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Physical Environmental Conditions in the southern Gulf of St. Lawrence during 2000

Conditions du milieu physique dans le sud du golfe du Saint-Laurent au cours de l'année 2000

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Abstract

Physical environmental conditions in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2000 were examined from air temperature, sea ice and oceanographic data. Air temperatures over the southern Gulf were above normal through most of 2000, although they declined relative to 1999. The latter, however, was the warmest year on records that span back over 125 years. The warm air temperatures led to a generally light ice year. Of special note was the early disappearance of ice leading to a shorter duration of sea-ice on the Magdalen Shallows. Temperatures throughout the Shallows, in both the bottom and surface were generally warmer-than-normal. This parallels the warming of the cold intermediate waters in the Gulf during 2000. It was the first year since the mid-1980s that the CIL waters were warmer than the long-term average. It also extends the warming trend of the last several years and is well above the cold conditions experienced from 1985 to the late 1990s. The exception was the western region of the Shallows where bottom temperatures tended to be near to or below the long-term mean.

Resumé

On a examiné les conditions du milieu physique dans le sud du golfe du Saint-Laurent (petits fonds des Îles de la Madeleine) au cours de l’année 2000 à partir de données sur la température de l’air, de données sur la glace de mer et de données océanographiques. Les températures de l’air dans le sud du golfe ont été supérieures à la normale durant presque toute l’année 2000, bien qu’elles aient été inférieures à celles de 1999, année qui a toutefois été la plus chaude depuis que les données ont commencé à être consignées il y a 125 ans. À cause des chaudes températures de l’air, il y a eu généralement peu de glace. Il faut noter tout particulièrement la fonte hâtive de la glace, ce qui a eu pour effet d’écourter la période pendant laquelle il y avait de la glace sur les petits fonds des Îles de la Madeleine. Les températures en profondeur et en surface sur l’ensemble des petits fonds ont été généralement supérieures à la normale. Le phénomène se passe en même temps que le réchauffement des eaux intermédiaires froides observé dans le golfe au cours de l’année 2000. Pour la première fois depuis le milieu des années 1980, les eaux intermédiaires froides ont été plus chaudes que la moyenne à long terme. La tendance au réchauffement des dernières années se poursuit donc, et les températures enregistrées ont été bien plus élevées que les températures froides observées entre 1985 et la fin des années 1990. La partie ouest des petits fonds fait toutefois exception avec des températures en profondeur qui ont été généralement proches de la moyenne à long terme ou inférieures à celle-ci.

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 2000 are described and comparisons are made to conditions in 1999 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 Chatham, New Brunswick (Fig. 1). Data for 2000 from these sites were obtained from the Environment Canada website and pre-2000 data from the climate indices database at the Bedford Institute of Oceanography (BIO).

Sea-ice data for 2000 covering the entire 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 the 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 for the Gulf of St. Lawrence for the years 1963 to present. From these, we have obtained estimates of the date of first presence of sea ice, last presence and duration of ice during the winter for 2000.

Extensive geographic coverage of surface and near-bottom temperatures during 2000 for the southern Gulf of St. Lawrence was available from three surveys. The mackerel survey was conducted in June (Fig. 2a), the annual snow crab survey during August-September (Fig. 2b) and the annual groundfish survey in September (Fig. 2c). Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the mackerel and groundfish surveys. A total of 57 CTD stations were taken on or adjacent to the Magdalen Shallows during the mackerel survey and 198 stations on the groundfish survey. The snow crab surveys obtained near-bottom temperatures with a thermistor recorder attached to the trawl at 274 stations. Other temperature and salinity data from the southern Gulf in 2000 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive, and were derived from research surveys and ships-of-opportunity. Pre-2000 data were taken from the historical hydrographic database maintained at the 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 (1961-1990, where possible) similar to that used by the meteorologists and adopted for use with oceanographic data by the DFO's Fisheries Oceanography Committee and the Scientific Council of the North Atlantic Fisheries Organization (NAFO).

The surface and near-bottom temperatures from data collected during all of the surveys were interpolated onto a specified 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 no large errors occurred as a result of this assumption. The maximum depth in the grid for the slope water area off the Scotian Shelf was taken as 1000 m. The temperature grid for the Gulf of St. Lawrence was 0.1° x 0.1° latitude-longitude. 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), 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 estimations using all available data for the years 1961-1990 in the historical temperature, salinity database at the BIO. Temperature anomalies were derived by subtracting these climatological means from the 2000 values. A negative anomaly indicates that the 2000 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 1999 optimally-estimated temperatures from the 2000 estimates. A negative value indicates that 2000 was cooler than 1999, 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 (1971-2000). 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 amount of bottom covered by water of <0ºC and <1ºC.

In addition, monthly mean temperature profiles for 2000 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 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 warmer than their long-term average in 11 of the 12 months of 2000 (Fig. 3). Warmer-than-normal air temperatures also were observed at Charlottetown and Chatham, although they had more months with below average values (3 and 2 months, respectively). The annual means were above normal at all three sites (Magdalen Islands, anomaly of 1.4ºC; Chatham, 1.0ºC; Charlottetown, 0.7ºC). 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 1961-90 average. Since the 1950s, there has been a tendency towards warmer than average values with oscillations of about a 15-year period. Recent temperatures have been well above normal. Indeed, 1999 was the highest temperature on record at all three sites.

Sea-Ice

The location of the ice edge within the Gulf of St. Lawrence at various times during the winter season is shown in Fig. 6. These represent snap shots and it must be remembered that the ice edge can vary rapidly over short periods of time. At the end of December light to moderate winds and near normal air temperatures in the latter half of the month resulted in near normal ice conditions. Ice was located in the southern Gulf of St. Lawrence along the coasts of Nova Scotia, New Brunswick, the Gaspe Peninsula and the north shore of Prince Edward Island. By mid-January the ice coverage and ice thickness were below normal due to warmer-than-usual air temperatures over the region. Near normal temperatures in the latter half of the month resulted in increased ice coverage over the Magdalen Shallows on 1 February but still remained below normal. Ice coverage continued to spread through February, eventually covering most of the Shallows. By 1 March the only area of the Shallows with open waters was the coastal region of northern New Brunswick and northern Prince Edward Island. This open water was due to offshore winds and was only temporary. Warmer-than-normal temperatures during March led to rapid ice melt over the Gulf in the second half of the month. Only small patches of ice were found on the Shallows by the 1 April and all of the ice disappeared by the middle of April.

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 January, ice had covered all of the Shallows for at least some period of time. Subtracting the long-term (1961-90) mean, indicates that the time of first ice was near normal (within <10 d) over the Shallows (Fig. 8). The last presence of ice was near the end of March and beginning of April (Fig. 7), approximately 10-20 days earlier than normal (Fig. 8). 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. On the Shallows the duration varied from a high of over 100 days around Miscou to 50 days along the edge adjacent to the Laurentian Channel (Fig. 9). This resulted in durations that were 10-30 days less than normal.

Hydrographic Conditions

Bottom Temperatures

The mackerel survey in June 2000 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 advection of cold Labrador Shelf water through the Strait of Belle Isle (Petrie et al., 1988).

Relative to the long-term (1961-90) mean, the bottom temperatures in June 2000 were slightly colder through much of the western region of the Shallows and off Cape Breton (Fig. 10). The largest negative anomalies (< -1°C) were located north of PEI and in Chaleur Bay. In contrast, over much of the eastern Shallows, temperatures were warmer-than-normal. Relative to the mackerel survey in 1999, temperatures had cooled over most of the bottom with the exception of the area near the Laurentian Channel (Fig. 11).

The longest running survey on the Magdalen Shallows is the groundfish survey (1971-present). Bottom temperatures in 2000 ranged from <0°C to over 10°C (Fig. 12). Most of the Shallows (50-80 m) were covered by temperatures <1°C. The coldest waters (<0°C) were limited to a region to the north of PEI. The decrease from June (mackerel survey) to September (groundfish survey) of 2000 in the amount near-bottom waters <0°C is typical.

Similar to June, September near-bottom temperature anomalies on the western half of the Shallows were principally near to or below normal, except close to shore (Fig. 12). The highest negative anomalies were located to the north of western PEI and in Chaleur Bay. On the eastern half of the Shallows, temperatures were generally above normal with the highest values around the Magdalen Islands and off eastern PEI (above 3°C). These latter must be viewed with caution, however, since the largest uncertainties in the 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 fictitious data in regions of strong horizontal temperature gradients.

Relative to 1999, bottom temperatures during the 2000 groundfish survey were warmer in regions to the east of the Gaspe, around the Magdalen Islands and off eastern PEI (Fig. 13). In contrast, an almost equal area of the bottom appeared colder than in 1999, principally in the central Shallows, off Cape Breton and in Chaleur Bay. This differs from the warming observed throughout most of the Shallows between 1998 to 1999.

From the gridded temperature data, time series of the area of bottom covered by each 1Cº were estimated. We have plotted the time series of the area of the bottom covered by <0ºC and <1Cº following Swain (1993) who first used this index. In 2000, there was an increase in area covered by <0ºC but a decline in the area covered by temperatures <1ºC relative to 1999 (Fig. 14). In both instances the changes were small. Both were below their long-term average.

The spatial pattern of the bottom temperatures from the snow crab survey in August-September is similar to that from the groundfish survey (Fig. 15). The major difference is the warmer values in most of the nearshore regions in the groundfish survey, presumably due to the increased influence of the seasonal deepening and warming of the upper mixed layer. In the deeper regions (>~50 m), the temperature and temperature patterns are similar, although not identical. For example, there is slightly more <0°C water recorded in the groundfish survey. In spite of these differences, over 70% of the gridded temperatures from the two surveys differ by <0.5°C for the same grid point and 94% were within 1°C. Possible causes of these differences besides seasonal warming in the shallow regions may be differences in instrument accuracy (the CTD being more accurate than the thermistor recorder), a relative rapid point measurement (CTD) versus an average over a trawl distance (snow crab survey), and the difference in depth of the measurement (the thermistor is on bottom while the CTD will be a few to several m above the bottom).

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 13°C off PEI and New Brunswick (Fig. 16). Temperatures generally increased shoreward. The 2000 surface values were above their long-term means throughout the Shallows, except off northern Cape Breton. The highest anomalies appeared off Chaleur Bay. Temperatures declined relative to 1999 by several degrees, however (Fig. 17). This was because of the very warm temperatures in 1999.

The surface temperatures from the groundfish survey in September ranged from 12°C off Gaspe to over 18°C in eastern Northumberland Strait (Fig. 18). As in June, the surface waters over most of the region were warmer their long-term means. The exception was north of PEI and some of the near shore regions (Fig. 18). There had been a substantial decline in the surface temperatures in the outer reaches of the Shallows between the groundfish surveys from 1999 to 2000 but north of PEI temperatures actually increased (Fig. 19).

Monthly Mean Temperatures and Salinities

Vertical profiles of the monthly mean temperature and salinity anomalies for the southern Gulf were calculated from all available data. To determine if there were possible 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. 20 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 over 100 stations. The long-term (1961-90) means for each area was calculated and then subtracted to obtain an anomaly. In addition to the vertical profiles, time series of temperature and salinity at 75 m are presented. This depth is considered representative of the near-bottom within both regions. Because of the possible limited amount of data from which the averages were made or the spatial variability in temperature within the regions, any one point or profile may not be truly representative of "average" conditions for the month. Interpretation of the anomalies therefore must be viewed with caution. While no significance should be placed on any individual monthly anomaly, persistent features are considered to be real.

Data for 2000 over the western Magdalen Shallows were available for 9 months between March and December, inclusive. The monthly anomaly profiles tend to show generally near to below-normal temperatures (up to -2°C) from 25 m to 75 m (Fig. 21). The three months, for which there were data at 100 m, all were above their long-term means although by <0.5ºC. In the upper 25 m, temperatures were typically above the long-term mean by upwards of 3ºC in July. Exceptions to the warm surface conditions were observed in March and May.

Although lower-than-average salinities were observed in the 25 to 75 m depth range in April and December, this depth range generally experienced saltier-than-normal (Fig. 22). They were within 0.4 of the long-term average with the exception of October when it reached over 1. In contrast to the general salty conditions in the deeper waters, the surface layers were fresher-than-normal, except in May.

On the eastern side of the Shallows, data were available in 5 months in 2000. Generally, temperatures were warmer-than-average throughout the water column with the largest anomalies in the upper 10-30 m (Fig. 23). At depths in the 50-100 m range, corresponding to the bottom depth over most of the Shallows, temperatures were up to 1ºC above their long-term average. These generally warm conditions on bottom contrast with the western side of the Shallows. Salinities on the eastern side tended to be fresher-than-normal in the surface layers and saltier-than-normal at 25 m and deeper (Fig. 24).

In addition to the anomaly profiles, time series of the monthly mean temperatures and salinities at 75 m and the surface were generated. 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. 25). 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 1990s exhibit the longest period of below average temperatures in the entire record. While the last couple of years have seen warming from these low temperatures, the eastern side of the Shallows experienced above normal temperatures in 2000 while the western side showed colder-than-normal conditions. The time series at the surface show much higher variability than at 75 m (Fig. 26). 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. 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 fresher-than-normal salinities near bottom on both sides of the Shallows (Fig. 27). In the surface, salinities through the late 1990s appear also to be fresher-than-normal (Fig. 28). An exception was the eastern Shallows in 1999 and 2000 where they were saltier-than-normal.

CIL Core Temperature

Gilbert and Pettigrew (1997), in a study of the cold intermediate layer (CIL), produced a Gulf-wide index of the core temperature for mid-July based upon available observed data and the mean measured warming rate. This index has continued to be updated by Dr. D. Gilbert who kindly provided us with the data. During 2000, the CIL mid-summer core temperature was 0.15°C (representing an anomaly of 0.13°C), and was warmer than 1999 by 0.30 °C and 1998 by 0.86°C (Fig. 29). The 2000 value represents the first year since the early to mid-1980s that the core temperature was above its long-term average. Gilbert and Pettigrew (1997) found high correlations between the variability in the 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 were above normal throughout 1999 and 2000, which may explain in part the accompanying warmer temperatures of the CIL waters.

Summary

Physical environmental conditions in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2000 were examined from air temperature, sea ice and oceanographic data. Air temperatures over the southern Gulf were above normal through most of 2000, although they declined relative to 1999. The latter, however, was the warmest year in records that span back over 125 years. The warm air temperatures lead to a generally light ice year. Of special note was the early disappearance of ice leading to a shorter duration of sea-ice on the Magdalen Shallows. Temperatures throughout the Shallows, in both the bottom and surface were generally warmer-than-normal. This parallels the warming of the cold intermediate waters in the Gulf during 2000. It was the first year since the early to mid-1980s that the CIL waters were warmer than the long-term average. It also extends the warming trend of the last several years and is well above the cold conditions experienced from 1985 to the late 1990s. The exception was the western region of the Shallows where bottom temperatures tended to be near to or below the long-term mean.

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We acknowledge J. McRuer at BIO for providing the CTD data from the groundfish surveys and M. Moriyasu, M. Biron and R. Gautreau at GFC in Moncton for temperature data from the snow crab surveys. The mackerel survey data were collected by scientists at IML in Mont Joli, Quebec, headed by F. Gregoire. D. Gilbert at IML supplied the CIL core-temperatures. We extend a special thanks to the scientists, technicians and crew who collected all of these data.

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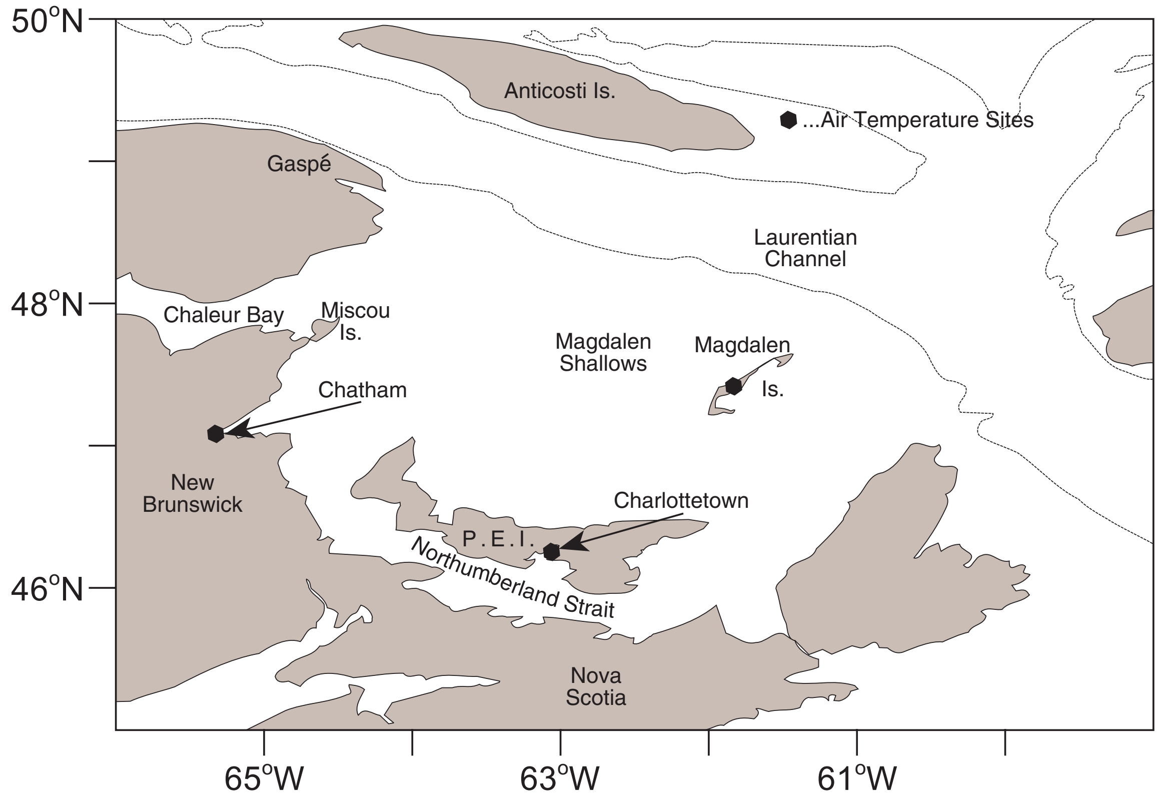


Fig. 1. Chart of the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text. Air temperature sites are also shown.

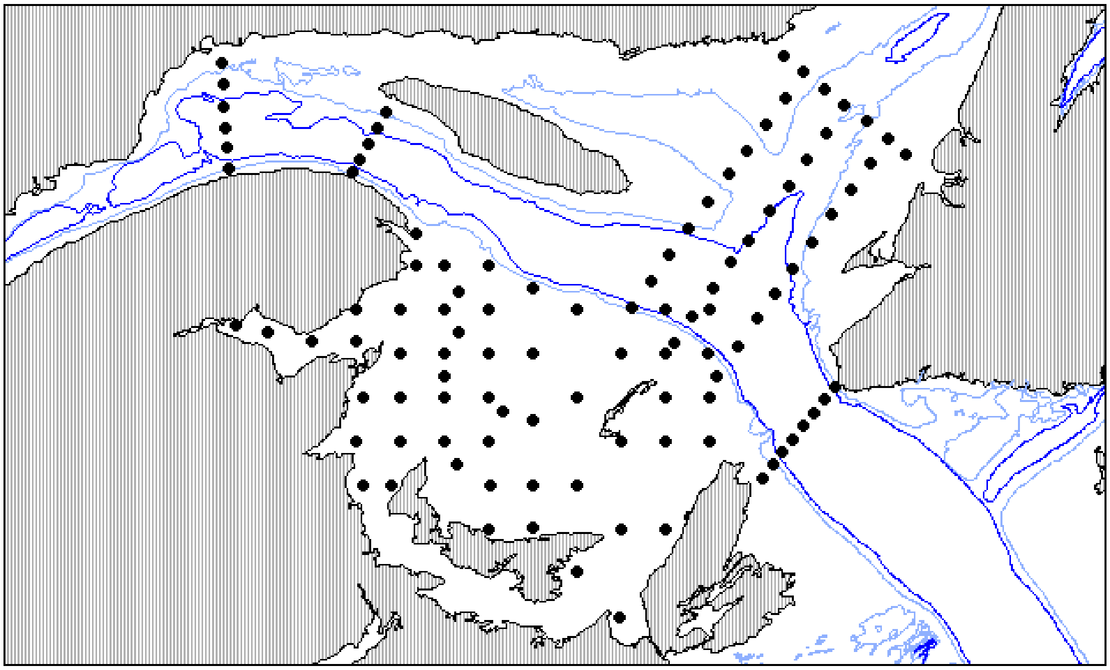


Fig. 2a. The location of the CTD temperature stations during the June 2000 mackerel survey.

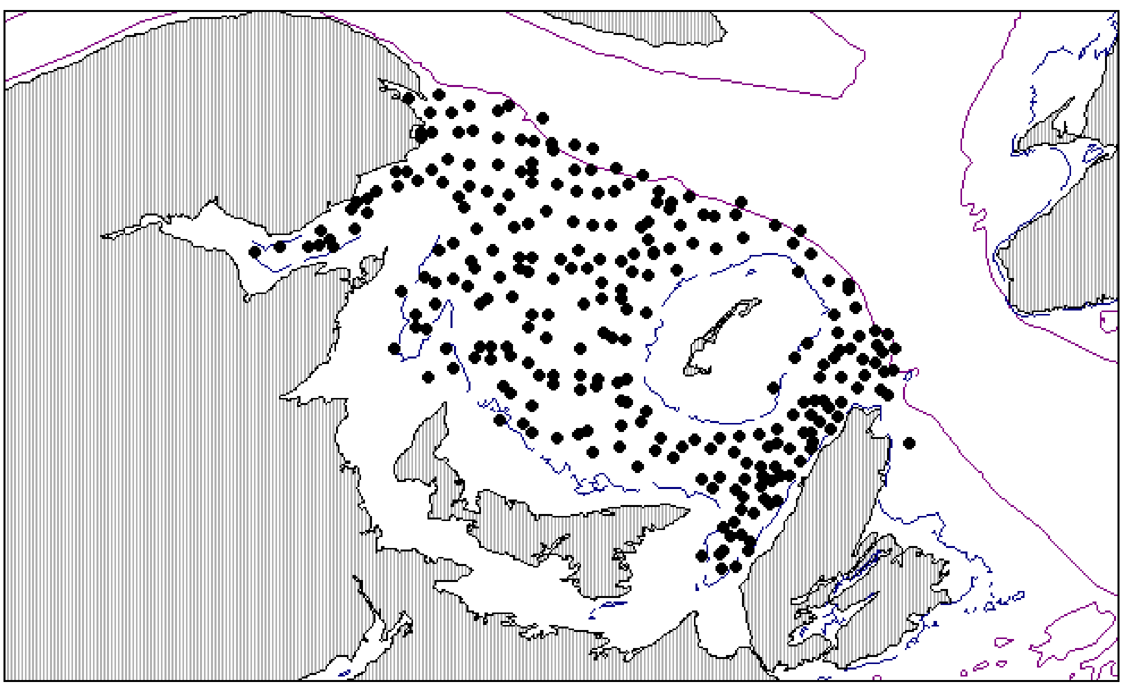


Fig. 2b. The location of the bottom temperature stations during the August-September 2000 snow crab survey.

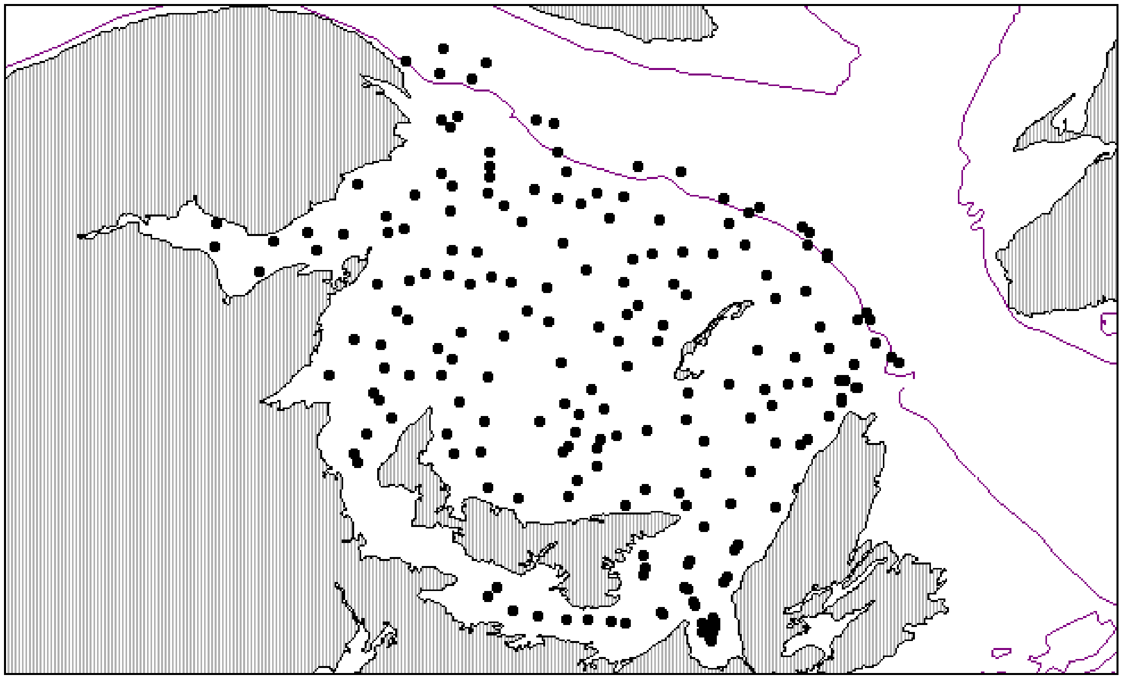


Fig. 2c. The location of the CTD stations during the September 2000 survey.

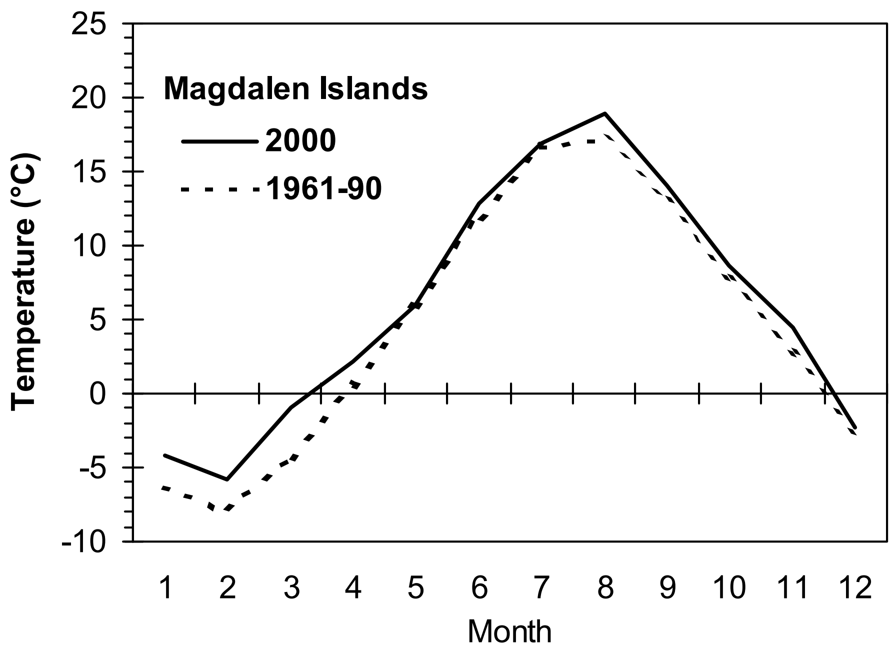


Fig. 3. The monthly mean air temperatures for the Magdalen Islands in 2000 and their long-term averages (1961-1990).

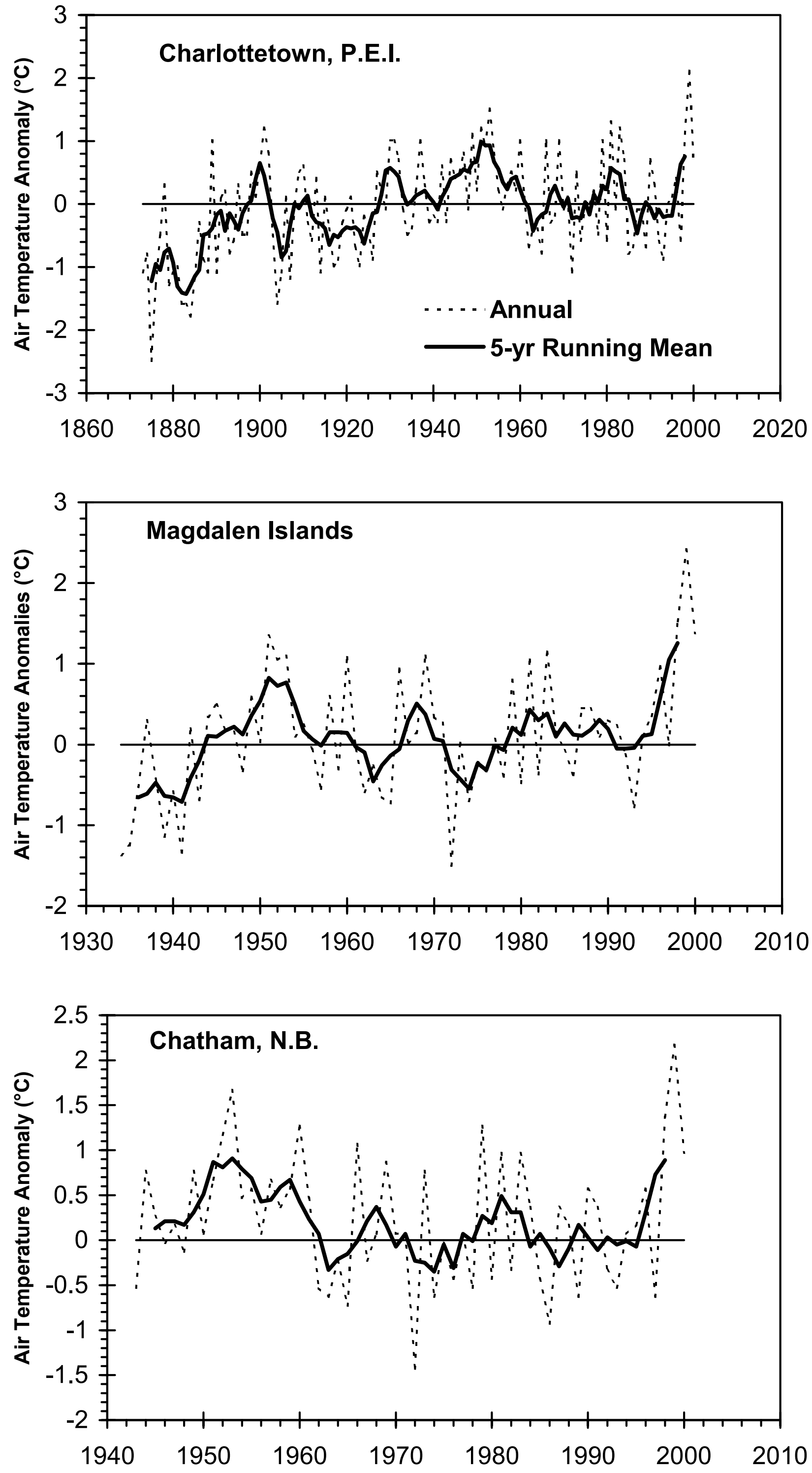


Fig. 4. Time series of the annual air temperatures (dashed) and their 5-year running means for Charlottetown, the Madgalen Islands and Chatham. Note the axis scales on all three diagrams are different.

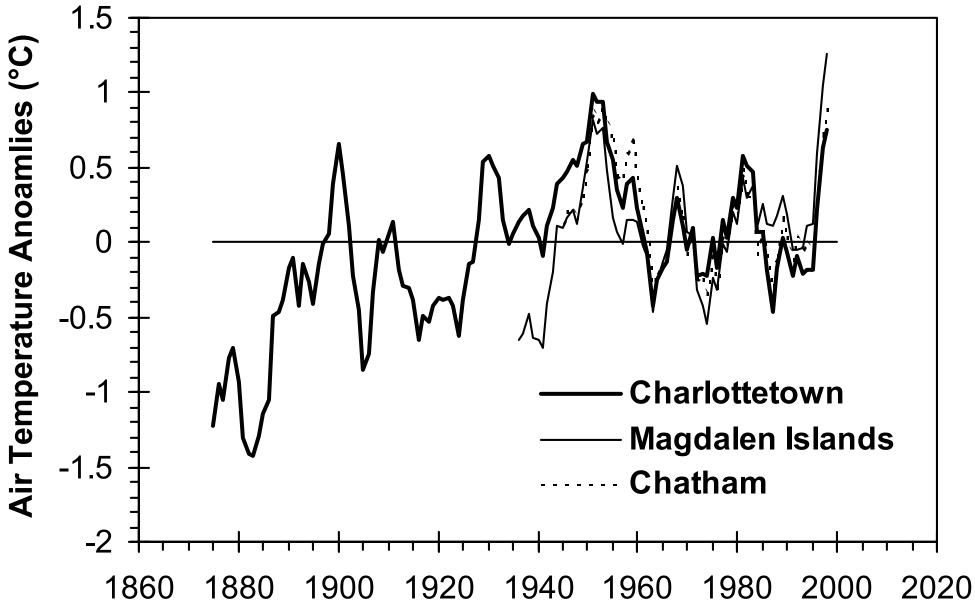


Fig. 5. The time series of the 5-year running means of air temperature anomalies at three sites in the southern Gulf of St. Lawrence.

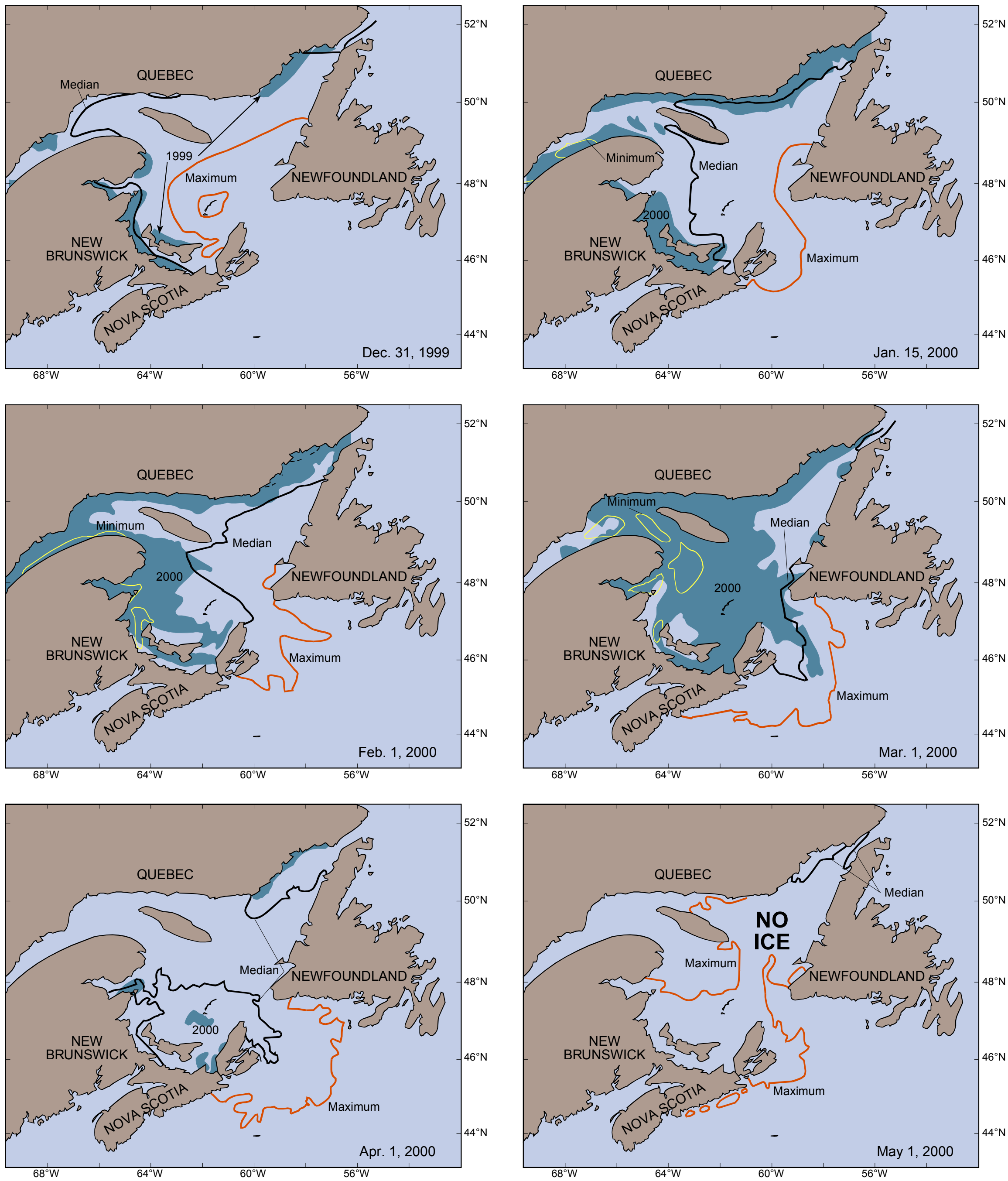


Fig. 6. The location of the ice (shaded area) between 31 December 1999 to 1 May 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

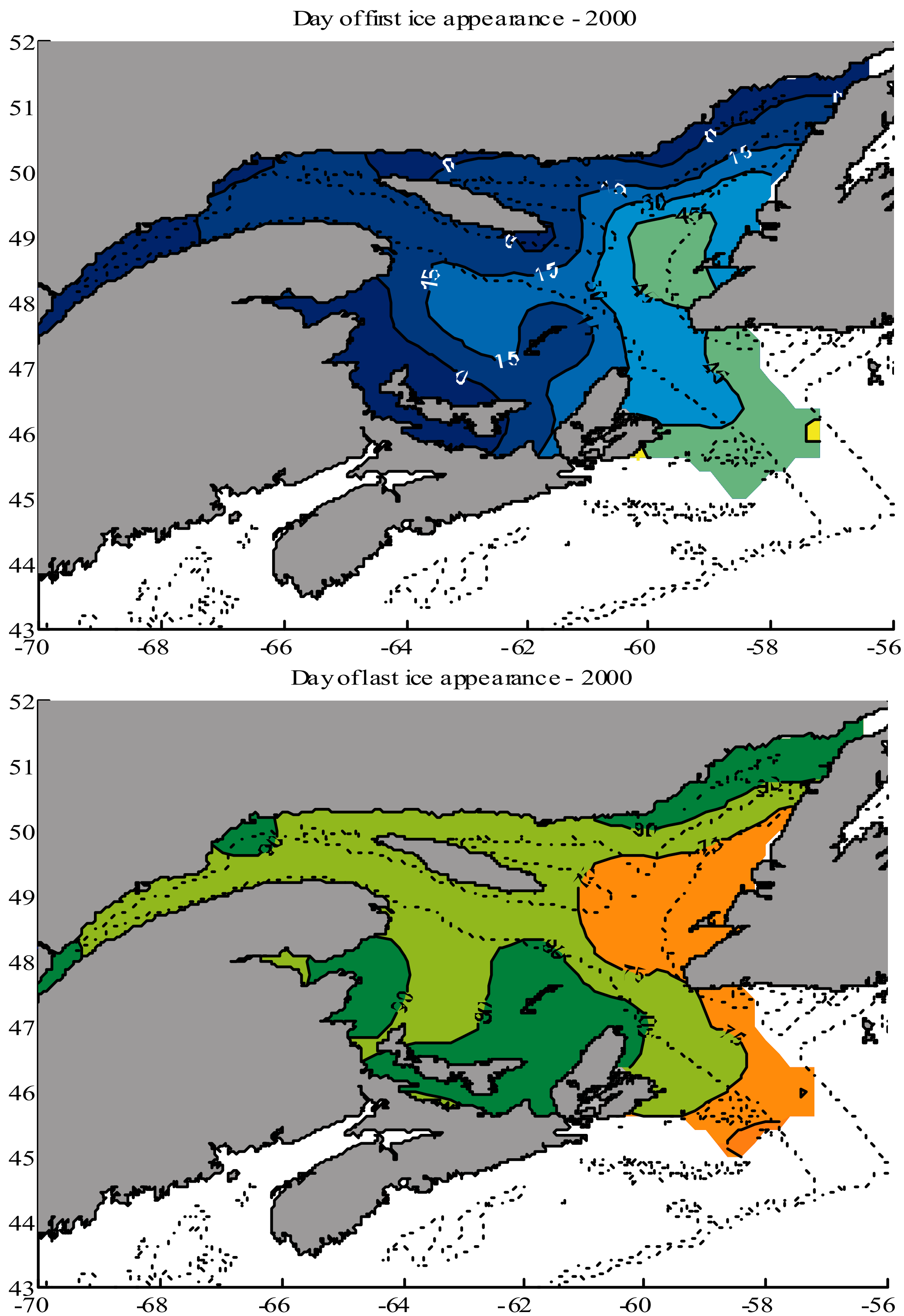


Fig. 7. The date of first (top panel) and last (bottom panel) presence of ice in days from the beginning of the year.

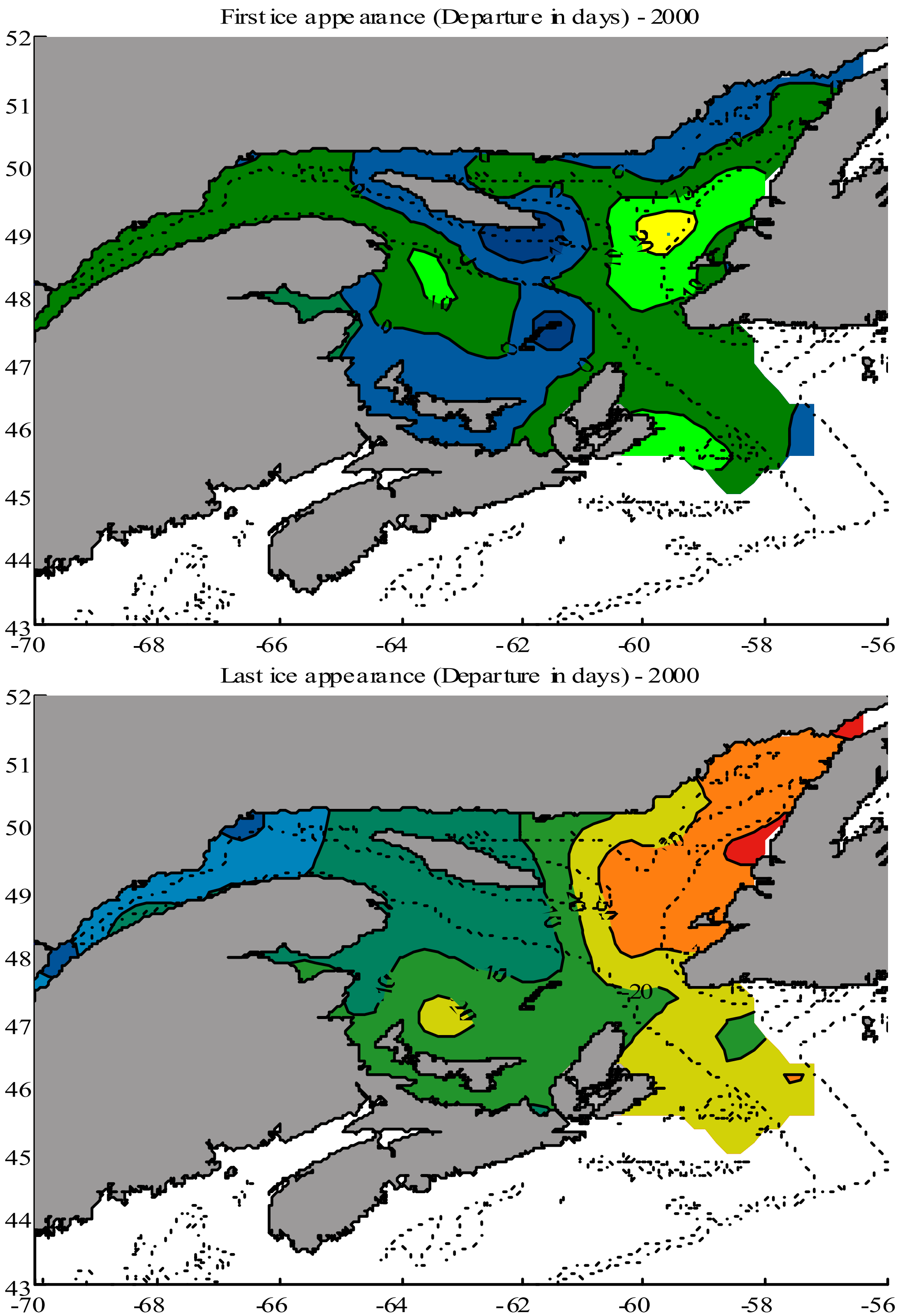


Fig. 8. The anomalies relative to 1961-90 average of the first (top panel) and last (bottom panel) presence of sea ice in days. The blue regions in the top panel indicate where ice appeared early and in the bottom panel when it disappeared late (negative anomalies).

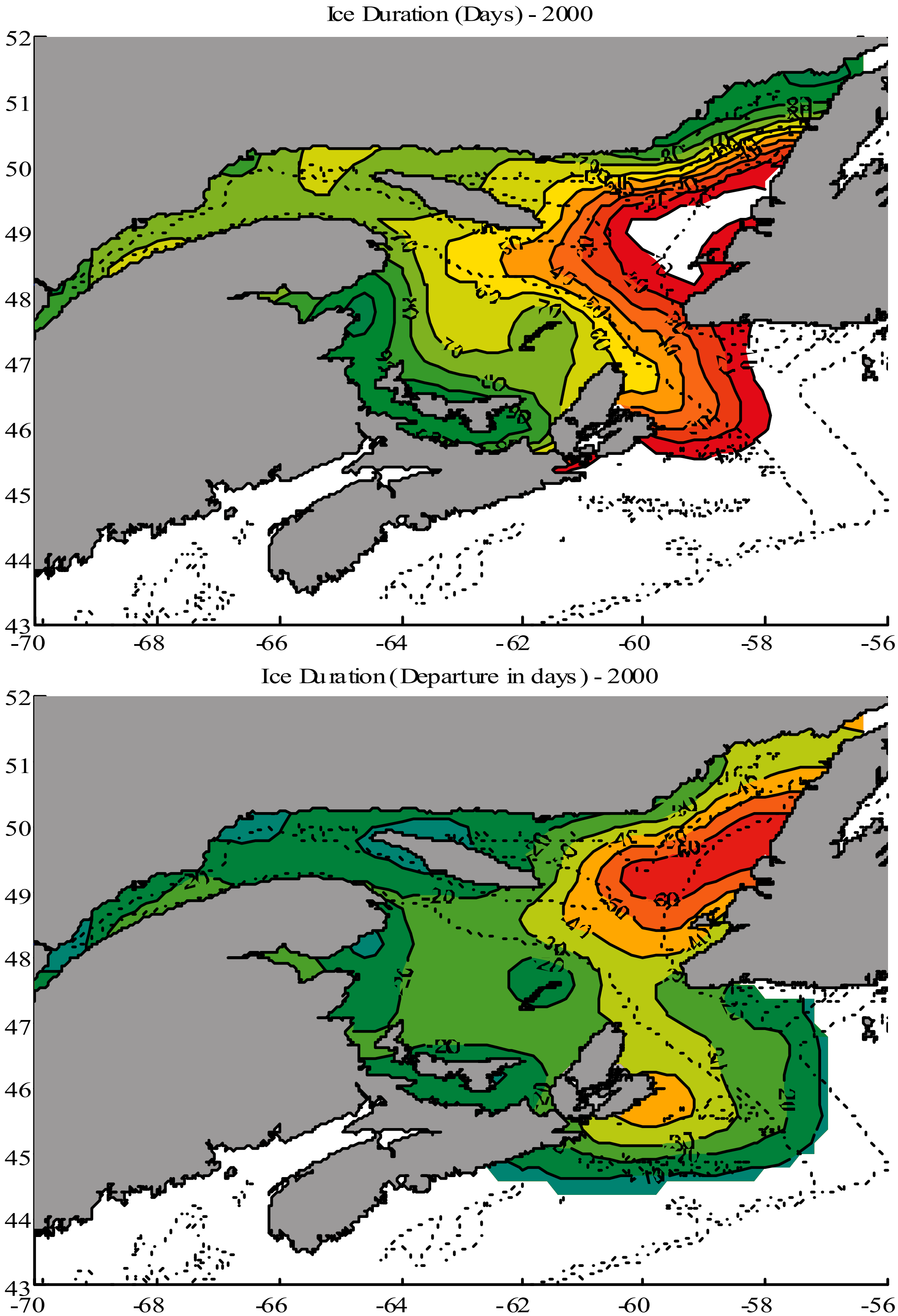


Fig. 9. The duration of sea-ice in days during 2000 (top panel) and their anomalies relative to 1961-90 average in days (bottom panel). Note that the ice duration in 2000 was less than average throughout the Gulf (negative anomalies).

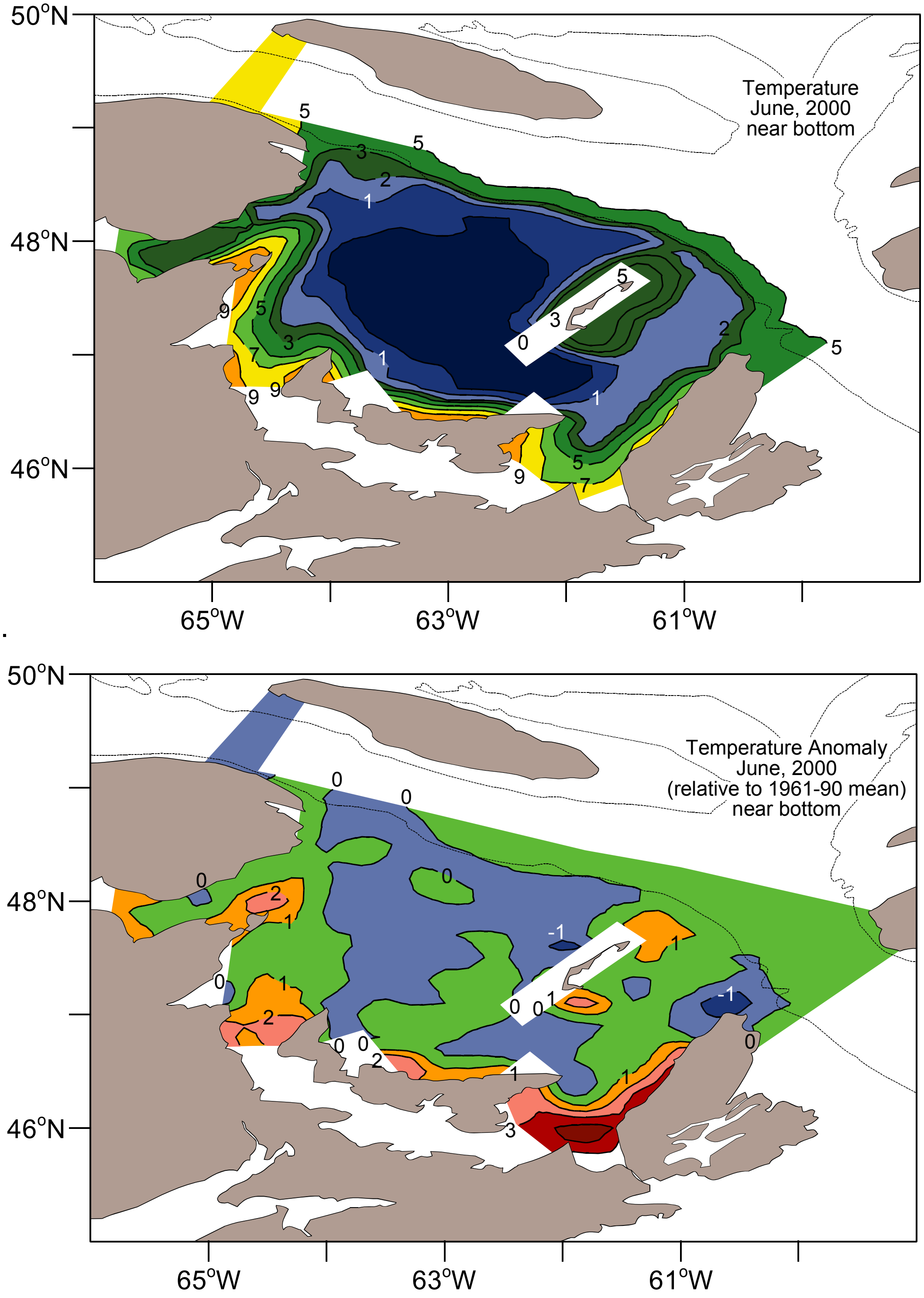


Fig. 10. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

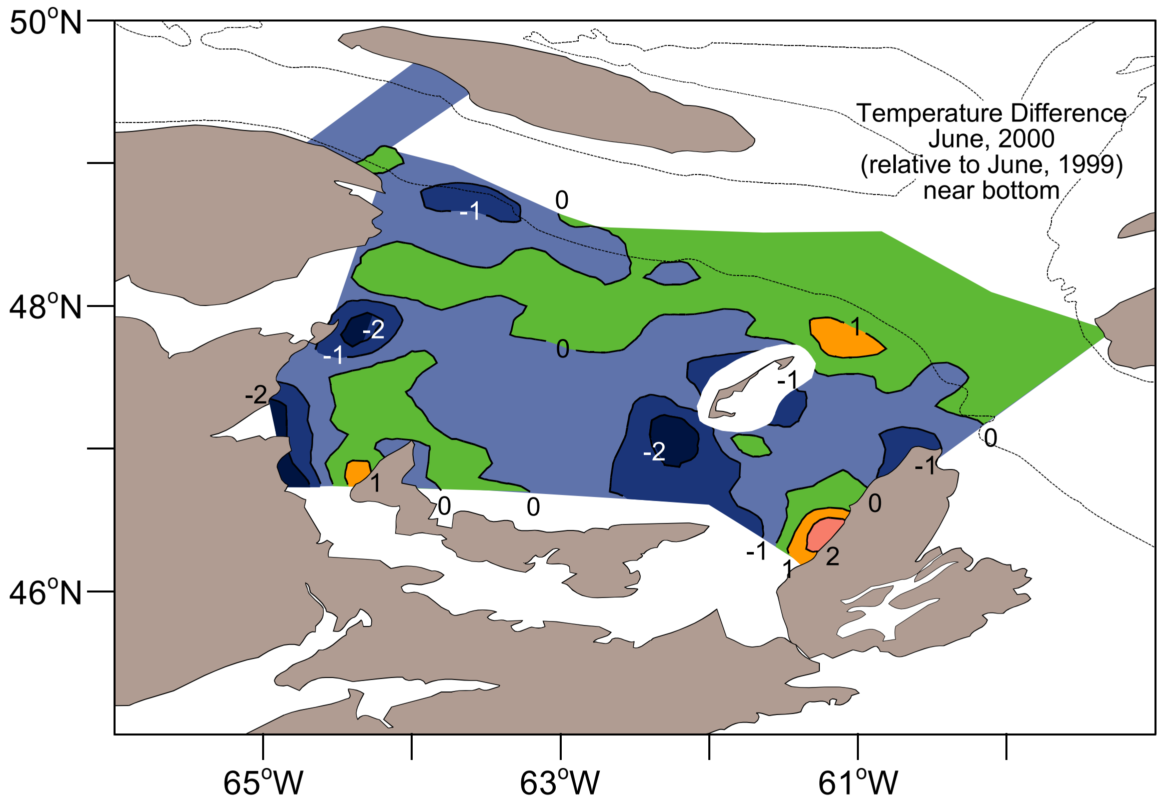


Fig. 11. The difference between the 2000 and 1999 near-bottom temperatures in the southern Gulf of St. Lawrence for the June mackerel survey. Positive values (green, orange and red) indicate temperatures in 2000 had warmed and negative values (blues) that they had cooled.

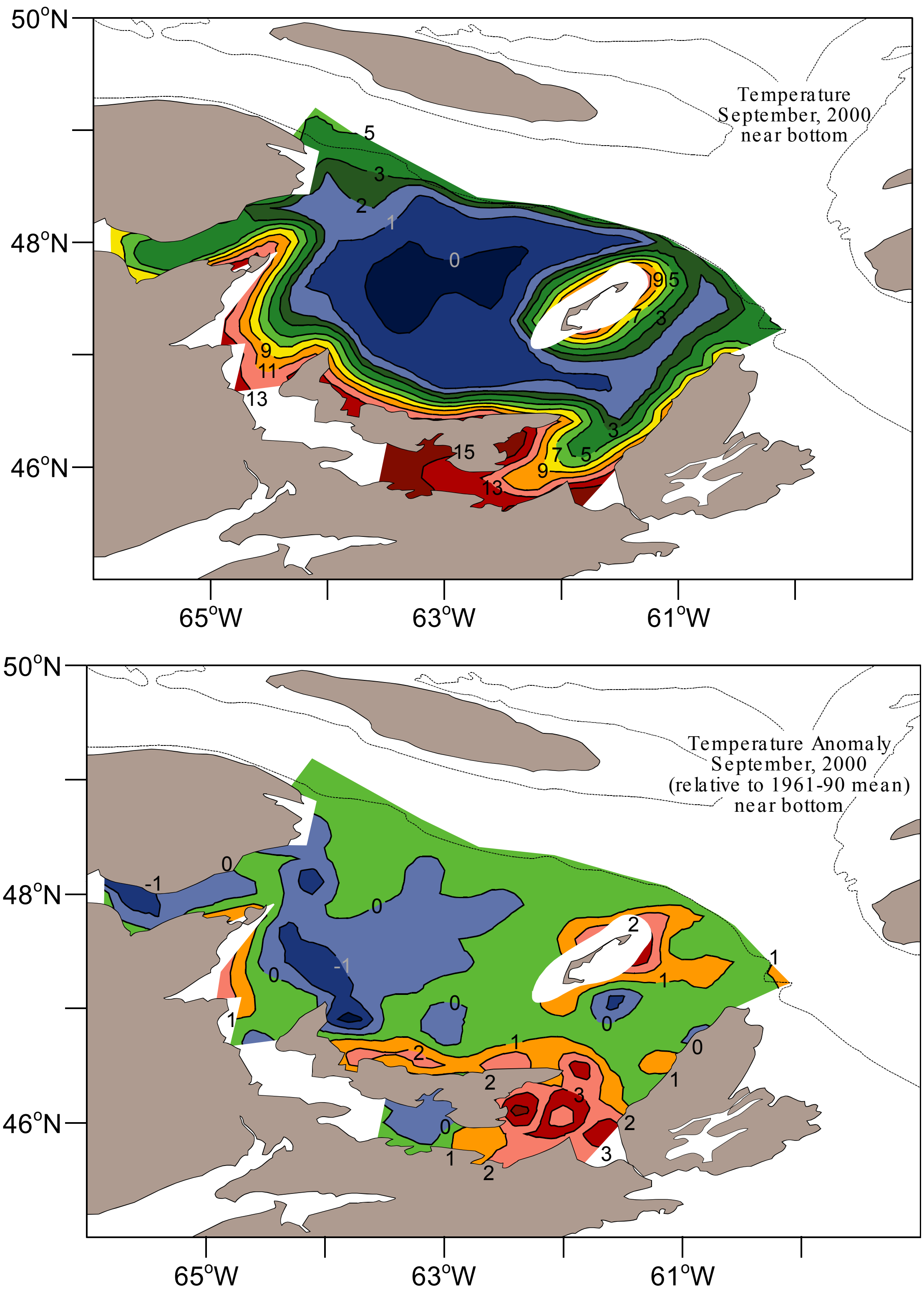


Fig. 12. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

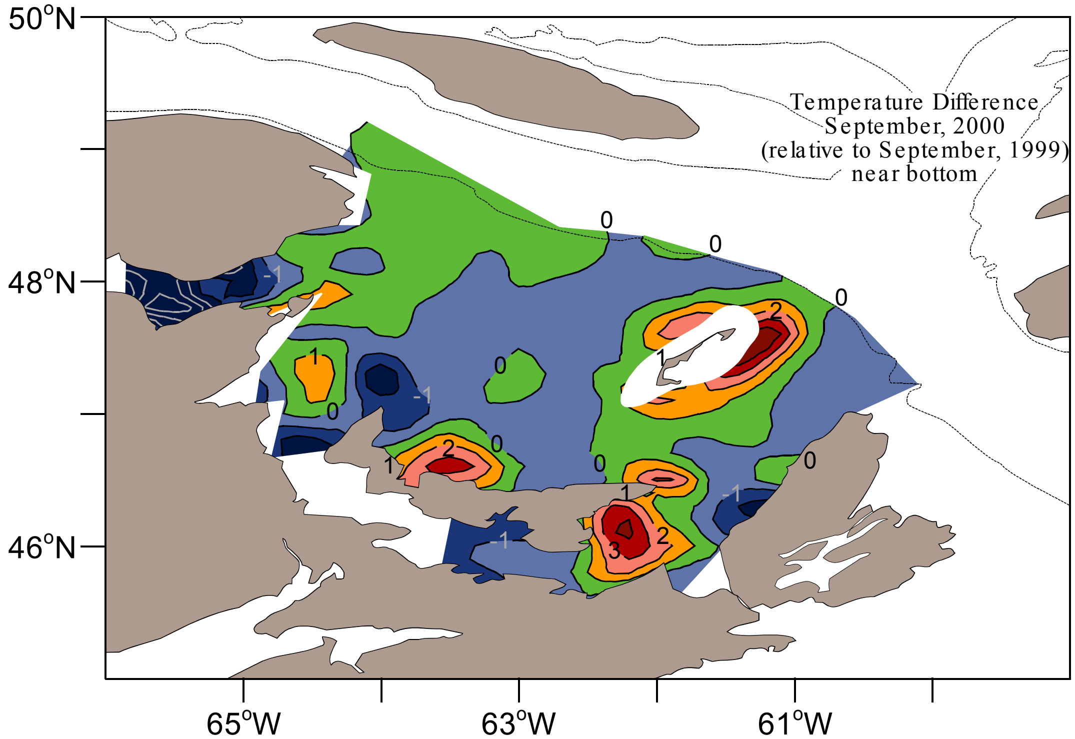


Fig. 13. The difference between the 2000 and 1999 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2000 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue.

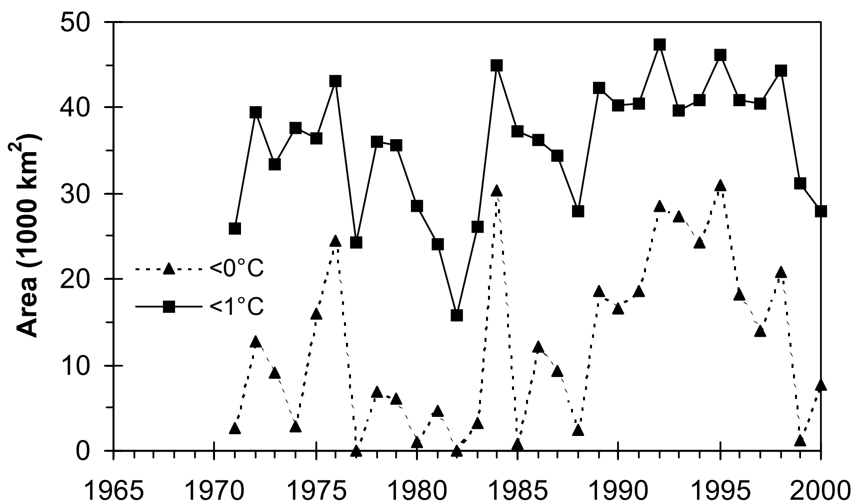


Fig. 14. Time series of the area of Magdalen Shallows covered by bottom temperatures < 0° and <1°C in September.

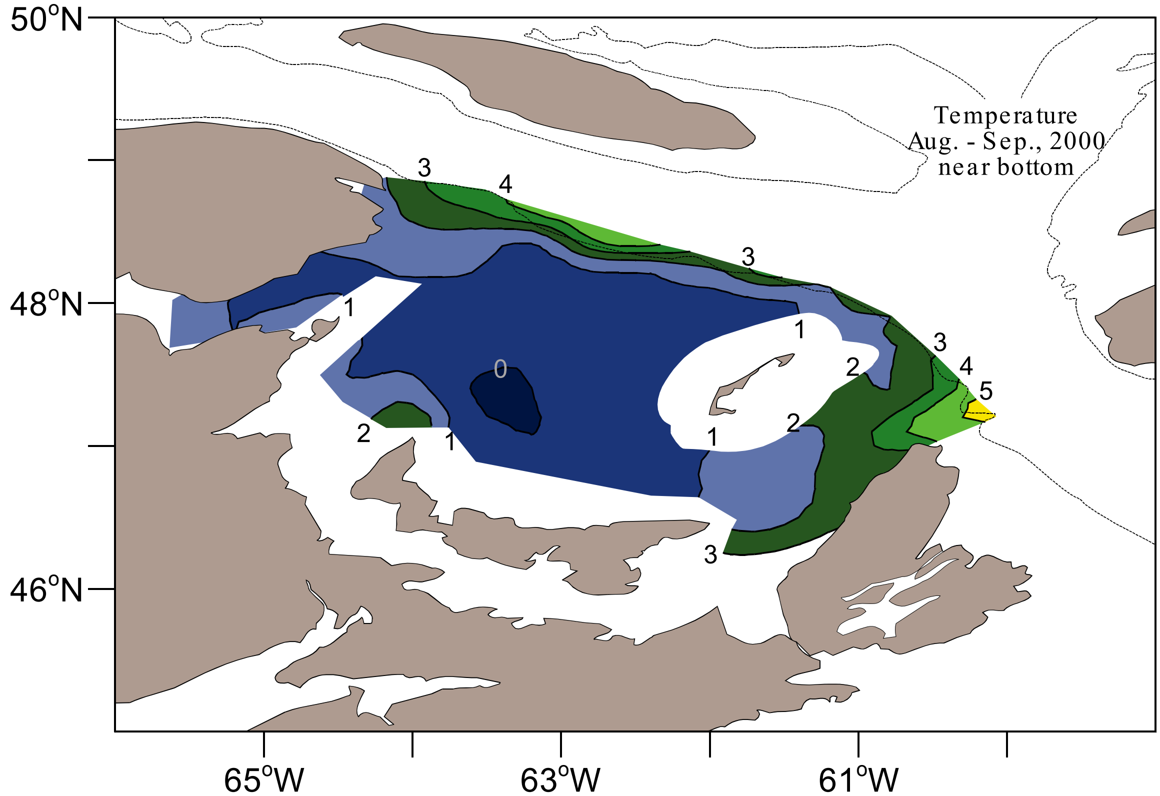


Fig. 15. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2000 August-September snow crab survey.

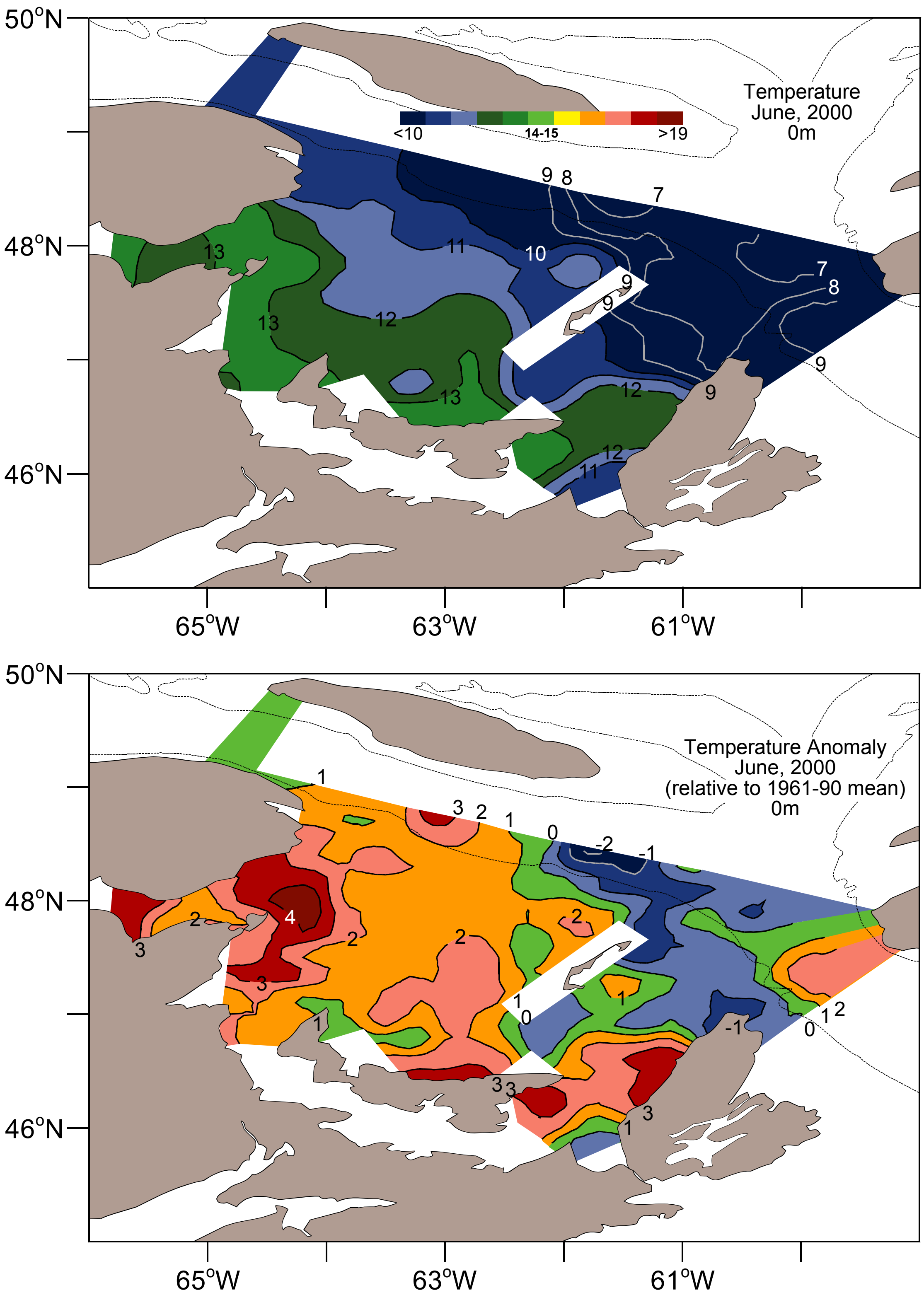


Fig. 16. Surface temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

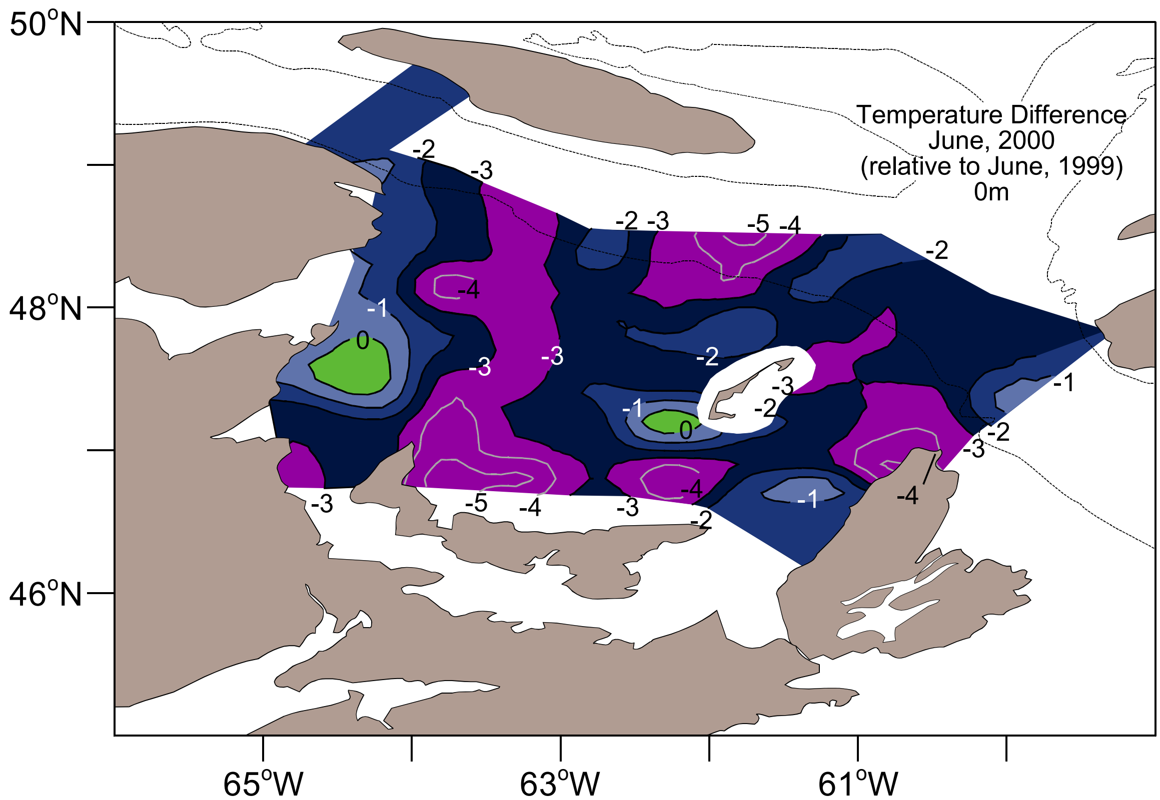


Fig. 17. The difference between the 2000 and 1999 surface temperatures in the southern Gulf of St. Lawrence during the June mackerel surveys. Positive values indicate temperatures in 2000 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue through violet.

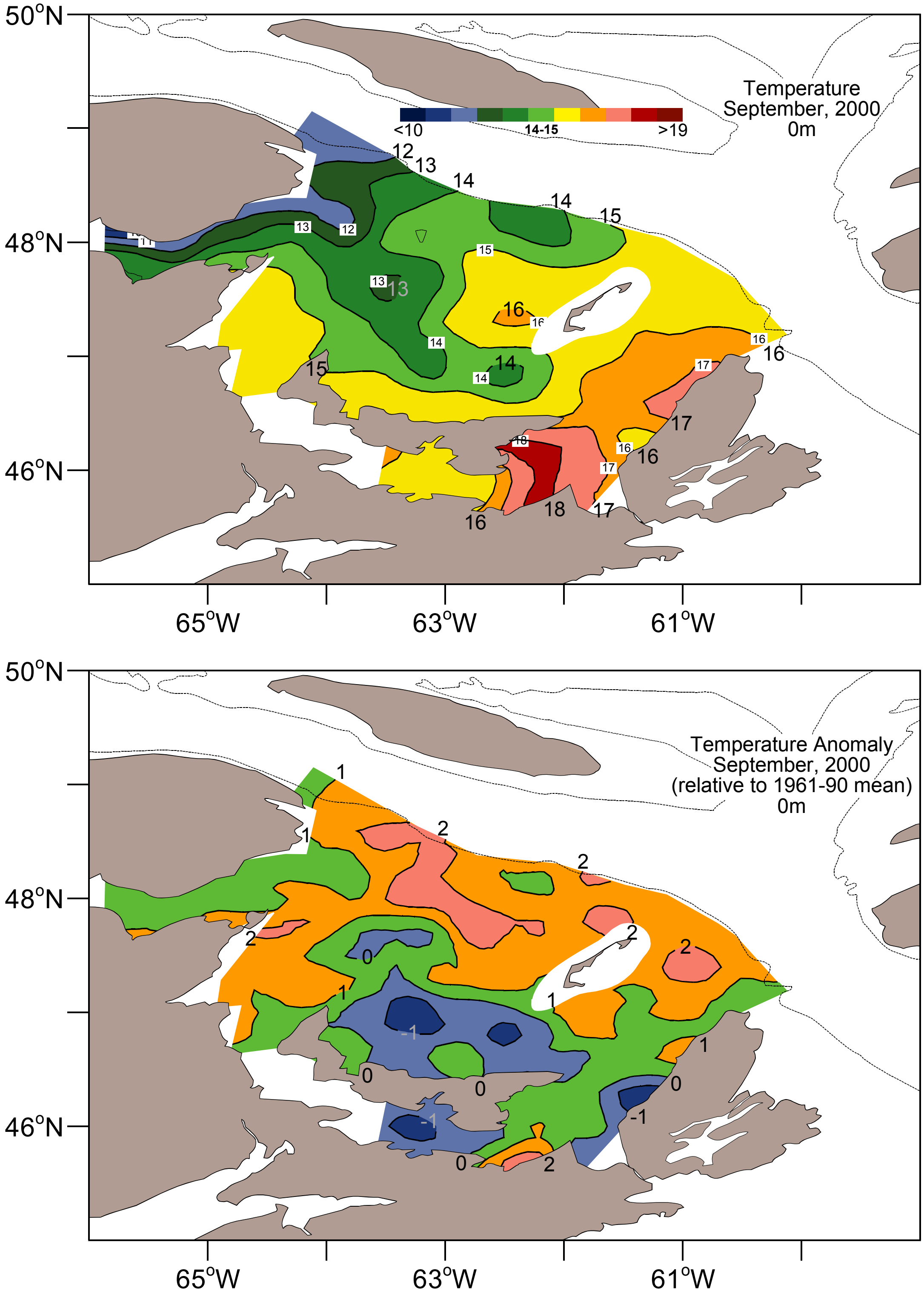


Fig. 18. Surface temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

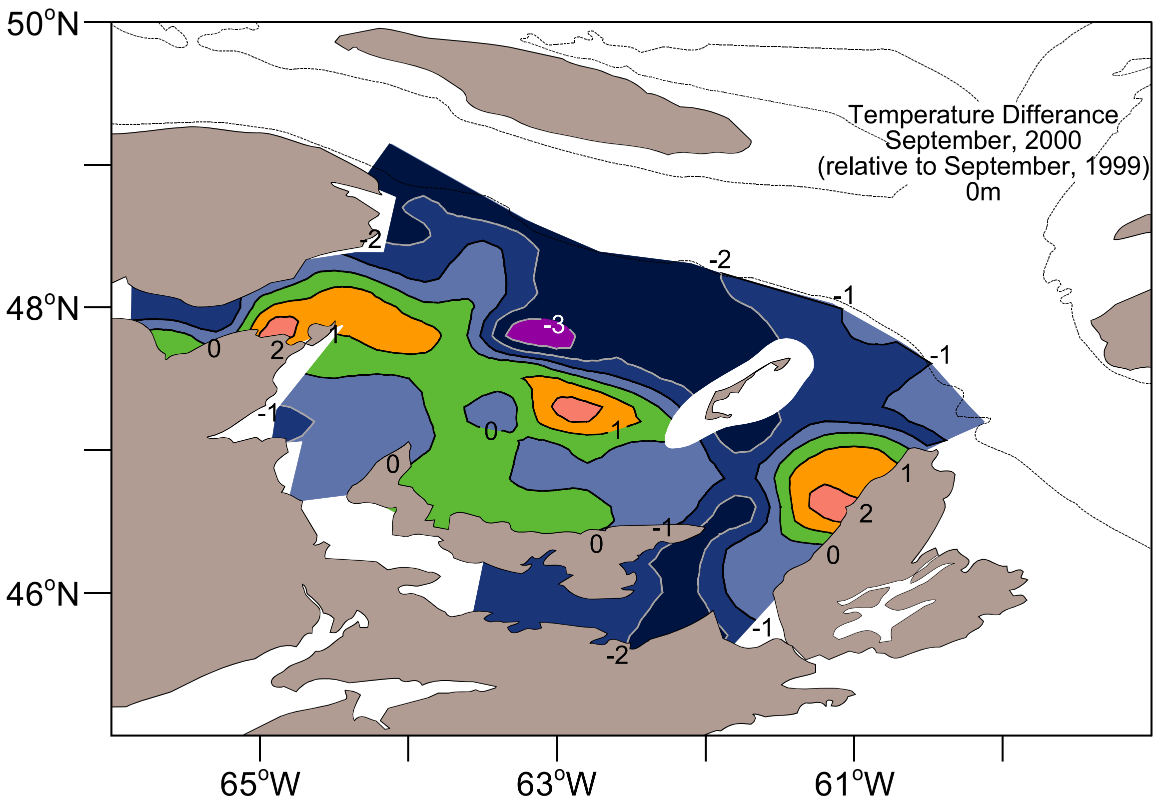


Fig. 19. The difference between the 2000 and 1999 surface temperatures in the southern Gulf of St. Lawrence during the September groundfish surveys. Positive values indicate temperatures in 2000 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue through violet.

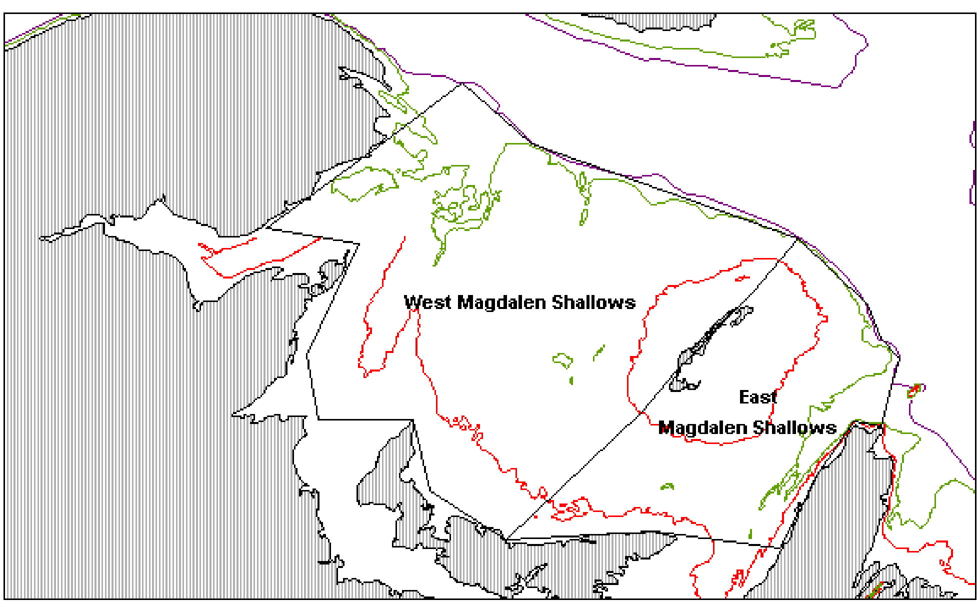
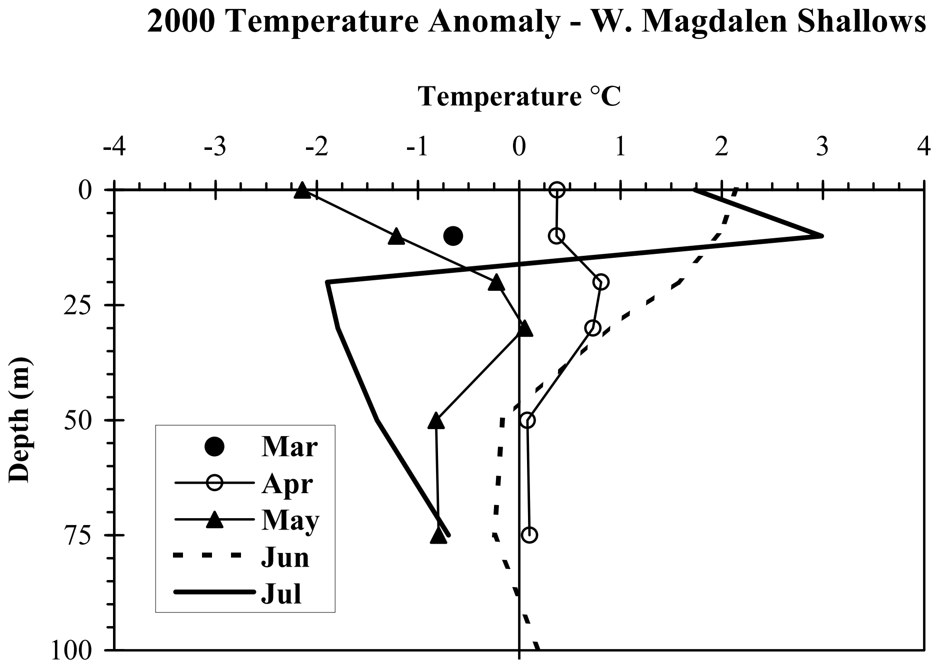


Fig. 20. The boundaries of the two regions of the Magdalen Shallows for which temperature and salinity analyses were carried out.



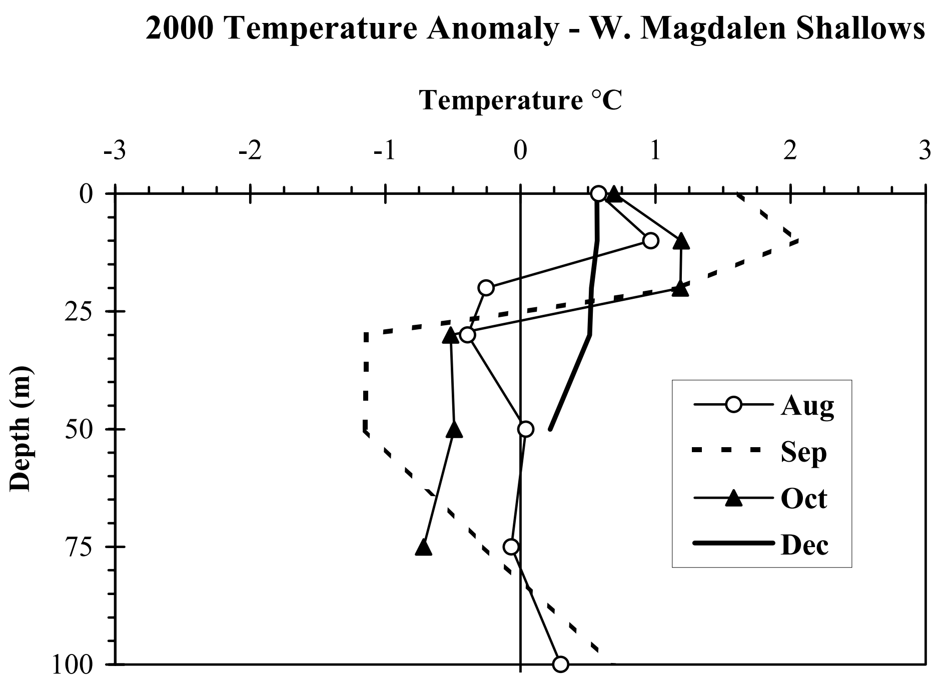
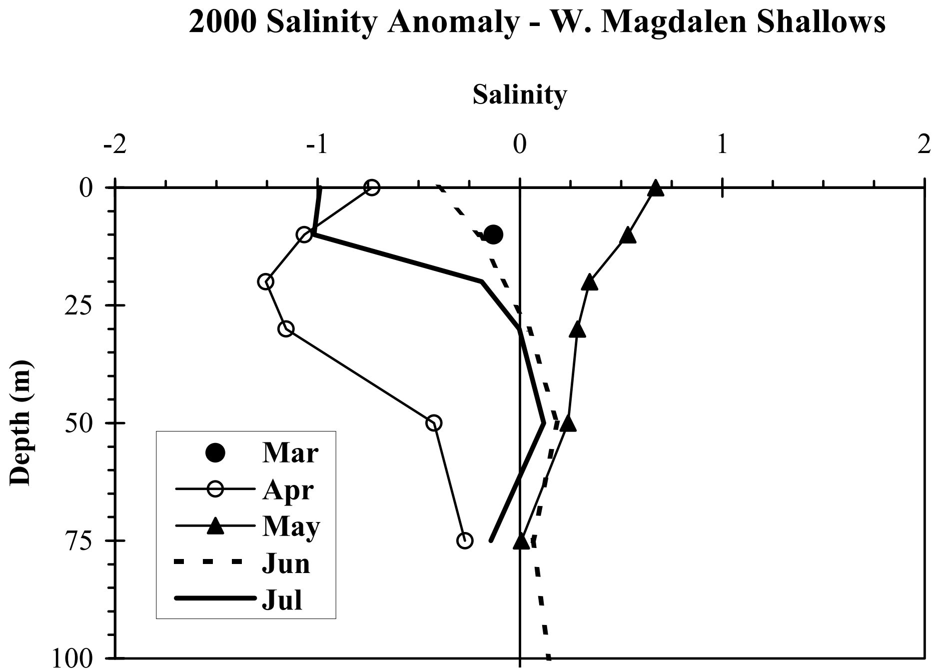


Fig. 21. The vertical profiles of the monthly mean temperatures for all available months within the western Magdalen Shallows region (see Fig. 20 for boundaries).



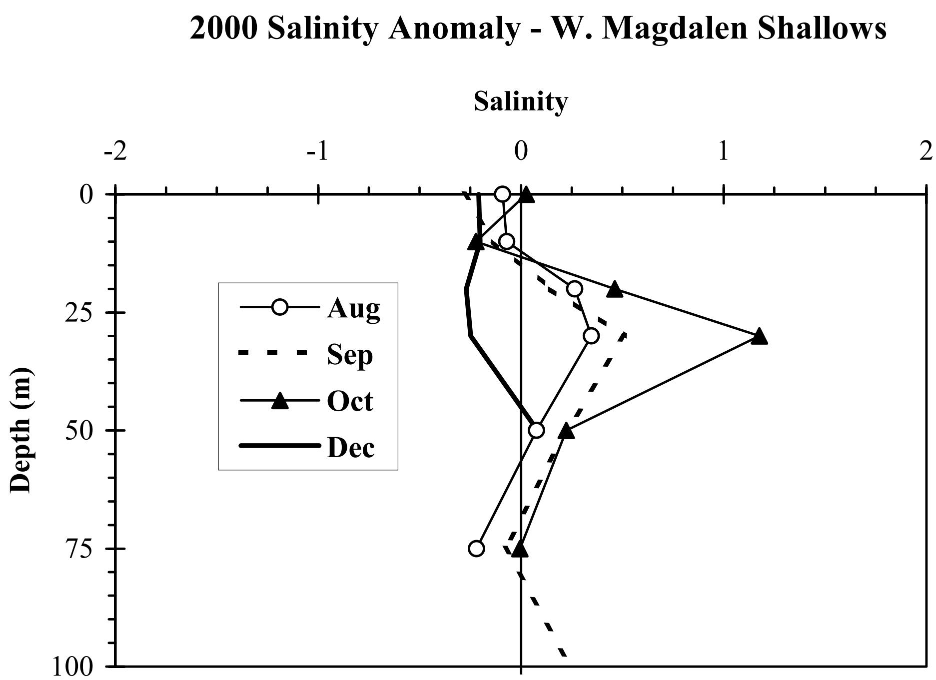


Fig. 22. The vertical profiles of the monthly mean salinities for all available months within the western Magdalen Shallows region (see Fig. 20 for boundaries).

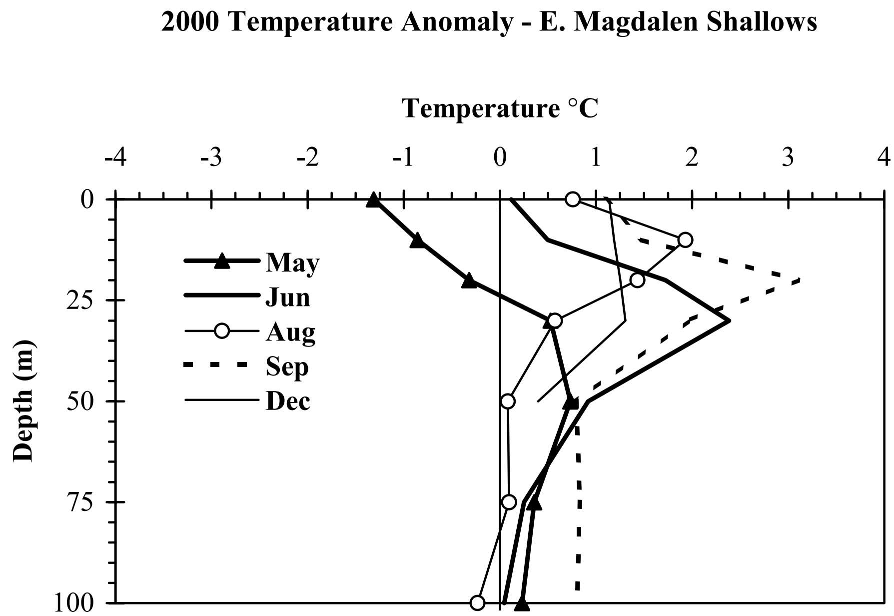


Fig. 23. The vertical profiles of the monthly mean temperatures for all available months within the eastern Magdalen Shallows region (see Fig. 20 for boundaries).

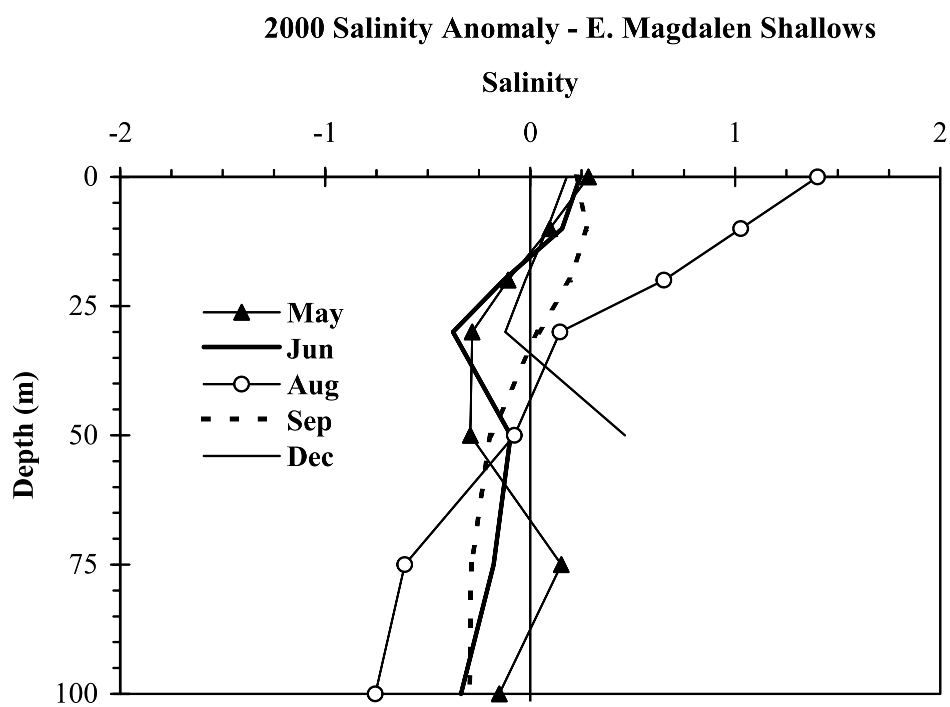


Fig. 24. The vertical profiles of the monthly mean salinities for all available months within the eastern Magdalen Shallows region (see Fig. 20 for boundaries).

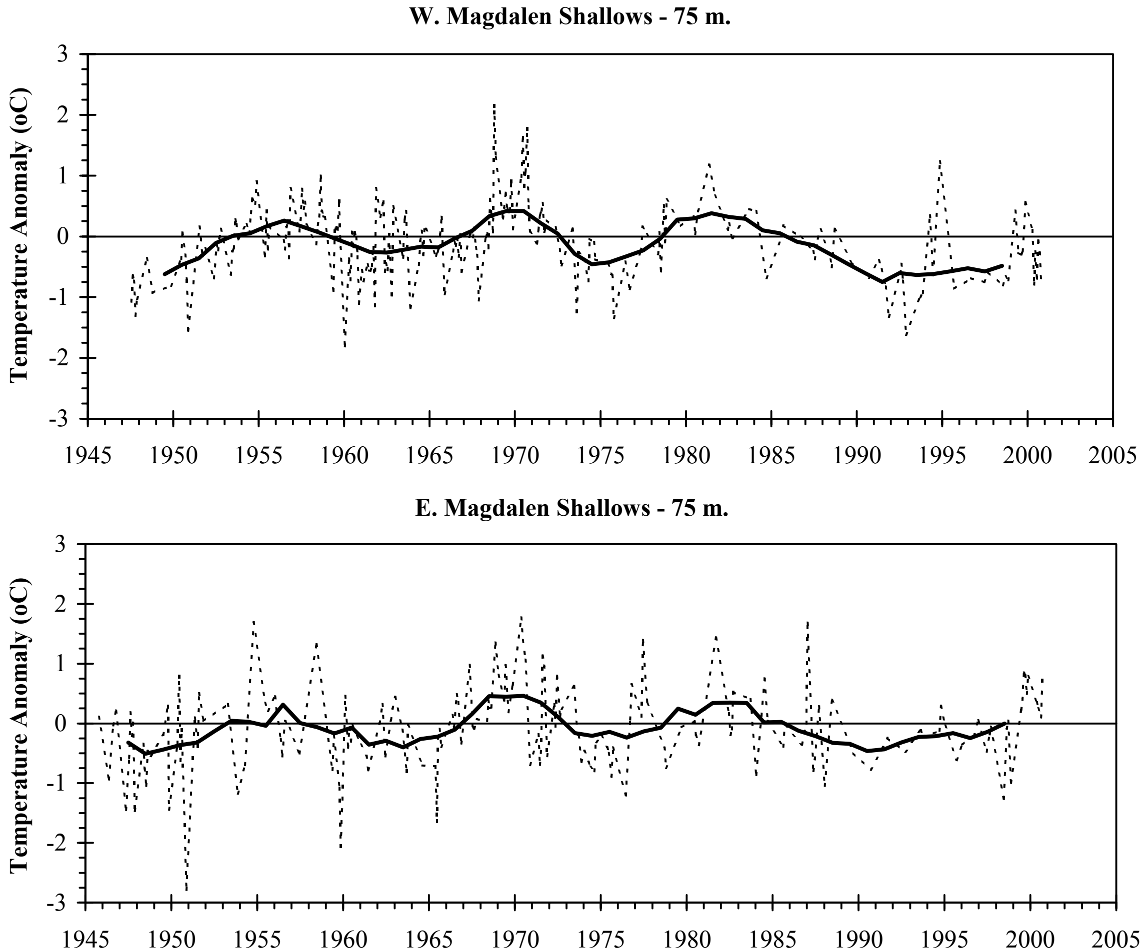


Fig. 25. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of temperature at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

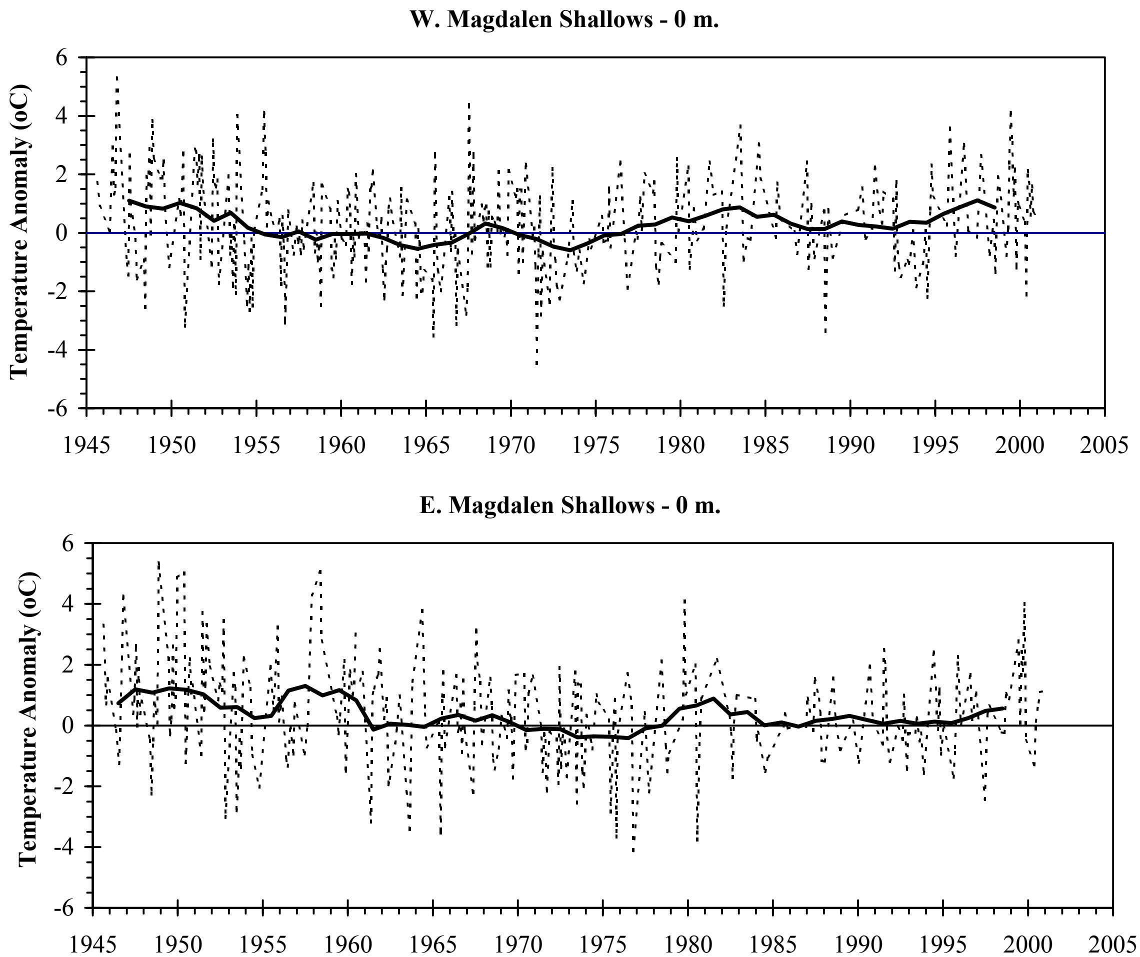


Fig. 26. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface temperature for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

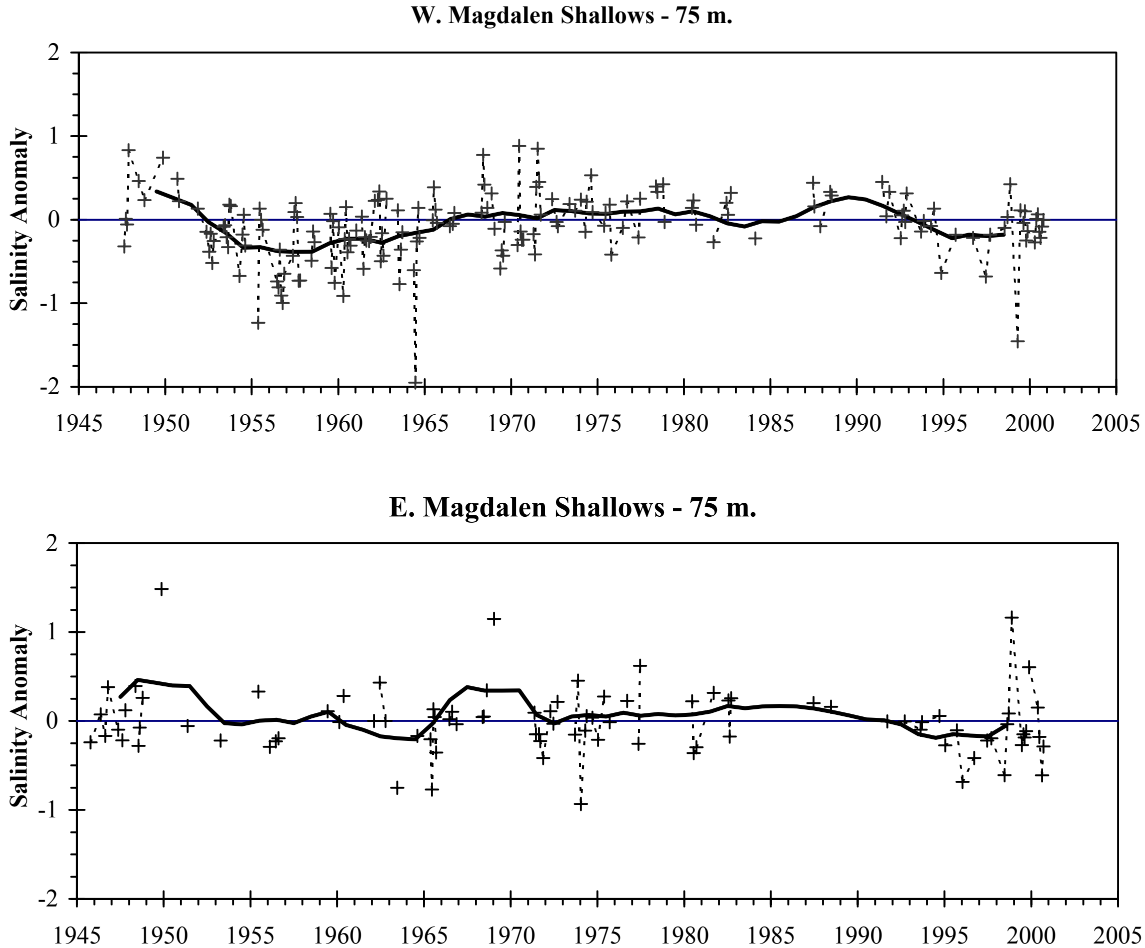


Fig. 27. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of salinity at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

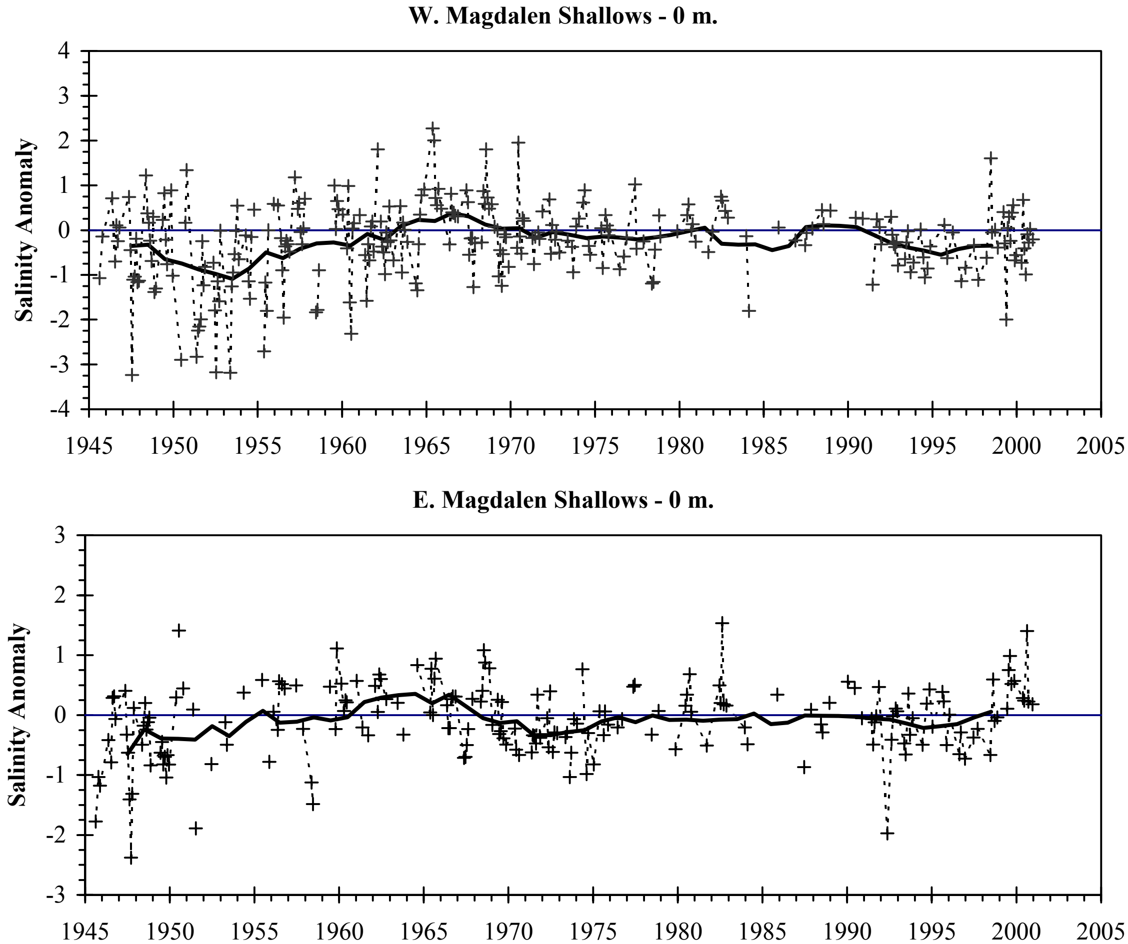


Fig. 28. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface salinity for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

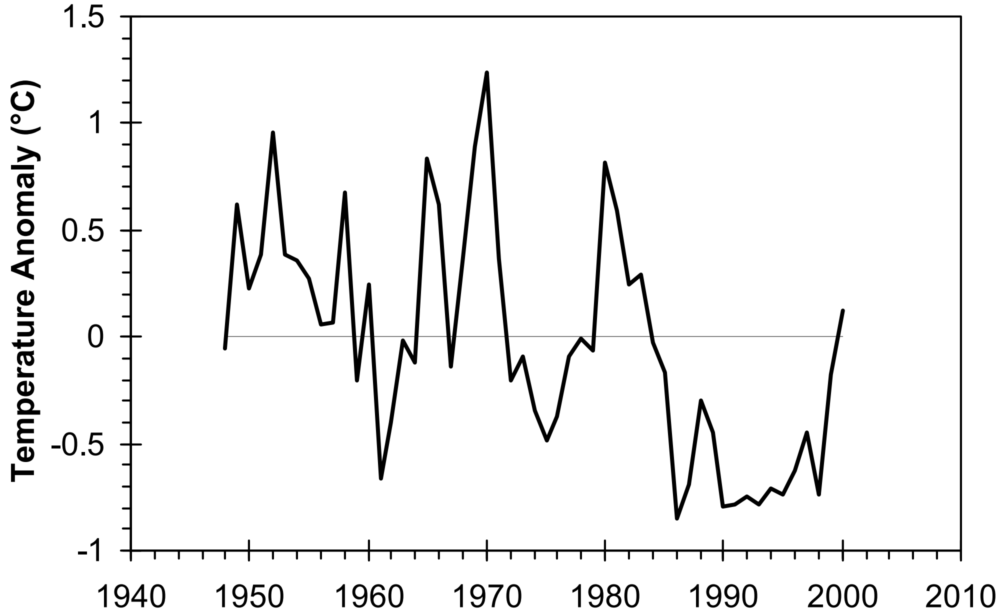


Fig. 29. Anomalies of the CIL core temperature (extrapolated to 15 July) for the Gulf of St. Lawrence relative to the 1961-90 mean.