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Overview of Environmental Conditions in the Northwest Atlantic in 1992

by

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ABSTRACT

A review of environmental conditions on the continental shelves and adjacent offshore areas off eastern Canada during 1992 is presented. Near record cold air temperatures persisted throughout the year in the coastal regions bordering the Labrador Sea. Cold air and accompanying strong northwesterly winds during the winter resulted in early ice formation, a greater areal extent than normal and late retreat of ice off northern Newfoundland and southern Labrador. New records for duration of ice were established in some areas of the outer northern Newfoundland shelf. At Station 27 ocean temperatures were generally below normal throughout the water column. The near-bottom waters warmed slightly compared to last year but were still 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 in summer off northern Newfoundland and southern Labrador decreased relative to last year but remained above normal. The cold conditions observed in the 1990s off Newfoundland are similar to those in the early 1970s and mid-1980s. On the Scotian Shelf and in the Gulf of Maine, sea surface temperatures were generally below normal throughout most of the year. In the deep basins and channels the lower layer waters warmed considerably from last year, due to an intrusion of warmer slope water. The shelf/slope front and the Gulf Stream were generally north of their long-term mean positions in 1992.

RÉSUMÉ

On effectue ici un survol des conditions environnementales ayant régné sur les plates-formes continentales et dans les zones adjacentes du large de la côte est du Canada en 1992. Dans les régions côtières bordant la mer du Labrador, la température de l'air a approché toute l'année les records les plus bas. Durant l'hiver, l'air froid et les forts vents du nord-ouest qui y étaient asssociés ont abouti, au nord de Terre-Neuve et au sud du Labrador, à la formation précoce de glaces, qui se sont étendues sur une surface plus vaste et se sont retirées plus tardivement que d'habitude. Dans certains endroits de la zone extérieure du nord de la plate-forme de Terre-Neuve, on a atteint de nouveaux records de durée des glaces. À la station 27, les températures de l'océan ont été généralement inférieures à la normale dans toute la colonne d'eau. À proximité du fond, les eaux se sont réchauffées légèrement par rapport à l'année dernière, mais sont demeurées inférieure à la normale, confirmant une tendance amorcée en 1983. La salinité a aussi été inférieure à la normale durant la majeure partie de l'année. L'étendue de la couche froide intermédiaire au nord de Terre-Neuve et au sud du Labrador durant l'été a diminué par rapport à l'an dernier, tout en restant supérieure à la normale. Les conditions de froid observées dans les années 90 au large de Terre-Neuve sont comparables à celles que l'on a connues dans le début des années 70 et le milieu des années 80. Sur la plate-forme Neo-Ecossaise et dans le golfe du Maine, les températures à la surface de l'eau ont été généralement inférieures à la normale pendant la plus grande partie de l'année. Dans les bassins et chenaux profonds, les basses couches d'eau se sont réchauffées considérablement par rapport à 1991, en raison de l'intrusion d'une eau de pente plus chaude. En 1992, le front de la plate-forme et du talus ainsi que le Gulf Stream se trouvaient généralement au nord de leur position moyenne à long terme.

INTRODUCTION

This paper provides a review of environmental conditions during 1992 in the Northwest Atlantic with emphasis on the Canadian continental shelf regions. It is based upon selected sets of oceanographic and meteorological data and the 1992 conditions are compared with those of the preceding year as well as with 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.

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.* The anomalies are calculated relative to the 30-yr mean 1951-80. Along the Labrador Shelf and northern Newfoundland negative anomalies persisted throughout most of 1992 (Fig. 1). The coldest anomalies (-6°C) occurred in February from Baffin Island to the southern Labrador coast. In this region negative anomalies persisted through the remainder of the winter, into spring and through most of the summer. While temperatures rose above normal in September and October, they again fell below the long-term mean in November and December. Cold air masses also covered most of the area between the Gulf of St. Lawrence and the Gulf of Maine during 1992 although the strength of the anomalies were generally weaker than those further north. Only in May, August and September were temperatures in the southern regions of eastern Canada above normal.

The predominance of colder-than-normal air temperatures in 1992 is also clearly evident in the monthly anomalies at six coastal sites from Godthab in Greenland to Sable Island off Nova Scotia (Fig. 3). The location of the stations are shown in Fig. 2. The data from Godthab indicate that the spatial extent of the cold air mass extended throughout the Labrador Sea. Temperatures in 1992 were typically colder than in 1991 (Fig. 3).

The annual air temperature anomalies show colder-than-normal conditions over all of eastern Canada, in contrast to the warmer-than-normal temperatures in the west (Fig. 4). The coldest region extended from central Baffin Island to southern Labrador and included 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 -1°C. These generally exceeded 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. Iqualuit recorded the 2nd coldest year since the station opened in 1945 (-2.7°C) with only 1972 being colder. It was the 3rd coldest year in Cartwright since its beginnings in 1931 (-1.7°C) and the coldest in over 50 years in St. Johns (-1.2°C). Similarly, Godthab in Greenland recorded the 3rd coldest winter this century (-2.8°C) with only 1982 and 1983 being chiller.

The time series of temperatures (25-month running means) at the six sites in Fig. 2 are plotted in Fig. 5. The interannual variability since 1970 at Godthab, Iqualuit, Cartwright, and, to a lesser extent, St. John's have been dominated by large amplitude fluctuations with periods of 5-10 yr. 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 were of much lower amplitude and showed no signs of a downward trend since 1970, but did contain minima in the early 1970s and the mid-1980s although not in the 1990s.

Sea Surface Air Pressures

Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas* by Deutscher Wetterierst, 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 1992 relative to the 1951-80 means are shown in Fig. 6. Winter includes December 1991 to February 1992, spring is March to May and summer is June to August. Data for autumn (September to November) are not yet available.

In winter a negative anomaly was centered over Greenland and Baffin Bay (exceeding -8 mb) and stretched southward to the Scotian Shelf. This contrasted with a center of positive anomalies (maximum of 12.6 mb) over western Europe. Such a pressure pattern promotes strong cold northwesterly winds over the Labrador Sea and relatively warm southeasterly winds to the Norwegian Sea between Europe and Greenland. The negative anomaly is consistent with a westward shift in the position of the Icelandic Low. In spring the Icelandic Low deepened (upwards of -6 mb) while the Bermuda-Azores High strengthened (up to 5 mb). This would have increased the westerly winds, especially over the eastern North Atlantic and western Europe. The summer anomaly pressure pattern was dominated by a low (minimum of -4.5 mb) centered over the northeastern North Atlantic. It would cause anomalous northeasterly winds along eastern Greenland with the distinct possibility of enhancing the flow in the East Greenland Current and hence its component of the West Greenland Current. Also, anomalous easterly winds would have developed over much of eastern Canada. Onshore winds in summer may have contributed to the cold conditions observed in the region in July.

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 plotted in Fig. 7 were derived from the measured monthly mean sea level pressures at Ponta Delgada in the Azores minus those at Akureyri in Iceland. Missing data were filled from adjacent stations. The NAO anomalies were then calculated by subtracting the 1951-80 mean. In 1992 the NAO anomaly was strongly positive indicative of higher-than-normal westerly winds across the North Atlantic. 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 the cold periods in the Labrador Sea (Fig. 5).

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 mean for the winter (December 1991, January and February 1992) and the anomalies relative to the 1951-80 means are plotted in Fig. 8. Normally there is a low, known as the Arctic Vortex, centered over the Arctic Islands. In 1992, it had deepened with a trough extending over eastern Canada, a pattern similar to last year. This produced negative upper level air pressure anomalies over the Labrador Sea and eastern Canada and induced stronger-than-normal northerly and northwesterly flow over the region, consistent with the sea level pressure anomalies. Positive upper level air pressure anomalies were observed over the United States and western Europe. The 1992 wintertime pattern 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 Labrador Sea.

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 were published by Coté (1989). Colder-than-normal air temperatures during December of 1991 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 at month's end (Fig. 9a). Through January, the ice pushed further southward so that by the beginning of February the ice was near its maximum southern extent (Fig. 9a). By March the ice coverage was still more extensive than normal with the eastern edge near the long-term maximum position although the southern edge lay between the median and maximum. The southern edge retracted during March and by 1 April it was located further north along the Newfoundland coast than normal (Fig. 9b). Offshore, however, the ice edge exceeded its long term maximum. Through April to July the ice coverage was generally greater-than-normal laying intermediate between the long-term median and maximum.

The Ice Climatology and Applications Division of Environment Canada 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. 10). For each site, the extracted data included ice duration in weeks for the 1991/1992 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 typically left late (Fig. 11). An exception is the earlier-than-normal disappearance of ice off southeastern Newfoundland. New records for the latest date of the last appearance of ice were established offshore of northern Newfoundland (N64, N66 and N68). The late presence resulted in the duration of ice at sites N66 and N114 equaling their long-term maxima (Fig. 12). Except offshore of southern Labrador (N23), the ice duration exceeded the long-term mean by more than a week. Ice was not observed at sites N25, N27 or N70, however, it has never appeared at the latter two sites and only reached N25 in 2 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. 13. 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 June 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 1991/92 iceberg season (October to September), a total of 876 icebergs were spotted south of 48°N. The monthly totals for February to September were 69, 53, 99, 230, 103, 171, 132 and 19 (Fig. 14). No icebergs were spotted from October, 1991, to January, 1992. This differed slightly from previous years in the relatively large proportion of icebergs observed late in the season. In the primary iceberg season of March to August, 788 icebergs were observed which represents 90% of the annual total. The total number of icebergs in 1992 were similar to those recorded in 1990, 3 to 4 times those between 1986 and 1989 but only half those observed in 1991 (Fig. 14). Several factors would have contributed to the relatively high number of bergs in 1992. Anomalously cold air temperatures would have caused a slower rate of melting than normal. Also, the late persistence of sea ice especially in the offshore areas of Labrador and northern Newfoundland would have helped to preserve the icebergs through reduced wave action.

Gulf of St. Lawrence

During the second half of December, 1991, below normal temperatures over the northern Gulf with accompanying mean northwesterly winds caused ice to form along the north shore of Quebec, in the St. Lawrence Estuary and along the western Magdalen Shallows including northern Prince Edward Island and most of the Northumberland Strait. This resulted in above normal ice coverage by the end of December (Fig. 15). During the first half of January, above normal air temperatures (by approximately 2°C) resulted in little new ice forming so that by the 15th of the month ice conditions were near normal. A cold Arctic air mass over the region in the second half of the month caused a rapid spread of ice such that by 1 February the Gulf was covered and the ice edge extended southward to western Cape Breton. During February continued cold air and northwesterly winds pushed the ice further onto the Scotian Shelf. The Gulf remained ice covered in March due to cold temperatures. On 1 April the ice edge extended further south and west reaching near 45°N and 61°W. At this time it was much closer to the maximum extent than the median. In May ice still covered the southern Magdalen Shallows, surrounded Cape Breton Island, and was located off western Newfoundland including the Strait of Belle Isle. This was again more extensive than normal. Early in May, light southwesterly winds caused air temperatures to rise above normal and hastened the ice retreat. By mid-May some ice still lay between Cape Breton Island, Prince Edward Island and Iles de la Madeleine and in the northeastern Gulf but by the end of the month all regions of the Gulf except Belle Isle Strait was generally clear of ice (Fig. 9b).

The first presence of ice was early along the northern shore of Quebec but late offshore of Cabot Strait (Fig. 11). Except north of Anticosti Island, the ice retreated later than normal with new records set for the presence of last ice on the Magdalen Shallows (sites G22, G31, G33). The ice duration (Fig. 12) was again longer than normal and equaled the maximum on the northwestern Magdalen Shallows (G22) and off the eastern tip of Cape Breton (G87).

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 53 times in 1992, with a monthly maximum of 11 in May and a minimum of 1 in January, March and August. 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 1992 together with their anomalies relative to 1951-80 are shown in Fig. 16.

Monthly mean surface temperatures at Station 27 were all below normal in 1992 with anomalies ranging from near zero in May and June to near -2°C in July and October (Fig. 16, 17). Throughout the water column temperature anomalies were generally below normal. Exceptions were the upper layer waters (10-50 m depth) during the spring and early summer, with a peak value of 1.7°C at 30 m in July, and from 50-125 m in December when temperatures were just above normal. During September and October anomalies exceeded -1°C throughout most of the top 75 m with a minimum in excess of -3°C at 50 m in September. Near bottom (175 m) temperature anomalies ranged between -0.2°C and -0.8°C (Fig. 17).

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, the water temperatures at Station 27 for the period 1987-92 were predicted (Drinkwater et al., 1992). The predicted and observed values were all below normal for the entire period (Fig. 18). There was poor agreement for 1987 but reasonable correspondence after that.

Surface salinities at Station 27 were fresher than the long-term mean by as much as 1 psu in February (Figs. 16, 17). This continued the below normal salinities observed in late 1991. From March to June surface salinities increased to slightly above normal but fell below normal during the remainder of the year. In the subsurface waters salinities were typically fresher than the long-term mean in 1992 with the largest negative anomalies occurring in the waters above 50 m at the beginning of the year and during the summer. Saltier conditions than normal occurred in the upper layer waters in spring and through much of the water column in autumn. The salinity-cod relationship first noted by Sutcliffe et al. (1983) and updated by Myers et al. (1993) suggests that cod recruitment in 1992 would be low based on the below normal salinities in the upper 50 m during the summer.

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970 to 1992 are displayed as bar graphs in Fig. 19. Note that the temperature anomaly scale for 0 and 50 m is larger than for 100 m and deeper. At the surface, 1992 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. As well 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 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 each year during the summer by the Northwest Atlantic Fisheries Center in St. John's, Newfoundland. The areal extent of the CIL, defined by waters <0°C, along each transect and the average of all of the transects are plotted in Fig. 20. The data are expressed as a ratio relative to the means over the period 1978-92. 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 1992 the CIL was slightly above normal having decreased from the peak values in 1990 or 1991. The area of the CIL along the four transects show a maximum around 1984-85, a minimum in 1986-87, and the peak in 1990-91 (Fig. 20). The CIL maxima correspond roughly with minima in the water and air temperatures and maxima in ice coverage as had also been noted by Petrie et al. (1992).

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 1991 and 1992 are shown in Fig. 21. The St. Andrews temperatures have in recent years been measured using continually recording thermographs. Problems with the instrument used during the first 7 months of 1992 resulted in poor quality data. For this period, I have calculated the means using temperatures from a thermistor located on the wharf at the Biological Station that were recorded 6 times daily. These data were further adjusted based on the comparison between the thermograph and the thermistor during the last 5 months of the year.

During 1992 the coastal SST anomalies at the three sites were predominantly negative with temperatures never reaching above normal at either St. Andrews or Halifax (Fig. 21). Temperatures at Boothbay were warmer than the long-term mean during 4 out of the first 6 months of the year but were below normal for the last half of the year. October and November were much colder-than-normal in the Gulf of Maine (an anomaly of approximately -1°C) while at Halifax anomalies exceeding -1°C occurred in February through April and again in August and September.

Annual SST mean temperatures for 1992 were 8.8°C (equaling the long-term mean) at Boothbay Harbor, 6.8°C (0.5°C below normal) at St. Andrews, and 7.0°C (0.8°C below normal) at Halifax. The long-term trends as shown in Fig. 22 reveal that the temperatures at all three sites have decreased over last year. This reverses the recent trend of increasing temperatures observed over the past couple of years at Boothbay Harbor and St. Andrews. At the latter site, SSTs have been 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 nineties 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.

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 1992. 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 1992, temperatures ranged from a minimum of less than 2°C in February and March to a maximum of just over 10°C in the near surface waters in August and September (Fig. 23). The temperature anomalies throughout the year were negative, except at the surface in January. Anomalies exceeded -1°C in May and during the summer and -2°C in the near surface waters in July and deeper in the water column in August. The long-term temperature records at surface and 90 m for Prince 5 show high similarity (Fig. 24). The annual anomalies in 1992 were -0.7°C at both the surface and bottom (90 m), a decrease from last year's means. The dominant high and low at both depths were in the early 1950s and the mid 1960s, respectively, with recent values near the long-term mean (Fig. 24), however, there has been a gradual decrease since the late 1970s at 90 m and the mid-1980s at the surface.

Salinities at Prince 5 during 1992 were fresher-than-normal throughout the water column except in the very surface waters in April and May (Fig. 23). The lowest salinities (<31.5 psu) occurred during the late spring and summer months. Anomalous salinities of -1 psu were observed in the surface in August and -0.5 psu in the upper 50 m in July and August and between 25 and 50 m in May. It appears that the low salinities that normally occur in the spring penetrated deeper in the water column in 1992 and persisted longer than normal. The long-term salinity record (not plotted) shows high-frequency variability with no low-frequency pattern.

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 (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 1992 six CTD profiles or BATFISH traces were obtained in Emerald Basin from research cruises. The time series of temperatures from 250 m are plotted in Fig. 25 as anomalies from the monthly means averaged over the period 1951-80. The long-term annual average is 8.1°C and the monthly means range from 7.1°C to 9.2°C. In 1992 temperatures rose to approximately 9.3°C resulting in anomalies of 1°-2°C above normal. These anomalies were representative of conditions below 75 m. The rise in temperature is 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. In the upper layers (0-50 m), temperatures were below normal during 4 of the 5 months in 1992 when measurements were taken. These near-surface negative anomalies are consistent with the coastal SST measurements at Halifax and St. Andrews and the temperatures throughout the water column (0-90 m) at Prince 5.

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. 26). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.2°C). This rapid increase is consistent with the temperature pattern in the deep waters in Emerald Basin and most likely 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 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 weekly by the U.S. Naval Oceanographic Office (experimental ocean frontal analysis (EOFA) charts; 1973-May 1980) and tri-weekly by NOAA through the National Weather Service and the National Environmental Satellite Service (the Oceanographic Analysis (OA) charts; May 1980 to present). From January 1973 until May 1978, the EOFA 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. Since the front is convoluted and may cross any degree of longitude several times the northern most position was used. The years 1973 to 1990 were used to determine the long-term monthly means. These were subtracted from the yearly values to obtain anomalies. The monthly anomalies were then averaged to obtain an annual average.

The overall average position of the shelf/slope front together with the minimum and maximum monthly mean values are shown in Fig. 27. The mean position lies close to the 200 m isobath along the mid-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. In 1992 the shelf/slope front between 75°W (Cape

Hatteras) and 65°W (eastern Georges Bank) lay near its long-term average (Fig. 28). However, from 65°W to 55°W the 1992 average position increased gradually to a peak of 0.6 degrees latitude (ca 67 km) north of the mean. The anomalous positions east of 55°W decreased rapidly and were south of the long-term mean off the Tail of the Grand Banks. The latter continue the trend of southerly anomalies begun just prior to or during 1990 (Fig. 29). West of 55°W anomalies have generally been north of, or near to, the long-term mean during the past several years.

Gulf Stream Front

Time series of the position of the northern boundary or "wall" of the Gulf Stream were also determined from satellite imagery (the EOFA and OA charts). Similar to the shelf/slope front, the series consists of the monthly position at each degree of longitude from 75°W to 50°W. In the case of multiple crossings the mean rather than the northern most position was used. Anomaly patterns using the northern or southern most positions show like variability to the mean. The average position of the north wall of the Stream is shown in Fig. 30. 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 1992 the Gulf Stream was positioned north of its mean location by an average of approximately 0.3-0.4 degrees latitude (ca 35-45 km; Fig. 31). This could be caused by geostrophic adjustment to a weaker Gulf Stream flow. The long-term anomalies of the position of the Stream at each 5° of longitude between 75°W and 50°W show that the Gulf Stream has been north of its mean position during the last three to four years (Fig. 32). There is high variability at each degree of longitude with differences between longitudes although a pattern of a southward position during the late 1970s, near normal through most of the 1980s and northward in the late 1980s and into the 1990s has been observed at most longitudes.

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 can interact with the waters on the shelves through entrainment off the shelf into the slope water if the rings are close enough to the shelf break. The life history of these warm-core Gulf Stream rings in the region from 45°W to 75°W during 1992 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 25 warm-core rings were present in the area during some portion of 1992, five of which survived from 1991 into the new year. Three of the 20 new rings which formed in 1992 persisted into 1993. Only 4 of the rings formed in 1992 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1992, ranged in age from 8 d to almost 10.5 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 displayed in Fig. 33. Only 1 ring formed west of 65°W and a maximum of 4 were generated in the 62.5-65°W. The number of rings present in each of the longitude zones varied from 1 to 6 with the highest number in the adjacent zones between 62.5 to 67.5°W. The distribution of rings present in the zones, given the areas of formation, reflect westward propagation. The maximum number of rings (3) formed in July, none formed in February or November, one formed in October and two rings formed in each of the remaining months.

SUMMARY

As in recent years, 1992 saw severe cold conditions over southern Labrador and northern Newfoundland. A strong negative air pressure anomaly was observed during the winter above the Labrador Sea in both the sea level and upper atmospheric data that lead to strong northwesterly winds. These winds carried cold Arctic air southward resulting in air temperature anomalies at several sites around the Labrador Sea reaching near record lows. The 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. Ice, in general, stayed much later than normal leading to a longer-than-average ice duration. Cold ocean temperatures were observed at Station 27 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. Bottom temperatures did, however, rise gradually through the year. The areal extent of the CIL was slightly above normal having decreased from a maxima in 1990 and 1991. On the Scotian Shelf and in the Gulf of Maine sea temperatures in the surface at coastal stations, throughout the water column at Prince 5, and in the upper 50 m in Emerald Basin were below normal in 1992. In contrast temperatures in the deep waters of Emerald Basin and in Cabot Strait were above normal showing a rapid rise from the very low values observed last year. These are believed to have resulted from intrusions of warm offshore slope waters into the deep basins and channels on the shelf. The shelf/slope and Gulf Stream fronts between Cape Hatteras and the Tail of Bank typically lay north of their mean positions.

OUTLOOK FOR 1993

The cold air temperatures in the Labrador Sea area during the last several years appear to be continuing in 1993 based on measured temperatures in January and February. 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 and on the Scotian Shelf air temperatures in the first two months of 1993 have also been below normal and some of the coldest for these months in recent years. This has produced a heavy ice year in the Gulf with accumulations extending as far south as Halifax on the Scotian Shelf, much further than normal. In addition, greater amounts of local ice have formed along the bays and inlets of the Atlantic coast of Nova Scotia.

On the basis of a cold winter in 1993 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 1993 being a cold year.

ACKNOWLEDGEMENTS

I wish to thank the many individuals who provided data or helped in the preparation of this paper, including A. Stroud and D.R. McLain of the U.S. National Marine Fisheries Service for the monthly mean offshore sea-surface temperature data; D. Smith of the Bigelow Laboratory for providing Boothbay Harbor temperature data; F. Page and R. Losier of the the Biological Station, St. Andrews, for providing St. Andrews and Prince 5 data; S. Narayanan of the Northwest Atlantic Fisheries Centre, St. John's, for the station 27 data and the transect data from which the CIL data were determined; B. Petrie of the Bedford Institute for the CIL data; P. Coté of the Ice Centre of Environment Canada in Ottawa for the data on the duration and presence of first and last ice; G. Bugden for the Cabot Strait temperature data; D. Lawrence for the Emerald Basin temperature data; and the U.S. Coast Guard for the iceberg data. A special thanks is due L. Petrie and R. Pettipas for technical assistance in the preparation of the manuscript. Digitization of the shelf/slope and Gulf Stream fronts was paid for through the Scotian Shelf Atlantic Fisheries Adjustment Program (AFAP-BIO) and the Northern Cod Science Program (Newfoundland Region).

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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 1991/92 (October-September) ice year with 1990/91 data in parentheses.

				Ice Duration (weeks)				
Site	Seasons studied	# of Yr	Yrs with ice	When ice present Min	Max	Mean	Over-all Mean	1991-92 (1990-91)
G-7	67/68-91/92	25	25	6	16	10.5	10.5	12 (9)
G-10	76/77-91/92	16	16	3	17	11.6	11.6	14 (15)
G-12	67/68-91/92	25	25	2	15	11.6	11.6	14 (12)
G-22	76/77-91/92	16	16	7	14	11.9	11.9	14 (12)
G-31	68/69-91/92	24	23	8	17	12.0	12.5	15 (14)
G-33	71/72-91/92	21	21	2	14	10.5	10.5	13 (14)
G-35	59/60-91/92	33	17	1	11	3.5	1.8	2 (1)
G-86	76/77-91/92	16	16	6	23	16.2	16.2	20 (20)
G-87	70/71-91/92	22	21	1	12	7.5	7.1	12 (9)
N-19	66/67-91/92	26	26	17	32	23.8	23.8	24 (32)
N-21	67/68-91/92	25	25	5	28	18.2	18.2	24 (18)
N-23	59/60-91/92	33	27	1	17	5.0	4.1	3 (6)
N-25	59/60-91/92	33	2	1	1	1.0	0.1	0 (0)
N-27	59/60-91/92	33	0	0	0	0.0	0.0	0 (0)
N-62	67/68-91/92	25	25	8	27	18.6	18.6	25 (27)
N-64	59/60-91/92	33	32	3	25	12.8	12.4	24 (22)
N-66	59/60-91/92	33	27	1	16	8.1	6.6	16 (10)
N-68	59/60-91/92	33	14	1	10	2.9	1.5	4 (3)
N-70	60/61-91/92	32	0	0	0	0.0	0.0	0 (0)
N-108	59/60-91/92	33	27	1	17	5.9	4.8	6 (12)
N-110	59/60-91/92	33	26	1	12	5.0	3.9	7 (10)
N-112	59/60-91/92	33	13	1	10	3.8	1.5	4 (3)
N-114	59/60-91/92	33	4	1	2	1.5	0.2	2 (0)
N-228	59/60-91/92	33	22	1	14	5.5	3.6	7 (11)

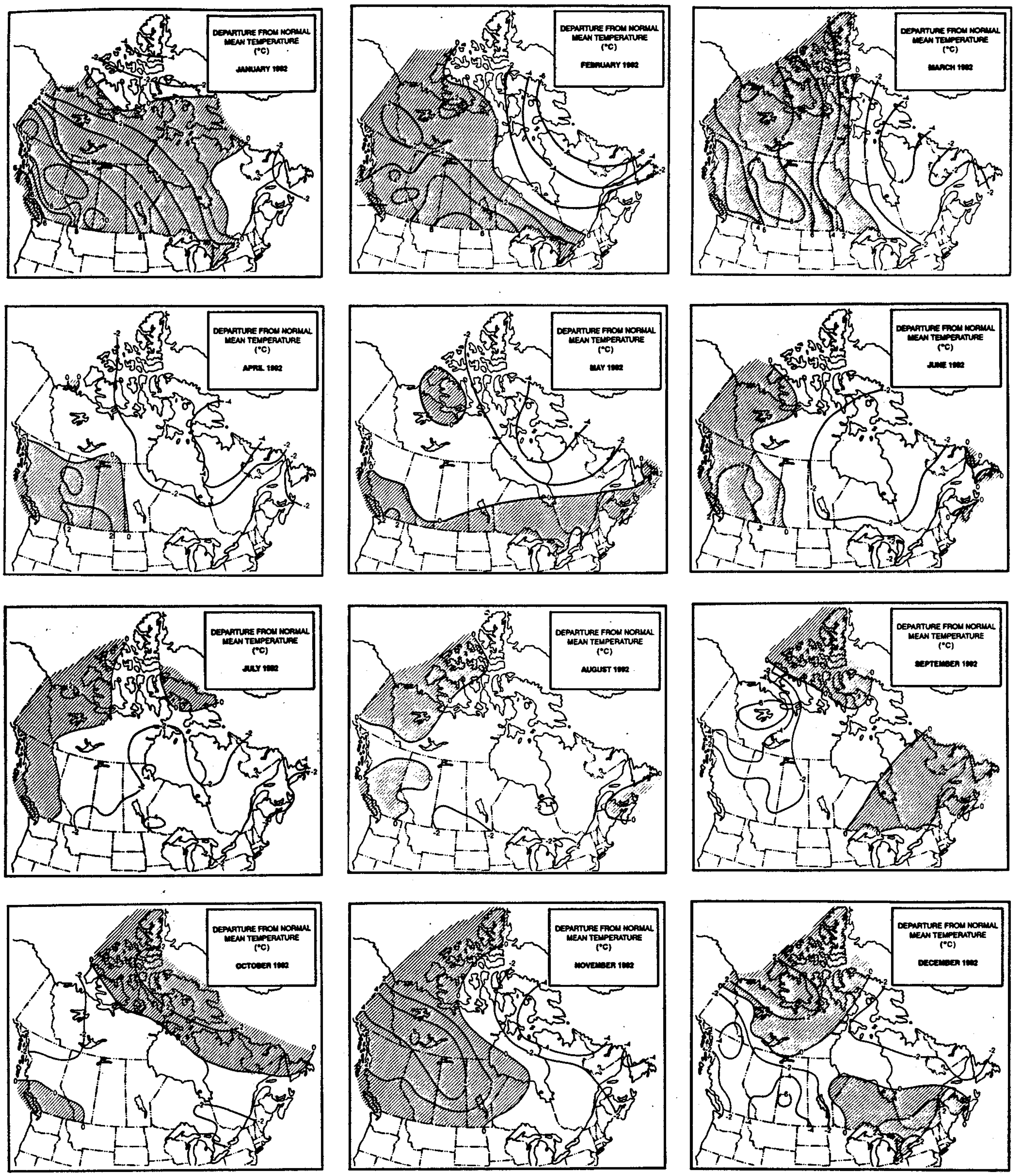


Fig. 1. Monthly air temperature anomalies (°C) over Canada in 1992 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 14)

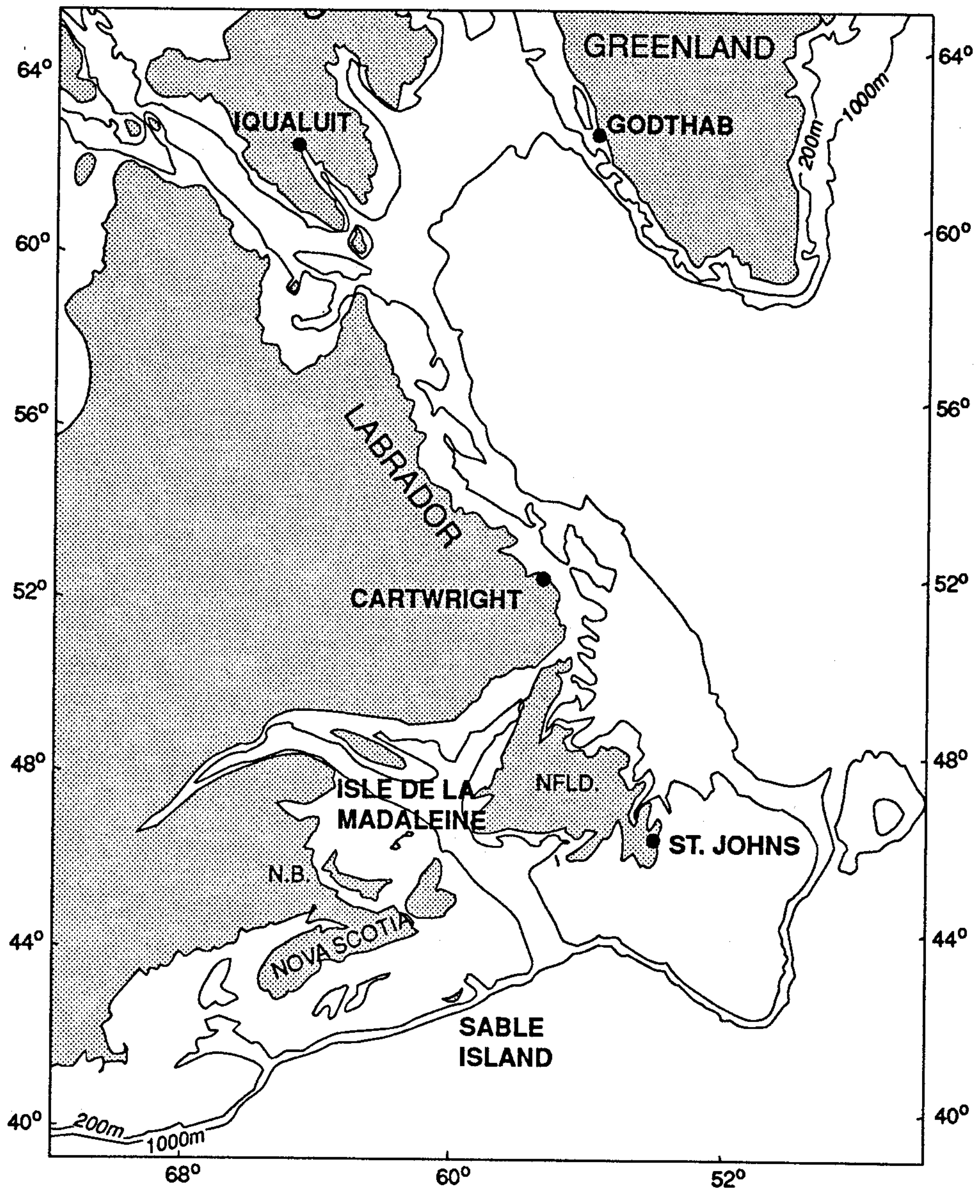


Fig. 2. Map showing coastal air temperature stations.

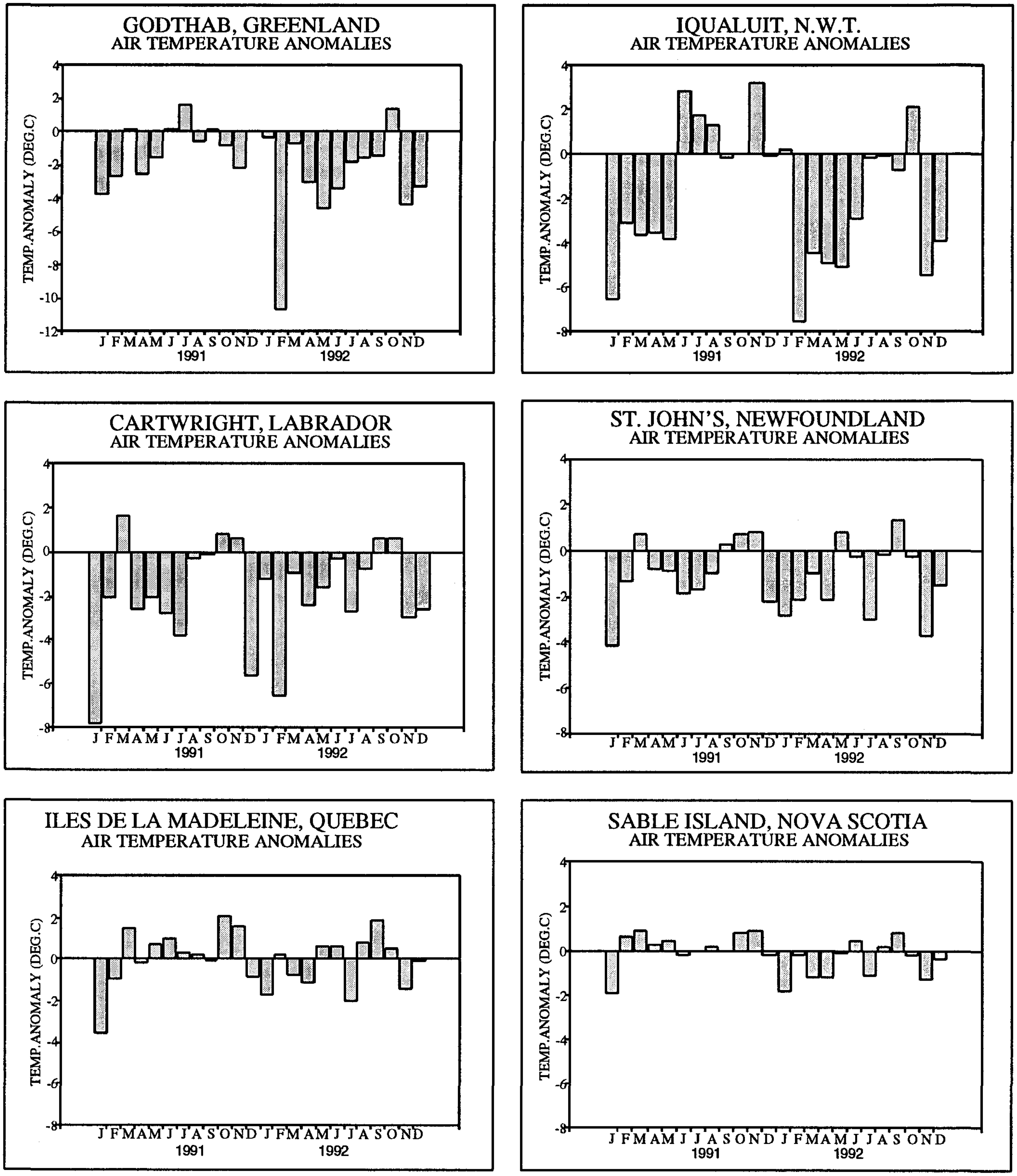


Fig. 3. Monthly air temperature anomalies at selected sites in 1991 and 1992.

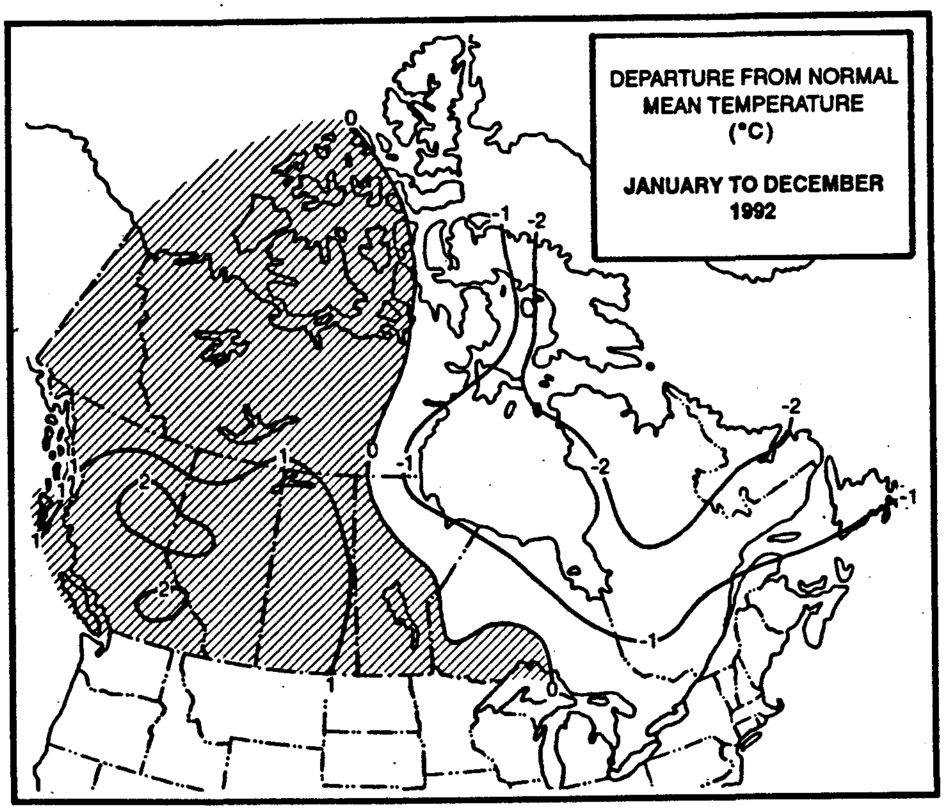


Fig. 4. Annual air temperature anomalies (°C) over Canada in 1992 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 15)

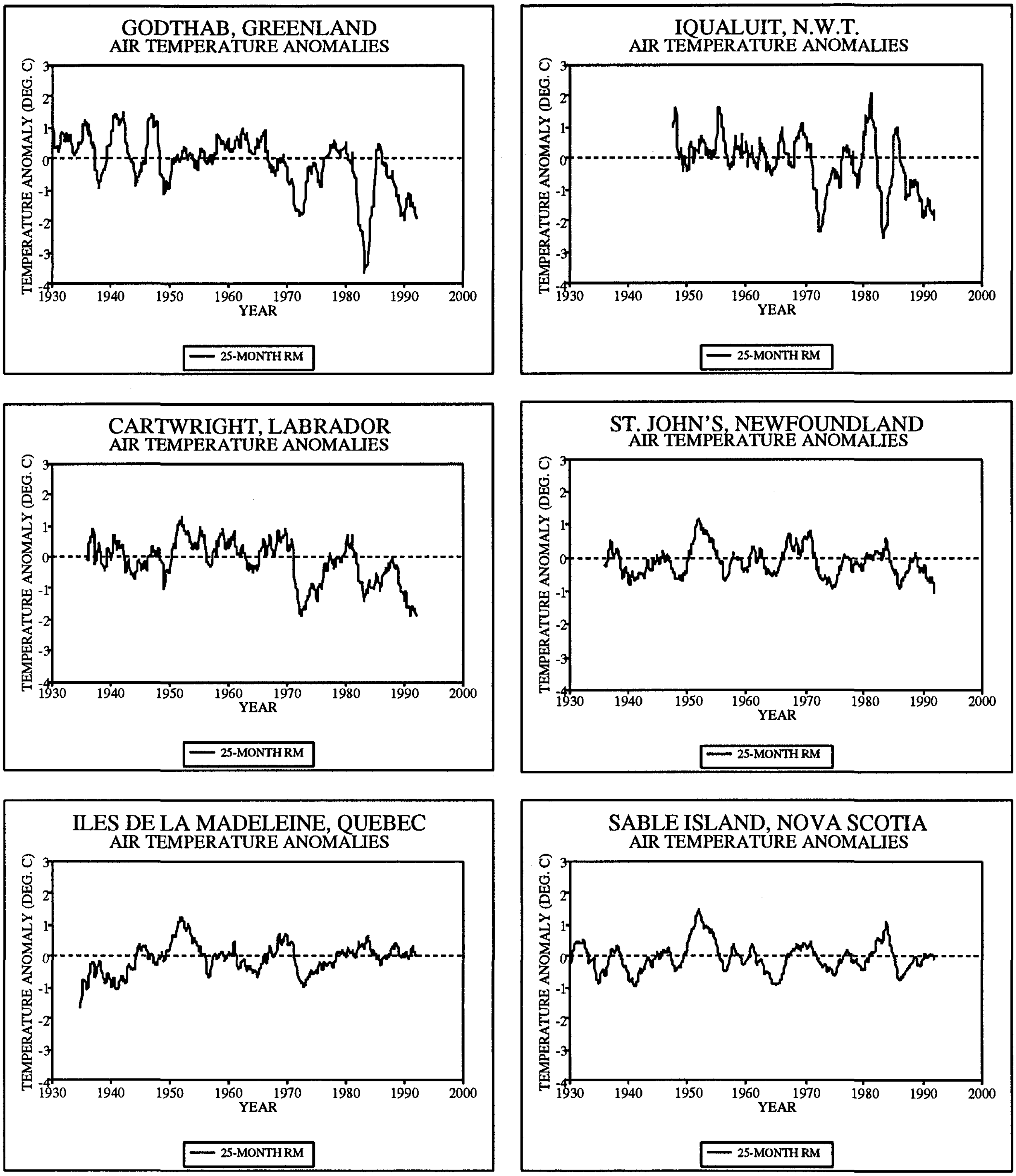


Fig. 5. Twenty-five month running means of monthly air temperature anomalies at selected sites.

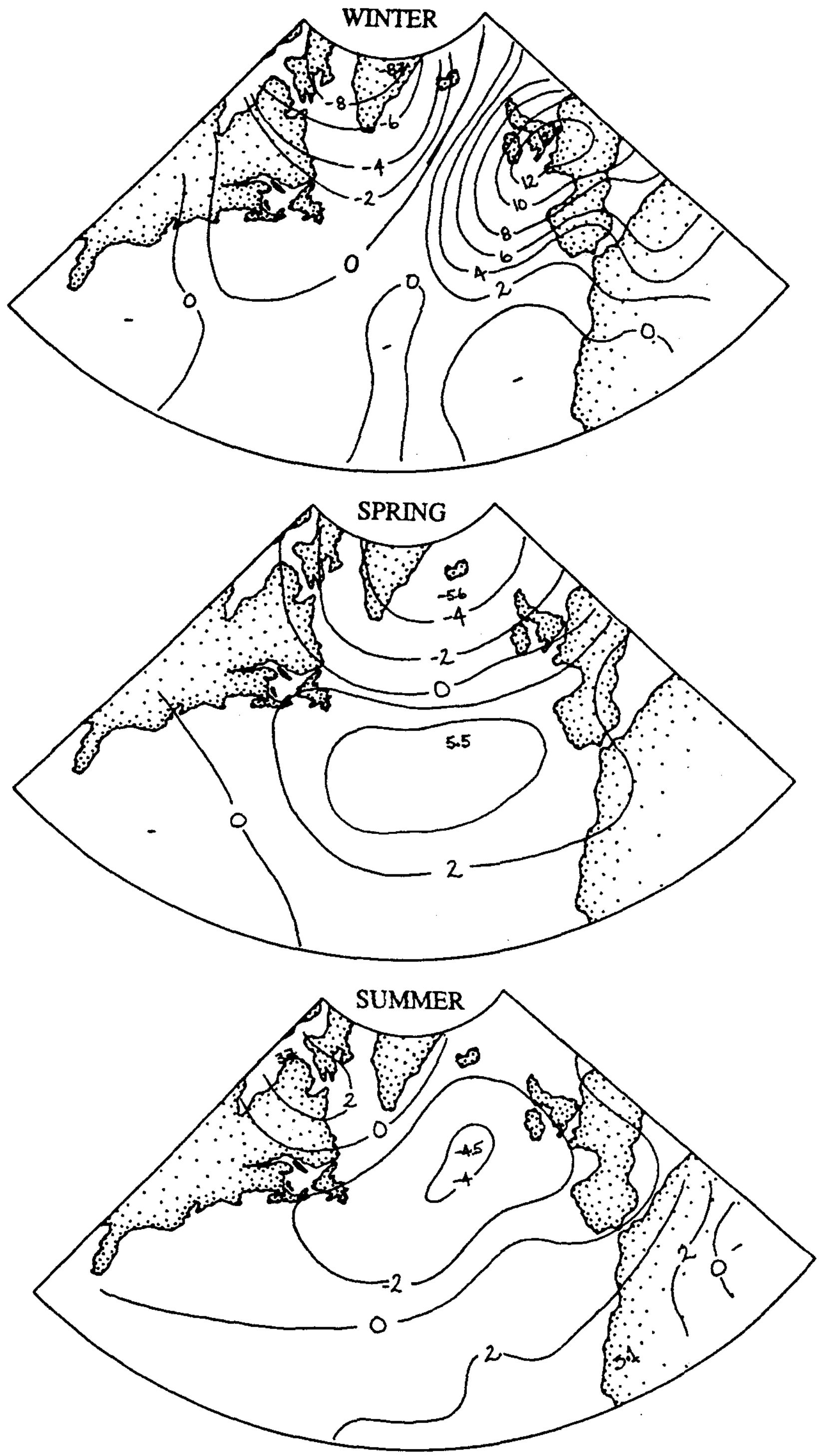


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1992 relative to the 1951-80 means.

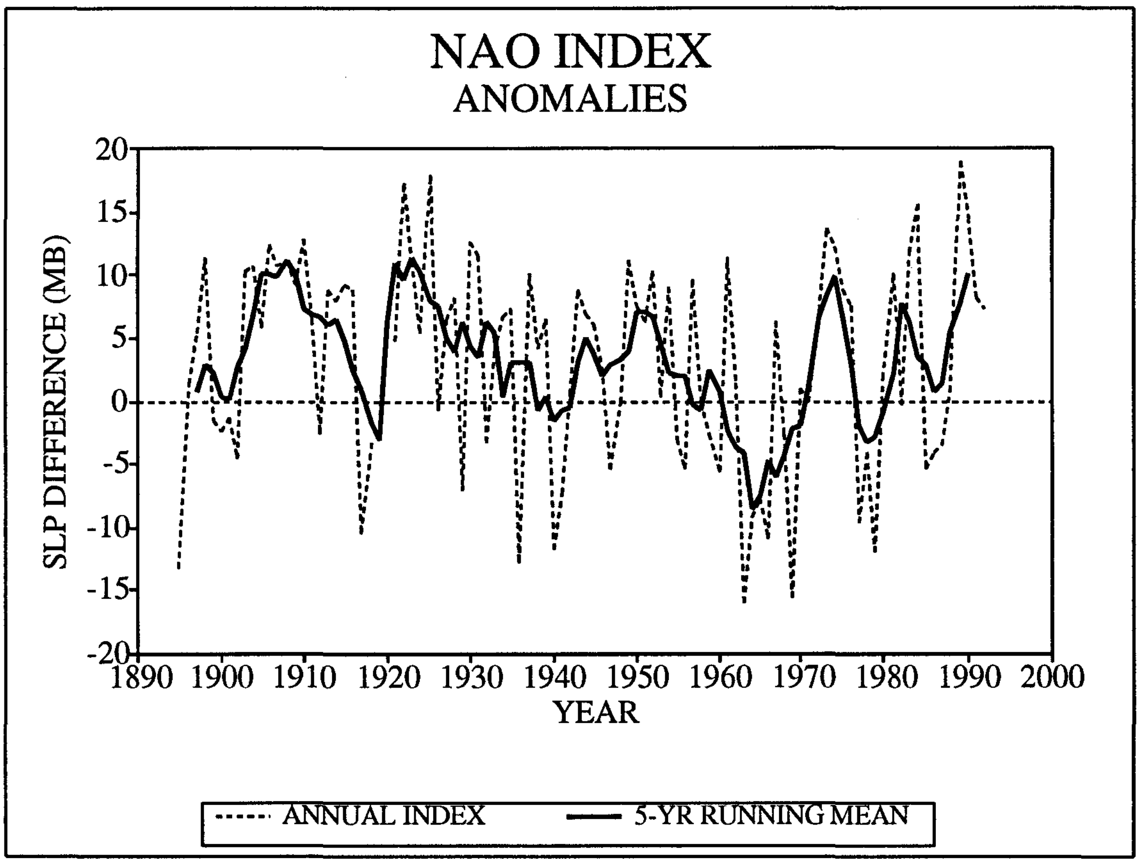


Fig. 7. The North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland.

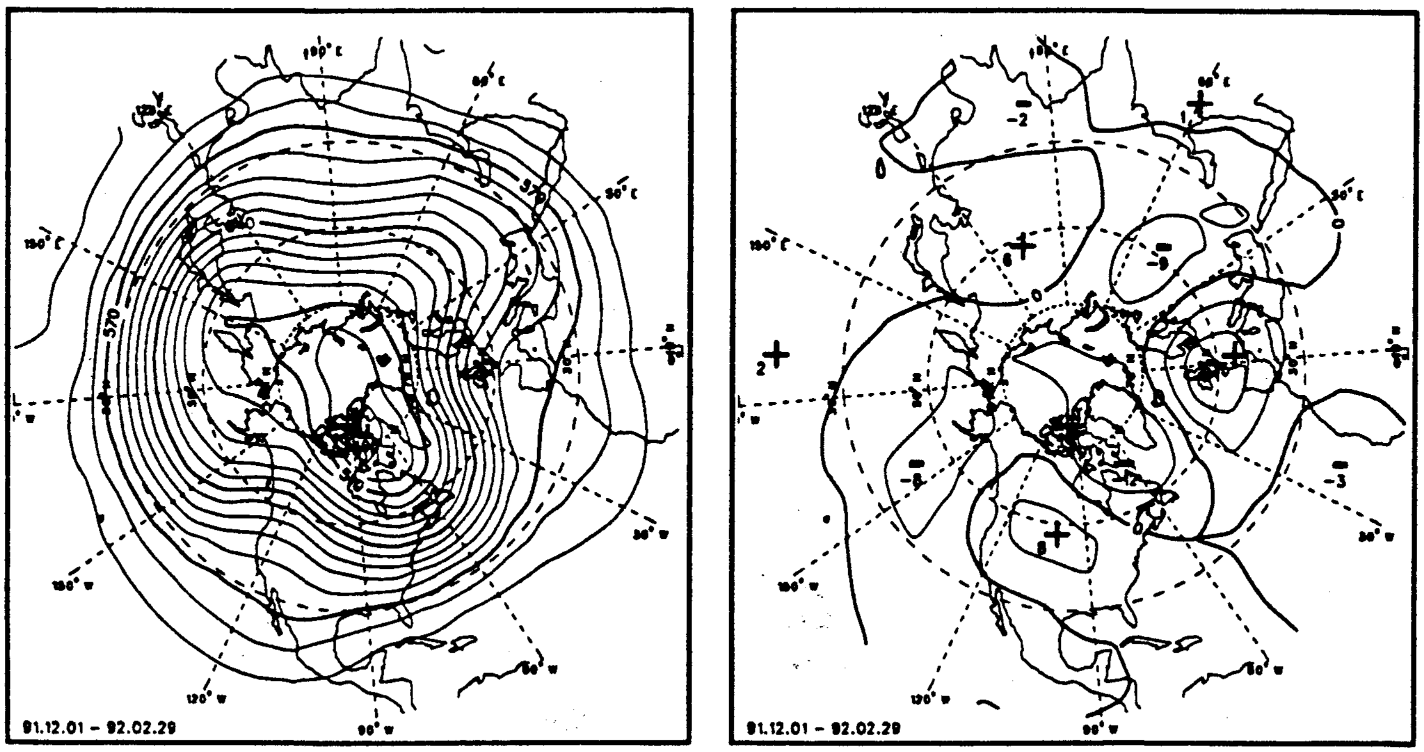


Fig. 8. The mean (left) and the anomaly (right) of the height in decametres of the 50 kPa atmospheric pressure field during the winter (December 1991, January and February 1992) (From *Climatic Perspectives*, Vol. 14)

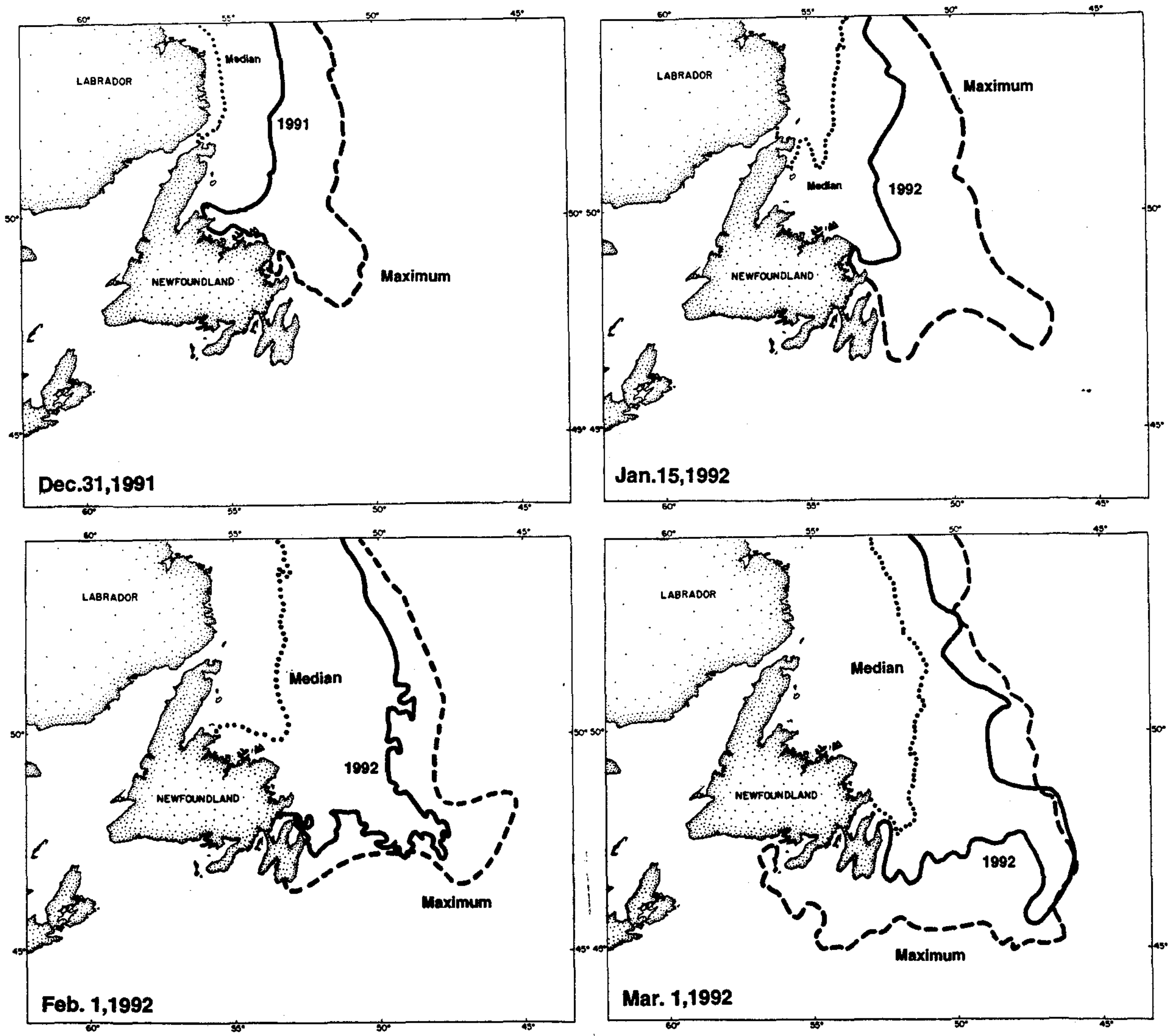


Fig. 9a. The location of the ice edge (concentrations >10%) off Newfoundland and Labrador between December 1991 and March 1992. The historical (1962-1987) median and maximum positions are also shown.

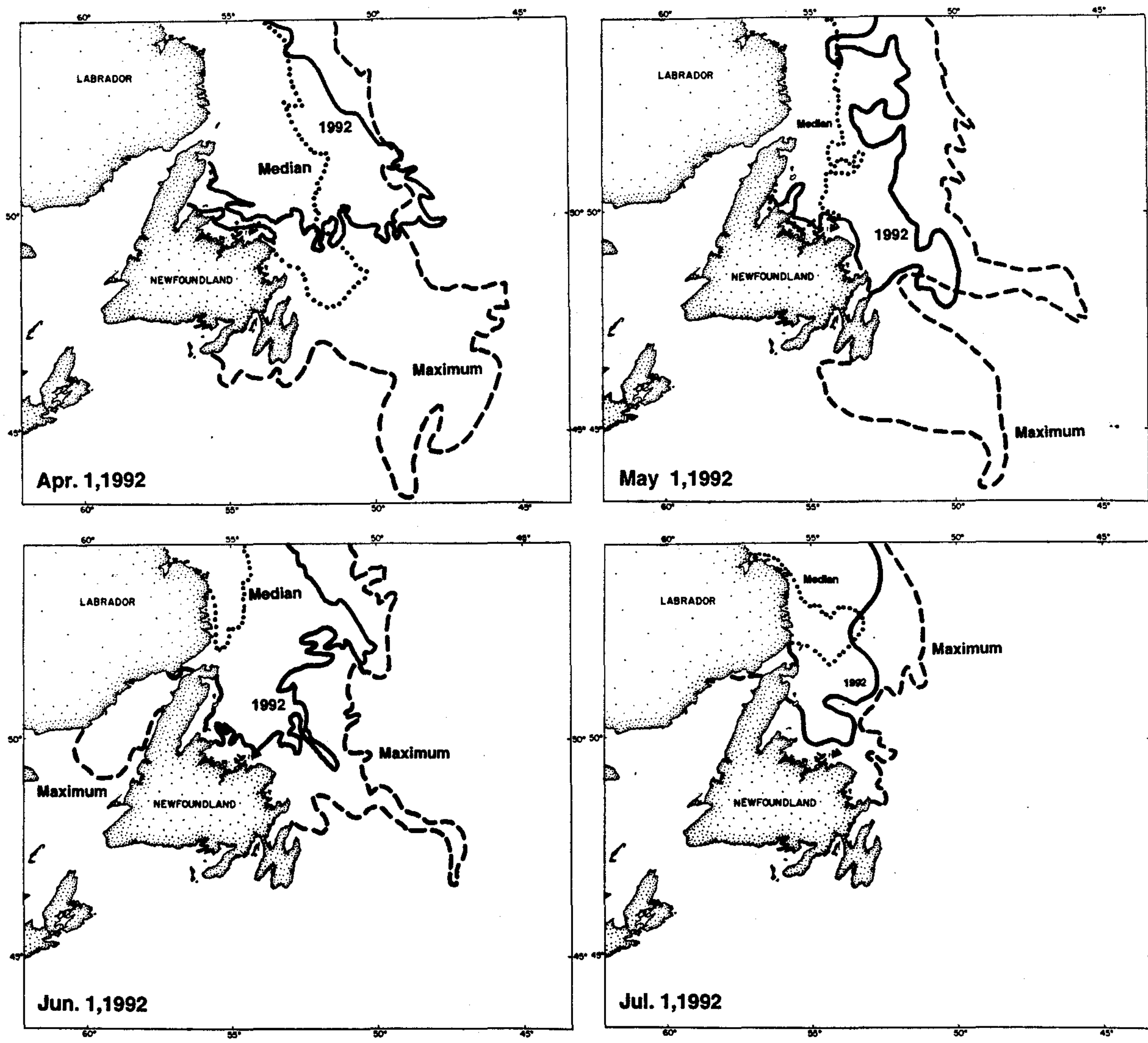


Fig. 9b. The location of the ice edge (concentrations >10%) off Newfoundland and Labrador between December 1991 and March 1992. The historical (1962-1987) median and maximum positions are also shown.

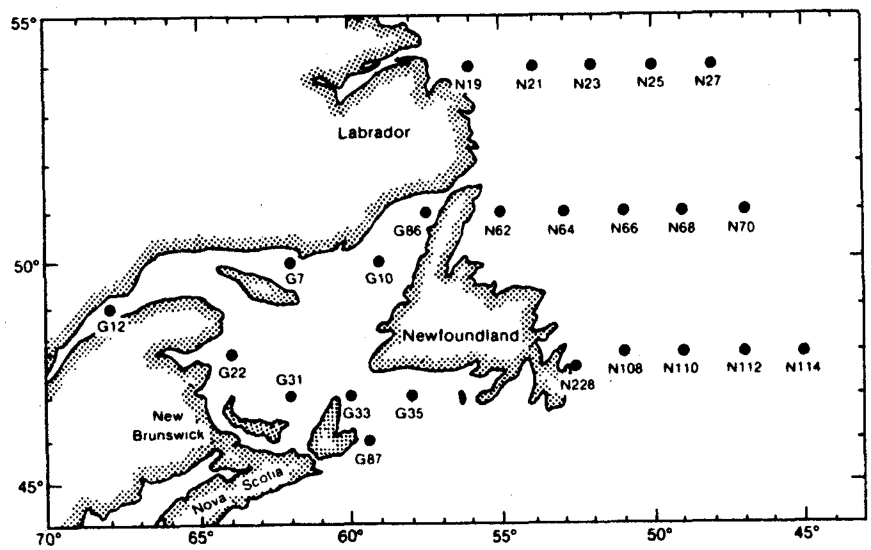
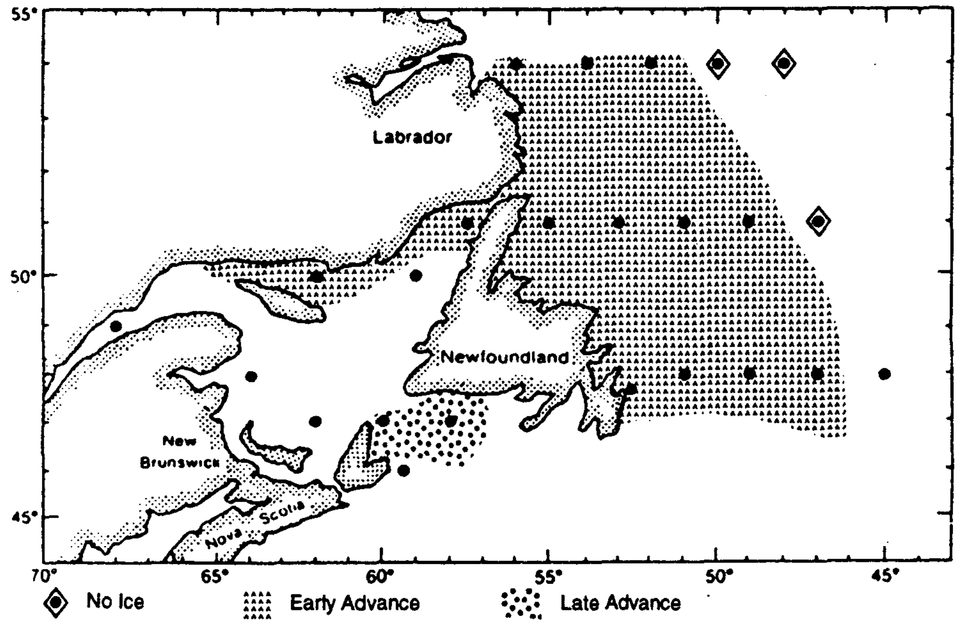


Fig. 10. Location of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

Presence of First Ice 1991/92



Presence of Last Ice 1991/92

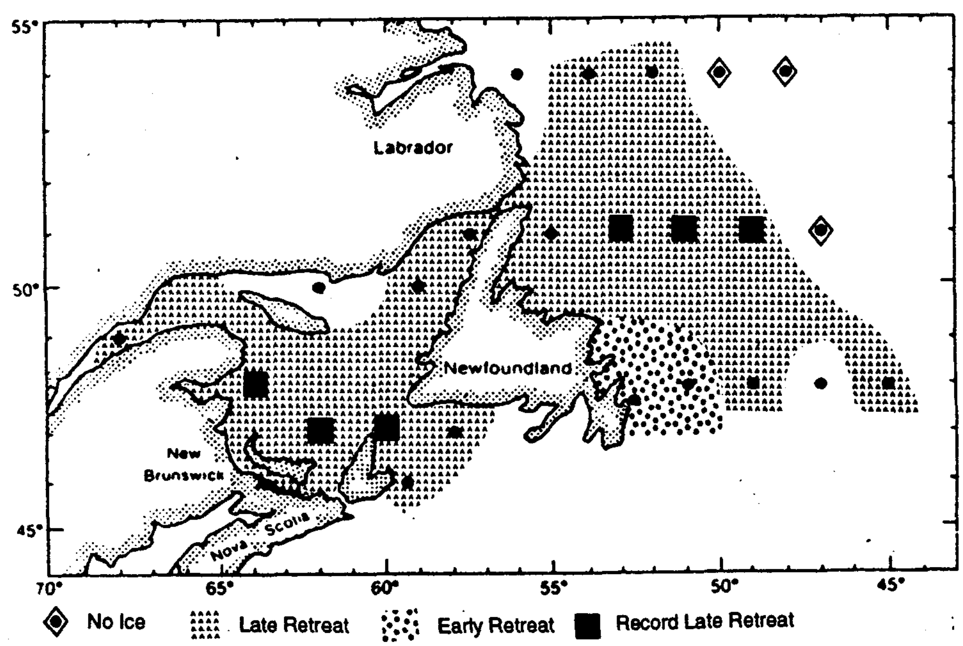


Fig. 11. The date of the presence of first (top) and last (bottom) ice relative to the long-term mean. Circles not surrounded by shading indicate sites where the ice advance was within 1 week of their mean dates. Early or late advance or retreat refers to differences exceeding 1 week. Sites marked as no ice means that ice was not present anytime through the ice season.

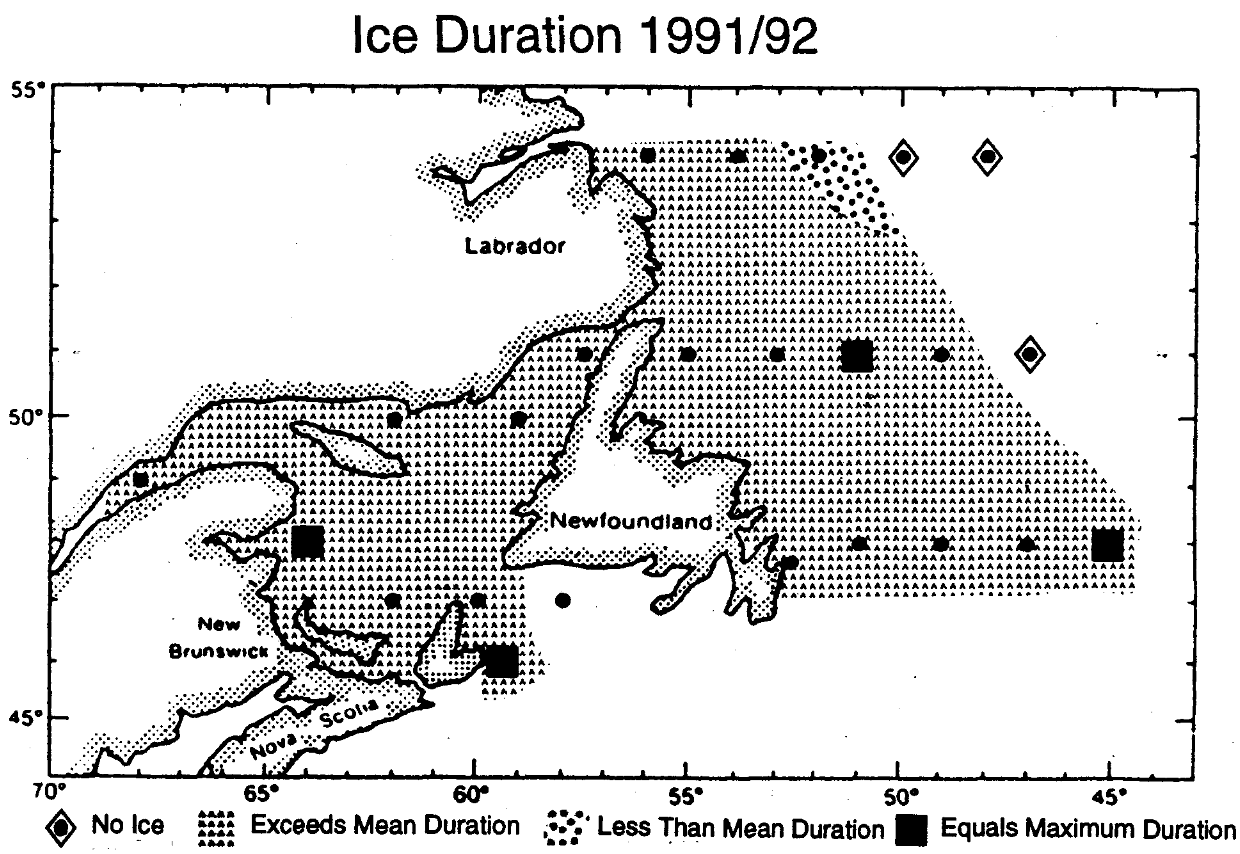


Fig. 12. The duration of ice relative to the long-term mean. Circles not surrounded by shading indicate sites where the duration was within 1 week of the mean. Shading indicates a duration longer or less than the mean by greater than 1 week.

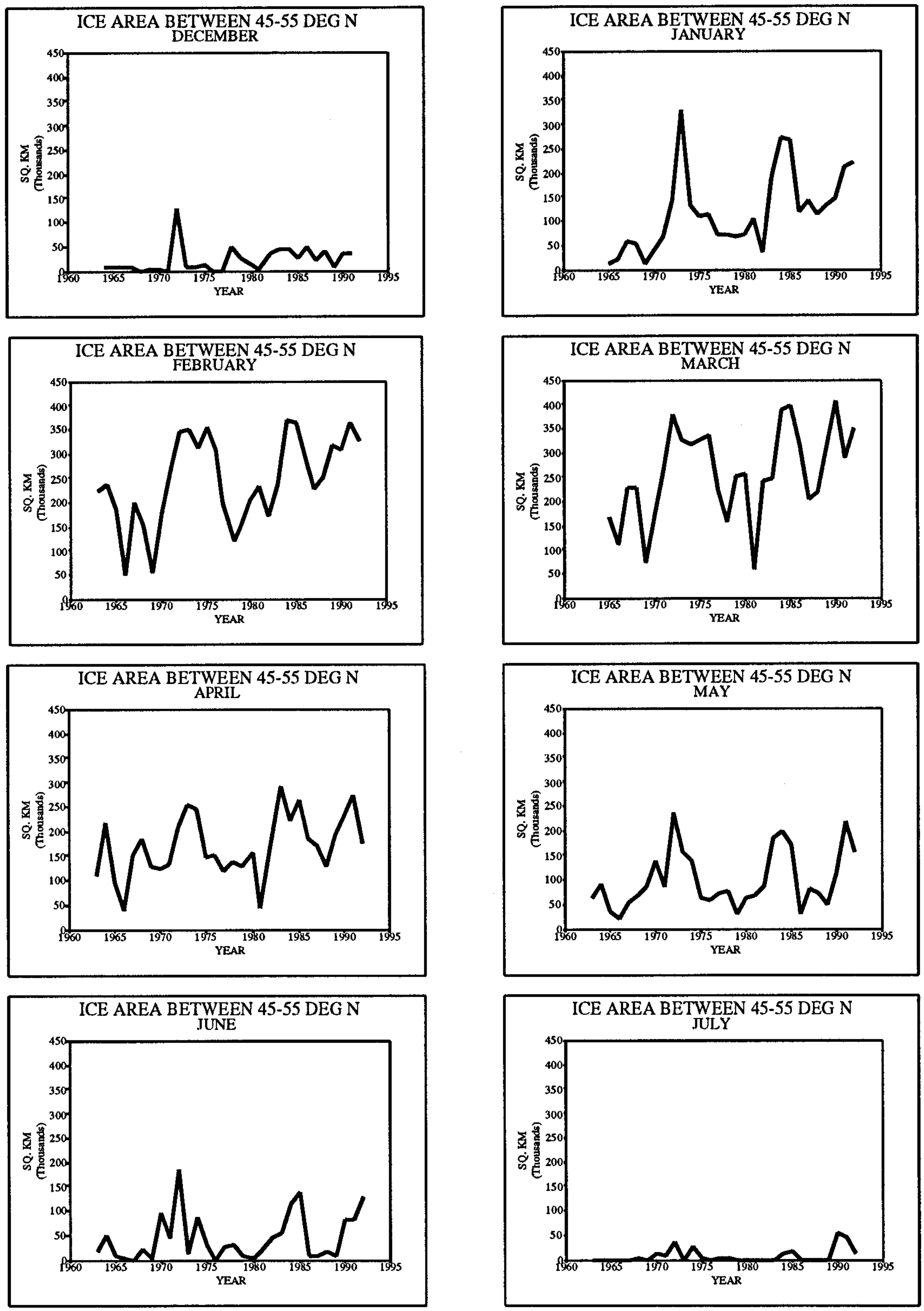
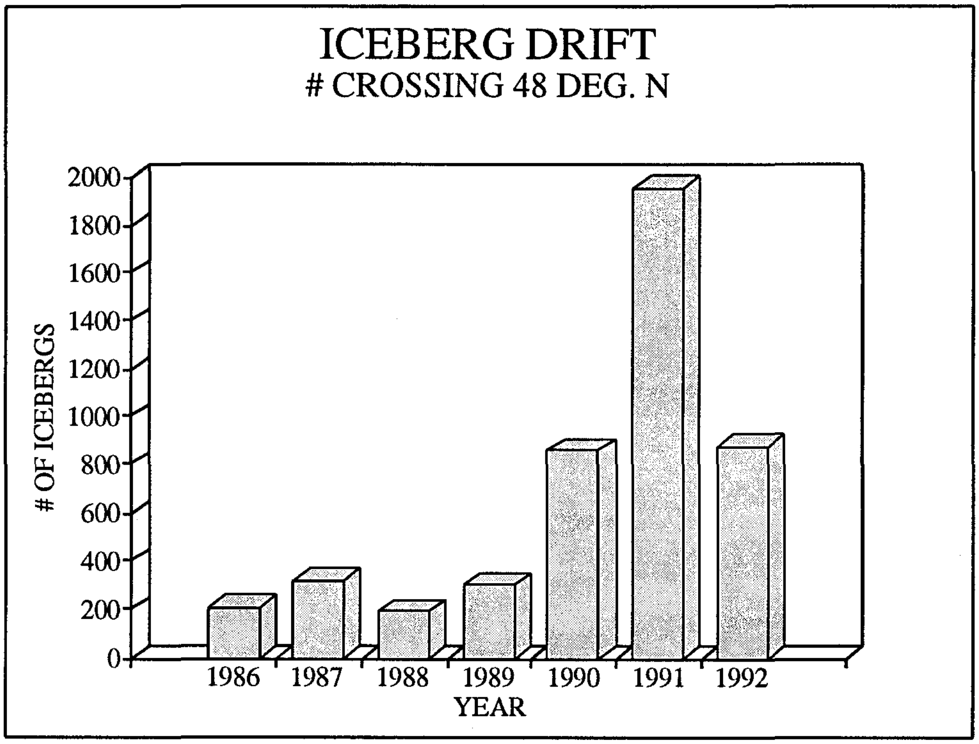


Fig. 13. The time series of ice area on the southern Labrador and northern Newfoundland shelves between 45°N-55°N by month.



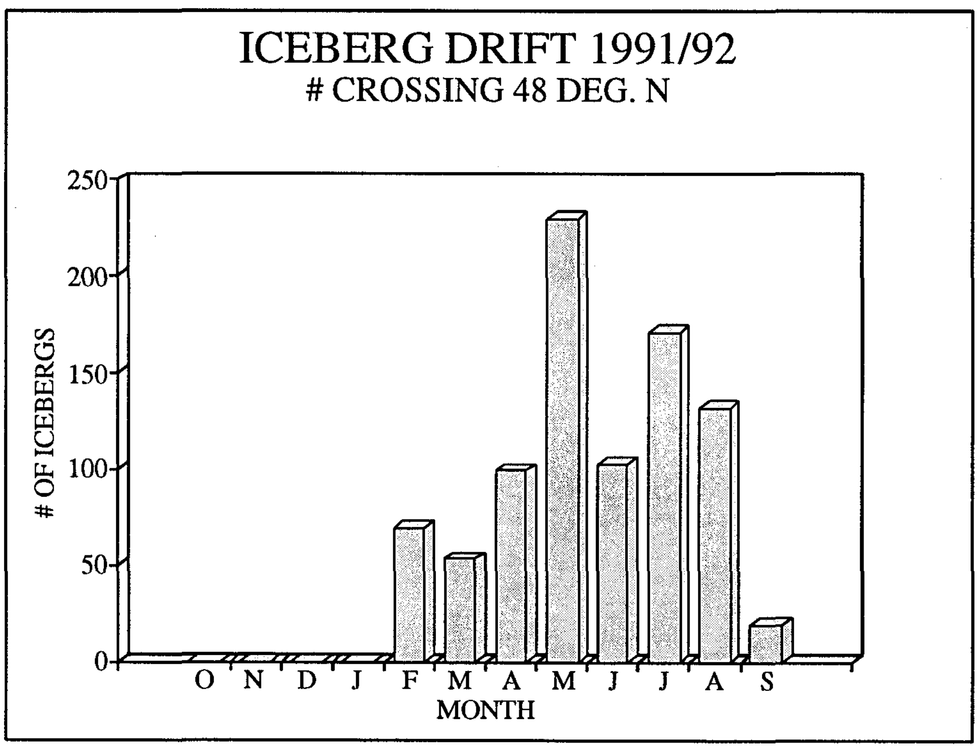


Fig. 14. The total number of icebergs in 1986-92 (top) and the monthly numbers of icebergs crossing south of 48°N during the iceberg season 1991/92 (bottom).

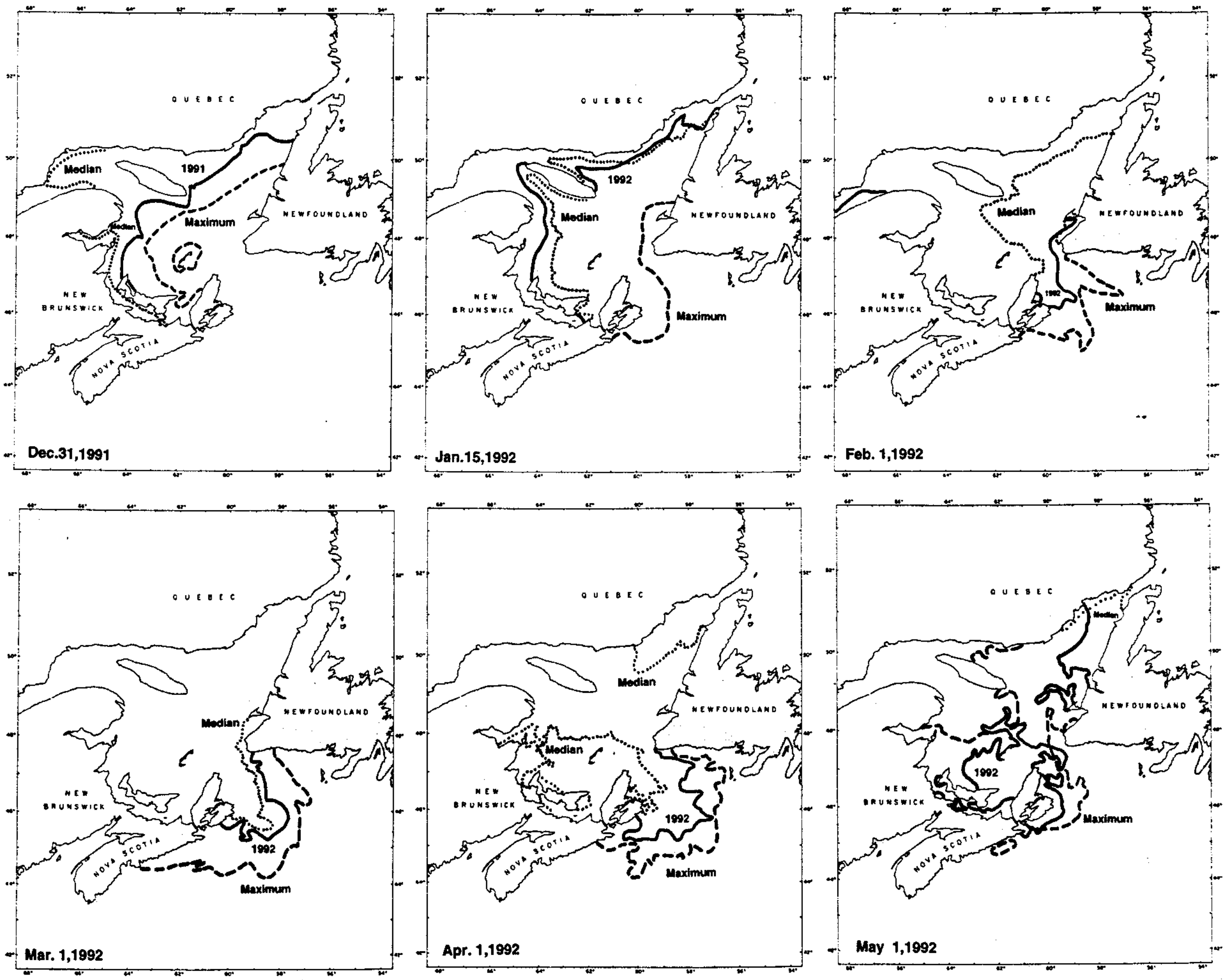


Fig. 15. The location of the ice edge (concentrations >10%) in the Gulf of St. Lawrence between December 1991 and May 1992. The historical (1962-1987) median and maximum positions of the ice edge are also shown.

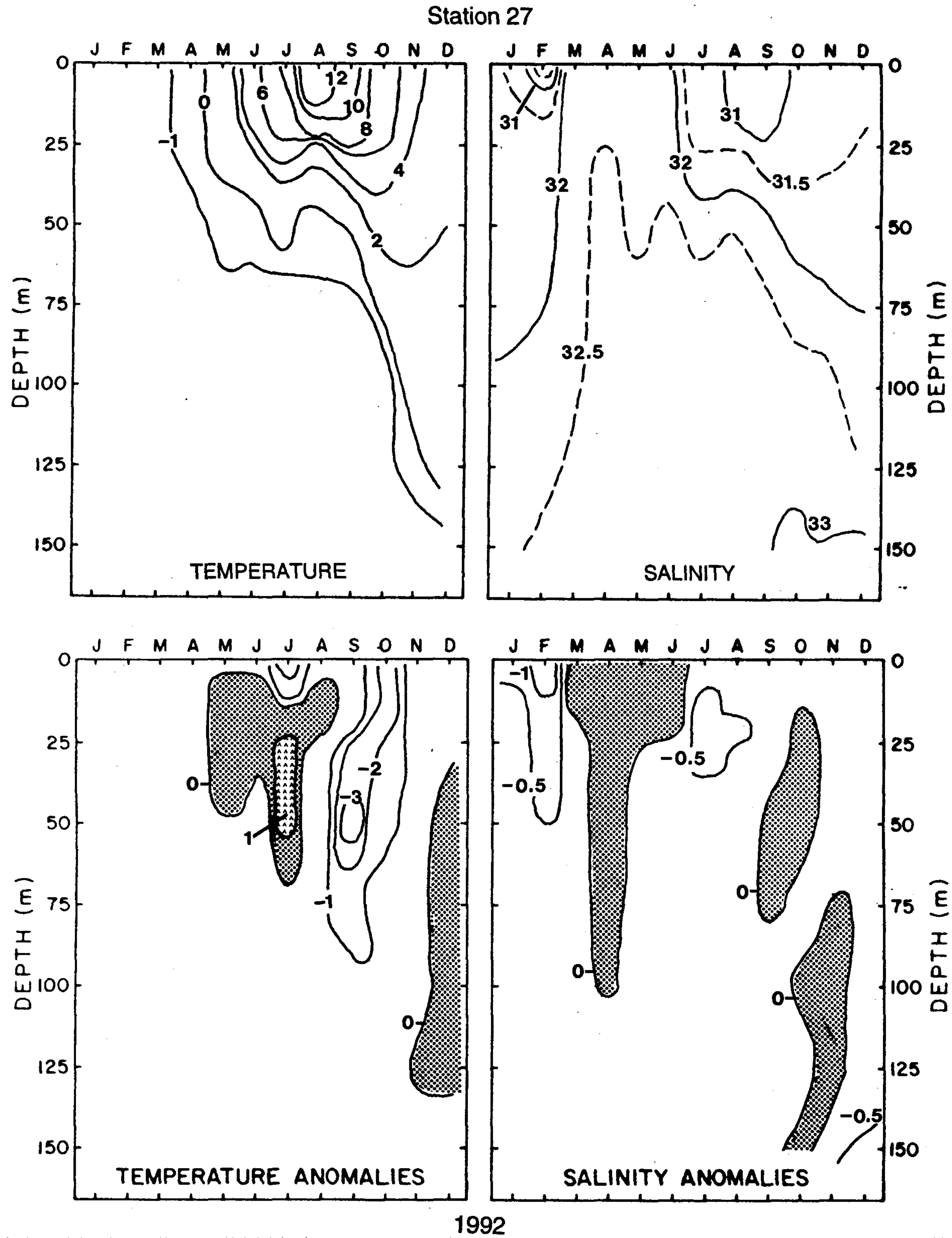
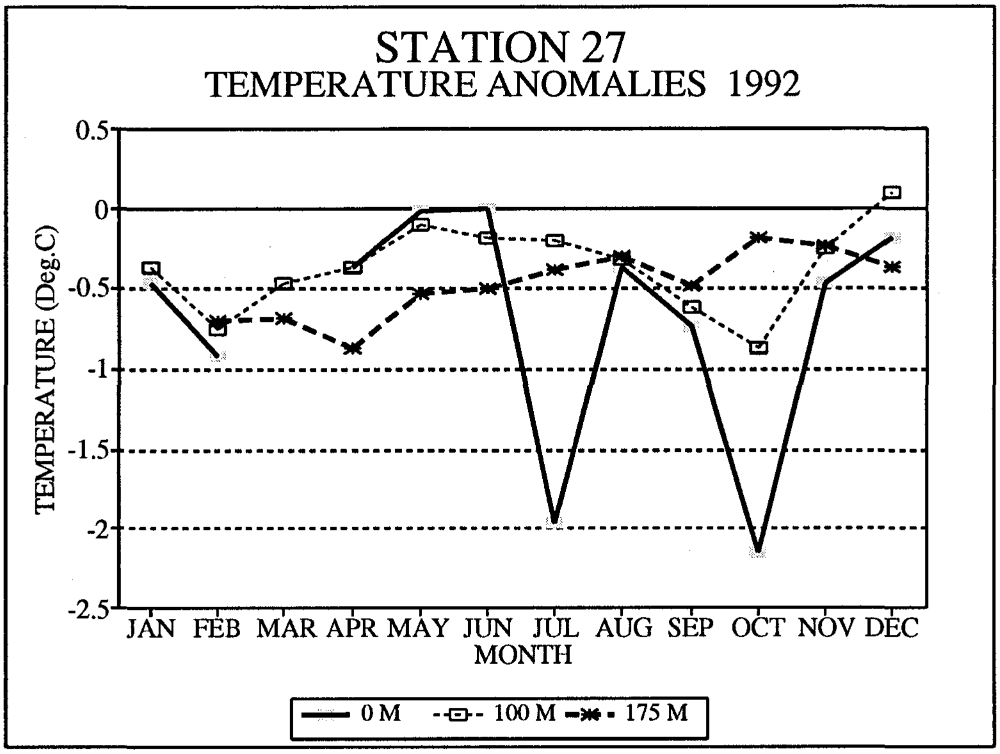


Fig. 16. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1992 relative to the 1951-80 means. Shaded areas are positive anomalies.



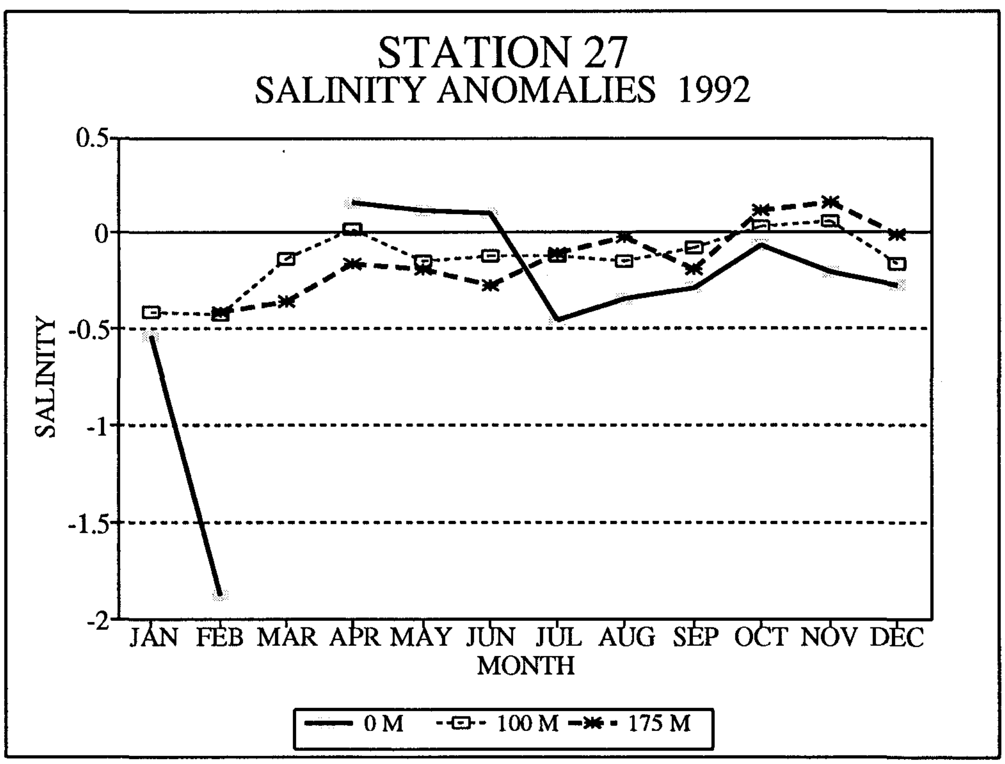


Fig. 17. Monthly temperature and salinity anomalies at 0, 100, and 175 m at Station 27 during 1992.

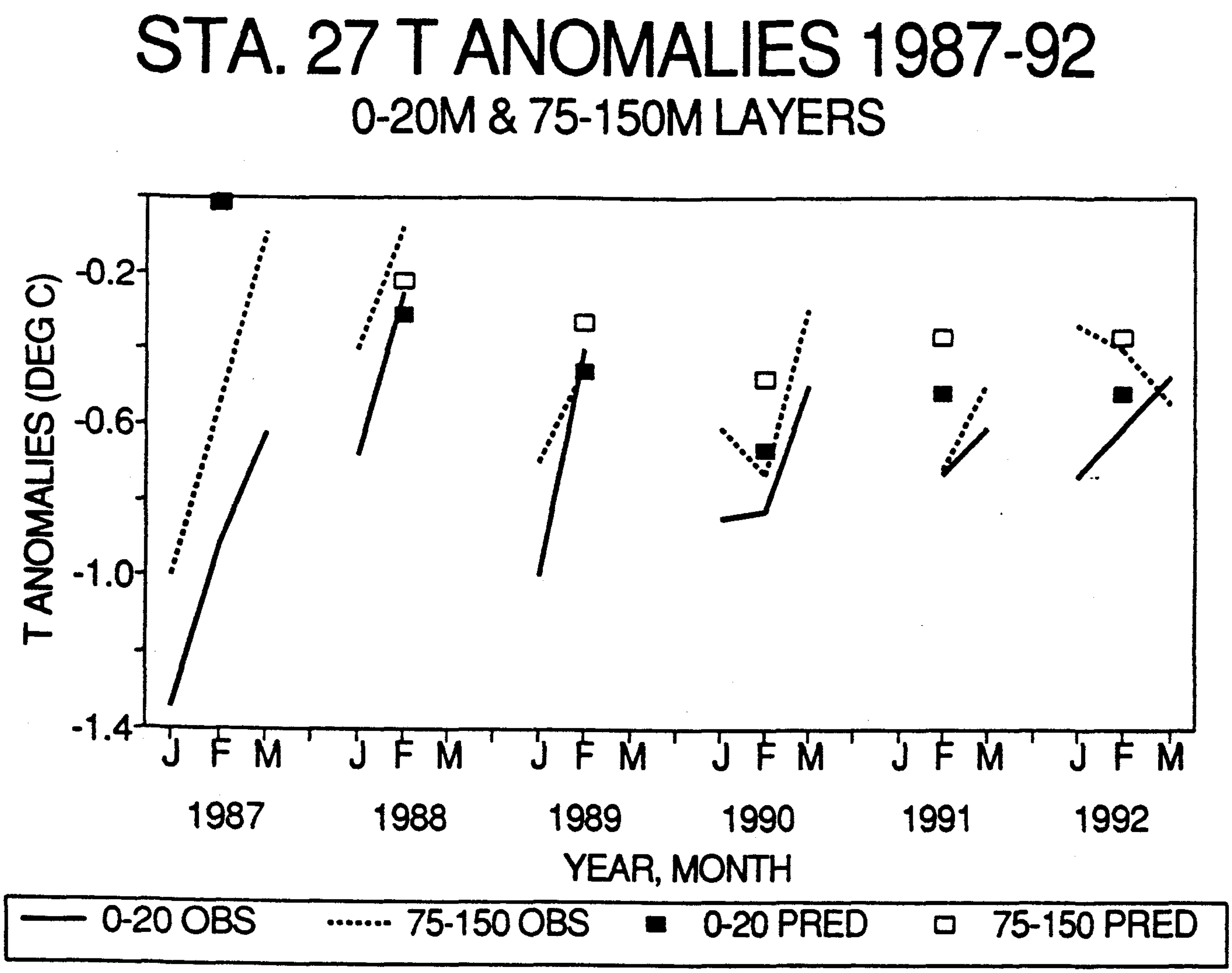


Fig. 18. Predicted March temperature anomalies at Station 27 (1987-1992) for 0-20 m (solid square) and 75-150 m (open square) along with the observed temperature anomalies for January-March, where available (taken from Drinkwater et al., 1992). The predicted temperatures are based upon the regression between air and water temperatures for 1963-86.

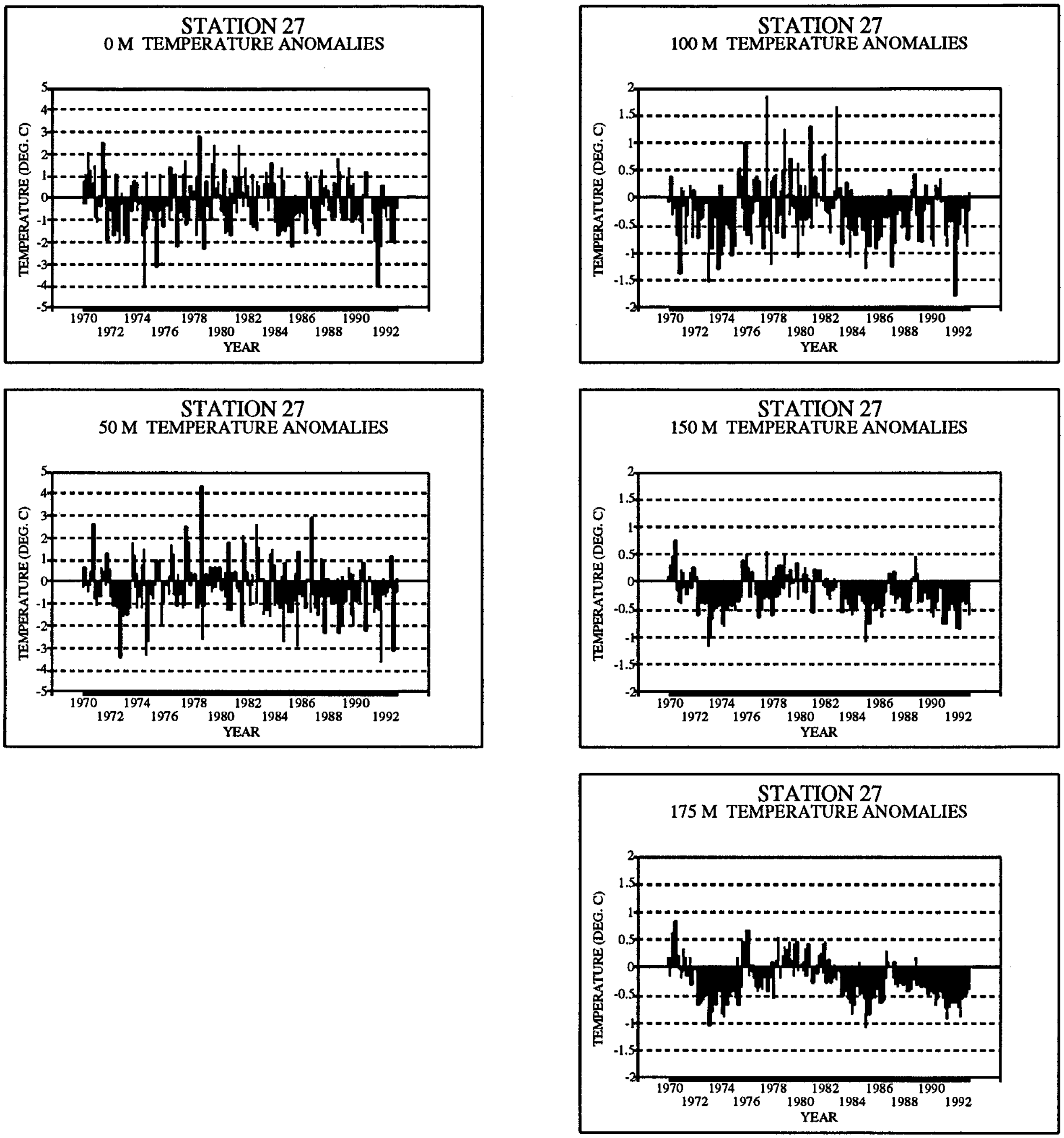


Fig. 19. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27.

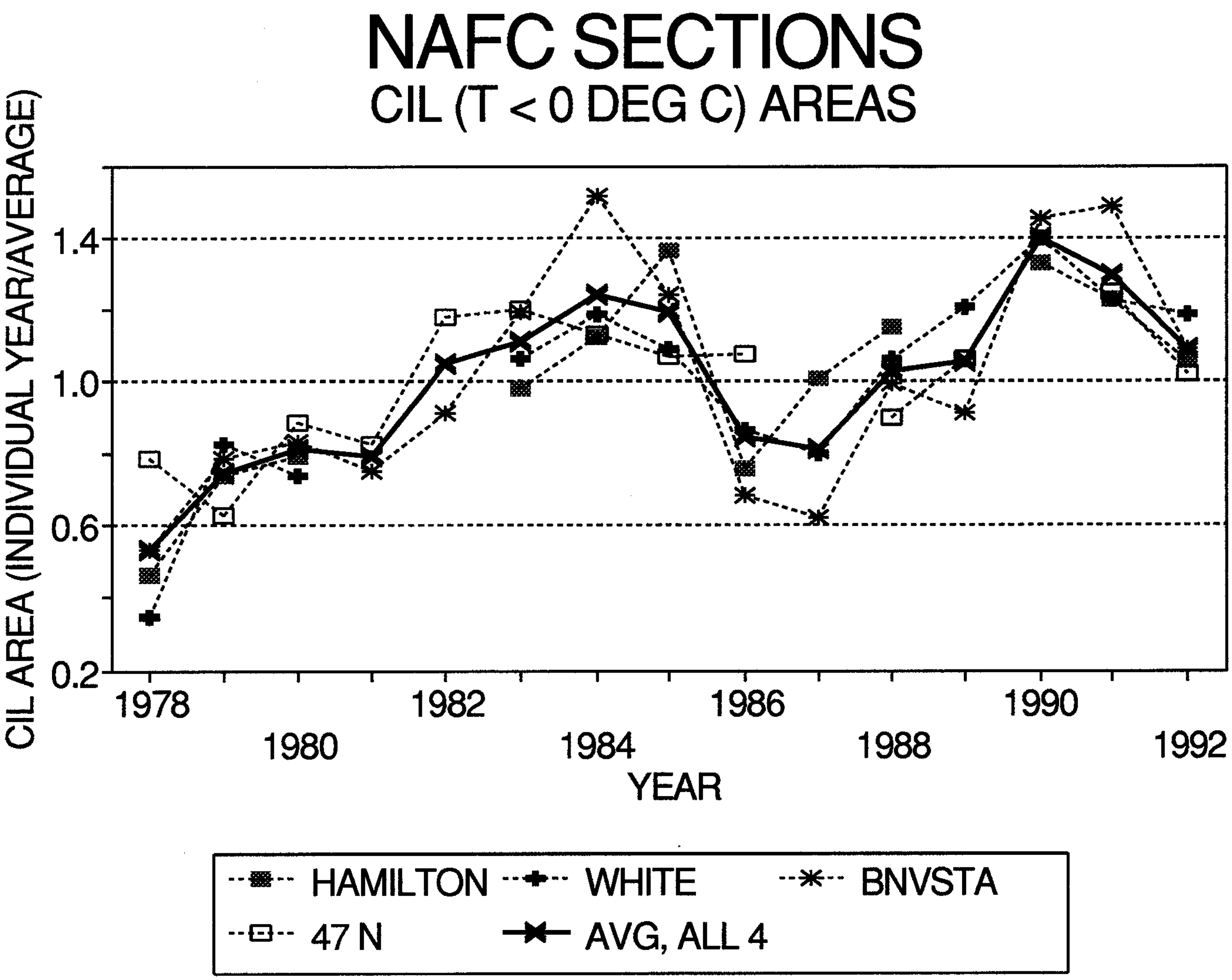


Fig. 20. The time series of the area of the CIL for the four standard sections off southern Labrador and northern Newfoundland.

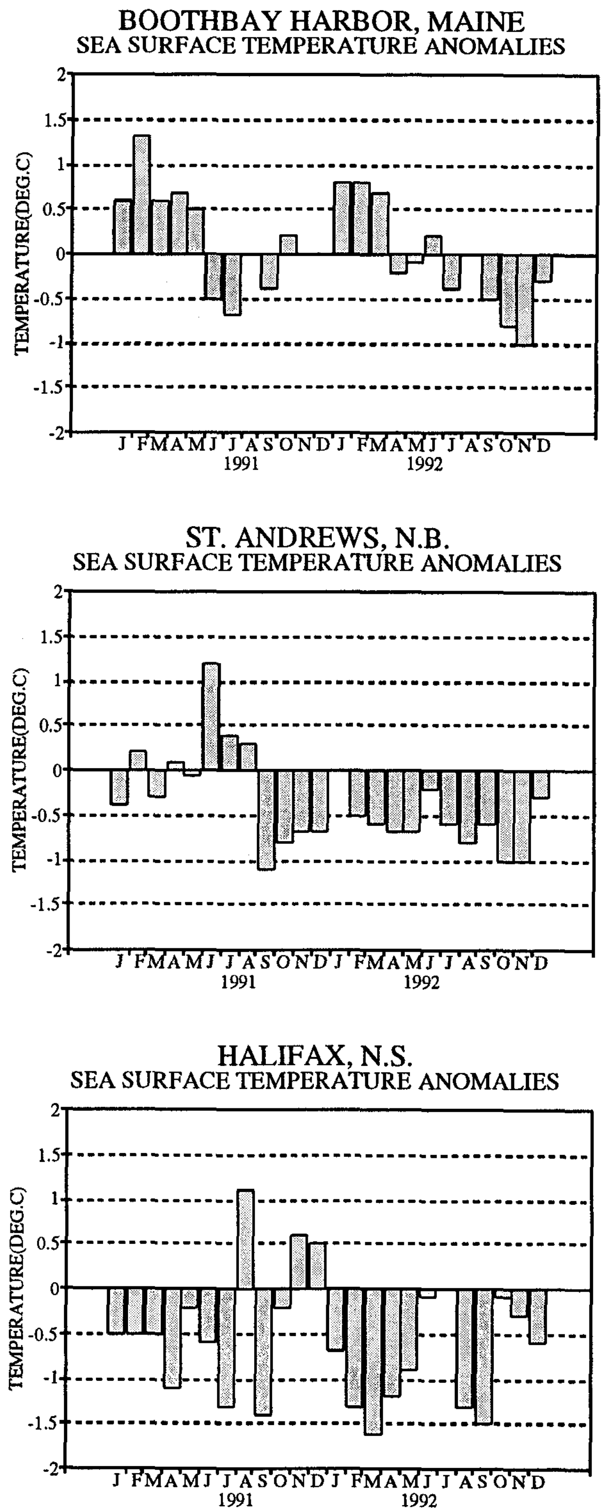


Fig. 21. The monthly sea surface temperature anomalies (relative to 1951-80) during 1992 for Boothbay Harbor, St. Andrews and Halifax.

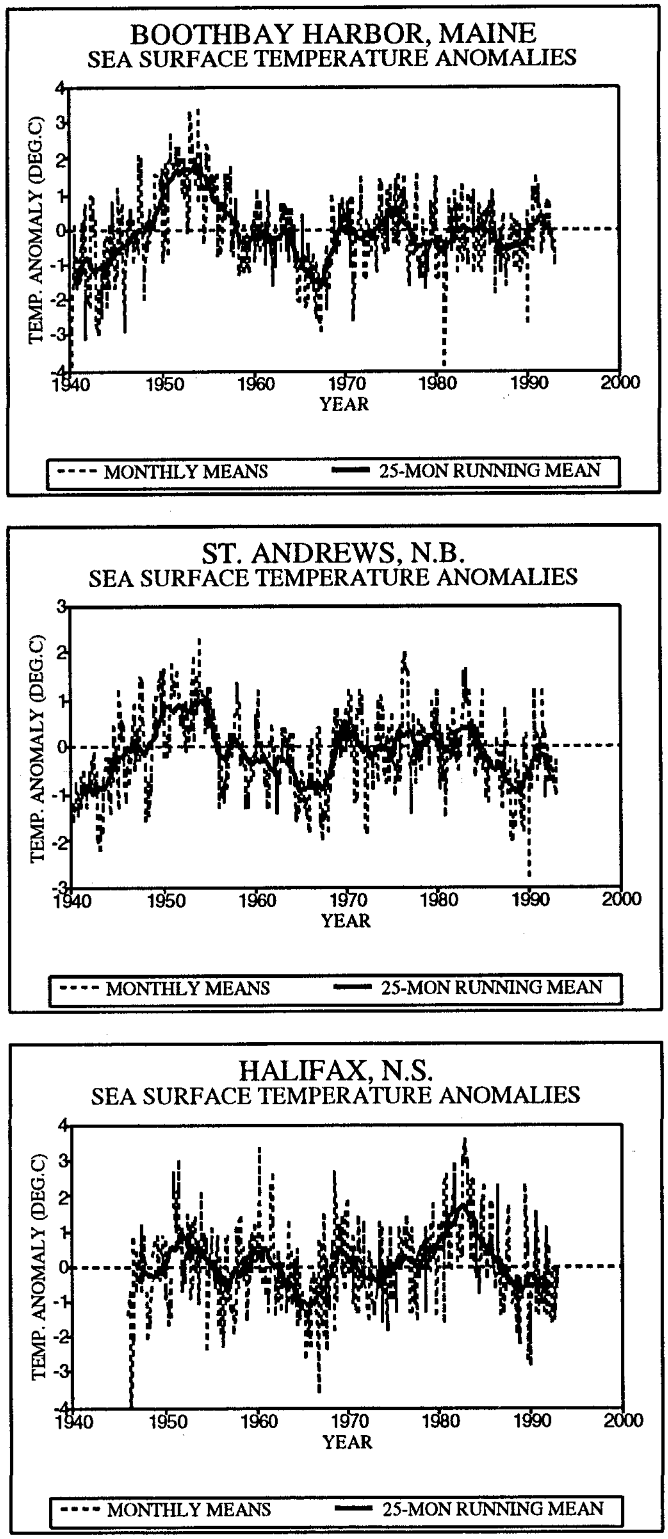


Fig. 22. The monthly means and the 25-month running means of the sea surface temperature anomalies (relative to 1951-80) for Boothbay Harbor, St. Andrews and Halifax.

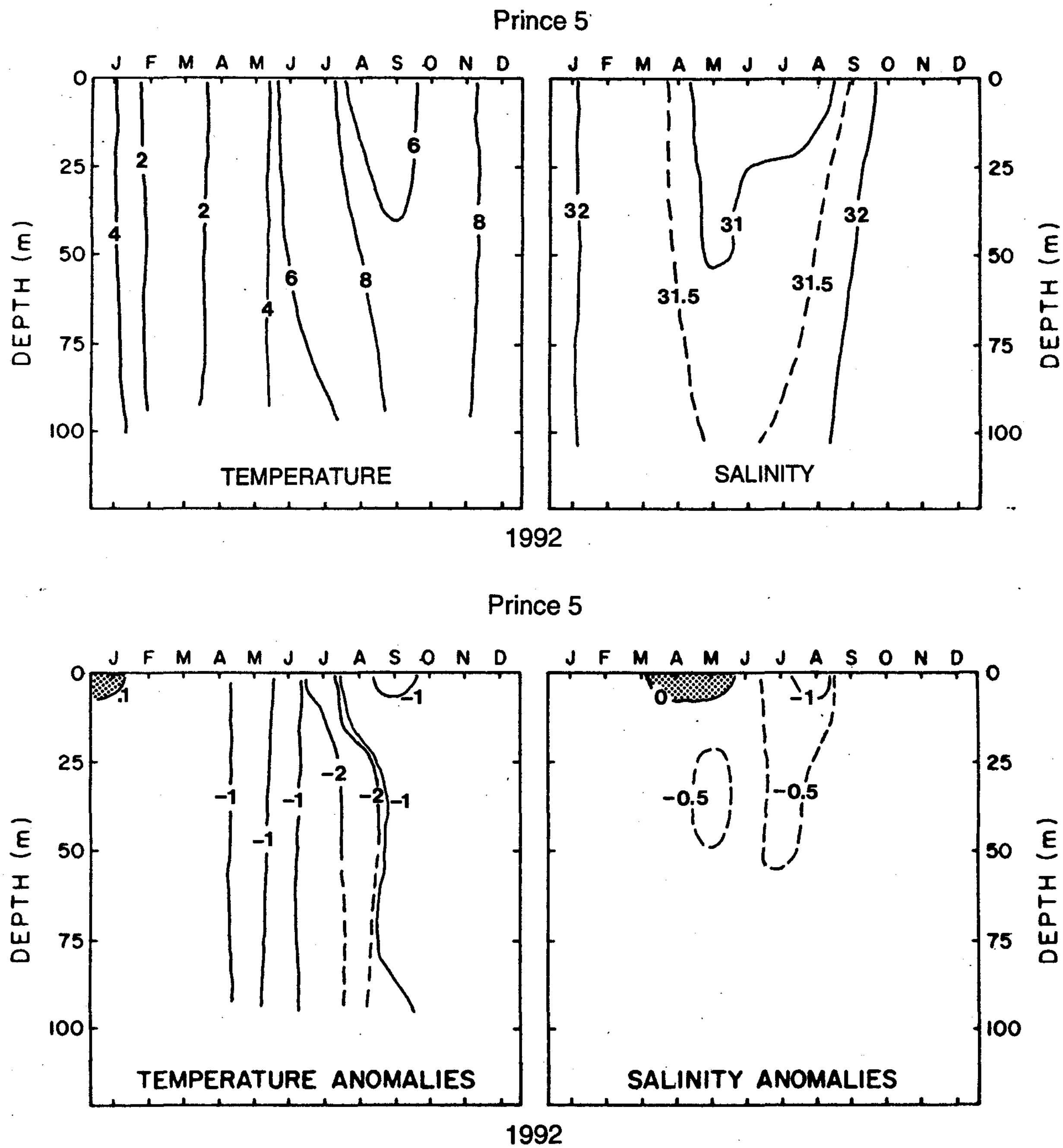
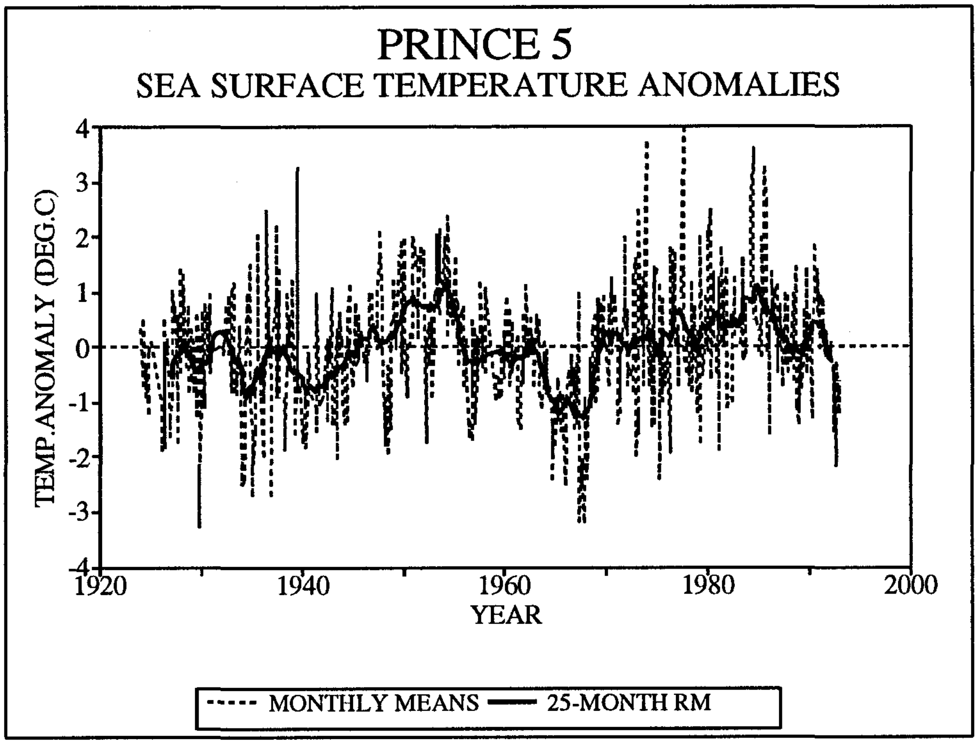


Fig. 23. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1992 relative to the 1951-80 means. Shaded areas are positive anomalies.



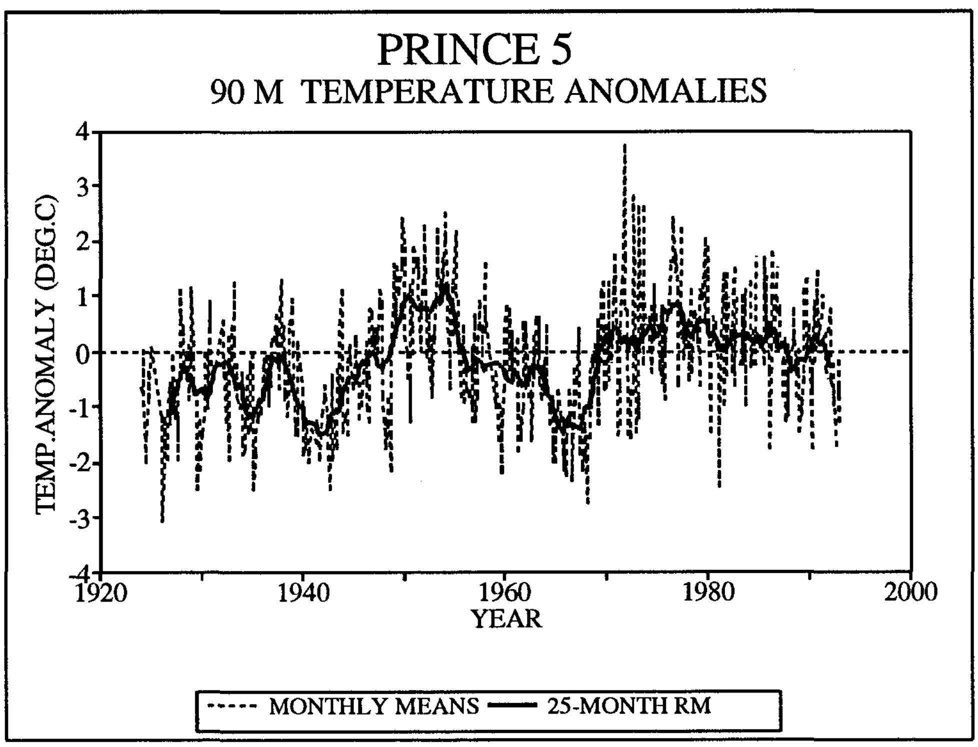


Fig. 24. The monthly means and the 25-month running means of the temperature anomalies for Prince 5, 0 and 90 m.

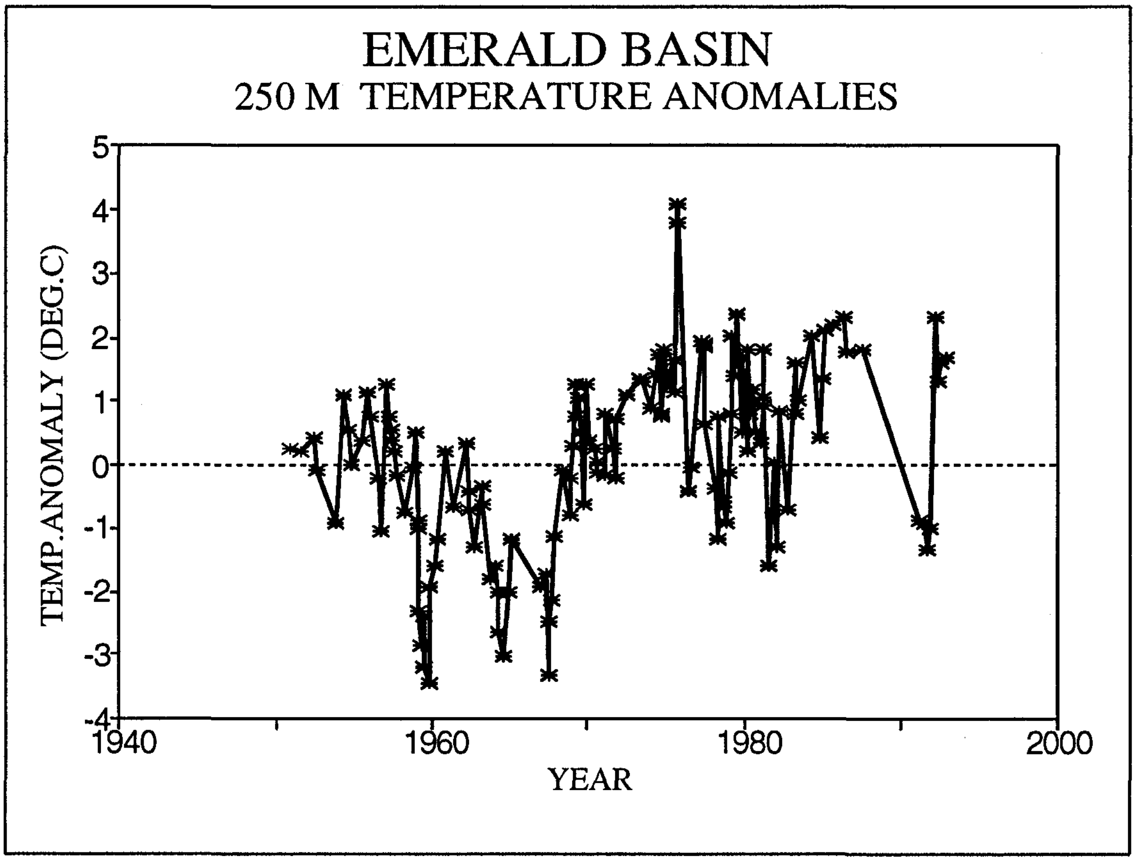


Fig. 25. Temperature anomalies (relative to 1951-80) at Emerald Basin at 250 m.

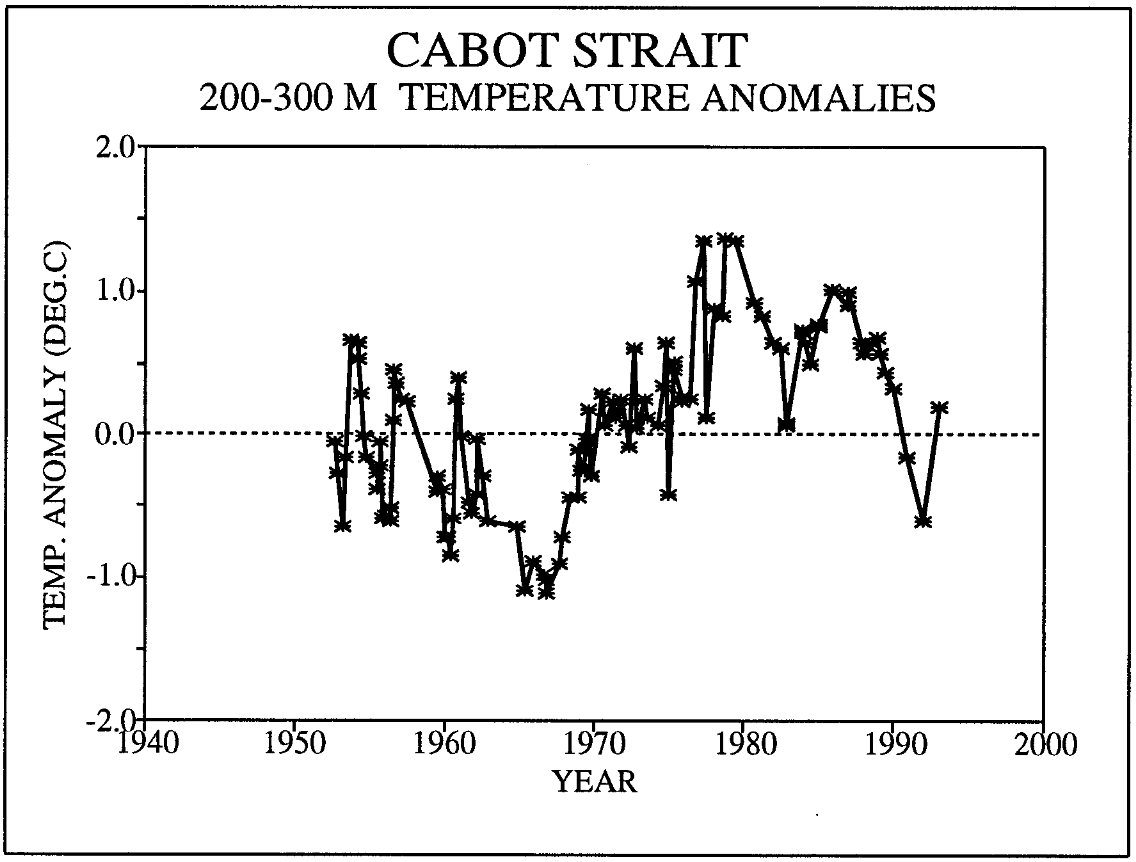


Fig. 26. Temperature anomalies (relative to 1951-90) for 200-300 m in Cabot Strait.

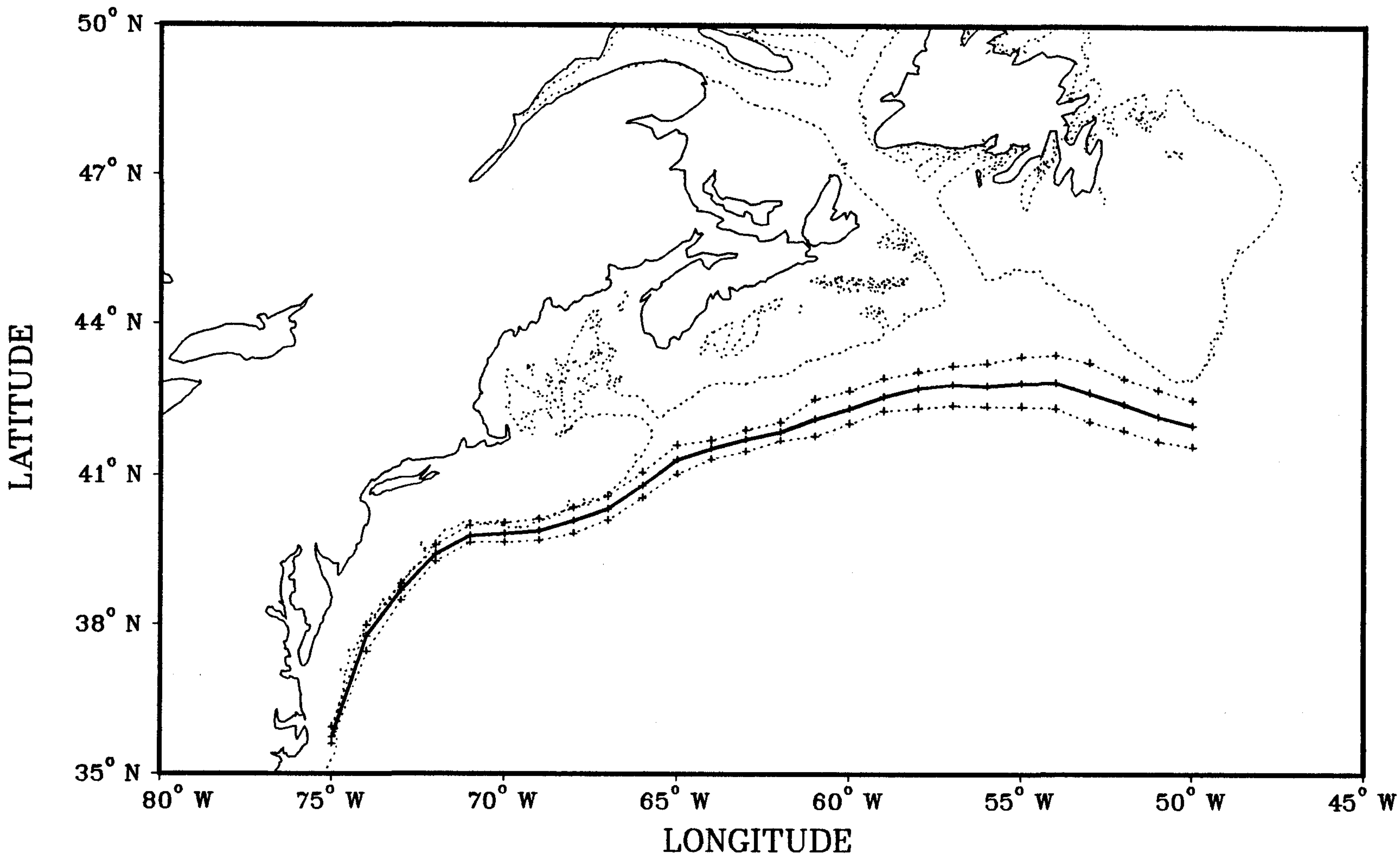


Fig. 27. The long-term (1973-90) mean position of the shelf/slope front and the maximum and minimum of the monthly averages.

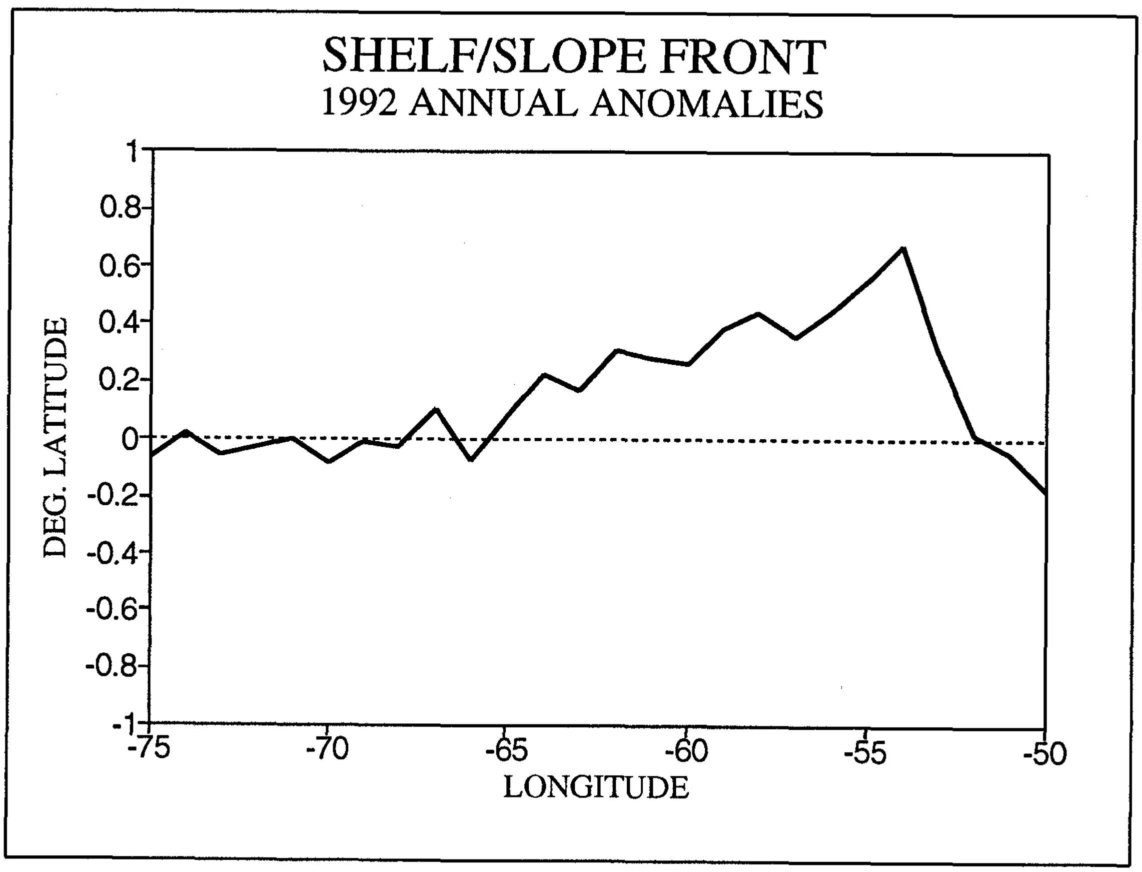


Fig. 28. The 1992 anomalies of the shelf/slope frontal position relative to its long-term mean.

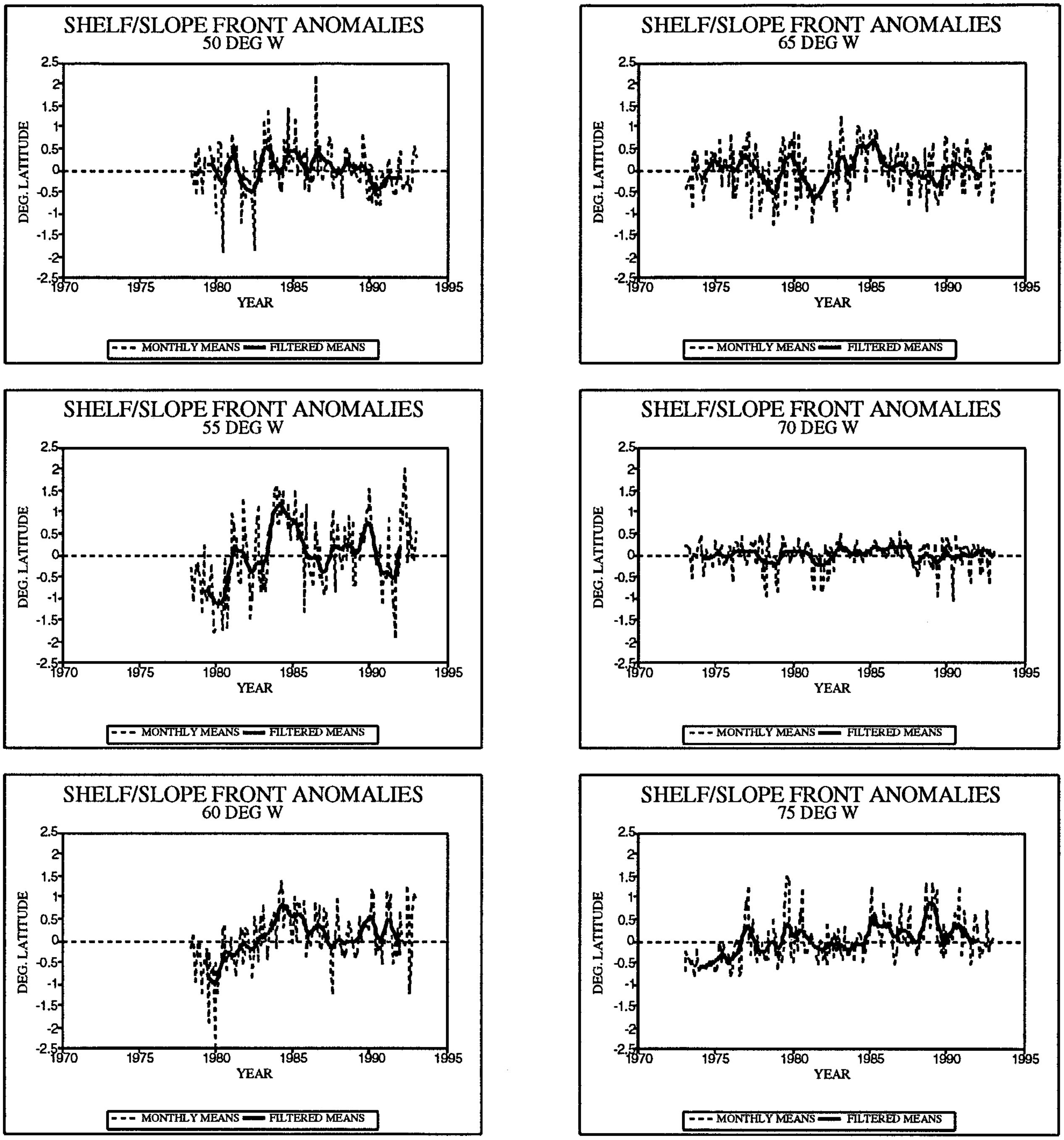


Fig. 29. The monthly and filtered time series of the anomalies of the shelf/slope frontal position at each 5° of longitude between 50°W and 75°W.

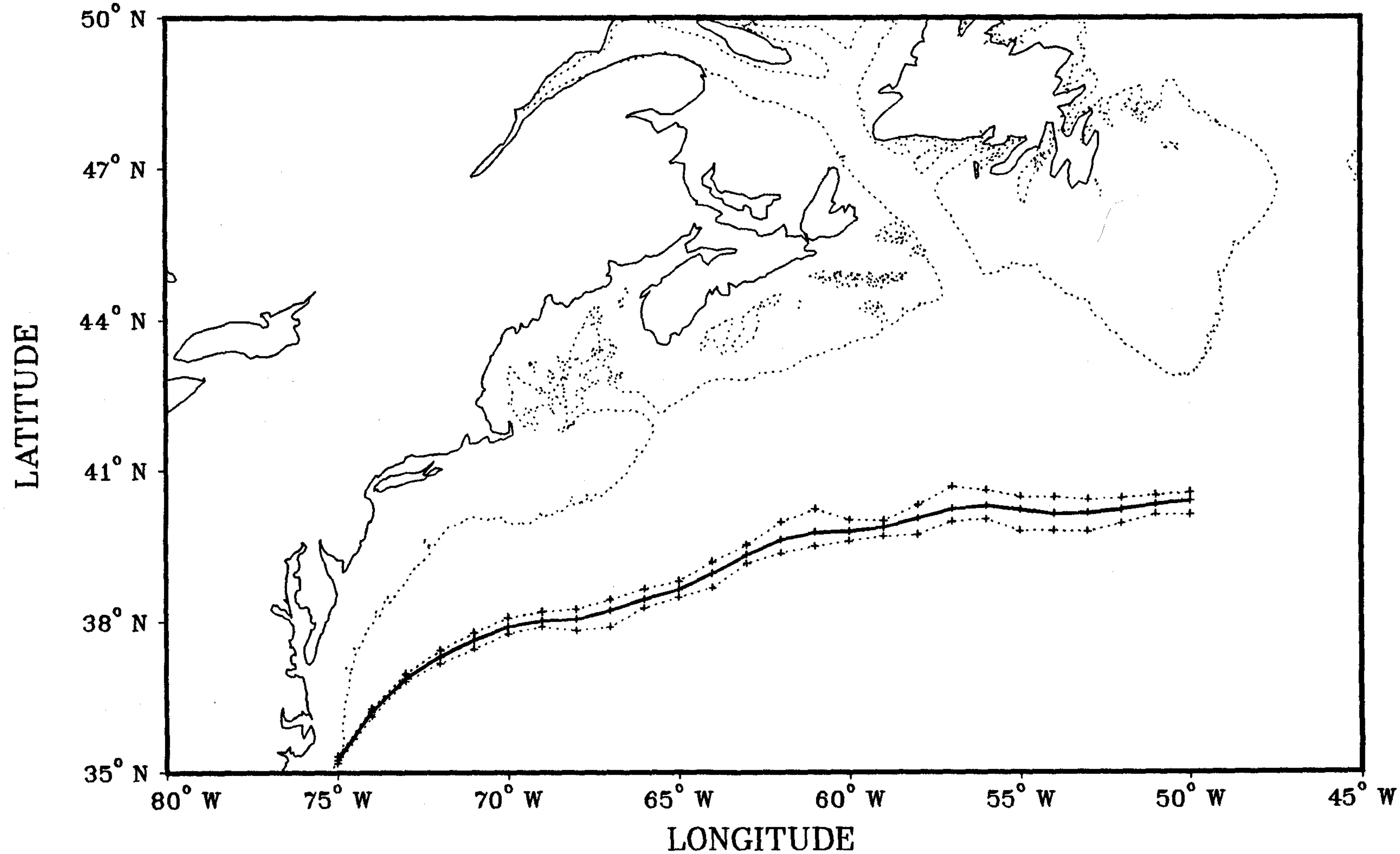


Fig. 30. The long-term (1973-90) mean position of the northern boundary of the Gulf Stream and the maximum and minimum of the monthly averages.

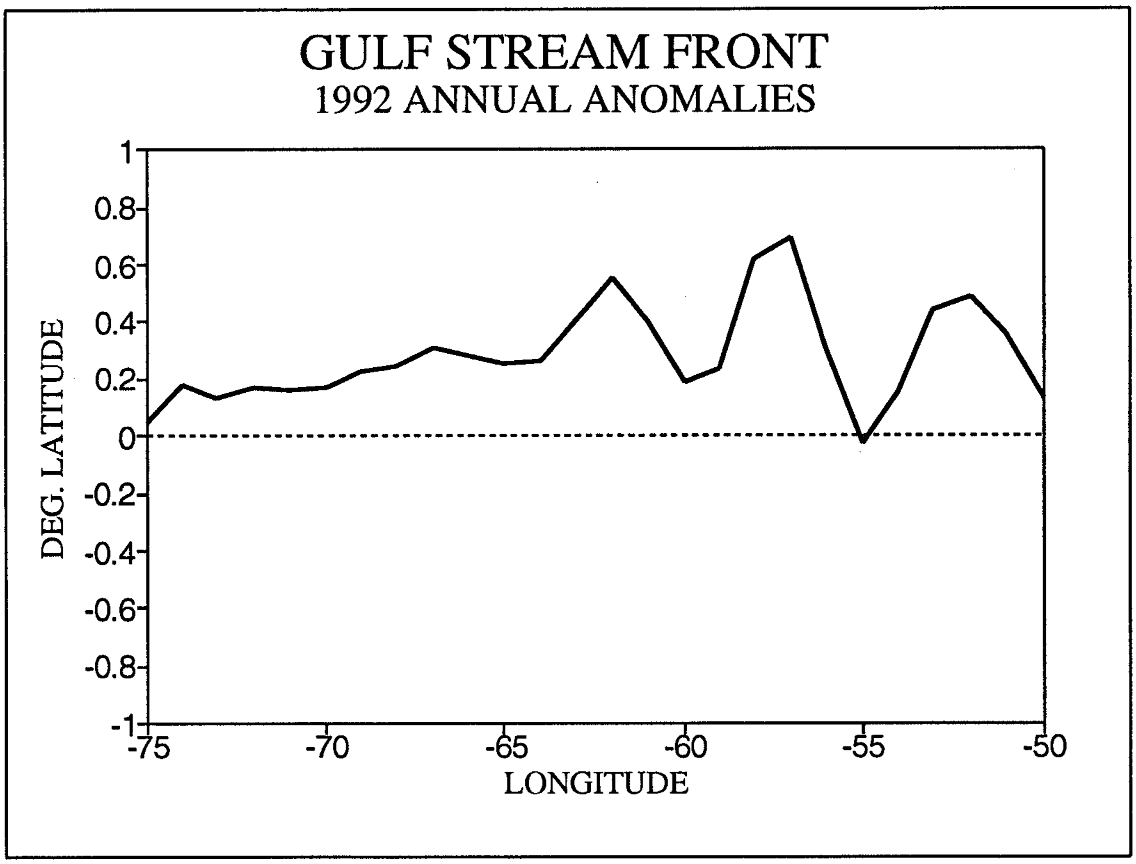


Fig. 31. The 1992 anomalies of the Gulf Stream frontal position relative to its long-term mean.

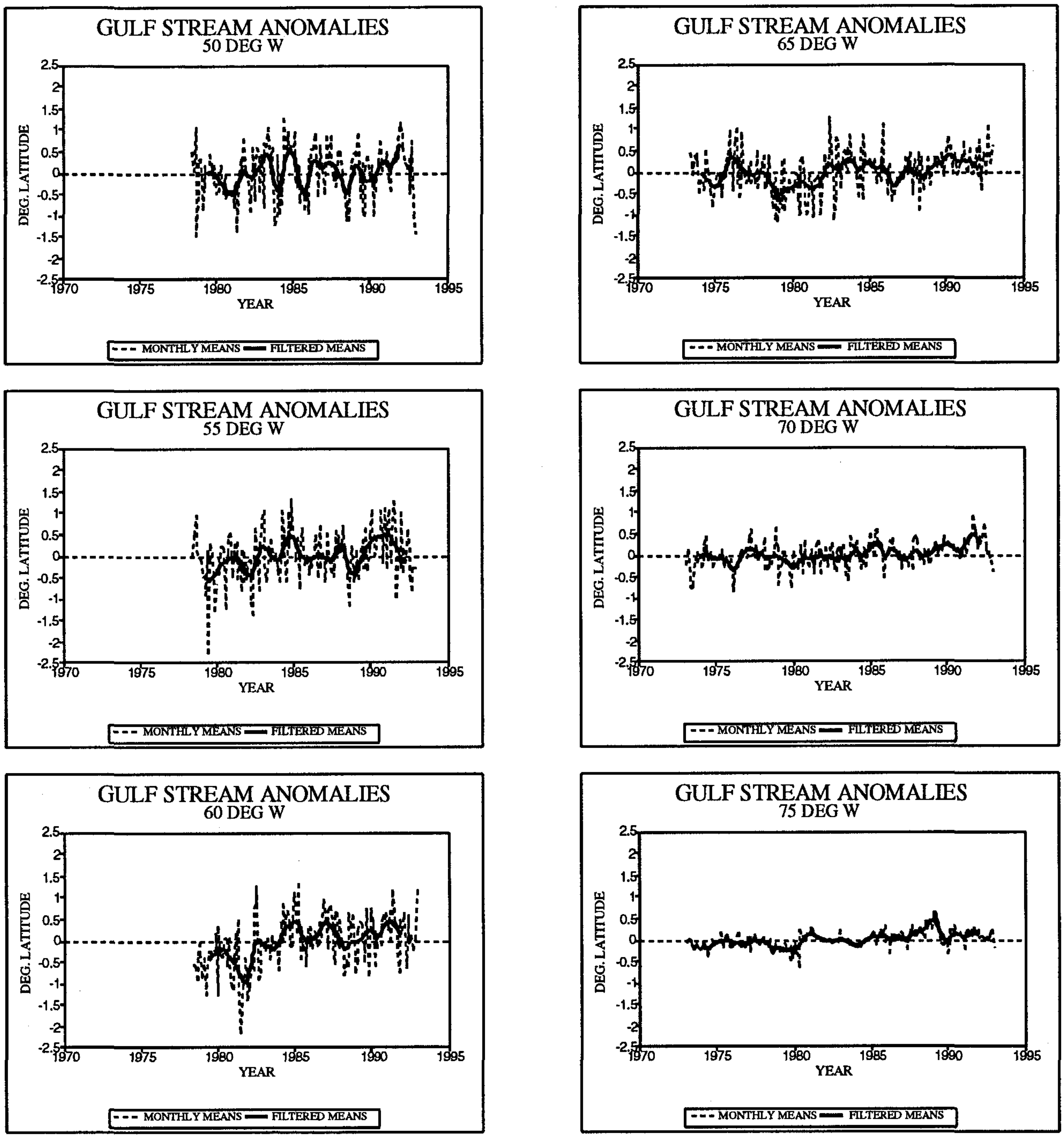


Fig. 32. The monthly and filtered time series of the anomalies of the Gulf Stream frontal position at each 5° of longitude between 50°W and 75°W.

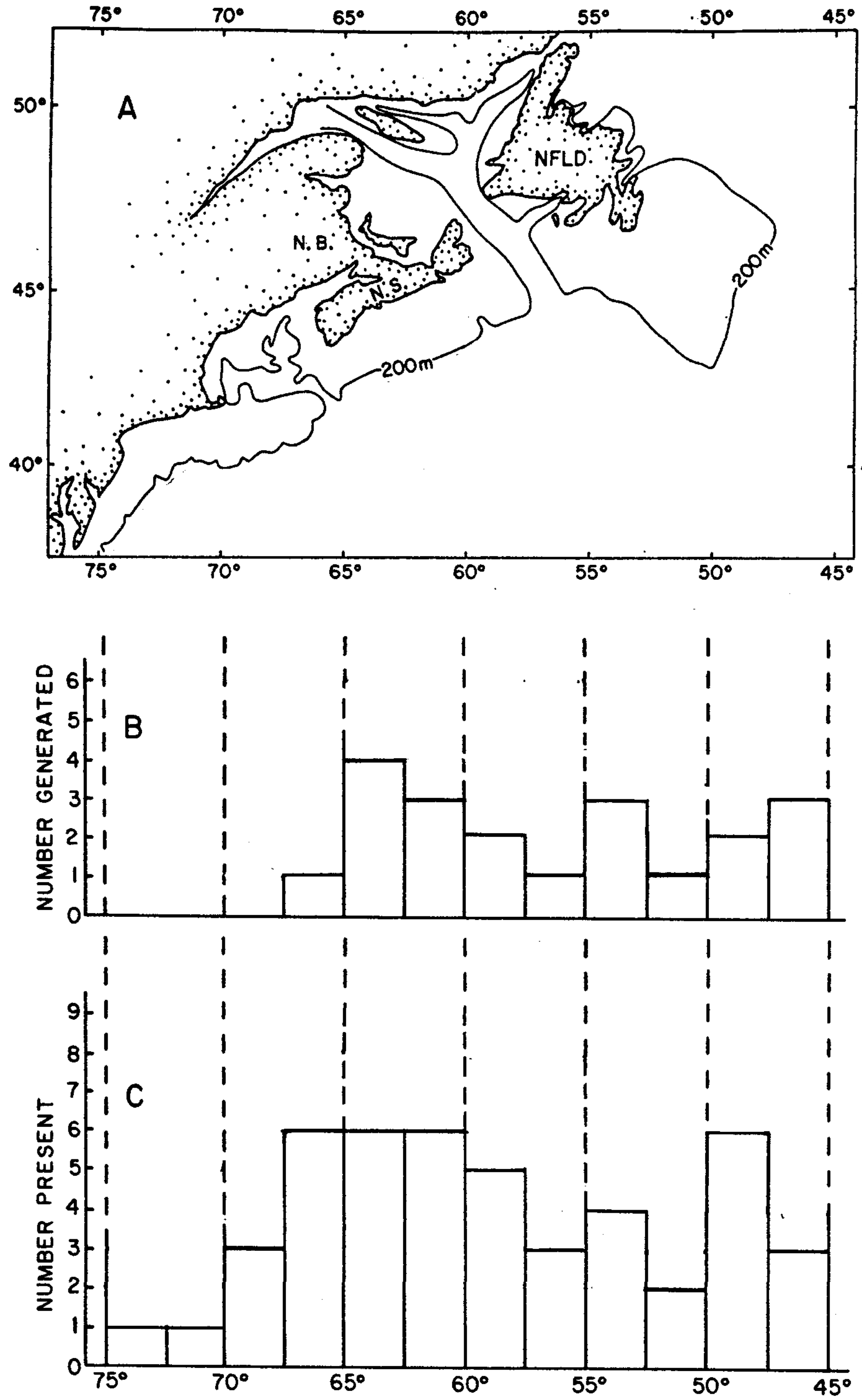


Fig. 33. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1991: (A) the chart of the area of interest; (B) the number of rings generated in each 2.5° zone of longitude; and (C) the number of rings present in each 2.5° zone during some part of the year.