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OVERVIEW OF ENVIRONMENTAL CONDITIONS IN THE NORTHWEST ATLANTIC IN 1997

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ABSTRACT

A review of environmental conditions on the continental shelves and adjacent offshore areas off northeastern North America during 1997 is presented. Annual air temperatures throughout most of the northwest Atlantic generally cooled relative to values in 1996 while anomalies were positive over much of the Labrador Sea, and negative along the Atlantic coast from Newfoundland to Cape Hatteras. In the regions north of the Gulf of St. Lawrence, temperatures changed from very warm in the early winter to extremely cold later in the winter. The NAO index in 1997 was below normal for the second consecutive year but above that recorded in 1996. Although the sea ice on the southern Labrador and Newfoundland shelves generally appeared late and left early resulting in a shorter duration than usual, the areal extent in 1997 exceeded that of 1996. The number of icebergs reaching the Grand Banks increased over 1996 by 60% but still remained well below the large numbers reported in the early 1990s. In the Gulf of St. Lawrence, ice generally appeared late but remained longer than expected. Temperatures continued their moderating trend over much of Labrador and northern Newfoundland shelves and the Grand Banks. This was evident from the near bottom temperatures and throughout much of water column throughout much of the year from Hamilton Bank in the north to the Grand Banks. An exception was over the shallow portions of the Grand Bank, where temperatures were colder than normal during late spring and early summer. The CIL volume was near the lowest on record, which began in 1980. In contrast to the generally warm conditions throughout much of the Newfoundland region, cold waters continue to occupy St. Pierre Bank area and were also observed in the deep waters on Flemish Cap. In both locations these cold conditions 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 continued to remain at below normal

temperatures in 1997 but have been moderating. In the deep waters of Cabot Strait (200-300 m), temperatures remained slightly above the long-term mean. On the Scotian Shelf and Gulf of Maine, conditions remained similar to recent years with colder-than-normal temperatures in the northeastern Scotian Shelf and at intermediate depths on the southwestern Scotian Shelf. These cold waters have lasted since the mid-1980s. In the deep basins, such as Emerald and Georges, the waters continued to display above-normal temperatures. A significant change in the offshore slope waters occurred in late 1997 as cold waters believed to be of Labrador origin flooded the outer edge of the Scotian Shelf. Both the slope/shelf front and the Gulf Stream were further seaward than normal in 1997.

Introduction

This paper examines the atmospheric, sea ice and hydrographic conditions in the Northwest Atlantic during 1997 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 the long-term means. In order to detect climate trends we have removed the seasonal cycle by expressing conditions as monthly deviations from their long-term means, called anomalies. Where possible, the long-term means have been averaged over a standardized 30-yr base period (1961-90) in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council.

Meteorological Observations

Air Temperatures

The German Weather Service publishes monthly air temperature anomalies relative to the 1961-90 means for the North Atlantic Ocean in their publication *Die Grosswetterlagen Europas*. During January, positive anomalies covered most of our area of interest with values reaching 4°C in Baffin Bay off West Greenland (Fig. 1). Air temperature anomalies on the northern Labrador Shelf exceeded 1°C. Rapid cooling during February resulted in very cold air temperatures with anomalies over the Labrador Sea exceeding -3°C. The air temperatures in the Gulf of St. Lawrence and the Newfoundland area were also below normal but of lower magnitude than over the Labrador Sea. South of Nova Scotia air temperature anomalies were above normal by as much as 3-4°C around the Cape Cod to New York region. Colder-than-normal conditions continued to cover most of the region during the late winter and spring. In March temperatures over the Gulf of St. Lawrence were 2-4°C below normal. In June, the Labrador Sea was covered by air whose temperatures were above normal while from the Gulf of St. Lawrence south, air temperatures were below normal by up to 2°C. During the summer months, the air temperature anomalies varied about normal both spatially and from month to month. In September, however, warm air pervaded the region. Over the Labrador Sea, temperatures generally remained above their long-term means through to the end of the year. From Newfoundland south, however, air temperatures were colder-than-normal during October and November but warmed to near normal and above by December.

Monthly air temperature anomalies for 1996 and 1997 relative to their 1961-90 means were calculated for Godthaab in Greenland, Iqaluit on Baffin Island, Cartwright on the Labrador coast, St. John's in Newfoundland, Magdalen Islands in the Gulf of St. Lawrence, Sable Island on the Scotian Shelf, Boston in the Gulf of Maine and Cape Hatteras on the eastern coast of the United States (see Fig. 2 for locations). Data from the Canadian air temperature sites were available from the *Canadian Climate Summaries* published by the Canadian Atmospheric Environment Service and from non-Canadian locations from the NOAA publication *Monthly Climatic Data for the World*. The warm air temperatures in the northern sites during January noted above were a continuation of conditions established in December 1996 (Fig. 3). This was followed by a rapid decline in temperature anomalies in February. Temperatures remained colder-than-normal at most of the northern sites for another month or two before returning to above normal values by the spring. From then until autumn, air temperature anomalies from Cartwright north were predominately above normal, while those from Sable Island south were below normal. The cold conditions at the latter stations followed a winter, which, in contrast to the northern regions, was warmer-than-normal. At St. John's and the Magdalen Islands air temperatures from the spring to the end of the year showed no strong trends, fluctuating about the long-term normal.

The annual mean air temperatures for 1997 were above normal at the northern most sites of Iqaluit (anomaly of 1.0°C) and Godthaab (0.2°C). At Cartwright and the Madgalen Islands they were normal while at St. John's and the remaining stations the annual anomalies were negative. The maximum negative anomaly was at St. John's (-0.6°C), followed by Sable Island (-0.4°C) and then Boston and Cape Hatteras (-0.3°C).

The time series of annual temperature anomalies for the eight sites are shown in Fig. 4. The 1997 anomalies generally declined from 1996 values except at Boston and Cape Hatteras were they were similar to last year's value (Fig. 4). Note that the interannual variability since 1960 at Godthaab, Iqaluit, Cartwright, and, to a lesser extent, St. John's have been dominated by the large amplitude fluctuations with minima in the early 1970s, early to mid-1980s and the early 1990s, suggesting a quasi-decadal period. Indeed, the recent rise in temperature at these sites is consistent with a continuation of this near decadal pattern. These oscillations coupled with a general downward trend has resulted in temperature anomalies since 1970 being predominantly below normal. Temperature anomalies at the Magdalen Islands and Sable Island have been of much lower amplitude than those to the north and show no signs of a general downward trend since 1970. They do, however, contain minima in the early 1970s (both sites), the mid-1980s (Sable Island only) and in the 1990s (Magdalen Islands only). At Boston and Cape Hatteras, there has also been decadal variability in air temperatures but they have generally been out of phase with the temperature fluctuations in the Labrador Sea area. Thus, for example, when the temperatures were very cold in Labrador during the early 1990s, they were relatively warm along the US seaboard (Fig. 4).

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale pressure patterns and associated atmospheric circulation. Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas*. The long-term seasonal means are dominated by the Icelandic Low centred between Greenland and Iceland and the Bermuda-Azores High centred between Florida and northern Africa (Fig. 5). Winds rotate counterclockwise around the Low and clockwise around the High. The strength of the wind is larger where the pressure contours are closer together (pressure gradients are steeper). 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 1997, relative to the 1961-90 means, are shown in Fig. 6. Winter includes December 1996 to February 1997, spring is March to May, summer is June to August and autumn is September to November.

In the winter of 1996/97, a positive air pressure anomaly developed over the western North Atlantic with a maximum (exceeding 3 mb) centred south of Newfoundland. A ridge of high pressure anomalies extended from there to the northeast covering eastern Greenland. This ridge separated two negative anomaly areas, one centred over Foxe Basin in eastern Canada (-2.6 mb) and the other near the Azores (near -3 mb). This pressure pattern suggests stronger than normal offshore winds off Labrador and northern Newfoundland but anomalous southerly winds along the Middle Atlantic Bight to the Gulf of St. Lawrence. Western Greenland would have experienced greater amounts of southwesterly winds. In the spring of 1997, a negative anomaly covered most of the northern North Atlantic with the center (-4.9 mb) east of Newfoundland. Further to the east, positive anomalies developed with two separate centers, one over France (5.6 mb) and the other over northern Greenland (3.1 mb). A second negative anomaly pressure system formed (minimum -3.3 mb) off northern Norway. In contrast to the winter, the winds off Labrador and northern Newfoundland would have been principally onshore, from the northwest in the Gulf of St. Lawrence, and offshore over the Scotian Shelf to the Middle Atlantic Bight. Both the winter and spring pressure patterns show more meridional flow than usual. In the summer, the springtime negative pressure anomalies over the North Atlantic weakened but extended further eastward to cover the entire ocean from North America to Europe. The largest negative anomaly (near -3 mb) was recorded over southwestern Ireland. To the north and south of this band of below-normal pressures were positive anomalies, with the maximum values being located on the eastern side of the Atlantic. Two centers of positive anomalies were observed in the north, one near Norway and the other over northern Greenland. In the south the center of positive pressure anomaly was situated just off West Africa. This pressure pattern resulted in a predominance of easterly to northeasterly winds over eastern North America. The autumn air pressure pattern is similar to that of summer but more intense. The negative pressure anomaly extended latitudinally both north and south with the center located to the southeast of Newfoundland (-5.3 mb). The center of the positive anomaly remained over northern Greenland (7.7 mb). This would cause anomalous eastward and southeastward winds on the Labrador coast and over the Labrador Sea and northeastward between Newfoundland and the Middle Atlantic Bight.

NAO Index

The North Atlantic Oscillation (NAO) Index is the difference in winter (December, January and February) sea level 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 also 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. The NAO anomalies were calculated by subtracting the 1961-90 mean.

In 1997, the NAO anomaly was below normal for the second consecutive but up from the minima observed in 1996 (Fig. 7). These two years contrast with the very high NAO anomalies that had persisted since the late 1980s and indicates the possibility of a significant shift in the large-scale atmosphere circulation. However, this decline also fits the pattern of near decadal variability that has persisted since the 1960s, and as such was expected, although its amplitude was greater than anticipated.

Sea Ice Observations

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The long-term medians, 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).

Newfoundland and Labrador

At the end of 1996, sea ice lay off the southern Labrador coast in the vicinity of Hamilton Inlet resulting in an areal coverage that was slightly less than the long-term median for that time of the year (Fig. 8a). This was in part due to above normal air temperatures during the second half of December that slowed ice formation. By the beginning of January, the ice extent along the south Labrador coast was approximately two weeks later than normal. By mid January, the ice had extended south to Belle Isle Strait but remained much closer inshore than normal. This resulted in much less ice covered than usual, due to the continuing relatively warm air temperatures, especially off southern Labrador. By the first of February, ice coverage was near its median value, a response to the presence of very cold temperatures during the second half of January. Continuing cold air temperatures and moderate to strong northwesterly winds during February pushed the ice pack southward and offshore, increasing the areal coverage to between median and maximum values by the beginning of March. Cold, windy conditions prevailed throughout March. These left the sea ice again intermediate between median and maximum extent by 1 April (Fig. 8b). Ice off northern Newfoundland was positioned offshore keeping many of the harbours and coast communities ice clear. By 1 May, strong northeasterly winds over southern Labrador and northern Newfoundland packed the ice inshore from St. John's north. Retreat of the ice proceeded during May resulting in ice coverage near the long-term median by 1 June. There was, however, an isolated patch of ice off northern Newfoundland between Notre Dame and White bays at this time. Ice remained off the mouth of Hamilton Inlet through June and was still there on 1 July. By 10 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°N; I. Peterson, personal communication, Bedford Institute) show the peak extent during 1997 was greater than in 1996 and was near, but slightly below, that of the early 1990s (Fig. 9). The average area during the period of general advancement (January to March) and retreat (April to June) also increased slightly compared to 1996. These values indicate that the areal coverage on average, however, was less than the early 1990s and was extremely low during the time of retreat. The monthly means plotted separately again show ice coverage in 1997 was typically higher than in 1996 but less than the early 1990s (Fig. 10). These data indicate 1997 was an average to lighter-than-average ice year on the Labrador and Newfoundland shelves. Note that during January through April there has been a general increase in the area of ice over the past 30 y but no such trend exists during May through July. Variations in ice volume tend to mirror the trends in ice area, based upon correlative studies we have carried out in the Gulf of St. Lawrence.

Past reviews included an analysis of the time of onset, duration and last presence of sea ice based upon data from 24 sites located off southern Labrador, the east and north coasts of Newfoundland and in the Gulf of St. Lawrence. Up to and including 1994, the data were provided by Ice Central of Environment Canada in Ottawa, afterwhich we continued the analysis. During this year, similar analyses were undertaken using more comprehensive sea-ice databases that are maintained at the Bedford Institute of Oceanography. The weekly concentration and types of ice within 0.5° latitude by 1° 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 determined. The databases begin in the early 1960s and persist 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 1997 values to obtain anomalies. Optimal estimation of the gridded data were used to smooth the data for plotting purposes. In 1997, ice first appeared north of Hamilton Bank off southern Labrador in late December, and gradually spread southward with ice first appearing on the northeastern Grand Bank in mid-March (near day 70, Fig. 11). Relative to the long-term mean, ice on the Newfoundland and Labrador shelves generally appeared slightly later-than-normal with the exception of some offshore locations where it arrived on schedule or slightly earlier (Fig. 11, note positive anomalies indicate ice formed late which is generally associated with warmer conditions). Ice began to disappear from some of the offshore and southern sites in March (Fig. 12). It started to retreat from northerm Newfoundland waters during April, from southern Labrador in May but lasted in the region south of Hamilton Inlet until 8 June. Over most of the Newfoundland and Labrador region ice disappeared earlier-than-normal (positive anomaly), greater than 30 days early off southern Labrador and northern Newfoundland. The only exceptions were small areas along the coast of Newfoundland and in the extreme offshore areas where ice was observed later-than-normal. The duration of the ice season ranged from less than a month off the northern Grand Banks and offshore to over 170 days north of Hamilton Inlet on the southern Labrador (Fig. 13). Note that the duration is not simply the date of the first presence minus the last presence because the ice may disappear for a time and then reappear. The ice duration was shorter-than-normal (negative anomaly) over most of the Labrador and Newfoundland waters. The duration off southern Labrador and northern Newfoundland was over 1-month shorter-than-normal. Exceptions included the White Bay area of northern Newfoundland and the far offshore regions, especially off southern Labrador where the duration was slightly longer-than-normal by upwards of 10 days or more in some locations.

Icebergs

The number of icebergs that pass south of 48°N latitude each year is monitored by the International Ice Patrol Division of the United States Coast Guard. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1996/97 iceberg season (October to September), a total of 1011 icebergs were spotted south of 48°N. The monthly totals for February to August were 10, 475, 162, 238, 80, 43, and 3 (Fig. 14). No icebergs were spotted between October 1996, and January 1997, inclusive, or in September 1997. In 1997, 98.7% of the icebergs were observed during the primary iceberg season of March to July, higher than the mean in 1983-97 of 91%. Almost 50% of the total number of icebergs during the 1996/97 season penetrated south of 48°N in March, proportionally more then on average during the years icebergs have been detected using SLAR (1983-96). Indeed, almost 50% of the icebergs in 1996 arrived in April. The total number of icebergs in 1997 was above the long-term mean and up from 1996 but was lower than the earlier years of the 1990s (Fig. 14). The decline in iceberg numbers matches the decline in sea ice extent and follows from the warmer air temperatures and reduced northwest winds. Note that periods of large number of icebergs reaching south of 48°N occurred in the early 1970s, the mid-1980s and the early to mid-1990s, all periods of cold air temperatures, strong NW winds and extensive ice cover.

Gulf of St. Lawrence

At the end of December 1996, no ice was present in the Gulf of St. Lawrence and the upper St. Lawrence Estuary due to warmer-than-normal air temperatures (Fig. 15). By mid-January, ice had formed in the western Gulf along the coast from the Gaspe Peninsula to Nova Scotia including throughout most of Northumberland Strait. Ice had also appeared along most sections of the north shore of Quebec from Anticosti Island to the Strait of Belle Isle. The ice was approximately two weeks behind schedule and the areal coverage was much less than the long-term median. This again was primarily due to the relatively warm air temperatures during the first half of January. In the second half of January, northwesterly winds and below normal temperatures over the northwestern portion of the Gulf resulted in rapid spreading of the ice, such that ice coverage was only slightly less than the long-term median by the beginning of February. The ice was thinner than normal, however. Cold air and strong northwest winds continued during February resulted in the Gulf being ice covered by 1 March, except in St. Georges Bay, Newfoundland. The ice edge was very near its median position at this time. Ice was retreating during March so that by 1 April it had left the Estuary and many of the coastal areas of the southwestern Gulf. There was, however, more ice than normal in the Gulf at this time. Ice continued to retreat through April and by 1 May, it was limited to the southern Magdalen Shallows and near the Strait of Belle Isle but there it still more extensive than normal. The ice from the southern Gulf disappeared by the 17 May but remained in the northern Gulf until 3 June. The last ice to disappear was located north of Anticosti Island.

During this last year, we completed the development of an ice database for the Gulf of St. Lawrence and Scotian Shelf and a comprehensive analysis of the first and last appearance of ice and the ice duration was carried out similar to that for the Newfoundland area. The Gulf and Scotian Shelf was divided into 130 areas of dimensions 0.5° latitude by 1° longitude. During 1997, ice formation within the Gulf (landward of Cabot Strait) ranged from near the beginning of the year (prior to day 15) along the north shore of Quebec, the St. Lawrence Estuary and the western Magdalen Shallows to after mid-February (day 45) off southwestern Newfoundland (Fig. 11). Except around the eastern end of Anticosti Island, this represented a later-than-normal appearance of ice, typically by 10 days to over 20 days with the later occurring off western Newfoundland. The day of last appearance shows the typical pattern with ice lasting longest in the southern Magdalen Shallows and along the north shore of Quebec through to the Strait of Belle Isle (Fig. 12). Over most of the region this represented later-than-normal disappearance, although in the outer St. Lawrence Estuary and part of the Magdalen Shallows, the ice left early. Note that north of Anticosti Island ice remained over 60 days later-than-usual. The duration of ice ranged from less than 60 days off southwestern Newfoundland to over 130 days along the Quebec north shore (Fig. 13). Relative to the long-term mean during years when ice was present, ice lasted longer than normal throughout the eastern Gulf, around Anticosti Island and the southern Magdalen Shallows. In contrast, there were fewer days of ice over the rest of the Magdalen Shallows and in most of the St. Lawrence Estuary. The maximum anomaly in duration of ice was around 20 days, off eastern Prince Edward Island and smaller areas off southwestern Newfoundland and the Quebec north shore.

Scotian Shelf

Sea ice normally flows out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwest winds and the mean ocean currents. Seaward of Cabot Strait, ice first appeared during the first half of February (Fig. 11) and continued to spread over the northeastern Scotian Shelf through March and appeared off the Atlantic coast of Nova Scotia south of Chedabucto Bay in mid-April. This was later-than-normal by 10 to over 50 days. Most of this ice had disappeared during the later half of April which is 10 to 30 days later than normal (Fig. 12). The duration of ice south of Cabot Strait ranged from 90 days off Cape North on Cape Breton Island to 10 and less on the northeastern Scotian Shelf and off southern Newfoundland (Fig. 13). Note that a duration of less than 10 days is not plotted in Fig. 13. The duration of ice in 1997 was similar to the long-term mean (Fig. 13).

The maximum area of ice seaward of Cabot Strait was near normal in 1997 and up from the very low value of 1996 (Fig. 16). While there were more ice days than usual seaward of Cabot Strait, the integrated ice area (sum of the ice area times the number of days) was less than normal. This suggests that the ice conditions on the Scotian Shelf were less severe than usual but it remained for a long time. This can also be seen from the monthly time series of ice area (Fig. 17). Based upon data collected since the 1960s, the furthest south that the ice penetrates is just past Halifax along the Atlantic coast of Nova Scotia. Historical records, albeit incomplete, suggest that in the past ice penetrated much further south, for example in the late 1800s sea ice was observed in the Gulf of Maine (A. Ruffman, 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 47 times in 1997, with a monthly maximum of 8 in May and again in July. No measurements were taken in February or March. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50 75, 100, 125, 150 and 175 m) and monthly means were calculated for each depth. The monthly averaged temperatures and salinities in 1996 together with their anomalies relative to 1961-90 are shown in Fig. 18.

The water column is usually isothermal during the winter with mean temperatures falling below -1°C in March. Although no data were available for March of 1997, it is believed that temperatures were in this range given the appearance of temperatures below -1°C at subsurface depths in April. Below 0°C waters were observed through to the autumn (Fig. 18). Upper layer (generally < 50 m) temperatures were below 0°C until April afterwhich they began to rise steadily and reached a peak of over 12°C at the surface in August before autumn cooling set in. The August mean temperature was approximately 2°C below that recorded in 1996. Note the propagation of surface layer heat down into the lower layers in the late autumn. Below normal temperatures dominated the anomaly pattern with the maximum amplitudes in the surface layer in spring and early summer and just below the surface layer in October (Fig. 18,19). Positive temperature anomalies were observed throughout the water column in January, in the surface layer in the autumn and near bottom during most of the year.

In 1997, near surface salinites at station 27 were slightly less than 32 in winter, rose above 32 in the spring and then declined to a minimum of < 31 in September and October (Fig. 18). 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 1997 were relatively fresh causing negative anomalies throughout most of the year (Fig. 18, 19). This is the third consecutive year of such conditions. The largest negative salinity anomaly was below -0.25 in the surface waters in May. Positive salinity anomalies appeared at mid-depth during the second half of the year and extended to the bottom in October.

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970-1996 are shown in Fig. 20. Note that the temperature scales for 100 m and above are twice that for those deeper than 100 m. At the surface and 50 m there is large, short-term variability reflecting atmospheric heating and cooling. Cooling was observed between 1996 and 1997, most evident from 50 to 150 m. This cooling resulted in below normal temperatures at 50 and 100 m and near normal temperatures by year's end elsewhere. At 150 and 175 m negative anomalies had persisted almost continuously from 1982 or so until 1996. The coldest periods roughly correspond to those identified from the air temperature anomalies, i.e. the early 1970s, the mid-1980s and the 1990s.

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. 21). The total heat content of the water column which reached a record low in 1991 increased sharply in 1996 reaching a level that matched those observed during the warm 1950s and 1960s. The heat content in 1997 decreased relative to 1996 and was near the long-term mean. The 0 to 50 m depth-averaged summer salinity is also plotted in Fig. 21. 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. 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 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 Center 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. 22. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects (Petrie et al., 1992). In 1997, the summertime CIL areas were below the long-term means and declined relative to 1996 at Seal Island and Bonavista but were slightly above normal and increased from 1996 values on the Flemish Cap section. The total cross-sectional area of <0°C water on the Newfoundland Shelf, except on the Grand Bank, is continuing a below normal trend established in 1995. 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 1997 was about -1.62 °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 about normal along the Flemish Cap transect at about -1.51 °C. These minimum temperatures were somewhat colder than values during the same time period in 1996.

Data are available to estimate the total volume of CIL water (<0°C) over the 2J3KL area since 1980 (Fig. 23). The method is described by Colbourne and Mertz (1995). Maximum volumes tend to occur during the cold periods of the mid 1980s and early 1990s. Since 1990, the summertime volume has been decreasing and by 1995 was similar to that recorded in the early 1980s and from 1986 to 1989. The 1997 volume was well below the mean over the period 1980-1994 of just over 4 x 10^4 km^3, which is roughly one-third the total volume of water on the shelf, and similar to the volume recorded in 1996. The volume in autumn shows similar interannual trends but its absolute value is about a half that observed in the summer. In the autumn of 1997, the CIL volume was similar to 1996 but near its lowest value on record. Unfortunately limited data prevent extending the volume estimates farther back in time than 1980.

Horizontal Temperature Distributions Near Bottom in 2J3KL

The mean (1961-90) and 1997 autumn temperatures over the shelf from southern Labrador to the Grand Banks from groundfish surveys are shown in Fig. 24 (dotted lines are the bathymetry). 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 has been 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 1995 the percentage area of water less than -0.5°C on the continental shelf declined significantly to below average and bottom temperatures have moderated in most areas of the Newfoundland Shelf with anomalies of +0.5°C.

Hydrographic Conditions on Hamilton Bank

The time series of temperature and salinity anomalies from 1950 to 1997 on Hamilton Bank at standard depths of 0, 50, 75 and 150 m are shown in Figs. 25 and 26, respectively. A low frequency trend was calculated by smoothing the time series using a five-point running mean. This suppresses the high frequency variations at seasonal scales, which gives an indication of the long-term variations. It should be noted that the monthly averages consist of a variable number of observations.

The time series is 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, where the trend was below normal from the early 1980s to recently, similar to conditions further south at Station 27. During 1997, temperatures appear to be near normal at the surface and above normal near bottom at 150 m depth. 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. With the exception of the surface layer, the below average salinities established in the early 1990s continued into 1996, however, measurements made during 1997 indicate a return towards average conditions.

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. 27). 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 moderated somewhat, however below normal conditions still exist below 100 m depth. Note the very cold waters at 200 m beginning around 1985.

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. 28). The trend in salinity values 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. In general, the temperature and salinity anomalies are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne 1993).

Hydrographic Conditions on St. Pierre Bank

Monthly temperature anomalies from 1950 to 1997 on St. Pierre Bank bounded by the 100 m isobath were computed at standard depths of 0, 20, 50 and 75 m (Fig. 29). This temperature time series is characterized by large variations in the monthly averages with amplitudes ranging from ± 3.0 °C. The long-term trend shows amplitudes generally less than ±1.0 °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 Canadian Continental Shelf. During the cold period beginning around 1984 temperatures decreased by up to 2.0 °C in the upper water column and by 1.0 °C in the lower water column. This below normal trend continued until 1994 in the upper water column. Since 1994 the temperature trend have moderated over the top 50 m of the water column but have remained below average at 75 m depth. During 1996 and 1997 temperature anomalies fluctuated above and below normal, respectively. Note the similarity in the smoothed trends at the deepest depths on St. Pierre Bank and Flemish Cap.

The mean (1961-90) and the 1997 bottom temperature maps for April within 3Ps and 3Pn are shown in Fig. 30. In general, the bottom isotherms follow the bathymetry around the Laurentian Channel and the Southwestern Grand Bank increasing from 2°C at 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 the western side. During April 1997 temperatures were above average over Burgeo Bank, in Hermitage Channel and along the western side of St. Pierre Bank. On the central and eastern side of St. Pierre Bank temperatures ranged from 0.5-1°C below average, similar to conditions through most of the 1990s.

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 reveal temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5°C and an anomaly exceeding -0.9°C; Fig. 31). Then temperatures rose dramatically reaching 6.0°C (anomaly of 0.6°C) in 1993. By 1994 temperatures had begun to decline although anomalies remained positive. Temperatures continued to fall in 1995 and 1996 towards near normal. In 1997, data available in January, November and December show temperatures between 5.5° and 6°C that are slightly above the long-term mean. This temperature pattern is believed to reflect principally changes in the slope water characteristics near the mouth of the Laurentian Channel (Bugden, 1991; Petrie and Drinkwater, 1993).

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 1997, the CIL thickness (defined by waters <0°C) decreased by approximately 5% relative to 1997, much less than the 40% decrease observed between 1996 and 1995. The largest decrease in 1997 was observed in the northwestern Gulf. 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. 32). After 1985, temperatures in the CIL have been below normal with minima in the late 1980s and early 1990s. Since 1994, temperatures have been slowly warming. The mid-summer core CIL temperature in 1997 was -

0.25°C (representing an anomaly of approximately -0.35C), warmer than 1996 by 0.2 °C. Gilbert and Pettigrew (1997) found high correlations between the variability in the CIL core temperatures and air temperatures along the west coast of Newfoundland, suggesting the possible importance of atmospheric forcing. Advection may also contribute to the low CIL temperatures of recent years as is suggested by the similar cold pattern observed in the deep waters on St. Pierre Bank (Fig. 29) and Flemish Cap (Fig. 27).

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. 33). Near-bottom temperature anomalies were predominantly below normal with the largest negative anomalies off the northwest point of Prince Edward Island (PEI). In spite of this dominance, more of the area of the Magdalen Shallows showed above-normal bottom temperatures than in the past several years. These were most noticeably north of PEI, around the Magdalen Islands and along the slope of the Laurentian Channel. Relative to 1996, bottom temperatures increased slightly over most of the Shallows but cooled in and around the Magdalen Islands, northwest of PEI and in St. Georges Bay east of PEI. Swain (1993) developed an index of near bottom temperature defined as the area of the Magdalen Shallows covered by waters <0°C and <1°C. These two indices show strong similarity (Fig. 34). Since 1990, including 1997, 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 decreased for the second consecutive year, however, with the area <0°C falling to almost normal. The shrinking of the area covered by these cold waters agrees with the gradually warming and decreasing thickness of the CIL.

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 (0-30, 30-100, 100-200 and 200-300 m) within each of the 21 areas defined by Petrie et al. (1996) and were compared to their monthly mean values. In the surface layer the average temperature ranged from over 6°C in the St. Lawrence Estuary to 14°C off eastern Prince Edward Island. This represents a slight warming compared to 1996 along the north shore of Quebec but a decrease over most of the southern Gulf, including off the west coast of Newfoundland. Relative to the long-term mean, the temperature anomalies in this layer varied spatially about the mean with no overall trend. In the 30-100 m layer, which encompasses the CIL, temperatures only varied from -0.1°C off western Newfoundland to 1.3°C in the St. Lawrence Estuary and near Cabot Strait. These were colder-than-normal for this time of the year with the largest negative anomaly (1.7°C) off the west coast of Newfoundland. Throughout most of the Gulf temperatures warmed relative to 1996 but only slightly (<0.5 °C). Temperatures in the 100-200 m layer ranged from 1.7°C in the northeastern Gulf to 4.4°C in Cabot Strait while in the deep layer (200-300 m) temperatures varied from 4.5°C to over 6°C in Cabot Strait. Temperature anomalies in both layers were above normal except in the 100-200 m layer in the northeast Gulf where they were 0.5°C below normal. Compared to 1996, the temperatures in both layers increased with the largest rise in Cabot Strait (>2°C in the 100-200 m) and immediately to the north (>1°C in the 200-300 m). The time series of the average temperature in the lower three layers indicates warming in 1997 with above normal conditions in the deepest layer but still below normal in the 30-100 m layer (Fig. 35).

Scotian Shelf and Gulf of Maine

Coastal Sea Surface Temperatures

Monthly averages of sea surface temperature (SST) for 1997 were available at Boothbay Harbor in Maine, St. Andrews in New Brunswick and Halifax in Nova Scotia. The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each site for 1996 and 1997 are shown in Fig. 36.

The dominant feature in 1997 at Boothbay Harbor and St. Andrews was the above normal temperatures throughout most of the year (8 out of the 12 months at both sites) which continues a trend of warm temperatures that began in June of 1994. The 1997 anomalies equalled or exceeded one standard deviation (based upon the years 1961-90) in 6 months at Boothbay Harbor (January-May and August) but in only one month at St. Andrews (July). The maximum monthly anomaly was near 1.9°C in January at Boothbay while at St. Andrews it was 0.8°C in October. The lower amplitude anomalies at St. Andrews compared to Boothbay are typical and due to the increased vertical mixing by the tides in the Bay of Fundy. In contrast, at Halifax negative sea surface temperature anomalies dominated with 7 of the 12 months being colder-than-normal including March to July inclusive (Fig. 36). These cold anomalies also continue a trend observed at Halifax over the last several years. Temperatures are increasing at Halifax, however, based upon the increasing number of months that positive temperature anomalies were observed in 1997. Only in 2 months did the temperature anomaly exceed the long-term standard deviations, those occurring in May and July.

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 minima in the late 1980s (Fig. 36). This minima was as low as that of the mid-1960s at St. Andrews but at Boothbay Harbor the minima was only slightly below normal. Consistent with the recent trends, the 1997 annual mean temperature was above normal (mean of 7.3°C and 0.2°C above normal at St. Andrews and 9.0°C and 0.5°C above normal at Boothbay). However, at both sites the temperature had fallen relative to 1996 and the recent peak in 1995. This decrease is consistent with the observed year-to-year variability and can not yet be construed as indicative of a downward trend in surface temperatures at longer time scales. In contrast, at Halifax temperatures have been below normal since the mid-1980s although there has been a slow but steady warming since the early 1990s. The 1997 annual sea-surface temperature at Halifax was 7.8°C producing an anomaly relative to the 1961-90 mean of -0.2 °C.

Prince 5

Temperature and salinity measurements have been taken once per month 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. Single observations per month, especially in the surface layers in the spring or summer may not necessarily be representative of the "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 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 1997, no data were collected in March. Monthly mean temperatures ranged from a minimum of over 2.5°C throughout the water column in February to a maximum of over 12°C near the surface in September (Fig. 37, 38). The monthly temperature anomalies were dominated by positive values, the exception being the latter half of the spring when anomalies were negative throughout the water column and continuing in the surface and near bottom during the summer (Fig. 37). In June, surface waters reached an anomaly of 1°C below normal. The annual mean temperatures exhibit high year to year variability (Fig. 38). In 1997 these mean temperatures were just above normal at both the surface (anomaly of 0.16°C) and near bottom at 90 m (0.10°C above normal). This represents a slight increase relative to 1996 at the surface while near bottom the 1997 temperature was similar to that of the previous year. These represent a decline from the peak in the mid-1990s but above the low levels of the early 1990s. At both depths, the maximum annual temperature occurred in the early 1950s and the minimum in the mid-1960s.

Salinities at Prince 5 during 1997 were mostly fresher-than-normal (Fig. 37). The lowest salinities (<31 psu) occurred during May and June but these were typically for this time of the year. The highest salinities (>32.5 psu) appeared near bottom in the autumn, and these also were near normal. The largest negative anomalies (below 0.5 psu) were observed throughout the water column in January and February. Time series show that the annual salinity anomalies in 1997 rose by approximately 0.4-0.5 relative to 1996 values at both the surface and 90 m (Fig. 39). The 1996 anomalies represented the lowest salinities recorded at Prince 5 and a continuation of the generally freshening that has been occurring since the late 1970s. The recent low values parallel salinity events occurring in the deep waters of Jordan and Georges Basin and appear to be related to advection from areas further to the north (P. Smith, BIO, personal communication).

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Center 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 any data within these by month at standard depths. Data for 1997 were only available for 8 months of the year.

Data from May and July 1997 are shown together with the site locations (center of the boxes) in Fig. 40. The temperature patterns are similar with high near surface thermal stratification and cool pool at intermediate depths in the central and western Gulf, well-mixed near surface waters in the eastern Gulf, and near bottom waters from approximately 7° to over 9°C. Depths below 50 m are predominantly warmer-than-normal while the upper 50 m varied about normal during the 2 months. Anomalies from the other months (not shown) indicate high variability in the surface waters with the sign and amplitude of the anomalies changing from month to month but generally warm conditions in the intermediate and deeper layers.

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 1997, temperature measurements in Emerald Basin were obtained to depths of 250 m in nine separate months with values ranging from 9.2° to 9.7°C. This produced monthly anomalies of 0.9°-1.6°C above normal (Fig. 41). The long-term (1961-90) annual average is 8.5°C and the long-term monthly means range from 7.9°C to 9.4°C. The high positive anomalies in 1997 were generally representative of conditions in the Basin below approximately 50 to 100 m. The recent period of relatively warm waters in the deeper regions of Emerald Basin began with an intrusion of warm slope water late in 1991 or early 1992. The high temperature anomalies have also been observed in the deep waters of the Gulf of Maine (Drinkwater et al., 1997). The bold solid line in Fig. 6 shows the long-term trends. This represents the 5-year running mean of the annual anomalies. The annual anomalies were the average of all available monthly values within that year. In some years data were available for 10-12 months of the year but in some years only 1 or 2 months were there data. The long term trend shows a maxima in the early 1950s declining to a minima in the early 1960s that has been 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 have been well above the long-term mean and at the highest sustained levels on record.

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. 42). Their analysis has been updated and extended to include all of the Gulf of Maine by Petrie et al. (1996). 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°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.

In previous analysis, Drinkwater and Pettipas (1994) examined long-term temperature time series for most of the areas on the Scotian Shelf and in the Gulf of Maine 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 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 anomalous 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 general patterns first identified by Drinkwater and Pettipas (1994) have continued into 1997. 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.

On Sydney Bight (area 1 in Fig. 42) monthly mean profiles from 7 different months show highly variable temperature anomalies throughout the water column (Fig. 43). In the near surface (<10 m) waters, however, temperatures were primarily above the long-term mean with the exception of August (Fig. 43). In the top 100 m August showed the coldest anomalies in 1997. The time series of the 100 m temperature anomalies show high temperature anomalies in the 1950s that fell to a minima 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 each year of above normal being observed since 1995.

Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 42) are available for 6 months during 1997. They show variable upper layer (0-30 m) temperatures (Fig. 44). However, below approximately 30 m temperatures are predominantly below the long-term mean throughout the year. Below 50 m, anomalies lay between -1° and 0°C but increase to as low as -2°C or colder at depths shallower than 50 m. The time series of the 100 m temperature anomalies show that these negative values have persisted since approximately the mid-1980s (Fig. 44). This pattern is indicative of the water column below 50 m. Recent years, although exhibiting generally below normal temperatures, have seen increasing temperatures 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 mid-1960s to the mid-1970s before rising to a maximum in the late 1970s. By the mid-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 1997.

At Lurcher, data were available in 8 months during 1997 (Fig. 45). There was high temperature variability about the long-term mean in the top 40 m. At depths between 40 and 80 m which covers most of the bottom of Lurcher Shoals, 1997 shows a greater number of months with below normal temperatures than above normal. At 100 m, which lays at the edge of the Shoals, temperatures again varied between above and below normal. The monthly 50 m temperature anomalies at Lurcher show mostly cooler-than-normal waters in 1997. This depth represents conditions over much of the bottom of the Shoals. Temperatures over Lurcher Shoals was 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. Since then temperatures have been warming and from 1994 on some positive monthly temperature anomalies have been observed although the annual means have remained below normal.

The time series of temperature in the deep regions of Georges Basin (Fig. 46; area 26 in Fig. 42) shows a striking similarity to that observed in Emerald Basin (Fig. 41). This includes the low values in the mid-1960s, rising sharply to a peak in the early 1970s and varying slightly but generally remaining above the long-term (1961-90) mean ever since. This is not surprising given that the source of the waters is primarily the offshore slope waters (Petrie and Drinkwater, 1993). On the Canadian portion of Georges Bank (area 28 in Fig. 42), the short period variability is of much higher amplitude than in Georges Basin, for example (Fig. 46). 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.

Offshore Conditions

Temperature conditions were obtained in the deep (200 m) waters off the northeastern and southwestern Scotian Shelf (areas 34 and 33, respectively in Fig. 42). The temperature trends in these offshore areas (Fig. 47) reveal trends similar to those in Emerald (Fig. 41) and Georges Basin (Fig. 46) consistent with the findings of Petrie and Drinkwater (1993). Of particular note, however, is the presence of very cold water offshore in late 1997. This water is as cold as that observed in the 1960s and is of Labrador Slope origin (Drinkwater et al. 1998). While similar cold water is often observed in the northern slope region off Banquereau, in the central slope (from Emerald to Browns Bank) such cold waters are relatively rare.

Temperatures during the Summer Ground Fish Survey

The most extensive temperature coverage over the entire Scotian Shelf occurs during the annual groundfish survey, usually in July. In 1997, around 200 conductivity-temperature-depth (CTD) stations were occupied. Temperatures were interpolated onto a 0.2 by 0.2 degree 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 500 m as we were primarily interested in the temperatures over the shelf. The 1997 temperatures were also compared to the 1961-90 means for July.

Temperatures in 1997 at the surface varied from <9° to >16°C with the coldest temperatures at the mouth of the Bay of Fundy and the warmest on Sydney Bight and the central Scotian Shelf (Fig. 48a). Warmer temperatures and weaker temperature gradients prevailed on the Scotian Shelf relative to the Bay of Fundy. Note that no data were collected on the Lurcher Shoals during this survey. At 50 m the coldest temperatures (<1°C) are in the extreme northeast and off Mahone Bay on the Atlantic coast of Nova (Fig. 48a). Note the warm waters (4°-5°C) appear to be penetrating onto the central shelf regions from the offshore. The 100 m temperatures show a pattern of cold waters (<3°C) in the northeast and warm waters (>5°C) to the southwest (Fig. 48b). Bottom temperatures show similar features to 100 m and are typical (Fig. 48b). 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°C in the Misaine Bank region. Temperatures in Emerald Basin exceeded 9°C. Relatively high temperatures also were found over southern Browns Bank and in the upper reaches of the Bay of Fundy.

Temperature anomalies at the surface show generally weak, spatially varying anomalies except in the Bay of Fundy, which was below normal by greater than 1°C (Fig. 49a). The dominant feature at 50 m is the below-normal temperatures over most of the shelf with maximum anomalies of below -2°C in the vicinity of Emerald Basin but not over the central Basin (Fig. 49a). At 100 m and near bottom the anomalies are below normal in the northeastern Scotian Shelf and extend onto Sable and Western Bank on the outer Shelf (Fig. 49b). At 100 m we also see colder-than-normal temperatures over Emerald Basin and in the Bay of Fundy. The colder-than-normal temperatures over Emerald Basin are different than 1996 when these were warmer-than-normal (Drinkwater et al., 1997). The warm water near bottom in Emerald Basin during the July survey is consistent with the 250 m temperature time series (Fig. 41) and the cold temperatures in the northeast with the temperature time series observed on Misaine Bank (Fig. 44).

FRONTAL ANALYSIS

Shelf/Slope Front

The waters on the continental shelves of the Northwest Atlantic 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 1997 and October to December of 1996 have been digitized, estimates of monthly means positions determined and anomalies relative to 1978 to 1997 were calculated.

The overall mean position of the Shelf/Slope front together with the 1997 annual mean position is shown in Fig. 50. 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 1997, the shelf/slope front was seaward of its long-term mean position along the entire pathway from 75°W to 56°W, the furthest east the reliable statistics could be determined. The largest deviations from the mean position occurred at the eastern end. 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. Since 1993, the front has been moving steadily seaward and is presently at its most seaward position since the early 1980s. Since 1993, the front has migrated approximately 40 km to the south.

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 the1997 annual mean is shown in Fig. 51. 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 1997, the average position of the Stream was seaward at each degree of longitude except the furthest eastern edge (56°W). 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. 51). 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. The 1996 position is not well defined, however, since it is based upon only three months of the data (October to December). The decline 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 1997, the wintertime large-scale atmospheric circulation (Icelandic Low and Bermuda-Azores High) remained weaker-than-normal for the second consecutive year. This resulted in a lower-than-average NAO index, and well below the high values of the earlier 1990s. Associated with the weakening of the Icelandic Low, the northwest winds would have been weaker than normal over the Labrador Sea which would account for the wintertime air temperatures being, on average, warmer-than-normal. The NAO index and the Icelandic Low strengthened relative to 1996, however, and air temperatures were not as warm. Notable was the significant change in air temperatures during the winter from very warm during the first half of the season to very cold in the latter half. The warm air temperatures and weaker winds early in the winter resulted in later-than-normal ice formation, but as the very cold conditions and strong northwest winds developed during the latter half of the winter the ice spread quickly. Ice lasted longer than normal in much of the Gulf and on the Scotian Shelf but not on the Newfoundland and Labrador shelves. In spite of the long lasting ice the areal extent of ice on the Scotian Shelf was below normal. The number of icebergs reaching the Grand Banks in 1997 was up from 1996 but below the large numbers recorded in the earlier years of the 1990s. In 1997, the air and sea ice conditions were more severe (colder and larger ice extent) than in 1996 but not as severe as the early 1990s. During spring, air temperature anomalies were generally below normal during 1997, consistent with the air pressure pattern and weaker northwest winds over the Labrador Sea. During the summer, air temperatures anomalies tended to relatively small, fluctuate about their long-term means, and vary spatially.

In the northern Newfoundland and Labrador areas, the relatively warm conditions that were first observed last year have generally continued. Time series of temperatures at Station 27 shows values ranging from 0.0 to 0.5 °C above normal for the winter months over most of the water column. By mid April a strong negative surface temperature anomaly developed with anomalies reaching near 1.0 °C below normal by mid May. These colder than normal temperatures appear to have propagate deeper into the water column reaching 100 m depth by October. Fall temperatures in the upper layer were about normal, while bottom temperatures throughout the year were near normal. Salinities over most of the water column were slightly below normal throughout the year except in the fall at mid depth when they were up to 0.5 PSU above normal. During the summer of 1997 the CIL area off Bonavista and Hamilton Bank was well below normal continuing a trend established in 1995. Along the Flemish Cap transect across the Grand Bank, the total volume of sub-zero °C water on the Newfoundland Shelf during both summer and autumn is continuing a below normal trend also established in 1995. Minimum CIL core temperatures were near normal over all areas during the summer of 1997. Bottom temperatures on Hamilton Bank and the Grand Bank during the fall period of 1996 increased significantly over previous years and were up to 0.5 °C above normal over many areas. During the fall of 1997 bottom temperatures were still above normal over many areas, particularly on the offshore portion of the Northeast Newfoundland Shelf.

Temperature anomalies on St. Pierre Bank show the cold period that started around 1984, continued to the spring of 1995 but showed some evidence of moderation during 1996, particularly in the upper layer. During 1997 however, temperatures decreased again to below normal values. During the spring of 1997 in division 3Ps deep water bottom temperatures appear to be above normal while most of St. Pierre Bank was below normal by more than 1.0 °C on the southeast portion of the bank. It appears that the cold trend on St. Pierre Bank is continuing.

In the Gulf of St. Lawrence, the moderating temperatures and reduction in the thickness of the CIL layer and decline in the area of near bottom on the Magdalen Shallows covered by cold waters observed over the past couple of years has continued. Indeed, a larger proportion of the bottom of the Shallows had near normal and even above normal temperatures in some places for the first time in several years.

In 1997, colder-than-normal conditions continued in the bottom waters and throughout much of the water column on the northeastern Scotian Shelf, along the Atlantic coast of Nova Scotia and off southwestern Nova Scotia. This pattern was established in the mid-1980s with maximum cooling in the early 1990s. In recent years there has been a slow but steady increase in temperatures in these regions. The presence of these cold waters are believed to be due to advection from the Gulf of St. Lawrence and off the Newfoundland Shelf and to a lesser extent *in situ* cooling during the winter although the relative importance has not yet been established. In contrast to these cool conditions, the waters in the central Scotian Shelf over Emerald Basin and in the deep basins of the Gulf of Maine were warmer-than-normal in 1997 and near the highest on record. These very warm conditions have persisted since 1992 and have generally reflected the presence of warm slope water offshore. However, for the first time in almost a decade cold offshore waters were observed along the outer edge of the Scotian Shelf with temperatures dropping to values last observed in the 1960s. By the spring of 1998, these cold waters had moved south to the Gulf of Maine and were penetrating onto the Shelf (Drinkwater et al. 1998).

The shelf/slope and Gulf Stream fronts appeared further seaward of their long-term mean positions during 1997. This appears associated with the low NAO index although the mechanisms are as yet unresolved.

ACKNOWLEDGEMENTS

We wish to thank those who provided data, especially I. Peterson of the Bedford Institute for the monthly areal ice extent data for the Newfoundland region; the U.S. Coast Guard for the iceberg data; Graham Glen at the Marine Environmental Data Service in Ottawa for hydrographic data; the Bigelow Laboratory for providing Boothbay Harbor temperature data; F. Page and R. Losier of the Biological Station in St. Andrews, for providing St. Andrews and Prince 5 data, J. McRuer of BIO for the Scotian Shelf July groundfish survey data; P. Fraser of the Halifax Laboratory and B. Petrie of the BIO for the Halifax sea surface temperature data, G. Bugden of the BIO for his Cabot Strait temperature data, D. Swain of the Gulf Fisheries Centre in Moncton for data from the Gulf of St. Lawrence. We also thank R. Pettipas, L. Petrie, C. Fitzpatrick, P. Dubé, B. Pettigrew, M. Couture and D. Foote for their technical support in preparation of this paper.

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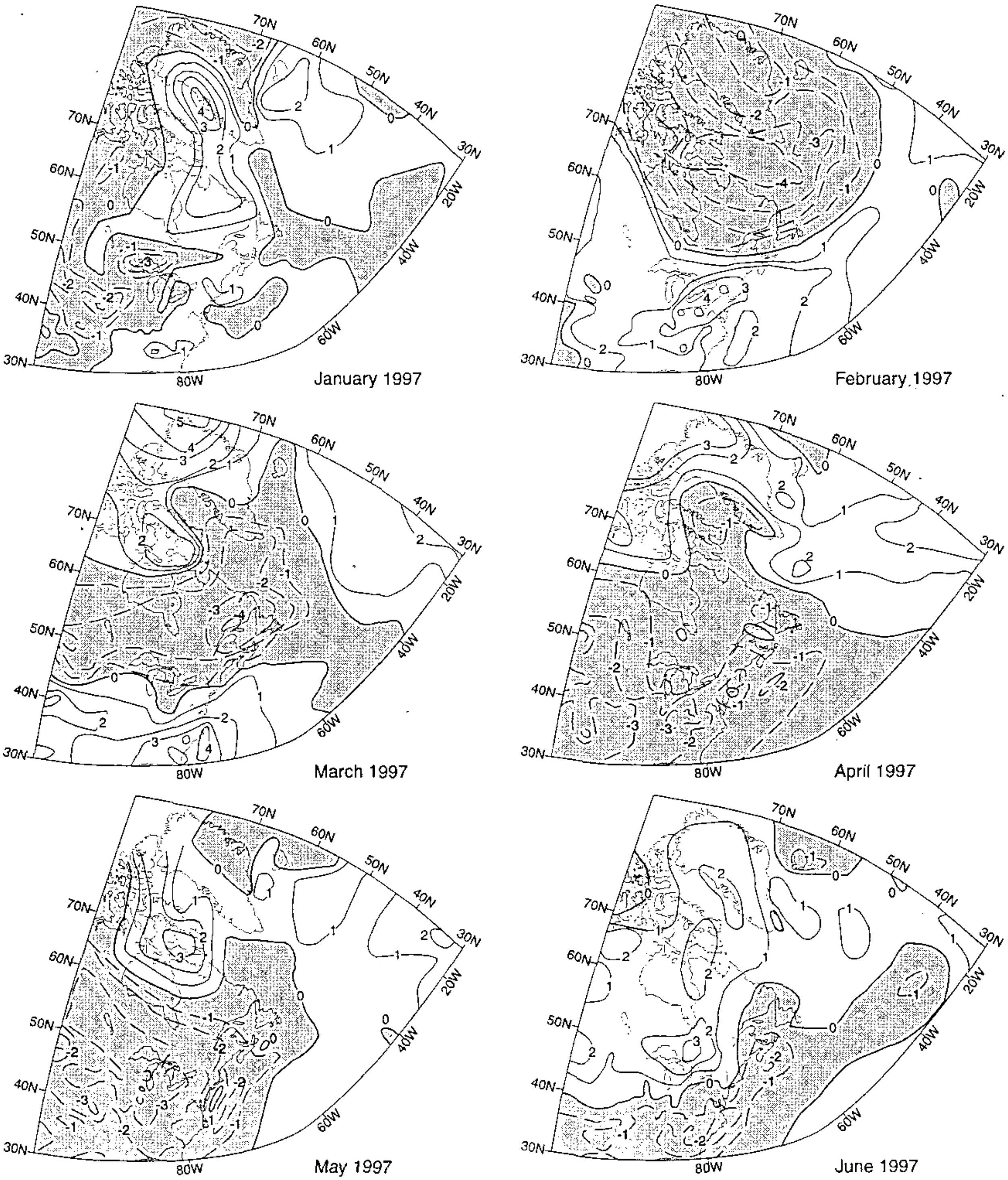


Fig. 1. Monthly air temperature anomalies (°C) over the Northwest Atlantic in 1997 relative to the 1961-90 means. Shaded areas are negative anomalies. (From *Grosswetterlagen Europas*)

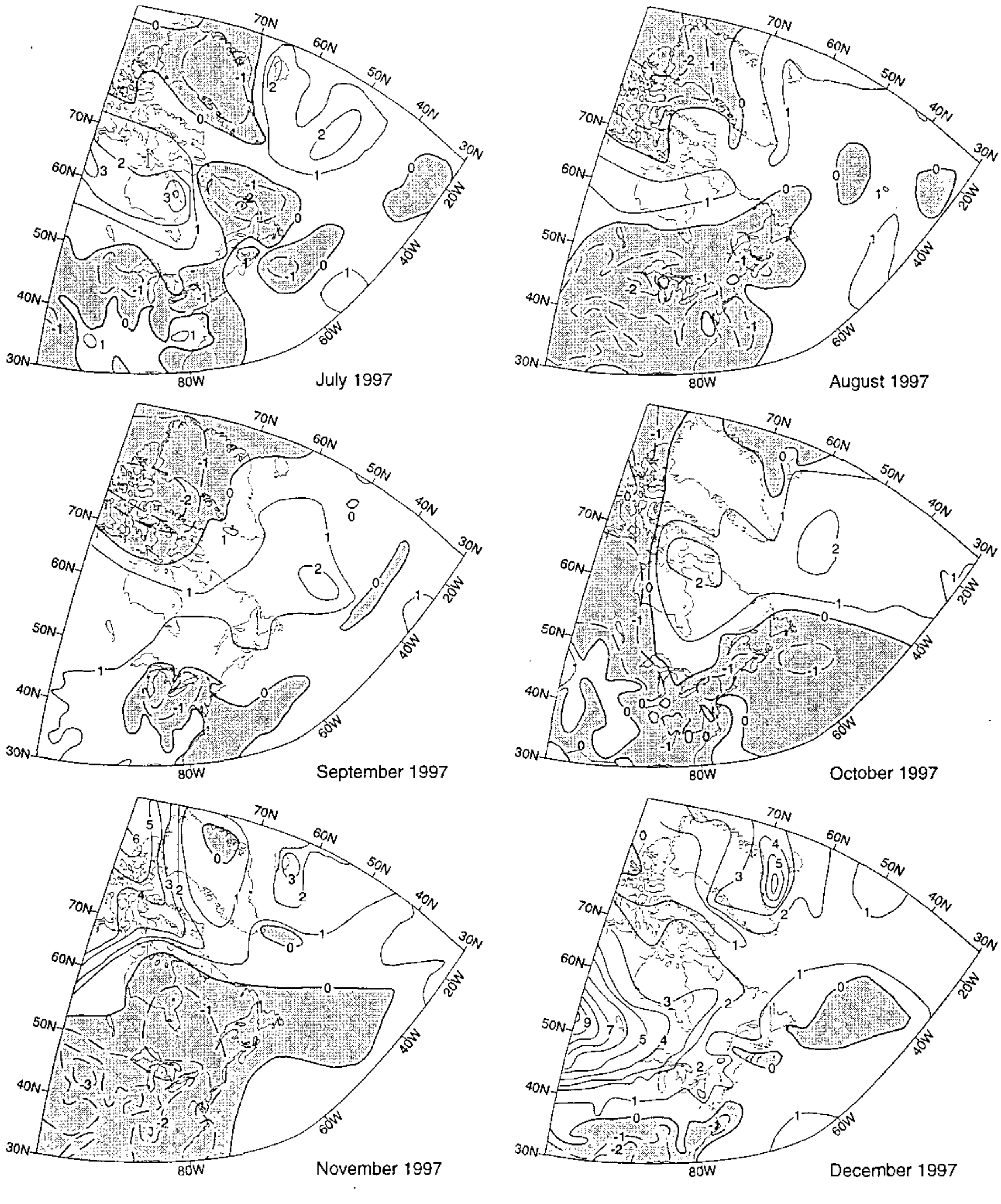


Fig. 1. (continued). Monthly air temperature anomalies (°C) over the Northwest Atlantic in 1997 relative to the 1961-90 means. Shaded areas are negative anomalies. (From *Grosswetterlagen Europas*)

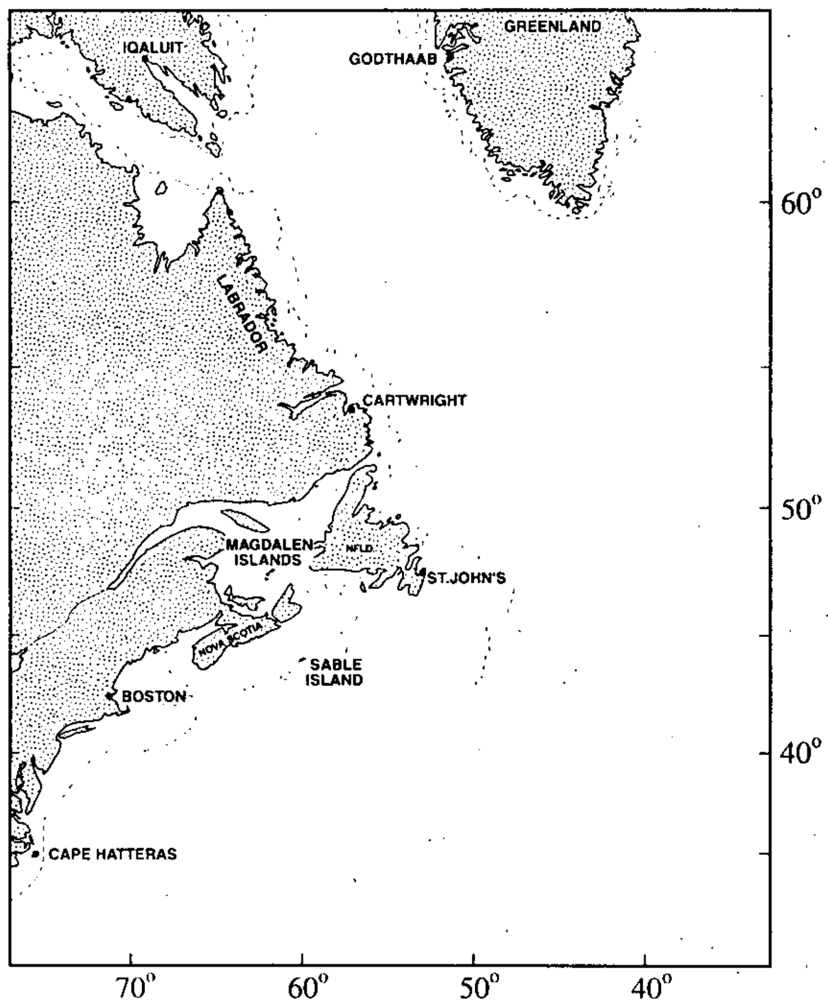


Fig. 2. Northwest Atlantic showing coastal air temperature stations.

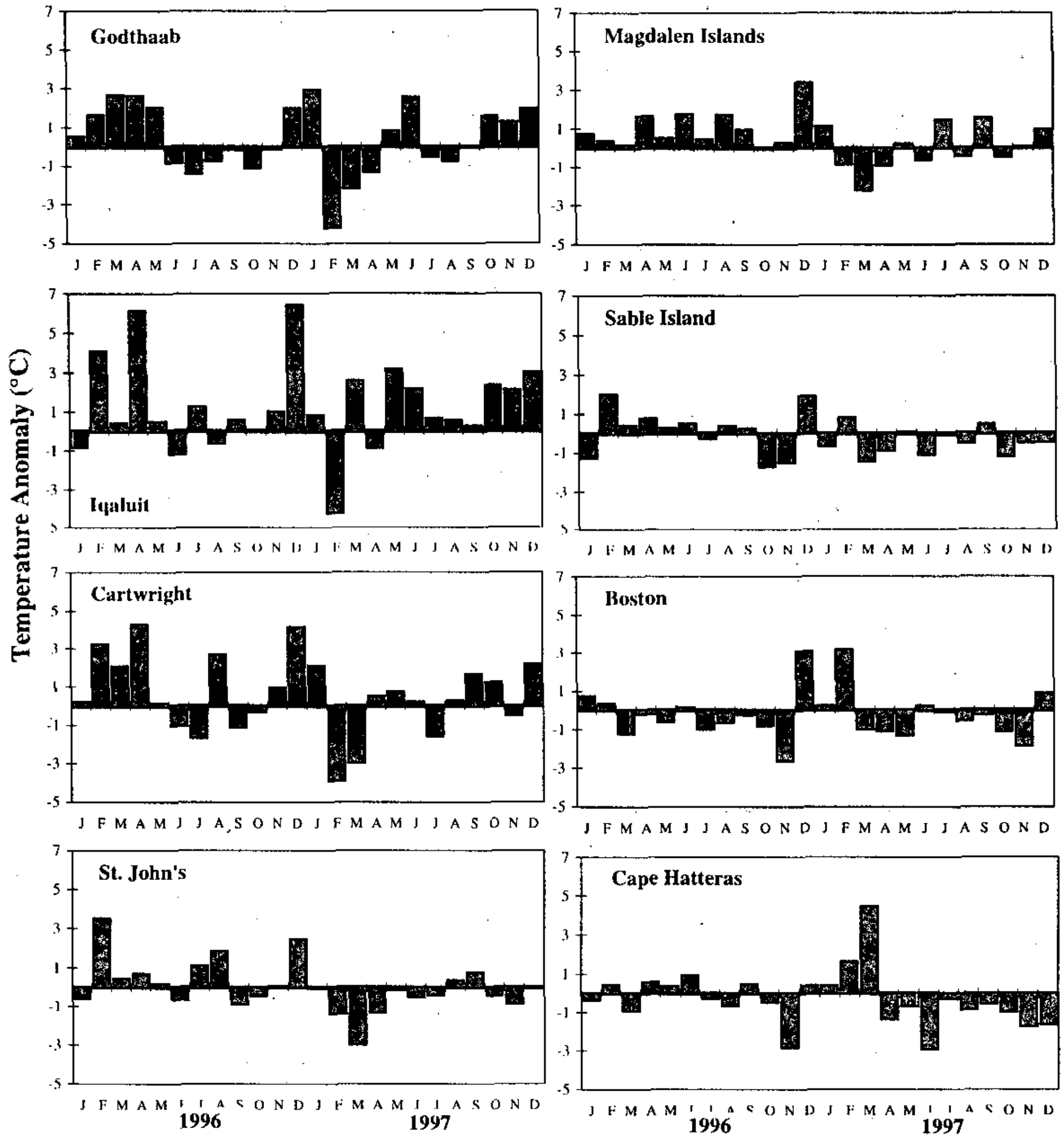


Fig. 3. Monthly air temperature anomalies in 1996 and 1997 at selected coastal sites (see Fig. 2 for locations).

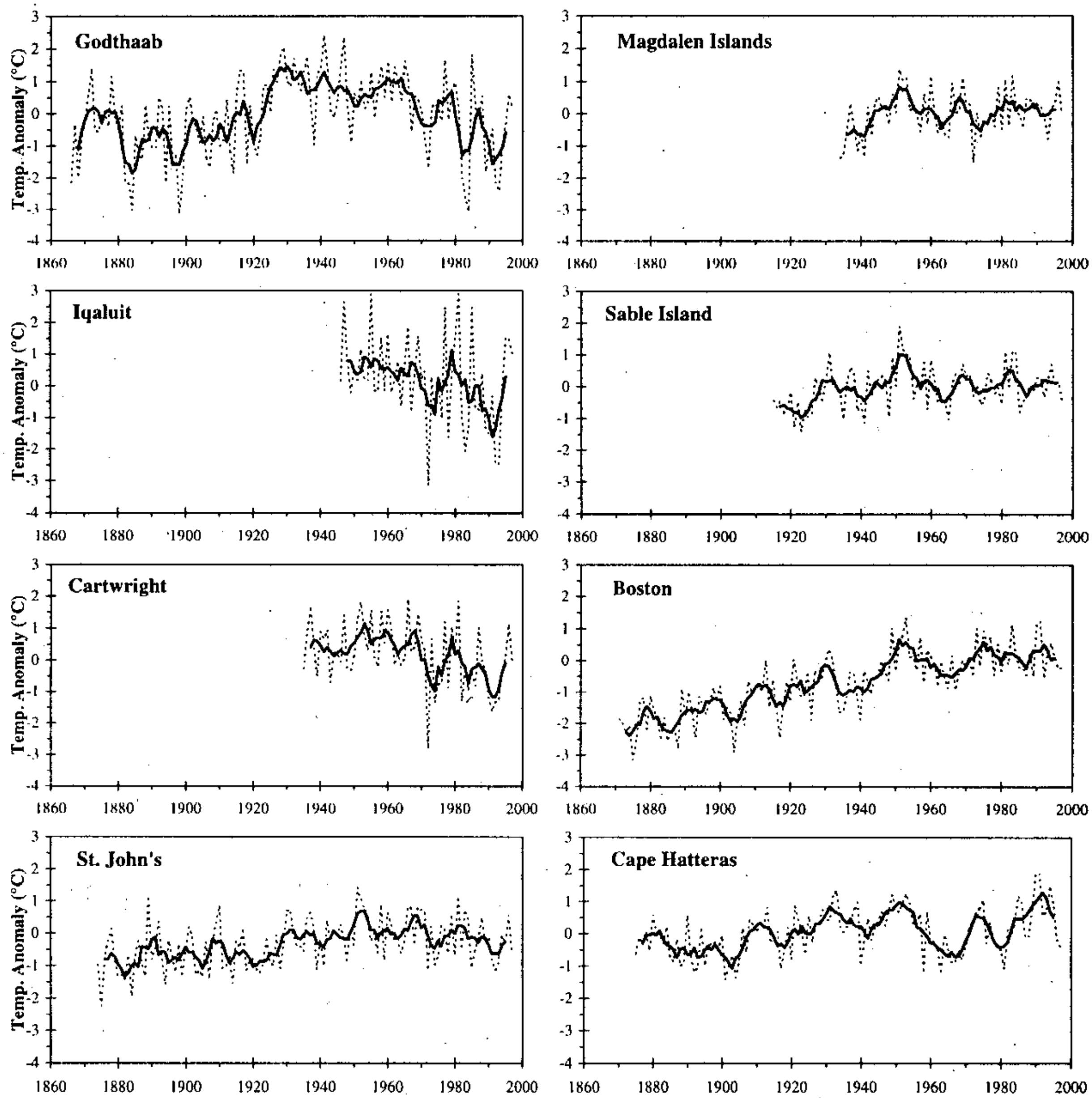


Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

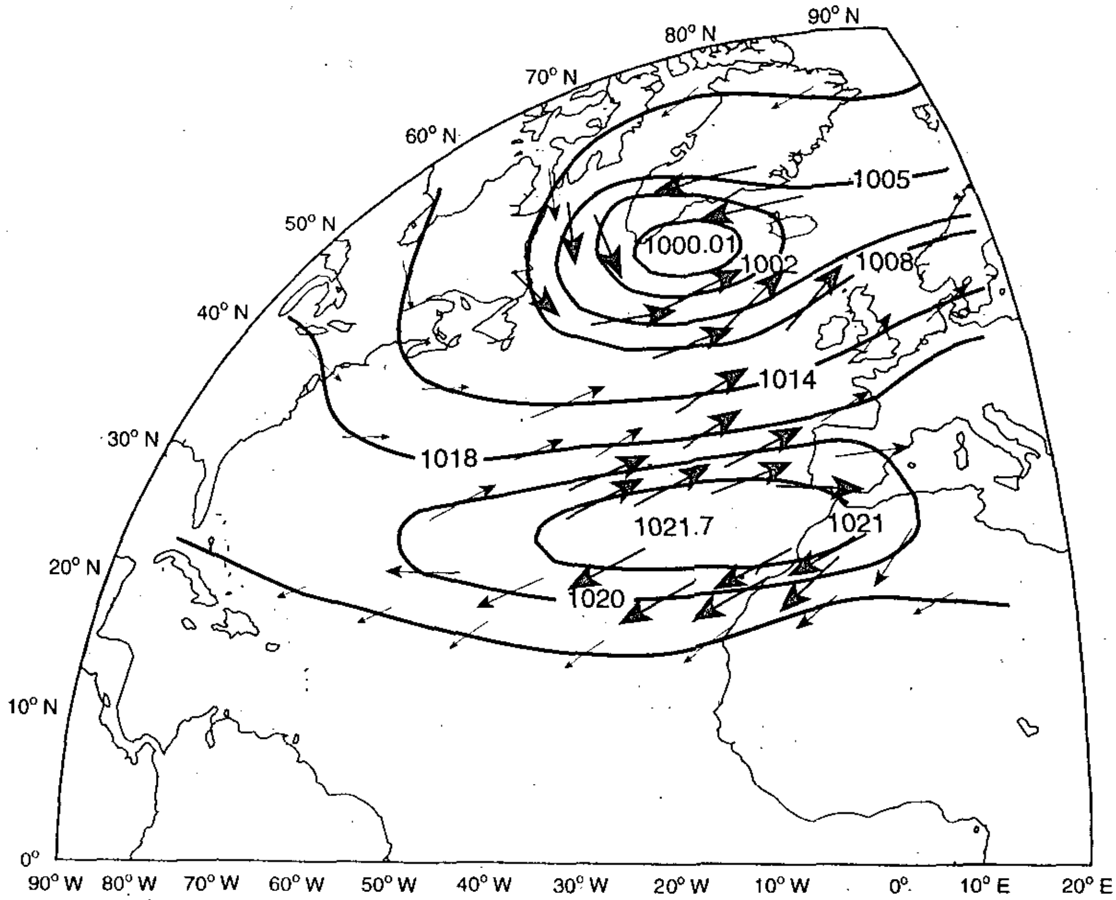


Fig. 5. The long-term (1961-90) mean sea surface pressure during the winter (average of December, January and February). A schematic of the wind field associated with the mean pressures is also shown.

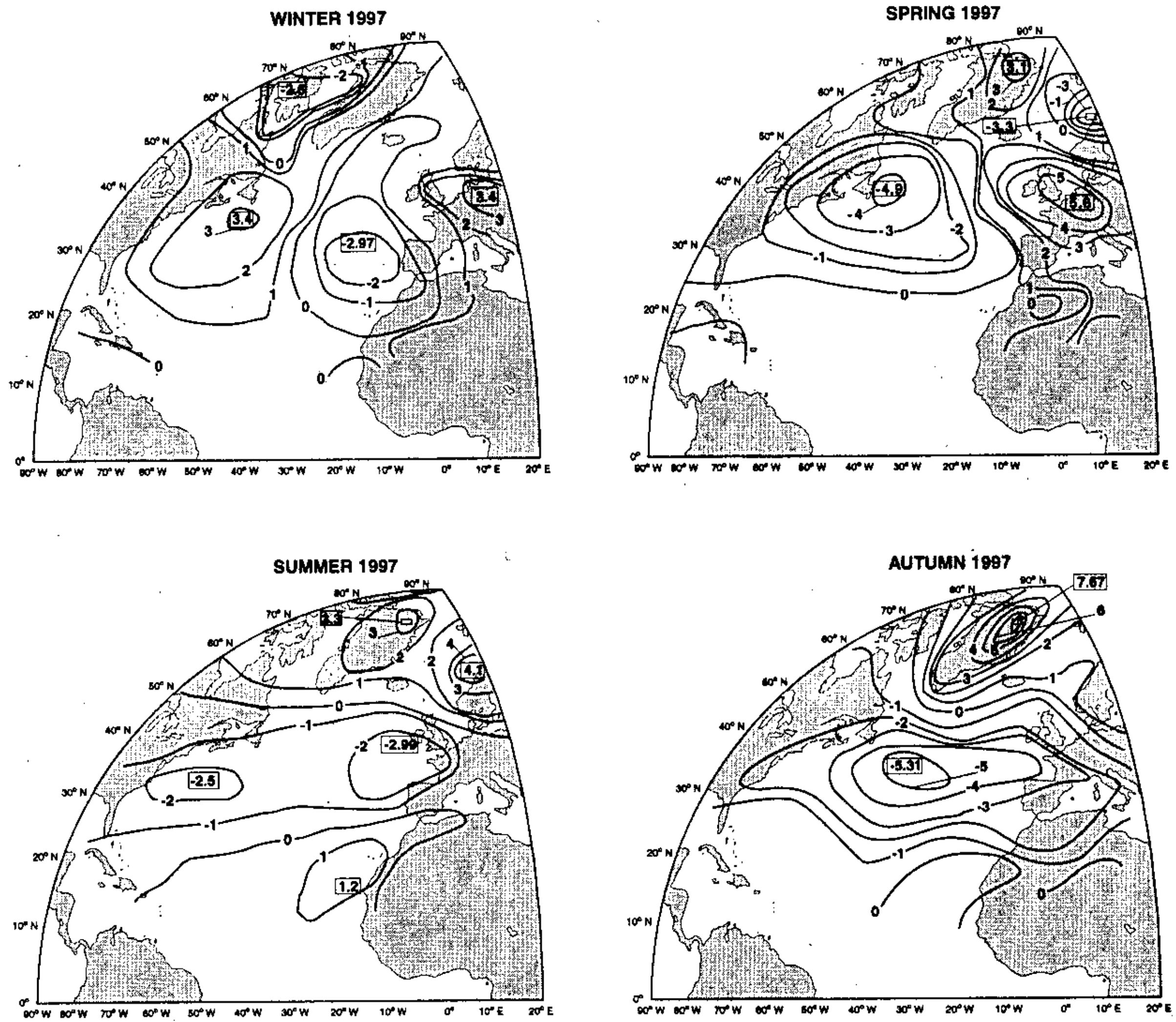


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1997 relative to the 1961-90 means.

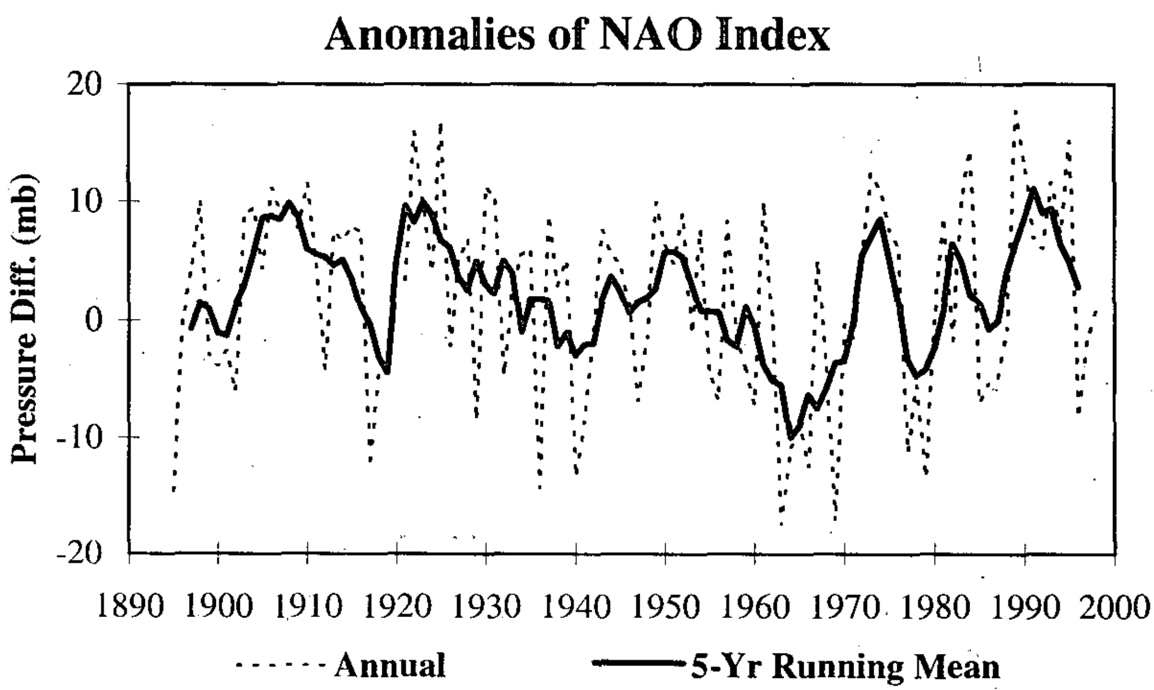


Fig. 7. Anomalies of the the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure at the Azores minus that in Iceland, relative to the 1961-90 mean.

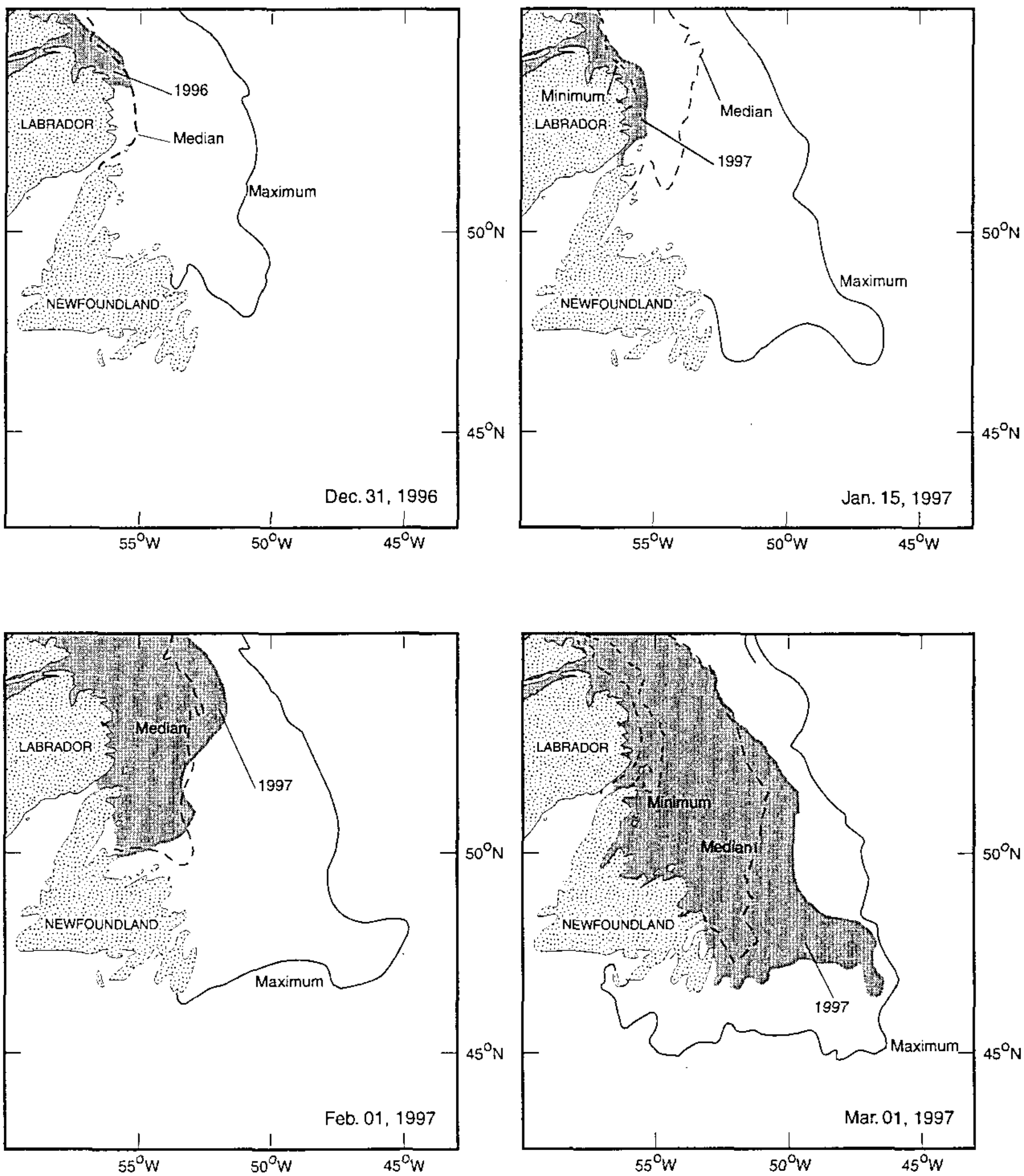


Fig. 8a. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between December 1996 and March 1997.

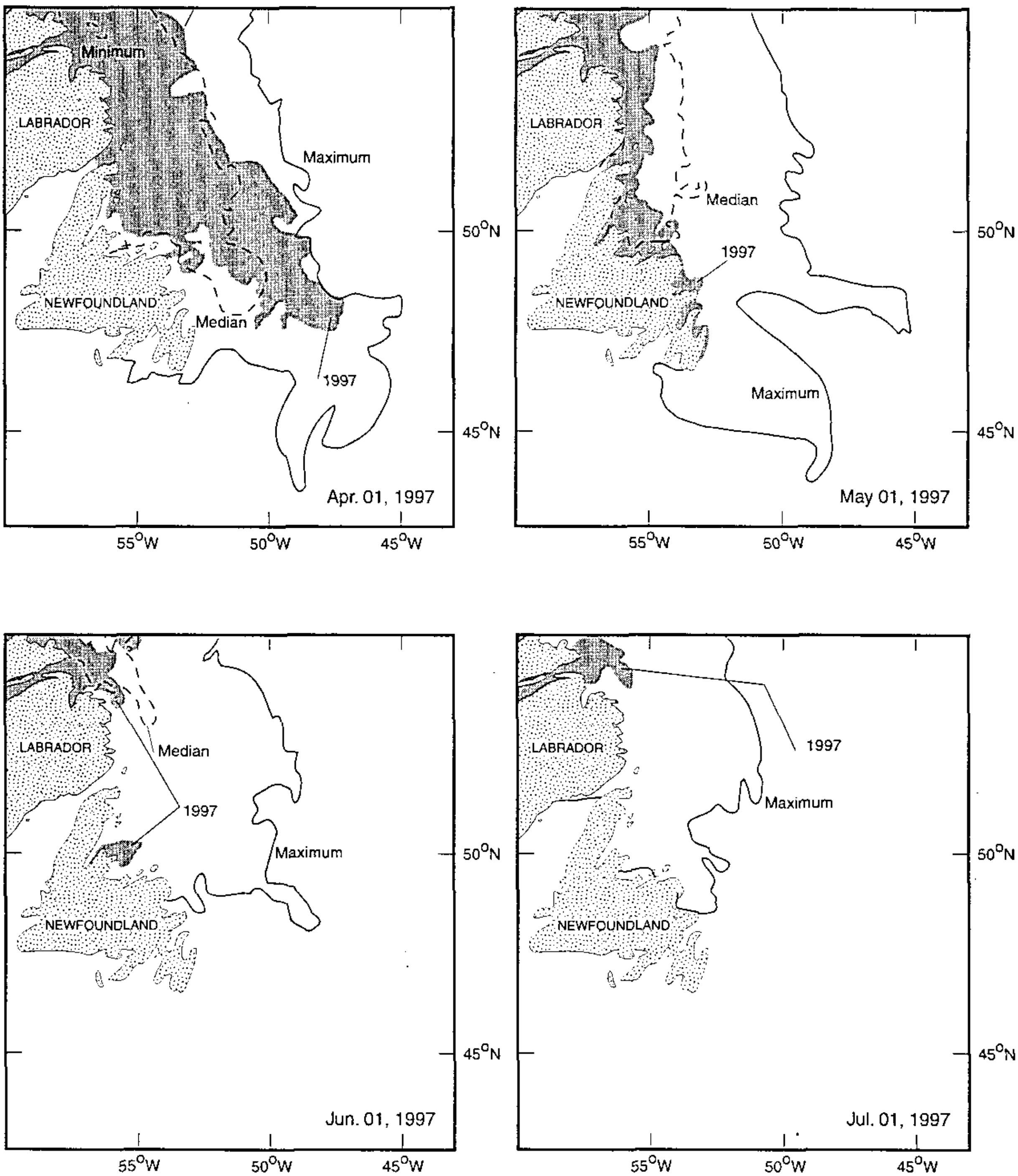


Fig. 8b. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between April and July 1997.

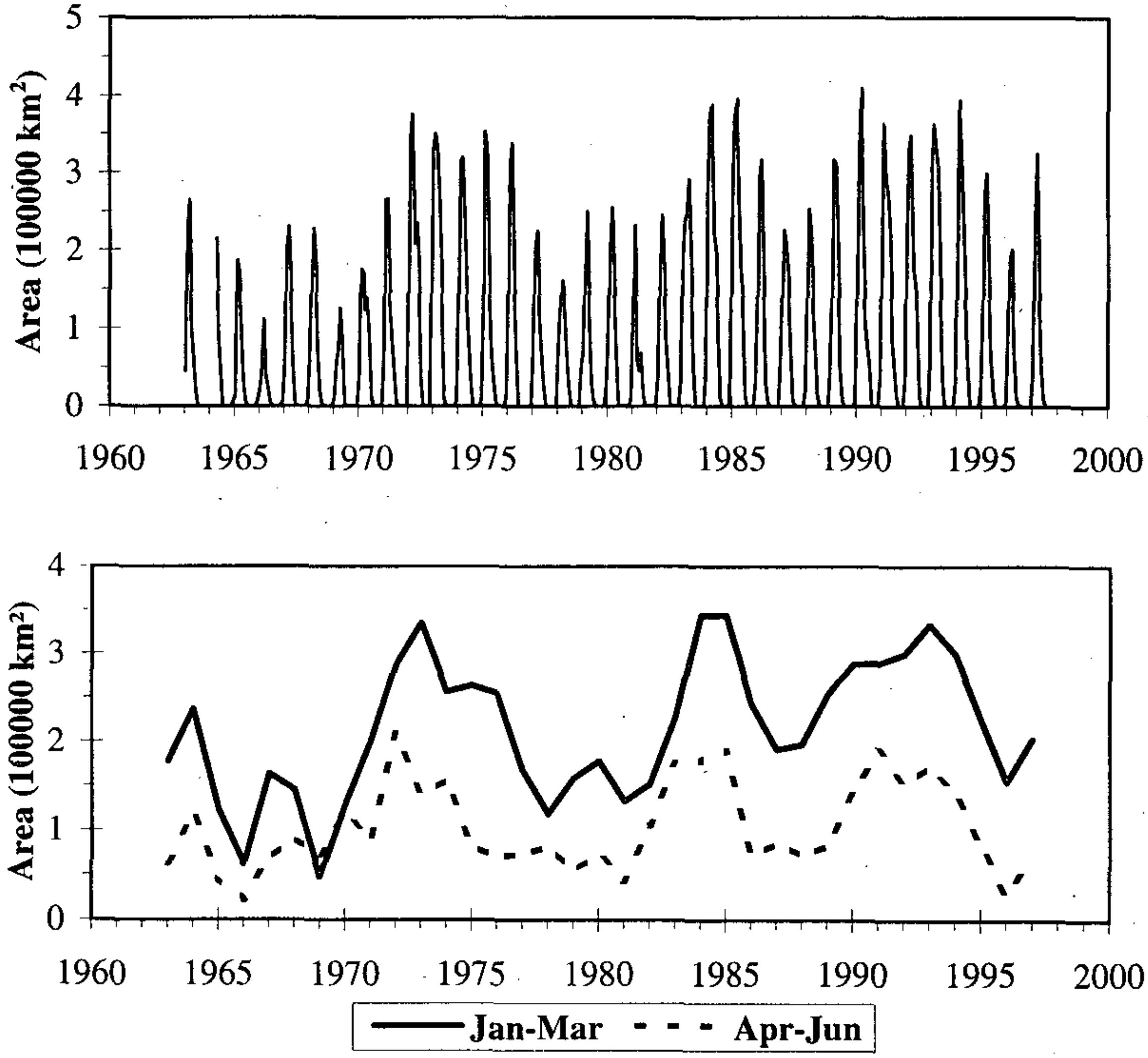


Fig. 9. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N and 55°N (top panel) and the average ice area during January to March and April to June (bottom panel).

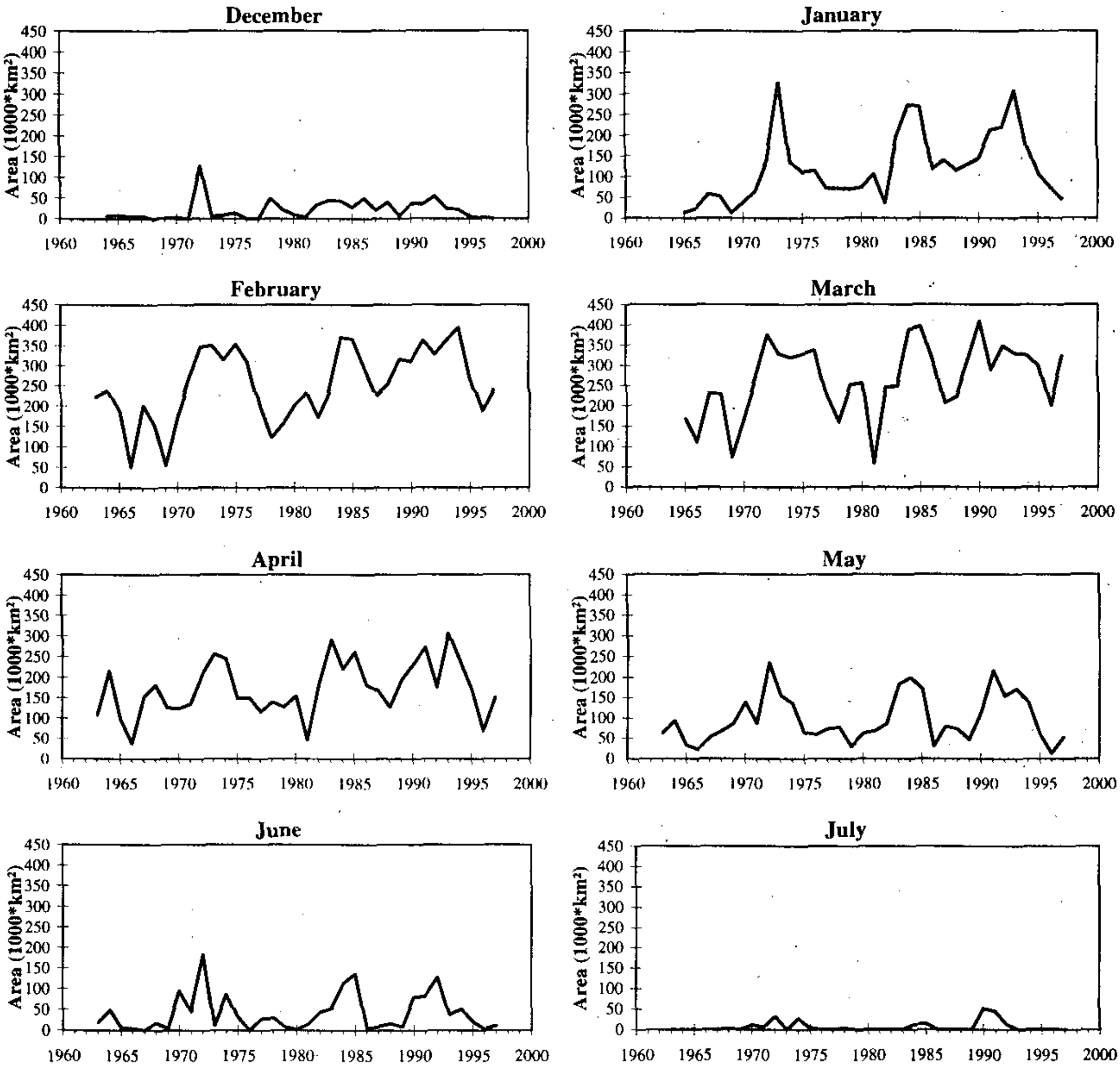


Fig.10. The time series of ice area on the southern Labrador and northern Newfoundland shelves between 45°N-55°N by month.

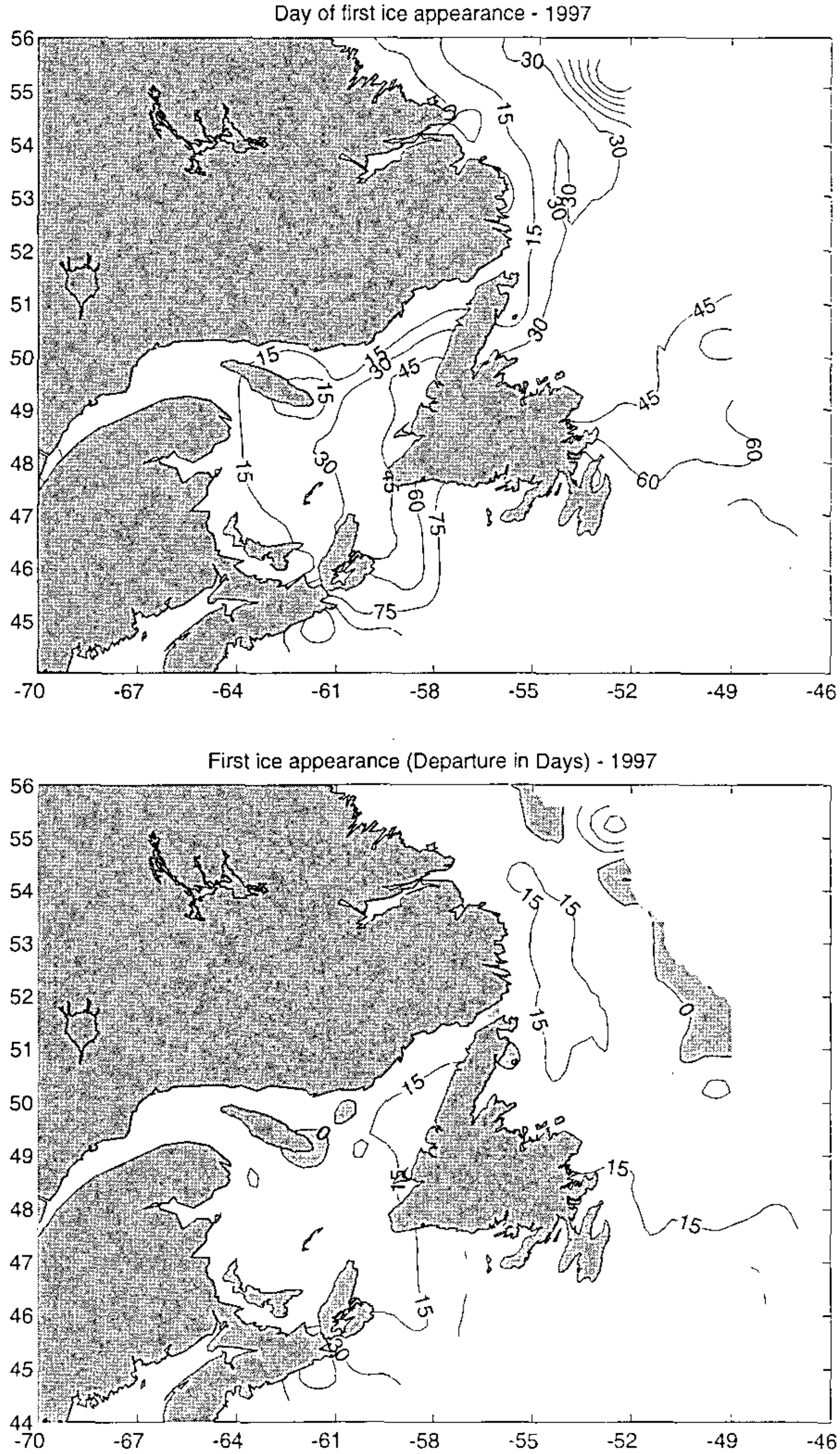


Fig. 11. The day of first presence of ice during 1997 measured in days from the end of 1996 (top panel) and their anomalies relative to the long-term mean in days (bottom panel). The shaded negative anomalies indicate ice appeared earlier than normal, which is generally associated with a cold year.

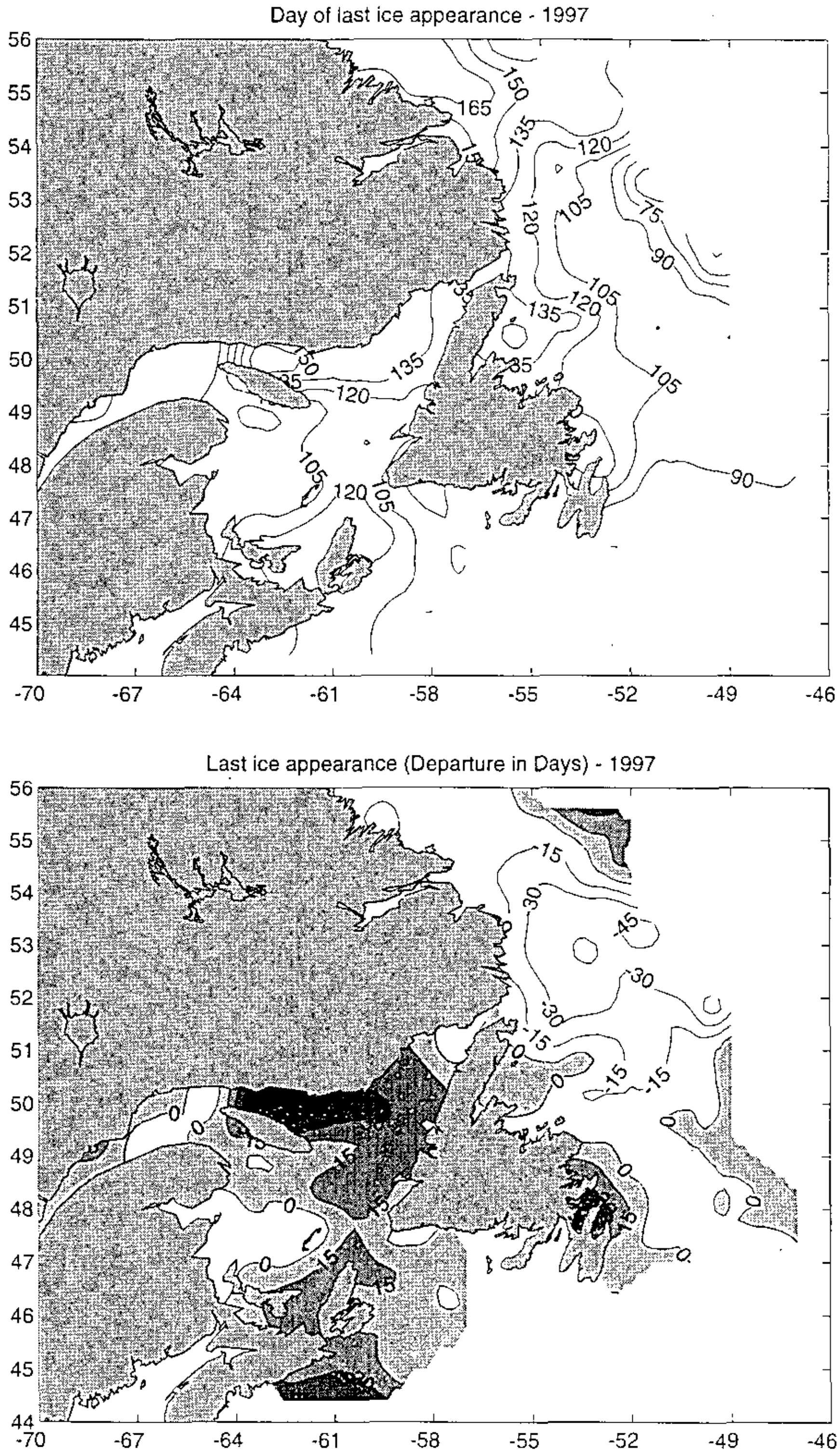
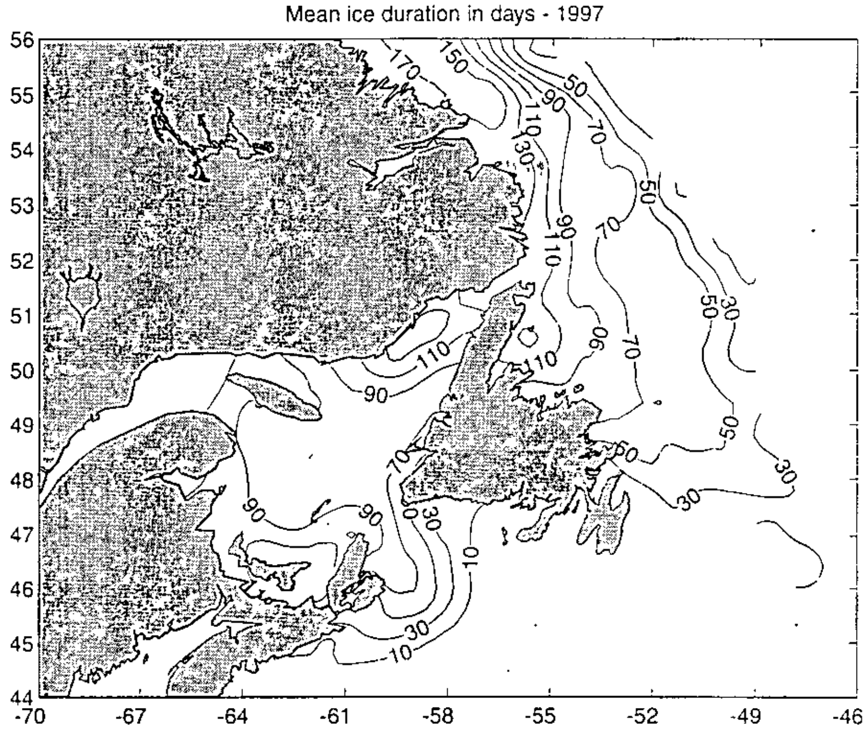


Fig. 12. The day of last appearance of ice in 1997 measured in days from the end of 1996 (top panel) and their anomalies relative to the long-term mean in days (bottom panel). The shaded positive anomalies indicate ice left later than normal, which is generally associated with a cold year.



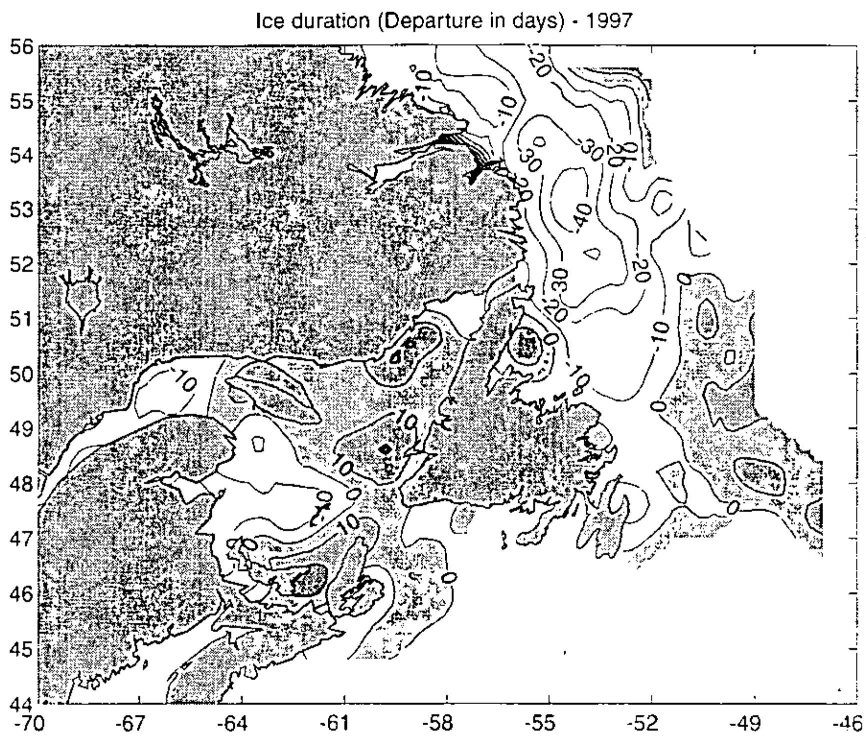


Fig. 13. The duration of sea ice in days during 1997 (top panel) and their anomalies relative to the long-term mean (bottom panel). The shaded positive anomalies indicate a duration longer than normal, which is generally associated with a cold year.

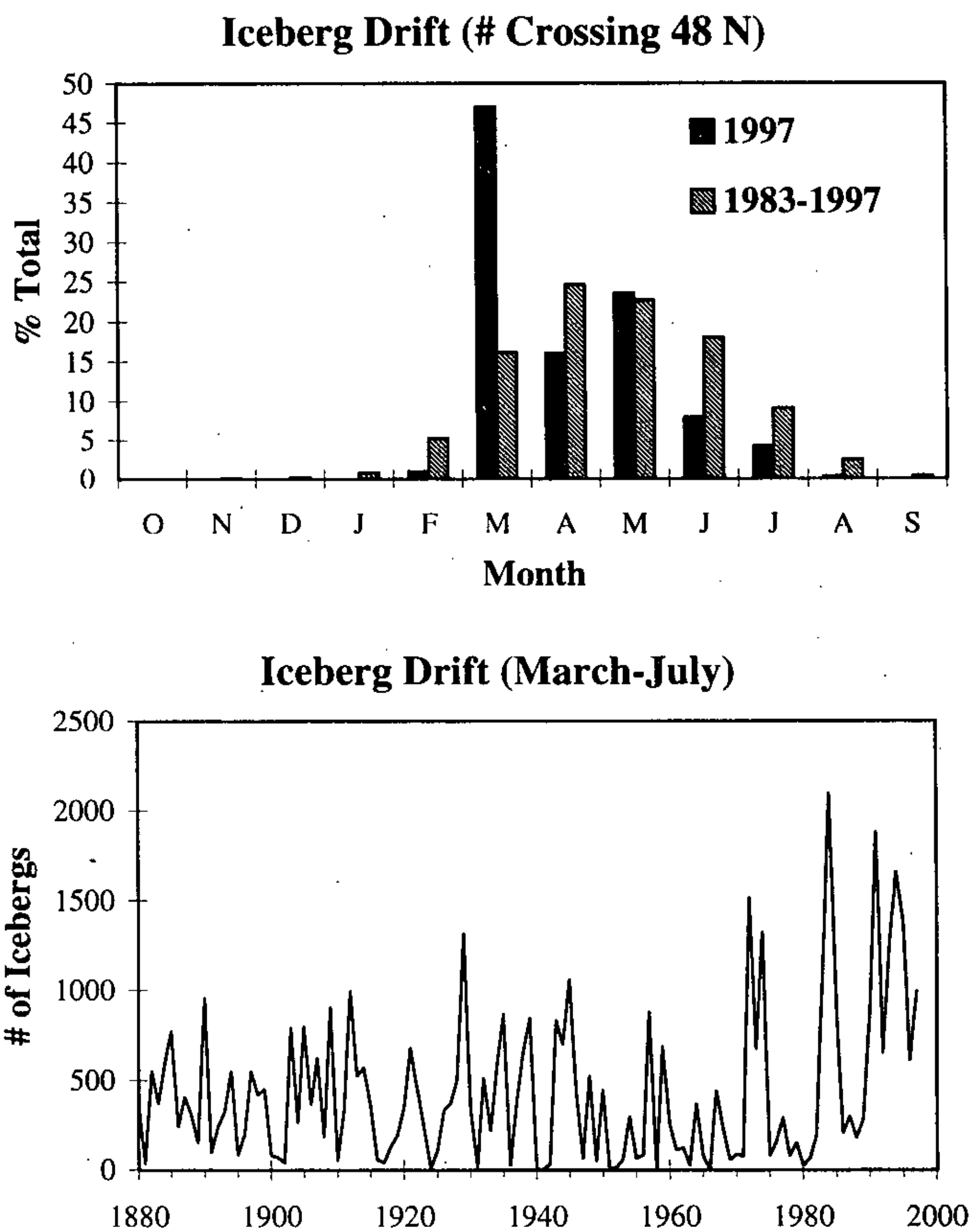


Fig.14. The percentage of the total number of icebergs crossing south of 48°N by month during the iceberg season 1996/97 (top panel) and the number of icebergs during March to July (bottom panel). The period 1983 to 1997 represent the time during which the iceberg counts were determined using SLAR.

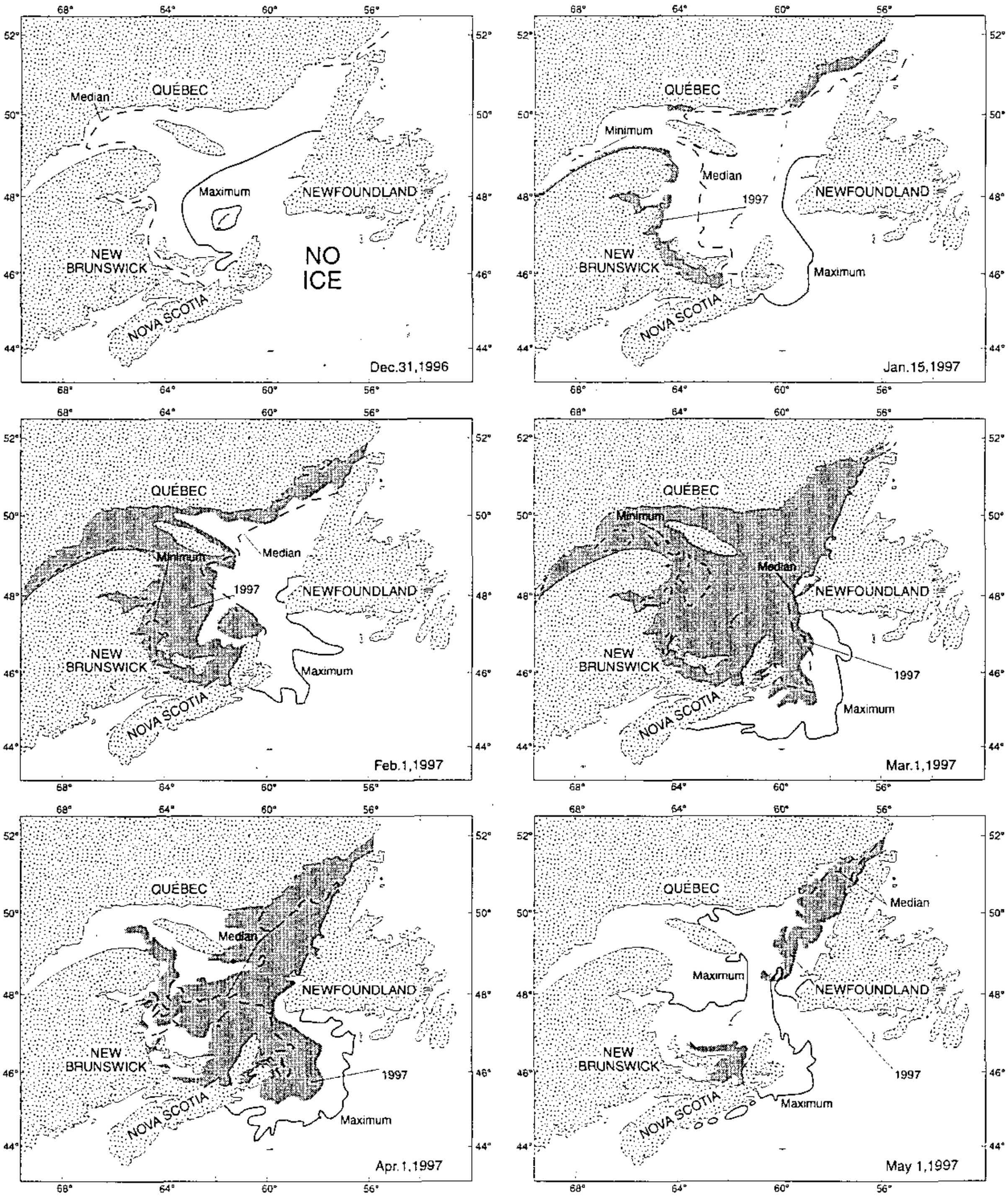
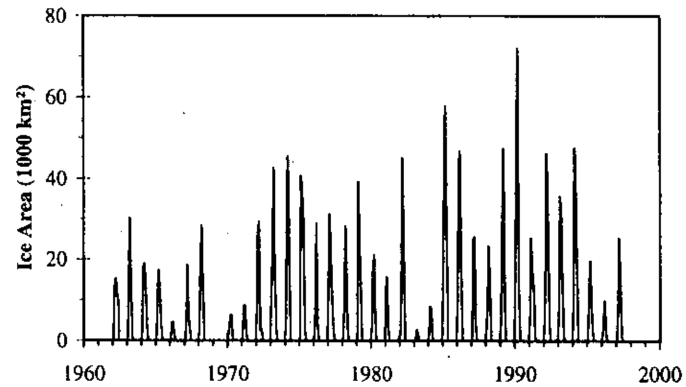
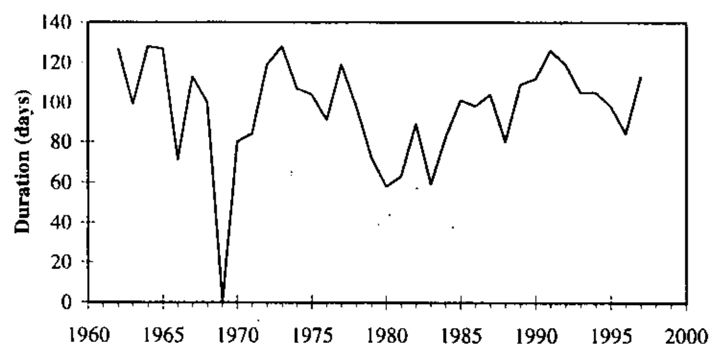


Fig. 15. The location of the ice edge together with the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence from December 1996 to May 1997.



Duration of Ice



Integrated Ice Area

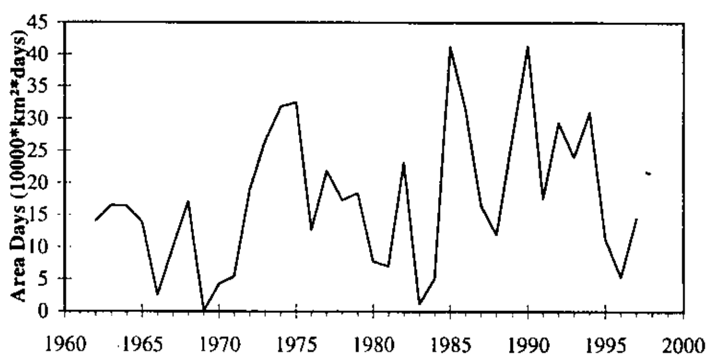


Fig.16. The time series of the monthly mean ice area seaward of Cabot Strait (top panel), the duration of ice (middle panel) and the annual integrated ice area (sum of the area times the number of days, bottom panel).

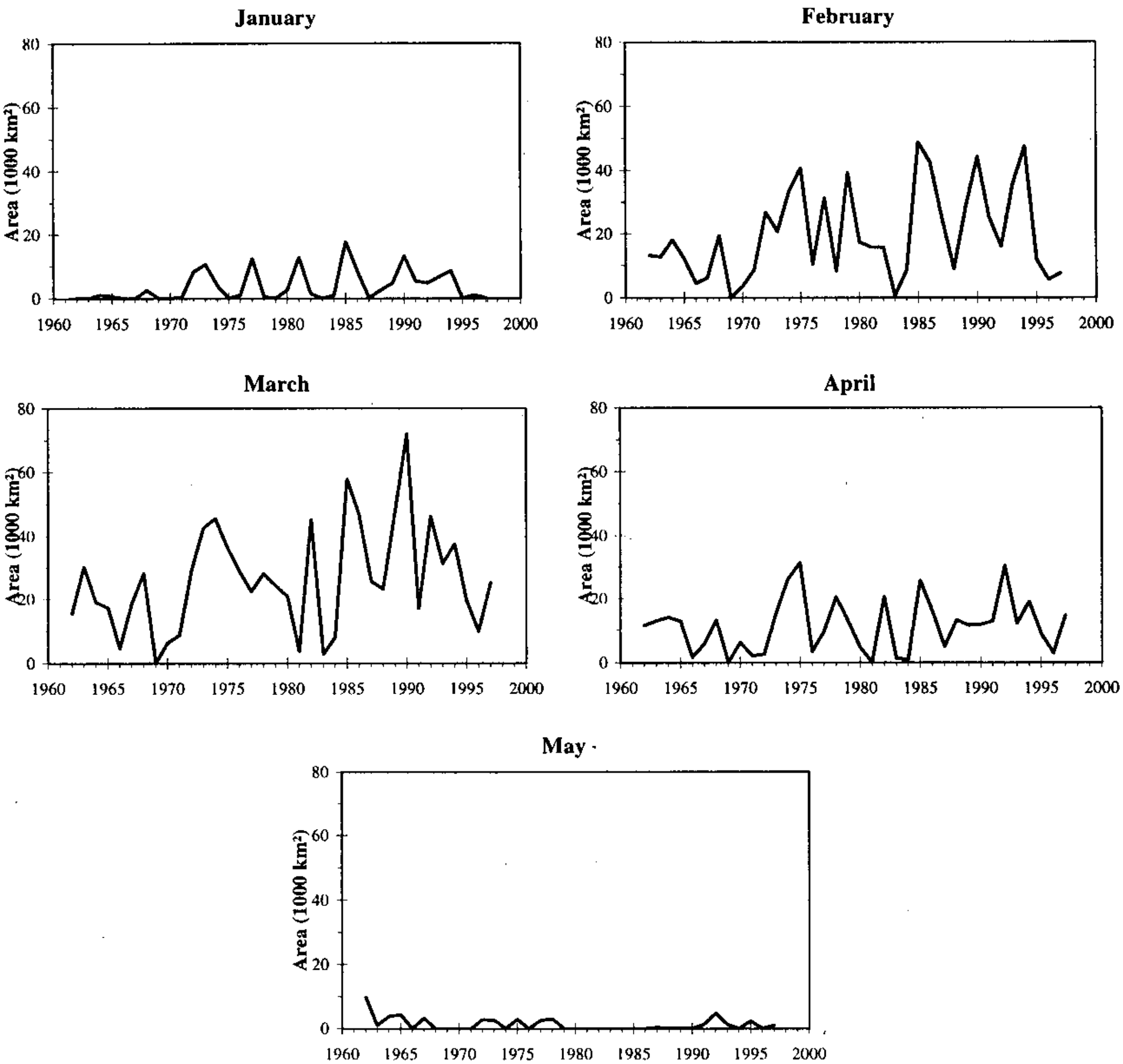


Fig.17. The time series of ice area seaward of Cabot Strait by month.

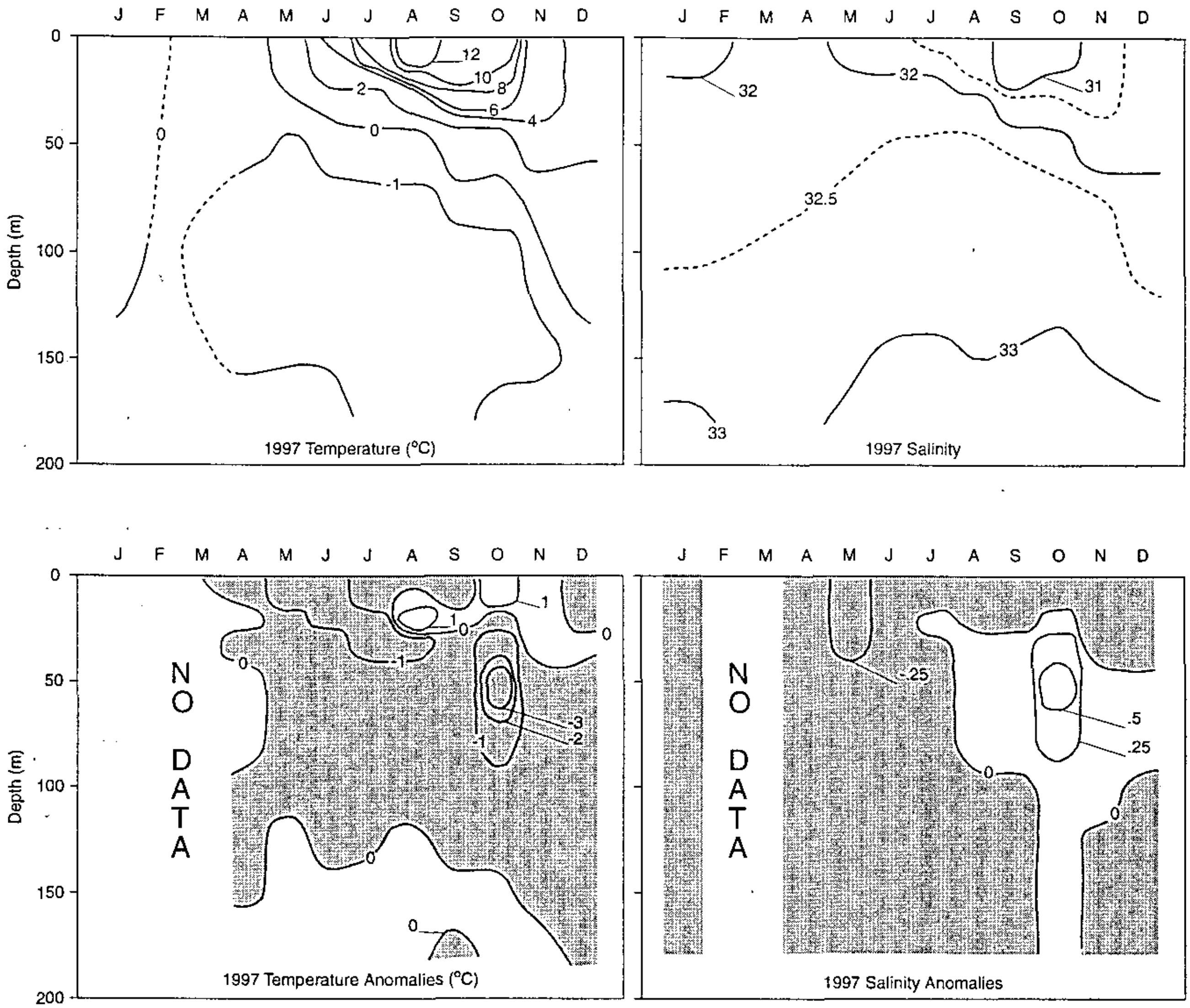


Fig. 18. Monthly mean (top panel) and anomalies relative to the 1961-90 long-term average (bottom panel) of temperature and salinity at Station 27 as a function of depth during 1997. The negative (colder, fresher) anomalies are shaded.

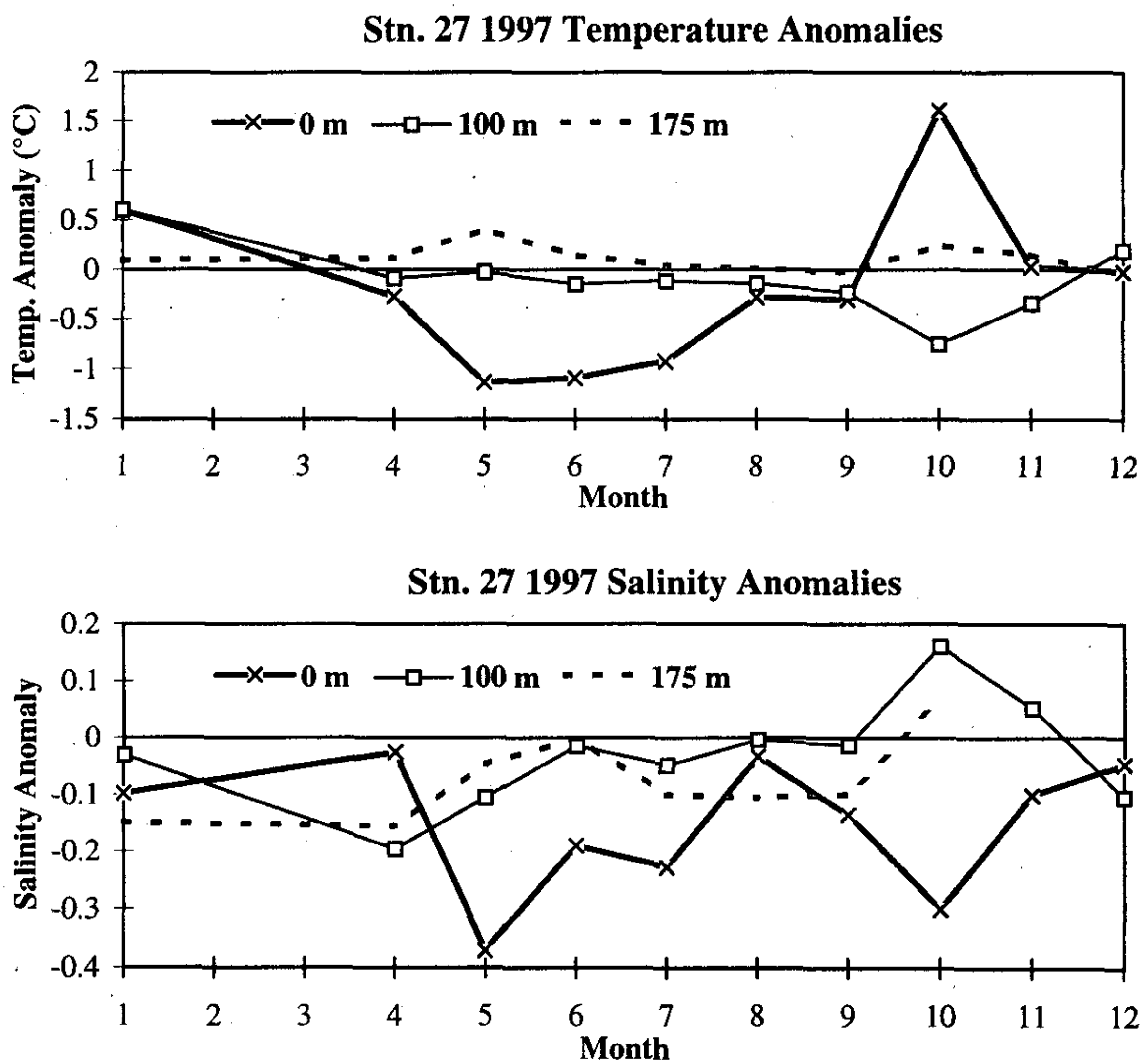


Fig.19. Monthly temperature (top panel) and salinity (bottom panel) anomalies at 0, 100, and 175 m at Station 27 during 1997.

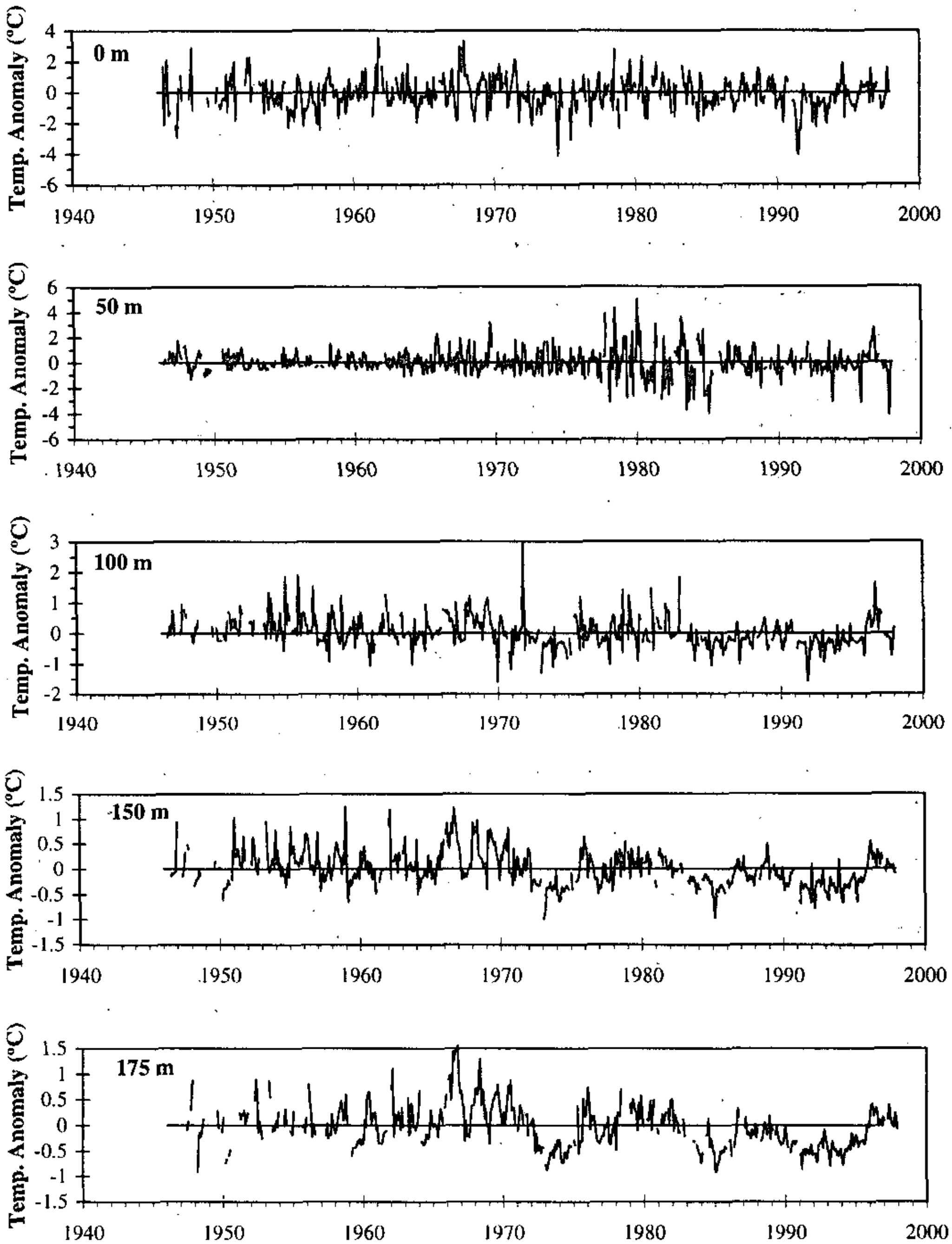


Fig.20. Monthly mean temperature anomalies relative to the long term mean (1961-90) at selected depths from Station 27.

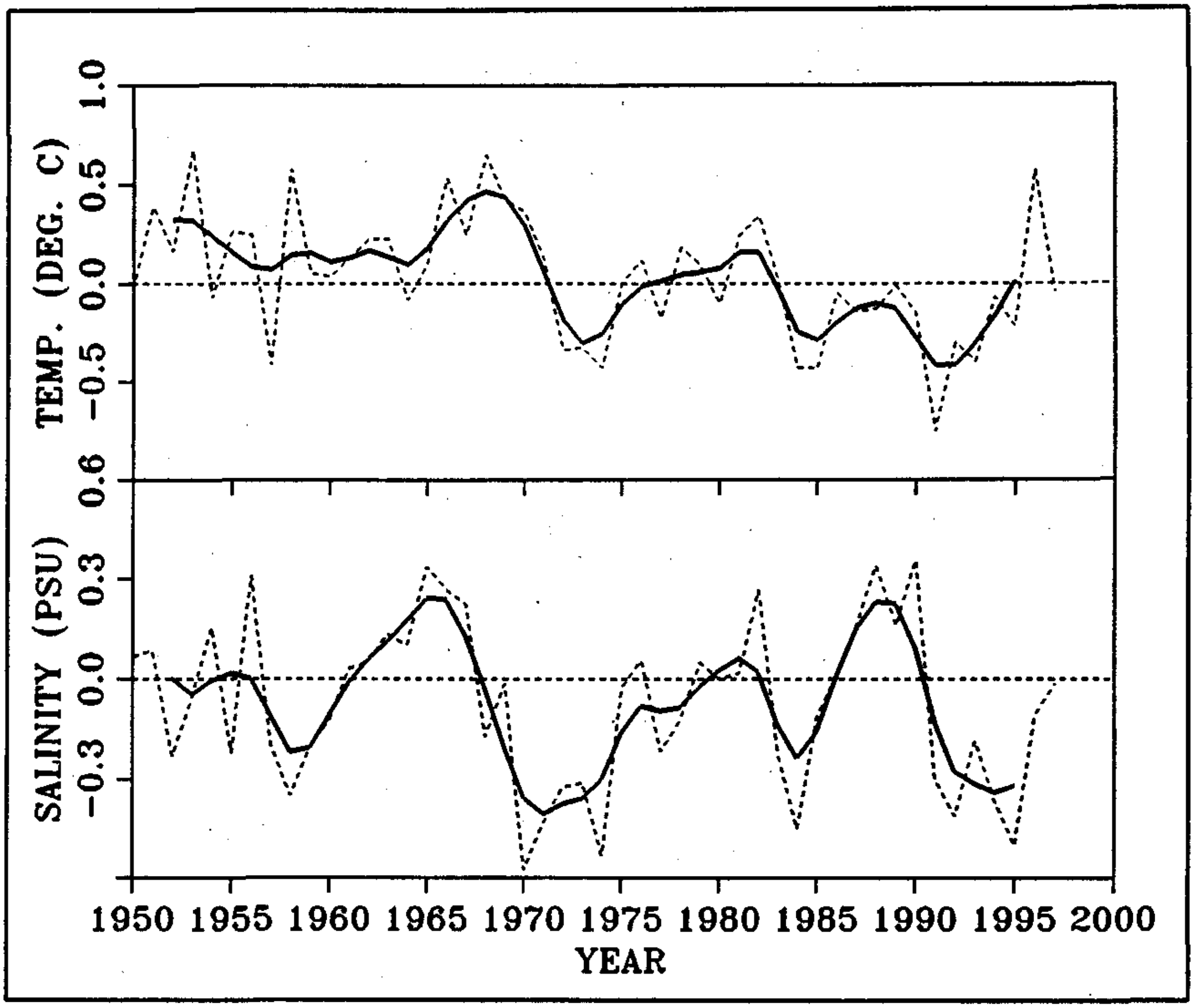


Fig.21. The vertically averaged (0-175 m) temperature and (0-50 m) salinity from Station 27.

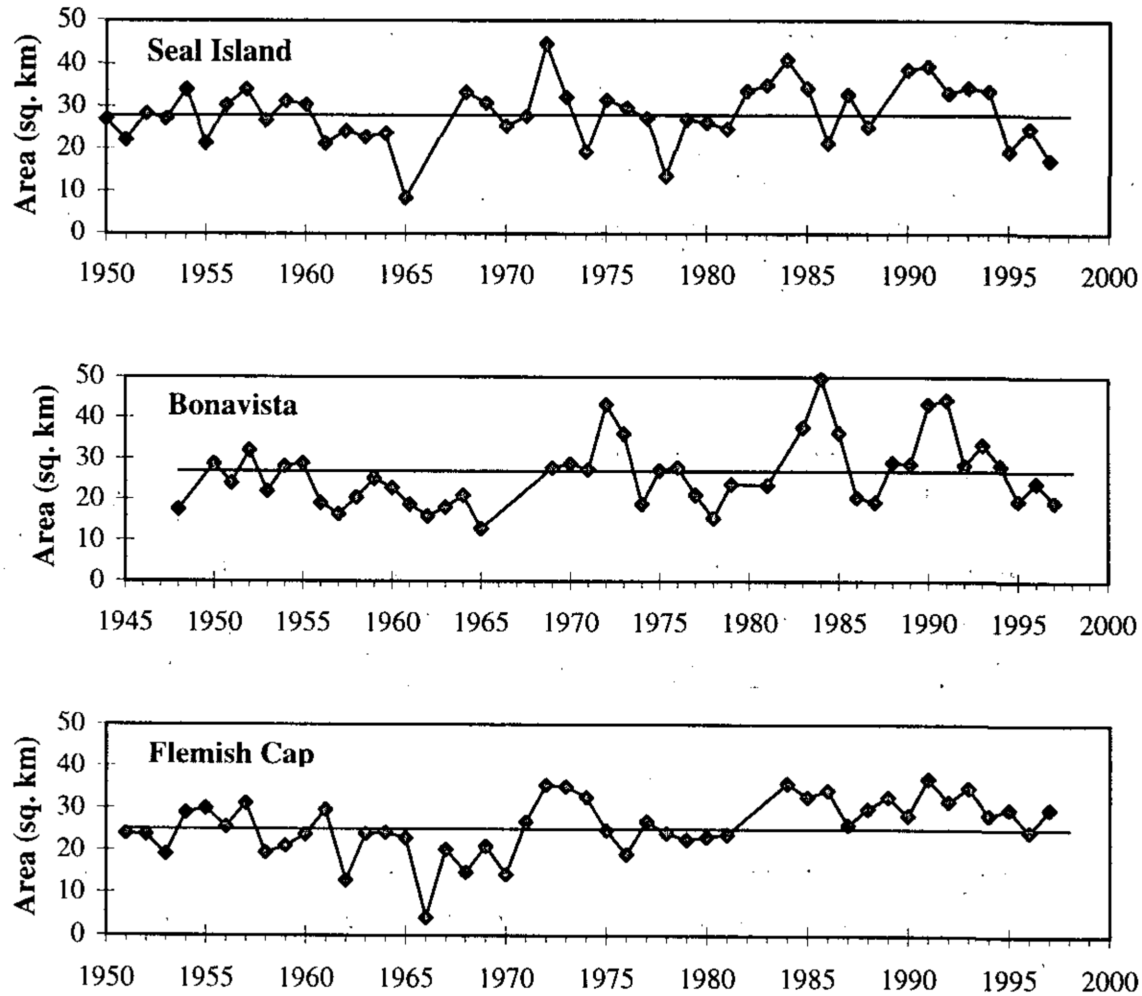


Fig.22. The CIL area (in km^2) during the summer along standard sections off Seal Island (southern Labrador), Bonavista Bay (northern Newfoundland) and Flemish Cap (Grand Banks).

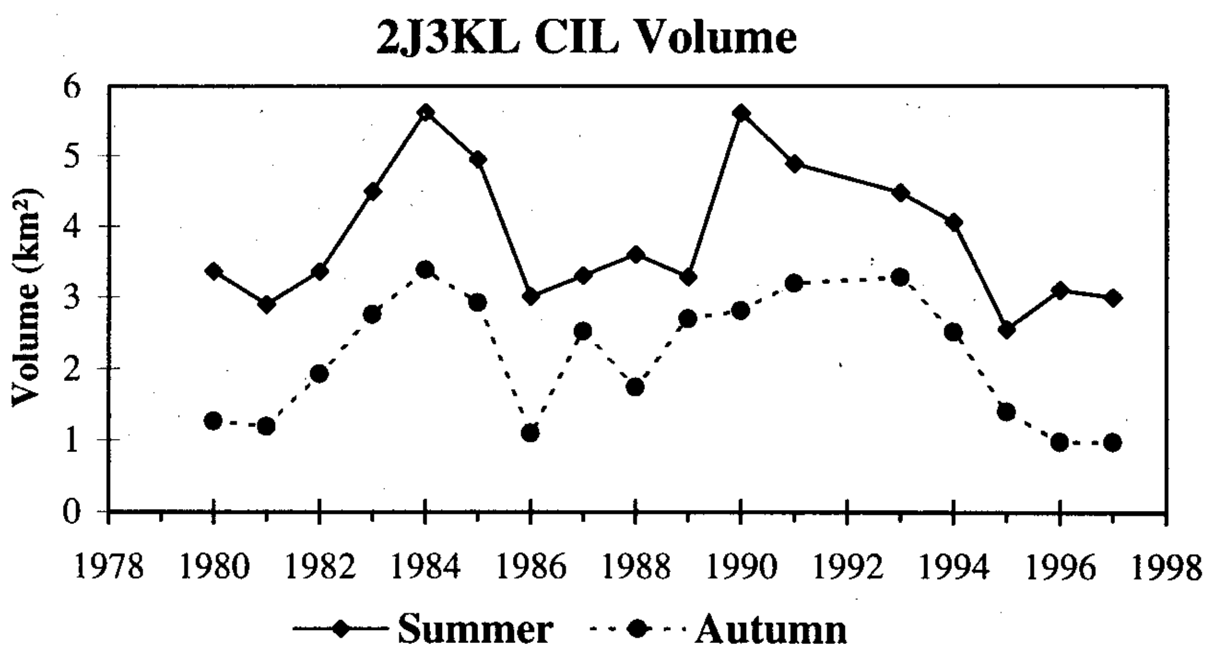


Fig.23. The CIL volume in the summer and fall within divisions 2J and 3KL.

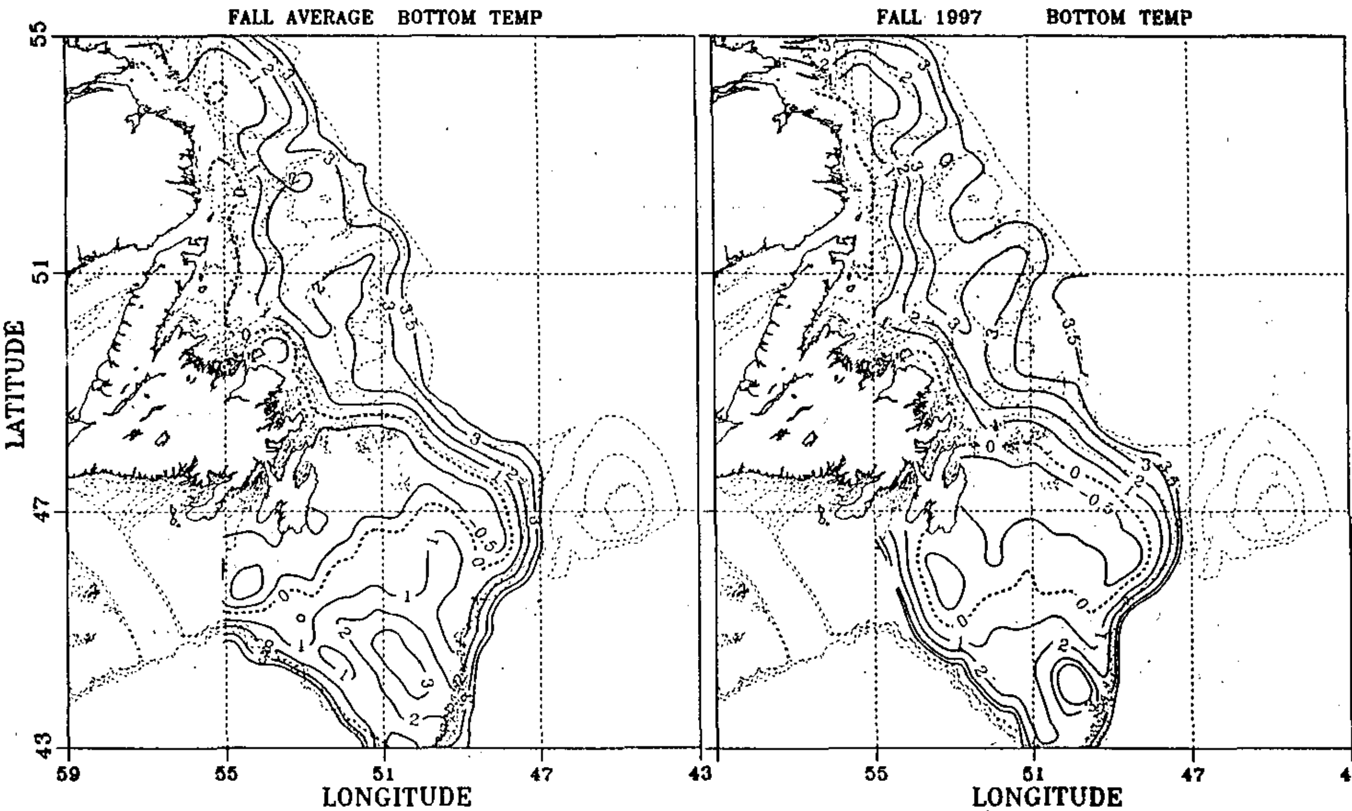


Fig.24. The 1961-90 average (left panel) and the 1997 (right panel) bottom temperatures during the autumn for the Newfoundland Shelf region.

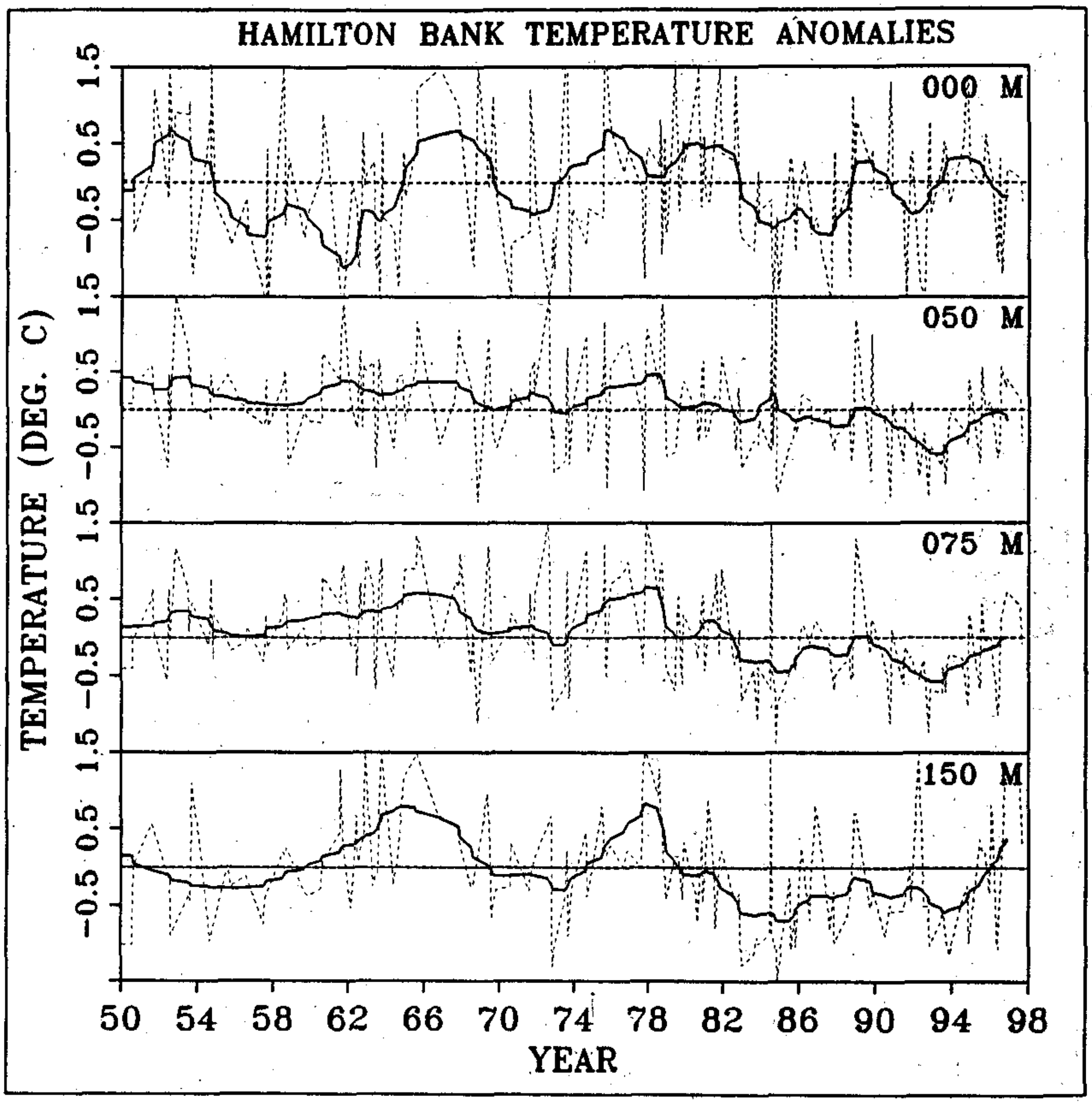


Fig.25. Monthly mean temperature anomalies at selected depths on Hamilton Bank in division 2J. The solid line represents the smoothed temperature anomalies.

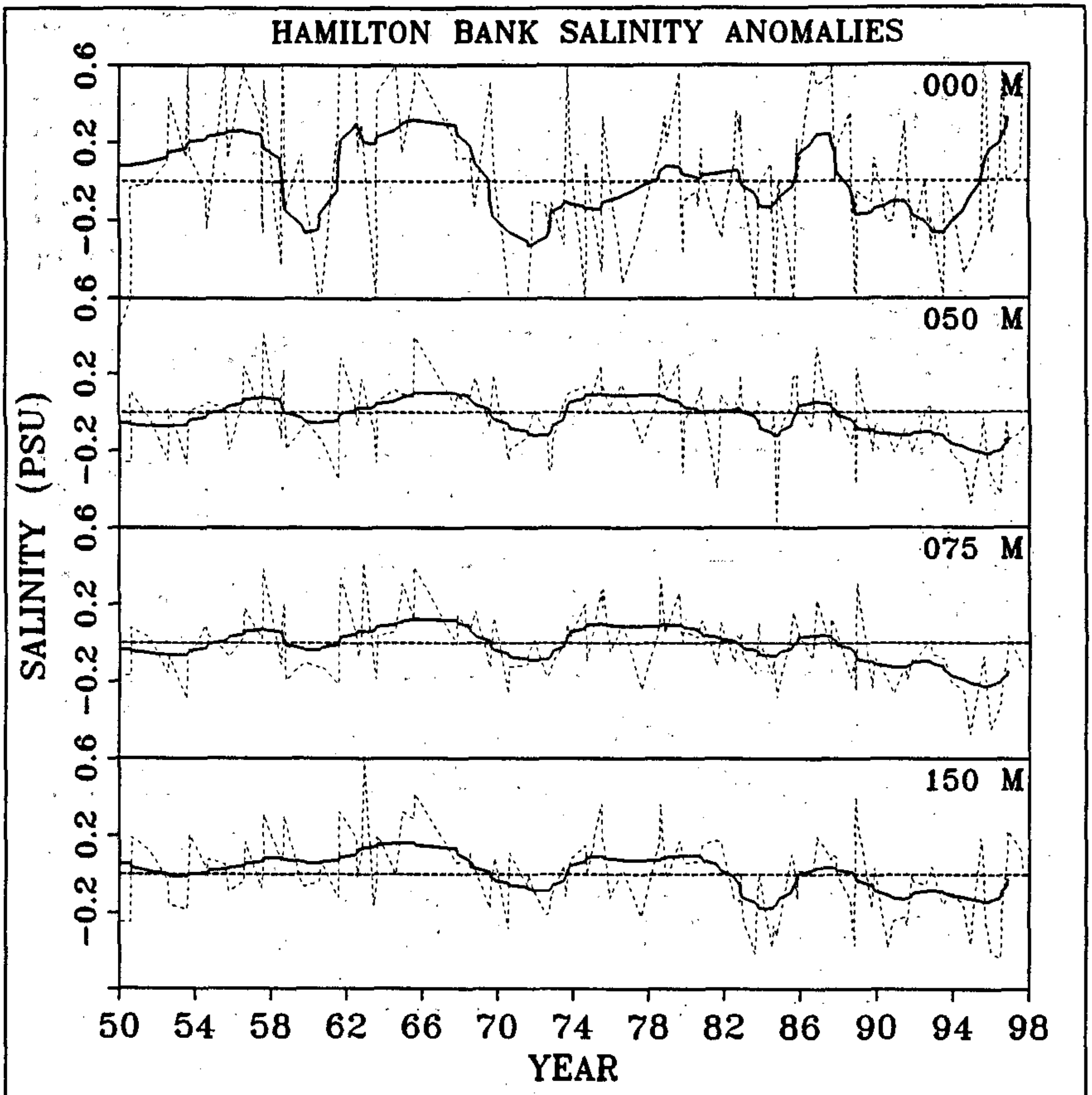


Fig.26. Monthly mean salinity anomalies at selected depths on Hamilton Bank in division 2J. The solid line represents the smoothed salinity anomalies.

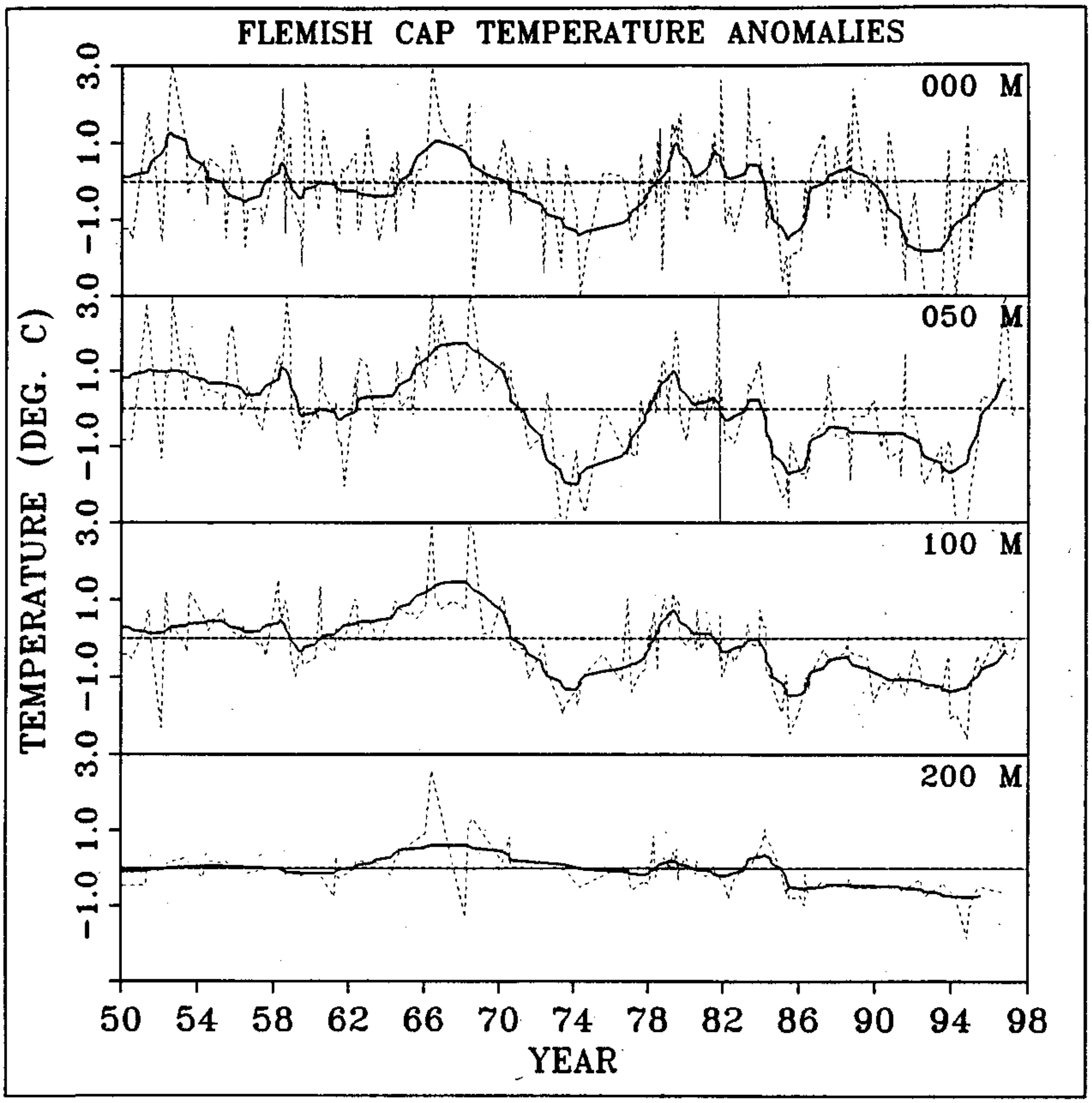


Fig.27. Monthly mean temperature anomalies at selected depths over Flemish Cap in division 3M. The solid line represents the smoothed temperature anomalies.

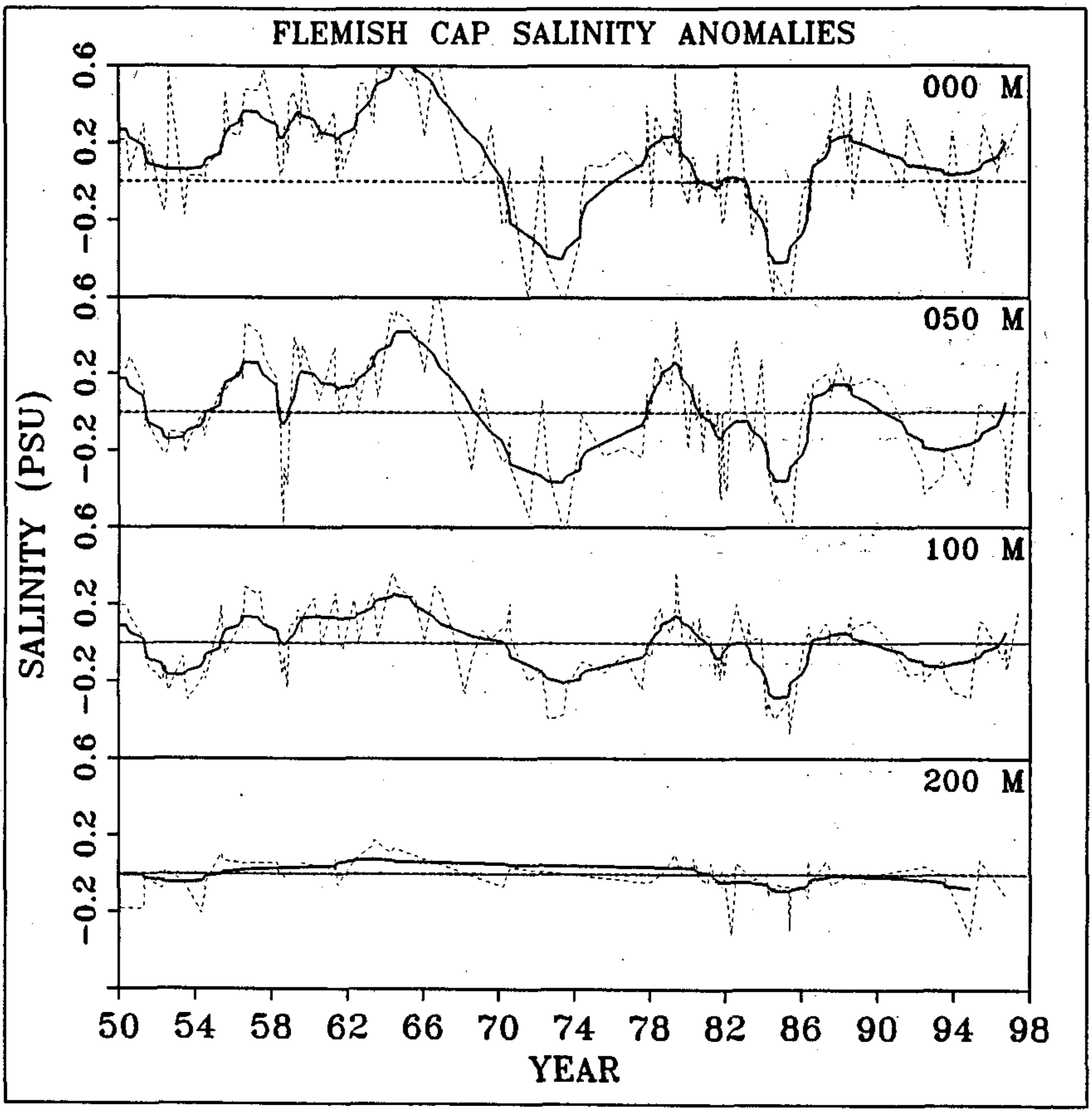


Fig.28. Monthly mean salinity anomalies at selected depths over Flemish Cap in division 3M. The solid line represents the smoothed salinity anomalies.

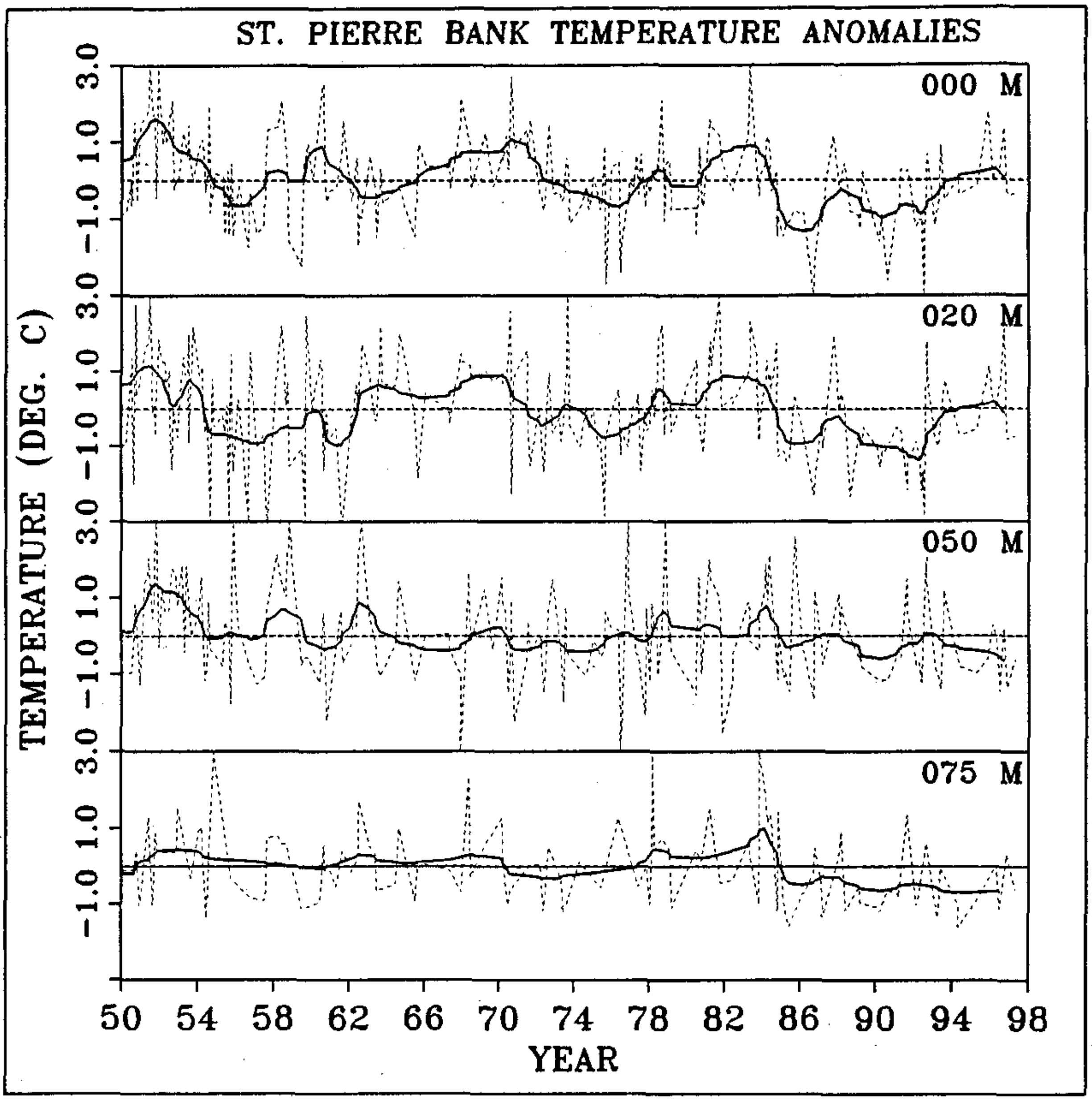
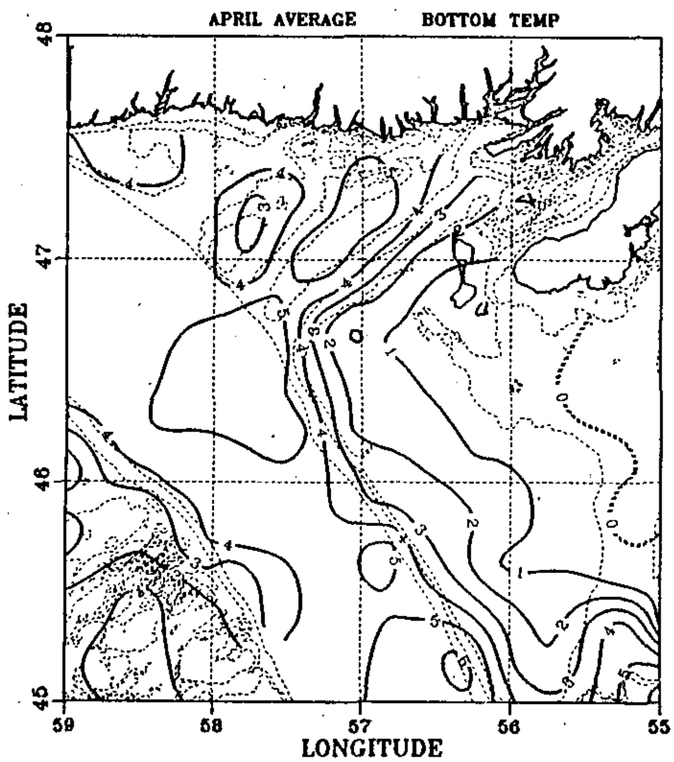


Fig.29. Monthly mean temperature anomalies at selected depths over St. Pierre Bank. The solid line represents the smoothed temperature anomalies.



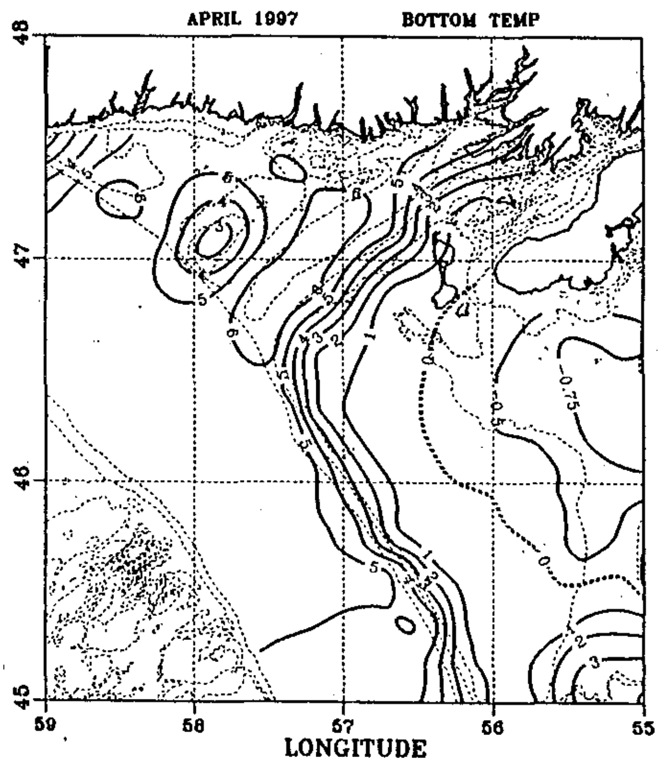


Fig.30. The 1961-90 average (left panel) and the 1997 (right panel) bottom temperatures during April off southern Newfoundland.

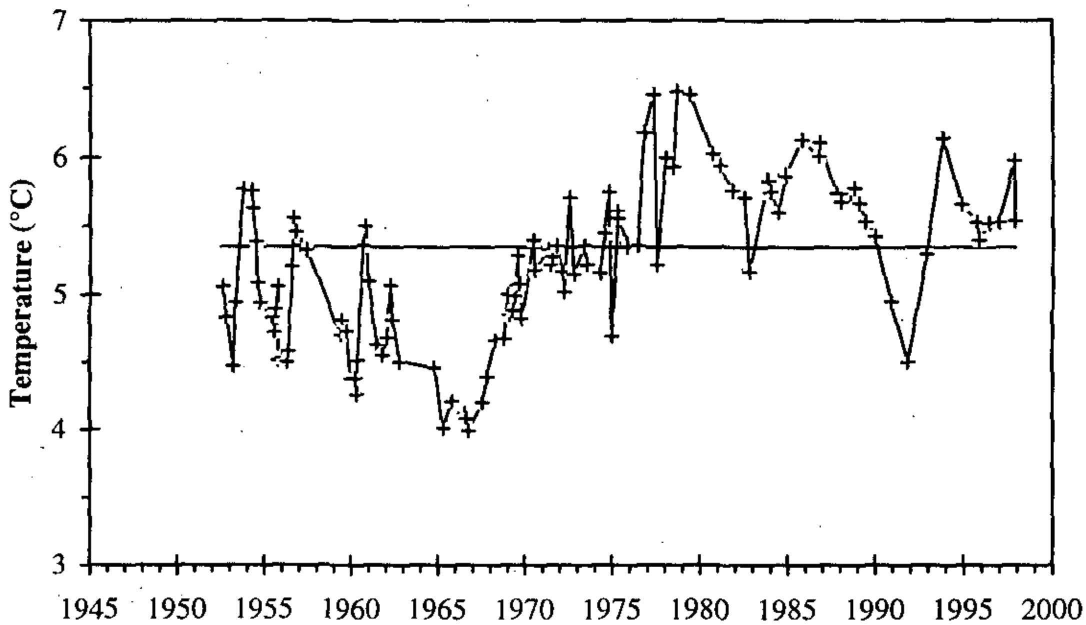


Fig.31. The average temperature for the 200-300 m deep layer in Cabot Strait. The horizontal line represents the long-term (1961-90) mean.

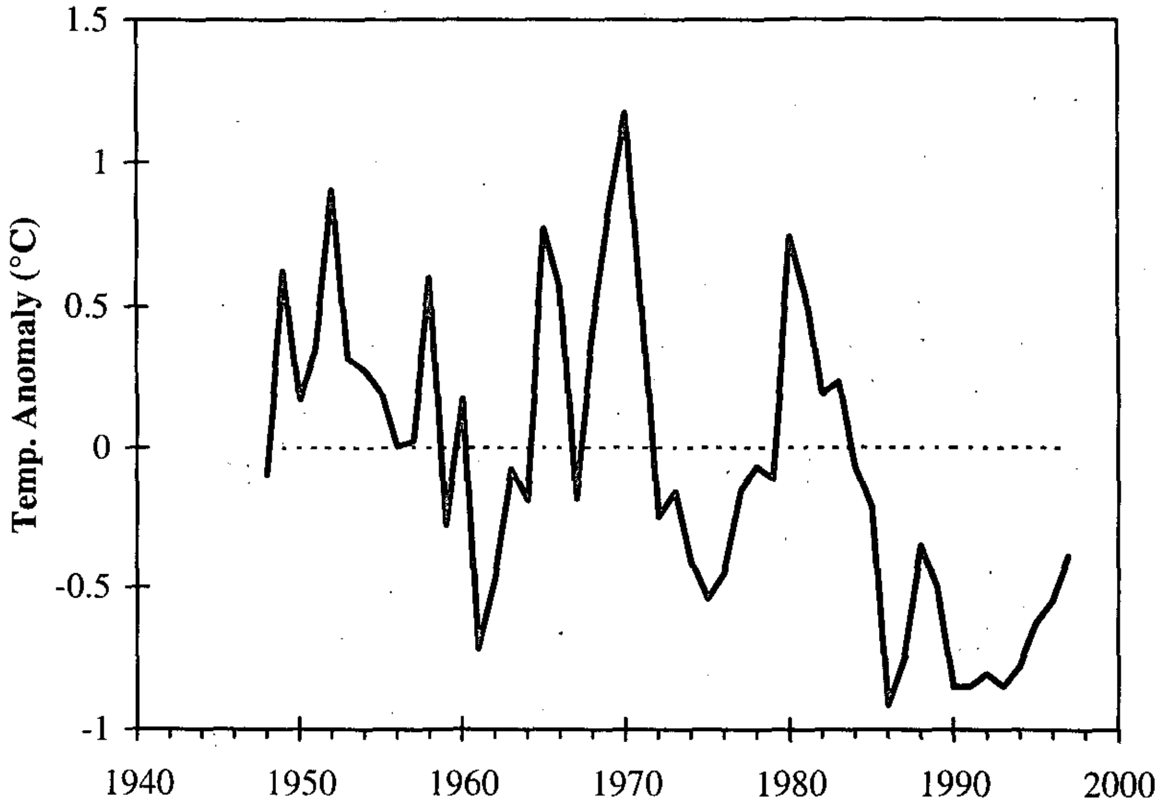
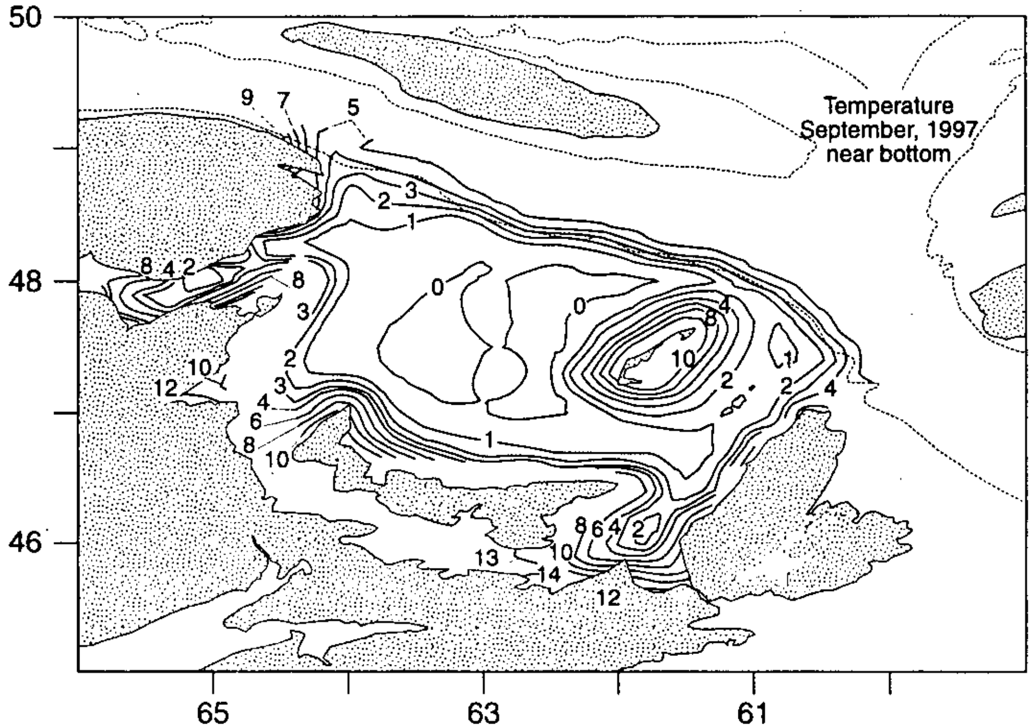


Fig.32. Anomalies of the CIL core temperatures (extrapolated to July 15) for the Gulf of St. Lawrence from the 1948-94 mean (0.08°C).



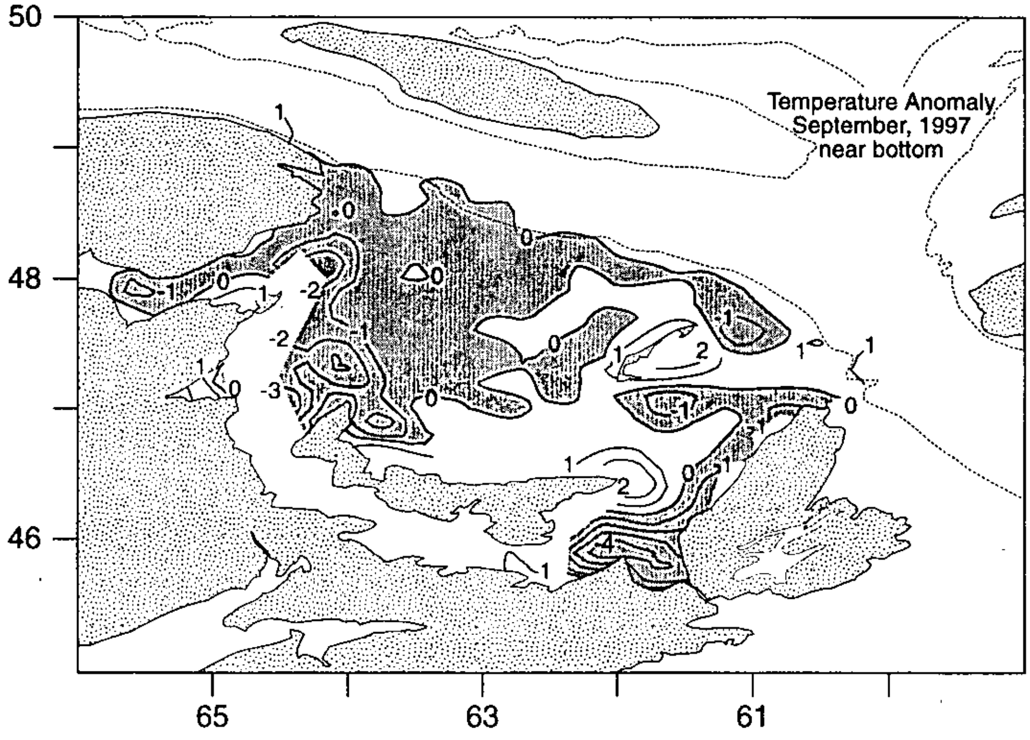


Fig. 33. Near bottom temperature (top panel) and temperature anomalies (bottom panel) in the southern Gulf of St. Lawrence in September 1997. Negative anomalies are shaded and the dotted line represents the 200 m isobath.

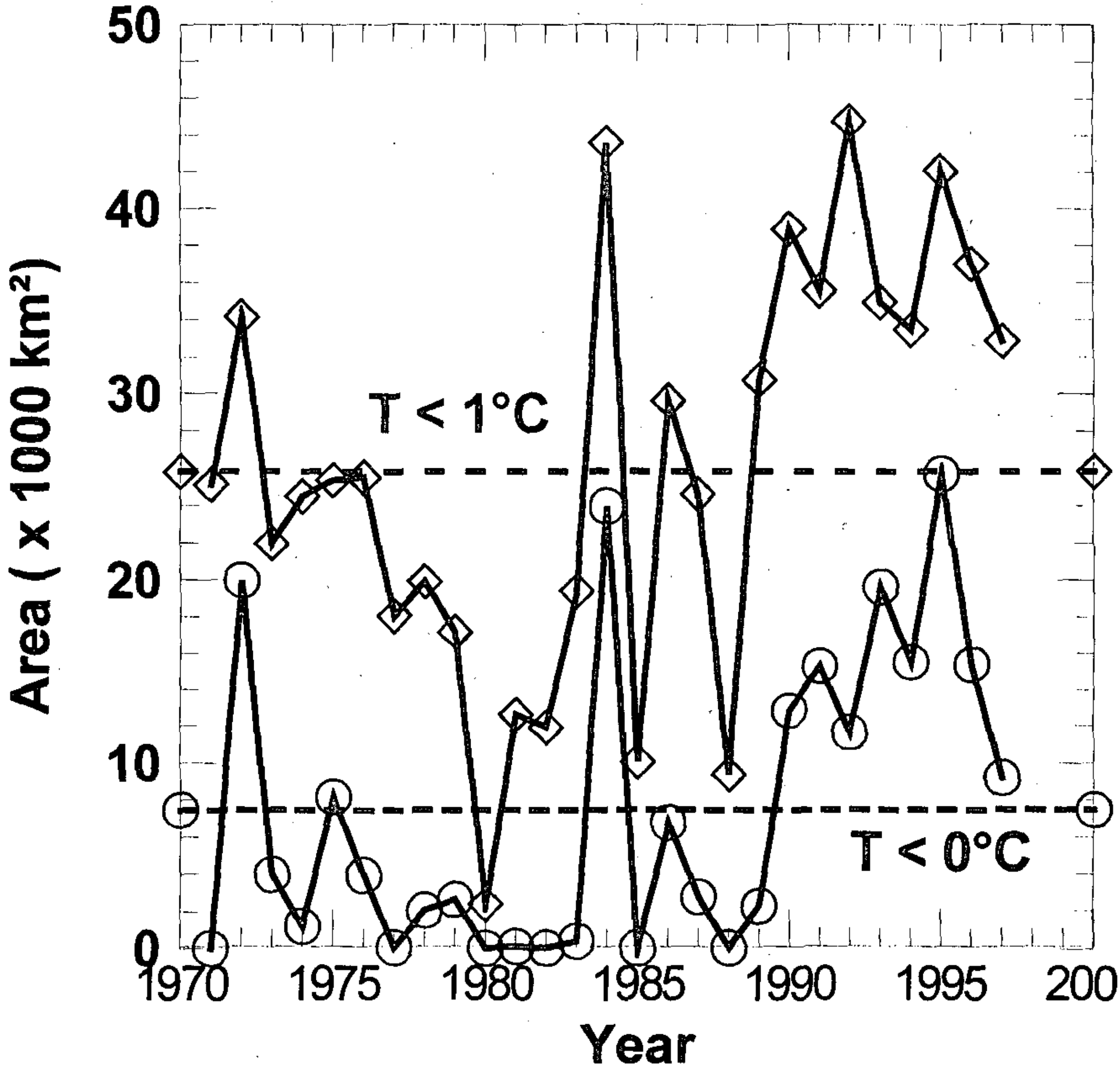


Fig.34. Area of the Magdallen Shallows with bottom temperatures <0°C and <1°C during September.

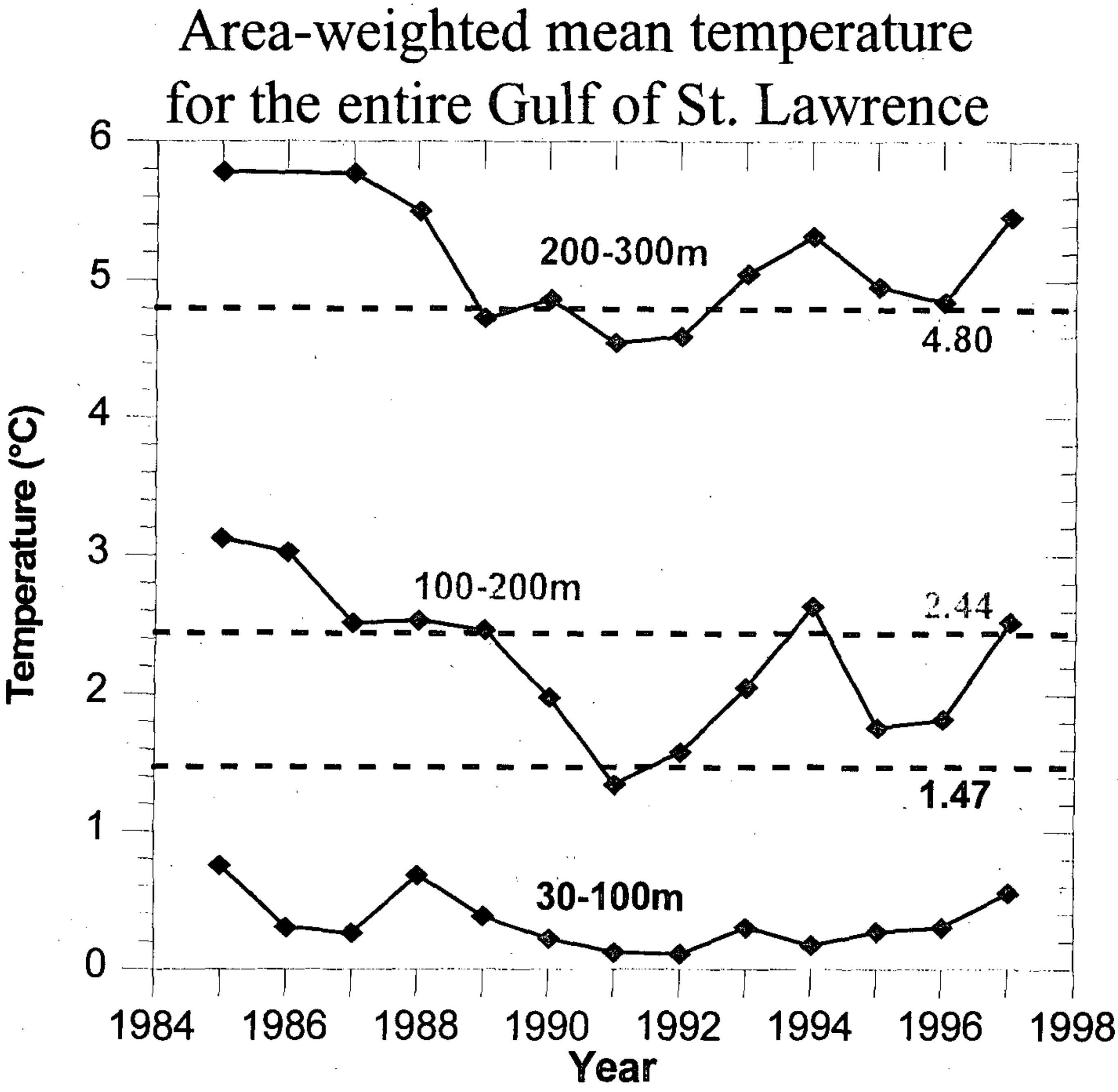


Fig.35. The temperature of the 30-100 m, the 100-200 m and the 200-300 m layers in the Gulf of St. Lawrence during August-September. The dashed lines indicate the long-term averages based upon Petrie (1990).

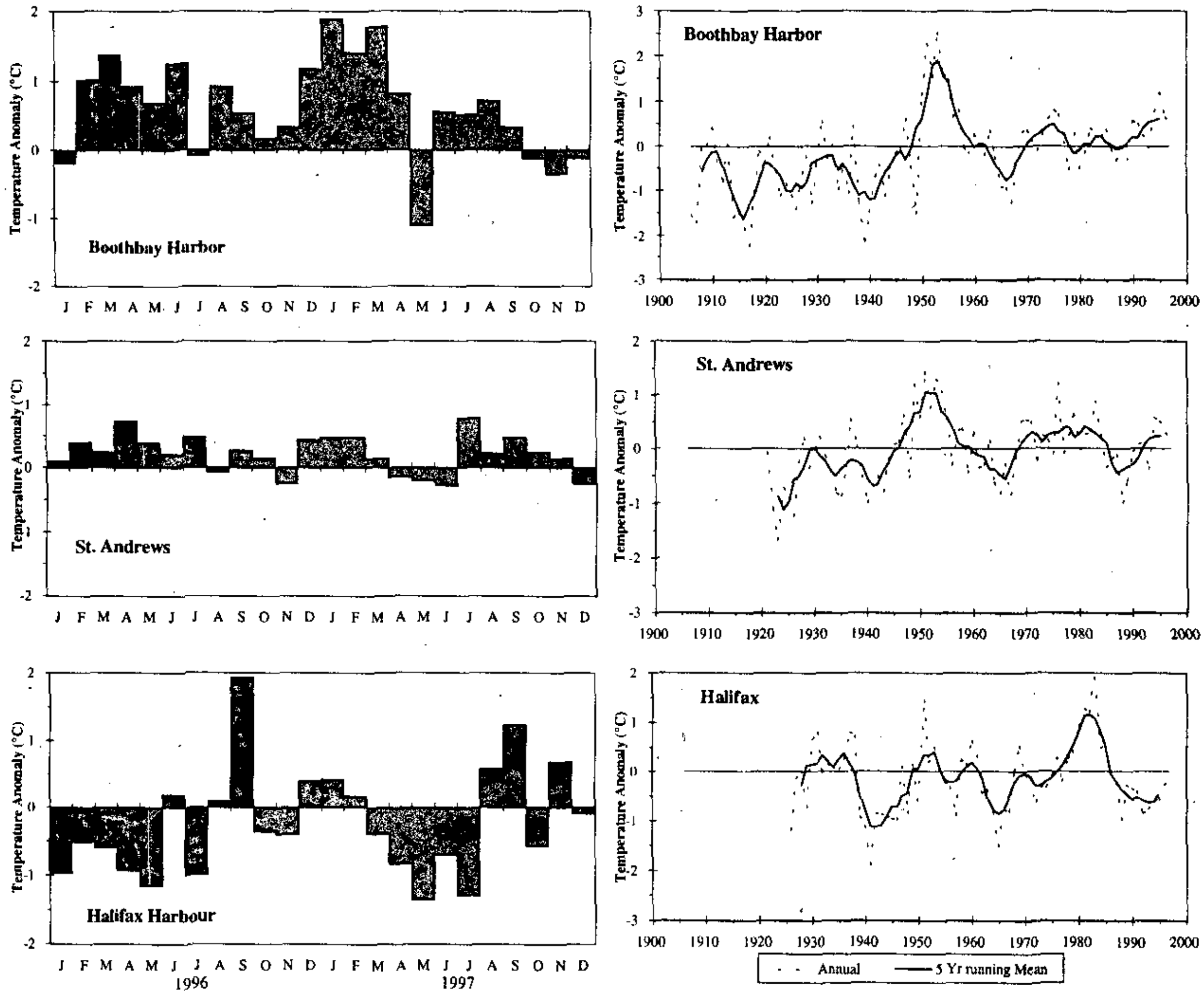


Fig.36. The monthly sea surface temperature anomalies during 1996 and 1997 (left) and the annual temperature anomalies and their 5-year running mean (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961-90 means.

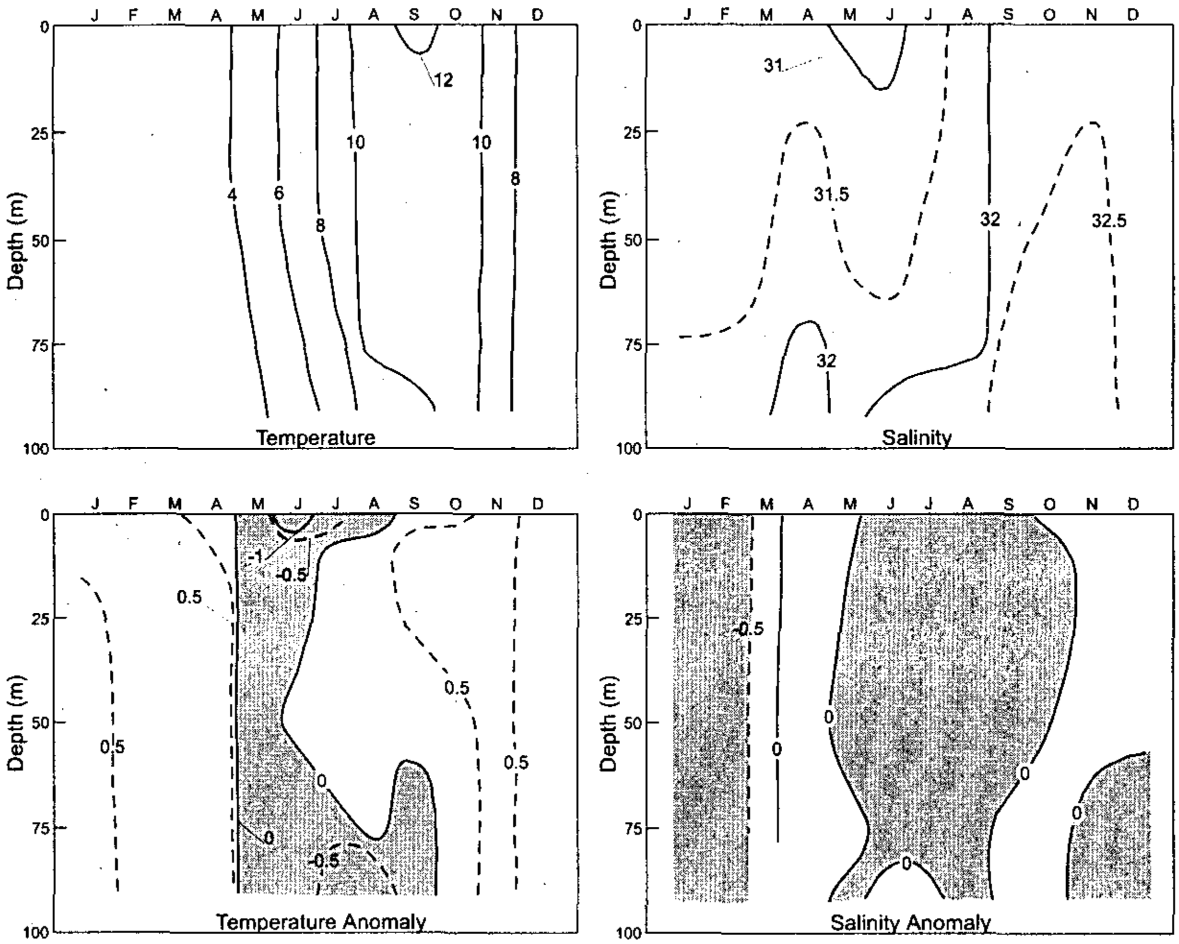


Fig. 37. Monthly temperatures and salinities (top panels) and their anomalies (bottom panels) at Prince 5 as a function of depth during 1997 relative to the 1961-90 means. Shaded areas are negative anomalies.

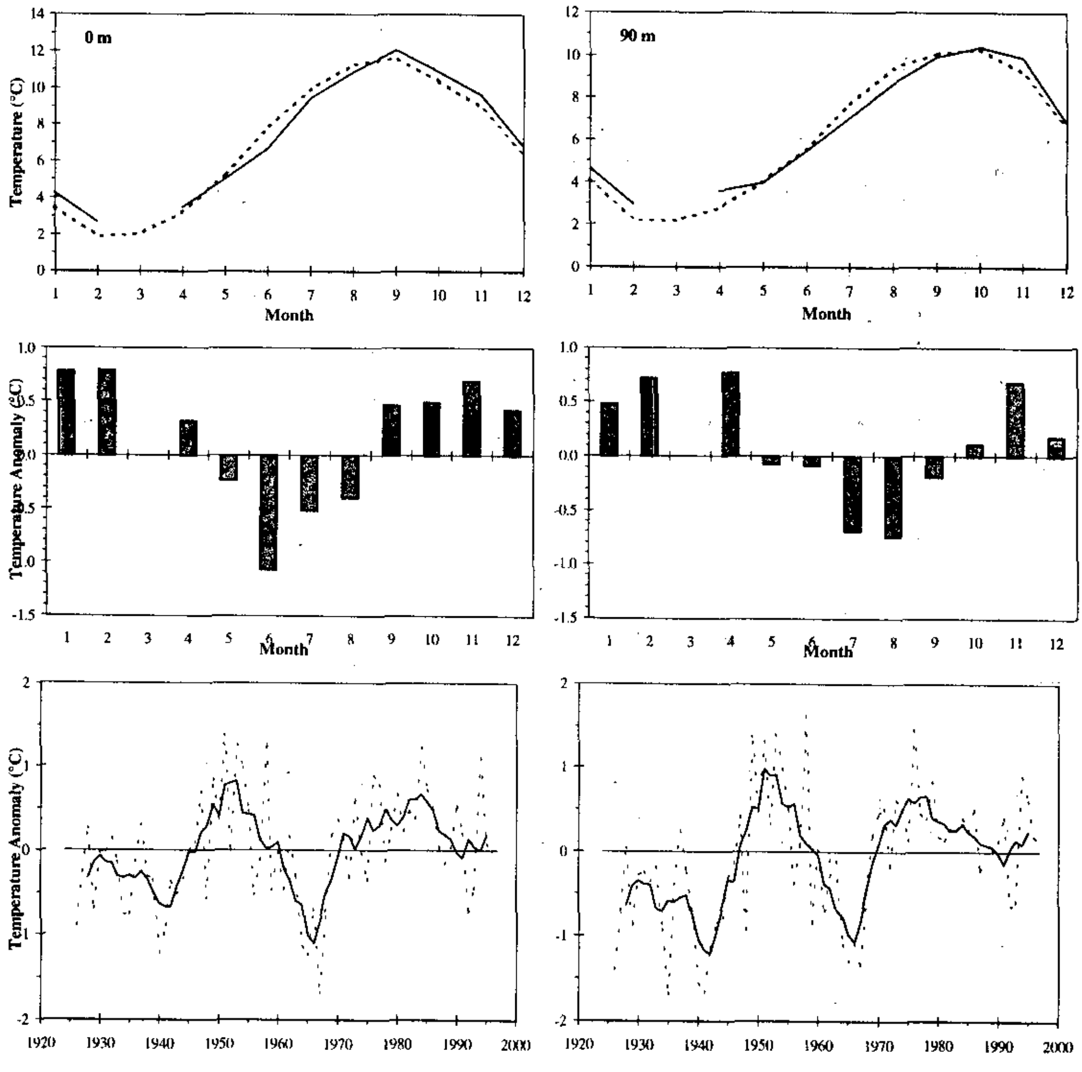


Fig.38. Monthly mean temperatures for 1997 (solid line) and the long-term means (top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panesl the time time series of the annual means (dashed line) and 5-yr running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

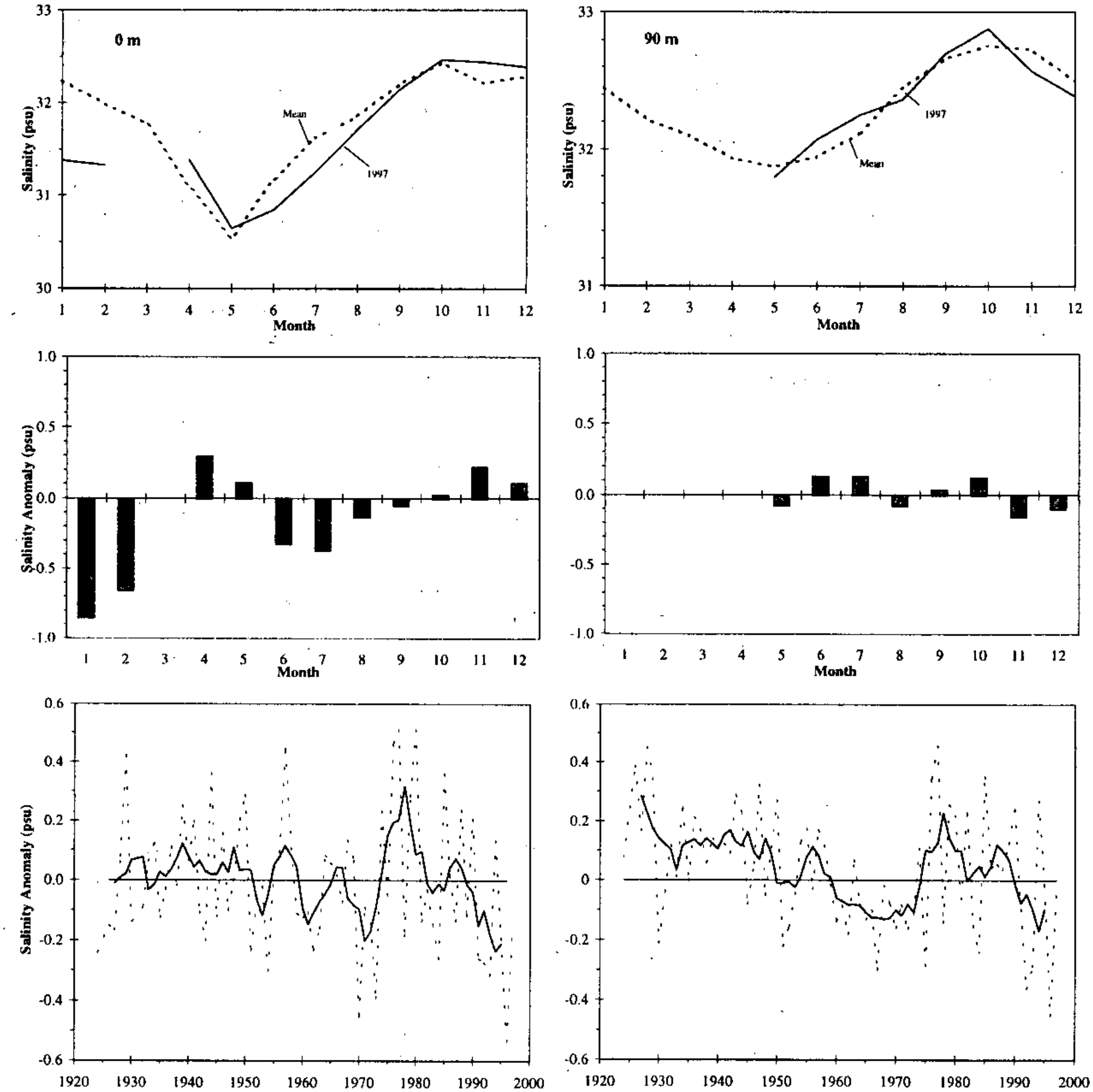


Fig.39. Monthly mean salinities for 1997 (solid line) and the long-term means (top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panesl the time time series of the annual means (dashed line) and 5-yr running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

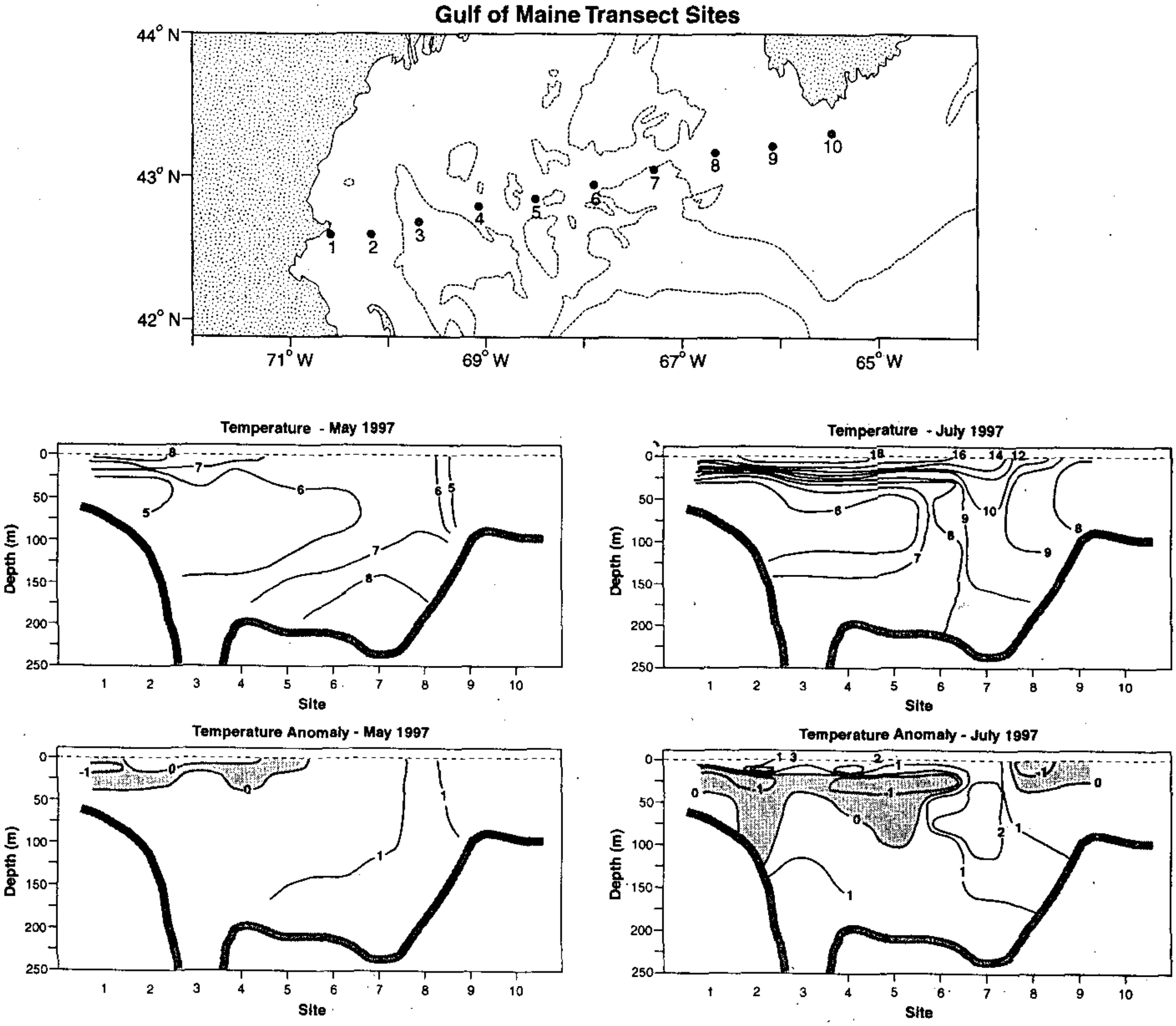


Fig. 40. The temperature (middle panels) and temperature anomalies (bottom pannels) in degrees Celsius along an XBT transect (top panel) across the Gulf of Maine during May and July 1997.

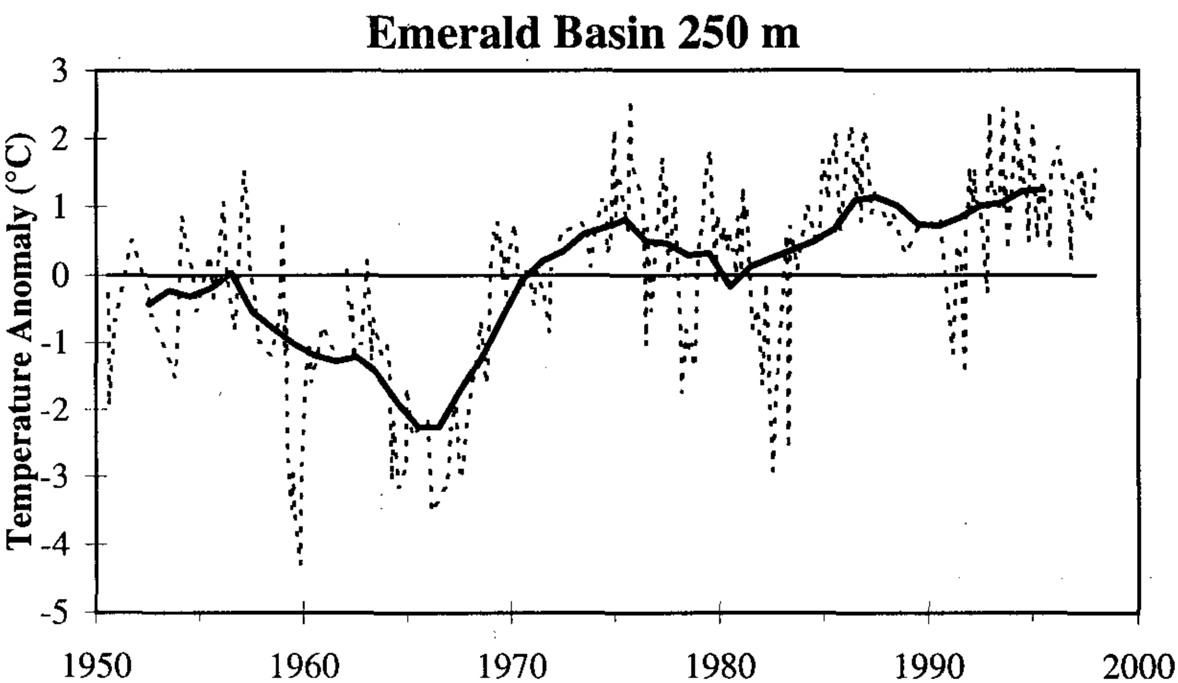
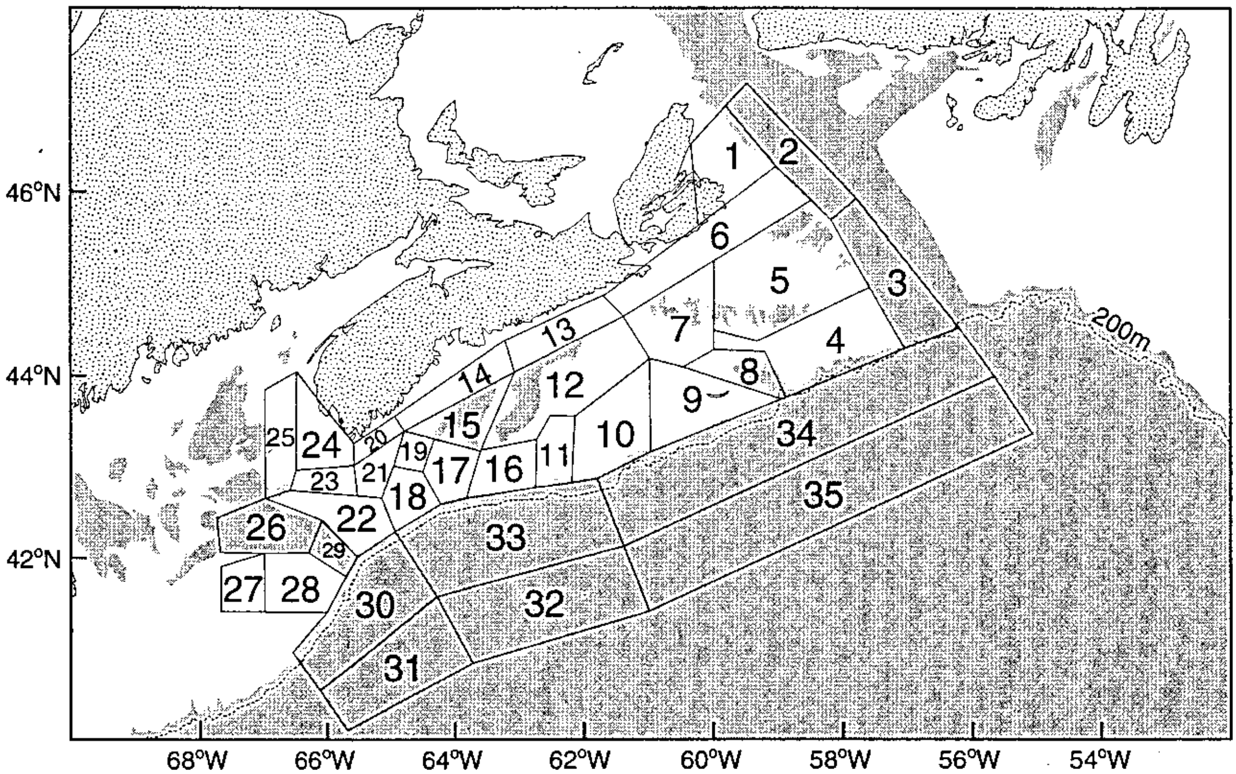


Fig.41. Monthly mean temperature anomalies relative to 1961-90 (dashed line) and estimates of their 5-yr running means (solid line) for Emerald Basin at 250 m.



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. 42. The areas in which monthly mean temperature and temperature anomalies were estimated (from Drinkwater and Trites, 1987).

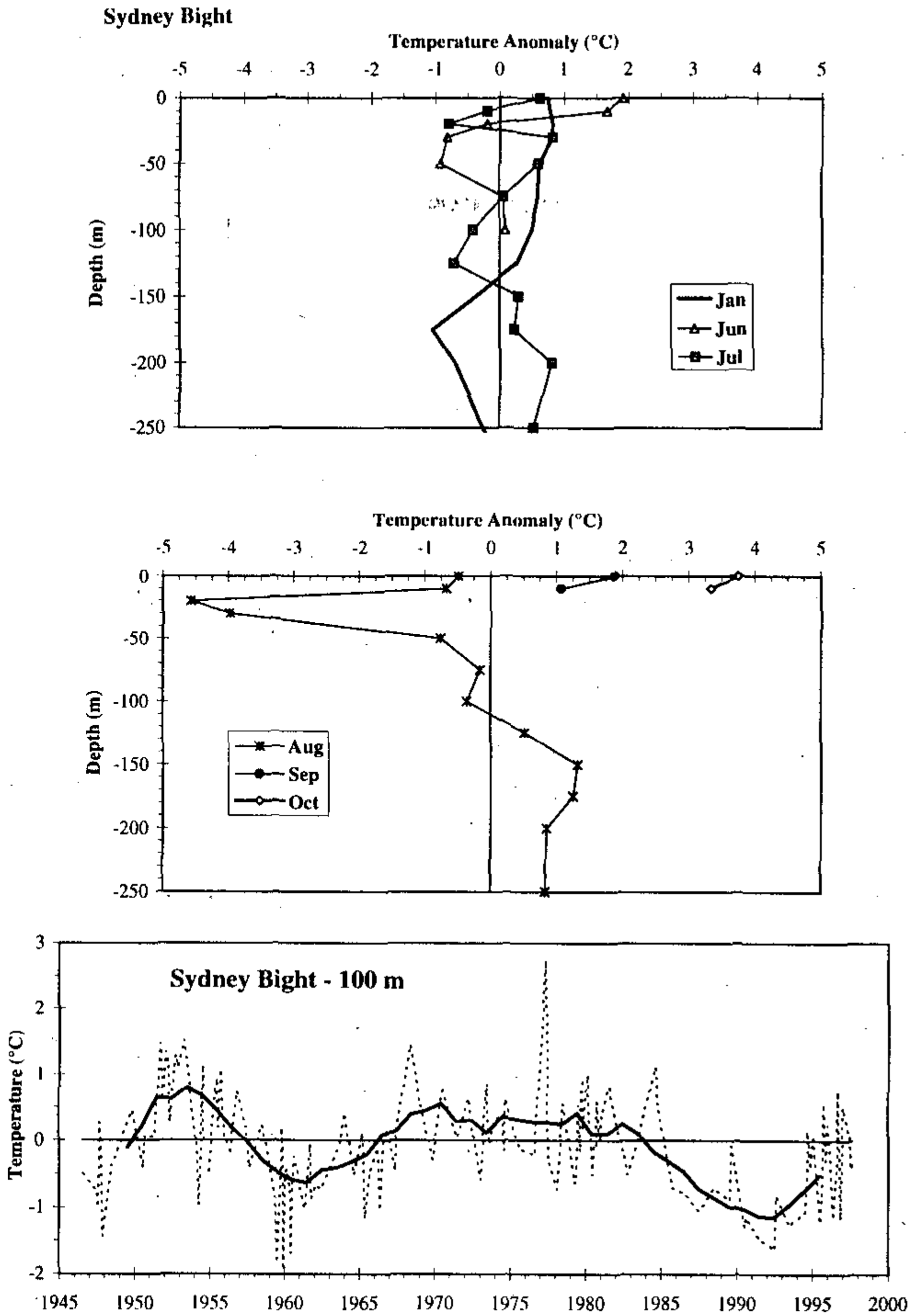


Fig.43. The 1997 monthly anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Sydney Bight (area 1 in Fig. 42).

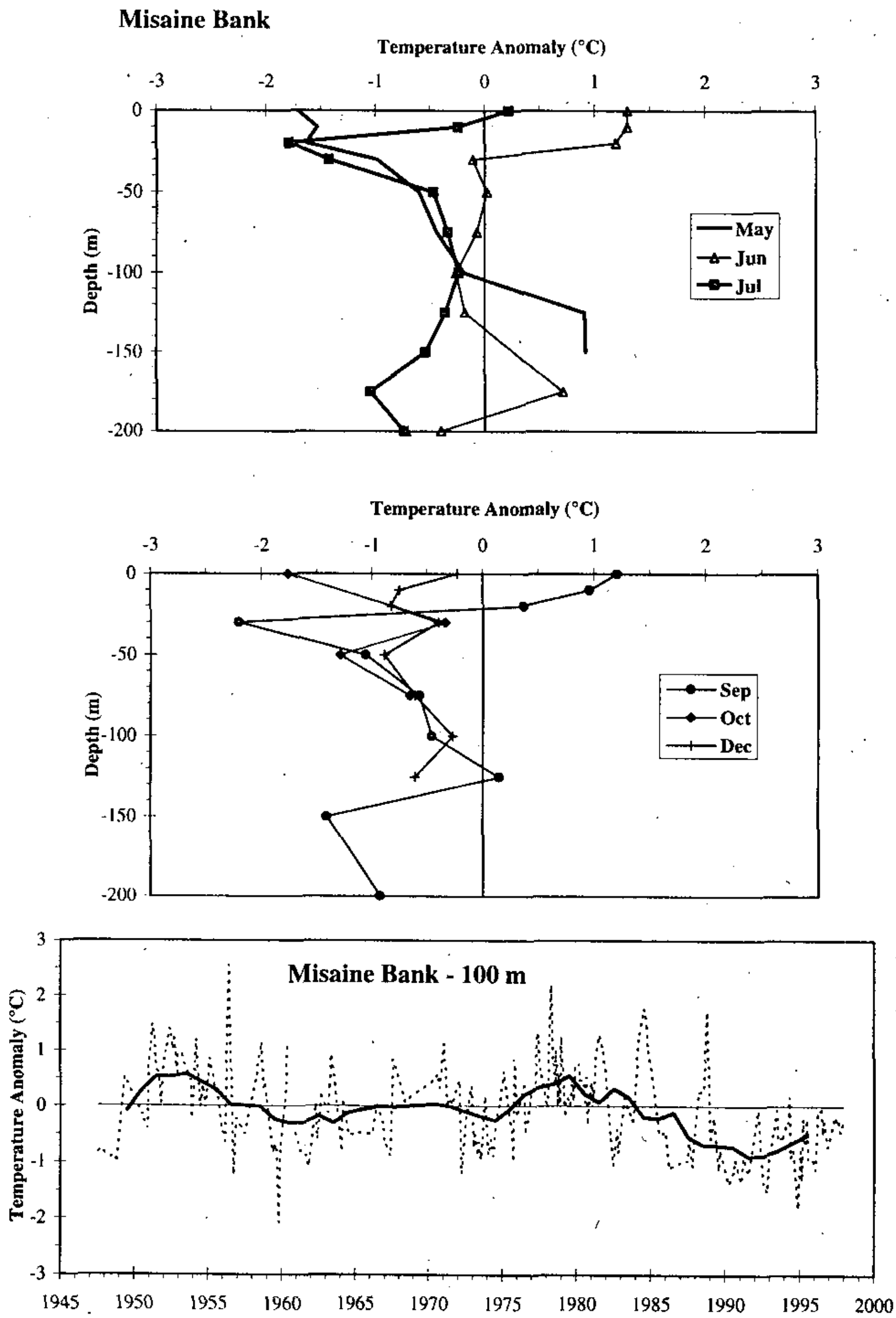


Fig.44. The 1997 monthly anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Misaine Bank (area 5 in Fig. 42).

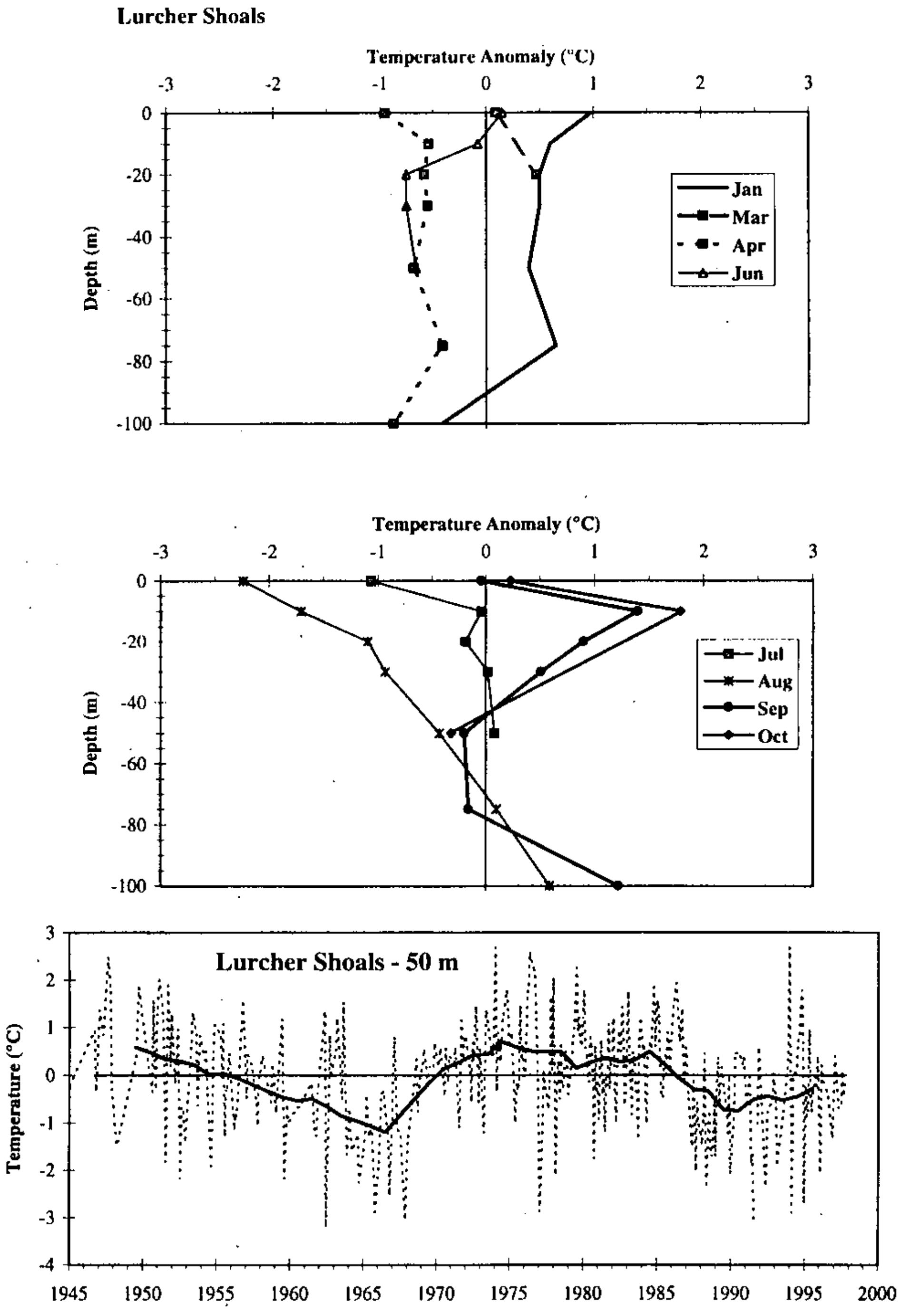


Fig.45. The 1997 monthly anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 50 m (bottom panel) for Lurcher Shoals (area 24 in Fig. 42).

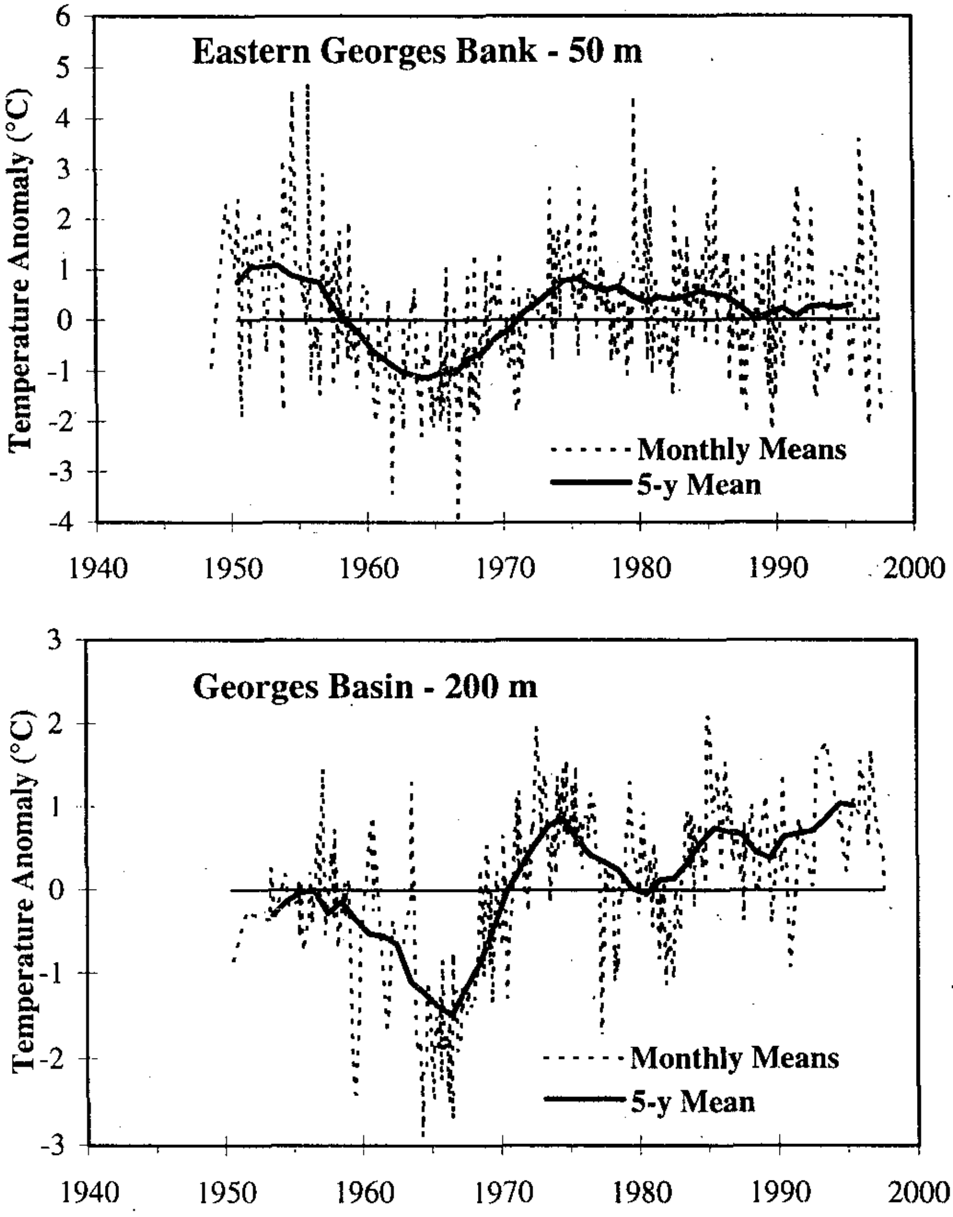
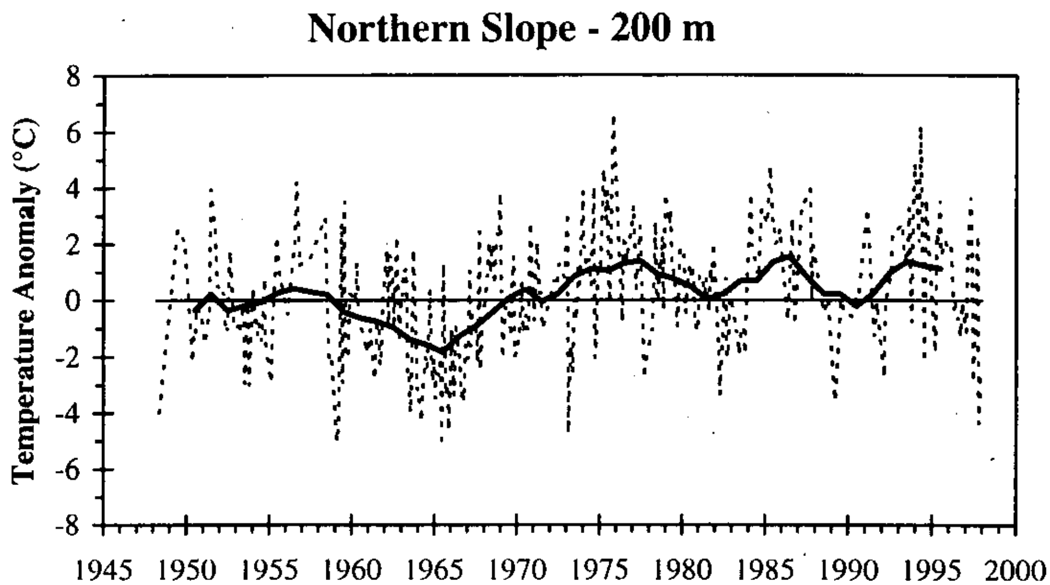


Fig.46. Monthly means (dashed lines) and the 5-yr running means of the annual anomalies at 50 m on eastern Georges Bank (top panel, area 28 in Fig. 42) and 200 m in Georges Basin (bottom panel; area 26 in Fig. 42).



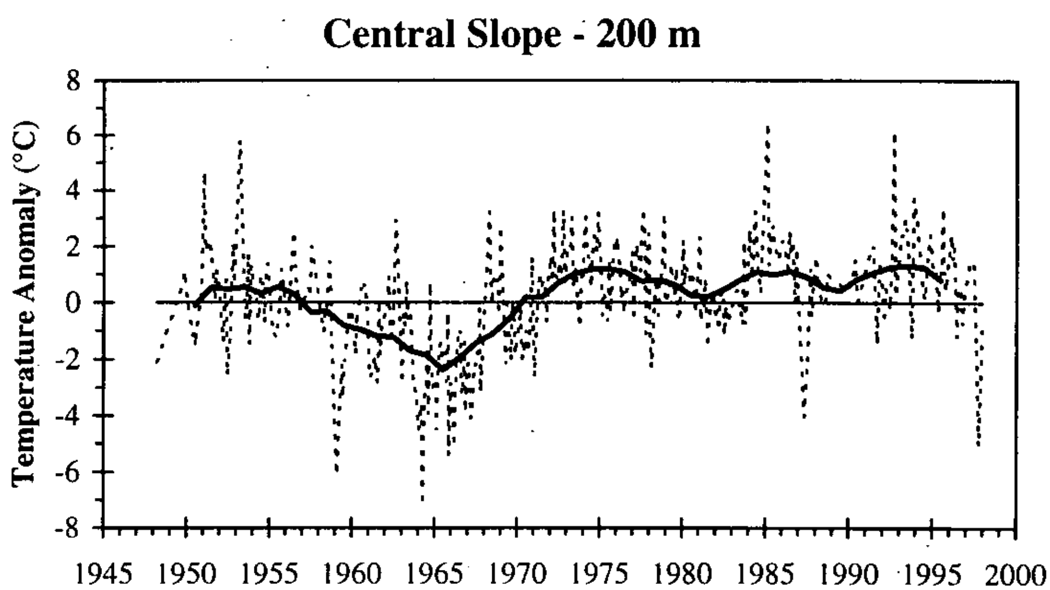


Fig.47. Monthly means (dashed lines) and the 5-yr running means of the annual anomalies at 200 m in the northern and central slope regions (areas 34 and 34 in Fig. 42, respectively).

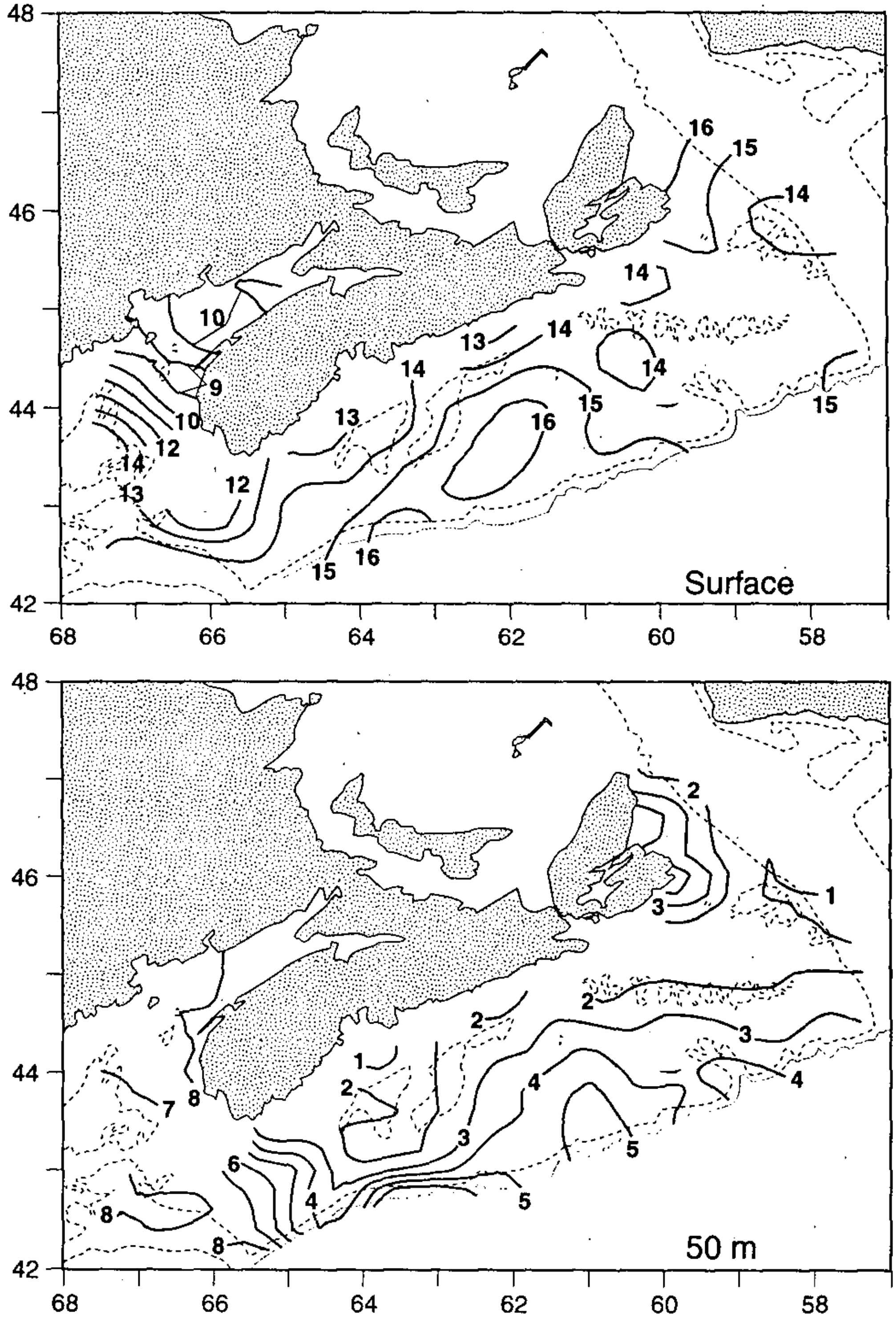


Fig. 48a. Contours of optimally estimated temperatures at the surface (top panel) and 50 m (bottom panel) during the 1997 July groundfish survey.

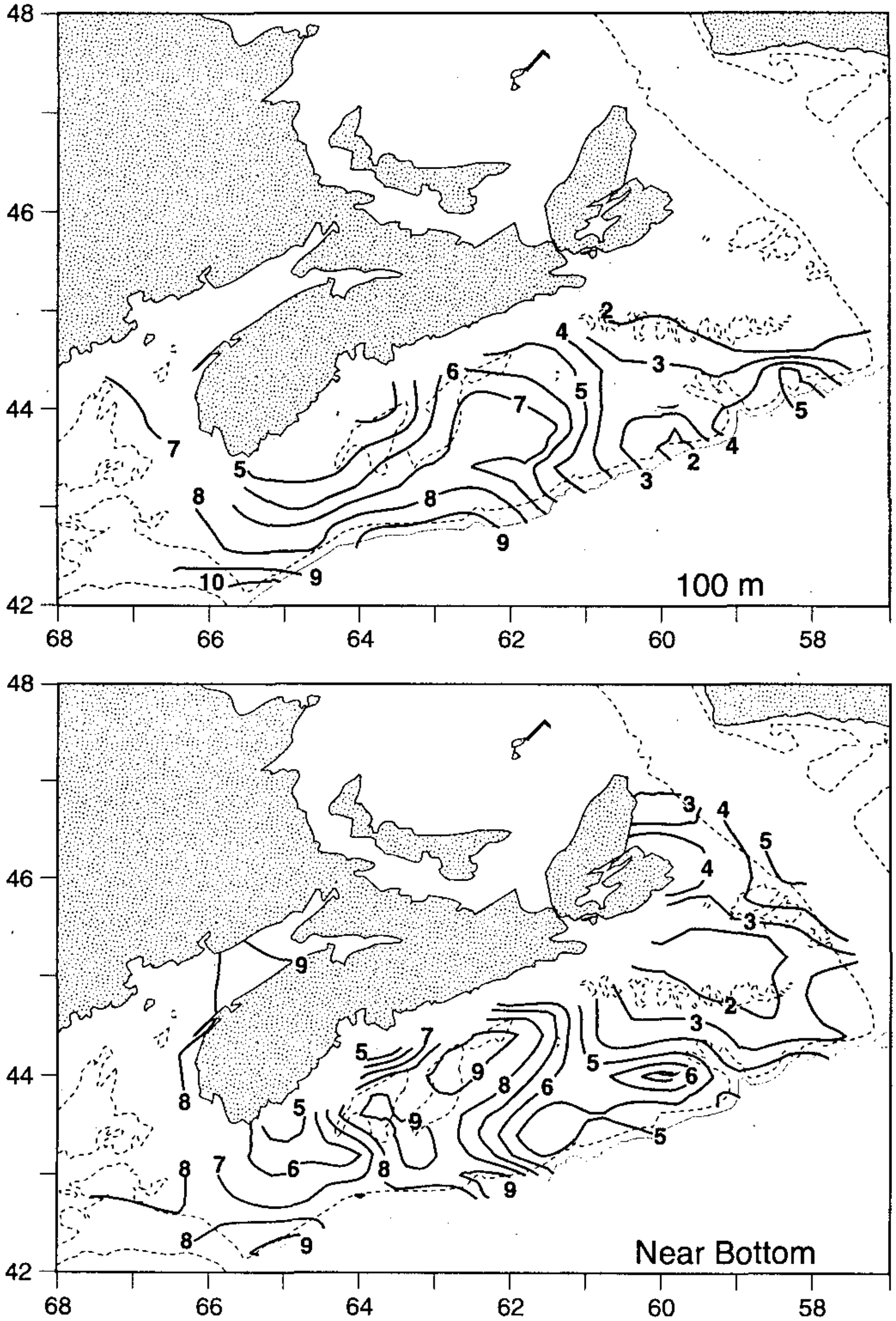


Fig. 48b. Contours of optimally estimated temperatures at 100 m (top panel) and near bottom (bottom panel) during the 1997 July groundfish survey.

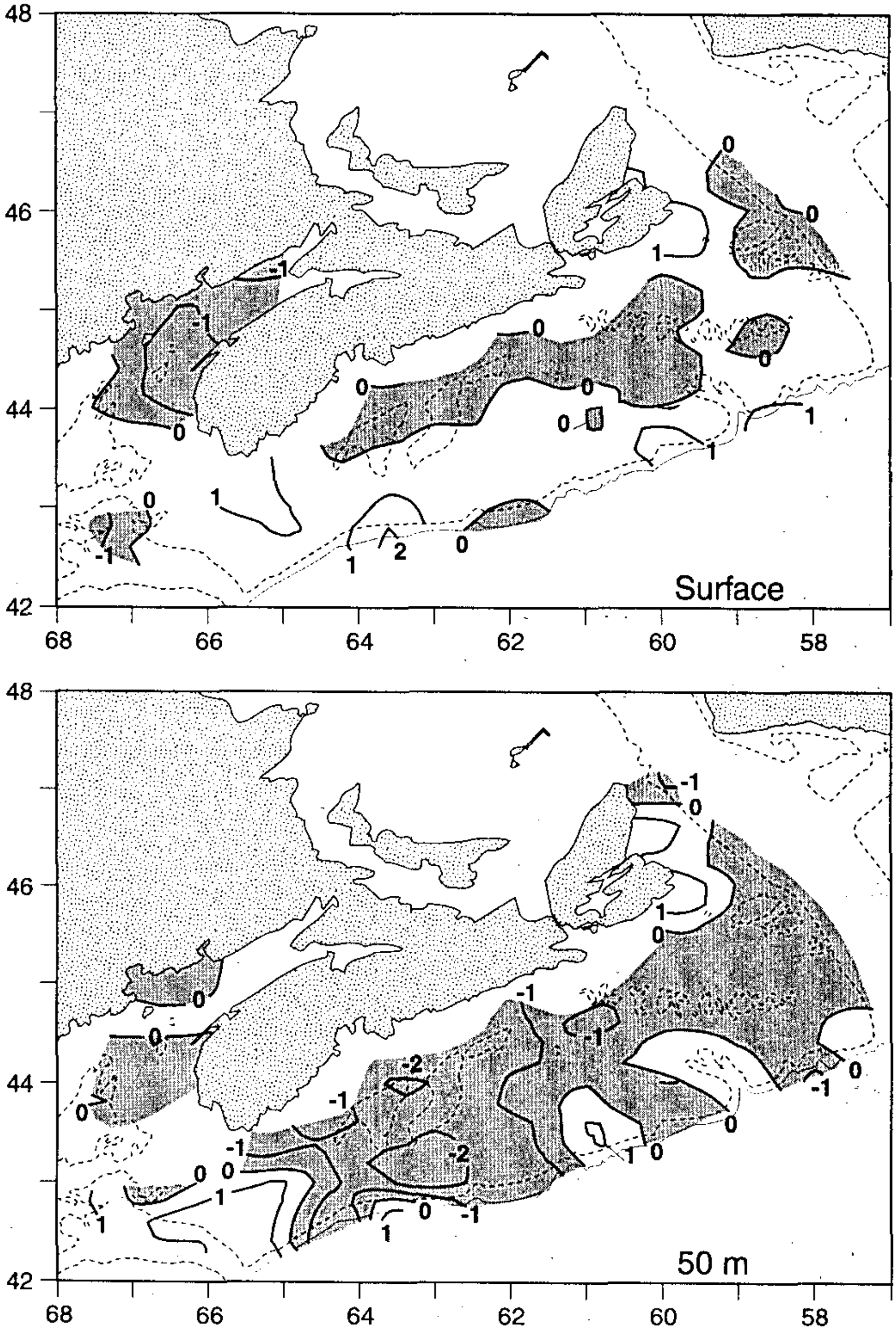


Fig. 49a. Contours of optimally estimated temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 1997 July groundfish survey.

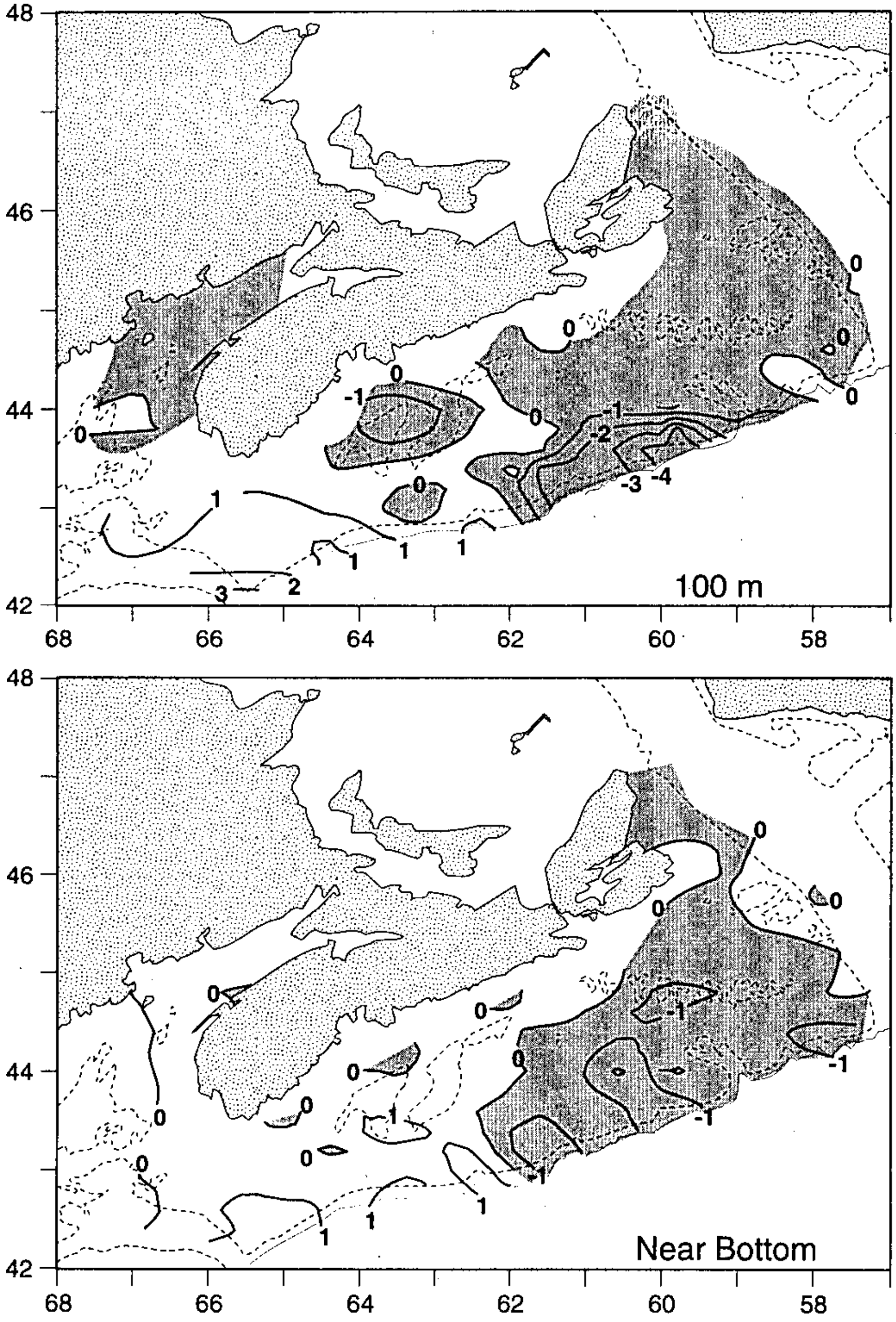


Fig. 49b. Contours of optimally estimated temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 1997 July groundfish survey.

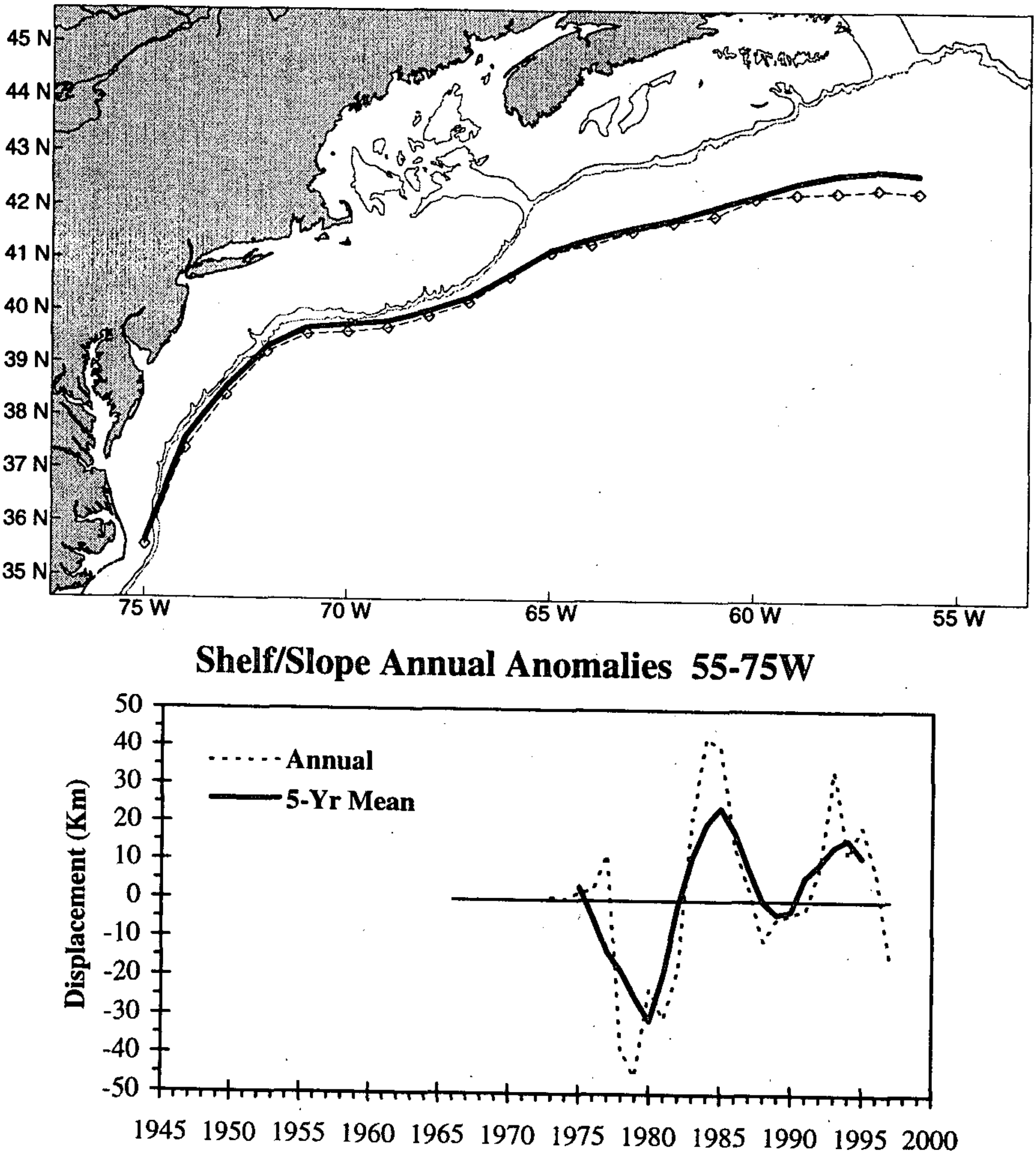
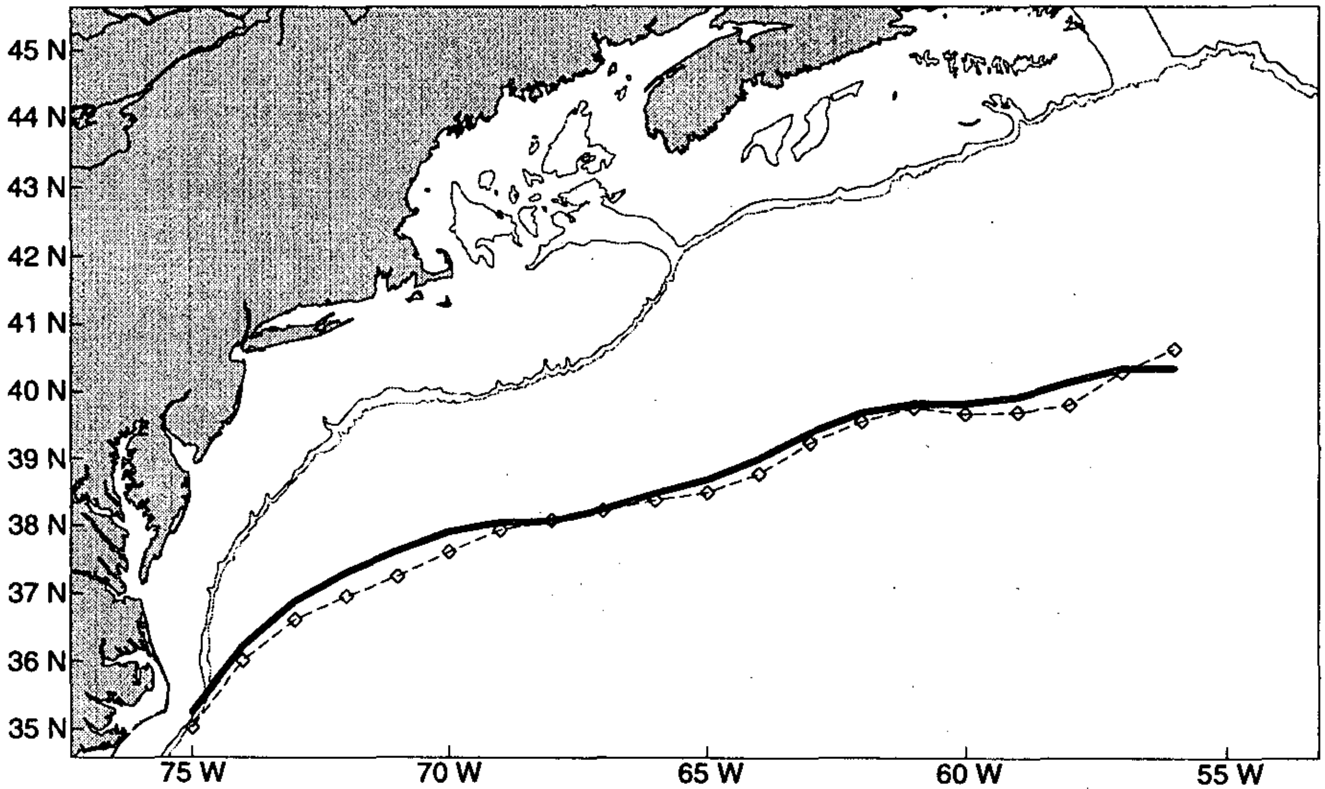


Fig. 50. The 1997 (dashed line) and long-term (1973-97); solid line) mean positions of the shelf/slope front (top) and the annual mean anomaly of the averaged (55°-75°W) position of the shelf/-slope front (bottom).



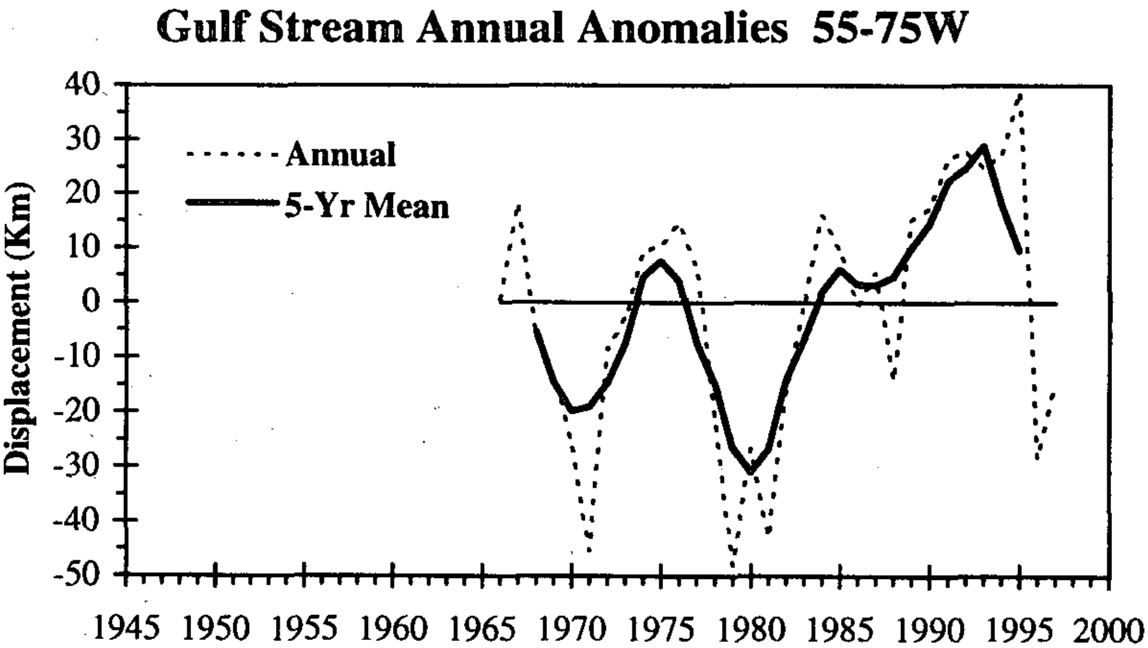


Fig. 51. The 1997 (dashed line) and long-term (1973-97); solid line) mean positions of the northern edge of the Gulf Stream (top) and the annual mean anomaly of the averaged (55°-75°W) position of the Gulf Stream front (bottom).