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Overview of Environmental Conditions in the Northwest Atlantic in 1991

by

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INTRODUCTION

This paper provides a review of environmental conditions in the Northwest Atlantic during 1991 and 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 (1951-1980) in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. This report is the tenth in a series of annual overviews to NAFO. This year we have added several new indices and the presentation follows a slightly different order than in previous reviews.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The Atmospheric Environment Service of Canada publishes the monthly mean air temperature anomalies for Canada in the *Monthly Supplement to Climatic Perspectives*. From Baffin Island to Newfoundland large negative anomalies dominated the winter and spring of 1991 (Fig. 1). The coldest anomalies (-8°C) occurred in January on the southern Labrador coast. During the summer, Newfoundland and southern Labrador air temperatures remained cold and the anomalies did not rise above normal until October and November. In contrast, air temperatures over the southern Gulf of St. Lawrence and Nova Scotia were generally warmer-than-normal throughout most of the year. In December a cold air mass covered the entire region with the largest anomalies (-4°C) again occurring in southern Labrador and northern Newfoundland.

The 1991 monthly mean air temperature anomalies for several coastal sites are plotted as bar graphs in Fig. 2. The cold winter and spring in the northern regions are clearly evident. Data from Godthab in Greenland suggest that the spatial extent of these anomalies extended throughout the Labrador Sea whereas the cold summer temperatures were limited to the Labrador coast and Newfoundland. The winter of 1990 had also been cold throughout the Labrador Sea and at Cartwright and St. John's, the December 1991 anomalies suggested the possibility of a cold winter in 1992, at least in the vicinity of southern Labrador and Newfoundland. At Iles de la Madeleine in the Gulf of St. Lawrence and Sable Island on the Scotian Shelf air temperature anomalies tended to be above normal through most of 1991 although January was cold. The anomaly patterns at these sites were similar in several respects to those recorded in 1990.

The annual air temperature anomaly pattern reflected the very cold conditions along the Labrador coast and off northern Newfoundland with negative values of over 2°C (Fig. 3). These exceeded the standard deviations of the long-term means by over 1°C. Slightly negative anomalies prevailed over most of the Gulf of St. Lawrence but in the southeastern Gulf and off Nova Scotia the annual air temperature anomalies were positive.

The interannual variability since 1970 at Godthab, Iqualuit and, to lesser extent, Cartwright have been dominated by large amplitude fluctuations with periods of 5-10 yr (Fig. 4). Since 1970, 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 1990. Temperature anomalies at St. John's, Iles de la Madeleine and Sable Island were of much lower amplitude, showed much less or no signs of a downward trend since 1970, but did contain minima in the early 1970s, in the mid-1980s and, at St. John's, in 1990/91.

Sea Surface Air Pressures

Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas* by Deutscher Wetterierst, Offenbach, Federal Republic of 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 1991 relative to the 1951-80 means are shown in Fig. 5. Winter includes December 1990 to February 1991, spring is March to May, summer is June to August and autumn is September to November.

During the winter the Icelandic Low deepened and shifted slightly to the northwest. This produced strong northwesterly winds over the Labrador Sea and Newfoundland. These winds carried cold air down from the Arctic giving rise to the extreme negative air temperature anomalies seen over the region. The winds were strongest over southern Labrador and northern Newfoundland which coincides with the largest air temperature anomalies. In spring the air pressure patterns were generally weak but in summer a negative anomaly developed over the northeastern Atlantic Ocean which caused onshore winds in southern Labrador and Newfoundland and offshore winds in the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine. The Icelandic Low weakened in autumn causing positive sea level pressure anomalies over the Labrador Sea and eastern Canada. This would tend to drive anomalous onshore winds on the Scotian Shelf and the Gulf of Maine and southeasterly winds along the Labrador coast.

Upper Atmosphere Pressures

The heights of the 50 kPa pressure field (approximately 5000 metres above the earth's surface) over the northern hemisphere are published in the *Monthly supplement to Climatic Perspectives* by Environment Canada. The long-term mean (1951-80), the mean for January 1991 and the anomaly fields are plotted in Fig. 6. The normal for the month consists of a low, known as the Arctic Vortex, centered over the Artic Islands. In 1991 this low had deepened with a trough extending over eastern Canada. This produced an anomaly pattern similar to that for the sea level pressures, i.e. negative values over the Labrador Sea and eastern Canada and positive values off the southeastern United States. The anomalous low induced stronger-than-normal northerly and northwesterly flow. The January pattern is representative of the 1991 wintertime conditions and is similar to the pattern identified as producing "cold" winters (Findlay and Deptuch-Stapf, 1991) and heavy ice years (Agnew and Silis, 1991).

In the spring a stronger-than-normal trough developed over northeastern Canada (Fig. 7) which contributed to the below normal temperatures. This trough strengthened and extended southward in summer producing the negative anomalies centered over the northwest Atlantic Ocean (Fig. 7) keeping temperatures on the Labrador coast and in Newfoundland colder-than-normal. A high pressure ridge centered over Hudson Bay produced warmer conditions in southern Baffin Bay and eastward to Greenland. The pattern reversed in autumn (Fig. 7) with a trough over Hudson Bay and a ridge over eastern Canada. The latter contributed to the warm conditions over eastern Canada in contrast to the colder-than-normal air temperatures in the rest of the country.

SEA ICE OBSERVATIONS

Newfoundland and Labrador

Extremely cold air temperatures in December of 1990 resulted in early ice formation off southern Labrador. The accompanying strong northwesterly winds advected this ice southward causing a greater areal extent of sea ice than normal (Fig. 8). Through the winter, cold air temperatures continued to promote ice growth while the strong northwesterly winds pushed the ice further southward so that by February the ice extent was near its maximum extent (Fig. 8). Winds were also slightly more onshore than normal tending to keep the ice on the shelf (Narayanan et al., 1992). In March stronger onshore winds developed which pushed the ice towards the coast thereby reducing the areal extent of the ice, at times, to below its normal value (Narayanan et al., 1992). The loss of area was compensated by an increase in the thickness caused by ice rafting. Onshore winds through into the summer prevented the ice from reaching the warmer offshore water which normally accounts for a large proportion of the heat necessary to melt the ice. Indeed, most of the ice in 1991 is believed to have melted on the shelf due to solar heating. Ice retreated slowly continuing to be present off the northern tip of Newfoundland up until the middle of July and off southern Labrador until early August which set new records for the time of the last presence of ice (Fig. 8).

The maxima in sea ice extent occurred in the early 1970s, the early to mid-1980s and in 1991 which is highly correlated with air temperature minima (Narayanan et al. 1992).

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 1990/91 iceberg season (October to September), a total of 1974 icebergs were spotted south of 48°N. The monthly totals for February to August were 20, 115, 144, 269, 1030, 325, and 71 (Fig. 9). No icebergs were spotted from October, 1990, to January, 1991, nor in September of 1991. In the primary iceberg season of March to August, 1954 icebergs were observed which represents 99% of the annual total. There were twice as many bergs recorded in 1991 than in 1990 and 6-9 times that in the years between 1986 and 1989 (Fig. 9). Several factors contributed to the high number of bergs in 1991. Anomalously cold air and water temperatures resulted in a slow rate of melting. Also the heavy concentrations of sea ice and its late persistence off Labrador and northern Newfoundland helped to preserve the icebergs through reduced wave action. Finally, the increased easterly winds kept the icebergs in the colder inshore waters longer.

Gulf of St. Lawrence

During early December, 1990, cold Arctic air with accompanying moderate northly to northwesterly winds covered the Gulf of St. Lawrence. By mid-December cumulative freezing degree days were up over the long term mean by 300% over the northern Gulf and an order of magnitude in the southern Gulf. This resulted in pack ice in Northumberland Strait and along the New Brunswick coast, the formation of new ice in the St. Lawrence Estuary and fast ice along sections of the North Shore of Quebec (Fig. 10). These ice conditions were about 3 weeks ahead of normal. By the end of December ice covered the Strait of Belle Isle, the Bay of Chaleur, and along the northern coast of New Brunswick which was near normal for that time of the year. At mid-January new ice formed over the central and northeastern regions of the Gulf, slightly earlier than normal, while over the western Gulf the ice thickened (Fig. 10). Cold air temperatures persisted through January which continued to increase the thickness and areal extent of the sea ice. The extent and thickness of the ice cover by mid-February remained greater than normal (Fig. 10). Ice began to drift through Cabot Strait with some reaching 45°N and 58°W. By the end of the month the ice had moved further onto the Scotian Shelf westward to Chedabucto Bay. Ice thickness in the Gulf still exceeded normal in mid-March but open areas developed along western Newfoundland, along the south shore of Prince Edward Island, around the Gaspe Peninsula, and along parts of the north shore of Quebec. During April ice conditions were typically 2 weeks later than normal. Warmer-than-normal temperatures in May lead to rapid melting so that by mid-May the only ice in the Gulf was that in the northeastern Gulf. Through June and into mid-July ice continued to drift into the Gulf through Belle Isle Strait due to the persistence of ice on the Labrador and Newfoundland shelves. Mid-July for the last presence of ice in the Belle Isle region set a new record as normally ice leaves the region by late April.

OCEANOGRAPHIC OBSERVATIONS

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 63 times in 1991, with a monthly maximum of 8 in April, October and December and a minimum of 0 in January. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50 75, 100, 125 and 150 m) and monthly means were calculated for each depth. The monthly averaged temperatures and salinities in 1991 together with their anomalies relative to 1951-80 are shown in Fig. 11.

Water temperatures at Station 27 were extremely cold in 1991. Monthly mean temperatures throughout the water column were colder than -1.5°C (anomalies lower than -1°C) in February and March. The seasonal warming of the waters above 50 m proceeded slowly causing the anomalies to decrease steadily through the spring and early summer reaching a minimum of -4°C in July (Fig. 11, 12). The anomalies gradually increased after July rising to slightly above normal by November and December. Temperature anomalies in the deep waters (> 75 m) were below normal throughout the year (generally -0.5 to -1°C). In the autumn anomalies were at or exceeded -1°C which is believed to be due to the mixing of the colder, near-surface water down through the water column.

Petrie et al. (1992) examined the relationship between winds and air temperatures on the water temperatures at Station 27 for the period 1963-86. They found that wind and air temperatures could account for 53% and 50% of the variance of 0-20 m and 75-150 m layer, respectively. Most of the variance was accounted for by air temperature. Based on their regression analysis and using air temperatures only as the geostrophic winds were not available past 1989, we predicted the water temperatures at Station 27 for the period 1987-92. The predicted and observed values are all below normal for the entire period (Fig. 13). There was poor agreement for 1987 but reasonable correspondence since then.

Surface salinities at Station 27 were fresher-than-normal by as much as 1 psu in July and again in November (Figs. 11, 12). The salinity minimum (30.35-30.40, anomalies of approximately -0.7) occurred on schedule in September-October. Ice melt from the larger-than-normal volume of sea ice contributed to these low salinities. The salinity anomaly minimum in June-July was likely due to local ice melt while the second minimum in November and December may have been associated with ice melt from the Labrador Shelf. The later has been shown to account for the interannual variability in the seasonal salinity minimum at Station 27 (Myers et al. 1990). In the deeper waters, the salinities were slightly below normal throughout most of 1991. The fresher conditions in 1991 contrast with the slightly more saline waters observed in 1990 (Drinkwater and Trites, 1991).

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970 to 1991 are shown in Fig. 14. Note that the scale for 0 and 50 m is larger than for 100 m and deeper. At the surface, 1991 contained the most persistent negative anomalies in the past 20 years. The monthly minimum in July matched a previous low in 1974. As one progressed deeper in the water column, there was a tendency towards a greater percentage of negative anomalies throughout the period. At 150 and 175 m negative anomalies have persisted almost continuously since 1982. At 100 m it has been since 1983. The coldest periods roughly correspond to those identified from air temperature anomalies, i.e. the early 1970s, the mid-1980s, and 1991. At these depths, 1991 continued a trend towards lower temperatures that began in 1988-89.

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 fresh warm 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.

Four standard hydrographic transects (Hamilton Bank, off White Bay, off Bonavista Bay and along 47°N) are occupied annually by the Northwest Atlantic Fisheries Center in St. John's, Newfoundland, during the summer. Narayanan et al. (1992) showed that in 1991 the CIL, defined by waters <0°C, covered most of the area of the shelf in the three transects that were occupied (the 47°N line was not occupied). Petrie et al. (1992) had earlier found that the annual anomalies of the cross-sectional areas of the CIL (1978-86) were highly correlated between transects with an average value of about 0.85. Areas calculated for 1987-91 and show that in 1991 the area of the CIL was much greater than normal (Fig. 15). For the Hamilton Bank transect, 1991 ranked the third highest in 11 years of data, at White Bay the second in 12 years, off Bonavista the second in 14 years, and along 47° the first in 12 years of data.

The area of the CIL along the four transects show a maximum around 1984-85, a minimum in 1986-87, and a peak in 1990-91 (Fig. 15). This corresponds roughly with minima in the water and air temperatures and maxima in ice coverage as noted earlier by Petrie et al. (1992).

Fyllas Bank

Hydrographic conditions on a standard section across Fyllas Bank off West Greenland are monitored by the Greenland Fisheries and Environment Research Institute, Copenhagen, Denmark, and the Sea Fisheries Institute, Hamburg, Federal Republic of Germany. This area is influenced by the relatively cold low-salinity water of the East Greenland Current and the warm high-salinity water of the Irminger Current. In 1991, the average temperature between 0 and 200 m, the limit of seasonal influence, was slightly above-normal (Stein, 1992). This was in contrast to the cold conditions off Labrador and Newfoundland. Temperature anomalies for this layer have been above or near normal since 1985 following the extreme minimum of 1983. Similar conditions and trends were observed at the Cape Farewell Section in the 0-200 m and the 200-300 m layers (Stein, 1992). The similarity supports the belief that the Irminger Current, which flows past Cape Farewell and up the west coast of Greenland, influences the hydrographic conditions at Fyllas Bank.

Offshore SST Data

Sea-surface temperature (SST) anomalies for 1991 determined from the "marine deck" observations were calculated for 24 areas in the Northwest Atlantic (35°-60°N, 40°-76°W) extending from Cape Hatteras to Greenland (Fig. 16). These data were derived primarily from ships-of-opportunity and obtained from measurements in the ship's intake. The areas into which the data were divided coincide with oceanographic regimes (e.g. the Labrador Current, Gulf Stream, etc.) or topographic features (e.g. Lahave Bank, Georges Bank, etc.). Monthly anomalies were determined by subtracting the long-term monthly averages for the 20-yr period 1971-1990.

The monthly anomalies for the 24 areas are listed in Table 1 and are contoured in Fig. 17. The cold conditions observed at Station 27 in the spring and summer can be seen to have extended over the entire Grand Banks, off southern Newfoundland, Flemish Cap, and along the Labrador coast. The coldest anomalies (-3°C) were observed in July, consistent with the Station 27 data. The annual means for the region were approximately 1°C below normal. Again similar to Station 27, the autumn SSTs in the region exceeded their long-term means. In the Gulf of St.Lawrence and off southwestern Newfoundland (area SP) significant warm water anomalies were observed during the autumn. From the southern Scotian Shelf to the Mid-Atlantic Bight there was a predominance of positive anomalies throughout the year with maximum values in the southern most shelf area during the spring and early summer. In the Western Slope Water negative anomalies were observed in all months except December.

The time series of annual mean anomalies of SST including 1991 for the 24 areas are shown in Fig. 18. As with the monthly values, the annual anomalies indicate very cold conditions in 1991 along the Labrador Shelf, throughout the Grand Banks, on Flemish Cap, and off southeastern Newfoundland. The 1991 values generally were near the minimum temperature anomalies recorded in 1985 and in the mid-1970s (Fig. 18A). The temperatures have declined in these regions by 1-2°C from highs in 1988. In the the Gulf of St. Lawrence, off southwestern Newfoundland and on the eastern Scotian Shelf, the annual anomalies were near normal with a slight tendency to positive values (Fig. 18B). The amplitude of the positive annual temperature anomalies increased southward with maximum values in the mid-Atlantic Bight (Fig. 18C). The opposing temperature trends on the Grand Banks and the mid-Atlantic Bight fit the 2nd mode of variability in an EOF analysis of SST in the region as determined by Thompson et al. (1988). The oscillating temperature trends between these two areas has been prominent through the 1980s and into the early 1990s. In the Slope Water during 1991 the eastern area was warmer-than-normal while the western region was colder-than-normal. Temperature variability in the Gulf Stream and Sargasso Sea was low through the period 1971-91.

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 1951-80 long-term averages (Trites and Drinkwater, 1984) at each of the sites for 1990 and 1991 are shown in Fig. 19.

The temperature patterns at the three sites show several differences. During the first five months of 1991 there appeared to be a gradient in SST across the region from above normal temperatures at Boothbay Harbor, to near normal at St. Andrews, and below normal at Halifax. In summer, Boothbay and Halifax temperatures were generally colder-than-normal but at St. Andrews they were warmer-than-normal. During the last four months of the year, temperatures at Halifax rose above normal, while at St. Andrews they fell below normal and at Boothbay they were near normal.

Annual SST mean temperatures for 1991 were 9.0°C (0.2°C above normal) at Boothbay Harbor, 7.15°C (0.15°C below normal) at St. Andrews, and 7.5°C (0.3°C below normal) at Halifax. The long-term trends as represented by the 25-month running means in Fig. 20 show that the temperatures at Boothbay Harbor have risen slightly in the past couple of years but are near their long-term mean. The warm anomalies during the last half of 1990 and the first part of 1991 are unusual in their duration compared to past anomalies (Fig. 20). At St. Andrews SSTs continued to rise from a minimum recorded in the late 1980s and appear to be approaching the long term mean. At Halifax the negative annual anomaly is consist with slightly colder-than-normal conditions that have persisted since the late 1980s. These temperatures are 2-2.5 C below the maximum anomaly recorded near the mid-1980s. We note that since 1985 the St. Andrews SSTs may be reading over 0.5°C lower than previous due to reconstruction of the wharf where the measurements are taken (Drinkwater et al. 1992). This will be explored further in the coming year.

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 1951-80 means were calculated for 1991. 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 1991 temperatures ranged from a minimum of approximately 2.5°C to a maximum of 11.5°C in August and near surface in September (Fig. 21). This resulted in positive anomalies of generally > 0.5°C in the upper 50 m and typically < 0.5°C below 50 m (Fig. 21). Slightly negative anomalies were observed in the near surface waters (< 25 m) during the last 4 months of the year but only during September and October did they extend throughout the water column. Waters at and below 50 m during November and December were above normal. The long-term temperature records at surface and 90 m for Prince 5 show high similarity (Fig. 22). The temperature anomalies were near normal but had increased from below normal values in the late 1980s. The dominant high and low were in the early 1950s and the mid 1960s, respectively.

In April, salinities at Prince 5 dropped below 29 which is equivalent to a negative anomaly exceeding 2 psu (Fig. 21). This may have been due to an early freshwater discharge from the Saint John River although the values may not be representative of the mean for the month. The general trend was for fresher-than-normal conditions throughout the year with the exception of the late spring and early summer. Relatively high negative anomalies were observed in the late autumn.

Emerald Basin Temperatures

Petrie et al. (1991) 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 (periods of several years). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (month to month) 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. In 1991 several CTD profiles were obtained in Emerald Basin by research cruises in the area. The time series of temperatures from 250 m are plotted in Fig. 23 as anomalies from the monthly means averaged over the period 1951-80. Below normal temperatures of approximately 1°C were observed in 1991. These values represent a 3°C drop since the late 1980s. The trends at 250 m were representative of the waters below 75 m. These cooler temperatures in Emerald Basin were accompanied by below normal salinities.

Cabot Strait Deep Temperatures

Long-term temperature variability in the deep waters (200-300 m average) of the Laurentian Channel in the Gulf of St. Lawrence has been studied by Bugden (1991) 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 time series for Cabot Strait has recently been updated (Bugden, BIO, personal communication). The data show that in recent years temperatures have steadily declined such that by November, 1991, the average temperatures in 200-300 m depth range had fallen to near 4.5°C (Fig. 24). This is the lowest mean deep water temperature in Cabot Strait since the late 1960s.

Warm-core Rings

The life history of anticyclonic warm-core Gulf Stream rings in the region from 45°W to 75°W during 1991 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 32 warm-core rings were present in the area during some portion of 1991, seven of which survived from 1990 into the new year. Five of the 25 new rings which formed in 1991 persisted into 1992. At least 12 of the rings formed in 1991 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1991, ranged in age from less than a week to more than 8.5 months and had a mean life of approximately 3.5 months. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are shown in Fig. 25. Only 2 rings formed west of 65°W with a maximum of 5 generated in the 55-57.5°W and the 45-47.5°W zones. The number of rings present in each of the longitude zones varied from 3 to 9 with the highest number (9) in the adjacent zones between 57.5 to 62.5°W. The distribution of rings present in the zones, given the areas of formation, reflect westward propagation.

SUMMARY

Strong climate anomalies highlighted 1991. Severe cold conditions were observed in the waters off northern and eastern Newfoundland. Sea surface temperature data from ships-of-opportunity showed that annual SST anomalies were negative for the Labrador Shelf, the Grand Banks, Flemish Cap, and the southeastern Newfoundland Shelf. Temporally, the largest anomalies occurred during the late spring and summer months with the maximum negative anomaly occurring on the Grand Banks in mid summer (3 to 4°C below normal). In contrast, warmer than normal SST anomalies were recorded from the central Scotian Shelf to the Mid-Atlantic Bight with the amplitude of the anomaly increasing southward. This gradient in annual SST anomaly was also observed at coastal stations and coincided with a southward increase in air temperature anomalies. The deep waters off Newfoundland at Station 27 showed colder-than-normal temperatures throughout the year and continued a pattern that has persisted since 1983. In the Laurentian Channel at Cabot Strait the average temperature for the depth range 200-300 m decreased for the third consecutive year and was the coldest recorded in two decades. Cold conditions also prevailed in the deep waters of Emerald Basin. These cold temperatures were not observed in the bottom waters at the Prince 5 Station at the mouth of the Bay of Fundy. Temperatures off West Greenland were also near normal in contrast to the cold conditions off Labrador and Newfoundland. Sea ice was severe throughout the region as it formed early, spread more rapidly than normal, and persisted longer than usual. Ice was held inshore along the northern Newfoundland coast by unusually strong and persistent easterly winds.

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Table 1. Monthly SST anomalies in degrees Celsius for 1991 from the long-term base period 1971-90. The area names are shown on Fig. 4.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CF	-0.81	-0.25	0.78	0.68	0.54	0.53	1.26	0.08	-0.21	0.40	-0.64	-1.23
LS	-0.12	-0.32	0.07	-0.32	0.78	-	-0.31	-0.86	-0.21	-0.02	-0.14	0.29
LCS	-0.68	-	0.85	0.19	-	-2.18	-0.27	-1.38	-0.64	-0.01	0.52	-0.49
OLC	-0.46	-0.46	-0.28	0.53	-0.59	-2.23	-2.21	-2.53	-1.39	-0.10	0.34	-0.28
ILC	0.35	0.21	0.10	0.07	-1.25	-1.74	-1.65	-1.39	-1.50	0.25	1.11	0.47
FC	-0.49	-0.16	-0.42	-0.64	-1.27	-1.65	-1.51	-2.83	-0.54	-0.76	-	0.06
CGB	-0.09	-0.06	-0.35	-0.43	-0.85	-1.99	-3.10	-1.80	-0.81	-0.22	0.46	0.47
WGB	-0.38	0.09	-0.11	-0.35	-0.47	-1.49	-2.54	-1.76	-1.22	0.02	0.96	-0.25
SP	0.59	-0.27	-0.04	0.11	0.24	0.53	-0.02	-0.86	-1.22	2.22	1.14	0.42
GSL	-0.74	-0.89	-0.45	0.33	0.43	0.05	-0.01	0.17	-0.48	1.10	1.27	0.65
ESS	0.65	0.22	0.48	0.36	-0.07	0.39	0.33	-0.53	-0.78	0.47	1.07	0.11
SI	0.02	0.16	0.20	0.01	-0.15	-0.55	-0.96	-0.70	-0.47	-0.09	-0.11	-0.28
SH	0.04	0.32	-0.11	0.74	-	-0.18	-0.39	0.11	-2.15	0.46	0.37	0.98
LHB	0.23	-0.01	1.66	0.82	0.69	1.14	0.34	0.91	0.13	0.89	0.67	-0.22
BR	-0.07	0.24	0.89	0.06	1.47	0.76	0.13	0.29	-0.54	0.46	0.14	1.32
Y	0.37	0.15	0.58	0.30	-0.62	0.52	0.40	-0.57	-1.09	0.31	1.17	1.18
GOM	0.26	0.30	0.13	0.41	-	0.76	-0.44	-0.26	-0.28	0.29	-0.32	0.13
GB	0.16	1.03	0.72	0.39	1.36	0.99	0.34	-0.46	-0.62	0.84	-0.53	-0.12
SNE	0.33	0.62	0.65	1.53	2.62	-0.41	1.08	-0.01	-0.01	2.30	0.34	-0.19
MAB	-0.15	1.51	1.70	1.72	2.56	1.10	1.34	0.35	0.24	0.35	0.03	0.36
ESW	1.44	-1.33	-0.70	0.12	-0.15	-1.79	-1.80	-0.43	-0.39	0.23	0.68	1.24
WSW	-0.10	-1.31	-0.72	-0.94	-0.35	-0.09	-0.20	-0.73	-0.87	-1.75	-0.92	0.47
GS	0.19	-0.44	-0.20	0.81	1.26	0.28	0.42	-0.14	0.26	-0.53	-1.32	-0.43
SS	0.66	0.45	0.57	0.35	-0.11	-0.24	-0.67	0.12	-0.50	-0.18	0.03	-0.06

CF - Cape Farewell
LS - Labrador Shelf
LCS - Labrador Coast
OLC - Outer Labrador Current
ILC - Inner Labrador Current
FC - Flemish Cap
CGB - Central Grand Bank
WGB - Western Grand Bank
SP - St. Pierre
GSL - Gulf of St. Lawrence
ESS - Eastern Scotian Shelf
SI - Sable Island Bank
SH - South Shore
LHB - LaHave Bank
BR - Browns Bank
Y - Yarmouth
GOM - Gulf of Maine
GB - Georges Bank
SNE - Southern New England
MAB - Mid-Atlantic Bight
ESW - Eastern Slope Water
WSW - Western Slope Water
GS - Gulf Stream
SS - Sargasso Sea

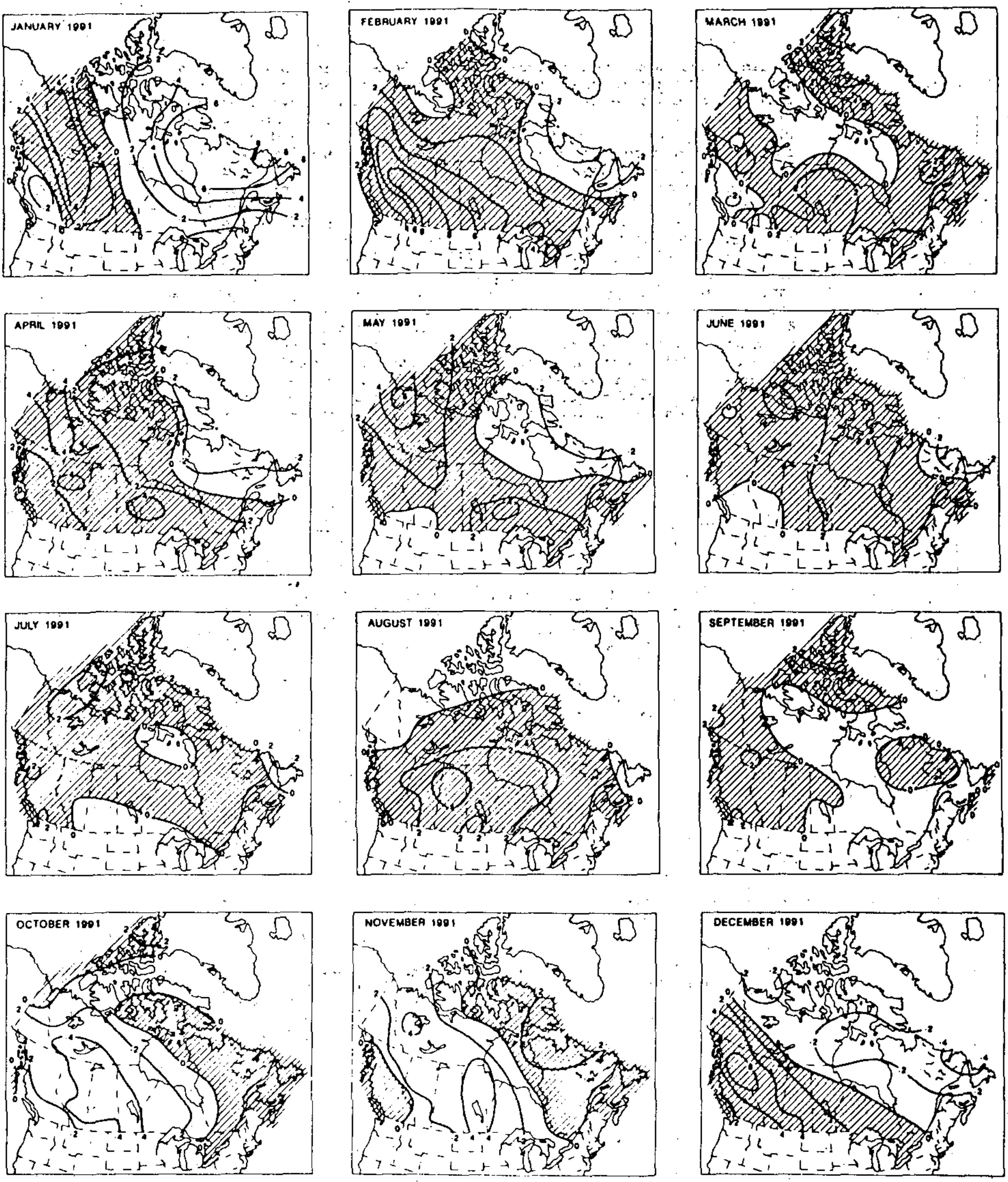


Fig. 1. Monthly air temperature anomalies (°C) over Canada in 1991 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 13)

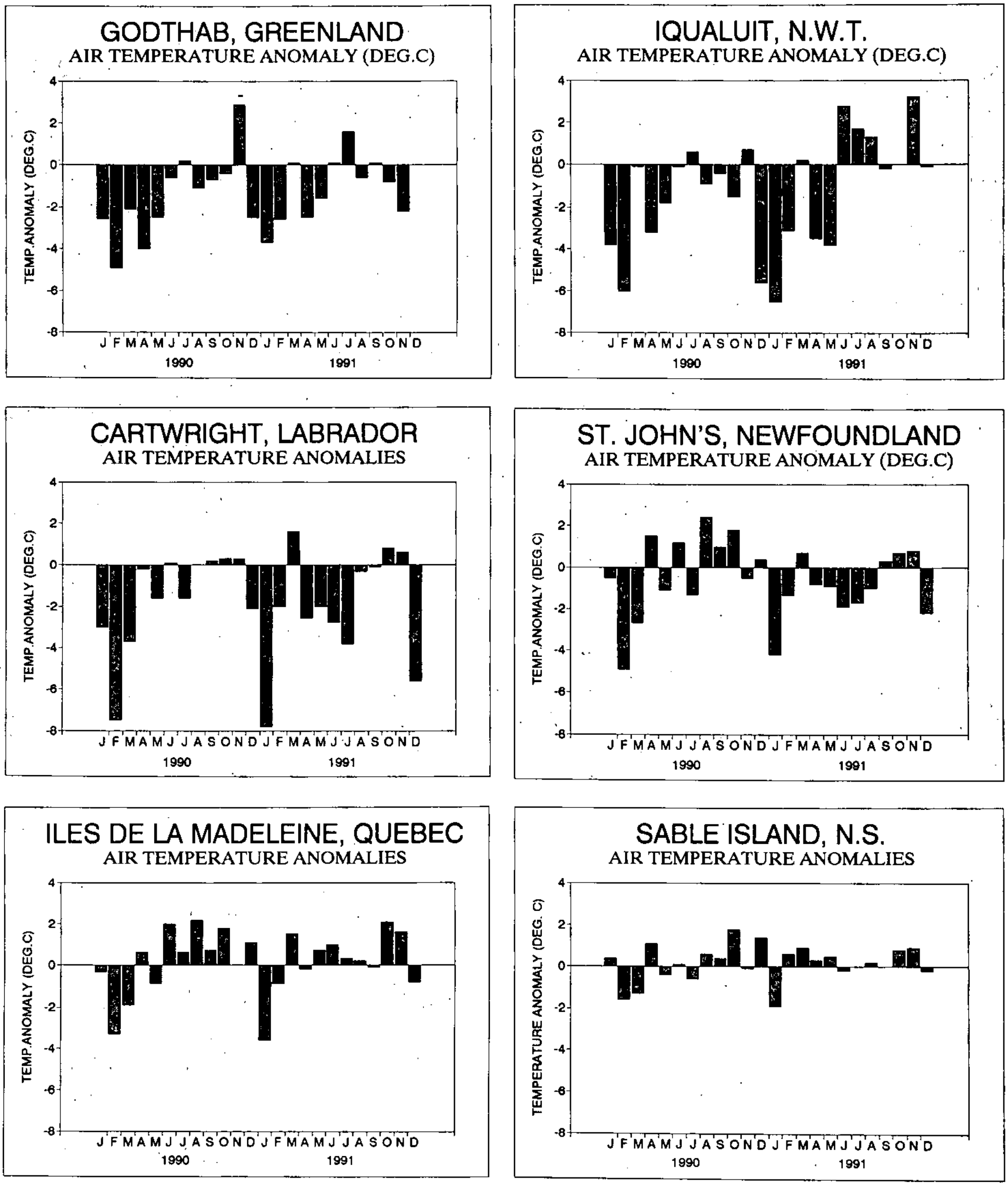


Fig. 2. Monthly air temperature anomalies at selected sites in 1990 and 1991.

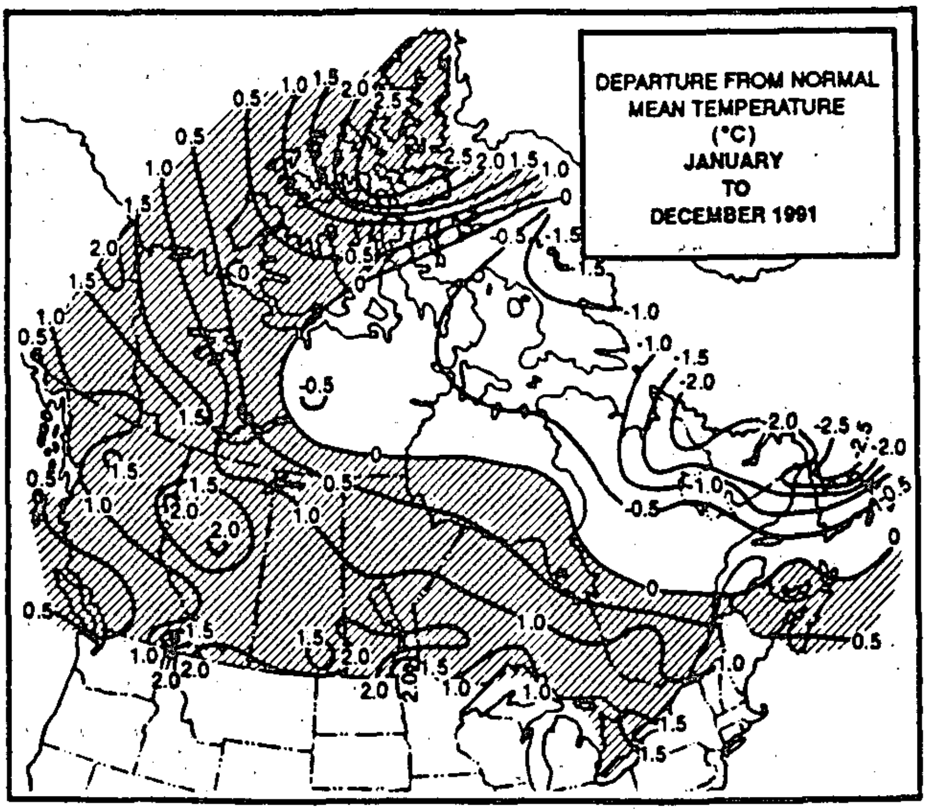


Fig. 3. Annual air temperature anomalies (°C) over Canada in 1991 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 14)

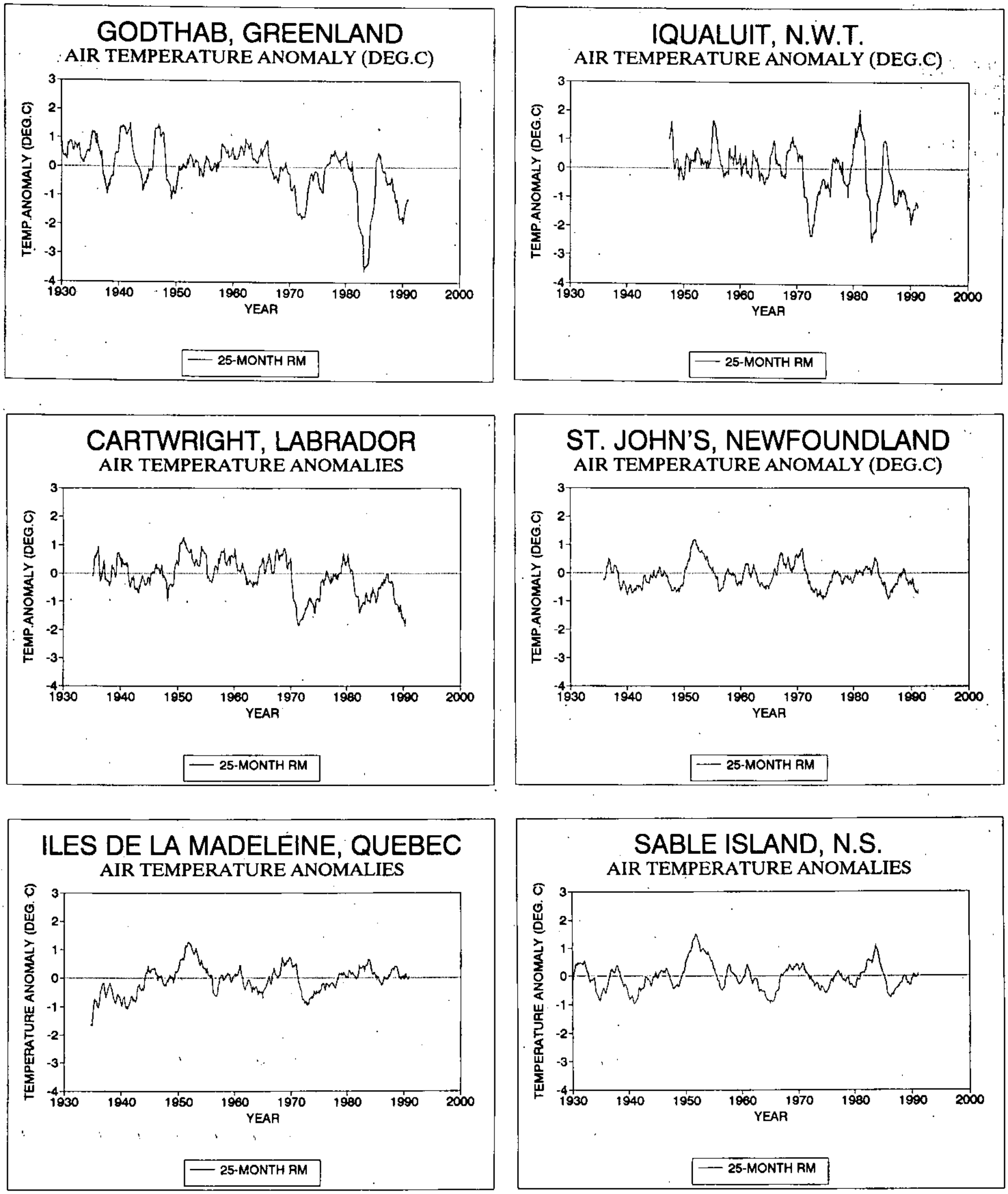


Fig. 4. Twenty-five month running means of monthly air temperature anomalies at selected sites.

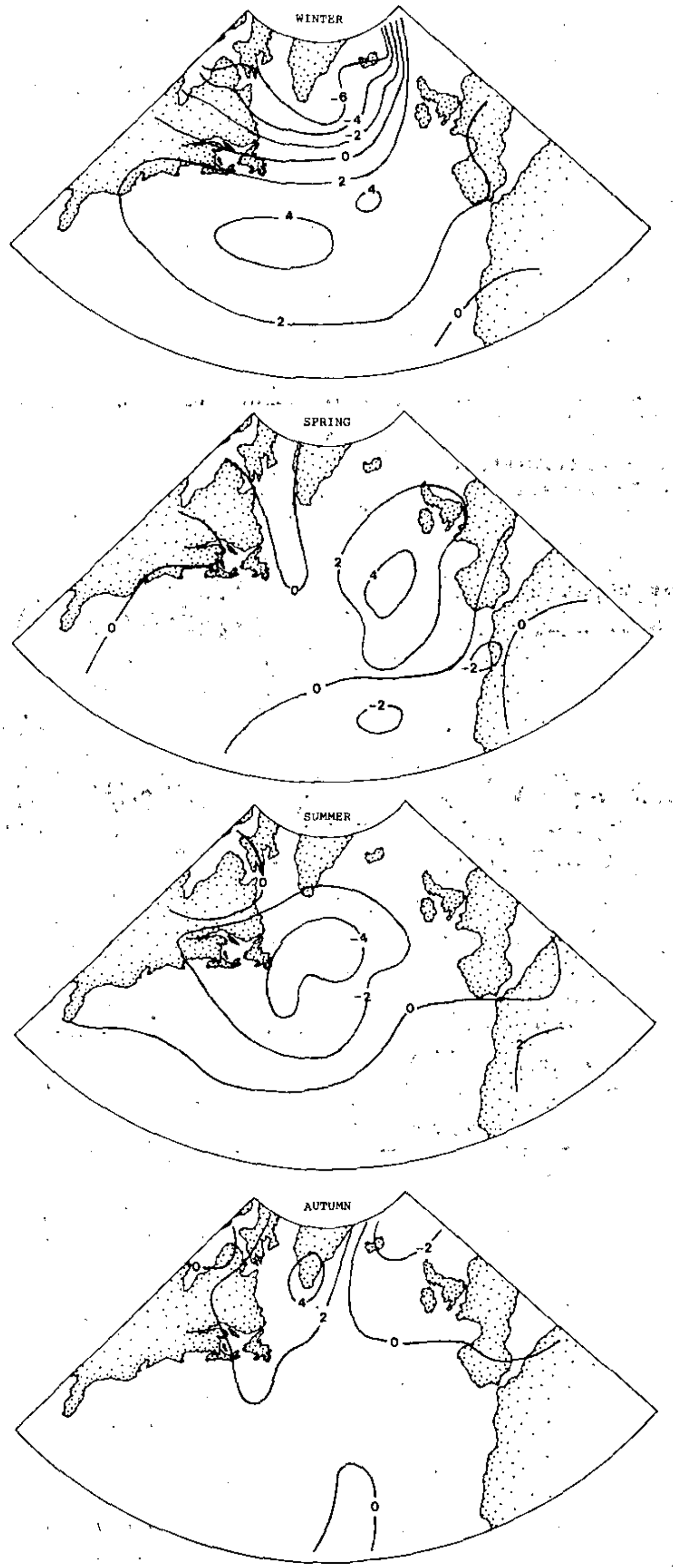


Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1991 relative to the 1951-80 means.

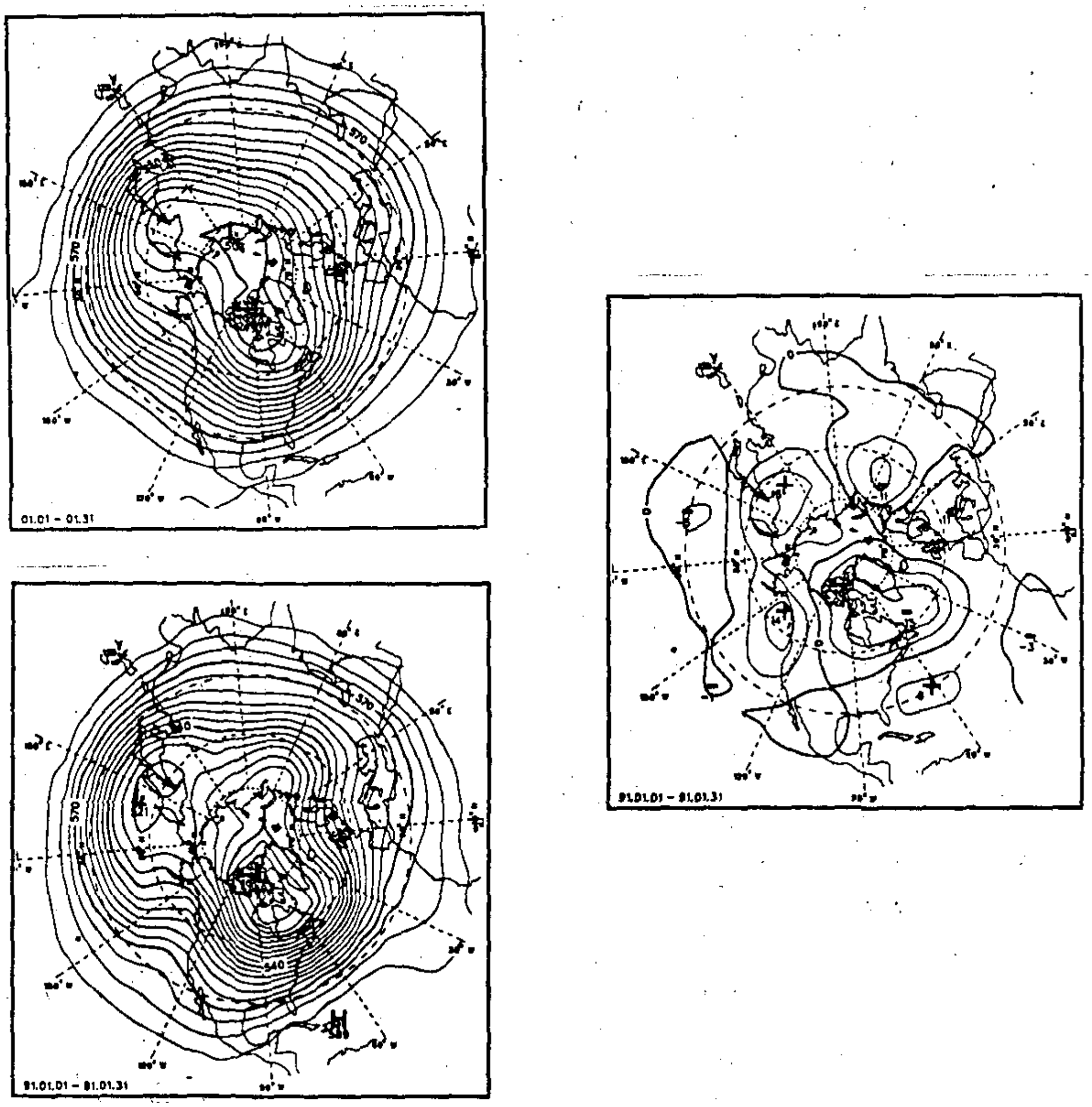


Fig. 6. The historical mean (upper left), the 1991 monthly mean (lower left) and the monthly anomaly (right) of the height in decametres of the 50 kPa atmospheric pressure field for January 1991.

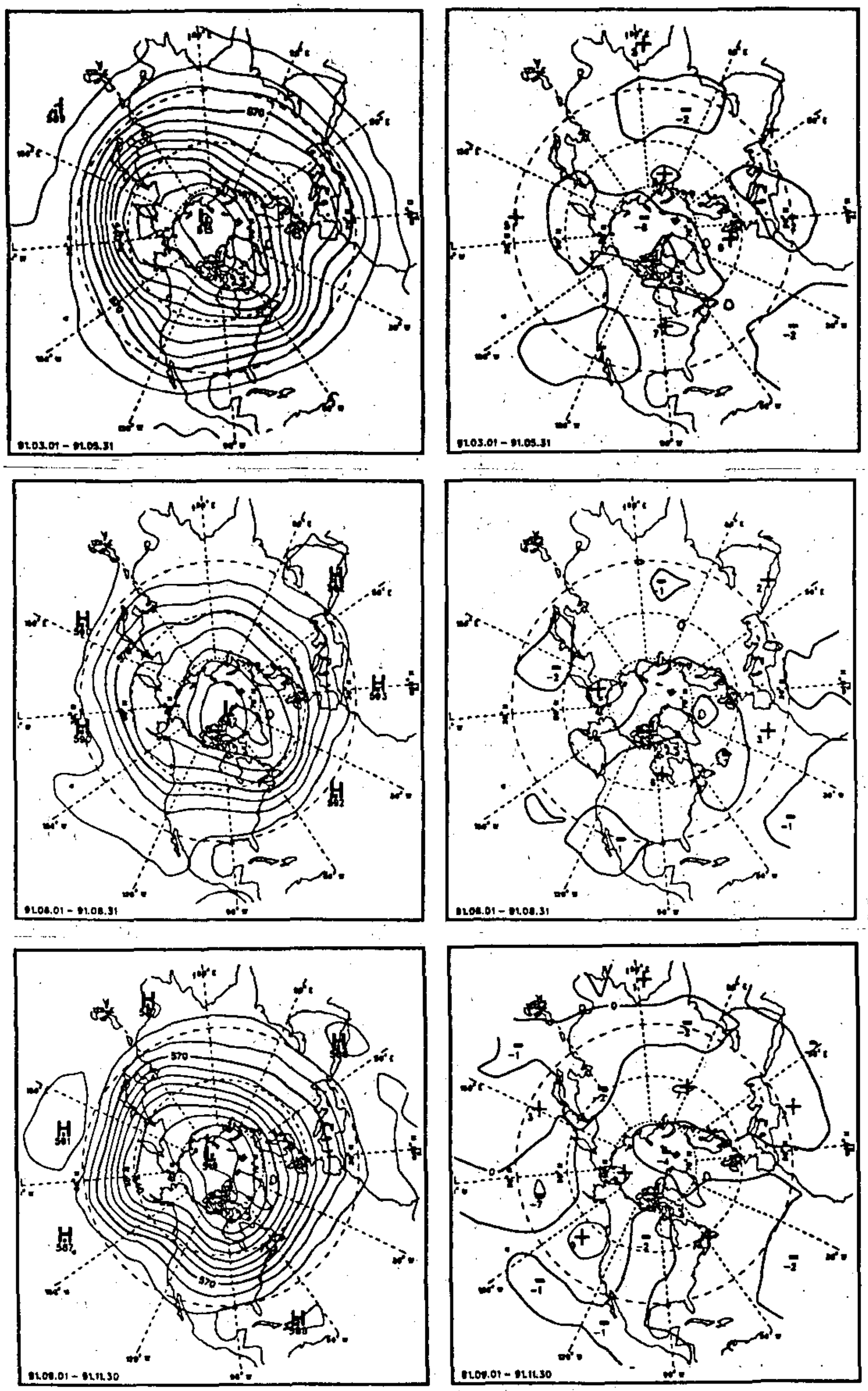


Fig. 7. The 1991 seasonal mean (left) and the anomaly (right) of the height in decametres of the 50 kPa atmospheric pressure field for spring (top), summer (middle) and autumn (bottom).

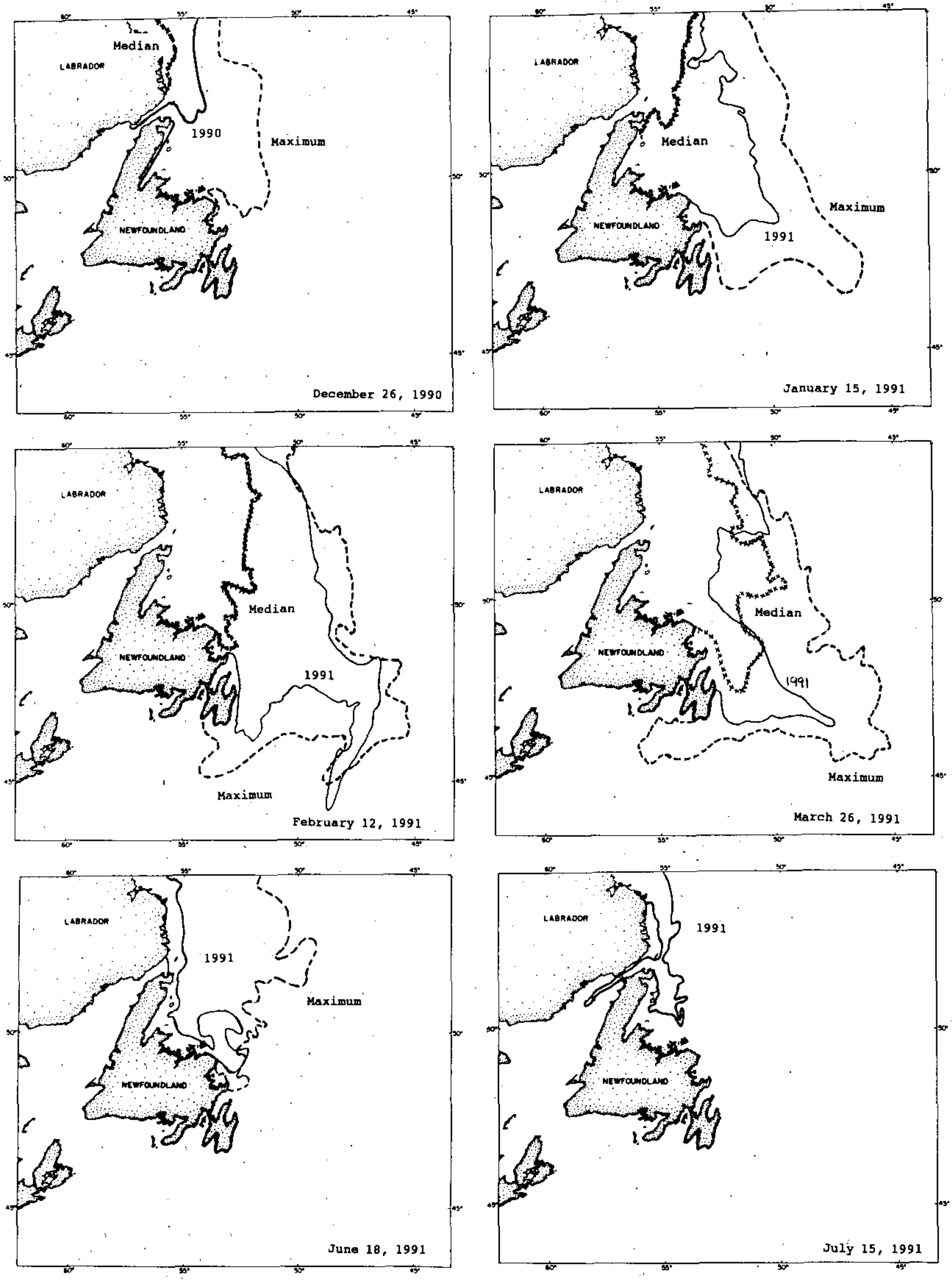
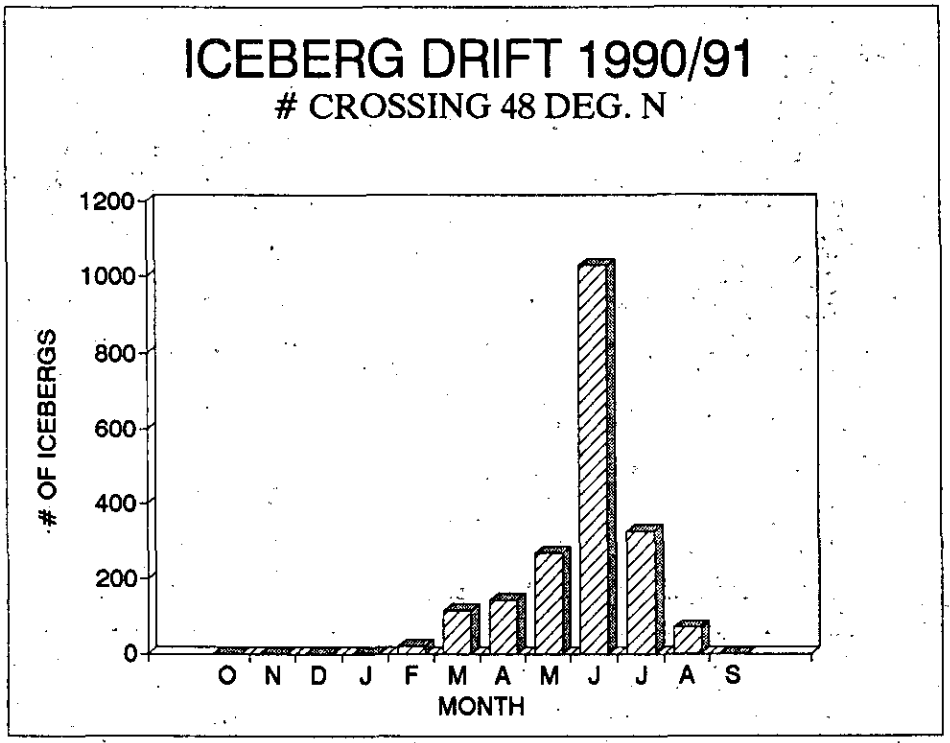


Fig. 8. The 1991 ice edge and the historical (1962-1987) median and maximum positions off Newfoundland and Labrador at various times during the ice season.



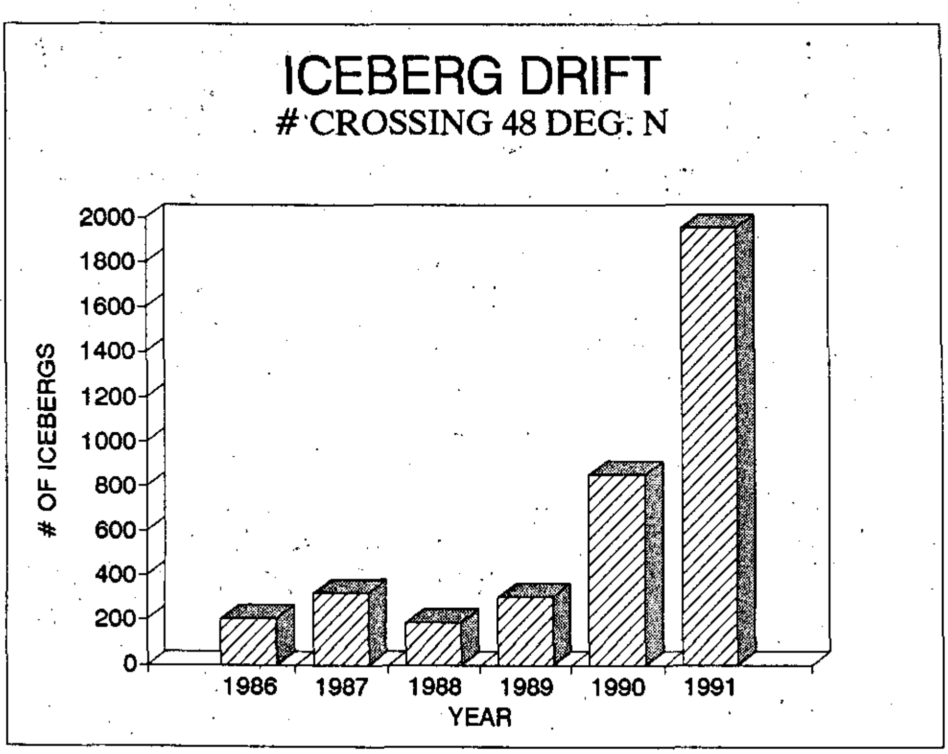


Fig. 9. The monthly numbers of icebergs crossing south of 48°N during the iceberg season 1990/91 (top) and the total number of icebergs compared to the previous five years.

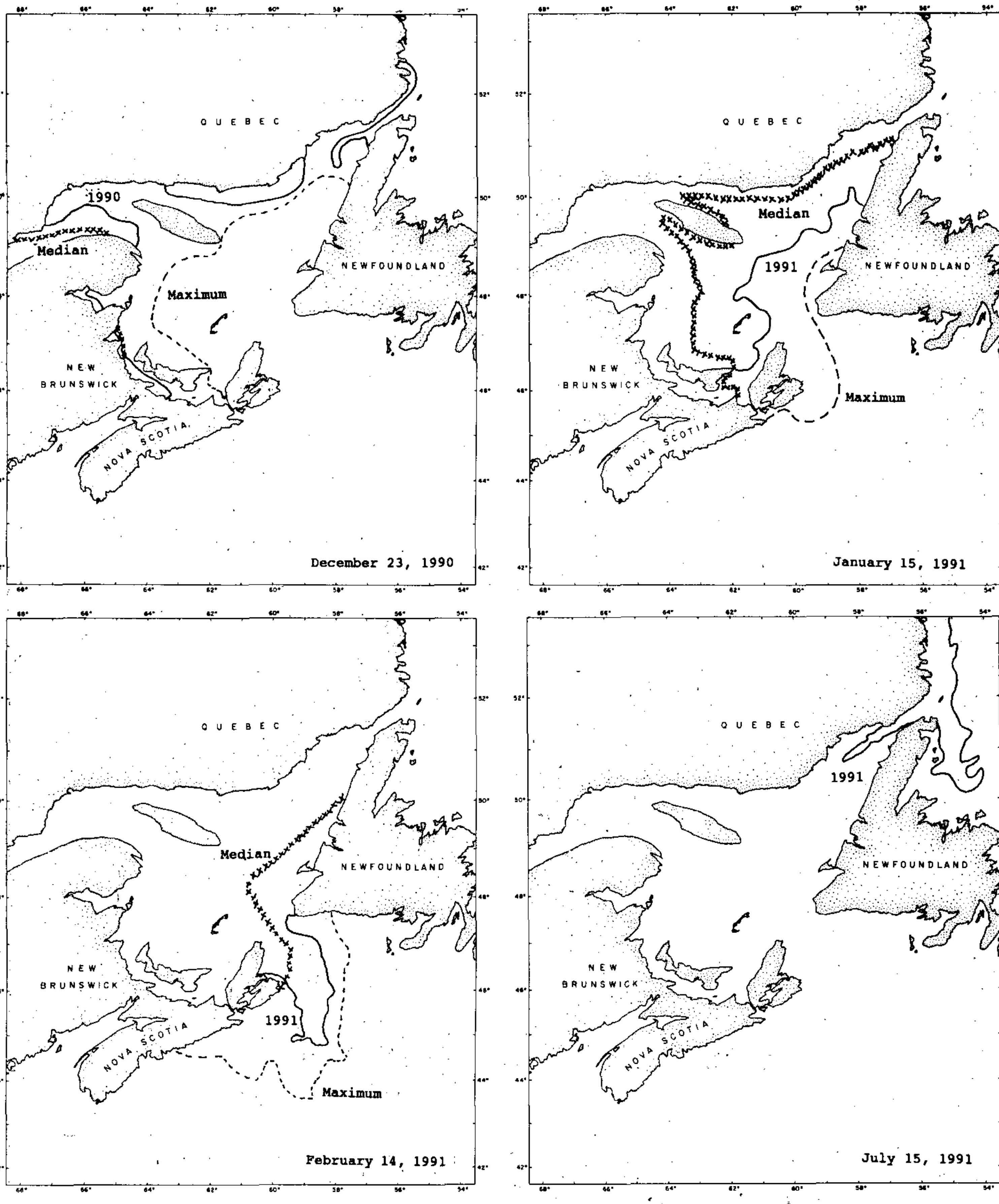


Fig. 10. The 1991 ice edge and the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence at various times during the ice season.

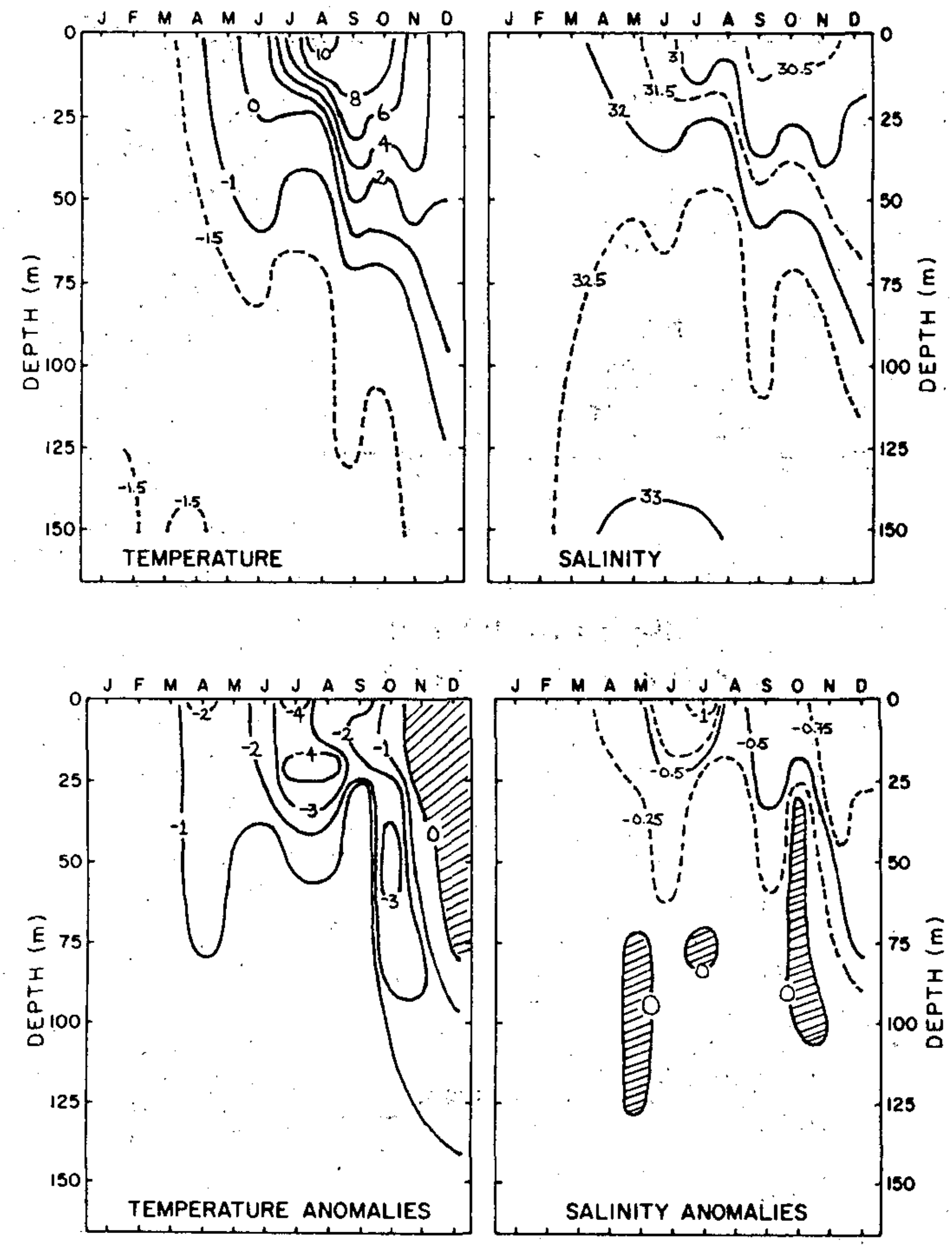
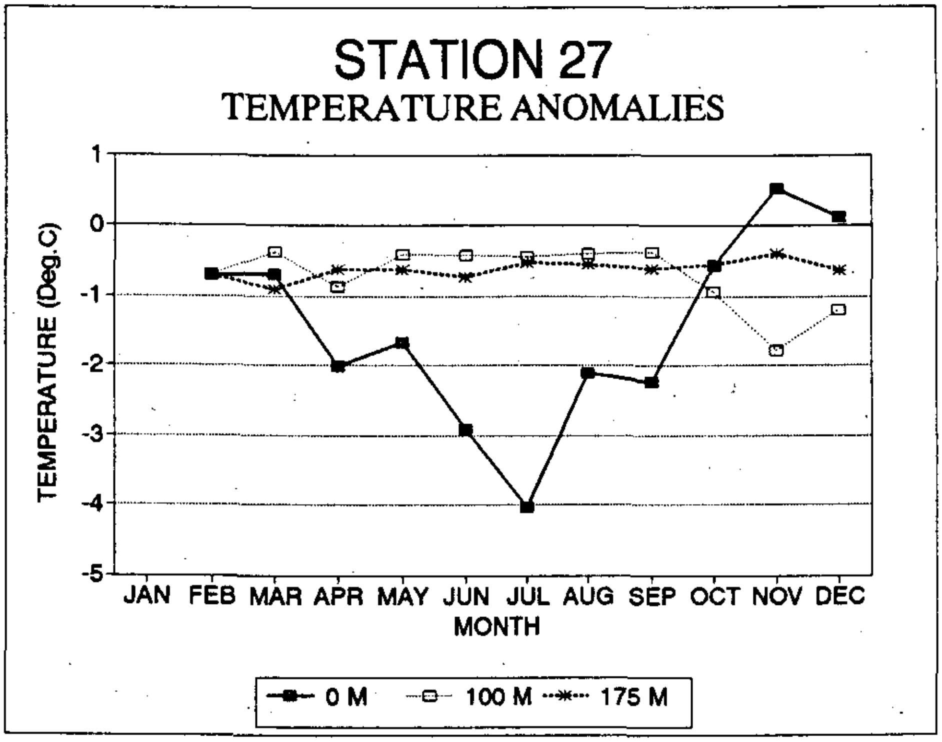


Fig. 11. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1991 relative to the 1951-80 means. Shaded areas are positive anomalies.



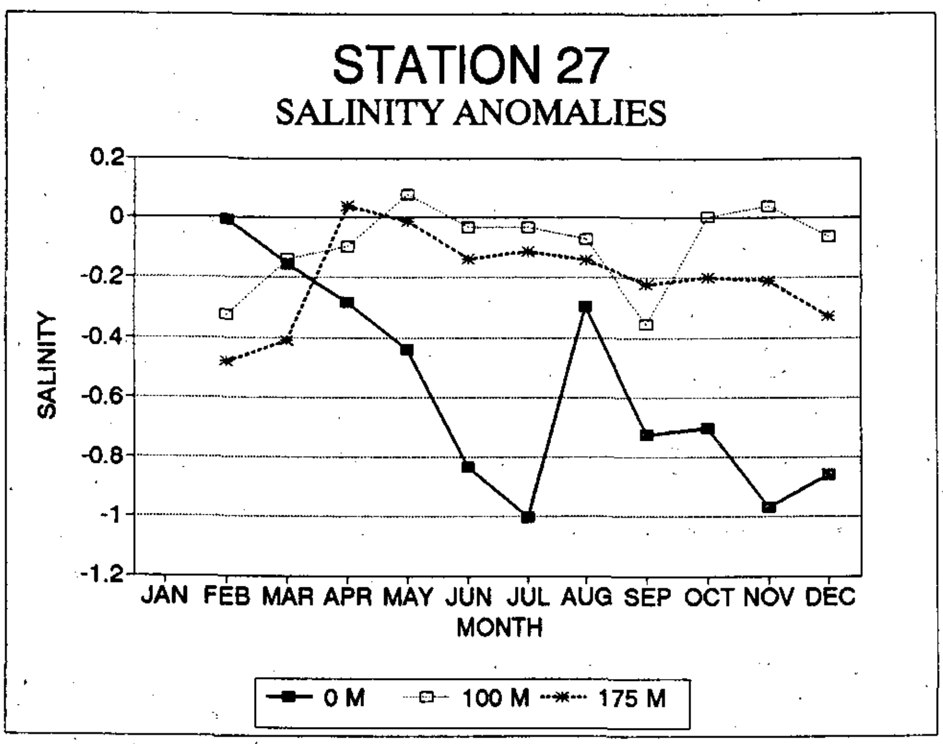


Fig. 12. Monthly temperature and salinity anomalies at 0, 100, and 175 m at Station 27 during 1991.

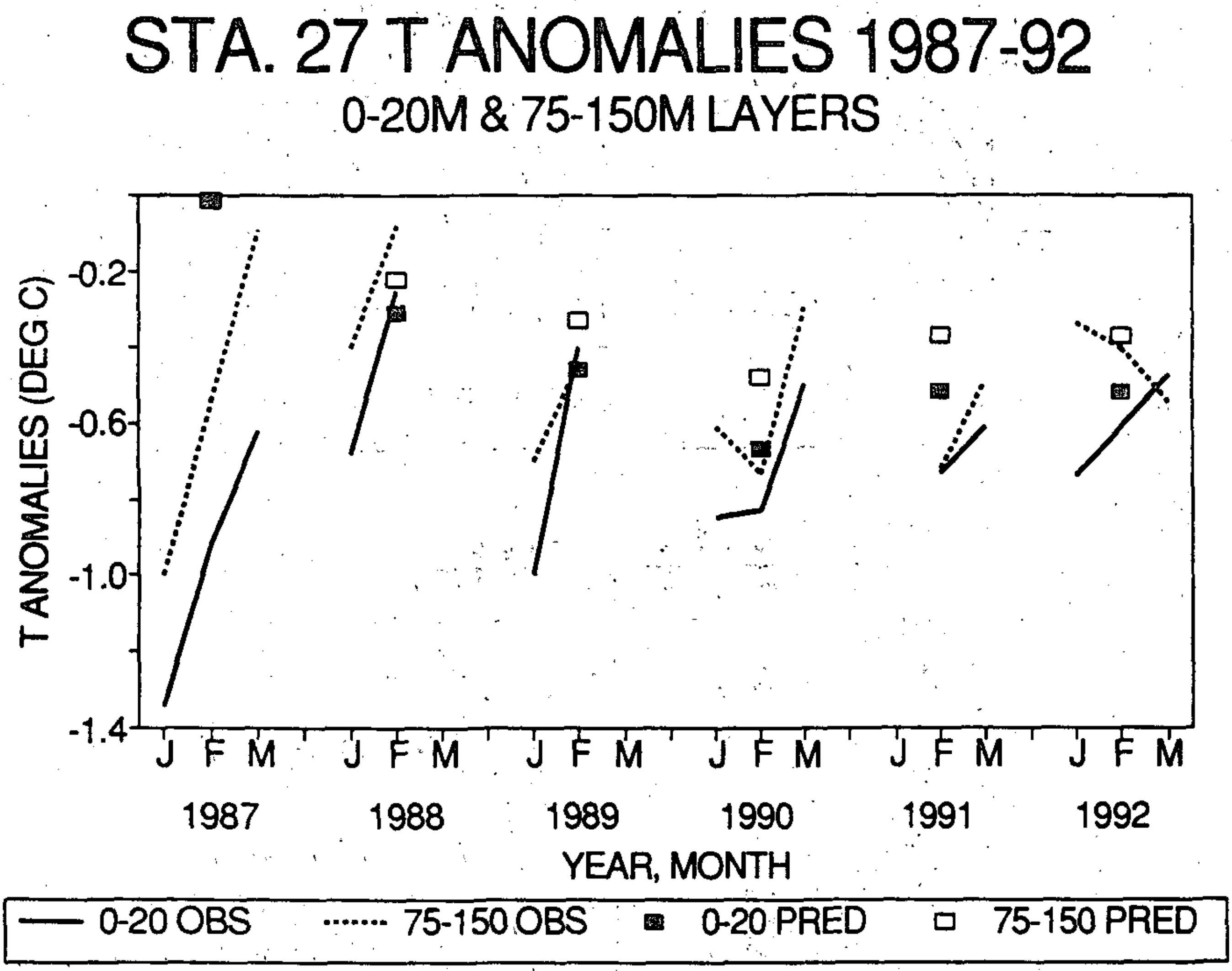


Fig. 13. Predicted March temperature anomalies at Station 27 (1987-1992) for 0-20 m (solid square) and 75-150 m (open square) along with the observed temperature anomalies for January-March, where available. The predicted temperatures are based upon the regression between air and water temperatures for 1963-86.

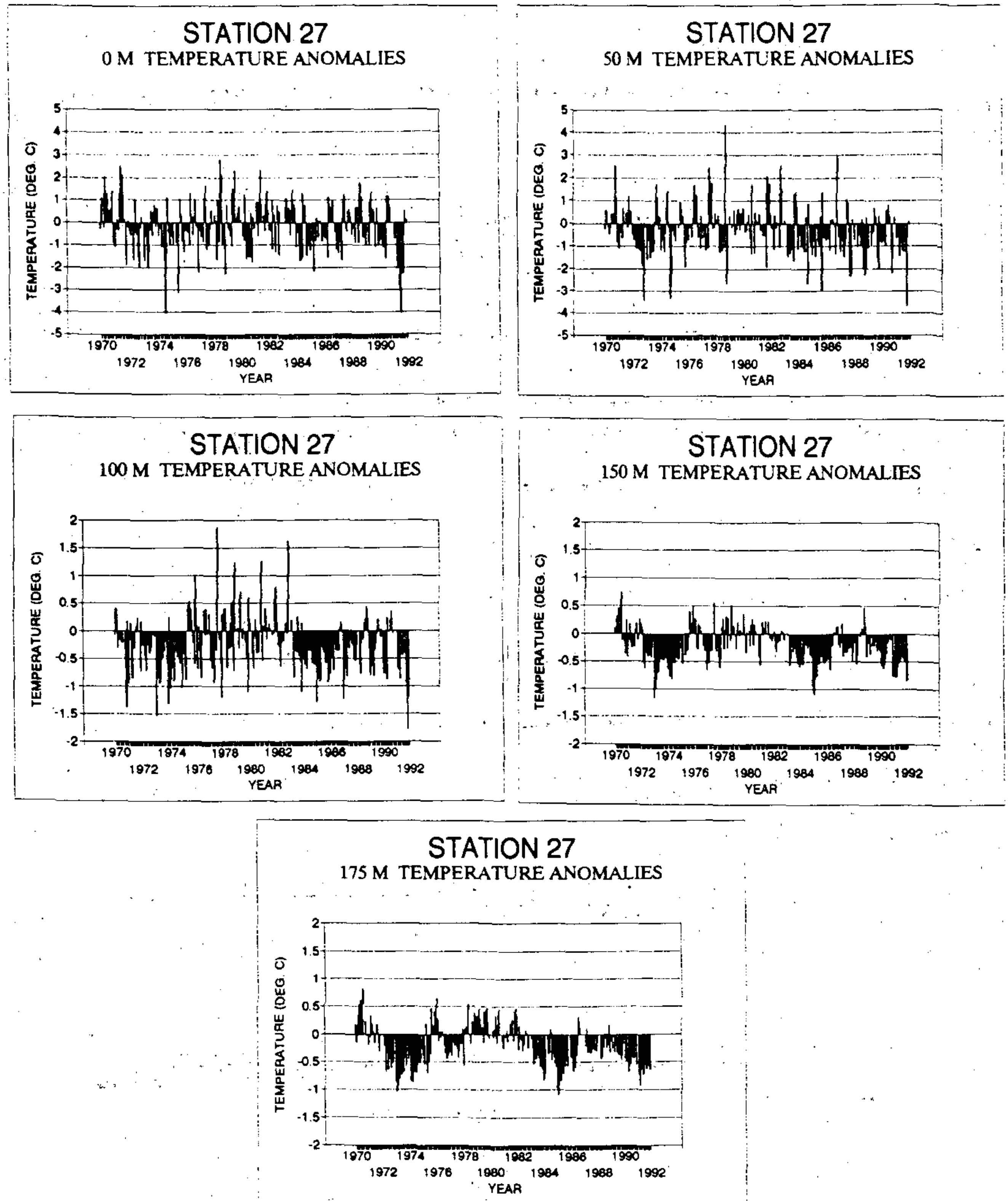


Fig. 14. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27.

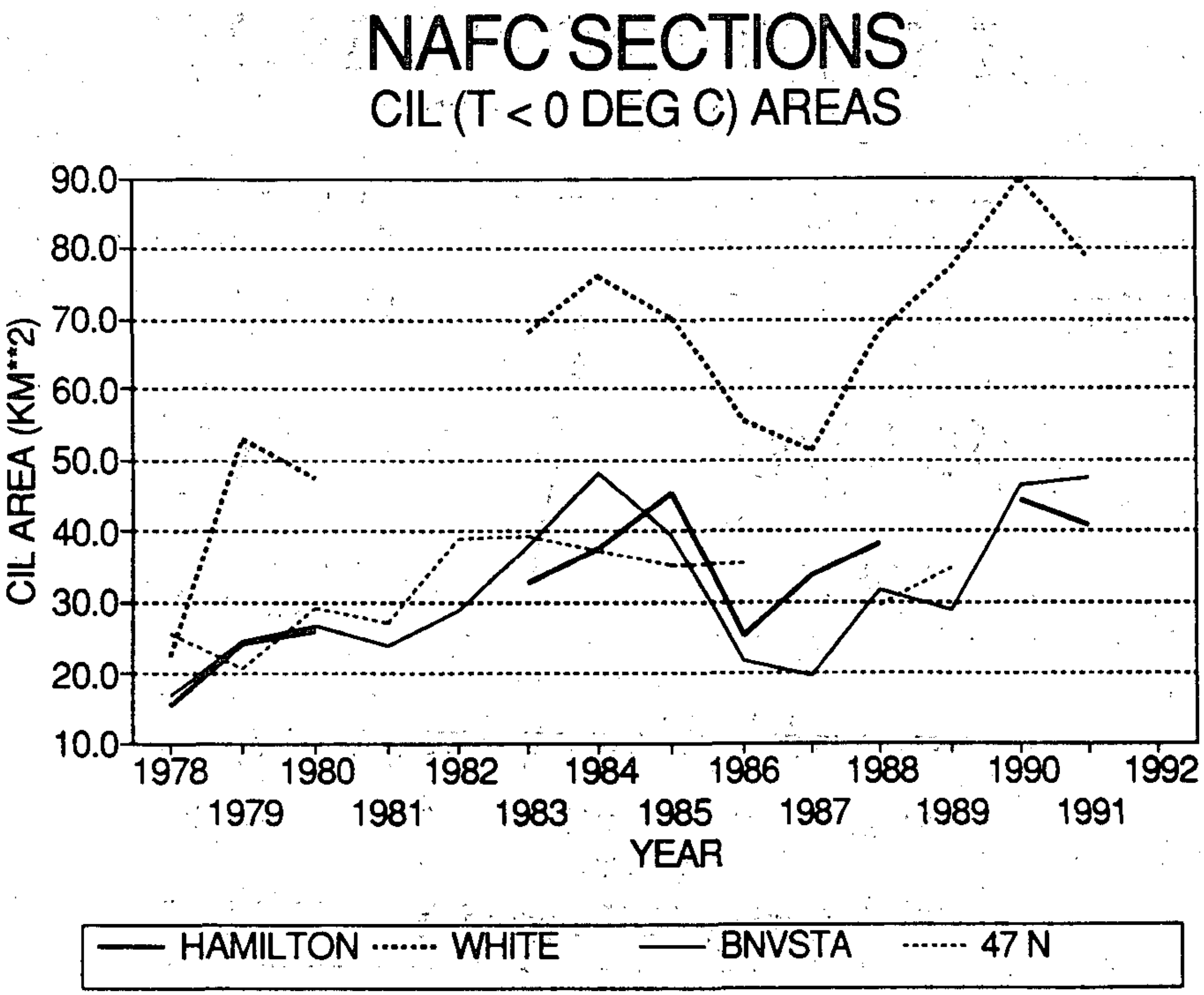


Fig. 15. The area of the CIL for the four standard sections off southern Labrador and northern Newfoundland.

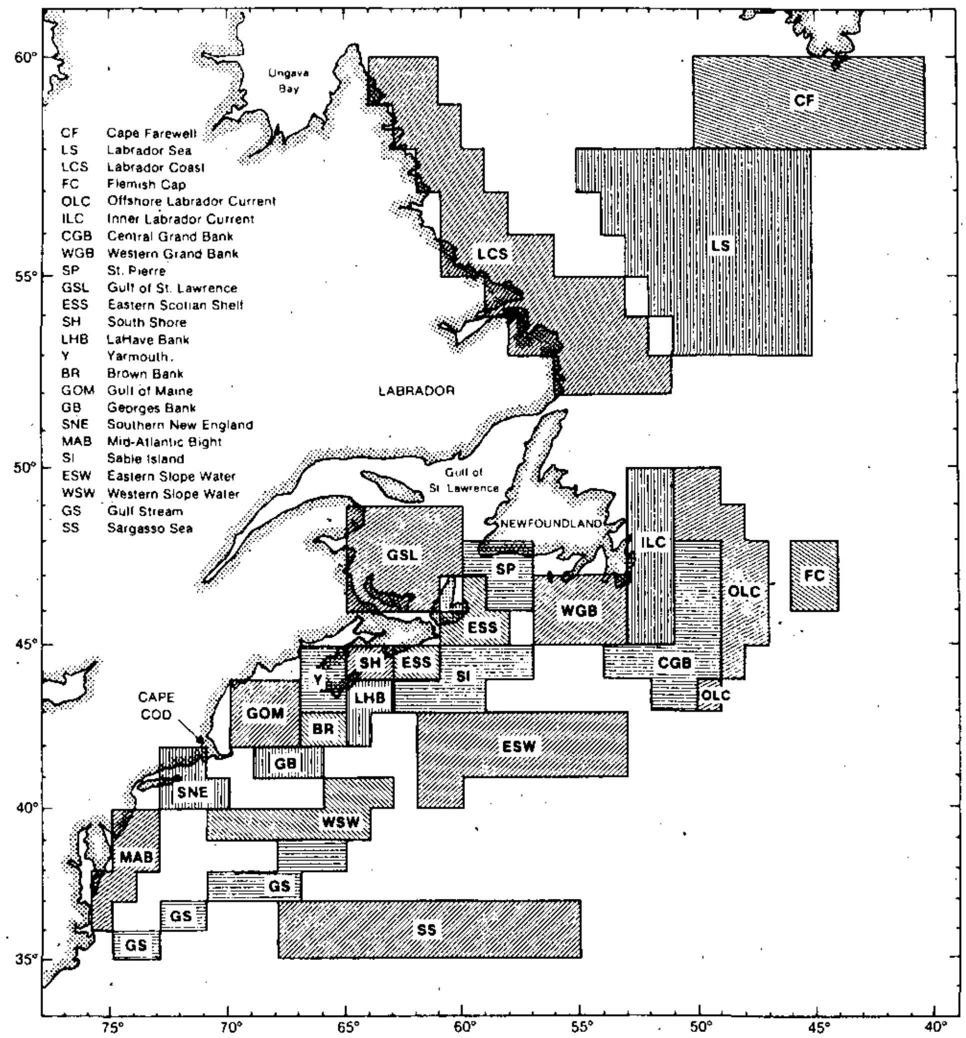


Fig. 16. The geographic boundaries of the 24 subregions for which sea surface temperatures were analyzed on a monthly basis.

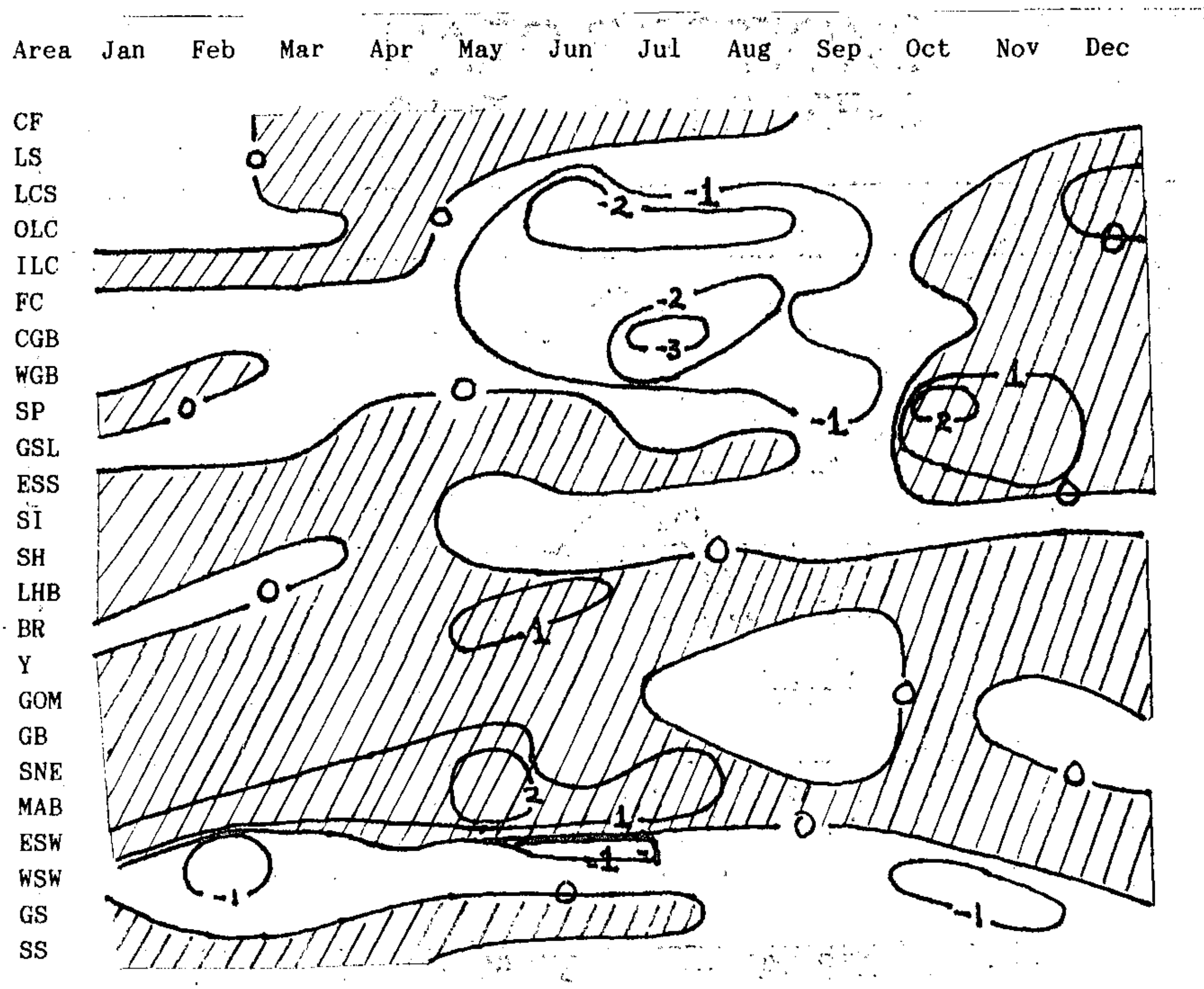


Fig. 17. Contours of the monthly mean sea-surface temperature anomalies for 24 areas in the NW Atlantic Ocean.

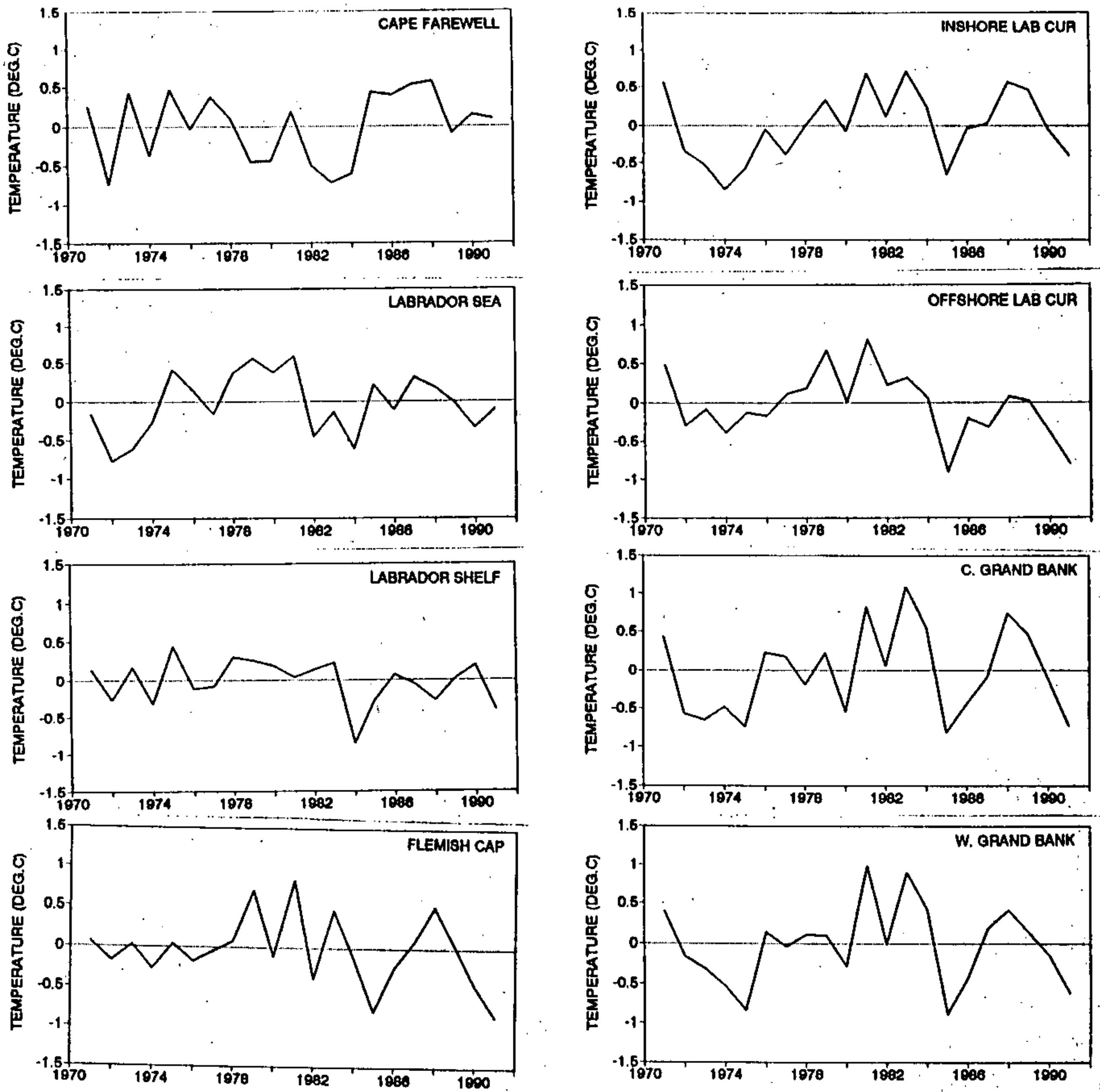


Fig. 18A. The annual temperature anomalies (relative to 1971-90) for the offshore areas - Cape Farewell to Western Grand Bank.

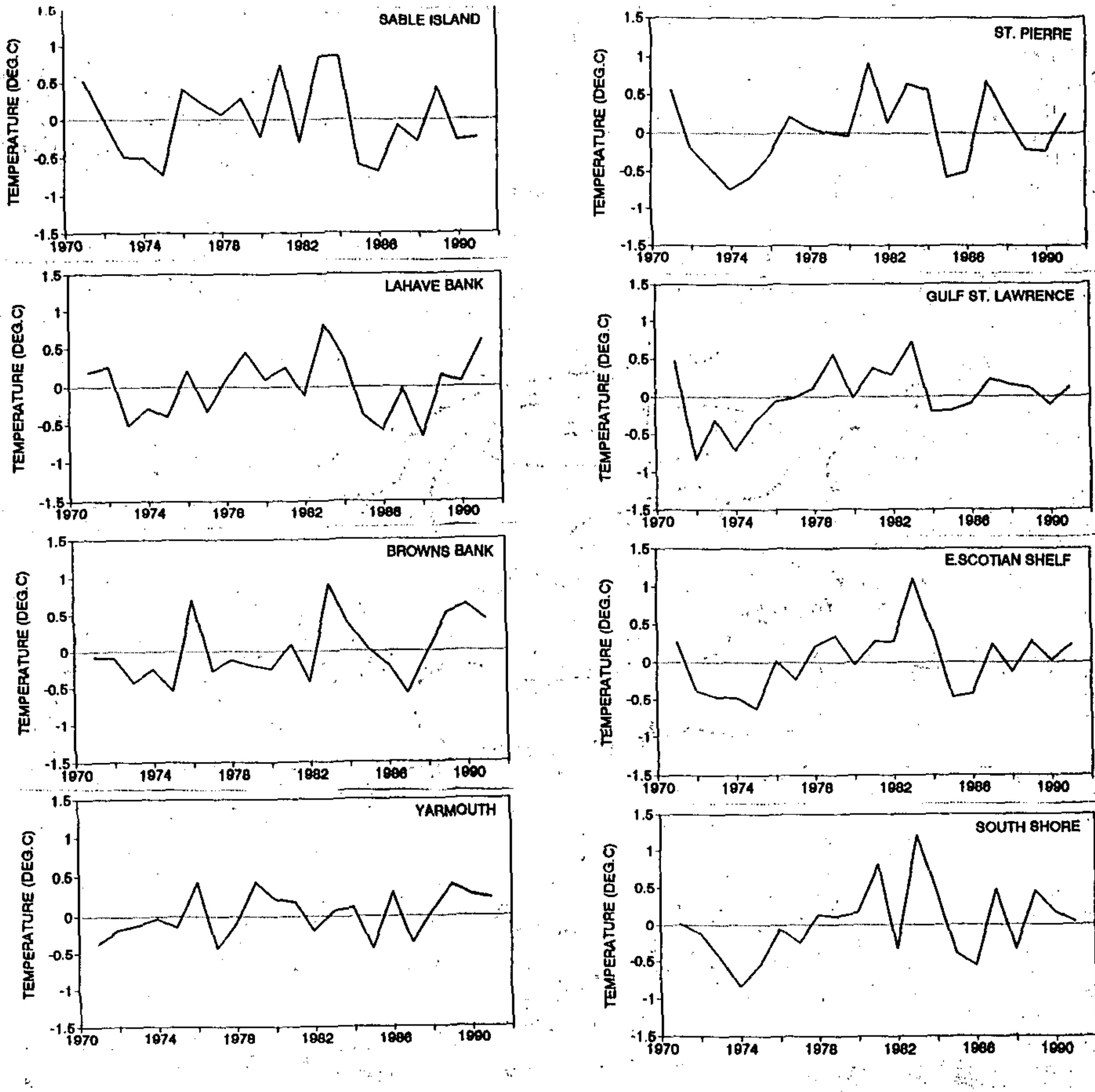


Fig. 18B. The annual temperature anomalies (relative to 1971-90) for the offshore areas - St. Pierre to Yarmouth.

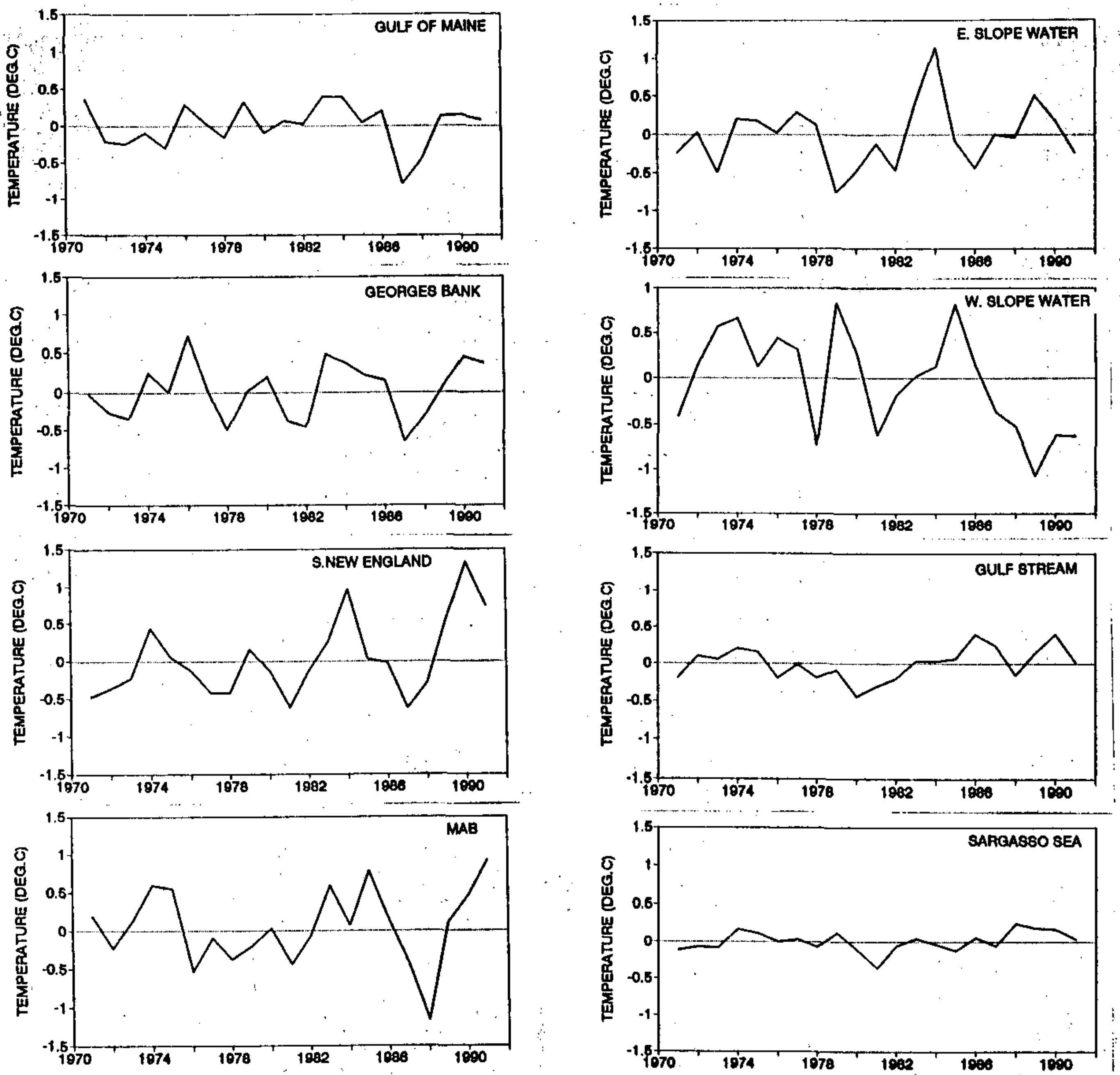


Fig. 18C. The annual temperature anomalies (relative to 1971-90) for the offshore areas - Gulf of Maine to the Sargasso Sea.

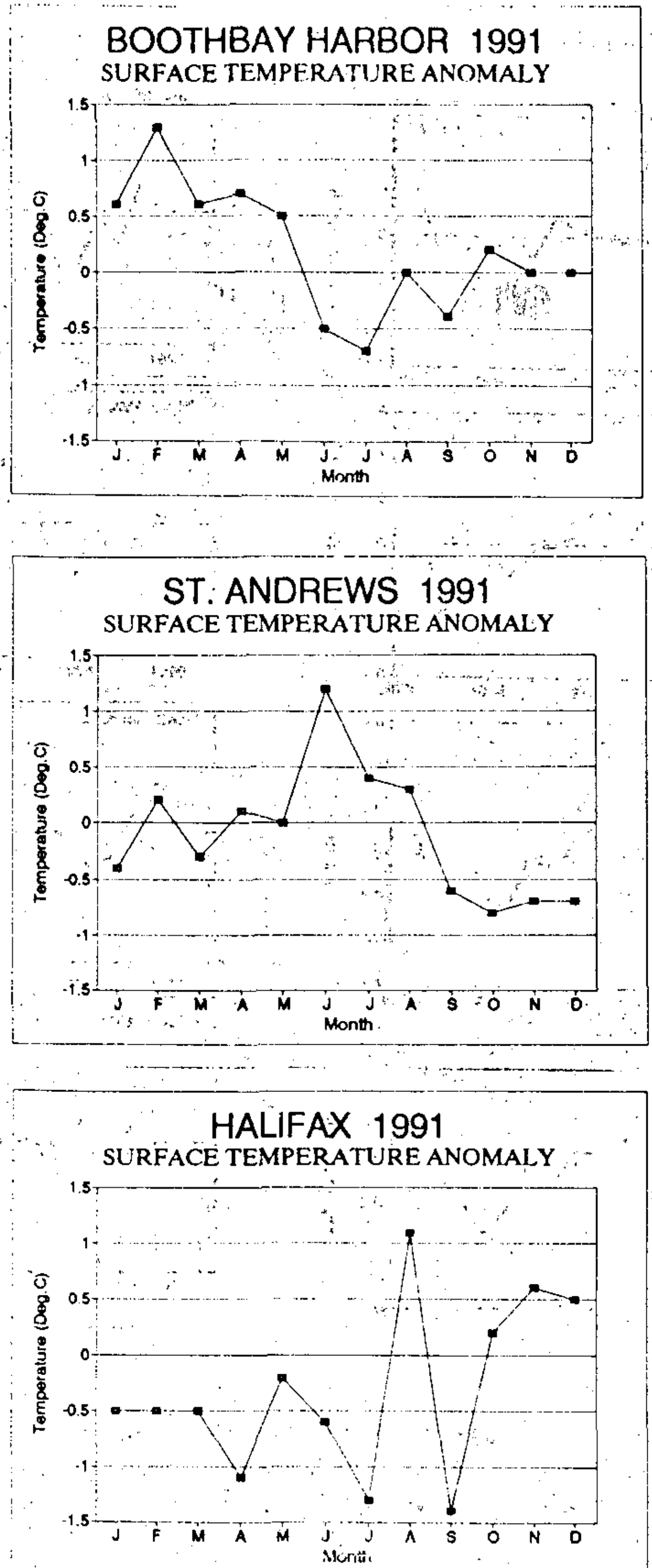


Fig. 19. The monthly sea surface temperature anomalies (relative to 1951-80) during 1991 for Boothbay Harbor, St. Andrews and Halifax.

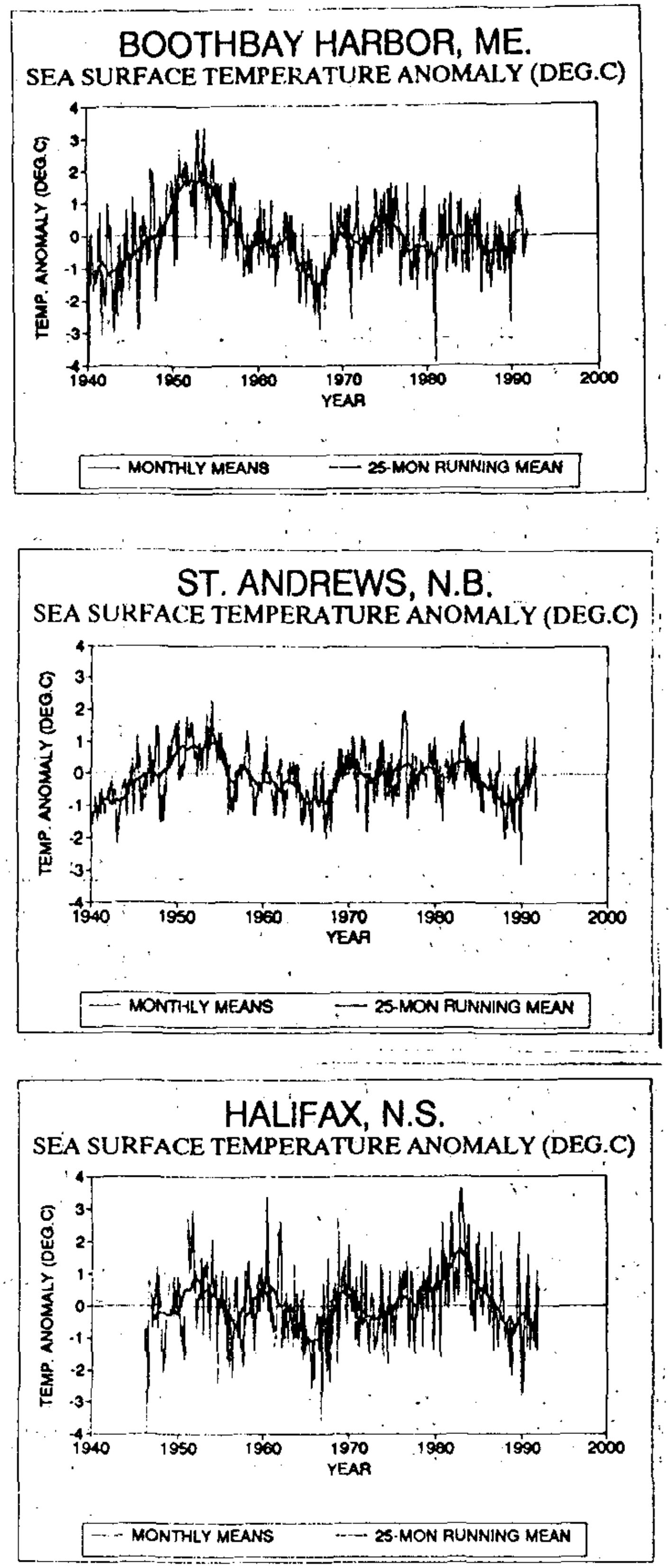


Fig. 20. The monthly means and the 25-month running means of the sea surface temperature anomalies (relative to 1951-80) for Boothbay Harbor, St. Andrews and Halifax.

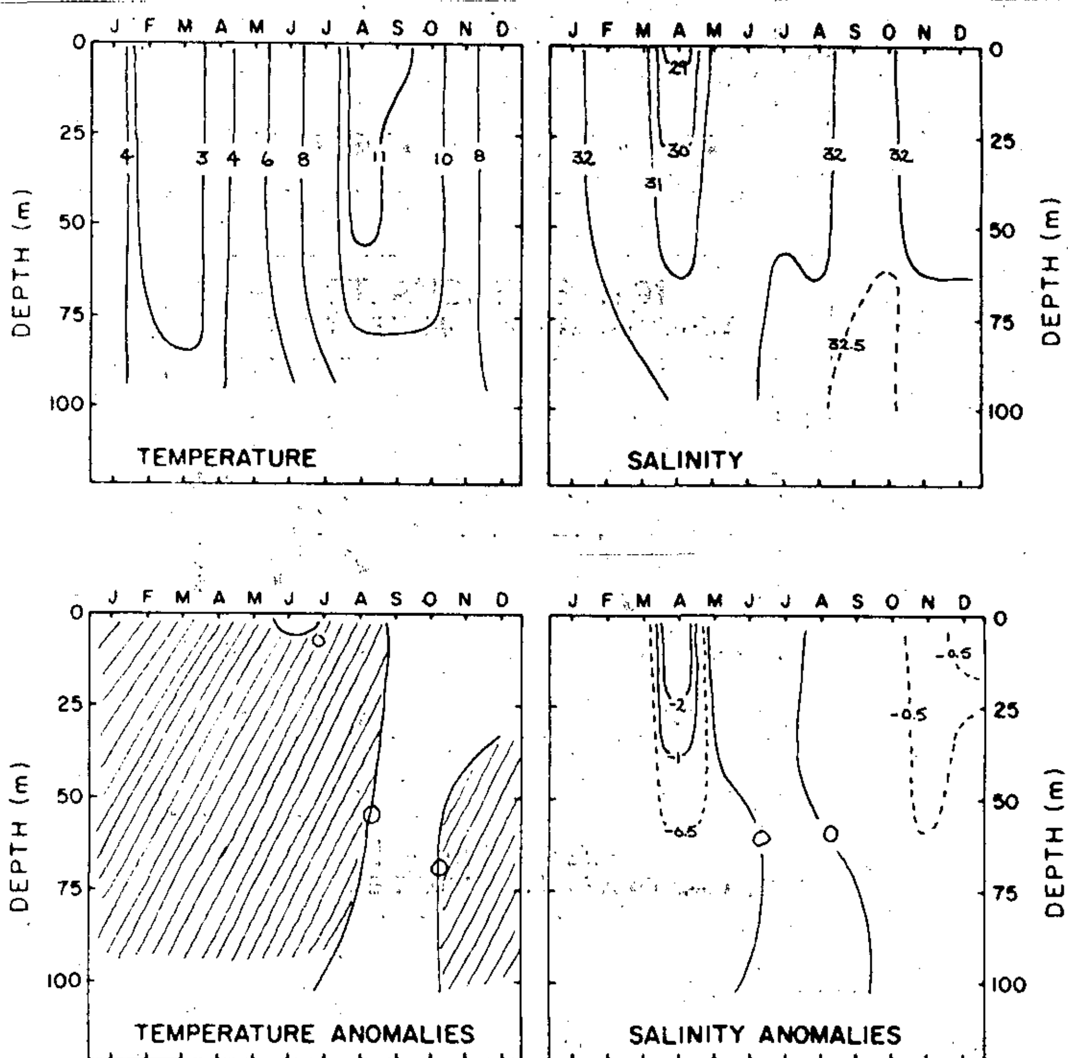
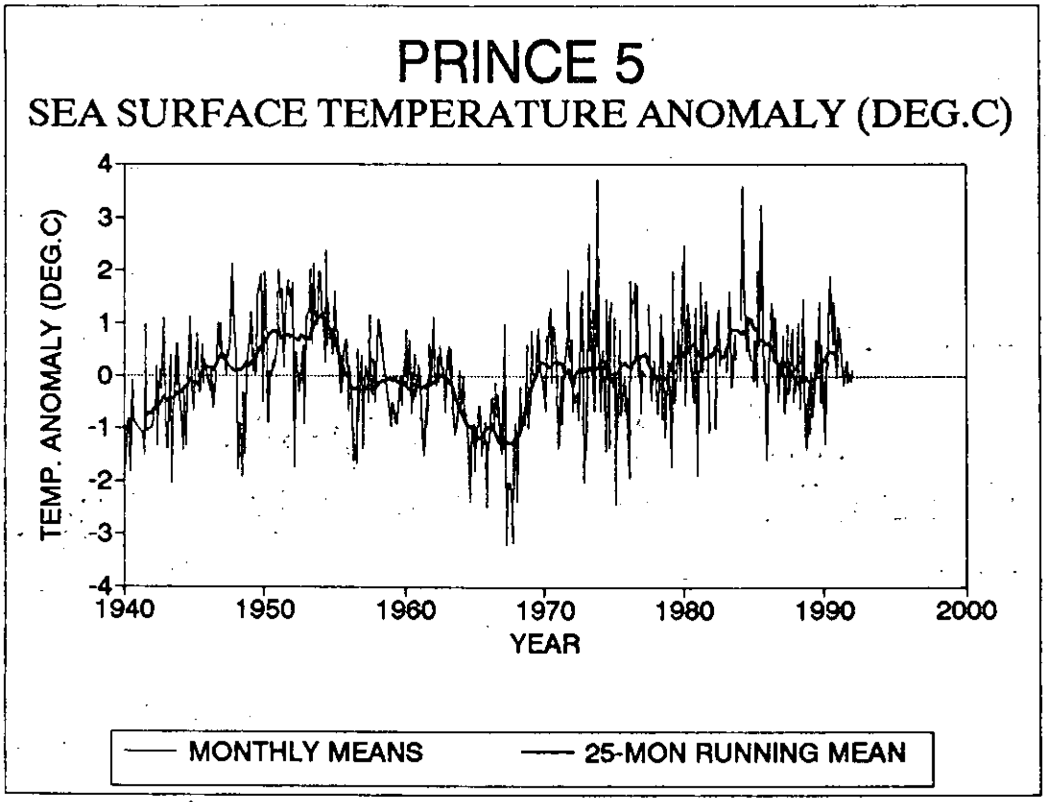


Fig. 21. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1991 relative to the 1951-80 means. Shaded areas are positive anomalies.



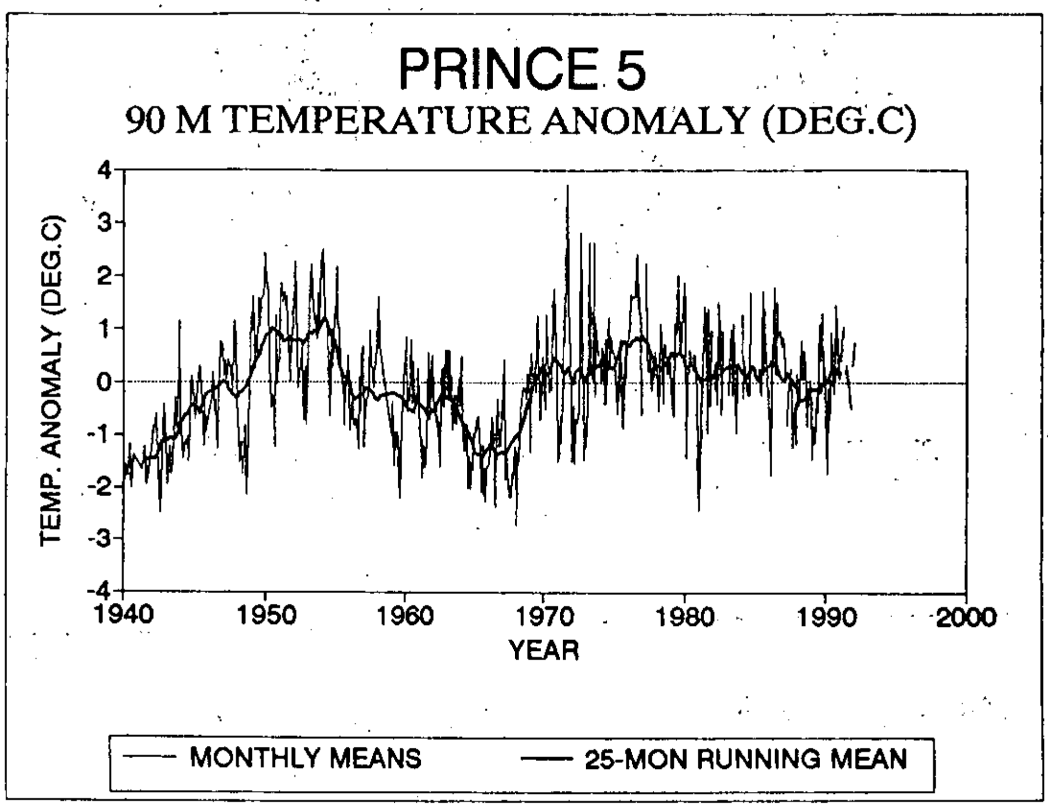


Fig. 22. The monthly means and the 25-month running means of the temperature anomalies for Prince 5, 0 and 90 m.

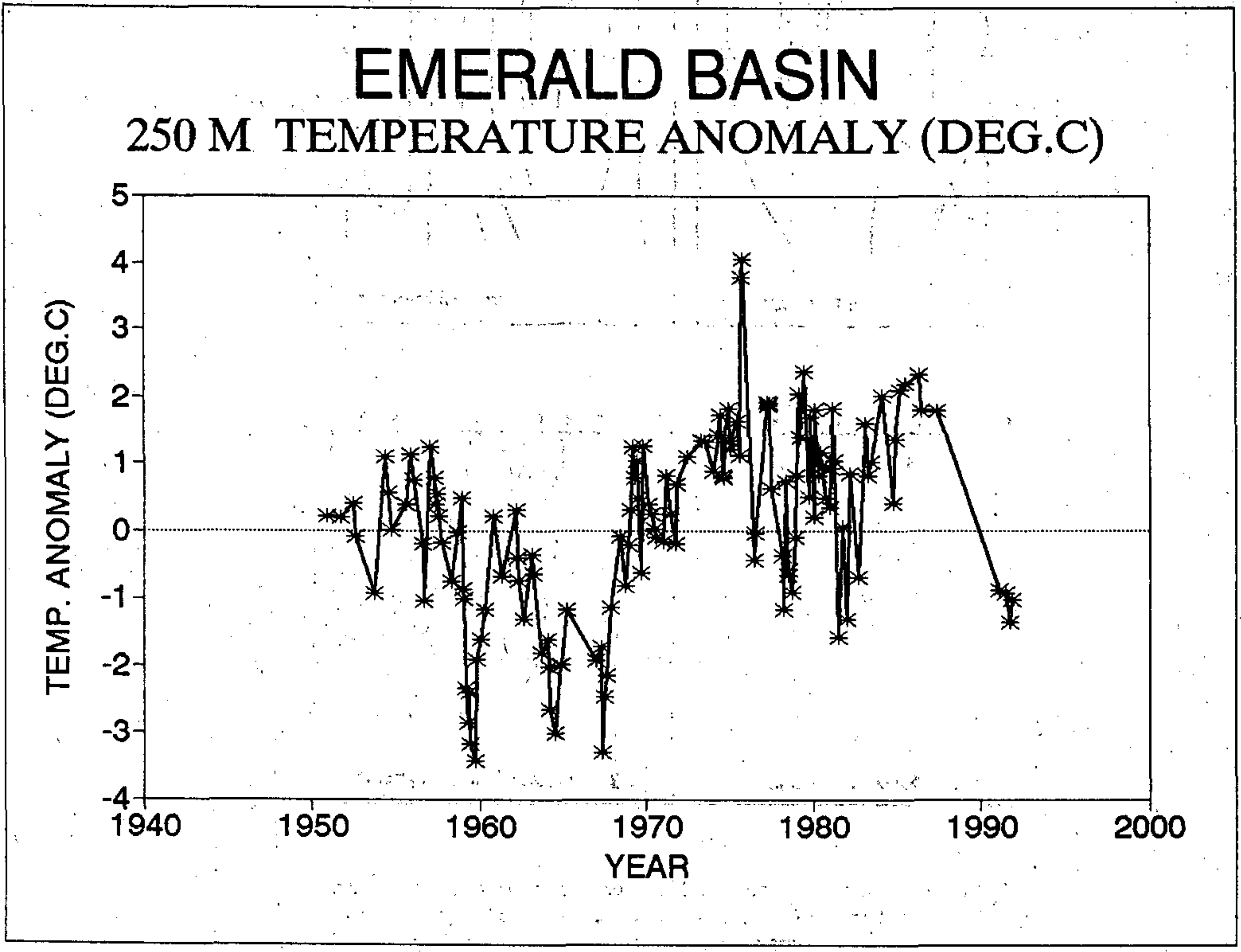


Fig. 23. Temperature anomalies (relative to 1951-80) at Emerald Basin at 250 m.

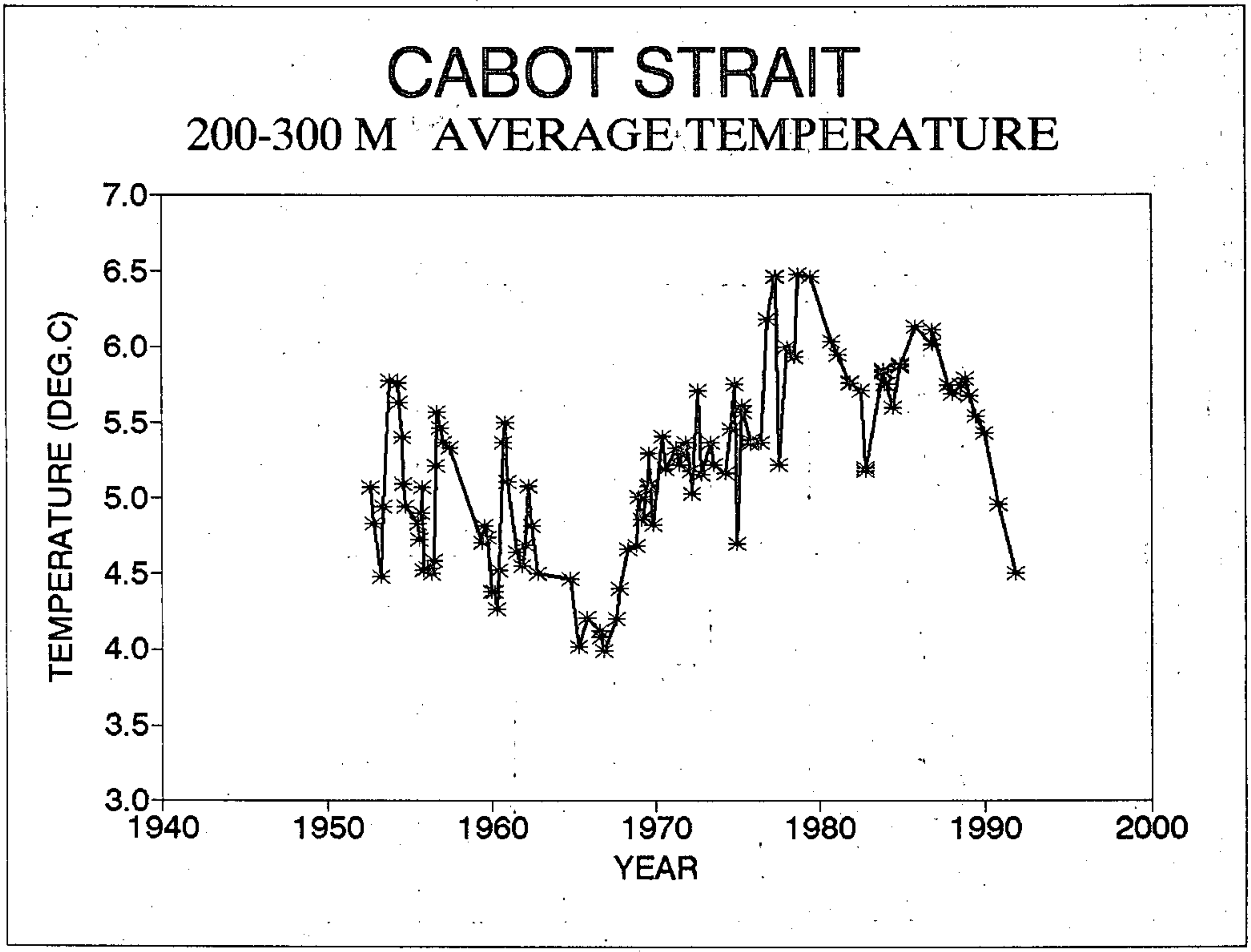


Fig. 24. Mean temperatures for 200-300 m in Cabot Strait.

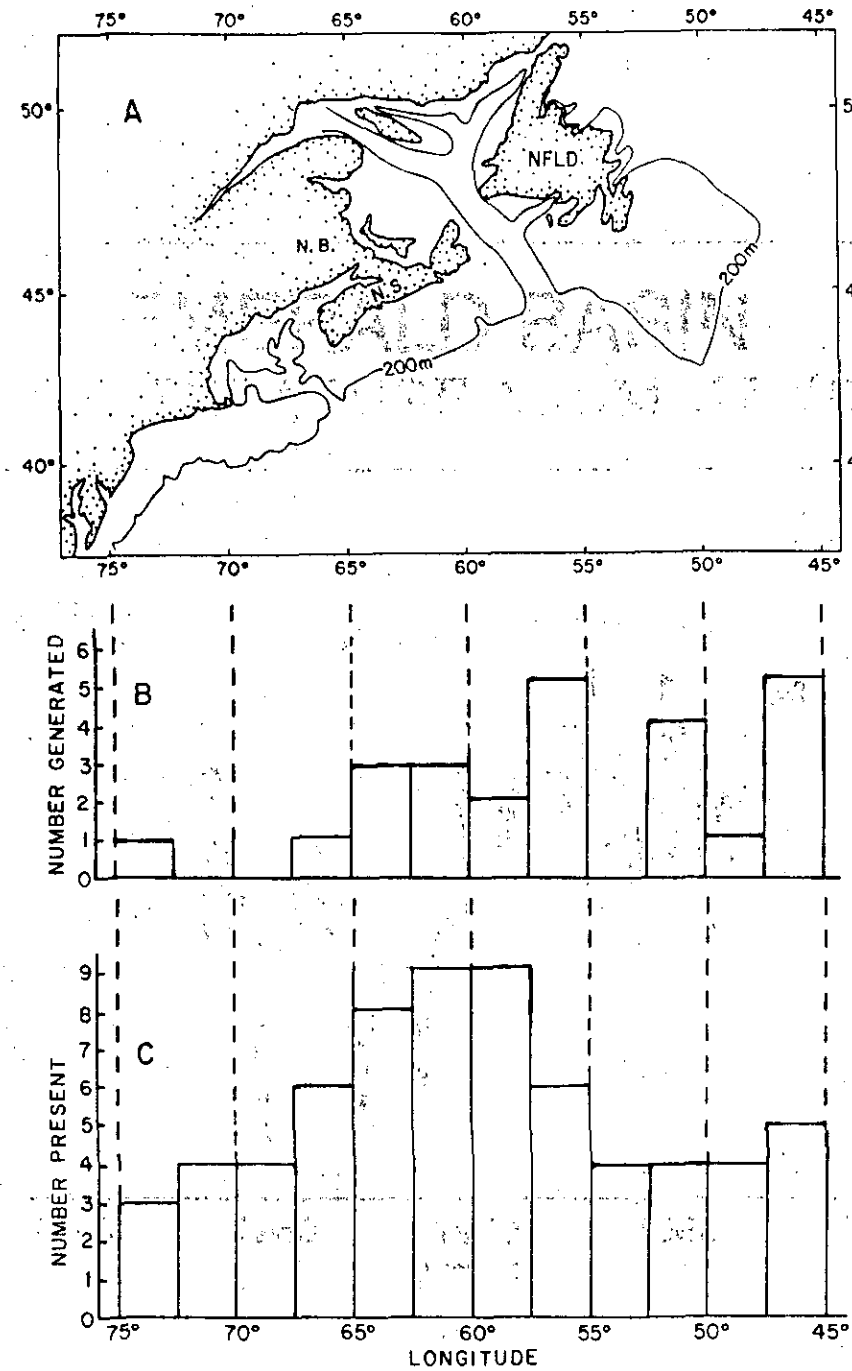


Fig. 25. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1991: (A) the chart of the area of interest; (B) the number of rings generated in each 2.5° zone of longitude; and (C) the number of rings present in each 2.5° zone during some part of the year.