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Research Document 2008/001

Document de recherche 2008/001

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Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2007

Conditions d'océanographie physique dans le golfe du Saint-Laurent en 2007

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ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

An overview of physical oceanographic conditions in the Gulf of St. Lawrence in 2007 is presented. Air temperatures ranged from normal to cooler than normal for most of the year in the western parts of the Gulf; however, the eastern regions were only significantly cooler than normal in April and May. Averaged over the whole Gulf for the entire year, air temperature was normal. The monthly averaged runoff at Québec City was below normal during all months of 2007. Near-surface water temperatures were much cooler in 2007 overall than in 2006 in all regions of the Gulf. Near-surface waters were warm in the St. Lawrence Estuary in January and February. Summer maximum surface temperatures occurred earlier than usual, followed by earlier-than-usual cooling. Surface temperatures were generally below normal for the rest of the year except for October in the Estuary. On the Magdalen Shallows, there was (almost) no bottom area covered by water with temperatures < 0°C in September 2007. Maximum sea-ice volume within the Gulf and on the Scotian Shelf was below normal but still much higher than the volume recorded in 2006. Winter inflow of cold and saline water from the Labrador Shelf occupied the Mecatina Trough from top to bottom. The spread of the intrusion had an area similar to that of 2006, but its volume was much larger and similar to that observed in 2004. The winter cold mixed layer volume was 13100 km^3, slightly above the 1996–2007 average, and corresponded to 39% of the total water volume of the Gulf. The higher winter volume of cold water compared with 2006 conditions led to a decrease of 0.44°C in the Cold Intermediate Layer (CIL) index, reaching -0.23°C in summer 2007, which is comparable to conditions observed in 2004. The index saw a large decrease after three consecutive years of warming. Regional patterns of the CIL show that the layer for T < 1°C and < 0 °C was much thicker in the northern half of the Gulf in 2007 than in 2006 and had a generally lower core temperature almost everywhere as well. Seasonal and regional patterns of water column temperatures in June were generally close to the 1971–2000 climatology at all depths, except for the very thick and cold CIL in the Anticosti Channel and warm deep waters in the northwest. This overall pattern persisted from August to September, but by late fall conditions were about normal everywhere except for the anomalously warm near-surface mixed layers in the northwest and warm near-surface waters on the Magdalen Shallows and in Cabot Strait. Averaged annually for the entire Gulf, the temperature and salinity from 150 m to 300 m were normal in 2007. Spatially, at 300 m, this was composed of warmer than normal waters near the Estuary, near-normal temperatures in the centre and colder than normal waters coming into the Gulf at Cabot Strait. The outlook for 2008 from the March 2008 survey is for a slight cooling of the CIL index to -0.47°C resulting from a thicker cold winter surface layer.

RÉSUMÉ

Les conditions d'océanographie physique dans le golfe du Saint Laurent en 2007 sont brièvement présentées. Les températures de l'air étaient généralement normales, ou inférieures à la normale, dans les parties ouest du Golfe. Par contre elles n'ont été sous les normales mensuelles qu'en avril et mai dans les parties est du Golfe. Moyennée sur toute l'année sur l'ensemble du Golfe, la température de l'air était normale. Le débit mensuel d'eau douce à Québec a été sous la normale durant toute l'année 2007. Les températures de surface de l'eau ont été plus froides en 2007 qu'en 2006. Des redoux au début janvier et encore en février ont causé des températures de surface au-dessus du point de congélation dans l'estuaire. Les maximums de température de surface estivale sont survenus plus tôt que la normale et ont été suivis d'un refroidissement plus hâtif. Les températures de surface ont alors été généralement sous la normale pour le reste de l'année sauf en octobre dans l'estuaire. Sur le Plateau madelinien, il n'y a presque pas eu d'eau plus froide que 0 °C au mois de septembre. Le volume de glace de mer durant l'hiver a été sous la normale, mais quand même beaucoup plus qu'en hiver 2006. L'intrusion hivernale d'eau froide et salée par le détroit de Belle Isle a occupé la fosse de Mecatina de la surface jusqu'au fond. L'étendue de l'intrusion était similaire à celle de 2006, bien que son volume en fût beaucoup plus grand et semblable à celui observé en 2004. Le volume de la couche mélangée d'eau froide hivernale était de 13100 km³, légèrement au-dessus de la moyenne 1997–2007, et correspondait à 39 % du volume d'eau total dans le Golfe. Cette couche mélangée plus profonde qu'en hiver 2006 s'est traduite par une baisse de 0,44 °C de l'indice de la couche intermédiaire froide (CIF) pour l'été 2007, après trois années consécutives de hausses. Celui-ci a atteint -0,23 °C, similaire aux conditions de 2004. La distribution régionale de la CIF indique que les couches sous 1 °C et 0 °C étaient plus épaisses dans le nord du Golfe en été 2007 qu'en 2006, et que le minimum de température était aussi généralement plus froid presque partout. La distribution saisonnière et régionale de la température de la colonne d'eau montre que la période de juin était relativement près des normales climatologiques de 1971–2000 à toutes les profondeurs, exception faite de l'épaisse et froide CIF dans le chenal Anticosti et des eaux profondes chaudes dans le nord-ouest. Ce patron a persisté en août et septembre mais les conditions sont revenues à la normale à la fin de l'automne, excepté pour la couche mélangée de surface chaude dans le nord-ouest et les eaux de surface chaudes sur le Plateau madelinien et dans le détroit de Cabot. Moyenné annuellement et pour l'ensemble du Golfe, la température et la salinité de 150 à 300 m étaient normales en 2007. Spatialement, cette normale à 300 m était composée d'eaux plus chaudes que la normale dans la région de l'estuaire, d'eaux de températures normales dans le centre plus, et d'eaux froides que la normale dans le détroit de Cabot. L'épaisseur de la couche de surface froide mesurée lors de la mission de mars 2008 nous laisse prévoir des conditions estivales 2008 de la CIF légèrement plus froide qu'en 2007, avec un indice de -0,47 °C.

INTRODUCTION

This paper examines the physical oceanographic conditions in the Gulf of St. Lawrence (Fig. 1) in 2007 and some atmospheric forcing. Specifically, it discusses air temperature, sea-ice volume, surface 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. It uses data obtained from the Department of Fisheries and Oceans' (DFO) Atlantic Zone Monitoring Program (AZMP), other DFO surveys and other sources. Environmental conditions are usually expressed as anomalies, i.e., deviations from their long-term mean or normal conditions calculated for the 1971–2000 reference period when possible. Furthermore, because these series have different units (^{o}C, m^3, m^2, etc.), each anomaly time series is normalized by dividing by its standard deviation (SD) which is also calculated using data from 1971-2000 when possible. This allows a more direct comparison of the various series. Missing data are represented by grey cells, values within 0.5 SD of the average as white cells, and conditions corresponding to warmer than normal (higher temperatures, reduced ice volumes, reduced cold water volumes or areas) by more than 0.5 SD as red cells, with more intense reds corresponding to increasingly warmer conditions. Similarly, blue represents colder than normal conditions. Higher than normal freshwater inflow and stratification are shown as red.

The last detailed report of physical oceanographic conditions in the Gulf of St. Lawrence was produced for the year 2006 (Galbraith et al. 2007).

AIR TEMPERATURE

The monthly air temperature anomalies for several stations around the Gulf are shown in Fig. 2. The 1971–2000 monthly climatologies expressed as the mean plus or minus one standard deviation are also shown for each station as well as tables showing the temperature anomaly for each month (see Table 1 for colour code). The western parts of the Gulf experienced mostly normal (normal is a value within ±0.5 SD) or cooler-than-normal temperatures for the greater part of 2007, contrasting with the very warm conditions in 2006. However, the three easternmost stations were only cooler than normal (by more than half of the standard deviation) in April, May and December. October was very warm almost everywhere, and December was cool. As will be shown in later sections, this pattern was observed in near-surface water temperatures as well.

The annual mean temperature time series are shown in Table 1. Annual mean air temperatures were either normal or slightly above normal at all stations, contrasting with the temperatures much above normal in 2006. The average of the nine stations provides an overall temperature index for the entire Gulf. It was normal in 2007 (only 0.1 × standard deviation above normal). A bulk air-temperature winter-severity index was also constructed in Table 1 by averaging the air temperature of all stations except Cap-aux-Meules (time series too short) from January to March of each year. It also was only slightly above normal in 2007 (by 0.3 × standard deviation).

PRECIPITATION AND FRESHWATER RUNOFF

Runoff data were obtained from the OSL (*Observatoire du Saint-Laurent* / St. Lawrence Observatory web site, www.osl.gc.ca), where they are updated monthly by D. Lefaivre (Institut Maurice-Lamontange, DFO using the water level method from Bourgault & Koutitonsky (1999). The monthly averaged runoff measured at Québec City was consistently below normal in 2007 (Fig. 3), and only the runoffs for January and March were within 0.5 × standard deviation of the mean. The annual mean is 1.5 standard deviations below normal, comparable to values observed from 2001 to 2003 (from -1.4 to -2.1 × standard deviation) but higher than the record low conditions observed from 1962 to 1965 (from -2.5 to -3.1 × standard deviation).

SURFACE LAYER

The surface layer conditions of the Gulf are monitored by various methods that complement each other. The shipboard thermosalinograph network provides year-round, near real-time coverage (except for occasional equipment failures) and is especially useful for monitoring the winter freeze-up. Its drawbacks are that it provides data along the main shipping route only and that semi-weekly ship tracks are irregular both in time interval and in the position where each longitude is crossed. The thermograph network is inexpensive and provides a growing record of near-surface temperature at fixed stations and at short time intervals, but not (for the most part) in real-time. It is very helpful in providing information in the southern Gulf and the northeast in areas not sampled by the thermosalinograph network. It also provides station climatologies based on longer time spans than the thermosalinograph network. NOAA satellite remote sensing is the third tool; it will be used more extensively in upcoming years once a climatology is completed and anomaly maps can be produced.

Shipboard thermosalinographs

The shipboard thermosalinographs were described by Galbraith et al. (2002) and by Gilbert et al. (2004). To summarize, thermosalinographs (SBE-21; Sea-Bird Electronics Inc., Bellevue, WA) have been installed on various ships starting with the commercial ship *Cicero* of Oceanex Inc. in 1999 (retired in 2006) and the *Cabot* since 2006. Oceanex ships sail year-round between Montréal and St. John's, NL, making a return trip once per week. Near-surface (3 m) water temperature and salinity are sampled using the shipboard thermosalinographs. The data are presented in near real-time on the St. Lawrence Observatory website (www.osl.gc.ca).

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 2007. Data were used from any instrumented ship within the main shipping route area 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. The most striking feature is the area at the head of the Laurentian Trough (69.5°W), where strong vertical mixing leads to cold summer water temperatures (around 5 to 6°C and sometimes lower) 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 eastward with time, usually just reaching Cabot Strait by the end of the winter.

Fig. 4 also shows the water temperature composite for 2007 and its anomaly. Sporadic winter thaws occurred in the St. Lawrence Estuary in early January and again in February that explain the above-freezing surface waters. After a rather uneventful spring, the summer maximum temperatures occurred earlier than usual everywhere in the Gulf (early August instead of mid-August). Earlier-than-usual cooling followed the maximum, and temperatures were below normal for the remainder of the year, especially in September, except for warm conditions in the Estuary in October.

Temperature time series and 2000–2007 climatologies were constructed for selected sections that are crossed by the ship (Table 2). Table 2 shows how different the near-surface temperature climatologies are at Tadoussac (head of the Laurentian Trough) compared to those nearby in the Estuary, as noted above. Winter temperatures are on average 0.7℃ warmer at the Tadoussac section; the maximum monthly mean temperature in summer is only 6.5℃ compared to 8.4℃ at the nearby Estuary section and up to 13.2℃ at the Mont-Louis section. The table provides a quick look at the inter-annual near-surface temperature variations at the selected sections as well as monthly averages for the year in review. The table highlights the same patterns described from Fig. 4, including above-average temperatures in February and October in the Estuary and the otherwise generally normal or cool temperatures at other times and elsewhere in the Gulf. The table also shows the cool contrast of 2007 compared to the very warm conditions observed in 2006.

Thermograph network

The thermograph network was described in a previous report (Gilbert et al. 2004) with updates described in Galbraith et al. (2007). The network consists of 23 stations with moored instruments measuring and logging 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. Twenty-two stations (Figure 5) have sufficiently long time series to permit the calculation of daily climatologies with standard deviations. The raw data from the thermograph network and various figures are available from the St. Lawrence Observatory (www.osl.gc.ca).

In order to compare the 2007 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. Daily averages for all stations are shown in Fig. 6, Fig. 7 and Fig. 8 along with daily climatologies (plus or minus one standard deviation). Table 3 lists the average monthly temperatures for each station and depth. The colour-coding of the scorecard is done according to the normalized anomalies using each station's climatology for individual months.

The Estuary near-surface water temperatures were above normal in October and below normal in September, as previously noted with the thermosalinograph network data. However, while near-surface waters in July and August were generally cool, the pattern is more variable than suggested from the thermosalinograph network (which is based on a shorter climatology and a longer sampling interval of twice-a-week).

The thermograph network provides information in the northeast and southern Gulf, where there are almost no shipboard thermosalinograph measurements. The pattern that emerges in the northeast from Table 3 is of consistently lower-than-normal near-surface temperatures in May and September. Water temperatures in May were consistent with air temperature anomalies, but those in September and October were less so. Water temperatures in other months were variable but tended to be below normal. Near-surface waters at southern Gulf stations were either normal or warmer than normal from May to July and lower than normal from August to the end of records in October, except for above-normal conditions in October and November at the Irving Whale station.

Table 4 shows the history of monthly averaged temperature anomalies for selected stations of the thermograph network both in the northeast and southern Gulf. The cold period from 1993 to 1998 (except 1996) is evident at Île Shag (as it was for air temperature in Table 1), and this long historical record helps to put the current year into a longer perspective. Near-surface temperatures were variable and tended to the cold side of normal, in stark contrast to warm conditions observed in 2006.

Both Table 3 and Table 4 highlight the difference in near-surface water temperatures between 2006 and 2007. While 2006 was truly an exceptionally warm year, these conditions did not continue into 2007.

NOAA Satellites

The 2007 annual sea-surface temperature cycle for the entire Gulf of St. Lawrence is shown on Fig. 9 and a comparison to 2006 is shown for selected months in Fig. 10. These maps are generated using National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite images acquired by the Maurice Lamontagne Institute reception facility. The raw data are processed using the Terascan software to detect clouds and project the results onto a geo-referenced grid of 1 km resolution. Average temperatures at each grid node are then calculated for every half-month. Fig. 9 shows a persistent intrusion of cold Labrador Shelf water entering the Gulf through the Strait of Belle Isle from April to June. Fig. 10 confirms the thermosalinograph measurements that show that near-surface water temperatures were much cooler in 2007 than in 2006 not only along the main shipping route, but in other parts of the Gulf as well.

MAGDALEN SHALLOWS BOTTOM WATER TEMPERATURES

The longest running, broad-scale temperature collection on the Magdalen Shallows is the September 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 typically range from <1°C to >18°C and are mostly depth-dependant (
Fig. 11). The deeper areas (50–80 m) are typically covered by waters with temperatures <1°C, which have slowly warmed since the previous winter.

Bottom temperature anomalies over most of the southern Gulf were slightly warmer than normal in September 2007 (Fig. 12). The highest positive anomalies (> +3°C) appeared in shallow water along the coast of New Brunswick and in St. Georges Bay, as in 2006. These coastal anomalies must be viewed with caution for two main reasons. 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 not on the next, perhaps in response to winds. This can cause large variability in the near-bottom temperatures in shallow regions. Second, the optimal estimation routine used to interpolate the data to a regular grid projects horizontal gradients to the coast if there are few data near-shore. This can lead to erroneous extrapolation in regions of strong horizontal temperature gradients. This is not the case in St. Georges Bay, where many casts were taken.

Relative to 2006, bottom temperatures during the 2007 multi-species survey were significantly warmer over the southwestern Magdalen Shallows while some northern parts were cooler (Fig. 13). From the gridded temperature data, time series of the bottom area covered by various temperature intervals were estimated (Fig. 14). As in September 2005 and 2006, there was very little bottom area covered by water with temperatures < 0℃ in 2007, which contrasts with the cold period observed in the 1990s. However, the area covered with water with temperatures from 0 to 1℃ was slightly larger in September 2007 than in 2006. The time series of areas of the Magdalen Shallows covered by water colder than 0, 1, 2 and 3℃ are also shown in Table 5. While waters colder than 1℃ covered slightly more of the bottom in 2007 than in 2006, the opposite can be said for waters colder than 3℃ (see also Table 5).

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 2007. Sea ice is typically produced in the northern parts of the Gulf and drifts towards the Îles-de-la-Madeleine and Cabot Strait. The combined Gulf and Scotian Shelf ice volume shown in the top panel of Fig. 15 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. 15 corresponds to that found seaward of Cabot Strait and represents the volume of ice exported from the Gulf.

In 2007, the Gulf and Shelf maximum ice volume was 34 km^3, which was below normal by 1.5 times the standard deviation but still much higher than recorded in 2006 (the lowest recorded value since 1969). The maximum ice volume reached during each winter is shown as a time series scorecard in Table 5. It bears only some resemblance to the air-temperature winter-severity index introduced in Table 1 and repeated in Table 5. Maximum ice volume in the Gulf is difficult to predict because it is sensitive to short thaw periods and wind storms. More information concerning the sea-ice areal coverage in the Gulf of St. Lawrence can be found in Petrie et al. (2008).

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).

Eighty-five stations were sampled March 5-16 2007 survey using 42.5 flight hours. Fig. 16 and Fig. 17 show gridded interpolations of near-surface temperature, temperature above freezing, salinity, cold layer thickness and where it hits bottom, thickness of Labrador Shelf intrusion for 2006 and 2007. The surface mixed layer is usually very close to the freezing point in many regions of the Gulf in March, and this was the case in 2007 in contrast to warm conditions in 2006. Relatively warm water (~ -0.5℃) entered the Gulf on the northeast side of Cabot Strait, similar to 2004, 2005 and 2006, and flowed northward along the western coast of Newfoundland. However, the patch was cooler than in previous years and its volume and area were smaller.

Near-freezing waters with salinity of around 32 are responsible for the (local) formation of the summertime CIL. These are coded in blue in the salinity panel of Fig. 16 and are typically found to the north and east of Anticosti Island. These waters were displaced by higher-salinity intruding waters in Mecatina Trough (see below) and occupied the area north of Anticosti Island as well as Esquiman Channel, although salinities were also generally higher than usual in the Anticosti Gyre region.

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. These waters occupied the surface over the Mecatina Trough and a large area northeast of Anticosti Island. The thickness of this intrusive layer is estimated in the lower panel of Fig. 17 and occupied the Mecatina Trough from top to bottom in winter 2007 (up to 235 m depth). In 2007, the spread of the intrusion had an area similar to that of 2006 (middle panel of Fig. 17), but its volume was much larger. The recent history of Labrador Shelf water intrusions is shown in Fig. 18 where its volume is shown as well as the fraction it represents of all the cold water volume in the Gulf. Both of these quantities were high in March 2007 (2850 km^3 and 22%) and similar to 2004 values.

The cold (< -1℃) mixed layer depth typically reaches an average of about 75 m in the Gulf, and conditions in 2007 were only slightly thicker than usual (see 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 small warm-water intrusion present on the northeast part of Cabot Strait decreases the overall cold-water volume in the Gulf, with a local cold layer thickness of 0 m. Integrating the mixed layer depth over the area of the Gulf yields a cold-water volume of 13100 km^3, a value higher than the 1996–2007 average by 0.4 × the standard deviation. This cold-water volume corresponded to 39% of the total water volume of the Gulf (34000 km^3). The time series scorecard is included in Table 5.

COLD INTERMEDIATE LAYER

Prediction from the March survey

The total volume of cold water (< -1℃) in March is highly correlated with the following summer's Gilbert & Pettigrew (1997) Cold Intermediate Layer minimum temperature index (Galbraith, 2006). This is expected because the CIL is the remnant of the winter cold surface layer. The updated relation for 2007 is shown in Fig. 19. Measuring the volume of cold water present in March is therefore a valuable environmental tool as it can immediately be used to forecast the coming summer CIL conditions.

The near-normal volume of cold water of 13100 km³ observed in March 2007 led to a CIL minimum temperature index forecast of -0.38℃ based on the correlation between the winter cold-water volume and the summertime CIL index for 1996–2006. This is a predicted decrease of nearly 0.6℃ from the previou s year. A large part of the CIL index decrease can be associated with the large increase in the volume of the Labrador Shelf water intrusion. Indeed, the linear relation between winter cold-water volume and summer CIL index implies that the 2850-km³ intrusion accounts for a 0.5℃ cooling of the CIL index.

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

In Galbraith et al. (2007), the CIL minimum temperature and the CIL thickness and volume for T < 0℃, 1℃, 2℃ and 3℃ were estimated using temperature profiles from the August–September groundfish surveys interpolated by kriging over areas deeper than 100 m. The method is updated this year to include the entire Gulf; attempts were made to obtain results back to 1971.

Temperature profiles from all sources were used for the months of August and September. The majority still come from the September groundfish survey for the Magdalen Shallows and the IML groundfish survey in August for the rest of the Gulf. The CIL minimum temperature grid was calculated by first finding the temperature and depth of the temperature minimum in each cast. Each cast must have data between 30 and 120 m to be considered, eliminating very sparse TESAC profiles. The temperature minimum is defined as simply the lowest recorded temperature for casts with data deeper than 100 m. For shallower casts, a temperature minimum is considered only if the temperature rises by least 0.5℃ below the minimum. The CIL minimum tem peratures and core depths are then interpolated to a regular grid, and a mask of where a CIL core was found is also interpolated. This interpolated minimum temperature grid is then checked at every grid point. Interpolated minimum temperatures are removed (and blanked) from the grid if the interpolated core depth is deeper than local bathymetry (blanking out a falsely interpolated CIL minimum temperature over shallowing bathymetry), or if the interpolated core-presence mask implies there should no CIL core at the location.

The CIL thickness was calculated by interpolating both the top and bottom CIL isotherms on a regular grid, and then checking the bathymetry at every grid point to see if the interpolated isotherms reach the bottom. If so, the thickness at the grid point was reduced appropriately.

Fig. 20 shows the gridded interpolation of the CIL thickness < 1℃ and < 0 °C and the CIL minimum temperature for August–September 2006 and 2007. It is apparent that the CIL < 1℃ and < 0 °C was much thicker in the northern half of the Gulf in 2007 than in 2006 and had a generally lower core temperature everywhere except the Mecatina Trough. Similar maps were produced for all years back to 1971 (although some years have no data in some regions), allowing the calculation of volumes for each region for each year. The time series of the regional CIL volumes are shown in Fig. 21 (for < 0℃ and < 1℃) and in Table 5 (for < 1℃). All regions show an in creased CIL (< 1℃) volume in 2007 compared to 2006, although this increase was very slight on the Magdalen Shallows.

Fig. 21 also shows the < 0℃ and < 1℃ time series using the method from Galbraith et al. (2007). The new methods give comparable results in most regions for which shallow areas cover a small fraction of the region, such as regions 1, 2, 3, 6 and 7. The previous method did not provide a volume estimate for the Magdalen Shallows (region 8) and underestimated the volume in the Mecatina Trough (region 4).

The 2007 average temperature minimum over the entire standard grid was -0.14℃. This is a decrease of 0.62℃ since 2006 (Fig. 23). The overall 2007 CIL water mass properties were similar to those observed in 2004. The time series of the regional average core temperatures are shown in Fig. 22.

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, adjusted to July 15. It was updated using all available temperature profiles measured within the Gulf between May and September inclusively since 1947 (Fig. 23 and Table 5). Fig. 23 also shows the average CIL core temperature and the total volume of CIL water (< 0℃ and < 1℃) of the August–September interpolated grids (e. g., Fig. 20). As expected, the CIL core temperature interpolated to July 15 is almost always colder than the estimate based on August and September data, without any temporal corrections made.

The Gilbert & Pettigrew (1997) CIL index for summer 2007 was -0.23℃. This was somewhat warmer than the prediction of -0.38℃ based on the March survey; it was comparable to conditions observed in 2004, as was the case for the winter cold-water volume. This was a large decrease of the index of 0.44℃ after three consecutive years of warming and brought it close to the 1971–2000 time series average of –0.32℃.

SEASONAL AND REGIONAL AVERAGES OF TEMPERATURE PROFILES

In order to show the seasonal progression of temperature profiles, regional averages are shown in Fig. 24 through Fig. 27 for the March helicopter survey, the June AZMP survey, the August groundfish survey (September survey for region 8) and the November AZMP survey. During the surveys, a total of 85 Conductivity-Temperature-Depth (CTD) casts in March, 92 casts in June, 112 casts in August, 176 in September and 106 in November were obtained. More casts were done in the Estuary during the November 2007 survey than usual.

Monthly temperature and salinity climatologies for 1971–2000 were constructed for various depths using a method similar to that 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 for each year. Monthly averages from all available years and their standard deviations are then computed. This two-fold averaging avoids the bias that occurs when the numbers of profiles in any given year are different. The temperature climatologies are shown in grey as the mean value plus or minus one standard deviation in Fig. 24 through Fig. 27.

The March water temperature conditions were discussed at length in earlier sections and are included here for completeness (Fig. 24). Temperatures in June 2007 (Fig. 25) were generally close to the 1971–2000 climatology at all depths, except for the very thick and cold CIL in Anticosti Channel (region 3) and Mecatina Trough (region 4), and warm deep waters in the Estuary (region 1) and the northwest Gulf (region 2). This overall pattern persisted in the August–September mean conditions (Fig. 26), except for the then-normal

CIL in Mecatina Channel and warm deep waters also found in Anticosti Channel. However, by October–November (Fig. 27), conditions were about normal everywhere except for anomalously warm near-surface mixed layers in the northwest Gulf and warm near-surface waters on the Magdalen Shallows (region 8) and in Cabot Strait (region 7). Average discrete-depth layer conditions are summarized for the 2006 and 2007 AZMP surveys in Table 6.

YEARLY LAYER AVERAGES OF DEEP (> 150 m) TEMPERATURE AND SALINITY

The aforementioned reconstructed temperature and salinity climatologies for 1971–2000 provide time series of monthly averaged values. These were averaged into regional yearly time series that are presented in Table 7 for 200 and 300 m. One can see that temperature anomalies travel up-channel from Cabot Strait to the northwest Gulf in 2 to 3 years, consistent with the findings of Gilbert (2004). The regional averages are weighted into a Gulf-wide average in accordance to the surface area of each region at the specified depth. The Gulf-wide yearly averages are also shown for 200, 250 and 300 m in Table 7 as well as in Fig. 28 for temperature and Fig. 29 for salinity. These two figures also show the temperature and salinity layer averages shown in Gilbert et al. (2004) for 30–100 m, 100–200 m and 200–300 m. The new 150 m layer time series replaces the old 100–200 m time series and the new 250 m layer time series replaces the old 200–300 m time series.

In 2007, the temperature and salinity were generally normal at 150 m to 300 m (salinity was only above normal at 0.5 × the standard deviation at 200 m). Temperature and salinity in this depth range decreased from 2006 to 2007, except for temperature at 300 m which remained constant. The near-normal Gulf-wide water temperatures at 300 m were composed of warmer waters near the Estuary (regions 1 and 2), near-normal temperatures in the centre (region 6) and colder waters coming into the Gulf at Cabot Strait (region 7). This cold anomaly would be expected to propagate inward during the next few years. However, the cold anomaly at Cabot Strait may have been a short-lived event since it was not observed in November (Table 6) and therefore may not be indicative of a longer-term trend. However, a cold anomaly was also present in the deepest waters of Cabot Strait throughout the year.

MONITORING HYPOXIA IN THE ST. LAWRENCE ESTUARY

The deeper waters of the Laurentian Channel are not ventilated during winter and are slowly advected toward the head of the Laurentian, Esquiman and Anticosti 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. 30 is an update of the Gilbert et al. (2005) oxygen time series and provides the mean dissolved oxygen value at depths greater than or equal to 295 m in the St. Lawrence Estuary, expressed as a percentage of saturation at surface pressure. Dissolved oxygen decreased very slightly in 2007 compared with 2006 observations. In the 1930s and early 1970s, oxygen levels were above the hypoxic threshold of 30% saturation. The deep waters of the Estuary were briefly hypoxic in the early 1960s and have consistently been hypoxic since 1984.

TIME SERIES OF TEMPERATURE AND SALINITY PROFILES AT FIXED AZMP STATIONS

The AZMP sampling (Therriault et al., 1998) by the Maurice Lamontagne Institute began in 1996 at two stations (Fig. 31) in the northwest Gulf of St. Lawrence: the Anticosti Gyre (49° 43.0' N, 66°15.0' W) and the Gaspé Current (49° 14.5' N, 66° 12.0' W). Both stations were originally planned to be sampled at 15-d intervals, but logistical problems often led to less frequent sampling (Fig. 31, top panels). The AZMP station in the Shediac Valley (47° 46.8' N, 64° 01.8' W) is sampled by the Bedford Institute of Oceanography. It has been sampled since 1947 and nearly every year since 1957. A station offshore of Rimouski (48° 40' N 68° 35' W) has also been sampled since 1991, typically once a week during summer, less often during spring and fall, and almost never in winter.

Isotherms and isohalines as well as monthly averages of layer temperature, salinity and CIL core temperature and thickness at 1℃ are shown for the Rimouski station in Fig. 32. Similar figures are provided for the Gaspé Current station (Fig. 33), the Anticosti Gyre station (Fig. 34) and the Shediac Valley station (Fig. 35). The scorecard climatologies are calculated from all available data at all stations except for Shediac, where the time series is sufficiently long to use the 1971–2000 period.

At the Rimouski station (Fig. 32), spring stratification occurred earlier than usual (see isohalines and negative salinity anomaly in April), yet warming of the surface layer was delayed. The CIL was thicker than normal in spring but quickly eroded to anomalously thin conditions by July. Deep waters were generally saltier than normal. Waters at all depths were warmer than usual in summer but not as remarkably so as in 2006.

There are no spring data for the Gaspé Current station (Fig. 33) or for the Anticosti Gyre station (Fig. 34). At the former station, the 0-50 m layer was anomalously cold and salty in August, and the deeper waters were anomalously warm and salty. At the latter station, waters were generally warm and salty (by 0.5 to 1.5 × standard deviation).

At the Shediac Valley station (Fig. 35), both spring restratification and warming were delayed (positive surface salinity anomaly and negative surface temperature anomaly in April), although this finding is based on sparse data. Stratification was weak in spring and summer. Temperatures were variable yet fairly close to normal thereafter until November, when waters were warmer than normal. Salinity was very high in August.

OUTLOOK FOR 2008

The March 2008 winter survey provides an outlook for CIL conditions expected for the remainder of 2008. Fig. 36 shows the cold (T < -1℃) surface mixed layer temperature, salinity, and thickness, as well as the thickness and extent of the cold and saline (S > 32.35 and T < -1℃) layer that has intruded into the Gulf from the Labrador shelf. The waters were near-freezing almost everywhere, the main exception being the warm water entering the Gulf on the eastern side of Cabot Strait as was also observed in many recent years. This warm layer extended to cover Esquiman Channel almost entirety. The intrusion of cold and saline water from the Labrador Shelf through the Strait of Belle Isle occupied a slightly larger area in March 2008 compared to 2007, and it extended to the surface. But it was a thinner layer that translated to a lower volume of 1850 km³ (down from 2850 km³ in March 2007, but still up from 1620 km³ in March 2006). The cold layer (<

-1°C) is thicker than usual south of Anticosti Island and its overall volume increased slightly from March 2007 conditions to 13.7 x 10^3 km^3, similar to conditions in 1996 and 1997. The relation between the cold water volume and the CIL index (Galbraith, 2006) forecasts cooler summertime CIL conditions in 2008 with an index of -0.47°C.

SUMMARY

- Air temperatures were normal or cooler than normal for most of the year in the western parts of the Gulf, contrasting with the very warm conditions in 2006. However, the eastern regions were only significantly cooler than normal in April and May. October was very warm almost everywhere. Averaged over the whole Gulf for the entire year, air temperature was normal in 2007 and only slightly above normal (by 0.3 × standard deviation) when considering only the January to March period.
- The monthly averaged runoff measured at Québec City was consistently below normal in 2007. The annual mean was 1.5 standard deviations below normal, which is comparable to values observed from 2001 to 2003.
- Near-surface waters were anomalously warm in the St. Lawrence Estuary in January and February. After a rather uneventful spring, the summer maximum temperatures occurred earlier than usual everywhere in the Gulf (early August instead of mid-August). Earlier-than-usual cooling followed the maximum, and temperatures were below normal for the rest of the year except for October in the Estuary. Near-surface water temperatures were much cooler in 2007 than in 2006 in all regions of the Gulf.
- Near-surface waters in the northeast were consistently lower than normal in May and September and variable to below-normal during other months. Near-surface waters in the southern Gulf were either normal or warmer than normal from May to July and generally lower than normal from August to the end of records in October.
- On the Magdalen Shallows, there was (almost) no bottom area covered by water with temperatures < 0°C in September 2007 (as for 2005 and 2006), which contrasts with the cold period observed in the 1990s. Waters colder than 1°C covered slightly more of the bottom in 2007 than in 2006, but the opposite can be said for waters colder than 3°C.
- Maximum sea-ice volume within the Gulf and on the Scotian Shelf was below normal by 1.5 times the standard deviation but still much higher than recorded in 2006 (the lowest recorded value since 1969).
- Winter inflow of cold and saline water from the Labrador Shelf occupied the Mecatina Trough from top to bottom in winter 2007 (up to 235 m in depth). The spread of the intrusion had an area similar to that of 2006, but its volume was much larger (2850 km^3), similar to that observed in 2004.
- The winter cold mixed layer volume was nearly normal at 13100 km^3, higher than the 1996–2007 average but only by 0.4 × the standard deviation. This cold-water volume corresponded to 39% of the total water volume of the Gulf.
- The Gilbert & Pettigrew (1997) CIL index for summer 2007 was -0.23°C, comparable to conditions observed in 2004. This was a large decrease in the index of 0.44°C after three consecutive years of warming and brought it close to the 1971–2000 time series average of –0.32°C. This was fairly well predicted following the March 2007 survey of the cold mixed layer water volume in the Gulf. Part of the decrease of the CIL index was due to the larger-than-normal winter intrusion of Labrador Shelf water from the Strait of Belle Isle.
- Regional patterns of the CIL show that the layers for T < 1°C and < 0 °C were much thicker in the northern half of the Gulf in 2007 than in 2006, and that the CIL had a generally lower core temperature everywhere else as well. The exception was the

Mecatina Trough, where core temperatures were similar to 2006 conditions, presumably due to the similar area extent of the cold Labrador Shelf water intrusion during both winters.

- Seasonal and regional patterns of water temperatures in the water column: Temperatures in June were generally close to the 1971–2000 climatology at all depths, except for the very thick and cold CIL in the Anticosti Channel and Mecatina Trough, and warm deep waters in regions 1 and2 . This overall pattern persisted in August–September, but by October–November conditions were about normal everywhere, except for anomalously warm near-surface mixed layers in regions 2 as well as the warm near-surface waters on the Magdalen Shallows (region 8) and in Cabot Strait (region 7).
- Temperature and salinity were generally normal at 150 m to 300 m after a decrease at most depths from 2006 to 2007. At 300 m, the near-normal temperatures were composed of warmer waters near the Estuary (regions 1 and 2), near-normal temperatures in the centre (region 6) and colder waters coming into the Gulf at Cabot Strait (region 7).
- The outlook for 2008 from the March 2008 survey is for a slight cooling of the CIL index to -0.47℃ resulting from a thicker cold wint er surface layer.

ACKNOWLEDGEMENTS

We are grateful to the many people responsible for CTD data acquisition during the many surveys used in this report:

- Fixed station monitoring: Chief scientist Alain Gagné; scientific personnel Rémi Desmarais
- Rimouski station monitoring: Chief scientist Pierre Joly; scientific personnel Stéphane Plourde, Jean-François St-Pierre, Laure Devine, Caroline Lafleur, François DeMontigny, Chantale Lacoste, Claire Bertolone, Geneviève Parent.
- March 2007 helicopter survey: Chief scientist Peter Galbraith; scientific personnel Rémi Desmarais; helicopter pilot Yvan Côté and aircraft technician Yvan P. Côté.
- AZMP transects in June: Chief scientist Alain Gagné; scientific personnel Jean-Louis Beaulieu and Daniel Thibeault; the officers and crew of the CCGS *Teleost*.
- Groundfish survey in August: Chief scientists Diane Archambault and Philippe Schwab; scientific personnel Sylvain Chartrand, Rémi Desmarais, Yves Gagnon, Caroline Lafleur; the officers and crew of the CCGS *Teleost*.
- AZMP transects in October–November (Ice Forecast Cruise): Chief scientist Alain Gagné; scientific personnel Laure Devine, Roger Pigeon, Daniel Thibeault; the officers and crew of the CCGS *Hudson*.
- Multi-species survey in September: Tom Hurlbut for providing the CTD data.
- Northumberland Strait survey: Chief scientist Mark Hanson for providing the CTD data.

Data from the following sources are also gratefully acknowledged:

- Thermosalinograph network: Denis Lefaivre, Roger Pigeon, Sylvain Cantin, Daniel Thibeault, Peter Galbraith.

- Thermograph network: Bernard Pettigrew, Rémi Desmarais and Daniel Thibeault.
- NOAA remote sensing: Pierre Larouche, Bernard Pettigrew and André Gosselin.
- Dissolved oxygen: Alain Gagné, Laure Devine, Pierre Joly and Marie-Lyne Dubé.

All tables and figure were illustrated using the free software Gri (Kelley & Galbraith, 2000).

We are grateful to Brian Petrie and Eugene Colbourne for reviewing the manuscript and providing insightful comments.

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Table 1. Air temperature mean anomalies; annual (top) and January-February-March (bottom) averages. The numbers on the right are the 1971–2000 climatological means and standard deviations. The numbers in the boxes are normalized anomalies.

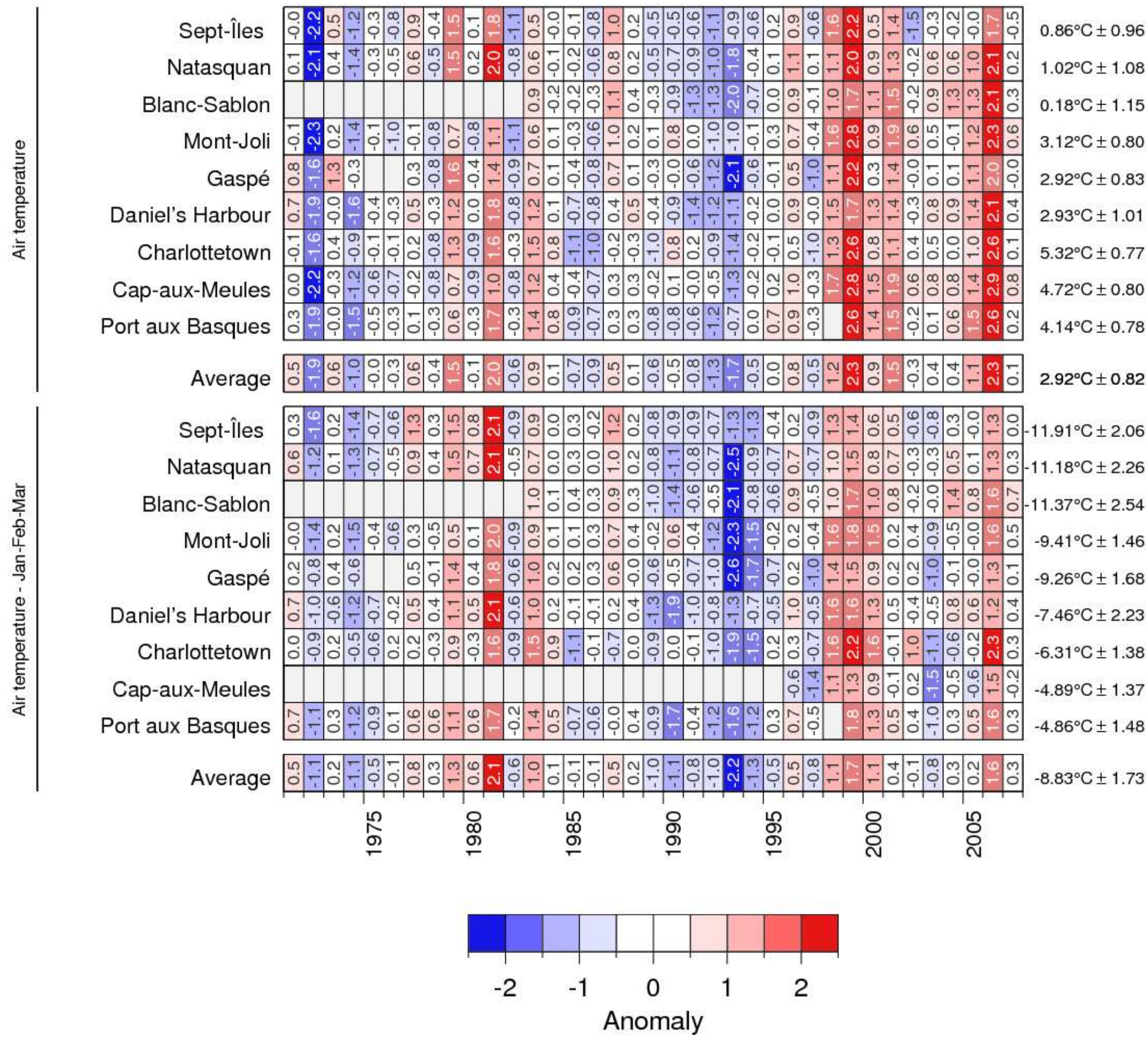


Table 2. Thermosaligraph near-surface temperature monthly anomalies for various sections along the main shipping lane. The numbers on the right are the 2000–2007 climatological means and standard deviations. The numbers in the boxes are normalized anomalies. The map shows all TSG data sampled in 2007. Those drawn in colour are within the main shipping corridor and are used in this report. Monthly average anomalies of temperatures measured close to the indicated blue section lines are shown in the other scorecard panels.

Tadoussac	2000	2001	2002	2003	2004	2005	2006	2007	
J	-0.5	-0.2	1.0	1.4	-1.5	0.4	-0.6		-0.23°C ± 0.44
F	-0.6	0.0	-1.1	1.6	0.1	-0.8	-0.6	1.4	-0.25°C ± 0.54
M	0.4	0.1	0.1	1.8	-1.3	-1.4	0.2	0.1	0.12°C ± 0.49
A	-0.3	0.3	1.9	-0.1	-1.5	-0.5	0.9	-0.5	1.21°C ± 0.43
M	-0.2	1.8	0.2	-0.6	-1.5	-0.1	0.9	-0.5	3.47°C ± 0.93
J	-1.7	1.2	0.0	-1.0	0.0	-0.3	0.9	0.9	5.53°C ± 1.09
J			1.2	-0.9	0.8	-1.3	0.6	-0.5	6.37°C ± 0.47
A		0.9	0.2	-1.1		0.2	1.2	-1.3	6.55°C ± 0.39
S	-0.1	-0.5		-1.2	0.1	1.9	0.5	-0.6	5.38°C ± 1.00
O	-0.8	0.3	-0.4	-1.2	0.6			1.5	3.90°C ± 0.59
N	0.4	-0.5	-1.1	-1.1	0.7	-0.1	1.9	-0.1	2.72°C ± 0.69
D	0.5	0.6	-0.4	-1.7	-0.5	-0.0	1.8	-0.2	0.84°C ± 0.70

Mont-Louis	2000	2001	2002	2003	2004	2005	2006	2007	
J	0.9	0.7	-0.2	0.3	-0.7	-1.9	0.9		-1.17°C ± 0.15
F	-0.6	-0.3	-0.7	-0.6	0.7	-0.9	0.5	1.9	-1.52°C ± 0.11
M	1.2	0.8	-1.0	-0.6	-0.9	-0.9	1.3	0.2	-1.21°C ± 0.25
A	-0.7	0.7	1.2	-1.3	-0.5	-0.7	1.4	-0.0	0.53°C ± 0.49
M	-0.3	2.1	-0.9	0.1	-1.0	-0.7	0.6	0.2	3.90°C ± 0.96
J	0.0	1.7	-0.7	0.1	-1.2	-0.2	1.1	-0.8	8.74°C ± 0.81
J		-1.4	-0.4	-0.7	0.2	1.8	0.5	-0.0	13.23°C ± 1.05
A		0.7	1.4	0.2	-0.7	-1.6	0.5	-0.4	12.55°C ± 0.82
S	-0.9	1.8	1.0	-0.5	-0.8	0.2	0.2	-1.0	9.53°C ± 0.73
O	-1.1	0.5	-1.3	0.3	1.3			0.3	5.78°C ± 0.65
N	-0.1	-0.5	-1.2	-1.2	0.9	1.3	1.1	-0.3	3.62°C ± 1.21
D	1.1	0.0	-0.7	-1.4	0.2	-0.0	1.6	-0.8	0.75°C ± 0.49

Cabot Strait / Détroit de Cabot	2000	2001	2002	2003	2004	2005	2006	2007	
J	0.4	-0.3	0.1	-1.8	-0.0	0.2	1.9	-0.3	1.42°C ± 0.61
F	-0.7	0.3	0.3	-1.7	-0.1	1.0	1.4	-0.6	-0.10°C ± 0.86
M	0.4	0.3	-0.2	-2.1	0.5	1.3	0.2	-0.5	-0.51°C ± 0.55
A	0.4	0.4	-0.7	-2.1	0.1	0.8	1.0	0.1	0.29°C ± 0.68
M	-0.6	0.5		-0.9	-0.6	-0.1	2.0	-0.3	3.14°C ± 0.84
J	0.1	0.8	-0.7	-0.6	-1.4		1.6	0.1	7.37°C ± 1.22
J			-1.2	-0.3	-0.4		1.5	0.3	12.80°C ± 1.28
A		1.4	0.1	-1.0			0.4	-0.9	16.13°C ± 1.02
S	-0.1	1.2		-1.1	-0.5		1.2	-0.6	12.88°C ± 1.04
O	-0.4	1.1	-1.4	1.0	0.2	0.7		-1.1	9.20°C ± 1.76
N	0.5	0.3	-1.8	-0.3	0.7		1.2	-0.6	6.06°C ± 1.50
D	0.6	0.2	-1.8	-0.5	0.0	1.0	1.2	-0.8	3.55°C ± 0.88

Estuary / Estuaire	2000	2001	2002	2003	2004	2005	2006	2007	
J	-0.4	0.1	1.8	-0.3	-1.5	0.2	0.2		-0.87°C ± 0.23
F	-0.4	0.7	-0.6	1.4	-1.0	-0.8	-0.7	1.3	-0.97°C ± 0.19
M	1.6	-0.1	0.2	0.8	-1.2	-1.5	0.4	-0.2	-0.19°C ± 0.38
A	-0.6	0.4	1.6	0.0	-1.4	-0.5	1.0	-0.7	1.48°C ± 0.45
M	0.4	1.7	-0.1	-0.6	-1.4	-0.6	1.1	-0.5	3.97°C ± 0.58
J	-0.8	1.7	-0.3	-1.1	-0.8	-0.1	1.2	0.3	6.55°C ± 0.94
J			1.4	-0.8	0.2	0.9	-0.5	-1.2	8.44°C ± 0.94
A		-0.2	1.7	-0.3		0.3	-0.2	-1.3	8.19°C ± 0.64
S	-0.5	0.0		-0.3	-0.7	2.2	0.0	-0.7	5.95°C ± 0.58
O	-0.8	0.1	0.1	-1.3	0.3			1.6	4.23°C ± 0.52
N	0.5	-0.2	-1.2	-1.3	0.7	-0.0	1.8	-0.2	2.52°C ± 0.73
D	-0.2	0.8	-0.3	-1.4	-0.4	0.2	1.9	-0.8	0.43°C ± 0.64

Centre	2000	2001	2002	2003	2004	2005	2006	2007	
J	-0.2	0.4	-0.6	-1.3	0.2	-1.2	1.2	1.4	-0.38°C ± 0.44
F	-0.4	0.2	-0.5	-1.0	0.3	-0.9	2.1	0.3	-1.43°C ± 0.22
M	0.5	0.0	-0.7	-1.3	-0.5	-0.5	1.9	0.5	-1.39°C ± 0.17
A	0.5	0.0	-0.5	-1.4	0.0	-0.4	2.1	-0.2	-0.24°C ± 0.53
M	-0.5	1.4		-1.0	-0.6	-0.6	1.4	-0.1	3.16°C ± 1.36
J	-0.7	1.3	-0.5	-0.4	-1.2		1.4	0.2	8.12°C ± 1.71
J			-0.7	-0.8	-0.4		1.6	0.4	13.94°C ± 1.68
A		-1.0	-1.1	0.6			0.3	1.2	14.99°C ± 0.54
S	0.9	-0.4		0.8	-0.3		0.7	-1.7	12.20°C ± 1.06
O	-0.9	1.0	-1.0	1.2	0.5			-0.7	8.11°C ± 0.83
N	0.7	-0.7	-1.6	-0.9	0.3	0.8	1.4	-0.0	4.50°C ± 0.77
D	0.6	-0.0	-1.1	-0.9	0.1	0.5	1.8	-1.0	1.83°C ± 0.64

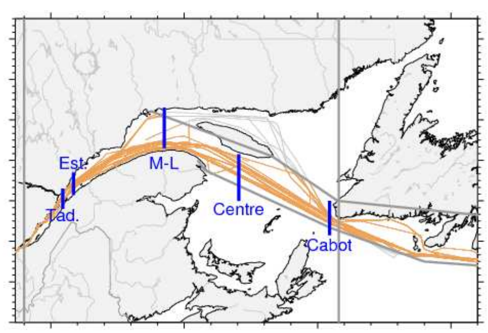


Table 3. Monthly mean temperatures at all stations of the IML thermograph network in 2006 and 2007. The colour-coding is according to the temperature anomaly relative to the climatology of each station for each month.

Estuary and NW Gulf / Estuaire et NO du Golfe

		J 2006	F 2006	M 2006	A 2006	M 2006	J 2006	J 2006	A 2006	S 2006	O 2006	N 2006	D 2006	J 2007	F 2007	M 2007	A 2007	M 2007	J 2007	J 2007	A 2007	S 2007	O 2007	N 2007
Tadoussac	30 m					2.2	3.7	3.9	3.8	3.5	3.3	4.0						1.3	3.3	3.4	3.5	2.8	3.2	2.4
Bic	1 m					4.9	7.5	8.2	8.1	6.3	4.8							4.4	6.7	7.7	7.1	5.5	4.9	
	2 m					4.6	7.0	7.7	7.8	6.2	4.7							4.1	6.4	7.4	6.8	5.4	4.8	
	5.8 m					2.5	3.4	3.8	4.0	3.7	3.1							1.2	2.3	2.8	3.1	2.9		
Rimouski	0.5 m					6.4	9.3	11.1	9.6	7.7	5.0							5.2	9.2	11.2	10.4	6.7	5.6	
IML	0.5 m																	5.3	8.4	11.0	10.3	7.3	5.6	
	13.5 m	-1.3	-1.1	-0.3	1.8	3.5	6.8	7.8	8.2	6.3	4.7	3.8	1.4	-0.2	-1.0	-0.8	0.9	3.0	5.7	7.1	7.1	5.8	4.2	
Baie-Comeau	1 m					6.1	11.0	12.2	11.1	9.1	6.3							5.3	10.1	10.9	9.8	7.0	6.2	
	80 m					0.6	0.7	0.8	1.1	1.3	2.4	2.6	2.1	1.9	2.2	-0.2	-0.8							
Mont-Louis	0.35 m					5.3	11.5	14.4	13.7	9.4	5.7							4.7	9.7	14.0	12.7	8.9	6.1	3.0
	0.5 m					5.1	11.4	14.4	13.7	9.4	5.7							4.4	9.7	14.0	12.7	8.9	6.1	3.0
	30 m					0.3	0.7	1.6	1.3									-0.3	0.2	0.2	0.5			
	1.1 m					5.3	11.3	14.4	13.7	9.4	5.7							4.6	9.6	14.0	12.7	8.9	6.1	3.0
	2.1 m					5.2	11.2	14.3	13.7	9.4	5.7							4.5	9.4	13.9	12.6	8.8	6.1	3.0
Anticosti Gyre	0.5 m						11.8	14.2	13.4	10.5	5.8								11.0	13.8	13.1	8.7	6.3	
	337 m						5.5	5.5	5.5	5.5	5.5								5.5	5.5	5.5	5.5	5.5	
Sept-Îles	1 m					7.6	13.0	15.3	11.3	9.0	6.0							4.8	11.3	14.0	12.4	8.1	5.1	
	2 m																	4.5	10.5	13.3	12.1	7.8	5.0	
	25 m					2.8	4.0	3.1	2.7	4.0	4.5							0.4	3.6	3.5	3.3	3.2	3.5	
Port-Menier	2 m					6.4	11.5	14.9	9.7	8.7	6.5							2.9	9.1	11.9	10.0	6.9	5.0	
	12.8 m					4.1	6.2	9.1	4.9	5.7	5.2							1.9	5.9	6.0	5.7	4.1	3.6	

Lower North Shore / Basse Côte Nord

		J 2006	F 2006	M 2006	A 2006	M 2006	J 2006	J 2006	A 2006	S 2006	O 2006	N 2006	D 2006	J 2007	F 2007	M 2007	A 2007	M 2007	J 2007	J 2007	A 2007	S 2007	O 2007	N 2007
Rivière-au-Tonnerre	1 m						10.4	12.7	8.5	6.1	5.2							3.7	7.3	10.2	8.2	5.8	4.8	
	16 m						5.4	5.1	4.6	4.8	4.6							1.4	3.9	5.0	4.7	3.9	4.3	
Havre-Saint-Pierre	0.5 m						9.8	12.8	8.4	8.2	6.5								7.2	12.1	9.9	6.3	5.6	
	1 m						9.8	12.8	8.4	8.2	6.3							3.0	7.2	12.1	9.9	6.3	5.7	
	100 m						1.0	1.0	1.1	1.2	1.6							-0.3	-0.3	-0.3	-0.1	0.1	0.9	
Natashquan	1 m						14.1	14.1	12.9	10.7	7.4							4.7	10.8	15.1	12.8	9.2	6.9	
	7.5 m						5.9	5.5	6.0	7.5	6.9							0.9	5.4	7.5	7.4	6.3	6.2	
La Romaine	1 m						9.1	11.2	12.7	11.8	8.1							1.9	6.6	11.6	12.8	9.5	7.2	
	2 m						8.9	11.1	12.6	11.8	8.0							1.8	6.5	11.4	12.7	9.5	7.2	
	14 m						2.1	2.6	4.1	5.5	7.0							0.4	0.8	1.0	2.8	4.2	6.3	
Beaugé	0.5 m					4.8	9.2	14.8	15.9	14.1	9.6							2.3	7.2	11.8	15.7	11.4	8.4	
	1 m					4.6	9.1	15.3	16.0	14.1	8.9							2.1	7.2	12.8	15.8	11.4	7.7	
	100 m					-0.5	-0.8	-0.1	0.1	0.6	0.9							-1.3	-0.8	-0.4	-0.1	0.2	0.7	
La Tabatière	1 m						6.7	10.4	12.5	11.4	8.0								5.5	8.8	12.0	9.1	6.5	
	36 m						2.1	3.6	5.6	6.0	6.6								-0.0	1.1	3.9	5.2	5.2	
Blanc-Sablon	1 m						4.6	10.7	12.6	9.0	6.4								2.2	9.4	11.2	8.7	3.8	
Belle Isle	105 m	-1.1	-1.8	-1.8	-1.3	0.2	1.0	3.6	3.1	1.5	2.7	2.5	0.4	-1.4	-1.8	-1.8	-1.6	-1.6	-0.6	0.3	1.0	2.6	2.7	

Southern Gulf / Sud du Golfe

		J 2006	F 2006	M 2006	A 2006	M 2006	J 2006	J 2006	A 2006	S 2006	O 2006	N 2006	D 2006	J 2007	F 2007	M 2007	A 2007	M 2007	J 2007	J 2007	A 2007	S 2007	O 2007	N 2007
Grande-Rivière	2 m					6.5	11.0	15.3	16.3	13.2	8.7							4.8	10.3	14.9	15.5	11.5	7.6	
	7 m					4.9	8.4	12.3	15.4	12.2	8.5							4.2	7.7	11.9	13.7	10.4	7.2	
Shediac	0.5 m					6.8	12.0	16.8	16.4	14.7								4.8	10.3	15.8	15.8	13.4		
	82 m					-0.0	0.6	0.8	1.0	1.1	1.0							0.1	0.3	0.4	0.5	0.7	0.9	
Irving Whale	0.5 m					6.9	12.6	17.7	17.8	15.4	11.3							3.7	10.0	17.0	16.9	14.0	11.2	6.0
	1 m					6.9	12.5	17.7	17.8	15.4	11.3							3.7	10.0	17.0	16.9	14.0	11.2	
	67 m					-0.5	-0.0	0.5	0.5	0.6	0.8							-1.1	-0.7	-0.2	-0.0	0.3	0.5	
Île Shag	0.5 m																	5.8	10.0	14.8	17.2	14.0		
	10 m	0.3	-1.3	-0.8	1.6	6.3	10.0	15.1	15.3	15.3	10.9	6.1	3.0	-0.5	-1.7	-1.5	-0.0	4.4	8.9	13.3	15.9	13.0		
La Perle	1 m						11.0											3.8	9.0	14.9	17.0	13.8	10.5	
	8.5 m						7.6											3.0	5.6	7.6	8.2	9.3	9.6	

Table 4. History of the monthly averaged temperature anomaly for selected stations of the thermograph network. The monthly numbers are the standardized anomalies (monthly mean, minus climatological mean, divided by the standard deviation of the climatology). The mean and standard deviation are indicated for each month on the right side of the table.

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Natashquan - 1 m	M								-0.8	1.2	0.0			0.7		-1.1	6.68°C ± 1.71
	J		-0.7	-0.7	0.2		0.0	0.8	-0.2	-0.3	-1.5	0.1	-0.9	0.6	2.6	0.1	10.60°C ± 1.35
	J		-0.3	0.8	-0.1		0.0	-1.8	0.8	-1.1	0.3	-0.6	1.7	-0.9	-0.1	1.3	14.13°C ± 0.79
	A		-0.3	-0.8	1.3		-1.2	0.9	1.7	-0.0	0.6	1.0	-0.8	-1.5	-0.4	-0.4	13.50°C ± 1.56
	S		-0.4	-0.0	0.4		1.2	1.7	-1.4	0.0	-0.1	-0.7	-1.6	1.4	0.2	-0.7	10.34°C ± 1.65
	O		0.7	0.1	-0.4		-1.4	0.2	-1.6	0.2	-1.7	1.1	0.9	1.3	0.5	0.1	6.76°C ± 1.36
Beaugé - 1 m	M									0.6	-0.7			0.1	1.3	-1.2	3.32°C ± 1.00
	J						-0.1	0.6	-1.0	1.2	-0.7	0.2	-1.9	0.7	1.3	-0.3	7.61°C ± 1.20
	J						-0.3	0.5	-0.8	0.1	-1.0	-0.9	-0.1	0.2	2.5	-0.2	12.93°C ± 0.98
	A						-1.6	-0.9	0.9	-0.5	-0.2	-0.3	1.7	-0.6	0.8	0.7	15.13°C ± 1.06
	S						-1.1	1.4	0.7	0.2	-1.4	-0.3	-0.5	0.2	1.6	-0.8	12.33°C ± 1.16
	O						-1.8	0.4	-0.7	0.5	-1.5	0.4	0.6	0.8	1.2	-0.0	7.69°C ± 1.04
La Tabatière - 1 m	J										-0.7	-0.4	-0.8	1.6	0.8	-0.6	5.99°C ± 0.82
	J										-1.2	1.1	-0.8	0.0	1.3	-0.3	9.13°C ± 1.01
	A										-0.1	1.3	-1.2	-1.1	0.9	0.2	11.84°C ± 0.75
	S										-0.7	0.1	0.2	1.3	0.6	-1.6	10.76°C ± 1.07
	O											0.2	-0.3	0.6	1.1	-1.5	7.39°C ± 0.59
Blanc-Sablon - 1m	J							1.3	0.9	-0.4	-0.1	-0.9	-1.4	0.5	1.2	-1.0	3.32°C ± 1.09
	J							0.4	-0.1	-0.6	-0.1	0.2	-1.9	-0.4	1.8	0.7	8.52°C ± 1.23
	A							0.4	1.2	-0.3	-0.9	-1.2	1.4	-0.9	0.9	-0.5	11.70°C ± 1.02
	S							0.4	1.3	-0.5	-1.8	0.1	-0.8	1.3	0.2	-0.2	8.80°C ± 0.84
	O							-0.2	-0.2	1.0	-1.6	1.5	-0.6	0.4	0.7	-1.1	5.35°C ± 1.45
Irving Whale - 0.5 m	M						1.1			-0.3	-0.2		-0.5	-1.4	1.6	-0.3	4.26°C ± 1.67
	J						0.5	1.5	-0.2	1.0	-0.5	-1.0	-1.1	-1.1	1.3	-0.5	10.71°C ± 1.42
	J						0.2	1.2	-0.5	0.2	-1.6	0.0	-1.4	-0.1	1.6	0.4	16.79°C ± 0.59
	A						-1.5	-1.1	1.6	0.9	0.0	-0.4	0.6	0.6	0.1	-0.9	17.71°C ± 0.91
	S						0.2	0.3	-0.2	1.0	-1.5	-0.1	-0.9	1.8	0.5	-1.1	14.96°C ± 0.89
	O						-1.5	-1.8	-0.8	1.0	-0.0	0.6	0.7	0.5	0.7	0.6	10.60°C ± 1.06
	N						-1.2	-0.1		0.5	-0.1	-0.8				1.6	5.17°C ± 0.53
Île Shag - 10 m	J		-1.3	-0.6	-1.0	0.3	-1.0	-1.2	0.6	0.4	0.6	0.2	0.4	-0.7	2.3	0.9	-0.99°C ± 0.58
	F		-1.2	-0.5	-0.8	-0.7	-0.5	-0.9	0.9	1.4	1.1	1.4	-0.1	-0.6	1.5	-0.8	-1.56°C ± 0.19
	M		-1.4	-0.6	-0.8	-0.9	0.6	-0.3	1.5	1.7	0.0	0.3	-0.6	-0.4	1.5	-0.6	-1.29°C ± 0.30
	A		-1.1	-1.5	-0.3	-1.2	0.6	0.6	1.9	0.4	0.4	-0.4	-0.3	-0.4	1.7	-0.5	0.36°C ± 0.74
	M		-1.3	-1.5	-0.0	-0.9	1.6	0.1	0.5	0.6	-0.7	-0.7	0.2	0.0	2.1	0.1	4.34°C ± 0.93
	J		-1.6	-0.5	-0.3	-1.0	1.3	1.5	-0.1	1.3	-0.5	-1.0	-0.7	-0.1	1.4	0.2	8.64°C ± 1.03
	J		-0.3	0.0	-0.2	-0.7	-0.2	1.8	0.8	1.0	-0.9	-1.8	-0.9	-0.1	1.7	-0.3	13.54°C ± 0.92
	A		-0.2	0.5	0.6	-0.4	-1.2	0.1	1.2	1.6	-0.8	-1.8	0.6	1.1	-1.1	-0.4	16.17°C ± 0.79
	S		-0.2	-1.5	0.8	0.1	-1.4	1.1	0.5	1.3	0.2	0.1	-1.0	1.1	0.5	-1.6	14.71°C ± 1.08
	O	-0.6	-1.8	-0.1	0.2	0.1	-1.7	-0.7	0.3	1.4	-0.5	1.6	0.5	1.0	0.3		10.63°C ± 0.93
	N	-1.0	-0.5	0.8	1.0	-0.2	-1.1	-1.4	1.5	1.1	-1.2	0.5	-0.8	0.9	0.1		6.00°C ± 0.57
	D	-0.6	-1.3	-1.1	1.0	-1.1	-1.1	1.7	0.4	0.7	-0.3	0.6	-0.7	0.6	1.3		2.02°C ± 0.73

Table 5. CIL and related properties. The top block shows the scorecard time series for winter air temperature averaged over 8 stations, the Gilbert & Pettigrew (1997) CIL index, March cold layer (< -1℃) volume, yearly maximum sea-ice volume, volume of Labrador Shelf Water intrusion in the Gulf observed in March and the August–September volume of cold water (< 0℃) observed in the Mecatina Trough. Titles in parentheses have their colour coding reversed (blue for high values). The middle block shows scorecard time series for August–September CIL volumes (<1℃) for all eight regions and for the entire Gulf when available. The bottom block shows the scorecard time series for the bottom areas of the Magdalen Shallows covered by waters colder than 0, 1, 2 and 3℃.

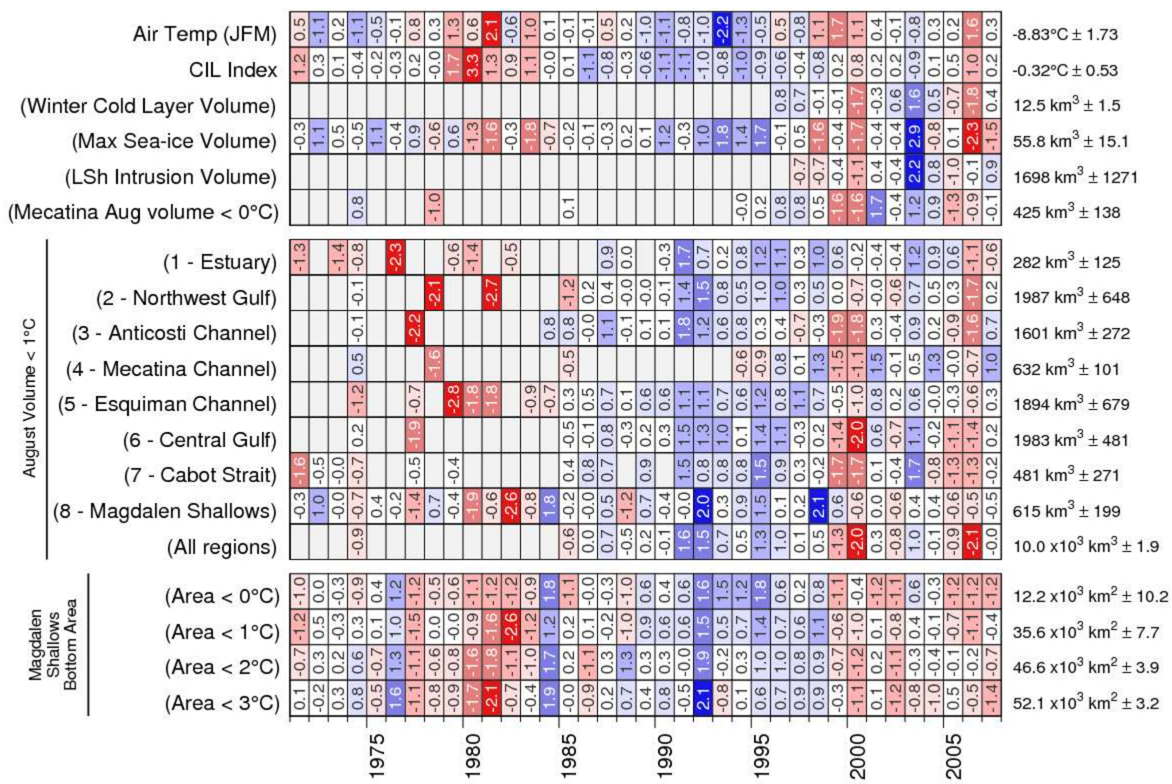


Table 6. Scorecard depth-layer average temperature summary of the eight Gulf-wide oceanographic surveys in 2006 and 2007. The colour-coding is according to the temperature anomaly relative to the monthly climatology of each region.

1 - Estuary / Estuaire

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Oct
0 m	-0.25	8.6	8.7	4.9	-0.41	8.2	8.8	3.7
10 m	-0.19	7.0	7.3	4.9	-0.19	5.8	6.6	3.6
20 m	0.0	5.4	4.8	5.1	0.1	2.8	3.9	3.4
30 m	0.2	4.0	3.1	5.2	0.9	1.9	2.8	3.2
50 m	-0.06	1.7	1.3	4.7	0.4	1.0	1.1	2.2
75 m	0.7	0.6	1.1	3.8	1.2	-0.0	0.7	1.2
100 m	1.6	1.4	1.6	2.5	1.7	0.4	1.3	1.3
150 m	3.2	3.3	3.5	1.9	3.9	2.5	3.0	2.9
200 m	4.3	4.3	4.5	3.3	4.8	4.0	4.2	4.1
250 m		4.9	5.0	4.5		4.6	4.8	4.8
300 m		5.2	5.3	5.1		5.0	5.2	5.1
350 m		5.2	5.3	5.2		5.2	5.2	5.2

2 - Northwest Gulf / Nord-ouest du Golfe

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-1.02	11.9	12.3	5.3	-1.46	10.8	10.8	4.7
10 m	-1.09	10.3	10.6	5.3	-1.45	8.2	9.2	4.7
20 m	-1.16	6.1	4.4	5.3	-1.38	3.9	4.5	4.7
30 m	-1.06	3.9	2.4	4.9	-1.27	2.2	2.5	4.3
50 m	-0.20	1.3	1.1	3.4	-0.47	0.4	0.7	2.4
75 m	0.9	0.6	1.1	2.4	0.9	0.3	0.3	1.1
100 m	1.9	1.4	1.8	1.9	2.0	1.0	0.8	1.1
150 m	3.7	3.3	3.6	2.6	4.4	3.3	3.0	3.2
200 m	4.9	4.5	4.7	4.2	4.9	4.6	4.5	4.5
250 m	5.4	5.1	5.3	5.0		5.3	5.2	5.2
300 m	5.5	5.4	5.4	5.3		5.4	5.4	5.4
350 m	5.5	5.4	5.4	5.4		5.4	5.4	5.4
400 m			5.3	5.4		5.5	5.4	

3 - Anticosti Channel / Chenal Anticosti

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-1.19		14.4	6.4	-1.72	7.6	13.3	4.5
10 m	-1.20		13.1	6.4	-1.71	6.4	12.9	4.5
20 m	-1.20		4.1	6.4	-1.71	4.2	6.2	4.5
30 m	-1.16		1.9	6.4	-1.70	1.9	2.4	4.5
50 m	-1.03		0.6	5.5	-1.68	-0.3	0.2	3.1
75 m	-0.04		0.1	2.8	-0.88	-1.0	-0.3	0.4
100 m	1.1		0.3	1.1	0.5	-1.0	-0.4	0.2
150 m	3.3		3.1	1.9	3.3	-0.3	1.5	2.4
200 m	4.6		5.1	4.9	4.7	3.2	4.8	4.7
250 m			5.6	5.6			5.8	5.7

4 - Mecatina Channel / Chenal Mécatina

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-1.50	9.9	14.9	5.1	-1.77	6.1	12.6	3.8
10 m	-1.55	7.2	14.6	5.1	-1.77	4.8	11.5	3.8
20 m	-1.62	3.0	12.3	5.1	-1.77	0.6	7.3	3.8
30 m	-1.66	1.5	7.0	5.0	-1.77	0.3	3.7	3.5
50 m	-1.71	0.2	3.5	3.9	-1.77	-0.9	1.3	3.1
75 m	-1.75	-0.5	1.3	3.0	-1.75	-1.1	0.2	2.5
100 m	-1.76	-0.6	-0.2	2.1	-1.70	-1.2	-0.5	1.6
150 m	-1.52		-0.9	0.9	-1.65	-0.9	-0.4	0.7
200 m	-1.75		0.1	0.2	-1.77	-0.1	0.9	1.3

5 - Esquiman Channel / Chenal Esquiman

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-0.75	10.6	16.0	6.4	-1.71	8.1	15.0	5.1
10 m	-0.81	10.1	15.9	6.4	-1.71	8.0	14.1	5.1
20 m	-0.86	7.1	12.5	6.1	-1.71	4.1	8.4	5.0
30 m	-0.81	4.5	5.2	5.7	-1.70	1.4	2.6	4.6
50 m	-0.74	1.0	1.3	2.0	-1.62	0.0	0.4	2.6
75 m	-0.32	0.1	0.6	0.8	-1.07	-0.0	-0.0	0.6
100 m	0.8	0.5	0.7	0.9	-0.10	0.1	0.3	0.5
150 m	3.3	3.5	3.1	3.3	2.3	2.5	2.7	2.2
200 m	4.8	5.3	4.9	5.1	3.9	4.9	4.9	4.7
250 m		5.7	5.6	5.7		5.6	5.7	5.6
300 m			5.7	5.6			5.7	5.7

6 - Central Gulf / Centre du Golfe

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-0.91	13.4	16.4	7.3	-1.66	9.6	15.4	5.1
10 m	-0.88	11.8	16.0	7.3	-1.66	8.4	13.5	5.0
20 m	-0.93	9.2	10.2	7.3	-1.66	6.0	6.0	5.0
30 m	-0.93	4.0	3.6	7.1	-1.66	3.4	2.7	5.0
50 m	-0.72	0.8	1.1	2.8	-1.57	0.4	0.7	2.3
75 m	0.2	0.8	0.8	1.6	-0.26	0.2	0.2	0.4
100 m	1.5	1.1	0.9	1.4	1.3	1.1	0.3	0.6
150 m	3.7	3.5	3.1	3.0	3.2	3.4	2.5	3.0
200 m	5.1	5.2	5.0	5.0	5.0	5.1	4.7	4.8
250 m		5.6	5.6	5.6		5.6	5.6	5.5
300 m		5.5	5.6	5.6		5.6	5.6	5.5
350 m		5.2	5.3	5.4		5.4	5.4	5.4
400 m		5.1	5.1	5.2		5.3	5.2	5.3
450 m			5.1	5.1		5.1	5.1	5.1

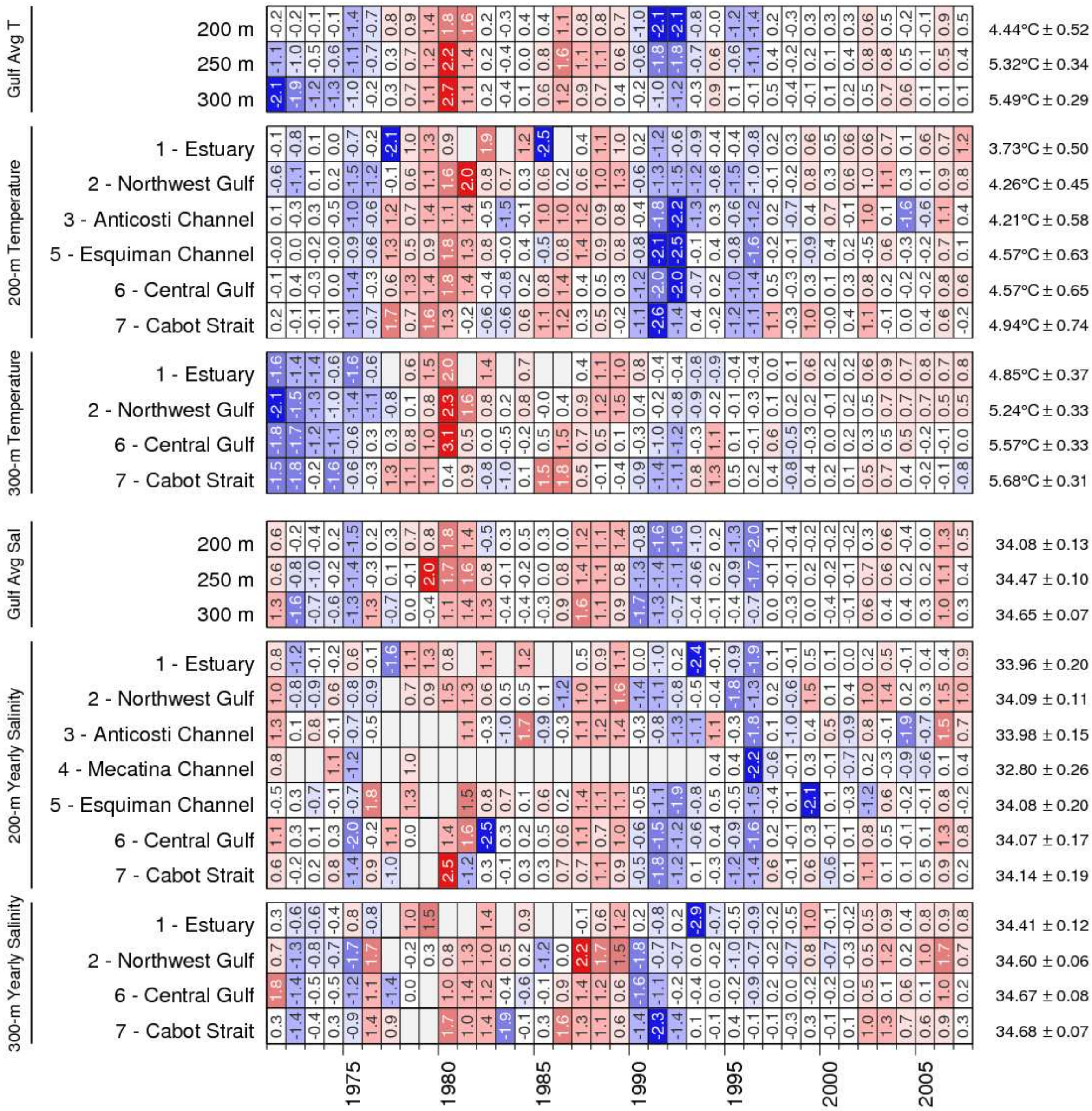
7 - Cabot Strait / Détroit de Cabot

	2006 Mar	2006 June	2006 Aug	2006 Nov	2007 Mar	2007 June	2007 Aug	2007 Nov
0 m	-1.13	13.4	15.5	7.8	-1.39	10.2	17.0	7.4
10 m	-1.15	12.3	13.9	7.8	-1.43	9.1	13.1	7.3
20 m	-0.98	7.7	6.8	7.6	-1.40	4.2	6.1	7.0
30 m	-0.82	3.7	3.2	7.5	-1.38	2.2	3.2	6.6
50 m	-0.68	1.6	1.7	5.0	-1.33	0.9	1.3	4.5
75 m	-0.13	1.3	1.4	2.4	-0.95	0.7	0.9	2.3
100 m	0.8	1.6	1.8	1.8	-0.44	1.1	0.9	1.3
150 m	3.4	4.1	4.3	2.9	2.8	2.7	3.2	3.0
200 m	5.6	5.8	5.5	5.0	4.8	4.5	4.9	4.8
250 m		5.9	5.8	5.9		5.4	5.5	5.4
300 m		5.6	5.6	5.8		5.5	5.4	5.5
350 m		5.3	5.3	5.4		5.3	5.2	5.3
400 m		5.0	5.1	5.2		5.1	5.1	5.2
450 m		5.0	5.0	5.1		4.9	4.9	5.0
500 m			5.0	5.0			4.8	4.9

8 - Magdalen Shallows / Plateau Madelinien

	2006 Mar	2006 June	2006 Sep	2006 Nov	2007 Mar	2007 June	2007 Sep	2007 Nov
0 m	-1.34	14.8	15.9	6.2	-1.60	11.7	14.3	7.1
10 m	-1.45	12.0	15.8	6.2	-1.62	9.8	14.1	7.0
20 m	-1.46	4.4	12.3	5.9	-1.63	5.7	12.8	7.0
30 m	-1.46	2.1	6.6	5.2	-1.65	2.3	8.0	6.7
50 m	-1.37	0.8	1.0	2.2	-1.59	0.3	1.3	4.1
75 m	-0.50	0.6	0.9	1.6	-1.55	-0.0	0.6	1.1
100 m		0.8	1.2					

Table 7. Deep layer temperature and salinity. Gulf averages are shown for 200, 250 and 300 m and regional averages are shown for 200 and 300 m.



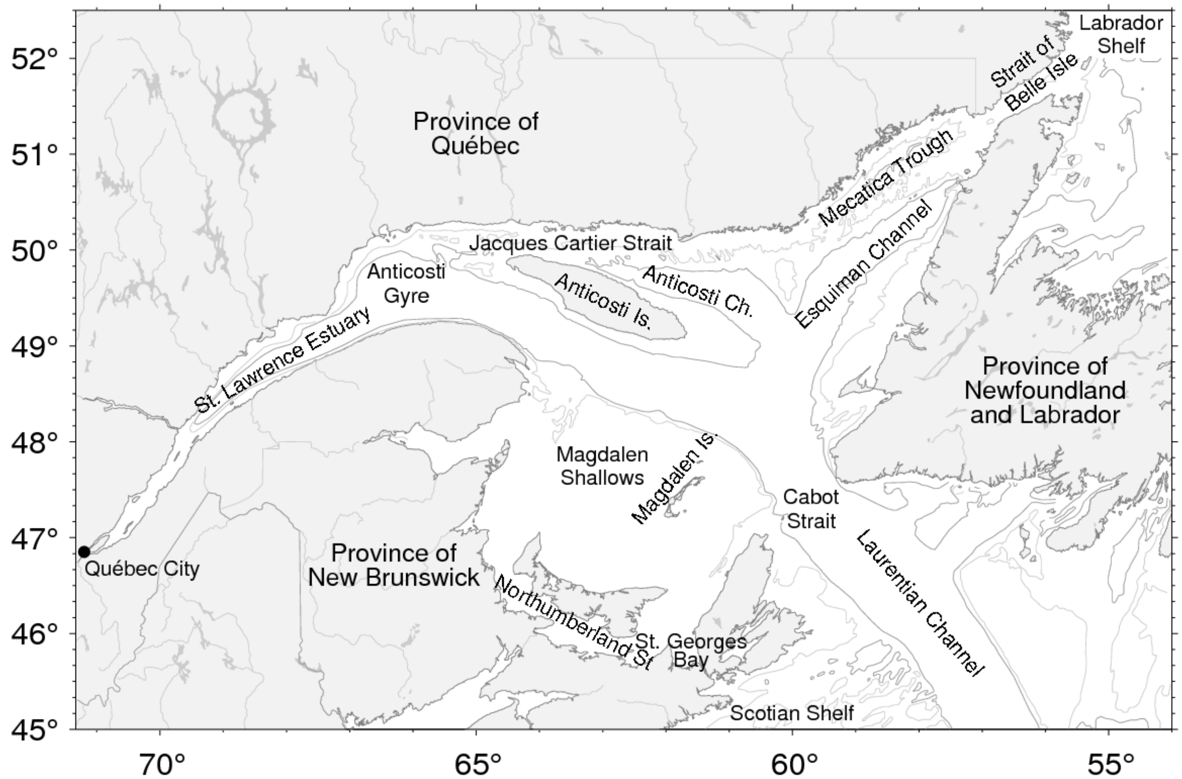


Fig. 1. The Gulf of St. Lawrence, with the100 and 200 m isobaths. Locations discussed in the text are indicated.

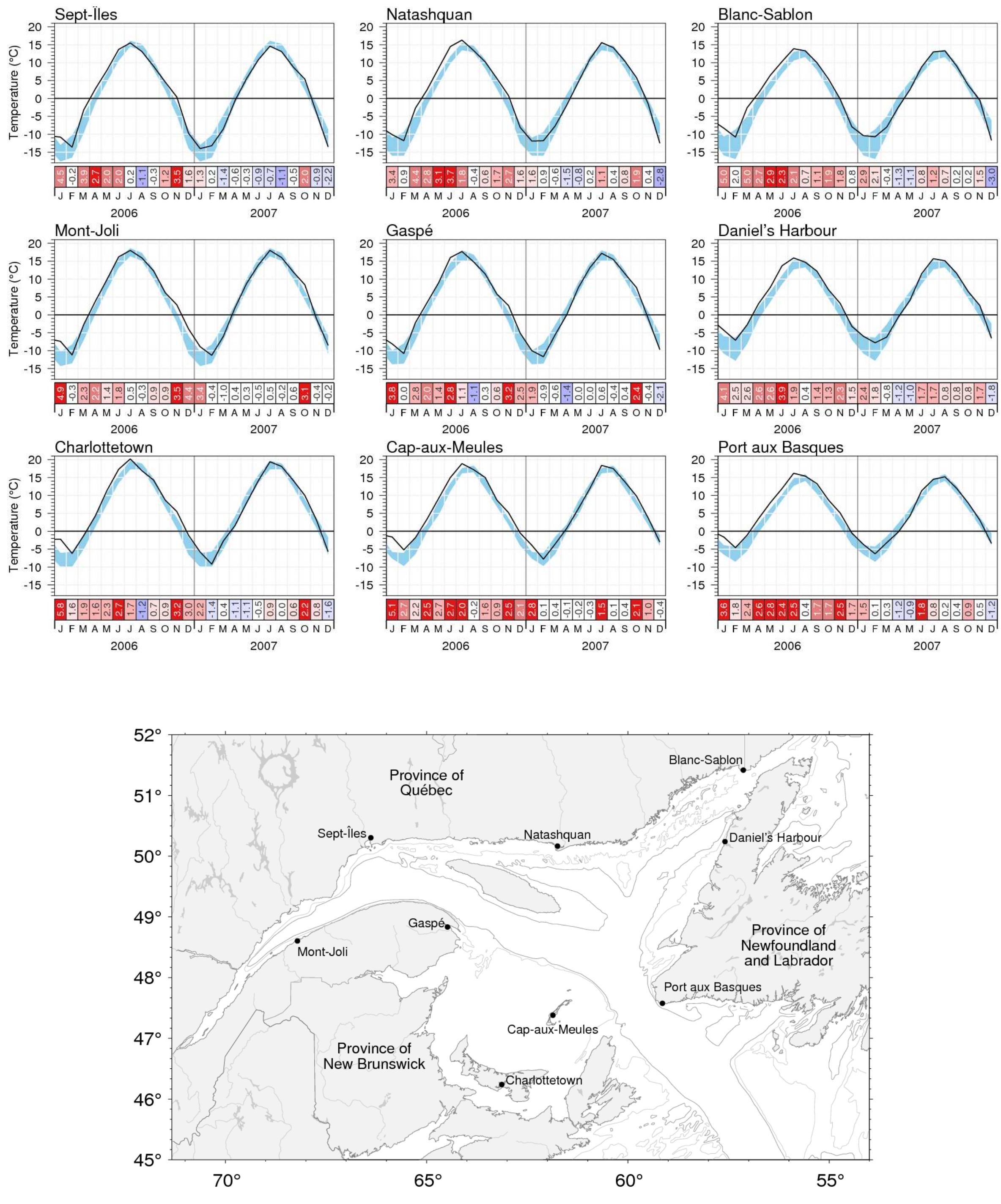


Fig. 2. Monthly air temperature anomalies for 2006 and 2007 (top panel) at 9 selected stations around the Gulf (shown in lower panel). The blue area represents the 1971–2000 climatological monthly mean plus or minus one standard deviation. The bottom scorecards are colour-coded according to the monthly standardized anomalies for each month, but the numbers are the monthly anomalies in ºC.

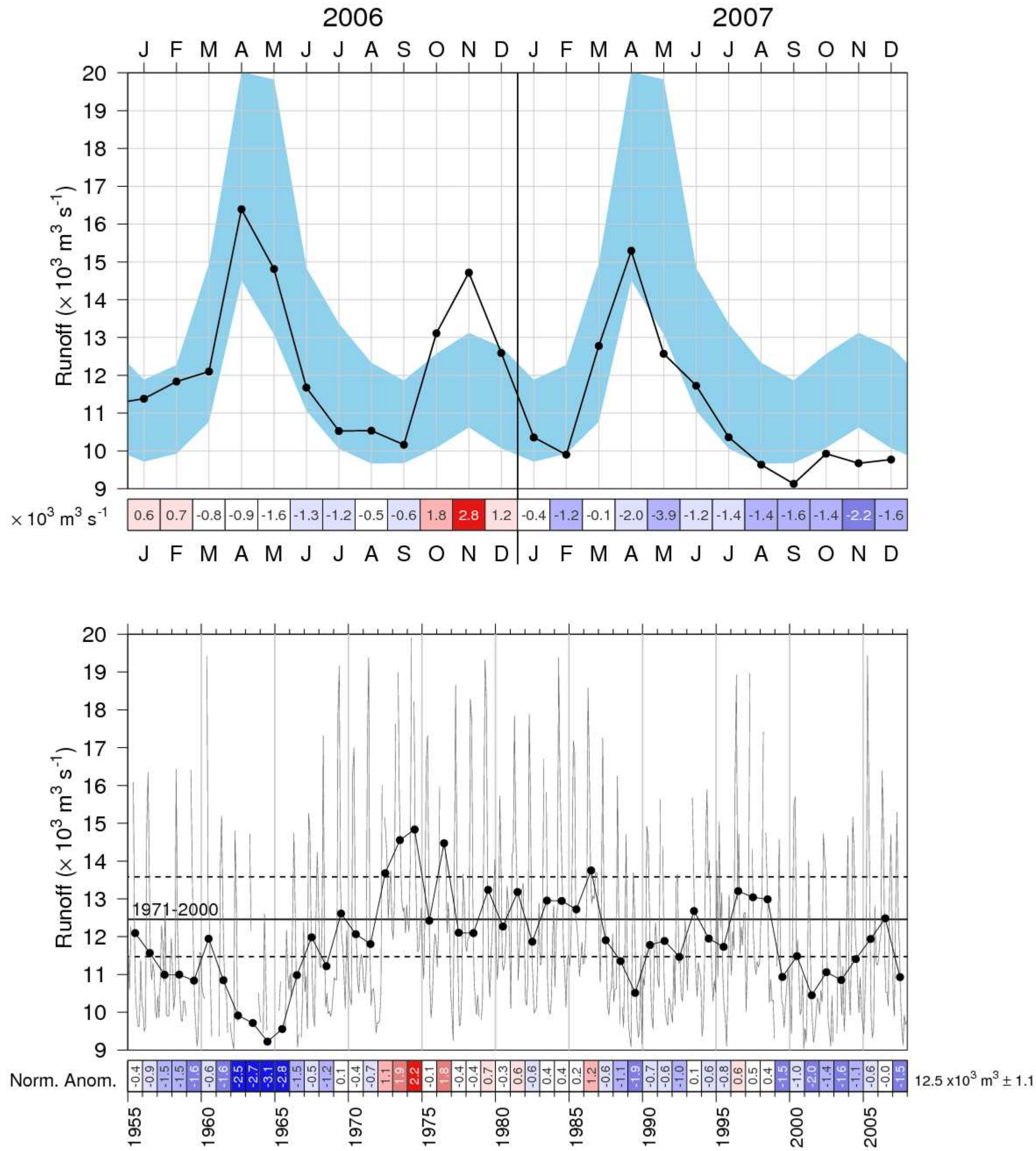


Fig. 3. Monthly (top panel) and annual (bottom panel) mean freshwater flow of the St. Lawrence River at Québec City. The 1971–2000 climatological mean, plus or minus one standard deviation, is shown for each month in the top panel (blue outline) and as horizontal lines for the annual time series in the bottom panel. The top-panel scorecard is colour-coded according to the monthly anomalies standardized for each month of the year, but the numbers are the actual monthly anomalies in $\times 10^3$ m^3 s^{-1}. The bottom-panel scorecard shows numbered normalized anomalies for which the mean and standard deviation are indicated on the right side.

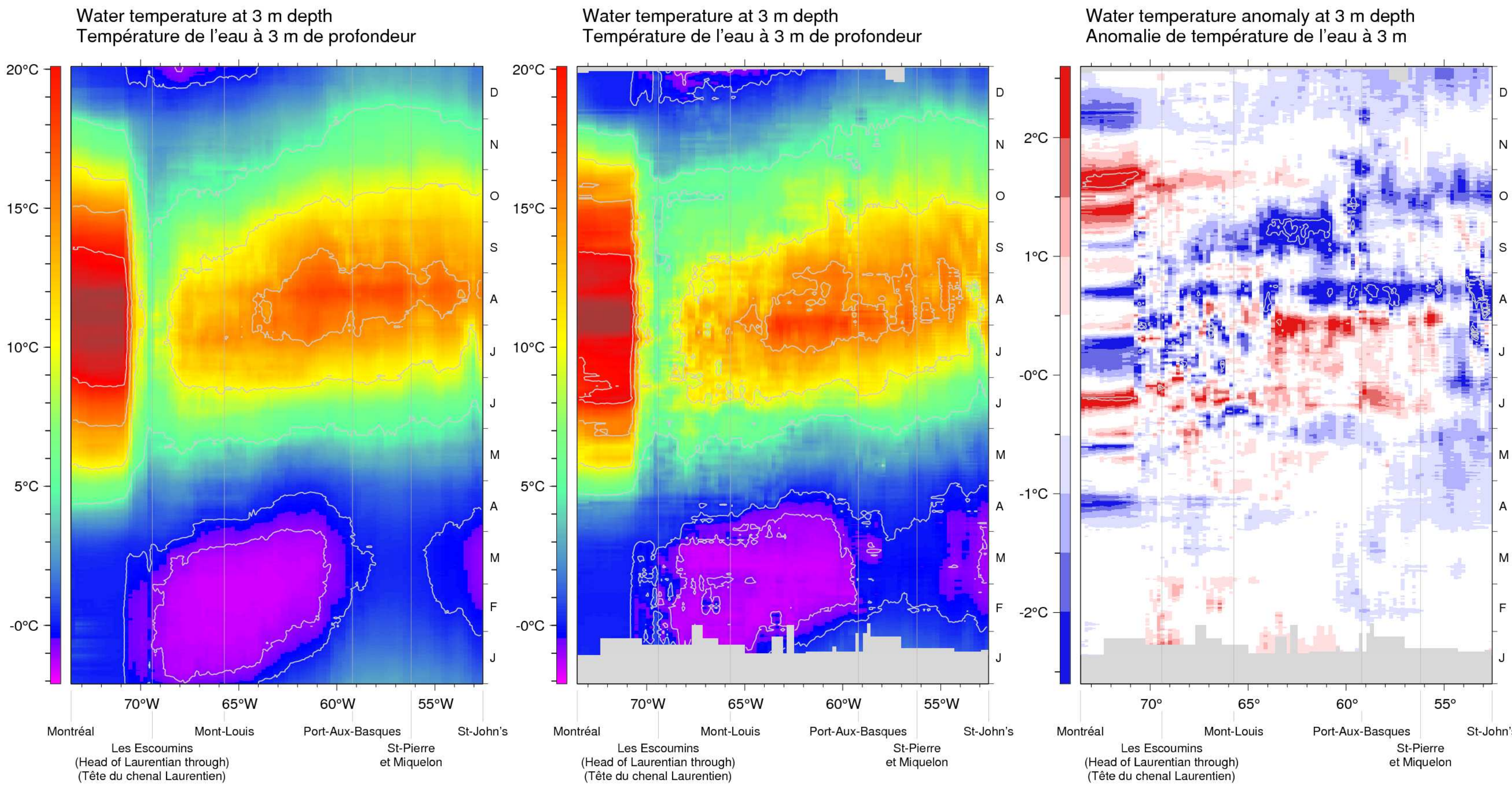


Fig. 4. Thermosalinograph data at 3-m depth along the Montréal to St. John's shipping route: composite mean annual cycle of the water temperature for the 2000–2006 period (left panel), composite annual cycle of the water temperature for 2007 (middle panel) and water temperature anomaly for 2007 relative to 2000–2007 composite (right panel).

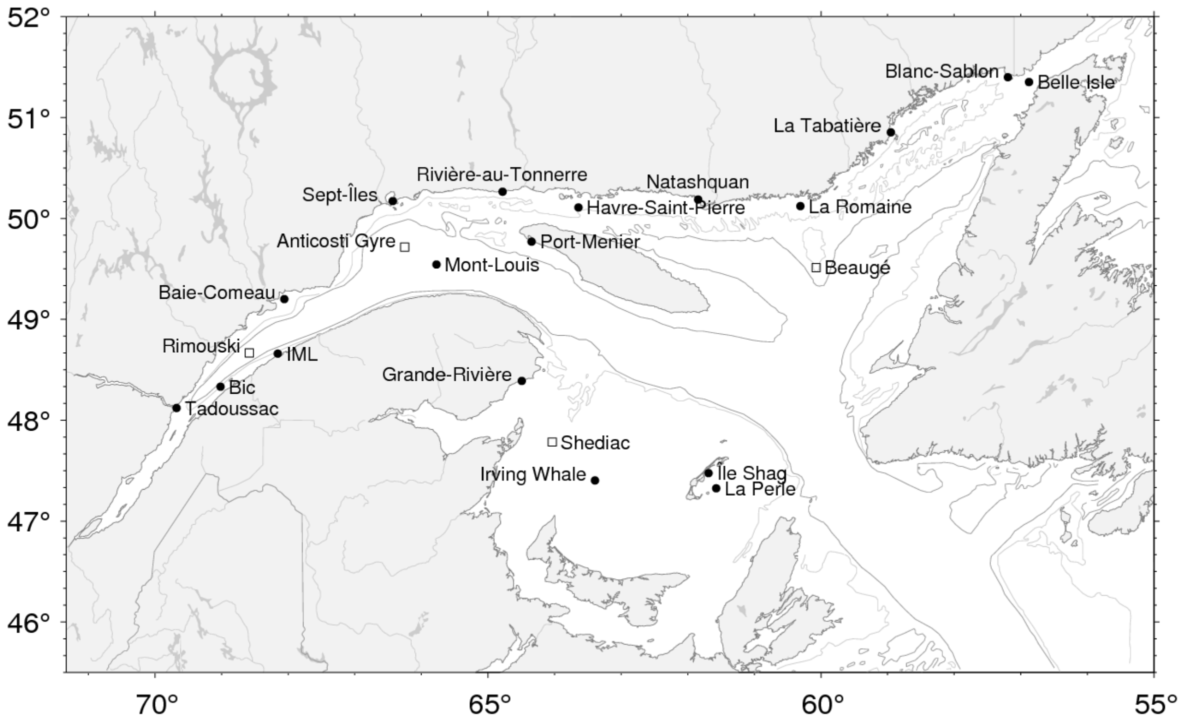


Fig. 5. Locations of IML thermograph network stations in 2007, including regular stations where data are logged internally and recovered at the end of the season (filled circles) and oceanographic buoys that transmit data in real time (open squares).

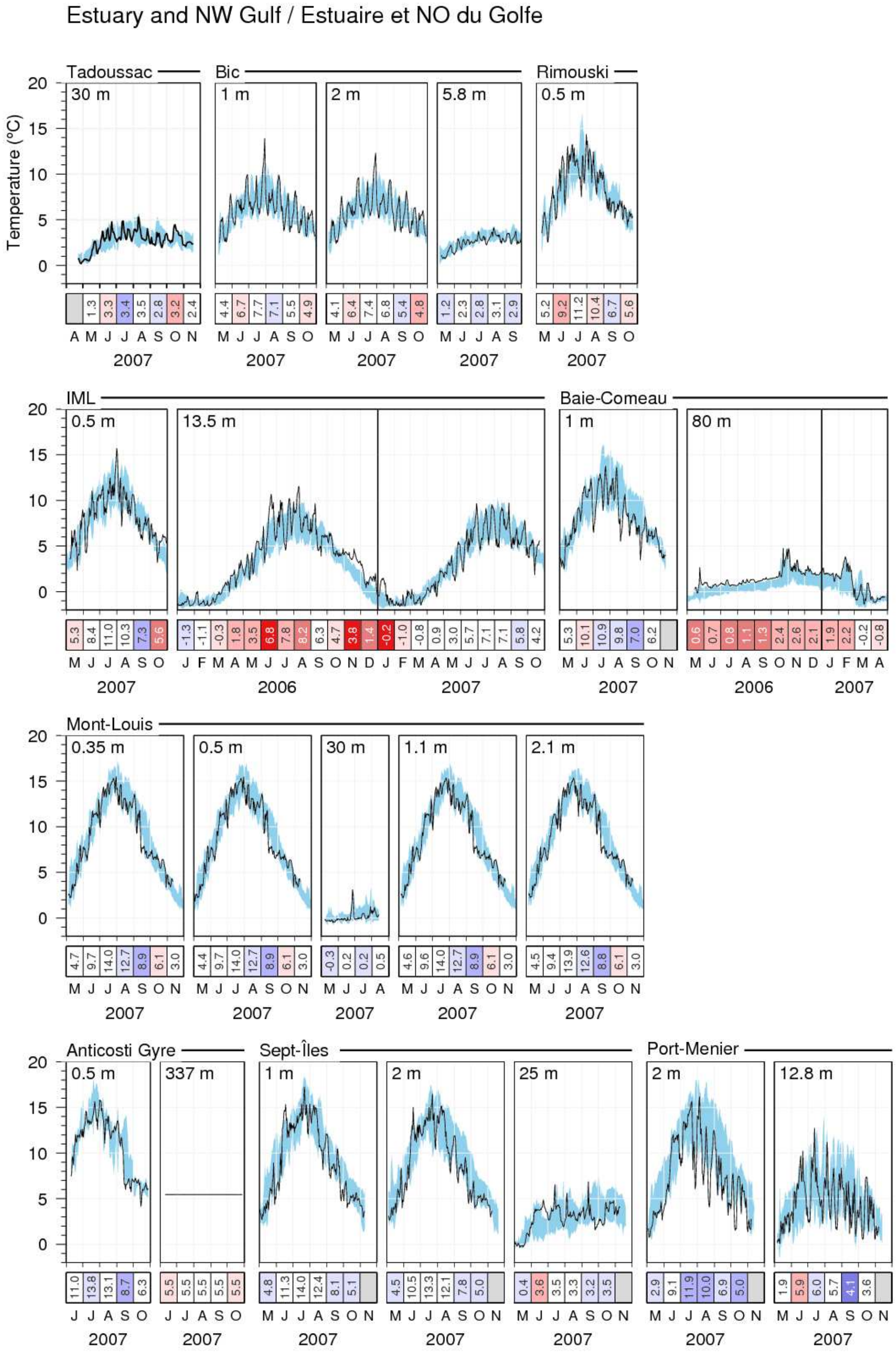


Fig. 6. Thermograph network data. Daily mean 2007 temperatures compared with the daily climatology (daily averages plus or minus one standard deviation; blue areas) computed from all available stations in the Estuary and northwestern Gulf. Score cards show monthly average temperature. Data from late in the year of 2006 are included if they were not shown in the previous report (Galbraith et al. 2007)

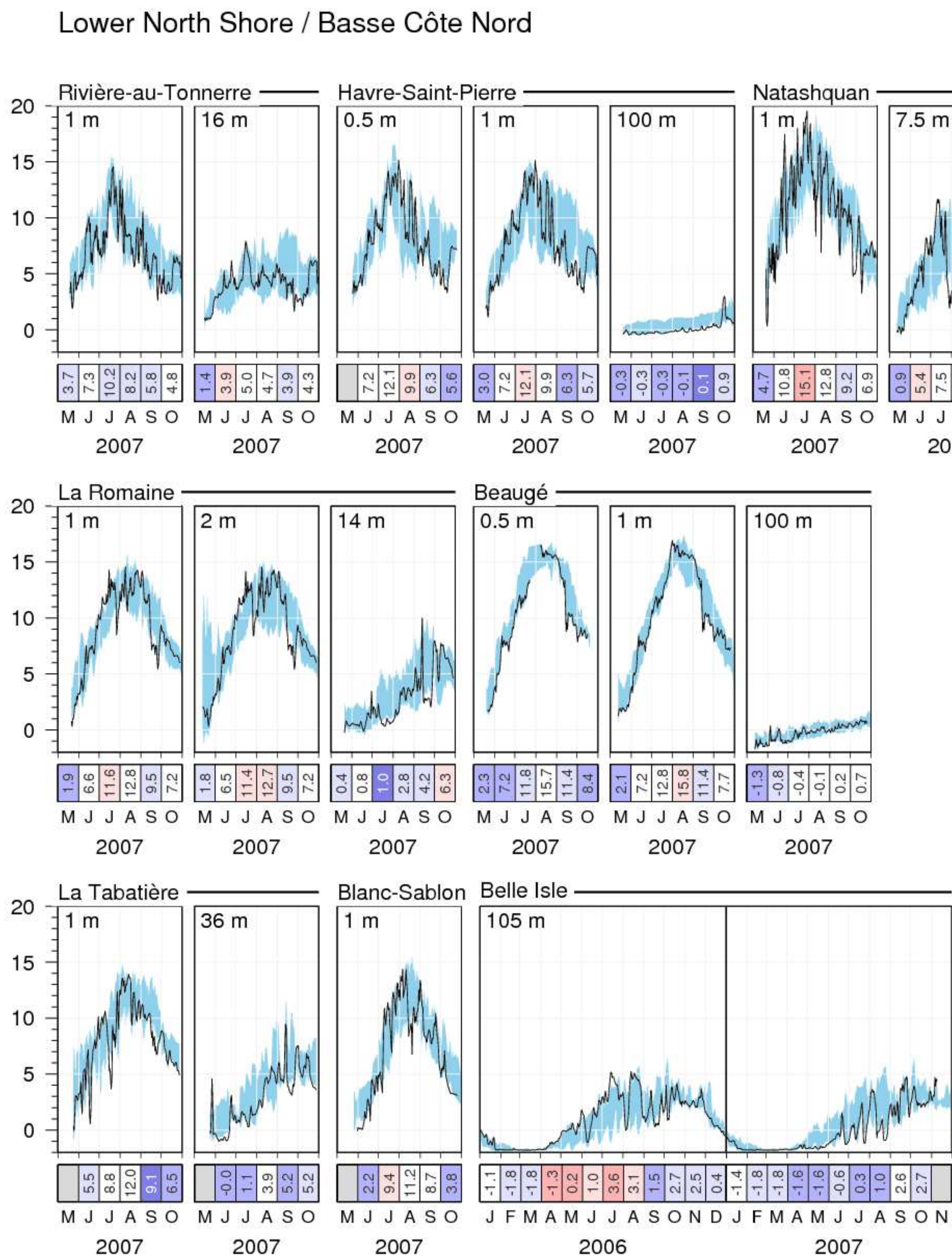


Fig. 7. Thermograph network data. Daily mean 2007 temperatures compared with the daily climatology (daily averages plus or minus one standard deviation; blue areas) computed from all available stations of the lower north shore.

Southern Gulf / Sud du Golfe

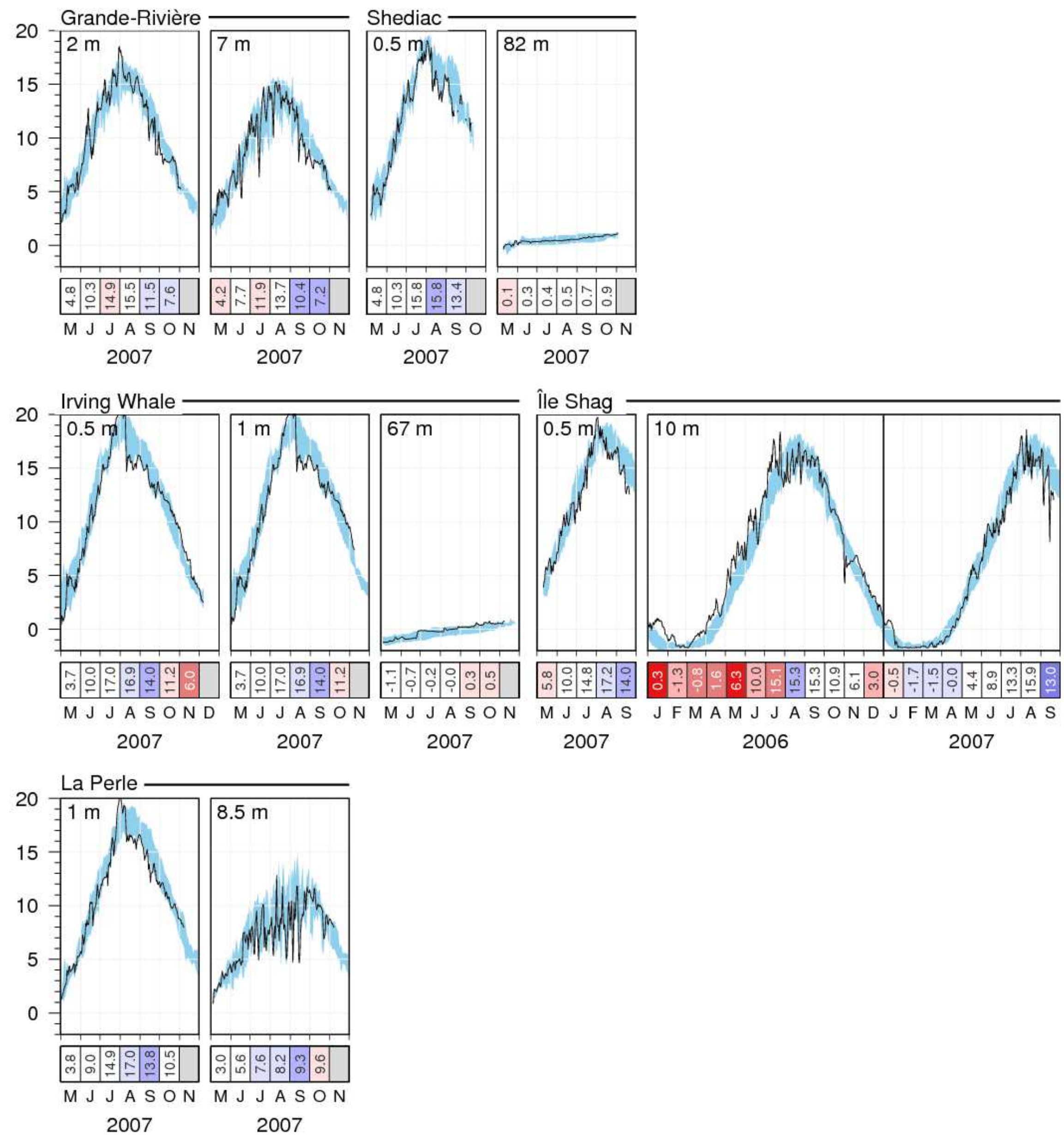


Fig. 8 Thermograph network data. Daily mean 2007 temperatures compared with the daily climatology (daily averages plus or minus one standard deviation; blue area) computed from all available stations of the southern Gulf.

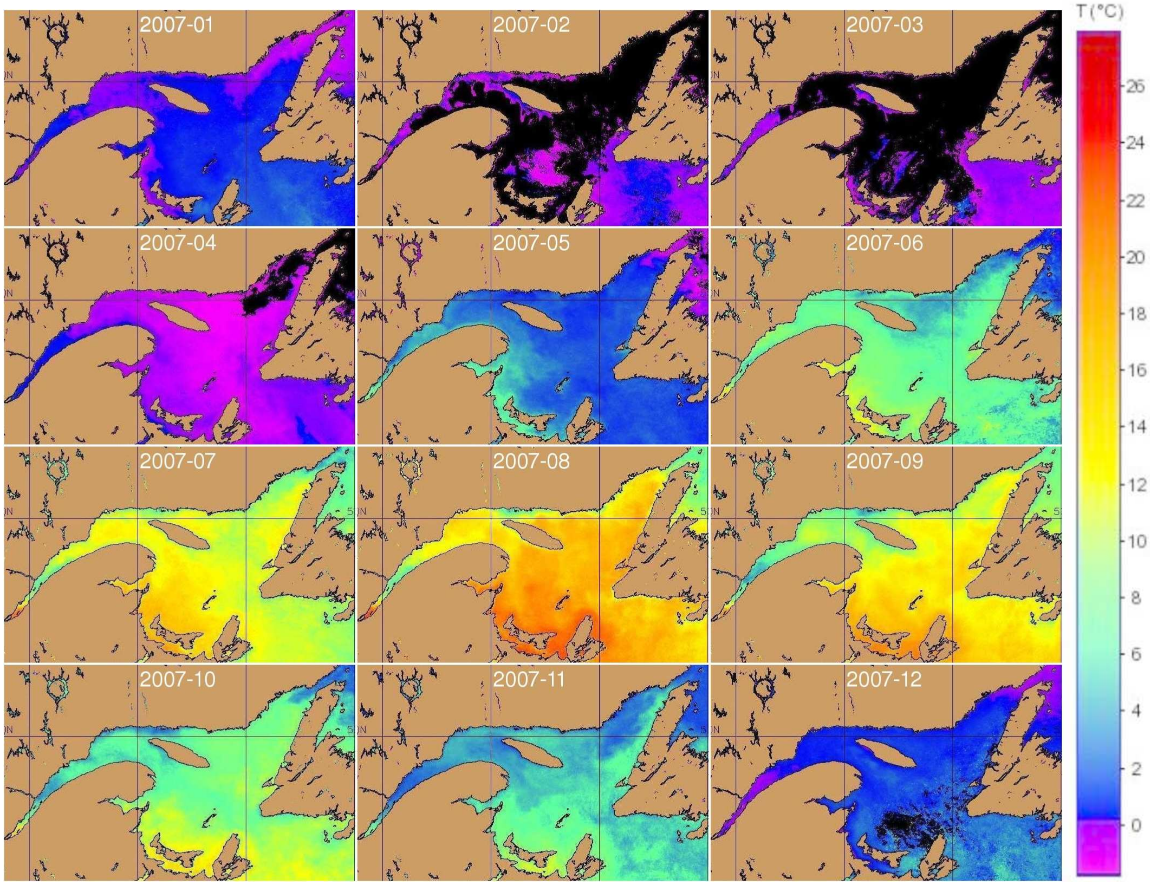


Fig. 9. Sea-surface temperature averages for the first half of each month of 2007, as observed from NOAA AVHRR remote sensing. Black areas have no data for the period due to clouds or ice cover.

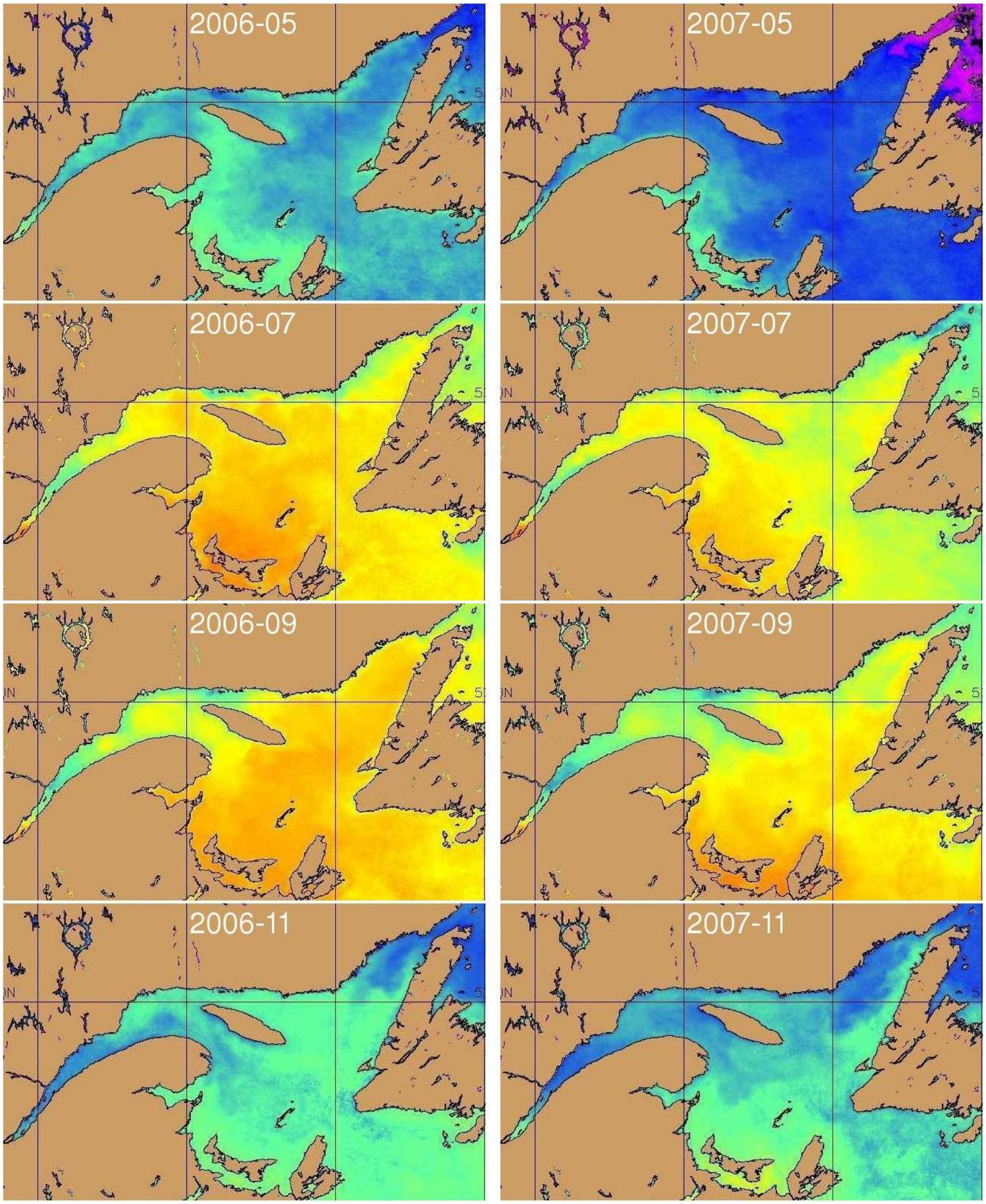


Fig. 10. Sea-surface temperature comparison for selected half-month periods of 2006 and 2007 as observed from NOAA AVHRR remote sensing. The colour palette is the same as for Fig. 9.

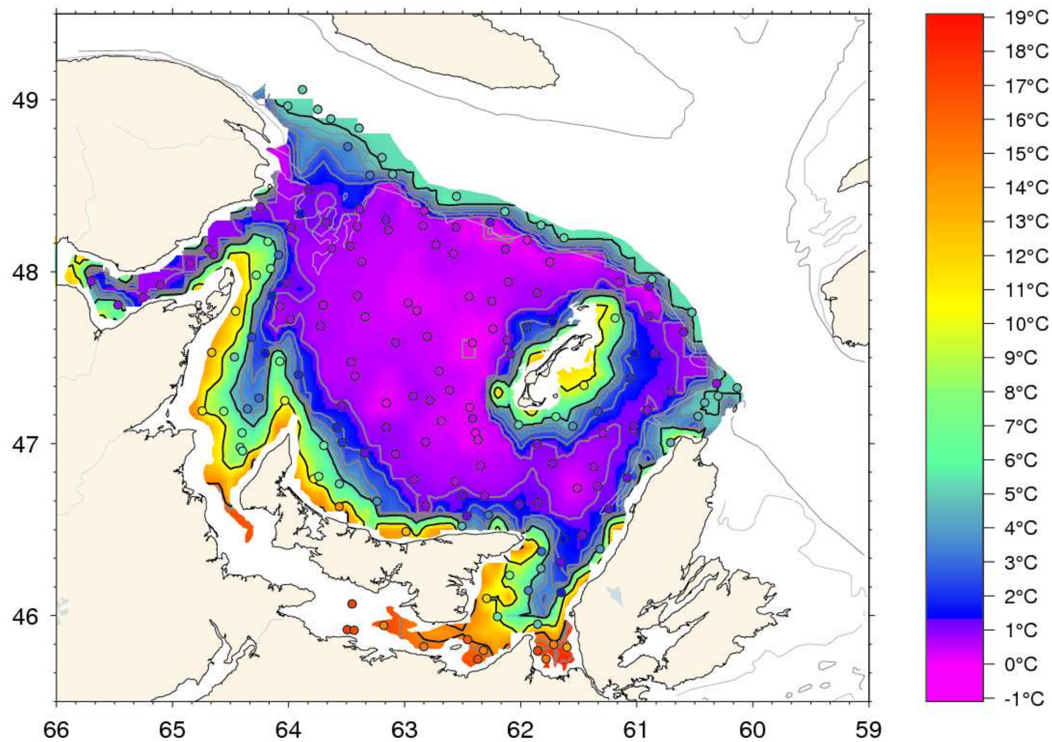


Fig. 11. Near-bottom temperatures during the 2007 September multi-species survey.

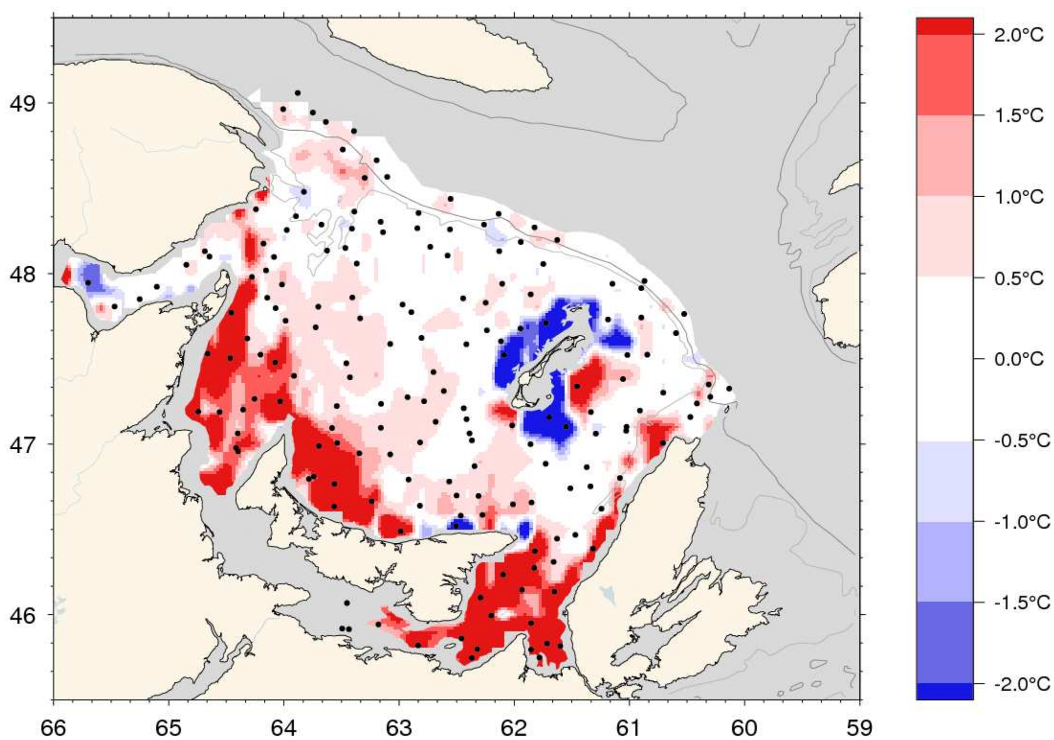


Fig. 12 Near-bottom temperature anomalies from the 1971–2000 climatology in the southern Gulf of St. Lawrence during the 2007 September multi-species survey.

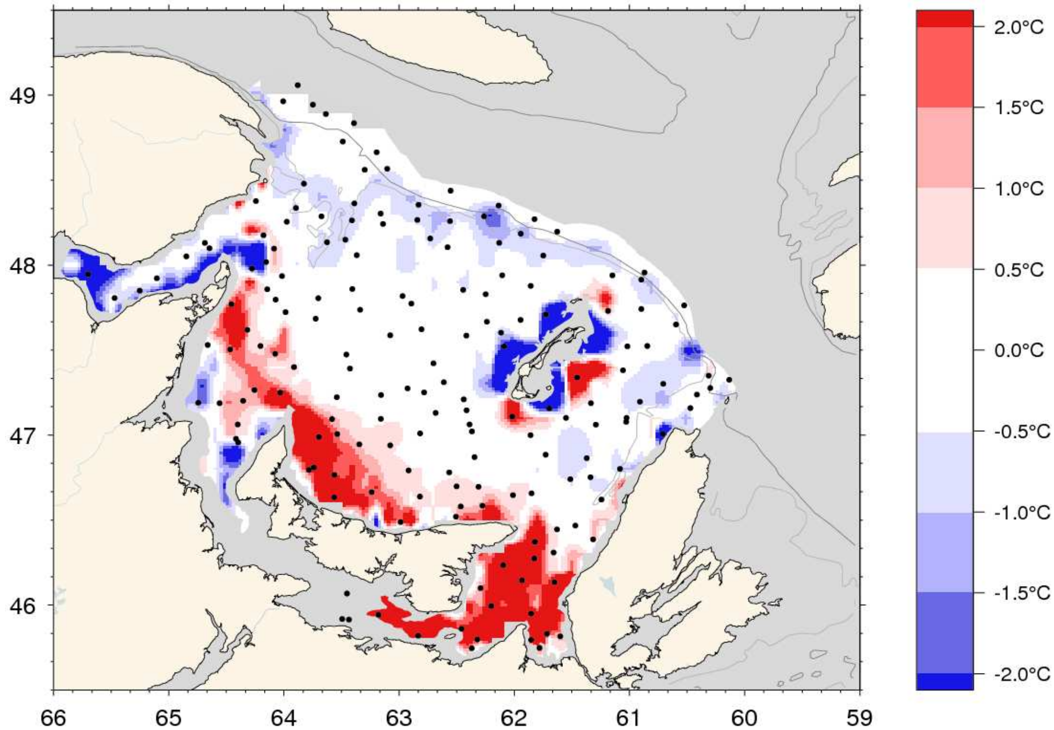


Fig. 13. The difference between the 2007 and 2006 bottom temperature fields in the southern Gulf of St. Lawrence for the September surveys.

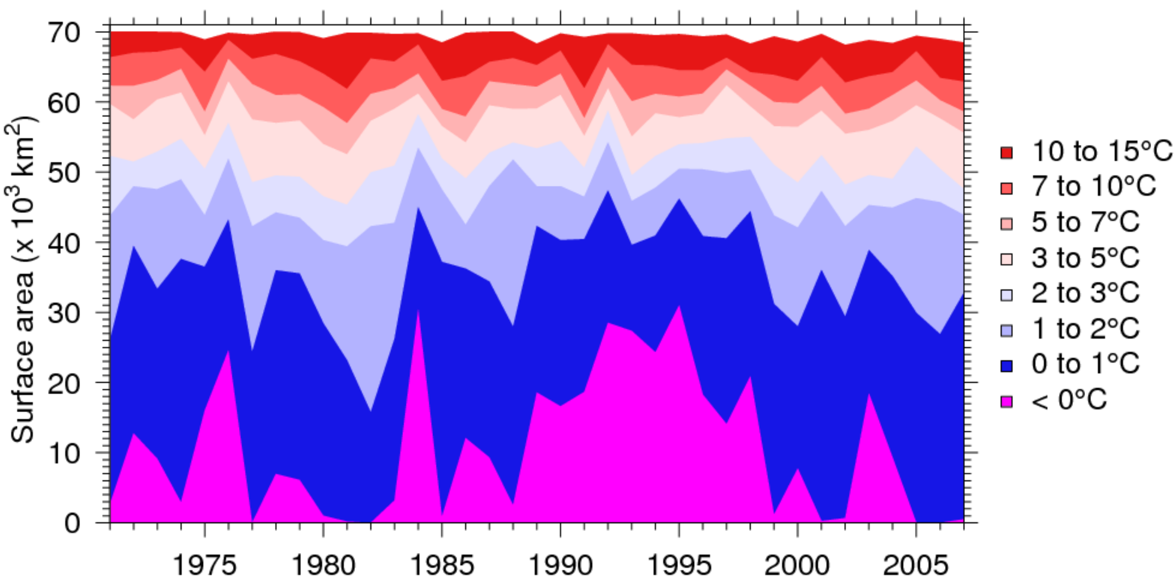


Fig. 14. Time series of the areas of the Magdalen Shallows covered by different temperature bins in September.

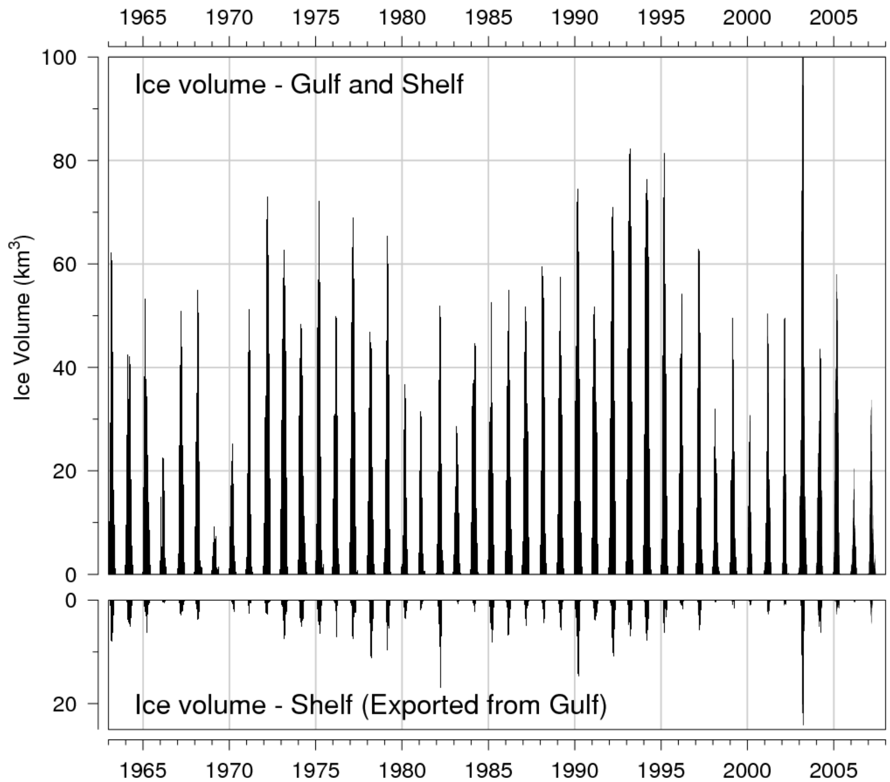


Fig. 15. Estimated ice volume in the Gulf of St. Lawrence and on the Scotian Shelf seaward of Cabot Strait (upper panel) and on the Scotian Shelf only (lower panel).

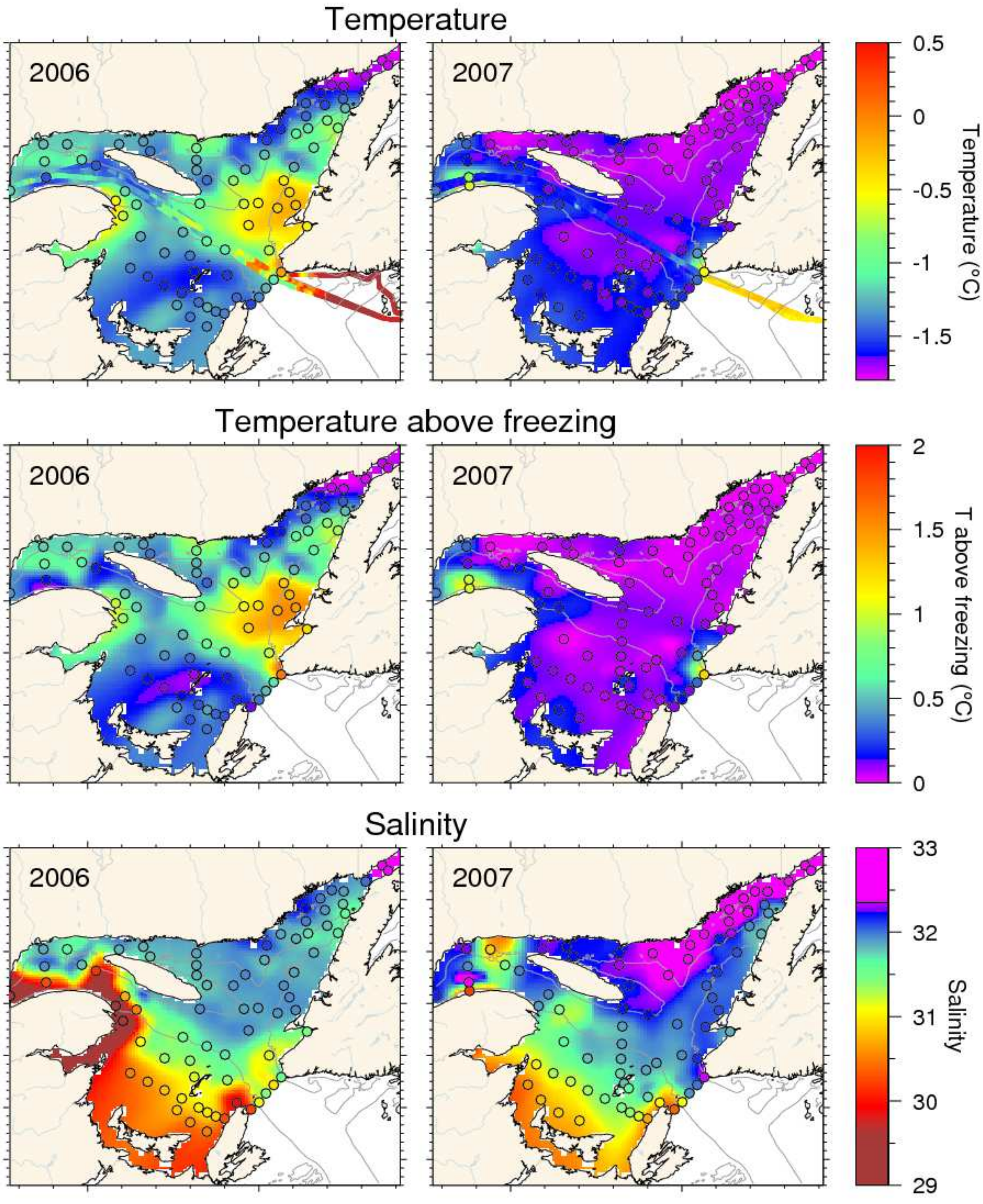


Fig. 16. Winter surface layer characteristics from the March 2006 and 2007 helicopter surveys. Surface water temperature (upper panel), temperature difference between surface water temperature and freezing point (middle panel) and salinity (lower panel). The temperature measurements from shipboard thermosalinographs taken during the survey are also shown in the upper panels. 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.

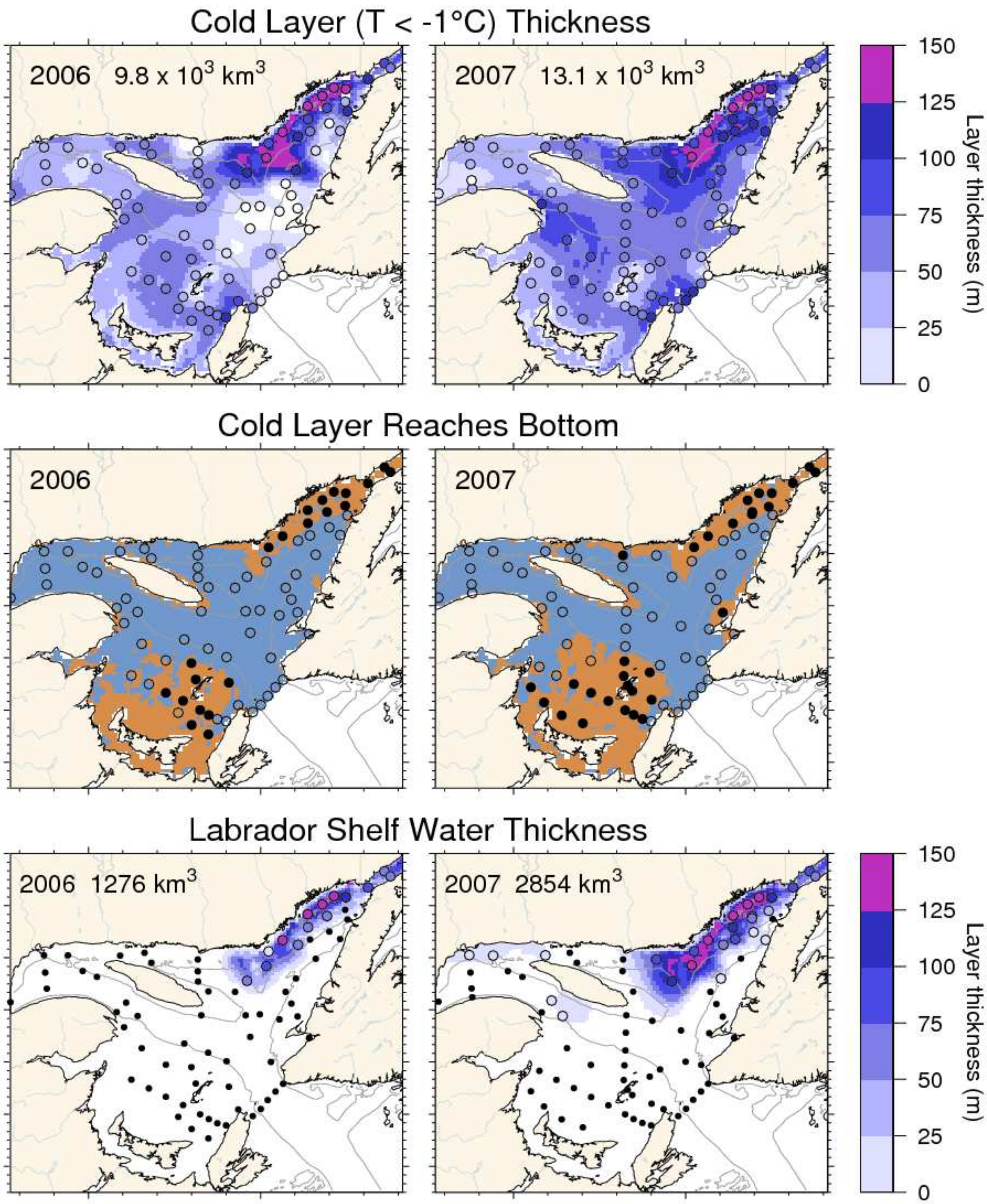


Fig. 17. Winter surface layer characteristics from the March 2006 and 2007 helicopter surveys. Cold layer (T < -1℃) thickness (upper pan els), maps indicating where the cold layer reaches the bottom (in brown; middle panels) and estimate of the thickness of the Labrador Shelf water intrusion (lower panels). Station symbols are coloured according to the observed values as in Fig. 16. For the middle panels, 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.

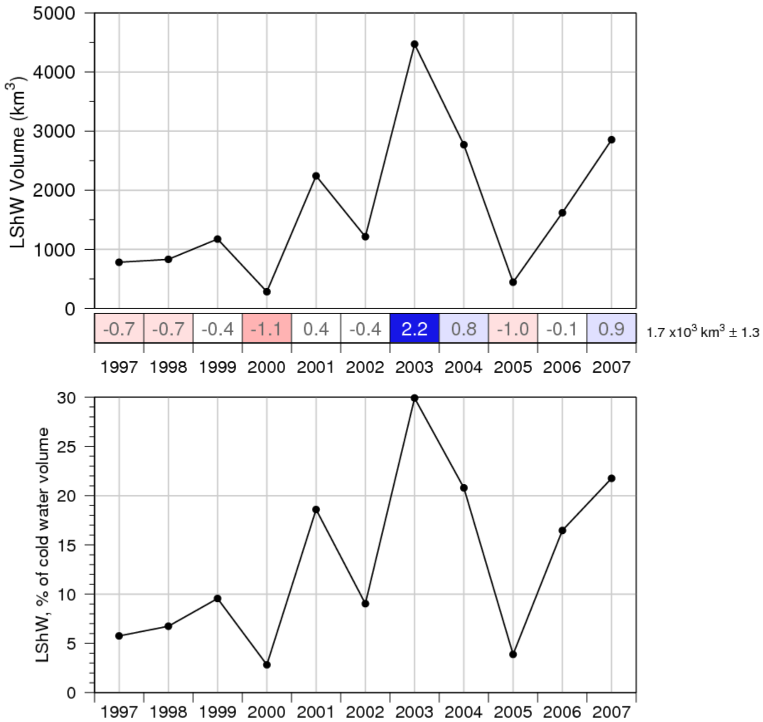


Fig. 18. Estimated volume of cold and saline Labrador Shelf water that flowed into the Gulf over the wintertime through the Strait of Belle Isle.

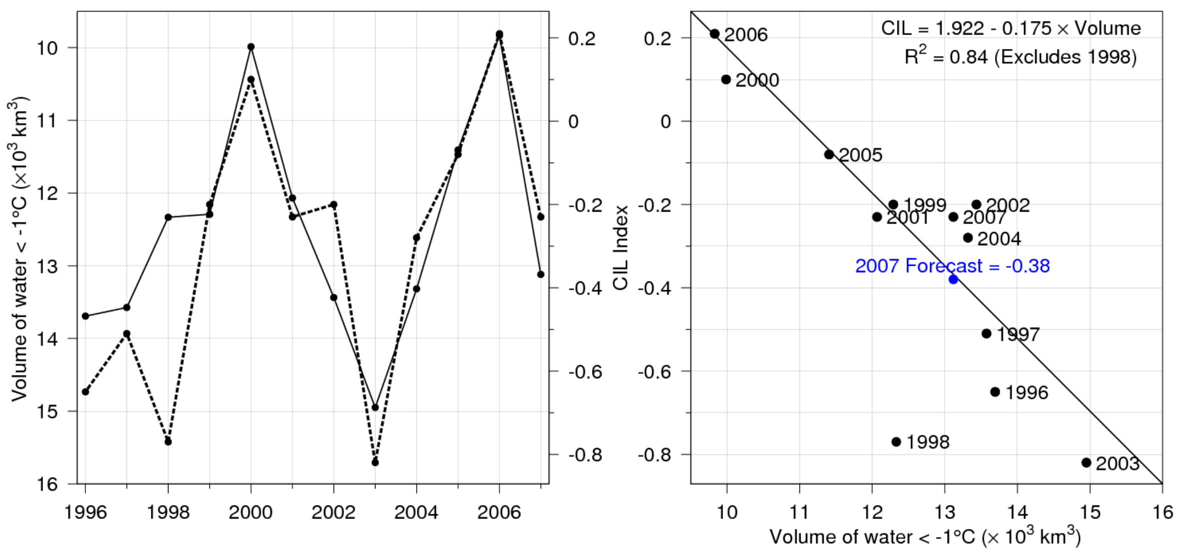


Fig. 19. Left panel: winter surface cold (T < -1°C) layer volume time series (solid line) and summer CIL index (dashed line). Right panel: Relation between summer CIL index and winter cold water volume. Note that the volume scale in the left panel is reversed. The volume observed in March 2007 forecasted a CIL index of -0.38ºC (in blue) for the summer 2007 (a cooling of 0.6ºC *vs.* 2006). The actual 2007 CIL index observed later in the year is also indicated (in black).

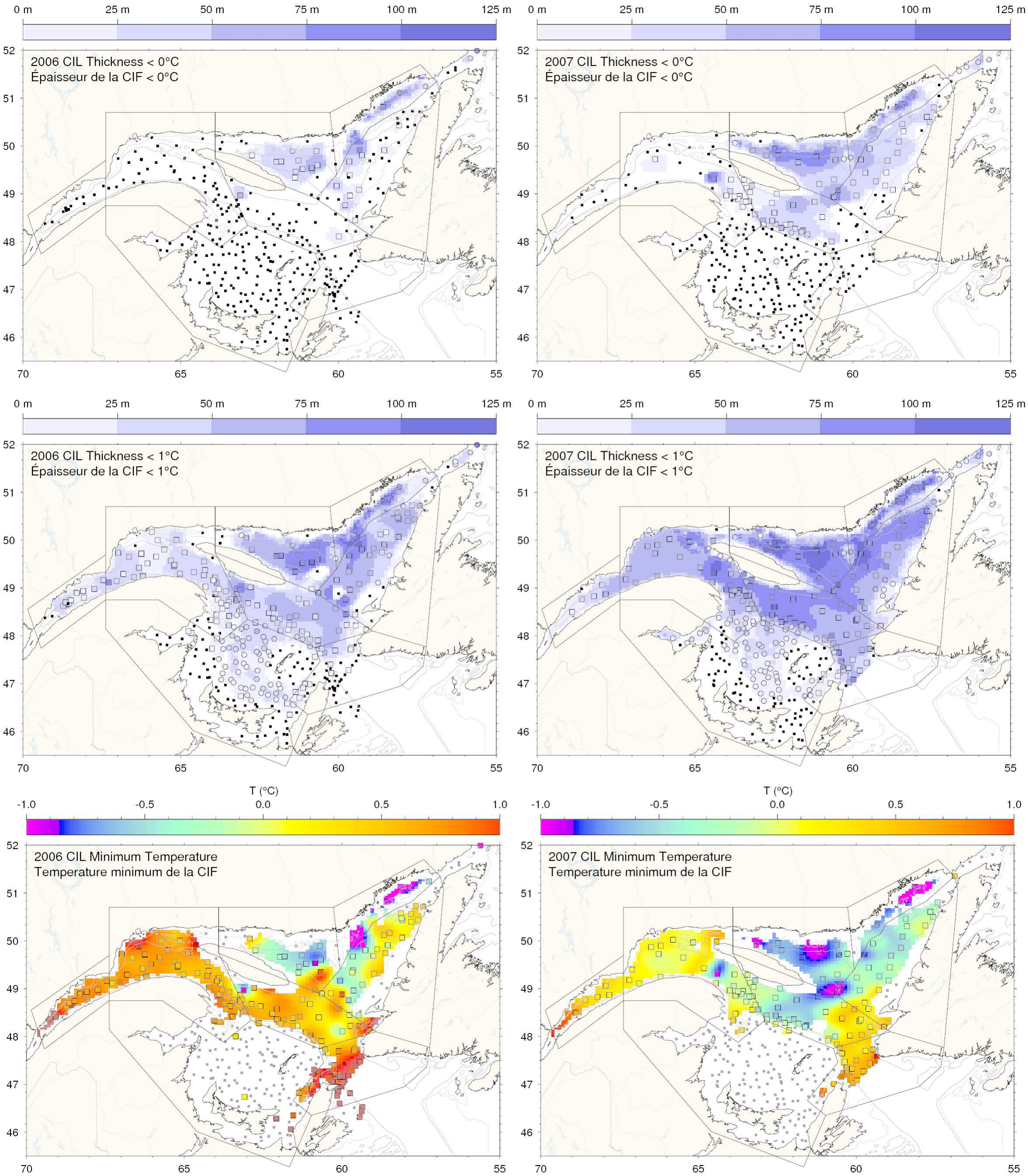


Fig. 20. Cold Intermediate Layer thickness (T < 0ºC, top panels; T < 1ºC, middle panels) and minimum temperature (bottom panels) in August and September 2006 (left) and 2007 (right).

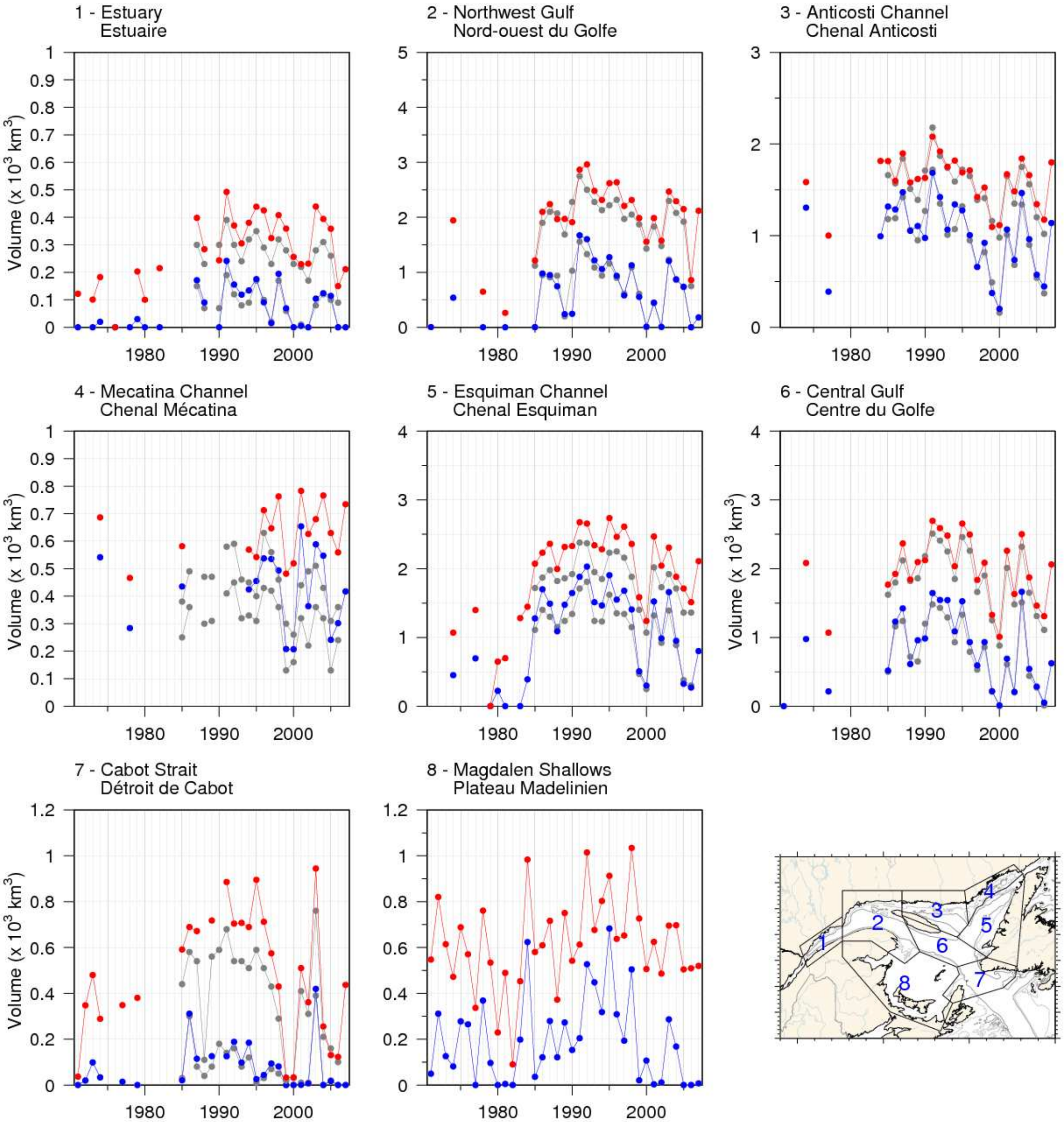


Fig. 21 Volume of the CIL colder than 0ºC (blue) and colder than 1ºC (red) in August and September (mostly region 8 in September). The grey lines are < 0ºC and < 1ºC volumes calculated over areas deeper than 100 m (from Galbraith et al. 2007).

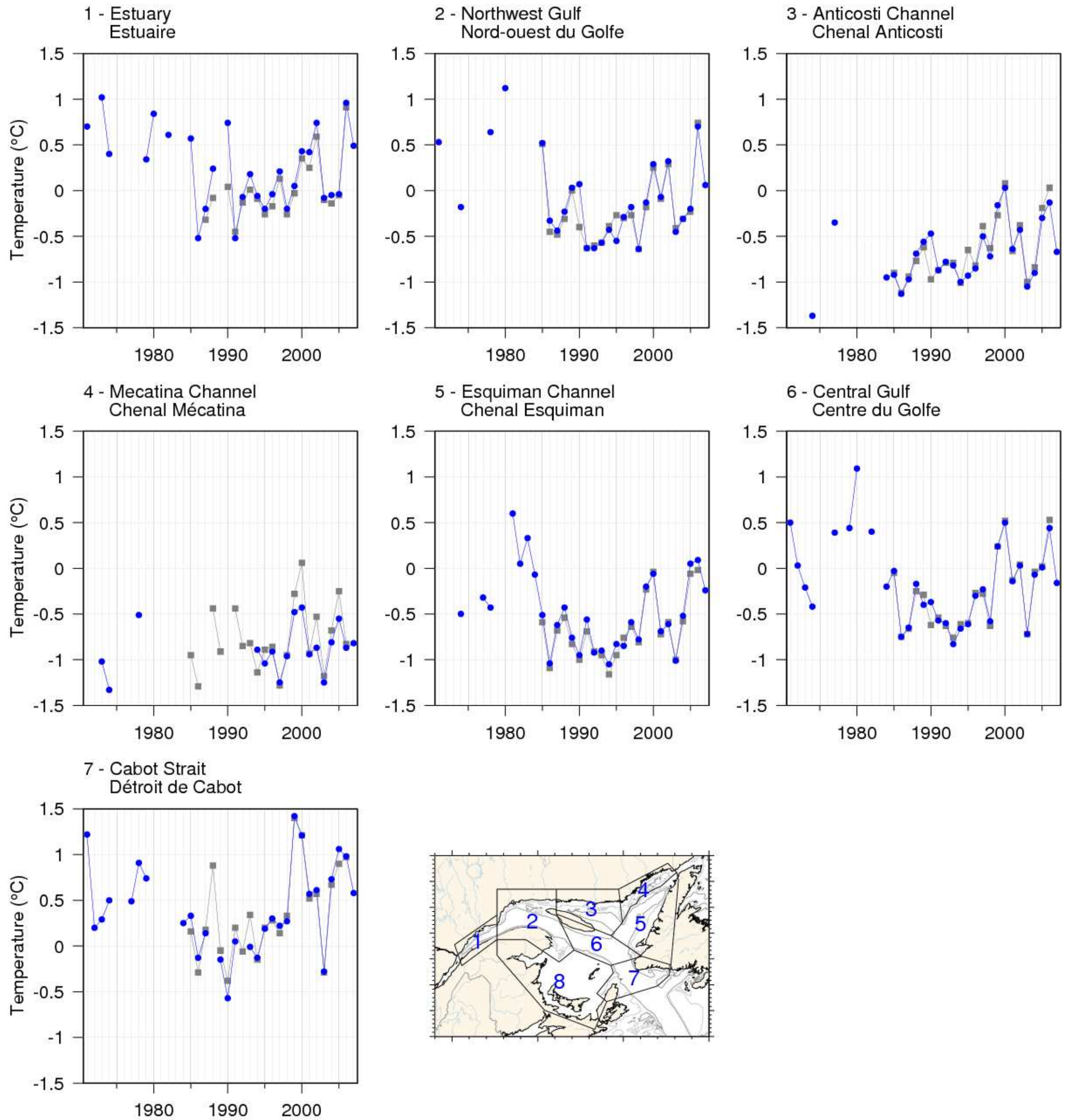


Fig. 22. Temperature minimum of the CIL spatially averaged for the 7 areas shown where the CIL was found (blue line). The grey line is the CIL temperature minimum calculated over areas deeper than 100 m (from Galbraith et al. 2007).

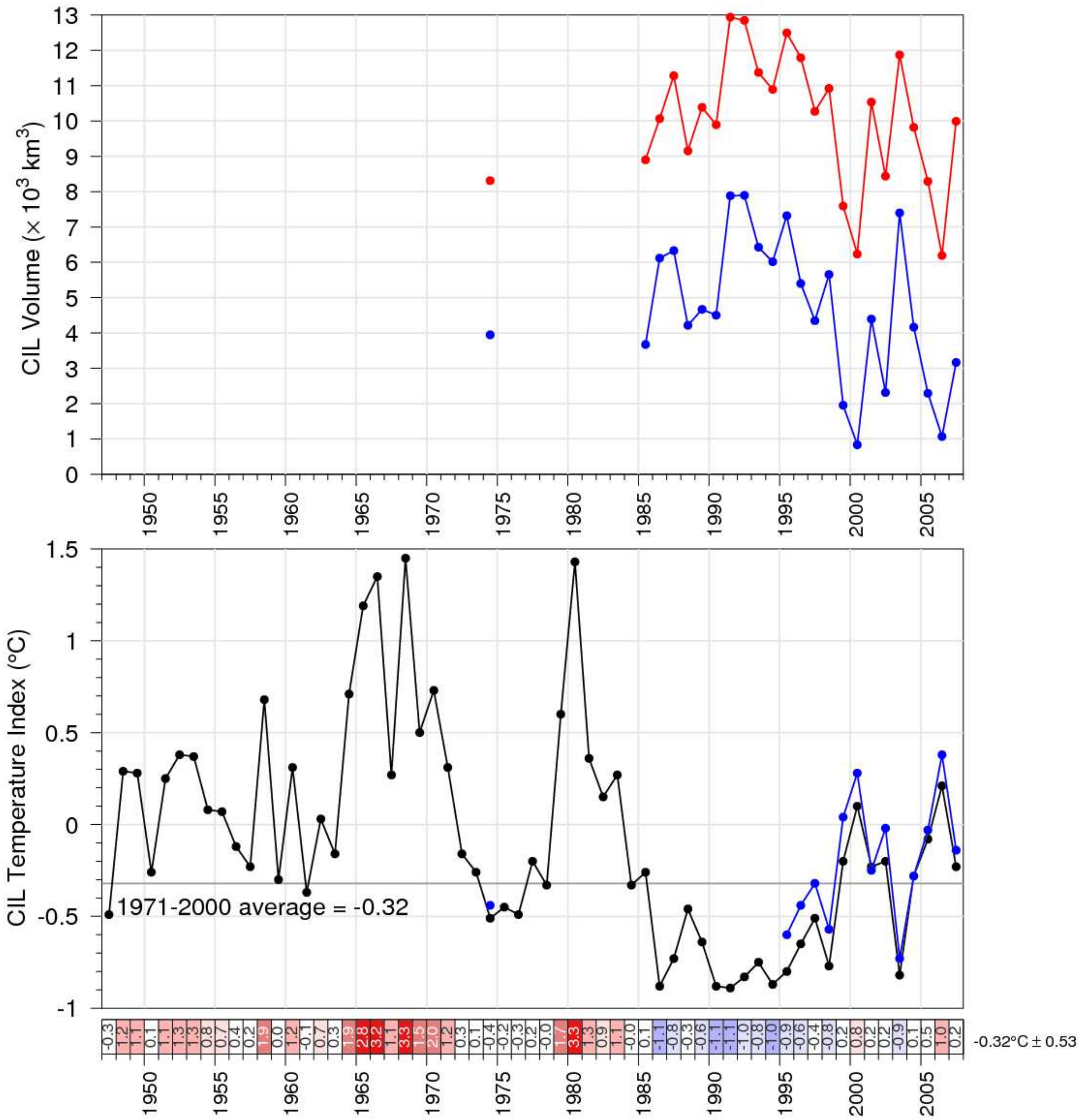


Fig. 23. CIL volume (top panel), delimited by the top and bottom 0ºC (in blue) and 1ºC (in red) isotherms, and minimum temperature index (bottom panel) in the Gulf of St. Lawrence. The volumes are integrals of each of the annual interpolated thickness grids such as the top panels of Fig. 20. In the lower panel, the black line is the updated Gilbert & Pettigrew (1997) index interpolated to July 15 and the blue line is the spatial average of each of the annual interpolated grid such as the two bottom panels of Fig. 20.

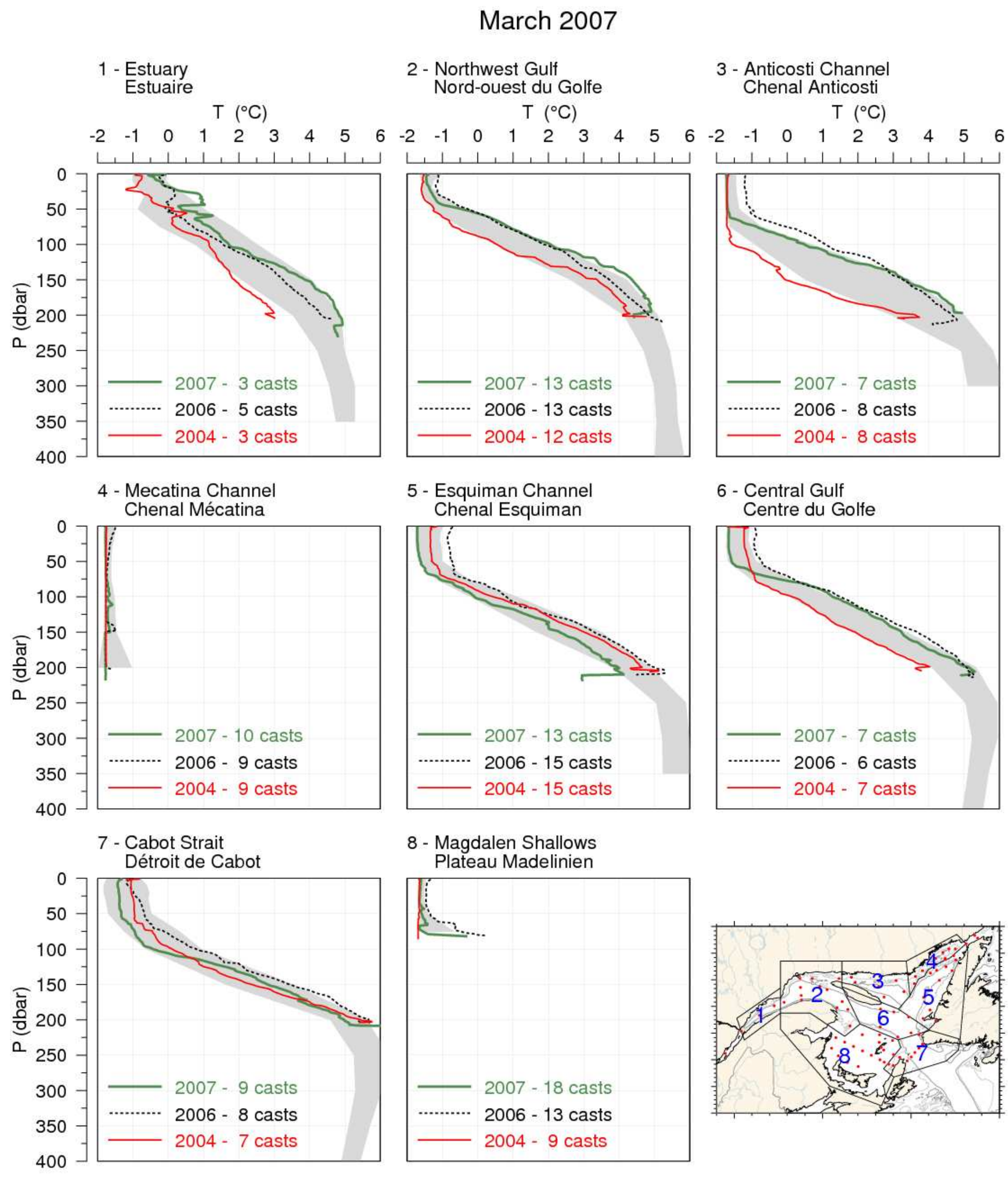


Fig. 24. Mean temperature profiles observed in each region of the Gulf during the March helicopter survey. The shaded area represents the 1971–2007 (but mostly 1996–2007) climatological monthly mean plus or minus one standard deviation. Mean profiles for 2004 and 2006 surveys are also shown for comparison.

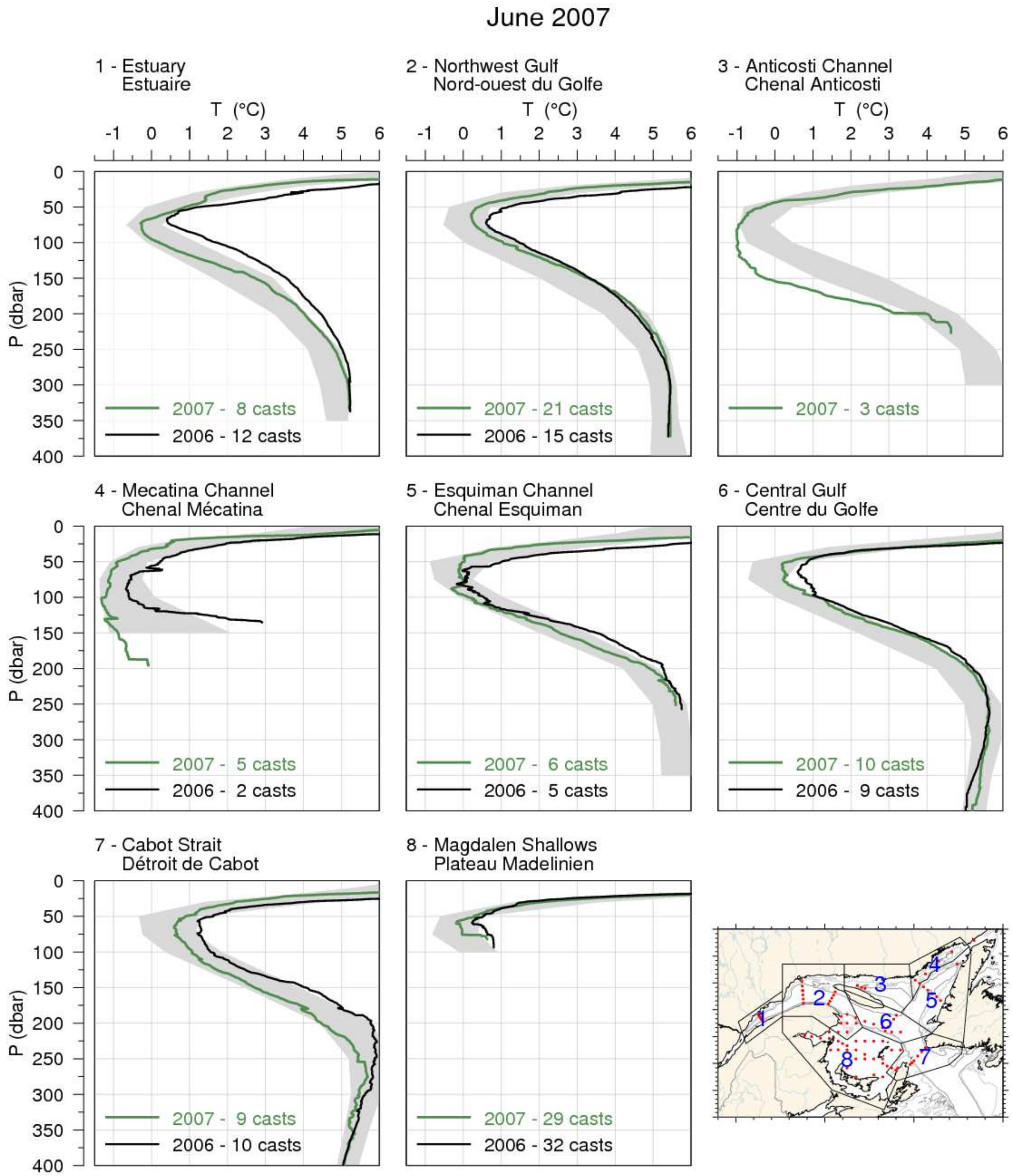


Fig. 25. Mean temperature profiles observed in each region of the Gulf during the June AZMP survey. The shaded area represents the 1971–2000 climatological monthly mean plus or minus one standard deviation. Mean profiles for the 2006 survey are also shown for comparison.

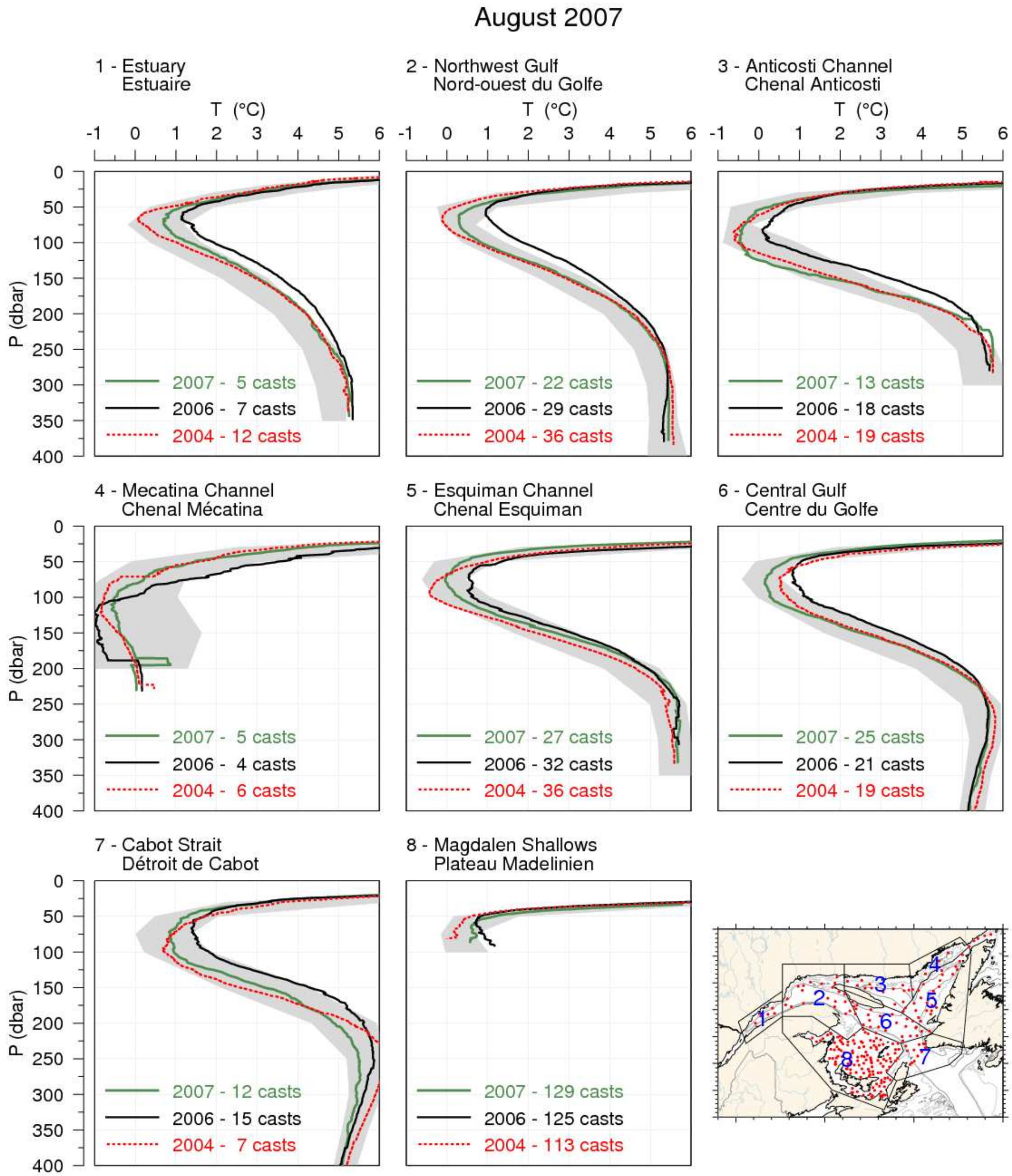


Fig. 26. Mean temperature profiles observed in each region of the Gulf during the summer groundfish surveys in August for regions 1 to 7 and in September for region 8. The shaded area represents the 1971–2000 climatological monthly mean plus or minus one standard deviation. Mean profiles for 2004 and 2006 surveys are also shown for comparison.

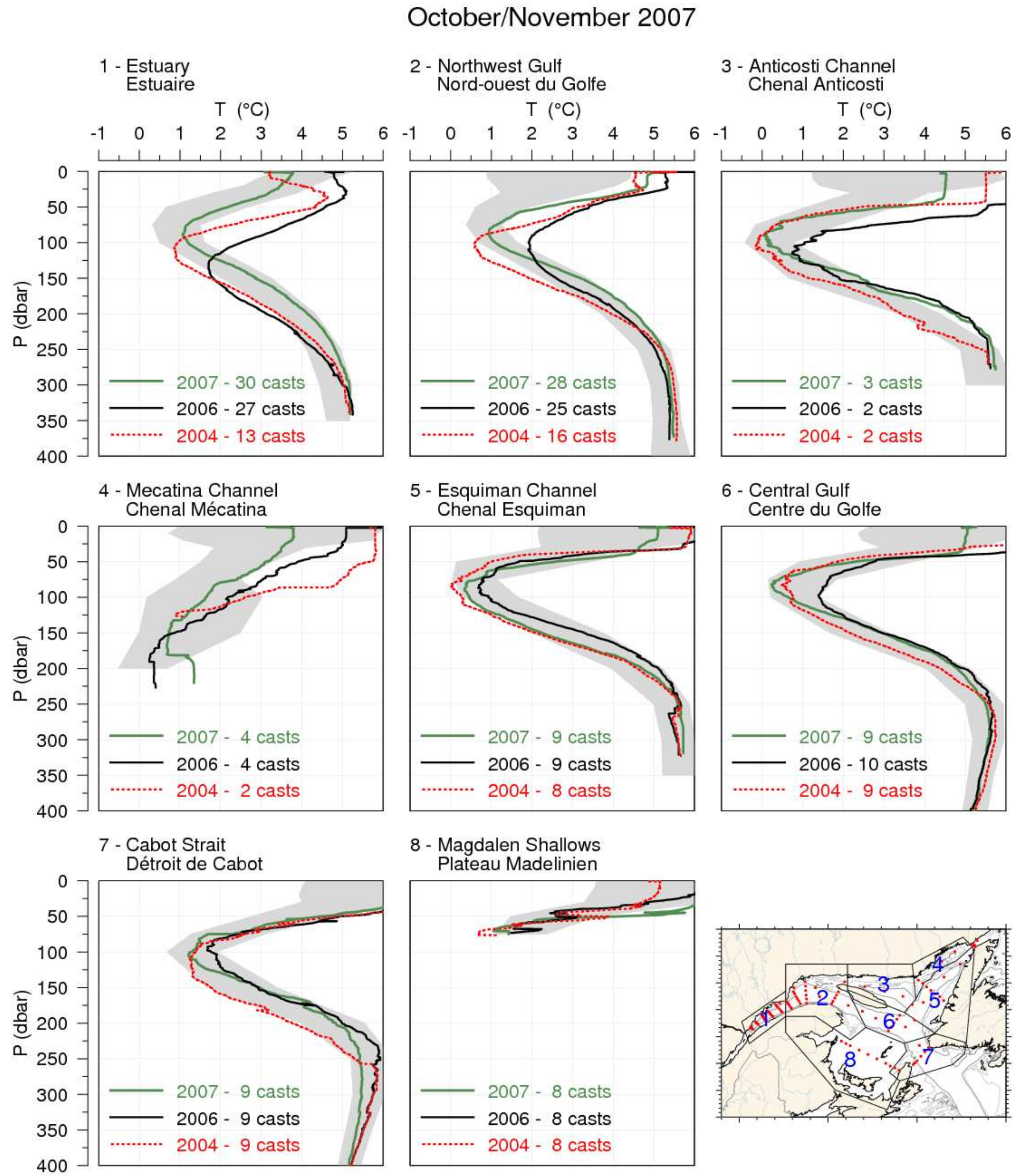


Fig. 27. Mean temperature profiles observed in each region of the Gulf during the November AZMP survey. The shaded area represents the 1971–2000 climatological monthly mean plus or minus one standard deviation. Mean profiles for 2004 and 2006 surveys are also shown for comparison.

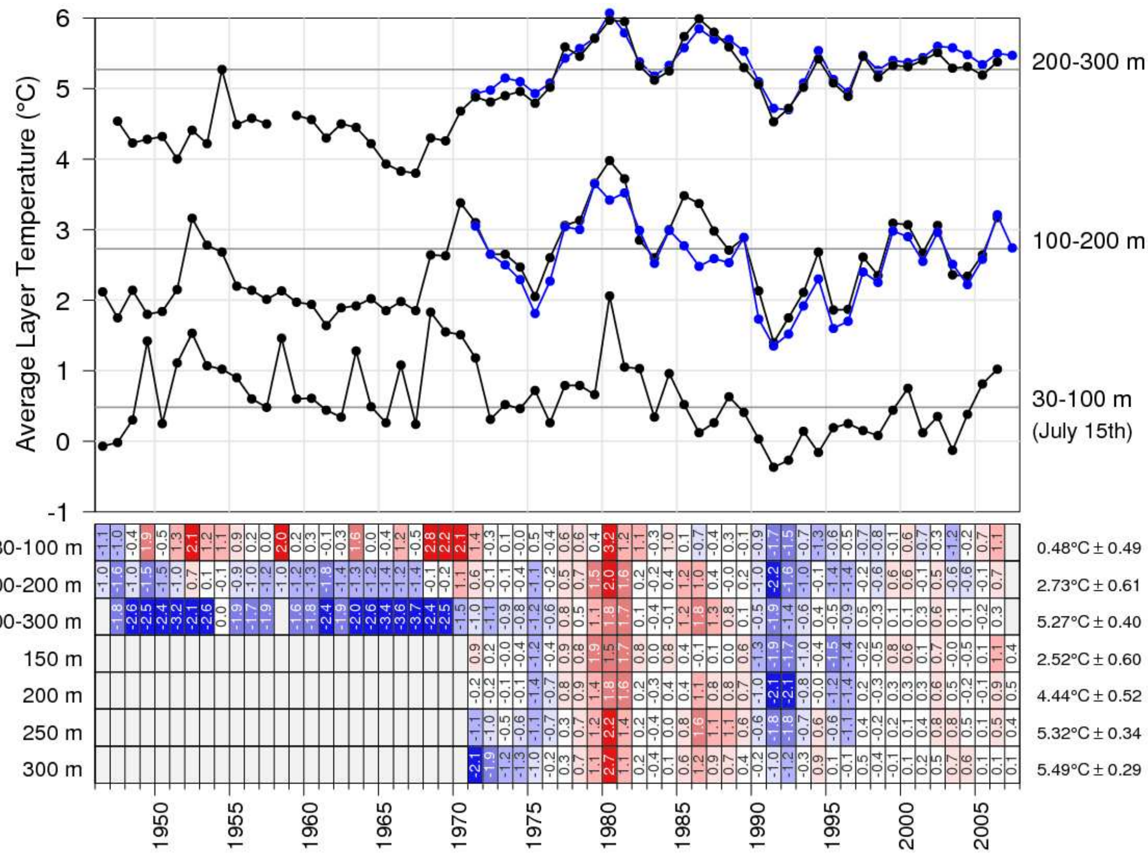


Fig. 28. Layer-averaged temperature time series for the Gulf of St. Lawrence. The top graph shows the 30–100 m, 100–200 m and 200–300 m layer averages as shown in Gilbert et al. (2004) but updated up to 2006. The blue lines are new time series for the 150 m and 250 m layers but will henceforth replace the older time series. The scorecard panel shows all the above time series as well as the 200 m and 300 m layers. The anomalies are calculated based on the 1971–2000 period.

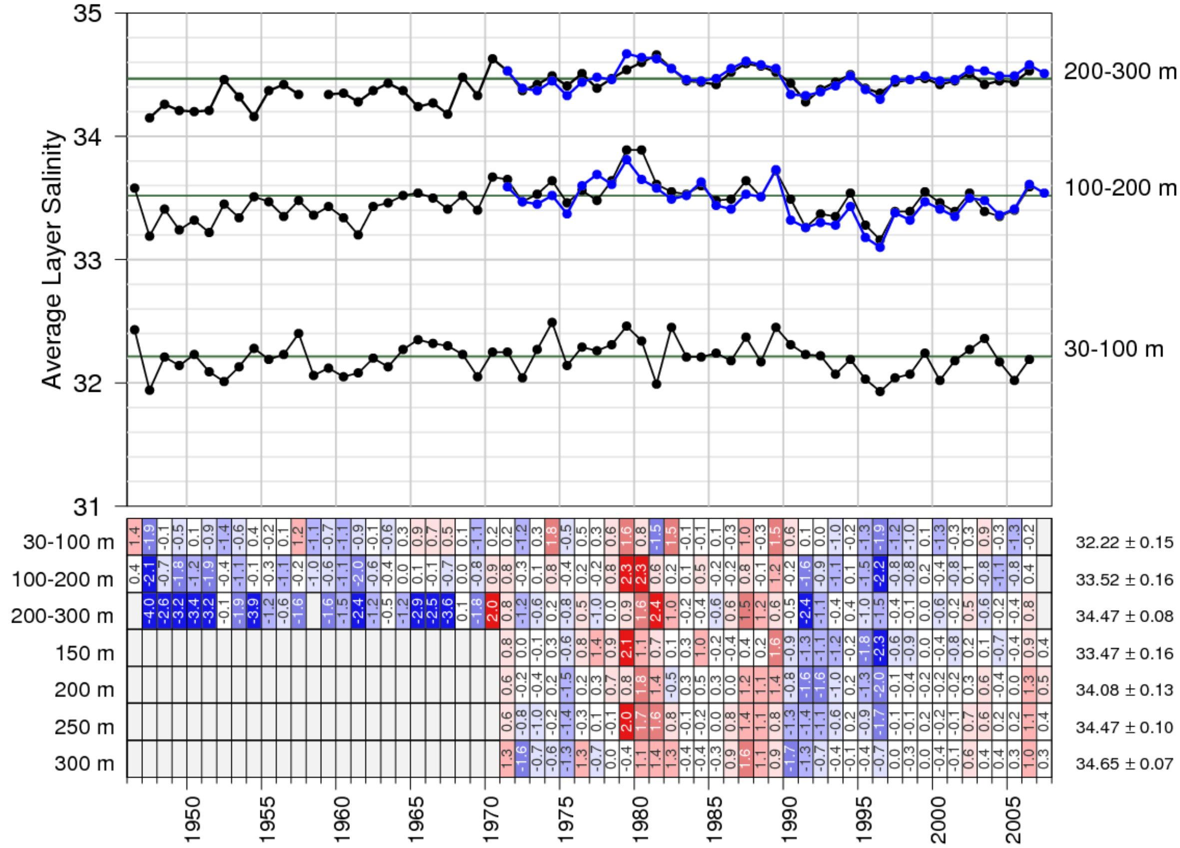


Fig. 29. Layer-averaged salinity time series for the Gulf of St. Lawrence. The top graph shows the 30–100 m, 100–200 m and 200–300 m layer averages as shown in Gilbert et al. (2004) but updated up to 2006. The blue lines are new time series for 150 m and 250 m layers but will henceforth replace the older time series. The scorecard panel shows all the above time series as well as the 200 m and 300 m layers. The anomalies are calculated based on the 1971–2000 period.

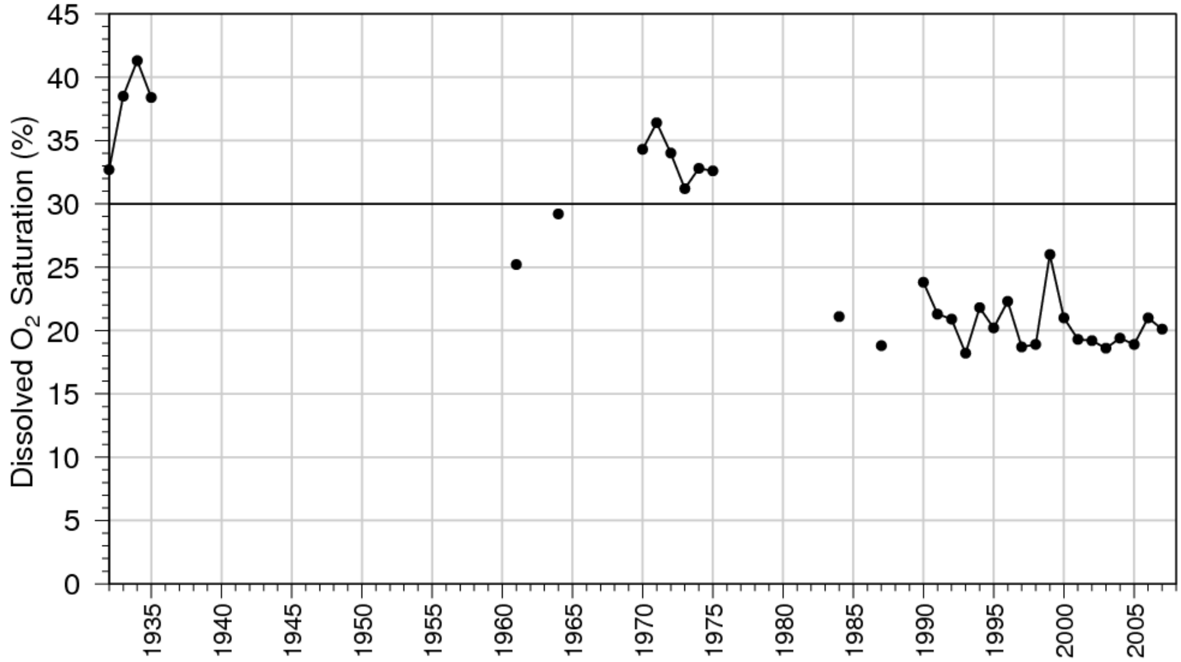


Fig. 30 Dissolved oxygen saturation between 295 m and the bottom in the central deep basin of the St. Lawrence Estuary. The horizontal line at 30% saturation marks the threshold of hypoxic conditions.

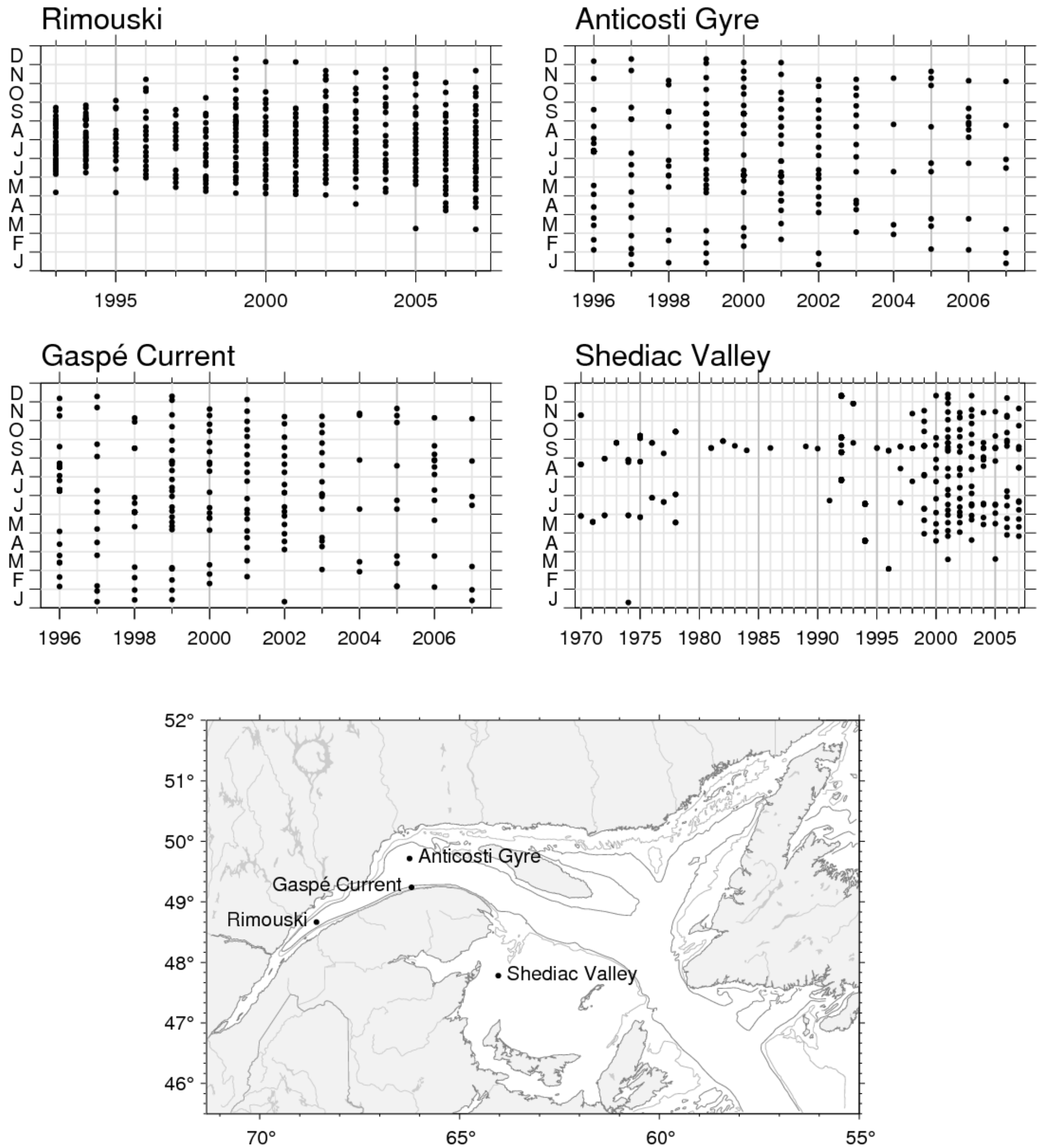


Fig. 31. Sampling frequency and positions of the AZMP stations (Rimouski, Anticosti Gyre, Gaspé Current and Shediac Valley).

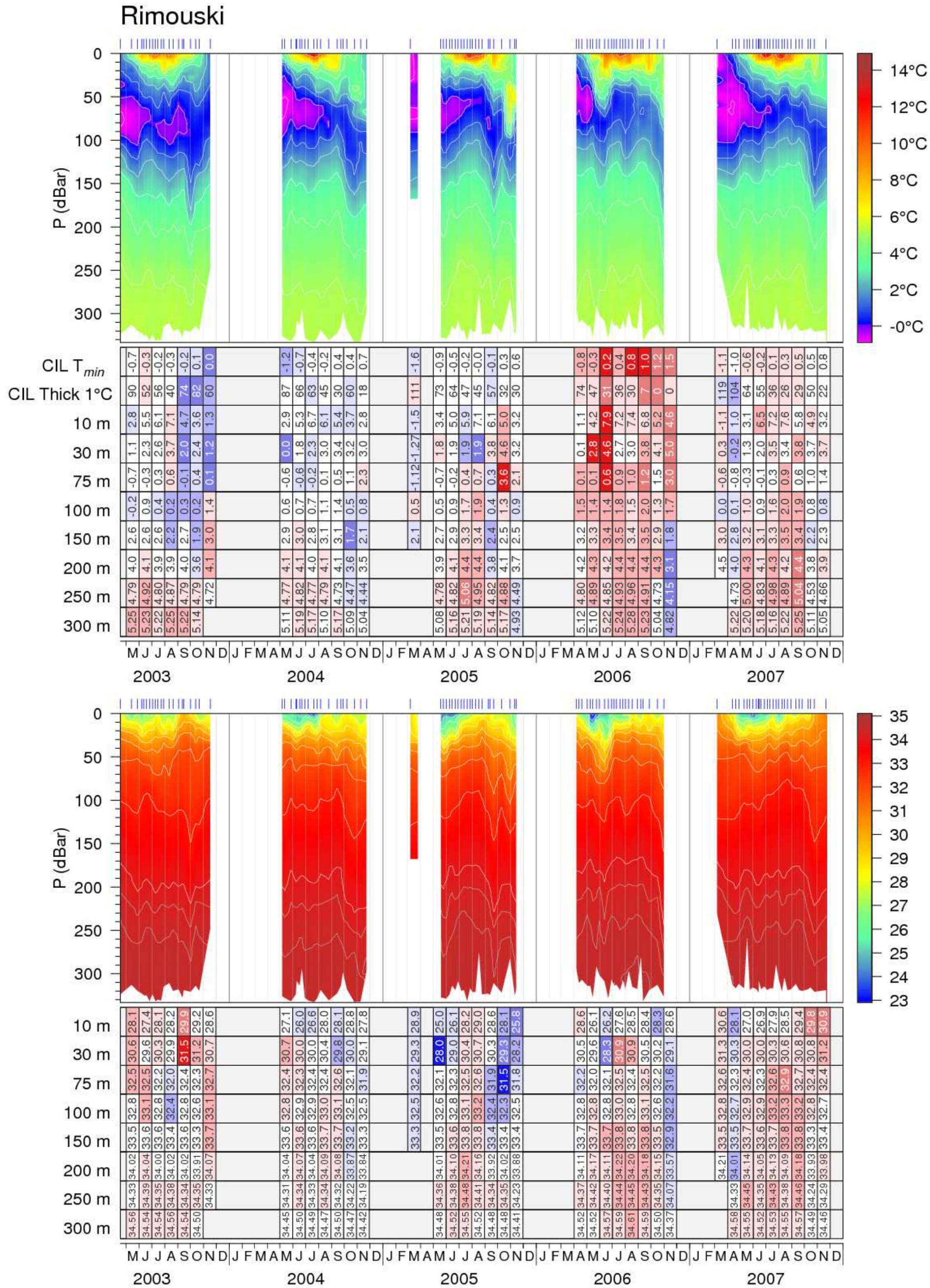


Fig. 32. Isotherm (top) and isohaline (bottom) time series at the Rimouski station; tick marks above indicate sample dates. Scorecard tables are monthly layer averages colour-coded according to the anomaly relative to the monthly climatology for the station (yearly climatology for 250 m and deeper).

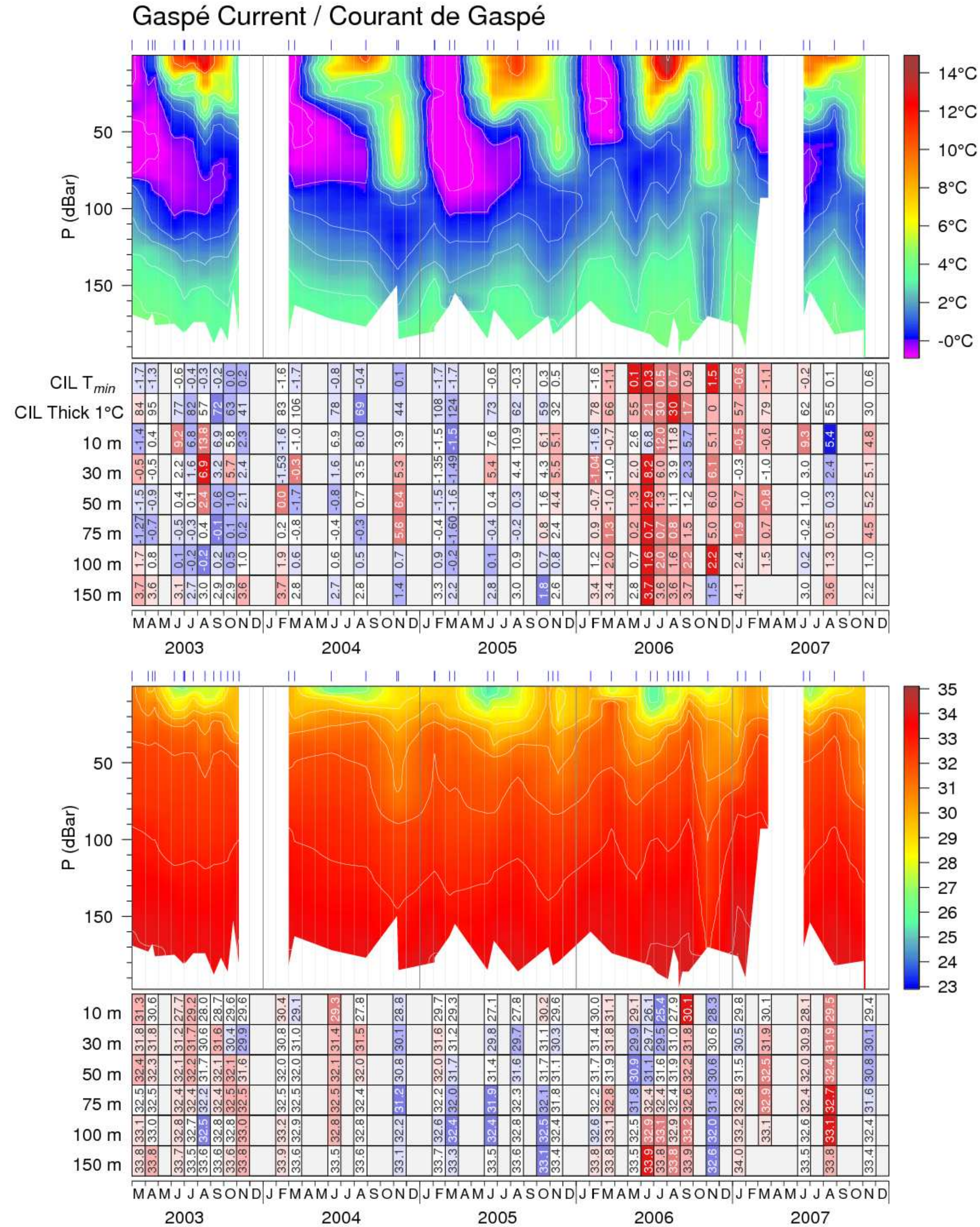


Fig. 33. Isotherm (top) and isohaline (bottom) time series at the Gaspé Current station; tick marks above indicate sample dates. Scorecard tables are monthly layer averages colour-coded according to the anomaly relative to the monthly climatology for the station.

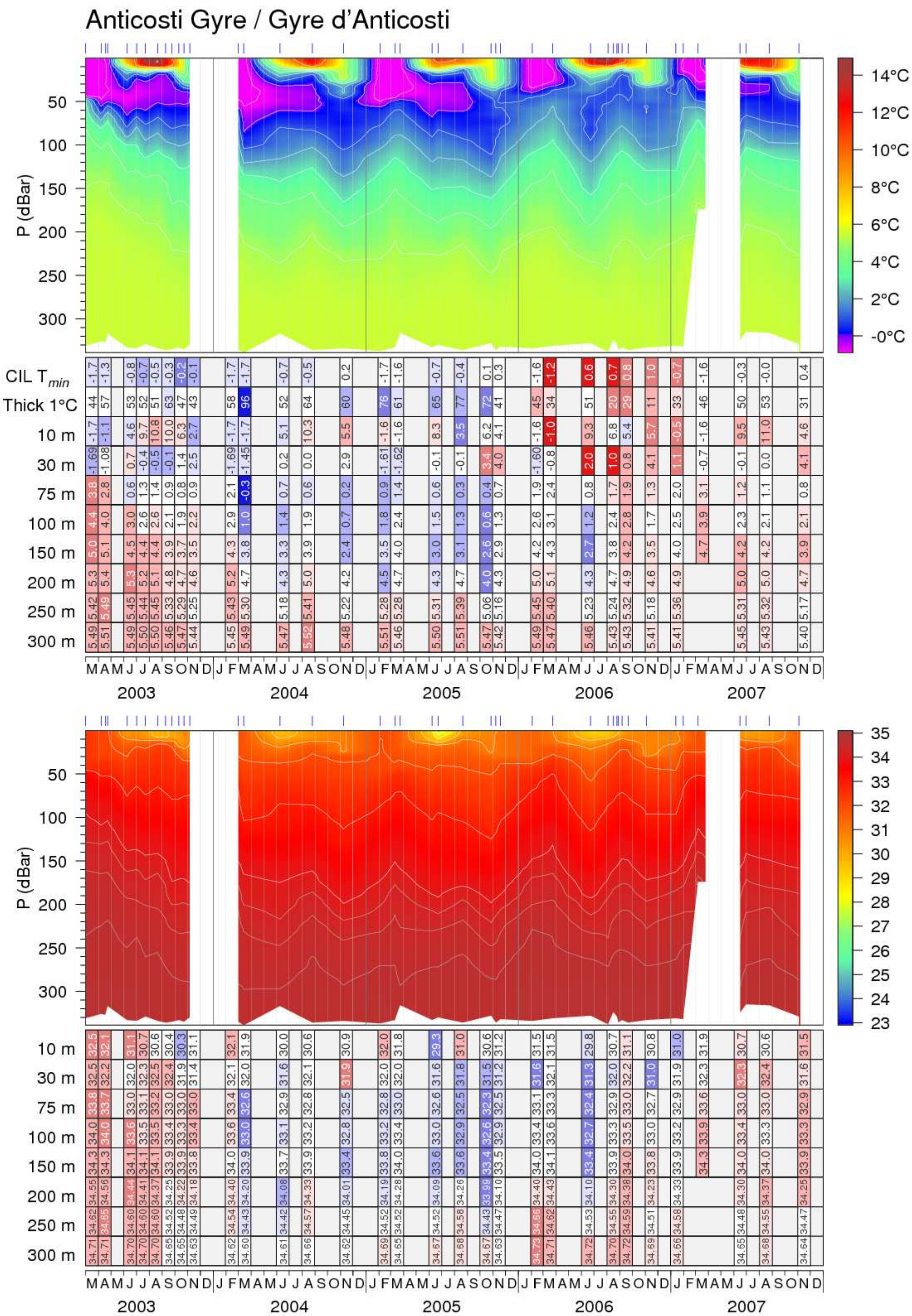


Fig. 34. Isotherm (top) and isohaline (bottom) time series at the Anticosti Gyre station; tick marks above indicate sample dates. Scorecard tables are monthly layer averages colour-coded according to the anomaly relative to the monthly climatology for the station (yearly climatology for 250 m and deeper).

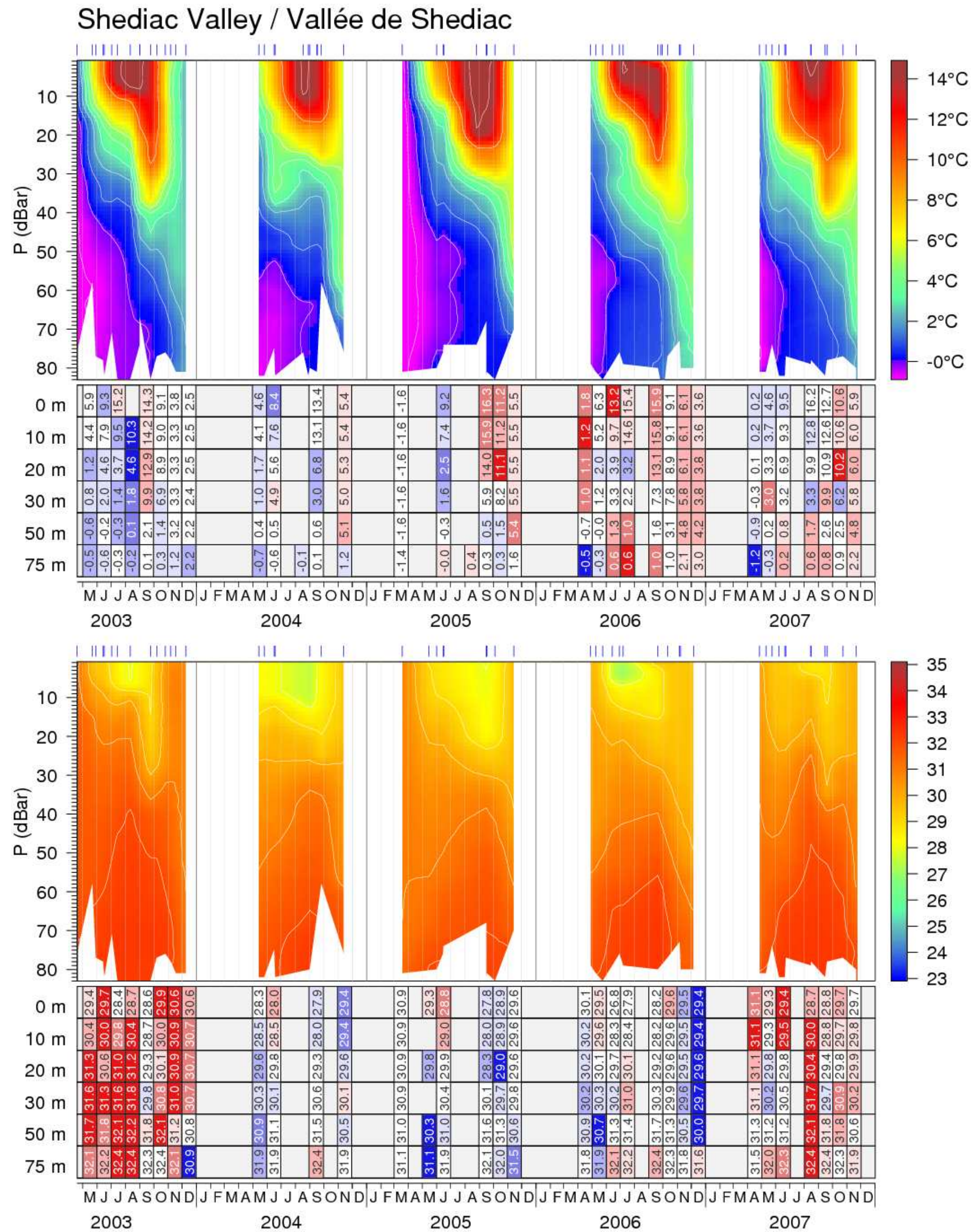


Fig. 35. Isotherm (top) and isohaline (bottom) time series at the Shediac Valley station; tick marks above indicate sample dates. Scorecard tables are monthly layer averages colour-coded according to the anomaly relative to the monthly climatology for the station.

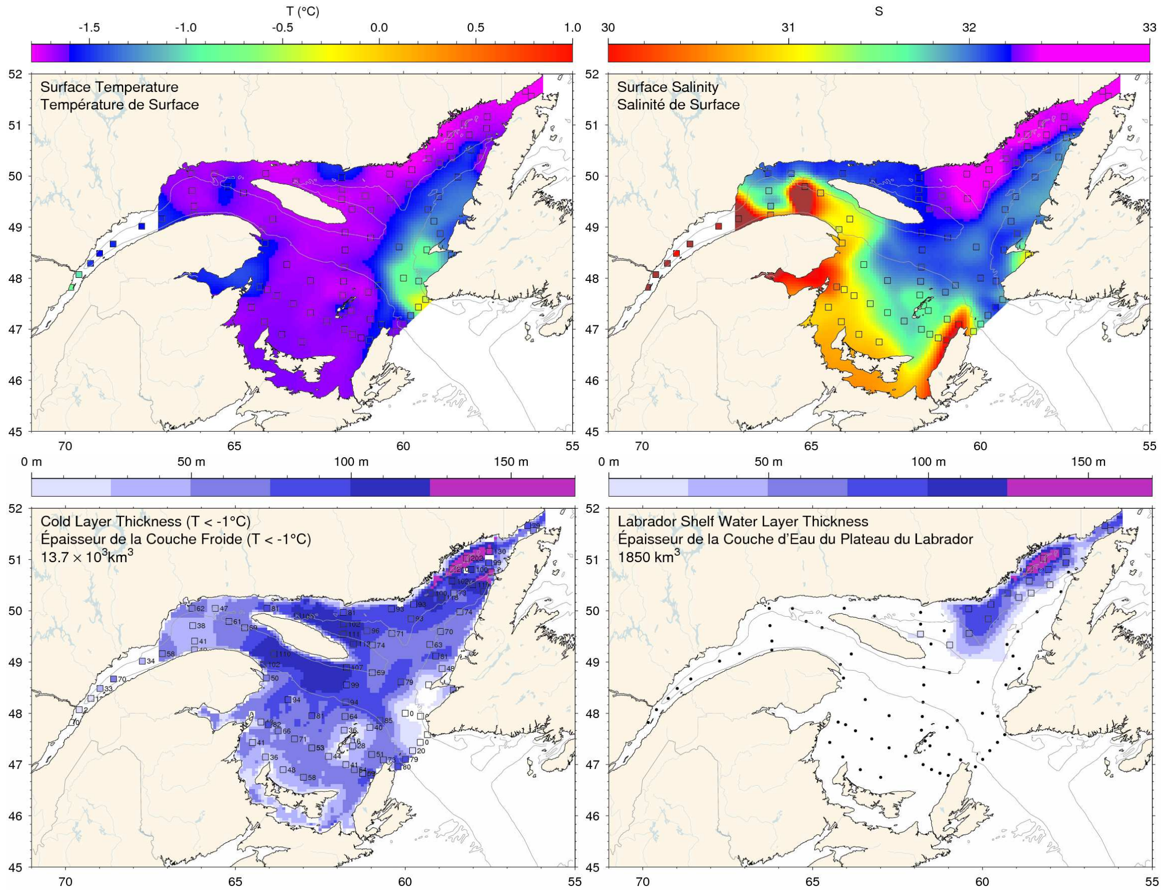


Fig. 36. Surface water temperature (upper-left), salinity (upper-right), cold layer (T < -1°C) thickness (lower-left) and estimate of the thickness of the Labrador Shelf water intrusion (lower-right) for the March 2008 winter survey. The symbols are coloured according to the value observed at the station, 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.