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# Overview of Environmental Conditions in the Northwest Atlantic in 1992

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**Abstract**

A review of environmental conditions on the continental shelf regions 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. Unprecedented long durations of ice were recorded 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 from 1991 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 1991 but remained above normal. The cold conditions observed in the early-1990s were 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 basins and channels the deep waters warmed considerably from 1991, due to an intrusion of warmer slope water. The shelf/slope front and the Gulf Stream both were north of their long-term mean positions.

*Key words*: Environment, currents, ice, meteorology, oceanography, salinity, temperature

## Introduction

This paper provides a review of environmental conditions in the Northwest Atlantic during 1992 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-year 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 eleventh in a series of annual overviews.

## 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-year mean of 1951–1980. 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 was also clearly evident in the monthly anomalies from six coastal sites from Godthaab in Greenland to Sable Island off Nova Scotia. The location of the stations are shown in Fig. 2. The data from Godthaab indicated that the spatial extent of the cold air mass along the Labrador coast described above, extended throughout the Labrador Sea. Temperatures in 1992 were typically colder than in 1991 (Fig. 3).

The annual air temperature anomalies showed 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

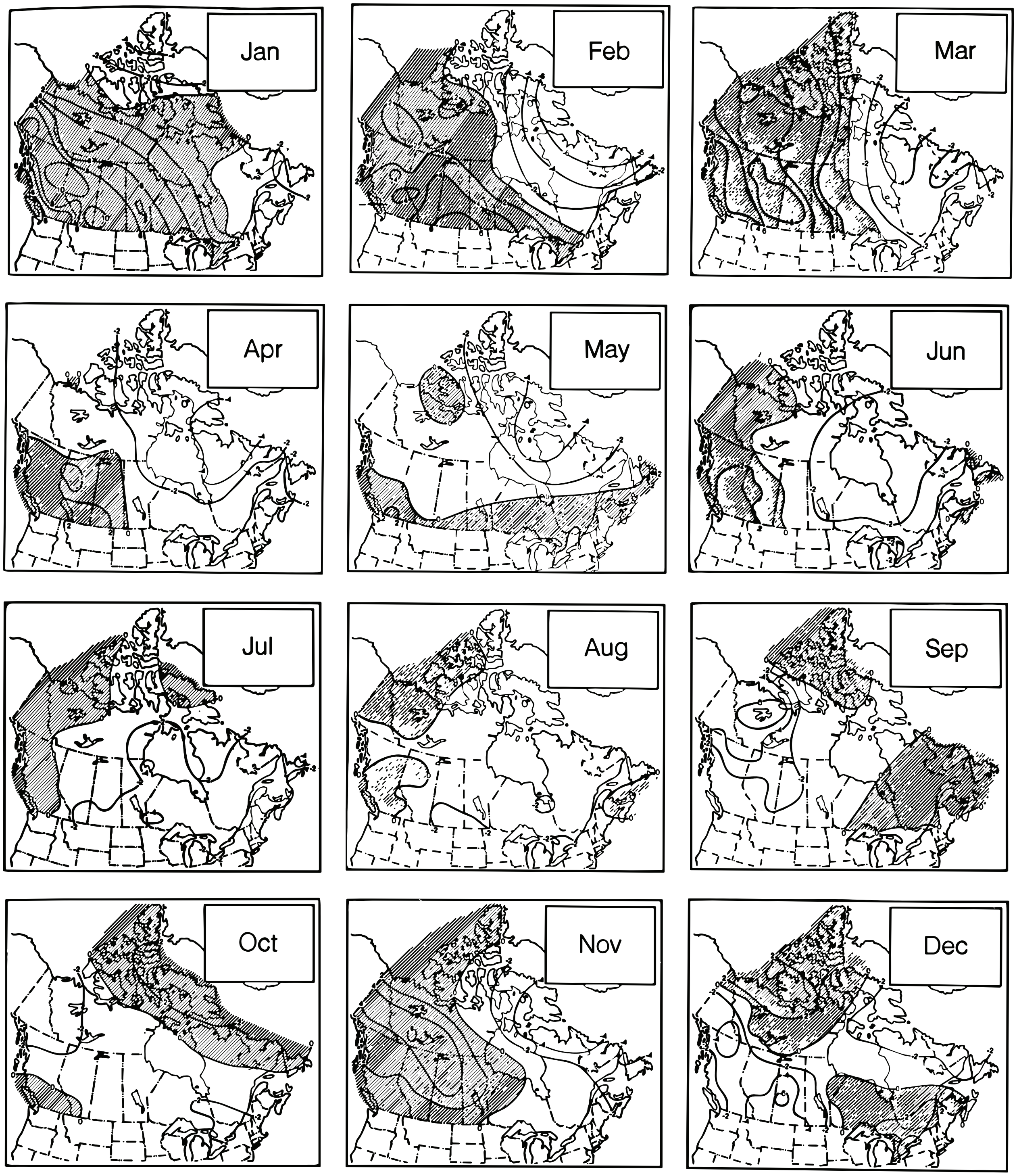


Fig. 1. Monthly mean air temperature anomalies (°C) over Canada in 1992 relative to the 1951–80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 14)

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. Iqaluit recorded the 2nd coldest year since the station

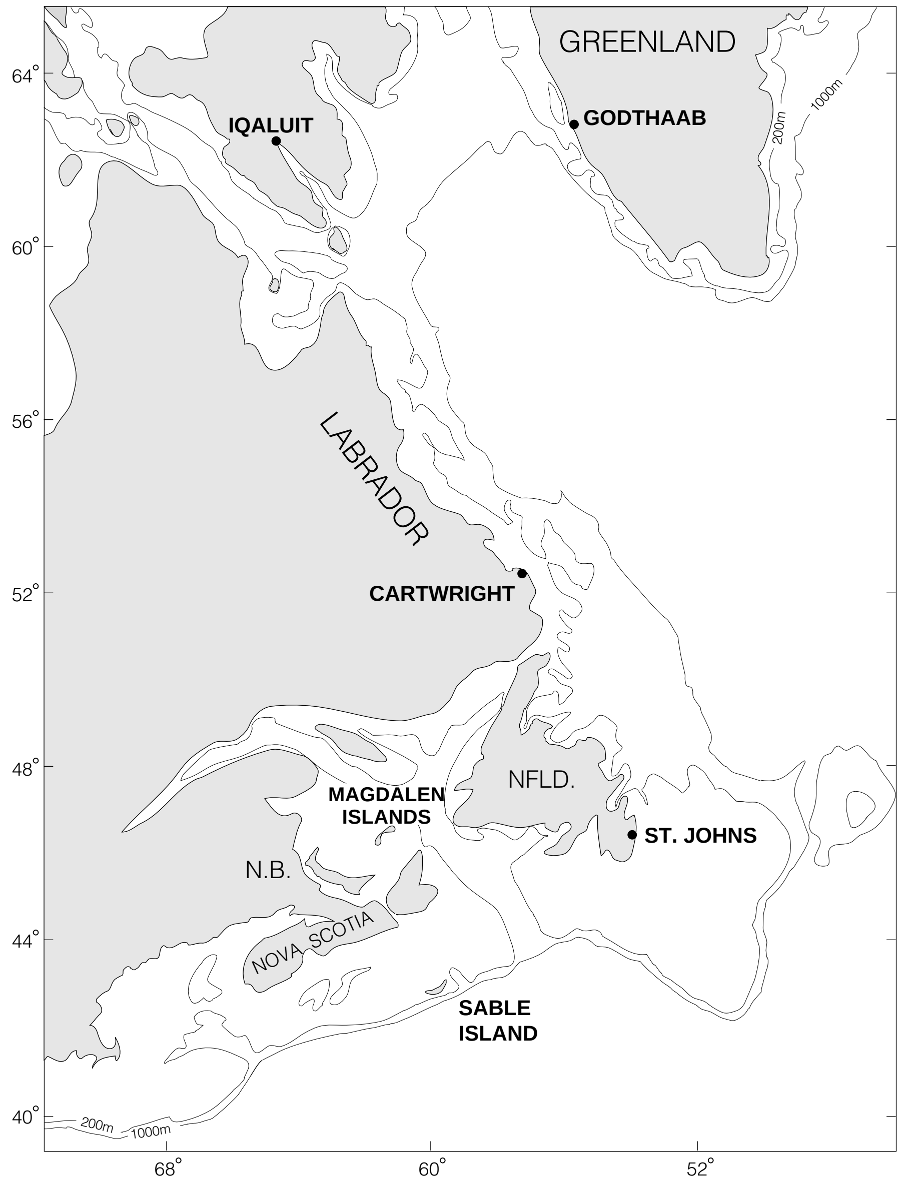


Fig. 2. Map of the Northwest Atlantic Ocean showing coastal air temperature stations.

opened in 1945 (-2.7°C) with only 1972 being colder. It was the 3rd coldest year in Cartwright since its earliest record in 1931 (-1.7°C), and the coldest in over 50 years in St. John's (-1.2°C). Similarly, Godthaab 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 Godthaab, Iqaluit, Cartwright, and to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with periods of about 10 years. Minima occurred in the early-1970s and the early- to mid-1980s, and temperatures were very low in the early-1990s. There has also been an overall downward trend, causing temperature anomalies since the early-1970s to be predominantly below normal. Temperature anomalies at the Magdalen Islands 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 in the mid-1980s although not in the 1990s.

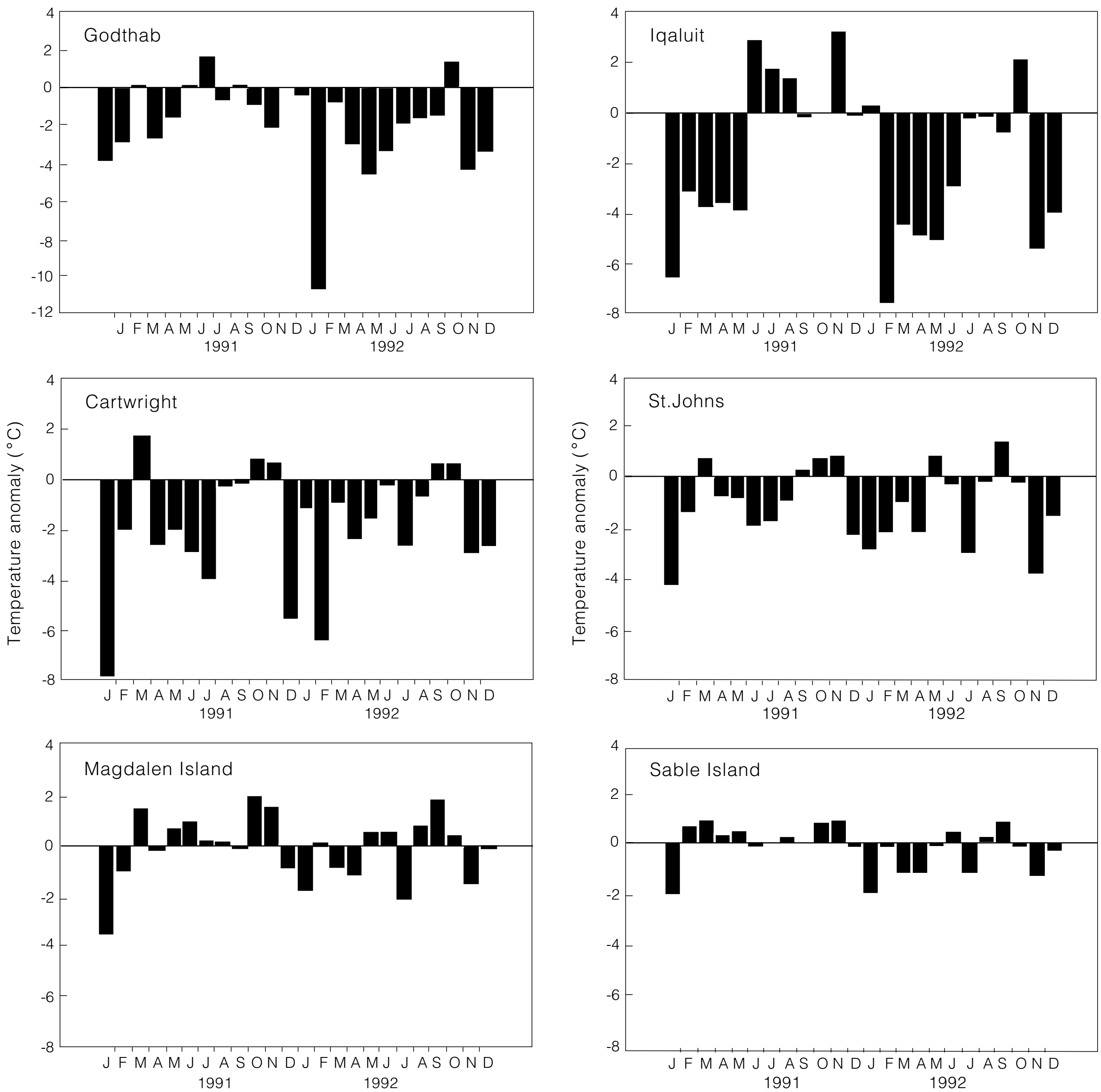


Fig. 3. Monthly mean air temperature anomalies at selected sites in 1991 and 1992.

## 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 were 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 varied seasonally from a winter maximum to a summer minimum. Seasonal anomalies of the sea-surface pressure for 1992 relative to the 1951–80 mean are shown in Fig. 6, where winter includes December 1991 to February 1992, spring is March to May, summer is June to August and autumn is September to November.

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 positive anomaly (maximum of 12.6 mb) over western Europe. Such a pressure pattern

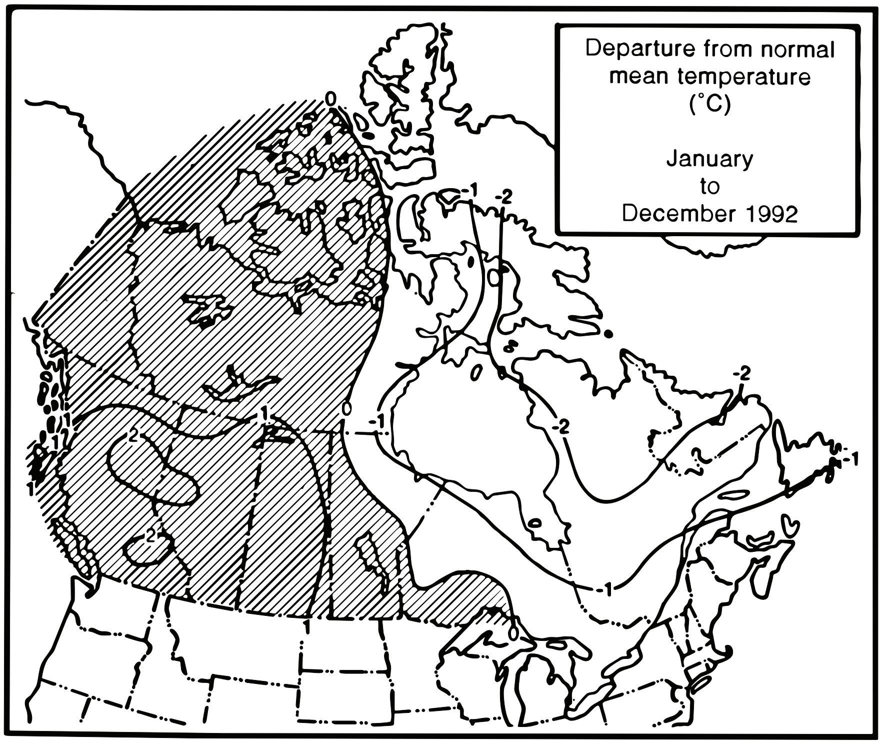


Fig. 4. Annual air temperature anomalies (°C) over Canada in 1992 relative to the 1951–80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 15).

promotes strong, cold northwesterly winds over the Labrador Sea and realtively warm southeasterly winds over the Norwegina Sea between Europe and Greenland. In spring the Icelandic Low deepend (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 during July. In autumn, a negative pressure anomaly developed voer England and the eastern North Atlntic. Anomalous highs developed over Greenland and of the southern United States and western Africa. This pressure pattern would have generated increased southwesterly winds over the southern NAFO region and decreased northwesterly winds over the Labrador Sea.

### NAO Indexes

The North Atlantic Oscillation (NAO) index is the difference in wintertime (December, January and February) sea level pressures between the Azores and Iceland and is a measure of the strength of the 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 Delgata 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, in dicating higher-than-normal westerly winds across the North Atlantic. This continued 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. It is noted that three most recent peasks in the NAO index correspond in time with the periods of cold air temperatues over the Labrador Sea (Fig. 5).

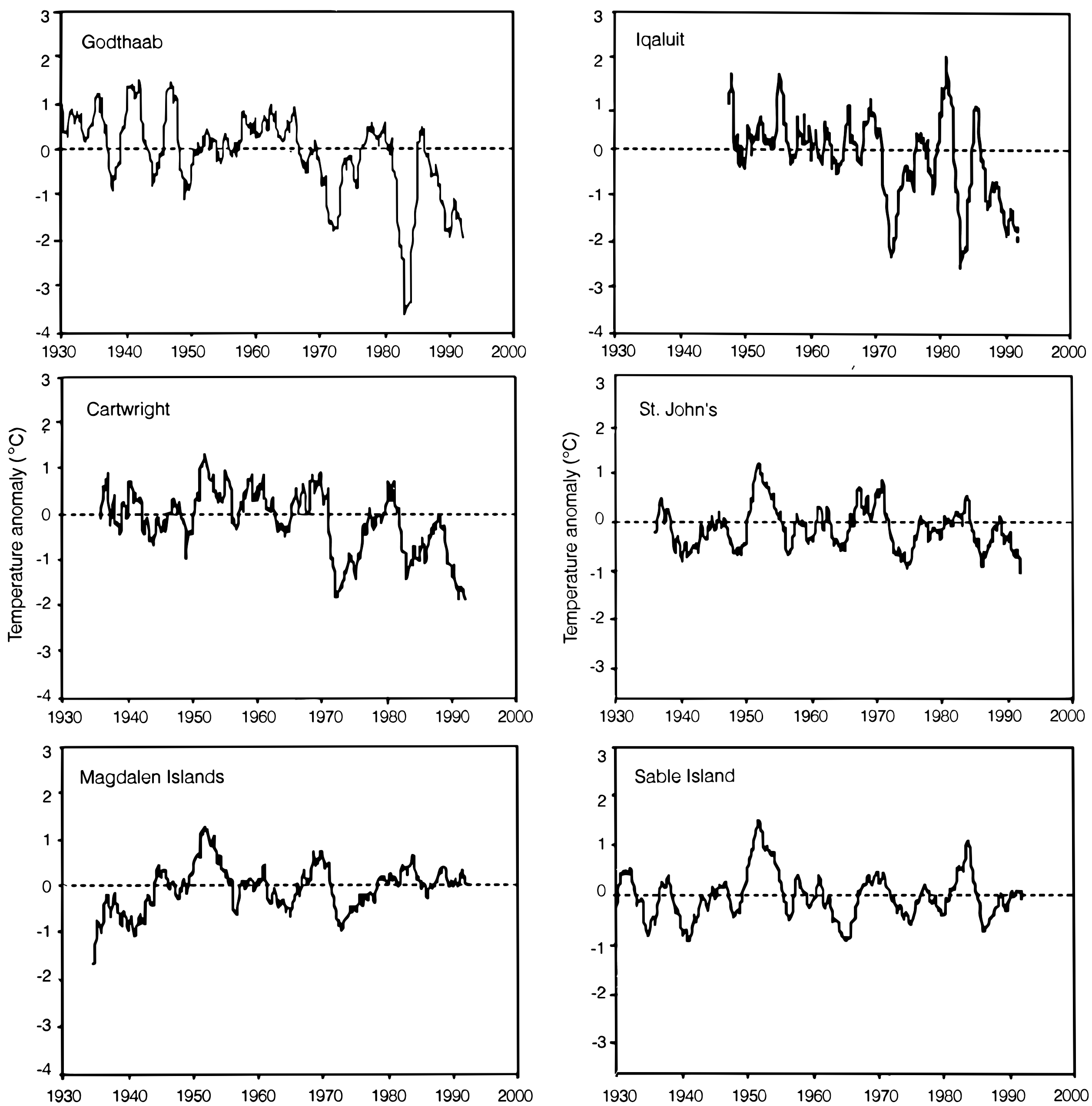


Fig. 5. Twenty-five month running means of monthly air temperature anomalies at selected sites.

### Upper atmosphere pressures

The heights of the 50 Kpa pressure field (approximately 5 000 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 1991. 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 was similar to the pattern identified

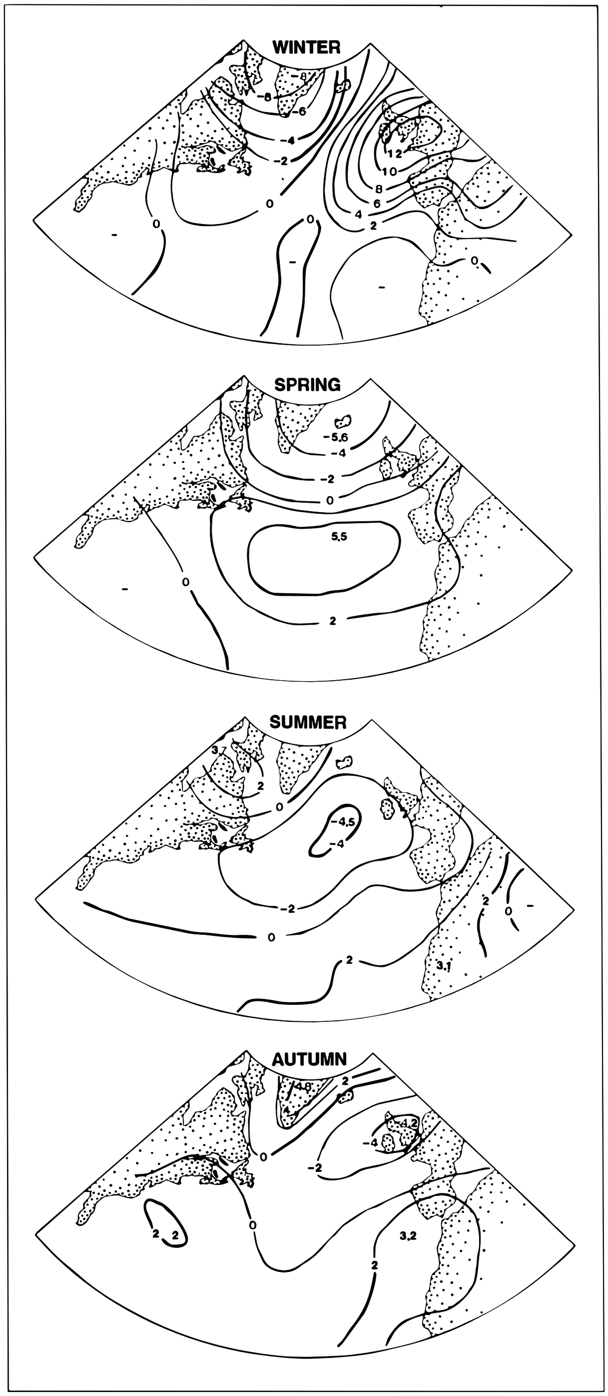


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1992 relative to the 1951–80 mean.

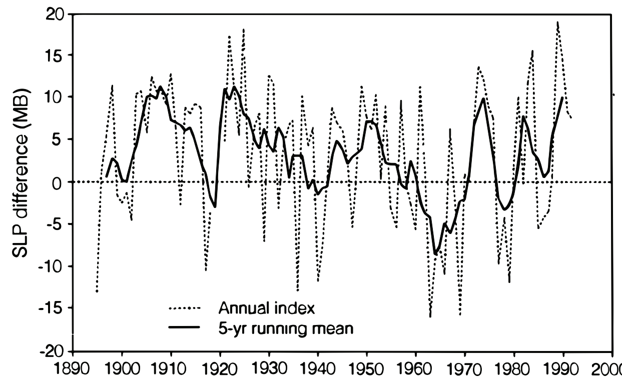


Fig. 7. The annual values and 5-year running mean of the North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus that at Akureyri in Iceland.

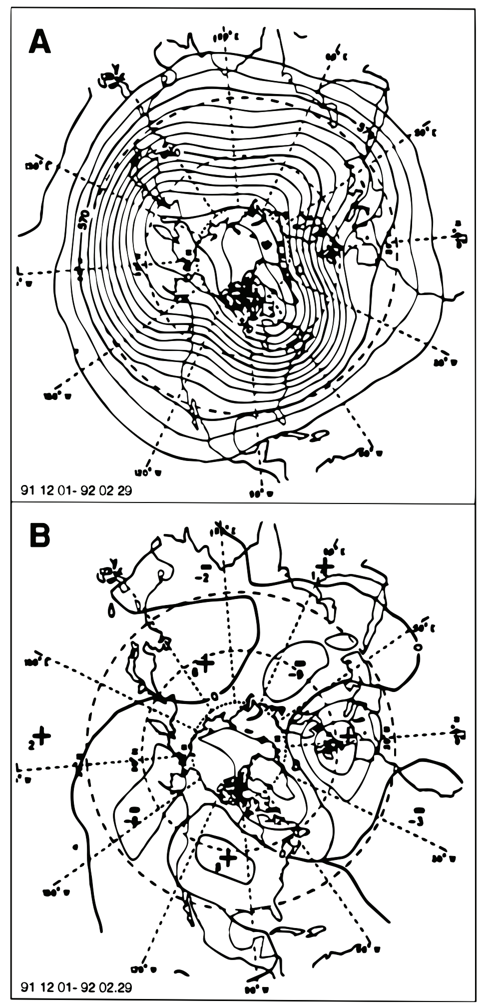


Fig. 8. The mean (**A**) and the anomaly (**B**) of the height in decameters of the 50 Kpa atmospheric pressure field during the winter (December 1991, January and February 1992) (From *Climatic Perspectives*, Vol. 14).

as producing “cold” winters (Findlay and Deptuch-Stapf, 1991) and heavy ice years (Agnew and Silis, 1991).

## Sea Ice Observations

### Newfoundland and Labrador

The location and concentration of sea ice are 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 1962–87 were reported by Coté (MS 1989). Colder-than-normal air temperatures during December 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. 9). Through January 1992, the ice pushed further southward so that by the beginning of February the ice was near its maximum southern extent. 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 rapidly during March such that by 1 April it was located further north than normal along the Newfoundland coast but the ice edge offshore exceeded it long-term maximum position. 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 Newfound-

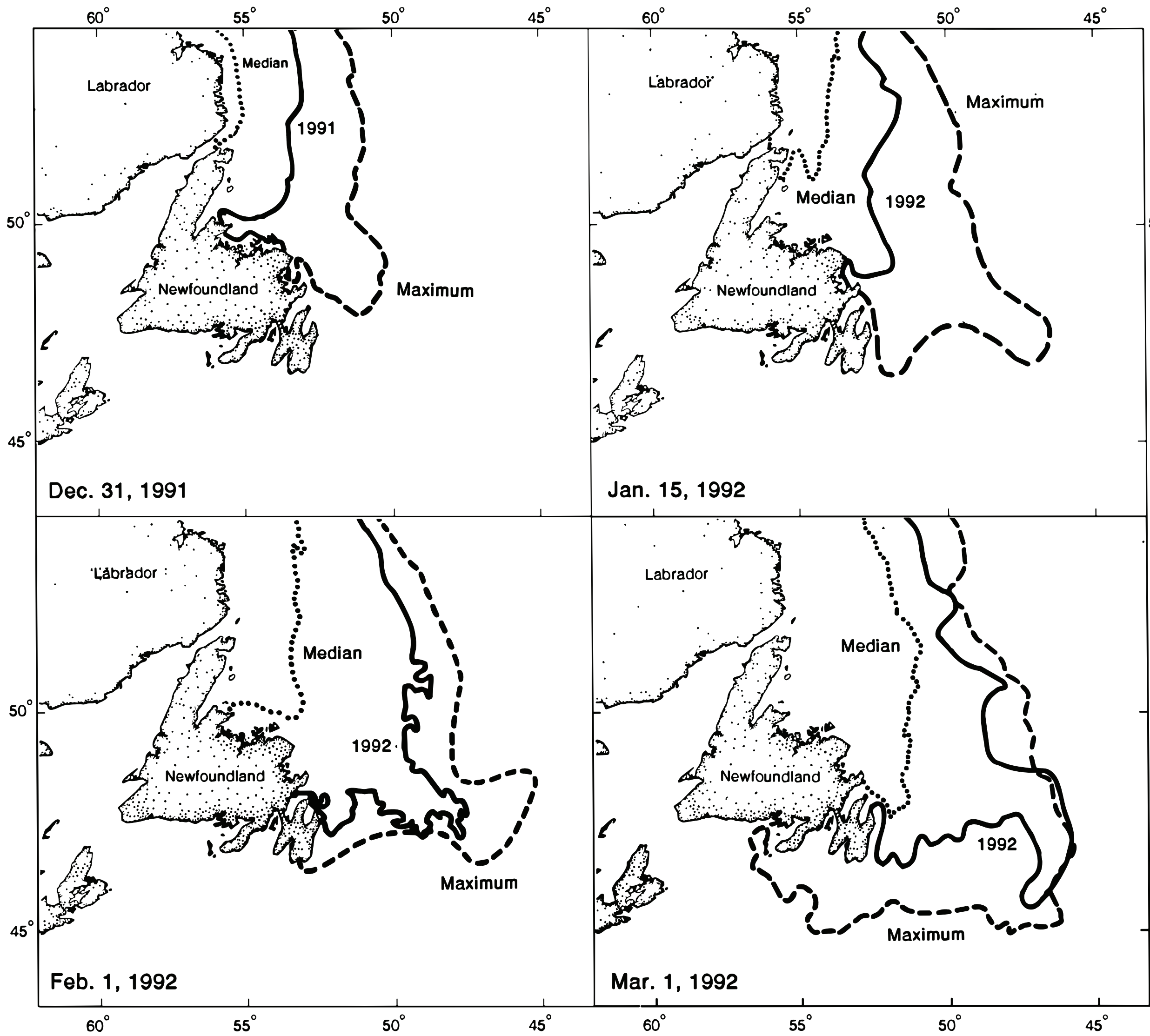


Fig. 9. The 1992 ice edge (concentrations of >10%) and its historical (1962–87) median and maximum positions off Newfoundland and Labrador on specific days during the ice season.

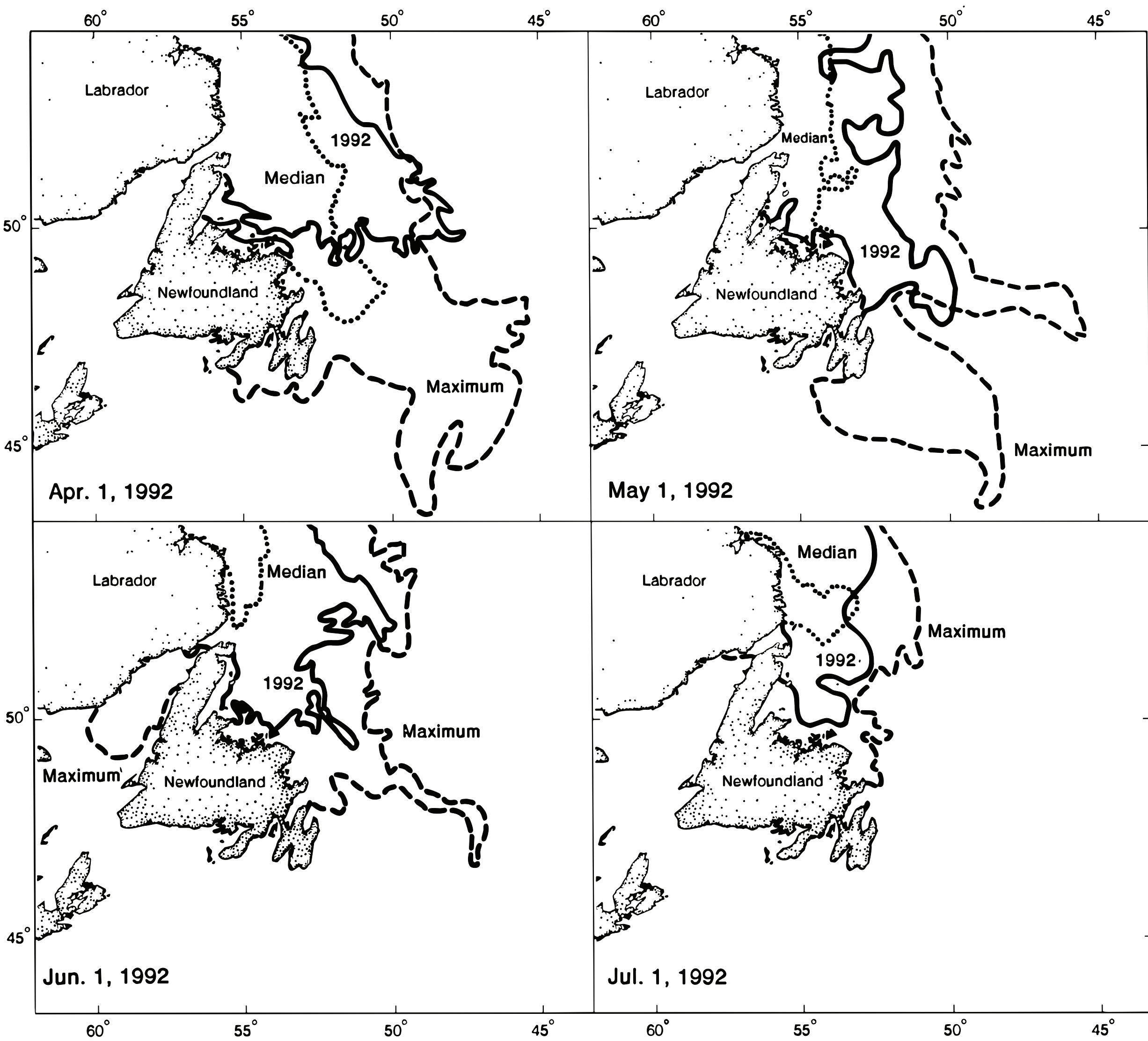


Fig. 9. (Continued). The 1992 ice edge (concentrations of >10%) and its historical (1962–87) median and maximum positions off Newfoundland and Labrador on specific days during the ice season.

land 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 (Fig. 11, Table 1). For the area east of Newfoundland and off southern Labrador, the ice appeared early and typically left late (Fig. 11, 12). An exception was 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 equalling their long-term maxima (Fig. 13). 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. 14. In January through April there has been a general increase in the area of ice over the past 30 years. In addition, there are maxima in the early-1970s, the mid-1980s and the 1990s, corresponding to air temperate minima in the Labrador Sea (Fig. 5) and maxima in the NAO

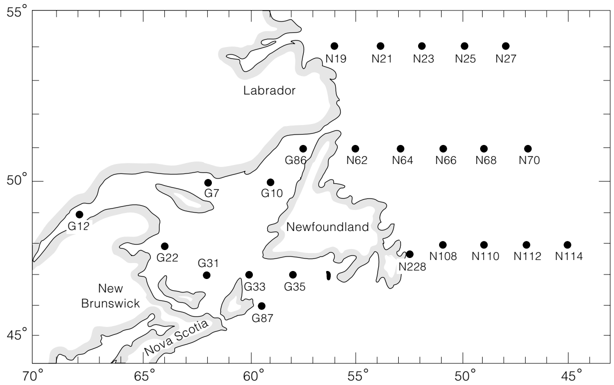


Fig. 10. Locations of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

index (Fig. 7). The 1992 ice 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 1983, data have been collected with Side-Looking Airborne Radar (SLAR). 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. 15). No icebergs were spotted from October, 1991, to January, 1992. This differed slightly from previous years

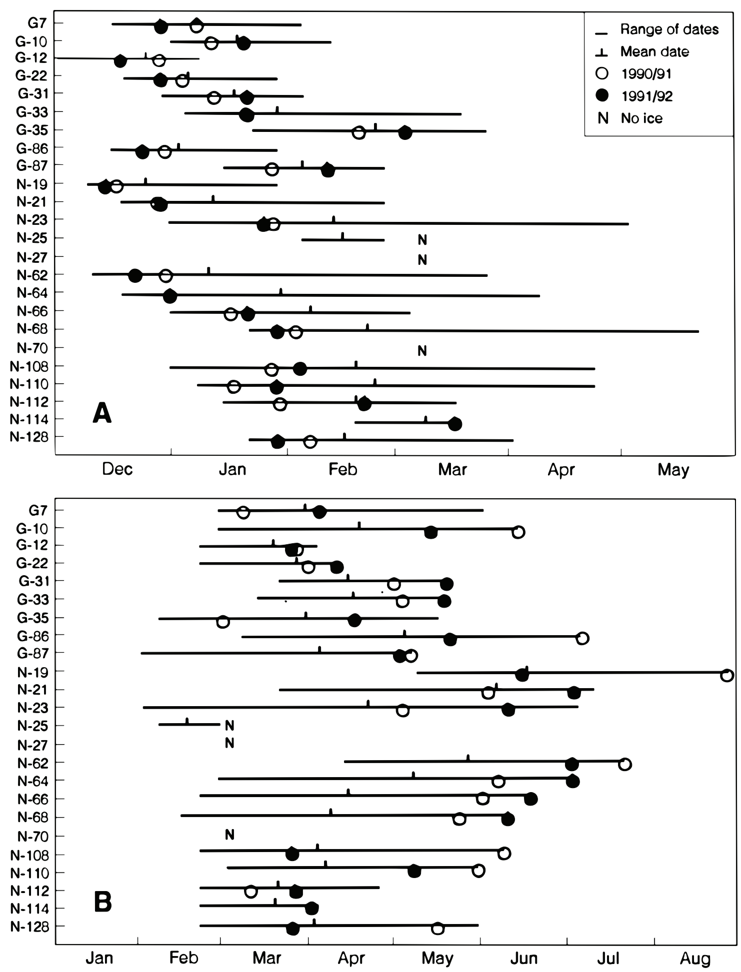


Fig. 11. Ranges of dates for the presence of (**A**) first sea-ice and (**B**) last sea-ice at 24 sites in the Northwest Atlantic (Fig. 10) with mean dates and the 1990/91 and 1991/92 dates. (Ice has never been observed at N27 and N70).

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.

| Site | Seasons studied | No. of years | Years with ice | When ice present Min | Max | Mean | Ice Duration (in weeks) Overall Mean | 1991–92 (1990–91) |
|---|---|---|---|---|---|---|---|---|
| G-7 | 67/68–91/92 | 26 | 26 | 6 | 16 | 10.6 | 10.6 | 13 (12) |
| G-10 | 76/77–91/92 | 17 | 17 | 3 | 17 | 11.9 | 11.9 | 17 (14) |
| G-12 | 67/68–91/92 | 26 | 26 | 2 | 15 | 11.6 | 11.6 | 13 (14) |
| G-22 | 76/77–91/92 | 17 | 17 | 7 | 15 | 12.1 | 12.1 | 15 (14) |
| G-31 | 68/69–91/92 | 25 | 24 | 8 | 17 | 12.6 | 12.1 | 15 (15) |
| G-33 | 71/72–91/92 | 22 | 22 | 2 | 14 | 10.7 | 10.7 | 14 (13) |
| G-35 | 59/60–91/92 | 34 | 18 | 1 | 11 | 3.4 | 1.8 | 1 (2) |
| G-86 | 76/77–91/92 | 17 | 17 | 6 | 23 | 16.4 | 16.4 | 19 (20) |
| G-87 | 70/71–91/92 | 23 | 22 | 1 | 12 | 7.5 | 7.2 | 9 (12) |
| N-19 | 66/67–91/92 | 27 | 27 | 17 | 32 | 23.8 | 23.8 | 25 (24) |
| N-21 | 67/68–91/92 | 26 | 26 | 5 | 28 | 18.5 | 18.5 | 25 (24) |
| N-23 | 59/60–91/92 | 34 | 28 | 1 | 17 | 5.3 | 4.3 | 12 (3) |
| N-25 | 59/60–91/92 | 34 | 2 | 1 | 1 | 1.0 | 0.1 | 0 (0) |
| N-27 | 59/60–91/92 | 34 | 0 | 0 | 0 | 0.0 | 0.0 | 0 (0) |
| N-62 | 67/68–91/92 | 26 | 26 | 8 | 27 | 18.8 | 18.8 | 23 (25) |
| N-64 | 59/60–91/92 | 34 | 33 | 3 | 25 | 13.1 | 12.7 | 21 (24) |
| N-66 | 59/60–91/92 | 34 | 28 | 1 | 17 | 8.4 | 6.9 | 17 (16) |
| N-68 | 59/60–91/92 | 34 | 15 | 1 | 10 | 3.5 | 1.6 | 3 (4) |
| N-70 | 60/61–91/92 | 33 | 0 | 0 | 0 | 0.0 | 0.0 | 0 (0) |
| N-108 | 59/60–91/92 | 34 | 28 | 1 | 17 | 6.2 | 5.1 | 15 (6) |
| N-110 | 59/60–91/92 | 34 | 27 | 1 | 16 | 5.4 | 4.3 | 16 (7) |
| N-112 | 59/60–91/92 | 34 | 14 | 1 | 10 | 3.9 | 1.6 | 5 (4) |
| N-114 | 59/60–91/92 | 34 | 4 | 1 | 2 | 1.5 | 0.2 | 0 (2) |
| N-228 | 59/60–91/92 | 34 | 23 | 1 | 14 | 5.7 | 3.9 | 12 (7) |

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. 15). Several factors would have contributed to the relatively high number of icebergs 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. 16). During the first half of January 1992, above normal air temperatures (by approximately 2°C) resulted in only small amounts of 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 rapid spreading 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 ice still lay between Cape Breton Island, Prince Edward Island and the Magdalen Islands and in the northeastern Gulf but

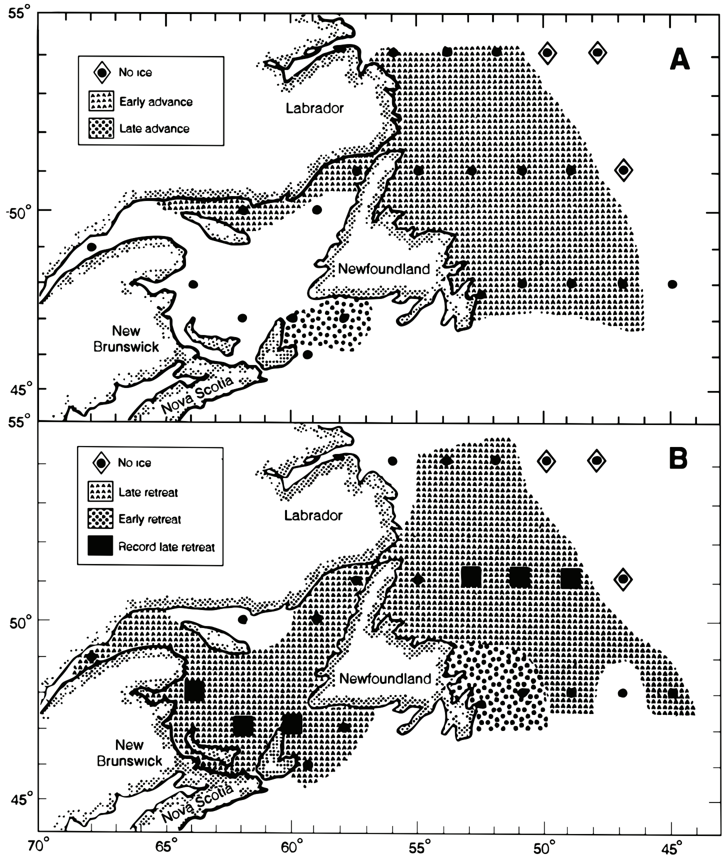


Fig. 12. The presence of (**A**) first and (**B**) last ice (1991/1992) relative to the long-term means at the grid points shown in Fig. 10. Circles not surrounded by shading indicate sites where the ice advance was within 1 week of their mean dates. An early or late advance or retreat refers to differences exceeding 1 week of the mean date. Sites marked as no ice means that ice was not present anytime through the ice season.

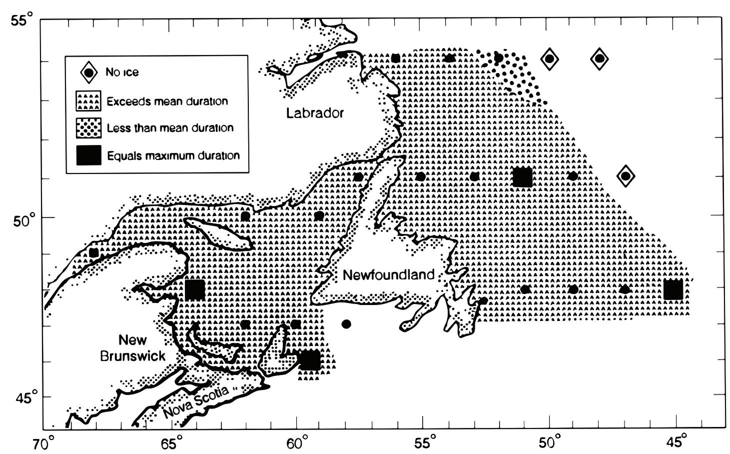


Fig. 13. The duration of ice (1991/1992) relative to the long-term mean at grid points shown in Fig. 10. Circles not surrounded by shading indicate sites where the ice duration was within 1 week of the mean date. Shading indicates a duration longer or less than the mean by greater than 1 week.

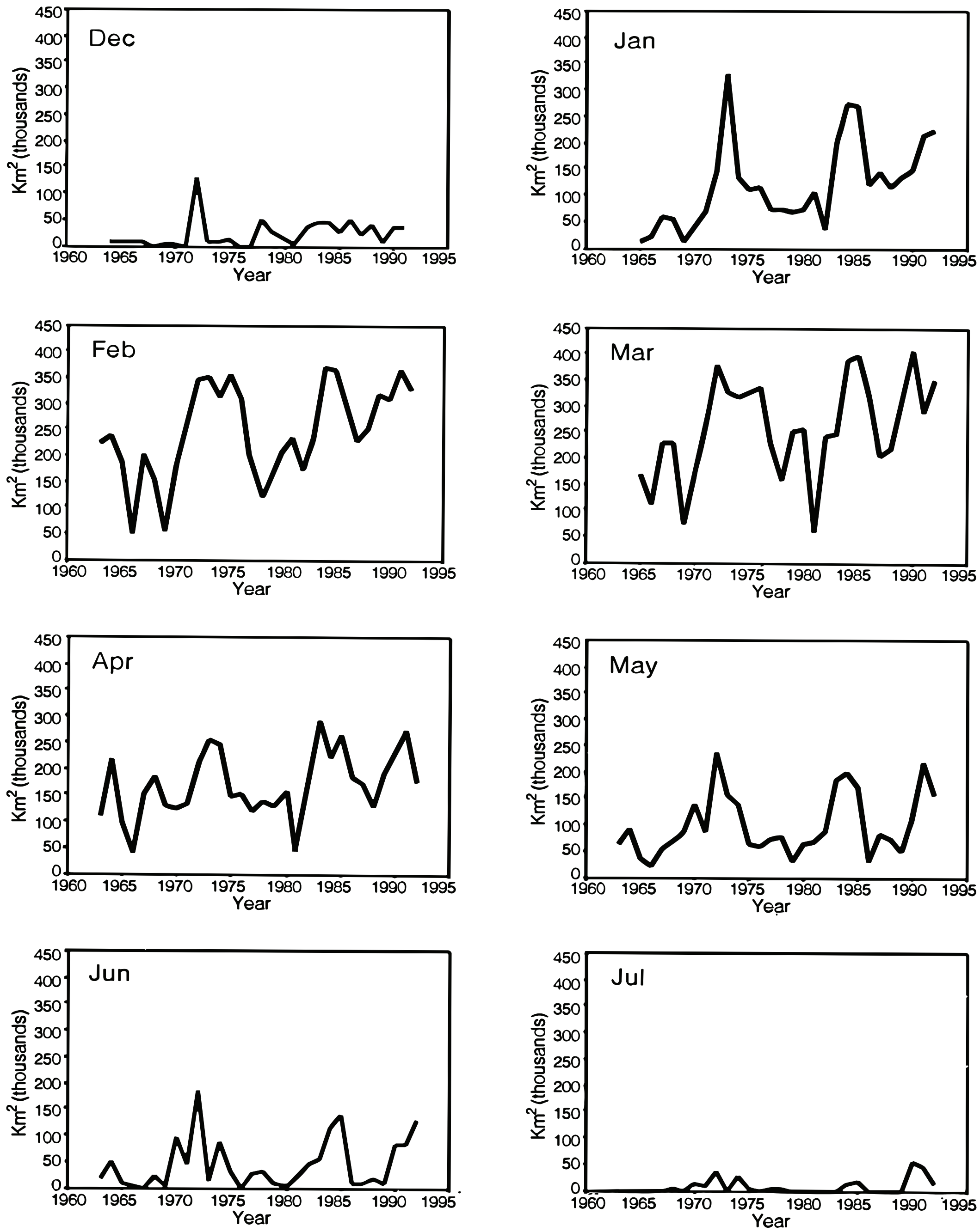


Fig. 14. The time series of the areal extent of ice on the southern Labrador and northern Newfoundland Shelves between 45°N and 55°N by month.

by the end of the month all regions of the Gulf except Belle Isle Strait were generally clear of ice (Fig. 9).

The first presence of ice was early along the northern shore of Quebec but late offshore of Cabot Strait (Fig. 11, 12). 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. 13) was again longer than normal and equalled the maximum on the northwestern Magdalen Shallows (G22) and off the eastern tip of Cape Breton (G87).

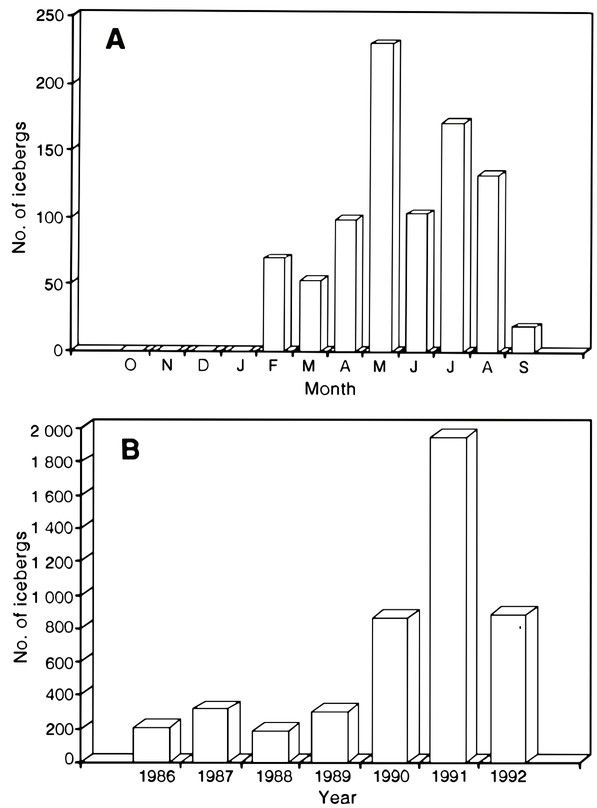


Fig. 15. The monthly number of icebergs (**A**) crossing south of 48°N during the iceberg season 1991/92 and the total number of icebergs (**B**) compared to the previous 6 years.

## Oceanographic Observations

### Fyllas Bank

Hydrographic conditions in West Greenland including the NAFO standard section across Fyllas Bank were monitored during June 1992 by the Royal Danish Administration of Navigation and Hydrography in Copenhagen, Denmark (Buch, MS 1993). 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 1992, the mean temperature on top of Fyllas Bank was up slightly (by 0.2°C) from a minimum in 1990 but was still below the long-term (1951–80) average (by 0.7°C). The temperatures in 1989–92 resembled those obtained during the cold periods of 1969–72 and 1982–84. The recent cold conditions have been attributed to local atmospheric cooling (Buch, MS 1993; Stein, 1995).

### Station 27

Since 1946, temperature and salinity have been routinely monitored at Station 27 located approximately 10 km off St. John's, Newfoundland. This site has been shown to be representative of conditions from southern Labrador to the Grand Bank (Petrie *et al.*, 1992). 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. 17.

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. 17, 18). 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. 18).

Surface salinities at Station 27 were fresher than the long-term mean by as much as 1 psu in February (Fig. 17, 18). 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.* (1994) 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 in Fig. 19. It is noted that the temperature scale for 0 and 50 m was 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 1960s (not shown) were above

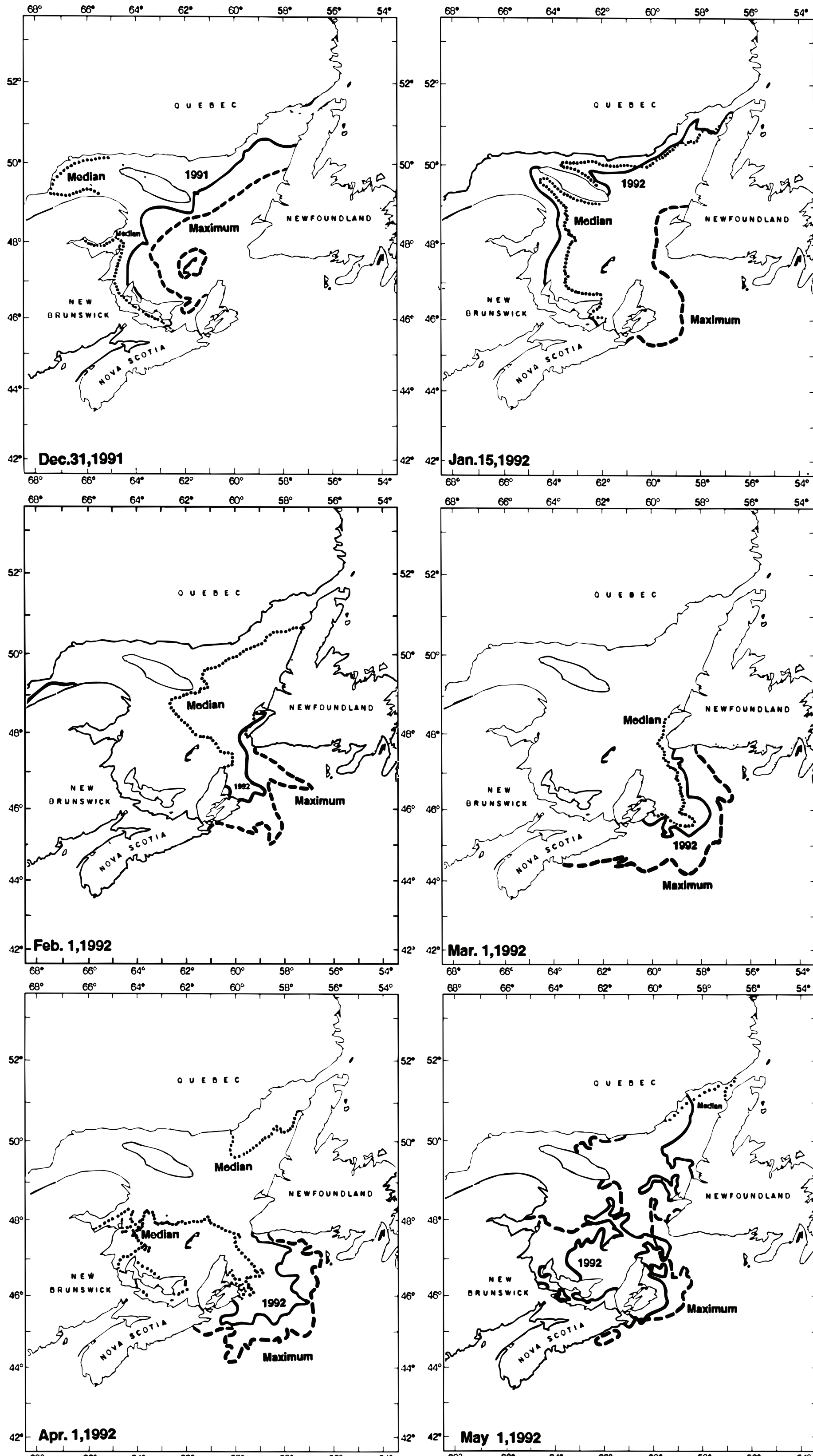


Fig. 16. The 1992 ice edge (concentrations of >10%) and its historical (1962–87) median and maximum positions in the Gulf of St. Lawrence on specific days during the ice season.

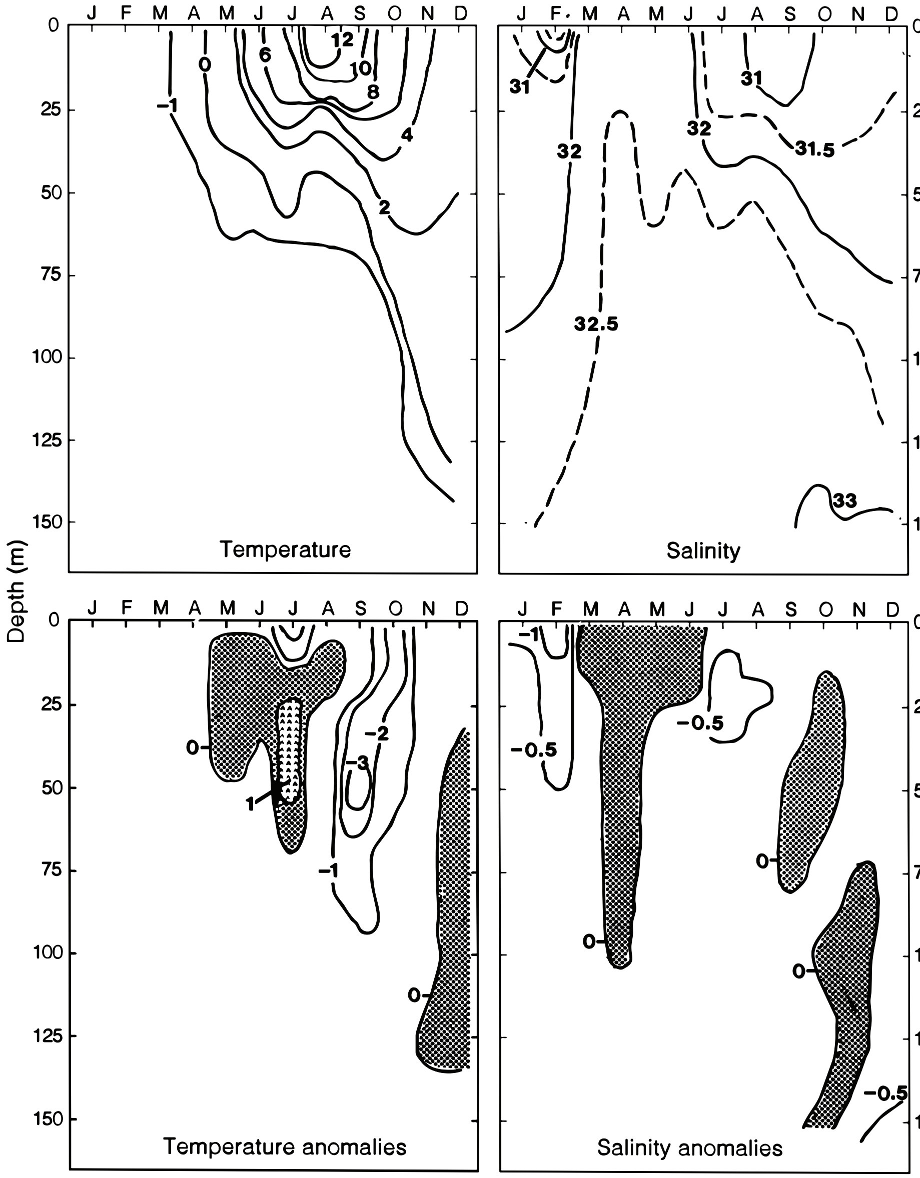


Fig. 17. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1992 relative to the 1951–80 means. Shaded areas are positive anomalies.

average). At 100, 150 and 175 m negative anomalies have persisted almost continuously since 1983. The coldest periods roughly corresponding 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.

**Cold intermediate layer**

On the continental shelves off eastern Canada from Labrador to the Scotian Shelf, intense vertical 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 downward heat transfer, and the waters below remain cold throughout the spring and summer. The latter are called the Cold Intermediate Layer (CIL) waters.

Three standard hydrographic transects (Seal Island (across Hamilton Bank), off Bonavista Bay and along 47°N) are occupied each year during the summer by the Northwest Atlantic Fisheries Centre

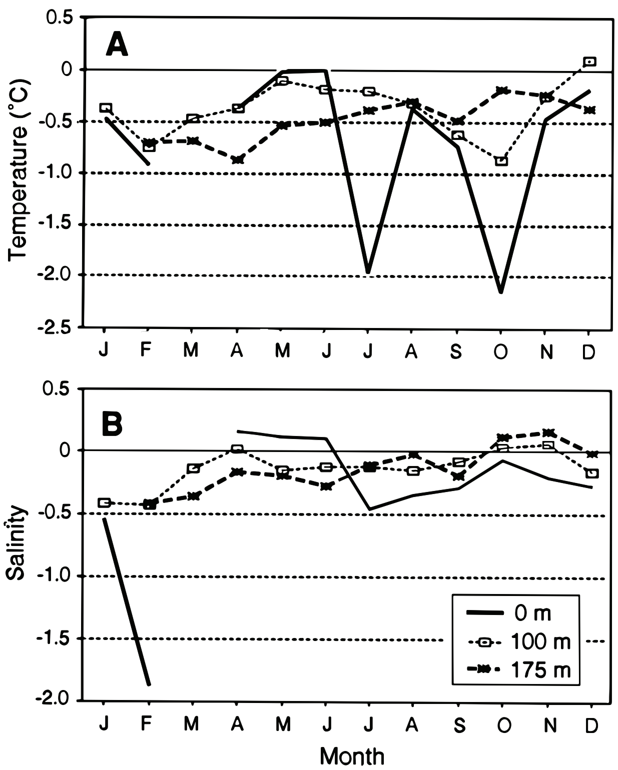


Fig. 18. Monthly (**A**) temperature anomalies and (**B**) salinity anomalies at 0, 100, and 175 m at Station 27 during 1992.

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 1951–80. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects. In 1992 the CIL was above normal by 20–40% but decreased from the peak values in 1990 and 1991. Other maxima occurred in 1972 and 1984–85, with distinct minima in the mid-1960s, the mid- to late-1970s and 1986–87 (Fig. 20). The timing of the CIL maxima corresponded roughly with minima in the water and air temperatures and maxima in ice coverage, as noted earlier by Petrie *et al.* (1992).

### Offshore sea-surface temperature data

Averaged sea-surface temperature (SST) data from the "marine deck" observations (obtained primarily from ships-of-opportunity through the ship's intake and research vessels) were supplied by the U.S. National Marine Fisheries Service. The monthly SST anomalies for 19 regions along the continental shelf from Chesapeake Bay to southern Labrador (Fig. 21) for 1992 were compared to earlier years (Fig. 22). Negative SST anomalies developed in the Middle Atlantic Bight (areas 1–4) during

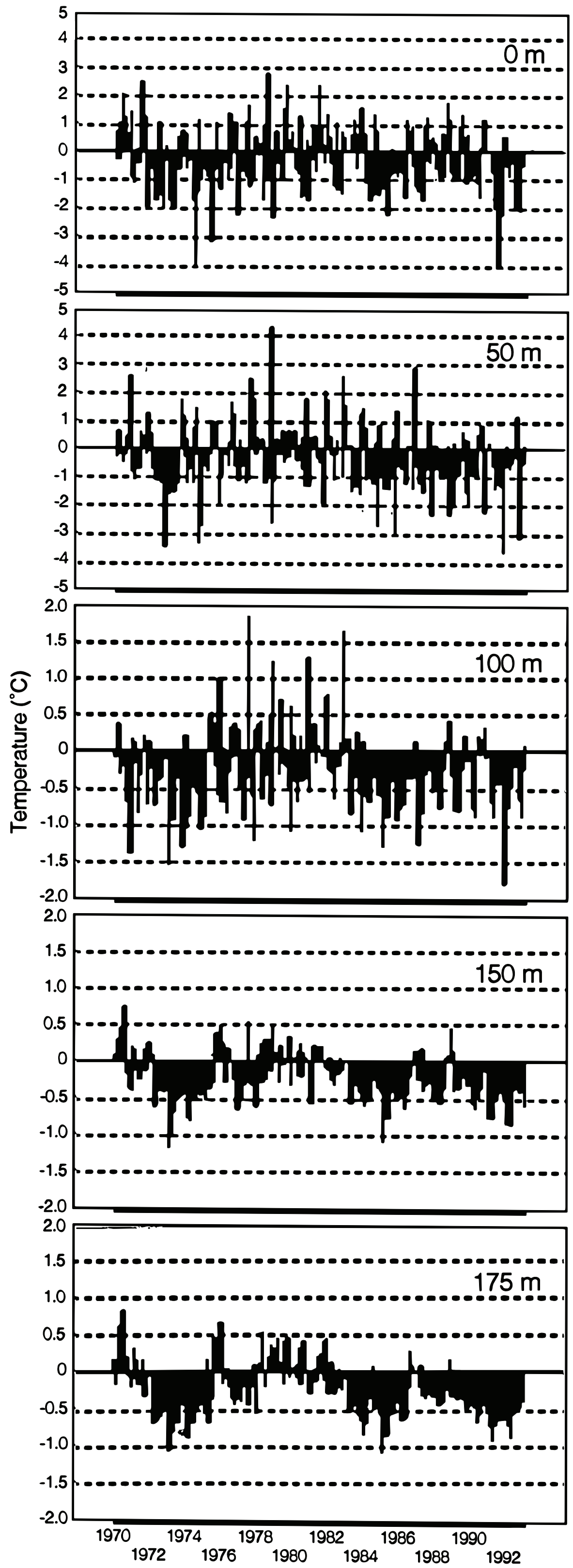


Fig. 19. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27 (1970–92).

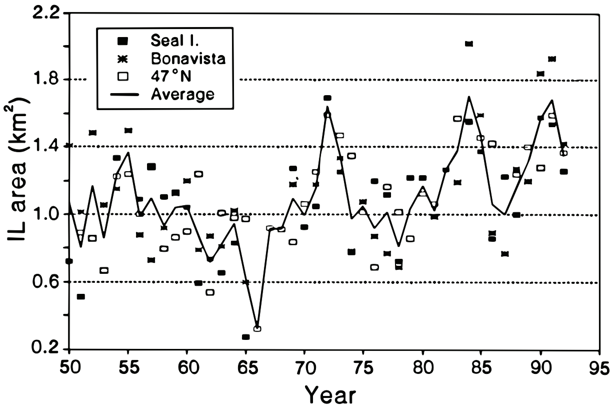


Fig. 20. The area of the cold intermediate layer (<0°C) (CIL) for the three standard sections off southern Labrador and northern Newfoundland.

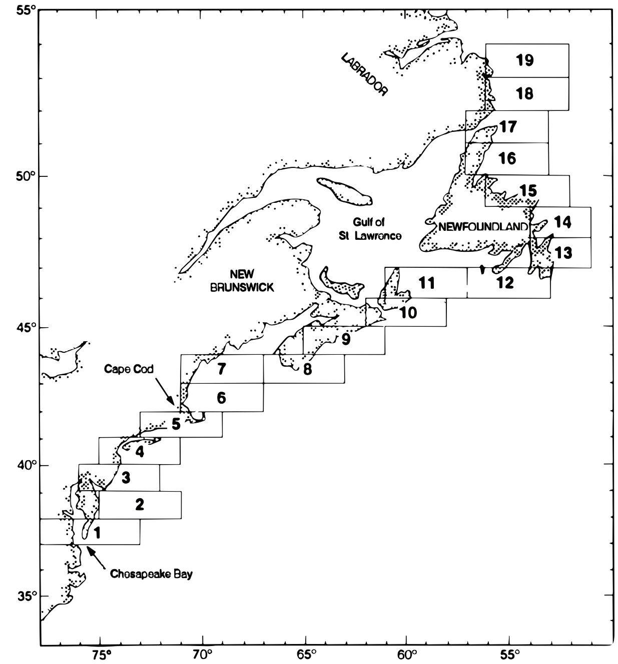


Fig. 21. Locations of 19 areas in the Northwest Atlantic (Chesapeake Bay to southern Labrador) for which sea-surface temperature data were grouped for analysis.

the spring and continued into the autumn. In the north, negative anomalies were observed with the largest values during the summer between Cape Race and Hamilton Bank. By autumn, however, SST anomalies rose to over 1°C above normal off northern Newfoundland (areas 14–17). From Cape Cod to Cape Race SSTs were generally near normal although they exceeded 1°C off Cape Breton (areas 10 and 11) during September (Fig. 22).

Sea-surface temperature anomalies were also determined for a larger region of the Northwest Atlantic (35°–60°N, 40°–76°W) extending from the southern boundary of the NAFO area northward to southern Greenland. As in past reviews (e.g. Drinkwater *et al.*, 1994a), the region was divided into 24 smaller areas (Fig. 23) to coincide with major water masses (Labrador Current, Gulf Stream, etc.) or fishing banks (LaHave, Georges, etc.). The monthly mean temperature for each area was computed for 1992. The annual anomalies for 1988–92 and the mean annual temperature for the base period (1972–90) are listed in Table 2. The means and anomalies varied slightly from those in previous reviews because the latter were determined relative to 1972–80. A space-time plot of the annual anomalies for the 24 areas during the 1972–92 period is shown in Fig. 24.

The 1992 annual pattern showed predominantly negative SST anomalies over the Labrador Shelf, the Grand Bank, the Gulf of Maine and the Middle Atlantic Bight (Fig. 24, 25; Table 2). Slightly warmer-than-normal conditions prevailed in the Labrador Sea, the Gulf of St. Lawrence and offshore in the Slope Water between the Scotian Shelf and the Grand Bank. The peak negative anomalies were recorded in the offshore branch of the Labrador Current (-0.86°C) and on the Middle Atlantic Bight (-0.67°C). Peak positive anomalies were recorded in the Slope Water (>0.6°C). This represents the third consecutive year of below normal SSTs in the area of the Grand Bank and Labrador Shelf. In contrast, the cold temperatures over the Middle Atlantic Bight represented a change from warmer-than-normal conditions observed over the past 3 years. The similarity in the sign of the SST anomalies on the Grand Bank and the mid-Atlantic Bight differs from the out of phase temperature trends between these two areas that had been prominent through most of the 1980s and the early-1990s (Fig. 24).

The time series of annual mean anomalies of SST for the 24 areas are shown in Fig. 26. The 1992 values on the Labrador Shelf, in the Labrador Current, on Flemish Cap and on the central Grand Bank were at or near the minima recorded in the mid-1980s and the mid-1970s. In these regions, the recent temperatures have declined by 0.5–1°C from highs in 1988. In the Gulf of St. Lawrence, off southwestern Newfoundland and on the Scotian Shelf, the annual anomalies were near normal. A significant decrease in the SST anomalies between 1991 and 1992 were recorded on the continental shelves from the LaHave Bank south. The largest drop was recorded in southern New England and on the Middle Atlantic Bight. For the second year in a row, the Slope Water in the eastern area was warmer-than-

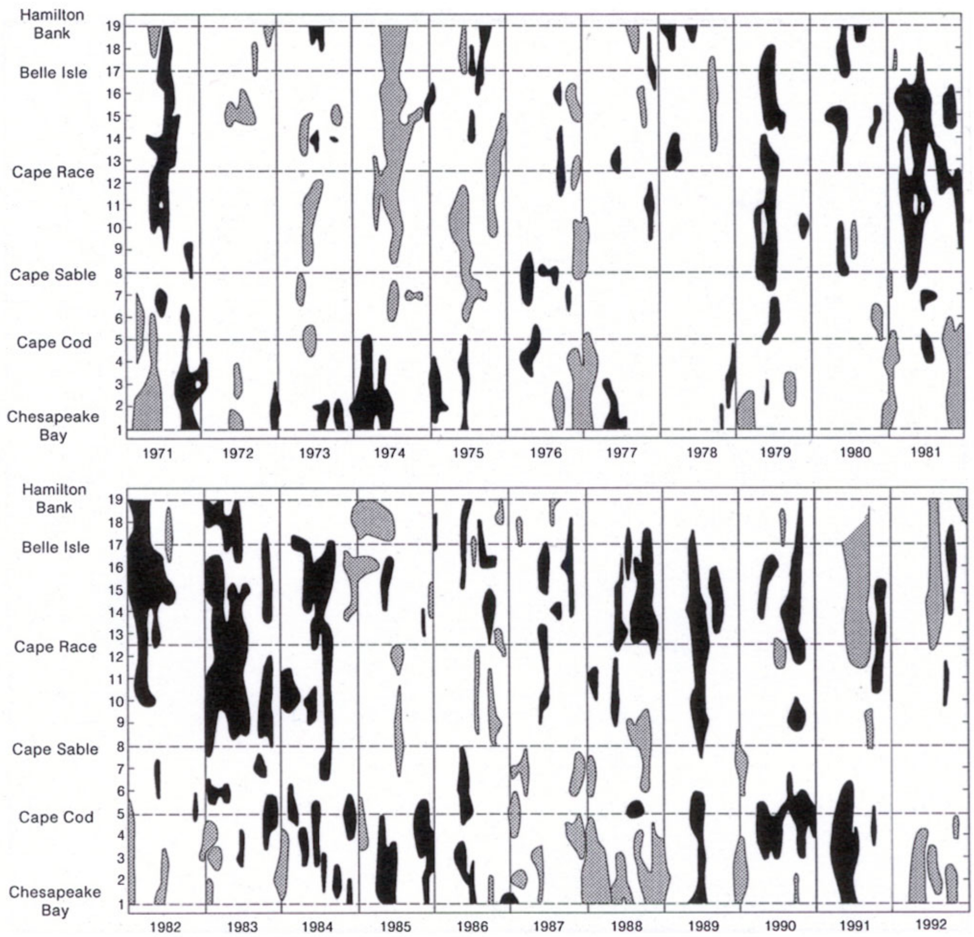


Fig. 22. Contoured monthly sea-surface temperature anomalies (relative to the 1971–80 means) for the 1971–92 period by area (Fig. 21). (Only anomalies exceeding 1°C (black) and less than -1°C (dotted) which extended in space through at least two neighbouring areas and in time for at least two consecutive months have been contoured.)

normal while in the western region it was colder-than-normal. Temperature variability in the Gulf Stream and Sargasso Sea has been low through the period 1971–92.

### Coastal sea-surface temperature 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. 27. 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, the means were calculated from temperatures measured 6 times daily with a thermistor located on the wharf at the Biological Station. These data were further adjusted based upon 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. 27). 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 (equalling the long-term mean) at Boothbay

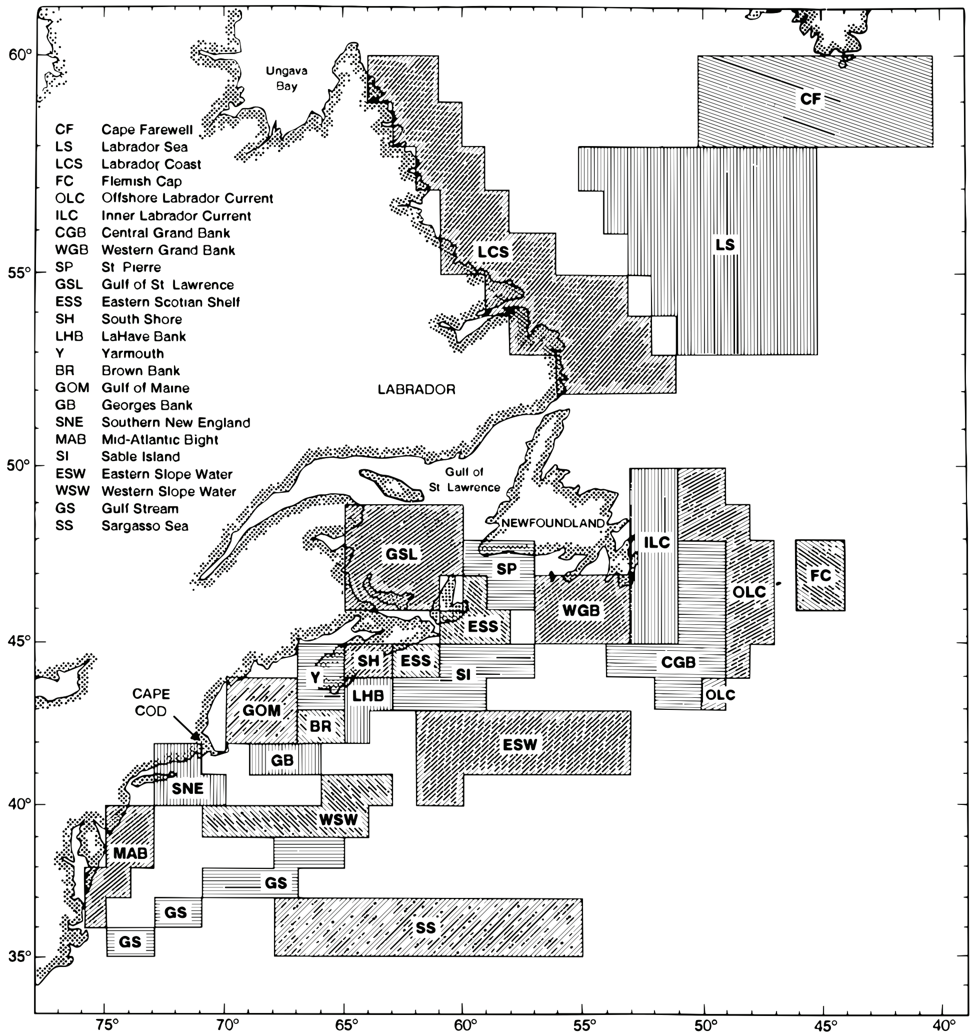


Fig. 23. The geographic boundaries of the 24 subregions for which sea surface temperatures were analyzed on a monthly basis.

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 revealed that the temperatures at all three sites had decreased since 1991 (Fig. 28). This reverses the recent trend of increasing temperatures observed over the previous 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 coincided with the reconstruction of the wharf at St. Andrews Biological Station where the measurements were recorded. Drinkwater *et al*. (MS 1992) noted inconsistencies in SSTs at St. Andrews between the pre- and post-reconstruction periods through comparisons with data from Prince 5, a standard hydrographic station at the mouth of the Bay of Fundy (see below). Differences in SSTs between the two sites were significantly greater after the reconstruction with St. Andrews being lower than Prince 5. They speculated that the negative anomalies in the late-1980s and early-1990s at St. Andrews may have been, in part, due to changes in the flow characteristics in and around the wharf.

**Temperatures and salinities in the Mid-Atlantic Bight**

Monthly monitoring of water column temperatures and surface salinities on a transect extending seaward from New York Harbor across the shelf into the Slope Water by the Northeast Fisheries Science Center in Narragansett, Rhode Island, continued in 1992 for the seventeenth consecutive year (Benway *et al*., MS 1993). The near surface annual average temperature was found to be approximately 0.5°C cooler than the long-term mean (1978–91) which is consistent with the marine deck SST data

TABLE 2. Mean sea-surface temperatures for selected areas of the Northwest Atlantic in 1971–90 and anomalies for 1988–92 relative to the base period. (Geographic locations of water masses are shown in Fig. 24. Blank space indicates that annual average not computed when data missing for one or more months.)

| Water mass | Mean temp. 1971–90 | Annual anomalies (°C) 1988 | 1989 | 1990 | 1991 | 1992 |
|---|---|---|---|---|---|---|
| CF | 4.22 | 0.57 | -0.10 | 0.15 | 0.09 | 0.20 |
| LS | 5.57 | 0.17 | -0.03 | -0.34 | -0.10 | 0.24 |
| LCS | 2.05 | -0.28 | -0.57 | | | |
| OLC | 5.18 | 0.07 | 0.01 | -0.38 | -0.81 | -0.86 |
| ILC | 5.11 | 0.57 | 0.46 | -0.07 | -0.41 | -0.43 |
| FC | 7.88 | 0.52 | 0.04 | -0.46 | -0.85 | -0.68 |
| CGB | 6.77 | 0.74 | 0.47 | -0.12 | -0.73 | -0.57 |
| WGB | 6.34 | 0.41 | 0.13 | -0.15 | -0.62 | -0.04 |
| SP | 6.14 | 0.19 | -0.22 | -0.22 | 0.23 | -0.13 |
| GSL | 6.00 | 0.15 | 0.11 | -0.11 | 0.12 | 0.21 |
| ESS | 7.29 | -0.15 | 0.26 | 0.01 | 0.22 | 0.11 |
| SI | 8.38 | -0.29 | 0.42 | -0.28 | -0.25 | -0.05 |
| SH | 8.07 | -0.34 | 0.45 | 0.17 | 0.04 | -0.12 |
| LHB | 8.92 | -0.67 | 0.14 | 0.06 | 0.61 | -0.19 |
| BR | 9.00 | -0.01 | 0.51 | 0.63 | 0.43 | 0.03 |
| Y | 7.64 | 0.05 | 0.38 | 0.27 | 0.22 | -0.35 |
| GOM | 9.65 | -0.45 | 0.14 | 0.15 | 0.08 | -0.47 |
| GB | 10.17 | -0.30 | 0.09 | 0.45 | 0.36 | -0.42 |
| SNE | 12.34 | -0.30 | 0.57 | 1.33 | 0.73 | -0.35 |
| MAB | 14.89 | -1.17 | 0.11 | 0.45 | 0.93 | -0.67 |
| ESW | 15.64 | -0.04 | 0.51 | 0.19 | -0.24 | 0.59 |
| WSW | 18.21 | -0.53 | -1.07 | -0.62 | -0.63 | -0.45 |
| GS | 22.99 | -0.16 | 0.14 | 0.40 | 0.01 | 0.14 |
| SS | 22.25 | 0.25 | 0.19 | 0.16 | 0.04 | -0.10 |

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

discussed above. Surface salinities were 0.7 psu above normal averaged over the year due to high values near shore in January through March and in July and August and at the shelf break during June and July. Bottom temperatures averaged 0.3°C cooler for the transect during the year.

### Temperatures and salinities in the Gulf of Maine

The Northeast Fisheries Science Center also occupies a transect across the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf (Benway *et al.*, MS 1993). Surface and bottom temperatures and surface salinities have been collected monthly for the past sixteen years. In 1992 below normal (relative to 1978–91 mean) SSTs were recorded during January through May and in the autumn resulting in an annual average of 0.6°C below the long-term mean for the entire transect. Surface salinities were 0.4 psu below normal on average in 1992. Bottom temperatures in the Gulf of Maine were generally near normal during the year with an average anomaly over the transect of -0.1°C. The negative anomaly was due primarily to the cold bottom temperatures on the Scotian Shelf where anomalies were -0.9°C for the year.

### 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

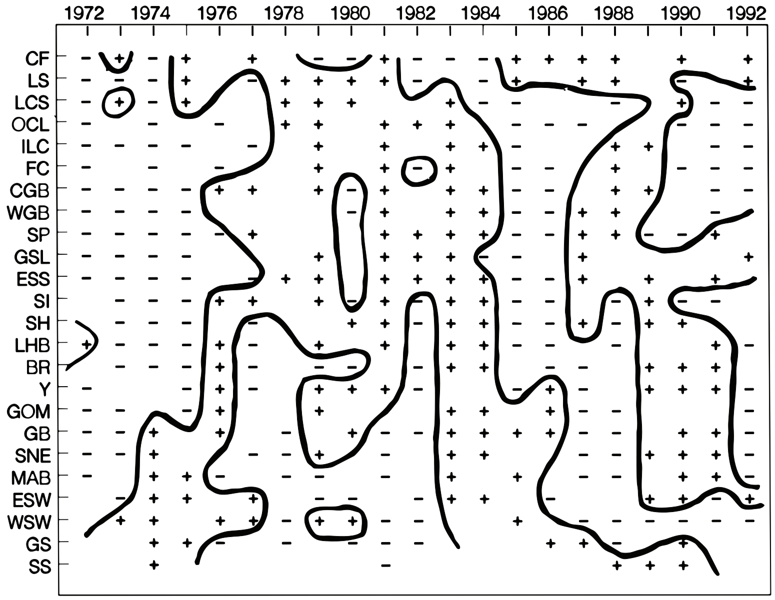


Fig. 24. Distribution of positive (+) and negative (-) annual sea-surface temperature anomalies in 1972–92 by subregion (Fig. 23) relative to the 1972–90 means. (Only anomalies less than -0.15°C and greater than +0.15°C were used in drawing the contours.)

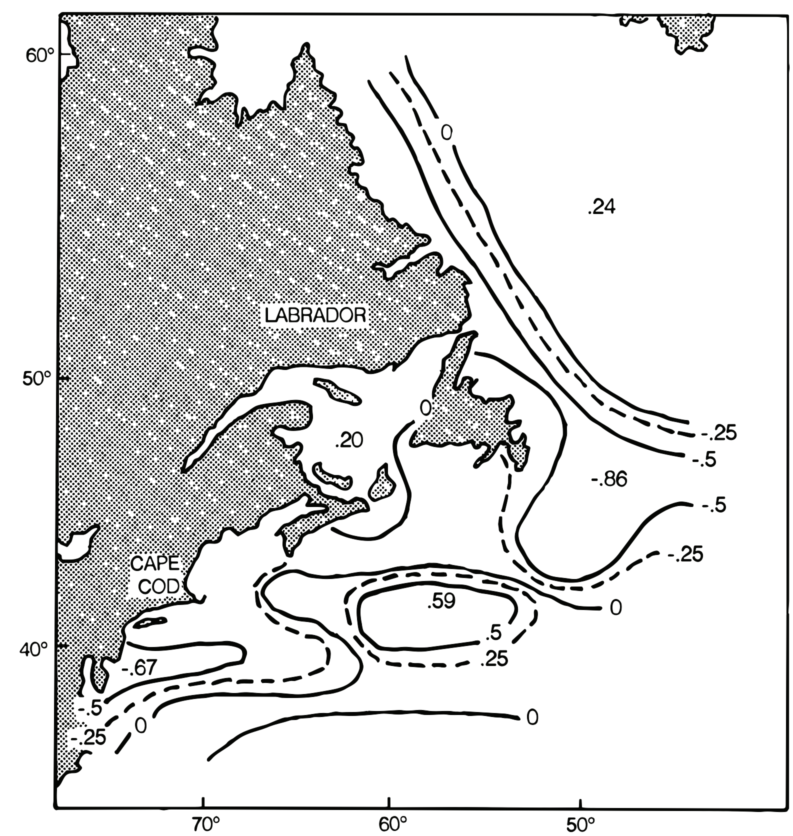


Fig. 25. Contours of the annual mean sea-surface temperature anomalies in 1992 for 24 areas in the NW Atlantic Ocean.

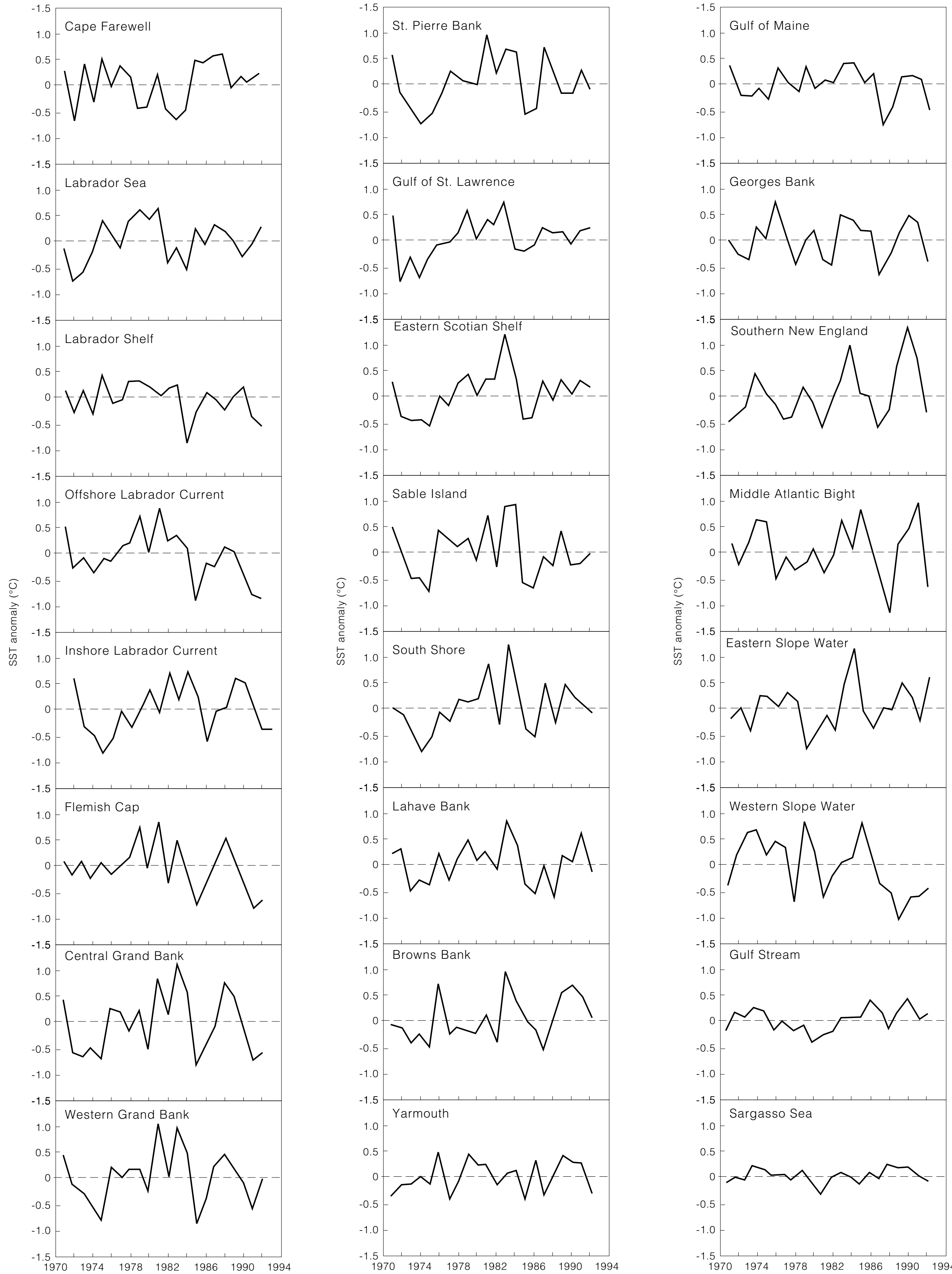


Fig. 26. The annual temperature anomalies (relative to 1971–90) for the offshore areas shown in Fig. 23.

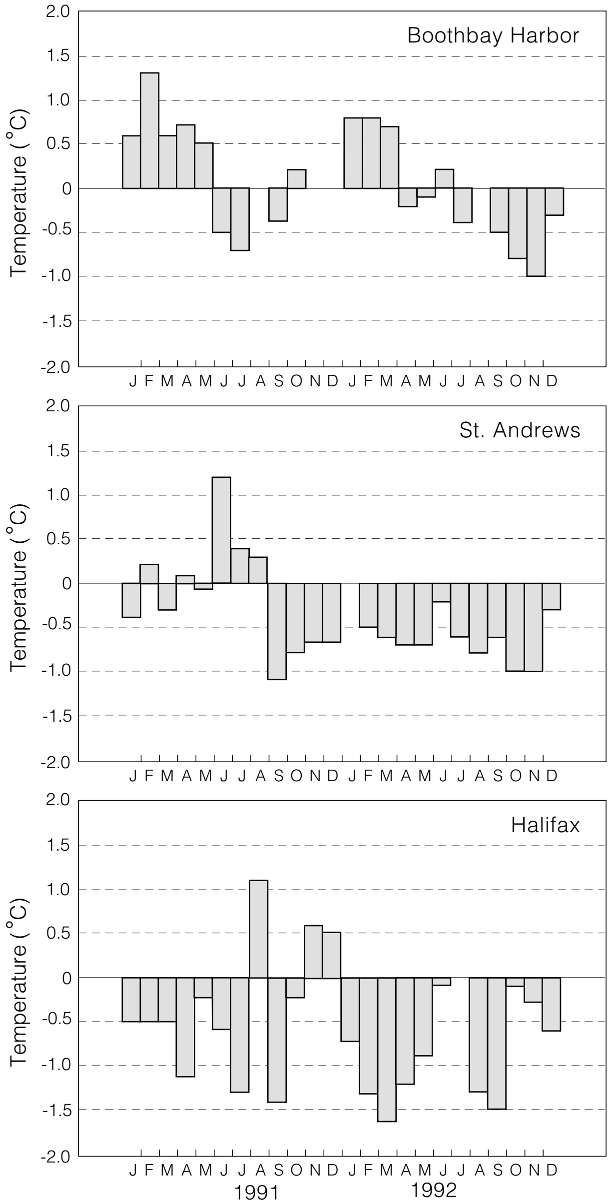


Fig. 27. The monthly sea surface temperature anomalies (relative to 1951–80) during 1991–92 for Boothbay Harbor, St. Andrews and Halifax.

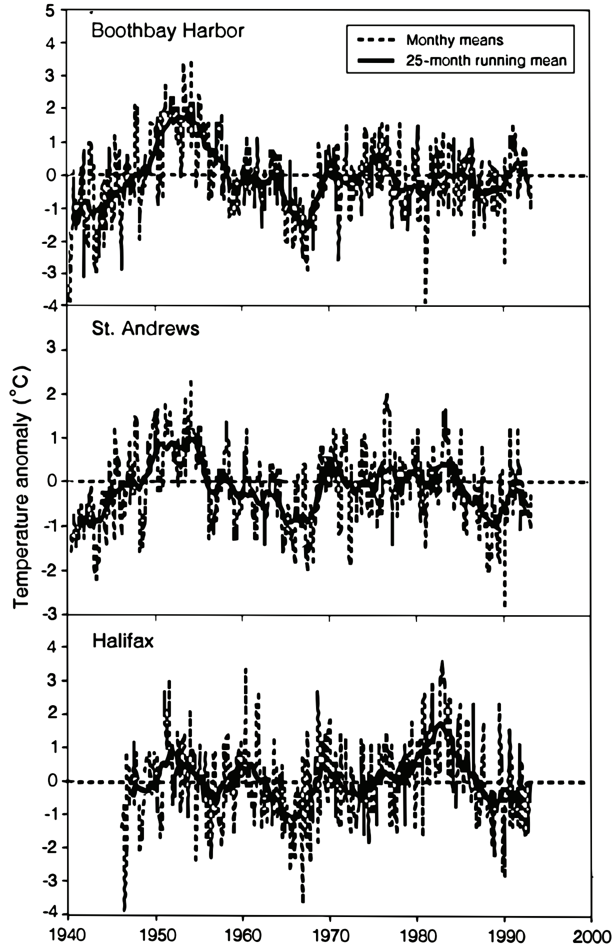


Fig. 28. The monthly means and the 25-month running means of the sea surface temperature anomalies (relative to 1951–80) for Boothbay Harbor, St. Andrews and Halifax.

Bay of Fundy. Monthly anomalies relative to the 1951–80 means were calculated for 1992. Single measurement 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 with depth of both temperature and salinity. This relative vertical homogeneity is principally due 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. 29). 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 showed high similarity (Fig. 30). The annual anomalies in 1992 were -0.7°C at both the surface and bottom (90 m), a decrease from the 1991 means. The dominant high and low at both depths were in the early-1950s and the mid-1960s, respectively, with recent

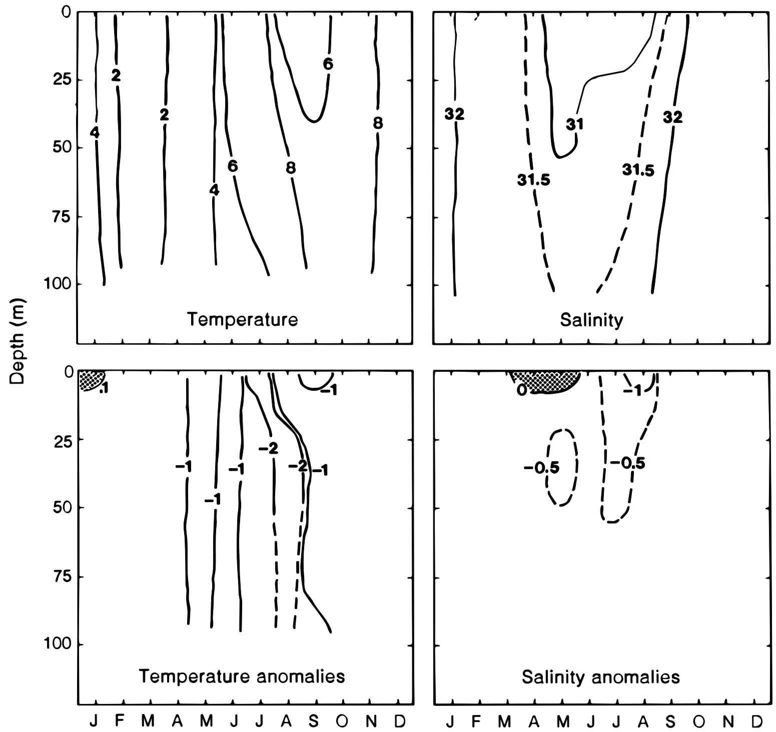


Fig. 29. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1992 relative to the 1951–80 means. Shaded areas are positive anomalies.

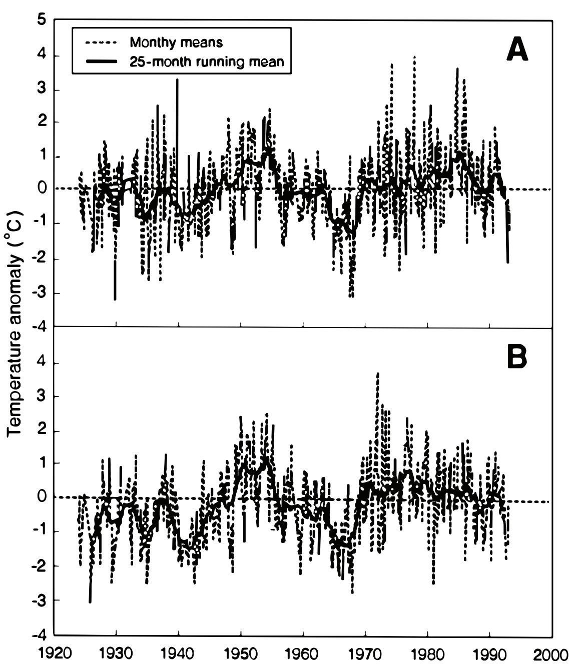


Fig. 30. The monthly means and the 25-month running means of the temperature anomalies for Prince 5, (**A**) 0 m and (**B**) 90 m.

values near the long-term mean (Fig. 30). There has, however, been a gradual decrease since the late-1970s at 90 m and the mid-1980s at the surface.

Salinities at Prince 5 during 1992 indicated that the water was fresher-than-normal throughout the water column except in the very surface waters in April and May (Fig. 29). 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 appear in the spring penetrated deeper in the water column in 1992 and persisted longer than normal.

## Emerald Basin temperatures

Petrie and Drinkwater (1993) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (decadal periods). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (year-to-year) variability. High coherence at these low frequencies was found throughout the water column as well as horizontally from the Mid-Atlantic Bight to the Laurentian Channel although year-to-year differences were observed. Six CTD profiles or BATFISH traces were obtained in Emerald Basin during 1992. The time series of temperatures from 250 m are plotted in Fig. 31 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°C to 2°C above normal. These anomalies were representative of conditions below 75 m. The rise in temperature was believed to be due to an intrusion of warm slope water late in 1991 or early in 1992. 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 measurements of SST 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. He also developed a deep water temperature index using data from 200–300 m from Cabot Strait. The updated index shows that temperatures declined steadily between 1988 and 1991 to their lowest value since the late-1960s (near 4.5°C) and an anomaly exceeding -0.5°C; Fig. 32). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.2°C). This rapid increase was consistent with the temperature pattern in the deep waters in Emerald Basin and most likely reflected 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 waters masses is called the shelf/slope front and its surface expression is regularly detected in satellite thermal imagery. 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 from 1973 to 1992 (Drinkwater *et al.*, 1994b). Prior to May 1978, the charts only covered the region northward to Georges Bank, but in June 1978 the areal coverage was extended to include the Scotian Shelf and the Grand Bank. The time series consists 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 1973–90 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 anomaly.

The overall average position of the shelf/slope front together with the minimum and maximum monthly mean values are shown in Fig. 33. The mean position lay close to the 200 m isobath along the mid-Atlantic Bight, separated slightly from the shelf edge off Georges Bank and then running between

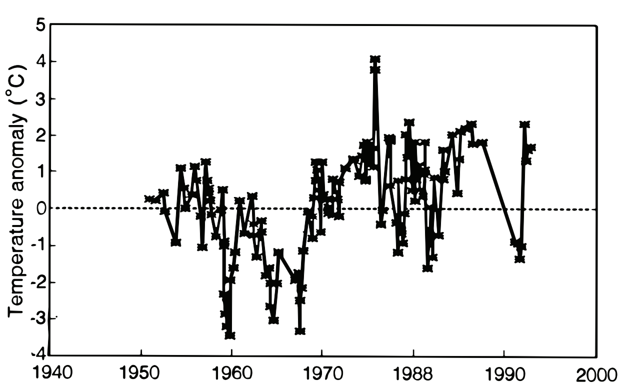


Fig. 31. Temperature anomalies (relative to 1951–80) at Emerald Basin at 250 m.

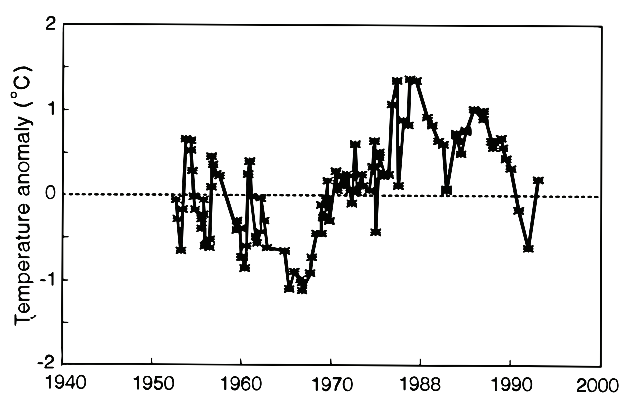


Fig. 32. Temperature anomalies (relative to 1951–80) for 200–300 m in Cabot Strait.

100–300 km from the shelf edge off the Scotian Shelf and the southern Grand Bank. In 1992, the shelf/slope front between 75°W (Cape Hatteras) and 65°W (eastern Georges Bank) lay near its long-term average (Fig. 34). 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 Bank. The latter continue the trend of southerly anomalies begun just prior to or during 1990 (Fig. 35). 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 obtained from Drinkwater *et al.* (1994b). 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 of the Gulf Stream along a single degree of longitude, the average position was used. The long-term mean position of the north wall of the Stream is shown in Fig. 36. The Stream was observed to leave the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position of the Stream lay east-west. During 1992 the Gulf Stream was positioned north of its mean location by an average of approximately 0.3°–0.4° latitude (ca 35–45 km; Fig. 37). A northward displacement of the Gulf Stream was also noted by Sigaev (MS 1993). This displacement may 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 3 to 4 years (Fig. 38). There is high variability at each degree of longitude 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 generally 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 Bank* reports

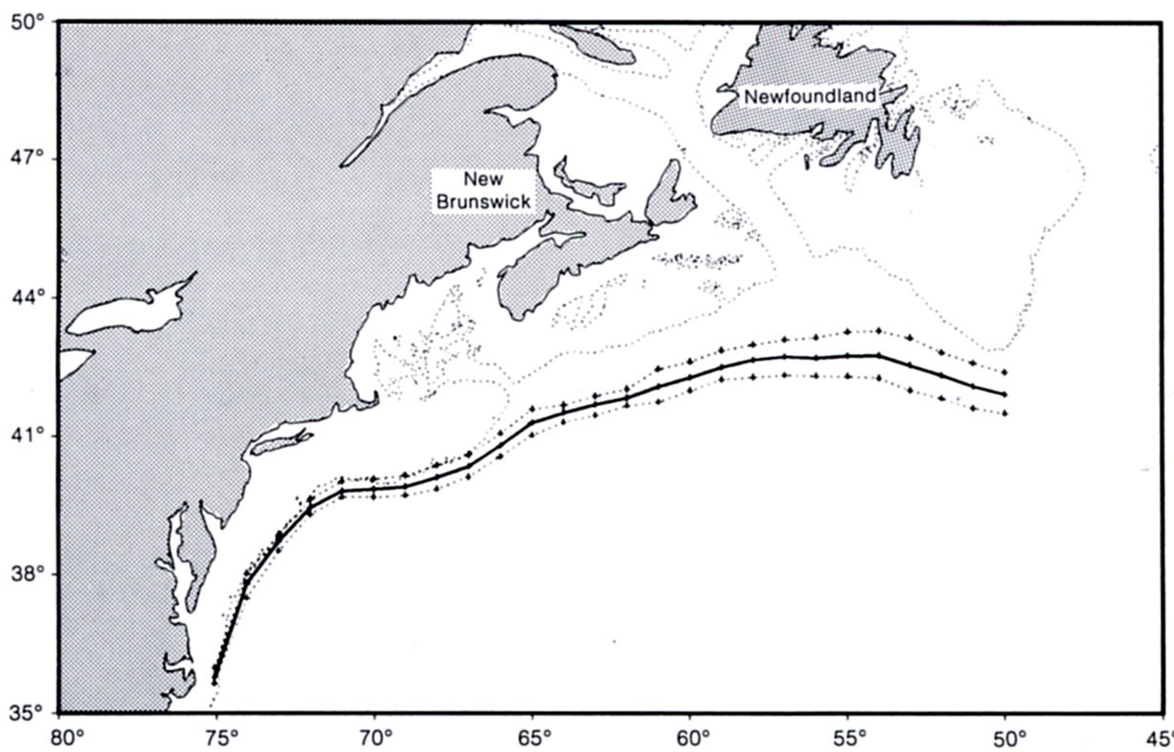


Fig. 33. The long-term (1973–90) mean position of the shelf/slope front and the maximum and minimum of the monthly averages.

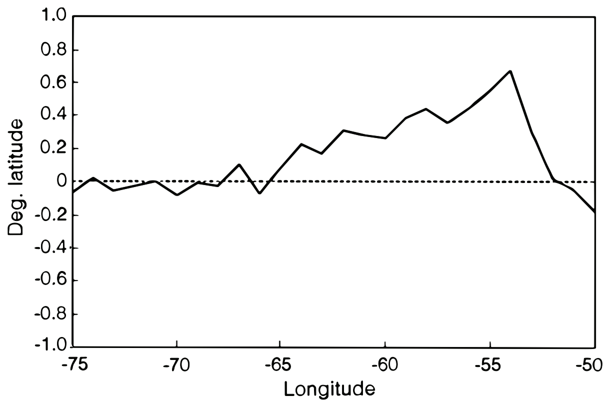


Fig. 34. The 1992 anomalies of the shelf/slope frontal position as a function of longitude relative to the long-term mean location.

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 frequent 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 days 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. 39. Only 1 ring formed west of 65°W and a maximum of 4 were generated in 62.5°W to 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°W 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

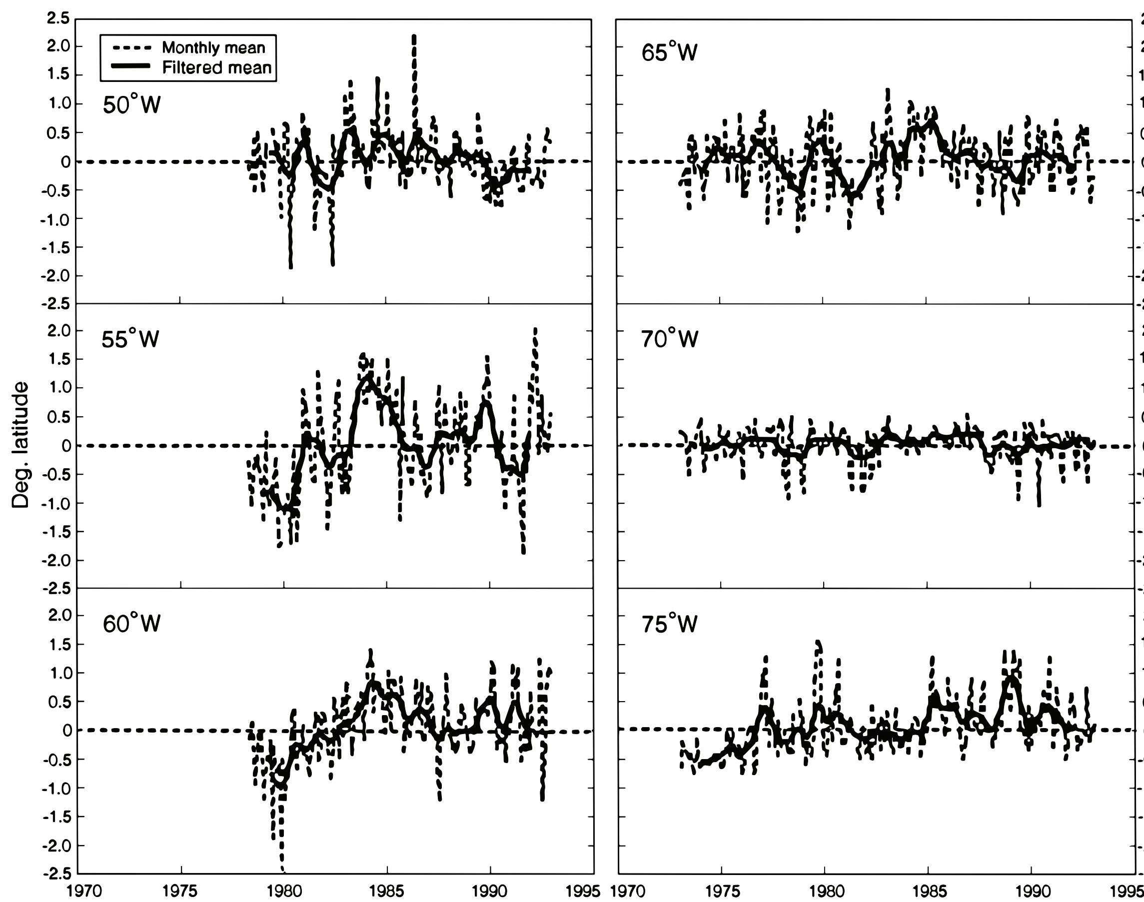


Fig. 35. The monthly and low-pass filtered time series of the anomalies of the shelf/slope frontal position at each 5° of longitude between 50°W and 75°W.

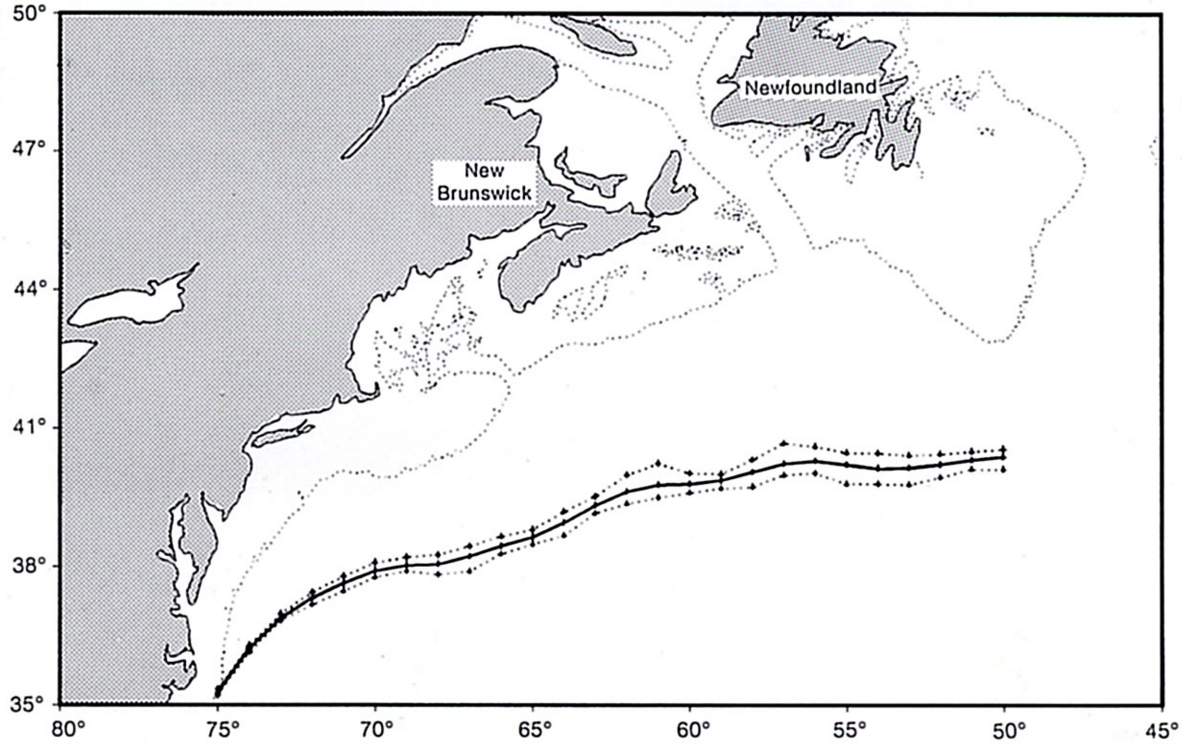


Fig. 36. The long-term (1973–90) mean position of the northern boundary of the Gulf Stream and the maximum and minimum of the monthly averages.

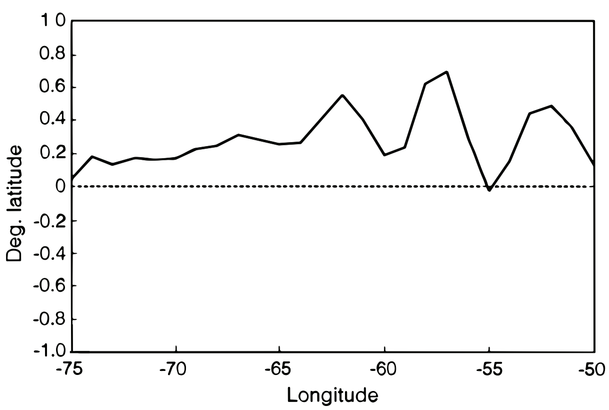


Fig. 37. The 1992 anomalies of the Gulf Stream frontal position as a function of longitude relative to its long-term mean location.

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 led 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 the trend of below normal temperatures observed since the early-1980s. Bottom temperatures did, however, rise slightly through the year. The areal extent of the CIL was above normal but had decreased from a maxima in 1990–91. 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 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 were generally located north of their mean positions.

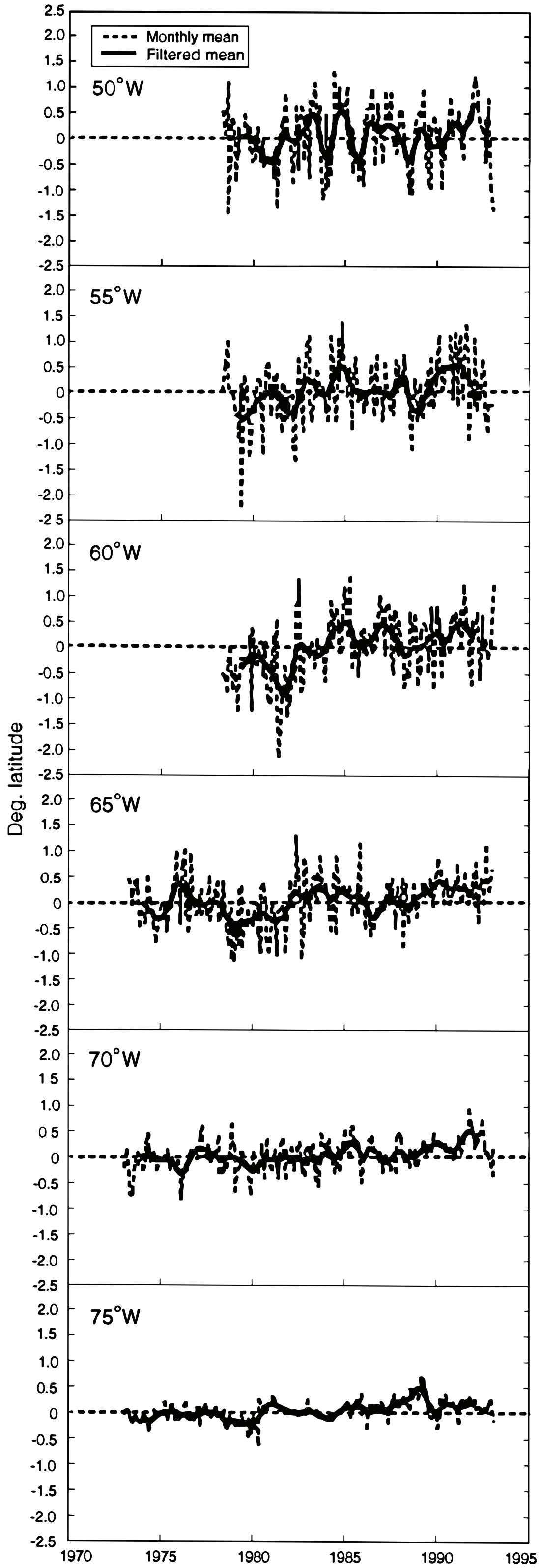


Fig. 38. The monthly and low-pass filtered time series of the anomalies of the Gulf Stream frontal position at each 5° of longitude between 50°W and 75°W.

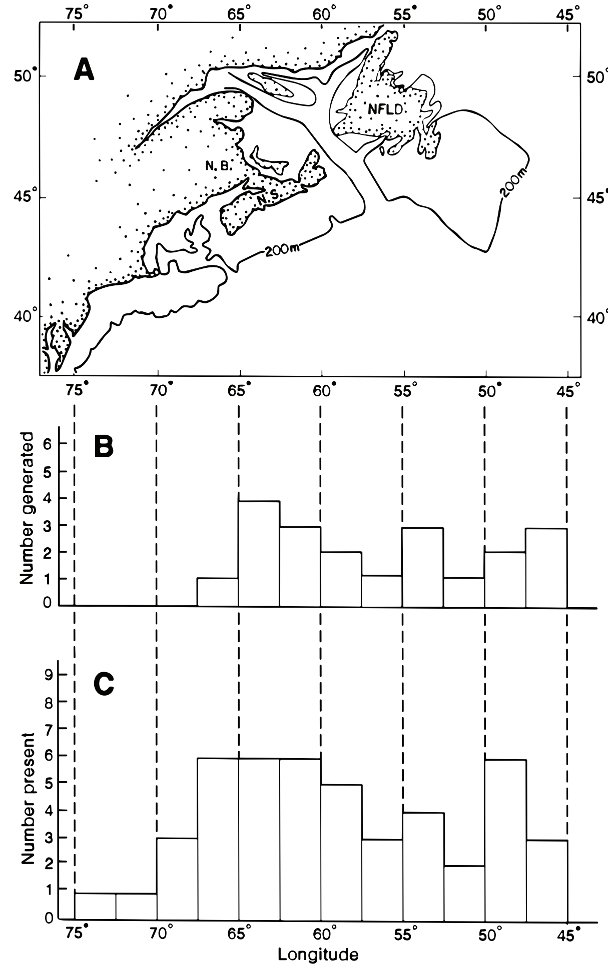


Fig. 39. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1992: (**A**) the chart of the area of interest; (**B**) the number of rings generated in each 2.5° zone of longitude; and (**C**) the number of rings present in each 2.5° zone during some part of the year.

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