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Marine Environmental Conditions in the Northwest Atlantic During 1995 Potentially Impacting Atlantic Salmon *(Salmo salar)*

by

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Abstract

This paper examines marine environmental conditions during 1996 in the Northwest Atlantic that potentially impact upon Atlantic salmon. Of particular interest is the Labrador Sea region where many of the salmon that spawn in Canadian east coast rivers overwinter. As background a general review of the relationship between atmospheric conditions, sea ice and oceanographic events in the Labrador Sea is presented. In years when the large-scale atmospheric circulation intensifies (more intense Icelandic Low and Bermuda-Azores High and a high NAO (North Atlantic Oscillation) index), there tends to be increased northwest winds over the Labrador Sea, colder air temperatures, more ice and colder ocean temperatures. When the circulation weakens, the northwest winds tend to be weak, air temperatures are warm, there is less ice and ocean temperatures are also warm. During 1995, air temperatures, sea ice and ocean temperatures indicated relatively cold conditions in the Labrador Sea, continuing a trend that has persisted for over a decade. However, slight warming and less ice suggest moderating conditions. In the Gulf of Maine where inner Bay of Fundy salmon stocks are believed to overwinter, sea surface temperatures were generally above their long-term normals. This is in contrast to the Scotian Shelf where temperatures have been below normal.

Résumé

On examine les conditions environnementales de l'Atlantique nord-ouest en 1996 qui peuvent avoir un impact sur le saumon atlantique. D'intérêt particulier est la région de la mer du Labrador où un grand nombre des saumons qui frayent dans les rivières de l'est du Canada passe l'hiver. On présente, pour faire état de la situation, un examen général de la relation entre les conditions atmosphériques dans la mer du Labrador, la couverture des glaces de mer et les événements océanographiques. Les années où la circulation atmosphérique à grande échelle s'intensifie (zone de basse pression de l'Islande et anticyclone des Bermudes et des Açores plus virulents, et index élevé de l'oscillation nord-atlantique), la tendance est à des vents du nord-ouest plus forts dans la mer du Labrador, des températures de l'air plus froides, des glaces plus abondantes et des températures de la mer plus froides. Lorsque la circulation ralentit, les vents du nord-ouest ont tendance à être plus faibles, l'air est chaud, les glaces sont moins abondantes et la température de l'eau est élevée. En 1995, la température de l'air, la couverture de glaces et la température de la mer indiquaient des conditions relativement froides dans la mer du Labrador, maintenant une tendance qui persiste depuis plus d'une décennie. Toutefois, un léger réchauffement et une couverture moins importante de glaces portent à croire que les conditions climatiques s'améliorent. Dans le golfe du Maine, où l'on croit que les stocks de saumon du fond de la baie de Fundy passent l'hiver, les températures de la mer en surface étaient généralement supérieures à la normale à long terme. Cela est à l'opposé du plateau néo-écossais où les températures se situaient sous la normale.

Introduction

Most Atlantic salmon (*Salmo salar*) stocks spawning in the rivers of eastern North America migrate in the fall to the Labrador Sea where they overwinter. Many facets of the life history of these salmon are influenced, if not controlled, by events and conditions during their marine phase. For example, winter temperatures in the Labrador Sea appear to play an important role in determining both recruitment survival and growth of several salmon stocks (Reddin and Shearer 1987; Ritter 1989; Friedland et al. 1993). Also, Reddin and Friedland (1993) and Narayanan et al. (1995) have shown that the timing and distribution of salmon catches in Newfoundland and Labrador are related to the arrival of 4°C water which is believed to occur through a temperature effect on migration. Such studies clearly indicate that assessment biologists must consider environmental conditions when attempting to explain annual changes in recruitment, growth, distribution and migration patterns of Atlantic salmon.

Since 1982, physical oceanographers have been providing annual environmental reviews for the Northwest Atlantic through NAFO (i.e., Drinkwater et al. 1996) and in recent years as part of the groundfish assessments by DFO. Recently, environment reviews have been requested that are tailored more to the needs of other fisheries; in the present case, salmon. The main purpose of this paper is to provide a general overview of meteorological, ice and temperature conditions during 1995 in those areas of the Northwest Atlantic where salmon inhabit or travel through. This includes the continental shelf regions from the Gulf of Maine to Labrador and the Labrador Sea. Climatic conditions within the paper are expressed as anomalies, i.e. differences from the long term mean. Where possible, long-term has been standardized to a 30-yr (1961-90) base period in accordance with the convention of the World Meteorological Organization. However, before presenting the 1995 environmental conditions, and because of the importance of the Labrador Sea area for many Atlantic salmon stocks (Reddin and Shearer 1987; Friedland et al. 1993), a brief review of the climate variability in this region is provided.

Review of the Climatology of the Labrador Sea

Friedland et al. (1993) carried out exploratory analysis of sea-surface temperatures in the Northwest Atlantic to identify habitat areas for Atlantic salmon and then compared these with salmon production indices, in particular the number of salmon returning to spawn. They found the distribution of winter (January-March) habitat (defined by the area within 4-8 °C) at the mouth of the Labrador Sea to be critical for North American salmon stocks with higher returns in those years when there was more suitable habitat. They hypothesized that the habitat limits salmon production through intraspecific competition. The area of the 4°C to 8°C winter habitat was also found to be linked with the atmospheric circulation over the North Atlantic Ocean, as revealed by the North Atlantic Oscillation (NAO) index (defined below). Therefore, as part of the following review, we examine the meteorological linkages to the ocean temperatures in an attempt to explain the relationship between the NAO index and the winter marine habitat for salmon. We begin by considering air temperatures.

Air Temperatures

During the past three decades, air temperatures over the Labrador Sea have generally been decreasing (Chapman and Walsh 1993) in contrast to the warming trend in the northern hemisphere (Folland et al. 1992). This cooling is evident at Godthaab on West Greenland (see Fig. 1 for location) where temperatures have fallen by approximately 2°C since the 1960s. Godthaab, which has the longest temperature record in the region, is considered representative of the Labrador Sea with high correlations ($r=0.6$-0.9, $p < 0.05$) between its annual mean air temperature and those at other coastal sites on Greenland, Baffin Island, Labrador, and Newfoundland. The Godthaab record suggests that cold temperatures persisted over the Labrador Sea region during the late 1800s through to the first two decades of the present century (Fig. 2). Temperatures rose rapidly in the 1920s, stayed high through to the 1960s and since then have been declining. During the past 30 years there has also been large amplitude fluctuations with a period of approximately ten years with temperature minima in the early-1970s, the mid-1980s and the 1990s. Seasonally, winter (December, January, February) temperatures exhibit the largest variability and have the greatest influence of any season on the annual temperature anomaly trends (Fig. 2).

Winds

The winds over the Labrador Sea are predominantly from the north-west, varying from a seasonal maximum in winter to a summer minimum (Drinkwater and Pettipas 1993). Air temperatures in the Labrador Sea are linked to the strength and direction of the winds. Thus, the declining air temperatures of the past 30 years have coincided with a general rise in the strength of the northwest winds (Fig. 3). (Note that the wind stress in Figure 3 is the force applied to the sea surface and is proportional to the square of the wind speed.) Air temperature minima in the 1970s, 1980s and 1990s correspond to periods of wind stress maxima. In years with stronger (weaker) northwest winds, greater (lesser) quantities of cold Arctic air are carried further south causing air temperatures to decline (increase). Correlation analysis indicates that the northwest wind stresses account for approximately 50% of the variance in air temperatures during the winter.

NAO

The winds over the Labrador Sea are, in turn, related to the large-scale atmospheric pressure patterns over the North Atlantic Ocean. These patterns are dominated by the Icelandic Low, centered between southern Greenland and Iceland, and the Azores High, centered roughly above the Azores (Fig. 4). This pattern dominates the pressure field throughout the year but varies seasonally, being most intense in winter and weakest during summer. The pattern also varies from year-to-year with the tendency for the low to deepen (or weaken), when the high strengthens (or weakens). This tendency is known as the NAO (North Atlantic Oscillation). Rogers (1984) defined an NAO index as the winter (December, January, February) sea surface pressure at the Azores minus that at Iceland. A high (low) NAO index occurs when the Icelandic Low deepens (weakens) and the Azores High strengthens (weakens). The index is a latitudinal pressure gradient and therefore an increase (decrease) reflects a corresponding increase (decrease) in the strength of the westerly winds across the northern North Atlantic. In addition, as the NAO increases, the northwest winds over the Labrador Sea increase. The NAO index has been increasing since a minimum in the 1960s with peaks in the 1970s, the 1980s and 1990s (Fig. 5) which correspond to times of air temperature minima (Fig. 2) and wind stress maxima (Fig. 3). The NAO index accounts for approximately 50% of the variance in both the winter NW winds in the Labrador Sea and the winter air temperatures at coastal stations.

Sea Ice

Sea ice appears seasonally on the Labrador and Newfoundland shelves, typically from December to July but with large year-to-year variability in total areal extent (Fig. 6). Monthly data of the area of ice between 45-55 °N on the Newfoundland and Labrador shelves were made available to us by I. Peterson and S. Prinsenberg, (personal communication, Bedford Institute). We then averaged these over the typical periods of ice advance (January-March) and retreat (April-June). For the period of ice advance, the areal extent of the ice has shown a general increase and a trend towards an early presence since the 1960s when systematic records of offshore ice conditions began (Fig. 7). Pronounced peaks in ice extent match the cold and windy periods of the early 1970s, mid-1980s and the 1990s. The NAO index accounts for approximately 50% of the variance in the ice extent (Prinsenberg and Petterson, 1994) through the combined effect of colder temperatures, which promote ice formation and delay melting, and stronger NW winds which advect the ice further southward. Since the 1960s there has also been increased number of icebergs reaching south onto the Grand Banks with peaks during the periods of strong winds, cold air and sea temperatures, and extensive ice cover.

Newfoundland Shelf Temperatures

Interannual variability in the hydrographic properties of the continental shelf waters from Labrador to the Grand Banks has been monitored since the late 1940s from occupation of standard oceanographic (temperature and salinity) stations. The longest time series is from Station 27 in the Avalon Channel just outside St. John's. Changes in temperature and salinity at Station 27 are representative of the shelf at horizontal distances up to 1000 km away, i.e. from southern Labrador to the Grand Banks, at interannual to decadal time scales (Petrie et al., 1992; Colbourne et al., 1994). Interannual variability of near-bottom (175 m) temperatures at Station 27 show near normal or slightly above normal temperatures during the late 1940s to the early 1960s, peak values in the late 1960s and a declining trend ever since (Fig. 8). Temperature minima appear in the early 1970s, the mid-1980s and the 1990s, matching the timing of the minima in air temperature and maxima in wind stress and ice extent. Temperatures during the 1990s have been at or near the coldest on record and followed a decade of below normal values.

Near-bottom temperature trends are similar to those elsewhere within the water column and reflect atmospheric cooling of the waters during the winter.

CIL

During the spring and summer on the Labrador and Newfoundland shelves, solar heating warms the surface 20-40 m. Cold waters formed the previous winter lay below this warm surface layer and above warm, salty waters that penetrate onto the shelf from offshore where bottom depths exceed approximately 200 m (Fig. 9). The cold waters (defined by temperatures <0°C) form the cold intermediate layer (CIL). The area of the CIL reflects the amount of cooling during the previous winter and varies greatly between years. The CIL area determined from a series of temperature stations taken offshore of Bonavista Bay each July since the late 1940s shows minimum in the 1960s, increasing through to the 1990s with maxima in the early 1970s, the mid-1980s and the 1990s (Fig. 10). This is inverse to the Station 27 temperatures (Fig. 8), indicating that in years when the water is colder, the <0°C water occupies a greater area over the shelf. The CIL areas off southern Labrador (Hamilton Bank Section) and across the Grand Banks (Flemish Cap Section along 47°N) show similar patterns to that off Bonavista (Drinkwater et al., 1996).

Central Labrador Sea Temperatures

Temperature data from the center of the Labrador Sea were collected on a routine basis from 1964 to 1974 when Ocean Weather Station Bravo was in service. Lazier (1980) has shown that the temperature at Bravo was relatively warm in the 1960s and extremely cold in the early 1970s. This mirrors temperature events on the continental shelves (Fig. 8). Also, the areal extent of the waters between 4-8 °C, defined by Friedland et al. (1993) as suitable winter thermal habitat for Atlantic salmon, shows a remarkable similarity to the ocean temperatures at Station 27. Therefore, we conclude that at interannual time scales, ocean temperature variability throughout the Labrador Sea exhibits similar trends.

Greenland Shelf Temperatures

Ocean temperatures are also monitored off Greenland by Danish and German scientists, with the longest and most frequent observations over Fyllas Bank near Godthaab. Upper layer (0-40 m) temperatures at Fyllas Bank exhibit similar near decadal variability to Newfoundland Shelf waters but with the peaks and troughs perhaps occurring prior to those on the western side of the Labrador Sea (Fig. 11).

Summary

In summary, there are strong relationships between meteorological, oceanographic and ice conditions in the Labrador Sea (Fig. 12). Increased NW winds, primarily in winter, over the

Labrador Sea bring cool Arctic air into the region. These in turn lead to increased ice formation and greater areal extent of the ice along the Labrador coast and off Newfoundland. They also lead to cooler ocean temperatures throughout the Labrador Sea. The increased winds are linked to the large-scale atmospheric circulation as revealed by the NAO index. This scenario is consistent with the findings of Battista et al., (1995) who has shown that surface temperatures in the Labrador Sea are controlled by heat exchanges with the atmosphere and explains the connection of the thermal habitat index of Friedland et al. (1993) with the NAO index. We now proceed to the description of the environment during 1995.

Physical Environmental Conditions in the Northwest Atlantic during 1995

Air Temperatures

The German Weather Service publishes monthly mean temperature anomalies (relative to 1961-90 means) for the North Atlantic Ocean in their publication *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. Temperatures were typically 2 to 3°C below normal with even colder anomalies persisting along sections of the West Greenland coast (Fig. 13). These conditions contrast with those over the Scotian Shelf and Gulf of Maine where temperatures were warmer-than-normal. The latter anomalies were maximum in March, reaching 1-2°C. The Gulf of St. Lawrence was also warmer except during February when it was colder-than-normal by 1-2°C. Air temperatures rose to above normal in eastern Canadian marine areas in April with maximum anomalies (2-6°C) from northern Labrador Sea into Baffin Bay. For the months May to September, air temperatures over the Labrador Sea were slightly above normal. Exceptions were in June and July in the southern Labrador Sea and off Northern Newfoundland with temperatures slightly below normal. Around the Maritime Provinces, air temperatures oscillated about normal through April to September. The most significant positive temperature anomaly was observed in October when air temperatures were 2-3°C above normal throughout the entire region (Fig. 13).

Monthly air temperature anomalies for 1994 and 1995 relative to their 1961-90 mean 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 and Sable Island on the Scotian Shelf (see Fig. 1 for locations) are shown in Fig. 14. 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 around the Labrador Sea from the coastal sites of Godthaab anticlockwise to St. John's. Wintertime temperatures were more severe than in 1994 at Godthaab but similar or less severe elsewhere. The warming in the latter part of the year was most noticeable at Iqaluit.

The time series of temperatures (25-month running means) for the six sites show the warming in 1995 as a continuation of the upward trend that began last year (Fig. 15). Note that the interannual variability since 1970 at Godthaab, Iqaluit, Cartwright, and, to a lesser extent, St. John's have been dominated by the large amplitude fluctuations with a period of approximately

10 yr with minima in the early 1970s, early to mid-1980s and the early 1990s as discussed above in the review of the climate in the Labrador Sea. Indeed, the recent rise in temperature is consistent with a continuation of this near decadal pattern. The overall downward trend has caused 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).

NAO Index

The NAO Index was estimated from the measured mean sea level pressures at Ponta Delgada in the Azores minus those at Akureyri in Iceland (Fig. 5). Anomalies were calculated by subtracting the 1961-90 mean. In 1995, the NAO anomaly was strongly positive and above last year's value, continuing the trend that has persisted since the late 1980s. This corresponds to a deepening of the Icelandic Low, bring increased NW winter winds, cold air temperatures and cold sea surface temperatures to the Labrador Sea region.

Sea Ice

Information on the location and concentration of sea ice for 1995 has been derived from daily ice charts published by Ice Central of Environment Canada in Ottawa. They are compared with the long-term median, maximum and minimum position of the ice edge (concentrations above 10%) based on the composite for the years 1962 to 1987 as described by Coté (1989).

Labrador and Newfoundland

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. 16). 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. Northwesterly winds during the last 2 weeks of March had also pushed the ice shoreward. Warm temperatures in April lead to extensive ice decay along the eastern and southern edges while east to northeasterly winds continued to push the ice onshore, 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 Conception and Bonavista Bays and by the end of the month ice had disappeared entirely from this area. 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 ice had disappeared from Newfoundland and southern Labrador.

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. 17. In January through April there has been a general increase in the area of ice over the past 30 y. 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 last three or four years.

Gulf of St. Lawrence and Scotian Shelf

Warmer-than-normal temperatures in the eastern Gulf of St. Lawrence during December 1994 resulted in less ice formation than normal on the Magdalen Shallows and in the St. Lawrence Estuary, however, colder-than-normal temperatures in the Esquiman Channel area produced more ice than usual along the north shore of Quebec (Fig. 18). In early January, 1995, 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 producing lighter ice conditions than normal. Extremely cold temperatures and northwesterly winds during the first two weeks of February pushed the ice edge southward and 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 Anticosti 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 ice from the Gulf. At the beginning of May only isolated patches of ice persisted. By 8 May ice disappeared from the Magdalen Shallows and a week later from around southern Cape Breton. The last ice to leave the Gulf was in the vicinity of Belle Isle Strait and it was gone by the first week in June.

Recently we have completed digitizing the location of the ice edge in the Cabot Strait and Scotian Shelf regions from the 1-3 weekly ice charts for the years 1970 to present. These data were combined to produce monthly estimates of the average ice area seaward of Cabot Strait (Fig. 19). The ice area time series are dominated by variability at periods of 3-5 y. The areal extent in 1995 was down significantly from last year. It was also late in arriving but lasted longer than normal. In terms of the total amount of ice that reached the Scotian Shelf it was an average year although the ice was presence for a longer time then usual.

Near Surface Ocean Temperatures

Labrador and Newfoundland

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, as discussed previously, changes in temperature at this site are considered to be representative of those over the shelf from southern Labrador to the Grand Banks at time scales of interannual to decadal (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. 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 1995 monthly temperature anomalies at the surface and 10 m were negative from February to September and again in November (Fig. 20). The anomalies were maximum at 0 m in July (-1.2°C). High positive anomalies were observed in December. A similar dominance of negative anomalies but of approximately half the amplitude of the surface values was observed at 175 m (Fig. 21). The bottom depth at Station 27 is 190 m. The time series of annual temperature anomalies at the surface together with those at 100 and 175 m are shown in Fig. 22. The annual temperature anomaly in 1995 at the surface was approximately -0.4. This represented a significant decrease from last year but was higher than the anomalies during the rest of the early 1990s. Note that the general trends at all three depths are similar, especially from the 1960s onward. The amplitude of the surface anomalies are slightly higher than those at depth with more high-frequency (small period) variability. Both features indicate the importance of atmospheric forcing. Colbourne (1996) has shown that during an extensive hydrographic survey from southern Newfoundland to the northern Grand Bank in July, near surface temperatures were 1-2°C below normal. This is consistent with the observations at Station 27 and confirm this station as a representative index of shelf wide temperature variability.

Only 2 oceanographic surveys covering the central Labrador Sea during 1995 are presently in the temperature, salinity database. Both surveys undertook measurements along a series of stations between Hamilton Bank off southern Labrador to Julianshaab on West Greenland at approximately 48°W. During June, temperatures were 4.5-5°C except near Greenland when they were 3-4°C. This resulted in predominantly negative anomalies generally less than -0.5°C, again except close to Greenland where the anomalies were 1-2°C below normal. In July, temperatures had risen to upwards of 6°C in the central Labrador Sea but temperatures there were still below normal. On the West Greenland side temperatures had risen to between 5-6°C and were then approximately 1°C above normal.

Gulf of Maine and Scotian Shelf

Some of the inner Bay of Fundy stocks do not migrate to the Labrador Sea area but instead are believed to stay in the Gulf of Maine region. Thus, knowledge of the temperature field in this area may also be relevant.

Monthly averages of sea surface temperature (SST) in 1995 derived from continuous thermograph records or twice daily readings were available at the time of writing from Halifax Harbour in Nova Scotia and Boothbay Harbor in Maine. At Boothbay Harbor temperatures were above normal throughout the entire year (Fig. 23). This continued a trend that began in June of 1994. This is in contrast to Halifax were negative SSTs dominated with only 2 of the 12 months exhibiting above normal temperatures. The largest negative anomalies were observed during the spring with anomalies of -1.5°C.

Time series of the annual anomalies show that at least since the late 1980s, the trends at the two sites are opposite. Whereas surface temperatures have generally been on the increase at Boothbay Harbor, in Halifax Harbour they have been decreasing. Occasional survey data from the Scotian Shelf region has indicated that the surface layers have appeared to be varying about the long-term mean both spatially and temporally. Tendencies have been for the northeastern Shelf, along the Atlantic coast of Nova Scotia and around Lurcher (Fig. 24) to have been colder-than-normal during recent years whereas on the offshore banks, in Emerald Basin and in the slope waters off the shelf, temperatures have been more above normal.

Hydrographic data have been collected once per month at Prince 5, a station at the mouth of the Bay of Fundy. Conditions there have been intermediate between those at Boothbay Harbor and at Halifax. Monthly surface temperature anomalies in 1995 were below normal from February to June and in December (Fig. 25). Strong positive anomalies were observed in January and July trough November. The annual anomaly was slightly positive. The time series suggests a decrease in 1995 relative to the very warm temperatures in 1994 (Fig. 25). Prior to 1994, temperatures were generally declining since about the mid-1980s.

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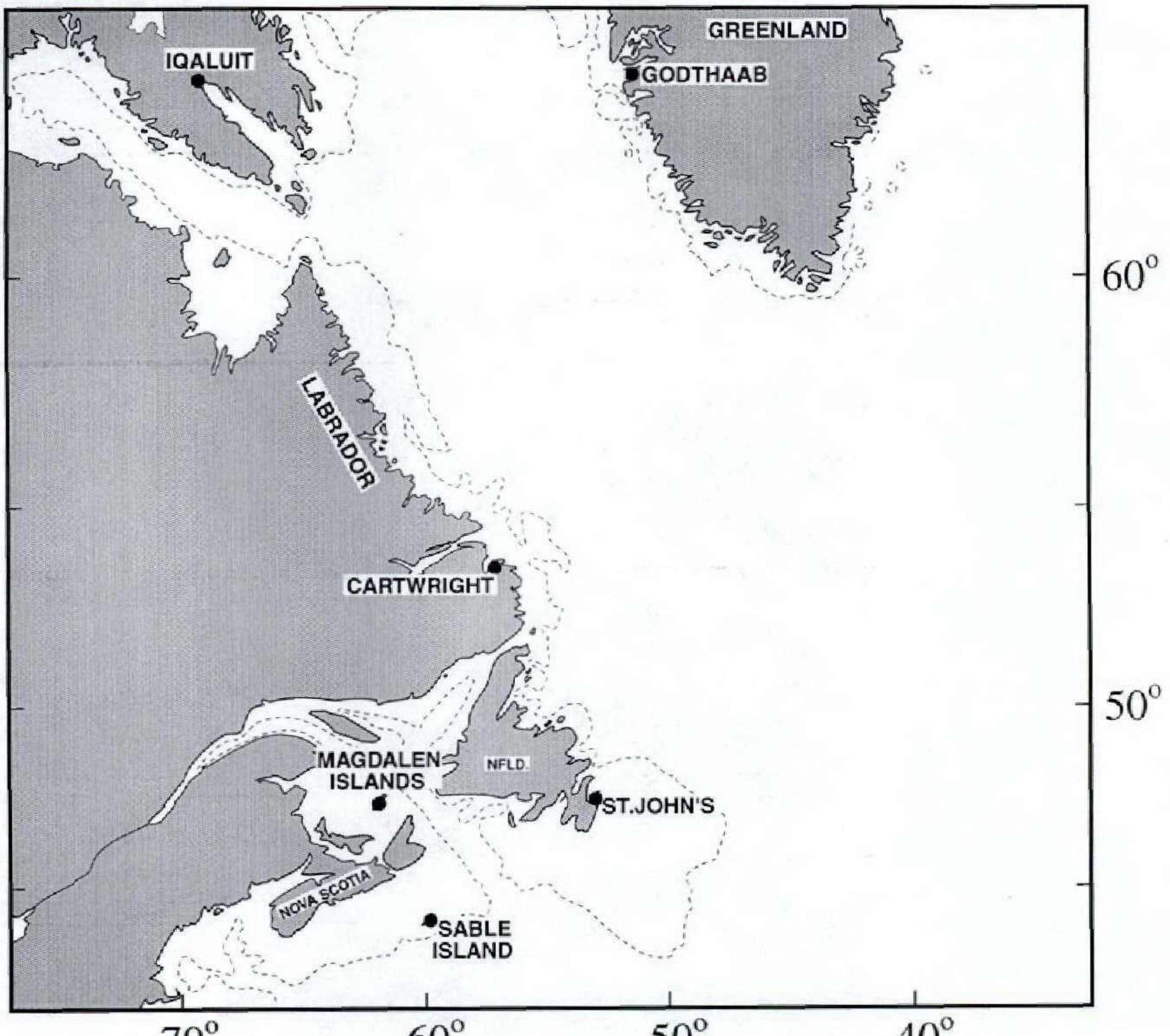

Fig. 1. The northwest Atlantic showing coastal air temperature sites.

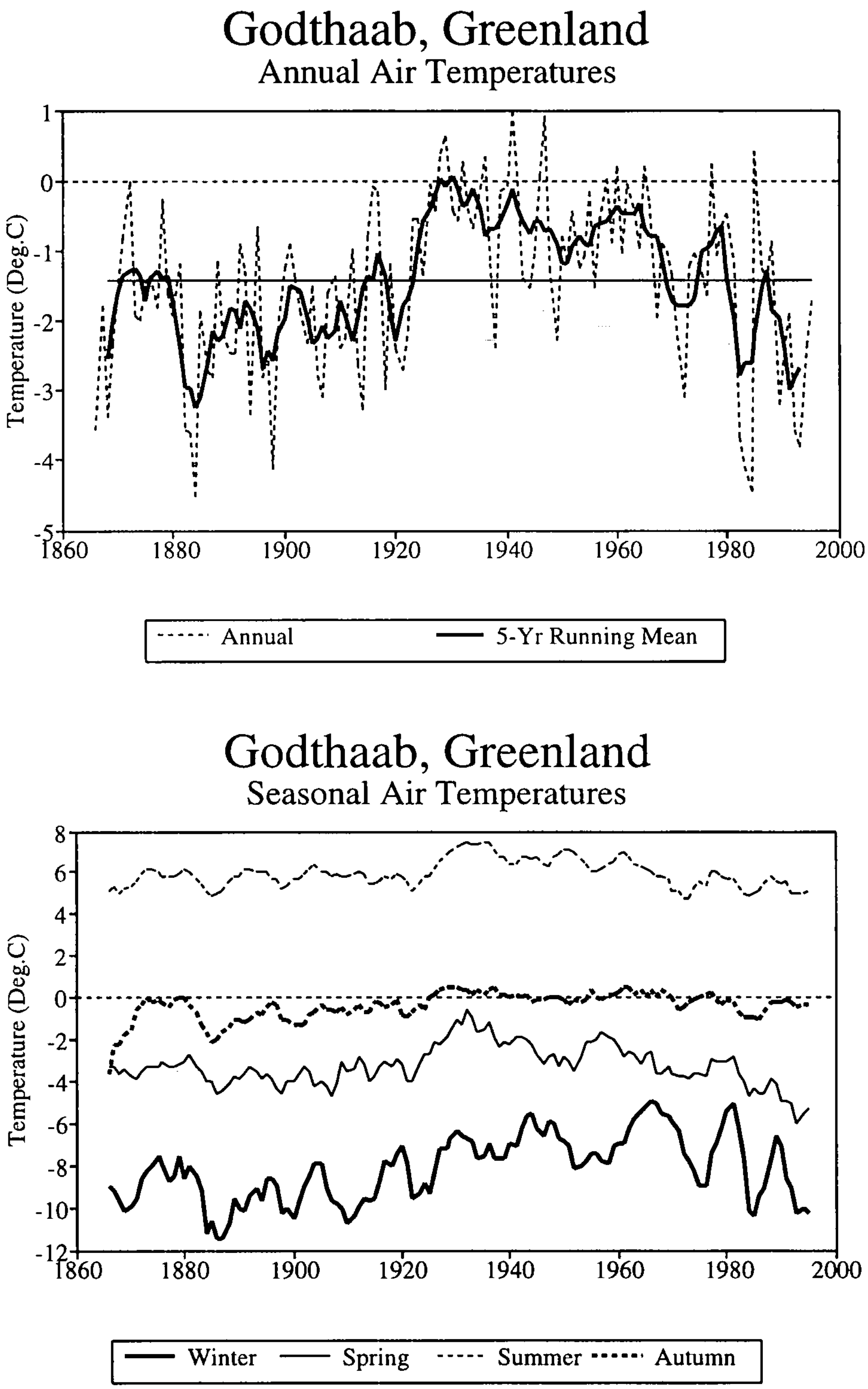

Fig. 2. The annual (top panel) and seasonal (bottom panel) air temperatures at Godthaab. The solid horizontal line in the top panel indicates the long-term annual average (1961-1990).

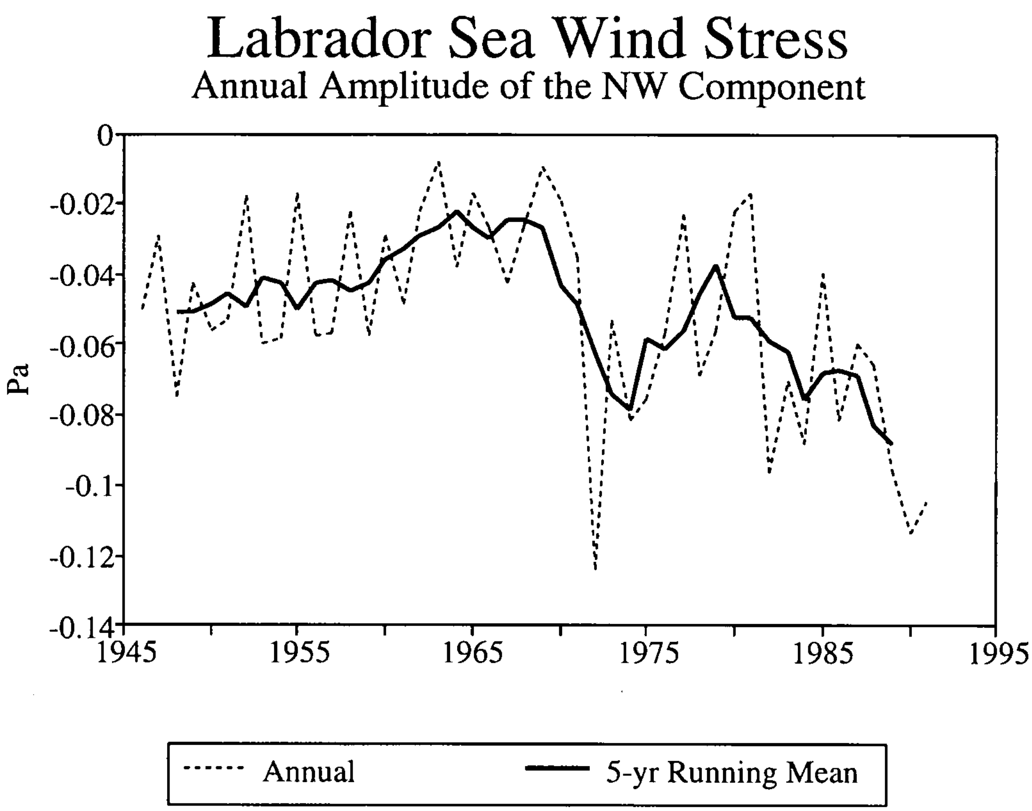

Fig. 3. The NW wind stress over the Labrador Sea.

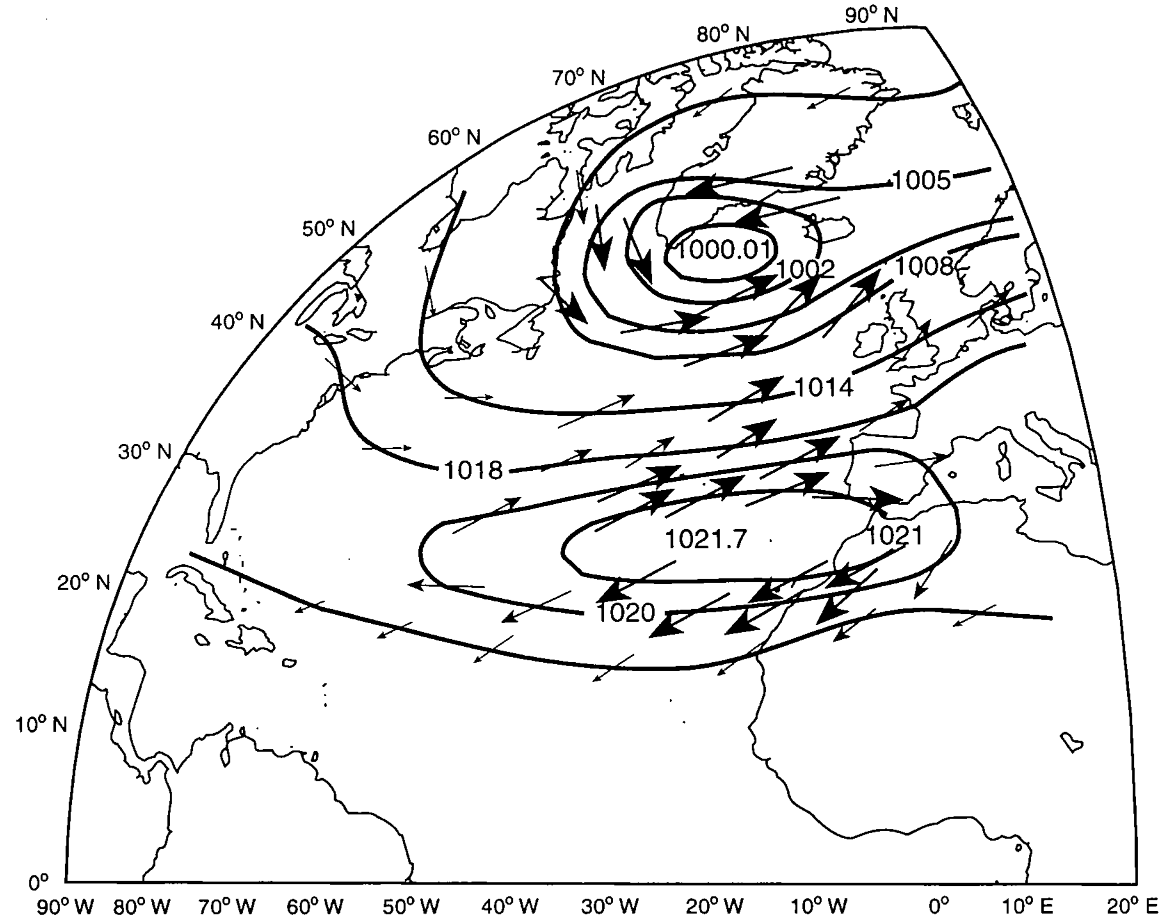

Fig. 4. The long-term (1961-90) mean sea surface pressure during the winter (average of December, January and February). The approximate wind field associated with the mean pressures are also shown.

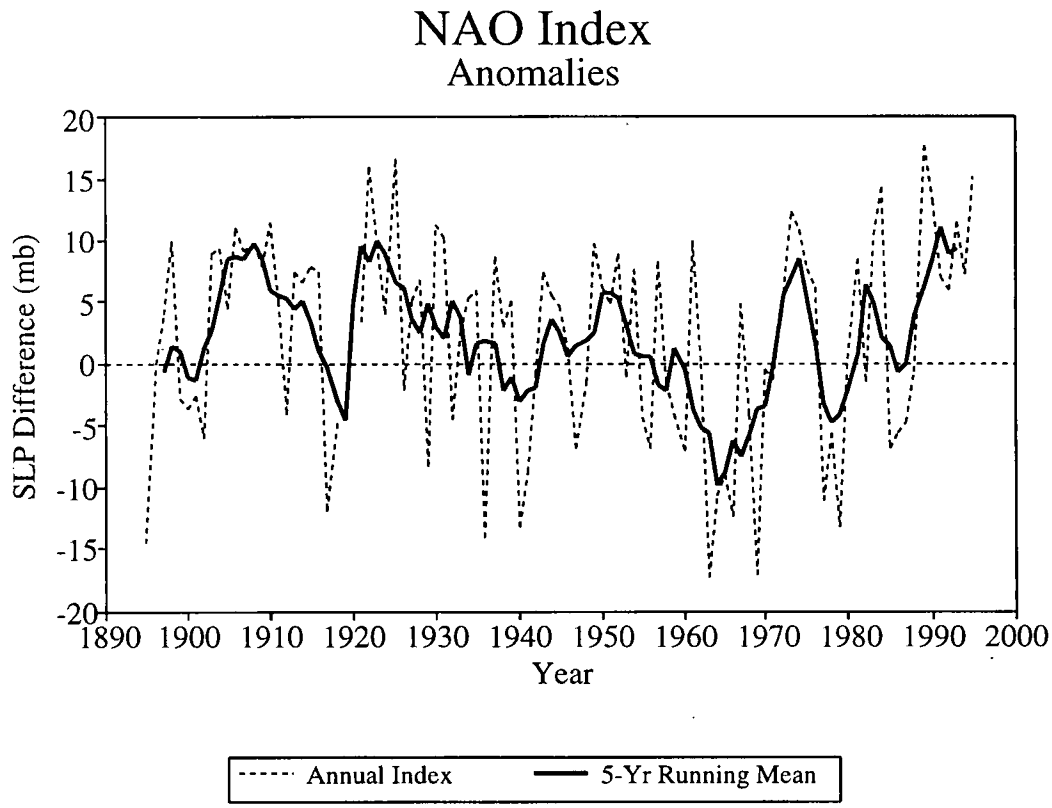

Fig. 5. The anomalies of the NAO index relative to the 1961-90 mean.

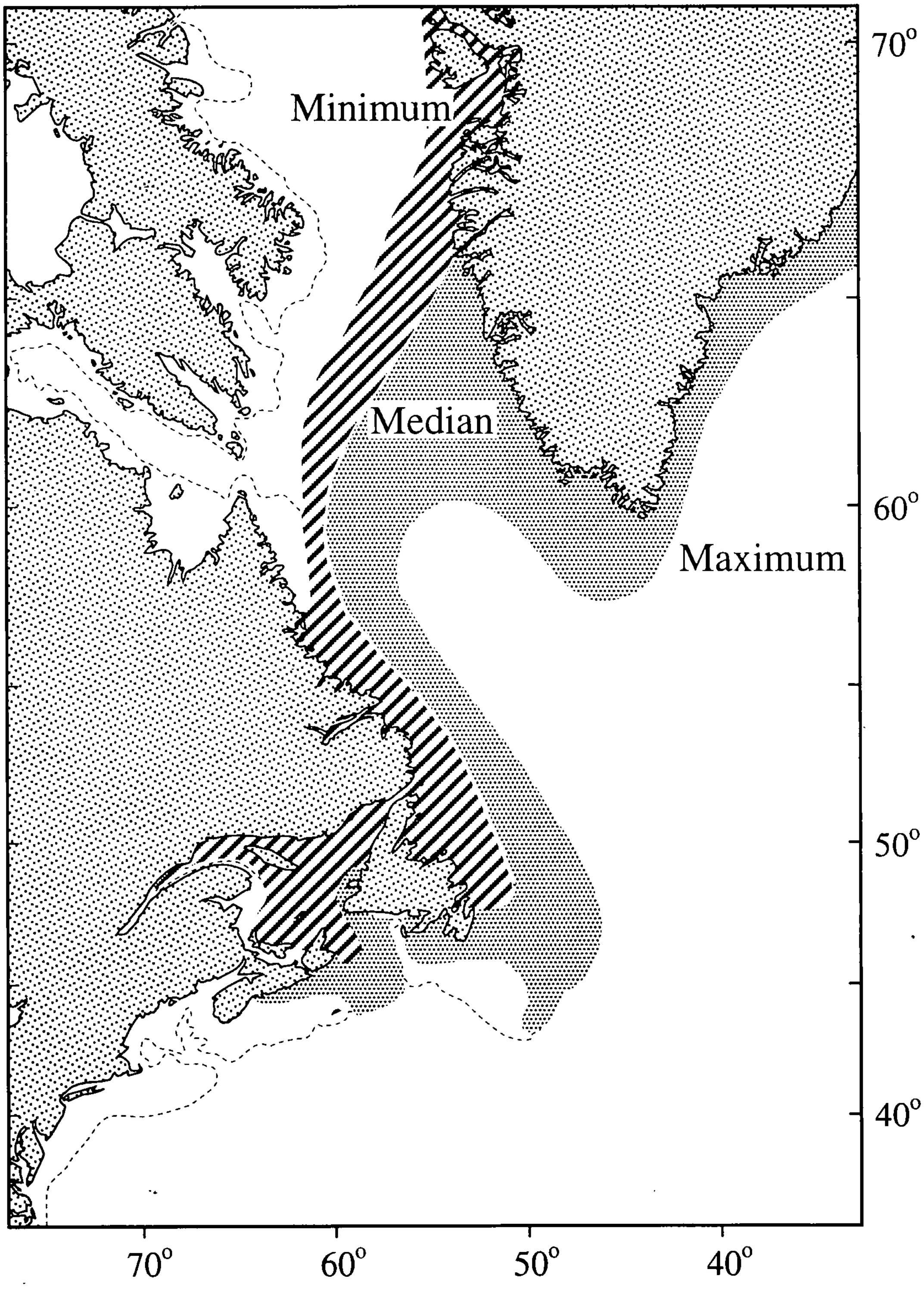

Fig. 6. The approximate location of the interannual minimum, median and maximum position of the edge of the sea ice (10%) concentration) during the peak ice season (based upon Coté, MS 1989).

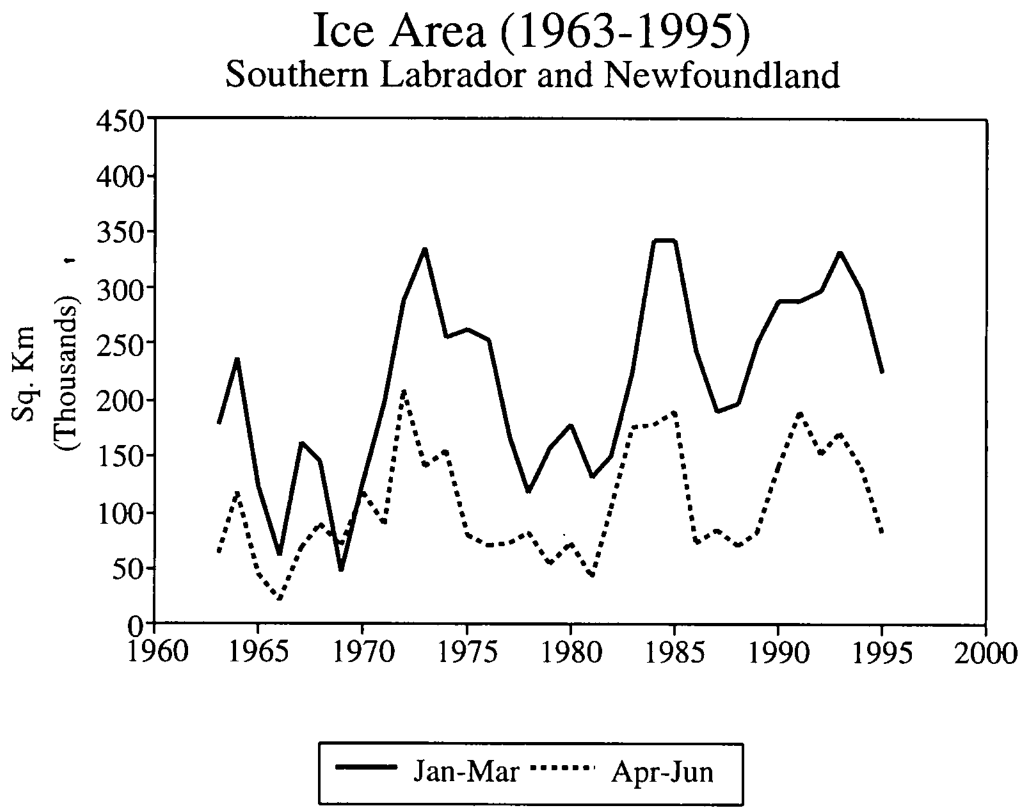

Fig. 7. The average area of ice between 45 and 55°N during ice advance (Jan to March) and ice retreat (April to June).

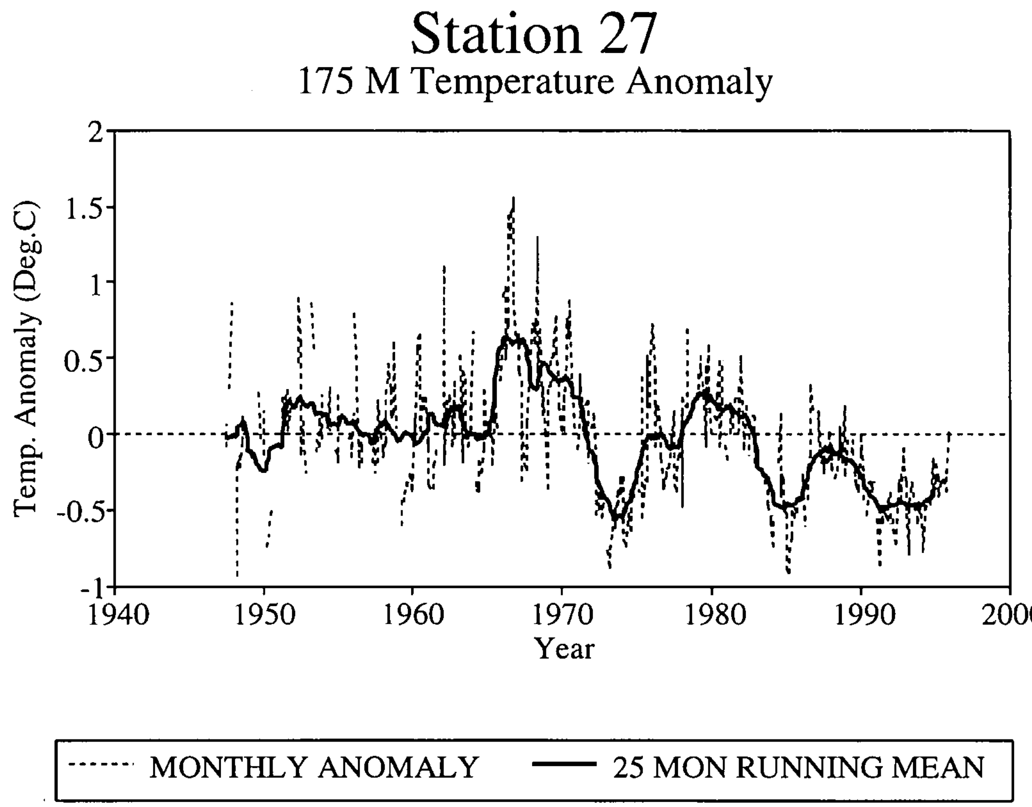

Fig. 8. The temperature anomalies relative to the 1961-90 mean at 175 m at Station 27. The filter is a 25 month running mean. The long term mean is near -0.5°C.

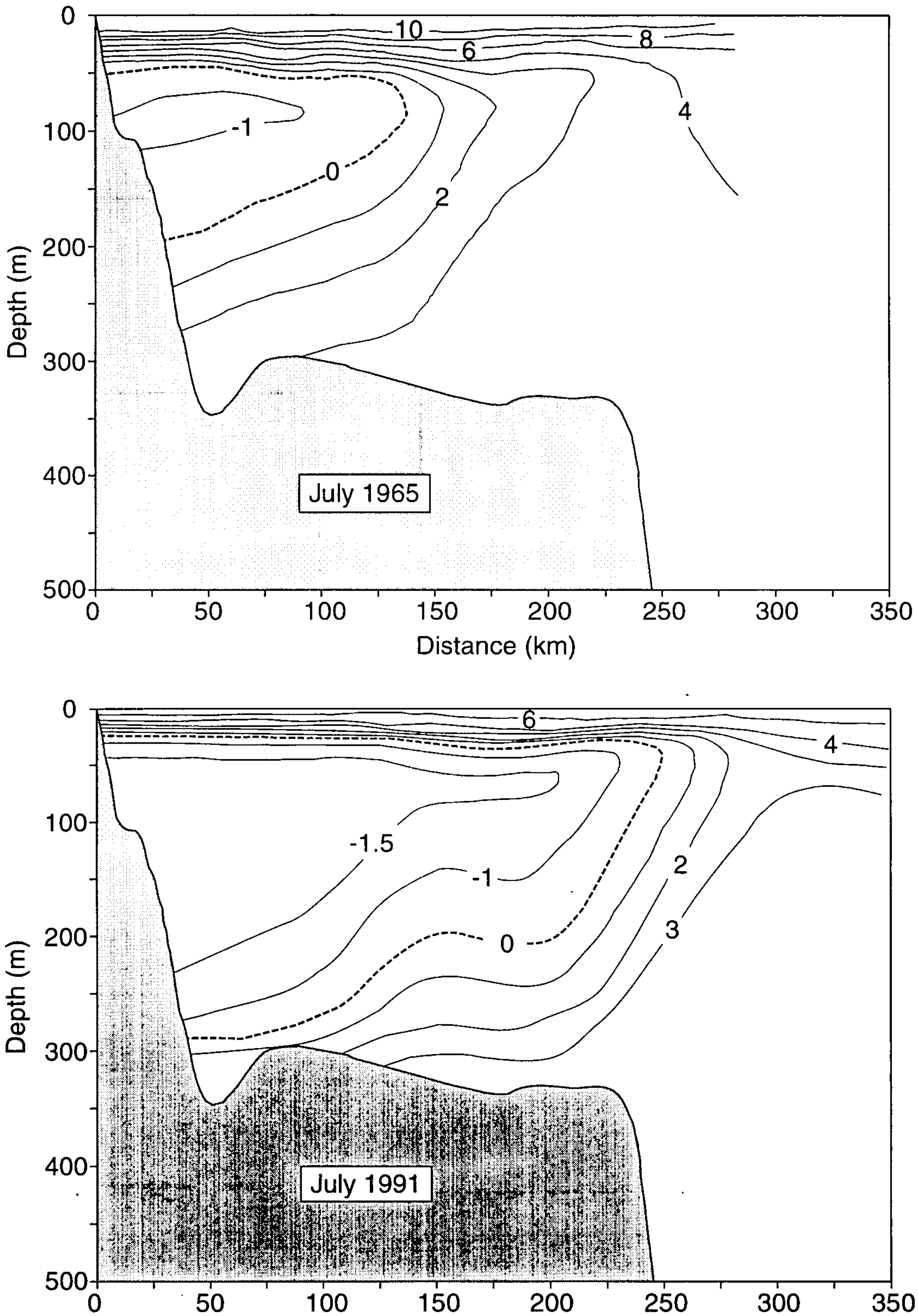

Fig. 9. The temperature contours along the Bonavista Line in summer during 1961 (top panel) and 1991 (bottom panel. Temperatures < 0^oC denote the CIL (Cold Intermmediate Layer) waters. Note the change in the area of CIL between the years.

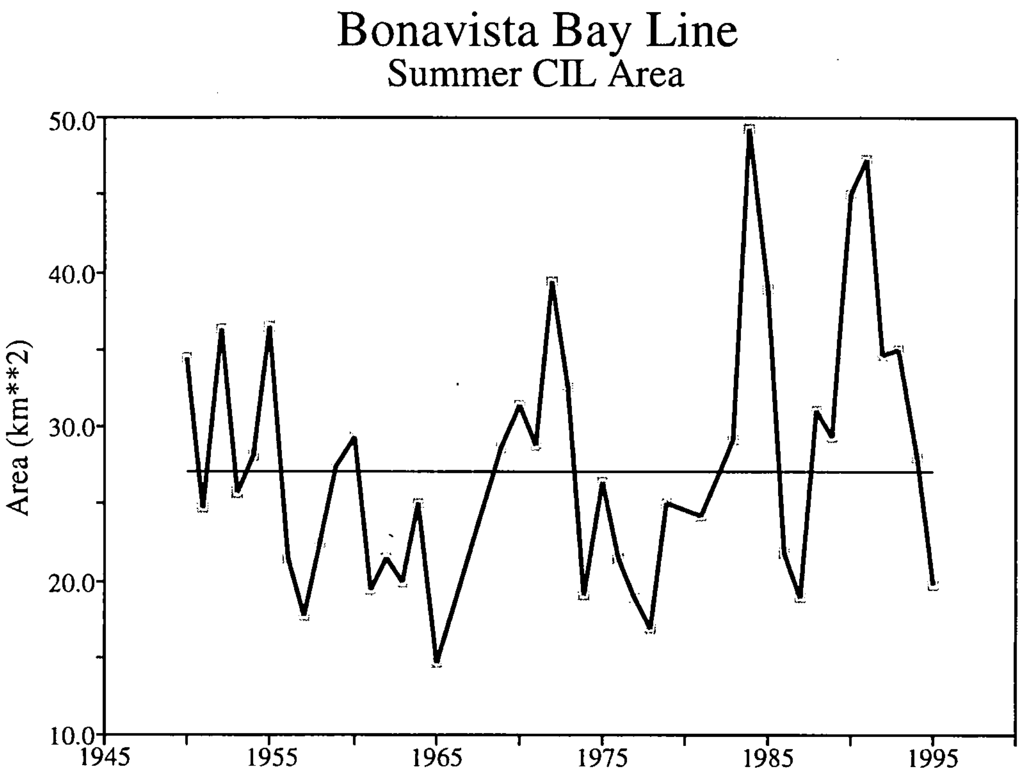

Fig. 10. The time series of the area of the cold intermediate layer (CIL) on the Bonavista Line in July.

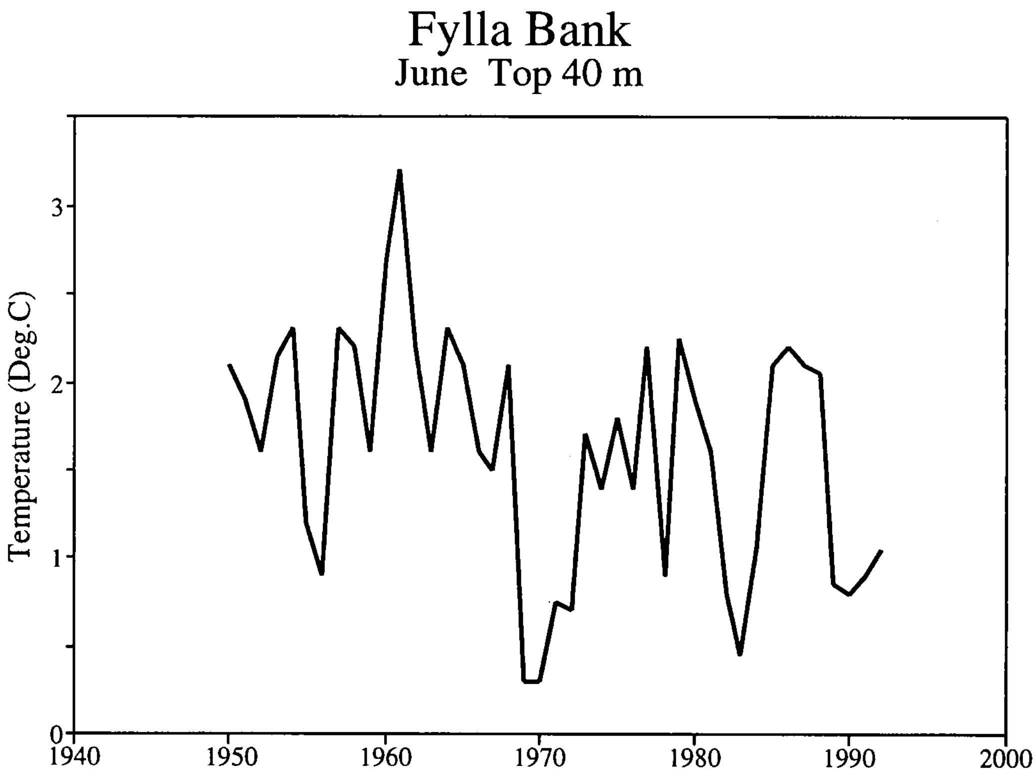

Fig. 11. The average mean temperature in June over the top 40 m at Fylla Bank off West Greenland.

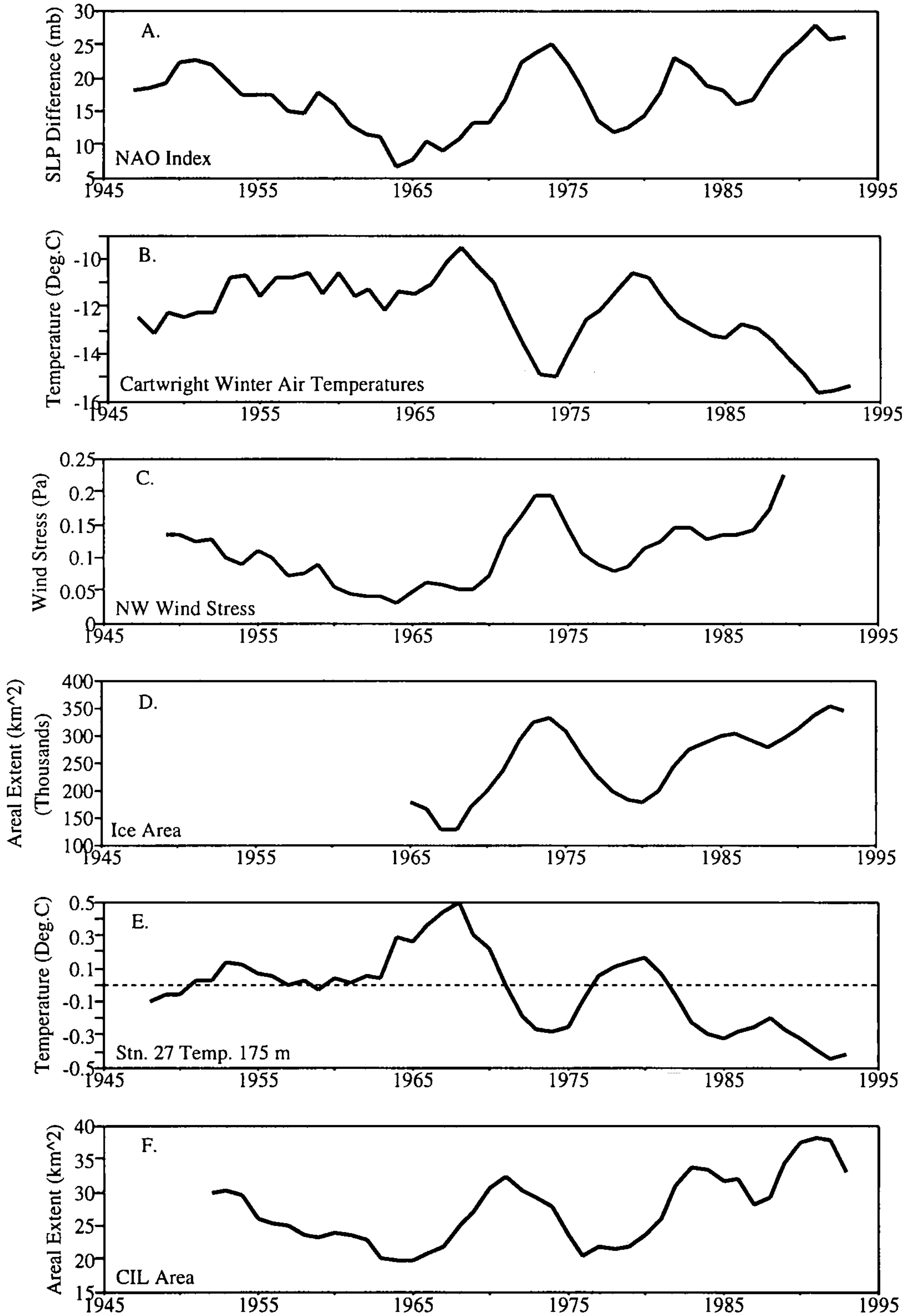

Fig. 12. The 5-y running means (from top to bottom) of the NAO index, Cartwright winter air temperatures, the northwest wind stress over the Labrador Sea, the February ice extent on the Labrador and northern Newfoundland shelves, Station 27 temperatures at 175 m and the CIL area on the Bonavista Line in summer.

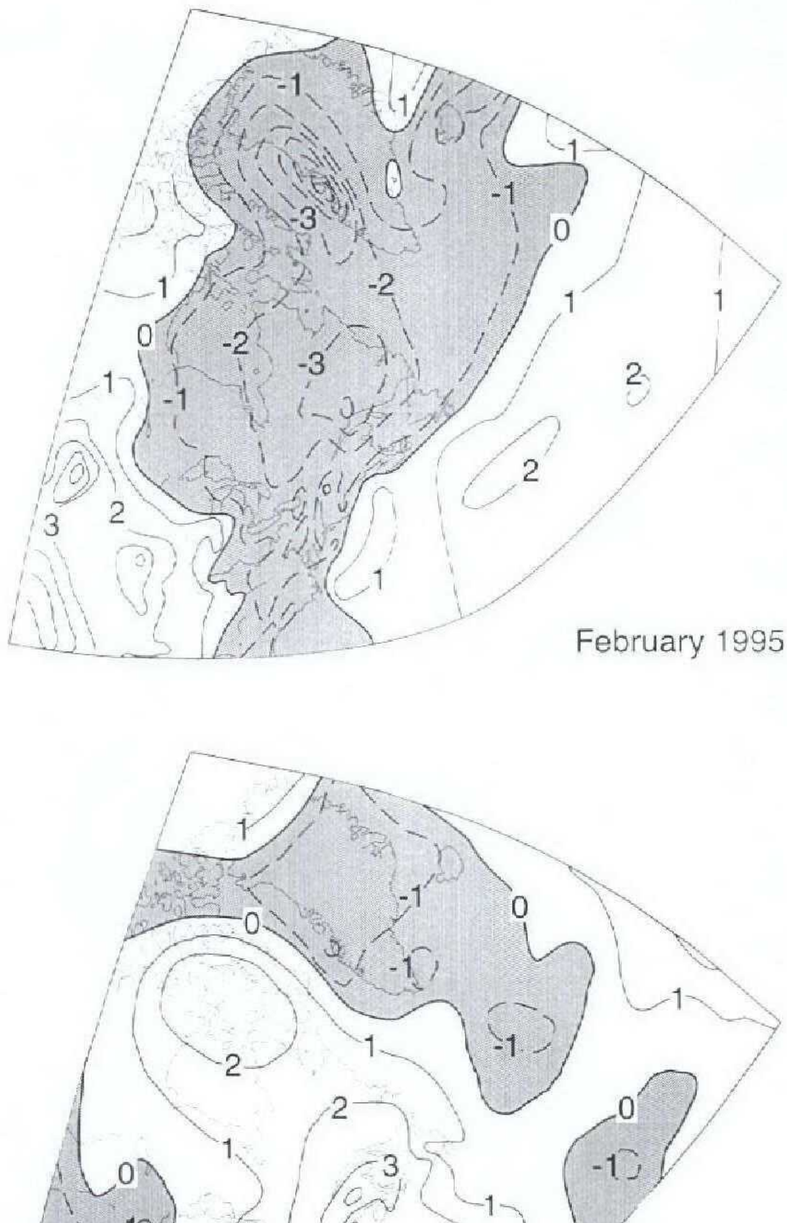

Fig. 13. Air temperature anomalies over the northwest Atlantic in February (top panel) and October (bottom panel) 1995 relative to the 1961-90 means. The shaded anomalies are below normal.

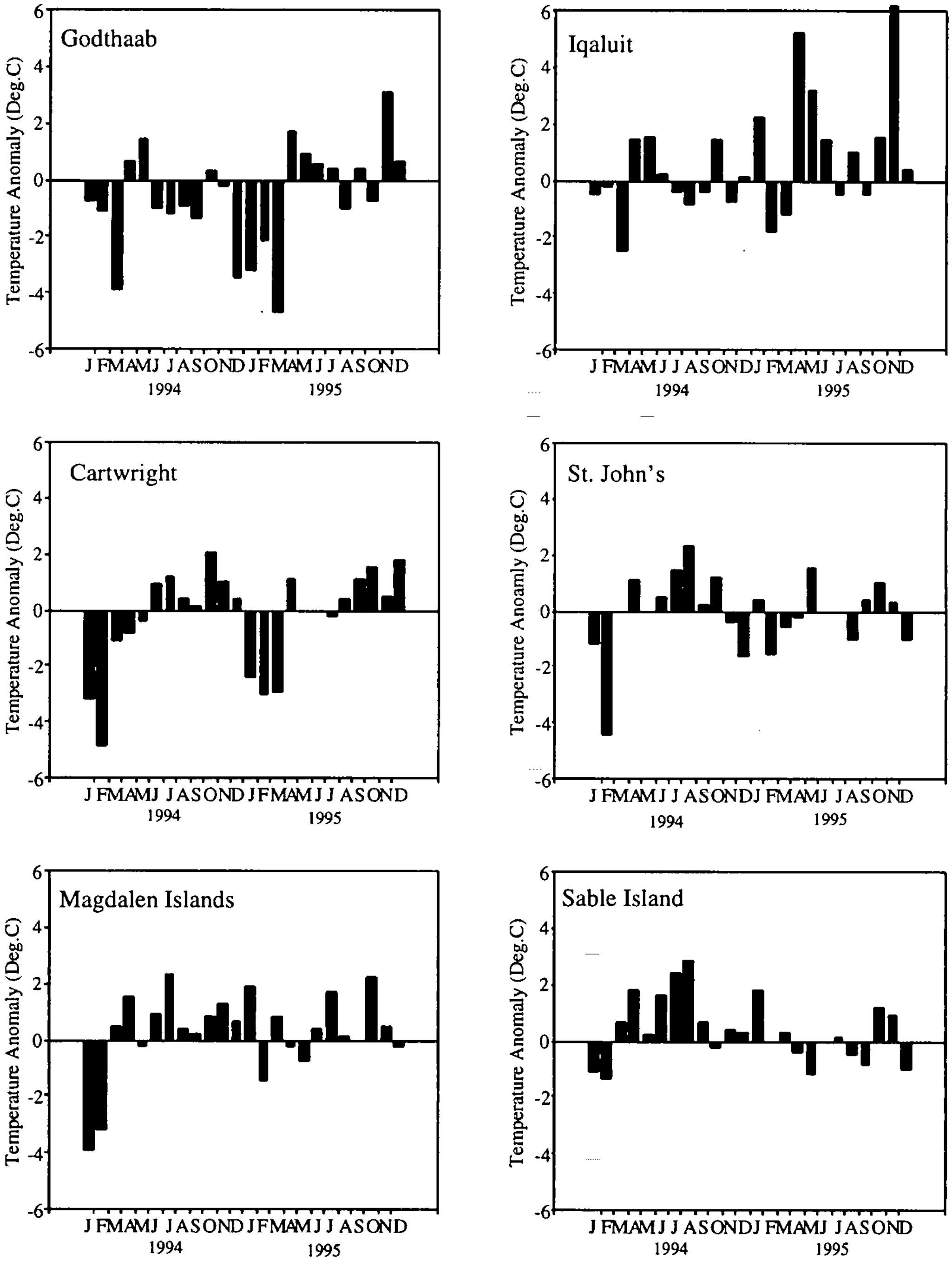

Fig. 14. Monthly mean air temperature anomalies for 1994 and 1995 for six coastal sites in the NW Atlantic.

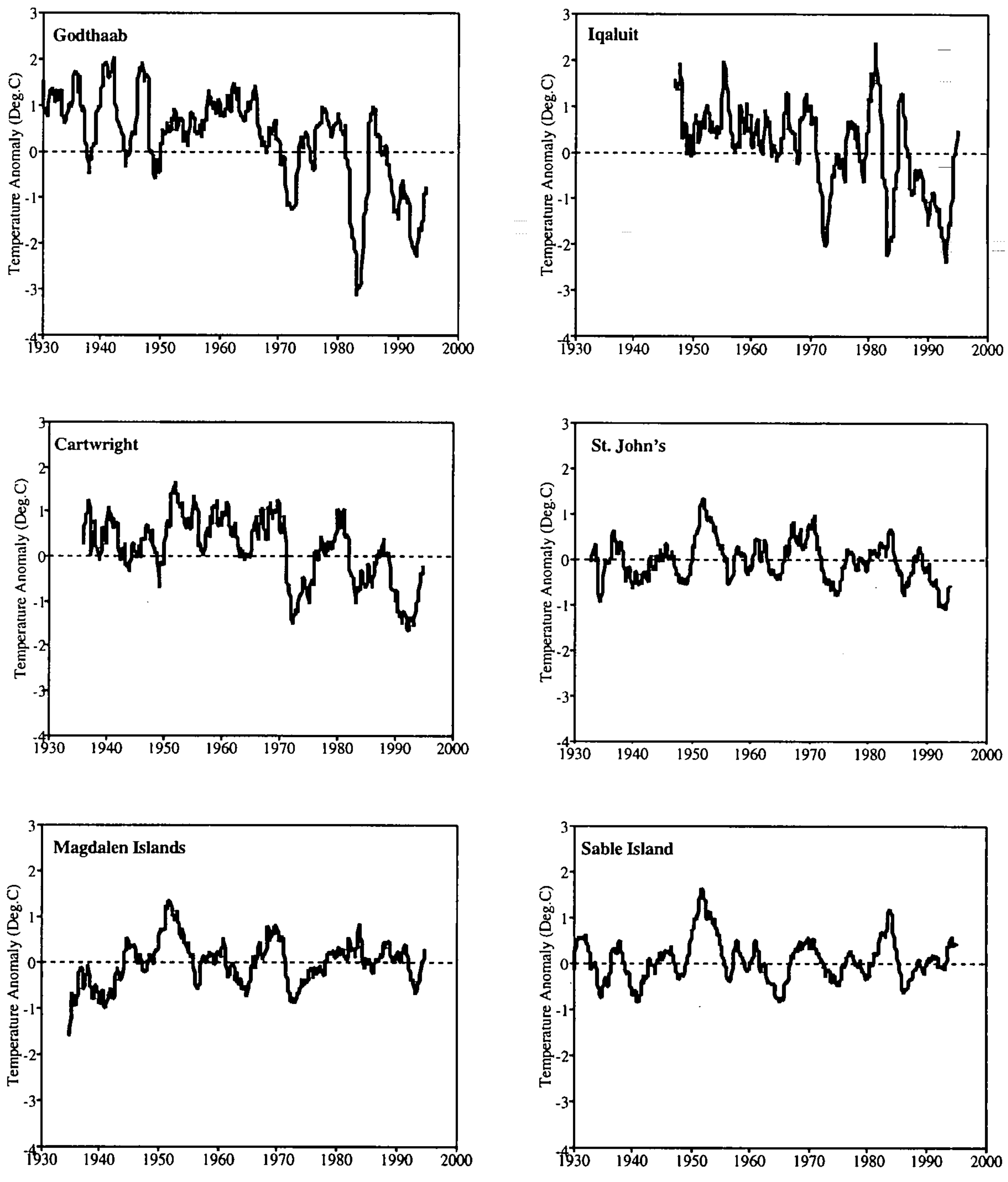

Fig. 15. The 25-month running means of air temperature anomalies at the six coastal sites.

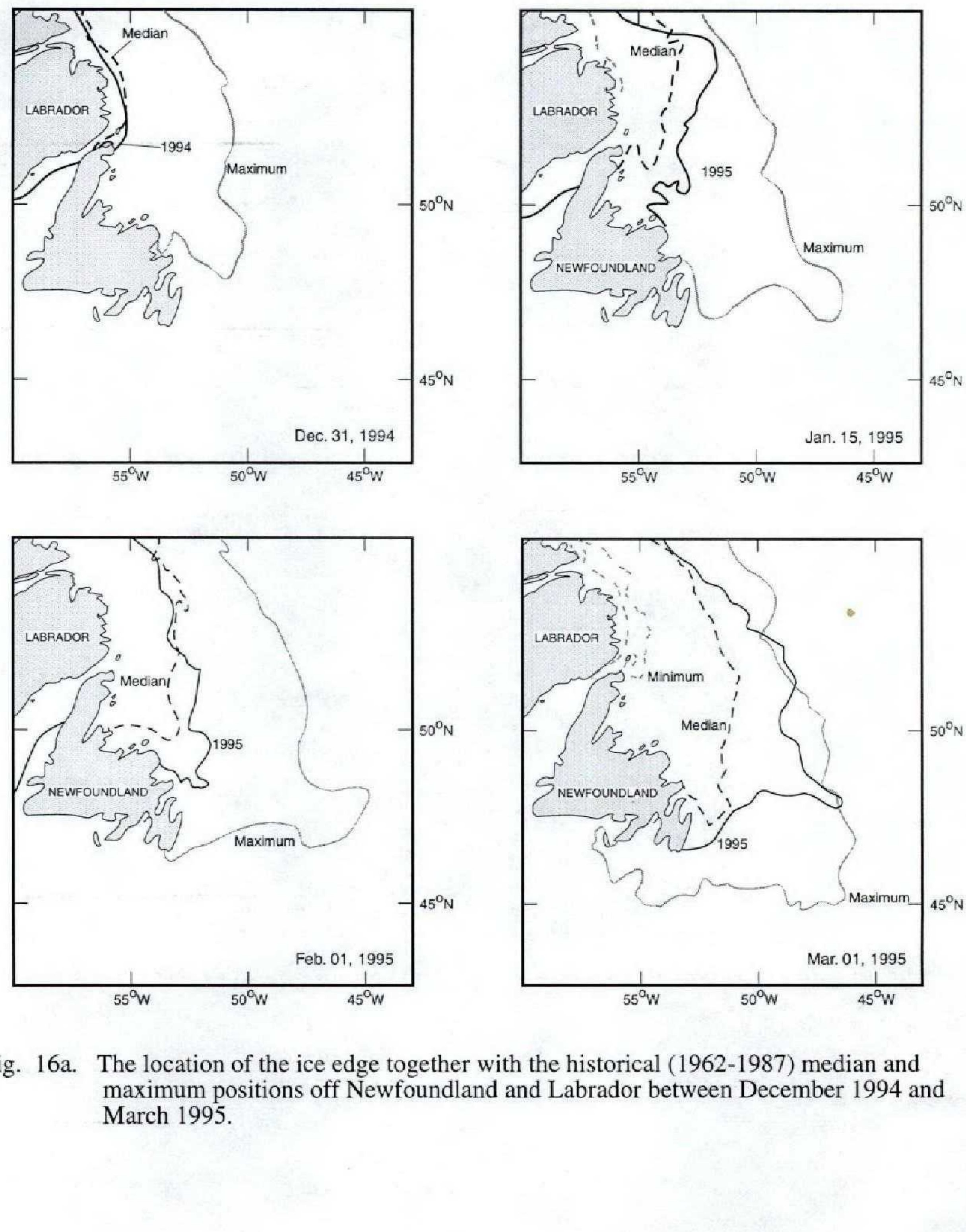

Fig. 16a. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between December 1994 and March 1995.

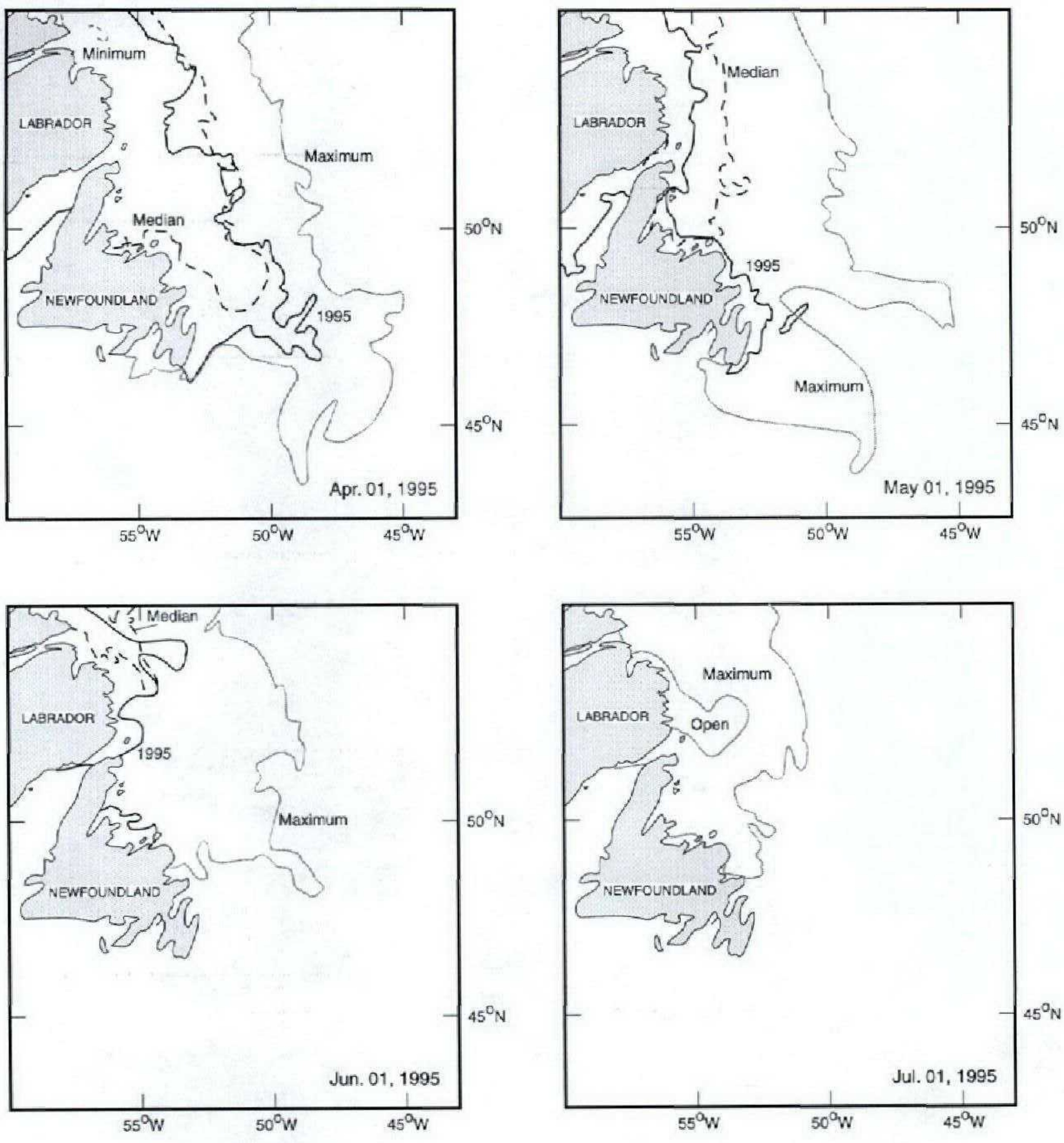

Fig. 16b. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Newfoundland and Labrador between April and July 1995.

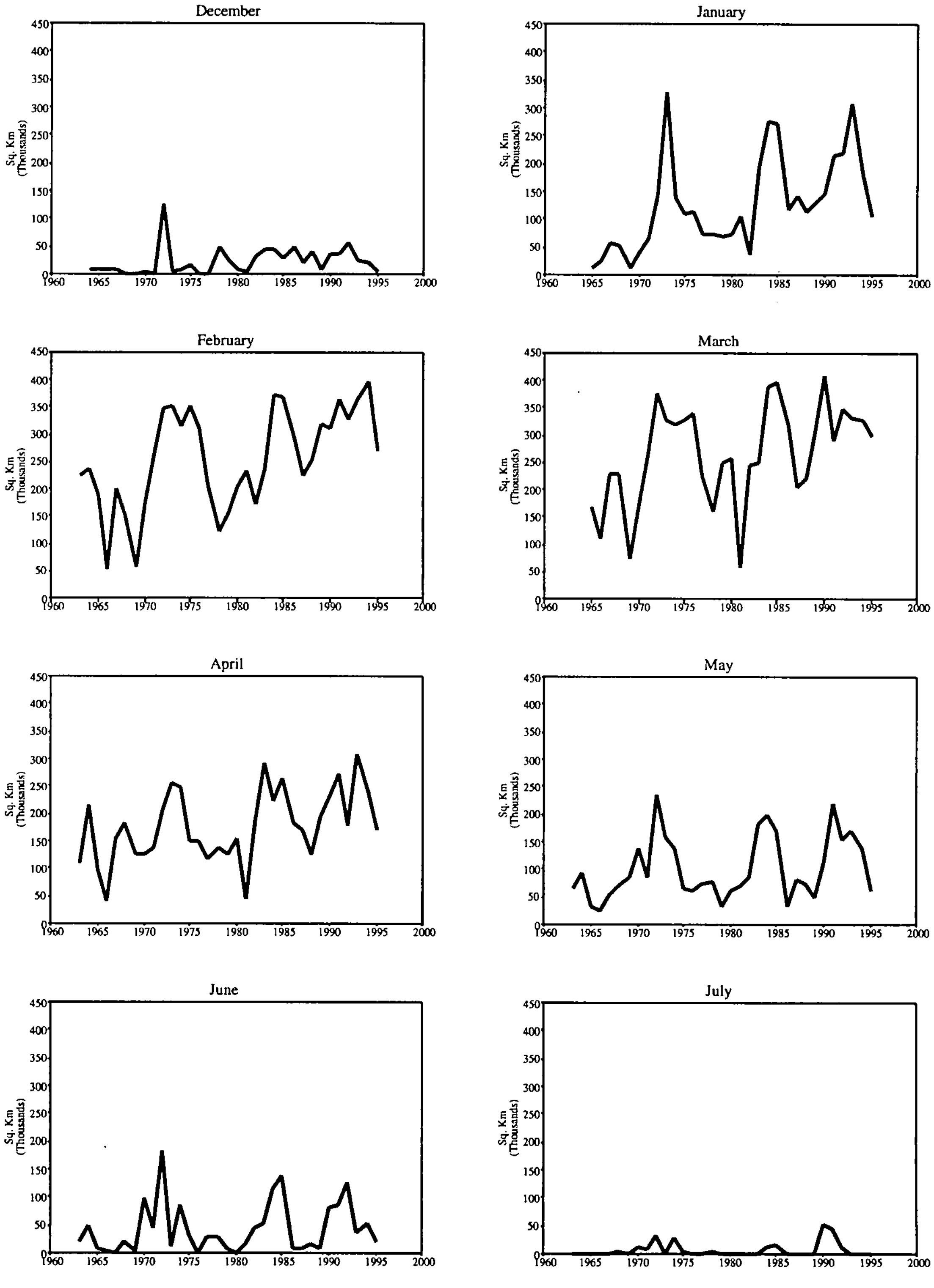

Fig. 17. Time series of the monthly mean ice areas off Labrador and northern Newfoundland between 45 and 55°N.

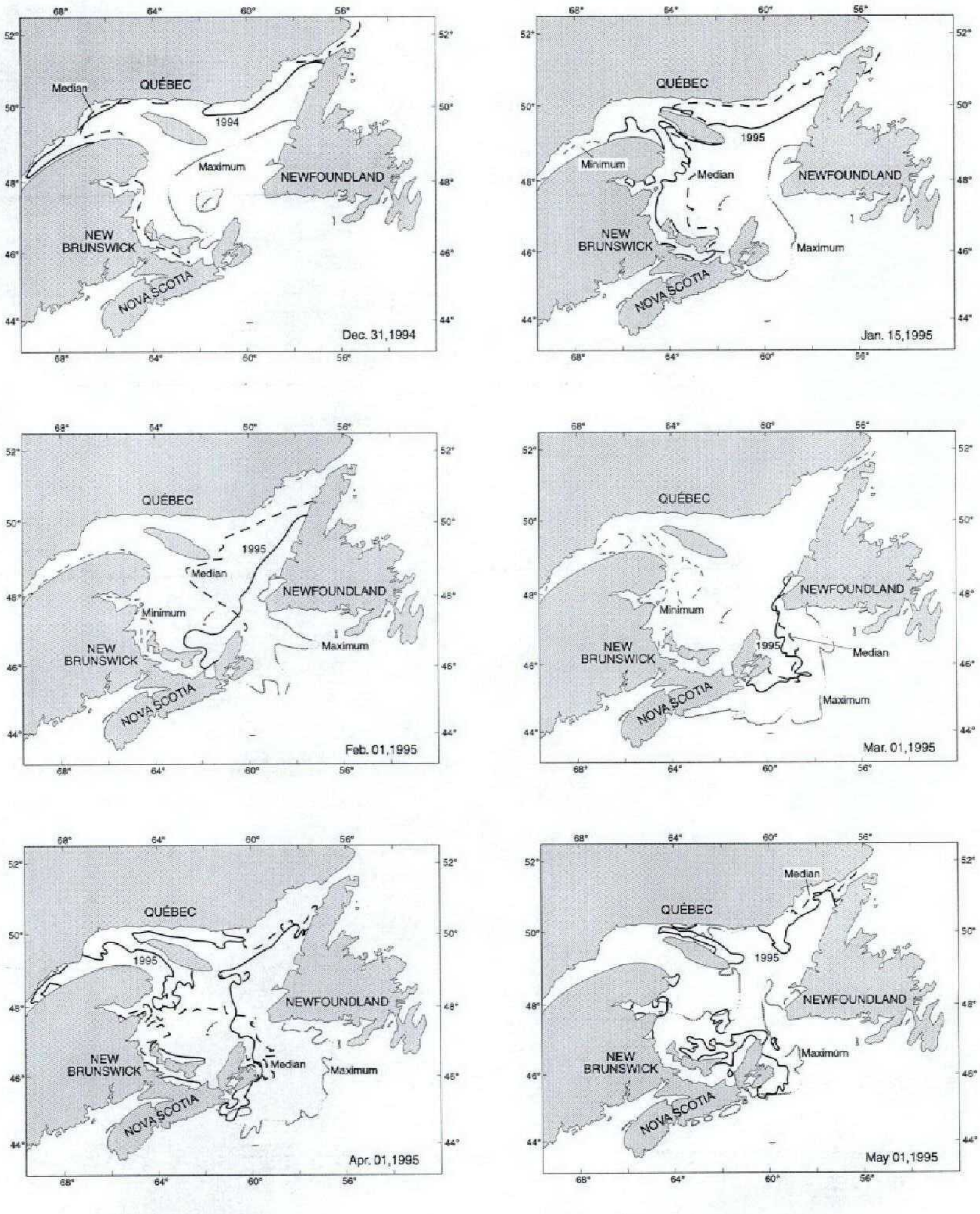

Fig. 18. The location of the ice edge together with the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence between December 1994 and May 1995.

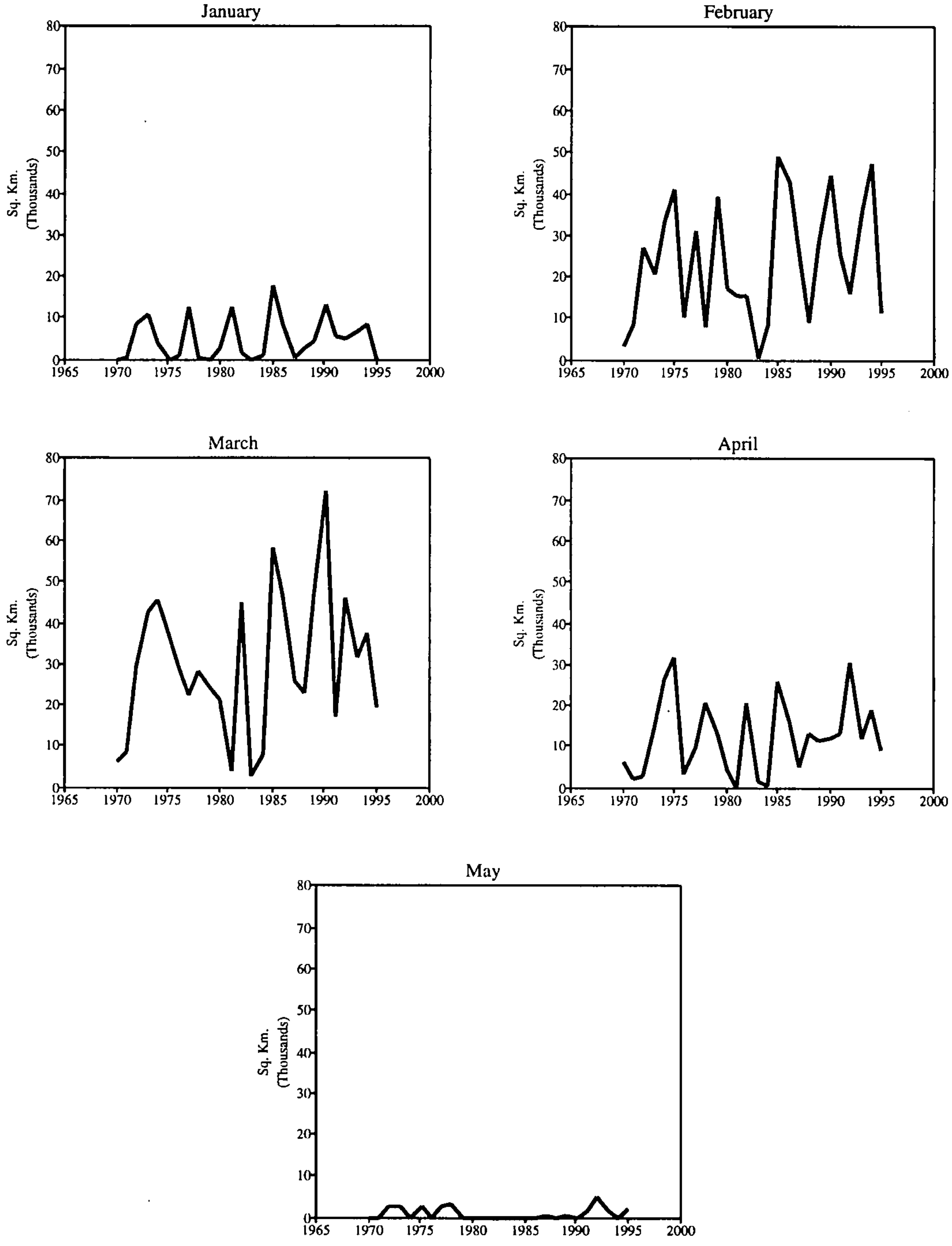

Fig. 19. Time series of the monthly mean ice areas seaward of Cabot Strait.

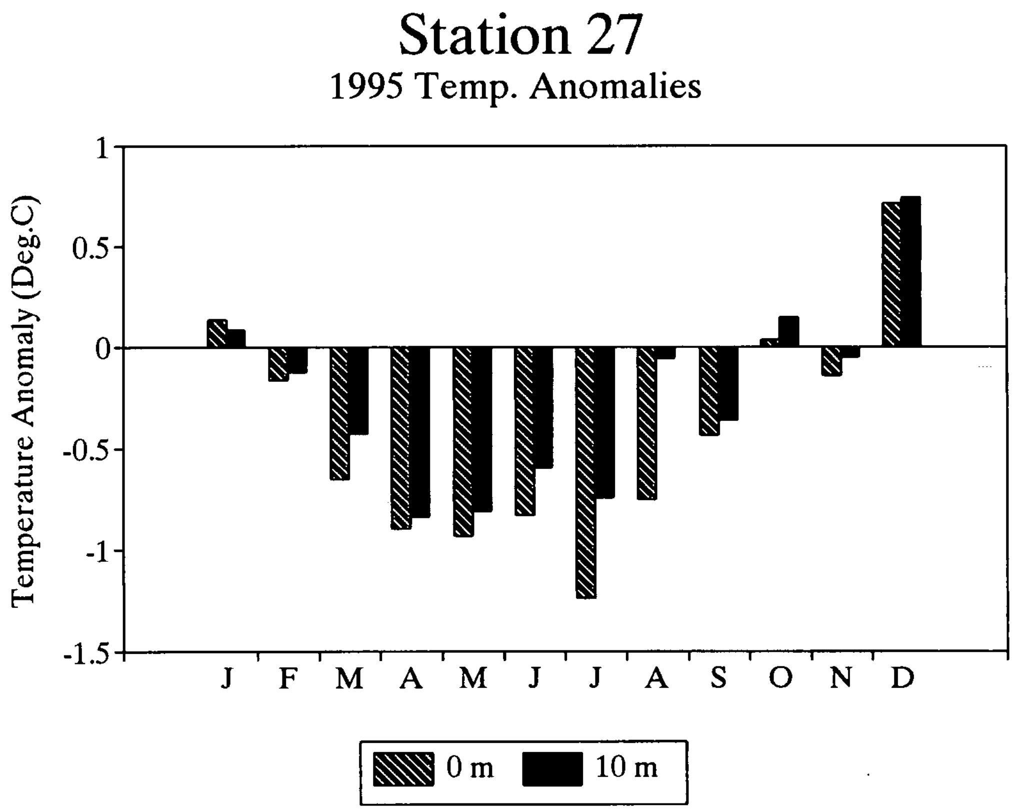

Fig. 20. The 1995 monthly mean temperature anomalies for 0 and 10 m at Station 27.

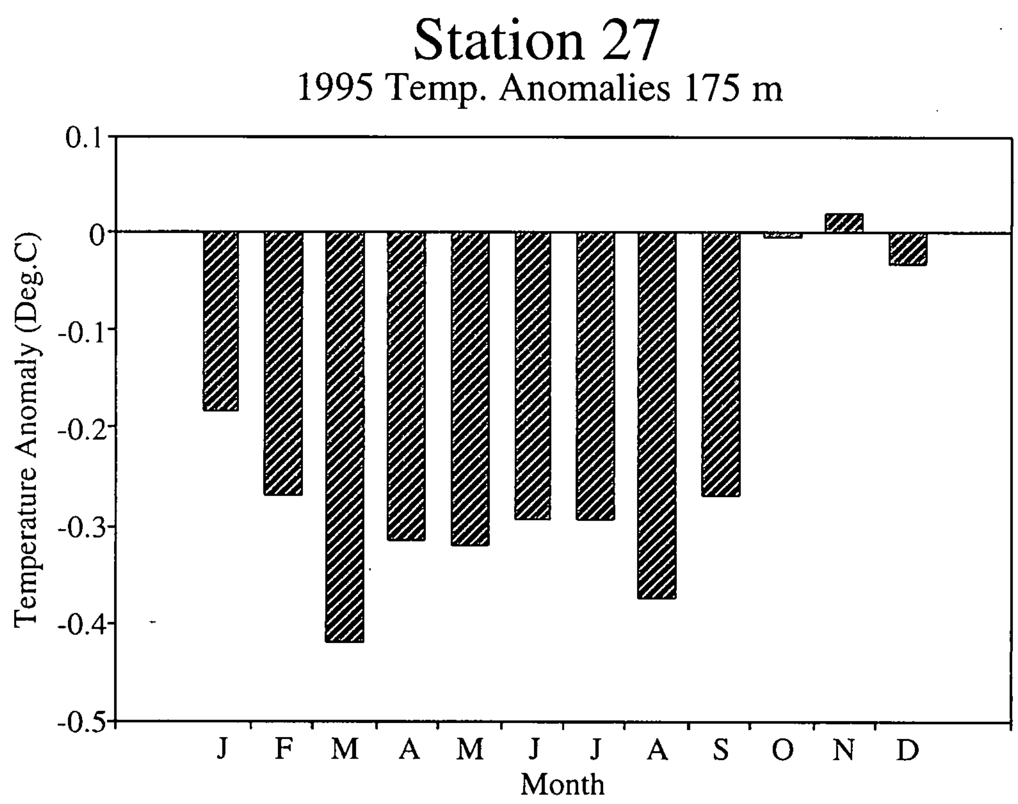

Fig. 21. The 1995 monthly mean temperature anomalies for 175 m at Station 27.

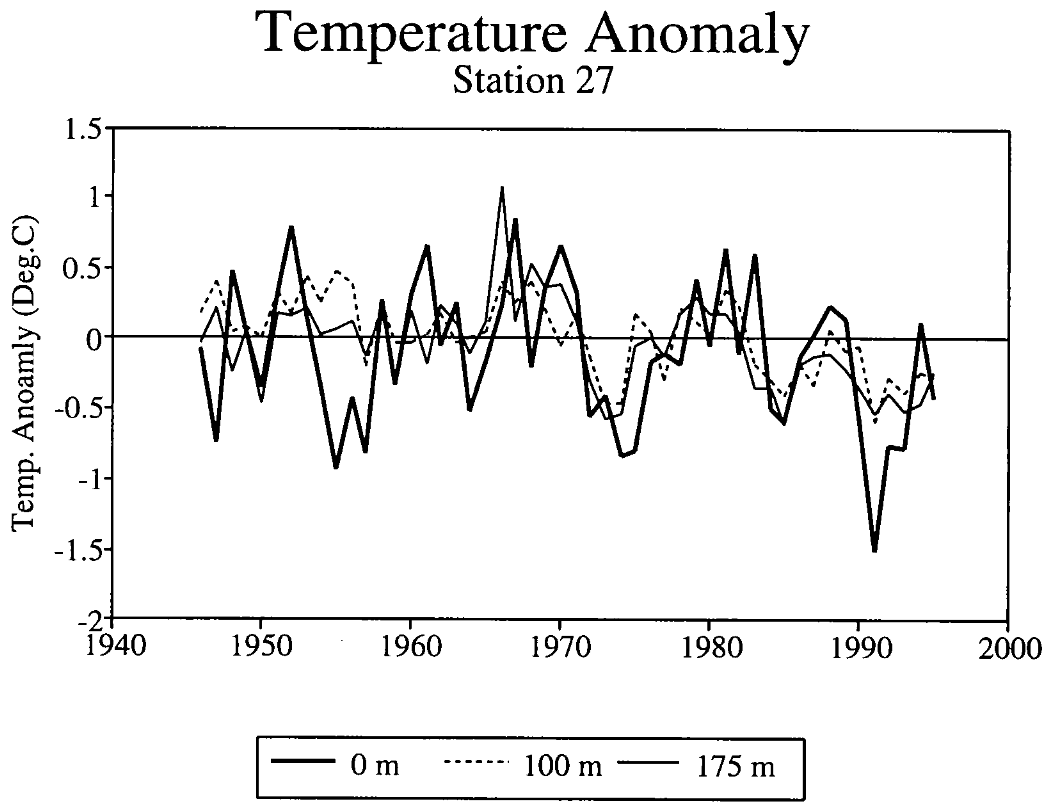

Fig. 22. The annual mean temperature anomalies at 0 m, 100 m, and 175 m at Station 27.

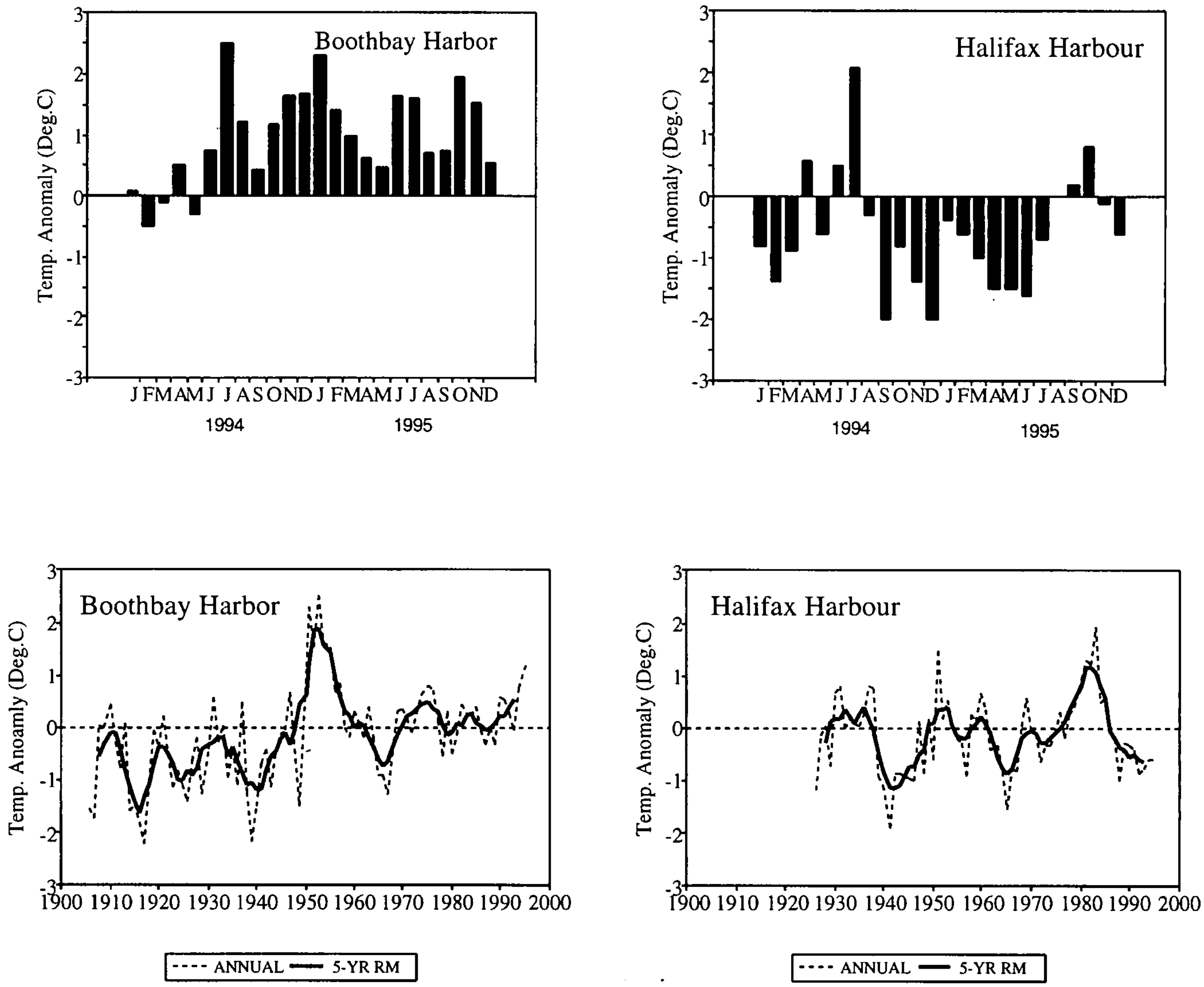

Fig. 23. The monthly mean surface temperature anomalies relative to 1961-90 (top panels) and the time series of the annual anomalies (bottom panels) for Boothbay Harbor, Maine (left panels) and Halifax Harbour, N.S. (right panels).

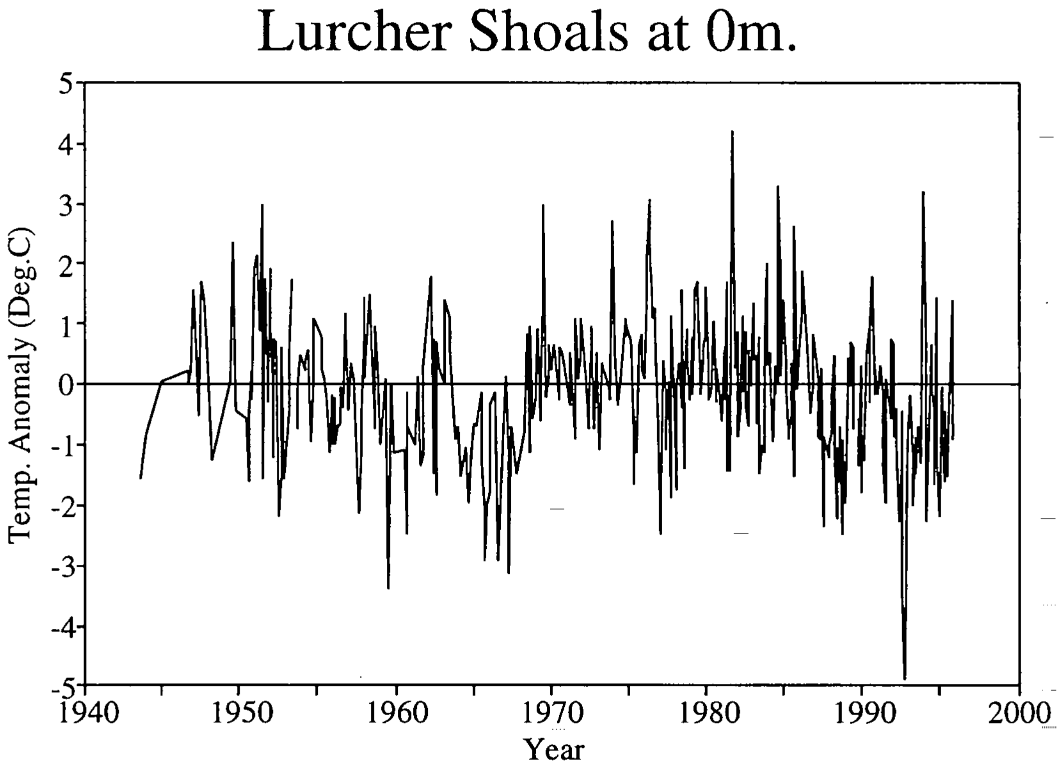

Fig. 24. The surface temperature anomalies relative to 1961-90 for Lurcher Shoals.

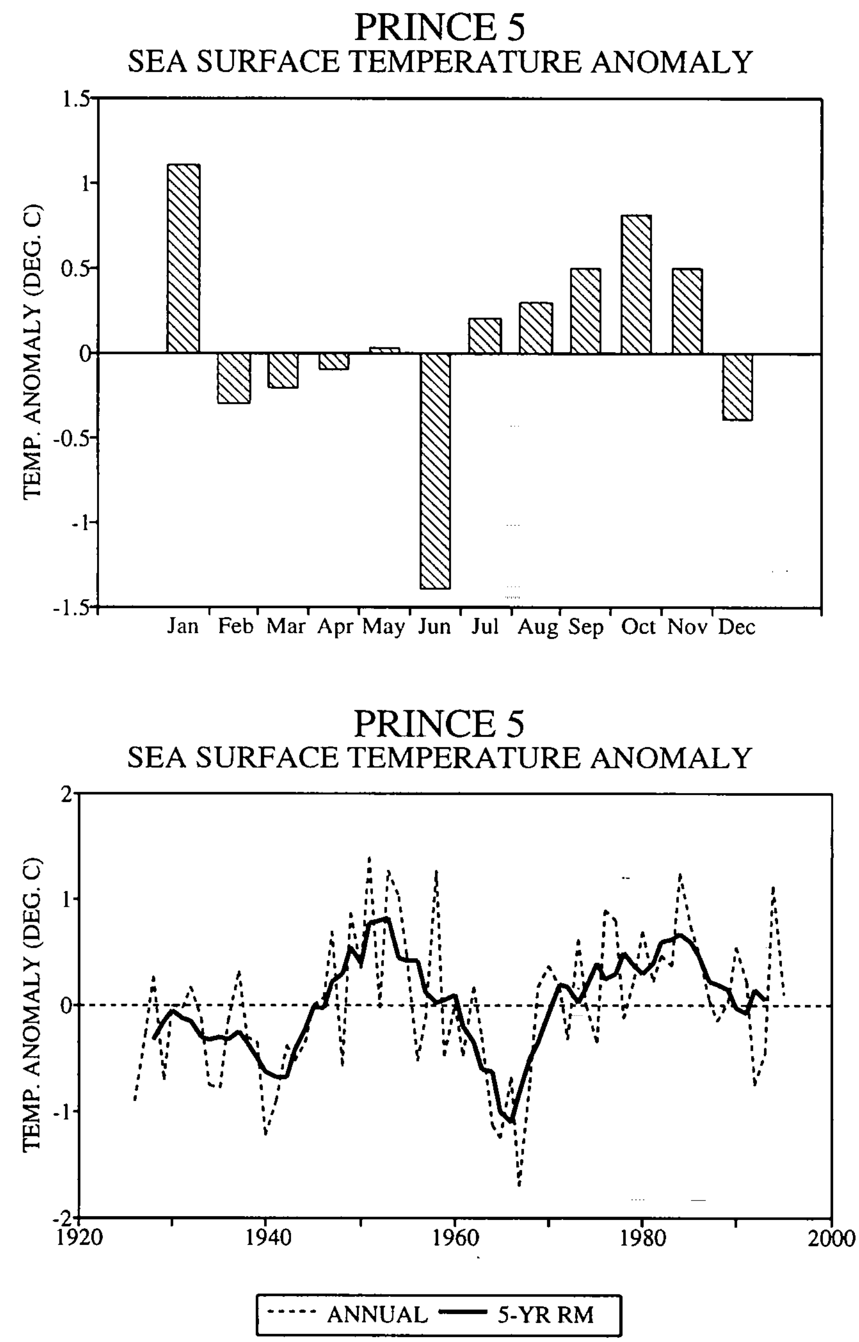

Fig. 25. The monthly mean surface temperature anomalies relative to 1961-90 (top panel) and the time series of the annual anomalies (bottom panel) for Prince 5.