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Overview of Environmental Conditions in the Northwest Atlantic in 1994

by

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ABSTRACT

A review of environmental conditions on the continental shelves and adjacent offshore areas off eastern Canada during 1994 is presented. Wintertime air temperatures over eastern Canada were generally colder-than-normal continuing the trend that has persisted through the 1990s. This was associated with the high positive value of the NAO 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 towards a large number of icebergs reaching the Grand Banks. Ocean temperatures off Newfoundland at Station 27 were below normal during the winter of 1994. By the summer, however, the surface waters had increased upwards of 2°C above normal and near normal in deeper water by the fall. The area of the CIL in summer across the northeast Newfoundland Shelf decreased from 1993 and is slightly above or near normal. Large areas of the continental shelf, particularly the Grand Bank, saw a continuation of the below normal bottom temperatures (up to 0.5°C below average) experienced during 1990s. Temperature anomalies off southern Newfoundland have also been cold since the mid-1980s. Similar conditions have been observed in the CIL in the Gulf of St. Lawrence and on the Scotian Shelf. Large areas of the Magdalen Shallows continue 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 Shelf appear to be moderating with maximum warming occurring over Emerald Bank due to mixing with warm bottom waters. The latter have occupied the lower layers of the Basin for the past few years and are consistent with the warm conditions observed in the Laurentian Channel and Cabot Strait to the north and in the Gulf of Maine to the south. The source of these deep waters are the offshore slope waters. Indeed, penetration of the slope water appears to have lead to warming throughout the Gulf of Maine during 1994.

INTRODUCTION

This paper examines the 1994 environmental conditions in the Northwest Atlantic and is the thirteenth annual review presented to NAFO. 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-yr 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 Atmospheric Environment Service of Canada publishes the annual and monthly mean air temperature anomalies (relative to 1951-80) for Canada in their publication *Climatic Perspectives*. The 1994 annual anomalies were slightly colder-than-normal over most of eastern Canada and contrast with the warmer-than-normal temperatures in the west (Fig. 1). This pattern is similar to that observed in both 1993 and 1992, although this year's anomalies over eastern Canadian were not as cold as in the previous two years. The coldest anomalies in 1994 (between -0.5°C and -1°C) were found along a narrow region encompassing the southern tip of Labrador, the northern Gulf of St. Lawrence and the St. Lawrence Estuary. Over most of the remainder of eastern Canada, the annual anomalies lay in the range of 0°C to -0.5°C, except on the Atlantic coast of Nova Scotia where annual temperatures were slightly above normal. All of the annual anomalies over eastern Canada were less than one standard deviation from their long-term means (Trites and Drinkwater, 1986).

The colder-than-normal air temperatures in eastern Canada did not persist throughout the year but rather were concentrated during the first five months (Fig. 2). During the latter half of 1994 the monthly anomalies were predominantly above normal but were not high enough to compensate the earlier cold period. Exceptions to the general warming in the second half of 1994 arose in August for areas north of central Labrador and in December over southern Labrador and Newfoundland. The largest negative anomalies during the year were reported in January and February when magnitudes exceeded -4 to -6°C along the Labrador coast and northern Newfoundland. Atlantic Canada experienced its 11th coldest winter in the past 100 years and it was the 10th winter in a row that temperatures were colder-than-average. The relatively warm conditions in eastern Canada during the autumn was the first in several years. The magnitude of the warming was higher in southern areas and weaker in the north, e.g. in the vicinity of southeastern Baffin Island only two of the last six months showed positive anomalies.

Monthly air temperature anomalies for 1993 and 1994 relative to their 1961-90 mean at five sites in eastern Canada and one on the west coast of Greenland (see Fig. 3 for locations) are shown in Fig. 4. The predominance of colder-than-normal air temperatures in the first few months of 1994 and warmer-than-normal during the latter half of the year is evident for all sites. At the two most northern sites, the wintertime temperatures were not as severe as 1993 whereas at Cartwright on the Labrador coast, and stations farther south, the winter air temperature anomalies were similar to last year. The warming in the latter part of the year was less evident or absent at Godthaab in West Greenland and at Iqaluit on Baffin Island compared to the more southerly stations. This warming was in contrast to events in 1993 (Fig. 4).

The time series of temperatures (25-month running means) show the warming in 1994 as a recent upward trend (Fig. 5). Note that 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 yr 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 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).

Iqaluit recorded an annual air temperature of -9.7°C which was near normal (anomaly of -0.1°C) but represents a rise of 2.8°C over last year. At the remaining four stations in Fig. 5, annual air temperatures rose between 0.7° and 1.0°C. At Cartwright, 1994 was the 16th coldest year out of a total of 63, but at Sable Island it was the 13th warmest in 80 years. At the Magdalen Islands and St. John's, Newfoundland, temperatures were near normal.

Precipitation

Annual precipitation anomalies over the Atlantic provinces of Canada and along the southern Labrador coast during 1994 were wetter-than-normal by upwards of 25% (Fig. 6). This contrasts with the northern Labrador coast and Baffin Island, as well as the Hudson Bay region, where precipitation was slightly below normal. Seasonally, wet conditions were observed over all of Atlantic Canada during the spring and over Newfoundland in the winter and summer as well. The autumn tended to be drier in all regions of Atlantic Canada expect for the northern shore of Newfoundland. Along the Labrador coast and Baffin Island, wet conditions were observed in the spring and summer and drier-than-normal conditions in the winter and autumn. Throughout most of central Canada, i.e. the drainage basin for the Great Lakes, dry conditions generally persisted during the year.

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale sea surface pressure patterns and atmospheric circulation. Monthly mean sea surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas* by the German Meteorological Service, Deutscher Wetterierst, in Offenbach, Germany. 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 (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 1994, relative to the 1961-90 means, are shown in Fig. 7. Winter includes December 1993 to February 1994, 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 -9 mb) centred slightly south of Iceland. This represents an intensification and slight shift southward in the position of the Iceland Low. In contrast, a center of positive anomalies (maximum of 5.8 mb) was observed over the southern North Atlantic and western Europe, consistent with a strengthening of the Bermuda-Azores High. Another anomalous high pressure pattern formed over northern Greenland. The resultant air pressure patterns would have strengthened the westerly winds across the North Atlantic and shifted them slightly southward. The winds over East Greenland were much stronger-than-normal and may have contributed to an increased transport of both the East Greenland Current and ice out of the Arctic into the Greenland Sea. NW winds would have been reduced over Baffin Bay but increased over the southern Labrador Sea. The latter tends to bring cold Arctic air masses farther south. The anomalous winds over Newfoundland and the Gulf of St. Lawrence would have also been from the northwest while over the Scotian Shelf and the Gulf of Maine they would have been more easterly. In spring and summer negative anomalies again dominated the atmospheric pressure pattern in the northern North Atlantic with positive anomalies in the southern North Atlantic. This resulted in a continuation of stronger-than-normal westerly winds across the Atlantic at mid-latitudes. Anomalous winds across the Scotian Shelf and in the Gulf of St. Lawrence would have been more southwesterly to westerly carrying with them warmer air. Note that the magnitude of the anomalies decreased with season. In autumn, a strong negative anomaly developed over the North Atlantic with a minimum value of -6 mb centred just to the east of Newfoundland. This would have brought anomalous easterly winds to Newfoundland. In contrast, anomalous westerly winds blew over northern Labrador in autumn which may have contributed to the above normal air temperatures.

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 air temperatures and heavy ice in the Labrador Sea are associated with a strong positive NAO index (Colbourne et al., 1994; Drinkwater, 1994a). 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. 8). The small number of missing data was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1961-90 mean. In 1994, the NAO anomaly was strongly positive but slightly below last year's value. This continues a trend of above average NAO anomalies that has existed 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 anomalies in the Labrador Sea (Fig. 5).

SEA ICE OBSERVATIONS

Newfoundland and Labrador

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The long-term medians, maximum and minimum positions of the ice edge (concentrations above 10%) based on the composite for the years 1962 to 1987 are taken from Coté (1989).

Near seasonal air temperatures and light to moderate NW winds during the second half of December 1993 resulted in near normal ice coverage by the end of the month. The southern limit of the ice edge lay near the Strait of Belle Isle (Fig. 9). The ice edge continued to move southward during early January at a rate consistent with its normal progression due to continuing seasonal temperatures and winds. However, in the latter half of January extremely cold air temperatures and strong NW winds acceleratedthe rate of southward movement. By the beginning of February the ice coverage lay between the long-term median and maximum. Cold weather and strong winds in February continued to push the ice south and offshore so that by the beginning of March the ice edge was close to the long-term maximum. The ice began to retreat along the coast of Newfoundland later in March and by April 1 the ice had shifted eastward, freeing most of the coastal communities of Newfoundland of ice. The offshore ice edge, however, still lay near its long-term maximum extent. Through April the ice moved back inshore along northern Newfoundland and remained there into June. It finally disappeared from the region around mid-June.

The Ice Climatology and Applications Division of Environment Canada also undertakes an annual analysis of ice conditions off the east coast of Newfoundland and southern Labrador and in the Gulf of St. Lawrence by determining the time of onset, duration and last presence of ice at 24 grid sites (Fig. 10). For each site, the extracted data include ice duration in weeks for the 1993/1994 season, mean duration for all years of record, as well as minimum, maximum and mean duration for years when ice was present (Table 1). Almost without exception in the area east of Newfoundland and southern Labrador, the ice appeared early and left late (Fig. 11, 12). The ice typically appeared 2 weeks early (Fig. 11). In the inshore areas it left 1-2 weeks late but offshore it lasted 3-7 weeks longer-than-normal (Fig. 12). This resulted in a much longer period of ice duration especially in the offshore region (Fig. 13). Note that ice duration is not simply the difference between the first and last presence of ice because ice may disappear for a time after first presence or before last presence. A new record for the date of the last appearance of ice was established in 1994 at the farthest offshore sites east of the Avalon Peninsula (N112 and N114). The appearance of ice at N114 was unusual in that ice has only been observed at this site in 5 out of the 35 years of record. Ice was not observed at sites N25, N27 or N70; however, ice has never appeared at sites N27 and N70 and only reached N25 in 2 out of 35 years.

The monthly time series of the areal extent of ice on the northern Newfoundland and southern Labrador shelves (between 45-55°N) from 1963 to 1994 are shown in Fig. 14. In January through April there has been a general increase in the area of ice over the past 30 y. In addition, there are maxima in the early 1970s, the mid-1980s and the 1990s, corresponding to air temperature minima at Iqaluit and Cartwright (Fig. 5) and maxima in the NAO index (Fig. 8). The 1994 areas from January to May were well above average and often near maximum values. In February 1994 the ice coverage was the maximum on record for that month. These data further support 1994 being a heavy ice year on the Labrador and Newfoundland shelves.

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 1993/94 iceberg season (October to September), a total of 1765 icebergs were spotted south of 48°N. The monthly totals for February to August were 79, 529, 208, 377, 387, 161, and 24 (Fig. 15). No icebergs were spotted between October, 1993, and January, 1994, inclusive, or in September, 1994. In the primary iceberg season of March to July, 1662 icebergs were observed which represents 94% of the annual total and is slightly higher than the 1983-1994 average of 89%. The percentage of the total number of icebergs by month for the 1993/94 season shows that proportionally a larger number than normal penetrated south of 48°N in March. The total number of icebergs in 1994 was similar to 1993, although last year more icebergs appeared earlier in the season. A recent analysis by the U.S. Coast Guard (G. Trivers, personal communication) has indicated that earlier concerns of the SLAR estimating a larger number of icebergs than previous methods appears to have been unfounded. Thus we have presented the time series of iceberg counts during March to July beginning in 1945 when aerial reconnaissance was first established (Fig. 15). In the 1990s the number of icebergs has been much higher than normal. 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. These same conditions are believed to have contributed to the relatively high number of bergs in 1994.

Gulf of St. Lawrence

During December, 1993, air temperatures were below normal over the Gulf and along the western coast of Newfoundland. This led to rapid ice formation along the north shore of Quebec, in the St. Lawrence Estuary and off eastern New Brunswick. Ice extent was above normal for this time of year (Fig. 16). During the first half of January, air temperatures dropped well below normal and the entire Magdalen Shallows became covered with ice by the middle of the month. In the eastern Gulf along the north shore the ice edge was near its long-term median position. Continuing cold temperatures and strong NW winds caused the entire Gulf to be ice covered by the beginning of February. The ice also moved out onto the Scotian Shelf, reaching as far south as Halifax along the Atlantic coast of Nova Scotia and beyond the 1962-1987 long-term maximum. The ice edge remained near its maximum extend throughout February and early March. By April 1, ice had begun to retreat with open areas in the western Gulf. Ice still remained in the Cabot Strait region and at the extreme northeastern end of the Scotian Shelf at this time. By the beginning of May only the northeastern Gulf was ice covered. The Strait of Belle Isle contained ice through to late May and early June.

As off Newfoundland and Labrador, ice in the Gulf of St. Lawrence appeared early (by 1-3 weeks; Fig. 11) and left late (also by 1-3 weeks; Fig. 12). A new record was set for the latest date of the last presence of ice on the Magdalen Shallows off Baie des Chaleurs (site G22; Fig. 10). The ice duration (Fig. 13) was longer-than-normal (by over 2 weeks) throughout most of the Gulf. Ice duration records were set on the northern Magdalen Shallows (G22) and equalled off Cape Breton (G33, G87) and in the northeastern Gulf (G10).

OCEANOGRAPHIC OBSERVATIONS

Newfoundland and Labrador

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 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 65 times in 1994, with a monthly maximum of 11 in January and a minimum of 3 in March and April. 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 1994 together with their anomalies relative to 1961-90 are shown in Fig. 17.

The water column was nearly isothermal during January to March with temperatures ranging from approximately -1° to -1.7°C. In the lower half of the water column temperatures remained less than -1.5°C through to the early autumn and below approximately 100 m they never rose above 0°C during the year. Temperatures in the upper layer (generally < 50 m) were below -1°C until April. By May they surpassed 0°C and at the surface reached a peak of over 14°C in August before autumn cooling began. Note the propagation of surface layer heat down into the lower layers in the late autumn. The upper layers generally experienced positive temperature anomalies from April to September and again in November with maximum values of 2°C above normal in July and August. In the lower half of the water column temperatures were typically below normal throughout the year. During the first three months of the year and in December temperatures throughout the water column were colder-than-normal with the lowest anomalies (below -0.5°C) in February.

Upper layer salinities were near normal during the winter and spring with values between 32 and 32.4. In the summer and early autumn they ranged from 32.2 to <31 producing fresher-than-normal salinities from August to October. Based on the studies of Myers et al. (1990) and Petrie et al. (1991), the lower salinities in late summer and early autumn are 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 during the latter half of the year resulting in slightly positive salinity anomalies.

The low-pass filtered time series of temperature and salinity anomalies at standard depths show three major cold and fresher-than-normal periods at near decadal time scales since the early 1970s (Fig. 18). At the surface and at 30 m depth the negative temperature anomalies that began in late 1990 and reached a peak in mid-1991, moderated to above normal conditions by July of 1994. At depths of 100 and 175 m strong negative temperature anomalies have persisted almost uninterrupted since 1983. The large fresher-than-normal salinity anomaly that began in early 1991 had returned to near normal conditions by early 1993 but freshened again by the summer of 1994.

The depth-averaged temperature, which is proportional to the total heat content within the water column, also shows large amplitude fluctuations at near decadal time scales with cold periods during the early 1970s, mid-1980s and early 1990s (Fig. 19). 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 0 to 50 m depth-averaged summer salinity is also plotted in Fig. 19. 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 summer salinities returned to more normal values but in 1994 again decreased slightly. 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).

CIL

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 Center 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. 20. The annual variability in the cross-sectional areas of the CIL are highly correlated between transects (Petrie et al., 1992). In 1994, the CIL area off Bonavista was about 7% above normal compared to 28% in 1993 and 68% in 1991. The CIL area along the Seal Island and Flemish Cap transects also remained above normal during the summer of 1994 at about 36% and 12%, respectively. These do, however, represent a decrease relative to last year. The minimum temperatures observed in the core of the CIL off Bonavista were -1.70°C in 1994 compared to -1.74°C in 1993 and slightly below the long-term average of -1.64°C. Along the Flemish Cap transect across the central portion of the Grand Bank 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 shows similar interannual trends as in summer, however, the average area decreases by approximately 25% due to vertical mixing from above and below. During the autumn of 1994 it was about 26 km^2 compared to about 30 km^2 in 1993, 27 km^2 in 1992 and about 22 km^2 in 1991. The CIL area in autumn off Seal Island is 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. The CIL area during the fall of 1994 was about 14 km^2 compared to 16 km^2 in 1993, 26 km^2 in 1992 and 11 km^2 in 1991.

The total volume of CIL water was also estimated over the 2J3KL area (Fig. 21). Maximum values occurred during the cold periods of the mid 1980s and early 1990s. Since 1990, the summertime volume of subzero water has been slowly decreasing, however it is still significantly above the values of the early 1980s and from 1986 to 1989. The 1994 volume matched the mean over the period 1980-1994 of just over 4 x 10^4 km^3, roughly one-third the total volume of water on the shelf. The time series during the fall shows similar trends but the total volume is about one-half that observed in the summer. Unfortunately limited data prior to 1980, prevent extending the volume estimates farther back in time.

Horizontal Temperature Distributions Near Surface and Bottom in 2J3KL

The mean (1961-90) and 1994 temperatures at 10 m over the shelf from southern Labrador to the Grand Banks are shown in Fig. 22 (bathymetry lines are 300 and 1000 m). The mean summer temperatures range from 5°C to 9°C shoreward of the shelf break in NAFO Divisions 2J3K and from 9°C to 12°C in Division 3L. During 1994, they ranged from approximately 3°C to 9°C in 2J3K and from 9°C to 14°C in 3L. This meant anomalies of up to 1°C below average in 2J, near normal in 3K and up to 2°C above average in 3L. During the autumn, the upper layer temperatures normally cool to 1°C to 1.5°C in Division 2J3K and to 1.5°C to 6°C in Division 3L. During the fall of 1994 they near normal in 2J3K and up to 1°C above average in the southern areas of 3L.

A similar analysis was carried out for the summer and fall bottom temperature in 2J3KL (Fig. 23, isotherms are -1,-0.5,0,1,2,and 3°C). The average bottom temperature over most of the northeast Newfoundland shelf (2J3K) in both summer and autumn ranges from < 0°C inshore, to 3°C offshore at the shelf break whereas over most of the Grand Bank it varies from -0.5°C to 3°C at the shelf break. In general, bottom isotherms follow 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 since 1990 has been significantly larger than the 1961-1990 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, 1994). During 1994 the percentage area of water less than -0.5°C on the continental shelf remained significantly above average.

Temperatures off Southern Newfoundland

Low-pass filtered temperature anomalies from St. Pierre Bank are shown in Fig. 24 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 are 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. Since 1991 temperatures have moderated over the top 50 m of the water column but have remained well below average at 75 m depth. During 1992 to 1994 the sign of the temperature anomalies changed at 20 and 50 m depth but remained negative at the surface and at 75 m depth.

The mean (1961-90) and the 1994 bottom temperature maps for April within 3Ps and 3Pn are shown in Fig. 25. 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 -0.75°C on the eastern side of St. Pierre Bank to 2°C on the western side. During April 1994 temperatures were up to 1°C above average over Burgeo Bank and Hermitage Channel, near average on the western side of St. Pierre Bank and about 0.5°C below average on the eastern side.

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 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 in November-December, show that temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5°C and an anomaly below -0.5°C; Fig. 26). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.2°C) and to over 6.0°C (anomaly of 1°C) in 1993. In 1994 temperature anomalies remained positive although temperatures decreased from last year to 5.6°C. 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).

CIL

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 Estuary. During 1994, the CIL thickness (also defined by waters <0°C) decreased relative to last year. Gilbert and Pettigrew (1995) recently analyzed interannual variability in 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. 27). Since then, temperatures in the CIL have been extremely cold being below normal during the last 9 years. Also, the last five years have been the five coldest years on record. This is consistent with the temperature pattern observed on St. Pierre Bank (Fig. 24).

Bottom Temperatures on the Magdallen Shallows

Annual groundfish surveys of the Magdallen Shallows in the southern Gulf of St. Lawrence have been carried out during September by the Canadian Department of Fisheries and Oceans (Gulf Region) since 1971. Bottom temperatures during the 1994 survey were lowest in the central region of the Magdalen Shallows and increased shoreward and with depth along the Laurentian Channel as is normally observed. Bottom temperatures of < 1°C covered 39% of the survey area and < 0°C over 20%. Time series plots of the area with bottom temperatures below 0°C and 1°C show strong similarity (Fig. 28). Since 1990, the areas have been well above the mean and at or near maximum values. In 1994 the areas decreased slightly from last year.

Summer Temperature and Salinity Fields

The hydrographic data collected in September during the 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 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 colder-than-normal conditions were observed in the western two-thirds of the Gulf, with maximum negative anomalies (-2°C) along the north shore of Quebec in the vicinity of, and west of, Anticosti Island. Salinities also rose in this area of the Gulf at this time. Satellite images of sea surface temperature show prolonged and intense upwelling along this shore throughout most of August (Pierre Larouche, IML, personal communication). A meteorological buoy located west of Anticosti Island that measured sea surface temperatures also confirmed the presence of colder-than-normal waters in August and further showed that the cold water persisted into October-November when the buoy was removed for the winter. The 30-100 m layer corresponds to the CIL and consistent with Fig. 27 was found to be very cold and little changed from last year. In the 100-200 m and the 200-300 m layers, temperatures rose above those observed in 1993 and are now slightly above the long-term mean. In addition there was an increase in salinity giving slightly above normal salinity anomalies. The only exception was in the Cabot Strait region were temperatures in both layers decreased relative to last year. This resulted in slightly below normal temperatures in the 100-200 m layer but still above the long-term mean in the 200-300 m layer.

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 dominant feature at Boothbay Harbor and St. Andrews was the above normal temperatures during the last 7 months of 1994 (Fig. 29). In five of the months the anomaly equalled or exceeded one standard deviation. The maximum warming (of approximately 2°C) occurred in July. Anomalies were also relatively high in November and December. These anomalies contrast with conditions in the first five months of the year when temperatures were cooler-than-normal at St. Andrews and of low amplitude but highly variability at Boothbay. The tendency of cold in the first half of the year and warm in the second half roughly corresponds to the air temperature pattern in the region. At Halifax, temperatures were colder-than-normal except during April, June and July. As at the other two sites, July had the highest anomalies (> 2°C) but in contrast, Halifax had strong negative SST anomalies during the latter months of 1994.

Annual mean SSTs for 1994 were 9.3°C (0.8°C above normal) at Boothbay Harbor, 7.7°C (0.6°C above normal) at St. Andrews, and 7.2°C (0.6°C below normal) at Halifax (Fig. 30). They represent a significant rise in temperature over last year at Boothbay (0.8°C) and St. Andrews (1°C) but a minimal increase at Halifax (0.1°C). At

Boothbay and St. Andrews, temperatures have generally increased since the late 1980s while at Halifax temperatures have declined over this same period.

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 1994 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 1994, temperatures ranged from a minimum of less than 2°C in February and March to a maximum of over 12°C in August and September (Fig. 31). With the exception of February and March, the monthly temperature anomalies were positive. Maximum values of 2-3°C were observed in June and July. Temperature anomalies from August to December were generally between 1-2°C indicative of significant warming and match similar conditions in the SSTs at St. Andrews. The long-term temperature records at the surface and bottom (90 m) for Prince 5 are highly coherent due to the strong tidal mixing in the Bay of Fundy (Fig. 32). The annual anomalies in 1994 were 1.0°C and 0.9°C at the surface and bottom, respectively. These are warmer than last year's means by 1.5°C. At both depths the maxima occurred in the early 1950s and the minima in the mid 1960s, with recent values below the long-term mean. The warming of the waters in 1994 reverses the general trend of declining temperatures at Prince 5 observed during recent years (Fig. 32).

Salinities at Prince 5 during 1994 were typically saltier-than-normal (Fig. 31). The lowest salinities (<30.5 psu) occurred during June resulting in an anomaly of -0.8 psu in the surface waters. This was short-lived, however, and is unlikely to have been representative of the true monthly mean. The highest salinities (>33 psu) appeared in the near bottom waters in the late summer and early autumn and produced an anomaly of 0.5-1 psu in August. The high salinities throughout the water column reverses the recent trend of below normal values (Fig. 33).

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Center in Narragansett, Rhode Island, has collected expendable bathythermograph (XBT) data from ships-of-opportunity since 1978 along a transect in the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf as part of their continuous plankton recorder program. Surface and bottom temperatures and surface salinities are reported annually to NAFO. In 1994 no salinity samples were collected. Surface temperatures were generally above the 1978-1992 mean with peak values of 2-3° in July and August. Negative surface temperature anomalies in Massachusetts Bay and on the Scotian Shelf during the first half of the year although data were not collected in all months in these locations. Near bottom temperatures also tended to be above normal with again the extreme western and eastern ends of the transect being exceptions.

We obtained the data and grouped them into 10 equally spaced boxes along the transect and averaged any data within these by month. The site locations (center of the boxes) are shown in Fig. 34. In 1994, data were available at 4 to 10 sites per month. They too revealed strong (1-3°C) positive anomalies in all months throughout most of the water column. Only at the two most eastern sites located on the Scotian Shelf were anomalies persistently negative. The July data captures the essence of the anomaly pattern during the year although the details do differ from month to month (Fig. 34). The warm waters are consistent with the anomalies at Prince 5 and the warm SSTs observed at Boothbay Harbor and St. Andrews during the latter half of 1994.

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 these low frequencies was found throughout the water column as well as horizontally from the mid-Atlantic Bight to the Laurentian Channel, although year-to-year differences between locations were observed. Temperature anomalies at 250 m have been used as a representative index.

In 1994, temperature measurements were obtained in four separate months with values at 250 m ranging from 10.5 to 9.98°C. This produced monthly anomalies of 0.5°-2.5°C above normal (Fig. 35). The long-term annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. These anomalies were typically representative of conditions below approximately 100 m. The warm temperatures of the past couple of years are believed to have begun with an intrusion of warm slope water late in 1991 or early in 1992.

Other Scotian Shelf and Georges Bank Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinity for irregularly shaped areas on the Scotian Shelf that generally corresponded to topographic features (Fig. 36). Monthly temperature anomalies were calculated for 1994 in several of these areas at standard depths (averaging any data within the month anywhere within these areas). 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 over interpreting such data and little weight given to any individual mean.

This analysis was first undertaken during the 1993 review (Drinkwater, 1994b). It identified several important features. First, the temperature of the upper 30 m during 1993 varied greatly from month to month and was presumed to be linked to direct atmospheric cooling. Second, at intermediate depths of 50 to over 100 m, temperatures in 1993 were colder-than-normal over most of the shelf. Temperatures in this layer had declined steadily from approximately the mid-1980s into the 1990s. This is consistent with the cold temperatures in the CIL layer off southern Newfoundland (Fig. 24) and in the Gulf of St. Lawrence (Fig. 27). 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 1993 data suggested that conditions may had begun to moderate. The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald and Georges. This warm deep water appeared to influence the intermediate depth waters above the basins as these anomalies were generally warmer than elsewhere on the shelves.

During the past year we examined the spatial extent of the cooling of the intermediate layer waters during the late 1980s and into the 1990s. Visually we were able to trace it throughout most of the Gulf of Maine although it was more apparent in the eastern regions and western inshore regions. Similar cooling at these depths was found to the north on Pierre Bank and at Station 27 off St. John's, Newfoundland and in the Gulf of St. Lawrence. The 1994 data indicate warming of the intermediate layers especially in the Gulf of Maine, e.g. on Lurcher Shoals (Fig. 37). This warming was also observed in the Gulf of Maine temperature transect (Fig. 34) and at Prince 5 (Fig. 31). Over Emerald Basin, conditions in the intermediate waters were again relatively warm, most likely due to mixing with the warm deep waters. While some warmer waters were observed in the northeast Scotian Shelf around Misaine and Banquereau Banks, they were not persistent and temperatures generally remained below normal (Fig. 38). Deep water temperatures (>100 m) in this area also were colder-than-normal (Fig. 38). From the available offshore data no consistent trend in the surface waters (<50 m) over the Scotian Shelf was evident, but rather there were large variations from month to month.

The best temperature coverage over the Scotian Shelf occurs during the month of July because of the annual groundfish survey by Canada. These data were averaged within the areas shown in Fig. 36 and expressed as anomalies. The results for 0, 50 and 100 m are plotted in Fig. 39. At the surface, warm conditions persisted over the entire Scotian Shelf except in the vicinity of Cape Sable in the western region. The highest anomalies were observed off the shelf and on Sydney Bight. At 50 m, the colder-than-normal temperatures extended over the entire Scotian Shelf with the exception of the Emerald Basin area as discussed above. The coldest anomalies (-1 to -2°C) were found over the offshore banks from Sable Island Bank to Browns Bank. Warm conditions were observed in the Gulf of Maine and offshore in the slope waters. At 100 m, warm conditions were observed in the Gulf of Maine, Emerald Basin, and in the slope waters offshore south of Sable Island. Colder-than-normal temperatures cover the rest of the Scotian Shelf (Fig. 39).

Middle Atlantic Bight

In addition to the Gulf of Maine transect, the Northeast Fisheries Science Center has been monitoring temperatures and surface salinities along a transect extending from New York Harbor across the shelf into the Slope Water for nineteen years (Benway and Jossi, 1995). During 1994, minimum surface temperatures were observed in February, a month earlier than normal by approximately 1 month. Surface temperatures for the year along the transect were half a degree warmer than the 1978-1992 mean although colder-than-normal temperatures were observed during February to April. Inshore, the cold waters arrived earlier, left later in the spring (May) and reappeared in the late summer but were of smaller magnitude. Warm surface waters observed off the shelf were caused by the presence of warm core eddies. Bottom temperatures over the Bight were, on average, below normal by 0.7°C. The cold temperatures were observed primarily in the first two-thirds of the year. Surface salinities averaged over the year along the transect were 0.03 psu higher than the long-term mean.

Offshore Waters

Shelf/Slope Front

The waters on the continental shelves off eastern Canada have distinct temperature and salinity characteristics from those found in the adjacent deeper slope waters offshore. The relatively narrow boundary between the shelf and slope waters is regularly detected in satellite thermal imagery. Monthly time series of the position of this front and of the northern boundary of the Gulf Stream between 50°W and 75°W were assembled through digitization of satellite derived SST charts (Drinkwater et al., 1994). From January 1973 until May 1978, the charts only covered the region northward to Georges Bank, but in June 1978 the areal coverage was extended to include the Scotian Shelf and the Grand Banks. The time series consist of the monthly mean position of the shelf/slope front in degrees latitude at each degree of longitude. The years 1973 to 1992 (or all of the data whichever were less) were used to determine long-term monthly means which were then subtracted from the yearly values to obtain monthly and annual anomalies.

The overall average position of the shelf/slope front together with the 1994 annual mean position are shown in Fig. 40. The average position lies close to the 200 m isobath along the Middle Atlantic Bight, separates slightly from the shelf edge off Georges Bank and then runs between 100-300 km from the shelf edge off the Scotian Shelf and the southern Grand Banks. It is typically furthest offshore in winter and onshore in late summer and early autumn. During 1994, the shelf/slope front was seaward of its long-term mean position between 50°W to 58°W, shoreward from 59°W to 70°W and near the mean west of 69°W. Monthly anomalies in the positions of the front were estimated, averaged between 50°W and 75°W, and then low-pass filtered (Cartwright filter with 25 weights and a 50% power reduction at a period of 15 months). The low-frequency variability, based upon these filtered values, indicate that the front was near its long-term mean from 1985 to 1992 but since then has been approximately 30 km northward (Fig. 38). The maximum northward position was observed in the mid-1980s whereas the minimum occurred around 1980. Earlier data limited to the area west of 65°W suggest that the front was closer to its long-term mean position in the 1970s.

Gulf Stream Front

Time series of the position of the northern boundary or "wall" of the Gulf Stream were also determined from satellite imagery (Drinkwater et al., 1994). Similar to the shelf/slope front, the series consists of the monthly position at each degree of longitude from 75°W to 50°W. The average position of the north wall of the Stream and the 1994 annual mean is shown in Fig. 41. The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position lies approximately east-west. During 1994, the Gulf Stream was generally positioned north of its mean location with the maximum (60-80 km) in the area from 53°W to 63°W. Off the Middle Atlantic Bight (< 71°W), the Gulf Stream was also positioned north of its long-term mean location. The monthly anomalies of the Gulf Stream position averaged over all longitudes were significantly shoreward of the long-term mean position in all months except for December and November when they were near the mean. The low-pass filtered positions (Cartwright filter, as described above for the Shelf/Slope front) show that Gulf Stream has been at or near its maximum northward extent during the last few years (Fig. 15). The Stream was located south of its mean position during the late 1970s and 1980, near it through most of the 1980s and north or it during the late 1980s and into the 1990s.

Warm-core Rings

Meanders in the Gulf Stream occasionally break off from the main current forming anticyclonic eddies that trap warm Sargasso Sea water in their center. These warm-core rings continue to rotate as they move slowly through the slope waters. If they become close to the continental shelf break they may entrain shelf water out into the slope water region. Evidence of reduced recruitment of groundfish species with enhanced ring activity during the spawning and larval periods was provided by Myers and Drinkwater (1989). The life history of these warm-core Gulf Stream rings in the region from 45°W to 75°W during 1994 was derived from the NOAA Oceanographic Analysis charts. 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 occasional uncertainty about the exact date of formation or disappearance of some rings.

A total of 38 warm-core rings were present in the area during some portion of 1994, three of which survived from 1993 into the new year. The 35 new rings which formed in 1994 represents the highest number on record (13 years) and 8 above the long-term average (1982-94). Two of the new rings persisted into 1995. Nine of the rings formed in 1994 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1993, ranged in age from 5 d to 7.7 months and had a mean life of approximately 1.6 months. The average lifespan since 1982 when reliable data have been available is 2.7 months. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are displayed in Fig. 42. The maximum number of rings generated in any 2.5 degree zone was 8 which matches the largest number ever recorded. This occurred in the zone 62.5-65°W which traditionally spawns the most rings. The number of rings present in each of the longitude zones varied from 2 to 10 with the highest number again in the zone between 62.5 to 65.0°W. The larger number of rings present in the far western zones, compared to the number formed there, reflects westward propagation. The maximum number of rings (6) formed in April, 5 formed in May, 4 in March, June and July, 3 in August, September and October and 1 in January, February and November. No new rings formed in December. The monthly pattern does not differ substantially from the long-term pattern of lower numbers formed during the first and last two months of the year and relatively equal numbers during the remaining 8 months.

SUMMARY

During 1994, wintertime air temperatures over eastern Canada were generally colder-than-normal continuing the trend that has persisted through the 1990s. This was associated with the high positive value of the NAO 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 towards a large number of icebergs reaching the Grand Banks. As the year progressed, air temperatures moderated and by summer and through into autumn air temperature anomalies rose above normal. The maximum warming occurred in the south and decreased in amplitude towards Baffin Island. Ocean temperatures at Station 27 were below normal during the winter of 1994 over all depth ranges. By the summer, however, the surface waters had increased upwards of 2°C above normal and near normal in deeper water by the fall. The area of the CIL in summer across the northeast Newfoundland shelf has returned to near normal at Bonavista but remained above normal on Hamilton Bank and slightly above normal on the Grand Bank. Large areas of the continental shelf, particularly the Grand Bank, saw a continuation of the below normal bottom temperatures (up to 0.5°C below average) experienced during 1991-1993. Temperature anomalies over St. Pierre Bank show a cold period which started around 1984 and has continued through the 1990s with temperatures up to 1.0°C below average over all depths and up to 2°C below the warmer surface temperatures of the late 1970s and early 1980s in the surface layers. A similar pattern of cold temperatures since the mid-1980s is also observed in the CIL in the Gulf of St. Lawrence and on the Scotian Shelf. In the Gulf the CIL temperatures remained below normal for the ninth consecutive year with the last five years being at or near record cold temperatures. Consequently large areas of the Magdalen Shallows continue 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 Shelf appear to be moderating with maximum warming occurring over Emerald Bank due to the mixing up of warm bottom waters. These have occupied the lower layers of the Basin for the past few years and are consistent with the warm deep waters observed in the Laurentian Channel and Cabot Strait to the north and in the Gulf of Maine to the south. The source of these deep waters are the offshore slope waters. Indeed, penetration of the slope water appears to have warmed most of the Gulf of Maine and has also resulted in higher salinities. This is supported by monthly XBT transects across the Gulf, hydrographic data from Prince 5, and during the second half of the year in the SST data at Boothbay Harbor and St. Andrews. Upper layer waters over the Scotian Shelf were significantly warmer-than-normal during the groundfish survey in July. The cause of the cold SSTs at Halifax from August to December remains unclear. Air temperatures were much warmer than normal which suggests the cause was advective, perhaps through increased upwelling. The shelf/slope front and the Gulf Stream both were generally situated north of their long-term mean position. Strong ring activity occurred with the largest number of rings being formed in 1994 over the entire 13 year record.

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TABLE 1. Historical data on presence and duration of sea ice at 24 sites off eastern Canada and ice duration at these sites in the 1992/93 (October-September) ice year with 1991/92 data in parentheses.

				Ice Duration (in weeks)				
				When ice present				
Site	Seasons Studied	# of Yrs	Yrs of ice	Min	Max	Mean	Overall Mean	93/94 (92/93)
G-7	67/68-93/94	27	27	6	16	10.7	10.7	14 (13)
G-10	76/77-93/94	18	18	3	17	12.1	12.1	15 (17)
G-12	67/68-93/94	27	27	2	15	11.6	11.6	12 (13)
G-22	76/77-93/94	18	18	7	15	12.2	12.2	15 (15)
G-31	68/69-93/94	26	25	8	17	12.6	12.2	13 (15)
G-33	71/72-93/94	23	23	2	14	10.8	10.8	13 (14)
G-35	59/60-93/94	35	19	1	11	3.5	1.9	4 (1)
G-86	76/77-93/94	18	18	6	23	16.6	16.6	20 (19)
G-87	70/71-93/94	24	23	1	12	7.6	7.3	8 (9)
N-19	66/67-93/94	28	28	17	32	23.9	23.9	25 (25)
N-21	67/68-93/94	27	27	5	28	18.6	18.6	23 (25)
N-23	59/60-93/94	35	29	1	17	5.2	4.3	5 (12)
N-25	59/60-93/94	35	2	1	1	1.0	0.1	0 (0)
N-27	59/60-93/94	35	0	0	0	0.0	0.0	0 (0)
N-62	67/68-93/94	27	27	8	27	18.8	18.8	20 (23)
N-64	59/60-93/94	35	34	3	25	13.2	12.8	18 (21)
N-66	59/60-93/94	35	29	1	17	8.7	7.2	16 (17)
N-68	59/60-93/94	35	16	1	10	3.5	1.6	3 (3)
N-70	60/61-93/94	34	0	0	0	0.0	0.0	0 (0)
N-108	59/60-93/94	35	29	1	17	6.2	5.1	6 (15)
N-110	59/60-93/94	35	28	1	16	5.6	4.5	10 (16)
N-112	59/60-93/94	35	15	1	10	4.1	1.8	7 (5)
N-114	59/60-93/94	35	5	1	2	1.6	0.2	2 (0)
N-228	59/60-93/94	35	24	1	14	5.7	3.9	4 (12)

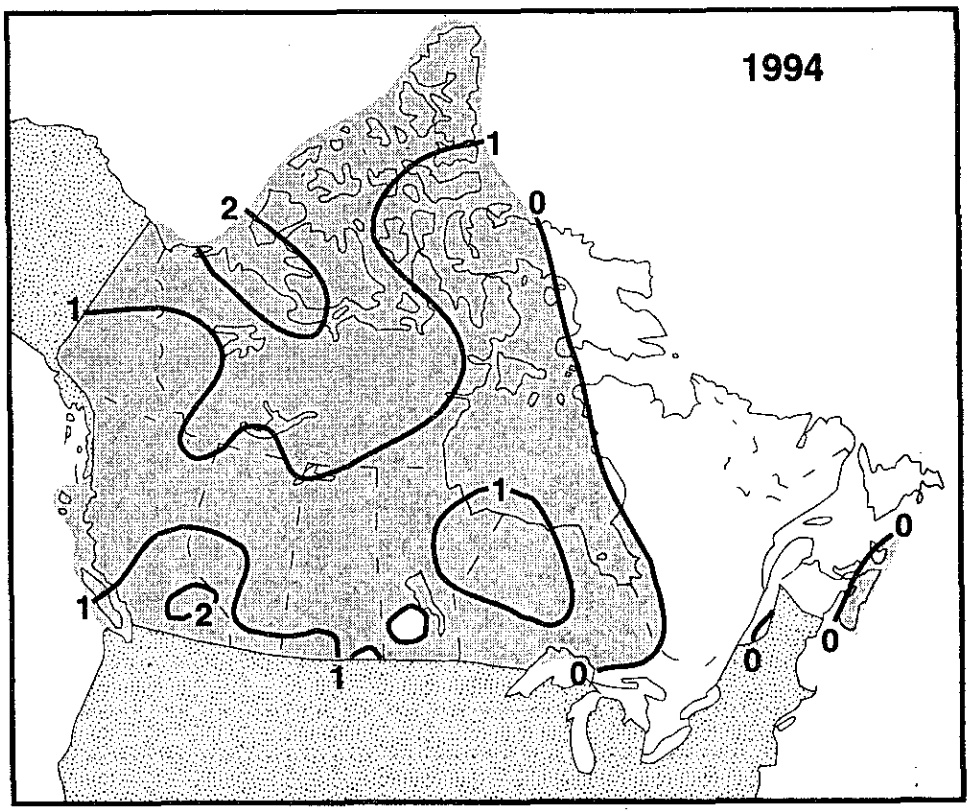


Fig. 1. Annual air temperature anomalies (°C) over Canada in 1994 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 16)

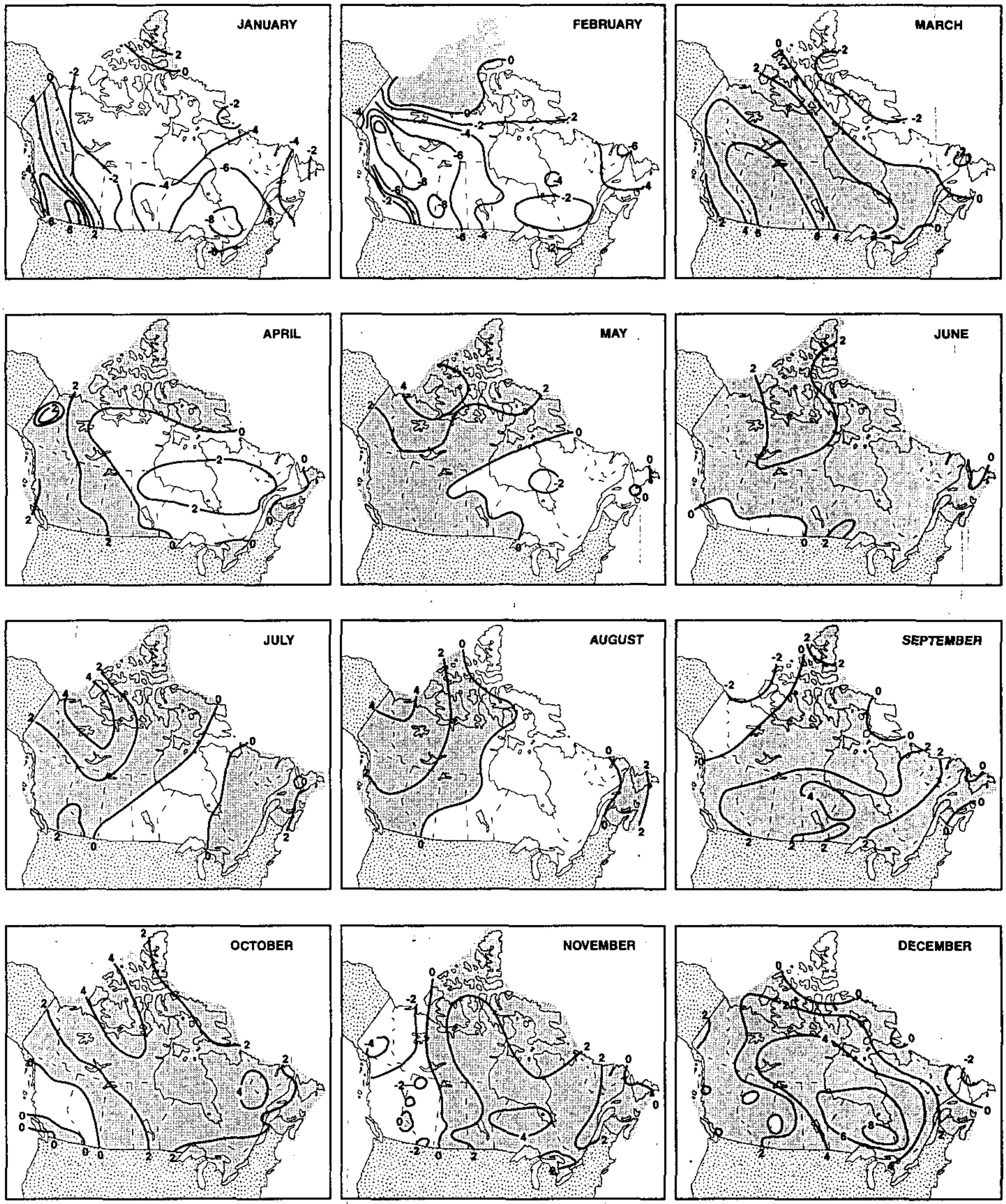


Fig. 2. Monthly air temperature anomalies (°C) over Canada in 1994 relative to the 1951-80 means. Shaded areas are positive anomalies. (From *Climatic Perspectives*, Vol. 15)

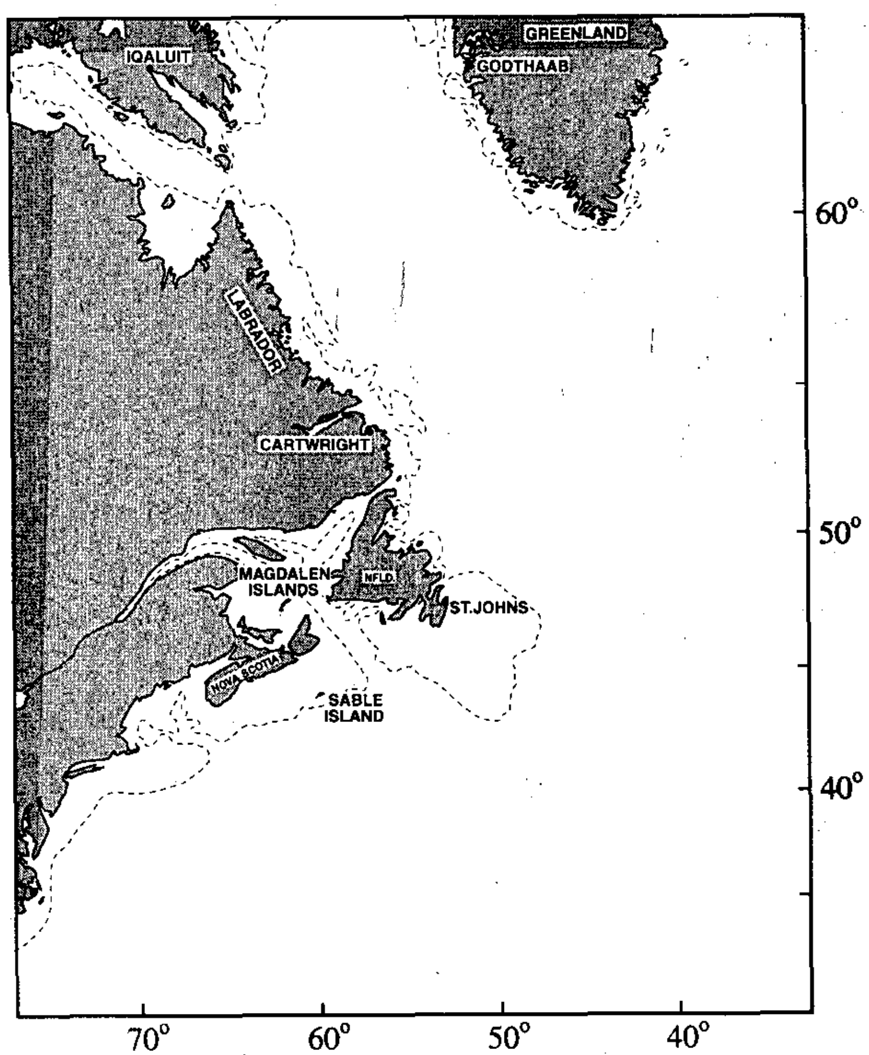


Fig. 3. Eastern Canada showing coastal air temperature stations.

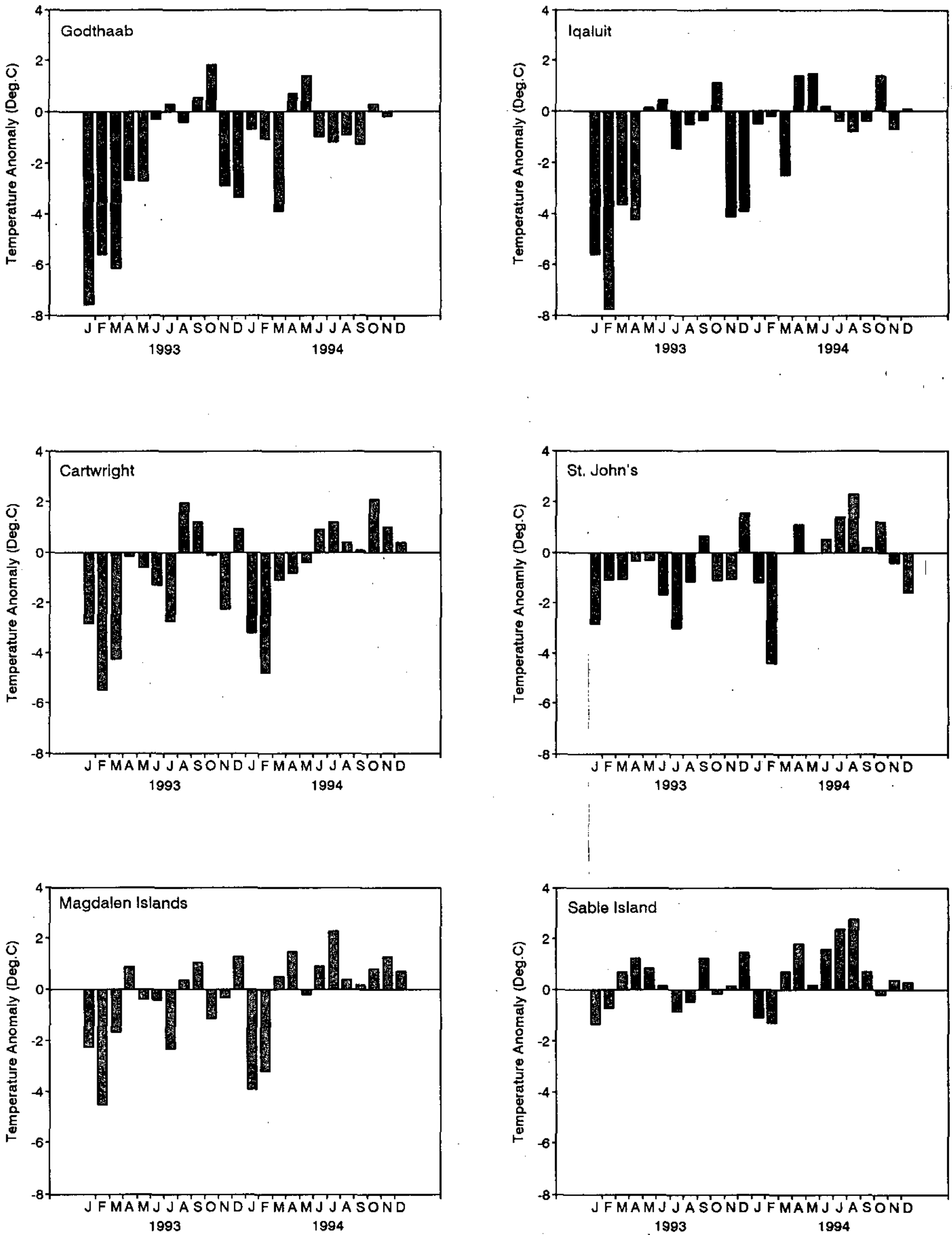


Fig. 4. Monthly air temperature anomalies in 1993 and 1994 at selected coastal sites (see Fig. 3 for locations).

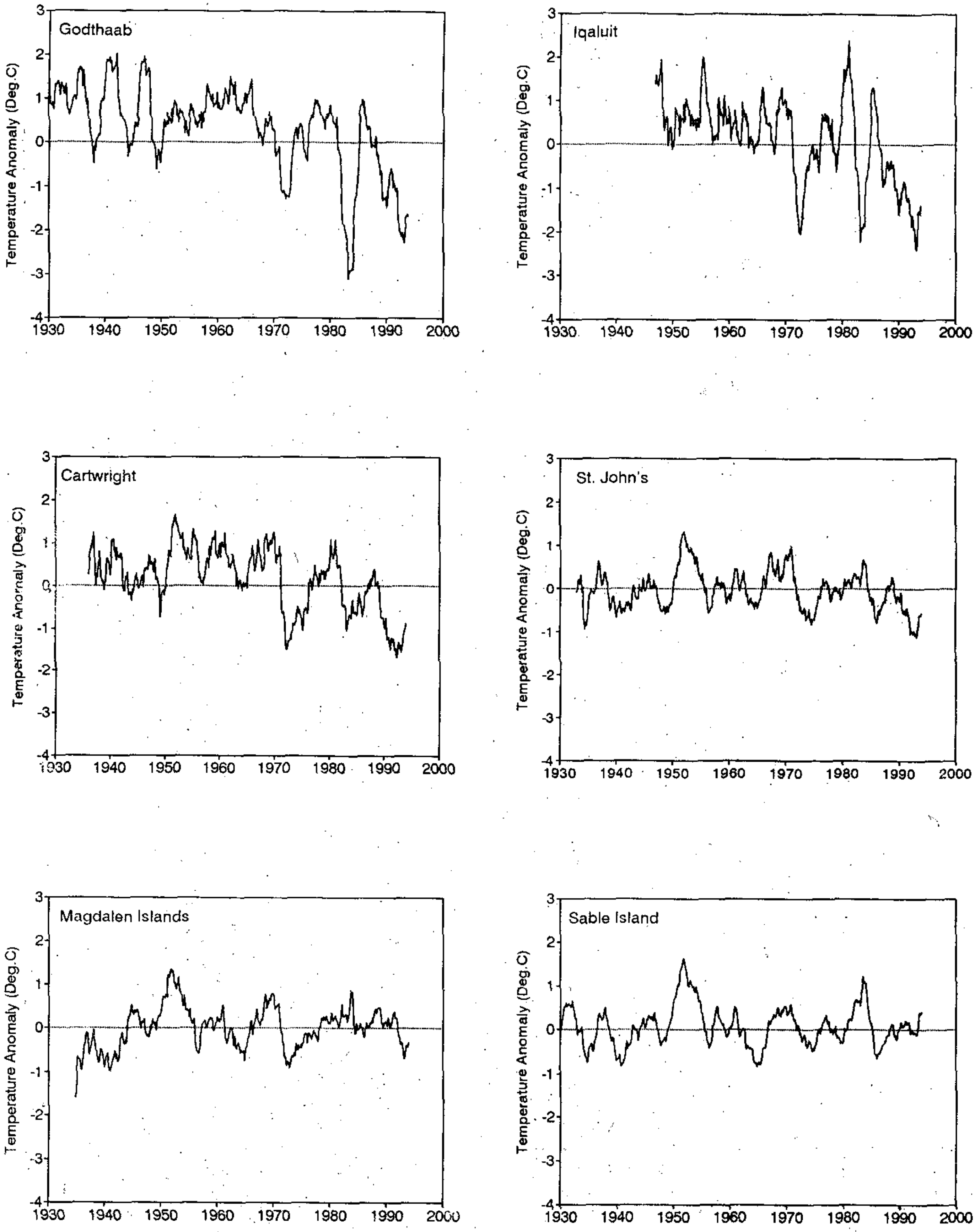


Fig. 5. Twenty-five month running means of monthly air temperature anomalies at selected sites.

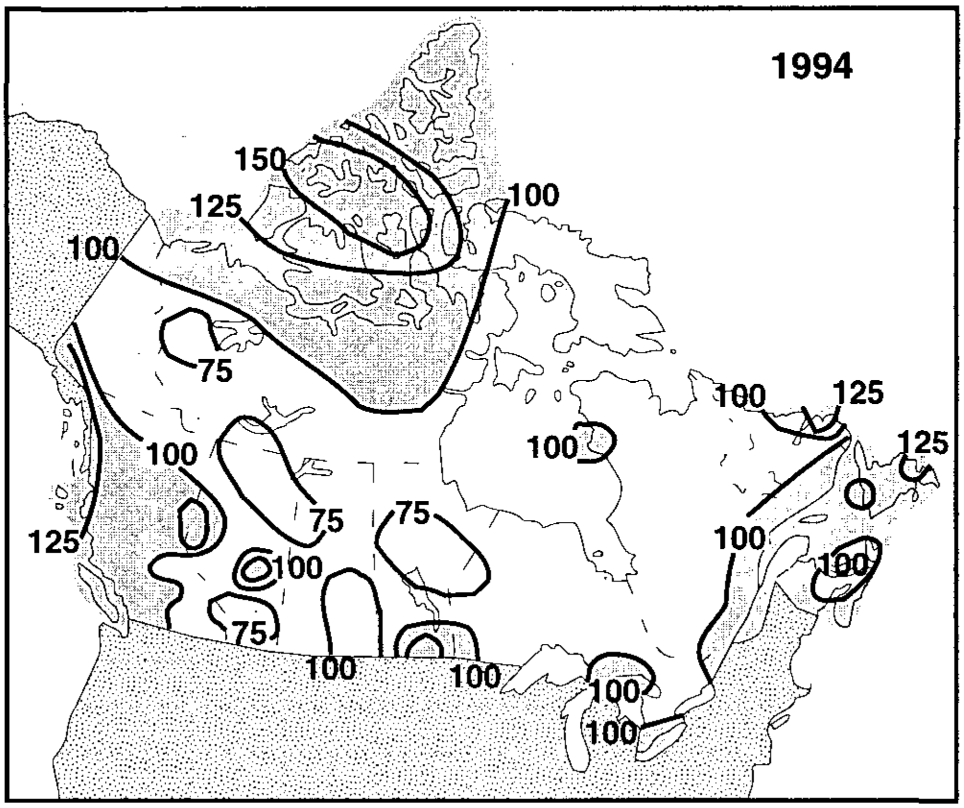


Fig. 6. Annual precipitation anomalies in percentage relative to the 1951-80 means (taken from *Climatic Perspectives*, Vol. 16).

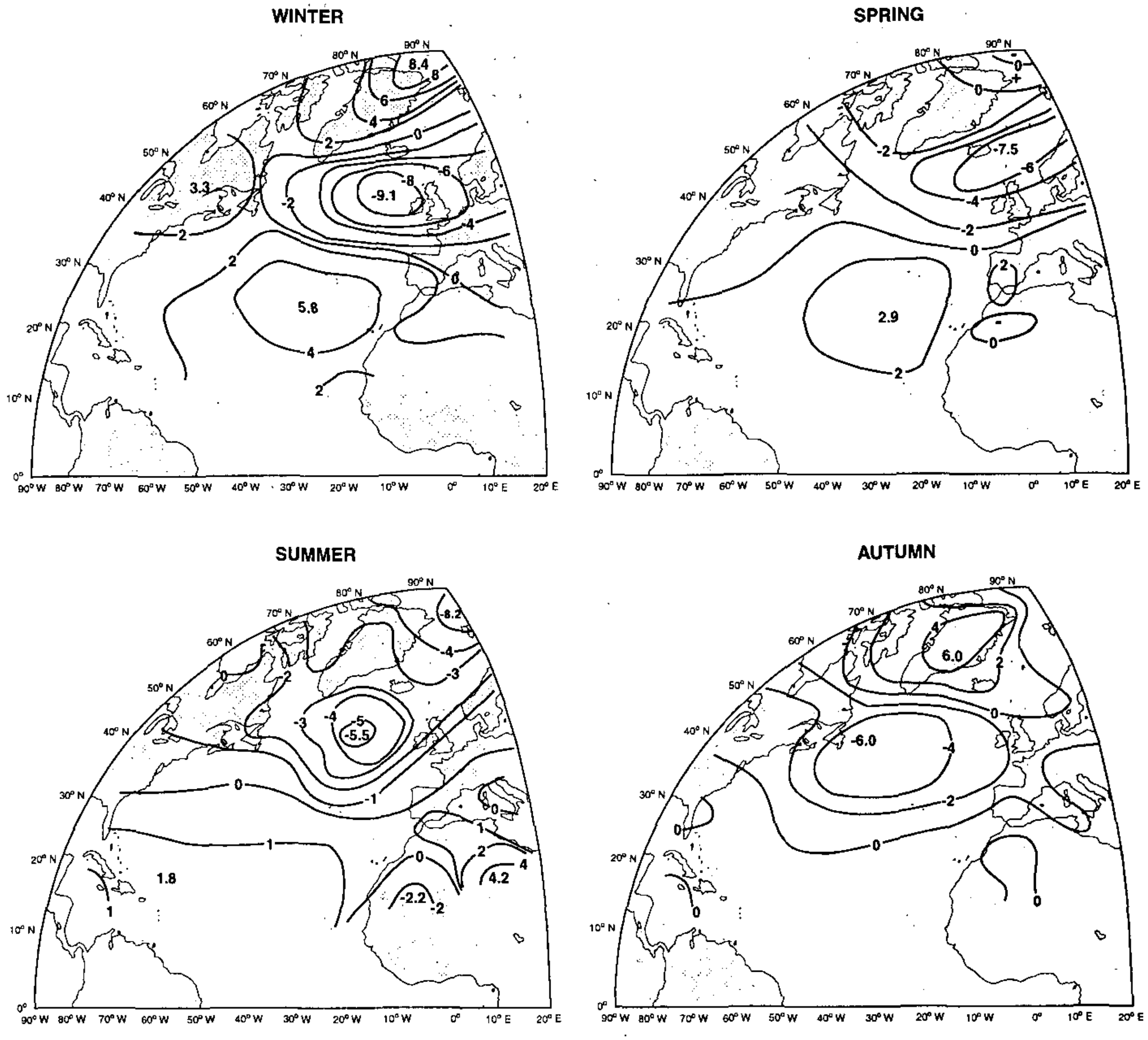


Fig. 7. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1994 relative to the 1961-90 means.

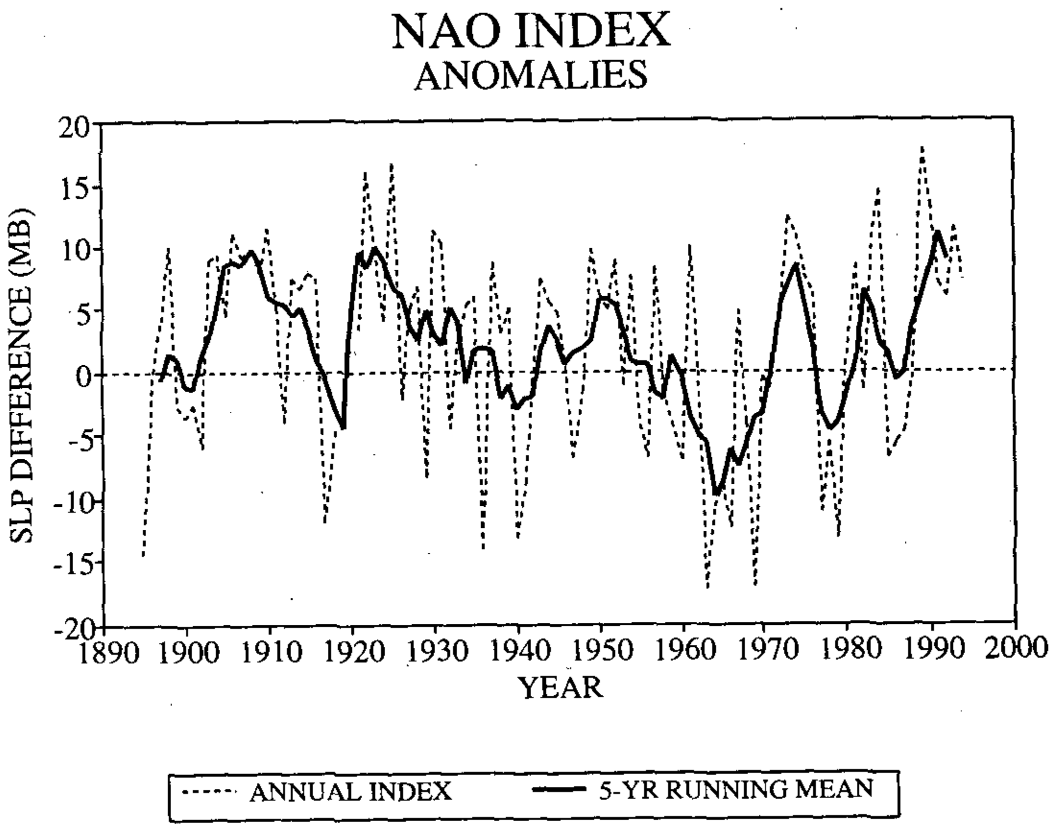


Fig. 8. The North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland.

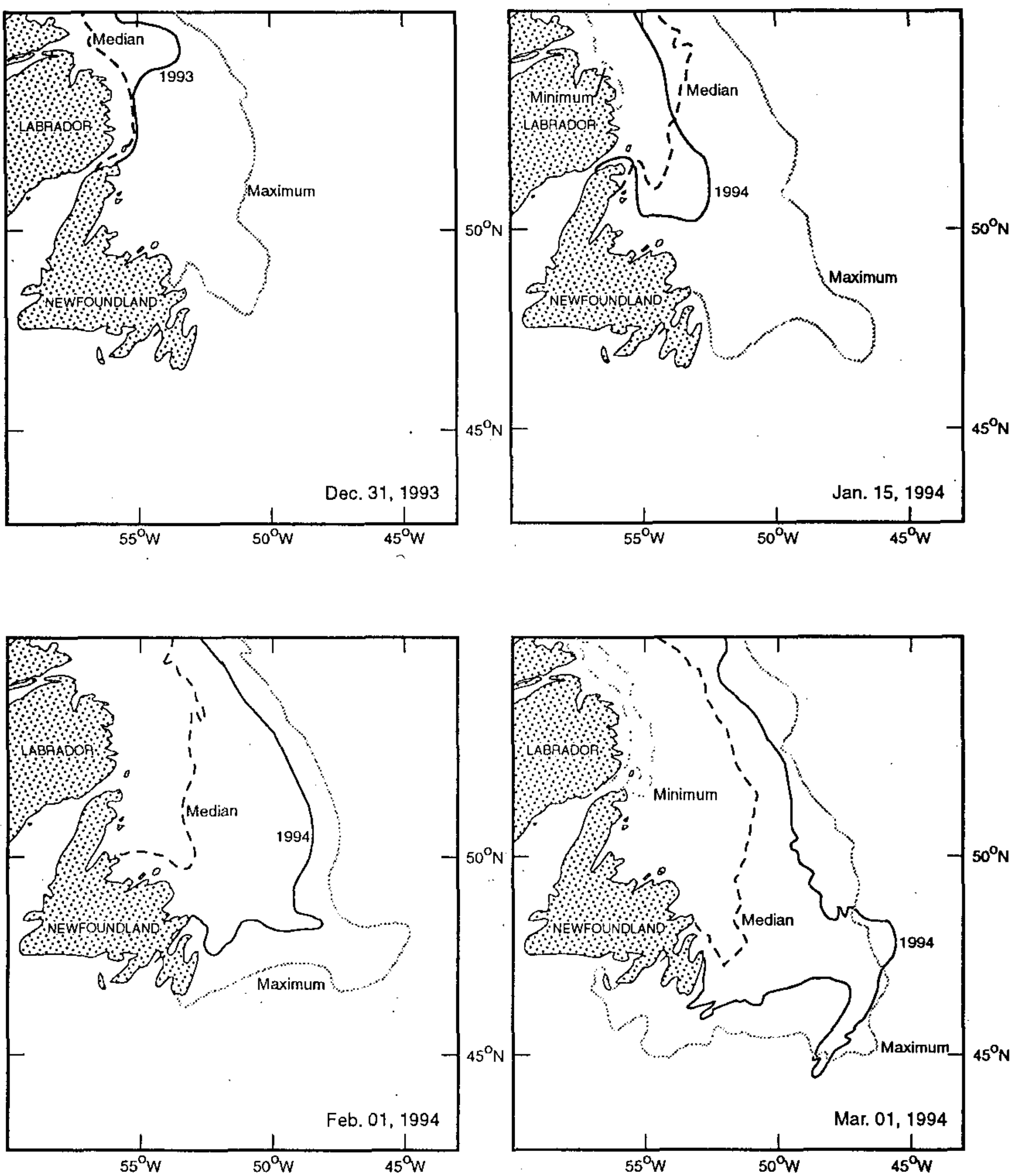


Fig. 9a. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between December 1993 and March 1994.

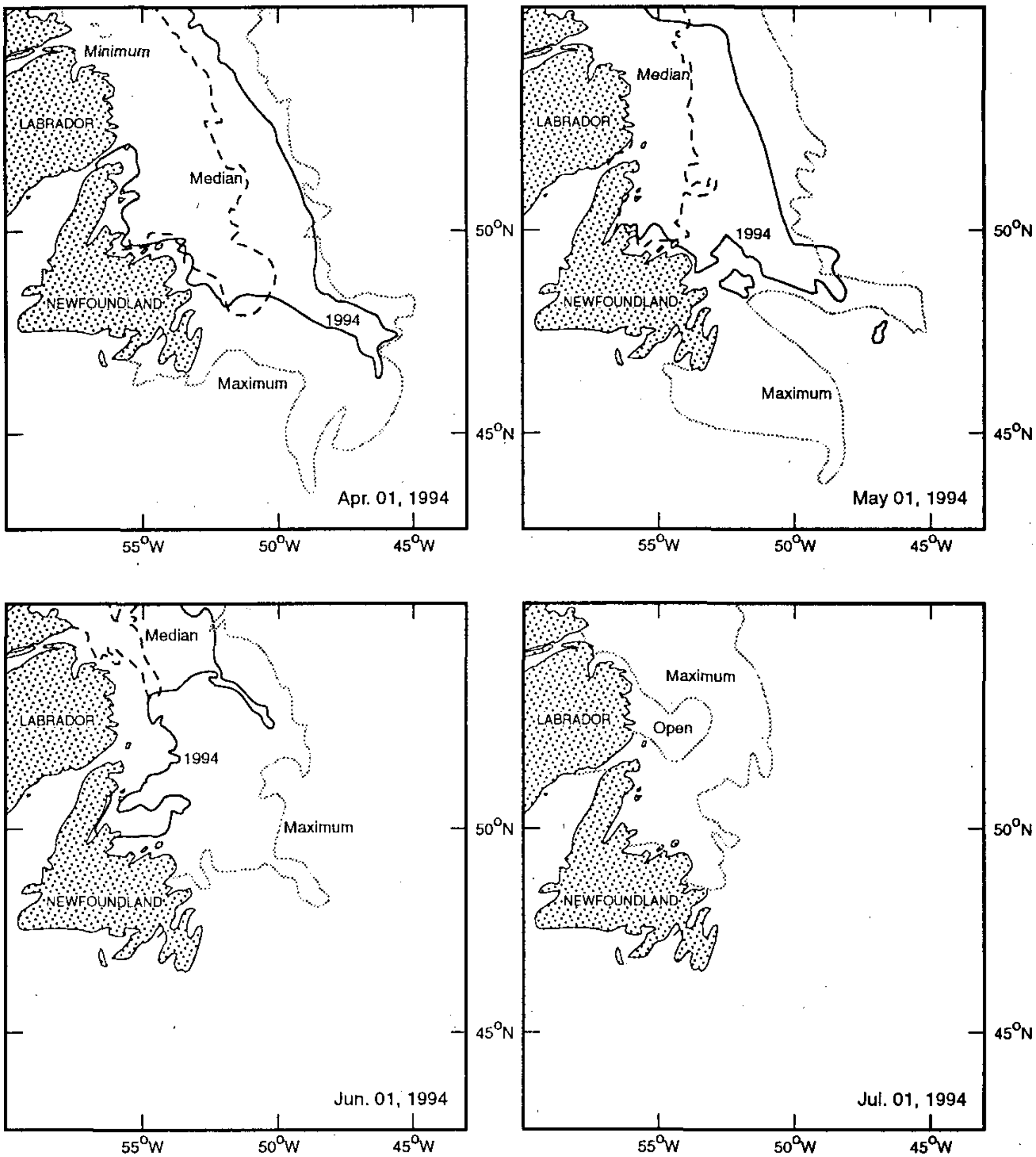


Fig. 9b. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between April and July 1994.

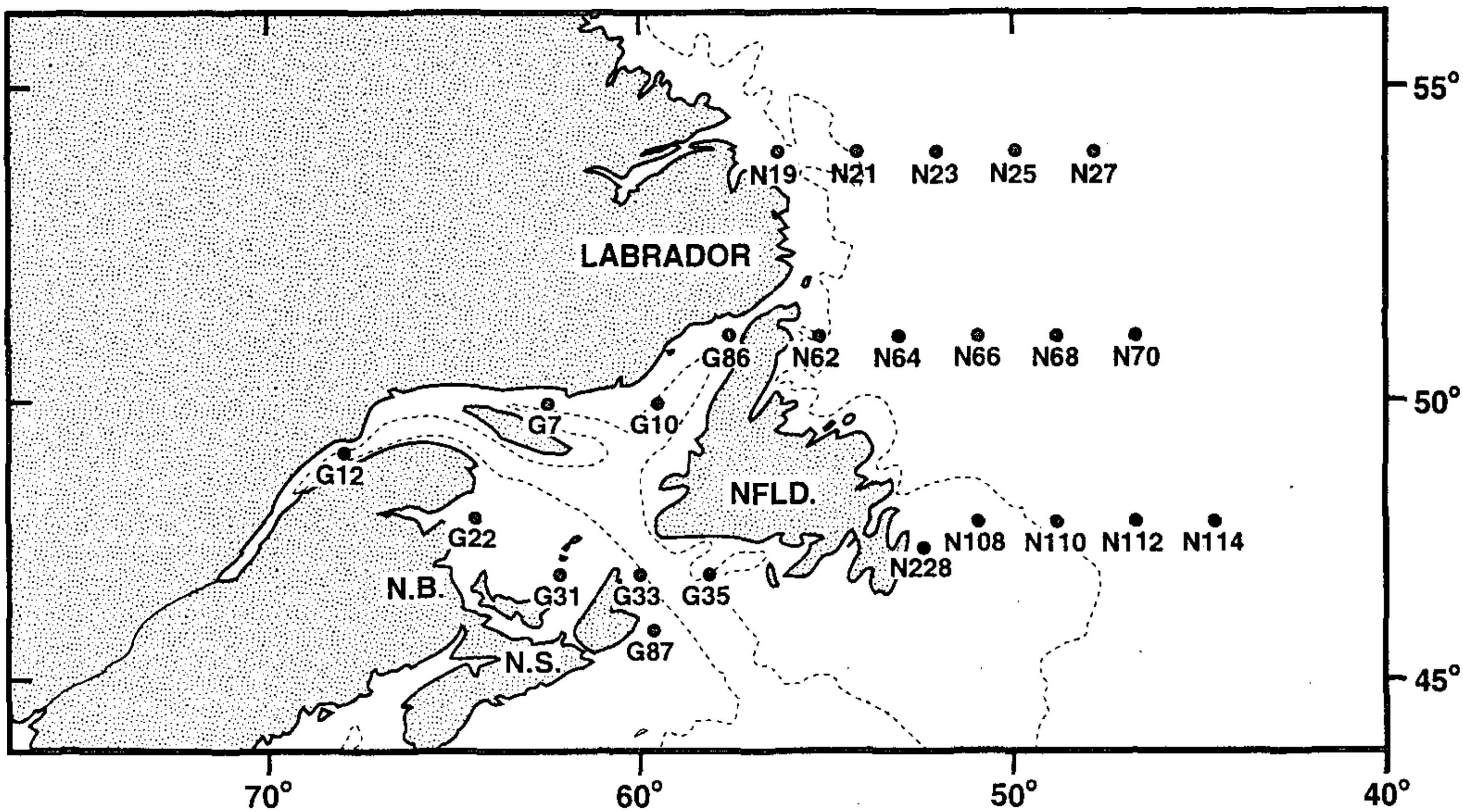


Fig. 10. Location of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

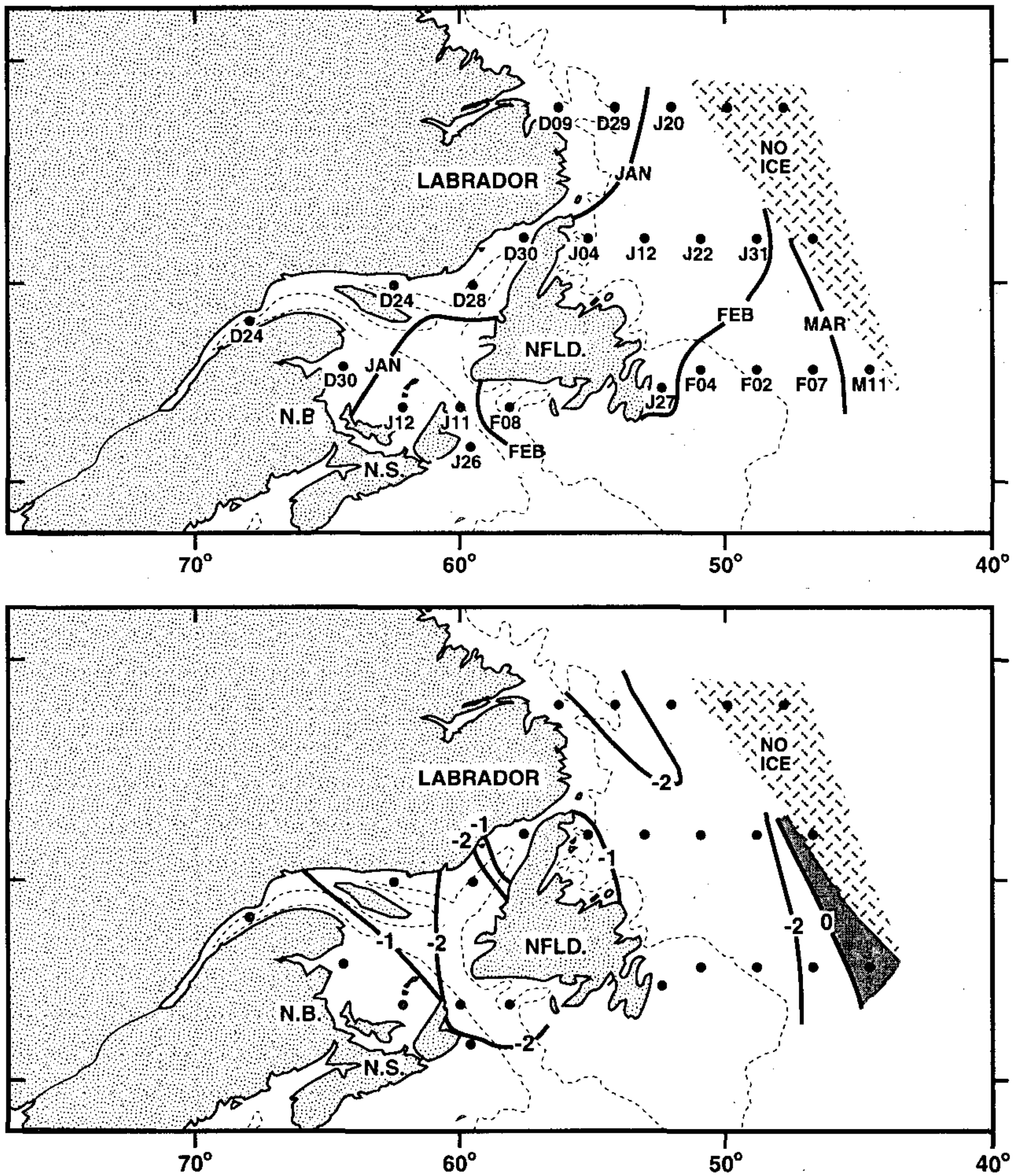


Fig. 11. The date at which ice first appears at the grid points in Fig. 10 (top) and their anomalies from the long term mean in weeks (bottom). A negative anomaly indicates ice appeared earlier than normal.

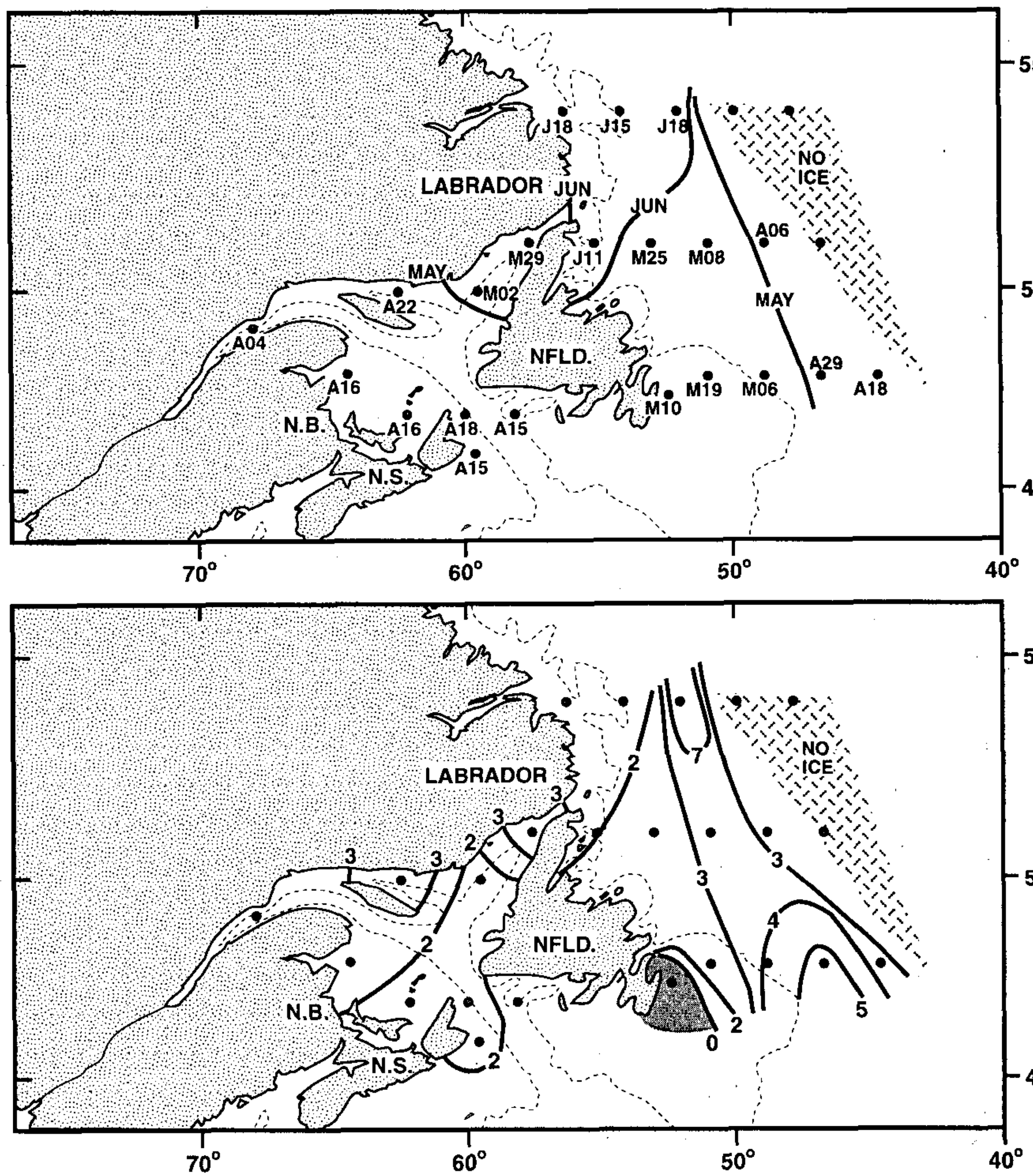


Fig. 12. The date at which ice last appears at the grid points in Fig. 10 (top) and their anomalies from the long term mean in weeks (bottom). A positive anomaly indicates ice lasted longer than normal.

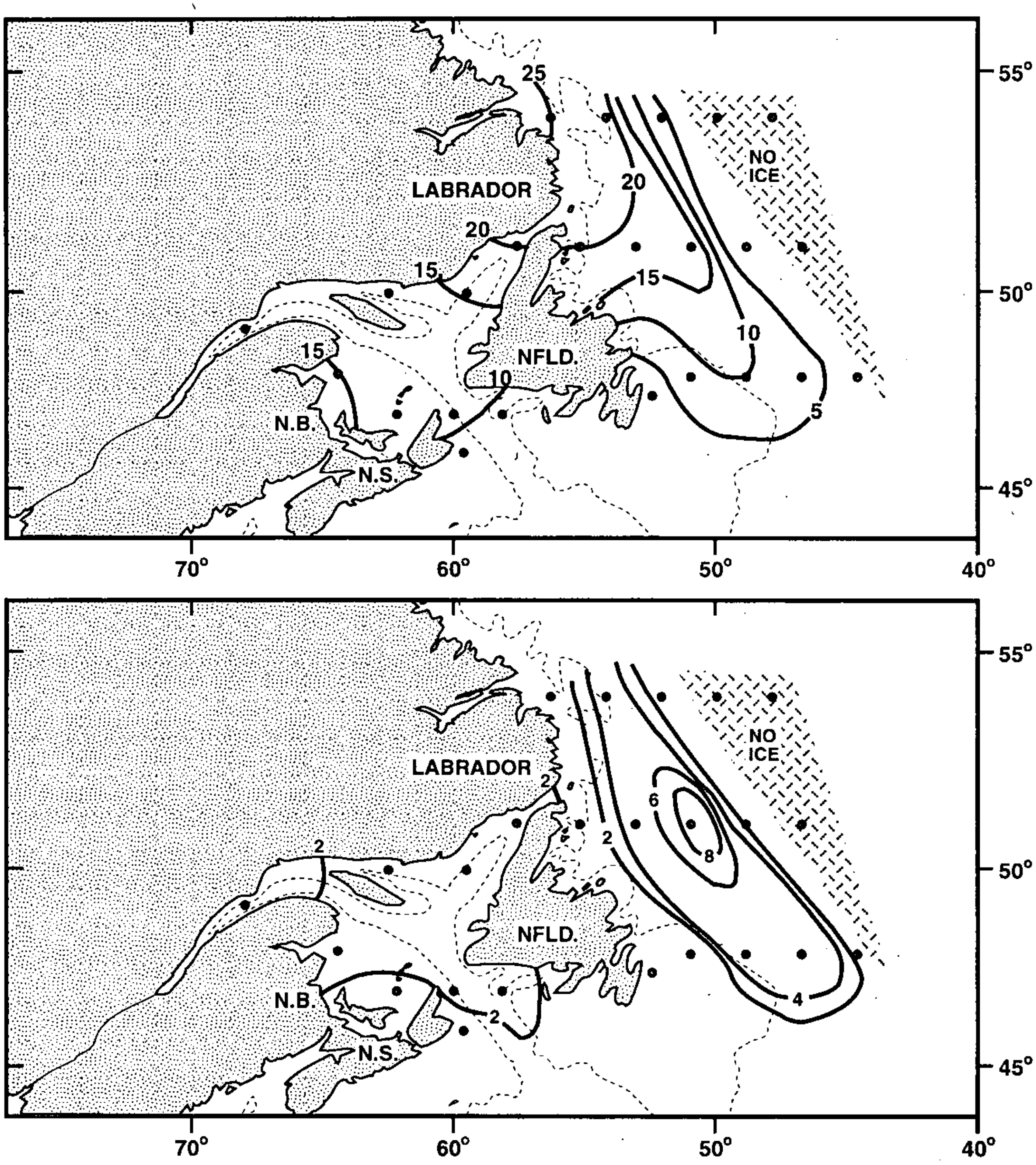


Fig. 13. The duration of ice (top) and its anomaly relative to the long-term mean in weeks (bottom). Positive anomalies indicate a duration longer than the mean.

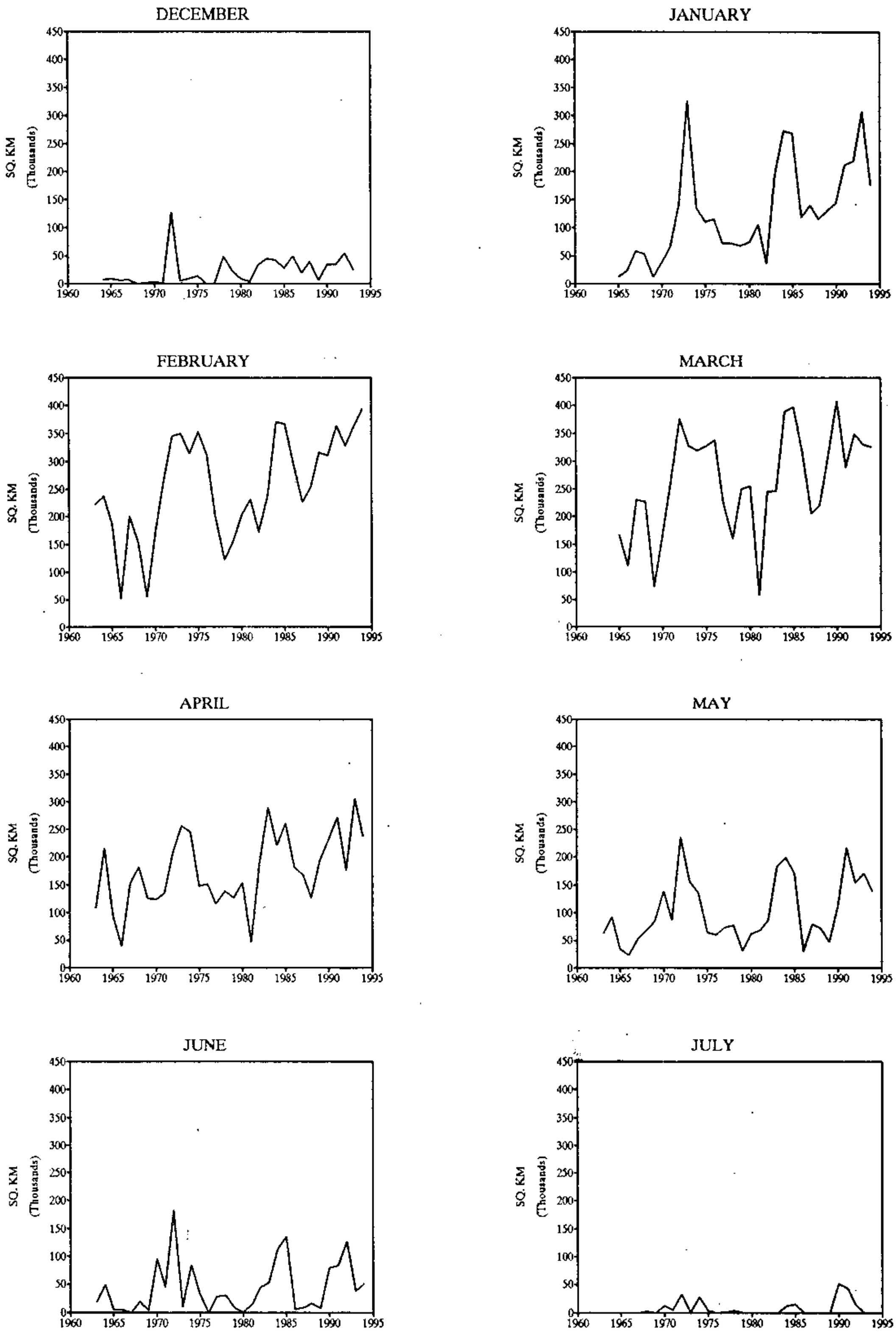
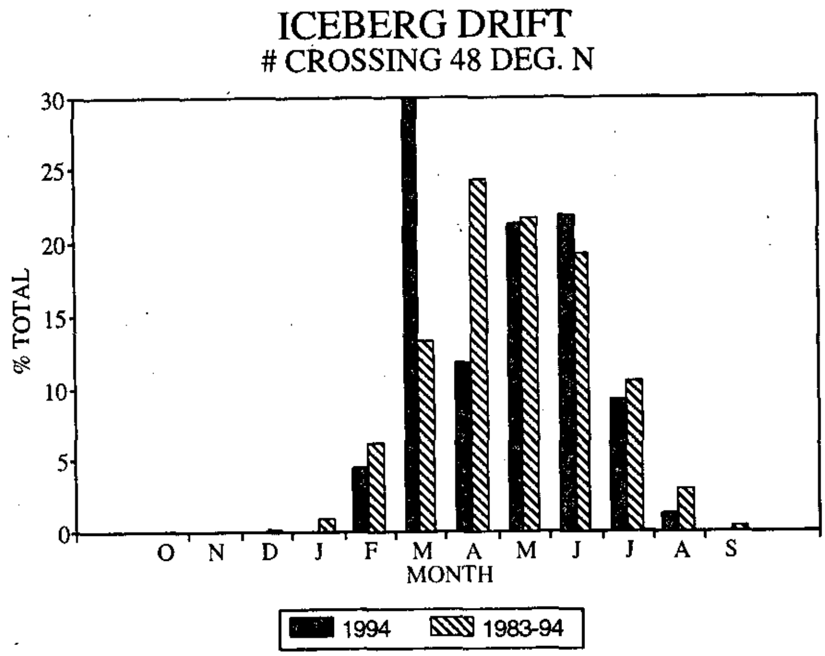


Fig. 14. The time series of ice area on the southern Labrador and northern Newfoundland shelves between 45°N-55°N by month.



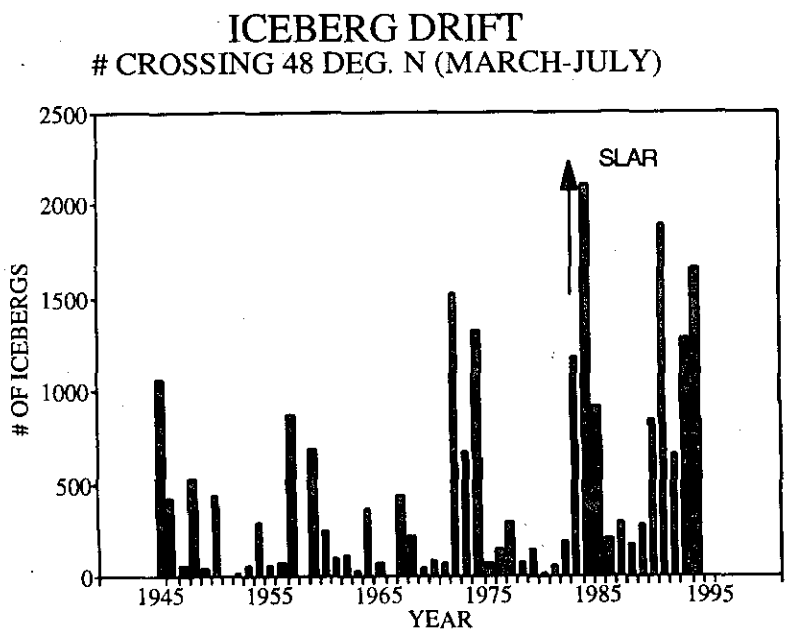


Fig. 15. The percentage of the total number of icebergs crossing south of 48°N by month during the iceberg season 1993/94 (top) and the number of icebergs during March to July from 1945 to 1994. The vertical arrow indicates the year they began to detect icebergs using SLAR.

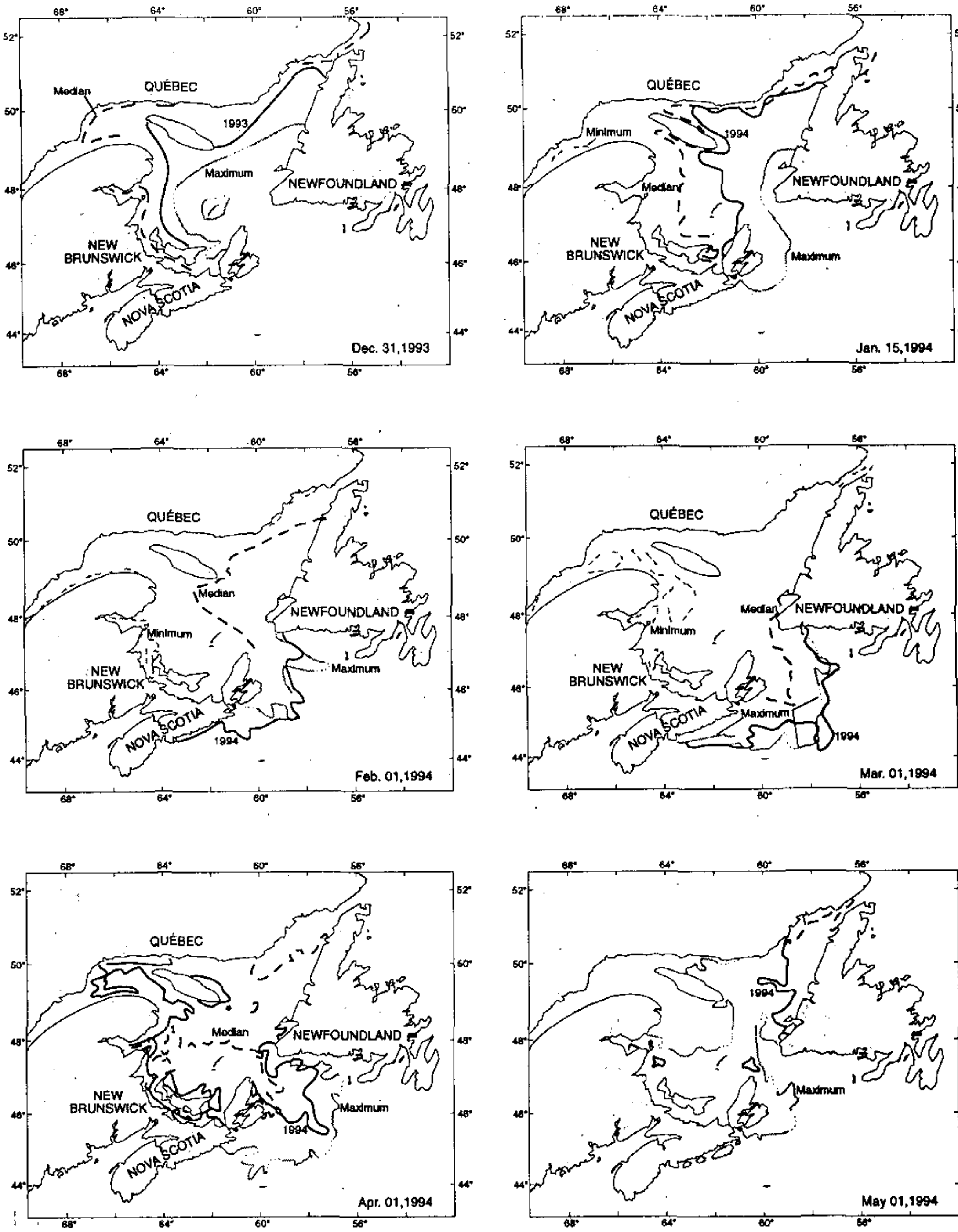


Fig. 16. The location of the ice edge together with the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence between December 1993 and May 1994.

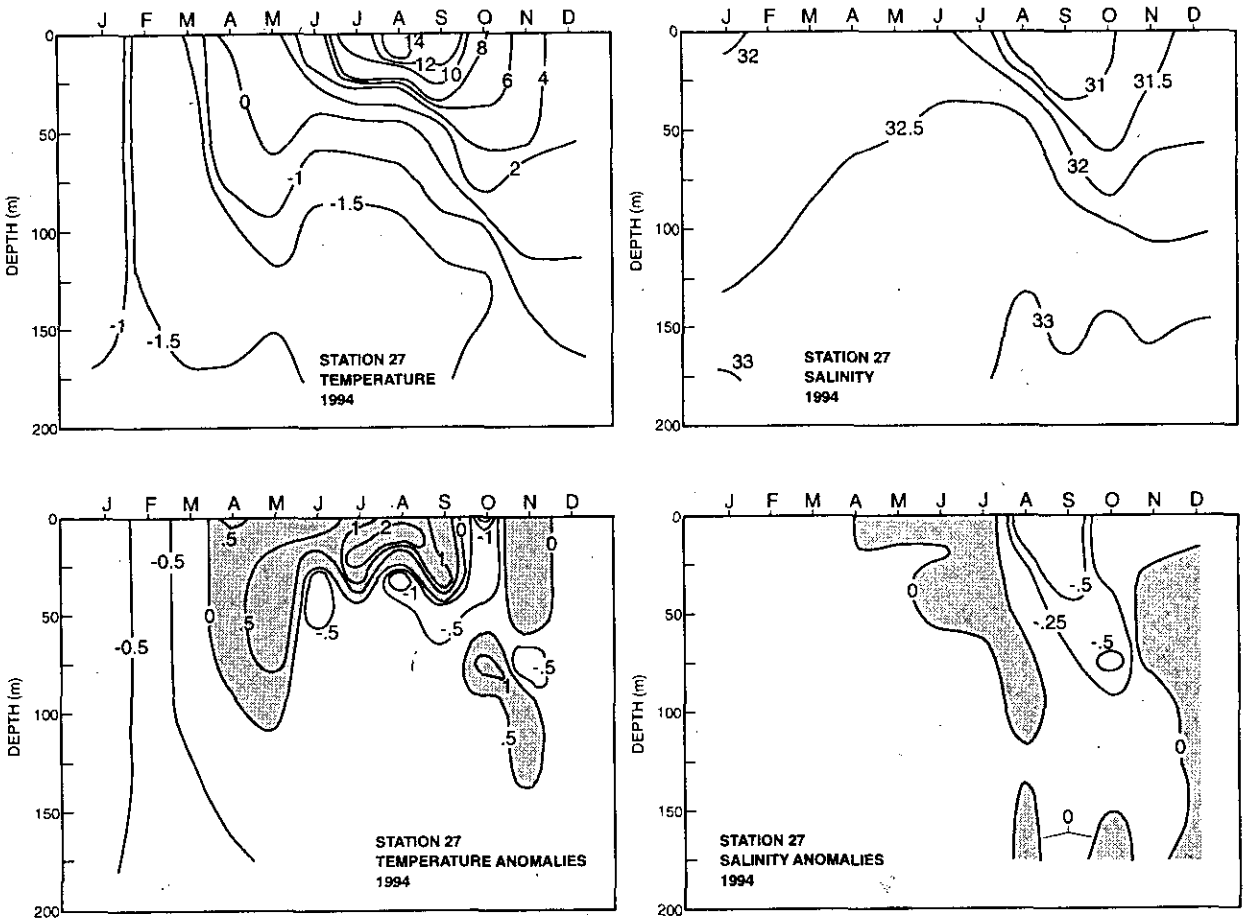


Fig. 17. Monthly temperatures and salinities and their anomalies at Station 27 as a function of depth during 1994 relative to the 1961-90 means. Shaded areas are positive anomalies.

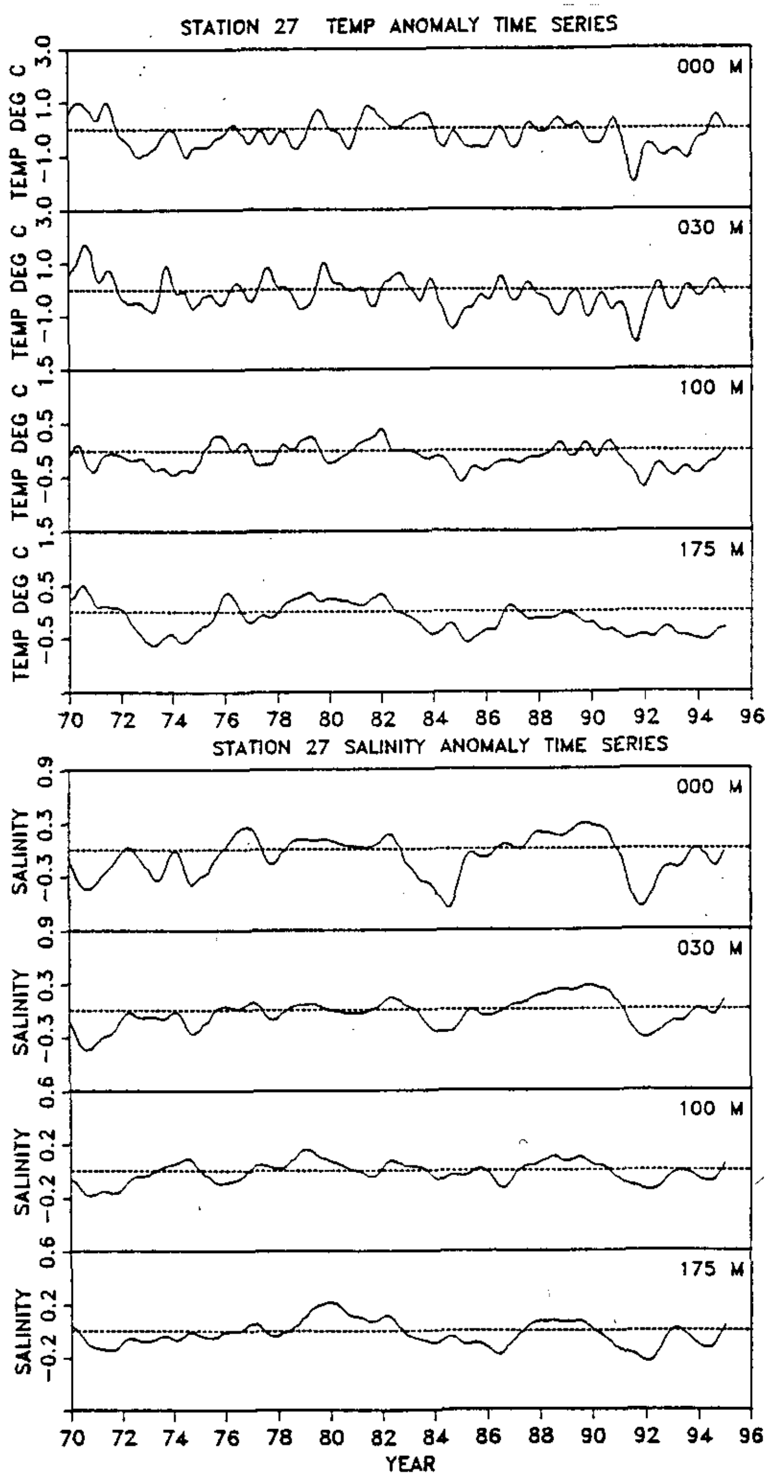


Fig. 19. Low-pass filtered time series of temperature and salinity anomalies at Station 27 at standard depths from 1970 to 1994.

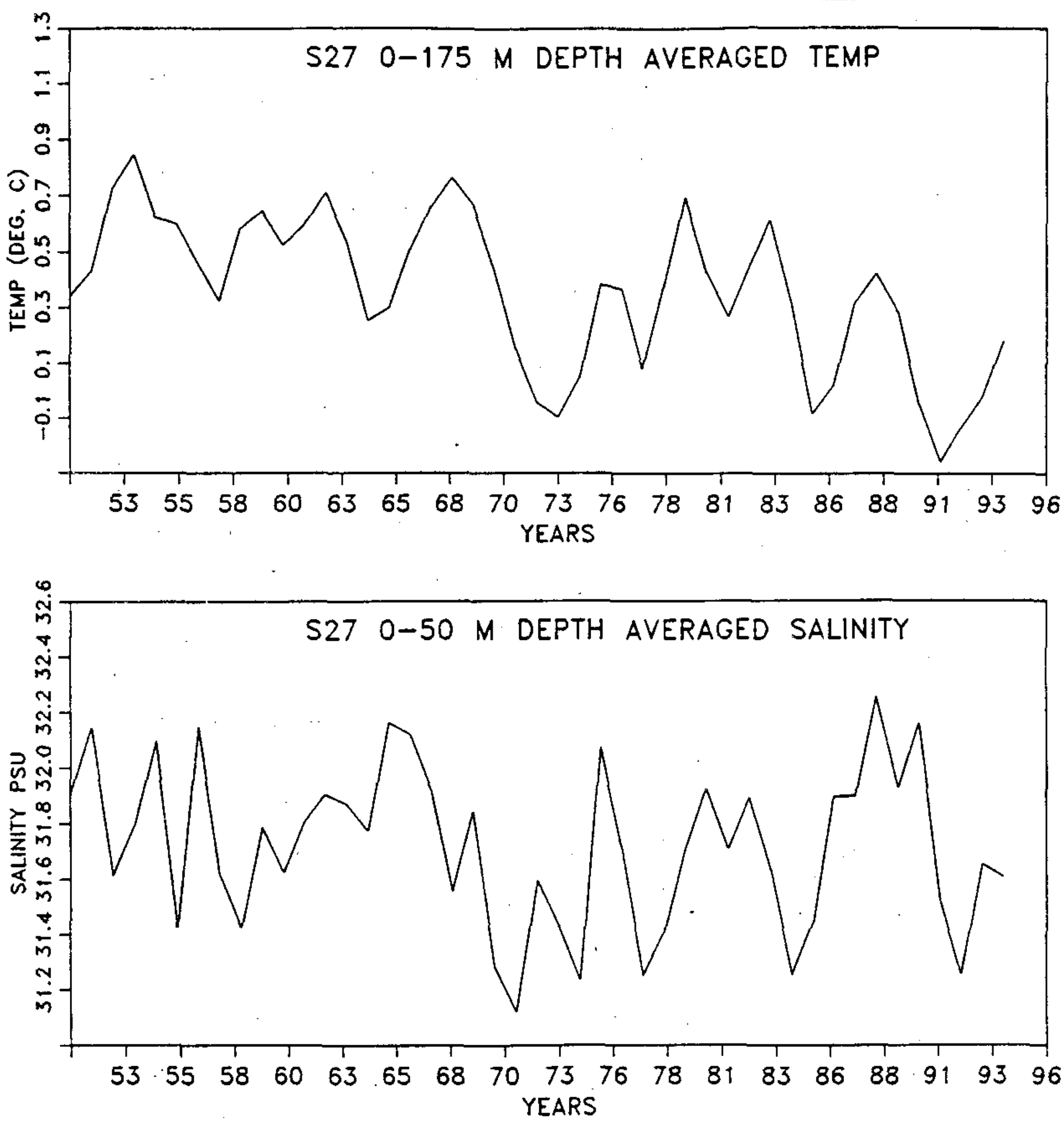


Fig. 19. Vertically-averaged (0-176 m) Station 27 annual temperature (top) and (0-50 m) summer (July-September) salinity.

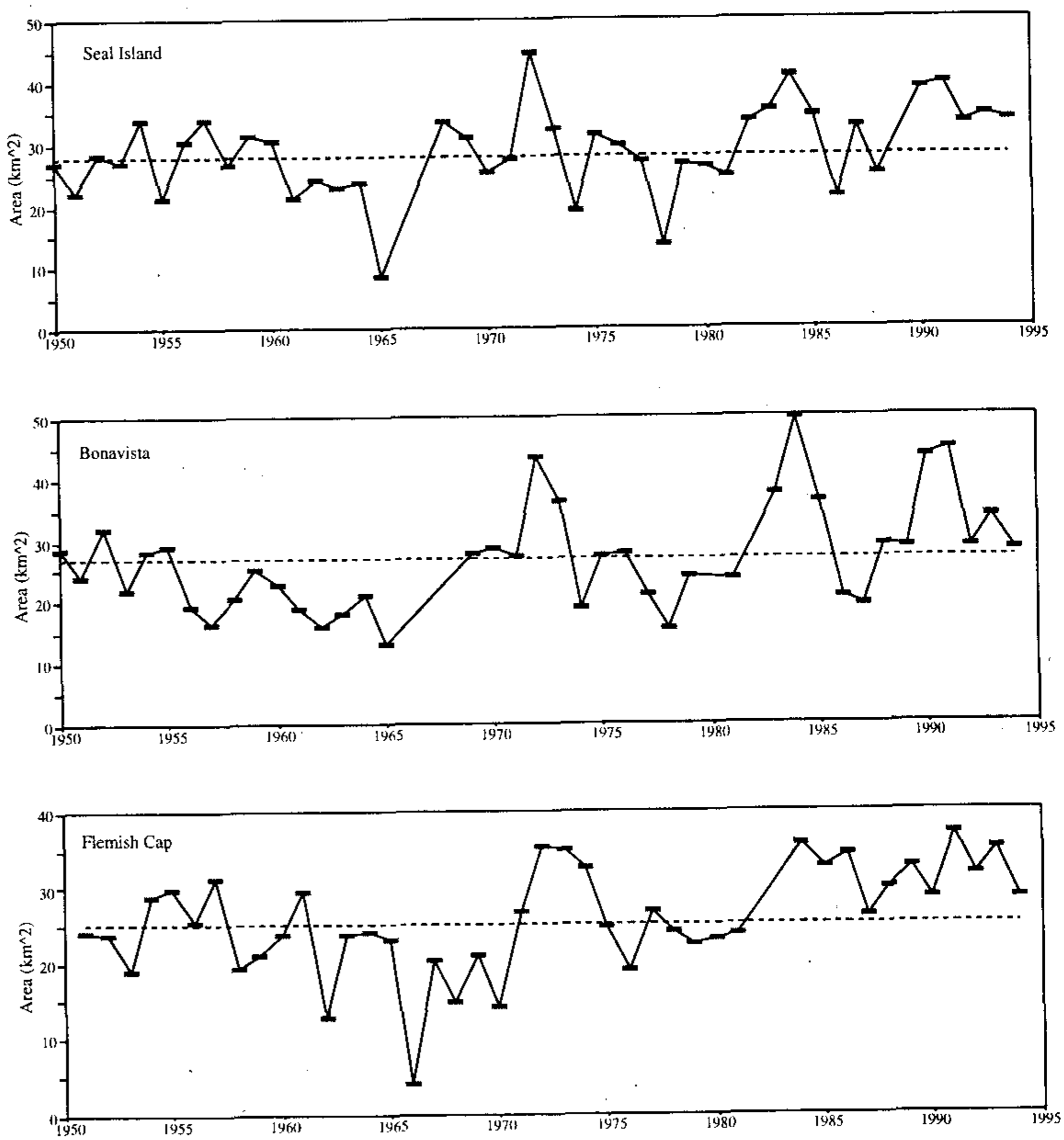


Fig. 20. The time series of the area of the CIL along standard sections off southern Labrador and northern Newfoundland.

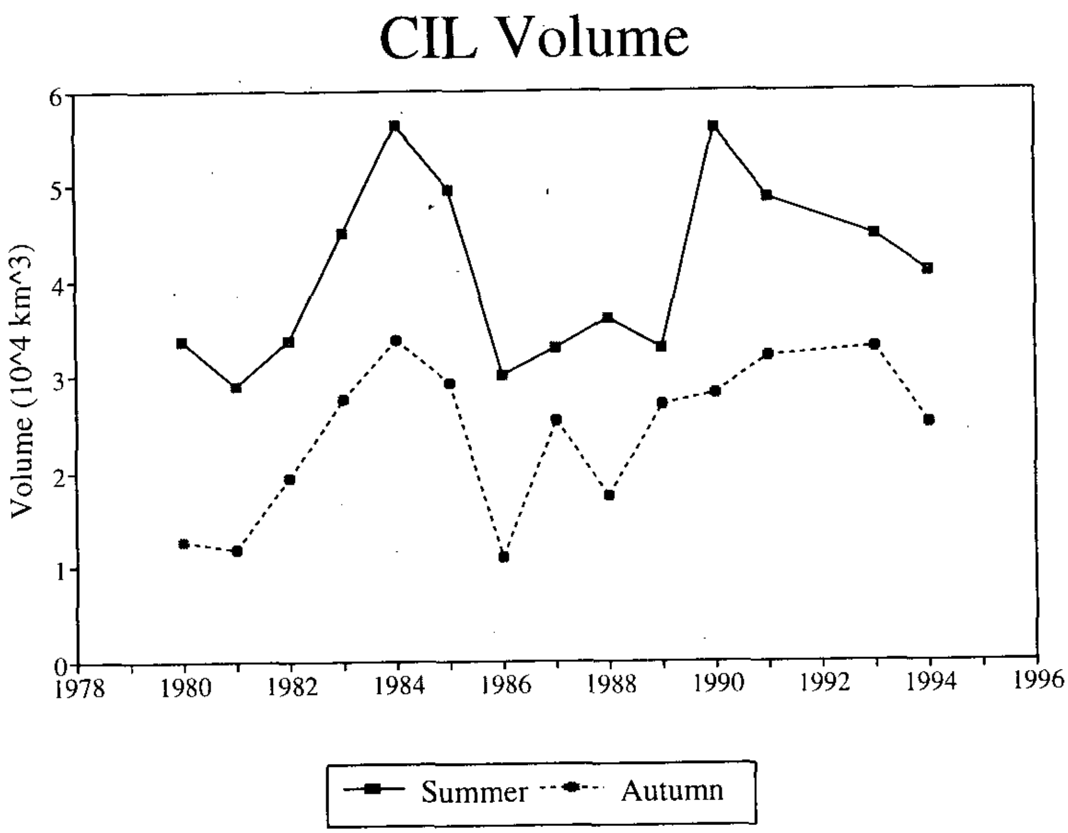


Fig. 21. The time series of the CIL volumes in the summer and autumn over Divisions 2J3KL.

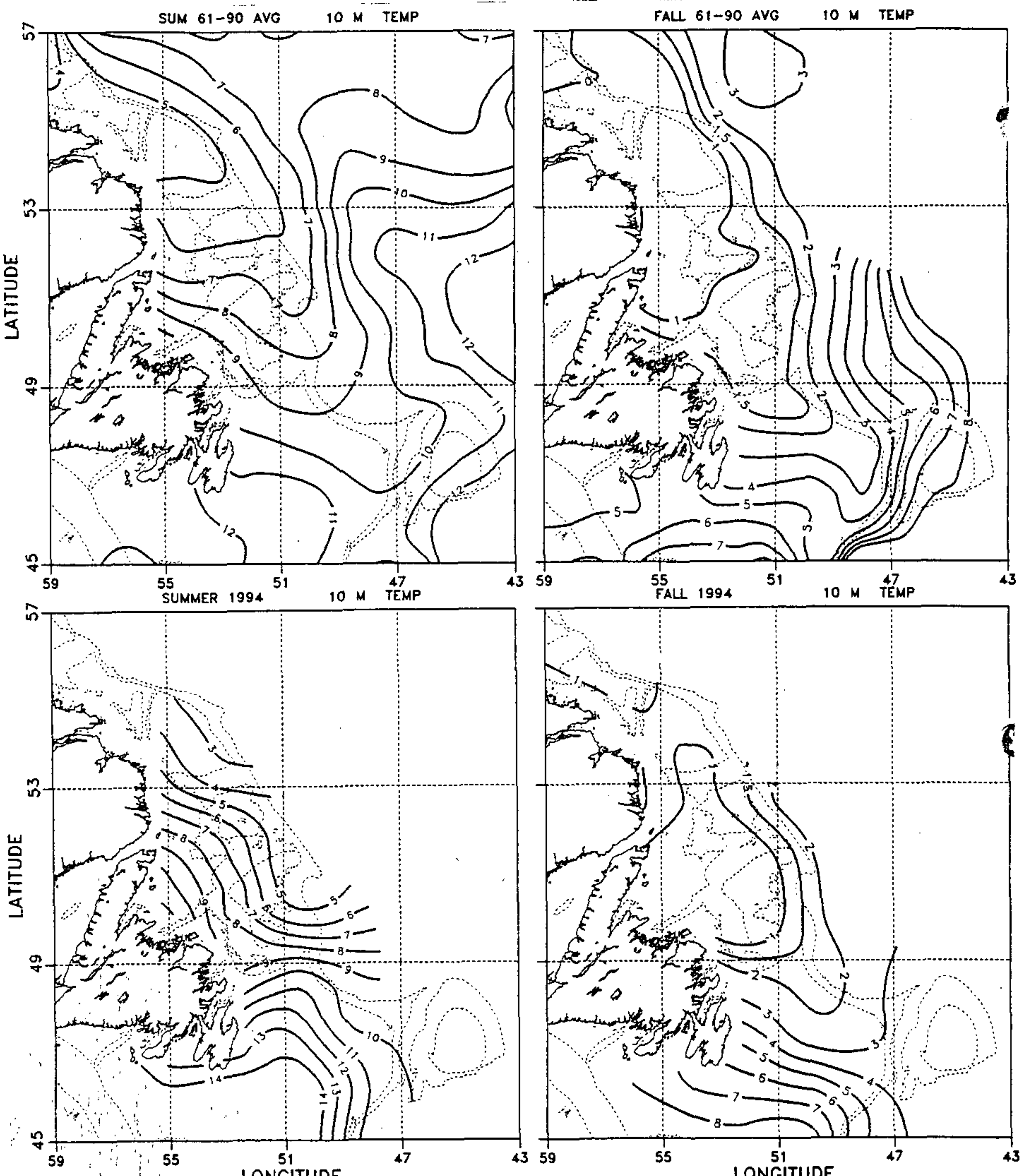


Fig. 22. The horizontal distribution of temperature at 10 m during the summer and fall, mean (1961-1990) conditions of the left and 1994 on the right.

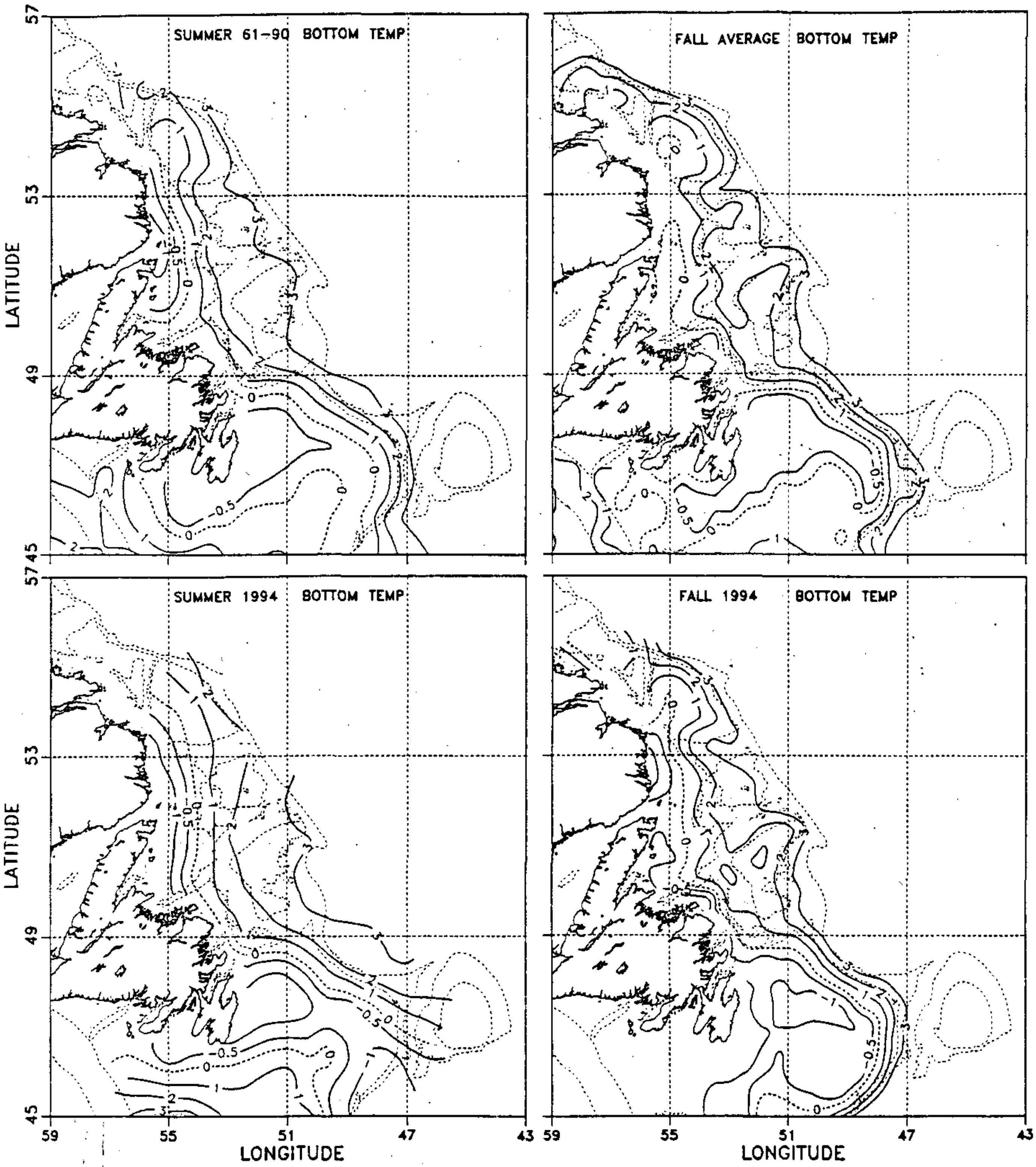


Fig. 23. The horizontal distribution of bottom temperature during the summer and fall, mean (1961-1990) conditions of the left and 1994 on the right.

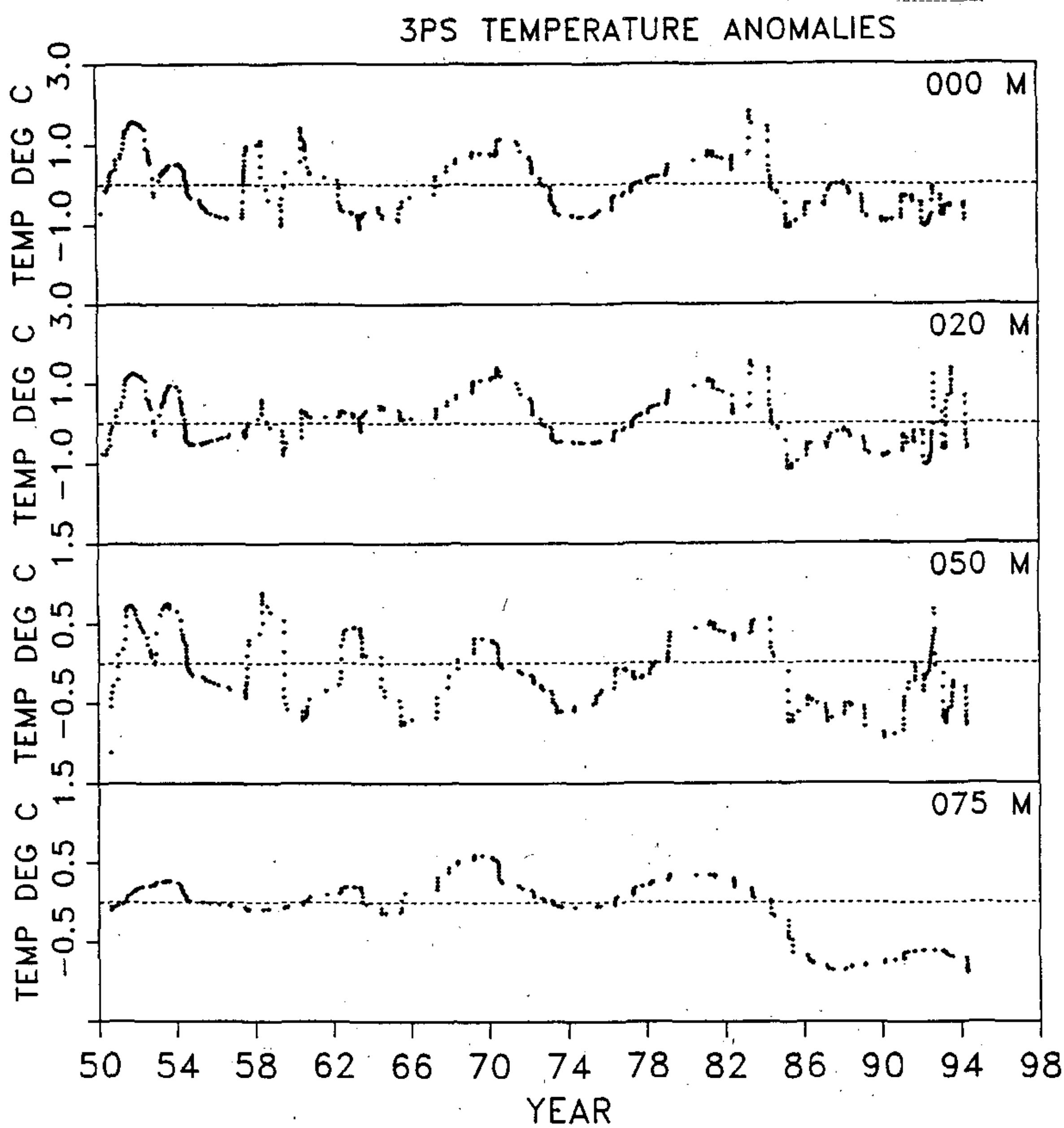


Fig. 24. Time series of temperature anomalies at standard depths over St. Pierre Bank.

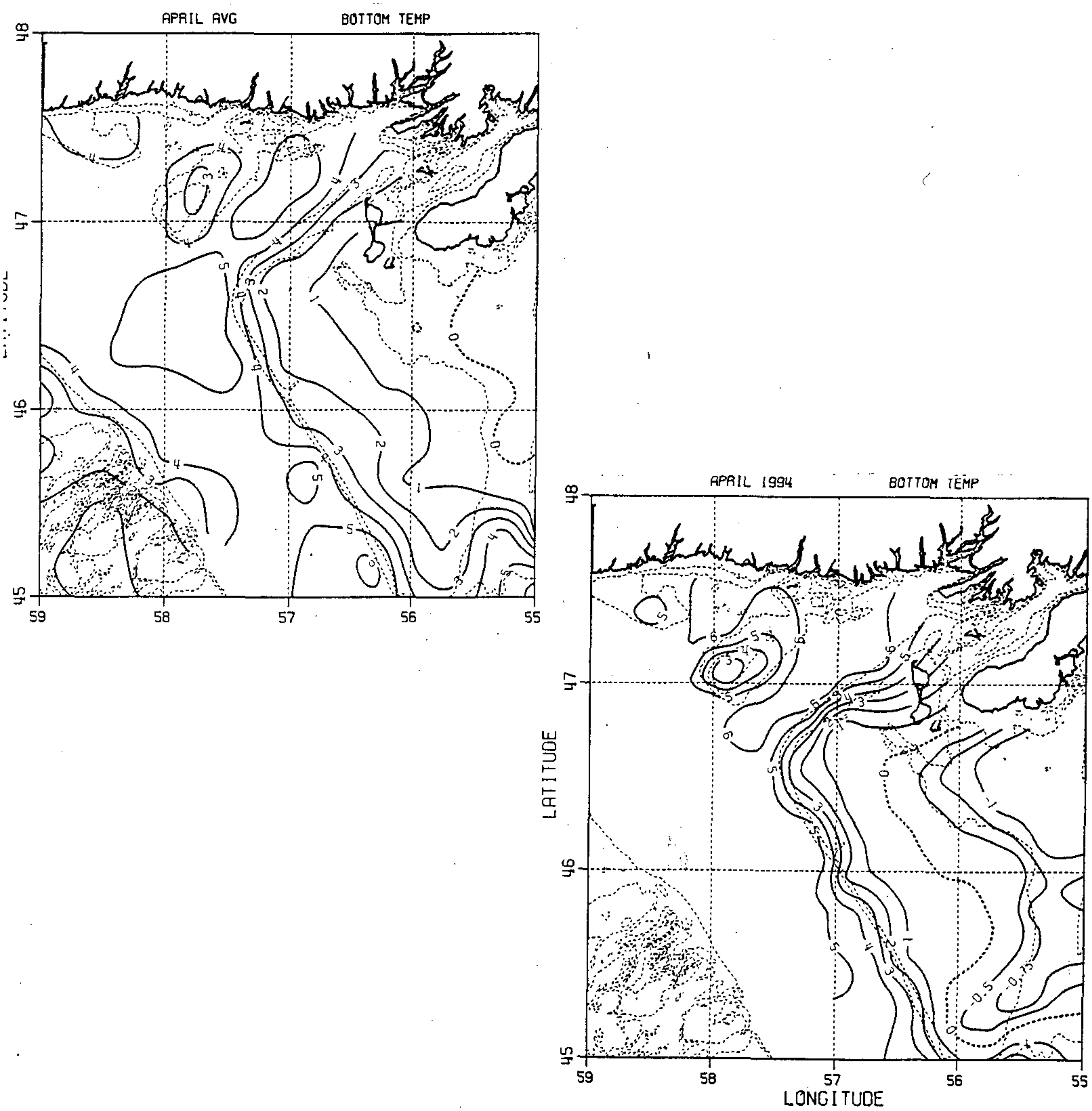


Fig. 25. The horizontal distribution of bottom temperature off southern Newfoundland during April. The mean (1961-1990) conditions are on the top and 1994 conditions are on the bottom.

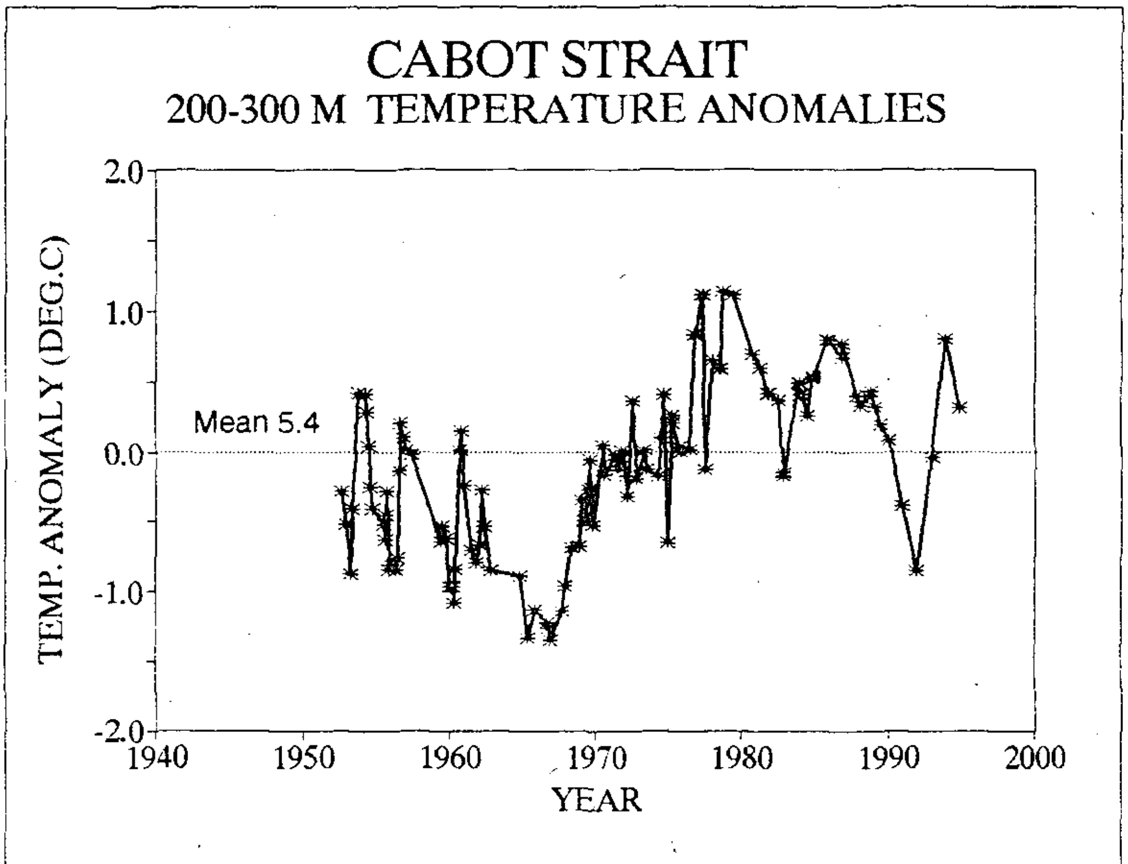


Fig. 26. Temperature anomalies (relative to 1961-1990) for the 200-300 m deep layer in Cabot Strait.

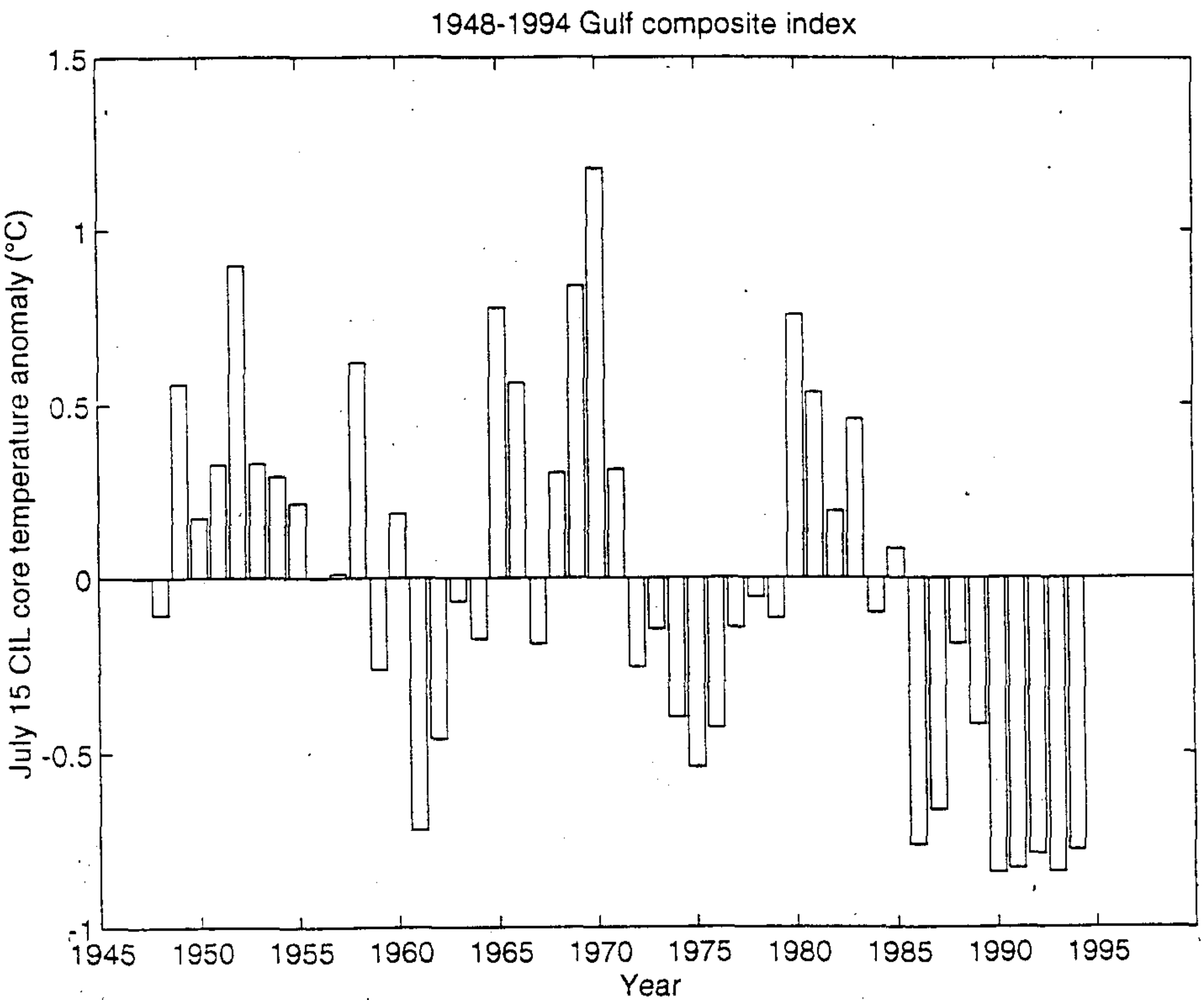


Fig. 27. Mid-summer composite index of CIL core temperature anomaly for the Gulf of St. Lawrence (from Gilbert and Pettigrew, 1995).

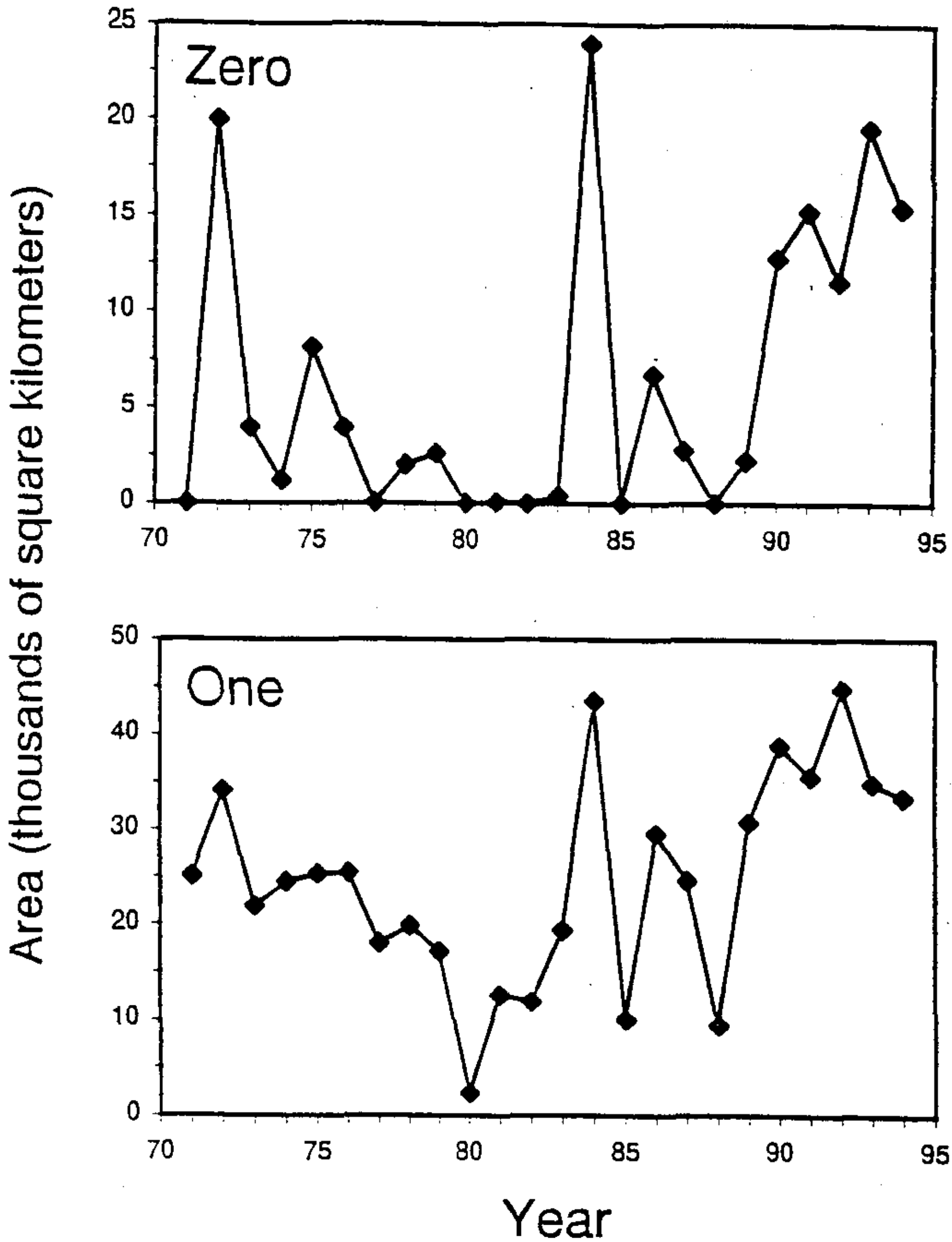


Fig. 28. Area of the Magdallen Shallows with bottom temperatures below 0°C and 1°C.

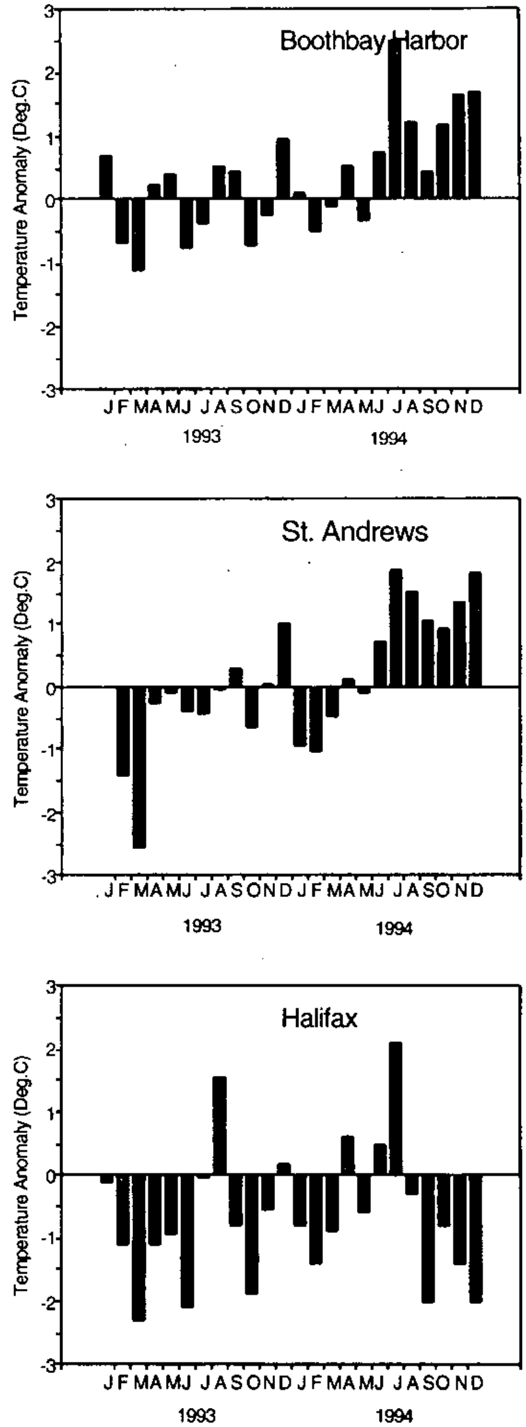
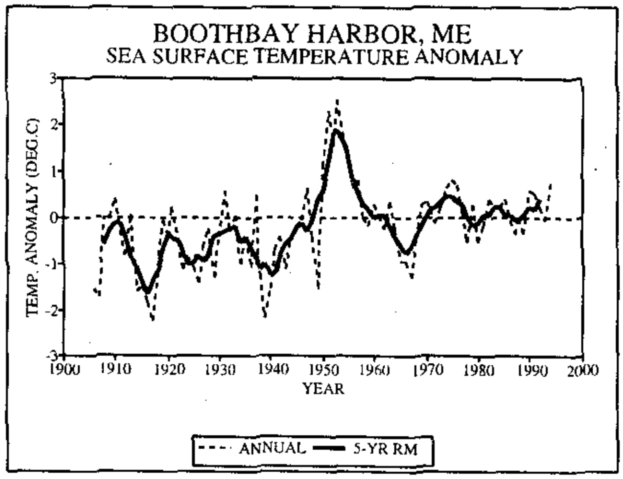
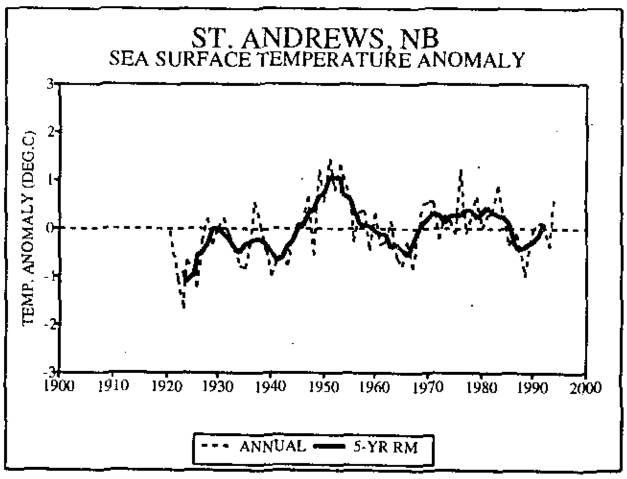


Fig. 29. The monthly sea surface temperature anomalies (relative to 1961-90) during 1993 and 1994 for Boothbay Harbor, St. Andrews and Halifax.





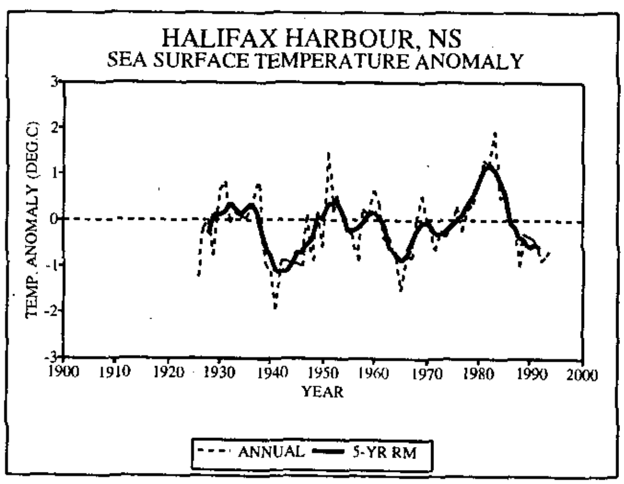


Fig. 30. The annual anomalies of sea surface temperature and their 5-yr running means at coastal sites.

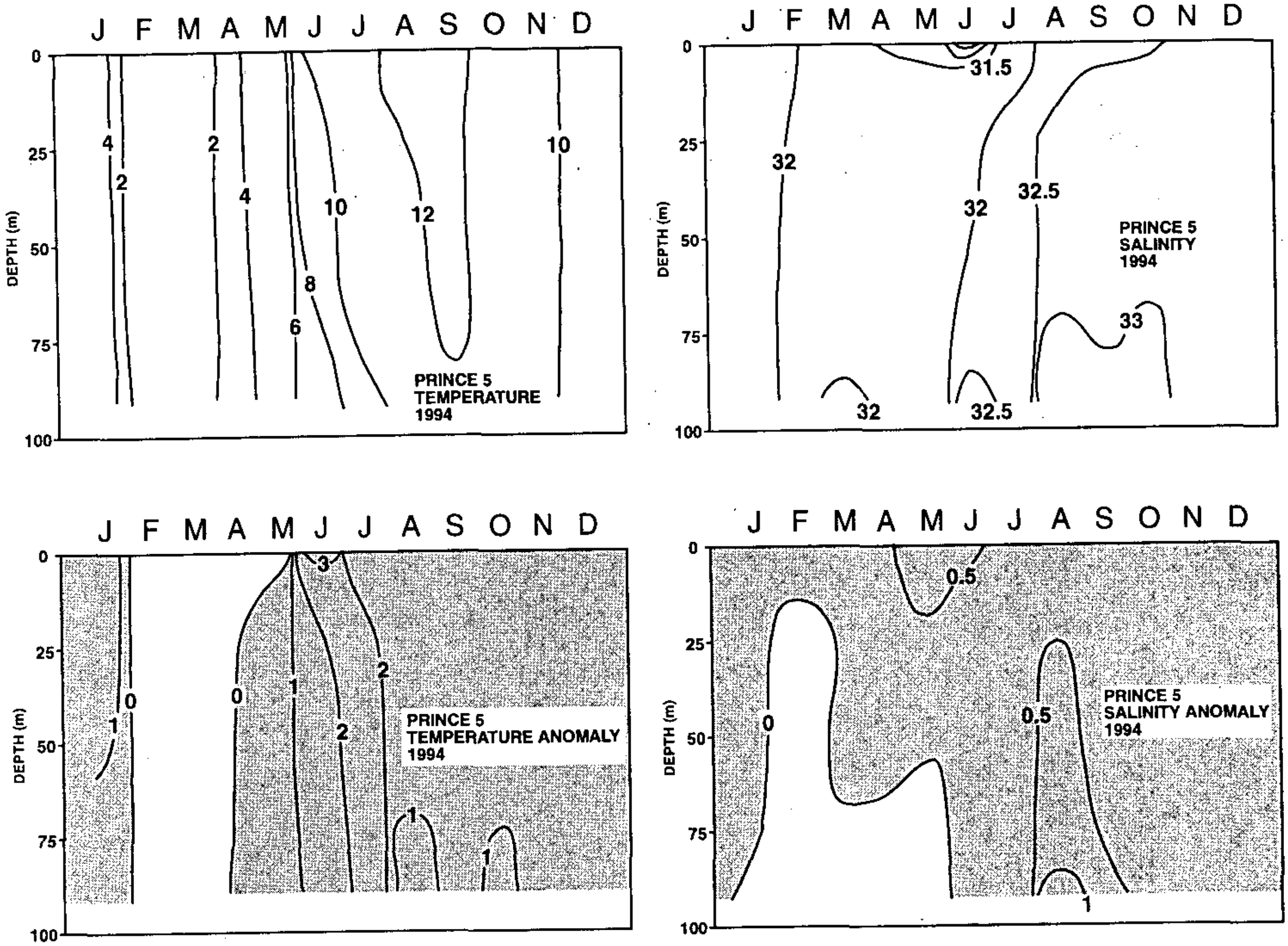
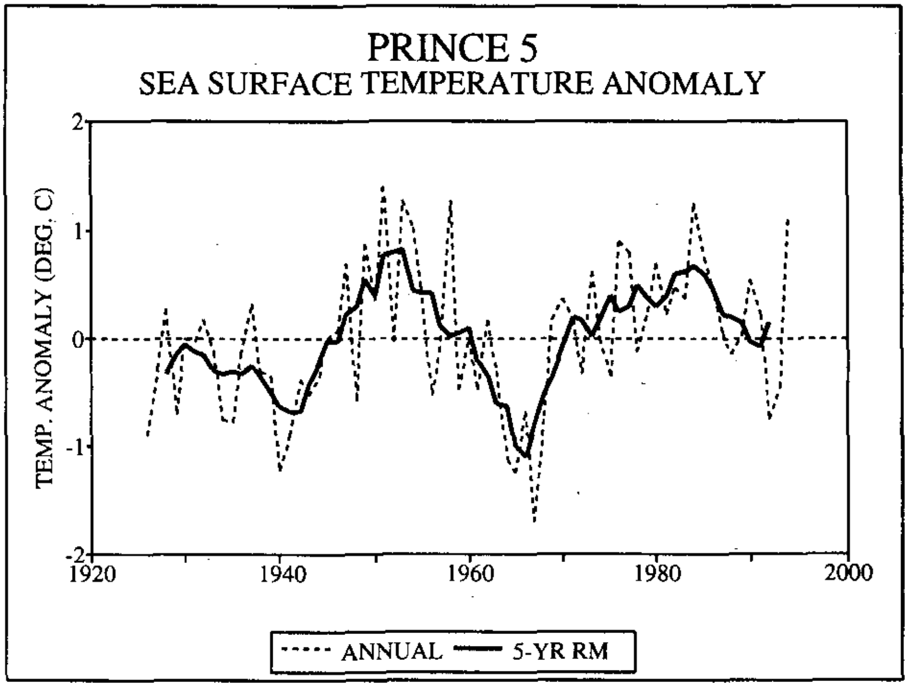


Fig. 31. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1993.



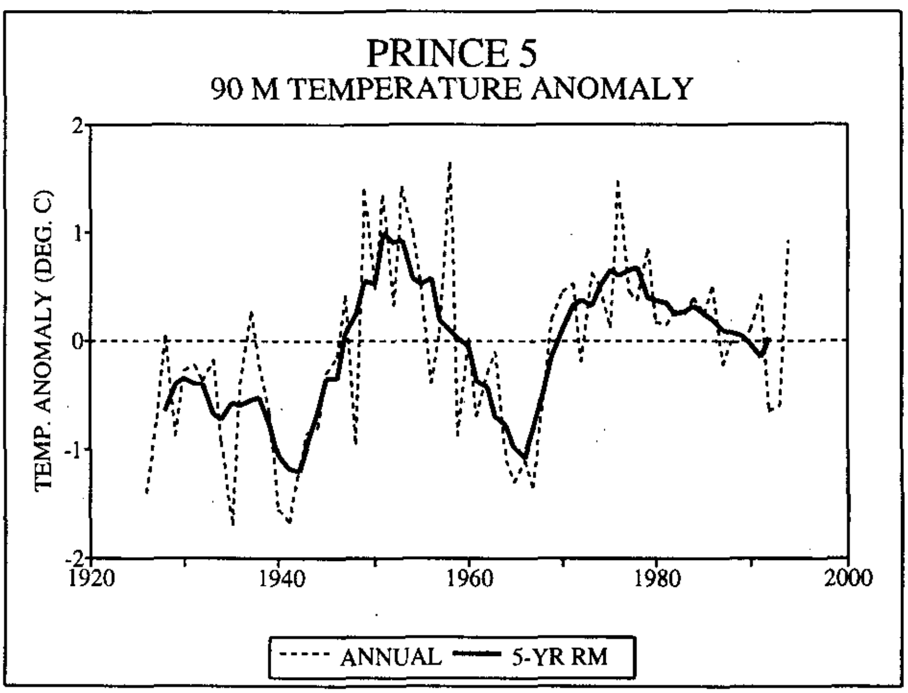
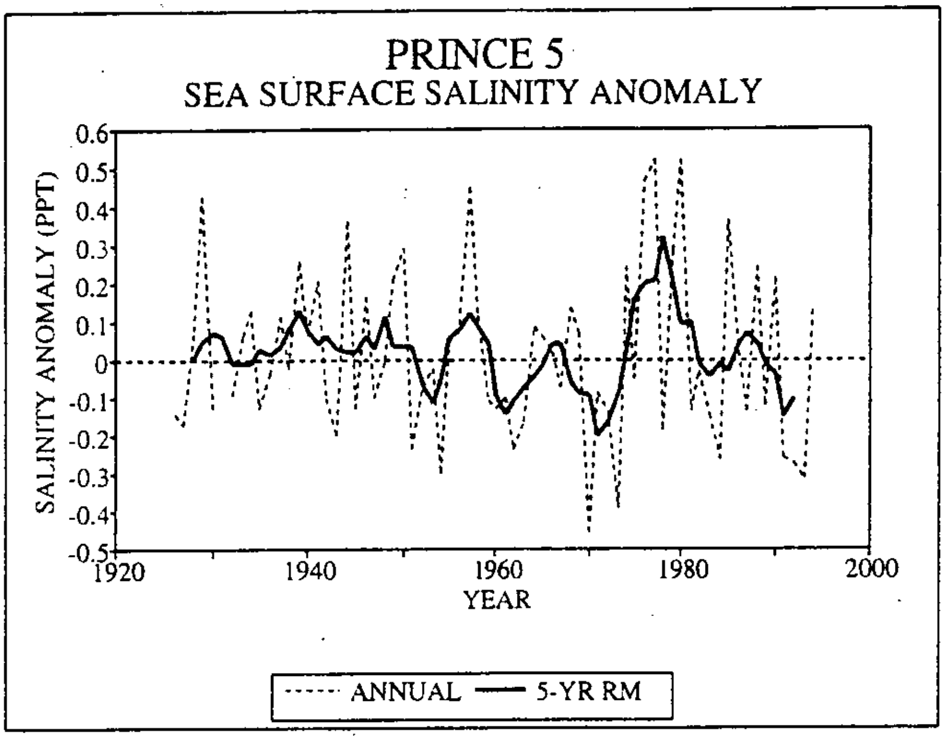


Fig. 32. The annual means and the 5-yr running means of the temperature anomalies at Prince 5, 0 and 90 m.



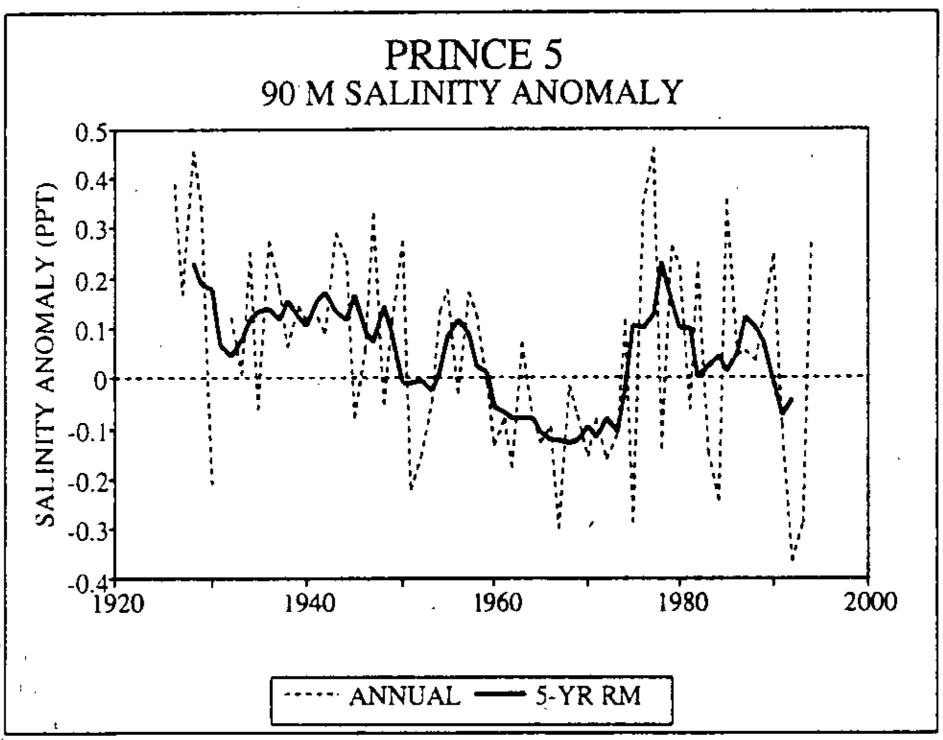


Fig. 33. The annual means and the 5-yr running means of the salinity anomalies at Prince 5, 0 and 90 m.

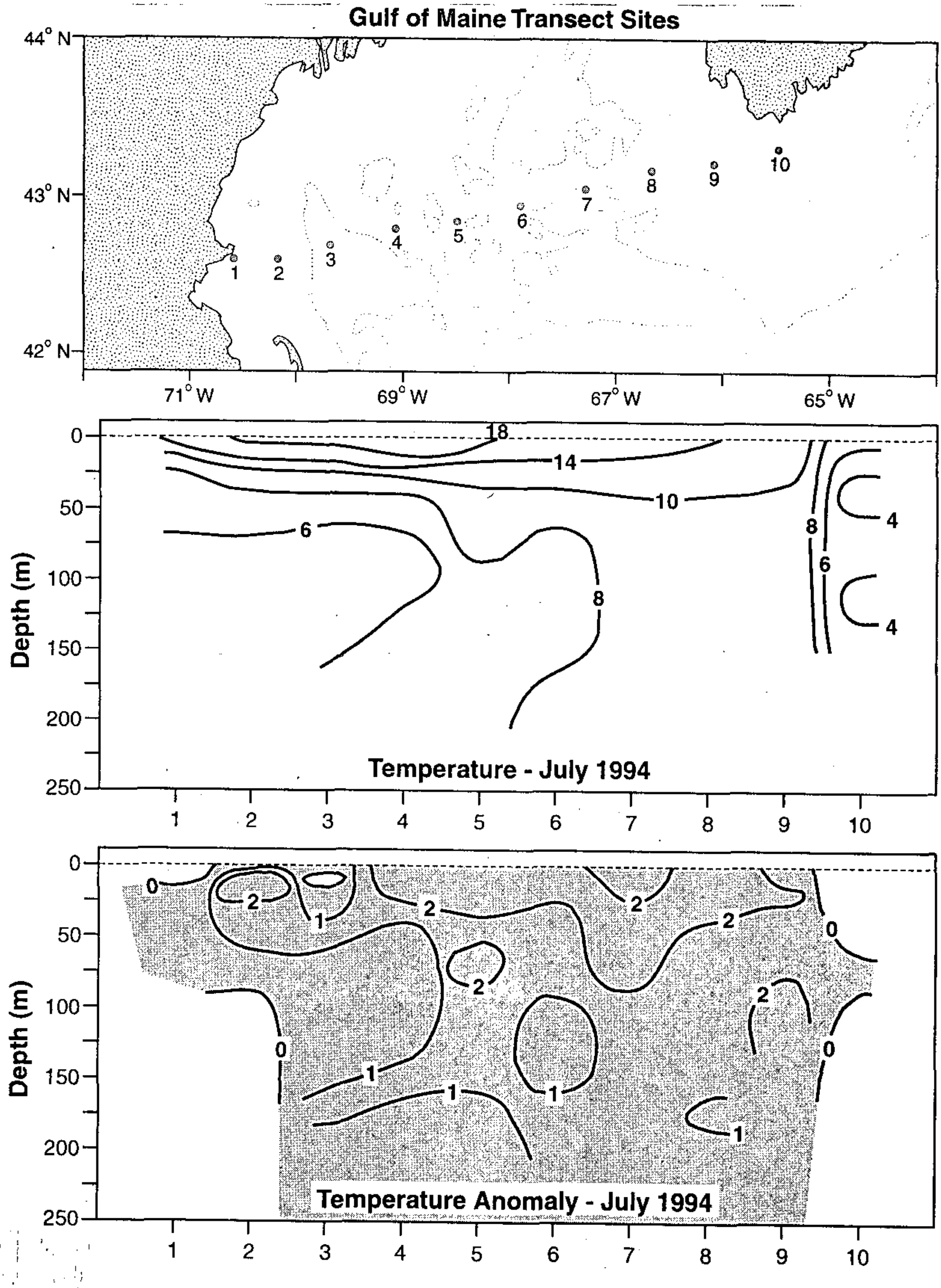


Fig. 34. The temperature (middle) and temperature anomalies (bottom) along a XBT transect (top) across the Gulf of Maine from Cape Ann, Mass. to Cape Sable, N.S.

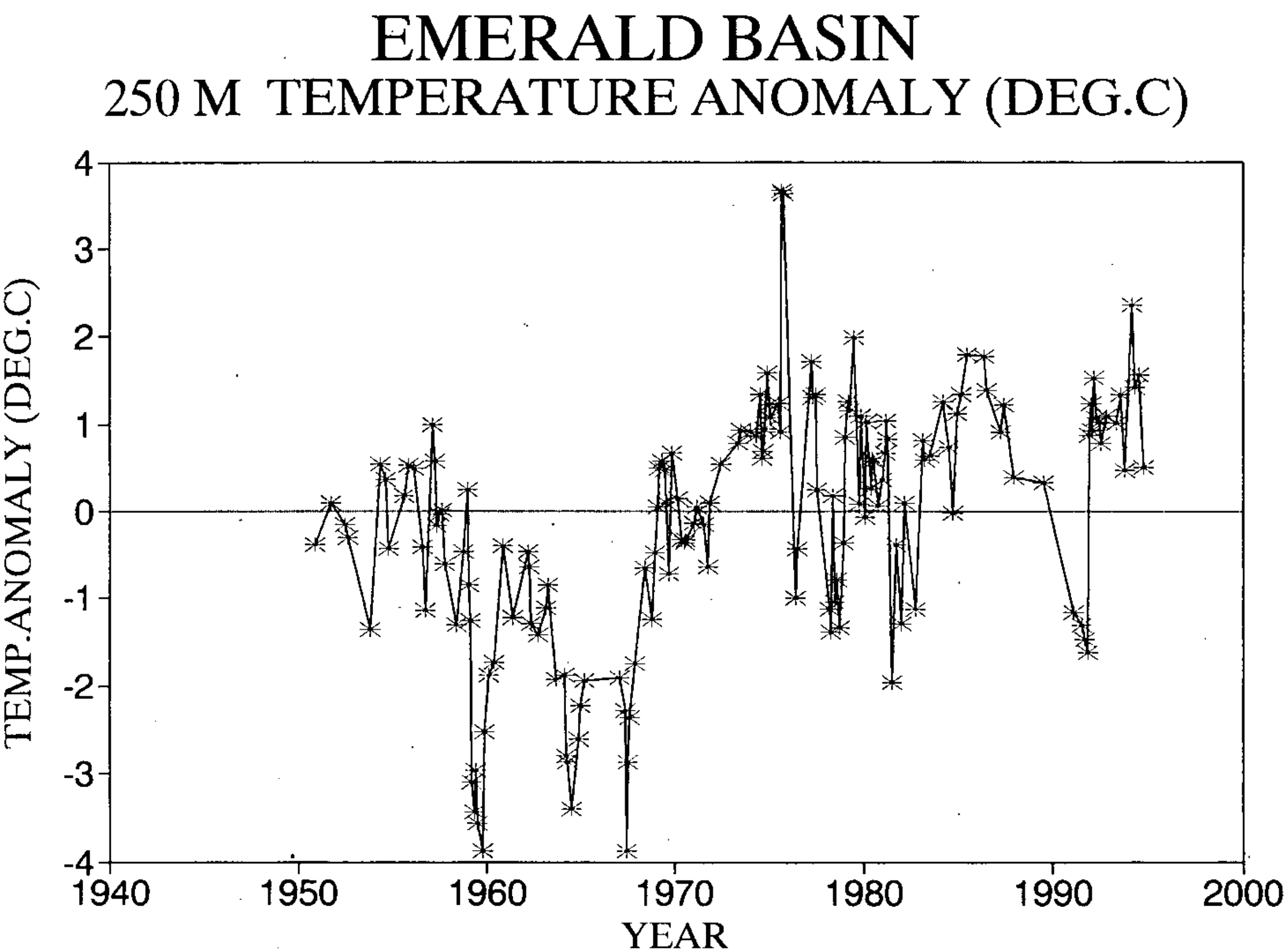
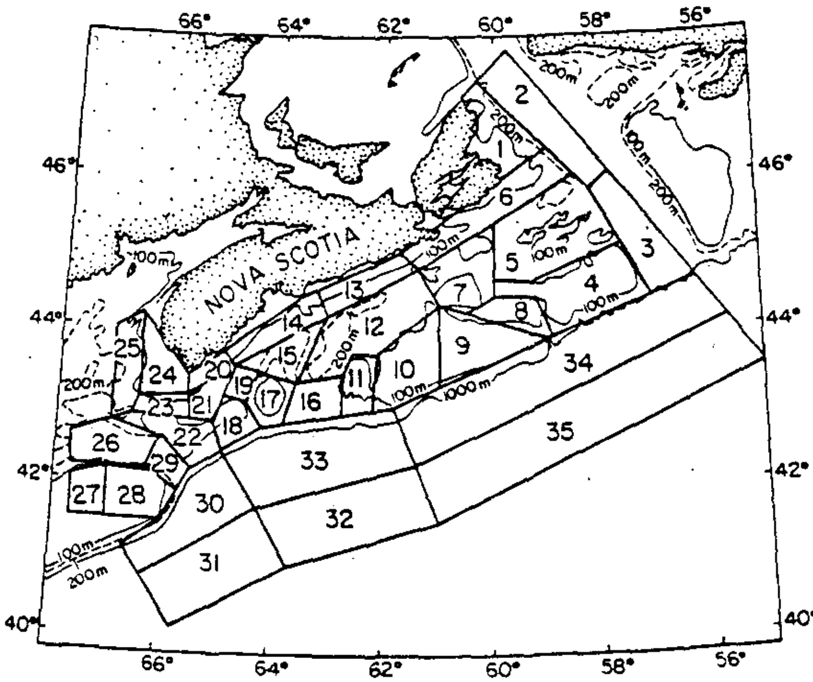


Fig. 35. Temperature anomalies at Emerald Basin at 250 m.



1. SYDNEY BIGHT
2. N. LAURENTIAN CHANNEL
3. S. LAURENTIAN CHANNEL
4. BANQUEREAU
5. MISAINE BANK
6. CANSO
7. MIDDLE BANK
8. THE GULLY
9. SABLE ISLAND
10. WESTERN BANK
11. EMERALD BANK
12. EMERALD BASIN
13. EASTERN SHORE
14. SOUTH SHORE
15. LAHAVE BASIN
16. SADDLE
17. LAHAVE BANK
18. BACCARO BANK
19. ROSEWAY BANK
20. SHELBURNE
21. ROSEWAY BASIN
22. BROWNS BANK
23. ROSEWAY CHANNEL
24. LURCHER SHOALS
25. E. GULF OF MAINE
26. GEORGES BASIN
27. GEORGES SHOAL
28. E. GEORGES BANK
29. N.E. CHANNEL
30. SOUTHERN SLOPE
31. SOUTHERN OFFSHORE
32. CENTRAL OFFSHORE
33. CENTRAL SLOPE
34. NORTHERN SLOPE
35. NORTHERN OFFSHORE

Fig. 36. The areas in which monthly mean temperature and temperature anomalies were estimated (from Drinkwater and Trites, 1987).

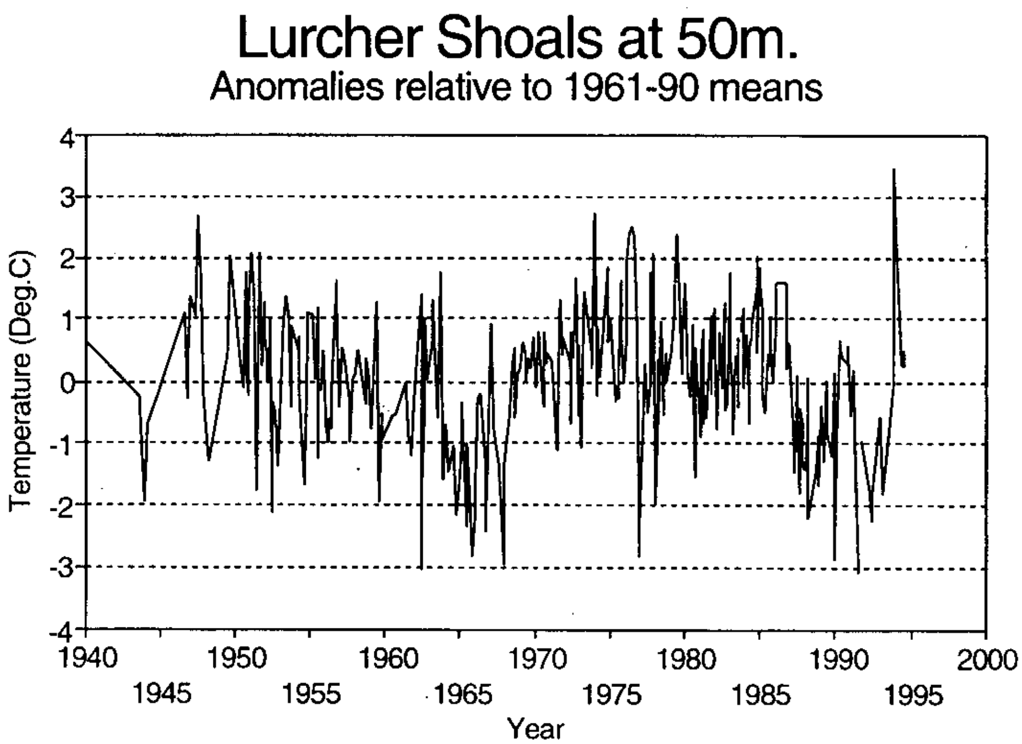
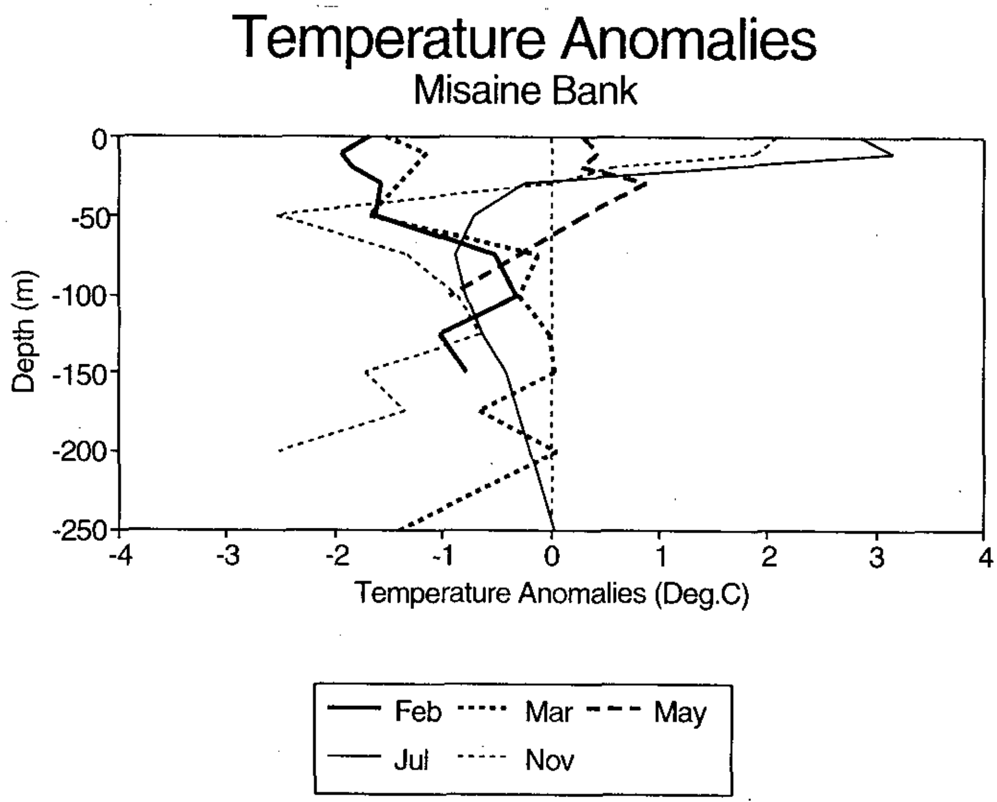


Fig. 37. The time series of temperature anomalies at 50 m for Lurcher Shoals (area 24 in Fig. 36).



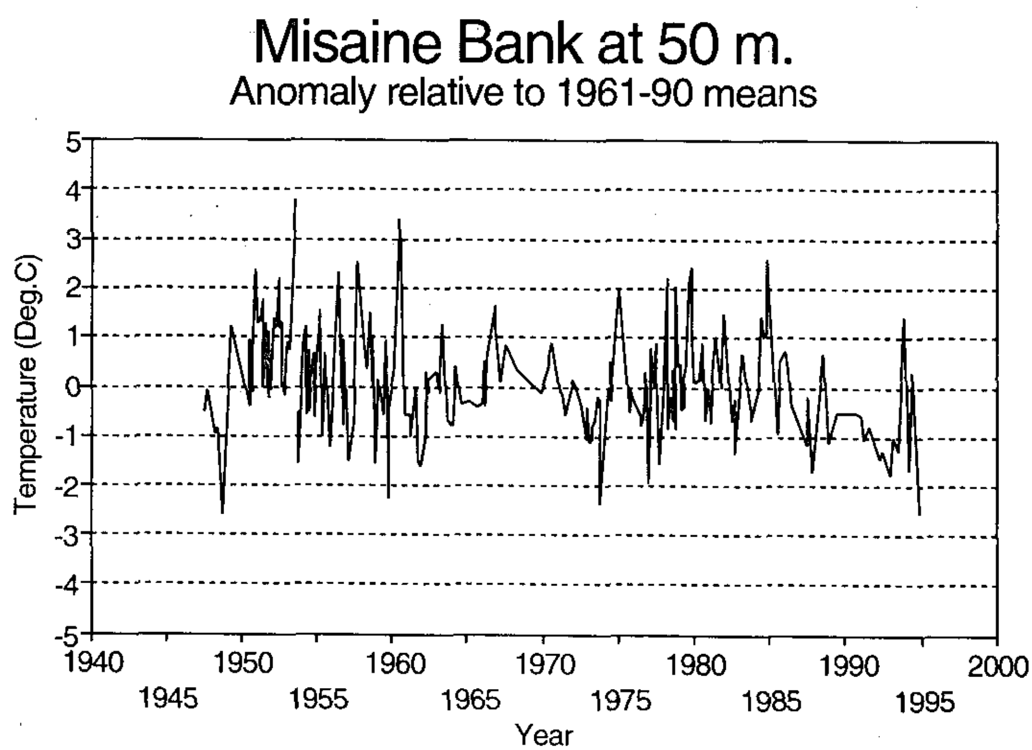


Fig. 38. The 1994 monthly anomaly profiles (top) and time series of temperature anomalies at 50 m (bottom) for Misaine Bank (area 5 in Fig. 36)

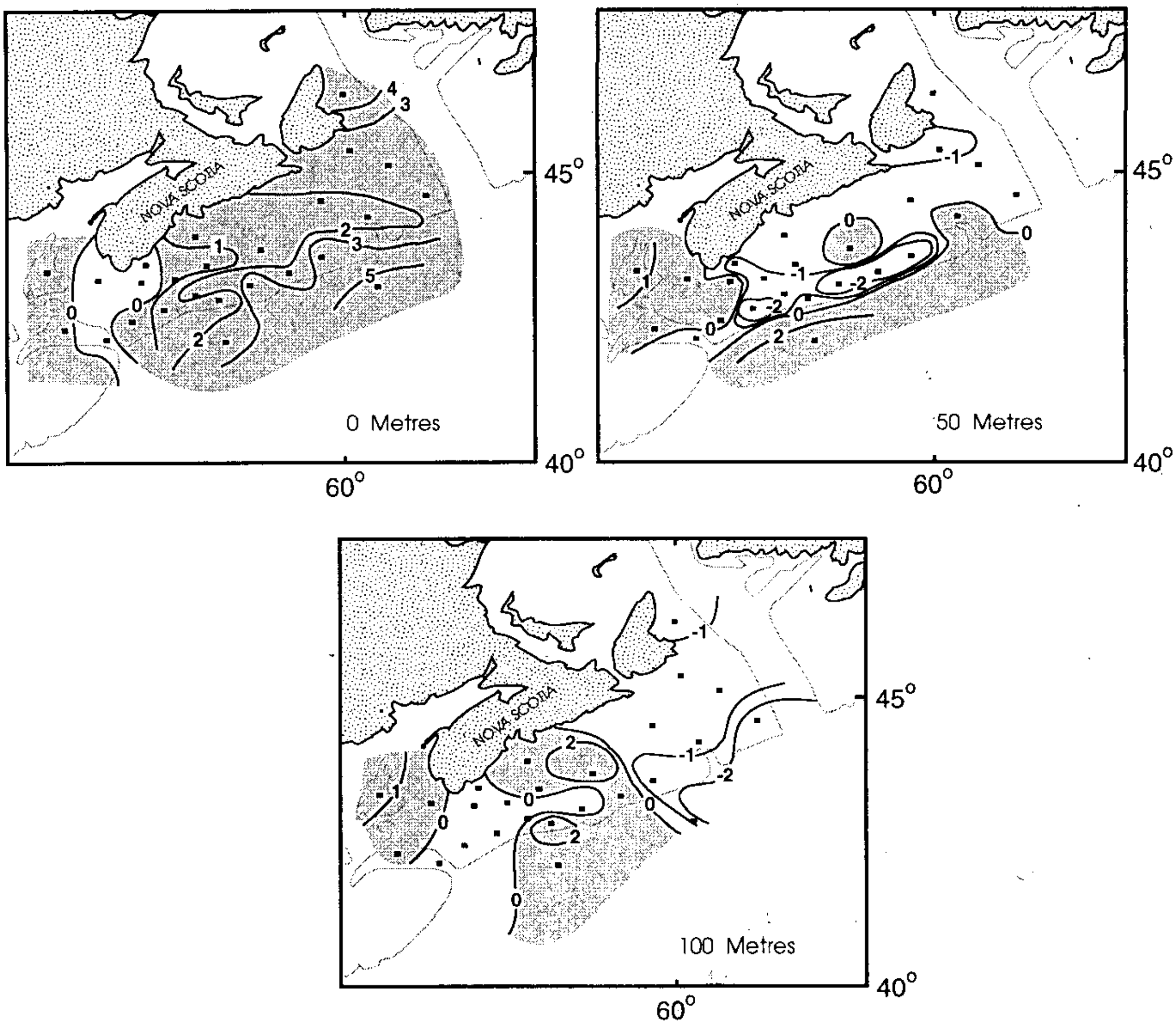
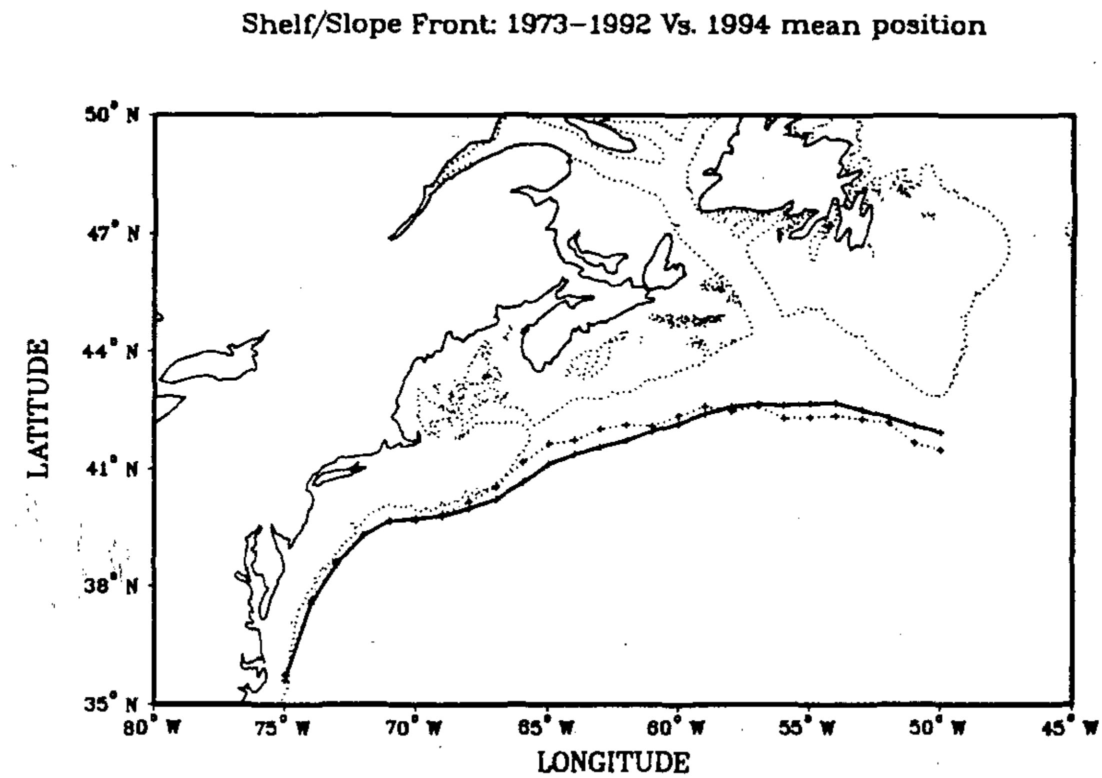


Fig. 39. The temperature anomalies during July at 0, 50, and 100 m based on July data averaged over areas in Fig. 36. Positive anomalies are shaded and the center of the areas in which there are data are denoted by a small square.



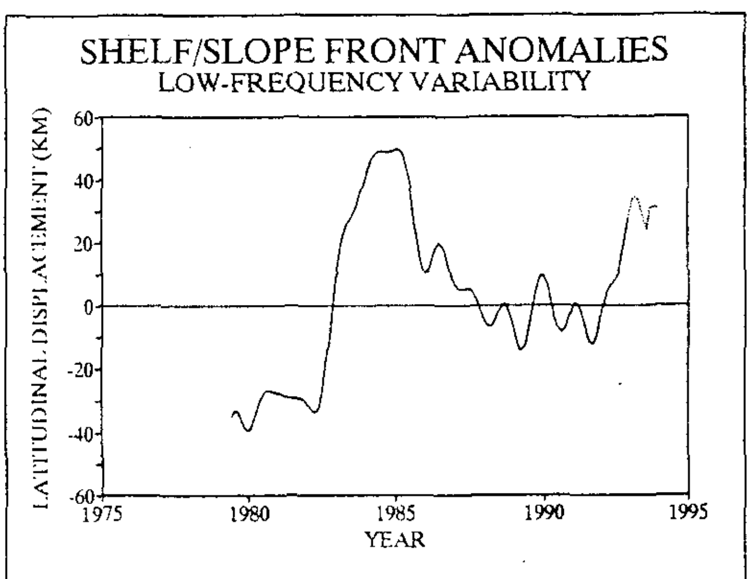
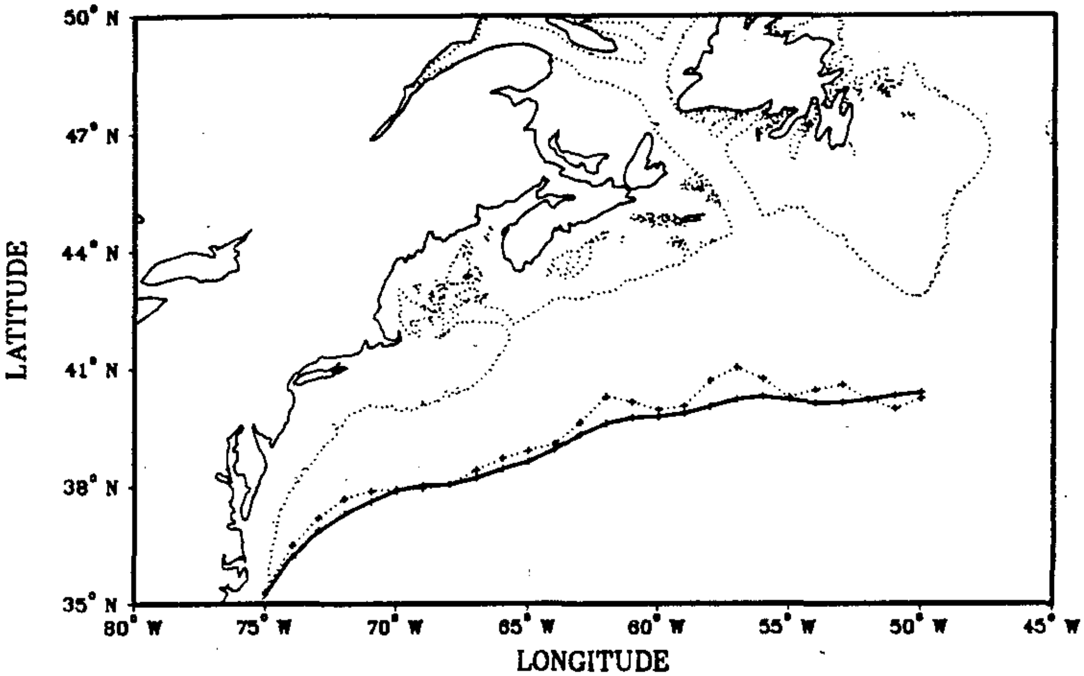


Fig. 40. The 1994 (dashed line) and long-term (1973-1990; solid line) mean position of the shelf/slope front (top) and the low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the shelf/slope front (bottom). The dashed line indicates the new data using the 1994 data.



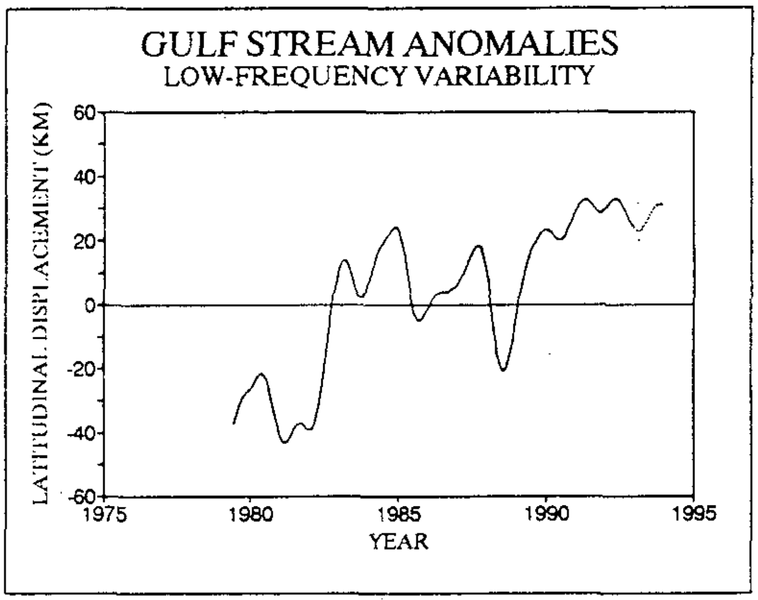


Fig. 40. The 1994 (dashed line) and long-term (1973-1990; solid line) mean position of the northern edge of the Gulf Stream (top) and the low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the Gulf Stream front (bottom). The dashed line indicates the new data using the 1994 data.

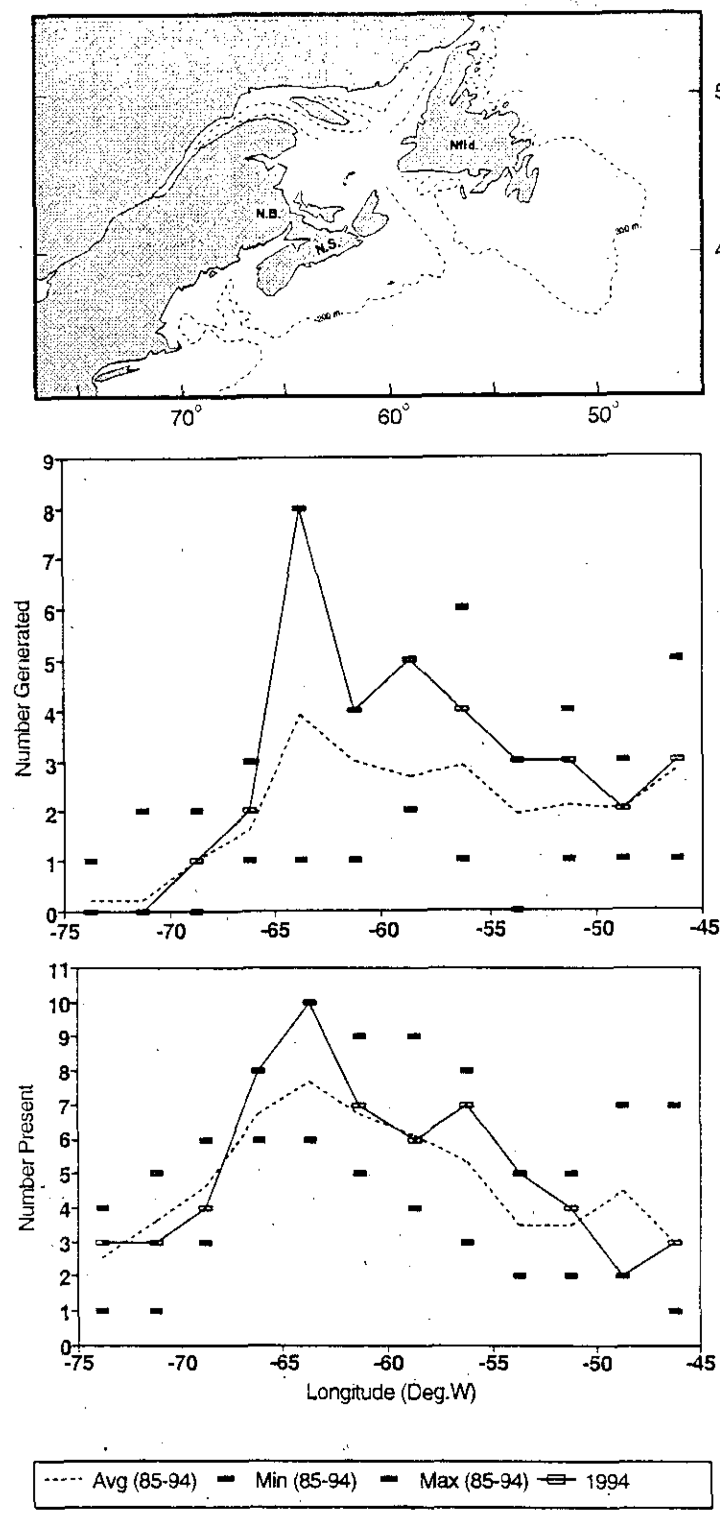


Fig. 42. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1994: (top) the area of interest; (middle) the number of rings generated in each 2.5° zone of longitude; and (bottom) the number of rings present in each 2.5° zone during some part of the year.