NAFO Sci. Coun. Studies, 20: 19–46

Overview of Environmental Conditions in the Northwest Atlantic in 1991

K.F. Drinkwater and B. Petrie
Department of Fisheries and Oceans, Physical and Chemical Sciences Branch
Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada B2Y 4A2

and

S. Narayanan
Department of Fisheries and Oceans, Science Branch,
Northwest Atlantic Fisheries Centre
St. John's, Newfoundland, Canada A1C 5X1

Abstract

Environmental conditions in the continental shelf waters off eastern Canada in 1991 are described using selected oceanographic and meteorological datasets. Very cold waters were observed on the Grand Bank, off northern Newfoundland and on the Labrador Shelf with negative annual sea-surface temperatures (SSTs) throughout the region. The largest negative values were observed during the late-spring and summer with monthly anomalies reaching -3° to -4°C on the Grand Bank. The deep waters off Newfoundland at Station 27 were colder-than-normal throughout the year and the area of the cold intermediate layer on the Newfoundland shelves was larger than the long-term mean. Cold air and sea temperatures in winter, together with strong northerly winds, resulted in a heavy ice year off Newfoundland and in the Gulf of St. Lawrence. Warmer-than-normal SSTs persisted from the Scotian Shelf to the mid-Atlantic Bight with the amplitudes increasing southward. In the Laurentian Channel and in Emerald Basin on the Scotian Shelf, the deep waters (200–300 m) were the coldest recorded in 20 years. These cold conditions were not observed in the deep waters of the Gulf of Maine.

Key words: Environment, ice, meteorology, oceanography, temperature

Introduction

This paper provides a review of environmental conditions in the Northwest Atlantic during 1991 and is based upon selected sets of oceanographic and meteorological data as well as information from research documents prepared for the NAFO Scientific Council. Environmental conditions are compared with those of the preceding year as well as the long-term means. Where possible, the latter have been standardized to a 30-year base period (1951–80) in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. This report is the tenth in a series of annual overviews to NAFO (see Drinkwater and Trites, 1993). This year we have added several new indices and the presentation follows a slightly different order than in previous reviews.

Meteorological Observations

Air temperatures

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

Bar graphs of the 1991 monthly mean air temperature anomalies for six coastal sites (see Fig. 2 for locations) are plotted in Fig. 3. Data from Godthaab in Greenland suggest that the cold winter and spring extended throughout the Labrador Sea. The cold summer temperatures, however, appeared restricted to the Labrador coast and Newfoundland. The winter of 1990 had also been cold throughout the Labrador Sea and at Cartwright and St. John's, the December 1991 anomalies suggested the possibility of a cold winter in 1992, at least in the vicinity of southern Labrador and Newfoundland. At the

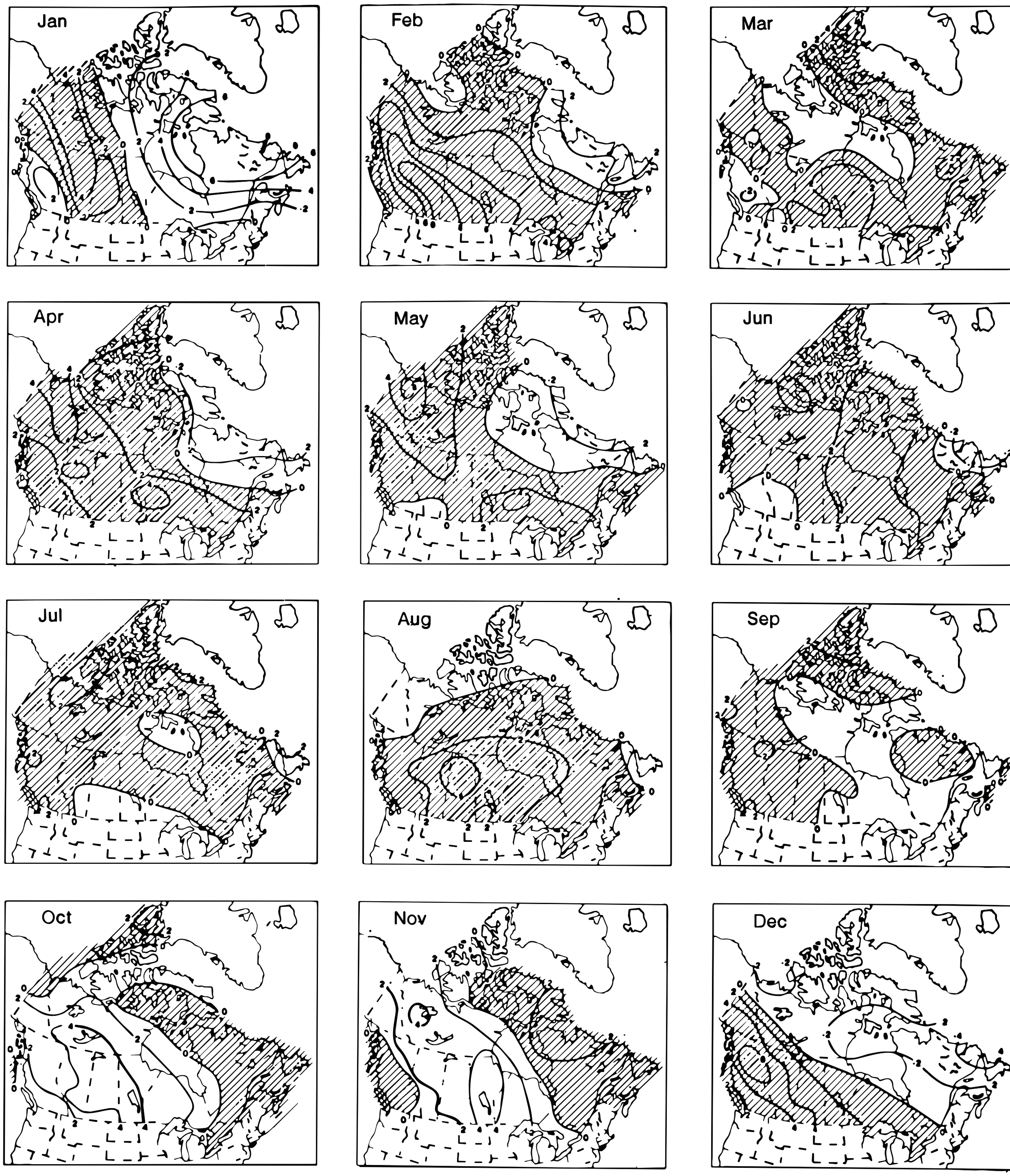

Fig. 1. Monthly air temperature anomalies (C) over Canada in 1991 relative to the 1951–80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 13).

Magdalen Islands in the Gulf of St. Lawrence and Sable Island on the Scotian Shelf air temperature anomalies tended to be above normal through most of 1991 although January was cold.

The annual air temperature anomaly pattern shows the very cold conditions along the Labrador coast and off northern Newfoundland with negative values of over 2°C (Fig. 4). These exceeded the

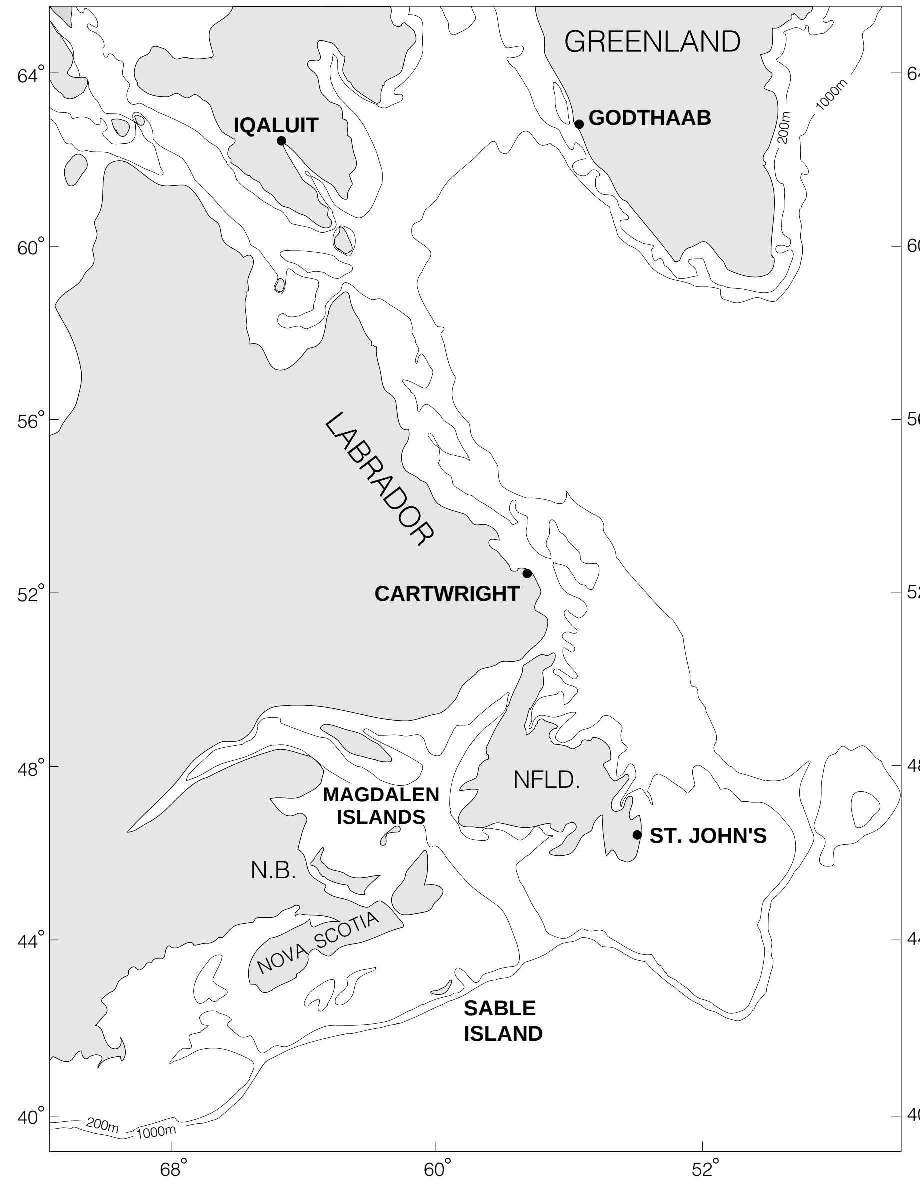

Fig. 2. Map of the Northwest Atlantic Ocean showing air temperature stations.

standard deviations of the long-term means by over 1°C. Slightly negative anomalies prevailed over most of the Gulf of St. Lawrence but in the southeastern Gulf and off Nova Scotia the annual air temperature anomalies were positive.

The interannual variability since 1970 at Godthaab, Iqaluit, Cartwright and, to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with periods of 5–10 years (Fig. 5). Since 1970, there has also been an overall downward trend causing temperature anomalies to be predominantly below normal with minima in the early-1970s, the early- to mid-1980s, and the 1990s. Temperature anomalies at Iles de la Madeleine and Sable Island were of much lower amplitude, showed no signs of a downward trend since 1970, but did contain minima in the early-1970s and in the mid-1980s but 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 Af-

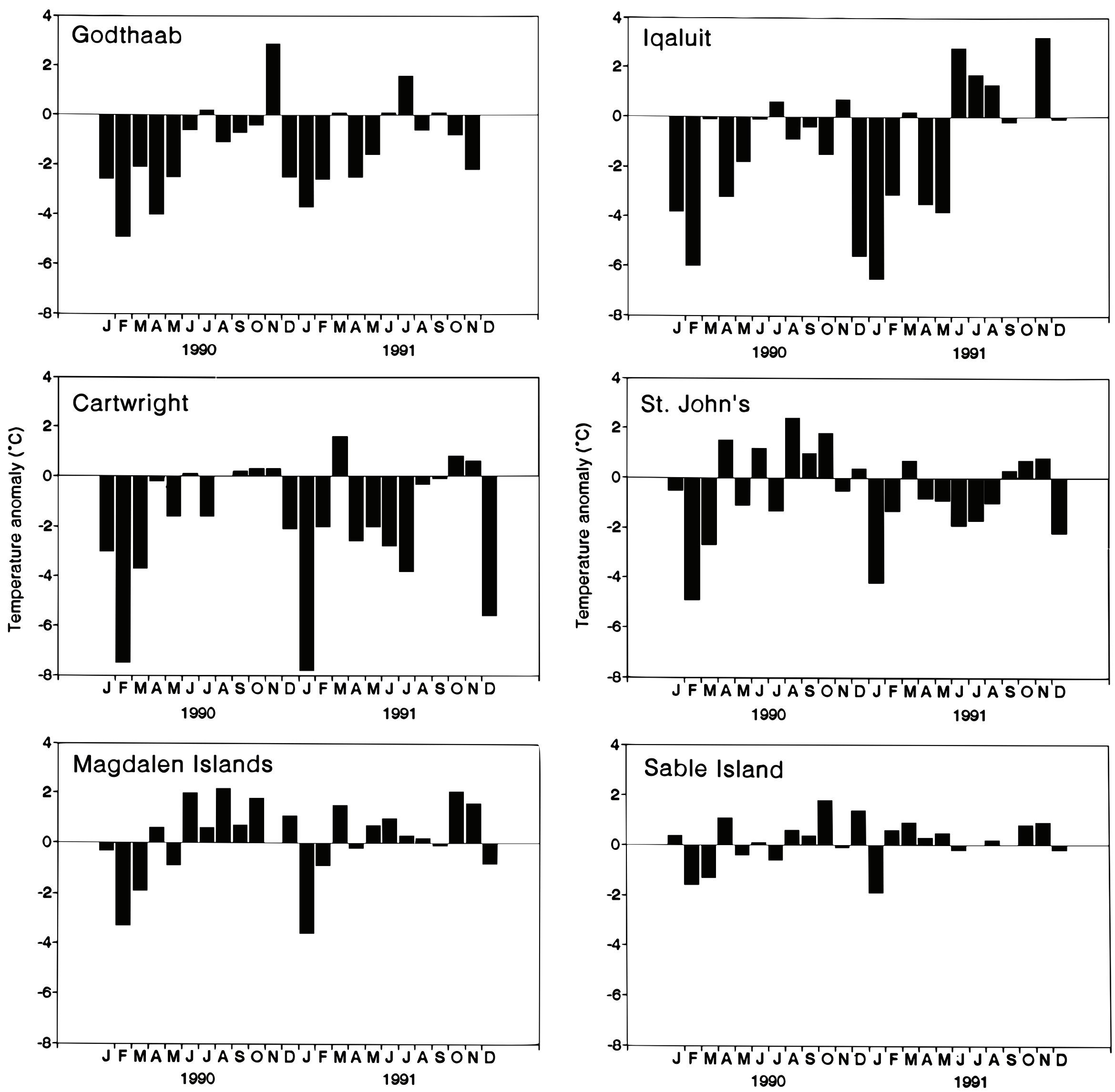

Fig. 3. Monthly air temperature anomalies at selected sites in 1990 and 1991.

rica (Thompson and Hazen, 1983). The strengths of the Low and High vary seasonally from a winter maximum to a summer minimum. Seasonal anomalies of the sea-surface pressure for 1991 relative to the 1951–80 means are shown in Fig. 6. Winter includes December 1990 to February 1991, spring is March to May, summer is June to August and autumn is September to November.

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

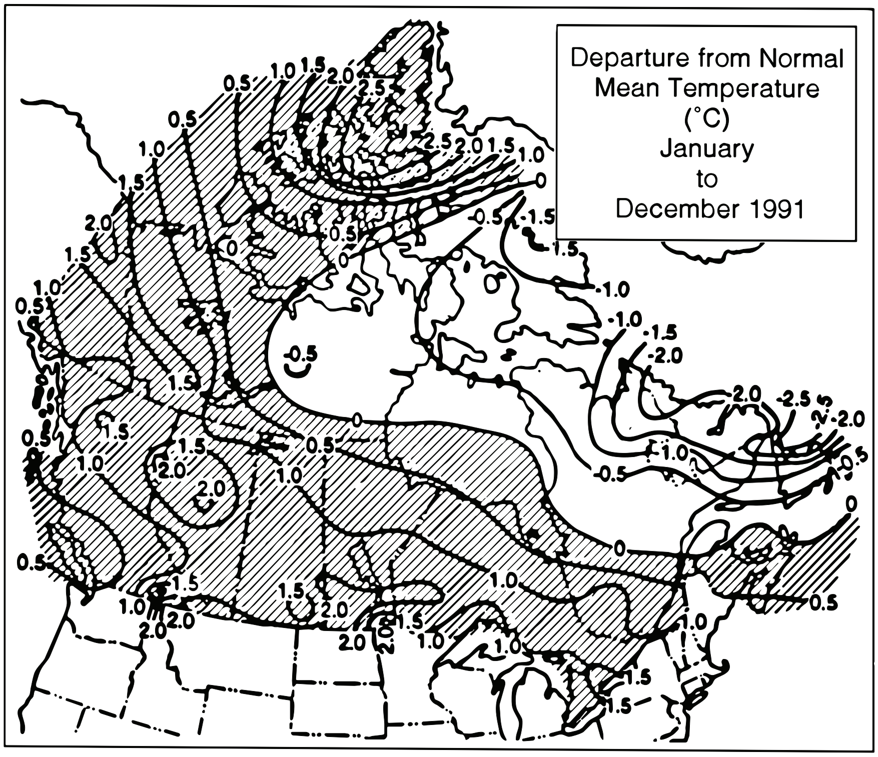

Fig. 4. Annual air temperature anomalies (°C) over Canada in 1991 relative to the 1951–80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives,* Vol. 14).

Upper atmosphere pressures

The heights of the 50 kPa pressure field (approximately 5 000 m above the earth's surface) over the northern hemisphere are published in the *Monthly Supplement to Climatic Perspectives* by Environment Canada. The long-term mean (1951–80), the mean for January 1991 and the anomaly fields are plotted in Fig. 7. The normal for the month consists of a low, known as the Arctic Vortex, centered over the Arctic Islands. In 1991 this low had deepened with a trough extending over eastern Canada. It produced an anomaly pattern similar to that for the sea level pressures, i.e. negative values over the Labrador Sea and eastern Canada and positive values off the southeastern United States. The anomalous low induced stronger-than-normal northerly and northwesterly flow. The January pattern is representative of the 1991 wintertime conditions and is similar to the pattern identified as producing "cold" winters (Findlay and Deptuch-Stapf, 1991) and heavy ice years (Agnew and Silis, 1991).

In the spring a stronger-than-normal trough developed over northeastern Canada (Fig. 8) which contributed to the below normal temperatures. This trough strengthened and extended southward in summer producing the negative anomalies centered over the Northwest Atlantic Ocean keeping temperatures on the Labrador coast and in Newfoundland colder-than-normal. A high pressure ridge centered over Hudson Bay produced warmer conditions in southern Baffin Bay and eastward to Greenland. The pattern reversed in autumn (Fig. 8) with a trough over Hudson Bay and a ridge over eastern Canada. The latter contributed to the warm conditions over eastern Canada in contrast to the colder-than-normal air temperatures in the rest of the country.

Sea Ice Observations

Newfoundland and Labrador

Extremely cold air temperatures in December of 1990 resulted in early ice formation off southern Labrador. The accompanying strong northwesterly winds advected this ice southward causing a greater areal extent of sea ice than normal (Fig. 9). Through the winter, cold air temperatures continued to promote ice growth while the strong northwesterly winds pushed the ice further southward so that by February the ice extent was near its maximum extent (Fig. 9). Winds were also slightly more onshore than normal tending to keep the ice on the shelf (Narayanan *et al.*, MS 1992). In March stronger onshore winds developed which pushed the ice

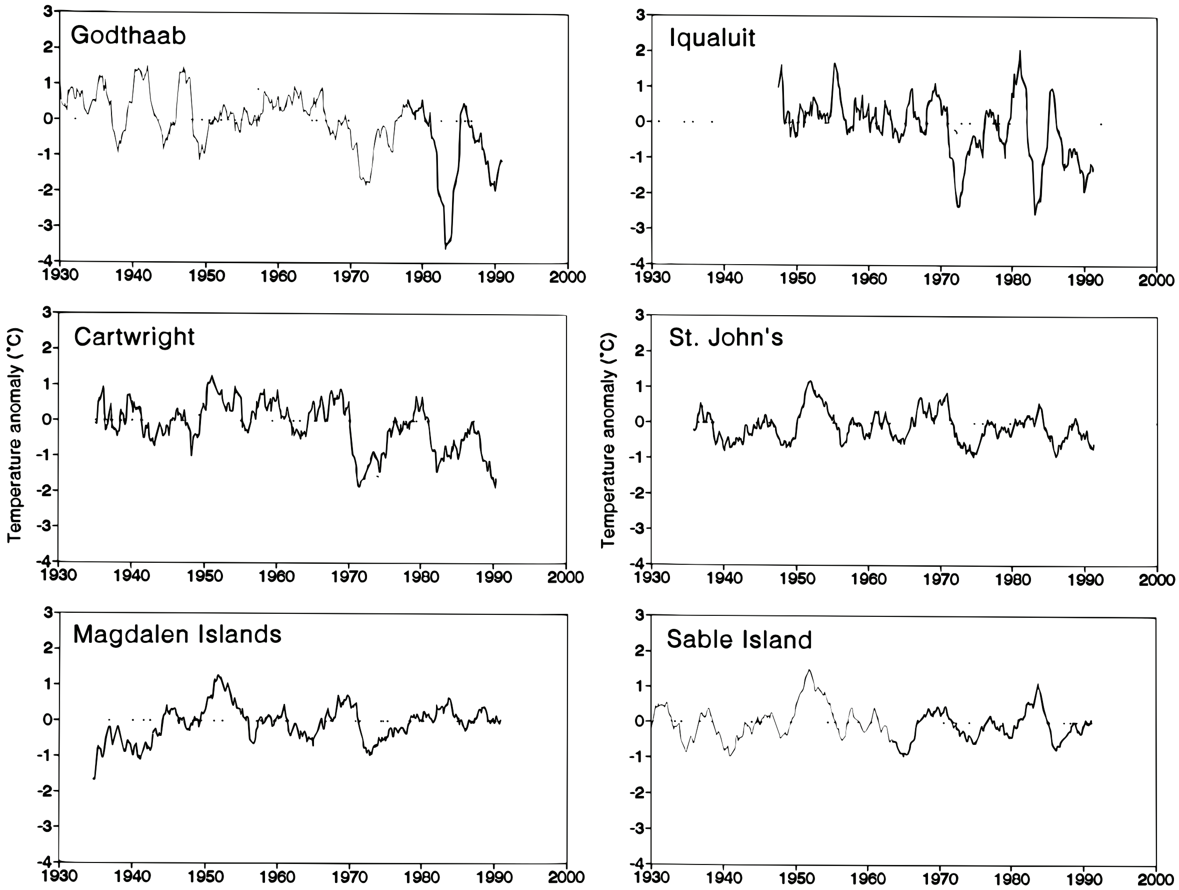

Fig. 5. Twenty-five month running means of monthly air temperature anomalies at selected sites.

towards the coast, thereby reducing the areal extent of the ice, at times, to below its normal value (Narayanan *et al.*, MS 1992). The loss of area was compensated by an increase in the thickness caused by ice rafting. Onshore winds through the spring and early summer prevented the ice from reaching the warmer offshore water. This water normally accounts for a large proportion of heat necessary to melt the ice. Indeed, most of the ice in 1991 is believed to have melted on the shelf due to solar heating. Ice retreated slowly, continuing to be present off the northern tip of Newfoundland up until the middle of July and off southern Labrador until early August which set new records for the time of the last presence of ice (Fig. 9).

The Ice Climatology Services Division of the Canadian Atmospheric Environment Service provides an annual analysis of the time of onset, duration of ice and the date of the last presence of ice at 24 grid sites off the east coast of Newfoundland and southern Labrador and in the Gulf of St. Lawrence (Fig. 10). For each site, the ice duration for the 1990/1991 season, the mean duration for all years of record, as well as minimum, maximum and mean duration for years when ice was present are listed in Table 1. Note that ice duration is based on the presence of ice which is not necessarily the time between the first and last siting of sea ice.

For most of the sites off northern Newfoundland and southern Labrador ice was present over a much longer period than normal in 1992 (Fig. 11, 12; Table 1). At the sites nearest the coast (N19, N62, N64, N228 and N108) the ice duration was 2 months longer than normal and new records were set off Whites Bay (N62) and coastal Labrador (N19). Although the ice advanced early, the long duration was primarily due to the late retreat of ice (Fig. 13). Indeed, the last ice at N62 was recorded on 20 July and at N19 on 25 August, both new records for the presence of last ice. These were over 8 weeks later than normal. Records for the date of last ice were also set at N108 and N110 east of Conception Bay.

The heavy ice year in 1991 matches maxima in sea ice extent that also occurred in the early-1970s and the early- to mid-1980s (Narayanan *et al.*, MS 1992). In each case, the large quantities of sea ice were associated with air temperature minima.

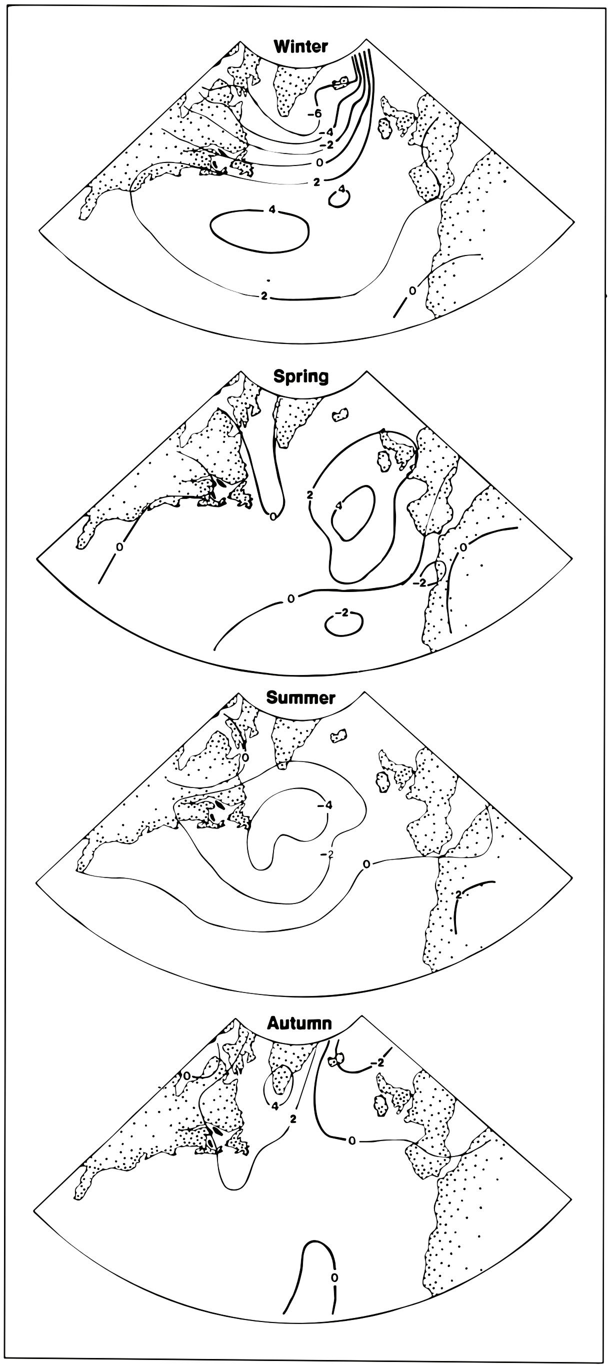

Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1991 relative to the 1951–80 means.

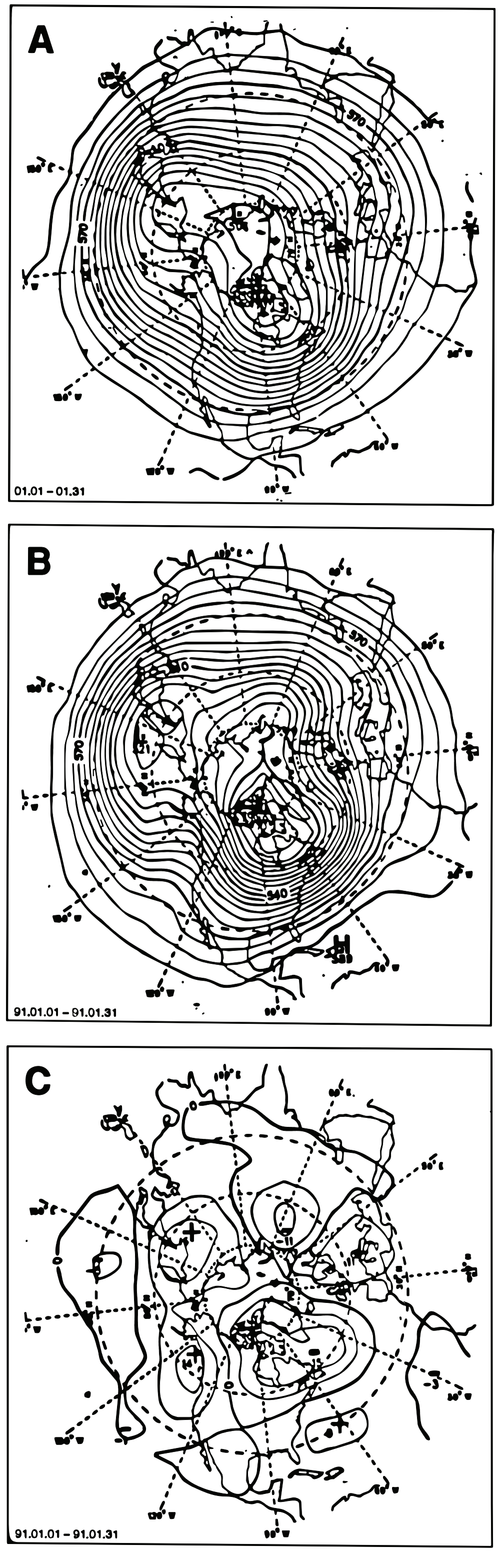

Fig. 7. (**A**) The historical mean, (**B**) the 1991 monthly mean and (**C**) the monthly anomaly of the height in decametres of the 50 kPa atmospheric pressure field for January 1991.

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

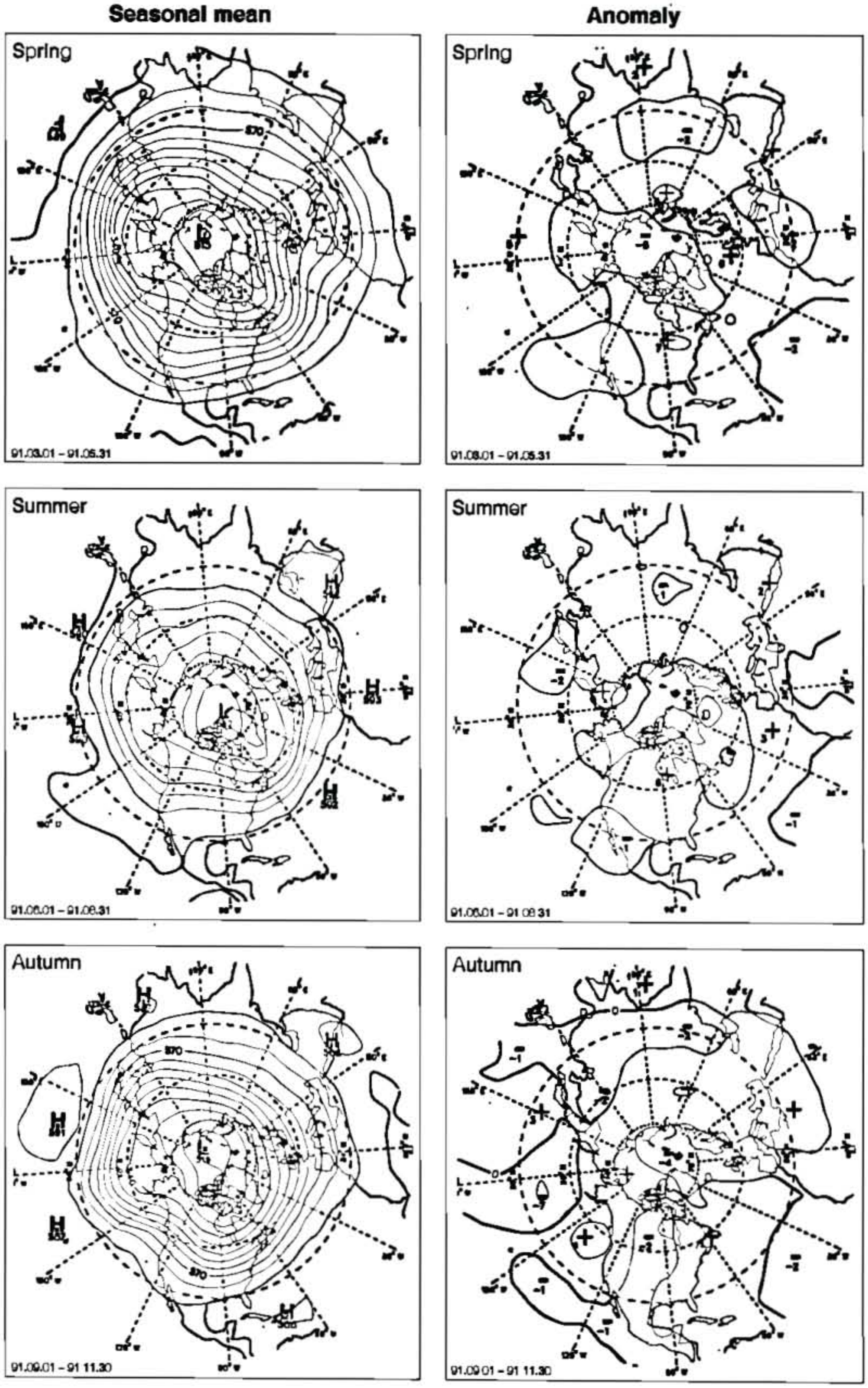

Fig. 8. The 1991 seasonal mean and the anomaly of the height in decametres of the 50 kPa atmospheric pressure field for spring, summer and autumn.

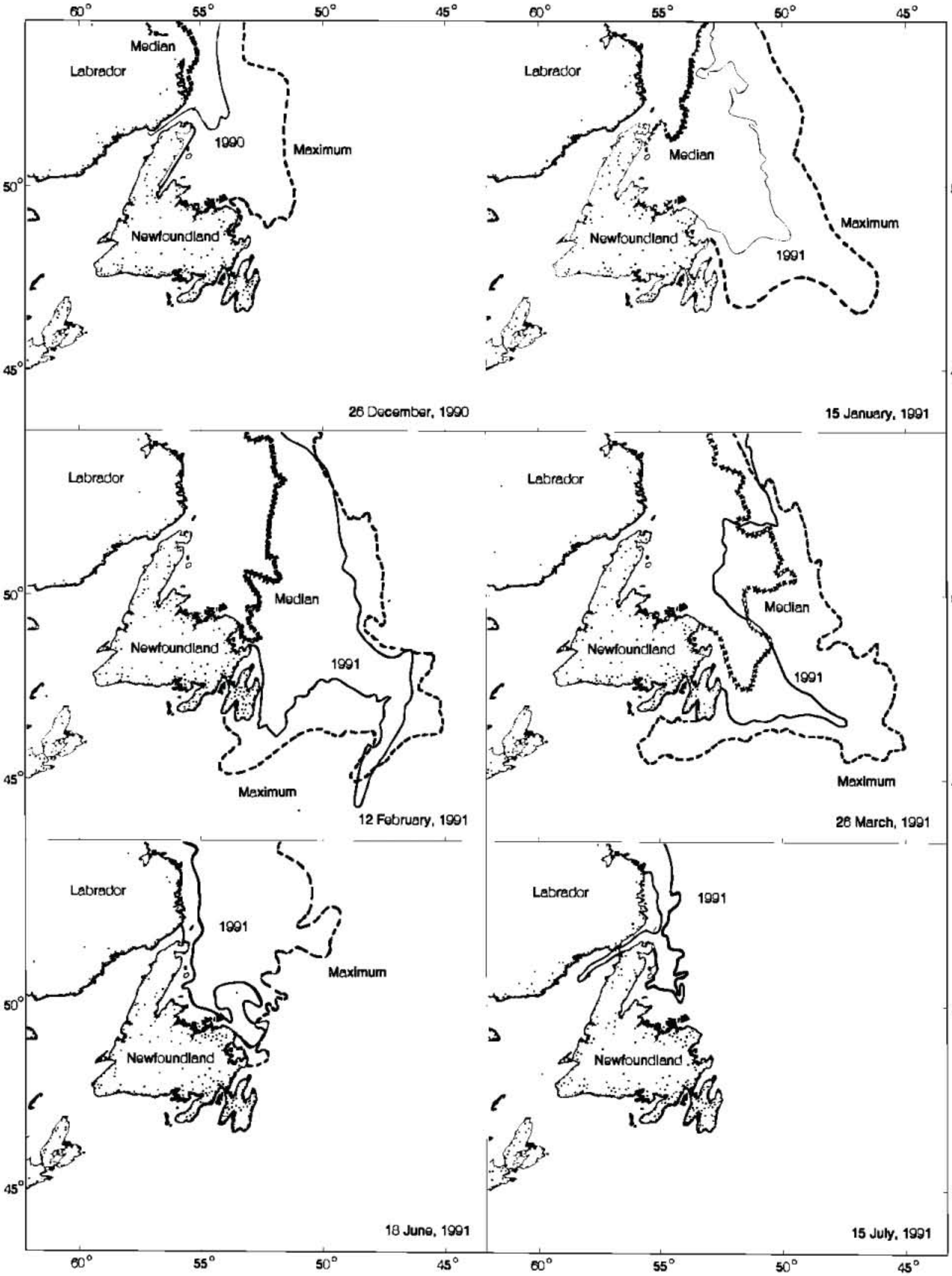

Fig. 9. The 1991 ice edge (concentrations of 10%) and its historical (1962–87) median and maximum positions off Newfoundland and Labrador on specific days during the ice season.

1990/91 iceberg season (October to September), a total of 1 974 icebergs were spotted south of 48°N. The monthly totals for February to August were 20, 115, 144, 269, 1 030, 325, and 71 (Fig. 14). No icebergs were spotted from October, 1990, to January, 1991, nor in September of 1991. In the primary iceberg season of March to August, 1954 icebergs were observed which represents 99% of the annual total. There were twice as many bergs recorded in 1991 than in 1990 and 6–9 times that in the years between 1986 and 1989 (Fig. 14). Several factors contributed to the high number of bergs in 1991. Anomalously cold air and water temperatures resulted in a slow rate of melting. Also the heavy concentrations of sea ice and its late persistence off Labrador and northern Newfoundland helped to preserve the icebergs through reduced wave action. Finally, the increased easterly winds kept the icebergs in the colder inshore waters longer.

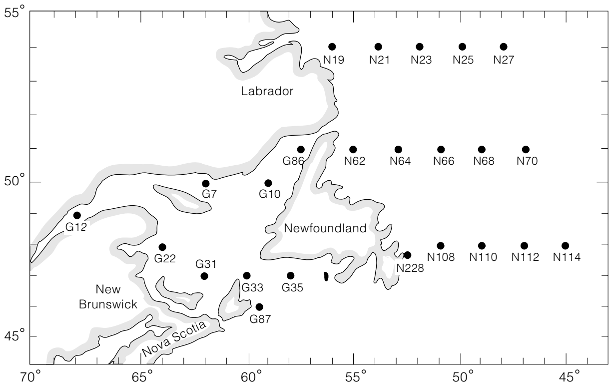

Fig. 10. Locations of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

Gulf of St. Lawrence

During early-December, 1990, cold Arctic air with accompanying moderate northerly to northwesterly winds covered the Gulf of St. Lawrence. By mid-December cumulative freezing degree days were up over the long term mean by 300% over the northern Gulf and an order of magnitude in the southern Gulf. This resulted in pack ice in Northumberland Strait and along the New Brunswick coast, the formation of new ice in the St. Lawrence Estuary and fast ice along sections of the North Shore of Quebec (Fig. 15). These ice conditions were about 3 weeks ahead of normal. By the end of December ice covered the Strait of Belle Isle, the Bay of Chaleur, and along the northern coast of New

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 1990/91 (October–September) ice year with 1989/90 data in parentheses.

Site	Seasons studied	No. of years	Years with ice	When ice present: Min	When ice present: Max	When ice present: Mean	Ice duration (weeks): Overall mean	Ice duration (weeks): 1990–91 (1989–90)
G-7	67/68–90/91	24	24	6	16	10.5	10.5	9 11)
G-10	76/77–90/91	15	15	3	17	11.5	11.5	15 (16)
G-12	67/68–90/91	24	24	2	15	11.5	11.5	12 (13)
G-22	76/77–90/91	15	15	7	14	11.7	11.7	12 (13)
G-31	68/69–90/91	23	22	8	17	12.4	11.9	14 (14)
G-33	71/72–90/91	20	20	2	14	10.4	10.4	14 (14)
G-35	59/60–90/91	32	16	1	11	3.7	1.8	1 (7)
G-86	76/77–90/91	15	15	6	23	15.9	15.9	20 (23)
G-87	70/71–90/91	21	20	1	12	7.3	6.9	9 (8)
N-19	66/67–90/91	25	25	17	32	23.8	23.8	32 (23)
N-21	67/68–90/91	24	24	5	28	18.0	18.0	18 (26)
N-23	59/60–90/91	32	26	1	17	5.1	4.1	6 (7)
N-25	59/60–90/91	32	2	1	1	1.0	0.1	0 (0)
N-27	59/60–90/91	32	0	0	0	0.0	0.0	0 (0)
N-62	67/68–90/91	24	24	8	27	18.3	18.3	27 (19)
N-64	59/60–90/91	32	31	3	25	12.5	12.1	22 (14)
N-66	59/60–90/91	32	26	1	16	7.8	6.3	10 (14)
N-68	59/60–90/91	32	13	1	10	2.8	1.4	3 (6)
N-70	60/61–90/91	31	0	0	0	0.0	0.0	0 (0)
N-108	59/60–90/91	32	25	1	17	5.9	4.8	12 (9)
N-110	59/60–90/91	32	25	1	12	4.9	3.8	10 (8)
N-112	59/60–90/91	32	12	1	10	3.8	1.4	3 (3)
N-114	59/60–90/91	32	3	1	2	1.3	0.1	0 (0)
N-228	59/60–90/91	32	21	1	14	5.4	3.5	11 (3)

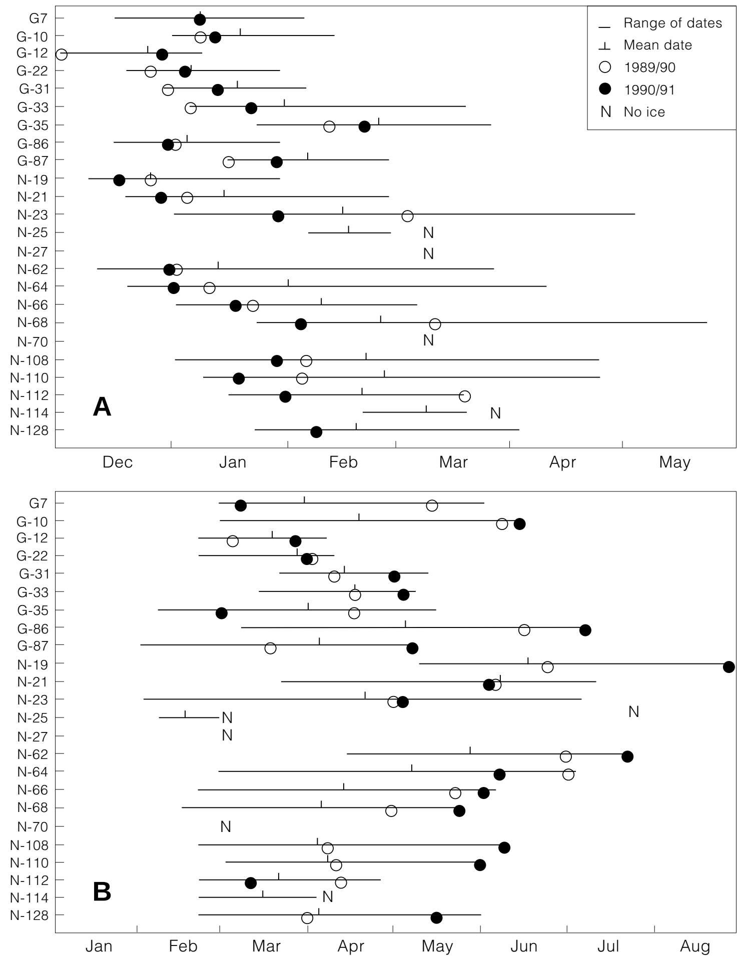

Fig. 11. Ranges of dates for the presence of (**A**) first sea-ice and (**B**) last sea-ice at 22 sites in the Northwest Atlantic (Fig. 10) with mean dates and the 1989/90 and 1990/91 dates. (Ice has never been observed at N27 and N70).

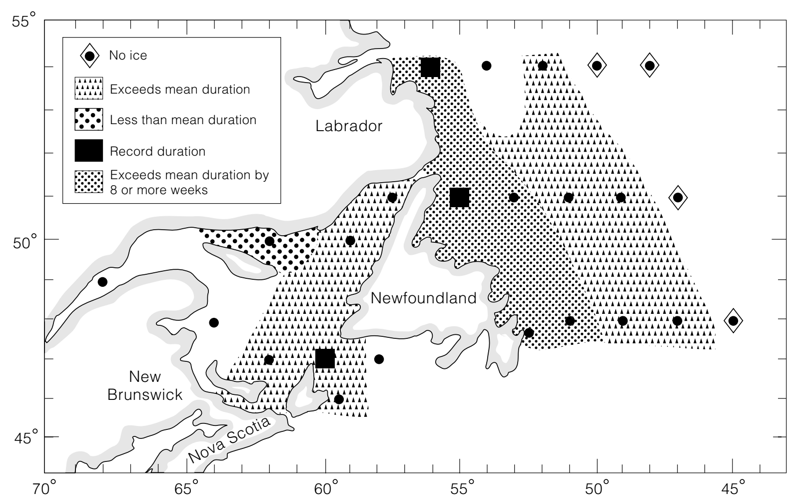

Fig. 12. Duration of ice (1990/91) relative to the long-term mean at grid points shown in Fig. 10. Circles not surrounded by shading indicate sites were the ice duration was within ± 1 week of the mean date. Shading indicates a duration longer or less than the mean by greater than 1 week.

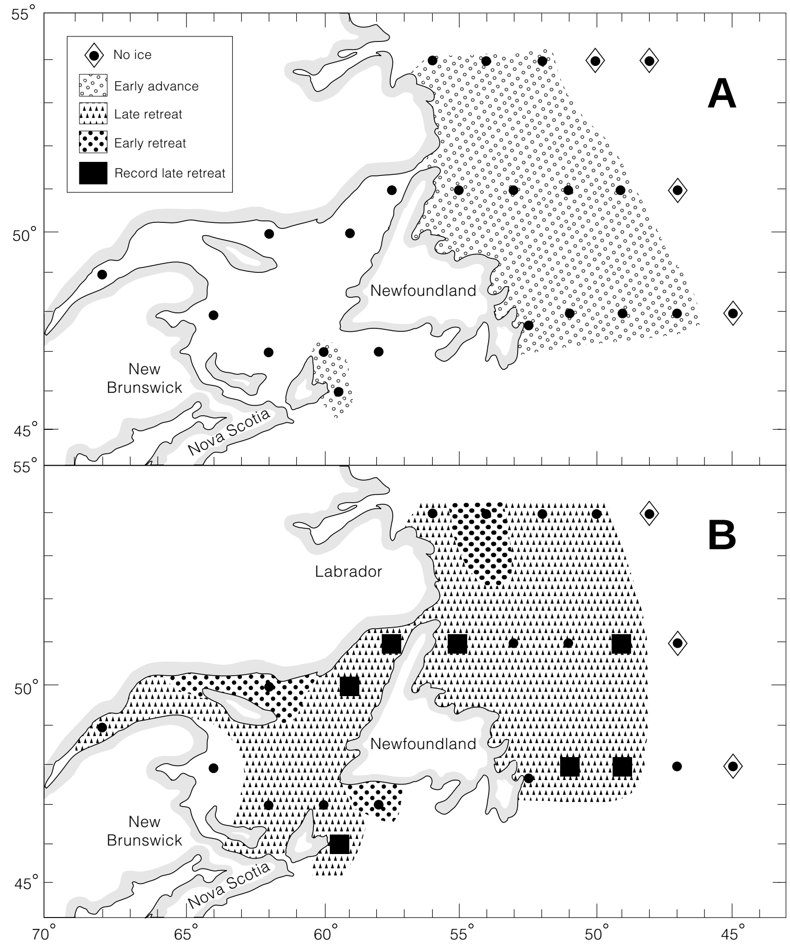

Fig. 13. The presence of (**A**) first ice and (**B**) last ice (1990/91) relative to the long-term means at the grid points shown in Fig. 10. Circles not surrounded by shading indicate sites where the ice advance or retreat was within 1 week of their mean dates. An early or late advance or retreat refers to differences exceeding 1 week of the mean date. Sites marked as having no ice means that ice was not present anytime through the ice season.

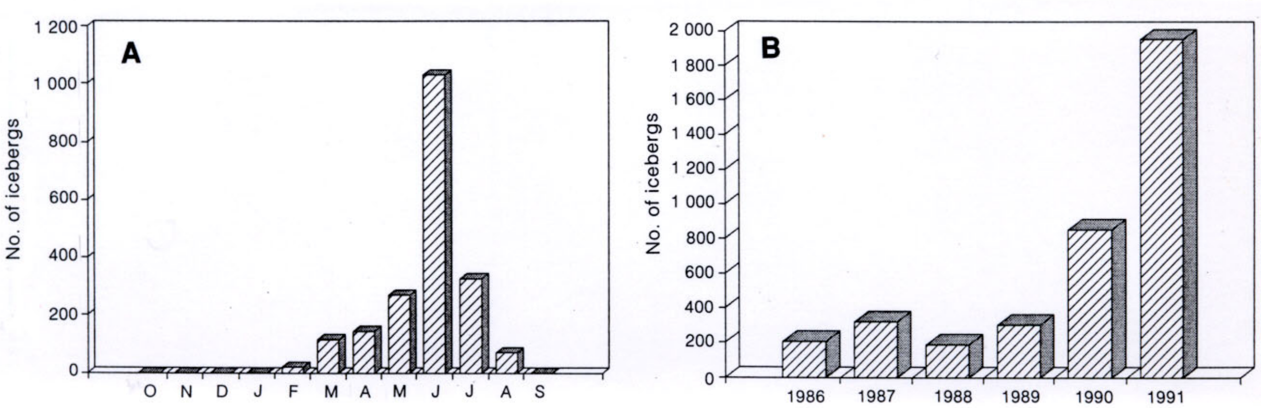

Fig. 14. (**A**) The monthly numbers of icebergs crossing south of 48°N during the iceberg season 1990/91 and (**B**) the total number of icebergs compared to the previous 5 years.

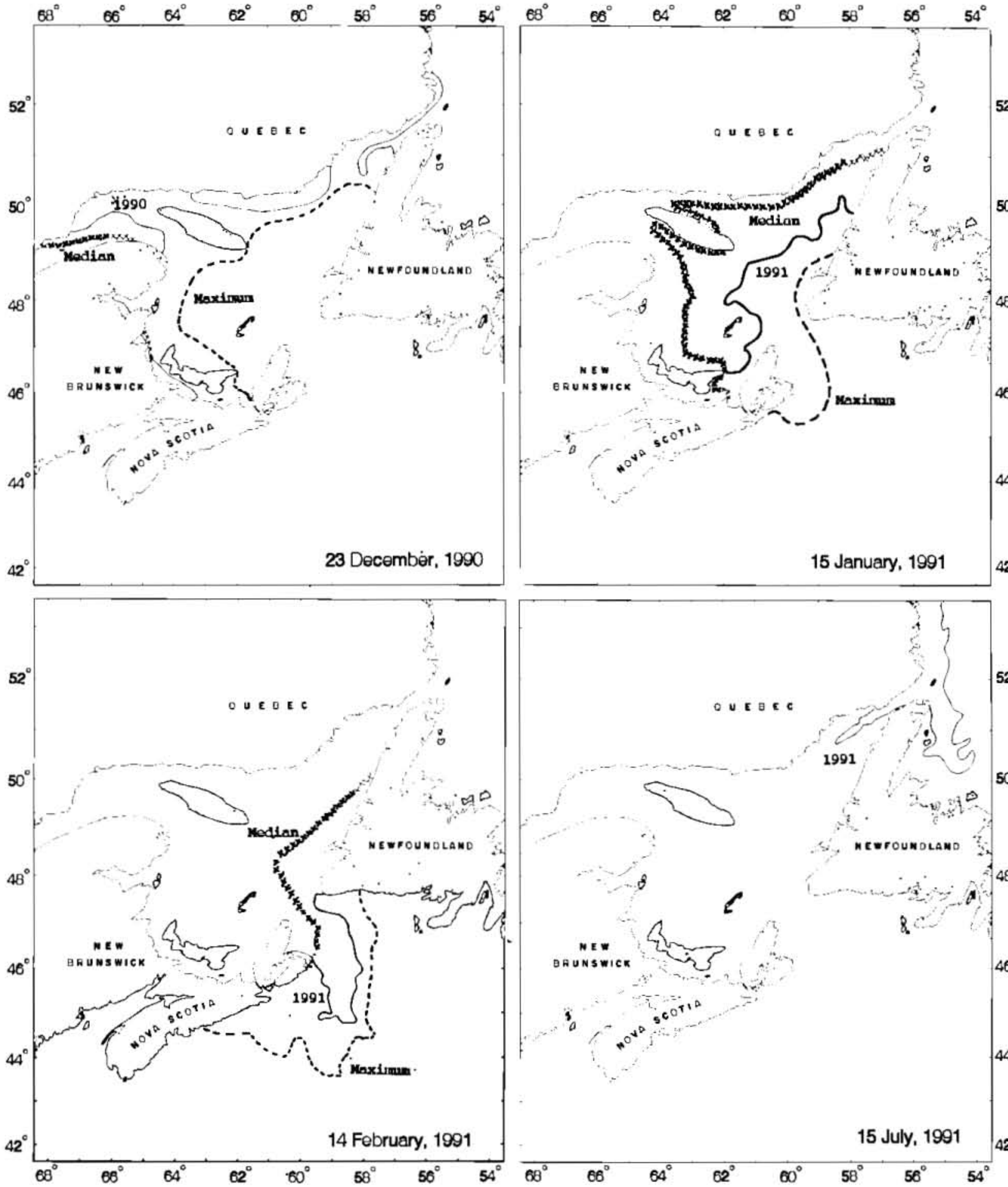

Fig. 15. The 1991 ice edge (concentrations of 10%)and its historical (1962–87) median and maximum positions in the Gulf of St. Lawrence on specific days during the ice season.

Brunswick which was near normal for that time of the year. At mid-January new ice formed over the central and northeastern regions of the Gulf, slightly earlier than normal, while over the western Gulf the ice thickened (Fig. 15). Cold air temperatures persisted through January which continued to increase the thickness and areal extent of the sea ice. The extent and thickness of the ice cover by mid-February remained greater than normal (Fig. 15). Ice began to drift through Cabot Strait with some reaching 45°N and 58°W. By the end of the month the ice had moved further onto the Scotian Shelf westward to Chedabucto Bay. Ice thickness in the Gulf still exceeded normal in mid-March but open areas developed along western Newfoundland, along the south shore of Prince Edward Island, around the Gaspé Peninsula, and along parts of the north shore of Quebec. During April ice conditions were typically 2 weeks later than normal. Warmer-than-normal temperatures in May led to rapid melting so that by mid-May the only ice in the Gulf was that in the northeastern Gulf. Through June and into mid-July ice continued to drift into the Gulf through Belle Isle Strait due to the persistence of ice on the Labrador and Newfoundland shelves.

The duration of sea ice exceeded the long-term mean in most of the western Gulf, southern Magdalen Shallows and off eastern Cape Breton (Fig. 11, 12, Table 1). Off Cape North ice was recorded for 14 weeks setting a new duration record. This was due to both an early advance and a late retreat (Fig. 13, Table 1). Throughout the Gulf, the date of the first ice was near normal but typically left later than normal. Mid-July for the last presence of ice in the Belle Isle region set a new record as normally ice leaves the region by late-April. This late presence of ice was due to advection from the Labrador Shelf.

Oceanographic Observations

Station 27

Measurements of temperature and salinity have been routinely taken since 1946 at Station 27 located approximately 10 km off St. John's, Newfoundland. This site is representative of the inshore Labrador Current. The station was visited 63 times in 1991, with a monthly maximum of 8 in April, October and December and a minimum of 0 in January. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50, 75, 100, 125 and 150 m) and monthly means were calculated for each depth. The monthly averaged temperatures and salinities in 1991 together with their anomalies relative to 1951–80 are shown in Fig. 16.

Water temperatures at Station 27 were extremely cold in 1991. Monthly mean temperatures throughout the water column were colder than -1.5°C (anomalies lower than -1°C) in February and March. The seasonal warming of the waters above 50 m proceeded slowly causing the anomalies to decrease steadily through the spring and early summer reaching a minimum of -4°C in July (Fig. 16, 17). The anomalies gradually increased after July rising to slightly above normal by November and December. Temperature anomalies in the deep waters (>75 m) were below normal throughout the year (generally -0.5° to -1°C). In the autumn anomalies were at or exceeded -1°C which is believed to be due to the mixing of the colder, near-surface water down through the water column. These cold bottom waters are consistent with the spring and autumn survey results by the USSR that showed below normal bottom temperatures on the Grand Banks (Borovkov and Tevs, MS 1992).

Surface salinities at Station 27 were fresher-than-normal by as much as 1 psu in July and again in November (Fig. 16, 17). Ice melt from the larger-than-normal volume of sea ice are believed to have contributed to these low salinities. The salinity anomaly minimum in June–July was likely due to local ice melt while the second minimum in November and December may have been associated with ice melt from the Labrador Shelf. The latter has been shown to account for the interannual variability in the seasonal salinity minimum (September–October) at Station 27 (Myers *et al.*, 1990). In the deeper waters, the salinities were slightly below normal throughout most of 1991. The fresher conditions in 1991 contrast with the slightly more saline waters observed in 1990 (Drinkwater and Trites, 1993).

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970–91 are shown in Fig. 18. Note that the temperature scale for 0 and 50 m is different to that for 100 m and deeper. At the surface, 1991 contained the most persistent negative anomalies in the past 20 years. The monthly minimum in July matched a previous low in 1974. Progessively deeper in the water column, there was a tendency towards a greater percentage of negative anomalies throughout the period. At 150 and 175 m negative anomalies have persisted almost continuously since 1982 and at 100 m since 1983. The coldest periods roughly correspond to those identified from air temperature anomalies, i.e. the early-1970s, the mid-1980s, and the 1990s. At these depths, 1991 continued a trend towards lower temperatures that began in 1988–89.

Cold intermediate layer

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 down-

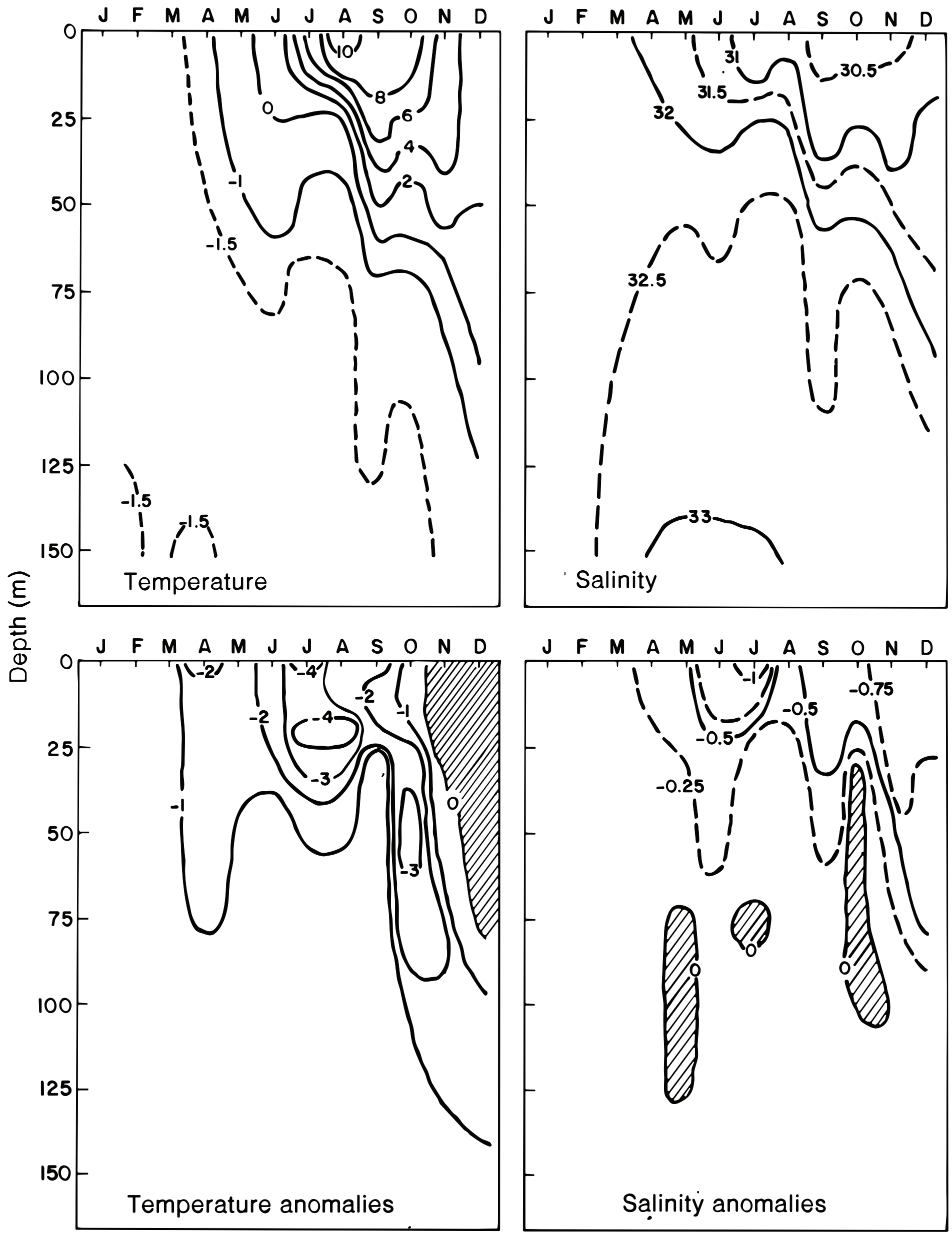

Fig. 16. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1991 relative to the 1951–80 means. Shaded areas are positive anomalies.

wards, and the waters below remain cold throughout the spring and summer. The latter are called the cold intermediate layer (CIL) waters.

Four standard hydrographic transects (Hamilton Bank, off White Bay, off Bonavista Bay and along 47°N) are occupied annually by the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland, during the summer. Narayanan *et al.* (MS 1992) showed that in 1991 the CIL, defined by waters <0°C, covered most of the area of the shelf in the three transects that were occupied (the 47°N line was not occupied). Petrie *et al.* (1992) had earlier found that the annual anomalies of the cross-sectional areas of the CIL (1978–86) were highly correlated between transects with an average value of about 0.85. The areas calculated for 1978–91 showed that in 1991 the area of the CIL was much greater than normal (Fig. 19). For the Hamilton Bank transect, 1991 ranked the third highest in 11 years of data, at White Bay the second in 12 years, and off Bonavista the second in 14 years.

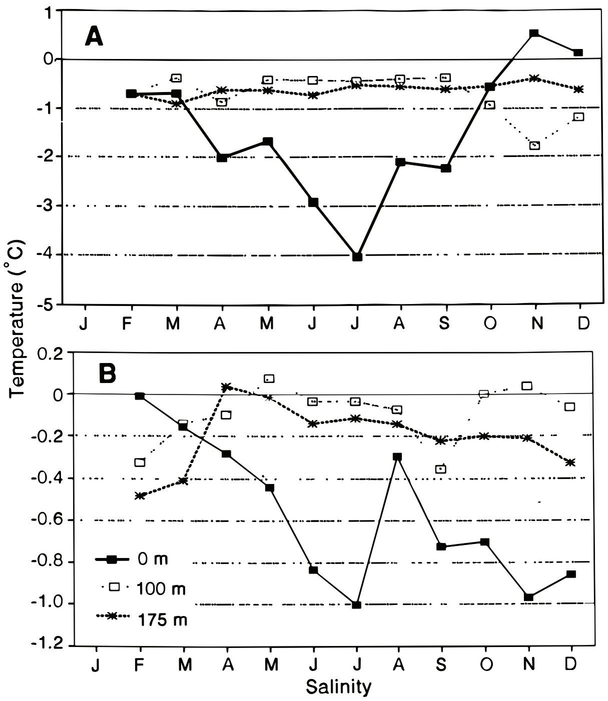

Fig. 17. Monthly (**A**) temperature anomalies and (**B**) salinity anomalies at 0, 100, and 175 m at Station 27 during 1991.

The area of the CIL along the four transects show maxima in 1984–85 and 1990–91 and a minimum in 1986–87 (Fig. 19). The maxima correspond roughly with minima in the water and air temperatures and maxima in ice coverage as noted earlier by Petrie *et al.* (1992).

Fyllas Bank

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

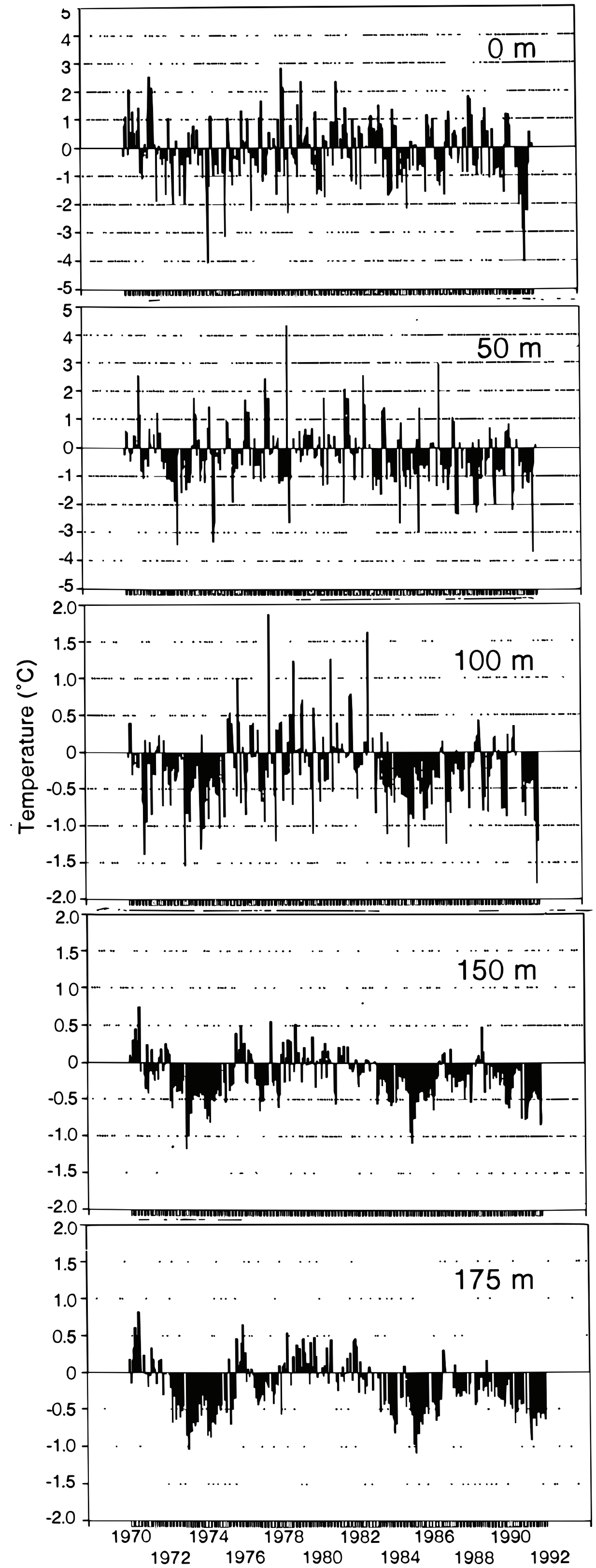

Fig. 18. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27 (1970–91).

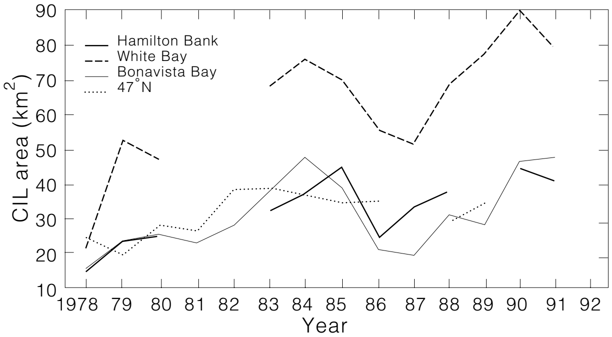

Fig. 19. The area of the cold intermediate layer (<0°C) (CIL) for the four standard sections off southern Labrador and northern Newfoundland.

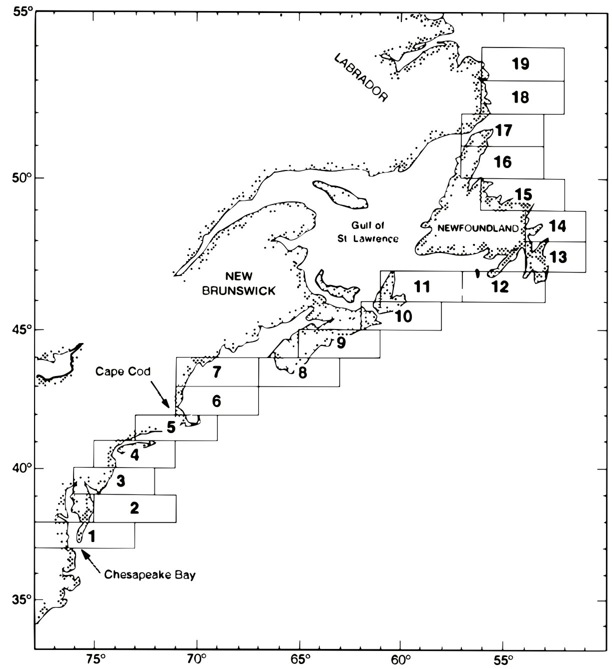

Fig. 20. Locations of 19 areas in the Northwest Atlantic (Chesapeake Bay to southern Labrador) for which sea-surface temperature data were grouped for analysis.

Offshore sea-surface temperatures

Sea-surface temperature (SST) data from the "marine deck" observations (obtained primarily from ships-of-opportunity through the ship's intake and research vessels) were supplied by the U.S. Marine Fisheries Service. The pattern of monthly SST anomalies for 19 regions along the continental shelf from Chesapeake Bay to southern Labrador (Fig. 20) for 1991 are compared to earlier years (Fig. 21). At the beginning of 1991 positive SST anomalies developed off Cape Breton (areas 10 and 11) in January. Conditions elsewhere were near normal until the spring when strong negative anomalies were observed off Newfoundland and positive anomalies off southern New England and on the Middle Atlantic Bight (areas 1–5). These anomalies continued into the summer months. In spite of the below normal temperatures in the north, by autumn these waters (from northern Newfoundland to Cape Breton Island; areas 10–15) had warmed to above normal.

SST anomalies were also determined for a larger region of the Northwest Atlantic (35°–60°N, 40°–76°W) extending from the southern boundary of the NAFO area northward to southern Greenland. As in past reviews (e.g. Drinkwater and Trites, 1993), the region was divided into 24 smaller areas (Fig. 22) to coincide with major water masses (Labrador Current, Gulf Stream, etc.) or fishing banks (LaHave, Georges, etc.). The monthly mean temperature for each area was computed for 1991. The annual anomalies for 1987–91 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 1972–91 period is shown in Fig. 23.

The 1991 annual pattern shows predominantly negative SST anomalies in the Labrador Sea, the Grand Banks and extending into the Slope Water region off the Scotian Shelf and Georges Bank (Fig. 23, 24; Table 1). This is in contrast to the warmer-than-normal conditions from the Gulf of St. Lawrence to Cape Hatteras. The peak negative anomalies were recorded on Flemish Cap and the western Grand Bank (<-0.8°C) and the peak positive anomalies off the southern New England shelf (>0.9°C). This represents the second consecutive year of below normal temperatures in the northern regions and the third year of above normal temperatures in the south.

The monthly anomalies for the 24 areas are listed in Table 3. The cold conditions observed at Station 27 in the spring and summer can be seen to have extended over the entire Grand Bank, off southern Newfoundland, Flemish Cap, and along the Labrador coast (Table 3; Fig. 25). The coldest anomalies (-3°C) were observed in July, consistent with the Station 27 data. Cold surface layer temperatures on the Grand Bank and southern Labrador in summer were also observed during the USSR surveys (Borovkov and Tevs, MS 1992). Again similar to Station 27, the autumn SSTs in the region exceeded their long-term means. In the Gulf of St. Lawrence and off southwestern Newfoundland (area SP) significant warm water anomalies were observed during the autumn. From the southern Scotian Shelf to the Mid-Atlantic Bight there was a predominance of positive anomalies throughout the year with maxi-

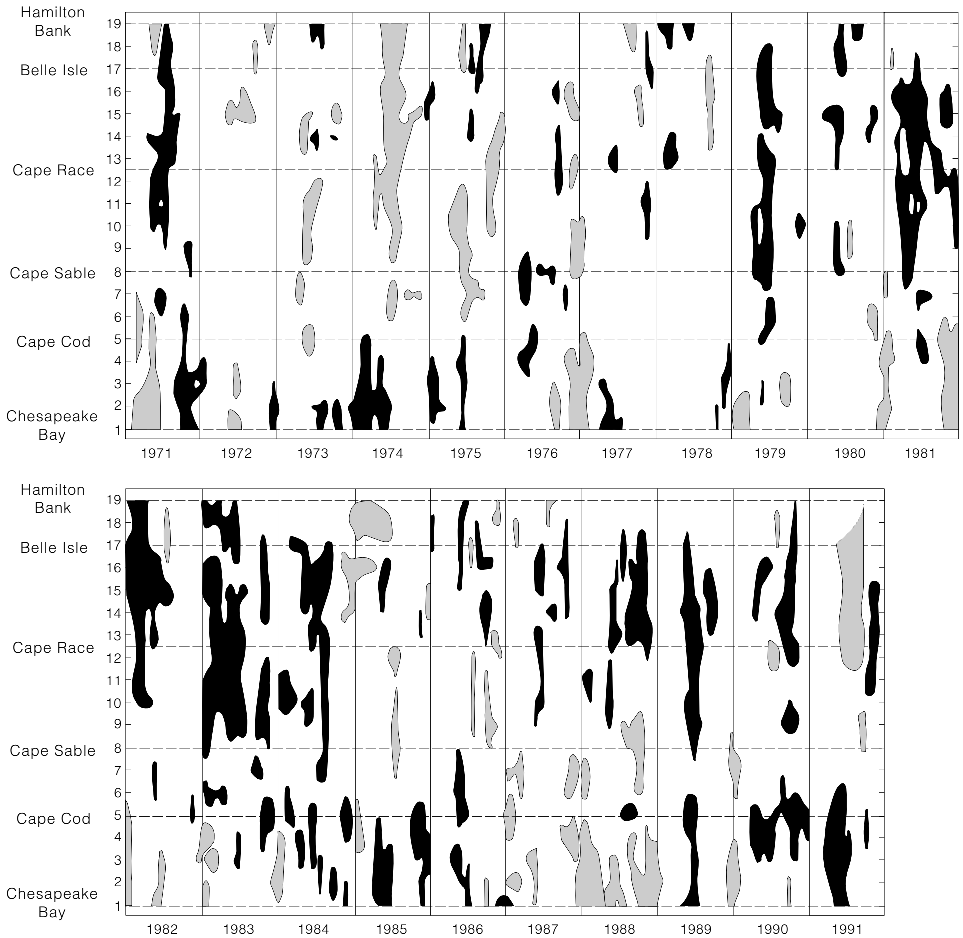

Fig. 21. Contoured monthly sea-surface temperature anomalies (relative to the 1971–80 means) for the 1971–90 period by area (Fig. 20). (Only anomalies exceeding 1°C (black) and less than -1°C (dotted) which extended in space through at least two neighbouring areas and in time for at least two consecutive months have been contoured.)

mum values in the southern most shelf area during the spring and early summer. In the Western Slope Water negative anomalies were observed in all months except December.

The time series of annual mean anomalies of SST for the 24 areas are shown in Fig. 26. The 1991 values generally were near the minimum temperature anomalies recorded in 1985 and in the mid-1970s (Fig. 26A). The temperatures have declined in these regions by 1° to 2°C from the highs in 1988. In the Gulf of St. Lawrence, off southwestern Newfoundland and on the eastern Scotian Shelf, the annual anomalies were near normal with a slight tendency to positive values (Fig. 26B). The amplitude of the positive annual temperature anomalies increased southward with maximum values in the Mid-Atlantic Bight (Fig. 26C). The opposing temperature trends on the Grand Bank and the Mid-Atlantic Bight fit the 2nd mode of variability in an EOF analysis of SST in the region as determined by Thompson *et al.* (1988). The oscillating temperature trends between these two areas has been prominent through the 1980s and into the early-1990s. In the Slope Water during 1991 the eastern area was warmer-than-normal while the western region was colder-than-normal. Temperature variability in the Gulf Stream and Sargasso Sea was low through the period 1971–91.

Coastal sea-surface temperatures

Monthly averages of SST are available from Halifax 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 are shown in Fig. 27.

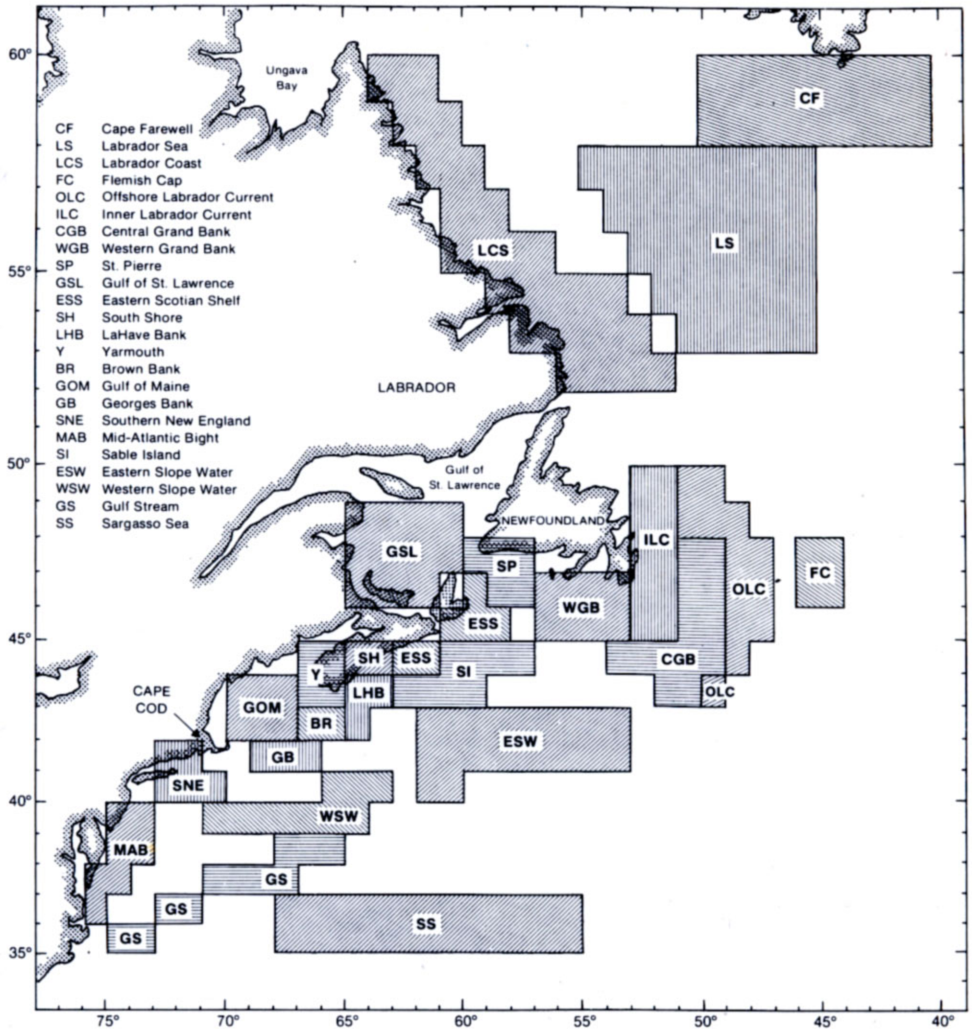

Fig. 22. The geographic boundaries of the 24 subregions for which sea surface temperatures were analyzed on a monthly basis.

The temperature patterns at the three sites showed several differences. During the first 5 months of 1991 there appeared to be a gradient in SST across the region from above normal temperatures at Boothbay Harbor, to near normal at St. Andrews, and below normal at Halifax. In summer, Boothbay and Halifax temperatures were generally colder-than-normal but at St. Andrews they were warmer-than-normal. During the last 4 months of the year, temperatures at Halifax rose above normal, while at St. Andrews they fell below normal and at Boothbay they were near normal.

Annual SST mean temperatures for 1991 were 9.0°C (0.2°C above normal) at Boothbay Harbor, 7.15°C (0.15°C below normal) at St. Andrews, and 7.5°C (0.3°C below normal) at Halifax. The long-term trends as represented by the 25-month running means in Fig. 28 show that the temperatures at Boothbay Harbor rose slightly in the past couple of years but were near their long-term mean. The warm anomalies during the last half of 1990 and the first part of 1991 were unusual in their duration compared to past anomalies (Fig. 28). At St. Andrews SSTs continued to rise from a minimum recorded in the late-1980s and appeared to be approaching the long term mean. At Halifax, the negative annual anomaly was consistent with slightly colder-than-normal conditions that have persisted since the late-1980s. These temperatures were 2° to 2.5°C below the maximum anomaly recorded near the mid-1980s. We note that since 1985 the St. Andrews SSTs may be reading over 0.5°C lower than previous due to changes in the flow field caused by reconstruction of the wharf where the measurements are taken (Drinkwater *et al.*, MS 1992).

TABLE 2. Mean sea-surface temperatures for selected areas of the Northwest Atlantic in 1971–90 and anomalies for 1987 to 1991 relative to the base period. (Geographic locations of water masses are shown in Fig. 22. Blank space indicates that annual average not computed when data missing for one or more months.)

Water	Mean temp.	Annual anomalies (°C)				
mass	1971–90	1987	1988	1989	1990	1991
CF	4.22	0.52	0.57	-0.10	0.15	0.09
LS	5.57	0.30	0.17	-0.03	-0.34	-0.10
LCS	2.05	-0.07	-0.28			
OLC	5.18	-0.31	0.07	0.01	-0.38	-0.81
ILC	5.11	0.03	0.57	0.46	-0.07	-0.41
FC	7.88	0.08	0.52	0.04	-0.46	-0.85
CGB	6.77	-0.10	0.74	0.47	-0.12	-0.73
WGB	6.34	0.18	0.41	0.13	-0.15	-0.62
SP	6.14	0.68	0.19	-0.22	-0.22	0.23
GSL	6.00	0.24	0.15	0.11	-0.11	0.12
ESS	7.29	0.23	-0.15	0.26	0.01	0.22
SI	8.38	-0.09	-0.29	0.42	-0.28	-0.25
SH	8.07	0.48	-0.34	0.45	0.17	0.04
LHB	8.92	-0.04	-0.67	0.14	0.06	0.61
BR	9.00	-0.58	-0.01	0.51	0.63	0.43
Y	7.64	-0.37	0.05	0.38	0.27	0.22
GOM	9.65	-0.79	-0.45	0.14	0.15	0.08
GB	10.17	-0.65	-0.30	0.09	0.45	0.36
SNE	12.34	-0.63	-0.30	0.57	1.33	0.73
MAB	14.89	-0.44	-1.17	0.11	0.45	0.93
ESW	15.64	-0.00	-0.04	0.51	0.19	-0.24
WSW	18.21	-0.36	-0.53	-1.07	-0.62	-0.63
GS	22.99	0.24	-0.16	0.14	0.40	0.01
SS	22.25	-0.07	0.25	0.19	0.16	0.04

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 1991 for the 16th consecutive year (Benway *et al.*, MS 1992). Consistent with the marine deck SST data, the near surface annual average temperature was found to be approximately 1°C warmer than the long-term mean (1978–91). Surface salinities were near normal through most of the year. Exceptions were high anomalies (>2 psu) in February and March within 25 km of the coast and in October to December 350–450 km offshore. The latter were due to the presence of a warm-core ring in the slope water region throughout most of this period. Bottom temperatures over the shelf were above normal and consistent with the near surface anomalies during the first four and last two months of 1991 when stratification was relatively weak. With the onset of stratification in late spring and summer, bottom temperatures were near or below normal. Anomalies were 1°C cooler-than-normal in September. The annual mean over the shelf was, however, 0.6°C above normal.

Temperatures and salinities in the Gulf of Maine

The Northeast Fisheries Science Center also occupies a transect across the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf (Benway *et al.*, MS 1992). Surface and bottom temperatures and surface salinities have been collected monthly for the past 15 years. In 1991 near normal (relative to 1978–91 mean) SSTs were recorded during January through April, above normal in May through September and below normal for most of the remainder of the year. The average temperature anomaly along the transect for the year was slightly above normal (0.5°C). Surface salinities were near normal throughout most of the year with an annual average that was slightly below normal (-0.12 psu). A notable exception to these near normal salinity conditions was a negative anomaly everywhere west of the Scotian Shelf in December. Bottom temperatures in the Gulf of Maine were generally above normal during the year with an

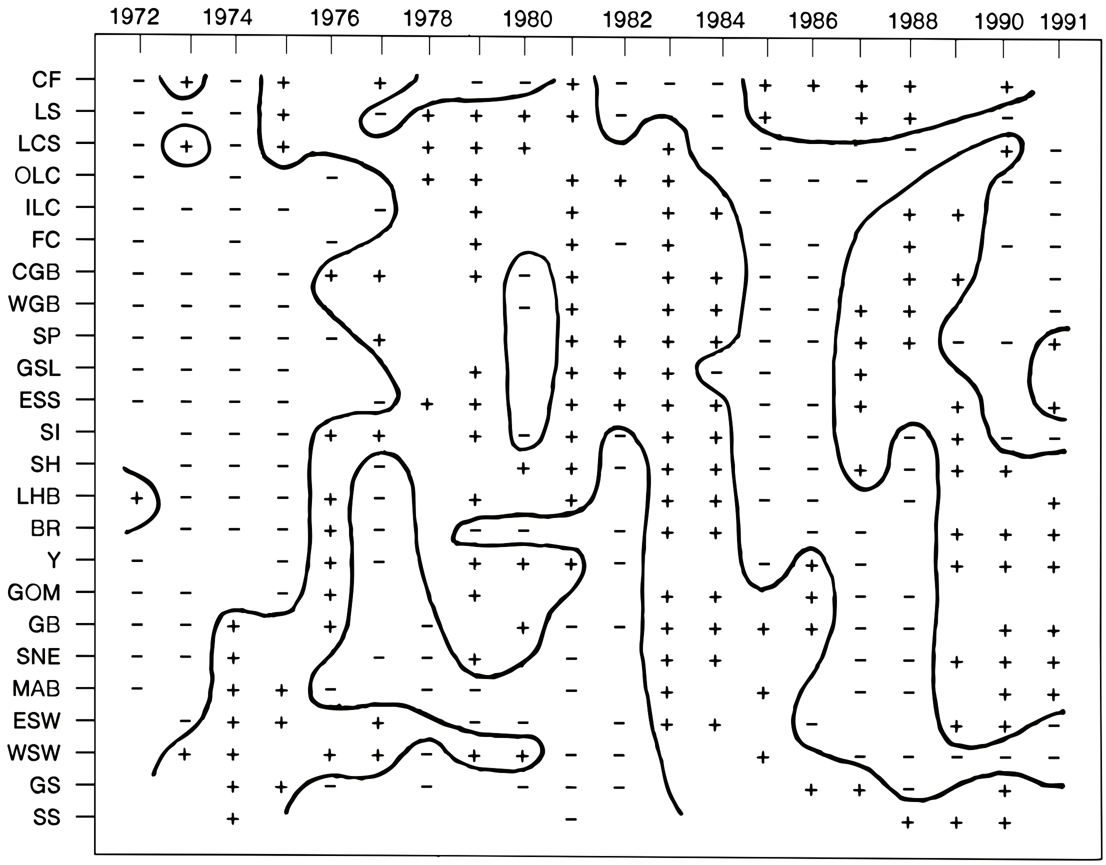

Fig. 23. Distribution of positive (+) and negative (-) annual sea-surface temperature anomalies in 1972–91 by subregion (Fig. 22) relative to the 1972–80 means. (Only anomalies less than -0.15°C and greater than +0.15°C were used in drawing the contours.)

average over the transect of 0.3°C. In contrast to the Gulf proper, the bottom temperatures on the Scotian Shelf were below normal (-0.3°C) during 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 Bay of Fundy. Monthly anomalies relative to the 1951–80 means (Drinkwater, 1987) were calculated for 1991. It is noted that the 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 of both temperature and salinity in all years throughout the water column. This relative homogeneity of the water column is due in large part to the strong tidal mixing in the Bay of Fundy.

In 1991 temperatures ranged from a minimum of approximately 2.5°C to a maximum of 11.5°C in August and near surface in September (Fig. 29). This resulted in positive anomalies of generally > 0.5°C in the upper 50 m and typically <0.5°C below 50 m (Fig. 29). Slightly negative anomalies were observed in the near surface waters (<25 m) during the last 4 months of the year but only during September and October did they extend throughout the water column. Waters at and below 50 m during November and December were above normal. The long-term temperature records at surface and 90 m for Prince 5 showed high similarity (Fig. 30). The temperature anomalies were near normal but had increased from below normal values in the late-1980s. The dominant high and low were in the early-1950s and the mid-1960s, respectively.

In April, salinities at Prince 5 dropped below 29, which is equivalent to a negative anomaly exceeding 2 psu (Fig. 29). This may have been due to an early freshwater discharge from the Saint John River although the values may not be representative of the mean for the month. The general trend was for

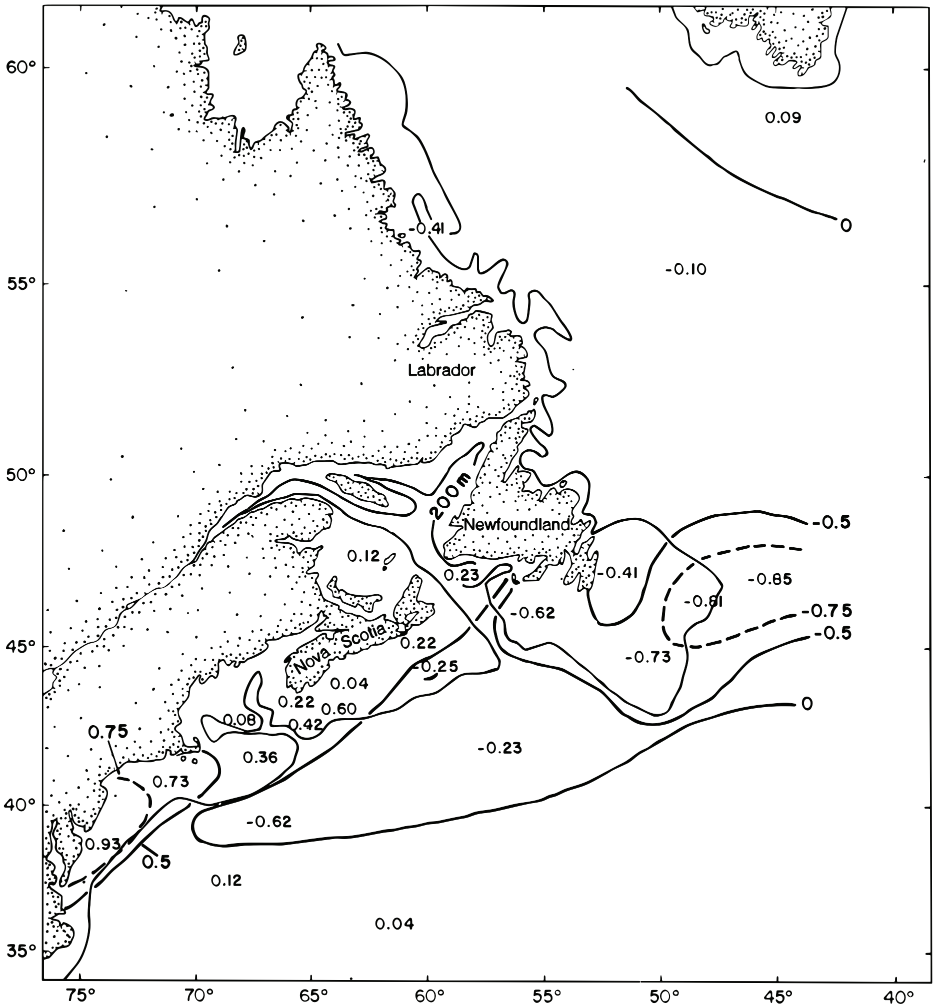

Fig. 24. Contours of the annual mean sea-surface temperature anomalies in 1991 for 24 areas in the Northwest Atlantic Ocean.

fresher-than-normal conditions throughout the year with the exception of the late spring and early summer. Relatively high negative anomalies were observed in the late autumn.

Emerald Basin temperatures

Petrie *et al.* (MS 1991) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (periods of several years). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (month to month) variability. High coherence at these low frequencies was found throughout the water column as well as horizontally from the Mid-Atlantic Bight to the Laurentian Channel. In 1991 several CTD profiles were obtained in Emerald Basin by research cruises in the area. The time series of temperatures from 250 m are plotted in Fig. 31 as anomalies from the monthly means averaged over the period 1951–80. Below normal temperatures of approximately 1°C were observed in 1991. These values represent a 3°C drop since the late 1980s. The trends at 250 m were representative of the waters below 75 m. These cooler temperatures in Emerald Basin were accompanied by below normal salinities.

Cabot Strait deep temperatures

Long-term temperature variability in the deep waters (200–300 m average) of the Laurentian Channel in the Gulf of St. Lawrence has been studied by Bugden (1991) from data collected between the late 1940s and 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

TABLE 3. Monthly SST anomalies in degrees Celsius for 1991 from the long-term base period 1971–90. The area names are provided below.

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

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

propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated temperature time series for Cabot Strait shows that in recent years temperatures have steadily declined such that by November, 1991, the average temperatures in 200–300 m depth range had fallen to near 4.5°C (Fig. 32). This is the lowest mean deep water temperature in Cabot Strait since the late-1960s.

Warm-core rings

The life history of anticyclonic warm-core Gulf Stream rings in the region from 45°W to 75°W during 1991 was derived from the NOAA/NWS Oceanographic Analysis maps and from the *State-of-the-Ocean: Gulf of Maine to the Grand Banks* reports issued monthly at the Bedford Institute of Oceanography. Owing to the relatively common occurrence of cloudy or foggy conditions, particularly in the eastern half of the region, several weeks may elapse between clear thermal images of the sea surface. Consequently there is frequently uncertainty about the creation or continued existence of a particular ring and, therefore, the statistics derived solely from this data source should be viewed cautiously.

A total of 32 warm-core rings were present in the area during some portion of 1991, seven of which survived from 1990 into the new year. Five of the 25 new rings which formed in 1991 persisted into 1992. At least 12 of the rings formed in 1991 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1991, ranged in age from less than a week to more than 8.5 months and had a mean life of approximately 3.5 months. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are shown in Fig. 33. Only two rings formed west of 65°W with a maximum of five generated in the 55–57.5°W and the 45–47.5°W zones. The number of rings present in each of the longitude zones varied from three to nine with the highest number in the adjacent zones between 57.5°W to 62.5°W. The distribution of rings present in the zones, given the areas of formation, reflect westward propagation.

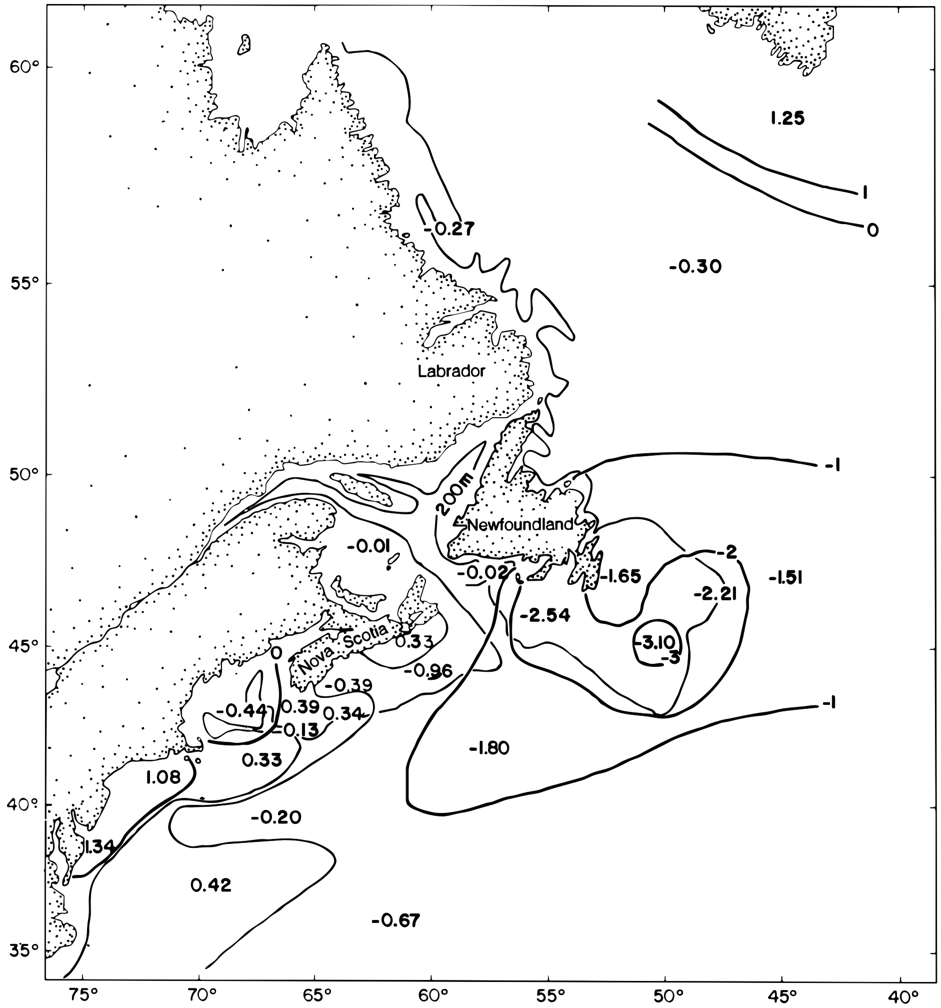

Fig. 25. Contours of the mean sea-surface temperature anomalies in July 1991 for 24 areas in the Northwest Atlantic Ocean.

Summary

Strong climate anomalies highlighted the events in 1991. Severe cold conditions were observed in the waters off northern and eastern Newfoundland. Sea-surface temperature data from ships-of-opportunity showed that annual SST anomalies were negative for the Labrador Shelf, the Grand Bank, Flemish Cap, and the southeastern Newfoundland Shelf. Temporally, the largest anomalies occurred during the late spring and summer months with the maximum negative anomaly occurring on the Grand Bank in mid-summer (3° to 4°C below normal). In contrast, warmer than normal SST anomalies were recorded from the central Scotian Shelf to the Mid-Atlantic Bight with the amplitude of the anomaly increasing southward. This gradient in annual SST anomaly was also observed at coastal stations and coincided with a southward increase in air temperature anomalies. The deep waters off Newfoundland at Station 27 showed colder-than-normal temperatures throughout the year and continued a pattern that has persisted since 1983. In the Laurentian Channel at Cabot Strait the average temperature for the depth range 200–300 m decreased for the third consecutive year and was the coldest recorded in 2 decades. Cold conditions also prevailed in the deep waters of Emerald Basin and the western Scotian Shelf. These cold temperatures were not observed in the bottom waters at the Prince 5 Station at the mouth of the Bay of Fundy nor in the deep basins of the Gulf of Maine. Temperatures off West Greenland were also near normal in contrast to the cold conditions off Labrador and Newfoundland. Sea ice was severe throughout the region as it

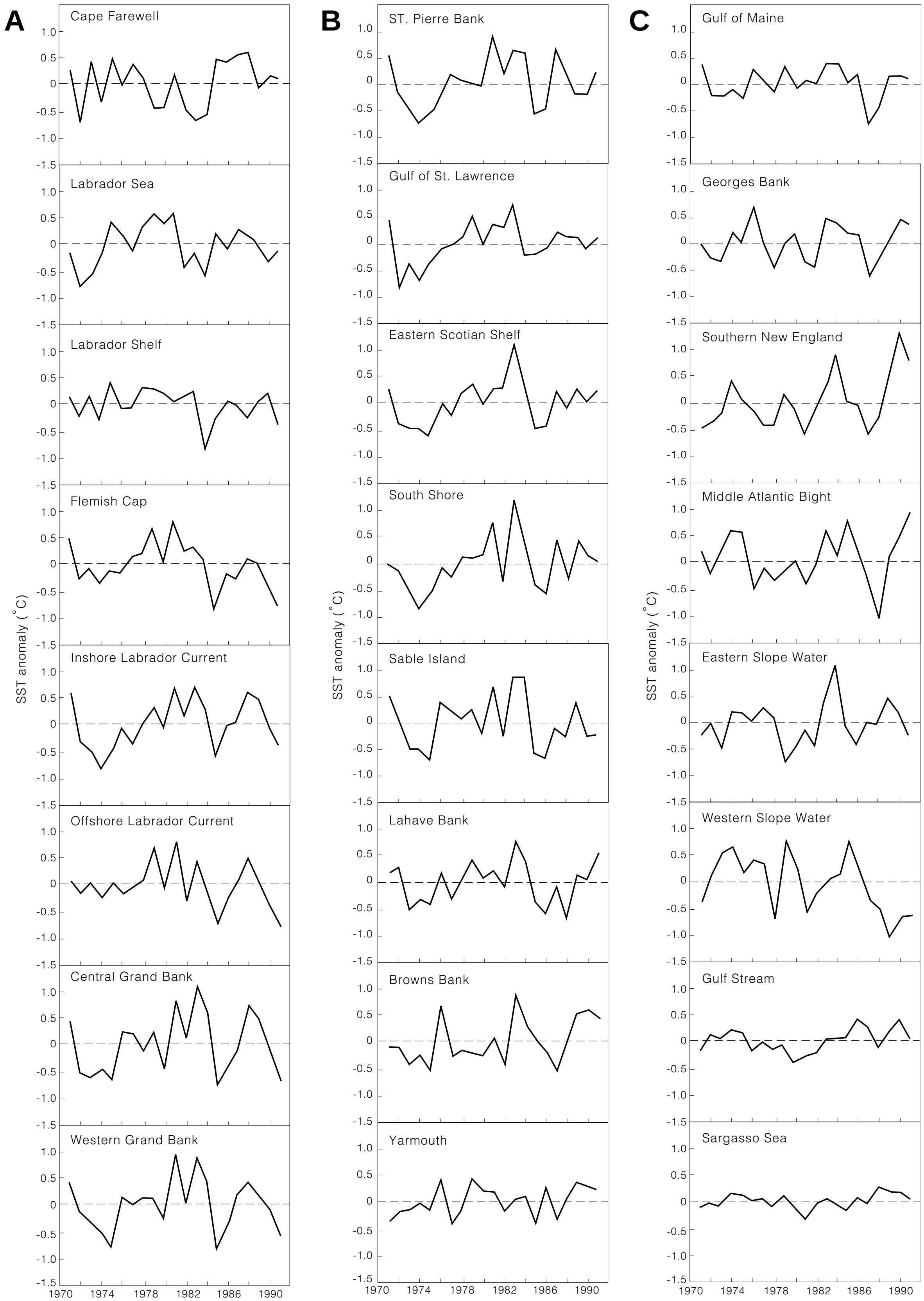

Fig. 26. The annual temperature anomalies (relative to 1971–90) for the offshore areas, (**A**) Cape Farewell to Western Grand Bank, (**B**) St. Pierre to Yarmouth and (**C**) Gulf of Maine to the Sargasso Sea..

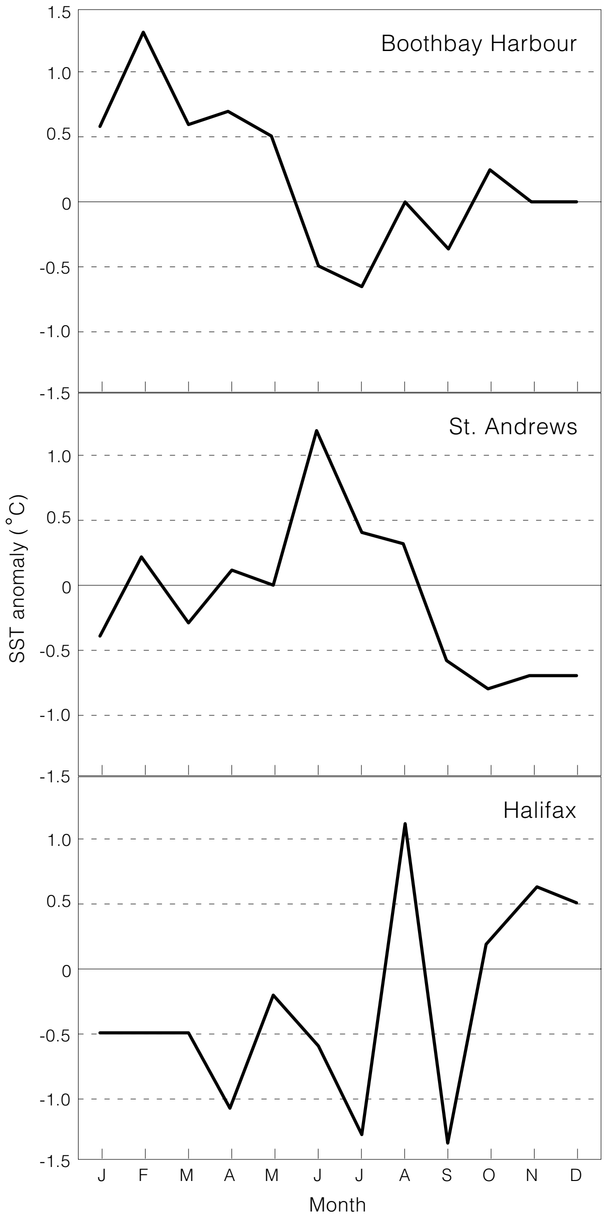

Fig. 27. The monthly sea surface temperature anomalies (relative to 1951–80) during 1991 for Boothbay Harbor, St. Andrews and Halifax.

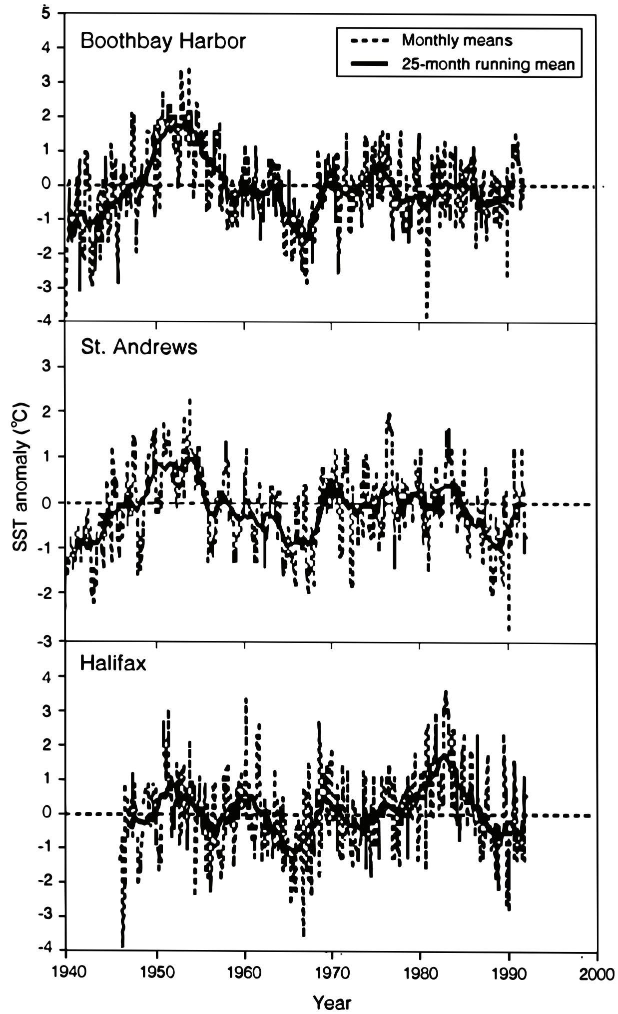

Fig. 28. The monthly means and the 25-month running means of the sea surface temperature anomalies (relative to 1951–80) for Boothbay Harbor, St. Andrews and Halifax.

formed early, spread more rapidly than normal, and persisted longer than usual. Ice was held inshore along the northern Newfoundland coast by unusually strong and persistent easterly winds.

Acknowledgements

We thank the many individuals who helped in the preparation of this paper, including A. Stroud and D.R. McLain of the U.S. National Marine Fisheries Service in Monterey, California, 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. Lossier of the Biological Station, St. Andrews, for providing St. Andrews and Prince 5 data; C. Fitzpatrick of the Northwest Atlantic Fisheries Centre, St. John's, for the station 27 data; P. Cote 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 U.S. Coast Guard for the data on icebergs. Thanks is also due to L. Petrie and R. Pettipas for technical assistance in the preparation of the manuscript.

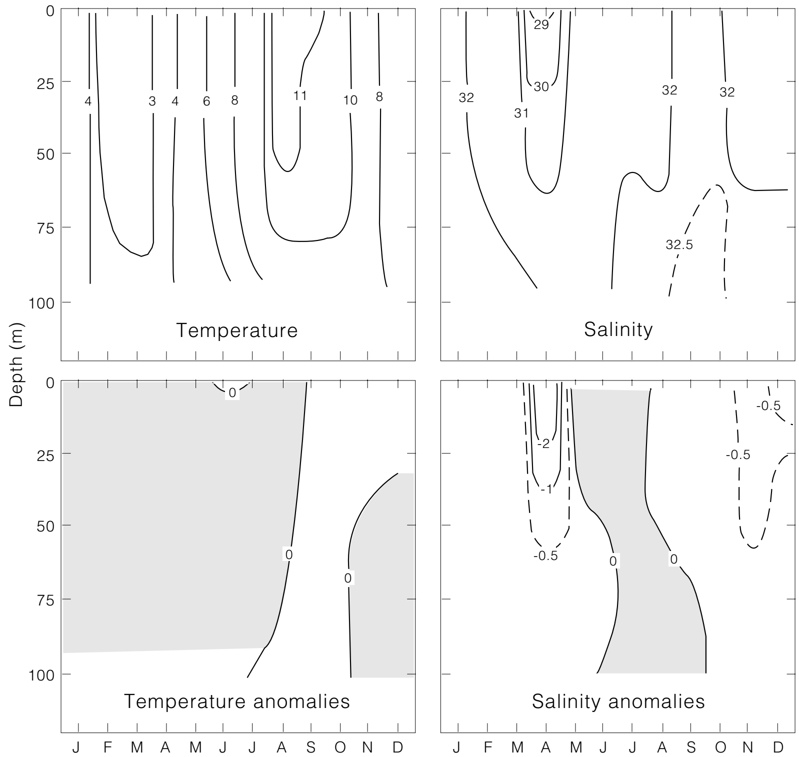

Fig. 29. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1991 relative to the 1951–80 means. Shaded areas are positive anomalies.

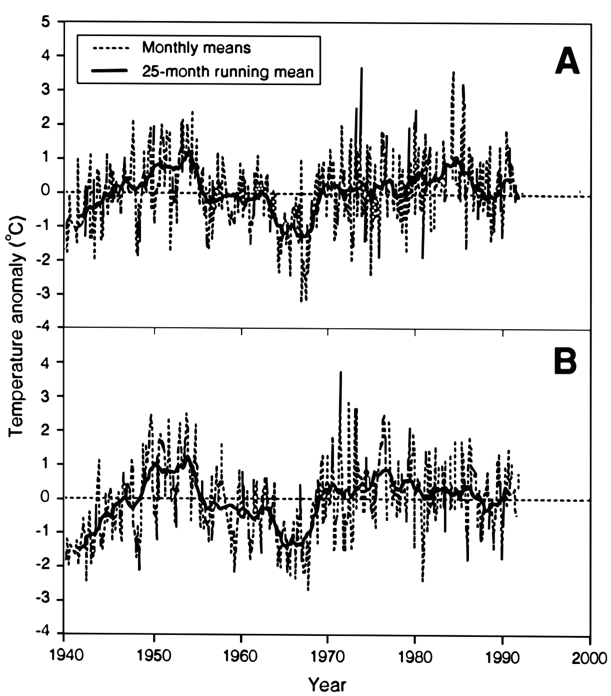

Fig. 30. The monthly means and the 25-month running means of the temperature anomalies for Prince 5, (**A**) 0 and (**B**) 90 m.

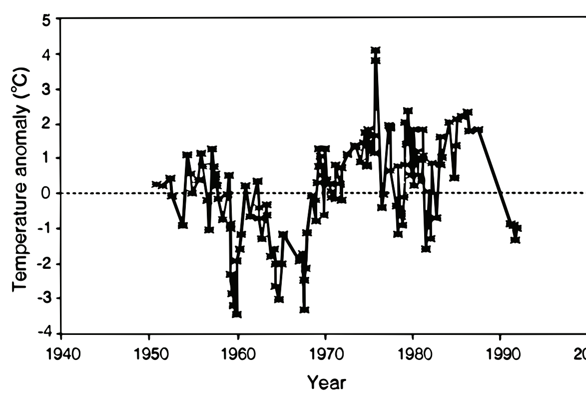

Fig. 31. Temperature anomalies (relative to 1951–80) at Emerald Basin at 250 m.

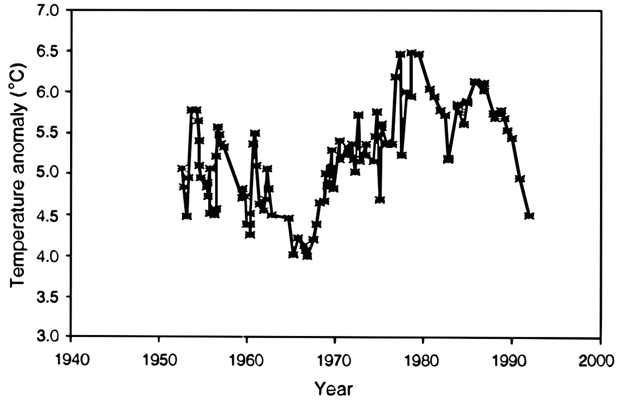

Fig. 32. Mean temperatures for 200–300 m in Cabot Strait.

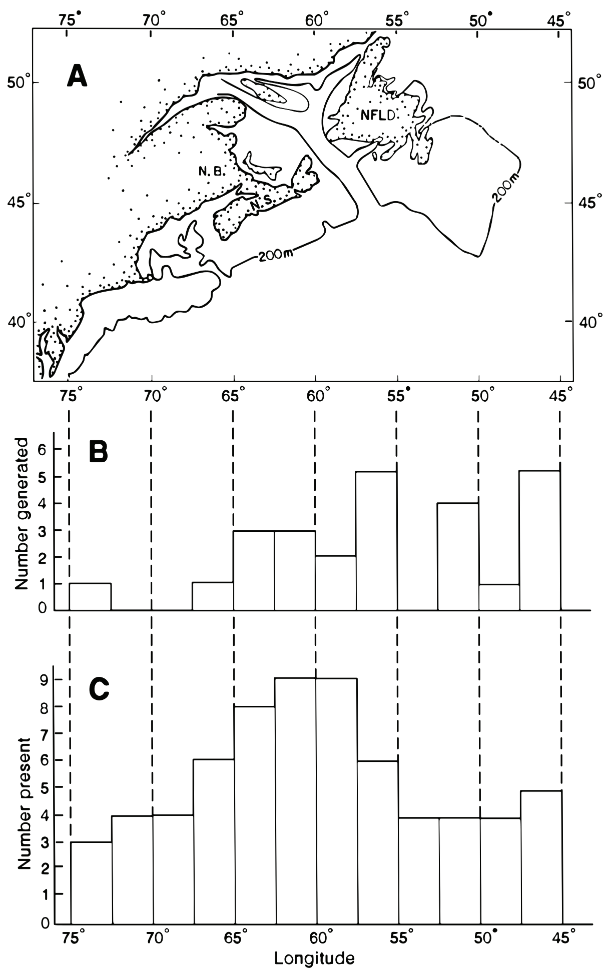

Fig. 33. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1991: (**A**) the chart of the area of interest; (**B**) the number of rings generated in each 2.5° zone of longitude; and (**C**) the number of rings present in each 2.5° zone during some part of the year.

References

AGNEW, T., and A. SILIS. 1991. Winter sea ice extent on the eastern Canadian seaboard. *Climatic Perspectives*, Vol. 13, February Monthly Review, p. 9–11.

BENWAY, R. L., J. W. JOSSI, and J. PREZIOSO. MS 1992. Surface and bottom temperatures, and surface salinities: New York to the Gulf Stream, Massachusetts to Cape Sable N.S. 1991. *NAFO SCR Doc.*, No. 16, Serial No. N2061, 14 p.

BOROVKOV, V. A., and I. I. TEVS. MS 1992. Oceanographic conditions in NAFO Subareas 0, 2 and 3 in 1991. *NAFO SCR Doc.*, No. 21, Serial No. N2068, 15 p.

BUGDEN, G. L. 1991. Changes in the temperature-salinity characteristics of the deeper waters of the Gulf of St. Lawrence over the past several decades. *In*: The Gulf of St. Lawrence: small ocean or big estuary? J.-C. Therriault [ed.]. *Can. Spec. Publ. Fish. Aquat. Sci.*, **113**: 139–147.

DRINKWATER, K. F. 1987. Mean temperature and salinity conditions near the entrance to the Bay of Fundy, 1951–80. *NAFO Sci. Coun. Studies*, **11**: 71–73.

DRINKWATER, K. F., P. C. SMITH, and R. PETTIPAS. MS 1992. The spatial and temporal scales of temperature variability in the Bay of Fundy. *NAFO SCR Doc.*, No. 71, Serial No. N2125, 20 p.

DRINKWATER, K. F., and R. W. TRITES. 1993. Overview of environmental conditions in the Northwest Atlantic in 1990. *NAFO Sci. Coun. Studies*, **19**: xx–xx.

FINDLAY, B. F., and A. DEPTUCH-STAPF. 1991. Colder than normal temperatures over northeastern Canada during the 1980's. *Climatic Perspectives*, Vol. 13, April Monthly Review, p. 9–12.

MYERS, R. A., S. A. AKENHEAD, and K. DRINKWATER. 1990. The influence of Hudson Bay runoff and ice-melt on the salinity of the inner Newfoundland Shelf. *Atmosphere-Ocean*, **28**: 241–256.

NARAYANAN, S., S. PRINSENBERG, and E. B. COLBOURNE. MS 1992. Overview of environmental conditions in 2J3KL NAFO subareas in 1991. *NAFO SCR Doc.*, No. 6, Serial No. N2039, 25 p.

PETRIE, B., K. F. DRINKWATER, and R. PETTIPAS. MS 1991. Temperature and salinity variability at decadal time scales on the Scotian Shelf and in the Gulf of Maine: some initial results. *NAFO SCR Doc.*, No. 86, Serial No. N1970, 22 p.

PETRIE, B., J. W. LODER, J. LAZIER, and S. AKENHEAD. 1992. Temperature and salinity variability on the eastern Newfoundland shelf: the residual field. *Atmosphere-Ocean*, **30**: 120–157.

STEIN, M. MS 1992. Variability of climate – impact on cod recruitment off West Greenland? *NAFO SCR Doc.*, No. 19, Serial No. N2064, 15 p.

THOMPSON, K. R., and M. G. HAZEN. 1983. Interseasonal changes in wind stress and Ekman upwelling: North Atlantic, 1950–80. *Can. Tech. Rep. Fish. Aquat. Sci.*, **1214**: 175 p.

THOMPSON, K. R., R. H. LOUCKS, and R. W. TRITES. 1988. Sea-surface temperature variability in the shelf-slope region of the Northwest Atlantic. *Atmosphere-Ocean*, **26**: 282–299.

TRITES, R. W., and K. F. DRINKWATER. 1984. Overview of environmental conditions in the Northwest Atlantic in 1983. *NAFO Sci. Coun. Studies*, **7**: 7–25.