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Overview of Environmental Conditions in the Northwest Atlantic in 2000

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Abstract

A review of environmental conditions in the northwest Atlantic during 2000 is presented. Warm conditions tended to dominate throughout the region, similar to last year. The large-scale atmospheric circulation, as reflected in the North Atlantic Oscillation (NAO) index was intense, matching conditions seen in 1999 but up significantly over 1998 values. In spite of the high NAO index, air temperatures over the shelf waters off the eastern U.S. and Canada were generally warmer-than-normal. These air temperatures did decrease compared to the record setting values of 1999, however. It was a light ice year in 2000, for the third year in a row, with significantly reduced duration of sea ice in most regions. Sea surface temperatures from satellite imagery and measured in situ both indicated high values, consistent with the warm air temperatures. Ocean temperatures at all depths over much of Labrador, northern Newfoundland shelves and the Grand Banks continued to be above normal but cooled slightly relative to 1999. Near-bottom temperatures on St. Pierre Bank continued above normal for the second year after almost 15 years of below normal values. In the Gulf of St. Lawrence, CIL waters were warmer-than-normal for the first time since the mid-1980s. On the Scotian Shelf and Gulf of Maine warmer-than-usual waters were evident from groundfish surveys, monitoring transects, fixed stations and opportunistic data. Salinities tended to vary with generally fresher conditions than normal in most areas where data were available. Strong near surface stratification continued on the Scotian Shelf, a trend established during the 1990s. The slope/shelf front and the Gulf Stream were located well seaward of their mean locations in 2000.

Introduction

This paper examines the atmospheric, sea ice and hydrographic conditions in the Northwest Atlantic during 2000 and continues the series of annual reviews presented to NAFO that began in 1982. It is based upon selected sets of oceanographic and meteorological data. Environmental conditions are compared with those of the preceding year as well as in terms of deviations from their long-term means, hereafter called anomalies. Unless otherwise stated, the long-term means have been averaged over a standardized 30-yr base period (1961-90) in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council.

Meteorological Observations

Air Temperatures

The German Weather Service publishes annual and monthly air temperature anomalies (relative to 1961-90) for the North Atlantic Ocean in their publication *Die Grosswetterlagen Europas* (Deutscher Wetterdienstes, 2000). Warmer-than-normal temperatures dominated over most of the Northwest Atlantic during 2000 (Fig. 1,2). Monthly data show that in January, warm air covered the continental shelves from southern Labrador through to the southern United States, with a maximum positive anomaly (>3°C) located well offshore of the Gulf of Maine and the Grand Banks. In contrast, over the Labrador Sea and Baffin Bay, air temperatures in January were below normal by upwards of 3°C. Mild conditions continued for the remainder of the winter over the region south of Labrador to the Middle Atlantic Bight with positive anomalies between 2°-3°C during February and 2°-5°C in March. In February, the Labrador Sea was again covered by a colder-than-normal air mass but gave way to warm conditions on the Canadian side in March. Air temperatures off southwest Greenland remained colder-than-normal. Temperatures over most marine areas of the northwest Atlantic in April were above normal with the warmest anomalies over Baffin Bay (>5°C). In May and June slightly colder-than-normal conditions returned to the Labrador Sea region. Through the summer, warmer-than-normal conditions prevailed over most of the northwest Atlantic. An exception was the Middle Atlantic Bight where cold temperature anomalies dominated. These conditions on the Bight extended into the autumn. While air temperature anomalies over southeastern Canadian waters varied through the fall, those over the Labrador Sea and Baffin Bay were warm during both November and December. The latter reached upwards of 5°C in Baffin Bay.

Monthly air temperature anomalies for 1999 and 2000 relative to their 1961-90 mean at eight sites in the northwest Atlantic from Nuuk (Godthaab) in Greenland to Cape Hatteras on the eastern coast of the United States are shown in Fig. 4 (see Fig. 3 for locations). Data from the Canadian sites were available from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA, 2000). At the time of writing data for November and December were not available at Boston and Cape Hatteras. The predominance of warmer-than-normal air temperatures over most of eastern Canadian waters during 2000, noted above, is clearly evident. At Sable Island, all months were above normal, on the Magdalen Islands and St. John's, all months but one (May and December, respectively), and at Cartwright all but two (May and October). Cape Hatteras also experienced generally warmer-than-normal conditions with only three of the available ten months below normal (June, July and October). Iqaluit, while recording below normal temperatures in 5 months, also had predominantly warm conditions and the highest temperature anomaly of the 8 sites examined (>9°C in December). Note that at the sites with a predominance of above normal temperatures, anomalies of +1° to +3°C were common but were generally lower than in 1999. In contrast to these warm conditions, Boston experienced colder-than-normal temperatures.

The mean annual air-temperature anomalies for 2000 were also calculated at all eight sites. For Boston and Cape Hatteras, the annual anomalies were the average of the available monthly anomalies. For all sites except Boston, the annual anomalies were above normal. The maximum anomaly was recorded on Sable Island (1.3°C) with values above +1°C from the Scotian Shelf to the southern Labrador. At the southern (Cape Hatteras) and northern extremes (Nuuk and Iqaluit) annual means rose compared to 1999. Elsewhere they declined but at these sites, 1999 set all time historic records. The time series of the annual anomalies are shown in Fig. 5. The generally positive air temperature anomalies in 2000 are clearly evident. Note that the interannual variability in air temperatures since 1960 at Nuuk, Iqaluit, Cartwright, and, to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with minima in the early 1970s, early to mid-1980s and the early 1990s, suggesting a quasi-decadal period. Indeed, the recent rise in temperature at most of these sites is consistent with a continuation of this near decadal pattern. Monthly temperature anomalies at the Magdalen Islands and Sable Island contained quasi-decadal fluctuations with minima in the early 1970s (both sites), the mid-1980s (Sable Island only) and in the 1990s (Magdalen Islands only). Air temperatures at Boston and Cape Hatteras have generally been out of phase with the temperature fluctuations in the Labrador region. Thus, for example, when the temperatures were very cold in Labrador during the early 1990s, they were relatively warm along the US seaboard (Fig. 5). Also note that all sites where data are available, cold conditions (relative to the 1961-90 mean) existed throughout the late 1800s and early 1990s. Temperatures rose to above normal values between the 1910s and 1950s, the actual timing being site-dependent.

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale pressure patterns and atmospheric circulation. Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas*. The long-term seasonal mean pressure patterns are dominated by the Icelandic Low centred between Greenland and Iceland and the Bermuda-Azores High centred between Florida and northern Africa (Fig. 6). The strengths of the Low and High vary seasonally from a winter maximum to a summer minimum. Seasonal anomalies of the sea-surface pressure for 2000, relative to the 1961-90 means, are shown in Fig. 7. Winter includes December 1999 to February 2000, spring is March to May, summer is June to August and autumn is September to November.

In winter, a strong dipole pattern was established with negative air pressure anomalies in the northern North Atlantic and positive anomalies to the south. The largest negative anomalies (below -10 mb) were located west of Norway and the largest positive anomalies (>10 mb) were centred over the central Atlantic. These high anomalies extended across the entire width of the Atlantic Ocean. This pattern indicates a strengthening of the atmospheric circulation with an intensification of both the Iceland Low and the Azores High. Strong westerly winds across the northern North Atlantic accompany this pressure pattern with the maximum wind anomalies over Western Europe. Over the Labrador Sea the pressure field also implied slightly stronger-than-normal westerly winds. Southeastern Canada and the northeastern United States came under the influence of the Azores High producing more southerly winds, which carried relatively warm air into the region. The spatial pattern of the pressure fields in 2000 was similar to that in 1999 but the pressure gradients were more intense. As seen in recent years, the centres of action of the pressure anomalies were located further eastward than usual.

In the spring of 2000, a relatively strong positive pressure anomaly (> 3 mb) developed over the Northwest Atlantic, with its center to the north of Greenland. Two smaller and weaker negative anomalies also formed, one off the eastern United States and another over the eastern Atlantic and Europe. In eastern Canada, the geostrophic winds associated with these anomaly pressure fields would be predominantly from the south and east.

As is typical in most years, the pressure anomaly field during the summer of 2000 was generally weaker than in the other seasons. Slightly higher pressures than normal covered the northwest Atlantic with the maximum (>2 mb) over Greenland and Iceland. There were several local maxima, all of which were slightly above 2 mb. The geostrophic winds accompanying this pressure anomaly field were also relatively weak.

In the autumn, there was a return to the wintertime pattern with an intensification of the Icelandic Low and Azores High, with a particular strong negative anomaly centred over Scotland. The northwestern Atlantic was covered by weak negative anomalies. Over eastern Canada and the northeastern United States, the winds associated with this pressure system were predominantly easterly.

NAO Index

The North Atlantic Oscillation (NAO) Index is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly winds over the northern North Atlantic (Rogers, 1984). A high NAO index corresponds to an intensification of the Icelandic Low and Azores High. Strong northwest winds, cold air and sea temperatures and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index (Colbourne et al. 1994; Drinkwater 1996). The annual NAO index is derived from the measured mean sea level pressures at Ponta Delgada (up to 1997) or Santa Maria (since 1997) in the Azores minus those at Akureyri in Iceland. The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1961-90 mean.

In 2000, the NAO index was above normal (+13.6 mb anomaly) but dropped slightly from its 1999 value (Fig. 8). It was similar to levels observed during the first half of the 1990s and well above the lower-than-average indices registered in 1996 and 1997. These recent changes in the NAO index fit the pattern of quasi-decadal variability that has persisted since the 1960s. As described above, high NAO is usually accompanied by cold conditions over the Labrador Sea in winter. However, in 2000 air temperatures in the region were above normal in spite of the high NAO index. A similar situation occurred last year. Two possible causes of the break down in the relationship between the NAO and air temperatures in the Labrador-Newfoundland area are apparent. First, most of the activity in the anomalous winter pressure field was over the eastern North Atlantic with weaker gradients over the Northwest Atlantic (Fig. 7). Weaker gradients lead to weaker winds. Second, the Azores High extended into southeastern Canada, especially in winter (Fig. 7). This brought more southerly winds into the region with accompanying warm air.

SEA ICE OBSERVATIONS

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The long-term median, maximum and minimum positions of the ice edge (concentrations above 10%) based on the composite for the years 1962 to 1987 are taken from Coté (1989). We also include an analysis of the time of onset, duration and last presence of sea ice based upon the sea-ice database maintained at the Bedford Institute of Oceanography (Drinkwater et al., 1999). The weekly concentration and types of ice within 0.5° latitude by 1° longitude areas were recorded through the ice season. The dates of the first and last appearance of ice within these areas, as well as the duration of ice, were determined. The database begins in the early 1960s and continues to the present. Long-term means (30-years, 1964-1993) of each variable were determined (using only data during the years ice was present) and subtracted from the 2000 values to obtain anomalies.

Newfoundland and Labrador

At the end of 1999, sea ice lay off the southern Labrador coast in the vicinity of Hamilton Inlet resulting in an areal coverage that matched closely the long-term median for that time of the year (Fig. 9a). This was aided by below normal air temperatures and strong northwest winds during the latter half of December. By mid-January, the ice had spread past the southern tip of Labrador and onto the northern Newfoundland coast, which was a little further south than its long-term median position. Elsewhere, however, the ice edge was near its median position. During the latter half of January light west to northwest winds prevailed and air temperatures were generally 1°-3°C above normal. By the first of February, the ice edge extended south to Notre Dame Bay and the extent and thickness of the ice were near normal. In spite of the warmer-than-normal air temperatures (3°-5°C) and light winds during February, by 1 March, the southern most ice edge still lay close to the long-term median position. However, the ice did not extend as far offshore as normal resulting in less ice extent than usual. This was in part due to the persistent northeast winds during the second half of February, which pushed ice shoreward. Winds from the southwest and above normal air temperatures during most of March resulted in an early retreat of the ice and by 1 April, the ice edge was inshore of its long-term median position on the northern Newfoundland shelf, although near it off southern Labrador (Fig. 9b). Warm air temperatures continued throughout April with the result that the ice continued to retreat faster-than-normal. By 1 May, the ice was restricted to the nearshore areas off northern Newfoundland and the inner Labrador Shelf. The ice edge lay well inshore of the long-term median location. On 1 June, the ice had retreated to the Labrador Shelf region north of Hamilton Inlet. The ice edge was near its normal position but the ice thickness was less than normal. By 1 July all traces of ice had disappeared from southern Labrador.

The time series of the areal extent of ice on the Newfoundland and southern Labrador shelves (between 45-55^{o}N; I. Peterson, personal communication, Bedford Institute) show that the peak extent during 2000 was slightly above that observed in 1999 (Fig. 10). Relative to 1999, the average ice area rose slightly during advancement (January to March) and retreat (April to June). During both periods, the average ice area was below the long-term mean and was much less than the early 1990s. The monthly means of ice area show that the 2000 coverage was above that of 1999 in February to April but below for January and May (Fig. 11). In the remaining months the ice area was similar to the previous year. In all months, the ice area was below the long-term average (1963-1990). In summary, 2000 was generally a lighter-than-average ice year on the Labrador and Newfoundland shelves. Although no estimates of ice volume were made for 2000, based upon studies in the Gulf of St. Lawrence (Drinkwater et al., 1999), the temporal variability of the ice volume is expected to be similar to that of the ice area.

An analysis of the first and last presence of ice was also carried out. In 2000, ice appeared along the southern Labrador coast in late December, and gradually spread southward to northeastern Newfoundland waters by mid-March (around day 75; Fig. 12). Only small quantities of ice reached the northern Grand Bank. Relative to the long-term mean, ice generally appeared slightly earlier-than-normal on the inner shelf off Labrador and the northern tip of Newfoundland (Fig. 13). Over the offshore regions and off most of Newfoundland ice arrived later-than-usual. Ice began to disappear from the offshore and southern sites by late March to early April (day 90-105; Fig. 12). Ice did not began to retreat from northern Newfoundland waters and southern Labrador until May but lasted in the region north of Hamilton Inlet until near mid-June. Over most of the region, ice disappeared earlier-than-normal (negative anomaly, generally associated with warm conditions), more than 30 days early over large sections of Northern Newfoundland (Fig. 13). The only regions where ice departed later-than-usual was at the shelf edge and these were generally near normal. The duration of the ice season ranged from less than 10 days on the northern Grand Banks and off the shelf edge to over 170 days north of Hamilton Inlet on the southern Labrador (Fig. 14). Note that the duration is not simply the date of the first presence minus the last presence because the ice may disappear for a time and then reappear. The ice duration was shorter-than-normal (negative anomaly) over most of the Newfoundland Shelf and south of Hamilton Inlet on the Labrador Shelf. Off northern Newfoundland, the duration was 20-40 days shorter-than-usual. Those small regions where the duration longer-than-normal, it was within a few days of normal.

Icebergs

The International Ice Patrol Division of the United States Coast Guard monitors the number of icebergs that pass south of 48ºN latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1999/2000 iceberg season (October 1999 to September 2000), a total of 843 icebergs were spotted south of 48^{o}N. The monthly totals for March to July were 286, 239, 212, 65 and 41, respectively (Fig. 15). No icebergs were spotted between October 1999 and February 2000, inclusive, or in August or September 2000. In 2000, all of the icebergs were observed during the primary iceberg season of March to July, which is higher than the 1985-2000 mean of 91.7%. The 1985-2000 is considered to represent the period of reliable SLAR measurements. A higher percentage of the icebergs in 2000 arrived in March and April than usual and a lower percentage in June and July. The total number of icebergs was up dramatically from the 22 icebergs recorded in 1999 and although the 2000 numbers were higher than average, there were less icebergs than in most of the years of the 1990s (Fig. 15).

Gulf of St. Lawrence

The location of the ice edge within the Gulf of St. Lawrence at various times during the 1999-2000 winter season is shown in Fig. 16. 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 typical 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 Gaspé 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.

During the 1999-2000 ice season in the Gulf, the first appearance of ice ranged from late December in the St. Lawrence Estuary and along the coastal regions of the Magdalen Shallows and the north shore of Quebec to mid February (day 45) off southwestern Newfoundland (Fig. 12). Although generally within 10 days of the typical date, ice appeared earlier-than-normal over much of the Magdalen Shallows, around Anticosti Island and on the north shore of Quebec from Anticosti to the Strait of Belle Isle (Fig. 13). The date of last appearance shows the standard pattern with ice lasting longest over the southern Magdalen Shallows and along the north shore of Quebec through to the Strait of Belle Isle (Fig. 12). In 2000, ice left the Gulf early except in the Estuary (Fig. 13). Ice left the Magdalen Shallows 1-2 weeks early and the eastern Gulf 2-4 weeks early. The duration of ice ranged from 10 days off southwestern Newfoundland to over 90 days in the Strait of Belle Isle (Fig. 14). Relative to the long-term mean, using only years when ice was present, ice duration was less than normal throughout the Gulf. The largest anomalies were in the northwest where there were 30 to over 60 fewer days of ice than usual.

Scotian Shelf

Sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwest winds and ocean currents. In 2000, ice first appeared seaward of Cabot Strait during early February (Fig. 11), which is later-than-usual (Fig. 12). It maintained a relatively constant presence through into early March off northeastern Cape Breton. This ice was primarily restricted to the Sydney Bight area with little ice reaching the Scotian Shelf proper. This ice had disappeared by the end of March (Fig. 11), a departure about 2 weeks earlier-than-normal (Fig. 12). The duration of ice south of Cabot Strait was up to 50 days off northern Cape Breton Island. This was less than the long-term mean in most areas, 30 to over 40 days off the northeastern Scotian Shelf (Fig. 13). Note that durations of less than 10 days are not plotted in Fig. 13.

The monthly estimates of the ice area seaward of Cabot Strait since the 1960s show that only small amounts were transported onto the Scotian Shelf during 1999 compared to the long-term mean (Fig. 17, 18). It was, however, slightly larger in magnitude than the ice area observed in 1999. There were fewer days than usual with ice present seaward of Cabot Strait, the second lowest in the 39-year record. The integrated ice area (summation of the area times the number of days) rose slightly but remained well below the long-term average. Indeed, it was the sixth lowest on record (Fig. 17). This was the third consecutive year of very light ice conditions seaward of Cabot Strait. Note that based upon data collected since the 1960s, the furthest south that the ice penetrates is along the Atlantic coast of Nova Scotia to just past Halifax. Historical records prior to 1960, albeit incomplete, suggest that during heavy ice years, it occasionally penetrated much further south, for example in the 1880s sea ice was observed in the southwestern Scotian Shelf (A. Ruffman, Geomarine Associates Ltd., Halifax, personal communication).

Oceanographic Observations

Remotely-Sensed Sea Surface Temperature

Estimates of sea surface temperature (SST) from satellite observations made by the Jet Propulsion Laboratory are archived by the Bedford Institute of Oceanography (BIO) in Dartmouth, Canada. The data provide broad coverage of SSTs from late 1981 to present. A discussion of their accuracy and utility as a climate indicator is provided by Mason et al. (1999) and Petrie and Mason (2000). The latter showed that the data from a number of locations could be reduced to a couple of time series that capture most of the variance in the annual temperature anomalies.

Temperature estimates were extracted from the BIO SST database for 23 areas that cover the Canadian Atlantic coast from Hudson Strait to Georges Bank (Fig. 19). Monthly means were determined for each area, monthly temperature anomalies calculated, and annual temperature anomalies computed from the monthly anomalies. The resulting 23 time series covering 18 years are analyzed using empirical orthogonal functions. This technique reduces the data into a smaller number of time series called modes, determined from the correlation matrix of the 23 time series.

The results indicate that 58.3 percent of the overall variance in the 23 series can be accounted for by mode 1, and an additional 15.1% by mode 2; i.e., about 73% of the overall variance can be accounted for by these two modes. The amplitude of mode 1 is almost constant for the sites from Hamilton Bank to Georges Bank, except for the St. Lawrence Estuary where the amplitude is reduced, and is low for Bravo (Labrador Sea), Hudson Strait, and Nain Bank (Fig. 20a). Mode 1 accounts for between about 50-95% of the temperature variance for the sites from Hamilton Bank to Georges Bank except for the Estuary and the Bay of Fundy where 15% and 36% is captured, respectively (Figure 19b). Mode 2 captures about 50-70% of the temperature variance from the 3 northernmost sites and about 30% from Hamilton Bank and St. Anthony (Fig. 20a,b). It accounts for little of the variance at the other sites.

The 17 times series with significant variance accounted for by mode 1, the 5 captured primarily by mode 2 and the remaining 3 time series from the Gulf of St. Lawrence are grouped together in Fig. 21a-c. The correspondence among the observations is evident in each plot. The mode 1 group exhibits more short term variability than the other 2 groups with annual temperatures 1-2^{o}C above normal the past 2 years; a longer trend is apparent in the mode 2 group comprised of the most northerly sites on the Labrador-Newfoundland Shelf and in the Labrador Sea. There the temperature anomaly has been about 1^{o}C above normal for the past 3 years except for Hudson Strait where the temperature was about normal in 2000. The Gulf of St. Lawrence group comprised of the Estuary, the Northwest Gulf and the Magdalen Shallows resembles the mode 1 group more than the northern sites but with temperatures about 0.5^{o}C above normal in 2000.

Newfoundland and Labrador

Station 27

Temperature and salinity have been monitored since 1946 at Station 27 located approximately 10 km off St. John's, Newfoundland. This site lies within the inshore branch of the Labrador Current but is considered to be representative of hydrographic conditions at long periods (interannual to decadal) over the continental shelf from southern Labrador to the Grand Banks (Petrie et al., 1992). The station was visited 59 times in 2000, with a monthly maximum of 9 in each of May and June and a minimum of 2 in January and March. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50 75, 100, 125, 150 and 175 m) and monthly means were calculated for each depth.

During 2000, as is typical, the water column cooled during January to March reaching monthly mean temperatures of almost -1^{o}C in the surface layers and colder than that in the subsurface waters. The latter (below –1^{o}C) extended through to November but deepened with time (Fig. 22). The very cold subsurface waters late in the year were likely advected into the region from the north. Upper layer (generally < 50 m) temperatures were below 0^{o}C until April. They then began to rise steadily, reaching a peak of over 15^{o}C at the surface in August before autumn cooling began. Note the propagation of surface layer heat down into the lower layers in the late autumn. From January to June, temperatures were primarily above normal with the maximum temperature anomalies occurring just below the surface in June (>1.5°C). By September, below normal temperatures appeared near surface and spread to encompass most of the water column during the last three months of the year.

In 2000, near surface salinities at station 27 were maximum (> 32.0) in May and June, then declined steadily reaching a minimum of <30.9 in September (Fig. 22). The autumn salinity minimum has been related to the arrival of summer ice melt from the Labrador Shelf (Myers et al. 1990; Petrie et al. 1991). The maximum salinities (>33) appeared near bottom. Salinities during 2000 were mostly fresher-than-normal (negative anomalies) with the largest values occurring in March and April, near surface (-0.4). The only significant positive anomalies (saltier-than-normal) appeared near surface in July (0.25) and around 50 m in October (>0.25). The latter are likely a result of lower than normal amounts on the Labrador Shelf the previous winter. The resultant effects of the temperature and salinity anomalies resulted in significant stronger stratification in the spring (March) and from August to November than usual. Slightly weaker-than-average stratification was observed from May through July.

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970-1998 are shown in Fig. 23. Note that the temperature scales differ with depth. At the surface and 50 m there is large, short-term variability reflecting atmospheric heating and cooling. Warmer-than-normal temperatures were observed throughout 2000 at 150 and 175 m, continuing a trend that began in 1996. This warming followed more than a decade of cold conditions. Note that the coldest periods roughly correspond to those identified from the air temperature anomalies, i.e. the early 1970s, the mid-1980s and the 1990s. In contrast to the deepest depths, at mid-depth (50 and 100 m), conditions were near normal with a slight tendency towards warm conditions. Surface temperature experience higher variability than at depth because of the heat exchange with the atmosphere. The gradual warming at the surface that began around 1992 continued into 2000. These results are consistent with the satellite imagery.

The depth-averaged temperature, which is proportional to the total heat content within the water column, also shows large amplitude fluctuations at near decadal time scales with cold periods during the early 1970s, mid- 1980s and early 1990s (Fig. 24). The total heat content of the water column, which fell to a record low in 1991 increased sharply in 1996 reaching a level only matched during the warm 1950s and 1960s. Since then the heat content decreased to slightly below normal and then increased again. Values in 1999 and 2000 were above normal and of similar magnitude. The 0 to 50 m depth-averaged summer salinity is also plotted in Fig. 24. The low salinity values of the early 1990s are comparable to values experienced during the Great Salinity Anomaly of the early 1970s (Dickson et al., 1988). In 1997, salinities rose to near-normal values, up from the very low salinities of 1995 and remained close to their long-term mean in 1998. While 1999 values declined, they returned to near normal conditions in 2000.

CIL

On the continental shelves off eastern Canada from Labrador to the Scotian Shelf, intense vertically mixing and convection during winter produce a near homogeneous cold upper layer that overlays a warmer deeper layer or occasionally may extend to the bottom in shallow areas. With spring heating, ice melt and increased river runoff, a warm low-saline surface layer develops. The strong stratification in this upper layer inhibits heat transfer downwards, and the waters below remain cold throughout the spring and summer. The latter are called the cold intermediate layer (CIL) waters.

Three standard hydrographic transects (Hamilton Bank, off Bonavista Bay and along 47^{o}N to Flemish Cap) have been occupied during the summer and autumn by the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland in most years since 1950. The areal extent of the CIL in summer along each transect (as defined by waters <0^{o}C) is plotted in Fig. 25. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects (Petrie et al., 1992). In 2000, the summertime CIL area along the Seal Island transect was above normal for the first time in six years. On the Bonavista line the CIL area was near the long-term mean but was also the highest value of the last six years. On the Flemish Cap transect the CIL area was similar to 1999, which was the lowest value since the late 1970s and early 1980s. In general, periods of warmer-than-normal core temperatures are correlated with smaller-than-normal CIL areas. The minimum temperature observed in the core of the CIL along the Seal Island transect during the summer of 2000 was about -1.59^{o}C compared to a normal of -1.57°C. Core temperatures along the Bonavista transect were -1.61^{o}C compared to a normal of -1.63^{o}C and along the Flemish Cap transect were at -1.47^{o}C, slightly below the normal of about -1.51^{o}C. These minimum temperatures cooled compared to 1999 levels at all three transects, with the largest decline on the Seal Island transect.

Estimates of the volume of CIL water (<0^{o}C) over the 2J3KL area are available since 1980 from data collected during the groundfish surveys (Fig. 26). A description of the analysis method can be found in Colbourne and Mertz (MS 1995). The long-term (1980-1994) mean volume of the CIL in summer of just over 4 x 10^4 km^3 is roughly one-third the total volume of water on the shelf. The volume in autumn shows similar interannual trends to those of summer but its absolute value is about half than of the summer. This is because the CIL is eroded through the summer due to mixing with warmer waters both at the surface and near bottom. Unfortunately, the data coverage in 2000 was not sufficient to make a reliable estimate of the summer CIL area and hence none is given. In terms of interannual variability, maximum CIL volumes tended to occur during the cold periods of the mid-1980s and early 1990s. In 1990, the summertime volume began to decrease and by 1995 was similar to that recorded in the early 1980s and again in the later 1980s. Since then the CIL volume has remained relatively low. In the autumn of 2000, the CIL volume remained below normal but rose relative to the very low value observed in 1999 and was at its highest level since 1995.

Horizontal Temperature Distributions Near-Bottom in 2J3KL

Extensive groundfish surveys run out of the Northwest Atlantic Fisheries Centre in St. John’s Newfoundland cover Divs. 3LNO in the spring and 2J, 3K and 3LNO in the autumn. All surveys show similar patterns with a dominance of warmer-than-normal bottom temperatures in 2000 (Fig. 27-29). The warm conditions contrast with the early 1990s when negative temperature anomalies dominated. There was, however, more of the bottom covered by below normal values compared to 1999, especially over the Grand Bank in the autumn (Fig. 27). Spring temperature anomalies over the Grand Bank, in contrast, were above normal suggestive of cooling. Consistent with this, cooling was observed at Station 27 in the latter part of the year although there the temperatures remained near normal (Fig. 22). Colder-than-normal temperatures were also suggested in the nearshore regions of northern Newfoundland and in the Strait of Belle Isle. Although predominantly warmer than normal in 2000, the bottom temperature anomalies generally decreased compared to 1999 as indicated by the increase in the amount of bottom covered by temperatures <0^{o}C. However, in 1999 the average temperatures in each of the autumn surveys were the warmest in the over 20-yr record.

Hydrographic Conditions on Hamilton Bank

The time series of annual mean temperature and salinity anomalies (relative to 1961-90 means) from 1950 to 1999 on Hamilton Bank at the surface and 150 are shown in Figs. 30 and 31, respectively. The 5-year running means of the annual values that are also plotted suppress the high frequency variations and provide a representation of the long-term trends. Note that the annually averages are estimated from the available monthly means, which is typically 1-6 months.

The annual values show a high degree of variability that may indicate spatial variability of the bank at these depths or reflect the variable number of observations. The time series are characterized by variations with amplitudes ranging from approximately ± 2°C and with periods of a 2-10 years. The cold periods of the early 1970s, the mid-1980s and to a lesser extent the early 1990s are present, however, the amplitude of these anomalies vary considerably with depth. Temperatures on Hamilton Bank have generally been warming since 1994, particularly in the deeper layers. There the waters were below normal from the early 1980s to 1994, similar to conditions further south at Station 27. During 2000, temperature anomalies at the surface increased substantially from 1999 and were well above the long-term mean. In contrast the temperature anomalies at 150 m declined from the near record highs in 1999 to near-normal in 2000. The salinity time series show similar conditions as elsewhere on the shelf with generally fresher-than-normal conditions in the early 1970s, mid 1980s and early 1990s. Salinity anomalies have generally been on the rise since the lows of the mid-1990s. In 2000, salinities were near normal but rose relative to 1999 at the surface while declining relative to 1999 at 150 m.

Hydrographic Conditions on Flemish Cap

Temperature anomalies at the surface and 150 m on Flemish Cap show several similarities, especially in the smoothed time series (Fig. 32). Following a warm period in the 1960s, temperature declined to a low in the early to mid-1970s, then rose and deeclined through to the early 1990s. Both depths also recorded minima in 1985. Since the low in the early 1990s, temperatures have been generally on the increase and in 2000 were above normal. At 150 m they did, however, fall towards normal after the maxima in 1999, whereas at the surface there was a slight increase compared to 1999. Salinity anomalies too showed similarities between surface and 150 m (Fig. 33). Of particular notice were the maximum and minimum values at both depths in the 1960s and early to mid-1970s, respectively. The latter corresponds to the timing of the Great Salinity Anomaly (Dickson et al., 1988). In recent years surface values have generally been above normal where as at 150 m they oscillated about normal. In 2000, salinities at both depths were about normal as a result of having declined slightly relative to 1999 values.

Hydographic Conditions on St. Pierre Bank

Monthly temperature anomalies from 1950 to 1998 on St. Pierre Bank bounded by the 100 m isobath were computed at the surface and 75 m (Fig. 34). The latter is considered representative of the near-bottom temperatures. These temperature time series are characterized by large variations with amplitudes ranging from ±2°C at the surface and slightly less at 75 m. The 5-year running means reveal amplitudes generally less than ±1ºC with periods from a couple of years to decadal. The cold periods of the mid-1970s and the mid-1980s in the upper water column are coincident with severe meteorological and ice conditions in the Northwest Atlantic and colder and fresher oceanographic anomalies over most of the Newfoundland continental shelves. During the cold period beginning in 1984-1985, temperatures decreased by up to 2°C in the upper water column and by 1°C in the lower water column. These below normal conditions continued until 1994 at the surface. Since then temperatures have been warmer than normal and in 2000 reached the highest anomaly since 1983. At 75 m, the cold period lasted almost 15 years. Similar to the surface, the temperature anomaly at 75 m in 2000 was the warmest since 1983.

The 2000 bottom temperature and temperature anomaly maps for the spring (April) within 3Ps and 3Pn are provided in Fig. 35. The temperatures show the typical east-west gradients with the coldest (<0ºC) waters to the east and increasing to >5ºC in the Laurentian Channel. Temperatures on the Bank were generally 1º-3ºC. Temperature anomalies show predominantly warmer-than-normal conditions with the highest anomalies (>1ºC) over the southern and western regions of the Bank as well as along the southern Newfoundland coast. Indeed, the estimated bottom temperature for the Bank indicates that it is the highest since 1984. Colder-than-normal bottom temperatures were observed in Hertiage Channel to the northwest of St. Pierre Bank and along the continental slope to the south of the Bank.

Gulf of St. Lawrence

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late 1940s to 1988. The variability in the average temperatures within the 200-300 m layer in Cabot Strait was dominated by low-frequency (decadal) fluctuations with no discernible seasonal cycle. A phase lag was observed along the major axis of the channel such that events propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated time series shows that temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5^{o}C and an anomaly exceeding -0.9^{o}C; Fig. 36). Then temperatures rose dramatically reaching 6^{o}C (anomaly of 0.6^{o}C) in 1993. Since then temperatures have remained above normal through most of the rest of the 1990s. Temperatures in 2000 also were above the long-term mean but declined from 1999 values.

CIL Core Temperature

Similar to Newfoundland waters, there exists within the Gulf of St. Lawrence in the summer and autumn a cold intermediate layer (CIL). Gilbert and Pettigrew (1997), in a study of the Gulf CIL, produced a Gulf-wide index of the core temperature at mid-July based upon observed data and the mean measured warming rate. This index has continued to be updated. During 2000, the CIL mid-summer core temperature was 0.15^{o}C (representing an anomaly of 0.13^{o}C), and was warmer than 1999 by 0.30 ^{o}C and 1998 by 0.86^{o}C (Fig. 37). 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.

Bottom Temperatures on the Magdalen Shallows

Canada has carried out annual groundfish surveys of the Magdalen Shallows in the southern Gulf of St. Lawrence during September since 1971. Bottom temperatures during the 2000 survey ranged between <0°C to over 10°C (Fig. 38). The majority of the bottom is covered by temperatures of <1°C with the coldest waters (<0°C) limited to a small region to the north of Prince Edward Island (PEI). September near-bottom temperature anomalies on the western half of the Shallows were principally near to or below normal, except nearshore. 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. 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.

Swain (MS 1993) developed an index of near bottom temperature defined as the area of the Magdalen Shallows covered by waters <0^{o}C and <1^{o}C. These two indices show strong similarity (Fig. 39). In 2000, there was an increase in area covered by <0ºC but a decline in the area covered by temperatures <1ºC relative to 1999. In both instances the changes were small and the areas were below their long-term averages.

Bottom Temperatures in the Northern Gulf

A groundfish survey is also conducted in the northern Gulf of St. Lawrence in August by the Canadian Department of Fisheries and Oceans out of the Institute Maurice Lamontagne. Bottom temperatures follow closely the topography (Fig. 40). In the Laurentian Channel and its offshoots to the northeast and around Anticosti Island are covered by temperatures of >5°C. In the shallower depths along the Quebec north shore and off western Newfoundland, temperatures generally range from <0° to 4°C in 2000. The temperature anomalies relative to the long-term (1961-90) means generally show but with a predominance of near normal conditions over most of the region. The western coast of Newfoundland in particular experienced warmer-than-normal bottom temperatures, similar to 1999.

Summer Temperature and Salinity Fields

The hydrographic data collected during groundfish surveys on the Magdalen Shallows and the northern Gulf were combined to estimate mean temperatures over the entire Gulf within specified layers (30-100, 100-200 and 200-300 m) (Fig. 41). In all layers the temperatures were above their long-term means, the first time since the mid-1980s. In the 30-100 m layer, 2000 temperatures increased slightly from 1999. This layer temperature mirrors closely the variability in the CIL core temperature (Fig. 37). Temperatures in the 100-200 m layer were similar to 1999 and in the deep layer (200-300 m), temperatures rose slightly.

Scotian Shelf and Gulf of Maine

Coastal Sea Surface Temperatures

Monthly averages of coastal sea surface temperature (SST) for 2000 were available at Boothbay Harbor in Maine, St. Andrews in New Brunswick and Halifax in Nova Scotia (see Fig. 42 for location). The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each site for 1999 and 2000 are shown in Fig. 43.

The dominant feature in the monthly mean anomalies for 2000 at all sites was the above normal temperatures (in all 12 months at Boothbay Harbor and St. Andrews and in 9 of the 12 months at Halifax). The 2000 anomalies equalled or exceeded one standard deviation (based upon the years 1961-90) in 10 months at Boothbay Harbor (all months but February and December) and at St. Andrews (all months but September and December). Data exceeding one standard deviation means that the value lies within approximately the upper 16% (if the anomaly is positive) or lower 16% (if negative) of the entire time series. Only four months equalled or exceeded one standard deviation at Halifax (Jan, March, July and August). The maximum monthly anomaly at Boothbay was in July, 2.6°C (over 3 standard deviations from the long-term mean) with June to September all having anomalies >2 °C. At St. Andrews the maximum positive anomaly was 1.2°C in January. A similar amplitude anomaly but negative was observed in September but this was less than 1 standard deviation from the long-term mean.

Time series of annual anomalies show that the surface temperature at both Boothbay Harbor and St. Andrews have been above their long-term means in recent years and generally on the increase since a minimum in the late 1980s (Fig. 43). That minimum was as low as one in the mid-1960s at St. Andrews but at Boothbay Harbor the minimum was only slightly below normal. In 2000, the annual mean temperature at these two sites was above normal (mean of 8.1°C and 1.0°C above normal at St. Andrews and 10.1°C and 1.6°C above normal at Boothbay). At Boothbay the temperature rose relative to 1999, was the 4th warmest year in the 95-year record and is at its highest level since 1954. At St. Andrews, the annual mean temperature fell below the 1999 value, but was still the 7th warmest year in the 80-year record. Halifax had an annual mean sea surface temperature anomaly of only 0.3 °C but rose compared to 1999.

Prince 5

Temperature and salinity measurements have been taken since 1924 at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy (Fig. 44). It is the longest continuously operating hydrographic monitoring site in eastern Canada. Prior to the 1990s, data were obtained using reversing thermometers and water bottles. Since then, data have been collected with a CTD (Conductivity, Temperature, Depth) profiler. Up to and including 1997, there was only one observation per month but since 1998, multiple occupations per month have been taken. In 2000, there were 3 measurements during March and November, 2 in May-September and December and 1 in January, February, April and October. For months with multiple measurements, an arithmetic average was used to estimate the monthly mean temperature and salinity. A single observation, or even three per month, especially in the surface layers in the spring or summer, may not necessarily produce results that are representative of the true monthly "average" conditions and therefore the interpretation of the anomalies must be viewed with some caution. No significance should be placed on any individual monthly anomaly but persistent anomaly features are likely to be real. The general vertical similarity in temperatures over the 90 m water column is due to the strong tidal mixing within the Bay of Fundy.

In 2000, monthly mean temperatures ranged from a minimum in February of around 2.8°C throughout most of the water column to a maximum in August of 12.4°C near surface (Fig. 44, 45). Monthly temperature anomalies were positive except in the upper 50 m in January. The highest positive anomalies (>2°C) occurred in May throughout most of the water column and in April at the bottom. From March to October, temperature anomalies were over 1°C above normal. This represents the third consecutive year of relatively warm temperatures. The annual mean temperatures exhibit high year to year variability (Fig. 45). In 2000, annual anomalies were approximately 1°C through the water column and were similar to those recorded in 1999. With the exception of the negative anomalies in the early 1990s, temperatures at Prince 5 have generally been warmer than their long-term means since the mid-1970s at the surface and the late-1960s near bottom. The maximum annual temperatures at this site occurred in the early 1950s and the minimum in the mid-1960s.

Salinities at Prince 5 during 2000 were saltier-than-normal except in April and May (Fig. 44, 46). The lowest salinities (<29 psu) occurred at the surface in April and the highest salinities (>33 psu) appeared near bottom in the autumn (Fig. 44). The former represented an anomaly of –2 and is most likely due to an early arrival or great quantity of St. John River runoff. The arrival of higher salinity waters in autumn is typical. Time series show that the annual salinity anomalies in 2000 were positive and although similar to 1999 values at both the surface and 90 m, they fell slightly (Fig. 46). There have been large fluctuations in salinity but the longer-term trends show that salinities generally freshened from the late 1970s to at least the late-1990s with the lowest salinities on record at Prince 5 occurring in 1996. These salinity changes parallel events in the deep waters of Jordan and Georges Basin and appear to be related to advection from areas further to the north (Smith, 2001). Salinities rose above normal by 1999.

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Centre in Narragansett, Rhode Island, has collected expendable bathythermograph (XBT) data approximately monthly from ships-of-opportunity since the late 1970s. The XBTs are dropped along a transect in the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf as part of their continuous plankton recorder program. We grouped the available data into 10 equally spaced boxes along the transect, and then averaged by month any data within these boxes at standard depths. Data for 2000 were available in 8 months of the year.

Data from April and November 2000 are shown together with the site locations (centre of the boxes) in Fig. 47. The upper layer temperatures in April increased from the Scotian Shelf (<7ºC) towards the western Gulf of Maine (>9ºC). In November the horizontal gradients near surface were weaker and the Scotian Shelf waters were warmer. Bottom layer temperatures ranged between 5° and 10°C. The cool subsurface waters in April is most likely the out flowing "cool pool" waters formed from in situ cooling in winter. Temperatures in 2000 were generally warmer than their long-term means. The highest anomalies were in the surface waters in April (+4 °C) with high subsurface values especially on the Scotian Shelf side of the Gulf (1º-3ºC). The surface anomalies are consistent with the high air temperatures while the subsurface anomalies are most likely due to an influx of warmer-than-usual slope water. The pattern of warm subsurface temperature anomalies in the east persisted throughout the other months of 2000 where data were available. These conditions are similar to 1999.

Halifax Line Station 2

A standard monitoring site was established in 1998 on the Scotian Shelf at Station 2 on the Halifax Line (H2, Fig. 42). It is situated approximately 30 km off the entrance to Halifax Harbour in about 150 m of water at the inner edge of Emerald Basin. It was considered far enough offshore to avoid contamination by high frequency upwelling and downwelling but close enough to shore to be able to be monitored on a monthly basis using small vessels. Hydrographic measurements are taken using a CTD and nutrient and biological samples taken. In this paper we only report on the hydrographic information. The long-term (1961-90) monthly means of temperature, salinity and density (sigma-t) for 1961-90 were discussed in Drinkwater et al. (2000).

Temperatures at H2 ranged from less than 2°C to over 18°C in 2000 and were predominantly warmer-than-normal (Fig. 48). Only intermediate layer waters during the last three months of the year were colder than their long-term averages. Upper layer waters in the spring and early summer were upwards of 2°-4°C warmer-than-usual. Similar amplitude anomalies were observed in the subsurface waters (deeper than 50 m), especially during the late winter and spring. This indicates that there was much less cold intermediate layer water present in 2000 than usual, being replaced by the waters with characteristics more similar to Slope Water. Consistent with this, salinities in the subsurface waters were generally saltier than normal up (by upwards of 0.5-1). The upper layer waters were fresher-than-normal in late winter and early spring and again during the last few months of the year. Salinities ranged from <31 to >34. At subsurface depths they rose during the summer, which is typical and is most likely related to coastal upwelling. In the surface layers, stratification began around May increasing in intensity through to August-September. During autumn, the surface layer heat and low salinity waters were gradually mixed down to 50 m and deeper resulting in a decrease in the depth of the isopycnals (lines of constant density or sigma-t). Sigma-t anomalies indicated large variability but generally less density water than normal in the surface waters during the first four months of the year and through much of the summer and autumn. These lower than normal densities also extended through the water column in the latter half of the year but were not much different than normal. Higher than usual densities were observed even in the surface waters in May and June. These results suggest stronger stratification during the winter and early spring and the summer with weaker stratification than normal in the late spring.

Deep Emerald Basin Temperatures

Emerald Basin is located in the central Scotian Shelf. The waters in the deep layers of the Basin underwent rapid cooling in 1998 in response to the appearance of cold Labrador Slope Water at the shelf edge in the autumn of 1997 and its subsequent transport onto the shelf (Drinkwater et al., 2000). In 1999, warm temperatures reappeared in the Basin as the Labrador Slope Water retracted northward and was replaced by Warm Slope Water. The time series of temperature anomalies at 250 m, which is reasonably representative of the lower layers from 100 m, shows this cooling and subsequent warming (Fig. 49). Dominant in the time series are the cool period of the 1960s and the relatively warm periods of the 1970s to the 1990s. In 2000, the water was warmer-than-normal by approximately 0.5°-1°C. This is up from 1999 and 1998 but below the values recorded through earlier years of the 1990s.

Other Scotian Shelf and Gulf of Maine Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities from available bottle data for irregularly shaped areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 50). Petrie et al. (1996) published a more recent atlas using these same areas but containing all available hydrographic data. In this report we produce monthly mean conditions for 2000 at standard depths for selected areas (averaging any data within the month anywhere within these areas) and compare them to the long-term averages (1961-90). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. As a result the series are characterized by short period fluctuations or spikes superimposed upon long-period trends with amplitudes of 1-2^{o}C. The spikes represent noise and most often show little similarity between regions. Thus care again must be taken in interpreting these data and little weight given to any individual mean. The long period trends often show similarity over several areas. To better show such trends we have estimated the annual mean anomaly based on all available means within the year and then calculated the 5-year running mean of the annual values. This is similar to our treatment of the Emerald Basin data.

Drinkwater and Pettipas (1994) examined long-term temperature time series for most of the areas on the Scotian Shelf and in the Gulf of Maine. They showed that the temperatures in the upper 30 m can vary greatly from month to month, due to atmospheric heating and cooling. Also, at intermediate depths of 50 m to approximately 150 m, temperatures had declined steadily from approximately the mid-1980s into the 1990s. On Lurcher Shoals off Yarmouth, on the offshore banks and in the northeastern Scotian Shelf the temperature minimum in this period approached or matched the minimum observed during the very cold period of the 1960s. This cold water was traced through the Gulf of Maine from southern Nova Scotia, along the coast of Maine and into the western Gulf. Cooling occurred at approximately the same time at Station 27 off St. John's, Newfoundland, off southern Newfoundland on St. Pierre Bank (Colbourne 1995) and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew 1997). From the mid-1990s, temperatures at these depths have been warming eventually reaching above normal values throughout the region by 2000 (Drinkwater et al. 2000). Below, we describe temperature conditions in several representative areas of the Scotian Shelf and Gulf of Maine.

On Sydney Bight (area 1 in Fig. 50) off eastern Cape Breton, mean profiles from 3 months show predominantly above normal temperatures throughout most of the water column (Fig. 51). The exception was below 100 m in July where they were slightly below normal. In August surface temperatures were over 4°C warmer-than-usual and 2°C in July. At 100 m, the high temperature anomalies in the 1950s fell to a minimum around 1960 and then rose steadily through the 1960s. Temperatures remained relatively high during the 1970s. By the 1980s temperatures began to decline and by the mid-1980s dropped to below normal with a minimum anomaly around -1°C in the early 1990s. Temperatures remained below normal through 1998, but were slowly rising from the early-1990s. Above normal temperatures were reached in 1999 and continued through into 2000.

Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 50) were collected in 7 months during 2000. They show primarily warmer-than-normal temperatures throughout the water column (Fig. 52). The only real exceptions were in the deepest layers in April, June and October. Surface anomalies tended to be high in all months with positive values of 1°-2°C. The time series of the 100 m temperature anomalies show 2000 to be the second consecutive year of positive values and contrast with the predominantly negative anomalies over the previous 15 years (Fig. 12). As in Emerald Basin, temperatures were relatively high in the 1950s. Temperatures then declined and at Misaine Bank reached a minimum around 1960, several years earlier than areas further to the southwest. Temperatures were near normal from the late-1960s to the mid-1970s before rising to a maximum in the late 1970s. By the late-1980s, temperatures fell below normal and reached a record sustained minimum of around -1°C in the first half of the 1990s. Since then, as on Sydney Bight, temperatures have been slowly but steadily increasing.

Lurcher Shoals is located off Yarmouth, Nova Scotia (area 24 in Fig. 50). This area exhibited warmer-than-normal temperatures in 2000 in the 6 months of 2000 when data were available (Fig. 53), similar to 1999. The warmest month was April when temperatures were approximately 2.5°C above normal throughout the water column. Anomalies in 4 months exceeded +1°C. The time series at 50 m clearly shows high temperature anomalies in 1999 and 2000 relative to the cold conditions over most of the past 15 years. Temperatures over Lurcher Shoals tended to be high in the late 1940s and early 1950s, declined to a mid-1960s minimum, rose rapidly into the 1970s and remained above normal into the mid-1980s. As in the northeastern Scotian Shelf, temperatures declined by the mid-1980s to below normal reaching a long-term minimum in the early 1990s. Although there had been some positive monthly temperature anomalies, annual mean temperatures and most monthly means remain below normal through the 1990s until 1999.

Georges Basin is located near the southeastern entrance to the Gulf of Maine (area 26 in Fig. 50) and is connected to the offshore slope water through the Northeast Channel. The time series of temperature in the deep regions (200 m) of Georges Basin (Fig. 54) shows a striking similarity to that of Emerald Basin including the very cold conditions in 1998 and warm in 1999 and 2000 (Fig. 49). Also, the low values in the mid-1960s, rising sharply to a peak in the early 1970s and varying slightly but generally remaining above the long-term (1961-90) mean until 1998 are similar in the two basins. This is not surprising given that the source of the waters for both is primarily the offshore slope waters (Petrie and Drinkwater, 1993).

Temperature conditions were also examined on eastern Georges Bank (area 28 in Fig. 50). The Georges Bank 50 m temperatures exhibit higher variability than many of the other sites, in large part because of its shallowness. In spite of this, the long-term trend as revealed by the 5-year running mean at 50 m, shows many similarities to those in Georges Basin and in areas on the Scotian Shelf (Fig. 55). These again include the low temperatures in the 1960s, the higher-than-average conditions in the 1970s into the 1990s. In 2000, temperatures were above normal as was observed in 1999.

Temperatures during the Summer Groundfish Surveys

The most extensive temperature coverage over the entire Scotian Shelf is obtained during the annual DFO groundfish survey, usually undertaken in July. A total of 218 CTD stations were taken during the 2000 survey and an additional 202 bottom temperature stations were obtained as part of the ITQ (Individual Transferable Quota) fleet survey. The ITQ survey fills in gaps in the DFO survey for the Bay of Fundy, off southwest Nova Scotia and in the southwestern Scotian Shelf. Temperatures from both surveys were combined and interpolated onto a 0.2° by 0.2° latitude-longitude grid using an objective analysis procedure known as optimal estimation. The interpolation method uses the 15 "nearest neighbours" and a horizontal length scale of 30 km and vertical length scale of 15 m in the upper 30 m and 25 m below that. Data near the interpolation grid point are weighted proportionately more than those further away. Temperatures were optimally estimated onto the grid for depths of 0, 50, 100 m and near bottom (Fig. 56). Maximum depths for the interpolated temperature field were limited to 1000 m off the shelf. The 2000 temperature anomalies relative to the July 1961-90 means were also computed at the same four depth levels (Fig. 15).

The broad spatial pattern of near-surface temperatures in July 2000 was similar to past years with the warmest waters (17°C) off the northeastern coast of Nova Scotia and the coldest (<11°C) in the Gulf of Maine/Bay of Fundy region (Fig. 56a). The cooler surface temperatures in the Gulf of Maine compared to the Scotian Shelf are due to the intense bottom-generated vertical mixing caused by the high tidal currents. The surface temperatures in 2000 were warmer than the long-term average throughout the northeastern Scotian Shelf whereas in the central and southeastern region of the Shelf the temperatures varied above and below normal (Fig. 57a). The maximum anomaly was over 4°C above normal off southern Cape Breton. Surface temperatures off southwest Nova Scotia were also warmer-than-usual by upwards of 2°C. This contrasts with the colder-than-normal temperatures in the Bay of Fundy, Northeast Channel and the outer central Shelf region. The generally warm conditions are consistent with the satellite imagery which has shown high sea surface temperature anomalies throughout the Scotian Shelf during much of 2000 (Drinkwater et al., 2001). Relative to 1999, the surface temperatures in 2000 generally decreased. This is not surprising given the extremely warm sea surface temperatures experienced during 1999, which in turn were due to record high air temperatures. This excess heat in the atmosphere would have lead to increased heat flux from the air to the ocean. Although air temperatures in 2000 were also generally above their long-term means, they were not as warm as in 1999. One exception to the cooler waters in 2000 compared to 1999 was off the southwest coast of Nova Scotia. In 1999, this was an area of active upwelling. The warmer-than-normal waters in 2000 suggest that there was less upwelling than normal.

The temperatures at 50 m ranged from 2-3°C to over 9°C with the coldest waters in the northeast and the warmest waters in the deep Gulf of Maine and the Bay of Fundy (Fig. 56a). There appears to be some penetration of warmer offshore waters (>6°C) in towards Emerald Basin. Temperature anomalies at 50 m (Fig. 57a) were predominantly positive over the Shelf (mostly 1°-2°C). Slightly below normal temperatures appeared along the shelf break. These must be regarded cautiously, however, due to the limited data in this region.

The spatial pattern of the 100 m temperatures resembles that at 50 m although the actual temperatures are higher (Fig. 56b). The temperatures at 100 m ranged from 2-3°C in the northeast to over 9°C in the Northeast Channel and Emerald Basin. The analysis also suggests the possibility of 10°C water along the shelf break but again data in this region must be viewed cautiously. Temperature anomalies at this depth were typically 0°-1°C in the northeast and 1°-2°C over most of the rest of the Shelf (Fig. 57b). The highest anomalies (>3°C) occurred along the inner shelf off the Nova Scotia coast near Halifax. This would appear to be due to a greater than usual inshore penetration of slope waters and is consist with the data collected at the Halifax 2 Station (Fig. 48).

Near-bottom temperatures over the Scotian Shelf ranged from 3°-4°C in the northeastern Scotian Shelf to over 10°C in the Bay of Fundy (Fig. 56b). High temperatures (>9°C) were also observed in the Northeast Channel and in Emerald and LaHave Basins. The pattern of colder temperatures in the northeastern Shelf and warmest in the Gulf of Maine with relatively warm waters in the deep basins of the central Shelf is typical. The colder waters are largely derived from the Gulf of St. Lawrence while in the deep basins of the Scotian Shelf and the Gulf of Maine, the waters mainly originate from the warmer offshore slope waters. The warm waters around Sable Island are due to the shallow depths and hence the close proximity to the warm surface mixed layer. Elsewhere on the shelf the bottom depths lay well below the mixed surface layer. Relative to the long-term mean (1961-90), the near bottom temperatures were predominantly warmer-than-normal (Fig. 57b). Similar to 100 m, the temperature anomalies on the northeastern Scotian Shelf were generally 0°-1°C and over the rest of the region were 1°-2°C. The largest deviation from the long-term mean (warmer by around 2°C) occurred just off the mainland coast of Nova Scotia, on Middle Bank in the northeast and at a couple of locations near the shelf edge.

We also estimated the area of the bottom covered by each one degree temperature range (i.e. 1-2°C, 2-3°C, 3-4°C, etc.) within NAFO Subareas 4Vn, 4Vs, 4W and 4X (see Fig. 42 for Subarea boundaries). These were obtained from optimally estimated temperatures from the July groundfish and ITQ surveys. The time series for each NAFO Subarea are shown in Fig. 58a,b. Several points are noteworthy. First is the increase in temperature from 4Vs/4Vn to 4W and 4X. In 4Vn most of the bottom is covered by waters <6°C and almost 50% <5°C (Fig. 58a). For 4Vs, 80-90% is <6°C and 75% <5°C (Fig. 58a). In 4W <50% and in 4X<20% is covered by temperatures <6°C (Fig. 58b). The time series for 4Vn and 4Vs show an increase in the 0°-1°C and especially <3°C waters during the late 1980s and early 1990s (Fig. 58a). Also in 4Vs there are waters <1°C during this colder period. In 4W there is an increase in the area of the waters <3°C but it is of smaller amplitude than in 4V (Fig. 58b). In 4X there is an increase in waters <4°C but it is not as large an amplitude as in the other regions (Fig. 58b). During 2000 in all areas there was a significant decrease in the area covered by temperatures in the colder temperature ranges.

Halifax Line

Seasonal sampling along the historical standard sections was re-established by the Canadian Department of Fisheries and Oceans in 1998. On the Scotian Shelf this included transects off Cape Sable, Halifax, Louisbourg and across Cabot Strait (Fig. 42). While four occupations per section has been the goal, this has not been achieved for all sections due primarily to budgetary constraints. Dedicated monitoring cruises have provided some of the section data while others have been obtained from fisheries surveys. In 2000, dedicated cruises were run during April and October and some of the sections were derived from data collected during the July survey. Similar to the standard stations, the data collected usually include CTDs, nutrient and chemical sampling and plankton. Only the hydrographic data from the Halifax Line are discussed in the present paper as it is the only transect were there are enough data to construct realistic long-term means. At the other sections, the historical data were considered of insufficient quantity to determine reliable means for this time period.

The Halifax Line was occupied 3 times in 2000 (April, June and October). Contours of temperature, salinity and sigma-t across the section are shown in Fig. 59, 60 and 61, respectively. In all three months, there is evidence of Warm Slope Water (temperatures, >8°C; salinities >34.8) along the shelf edge. Waters in the deep Emerald Basin in all months display temperatures and salinities characteristic of the Warm Slope Water. Seasonal warming and freshening are also clearly evident in the upper layers, which result in increased stratification from spring through to the summer and into the autumn. Minimum temperatures (<6°C) in the cold intermediate layer are located near shore. Relative to the long-term means, temperatures were predominantly above normal throughout the water column. High positive anomalies (>3°C) occurred over Emerald Basin at depths of 30-100 m in April (Fig. 59), between 20-30 m in June (Fig. 60) and in October (Fig. 61). The only exceptions to the warmer-than-normal conditions appeared near bottom on Emerald Bank in April and June and above Emerald Bank (20-50 m) in October. Also, temperatures at the farthest offshore stations were lower-than-normal and salinities fresher-than-normal. Salinites were predominantly saltier-than-normal during 2000. Exceptions in addition to the offshore waters in October were on the outer edge of Emerald Bank in April and June and in the inshore half of the shelf in April (surface only) and October. These resulted in generally lower-than-normal densities in the surface waters and higher-than-normal in the deep waters (>50-100 m). Consequently the vertical stratification was stronger than normal.

Compared to 1999, temperatures in Emerald Basin appears warmer and fresher in 2000. While surface layer temperatures were generally warmer in 1999, at intermediate layer depths temperatures they were warmer in 2000. Salinities in 2000 tended to be fresher than in 1999 in the upper layers but saltier in the deeper layers. Stratification appeared stronger in 1999.

Density Stratification

Stratification of the upper water column is an important characteristic that influences both physical and biological processes. Stratification can affect the extent of vertical mixing, the vertical structure of the wind forcing, the timing of the spring bloom, vertical nutrient fluxes and plankton speciation to mention just a few. Under increased stratification, there is a tendency for more primary production to be recycled within the upper mixed layer and hence less available for the deeper, lower layers. We examined the variability in stratification by calculating the density (sigma-t) difference nominally between 0 and 50 m. The density difference was based on a monthly mean density profile calculated for each area in Fig. 50. The long-term monthly mean density gradients for the years 1961-90 were estimated and these then subtracted from the monthly values to obtain monthly anomalies. Annual anomalies were estimated by averaging all available monthly means within a calendar year. A 5-yr running mean of the annual anomalies was then calculated. The monthly and annual means show high variability but the 5-yr running means show some distinctive trends. The density anomalies are presented in g/ml/m. A value of 0.1 represents a difference of 0.5 a sigma-t unit over the 50 m. As reported last year (Drinkwater et al., 2000), the dominant feature is the higher stratification during recent years throughout the Scotian Shelf (Fig. 62a,b). The 5-year running mean began to increase steadily around 1990 and the most recent values are at or near the highest values in the approximate 50-year records in most areas. The 2000 values confirm a continuation of high stratification but there has been a general decrease in its strength during the past two years. There is surprising consistency from area to area, over the Scotian Shelf. This higher-than-average stratification does not extend into the Gulf of Maine region and tends to be absence or weak in the Laurentian Channel and Sydney Bight areas. One expects the anomalies in density stratification in the Gulf of Maine to be lower than on the Scotian Shelf due to the more intense tidal mixing in the former. Examination of the temperature and salinity characteristics reveals that the primary cause of the increased stratification was due to changes in surface salinity, although in 2000 the high surface temperatures also contributed.

Frontal Analysis

Shelf/Slope Front

The waters on the Scotian Shelf and in the Gulf of Maine have distinct temperature and salinity characteristics from those found in the adjacent deeper slope waters offshore. The relatively narrow boundary between the shelf and slope waters is regularly detected in satellite thermal imagery. Positions of this front and of the northern boundary of the Gulf Stream between 50°W and 75°W for the years 1973 to 1992 were assembled through digitization of satellite derived SST charts (Drinkwater et al., 1994). From January 1973 until May 1978, the charts covered the region north to Georges Bank, but in June 1978 the areal coverage was extended to include east to 55°W and eventually 50°W. Monthly mean positions of the shelf/slope front in degrees latitude at each degree of longitude were estimated. NOAA updated this data set until the termination of the satellite data product in October 1995. A commercial company has continued the analysis but did not begin until April 1996. These initial charts did not contain data east of 60°W but within a year were extended east to 56°W. Data for 2000 have been digitized, estimates of monthly means positions determined and anomalies relative to the 20 year period, 1978 to 1997, were calculated.

The overall mean position of the Shelf/Slope front together with the 2000 annual mean position is shown in Fig. 63. The average position is close to the 200 m isobath along the Middle Atlantic Bight, separates slightly from the shelf edge off Georges Bank and then runs between 100-300 km from the shelf edge off the Scotian Shelf and the southern Grand Bank. It is generally furthest offshore in winter and onshore in late summer and early autumn. During 2000, the shelf/slope front was shoreward of its long-term mean position except at its eastern end. The largest positive deviations occurred just east of Cape Hatteras. The time series of the annual mean position (averaged over 56°W-75°W) shows the front was at a maximum seaward location in 1985 and again in 1993. Since 1993, the front moved steadily seaward approximately 40 km, reaching its most southerly position in 1997. During 1998 through 2000, the position of the Shelf/Slope front moved northward with the largest increased recorded in 1999. The position in 2000 was near to but slightly farther north than in 1999.

Gulf Stream

The position of the northern boundary or "wall" of the Gulf Stream was also determined from satellite imagery by Drinkwater et al. (1994) up to 1992 and has been updated in a manner similar to that for the shelf/slope front. Thus, the time series consists of the monthly position at each degree of longitude from 56°W to 75°W. The average position of the north wall of the Stream and the 2000 annual mean is shown in Fig. 64. The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position lies approximately east-west. During 2000, the average position of the Stream was shoreward of its long-term mean position at all degrees of longitude except 75°W and 64°W. The time series of the position shows the Stream was located south of its mean position during the late-1970s and 1980, near the long term mean through most of the 1980s and north of it during the late-1980s and into the first half of the 1990s (Fig. 64). The annual anomaly of the Gulf Stream was at its most northerly position in 1995. This was followed by a rapid decline in 1996 and remained low through 1997 and 1998. The 1996 position is not well defined, however, since it is based upon only three months of the data (October to December). In 1999, the average position of the front moved shoreward but remained south of the mean. By 2000 the position of the Gulf Stream was shoreward of its long-term mean and was the 2nd highest positive anomaly behind only 1995. The trend roughly matches that of the NAO index.

Summary

During 2000, the NAO index was high and of similar magnitude to that recorded during 1999. Air temperatures over most of the Northwest Atlantic were above normal but declined relative to the 1999 record setting temperatures from southern Labrador to eastern Gulf of Maine. The exception to the warm conditions was at Boston where available air temperatures indicate colder-than-normal conditions. The relatively warm winter temperatures resulted in less ice than normal off Newfoundland and Labrador, and in the Gulf of St. Lawrence. Ice generally arrived late or on schedule but left early, causing fewer days of ice in these areas. Little ice reached the Scotian Shelf proper and seaward of Cabot Strait the amount of ice was the 6th lowest in the 39-year record. The number of icebergs that reached the Grand Banks was 843, significantly higher than 1999 when only 22 bergs were spotted on the Banks.

Past studies have shown that high NAO years usually bring cold air temperatures and extensive ice off Newfoundland and Labrador (Colbourne et al., 1994; Drinkwater et al., 1996). This was not the case in 2000, or in 1999. In these years, warm conditions over much of eastern Canada, especially in winter, were due to the extended influence of the Azores High and its associated southerly winds.

Analysis of satellite-derived sea-surface temperature has shown that on the annual time scale, there is broad-scale, coherent variability from the Gulf of Maine to the Labrador Shelf with predominantly above normal temperatures in 2000.

During 2000, warm conditions dominated in the Newfoundland and Labrador regions. Although the waters at Station 27 cooled slightly compared to 1999, they remained above their long-term means. Near bottom, the waters were warm through the first half of the year but became cooler-than-normal later in the year. The amount of CIL waters (<0ºC) increased and the minimum core temperatures decreased slightly in 2000 compared to 1999. The CIL area was below normal on southern Labrador Shelf, near normal on the northern Newfoundland Shelf and slightly below normal on the Grand Bank. Bottom temperatures during the groundfish surveys revealed above normal temperatures although a temperature decrease was observed in the autumn compared to early months. This is consistent with conditions at Station 27. Salinities during 2000 were similar to 1999 values, generally fresher-than-normal thorughout most of Newfoundland and Labrador waters and continues the trend observed during most of the 1990s.

In the Gulf of St. Lawrence during 2000, temperatures over the Magdalen 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. In the northern Gulf, the results from the ground fish surveys suggests that there is a tendency to above normal bottom temperatures in most regions, with the highest values along the west Newfoundland coast.

For the second consecutive year, warm conditions were prevalent throughout the Scotian Shelf and Gulf of Maine at all depths. Coastal sea surface temperatures, the fisheries surveys in July and other CTD stations all indicate that surface temperatures were well above normal. Subsurface temperatures in the northeastern portions of the Scotian Shelf continued their warming trend and were above normal throughout the region. This follows nearly 15 years of below normal temperatures with the minimal temperatures recorded in the early to mid-1990s. Waters in the deep basins both on the Shelf and in the Gulf of Maine indicate continuance of the warm conditions re-established in 1999 after the cold waters of 1998. Near bottom temperatures throughout the Scotian Shelf were also above normal with the area of bottom covered by the colder temperatures having decreased significantly. The cold intermediate layer waters emulating from the Gulf also appeared to be warmer-than-usual. Warm Slope Water was located offshore and there was no evidence of Cold Slope Water along the Scotian Shelf or off the Gulf of Maine during 2000. While the vertical stratification in the upper water column (between surface and 50 m) over the Scotian Shelf generally weakened in 2000 relative to 1999, it remained higher than normal. This high stratification was not observed in the Gulf of Maine. The Shelf/Slope Front and the Gulf Stream were well seaward of their normal positions. For the Gulf Stream it was the 2nd most seaward position in the 29-year record.

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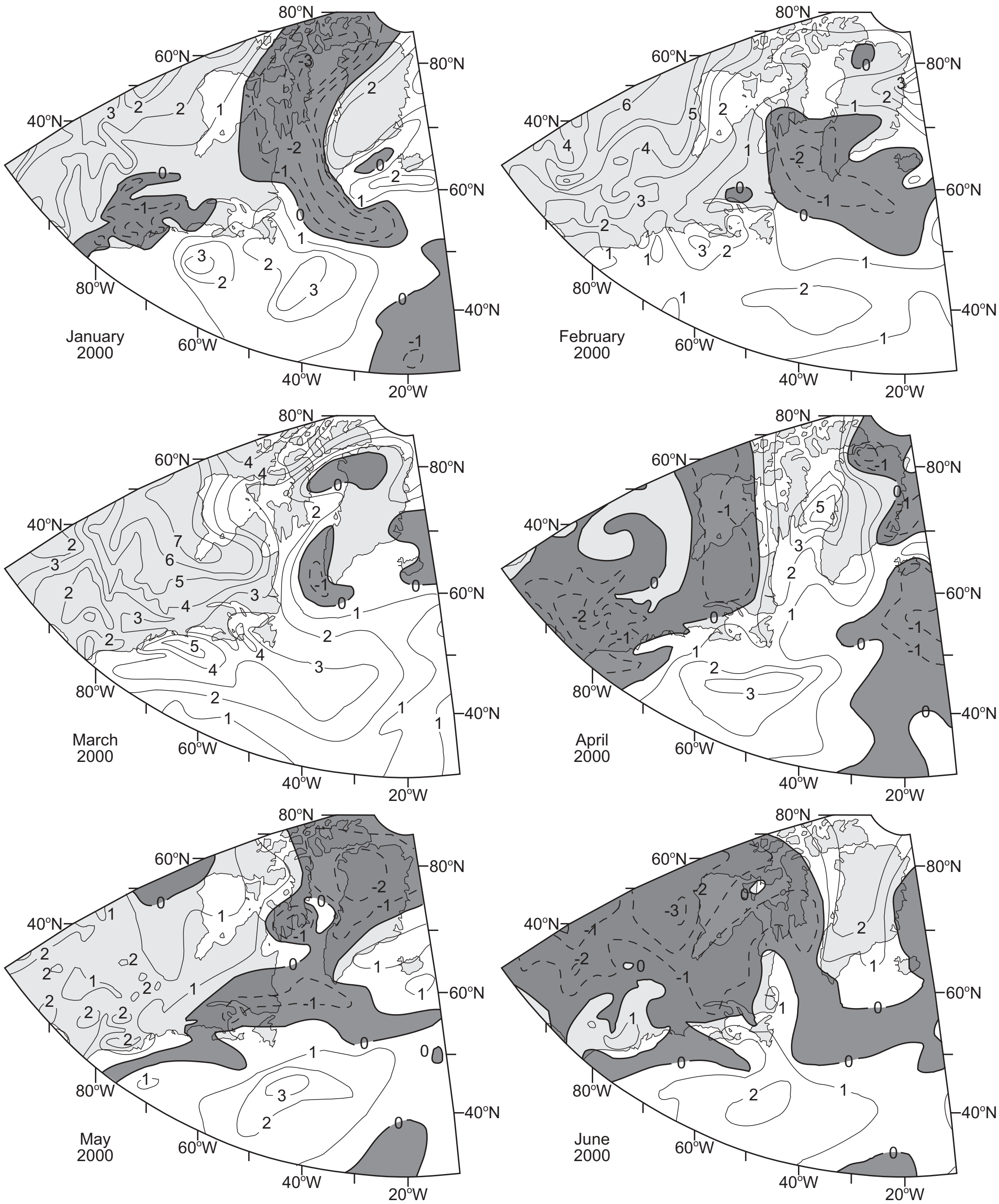


Fig. 1. Monthly air temperature anomalies (°C) over the Northwest Atlantic in 2000 (January-June) relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

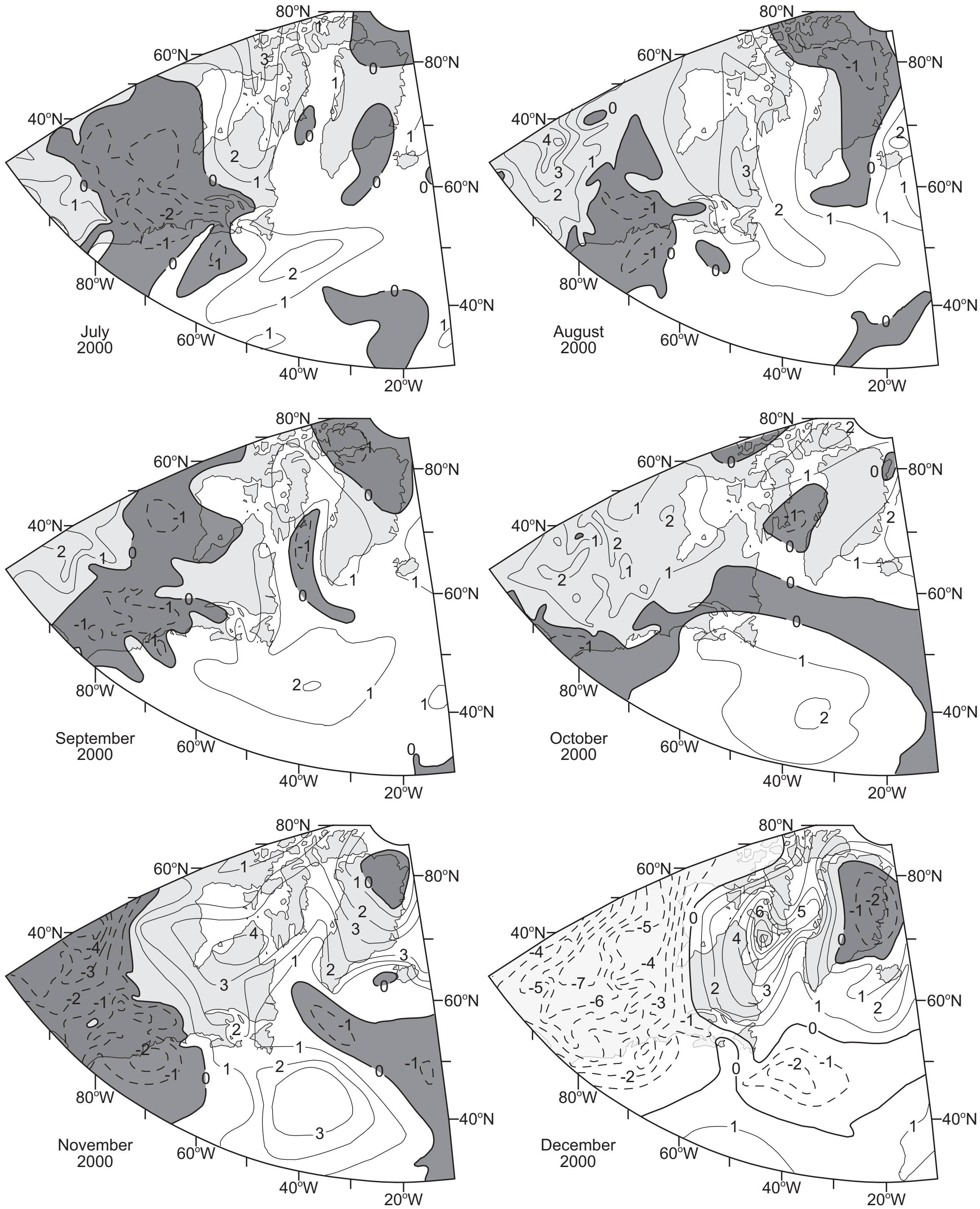


Fig. 2. Monthly air temperature anomalies (^{o}C) over the Northwest Atlantic in 2000 (July-December) relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

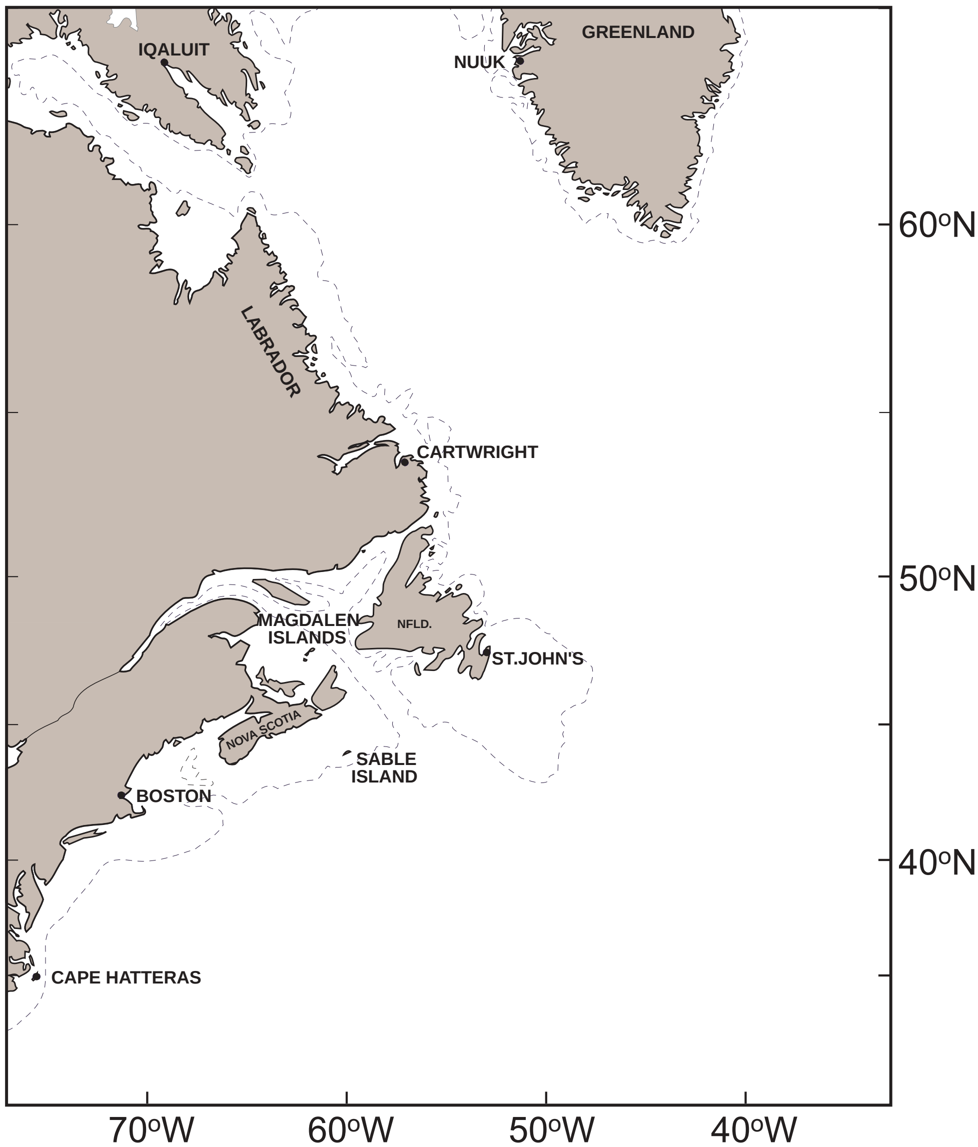


Fig. 3. Northwest Atlantic showing coastal air temperature stations. The dashed line denotes the 200 m isobath.

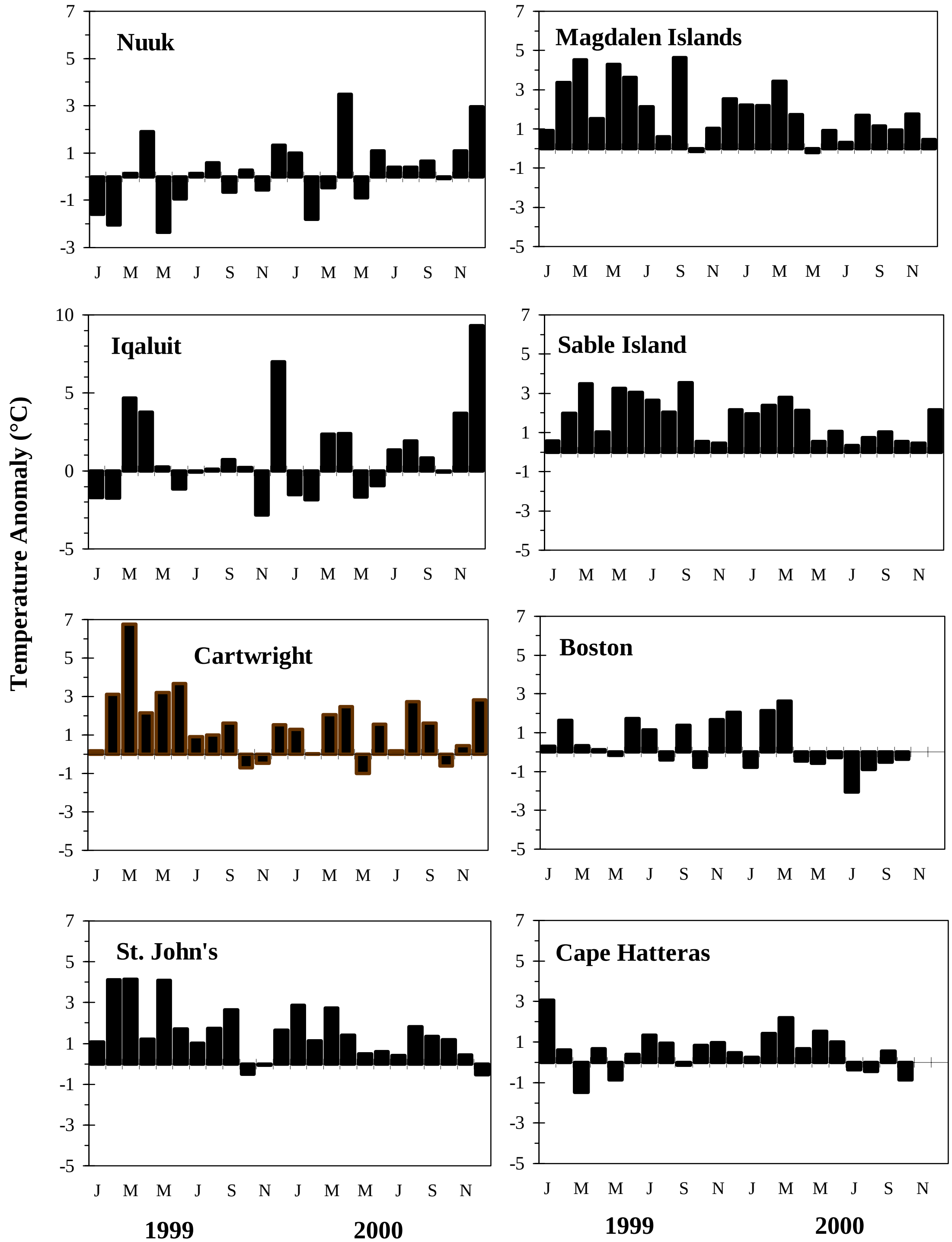


Fig. 4. Monthly air temperature anomalies in 1999 and 2000 at selected coastal sites (see Fig. 3 for locations).

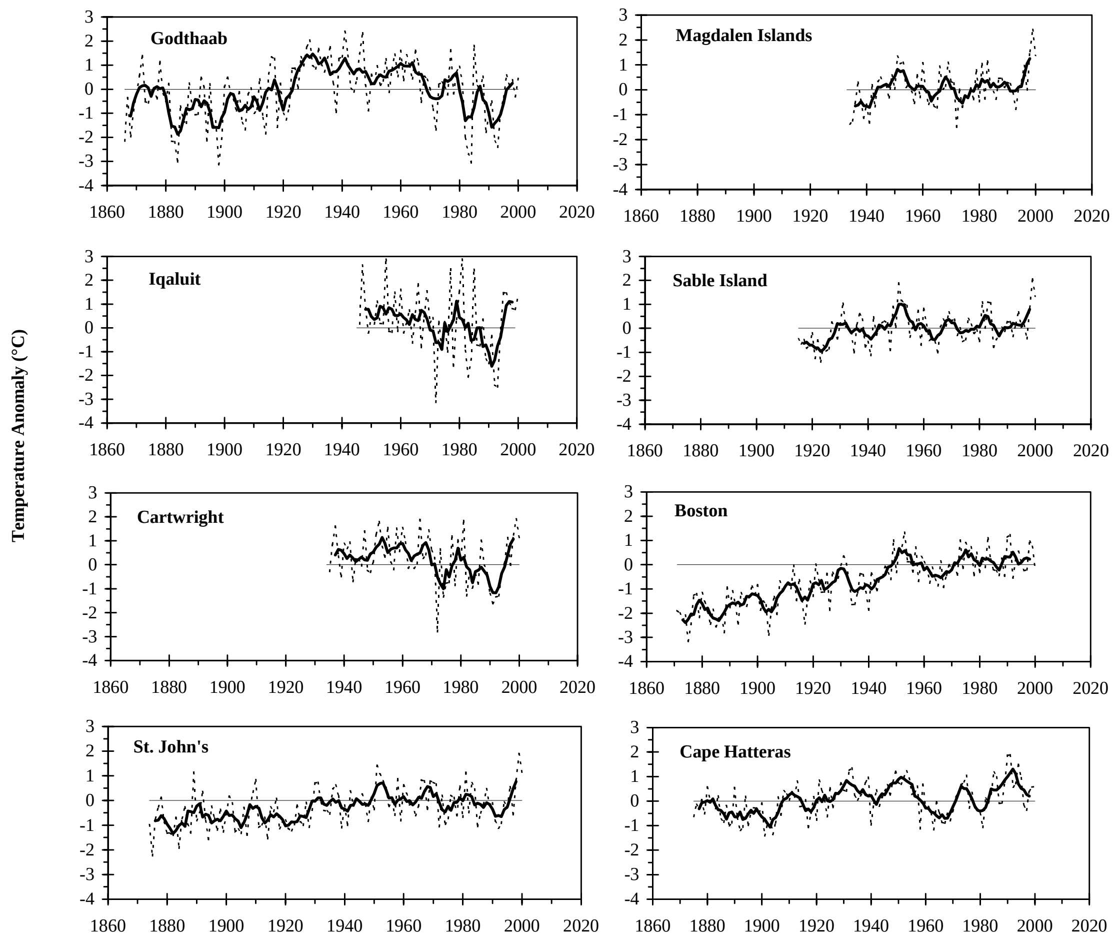


Fig. 5. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

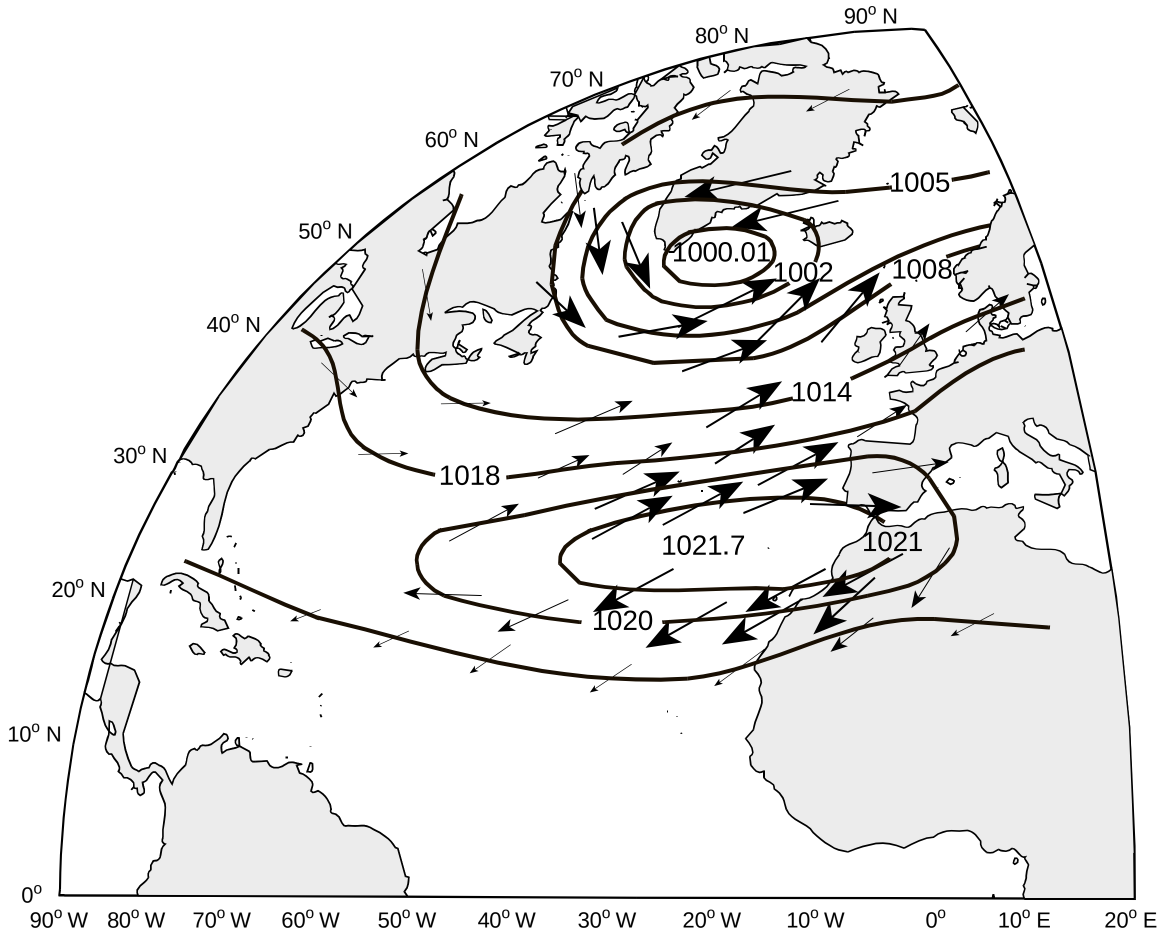


Fig. 6. The long-term (1961-90) mean sea surface pressures during winter (average of December, January and February) and a schematic of the associated wind field.

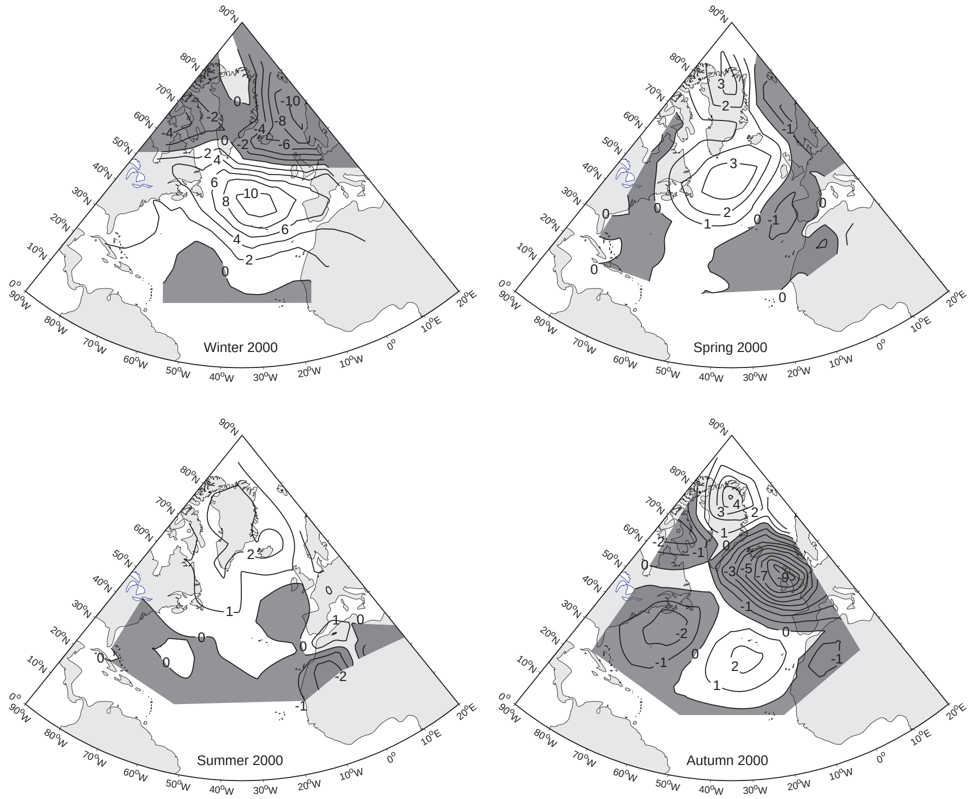


Fig. 7. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2000 relative to the 1961-90 means.

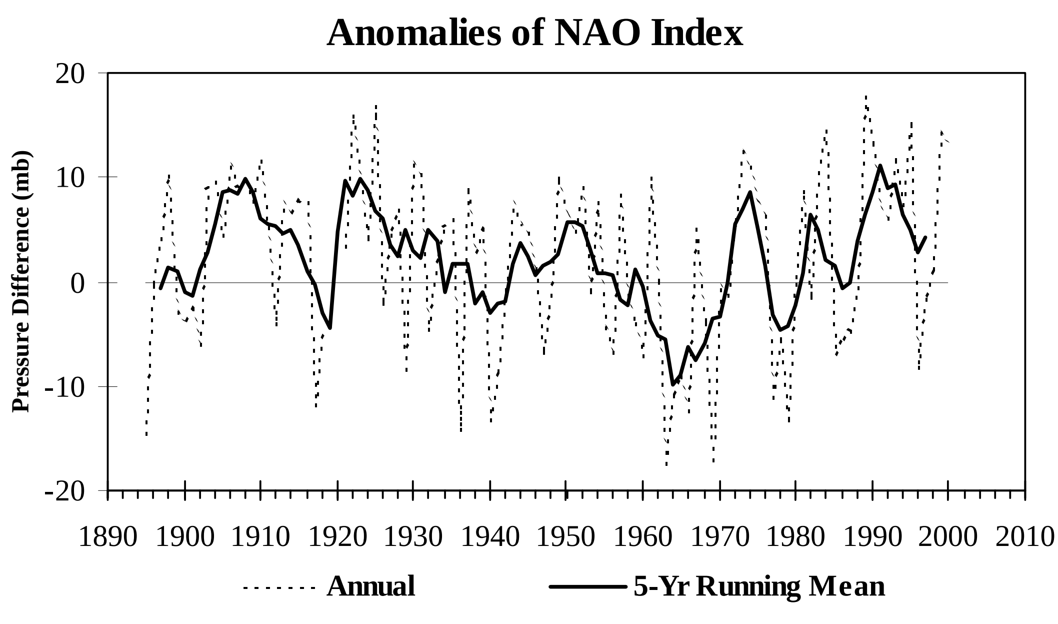


Fig. 8. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1961-90 mean.

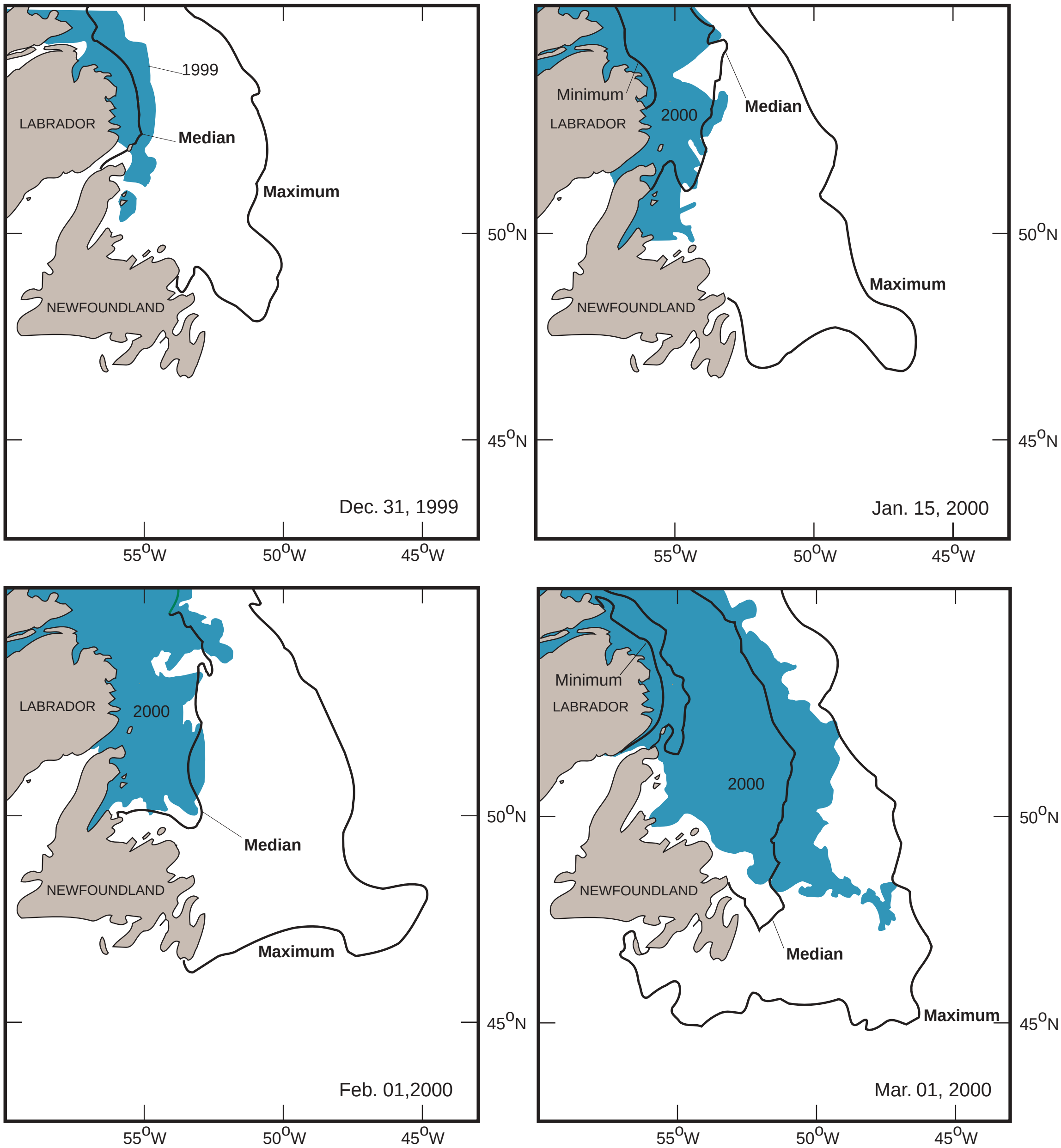


Fig. 9a. The location of the ice (shaded area) between December 1999 and March 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

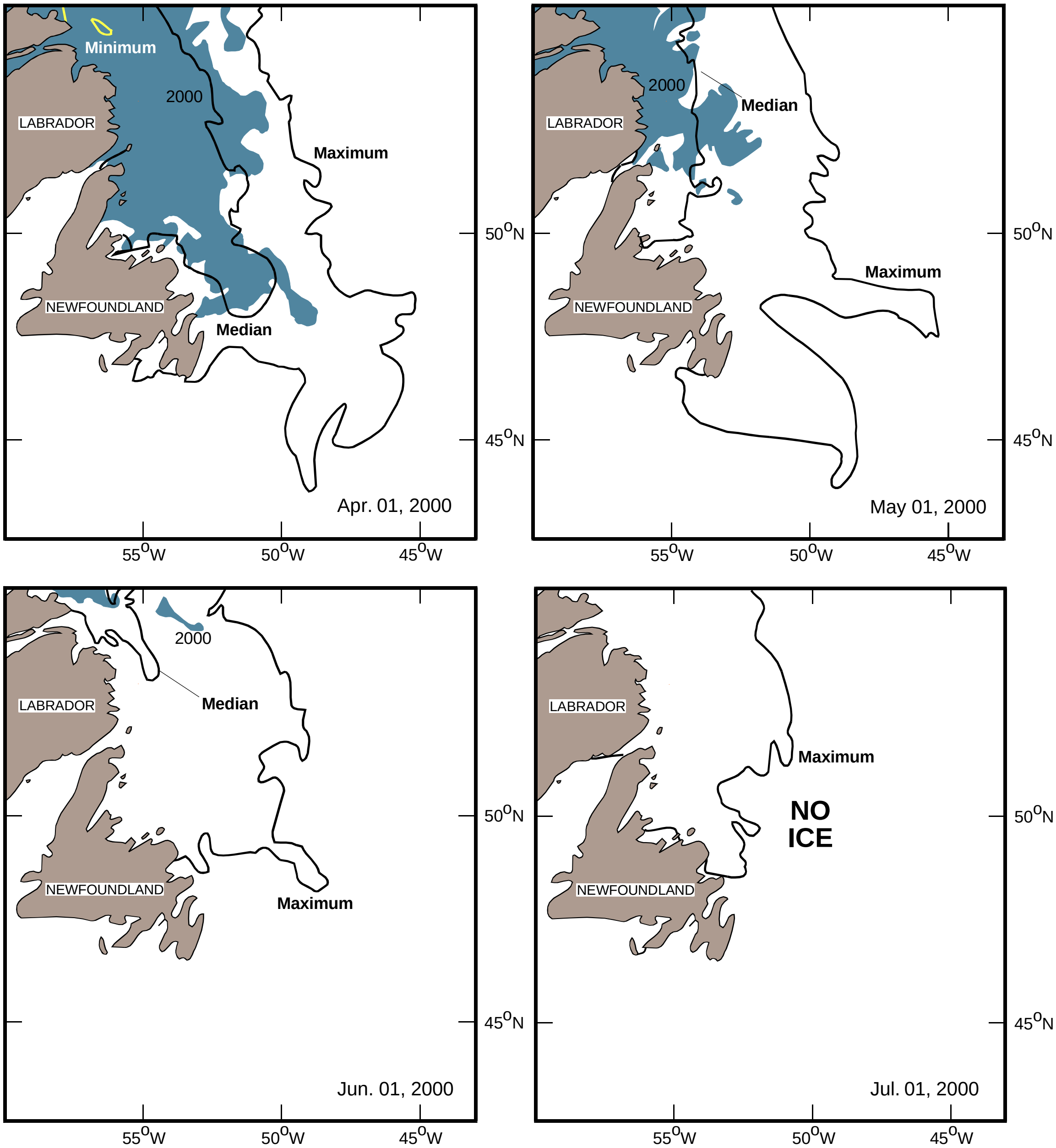


Fig. 9b. The location of the ice (shaded area) between April and July 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

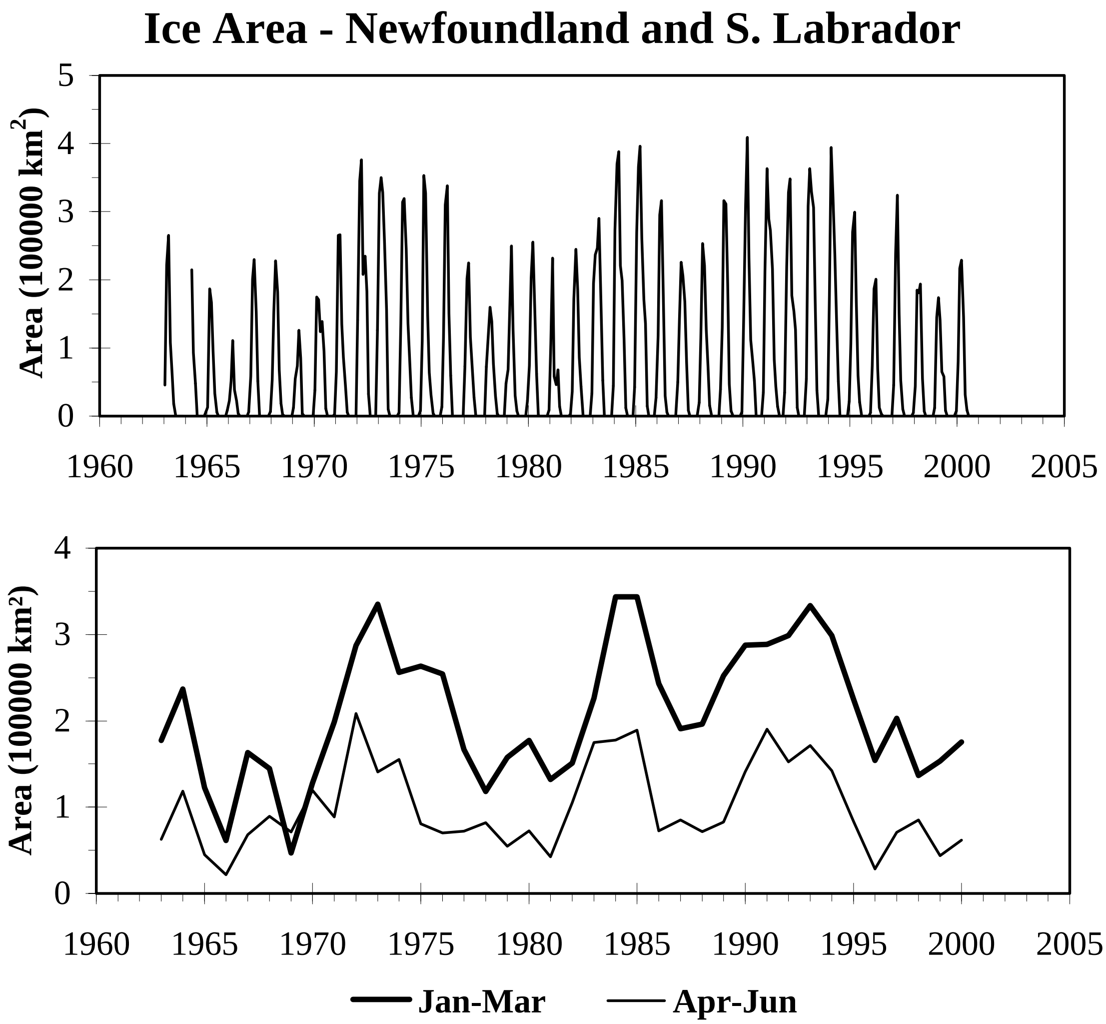


Fig. 10. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

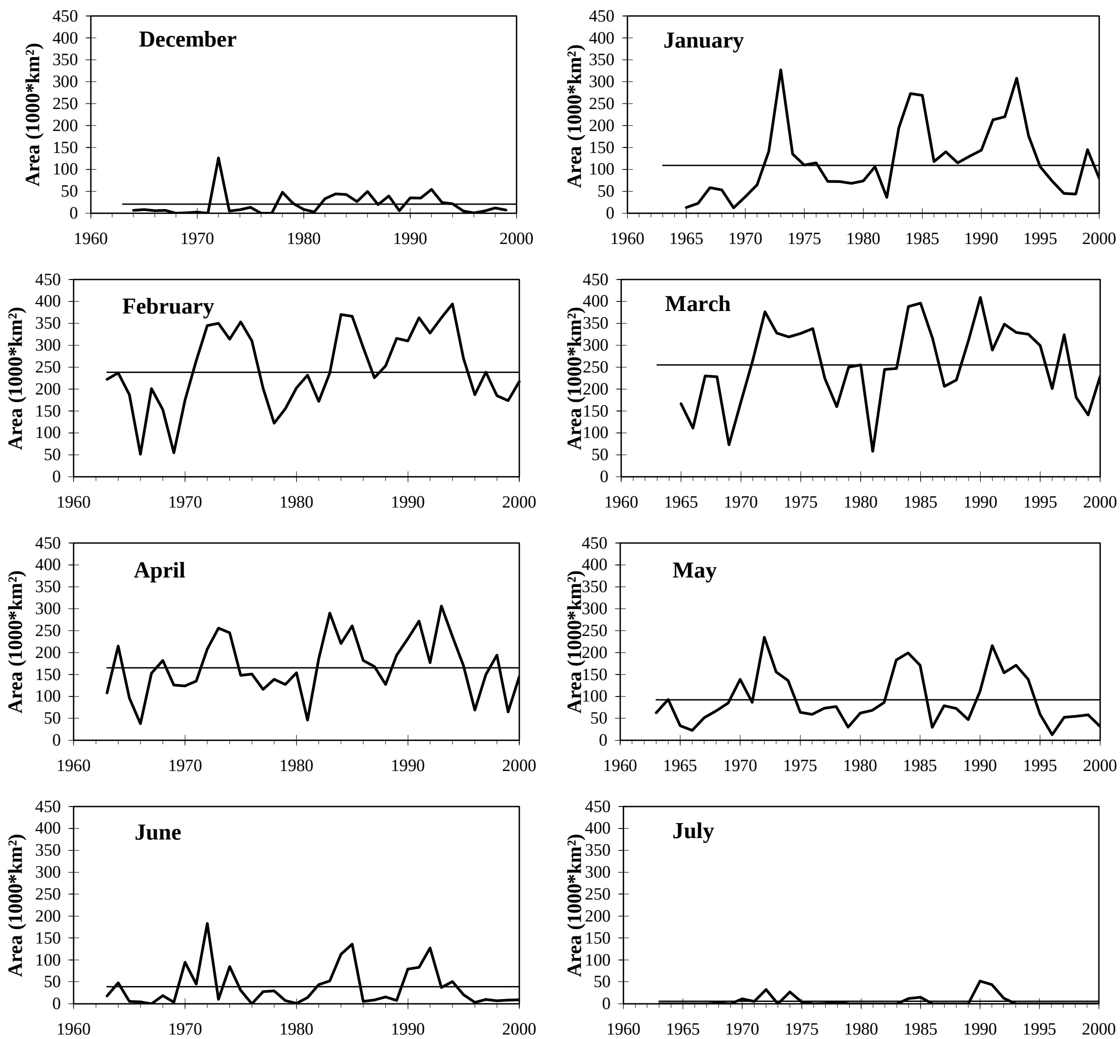


Fig. 11. The time series of ice area off Newfoundland and Labrador, by month. The horizontal lines represent the long-term (1963-90) means.

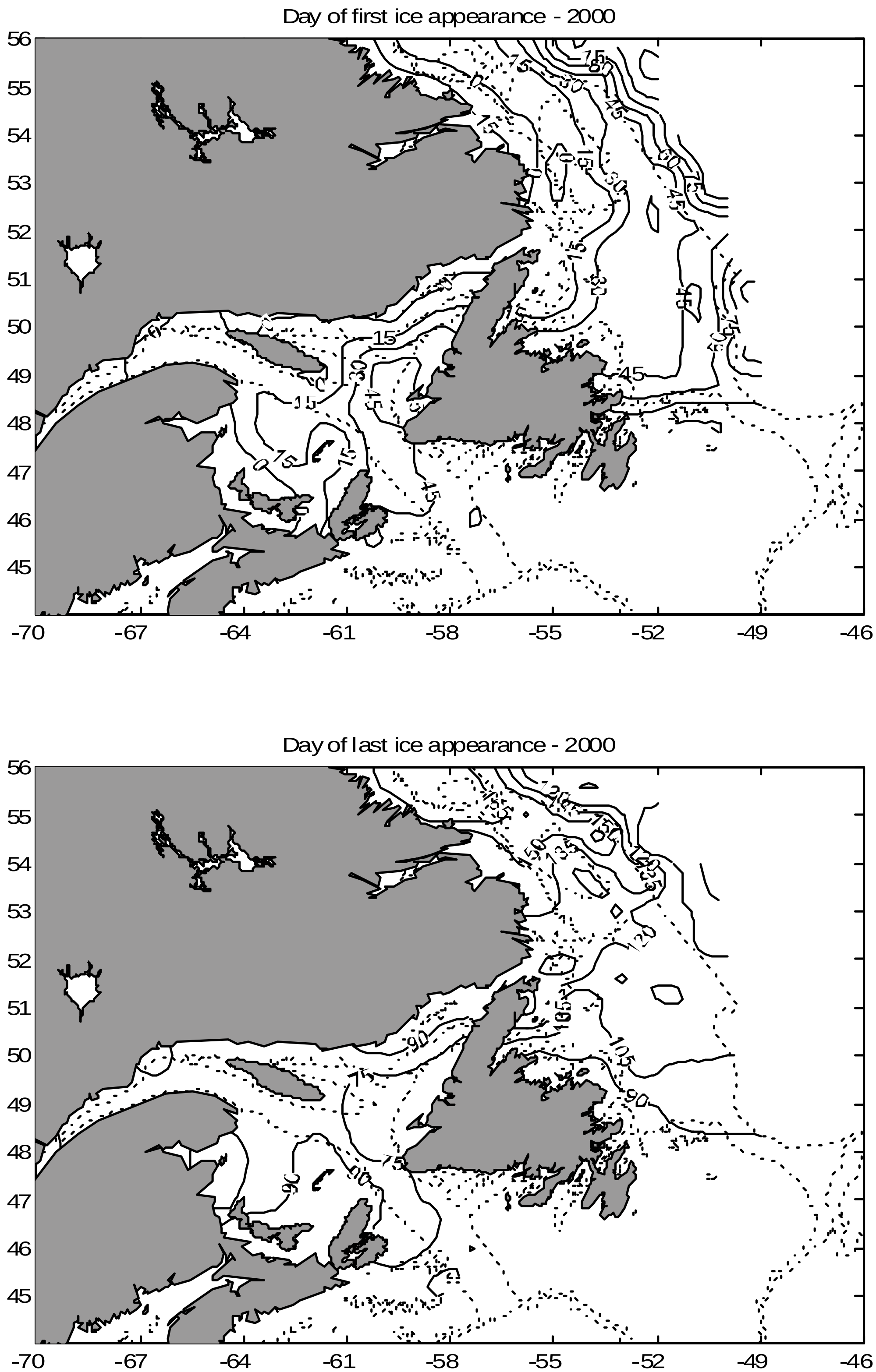
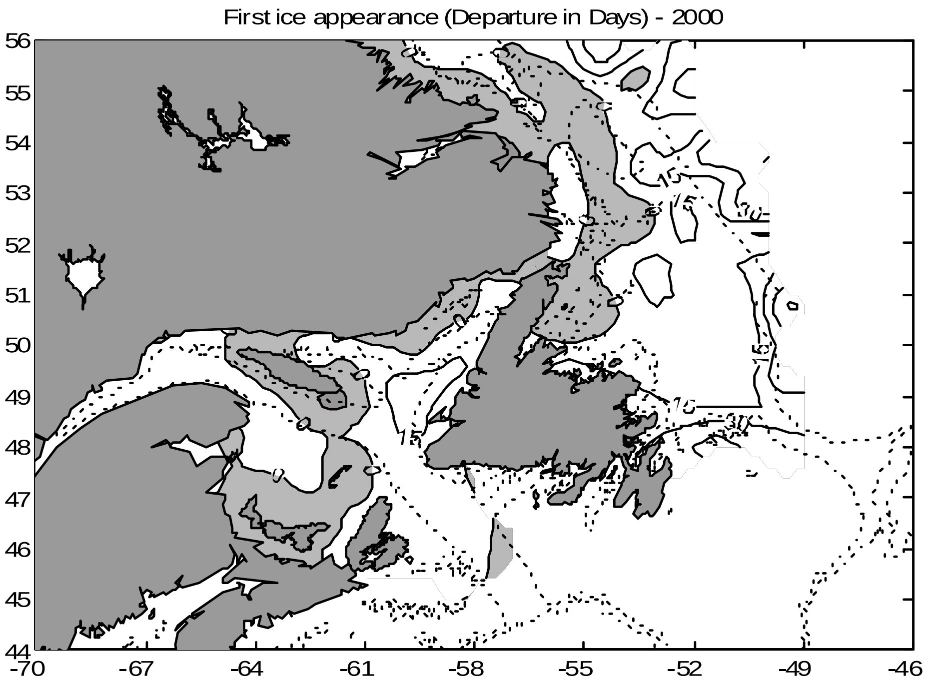


Fig. 12. The time when ice first appeared (top panel) and last appeared (bottom panel) during 2000 in days from the beginning of the year.



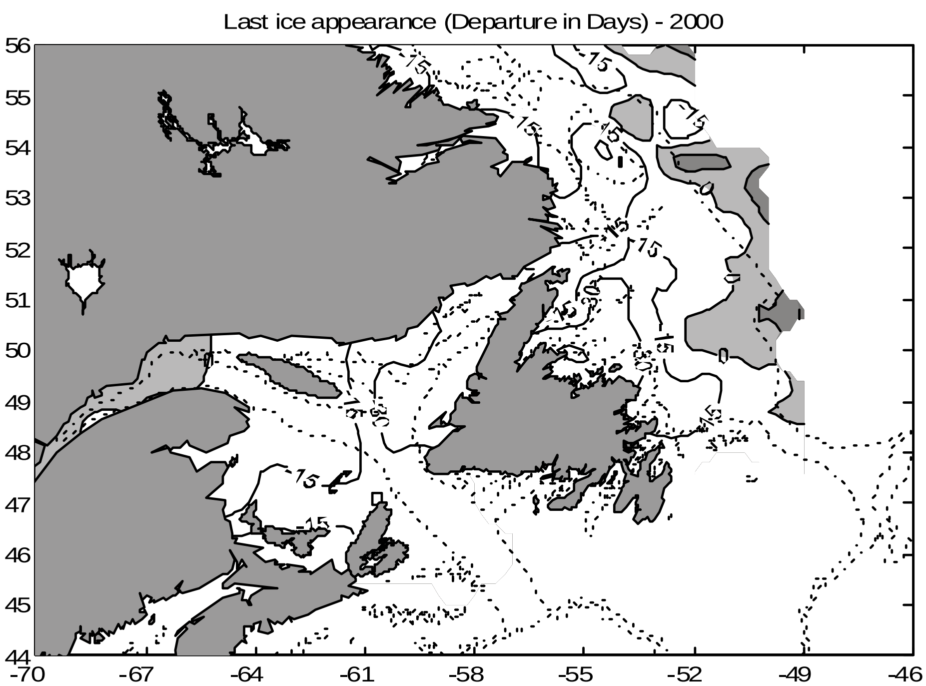


Fig. 13. The anomaly of the time when ice first appeared (top panel) and was last reported (bottom panel) during 2000 in days from the beginning of the year. Negative anomalies indicate earlier-than-normal and positive are later-than-normal. The shaded anomalies indicate conditions generally associated with cold years, i.e. earlier ice appearance and later-than-normal disappearance.

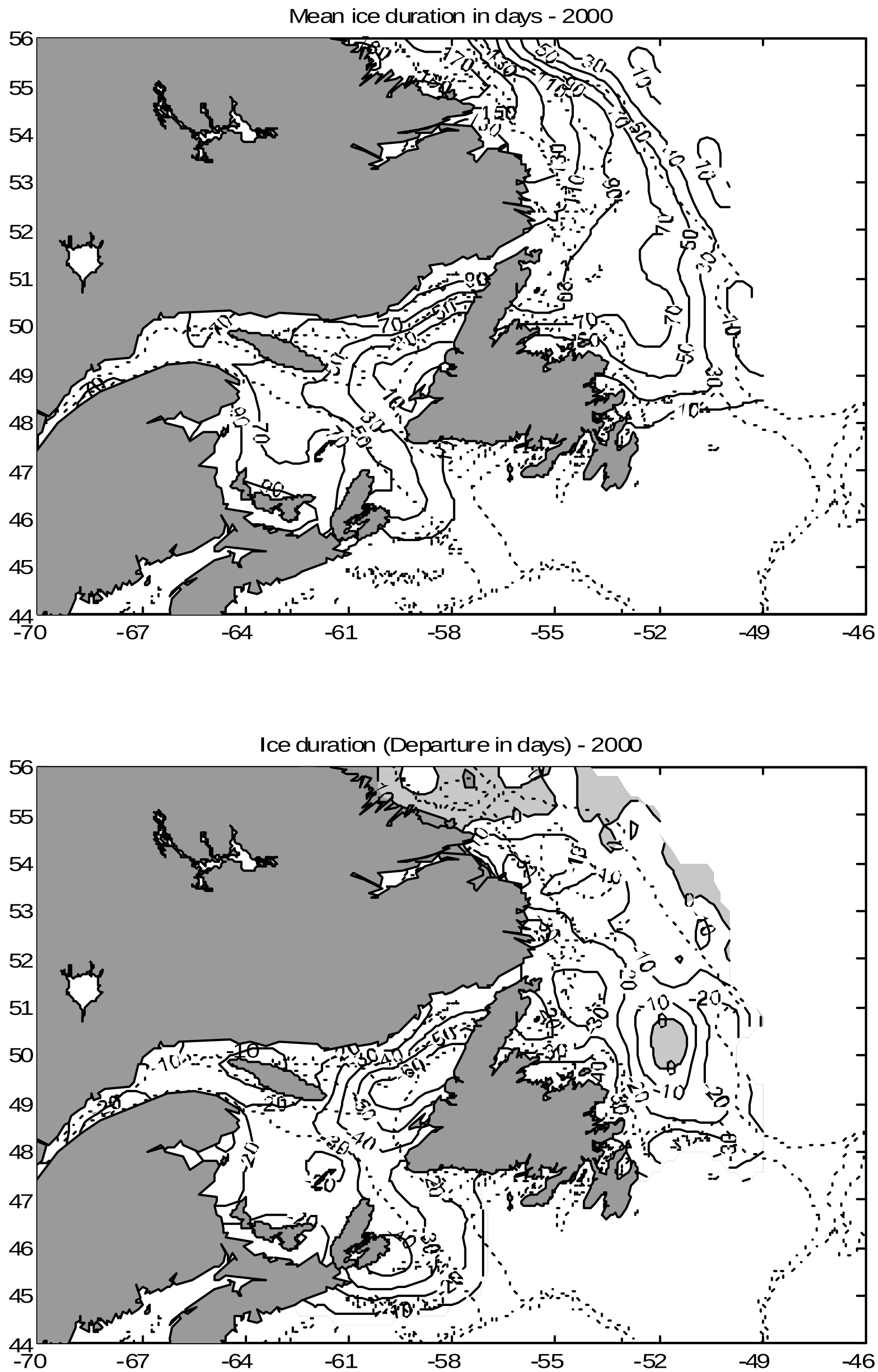


Fig. 14. The duration of ice in days (top panel) during 2000 and their anomaly from the long term mean in days (bottom panel). The shaded positive anomalies indicate a duration longer than the mean, which is generally associated with a cold year.

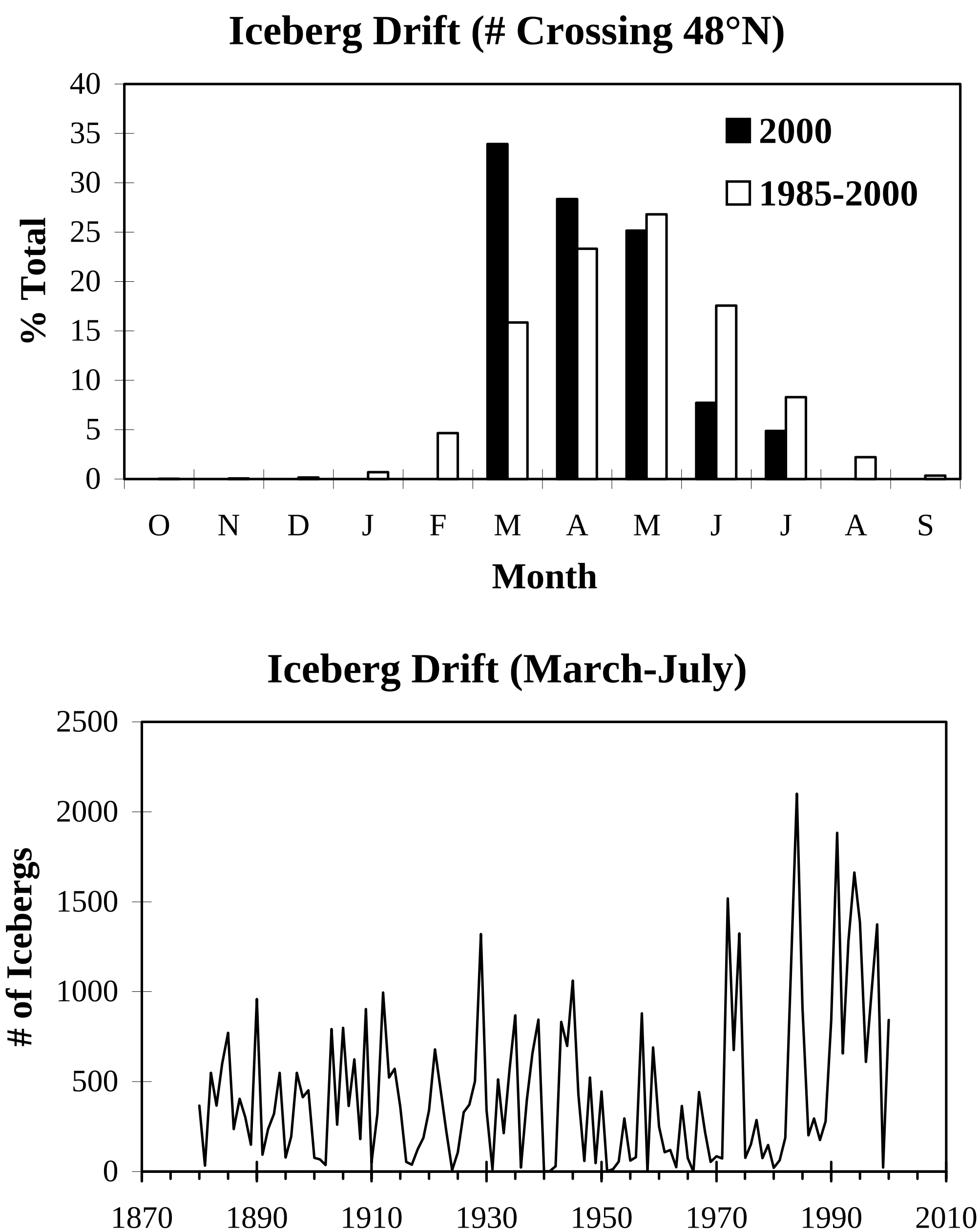


Fig. 15. The number of icebergs crossing south of 48°N during the iceberg season 1999/2000 expressed as a percent of the total by month compared to the mean during 1985-2000, the years SLAR has been used (top panel) and the time series of total number of icebergs observed during March to July (bottom panel).

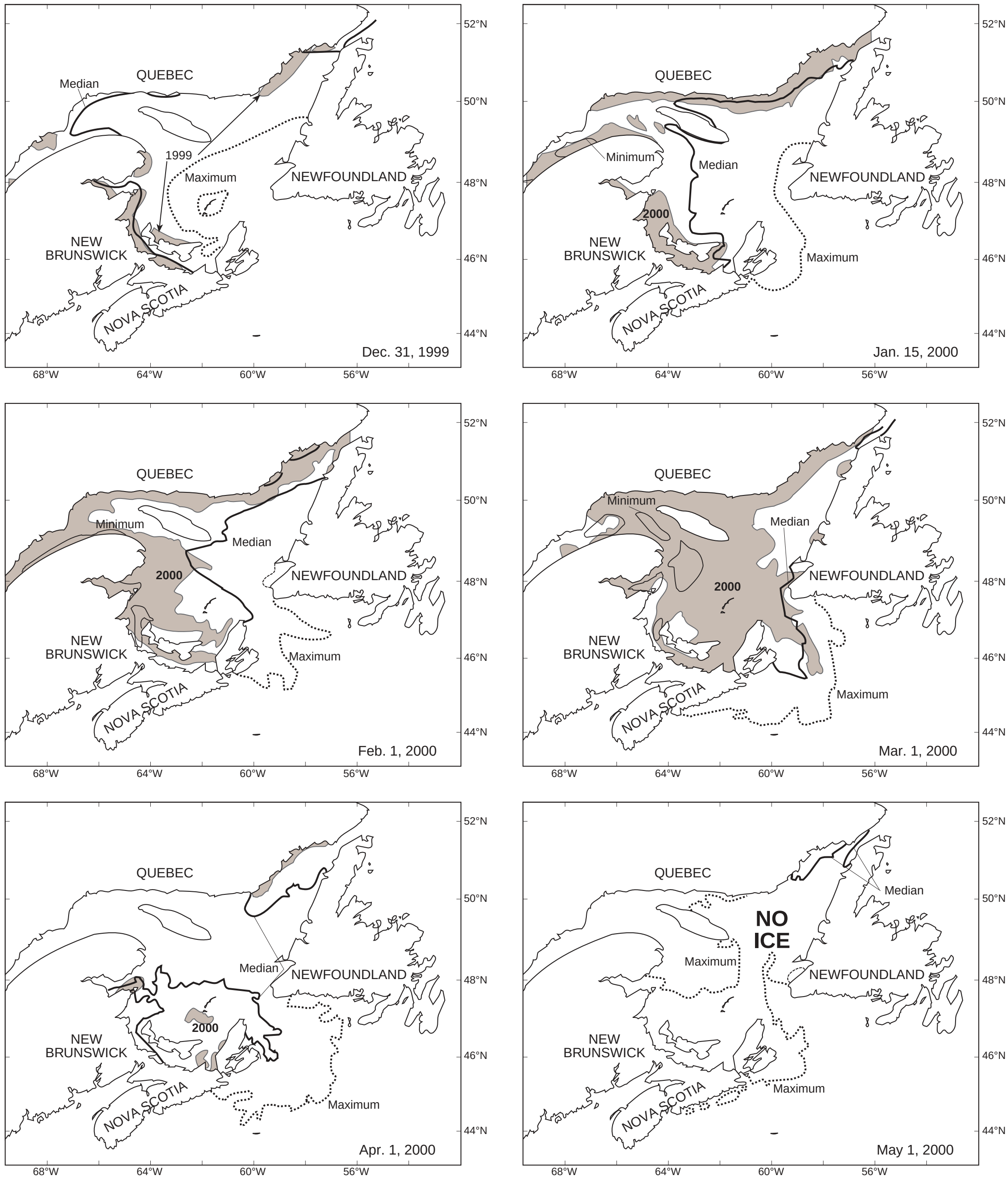


Fig. 16. The location of the ice (shaded area) between December 1999 and May 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

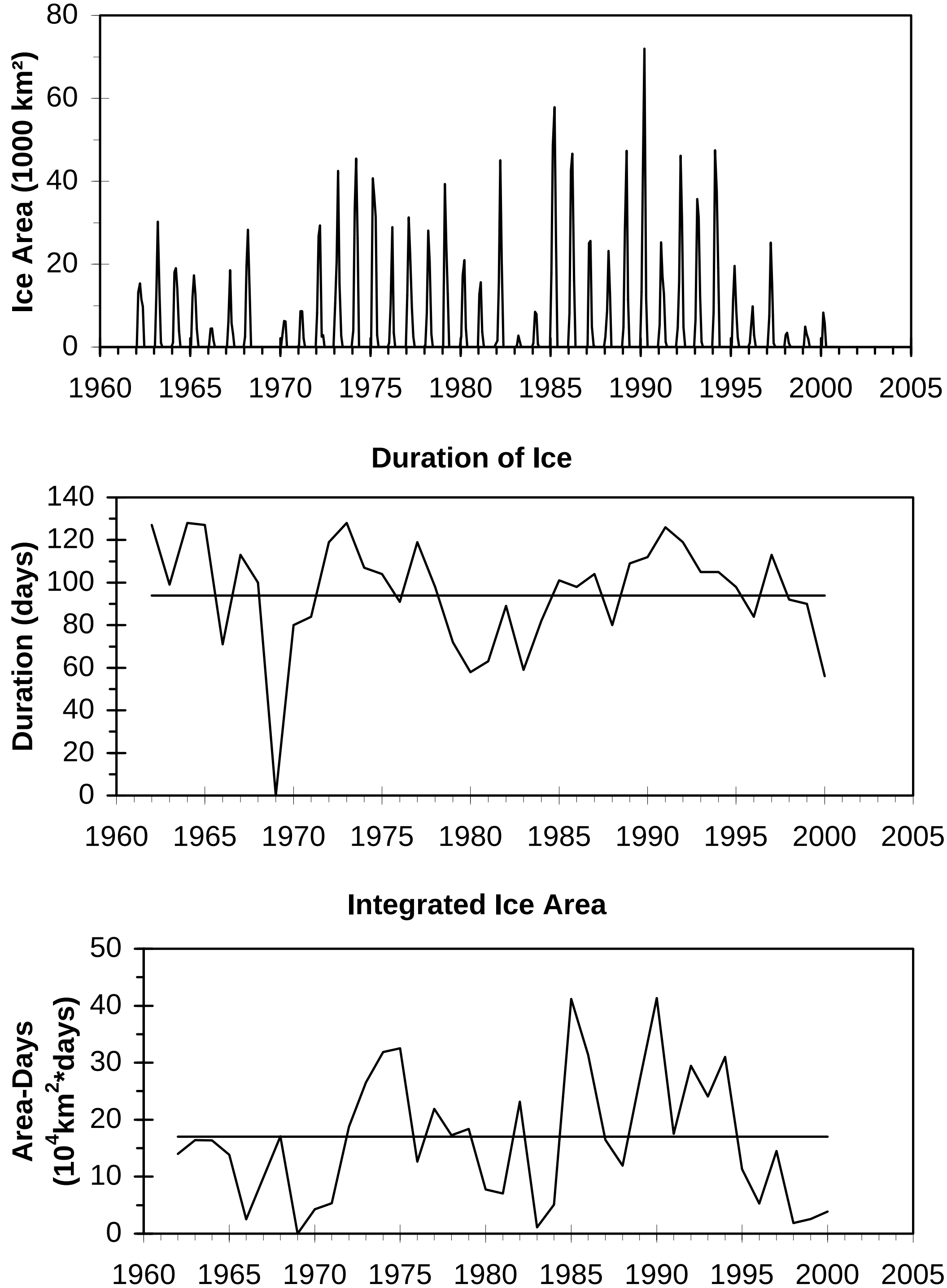


Fig. 17. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1962-1990) means.

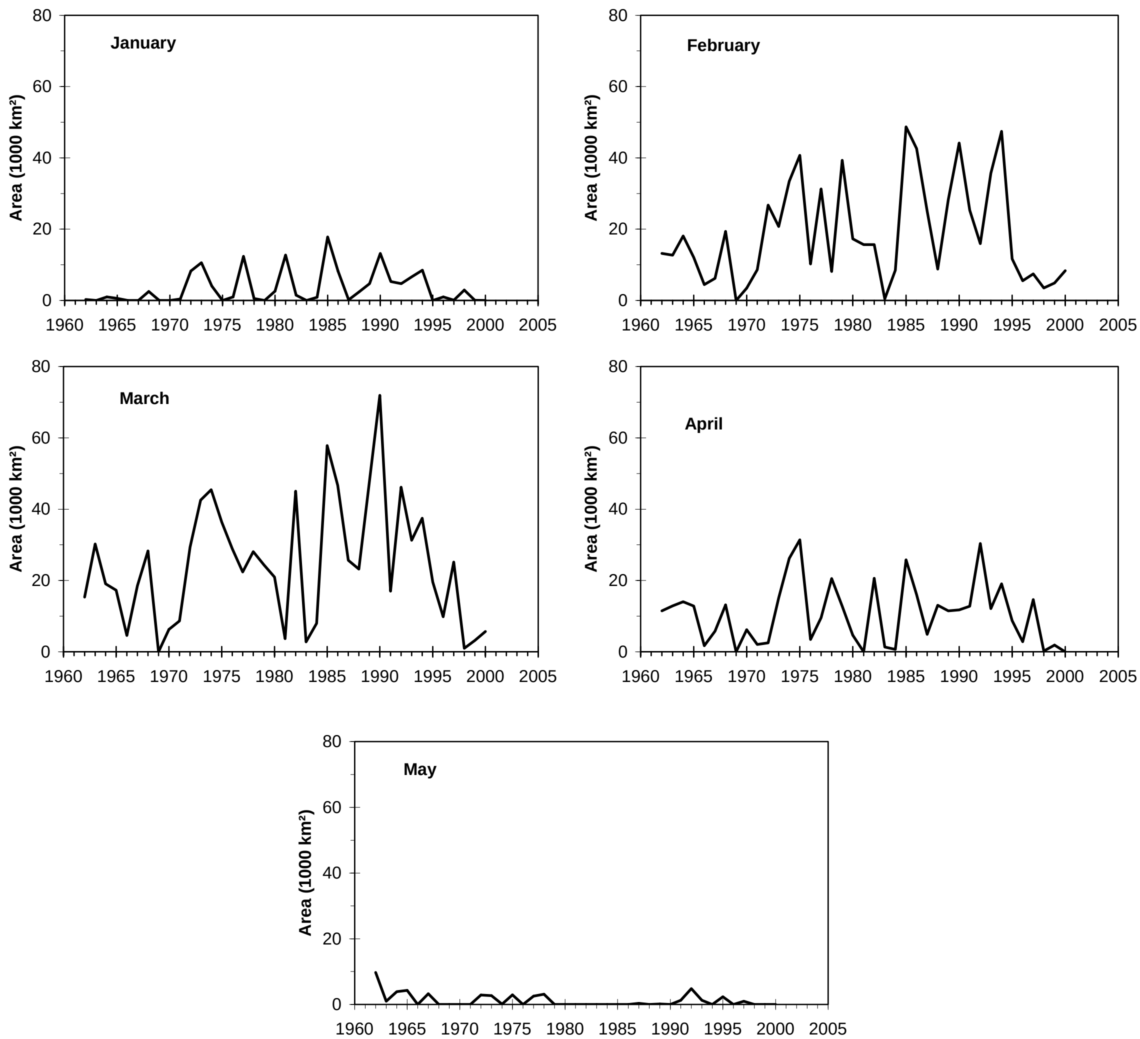


Fig. 18. The time series of ice area seaward of Cabot Strait, by month. The horizontal lines represent the long-term (1962-1990) monthly means.

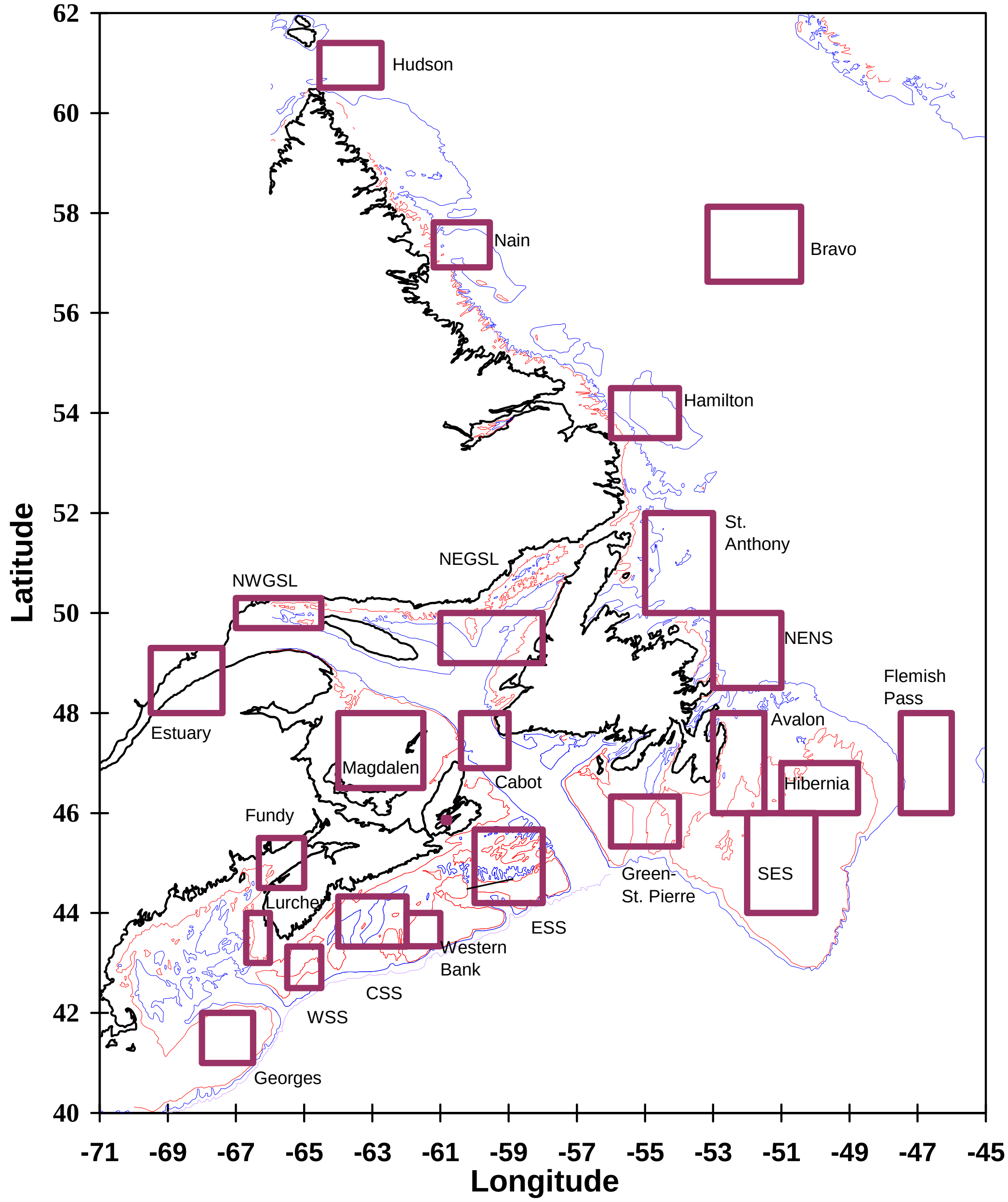


Fig. 19. The areas in the northwest Atlantic used for extraction of sea-surface temperature.

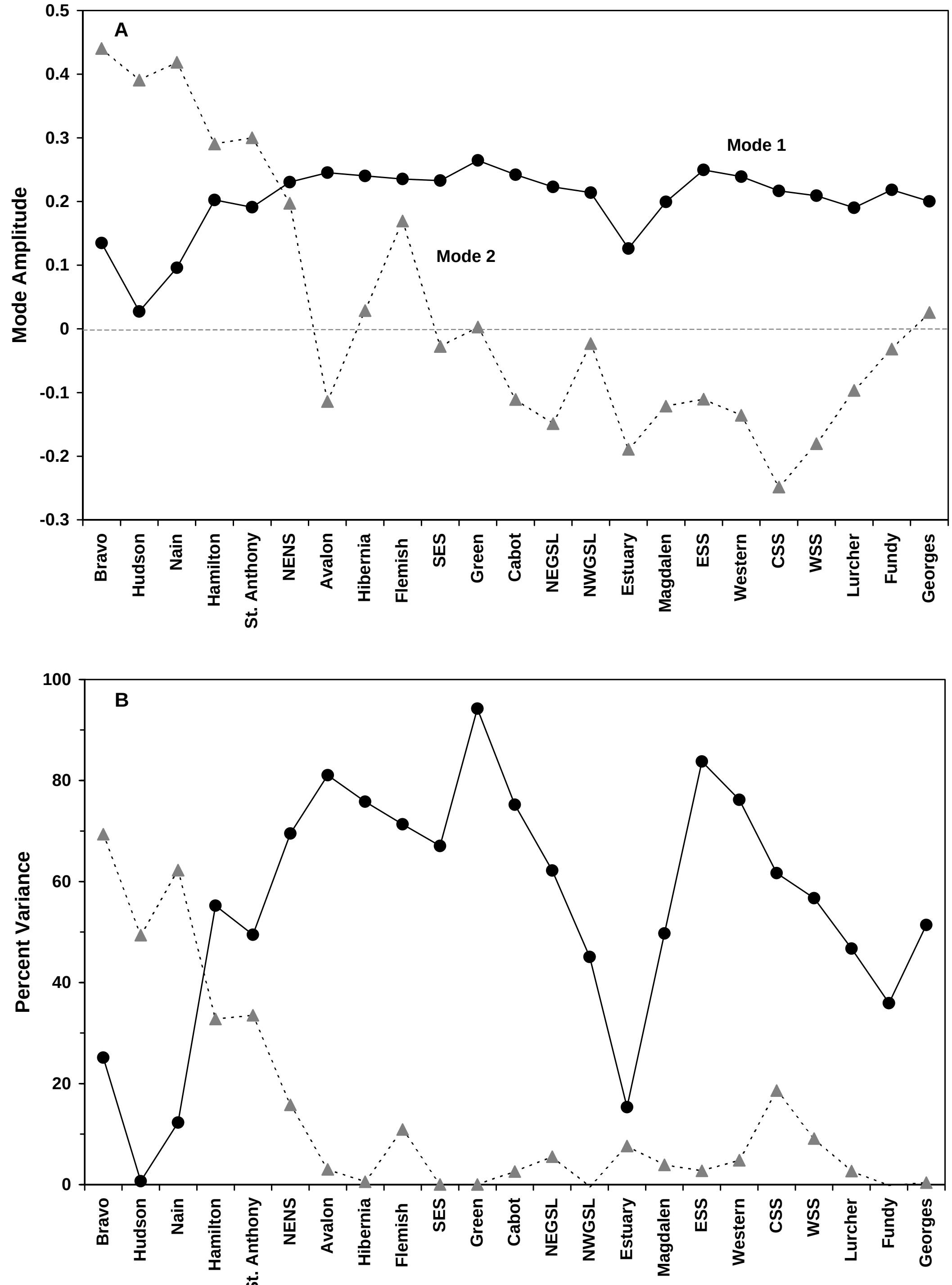


Fig. 20. (A) The time series of the amplitudes of the first modes 1 and 2.
(B) The percent variance accounted for by modes 1 and 2 at each site.

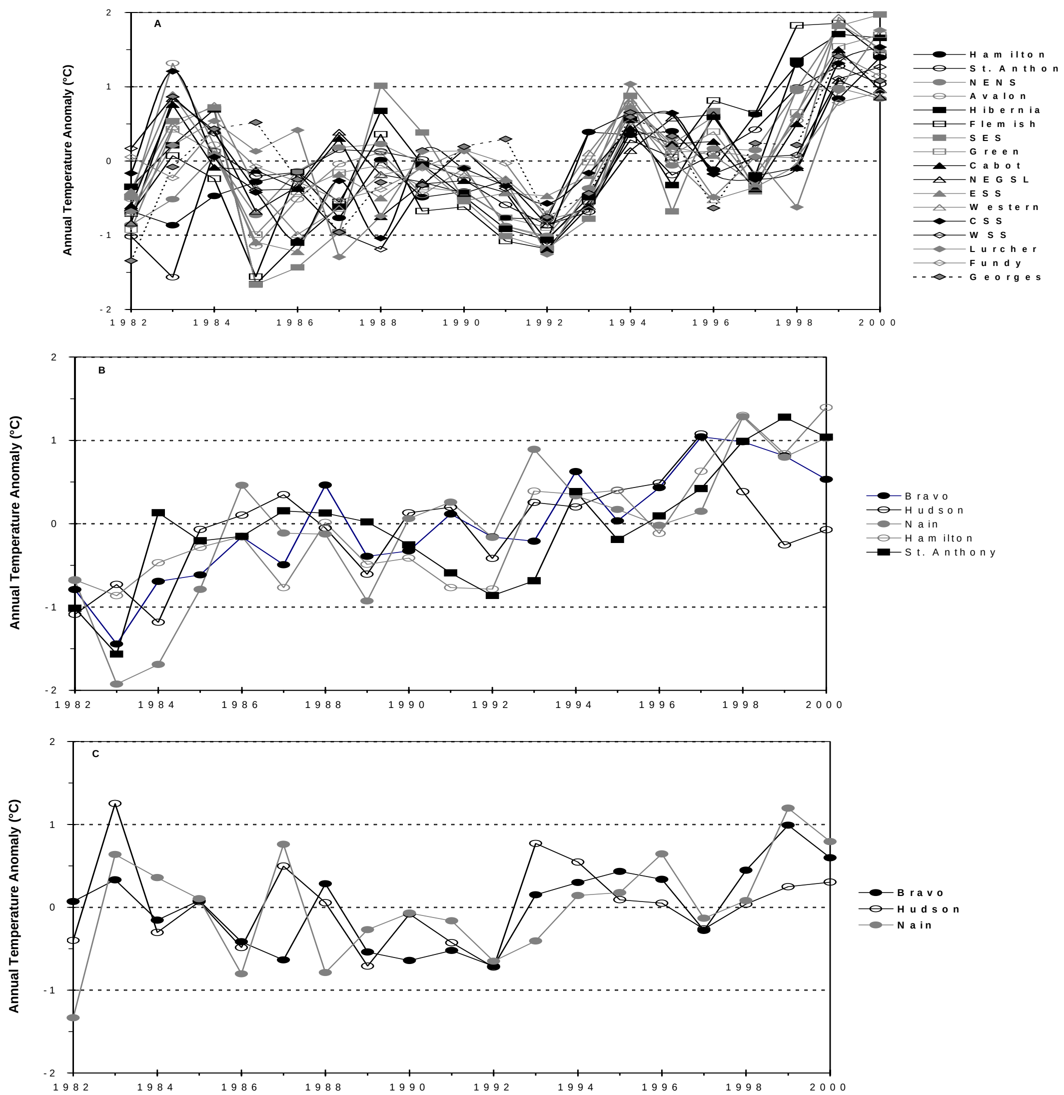


Fig. 21. Time series of annual sea-surface temperature anomalies for (a) Newfoundland Shelf, Scotian Shelf and Gulf of Maine, (b) northern sites, and (c) Gulf of St. Lawrence.

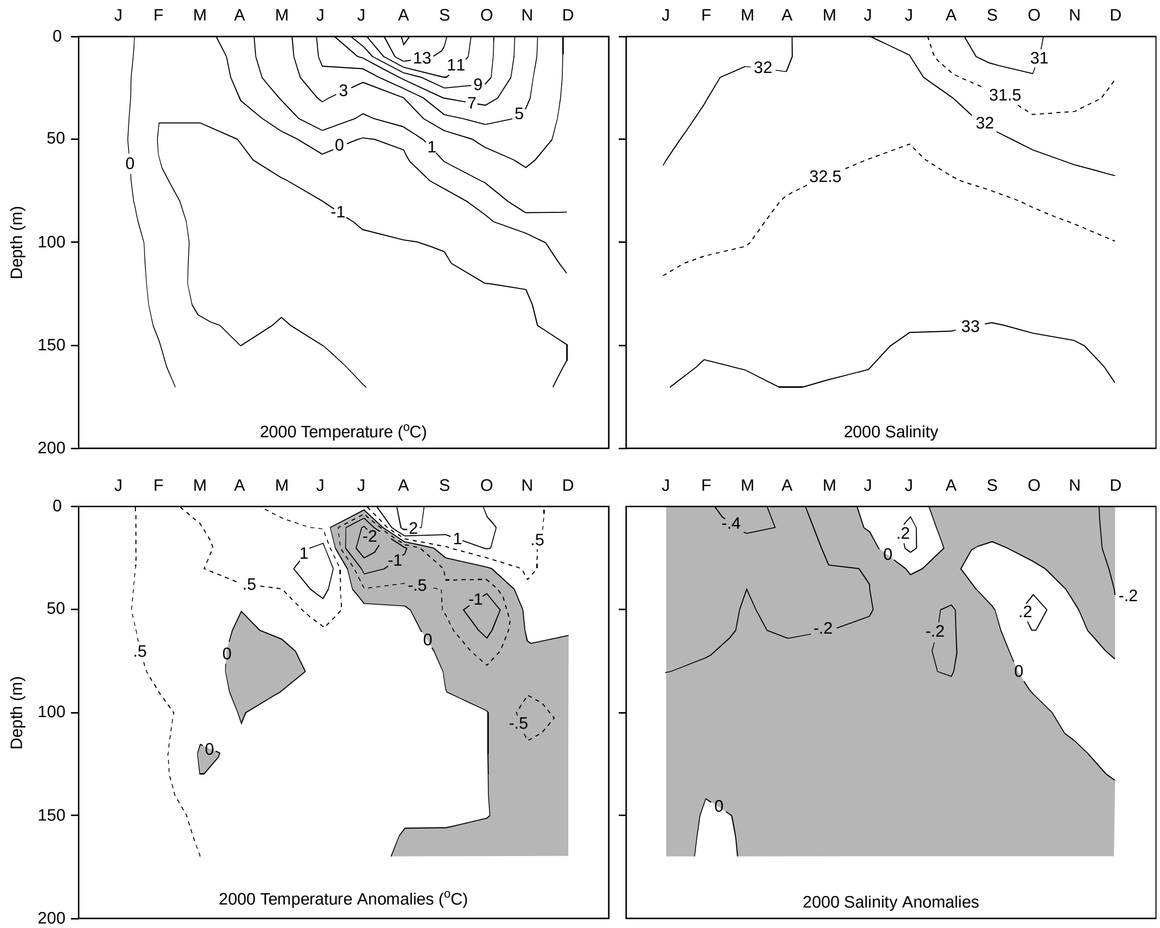


Fig. 22. Monthly mean temperature and salinity and their anomalies relative to the 1961-90 mean at station 27 as a function of depth during 2000.

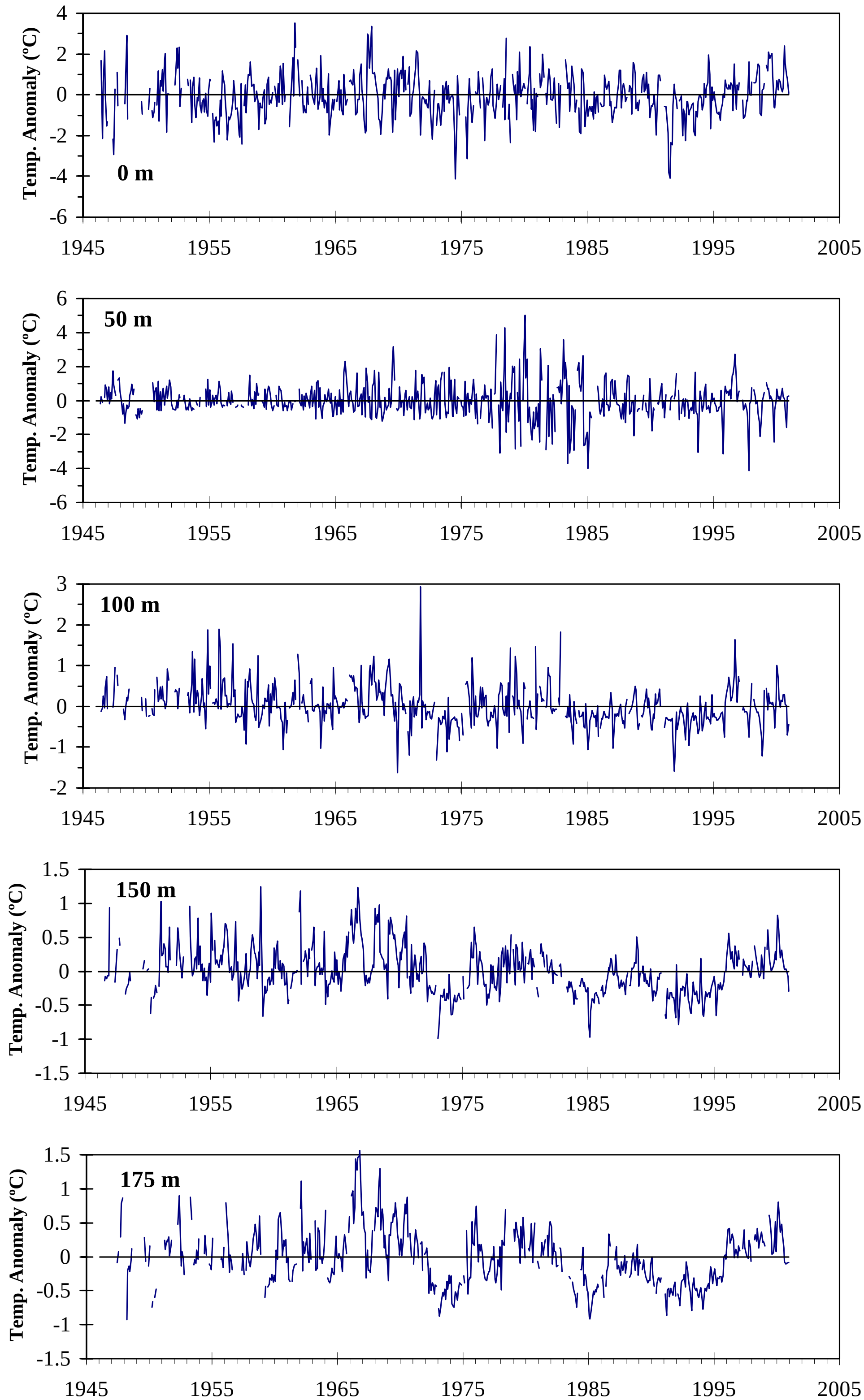


Fig. 23. Monthly mean temperature anomalies at selected depths from Station 27.

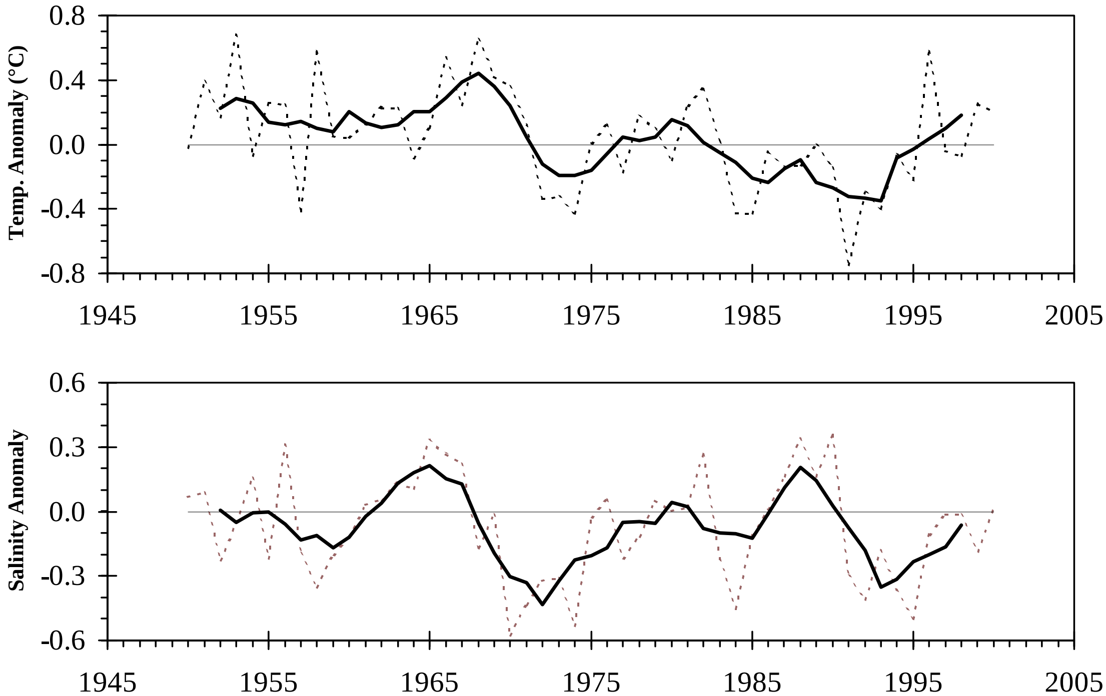


Fig. 24. Vertically averaged (0-176 m) temperature and (0-50 m) salinity from Station 27.

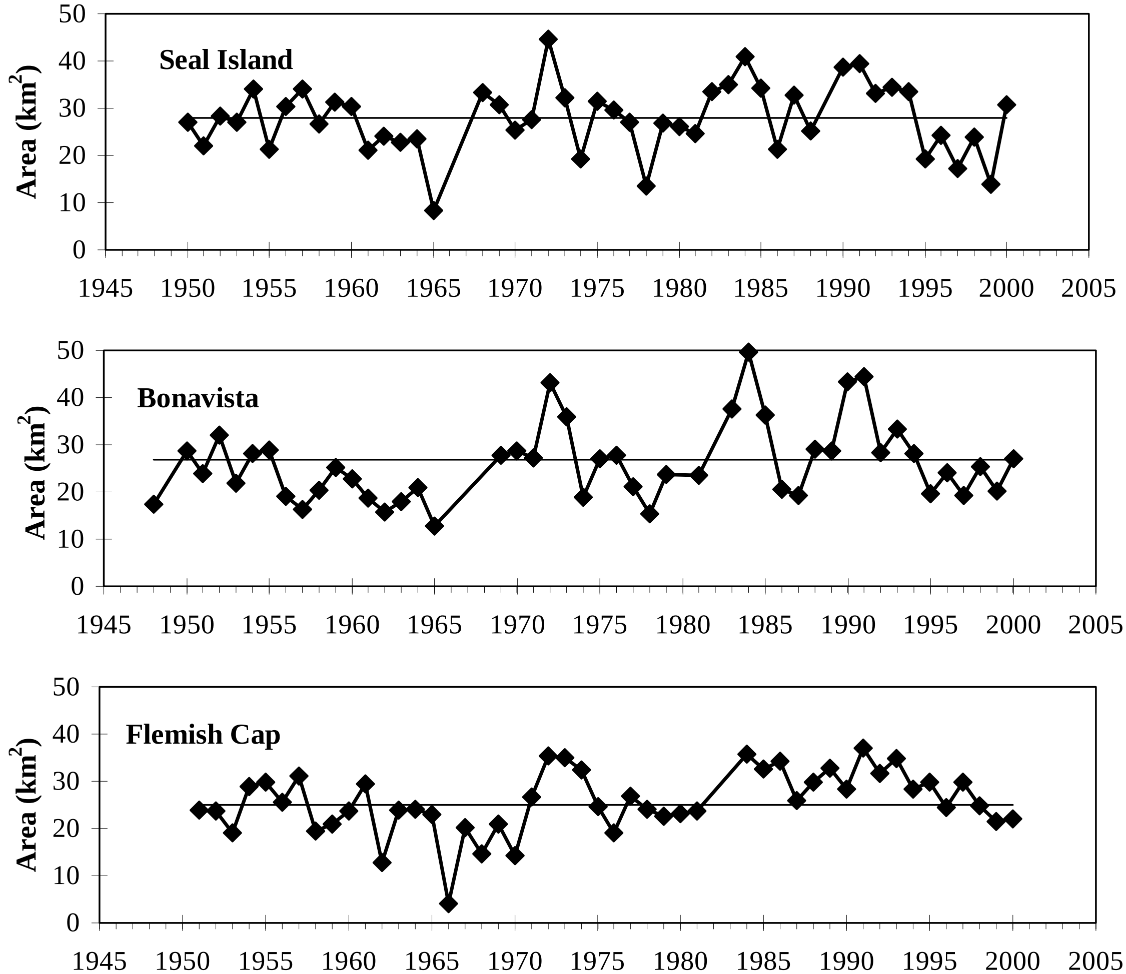


Fig. 25. The CIL area (in km^3) during the summer along standard sections off Seal Island (southern Labrador), Bonavista Bay (northeastern Newfoundland) and Flemish Cap (Grand Banks).

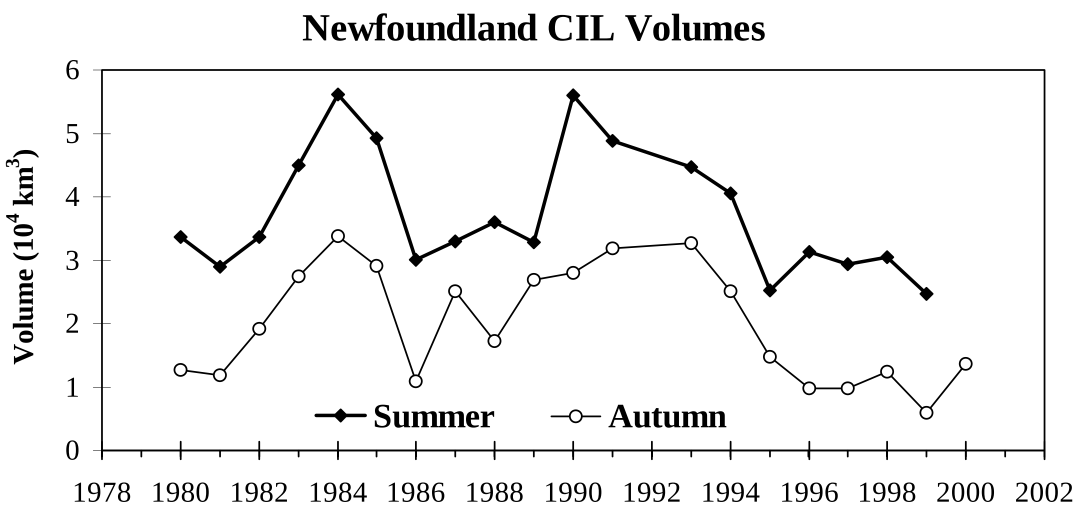


Fig. 26. The CIL volume in the summer and autumn within Divisions 2J and 3KL.

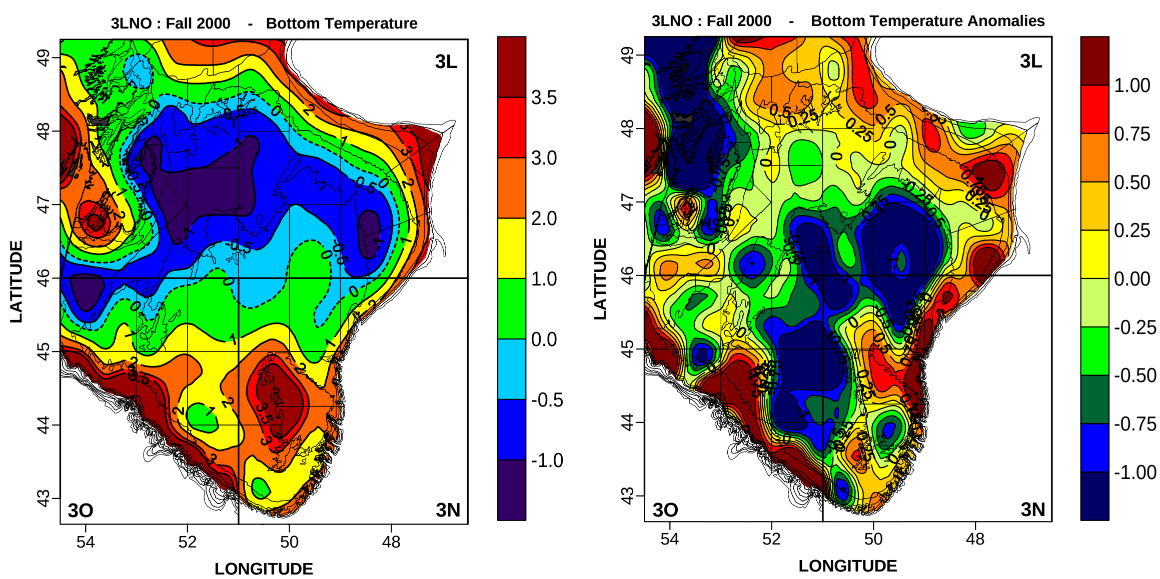
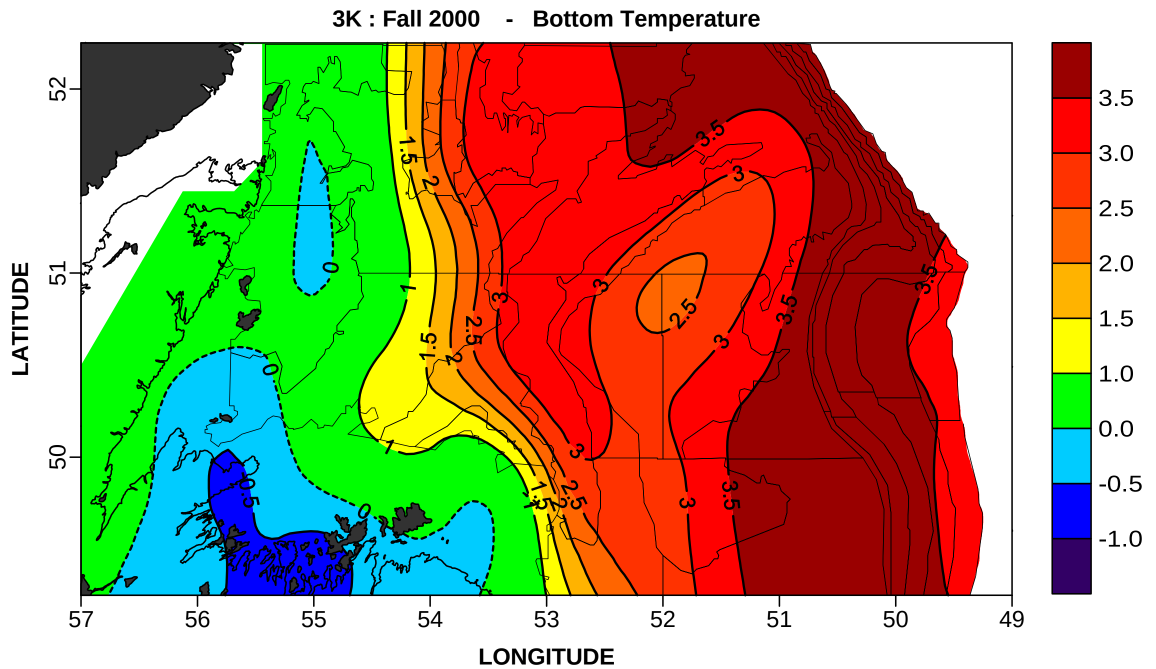


Fig. 27. Bottom temperatures and their anomalies (in C) during the autumn in Divisions 3LNO.



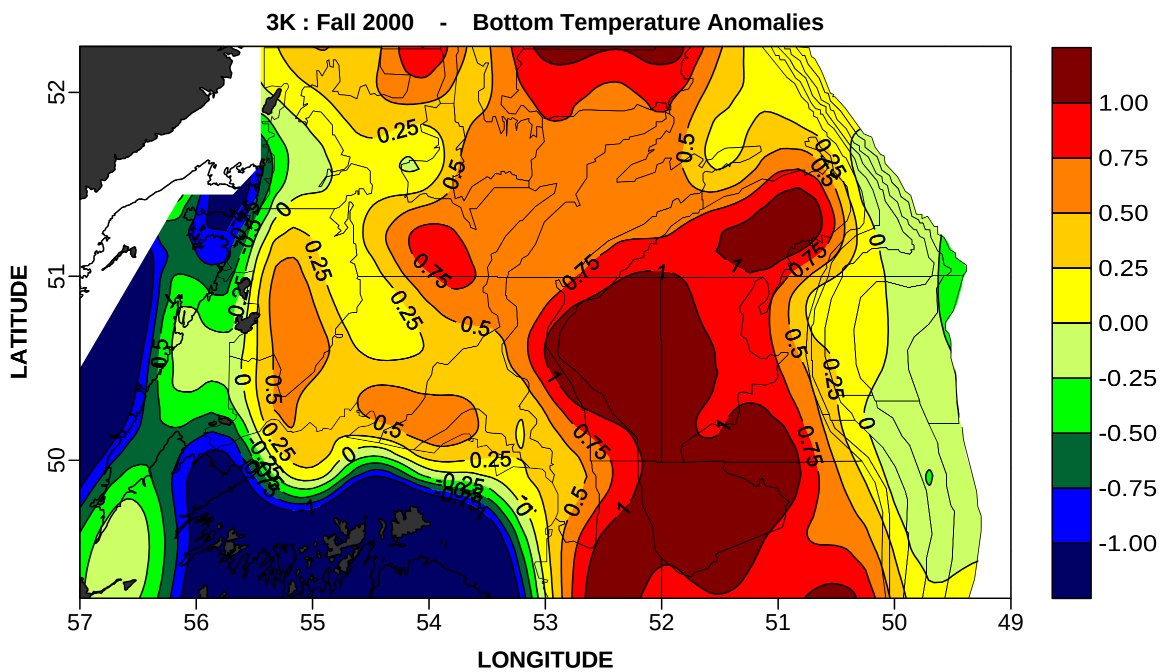
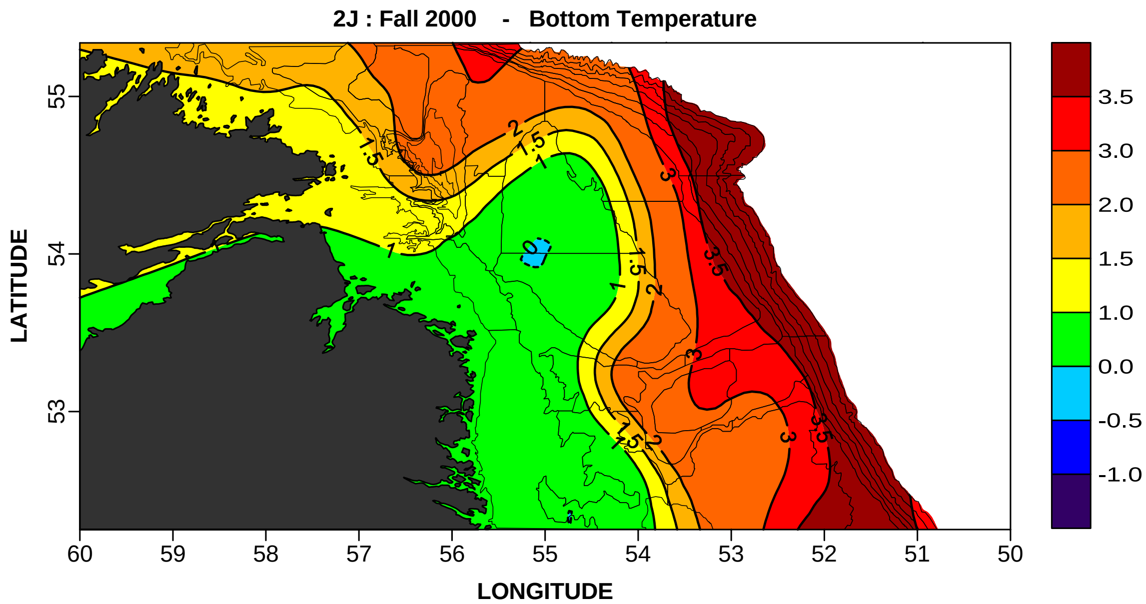


Fig. 28. Bottom temperature and their anomalies (in C) during the autumn in Division 3K.



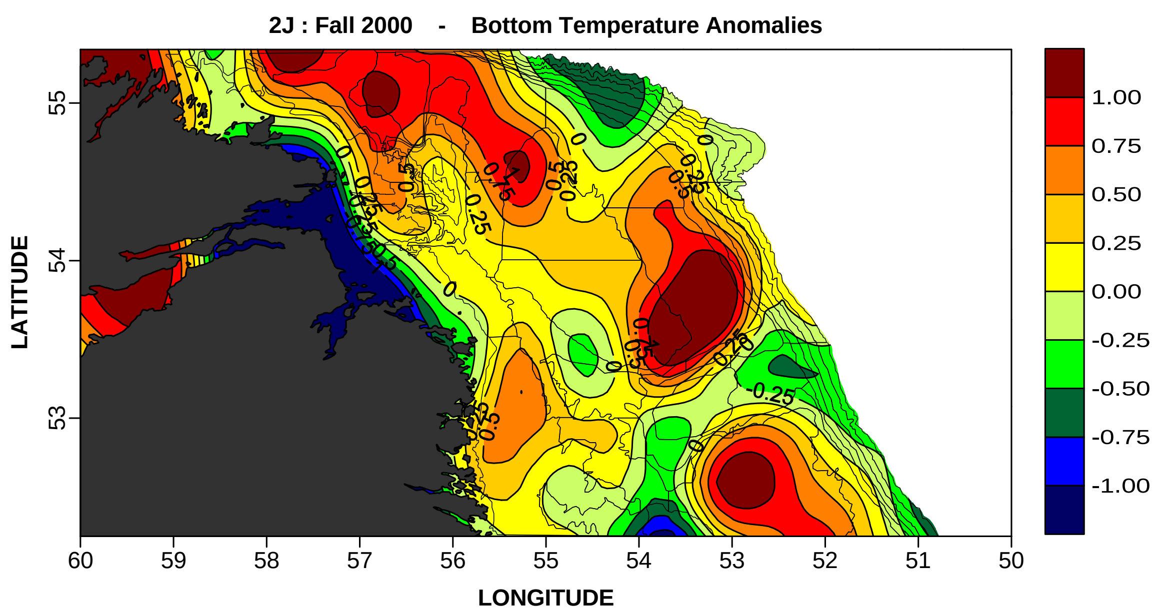
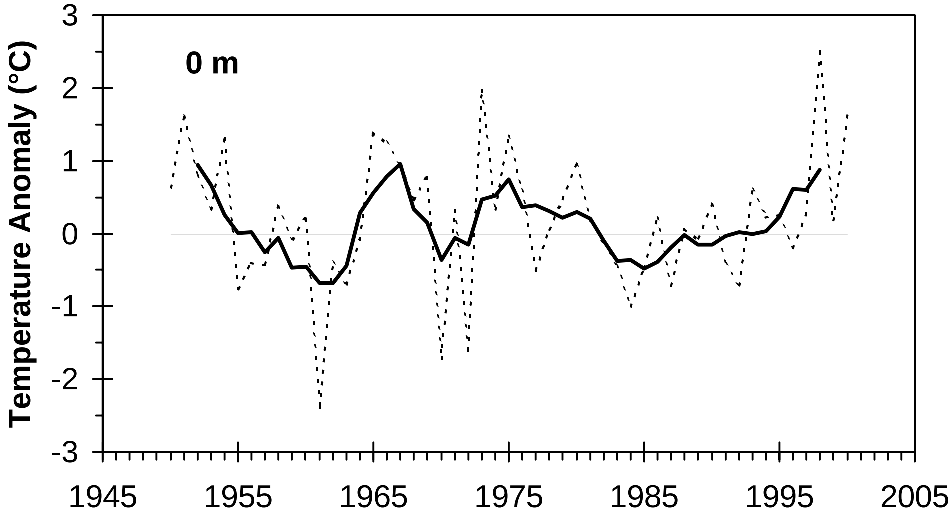


Fig. 29. Bottom temperatures and their anomalies (in C) during the autumn in Division 2J.



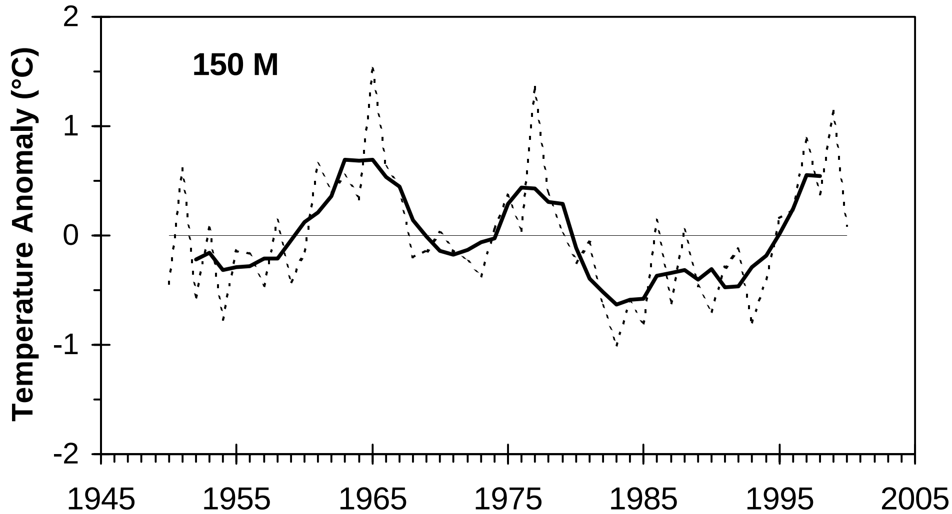


Fig. 30. Monthly mean temperature anomalies at the surface (top panel) and at 150 m (bottom panel) over Hamilton Bank (Div. 2J). The dashed lines are the annual means and the solid line the 5-year running means.

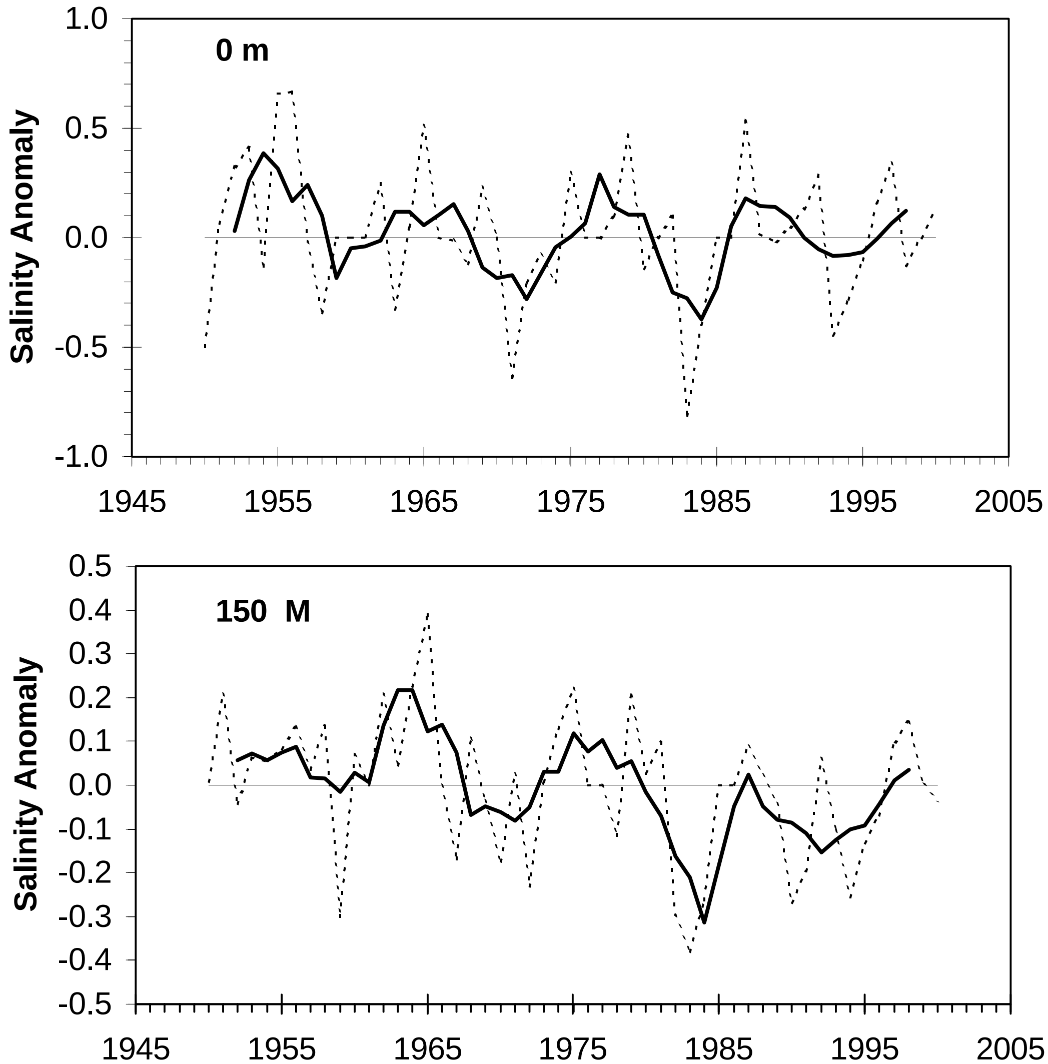


Fig. 31. Monthly mean salinity anomalies at the surface (top panel) and at 150 m (bottom panel) over Hamilton Bank (Div. 2J). The dashed lines are the annual means and the solid line the 5-year running means.

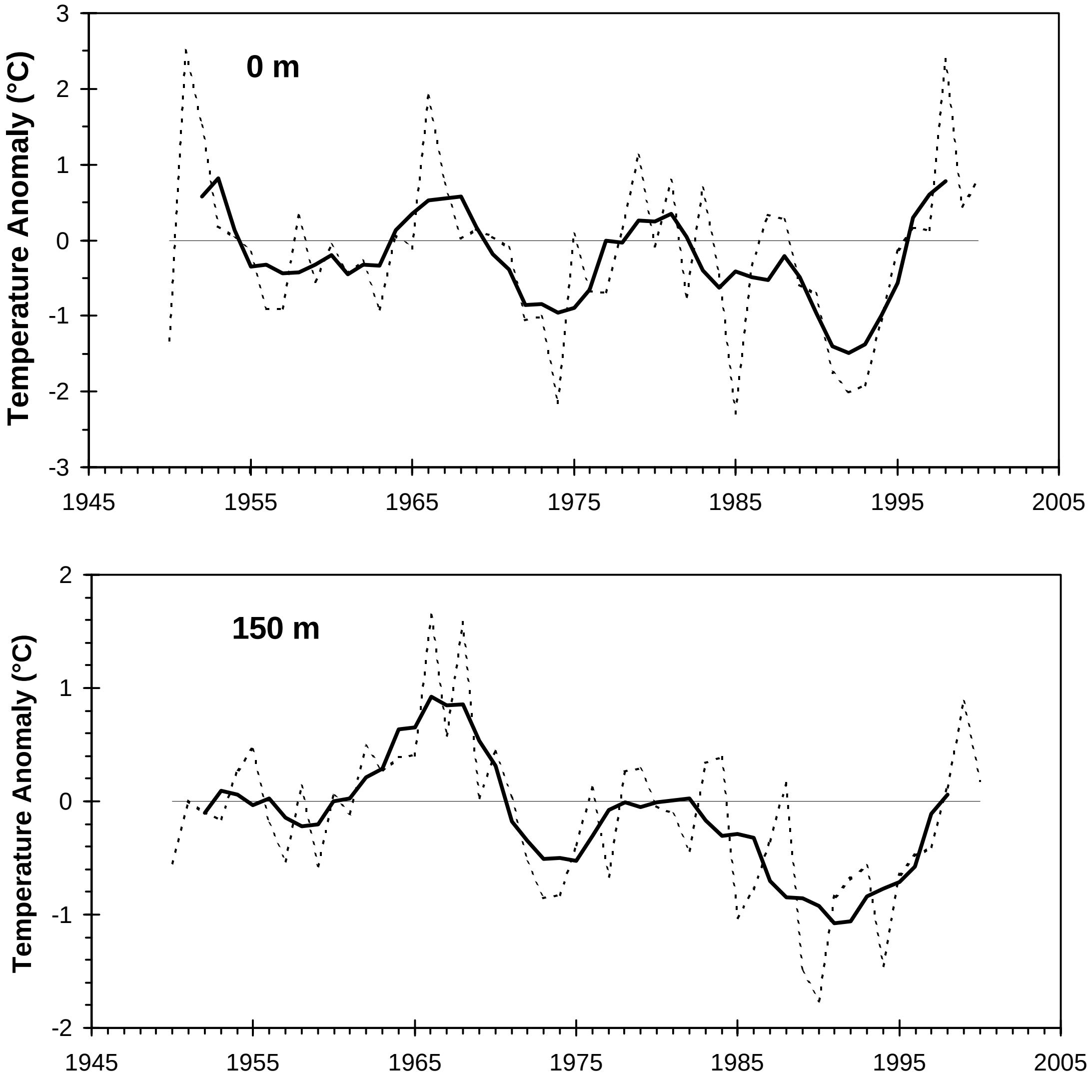
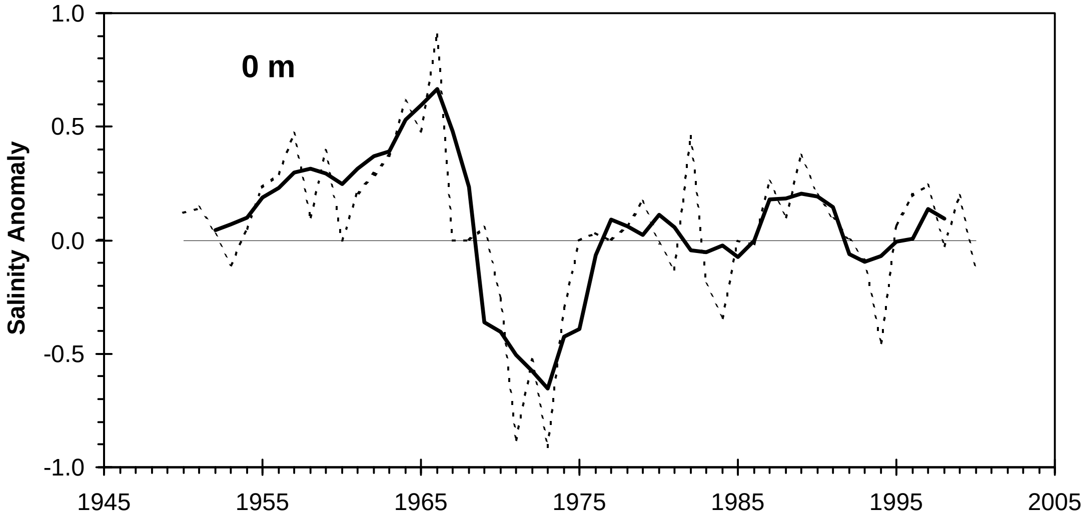


Fig. 32. Monthly mean temperature anomalies at selected depths over Flemish Cap (Div. 3M). The dashed lines are the annual means and the solid line the 5-year running means.



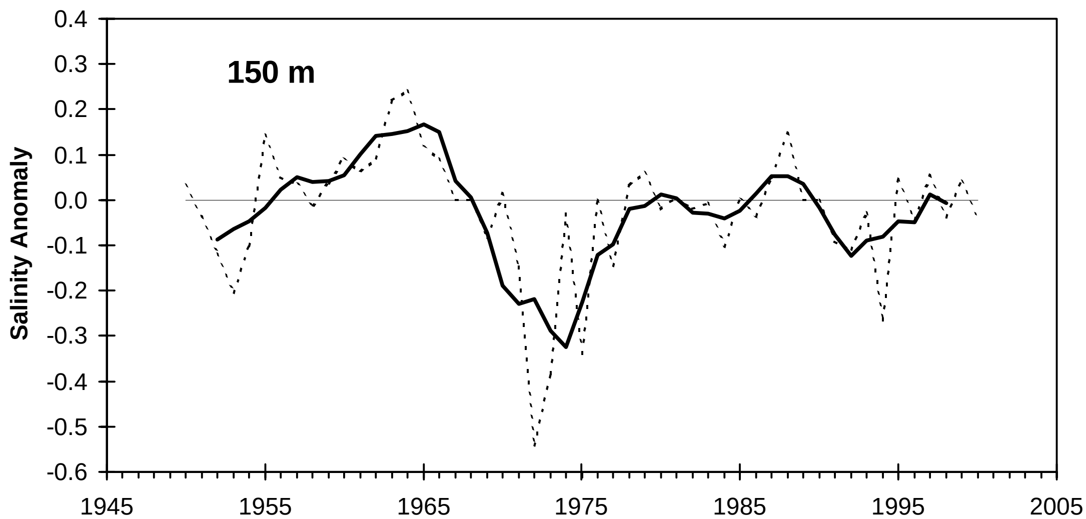


Fig. 33. Monthly mean salinity anomalies at selected depths over Flemish Cap (Div. 3M). The dashed lines are the annual means and the solid line the 5-year running means.

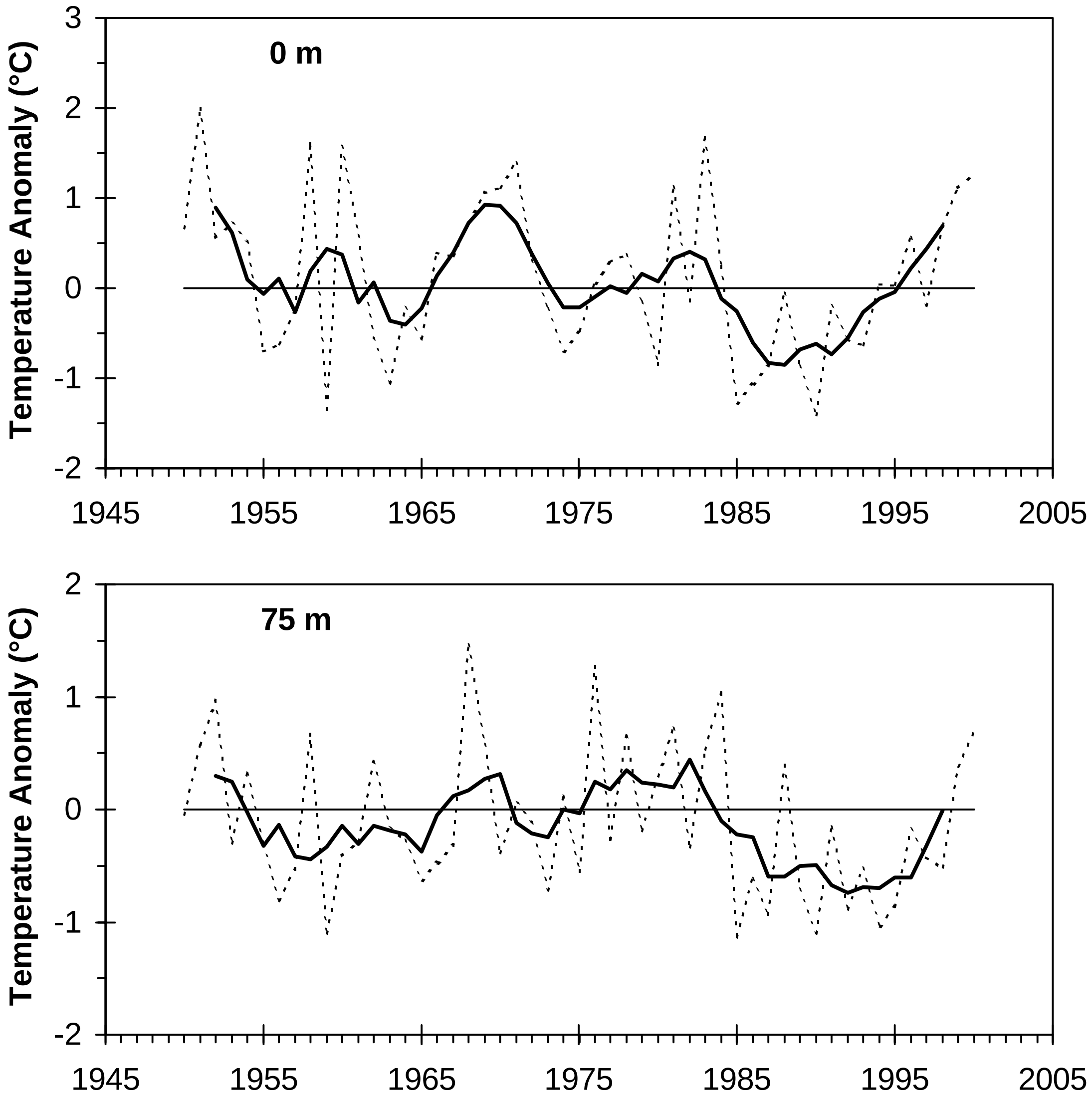


Fig. 34. Monthly mean temperature anomalies at the surface (top panel) and near bottom (75 m, bottom panel) over St. Pierre Bank (Div. 3Ps). The dashed lines are the annual means and the solid line the 5-year running means.

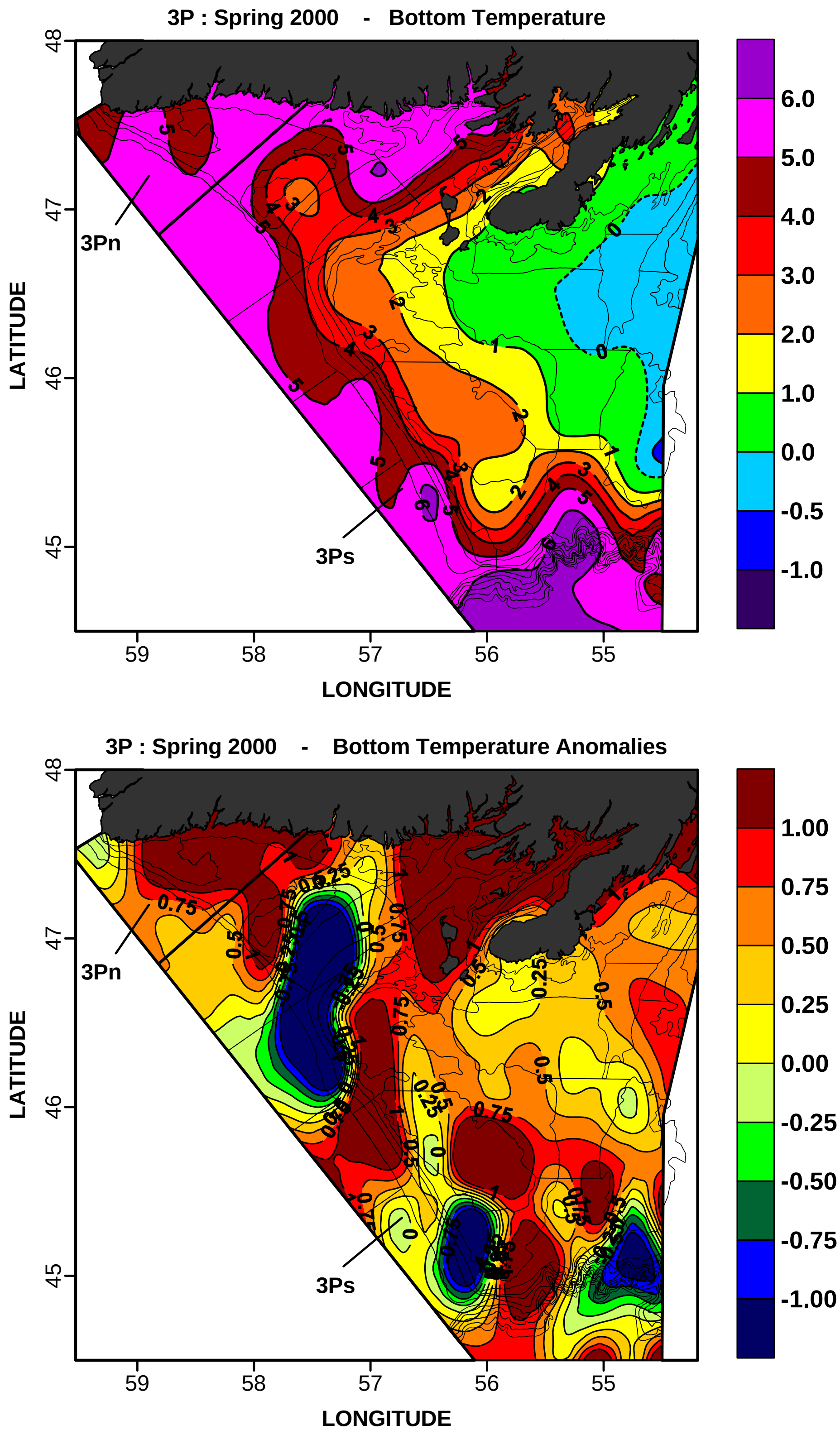


Fig. 35. Bottom temperature and their anomalies (in C) during the spring in the vicinity of St. Pierre Bank (Div. 3Ps).

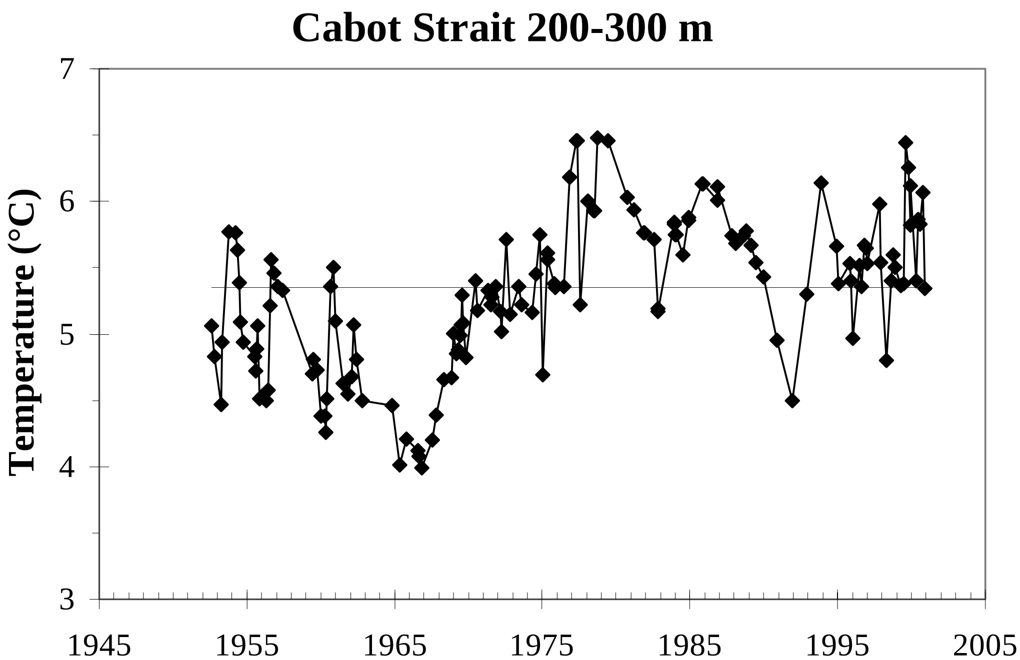


Fig. 36. The average temperature in the 200-300 m layer in Cabot Strait.

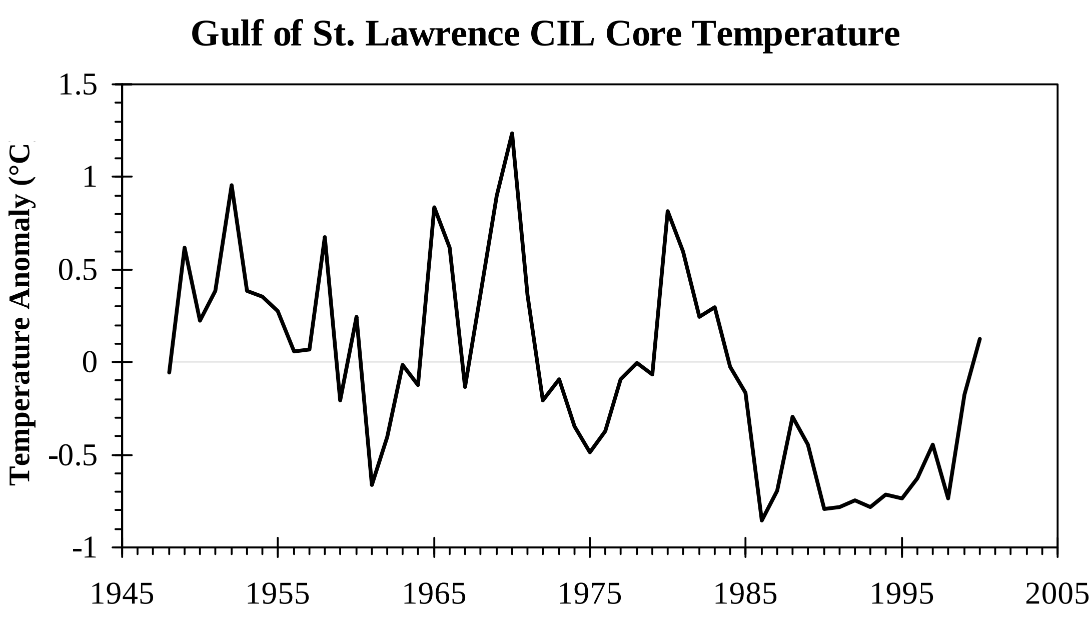


Fig. 37. Anomalies of the CIL core temperature (extrapolated to July 15) for the Gulf of St. Lawrence.

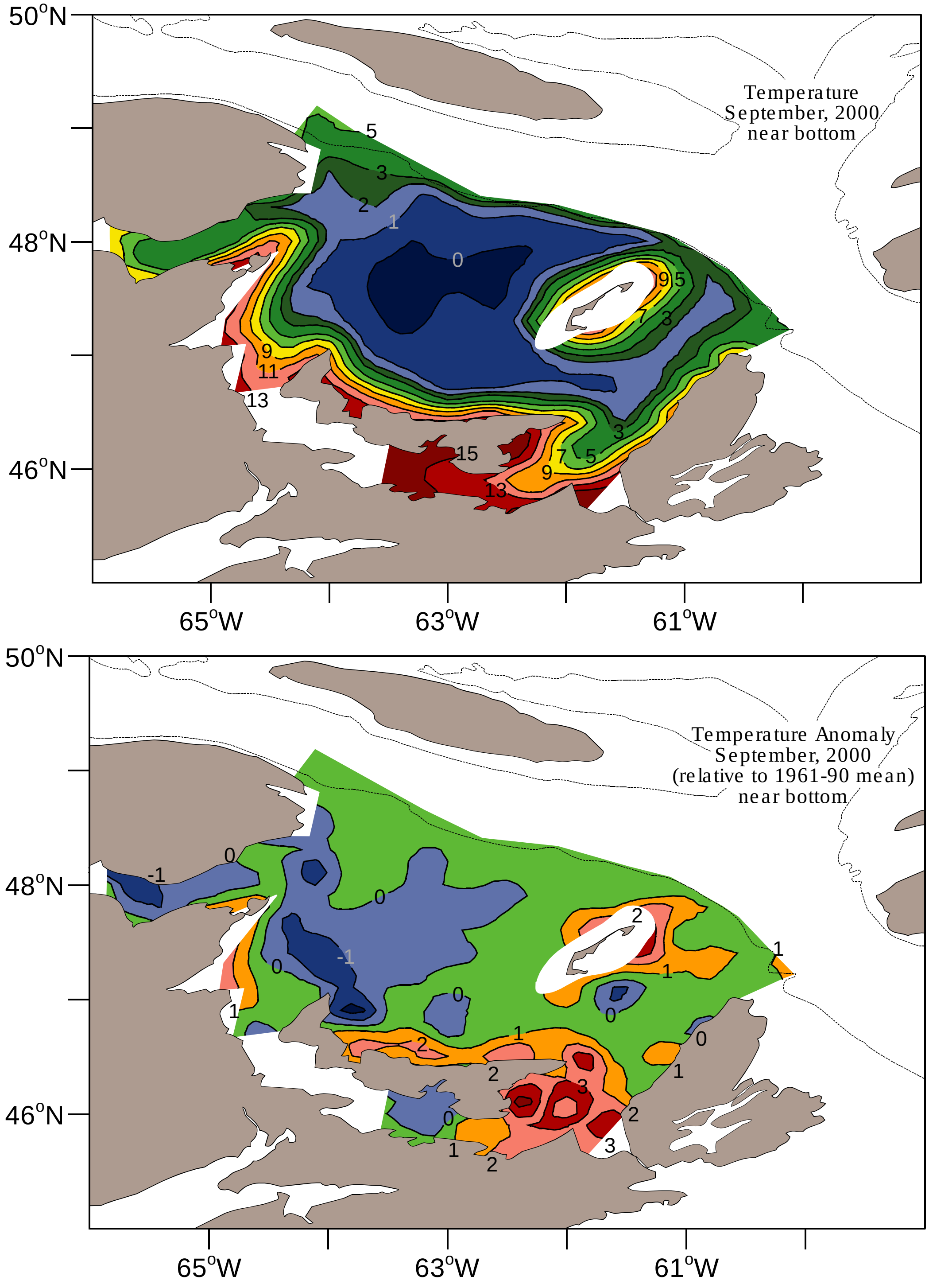


Fig. 38. Near-bottom temperatures (top panel) and their departure from the long-term (1961-90) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 September survey.

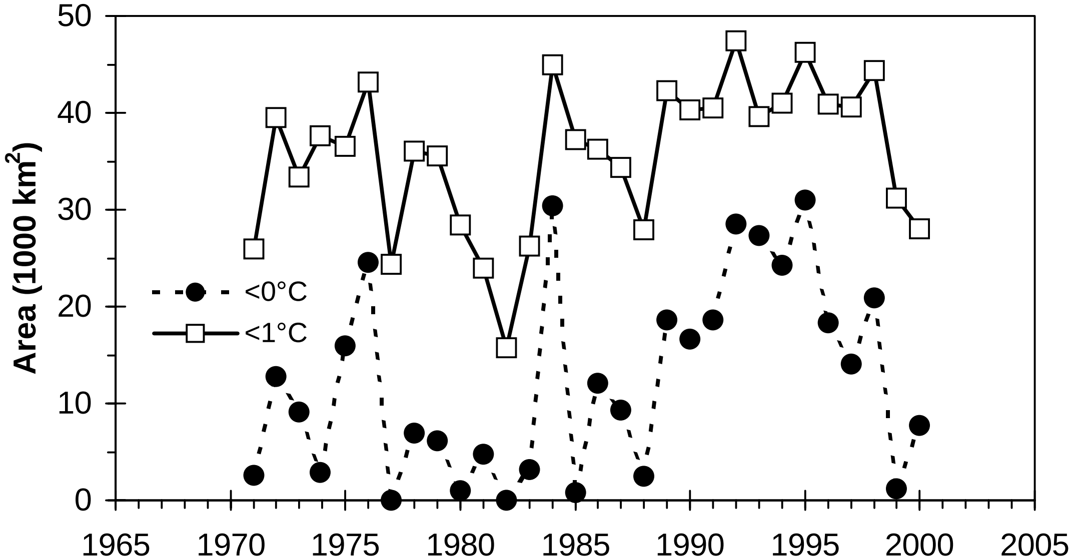


Fig. 39. The area of the Magdalen Shallows with bottom temperatures <0ºC and <1ºC during September.

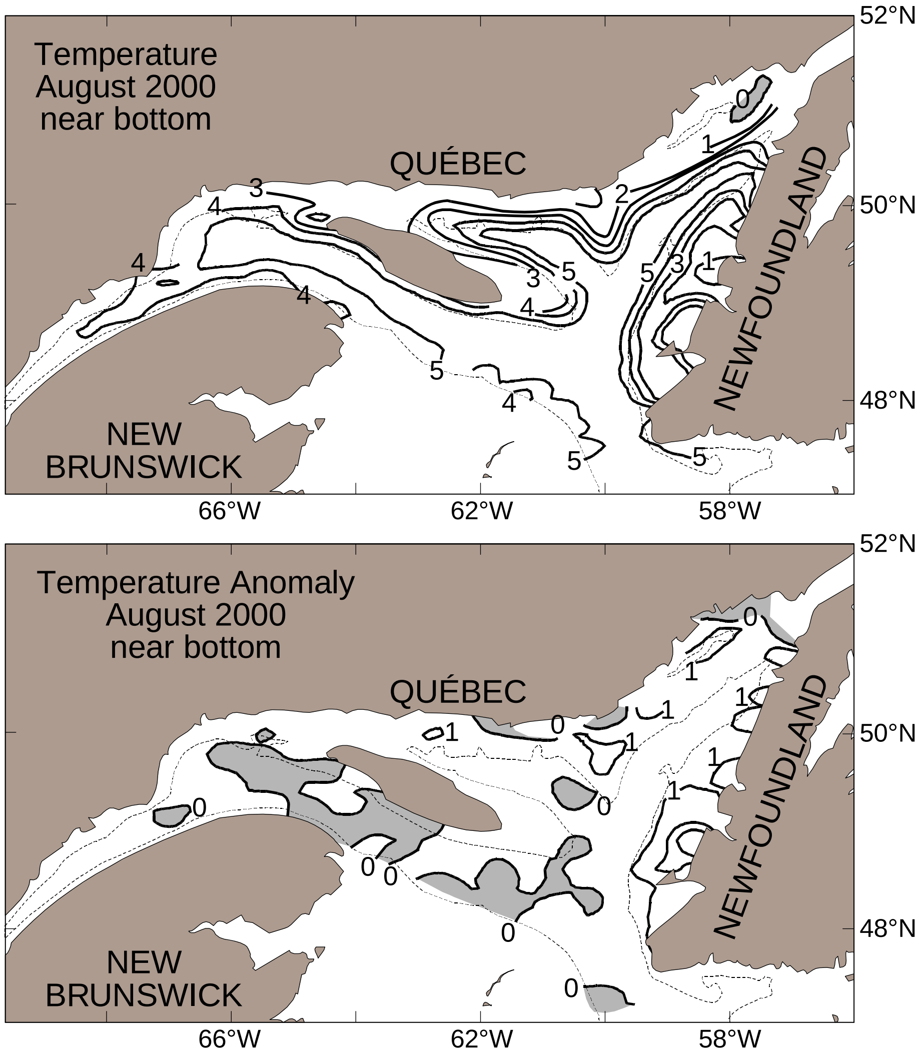


Fig. 40. Near-bottom temperatures (top panel) and their departure from the long-term (1961-90) means (bottom panel) in the northern Gulf of St. Lawrence during the 2000 August survey.

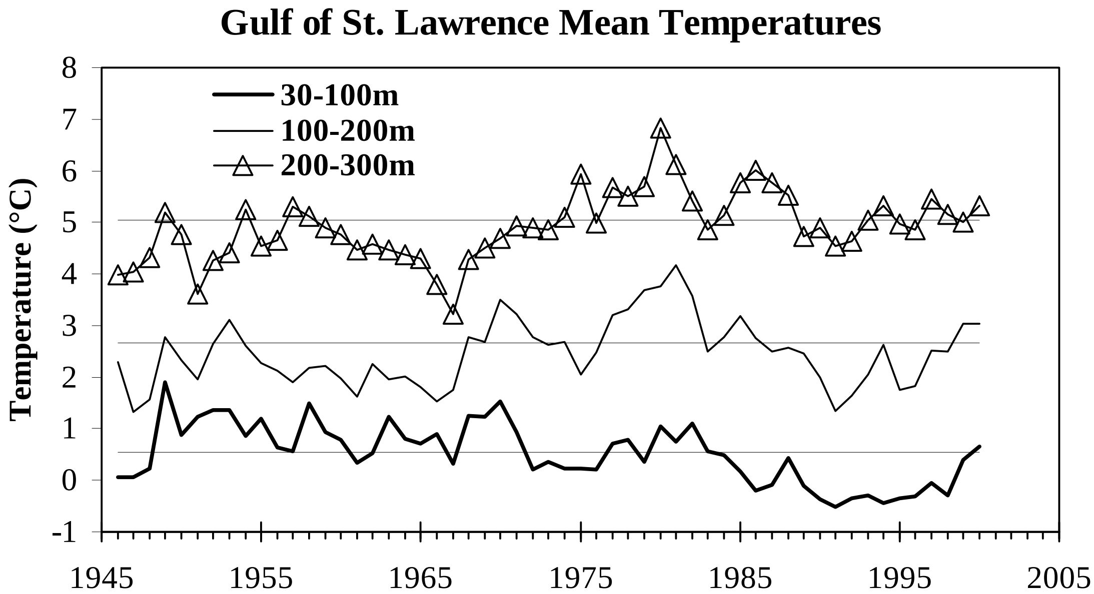


Fig. 41. The temperature of the 30-100 m, the 100-200 m and the 200-300 m layers in the Gulf of St. Lawrence during August-September. The horizontal lines indicate the long-term averages.

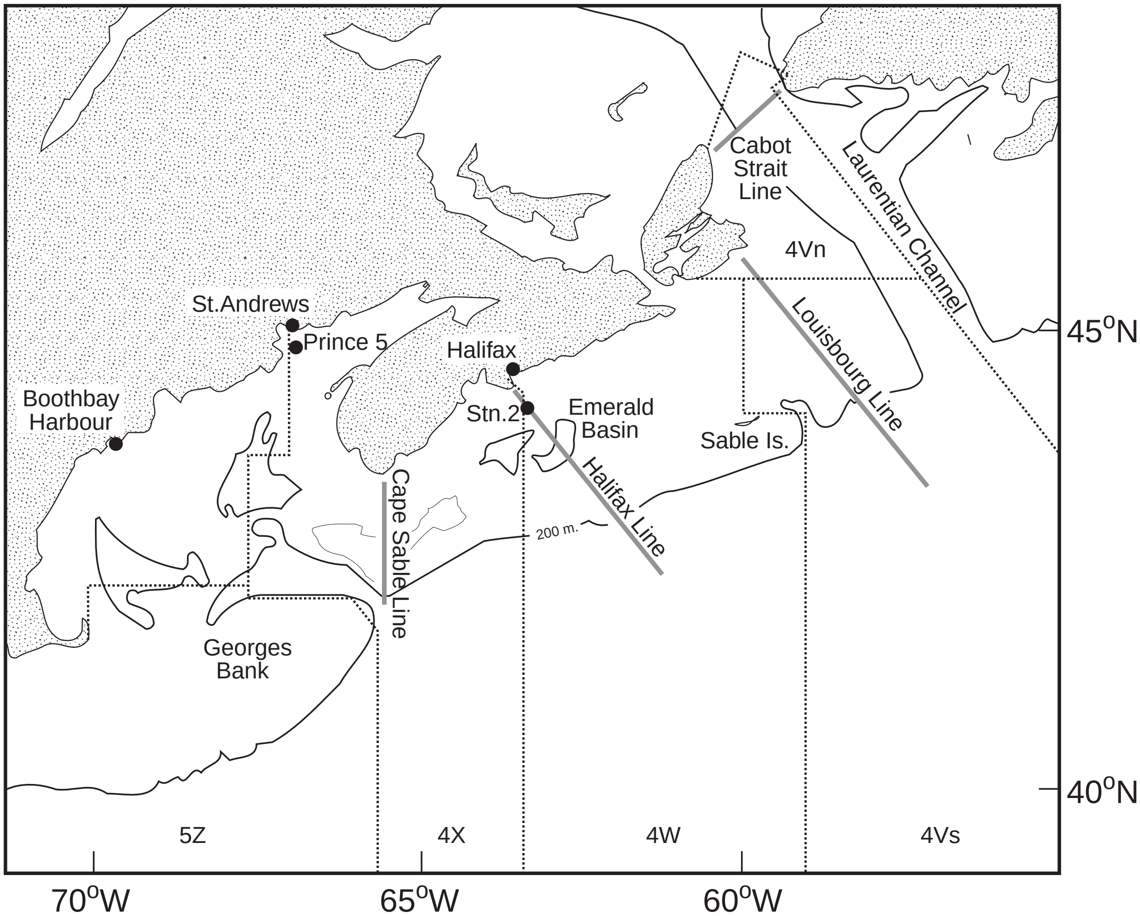


Fig. 42. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the NAFO Subareas.

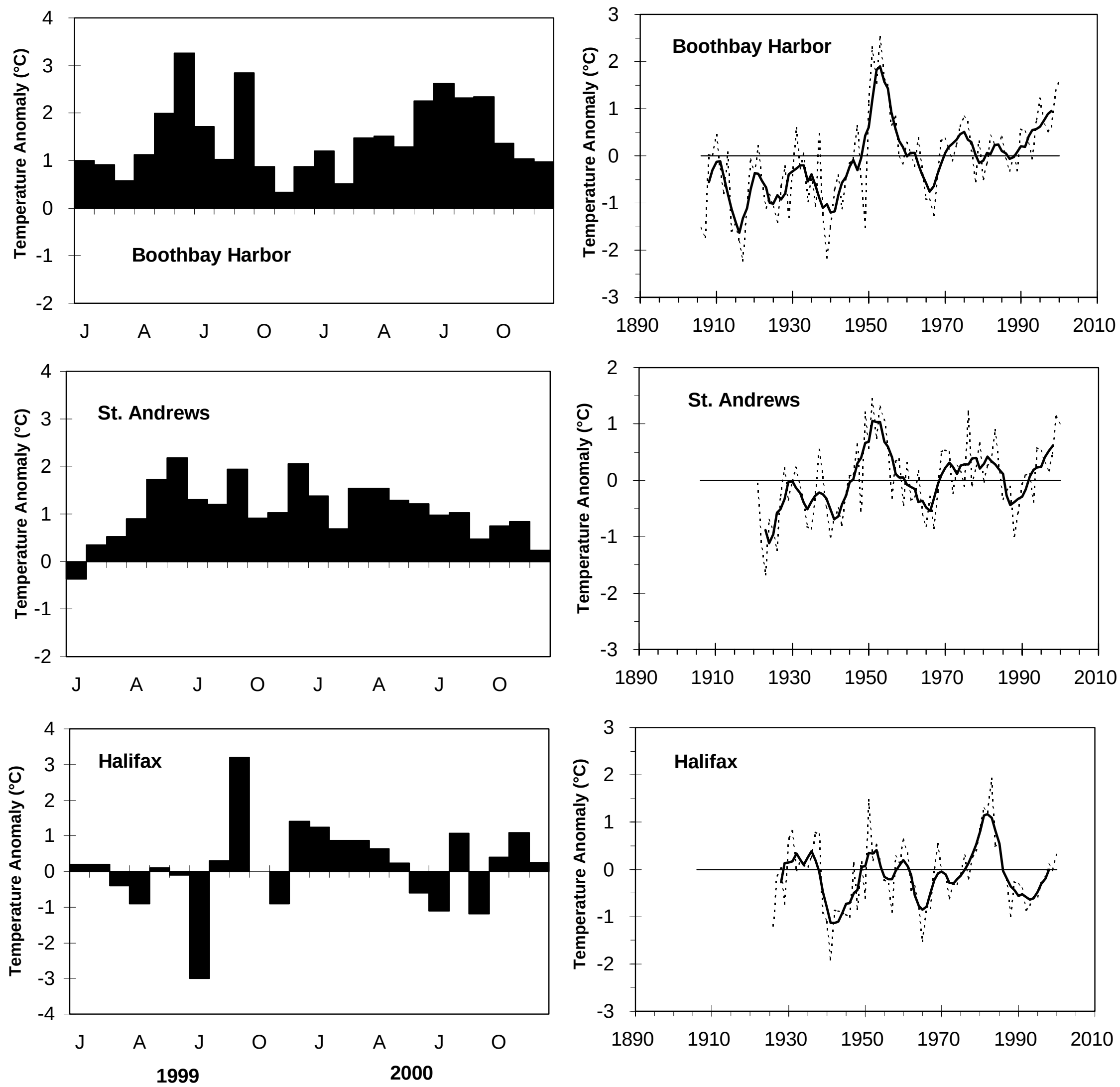


Fig. 43. The monthly sea surface temperature anomalies during 1999 and 2000 (left) and the annual temperature anomalies and their 5-year running means (right) for Boothbay Harbor, St. Andrews and Halifax Harbour. Anomalies are relative to the 1961-90 means.

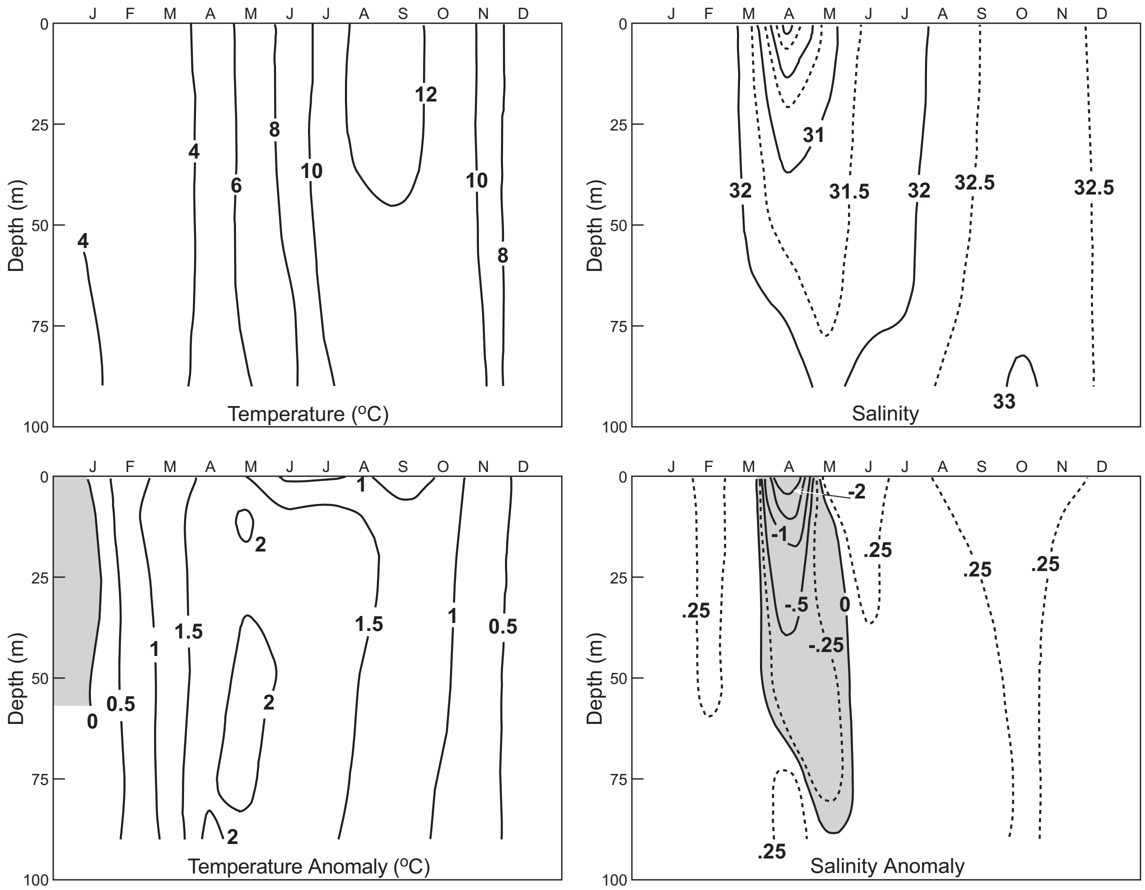


Fig. 44. Contours of monthly mean temperature (left) and salinity (right) and their anomalies (bottom panels) at Prince 5 as a function of depth during 2000 relative to the 1961-90 means. Colder and fresher-than-normal conditions are shaded.

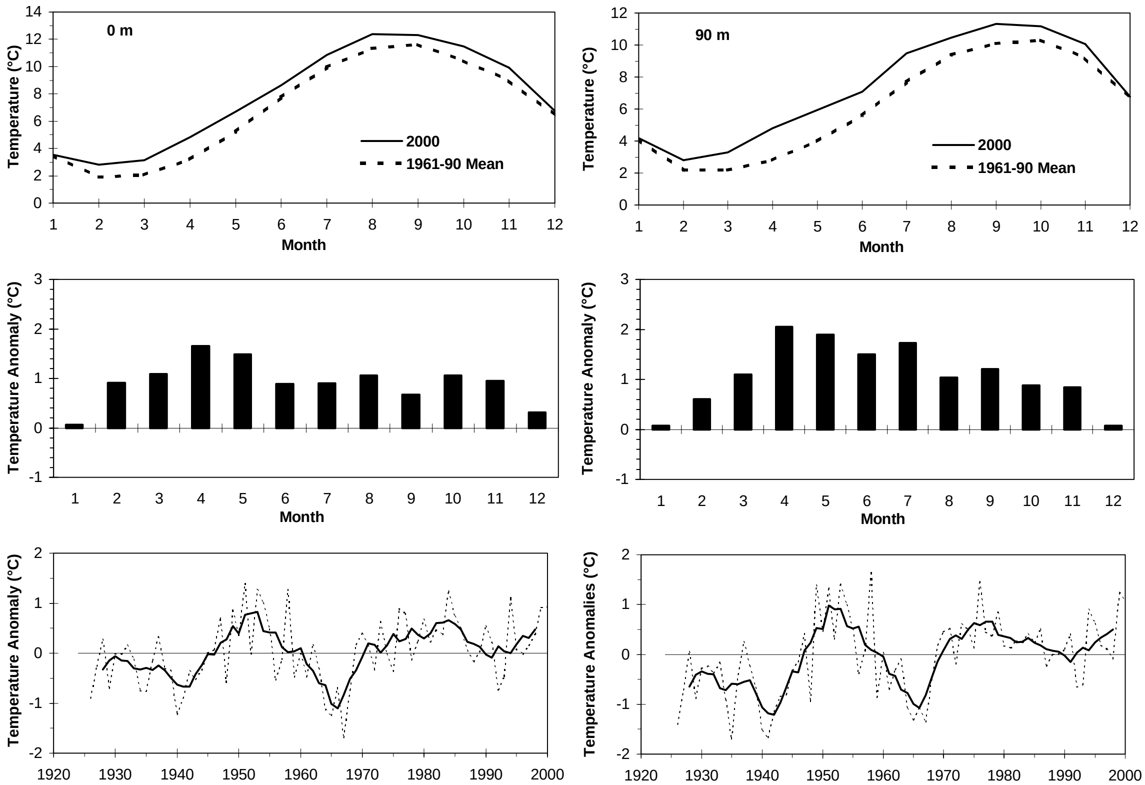


Fig. 45. The monthly mean temperatures for 2000 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

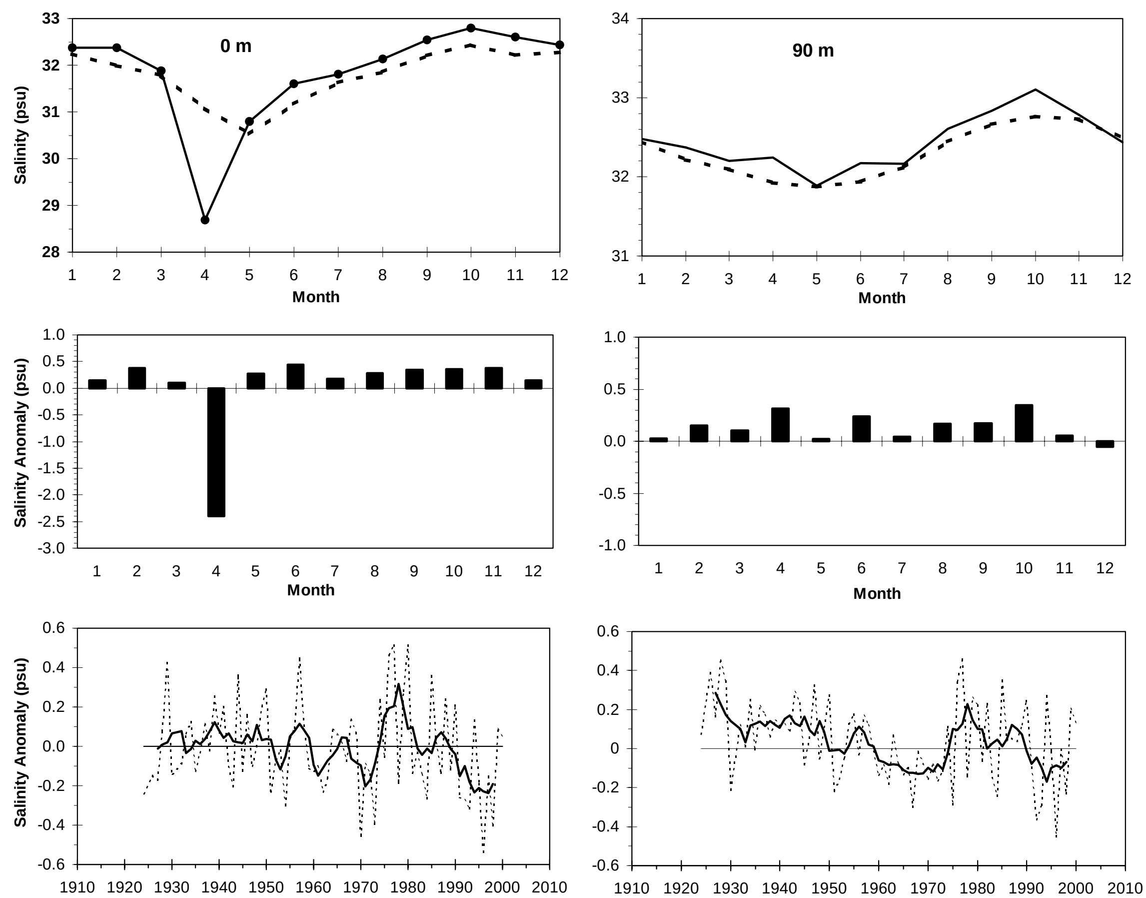


Fig. 46. The monthly mean salinities for 2000 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running averages (solid line) for Prince 5, 0 m (left) and 90 m (right).

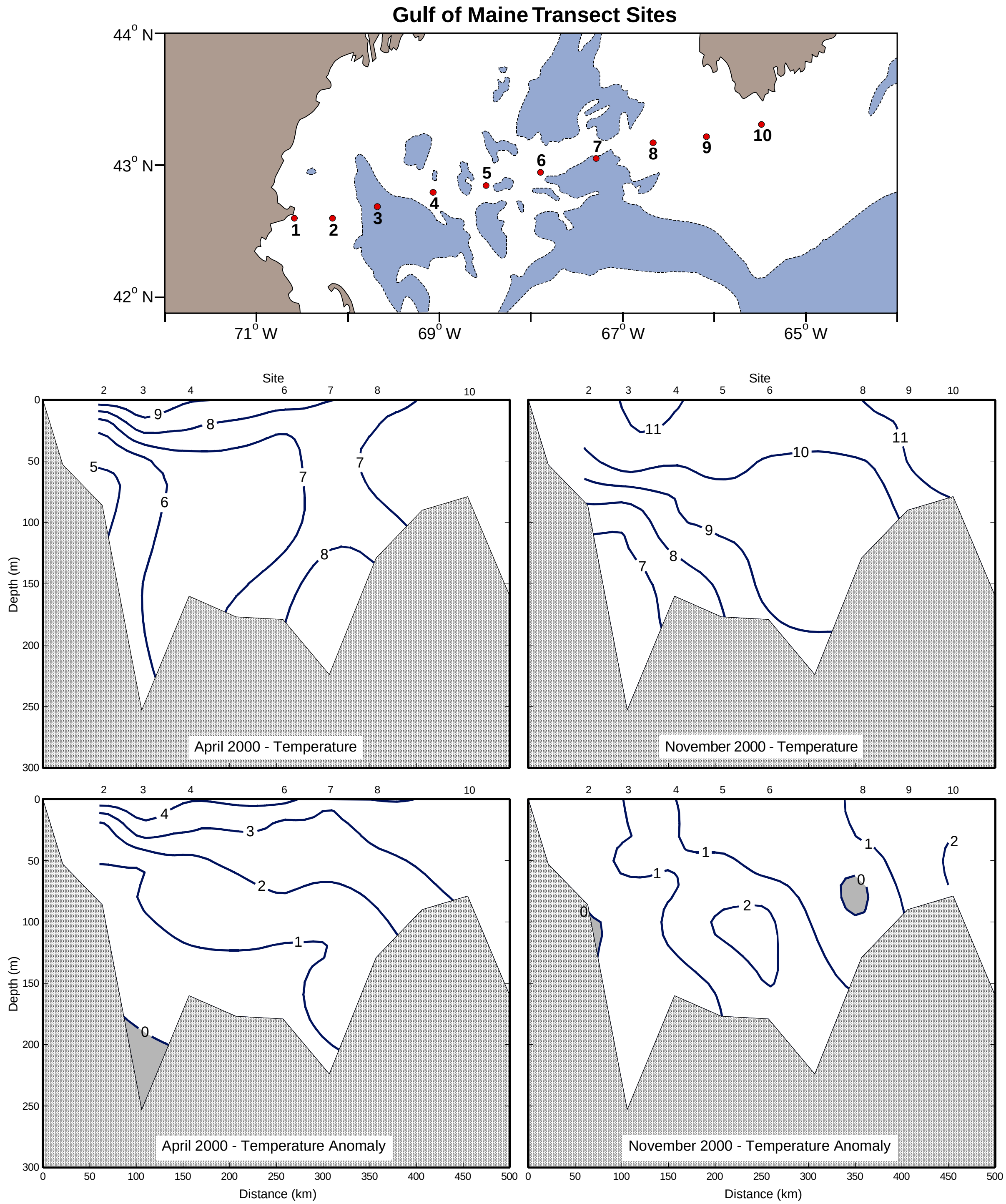


Fig. 47. The temperature (middle panels) and temperature anomalies (bottom panels) in ºC along a XBT transect (top panel) across the Gulf of Maine during April and November 2000.

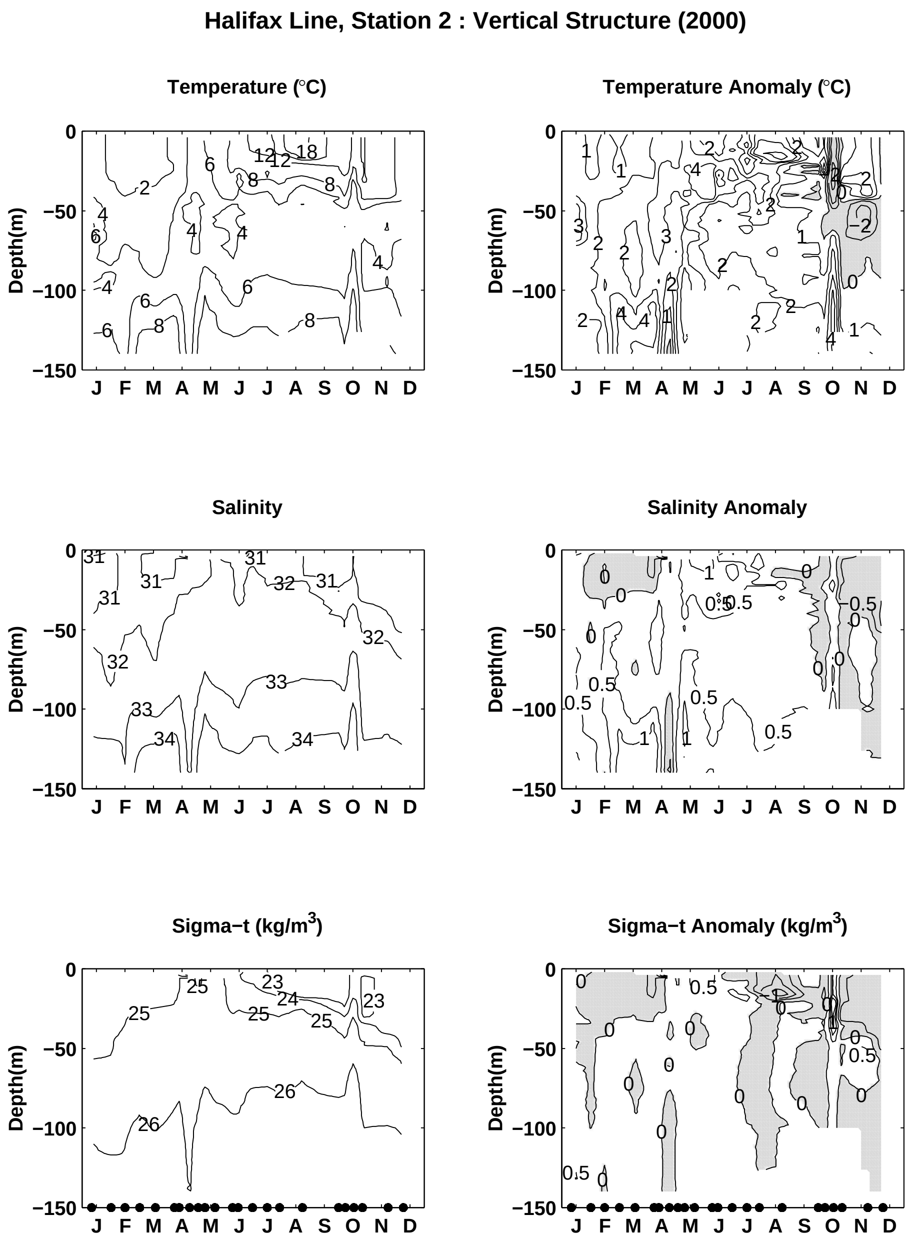


Fig. 48. Contours of temperature, salinity and density (sigma-t) for 2000 (left) and their anomalies (right) at the standard station H2.

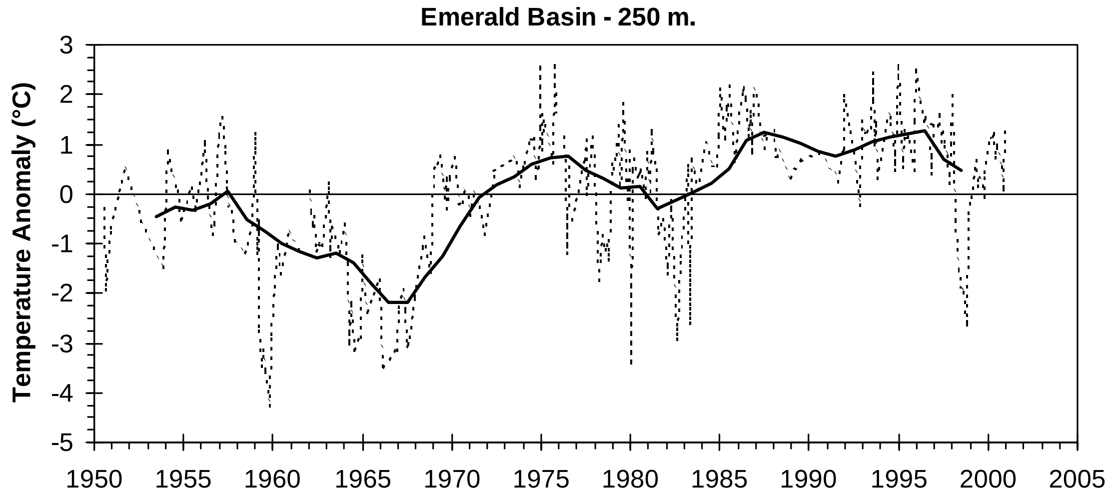


Fig. 49. Time series of available monthly mean temperature anomalies at 250 m in Emerald Basin Bank (dashed line) and their 5-year running means (solid line).

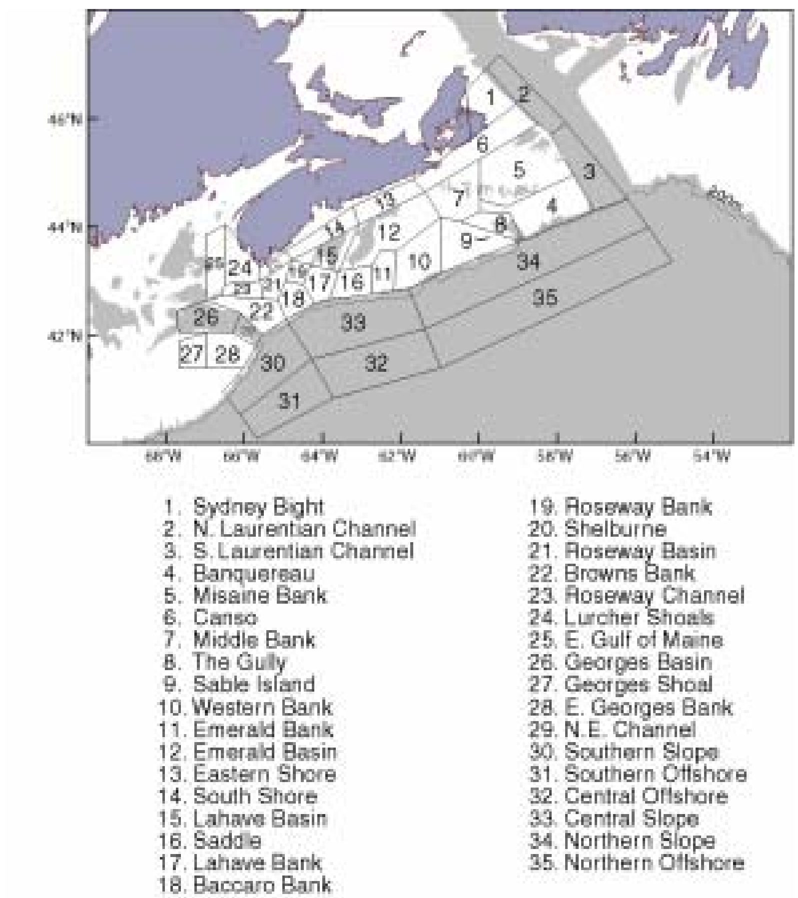
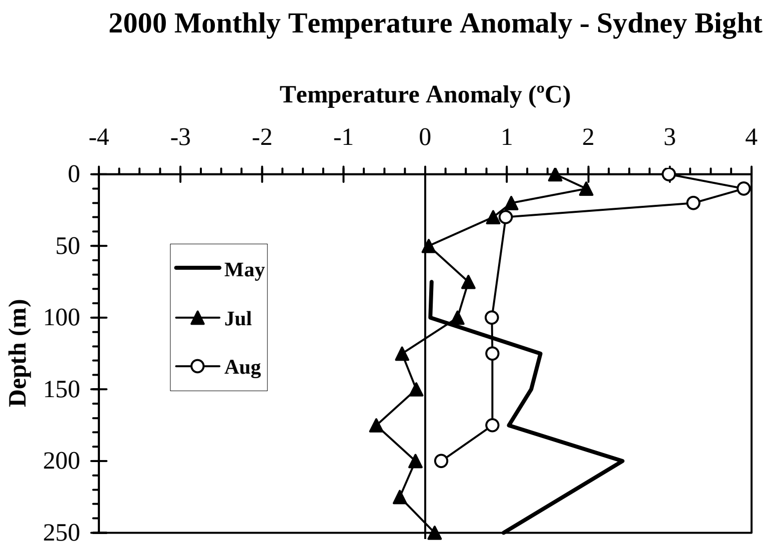


Fig. 50. Areas on the Scotian Shelf and eastern Gulf of Maine from Drinkwater and Trites (1987).



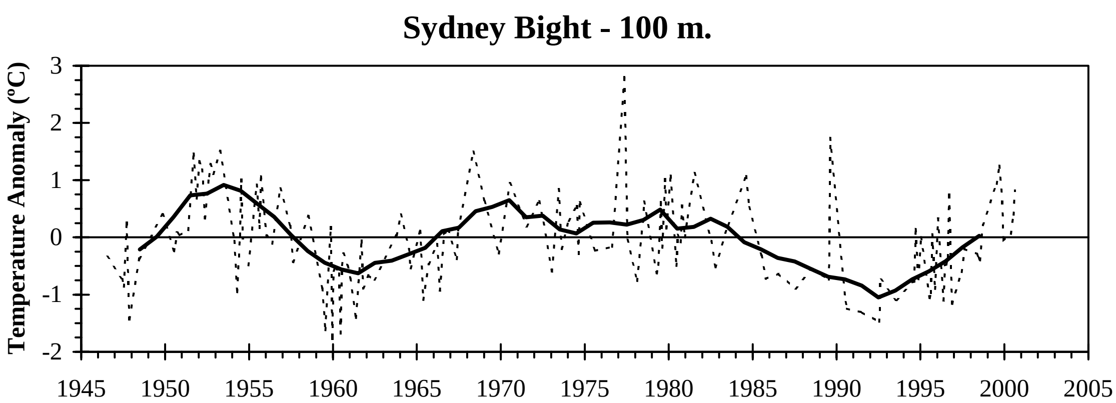
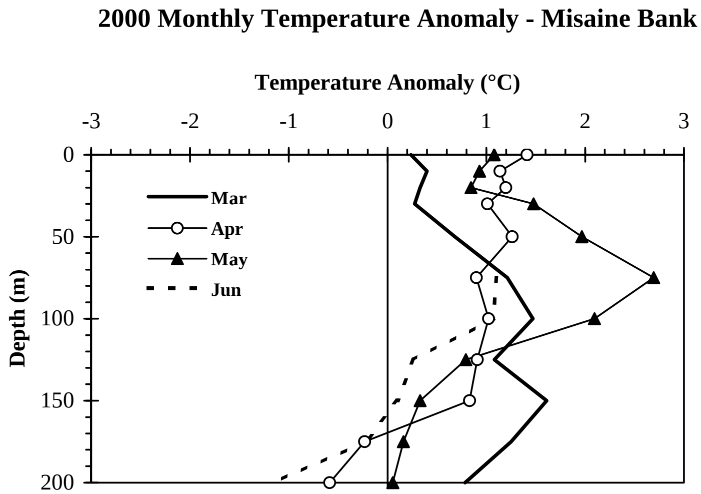
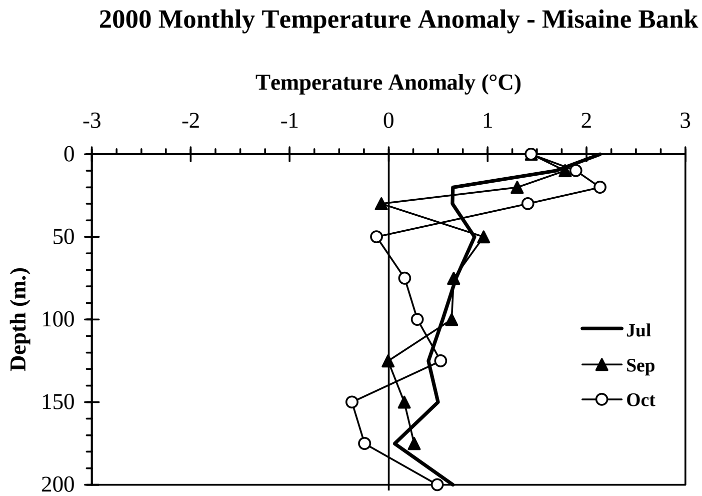


Fig. 51. 2000 monthly temperature anomaly profiles (top panel) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Sydney Bight (area 1-Fig. 50).





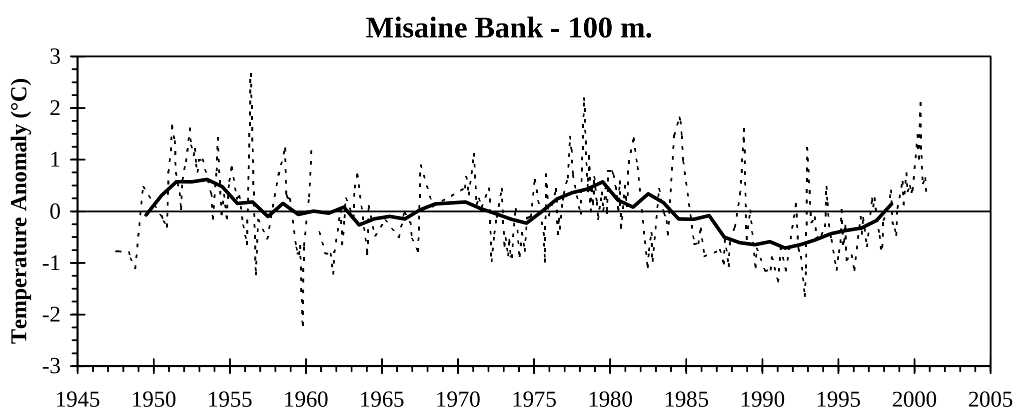
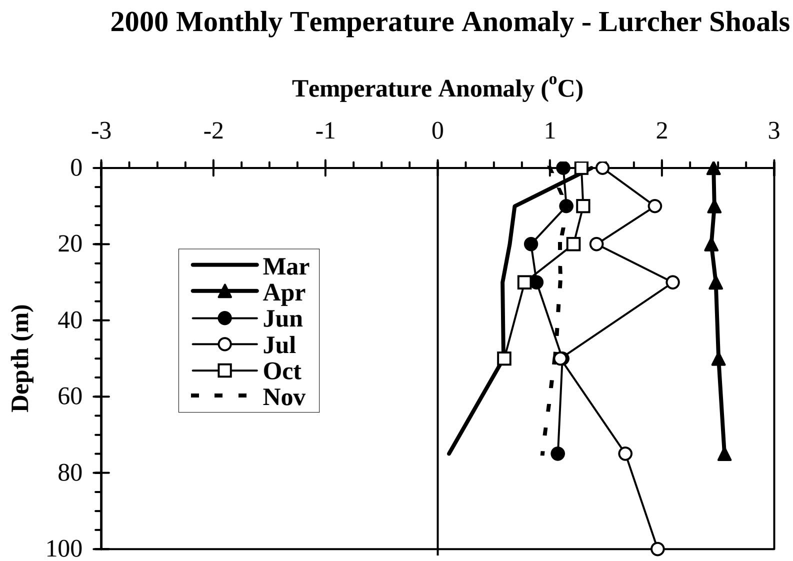


Fig. 52. 2000 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Misaine Bank (area 5-Fig. 50).



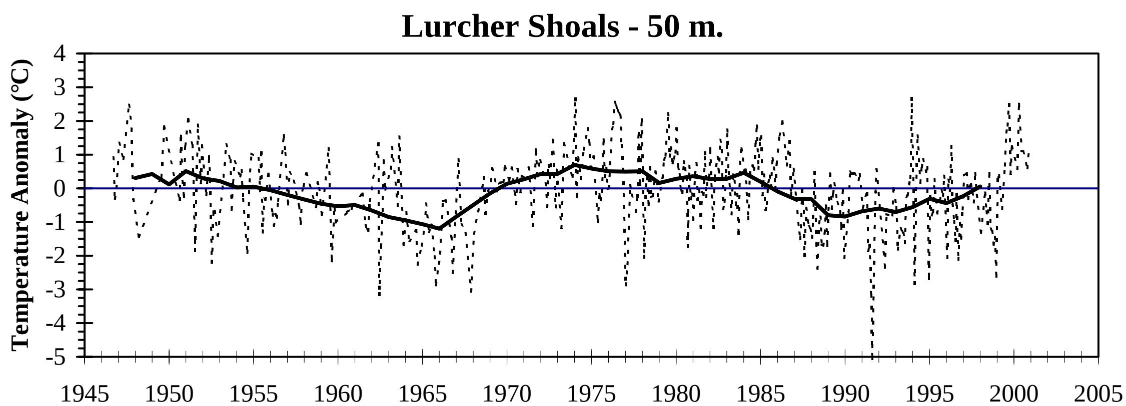


Fig. 53. 2000 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Lurcher (area 24-Fig. 50).

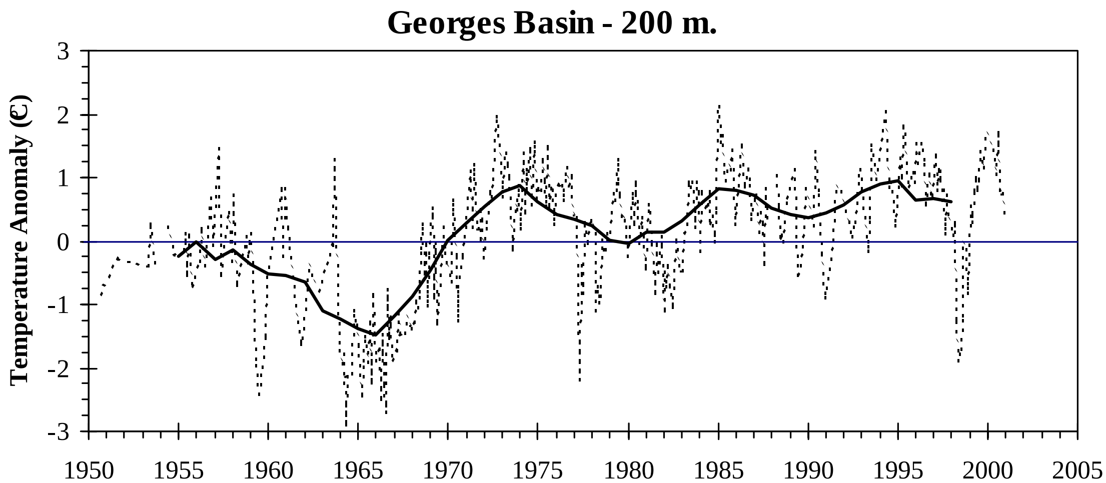


Fig. 54. Time series of monthly mean temperature anomalies at 200 m in Georges Basin (dashed lines) and their 5-year running means (solid line).

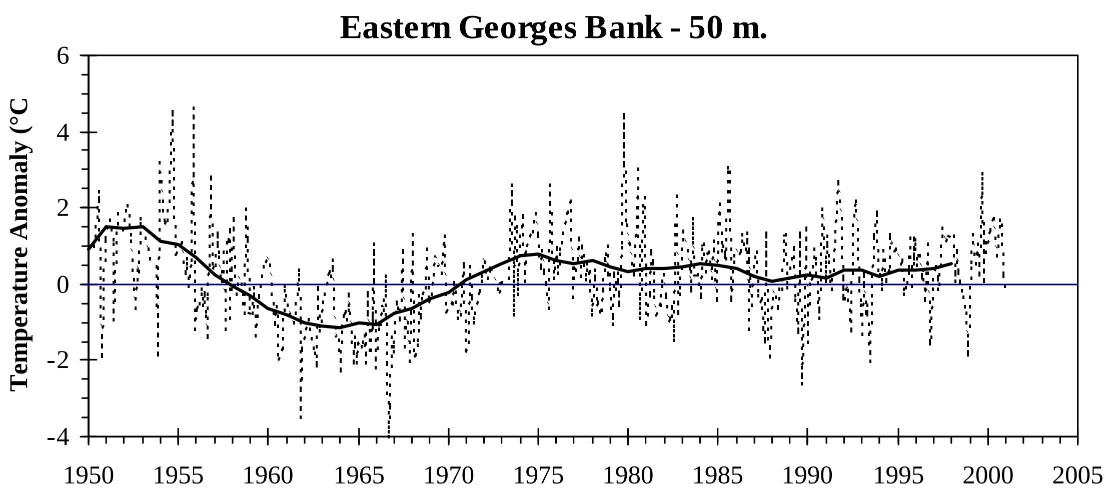


Fig. 55. Time series of monthly mean temperature anomalies at 50 m on eastern Georges Bank (dashed lines) and their 5-year running means (solid line).

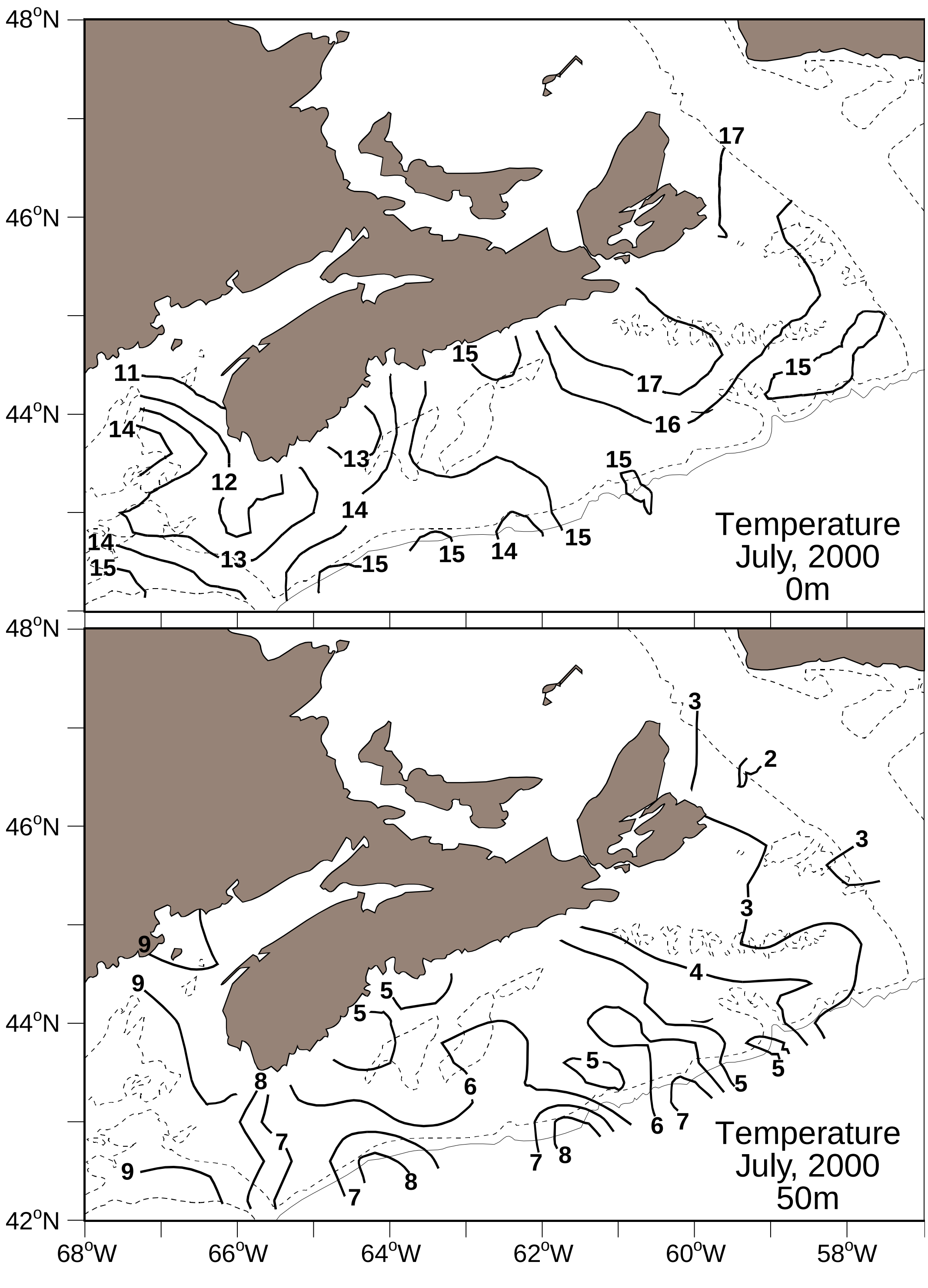


Fig. 56a. Contours of temperatures at the surface (top panel) and 50 m (bottom panel) during the 2000 July groundfish and ITQ surveys.

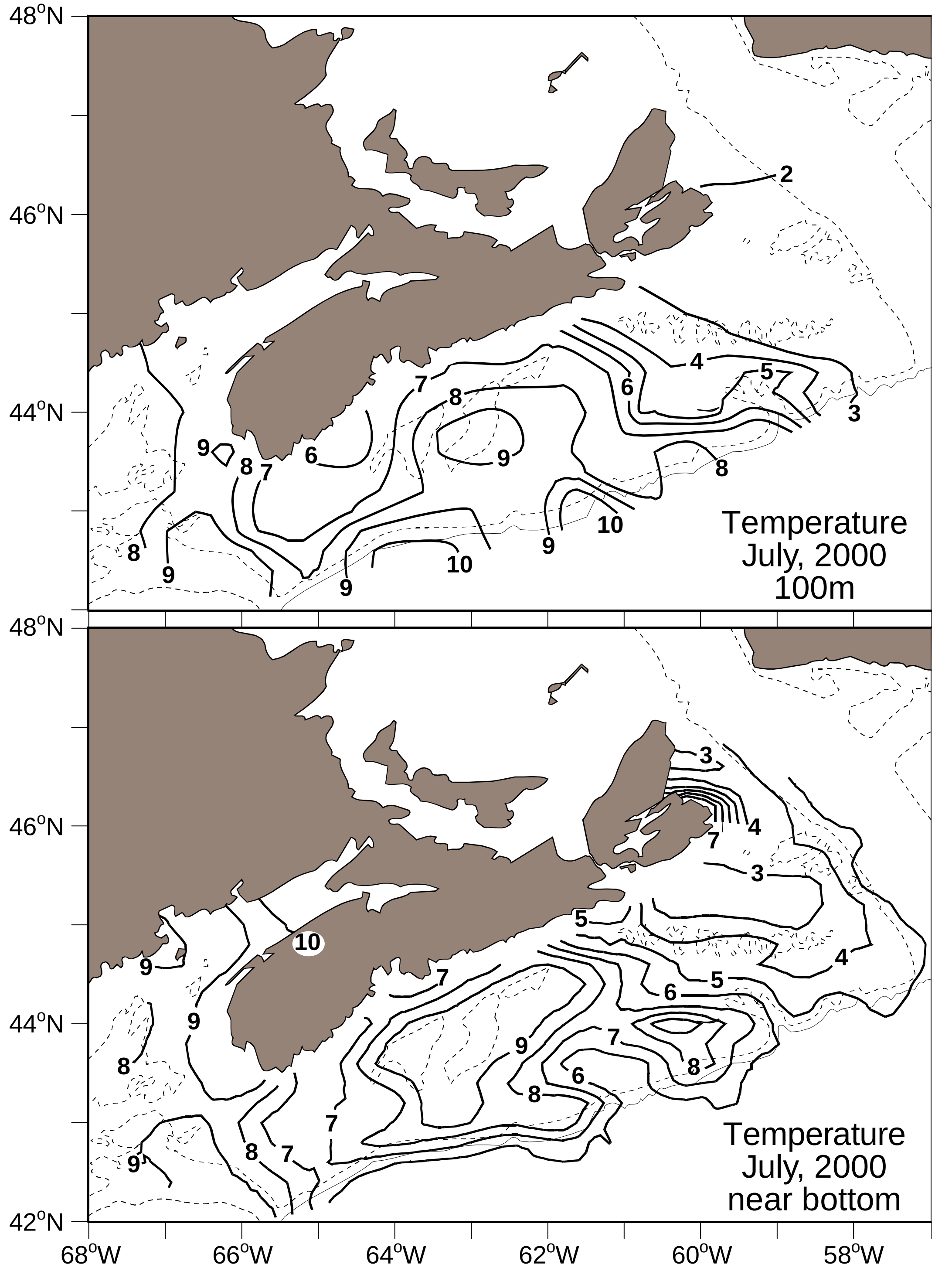


Fig. 56b. Contours of temperatures at 100 m (top panel) and near bottom (bottom panel) during the 2000 July groundfish and ITQ surveys.

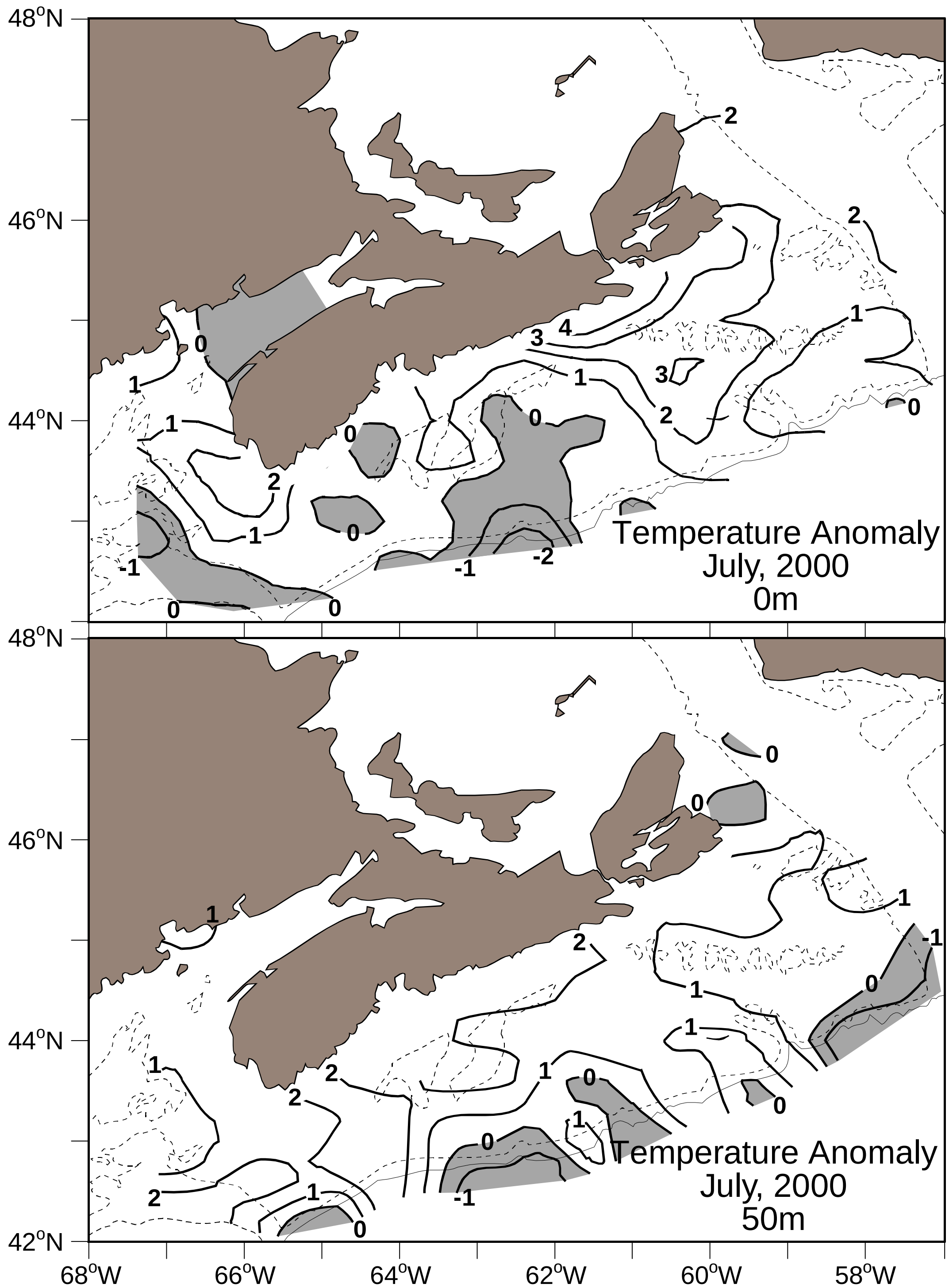


Fig. 57a. Contours of temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 2000 July groundfish and ITQ surveys.

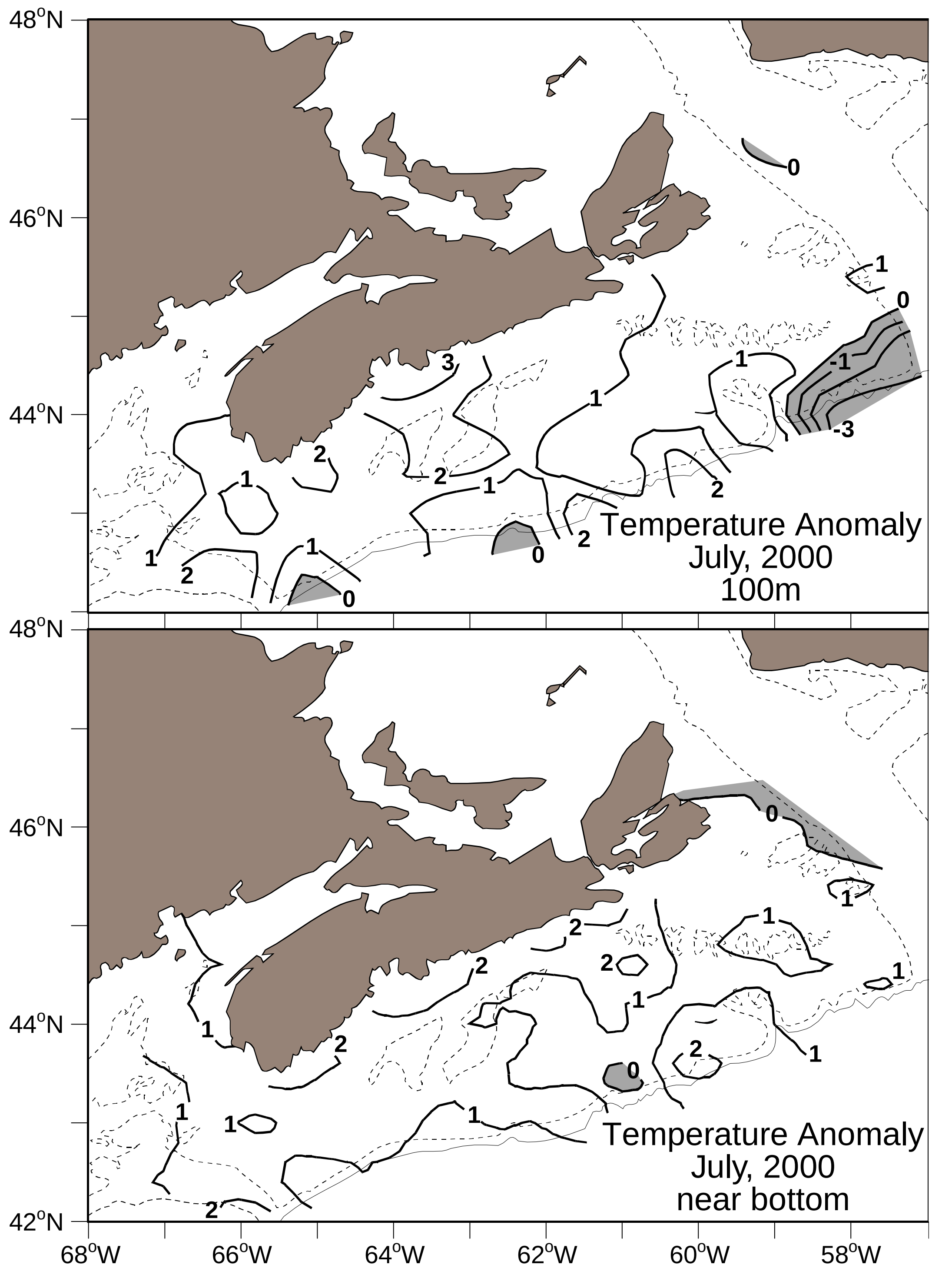


Fig. 57b. Contours of temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 2000 July groundfish and ITQ surveys.

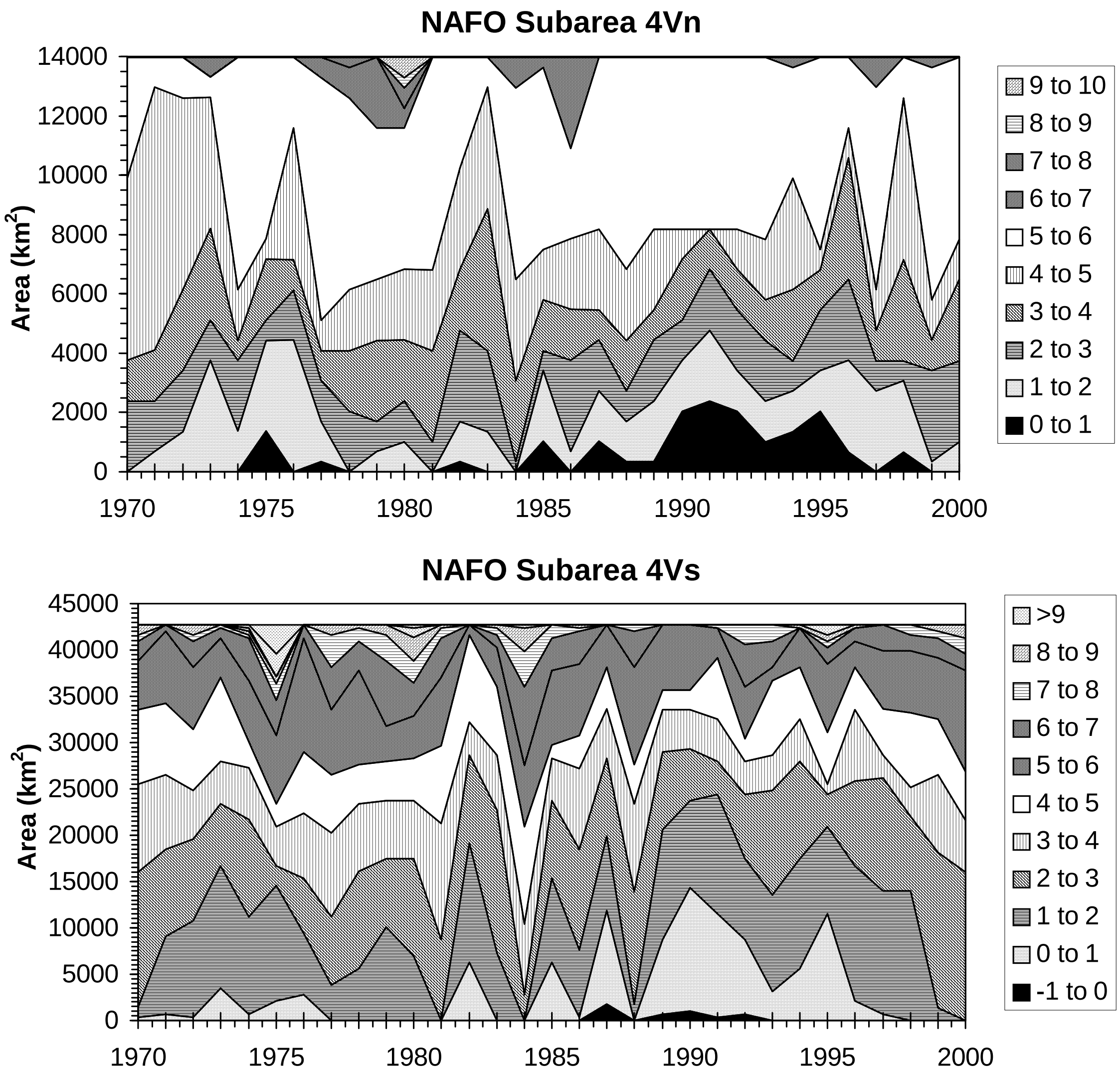


Fig. 58a. The time series of the area of the bottom for each 1 degree temperature range for NAFO Subareas 4Vn (top panel) and 4Vs(bottom panel).

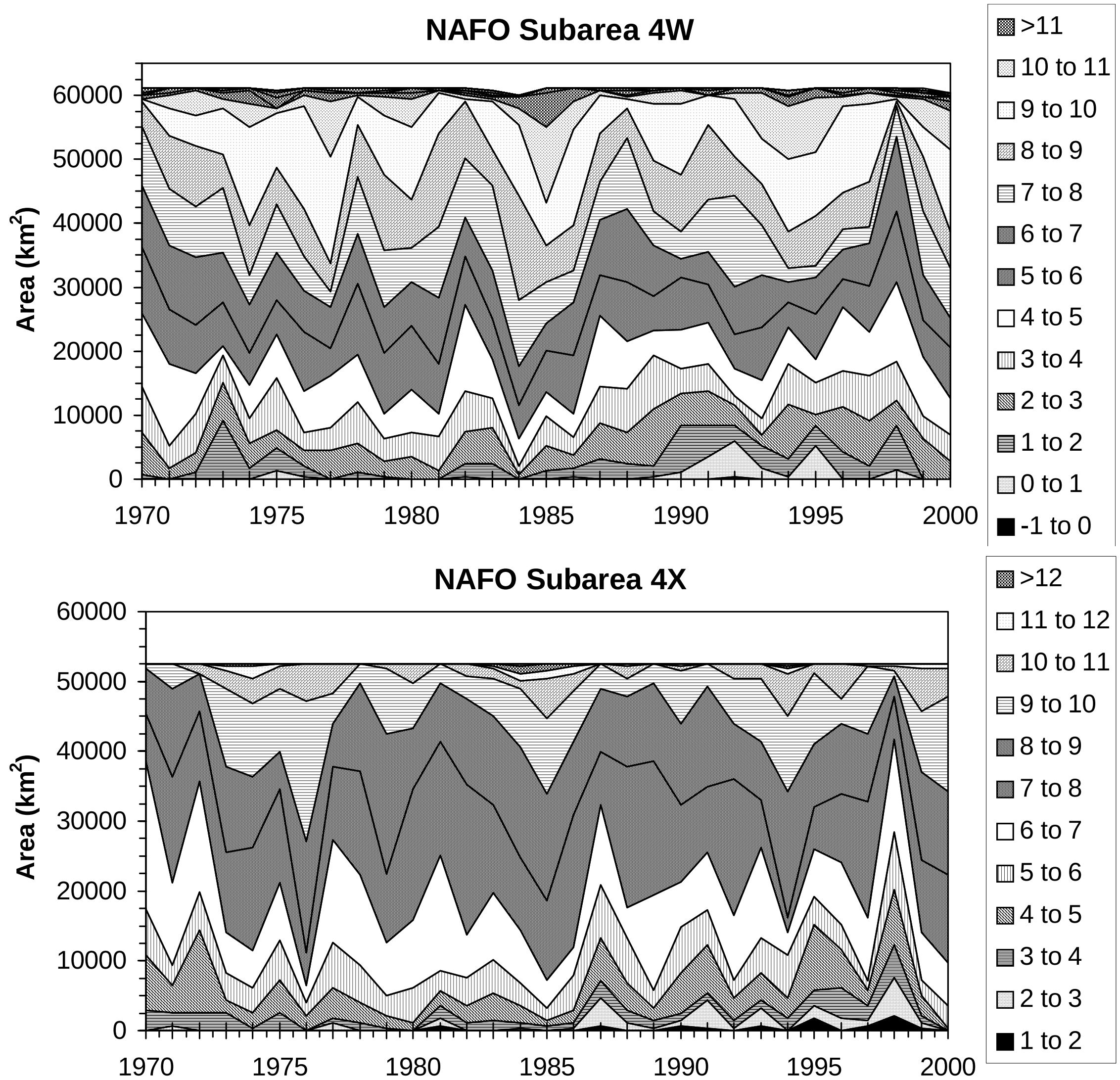


Fig. 58b. The time series of the area of the bottom for each 1 degree temperature range for NAFO Subareas 4W (top panel) and 4X(bottom panel).

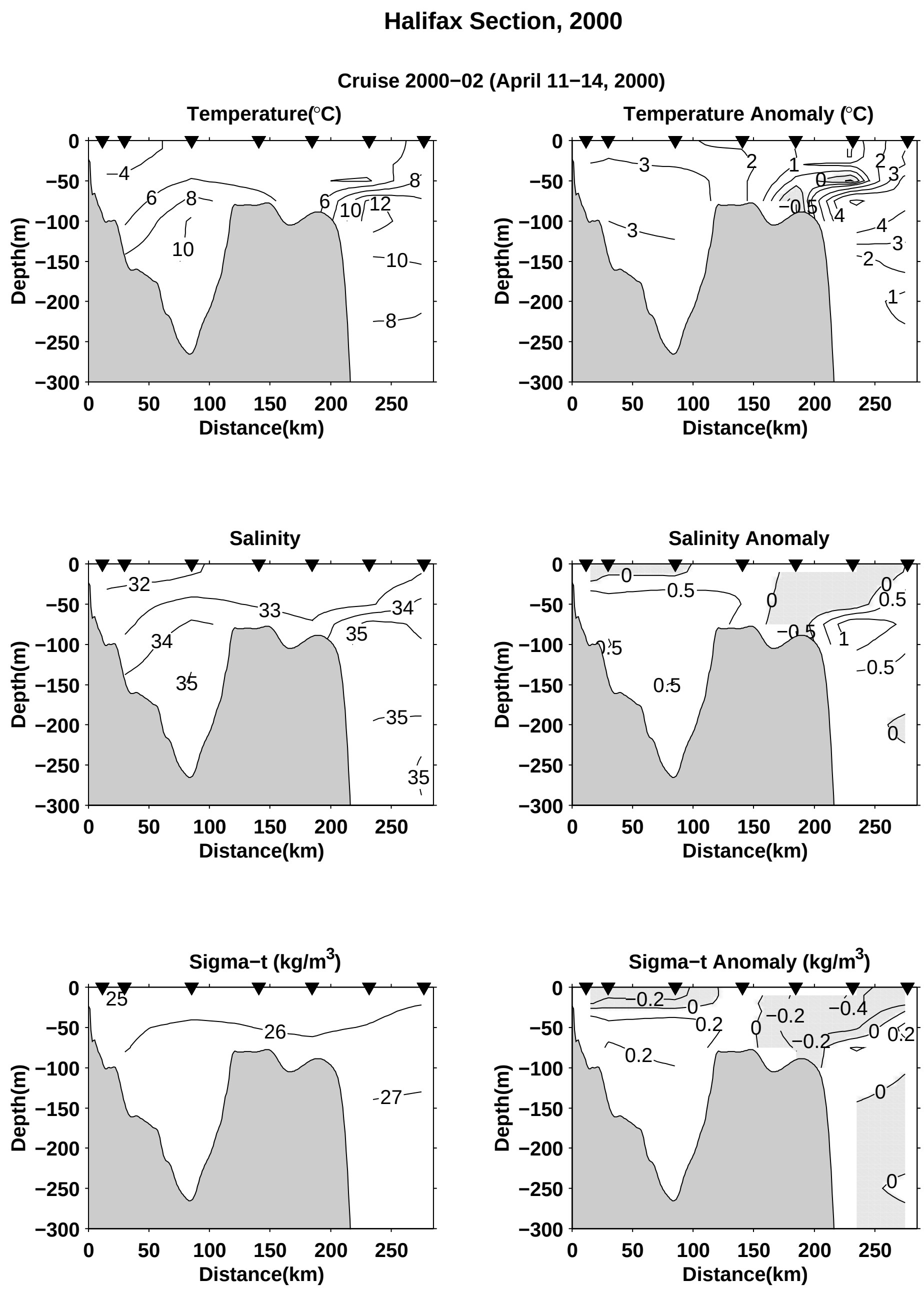


Fig. 59. Contours of the temperature, salinity and sigma-t (left panels) and their anomalies (right panels) along the Halifax Line during April 2000 (left panels). The triangles denote the location of the standard stations.

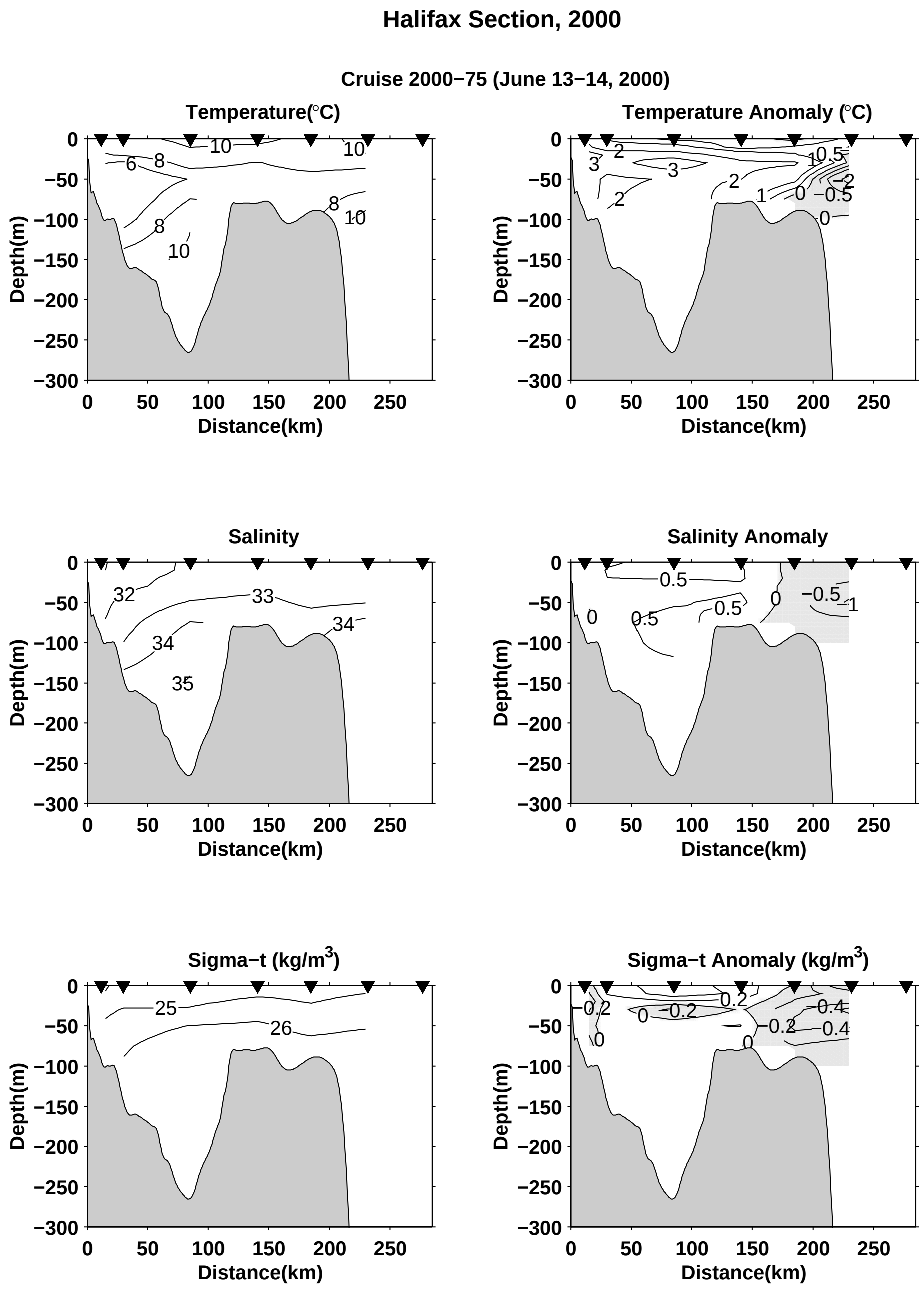


Fig. 60. Contours of the temperature, salinity and sigma-t (left panels) and their anomalies (right panels) along the Halifax Line during June 2000 (left panels). The triangles denote the location of the standard stations.

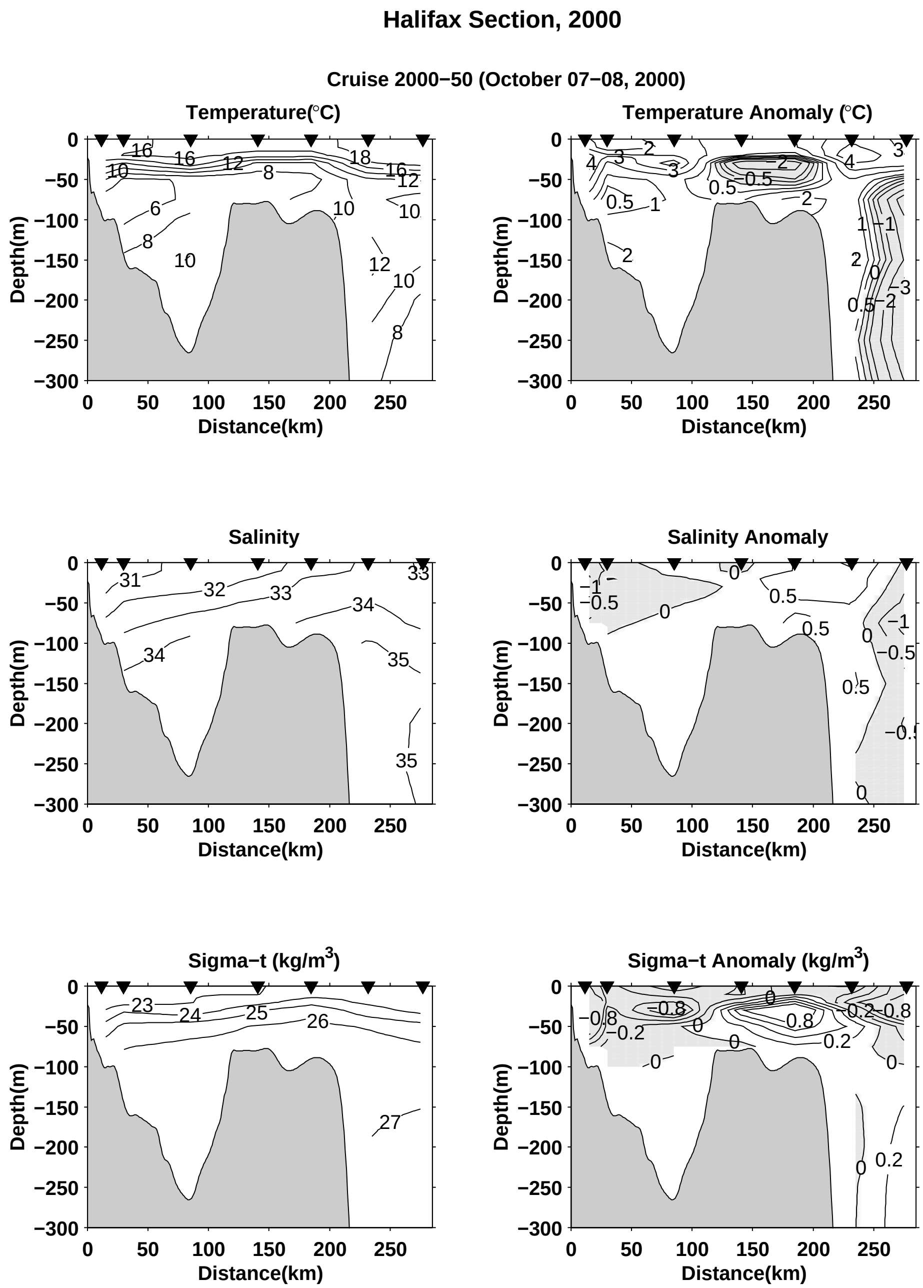


Fig. 61. Contours of the temperature, salinity and sigma-t (left panels) and their anomalies (right panels) along the Halifax Line during October 2000 (left panels). The triangles denote the location of the standard stations.

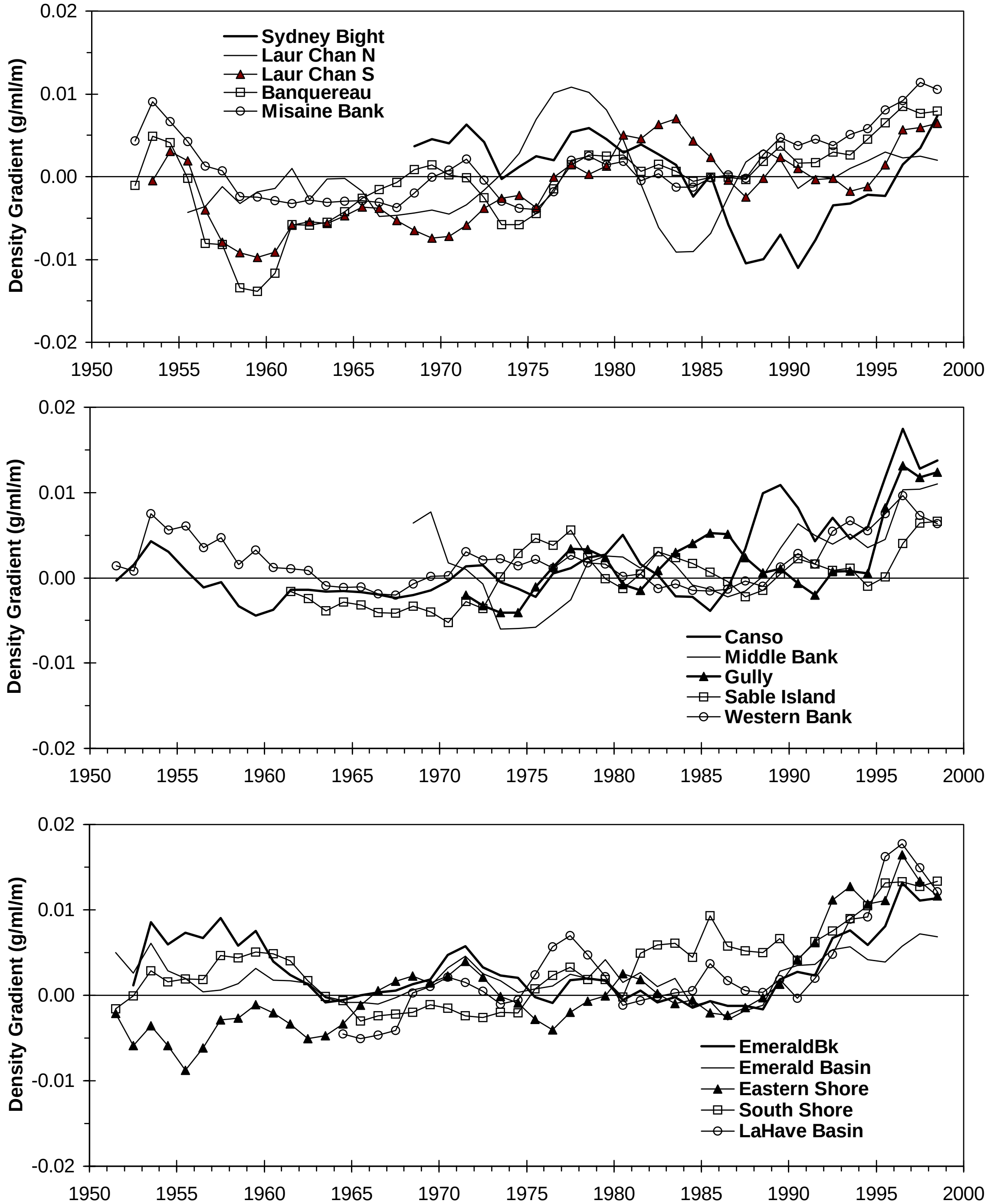


Fig. 62a. Five-yr running means of the annual anomalies of the density gradient between the surface and 50 calculated for the areas 1-15 in Fig. 8.

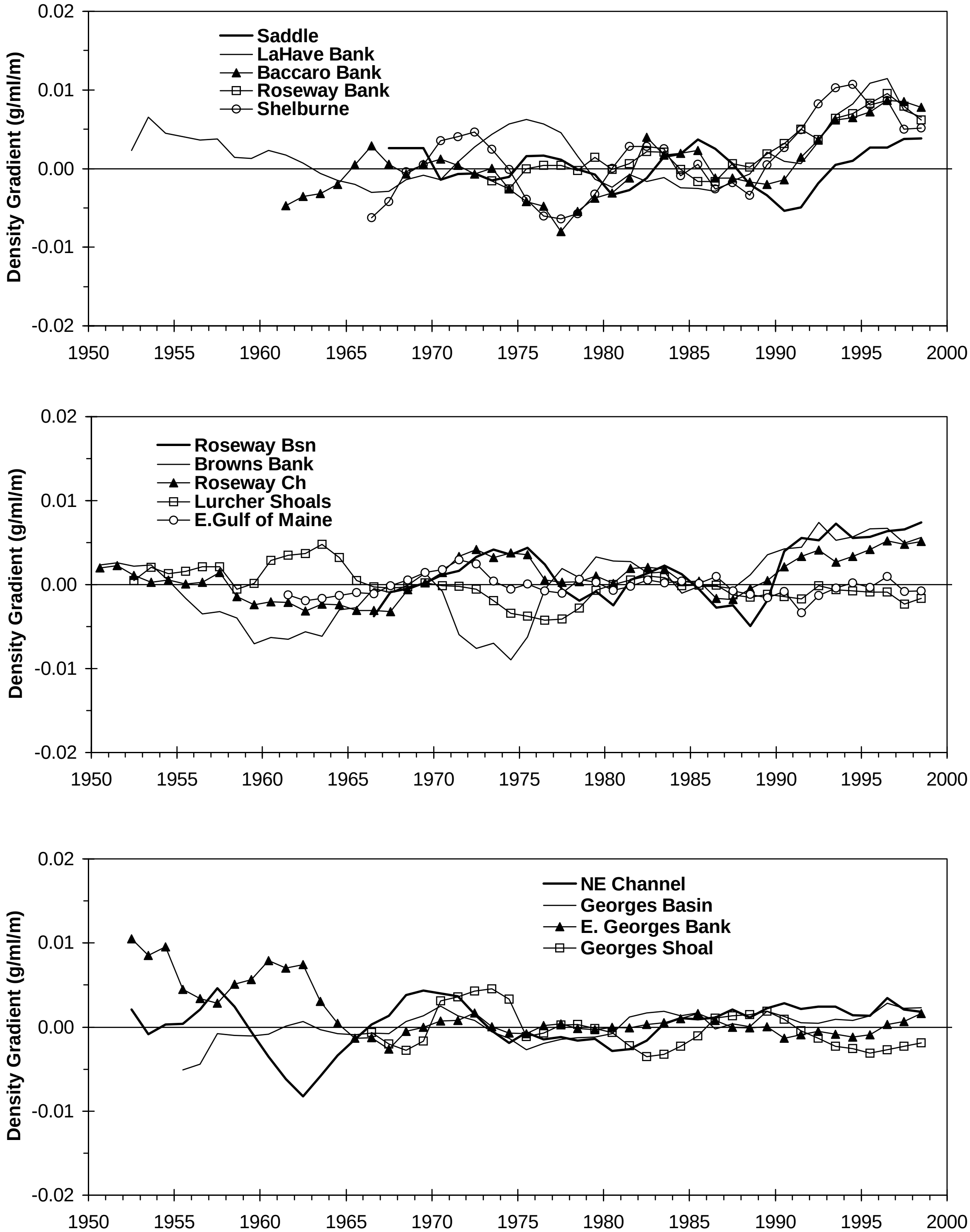
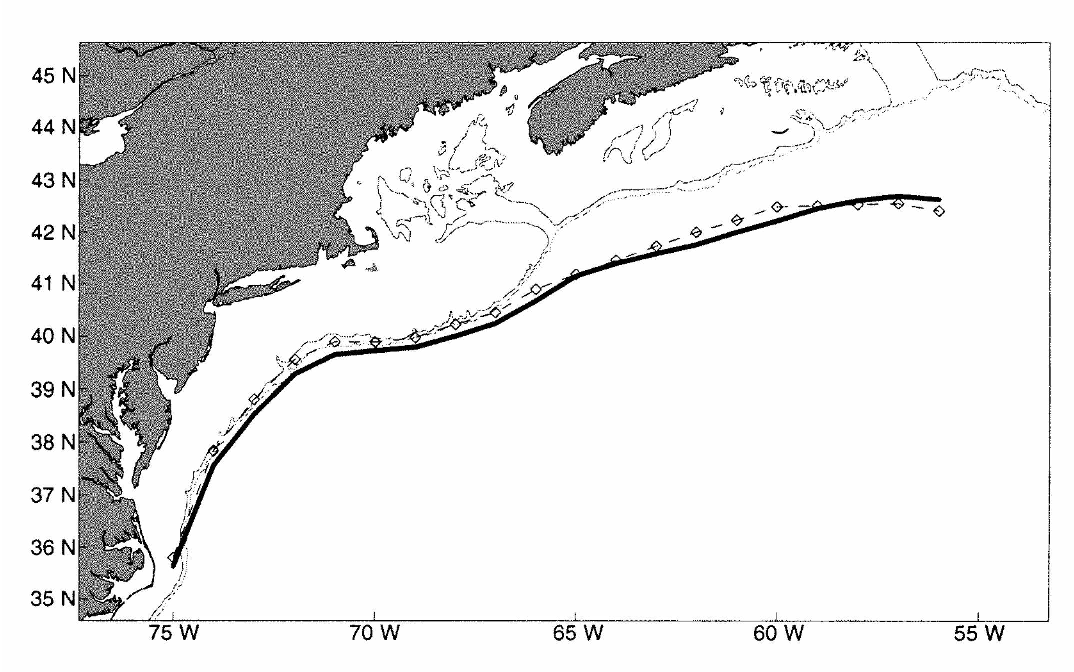


Fig. 62b. Five-yr running means of the annual anomalies of the density gradient between the surface and 50 calculated for the areas 16-29 in Fig. 8.



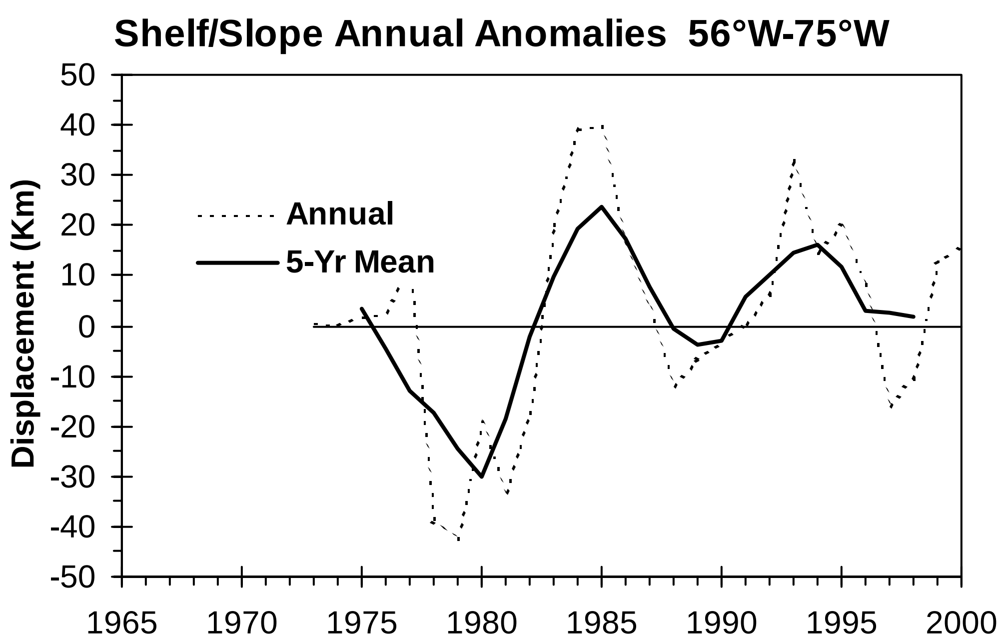


Fig. 63. The 2000 (dashed line) and long-term mean (1973-97; solid line) positions of the shelf/slope front (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the shelf/slope front (bottom panel).

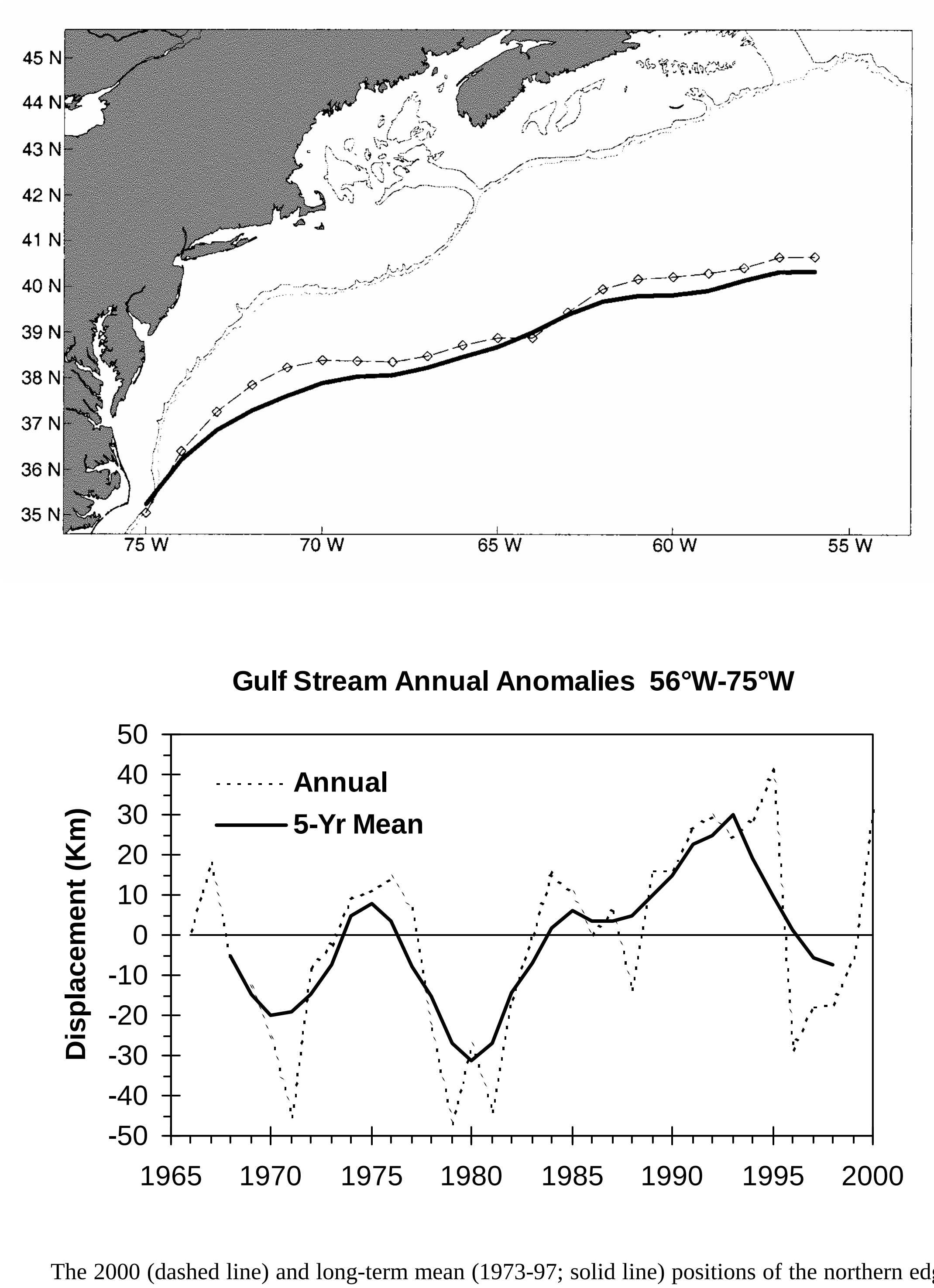


Fig. 64. The 2000 (dashed line) and long-term mean (1973-97; solid line) positions of the northern edge of the Gulf Stream (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the Gulf Stream front (bottom panel).