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Overview of Environmental Conditions in the Northwest Atlantic in 1993

by

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ABSTRACT

A review of environmental conditions on the continental shelves and adjacent offshore areas off eastern Canada during 1993 is presented. Similar to last year, near record cold annual air temperatures were observed in the coastal regions bordering the Labrador Sea. This cold air mass in winter with accompanying strong northwesterly winds resulted in ice forming early, being of greater areal extent than normal and lasting longer off northern Newfoundland and southern Labrador. New records for duration of ice were established in some areas of the outer northern Newfoundland shelf. These meteorological and subsequent ice conditions are believed to be related to a strengthening of the atmospheric circulation patterns as indicated by the high positive North Atlantic Oscillation (NAO) index. In addition to the large quantities of sea ice off Newfoundland, there were large numbers of icebergs in 1993. At Station 27 ocean temperatures were generally below normal throughout the water column. The near-bottom waters remained colder-than-normal, continuing a trend that began in 1983. Salinities were also below normal during most of the year. The areal extent of the cold intermediate layer (CIL) in summer off northern Newfoundland and southern Labrador increased relative to last year and remained well above normal. The cold conditions observed throughout the 1990s off Newfoundland are similar to those in the early 1970s and mid-1980s.

Ice conditions were also severe in the Gulf of St. Lawrence with an early formation and larger than normal areal extent. Ice on the Scotian Shelf extended along the coast as far as St. Margarets Bay, much further south than usual. At Halifax and St. Andrews, sea surface temperatures were generally below normal throughout most of the year whereas at Boothbay Harbor they were near normal. In the deep basins and channels on and adjacent to the Scotian Shelf, the lower layer waters remained approximately 1°C warmer than normal. In the upper 30 m of the Scotian Shelf, temperatures fluctuated about the long term mean but in the 50-100 m layer, i.e. the CIL, temperatures were generally colder-than-normal and in several locations as cold as the mid-1960s. In the waters off the Shelf, temperatures throughout the water column were warm, perhaps related to the more northward position of both the shelf/slope front and the Gulf Stream.

INTRODUCTION

This paper examines the 1993 environmental conditions in the Northwest Atlantic and is the twelfth annual review presented to NAFO. It is based upon selected sets of oceanographic and meteorological data as well as information from research documents prepared for the NAFO Scientific

Council. Environmental conditions are compared with those of the preceding year as well as the long-term means. Where possible, the latter have been standardized to a 30-yr base period in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. The base period has been updated to 1961-90 which differs from previous reviews (e.g. Drinkwater, 1993) which used the period 1951-80.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The Atmospheric Environment Service of Canada publishes the monthly mean air temperature anomalies (1951-80) for Canada in the *Monthly Supplement to Climatic Perspectives.* Along the Labrador Shelf and northern Newfoundland, negative temperature anomalies persisted throughout the first four months of 1993 (Fig. 1). The coldest anomalies (-6°C) were in February between southern Baffin Island and northern Newfoundland. From May to October, air temperatures in this coastal region oscillated above and below normal. In November, air temperature anomalies decreased to -2 to -4°C. Although cold temperatures also persisted during December off southern Baffin Island and northern Labrador, in southern Labrador and northern Newfoundland they were above normal. Extremely cold air masses also covered most of the area between the Gulf of St. Lawrence and the Gulf of Maine during the first three months of 1993. During the remainder of the year temperatures tended to fluctuate about the long-term mean.

Monthly air temperature anomalies for 1993, as well for 1992, at six sites (see Fig. 2 for locations) are shown in Fig. 3. These anomalies have been calculated relative to the 1961-90 means. The predominance of colder-than-normal air temperatures in 1993 is evident for all sites except Sable Island off Nova Scotia where most months were above-normal. The data from Godthab indicate that the spatial extent of the cold air mass in winter observed off southern Baffin Island and along the Labrador coast, as described above, extended throughout the Labrador Sea. Air temperatures in 1993 were typically colder than in 1992 (Fig. 3), which in turn had been colder than 1991.

The 1993 annual air temperature anomalies were colder-than-normal over all of eastern Canada and contrast with the warmer-than-normal temperatures in the west (Fig. 4), similar to the pattern observed in 1992. The coldest region covered from central Baffin Island to northern Labrador and included eastern Hudson Strait where annual air temperature anomalies exceeded -2°C. Over most of the remainder of the eastern Canadian marine areas, the annual anomalies ranged from -0.5°C to -2°C. These generally exceed the standard deviations of the long-term means (Trites and Drinkwater, 1986), off Baffin Island and the northern Labrador coast by upwards of 1°C. Iqaluit recorded the 2nd coldest year since the station opened in 1945 (annual mean temperature of -12.5°C) and was 0.09°C colder than last year. Only 1972 was colder than 1993. It matched the 5th coldest year in Cartwright since its beginnings in 1931 with a mean temperature of -1.7°C but was slightly warmer (by 0.05°C) than last year. The annual air temperature at St. John's was 3.75°C and was the fifth coldest in the last 50 years. Godthab in Greenland also recorded well below-normal temperatures in 1993 (mean temperature of -3.8°C) which was 2.4°C below normal. It was the 3rd coldest winter this century with only 1982 and 1983 being chiller and was 0.25°C colder than last year. At Sable Island, annual air temperatures were above normal by 0.2°C.

The time series of temperatures (25-month running means) show that the interannual variability since 1970 at Godthab, Iqaluit, Cartwright, and, to a lesser extent, St. John's have been dominated by large amplitude fluctuations with periods of 5-10 yr (Fig. 5). There has also been an overall downward trend causing temperature anomalies to be predominantly below normal with minima in the early 1970s, the early to mid-1980s, and the early 1990s. Temperature anomalies at Iles de la Madeleine and Sable Island have been of much lower amplitude and show no signs of a general downward trend since 1970. They do, however, contain minima in the early 1970s and the mid-1980s but not in the 1990s. Recent filtered values at all sites except Sable Island show extremely low temperatures (Fig. 5).

Sea Surface Air Pressures

Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas* by the German Meteorological Service, Deutscher Wetterierst, in Offenbach, Germany. The long-term mean pressure patterns are dominated by the Icelandic Low, a low pressure system centered between Greenland and Iceland, and the Bermuda-Azores High, a high pressure system centered between Florida and northern Africa (Thompson and Hazen, 1983). 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 1993 relative to the 1961-90 means are shown in Fig. 6. Winter includes December 1992 to February 1993, spring is March to May, summer is June to August and autumn is September to November.

In winter, negative air pressure anomalies covered the northern North Atlantic with peak values (exceeding -11 mb) centered over the Norwegian Sea. This suggests an eastward shift in the position of the Iceland Low. In contrast, a center of positive anomalies (maximum of 8.2 mb) was observed over the western Atlantic and western Europe, south of approximately 50°N. This is consistent with a strengthening of the Bermuda-Azores High and a shift eastward. The resultant air pressure pattern would cause stronger-than-normal winds, northwesterly over the Labrador Sea and westerly across the northern North Atlantic and northern Europe. Strong southward winds would also develop along the east coast of Greenland, perhaps increasing the ice flow from the Arctic to the Greenland Sea. Over the Gulf of St. Lawrence to the Gulf of Maine winds would have been near normal. In spring, both the Icelandic Low and the Bermuda-Azores High weakened, decreasing the westerly winds across the Atlantic Ocean but maintaining relatively strong southward winds along the east coast of Greenland. The summer anomaly pressure pattern was dominated by a high over Greenland (maximum of 7.6 mb) and a low over the western North Atlantic (minimum of -5.8). This indicates continued weakening of the westerly winds. A complex anomaly pattern emerged during autumn. Two negative anomaly regions were observed, one centered at the eastern entrance to Hudson Strait (-6.5 mb) and the other off the northwest coast of Spain (-4 mb). Two positive anomaly regions were also found, one centered off southern Norway (10.1 mb) and the other in the southwestern north Atlantic (2.5 mb). This would result in anomalous winds from south to southeast over the eastern Labrador Sea, from the west off northern and eastern Newfoundland and from the southwest over the Scotian Shelf and Gulf of Maine.

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. Cold temperatures and heavy ice in the Labrador Sea area are generally associated with a strong positive NAO index. The annual indices are derived from the measured mean sea level pressures at Ponta Delgada in the Azores minus those at Akureyri in Iceland (Fig. 7). Missing data were filled from adjacent stations. The NAO anomalies were then calculated by subtracting the 1961-90 mean. In 1993, the NAO anomaly was again strongly positive and slightly above last year's value. This continues a trend of above average NAO anomalies that began around 1980. Over the past 30 years there has been large decadal variability superimposed upon a general upward trend from a minima in the mid-1960s. Note that the three most recent peaks in the NAO index roughly correspond with periods of cold air temperature anomalies in the Labrador Sea (Fig. 5).

SEA ICE OBSERVATIONS

Newfoundland and Labrador

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%) for the years 1962 to 1987 are taken from Coté (1989).

Air temperatures of 2° to 4°C during December of 1992 resulted in early ice formation off southern

Labrador. Accompanying northwesterly winds helped to advect this ice southward causing a greater areal extent of sea ice than normal by month's end (Fig. 8). Through January, the ice pushed further southward so that by the beginning of February the ice was near or at its maximum southern extent for that time of the year (Fig. 8). During March the ice edge moved offshore, freeing up many of the northern Newfoundland coastal communities. At the same time the offshore position was pushed to near its long-term maximum position. Through April to June the ice coverage was generally greater-than-normal laying intermediate between the long-term median and maximum positions.

The Ice Climatology and Applications Division of Environment Canada also undertakes an annual analysis of ice conditions off the east coast of Newfoundland and southern Labrador and in the Gulf of St. Lawrence by determining the time of onset, duration and last presence of ice at 24 grid sites (Fig. 9). For each site, the extracted data included ice duration in weeks for the 1992/1993 season, mean duration for all years of record, as well as minimum, maximum and mean duration for years when ice was present (Table 1). For the area east of Newfoundland and southern Labrador, the ice appeared early and left late (Fig. 10). An exception was along the continental slope off northern Newfoundland where the disappearance of ice occurred within a week of the median day. A new record for the date of the first appearance of ice was established at the nearshore station off southeastern Newfoundland (N228). The early appearance and late presence of ice resulted in longer-than-normal durations at all but one site off southern Labrador and northern Newfoundland (Fig. 11). At sites N66 and N110 new records were set for ice duration (Fig. 11). Ice was not observed at sites N25, N27, N70, or N114; however, ice has never appeared at sites N27 and N70, only reached N25 in 2 out of 33 years and only reached N114 in 4 out of 33 years.

The monthly time series of the areal extent of ice on the northern Newfoundland and southern Labrador shelves (between 45-55°N) from 1963 to 1992 are shown in Fig. 12. In January through April there has been a general increase in the area of ice over the past 30 y. In addition, there are maxima in the early 1970s, the mid-1980s and the 1990s, corresponding to air temperature minima in the Labrador Sea (Fig. 5) and maxima in the NAO index (Fig. 7). The 1992 areas from January to May were well above average and often near maximum values.

Icebergs

The number of icebergs that pass south of 48°N latitude in each year is monitored by the International Ice Patrol Division of the United States Coast Guard. Since 1986, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1992/93 iceberg season (October to September), a total of 1753 icebergs were spotted south of 48°N. The monthly totals for December to September were 16, 112, 336, 276, 428, 338, 188, 50, 8 and 1 (Fig. 13). No icebergs were spotted in October or November of 1992. In the primary iceberg season of March to August, 1288 icebergs were observed which represents 73.5% of the annual total. This compares to the 1986-1992 average of 97%. Thus 1993 differed from previous years in the relatively large proportion of icebergs observed prior to March. The total number of icebergs in 1993 were slightly less than in 1991, 5 to 8 times those between 1986 and 1989 and approximately twice the number observed last year and in 1990 (Fig. 13). Anomalously cold air temperatures and heavy ice conditions are believed to have contributed to the relatively high number of bergs in 1993.

Gulf of St. Lawrence

During December, 1992, air temperatures were 1° to 2°C below normal over the northern Gulf and along the western coast of Newfoundland. Near normal air temperatures were observed elsewhere over the Gulf. Ice formed along the north shore of Quebec, in the St. Lawrence Estuary and off eastern New Brunswick. Conditions were near normal except along the north shore of Quebec where there was more ice than usual (Fig. 14). During the first half of January, below normal air temperatures (by approximately 3.5°C) resulted in the rapid formation of new ice such that by the 15th of the month ice coverage was much more extensive than normal. Further cooling in the second half of the month caused ice to continue to spread. By 1 February the Gulf was covered except for a small area off southwestern Newfoundland. At this time, the ice edge had also extended onto Sydney Bight, off western Cape Breton, similar to last year. During February continued cold air and northwesterly winds pushed the ice further southward and onto the Scotian Shelf. By the beginning of March, the ice edge was south of Halifax and beyond the (1962-87) long-term maximum value. The offshore position over the Scotian Shelf at this time generally lay betwen the median and maximum long-term positions. The Gulf remained ice covered throughout most of March due to below normal air temperatures. On 1 April, there was still ice on the eastern Scotian Shelf. Within the Gulf, ice was beginning to break-up, most noticeably in the St. Lawrence Estuary and along the north shore of Quebec with ice coverage being much closer to the maximum extent than the median. In May, ice still covered most of the southern Magdalen Shallows and the northeastern Gulf including the Strait of Belle Isle. This was again more extensive than normal. Early in May, air temperatures rose above normal, hastening the ice retreat. By mid-May the Gulf was essentially ice free (Fig. 14).

In 1993, ice appeared early in the St. Lawrence Estuary, the Esquiman Channel in the northeast and western Cabot Strait. Elsewhere it appeared within a week of the median date except off southern Newfoundland where there was a late appearance of ice (Fig. 10). Except off southern Newfoundland, the ice retreated later-than-normal. A new record was set for the latest date for the last presence of ice on the Magdalen Shallows off Baie des Chaleurs (site G22). The ice duration (Fig. 11) was longer-than-normal throughout the Gulf and off Cape Breton Island. The only exception was off southern Newfoundland where the duration was less-than-normal. Ice duration records were set at G22 and tied off Cape Breton (G33, G87) and in the northeastern Gulf (G10).

OCEANOGRAPHIC OBSERVATIONS

West Greenland

Hydrographic conditions off West Greenland are influenced by the relatively cold low-salinity water of the East Greenland Current and the warm high-salinity water of the Irminger Current. In the autumn of 1993 across Fyllas Bank, the mean temperature averaged over the top 200 m was warmer-than-normal by 0.4°C relative to the 1963-93 mean (Stein, MS 1994). In the top 50 m the temperature anomaly was 1°C above normal. Stein (MS, 1994) has speculated that this might reflect the warm autumn air temperatures in the region. The highest anomalies in the surface (0-50 m) waters were observed along the Cape Desolation transect further to the south. There, anomalies were upwards of 2°C above normal.

Station 27

Measurements of temperature and salinity have been routinely taken since 1946 at Station 27 located approximately 10 km off St. John's, Newfoundland. This site is representative of the inshore Labrador Current. The station was visited 58 times in 1993, with a monthly maximum of 10 in June and a minimum of 1 in December. 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 1993 together with their anomalies relative to 1961-90 are shown in Fig. 15.

Monthly mean surface temperatures at Station 27 were all below normal in 1993 except December when values were near normal. Maximum negative anomalies (-2°C) occurred in July (Fig. 15, 16). Throughout the water column temperature anomalies were generally below normal. Exceptions were the mid-depth waters (25-75 m depth) during July, with a peak value of over 1.0°C at 30 m in July, and throughout the water column in December when temperatures were just above normal. During October, sea temperature anomalies exceeded -1°C between 25 and 75 m with a minimum in excess of -3°C at 50 m. Near bottom (175 m) temperature anomalies ranged between -0.3°C and -0.8°C (Fig. 16), similar to last year.

Surface salinities at Station 27 were slightly fresher than the long-term mean from January to August. The maximum negative anomaly was 0.5 psu in March (Figs. 15, 16). This continued the below normal salinities observed since the later half of 1991. In September, surface salinities rose above normal but had fallen below normal by December. In the subsurface waters salinities were typically saltier than the long-term mean in the last four months of 1993 with the largest negative anomalies occurring at 25 m. Fresher conditions than normal occurred in the upper layer waters from January to August. The salinity-cod relationship first noted by Sutcliffe et al. (1983) and updated by Myers et al. (1993) suggests that cod recruitment is influenced by the summer salinities (50 m depth-averaged at Station 27) in the year following spawning. Higher recruitment is associated with higher salinities. This relationship has predicted recent fluctuations in recruitment (Myers et al., 1993). In 1993, the depth-averaged salinities returned to near normal conditions and a rise from the extremely low values of the previous 2 years (Fig. 17). This suggests that environmental conditions are becoming more favourable for cod recruitment.

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970 to 1993 are displayed as bar graphs in Fig. 18. Note that the temperature anomaly scale for 0 and 50 m is larger than for 100 m and deeper. At the surface, 1993 continued the persistent negative anomalies that began last year. Progressing deeper in the water column, there was a tendency towards less high-frequency variability and a dominance of low-frequency fluctuations. In addition, the anomalies over this period were predominantly negative. (Note that anomalies in the sixties were above average.) At 100, 150 and 175 m negative anomalies have persisted almost continuously since 1983. The coldest periods roughly correspond to those identified as years of cold air temperature anomalies, heavy ice, and high NAO index, i.e. the early 1970s, the mid-1980s, and the 1990s.

CIL

On the continental shelves off eastern Canada from Labrador to the Scotian Shelf, intense vertically mixing and convection during winter produce a cold layer that overlays a warmer deeper layer or occasionally may extend to the bottom. 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 late July or early August by the Northwest Atlantic Fisheries Center in St. John's, Newfoundland in most years since 1950. The areal extent of the CIL, defined by waters <0°C, along each transect is plotted in Fig. 19. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects, a result observed earlier by Petrie et al. (1992). In 1993, the CIL area at all three transects was above normal, having decreased from the peak values in 1990 or 1991 but increased slightly over last year or remained the same (Bonavista). The area of the CIL along the three transects show maxima in 1972, 1983-85 and in 1990-91 (Fig. 19) which correspond roughly with minima in air and sea temperatures and maxima in ice coverage. Please note that in last year's review (Drinkwater, 1993), the plot of the CIL areas mistakenly included some spring and autumn data.

Offshore SST Data

Sea-surface temperature (SST) data from the "marine deck" observations (obtained primarily from ships-of-opportunity through the ship's intake and research vessels) were supplied by the U.S. Marine Fisheries Service. The pattern of monthly SST anomalies for 19 regions along the continental shelf from Chesapeake Bay to southern Labrador (Fig. 20) for 1993 are compared to earlier years (Fig. 21). Negative SST anomalies were observed off southern Labrador (areas 18, 19) in January continuing the cold conditions established late in 1992. Unfortunately, no data were available from these northern areas from February to May or June. In the late winter and early spring, cold conditions also developed in the Middle Atlantic Bight (areas 1 to 4) with peak values (<-2°C. The dominant feature was the very cold conditions in the summer off eastern and northern Newfoundland (areas 13-17). Maximum negative temperature anomalies were observed during July and reached almost -4°C off White Bay (area 16). Cold conditions in July were also observed on the Scotian Shelf (areas 8-11) but these were not as intense or as extensive as off Newfoundland. Although much of the Gulf of Maine, Scotian Shelf and southern Newfoundland region experienced positive SST anomalies in the late winter and spring, anomalies exceeding 1°C were rare, occuring only in May and again in August and September on the northern Middle Atlantic Bight (area 5) and in November off eastern Newfoundland (area 13, 14).

SST anomalies were also determined for a larger region of the Northwest Atlantic (35°-60°N, 40°-76°W) extending from the southern boundary of the NAFO area northward to southern Greenland.

As in past reviews (e.g. Drinkwater, MS 1993), the region was divided into 24 smaller areas (Fig. 22) to coincide with major water masses (Labrador Current, Gulf Stream, etc.) or fishing banks (Lahave, Georges, etc.). The monthly mean temperature for each area was computed for 1993. The annual anomalies for 1989 to 1993 and the mean annual temperature for the base period (1972-90) are listed in Table 2. A space-time plot of the annual anomalies for the 24 areas during the 1972-91 period is shown in Fig. 23.

The 1993 annual pattern shows negative SST anomalies off Greenland, on Flemish Cap and over the outer Grand Banks (Fig. 24; Table 2). Colder-than-normal conditions were also observed in the south including the Sargasso Sea, the Gulf Stream and the Middle Atlantic Bight although the former two areas were only slightly negative. The Gulf of Maine was also colder-than-normal as was the inshore region of the western Scotian Shelf. The remainder of the region experienced positive annual SST anomalies in 1993 with the eastern Slope Water having the highest value, almost 1.3°C above normal.

The time series of annual mean anomalies of SST for the 24 areas are shown in Fig. 25. In almost all areas, the 1993 annual temperature anomaly showed a positive increase over last year. Colder-than-normal temperatures continued, however, off the eastern Grand Bank and on Flemish Cap. Elsewhere off Newfoundland and Labrador, annual SSTs were slightly above or near normal. On the Scotian Shelf generally warm conditions prevaled except off the western coast of Nova Scotia. There, SST anomalies were slightly colder-than-normal. Gulf of Maine, Georges Bank and the Middle Atlantic Bight were colder-than-normal but up from last year. The largest anomaly was recorded in the Eastern Slope Water region which recorded the maximum value since the records were assembled in 1971. The western Slope Water was also warmer-than-normal. The Gulf Stream and Sargasso Sea regions were near normal.

Coastal SST data

Monthly averages of SST are available from Halifax Harbour in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine. The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each of the sites for 1992 and 1993 are shown in Fig. 26. The St. Andrews temperatures have in recent years been measured using continually recording thermographs. Unfortunately, no data were available during April and May as the recorder broke loose from its moorings and was recovered away from the wharf. For this period and in December, we have calculated the means using temperatures from a thermistor located on the wharf at the Biological Station that were recorded 5 times daily.

During 1993 the coastal SST anomalies at the three sites were generally negative with monthly mean temperatures at St. Andrews and Halifax reaching above normal only during two and three months of the year, respectively (Fig. 26). At Boothbay Harbor, temperatures were above normal for half of the year and below normal for the other six months. February and March, in particular, were well below normal at all three sites with anomalies in excess of -2°C at both St. Andrews and Halifax. December, on the other hand, was above normal at all sites with anomalies of upwards of 1°C at Boothbay and St. Andrews.

Annual SST mean temperatures for 1993 were 8.5°C (equalling the 1961-90 mean) at Boothbay Harbor, 6.7°C (0.4°C below normal) at St. Andrews, and 7.1°C (0.7°C below normal) at Halifax. Similar to last year, the magnitude of the anomalies decreased southwards. The annual temperatures at all three sites decreased relative to the previous year (Fig. 27). At St. Andrews, SSTs have been generally below the long-term normal since the mid-1980s. The beginning of this period coincides with the reconstruction of the wharf at St. Andrews Biological Station where the measurements are recorded. Drinkwater et al. (1992) noted inconsistencies in the SSTs between the pre- and post-reconstruction periods through comparisons with Prince 5 data. Differences in SSTs were significantly greater after the reconstruction with St. Andrews being lower than Prince 5. They speculated that the negative anomalies in the late 1980s and early 1990s at St. Andrews may, in large part, be due changes in the flow characteristics in and around the wharf resulting from the reconstruction rather than reflecting a true decrease in surface temperatures in the region. Although caution must used in interpreting both the timing and the magnitude of the recent decrease, other data (see below) corroborate this decline.

Prince 5

Temperature and salinity measurements are taken once per month at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy. Monthly anomalies relative to the 1961-90 means were calculated for 1993. Single measurements per month, especially in the surface layers in the spring or summer, under stratified conditions are not necessarily 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. There is generally strong similarity in the anomaly patterns of both temperature and salinity in all years throughout the water column. This relative homogeneity of the water column is due in large part to the strong tidal mixing in the Bay of Fundy.

In 1993, temperatures ranged from a minimum of less than 2°C in February and March to a maximum of over 10°C in September (Fig. 28). The temperature anomalies throughout the year were mostly negative, although in December positive anomalies of over 1°C were observed. Anomalies exceeded -1°C in March and in the lower half of the water column from May to August. The maximum negative anomaly was approximately -1.5°C in the waters just above the bottom in August. The long-term temperature records at surface and 90 m for Prince 5 show high similarity (Fig. 29). The annual anomalies in 1993 were -0.5°C and -0.6°C at the surface and bottom (90 m), respectively. These are slightly warmer than last year's means, by 0.2°C and 0.1°C, respectively. The extremes at both depths were maxima in the early 1950s and minima in the mid 1960s, with recent values below the long-term mean (Fig. 29). With the advent of very cold temperatures during the last two years, the 25-month running means of the temperatures show a rapid decrease in recent years. There has been, however, a gradual temperature decrease since the late 1970s at 90 m and since the mid-1980s at the surface.

Salinities at Prince 5 during 1993 were fresher-than-normal (Fig. 28). The lowest salinities (<30.5 psu) occurred during April resulting in salinity anomalies of -0.8 psu in the surface waters. These low salinities in spring also penetrated throughout the water column. This continues the recent trend of below normal salinities (Fig. 30).

Temperatures and salinities in the Mid-Atlantic Bight

Monthly monitoring of water column temperatures and surface salinities on a transect extending seaward from New York Harbor across the shelf into the Slope Water by the Northeast Fisheries Science Center in Narragansett, Rhode Island, continued in 1993 for the eighteenth consecutive year (Benway and Jossi, 1994). Surface and bottom temperatures and surface salinities were generally below their 1978-1992 means. Surface temperatures on average through the year were 1.4°C below normal, bottom temperatures were 0.4°C cooler-than-normal and surface salinities 0.46 psu below normal.

Temperatures and salinities in the Gulf of Maine

The Northeast Fisheries Science Center also occupies a transect across the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf (Benway and Jossi, 1994). Surface and bottom temperatures and surface salinities have been collected monthly for the past seventeen years. In 1993, below normal (relative to 1978-1992 mean) SSTs were recorded during January through May and in the autumn resulting in an annual average of 0.6°C below the long-term mean for the entire transect. Surface salinities were 0.4 psu below normal on average in 1992. Bottom temperatures in the Gulf of Maine were generally near normal during the year with an average anomaly over the transect of -0.1°C. The negative anomaly was due primarily to the cold bottom temperatures on the Scotian Shelf where anomalies were -0.9°C for the year. The negative anomalies were principally at depths of less than 100 m. In Crowell Basin, in depths of around 200 m, bottom temperature anomalies were generally positive.

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 these 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 were observed.

In 1993 the deep temperature anomalies (250 m) were 1°-2°C above normal (Fig. 31). The long-term annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. These anomalies were typically representative of conditions below approximately 100 m (see below). The warm temperatures are believed to be due to an intrusion of warm slope water late in 1991 or early in 1992. These warm anomalies contrast sharply with the 1991 anomalies of below -1°C.

Other Scotian Shelf and Georges Bank Temperatures

Drinkwater and Trites (1987) tabulated monthly mean conditions for irregularly shaped areas on the Scotian Shelf that generally corresponded to topographic features (Fig. 32). From data collected in 1993, we have produced monthly mean conditions at standard depths (averaging any data within the month anywhere within these areas) and compared them to the long-term averages published by Drinkwater and Trites (1987). Unfortunately, data are not available for each month at each areaand in some areas the monthly means are based upon only one profile. Thus care again must be taken in interpreting these data and little weight given to any individual mean.

a. Lurcher Shoals. Monthly mean temperature profiles for Lurcher Shoals (area 24, Fig. 32) show that from January to November of 1993 temperatures were below normal (Fig. 33). In December, however, a strong positive anomaly of upwards of 3°C was observed. This must be viewed with some caution because it is based upon only one observation. It also was taken at the edge of the shoals almost in Roseway Channel (area 23). However, comparison with Prince 5 shows strong similarity indicating the likelihood of a positive anomaly at that time. A time series of monthly mean temperature data at 50 m shows that in recent years cold conditions have prevailed (Fig. 33). The long-term trend has been dominated by warm periods in the 1950s and mid-1970s to mid-1980s and cool periods in the 1960s and since the mid-1980s. These conditions are generally representative of the average conditions throughout the water column.

b. Roseway Channel. Roseway Channel separates Lurcher Shoals from Browns Bank and connects Roseway Basin with the Gulf of Maine (area 23; Fig. 32). The 1993 monthly mean profiles show that during most of the year, the upper layer temperatures were colder-than-normal although in October, warmer conditions were observed down to the maximum depth of 100 m (Fig. 34). In July, when the deepest profile was obtained, the upper waters were colder-than-normal but the deep waters were warmer-than-normal, consistent with the Emerald Basin deep water temperatures. The time series of monthly mean temperatures at 50 m shows cooler conditions in recent years, similar to Lurcher Shoals but of slightly lower amplitude (Fig. 34).

c. Middle Bank. Middle Bank lies inshore of Sable Island (area 7, Fig. 32). Data in the first two months of 1993 show that the upper water column was slightly warmer than normal (Fig. 35). However, by March and April these waters had cooled to below normal. May was again slightly above normal but July and August were subtantially below. The deeper waters (100 m and greater) were above normal in each of the three months when they were sampled. Few data are available in recent years at Middle Bank, however they suggest a pattern of below normal temperatures in the 50-100 m depth range (Fig. 35).

d. Misaine Bank. Misaine Bank is located inshore of Banquereau Bank (area 5, Fig. 32). Temperature measurements were only recorded in three months during 1993. In each month the water from 50 m to 100 or 150 m was colder-than-normal (Fig. 36). This is the CIL (cold intermediate layer) water. The waters above 50 m were also colder-than-normal in March and July but warmer than normal in November. The waters below 200 m which were sampled in July were warmer-than-normal. These data were obtained at the shelf edge on the southern side of the Laurentian Channel. A pattern of warm in the 1950s and 1980s and cold in the 1960s and recent years is observed at 50 m (Fig. 36) and is representative of 100 and 150 m as well.

e. Shelf Temperatures in July. Extensive temperature data are available during July, 1993, for all of the Scotian Shelf. I averaged the data for the areas in Fig. 32 and expressed them as anomalies relative to their 1961-90 means. The results for 0, 50 and 100 m are plotted in Fig. 37. They show that at the surface cold conditions persisted over the Scotian Shelf except in the vicinity of Roseway Basin in the western region. Warmer-than-normal temperatures were observed off the shelf and on Georges Bank. The warm offshore waters were, indeed, representative of conditions throughout the year. In July, a warm-core ring at the mouth of Northeast Channel contributed to the very high anomalies in that region. At 50 m cold conditions continued to persist although there is evidence of penetration of the warmer slope waters in the Gully and Northeast Channel. Roseway Basin also shows warm conditions at 50 m. At 100 m the coldest waters are found near shore although the outer banks also show evidence of these cold waters. Elsewhere the influence of the offshore waters caused warm conditions.

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters (200-300 m average) of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late 1940s to 1988. The variability 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 based upon ice forecast cruises conducted by the Bedford Institute in November-December show that temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5°C and an anomaly of exceeding -0.5°C; Fig. 38). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.2°C) and to over 6.0°C (anomaly of 1°C) in 1993. This temperature pattern is similar to that in the deep waters in Emerald Basin and reflects changes in the slope water characteristics near the mouth of the Laurentian Channel (Bugden, 1991; Petrie and Drinkwater, 1993).

Shelf/Slope Front

The waters on the continental shelves off eastern Canada have distinct temperature and salinity characteristics from those found in the adjacent deeper offshore waters, known as slope water. The relatively narrow boundary between these water masses is called the shelf/slope front and its surface expression is regularly detected in satellite thermal imagery. Recently, monthly time series of the position of this front and of the northern boundary of the Gulf Stream between 50°W and 75°W have been assembled through digitization of satellite derived SST charts published at least weekly (Drinkwater et al., 1994). From January 1973 until May 1978, the charts only covered the region northward to Georges Bank, but in June 1978 the areal coverage was extended to include the Scotian Shelf and the Grand Banks. The time series consist of the monthly means of the position of the shelf/slope front in degrees latitude at each degree of longitude. The years 1973 to 1992 were used to determine long-term monthly means which were then subtracted from the yearly values to obtain anomalies.

The overall average position of the shelf/slope front together with the minimum and maximum monthly mean values are shown in Fig. 39. The average position lies 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 Banks. It is typically furthest offshore in winter and onshore in late summer and early autumn. During 1993, the shelf/slope front was generally shoreward of its long-term mean position. In the region between approximately 65°W (eastern Georges Bank) and 55°W (south of St. Pierre Bank) it was 50-60 km northward of its long-term average (Fig. 40). On the other hand, off the northern region of the Middle Atlantic Bight (73°W-70°W) and near the Tail of the Grand Bank (50°W-51°W) the annual anomaly was slightly negative, indicating the front was seaward of the long-term mean. The position averaged over all longitudes shows a trend from maximum onshore in January decreasing to slightly further offshore than the long-term mean in October (Fig. 41). During November and December the front again moved onshore. The positions of the shelf/slope front were low-pass filtered (Cartwright filter with 25 weights and a 50% power reduction at a period of 15 months). The low-frequency variability, based upon these filtered values, indicate that the front was near its long-term mean from 1985 to 1992 but recently has moved northward (Fig. 42). The maximum northward position was observed in the mid 1980s whereas the minimum occurred around 1980.

Gulf Stream Front

Time series of the position of the northern boundary or "wall" of the Gulf Stream were also determined from satellite imagery (Drinkwater et al., 1994). Similar to the shelf/slope front, the series consists of the monthly position at each degree of longitude from 75°W to 50°W. The average position of the north wall of the Stream is shown in Fig. 43. The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position of the Stream lies east-west. During 1993 the Gulf Stream was generally positioned north of its mean location with the maximum (60-80 km) in the area from 57°W to 65°W and also at 53-54°W (Fig. 44). Off the Middle Atlantic Bight (< 71°W), on the other hand, the Gulf Stream was positioned south of its long-term mean location. This mirrors conditions in the position of the Shelf/Slope front. The monthly anomalies of the Gulf Stream position averaged over all longitudes peaked in July and was minimum in March but was positive throughout the year (Fig. 45). The low-pass filtered positions (Cartwright filter, as described above for the Shelf/Slope front) show that Gulf Stream has been at or near its maximum northward extent during the last couple of years (Fig. 46). Although there is high variability at each degree of longitude with differences between longitudes, there has been a general pattern of a southward position during the late 1970s and 1980, near normal through most of the 1980s and northward in the late 1980s and into the 1990s (Fig. 46).

Warm-core Rings

Meanders in the Gulf Stream sometimes break off from the main current forming anticyclonic eddies that trap warm Sargasso Sea water in their center. These rings move slowly through the slope waters and can interact with the waters on the shelves if they are close to the shelf break. They can entrain shelf water out into the slope water region which will then be mixed into the slope waters. The life history of these warm-core Gulf Stream rings in the region from 45°W to 75°W during 1993 was derived from the NOAA/NWS Oceanographic Analysis maps and from the "State-of-the-Ocean: Gulf of Maine to the Grand Banks" reports issued monthly at the Bedford Institute of Oceanography. Owing to the relatively common occurrence of cloudy or foggy conditions, particularly in the eastern half of the region, several weeks may elapse between clear thermal images of the sea surface. Consequently there is frequently uncertainty about the creation or continued existence of a particular ring and, therefore, the statistics derived solely from this data source should be viewed cautiously.

A total of 27 warm-core rings were present in the area during some portion of 1993, three of which survived from 1992 into the new year. Three of the 24 new rings which formed in 1993 persisted into 1994. Eight of the rings formed in 1993 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1993, ranged in age from 5 d to almost 11.5 months and had a mean life of approximately 2.3 months. The average lifespan since 1981 when reliable data have been available is 2.75 months. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are displayed in Fig. 47. In comparison to last year when only 1 ring formed west of 65°W, this year there were 5. However, similar to 1993, the maximum number of rings generated in any 2.5 degree zone was 4 and in both years this occurred in the zone 62.5-65°W. The number of rings present in each of the longitude zones varied from 1 to 8 with the highest number in the adjacent zones between 62.5 to 65.0°W. The distribution of rings present in the zones, given the areas of formation, reflect westward propagation. The maximum number of rings (4) formed in July, none formed in January, 3 in June and April and 2 in March, May, August, September and November. One new ring was formed in each of the remaining months (February, October and December).

SUMMARY

Again in 1993 severe cold conditions existed over southern Labrador and northern Newfoundland. Strong northwesterly winds carried cold Arctic air southward resulting in air temperature anomalies reaching near record lows at several sites around the Labrador Sea and continuing the trend of rapidly declining air temperatures established a decade ago. These low temperatures and strong northwesterly winds led to early ice formation and a greater southern extent than normal on the southern Labrador and northern Newfoundland shelves. As in the past couple of years, ice generally stayed much later than normal leading to a longer-than-average ice duration. Ocean temperatures at Station 27 were also colder-than-normal throughout the majority of the year and the negative anomalies in the near bottom waters continued a trend of below normal temperatures for most of the past ten years. The areal extent of the CIL was above normal having increased relative to last year but still below the maxima in 1990 and 1991. At Halifax and St. Andrews, sea surface temperatures were generally below normal. Similar conditions were observed throughout the water column during most of the year at Prince 5, as well. SST data showed slightly warmer-than-normal conditions on the Scotian Shelf but colder-than-normal throughout most of the Gulf of Maine. Similar warm temperatures are observed in the deep waters of the Gulf of Maine, Emerald Basin, and in Cabot Strait. At the latter two sites, temperatures rose significantly from last year. However, in the CIL on the Scotian Shelf (approximately 50-100 m) temperatures were much colder-than-normal and continue a pattern established in the late 1980s. In the inner half of the Shelf temperatures in the CIL were as cold as in the mid-1960s. In the Slope waters off the Scotian Shelf waters were warmer than usualy which may be related to the northward shift of the shelf/slope. The average postion of the Gulf Stream front between Cape Hatteras and the Tail of Bank also lay north of its mean position.

OUTLOOK FOR 1994

The cold wintertime air temperatures in the Labrador Sea area during the last several years have continued through the first three months of 1994. The cold air has been accompanied by strong northwesterly winds. This combination has produced a larger areal extent of ice than normal. In the Gulf of St. Lawrence extreme ice conditions have persisted in 1994 and extensive ice has covered the Scotian Shelf reaching as far south as Halifax, much further than normal but comparable to the last two years. In April, very warm air temperatures were observed over the Maritime provinces of Canada and eastern Newfoundland.

On the basis of a cold winter in 1994 and conditions during the last several years I expect lower-layer water temperatures in the Newfoundland area to again be colder-than-normal and a greater areal extent of the CIL. Surface layer temperatures in the winter and spring are expected to be colder-than-normal. With heavy concentrations of ice off Newfoundland salinities should be fresher than the long-term average in the spring and summer again this year. Given the extremely cold winter in the Gulf of St. Lawrence, on the Scotian Shelf and in the Gulf of Maine, surface ocean temperatures through to spring are expected to be colder-than-normal. Summer and autumn surface ocean temperatures off Newfoundland and further south will depend on the local heat fluxes during those seasons. Initial indications, however, point to 1994 being another cold year.

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TABLE 1. Historical data on presence and duration of sea ice at 24 sites off eastern Canada and ice duration at these sites in the 1992/93 (October-September) ice year with 1991/92 data in parentheses.

				Ice Duration (in weeks)				
				When ice present				
Site	Seasons Studied	# of Yrs	Yrs of ice	Min	Max	Mean	Overall Mean	1992-93 (1991-92)
G-7	67/68-92/93	26	26	6	16	10.6	10.6	13 (12)
G-10	76/77-92/93	17	17	3	17	11.9	11.9	17 (14)
G-12	67/68-92/93	26	26	2	15	11.6	11.6	13 (14)
G-22	76/77-92/93	17	17	7	15	12.1	12.1	15 (14)
G-31	68/69-92/93	25	24	8	17	12.6	12.1	15 (15)
G-33	71/72-92/93	22	22	2	14	10.7	10.7	14 (13)
G-35	59/60-92/93	34	18	1	11	3.4	1.8	1 (2)
G-86	76/77-92/93	17	17	6	23	16.4	16.4	19 (20)
G-87	70/71-92/93	23	22	1	12	7.5	7.2	9 (12)
N-19	66/67-92/93	27	27	17	32	23.8	23.8	25 (24)
N-21	67/68-92/93	26	26	5	28	18.5	18.5	25 (24)
N-23	59/60-92/93	34	28	1	17	5.3	4.3	12 (3)
N-25	59/60-92/93	34	2	1	1	1.0	0.1	0 (0)
N-27	59/60-92/93	34	0	0	0	0.0	0.0	0 (0)
N-62	67/68-92/93	26	26	8	27	18.8	18.8	23 (25)
N-64	59/60-92/93	34	33	3	25	13.1	12.7	21 (24)
N-66	59/60-92/93	34	28	1	17	8.4	6.9	17 (16)
N-68	59/60-92/93	34	15	1	10	3.5	1.6	3 (4)
N-70	60/61-92/93	33	0	0	0	0.0	0.0	0 (0)
N-108	59/60-92/93	34	28	1	17	6.2	5.1	15 (6)
N-110	59/60-92/93	34	27	1	16	5.4	4.3	16 (7)
N-112	59/60-92/93	34	14	1	10	3.9	1.6	5 (4)
N-114	59/60-92/93	34	4	1	2	1.5	0.2	0 (2)
N-228	59/60-92/93	34	23	1	14	5.7	3.9	12 (7)

TABLE 2. Mean SST for selected areas in the Northwest Atlantic for 1971-90 and anomalies for 1989 to 1992. (Geographic locations of areas are shown in Fig. 22. Blank space indicates that the annual average was not computed due to one or more months of missing data.

AREA	Mean Temp 1971-90	Annual Temperature Anomalies (°C)				
		1989	1990	1991	1992	1993
CF	4.22	-0.10	0.15	0.09	0.20	-0.13
LS	5.57	-0.33	-0.34	-0.10	0.24	0.48
LCS	2.05				-0.57	0.16
OLC	5.18	0.01	-0.38	-0.81	-0.86	-0.36
ILC	5.11	0.46	-0.07	-0.41	-0.43	0.03
FC	7.88	0.04	-0.46	-0.85	-0.68	-0.47
CGB	6.77	0.47	-0.12	-0.73	-0.57	-0.39
WGB	6.34	0.13	-0.15	-0.62	-0.04	0.20
SP	6.14	-0.22	-0.22	0.23	-0.13	0.32
GSL	6.00	0.11	-0.11	0.12	0.21	0.17
ESS	7.29	0.26	0.01	0.22	0.11	0.24
SI	8.38	0.42	-0.28	-0.25	-0.05	0.26
SH	8.07	0.45	0.17	0.04	-0.12	-0.06
LHB	8.92	0.14	0.06	0.61	-0.19	0.32
BR	9.00	0.51	0.63	0.43	0.03	0.58
Y	7.64	0.38	0.27	0.22	-0.35	0.18
GOM	9.65	0.14	0.15	0.08	-0.47	-0.17
GB	10.17	0.09	0.45	0.36	-0.42	-0.27
SNE	12.34	0.57	1.33	0.73	-0.35	0.26
MAB	14.89	0.11	0.45	0.93	-0.67	-0.22
ESW	15.64	0.51	0.19	-0.24	0.59	1.29
WSW	18.21	-1.07	-0.62	-0.63	-0.45	0.24
GS	22.99	0.14	0.40	0.01	0.14	-0.09
SS	22.25	0.19	0.16	0.04	-0.10	-0.01

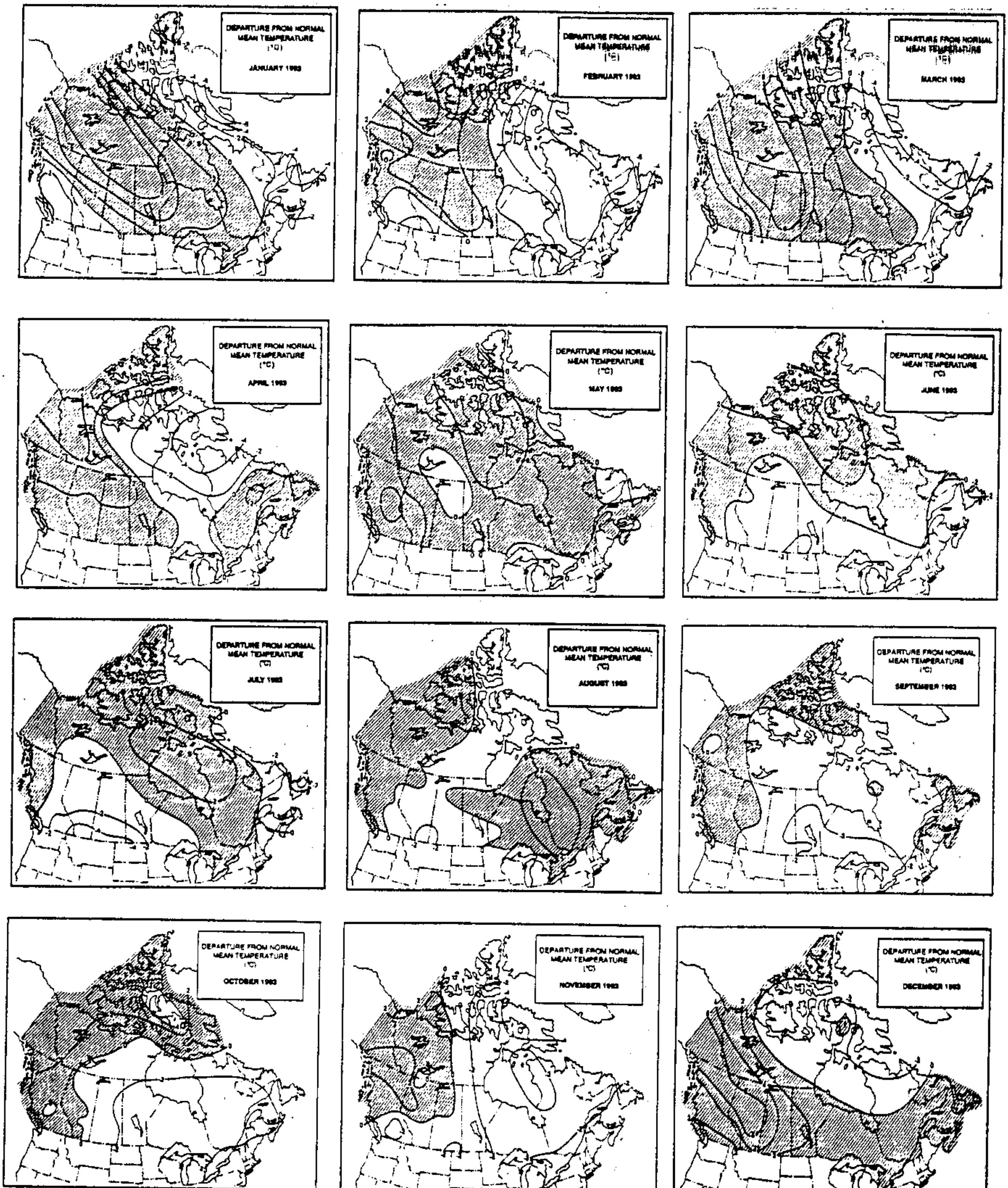


Fig. 1. Monthly air temperature anomalies (°C) over Canada in 1993 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 14)

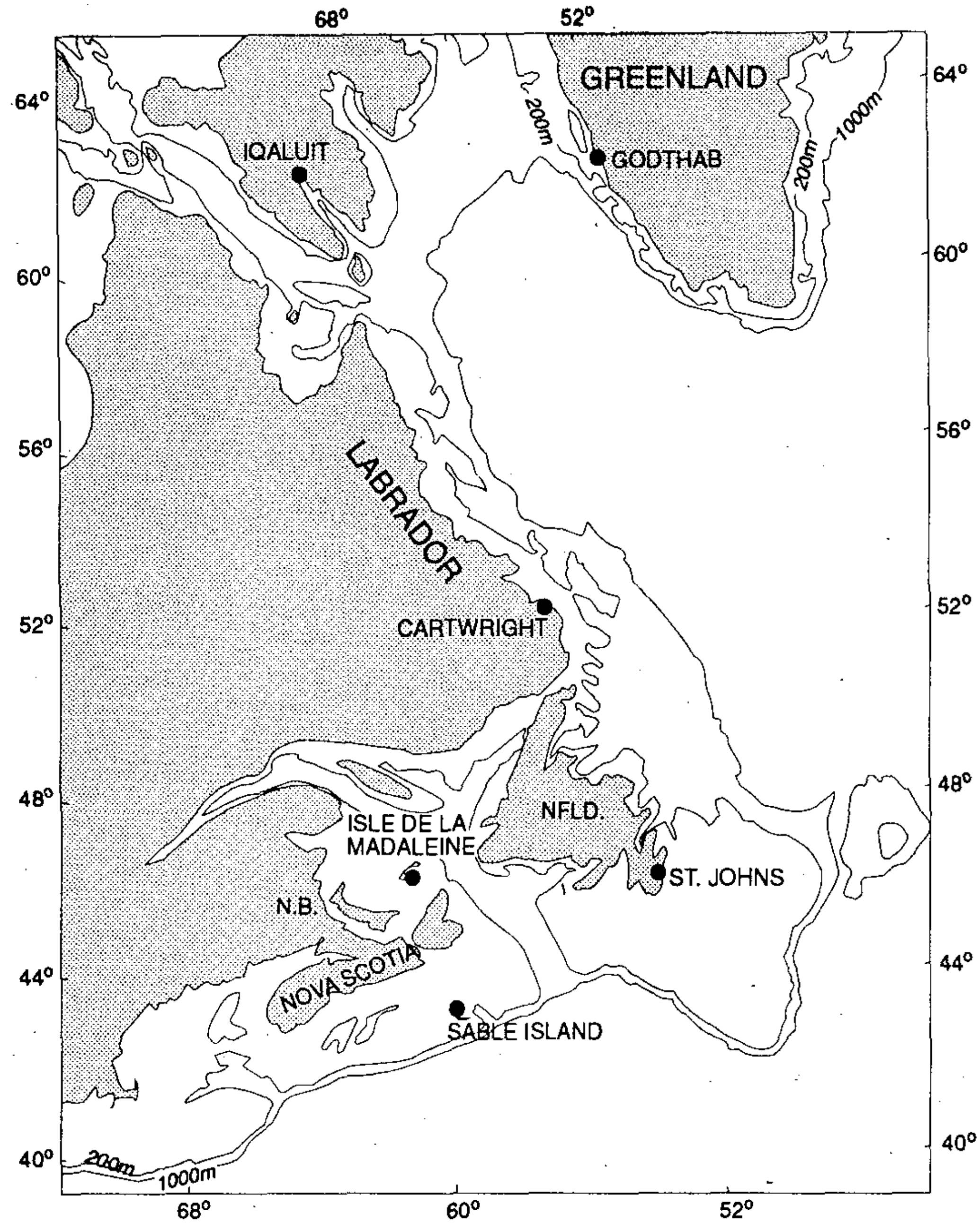


Fig. 2. Map showing coastal air temperature stations.

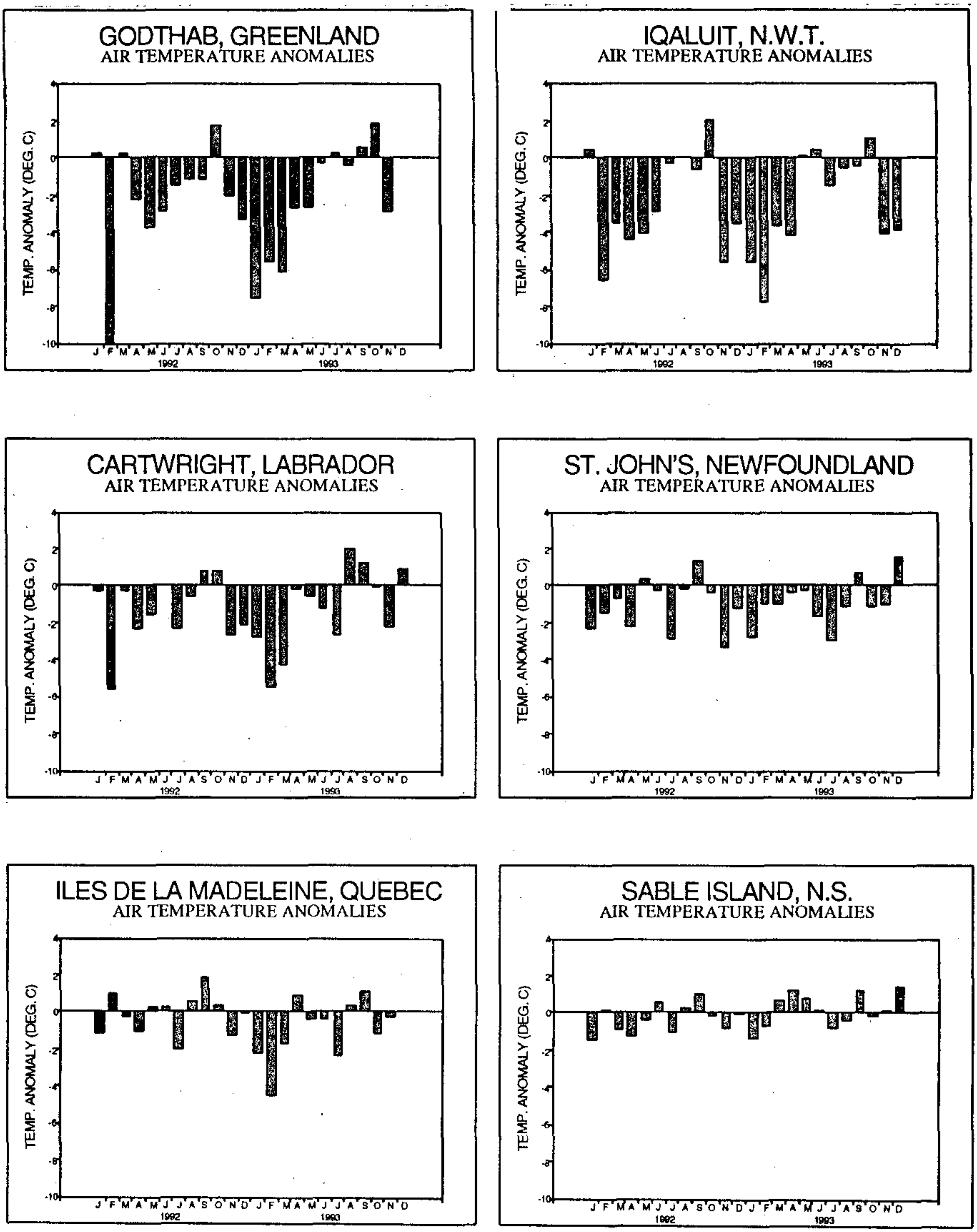


Fig. 3. Monthly air temperature anomalies at selected sites in 1992 and 1993.

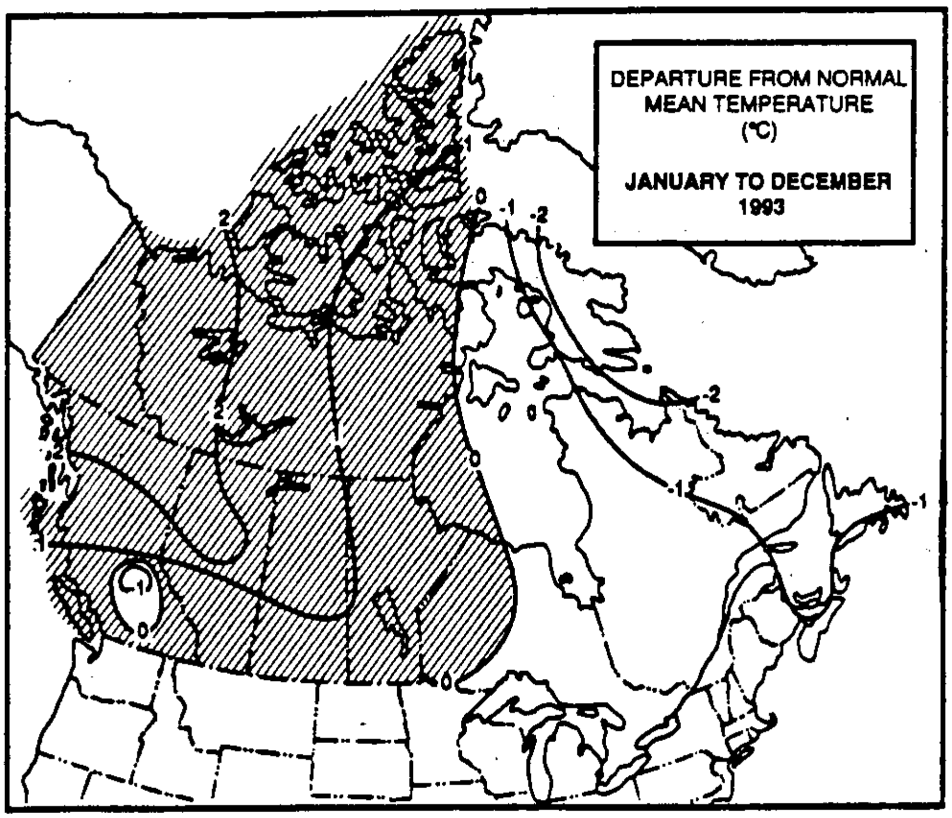


Fig. 4. Annual air temperature anomalies (°C) over Canada in 1993 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 15)

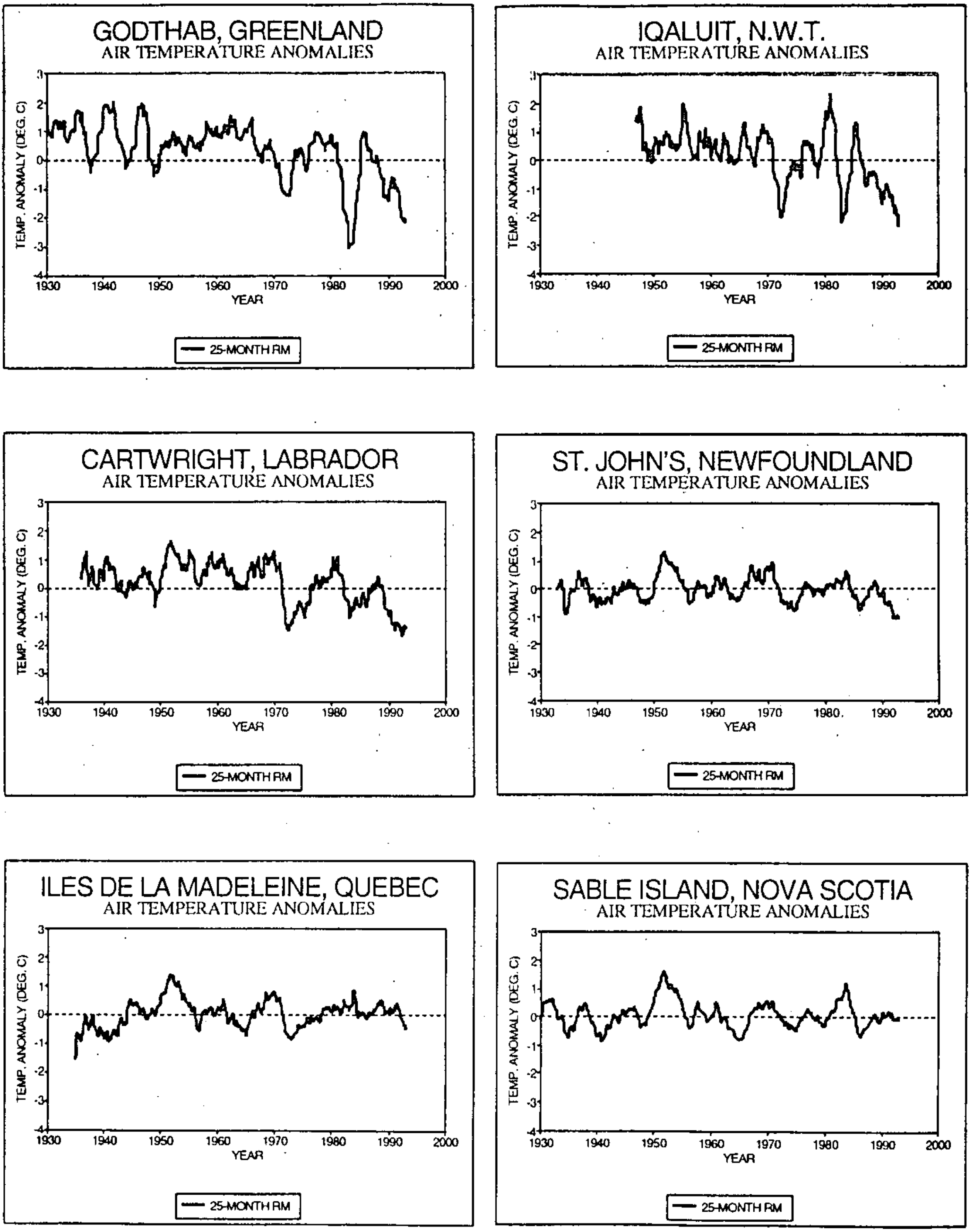


Fig. 5. Twenty-five month running means of monthly air temperature anomalies at selected sites.

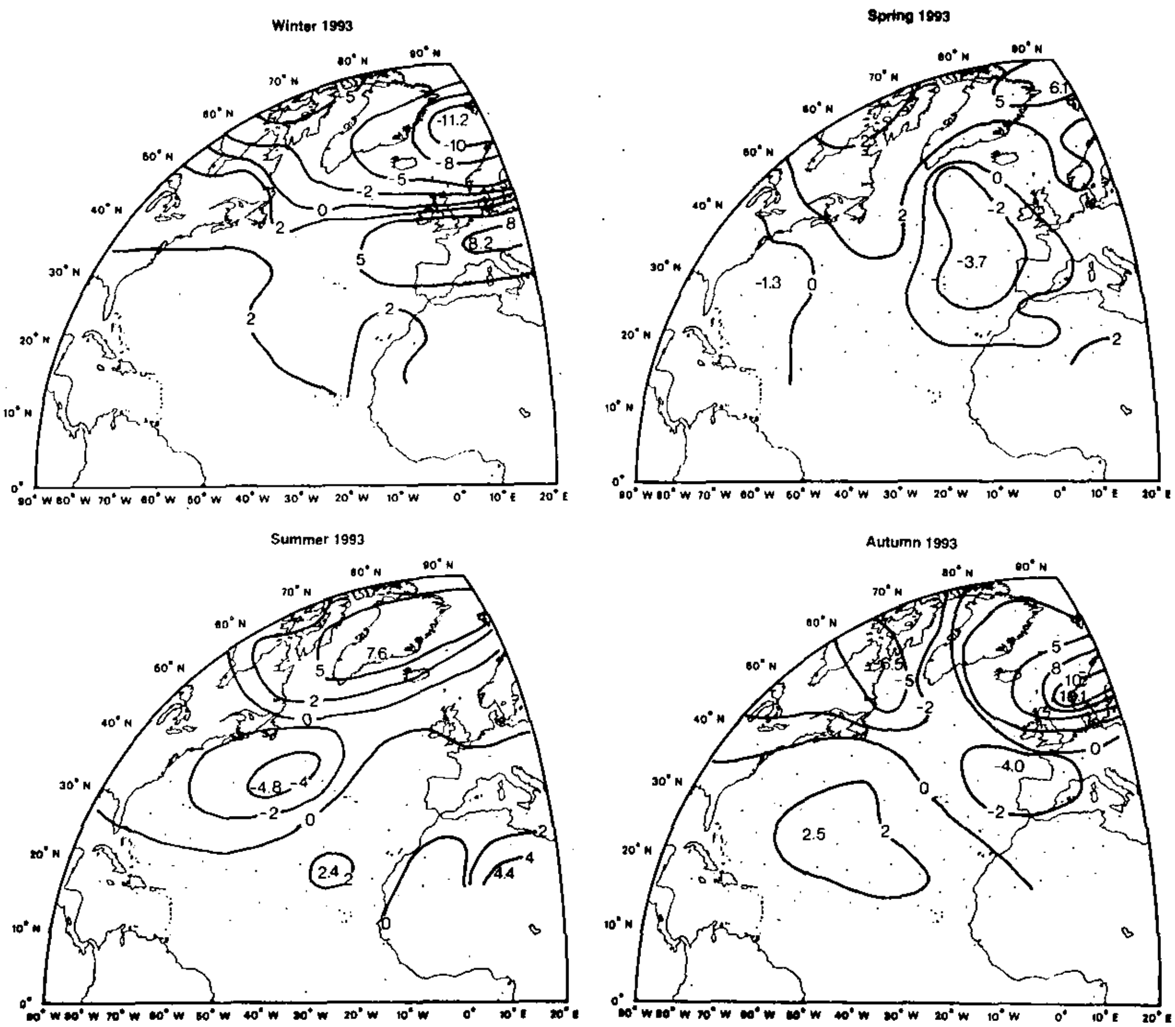


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1993 relative to the 1961-90 means.

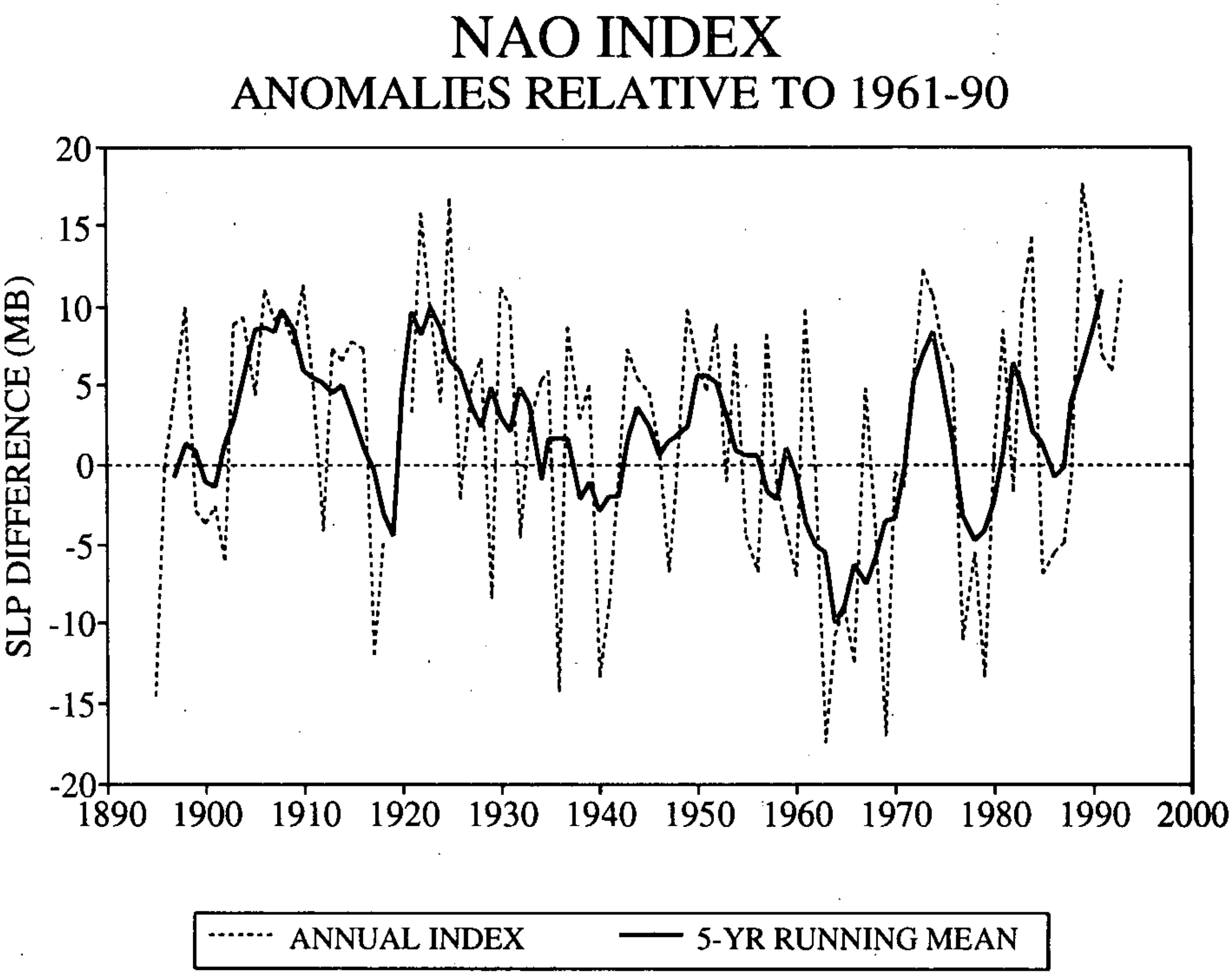


Fig. 7. The North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland.

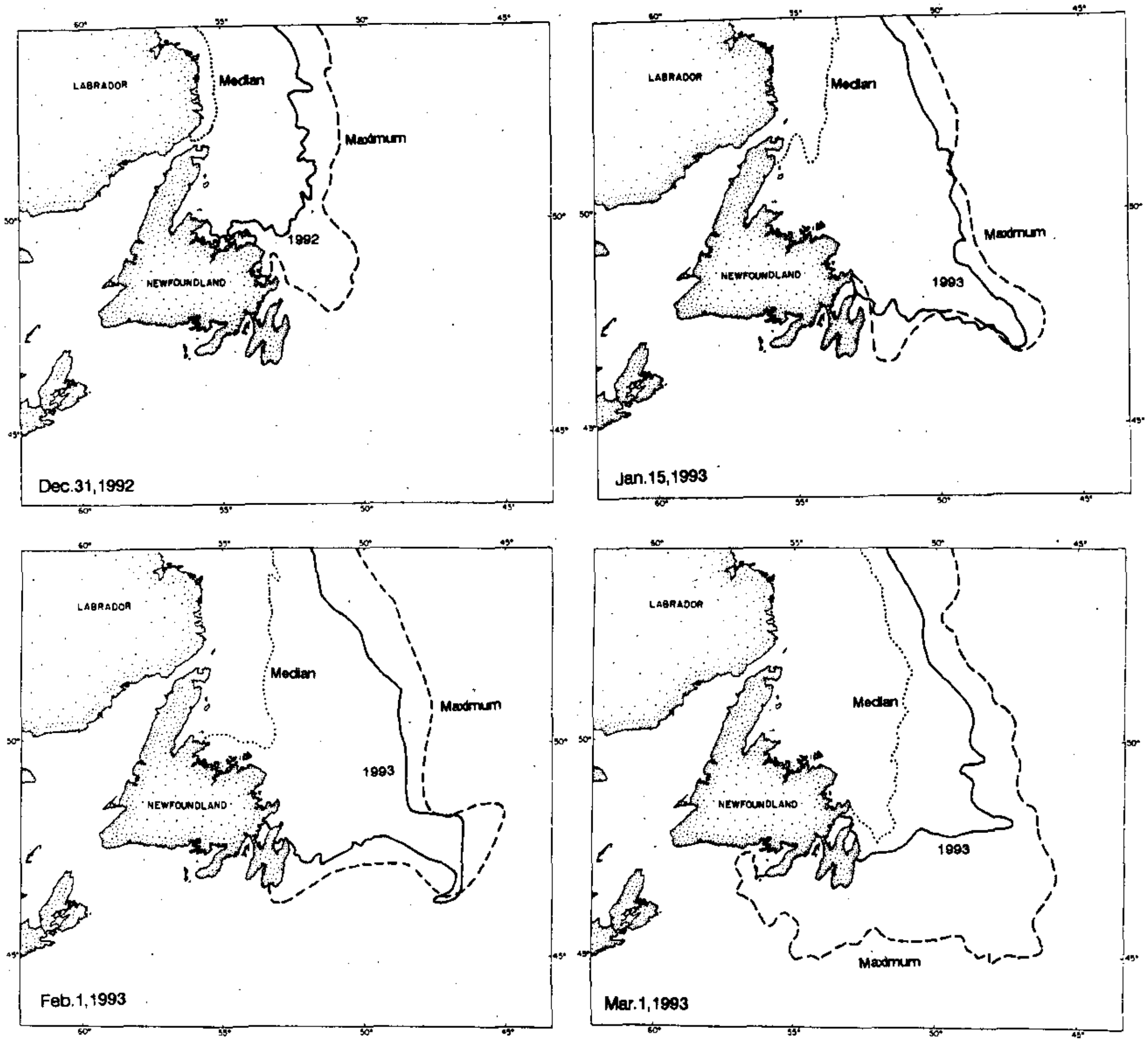


Fig. 8a. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between December 1992 and March 1993.

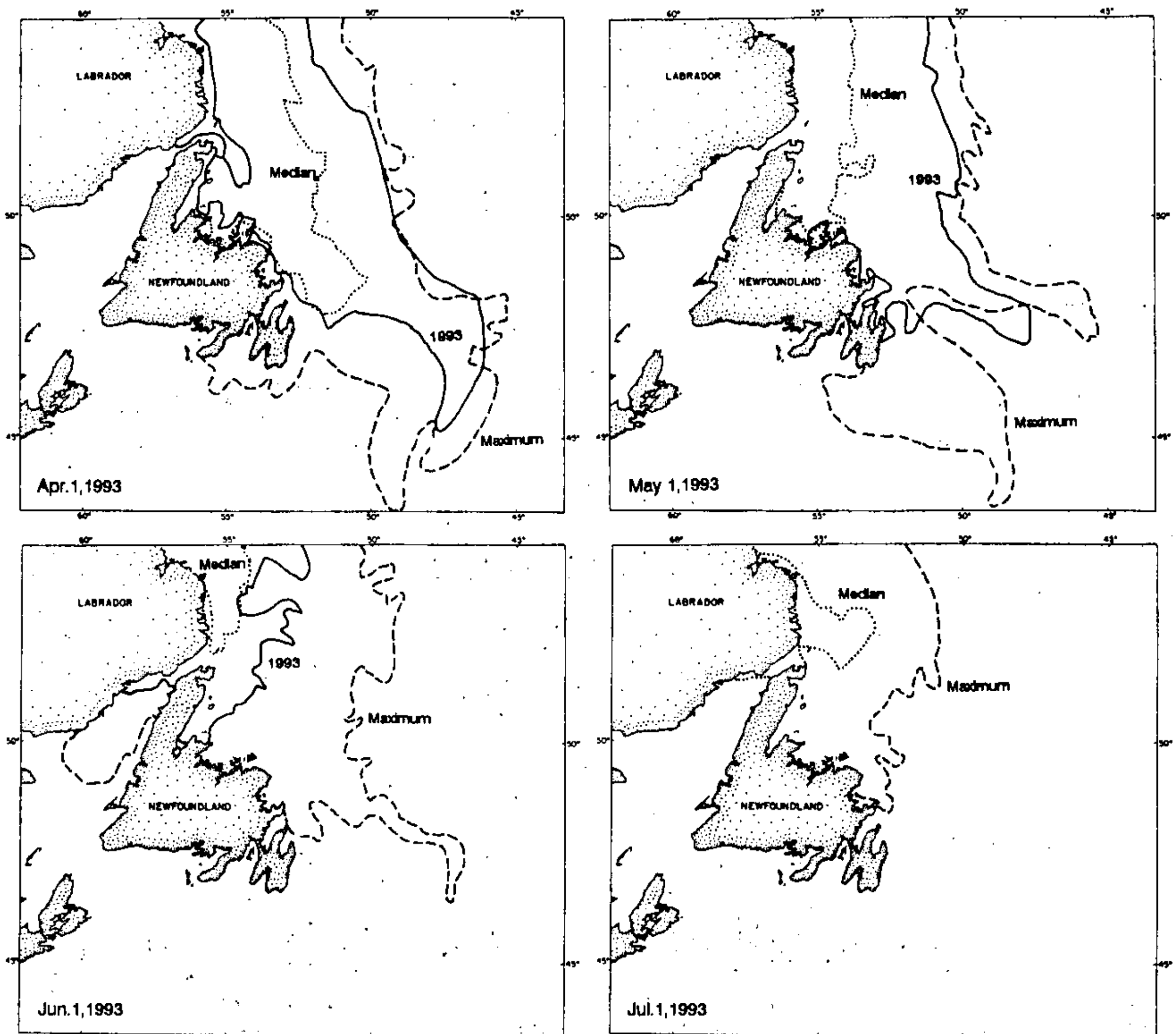


Fig. 8b. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between April and July 1993.

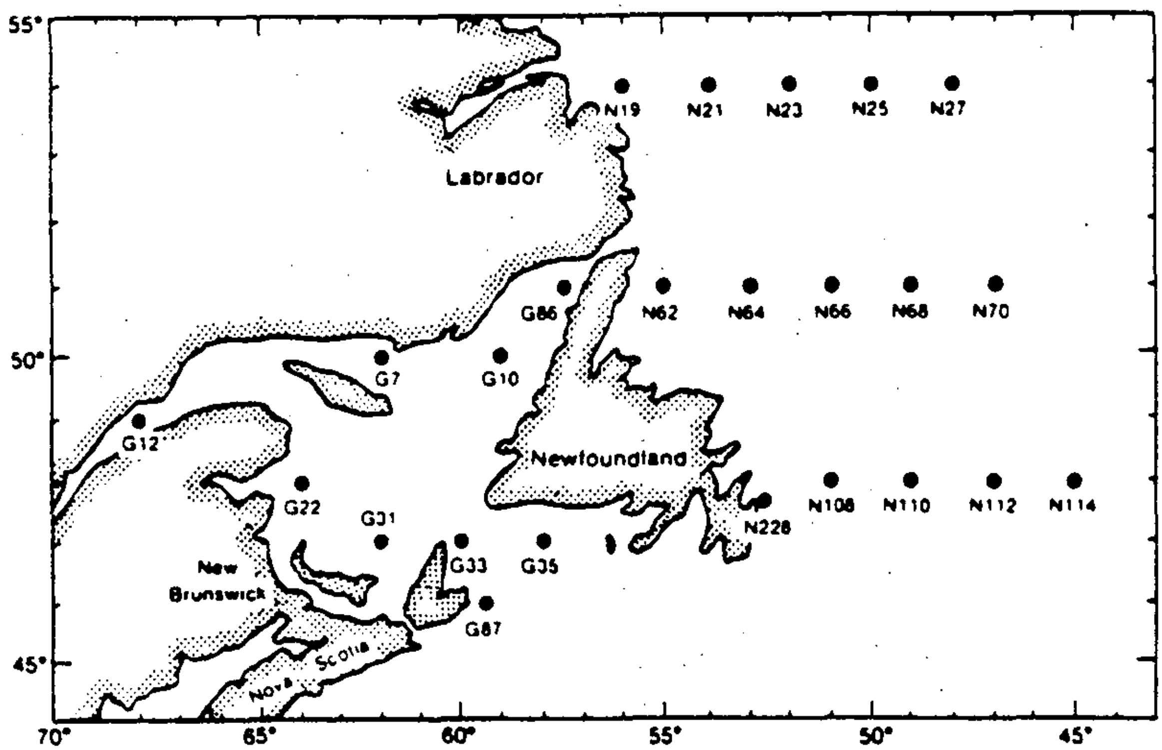
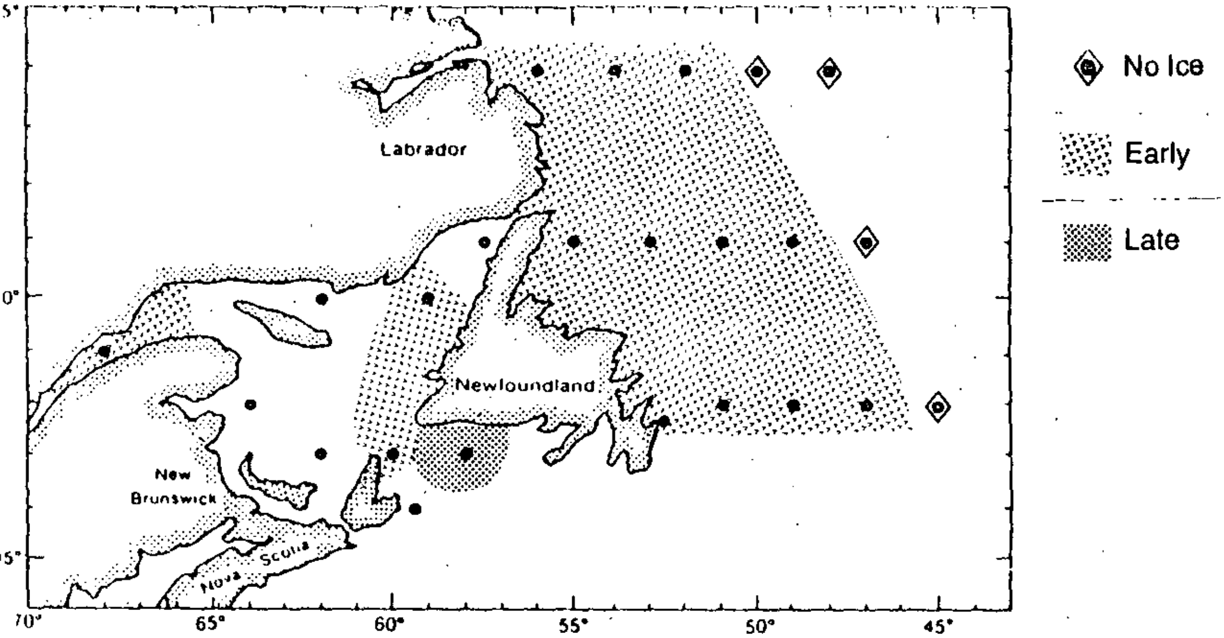


Fig. 9. Location of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

First Presence of Sea Ice 1992/93



Last Presence of Sea Ice 1992/93

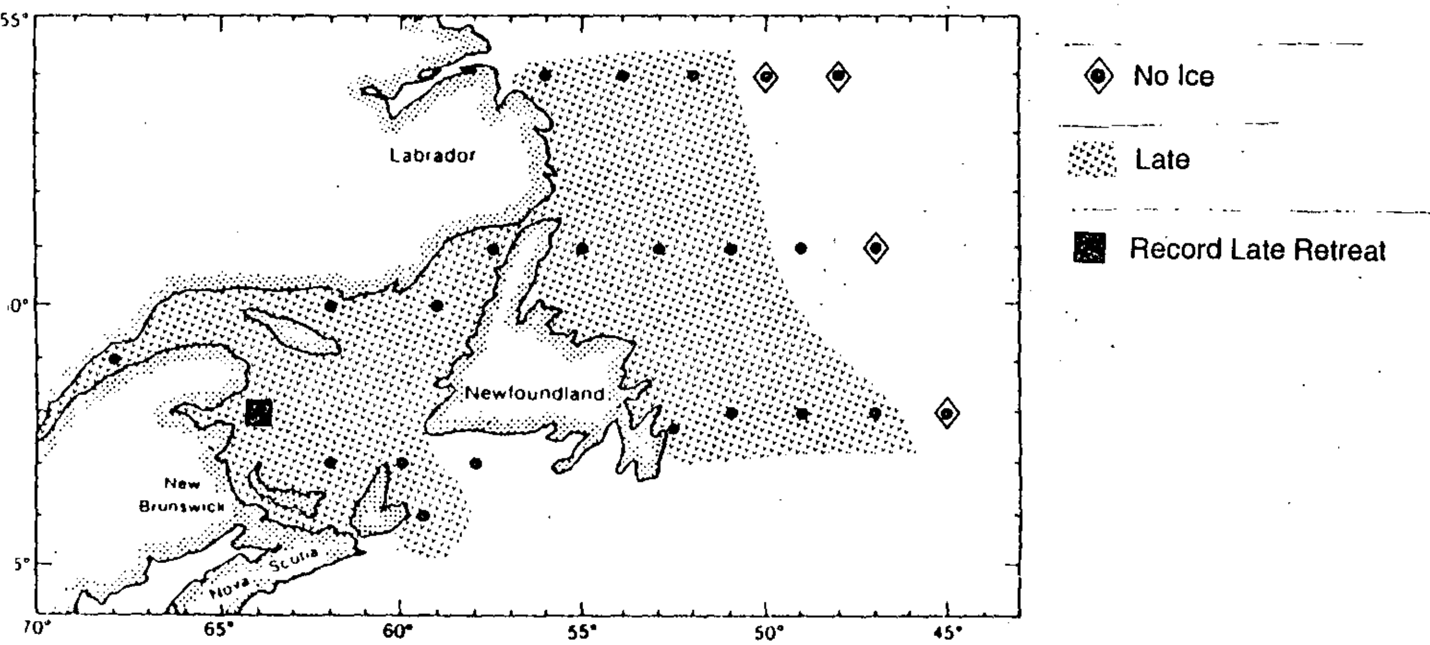


Fig. 10. The date of the presence of first (top) and last (bottom) ice relative to the long-term mean. Circles not surrounded by shading indicate sites where the ice advance was within 1 week of their mean dates. Early or late advance or retreat refers to differences exceeding 1 week. Sites marked as no ice means that ice was not present anytime through the ice season.

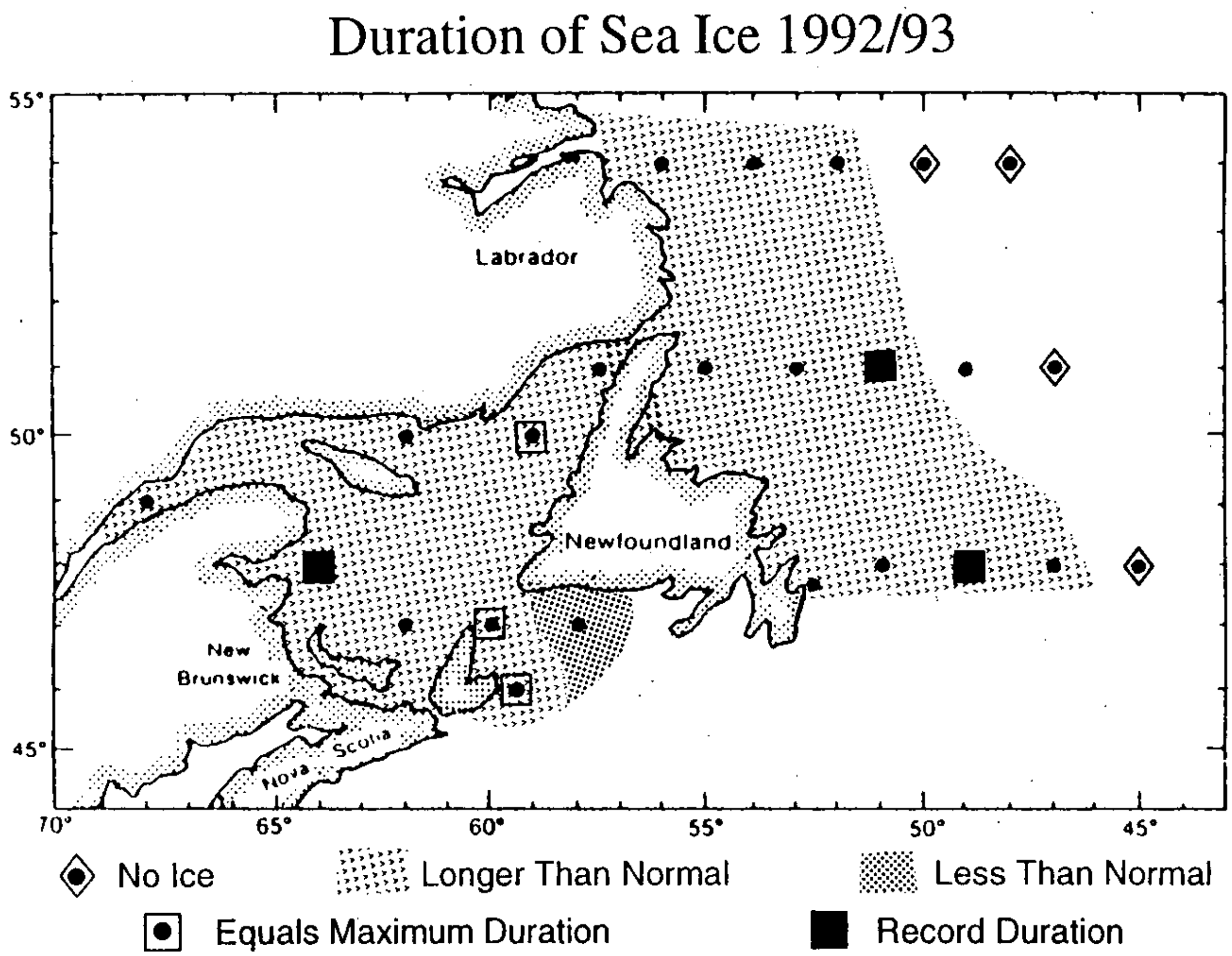


Fig. 11. The duration of ice relative to the long-term mean. Circles not surrounded by shading indicate sites where the duration was within 1 week of the mean. Shading indicates a duration longer or less than the mean by greater than 1 week.

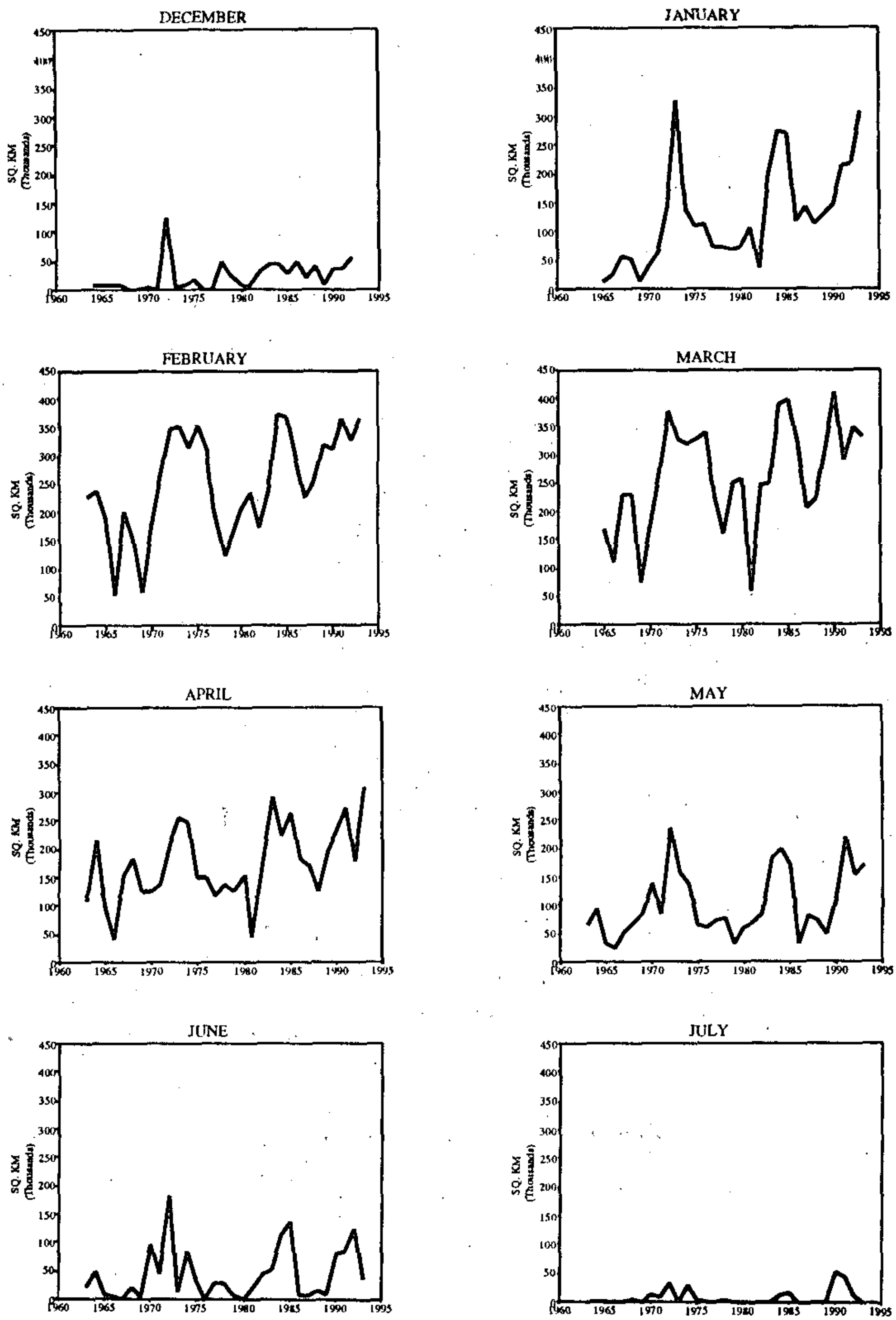
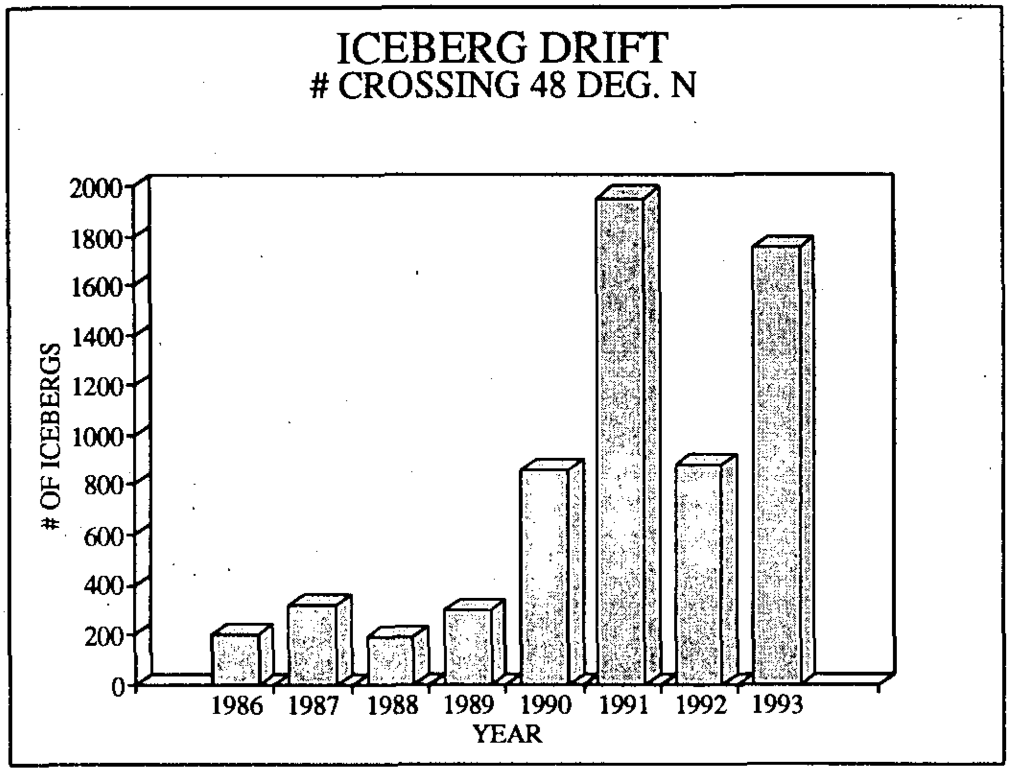


Fig. 12. The time series of ice area on the southern Labrador and northern Newfoundland shelves between 45°N-55°N by month.



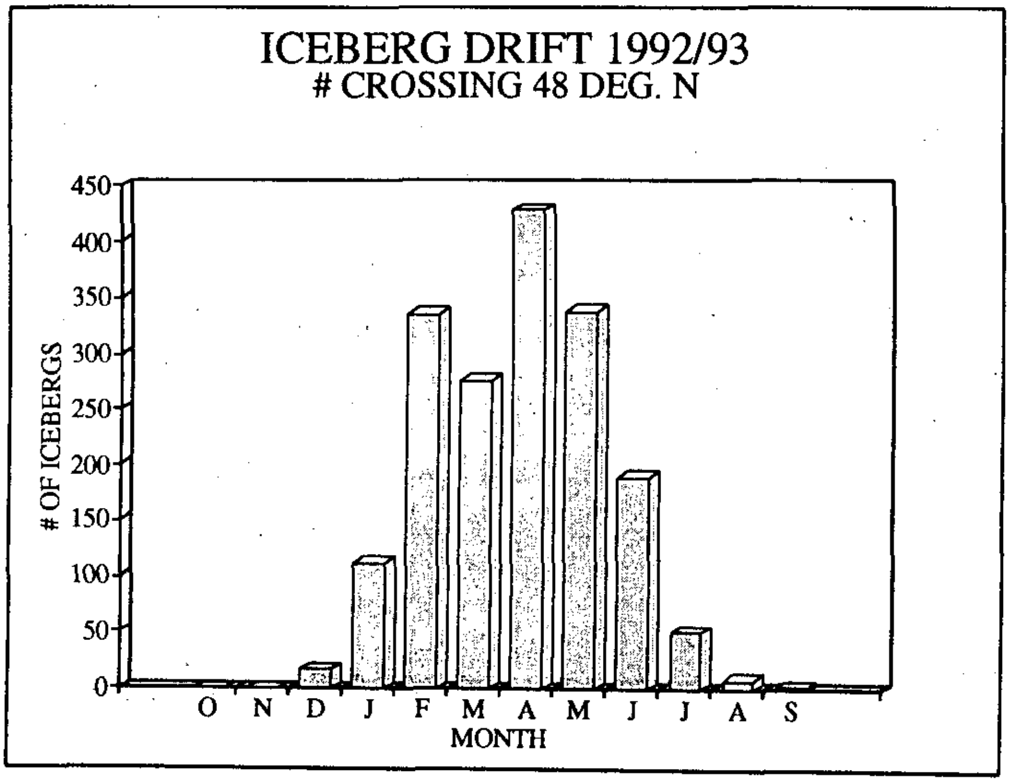


Fig. 13. The total number of icebergs in 1986-93 (top) and the monthly numbers of icebergs crossing south of 48°N during the iceberg season 1992/93 (bottom).

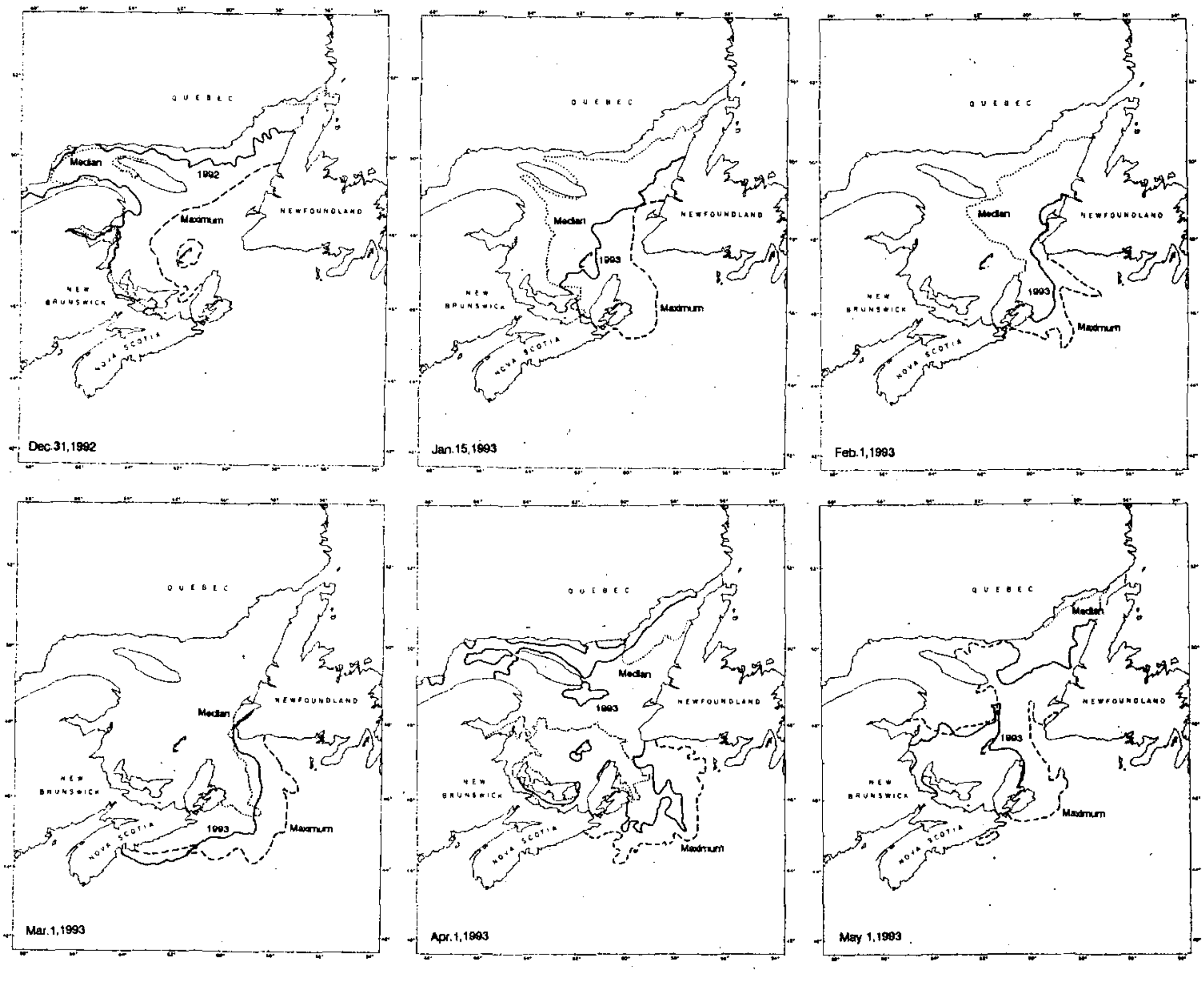


Fig. 14. The location of the ice edge together with the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence between December 1992 and May 1993.

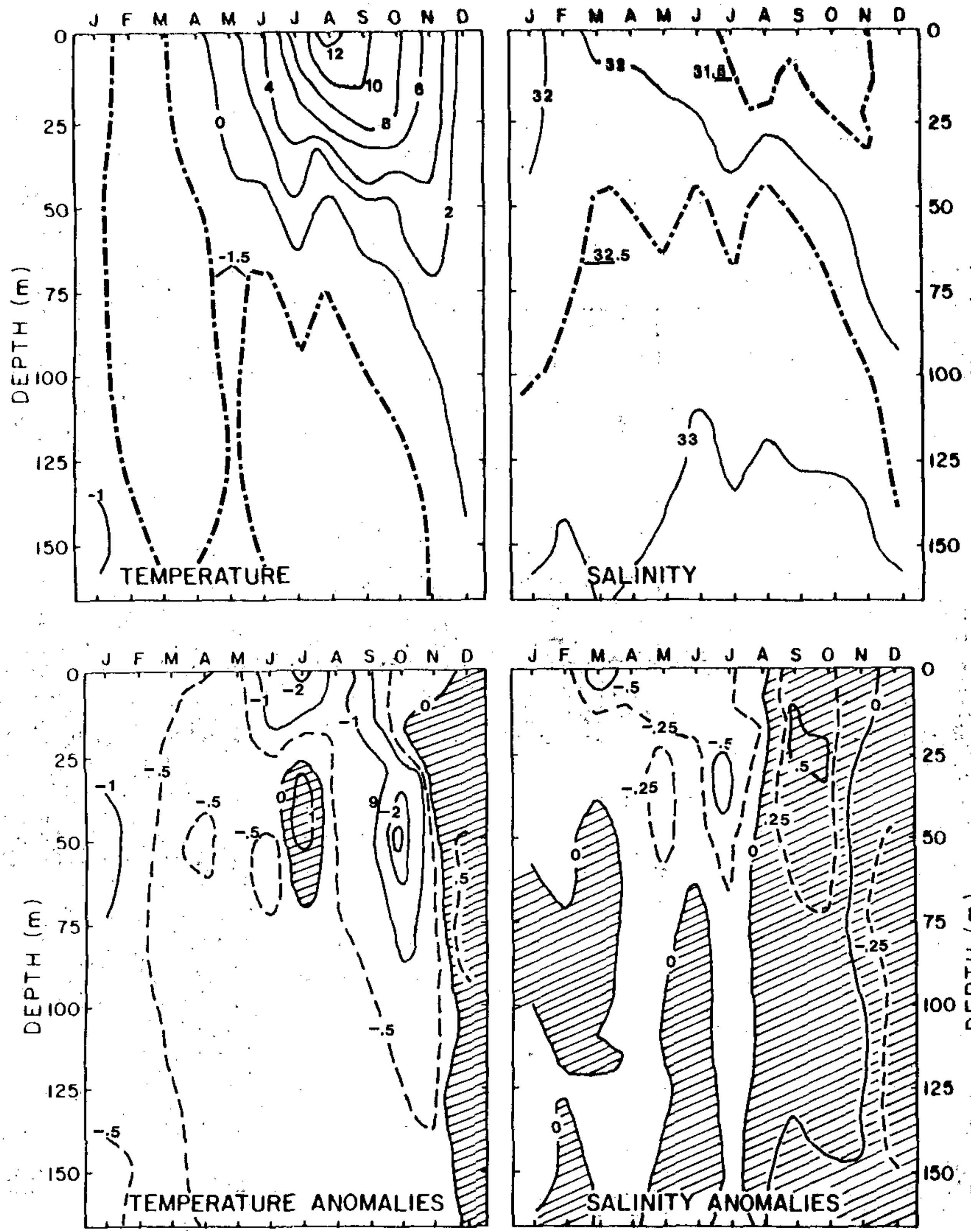


Fig. 15. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1993 relative to the 1961-90 means. Shaded areas are positive anomalies.

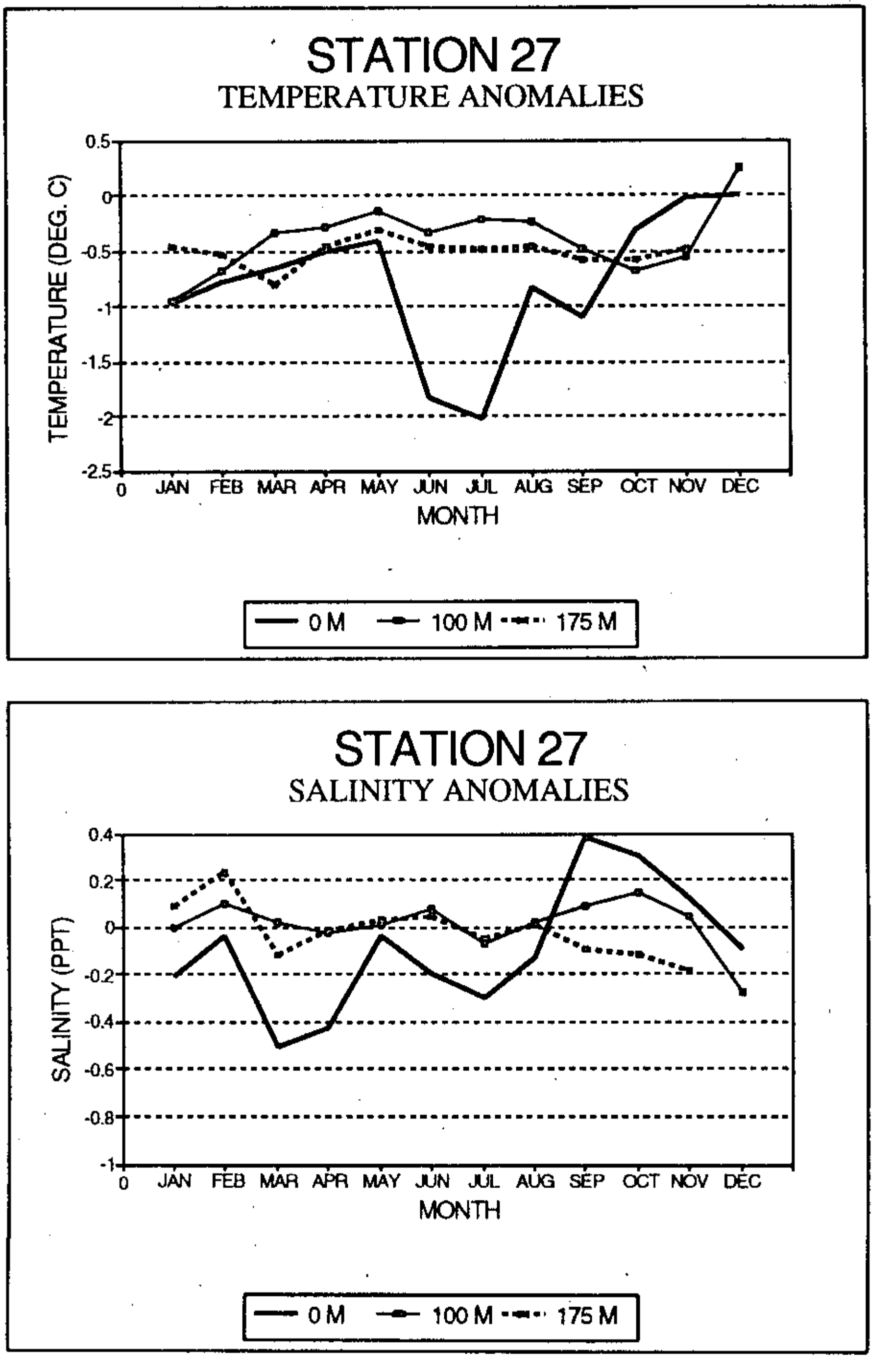


Fig. 16. Monthly temperature and salinity anomalies at 0, 100, and 175 m at Station 27 during 1993.

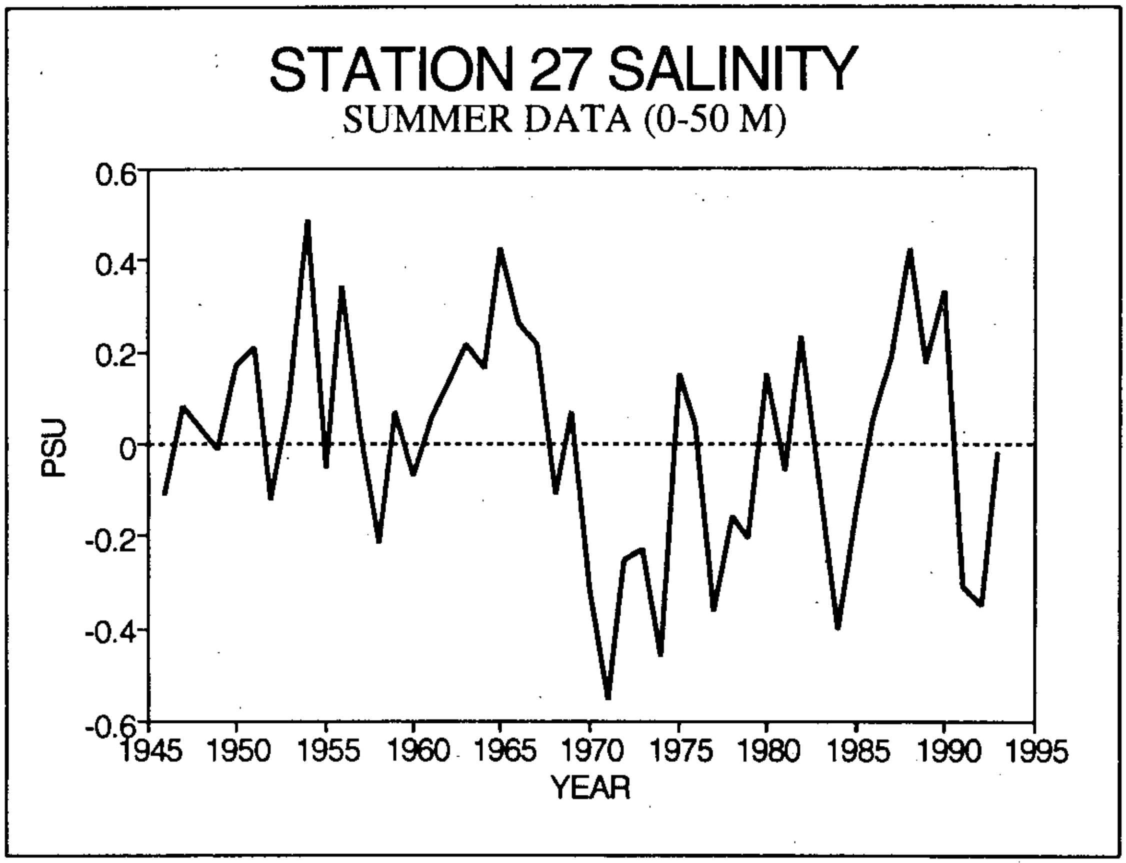


Fig. 17. The 50-m depth-averaged salinities at Station 27 during summer (July, August and September).

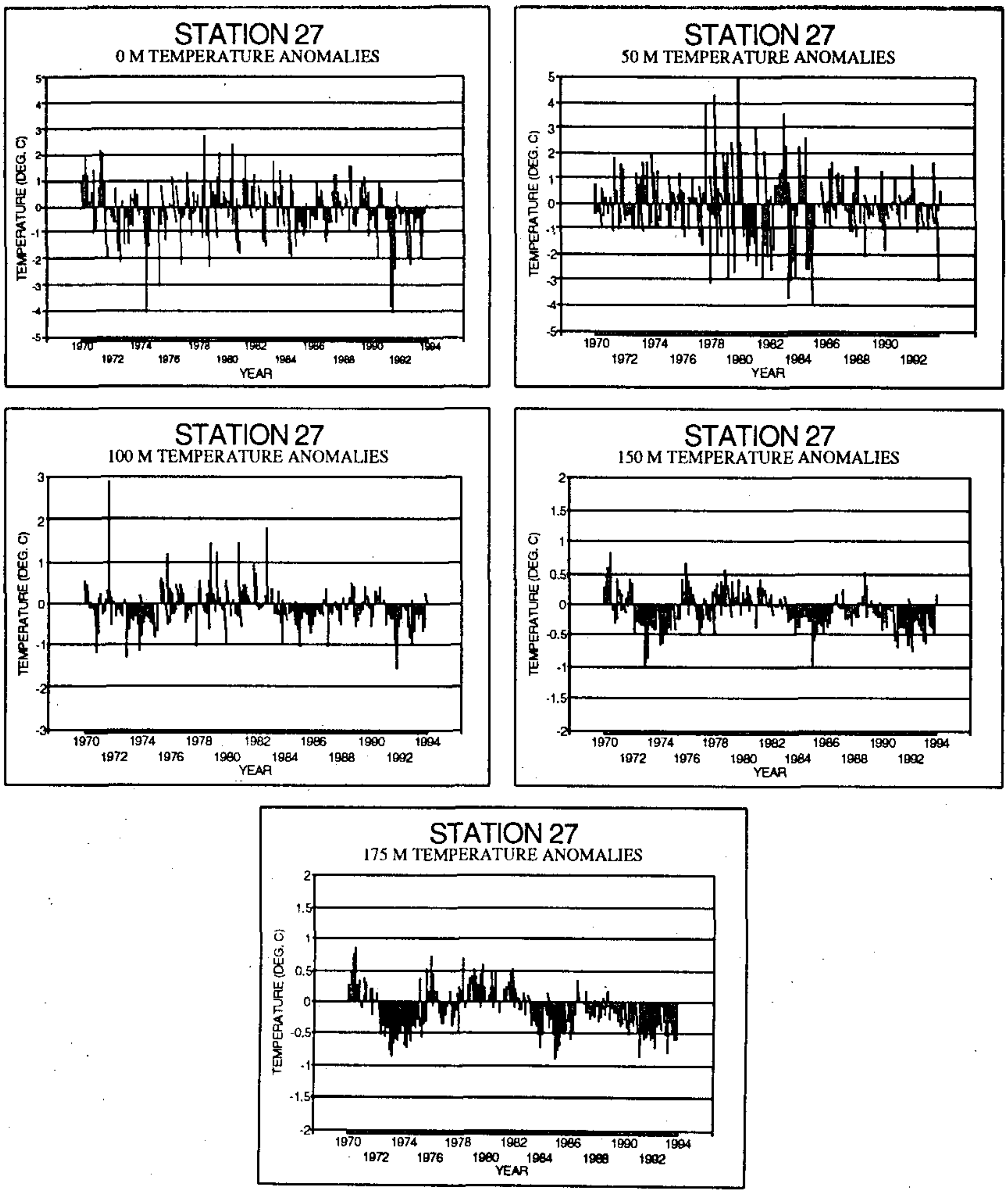


Fig. 18. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27.

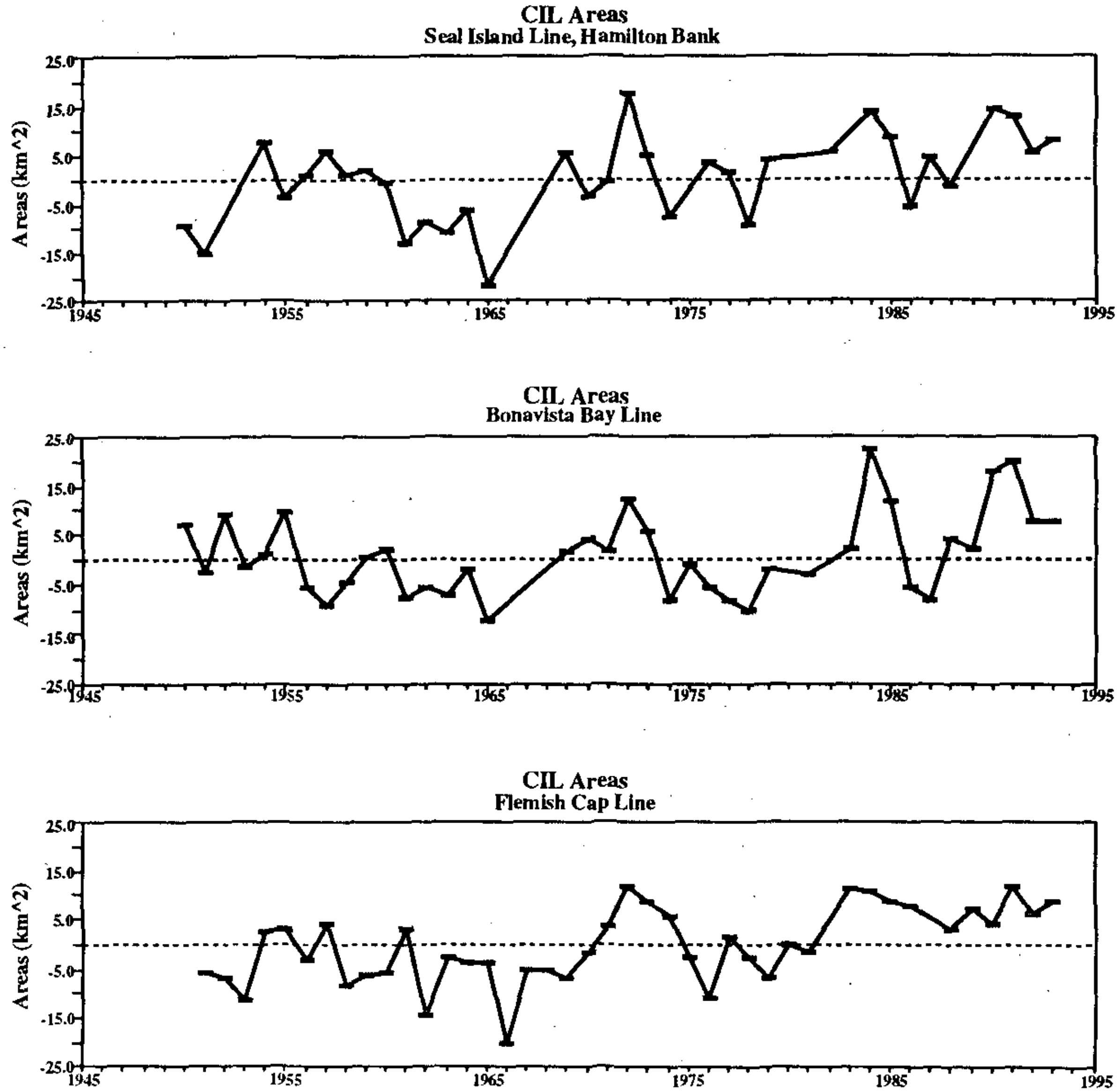


Fig. 19. The time series of the area of the CIL along standard sections off southern Labrador and northern Newfoundland.

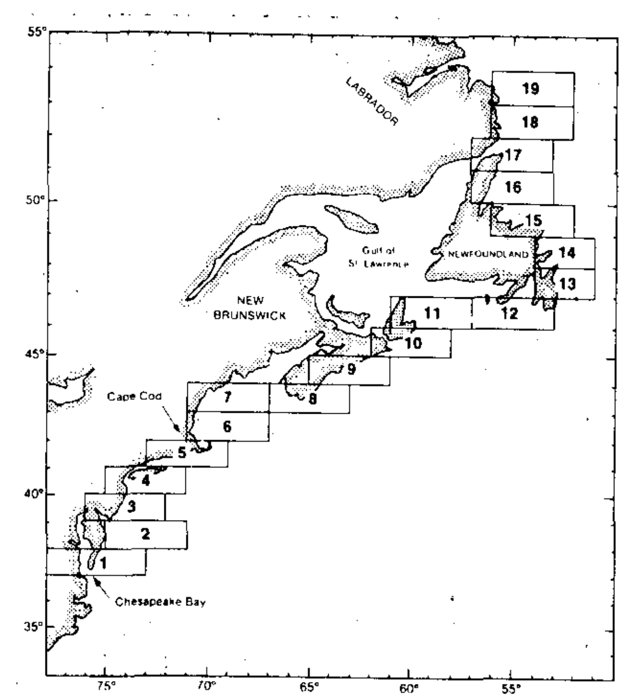


Fig. 20. Locations of 19 areas in the Northwest Atlantic (Chesapeake Bay to southern Labrador) for which sea-surface temperature data were grouped for analysis.

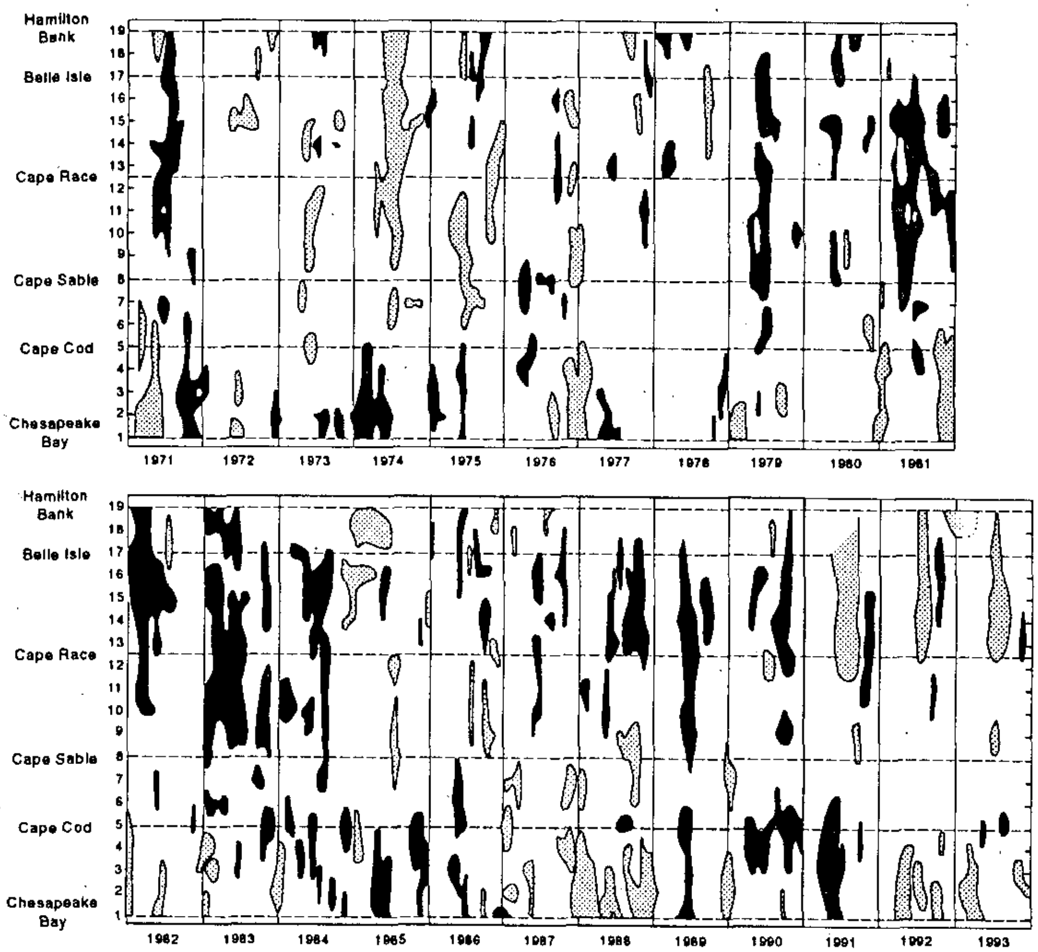


Fig. 21. Contoured monthly SST anomalies (relative to 1971-90 means) by area (Fig. 20). (Only anomalies exceeding 1°C (black) and less than -1°C (dotted) which extended in space through at least two neighbouring areas or in time for at least two consecutive months have been contoured.

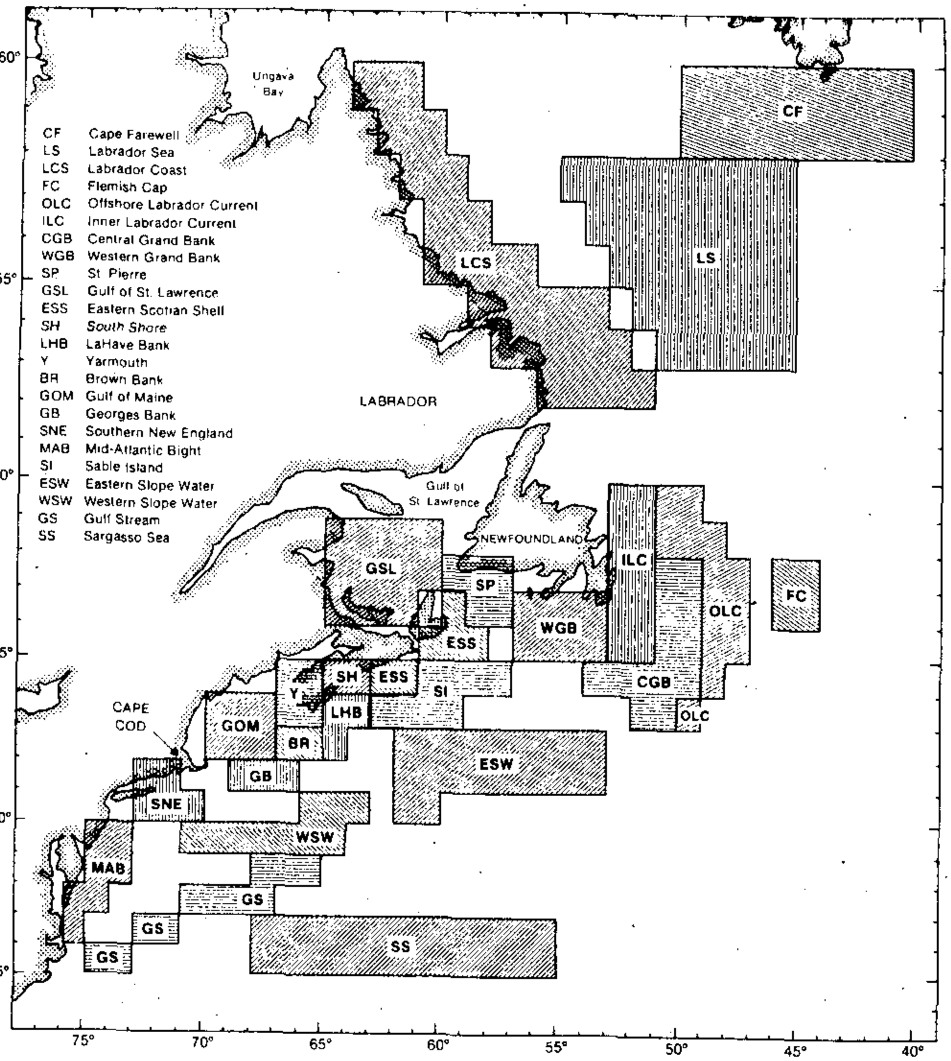


Fig. 22. The geographic boundaries of the 24 subregions for which sea surface temperatures were analyzed on a monthly basis.

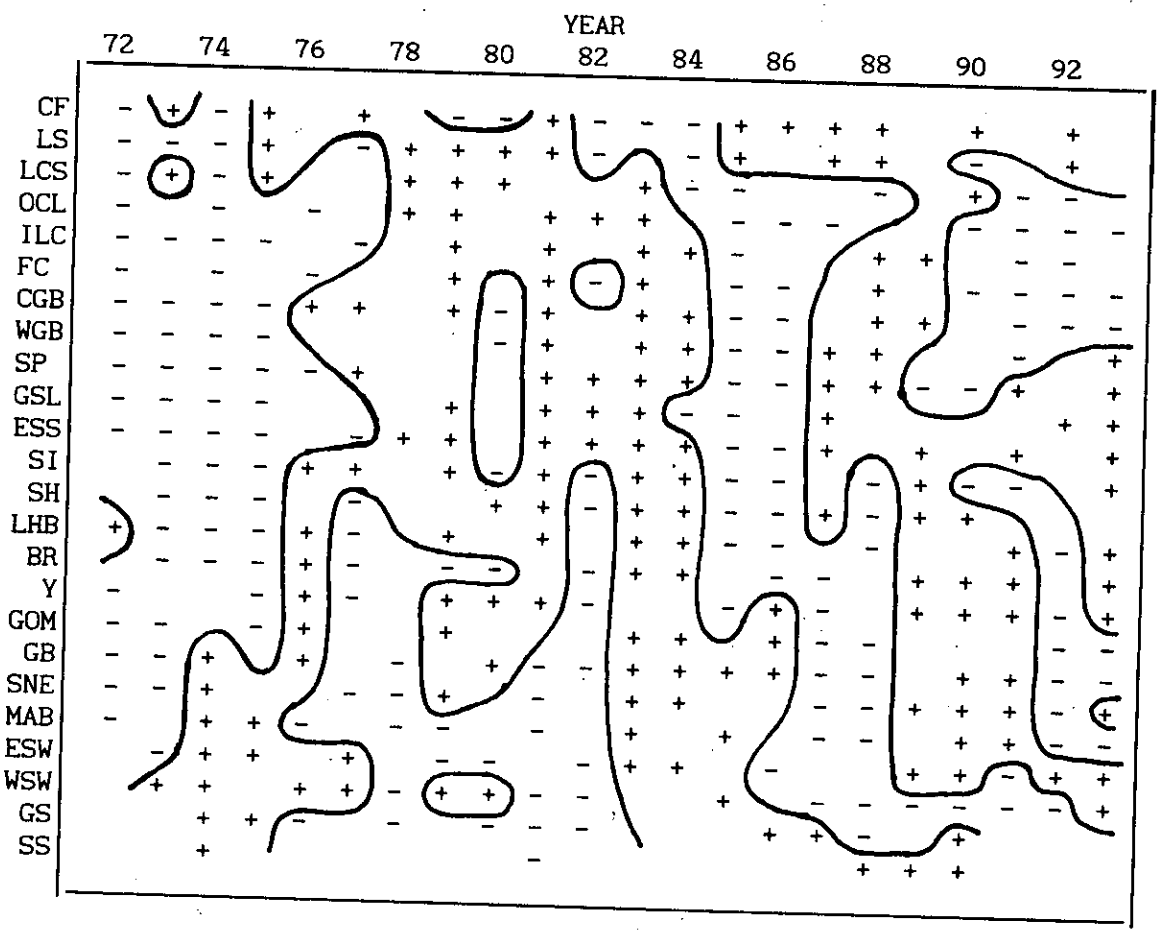


Fig. 23. Distribution of positive (+) and negative (-) annual sea-surface temperature anomalies in 1972-90 by subregion (Fig. 24) relative to the 1972-90 means. (Only anomalies less than -0.15°C and greater than +0.15°C were used in drawing the contours.)

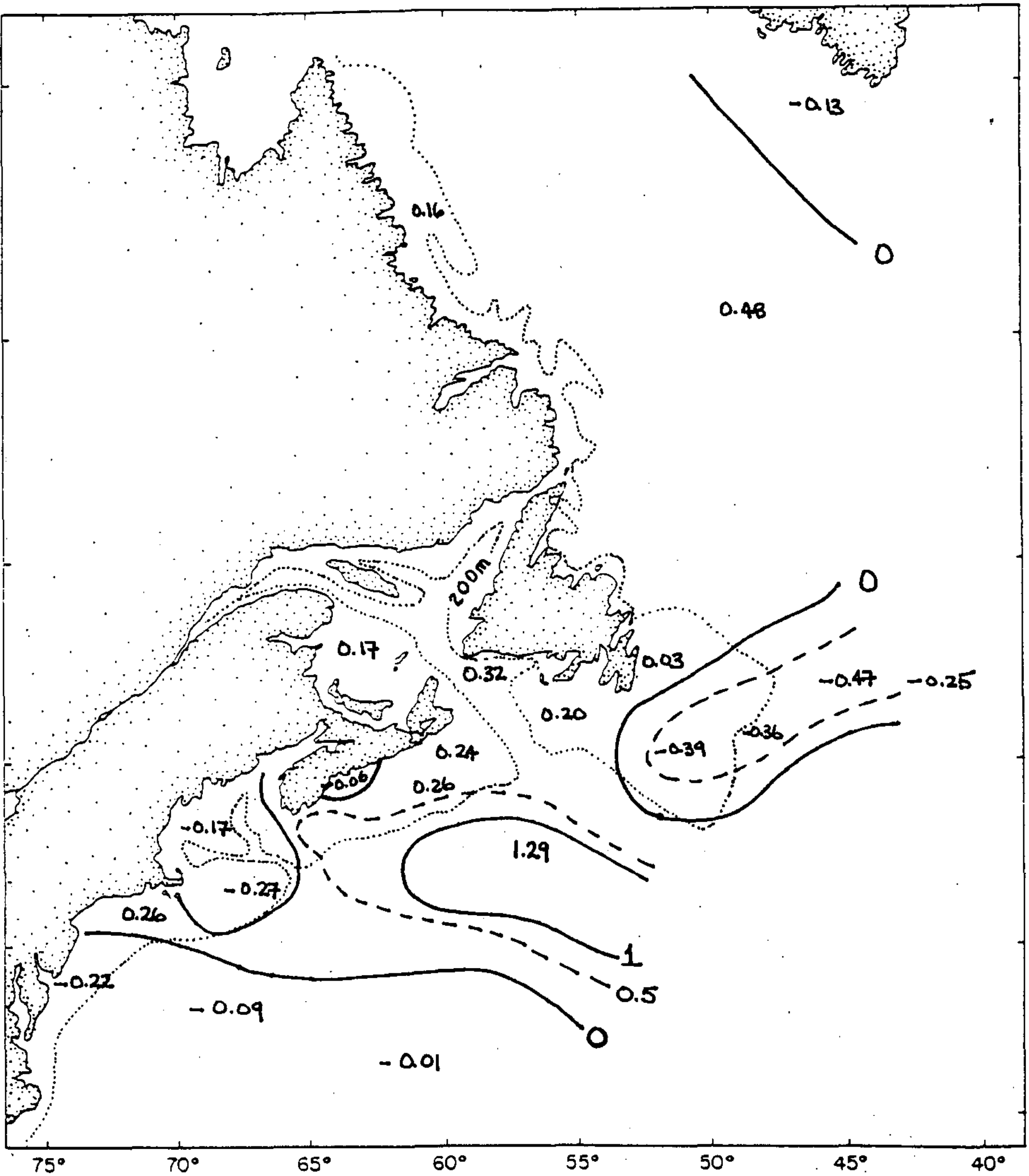


Fig. 24. Contours of the annual mean sea-surface temperature anomalies in 1993 for 24 areas in the NW Atlantic Ocean.

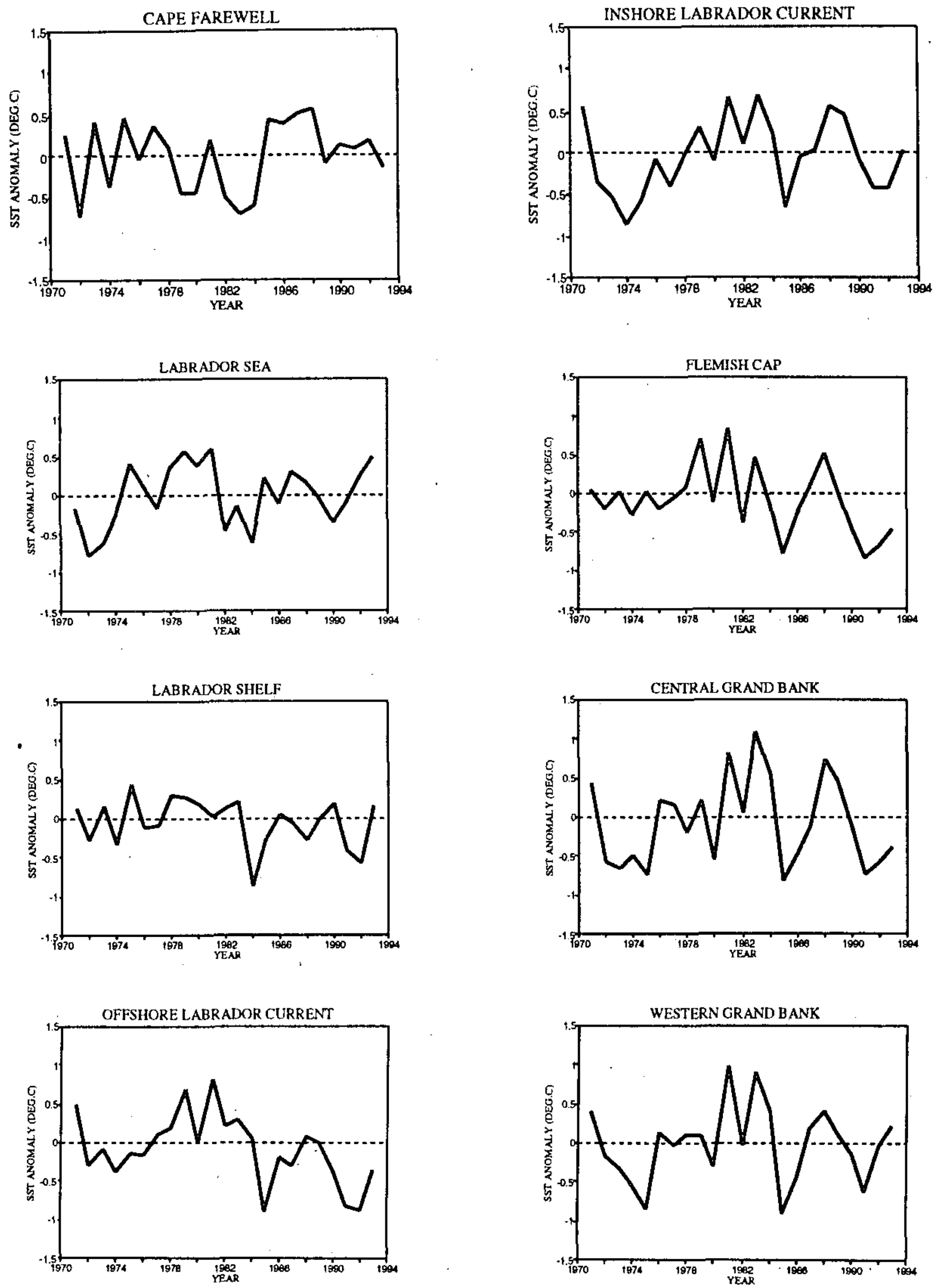


Fig. 25A. The annual temperature anomalies (relative to 1971-90) for the offshore areas - Cape Farewell to Western Grand Bank.

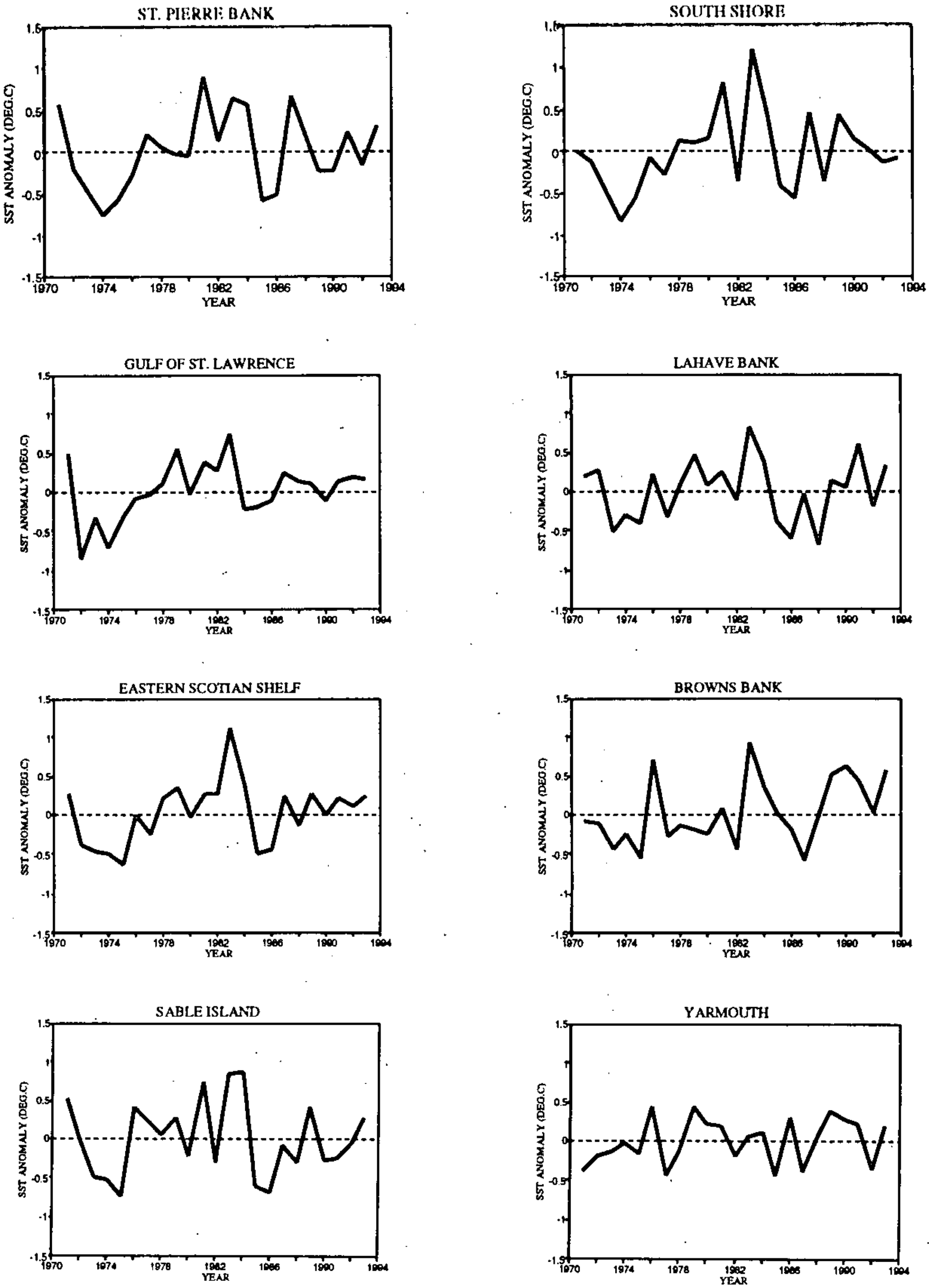


Fig. 25B. The annual temperature anomalies (relative to 1971-90) for the offshore areas - St. Pierre to Yarmouth.

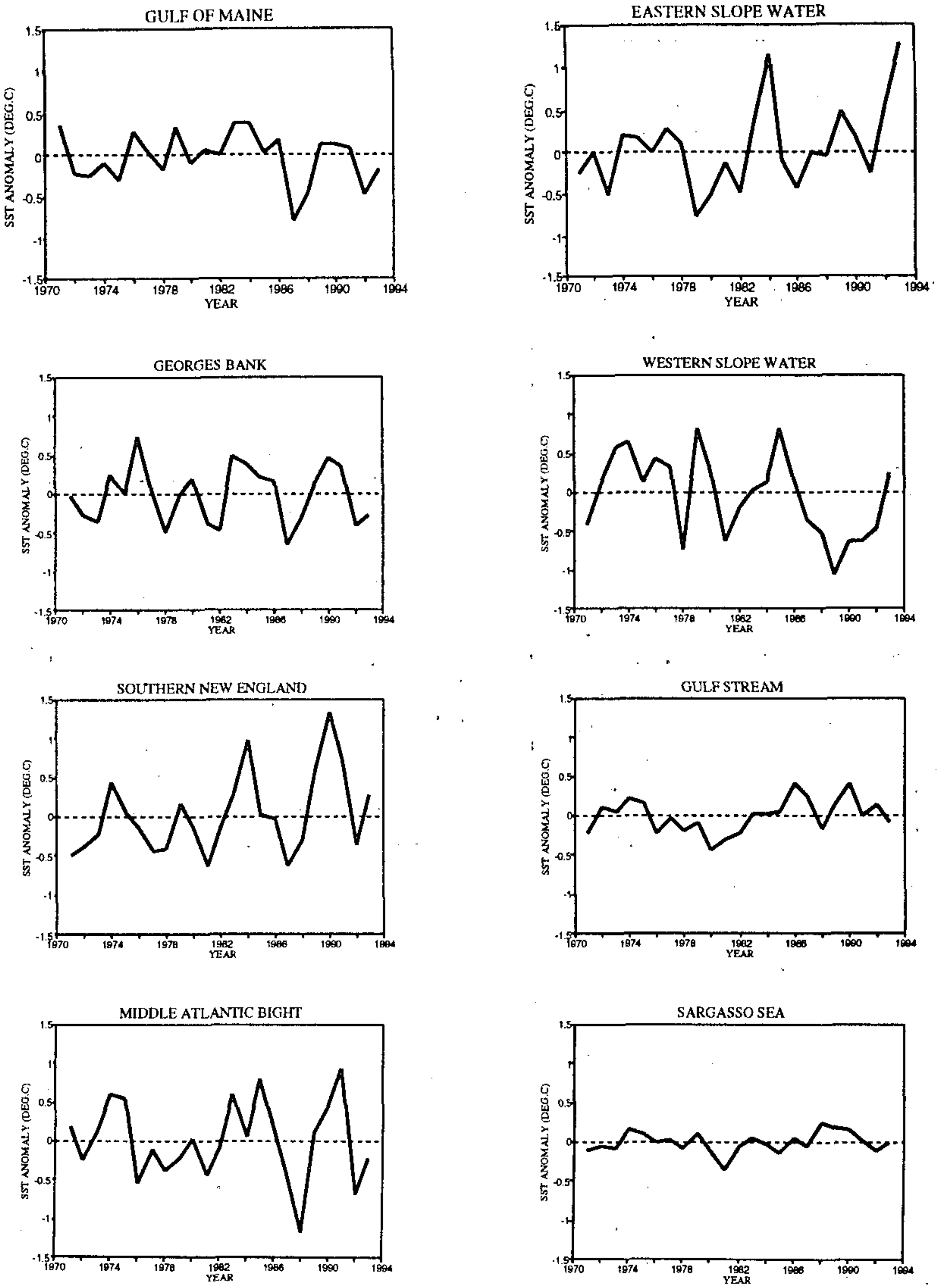
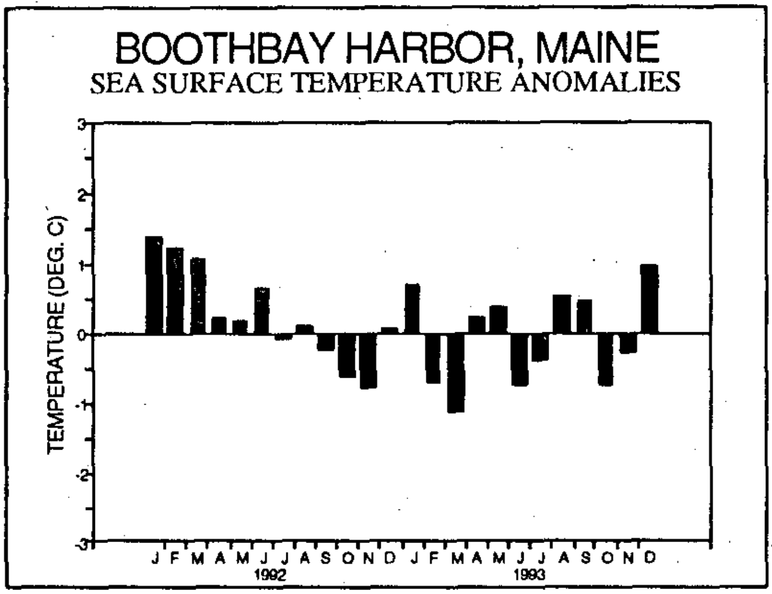
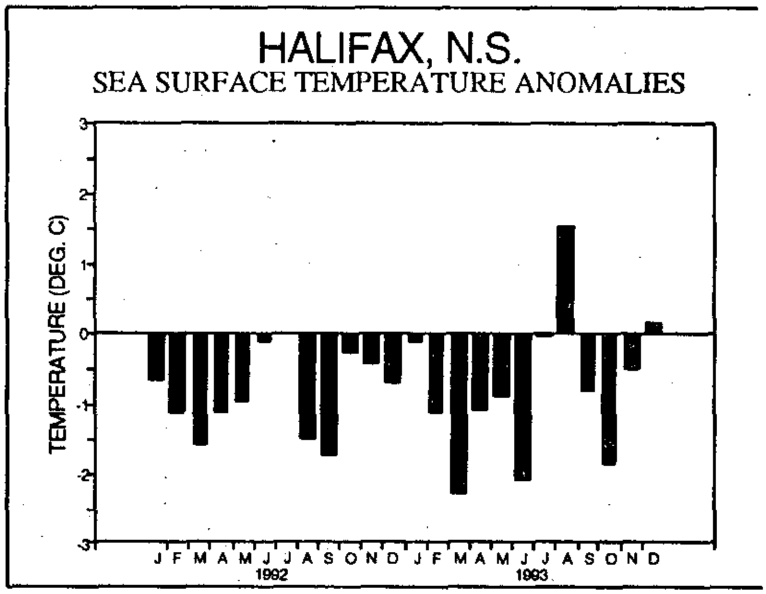


Fig. 25C. The annual temperature anomalies (relative to 1971-90) for the offshore areas - Gulf of Maine to the Sargasso Sea.





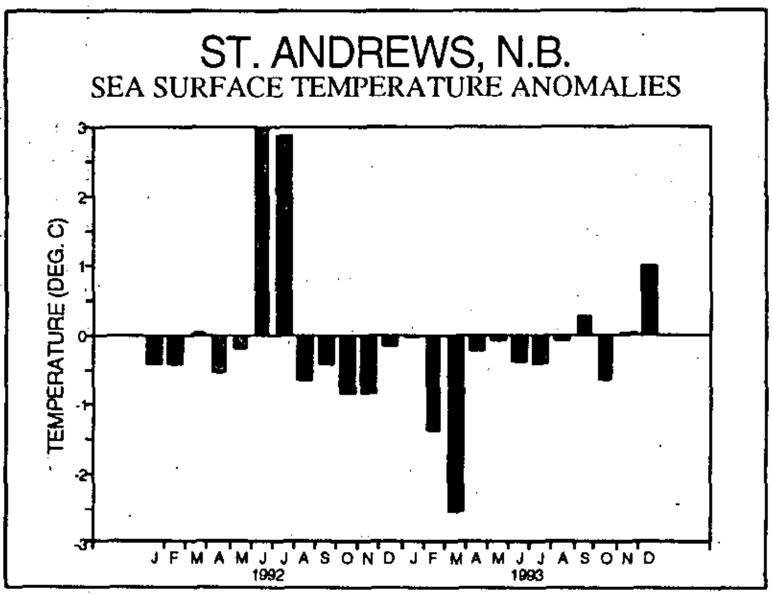
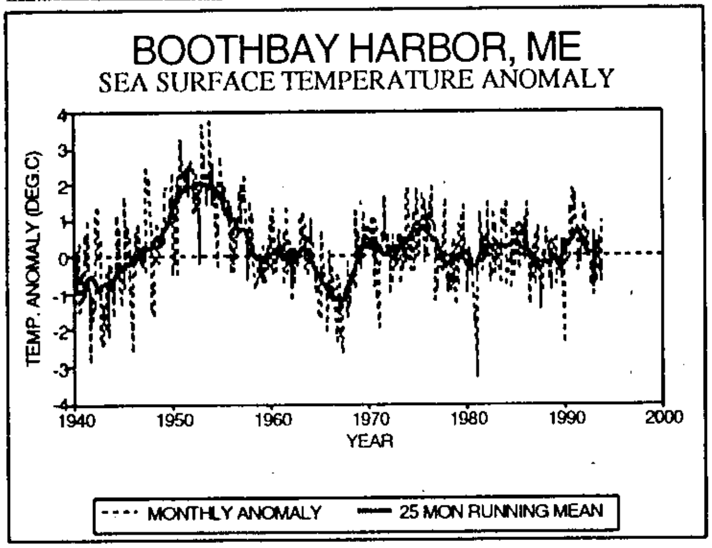
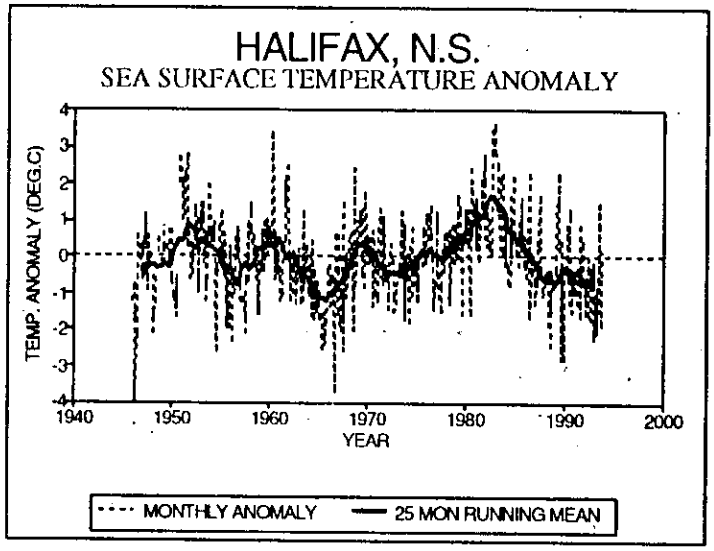


Fig. 26. The monthly sea surface temperature anomalies (relative to 1961-90) during 1993 for Boothbay Harbor, St. Andrews and Halifax.





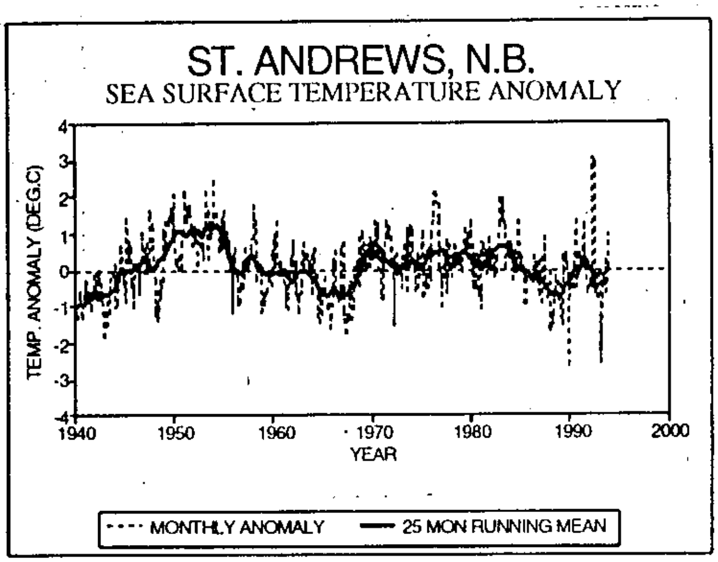


Fig. 27. The monthly means and the 25-month running means of the sea surface temperature anomalies (relative to 1961-90) for Boothbay Harbor, St. Andrews and Halifax.

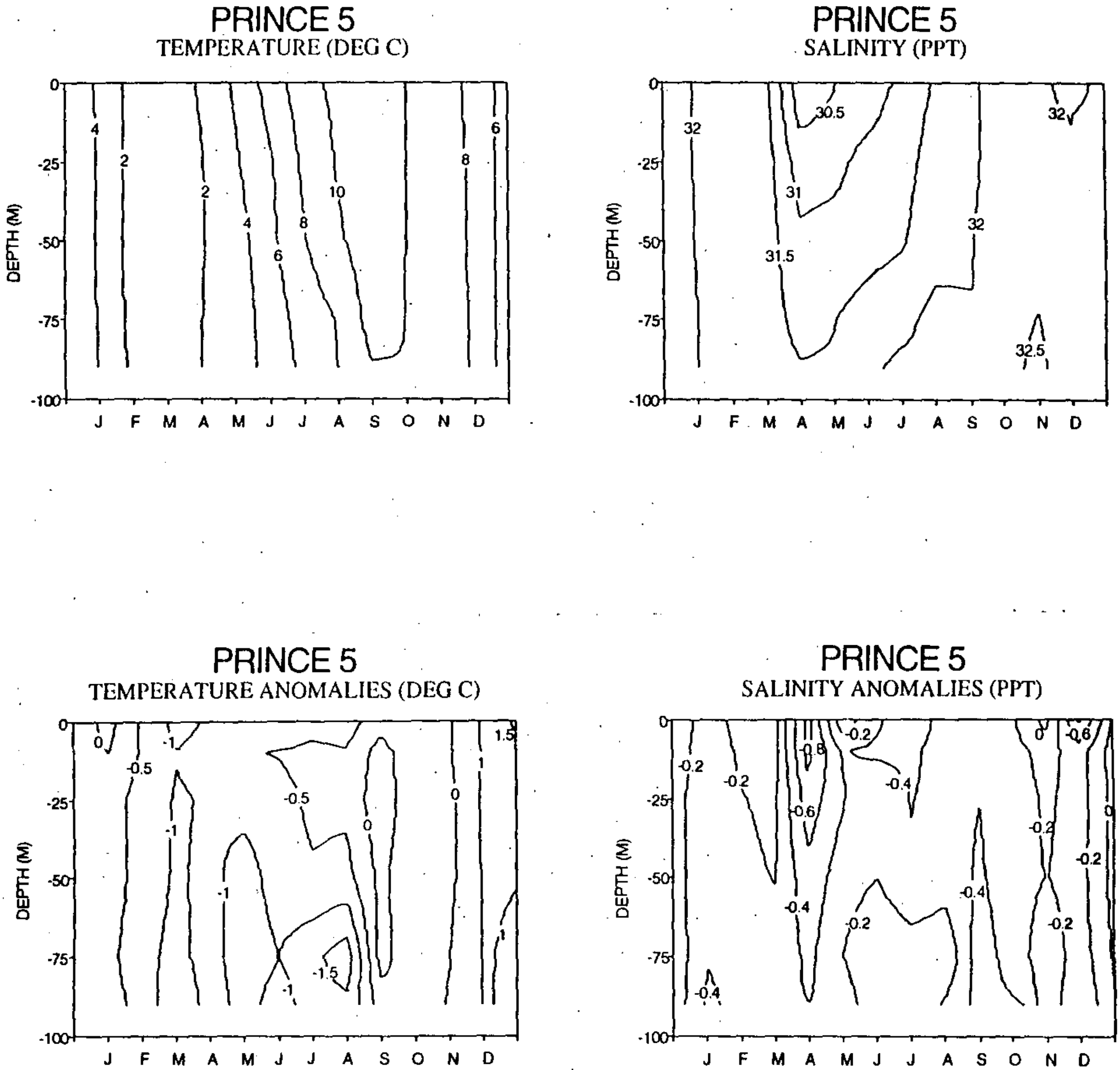
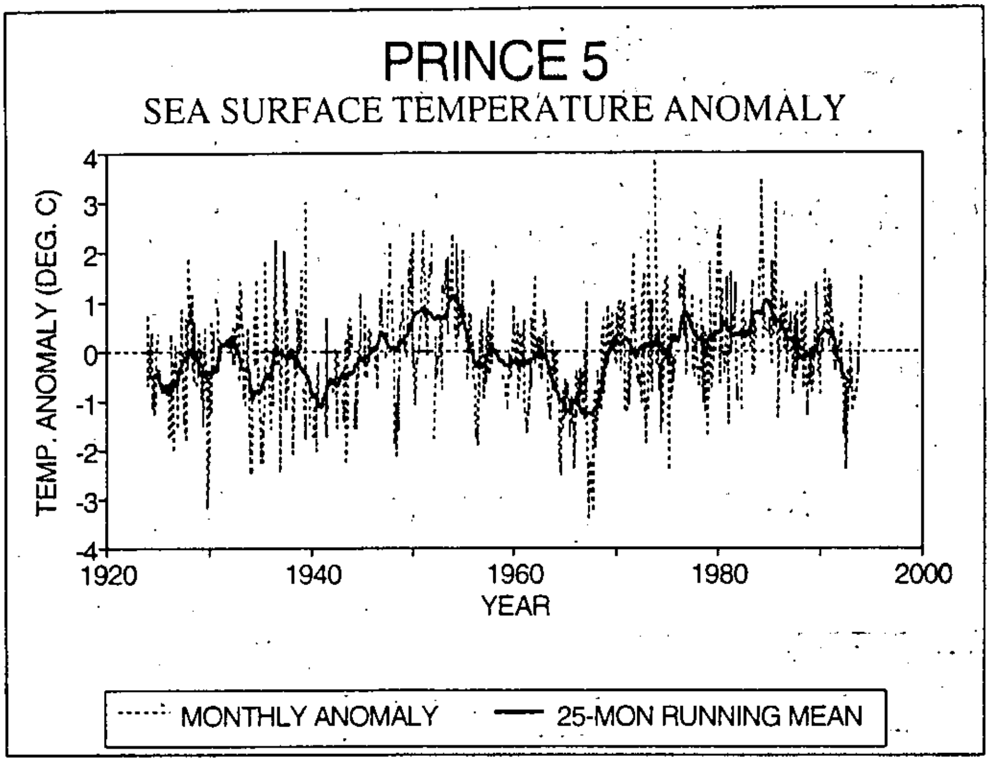


Fig. 28. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1992 relative to the 1961-90 means. Shaded areas are positive anomalies.



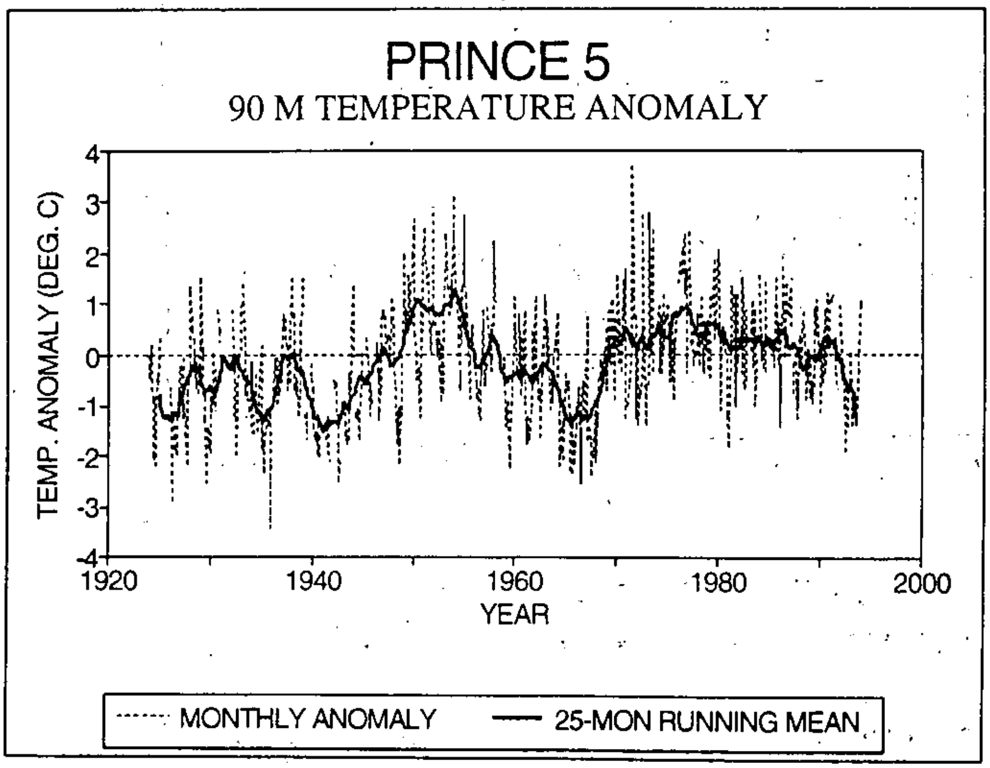
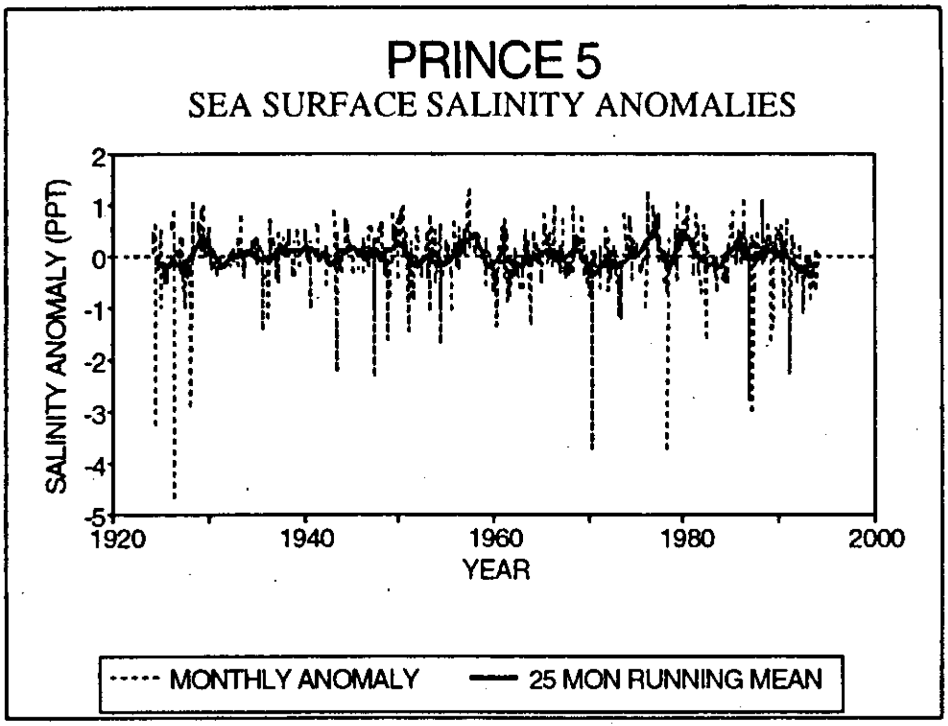


Fig. 29. The monthly means and the 25-month running means of the temperature anomalies for Prince 5, 0 and 90 m.



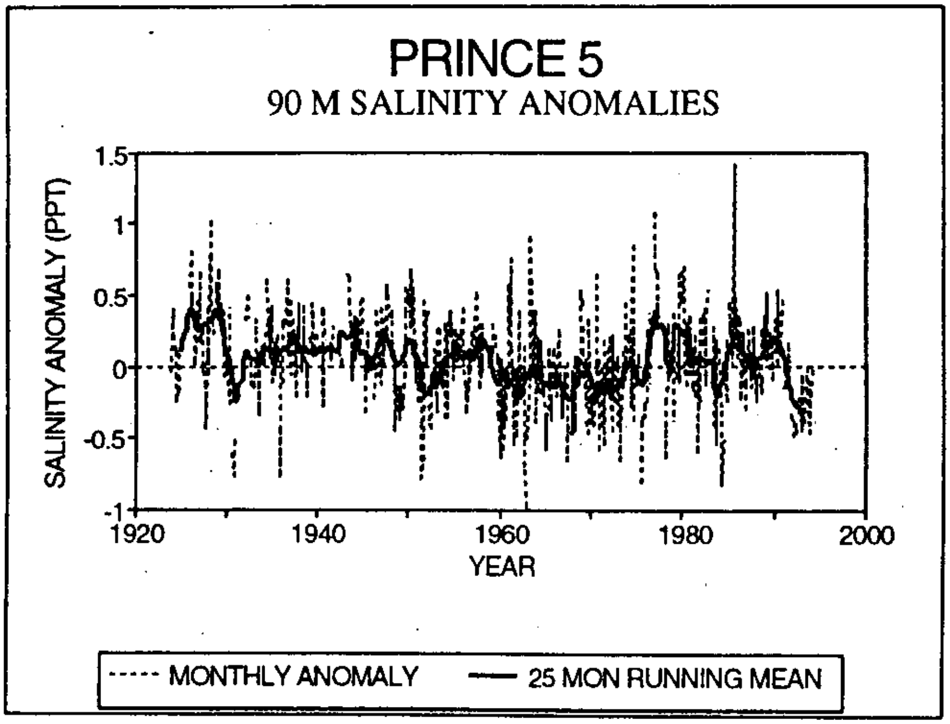


Fig. 30. The monthly means and 25-month running means of the salinity anomalies for Prince 5, 0 and 90 m.

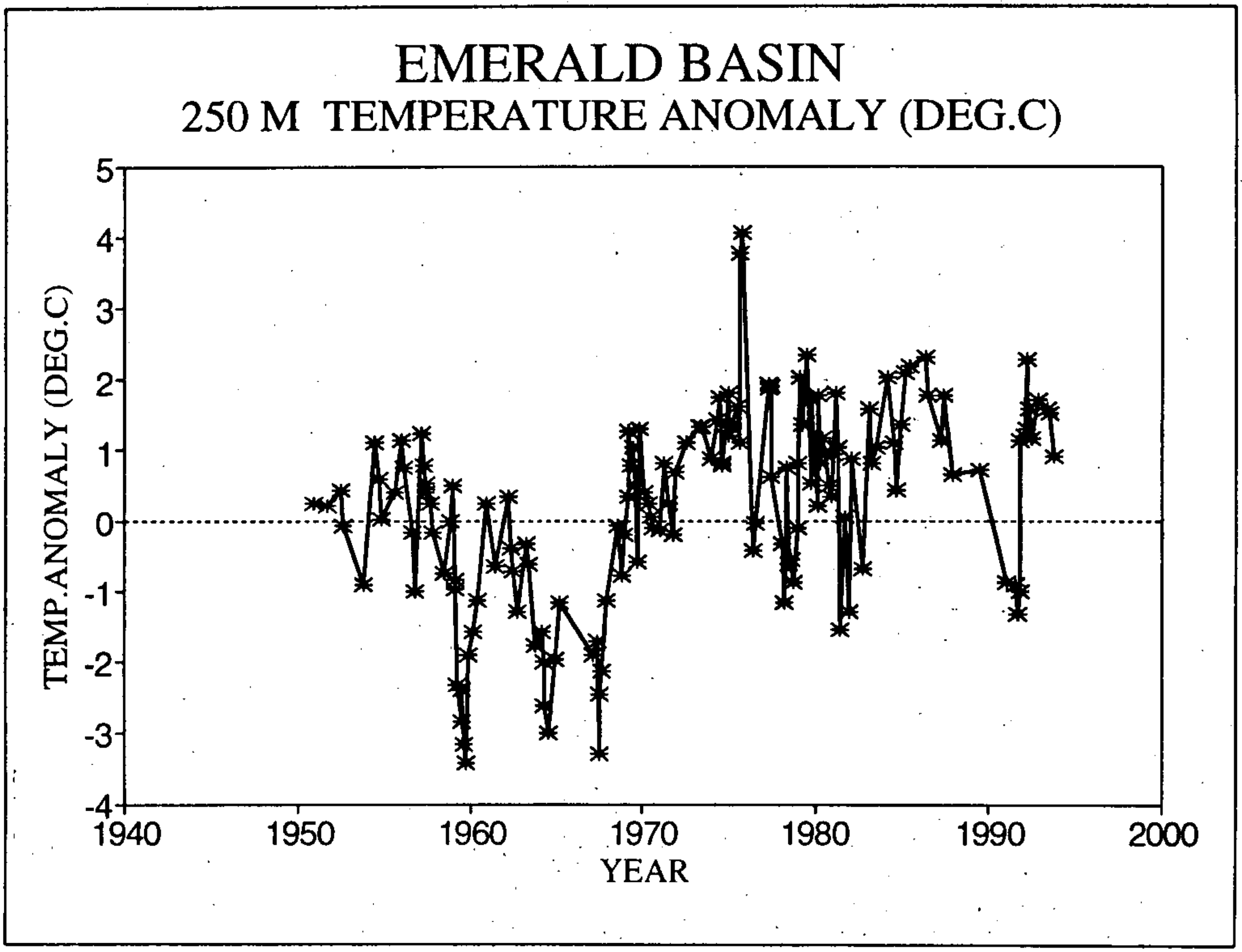
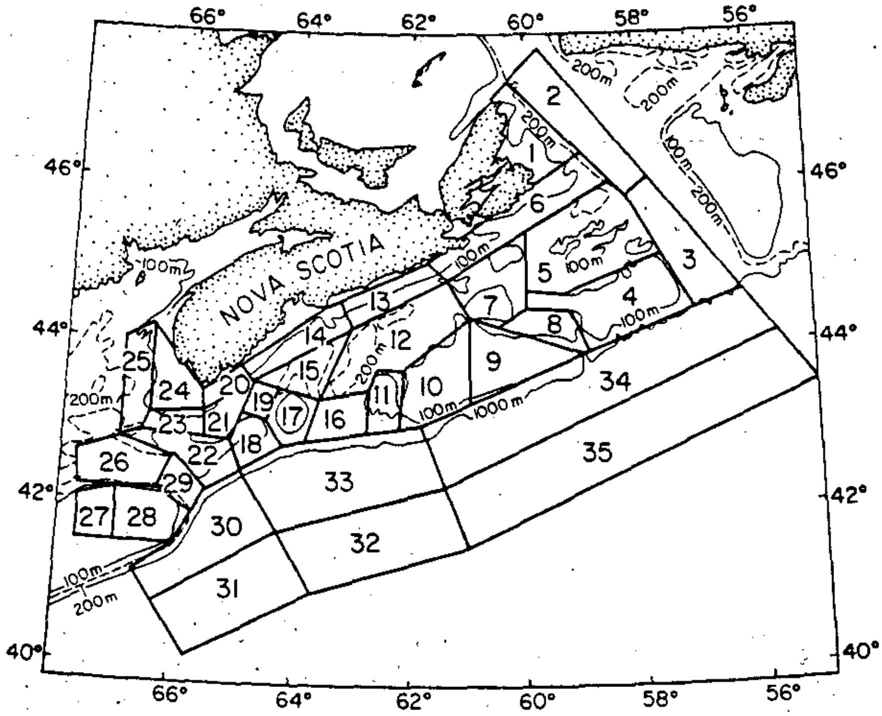
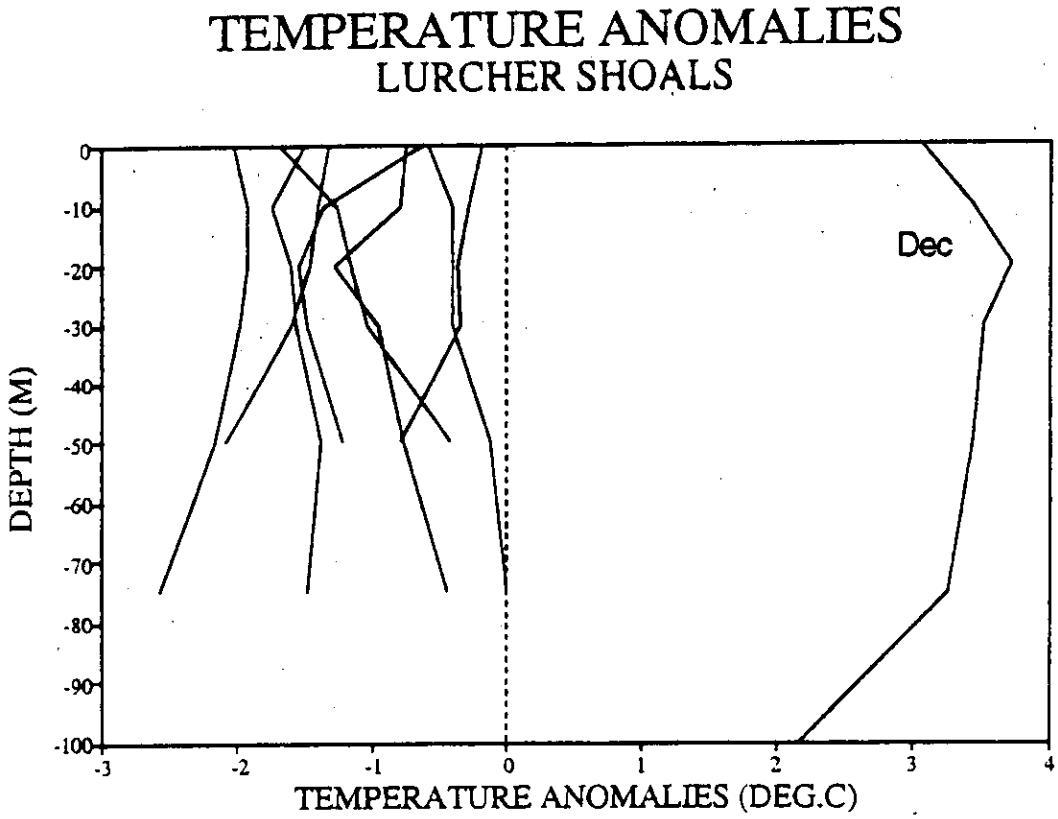


Fig. 31. Temperature anomalies (relative to 1961-90) at Emerald Basin at 250 m.



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



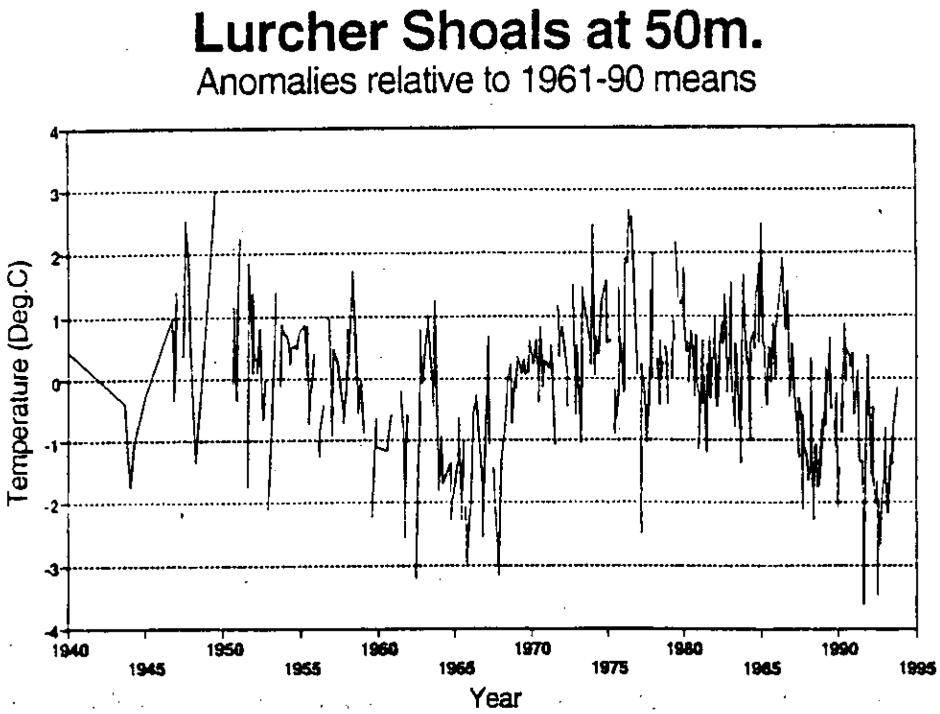
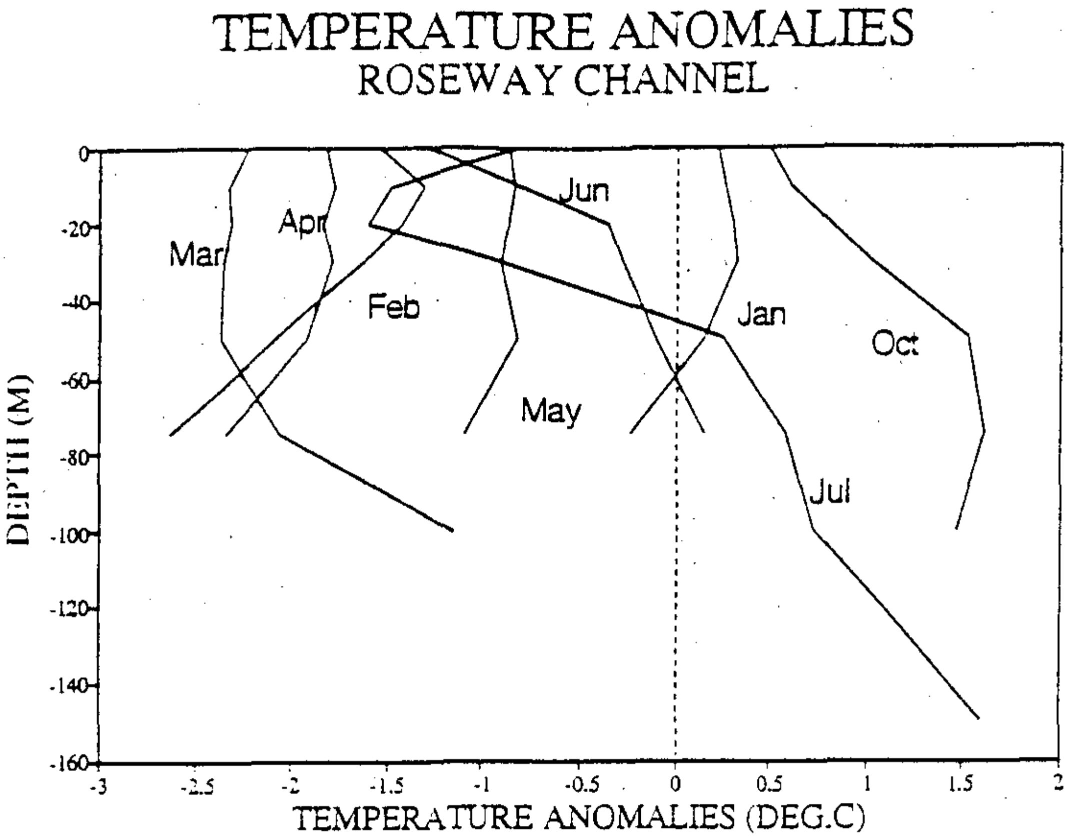


Fig. 33. The 1993 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m for Lurcher Shoals (area 24 in Fig. 32).



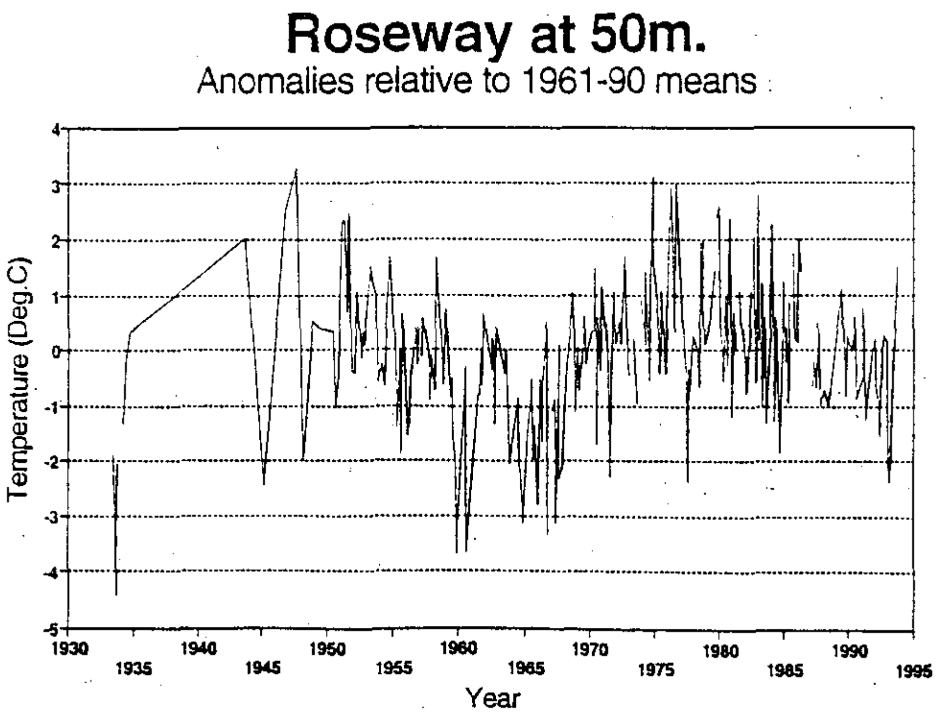
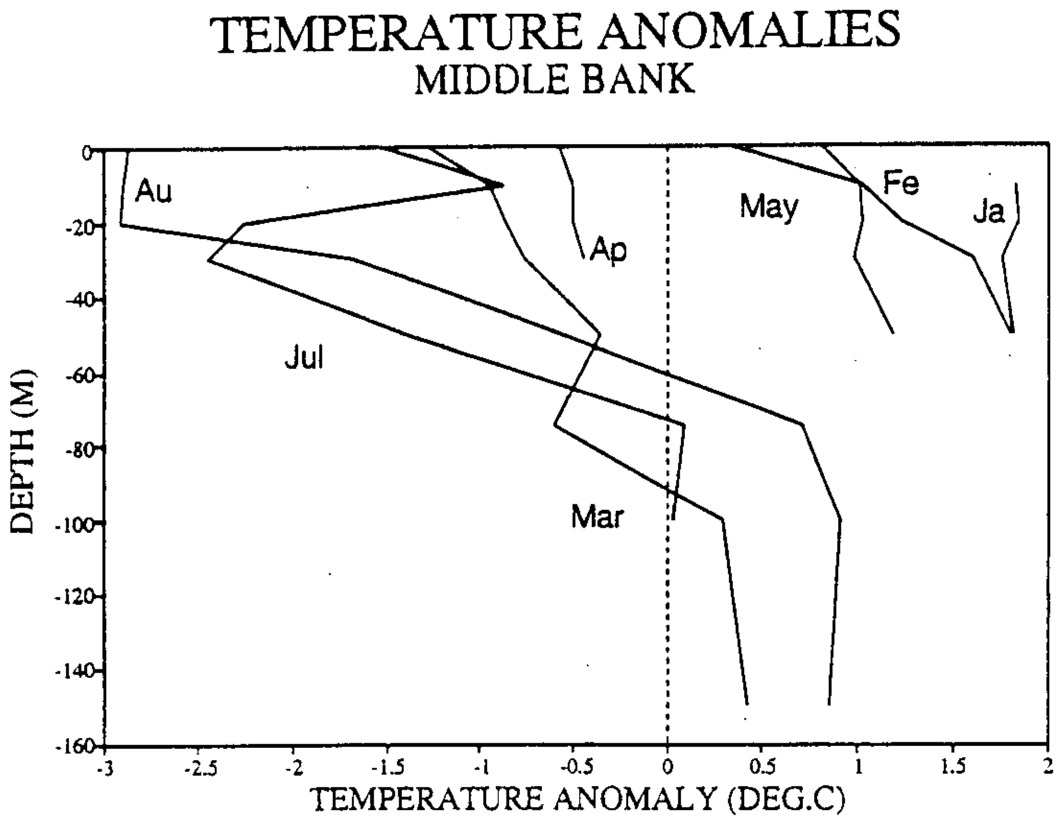


Fig. 34. The 1993 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m for Roseway Channel (area 23 in Fig. 32).



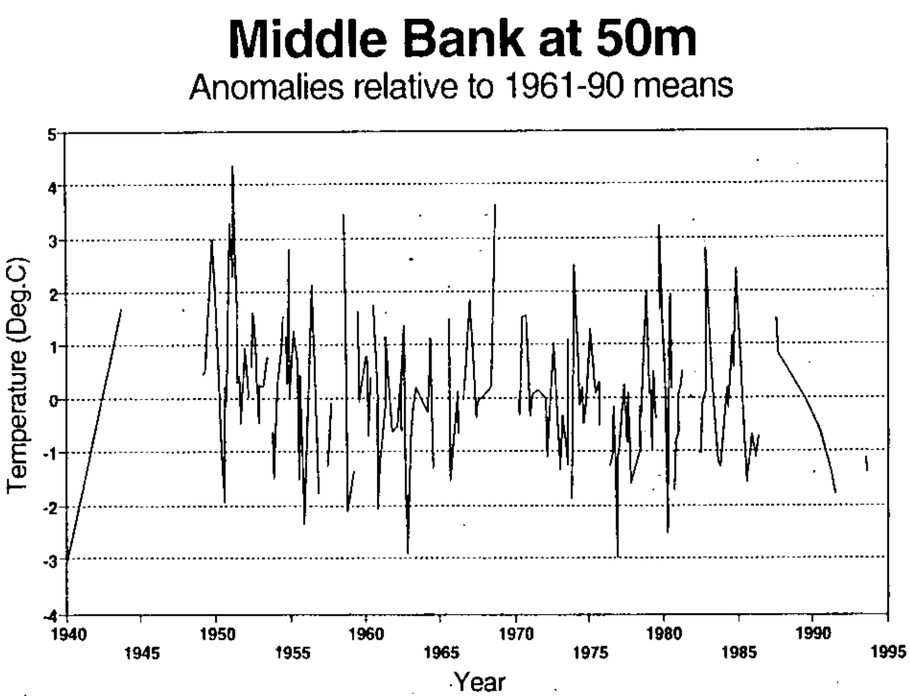
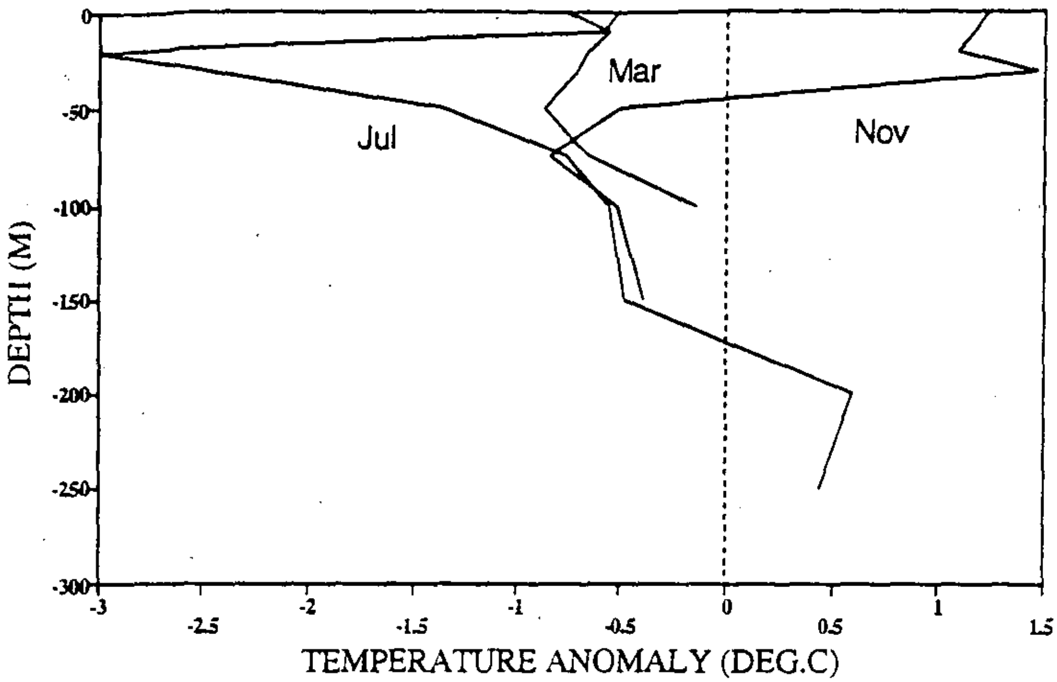


Fig. 35. The 1993 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m for Middle Bank (area 7 in Fig. 32).

TEMPERATURE ANOMALIES
MISAINE BANK



Misane Bank (50 m.)
Anomaly relative to 1961-90 means

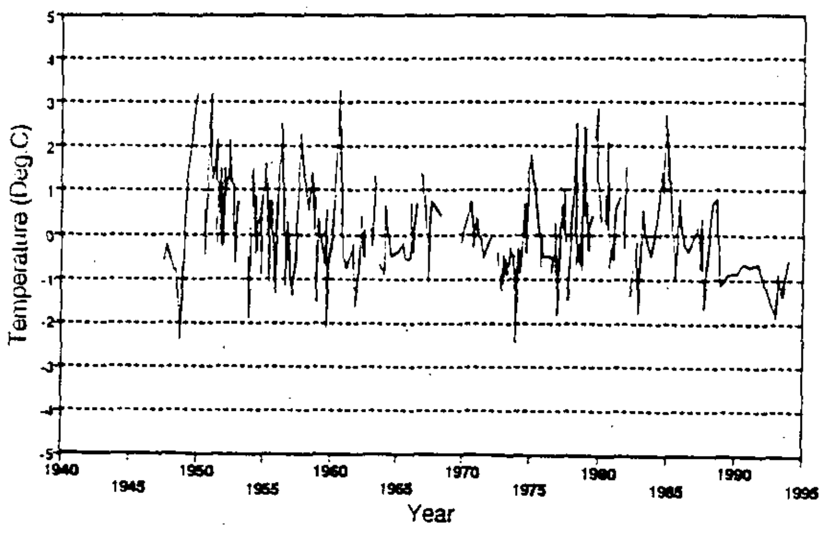


Fig. 36. The 1993 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m for Missaine Bank (area 5 in Fig. 32).

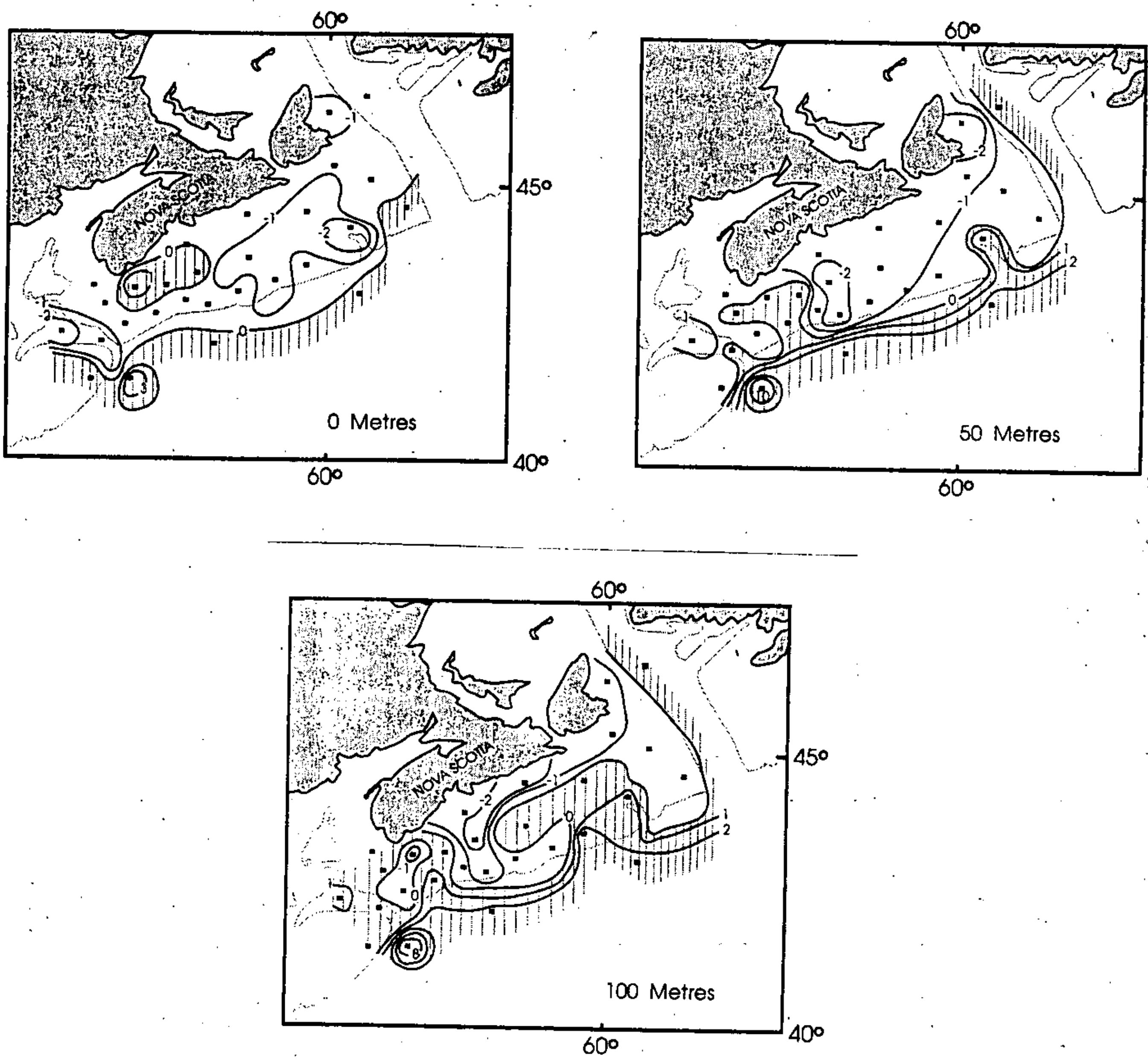


Fig. 37. The temperature anomalies during July at 0 (top left), 50 (top right) and 100 m (bottom) based on data averaged over areas in Fig. 32. Positive anomalies are shaded and the center of the areas are denoted by a square.

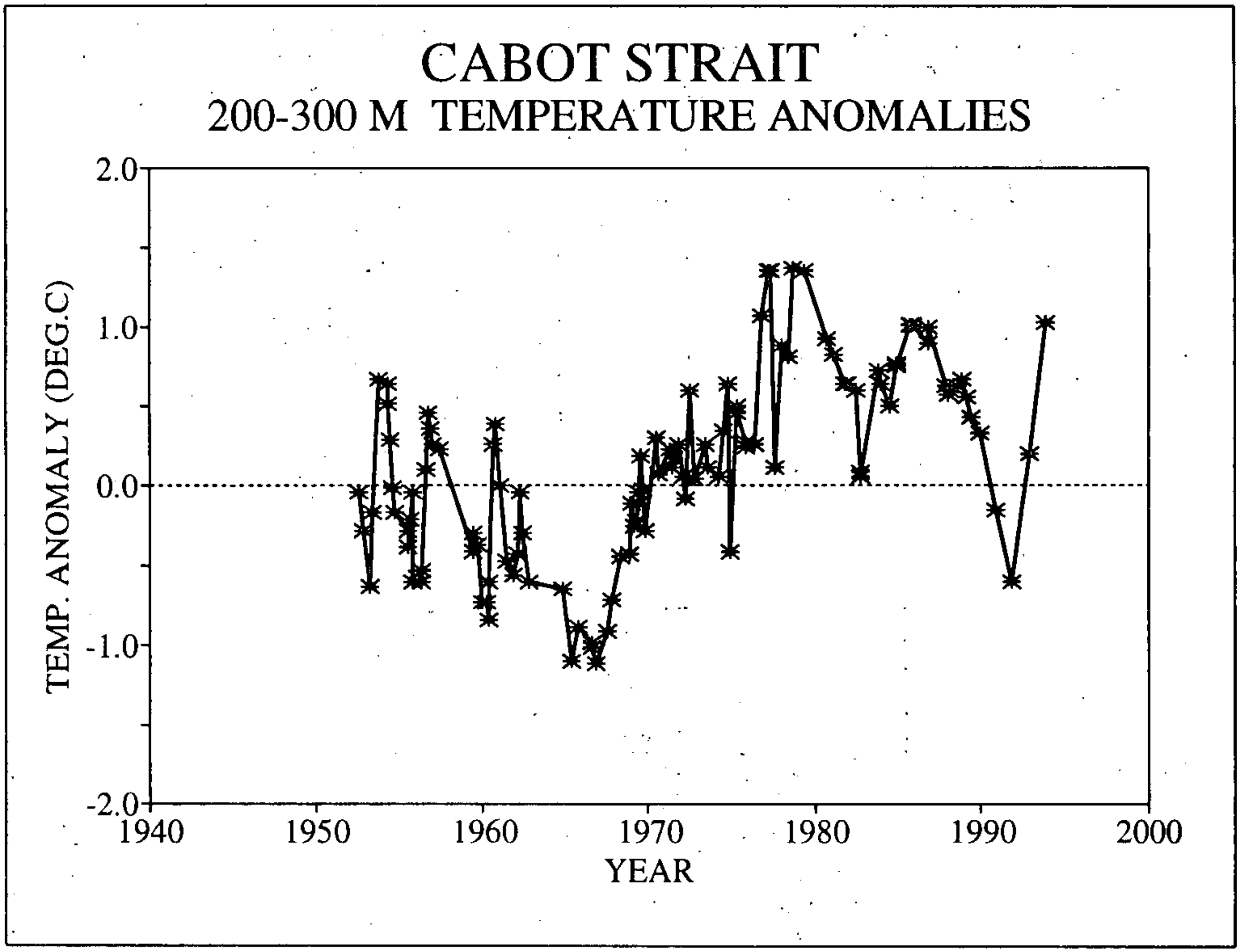


Fig. 38. Temperature anomalies (relative to 1961-90) for 200-300 m in Cabot Strait.

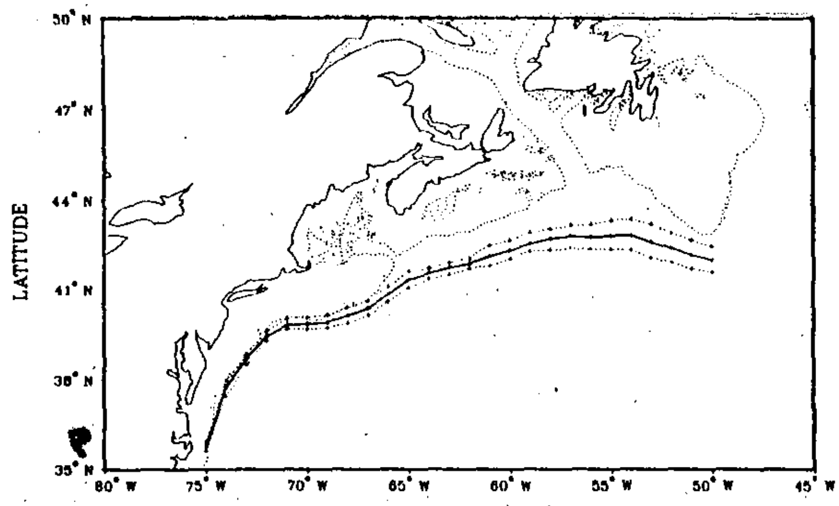


Fig. 39. The long-term (1973-90) mean position of the shelf/slope front and the maximum and minimum of the monthly averages.

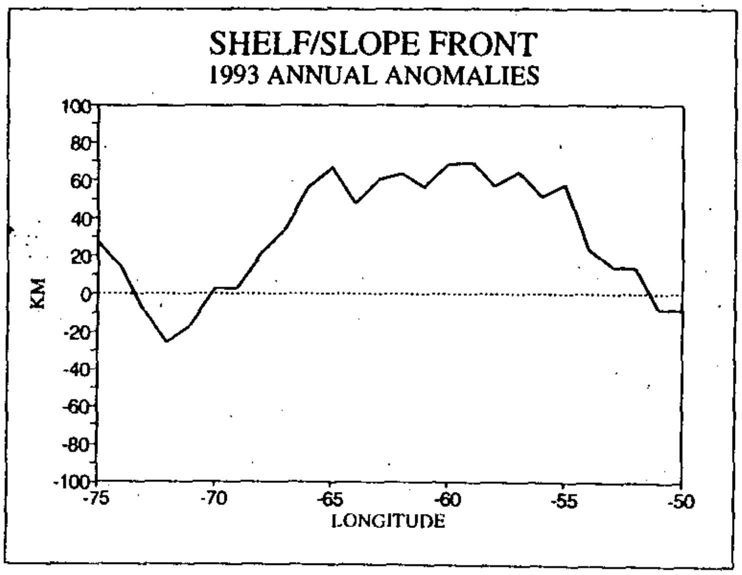


Fig. 40. The 1993 anomalies of the shelf/slope frontal position relative to its long-term mean.

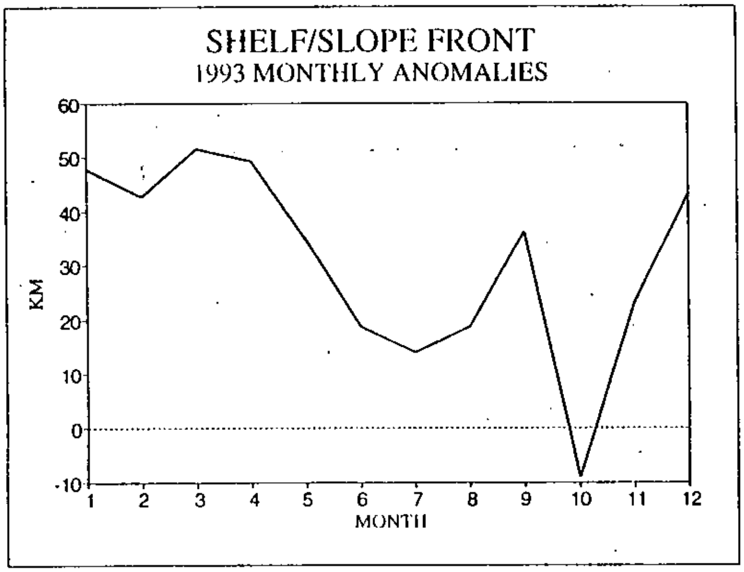


Fig. 41. The 1993 monthly anomalies of the Shelf/Slope front averaged between 50° and 75°W.

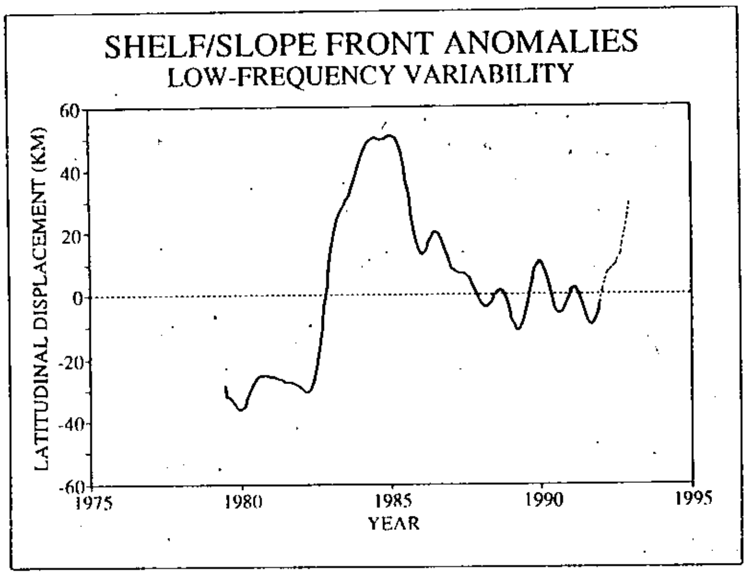


Fig. 42. The low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the Shelf/Slope front. The dashed line indicates the new data using the 1993 data.

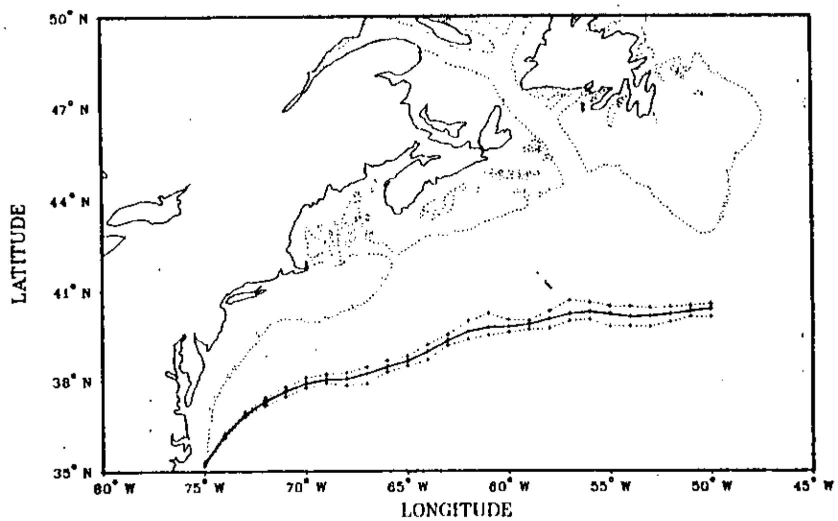


Fig. 43. The long-term (1973-90) mean position of the northern edge of the Gulf Stream and the maximum and minimum of the monthly averages.

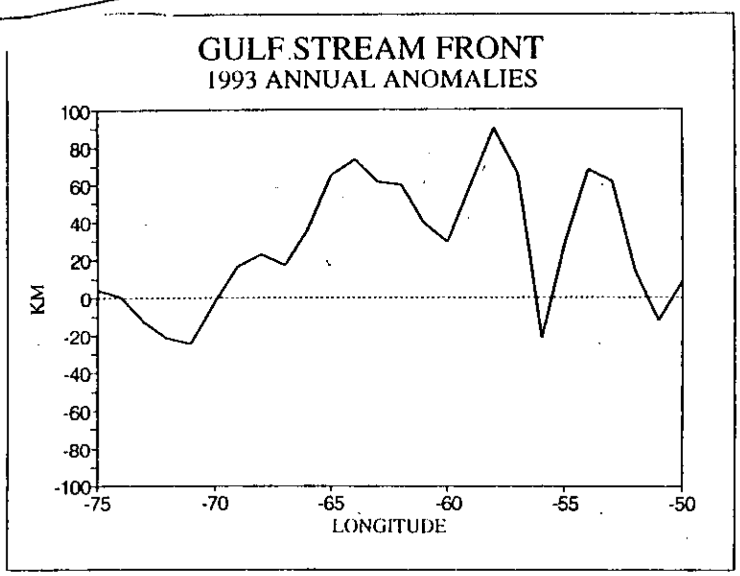


Fig. 44. The 1993 anomalies of the Gulf Stream frontal position relative to its long-term mean.

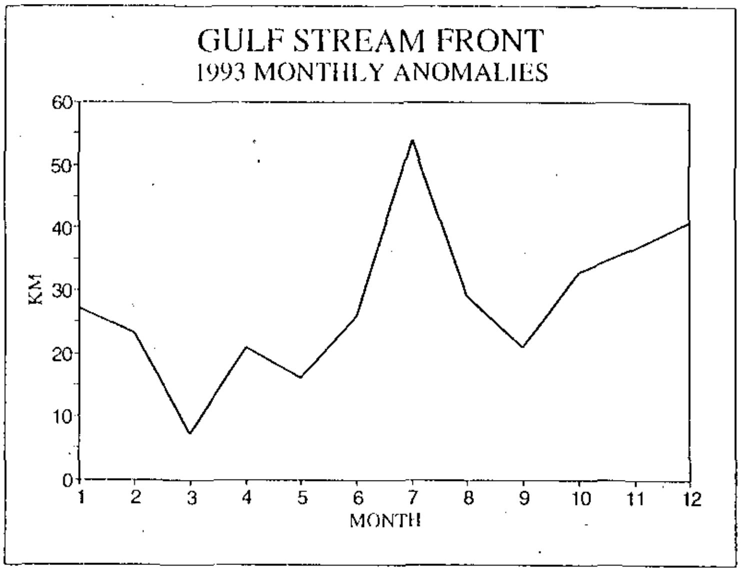


Fig. 45. The 1993 monthly anomalies of the Gulf Stream front averaged between 50° and 75°W.

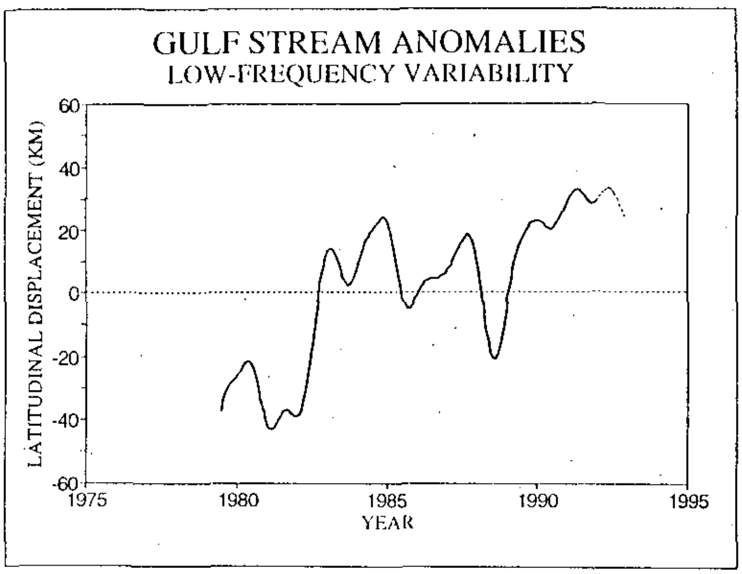


Fig. 46. The low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the Gulf Stream front. The dashed line indicates the new data using the 1993 data.

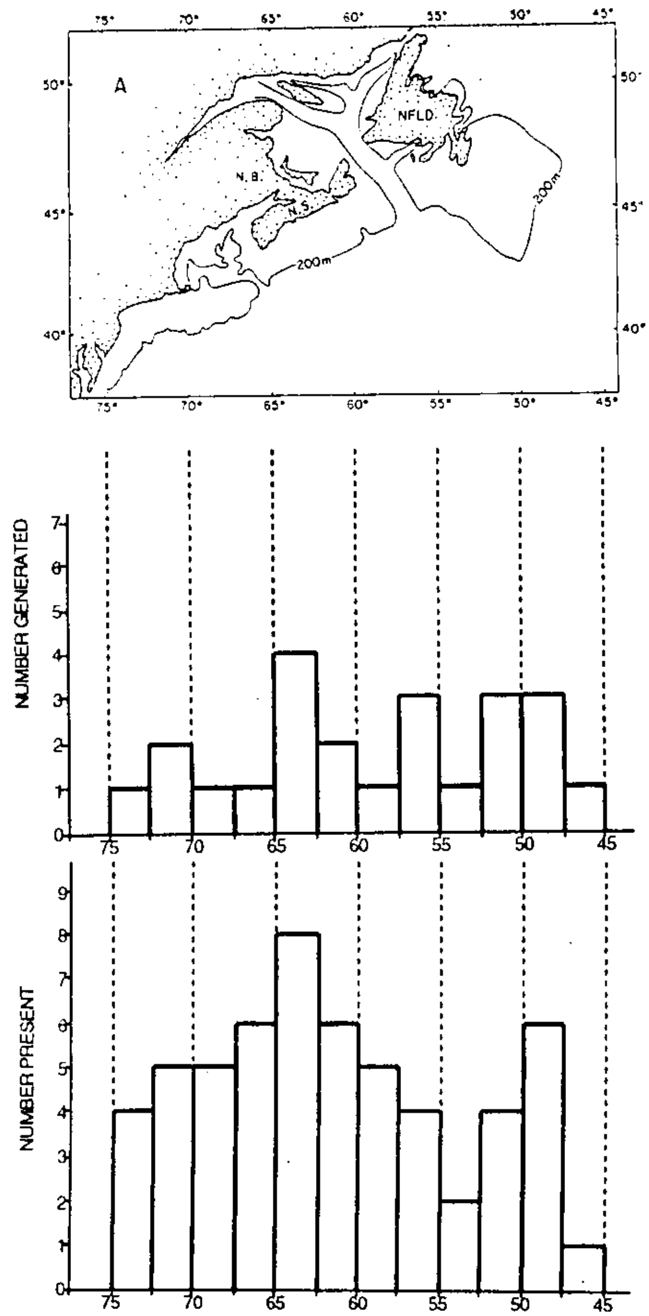


Fig. 47. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1991: (A) the chart of the area of interest; (B) the number of rings generated in each 2.5° zone of longitude; and (C) the number of rings present in each 2.5° zone during some part of the year.