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# Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2006

# Conditions d'océanographie physique dans le golfe du Saint-Laurent en 2006

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## ABSTRACT

An overview of physical oceanographic conditions in the Gulf of St. Lawrence in 2006 is presented. Air and surface water temperatures were above normal except for late summer in most parts of the Gulf. Bottom water temperatures on the Magdalen Shallows were unusually warm; no observations below 0°C were recorded in September. The yearly total freshwater runoff at Québec City was normal but included an anomalous strong fall peak. Sea ice coverage and volume within the Gulf during the winter was the lowest recorded since 1969. The winter cold mixed layer volume was the smallest recorded in the 11 year history of the winter helicopter survey and corresponded to 29% of the total water volume of the Gulf. This shallow winter mixed layer led to the CIL index for summer 2006 increasing to +0.21ºC. This is the warmest value since 1983, but only 0.1°C warmer than in 2000 which was the second warmest. Regional patterns of the CIL minimum temperatures show that increases between 2005 and 2006 were more pronounced in the Laurentian Channel than elsewhere. The minimum temperature actually decreased in Mecatina Trough, presumably due to the increased inflow of a thick layer of cold and highly saline water, which was observed from the annual March survey, through the Strait of Belle Isle. Regional patterns similar to those found for the CIL minimum temperatures were seen in the regional CIL thickness distribution. The CIL volume ($T < 1°C$) for the Magdalen Shallows during the September groundfish survey was the lowest since 1982. Water temperatures were generally one standard deviation above the mean, based on the 1971-2000 climatology at all depths for most of the year. Exceptions to this included the CIL in Esquiman Channel and Mecatina Trough and the deeper waters (> 300 m) of the southern half of the Laurentian Channel which were colder. The most noteworthy thermal features in November were the anomalously deep CIL in the Estuary and northwestern Gulf regions and the anomalously warm waters above the CIL everywhere in the Gulf. The outlook for 2007 based on the March 2007 survey is for a 0.6ºC cooling of the summer CIL index forecast from a thicker winter cold surface layer and increased inflow of Labrador Shelf water through the Strait of Belle Isle.

**RÉSUMÉ**

Les conditions d'océanographie physique dans le golfe du Saint Laurent en 2006 sont brièvement présentées. Les températures de l'air et des eaux de surface étaient supérieures à la normale, sauf à la fin de l'été, dans la plupart des régions du Golfe. Les températures de l'eau près du fond du Plateau madelinien ont été exceptionnellement chaudes en septembre, aucune température inférieure à 0 °C n'ayant été observée à ce moment-là. Le débit d'eau douce à Québec avait une moyenne annuelle normale, mais sa répartition mensuelle incluait une crête anormalement forte à l'automne. La superficie et le volume de glace de mer durant l'hiver ont été les plus faibles enregistrés depuis 1969. Le volume de la couche mélangée d'eau froide hivernale était le plus faible en 11 ans de relevés par hélicoptère et correspondait à 29 % du volume d'eau total dans le Golfe. Cette couche mélangée moins profonde s'est traduite par une hausse de l'indice de la CIF pour l'été 2006. Celui-ci a atteint +0,21 °C. Il s'agissait de la température la plus chaude enregistrée depuis 1983, bien qu'elle n'ait été que légèrement plus chaude qu'en 2000. La distribution régionale des températures minimales de la CIF estivale montrent que les augmentations de 2005 à 2006 ont été plus prononcées dans le chenal Laurentien qu'ailleurs. En effet, la température minimale a même diminué dans la fosse de Mécatina, causée par l'intrusion hivernale d'une épaisse couche d'eau froide et salée par le détroit de Belle Isle. La répartition spatiale de l'épaisseur de la CIF est semblable à celle de la température minimale. Le volume de la CIF (T < 1 °C) observé sur le Plateau madelinien pendant le relevé multidisciplinaire de septembre a été le plus faible enregistré depuis 1982. Les températures de l'eau étaient généralement au dessus de la moyenne climatologique de 1971 à 2000 par un écart-type, à toutes les profondeurs pour une grande partie de l'année. Les exceptions comprenaient la CIF dans le chenal Esquiman et dans la fosse de Mécatina ainsi que les eaux profondes (> 300 m) de la partie sud du chenal Laurentien, où les eaux ont été plus froides que la normale. En novembre, les caractéristiques les plus remarquables de la température de l'eau ont été une CIF anormalement profonde dans l'estuaire et dans la partie nord-ouest du Golfe ainsi que les eaux anormalement chaudes au-dessus de la CIF partout dans le Golfe. Les perspectives pour 2007, d'après le relevé de mars 2007, comprennent un refroidissement de 0,6 °C de l'indice de la CIF estivale par-rapport à 2006, en raison de la couche de surface froide plus épaisse en hiver 2007 et de l'apport hivernal plus important en provenance du plateau continental du Labrador via le détroit de Belle Isle.

## INTRODUCTION

This paper examines the physical oceanographic conditions in the Gulf of St. Lawrence (Fig 1) in 2006 and some driving atmospheric conditions. Specifically, it discusses air temperature, sea-ice volume, water temperature and salinity, winter water mass conditions, such as the near-freezing mixed layer volume, and the volume of dense water that entered through the Strait of Belle Isle, the summertime Cold-Intermediate-Layer (CIL), and the temperature, salinity and dissolved oxygen of the deeper layers. Environmental conditions are compared with long-term means, usually expressed as anomalies, i.e. deviations from their long-term mean or normal conditions calculated for 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 Organisation (NAFO) and the Fisheries Oceanography Committee (FOC). Having a standardised base period allows for 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 2003 (Gilbert et al. 2004).

## AIR TEMPERATURE

The monthly air temperature anomalies for Mont-Joli, Sept-Îles and the Magdalen Islands are shown in Fig. 2. Mont-Joli has a weather station with a 128-year long record meeting the highest quality standards from the WMO. Sept-Îles is located in the northeast Gulf in an area important for winter ice production; the Magdalen Islands are more representative of the weather for the southern Gulf. In fall 2005, monthly mean air temperatures at all three weather stations were above normal, typically by as much as 2°C. This indicates warm atmospheric conditions for the preconditioning of the winter surface mixed layer. This was followed by very warm conditions in January of 2006 with air temperatures 4 to 5°C warmer than normal, which included a thaw that lasted for several days (not shown). In spite of normal air temperatures during February at the two northern stations, the overall warm winter led to the least ice cover observed since 1969. For the remainder of the year, most months were characterised by above-average air temperatures except for late summer. As will be shown in later sections, this pattern was observed in near-surface water temperatures as well.

## PRECIPITATION AND FRESHWATER RUNOFF

Runoff data were obtained from the OSL (*Observatoire du Saint-Laurent* or St. Lawrence Observatory web site at www.osl.gc.ca) where they are updated monthly by D. Lefaivre using the water level method from Bourgault & Koutitonsky (1999). The yearly average runoff measured at Québec City was normal in 2006 (Fig. 3), however the overall distribution did not follow the typical cycle. Runoff was 1000 to 2000 $m^3 s^{-1}$ lower than normal from February to September, but this was compensated for by an anomalous, strong fall runoff, whose peak magnitude was almost as strong as the one in spring.

## SURFACE LAYER

The surface layer conditions of the Gulf are monitored by various methods that complement each other: the thermograph network, the shipboard thermosalinographs and NOAA satellite remote sensing.

### Shipboard thermosalinographs

The shipboard thermosalinographs were described by Galbraith et al (2002) and Gilbert et al. (2004). To summarize, thermosalinographs (SBE-21 from Seabird Electronics Inc, Seattle) have been installed on various ships starting with the commercial ship Cicero of Oceanex Inc. in 1999. The ship sails year-round between Montréal and St. John's, making a return trip once per week. Near-surface (3 m) water temperature and salinity are sampled along this corridor during each return trip. The data are presented in near-real time on the St. Lawrence Observatory website (www.osl.gc.ca).

The Oceanex ship Cabot was equipped with a thermosalinograph in 2006. It travels on the same Montréal to St. John’s route as the Oceanex ship Cicero, which was retired in 2006.

Fig. 4 shows a mean annual cycle of water temperature at a depth of 3 m along the Montréal to St. John’s shipping route from 2000 to 2006. Only data from the Cicero are used for the first four years and data from any instrumented ship that crossed the shipping route was used for the last three years in order to fill data gaps. The data were averaged for each day of the year at intervals of 0.1 degree of longitude 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 that are always above freezing (Galbraith et al. 2002). The progression to winter conditions is shown to first reach near-freezing temperatures in the Estuary. Freezing conditions then progress towards Cabot Strait with time, usually just reaching there by the end of the winter.

Fig. 4 also shows the water temperature composite for 2006. Winter freeze-up occurred earlier than average in the estuary and the Anticosti Gyre (66ºW), but a thaw occurred in January, and was partly responsible for the lowest sea-ice volume since 1969. The spring thaw also came early as seen from the disappearance of the magenta colour that is associated with near-freezing waters. This is also apparent in 5 which shows the 2006 water temperature anomaly along the shipping route, relative to the 2000-2006 average. The figure illustrates that except for the early freeze-up and mild mid-August temperatures, the surface temperatures were always much warmer than the 2000-2006 average conditions, sometimes by more than 4ºC.

### Thermograph network

The thermograph network was described in a previous report (Gilbert et al. 2004) so only a brief summary as well as updates to the network are discussed here. The network consists of 23 stations with moored instruments that measure and log water temperature every 30 minutes. Most instruments are installed on Coast Guard buoys that are deployed in the ice-free season, but a few stations are occupied year-round. The data are typically only available after the instruments are recovered except for the five oceanographic buoys that transmit data in real-time. The stations are shown in 6. The following updates to the network have occurred since the publication of the last report (Gilbert et al. 2004):

- The station at Bonne Bay on the west coast of Newfoundland was abandoned in 2005 due to the unavailability of a local contact person to deploy and recover the logger.
- The station at Borden was last sampled in 2002, but a re-deployment is planned for the 2007 season.
- Real-time oceanographic buoys were added at the Gaspé Current, Anticosti Gyre (both in 2005) and Shediac (in 2004) stations.

In order to compare the 2006 observations to temperature measurements from previous years, climatological daily average temperatures were calculated using all available data for each day of the year at each station and depth. Since the IML thermograph stations are at most 14 years old, we cannot use the 1971–2000 reference period. Instead, we computed daily averages based on at least n-1 years with data, where n is the number of years that potentially had observations. Daily averages for four stations that display the general observation pattern are shown in Fig. 7. Nearly all regions of the Gulf had above-normal near-surface waters temperatures in June and July, indicating that the onset of summer was about two weeks early. The Mont-Louis station is characterised by near-average August and October temperatures and below average temperatures in September. The reference periods used to calculate the average climatology anomalies are different than those used for the shipboard thermosalinograph data, and this causes slightly different anomaly values for both systems. The temperatures recorded when the ships were in proximity to thermograph stations are in agreement with simultaneous thermograph records (not shown).

The thermograph network provides information in the northeast Gulf, where there there are almost no shipboard thermosalinograph measurements. The temperatures at Beaugé Bank are above average for nearly the entire record of June to October, whereas the Blanc-Sablon values are above-average for the same period except for September.

Table 1 lists the average monthly temperatures for each station, following the method described in Gilbert *et al*. (2004). The long-term data coverage for each month having at least 28 days of data is listed in Table 2 for all stations and sampling depths. Monthly temperature anomalies were then obtained by subtracting the climatological mean temperatures from the 2006 observations (Table 3). We also present normalised anomalies which were obtained by dividing the monthly anomalies by the interannual standard deviation of temperature at each station and depth (Table 4). The most notable results are that data at the Irving Whale and Beaugé Bank stations were warmer than normal from June to October (all months with available data) and that near-surface temperatures in June were above normal at all network stations.

The raw data from the thermograph network, as well as monthly temperature anomaly figures and other results, are available from the St. Lawrence Observatory (www.osl.gc.ca).

**NOAA Satellites**

The annual sea surface temperature cycle for the entire Gulf of St. Lawrence is shown on figure 8. These maps are generated using NOAA AVHRR satellite images acquired by the IML reception facility. The raw data are processed using the Terascan software to detect clouds and project the results on a geo-referenced grid of 1 km resolution. Average temperatures at each grid node are then calculated twice per month.

In 2006, the ice cover (black pixels) disappeared early in the spring, the Gulf being essentially ice free by mid-March. A small band of ice coming from the Strait of Belle Isle is seen in the northeast Gulf until the beginning of April. Surface temperature increases rapidly in the whole Gulf reaching its maximum in August. In the Estuary, the effect of the upwelling and tidal mixing at the head of the Laurentian Channel maintains relatively cold surface temperatures in the western half of the Estuary. As soon as the surface temperature becomes higher than the temperature of the cold intermediate layer, it is possible to observe regular occurrences of coastal upwelling along the north shore of the Gulf and particularly in the Jacques Cartier Strait region. The fall cooling begins in September. No trace of ice is visible in the images until the end of December when cold surface water coming from the Labrador Shelf enters the Gulf.

When compared to the climatological means generated using the 1995-2004 satellite images (not shown), the 2006 images show spring and summer periods warmer than normal (more than 3°C above the 1995-2004 climatology) for the entire Gulf and in the Estuary. From August 15 to September 30, waters colder than normal (approximately 3°C below the climatology) appear in the northwest and southern Gulf regions while the northeastern Gulf region temperatures were always above normal. From mid-November to the end of December, the surface temperatures measured using remote sensing show a surface layer above normal (about 3°C above the climatology) for the entire Gulf and the Estuary.

## BOTTOM WATER TEMPERATURES

The longest running, broad scale temperature collection on the Magdalen Shallows is the multi-species survey (1971-present, formerly called the groundfish survey). The measurements were combined with those from Northumberland Strait to obtain a quasi-complete picture of the southern Gulf temperatures. Bottom temperatures in 2006 ranged from <1°C to over 20°C (Fig. 9), a gradient that followed bottom topography. Most of the Shallows (50-80 m) were covered by waters with temperatures <1°C, which had slowly warmed since the previous winter. Usually, the bottom is still covered with some water below 0°C at this time of year but none was observed in September 2006.

Bottom temperature anomalies over most of the southern Gulf were still significantly warmer than normal in September (Fig. 10). The highest positive anomalies (+3°C) appeared along the coast of New Brunswick and in St. Georges Bay. These coastal anomalies must be viewed with caution, however, since the largest uncertainties in the bottom temperature fields are in the near shore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lie close to the thermocline, i.e. the strong vertical gradient in temperature. In these regions the mixed layer may extend to the bottom one day and be near the surface on the next, perhaps in response to wind storms. This can cause large variability in the near-bottom temperatures in shallow regions. Second, the optimal estimation routine projects horizontal gradients to the coast if there are few data near-shore. This can lead to erroneous extrapolation of data in regions of strong horizontal temperature gradients.

Relative to 2005, bottom temperatures during the 2006 multi-species survey were significantly warmer over the western Magdalen Shallows while the eastern part was cooler (Figure 11). The region south of the Magdalen Islands was especially cooler with a temperature difference of -3°C. The Northumberland Strait was also cooler in September 2006 than in September 2005 with a difference of -1°C around the middle of the Strait. However, the eastern Northumberland Strait was significantly warmer in 2006 than in 2005 with a difference of over 4°C around Pictou Island.

From the gridded temperature data, time series of the area of bottom covered by each 1ºC interval were estimated (12). As in 2005, there was no bottom area covered by water with temperatures <0ºC in 2006, which contrasts with the cold period observed in the 1990s. Correspondingly, the volume of water with temperatures from 0 to 2 ºC increased in 2005 and 2006.

## SEA ICE

The ice volume is estimated from a gridded database of ice cover and ice categories (Drinkwater et al. 1999) updated to include sea ice conditions up to 2006. Sea-ice is typically produced in the northern parts of the Gulf and drifts towards the Magdalen Islands and Cabot Strait. The combined Gulf and Scotian Shelf ice volume shown in the top panel of Fig. 13 is indicative of the total volume of ice produced in the Gulf, including the advection out of the Gulf, but also includes the thicker sea-ice that drifts into the Gulf from the Strait of Belle Isle. The volume shown on the bottom panel of Fig. 13 corresponds to that found seaward of Cabot Strait and represents the volume of ice exported from the Gulf.

In 2006, the Gulf and Shelf ice volume reached the lowest value recorded since 1969. More information concerning the sea-ice area coverage in the Gulf of St. Lawrence can be found in Petrie et al. (2007).

## WINTER WATER MASSES

A wintertime survey of the Gulf of St. Lawrence waters (0-200 m) 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 survey and sampling methods are briefly described in Gilbert et al. (2004) and in Galbraith et al. (2006), and gridding methods as well as results concerning the cold-water volume formed in the Gulf and the estimate of the water volume advected into the Gulf via the Strait of Belle Isle over the winter are explained in Galbraith (2006).

A total of 82 stations were sampled during the March 2006 survey using 40.5 flight hours. The survey took place at the end of winter, from March 15th to 23rd. While this period is usually before spring warming, it appears to have been a little late in 2006 due to the early spring (See Shag Island thermograph data in Fig. 7).

Fig. 14 shows gridded interpolations of near-surface characteristics (temperature, salinity, cold layer thickness and thickness of Labrador Shelf intrusion). The surface mixed layer is usually very close to the freezing point in many regions of the Gulf in March; however, in 2006 waters were generally above the freezing point almost everywhere (See also Fig. 15). Although the 2006 survey took place after spring warming began, there was also very little ice present which is consistent with these warm waters. Warm water (~0ºC) entered the Gulf on the northeast side of Cabot Strait, similar to 2004 and 2005, and flowed northward along the western coast of Newfoundland.

Near-freezing waters with salinity of around 32 are responsible for the formation of the summertime Cold Intermediate Layer (CIL). These are coded in blue in the salinity panel of Fig. 14 and are typically found to the north and east of Anticosti Island. These waters covered a smaller area in 2006 compared to the typical conditions of the last decade, resembling conditions observed in March 2000 (16).

Near-freezing waters with salinity colour-coded in violet are considered to be too saline (typically > 32.35) to be formed from waters originating within the Gulf (Galbraith, 2006) and are presumed to have been advected from the Labrador Shelf through the Strait of Belle Isle. There was none of these waters at the surface within the Gulf in 2006, apart from some in the Strait of Belle Isle. The thickness of this intrusive layer is estimated in the lower-right panel of Fig. 14 and manifested as a sub-surface intrusion in 2006; it was not in contact with the surface. The intrusion exceeded 150 m in thickness again in 2006, reaching the bottom below 200 m in Mecatina Trough (Fig. 17).

The recent history of Labrador Shelf water intrusions is shown in Fig. 18 as thickness maps and in Fig. 19 as the integrated volume and fraction of total cold water volume in the Gulf. In 2006, the spread of the intrusion has an area similar to that of 2004, but its volume was smaller with the water mass mainly restricted to a deeper tongue of water intruding into the Gulf with a total volume of 1620 km$^3$.

While the cold (< -1ºC) mixed layer depth usually reaches 75 m in the Gulf (See Fig. 20), in 2006 it was more typically around 50 m or less (See Fig. 14, lower-left panel). One consequence of this shallower convection (or mixed layer) is that the cold layer did not reach the bottom in the northern Magdalen Shallows (Fig. 17). The cold surface layer is the product of local convection as well as cold waters advected from the Labrador Shelf, and can consist either of a single water mass or of layers of increasing salinity with depth. The previously-noted warm water intrusion present on northeast part of Cabot Strait led to a local thickness of 0 m (20). Integrating the mixed layer depth over the area of the Gulf yields a cold-water volume of 9800 km$^3$, the smallest volume recorded in the 11 year history of the survey. This cold water volume corresponded to 29% of the total water volume of the Gulf (34000 km$^3$).

## COLD INTERMEDIATE LAYER

### Prediction from the March survey

The total volume of cold water (< -1ºC) in March is highly correlated with the following summer's Cold Intermediate Layer index (Galbraith, 2006). This is expected because the CIL is the cold remnant of the winter cold surface layer. The relation is shown in Figure 21. Measuring the cold water volume in March is therefore a valuable environmental tool as it can immediately be used to forecast coming summer CIL conditions.

The low volume of cold water of 9800 km³ observed in 2006 was the smallest in the 11 year history of the survey, and led to the warmest CIL forecast since 1996 of +0.23ºC, a predicted increase of 0.3ºC over the previous year.

### Update of the Gilbert & Pettigrew (1997) CIL Index based on all available data

The Gilbert & Pettigrew (1997) CIL index is defined as the mean of the CIL minimum core, temperatures observed between May 1 and September 30 of each year, interpolated to July 15. It was updated using all available temperature and salinity profiles measured within the Gulf between the months of May and September inclusively since 1947 (Figure 22). The CIL index for summer 2006 is +0.21ºC which is very close to the prediction of +0.23ºC based on the March survey. This is the third consecutive year the index has increased; it is now 0.53ºC above the 1971-2000 time series average of –0.32ºC. It is similar to that observed in 2000, as was the case for the winter cold-water volume.

### Update of the August CIL time series based on the groundfish survey

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 with a minimum depth of 100 m from the August-September groundfish surveys since 1985 (Figure 23). This CIL temperature minimum differs from the Gilbert & Pettigrew (1997) index in area coverage and includes only data from the groundfish survey instead of all data between May and September. The CIL thickness and temperature minimum were obtained from each individual profile. Both variables were then interpolated using kriging over a 1/6° x 1/6° grid of the Gulf of St. Lawrence where the local depth exceeds 100 m. CIL volumes were estimated using the gridded thickness and the grid cell areas. The kriging method is described in Simard et al. (1992).

The 2006 average temperature minimum over the entire standard grid was 0.37°C ± 0.1°C. This is an increase of 0.42°C ± 0.3°C since 2005. The temperature has increased since 2004 to reach the highest value of the 1985-2006 time series. The CIL volume for T = 0°C, 1°C or 2°C also reached the lowest value of the time series, tied with 2000. The overall 2006 CIL water mass properties were similar to those observed in 2000.

Regional estimates of CIL thickness and volume are shown in Figures 24 and 25 using the same geographical regions introduced in the last report (Gilbert et al. 2004). Regional estimates of CIL thickness (or minimum temperature) are obtained by averaging the gridded estimates of CIL thickness (or minimum temperature) for all grid cells located within each of the seven deep regions. 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.

These regional analyses show that increases in CIL minimum temperature between 2005 and 2006 were more pronounced in the Laurentian Channel (regions 1, 2 and 6) than elsewhere. The minimum temperature actually decreased in Mecatina Trough, presumably due to the increased inflow of a thick layer of cold and highly saline water mass through the Strait of Belle Isle (as observed from the annual March survey). The same pattern is seen in the regional CIL thickness distribution. The thickness decreased everywhere reaching near-record lows, most notably in the Laurentian Channel, except in Mecatina Trough where the thickness at the 0°C isotherm increased. Again, conditions were, for the most part, similar to those observed in 2000, except in Mecatina Trough (the lowest volume of cold and saline water coming from the Labrador Shelf was observed in 2000, leading to warm CIL core temperatures that year).

For the Magdalen Shallows (excluded from the above analysis because it is mostly <100 m), the CIL volume (T < 1°C) observed during the September 2006 multidisciplinary survey is shown in Fig 26. The 2006 volume was the lowest since 1982 (only 1981 and 1982 had lower volumes since 1971), but again the volume was only slightly less than that of 2000.

## SEASONAL AND REGIONAL AVERAGES OF TEMPERATURE PROFILES

In order to show the seasonal progression of temperature profiles, averages are shown in Figures 27 through 30 for the 8 geographical regions used earlier (See Fig. 24 and Gilbert et al, 2004) for the March helicopter survey, the June AZMP survey, the August groundfish survey (September survey for region 8) as well as the November AZMP survey. During the surveys a total of 82 CTD casts in March, 86 casts in June, 130 casts in August, 193 in September and 97 in November were obtained.

Monthly temperature and salinity climatologies for 1971-2000 were constructed for various depths using the same method used by Petrie et al. (1996) but using the new geographical regions. All available data obtained during the same month, within a region, and close to each depth bin are first averaged together. Monthly averages from all available years and their standard deviation are then computed. This two-fold averaging avoids the bias that occurs when the number of profiles in a given year are different. The temperature climatologies are shown in grey as the mean value plus and minus one standard deviation in Figs. 27 through 30.

The March water temperature conditions were discussed at length earlier and are included here for completeness (27). Temperatures in the June-July period (Fig. 28) were generally above the mean plus one standard deviation of the 1971-2000 climatology at all depths, except the CIL in Esquiman Channel and Mecatina Trough (as discussed earlier) and deeper waters (> 300 m) of the southern half of the Laurentian Channel (Areas 6 and 7). This overall pattern persisted in the August-September mean conditions (Fig. 29). In November (Fig. 30), the most noteworthy features at that time were the anomalously deep CIL in the Estuary and Northwestern Gulf regions and the anomalously warm waters above the CIL throughout the Gulf.

## TIME SERIES OF TEMPERATURE AND SALINITY PROFILES AT FIXED AZMP STATIONS

The AZMP sampling by Maurice Lamontagne Institute began in 1996 at two stations (Fig. 31, top panel) 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 led to less frequent sampling (Fig. 31, lower panel). Another AZMP station in the Shediac Valley (47.78°N, 64.03°W) is sampled by the Bedford Institute of Oceanography. A station offshore of Rimouski has also been sampled since 1991 typically once a week during summer and less often during other months. Data from the Rimouski and Anticosti Gyre are shown here to highlight the temporal evolution of temperature and salinity profiles.

The temperature at the Rimouski station shows a strong positive anomaly in all layers in 2006. The CIL was thinner and warmer than in previous years (Fig. 32). The deeper waters were also warmer and saltier as seen by a shallowing of the depths of isotherms and isohalines (Fig. 32 and 33).

The temperature at the Anticosti Gyre station also had positive anomalies in all layers (Fig. 34). The CIL was thin and waters colder than 1°C disappeared completely by the fall. The 200-300 m layer was warmer and saltier than normal, and characterised by a shallowing in winter and late fall and a deepening during summer (Fig. 35).

## DISSOLVED OXYGEN IN DEEP WATERS

The deeper waters of the Laurentian Channel are not ventilated during winter and are slowly advected toward the head of the Laurentian, Esquiman and Jacques-Cartier Channels. Therefore the dissolved oxygen concentrations and saturations are lowest at the Channel heads, and in particular at the head of the longer Laurentian Channel. Fig. 36 is an update of the Gilbert et al. (2005) time series and provides the mean dissolved oxygen value at depths greater or equal to 300 m in the St. Lawrence Estuary, expressed as a percentage of saturation at surface pressure. Dissolved oxygen increased very slightly in 2006 to match the 2000 observations, but still remained very low compared to earlier periods.

## OUTLOOK FOR 2007

The March 2007 winter survey provides an outlook for conditions expected for the remainder of 2007. Fig. 37 shows the same information, updated for 2007, as was shown for the 2006 survey in Fig. 14. The waters were near-freezing almost everywhere, and there was no warm water entering the Gulf on the eastern side of Cabot Strait as was observed in recent years. Warm and salty waters were only observed at the station closest to the coast near Port-aux-Basques. The intrusion of cold and saline water from the Labrador Shelf through the Strait of Belle Isle occupied a slightly larger area in March 2007 compared to 2006, but its extension up to the surface instead of a subsurface tongue (observed in 2006) translates to a large increase in volume to 2854 $km^3$ (up from 1618 $km^3$ in March 2006). The 2007 volume is similar to that observed in March 2004. The cold layer (< -1°C) thickness is also greater elsewhere in the Gulf in 2007 and translates to a volume of 13.1 x $10^3$ $km^3$, again similar to conditions in March 2004. The relation between the cold water volume and the CIL index (Galbraith, 2006) forecasts cooler summertime CIL conditions in 2007 with an index of -0.38°C. This is a predicted decrease of 0.6°C after three years of warming and a return to the near-average (1971-2000) conditions observed in 2004. This is very surprising considering the very warm precondition of the Gulf in November 2006 (Fig. 30) and the mild early winter conditions up to mid-January 2007.

## SUMMARY

- Air temperatures and surface water temperatures were above normal (by 2°C to 4°C) all year except for late summer in most parts of the Gulf.
- The total runoff measured at Québec City was normal but its temporal distribution was not. Runoff was 1000 to 2000 $m^3 s^{-1}$ lower than normal from February to September, but this was compensated for by an anomalous strong fall runoff, almost as large as in spring.
- Near-surface temperatures were generally above-normal during spring and summer (more than 3°C above the 1995-2004 climatology). From August 15 to September 30, waters colder than normal (approximately 3°C below the climatology) appeared in the northwest and southern Gulf regions while the northeastern Gulf region temperatures were always above normal. From mid-November to the end of December, the surface temperatures were again about 3 °C above normal.
- No near-bottom waters below 0°C in were observed in September 2006 in the Magdalen Shallows.
- Sea ice coverage and volume within the Gulf during the winter were the lowest recorded since 1969.
- Winter inflow of cold and saline water from the Labrador Shelf was a sub-surface intrusion that exceeded 150 m in thickness again in 2006, hitting the bottom below 200 m depth in Mecatina Trough (Fig. 17). Its volume, 1620 $km^3$, was intermediate relative to values of the past decade.
- The 2006 winter cold mixed layer volume was the smallest recorded in the then 11 year history of the winter survey (9800 $km^3$), and corresponded to 29% of the total water volume of the Gulf.
- This shallow winter mixed layer has led to the Cold Intermediate Layer (CIL) index for summer 2006 increasing to +0.21ºC. This was the warmest value since 1983, but only slightly warmer than in 2000.
- Regional patterns of the CIL minimum temperature showed more pronounced increases in the Laurentian Channel than elsewhere. The minimum temperature decreased in Mecatina Trough. Similar regional patterns were seen in the CIL thickness distribution.
- The CIL volume ($T < 1$°C) for the Magdalen Shallows observed during the September groundfish survey was the lowest since 1982 (only 1981 and 1982 had lower volumes since 1971), but the volume was only slightly less than that of 2000.
- Water temperatures were generally above the mean, plus one standard deviation of the 1971-2000 climatology, at all depths for most of the year. The exceptions were the CIL in Esquiman Channel and Mecatina Trough and deeper waters (> 300 m) of the southern half of the Laurentian Channel, where waters were colder than normal.
- The most noteworthy water temperature features in November were the anomalously deep CIL in the Estuary and northwestern Gulf regions and the anomalously warm waters shallower than the CIL everywhere in the Gulf.

- Dissolved oxygen in the St. Lawrence Estuary remained low in spite of a slight increase from previous years.
- The outlook for 2007 from the March 2007 survey is for a 0.6ºC cooling of the CIL index resulting from a thicker cold surface layer and increased inflow of Labrador Shelf water through the Strait of Belle Isle.


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## LIST OF ACRONYMS

AZMP: Atlantic Zone Monitoring Program
AVHRR: Advanced Very High Resolution Radiometer
CIL: Cold Intermediate Layer
CTD: Conductivity-Temperature-Depth
IML: Institut Maurice-Lamontagne
NOAA: National Oceanic and Atmospheric Administration
SBE: SeaBird Electronics
WMO: World Meteorological Organization

Table 1. Monthly mean temperatures at all stations of the IML thermograph network in 2006.

| Station | Depth (m) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaugé Bank | 1 | | | | | | 9.1 | 15.3 | 16.0 | 14.1 | 9.3 | | |
| Beaugé Bank | 100 | | | | | | -0.8 | -0.2 | 0.2 | 0.6 | 0.9 | | |
| Baie-Comeau | 1 | | | | | | 11.0 | 12.2 | 11.1 | 9.1 | 6.3 | | |
| Baie-Comeau | 80 | | | | | | 0.7 | 0.8 | 1.1 | 1.3 | 2.4 | | |
| Belle Isle | 105 | -1.0 | -1.8 | -1.8 | -1.3 | 0.2 | 1.0 | 3.6 | 3.1 | 1.5 | 2.7 | | |
| Bic | 1 | | | | | | 7.5 | 8.2 | 8.1 | 6.4 | | | |
| Bic | 5.8 | | | | | | 3.4 | 3.8 | 4.0 | 3.7 | | | |
| Blanc Sablon | 1 | | | | | | 4.6 | 10.7 | 12.6 | 9.0 | 6.6 | | |
| Blanc Sablon | 22 | | | | | | 3.8 | 8.0 | 9.1 | 7.5 | 6.0 | | |
| Grande-Rivière | 2 | | | | | 6.5 | 11.0 | 15.3 | 16.3 | 13.2 | 8.7 | | |
| Grande-Rivière | 7 | | | | | 4.9 | 8.4 | 12.3 | 15.4 | 12.2 | 8.5 | | |
| Havre St-Pierre | 1 | | | | | | 9.8 | 12.8 | 8.4 | 8.2 | | | |
| Havre St-Pierre | 100 | | | | | | 1.0 | 1.0 | 1.1 | 1.2 | | | |
| IML | 13.5 | -1.3 | -1.1 | -0.3 | 1.8 | 3.4 | 6.8 | 7.8 | 8.2 | 6.3 | 4.7 | | |
| Irving Whale | 1 | | | | | 6.9 | 12.5 | 17.7 | 17.8 | 15.4 | 11.3 | | |
| Irving Whale | 67 | | | | | -0.5 | 0.0 | 0.4 | 0.5 | 0.6 | 0.8 | | |
| Ile Shag | 10 | 0.3 | -1.3 | -0.8 | 1.6 | 6.3 | 10.0 | 15.1 | 15.3 | | | | |
| La Romaine | 1 | | | | | | 9.1 | 11.2 | 12.7 | 11.8 | 8.3 | | |
| La Romaine | 14 | | | | | | 2.1 | 2.6 | 4.1 | 5.5 | 7.0 | | |
| Mont-Louis | 0.5 | | | | | | 11.4 | 14.4 | 13.7 | 9.4 | 5.6 | | |
| Natashquan | 1 | | | | | | 14.1 | 14.0 | 12.9 | 10.7 | 7.7 | | |
| Natashquan | 7.5 | | | | | | 5.9 | 5.5 | 6.0 | 7.5 | 7.0 | | |
| Port-Menier | 2 | | | | | | 11.5 | 14.9 | 9.7 | 8.7 | 6.5 | | |
| Port-Menier | 12.8 | | | | | | 6.2 | 9.1 | 4.9 | 5.7 | 5.2 | | |
| Rivière-au-Tonnerre | 1 | | | | | | 10.4 | 12.7 | 8.5 | 6.1 | | | |
| Rivière-au-Tonnerre | 16 | | | | | | 5.4 | 5.1 | 4.6 | 4.8 | | | |
| Rimouski | 0.5 | | | | | | 9.3 | 11.1 | 9.6 | 7.7 | | | |
| Shediac | 0.5 | | | | | | 12.0 | 16.8 | 16.4 | 14.9 | | | |
| Sept-Iles | 1 | | | | | | 13.0 | 15.3 | 11.3 | 9.9 | 6.0 | | |
| Sept-Iles | 25 | | | | | | 4.0 | 3.1 | 2.7 | 4.0 | 4.5 | | |
| La Tabatière | 1 | | | | | | 6.7 | 10.4 | 12.5 | 11.4 | 7.9 | | |
| La Tabatière | 36 | | | | | | 2.1 | 3.6 | 5.6 | 6.0 | 6.6 | | |
| Tadoussac | 2 | | | | | 5.0 | 7.9 | 8.4 | 8.0 | 6.2 | 5.2 | | |
| Tadoussac | 30 | | | | | 2.2 | 3.7 | 3.9 | 3.8 | 3.4 | 3.3 | | |

Table 2. Reference periods over which the average 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.

| Station | Depth (m) | Reference Period | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaugé Bank | 1 | 1998-2006 | | | | | | 0.9 | 1.0 | 1.0 | 1.0 | 0.7 | | |
| Beaugé Bank | 100 | 1998-2006 | | | | | | 0.8 | 0.9 | 0.9 | 0.9 | 0.6 | | |
| Baie-Comeau | 1 | 1999-2006 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Baie-Comeau | 80 | 2000-2006 | | | | | | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | | |
| Belle Isle | 105 | 2004-2006 | 0.7 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Bic | 1 | 1994-2006 | | | | | | 0.8 | 0.8 | 0.8 | 0.8 | | | |
| Bic | 5.8 | 1996-2006 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | | | |
| Blanc Sablon | 1 | 1999-2006 | | | | | | 0.8 | 1.0 | 1.0 | 1.0 | 0.6 | | |
| Blanc Sablon | 22 | 1999-2006 | | | | | | 0.8 | 1.0 | 1.0 | 1.0 | 0.8 | | |
| Grande-Rivière | 2 | 1994-2006 | | | | | 0.2 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | | |
| Grande-Rivière | 7 | 1996-2006 | | | | | 0.2 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | | |
| Havre St-Pierre | 1 | 1997-2006 | | | | | | 0.8 | 1.0 | 1.0 | 1.0 | | | |
| Havre St-Pierre | 100 | 1996-2006 | | | | | | 0.6 | 0.8 | 0.8 | 0.8 | | | |
| IML | 13.5 | 1994-2006 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.7 | 0.8 | | |
| Irving Whale | 1 | 1998-2006 | | | | | 0.2 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Irving Whale | 67 | 1998-2006 | | | | | 0.1 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | | |
| Ile Shag | 10 | 1994-2006 | 1.0 | 1.0 | 1.0 | 0.8 | 0.9 | 1.0 | 1.0 | 1.0 | | | | |
| La Romaine | 1 | 1994-2006 | | | | | | 0.5 | 0.6 | 0.6 | 0.6 | 0.4 | | |
| La Romaine | 14 | 1996-2006 | | | | | | 0.8 | 0.9 | 0.9 | 0.9 | 0.6 | | |
| Mont-Louis | 0.5 | 1994-2006 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | | |
| Natashquan | 1 | 1994-2006 | | | | | | 0.8 | 0.9 | 0.9 | 0.9 | 0.7 | | |
| Natashquan | 7.5 | 1994-2006 | | | | | | 0.8 | 0.9 | 0.9 | 0.9 | 0.7 | | |
| Port-Menier | 2 | 1994-2006 | | | | | | 0.9 | 0.9 | 0.9 | 0.8 | 0.7 | | |
| Port-Menier | 12.8 | 1996-2006 | | | | | | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | | |
| Rivière-au-Tonnerre | 1 | 1998-2006 | | | | | | 0.8 | 0.9 | 0.9 | 0.9 | | | |
| Rivière-au-Tonnerre | 16 | 1996-2006 | | | | | | 0.9 | 1.0 | 1.0 | 1.0 | | | |
| Rimouski | 0.5 | 2002-2006 | | | | | | 0.8 | 1.0 | 1.0 | 0.8 | | | |
| Shediac | 0.5 | 2004-2006 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | | | |
| Sept-Iles | 1 | 2001-2006 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Sept-Iles | 25 | 1996-2006 | | | | | | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | | |
| La Tabatière | 1 | 2002-2006 | | | | | | 0.8 | 1.0 | 1.0 | 1.0 | 0.4 | | |
| La Tabatière | 36 | 2002-2006 | | | | | | 0.8 | 0.8 | 0.8 | 0.8 | 0.4 | | |
| Tadoussac | 2 | 1993-2006 | | | | | 0.4 | 0.6 | 0.6 | 0.8 | 0.8 | 0.7 | | |
| Tadoussac | 30 | 1996-2006 | | | | | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | | |

Table 3. Monthly mean temperature anomalies (°C) in 2006 at all stations of the IML thermograph network.

| Station | Depth (m) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaugé Bank | 1 | | | | | | 1.5 | 2.4 | 1.0 | 1.7 | 1.5 | | |
| Beaugé Bank | 100 | | | | | | -0.3 | 0.2 | 0.1 | 0.3 | 0.1 | | |
| Baie-Comeau | 1 | | | | | | 1.8 | 0.5 | -0.2 | 0.1 | 0.2 | | |
| Baie-Comeau | 80 | | | | | | 0.7 | 0.6 | 0.6 | 0.6 | 0.8 | | |
| Belle Isle | 105 | 0.3 | -0.1 | -0.0 | 0.1 | 0.5 | 0.4 | 1.3 | 0.2 | -0.8 | -0.7 | | |
| Bic | 1 | | | | | | 1.2 | 0.6 | 0.7 | 0.5 | | | |
| Bic | 5.8 | | | | | | 0.9 | 0.6 | 0.7 | 0.4 | | | |
| Blanc Sablon | 1 | | | | | | 0.9 | 2.3 | 0.9 | 0.2 | 0.7 | | |
| Blanc Sablon | 22 | | | | | | 0.9 | 1.7 | 1.0 | 0.1 | 0.3 | | |
| Grande-Rivière | 2 | | | | | -0.1 | 1.2 | 1.4 | 1.0 | 0.7 | 0.6 | | |
| Grande-Rivière | 7 | | | | | 0.4 | 0.6 | 1.0 | 2.0 | 0.7 | 0.7 | | |
| Havre St-Pierre | 1 | | | | | | 2.8 | 2.3 | -1.5 | -1.3 | | | |
| Havre St-Pierre | 100 | | | | | | 0.7 | 0.6 | 0.5 | 0.3 | | | |
| IML | 13.5 | -0.1 | 0.0 | 0.3 | 0.6 | 0.5 | 1.1 | 0.6 | 0.9 | 0.2 | 0.4 | | |
| Irving Whale | 1 | | | | | 0.4 | 1.7 | 1.0 | 0.0 | 0.3 | 0.8 | | |
| Irving Whale | 67 | | | | | | 0.7 | 0.9 | 0.7 | 0.6 | 0.6 | | |
| Ile Shag | 10 | 1.4 | 0.3 | 0.4 | 1.1 | 1.9 | 1.4 | 1.5 | -0.9 | | | | |
| La Romaine | 1 | | | | | | 2.1 | 0.5 | 0.2 | 1.1 | 1.0 | | |
| La Romaine | 14 | | | | | | 1.0 | 0.0 | 0.4 | -0.5 | 1.7 | | |
| Mont-Louis | 0.5 | | | | | | 1.5 | 0.8 | 0.3 | -0.8 | -0.2 | | |
| Natashquan | 1 | | | | | | 3.5 | 0.0 | -0.7 | 0.3 | 0.9 | | |
| Natashquan | 7.5 | | | | | | 1.6 | -1.6 | -1.0 | -0.7 | 0.8 | | |
| Port-Menier | 2 | | | | | | 2.4 | 1.7 | -3.1 | -1.1 | -0.1 | | |
| Port-Menier | 12.8 | | | | | | 1.5 | 2.2 | -1.7 | -0.5 | 1.3 | | |
| Rivière-au-Tonnerre | 1 | | | | | | 2.9 | 1.9 | -0.9 | -1.0 | | | |
| Rivière-au-Tonnerre | 16 | | | | | | 2.0 | 0.2 | -0.4 | -1.0 | | | |
| Rimouski | 0.5 | | | | | | 1.4 | 0.1 | 0.0 | 0.0 | | | |
| Shediac | 0.5 | | | | | | 1.7 | 0.6 | -0.7 | 0.4 | | | |
| Sept-Iles | 1 | | | | | | 2.3 | 1.0 | -1.3 | -0.2 | -0.1 | | |
| Sept-Iles | 25 | | | | | | 1.9 | 0.0 | -0.4 | -0.3 | 0.2 | | |
| La Tabatière | 1 | | | | | | 0.5 | 1.2 | 0.7 | 0.3 | 0.2 | | |
| La Tabatière | 36 | | | | | | 0.6 | 1.0 | 0.8 | -0.4 | -0.1 | | |
| Tadoussac | 2 | | | | | 0.7 | 0.8 | 0.0 | 0.0 | -0.3 | 0.6 | | |
| Tadoussac | 30 | | | | | 0.6 | 0.9 | 0.1 | 0.4 | 0.1 | 0.7 | | |

Table 4. Normalised monthly mean temperature anomalies (standard deviations) in 2006 at all stations of the IML thermograph network. The anomalies are relative to the reference periods given in Table 2, with anomalies below one standard deviation indicated in blue and anomalies above one standard deviation indicated in red.

| Station | Depth(m) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaugé Bank | 1 | | | | | | 1.1 | 2.3 | 0.9 | 1.4 | 1.2 | | |
| Beaugé Bank | 100 | | | | | | -1.0 | 0.3 | 0.2 | 0.5 | 0.3 | | |
| Baie-Comeau | 1 | | | | | | 1.7 | 0.4 | -0.2 | 0.0 | 0.3 | | |
| Baie-Comeau | 80 | | | | | | 1.4 | 1.5 | 1.6 | 1.5 | 1.1 | | |
| Belle Isle | 105 | 0.7 | -0.7 | -1.1 | 1.0 | 1.1 | 0.4 | 1.1 | 1.1 | -0.9 | -1.1 | | |
| Bic | 1 | | | | | | 1.9 | 1.0 | 1.4 | 0.9 | | | |
| Bic | 5.8 | | | | | | 1.7 | 1.5 | 1.6 | 0.9 | | | |
| Blanc Sablon | 1 | | | | | | 0.8 | 1.8 | 0.8 | 0.2 | 0.8 | | |
| Blanc Sablon | 22 | | | | | | 0.9 | 1.3 | 1.5 | 0.2 | 0.3 | | |
| Grande-Rivière | 2 | | | | | -0.7 | 1.2 | 1.6 | 1.3 | 0.8 | 1.1 | | |
| Grande-Rivière | 7 | | | | | 0.7 | 1.0 | 1.1 | 2.1 | 1.0 | 1.6 | | |
| Havre St-Pierre | 1 | | | | | | 1.7 | 1.3 | -0.7 | -0.5 | | | |
| Havre St-Pierre | 100 | | | | | | 1.4 | 1.3 | 1.0 | 0.7 | | | |
| IML | 13.5 | -0.5 | 0.1 | 0.7 | 1.2 | 0.9 | 1.9 | 1.1 | 1.5 | 0.3 | 1.2 | | |
| Irving Whale | 1 | | | | | 0.7 | 1.1 | 1.6 | 0.0 | 0.3 | 0.7 | | |
| Irving Whale | 67 | | | | | | 1.7 | 1.8 | 1.6 | 1.6 | 1.8 | | |
| Ile Shag | 0.5 | | | | | | | | | | | | |
| Ile Shag | 10 | 2.3 | 1.3 | 1.5 | 1.3 | 1.9 | 1.3 | 1.6 | -1.1 | | | | |
| La Romaine | 1 | | | | | | 1.5 | 0.5 | 0.2 | 0.9 | 0.9 | | |
| La Romaine | 14 | | | | | | 1.4 | -0.1 | 0.3 | -0.3 | 1.3 | | |
| Mont-Louis | 0.5 | | | | | | 1.7 | 0.9 | 0.4 | -1.0 | -0.3 | | |
| Natashquan | 1 | | | | | | 2.4 | 0.0 | -0.4 | 0.2 | 0.7 | | |
| Natashquan | 7.5 | | | | | | 1.1 | -0.8 | -0.4 | -0.3 | 0.6 | | |
| Port-Menier | 2 | | | | | | 1.5 | 1.5 | -1.4 | -0.5 | 0.0 | | |
| Port-Menier | 12.8 | | | | | | 1.8 | 1.7 | -1.1 | -0.6 | 1.1 | | |
| Rivière-au-Tonnerre | 1 | | | | | | 1.6 | 1.8 | -0.6 | -0.5 | | | |
| Rivière-au-Tonnerre | 16 | | | | | | 1.7 | 0.2 | -0.3 | -0.5 | | | |
| Rimouski | 0.5 | | | | | | 1.5 | 0.1 | 0.1 | 0.1 | | | |
| Shediac | 0.5 | | | | | | 1.1 | 0.7 | -1.0 | 0.3 | | | |
| Sept-Iles | 1 | | | | | | 1.5 | 0.7 | -0.8 | -0.2 | 0.0 | | |
| Sept-Iles | 25 | | | | | | 2.2 | 0.0 | -0.3 | -0.2 | 0.2 | | |
| La Tabatière | 1 | | | | | | 0.5 | 1.1 | 0.8 | 0.4 | 0.7 | | |
| La Tabatière | 36 | | | | | | 0.9 | 0.8 | 0.5 | -0.7 | -0.7 | | |
| Tadoussac | 2 | | | | | 1.1 | 1.0 | 0.0 | 0.0 | -0.3 | 1.0 | | |
| Tadoussac | 30 | | | | | 1.4 | 1.0 | 0.4 | 0.4 | 0.2 | 1.7 | | |

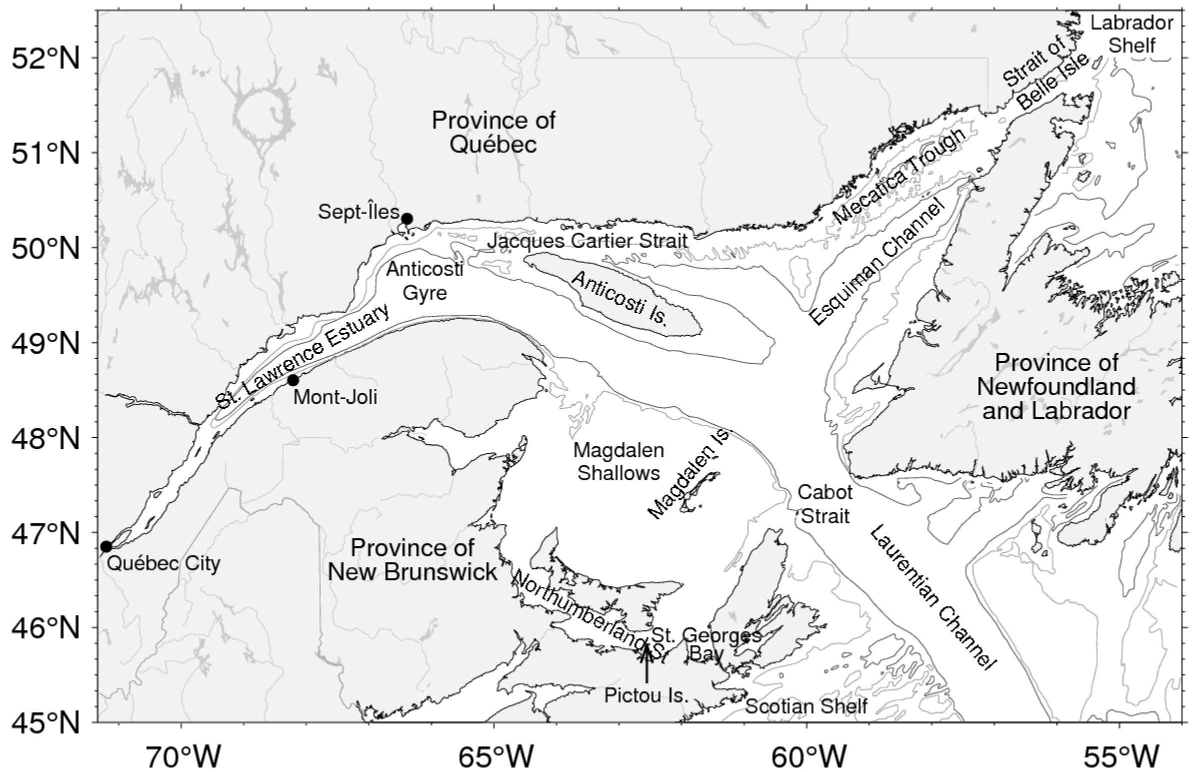


Figure 1. The Gulf of St. Lawrence, with isobaths for 100 and 200 m. Locations discussed in the text are indicated.

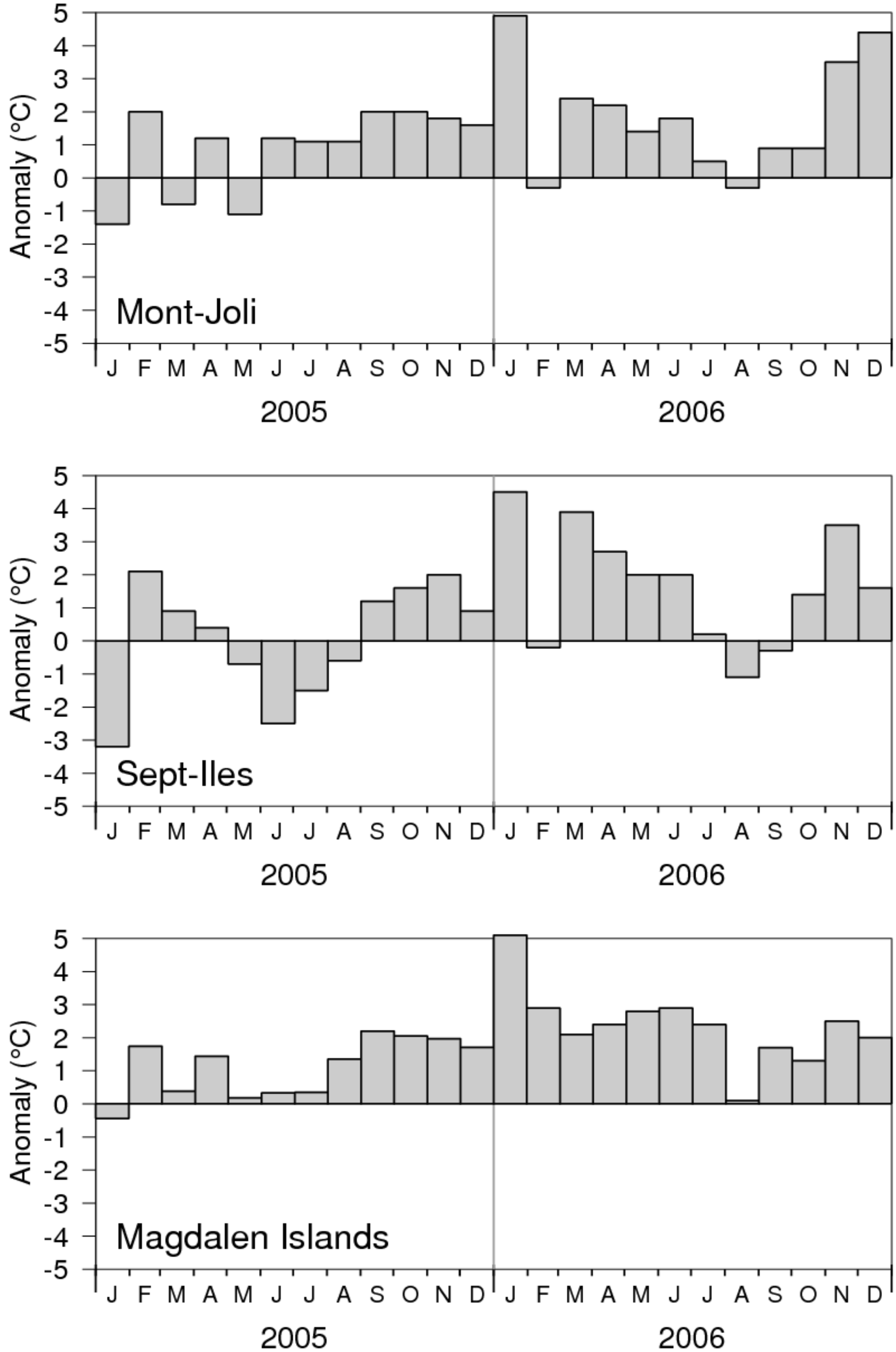


Figure 2. Monthly air temperature anomalies for 2005 and 2006 at Mont-Joli, Sept-Iles and the Magdalen Islands.

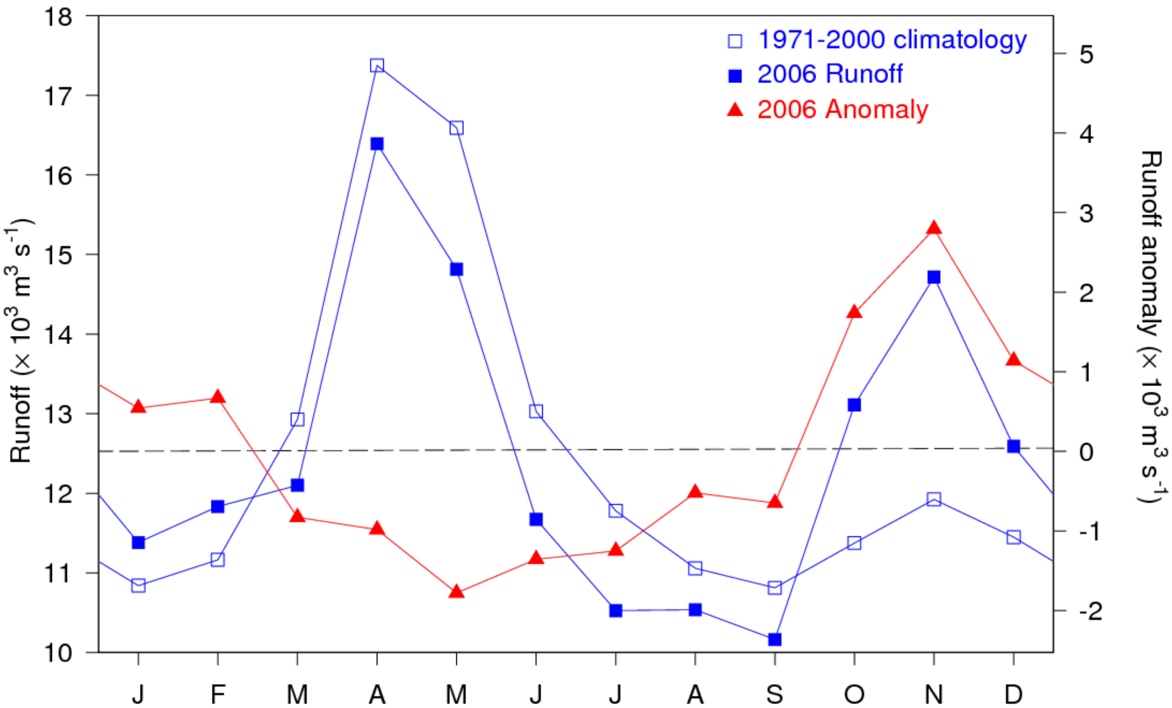


Figure 3. Monthly mean freshwater flow of the St. Lawrence River at Québec City in 2006 (blue filled squares) compared with the 1971-2000 climatology (blue hollow squares). The 2006 monthly anomalies are shown in red.

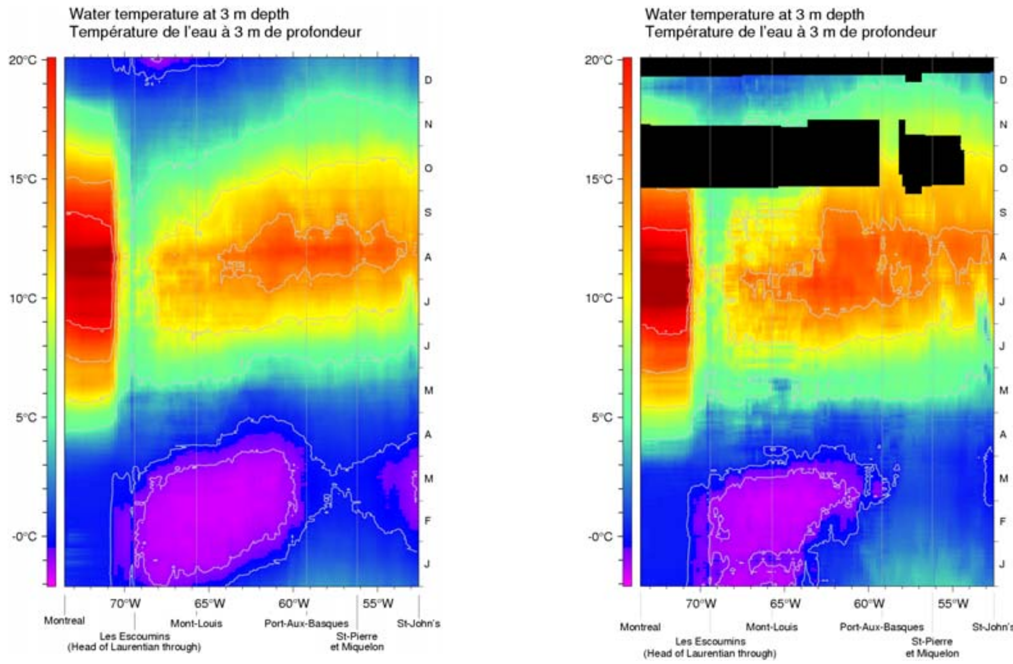


Figure 4. Composite mean annual cycle of 3-m depth water temperature along the Montréal to St. John's shipping route for 2000 to 2006 (left panel) and composite annual cycle for 2006 of the water temperature measured at 3 m depth (right panel).

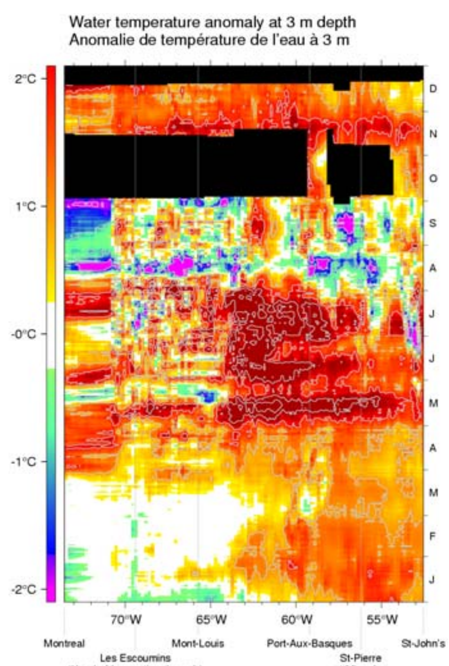


Figure 5. Water temperature anomaly for 2006 along the Montréal to St. John's shipping route. The anomaly is defined as the difference between 2006 temperatures and the 2000-2006 average both shown in 4. White areas are of similar temperature to the average

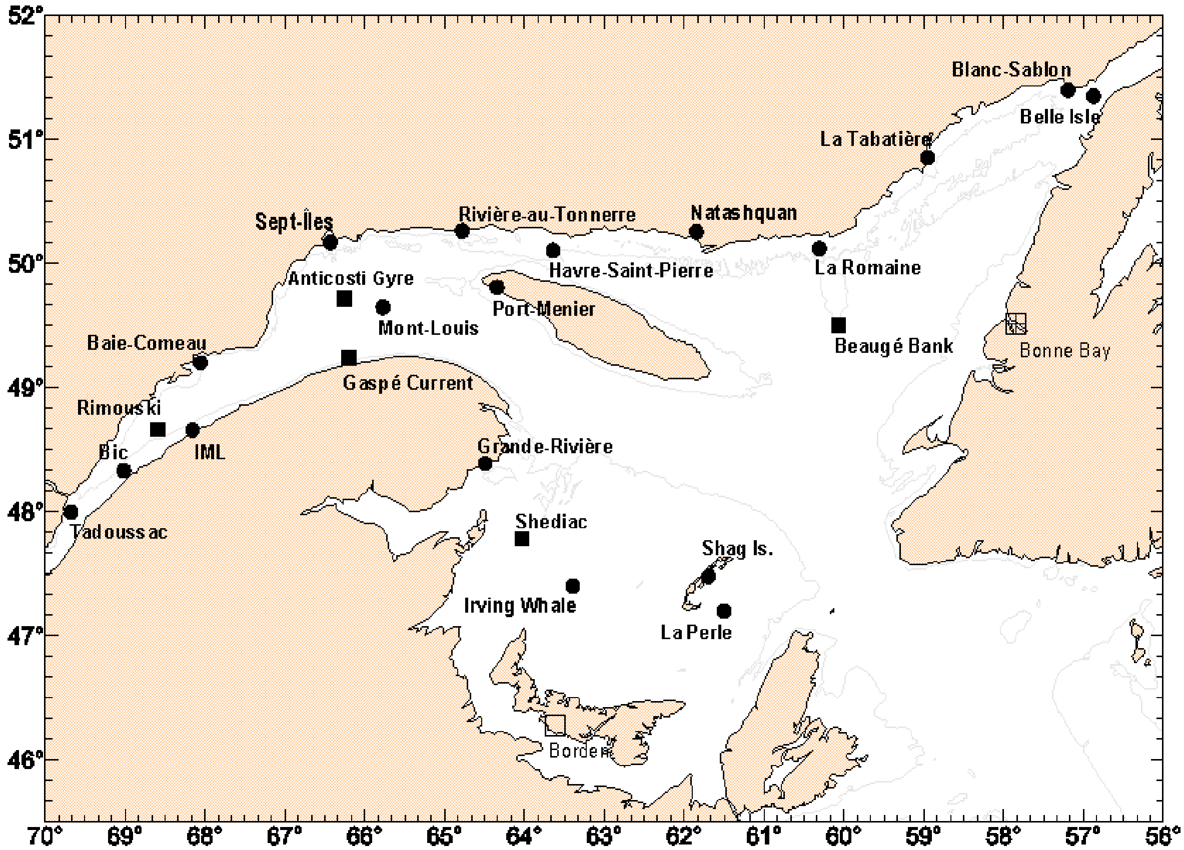


Figure 6. Locations of IML thermograph network stations in 2006, including regular stations were data are logged internally and recovered at the end of the season (circles) and oceanographic buoys that transmit data in real-time (solid squares). Locations for Borden and Bonne Bay are also shown (open squares) although they are no longer occupied.

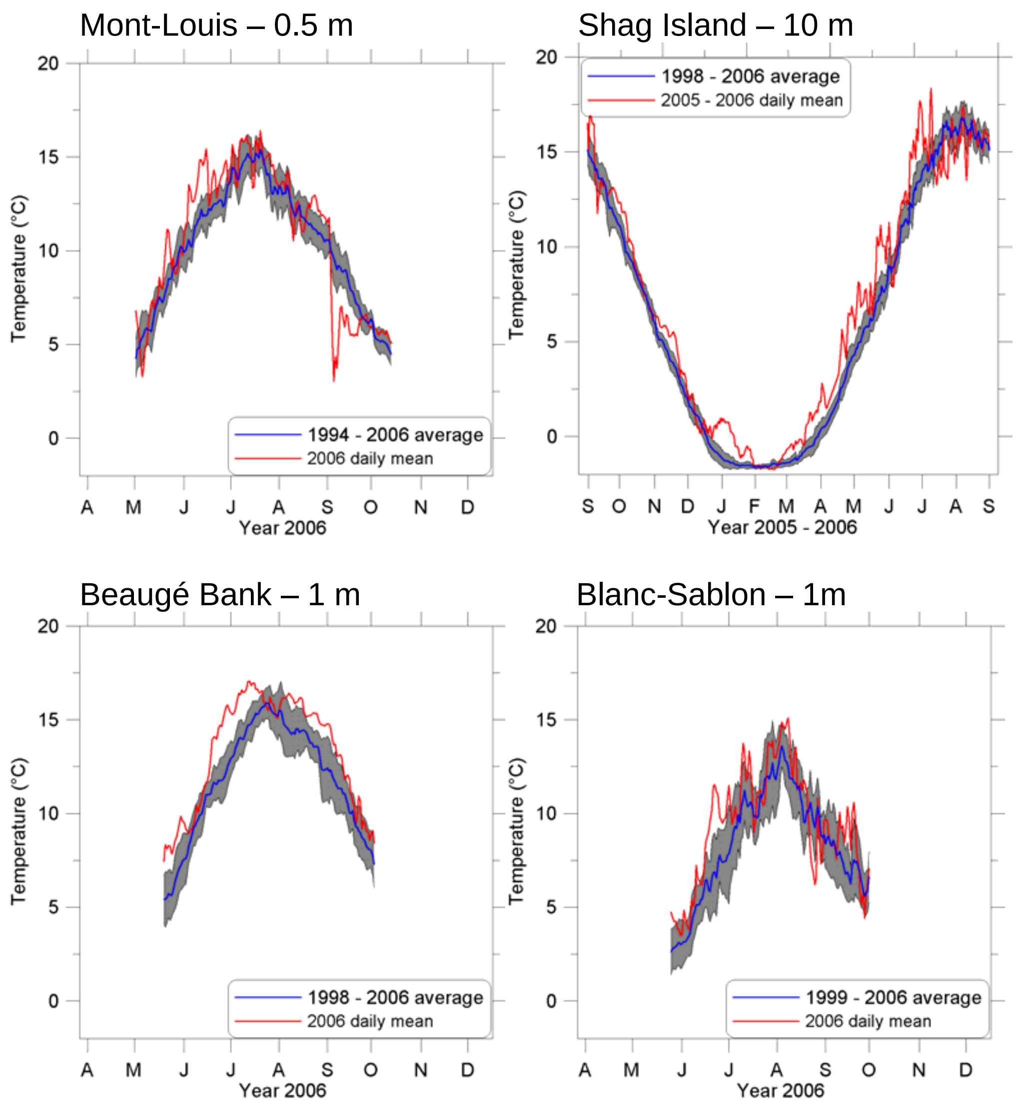


Figure 7. Daily mean 2006 temperatures (red curves) compared with the daily averages (blue curves) computed from all available data at 0.5 m depth at Mont-Louis (upper left panel), at 10 m depth at Shag Island (upper right panel), at 1 m depth at Beaugé Bank (lower left panel) and at 1 m depth at Blanc-Sablon (lower right panel). The shaded area represents the 95% confidence interval on the mean. Data from Shag Island spans the entire year but observations from the preceeding fall are included because fall 2006 data will not be available before the instrument is recovered in the fall of 2007.

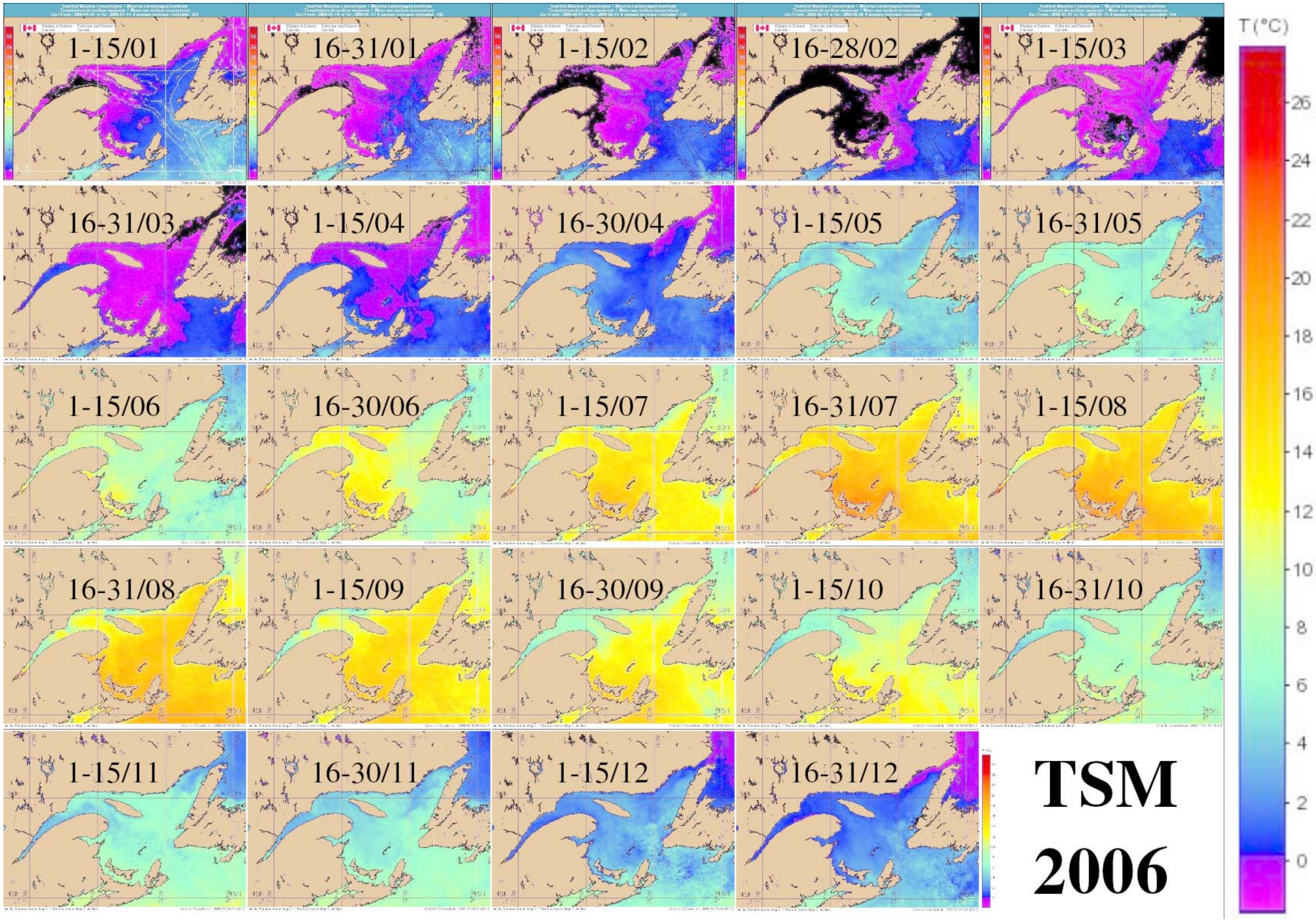


Figure 8. Sea surface temperature averages for half-month periods of 2006, as observed from NOAA remote sensing.

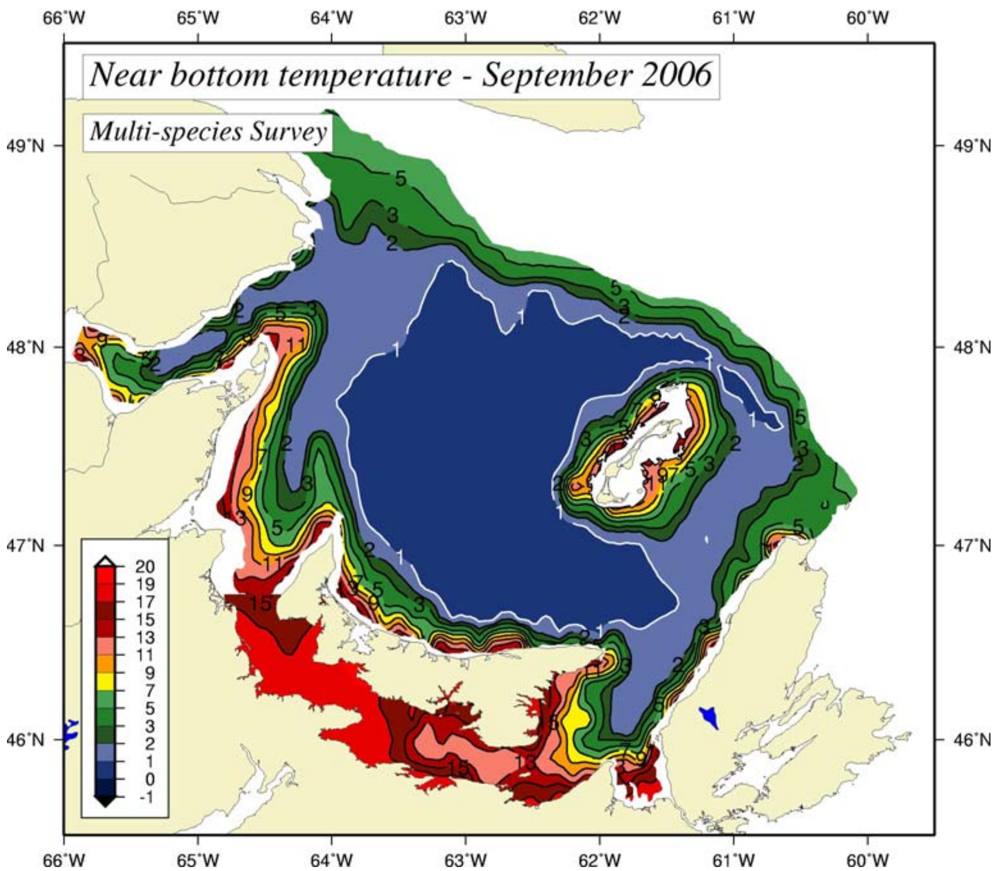


Figure 9. Near-bottom temperatures during the 2006 September multi-species survey.

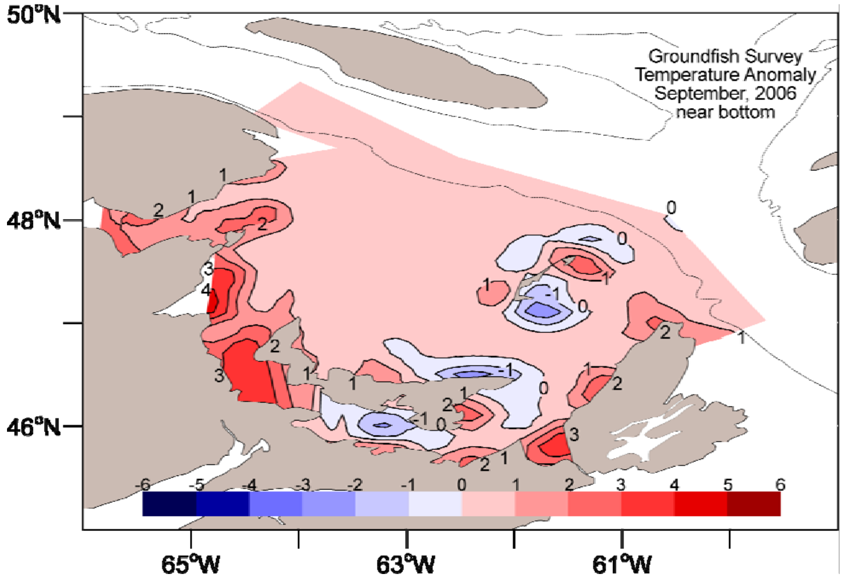


Figure 10. Near-bottom temperatures anomalies from the 1971-2000 climatology in the southern Gulf of St. Lawrence during the 2006 September multi-species survey.

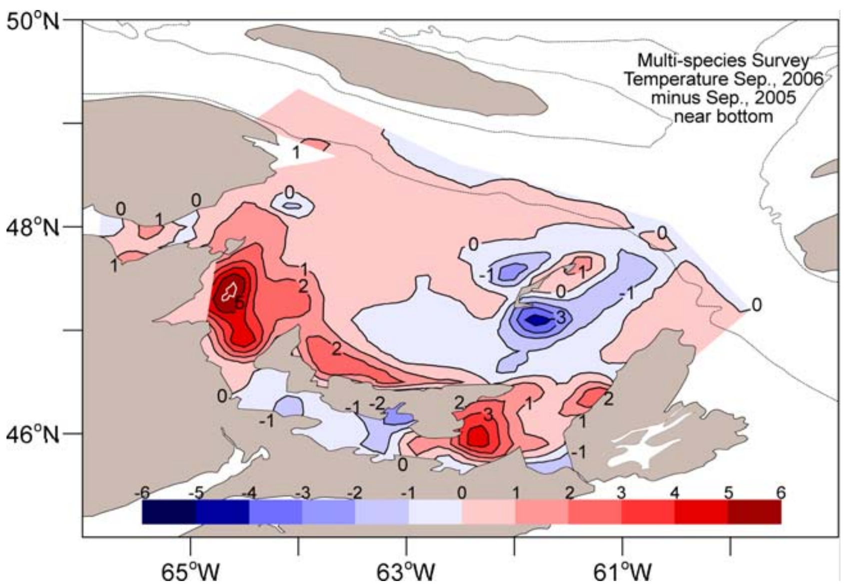


Figure 11. The difference between the 2006 and 2005 temperature fields in the southern Gulf of St. Lawrence for the September surveys.

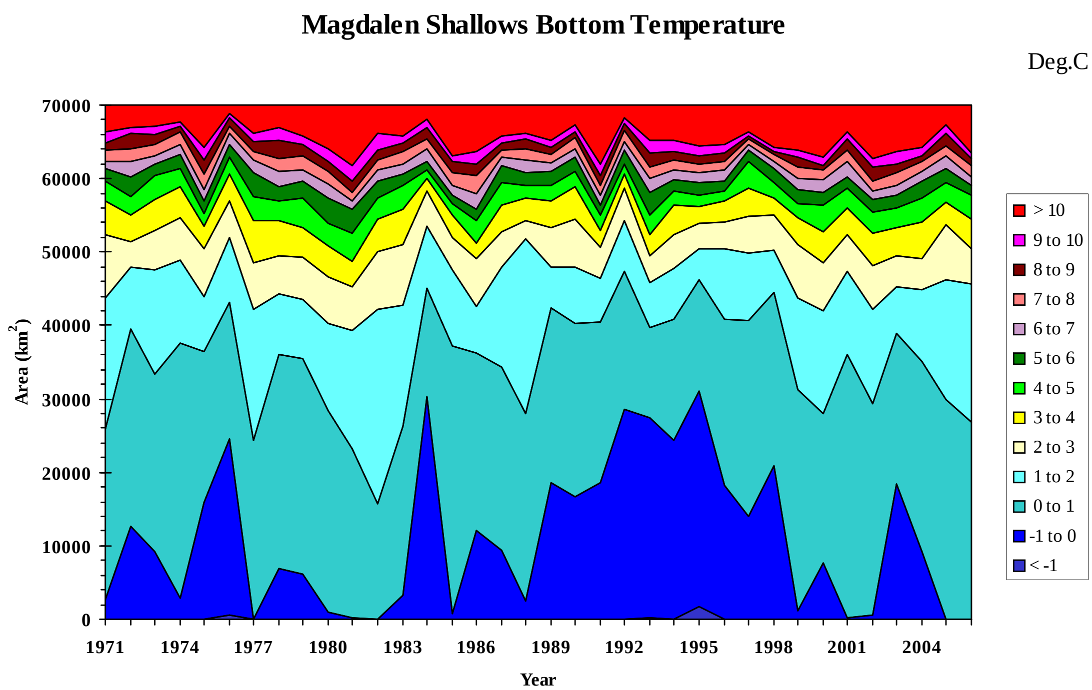


Figure 12. Time series of the areas of the Magdalen Shallows covered by different temperature bins in September.

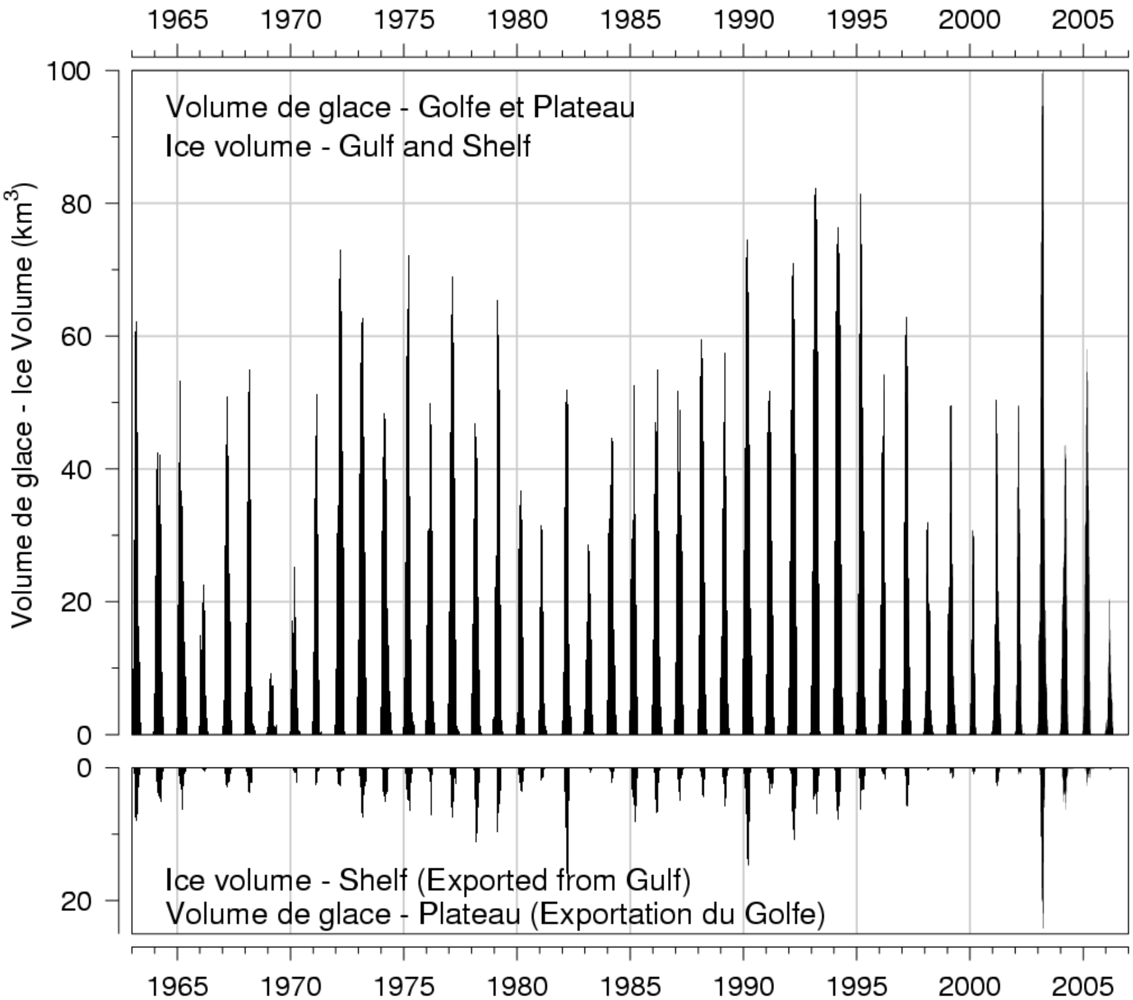


Figure 13. Estimated ice volume in the Gulf of St. Lawrence and on the Scotian Shelf seaward of Cabot Strait (upper panel) and on the Shelf only (lower panel).

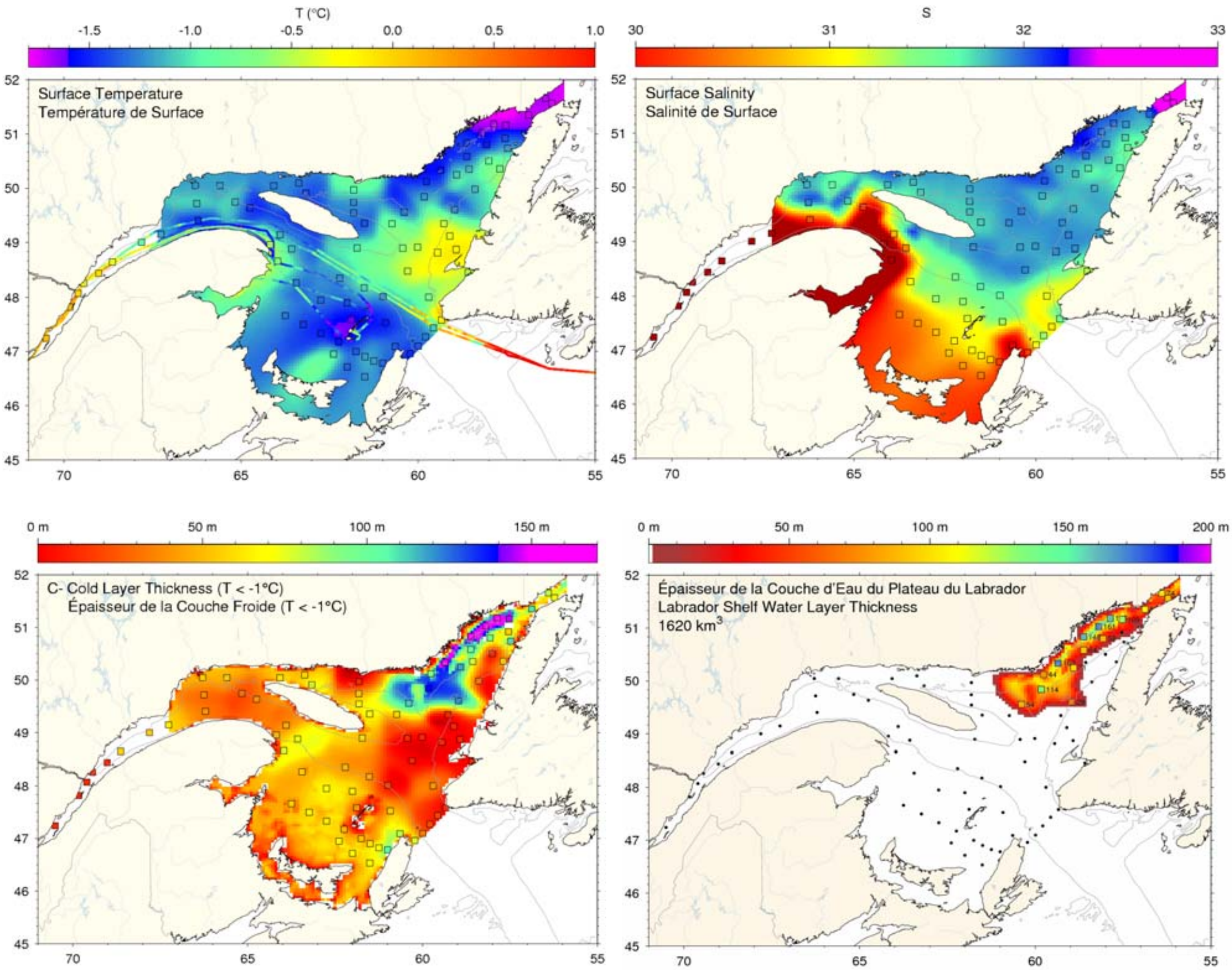


Figure 14. Surface water temperature (upper-left), salinity (upper-right), cold layer (T < -1°C) thickness (lower-left) and estimate of the thickness of the Labrador Shelf water intrusion (lower-right) for the March 2006 helicopter survey. The temperature measurements from shipboard thermosalinographs taken during the survey are also shown in the upper-left panel. The symbols are coloured according to the value observed at the station, using the same colour palette as the interpolated image. A good match is seen between the interpolation and the station observations where the station colours blend into the background.

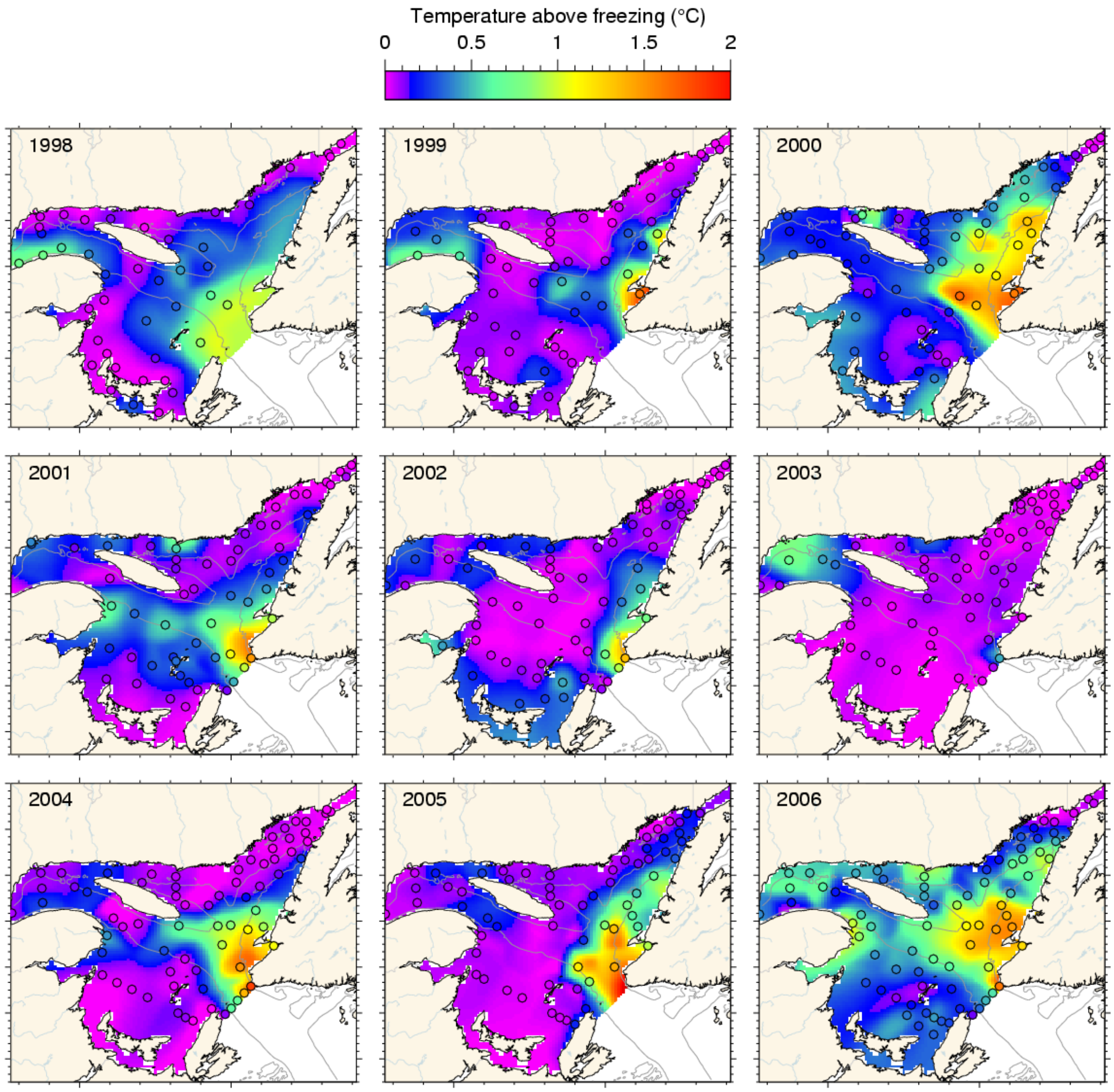


Figure 15. Difference between near-surface water temperature and freezing point temperature during the March survey for the last 9 years. Station symbols are coloured according to the observed values as in Fig. 14.

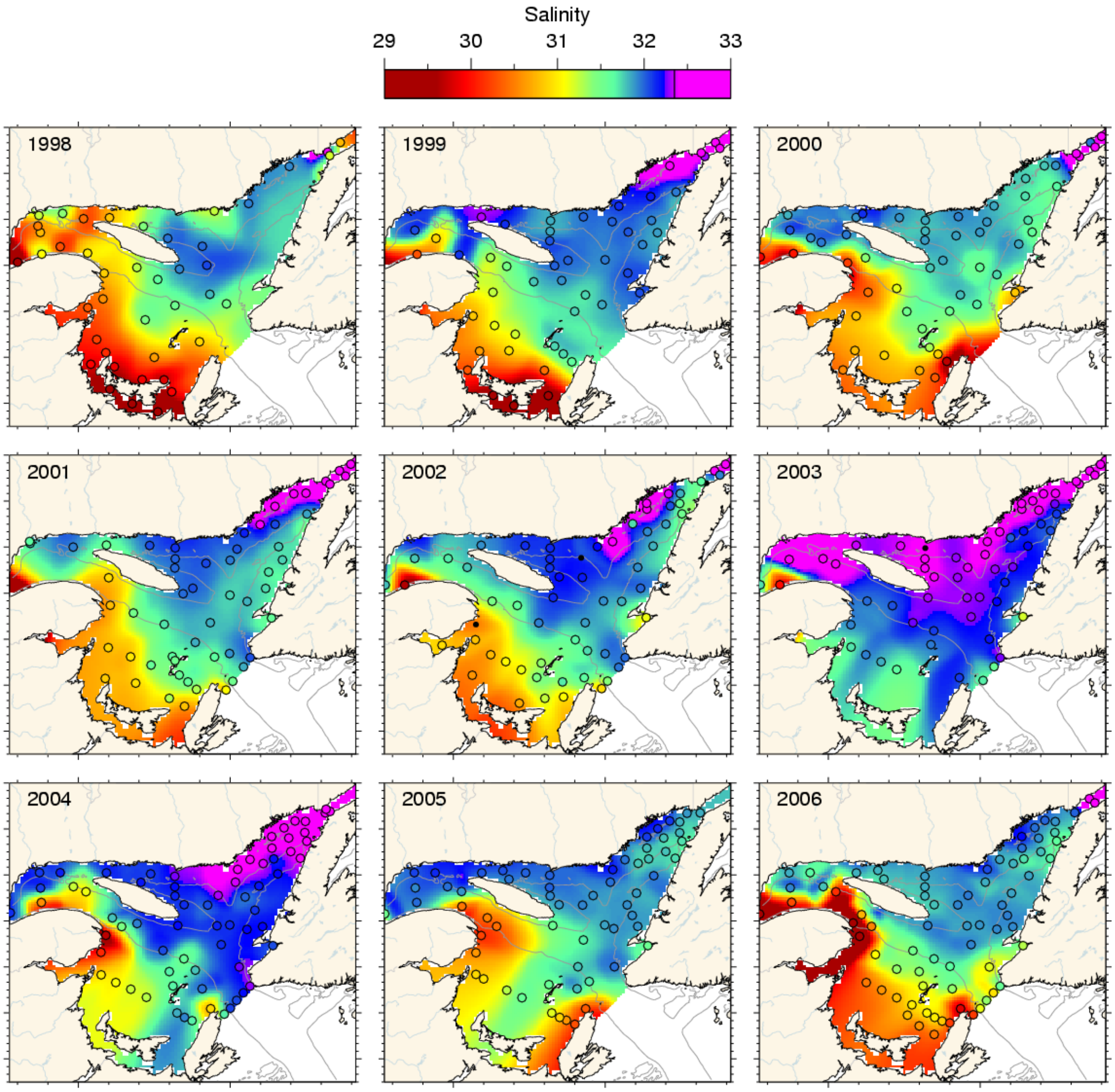


Figure 16. Near-surface salinity during the March survey for the past 9 years.

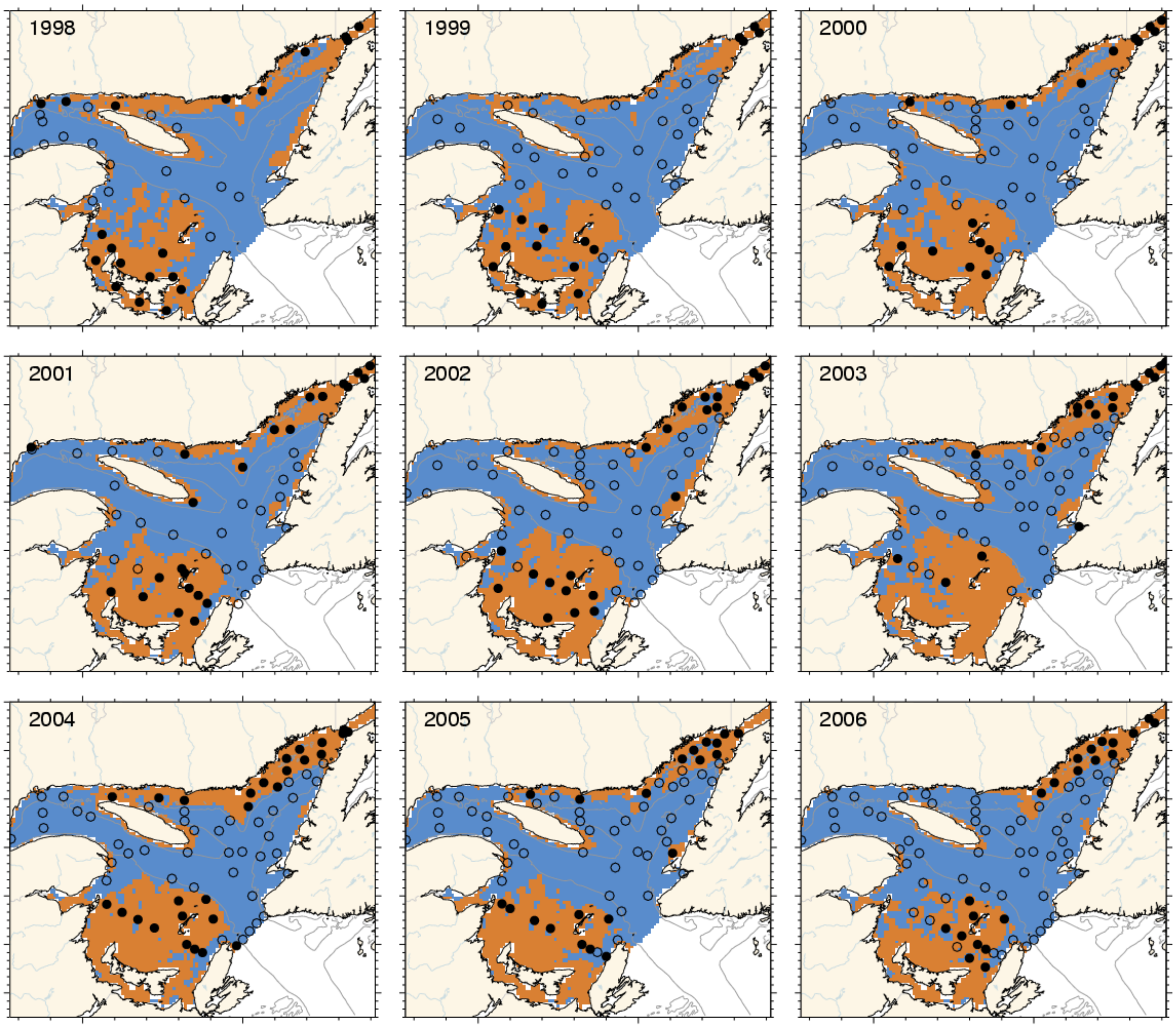


Figure 17. Maps indicating where the cold layer shown in Fig. 16 hits the bottom (in brown). The past 9 years are shown. The stations where the cold layer reached bottom are indicated with solid circle symbols, and open circles represent stations where the layer did not reach to the bottom.

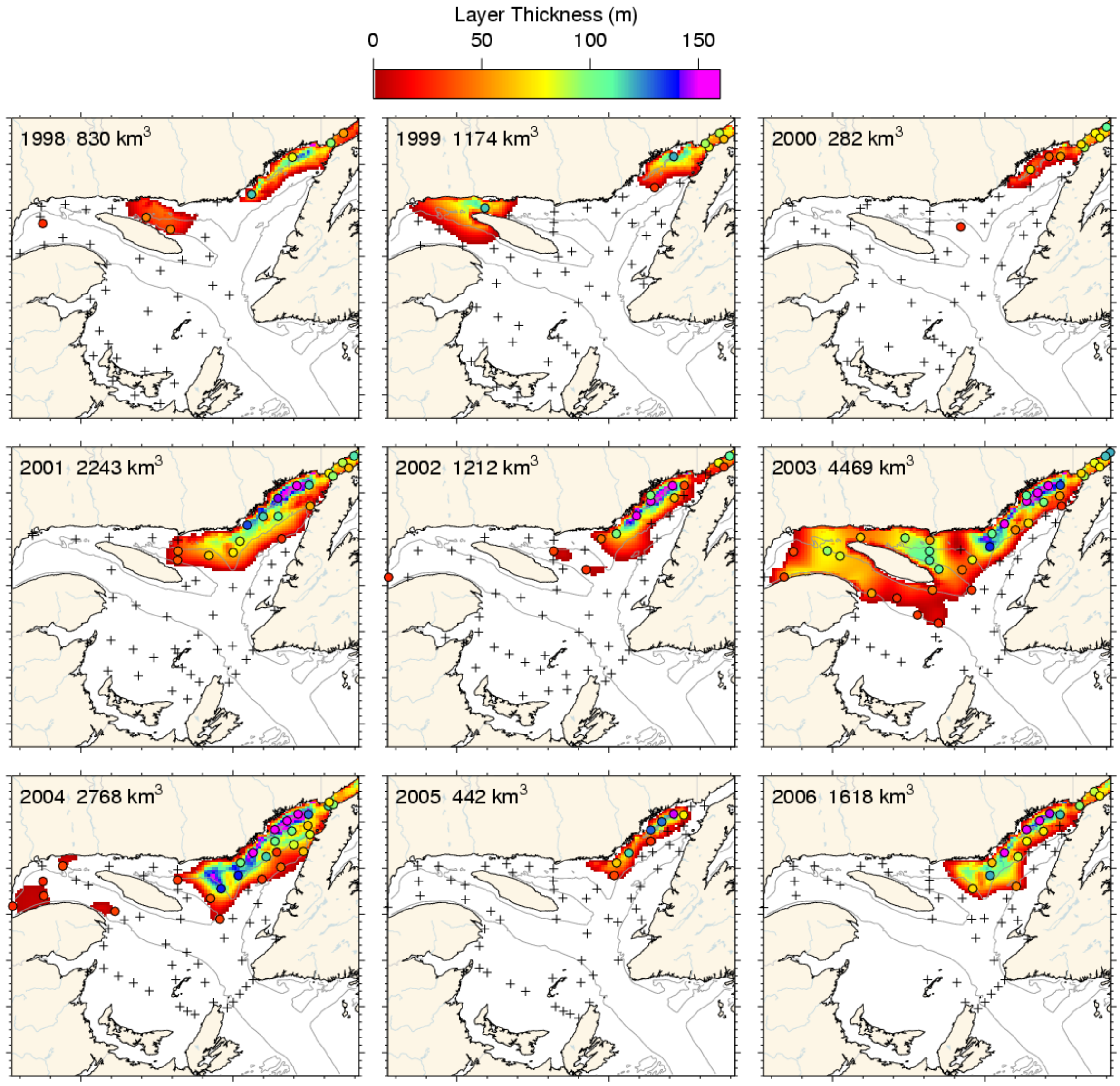


Figure 18. Thickness of the Labrador Shelf water mass layer that has intruded into the Gulf, as observed during the March survey, for the last 9 years. The volume obtained by integrating the thickness over the colour-coded area is shown in each panel.

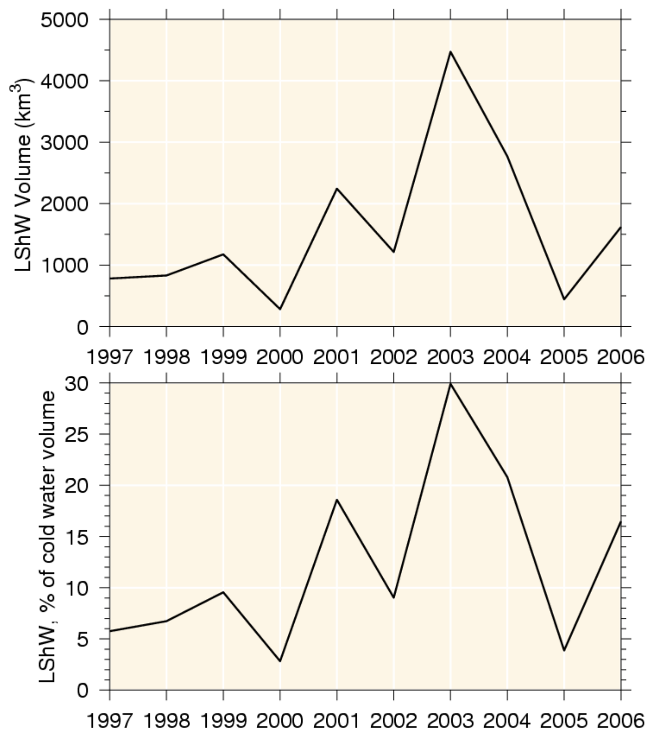


Figure 19. Estimated volume of cold and saline Labrador Shelf water that has flowed into the Gulf over the wintertime through the Strait of Belle Isle.

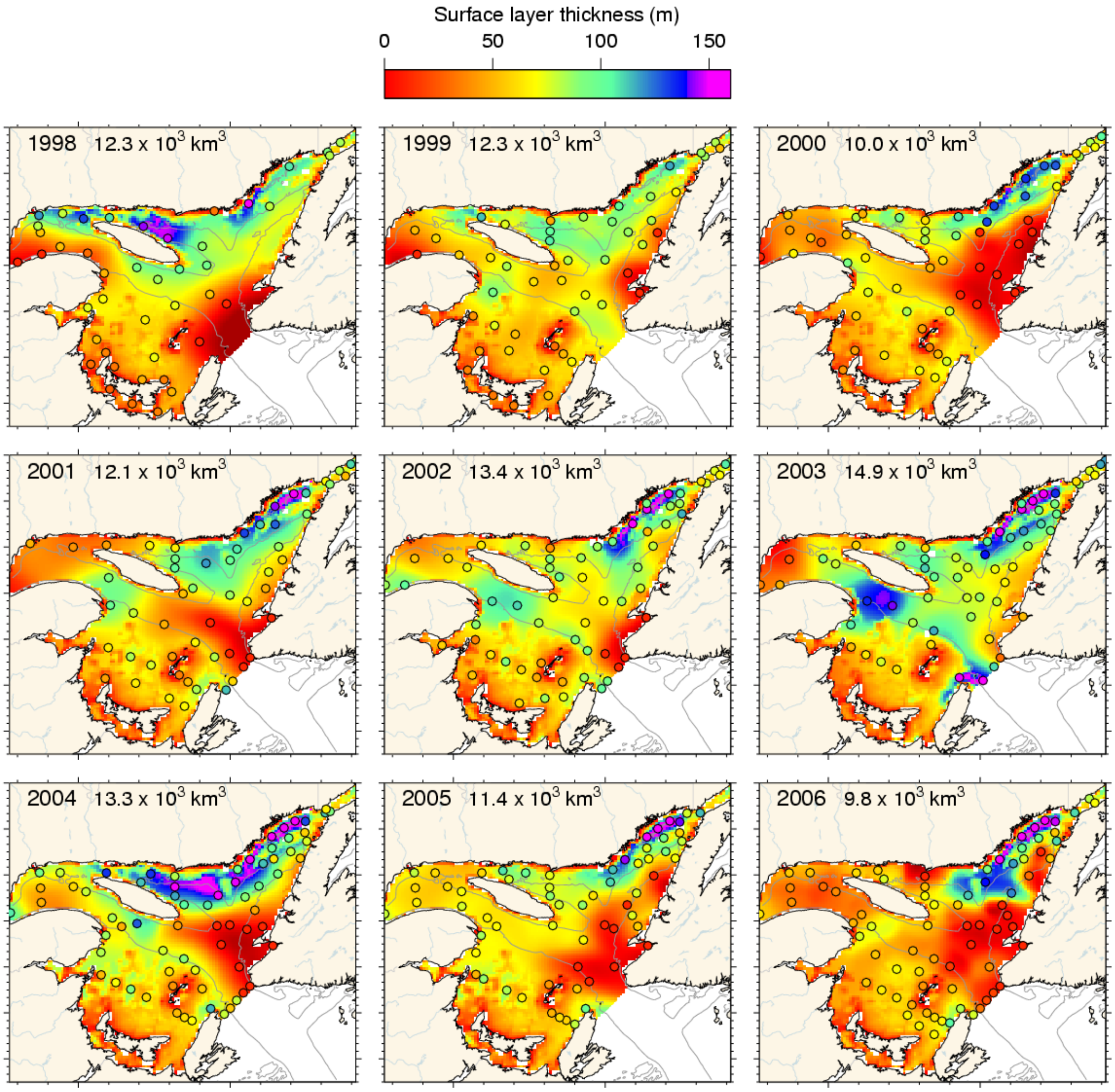


Figure 20. Surface cold water (< -1ºC) layer thickness during the March survey for the past 9 years. The associated cold water volume for each year is indicated in each panel.

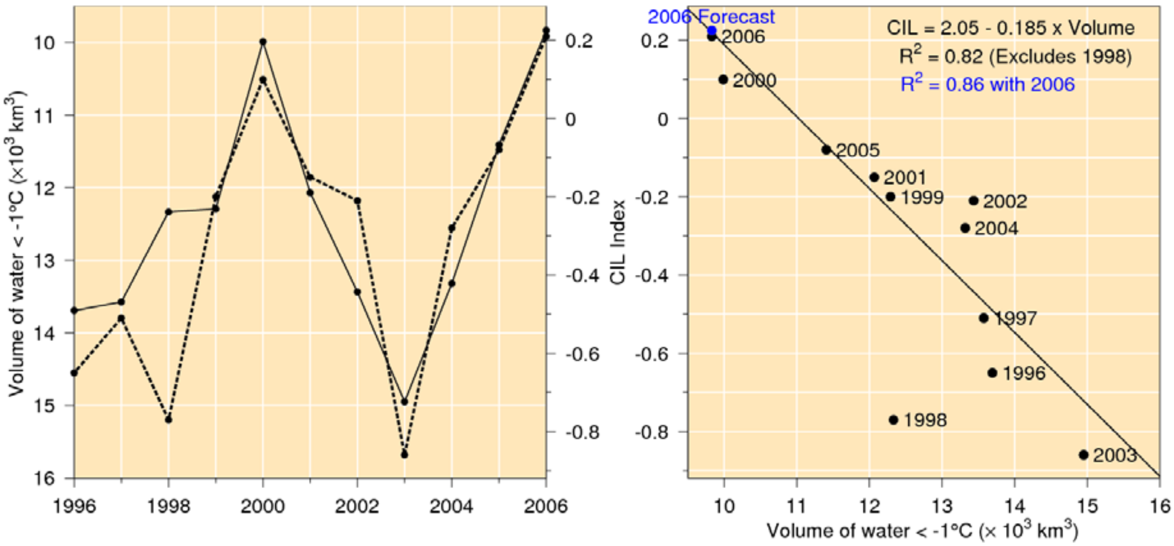


Figure 21. Left panel: Winter surface cold (T < -1°C) layer volume time-series (solid line) and summer CIL index (dashed line). Right panel: Relation between summer CIL index and winter cold water volume. Note that the volume scale in the left panel is reversed. The volume observed in March 2006 forecasted a CIL index of +0.23ºC (in blue) for the summer 2006 (a warming of 0.3 ºC *vs* 2005). The actual CIL index observed later in the year is also indicated (in black).

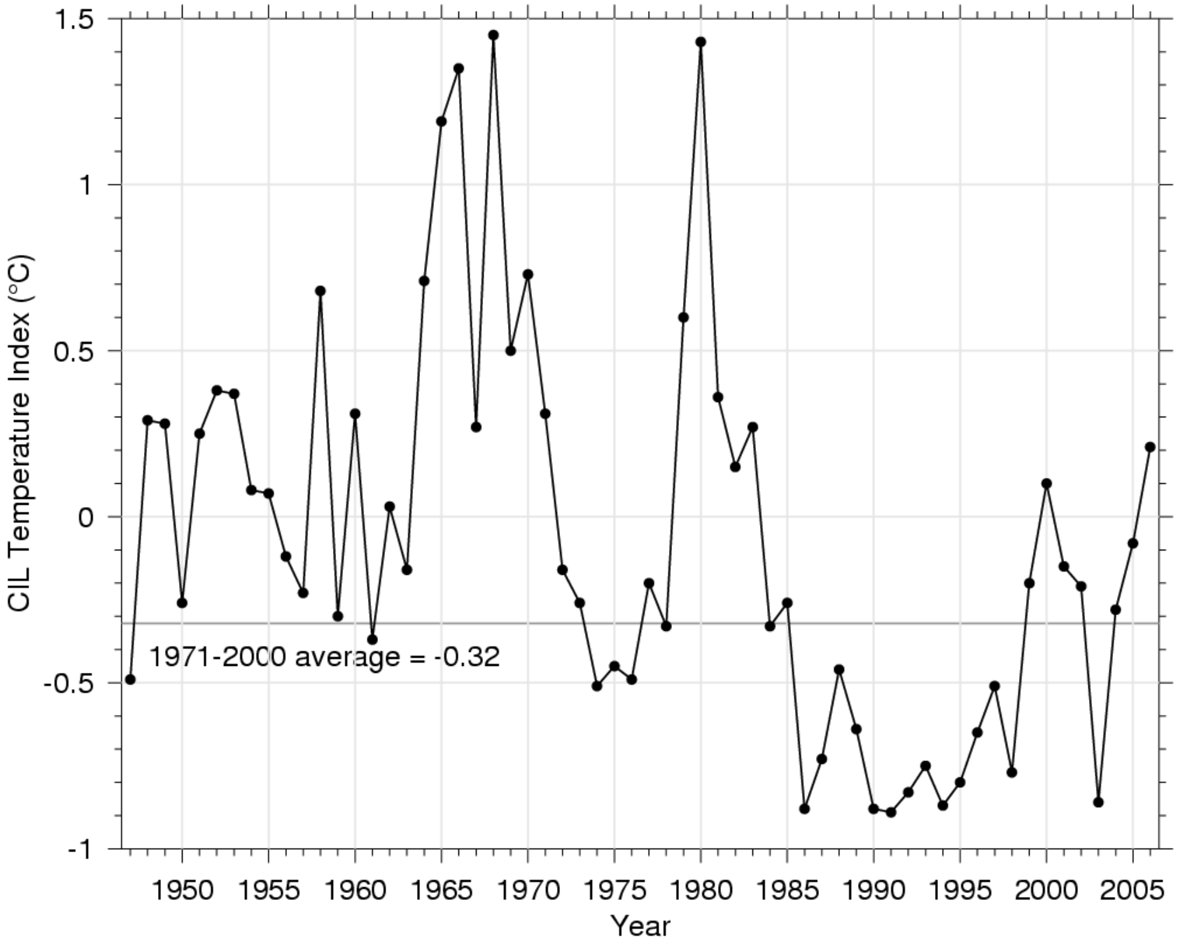


Figure 22. CIL minimum temperature index in the Gulf of St. Lawrence interpolated to July 15.

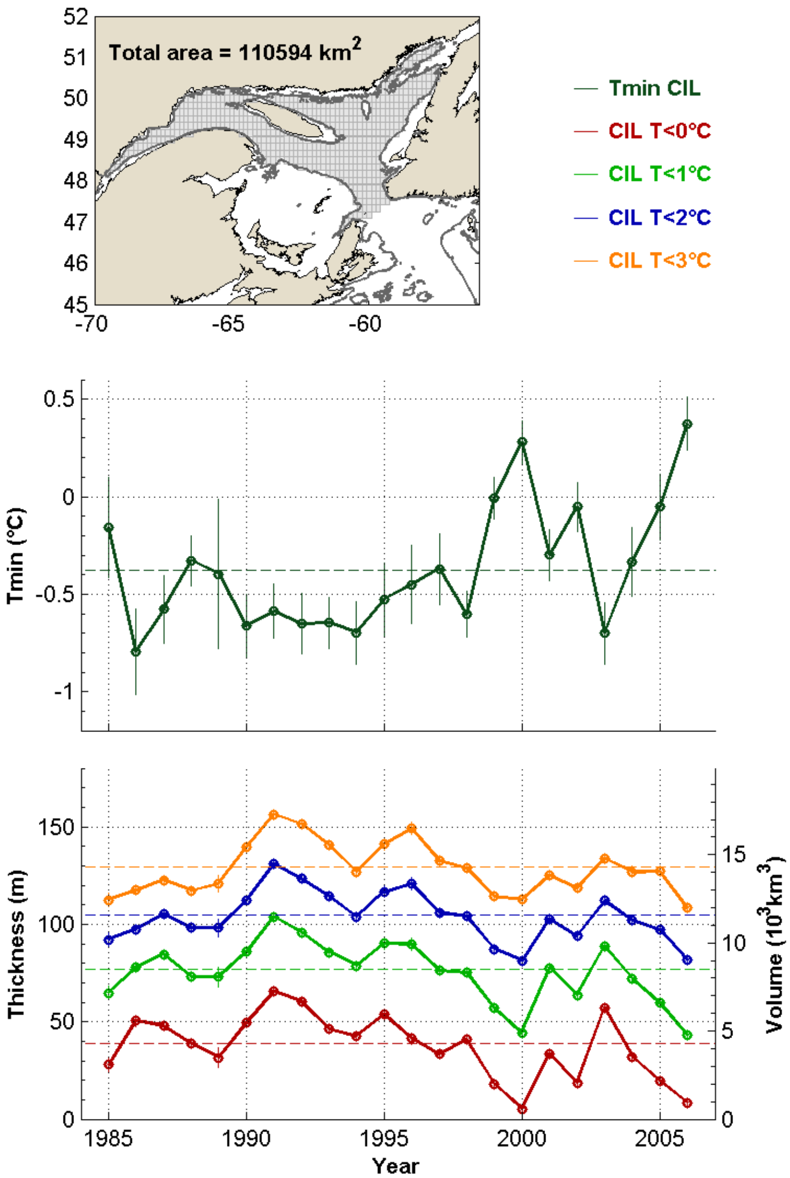


Figure 23. Temperature minimum of the CIL (middle panel) averaged over the gridded area shown (top panel), as well as averaged thickness and volume of the CIL delimited by the top and bottom 0ºC, 1ºC, 2ºC and 3ºC isotherms (lower panel). The dashed horizontal lines are averages for 1985-2006.

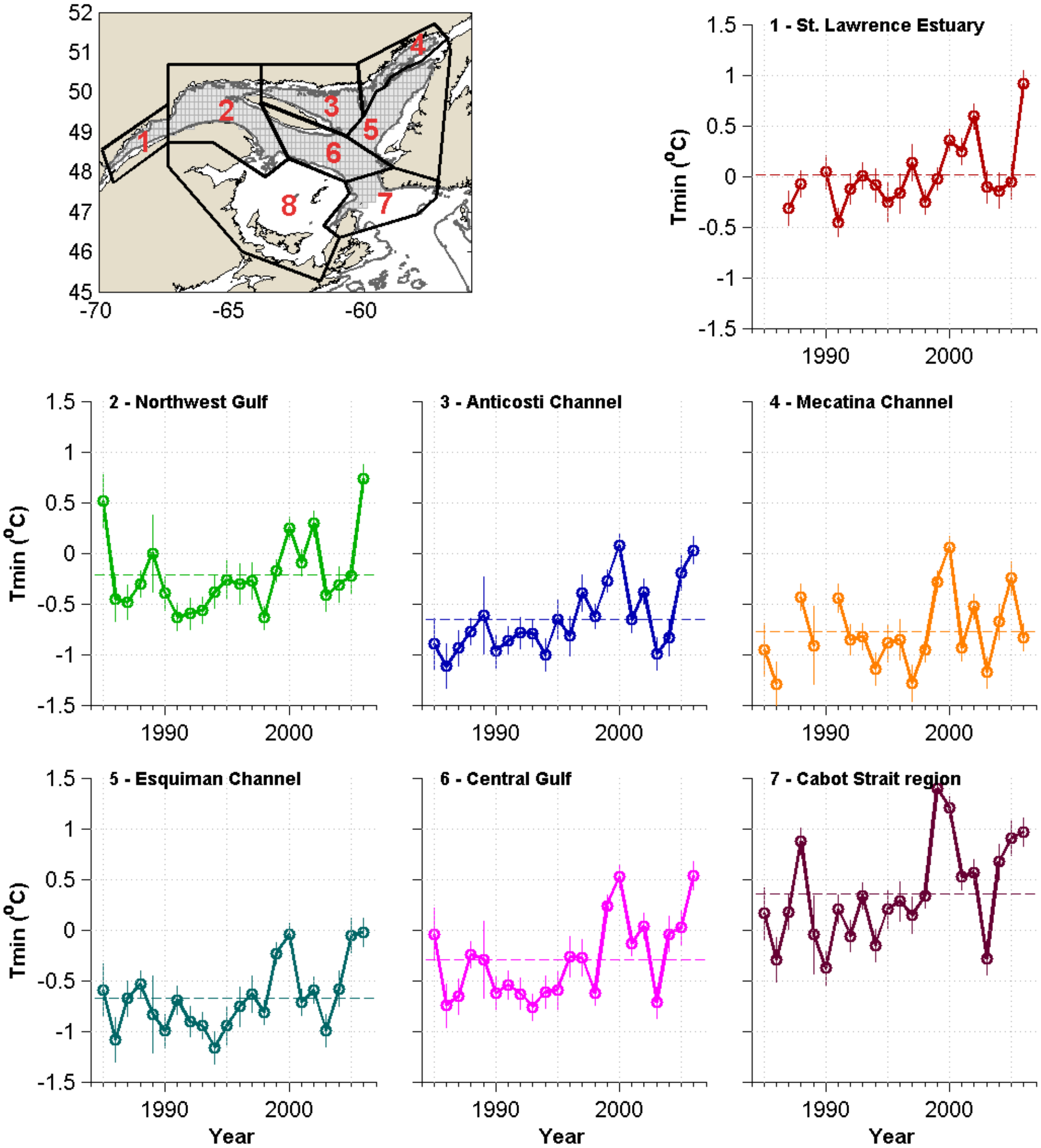


Figure 24. Temperature minimum of the CIL averaged over 7 gridded areas shown (top left panel). The dashed horizontal lines are averages for 1985-2006.

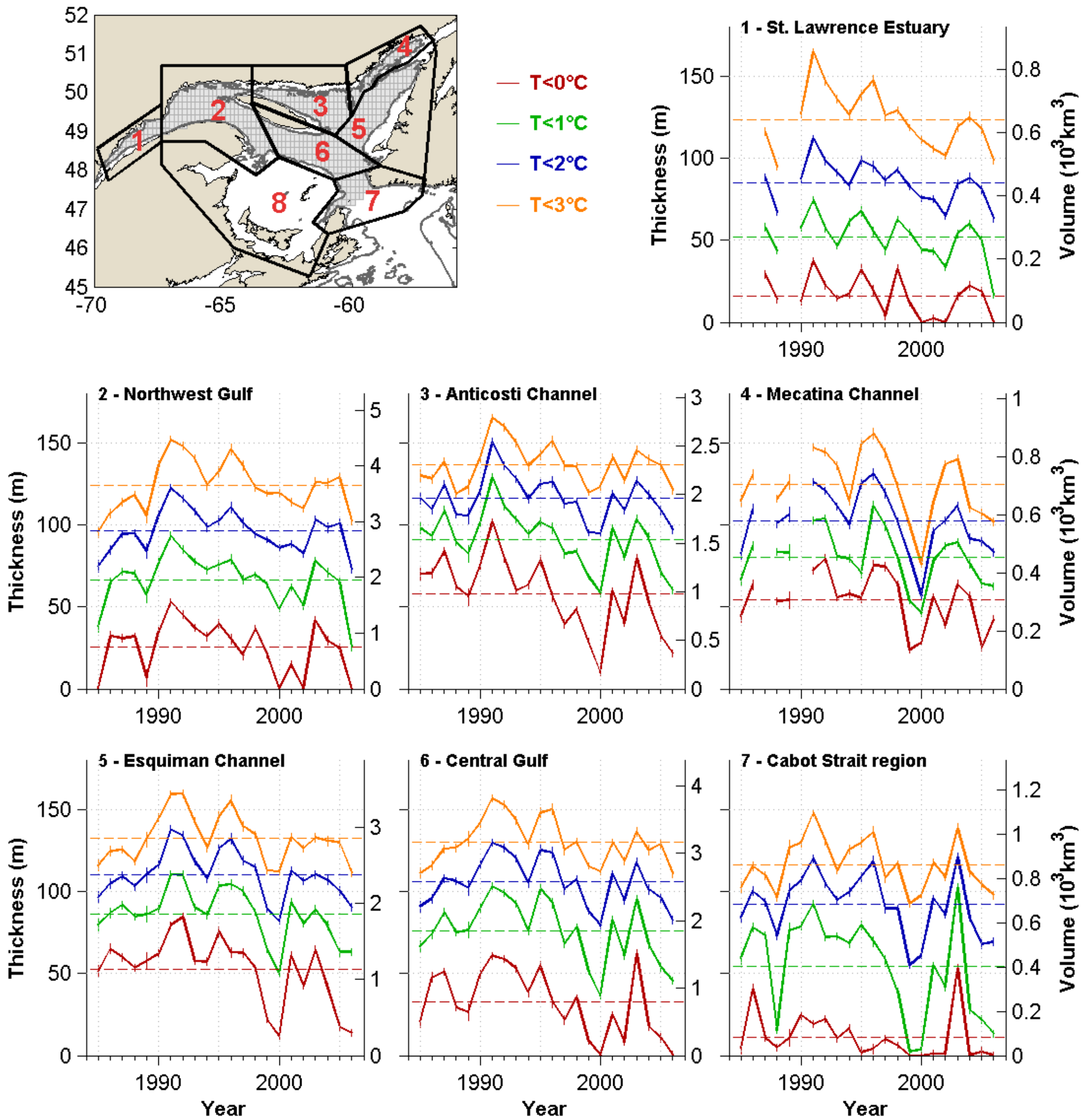


Figure 25. Thickness and volume of the CIL, as delimited by the top and bottom 0ºC, 1ºC, 2ºC and 3ºC isotherms, CIL averaged over 7 gridded areas shown (top left panel). The dashed horizontal lines are averages for 1985-2006.

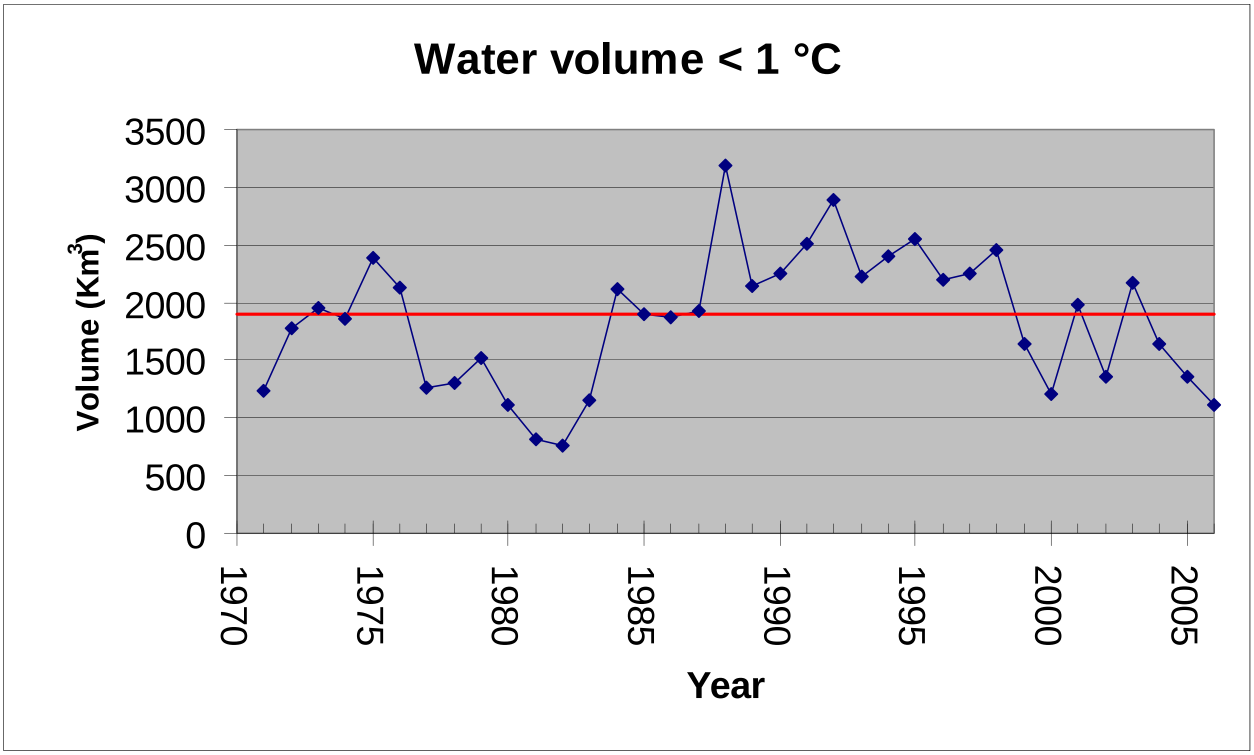


Figure 26. Cold intermediate layer volume (T < 1°C) on the Magdalen Shallows in September. The red line is the 1971-2000 average volume. Since 1971, only the years 1981 and 1982 had lower CIL volumes than in 2006.

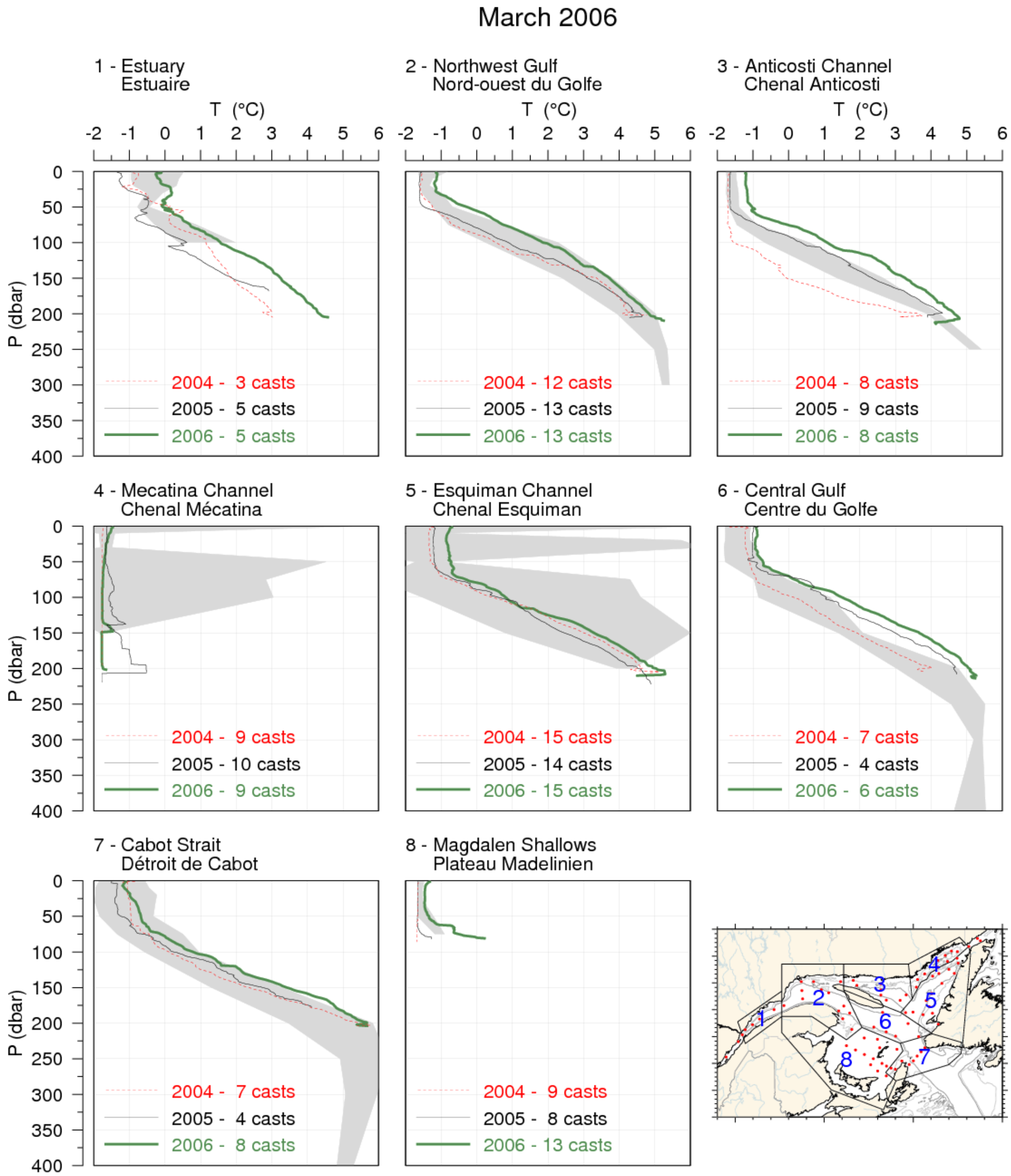


Figure 27. Mean temperature profile observed in each region of the Gulf during the March helicopter survey. The shaded area represents the 1971-2000 climatological monthly mean plus or minus one standard deviation.

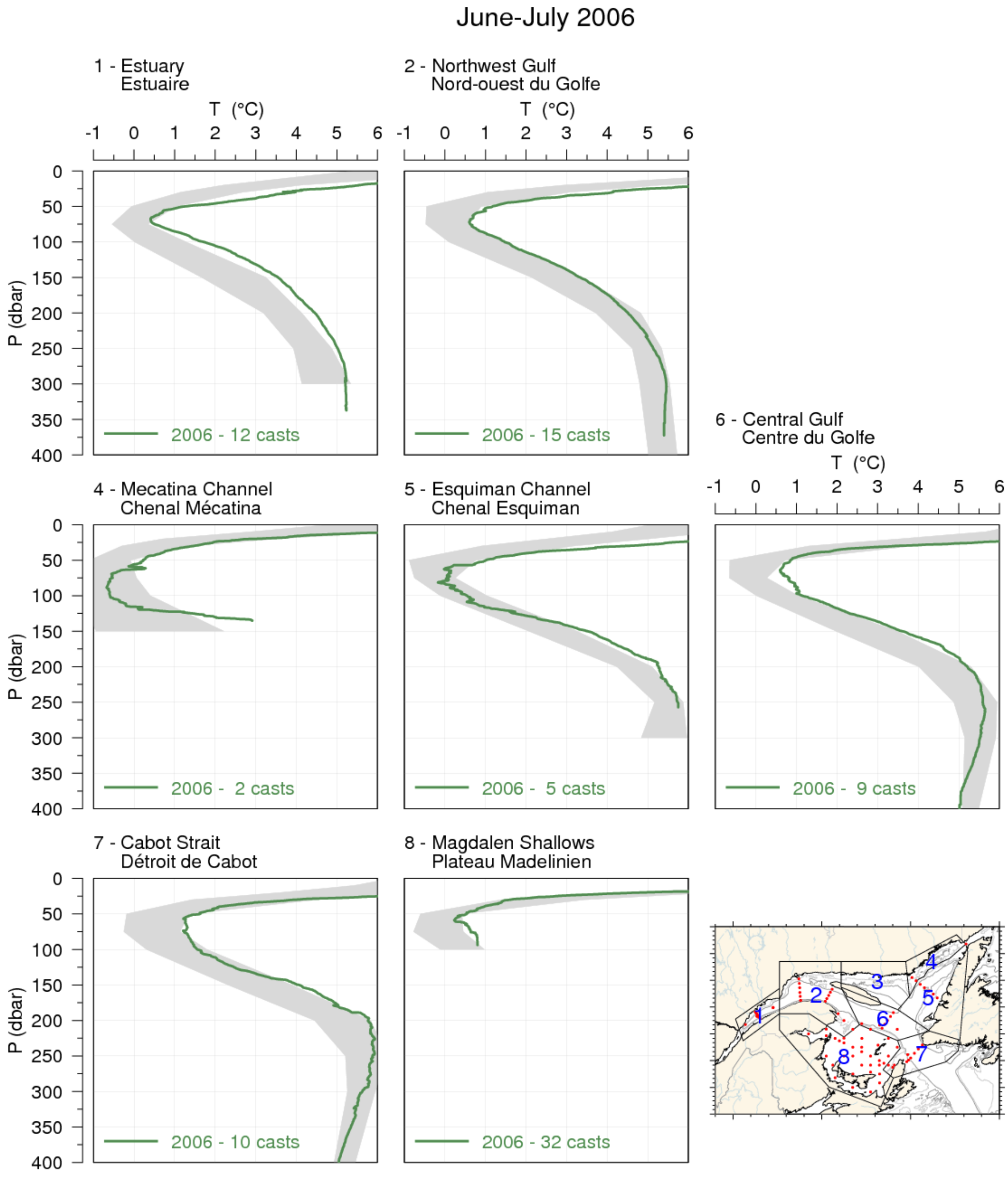


Figure 28. Mean temperature profile observed in each region of the Gulf during the June-July AZMP survey. The shaded area represents the 1971-2000 climatological monthly mean plus or minus one standard deviation.

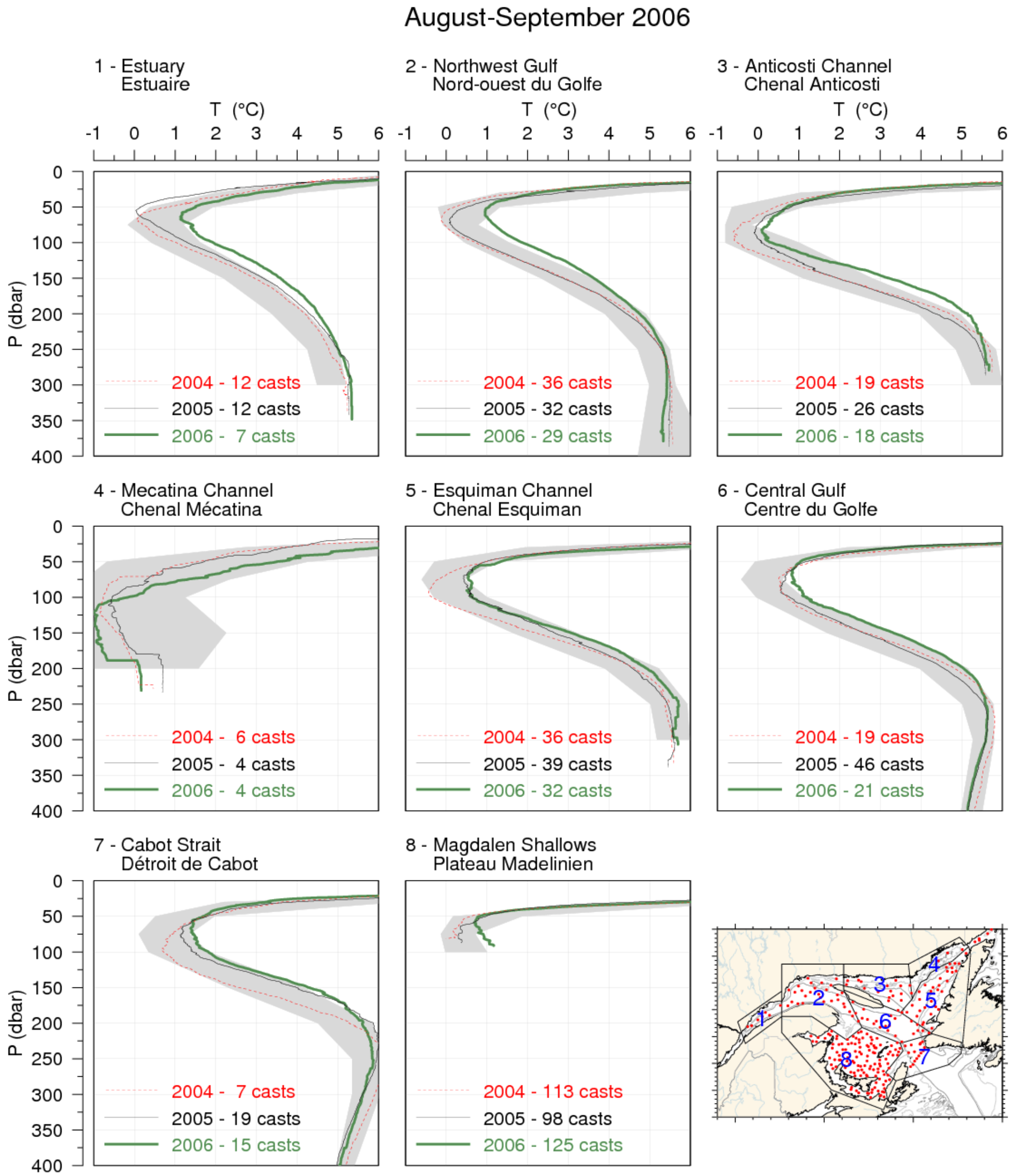


Figure 29. Mean temperature profile observed in each region of the Gulf during the summer groundfish surveys, in August-September. The shaded area represents the 1971-2000 climatological monthly mean plus or minus one standard deviation. Mean profiles for 2004 and 2005 surveys are also shown for comparison.

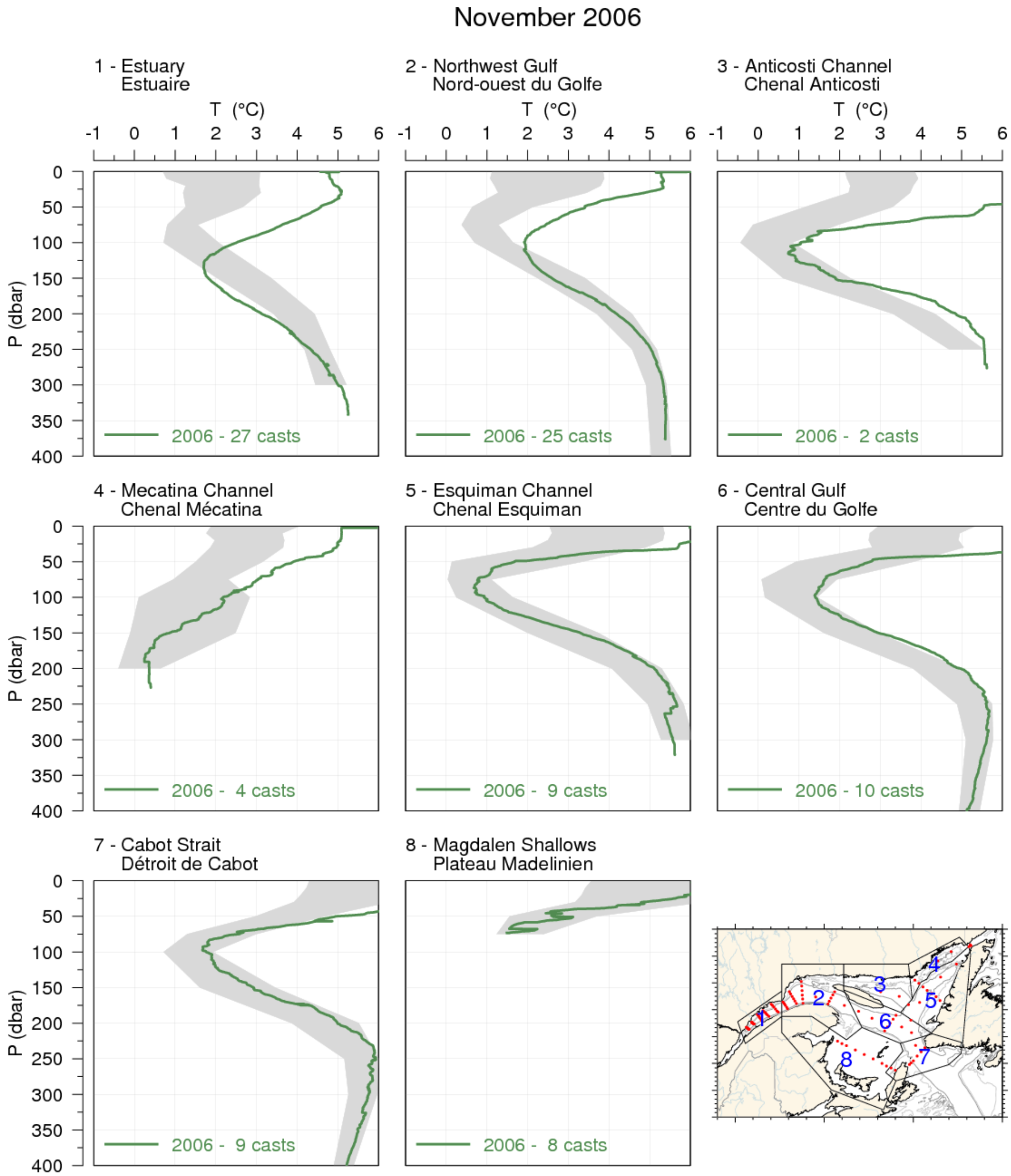


Figure 30. Mean temperature profile observed in each region of the Gulf during the November AZMP survey. The shaded area represents the 1971-2000 climatological monthly mean plus or minus one standard deviation.

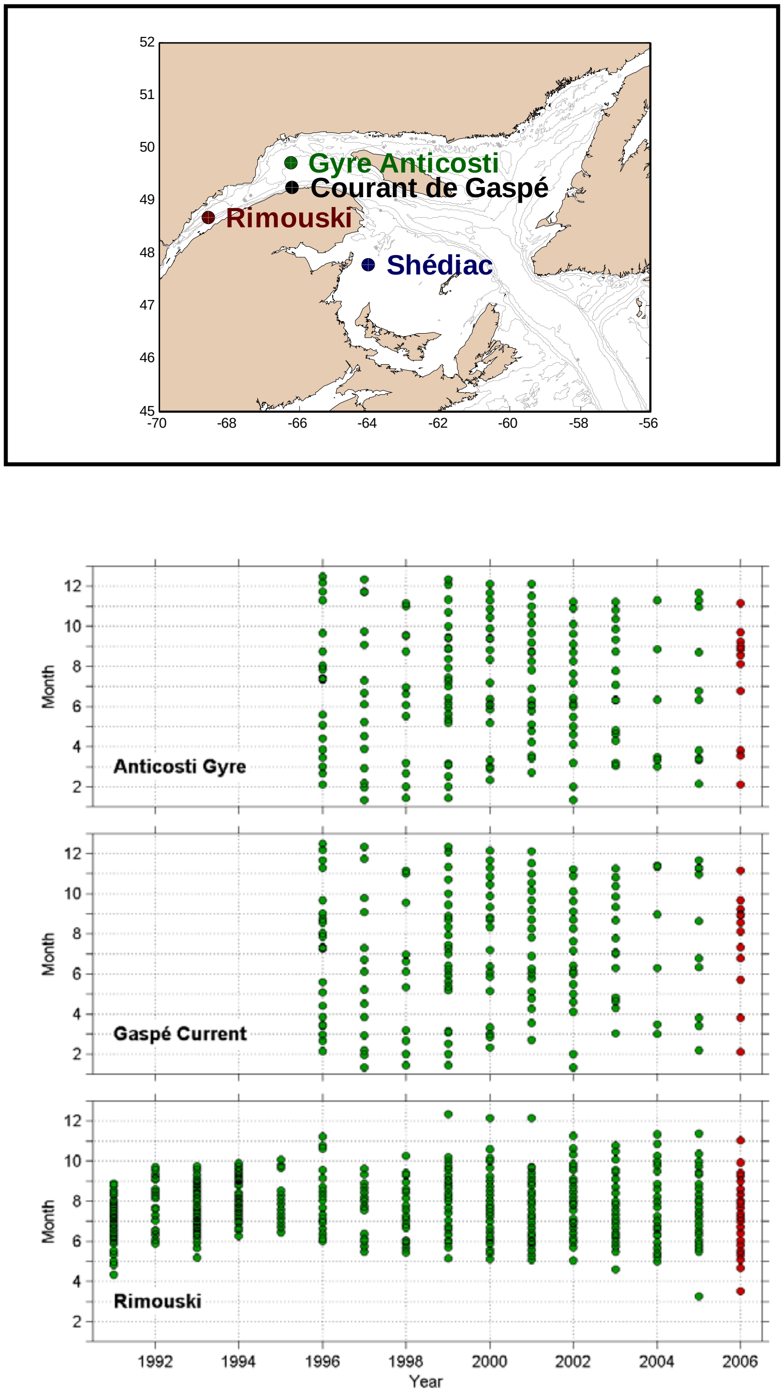


Figure 31. Positions of AZMP and Rimouski stations (top panel) and sampling frequency of Anticosti Gyre, Gaspé Current and Rimouski stations (lower panel).

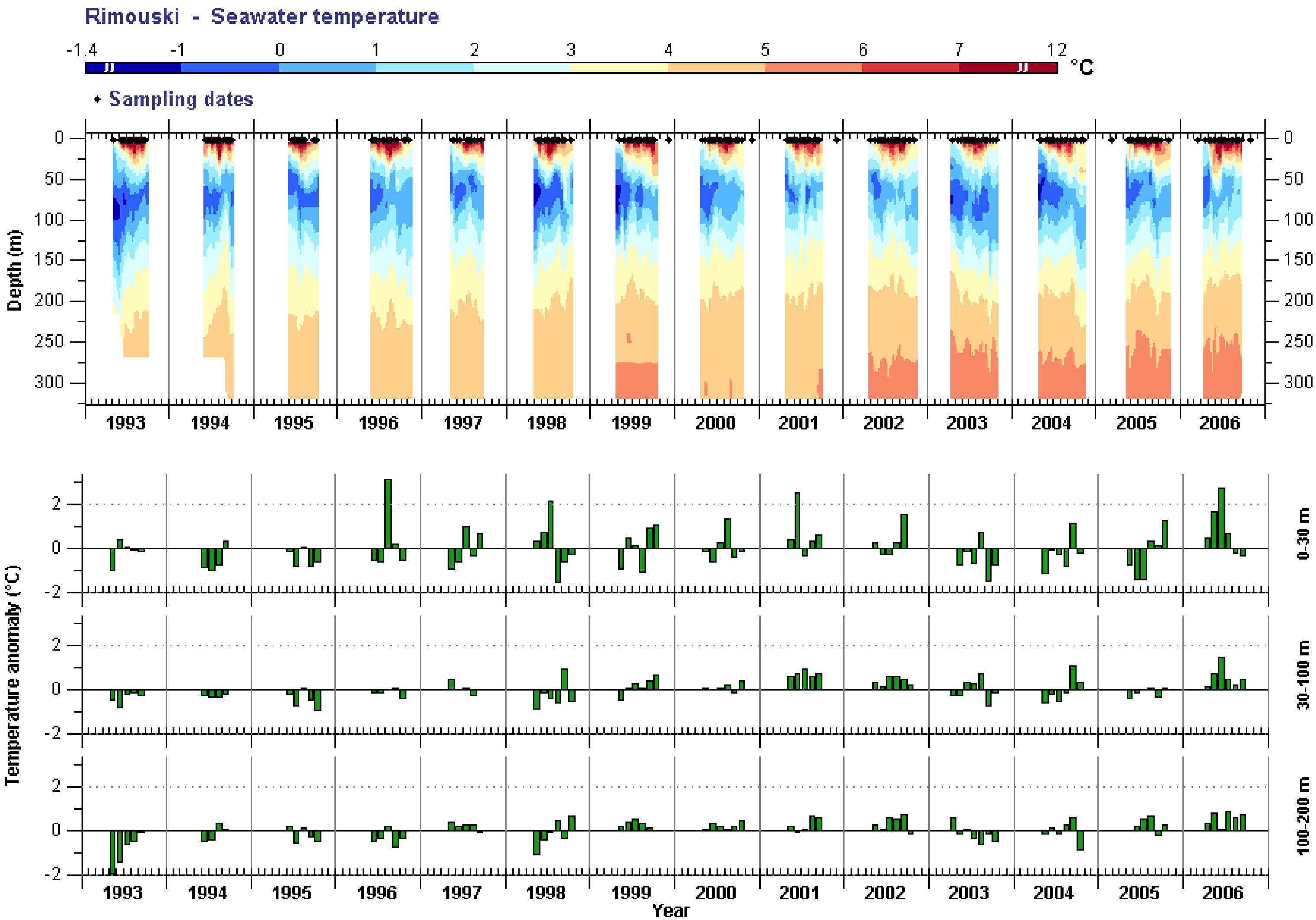


Figure 32. Isotherm time-series at Rimouski station (top panel) and temperature anomaly by depth layers (lower panel).

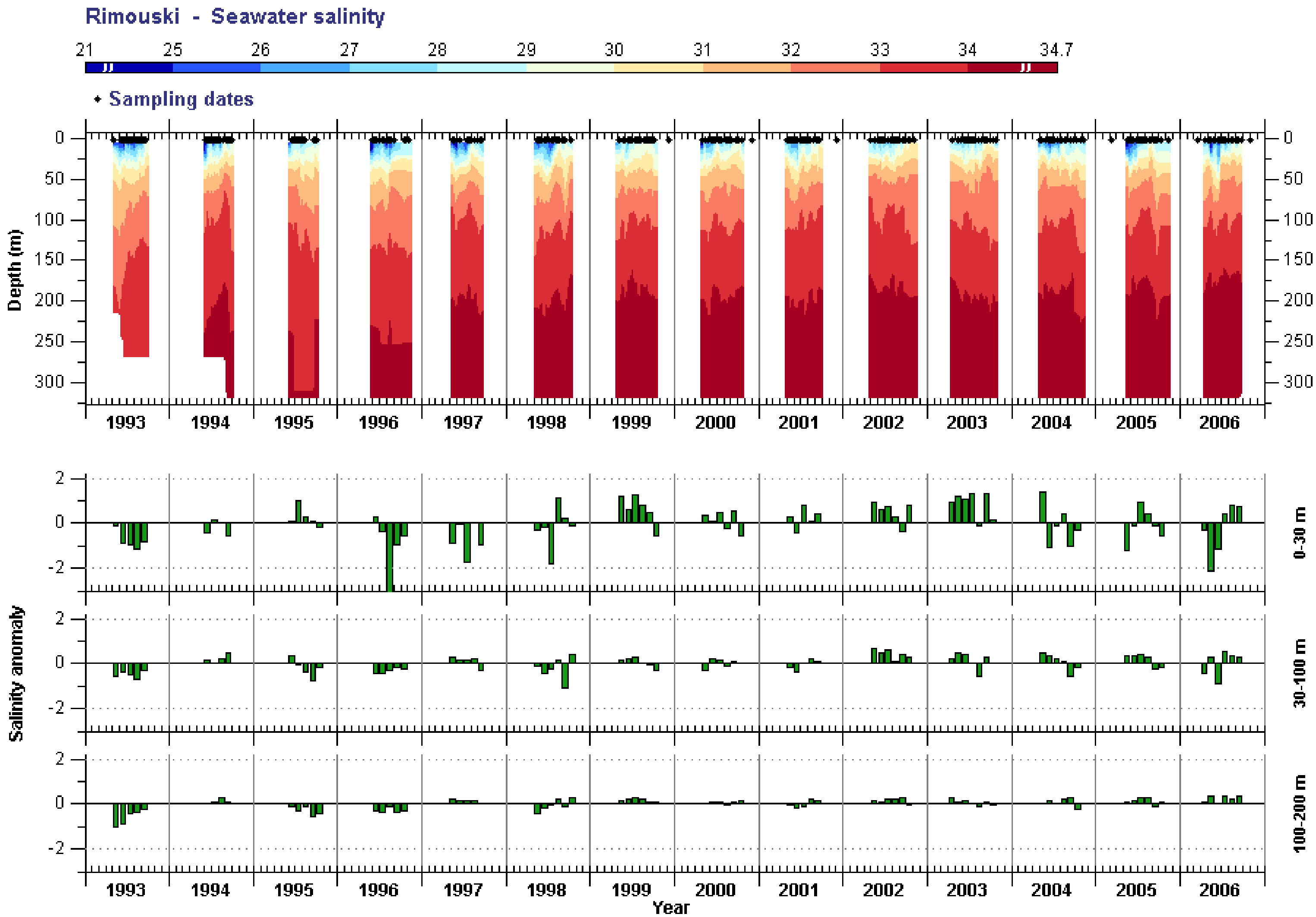


Figure 33. Isohaline time-series at the Rimouski station (top panel) and temperature anomaly by depth layers (lower panel).

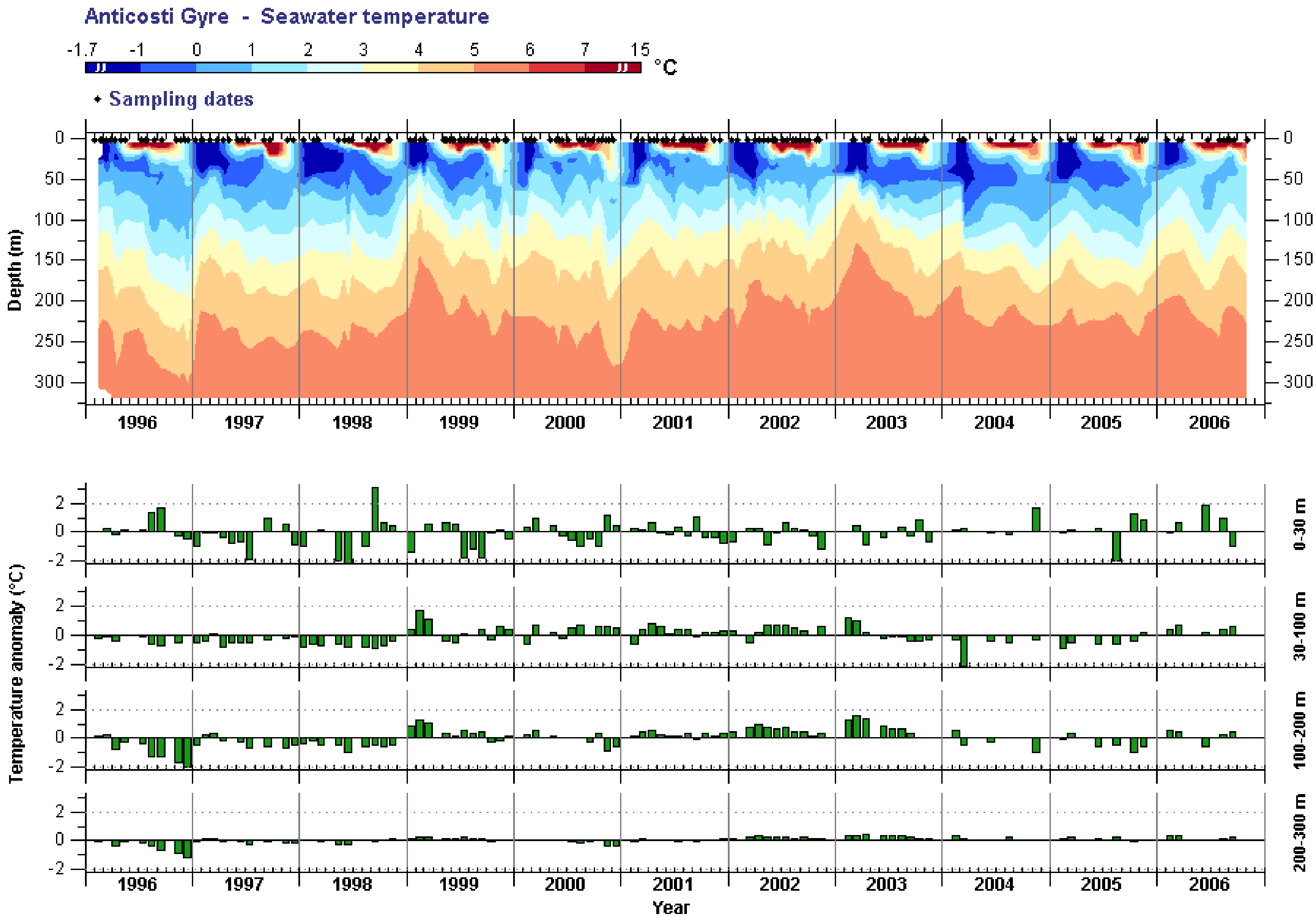


Figure 34. Isotherm time-series at the Anticosti Gyre station (top panel) and temperature anomaly by depth layers (lower panel).

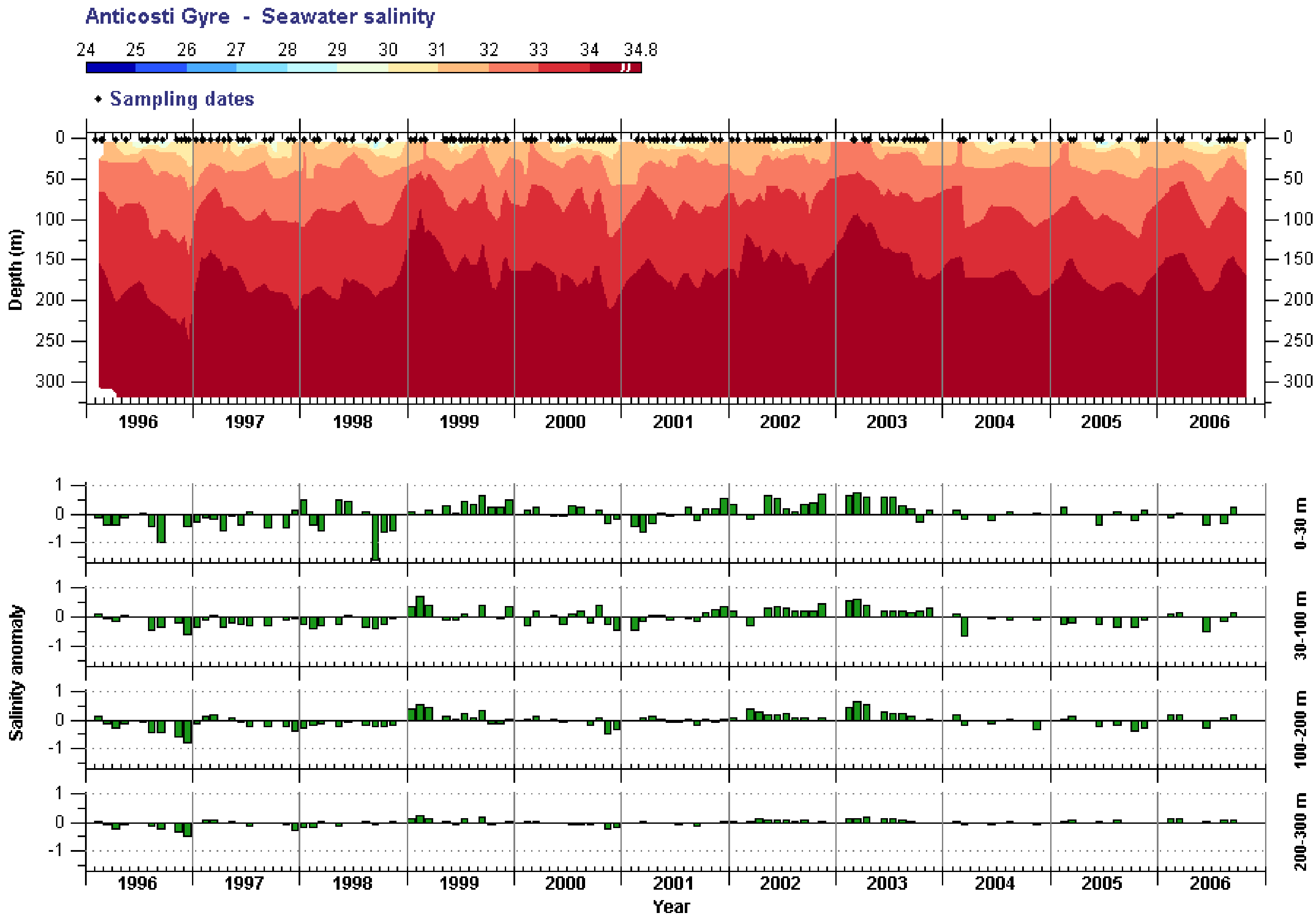

Figure 35. Isohaline time-series at Anticosti Gyre station (top panel) and temperature anomaly by depth layers (lower panel).

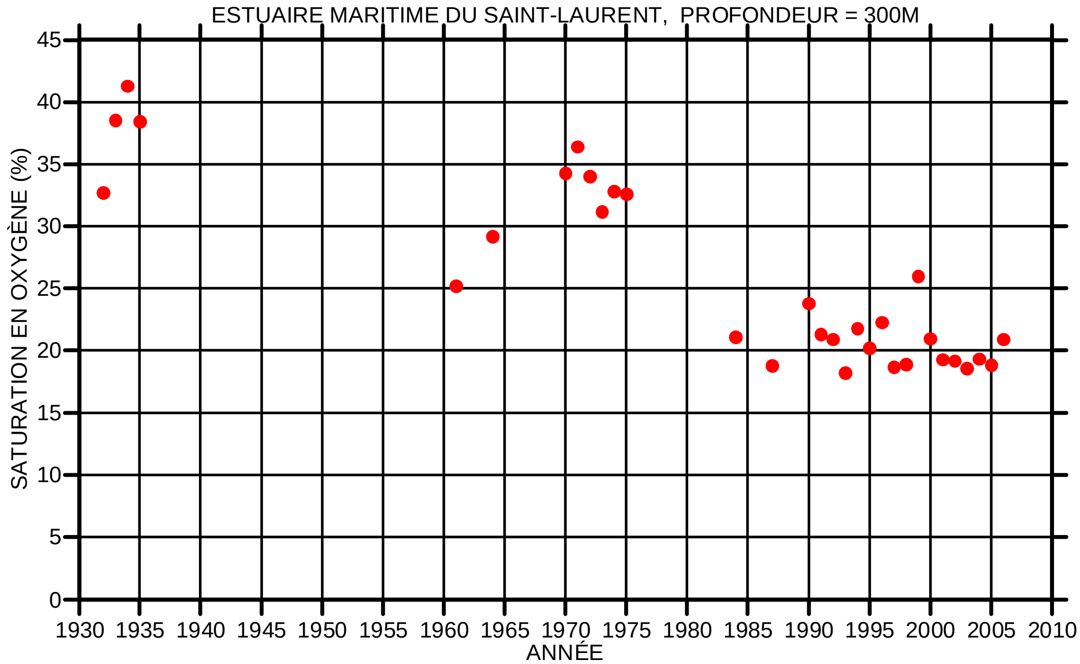


Figure 36. Dissolved oxygen saturation between 300 m and the bottom in the central deep basin of the St. Lawrence Estuary.

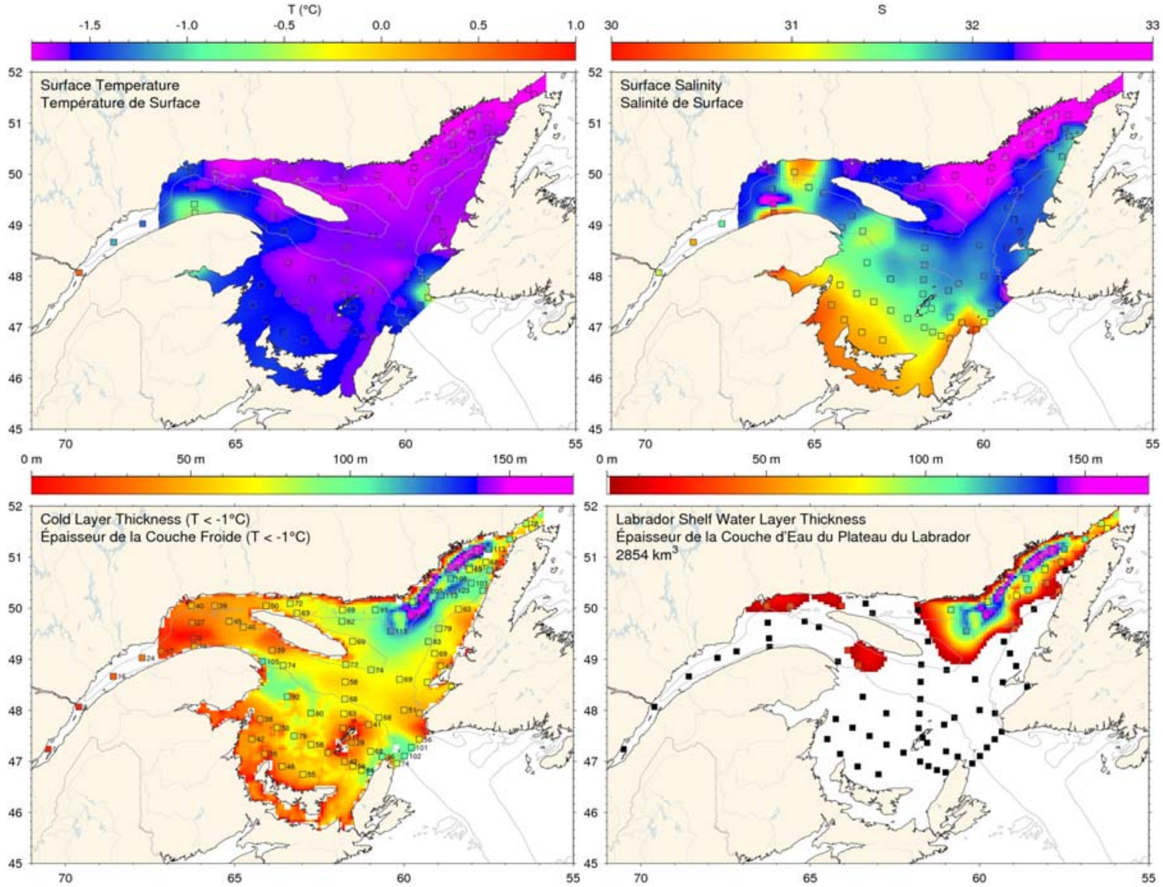


Figure 37. Surface water temperature (upper-left), salinity (upper-right), cold layer (T <- 1°C) thickness (lower-left) and estimate of the thickness of the Labrador Shelf water intrusion (lower-right) for the March 2007 winter survey. The symbols are coloured according to the value observed at the station, using the same colour palette as the interpolated image. A good match is seen between the interpolation and the station observations where the station colours blend into the background.