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Physical Environmental Conditions in the southern Gulf of St. Lawrence during 2004

Conditions du milieu physique dans le sud du golfe du Saint-Laurent au cours de l'année 2004

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ABSTRACT

Physical environmental conditions in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2004 were examined using air temperature, sea ice and oceanographic data. Air temperatures were near normal for most of the year. Ice conditions were more severe than average, with the ice appearing slightly earlier and lasting longer than normal. Bottom conditions were variable but tended to have warmed over much of the deeper part of the Magdalen Shallows compared to 2003, although some shallow parts, along the coast, were cooler. A band of water extending from Chaleur Bay to Western Cape-Breton shows temperatures below the long-term average. Surface waters were significantly cooler than normal in 2004. This contrasts with a decrease in the volume of the Cold Intermediate Layer (CIL) from 2003. The longer term cooling trend at both the surface and bottom (75 m) seems to be continuing while salinities continue to increase since their minimum values around 1995 (Western Shallows).

RÉSUMÉ

Les conditions du milieu physique qui ont prévalu en 2004 dans le sud du golfe du Saint-Laurent (Plateau madelinien) ont été examinées en utilisant des données sur la température de l'air, la glace de mer et l'océanographie. Les températures de l'air se sont maintenues près des normales pendant la majeure partie de l'année. Les conditions de glace ont été plus intenses que la moyenne, les glaces étant apparues légèrement plus tôt et la période pendant laquelle elles sont restées ayant été plus longue que la normale. Les conditions observées dans les couches de fond du Plateau ont varié mais ont eu tout de même tendance à être plus chaudes dans presque toute la partie la plus profonde du Plateau madelinien comparativement à 2003. Toutefois, les conditions ont été plus fraîches dans certaines parties peu profondes le long de la côte. Une bande d'eau s'étendant de la Baie des Chaleurs à l'ouest du Cap-Breton a affiché des températures inférieures à la moyenne à long terme. En 2004, les eaux de surface ont été sensiblement plus fraîches que la normale, ce qui contraste avec une diminution du volume de la couche intermédiaire froide (CIF) observée en 2003. La tendance de refroidissement à plus long terme à la fois dans les couches de surface et de fond (75 m) semble se poursuivre alors que les niveaux de salinité continuent d'augmenter depuis que des valeurs minimales ont été observées vers 1995 (ouest du Plateau).

Introduction

Annual assessments of the stock abundance, fishing effort, and biological characteristics of several groundfish species in the southern Gulf of St. Lawrence (Fig. 1) are undertaken by the Gulf Region of the Department of Fisheries and Oceans (DFO). The purpose of this paper is to provide environmental information as background for these assessments. Air temperatures, sea-ice conditions and ocean temperatures and salinities over the Magdalen Shallows are examined. Conditions during 2004 are described and comparisons are made to conditions in 2003 and the long-term averages. The ocean properties include surface and near-bottom temperatures from several fisheries surveys. In addition, vertical profiles and time series of the monthly mean temperatures and salinities within the southern Gulf are provided together with indices of the area of the bottom covered by specified temperatures. We begin with a description of the datasets, then provide details of the methods used to analyze the data and finally present the results.

Data

Air temperature records were available from the Magdalen Islands, Quebec, Charlottetown, Prince Edward Island (PEI) and Miramichi, New Brunswick (Fig. 1). Data for 2004 from these sites were obtained from the Environment Canada website and pre-2004 data from the climate indices database at the Bedford Institute of Oceanography (BIO). Fresh water Runoff data for the Miramichi River were available from the Environment Canada website. The data are daily estimates.

Sea-ice data for 2004 covering the Southern Gulf of St. Lawrence were obtained from the Canadian Ice Service (CIS). Daily charts were examined to determine the position of the ice edge (10% concentration) at specified dates through the winter. Digital versions of the weekly ice charts from CIS were used to update the gridded sea-ice database at BIO (Drinkwater et al. 1999). This database contains the concentrations by ice type and the area covered (in tenths) within each 0.5º latitude by 1º longitude region in the Gulf of St. Lawrence for the years 1963 to present. From this data, we have obtained estimates of the date of first presence of sea ice, last presence and duration of ice during the winter of 2004.

Extensive geographic coverage of surface and near-bottom temperatures during 2004 for the southern Gulf of St. Lawrence was available from three main surveys. The mackerel survey was conducted in June (Fig. 2a), the snow crab survey from July to October and the annual groundfish survey in September (Fig. 2b). Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the mackerel and groundfish surveys. A total of 70 CTD stations were taken on or adjacent to the Magdalen Shallows during the mackerel survey and 172 stations on the groundfish survey. The snow crab surveys obtained near-bottom temperatures with a thermistor attached to the trawl at 340 stations. Other temperature and salinity data from the southern Gulf in 2004, obtained from research surveys and ships-of-opportunity, were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive. Pre-2004 data were taken from the historical hydrographic database maintained at BIO. This database contains an edited version of the entire MEDS holdings for the region.

Methods

Anomalies, defined as the difference from the long-term averages, were estimated for all of the environmental data. The averages were calculated over a 30-year period (1971-2000, where possible) similar to that used by the meteorologists and adopted for use with oceanographic data by DFO's Fisheries Oceanography Committee (FOC) and the Scientific Council of the North Atlantic Fisheries Organization (NAFO).

The surface and near-bottom temperatures from data collected during each of the surveys were interpolated onto a 0.1° x 0.1° latitude-longitude grid using an objective analysis procedure known as optimal estimation. This method is similar to other objective techniques such as kriging but offers the advantage that the interpolation is 4-dimensional; i.e. three space dimensions, two horizontal and one vertical, and the time dimension, rather than 2-dimensional (the two horizontal dimensions). In this study the surveys were treated as synoptic and no interpolation in time was carried out. The details of the procedure are found in Drinkwater and Pettipas (1996). For the surveys using CTDs, the maximum profile depth from the CTD trace for each station was assumed to be at the bottom. Checks against bathymetric charts were carried out to ensure that no large errors occurred as a result of this assumption. The bottom temperature data were then smoothed for the purpose of contouring. Note that the smoothing routine tends to spread out sharp near-bottom temperature gradients (e.g. those near the coast), and thus the gradients depicted in the plots are not as sharp as in reality.

Long-term monthly climatological means of the surface and near-bottom temperatures were estimated at each grid point based upon optimal estimation using all available data for the years 1971-2000 in the historical temperature, salinity database at BIO. Temperature anomalies were derived by subtracting these climatological means from the 2004 values. A negative anomaly indicates that the 2004 temperature was colder than the long-term mean and a positive anomaly indicates that it was warmer than the long-term mean. We also examined the change in temperature since the previous year by subtracting the 2003 optimally-estimated temperatures from the 2004 estimates. A negative value indicates that 2004 was cooler than 2003, a positive value that it was warmer.

From the optimally estimated bottom temperatures obtained during the groundfish survey, the area of bottom covered by each 1Cº temperature bin was estimated for the entire series (1971-2004). For this, the temperature at each grid point was assigned the area of bottom associated with that particular grid point. These have been used to estimate the area of bottom covered by water of <0ºC and <1ºC.

In addition, annual mean temperature and salinity profiles for 2004 were determined within the eastern and western regions of the Magdalen Shallows from the BIO database. All available data within each of these areas were averaged by month at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, and 300 m where possible). An "annual" anomaly profile was determined by averaging over the available monthly anomalies, regardless of whether there were data available in 1 or 12 months of the year. Time series of monthly mean temperatures and salinities at representative depths for each area are also provided. Long-period trends are shown in the plots of these monthly means. They are the 5-year running averages of the "annual" anomalies.

Results

Air Temperatures

The mean air temperatures on the Magdalen Islands were slightly warmer than their long-term average in 10 of the 12 months of 2004 (Fig. 3). January and June show just below normal mean air temperatures. Similar air temperature conditions also were observed at Charlottetown (PEI) and Miramichi (NB). The annual means were above normal at all three sites (Magdalen Islands, anomaly of 0.61ºC; Miramichi, 0.18ºC; Charlottetown, 0.01ºC). The time series at each of the sites show similar trends (Fig. 4, 5). The longest record is from Charlottetown, which began in 1873. It shows that in most years prior to 1930 the annual mean temperatures were below the 1971-2000 average. The 1950s show warmer than normal conditions and oscillations of about a 15-year period can be seen until the late 1990's. Recent temperatures have been above normal. Indeed, 1999 was the highest temperature on record at all three sites.

Runoff

The time series of the Miramichi River freshwater runoff is shown in Fig. 6. The annual average runoff dropped from a value of 146 m^3/s in 2003 to 77 m^3/s in 2004. The mean runoff in 2004 was the third lowest value since 1962 and is 43 m^3/s below the long-term average of 120 m^3/s.

Sea-Ice

The times of first presence of ice show ice forming initially along the coastal regions of the Magdalen Shallows and spreading eastward (Fig. 7). By mid January, ice had covered all of the Shallows for at least some period of time. Subtracting the long-term (1971-2000) mean indicates that the time of first ice was earlier that normal over most of the Southern Gulf in 2004 (Fig. 8, top panel). The last presence of ice was near the end of April in Chaleur Bay and along the western shore of Cape Breton (Fig. 7), approximately 10-15 days later than normal (Fig. 8, bottom panel). The duration of sea ice is the number of days ice was present. It is not the simple difference between the dates of first presence and last presence since the ice may come and go. The ice duration varied from a high of over 130 days around the mouth of Miramichi Bay to 80-90 days along the edge adjacent to the Laurentian Channel (Fig. 9). This resulted in durations that were around 20 days more than normal close to Miramichi Bay and Western Cape Breton.

Hydrographic Conditions

Bottom Temperatures

The mackerel survey in June 2004 shows a large area of the central Shallows covered by temperatures <0°C (Fig. 10). From there, bottom temperatures tended to increase towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because in the Gulf of St. Lawrence throughout the summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel that originate from the slope water region off the continental shelf. These cold waters are known as the cold intermediate layer (CIL). Although the deeper waters are warmer than the CIL, their density is higher because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with an additional 35% from the advection of cold Labrador Shelf water through the Strait of Belle Isle (Petrie et al., 1988).

Relative to the long-term (1971-2000) mean, the bottom temperatures in June 2004 were slightly colder through much of the western region of the Shallows and off Cape Breton (Fig. 10), although St. Georges Bay was warmer than usual. The largest negative anomalies (< -1°C) were located northwest of PEI, in the western part of Northumberland Strait and at the head of Chaleur Bay. In contrast, the portion over the Laurentian Channel shows warmer-than-normal bottom waters. Relative to the June survey in 2003, temperatures had slightly cooled over a large portion of the shallows and in Chaleur Bay, while the bottom near the Laurentian Channel and off Cape Breton had warmed during the year (Fig. 11).

The longest running survey on the Magdalen Shallows is the groundfish survey (1971-present). Bottom temperatures in 2004 ranged from <0°C to over 17°C (Fig. 12). Most of the Shallows (50-80 m) were covered by temperatures <1°C. The coldest waters (<0°C) were over a large portion of the mid shallows. The decrease from June (mackerel survey) to September (groundfish survey) of 2004 in the amount of near-bottom waters <0°C is typical.

Temperature anomalies over a strip, extending from Chaleur Bay to Western Cape Breton (on the Magdalen Shallows), were slightly below normal while the shallower parts along the coasts and the deeper parts along the Laurentian Channel exhibit warmer than normal conditions (Fig. 12). The negative anomalies are mostly between 0 and -1°C which are not exceptional for the area. The highest positive anomalies (+2°C) appeared off north-western PEI and in St. Georges Bay. These latter must be viewed with caution, however, since the largest uncertainties in the bottom temperature fields are in the near shore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lay close to the thermocline, i.e. the strong vertical gradient in temperature. In these regions the mixed layer may extend to the bottom one day and be near the surface the next day as conditions respond to wind storms. This produces large variability in the near-bottom temperatures in shallow regions. Second, the optimal estimation routine projects horizontal gradients to the coast if there are few data nearshore. This can lead to erroneous extrapolation of data in regions of strong horizontal temperature gradients.

Relative to 2003, bottom temperatures during the 2004 groundfish survey were significantly warmer over the northern part of the Magdalen Shallows while the southern part was significantly cooler (Fig. 13). The region off north-western PEI was especially cooler with a temperature departure of -3°C. This cooling might be partially due to the lack of data for year 2003 as discussed in the previous paragraph. The Northumberland Strait was warmer in 2004 than in 2003 with an anomaly of over 1°C in St. Georges Bay.

From the gridded temperature data, time series of the area of bottom covered by each 1ºC interval were estimated. We have plotted the time series of the area of the bottom covered by each temperature bin in Figure 14. In 2004, there was a decrease in area covered by <0ºC as well as for the area covered by temperatures <1ºC relative to 2003.

Surface Temperatures

In addition to the near bottom temperatures, we have investigated the surface (0-5 m) temperatures from the surveys. In the June mackerel survey, surface temperatures over the Shallows ranged from 7°C in the Laurentian Channel region to over 11°C off New Brunswick and in St. Georges bay (Fig. 15). Temperatures generally increased shoreward. The 2004 surface values were mostly below their long-term means over the whole Southern Gulf, except off western Cape Breton. The highest negative anomalies appeared in Chaleur Bay (-4°C). Temperatures significantly declined relative to 2003 by several degrees over the western shallows while the northeast part shows warmer conditions (Fig. 16).

The surface temperatures from the groundfish survey in September ranged from 10°C off Gaspé to over 19°C in St. Georges Bay (Fig. 17). As in June, the surface waters over most of the region were cooler than their long-term means. The exception was in Northumberland Strait and offshore of Cape Breton (Fig. 17). There was a substantial decline in the surface temperatures over most of the Southern Gulf between the groundfish surveys from 2003 to 2004 except for some shallow waters along the coast of Nova-Scotia where the temperatures increased (Fig. 18). It should be noted, though, that June and September are months of rapid warming and cooling respectively in the surface waters of the Gulf; there might be some bias in these inter-annual and long-term differences because of slight differences in the timing of the survey between years.

Monthly Mean Temperatures and Salinities

Vertical profiles of the annual mean temperature and salinity anomalies for the southern Gulf were calculated from all available data. To determine if there were spatial differences in temperature trends across the Magdalen Shallows, we divided it into eastern and western regions for the purposes of our analysis (see Fig. 19 for the area boundaries used in the temperature analysis). The monthly mean temperatures and salinities at standard depths were estimated by averaging all of the available data within each region regardless of when in the month it was collected. Similarly, no adjustments were made for the spatial distribution of data or the amount of data that contributed to the average. In some cases the “average” was based upon only one measurement while in other months it was based on over 100 stations. The long-term (1971-2000) means for each area were calculated and then subtracted from the individual monthly means to obtain an anomaly. Then, annual means were constructed by averaging the available monthly profiles of the anomalies. Only the annual mean profiles are discussed here. Because of the possible limited amount of data from which the averages were calculated or the spatial variability in temperature within the regions, any one point or profile may not be truly representative of “average” conditions for the year. Interpretation of the anomalies therefore must be viewed with caution. While no reliance should be placed on any individual monthly or yearly anomaly, persistent features are considered to be real.

Data for 2004 over the western Magdalen Shallows were available for 7 months: March, May to September and November. The annual anomaly profile tends to show generally near to below-normal temperatures in the surface layer, then warmer than normal conditions between 10 and 50 m and cooler conditions at greater depths (Fig. 20). Lower-than-average salinities were observed in whole water column on the Western Shallows in 2004. The average salinity anomaly is around 0.2 (Fig. 21).

On the eastern side of the Shallows, data were available in 5 months in 2004: March, June, August, September and November. The annual mean anomaly profile of temperature shows non-significant differences from normal conditions from the surface to 50 m and warmer conditions down below (Fig 22). Salinities on the eastern side tended to be significantly higher-than-normal in most of the water column except at 75m where fresher waters can be seen (Fig. 23).

In addition to the anomaly profiles, time series of the monthly mean temperatures and salinities at 75 m and the surface were generated. The former depth is considered representative of the near-bottom within both regions. Note that data are not available in every month. There are less salinity data and hence the long-term trends for salinity are not as reliable as for temperature. Although there are some differences in the temperatures in the two sides of the Shallows at 75 m, the long-term trends in both regions are similar (Fig. 24). Relatively warm conditions persisted around the mid-1950s, near 1970, and in the early 1980s separated by colder-than-normal periods. The late 1980s and early 1990s exhibit the longest period of below average temperatures in the entire record. Then the late 1990s have seen warming from these low temperatures. The time series show a decline on both sides of the Shallows over the last 4-5 years. The time series at the surface show higher variability than at 75 m (Fig. 25). This is because of the importance of atmospheric heat fluxes in heating or cooling the surface waters. These fluxes can undergo large changes from month to month. The surface temperature trends are somewhat similar between the two sides of the Shallows but not as strong as at 75 m. Surface layer waters were warm in the late 1940s and 1950s, near normal through most of the 1960s, warm around 1980 and slightly above normal through the 1980s and into the 1990s. The late 1990s showed higher positive temperature anomalies than the previous decade, but the temperature started to slowly decline after year 2000. The salinities at 75 m show several differences between the two regions but this may be due in part to the small number of samples. In recent years there appears to be around normal salinities near bottom on both sides of the Shallows (Fig. 26), except in 2005 over the Western Shallows. In the surface, salinities through the late 1990s appear also to be fresher-than-normal (Fig. 27). Then, they increase to slightly above normal values after year 2000.

CIL Volume

A volume index of the cold intermediate layer (CIL) was developed for the month of September using the information from the groundfish survey. It consists in calculating the volume of water that has a temperature below 1°C in the Southern Gulf. During 2004, the CIL September volume was 1647 km^3 and was below the long-term mean (1971-2000) of 1903 km^3 . (Fig. 28). This is a decrease compared to 2003 when the index was above the long term mean at 2172 km^3. The 1999 value represented the first year since the early to mid-1980s that volume index was below normal suggesting warmer conditions in the Southern Gulf. Since then, there has been three years with a below average quantity of cold water. Gilbert and Pettigrew (1997) found high correlations between the variability in the Gulf wide CIL core temperatures and air temperatures along the coast of western Newfoundland, suggesting the possible importance of atmospheric forcing in determining the temperature and extent of the CIL waters in the Gulf. These air temperatures have been mostly above or close to normal since 1999, which may explain in part the lesser quantity of cold water in the Southern Gulf.

Summary

Physical environmental conditions in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2004 were examined from air temperature, sea ice and oceanographic data. Air temperatures were near normal for most of the year. Ice conditions were more severe than average with the ice appearing slightly earlier and lasting longer than normal. Bottom conditions were variable but tended to have warmed over much of the deeper part of the Magdalen Shallows compared to 2003, although the shallow parts were cooler. A band of water, extending from Chaleur Bay to Western Cape-Breton on the Magdalen Shallows, shows below long-term average temperatures. Surface waters were significantly cooler than normal in 2004. This contrasts with a decrease in the volume of the CIL from 2003. The cooling trend at both the surface and bottom (75 m) seems to be continuing while the salinities continue to increase since their minimum values around 1995 (Western Shallows).

Acknowledgements

We acknowledge J. McRuer at BIO for providing the CTD data from the groundfish surveys. The mackerel survey data were collected by scientists at IML in Mont Joli, Quebec, headed by F. Gregoire. We extend a special thanks to the scientists, technicians and crew who collected all of these data. We thank Dr. K. Drinkwater for providing the schematic of this document and the text of an earlier similar document that was used as a template.

References

Drinkwater, K.F. and R. Pettipas. 1996. Near-bottom temperatures on Sydney Bight and the northeastern Scotian Shelf during 1995. DFO Atlan. Fish. Res. Doc. 96/136, 14 p.

Drinkwater, K.F., R.G. Pettipas, G.L. Bugden and P. Langille. 1999. Climatic data for the Northwest Atlantic: A sea ice database for the Gulf of St. Lawrence and the Scotian Shelf. Can. Tech. Rep. Hydrogr. Ocean Sci. 199, 134 p.

Gilbert, D. and B. Pettigrew. 1997. Interannual variability (1948-1994) of the CIL core temperature in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. Vol. 54 (Suppl. 1): 57-67.

Petrie, B., B. Toulany and C. Garrett. 1988. The transport of water, heat and salt through the Strait of Belle Isle. Atmosphere-Ocean 26: 234-251.

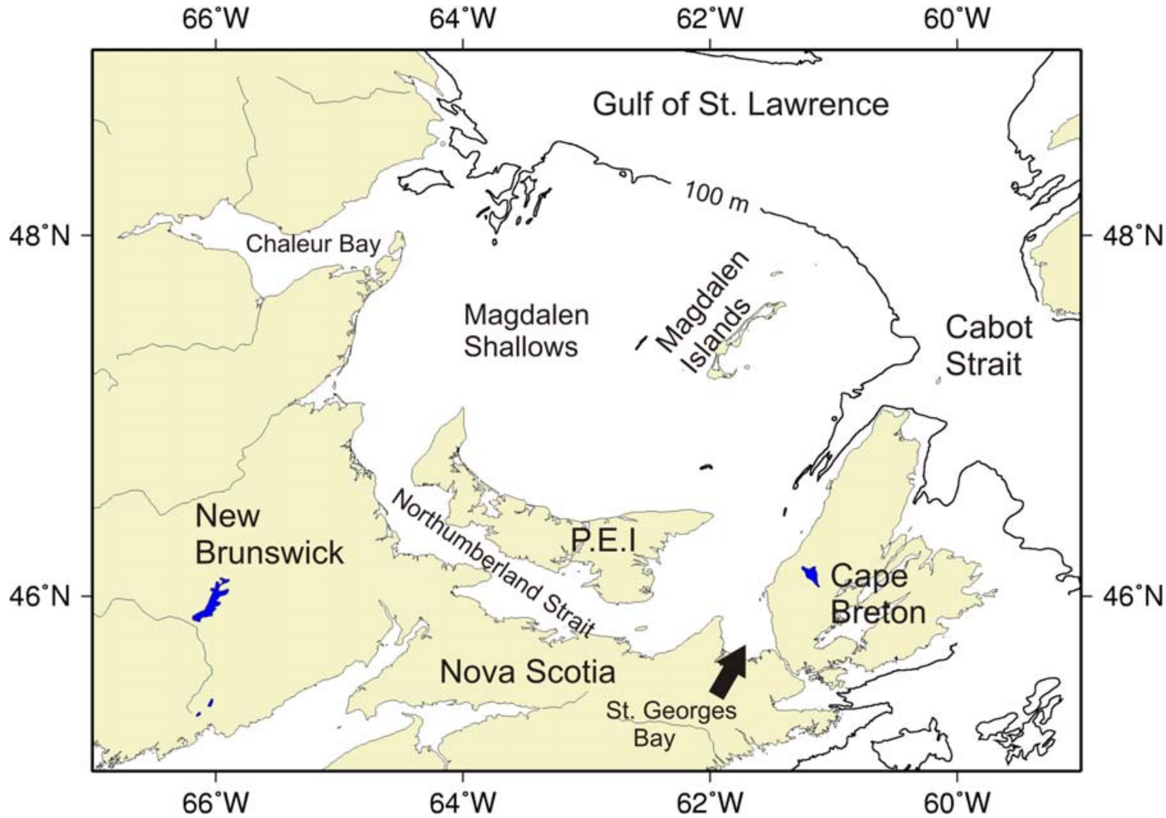


Fig. 1. Chart of the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

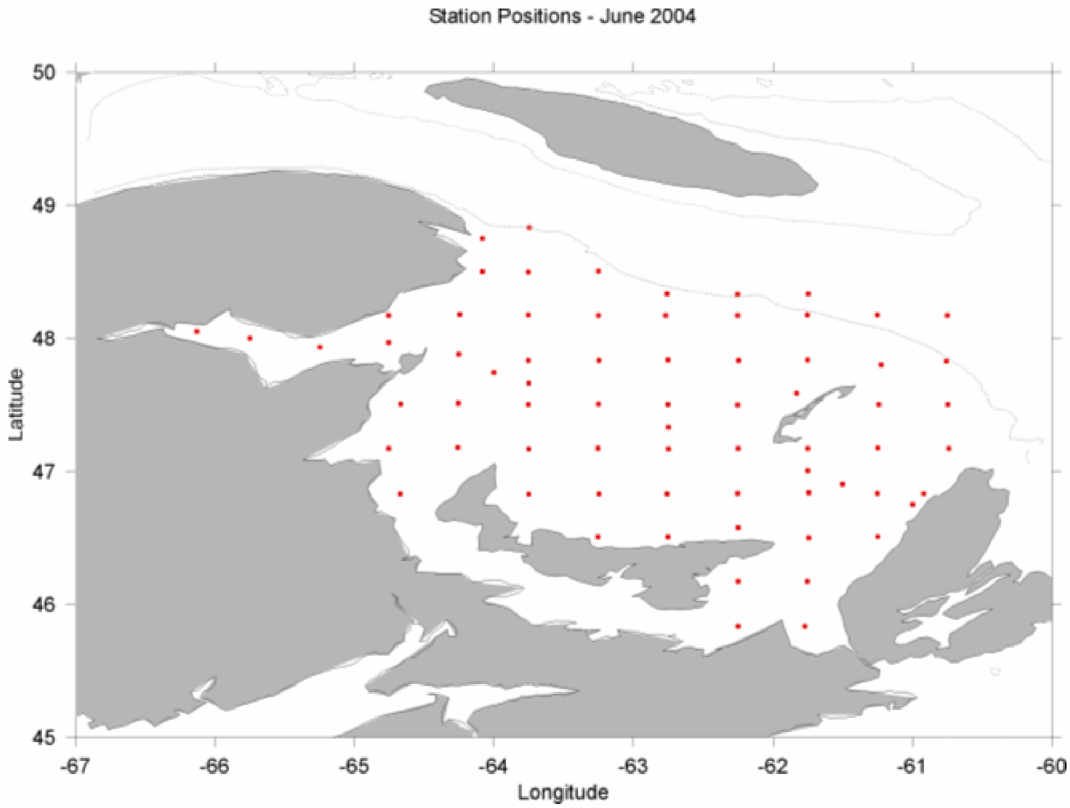


Fig. 2a. The location of the CTD temperature stations during the June 2004 mackerel survey.

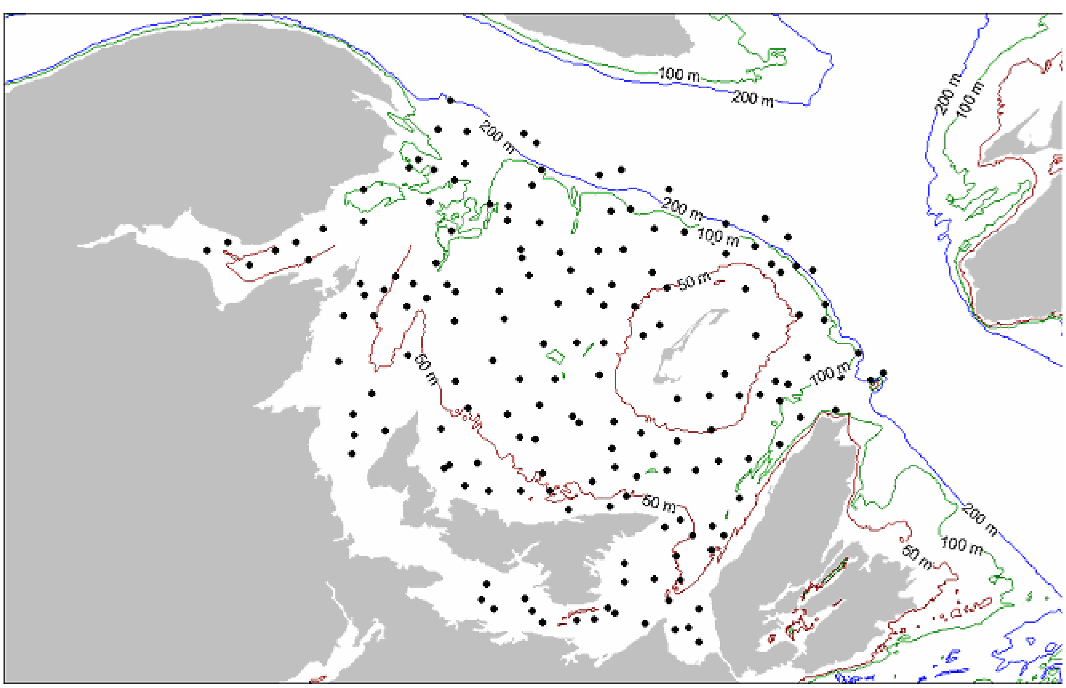


Fig. 2b. The location of the CTD stations during the September 2004 survey.

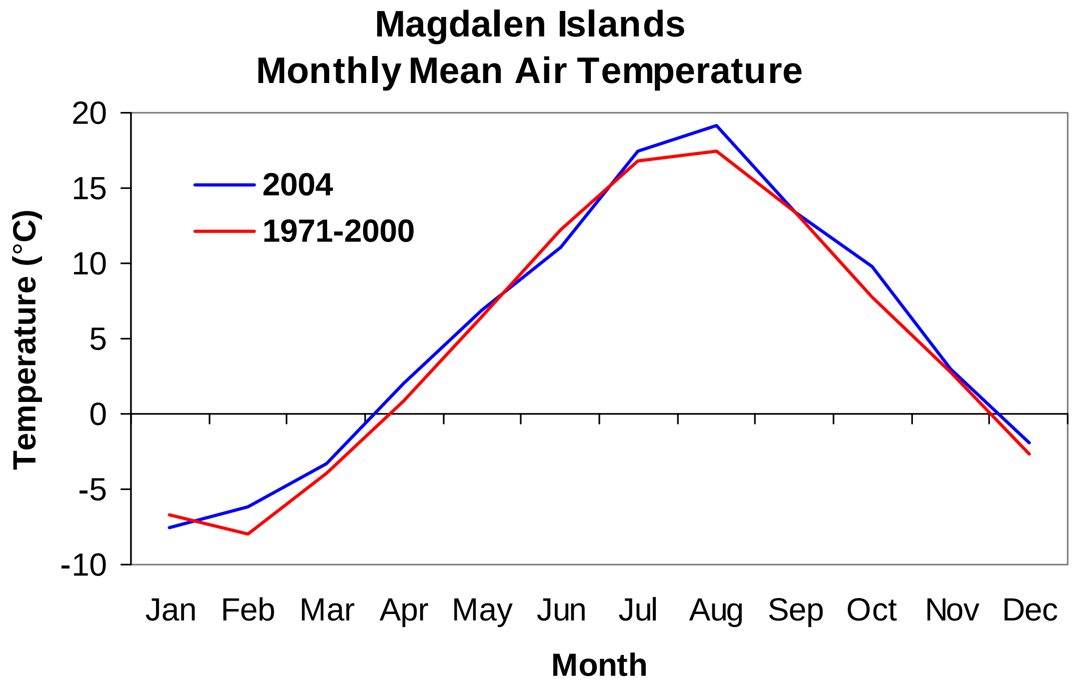


Fig. 3. The monthly mean air temperatures for the Magdalen Islands in 2004 and their long-term averages (1971-2000).

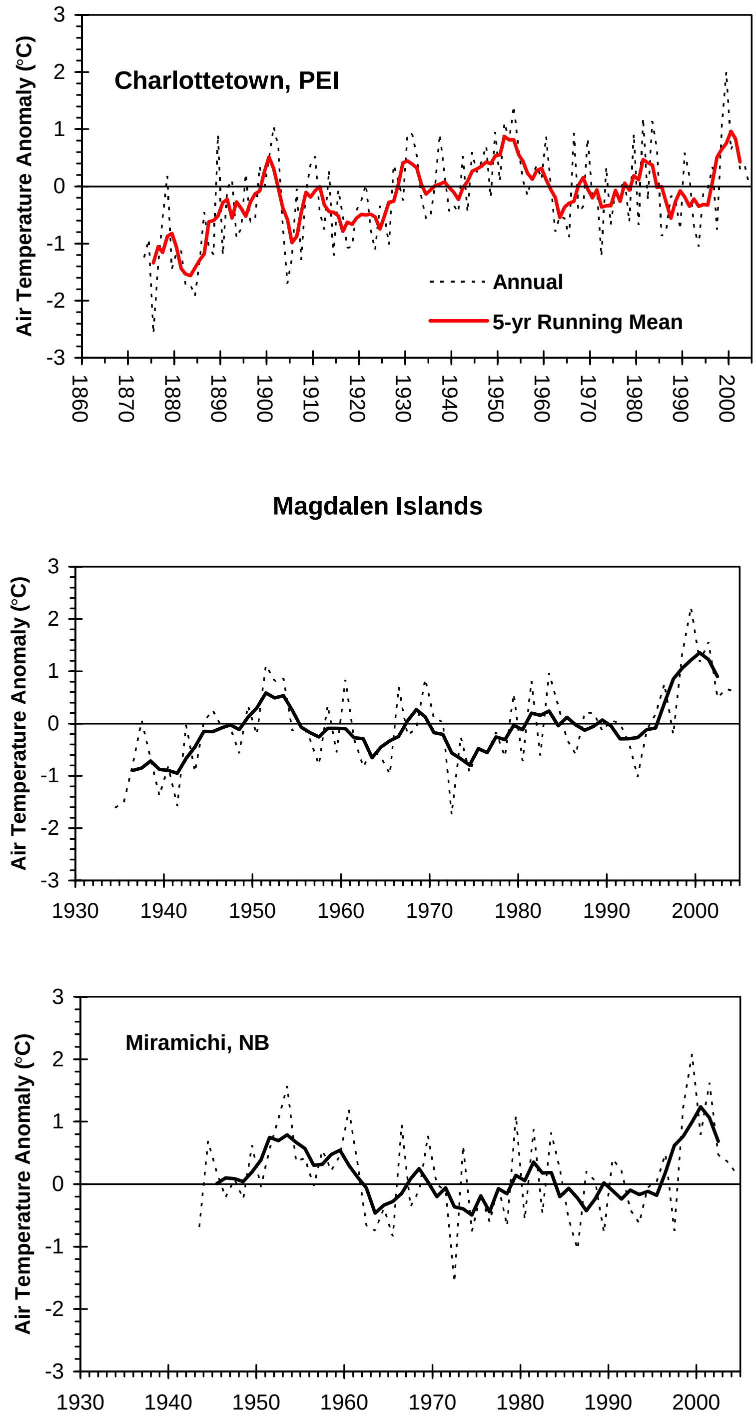


Fig. 4. Time series of the annual air temperatures (dashed) and their 5-year running means for Charlottetown, the Madgalen Islands and Miramichi. Note the time scale on the Charlottetown plot is different.

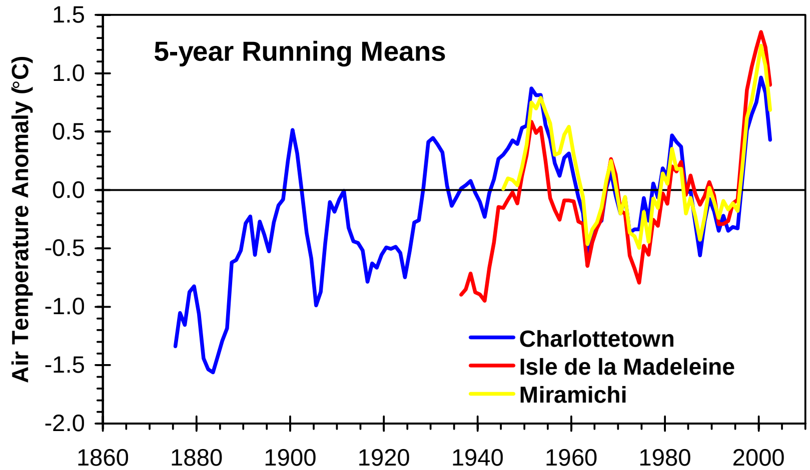


Fig. 5. The time series of the 5-year running means of air temperature anomalies at three sites in the southern Gulf of St. Lawrence.

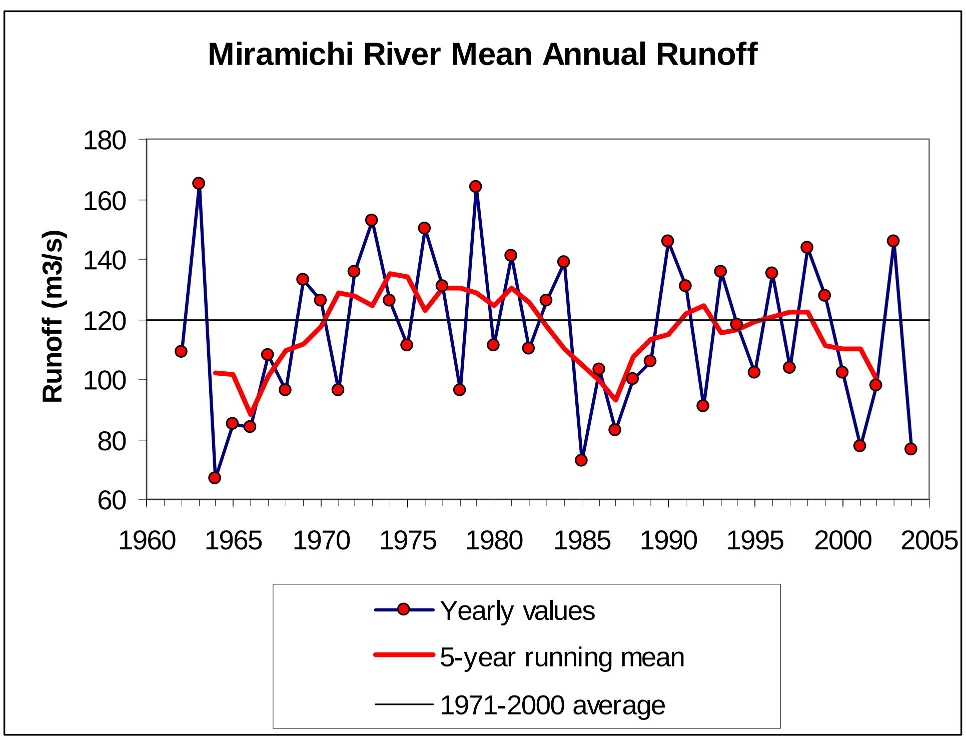


Fig. 6. The Miramichi River freshwater runoff. 2004 is the third lowest value of the timeseries.

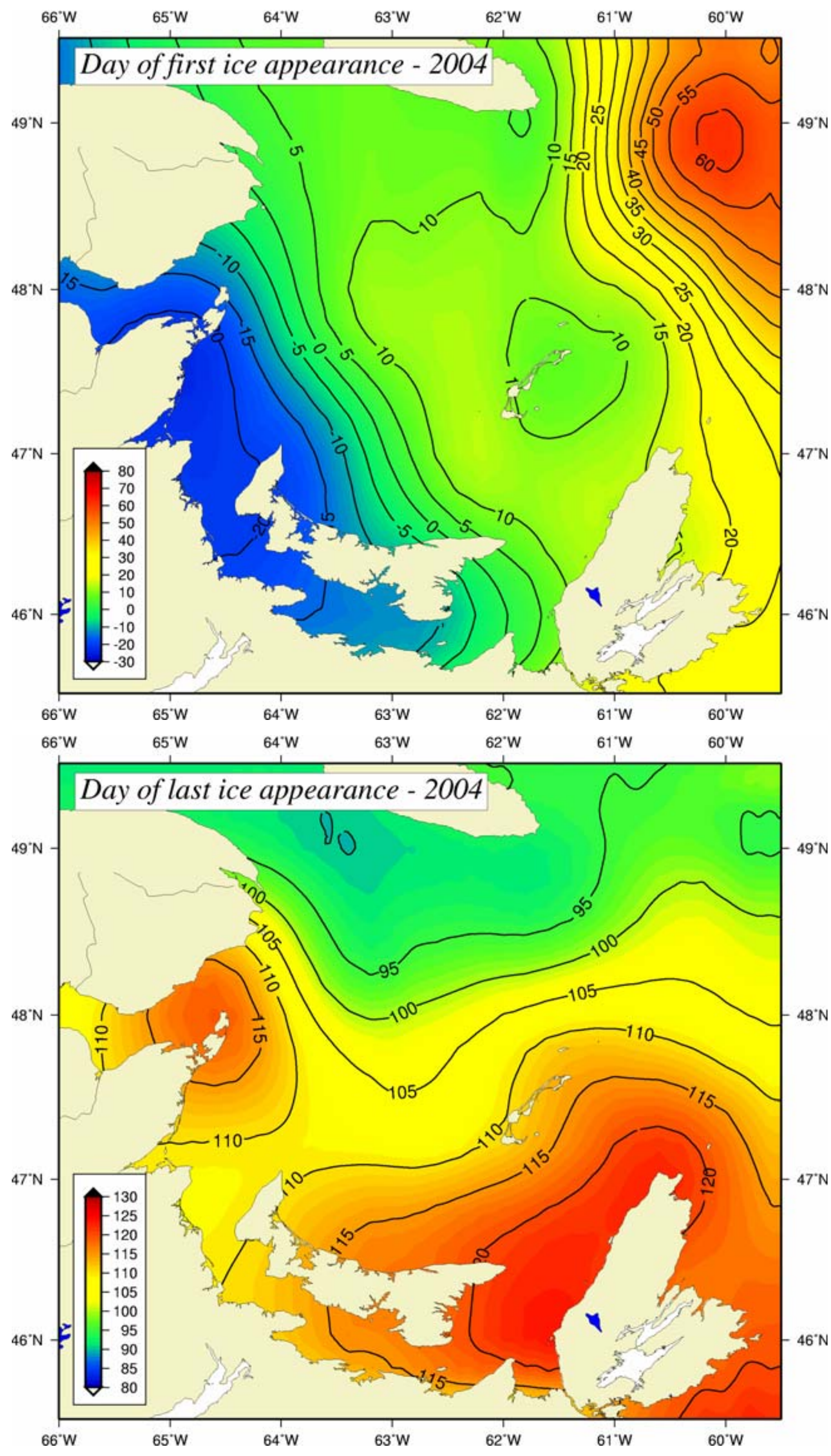


Fig. 7. The date of first (top panel) and last (bottom panel) presence of ice in days from the beginning of the year.

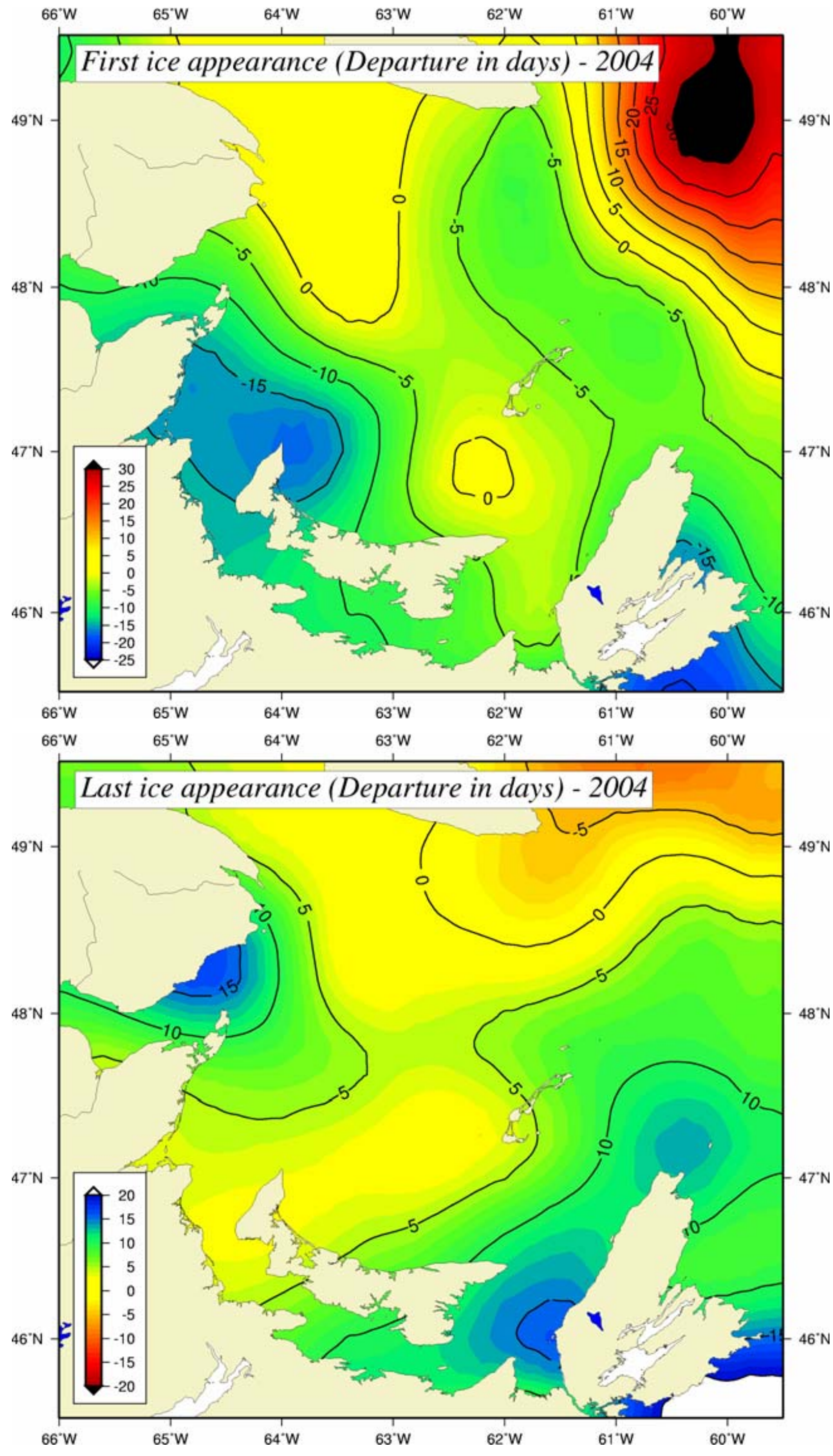


Fig. 8. The anomalies relative to the1971-2000 average of the first (top panel) and last (bottom panel) presence of sea ice in days. The blue regions in the top panel indicate where ice appeared early and, in the bottom panel, when it disappeared late (negative anomalies).

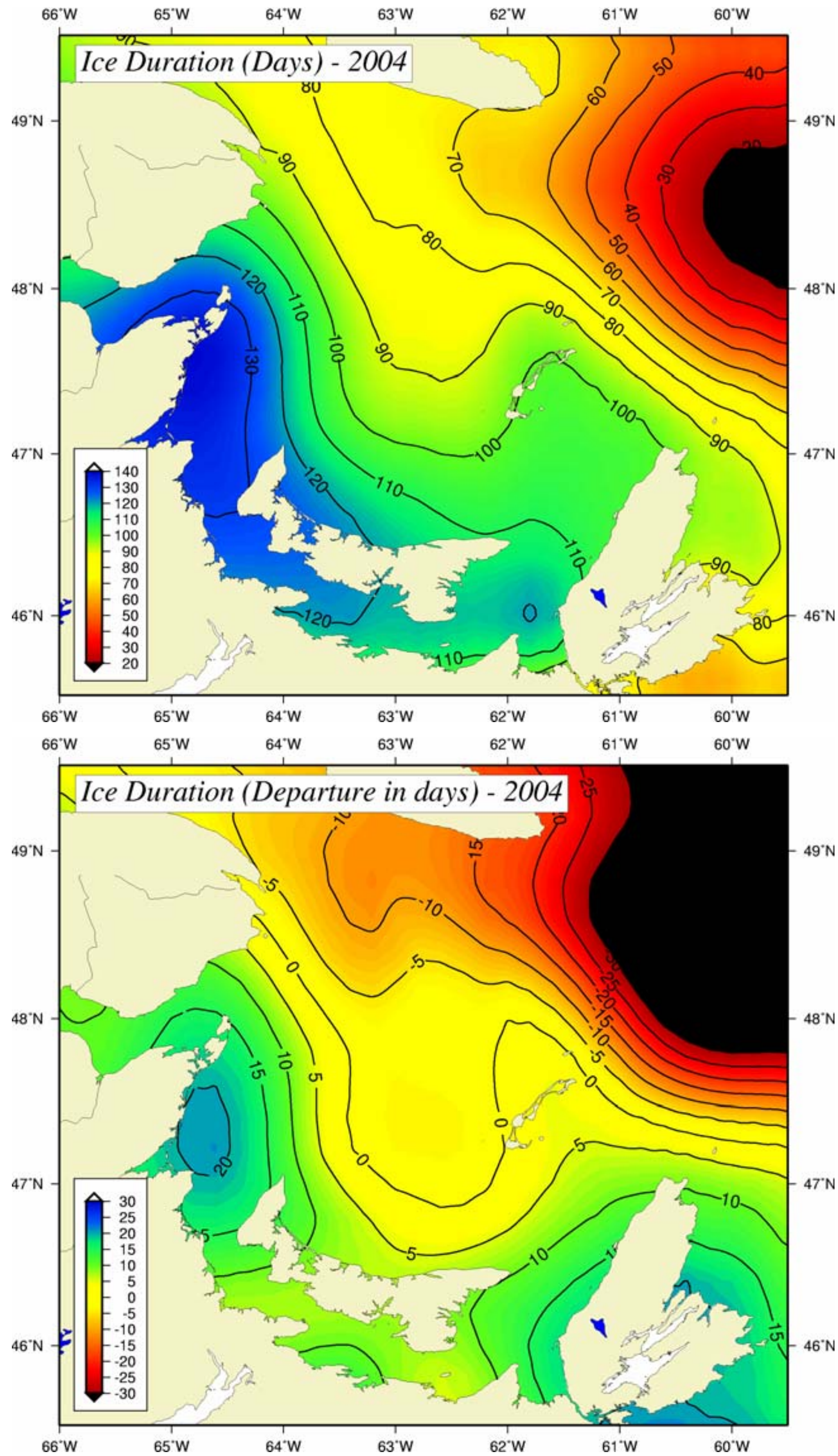


Fig. 9. The duration of sea-ice in days during 2004 (top panel) and their anomalies relative to the 1971-2000 average in days (bottom panel).

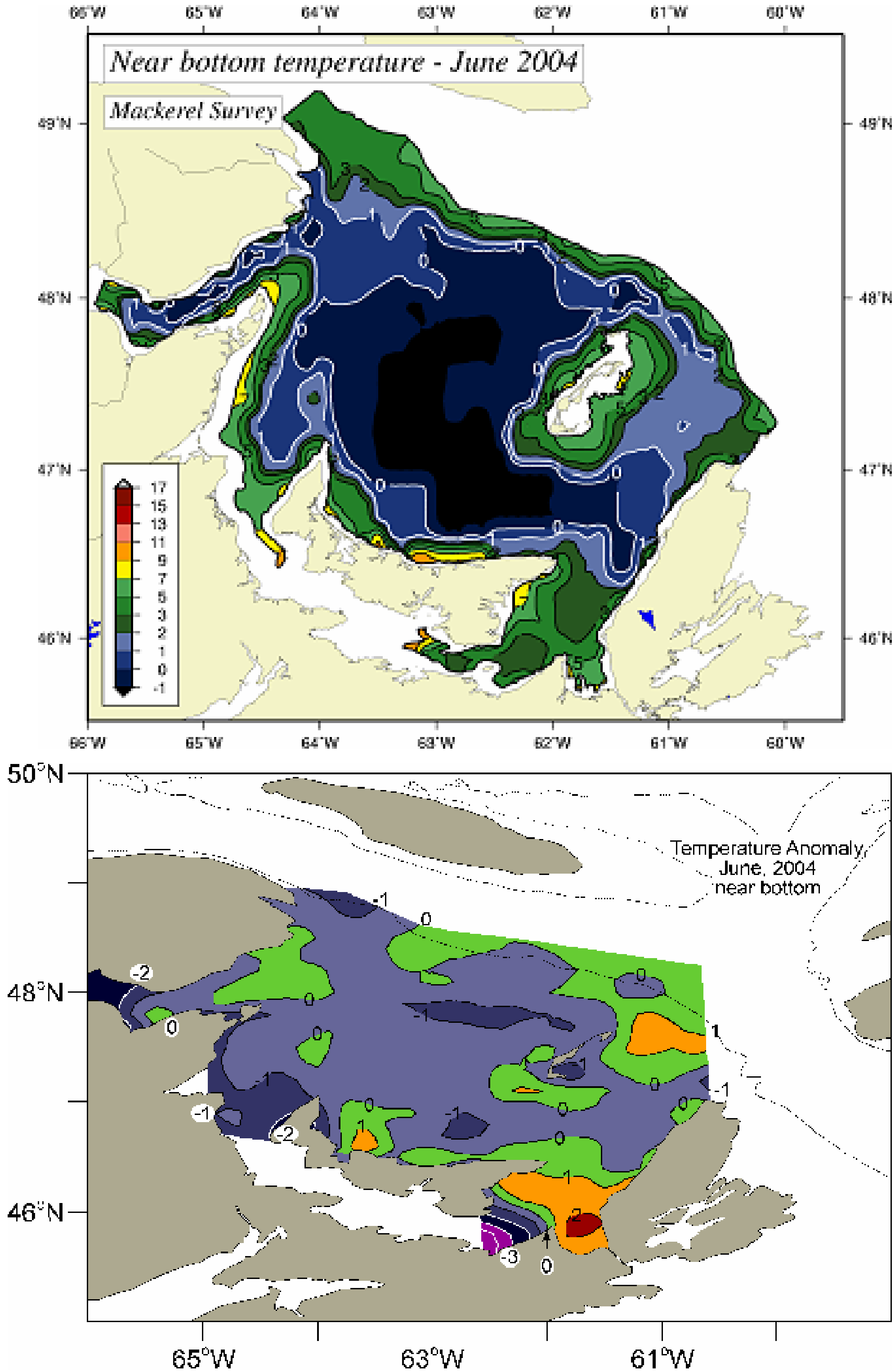


Fig. 10. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2004 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

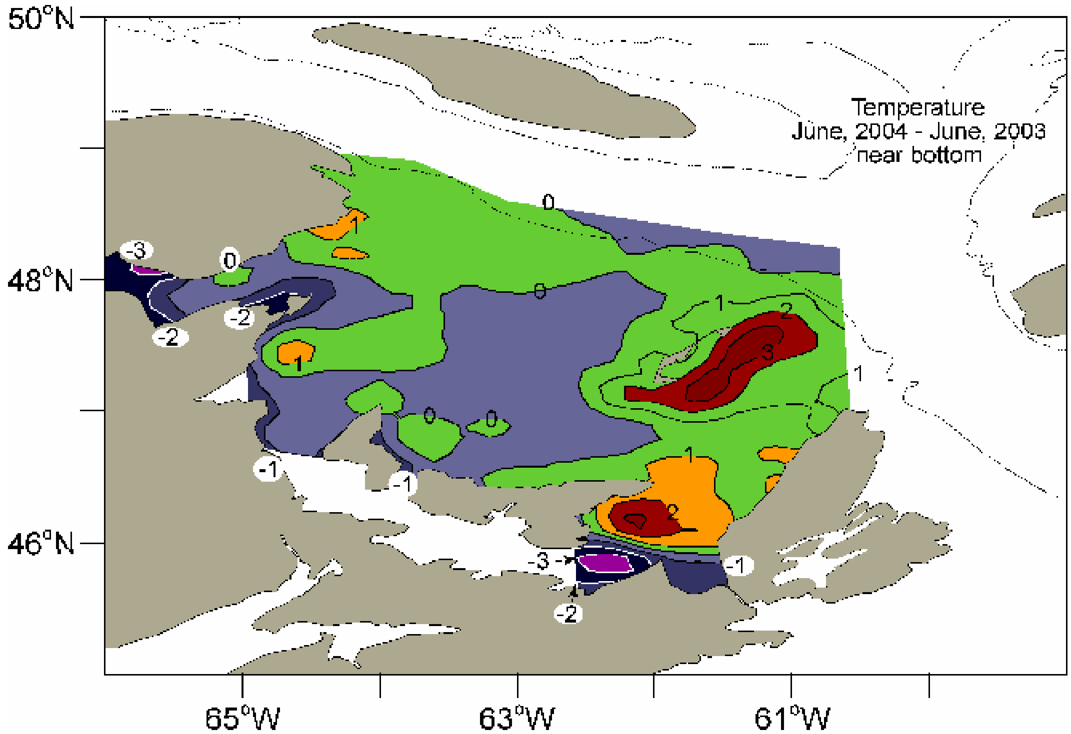


Fig. 11. The difference between the 2004 and 2003 near-bottom temperatures in the southern Gulf of St. Lawrence for the June mackerel survey. Positive values (green, orange and red) indicate temperatures in 2004 had warmed and negative values (blues) that they had cooled.

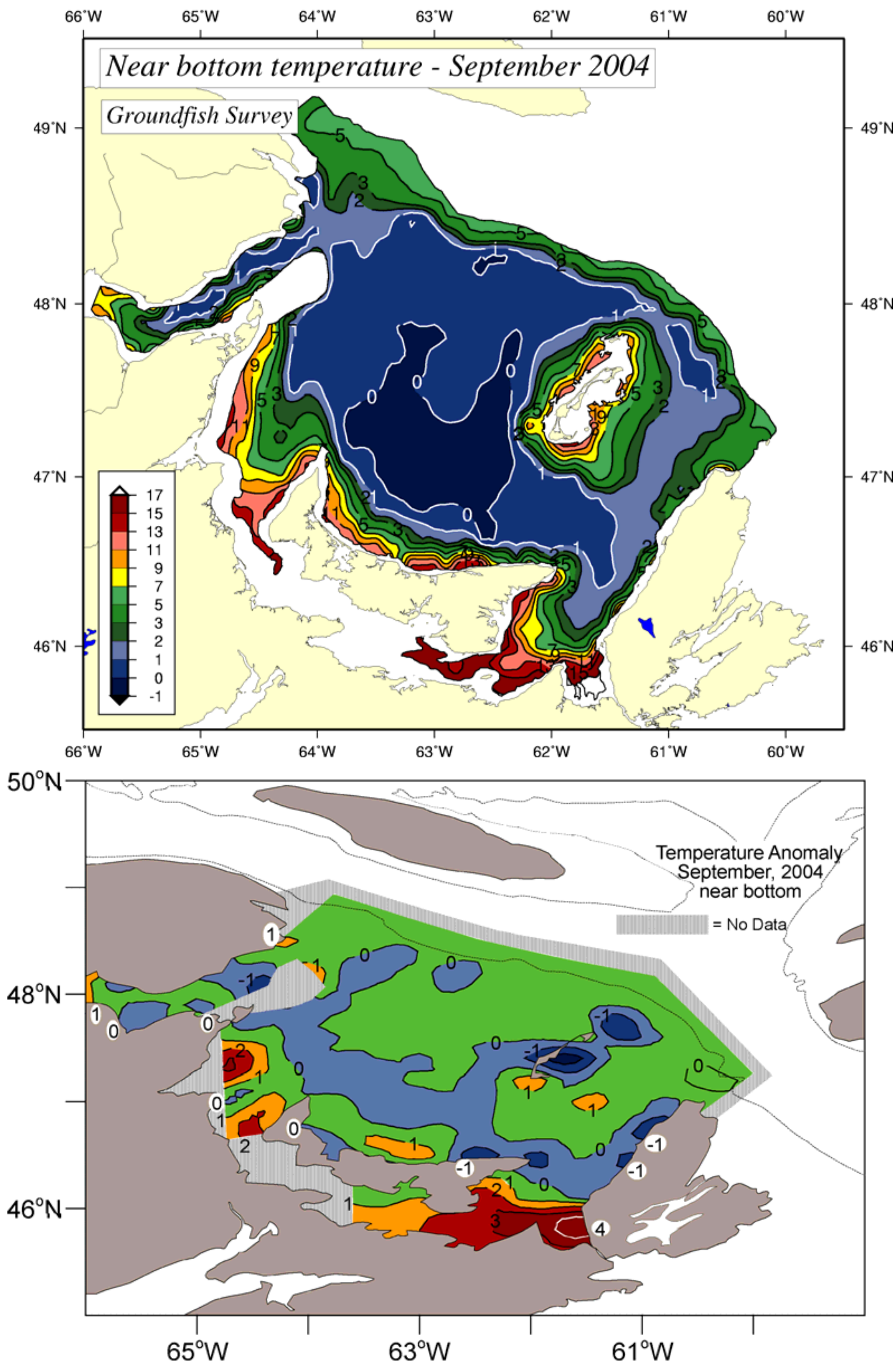


Fig. 12. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2004 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

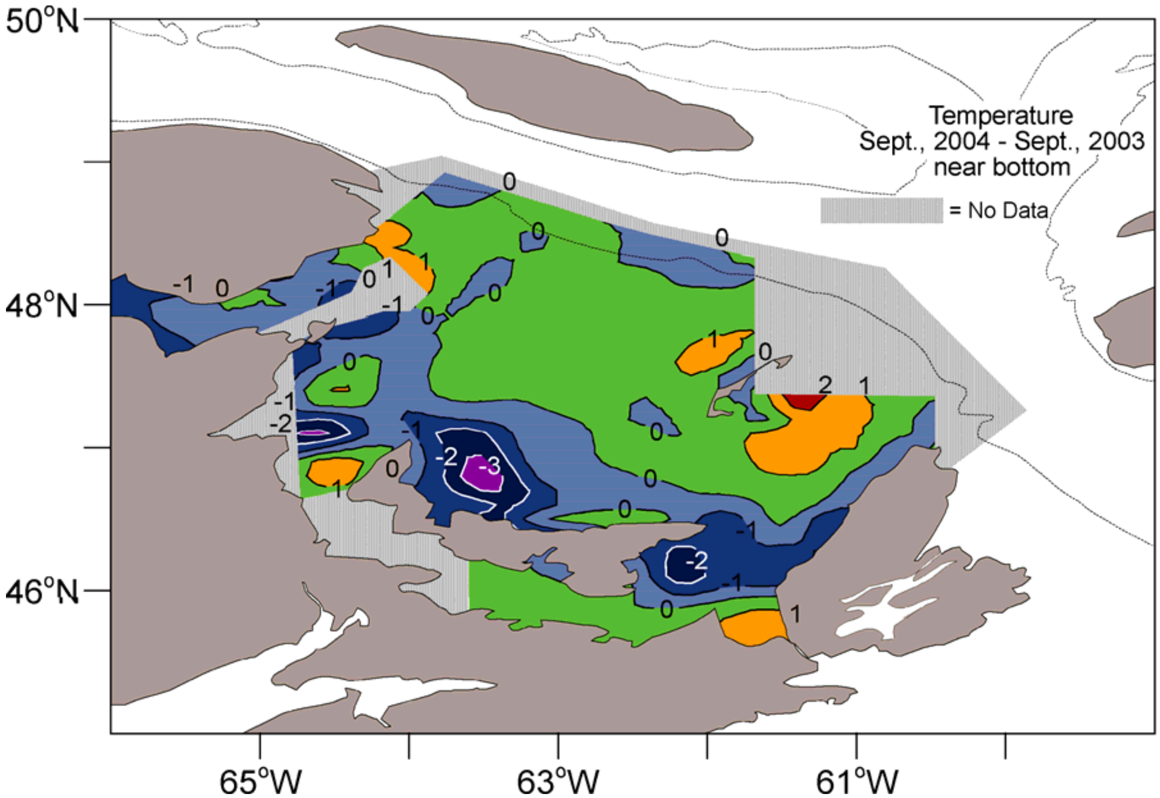


Fig. 13. The difference between the 2004 and 2003 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2004 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue.

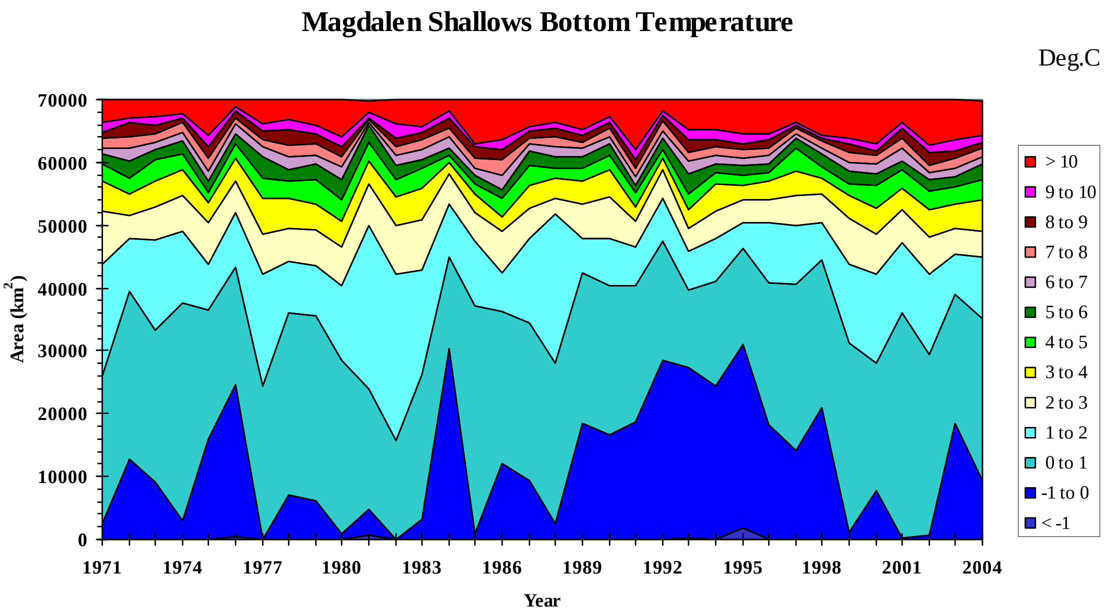


Fig. 14. Time series of the area of the Magdalen Shallows covered by different temperature bins in September.

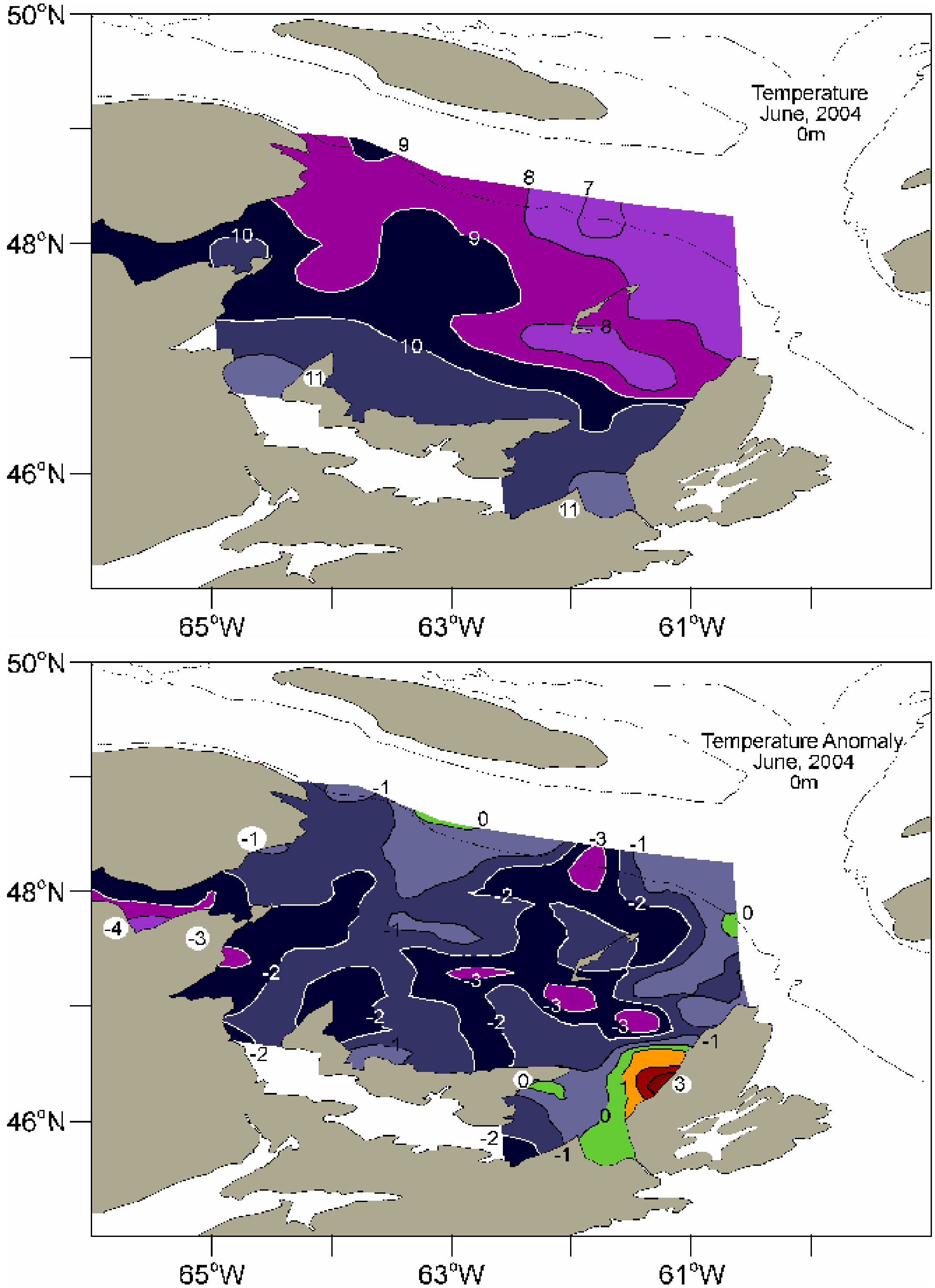


Fig. 15. Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2004 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

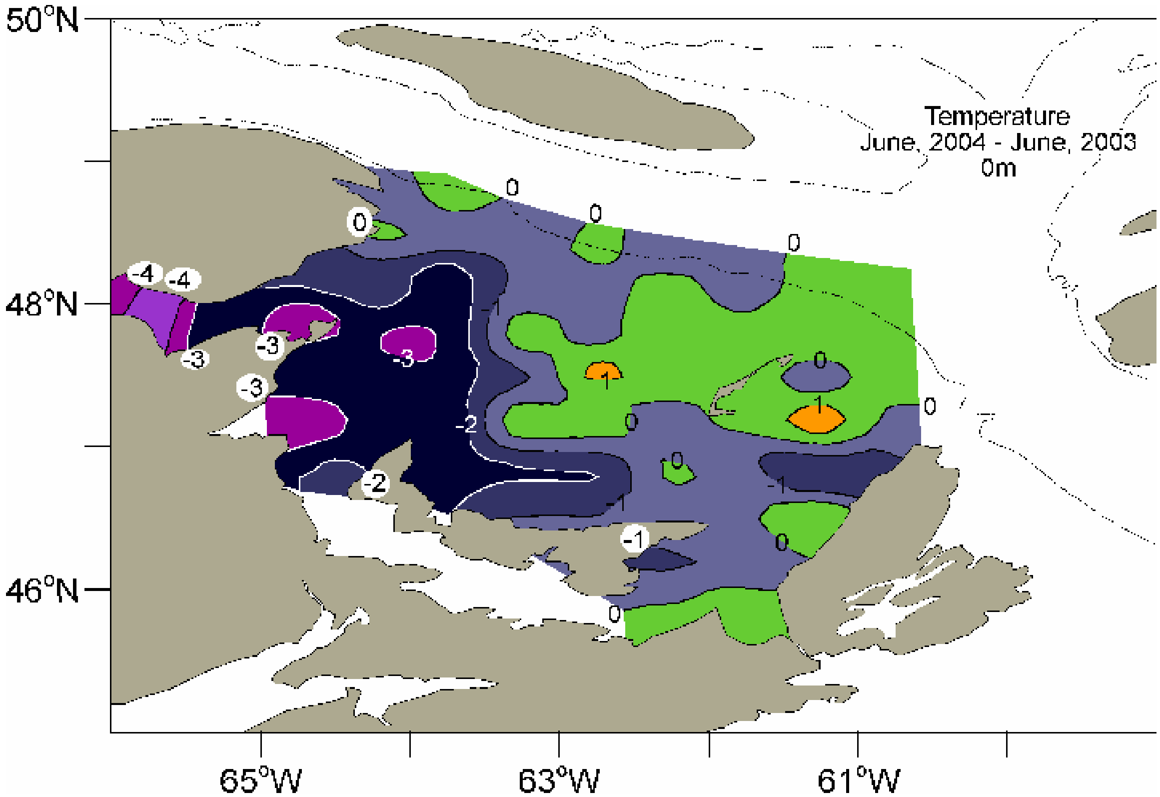


Fig. 16. The difference between the 2004 and 2003 surface temperatures in the southern Gulf of St. Lawrence during the June mackerel surveys. Positive values indicate temperatures in 2004 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue through violet.

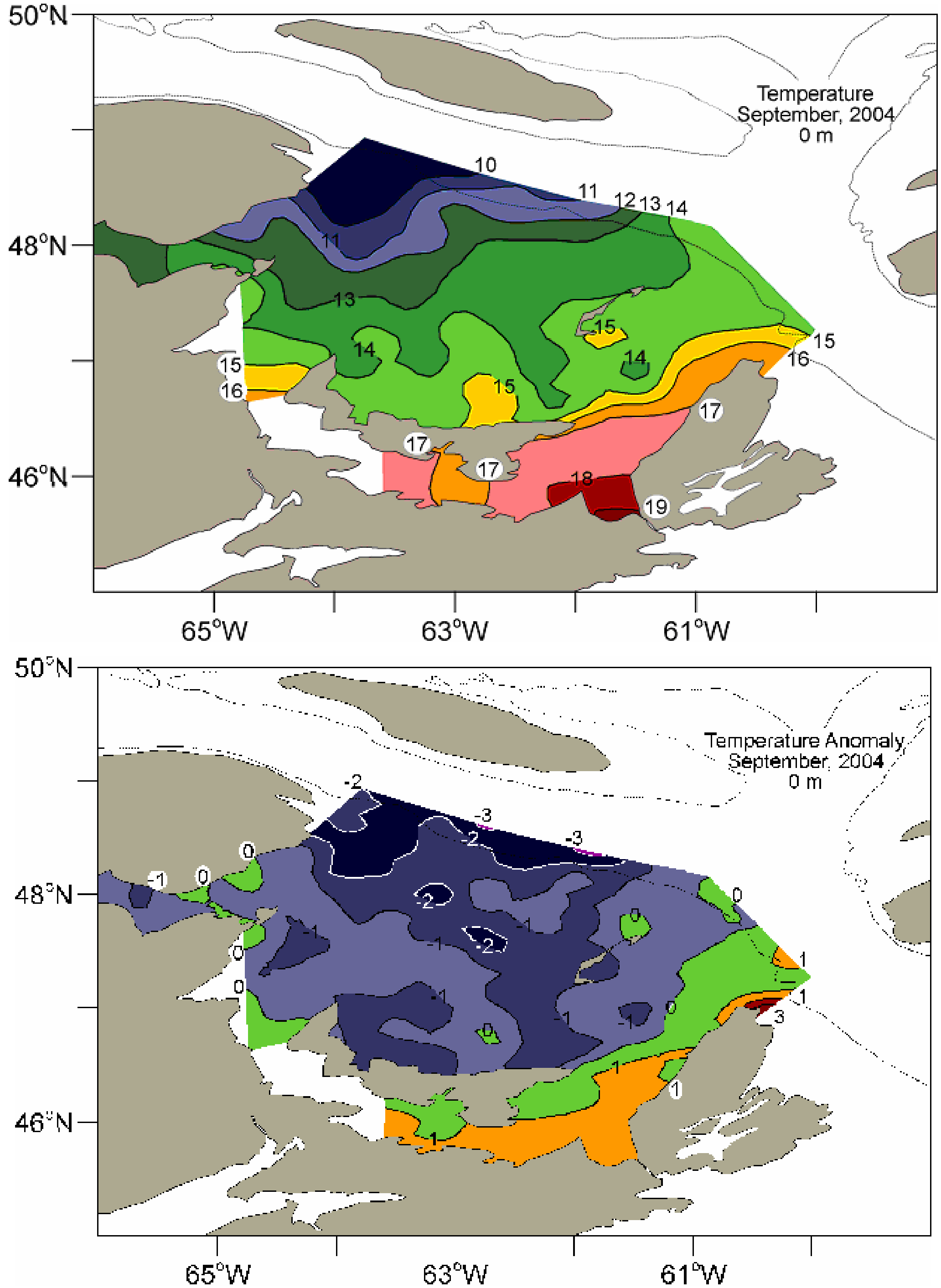


Fig. 17. Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2004 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

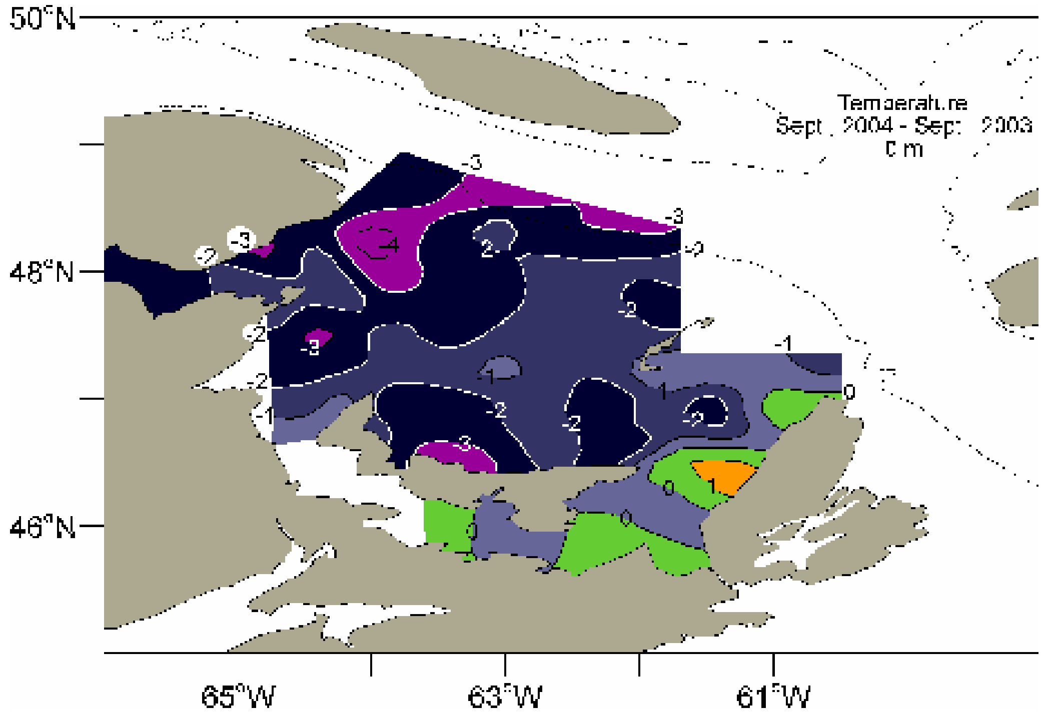


Fig. 18. The difference between the 2004 and 2003 surface temperatures in the southern Gulf of St. Lawrence during the September groundfish surveys. Positive values indicate temperatures in 2004 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue through violet.

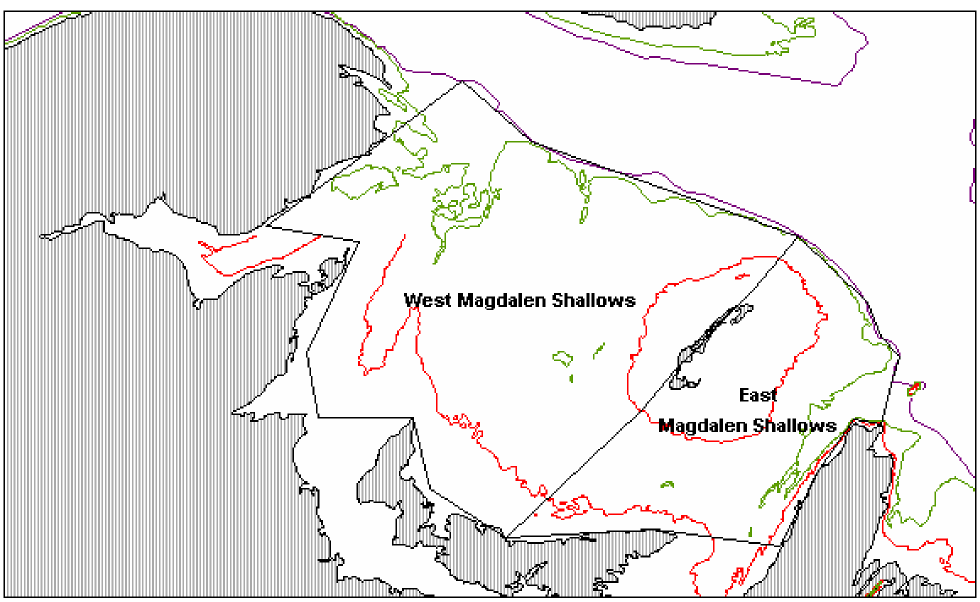


Fig. 19. The boundaries of the two regions of the Magdalen Shallows for which temperature and salinity analyses were carried out.

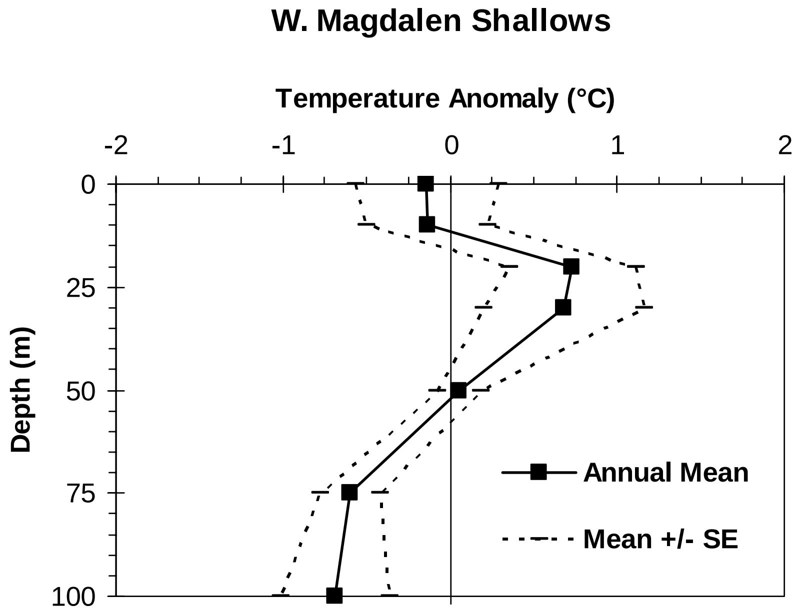


Fig. 20. The vertical profiles of the annual mean temperatures within the western Magdalen Shallows region.

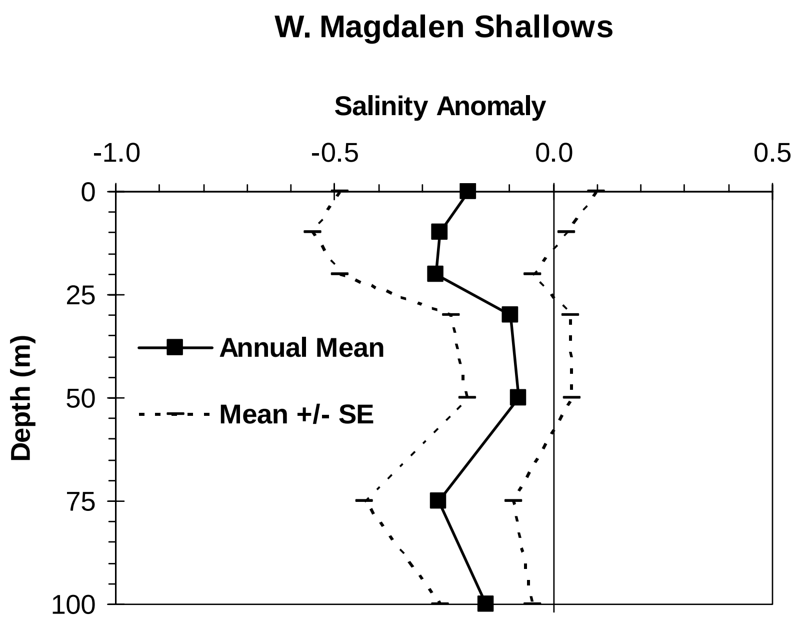


Fig. 21. The vertical profiles of the annual mean salinities within the western Magdalen Shallows region.

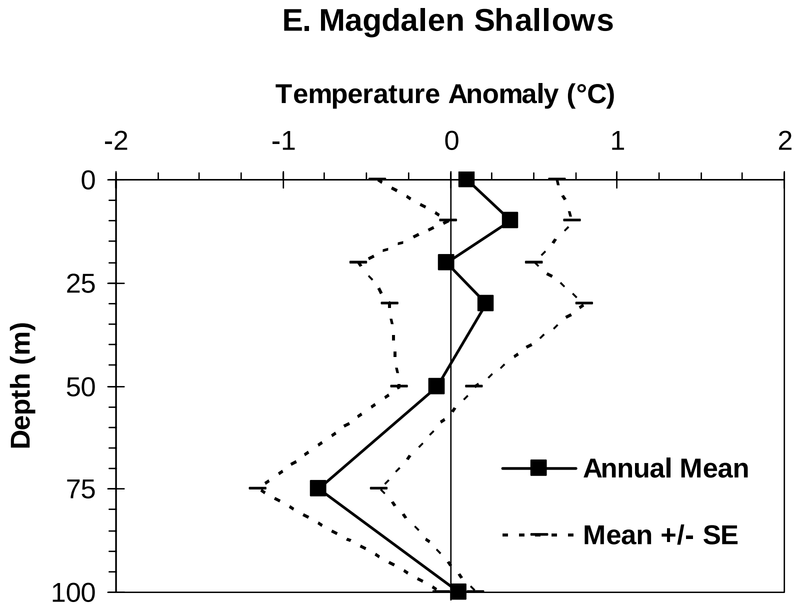


Fig. 22. The vertical profiles of the annual mean temperatures within the eastern Magdalen Shallows region.

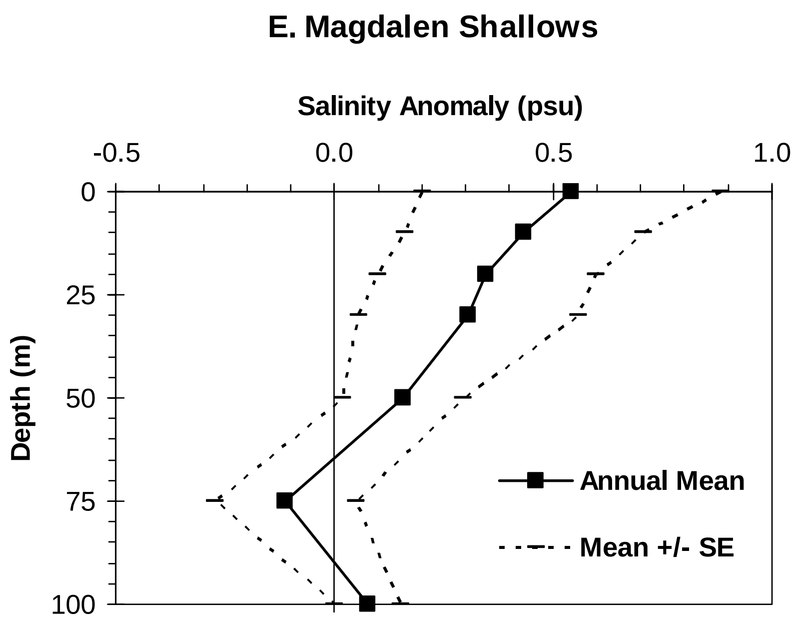


Fig. 23. The vertical profiles of the annual mean salinities within the eastern Magdalen Shallows region.

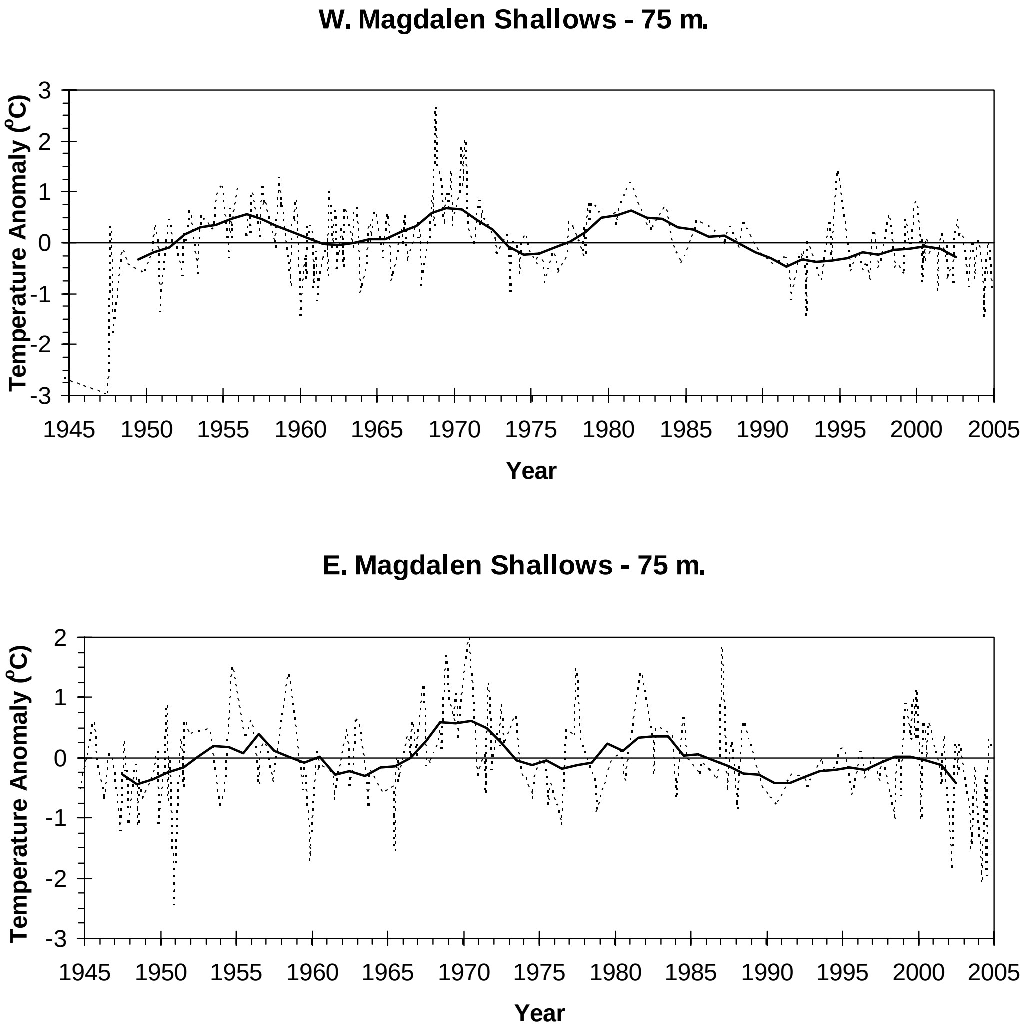
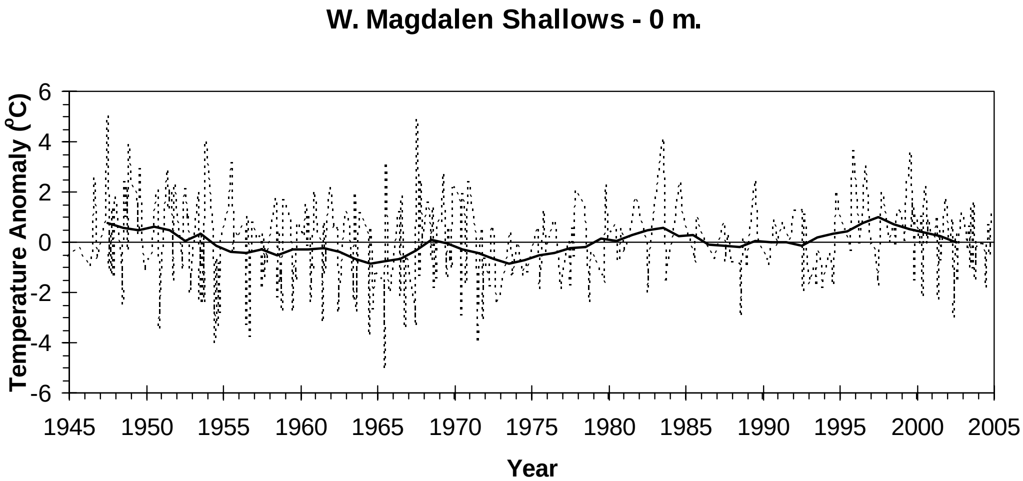


Fig. 24. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of temperature at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.



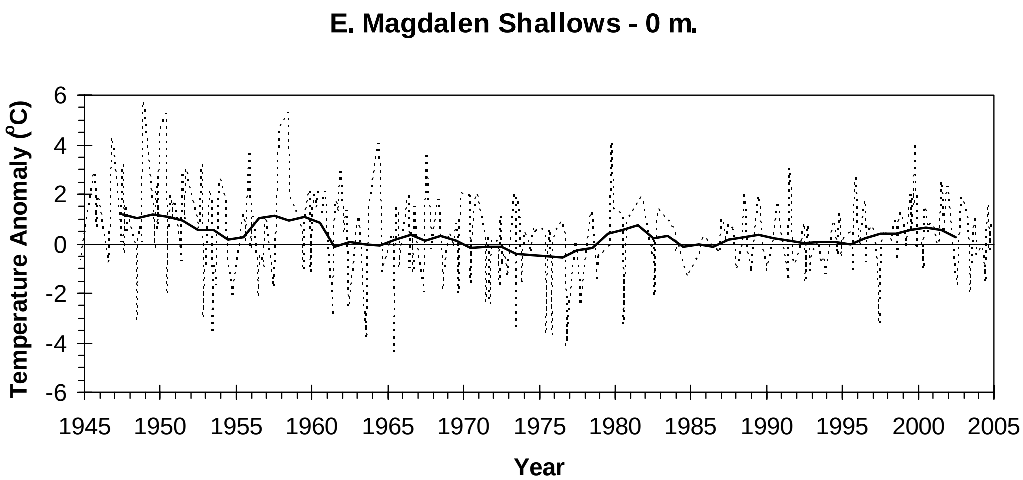
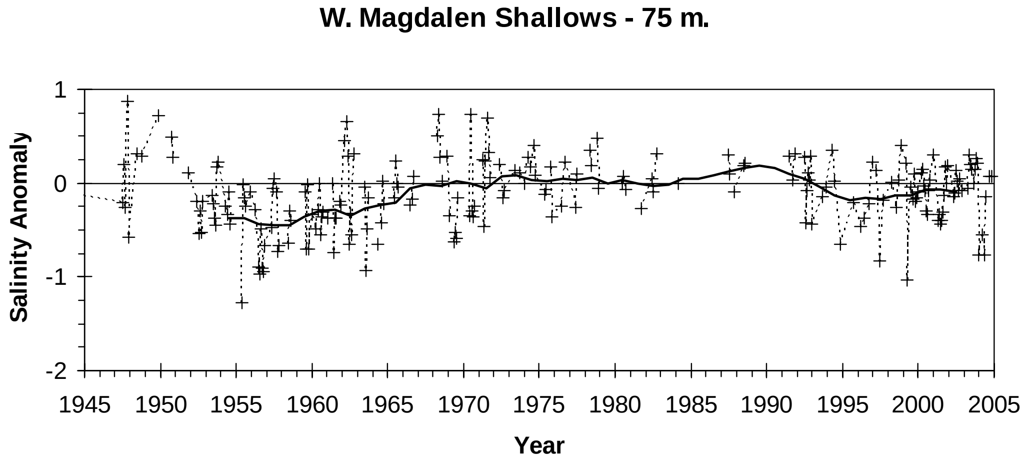


Fig. 25. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface temperature for the western (top panel) and eastern (bottom panel) Magdalen Shallows.



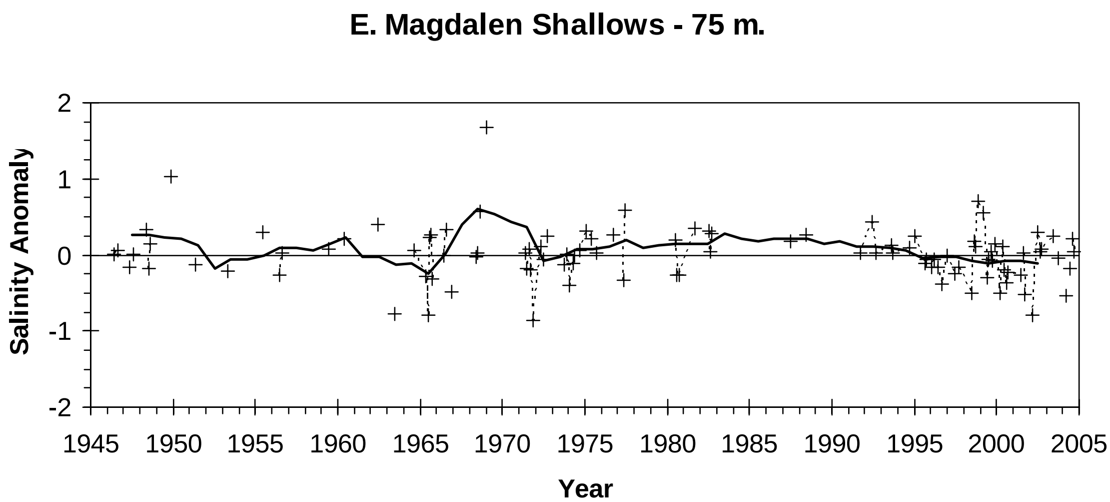


Fig. 26. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of salinity at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

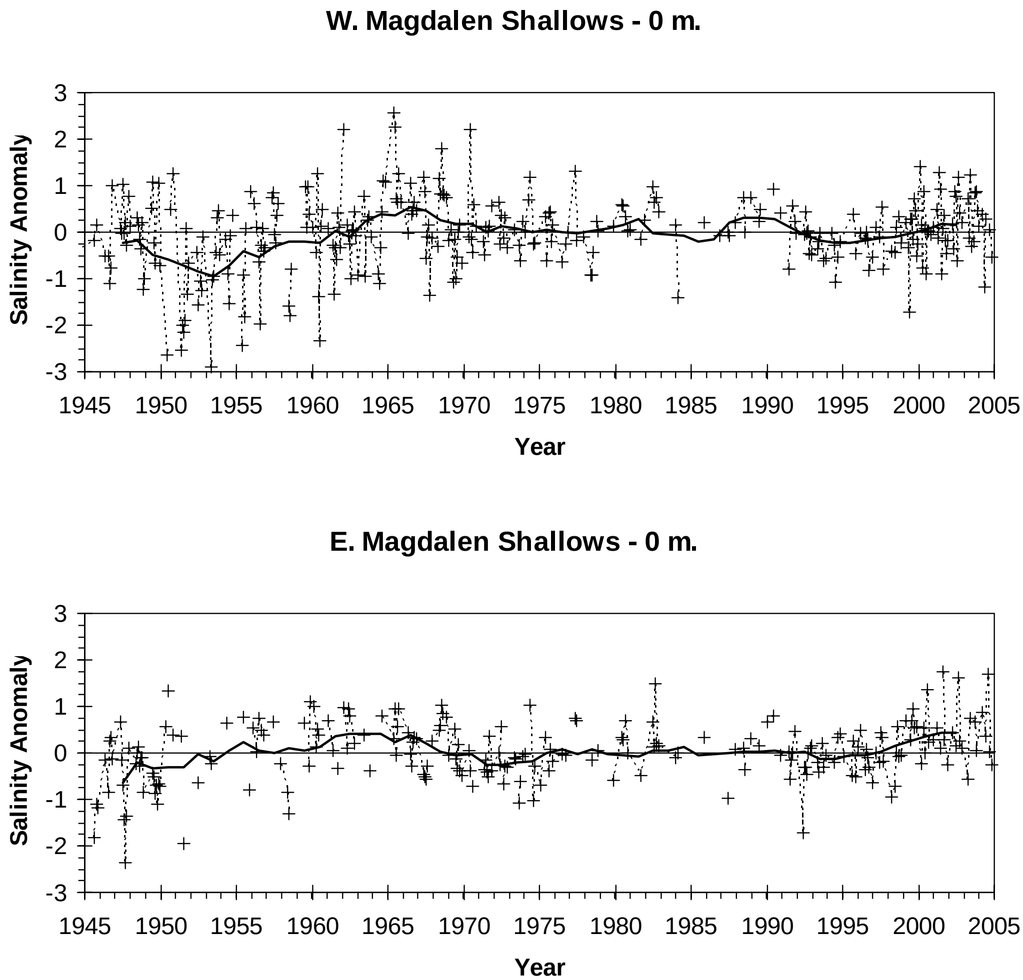


Fig. 27. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface salinity for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

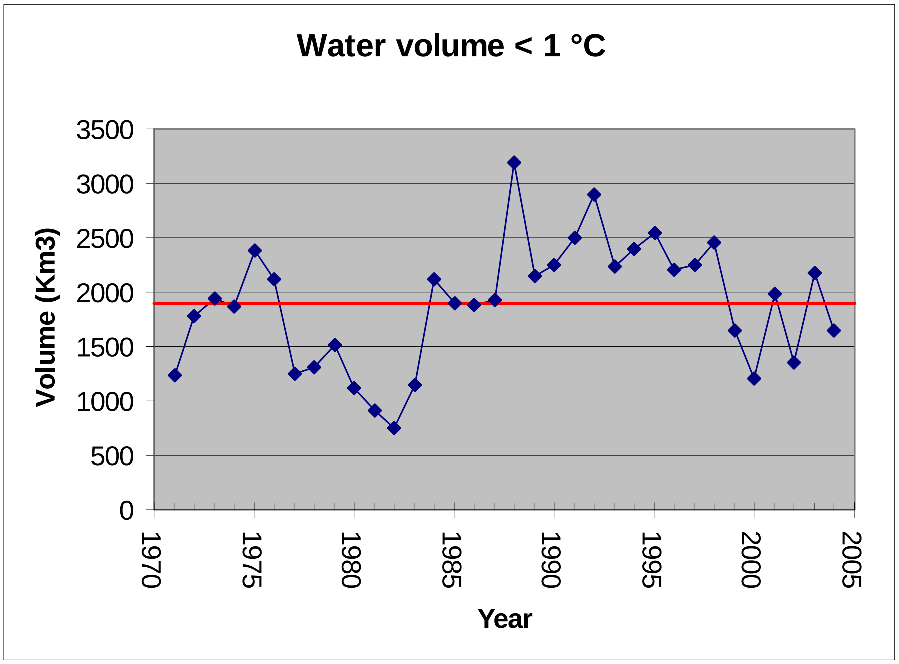


Fig. 28. Volume of the Cold Intermediate Layer in September for the Southern Gulf of St. Lawrence. The red line is the 1971-2000 long term average.