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Overview of Environmental Conditions in the Northwest Atlantic in 1995

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Abstract

A review of environmental conditions on the continental shelves and adjacent offshore areas off northeastern North America during 1995 is presented. Wintertime air temperatures over eastern Canada with the exception of Nova Scotia were colder than normal continuing the trend that has persisted through the 1990s. This was associated with the high positive value of the North Atlantic Oscillation Index caused by the intensification of the Icelandic Low and Azores High. Strong NW winds over the region brought cold air farther south. The cold air temperatures and stronger NW winds resulted in early ice formation, greater areal extent of ice and a longer presence of ice, both on the Labrador/Newfoundland shelves and in the Gulf of St. Lawrence/Scotian Shelf. The cold temperatures, strong winds and heavy ice all contributed to a larger number of icebergs than normal reaching the Grand Banks. Temperatures were not as severe, however, as in recent years and appear to be moderating. Ocean temperatures off Newfoundland at Station 27 were below normal during most of 1995 but they had warmed relative to the extreme cold period of the early-1990s. The area of the CIL in summer across the northeast Newfoundland Shelf generally decreased in 1995 and at two out of the three transects surveyed the area was below normal. The volume of the CIL area declined significantly and its core temperature generally rose. Large areas of the continental shelf, particularly the Grand Banks, contained warmer-than-normal bottom temperatures in the autumn, the first time in several years that this has occurred. Temperature anomalies off southern Newfoundland remained cold, continuing a trend established in the mid-1980s. Similar cold conditions were observed within the CIL in both the Gulf of St. Lawrence and on the Scotian Shelf. Large areas of the Magdalen Shallows continued to be covered by bottom waters of less than 1° and less than 0°C during the summer. Temperatures in the CIL layer on the Scotian Shelf appeared, in general, to be moderating with maximum warming over Emerald Basin due to mixing with warm bottom waters. An exception to this warming of the CIL layers was in the northeastern Scotian Shelf, where near record cold temperatures continued to be found. The warm waters in Emerald Basin have occupied the lower layers for the past few years and are consistent with warm temperatures in the deep waters of the Gulf of Maine. The source of these deep waters are the offshore slope waters. Indeed, penetration of the slope water appears to have led to significant warming throughout the entire Gulf of Maine since 1994.

Key words: climate, Grand Bank, Gulf of Maine, Gulf of St. Lawrence, environment, oceanography, Scotian Shelf, temperature

Introduction

This paper examines the physical environmental conditions in the Northwest Atlantic during 1995 and continues the series of annual reviews presented to NAFO that began in 1982. It is based upon selected sets of oceanographic and meteorological data as well as information from research documents prepared for the NAFO Scientific Council. Environmental conditions are compared with those of the preceding year as well as the long-term means. Where possible, the latter have been standardized to a 30-year base period (1961–90) in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council.

Meteorological Observations

Air temperatures

The German Weather Service, Deutscher Wetterierst, in Offenbach, Germany, publishes monthly mean temperature anomalies (relative to 1961–90) for North Atlantic Ocean in their publication *Die Grosswetterlagen Europas*. During the first three months of the year, colder-than-normal air temperatures were observed over the Labrador Sea and northern Newfoundland regions (Fig. 1). Anomalies were typically -2 to -3°C but colder along the northwest coast of Greenland. These conditions contrast with those over the Scotian Shelf, the Gulf of Maine and the Middle Atlantic Bight where winter air temperatures were generally warmer than normal, e.g. in January, anomalies were 2–5°C. On average, winter temperatures over the western and southeastern Gulf of St. Lawrence were also warmer than normal although February was an exception with anomalies of -1 to -2°C. In the northeastern Gulf, colder-than-normal air temperatures persisted throughout the winter. For the months April to November, air temperatures over the Labrador Sea were generally above normal. Exceptions included the southern Labrador Sea and northern Newfoundland during June and July. By November, temperature anomalies reached 2–7°C over Davis Strait and Baffin Bay. Around the Maritime Provinces, air temperatures oscillated about their normals through April to September. The most significant anomaly was observed in October when air temperatures were 2–3°C above normal although by November, they had fallen back to near normal. In the southern NAFO region from the Gulf of Maine to Cape Hatteras, temperatures were generally warmer than normal except during the last two months of 1995.

Monthly air temperature anomalies for 1994 and 1995 relative to their 1961–90 means at Godthaab in Greenland, Iqaluit on Baffin Island, Cartwright on the Labrador coast, St. John’s in Newfoundland, Magdalen Islands in the Gulf of St. Lawrence, Sable Island on the Scotian Shelf, Boston in the western Gulf of Maine, and Cape Hatteras at the southern boundary of the NAFO region (see Fig. 2 for locations) are shown in Fig. 3. The predominance of colder-than-normal air temperatures in the first three months of 1995 and generally warmer than normal during the rest of the year is evident at sites around the perimeter of the Labrador Sea from Godthaab to St. John’s, Newfoundland. Wintertime temperatures at Godthaab were more severe than in 1994 but elsewhere they were similar to or less severe than in 1994. The warming during the latter half of the year was most noticeable at Iqaluit. Warm temperature anomalies tended to dominate throughout most of 1995 at Cape Hatteras, continuing the 1994 pattern. The exception was very cold temperatures in November and December of 1995, which contrast with the warm temperatures in the northern regions, especially the Labrador Sea.

Iqaluit recorded an annual mean temperature of 8.1°C. This represents an anomaly of 1.5°C above normal and a rise of over 1.5°C since 1994 and 4.4°C since 1993. At Cape Hatteras, the annual air temperature was also significantly above normal (17.6°C, anomaly of 0.95°C). At the remaining six sites, annual air temperatures were <0.5°C from their long-term mean values. From the Gulf of St. Lawrence and Newfoundland north, air temperature anomalies rose relative to 1994 whereas to the south air temperature anomalies generally fell relative to 1994. (Note that at the Magdalen Islands, the average anomaly over the first eleven months was assumed to be representative of the annual average).

The time series of mean annual air temperatures and their 5-year running means for the eight sites show the warming in 1995 at the five most northern sites and a continuation of the upward trend that began in 1994 (Fig. 4). Note that the interannual variability since 1970 at Godthaab, Iqaluit, Cartwright, and, to a lesser extent, St. John's, Newfoundland, have been dominated by large amplitude fluctuations with periods of 5–10 year with minima in the early-1970s, early to mid-1980s and the early-1990s. Indeed, the recent rise in temperature is consistent with a continuation of this near-decadal pattern. In addition, there has also been an overall downward trend causing temperature anomalies since 1970 to be predominantly below normal. Temperature anomalies at the Magdalen Islands and Sable Island have been of much lower amplitude and show no signs of a general downward trend since 1970. They do, however, contain minima in the early-1970s (both sites), the mid-1980s (Sable Island only) and in the 1990s (Magdalen Islands only). At Boston, the steepest trend was from the 1800s into the middle of the 1900s. This has been followed by oscillations without any trend as has also been observed on the Magdalen Islands and Sable Island. At Cape Hatteras, temperatures are near their long-term maximum and have been rising steadily since the early-1980s. Temperature oscillations since the 1960s, have generally been opposite those in the northern regions, i.e. when it was cold in the north, it tended to be warm at Cape Hatteras.

Sea-surface air pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale pressure patterns and atmospheric circulation. Monthly mean sea-

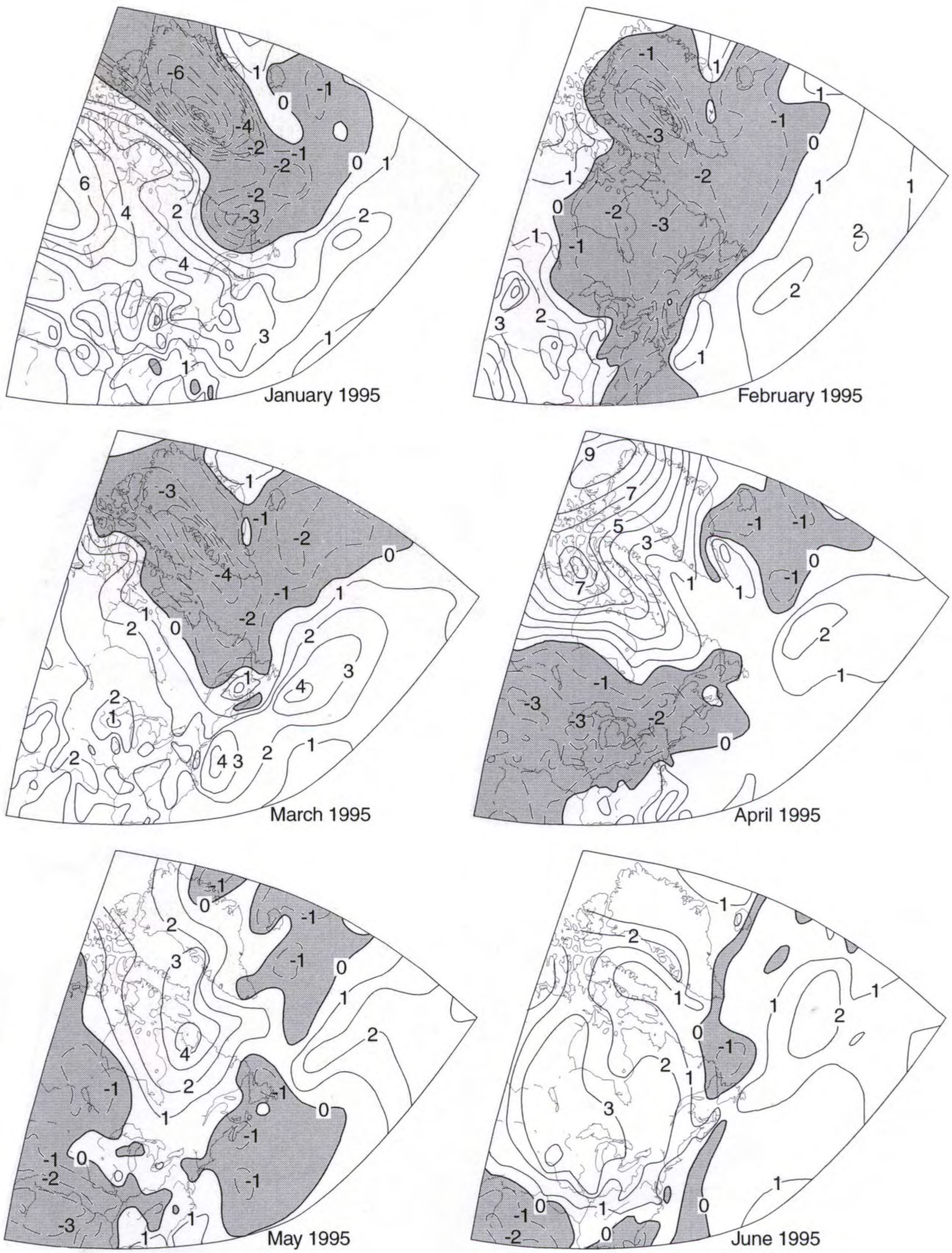


Fig. 1. Monthly air temperature anomalies (°C) over the NW Atlantic in 1995 relative to the 1961–90 means. Shaded areas are negative anomalies. (From Grosswetterlagen Europas).

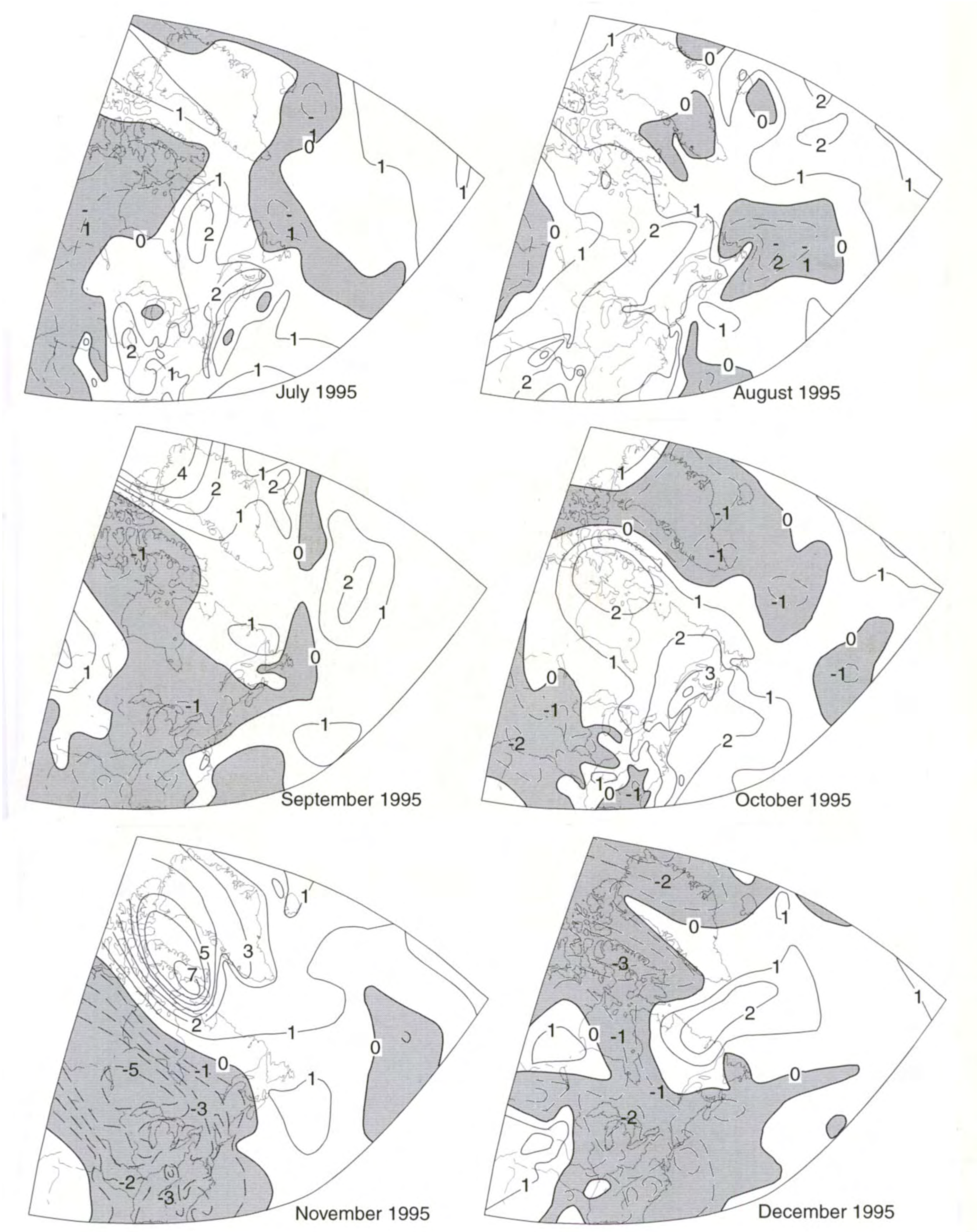


Fig. 1. (Continued). Monthly air temperature anomalies (°C) over the NW Atlantic in 1995 relative to the 1961–90 means. Shaded areas are negative anomalies. (From Grosswetterlagen Europas).

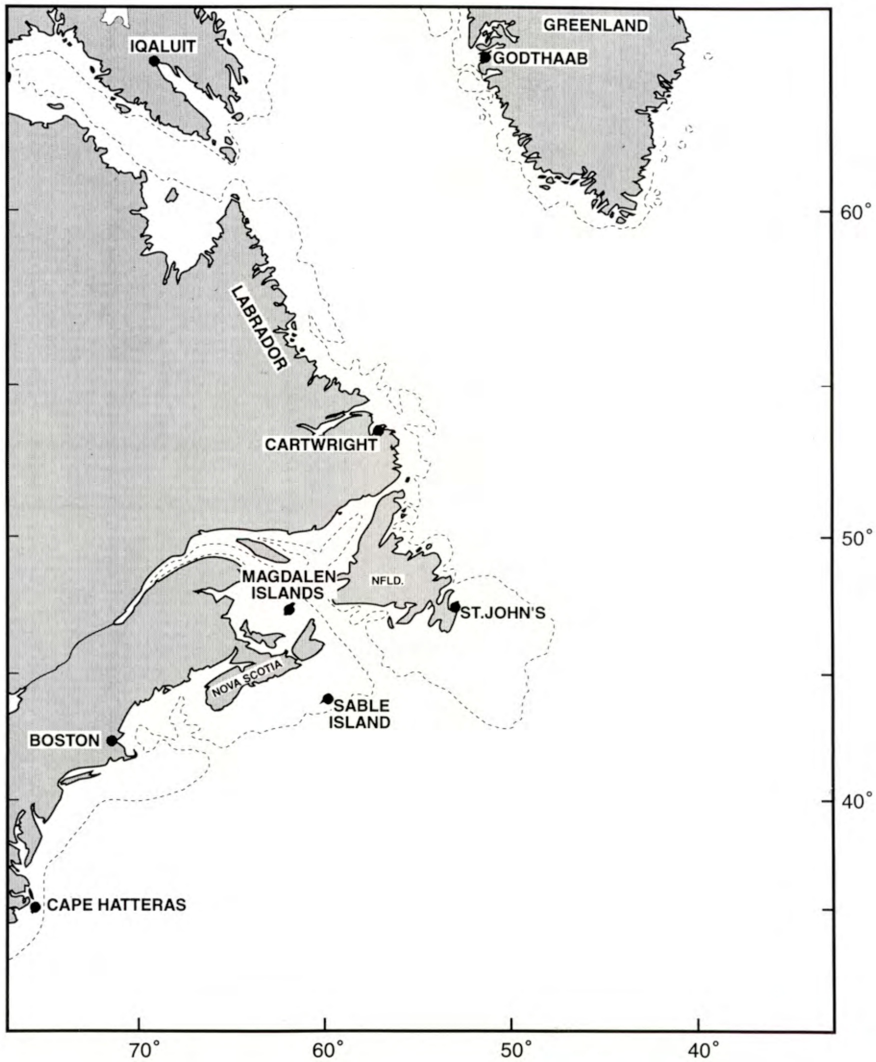


Fig. 2. Northwest Atlantic showing coastal air temperature stations.

surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas*. The long-term seasonal mean pressure patterns are dominated by the Icelandic Low centred between Greenland and Iceland and the Bermuda-Azores High centred between Florida and northern Africa (Fig. 5). Winds rotate counterclockwise around the Low and clockwise around the High. The strength of the wind increases as the pressure gradients steepen. The intensity of the Low and High vary seasonally from a winter maximum to a summer minimum. Seasonal anomalies of the sea-surface pressure for 1995, relative to the 1961–90 means, are shown in Fig. 6. Winter includes December 1994 to February 1995, spring is March to May, summer is June to August and autumn is September to November.

In winter, negative air pressure anomalies covered the northern North Atlantic with peak values (exceeding -13 mb) centred over the Norwegian Sea. This was due to an intensification and northeastward extension of the Iceland Low. In contrast, a center of positive anomalies (maximum of 6.1 mb) was observed over the southeastern North Atlantic, indicating a strengthening and eastward shift of the Bermuda-Azores High. A weak anomalous high pressure system also formed over northern Quebec. The resultant air pressure patterns would have strengthened the westerly winds in the eastern sections of the North Atlantic. The northerly winds over East Greenland should have been much stronger than normal and may have contributed to an increased transport of both the East Greenland Current and ice out of the Arctic

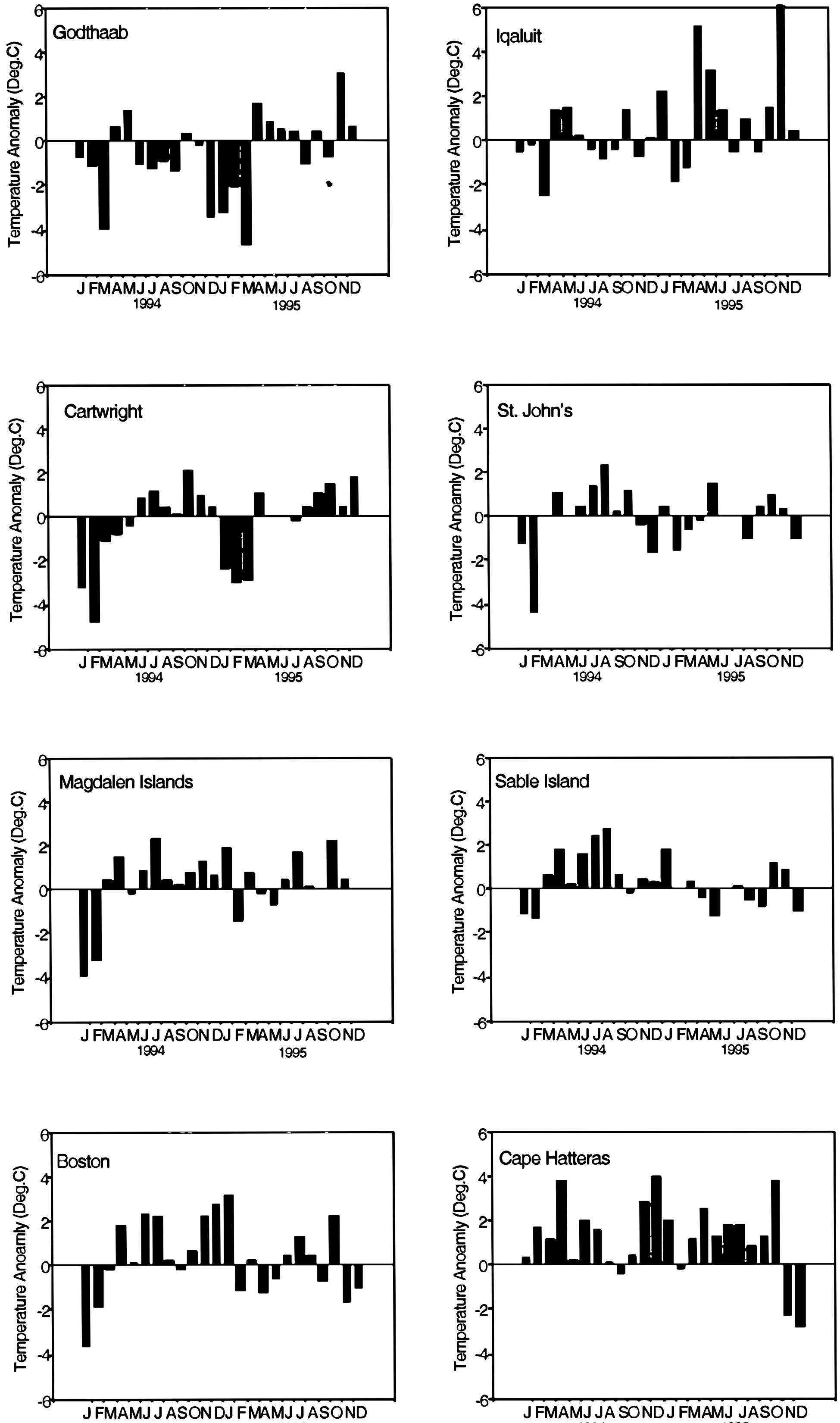


Fig. 3. Monthly air temperature anomalies in 1994 and 1995 at selected coastal sites (see Fig. 2 for locations).

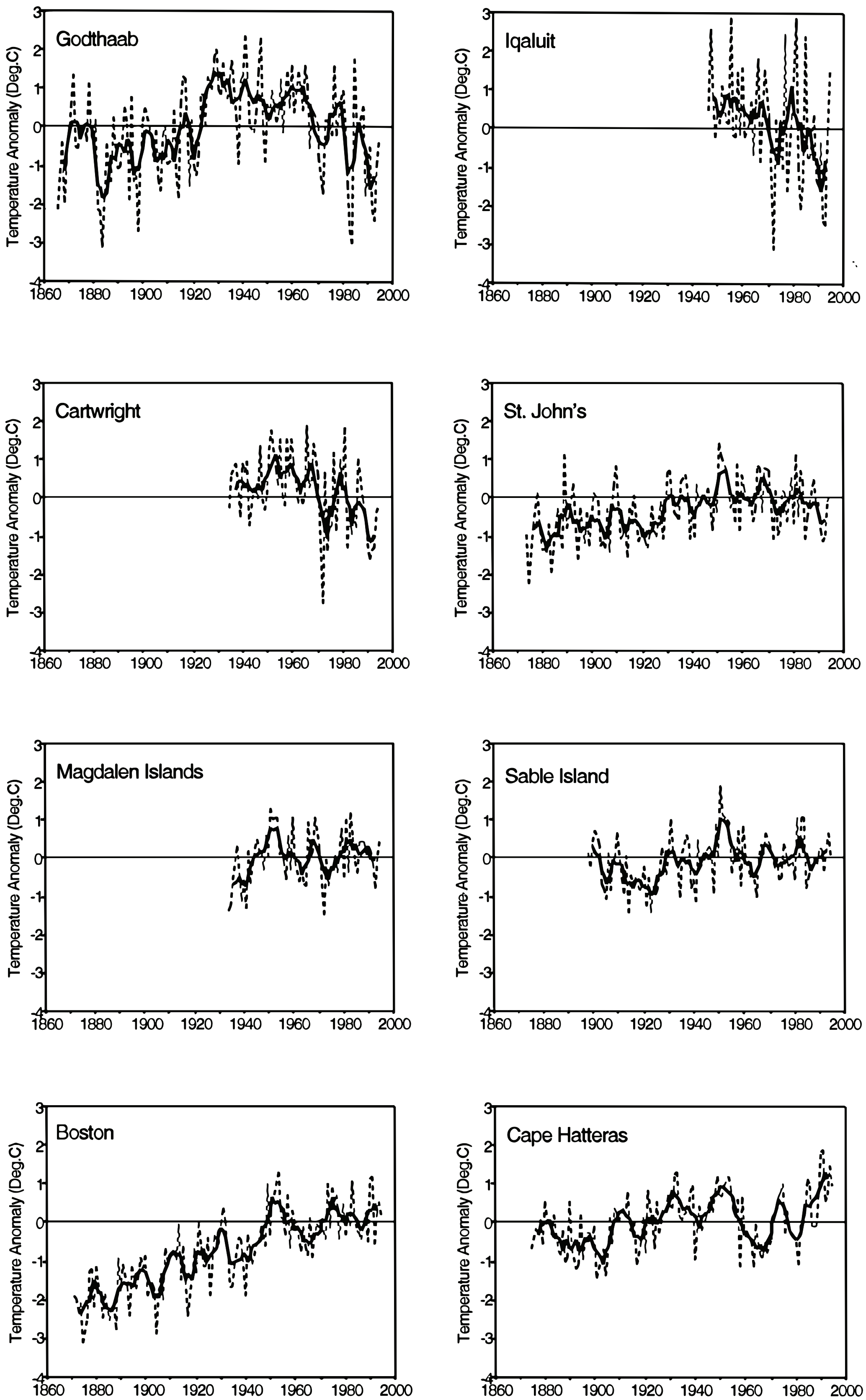


Fig. 4. Annual and 5-year running means of the air temperature anomalies at selected sites.

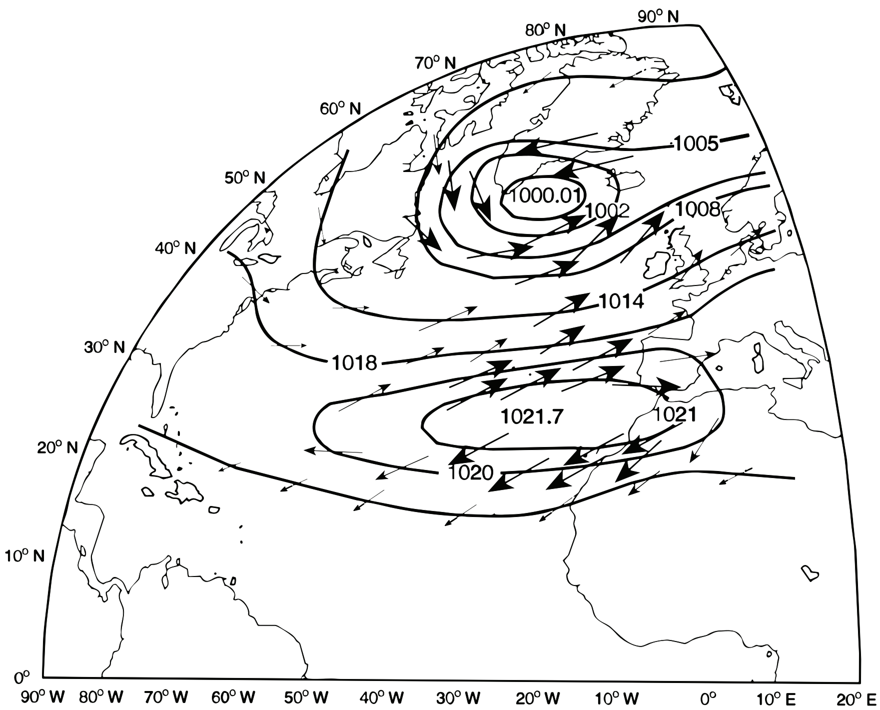


Fig. 5. The long-term (1961–90) mean sea surface pressure during the winter (average of December, January and February). A schematic of the wind field associated with the mean pressures is also shown.

into the Greenland Sea. North winds over Baffin Bay and the Labrador Sea would have been slightly stronger than usual while anomalous winds in winter over Newfoundland, the Gulf of St. Lawrence and the Scotian Shelf/Gulf of Maine would have been more northeasterly. In spring a strong positive anomaly developed over Greenland (maximum anomaly of 7.6 mb) while negative centres appeared in the central region of the North Atlantic and over Europe. The winds associated with these systems would have mainly generated northeasterlies over the southern Labrador Sea and southerly winds over Davis Strait and Baffin Bay. In summer a relatively strong low developed east of Newfoundland with a maximum pressure anomaly of -5.5 mb. This would contribute to weaker southerly and southwesterly winds than usual along the eastern coast of North America. Similar to the summer, a high positive anomaly (maximum +9.8 mb) developed over Greenland in the autumn. This, together with the low pressure over eastern Canada would have brought southerly and southwesterly anomalous winds to eastern Canada, the Labrador Sea and Baffin Bay. These winds are believed to have contributed to the above normal air temperatures in the autumn in the Davis Strait and Baffin Bay regions.

NAO index

The North Atlantic Oscillation (NAO) Index is the difference in winter (December, January and February) sea level pressures between the Azores and Iceland and is a measure of the strength of the winter westerly winds over the northern North Atlantic (Rogers, 1984). Strong NW winds, cold temperatures and heavy ice in the Labrador Sea area are also associated with a strong positive NAO index (Colbourne *et al.*, 1994; Drinkwater, 1996). The annual NAO index is derived from the measured mean sea level pressures at Ponta Delgada in the Azores minus those at Akureyri in Iceland (Fig. 7). The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1961–90 mean. In 1995, the NAO anomaly was strongly positive and above the 1994 value, continuing a trend of above average NAO anomalies since the late-1980s. Over the past 30 years there has been large decadal variability superimposed upon a general upward trend from a minima in the mid-1960s. Note that the timing of the three most recent peaks in the NAO index corresponds to the periods of cold air temperature

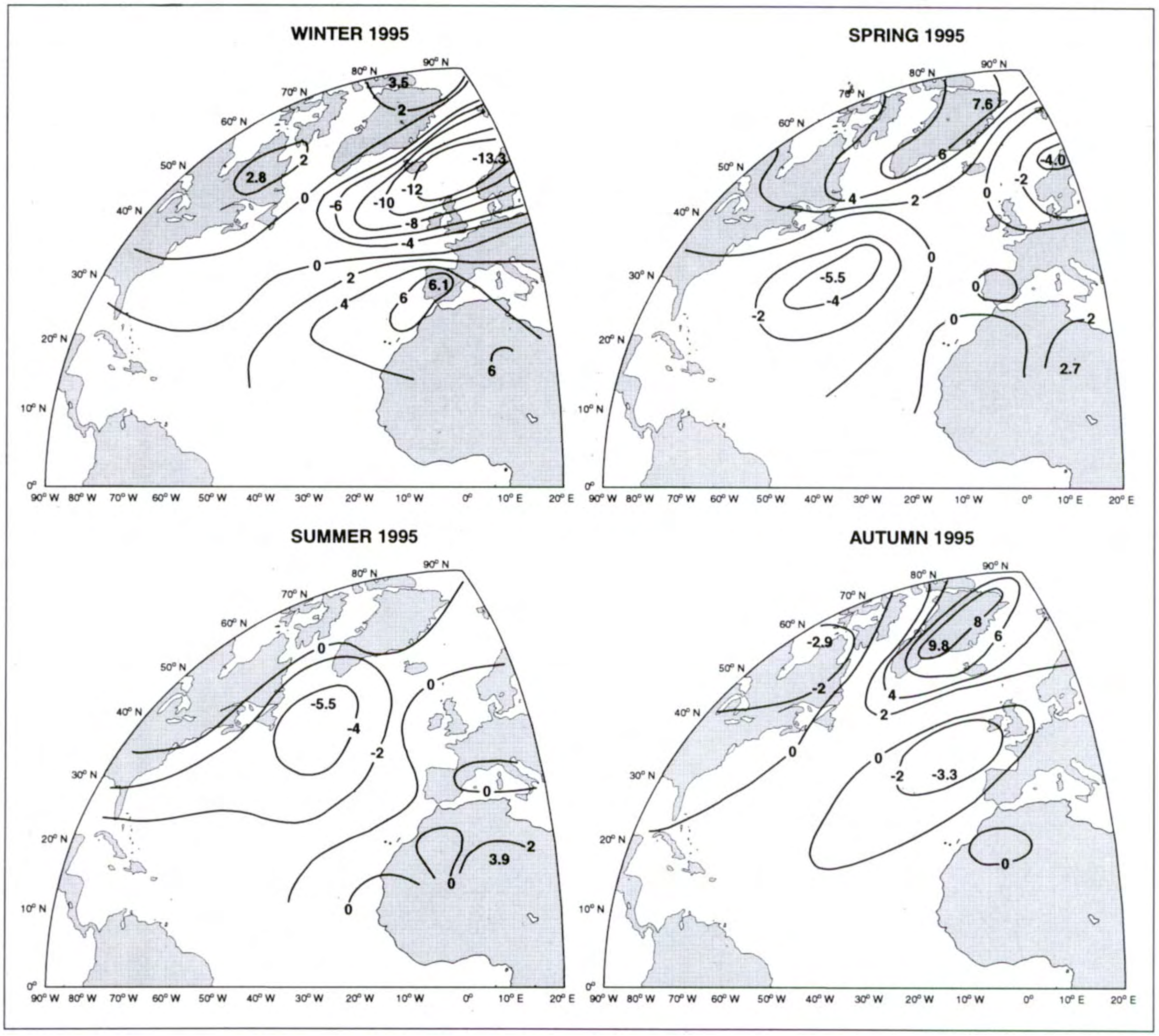


Fig. 6. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1995 relative to the 1961–90 means.

anomalies in the Labrador Sea (Fig. 4). Given the high value of the NAO index in 1995, it was expected that the air temperatures in the Labrador Sea region should have been colder than in recent years (Colbourne *et al.*, 1994; Drinkwater *et al.*, 1996). However, the Icelandic Low also shifted eastward reducing its influence over the Labrador Sea below that expected during a typical high NAO index year.

Sea Ice Observations

Newfoundland and Labrador

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in

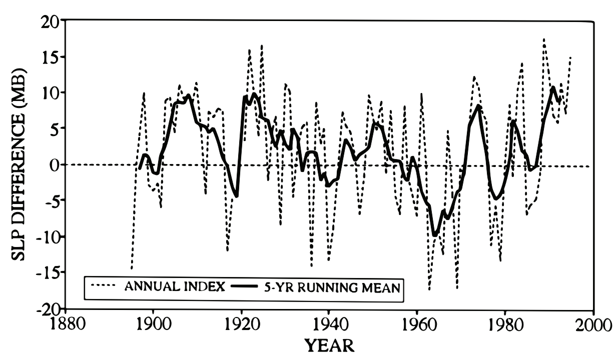


Fig. 7. The North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland.

Ottawa. The long-term medians, maximum and minimum positions of the ice edge (concentrations above 10%) based on the composite for the years 1962 to 1987 are taken from Coté (MS 1989).

At the end of December 1994, ice had spread south to the Strait of Belle Isle and the ice edge was near its long-term median position (Fig. 8). During the first two weeks of January, very cold air temperatures promoted ice formation and strong northwesterly winds also pushed the ice rapidly southward. This lead to the ice edge laying between the long-term median and maximum positions by 15 January. The southward advance continued through the rest of the month at a normal rate so that by 1 February the ice edge still maintained its position between the median and maximum locations. The offshore boundary off Labrador was near normal, however. Cold, windy conditions in February resulted in the ice edge reaching the Avalon Peninsula by the middle of the month, almost two weeks ahead of schedule. By 1 March, the southward movement slowed but westerly winds pushed the ice offshore of northern Newfoundland to near its long-term maximum location. At the beginning of April, ice along the Newfoundland coast was at its maximum southward extent. Northeasterly winds during the last 2 weeks of March pushed the ice shoreward. Warm temperatures in April lead to extensive ice decay along the eastern and southern edges while east to northeasterly winds kept the ice inshore, compacting it further into the coastal regions. Increasing temperatures lead to further decay of the ice and the northward retreat of the ice edge. Westerly winds in May pushed all of the ice from

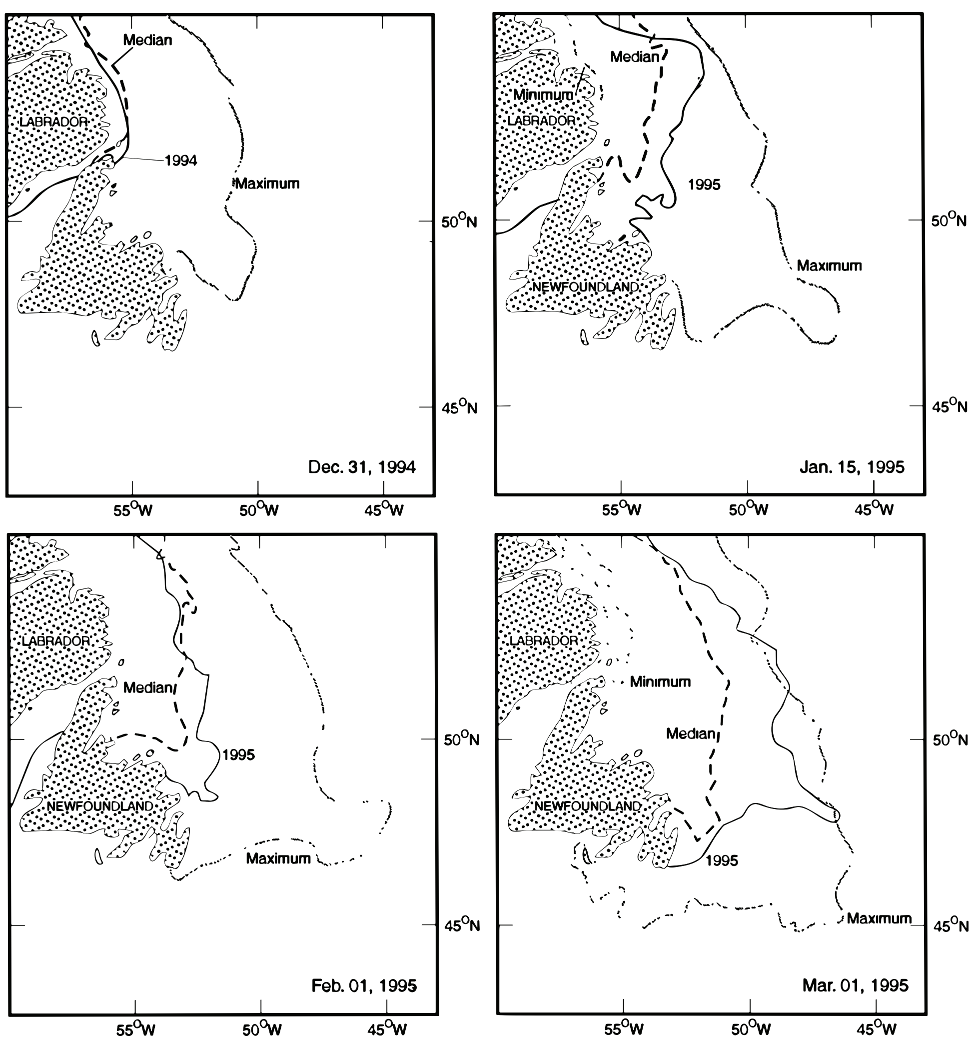


Fig. 8a. The location of the ice edge together with the historical (1962–87) median and maximum positions off Newfoundland and Labrador between December 1994 and March 1995.

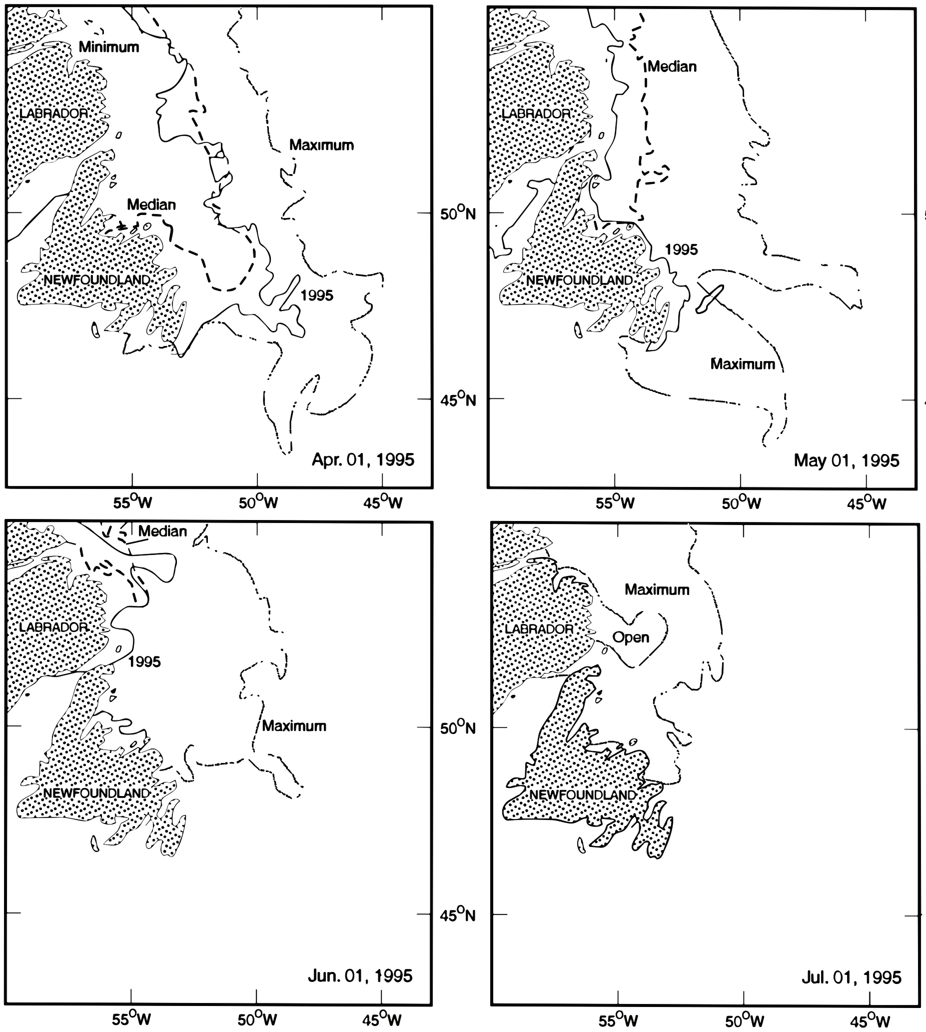


Fig. 8b. The location of the ice edge together with the historical (1962–87) median and maximum positions off Newfoundland and Labrador between April and July 1995.

Conception and Bonavista Bays and by the end of the month it had disappeared entirely. Ice remained offshore of White Bay and Notre Dame Bay and along the coast of Labrador, however. June saw the continual retreat of the ice edge and by 1 July all of the sea ice had disappeared from Newfoundland and southern Labrador waters.

In previous years, the Ice Climatology and Applications Division of Environment Canada supplied us with the results of an analysis of ice conditions off the east coast of Newfoundland and southern Labrador and in the Gulf of St. Lawrence by determining the time of onset, duration and last presence of ice at 24 grid sites (Fig. 9). For each

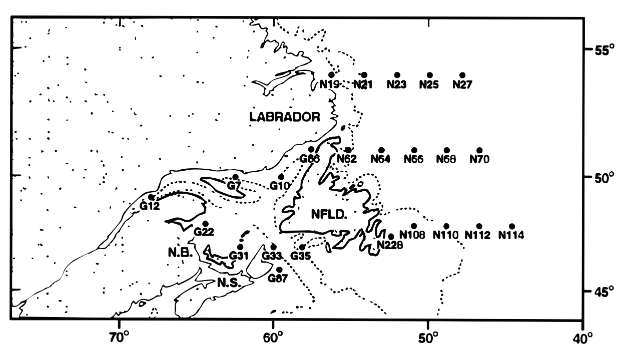


Fig. 9. Location of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

site, the extracted data included ice duration in weeks, as well as minimum, maximum and mean duration for years when ice was present (Table 1). For the 1994/1995 ice season, we undertook the analysis. Ice first appeared off southern Labrador in mid-December of 1994, approximately 1 week earlier than normal (Fig. 10, negative anomaly). On the Newfoundland shelf and the Grand Banks, the ice generally appeared earlier-than-normal by 1–2 weeks except nearshore, off St. John's, Newfoundland, and far offshore at N66 where it arrived within a few days of its normal date. Ice was not observed during the season at the far offshore sites N25, N27, N68, N70, N112, and N114. Ice has never been observed at sites N27 and N70, and in 36 years of observations has only reached N25 and N114 in 2 and 5 years, respectively, and in less than half the years at N68 and N112. In 1995, at the furthest offshore sites where ice was observed, ice left early by upwards of 3 weeks (Fig. 11), due primarily to strong easterly winds pushing the ice inshore. On the rest of the shelf, the ice lasted longer than normal, over 4 weeks off St. John's, Newfoundland. This resulted in the duration being longer than normal off southern Newfoundland and inshore Labrador but it was shorter-than-normal further offshore and off northern Newfoundland (Fig. 12). Note that the duration is not simply the date of the first presence minus the last presence because the ice can disappear and then reappear.

The monthly time series of the areal extent of ice on the northern Newfoundland and southern Labrador shelves (between 45–55°N) from the 1960s to present are shown in Fig. 13. In January through April there has been a general increase in the area of ice over the past 30 years. The ice coverage from January to April 1995 was generally above average but declined relative to 1994. These data support 1995 being a heavier-than-average ice year on the Labrador and Newfoundland shelves but not as severe as the previous three or four years.

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 SLAR (Side-Looking Airborne Radar). During the 1994/95 iceberg season (October to September), a total of 1432 icebergs were spotted south of 48°N. The monthly totals for February to August were 43, 385, 334, 405, 218, 41, and 6 (Fig. 14). No icebergs were spotted between October,

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 1994/95 (October–September) ice year with 1993/94 data in parentheses.

				Ice Duration (in weeks)				
		# of	Yrs	When ice present			Overall	94/95
Site	Seasons Studied	Yrs	ice	Min	Max	Mean	Mean	(93/94)
G–7	67/68–94/95	28	28	6	16	10.8	10.8	14 (14)
G–10	76/77–94/95	19	19	3	17	12.4	12.4	17 (15)
G–12	67/68–94/95	28	28	2	15	11.7	11.7	13 (12)
G–22	76/77–94/95	19	19	7	17	12.3	12.3	17 (15)
G–31	68/69–94/95	27	26	8	17	12.6	12.1	12 (13)
G–33	71/72–94/95	24	24	2	14	10.8	10.8	10 (13)
G–35	59/60–94/95	36	19	1	11	3.5	1.8	0 (4)
G–86	76/77–94/95	19	19	6	23	16.7	16.7	18 (20)
G–87	70/71–94/95	25	24	1	12	7.6	7.3	7 (8)
N–19	66/67–94/95	29	29	17	32	23.9	23.9	25 (25)
N–21	67/68–94/95	28	28	5	28	18.6	18.6	18 (23)
N–23	59/60–94/95	36	30	1	17	5.1	4.2	1 (5)
N–25	59/60–94/95	36	2	1	1	1.0	0.1	0 (0)
N–27	59/60–94/95	36	0	0	0	0.0	0.0	0 (0)
N–62	67/68–94/95	28	28	8	27	18.7	18.7	16 (20)
N–64	59/60–94/95	36	35	3	25	13.2	12.8	13 (18)
N–66	59/60–94/95	36	30	1	17	8.6	7.1	5 (16)
N–68	59/60–94/95	36	16	1	10	3.5	1.6	0 (3)
N–70	60/61–94/95	35	0	0	0	0.0	0.0	0 (0)
N–108	59/60–94/95	36	30	1	17	6.3	5.3	10 (6)
N–110	59/60–94/95	36	29	1	16	5.6	4.6	7 (10)
N–112	59/60–94/95	36	15	1	10	4.1	1.7	0 (7)
N–114	59/60–94/95	36	5	1	2	1.6	0.2	0 (2)
N–228	59/60–94/95	36	25	1	14	5.9	4.1	10 (4)

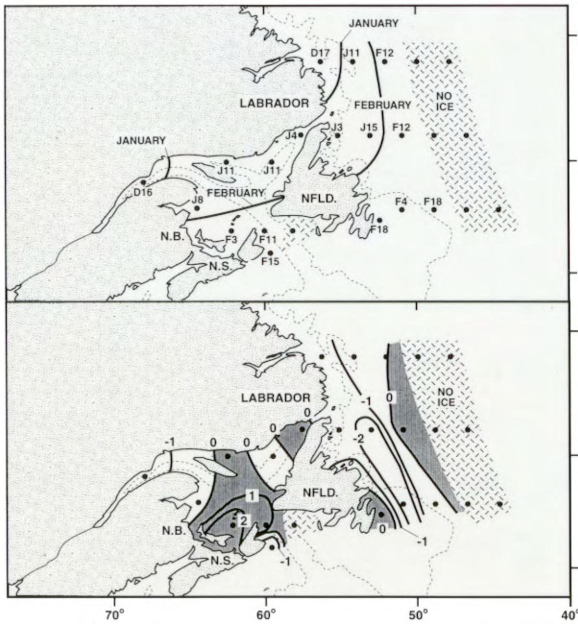


Fig. 10. The date in 1994 or 1995 at which ice first appeared at the grid points in Fig. 9 (top) and their anomalies from the long-term mean in weeks (bottom). A negative anomaly indicates ice appeared earlier than normal.

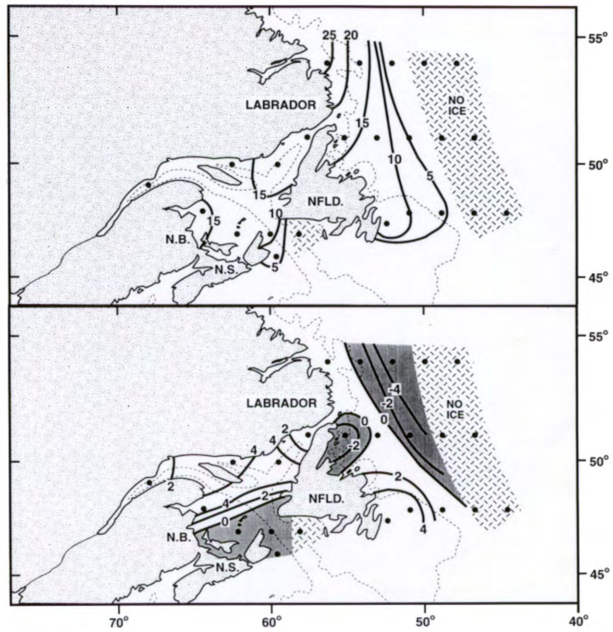


Fig. 12. The duration of ice (top) and its anomaly, in weeks, relative to the long-term mean (bottom). Positive anomalies indicate a duration longer than the mean.

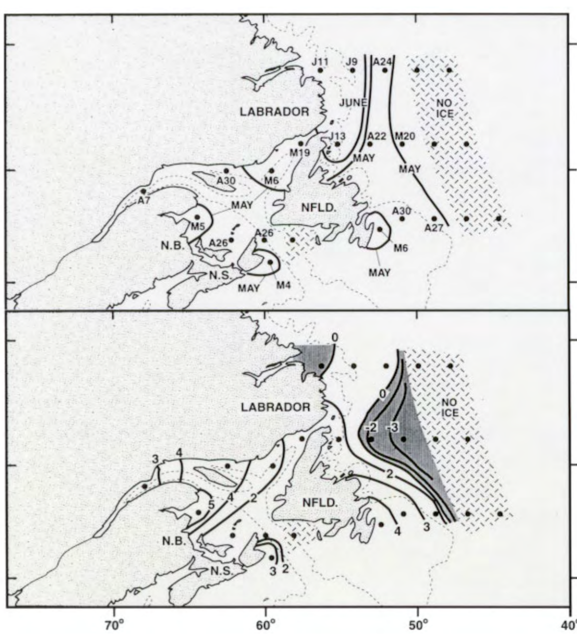


Fig. 11. The date in 1995 at which ice last appeared at the grid points in Fig. 9 (top) and their anomalies from the long-term mean in weeks (bottom). A positive anomaly indicates ice disappeared later than normal.

1994, and January, 1995, inclusive, or in September, 1995. In the primary iceberg season of March to July, 1383 icebergs were observed which represents 97% of the annual total and is higher than the 1983–94 average of 89%. The percentage of the total number of icebergs by month for the 1994/95 season shows that proportionally more penetrated south of 48°N in March and May then normal and fewer after May. Although the total number of icebergs in 1995 was relatively high, it was down by approximately 200 from 1994. The time series of iceberg counts during March to July beginning in 1945 when aerial reconnaissance was first established shows that in the 1990s the number of icebergs has been much higher than normal (Fig. 14). Other periods of large number of icebergs reaching south of 48°N occurred in the mid-1980s, and the early-1970s, all periods of cold air temperatures, strong NW winds and extensive ice cover.

Gulf of St. Lawrence

Relatively warm temperatures in the western Gulf of St. Lawrence during December 1994 resulted in less ice formation than normal on the Magdalen Shallows, however, colder-than-normal temperatures in the Esquiman Channel area produced

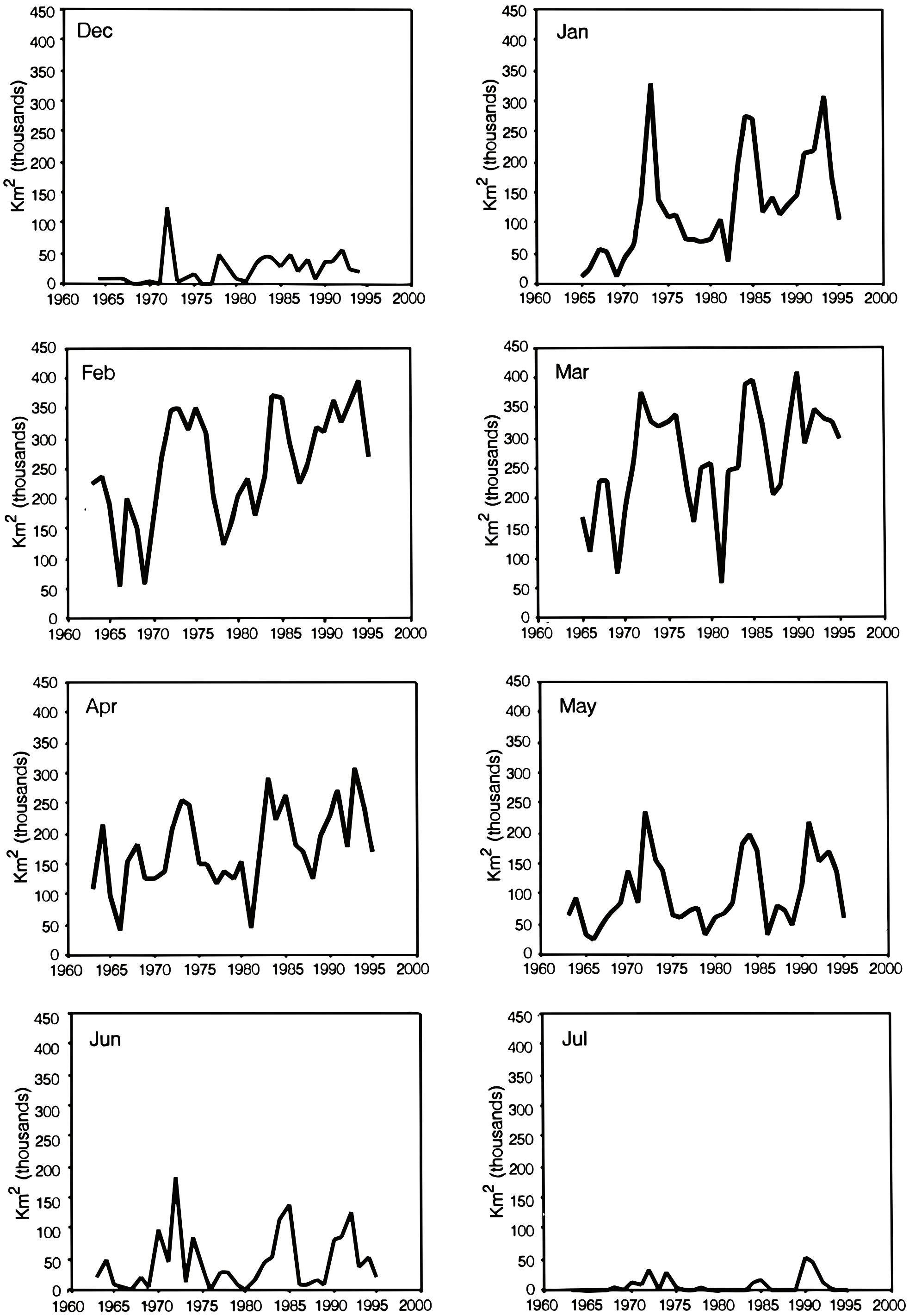


Fig. 13. The time series of ice area on the southern Labrador and northern Newfoundland shelves between 45°N–55°N by month.

more ice than usual along the north shore of Quebec (Fig. 15). In early-January air temperatures dropped below normal throughout the Gulf. This advanced freeze-up, although by mid-month the ice coverage on the Magdalen Shallows was still less than usual. Along the north shore of the Gulf, ice conditions remained slightly ahead of normal. During the latter half of January, temperatures rose above normal slowing the spread of ice but extremely cold temperatures and northwesterly winds during the

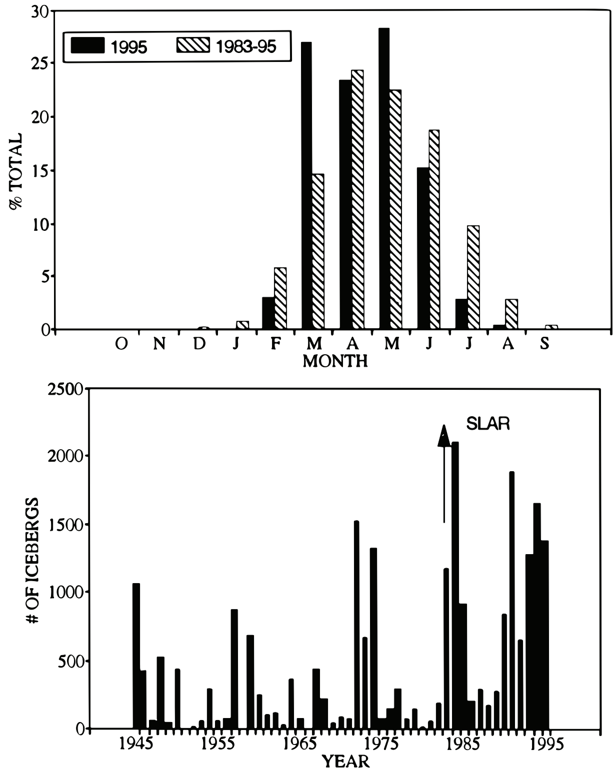


Fig. 14. The percentage of the total number of icebergs crossing south of 48°N by month during the iceberg season 1994/95 (top) and the number of icebergs during March to July from 1945 to 1995. The vertical arrow indicates the year they began to detect icebergs using SLAR.

first two weeks of February quickened the southward advance and pushed the ice out through Cabot Strait. By late-February the Gulf was ice covered except for a small area off SW Newfoundland. Ice extended onto the northeastern Scotian Shelf and lay near its normal position by 1 March. Cold temperatures in early-March produced heavier than normal ice conditions. Later in the month, rising temperatures and northeasterly winds caused large areas of open water to develop off western Newfoundland, off Anitcosti Island and along the Quebec north shore. The winds also packed ice into the southern Estuary, Chaleur Bay and eastern Cape Breton and pushed it southwestward along the Atlantic coast of Nova Scotia to Canso. Near normal temperatures and light to moderate northeasterly winds during April cleared much of the ice from the Gulf. By the beginning of May only isolated patches of ice persisted in the Gulf. By 8 May ice disappeared from the Magdalen Shallows and a week later from around southern Cape Breton. The last ice in the Gulf left the vicinity of Belle Isle Strait by the first week in June.

Ice in the Gulf of St. Lawrence generally appeared within a week of its usual arrival date or was later than normal (up to 2 weeks; Fig. 10). Exceptions were in the Estuary and off eastern Cape Breton where the ice arrived over a week early. No ice was observed off southern Newfoundland at grid point G35. Throughout the Gulf and on the Scotian Shelf the ice stayed around longer than normal by upwards of 5 weeks on the northern Magdalen Shallows (Fig. 11) with a new record established for the latest date of the last presence of ice off Baie des Chaleurs (site G22; Fig. 11). The ice duration (Fig. 12) was longer than normal (by 2-4 weeks) throughout most of the northern Gulf but less than normal in the southern Magdalen Shallows and in the Cabot Strait region. A record for ice duration was set on the northern Magdalen Shallows (17 weeks at G22) and equalled in the northeastern Gulf (17 weeks at G10).

Recently, the location of the ice edge in the Cabot Strait and Scotian Shelf regions were digitized from the 1-3 ice charts per week for the years 1970 to present. These data were combined to produce monthly estimates of the average ice area seaward of Cabot Strait (Fig. 16). The ice area time series are dominated by variability at 3-5 year periods. The areal extent in 1995 was down significantly from 1994. It arrived late but lasted longer than normal, at least in the inshore areas around Cape Breton Island. This late ice did not extend to the grid points in Fig. 11. In terms of the total amount of ice that reached the Scotian Shelf it was generally an average year although the ice was present for a longer time than usual.

Oceanographic Observations

Newfoundland and Labrador

Station 27. Measurements of temperature and salinity have been taken routinely since 1946 at Station 27 located approximately 10 km off St. John's, Newfoundland. This site lies within the inshore branch of the Labrador Current but is considered to be representative of hydrographic conditions at low frequencies (interannual to decadal) over the shelf from southern Labrador to the Grand Banks (Petrie *et al.*, 1992). The station was visited 57 times in 1995, with a monthly maximum of 11 in May and a minimum of 1 in March. In January and March no salinity measurements were taken. 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 1995 together with their anomalies relative to 1961–90 are shown in Fig. 17.

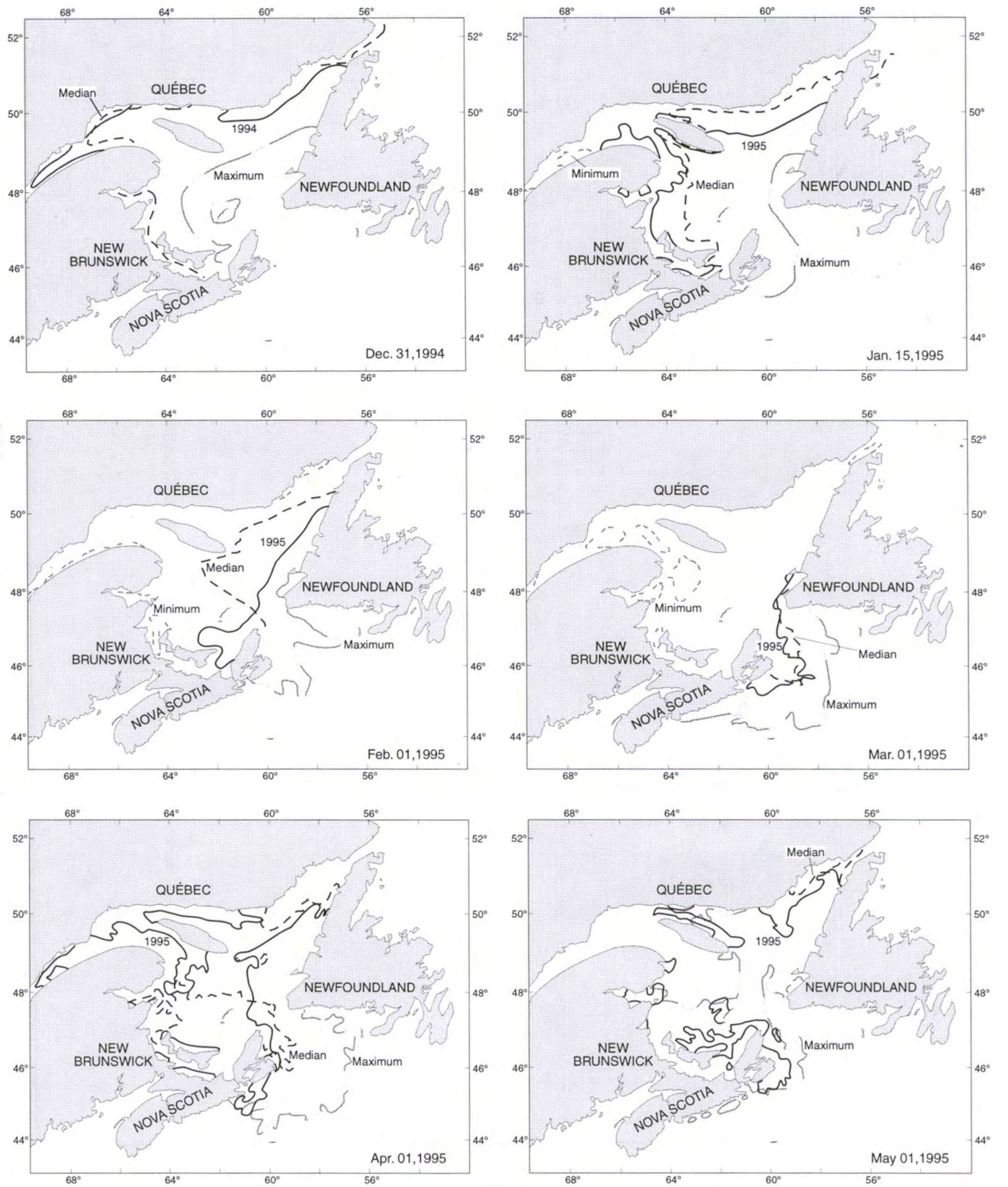


Fig. 15. The location of the ice edge together with the historical (1962–87) median and maximum positions in the Gulf of St. Lawrence between December 1994 and May 1995.

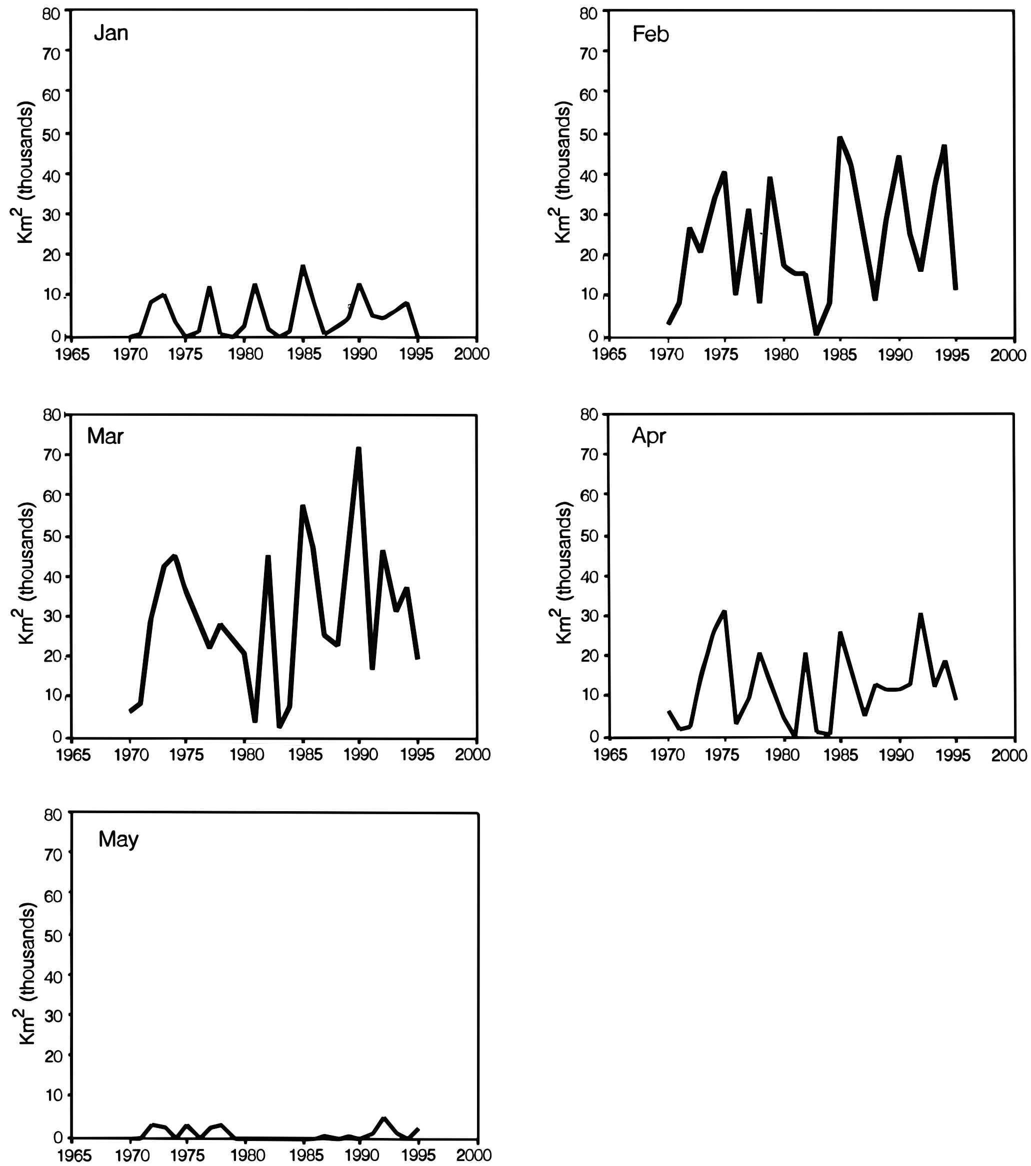


Fig. 16. Monthly time series of ice area seaward of Cabot Strait.

The water column was nearly isothermal during the winter with temperatures falling to -1.7°C in March. In the lower half of the water column, temperatures remained less than -1.5°C through to the late-summer, and below approximately 100 m they never rose above 0°C. Upper layer temperatures (generally < 50 m) were below -1°C until April. By May they began to rise above 0°C and at the surface reached a peak of over 12°C in August before autumn cooling set in. The August mean temperature was approximately 2°C below that recorded in 1994. Note the propagation of surface layer heat down into the lower layers in the late-autumn. The upper layers generally experienced negative temperature anomalies from February to September with minimum values near -1°C below normal in April, May and July (Fig. 17, 18). Warmer-than-normal temperatures were observed in January, towards the end of 1995, and from 20 m to 75 m in mid-summer. In the lower half of the water column temperature anomalies were smaller than in the surface waters but remained below normal throughout the year (Fig. 17, 18).

Salinities were predominantly fresher than normal in 1995 (Fig. 17, 18). Near surface values were slightly less than 32 in winter and reached a minimum of <30.5 in August. These salinities

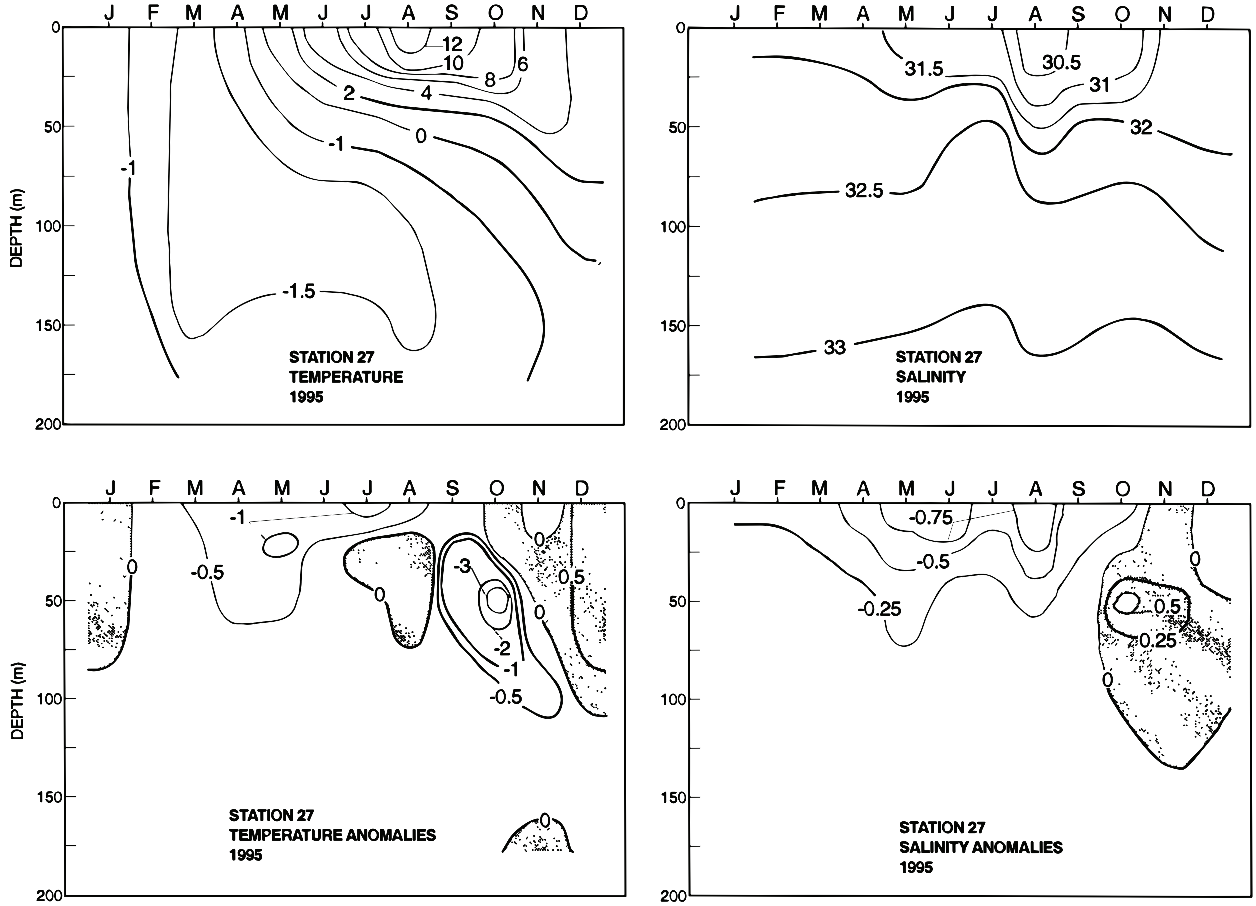


Fig. 17. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1995 relative to the 1961–90 means. Shaded areas are positive anomalies.

resulted in negative anomalies with the maximum amplitude occurring in late-spring and in August. Positive salinity anomalies appeared during the last three months of the year, with maximum values around 50 m in October. The highest salinity anomalies correspond with the largest negative temperature anomalies. Based on the studies of Myers *et al*. (1990) and Petrie *et al*. (1991), the lower salinities in late-summer and early-autumn were most likely related to an increased volume of ice melt. Throughout the year salinity anomalies in the lower layer were near normal with a tendency towards slightly fresher-than-normal conditions. The maximum salinities (>33) appeared near bottom but these too represented slightly negative salinity anomalies.

The time series of monthly temperature anomalies at Station 27 at 0, 50, 100, 150 and 175 m for 1970–95 are shown in Fig. 19. Note that the temperature scale for 0 and 50 m is different to that for 100 m and deeper. At the surface and 50 m there was large, short-term variability reflecting atmospheric heating and cooling. The cooling during 1995 discussed above predominated at 0 and 50 m but by the end of the year temperatures were above their long-term means. Progressively deeper in the water column, there was a tendency towards more negative anomalies and reduced short-term variability. 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 the air temperature anomalies, i.e. the early-1970s, the mid-1980s and the 1990s. Temperature anomalies at these depths, although remaining below normal, have been moderating from the extreme cold conditions experienced in the early-1990s. At the end of 1995 temperatures approached near normal in the deep waters.

The depth-averaged temperature, which is proportional to the total heat content within the water column, also shows large amplitude fluctuations at

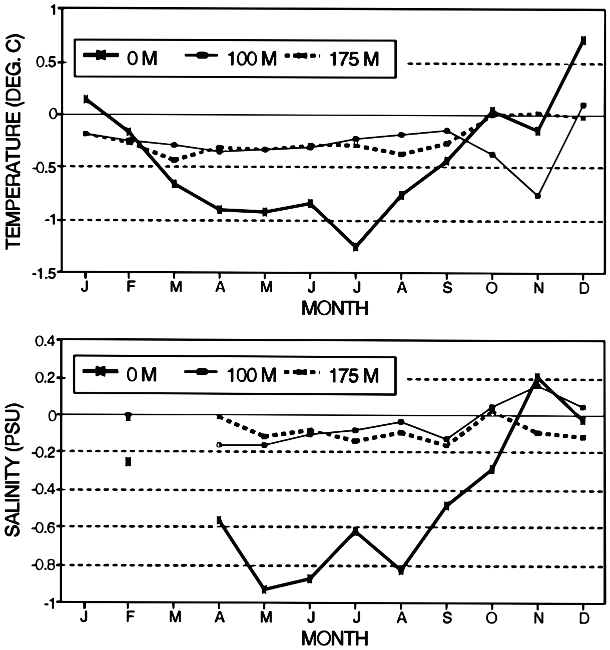


Fig. 18. Monthly temperature (top) and salinity (bottom) anomalies at 0, 100, and 175 m at Station 27 during 1995.

near decadal time scales with cold periods during the early-1970s, mid-1980s and early-1990s (Fig. 20). The total heat content of the water column which reached a record low in 1991 has partially recovered but still remains well below that observed during the warm 1950s and 1960s. The heat content in 1995 was similar to that observed in 1994. The 0 to 50 m depth-averaged summer salinity is also plotted in Fig. 20. The low salinity values of the early-1990s are comparable to values experienced during the Great Salinity Anomaly of the early-1970s (Dickson *et al.*, 1988). During 1993 and 1994 summer salinities returned to more normal values but in 1995, salinities again decreased to near the 1992 value. The depth-averaged summer salinities have been shown to be positively related to cod recruitment (Sutcliffe *et al.*, 1983; Myers *et al.*, 1993) although changes in recruitment estimates in recent cod assessments now places this relationship into doubt (Hutchings and Myers, 1994).

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 homogeneous cold upper layer that overlays a warmer deeper layer or occasionally may extend to the bottom. With spring heating, ice melt and increased river runoff, a warm low-saline surface layer develops. The strong stratification in this upper layer inhibits heat transfer downwards, and the waters below remain cold throughout the spring and summer. The latter are called the cold intermediate layer (CIL) waters.

Three standard hydrographic transects (Hamilton Bank, off Bonavista Bay and along 47°N to Flemish Cap) have been occupied during the summer and autumn by the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland in most years since 1950. The areal extent of the CIL along each transect (as defined by waters <0°C) is plotted in Fig. 21. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects (Petrie *et al.*, 1992). In 1995, the CIL area off Bonavista was about 30% below normal compared to 7 and 28% above normal in 1994 and 1993, respectively. The CIL area along the Seal Island transect also fell below the long-term mean (32% below average) but along the Flemish Cap section, the CIL area remained above normal by 8%. At Seal Island and Bonavista transects, the CIL area decreased relative to 1994 while on the Flemish Cap section there was a very slight increase. The minimum temperatures observed in the core of the CIL off Bonavista and Flemish Cap were near -1.6°C in 1995 which was about normal for Bonavista but colder by 0.1°C along Flemish Cap. Across the central portion of the Grand Bank on the Flemish Cap transect, minimum temperatures have remained below the 1961–90 average since the late-1980s. In general, periods of colder-than-normal core temperatures are highly correlated with larger than normal CIL areas.

The CIL area in autumn along the Bonavista transect showed similar interannual trends as in summer, however, the average area was smaller by approximately 25% due to vertical mixing from above and below. During the autumn of 1995 it was only 7 km^2 compared to about 26 km^2 in 1994 and 30 km^2 in 1993. The CIL area in autumn off Seal Island was more variable and of smaller magnitude than the more southerly Bonavista transect, and in some years there was no water below 0°C. The average CIL area during the autumn along this transect was about 13 km^2 with a standard deviation of about 11 km^2. Unfortunately, no data were available from the Seal Island section in the autumn of 1995.

Data were available to estimate the total volume of CIL water (<0°C) over the Div. 2J+3KL area since 1980 (Fig. 22). Maximum volumes occurred during the cold periods of the mid-1980s and early-1990s. Since 1990, the summertime volume had been decreasing and by 1995 was similar to that recorded in the early-1980s or from 1986 to 1989. The 1995 volume was well below the mean over the period 1980–94 of just over 4×10^4 km^3 which is roughly one-third the total volume of water on the shelf.

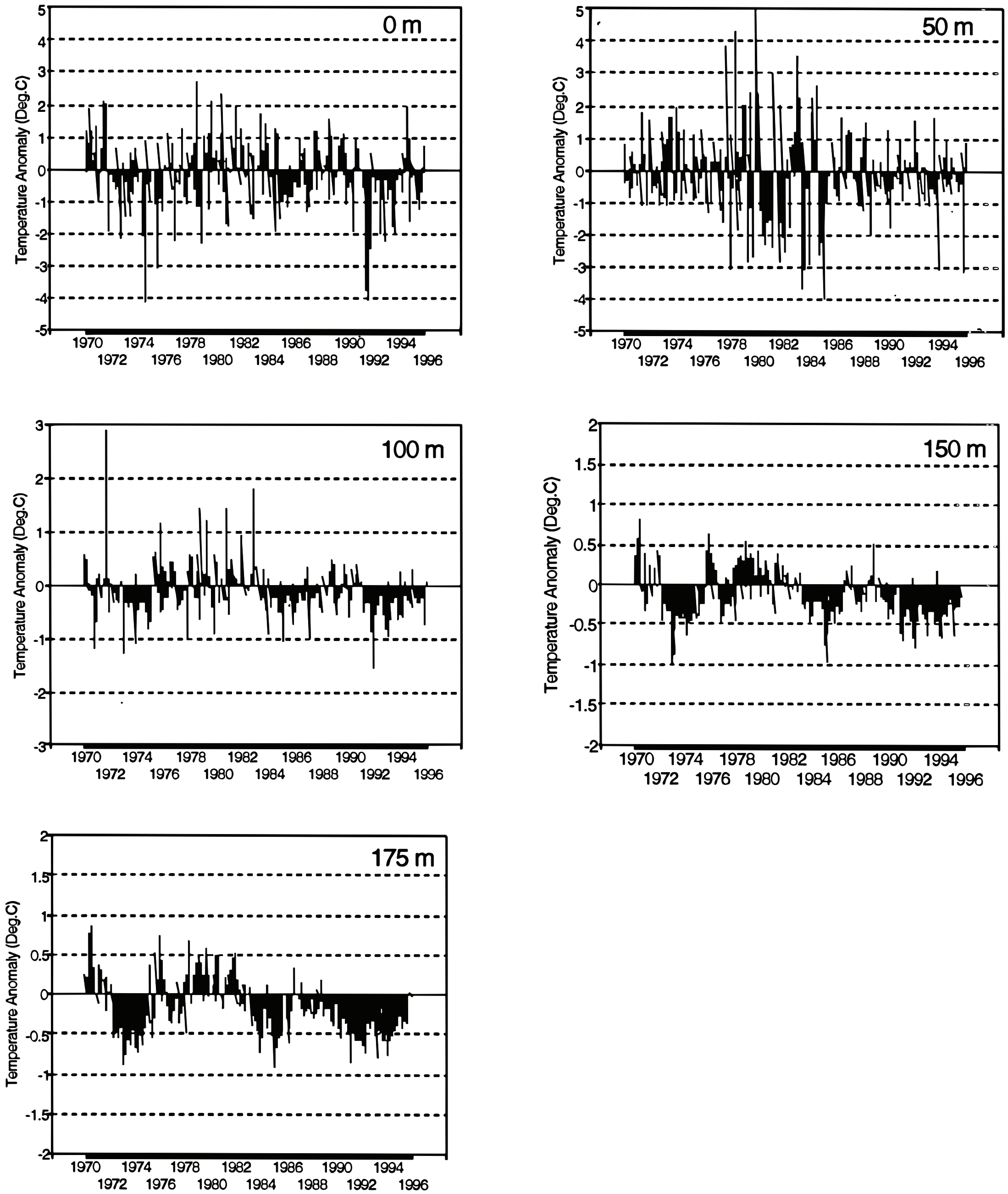


Fig. 19. The time series of monthly mean temperature anomalies at 0, 50, 100, 150 and 175 m at Station 27 relative to the long term mean (1961–90).

Compared to summer, the volume in autumn showed similar interannual trends but its absolute value was about a half that observed in the summer. Unfortunately limited data prevent extending the volume estimates farther back in time than 1980.

Horizontal temperature distributions near surface and bottom in Div. 2J+3KL. The mean (1961–90) and 1995 July temperatures at 10 m over the shelf from southern Labrador to the Grand Banks are shown in Fig. 23 (bathymetry lines are 300 and 1 000 m). The mean summer temperatures ranged from 12°C over the Grand Bank to 5°C off southern Labrador on Hamilton Bank. During 1995, they ranged from 9.5°C over the Grand Bank to about 4.5–5°C on Hamilton Bank. This meant anomalies

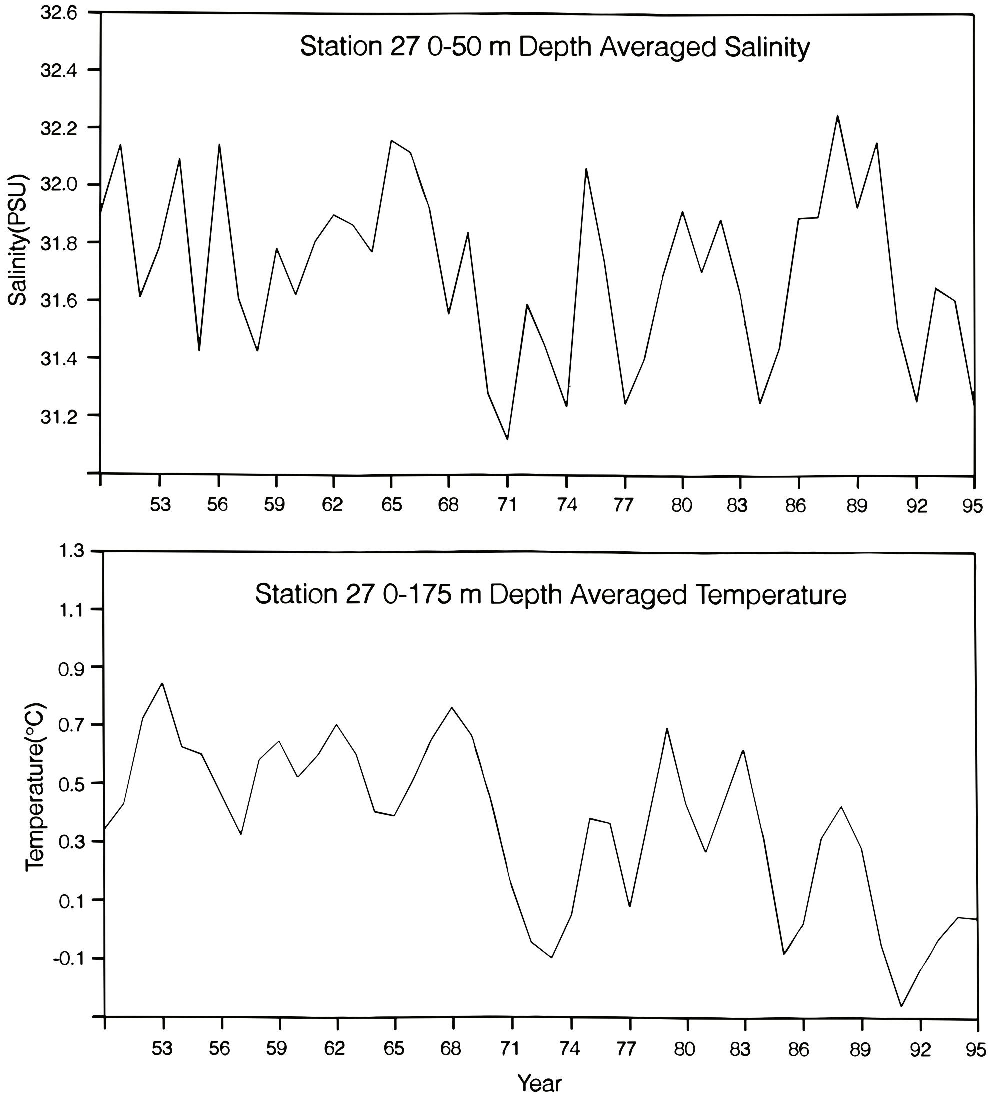


Fig. 20. Time series of the vertically averaged (0–175 m) temperature and (0-50 m) salinity for Station 27.

of up to 1–2°C below average throughout most of region. During the autumn, the upper layer temperatures normally cool to 1°C to 1.5°C in Div. 2J+3K and to 1.5°C to 6°C in Div. 3L. During the autumn of 1995 the waters were warmer than normal by 1–3°C on the Grand Banks and in Div. 3K but colder than normal in Div. 2J.

A similar analysis was carried out for the autumn bottom temperatures in Div. 2J+3KL (Fig. 24). The average bottom temperature over most of the northeast Newfoundland Shelf (Div. 2J+3K) in autumn ranged from <0°C inshore, to 3°C offshore at the shelf break whereas over most of the Grand Bank it varied from -0.5° to 3°C at the shelf break. In general, bottom isotherms followed the bathymetry exhibiting east-west gradients over most of the northeast shelf. The percentage area of water less than -0.5°C over the Grand Bank and northeast shelf from 1990 to 1994 has been significantly larger than the 1961–90 average. In 1992 and 1993 the bottom temperature anomalies ranged from -0.25°C to -0.75°C over the northeast shelf and from -0.25°C to -1°C over the Grand Bank (Colbourne, MS 1994). During 1995 the percentage area of water less than -0.5°C on the continental shelf declined significantly to below average and bottom temperatures have moderated in most areas of the Newfoundland Shelf with anomalies of +0.5°C.

Temperature and salinity over Flemish Cap. The smoothed time series of temperature anomalies on

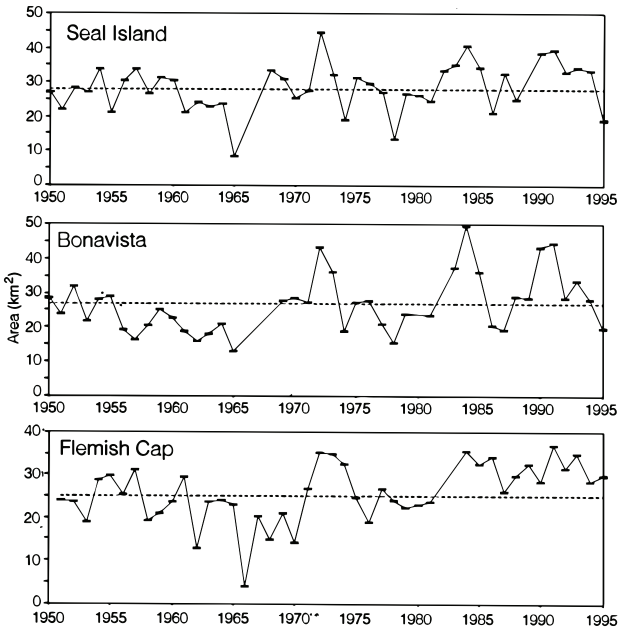


Fig. 21. The time series of the area of the CIL along standard sections off southern Labrador (Seal Island) and Newfoundland (Bonavista and Flemish Cap).

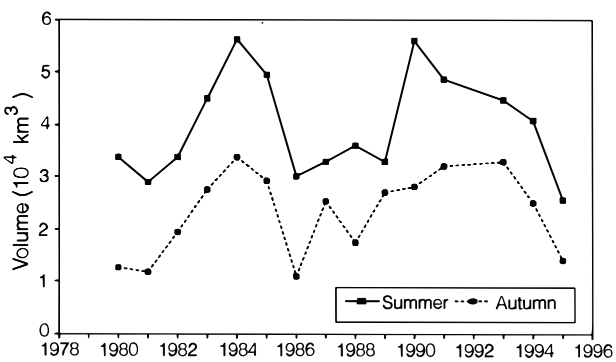


Fig. 22. The time series of the CIL volumes in the summer and autumn within Div. 2J+3KL.

Flemish Cap at standard depths down to 100 m are characterized by the 3 major cold periods identified at other sites, i.e. the 1970s, the mid-1980s and the late-1980s to early-1990s (Fig. 25). The upper layer waters exhibited colder-than-normal temperature anomalies beginning around 1971 and continued until 1977. Temperature anomalies in the 1970s near the bottom at 200 m were near normal. From 1978 to 1984 the temperature anomalies showed a high degree of variability in the upper water column with a stronger tendency towards positive anomalies. By 1985, in the top 100 m, intense negative temperature anomalies had returned with peak amplitudes reaching near -3.0°C to 50 m depth. This cold period moderated briefly in 1987 but returned again by 1988. By 1995, upper layer temperatures moderated, however, below normal conditions still existed throughout the water column.

Salinity anomalies exhibited large fresher-than-normal conditions from 1971 to 1976 and from 1983 to 1986 in the upper 100 m with peak amplitudes reaching 0.5 psu below normal. Salinities during the early-1990s range from slightly below normal in 1992 (from 20 to 100 m) to slightly above normal in 1995. In general, the temperature and salinity anomalies were very similar to those at Station 27 and elsewhere on the Newfoundland and Labrador continental shelves over similar depth ranges.

Temperature off Southern Newfoundland. Low-pass filtered temperature anomalies from St. Pierre Bank are shown in Fig. 26 at standard depths of 0, 20, 50 and 75 m. They are characterized by large variations with amplitudes ranging from + 1.0°C and with periods between 5 to 10 years with some higher frequency variations in the upper water column. The cold periods of the mid-1970s and the mid-1980s were coincident with severe meteorological and ice conditions in the Northwest Atlantic and colder and fresher oceanographic anomalies over most of the continental shelf surrounding Newfoundland. During the cold period beginning in 1984 temperatures decreased by up to 2.0°C in the upper water column and by 1.0°C in the lower water column and continued below normal until 1990. After 1991, temperatures moderated over the top 50 m but remained well below average at 75 m depth. During 1995 temperature anomalies were negative except at 20 m.

The mean (1961–90) and the 1995 bottom temperature maps for April within Subdiv. 3Ps and Subdiv. 3Pn are shown in Fig. 27. In general, the bottom isotherms follow the bathymetry around the Laurentian Channel and the Southwestern Grand Bank increasing from 2°C at 200 m depth to 5°C in the deeper water. The average April bottom temperatures ranged from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3°C to 4°C on Rose Blanche Bank and on Burgeo Bank and from 0°C on the eastern side of St. Pierre Bank to 2°C on the western side. During April 1995 temperatures were near average over Burgeo Bank, in Hermitage Channel and along the western side of St. Pierre Bank. On the central and eastern side of St. Pierre Bank temperatures ranged from 0.5–1°C below average, similar to 1994.

Gulf of St. Lawrence

Cabot Strait deep temperatures. Bugden (1991) investigated the long-term temperature variability in the deep waters (200–300 m average) of the

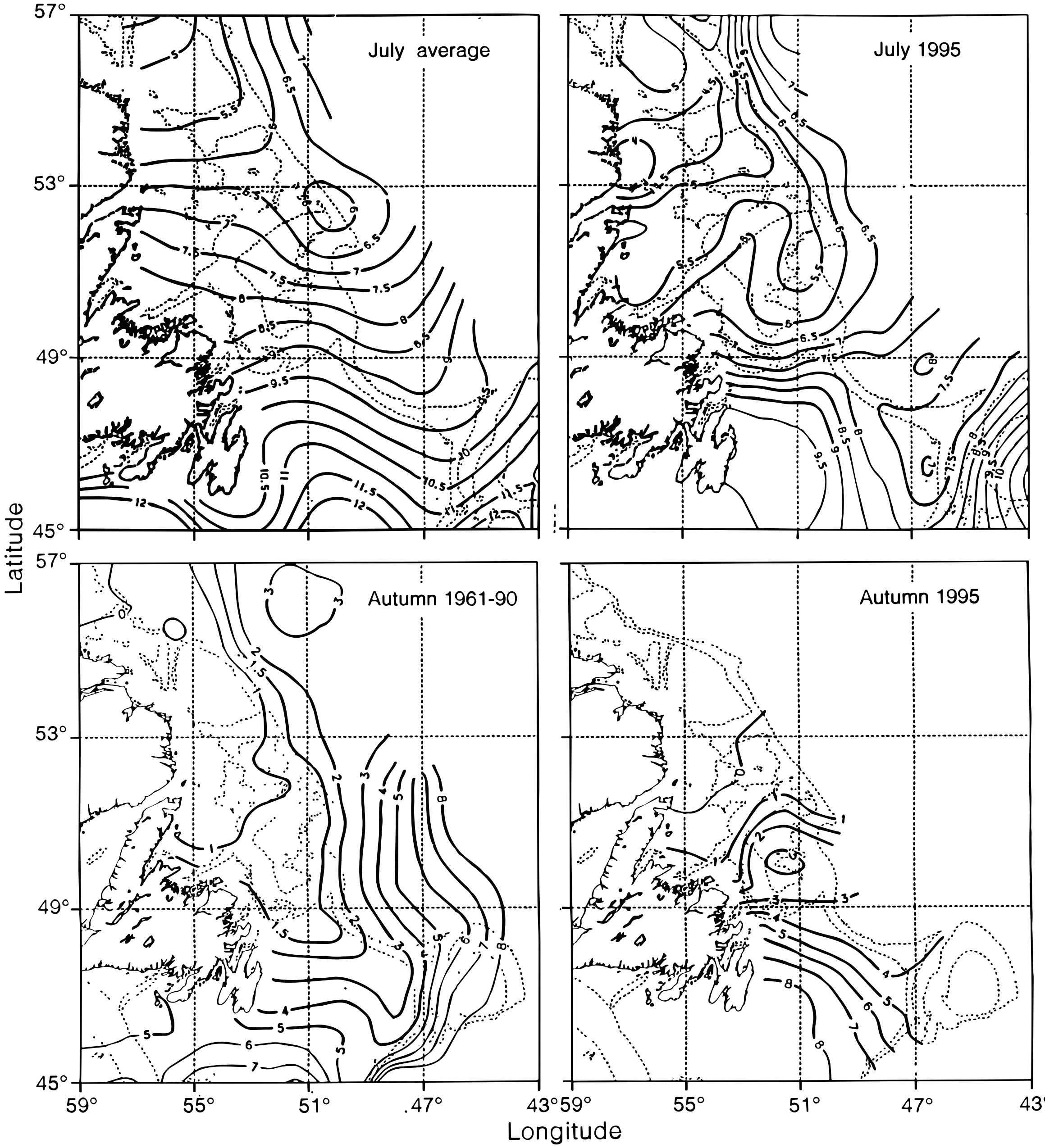


Fig. 23. The horizontal distribution of temperature at 10 m during the summer and the autumn, mean (1961–90) conditions on the left and 1995 on the right.

Laurentian Channel in the Gulf of St. Lawrence from data collected between the late-1940s to 1988. The variability was dominated by low-frequency (decadal) fluctuations with no discernible seasonal cycle. A phase lag was observed along the major axis of the channel such that events propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated time series, based principally upon ice forecast cruises conducted by the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, in November-December, showed that temperatures declined steadily between 1988 and 1991 to their lowest value since the late-1960s (4.5°C and an anomaly of -0.85°C; Fig. 28). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of -0.05°C) and to over 6.0°C (anomaly of 0.8°C) in 1993. In 1994 temperatures fell although anomalies remained positive. Temperatures continued to fall in 1995 such that by November they

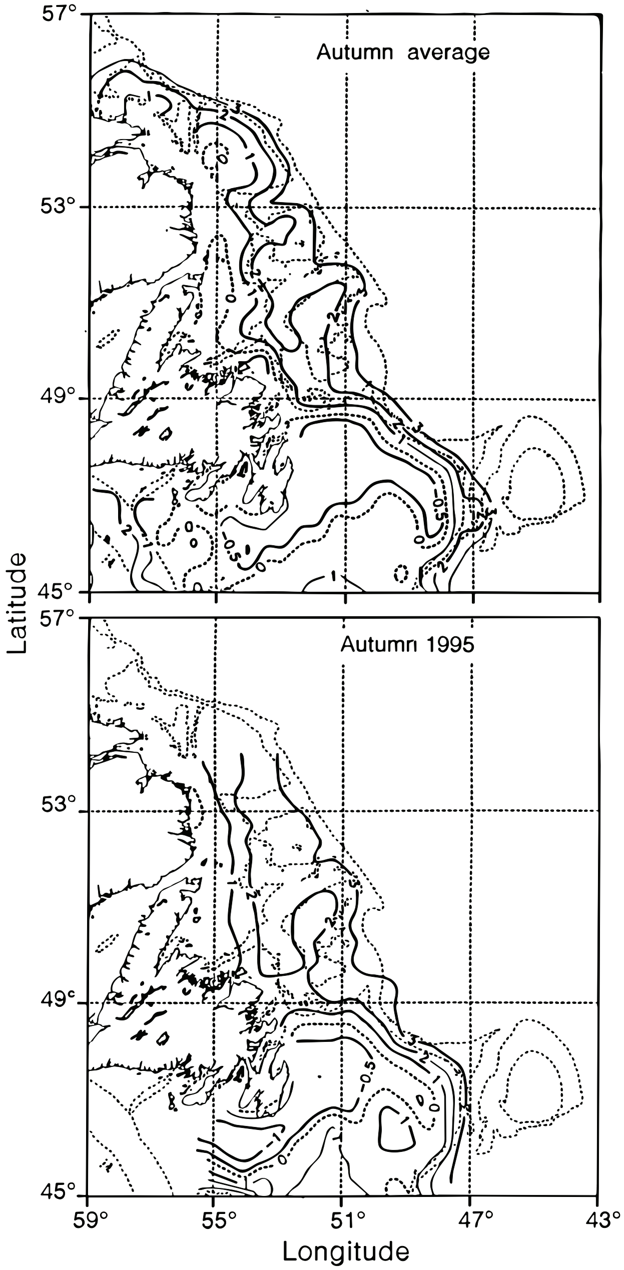


Fig. 24. The horizontal distribution of bottom temperature during the autumn, mean (1961–90) conditions on the top and 1995 on the bottom.

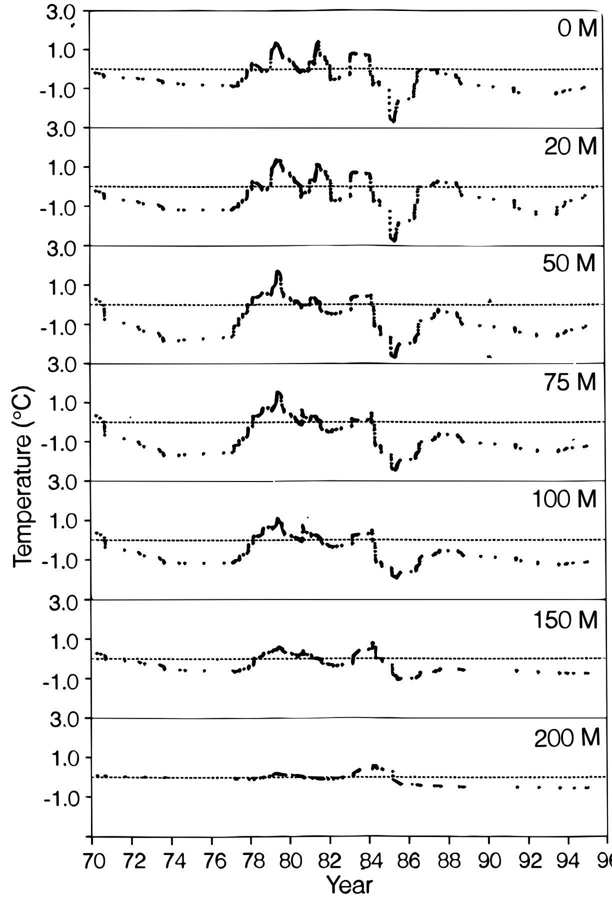


Fig. 25. Smoothed time series of temperature anomalies at standard depths over Flemish Cap.

were near normal. This temperature pattern is believed to reflect changes in the slope water characteristics near the mouth of the Laurentian Channel (Bugden, 1991; Petrie and Drinkwater, 1993).

Cold intermediate layer. The CIL in the Gulf of St. Lawrence has a maximum thickness in the northeast and a minimum (where depths exceed 100 m) in Cabot Strait and the St. Lawrence Estuary. During 1995, the CIL thickness (defined by waters <0°C) increased relative to 1994. Gilbert and Pettigrew (1997) recently analyzed interannual variability of the CIL in the Gulf. They produced a mid-summer composite index of core temperatures for mid-July based upon observed data from different dates and the mean measured warming rate. Their index shows temperature anomalies having an approximate 5–8 year periodicity prior to 1985 (Fig. 29). Since then, temperatures in the CIL have been extremely cold being below normal during the last 10 years. The mid-summer core CIL temperature was -0.7°C (representing an anomaly of approximately -0.8°C). The last six years have been near the coldest years on record. Gilbert and Pettigrew (1997) found high correlations between the variability in the CIL core temperatures and air temperatures along the west coast of Newfoundland, suggesting the possible importance

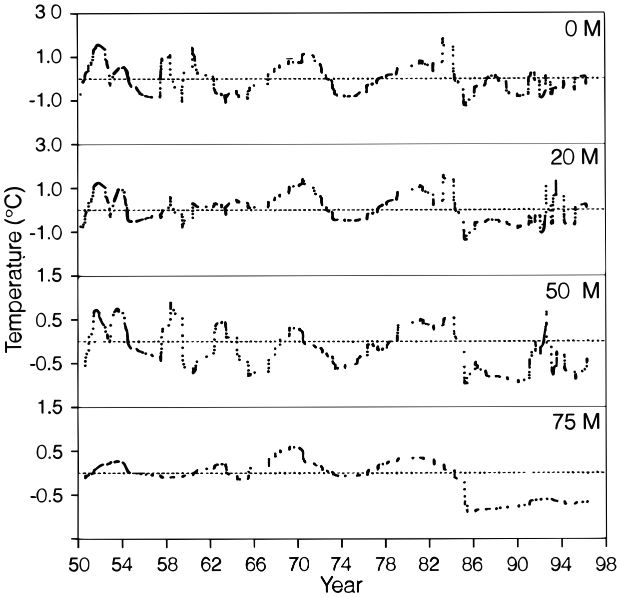


Fig. 26. Smoothed time series of temperature anomalies at standard depths over St. Pierre Bank. The apparent vertical lines in the plots are surveys conducted over a day or two and thus reflect both spatial and temporal variability over the Bank.

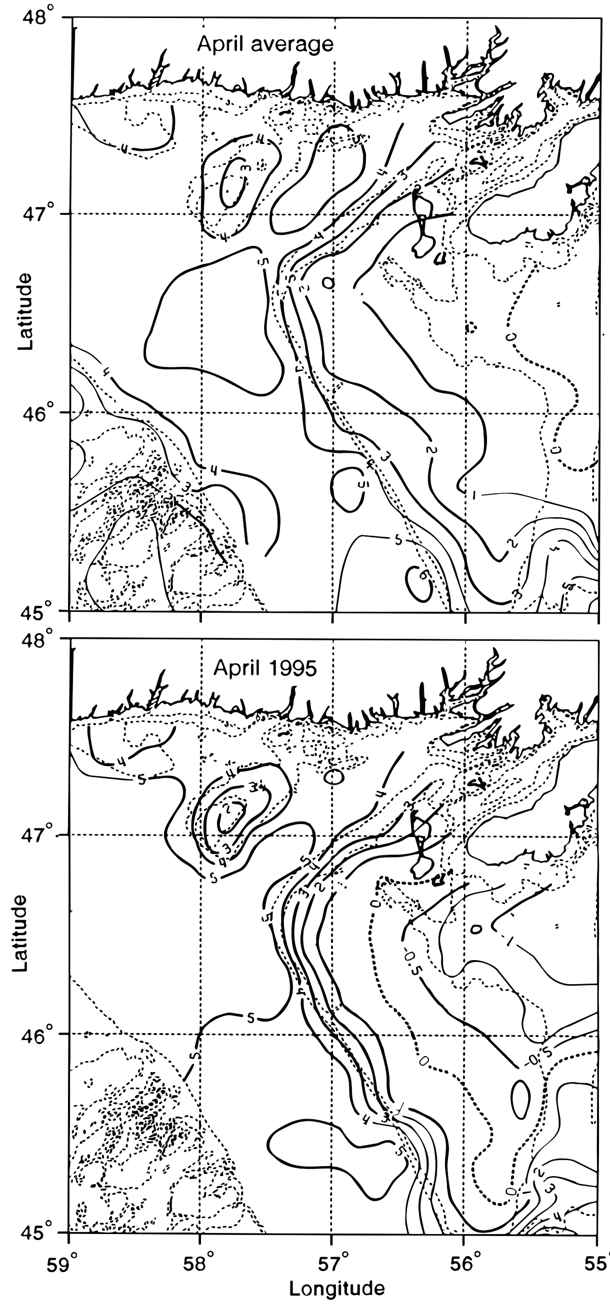


Fig. 27. The horizontal distribution of bottom temperature off southern Newfoundland during April. The mean (1961–90) conditions are on the top and 1995 conditions are on the bottom.

of atmospheric forcing although advection of cold waters from off the Labrador Shelf through Belle Isle Strait may also contribute. The temperature pattern in the Gulf was similar to that observed in the deep waters on St. Pierre Bank (Fig. 24).

Bottom temperatures on the Magdalen Shallows. Annual groundfish surveys of the Magdalen Shallows in the southern Gulf of St. Lawrence have been carried out by Canada during September since 1971. Bottom temperatures during the 1995 survey were lowest in the central region of the Magdalen Shallows and increased shoreward and at deeper depths along the Laurentian Channel as is normally observed. Bottom temperatures of <1°C covered almost 50% of the survey area and <0°C over 33%. Time series plots of the area with bottom temperatures <0°C and <1°C show strong similarity (Fig. 30). Since 1990, the areas have been well above the mean and at or near maximum values. In 1995, the areas increased relative to 1994. The area of bottom covered by <0°C was the largest on record and for <1°C was the third largest on record. This large increase in cold bottom water temperatures over the Magdalen Shallows is consistent with the colder-than-normal CIL observed in 1995, as the CIL is in direct contact with the bottom over much of the shallows region.

Summer temperature and salinity fields. The hydrographic data collected during the September groundfish surveys on the Magdallen Shallows were combined with data from fisheries surveys conducted throughout the remainder of the Gulf during August–September. Mean temperatures and

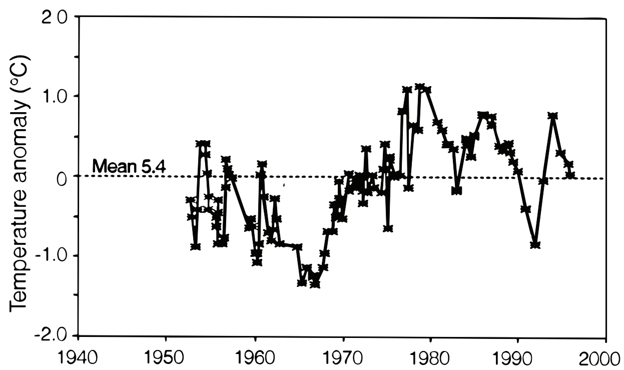


Fig. 28. Temperature anomalies (relative to 1961–90) for the 200–300 m deep layer in Cabot Strait.

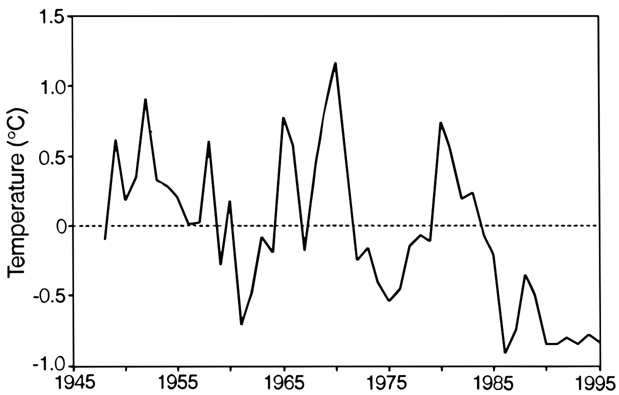


Fig. 29. Anomalies of the CIL core temperatures (extrapolated to July 15) for the Gulf of St. Lawrence from the 1948–94 mean (0.08°C).

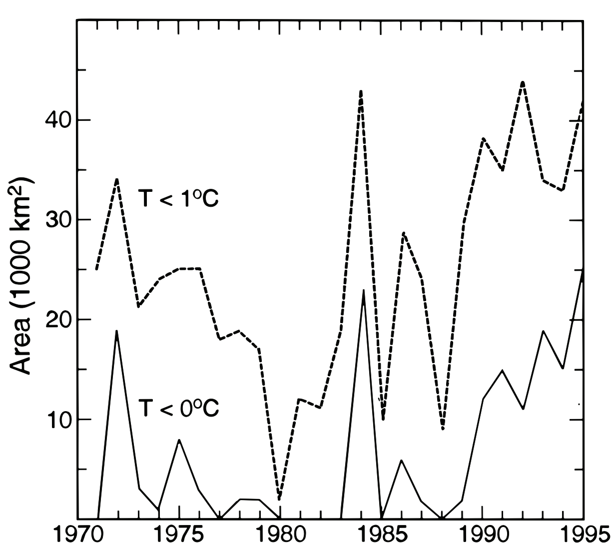


Fig. 30. Area of the Magdallen Shallows with bottom temperatures <0°C and <1°C during September.

salinities were then calculated by layers (0–30, 30–100, 100–200 and 200–300 m) within each of the 17 areas defined by Petrie (1990) and were compared to his monthly mean values. In the surface layer the average temperature ranged from 6°C in the St. Lawrence Estuary to 15°C off eastern Prince Edward Island. This represented significant warming compared to 1994 with the largest difference along the north shore of Quebec where temperatures were upwards of 3.5°C warmer in 1995 than in 1994. Intense upwelling along this coast had caused low temperatures in 1994. This upwelling was not evident in 1995. Relative to the long-term mean, the temperature anomalies in this layer were generally positive with some small pockets of slightly colder than normal off the northern Gaspe Peninsula, the west coast of Newfoundland and in the vicinity of the Magdalen Islands. In the 30–100 m layer, which encompasses the CIL, temperatures only varied from -0.1°C on the Magdalen Shallows to -1.77°C in the northeastern Gulf. These were colder than normal for this time of the year with the largest negative anomaly (-2°C) in the northeast, however, they represent a warming relative to 1994, the largest increase (1°C) being in the central Gulf. Temperatures in the 100–200 m layer ranged from 0.8°C along the north shore of Quebec to 2.4°C in the Estuary while in the deep layer (200–300 m) temperatures were within 0.5°C of 5°C everywhere in the Gulf. Compared to 1994, the temperatures in the 100–200 m layer decreased with the largest decline in the northeastern Gulf where anomalies reached -1.3°C. In the 200–300 m layer, temperatures were generally near normal. The time series of the average temperature in the lower three layers indicates that the warmest conditions were observed in the early- to mid-1980s and that for 30–200 m, 1995 conditions were relative cool (Fig. 31).

Scotian Shelf and Gulf of Maine

Coastal sea-surface temperatures. Monthly averages of sea-surface temperature (SST) derived from continuous thermograph records or twice daily readings are available from Halifax Harbour in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine. The monthly mean temperature anomalies relative to the 1961–90 long-term averages at each of the sites for 1994 and 1995 are shown in Fig. 32. The dominant feature at Boothbay Harbor and St. Andrews was the above normal temperatures throughout all or most of the year. This continued a trend of warm temperatures that began in June of 1994. The 1995 anomalies equalled or exceeded one standard deviation (based upon the years 1961–90) in 8 and 3 months at Boothbay Harbor and St. Andrews, respectively. The maximum monthly anomaly was over 2.3°C in January at Boothbay while at St. Andrews it was 1.3°C in October. In contrast, sea surface temperature anomalies at Halifax were

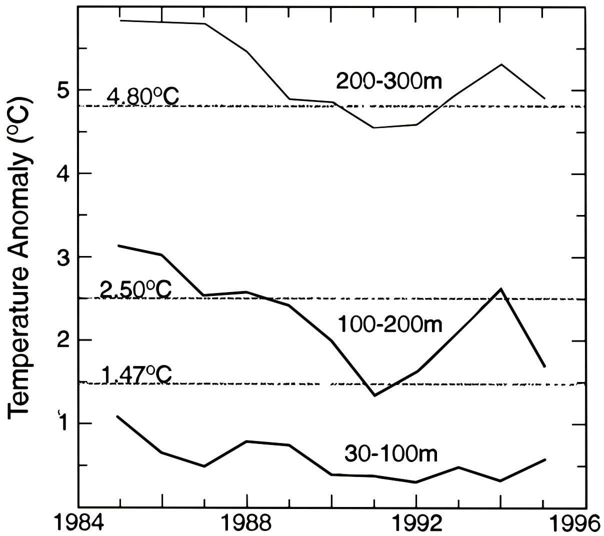


Fig. 31. The temperature of the 30–100 m, the 100–200 m and the 200–300 m layers in the Gulf of St. Lawrence during August–September. The dashed lines indicate the long-term averages based on Petrie (1990).

predominantly negative. Only in August and September were above normal anomalies observed. The largest negative anomalies occurred during the spring, reaching -1.6°C in June. The cold temperatures in Halifax continues the anomaly pattern established in 1994.

Time series of the annual anomalies show that since the late-1980s, the temperatures in the Gulf of Maine and Bay of Fundy waters have generally been on the increase whereas those along the Atlantic coast of Nova Scotia have been decreasing (Fig. 32). Annual SST mean temperatures for 1995 were 9.8°C (1.3°C above normal) at Boothbay Harbor, 7.8°C (0.6°C above normal) at St. Andrews, and 7.2°C (0.6°C below normal) at Halifax. These represent a rise in temperature over 1994 at Boothbay (by 0.5°C) and St. Andrews (0.1°C) but similar to 1994 at Halifax. At Boothbay the temperature was the highest since the early-1950s whereas at Halifax they are nearly as cold as the mid-1960s.

Prince 5. Temperature and salinity measurements have been taken nominally once per month since 1924 at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy. This is the longest continuously operating hydrographic monitoring site in eastern Canada. Monthly anomalies for 1995 were calculated except for April when no measurements were available. Single observations 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 features are likely to be real.

In 1995, monthly observations ranged from a minimum of less than 2°C in the upper half of the water column in February to a maximum of over 12°C in the near surface waters in September (Fig. 33). Monthly temperature anomalies were generally positive with maximum values >1°C in February and towards the end of the year (Fig. 33). The predominance of positive temperature anomalies match similar conditions in the SSTs at St. Andrews and Boothbay Harbor (Fig. 32). The annual temperature anomalies in 1995 were 0.2°C and 0.6°C at the surface and near bottom (90 m), respectively (Fig. 34). These are cooler than 1994 but well above 1992 and 1993 values. At both depths, the maximum annual temperature occurred in the early-1950s and the minima in the mid-1960s.

Salinities at Prince 5 during 1995 oscillated between saltier and fresher than normal (Fig. 33). The lowest salinities (<30.5 psu) occurred during May resulting in an anomaly of -0.5 psu in the surface waters. This was short-lived, however, and may not have been truly representative of the monthly mean. A second salinity minima of 31 (anomaly of -1) was observed in November in the near surface waters. The highest salinities (>32.5) appeared near bottom in January and again in the autumn. These produced near-normal to slightly saltier-than-normal anomalies. Time series show that the annual salinity anomalies in 1995 fell by 0.3–0.4 from 1994, to a near normal value at 90 m and below normal at the surface (Fig. 35).

Gulf of Maine temperature transect. The Northeast Fisheries Science Center in Narragansett, Rhode Island, has collected expendable bathythermograph (XBT) data approximately monthly from ships-of-opportunity since the late-1970s along a transect in the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf as part of their continuous plankton recorder program. The available data were grouped into 10 equally spaced boxes along the transect, then averaged any data within these by month at standard depths. In 1995, data were collected in 11 months (none in August) with 4 to 9 sites occupied per month and an average of 7.

Data from January and July 1995 are shown together with the site locations (center of the boxes) in Fig. 36 and 37, respectively. January data (none

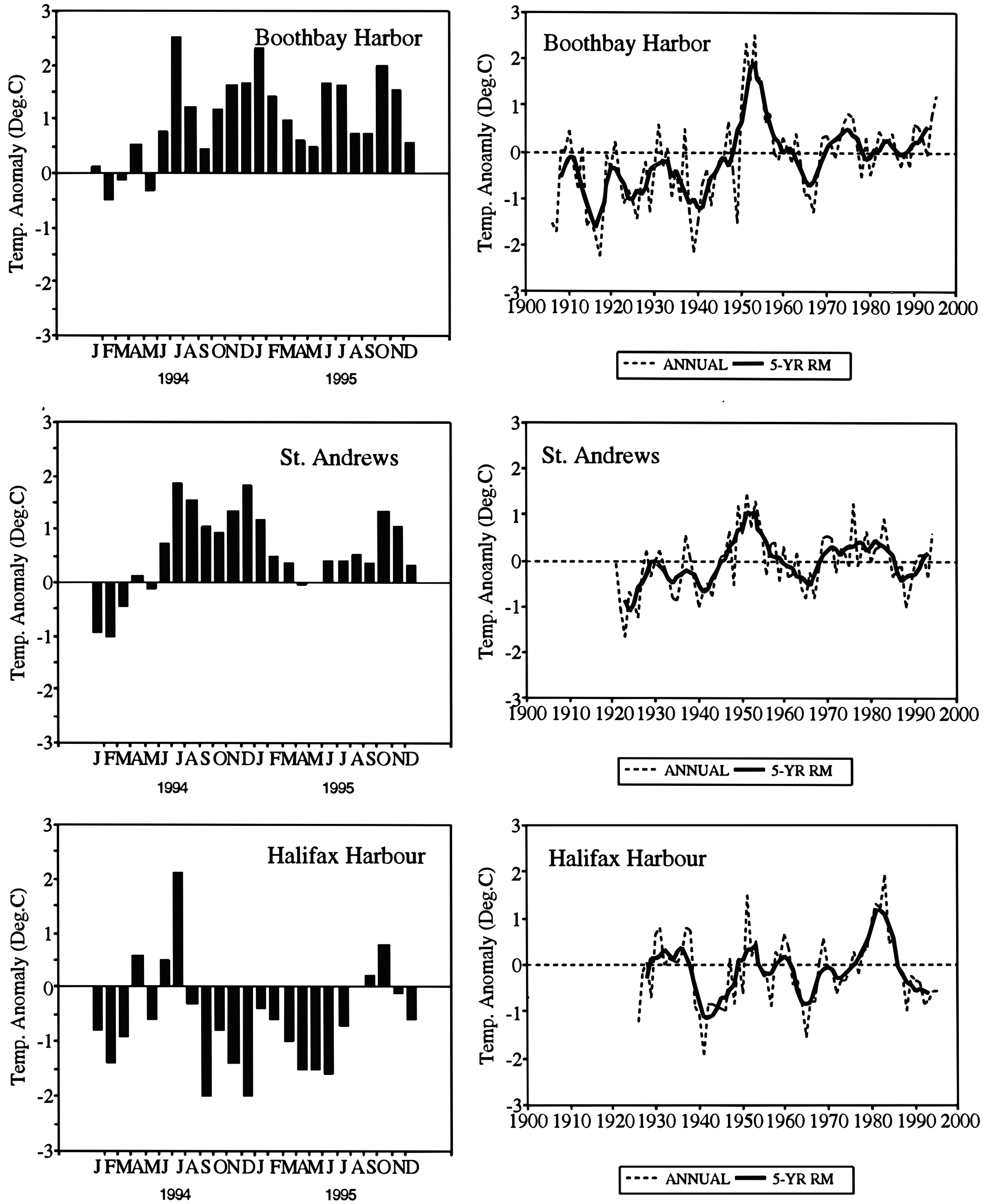


Fig. 32. The monthly sea surface temperature anomalies during 1994 and 1995 (left) and the annual temperature anomalies and their 5-year running mean (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961–90 means.

available at sites 1 and 10) show the coldest waters off Nova Scotia and the warmest in the deep (150–200 m) layers of Georges Basin (site 7). The latter originated in the offshore slope waters and

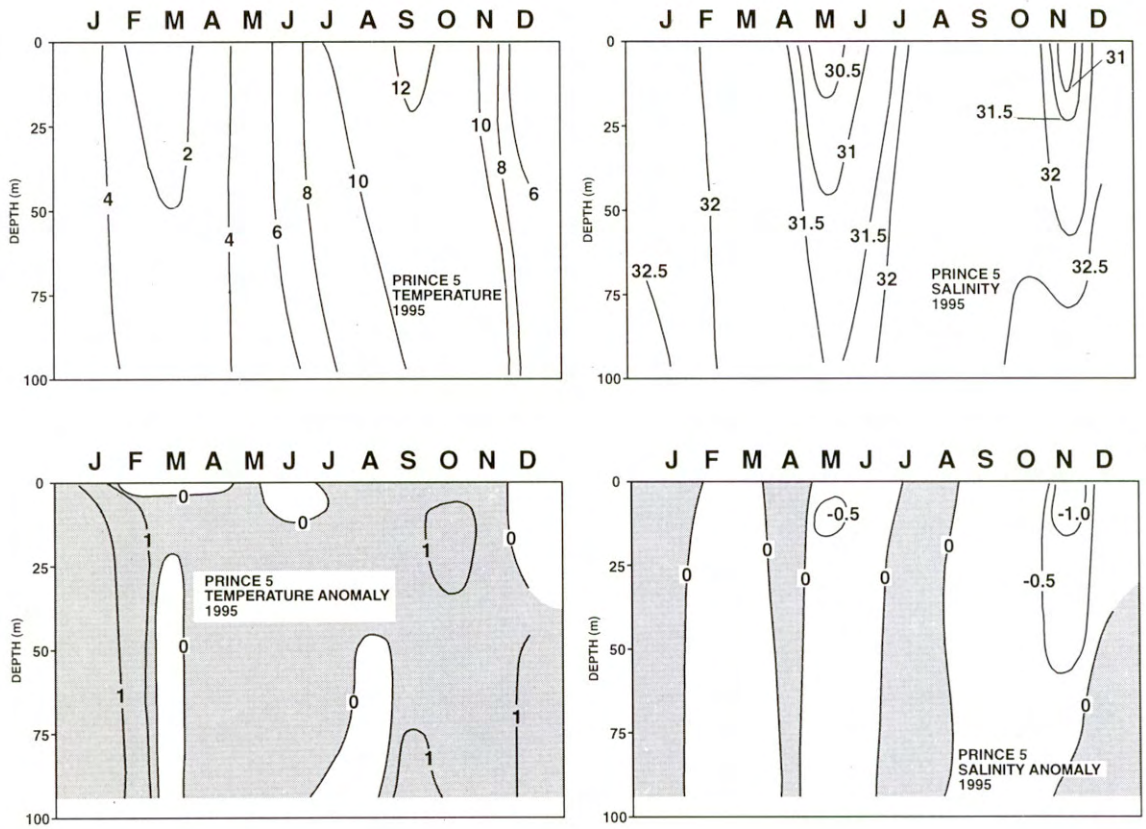


Fig. 33. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1995 relative to the 1961–90 means. Shaded areas are positive anomalies.

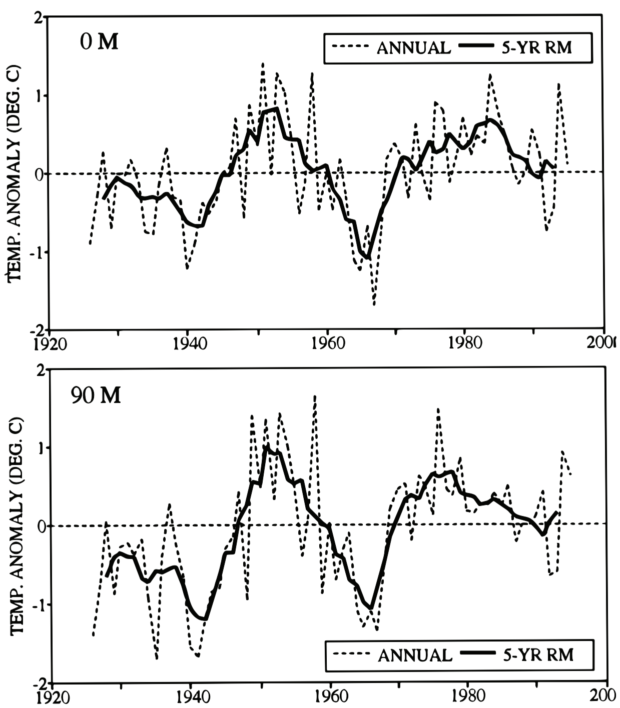


Fig. 34. The annual means and the 5-year running means of the temperature anomalies at Prince 5, 0 and 90 m.

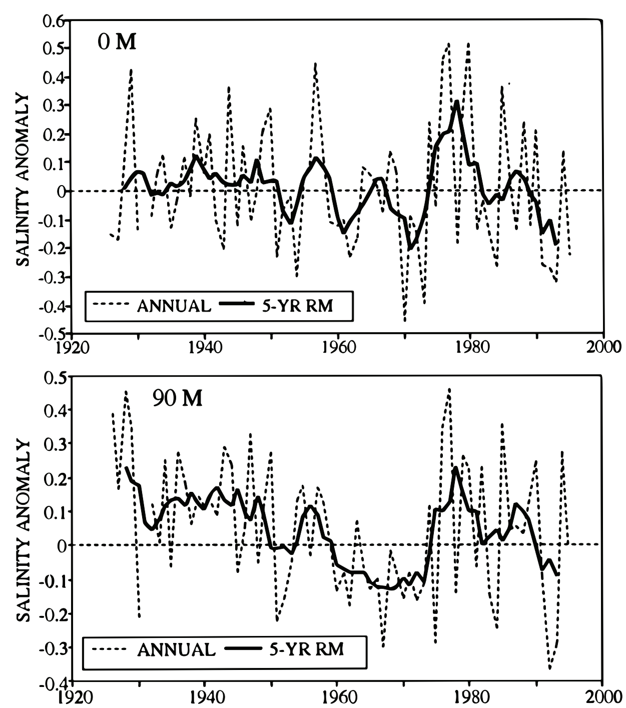


Fig. 35. The annual means and the 5-year running means of the salinity anomalies at Prince 5, 0 and 90 m.

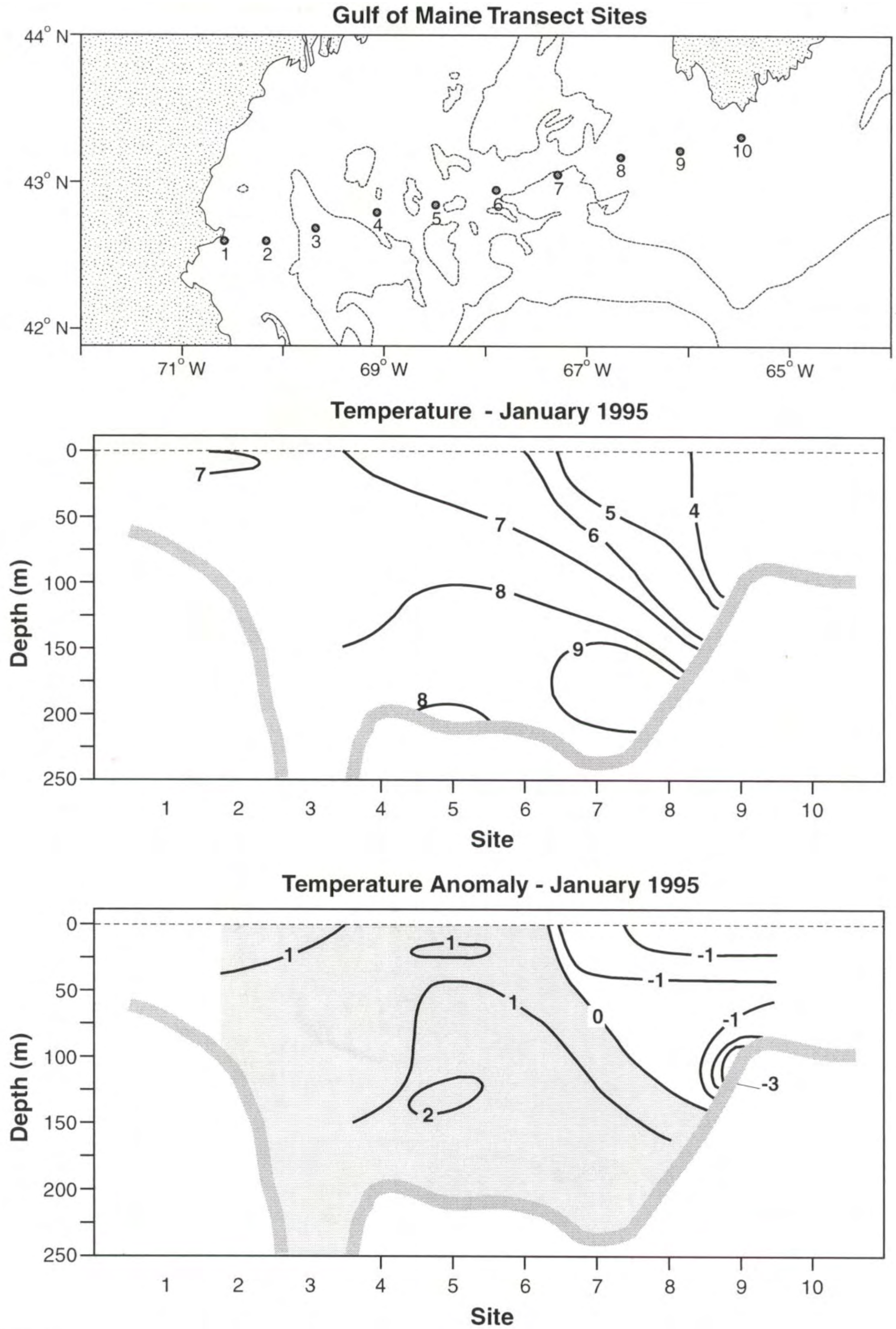


Fig. 36. The temperature (middle) and temperature anomalies (bottom) in °C along a XBT transect (top) across the Gulf of Maine during January 1995.

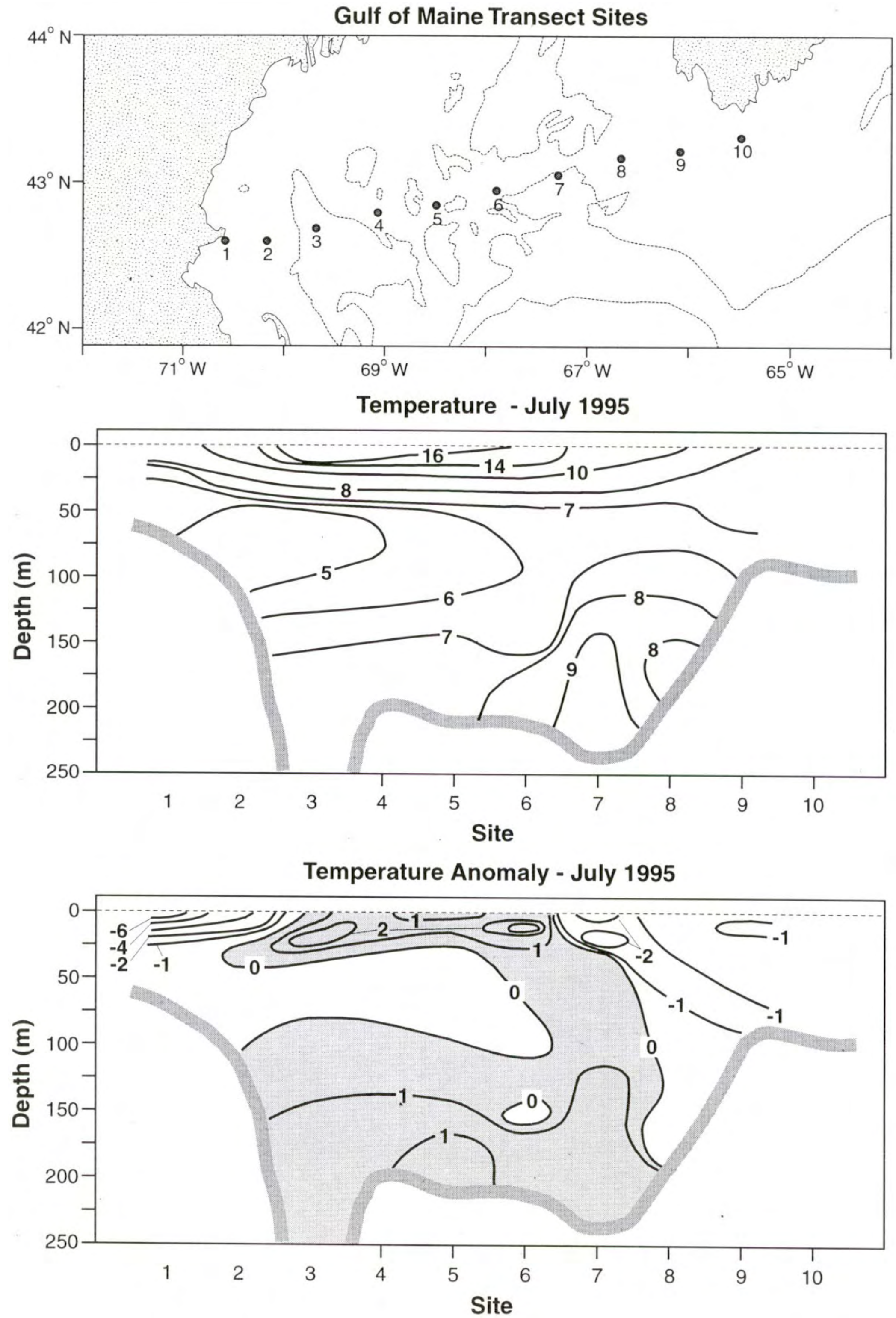


Fig. 37. The temperature (middle) and temperature anomalies (bottom) in °C along a XBT transect (top) across the Gulf of Maine during July 1995.

transported onto the shelf through the Northeast Channel by cross-shelf exchange processes. To the east on the Scotian Shelf, the waters were colder than normal, typically by 0.5–1.5°C, whereas in the central and western regions anomalies were generally warm, reaching upwards of 2°C in the deeper waters of the Gulf. In July, the Gulf was strongly stratified with maximum temperatures >16°C in the surface waters of the central Gulf. The coldest waters, in contrast to January, were at intermediate depths in the western Gulf. These waters are often referred to as the "cool pool" and is formed principally by in situ winter cooling. Water off Nova Scotia (sites 8–9) was again colder than normal while warm temperature anomalies occupied the deep layers (>100 m). The "cool pool" waters were slightly colder than normal while off the northern tip of Massachusetts Bay, while the near surface waters were very cold (anomaly colder than -6°C). The latter was perhaps due to wind-induced upwelling. The warm deep water observed in January and July was a persistent feature throughout the remainder of 1995. The cold waters off Nova Scotia were also typical in 1995, with below normal temperatures in 7 of the 11 months when measurements were taken. In three of the remaining 4 months, temperatures were near normal and only in September were temperatures above normal. The near surface and intermediate depth temperatures, however, showed more spatial and temporal variability than the bottom waters. In the central Gulf within the upper 100 m, below normal temperatures appeared in 7 of the 11 months, while in the west they appeared in only 5 months.

Deep Emerald Basin temperatures. Petrie and Drinkwater (1993) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (decadal periods). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (year-to-year) variability. High coherence at 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 between locations were observed. Temperature anomalies at 250 m have been used as a representative thermal index.

In 1995, temperature measurements in Emerald Basin were obtained in six separate months with values at 250 m ranging from 10.9 to 9.3°C. This produced monthly anomalies of 1.0–2.5°C above normal (Fig. 38). The long-term (1961–90) annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. The anomalies were generally

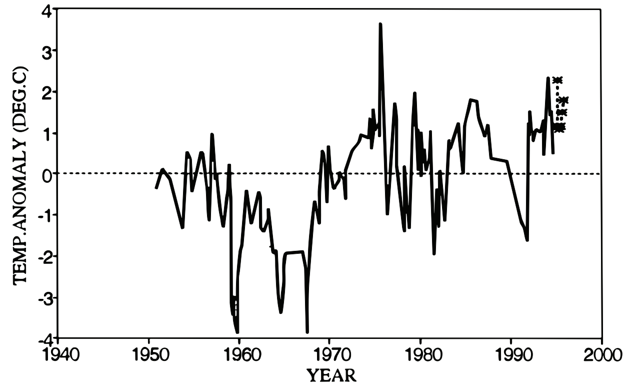
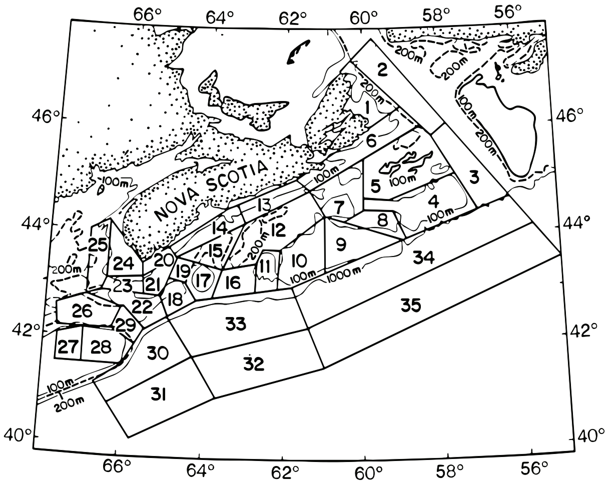


Fig. 38. Temperature anomalies (relative to 1961–90) at Emerald Basin at 250 m.

representative of conditions throughout the water column including the near surface waters. An exception was February when temperatures in the top 75 m were 2–3°C below normal. The generally warm temperatures, especially in the deep waters, during the last three years began with an intrusion of warm slope water in late-1991 or early-1992.

Other Scotian Shelf and Georges Bank temperatures. Drinkwater and Trites (1987) tabulated monthly mean conditions for irregularly shaped areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 39). From data collected in 1995, we have produced monthly mean conditions at standard depths (averaging any data within the month anywhere within these areas) and compared them to the long-term averages (1961–90). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. Thus care again must be taken in interpreting these data and little weight given to any individual mean.

This analysis was first undertaken during the 1993 review (Drinkwater 1995). It identified several important features. First, the temperatures in the upper 30 m tended to vary greatly from month to month, due to the greater influence of atmospheric heating and cooling. Second, at intermediate depths of 50 m to approximately 150 m, temperatures had declined steadily from approximately the mid-1980s into the 1990s. On Lurcher Shoals off Yarmouth, on the offshore banks and in the northeastern Scotian Shelf the temperature minimum in this period approached or matched the minimum observed during the very cold period of the 1960s. The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald on the Scotian



1 Sydney Bight	13. Eastern Shore	25. E. Gulf of Maine
2 N. Laurentian Channel	14. South Shore	26. Georges Basin
3. S. Laurentian Channel	15. LaHave Basin	27 Georges Shoal
4. Banquereau	16. Saddle	28 E. Georges Bank
5. Misaine Bank	17. LaHave Bank	29. N. E. Channel
6 Canso	18. Baccaro Bank	30 Southern Slope
7 Middle Bank	19. Roseway Bank	31 Southern Offshore
8. The Gully	20. Shelburne	32 Central Offshore
9. Sable Island	21. Roseway Basin	33 Central Slope
10. Western Bank	22. Browns Bank	34. Northern Slope
11. Emerald Bank	23. Roseway Channel	35. Northern Offshore
12. Emerald Basin	24. Lurcher Shoals	

Fig. 39. The areas in which monthly mean temperature and temperature anomalies were estimated (from Drinkwater and Trites, 1987).

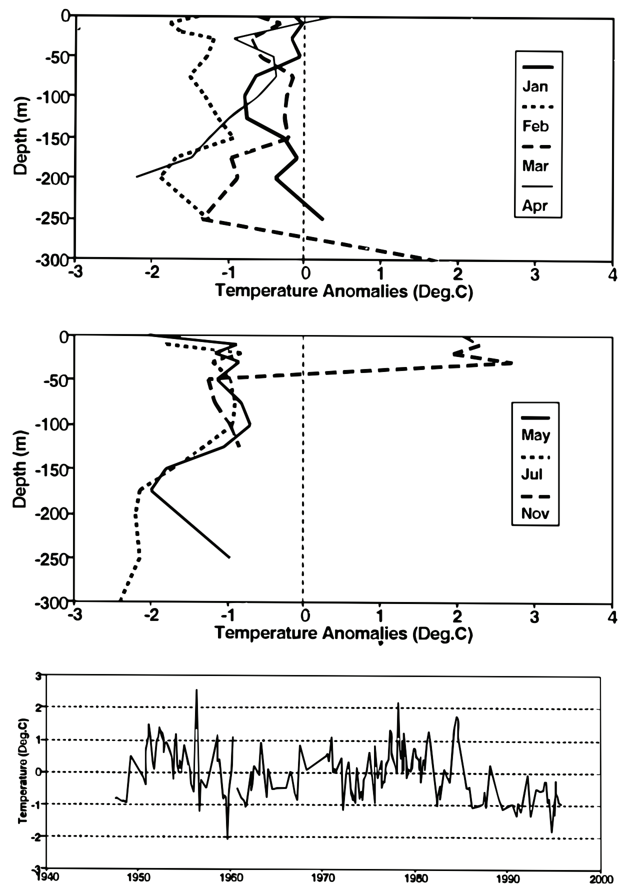


Fig. 40. The 1995 monthly anomaly profiles (upper 2 panels) and temperature anomaly time series at 100 m (bottom panel) for Misaine Bank (area 5 in Fig. 39).

Shelf and Georges in the Gulf of Maine. This warm deep water appeared to influence the intermediate depth waters above the basins as their anomalies were generally warmer than elsewhere on the shelves.

The spatial extent of the cooling of the intermediate layer waters during the late-1980s and into the 1990s was examined by Drinkwater *et al.* (1996). The cold water was traced through the Gulf of Maine from southern Nova Scotia, along the coast of Maine and into the western Gulf. Similar cooling occurred at approximately the same time at Station 27 off St. John's, Newfoundland, off southern Newfoundland on St. Pierre Bank and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew, 1997). Data from 1994 indicated warming of the intermediate layers in the Gulf of Maine but continued cold water on much of the Scotian Shelf.

Monthly mean temperature anomaly profiles during 1995 show that the general patterns identified by Drinkwater (1995) have continued. Cold conditions prevailed in the northeast Scotian Shelf (Fig. 40), along the Atlantic coast of Nova Scotia to Lurcher Shoals (Fig. 41) and on some of the outer Banks, such as Western, Sable and LaHave. Warmer-than-normal conditions were observed in Emerald and Georges Basins and, in most months that observations were taken, on some of the other outer banks, such as Browns, Emerald and Banquereau. The warm conditions on these banks are believed to be due to the influence of slope waters. On Sydney Bight, temperatures oscillated between above and below normal through the year. The cold conditions at Lurcher and warm in the deep sections of Georges Basin were seen earlier from the XBT data (Fig. 36 and 37). Also, the warm waters in Emerald Basin were consistent with the temperature data shown in Fig. 38.

The time series of monthly mean temperatures at 50 m for Lurcher and 100 m at Misaine Bank show that the long-term trend has been dominated by warm periods in the 1950s and mid-1970s to mid-1980s and cool periods in the 1960s and since the mid-1980s. These conditions were generally

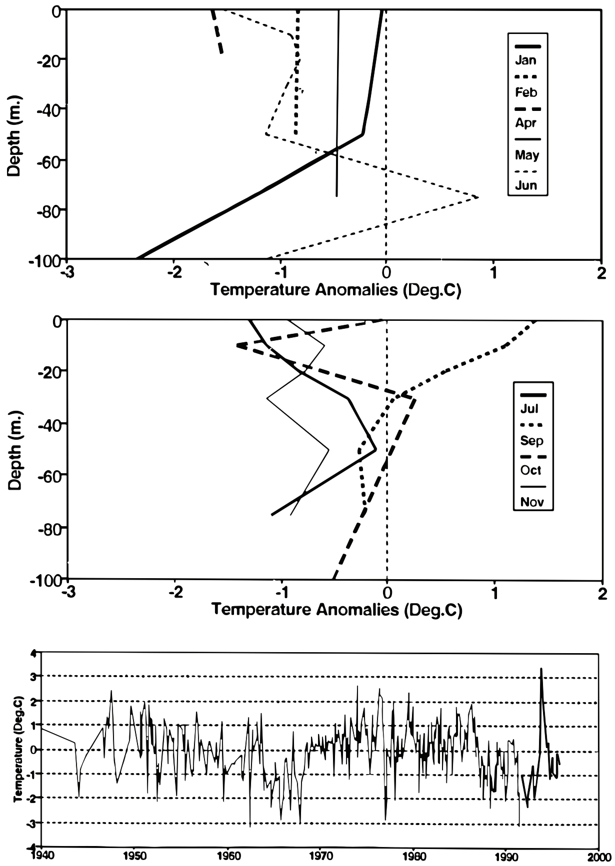


Fig. 41. The 1995 monthly anomaly profiles (upper 2 panels) and temperature anomaly time series at 50 m (bottom panel) for Lurcher Shoals (area 24 in Fig. 39).

representative of the average conditions throughout the water column at Lurcher because of the strong tidal mixing and below approximately 50 m in the northeastern Scotian Shelf region. These cold temperatures appeared to be moderating at Lurcher but not in the northeast at Misaine.

Temperatures during the summer groundfish survey. The best temperature coverage over the entire Scotian Shelf occurs during the annual Canadian groundfish survey, usually undertaken in July. During the 1995 survey, 30–40 XBTs were taken in the western Scotian Shelf and Lurcher areas in addition to the CTD profiles obtained at the trawl sites. These data were combined and temperatures were interpolated onto a 0.2 by 0.2 degree latitude–longitude grid using an objective analysis procedure known as optimal estimation. The interpolation method used the 15 "nearest neighbours" within a radius of 30 km. The data were also interpolated in the vertical, 15 m in the upper 30 m and 25 m below that. Temperatures at 0, 50, 100 m and near bottom were optimally estimated. Maximum depths were limited to 300 m as we were primarily interested in the temperatures over the shelf. In addition, the 1961–90 means for July were estimated onto the same grid in order to calculate temperature anomalies.

Surface temperatures in 1995 varied from 9–16°C with the coldest temperatures in the Bay of Fundy and off Lurcher due to strong tidal mixing, and the warmest temperatures off Sydney Bight, originating from the Magdalen Shallows in the Gulf of St. Lawrence (Fig. 42a). Other features were the cooler waters in the northeast Scotian Shelf and off the coast of Nova Scotia and warm temperatures near Emerald Basin. At 50 m the coldest temperatures were in the northeast and the warmest along the continental shelf through the presence of slope waters (Fig. 42b). Note the cold waters covering most of the northeastern Scotian Shelf and off the Atlantic coast of southwestern Nova Scotia. Warm waters penetrated the central shelf regions over Sable Island Bank and into Emerald Basin. The 100 m temperatures show a pattern similar to that for 50 m but with temperatures slightly higher, especially over the Emerald Basin region (Fig. 42c). Bottom temperatures show several standard features (Fig. 42d). First is the large contrast between the northeast and central Scotian Shelf. In the northeast, bottom temperatures were generally cold with minima less than 1°C in the Misaine Bank region. Cool waters were also found along the Atlantic coast of Nova Scotia, especial to the south. Temperatures in Emerald Basin exceeded 9°C as did those in the central Gulf of Maine. Relatively high temperatures also were found along the continental slope and the upper reaches of the Bay of Fundy.

Temperature anomalies at the 3 depth levels and near bottom, all show similar patterns (Fig. 43). To the northeast extending from the Laurentian Channel to Sable and Western Banks, temperatures were below normal. Maximum values were -3°C in the surface waters between Chedabucto Bay and Sable Island. Elsewhere through the water column, anomalies were typically -0.5 to over -1°C. The southwestern end of the Shelf was also cold with surface anomalies of -2°C and deeper anomalies similar to that in the northeast. In contrast, anomalies in the central Scotian Shelf region were above normal except at the surface. The largest positive anomalies were near bottom and had magnitudes of 1-2°C. This was consistent with the 250 m temperatures in Emerald Basin (Fig. 38).

Summary

During 1995, wintertime air temperatures over the Northwest Atlantic were generally colder than

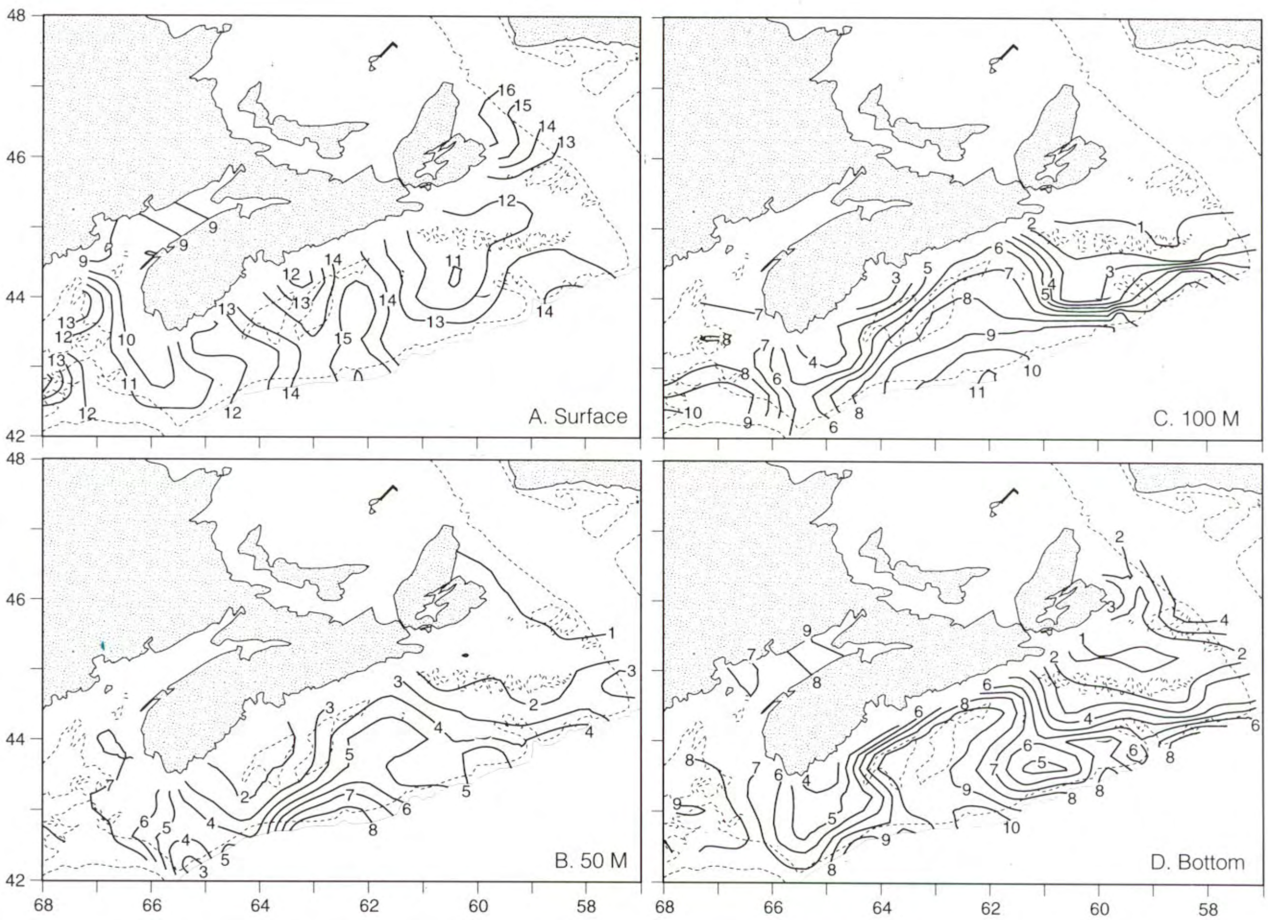


Fig. 42. Contours of optimally estimated temperatures at (**A**) the surface, (**B**) 50 m, (**C**) 100 m and (**D**) near bottom during the 1995 July groundfish survey.

normal except along the Middle Atlantic Bight. This was consistent with the high positive value of the NAO index caused by the intensification of the Icelandic Low and Azores High. This intensification resulted in stronger northwest winds over northern regions which brought cold Arctic air farther south. The cold conditions and stronger NW winds resulted in earlier ice formation, greater areal extent of ice than normal and a longer duration of ice, over much of the Labrador and Newfoundland as well as in the Gulf of St. Lawrence and on the Scotian Shelf. The cold temperatures, strong winds and extensive ice off Newfoundland and Labrador all contributed towards a large number of icebergs reaching the Grand Banks. Winter conditions were not as severe as 1994 or the early-1990s although the NAO index in 1995 was the highest since 1990. The very high NAO index might have been expected to result in even colder air temperatures and more ice off Labrador and Newfoundland than was observed based upon past relationships, but while the Icelandic Low and the Azores High intensified, causing the high NAO index, they also shifted eastward to northeastward, which reduced their influence in the western Atlantic including the Labrador Sea. This is believed to be the reason that although the NAO index increased relative to the other years in the 1990s, the winter conditions in the Labrador Sea were not as severe. The strengthening of the Azores High would have resulted in stronger southerly winds over the Middle Atlantic Bight region which would carry warm, moist air and produce the observed warmer-than-normal conditions in that region.

During the spring to autumn, air temperature anomalies were generally above normal throughout the NAFO region. Maximum warming occurred in the north during the autumn and is related to strong southwesterly to southerly winds caused by an anomalous high pressure system that developed over Greenland. These warm conditions resulted in annual air temperatures that were near or above their long-term means and represented significant

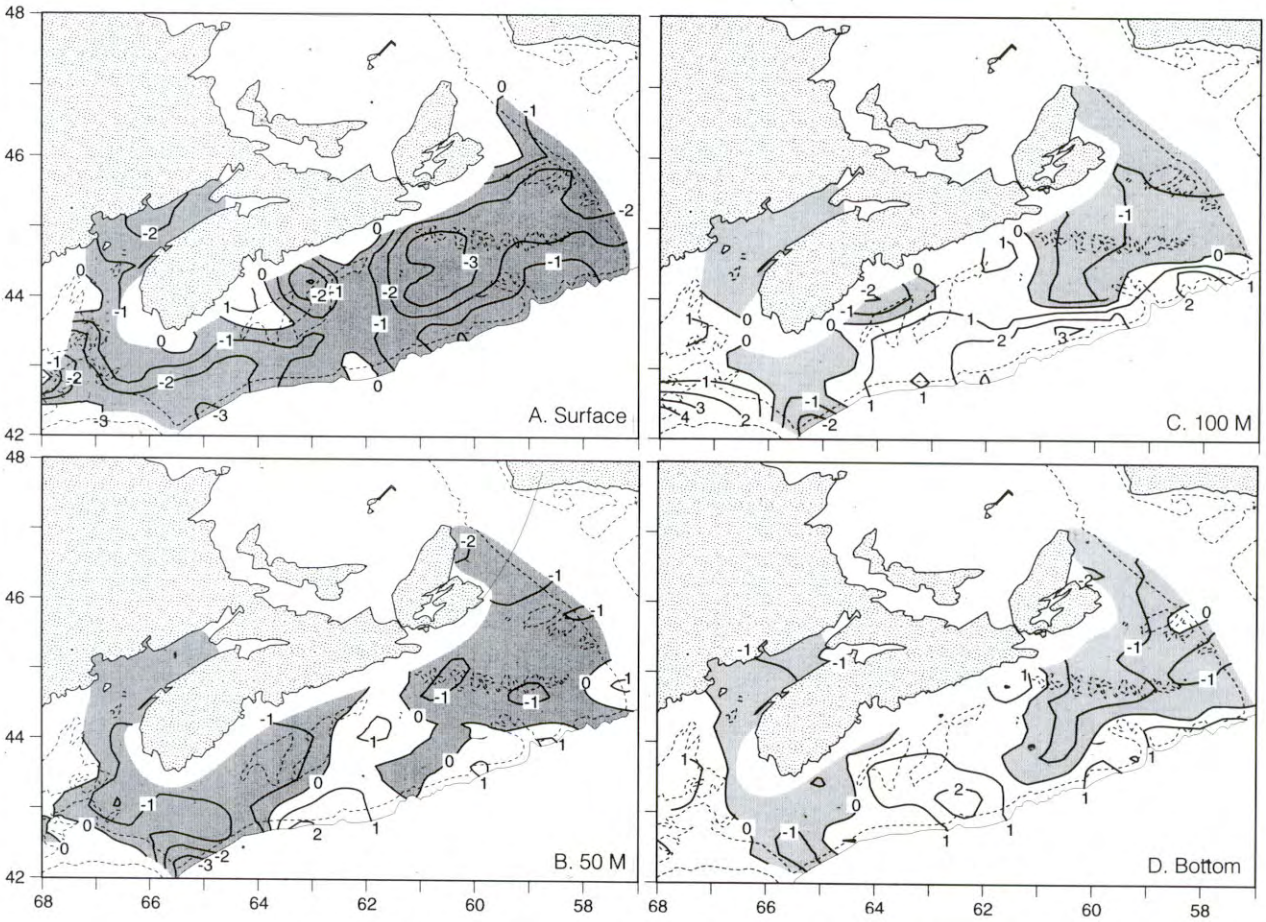


Fig. 43. Contours of optimally estimated temperature anomalies at (**A**) the surface, (**B**) 50 m, (**C**) 100 m and (**D**) near bottom during the 1995 July groundfish survey. Negative anomalies are shaded.

warming compared to recent years. The warmest site was Iqaluit on Baffin Island where the annual anomaly was 1.6°C above normal. While most of coastal air temperature sites from Newfoundland to the Gulf of Maine recorded near normal values, at Cape Hatteras the annual mean was warmer than normal. From the Gulf of St. Lawrence and Newfoundland north, air temperatures in 1995 increased relative to 1994 while to the south they decreased.

Colder-than-normal sea temperatures prevailed over most of the southern Labrador and Newfoundland regions again in 1995, continuing the pattern established in the early- to mid-1980s. However, sea temperatures appeared to be moderating with most regions experiencing a warming relative to recent years. This included warming at Station 27, a reduction in the amount of CIL waters, a warming of the CIL core temperature, and an increase of near bottom temperatures over the Grand Banks by the autumn of 1995. South of Newfoundland, around St. Pierre Bank, deep temperatures over the central and eastern Bank remained very cold and showed no signs of warming. This was also true of the CIL waters in the Gulf of St. Lawrence where near record cold temperatures have been recorded during the past decade. More of the Magdalen Shallows were covered with cold waters in 1995 than in 1994 with the area covered by temperatures below 1°C and 0°C was at or near its long-term maximum. Very cold temperatures in the 30–200 m layers were also recorded in the northeastern Gulf of St. Lawrence. The upper layer (0–30 m) waters during late-summer and early-autumn did warm relative to 1994 and were slightly above their long-term mean. Cold conditions were also observed in the CIL layer and near-bottom waters on the northeastern Scotian Shelf, inshore along the Atlantic coast of Nova Scotia and off southwestern Nova Scotia. This continued a pattern established in the middle of the 1980s. These cold waters are believed to be advected onto the Scotian Shelf from the Gulf of St. Lawrence and perhaps off the Newfoundland Shelf and to a lesser extent from in situ cooling during the winter although the relative importance has not yet been established. In contrast to these cool conditions, the waters in the central Scotian Shelf over Emerald Basin and along the continental slope, were warmer than normal. These conditions have persisted since 1992 and reflect the presence of warm slope water offshore. In the Gulf of Maine, temperatures were predominantly warmer than normal which is believed to be due to the influx of slope water into the region through the Northeast Channel.

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