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Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2003

Conditions d'océanographie physique dans le golfe Saint-Laurent en 2003

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ABSTRACT

An overview of physical oceanographic conditions in the Gulf of St. Lawrence in 2003 is presented. Air temperatures and surface water temperatures were below normal in winter and above normal in the fall. During winter 2003, sea ice coverage within the Gulf was about 10% above the long-term mean, the first year above normal since 1995. But of more significance, a record amount of ice was advected out of the Gulf through Cabot Strait during winter 2003, and the total volume of ice formation in the Gulf was much higher than normal. Moreover, the inflow of water through the Strait of Belle Isle in the northeast Gulf was by far the largest one observed over the 9-year period of helicopter CTD surveys conducted in March. This inflow of cold and salty water from Belle Isle Strait together with the large amount of ice produced in the Gulf in the winter of 2003 caused a huge increase in the summertime thickness and volume of T < 0°C waters (+300%) and T < 1°C waters (+40%) relative to 2002. This was accompanied by a 0.65°C drop in the cold intermediate layer minimum temperature index which is now 0.54°C below the 1971-2000 normal conditions and the fifth coldest in 57 years. The annual mean runoff of the St. Lawrence River at Québec City was 13.4% below normal. This led to above normal surface salinities and below normal surface layer stratification during most of 2003. In the 30-100 m layer, the 2003 temperature was colder than normal while salinity was higher than normal. In the 100-200 m layer, the 2003 temperature was colder than normal but salinity was close to normal. Finally, in the 200-300 m layer, both temperature and salinity were close to normal. The 2003 annual mean oxygen concentration in the bottom waters (≥ 300 m) of the Lower St. Lawrence Estuary (18.3% saturation) was the second lowest ever observed.

RÉSUMÉ

Nous présentons un survol des conditions d'océanographie physique dans le golfe du Saint-Laurent en 2003. Les températures de l'air et les températures de surface de l'eau étaient sous la normale pendant l'hiver et au-dessus de la normale en automne. Durant l'hiver 2003, la couverture de glace de mer à l'intérieur du Golfe était environ 10 % supérieure à la moyenne à long terme, et ce pour la première fois depuis 1995. Mais encore plus important, une quantité record de glace fut transportée hors du Golfe à travers le détroit de Cabot pendant l'hiver 2003 et le volume total de glace formée dans le Golfe fut beaucoup plus élevé que la normale. De plus, les entrées d'eau à travers le détroit de Belle Isle dans le nord-est du Golfe furent de loin les plus importantes observées parmi les 9 années de mission héliportée du mois de mars. Ces entrées d'eau froide et salée en provenance du détroit de Belle Isle ainsi que l'énorme quantité de glace produite dans le Golfe pendant l'hiver 2003 ont entraîné une forte augmentation de l'épaisseur et du volume estival d'eaux avec $T < 0$ °C (+300 %) et $T < 1$ °C (+40 %) comparativement à l'année 2002. Ceci fut accompagné d'une chute de 0,65 °C de la température minimale de la couche intermédiaire froide qui se trouve maintenant 0,54 °C sous les conditions normales de 1971-2000 et au cinquième rang des années plus froides parmi les 57 dernières années. Le débit annuel moyen du fleuve Saint-Laurent à Québec fut 13,4 % sous la normale. Cela a mené à des salinités de surface au-dessus de la normale et à une stratification de la couche de surface plus faible que la normale pendant la majeure partie de 2003. Dans la couche de 30 à 100 m, la température était plus froide que la normale tandis que la salinité était plus élevée que la normale en 2003. Dans la couche de 100 à 200 m, la température était plus froide que la normale mais la salinité était près de la normale. Enfin, dans la couche de 200 à 300 m, la température et la salinité étaient près de la normale. La concentration annuelle moyenne d'oxygène dans les eaux profondes (≥ 300 m) de l'estuaire maritime du Saint-Laurent en 2003, à 18,3 % de saturation, fut la deuxième plus basse jamais observée.

INTRODUCTION

This paper examines the physical oceanographic conditions of the Gulf of St. Lawrence in 2003 and some driving atmospheric conditions. Specifically, it discusses air temperature, sea-ice, water temperature, salinity, dissolved oxygen, and the stratification of the upper water column. Environmental conditions are compared with those of the preceding year as well as to the long-term means. The latter comparisons are usually expressed as anomalies, i.e. deviations from their long-term mean or normal conditions calculated over the 1971-2000 reference period where data exist. This is in accordance with the convention of North American meteorologists and the recommendations of both the Northwest Atlantic Fisheries Organization (NAFO) and the Fisheries Oceanography Committee (FOC). Having a standardized base period allows direct comparison of anomaly trends both between sites and between variables. The last detailed report of physical oceanographic conditions in the Gulf of St. Lawrence was produced for the year 1995 (Gilbert et al. 1997).

AIR TEMPERATURE

There are several weather stations surrounding the Gulf of St. Lawrence, but we only show here the monthly mean air temperatures from 1) Mont-Joli, a weather station with a 128-year long record meeting the highest quality standards from the WMO; and 2) the Magdalen Islands, a centrally located site within the Gulf that is sufficiently remote from the continent to give it a 'marine' character. In 2003, monthly mean air temperatures at the Magdalen Islands were about 1°C colder than normal from February to April but became 1°C to 3°C warmer than normal from September to December (Fig. 1). The pattern of monthly anomalies at Mont-Joli was qualitatively similar to that observed at the Magdalen Islands with a colder than normal winter and a warmer than normal fall (Fig. 1).

The long-term trends in annual mean air temperature are shown in Fig. 2. The 2003 air temperature anomaly was +0.7°C at the Magdalen Islands and +0.3°C at Mont-Joli. At both locations, the change in annual mean air temperature from 2002 to 2003 was less than 0.2°C. The 1999 annual air temperature anomaly (2.2°C) represents the highest temperature ever observed in the 128-year record at Mont-Joli.

PRECIPITATION AND FRESHWATER RUNOFF

Precipitations were below normal over the entire drainage basin of the Great-Lakes and St. Lawrence River during the winter of 2003. This was followed by slightly below normal precipitations in the spring and summer of 2003, and above normal precipitation in the fall. These patterns are reflected in the index of freshwater flow at Québec City (Bourgault and Koutitonsky 1999), which is updated monthly on the St. Lawrence Observatory (www.osl.gc.ca). Below normal monthly flow anomalies were observed during most of 2003 (Fig. 3). The only months with above normal flow values occurred in November and December 2003. The 2003 annual mean flow was 13.4% (1670 m^3 s^{-1}) below the 1971-2000 normal, ranking 9th lowest in the last 49 years (Fig. 4).

SEA ICE

The sea ice conditions of 2003 in the Gulf of St. Lawrence are described by Petrie et al. (2004). Ice cover area was above normal in 2003, due mostly to the very severe March ice conditions (Fig. 5). The times of first appearance of ice in the Gulf of St. Lawrence were generally 0-15 days earlier than normal while last presence of ice was generally 0-15 days later than normal. Ice duration was 21 days longer than normal, making the 2003 ice season the fifth longest in 41 years.

Two ice volume indices were computed from a gridded database of ice cover and ice categories (Drinkwater et al. 1999) updated to include sea ice conditions up to 2003. The combined Gulf and Shelf ice volume index is calculated from ice cover and thickness data from all 130 cells of the ice database covering the Gulf of St. Lawrence, the Scotian Shelf and part of the southern Newfoundland Shelf west of the Burin peninsula. A second index, which we shall refer to as the Shelf ice volume index, is based on ice cover and thickness data from the subset of 51 cells (cells 80 to 130) located seaward of Cabot Strait, and represents the volume of ice exported from the Gulf. From 1999 onwards, ice thicknesses were estimated by the Canadian Ice Service from Radarsat satellite data. From 1963 to 1998, mean ice thicknesses of 5 cm, 12.5 cm, 22.5 cm and 50 cm were attributed to new ice (0-10 cm), grey ice (10-15 cm), grey-white ice (15-30 cm) and first-year ice (> 30 cm) respectively (Roger Pettipas, pers. comm.).

In 2003, the Gulf and Shelf ice volume index reached the highest value of the 41-year record. The Shelf ice volume index also reached a record high in 2003 (Fig. 6), possibly due to wind pattern anomalies that were favourable to exporting larger than normal amounts of sea ice out of the Gulf of St. Lawrence during winter (Petrie *et al*. 2004).

WINTER WATER MASSES AND SUMMER COLD INTERMEDIATE LAYER

A wintertime survey of the Gulf of St. Lawrence surface waters has been undertaken in early March since 1996 using a Canadian Coast Guard helicopter, adding a considerable amount of data to the previously very rare winter data for the region. The sampling techniques have evolved over the years, and since 2002 we profile the top 200 m of the water column from the airborne helicopter in the absence of sufficient ice to land on. In addition, a water sample is taken at 2-m depth for nutrient analysis and salinity calibration. Since the cold surface layer is usually homogeneous, this single sample is representative of the entire layer.

The CTD probe used is a Seabird SBE-19 sampling internally at 2 Hz. Upon arrival at a sampling station, the instrument is quickly lowered into the water from an altitude of about 25 m and left to equilibrate for one minute before being raised close to the surface and then lowered to begin the profile down to 200 m. We have found this time span to be sufficient for the temperature and salinity to reach near-equilibrium since the instrument remains relatively cool in the helicopter. Adding a single minute to the protocol adds about one hour of total flight time to the survey, which is usually entirely done within 40 to 45 flight hours, and so the shortest time duration is spent equilibrating.

The CTD instrument used is adequate to resolve spatial and inter-annual differences in the temperature and salinity of the thick homogeneous surface layer. Proper sampling is aided by the decoupling of the downcast from the vertical motion of surface waves, a common problem when sampling from a ship. However the instrument is not really adequate to correctly sample the strong thermocline under the homogenous layer, so the details of the structures beneath the homogenous surface layer are not considered here.

A total of 67 stations were sampled during the March 2003 survey using 38 flight hours. The southwestern portion of the Gulf was not sampled due to mechanical problems on the helicopter. The surface salinity is shown on Fig. 7 for all surveys. The surface salinity is usually representative of the entire cold-water layer, the thickness of which typically exceeds 70 m (Fig. 8), although sometimes an intrusion of saltier water occupies the deeper part of the cold layer. The grids of Fig. 7 and Fig. 8 were interpolated/extrapolated using the Barnes objective map analysis scheme (Koch et al. 1983). Surface waters were more saline in 2003 than in all previously sampled years (since 1996), with an east-west gradient from 0.3 more saline than average on the west coast of Newfoundland up to 1 more saline than average in the Anticosti gyre. Near-freezing waters with salinities coloured in violet are considered to be too saline (> 32.35) to be formed from waters originating within the Gulf and are presumed to have been advected from the Labrador shelf through the Strait of Belle-Isle. The salinity distribution in 2003 is consistent with increased circulation through the Gulf with strong inflow from the Labrador Shelf through the Strait of Belle-Isle and strong outflow through Cabot Strait, leading to a general increase in salinity. This is also consistent with the strong export of sea-ice through Cabot Strait that has occurred during the winter of 2003 (Fig. 6).

Fig. 8 shows the thickness of the cold surface layer ($T < -1°C$) for all surveys. This includes local convection and advected cold waters from the Labrador shelf, and can consist of a single water mass or layers of increasing salinity with depth. While local convection typically reaches 75 m or so in the centre of the Gulf, the Labrador shelf waters in the Mecatina Channel reached down to 200 m in 2003, as had also occurred in 2002. The 2003 thickness was generally high everywhere in the Gulf, leading to a larger total cold-water volume than in any previous year of the survey. The 2003 volume ($T < -1°C$) is estimated to be 4975 km^3 compared to 4470 km^3 in 2002. Another notable feature is the very thick cold surface layer next to Cape Breton in Cabot Strait. This is the first time such a thick cold layer has been observed at such a southern location as part of the March helicopter survey.

The very cold surface water conditions observed during winter 2003 have lead to a major increase in the thickness of the summertime cold intermediate layer (CIL) in the Gulf of St. Lawrence. Overall, the Gulf-wide average thickness of waters with $T < 0°C$ increased by 42 m and the thickness of waters with $T < 1°C$ increased by 35 m from 2002 to 2003. Meanwhile, the CIL minimum temperature decreased by 0.65°C relative to 2002 and became 0.54°C colder than the 1971-2000 normal (Fig. 9). The 2003 CIL minimum temperature index (Gilbert and Pettigrew 1997) is the fifth coldest of the 57 years record.

THERMOGRAPH NETWORK

The IML Thermograph Network started measuring sea surface temperature in 1993 with 6 monitoring stations. In 2003, thermographs at 21 stations were measuring temperature at the surface (0.5 – 2 meters) and near the bottom at locations spread along the shores of the St. Lawrence Estuary and Gulf of St. Lawrence (Fig. 10). All thermographs sample temperature every 30 minutes. Most of the instruments are installed on Canadian Coast Guard buoys except the stations of Rimouski, Mont-Louis, Irving Whale, Havre St-Pierre and Banc Beaugé (see Fig. 10). The latter stations, in comparison with the other nearshore stations, can be referred to as the offshore stations of the Thermograph Network. Instruments at the Île Shag, Bonne Bay and Borden stations are installed by local collaborators or IML staff. Due to ice cover, the buoys are installed around mid-May and recovered around mid-October. This implies that most stations only have 5 to 6 months of continuous data. Only the stations of Île Shag, Bonne Bay, Borden, IML and Baie-Comeau measure bottom water temperature year round. The 2003 monthly mean temperatures at all stations and depths are given in Table 1.

In order to compare the 2003 observations to temperature measurements from previous years, we had to calculate climatological monthly mean temperatures. Since the IML thermograph stations are at most 11 years old, we cannot use the 1971–2000 reference period. Instead, we computed "normals" based on all years with data (Table 2). These "normal" temperatures were obtained by first computing the mean temperatures for all months that have at least 28 days of data and then by averaging the monthly mean temperature from all years to obtain the normal for each month (Table 2). Monthly temperature anomalies were then obtained by subtracting the climatological mean temperatures from the 2003 observations (Table 3). We also present normalized anomalies which were obtained by dividing the monthly anomalies of Table 3 by the interannual standard deviation of temperature at each station and depth (Table 4). At Bonne Bay and Borden, we note that winter surface temperatures were colder than normal whereas fall surface water temperatures were warmer than normal, consistent with the meteorological forcing (Fig. 1). Thermographs deployed in the depth range of the CIL (30 m to 100 m) all indicate below normal temperatures in 2003 (Table 4).

One of the longest and continuous time series has been recorded at Île Shag station at 10 meters depth. The missing monthly mean temperature values for April and May 2003 were caused by a data gap from April 23 to May 19. Temperatures were below normal from June to August 2003, with a monthly mean temperature about 1.4°C colder than normal in August (Fig. 11). The monthly mean temperatures at La Perle station, located about 30 km south of Île Shag station, were close to 2°C colder than normal during summer (Fig. 11), so that the entire Magdalen Islands region had colder than normal near-surface temperatures during the summer. At the Mont-Louis station monthly mean temperatures were close to normal except for August which was nearly 1°C below normal (Fig. 11). The Québec North Shore is well known for its episodic upwelling events induced by wind forcing along the coast. At the Havre St-Pierre station monthly mean temperatures were above normal during July and August whereas the September temperature was about 3°C below normal due to a well-developed upwelling event in that region (Fig. 11, Table 3). These monthly mean temperatures at Havre

St-Pierre are consistent with the bi-monthly mean SST maps from NOAA AVHRR imagery recorded at the IML Remote Sensing Laboratory in August and September 2003 (Fig. 12; Fig. 13). We do not present the monthly temperature anomalies from all stations and depths due to lack of space. However, the complete set of figures and original data can be obtained from the St. Lawrence Observatory (www.osl.gc.ca).

NEAR SURFACE TEMPERATURE FROM A SHIPBOARD THERMOSALINOGRAPH

An instrument (SBE-21 from Seabird Electronics Inc, Seattle) measuring water temperature (T) and salinity (S) was installed in December 1999 on board the commercial ship Cicero of Oceanex Inc. The ship sails year-round between Montreal and St. John's (Fig. 14), making a return trip once per week, sampling the near-surface (3 meter depth) water temperature and salinity along this corridor. The data are presented in near-realtime on the St. Lawrence Observatory web site (www.osl.gc.ca) along with data from a few other ships.

Fig. 15 shows a mean annual cycle of water temperature at 3m depth from the 4 years (2000 to 2003) of measurements aboard the Cicero. The data were averaged for each day of the year at intervals of 0.1 degree of longitude between St. John's and Montreal to create a composite along the ship track. Perhaps the most striking feature is the area of the head of the Laurentian trough (69.5°W) where strong vertical mixing leads to cold summer water temperatures (around 5°C) and winter temperatures always above freezing (Galbraith et al. 2002). The progression to winter conditions is shown to reach near-freezing temperatures first in the Estuary. Freezing conditions progress towards Cabot Strait with time, usually just reaching Cabot Strait by the end of the winter.

Fig. 16 shows the water temperature composite for 2003. It is characterised by winter near-freezing conditions lasting longer into the year and extending further out past Cabot Strait (Port-aux-Basques) compared to the 2000-2003 average (Fig. 15). This is also apparent in Fig. 17 which shows the 2003 water temperature anomaly along the Cicero ship track, relative to the 2000-2003 average. Shades of green, blue to pink indicate cooler than average temperatures and yellow to red shades indicate warmer than average temperatures. White areas are of similar temperature to the average. The figure illustrates that near-surface waters were cooler than the preceding 3 years until June except for the head of the Laurentian trough area. Most of the Gulf was much warmer from mid-September to early November 2003 due to warmer than normal air temperatures (Fig. 1). Cooler conditions prevailed to finish 2003 with near-freezing conditions in the estuary by early December, two weeks ahead of prior years.

TEMPERATURE AND SALINITY DATA FROM THE GROUNDFISH SURVEY

About 400 STD profiles are collected each year during the DFO shrimp and groundfish stocks assessment survey in the Gulf of St. Lawrence, making this survey the largest single source of information about the physical climate of the Gulf of St. Lawrence. Generally, some 200 STD profiles are collected in the northern Gulf during August by staff from the *Maurice*

Lamontagne Institute and another 200 STD profiles are collected in the southern Gulf during September by staff from the *Gulf Fisheries Centre*. These two data sources are then put together to provide a quasi-synoptic picture of temperature and salinity in the Gulf of St. Lawrence. Unfortunately, a fire aboard the Needler reduced the number of STD profiles from the southern Gulf to only 83 in 2003. There were also some problems with STD data collection in the northern Gulf due to a faulty STD pump that forced us to eliminate 96 salinity profiles (upper 250 m) and 10 temperature profiles, mostly in the Cabot Strait and Esquiman channel regions. A detailed report (Gilbert 2004) containing about 40 figures presents the temperature, salinity and stratification conditions during the August-September 2003 shrimp and groundfish stock assessment survey. We simply reproduce two particularly interesting figures from that HTML report. The surface layer was much saltier than normal in the southern Gulf of St. Lawrence in September 2003 (Fig. 18), consistent with the lower than normal flow of the St. Lawrence River in preceding months (Fig. 3). We also note that the 30 m to 100 m layer was much colder than normal (Fig. 19).

Thickness and volume of the cold intermediate layer (CIL)

The CIL minimum temperature (Tmin) and the CIL thickness and volume for T < 0°C, 1°C, 2°C and 3°C were estimated using temperature profiles from the 1985 to 2003 August-September groundfish surveys. CIL thickness and Tmin were obtained from each individual profile. Both variables were then kriged over a 1/6° x 1/6° grid of the Gulf of St. Lawrence where the local depth exceeds 100 m (Fig. 20). CIL volumes were estimated using the gridded thickness and the grid cell areas. The kriging method is described in Simard et al. (1992). The 2003 CIL minimum temperature (Fig. 21) was below normal, with only the 1986 value being colder. The 2003 Gulf-wide CIL thickness and volume (Fig. 22) were both above the 1985-2003 means for all four CIL definitions. From 2002 to 2003, the thickness and volume of T < 0°C waters tripled (300 % increase). For T < 1°C waters, the change in thickness and volume relative to 2002 was more modest (+40%).

Regional estimates of CIL thickness and volume

Year to year changes in CIL thickness and volume are not spatially uniform throughout the Gulf of St. Lawrence. At the request of fisheries scientists, we therefore generated regional time series of CIL thickness and volume for the eight regions shown on Fig. 23. The geographical limits of those regions represent a compromise between various requests received from fisheries scientists responsible for the capelin, cod, herring, mackerel, shrimp and Greenland halibut stock assessments. We obtained regional estimates of CIL thickness by averaging the kriged estimates of CIL thickness for all grid cells (Fig. 20) located within each of the seven deep regions (Fig. 23). Regional estimates of CIL volume are directly proportional to CIL thickness, as they simply involve a multiplication of the regional CIL thickness by the number of grid cells found in each region and by the area of a single grid cell.

For the four CIL definitions, CIL thickness (Fig. 24) and volume (Fig. 25) generally increased from 2002 to 2003. The thickness and volume of T < 0°C waters reached record high values in 2003 in the Central Gulf and Cabot Strait regions, whereas in other regions the record high of 1991 was left unbeaten. For T < 1°C waters, a record high CIL thickness and volume was observed in the Cabot Strait region in 2003. Finally, the thickness and volume of both T < 2°C and T < 3°C waters was close to the 1985-2003 average in all regions but Cabot Strait where the 2003 values were well above normal.

Regional profiles of temperature in 2002 and 2003

To compare the vertical profiles of temperature collected in 2002 and 2003 during the groundfish stock assessment surveys, we computed average profiles of temperature for the eight regions of Fig. 23. These regional temperature profiles clearly show a general increase in CIL thickness and a decrease in CIL minimum temperature from 2002 to 2003 (Fig. 26).

Bottom area with T < 0°C and T < 1°C

In the southern Gulf, a large expanse of the sea bed lies within the depth range of the cold intermediate layer. The bottom area with temperatures < 0°C made a remarkable increase from about 700 km^2 in 2002 to over 18000 km^2 in 2003 (Fig. 27). Meanwhile the bottom area with temperatures < 1°C increased by 32% compared with 2002. The bottom areas occupied by these two categories of cold waters were both above the 1971-2000 average in 2003. In the northern Gulf, the CIL comes in contact with the bottom mainly along the sloping sides of the deep channels. In August 2003, the bottom area with temperatures < 0°C and < 1°C increased by 85% and by 36% respectively compared with August 2002 (Fig. 28). The 2003 bottom areas occupied by these cold waters were well above the 1984-2003 average. The calculation methods for estimating bottom areas with T < 0°C and T < 1°C in both the southern and northern Gulf of St. Lawrence are the same as in Drinkwater et al. (2003).

FIXED STATIONS OF THE ATLANTIC ZONE MONITORING PROGRAM (AZMP)

In the DFO-Québec region, AZMP oceanographic monitoring began in 1996 at two stations (Fig. 29) in the northwest Gulf of St. Lawrence: Anticosti Gyre (49° 43.0' N, 66°15.0' W) and Gaspé Current (49° 14.5' N, 66° 12.0' W). Both stations were originally planned to be sampled regularly at 15 days intervals (Therriault et al. 1998), but logistical problems often lead to much longer intervals (Fig. 30). A third station is sampled by staff from the Bedford Institute of Oceanography in the Shediac Valley (47.78°N, 64.03°W), but we do not present data from this station here. The three AZMP fixed stations are shown on Fig. 29 together with the positions of stations that constitute the AZMP fixed sections. Physical data are acquired with a Conductivity, Temperature, Depth profiler (CTD) mounted on a rosette.

Profile data are first quality-controlled. Temperature and salinity data are binned in 5 m depth intervals and linearly interpolated in time at 1 month intervals. Stratification indices (Gilbert 2004) are calculated for each profile and then interpolated in time at 1 month intervals. Time series of anomalies are calculated relative to the 1996 to 2003 normals. From

100 m down to the bottom, the normals were determined by arithmetic means over all years. From 5 m to 95 m depth, annual cycles of temperature, salinity and stratification were determined by fitting 12 and 6 month harmonics (Smith, 1983; Petrie, 1990) to the data. Anomalies were interpolated in time at 1 month intervals.

Temperature and salinity anomaly time series are displayed in Fig. 31 to Fig. 34 for both fixed stations at the surface depth of 5 m, the intermediate depths of 50 and 100 m, and the bottom depths of 150 m or 300 m. Relative to the 1996-2003 reference period, the 2003 surface (5 m) temperatures at both stations were relatively close to normal. At 50 m depth at the Gaspé Current (GC) station, temperature was close to normal in winter but dropped to 1°C below normal in September-October (Fig. 31). At the Anticosti Gyre (AG) station, the 50 m temperatures were about 1°C warmer than normal in winter but became about 0.5°C colder than normal in spring and summer 2003 (Fig. 32). At 100 m depth, temperatures were generally colder than normal at the GC station but were warmer than normal at the AG station. The temperature anomalies of opposite sign at 100 m depth at the GC and AG stations may have been caused by a stronger than normal isotherm and isopycnal doming due to a stronger than normal gyre circulation in the northwest Gulf. The 2003 bottom temperatures were higher than the 1996-2003 means (Fig. 31, Fig. 32). Salinities were higher than normal at both stations at all depths in 2003 (Fig. 33, Fig. 34). Stratification indices at both stations indicate less surface stratification (0 to 25 m and 0 to 50 m) during the winter and spring of 2003 relative to the 1996-2003 average (Fig. 35, Fig. 36). This may be indicative of a deeper convective layer in 2003, although this was apparently not the case in the vicinity of the two AZMP stations during the March helicopter survey (Fig. 8).

TEMPERATURE, SALINITY, DENSITY AND OXYGEN ALONG AZMP TRANSECTS

As part of the AZMP, 6 to 8 transects are visited two to three times a year in June and November, and occasionally in April as was the case in 2003. A transect is composed of a series of predefined stations sampled with the same methodology as the AZMP fixed stations (Fig. 29). Because the transects are only sampled two to three times a year, we cannot fit annual and semi-annual harmonics to the data as we did for the fixed stations. This is only feasible at Cabot Strait where there are enough historical data over the 12 months of the year to determine a climatological annual cycle of T-S properties for the 1971-2000 reference period. However, this did not properly resolve the annual cycle of T-S in the coastal jet along Cape Breton Island, and we are still working on improving the Cabot Strait transect climatology. Therefore, we simply present the raw 2003 observations without accompanying anomaly maps.

The CTD-O2 data of the Ice Forecast cruise held in late October 2003 are displayed in Fig. 37 to Fig. 41. We do not show the April and June 2003 measurements for which contour plots together with the original data can be retrieved from the AZMP website (http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html). The three-layer thermal structure (warm upper layer, cold intermediate layer and warm deeper layer) of the Gulf is observed at all sections except the Magdalen Islands section where only the warm upper layer and CIL are present due to shallower depths (Fig. 37). The salinities monotonically increase with depth (Fig. 38). In the surface layer (0 to 30 m layer), we clearly see the outflow of relatively warm (Fig. 37), fresh (Fig. 38) and light (Fig. 39) water on the Cape Breton side of Cabot Strait. The lightest surface waters are found in the Lower St. Lawrence Estuary (Fig. 39) where we also found the lowest surface salinities (Fig. 38) during October 2003.

Starting with the fall 2001 survey, a SBE 43 oxygen sensor (Seabird Electronics Inc., Seattle, WA) has routinely been used on the STD probe of AZMP surveys. This sensor has been calibrated with Winkler titrations by following the procedures suggested by Seabird Electronics. The contour plots of oxygen concentration show oxygen-rich waters in the surface layer and in the cold intermediate layer (Fig. 40). At Cabot Strait, a subsurface oxygen minimum is reached around 250 m to 350 m depth. We also note (Fig. 41) that below about 150 m depth, waters get progressively poorer in oxygen as they follow the landward deep estuarine circulation from Cabot Strait (50 % saturation) to the Estuary (< 20 % saturation). The 2003 annual mean oxygen concentration in the bottom waters (≥ 300 m) of the Lower St. Lawrence Estuary (18.3 % saturation) was the second lowest value ever observed. Gilbert et al. (2004) showed that oxygen concentrations have decreased by half from the 1930s to the 1984-2003 period in the bottom waters of the LSLE. They attributed two thirds of this oxygen depletion to a 1.65°C warming of the bottom waters over the same period of time.

LAYER-AVERAGED TEMPERATURES AND SALINITIES

Gulf-wide indices of interannual temperature and salinity variability were calculated from all possible sources of data from 1946 to 2003, including bottle data, bathythermograph data and CTD data from research surveys, AZMP monitoring surveys and its predecessor ice forecast cruises, groundfish surveys, etc. The twelve months of the year were included in our analyses. We do not present any results from the 0 to 30 m layer because we have not yet sufficiently well defined the very strong seasonal cycle of temperature and salinity in this layer.

For the 30–100 m layer, we adjusted our estimates of temperature for seasonal warming by assuming an average April to November warming rate of 0.0113°C/day (Petrie et al. 1996, p. 250) and extrapolating all temperatures to a common mid-summer date of July 15. The largest departures of the mean date of temperature measurements on either side of July 15 were +92 days in 1983 (Oct. 15) and -45 days in 1984 (May 31). These two extreme values of mean date of measurements are well within the time window (mid-April to mid-November) for which the temperature of the 30-100 m layer increases linearly with time (Petrie et al. 1996, p. 250), so that our seasonal adjustment procedure should perform reasonably well for standardizing our temperature time series to a common mid-summer date. We did not make any seasonal adjustment to the salinity time series of the 30-100 m layer, because there was no obvious annual cycle of salinity in that layer. Likewise, we did not need to make any seasonal adjustment to the temperature and salinity time series of the 100-200 m layer and the 200 – 300 m layer for which there is no detectable annual cycle.

The 1946-2003 time series of layer-averaged temperature and salinity for the entire Gulf of St. Lawrence are presented in Fig. 42 and Fig. 43 respectively. In the 30-100 m layer, which roughly corresponds to the CIL, the temperature was colder than normal while salinity was higher than normal in 2003. In the 100-200 m layer, the 2003 temperature was colder than normal but salinity was close to normal. Finally, in the 200-300 m layer, both temperature and salinity were close to normal.

SUMMARY

- In 2003, colder than normal winter air temperatures led to above normal sea ice areal coverage and volume in the Gulf of St. Lawrence. The volume of sea ice exported on the Shelf seaward of Cabot Strait reached a record high value at the same time as a record high volume of cold ($T < -1°C$) and salty ($S > 32.35$) waters were imported through the Strait of Belle Isle.
- As a result, the thickness and volume of surface waters with near-freezing temperatures (< -1°C) was larger than in preceding winters during March 2003. This cold anomaly persisted through the summer and led to a 0.65°C decline in the mid-summer index of the CIL minimum temperature relative to 2002. The thickness and volume of the CIL ($T < 0°C$ and $T < 1°C$) as estimated during the summer groundfish survey showed remarkable increases from 2002 to 2003, especially in the Cabot Strait region.
- The annual mean runoff at Québec City was 13.4% below normal, with positive anomalies being observed only during the months of November and December 2003. The low runoff values in the first months of 2003 probably caused the generally higher than normal surface salinities and weaker than normal surface stratification observed at the AZMP fixed stations in 2003.
- At the IML thermograph sites, water temperatures were generally colder than normal in the depth range of the cold intermediate layer. The near-surface temperatures displayed much more signal heterogeneity from site to site as well as from month to month.
- The thermosalinograph aboard the Cicero proved its ability to detect physically meaningful signals of near-surface temperature along its track. In 2003, its temperature measurements at 3 m depth indicated colder than normal temperatures in the winter, close to normal temperatures in the summer, and a warm fall.
- The 200 to 300 m deep layer had close to normal temperature and salinity in 2003.
- Oxygen concentrations were near a historical low in the Lower St. Lawrence Estuary.

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List of Acronyms

AG: Anticosti Gyre
AZMP: Atlantic Zone Monitoring Program
AVHRR: Advanced Very High Resolution Radiometer
CIL: Cold Intermediate Layer
CTD: Conductivity-Temperature-Depth
CTD-O2: Conductivity-Temperature-Depth-Oxygen
DFO: Department of Fisheries and Oceans
GC: Gaspé Current
HTML: HyperText Markup Language
IML: Institut Maurice-Lamontagne
NOAA: National Oceanic and Atmospheric Administration
SBE: SeaBird Electronics
STD: Salinity-Temperature-Depth
SST: Sea Surface Temperature
WMO: World Meteorological Organization

Table 1. Monthly mean temperatures at all stations of the IML thermograph network in 2003.

Station	Depth (m)	J	F	M	A	M	J	J	A	S	O	N	D
Banc Beaugé	1							12.0	14.9	12.0			
Banc Beaugé	100							-0.7	-0.3	-0.1			
Bonne Bay	25	-0.8	-1.6	-1.7	-1.4	0.4			15.2	15.2	12.3	6.9	
Baie-Comeau	1						9.3	12.3	13.0	8.2	6.1		
Baie-Comeau	80	1.6	1.4	1.2	-0.7	-0.5	-0.2	0.0	0.2	0.3	0.4		0.5
BIC	1						5.9	6.9	7.6	5.4			
BIC	2						5.6	6.6	7.3	5.2			
BIC	5.8						2.0	3.0	3.4	2.4			
Borden	3.5	-1.5	-1.5	-1.5	0.5	7.0	13.2	16.8	19.1	17.7	13.3		
Blanc Sablon	1							8.8	10.4	8.9			
Grande-Rivière	2						10.0	14.2	14.3	12.9	8.7		
Grande-Rivière	7						7.3	11.5	12.4	11.4	7.9		
Havre St-Pierre	1							11.5	13.6	6.6			
Havre St-Pierre	100							-0.3	-0.2	0.2			
IML	0.5						8.4	10.5	11.4	7.8			
Irving Whale	1						9.3	16.8	17.3	14.8	11.2	4.8	
Irving Whale	67						-1.0	-0.9	-0.8	-0.6	-0.2	0.6	
Ile Shag	0.5						9.1	14.3	16.8				
Ile Shag	10	-0.9	-1.3	-1.2			7.6	11.9	14.8	14.9	12.2	6.3	2.4
La Romaine	1							11.6	14.1	10.3			
La Romaine	2							11.4	13.8	10.1			
La Romaine	14							2.0	4.4	5.0			
Mont-Louis	0.5						9.4	13.4	12.6	10.4	5.8	2.1	
Natashquan	1							13.6	15.0	9.2			
Natashquan	7.5							9.2	11.2	6.5			
La Perle	1						8.1	14.8	16.9	15.4	11.7	6.6	
La Perle	8.5						3.1	6.1	7.8	10.8	9.0	6.4	
Rivière-au-Tonnerre	1							10.2	11.6	5.9			
Rivière-au-Tonnerre	16							5.6	7.1	3.4			
Rimouski	0.5						7.4	9.4	9.4	6.6			
Sept-Iles	1						10.4	13.9	14.8	8.6	6.2		
Sept-Iles	25						1.8	4.6	5.5	3.0	3.5		
La Tabatière	1							10.2	12.8	10.9			
La Tabatière	36							3.4	4.6	5.4			
Tadoussac	2						6.3	7.7	8.9	5.6	4.0		

Table 2. Reference periods over which the climatological monthly mean temperatures and standard deviations were calculated. For each site and depth, we give the ratio of the number of years with data over the number of years of the reference period. For example, for the BIC station at 1 m depth, we have data for 7 of 10 years from June to September.

Station	Depth (m)	Reference Period	J	F	M	A	M	J	J	A	S	O	N	D
Banc Beaugé	1	1998-2003							1.0	1.0	1.0			
Banc Beaugé	100	1998-2003							0.8	0.8	0.8			
Bonne Bay	25	1993-2003	0.7	0.7	0.7	0.7	0.6			0.8	0.8	0.8	0.7	
Baie-Comeau	1	1999-2003						1.0	1.0	1.0	1.0	1.0		
Baie-Comeau	80	2000-2003	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.5		0.5
BIC	1	1994-2003						0.7	0.7	0.7	0.7			
BIC	2	1994-2003						1.0	1.0	1.0	1.0			
BIC	5.8	1996-2003						1.0	1.0	1.0	1.0			
Borden	3.5	1995-2003	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	1.0	1.0		
Blanc Sablon	1	1999-2003							1.0	1.0	1.0			
Grand-Rivière	2	1994-2003						1.0	1.0	1.0	1.0	1.0		
Grande-Rivière	7	1996-2003						1.0	1.0	1.0	1.0	1.0		
Havre St-Pierre	1	1997-2003							1.0	1.0	1.0			
Havre St-Pierre	100	1996-2003							0.9	0.9	0.9			
IML	0.5	1994-2003						0.5	0.9	0.8	0.9			
Irving Whale	1	1998-2003						0.8	1.0	1.0	1.0	1.0	0.7	
Irving Whale	67	1998-2003						0.7	0.7	0.7	0.7	0.7	0.3	
Ile Shag	0.5	1995-2003						0.7	0.8	0.8				
Ile Shag	10	1993-2003	0.9	0.9	0.9	--	--	0.9	0.9	0.9	0.9	0.9	1.0	1.0
La Romaine	1	1995-2003							0.7	0.7	0.7			
La Romaine	2	1994-2003							1.0	1.0	1.0			
La Romaine	14	1996-2003							0.9	0.9	0.9			
Mont-Louis	0.5	1994-2003						1.0	1.0	1.0	1.0	0.9	0.3	
Natashquan	1	1994-2003							0.9	0.9	0.9			
Natashquan	7.5	1994-2003							0.9	0.9	0.9			
La Perle	1	1996-2003						0.9	1.0	1.0	1.0	1.0	0.5	
La Perle	8.5	1997-2003						0.9	1.0	1.0	1.0	1.0	0.9	
Rivière-au-Tonnerre	1	1998-2003							0.8	0.8	0.8			
Rivière-au-Tonnerre	16	1996-2003							1.0	1.0	1.0			
Rimouski	0.5	2002-2003						0.5	1.0	1.0	1.0			
Sept-Iles	1	1993-2003						0.9	0.9	1.0	1.0	0.9		
Sept-Iles	25	1996-2003						0.9	0.9	0.9	0.9	0.9		
La Tabatière	1	2002-2003							1.0	1.0	1.0			
La Tabatière	36	2002-2003							1.0	1.0	1.0			
Tadoussac	2	1993-2003						0.5	0.5	0.7	0.7	0.6		

Table 3. Monthly mean temperature anomalies (°C) in 2003 at all stations of the IML thermograph network. The anomalies are relative to the reference periods given in Table 2, with anomalies below -0.5°C indicated in **blue** and anomalies above 0.5°C indicated in **red**.

Station	Depth (m)	J	F	M	A	M	J	J	A	S	O	N	D
Banc Beaugé	1							-0.5	0.2	-0.2			
Banc Beaugé	100							-0.4	-0.4	-0.4			
Bonne Bay	25	-0.8	-0.4	-0.6	-1.1	-1.3			1.2	4.0	3.4	2.0	
Baie-Comeau	1						0.2	0.5	0.8	-0.8	0.2		
Baie-Comeau	80	0.0	0.3	0.0	0.0	0.0	-0.3	-0.2	-0.1	-0.3	-0.3		-0.6
BIC	1						-0.3	-0.4	0.2	-0.2			
BIC	2						-0.2	-0.5	0.3	-0.4			
BIC	5.8						-0.4	-0.2	0.1	-0.8			
Borden	3.5	0.0	-0.3	-0.3	-0.7	-0.9	-0.1	-0.2	0.1	0.3	1.5		
Blanc Sablon	1							0.3	-1.1	0.2			
Grande-Rivière	2						0.1	0.5	-0.8	0.4	0.6		
Grande-Rivière	7						-0.6	0.2	-0.6	-0.2	0.2		
Havre St-Pierre	1							1.3	3.0	-3.1			
Havre St-Pierre	100							-0.6	-0.7	-0.7			
IML	0.5						-0.5	-0.1	0.8	-0.3			
Irving Whale	1						-1.8	0.1	-0.3	-0.1	1.1	-0.1	
Irving Whale	67						-0.3	-0.4	-0.4	-0.3	-0.2	0.0	
Ile Shag	0.5						-1.0	-0.9	-0.9				
Ile Shag	10	0.3	0.3	0.1			-1.0	-1.6	-1.4	0.0	1.6	0.3	0.5
La Romaine	1							1.1	1.4	0.1			
La Romaine	2							1.1	2.0	-0.6			
La Romaine	14							-0.6	0.7	-0.8			
Mont-Louis	0.5						-0.5	0.1	-0.8	0.0	0.2	-0.1	
Natashquan	1							-0.3	1.0	-1.3			
Natashquan	7.5							2.0	3.6	-1.8			
La Perle	1						-1.1	-0.2	-0.9	0.0	0.9	0.2	
La Perle	8.5						-2.2	-2.1	-1.4	0.4	0.0	0.5	
Rivière-au-Tonnerre	1							0.0	1.8	-1.3			
Rivière-au-Tonnerre	16							0.5	1.9	-2.7			
Rimouski	0.5						0.0	-1.0	-0.4	-1.0			
Sept-Iles	1						0.3	0.5	2.0	-0.8	0.4		
Sept-Iles	25						0.1	1.4	2.0	-1.2	-0.1		
La Tabatière	1							1.2	0.5	0.4			
La Tabatière	36							0.3	-0.2	-0.4			
Tadoussac	2						-0.8	-0.7	0.6	-0.8	-0.4		

Table 4. Normalized monthly mean temperature anomalies (standard deviations) in 2003 at all stations of the IML thermograph network. The anomalies are relative to the reference periods given in Table 2, with anomalies below -0.5 standard deviation indicated in **blue** and anomalies above 0.5 standard deviation indicated in **red**.

Station	Depth (m)	J	F	M	A	M	J	J	A	S	O	N	D
Banc Beaugé	1							-0.9	0.2	-0.2			
Banc Beaugé	100							-0.6	-0.5	-0.7			
Bonne Bay	25	-1.1	-0.9	-1.2	-1.3	-0.6			0.4	1.1	1.6	1.3	
Baie-Comeau	1						0.2	0.4	1.1	-0.5	0.3		
Baie-Comeau	80					-0.7	-0.7	-0.7	-0.7	-0.7	-0.7		-0.7
BIC	1						-0.5	-0.7	0.4	-0.3			
BIC	2						-0.3	-0.8	0.6	-0.6			
BIC	5.8						-0.7	-0.5	0.2	-1.8			
Borden	3.5	-0.9	-0.9	-0.9	-0.6	-0.9	-0.2	-0.3	0.1	0.3	1.2		
Blanc Sablon	1							0.7	-1.1	0.2			
Grande-Rivière	2						0.1	0.6	-1.3	0.4	1.2		
Grande-Rivière	7						-1.1	0.3	-1.1	-0.5	0.4		
Havre St-Pierre	1							0.8	1.3	-1.2			
Havre St-Pierre	100							-1.2	-1.4	-1.7			
IML	0.5						-0.9	-0.1	0.8	-0.5			
Irving Whale	1						-1.3	0.1	-0.3	-0.1	0.9	-0.4	
Irving Whale	67						-1.1	-1.1	-1.1	-0.9	-1.1	0.7	
Ile Shag	0.5						-1.0	-1.0	-1.5				
Ile Shag	10	0.6	1.3	0.2			-0.9	-1.7	-1.7	0.0	1.6	0.5	0.6
La Romaine	1							1.3	1.4	0.1			
La Romaine	2							1.3	1.1	-0.4			
La Romaine	14							-0.9	0.7	-0.4			
Mont-Louis	0.5						-0.6	0.1	-0.8	0.0	0.6	-0.1	
Natashquan	1							-0.5	0.6	-0.8			
Natashquan	7.5							1.0	1.4	-0.7			
La Perle	1						-0.9	-0.2	-1.0	-0.1	1.0	0.2	
La Perle	8.5						-1.7	-1.6	-0.9	0.4	0.0	0.8	
Rivière-au-Tonnerre	1							0.0	1.0	-0.6			
Rivière-au-Tonnerre	16							0.5	1.4	-1.1			
Rimouski	0.5							-0.7	-0.7	-0.7			
Sept-Iles	1						0.3	0.6	1.1	-0.5	0.3		
Sept-Iles	25						0.2	1.2	1.6	-0.8	-0.1		
La Tabatière	1							0.7	0.7	0.7			
La Tabatière	36							0.7	-0.7	-0.7			
Tadoussac	2						-0.7	-0.8	0.7	-0.7	-0.8		

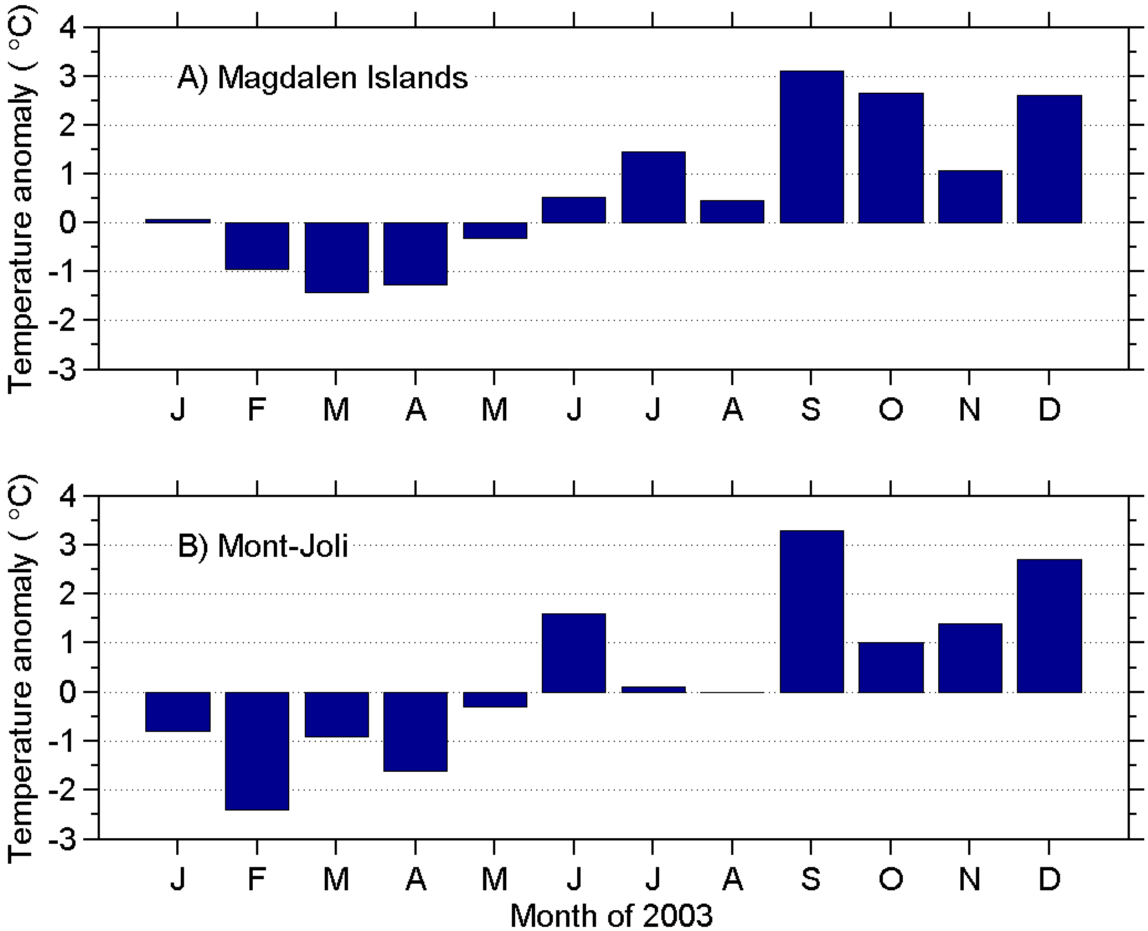


Fig. 1. Monthly air temperature anomalies at the Magdalen Islands in 2003.

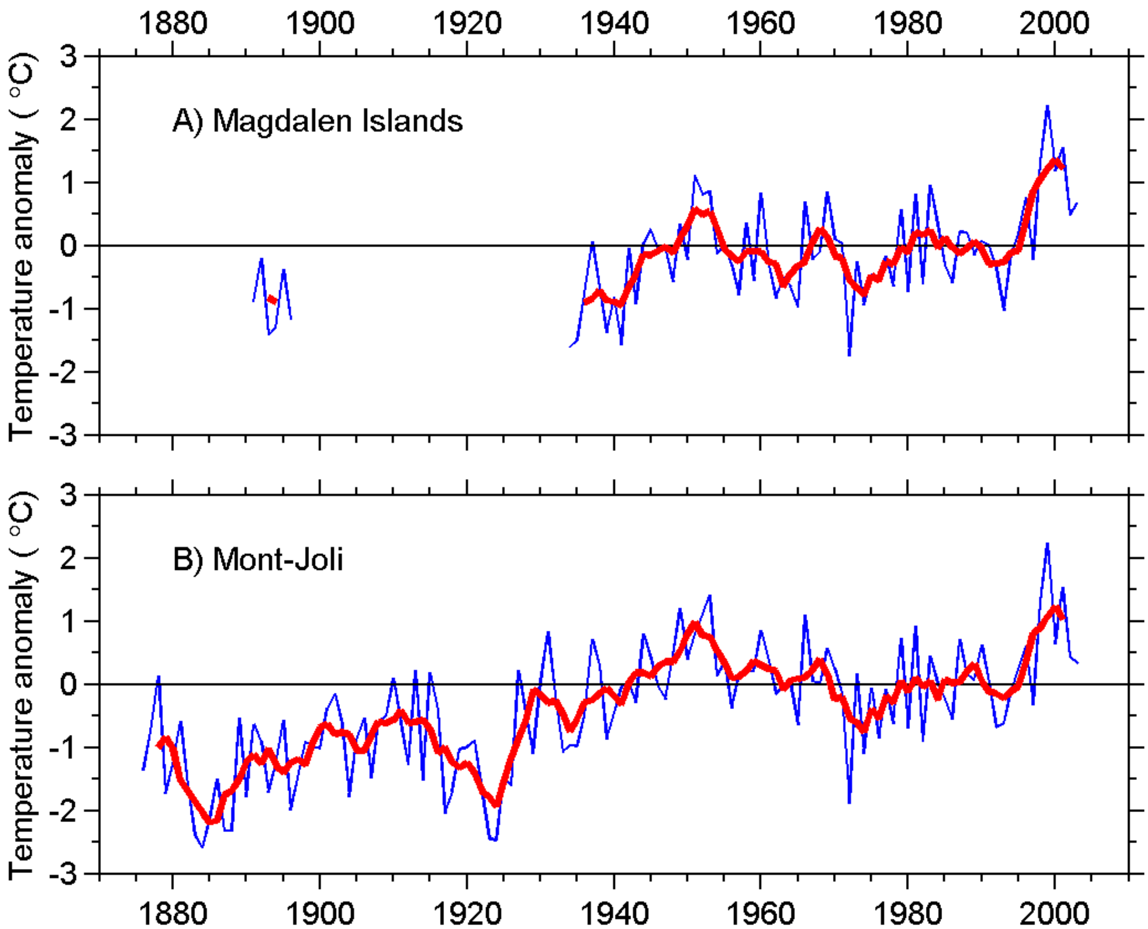


Fig. 2. Annual mean air temperature anomalies at the Magdalen Islands (A) and at Mont-Joli (B). The thick red lines represent five-year running means.

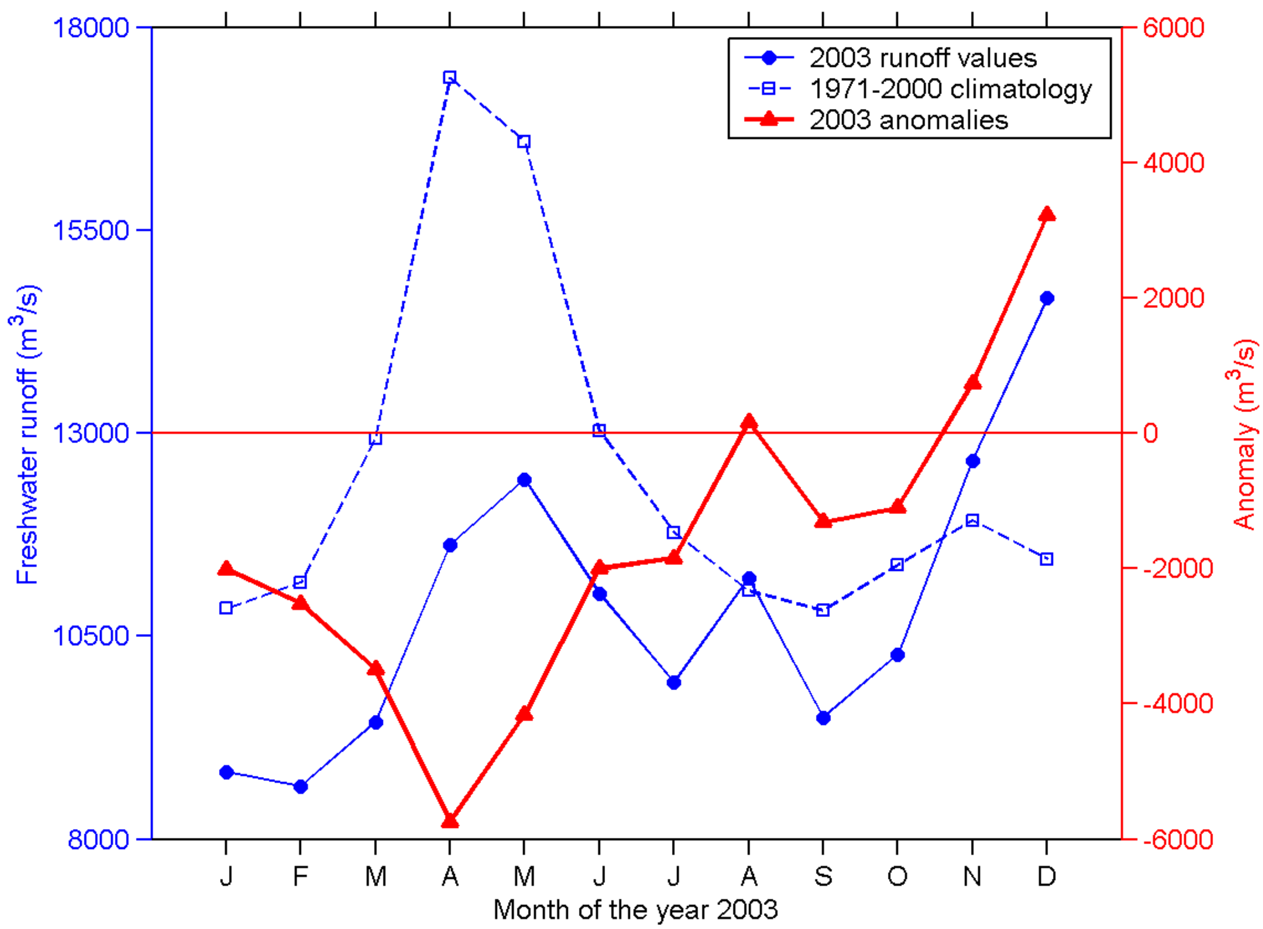


Fig. 3. Monthly mean freshwater flow of the St. Lawrence River at Québec City in 2003 (continuous blue line) compared with the 1971-2000 climatology (dashed blue line). The 2003 monthly anomalies are shown in red.

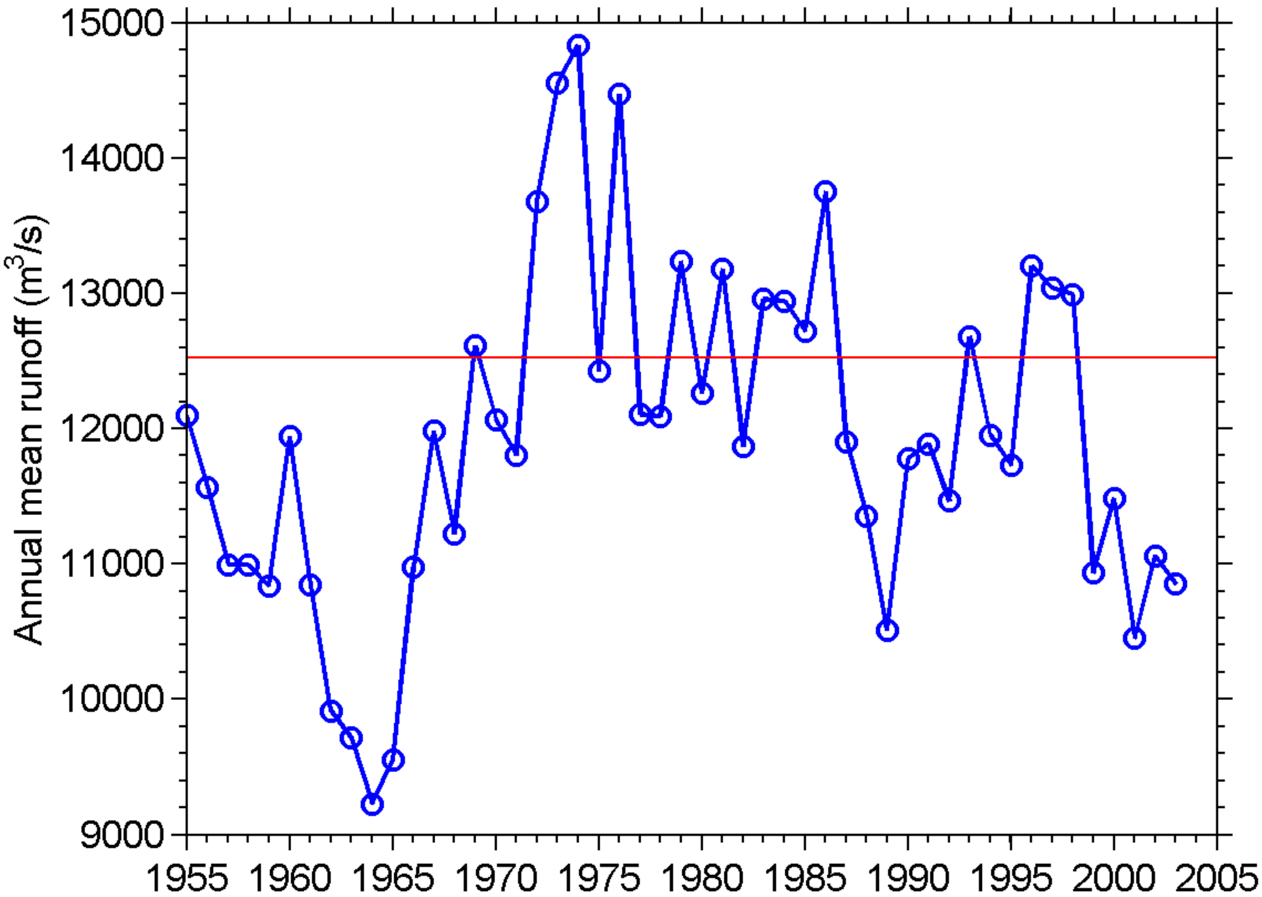


Fig. 4. Annual mean freshwater flow of the St. Lawrence River at Québec City. The horizontal line represents the 1971-2000 average.

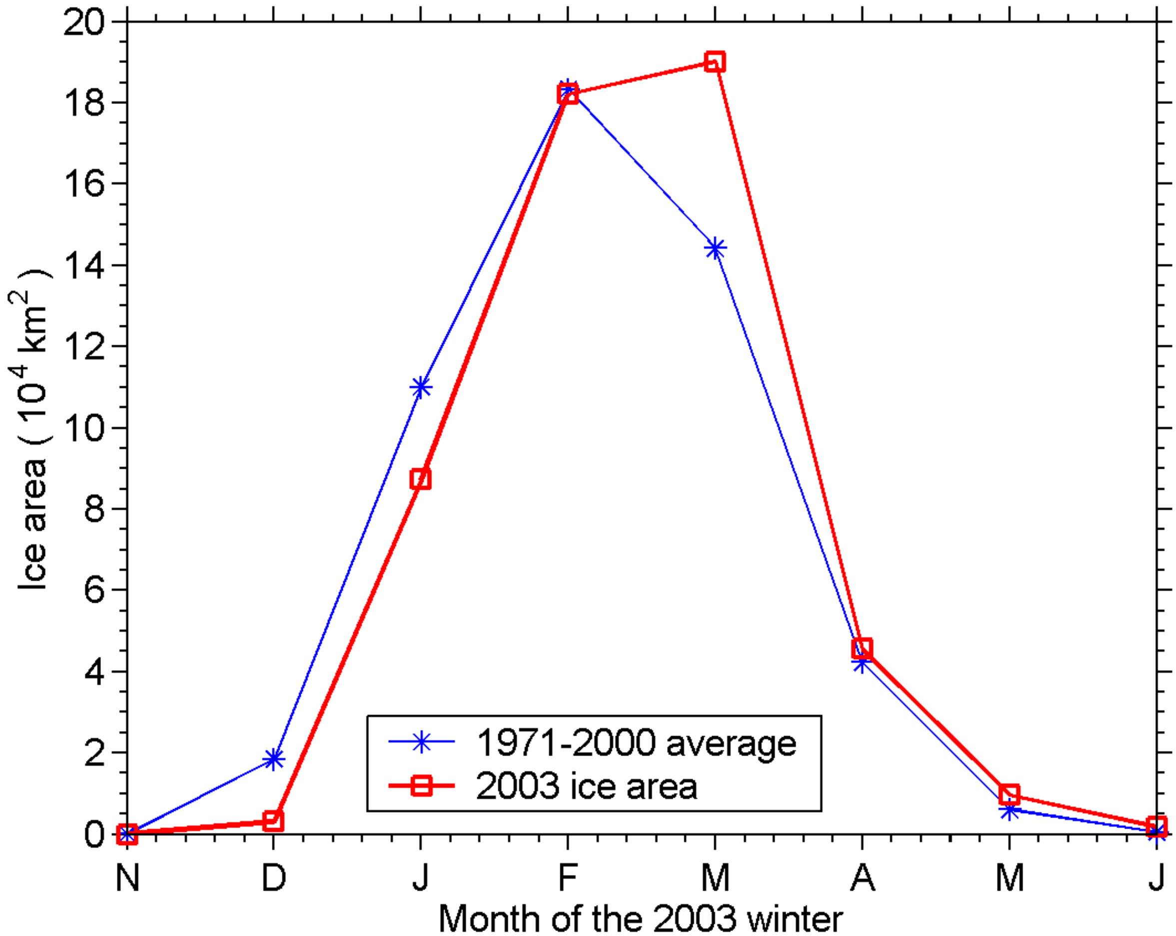


Fig. 5. Monthly ice cover area in the Gulf of St. Lawrence (red squares) compared with the 1971-2000 normal (blue asterisks).

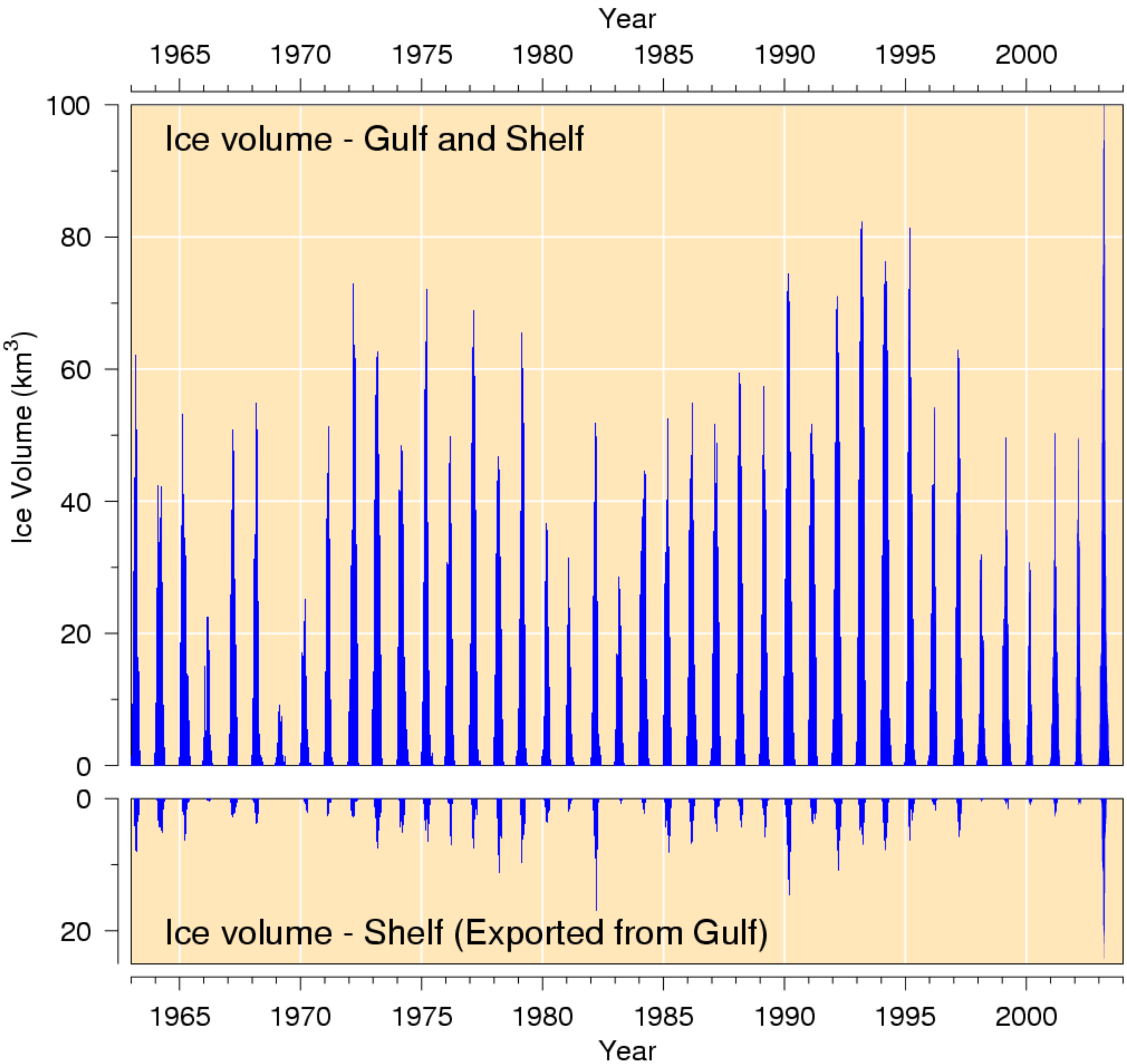


Fig. 6 Index of ice volume in the Gulf of St. Lawrence and on the Shelf seaward of Cabot Strait (upper panel) and on the Shelf only (lower panel).

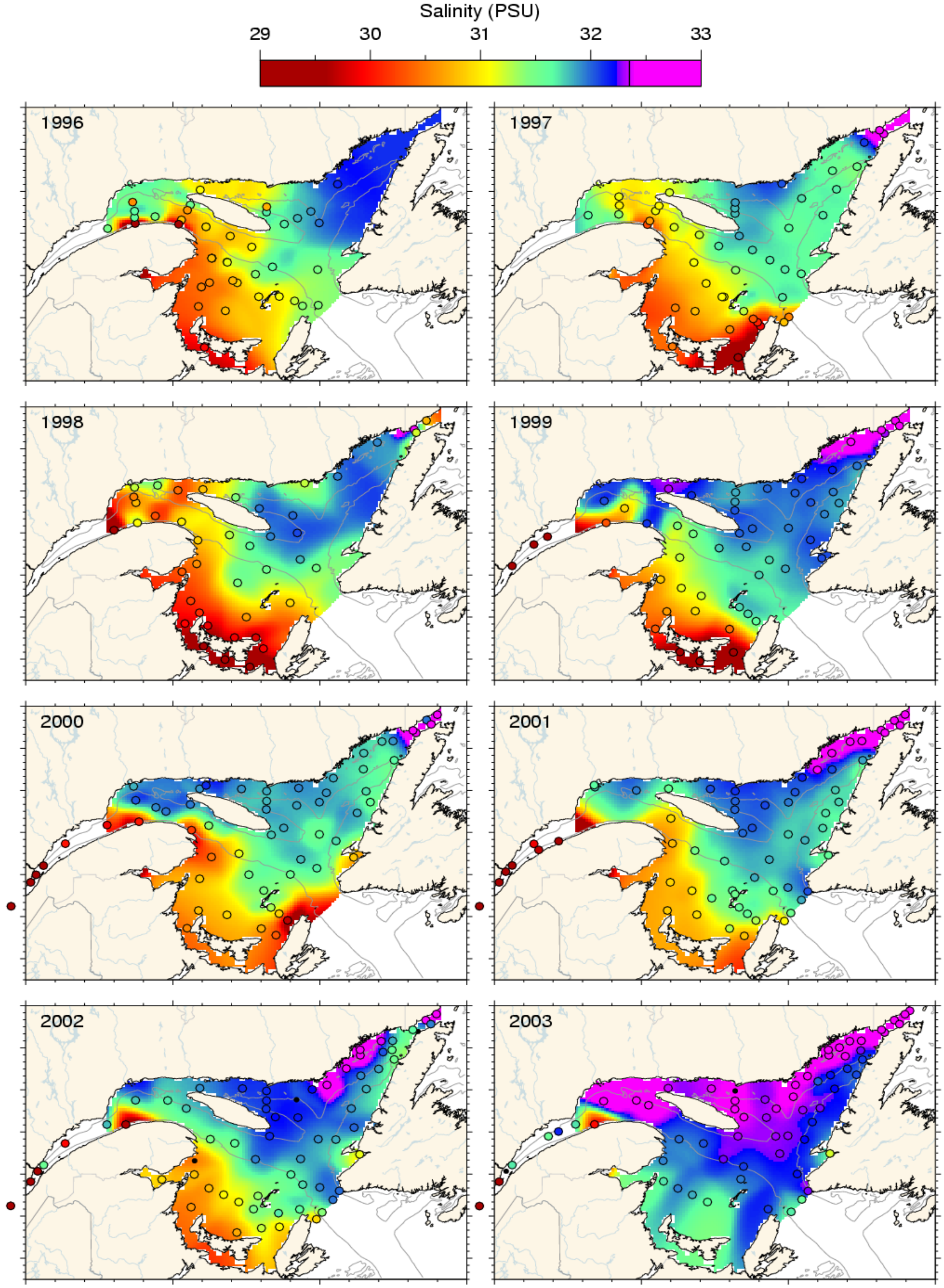


Fig. 7. Surface salinity for all March surveys (1996-2003). The circles indicate station locations, and are colour-coded according to the value observed at each station.

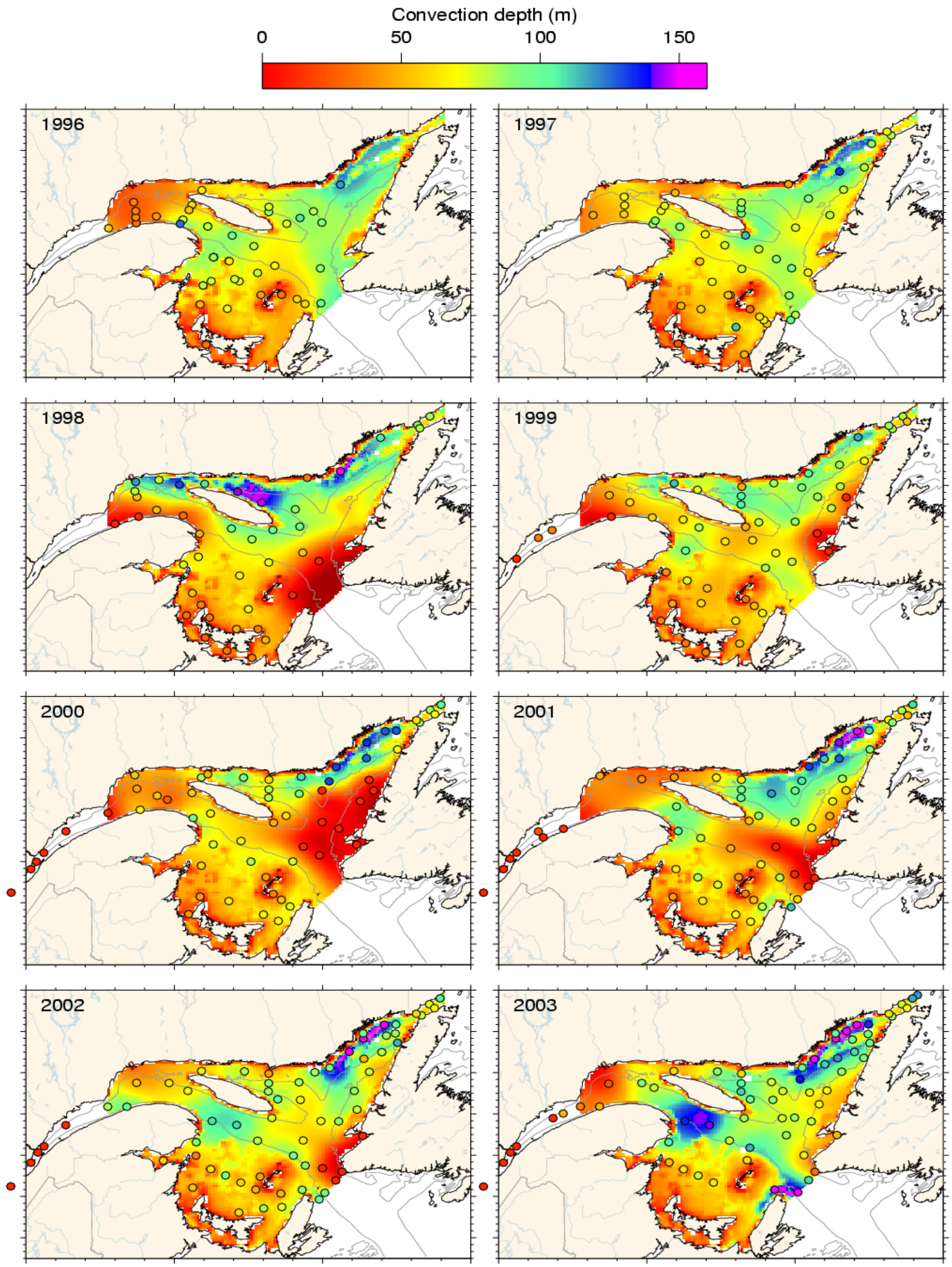


Fig. 8. Thickness of the cold surface layer (T < -1°C) for all March surveys (1996-2003). The circles indicate station locations, and are colour-coded according to the value observed at each station.

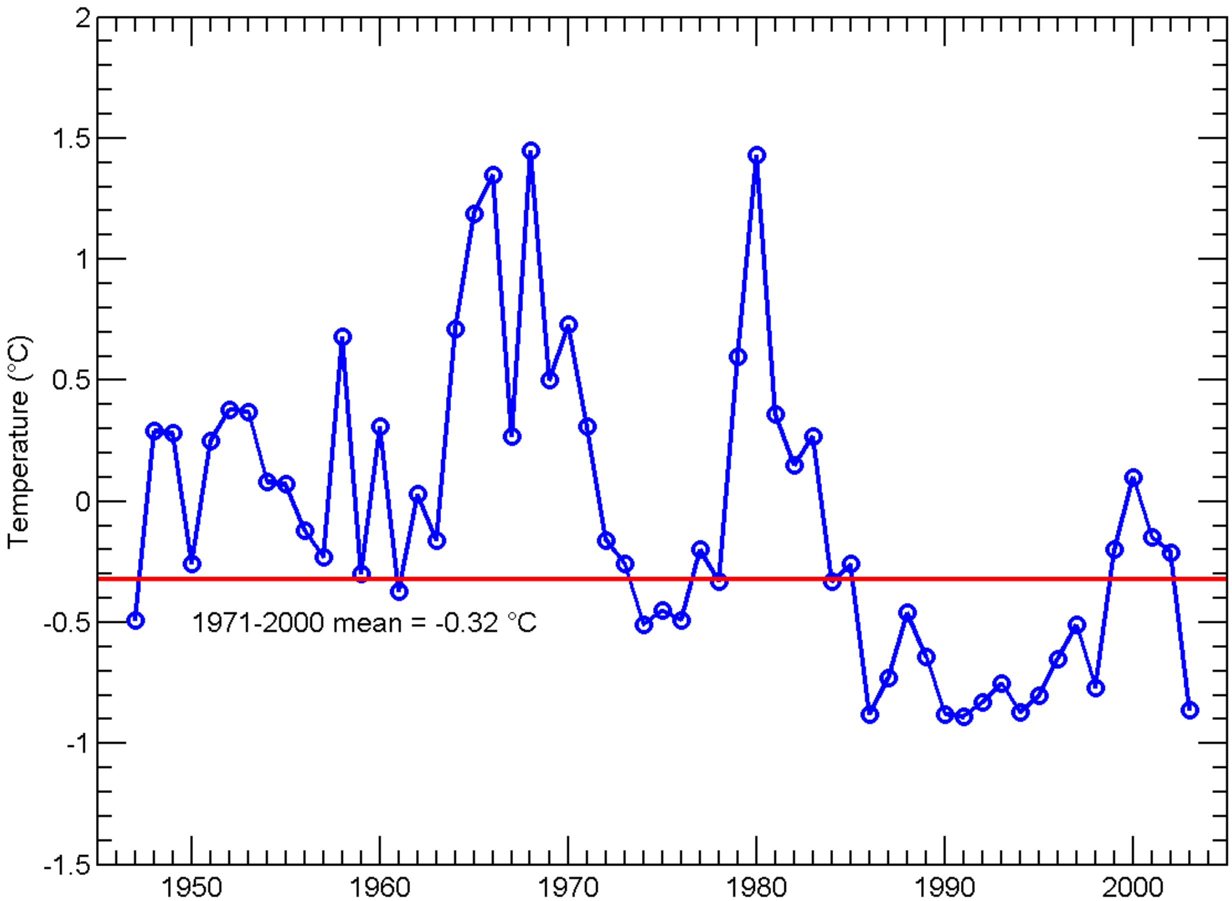


Fig. 9. CIL minimum temperature in the Gulf of St. Lawrence interpolated to July 15.

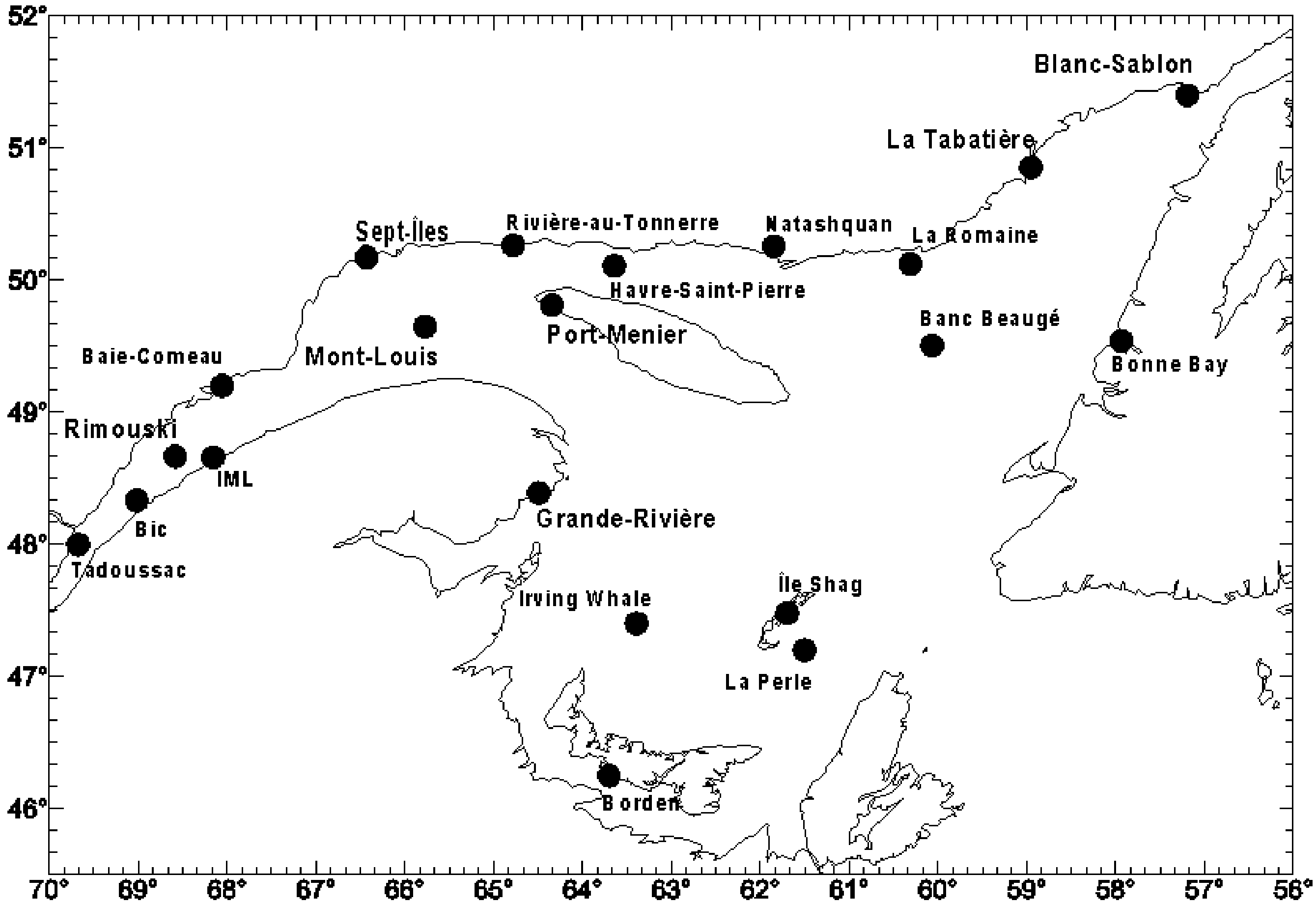


Fig. 10. Locations of IML thermograph network stations in 2003.

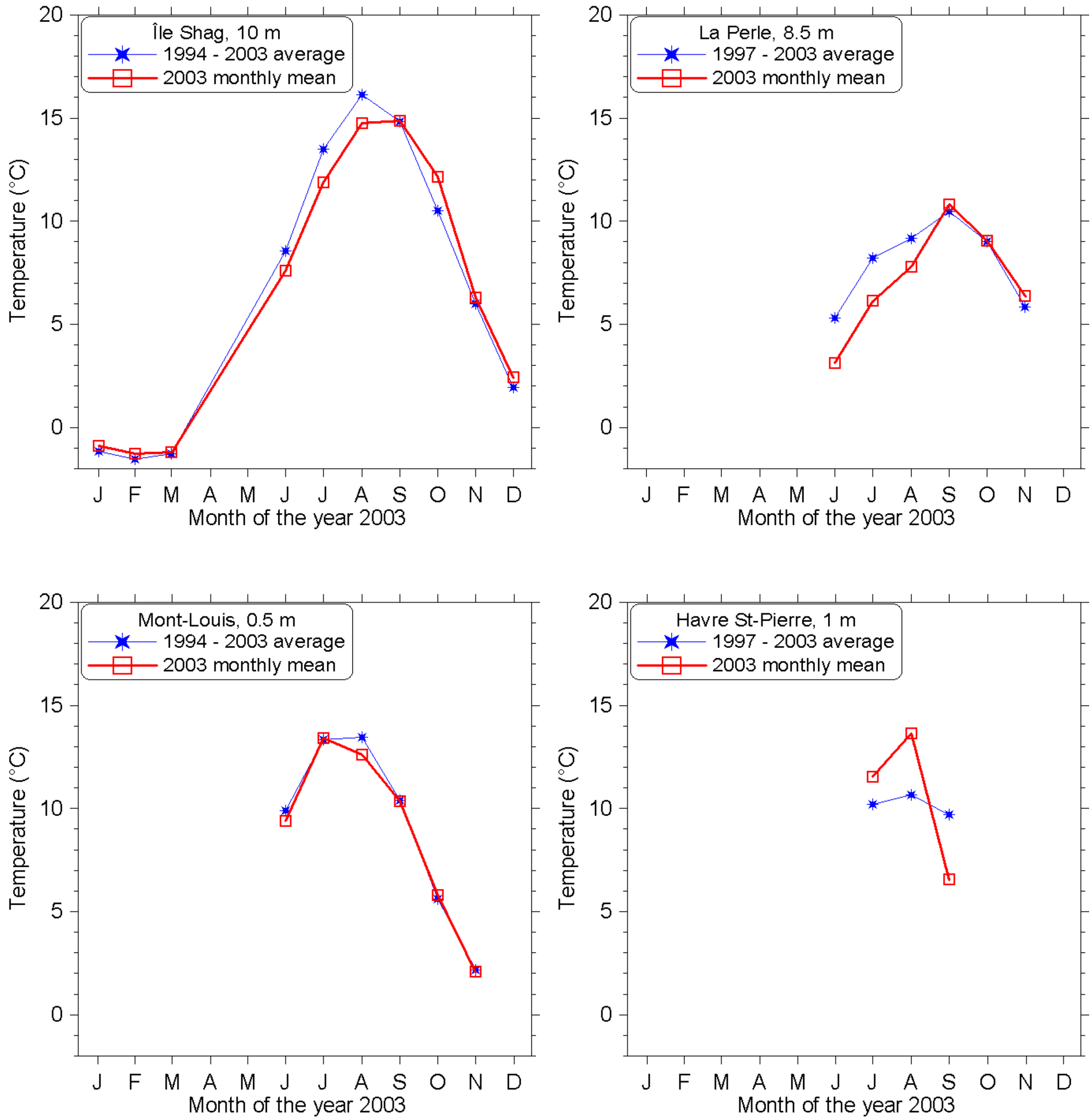
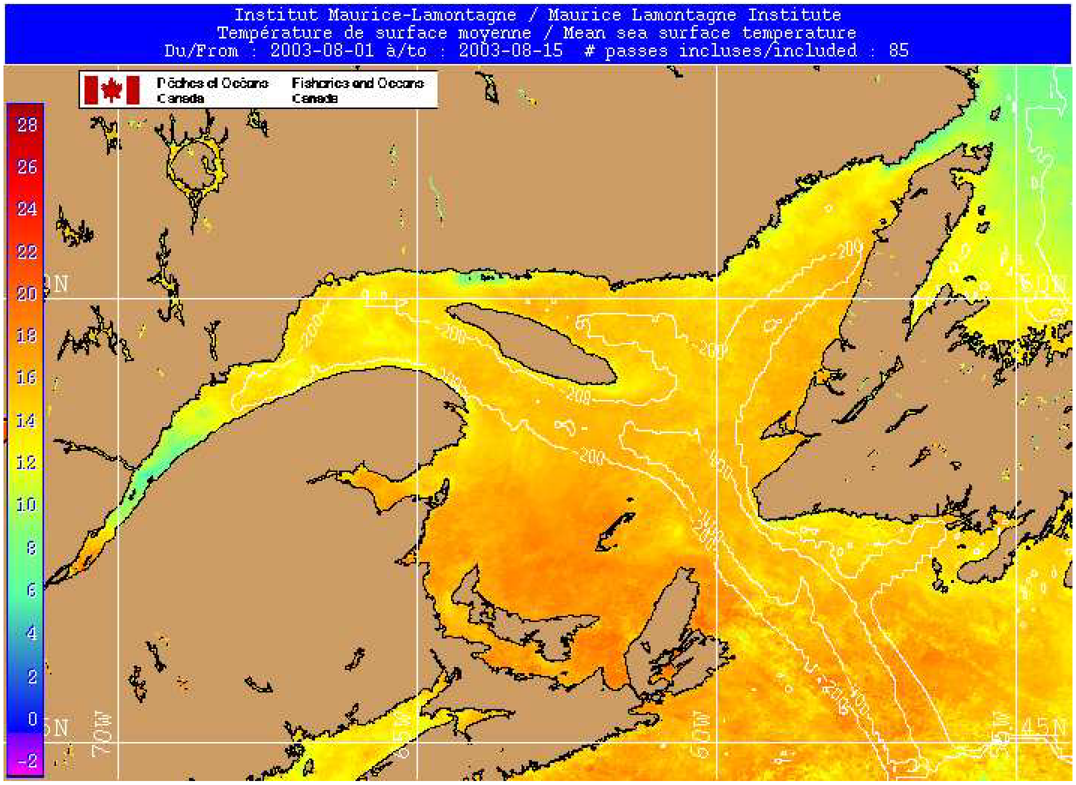


Fig. 11. Monthly mean 2003 temperatures (red curves) compared with the 199x-2003 normals (blue curves) computed from all available data at 10 m depth at Île Shag (upper left panel), at 8.5 m depth at La Perle (upper right panel), at 0.5 m depth at Mont-Louis (lower left panel) and at 1 m depth at Havre St-Pierre (lower right panel).



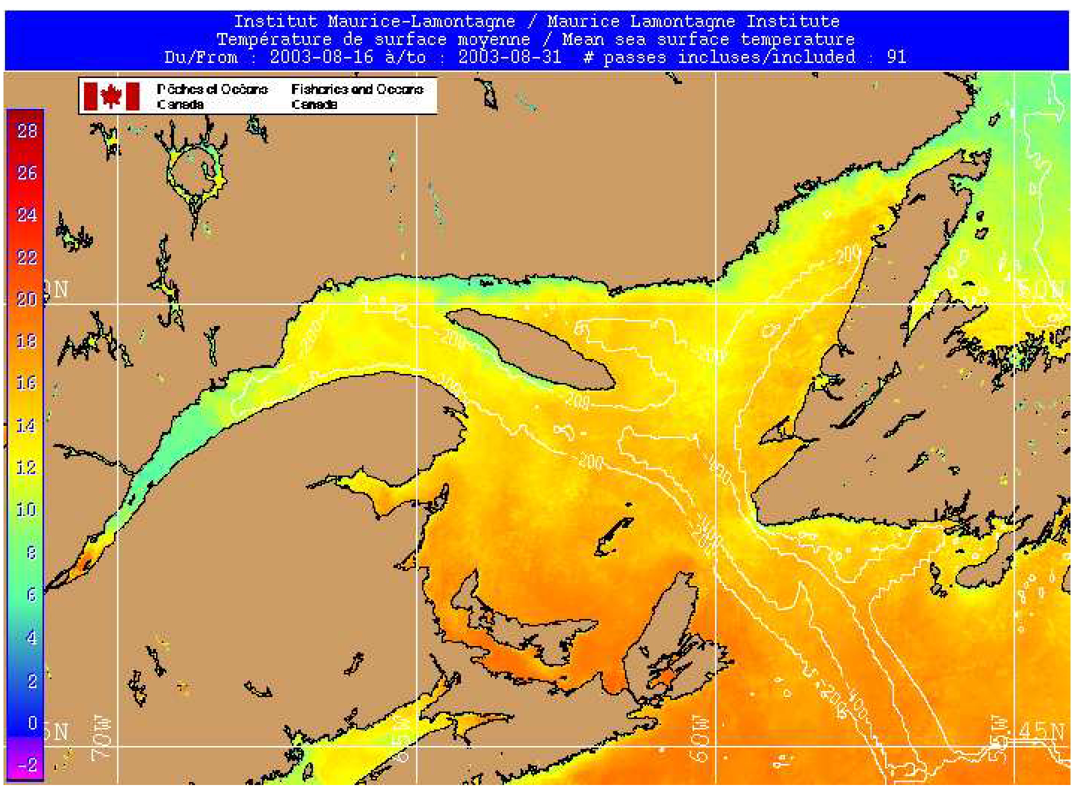
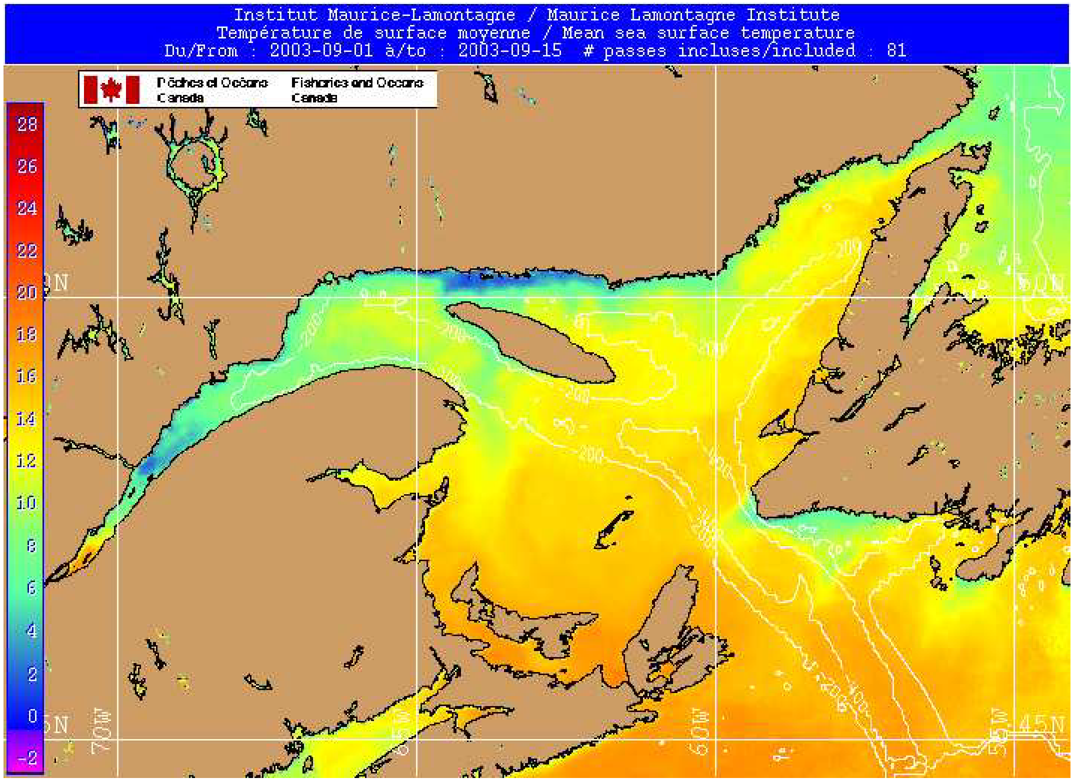


Fig. 12. Biweekly maps of sea surface temperature in August 2003 produced from NOAA AVHRR satellite imagery.



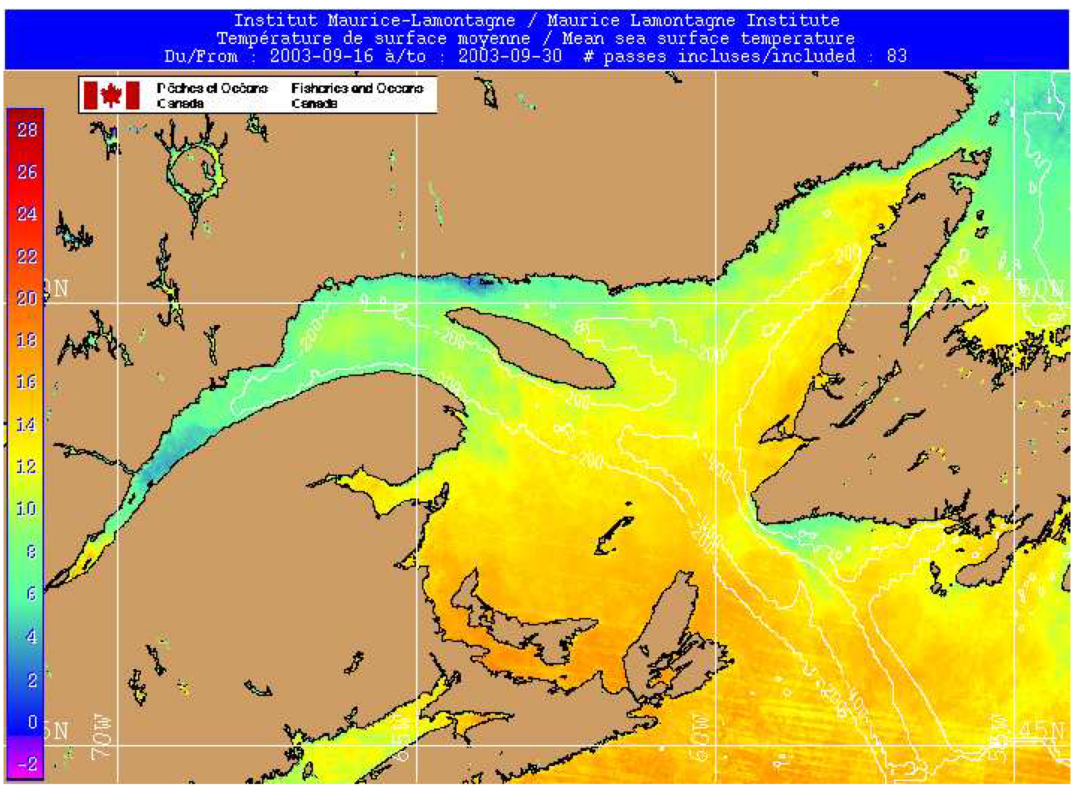


Fig. 13. Biweekly maps of sea surface temperature in September 2003 produced from NOAA AVHRR satellite imagery.

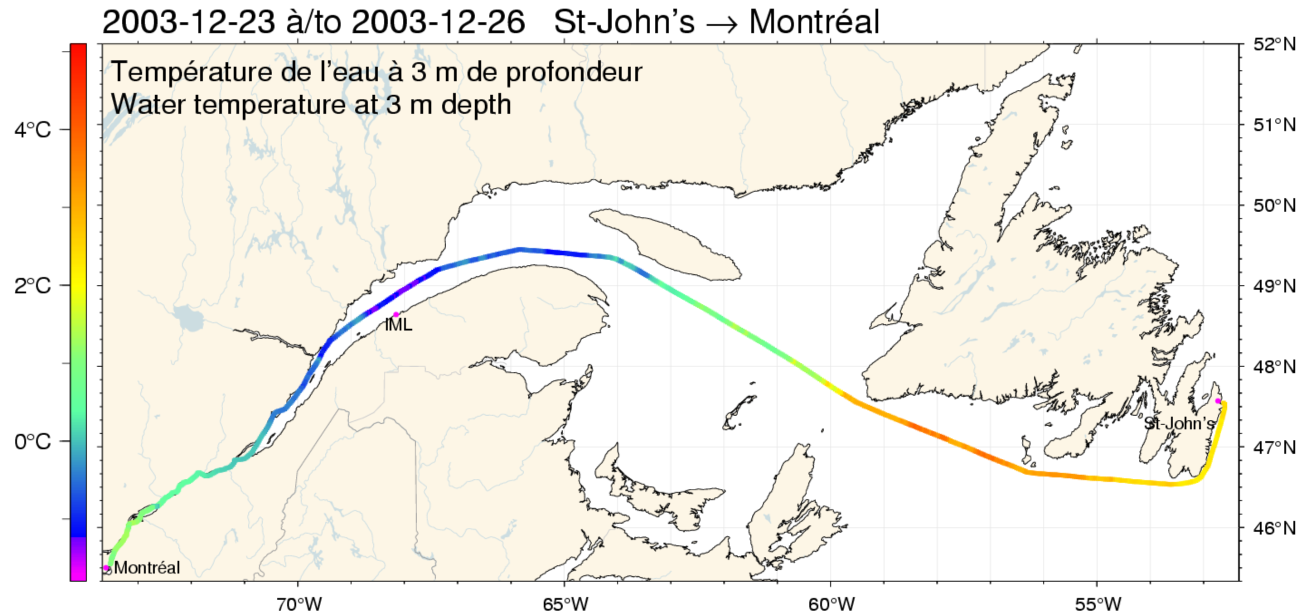


Fig. 14. Ship track of the Cicero during a 3-day trip from St. John's to Montréal in December 2003. The track is color-coded according to measured sea surface temperature at 3 m depth.

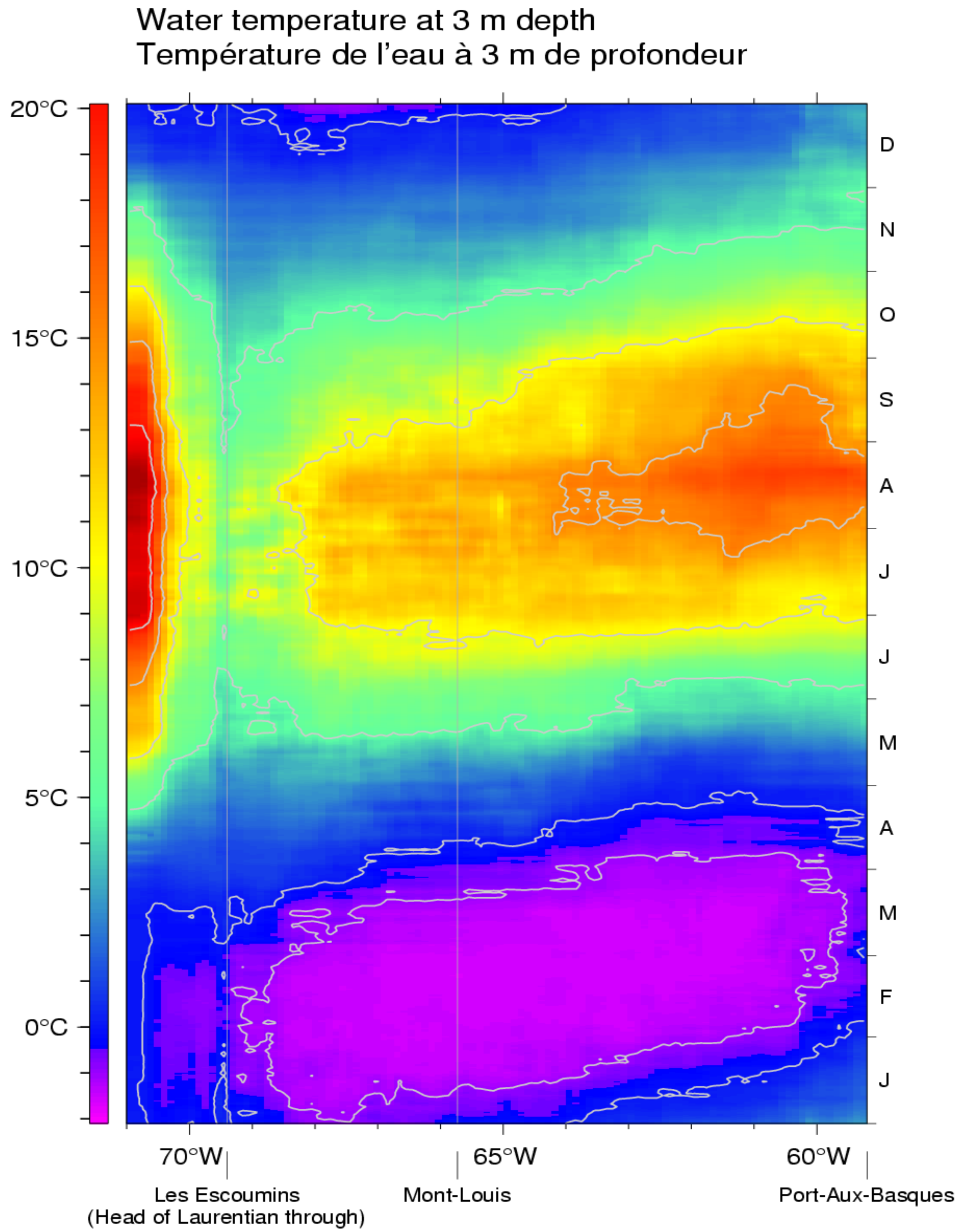


Fig. 15. Composite mean annual cycle of water temperature measured from the Cicero at 3 m depth during 4 years (2000 to 2003).

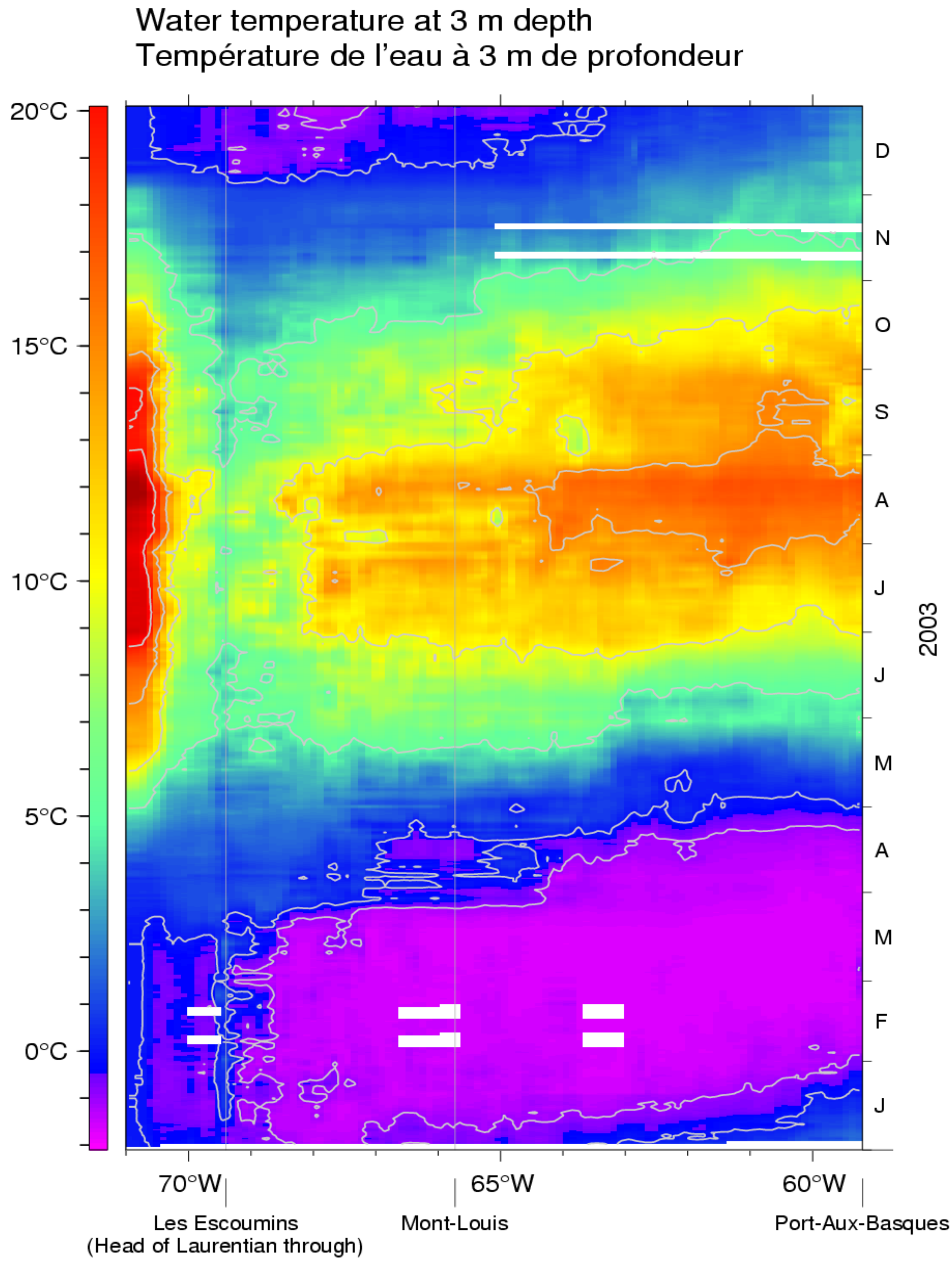


Fig. 16. Composite annual cycle of water temperature measured from the Cicero at 3 m depth during 2003.

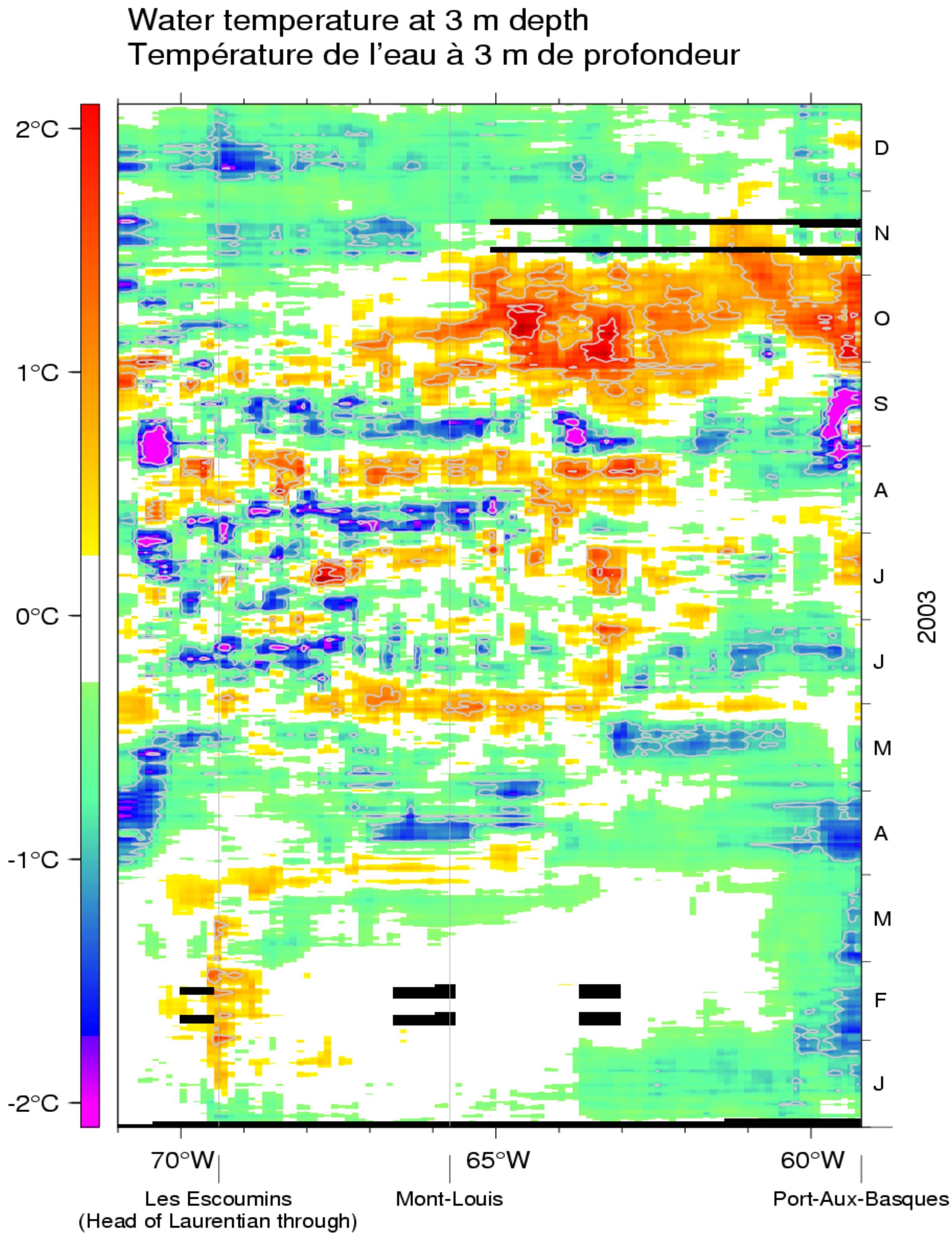


Fig. 17. Water temperature anomaly for 2003 along the Cicero ship track. The anomaly is defined as the difference between 2003 temperatures shown in Fig. 16 and the 2000-2003 average shown in Fig. 15.

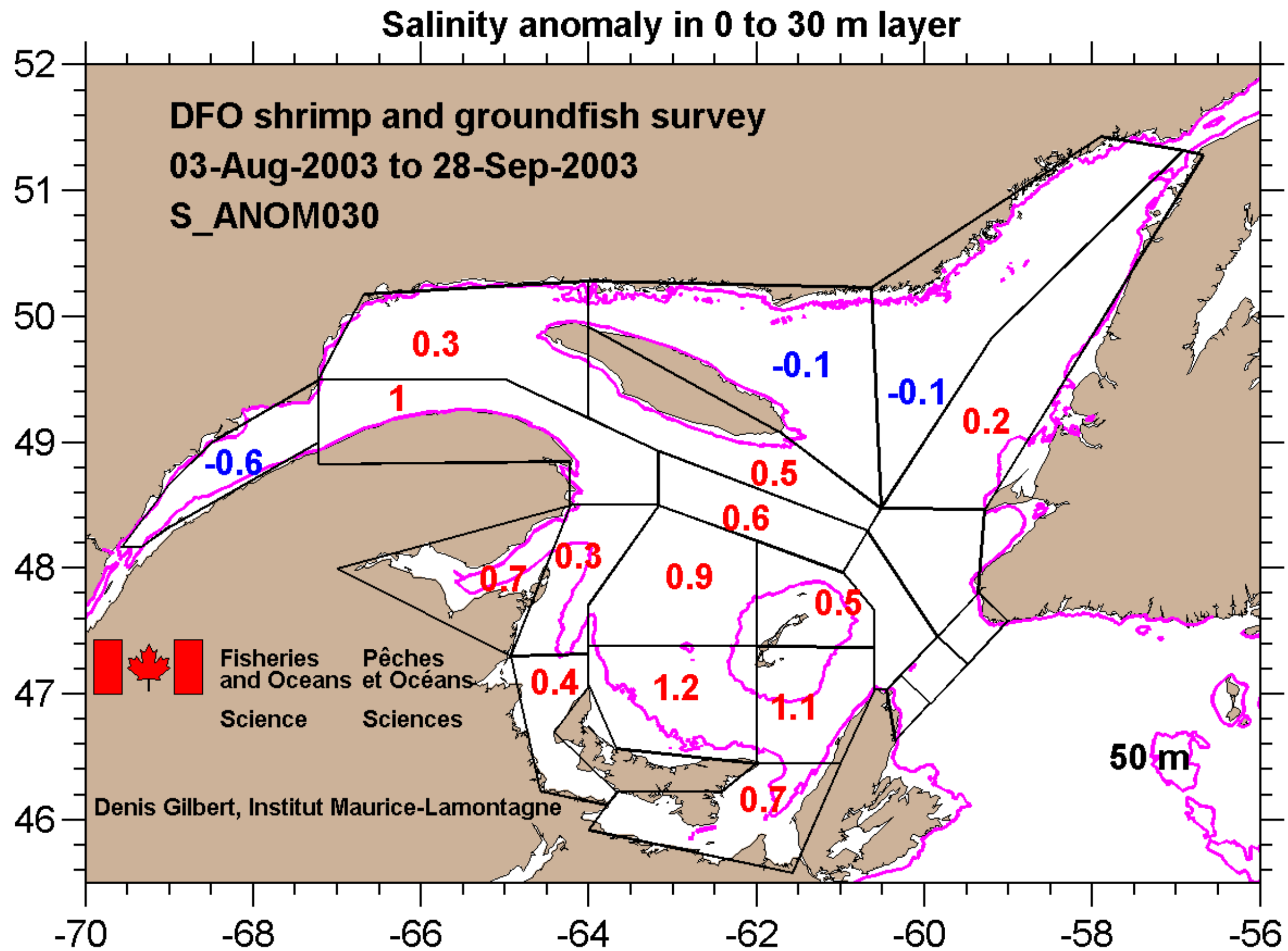


Fig. 18. Salinity anomaly in the 0-30 m layer during the August-September 2003 shrimp and groundfish survey.

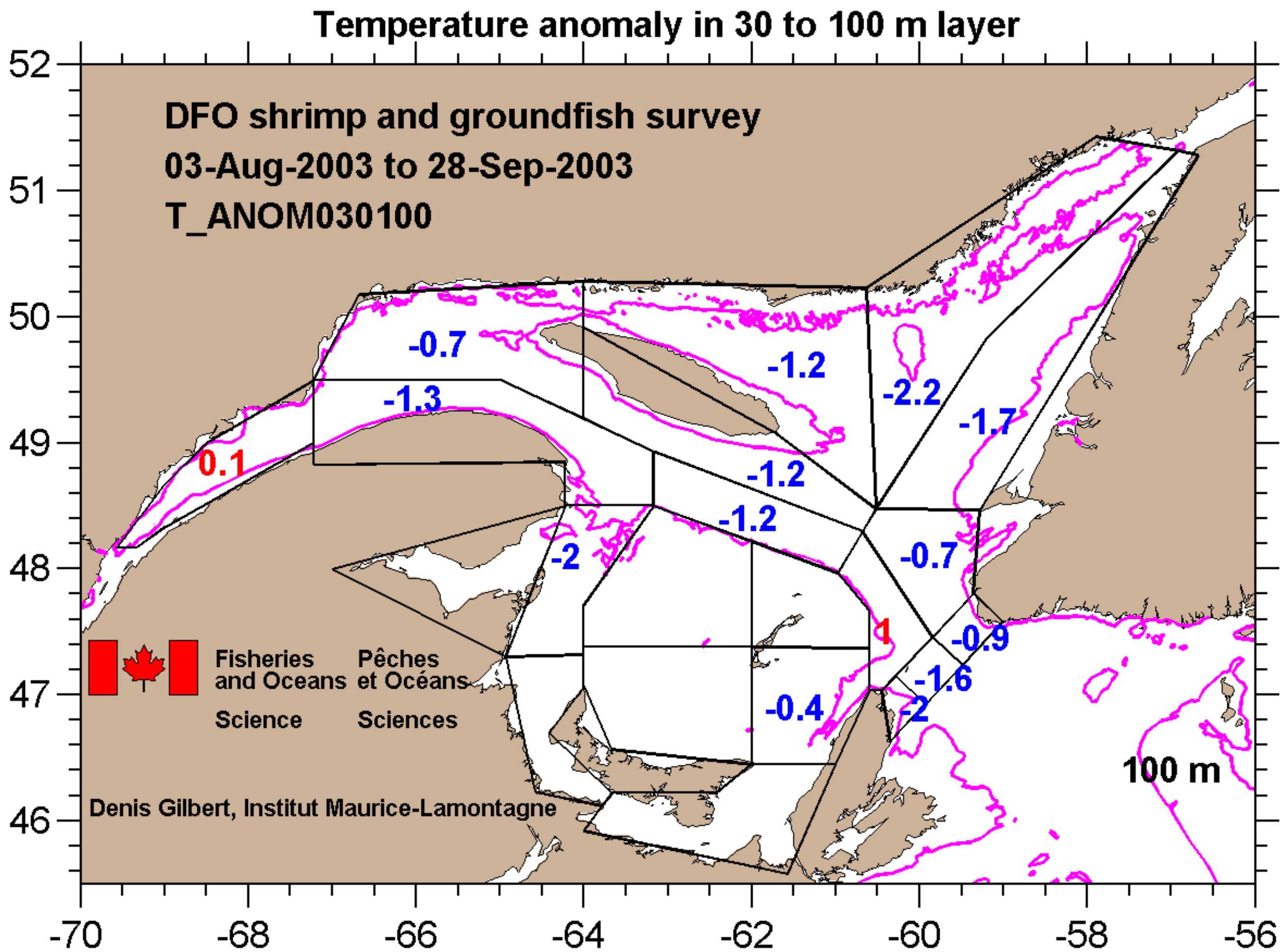


Fig. 19. Temperature anomaly in the 30-100 m layer during the August-September 2003 shrimp and groundfish survey.

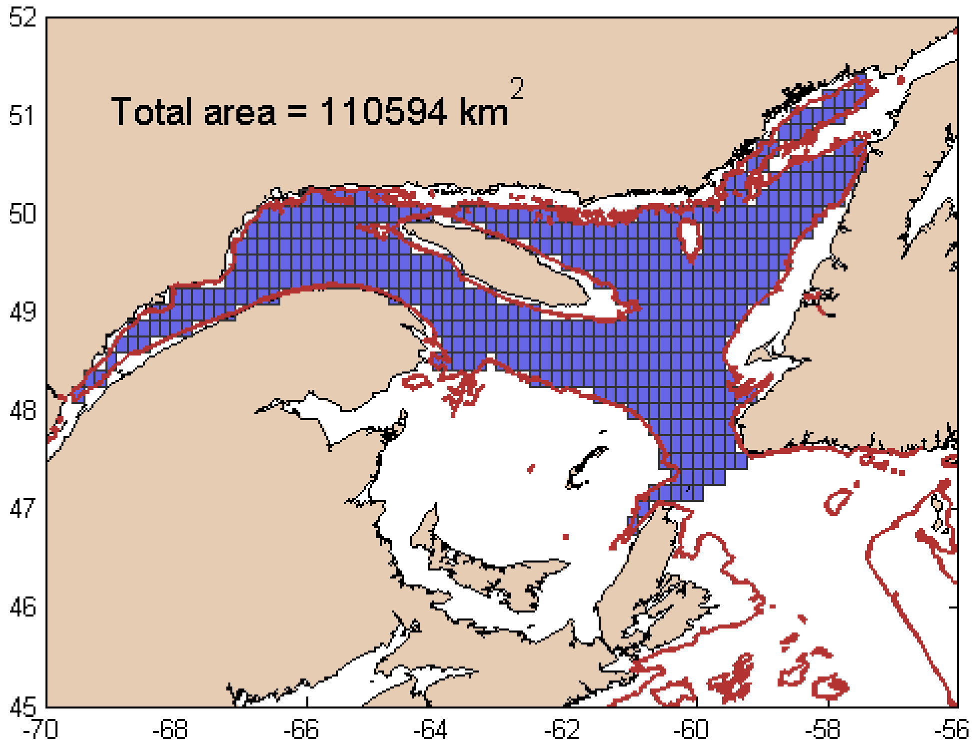


Fig. 20. Interpolation grid used to determine the mean August-September CIL thickness, volume and minimum temperature in the Estuary and Gulf of St. Lawrence during the groundfish survey. The grid is delimited by the 100 m isobath and Cabot Strait.

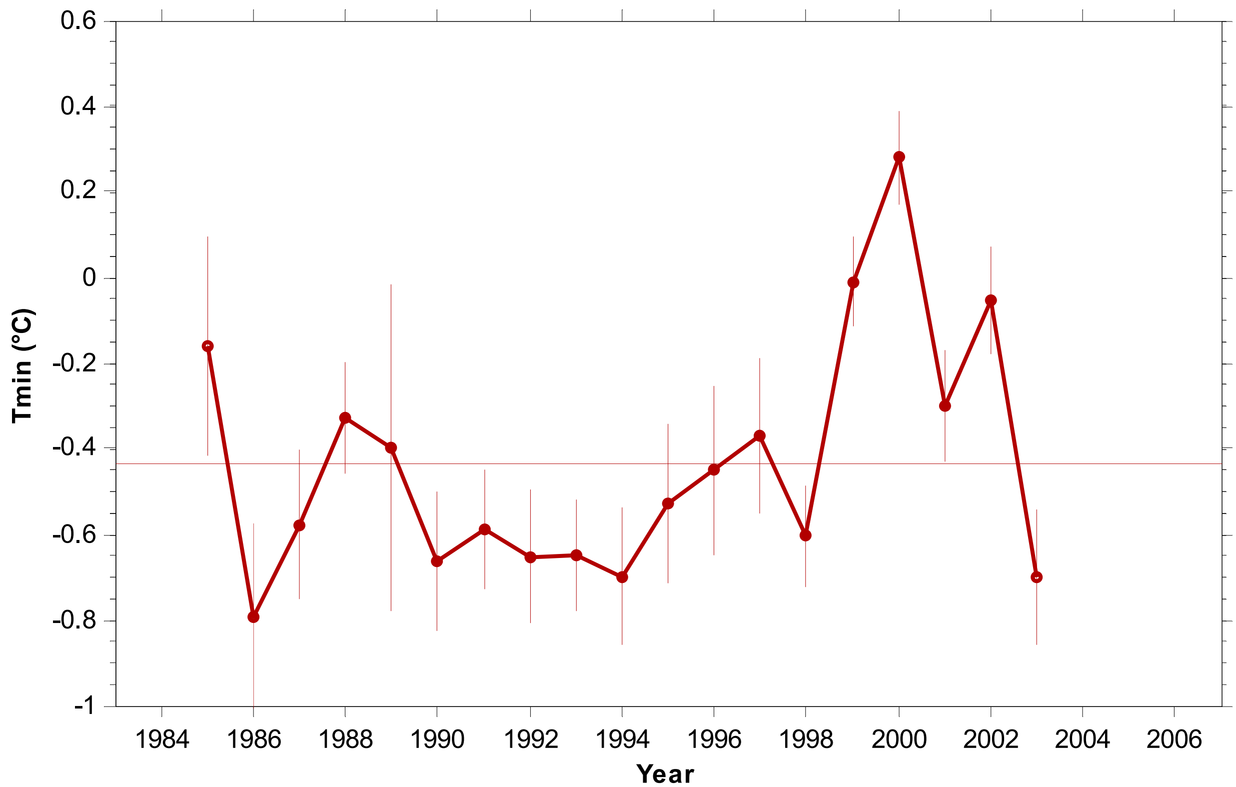


Fig. 21. Time series of the mean CIL minimum temperature for the Estuary and Gulf of St. Lawrence measured during the August-September groundfish survey. The horizontal line shows the 1985 to 2003 average and the vertical bars indicate standard deviations.

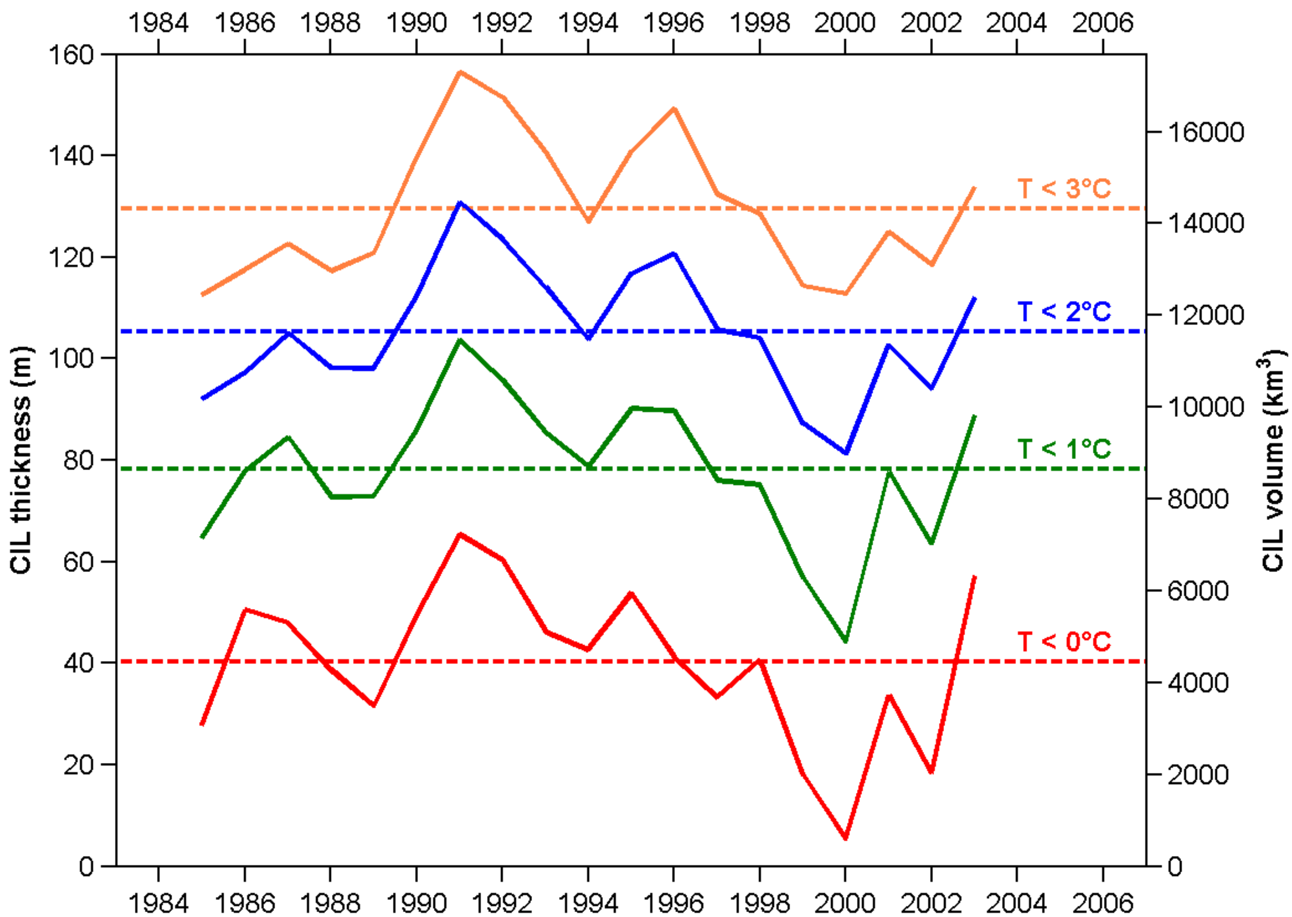


Fig. 22. Time series of the mean CIL thickness (left y-axis) and volume (right y-axis) in the Estuary and Gulf of St. Lawrence during the August-September groundfish survey. The horizontal lines show the 1985 to 2003 averages.

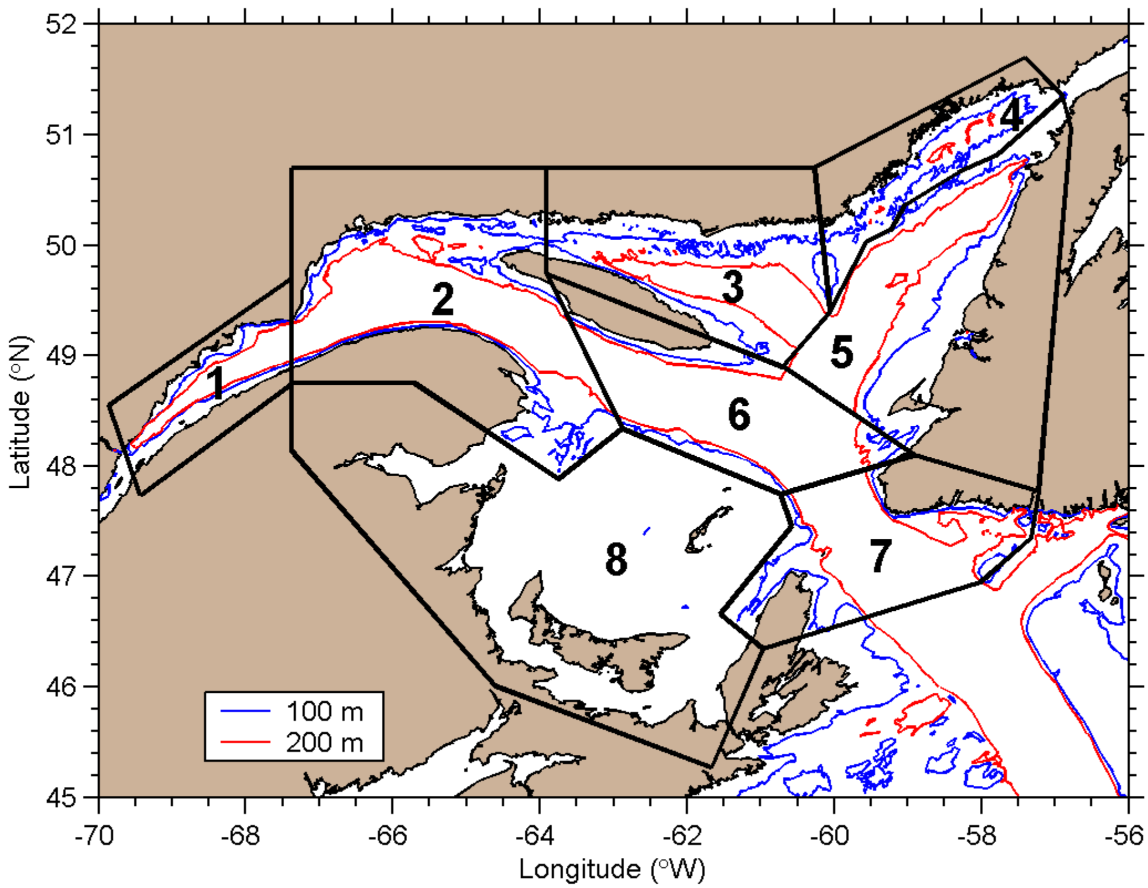


Fig. 23. Map of the Gulf of St. Lawrence showing the regions for which we produced time series of CIL thickness and volume from the groundfish surveys of 1985 to 2003, and for which we also computed average vertical profiles of temperature in 2002 and 2003.

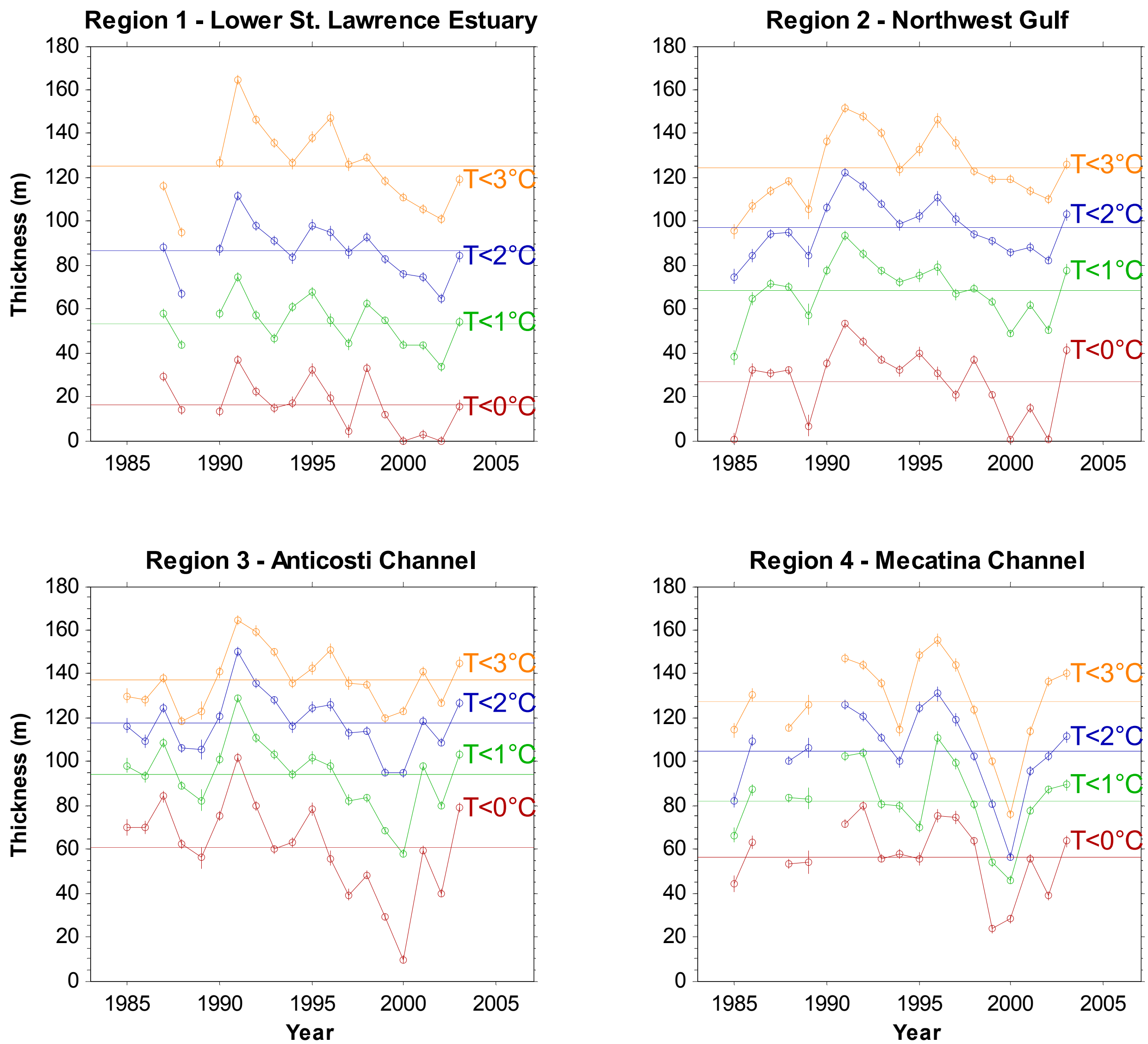


Fig. 24. Time series of the mean August-September CIL thickness in the Lower St. Lawrence Estuary (upper left panel), in the northwest Gulf (upper right panel), in the Anticosti Channel (lower left panel) and in the Mecatina Channel (lower right panel). The horizontal lines are the 1985 to 2003 means. The vertical bars indicate standard deviations.

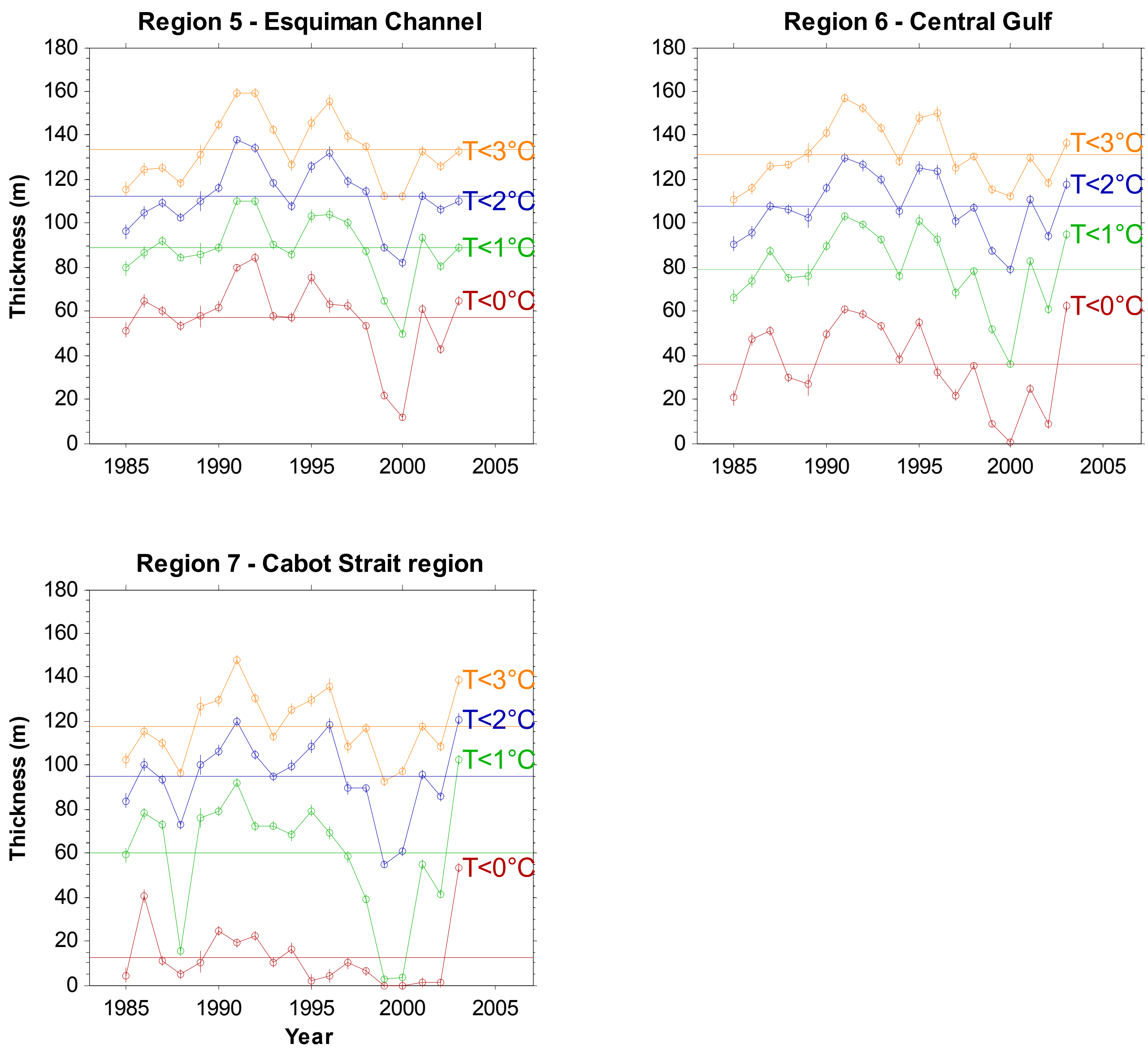


Fig. 24 (continued). Time series of the mean August-September CIL thickness in the Esquiman Channel (upper left panel), in the central Gulf (upper right panel) and in the Cabot Strait region (lower left panel). The horizontal lines are the 1985 to 2003 means. The vertical bars indicate standard deviations.

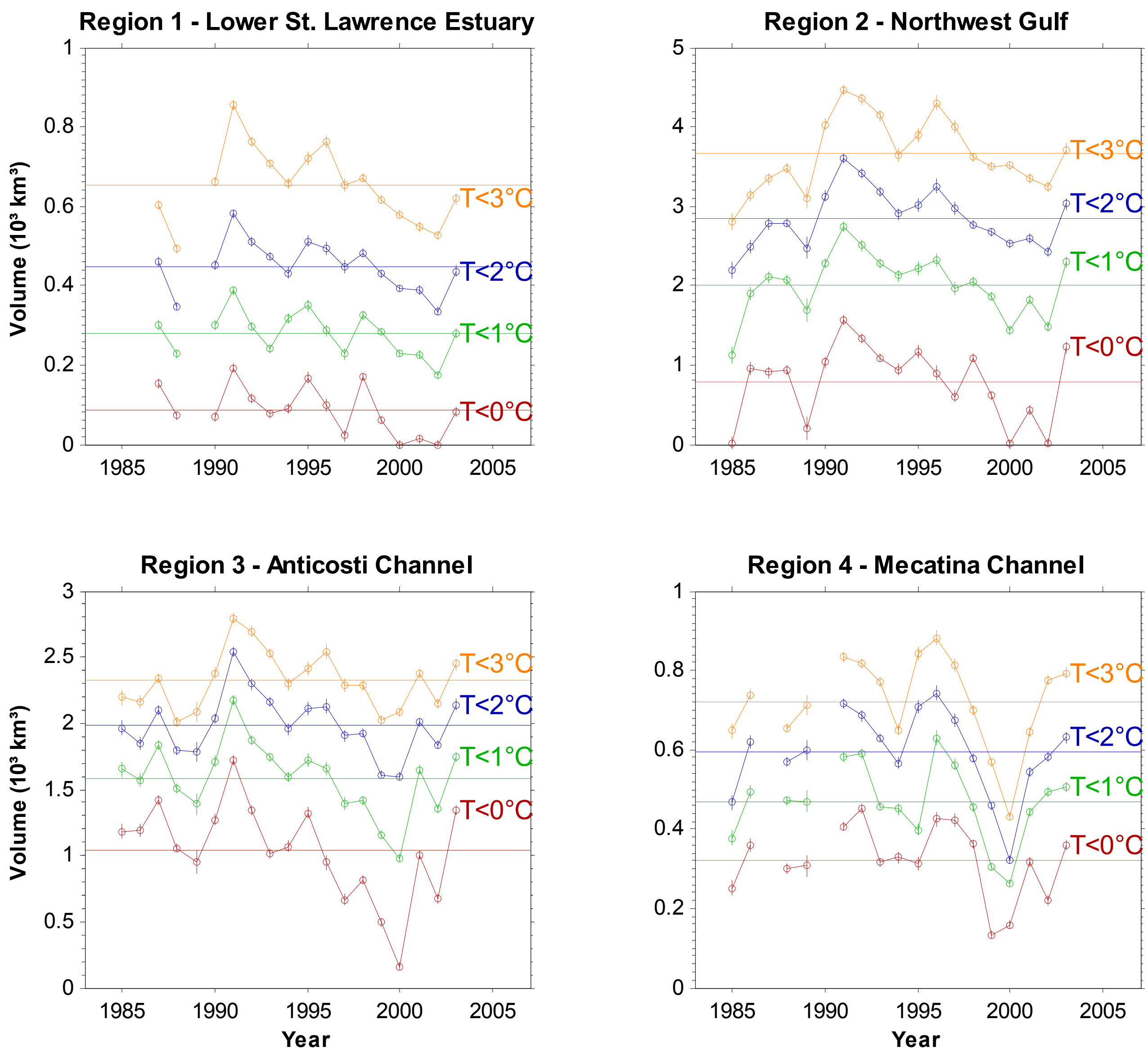


Fig. 25. Time series of the mean August-September CIL volume in the Lower St. Lawrence Estuary (upper left panel), in the northwest Gulf (upper right panel), in the Anticosti Channel (lower left panel) and in the Mecatina Channel (lower right panel). The horizontal lines are the 1985 to 2003 means. The vertical bars indicate standard deviations.

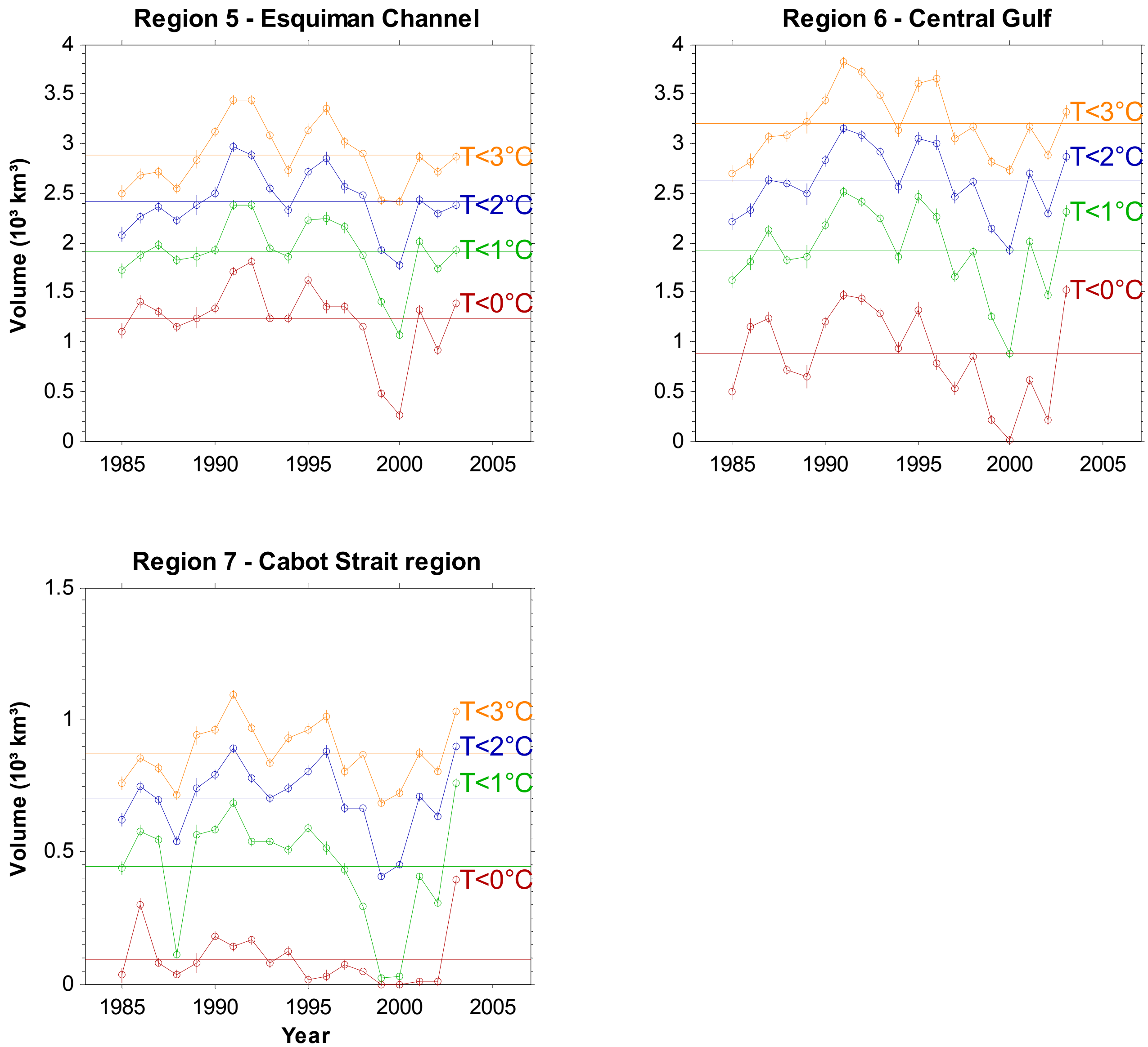


Fig. 25 (continued). Time series of the mean August-September CIL volume in the Esquiman Channel (upper left panel), in the central Gulf (upper right panel) and in the Cabot Strait region (lower left panel). The horizontal lines are the 1985 to 2003 means. The vertical bars indicate standard deviations.

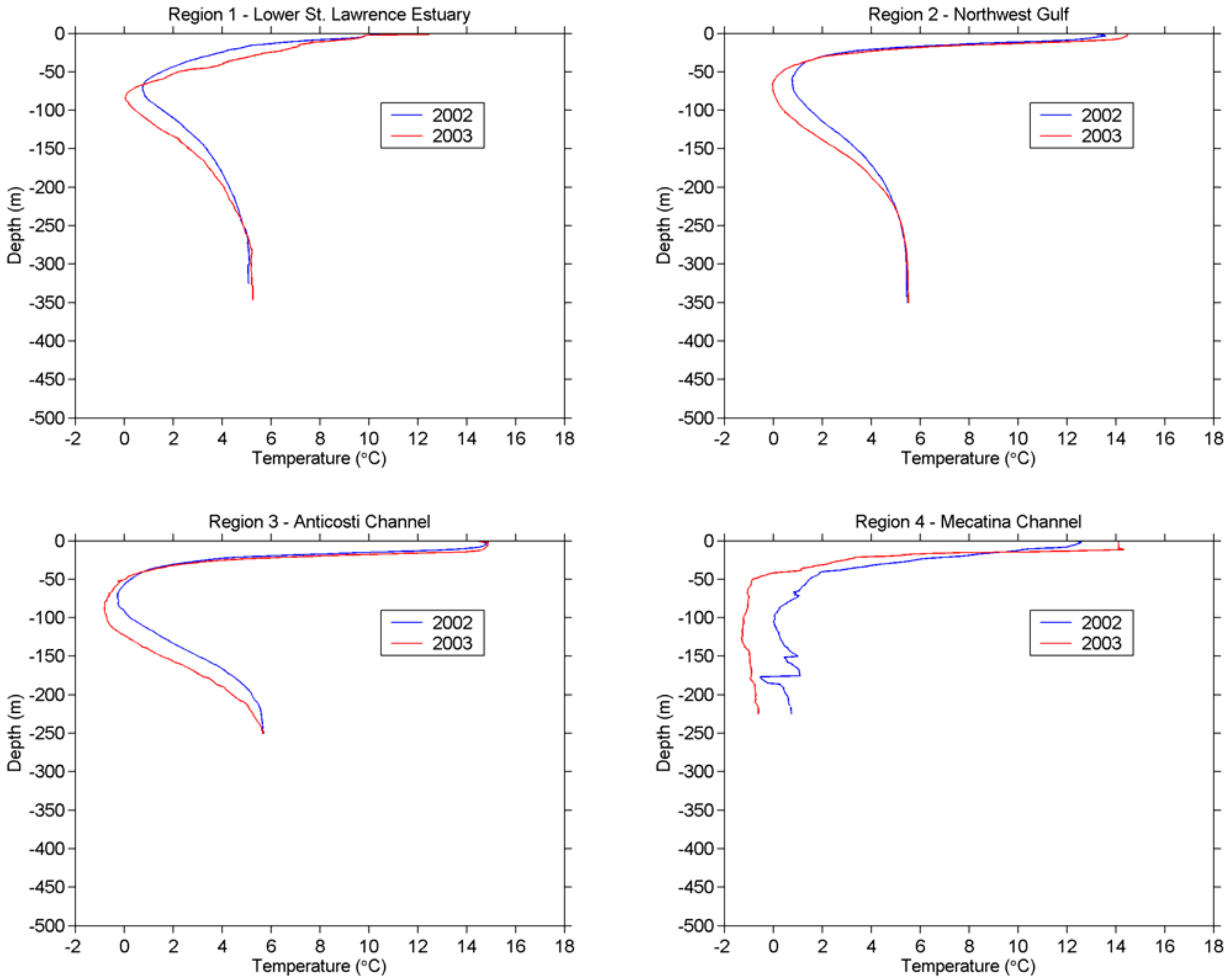


Fig. 26. Average vertical profiles of temperature calculated exclusively from CTD profiles taken during the 2002 and 2003 August shrimp and groundfish surveys in the Lower St. Lawrence Estuary (upper left panel), in the northwest Gulf (upper right panel), in the Anticosti Channel (lower left panel) and in the Mecatina Channel (lower right panel). The regional polygons are shown on Fig. 23.

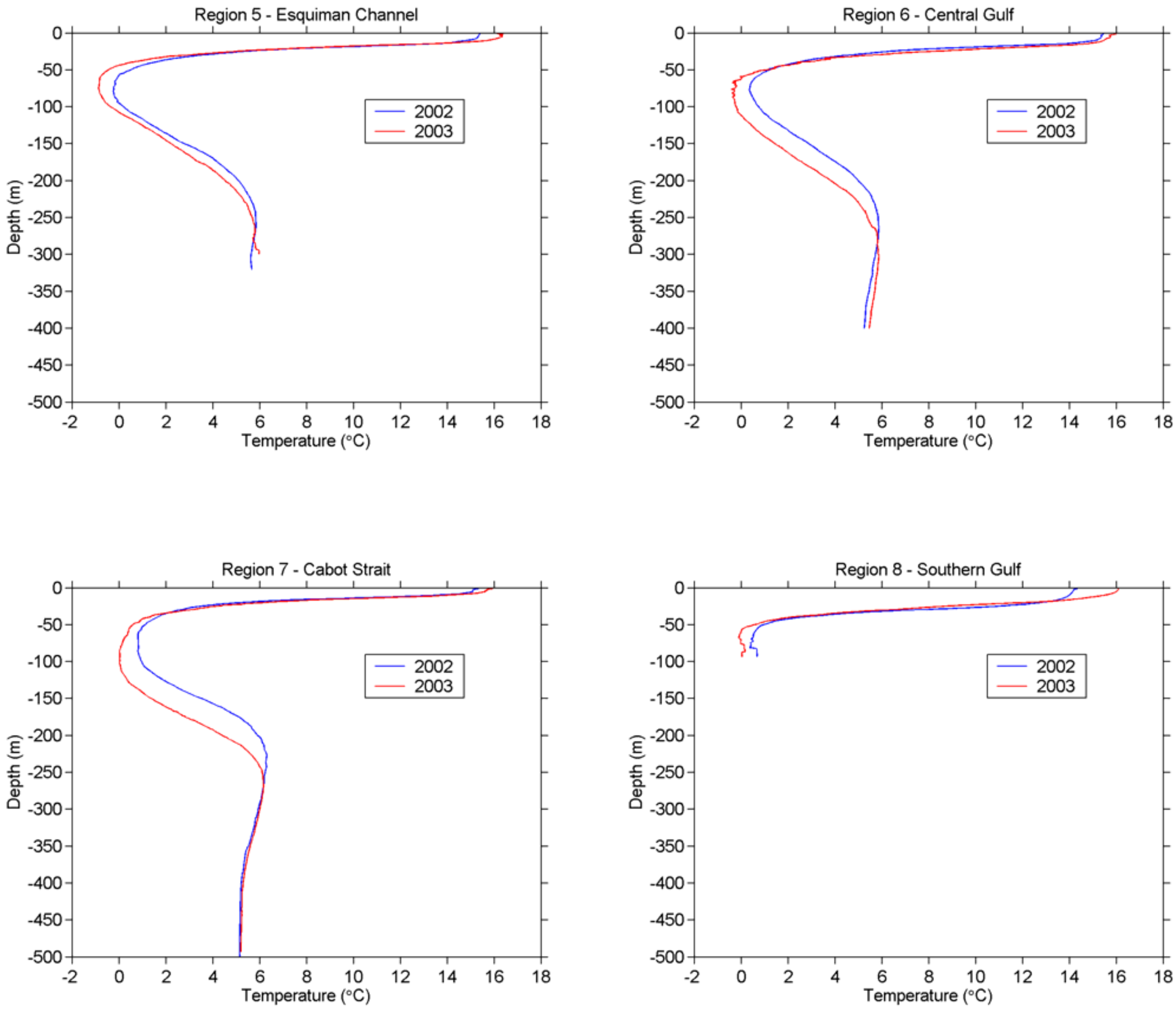


Fig. 26 (continued) Average vertical profiles of temperature calculated exclusively from CTD profiles taken during the 2002 and 2003 August shrimp and groundfish surveys in the Esquiman Channel (upper left panel), in the central Gulf (upper right panel), in the Cabot Strait region (lower left panel) and in the southern Gulf (lower right panel). The regional polygons are shown on Fig. 23.

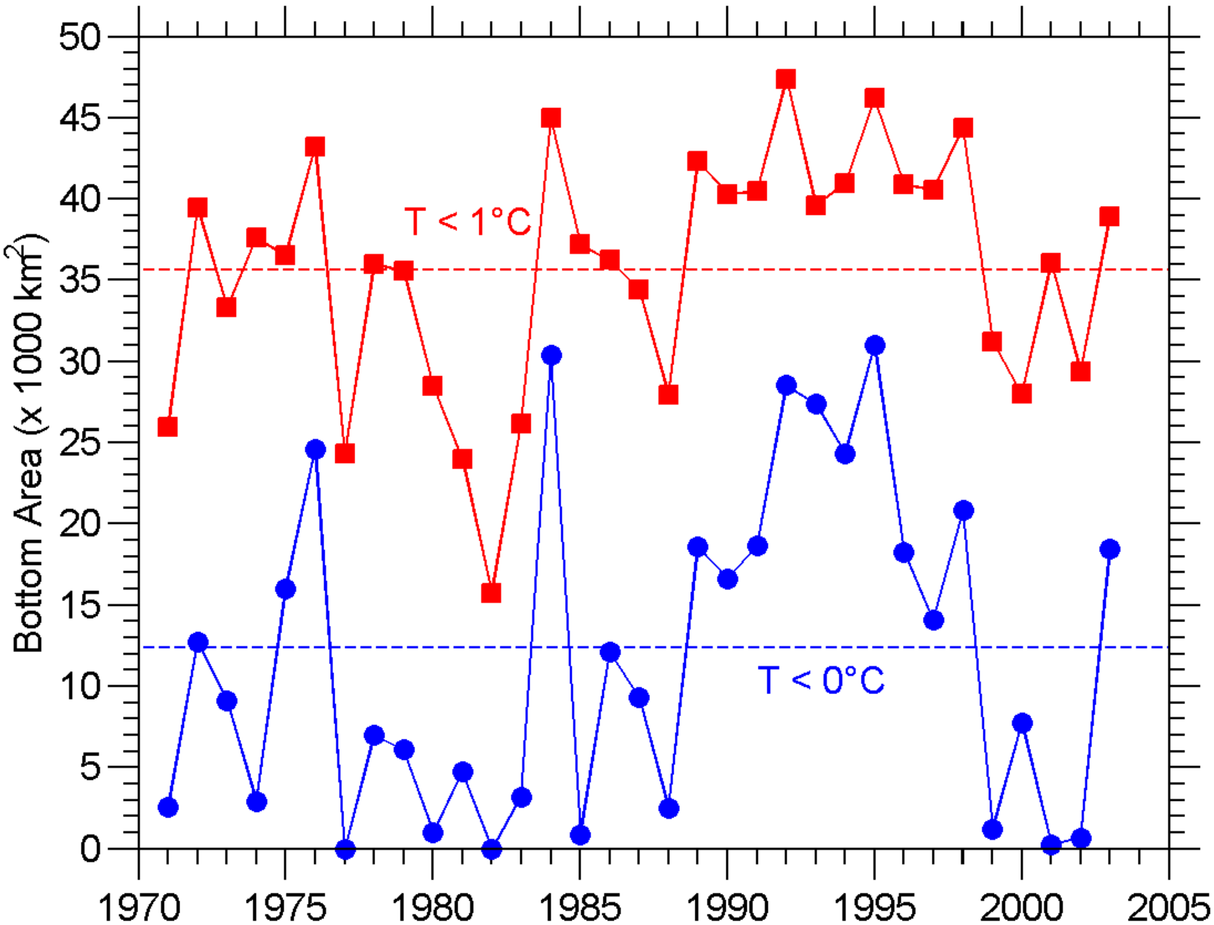


Fig. 27. Bottom area bathed with T < 0°C waters (blue) and with T < 1°C waters (red) in the southern Gulf of St. Lawrence. The horizontal lines represent the 1971-2000 average.

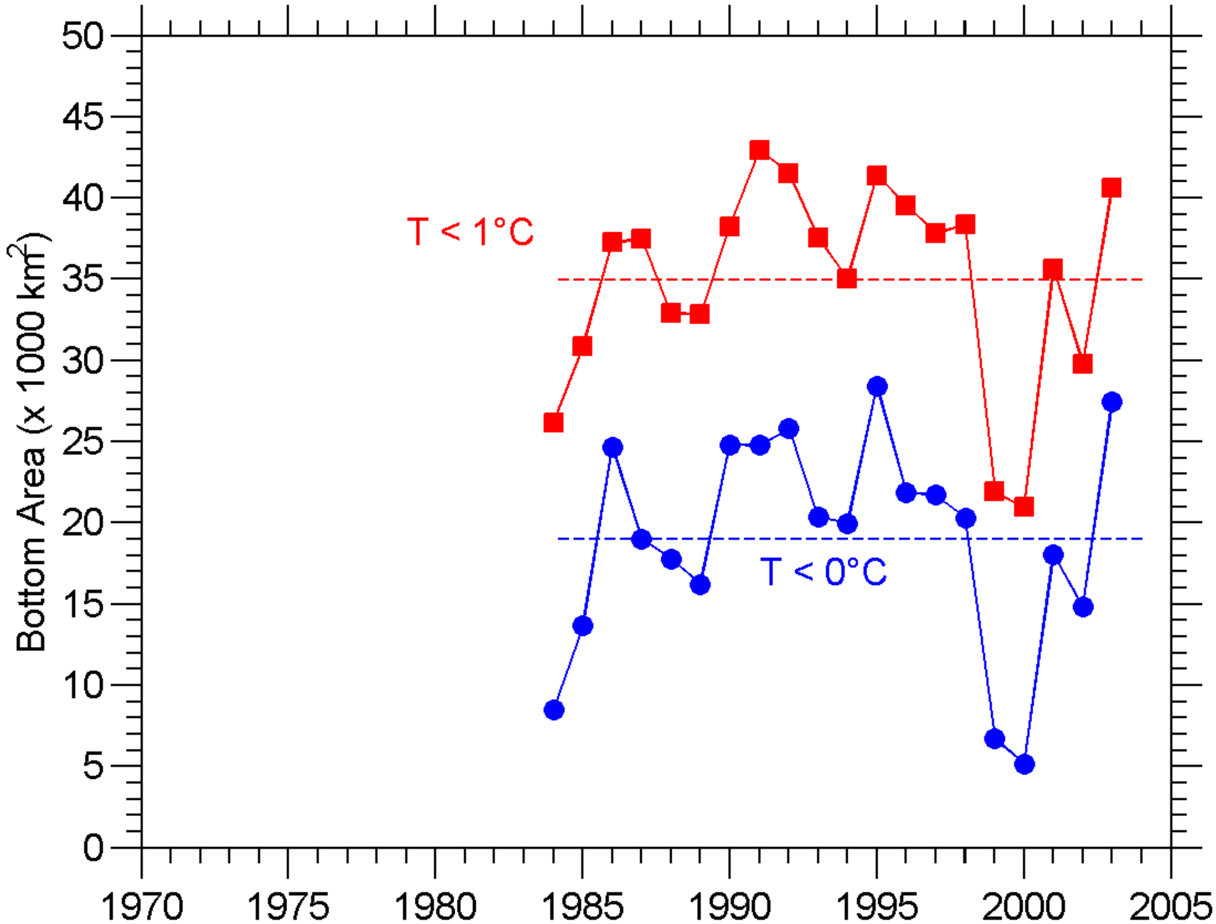


Fig. 28. Bottom area bathed with T < 0°C waters (blue) and with T < 1°C waters (red) in the northern Gulf of St. Lawrence. The horizontal lines represent the 1984-2003 average.

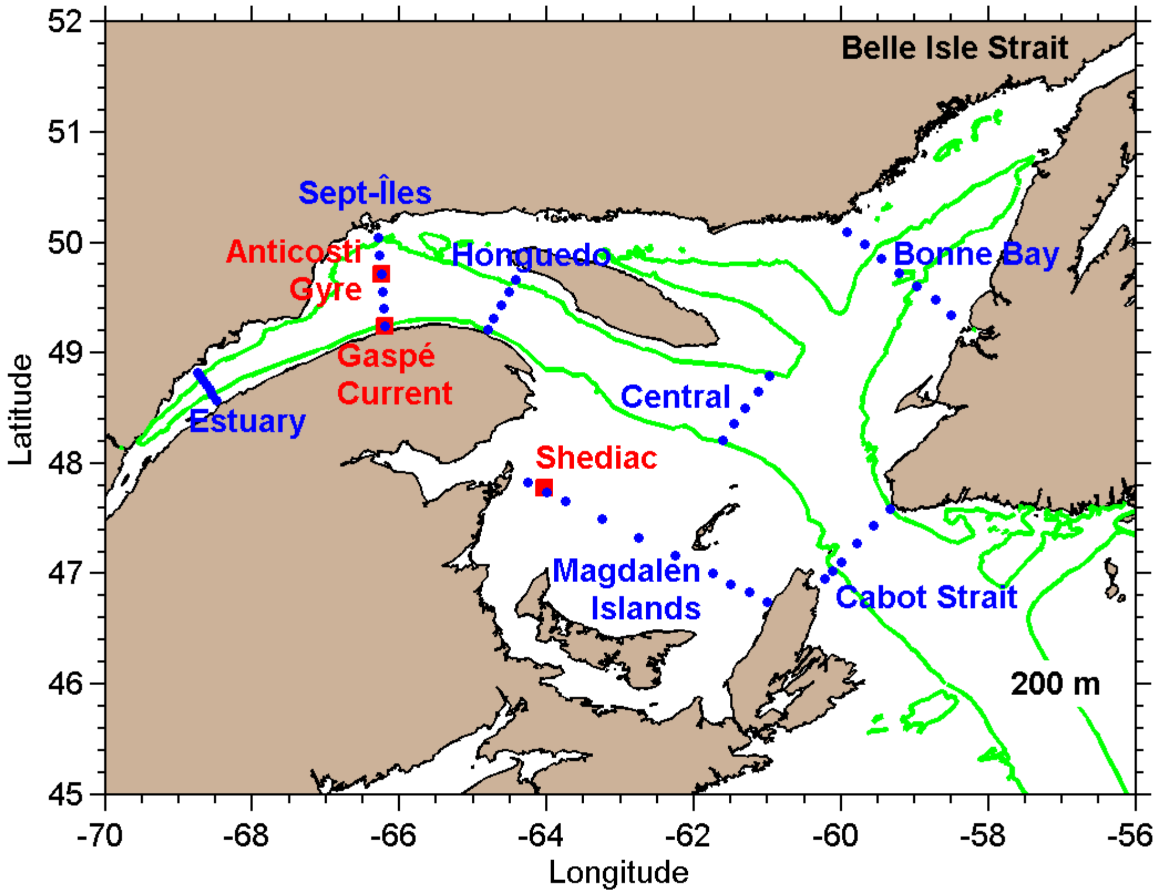


Fig. 29. Map showing the positions of standard oceanographic sections (blue dots) and fixed stations (red squares) of DFO's Atlantic Zone Monitoring Program (AZMP) in the Gulf of St. Lawrence.

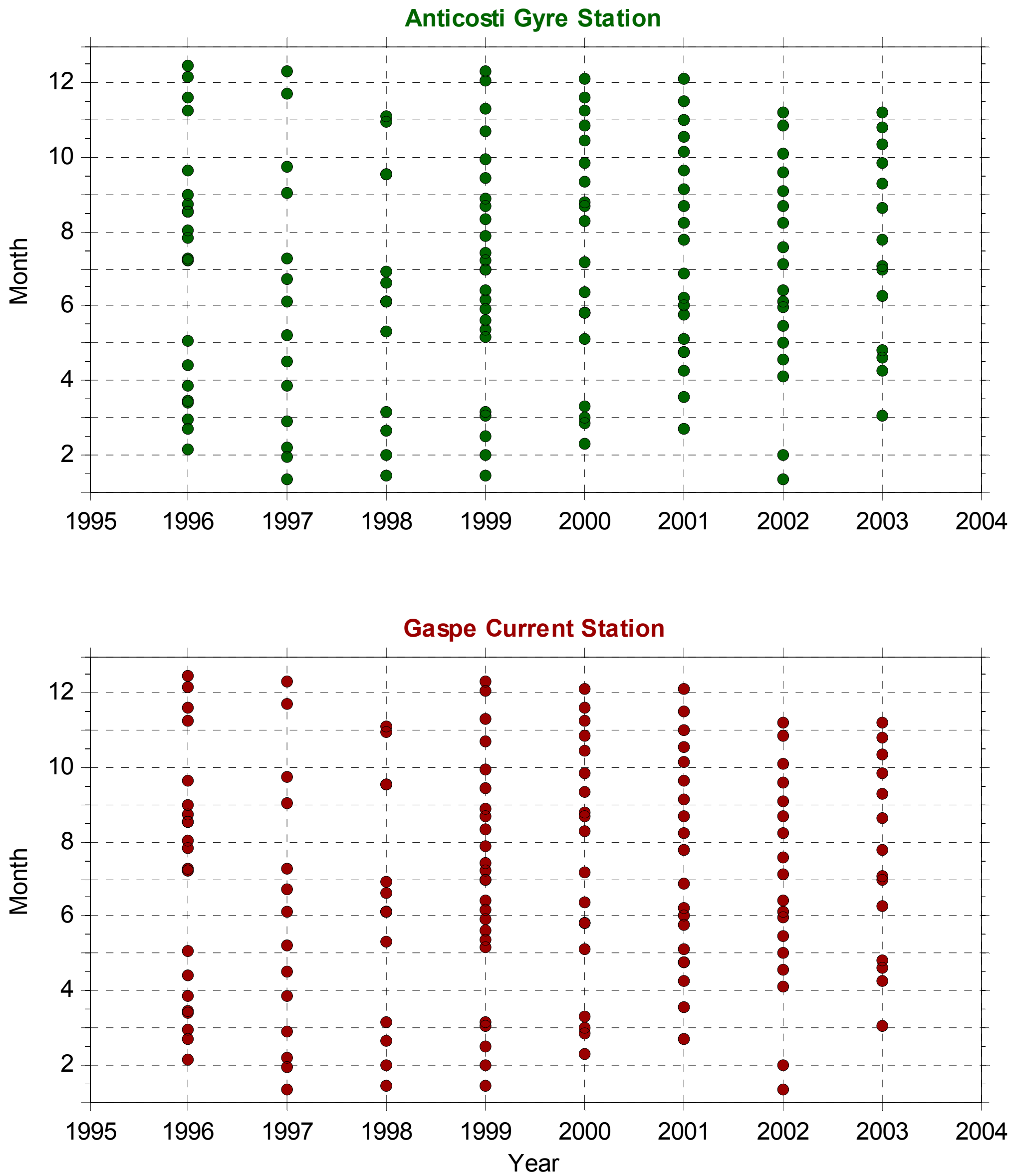


Fig. 30. Sampling dates at the Anticosti Gyre station (upper panel) and the Gaspé Current station (lower panel) since the beginning of the Atlantic zone monitoring program in 1996.

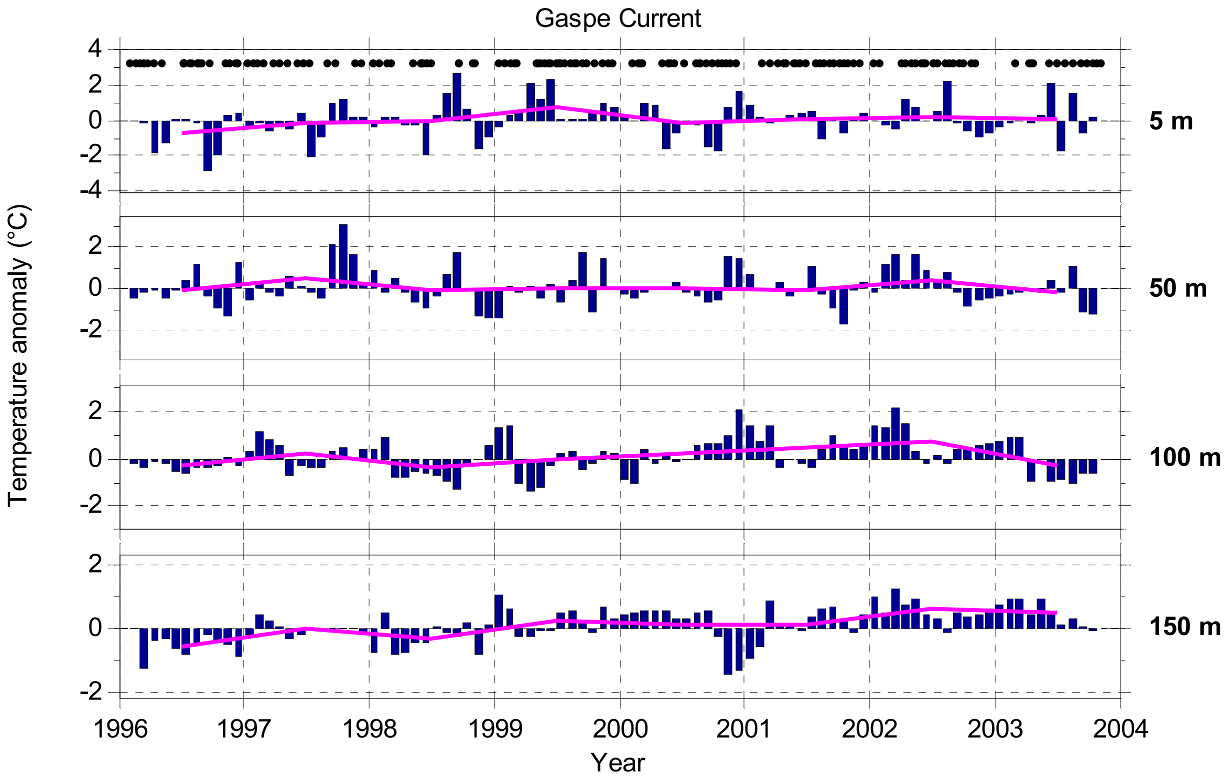


Fig. 31. Time series of temperature anomalies at the Gaspé Current station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies.

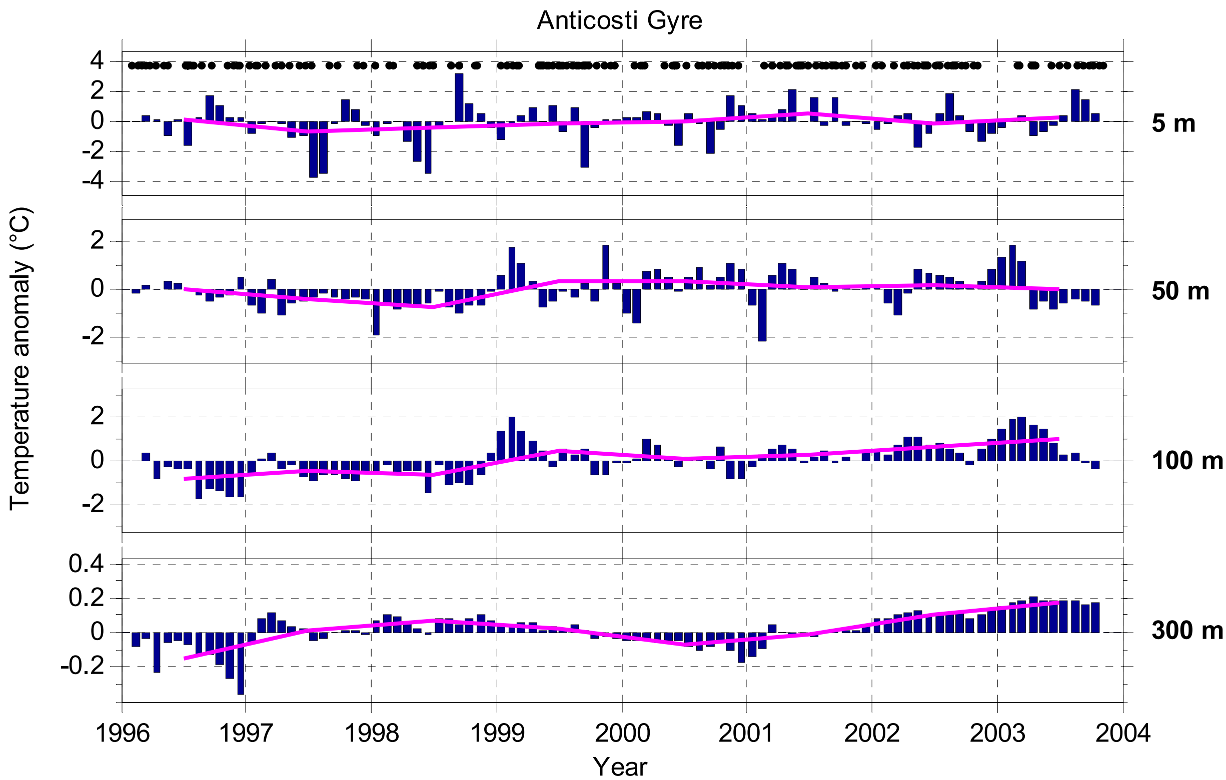


Fig. 32. Time series of temperature anomalies at the Anticosti Gyre station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies.

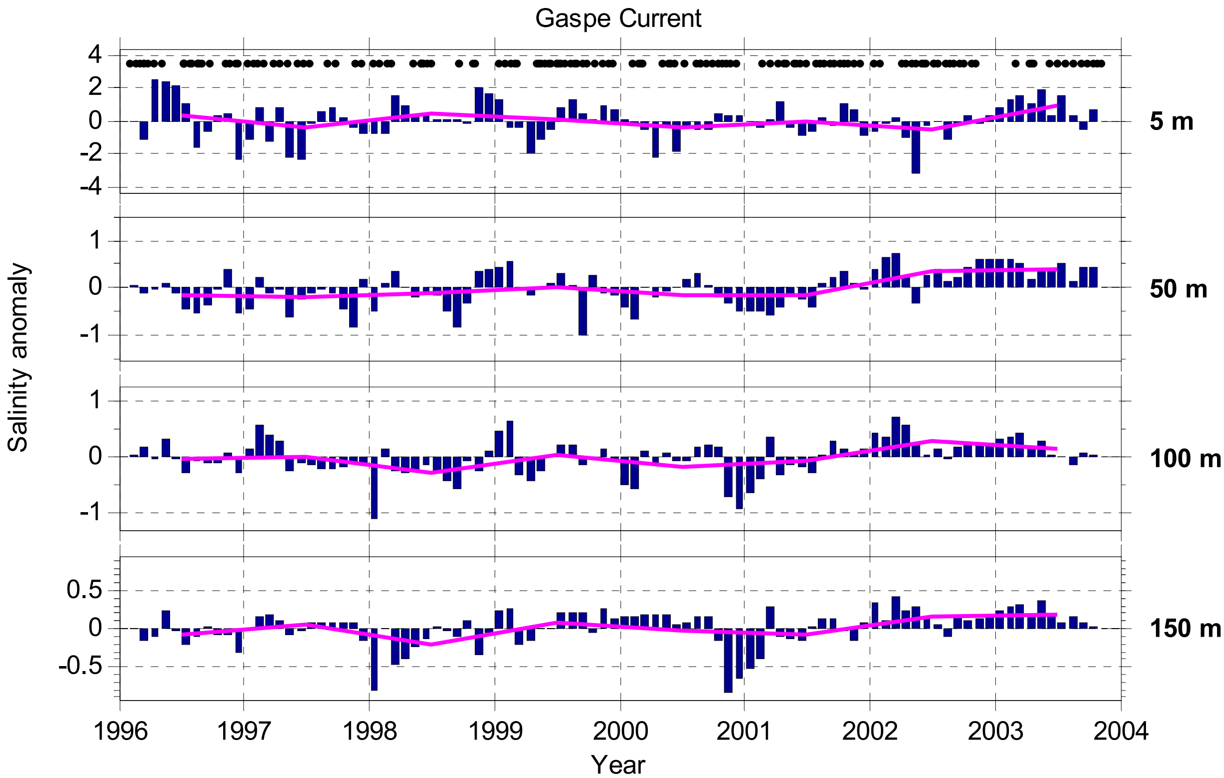


Fig. 33. Time series of salinity anomalies at the Gaspé Current station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies.

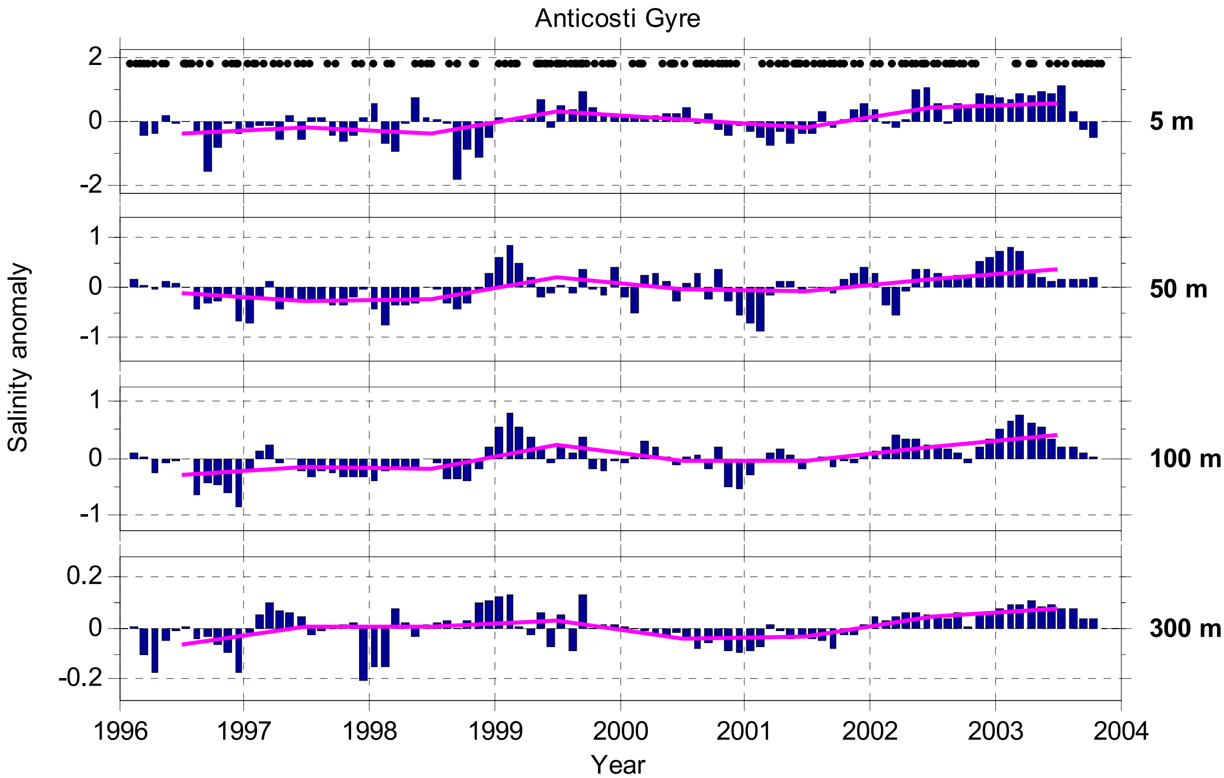


Fig. 34. Time series of salinity anomalies at the Anticosti Gyre station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies.

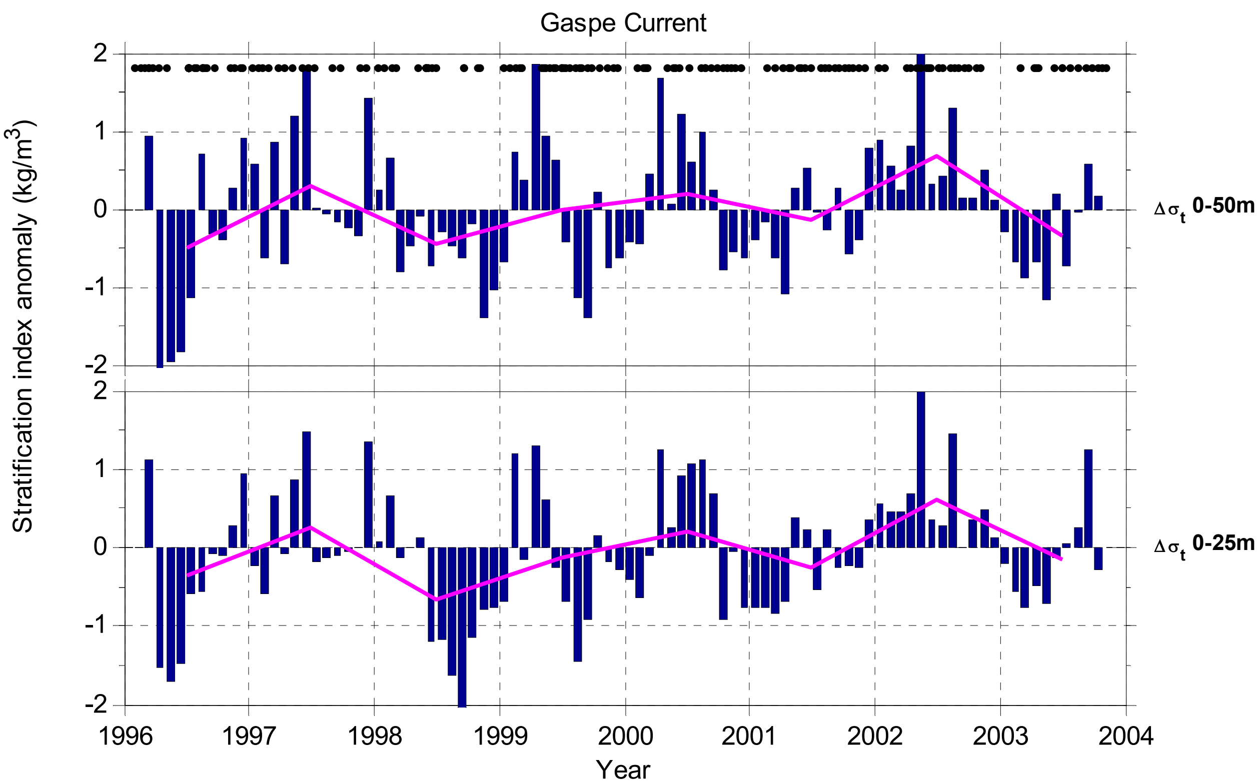


Fig. 35. Time series of stratification index anomalies at the Gaspé Current station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies. In the upper panel, the stratification index is defined as the sigma-t difference between 50 m and the surface. In the lower panel, the stratification index is obtained by the difference in sigma-t between 25 m and the surface.

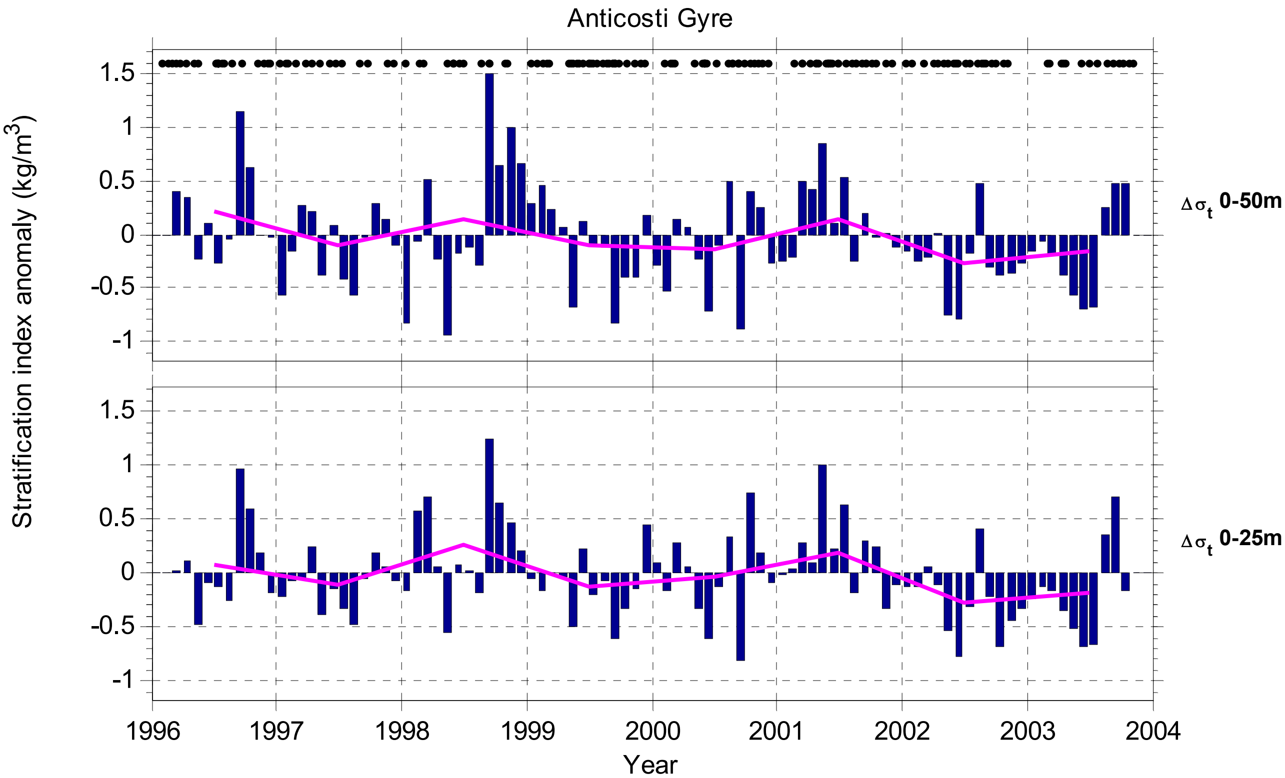


Fig. 36. Time series of stratification index anomalies at the Anticosti Gyre station relative to the 1996-2003 period. Blue bars represent monthly anomalies. Magenta lines show the annual means of monthly anomalies. In the upper panel, the stratification index is defined as the sigma-t difference between 50 m and the surface. In the lower panel, the stratification index is obtained by the difference in sigma-t between 25 m and the surface.

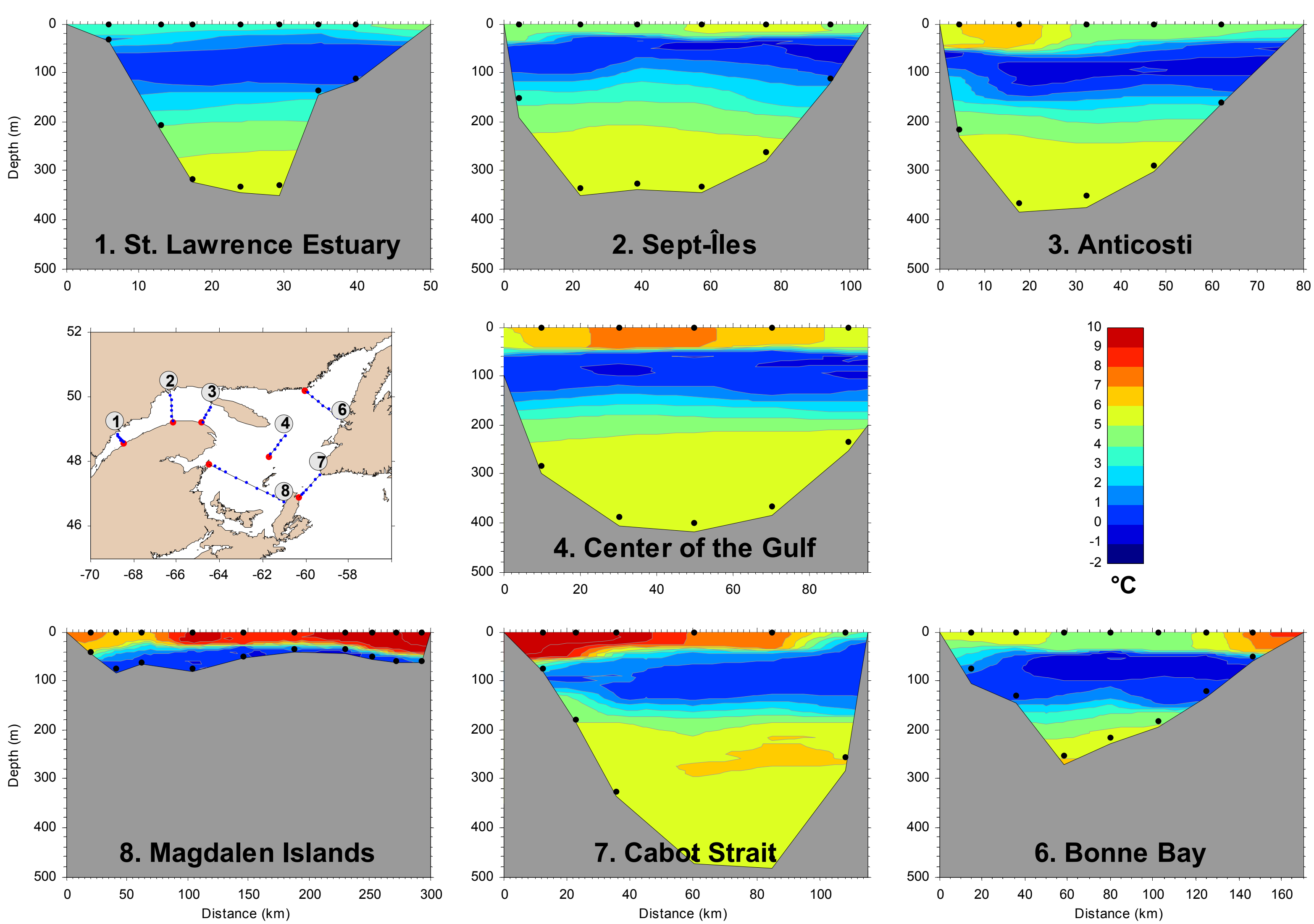


Fig. 37. Temperature contours of AZMP transects during the Ice Forecast cruise held from October 23 to November 5, 2003. Distances are calculated in kilometres from the red dots displayed on the chart of the Gulf of St. Lawrence. Black dots on contour plots show the positions of sampling and the upper and lower depths of CTD profiles.

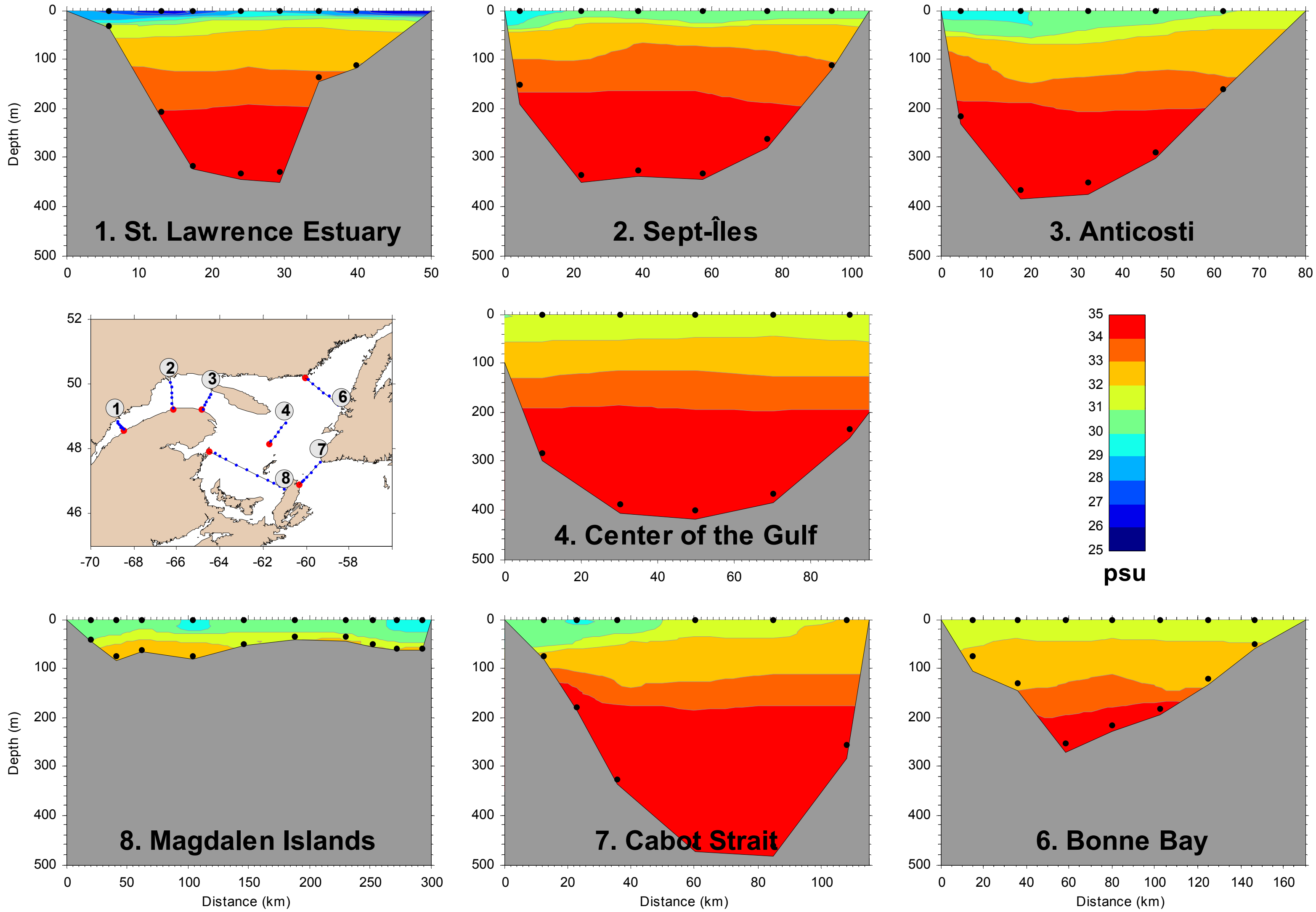


Fig. 38. Salinity contours of AZMP transects during the Ice Forecast cruise held from October 23 to November 5, 2003. Distances are calculated in kilometres from the red dots displayed on the chart of the Gulf of St. Lawrence. Black dots on contour plots show the positions of sampling and the upper and lower depths of CTD profiles.

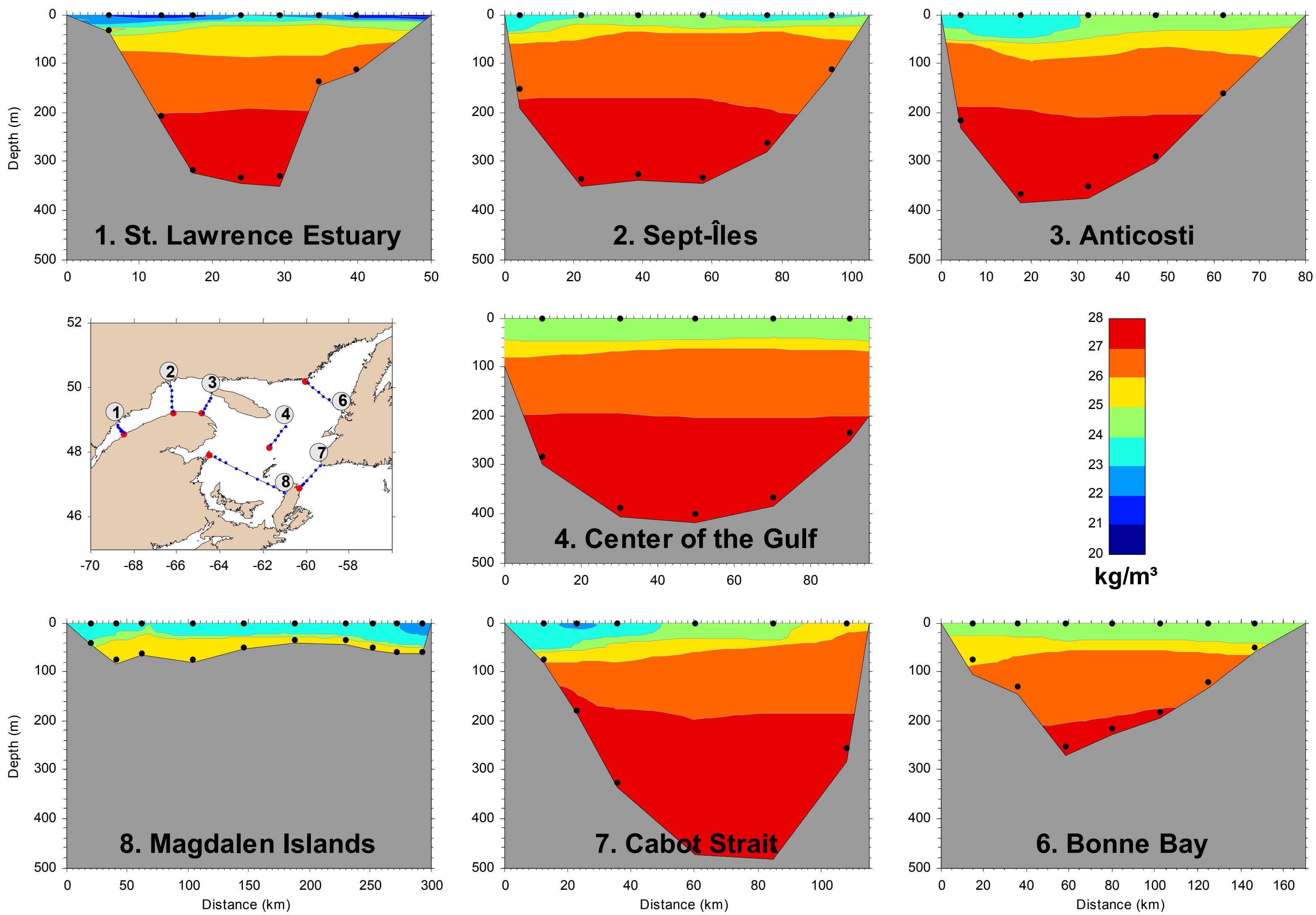


Fig. 39. Water density (sigma-t) contours of AZMP transects during the Ice Forecast cruise held from October 23 to November 5, 2003. Distances are calculated in kilometres from the red dots displayed on the chart of the Gulf of St. Lawrence. Black dots on contour plots show the positions of sampling and the upper and lower depths of CTD profiles.

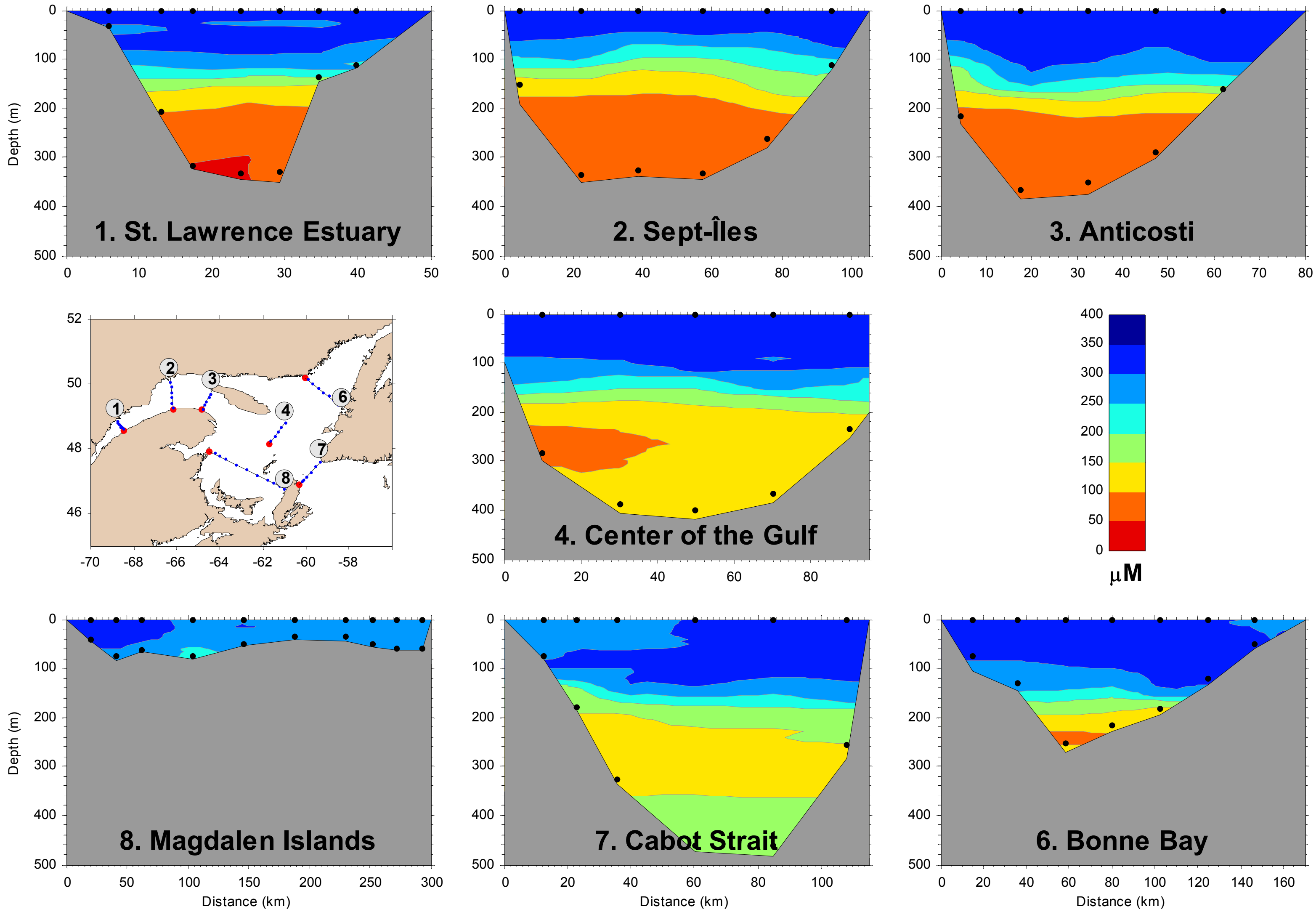


Fig. 40. Dissolved oxygen concentration contours of AZMP transects during the Ice Forecast cruise held from October 23 to November 5, 2003. Distances are calculated in kilometres from the red dots displayed on the chart of the Gulf of St. Lawrence. Black dots on contour plots show the positions of sampling and the upper and lower depths of CTD profiles.

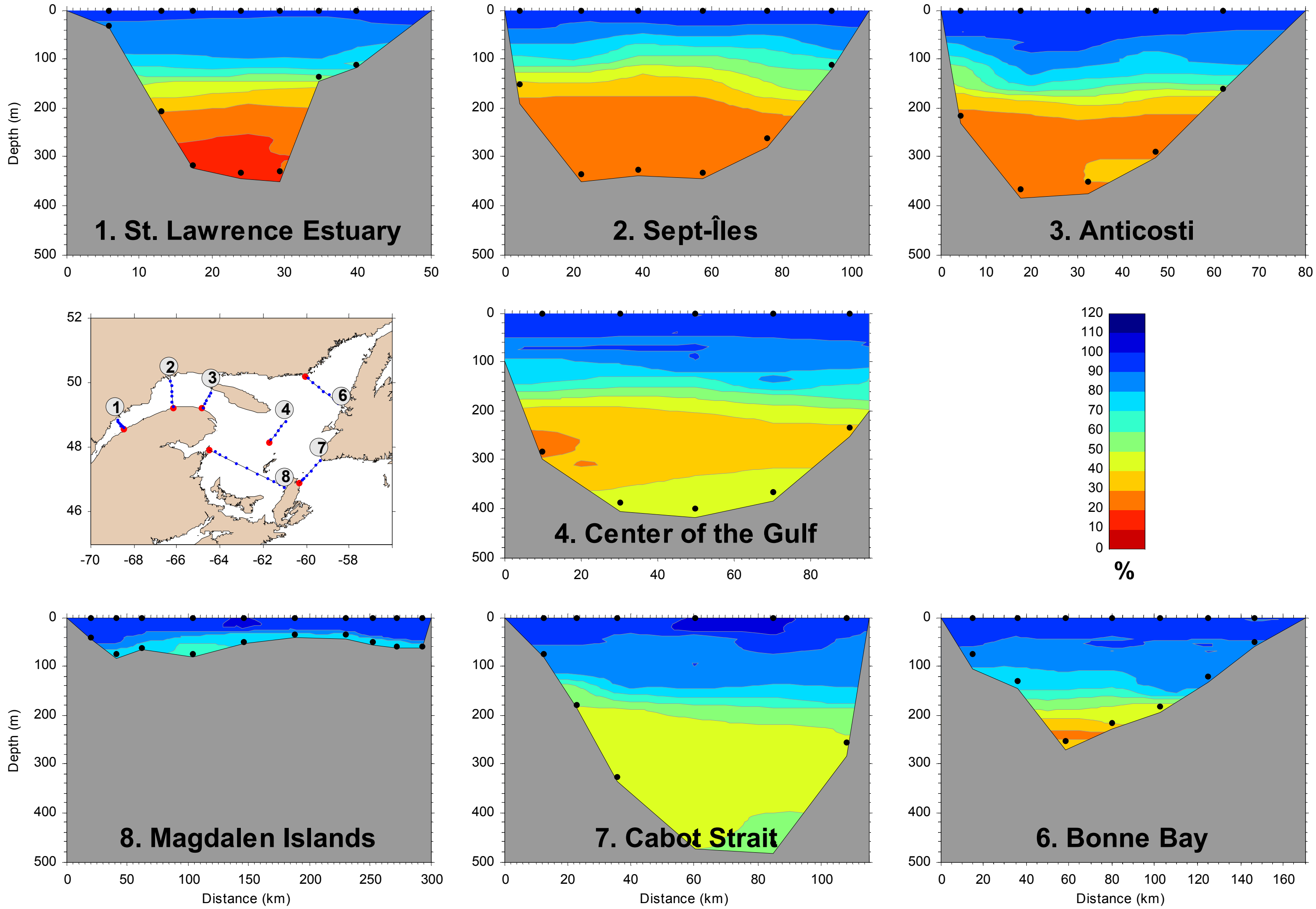


Fig. 41. Dissolved oxygen saturation contours of AZMP transects during the Ice Forecast cruise held from October 23 to November 5, 2003. Distances are calculated in kilometres from the red dots displayed on the chart of the Gulf of St. Lawrence. Black dots on contour plots show the positions of sampling and the upper and lower depths of CTD profiles.

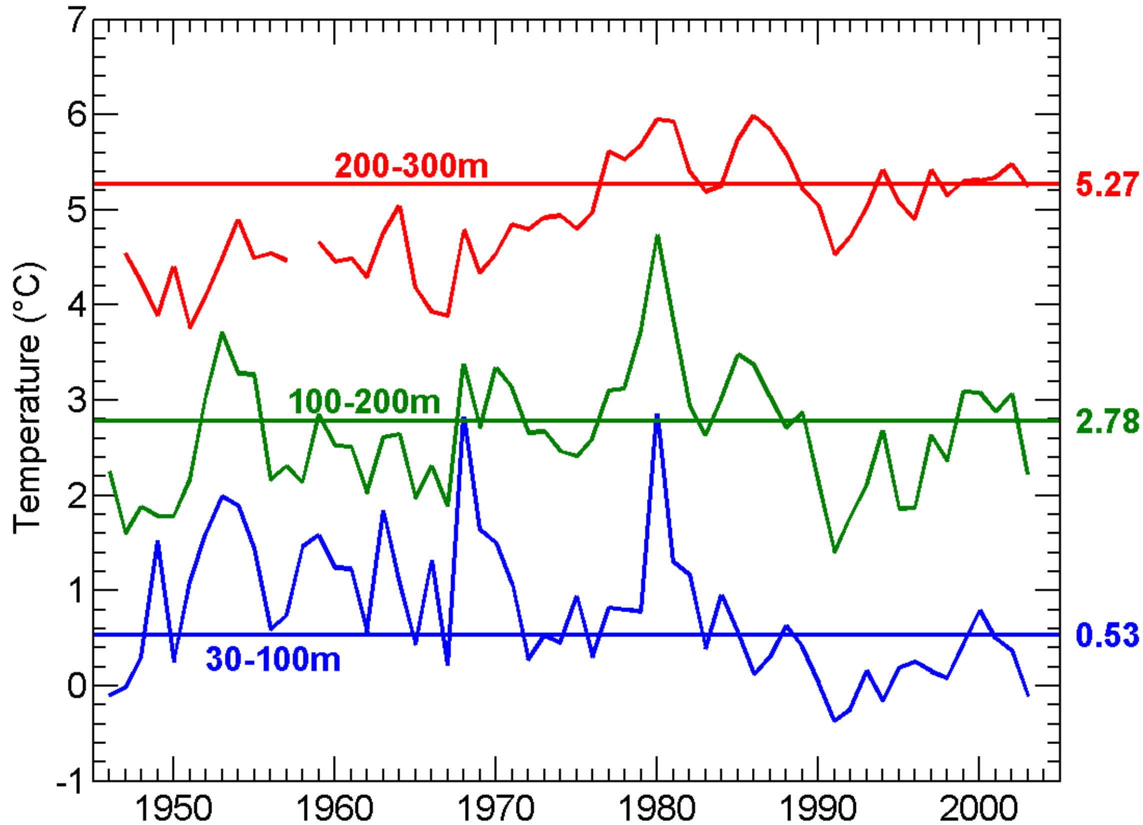


Fig. 42. Indices of layer-averaged temperature for the entire Gulf of St. Lawrence in the 30-100 m layer (blue), 100-200 m layer (green) and 200-300 m layer (red). The mean temperatures (in °C) over the 1971-2000 reference period are indicated by the horizontal lines and the numbers appearing next to the right y-axis.

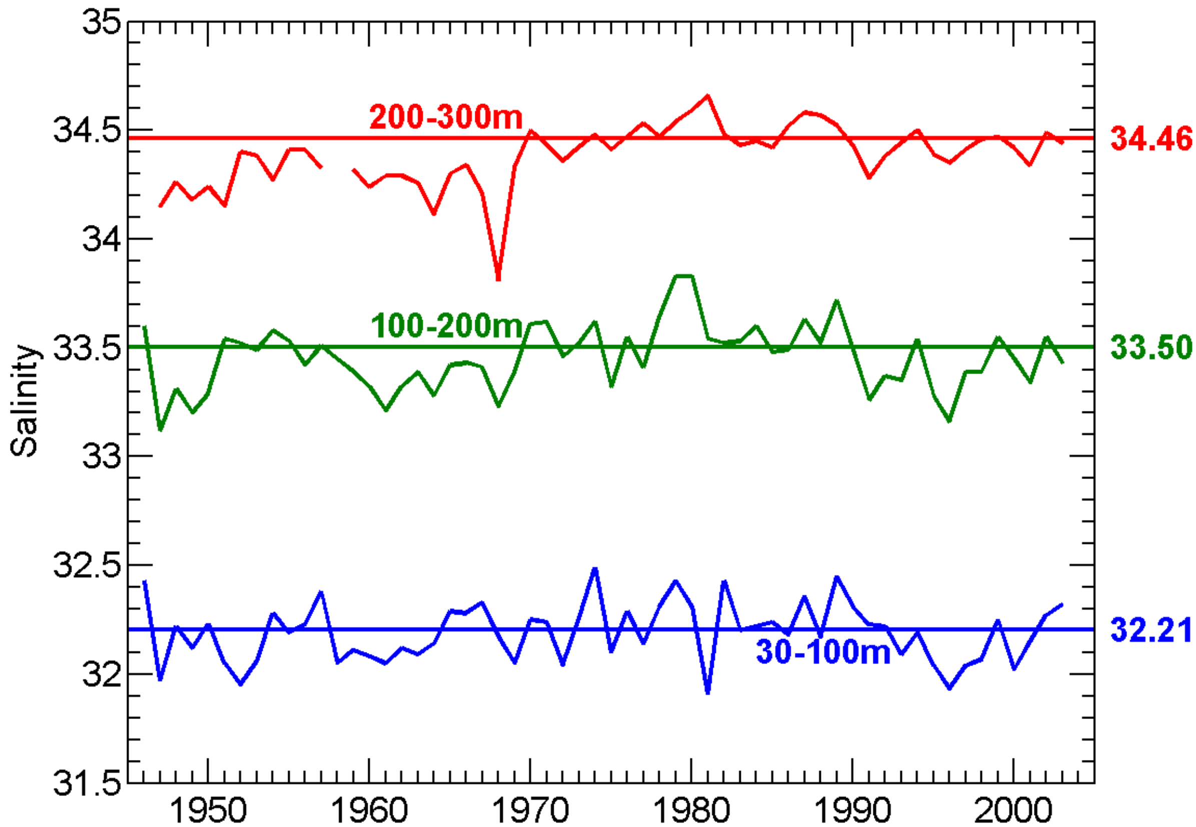


Fig. 43. Indices of layer-averaged salinity for the entire Gulf of St. Lawrence in the 30-100 m layer (blue), 100-200 m layer (green) and 200-300 m layer (red). The mean salinities over the 1971-2000 reference period are indicated by the horizontal lines and the numbers appearing next to the right y-axis.