 2004 to just over 0.5°C above normal, the 7th highest on record. Annual surface temperatures at Station 27 were identical to 2004, 1°C above normal, the highest in the 60 year record. Bottom temperatures were also above normal by 0.8°C, the 3rd highest in the 60-year record. Annual surface temperatures on Hamilton Bank were 1°C above normal, the 4th highest on record, on the Flemish Cap they were 2°C above normal, the 3rd highest and on St. Pierre Bank they were 1.7°C above normal, the highest in 56 years. Upper-layer salinities at Station 27 were above normal for the 4th consecutive year. The area of the cold-intermediate-layer (CIL) water mass on the eastern Newfoundland Shelf during 2005 was below normal for the 11th consecutive year and the 5th lowest since 1948. The near-bottom thermal habitat on the Newfoundland and Labrador Shelf continued to warm in 2005, with bottom temperatures reaching a record of 2°C above average on Hamilton Bank off southern Labrador during the fall. Bottom temperatures on St. Pierre Bank were above normal during the spring of 2005, the highest since 2000 and the 6th highest in 36 years. The area of bottom habitat on the Grand Banks covered by sub-zero water has decreased from >50% during the first half of the 1990s to near 15% during the past 2 years. In general water temperatures on the Newfoundland and Labrador Shelf decreased slightly from 2004 values, but remained well above their long-term means, continuing the warm trend experienced since the mid to late 1990s. Newfoundland and Labrador Shelf water salinities, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal at shallow depths during 2005.

# RÉSUMÉ

Des observations océanographiques effectuées sur la plate-forme continentale de Terre-Neuve et du Labrador en 2005 sont présentées en regard des moyennes à long terme (1971 à 2000). La température annuelle moyenne de la colonne d'eau, à la station 27, au large de St. John's, a diminué légèrement par rapport au sommet historique atteint en 2004, à un peu plus de 0,5 °C au dessus de la normale, soit la 7$^{e}$ moyenne la plus élevée. À la station 27 toujours, les températures annuelles de l'eau de surface étaient identiques à celles de 2004, soit 1 °C au-dessus de la normale, un record en 60 ans. Les températures de fond étaient aussi supérieures à la normale de 0,8 °C, la troisième moyenne la plus élevée en 60 ans. Les températures annuelles de l'eau de surface sur le banc Hamilton étaient supérieures à la normale de 1 °C, soit la quatrième valeur la élevée jamais enregistrée, tandis que sur le Bonnet flamand, elles étaient de 2 °C au-dessus de la normale, la troisième valeur la plus élevée, et sur le banc de Saint-Pierre, de 1,7 °C au-dessus de la normale, soit la plus élevée en 56 ans. La salinité dans le haut de la colonne d'eau à la station 27 a été supérieure à la normale pour la quatrième année consécutive. En 2005, la masse d'eau qui compose la couche intermédiaire froide (CIF) dans l'est du plateau continental de Terre-Neuve est demeurée sous la normale pour la onzième année consécutive; elle était aussi la cinquième plus faible depuis 1948. L'habitat thermique du fond sur la plate-forme continentale de Terre-Neuve et du Labrador a continué de se réchauffer en 2005, les températures de fond ayant atteint un record de 2 °C de plus que la normale sur le banc Hamilton, au sud du Labrador, au cours de l'automne. La température de fond sur le banc de Saint-Pierre est aussi demeurée supérieure à la normale au printemps 2005, la plus élevée depuis 2000 et la sixième plus élevée en 36 ans. L'aire de l'habitat de fond couverte par de l'eau à moins de zéro degré sur les Grands Bancs a rétréci, passant de plus de 50 % pendant la première moitié des années 1990 à près de 15 % au cours des deux dernières années. En général, la température de l'eau sur la plate-forme de Terre-Neuve et du Labrador a diminué légèrement par rapport aux valeurs de 2004, mais est demeurée bien supérieure à sa moyenne à long terme, soit dans le sens de la tendance au réchauffement amorcée au milieu des années 1990. La salinité sur la plate-forme continentale de Terre-Neuve et du Labrador, qui a été inférieure à la normale pendant une grande partie des années 1990, a augmenté pour atteindre, en 2002, un niveau inégalé en dix ans, demeurant supérieure à la normale dans les zones peu profondes en 2005.

# INTRODUCTION

This manuscript presents an overview of physical oceanographic conditions in the Newfoundland and Labrador (NL) Region during 2005, in relation to long-term average conditions based on historical data. Where possible the long-term averages were standardized to a 'normal' base period from 1971-2000 in accordance with the recommendations of the World Meteorological Organization. The information presented for 2005 is derived from three principal sources; (1) observations made at the fixed 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 2005. These data are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and maintained in databases at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's Newfoundland.

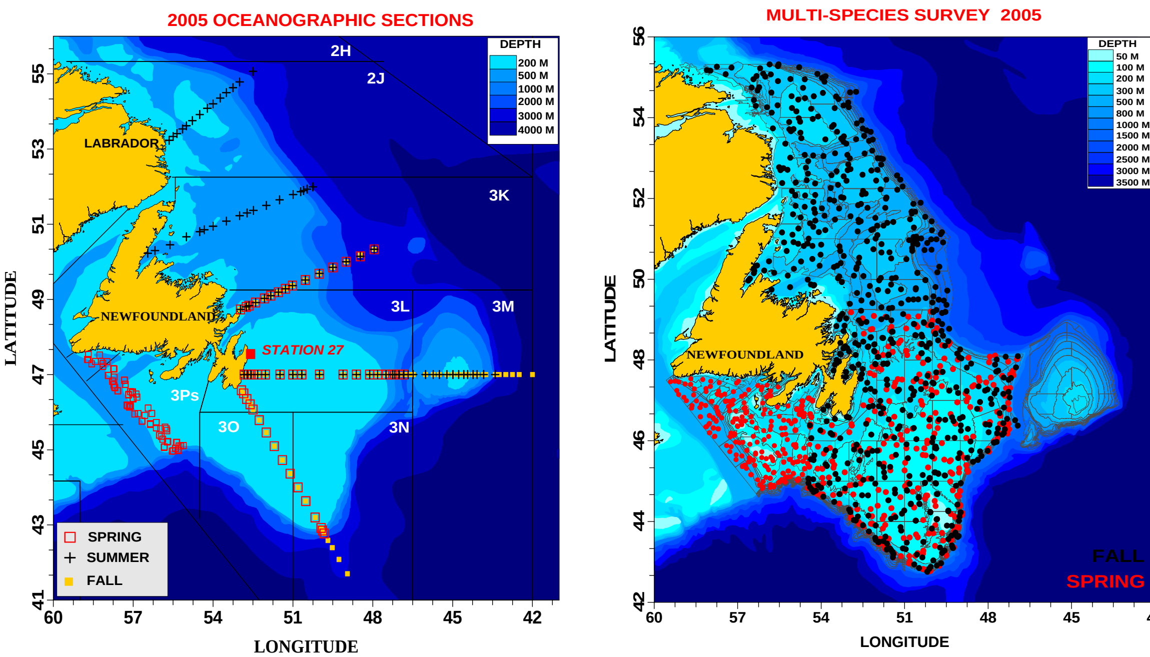


Fig. 1. Maps showing sections sampled on the NL Shelf during 2005, the location of Station 27 and the positions of trawl-mounted CTD profiles obtained from the spring and fall multi-species assessment surveys.

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 should be noted that monthly and annual estimates of anomalies are often based on a varying number of observations; 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 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 probably not significantly different from the long-term mean. Water property time series and derived ocean climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2005 are presented as normalized anomalies in 0.5 standard deviation (SD) units and summarized in tables. The anomalies are color coded with blues representing 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. 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 color coding scale.

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

## METEOROLOGICAL AND SEA-ICE CONDITIONS

The North Atlantic Oscillation (NAO) Index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly and northwesterly winds over the Northwest Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High, which in most years creates 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 this region due to shifting anomalies in the sea level pressure (SLP) fields. The NAO index for 2002 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 however, similar to 1999 and 2000, the spatial patterns in the SLP fields during the winter months resulted in very weak northwesterly winds over the Newfoundland and Labrador area. 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).

Table 2. Atmospheric and ice anomalies from several locations in the Northwest Atlantic during 1990 to 2005. The anomalies are normalized with respect to their standard deviations over the indicated base period.

| INDEX | REGION | REFERENCE | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| | 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 |
| | 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 |
| AIR | 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 |
| TEMPERATURES | 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 |
| | 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 |
| | 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 |
| | 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 |
| | 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 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| SEA ICE | 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 | -1.44 |
| COVERAGE | 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 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| 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 |

Air temperature anomalies at five sites in the northwest Atlantic, Nuuk Greenland, Iqaluit on Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland are also shown in Table 2. The predominance of warmer-than-normal annual air temperatures at all sites from the mid-1990s to 2005 is clearly evident, with 2005 annual values ranging from 1-2 standard deviations (SD) above normal. Winter values were also above normal, however the anomalies were generally <1 SD in magnitude. In terms of recent extremes, 1999 was a record breaking year at Cartwright (1.82 SD above normal) and at St. John's (2.51 SD above normal). The coldest overall air temperatures in the Northwest Atlantic since the 1990s occurred in 1993, when the annual anomalies were all >1 SD below normal.

The location and concentration of sea ice are available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The time series of the areal extent of sea ice on the NL Shelf (between $45^o$-$55^o$N) show that spring conditions during 2005 were slightly lighter than 2004 and the overall sea-ice extent remained below average for the $11^{th}$ consecutive year (Table 2). The winter of 2004 had the lowest amount of sea-ice on the NL Shelf since 1965. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate a total of 11 icebergs drifted south of $48^o$N onto the Northern Grand Bank during 2005, the lowest number since 1966 and well below the 106 year average of 477. In 2004 there were 262 icebergs observed on the Northern Grand Bank and in some years of the early 1990s, over 1500 icebergs drifted onto the northern Grand Bank. Years with low iceberg numbers on the Grand Banks generally correspond to warmer than normal meteorological and oceanographic conditions on the NL Shelf.

More extensive analysis of meteorological, ice conditions and sea-surface temperature conditions in the Northwest Atlantic including the Newfoundland and Labrador Shelf are reported on an annual basis by Petrie et al. (2006).

## TIME TRENDS IN TEMPERATURE AND SALINITY

Station 27, located in the Avalon Channel off Cape Spear NL (Fig. 1), was sampled 49 times (42 CTD profiles, 7 XBT profiles) during 2005. Depth versus time contours of the annual temperature cycle for 2005 are displayed in Fig. 2. The cold isothermal water column during late January to early April has temperatures ranging from near $0^o$ to $-1^o$C. These temperatures persisted throughout the year below 100 m. Upper layer temperatures warmed to $>0^o$C by mid-April and to $>15^o$C by August, after which the fall cooling commenced with values decreasing to $2^o$C by December. The seasonally heated upper-layer initially penetrated to about 60 m depth in June, then shoaled to 30-40 m during mid-summer due to local coastal upwelling and then gradually deepened to a maximum of about 100 m by late November.

Annual surface and bottom temperatures at Station 27 were similar to 2004 values, >2 SD above their long-term means. Vertically averaged values over various depths were also above normal by close to 2 SD. In general, Station 27 temperatures were below normal from 1990-1995, reaching minimum values in 1991 when they dipped to 2-3 SD below normal. Temperatures warmed during the mid-1990s and have remained, for the most part, above normal for the past 10 years near bottom (Table 3). At other locations (Hamilton Bank, Flemish Cap and St. Pierre Bank) temperatures remained significantly above normal during both 2004 and 2005 with anomalies reaching a record 2.7 SD above normal on Hamilton Bank. Temperature time series obtained from thermographs deployed at inshore sites along the coast during the summer in water depths from 5-10 m show considerable variability about the mean due to local wind driven upwelling. 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 (Table 3).

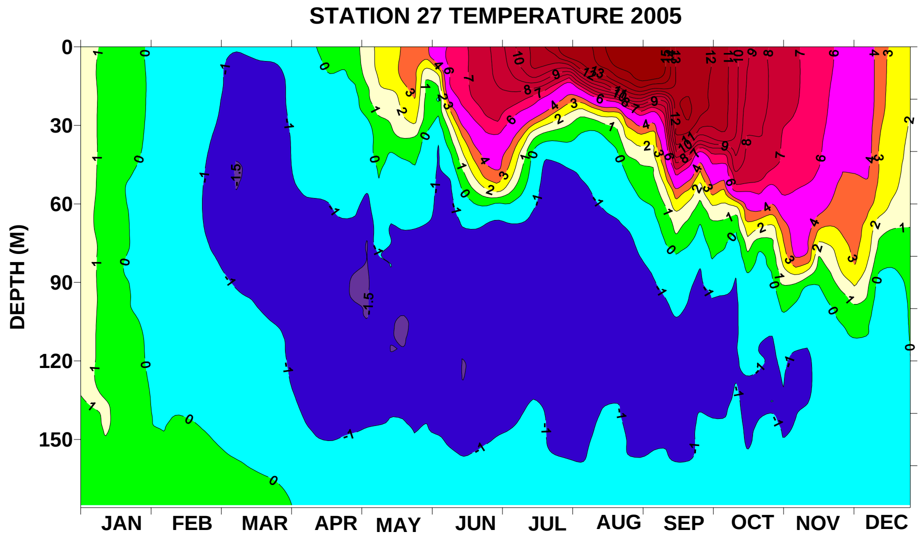


Fig. 2. Contours of temperature observations (in °C) as a function of depth at Station 27 for 2005.

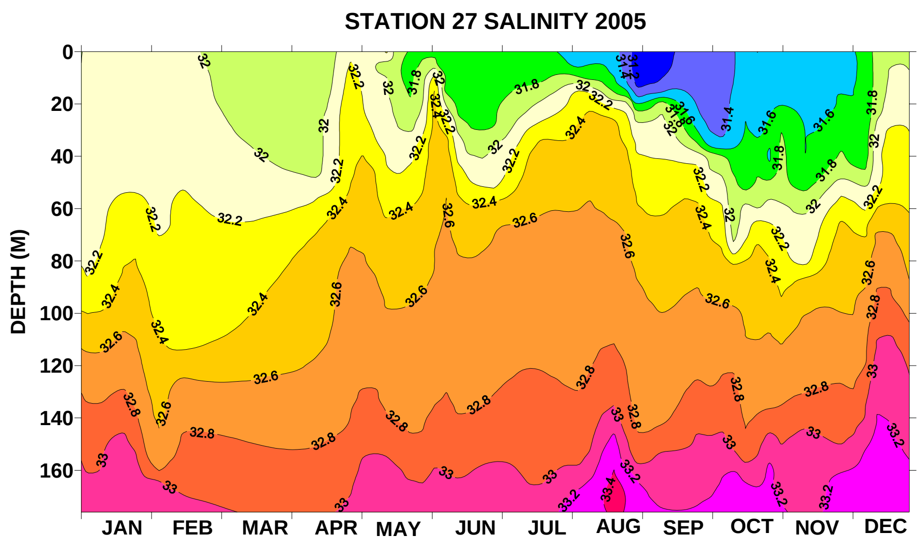


Fig. 3. Contours of salinities observations as a function of depth at Station 27 for 2005.

Depth versus time contours of the annual salinity cycle for 2005 are displayed in Fig. 3. Surface salinities reached maximum values in early winter (>32) and decreased to minimum values by late summer (<31.2 in August). In the depth range from 50-100-m, salinities ranged from 32 to 32.7 and near bottom they varied throughout the year between 32.8 and 33.4. The period of low salinity values at shallow depths in late summer to late fall, a prominent feature of the salinity cycle on the Newfoundland Shelf, is due largely to melting sea-ice off Labrador earlier in the year followed by advection southward onto the Grand Banks. Annually, surface salinities at Station 27 were only slightly above normal during 2005, a decrease from the values in 2002-2004. Depth averaged values also remained slightly above normal with the most significant anomalies at shallow depths. Upper-layer salinities during the past four 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).

On Hamilton Bank and Flemish Cap, surface salinities were also higher than normal during 2005. In fact salinities on the Flemish Cap have been above normal since 2001. 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 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.

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.

| INDEX | LOCATION | REFERENCE | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| SURFACE | FLEMISH CAP | 1971-2000 | -0.51 | -1.30 | -1.54 | -1.66 | -0.73 | 0.01 | 0.17 | 0.32 | 2.50 | 0.13 | 0.85 | 0.48 | -0.66 | 0.20 | 0.53 | 1.97 |
| TEMPERATURE | STATION 27 | 1971-2000 | 0.05 | -2.49 | -1.40 | -1.37 | 0.32 | -0.60 | 0.32 | -0.39 | 0.86 | 1.81 | 1.15 | 0.92 | -0.08 | 1.34 | 2.00 | 2.00 |
| | 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 | 2.18 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| SURFACE | FLEMISH CAP | 1971-2000 | 0.75 | 0.47 | | 0.00 | -1.38 | 0.80 | 0.60 | 1.14 | -0.06 | 0.82 | -0.29 | 1.26 | 1.49 | 2.27 | 1.46 | 1.20 |
| SALINITY | STATION 27 | 1971-2000 | 1.48 | -1.85 | -0.96 | -0.04 | -0.33 | -1.82 | 0.22 | -0.26 | -0.29 | -0.37 | -0.23 | -0.56 | 1.06 | 1.01 | 0.58 | 0.44 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| BOTTOM | FLEMISH CAP | 1971-2000 | -2.30 | -1.02 | -0.66 | -0.41 | -2.59 | -0.51 | -0.48 | -0.11 | 0.82 | 1.78 | 0.36 | -0.16 | 0.11 | 0.84 | 1.08 | 2.12 |
| TEMPERATURE | HAMILTON BANK | 1971-2000 | -1.19 | -0.45 | -0.96 | -1.29 | -0.64 | 0.49 | 0.67 | 1.71 | 0.65 | 1.56 | 0.28 | 1.79 | 1.72 | 1.19 | 2.25 | 1.86 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| VERTICALLY | STATION 27 (0-50 M) | 1971-2000 | -0.18 | -3.04 | -0.57 | -0.54 | 0.63 | -0.13 | 1.62 | 0.03 | 0.18 | 1.26 | 0.95 | 1.73 | -0.11 | 1.48 | 1.96 | 1.94 |
| AVERAGED | STATION 27 (0-100 M) | 1971-2000 | 0.20 | -2.71 | -0.59 | -0.89 | 0.59 | -0.34 | 2.24 | -0.33 | -0.28 | 1.23 | 0.87 | 1.12 | 0.56 | 1.30 | 2.61 | 1.89 |
| TEMPERATURE | STATION 27 (0-175 M) | 1971-2000 | -0.13 | -2.46 | -0.69 | -1.04 | 0.16 | -0.40 | 2.47 | -0.05 | -0.05 | 1.18 | 1.14 | 1.25 | 0.68 | 1.18 | 2.95 | 1.98 |
| | 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 | 0.84 |
| | | | | | | | | | | | | | | | | | | |
| VERTICALLY | STATION 27 (0-20 M) | 1971-2000 | 1.57 | -1.81 | -0.95 | 0.02 | -0.26 | -1.77 | 0.17 | -0.31 | -0.24 | -0.35 | -0.19 | -0.62 | 1.10 | 1.08 | 0.61 | 0.48 |
| AVERAGED | STATION 27 (0-50 M) | 1971-2000 | 1.90 | -1.63 | -1.46 | -0.17 | -0.31 | -1.35 | -0.17 | -0.20 | -0.03 | -0.17 | -0.44 | -0.79 | 1.10 | 1.16 | 0.43 | 0.47 |
| SALINITY | STATION 27 (0-100 M) | 1971-2000 | 1.91 | -1.37 | -1.57 | -0.07 | -0.63 | -1.00 | -0.74 | 0.16 | 0.08 | -0.32 | -0.71 | -0.78 | 0.77 | 0.85 | -0.31 | 0.01 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| MIXED-LAYER | STATION 27 (WINTER) | 1990-2004 | -0.76 | -1.11 | -0.83 | -0.92 | 1.39 | -0.86 | 0.88 | 0.69 | -0.78 | -0.13 | -0.90 | 0.72 | 0.94 | -0.29 | 1.95 | 0.79 |
| MIXED-LAYER | STATION 27 (ANNUAL) | 1990-2004 | -0.95 | -1.34 | 0.11 | -0.04 | 1.13 | -1.60 | 0.60 | -0.60 | -0.27 | -0.17 | -0.50 | 0.45 | 1.18 | -0.27 | 2.18 | 0.09 |
| MIXED-LAYER | STATION 27 (SPRING) | 1990-2004 | -0.72 | -0.79 | -0.13 | -0.13 | 0.38 | -1.21 | -0.45 | -1.20 | 1.55 | -1.11 | -0.13 | 0.98 | 0.91 | 0.02 | 2.03 | -0.64 |
| 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 |
| 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 |
| STRAT ONSET | ONSET (25% OF MAX) | 1993-2004 | | | | -0.46 | 0.77 | -2.10 | 0.50 | -1.01 | -1.01 | -0.46 | 0.63 | 0.22 | 0.91 | 0.91 | 1.09 | 0.36 |
| STRAT PHASE | TIME OF MAX AMPLITUDE | 1993-2004 | | | | 0.48 | 0.23 | -1.35 | 1.72 | -0.43 | -1.10 | -1.35 | 0.56 | -0.60 | 0.39 | 1.39 | 0.06 | 0.64 |
| | | | | | | | | | | | | | | | | | | |
| 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 |
| 10 M TEMPERATURE | COMFORT COVE NDB | 1982-2004 | 1.16 | -1.97 | -0.71 | -1.73 | 0.13 | -1.05 | 0.79 | -0.61 | -0.09 | 0.94 | 1.10 | | 0.72 | 0.83 | | 0.40 |
| 10 M TEMPERATURE | ARNOLDS COVE PB | 1981-2004 | 0.81 | -1.86 | -1.23 | -1.42 | 0.56 | -0.68 | 0.72 | -0.26 | 0.56 | 2.33 | 1.03 | 0.52 | 0.59 | 1.10 | -0.12 | 0.44 |
| 5 M TEMPERATURE | BRISTOL'S HOPE | 1989-2004 | -0.57 | -2.81 | | -0.52 | 0.64 | 0.14 | 0.22 | 0.06 | -0.54 | 1.15 | 0.83 | 0.78 | 0.18 | 1.03 | 0.37 | 0.98 |
| 9 M TEMPERATURE | HAMPDEN WB | 1992-2004 | | | -0.24 | 0.37 | -1.32 | -2.01 | -0.20 | -0.72 | 0.60 | 0.37 | 1.61 | -0.73 | 0.75 | 0.50 | 1.02 | 1.11 |
| 10 M TEMPERATURE | OLD BONAVENTURE | 1991-2004 | | -1.76 | -1.11 | -0.98 | 2.05 | 0.17 | 0.62 | -0.01 | | -0.46 | 0.09 | 1.25 | 0.36 | 0.20 | -0.41 | 0.63 |
| 10 M TEMPERATURE | UPPER GULLIES CB | 1990-2004 | -1.44 | -1.57 | 1.13 | -0.38 | 0.39 | 0.50 | -1.03 | 0.00 | -1.23 | 1.78 | -0.15 | 0.22 | 0.50 | 1.26 | 0.02 | 1.85 |

The stratification of the water column (defined as the density difference between 0 and 50 m divided by 50) was computed from temperature and salinity data collected at Station 27. The annual stratification was generally below normal in the early 1990s, increased to above normal from 1997-

2001 and has since varied slightly about the mean. The spring values show similar patterns, however they were significantly below normal in 2002 and 2003. Before 1997 (except 1995) stratification was mostly below normal. The time of the spring onset of stratification and of maximum amplitude are highly variable; the initial onset was slightly later than normal from 2000-2005, although the 2001 and 2005 values were not significant. The mixed layer depth (MLD), estimated as the depth of maximum density gradient, is also highly variable on the inner NL Shelf. During 2004 the MLD was significantly (>2 SD) deeper than normal but shoaled to near normal depths during 2005. The 2005 values also exhibited seasonal differences with the winter value deeper than normal and the spring values slightly shallower than 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 2005 the Southeast Grand Bank section was sampled during April and November, the Flemish Cap section during April, July and December, the Bonavista section during May, July and December and the White Bay and Seal Island sections during late July. In addition a section along the south coast of Newfoundland was constructed based on temperature and salinity data collected using a net-mounted CTD during the April multi-species survey (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 -1° to 2°C and salinities of 32 to 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° to 4°C and salinities in the range of 34 to 34.75. Surface temperatures normally warm to 10° to 12°C during late summer, while bottom temperatures remain <0°C over the Grand Banks but increase to 1° to 3.5°C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3° to 4°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 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 a strong temperature and density front (Fig. 4). This winter formed water mass is commonly referred to as the cold intermediate layer or CIL (Petrie *et al.*, 1988) and is generally regarded as a robust index of ocean climate conditions off the eastern Canadian continental shelf. While the 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 increases the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although it continues to undergo a gradual decay during late summer reaching a minimum in late fall due mainly to wind forced mixing. The seasonal extent of this winter chilled water mass is evident in the contour plots of the temperature along the Bonavista section in 2005 (Fig. 4). The water mass extended to near the surface during spring, was the 5th smallest since 1948 in the summer and was nearly gone by late autumn. Seasonal cross sections of salinity for 2005 show remarkable similarities from spring to fall with slightly fresher upper-layer shelf values occurring during the summer (Fig. 4).

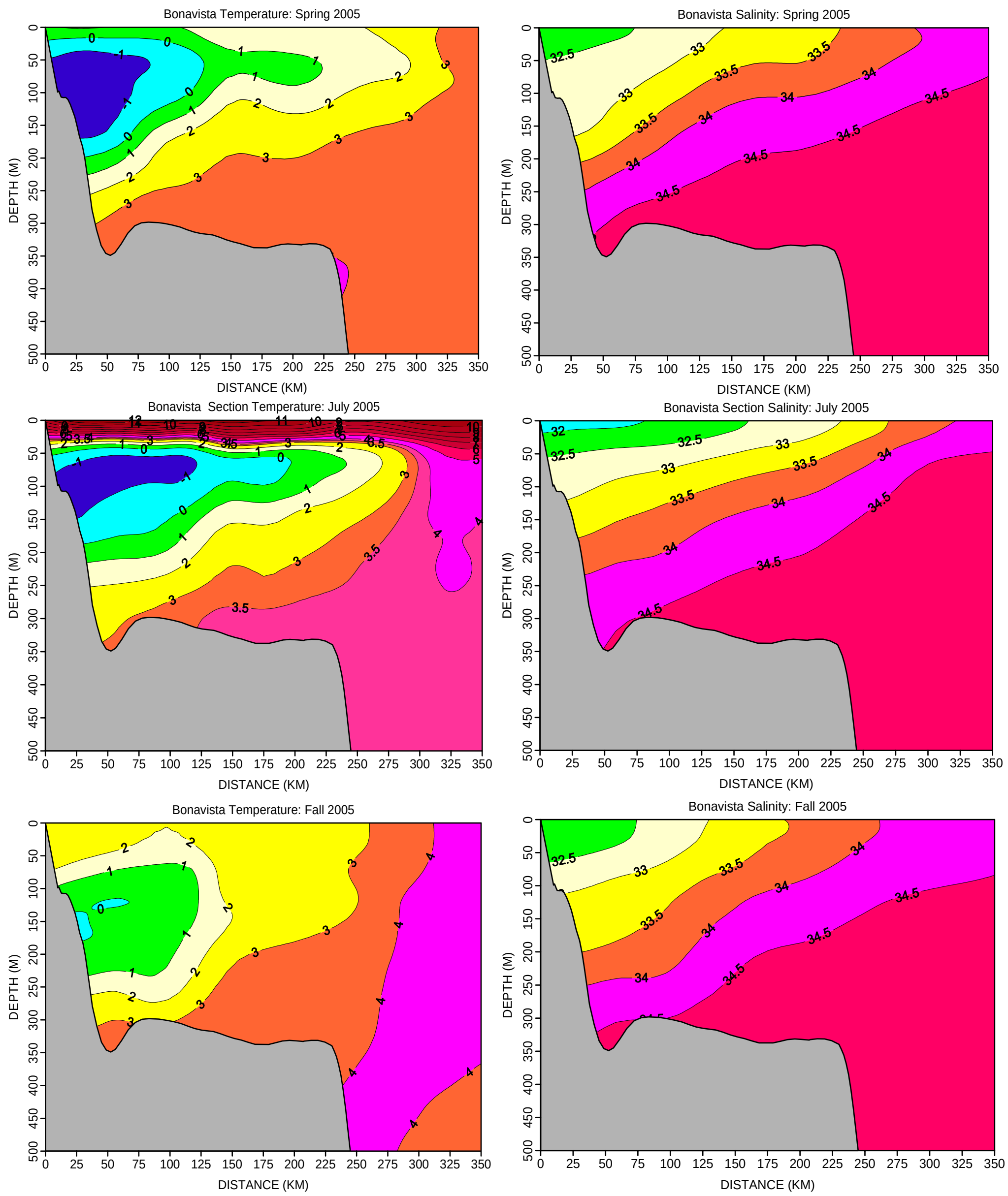


Fig. 4. Contours of temperature (°C) and salinity across the Newfoundland Shelf along the Bonavista Section (Fig. 1) during the spring, summer and fall of 2005.

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 1990-2005. On the southern Labrador Shelf south to eastern Newfoundland temperature and salinity has been increasing since the near-normal year of 2000 reaching near-record high values in 2004 and continuing warm and salty during 2005. From 1990 to 1994 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 and 2005 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.

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.

| REGION/SECTION | INDEX | REFERENCE | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| SOUTHERN | 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 |
| LABRADOR | 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 |
| SEAL ISLAND | MEAN SECTION TEMPERATURE | 1971-2000 | -1.32 | -1.24 | -1.04 | -0.98 | -0.51 | 0.66 | 0.37 | 1.02 | 0.90 | 1.26 | 0.35 | 0.55 | 0.82 | 1.12 | 2.03 | 1.42 |
| SECTION | MEAN SECTION SALINITY | 1971-2000 | -0.62 | -0.72 | 1.02 | -0.14 | -0.35 | 0.81 | -0.14 | 0.86 | 0.44 | 0.91 | -0.35 | 0.44 | 1.18 | 0.28 | 1.34 | 0.81 |
| (SUMMER) | 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 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| NORTHEAST | 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 |
| NEWFOUNDLAND | 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 |
| WHITE BAY SECTION | 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 |
| (SUMMER) | 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 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 | -0.90 |
| | 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 |
| | 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 |
| EASTERN | | | | | | | | | | | | | | | | | | |
| NEWFOUNDLAND | 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 |
| BONAVISTA | 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 |
| SECTION | MEAN SECTION TEMPERATURE (SUMME | 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 |
| | 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 |
| | 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 |
| | LABRADOR CURRENT TRANSPORT (SUI | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| GRAND BANK | 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 |
| FLEMISH PASS | 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 |
| FLEMISH CAP | | | | | | | | | | | | | | | | | | |
| | 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 |
| 47 $^{o}$N | 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 |
| SECTION | MEAN SECTION TEMPERATURE (SUMME | 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 |
| | 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 |
| | 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 |
| | LABRADOR CURRENT TRANSPORT (SUI | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| | 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 |
| SOUTHEAST | 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 |
| GRAND BANK | | | | | | | | | | | | | | | | | | |
| SECTION | CIL AREA (FALL) | 1990-2004 | -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 |
| | MEAN CIL TEMPERATURE (FALL) | 1990-2004 | -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 |
| | MEAN SECTION TEMPERATURE (FALL) | 1990-2004 | -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 |
| | | | | | | | | | | | | | | | | | | |
| | CIL AREA | 1993-2004 | | | | 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 |
| ST. PIERRE | MEAN TEMPERATURE (< 100 M) | 1993-2004 | | | | -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 |
| BANK | MEAN SECTION TEMPERATURE | 1993-2004 | | | | -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 |
| SECTION | MEAN SALINITY < 100 M | 1993-2004 | | | | 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 |
| (SPRING) | MEAN SECTION SALINITY | 1993-2004 | | | | 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 |

In 2005 the CIL areas along all sections during spring, summer and fall were below normal, implying warmer-than-normal water temperatures on the continental shelf. Along the Bonavista section for example, the summer CIL area was below normal for the 11$^{th}$ consecutive year ranking the 5$^{th}$ warmest year in the 57 year time series. This represents only a slight cooling from 2004 when it was the 2$^{nd}$ lowest on record. The overall average temperature along the Bonavista section was the 3$^{rd}$ highest on record in 2005, surpassed only by 2004 and 1965.

On the Grand Bank along the 47$^{o}$N section, the summer CIL area was below normal for the 8$^{th}$ consecutive year and along the southeast Bank section it was below normal for the 6$^{th}$ consecutive year with the spring of 2005 the 2$^{nd}$ lowest and 2003 the highest since 1972. On St. Pierre Bank the CIL area decreased sharply over the record high value during the cold spring of 2003. In this area, 1999 appears to be the warmest year in the time series. Salinities continued above normal along northern sections (Bonavista, White Bay and Seal Island) but were near normal on the Grand Bank and St. Pierre Bank. The baroclinic transport in the offshore branch of the Labrador Current was above normal during 2005 off southern Labrador and off the Grand Bank through the Flemish Pass, continuing a 6-year trend. Along the Bonavista Section however, where a significant component of the flow is in the offshore direction, there are no apparent patterns in the estimates of transport in recent years.

## 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 since 1989 trawl-mounted CTDs have provided profiles of salinity. These surveys provide 2 large spatial-scale oceanographic data sets on an annual basis 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 provide an assessment of the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of data products based on these data is used to characterize the oceanographic habitat. Among these are contoured maps of the bottom temperatures and their anomalies, a thermal habitat areal 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.

### *Spring Conditions*

Bottom temperature maps for NAFO Divisions 3P and 3LNO during the spring of 2005 are displayed in Fig. 5. Bottom temperatures over most of St. Pierre Bank ranged from <1$^{o}$ to 3$^{o}$C, which were above the long-term mean, similar to 2004 and a significant increase over 2003 values in this area. The area of the bottom covered by water with temperatures <0$^{o}$C was very similar to 2004, which was the lowest since 1988. In the deeper regions, (Laurentian and Hermitage Channels) temperatures were mostly below the long-term average but still generally >3$^{o}$C (Fig. 5).

Spring bottom temperatures in Div. 3L ranged from <0$^{o}$C to 1$^{o}$C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 1$^{o}$ to >3$^{o}$C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1$^{o}$C to 3.5$^{o}$C and generally >3.5$^{o}$C along the southwest slopes of the Grand Bank in Div. 3O. The spring of 2005 had the 4$^{th}$ lowest area of <0$^{o}$C near-bottom water in Division 3L since the surveys began in the early 1970s (Fig. 5). The thickness of the CIL in 3L ranged from 20 to >100 m in northern areas and generally <20 m in southern areas of the Grand Bank and the 3P region. In 3Ps mixed layer depths ranged from 50-130 m, with very low stratification values 1-10 ($10^{-3}$ kg $m^{-4}$) compared to the Grand Bank where mixed-layer depths ranged from 50-80 m and stratification values from 8-20 ($10^{-3}$ kg $m^{-4}$). In northern areas of 3L mixed-layer depths were <20 m with stratification values generally >20 ($10^{-3}$ kg $m^{-4}$). Most of these spatial differences can be attributed to temporal variability in the data collection with the 3P survey starting in early April and the 3L survey finishing up in late May or early June. Efforts are underway to examine inter-annual changes in mixed-layer depth and stratification for the years with consistent survey timing.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990-2005 are displayed in Table 5 as normalized anomalies. In both 3Ps and 3LNO bottom temperatures were generally lower than normal from 1990-1995 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 from 1998 to 2005 with the exception of 2003 temperatures were above normal 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 2.13 SD below normal (Table 5).

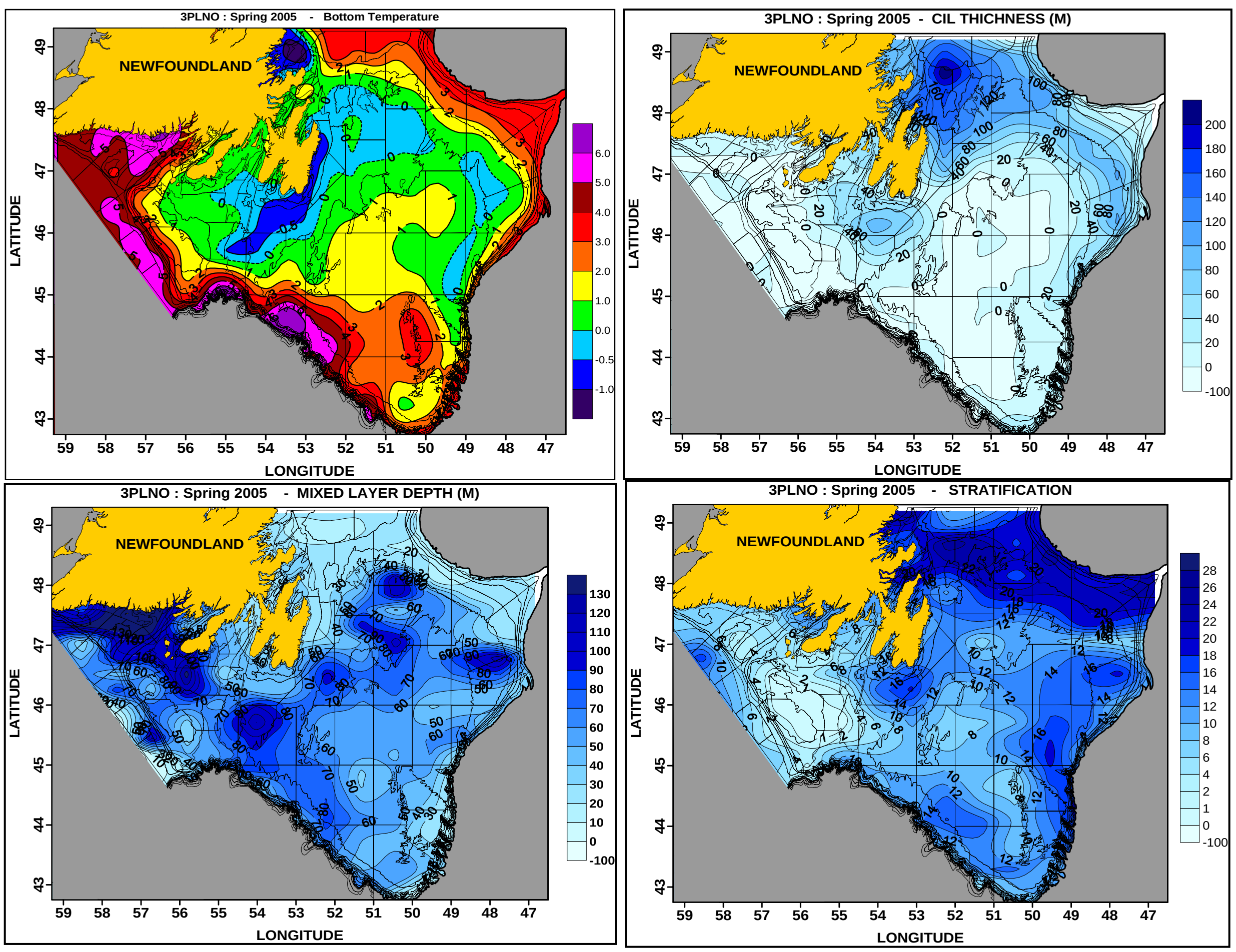


Fig. 5. Contour maps of bottom temperature (in °C), CIL thickness (in m), mixed-layer depth (in m) and stratification ($10^{-3}$ kg $m^{-4}$) during the spring of 2005 in NAFO Divisions 3PLNO.

In 3P bottom temperatures were below normal from 1990-1995, 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 1.57 SD below normal, the coldest since 1990. During the past 2 years temperatures have again increased to above normal values with 2005 the highest on St. Pierre Bank since 2000, ranking the 6$^{th}$ highest in the 36 year time series (Table 5).

***Fall Conditions***

Bottom temperature and temperature anomaly maps for the fall of 2005 in NAFO Divisions 2J, 3K and 3LNO are displayed in Fig. 6. Bottom temperatures during the fall of 2005 in Div. 2J ranged from <2$^o$C inshore, to >3.5$^o$C offshore at the shelf break. Over Hamilton Bank they ranged from 2$^o$C to 3$^o$C, about 1.5$^o$ to 2$^o$C above the long-term average. 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 during the fall of 2005 ranged between 2$^o$ to 3$^o$C, which were about 0.5$^o$ to 1.5$^o$C above their long-term means. In the near-shore areas temperatures were above normal by 1$^o$C to 2$^o$C. The isolated areas of below normal values near the coast and within some bays are likely due to extrapolation by the gridding algorithm into areas of no data coverage and hence are not reliable. Near the edge of the continental shelf in water depths >500 m, temperatures were generally near normal around 3.5$^o$C. Fall bottom temperatures in Divs. 3LNO generally ranged from <0$^o$C on the northern Grand Bank and in the Avalon Channel to 3.5$^o$C along the shelf edge. Over the southern areas, bottom temperatures ranged from 1$^o$ to 3.5$^o$C during 2005 and to >3.5$^o$C along the edge of the Grand Bank. During 2005 bottom temperatures were predominately above normal on the northern Grand Bank but varied about the mean in southern areas with an area of below normal values in the shallow waters of the southeast shoal of the Grand Bank (Fig. 6). Overall however, the area of <0$^o$C bottom water on the Grand Banks during the spring was the 2$^{nd}$ lowest on record in 2005 with 2004 the lowest.

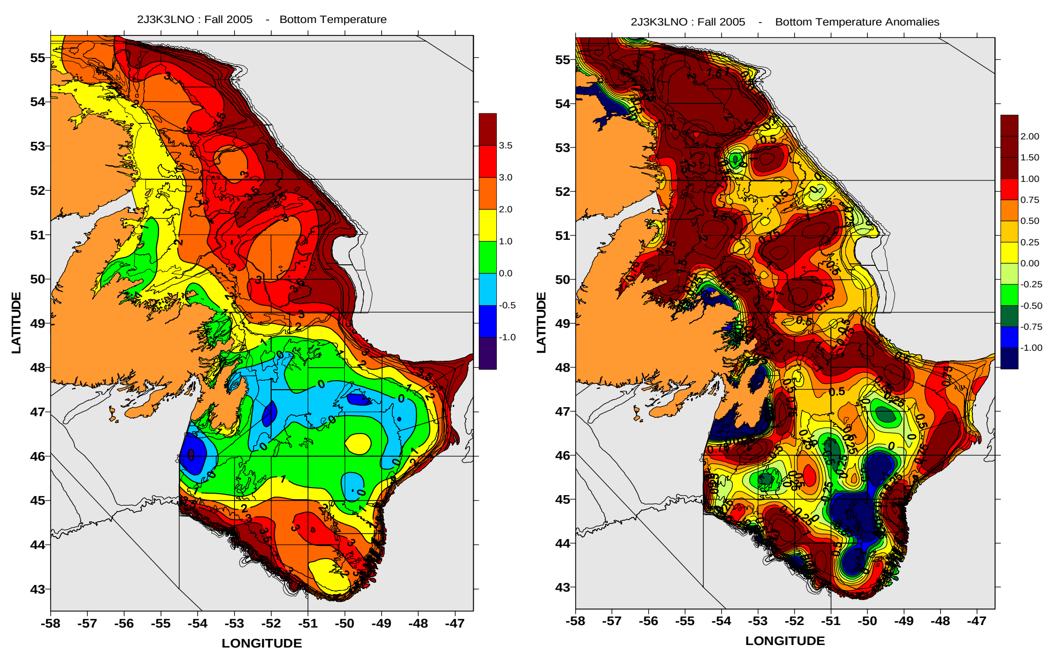


Fig. 6. Contour maps of bottom temperature and temperature anomalies (in °C) during the fall of 2005 in NAFO Divisions 2J, 3KLNO.

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990-2005 are displayed in Table 5. In 2J bottom temperatures were generally colder than normal from 1990-1995, with the coldest anomalies observed in 1992 when they reached >1.7 SD below normal on Hamilton Bank (<200 m depth). From 1996 to 2005 bottom temperatures were above normal reaching record high values in 2004 and 2005 (2.5 SD above normal). Since 1998, near-bottom water with temperatures <0°C have disappeared from the Hamilton Bank during the fall with a corresponding increase in the area covered by water >2°C. In 3K conditions were very similar with the 3 warmest years on record occurring in 1999, 2004 and 2005. In 3LNO during the fall bottom temperatures were somewhat cooler than those further north in 2J and 3K with record high values in 1999, near normal values in 2000-2003 and above normal temperatures during 2004 and 2005, with 2005 the 2nd highest in the time series. The total volume of CIL water remaining on the shelf during the fall was the lowest in the 26 year record during 1999, followed by 2004 and 2005 (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.

| REGION | INDEX | REFERENCE | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| NAFO DIV. 2J | 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 |
| FALL | 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 |
| | THERMAL HABITAT AREA <0°C | 1978-2000 | 0.05 | -0.32 | 1.15 | 0.80 | -0.14 | 0.59 | | -0.58 | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| NAFO DIV. 3K | 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 |
| FALL | 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 |
| | 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 | | |
| | | | | | | | | | | | | | | | | | | |
| | BOTTOM TEMPERATURES | 1990-2004 | -0.38 | -0.08 | -1.26 | -1.69 | -1.58 | 0.08 | 0.12 | 0.30 | 0.51 | 2.32 | 0.06 | 0.29 | 0.11 | 0.19 | 1.01 | 1.98 |
| NAFO DIV. 3LNO | BOTTOM TEMPERATURES <100 M | 1990-2004 | 0.02 | -0.96 | -0.87 | -1.28 | -1.46 | 0.37 | 0.71 | 0.49 | 0.71 | 2.56 | 0.09 | -0.31 | -0.50 | -0.08 | 0.50 | 1.54 |
| FALL | THERMAL HABITAT AREA >2°C | 1990-2004 | -1.09 | -0.40 | -0.88 | -1.73 | -0.83 | -0.08 | 0.32 | 0.24 | 0.78 | 2.77 | 0.15 | 0.22 | -0.38 | -0.05 | 0.51 | 0.49 |
| | THERMAL HABITAT AREA <0°C | 1990-2004 | 0.21 | 1.15 | 1.21 | 1.55 | 1.46 | -0.90 | -0.32 | 0.14 | -0.69 | -1.47 | 0.35 | -0.27 | -0.74 | -0.17 | -1.51 | -1.25 |
| | | | | | | | | | | | | | | | | | | |
| | CIL VOLUME (SUMMER) | 1980-1999 | 1.90 | 1.16 | | 0.74 | 0.32 | -1.23 | -0.61 | -0.81 | -0.70 | -1.28 | | | | | | |
| NAFO DIV 2J3KL | CIL VOLUME (FALL) | 1980-2004 | 0.94 | 1.05 | 1.46 | 1.55 | 0.74 | -0.34 | -0.85 | -0.85 | -0.58 | -1.81 | -0.45 | -0.76 | -0.57 | -0.78 | -1.47 | -0.86 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| NAFO DIV. 3LNO | 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 |
| SPRING | 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 |
| | 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 |
| | | | | | | | | | | | | | | | | | | |
| | 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 |
| NAFO DIV. 3PS | 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 |
| SPRING | 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 |
| | 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 |

## SUMMARY

The North Atlantic Oscillation winter index for 2005 was 0.47 SD above normal. However, arctic outflow to the Northwest Atlantic was weaker-than-normal as the most significant SLP anomalies were shifted to the east. Annual air temperatures were above normal 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 remained below average for the 11th consecutive year. As a consequence, water temperatures on the Newfoundland and Labrador Shelf remained well above normal in 2005, continuing the warm trend experienced since the mid-to-late 1990s. The 2005 values however decreased slightly over the record highs of 2004. Salinities on the NL Shelf, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal during the past 3 years.

In summary:

- Annual air temperatures were above normal in Newfoundland and Labrador during 2005 by 1.8°C at Cartwright and by nearly 1°C at St. John's.

- Annually, sea ice extent remained below normal for the $11^{th}$ consecutive year on the Newfoundland and Labrador Shelf in 2005. The ice extent increased slightly during the winter but decreased during the spring compared to that of 2004.

- Only 11 icebergs drifted south of $48^{o}$N onto the Northern Grand Bank during 2005, the lowest number since 1966, well below the 106 year average of 477.

- The Station 27 depth-averaged annual water temperature off St. John's decreased over the record high of 2004 to just over 0.5°C above normal, the $7^{th}$ highest on record.

- Annual surface temperatures off St. John's at Station 27 remained at the 60 year record high value of 2004 at 1°C above normal.

- Bottom temperatures at Station 27 have been above normal for the past 10 years. In 2005 they were 0.8°C (2.65 SD) above normal, the $3^{rd}$ highest in the 60-year record.

- Annual surface temperatures on Hamilton Bank were 1°C above normal, the $4^{th}$ highest on record. On the Flemish Cap they were 2°C above normal, the $3^{rd}$ highest and on St. Pierre Bank they were 1.7°C above normal and the highest in 56 years.

- Near surface salinities off St. John's at Station 27 were above normal for the $4^{th}$ consecutive year. The average salinity along the Bonavista section has remained above normal since 2002.

- The area of <0°C (CIL) water mass on the eastern Newfoundland Shelf during 2005 was below normal for the $11^{th}$ consecutive year and the $5^{th}$ lowest since 1948.

- The density driven component of the shelf-slope Labrador Current volume transport shows an increasing trend off southern Labrador and through the Flemish Pass from 2000-2005.

- Bottom temperatures on St. Pierre Bank were above normal during the spring of 2005, the highest since 2000 and the $6^{th}$ highest in 36 years.

- Bottom temperatures during the fall of 2005 on the Newfoundland and Labrador Shelf were above normal in almost all areas, reaching 2°C above average off Southern Labrador.

- The area of bottom habitat on the Grand Banks covered by sub-zero water has decreased from >50% during the first half of the 1990s to near 15% during the past 2 years.

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