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Quebec Region
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Science Advisory Report 2007/036

STATE OF THE OCEAN 2006: PHYSICAL OCEANOGRAPHIC CONDITIONS IN THE GULF OF ST. LAWRENCE

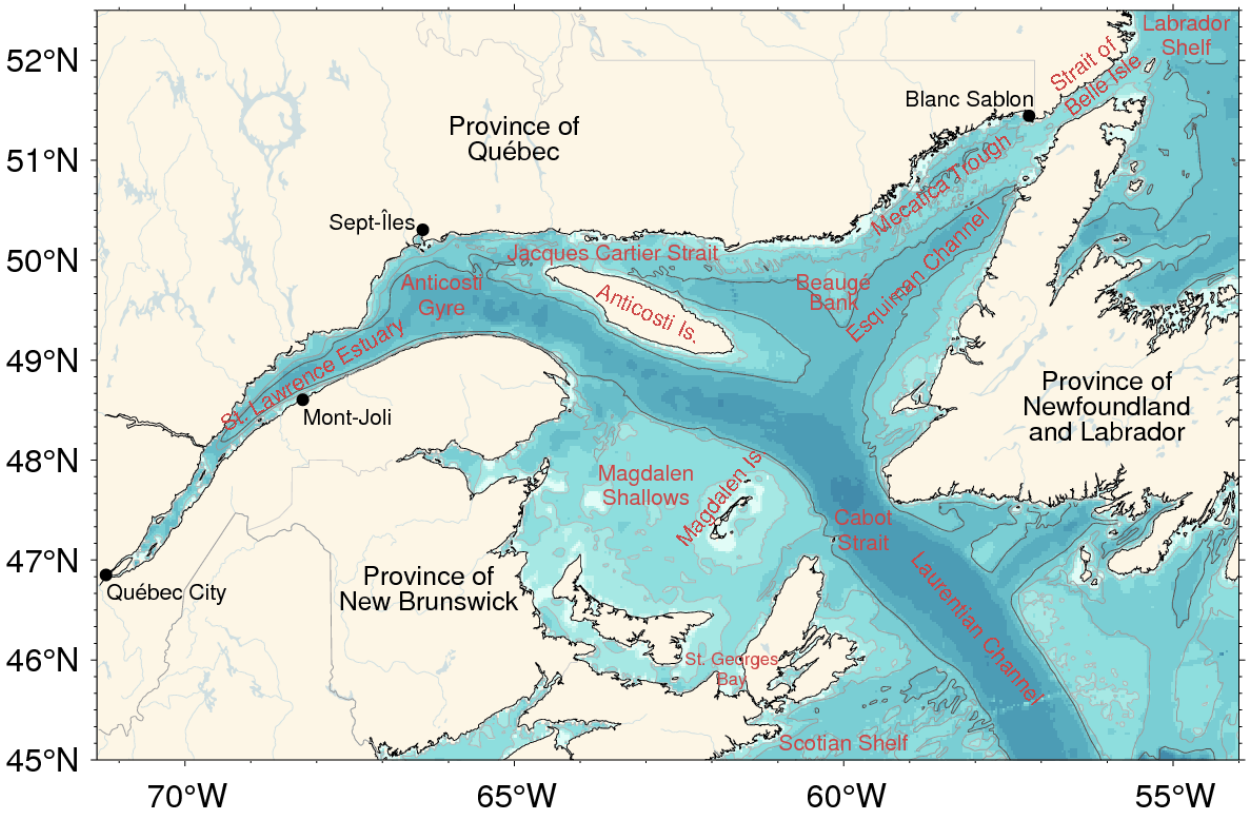

Figure 1: Gulf of St. Lawrence

Context

The physical oceanographic environment influences the yield (growth, reproduction, survival), and behaviour (distribution, catchability, availability) of marine organisms as well as the operations of the fishing industry. Environmental changes may contribute directly to variations in resource yield, reproductive potential, catchability, year-class size (recruitment) and spawning biomass; they may also influence the perception of the resource status and the efficiency and profitability of the industry.

*Physical oceanographic conditions (mainly water temperature and salinity) are therefore measured during research vessel resource surveys and regularly at fixed sites as part of the **Atlantic Zone Monitoring Program (AZMP)**. Additional hydrographic, meteorological and sea ice data are obtained from a variety of sources, including standard monitoring stations, research studies, ships-of-opportunity, fishing vessels and remote sensing (satellites). A state of the ocean report is completed annually for each region of the Atlantic coast based on this information.*

Hydrographic data are edited and archived in the Oceanographic Data Management System on the St. Lawrence Observatory (www.osl.gc.ca) and at the Marine Environmental Data Service (MEDS) database.

SUMMARY

- Air and surface water temperatures were 2° - 4°C above normal in most parts of the Gulf during the year, except for late summer when conditions were 3°C below normal in the northwest and southern regions.

- Bottom water temperatures on the Magdalen Shallows were unusually warm in September when no observations below 0°C were recorded.

- Sea ice coverage and volume within the Gulf during the winter were the lowest recorded since 1969.

- A sub-surface intrusion of cold-saline water from the Labrador Shelf exceeding 150 m in thickness was present in Mecatina Trough in 2006, extending to the bottom below 200 m depth. Its volume, 1620 km³, was intermediate relative to values of the past decade.

- The 2006 winter cold mixed layer volume was the smallest recorded in the 11 year history of winter surveys (9800 km³), which corresponded to 29% of the total water volume of the Gulf.

- The shallow winter mixed layer resulted in a Cold Intermediate Layer (CIL) index for the summer 2006 of 0.21ºC, 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 multidisciplinary 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 warmer-than-normal 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 throughout the Gulf.

- Dissolved oxygen in the St. Lawrence Estuary remained low in spite of a slight increase from previous years.

- The outlook for 2007 based on 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.

BACKGROUND

Temperature and salinity conditions in the Gulf of St. Lawrence are influenced by heat transfer between the ocean and atmosphere, exchanges through Cabot Strait and the Strait of Belle Isle, freshwater runoff, precipitation, production and melting of sea-ice, vertical mixing and advection by currents. The deep layer is a mixture of Labrador and Slope Water that enter the Laurentian Channel from the continental shelf and is advected up the channel by estuarine circulation. The 0-150 m layer undergoes seasonal variations from exchanges with the surface. The winter near-freezing mixed layer reaches an average of 75 m, but can reach over 200 m in the less stratified Mecatina Trough. The surface is stratified in spring by the melt of sea-ice and freshwater runoff, but a Cold Intermediate Layer persists through summer which is gradually eroded until the following winter.

Where possible observations are expressed as differences or anomalies from their long-term averages. The standardised reference period used for climate normals is 1971-2000.

ASSESSMENT OF CONDITIONS IN 2006

The monthly air temperature anomalies for Mont-Joli, Sept-Îles and the Magdalen Islands (Figure 2) were above normal in the fall of 2005, typically by as much as 2°C. This indicates warm conditions for the preconditioning of the winter surface mixed layer. This was followed by very warm conditions in January when temperatures were 4 to 5°C warmer than normal. 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.

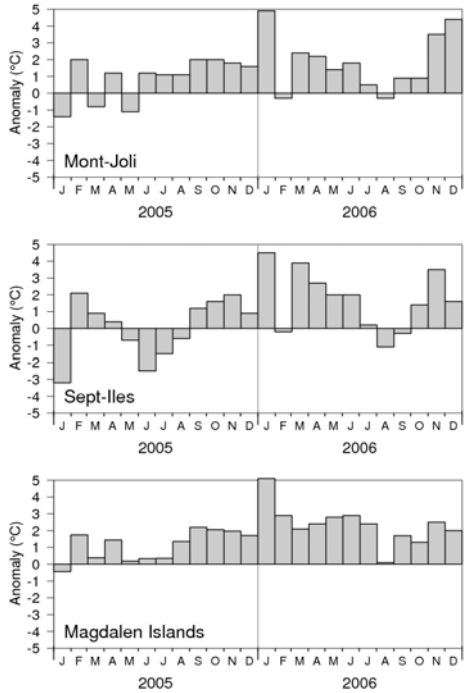

Figure 2. Monthly air temperature anomalies for 2005 and 2006 at Mont-Joli, Sept-Îles and the Magdalen Islands.

The surface layer conditions of the Gulf are monitored by various methods that complement each other: the thermograph network, the shipboard thermosalinographs, research surveys and NOAA satellite remote sensing. Thermosalinographs have been installed on commercial ships Cicero (now retired) in 1999 and Cabot in 2006, both of Oceanex Inc. The ships sail year-round between Montréal and St. John's, making a return trip once per week, sampling the near-surface (3 m) water temperature and salinity along their track. Figure 3 (left panel) shows the 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. 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. 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. Figure 3 also shows the water temperature composite for 2006 and its anomaly relative to the average. 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. The water temperature anomalies illustrate that except for the early freeze-up and mild mid-August temperatures, the surface temperatures were much warmer than the 2000-2006 average conditions, sometimes by more than 4ºC.

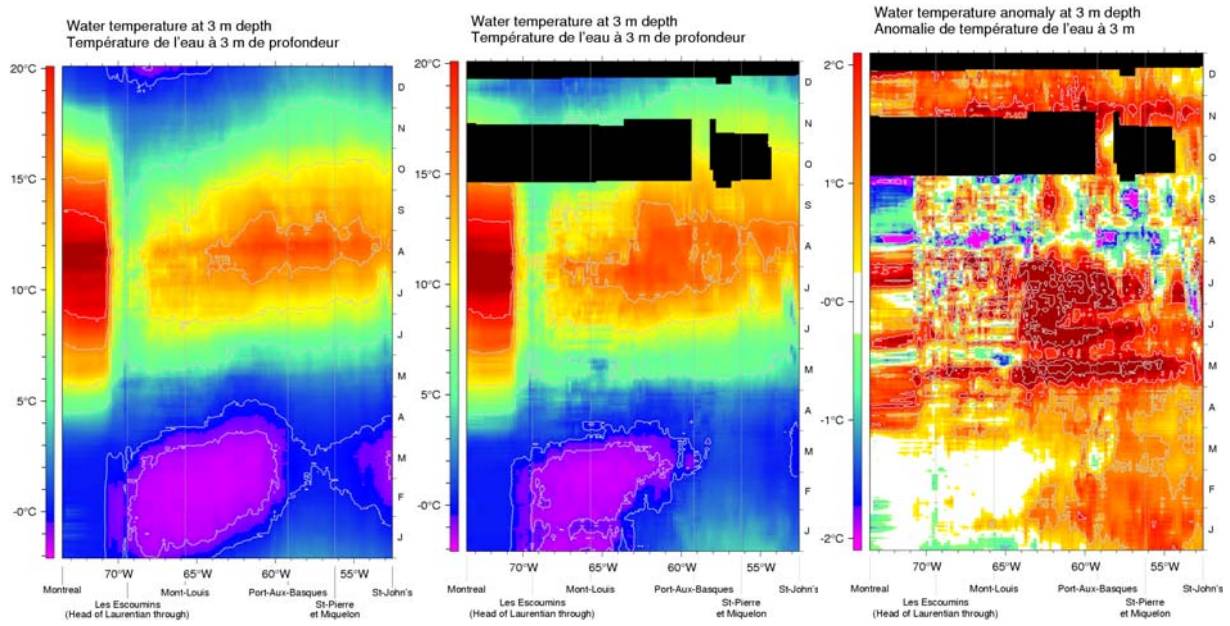

Figure 3 Composite mean annual cycle of 3-m depth water temperature along the Montréal to St. John's shipping route for 2000 to 2006 average (left panel), composite annual cycle for 2006 (middle panel) and water temperature anomaly for 2006 (right panel). The anomaly is defined as the difference between 2006 temperatures and the 2000-2006 average.

The thermograph network consists of 23 stations with moored instruments that measure and record water temperature every 30 minutes. Most instruments are installed on Coast Guard buoys that are deployed in the ice-free season; a few stations are occupied year-round. In order to compare the 2006 observations to temperature measurements from previous years, daily average temperatures were calculated using all available data for each day of the year at each station and depth. The network covers the entire Gulf, but only a few stations will be shown here to represent regions not covered by the shipboard thermosalinographs (Figure 4). Surface temperatures at Shag Island in the Magdalen Islands did not reach the freezing point before early February and the onset of spring warming came about two weeks early. This lead-time persisted until the summer maximum was reached, which also occurred earlier than usual. The temperatures at Beaugé Bank were above average for the entire sampling season from June to October, whereas the Blanc-Sablon values were also above-average for the same period except for September.

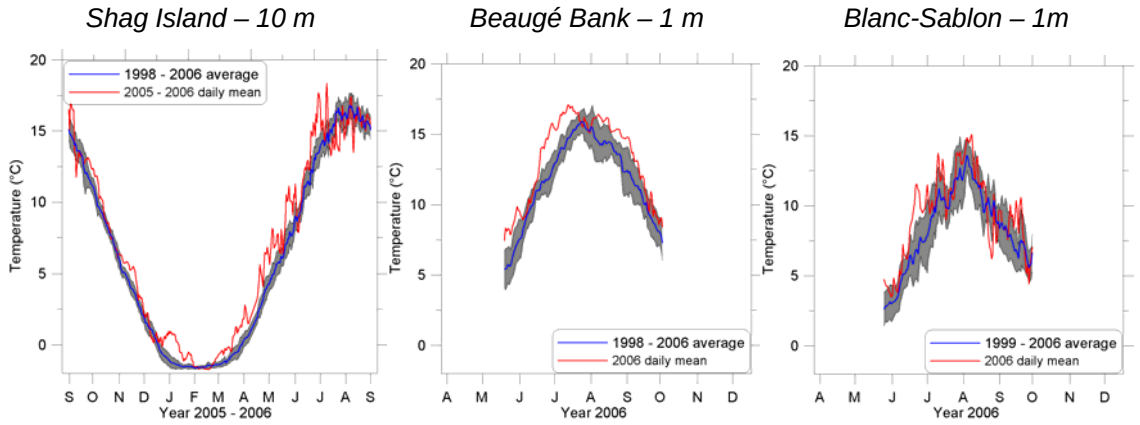

Figure 4. Daily mean 2006 temperatures (red curves) compared with the 1998/9 - 2006 daily averages (blue curves) computed from all available data at 10 m depth at Shag Island (left panel), at 1 m depth at Beaugé Bank (middle panel) and at 1 m depth at Blanc-Sablon (right panel). The shaded area represents the 95% confidence interval on the mean (plus and minus twice the standard error). Data from Shag Island span 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.

The NOAA satellite remote sensing observations are consistent with thermograph and thermosalinograph data. When compared to the climatological means generated using the 1995-2004 satellite images, the 2006 images show spring and summer periods warmer than normal (more than 3ºC above the 1995-2004 climatology) for the entire Gulf and in the Estuary. From August 15 to September 30, waters colder than normal (approximately 3ºC below the climatology) appear in the northwest and southern Gulf regions, while the northeastern Gulf region temperatures remained above normal. From mid-November to the end of December, remote sensing shows the surface layer to be above normal by about 3ºC for the entire Gulf and the Estuary.

Water temperatures on the bottom of the Magdalen Shallows are obtained in September of each year from the multi-species survey (1971-present). Bottom temperatures in 2006 ranged from <1°C to over 20°C, a gradient mostly related to bottom depth. Most of the Shallows (50-80 m) were covered by waters with temperatures <1°C, which had slowly warmed since the previous winter. Bottom temperature anomalies over most of the southern Gulf were still significantly warmer than normal in September (Figure 5). The highest positive anomalies (+3°C) appeared along the coast of New Brunswick and in St. Georges Bay but must be viewed with caution since the largest

uncertainties are in the near shore regions. The time series of the area of bottom covered by each 1ºC interval is shown in Figure 6. 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.

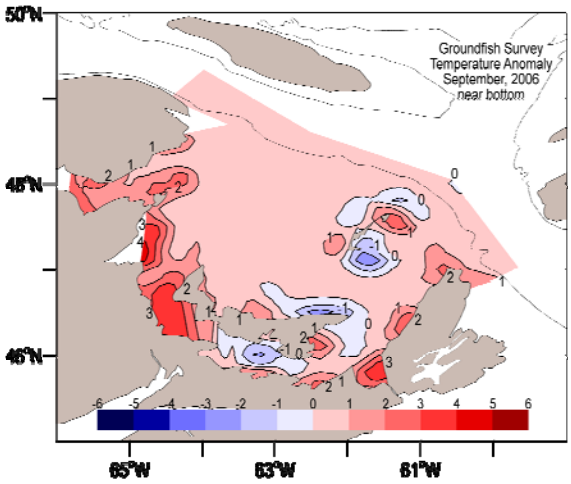

Figure 5. Near-bottom temperatures anomalies from the 1971-2000 climatology in the southern Gulf of St. Lawrence during the 2006 September multi-species survey.

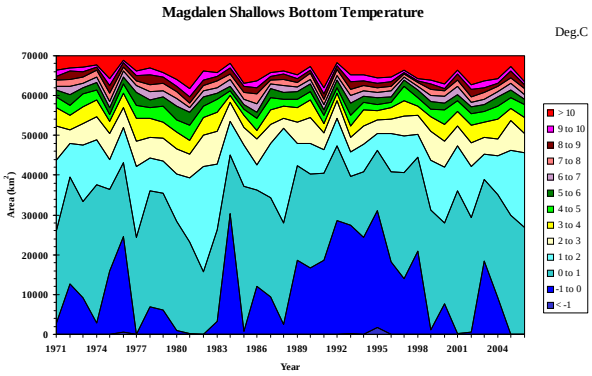

Figure 6. Time series of the areas of the Magdalen Shallows covered by water in different temperature bins in September.

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 part of Figure 7 and 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 part of Figure 7 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, a fact heavily reported by public media. More information concerning the sea-ice area coverage in the Gulf of St. Lawrence can be found in Petrie et al. (2007).

A helicopter-based survey has been monitoring wintertime conditions in the Gulf of St. Lawrence since 1996. The March 2006 survey of 82 stations 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 Figure 4).

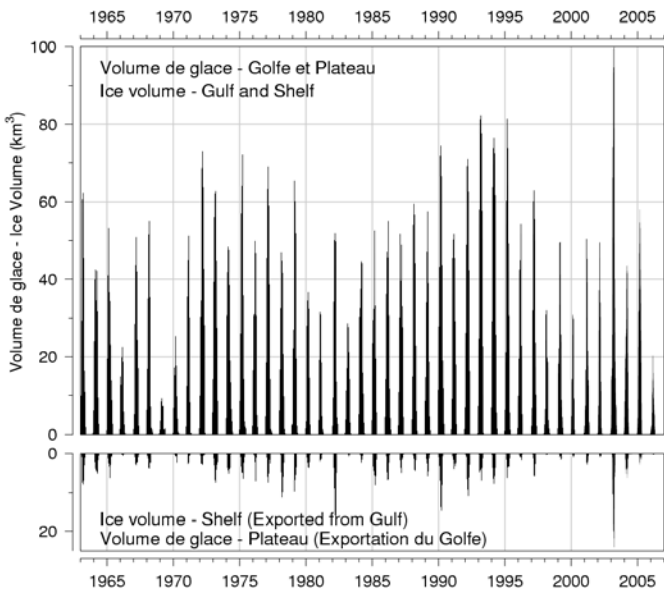

Figure 7. Estimated ice volume in the Gulf of St. Lawrence and on the Scotian Shelf seaward of Cabot Strait (upper panel) and on the Shelf only (lower panel).

Figure 8 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. 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 (approx. 0ºC) entered the Gulf on the northeast side of Cabot Strait, similar to 2005 and 2004, and flowed northward along the west 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 Figure 8 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. 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 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, sub-surface layer is estimated in the lower-right panel of Figure 8. The intrusion exceeded 150 m in thickness again in 2006, reaching the bottom below 200 m in Mecatina Trough. Its spread had an area similar to that of 2004, but its volume of 1620 km³ was smaller because it did extend to the surface.

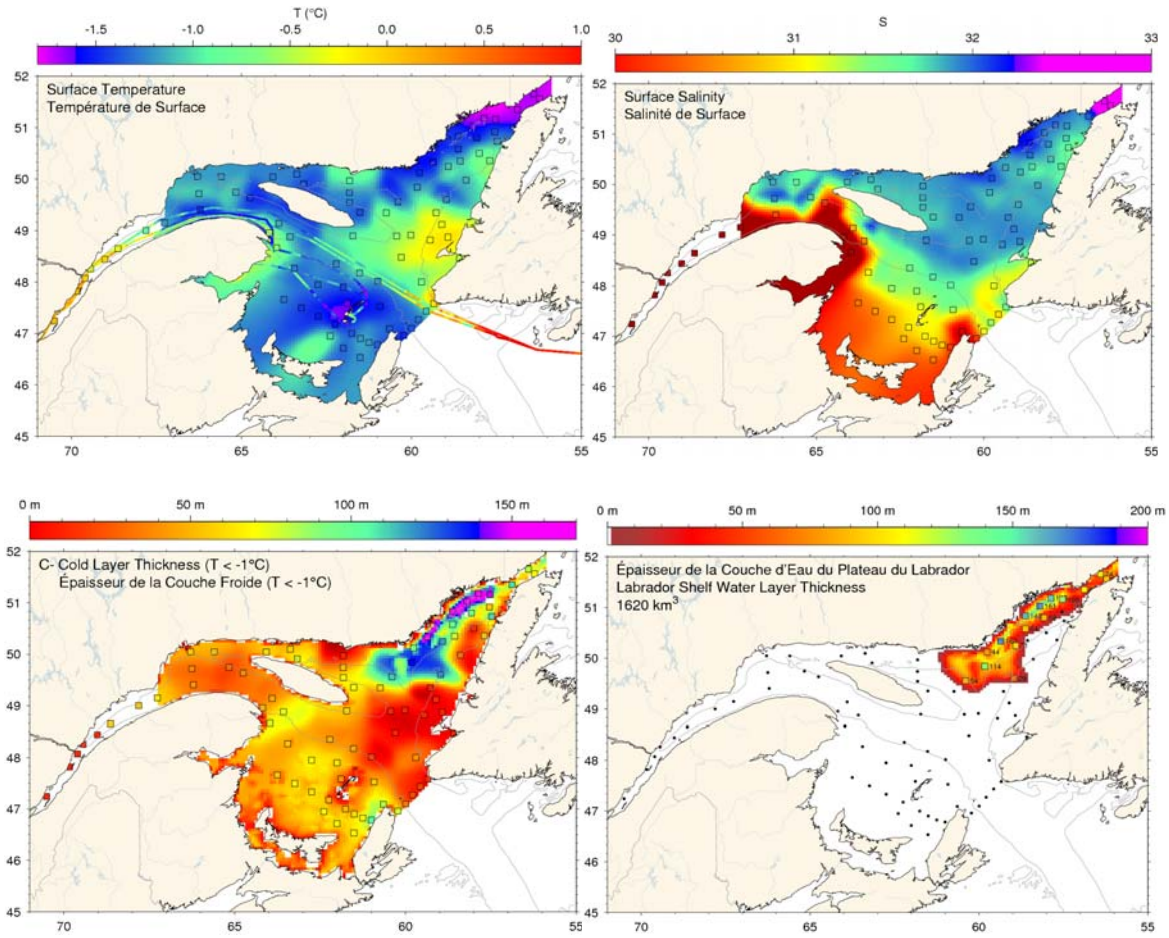

Figure 8. Surface water temperature (upper-left), salinity (upper-right), cold layer (T < -1°C) thickness (lower-left) and estimate of the thickness of the Labrador Shelf water intrusion (lower-right) for the March 2006 helicopter survey. The symbols are coloured according to the value observed at the 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. The temperature measurements from shipboard thermosalinographs taken during the survey are also shown in the upper-left panel.

The cold (< -1ºC) surface layer is the product of local convection and cold waters advected from the Labrador Shelf. Although its depth usually reaches 75 m in the Gulf, in 2006 it was more typically around 50 m or less (See Figure 8, lower-left panel). It did not reach the bottom in the northern Magdalen Shallows. Integrating over the area of the Gulf yields a cold-water volume of 9800 km³, the smallest volume recorded in the 11 year history of the survey. It corresponds to 29% of the total water volume of the Gulf (34000 km³). The total volume of cold water (< -1ºC) in winter is related to the following summer's CIL index since the CIL is the remnant of the winter cold surface layer. This volume was used to issue a forecast of the CIL Index for the summer of 2006 of +0.23ºC, a predicted increase of 0.3ºC over the previous year.

The CIL index is defined as the mean of CIL minimum, or 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 9). The CIL index for summer 2006 is +0.21ºC which agrees with the predicted value 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.

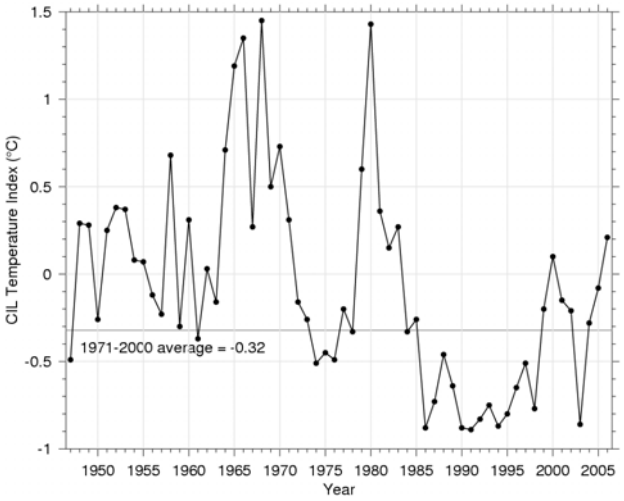

Figure 9. CIL minimum temperature index in the Gulf of St. Lawrence interpolated to July 15.

Regional estimates of CIL minimum temperature, thickness and volume are based on the August and September multidisciplinary surveys for stations deeper than 200 m. Increases in CIL minimum temperature 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 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 the CIL volume (T < 1°C) observed during the September 2006 multidisciplinary survey was the lowest since 1982 (only 1981 and 1982 had lower volumes in the 1971-2006 time series); but the volume was only slightly less than that of 2000.

In order to show the seasonal progression of temperature profiles, averages were computed for the 8 main geographical regions of the Gulf for the March helicopter survey, the June AZMP survey, the August multidisciplinary survey (September survey for the Magdalen Shallows) as well as the November AZMP survey. These average profiles were compared to 1971-2000 monthly climatologies within each region. Temperatures in the June-July period 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. This overall pattern persisted in the August-September mean conditions. In November, the most noteworthy features at that time were the anomalously deep CIL waters in the Estuary and Northwestern Gulf regions and the anomalously warm waters above the CIL everywhere in the Gulf.

The deeper waters of the Laurentian Channel are mostly isolated from exchanges with the surface 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. The mean dissolved oxygen value at depths greater or equal to 300 m in the St. Lawrence Estuary increased very slightly in 2006 to match the 2000 observations, but still remained very low.

CONCLUSION AND OUTLOOK

Water temperatures in the Gulf of St. Lawrence during 2006 were generally above normal at all depths except for the CIL in Esquiman Channel and Mecatina Trough and deeper waters (> 300 m) of the southern half of the Laurentian Channel.

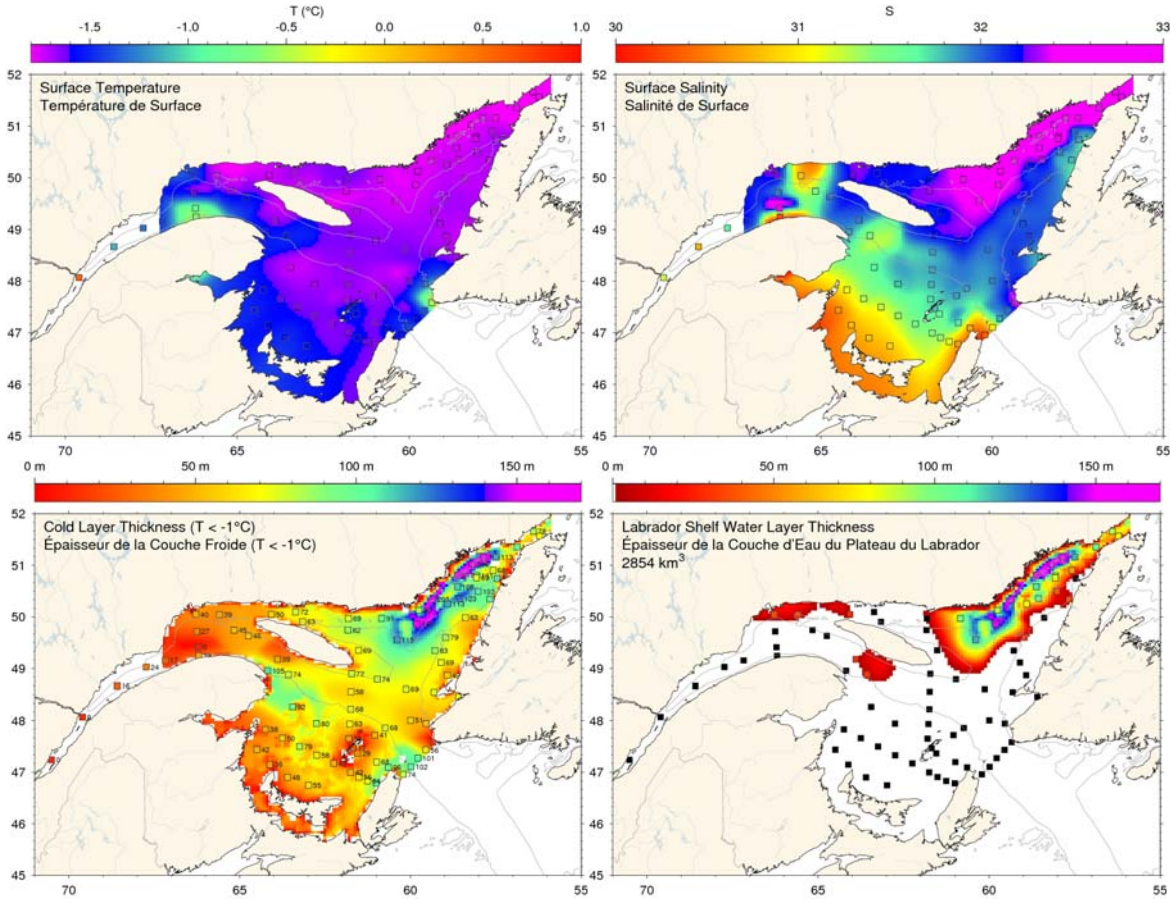

Figure 10. Surface water temperature (upper-left), salinity (upper-right), cold layer (T < -1°C) thickness (lower-left) and estimate of the thickness of the Labrador Shelf water intrusion (lower-right) for the March 2007 winter survey.

The March 2007 winter survey provides an outlook for conditions expected for the remainder of 2007. Figure 10 shows the same information, updated for 2007, as was shown for the 2006 survey in Figure 8. The waters were near-freezing almost everywhere, and there was no patch of 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. 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. Its extension to the surface instead of as only a subsurface tongue (as observed in 2006) translates to a large increase in volume to 2854 km³ (up from 1618 km³ in March 2006). The 2007 volume is similar to that observed in March 2004. The cold layer (< - °C) thickness is also greater elsewhere in the Gulf in 2007 and translates to a volume of 13.1 x 10^3 km³, again similar to conditions in March 2004. The relation between the cold-water volume and the CIL index 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 similar near-average (1971-2000) conditions observed in 2004. This is very surprising considering the very warm precondition of the Gulf in November 2006 and the mild early winter conditions up to mid-January 2007.

SOURCES OF INFORMATION

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