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Overview of Environmental Conditions in the Northwest Atlantic in 1998

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Abstract

A review of environmental conditions on the continental shelves and adjacent offshore areas off northeastern North America during 1998 is presented. Annual air temperatures throughout most of the northwest Atlantic warmed relative to values in 1997 and were warmer than the long-term mean by between 0.4 and 1.5C. The maximum air temperature anomaly, and the largest increase relative to 1997, was in the Gulf of St. Lawrence. The NAO index in 1998 increased only slightly from 1997 and was just above normal. Sea ice on the southern Labrador and Newfoundland shelves as well as in the Gulf of St. Lawrence and on the Scotian Shelf generally appeared late and left early resulting in a shorter duration than usual and less ice than in 1997. The number of icebergs reaching the Grand Banks increased over 1997 by 36% but remained well below the large numbers reported in the early 1990s. Ocean temperatures were generally above normal over much of Labrador and northern Newfoundland shelves and the Grand Banks. This was evident from the near bottom temperatures and in much of water column throughout the year from Hamilton Bank in the north to the Grand Banks. At Station 27, however, colder-than-normal temperatures dominated from April to December. The CIL volume over the northern Newfoundland Shelf was up slightly from 1997 but remained well below normal. Although near bottom temperatures on St. Pierre Bank remained colder-than-normal, there was substantial moderation relative to previous years. The cold conditions on St. Pierre Bank area have persisted since the mid-1980s. Similar colder-than-normal conditions since the mid-1980s have been observed in the CIL in the Gulf of St. Lawrence and in the near bottom waters on the Magdalen Shallows. These waters remained at below normal temperatures in 1998 and cooled relative to 1997 reversing a trend of slow warming. In the deep waters of Cabot Strait (200-300 m), temperatures were near their long-term means. The most significant change from 1997 conditions was the arrival of cold, Labrador-type slope water along the shelf edge of the Scotian Shelf and the Gulf of Maine. This cold water penetrated onto the shelf through channels and gullies and replaced the warm slope water remnants that were in the deep basins such as Emerald Basin and Georges Basin. These cold waters remained for the rest of the year. Temperature changes in the deep region of Emerald Basin were of order 2°-3°C colder than last year and well below the long-term mean. In the northeastern Scotian Shelf, waters continued to experience below normal temperatures. This pattern was established in the mid-1980s with maximum cooling in the early 1990s. In recent years, including 1998, there has been a slow but steady increase in temperatures in these regions. The presence of these cold waters is believed to be due to a combination of advection from the Gulf of St. Lawrence and off the Newfoundland Shelf and *in situ* cooling during the winter although the relative importance has not yet been established. Also of significance was the establishment of increased stratification in the upper water column (between surface and 50 m) throughout the Scotian Shelf since the

1950s with maximum values in recent years. This high stratification was not observed in the Gulf of Maine, however. Both the slope/shelf front and the Gulf Stream were further seaward than normal in 1998.

Introduction

This paper examines the atmospheric, sea ice and hydrographic conditions in the Northwest Atlantic during 1998 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, called anomalies. Unless otherwise stated, these 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 monthly air temperature anomalies for the North Atlantic Ocean in their publication *Die Grosswetterlagen Europas* (Deutscher Wetterdienstes, 1998). Warmer-than-normal temperatures dominated most regions of the northwest Atlantic during 1998. In January, they covered the continental shelves off West Greenland and from southern Labrador to the Middle Atlantic Bight, the latter reaching anomalies of > 3°C (Fig. 1). In contrast, over the central Labrador Sea, northern Labrador, Baffin Island and off eastern Newfoundland, temperatures in this month were below normal. Mild conditions continued for the remainder of the winter over the region south of Labrador with anomalies between 2°-4°C during February and March. The most intense cold during the year appeared in February over Davis Strait and extended from Baffin Island to Greenland and Iceland, with negative anomalies reaching -7°C. Springtime temperatures were above normal in most regions, the notable exception being the Middle Atlantic Bight. These lower-than-average temperatures in the vicinity of the Bight remained until August. During the summer of 1998, temperatures generally remained above normal although the amplitudes were lower than those observed earlier in the year. However, the colder-than-normal temperatures off the Middle Atlantic Bight extended further northward to cover large portions of the Gulf of Maine, especially during June and July. In September, a small area off eastern Newfoundland experienced below average air temperatures while most of the rest of the northwest Atlantic continued the higher-than-normal temperatures. Much of the Labrador Sea experienced above normal air temperatures in October although slightly below or near average values spread over the Scotian Shelf, Gulf of Maine and off southwestern Greenland. These conditions also extended into November, with the colder-than-normal air mass expanding slightly to include the Gulf of St. Lawrence and the Middle Atlantic Bight. In December, relatively high anomalies (1°-4°C) covered all regions except near the mouth of the Labrador Sea where cold conditions prevailed.

Monthly air temperature anomalies for 1997 and 1998 relative to their 1961-90 mean at eight sites in the northwest Atlantic from Godthaab in Greenland to Cape Hatteras on the eastern coast of the United States are shown in Fig. 3 (see Fig. 2 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, 1998). The predominance of warmer-than-normal air temperatures during 1998, noted above, is clearly evident (Fig. 3). At Cartwright, all months were above normal and at the Magdalen Islands and Sable Island all months but one (November). The cold conditions in the northern Labrador Sea during February are clearly seen at Godthaab and Iqaluit with anomalies at both sites near -4°C. At Iqaluit, cold conditions were observed in January and March as well. The highest anomalies in 1998 tended to occur in the winter months at Godthaab, Cartwright, the Magdalen Islands and on Sable Island with the maximum value on the Magdalens (3.4°C). At St. John's, the highest anomalies occurred in May and August. The highest monthly anomaly recorded at all sites in 1998 was at Iqaluit in November (4.2°C).

Annual mean air temperatures for 1998 were warmer-than-normal at all sites. Annual anomalies decreased from a maximum of 1.5°C at the Magdalen Islands near the center of the study area, to 0.4°C at the northern (Godthaab) and southern (Cape Hatteras) extremes. The second highest anomaly was at Cartwright (1.2°C). At all of the sites except Godthaab and Cape Hatteras, anomalies exceeded 0.8°C. At Boston, 1998 was within the top 5% of the warmest years in the over 100 year record. From Sable Island north to Cartwright, 1998 annual mean air temperatures were within the warmest 8-16% on record.

The 1998 annual temperature anomaly increased relative to 1997 values at all sites except Iqaluit (Fig. 4). From Cartwright to Boston, the change in annual mean air temperature was over 1°C with a maximum of over 1.5°C at the Magdalen Islands in the Gulf of St. Lawrence. Note that the interannual variability in air temperatures since 1960 at Godthaab, 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 is consistent with a continuation of this near decadal pattern. Temperature anomalies at the Magdalen Islands and Sable Island have generally been of lower amplitude than those to the north but do contain 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 also exhibit decadal variability but are out of phase with the temperature fluctuations in the Labrador region. Thus, when the temperatures were very cold in Labrador during the early 1990s, they were relatively warm along the US seaboard (Fig. 4). 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* (Deutscher Wetterdienstes, 1998). 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. 5). 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 1998 are shown in Fig. 6. Winter includes December 1997 to February 1998, spring is March to May, and summer is June to August.

In winter, a negative air pressure anomaly extended throughout most of the North Atlantic with minima over the southeastern seaboard of the United States (-4.9 mb) and south of Iceland (-3.7 mb). Strong positive anomalies persisted from eastern Canada north of Newfoundland, across to Greenland and to Svalbard, the islands east of Greenland, with maxima (≥ 3.5 mb) centered over Hudson Bay and north of Svalbard. A ridge of high pressure anomalies also existed in the southeastern region with maxima over western Europe and north Africa. This pressure pattern suggests stronger than normal onshore winds along the Labrador coast and Newfoundland and anomalous easterly winds over the Maritime provinces through to the Middle Atlantic Bight. These winds could have contributed to the generally warmer-than-normal air temperatures.

In the spring of 1998, a positive air pressure anomaly formed over most of the northern North Atlantic with centres east of Newfoundland (2.9 mb) and off the northeastern tip of Greenland (3.6 mb). Another high-pressure anomaly was observed over the extreme southeast of the study area in north Africa. To the east over northern Europe and in the west over the eastern seaboard of the United States, weaker negative anomalies formed with centres over Norway and the southern United States. In contrast to the winter, the air pressure patterns suggest that the winds during spring over much of the Labrador Sea, Newfoundland and the Gulf of St. Lawrence were primarily from the south to southwest. These would have contributed to the warmer-than-normal air temperatures over the region. Over the Gulf of Maine, the winds in springtime were from the southeast.

In the summer, a broad band of negative anomalies stretched from North America across the Atlantic into Europe. The largest negative anomaly (-2.9 mb) was recorded over northern Norway and another (-2.5 mb) over the southeastern United States. Both to the north and southeast of this band were positive pressure anomalies, with maximum values again being located on the eastern side of the Atlantic. The centre of the positive anomalies in the north was located over northeastern Greenland whereas in the south it was situated near the Azores. Over eastern North America, this pressure pattern resulted in a predominance of easterly to southeasterly winds.

The autumn air pressure pattern bears some resemblance to that of summer. The negative pressure anomaly across the northern North Atlantic had intensified but still had two minima. The western most centre shifted slightly northward, relative to summer, with a minimum value of -3.4 mb off Nova Scotia. Positive pressure anomalies again lay to the north and southeast with the largest change compared to summer being in the intensity of the anomalous high centered over northern Greenland (11.9 mb). The autumn pressure pattern resulted in anomalous winds from the east and southeast in Newfoundland, along the Labrador coast, and over the southern Labrador Sea. These would have contributed to the warmer-than-normal air temperatures during the autumn months.

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 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.

In 1998, the NAO anomaly was near normal (+1.2 mb) and had increased only slightly from 1997, when it was just below normal (Fig. 7). The 1998 value was, however, significantly above the low index registered in 1996 but well below the very high NAO anomalies of the first half of the 1990s. The recent NAO indices fit the pattern of near decadal variability that has persisted since the 1960s.

Sea Ice Observations

Information on the location and concentration of sea ice is available from the daily ice charts published by the Canadian Ice Service 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). As in the 1997 overview (Drinkwater et al., 1999a), we include an analysis of the time of onset, duration and last presence of sea ice in eastern Canadian waters based upon up-to-date comprehensive sea-ice databases maintained at the Bedford Institute of Oceanography (Peterson and Prinsenberg, 1990; Drinkwater et al., 1999a). The weekly concentrations by ice type within 0.5º of latitude by 1º of longitude areas were recorded through the ice season. The date of the first and last appearance of ice within these areas, as well as the duration of ice, were then determined. The databases begin in the early 1960s and continue 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 1998 values to obtain anomalies.

Newfoundland and Labrador

At the end of 1997, 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. 8a). This was in part due to above normal air temperatures during the first half of December that had initially slowed ice formation in the region. By early January, however, the ice had spread to the southern tip of Labrador and by mid-month, the ice edge lay just south of the Strait of Belle Isle. It was closer inshore than normal, which resulted in less ice coverage in spite of colder-than-normal air temperatures during the first half of January. By 1 February, ice coverage was back to near normal and by 1 March, the southern most ice edge lay near but slightly north and west of its long-term median. On 1 April, the ice edge still was very close to its long-term median position (Fig. 8b). By mid-April (not shown) the ice was south of the median but only in the inshore regions off eastern Newfoundland. The ice retreated at approximately the long-term mean rate such that the ice edge on 1 May lay near the long-term median location except in the nearshore regions of White Bay and Notre Dame Bay where it was further south than usual. By June, the ice was limited to an area off Hamilton Inlet and was still near its long-term median position.

Ice remained off Hamilton Inlet until mid-June and 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 the peak extent during 1998 decreased relative to 1997 and was near that of 1996 (Fig. 9). The average area during the period of general advancement (January to March) fell slightly relative to 1997 and during the period of retreat (April to June) it was similar to 1997. During both advance and retreat periods, the average ice area was below the long-term mean and was much less than the early 1990s. Variations in ice area generally reflect changes in ice volume as the two are reasonably well correlated based on studies carried out in the Gulf of St. Lawrence (Drinkwater et al., 1999b).

Analysis of the first presence of ice reveals that in 1998, ice appeared along the southern Labrador coast in late December, and gradually spread southward to northeastern Newfoundland waters by mid-March (Fig. 10). Only small quantities of ice reached the northern Grand Bank (around day 75). Relative to the long-term mean, ice generally appeared later-than-normal, the only exceptions being on the extreme outer shelf. Ice began to disappear from the offshore and southern sites by early April (day 105; Fig. 11). Ice did not begin to retreat from northern Newfoundland waters and southern Labrador until May but north of Hamilton Inlet lasted until near mid-June. Over most of the region, ice disappeared earlier-than-normal (negative anomaly, generally associated with warm conditions), more than 15 days early over all of southern Labrador waters. The only regions where ice departed later-than-usual were off White Bay and the outer half of the shelf to the northeast of Bonavista Bay. The duration of the ice season ranged from less than a month off northeastern Newfoundland to over 170 days north of Hamilton Inlet on the southern Labrador (Fig. 12). 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 almost all of the Labrador and Newfoundland waters. Off northeastern Newfoundland, southern Labrador and northeast of Hamilton Inlet, the duration was over 1 month shorter-than-normal. Only off the White Bay area of northern Newfoundland and northeast of Bonavista Bay was the duration longer-than-normal, and there it was within a few days of normal. In summary, 1998 was generally a lighter-than-average ice year on the Labrador and Newfoundland shelves.

Icebergs

The International Ice Patrol Division of the United States Coast Guard monitors the number of icebergs that pass south of 48°N latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1997/98 iceberg season (October 1997 to September 1998), a total of 1384 icebergs were spotted south of 48^{o}N. The monthly totals for January to July were 1, 8, 26, 70, 1017, 247, and 15 (Fig. 13). No icebergs were spotted between October and December, 1997, inclusive or in August or September, 1998. In 1998, 99.3% of the icebergs were observed during the primary iceberg season of March to July, higher than the mean for 1983-98 of 91%. Over 73% of the total number of icebergs during the 1997/98 season penetrated south of 48^{o}N in May, the highest percentage of the total annual number in any one month during the past 5 years. The total number of icebergs in 1998 was up from 1997 by 36% and above the long-term mean but was still below the numbers recorded in the earlier years of the 1990s (Fig. 13). The relatively large numbers of icebergs in 1998 was somewhat unexpected given the lower amount of sea ice, warm air temperatures and reduced northwest winds during the winter. In the past, such environmental conditions have usually resulted in low numbers of icebergs (Marko et al., 1994). Note, for example, that the years when large number of icebergs passed south of 48^{o}N, such as the early 1970s, the mid-1980s and the early to mid-1990s, were all periods of cold air temperatures, strong NW winds and extensive ice cover. This relationship is believed to be due primarily to reduced melting from the colder temperatures and sea ice protecting the bergs from breaking waves (Marko et al., 1994).

Gulf of St. Lawrence

At the end of December 1997, ice was only present in the St. Lawrence Estuary and along the eastern coast of the Magdalen Shallows in the Gulf of St. Lawrence due to warmer-than-normal air temperatures which delayed ice formation (Fig. 14). By mid-January, ice had formed throughout the Estuary, along the north shore of the Gulf and spread eastward on the Magdalen Shallows to surround all of Prince Edward Island. The ice edge lay shoreward of its median position. During the second half of January, ice spread such that the coverage was near the long-term median by the beginning of February. By 1 March the areas north of Cape Breton and off western Newfoundland still remained ice free and the ice coverage was less than usual. Ice retreated during March and by 1 April it had left the Estuary and many of the coastal areas of the southwestern Gulf. There was generally less ice than normal in the Gulf at this time although there was more ice along the north shore of Quebec around Anticosti Island. Ice continued to retreat through April and by 1 May ice was only located in the Strait of Belle Isle. The ice disappeared from the northern Gulf around 20 May.

During 1998 within the Gulf (landward of Cabot Strait), first ice formation ranged from the beginning of the year (day 0) along the St. Lawrence Estuary and the western Magdalen Shallows to after mid-February (day 45) off southwestern Newfoundland (Fig. 10). This represented a later-than-normal appearance of ice, over 15 days in some areas of the central Gulf. The date of last appearance shows the typical pattern of ice lasting longest over the southern Magdalen Shallows and along the north shore of Quebec through to the Strait of Belle Isle (Fig. 11). In 1998, there was an earlier-than-normal disappearance over the Magdalen Shallows and the eastern Gulf, up to 45 days off western Newfoundland. A later than normal departure was observed in the Estuary and around Anticosti Island. The duration of ice ranged from less than 30 days off southwestern Newfoundland to over 120 days in the Strait of Belle Isle (Fig. 12). Relative to the long-term mean using only years when ice was present, ice duration was less than normal throughout the entire Gulf, except for a small area to the west of Anticosti Island. Near Cabot Strait, the duration of ice was 50 days less than the long-term mean while much of the Gulf had durations of at least 30 days less-than-normal.

Scotian Shelf

Sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwest winds and the mean ocean currents. In 1998, ice first appeared seaward of Cabot Strait during the first half of January (Fig. 10) approximately 15 days later-than-normal, and maintained a relatively constant presence through into March. This ice was primarily restricted to the Sydney Bight area with little to no ice reaching the Scotian Shelf proper. Most of this ice had disappeared by the end of March with small amounts remaining until the later half of April (Fig. 11). This departure was over a month to a month and half earlier-than-normal. The duration of ice south of Cabot Strait ranged from 50 days off Cape North on Cape Breton Island to 10 days or less around the eastern most point and southern coast of Cape Breton Island, which was less than the long-term mean by 30 to 50 days in most areas (Fig. 12). Note that a duration of less than 10 days is not plotted in Fig. 12.

The monthly estimates of the ice area seaward of Cabot Strait since the 1960s shows that much less ice than normal was transported onto the Scotian Shelf during 1998 compared to either 1997 or the long-term mean (Fig. 15). There were fewer days than usual when ice was present seaward of Cabot Strait and the integrated ice area (summation of the area times the number of days) was the third lowest on record, after 1969 (when no ice was observed outside of the Gulf) and 1983 (Fig. 15). Thus, 1998 was a very light ice year 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 late 1800s sea ice was observed in the Gulf of Maine (A. Ruffman, Geomarine Associates Ltd., Halifax, personal communication).

Oceanographic Observations

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 53 times in 1998, with a monthly maximum of 10 in June. No measurements were taken in February. 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. The monthly averaged temperatures and salinities in 1998 together with their anomalies are shown in Fig. 16.

During 1998, the water column cooled through to March reaching temperatures less than 0^{o}C in the surface layers and below –1^{o}C in the subsurface waters. The latter extended through to November with the minimum temperatures of below –1.5^{o}C in August (Fig. 16). These very cold waters were most likely advected into the region from the north. Upper layer (generally < 50 m) temperatures were below 0^{o}C until April afterwhich they began to rise steadily and reached a peak of over 12^{o}C at the surface in August before autumn cooling set in. The August mean temperature was similar to that recorded in 1997. Note the propagation of surface layer heat down into the lower layers in the late autumn. From January to April, temperatures were slightly above normal. By May below normal temperatures appeared at mid-depths and spread gradually to encompass almost the entire water column by the autumn. The coldest anomalies (-1^{o} to -4^{o}C) occurred in the vicinity of the thermocline suggesting a shallower upper layer than normal. This is consistent with the warmer, fresher conditions during the late spring and summer as stratification developed. Near bottom temperatures remained above the long-term mean through out the year (Fig. 16, 17).

In 1998, near surface salinites at station 27 were slightly less than 32 in January, rose above 32 from February to April and then declined to a minimum of < 31.5 from June to November (Fig. 16). Based on the studies of Myers et al. (1990) and Petrie et al. (1991), the low salinities in late summer and early autumn are related to the arrival of ice melt from the Labrador Shelf. The maximum salinities (>33) appeared near bottom. Salinities in 1998 were relatively fresh from January to July-August, but then shifted to above normal and remained there through the remainder of 1998 (Fig. 16, 17). The largest negative salinity anomaly (-0.5 to -0.6) was in the surface waters during June and July. The largest positive salinity anomalies (0.3) appeared at the same depths as the band of –1^{o}C temperature anomalies. This is consistent with the interpretation of a shallower upper layer. If the warmer, fresher waters in the surface layer were not mixed down as deep, this would result in the waters below this layer being colder and saltier than normal, as was observed.

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. 18. 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 continued in 1998 at 150 and 175 m, continuing a trend that began in 1996. This warming has 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), cool conditions prevailed thus appearing to return to the below normal temperature trend of the late 1980s and early nineties. In spite of the high variability at the surface, a slow warming trend appears to be present since 1992.

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. 19). 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. The heat content decreased in 1997 to slightly below the long-term mean and remained there in 1998. The 0 to 50 m depth-averaged summer salinity is also plotted in Fig. 19. 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. The depth-averaged summer salinities had been shown to be positively related to cod recruitment by Sutcliffe et al. (1983) and Myers et al. (1993) but the validity of this relationship has been seriously questioned (Hutchings and Myers, 1994).

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°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°C) is plotted in Fig. 20. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects (Petrie et al., 1992). In 1998, the summertime CIL areas along the Bonavista and Flemish Cap were near their long-term means while off Seal Island it was below normal by 15%. Relative to 1997, the area of CIL waters decreased on the Flemish Cap transect but increased on the other two. On the Seal Island and Bonavista transects the area of CIL waters have been below normal for the past 4 years while on the Flemish Cap it has been above the long-term mean since the mid-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 1998 was about -1.58°C compared to a normal of –1.57°C. Core temperatures along the Bonavista transect were -1.66°C compared to a normal of -1.63°C and along the Flemish Cap transect were at –1.62°C, below the normal of about -1.51°C. These minimum temperatures were similar to those in 1997 expect on the Grand Bank were the core temperature decreased in 1998.

Estimates of the volume of CIL water (<0°C) over the 2J3KL area are available since 1980 (Fig. 21). 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 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. The CIL is eroded through the summer due to mixing with the warmer surface and near bottom waters. 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 1998, the CIL volume was up slightly from 1997 but remained well below normal.

Horizontal Temperature Distributions Near-Bottom in 2J3KL

The mean (1961-90) and 1998 autumn temperatures over the shelf from southern Labrador to the Grand Banks from groundfish surveys are shown in Fig. 22. The average bottom temperature over most of the northeast Newfoundland shelf (2J3K) in autumn ranges from < 0°C inshore, to >3°C offshore at the shelf break whereas over most of the Grand Bank it varies from <-0.5°C to 3°C. In general, bottom isotherms follow the bathymetry exhibiting east-west gradients over most of the northeast shelf. The percentage area of water less than -0.5°C over the Grand Bank and northeast shelf from 1990 to 1994 was significantly larger than the 1961-1990 average. In 1992 and 1993 the bottom temperature anomalies ranged from -0.25°C to -0.75°C over the northeast shelf and from -0.25°C to -1°C over the Grand Bank (Colbourne, MS 1994). During 1996 the percentage area of water less than -0.5°C on the continental shelf declined significantly to below average and bottom temperatures moderated in most areas of the Newfoundland Shelf with anomalies of +0.5°C being common. There was also a complete absence of <0°C waters. Bottom temperatures during the fall of 1997 and again in 1998 remained above normal over most areas, particularly on the offshore portion of the shelf.

Hydrographic Conditions on Hamilton Bank

The time series of monthly mean temperature and salinity anomalies from 1950 to 1998 on Hamilton Bank at standard depths of 0, 50, 75 and 150 m are shown in Figs. 23 and 24, respectively. Annual anomalies were calculated from all available monthly anomalies and then a 5-year running mean estimated. This suppresses the high frequency variations and provides a representation of the long-term trends. Note that the monthly averages consist of a variable number of observations.

The time series are characterized by large variations with amplitudes ranging from ± 1.0°C and with periods ranging from 2 to 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 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 1998, temperatures rose sharply at the surface to reach record highs. At subsurface depths of 50 and 75 m, temperatures oscillated about their long-term means whereas at 150 m temperatures were above normal. The smoothed salinity time series show very similar conditions as elsewhere on the shelf with fresher than normal conditions in the early 1970s, mid 1980s and early 1990s. Salinities have been increasing since their low values of the mid-1990s and are now above normal throughout the water column.

Hydrographic Conditions on Flemish Cap

Three major cold periods are evident from the temperature anomalies over the top 100 m on Flemish Cap; most of the 1970s, the mid-1980s and the late 1980s to early 1990s (Fig. 25). The cold conditions beginning around 1971 continued until 1977 in the upper layers. From 1978 to 1984, temperature anomalies showed a high degree of variability in the upper water column with a tendency towards positive anomalies. By 1985, negative temperature anomalies had returned in the top 100 m of the water column. This cold period moderated briefly in 1987 but returned again by 1988 and continued into the early 1990s. Since 1995 upper layer temperatures have been warming in the top 100 m, to above normal (0 m) to near normal (50 and 100 m) conditions. At 200 m, however, temperatures have remained below normal and continue the trend established in the mid-1980s.

Fresher-than-normal salinities persisted on Flemish Cap from 1971 to 1976 and from 1983 to 1986 in the upper 100 m of the water column with peak amplitudes reaching 0.6 psu below normal (Fig. 26). The trend in salinity during the early 1990s range from slightly above normal at the surface to below normal at 50 and 100 m depth and about normal at 200 m depth. During the past few years, salinities at Flemish Cap have been increasing and are now saltier than normal in the top 100 m. In general, the temperature and salinity trends are similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges.

Hydrographic 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 standard depths of 0, 20, 50 and 75 m (Fig. 27). This temperature time series is characterized by large variations with amplitudes ranging from ±3°C. The long-term trend shows amplitudes generally less than ±1°C with periods between 5 to 10 years. 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 in the upper water column. Since 1994 the temperatures have been warmer than normal over the top 20 m but remained below average at 50 and 75 m depth. Note the similarity in the low-frequency trends at the deepest depths on St. Pierre Bank and Flemish Cap.

The mean (1961-90) and the 1998 bottom temperature maps for April within 3Ps and 3Pn are shown in Fig. 28. In general, the bottom isotherms follow the bathymetry around the Laurentian Channel and the Southwestern Grand Bank increasing from 2°C at around 200 m depth to 5°C in the deeper water. The average April bottom temperatures ranged from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3°C to 4°C on Rose Blanche Bank and on Burgeo Bank and from 0°C on the eastern side of St. Pierre Bank to 2°C on its western side. During April 1998 temperatures were near average over Burgeo Bank, in Hermitage Channel and along the western slope of St. Pierre Bank. On the central and eastern side of St. Pierre Bank temperatures were slightly below average as indicated by the position of the 0° and 1°C isotherm lines.

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 show 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. 29). Then temperatures rose dramatically reaching 6.0^{o}C (anomaly of 0.6^{o}C) in 1993. By 1994 temperatures had begun to decline although anomalies remained positive. Temperatures continued to fall in 1995 and 1996 towards normal. In 1998, temperatures were generally near the long-term mean and not that different from 1997 values.

CIL

The CIL in the Gulf of St. Lawrence has a maximum thickness in the northeast and a minimum (where depths exceed 100 m) in Cabot Strait and the St. Lawrence Estuary. During 1998, the CIL thickness (defined by waters <0^{o}C) increased by approximately 21% relative to 1997. The largest increase in 1998 was observed in the St. Lawrence Estuary where it increased by 30 m. Gilbert and Pettigrew (1997), in a study of the CIL layer, produced a Gulf-wide index of core temperatures for mid-July based upon available observed data and the mean measured warming rate. Their index shows temperature anomalies having an approximate 5-8 year periodicity prior to 1985 (Fig. 30). Since 1985, temperatures in the CIL have remained below normal with minima in the late 1980s and early 1990s. From 1994 to 1997, temperatures slowly but steadily warmed. The mid-summer core CIL temperature in 1998 was -0.71^{o}C (representing an anomaly of -0.73^{o}C), and was cooler than 1997 by approximately 0.3^{o}C. 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. However, these air temperatures were above normal throughout 1998 and cannot explain the cooler temperatures in the CIL. Advection may have contributed to the low CIL in 1998.

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. Similar to past years, bottom temperatures during the 1997 survey were lowest in the central region of the Magdalen Shallows and increased shoreward and toward the deeper Laurentian Channel (Fig. 31). Near-bottom temperature anomalies were predominantly below normal north of Prince Edward Island with the largest negative anomalies off the northwest point of P.E.I. and around the Magdalen Islands. Waters around P.E.I. were above normal with maximum anomalies occurring in eastern Northumberland Strait. More of the area of the Magdalen Shallows showed below normal bottom temperatures than in 1997. Swain (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. 32). Since 1990, including 1998, these areal indices have been above their long-term means. This is consistent with the colder-than-normal CIL since the CIL is in direct contact with the bottom over much of the Shallows. The areal indices increased relative to 1997 reversing the decreasing trend of the previous two years.

Summer Temperature and Salinity Fields

The hydrographic data collected during the September groundfish surveys on the Magdalen Shallows were combined with data from fisheries surveys conducted throughout the remainder of the Gulf during August-September. Mean temperatures and salinities were then calculated by layers (30-100, 100-200 and 200-300 m) within each of the 21 areas defined by Petrie et al. (1996b) and were compared to their monthly mean values. In the 30-100 m layer, which encompasses the CIL, temperatures varied by only a little over 1^{o}C and were colder-than-normal for this time of the year. Throughout most of the Gulf, temperatures cooled by around 1^{o}C relative to 1997. Temperatures in the 100-200 m layer ranged from 1.9^{o}C in the northeastern Gulf to 3.1^{o}C east of Anticosti Island resulting in weak anomalies. They were generally above normal in the southwest and below normal in the northeast. In the deep layer (200-300 m), temperatures varied from 4.7^{o}C in the Estuary to 5.5^{o}C in Cabot Strait and anomalies were above normal by 0.1^{o} to 0.7^{o}C. Compared to 1997, the temperatures in both layers decreased in the region of Cabot Strait to Anticosti Island (upwards of 1.5^{o}C in the Strait within the 100-200 m layer). The time series of the average temperature in the lower three layers indicates cooling in 1998 relative to 1997 with above normal conditions in the deepest layer, just below normal in the 100-200 m layer and still well below normal in the 30-100 m layer (Fig. 33).

Scotian Shelf and Gulf of Maine

Coastal Sea Surface Temperatures

Monthly averages of sea surface temperature (SST) for 1998 were available at Boothbay Harbor in Maine, St. Andrews in New Brunswick and Halifax in Nova Scotia. The Halifax data have been collected at the DFO Halifax Laboratory wharf and data collected twice a day during weekdays. With the closing of the Halifax Laboratory, no data were collected after August 1998. A continuous recording thermistor submerged just below low water on the wharf in Halifax Harbour by the Maritime Museum of the Atlantic will replace the Halifax Laboratory values in future. Note the August data for 1998 was based on only 11 days of data and so may not be truly representative of the entire month. The monthly mean temperature anomalies at each site for 1997 and 1998 are shown in Fig. 34.

The dominant feature in 1998 at Boothbay Harbor and St. Andrews was the above normal temperatures throughout most of the year (9 and 10 out of the 12 months, respectively) which continues a trend of warm temperatures that began in June of 1994. The 1998 anomalies equalled or exceeded one standard deviation (based upon the years 1961-90) in 6 months at Boothbay Harbor (March-May, July, August and December) and in four months at St. Andrews (March-May and October, the latter having below normal anomalies). The maximum monthly anomaly was near 1.4^{o}C in April at Boothbay while at St. Andrews it was 1.6^{o}C in May. The similar amplitude anomalies at St. Andrews compared to Boothbay are unusual as the increased vertical mixing by the tides in the Bay of Fundy typically result in lower amplitude anomalies at St. Andrews. At Halifax, positive sea surface temperature anomalies also dominated 1998 with 6 of the available 8 months being warmer-than-normal (Fig. 34). These warm anomalies reverse the trend of colder-than-normal conditions observed at Halifax over the last several years. In 4 months, the temperature anomaly exceeds the long-term standard deviations, those occurring in May through August.

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. 34). This minimum was as low as that of the mid-1960s at St. Andrews but at Boothbay Harbor the minimum was only slightly below normal. Consistent with the recent trends, the 1998 annual mean temperature was above normal (mean of 7.6^{o}C and 0.5^{o}C above normal at St. Andrews and 9.1^{o}C and 0.6^{o}C above normal at Boothbay). At both sites the temperature rose relative to 1997 but remained below the recent peak of 1995 (Fig. 34). No annual mean in 1998 was estimated for Halifax because of the missing data from September to December.

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. It is the longest continuously operating hydrographic monitoring site in eastern Canada. Up until this year, only one observation per month was taken but in 1998 multiple occupations were taken in some months. All months had at least one measurement in 1998. In April, June, July and December there were two measurements and during September and November there were 3. In those months when there was more than one measurement, an arithmetic average was used to estimate the mean temperature and salinity for the month. A single, or even three observations per month, especially in the surface layers in the spring or summer, may not necessarily produce results that are representative of the true "average" conditions for the month 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 1998, monthly mean temperatures ranged from a minimum of over 2.5°C throughout the water column in February to a maximum of over 11°C near the surface in August and September (Fig. 35). Following mainly below normal temperatures in January, the monthly temperature anomalies were dominated by positive values through until July-August. In July, below normal temperatures were observed at 75 m and 90 m. These negative anomalies extended throughout most of the water column by September and continued for the remainder of the year. The highest negative anomalies were in September near bottom with anomalies of –1.6° to –1.7°C. The annual mean temperatures exhibit high year to year variability (Fig. 36). In 1998, the annual mean temperatures were above normal at the surface (anomaly of 0.4°C) and almost normal near bottom at 90 m (0.08°C above normal). This represents an increase relative to 1997 at the surface while near bottom the temperature in 1998 decreased slightly. With the exception of the negative temperature anomalies in the early 1990s, temperatures at Prince 5 have been warmer than the long-term mean since the 1970s. The maximum annual temperatures at this site occurred in the early 1950s and the minimum in the mid-1960s.

Salinities at Prince 5 during 1998 were mostly fresher-than-normal (Fig. 35). The lowest salinities (<30.5 psu) occurred in the upper half of the water column during April and May and the highest salinities (>32.5 psu) appeared near bottom in the autumn. The arrival of high salinity waters in autumn is typical. The largest negative anomalies (below 1 psu) were observed throughout most of the water column in March and April and at mid-depth in May. Time series show that the annual salinity anomalies in 1998 fell by approximately 0.2 relative to 1997 values at both the surface and 90 m (Fig. 37). Although there has been large fluctuations in salinity anomalies throughout the water column, the longer-term trend shows that salinities have been freshening since the late 1970s with the lowest salinities on record at Prince 5 occurring in 1996. The recent low values parallel salinity events occurring in the deep waters of Jordan and Georges Basin and are related to advection from areas further to the north (P. Smith, BIO, personal communication).

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, then averaged by month any data within these boxes at standard depths. Data for 1998 were only available for 8 months of the year.

Data from January and October 1998 are shown together with the site locations (centre of the boxes) in Fig. 38. The upper layer temperatures in January increase from the Scotian Shelf towards the western Gulf of Maine but cool again inshore. In October higher thermal stratification was observed although the increase in temperature from east to west across the Gulf was still evident. Bottom layer temperatures generally ranged between 7° and 8°C. Temperatures in 1998 were colder than their long-term means on the eastern side of the Gulf with anomalies over much of the water column of -1° to -2°C below normal. On the western side of the Gulf temperatures in both months were generally above their long term mean. An exception was in October at station 2 where upwelling appears to have resulted in cold conditions. The time scale of this event is unclear. The pattern of cold anomalies in the east and warm ones in the west was repeated in many of the transects taken in other months of 1998 (not shown).

Deep Emerald Basin Temperatures

Petrie and Drinkwater (1993) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (decadal periods). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (year-to-year) variability. High coherence at low frequencies was found throughout the water column as well as horizontally from the mid-Atlantic Bight to the Laurentian

Channel, although year-to-year differences between locations were observed. Temperature anomalies at 250 m have been used as a representative index.

In 1998, temperature measurements in Emerald Basin were obtained to depths of 250 m in eight separate months with values ranging from 6.4^o to 8.0^{o}C. This produced monthly anomalies of -0.4^o to –2.6^{o}C below normal (Fig. 39). The long-term (1961-90) annual average is 8.5^{o}C and the long-term monthly means range from 7.9^{o}C to 9.4^{o}C. The strong negative anomalies in 1997 were generally representative of conditions in the Basin below approximately 50 m. These colder-than-normal temperatures represent a significant cooling (2° to 3°C) relative to 1997 and most of the past decade. Cause of this cooling is due to the arrival along the outer Scotian Shelf of Labrador Slope water (Drinkwater et al., MS 1998). This cooler (typically 4°-8°C) slope water arrived in the autumn of 1997 off Banquereau and Emerald Banks replacing Warm Slope water (8°-12°C). The Labrador Slope water began to penetrate into Emerald Basin in December and by mid-February had replaced most of the warmer waters in the Basin. A similar pattern was observed in Georges Basin. The cold Labrador Slope water was observed entering Northeast Channel in January, 1998 (Drinkwater et al., 1998) and flooded Georges Basin by at least April, when the first measurements of 1998 were available in its deep waters. The long-term trend shows a maximum in the early 1950s declining to a minimum in the early 1960s, a trend described in detail by Petrie and Drinkwater (1993). The temperatures rose rapidly in the late 1960s, remained relatively high in the 1970s but dropped in the late 1970s and again in the early 1980s. With the exception of a short period in the early 1990s, the temperatures in the deep basin were well above the long-term mean and at the highest sustained levels on record in the mid-1990s.

Other Scotian Shelf and Gulf of Maine Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities 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. 40). Their analysis has been updated by Petrie et al. (1996a). We produced monthly mean conditions for 1997 at standard depths for selected areas (averaging any data within the month anywhere within these areas) and compared 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, however. 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 (1995) examined long-term temperature time series for most of the areas on the Scotian Shelf and in the Gulf of Maine and identified several important features. First, the temperatures in the upper 30 m tended to vary greatly from month to month, due to the greater influence of atmospheric heating and cooling. Second, 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, MS 1995) and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew, 1997). Data in 1994 and 1995 indicated warming of the intermediate layers in the Gulf of Maine but a continuation of colder-than-normal water on most of the Scotian Shelf (Drinkwater et al., 1996). The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald on the Scotian Shelf and Georges in the Gulf of Maine. This warm deep water appeared to influence the intermediate depth waters above the basins, as their anomalies were generally warmer than elsewhere on the shelves.

The first two temperature patterns first identified by Drinkwater (1995) have continued into 1998. Monthly mean temperature profiles reveal that cold conditions prevailed in the deeper waters on Sydney Bight, on Misaine Bank in the northeast Scotian Shelf, and on Lurcher Shoals. However, as revealed by the Emerald Basin temperatures discussed above, the warmer-than-normal conditions that have prevailed over most of the last 20 to 30 years were replaced by below normal values in 1998 (Fig. 39). Below, we describe temperature conditions in other representative areas of the Scotian Shelf.

On Sydney Bight (area 1 in Fig. 40) monthly mean profiles from 5 different months show highly variable temperature anomalies throughout the water column (Fig. 41). In the near surface (<10 m) waters temperatures were primarily above the long-term mean (Fig. 41). The exception was in July when the 20 to 30 m layer was 1°-3°C below normal. The time series for 100 m shows high temperature anomalies in the 1950s that 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 quickly to below normal values reaching a minimum anomaly around -1°C in the early 1990s. Temperatures in recent years have generally remained below normal but have been slowly increasing with several monthly anomalies of above normal being observed since 1995. The 1998 anomalies at 100 m remained below normal.

Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 40) are available for 6 months during 1998. They show primarily warmer-than-normal upper layer (0-30 m) temperatures (Fig. 42). From 75 m and deeper, however, the temperatures were principally below normal except in November. Between 30 and 75 m, the temperatures varied between above and below normal. The time series of the 100 m temperature anomalies show that these negative values have persisted since approximately the mid-1980s (Fig. 42). This pattern is generally indicative of the water column below 50-75 m. Recent years, although exhibiting generally below normal temperatures, have seen temperatures increasing slowly from the minimum in the early 1990s. As at 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 to 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 remained below normal but with evidence of a slow but steady increase that continued into 1998.

At Lurcher, data were available in 9 months during 1998 (Fig. 43). The dominant feature was below normal temperatures throughout most of the water column. Anomalies in January, August, October and November exceeded -1°C, and in December exceeded -2°C. The monthly 50 m temperature anomalies at Lurcher show mostly cooler-than-normal waters in 1998, the only exception being in July. This depth represents conditions over much of the bottom of the Shoals. Temperatures over Lurcher Shoals were 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 elsewhere, temperatures declined by the mid-1980s to below normal reaching a long-term minimum in the early 1990s. Although there was a slight hint of warming since the early 1990s, and there have been some positive monthly temperature anomalies, annual mean temperatures and most monthly means continue to remain below normal.

The time series of temperature in the deep regions of Georges Basin (Fig. 44; area 26 in Fig. 40) shows a striking similarity to that observed in Emerald Basin. This includes the very cold conditions in 1998 (Fig. 39), as well as the low values in the mid-1960s, the sharp rise to a peak in the early 1970s and variable but generally above normal conditions until 1998. This similarity between basins is not surprising given that the source of the waters for both are the offshore slope waters (Petrie and Drinkwater, 1993). On the Canadian portion of Georges Bank (area 28 in Fig. 39), the short period variability is of much higher amplitude than in Georges Basin, for example (Fig. 44). This reflects not only the higher temporal fluctuations but also spatial differences within area. The longer-term trend shows positive anomalies in the 1950s, the low 1960s and a tendency towards positive anomalies since the 1970s. However, from the late 1980s on, the long-term temperature trend has not been significantly different than normal. The cold water that was present in the deep waters in 1998 also appeared to influence the bank water.

Temperatures during the Summer Ground Fish Survey

The most extensive temperature coverage over the entire Scotian Shelf occurs during the annual groundfish survey, usually undertaken in July. In 1998, 175 conductivity-temperature-depth (CTD) stations were occupied. Off southwestern Nova Scotia, an ITQ survey was also conducted that collected CTD data at another 161 stations. Many of the latter were located in areas not traditionally occupied during the government run groundfish survey, e.g. over Lurcher

Shoals and other inshore areas. Temperatures from both surveys were 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 scale length of 30 km and vertical scale lengths 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. Maximum depths for the interpolated temperature field were limited to 1000 m. The 1998 temperatures were also compared to the 1961-90 means for July.

Temperatures in 1998 at the surface varied from <9^o to >18^{o}C with the coldest temperatures on the Lurcher Shoals off Yarmouth and the warmest in the vicinity of Western Bank in the central Scotian Shelf region (Fig. 45a). Warmer temperatures and weaker temperature gradients prevailed on the Scotian Shelf relative to off southwest Nova Scotia and the Bay of Fundy. At 50 m the coldest temperatures (<2^{o}C) cover much of the northeastern Shelf (Fig. 45a). Note the warm waters (4^o-5^{o}C) appear to be penetrating onto the central shelf regions from the offshore. The 100 m temperatures show a pattern of cold waters (<2^{o}C) in the northeast and warm waters (>5^{o}C) in the Gulf of Maine and along the outer Banks in the southwestern region of the Shelf (Fig. 45b). Bottom temperatures show similar features to 100 m and are common (Fig. 45b). First is the large contrast between the northeast and central Scotian Shelf. In the northeast, bottom temperatures were generally cold with minima less than 2^{o}C in the Misaine Bank region. Cool waters (<4°C) were also observed in Roseway Basin and over Browns Bank. Temperatures in Emerald Basin exceeded 7^{o}C. Relatively high temperatures also were found in the upper reaches of the Bay of Fundy and in the deeper areas of the Gulf of Maine.

Temperature anomalies at the surface show generally positive anomalies over most of the Scotian Shelf by 2° to 3°C over Sable and Middle Banks and off the southeastern tip of Cape Breton (Fig. 46a). In contrast, in the Bay of Fundy and the rest of the Gulf of Maine, surface temperatures were below normal by around 1°C. The dominant feature at 50 m is the below-normal temperatures over the shelf and throughout the Gulf of Maine and Bay of Fundy (Fig. 46a). The anomalies generally were between normal and -2°C. At 100 m and near bottom the anomalies are below normal throughout almost all of the Scotian Shelf and Gulf of Maine (Fig. 46b). The greatest negative anomalies (-4°C at 100 m and -3°C near bottom) lay over Emerald Basin. The cause of these low anomalies was the influx of the cold Labrador Slope Water into the Basin as discussed above. The colder-than-normal temperatures over Emerald Basin are different than 1997 when these were warmer-than-normal (Drinkwater et al., MS 1998). The cold water near bottom in Emerald Basin during the July survey is consistent with the 250 m temperature time series (Fig. 39) and the cold temperatures in the northeast with the temperature time series observed on Misaine Bank (Fig. 42).

Density Stratification

Stratification of the upper water column is an important characteristic that influences both physical and biological processes. The extent of the stratification can affect vertical mixing, the vertical structure of the wind forced current, 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 stratification by calculating the density (sigma-t) difference between 0 and 50 m. We first calculated the monthly mean density profile for each of the areas in Fig. 40. The density difference is then based upon these monthly profiles. The long-term monthly mean density stratification 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 five-year running mean of the annual anomalies was then calculated. The monthly and annual means show high variability but the 5-year running means show some distinctive trends. The density anomalies are presented in gm/ml/m. A value of 0.1 represents a difference of 0.5 a sigma-t unit over the 50 m. The dominant feature is the higher stratification during recent years throughout the Scotian Shelf (Fig. 47). The 5-year running mean began to increase steadily around 1990 and the most recent value represents the highest stratification in the approximate 50 year records in most areas. What is most surprising is the consistency from area to area, through most of the Scotian Shelf. This increased and high stratification does not seem to extend into the Gulf of Maine region and it was absence or weak in the Laurentian Channel and Sydney Bight areas. One expects the anomalies in density stratification in the Gulf to be lower than on the Scotian Shelf due to the more intense tidal mixing, however, if there were increased stratification in the Gulf of Maine, we should have detected it. This increased stratification is principally a response to lower surface salinities.

Offshore Waters

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. This data set was updated until the termination of the satellite data product by NOAA in October 1995. A commercial company has continued the analysis but did not begin until April 1996. Even then, the initial charts did not contain data east of 60°W. Data for October to December of 1996 as well as 1997 and 1998 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 1998 annual mean position is shown in Fig. 48. 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 1998, the shelf/slope front was seaward of its long-term mean position from 75°W to 65°W, and also at 62°-61°W and 55°W. The largest deviations from the mean position occurred near the western end, the maximum value being at 72. The time series of the annual mean position (averaged over 55°W-75°W) shows the front was at a maximum seaward location in 1985 and again in 1993 (Fig. 48). Since 1993, the front has been moving steadily seaward approximately 40 km, reaching its most southerly position since the early 1980s in 1997. In 1998, the frontal position was near that of 1997, although slightly more shoreward.

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 55°W to 75°W. The average position of the north wall of the Stream and the 1998 annual mean is shown in Fig. 49. 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 1998, the average position of the Stream was seaward at each degree of longitude except from 61° to 63°W. Similar to 1997, the largest deviations occurred west of 70°W. 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. 49). The annual anomaly of the Gulf Stream was at its most northerly position in 1995. This was followed a rapid decline in 1996 and remained low through 1997 and again in 1998. The 1996 position is not well defined, however, since it is based upon only three months of the data (October to December). The time of the southward shift in the Gulf Stream does match the large decline in the NAO index in 1996 and is consistent with the finding of a significant positive correlation between the Gulf Stream position and the NAO.

Summary

During 1998, the NAO index was near its long-term mean indicating an intensification of the Icelandic Low and Azores High relative to 1996 but weaker than the early 1990s. The index rose only marginally compared to 1997 but just enough to revert back to positive anomalies compared to the negative values registered during the past 2 years. Air temperatures over most of the northwest Atlantic were above normal continuing the warming trend of the past 2 years. Indeed, from the Labrador coast, through Newfoundland and the Gulf of St. Lawrence, to the Gulf of Maine, 1998 ranked within the top 5-15% of the warmest years on record, the exact value depending on location. Almost all months in 1998 experienced warmer-than-normal temperatures, the major exception being February in the northern Labrador Sea and Baffin Island regions. The warmer-than-normal winter temperatures resulted in less ice than normal off Newfoundland and Labrador, and in the Gulf of St. Lawrence. Ice typically arrived late and left early, causing fewer days of ice in most areas. Little to no ice reached the Scotian Shelf proper and seaward of Cabot Strait, the amount of ice was the 3rd lowest in the 37-year record. In spite of the reduced amount of sea ice and warmer temperatures, the number of icebergs that reached the northern Grand Banks increased relative to 1997, up by 36%. The number of icebergs was greater than the long-term average but below the record numbers of the early 1990s.

During 1998, ocean temperature indices suggested much of the southern Labrador, northern Newfoundland and the Grand Banks area were generally above normal, continuing a trend that began in 1996. This was seen especially at Hamilton Bank and in the upper 100 m of Flemish Cap, and in the near bottom temperatures during the spring on the Grand Banks, during the autumn off northern Newfoundland, and at Station 27 throughout the year. As well, the CIL volume both in summer and autumn were well below normal. Higher up in the water column at Station 27 temperatures were warmer-than-normal from January to April but through most of the remainder of the year temperatures were relatively cool compared to the long-term means. The maximum negative temperature anomalies lay just below the upper layer and are interpreted as being due to increased stratification. Salinities in the upper layer at Station 27 were fresher than normal from January to August, and were saltier than normal from September to December. On St. Pierre Bank, Conditions moderated somewhat following over a decade of very cold conditions in the bottom waters, although temperatures still remain below normal. In the surface waters (0-20m) temperatures were well above normal on the Bank.

In the Gulf of St. Lawrence, the CIL waters generally increased in depth and core temperatures cooled. This reversed the slow warming trend observed in recent years. Cause of this reversal is unknown. While earlier studies had found a relationship with air temperatures off western Newfoundland with colder winters resulting in more and colder CIL waters, the winter of 1997/98 was relatively mild and so a reduction in the amount of CIL water and a warming of the core temperatures was expected. That this did not happen may indicate strong advection from either the Labrador. The cooling of the CIL and its expansion resulted in more of the bottom of the Magdalen Shallows being covered by colder waters (<0° and <1°C) than observed in 1997. In the 200-300 m deep layer in the Gulf (i.e. within the Laurentian Channel), temperatures were near their long-term mean.

In 1998, the most significant change in the Scotian Shelf and Gulf of Maine was the arrival of cold, Labrador-type slope water along the shelf edge. This cold water penetrated onto the shelf through channels and gullies and replaced the warm slope water remnants that were in the deep basins such as Emerald Basin and Georges Basin. These cold waters remained for the rest of the year. Temperature changes in the deep region of Emerald Basin was of order 2°-3°C colder than last year and well below the long-term mean. In the northeastern Scotian Shelf, waters continued to experience below normal temperatures. This pattern was established in the mid-1980s with maximum cooling in the early 1990s. In recent years, including 1998, there has been a slow but steady increase in temperatures in these regions. The presence of these cold waters is believed to be due to a combination of advection from the Gulf of St. Lawrence and off the Newfoundland Shelf and *in situ* cooling during the winter although the relative importance has not yet been established. Also of significance was the establishment of increased stratification in the upper water column (between surface and 50 m) throughout the Scotian Shelf since the 1950s with maximum values in recent years. This high stratification was not observed in the Gulf of Maine, however.

Acknowledgements

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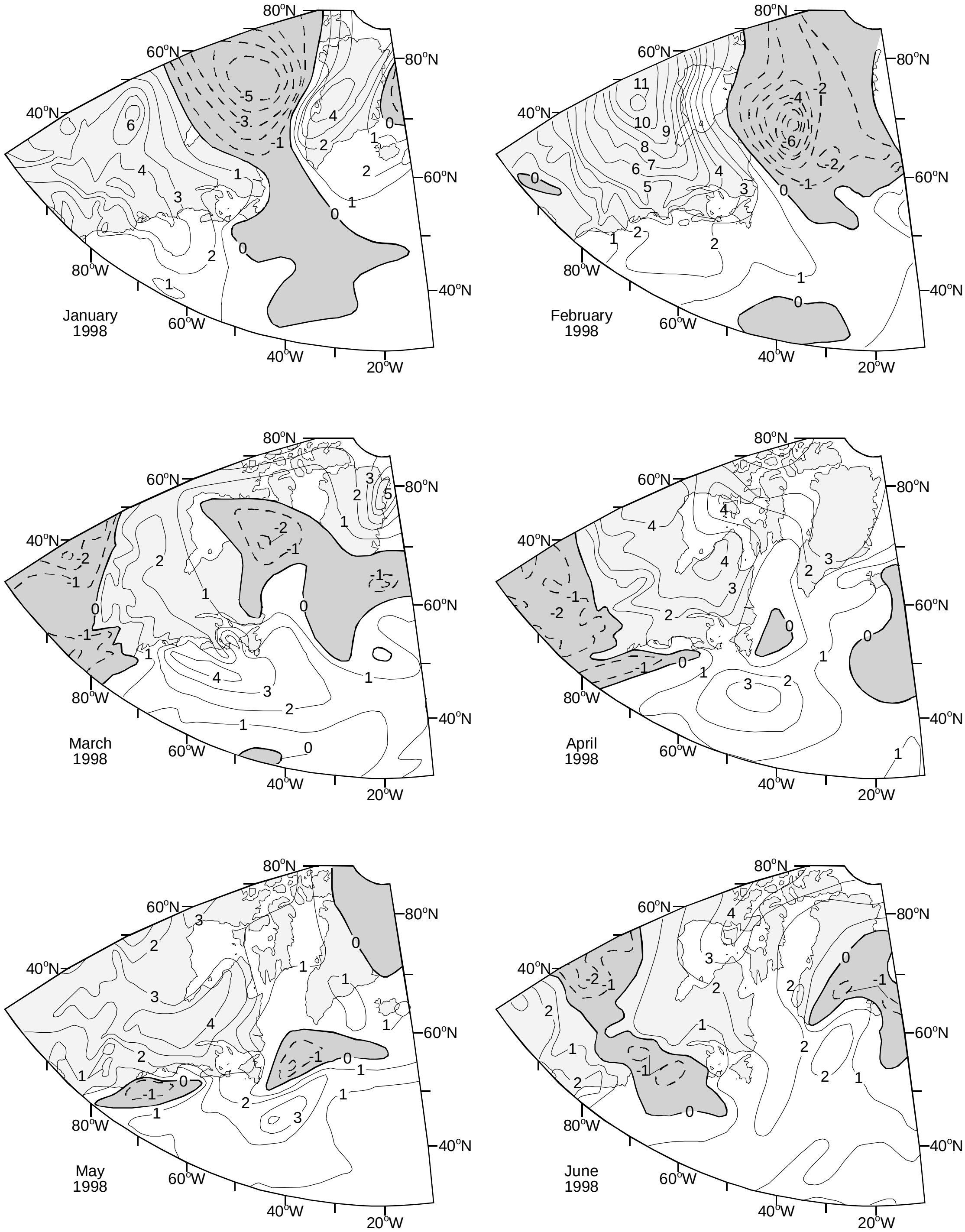


Fig. 1. Monthly air temperature anomalies (°C) over the Northwest Atlantic and eastern Canada in 1998 relative to the 1961-90 means. Shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

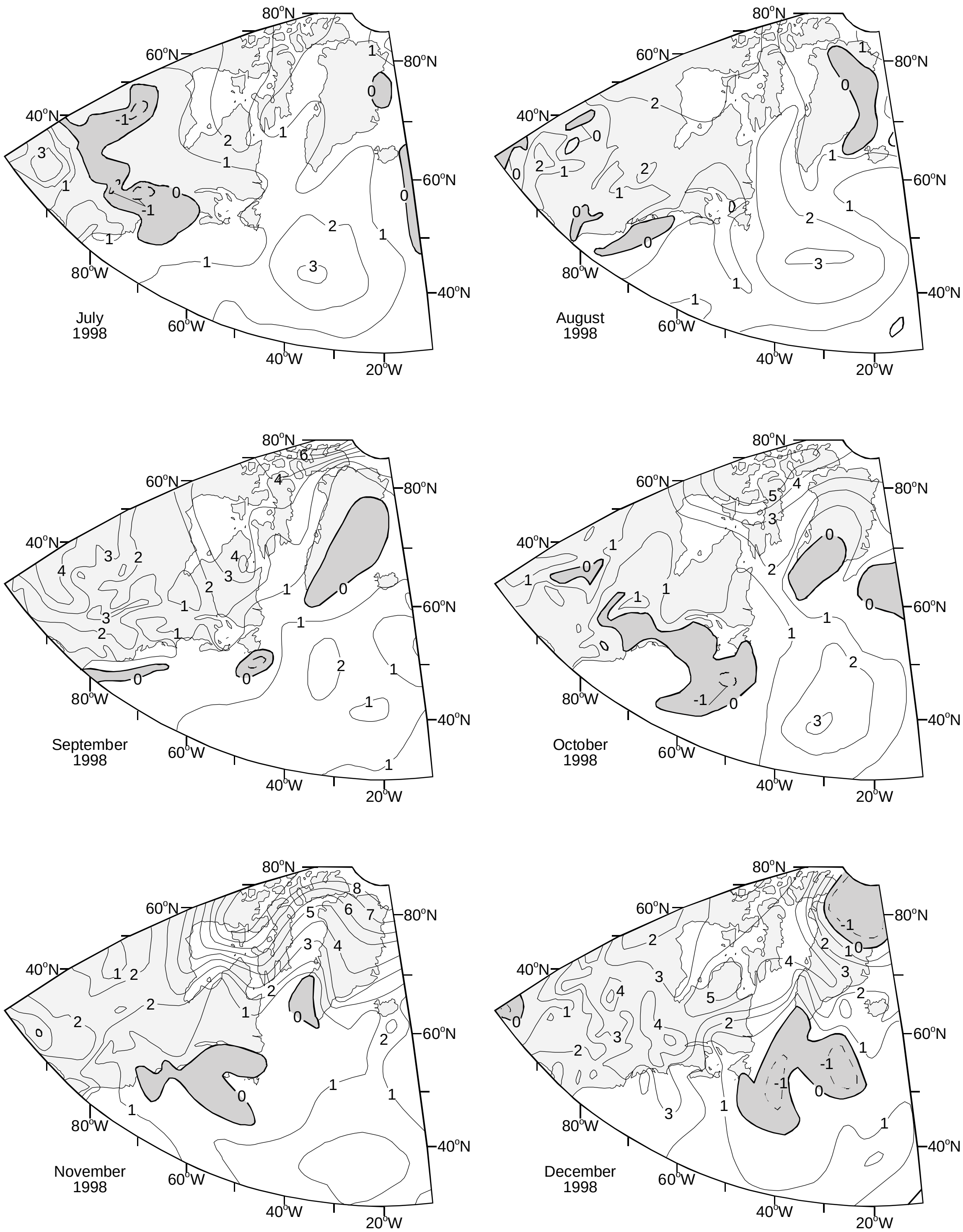


Fig. 1 (continued). Monthly air temperature anomalies (°C) over the Northwest Atlantic and eastern Canada in 1998 relative to the 1961-90 means. Shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

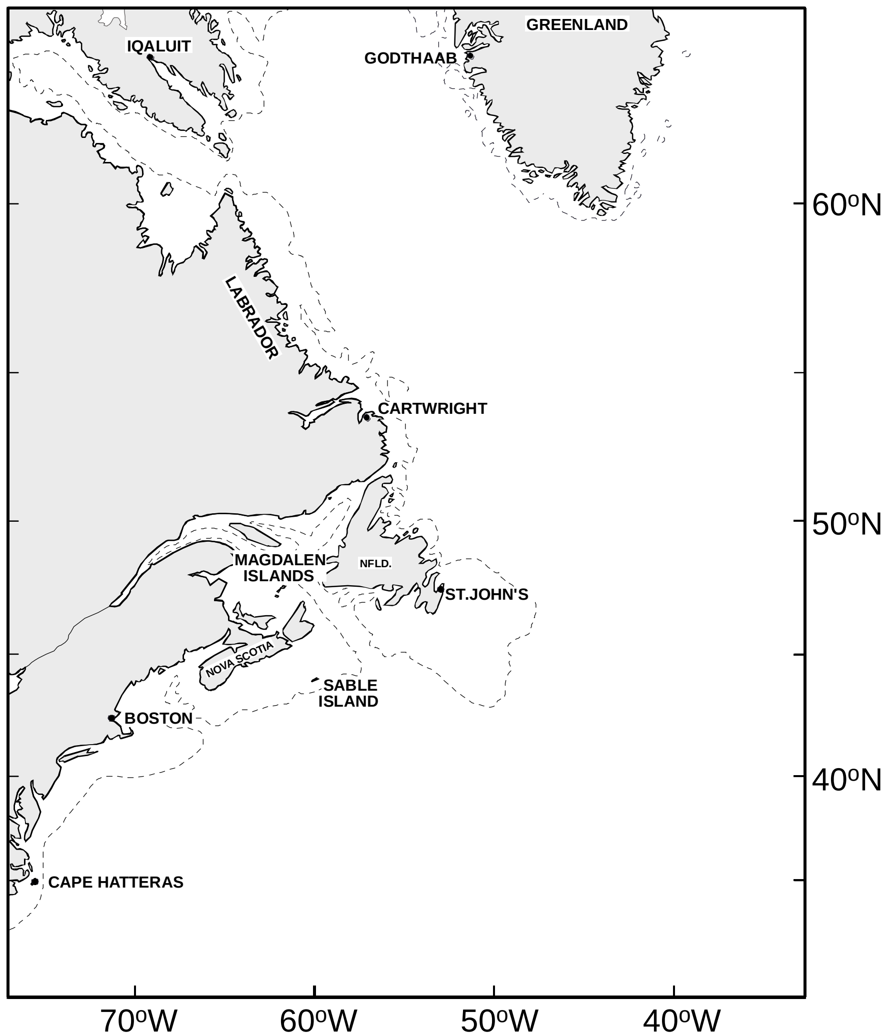


Fig. 2. Northwest Atlantic showing coastal air temperature stations. The dashed line denotes the 200 m isobath.

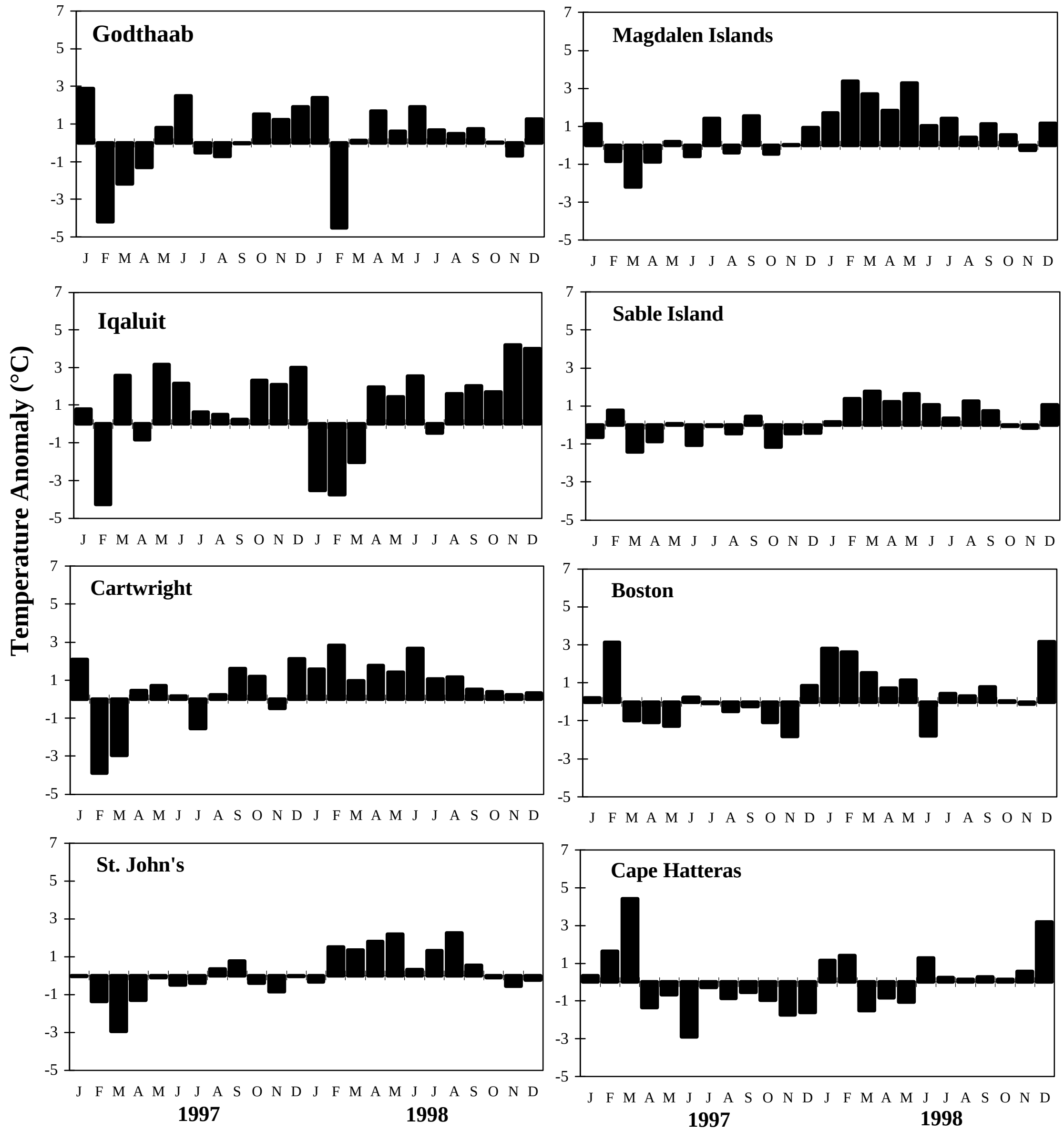


Fig. 3. Monthly air temperature anomalies in 1997 and 1998 at selected coastal sites (see Fig. 2 for locations).

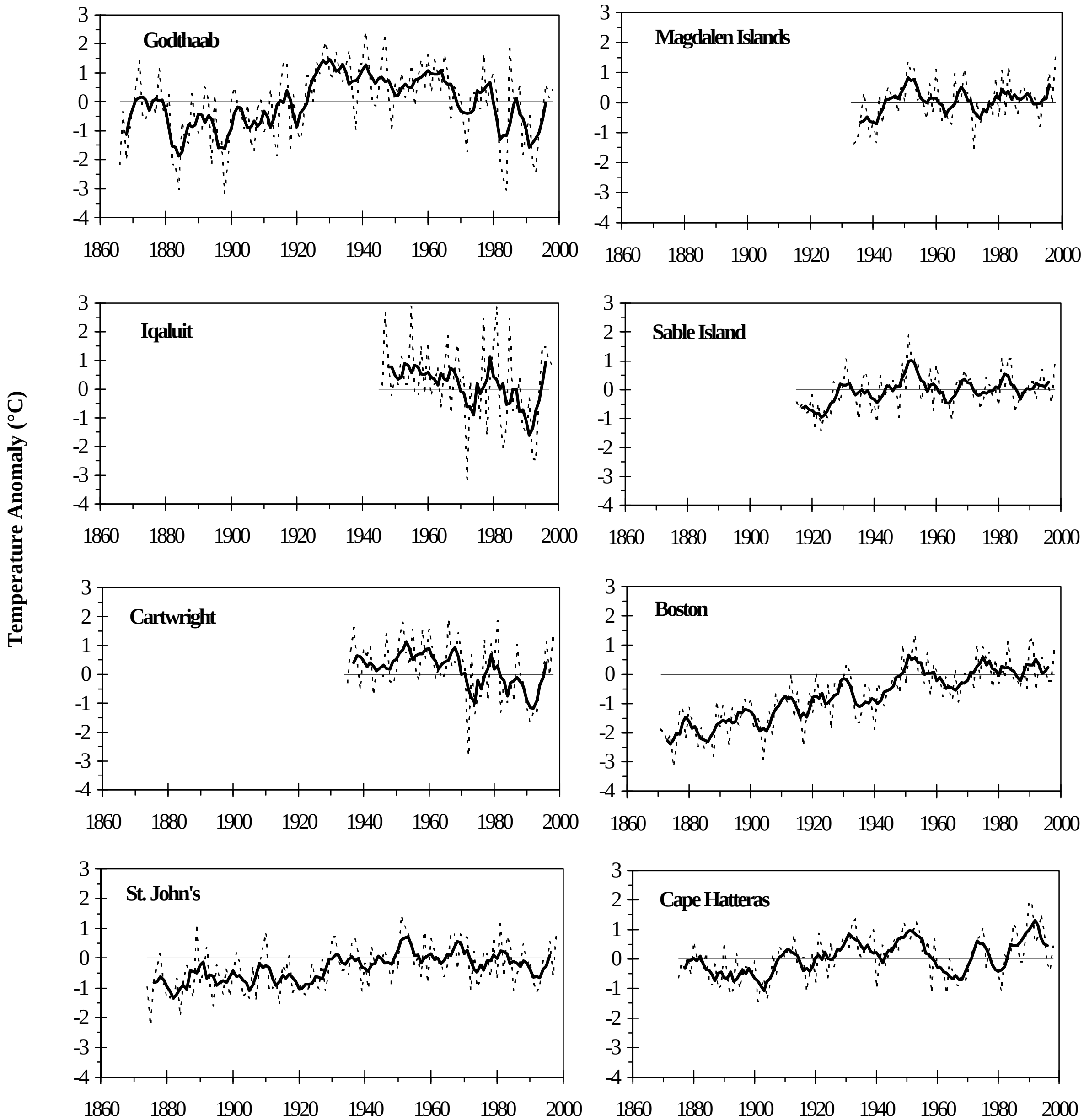


Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

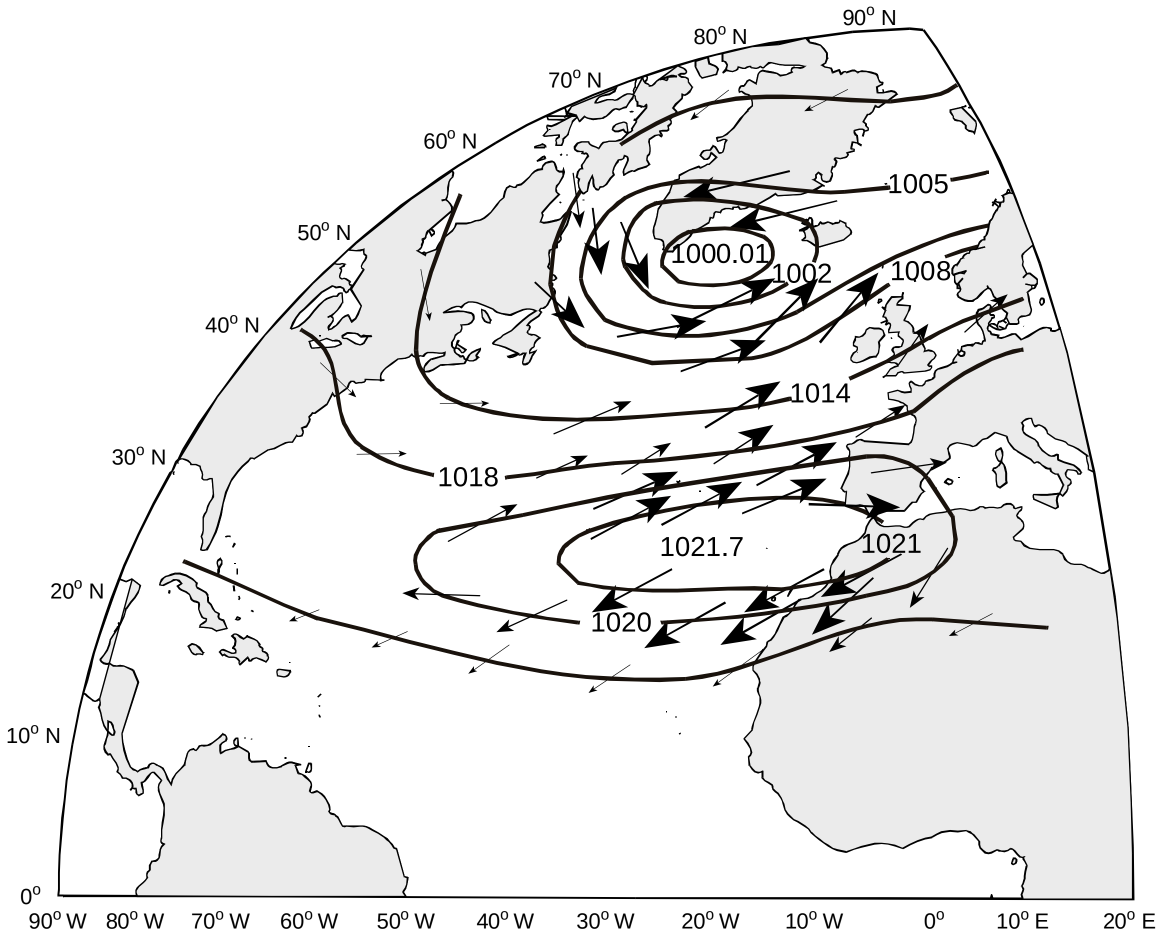


Fig. 5. The long-term (1961-90) mean sea surface pressures during winter (average of December, January and February). A schematic of the associated wind field is also shown.

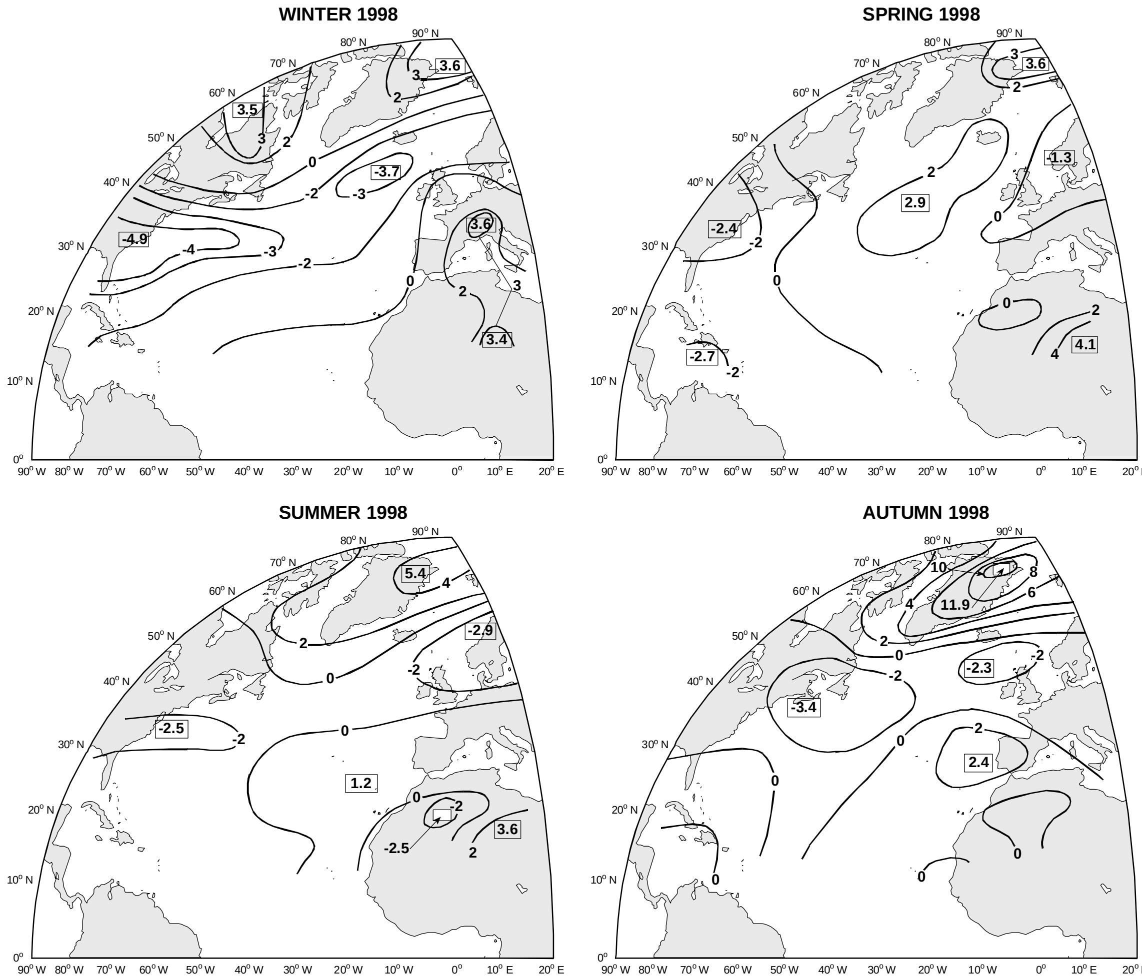


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1998 relative to the 1961-90 means.

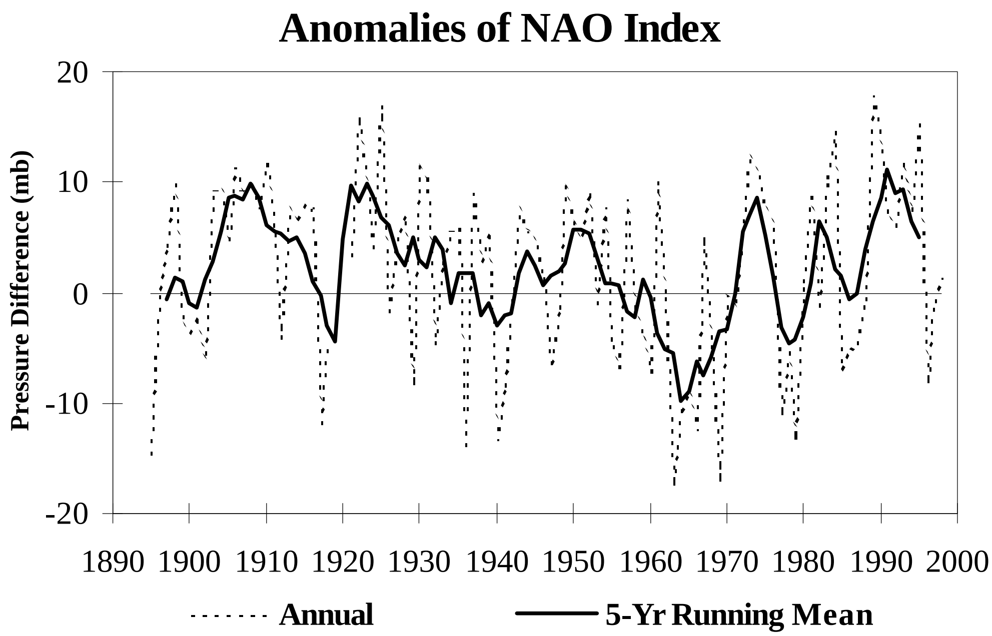


Fig. 7. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland, relative to the 1961-90 mean.

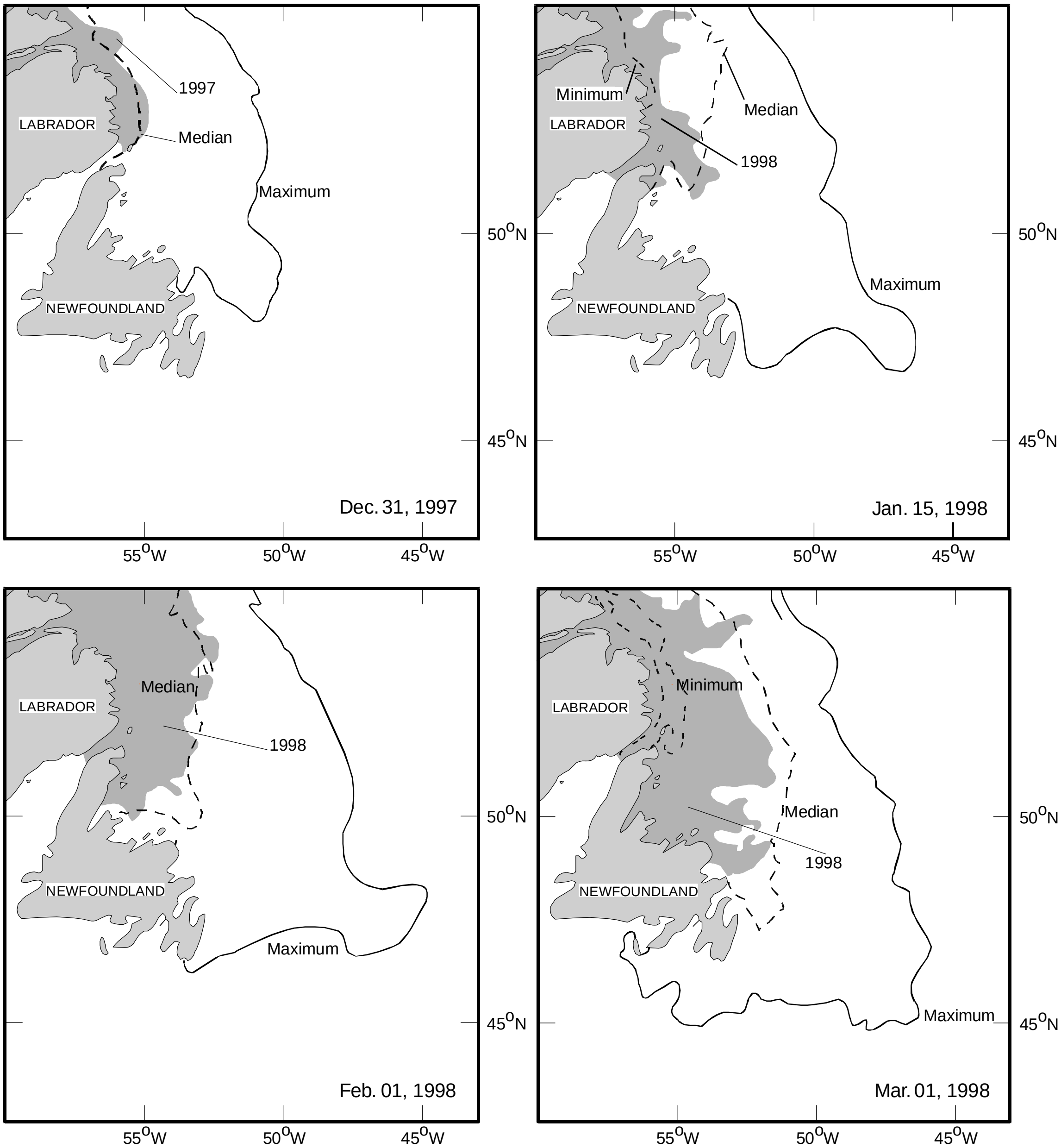


Fig. 8a. The location of the ice (shaded area) between December 1997 and March 1998 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

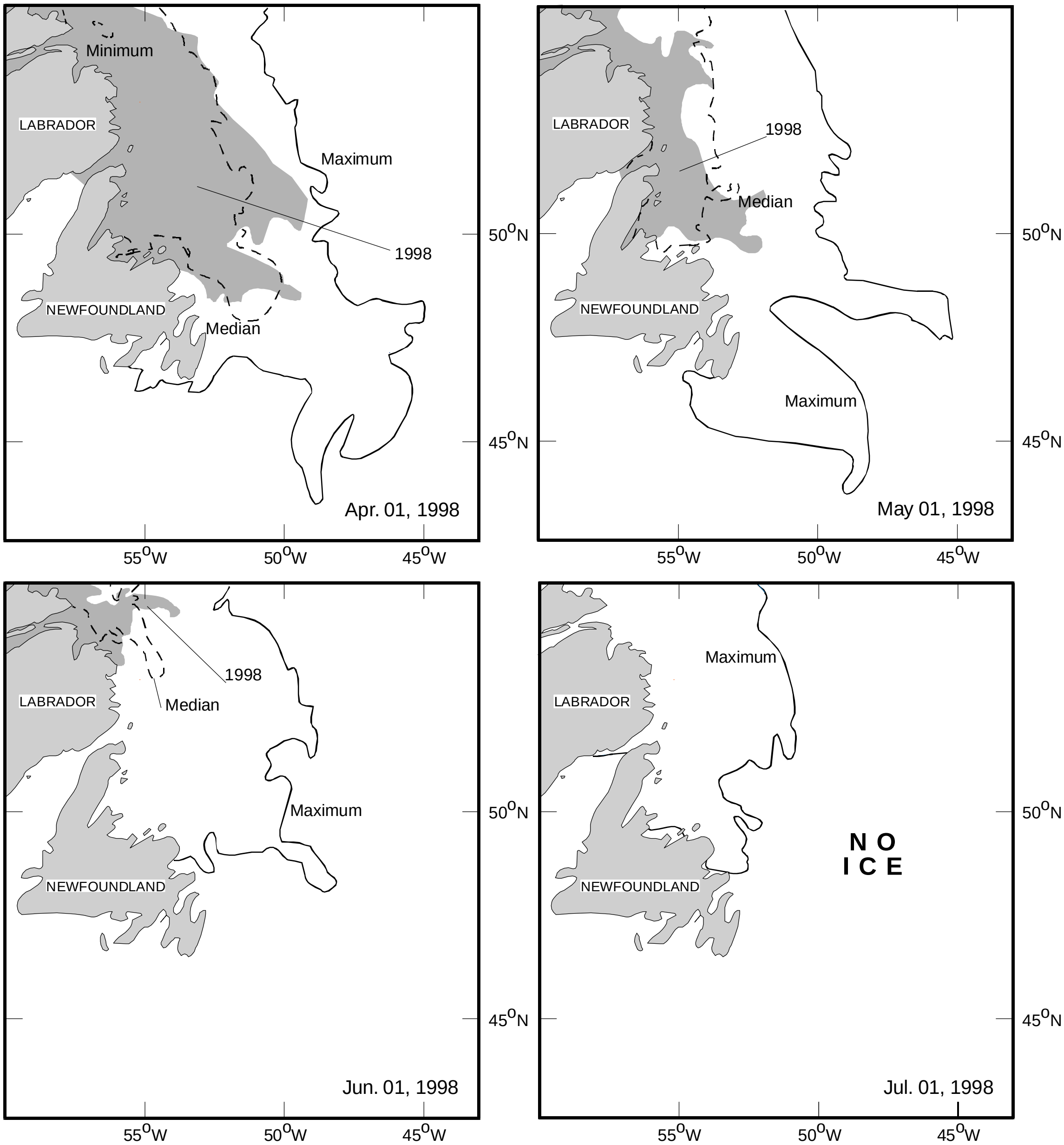


Fig. 8b. The location of the ice (shaded area) between April and July 1998 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

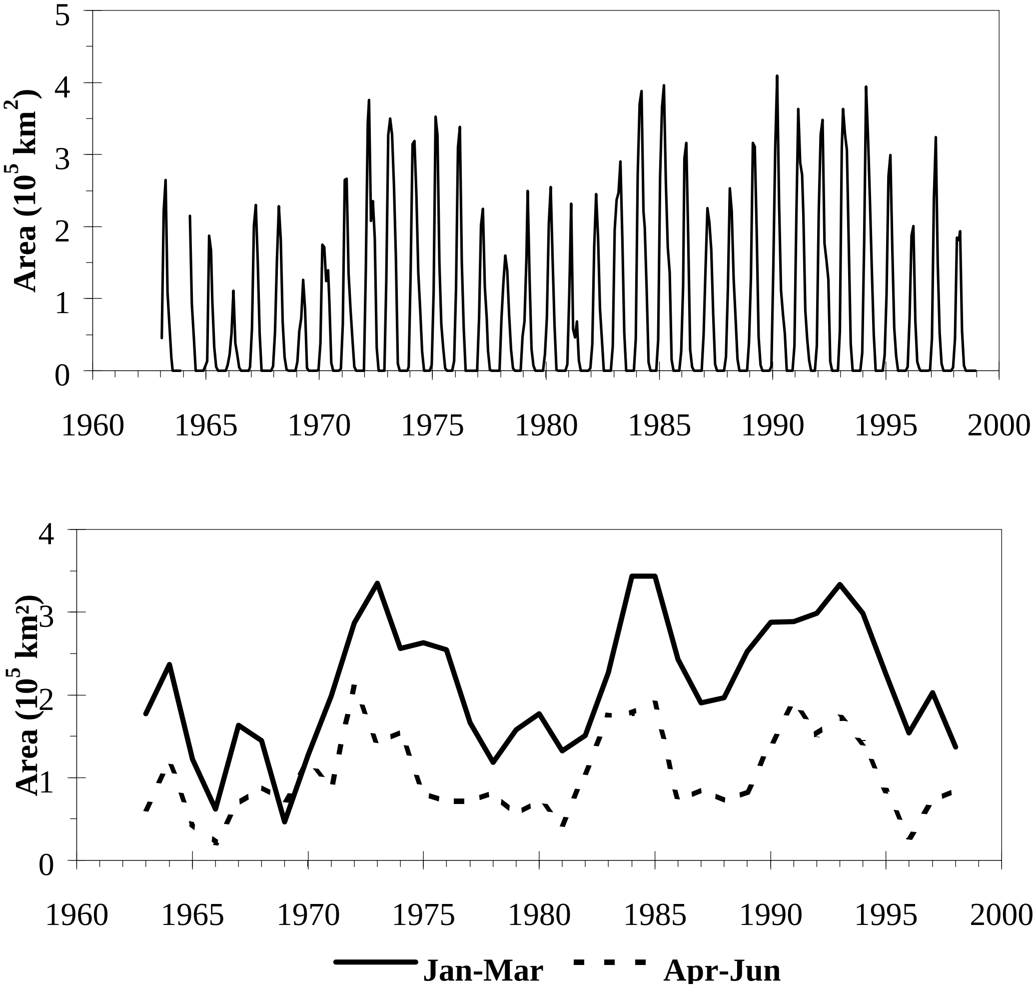


Fig. 9. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N- 55°N (top panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

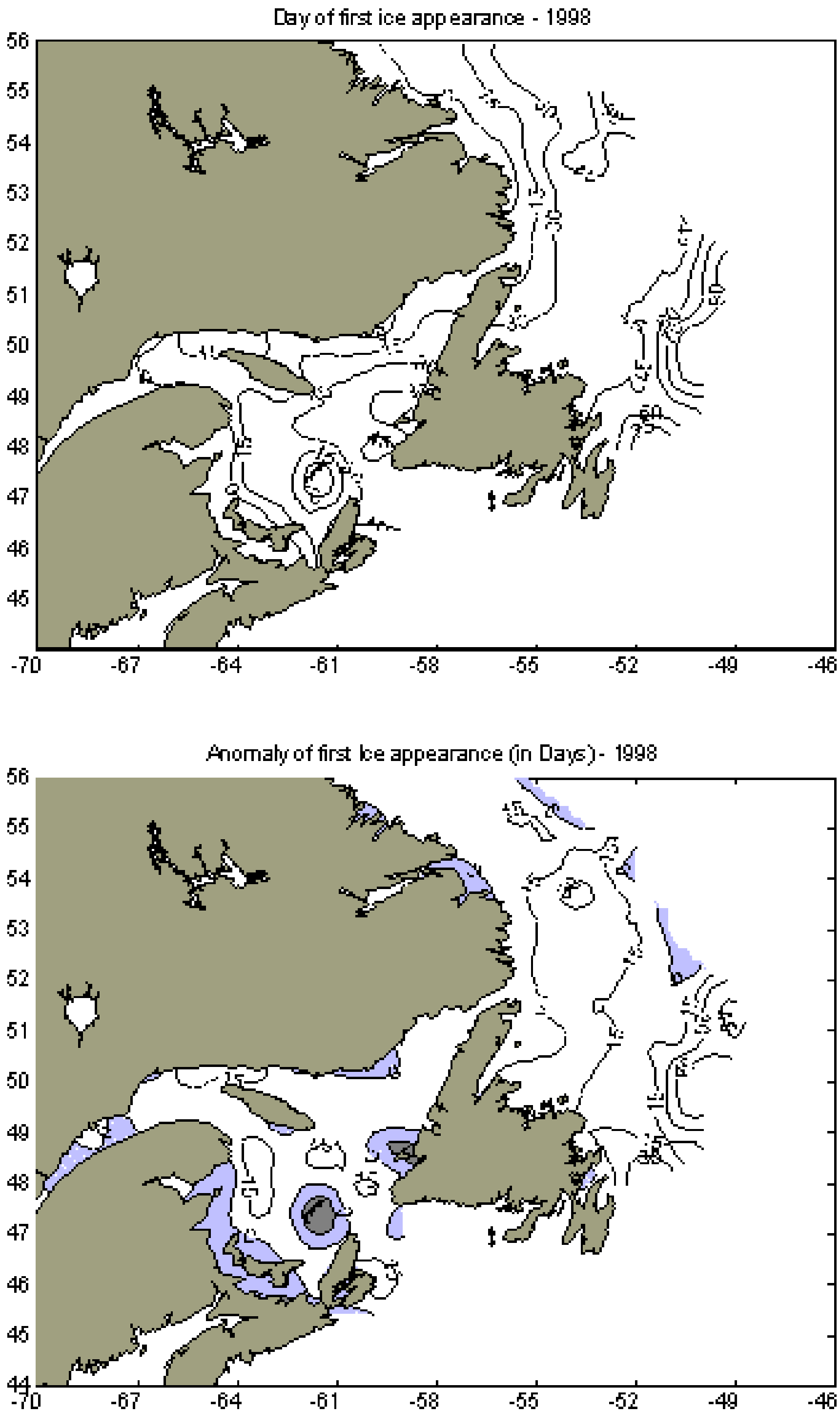
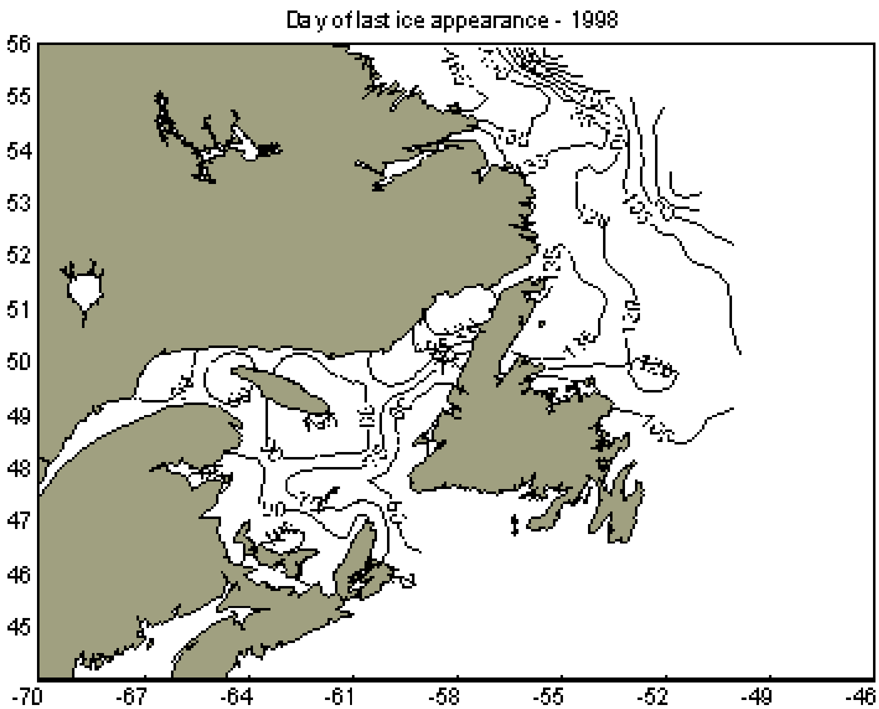


Fig. 10. The time when ice first appeared during 1998 in days from the beginning of the year (top panel) and their anomaly from the long term mean in days (bottom panel). The shaded negative anomaly indicates ice appeared earlier-than-normal which is generally associated with a cold year.



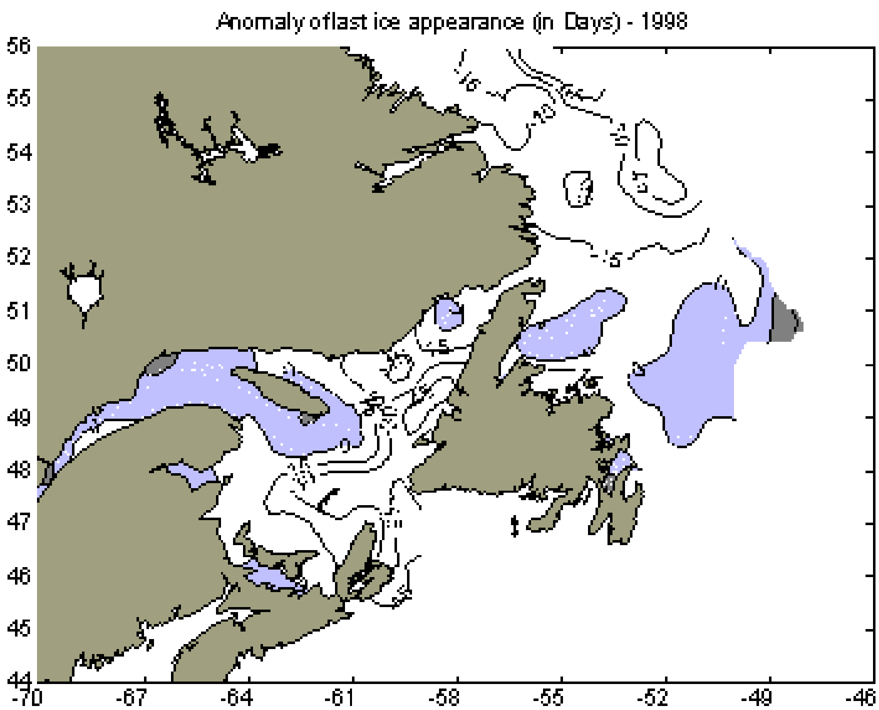


Fig. 11. The time when ice was last reported in days from the beginning of the year (top panel) and their anomaly from the long term mean in days (bottom panel). The shaded positive anomaly indicates ice lasted longer-than-normal which is generally associated with a cold year.

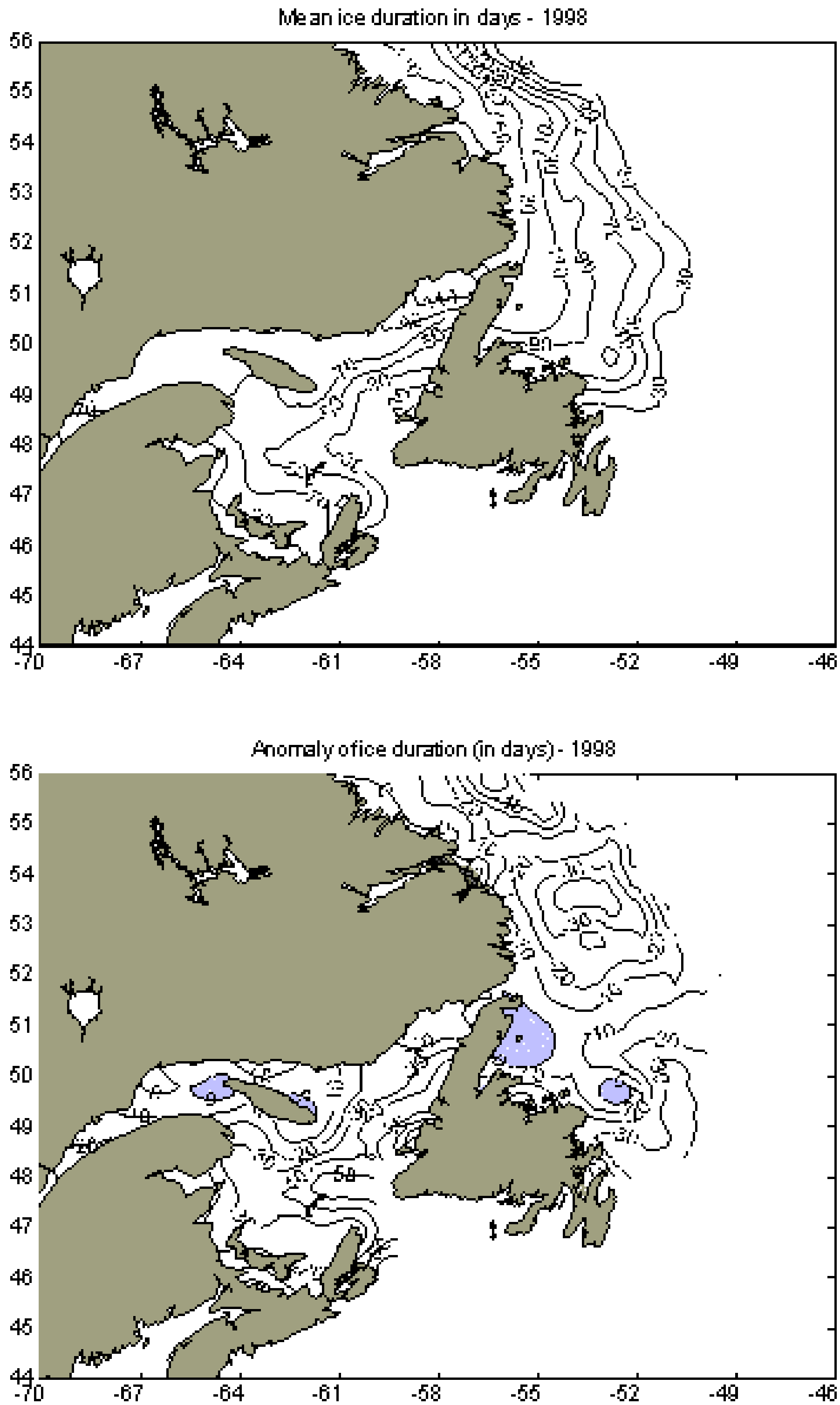
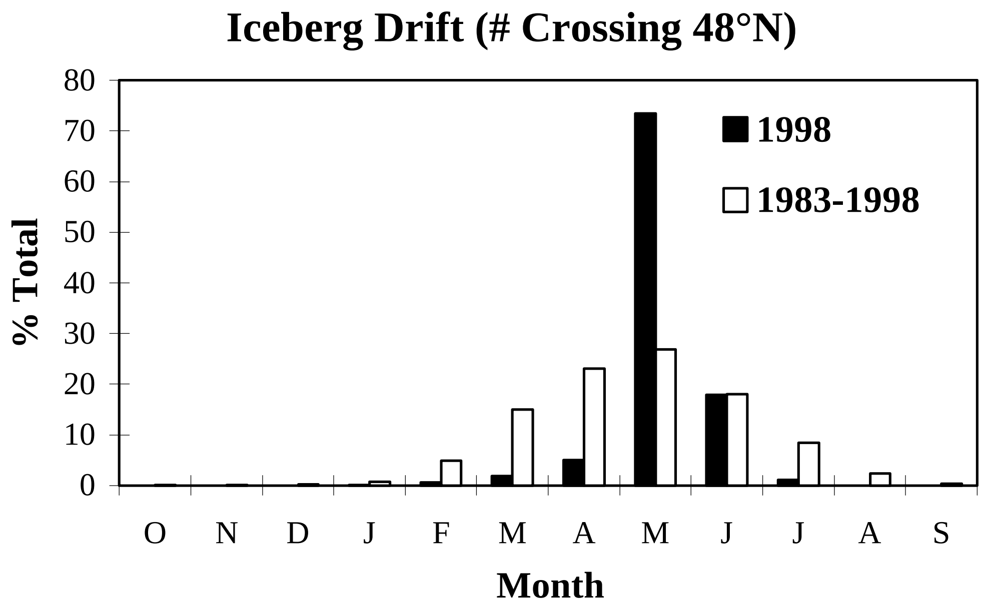


Fig. 12. The duration of ice in days (top panel) and their anomaly from the long term mean in days (bottom panel). The shaded positive anomalies indicate a duration longer than the mean which is generally associated with a cold year.



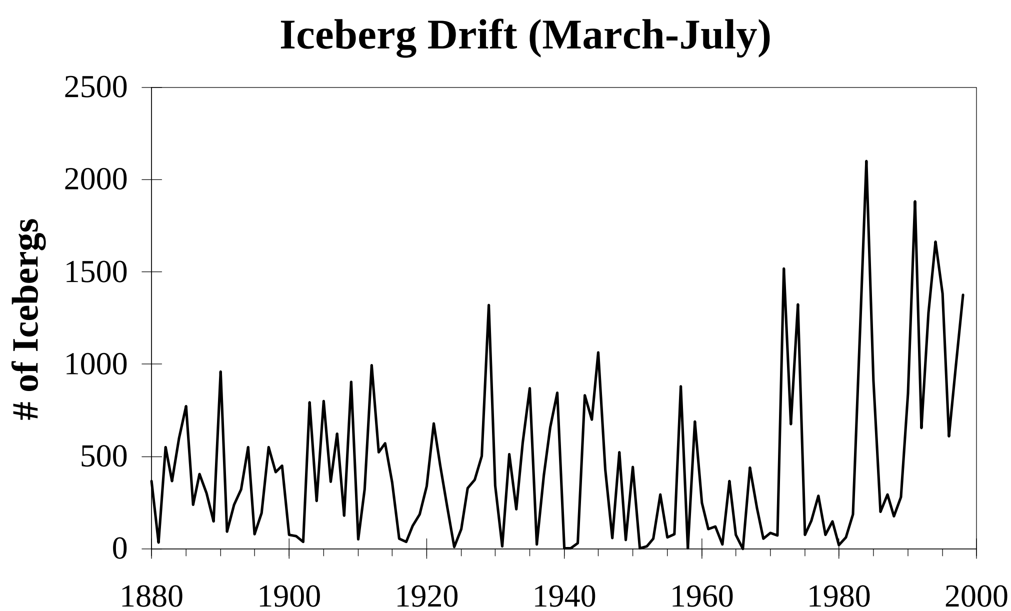


Fig. 13. The number of icebergs crossing south of 48°N during the iceberg season 1997/98 expressed as a percent of the total by month compared to the mean during 1983-98, the years SLAR has been used (top panel) and the time series of total number of icebergs observed during March to July (bottom panel).

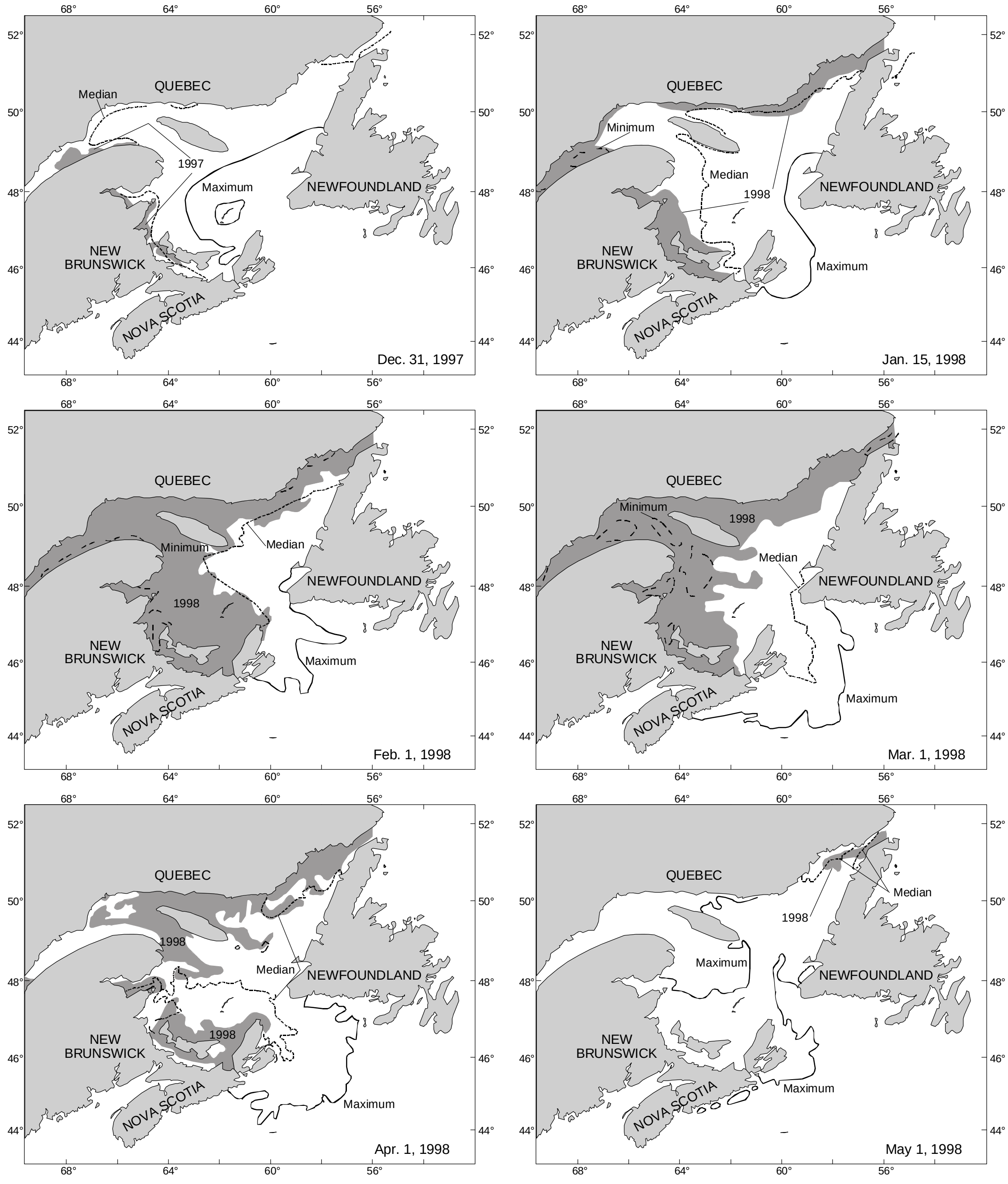


Fig. 14. The location of the ice (shaded area) between December 1997 and May 1998 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

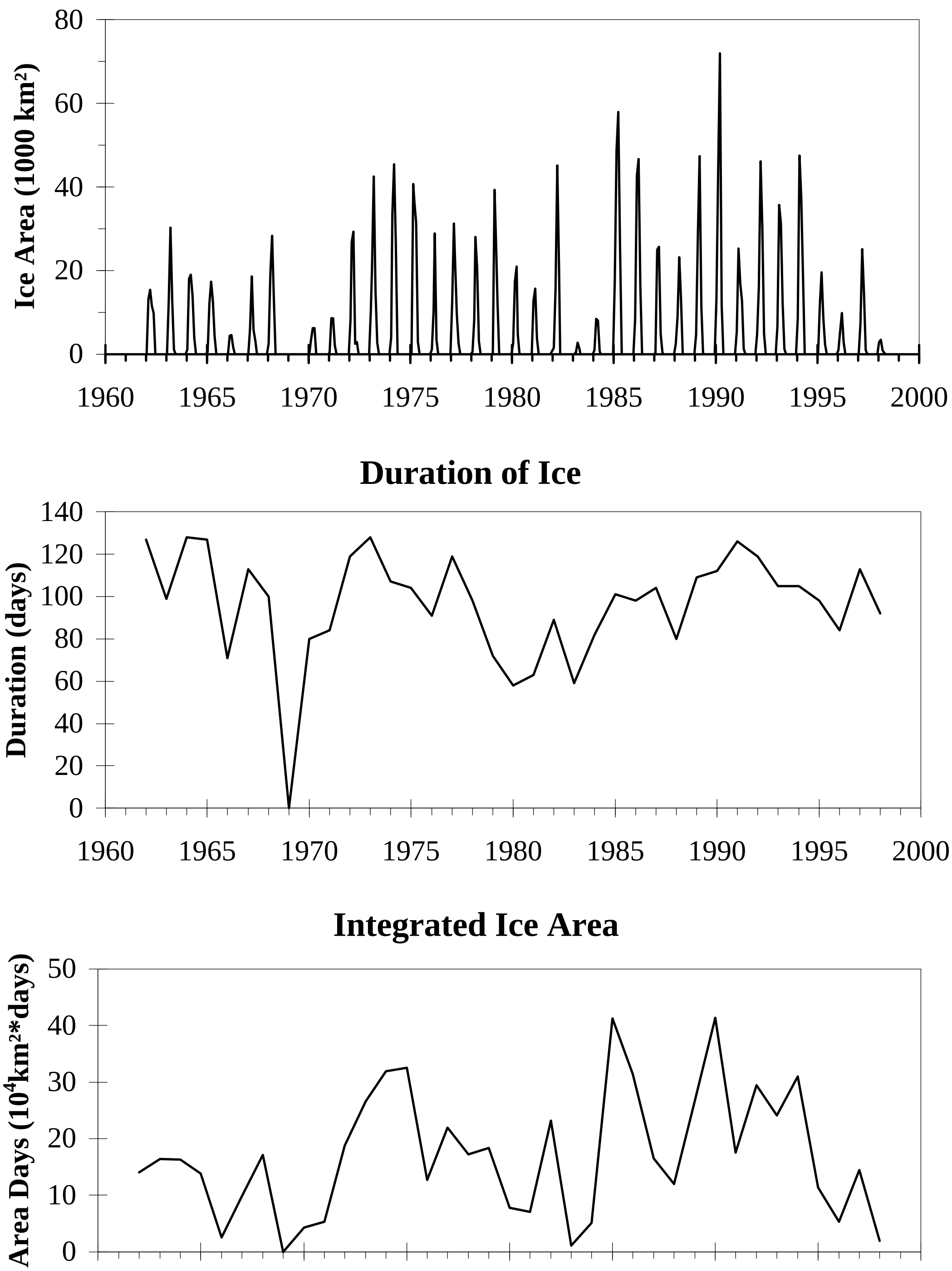


Fig. 15. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days).

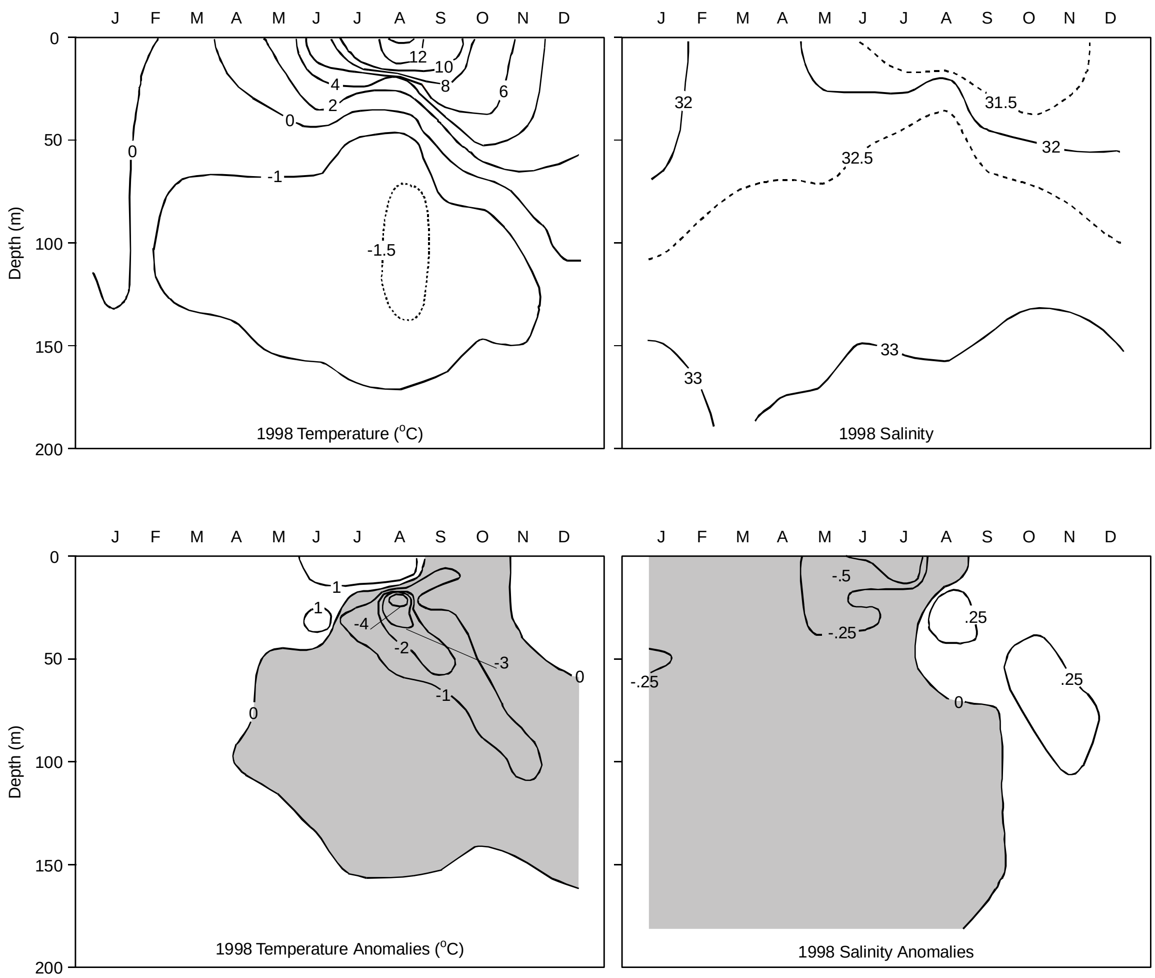
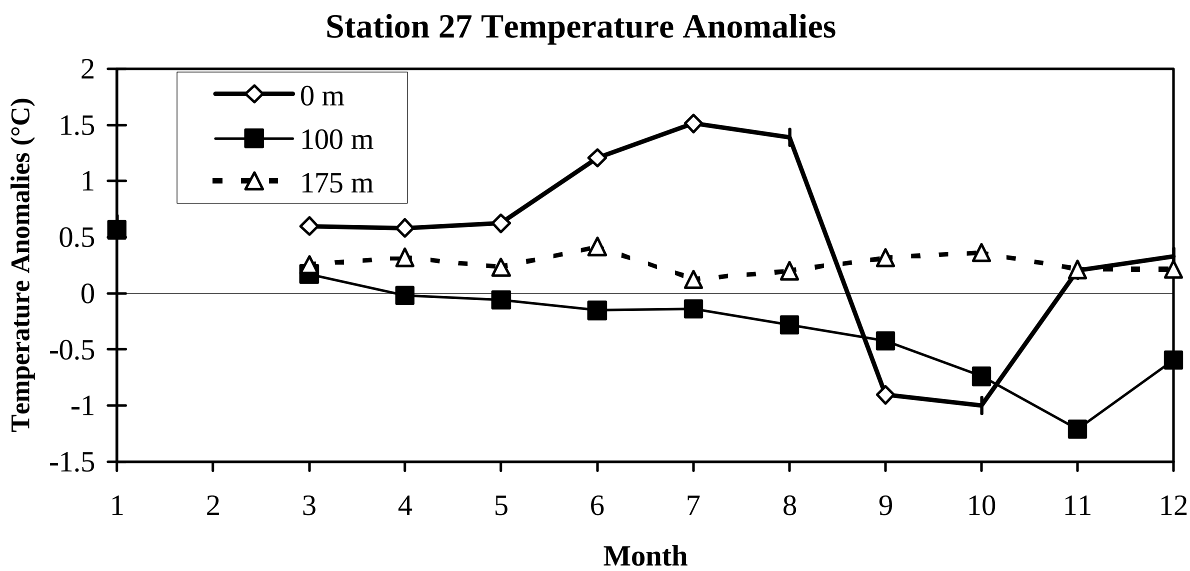


Fig. 16. The monthly mean and anomalies of temperature and salinity at Station 27. The negative (colder, fresher) anomalies are shaded.



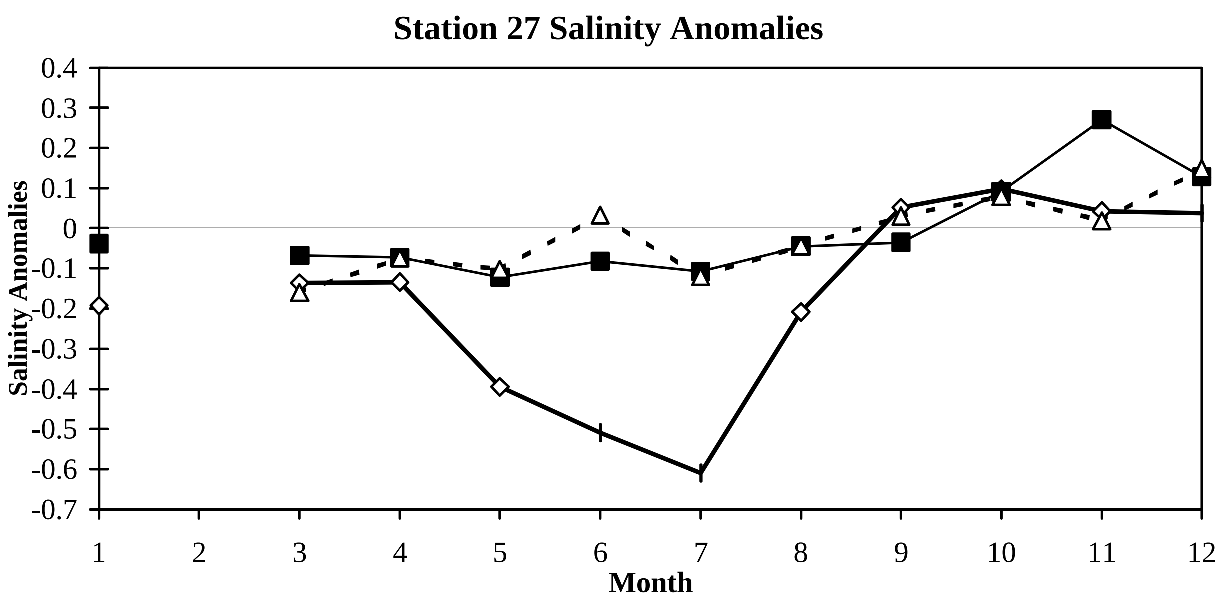


Fig. 17. Monthly temperature (top panel) and salinity (bottom panel) anomalies at 0, 100 and 175 m at Station 27 during 1998.

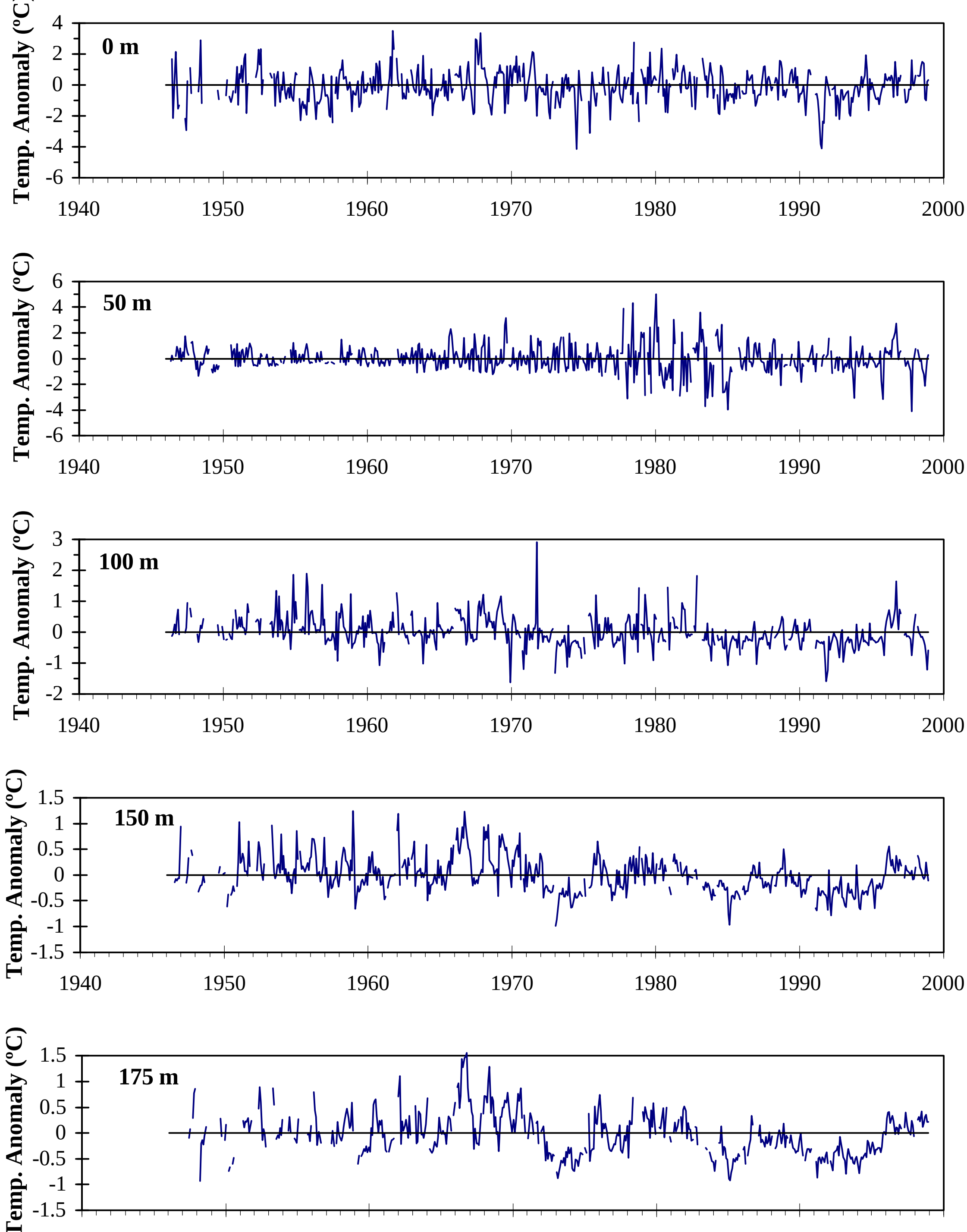


Fig. 18. Time series of monthly mean temperature anomalies at selected depths from Station 27.

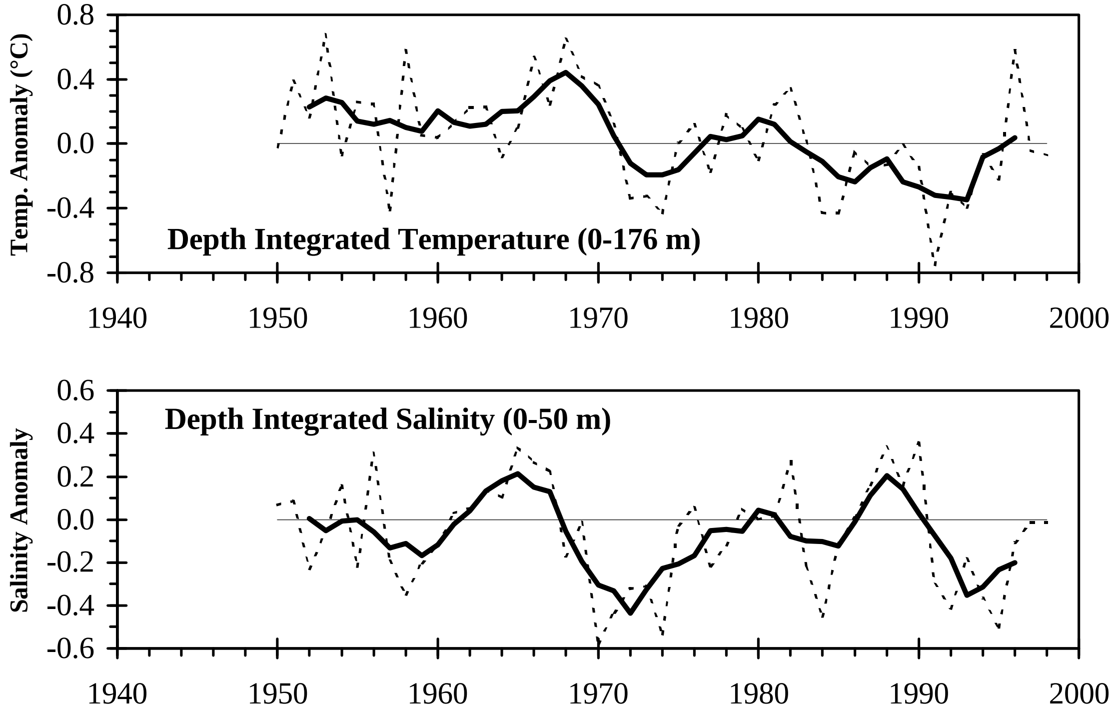


Fig. 19. Vertically-averaged temperature (0-176 m) and salinity (0-50 m) anomalies from Station 27. Dashed lines are the annual values and the sold dark line is the 5-yr running mean.

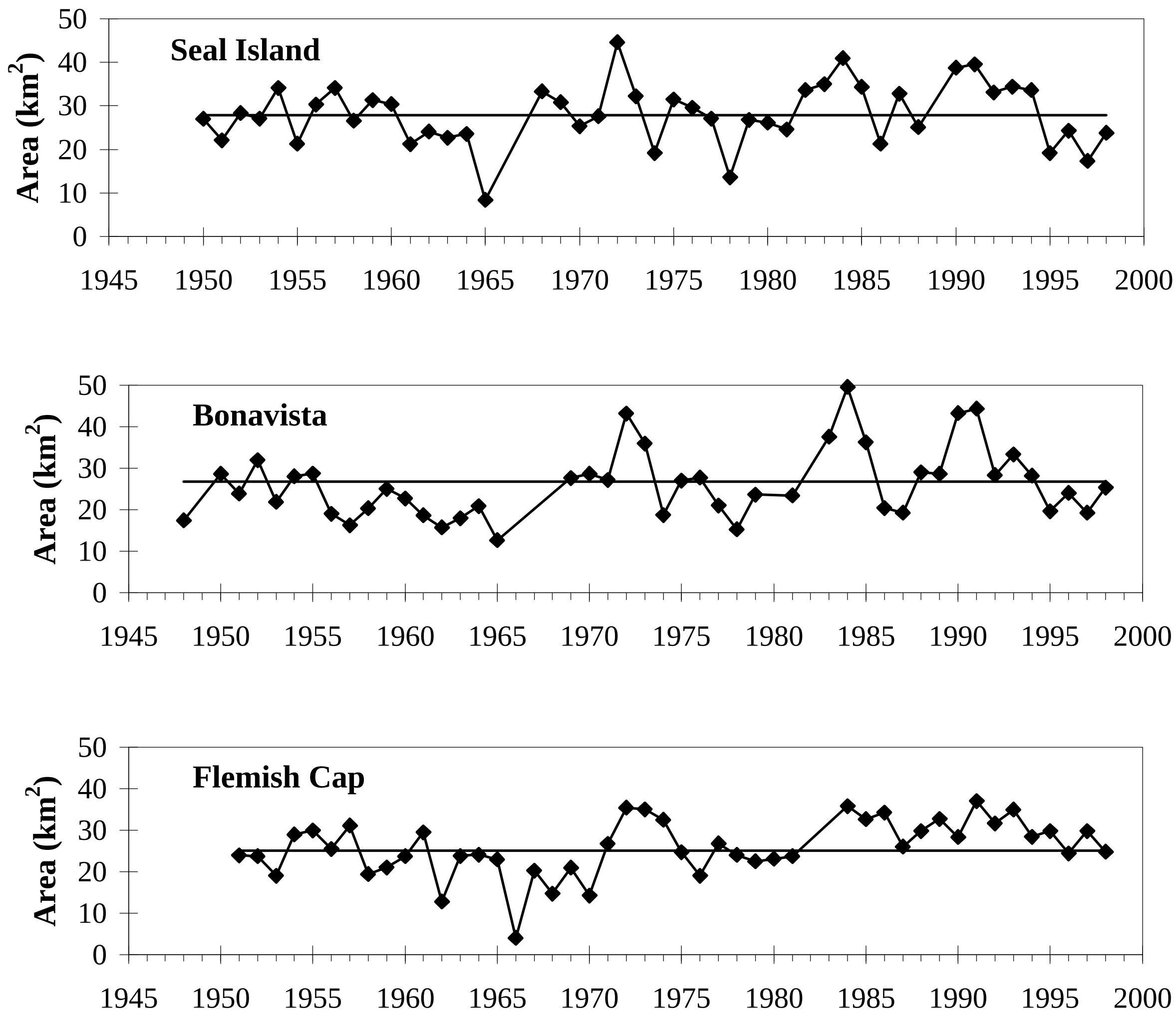


Fig. 20. The CIL cross-sectional area (in km^2) during the summer along transects off the Seal Island (southern Labrador), Bonavista Bay (northern Newfoundland), and Flemish Cap (Grand Banks).

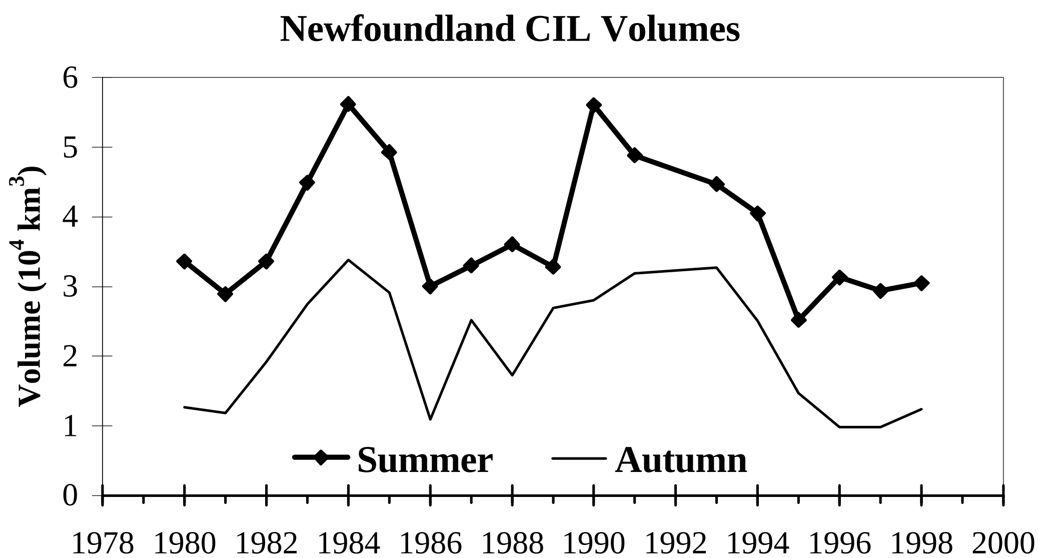


Fig. 21. The CIL volume in the summer and autumn within Divs. 2J and 3KL.

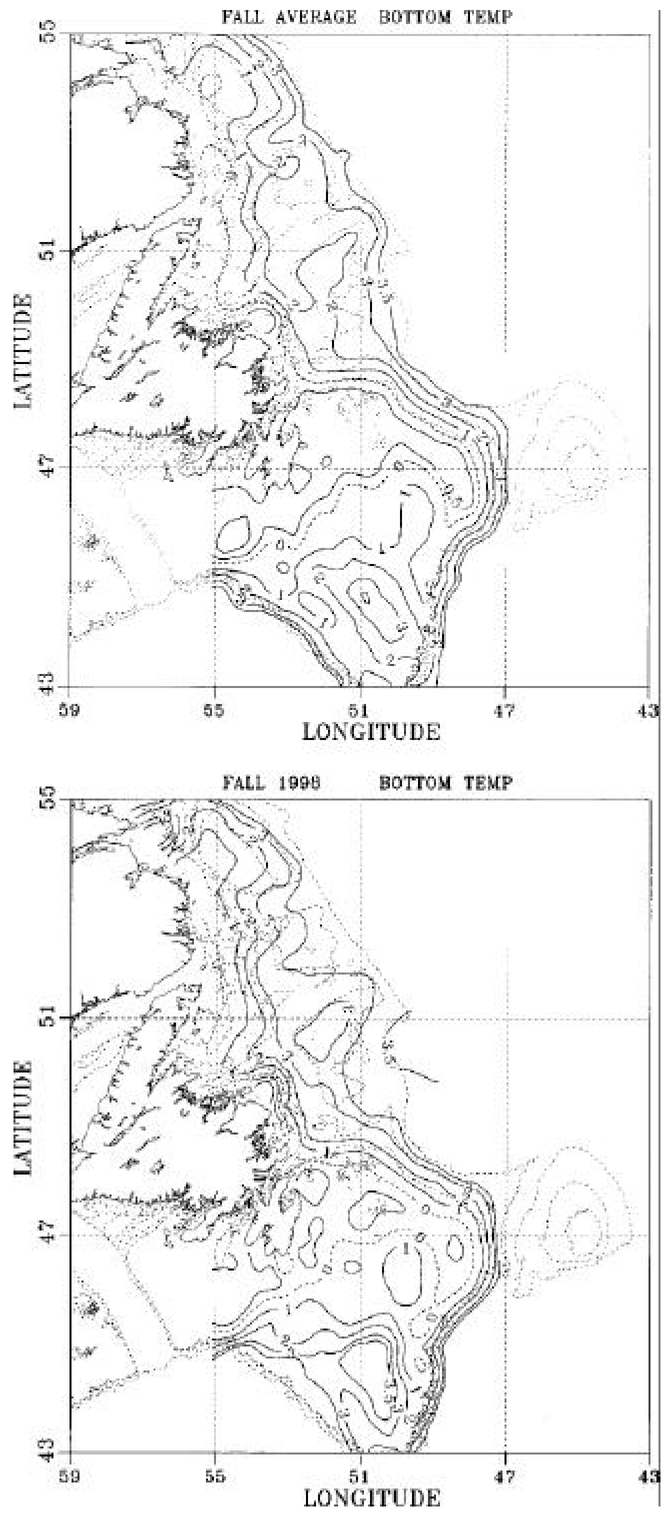


Fig. 22. Contours of the long-term mean (1961-1990) and 1998 autumn bottom temperatures for the Newfoundland Shelf.

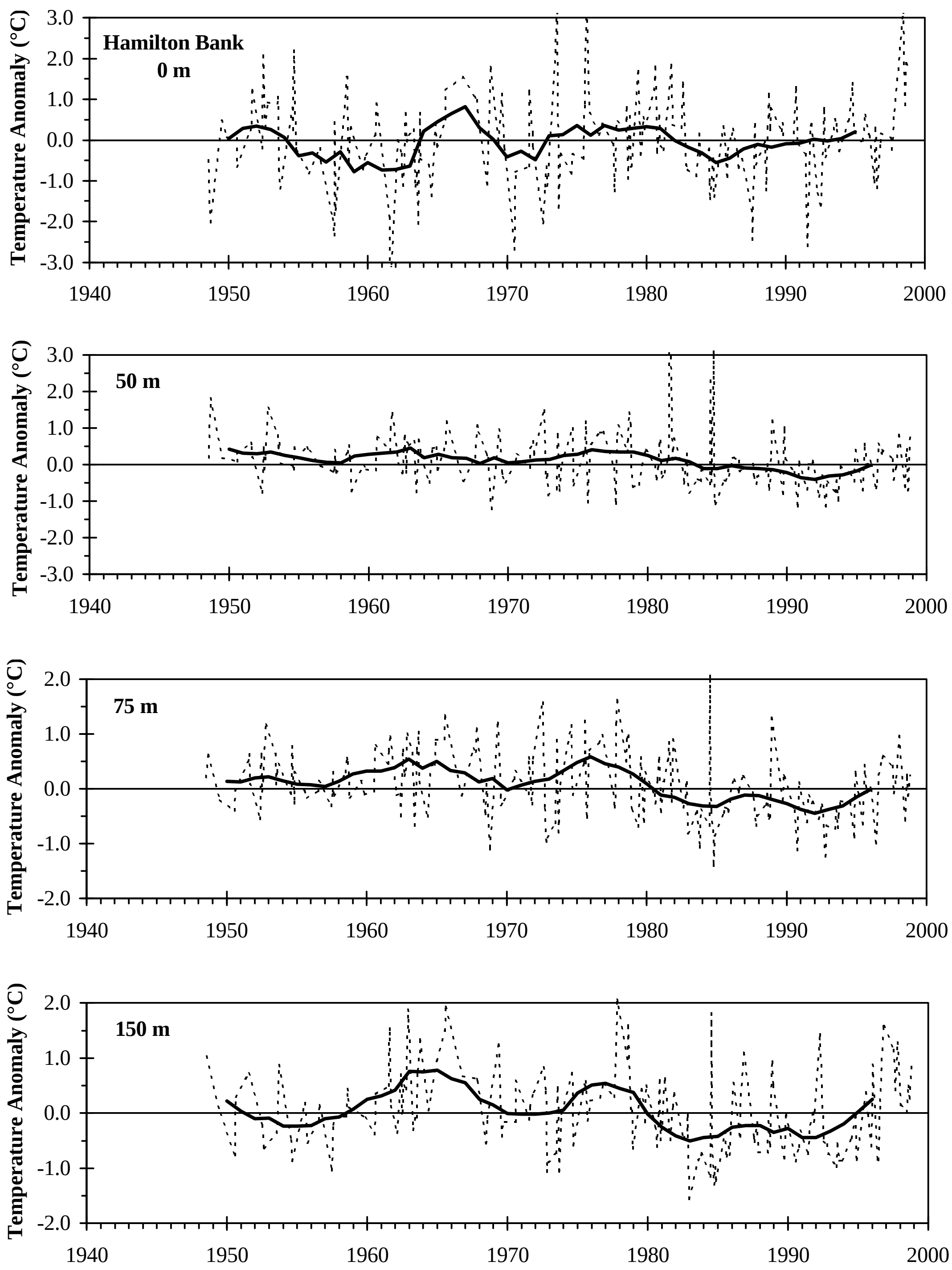


Fig. 23. Monthly (dashed) and 5-yr running means (solid line) of temperature anomalies for different depths on Hamilton Bank.

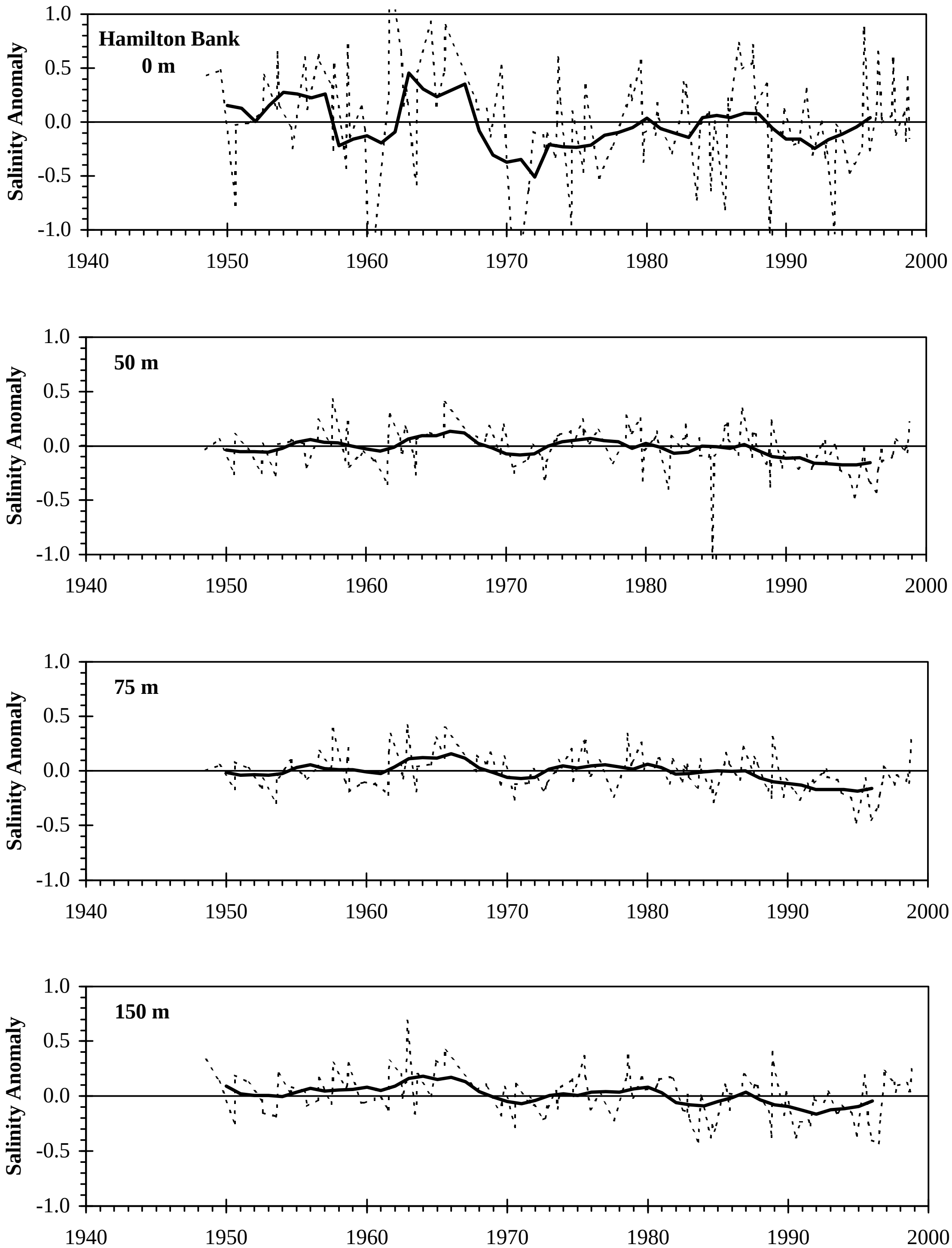


Fig. 24. Monthly (dashed) and 5-yr running means (solid line) of salinity anomalies for different depths on Hamilton Bank.

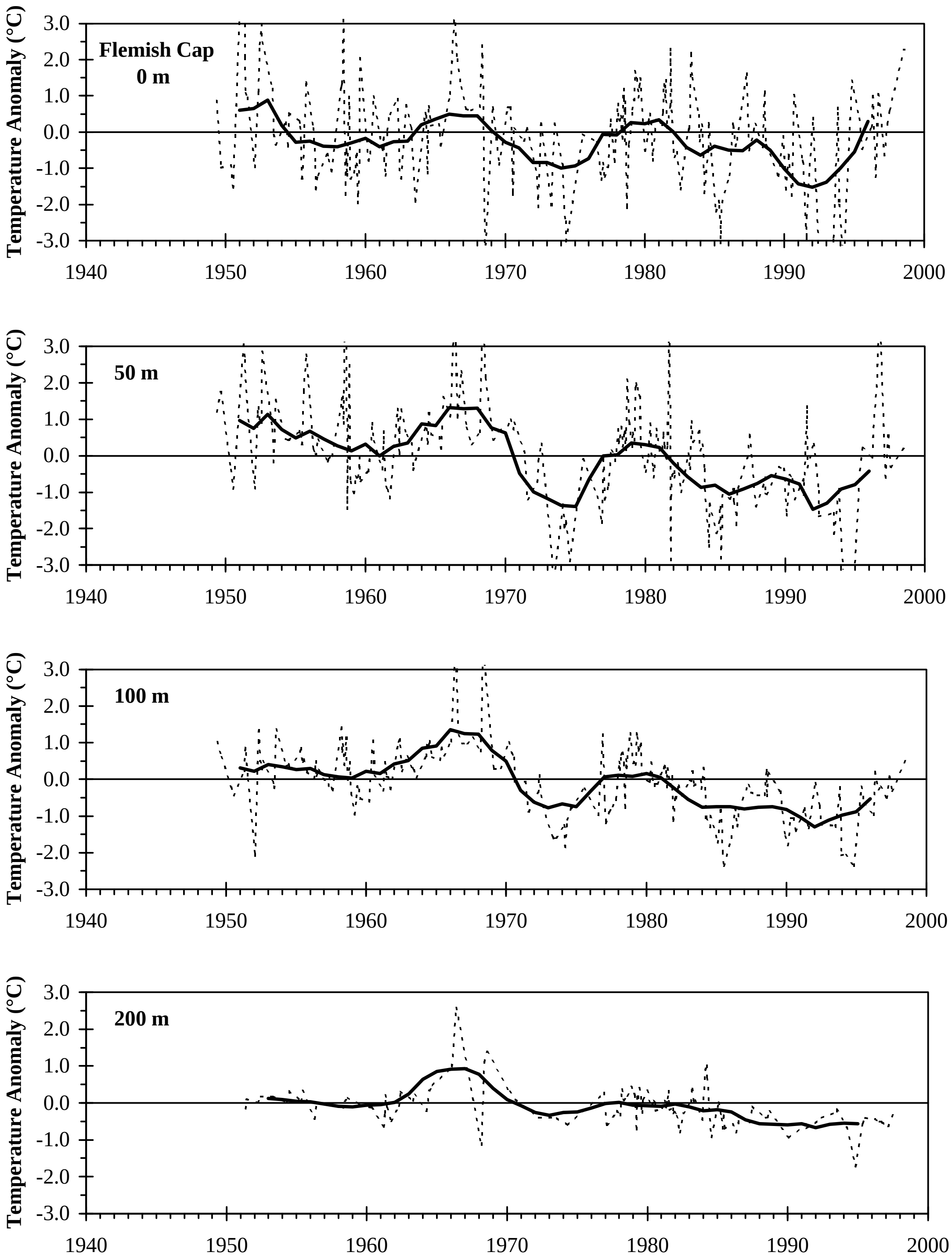


Fig. 25. Monthly (dashed) and 5-yr running means (solid line) of temperature anomalies for different depths on Flemish Cap.

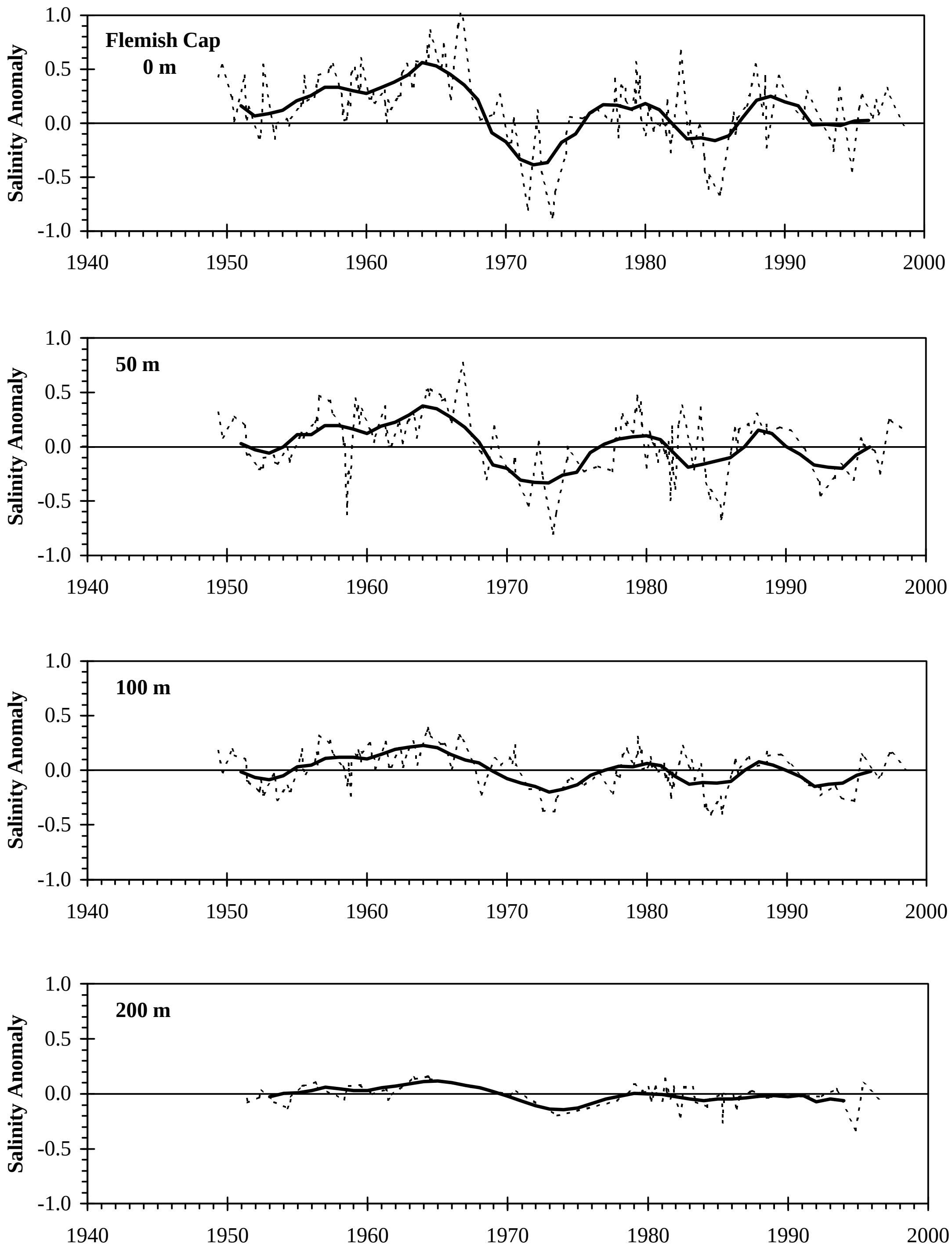


Fig. 26. Monthly (dashed) and 5-yr running means (solid line) of salinity anomalies for different depths on Flemish Cap.

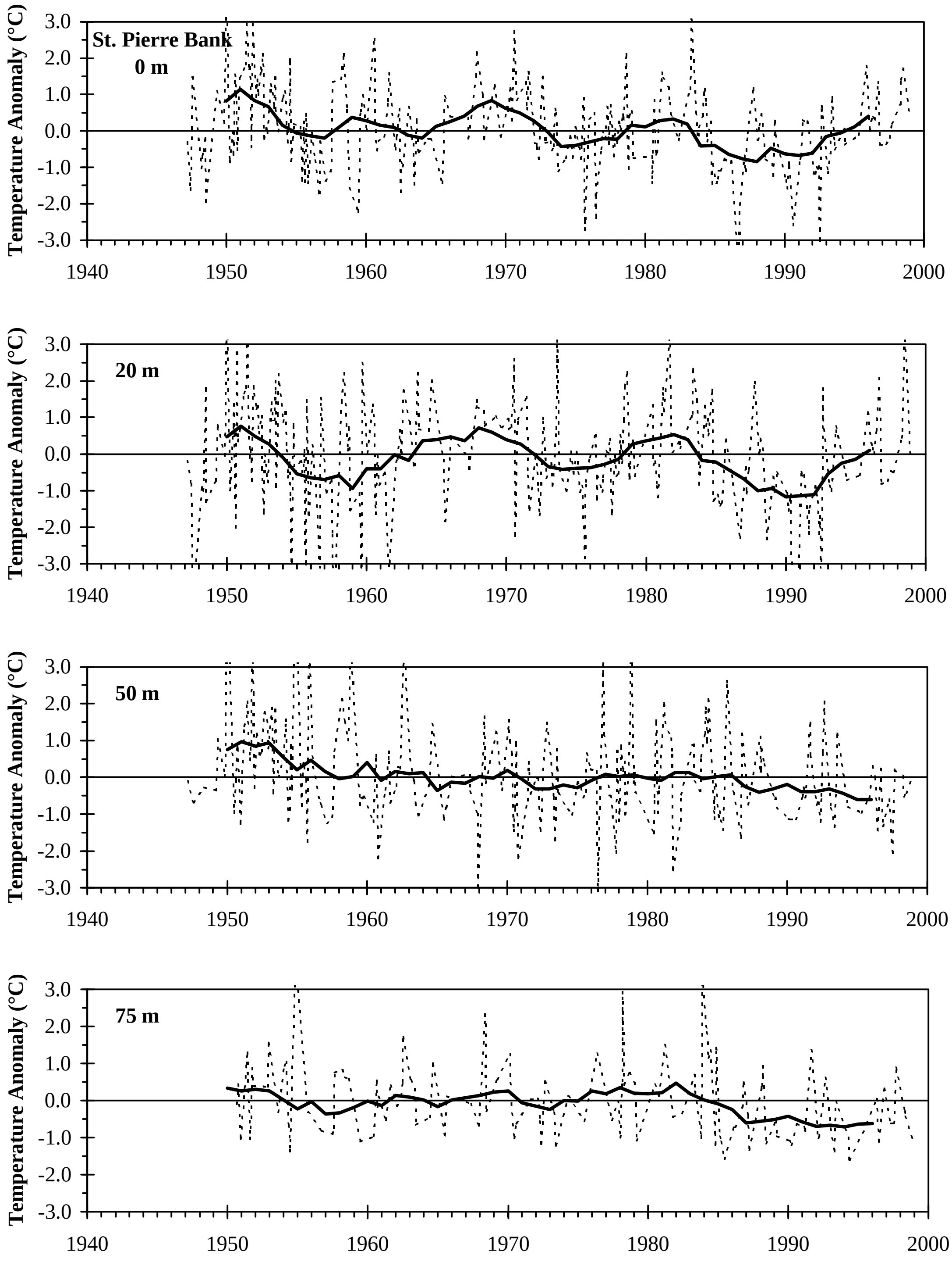


Fig. 27. Monthly (dashed) and 5-yr running means (solid line) of temperature anomalies for different depths on St. Pierre Bank.

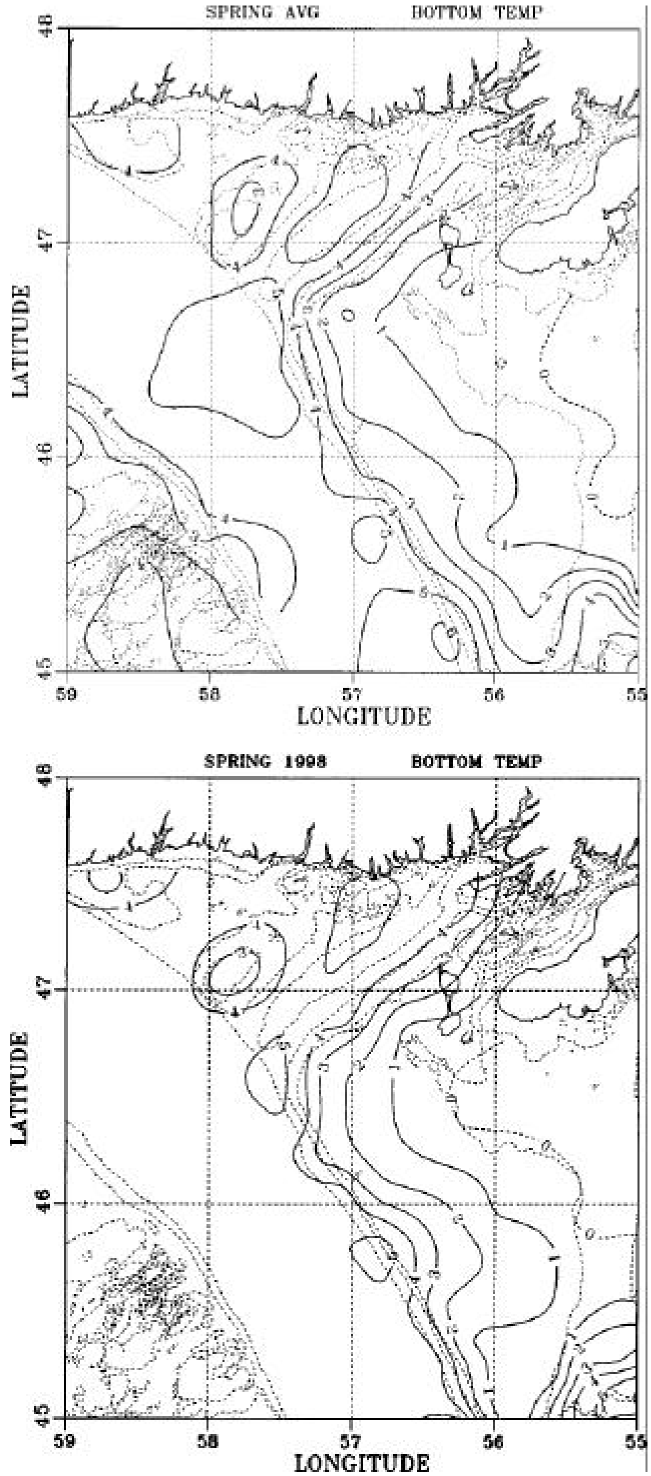


Fig. 28. Contours of the long-term (1961-90) mean and the 1998 spring bottom temperatures in 3Ps and 3Pn.

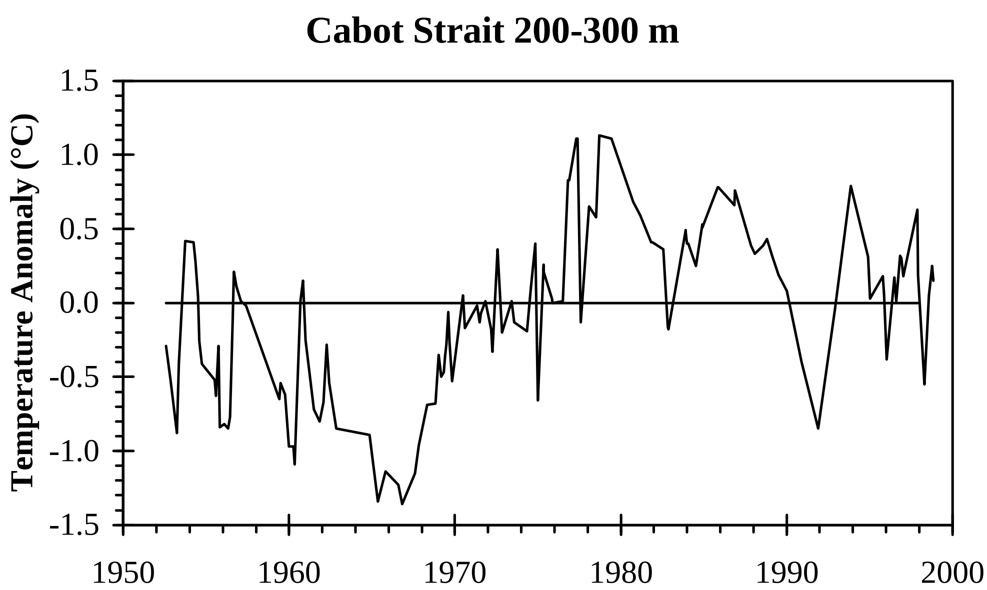


Fig. 29. Anomalies in the average temperature in the 200-300 m layer in Cabot Strait.

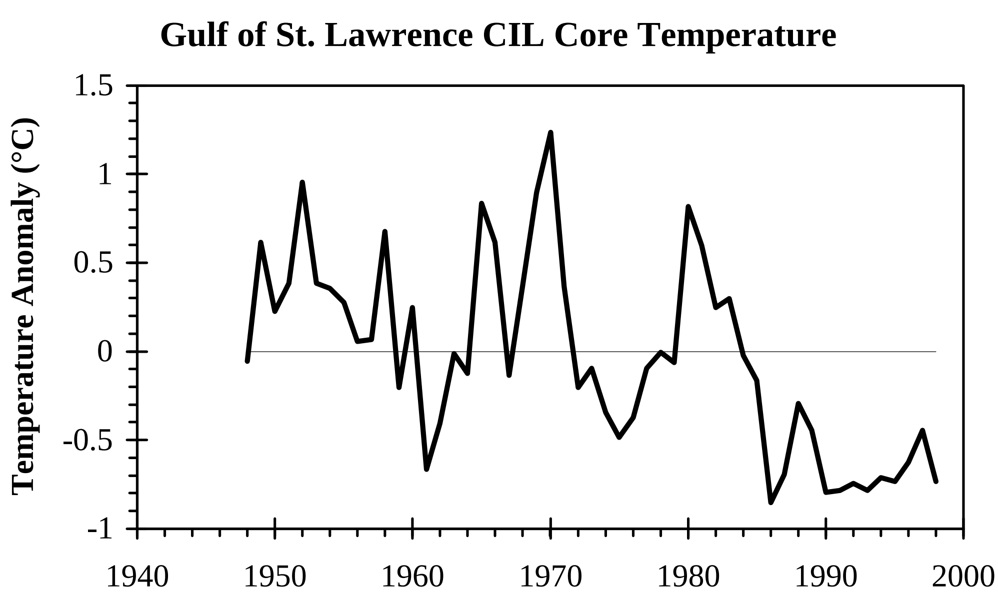


Fig. 30. Anomalies of the CIL core temperatures (extrapolated to July 15) for the Gulf of St. Lawrence relative to the 1961-90 mean.

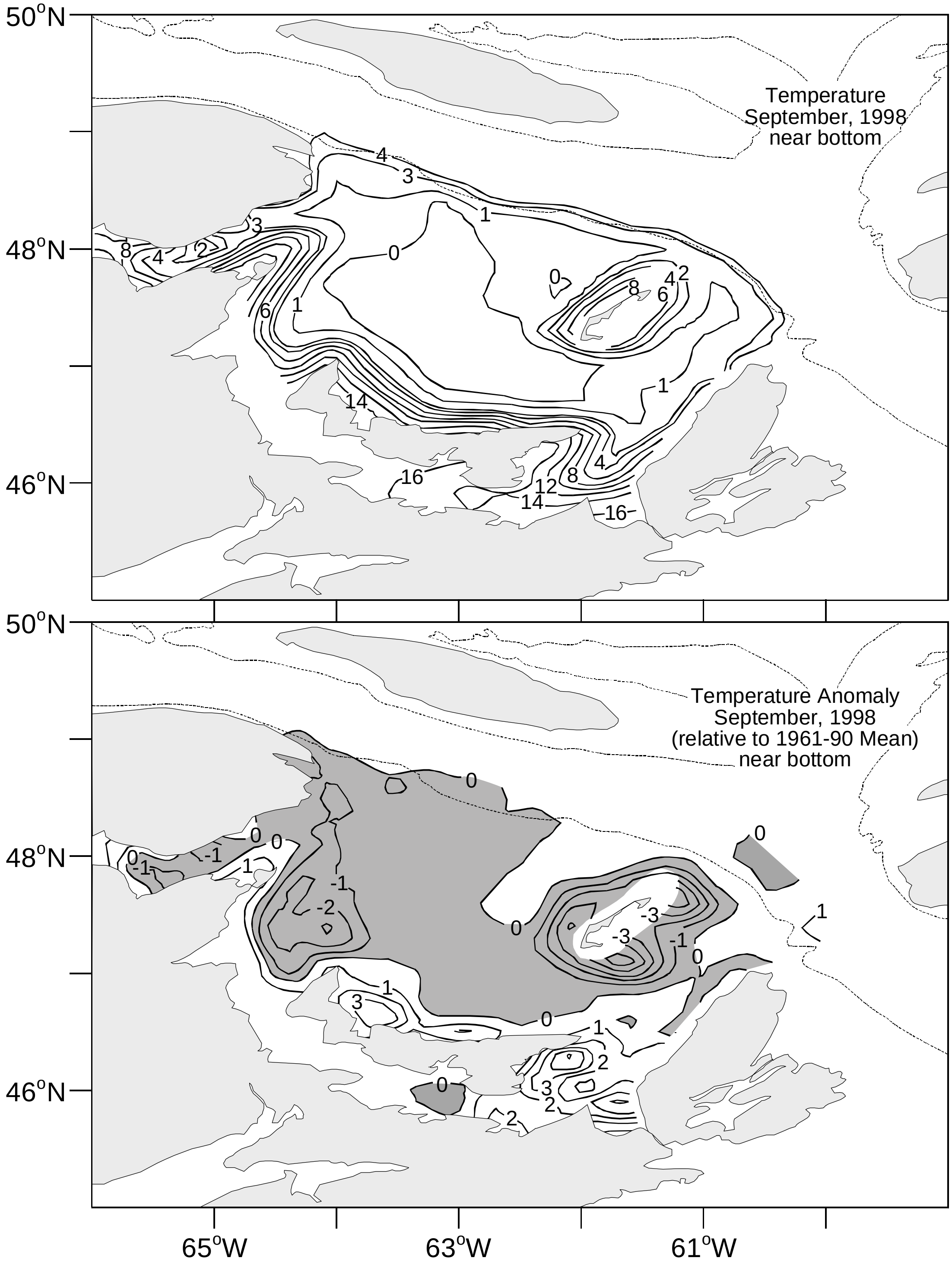


Fig. 31. Temperature (top panel) and temperature anomalies (bottom panel) in the southern Gulf of St. Lawrence in September 1998. Contours are in °C and negative anomalies are shaded.

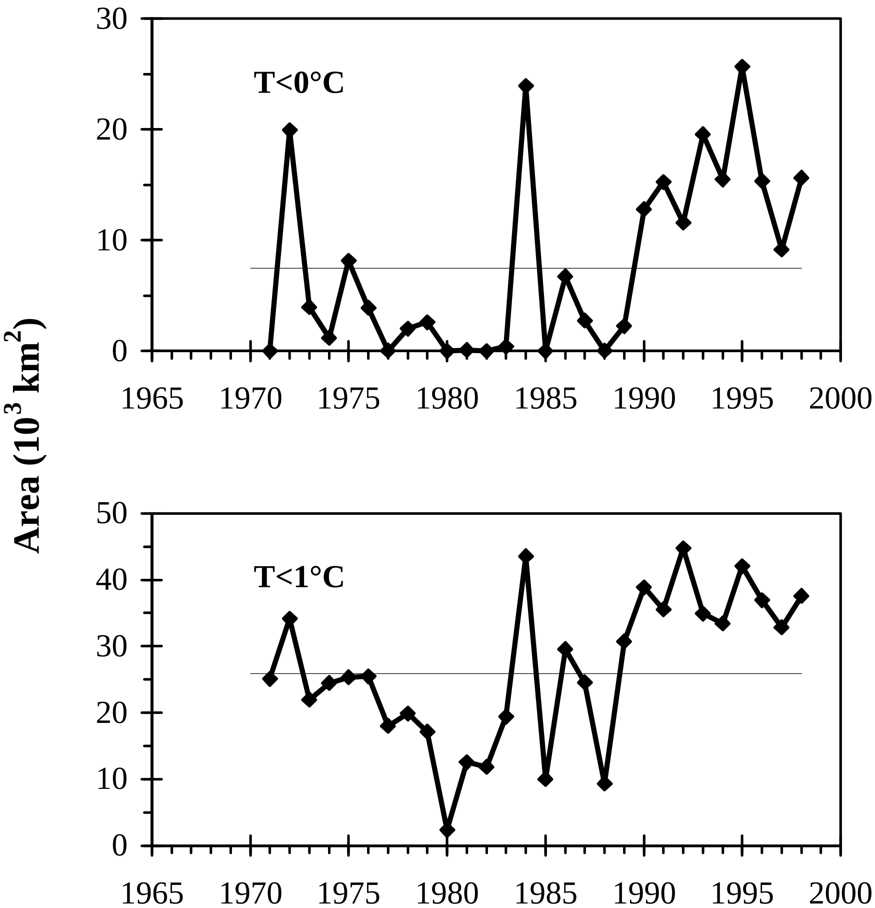


Fig. 32. Area of the Magdalen Shallows with bottom temperatures <0°C (top panel) and <1°C (bottom panel) during September.

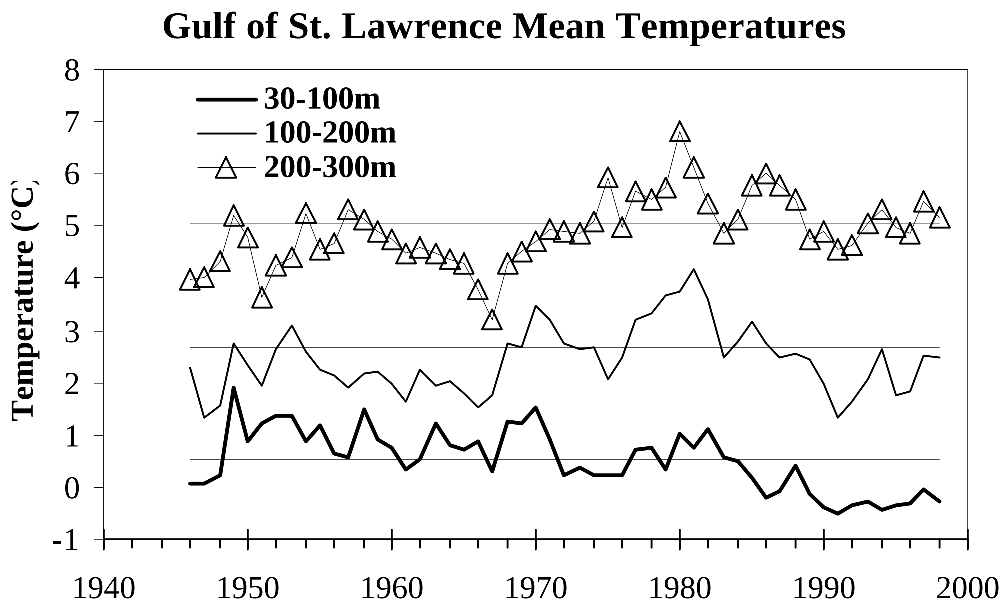


Fig. 33. Areally-weighted mean temperatures in the 30-100 m, 100-200 m, and 200-300 m layers in the Gulf of St. Lawrence during August-September. The horizontal lines indicate the 1961-90 means.

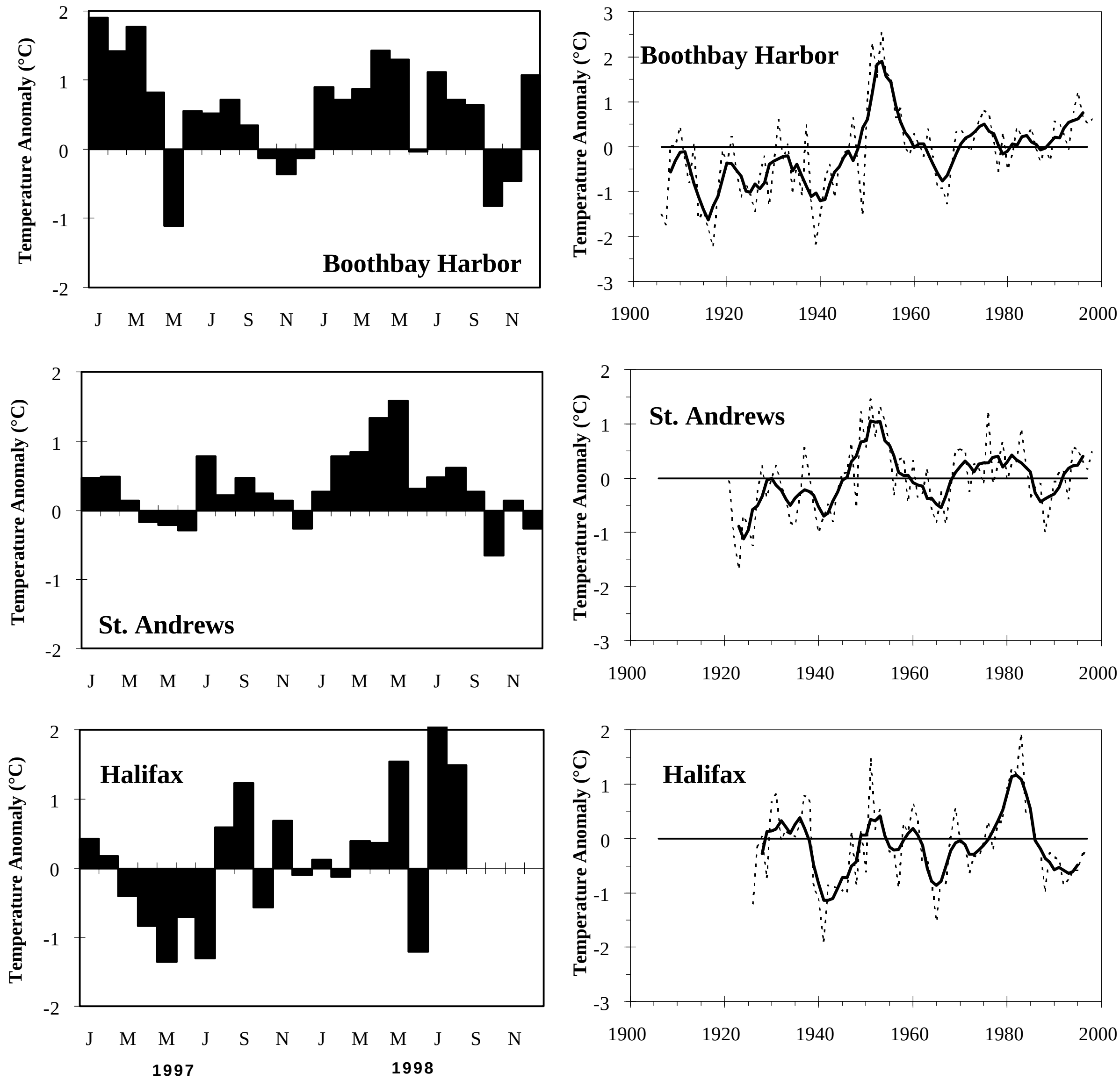


Fig. 34. The monthly sea surface temperature anomalies during 1997 and 1998 (left) and the annual temperature anomalies and their 5-yr running means (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961-90 means.

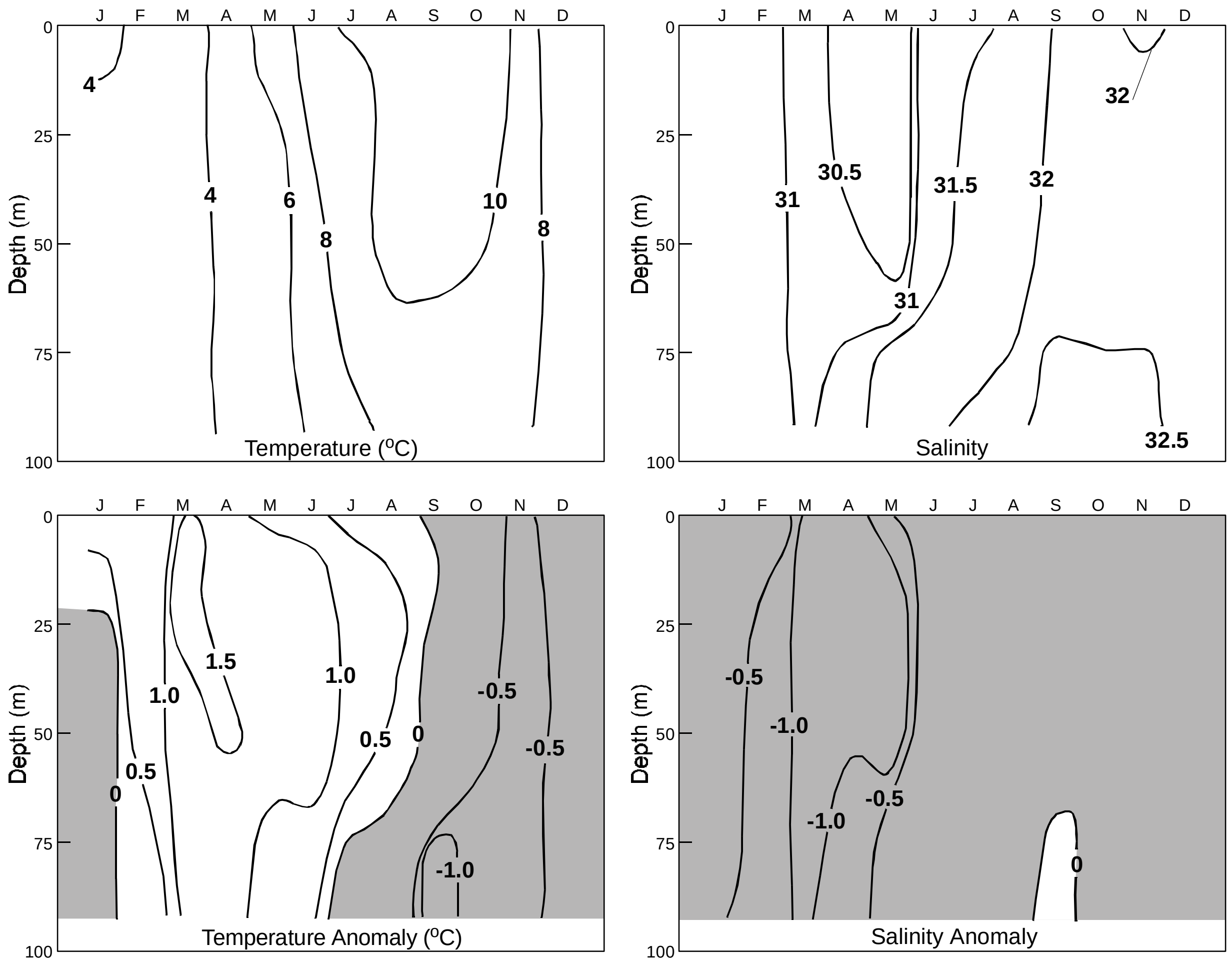


Fig. 35. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1998 relative to the 1961-90 means. Shaded areas are negative anomalies.

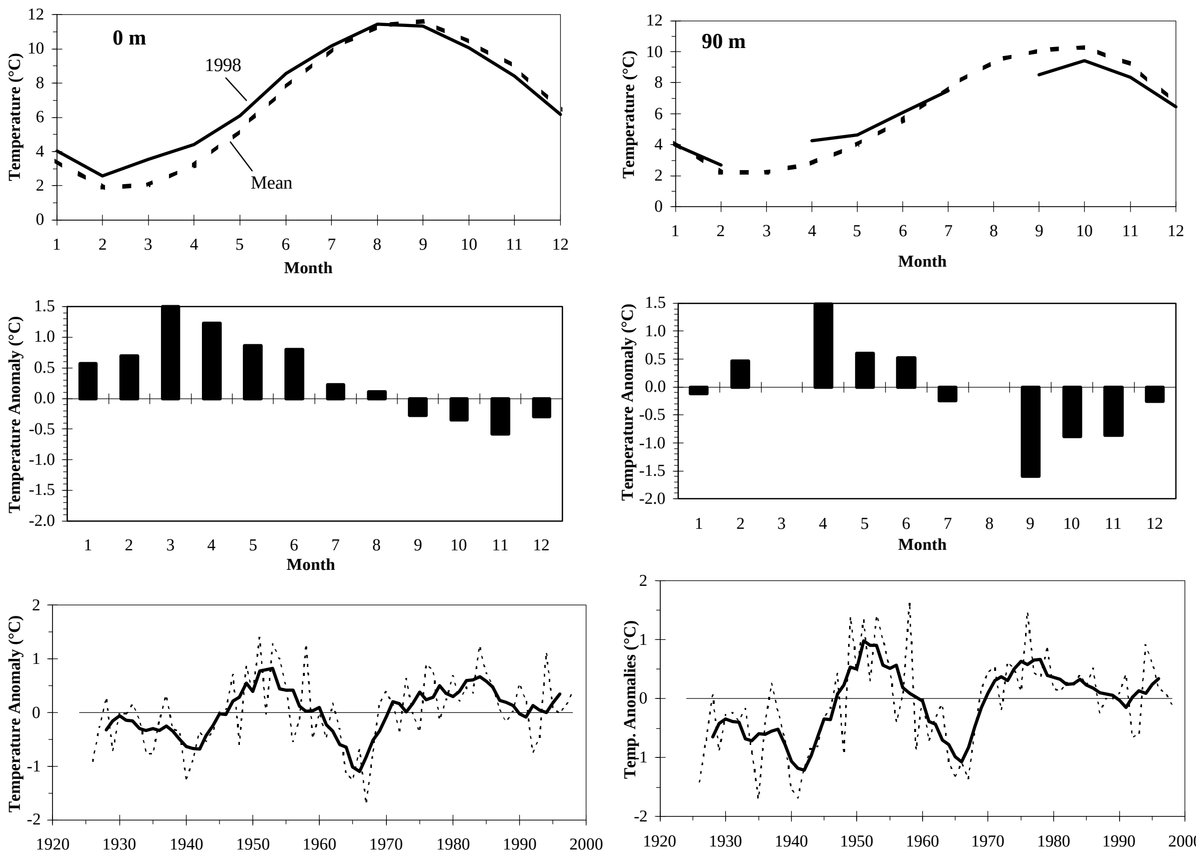


Fig. 36. The monthly mean temperatures for 1998 (solid line) and the long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels the time series of the annual means (dashed line) and 5-yr running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

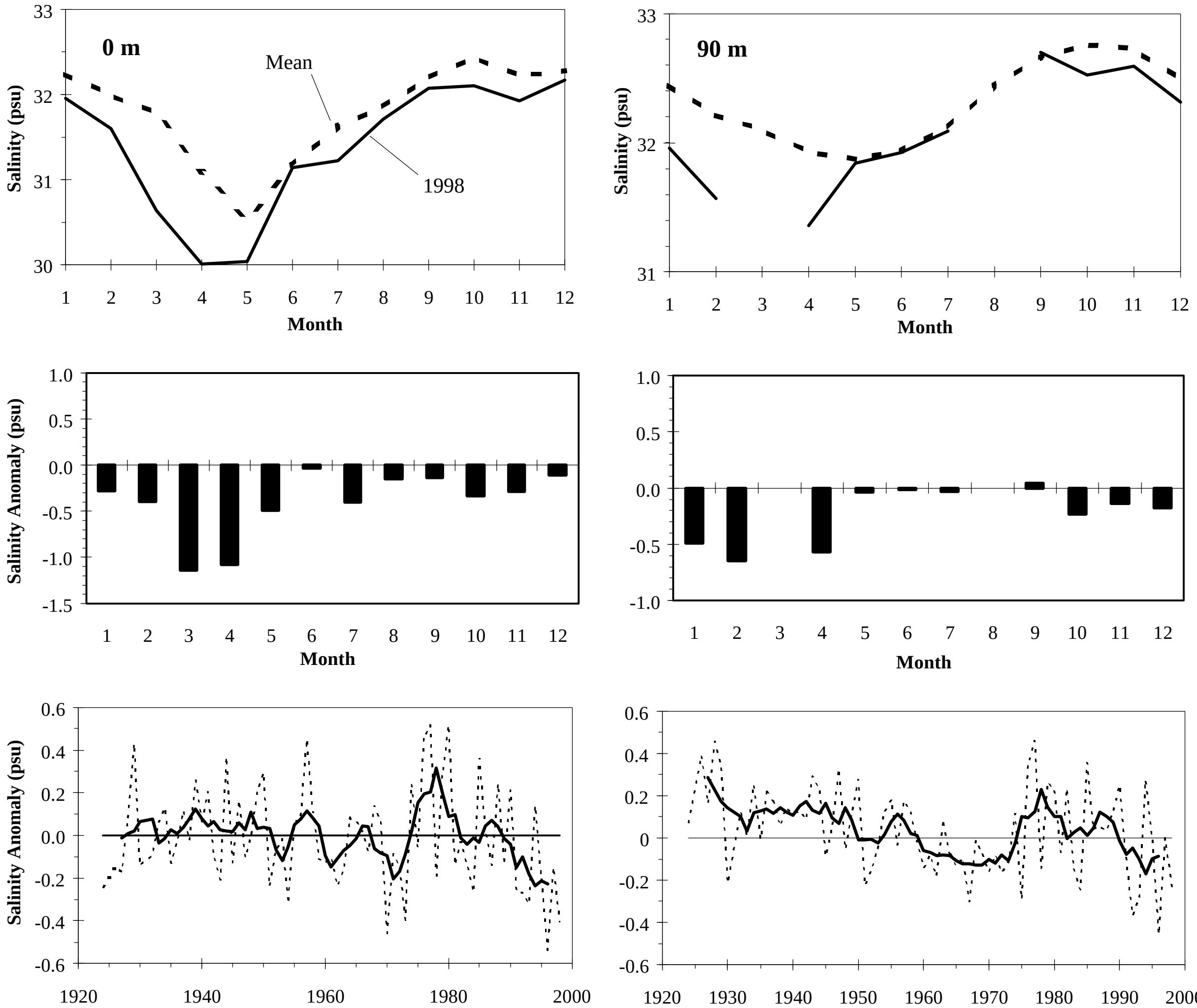


Fig. 37. The monthly mean salinities for 1998 (solid line) and the long-term means (top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels the time series of the annual means (dashed line) and 5-yr running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

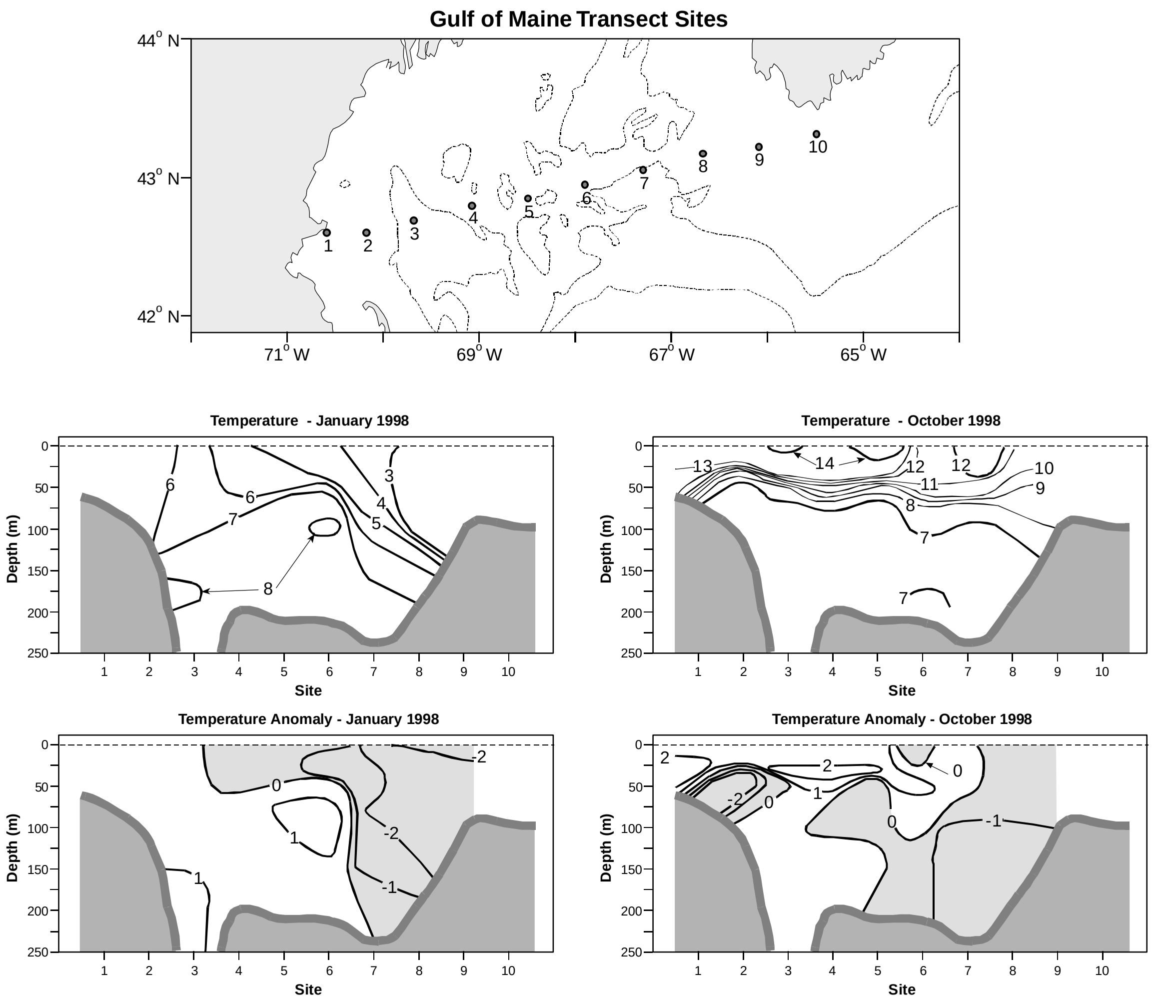


Fig. 38. Temperature (middle panels) and temperature anomalies (bottom panels) in °C during January and October 1998 along a XBT transect across the Gulf of Maine (top panel).

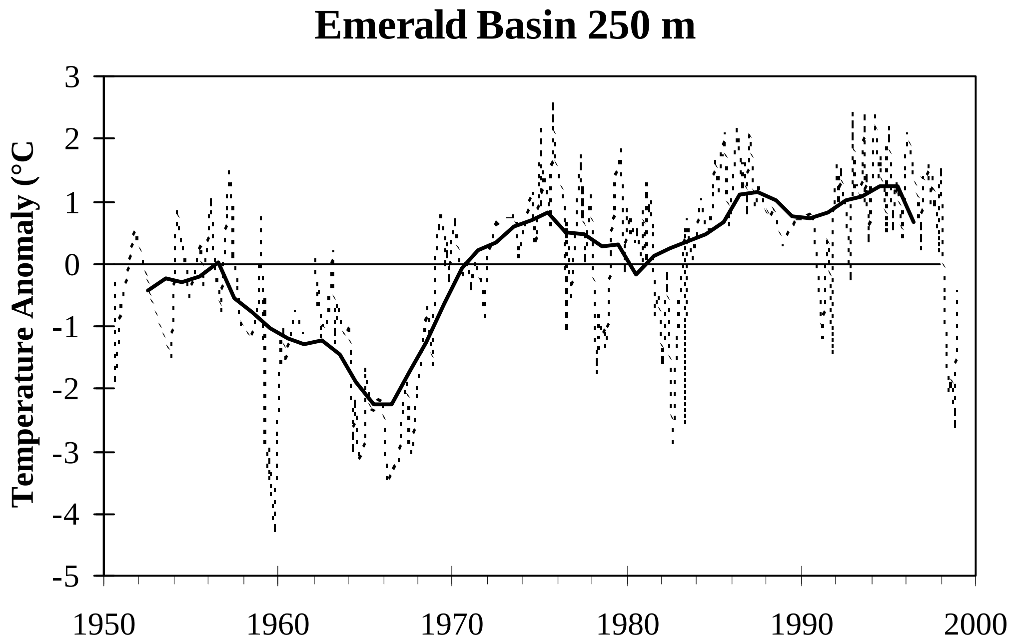
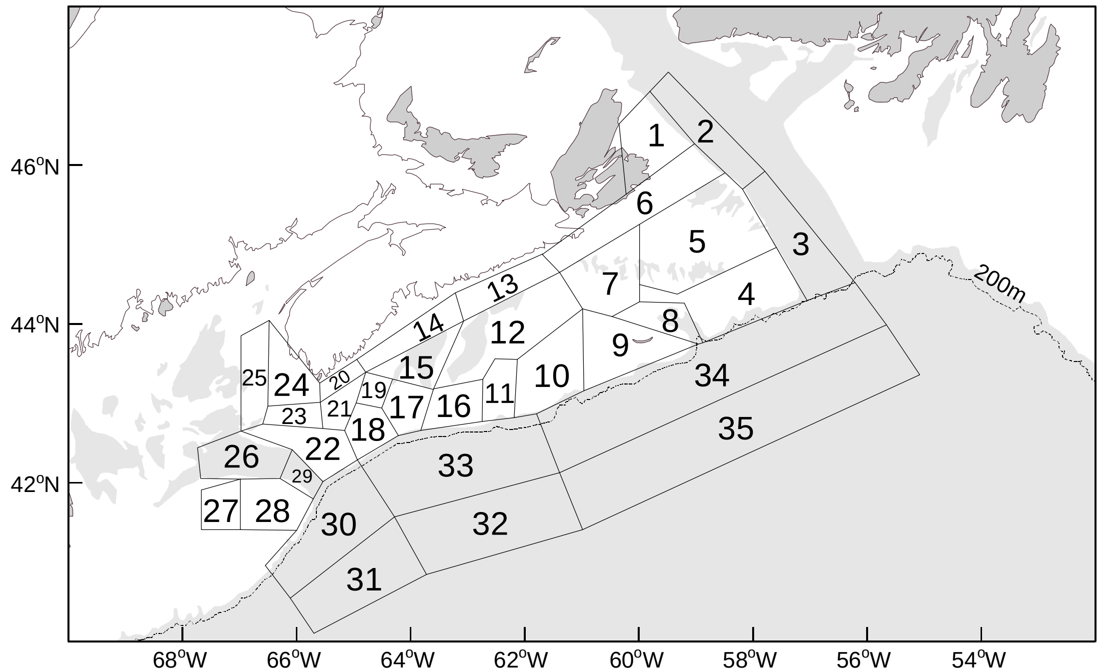
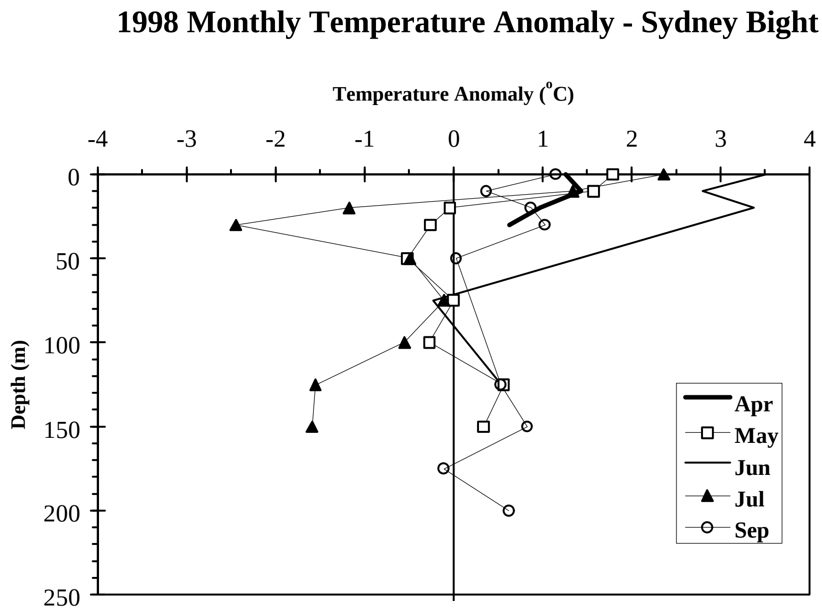


Fig. 39. Temperature anomalies (relative to 1961-90) at 250 m in Emerald Basin.



1. Sydney Bight
2. N. Laurentian Channel
3. S. Laurentian Channel
4. Banquereau
5. Misaine Bank
6. Canso
7. Middle Bank
8. The Gully
9. Sable Island
10. Western Bank
11. Emerald Bank
12. Emerald Basin
13. Eastern Shore
14. South Shore
15. Lahave Basin
16. Saddle
17. Lahave Bank
18. Baccaro Bank
19. Roseway Bank
20. Shelburne
21. Roseway Basin
22. Browns Bank
23. Roseway Channel
24. Lurcher Shoals
25. E. Gulf of Maine
26. Georges Basin
27. Georges Shoal
28. E. Georges Bank
29. N.E. Channel
30. Southern Slope
31. Southern Offshore
32. Central Offshore
33. Central Slope
34. Northern Slope
35. Northern Offshore

Fig. 40. The areas in which monthly means of temperature were estimated by Drinkwater and Trites (1987).



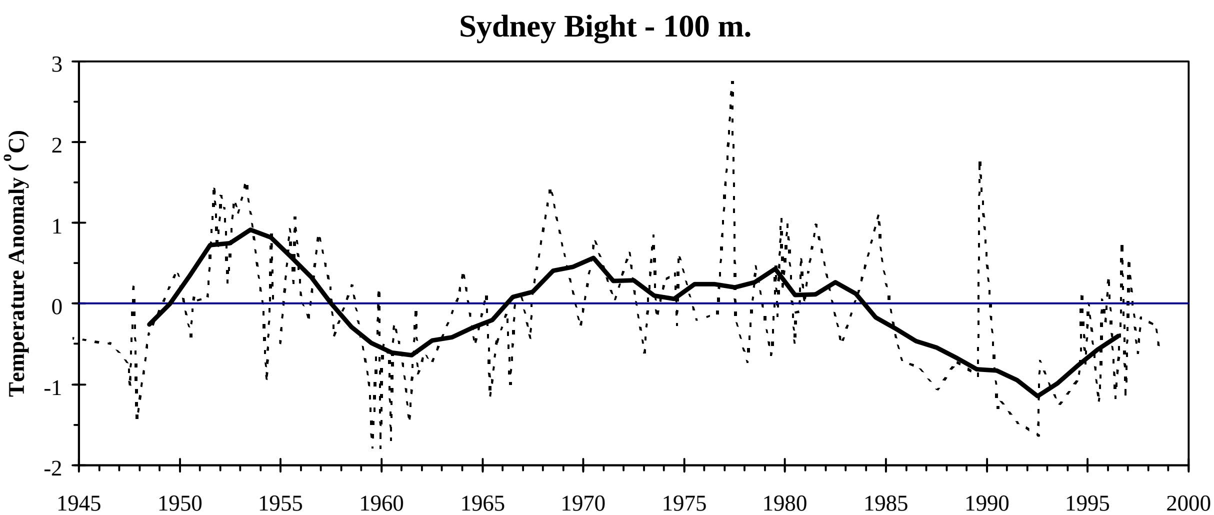


Fig. 41. 1998 monthly temperature anomaly profiles (top panel) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Sydney Bight (area 1-Fig. 40).

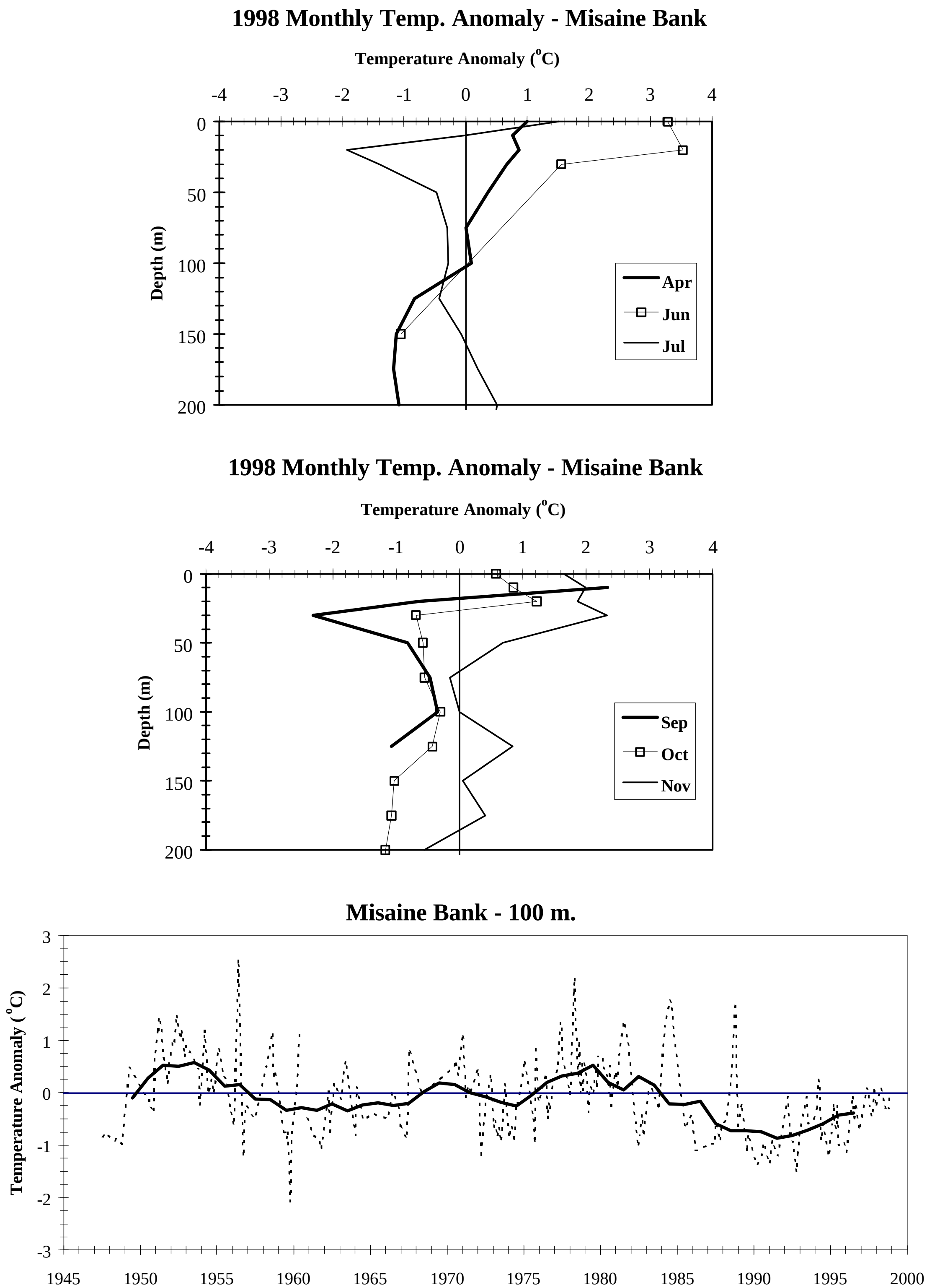


Fig. 42. 1998 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (bottom panel-dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Misaine Bank (area 5-Fig. 40).

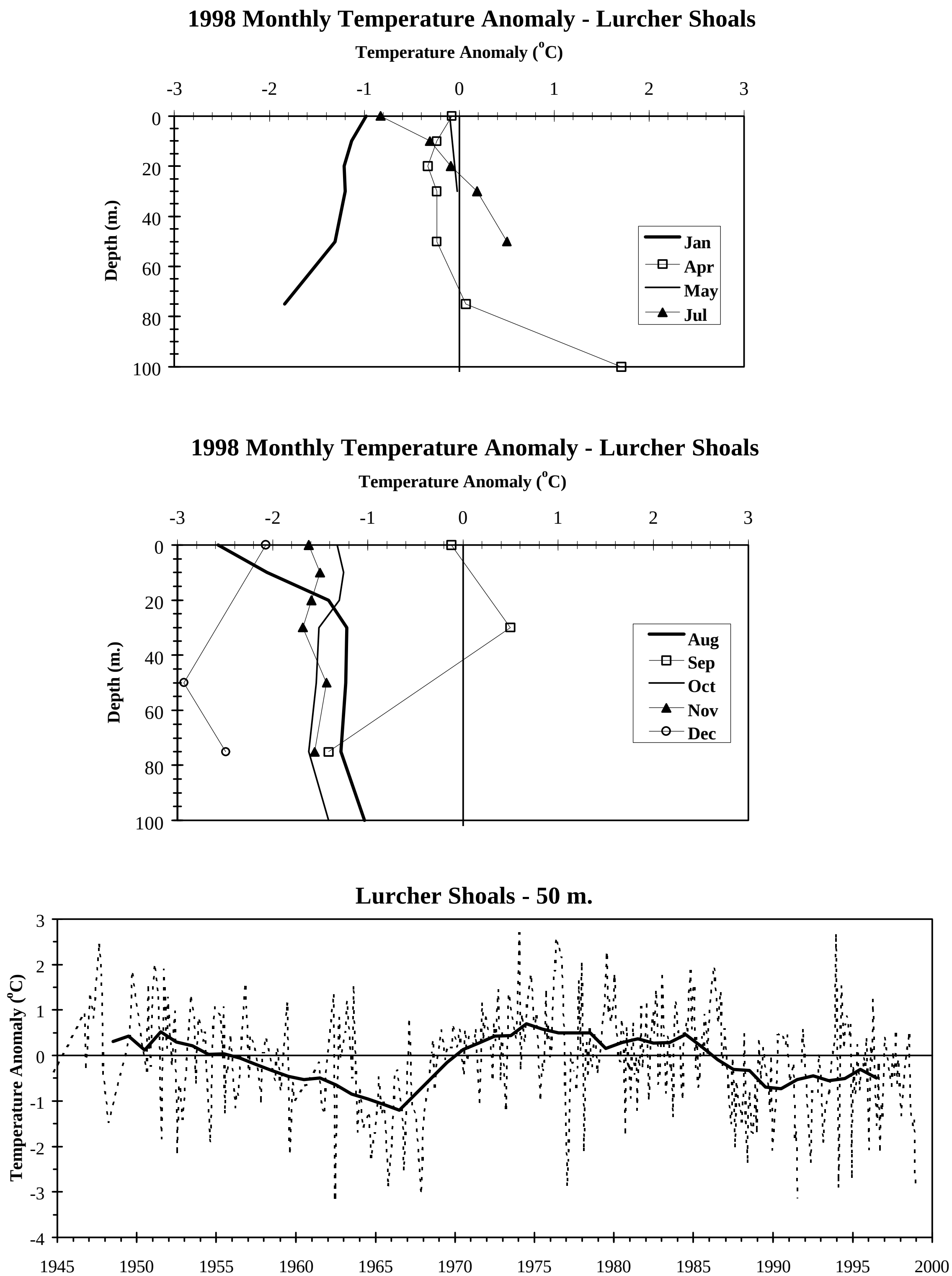


Fig.43. 1998 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 50 m for Lurcher (area 24-Fig. 40).

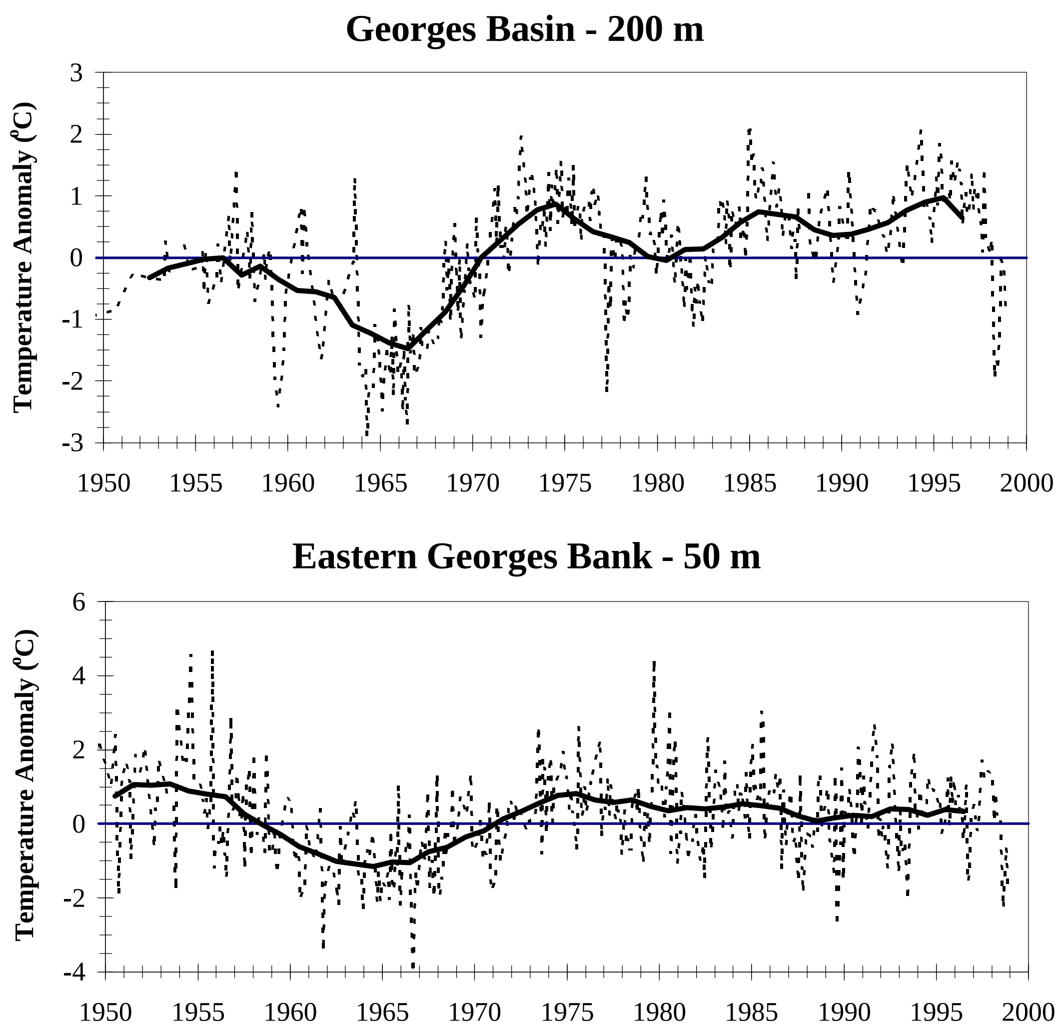


Fig.44. Time series of the monthly means (dashed lines) and the 5-year running means of the annual anomalies at 200 m in Georges Basin (top panel; area 26 in Fig. 40) and eastern Georges Bank (bottom panel; area 28 in Fig. 40).

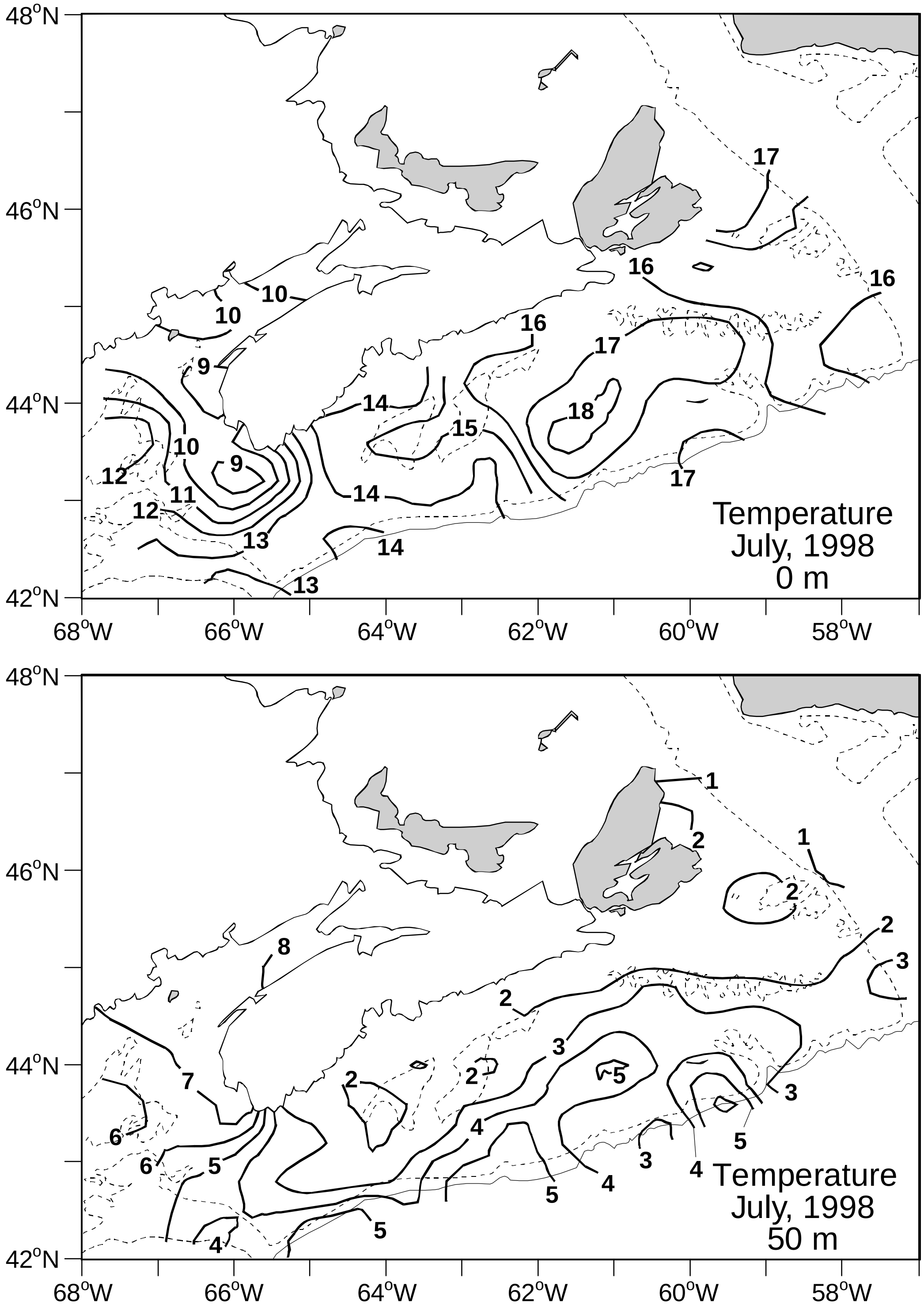


Fig. 45a. Contours of optimally estimated temperatures at the surface (top panel) and 50 m (bottom panel) during the 1998 July groundfish and ITQ surveys.

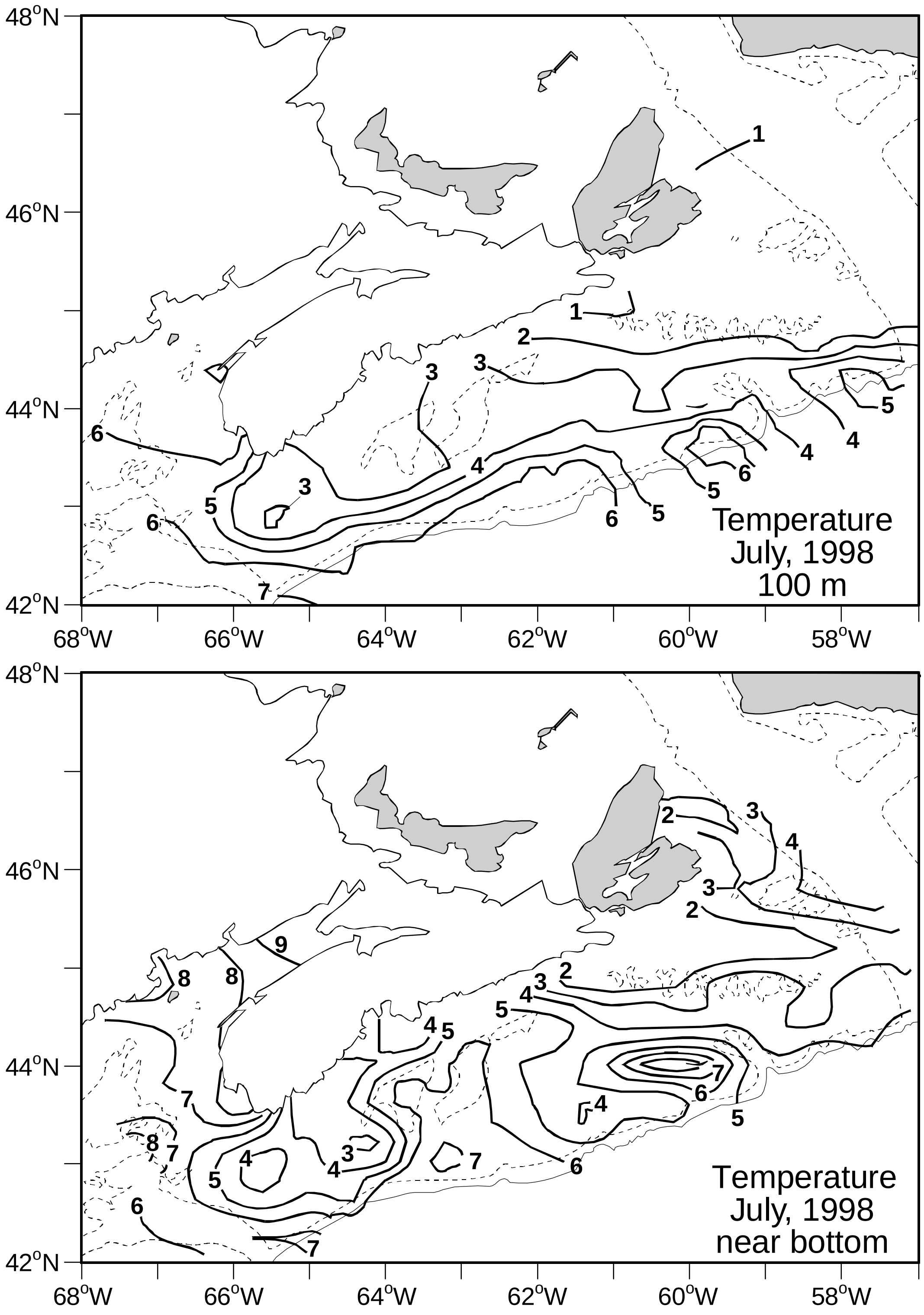


Fig. 45b. Contours of optimally estimated temperatures at 100 m (top panel) and near bottom (bottom panel) during the 1998 July groundfish and ITZ surveys.

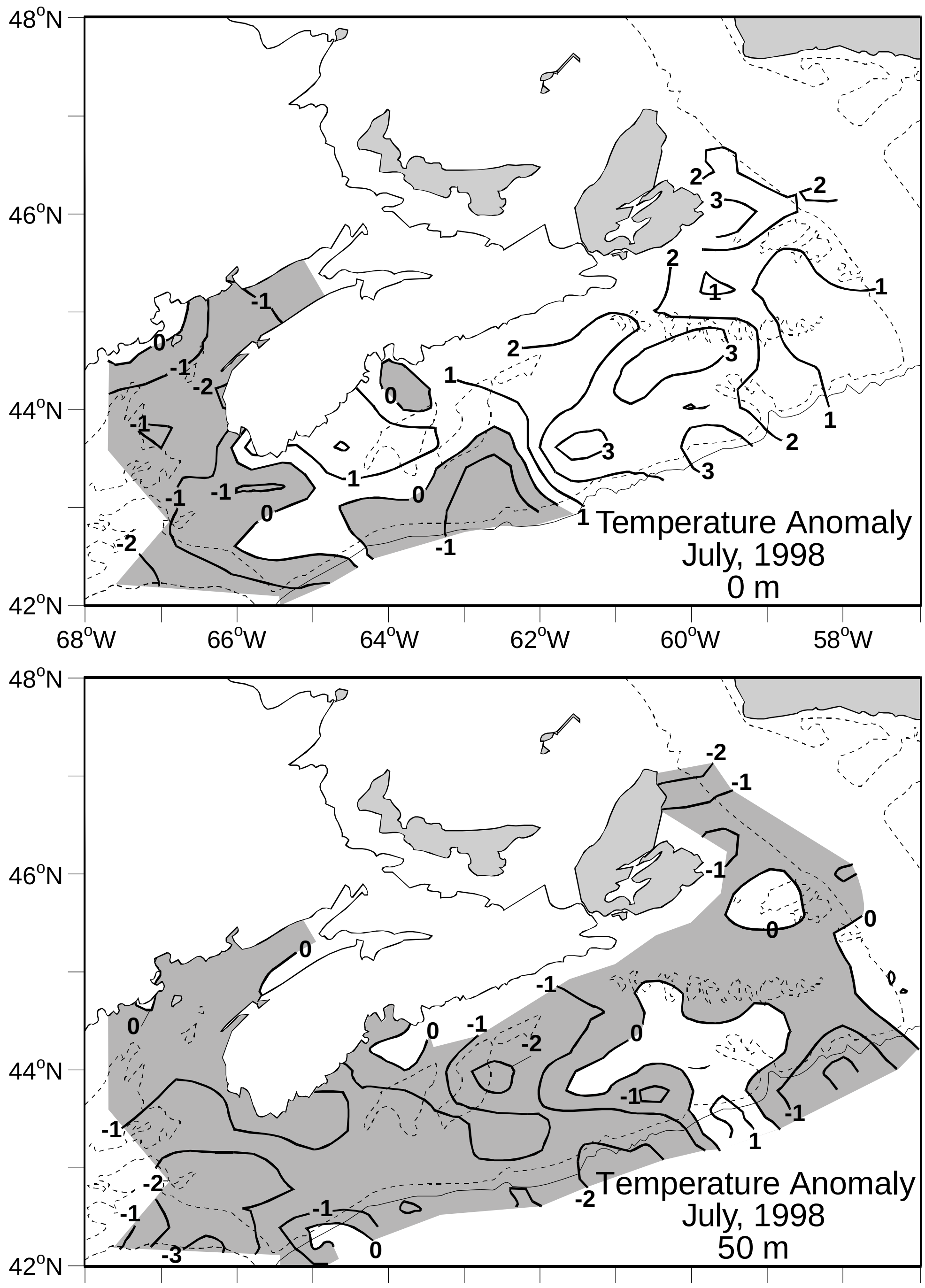


Fig. 46a. Contours of optimally estimated temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 1998 July groundfish and ITQ surveys.

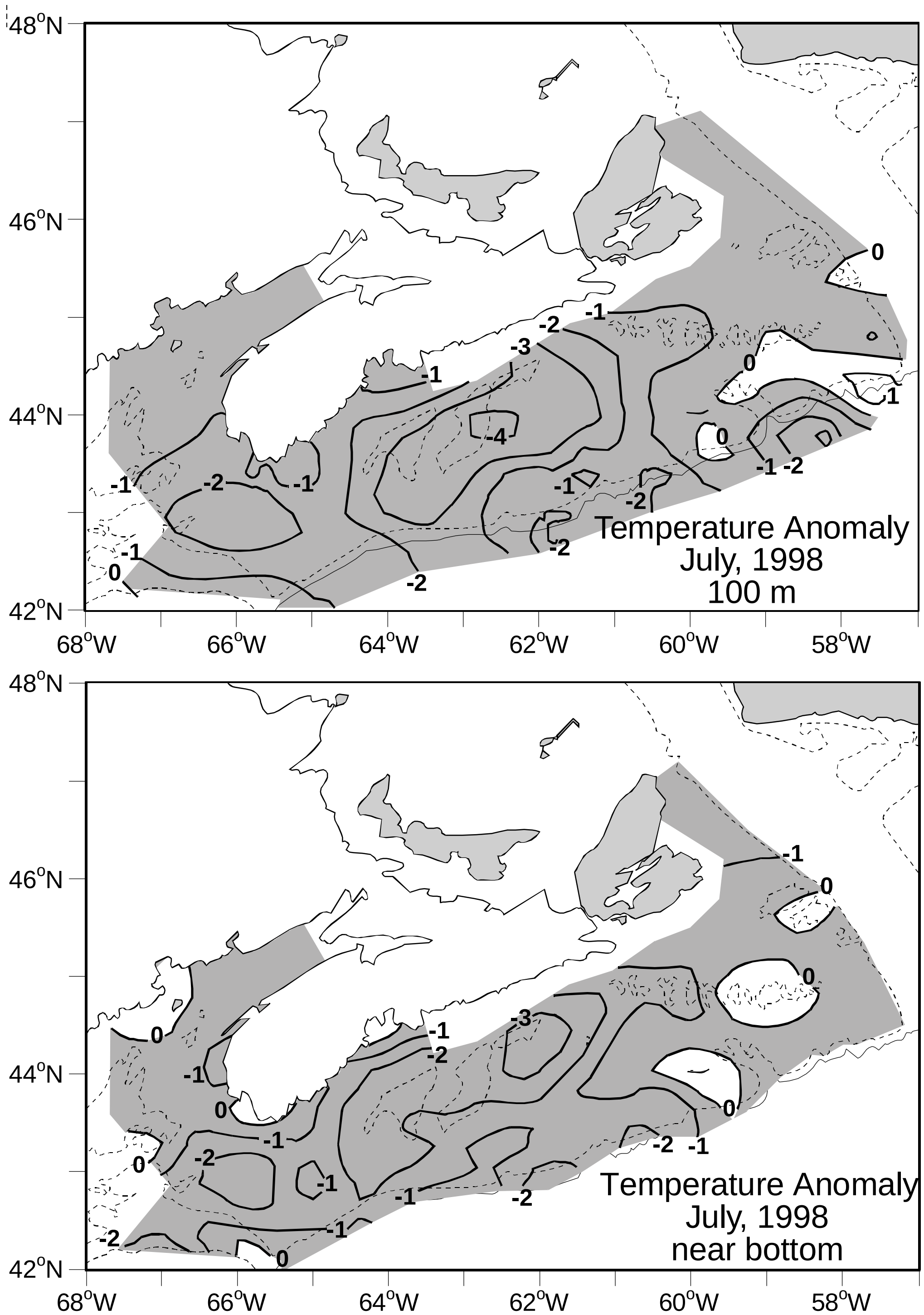


Fig. 46b. Contours of optimally estimated temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 1998 July groundfish and ITQ surveys.

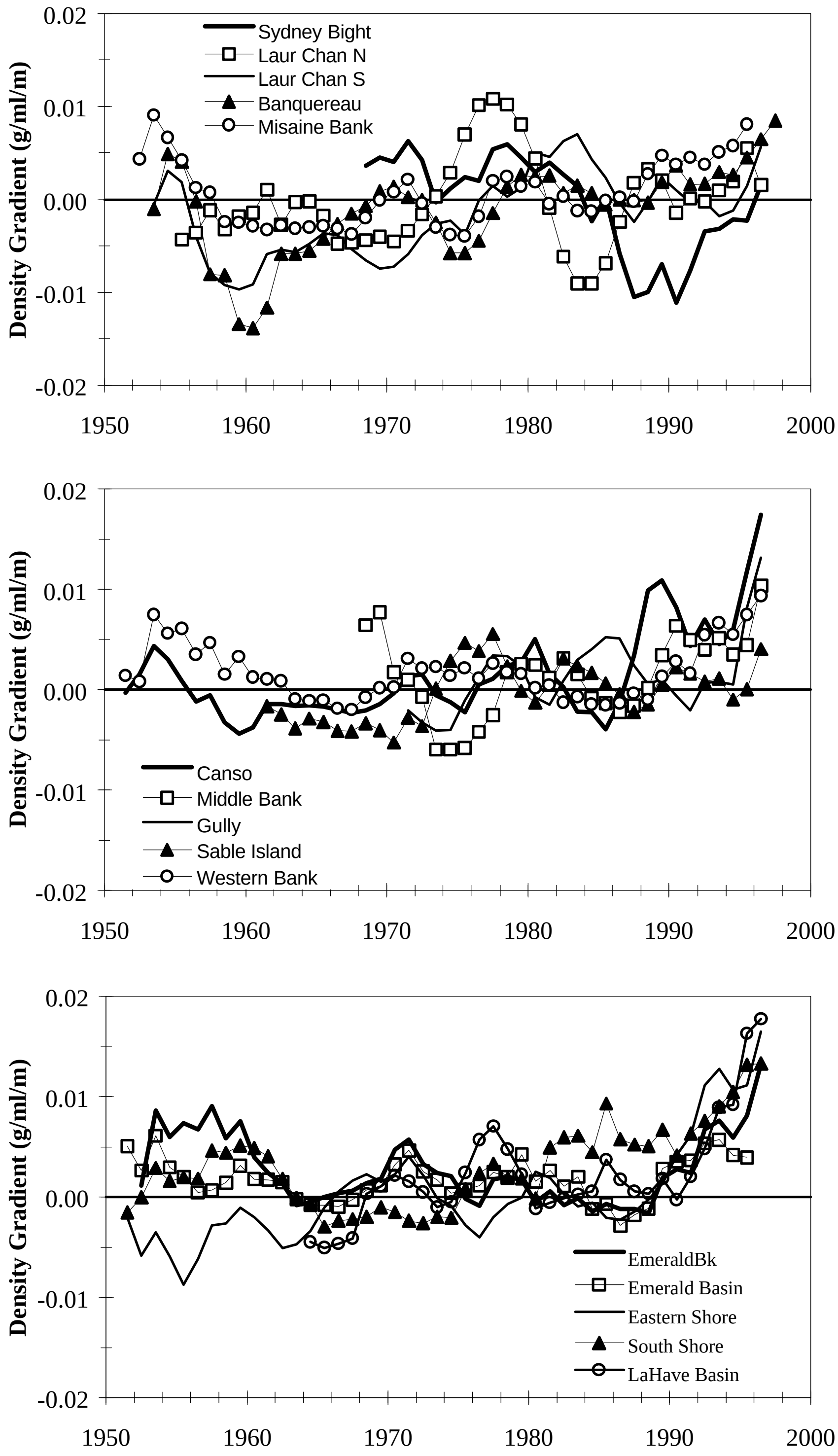


Fig. 47a. Five-year running means of the annual anomalies of the density gradient between the surface and 50 m calculated for the areas 1-15 in Fig. 40.

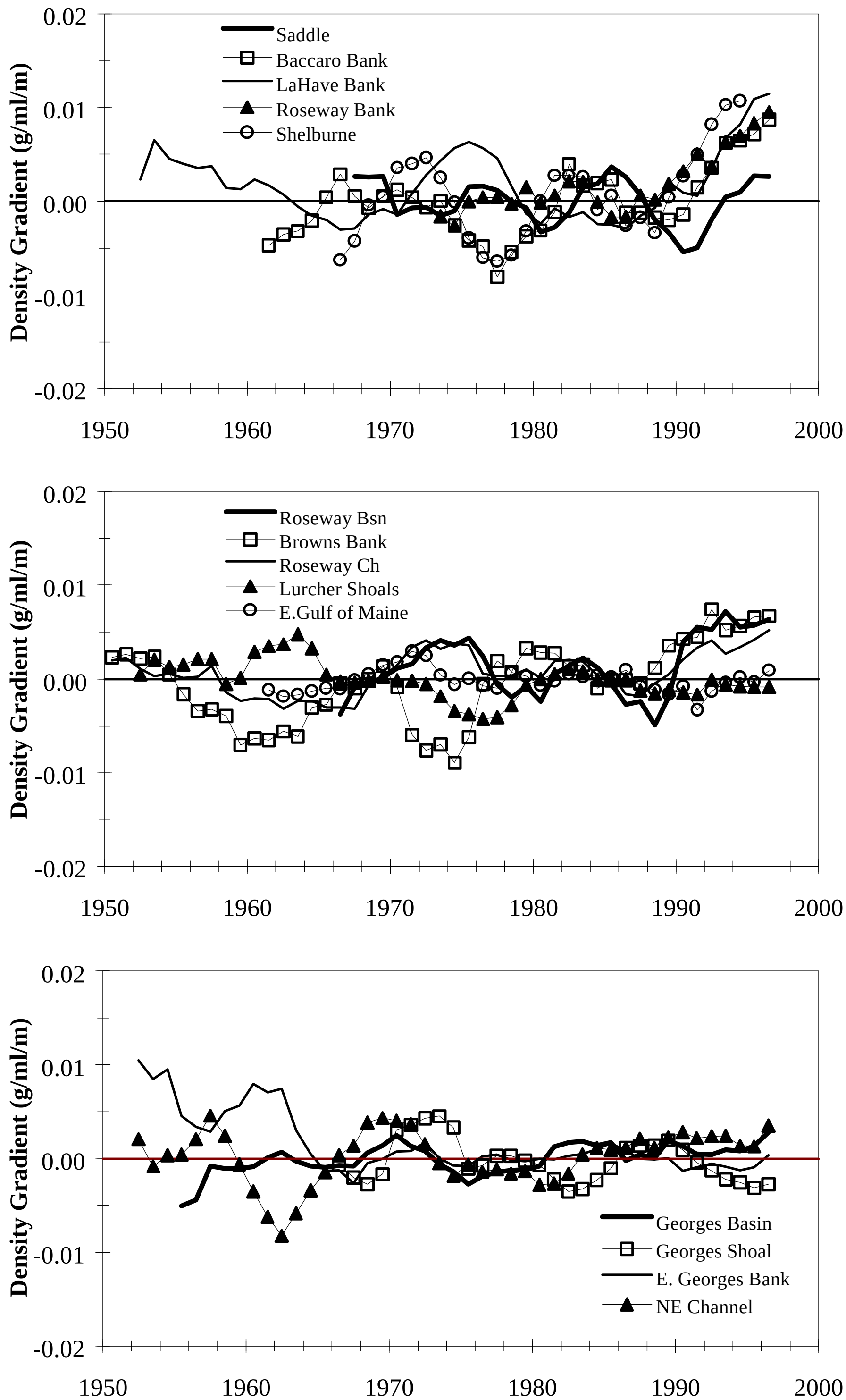


Fig. 47b. Five-year running means of the annual anomalies of the density gradient between the surface and 50 m calculated for the areas 16-29 in Fig. 40.

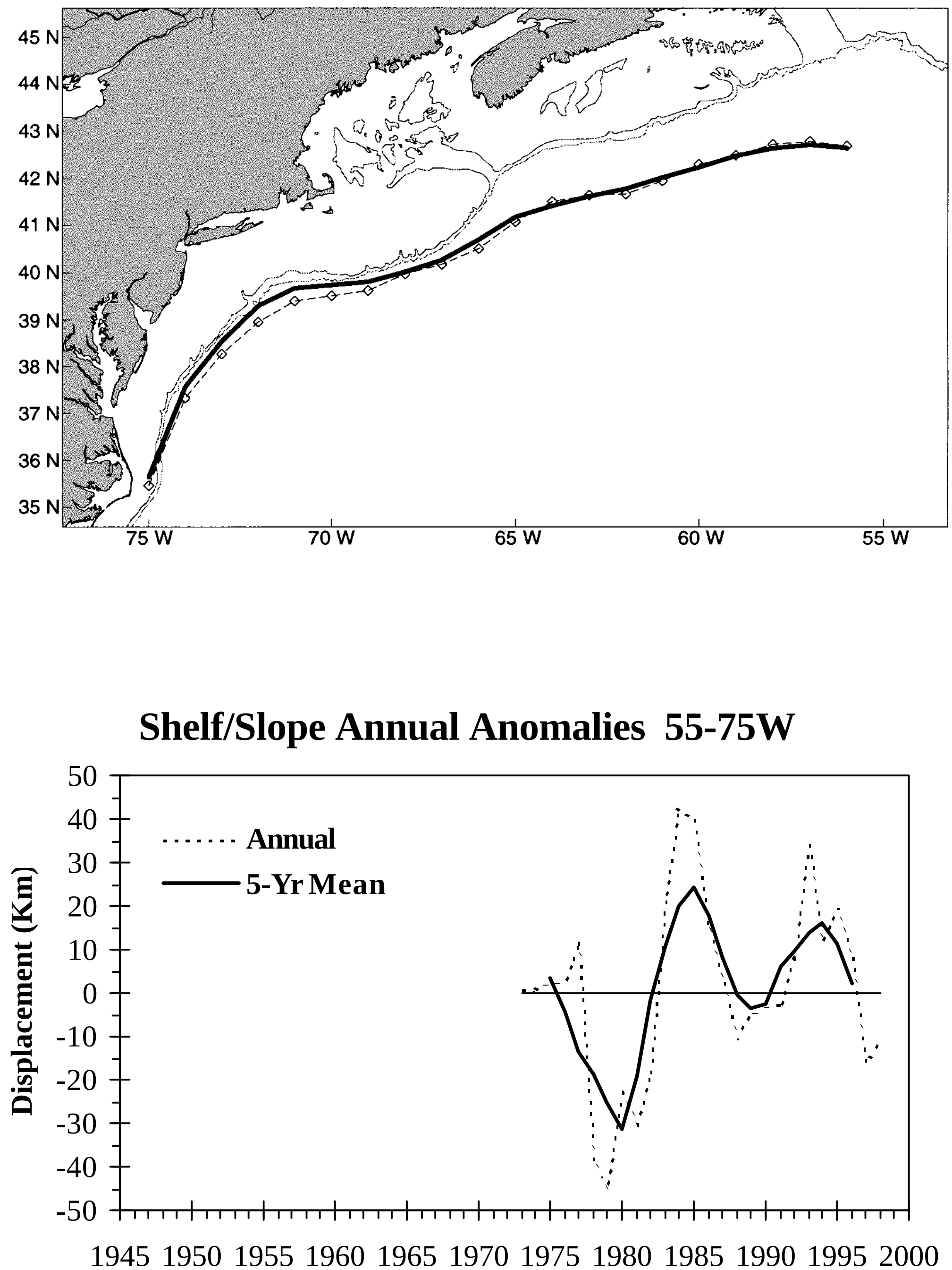
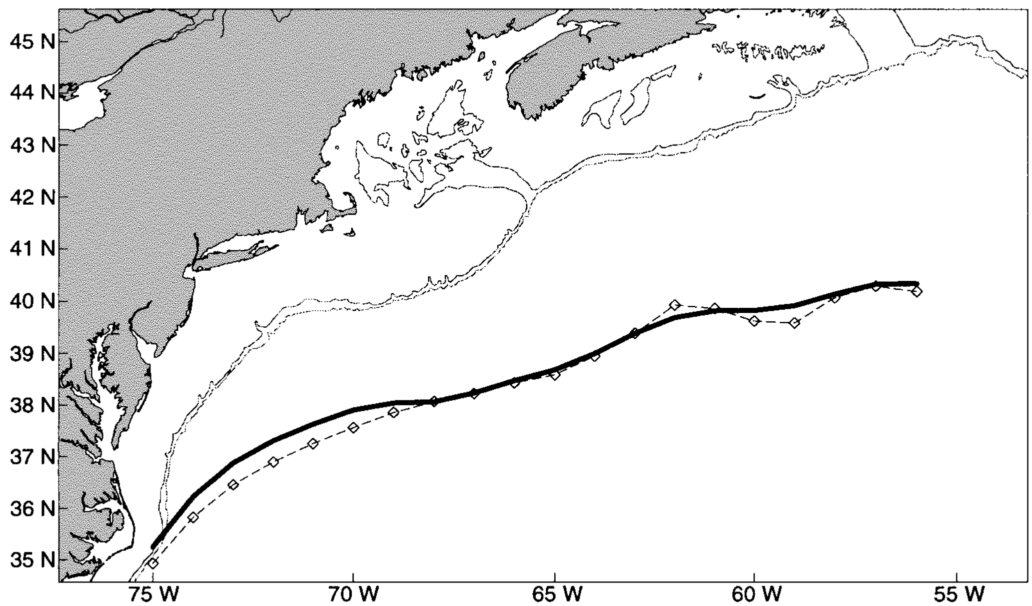


Fig. 48. The 1998 (dashed line) and long-term (1973-97; solid line) mean positions of the shelf/slope front (top panel) and the annual mean anomaly of the averaged (55°-75°W) position of the shelf/slope front (bottom panel).



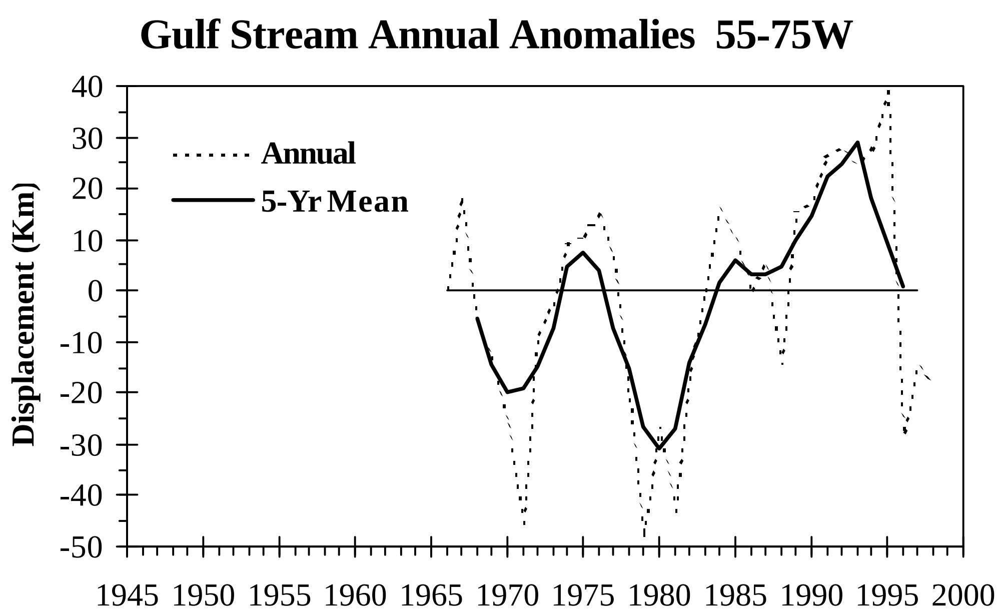


Fig. 49. The 1998 (dashed line) and long-term (1973-97; solid line) mean positions of the northern edge of the Gulf Stream (top panel) and the annual mean anomaly of the averaged (55°-75°W) position of the Gulf Stream front (bottom panel).