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Marine Environmental Conditions in the Northwest Atlantic During 1996 Potentially Impacting Atlantic Salmon (*Salmo Salar*)

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ABSTRACT

Marine environmental conditions during 1996 in the Northwest Atlantic that could potentially impact eastern Canadian Atlantic salmon stocks are reviewed from available atmospheric and oceanographic datasets. The Labrador Sea is of particular interest because it is the overwintering site for most of these stocks. In the Labrador Sea, environmental conditions moderated during 1996 resulting in above normal air and ocean temperatures, the latter for the first time in over a decade. This warming is related to lower northwest winds over the region which in turn is linked to a weakening of the Icelandic Low air pressure system and a drop in the North Atlantic Oscillation (NAO). The NAO index, a measure of the strength of the large-scale atmospheric circulation, experienced its largest annual decrease in over 100 years of record. Based upon previous studies, these warmer winter conditions in the Labrador Sea should help to improve marine survival of salmon. Some of the inner Bay of Fundy salmon stocks are known to overwinter in the Gulf of Maine instead of migrating to the Labrador Sea. In the Gulf of Maine, temperatures are believed to be above normal as suggested by measurements at Boothbay Harbor, Maine. An exception is on Lurcher Shoals off southern Nova Scotia were temperatures were below normal through most of the year.

RÉSUMÉ

On utilise des séries de données atmosphériques et océanographiques pour passer en revue les conditions du milieu marin de l'Atlantique nord-ouest en 1996 qui pourraient avoir eu un impact sur les stocks canadiens de saumon atlantique. La mer du Labrador est d'intérêt particulier parce que la plupart de ces stocks y passent l'hiver. Les conditions de ce milieu se sont adoucies en 1996, résultant en des températures de l'air et de la mer au-dessus de la normale, la première fois en plus de dix ans dans le cas de la température de la mer. Ce réchauffement est lié à un norois moins fort dans la région qui, en retour, est lié à un affaiblissement de la dépression d'Islande et à une baisse de l'oscillation nord-atlantique (ONA). L'indice ONA, mesure de la force de la circulation atmosphérique à grande échelle, a montré la plus forte baisse annuelle en plus d'un siècle d'enregistrements. D'après des études antérieures, les conditions plus chaudes de la mer du Labrador en hiver devraient aider à améliorer la survie du saumon en mer. On sait que certains des stocks de saumon du fond de la baie de Fundy passent l'hiver dans le golfe du Maine au lieu de migrer vers la mer du Labrador. On croit que les températures dans le golfe du Maine se situent au-dessus de la normale comme le laissent croire les mesures effectuées à Boothbay Harbour, au Maine. Les hauts-fonds Lurcher, au sud de la Nouvelle-Écosse, font exception, la température s'y étant située au-dessous de la normale pendant presque toute l'année.

Introduction

This paper presents atmospheric and physical oceanographic conditions during 1996 that may have influenced Atlantic salmon (*Salmo salar*) stocks during their marine phase. These fish spawn in the rivers of eastern North America and most migrate in the fall to the Labrador Sea where they overwinter (Reddin and Friedland, 1993). Exceptions to this pattern are the inner Bay of Fundy stocks that are believed to overwinter somewhere within the Gulf of Maine region, although the exact location is unknown. Earlier studies have revealed that oceanic variability influences both recruitment survival and growth of several salmon stocks (Reddin and Shearer 1987; Ritter 1989; Friedland et al. 1993) as well as the timing and location of the return migration (Reddin and Friedland, 1993; Narayanan et al., 1995). Similar to last year (Drinkwater, 1996), the focus of this review is upon the meteorological, ice and temperature conditions during 1996 in those areas of the Northwest Atlantic where salmon are found during their marine phase. This covers the continental shelf regions from the Gulf of Maine to Labrador and the Labrador Sea (Fig. 1). Climatic conditions within the paper are often expressed as anomalies, i.e. differences from their long term mean. Where possible, long-term has been standardized to a 30-yr (1961-90) base period in accordance with the convention of meteorologists and recommendations of the North Atlantic Fisheries Organization. We begin with background information on the linkages between the atmospheric and oceanic connections in the Labrador Sea. This is followed by discussion of the 1996 environmental conditions in the Labrador Sea and in the waters around the Maritime provinces of Canada.

Atmospheric and Oceanic Linkages in 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). In last year's review (Drinkwater, 1996), a detailed description of the linkages between the NAO index, meteorological conditions, sea ice and ocean temperatures was provided. As background, a brief summary precedes our examination of the 1996 data.

The large-scale atmospheric pressure patterns over the North Atlantic Ocean are dominated by the Icelandic Low, centered between southern Greenland and Iceland, and the Azores High, centered roughly above the Azores (Fig. 2). This pattern occurs year round but is most intense in winter. The strength of the Low and High vary from year-to-year with the tendency for both pressure systems to intensify (or weaken) in the same year. 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 index corresponds to a deep Icelandic Low and an intense Azores High. The index is a latitudinal pressure gradient and therefore its increase results in corresponding increases in the strength of the westerly winds across the northern North Atlantic. It also means stronger northwest winds over the Labrador Sea (Fig. 3). In such years, these northwest winds carry cold Arctic air masses further south causing winter air temperatures to decrease (Fig. 3). This in turn results in earlier and more ice formation and the stronger northwest winds push the ice further south leading to more extensive ice coverage (Fig. 3). The cold, windy conditions in winter also result in high air-sea heat exchanges leading to extensive cooling of the waters over the shelf and in the Labrador Sea (Cayan, 1992). In years of low NAO, the opposite tends to occur, i.e. weakened Icelandic Low, reduced northwest winds, warmer-than-normal winter air temperatures, later and less extensive ice, reduced heat exchange leading to warmer ocean temperatures. We now turn our attention to conditions during 1996.

Physical Environmental Conditions in the Northwest Atlantic during 1996

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. In 1996, the index fell dramatically producing an anomaly that was strongly negative and well below last year's value (Fig. 4). This reverses the trend of very high NAO indices that had persisted since the late 1980s and suggests the possibility of a significant shift in the large scale atmosphere circulation. It fits the pattern of near decadal variability that has persisted since the 1960s but the amplitude of the decline (23.3 mb) is surprising, being the largest annual decrease recorded in the over 100 year record. This low NAO index during 1996 corresponds to a weak Icelandic Low and suggests reduced northwest winter winds over the Labrador Sea.

Air Temperatures

A strong association exists between air and sea surface temperatures. The German Weather Service publishes monthly mean temperature anomalies relative to the 1961-90 means for the North Atlantic Ocean in their publication *Grosswetterlagen Europas*. At the time of writing only data up to and including November 1996 were available (Fig. 5). During January negative anomalies of typically less than 1°C were observed over most of the Labrador Sea, Newfoundland, and the northeastern Scotian Shelf. In contrast, over the Gulf of St. Lawrence, the remainder of the Scotian Shelf and the Gulf of Maine, temperatures were slightly above normal. From February to May over the Labrador Sea temperatures were above normal with the maximum values in April when anomalies ranged from 1-6°C. The highest anomalies during this month were along the Labrador coast. High anomalies (1-4°C) also were observed during

February. Warmer-than-normal air temperatures also dominated the southern regions of Atlantic Canada from February to April. From June to November, air temperature anomalies showed no strong pattern being typically less than 1°C from the normal, with both the amplitude and sign of the anomalies varying spatially and from month to month.

Monthly air temperature anomalies for 1995 and 1996 relative to their 1961-90 means at Godthaab in Greenland, Iqaluit on Baffin Island, Cartwright on the Labrador coast, St. John's in Newfoundland, Magdalen Islands in the Gulf of St. Lawrence and Sable Island on the Scotian Shelf (see Fig. 1 for locations) are shown in Fig. 6. The predominance of warmer-than-normal air temperatures in the first half of 1996 is evident, with the exception of Iqaluit where only 2 of the first 6 months experienced positive anomalies. However, these two months were well above normal. Note that during December, temperatures show extremely warm conditions. This suggests continuing milder weather in winter than had persisted through the early 1990s.

The time series of annual temperature anomalies for the six sites show above normal conditions at all sites in 1996 except Sable Island (Fig. 7). Temperatures generally increased relative to last year continuing a trend that began in 1994. 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. A general 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).

Sea Ice

Information on the location and concentration of sea ice for 1996 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 positions 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 1995, ice lay along the southern Labrador coast in the vicinity of Hamilton Inlet and its areal coverage was slightly less than the long-term mean (Fig. 8). This was due to well above normal air temperatures during the second half of December that delayed further ice formation, coupled with strong northeasterly winds over south Labrador that pushed ice inshore. During the first half of January 1996, ice spread rapidly south to St. Anthony on Newfoundland's northern Peninsula and offshore such that the ice edge was near its long-term median position by the middle of the month (Fig. 8). Moderating air temperatures and southwesterly winds later in the month slowed the ice advancement and by 1 February the ice coverage off northern Newfoundland again was less than the long term normal. During February, continuing positive temperature anomalies and strong southwesterly winds caused the southern ice edge to retreat northward, which is very unusual for this time of the year. Several strong wind storms also acted to break up and loosen the ice. By 1 March the ice edge was well north of its long-term median position but its offshore location off Labrador lay close to the long-term maximum. Variable temperatures and wind through March left the southern ice edge well north of the long-term median location by 1 April and between the median and maximum locations offshore. During April the ice retreated quickly northward and the southern limit by 1 May was well north of the long-term median. Ice was only observed in southern Labrador and was patchy. Ice continued to remain offshore of Hamilton Inlet through June but by 1 July all of the ice had disappeared.

The time series of the areal extent of ice on the northern Newfoundland and southern Labrador shelves (between 45-55°N; I. Peterson and S. Prinsenberg, personal communication, Bedford Institute) show that the peak extent during 1996 declined for the second consecutive year, was well below the high values in the early 1990s and was the lowest in almost 20 years (Fig. 9). The average area during those months when ice is typically advancing (January-March) and retreating (April-June) also show ice coverage in 1996 was less than observed during the last few years and is the lowest since the late 1970s (Fig. 9). These data support 1996 being a lighter-than-average ice year on the Labrador and Newfoundland shelves.

Gulf of St. Lawrence and Scotian Shelf

Near normal temperatures over the Gulf of St. Lawrence during December resulted in the ice edge being close to its long-term median position at the end of the 1995 (Fig. 10). Ice had formed in the St. Lawrence Estuary and along the eastern coast from Baie des Chaleur to Pictou, Nova Scotia. Ice advanced at a normal rate through January and its edge remained near the median location on 1 February. However, the ice was looser than normal, in large part because of several strong wind storms that caused considerable ice destruction. Uncharacteristically warm temperatures during February slowed the ice advance and left the ice edge north of the long term median by 1 March. Winds also pushed ice away from the shores of northern Prince Edward Island, off Cape Breton, western Newfoundland and out of the St. Lawrence Estuary. Wind storms continued to keep the ice loose. Ice coverage remained near the long-term median by 1 April but continued to be thinner and looser-than-normal. Above normal temperatures during April caused rapid melting and by mid-month most of the ice had disappeared from the Gulf. By 1 May the only significant amount of ice left in the Gulf was located in the Strait of Belle Isle and this disappeared by 5 May. In summary, the ice coverage in the Gulf was near normal during 1996 but the ice was thinner and more loose than normal.

The monthly estimates of the ice area seaward of Cabot Strait shows that less ice than normal was transported onto the Scotian Shelf during 1996 and it was significantly less than last year (Fig. 11). The loose and thin ice observed in the Gulf would have meant that once it reached the Scotian Shelf it would tend to break up and melt more quickly. Thus, 1996 was a light ice year on the Scotian Shelf.

Near Surface Ocean Temperatures

Labrador Sea

As previously mentioned, most of the salmon that spawn in the rivers of eastern Canada overwinter in the Labrador Sea. These fish are generally thought to inhabit the upper few meters of the water column, thus in examining possible ocean temperature effects on salmon we are concerned primarily with the near surface layers. Ocean surface temperatures in the Labrador Sea region are mainly controlled by heat exchange with the atmosphere which in turn is related to the strength of the northwest winds (Cayan, 1992; Battisti et al., 1995). High variability in sea temperatures can vary greatly from month to month reflecting the variability in the atmospheric heat fluxes. Atmospheric fluxes are also important in determining monthly variability in the surface layer temperatures on the Scotian Shelf and in the Gulf of Maine, but advection of offshore waters onto the shelf accounts for a larger amount of the long-term (decadal) temperature trends both surface and subsurface than the atmospheric heat fluxes (Petrie and Drinkwater, 1993).

The area of the Labrador Sea with temperatures 4-8°C has been shown by Friedland et al. (1993) to be important to salmon recruitment (see discussion above). The areal index of Labrador Sea water conducive for salmon survival is shown in Fig. 12. The higher the index the greater the area of water temperatures suitable for salmon and the higher the salmon survival rate. These data were provided by D. Reddin (DFO, Newfoundland Region, St. John's, personal communications). The areal index for 1996 shows an increase from the very low values during 1991 to 1995. Based upon Friedland et al. (1993), it might be expected that there would be higher salmon returns in 1996. The increase in the areal index is consistent with increases in the air temperatures and decreases in the NAO index and ice coverage.

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 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,; Colbourne et al., 1994). The station was visited 58 times in 1996, with a monthly maximum of 8 in May and a minimum of 2 in August. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50 75, 100, 125, 150 and 175 m) and monthly means were calculated for each depth. For this report we only present the surface values.

The 1996 monthly temperature anomalies at the surface varied from below 0°C to approximately 14°C (Fig. 13). Anomalies were predominantly positive with the maximum amplitude in August (Fig. 13). Negative anomalies were observed only in July and October. The annual temperature anomaly in 1996 at the surface was approximately 0.3°C. This represented a significant increase from last year and is the highest anomaly since the late 1980s (Fig. 13). It continues the warming trend that followed the extreme low of the early 1990s. Temperature trends at the surface at Station 27 generally match those at other depths but with greater amplitude variability and more month-to-month fluctuations.

Gulf of Maine, Scotian Shelf and Gulf of St. Lawrence

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 very important. In addition, marine temperatures may be important during the migration from overwintering grounds to the rivers and back.

Monthly averages of sea surface temperature (SST) in 1996 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 most the year (Fig. 14). This continued a trend that began in June of 1994. This is in contrast to Halifax were negative SSTs dominated with only 4 months exhibiting above normal temperatures. The largest negative anomalies were observed during the spring. The seasonal pattern in 1996 is similar to that observed in 1995.

Time series of the annual anomalies show that at least since the late 1980s, the trends at the two sites are opposite (Fig. 14). Whereas surface temperatures have generally been on the increase at Boothbay Harbor, in Halifax Harbour they have been decreasing. Other temperature data from the Scotian Shelf region indicate that the surface layers have tended to be colder-than-normal during recent years for the northeastern Shelf, along the Atlantic coast of Nova Scotia and around Lurcher (Fig. 15) whereas on the offshore banks and in the slope waters off the shelf, temperatures have generally been above normal. Note the high month-to-month variability in the surface temperatures at Lurcher (Fig. 15).

Temperature and salinity data have also been monitored once per month at Prince 5, a station at the mouth of the Bay of Fundy since the 1920s. Conditions at this station during 1996 were intermediate between those at Boothbay Harbor and at Halifax. Monthly surface temperature anomalies were below normal from January to August with the exception of February (Fig. 16). Note that no data were available in April. From September to December, temperatures became warmer-than-normal with a maximum of near 1°C in October. The annual anomaly was near normal. The time series indicates a slight decrease in 1996 relative to 1995 and remained well below the very warm temperatures in 1994 (Fig. 16). Prior to 1994, temperatures had been generally declining since about the mid-1980s. The two most dominant features in the Prince 5 temperature record are the very warm 1950s and the cold 1960s. Similar temperature patterns have been seen in the waters from the Laurentian Channel to the Middle Atlantic Bight (Petrie and Drinkwater, 1993).

Good spatial coverage of the temperatures in our coastal waters from ship surveys are rare. However, the summer groundfish surveys in July on the Scotian Shelf and in September for the southern Gulf of St. Lawrence are exceptions. Extensive CTD (conductivity-temperature-depth) profiles are taken. We then interpolated the temperature data onto a standardized grid that is 0.2° by 0.2° of latitude and longitude for the Scotian Shelf and 0.1° by 0.1° in the Gulf of St. Lawrence. The temperatures at the surface were contoured and anomalies from the long-term 1961-90 mean determined. The July survey shows surface temperatures of 13° to 15°C over most of the shelf with the warmest waters on Sydney Bight and off central Nova Scotia (Fig. 17). Waters as low as <8°C were observed off southern Nova Scotia and in the Bay of Fundy. These reflect enhanced vertical mixing due to the strong tidal currents and high tidal elevations. Relative to the long-term mean, temperatures were primarily below normal (Fig. 17) and are consistent with data from Halifax Harbour (Fig. 14), Lurcher (Fig. 15) and Prince 5 (Fig. 16).

In contrast to the Scotian Shelf in July, the surface waters in the southern Gulf of St. Lawrence during September were warmer than normal by 2°C over most of the Magdalen Shallows. Temperatures north of Prince Edward Island were above 17°C and decreased radially outward towards the Laurentian Channel, the Gaspe and Cape Breton. Off Cape Breton temperatures of 11°-14°C resulted in negative anomalies of up to -4°C. One must remember, however, that surface temperatures and temperature anomalies can vary substantially from one month to the next.

Summary

During 1996, conditions moderated during the winter in the Labrador Sea relative to the very cold period of the early 1990s. This moderation was linked to changes in the large-scale atmospheric circulation pattern. A weakening of the Icelandic Low (low NAO index) in 1996 resulted in a reduction in the strength of the northwest winds over the Labrador. Air temperatures thus were generally above normal while less ice formed and the areal extent of ice declined significantly for the second year in a row. Sea temperatures also rose as indicated by the areal index of favourable salmon habitat and by the surface temperatures at Station 27 off St. John's. The warming fits the pattern of decadal temperature fluctuations in the Labrador Sea region that has been observed since the 1960s.

On the Scotian Shelf and off southwest Nova Scotia, there was a tendency towards colder-than-normal surface temperatures in 1996. Data from Boothbay Harbor suggests that the Gulf of Maine temperatures remained above normal, a trend that has persisted since 1994.

Acknowledgments

We would like to thank D. Reddin for the Labrador Sea salmon habitat index, R. Losier and F. Page at the St. Andrews Biological Station for the Prince 5 data, C. Fitzpatrick and S. Narayanan for access to the Station 27 data, K. Freeman of AES Bedford for the Canadian air temperature data, D. Swain of DFO Moncton for the September survey data, B. Petrie for the Halifax sea surface temperatures, and I. Peterson and S. Prinsenberg for the Newfoundland ice area data.

References

Battisti, D.S., U.S. Bhatt and M.A. Alexander. 1995. A modeling study of the interannual variability in the wintertime North Atlantic Ocean. J. Climate 8: 3067-3083.

Cayan, D.R. 1992. Latent and sensible heat flux anomalies over the northern oceans: the connection to monthly atmospheric circulation. J. Climate 5: 354-369.

Coté, P.W. 1989. Ice limits eastern Canadian seaboard. Environment Canada, Ottawa. 39 p. (Unpublished Manuscript)

Colbourne, E., S. Narayanan and S. Prinsenberg. 1994. Climatic changes and environmental conditions in the Northwest Atlantic, 1970-1993. ICES mar. Sci. Symp. 198: 311-322.

Drinkwater, K.F. 1996. Marine environmental conditions in the northwest Atlantic during 1995 potentially impacting Atlantic salmon (*Salmo salar*). DFO Atl. Fish. Res. Doc. 97/137.

Friedland, K.D., D.G. Reddin and J.F. Kocik. 1993. Marine survival of North American and European Atlantic salmon: effects of growth and environment. ICES J. mar. Sci. 50: 481-492.

Narayanan, S., J. Carscadden, J.B. Dempson, M.F. O'Connell, S. Prinsenberg, D.G. Reddin, and N. Shackell. 1995. Marine climate off Newfoundland and its influence on Atlantic salmon (*Salmo salar*) and capelin (*Mallotus villosus*), p. 461-474. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Petrie, B. and K. Drinkwater. 1993. Temperature and salinity variability on the Scotian Shelf and in the Gulf of Maine 1945-1990. J. Geophys. Res. 98: 20079-20089.

Petrie, B., J.W. Loder, S. Akenhead and J. Lazier. 1992. Temperature and salinity variability on the eastern Newfoundland Shelf: The residual field. Atmosphere-Ocean 30: 120-139.

Reddin, D.G. and K.F. Friedland. 1993. Marine environmental factors influencing the movement and survival of Atlantic salmon. p. 79-103. *In* D. Mills [ed.] Salmon in the sea. Blackwell Sci. Pub., London, UK.

Reddin, D.G. and W.M. Shearer. 1987. Sea-surface temperature and distribution of Atlantic salmon in the northwest Atlantic Ocean. Amer. Fish. Soc. Symp. 1: 262-275.

Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic salmon (*Salmo salar* L.). Can. Manu. Rep. Fish. Aquat. Sci. 2041.

Rogers, J.C. 1984. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. Mon. Wea. Rev. 112: 1999-2015.

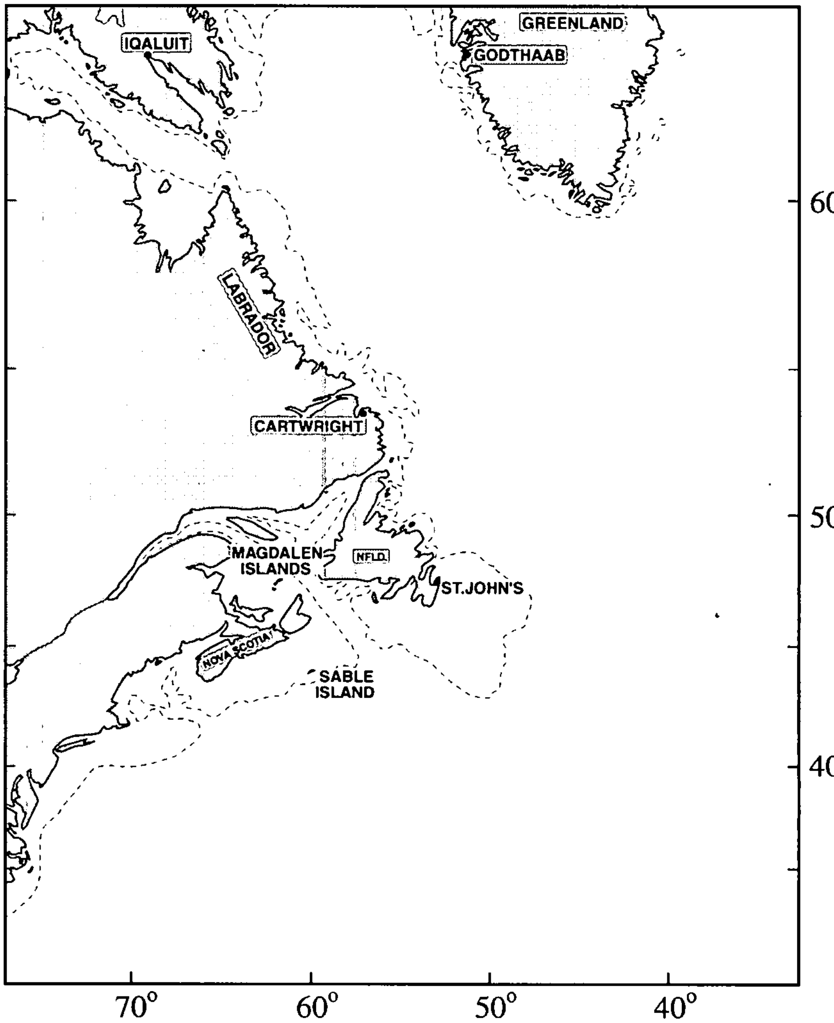


Fig. 1. Study area showing coastal air temperature sites.

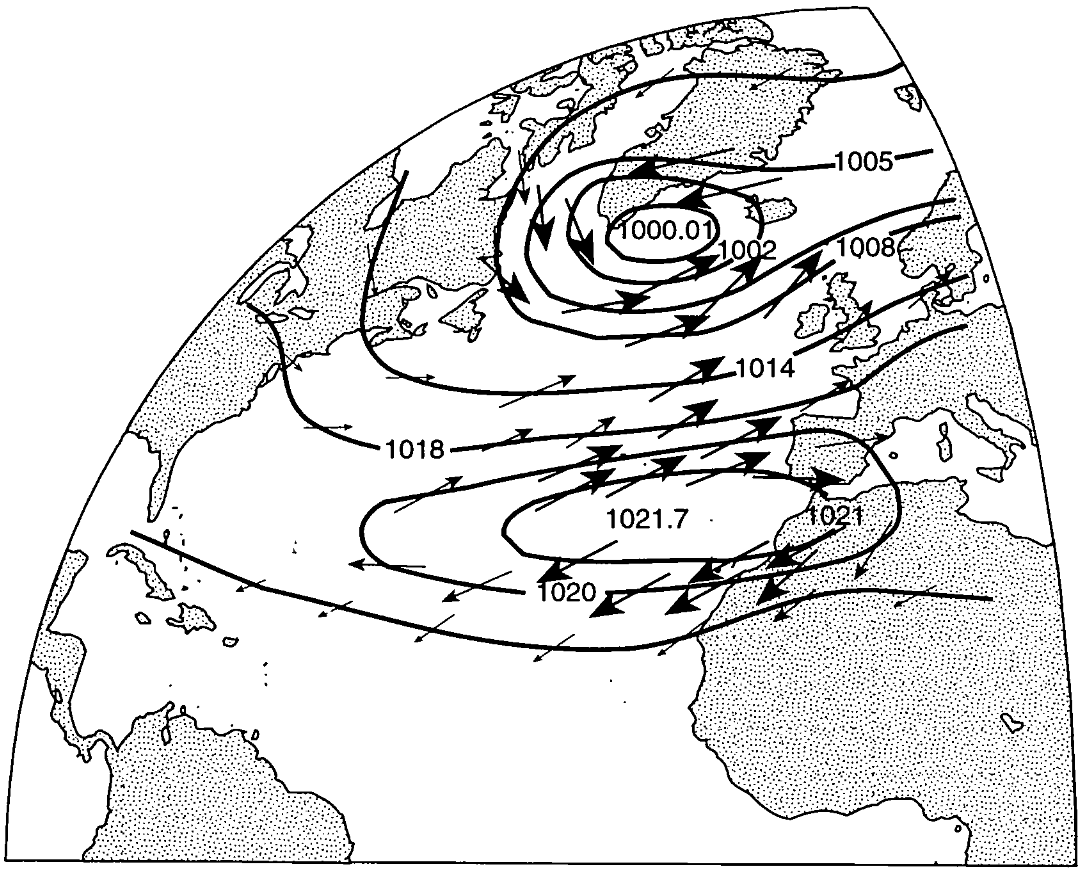


Fig. 2. Mean (1961-1990) sea surface pressure in winter showing the Icelandic Low and Azores High. Winds are shown schematically.

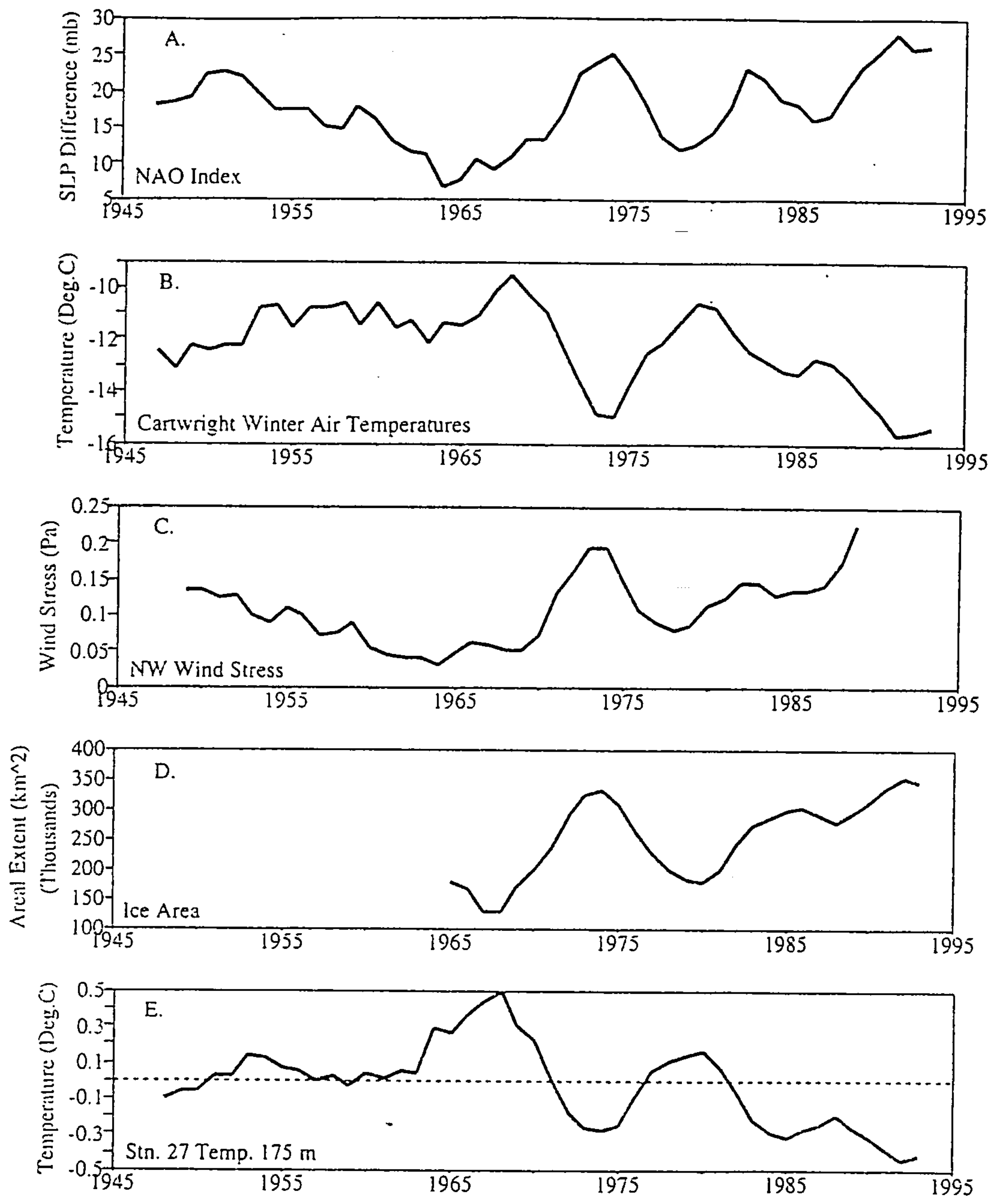


Fig. 3. The 5-yr running mean of the annual values of the NAO index (A), the winter (January, February and March) air temperatures at Cartwright on the Labrador Shelf (B), the northwest wind stress over the Labrador Sea (C), the area of ice between Newfoundland and southern Labrador in February (D) and the temperature of the near bottom waters at Station 27 off St. John's, Newfoundland (E).

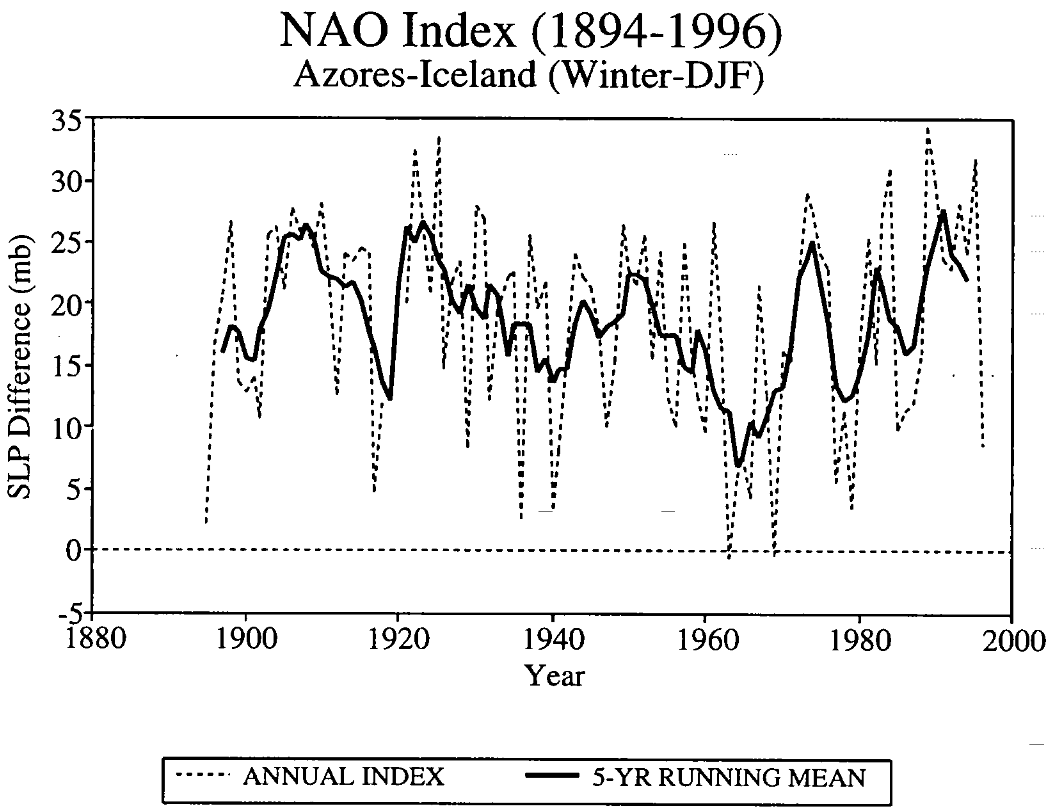


Fig. 4. The North Atlantic Oscillation Index defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland.

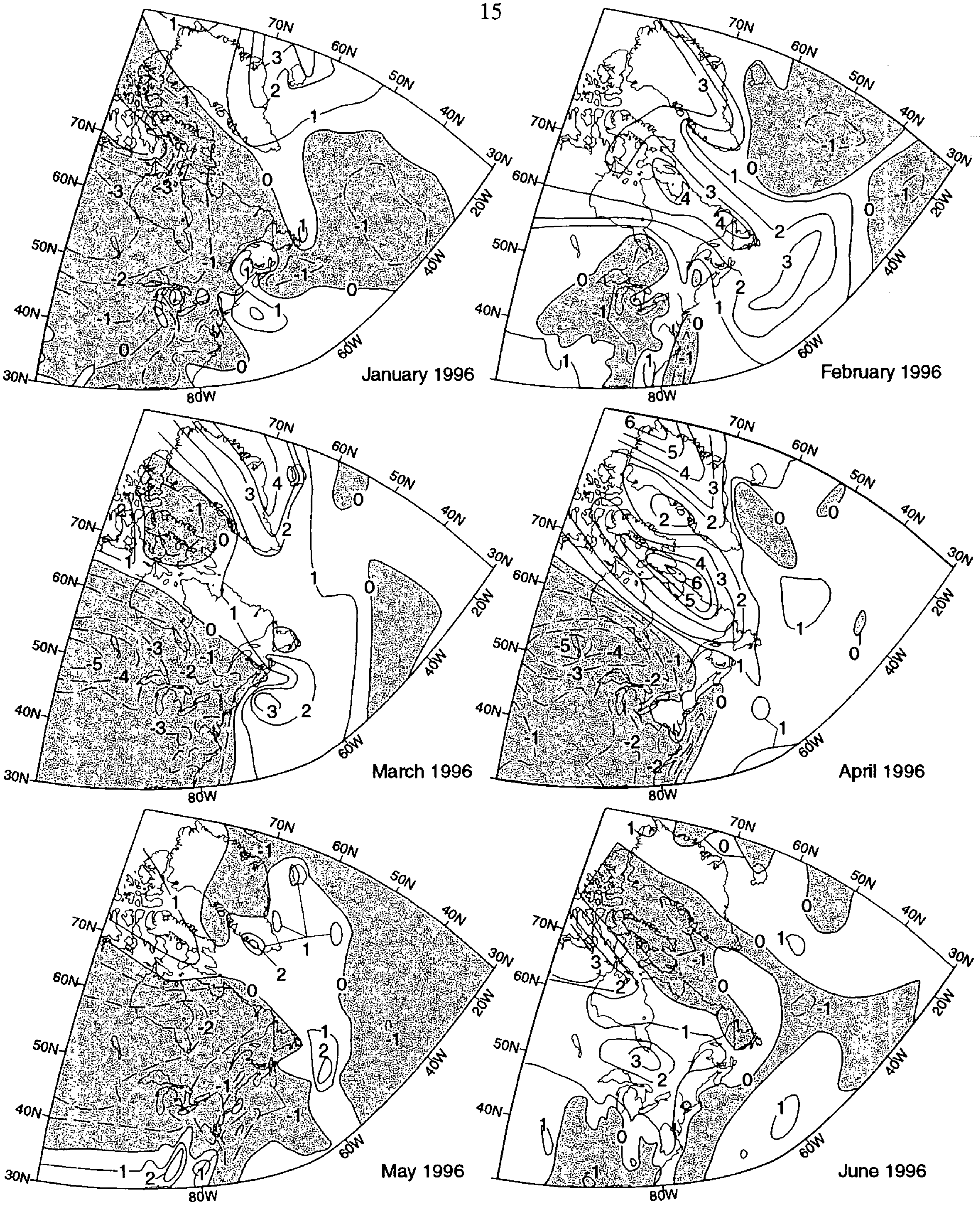


Fig. 5. Monthly air temperature anomalies (in °C) over the northwest Atlantic in 1996 relative to the 1961-90 means (from *Grosswetterlagen Europas)*. The shaded anomalies indicate areas of below normal temperatures.

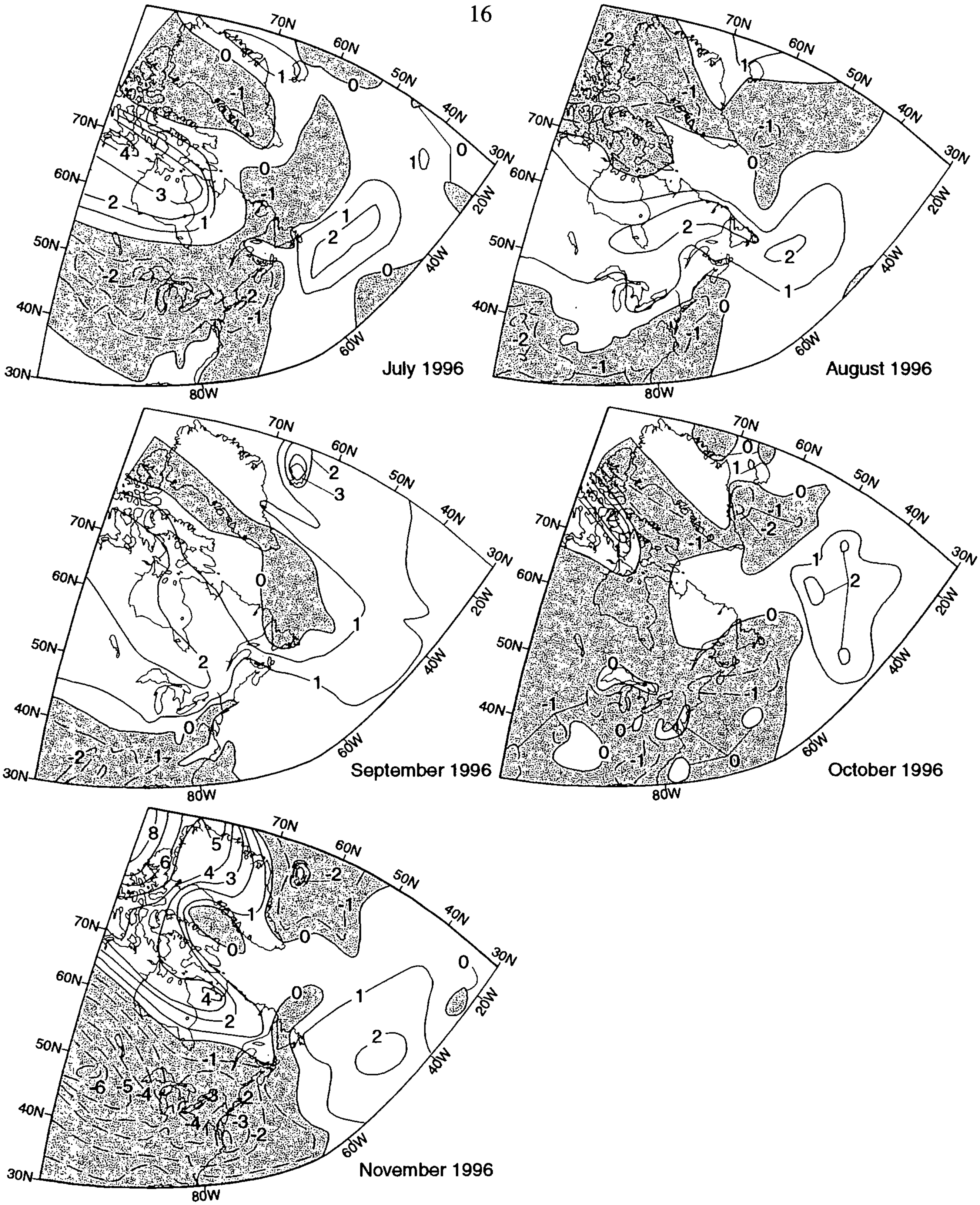


Fig. 5.continued Monthly air temperature anomalies (in °C) over the northwest Atlantic in 1996 relative to the 1961-90 means (from *Grosswetterlagen Europas)*. The shaded anomalies indicate areas of below normal temperatures.

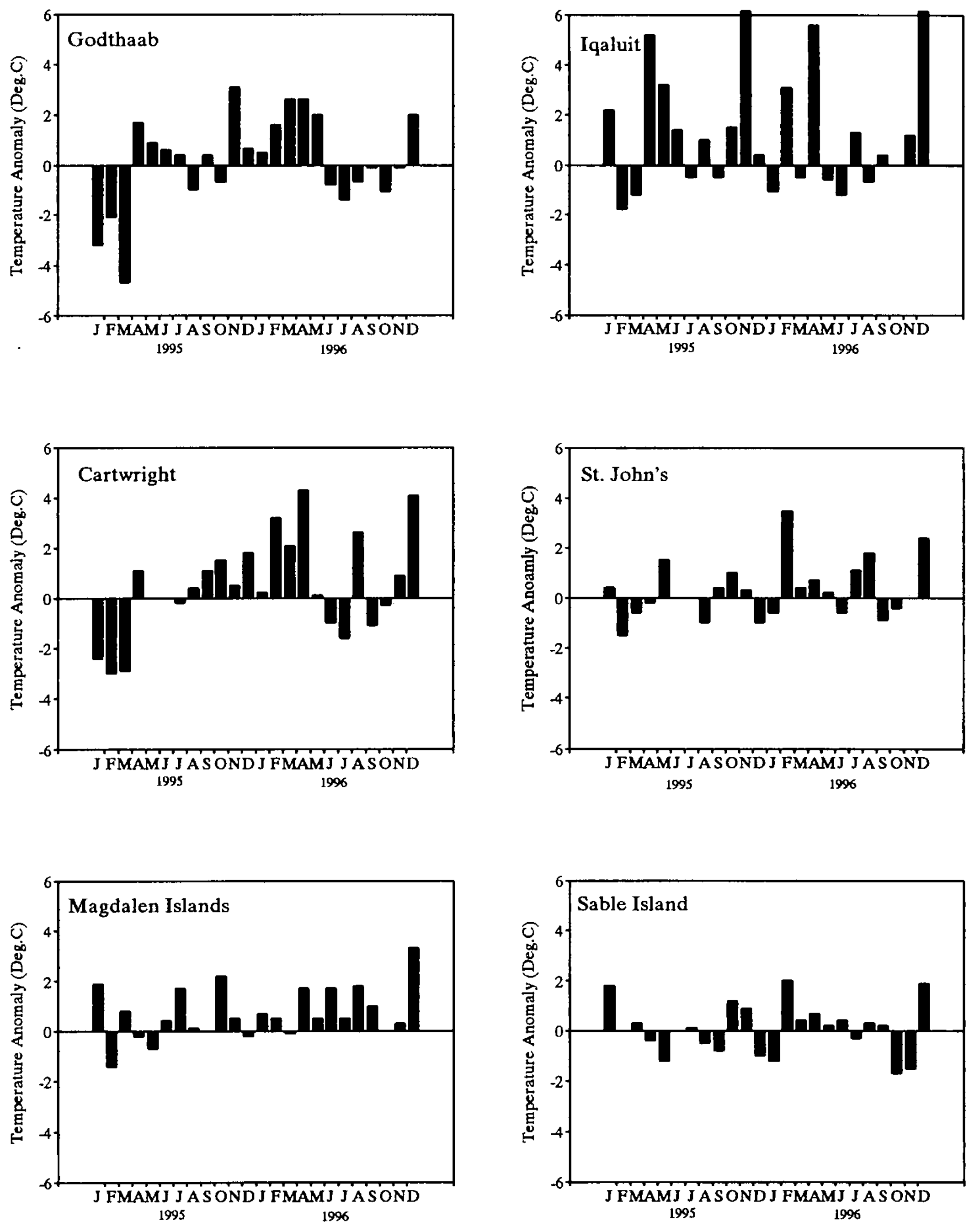


Fig. 6. Monthly air temperature anomalies in 1995 and 1996 at selected coastal sites (See Fig. 1 for locations).

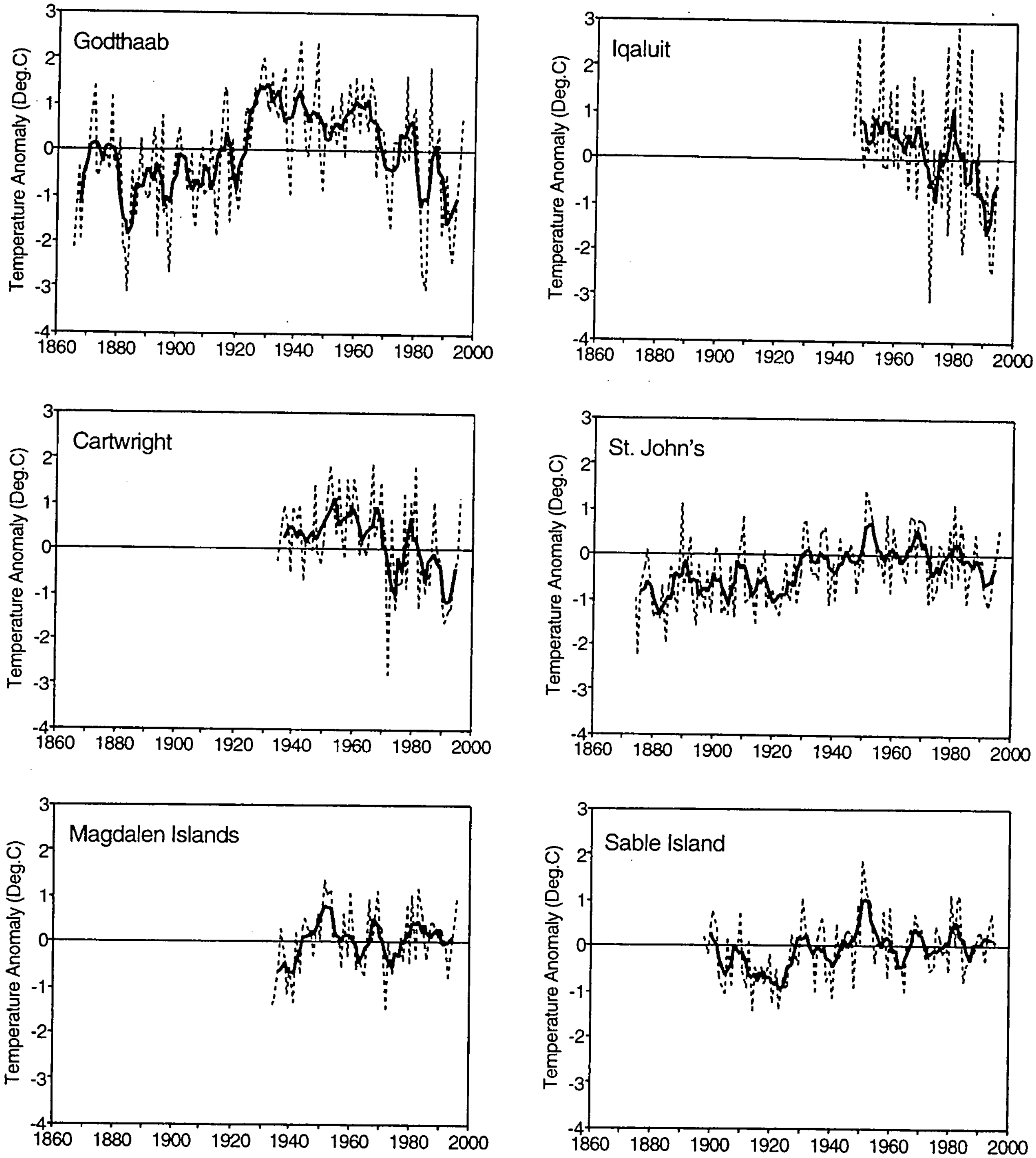


Fig. 7. Annual (dashed line) and 5-yr running means (solid line) of the air temperature anomalies at selected sites.

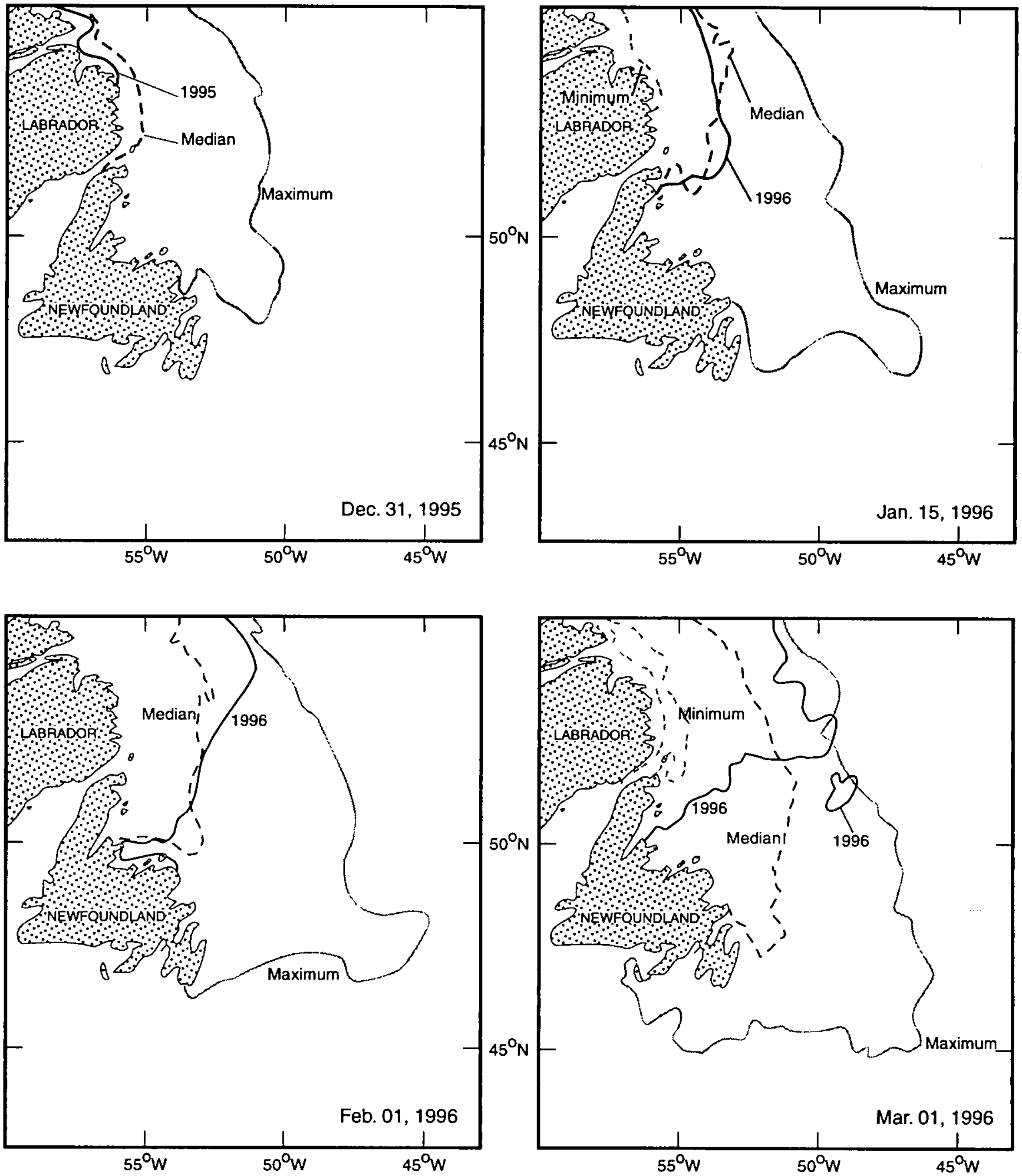


Fig. 8. The location of the ice edge together with the historical (1962-1987) median and maximum positions off Labrador and Newfoundland between December 1995 and July 1996.

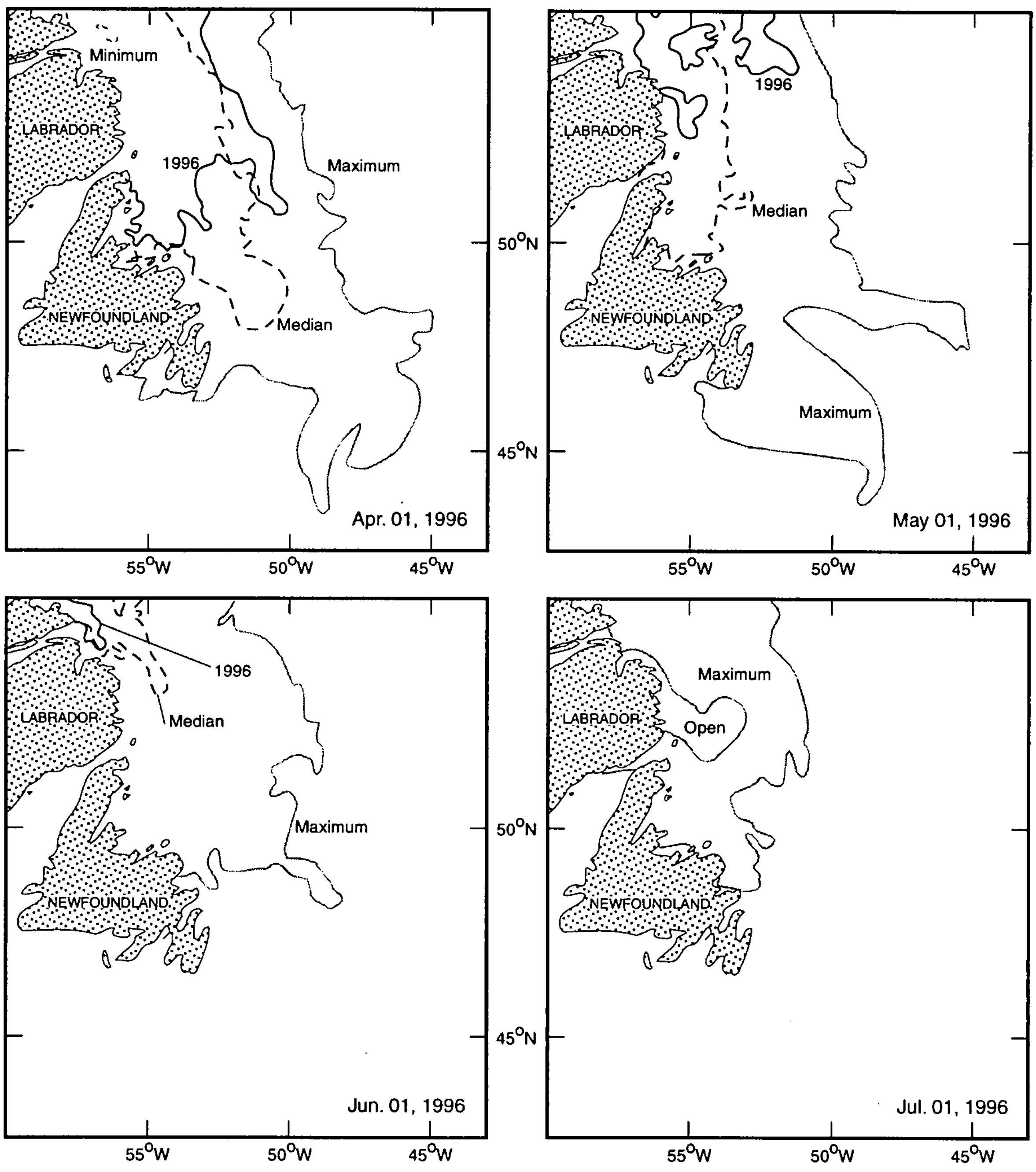
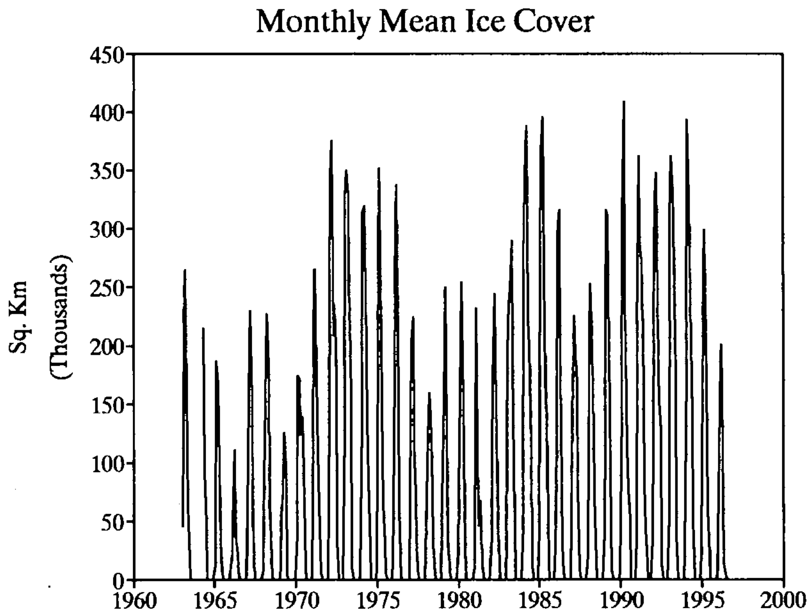


Fig. 8.continued The location of the ice edge together with the historical (1962-1987) median and maximum positions off Labrador and Newfoundland between December 1995 and July 1996.



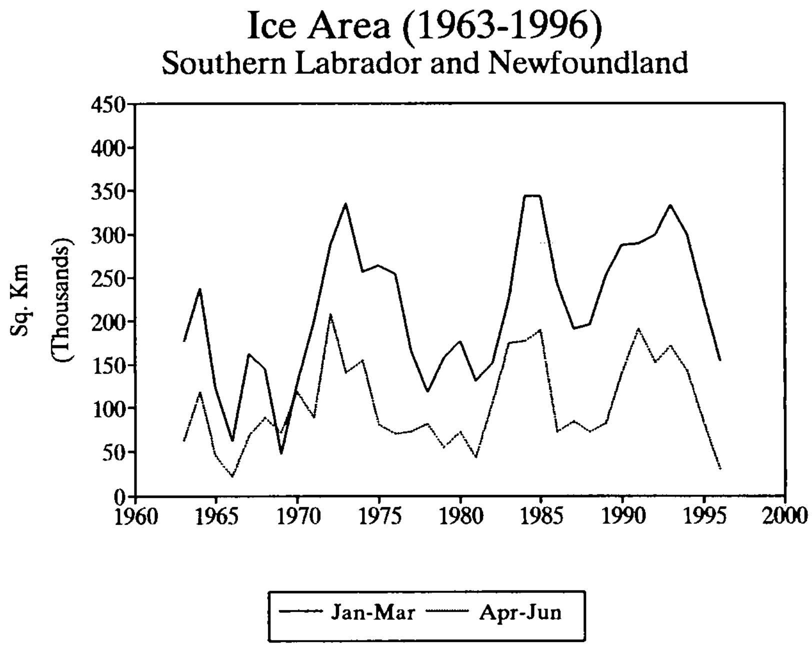


Fig. 9. The monthly mean ice cover (top) and average ice area during Jan-Mar and Apr-Jun (bottom) between 45-55°N (Newfoundland to southern Labrador).

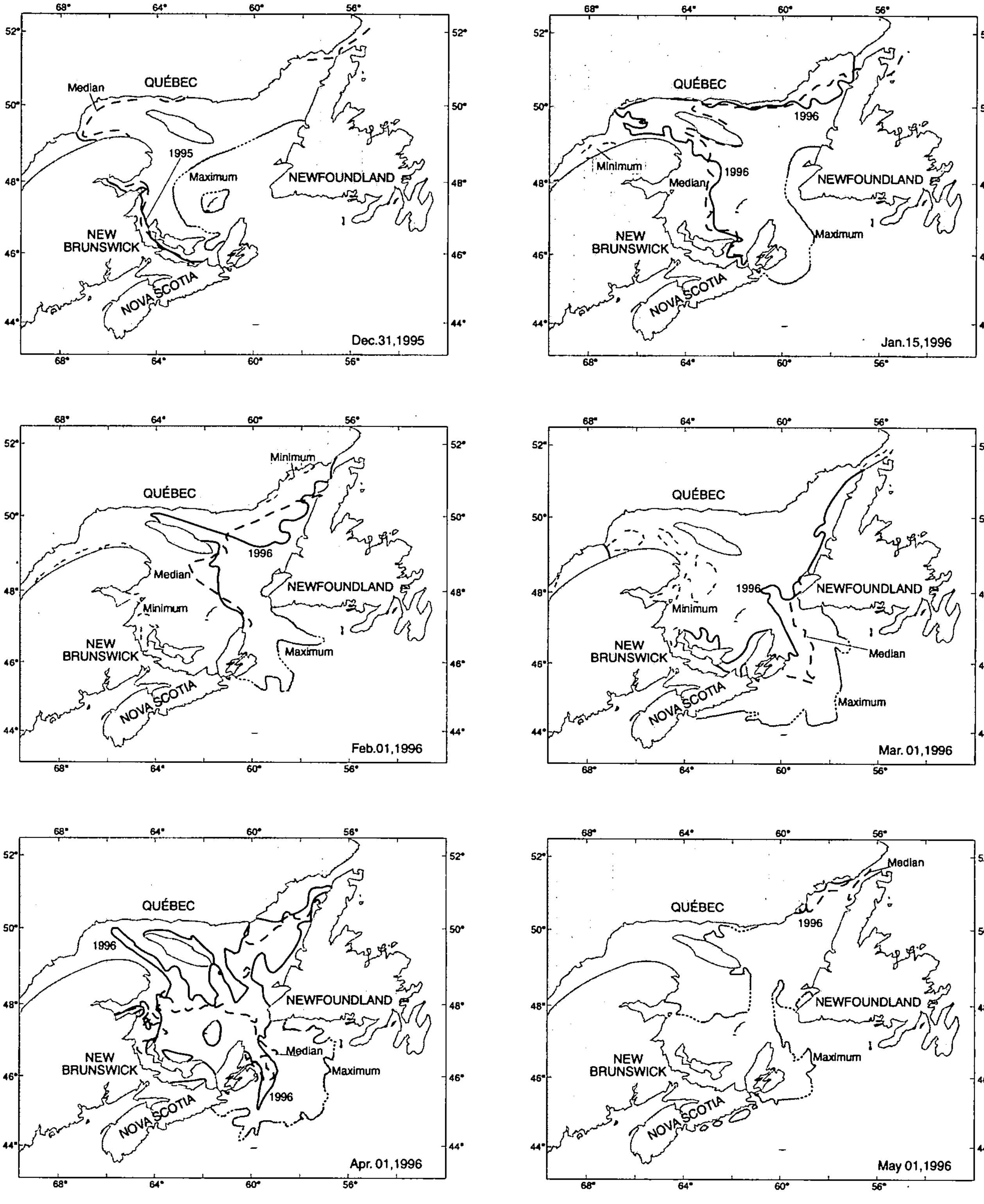


Fig. 10. The location of the ice edge together with the historical (1962-1987) median and maximum positions in the Gulf of St. Lawrence between December 1995 and May 1996.

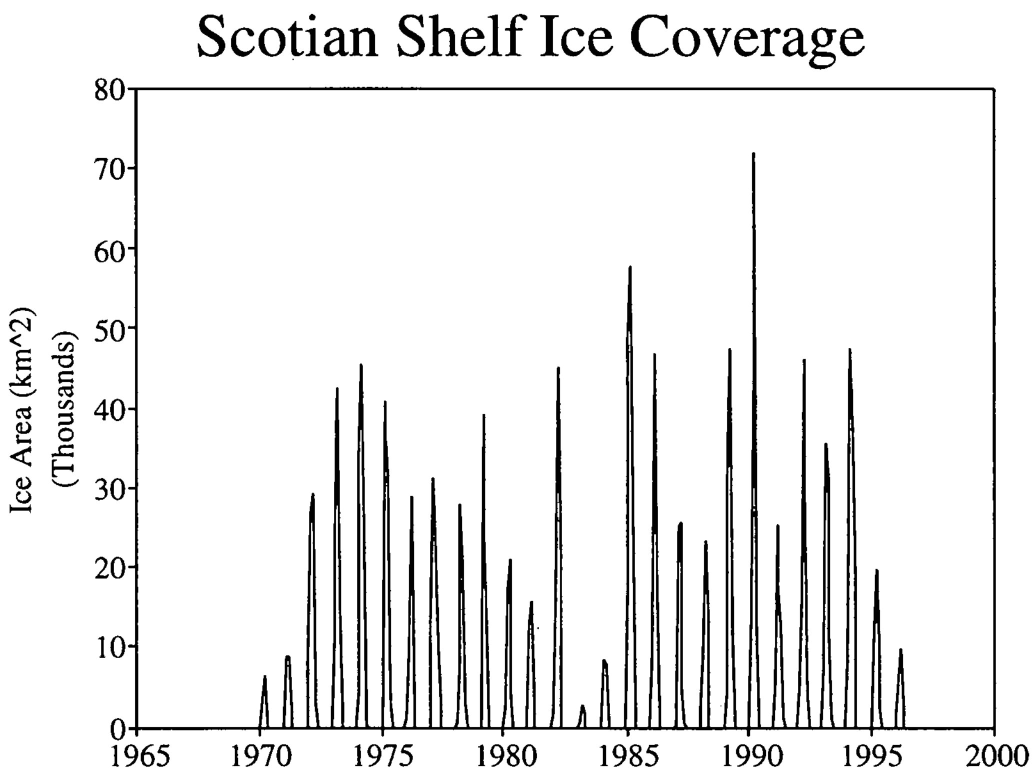


Fig. 11. The monthly mean area of ice cover seaward of Cabot Strait.

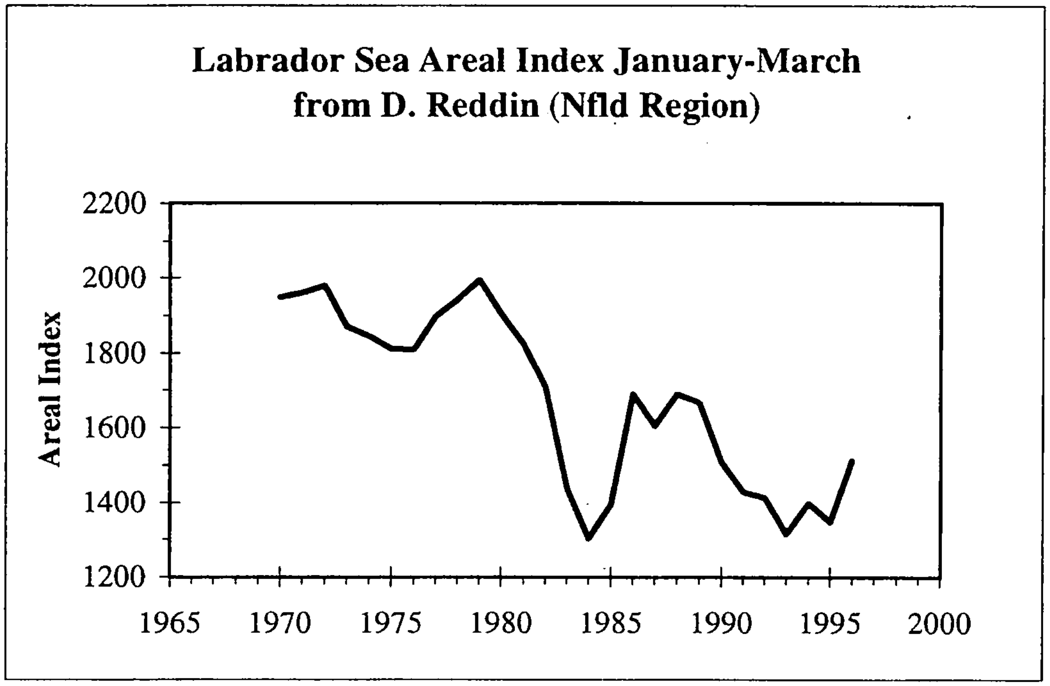


Fig. 12. The areal index of salmon habitat in the Labrador Sea.

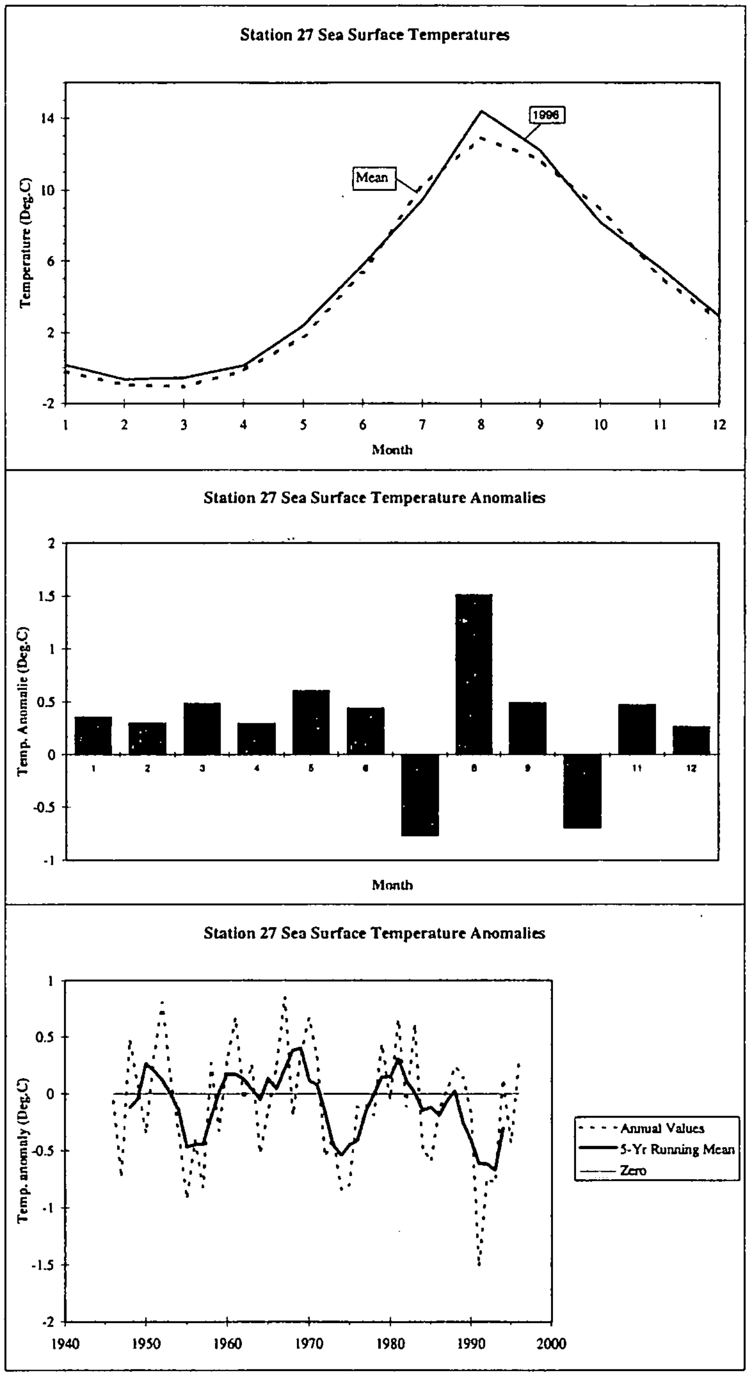


Fig.13. Monthly mean Station 27 sea surface temperatures. The 1996 and long-term mean temperatures (top), the 1996 temperature anomalies (middle) and time series of annual averages and their 5-yr running means(bottom).

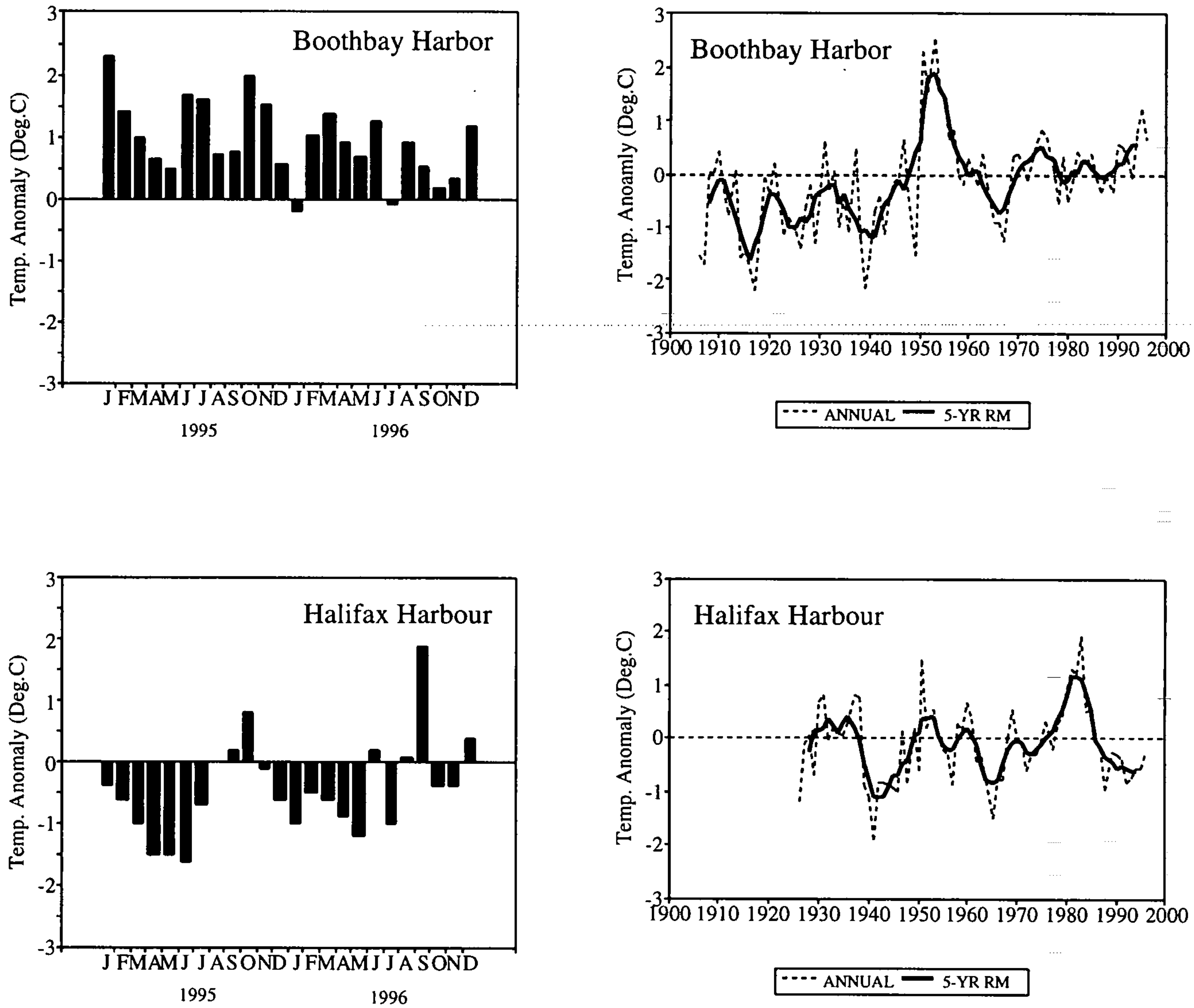


Fig.14. The monthly mean temperature anomalies (left) and time series of the temperature anomalies (right) for the coastal sea surface temperature sites of Boothbay Harbor (top) and Halifax Harbour (bottom).

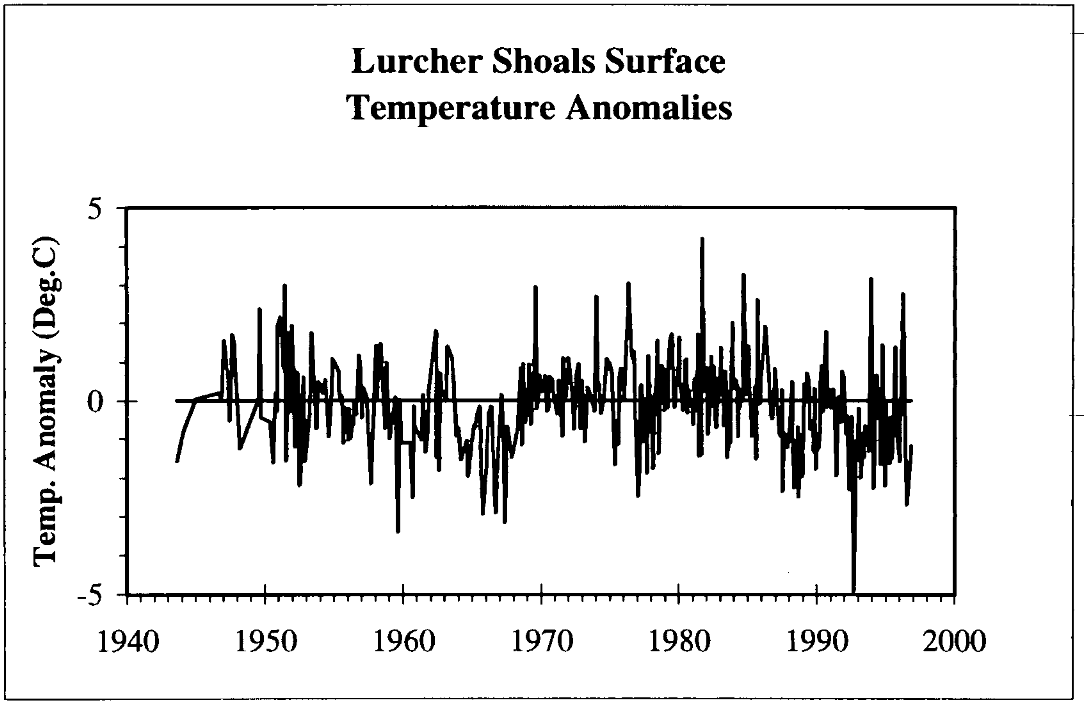


Fig. 15. The monthly mean temperature anomalies at the surface on Lurcher Shoals off southwest Nova Scotia.

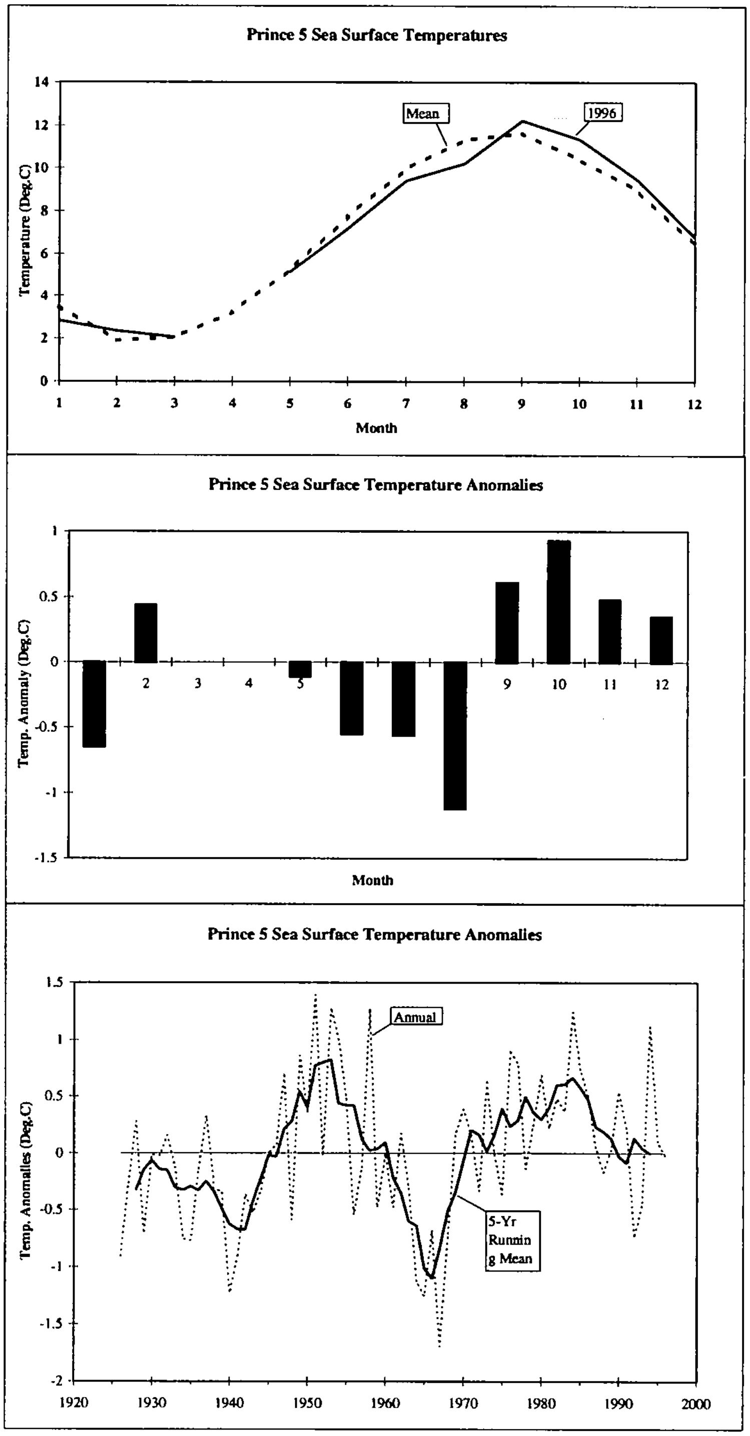


Fig.16. Monthly mean Prince 5 sea surface temperatures. The 1996 and long-term mean temperatures (top), the 1996 temperature anomalies (middle) and time series of annual averages and their 5-yr running means(bottom).

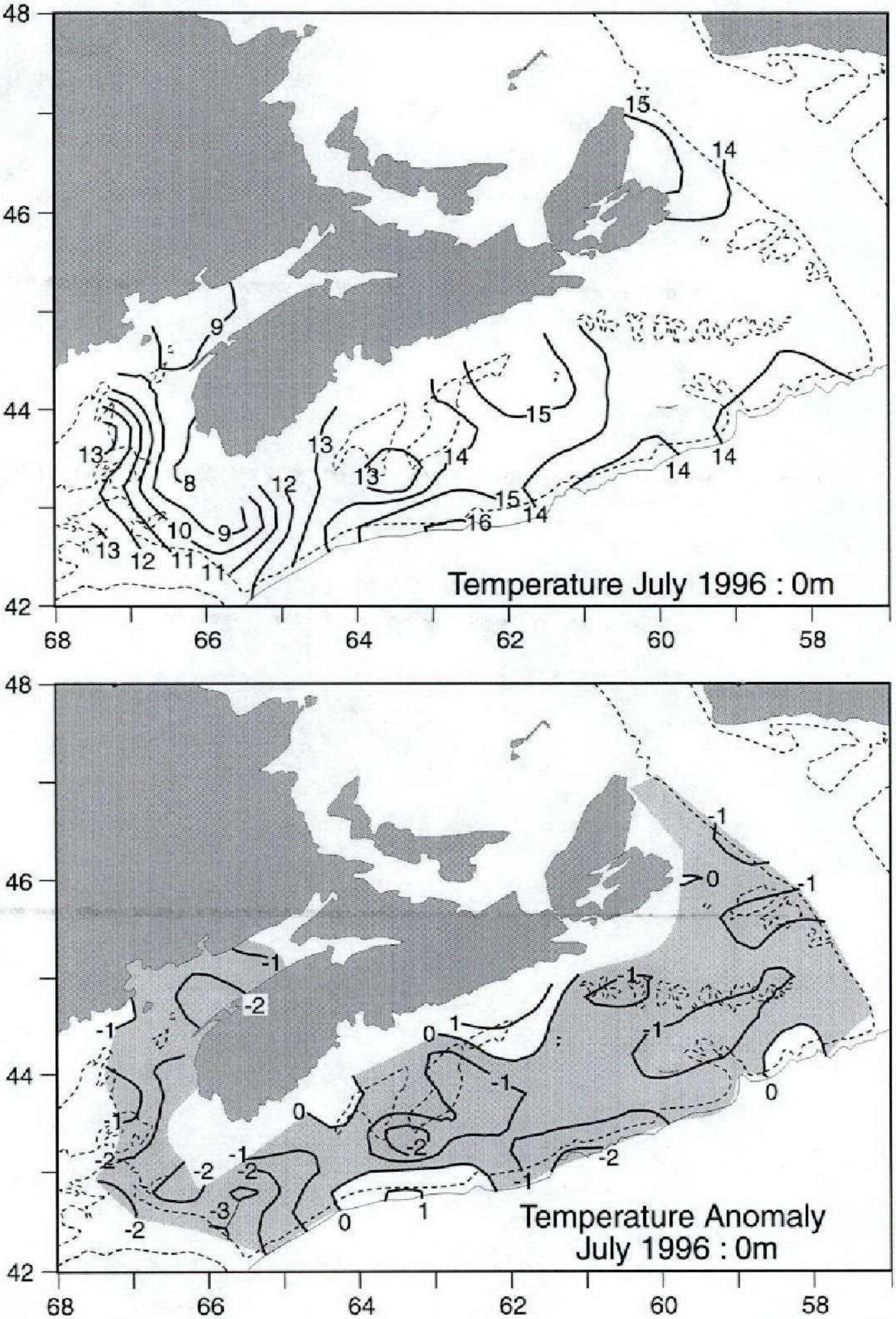


Fig. 17. Temperature and temperature anomalies at the surface during the July groundfish survey.

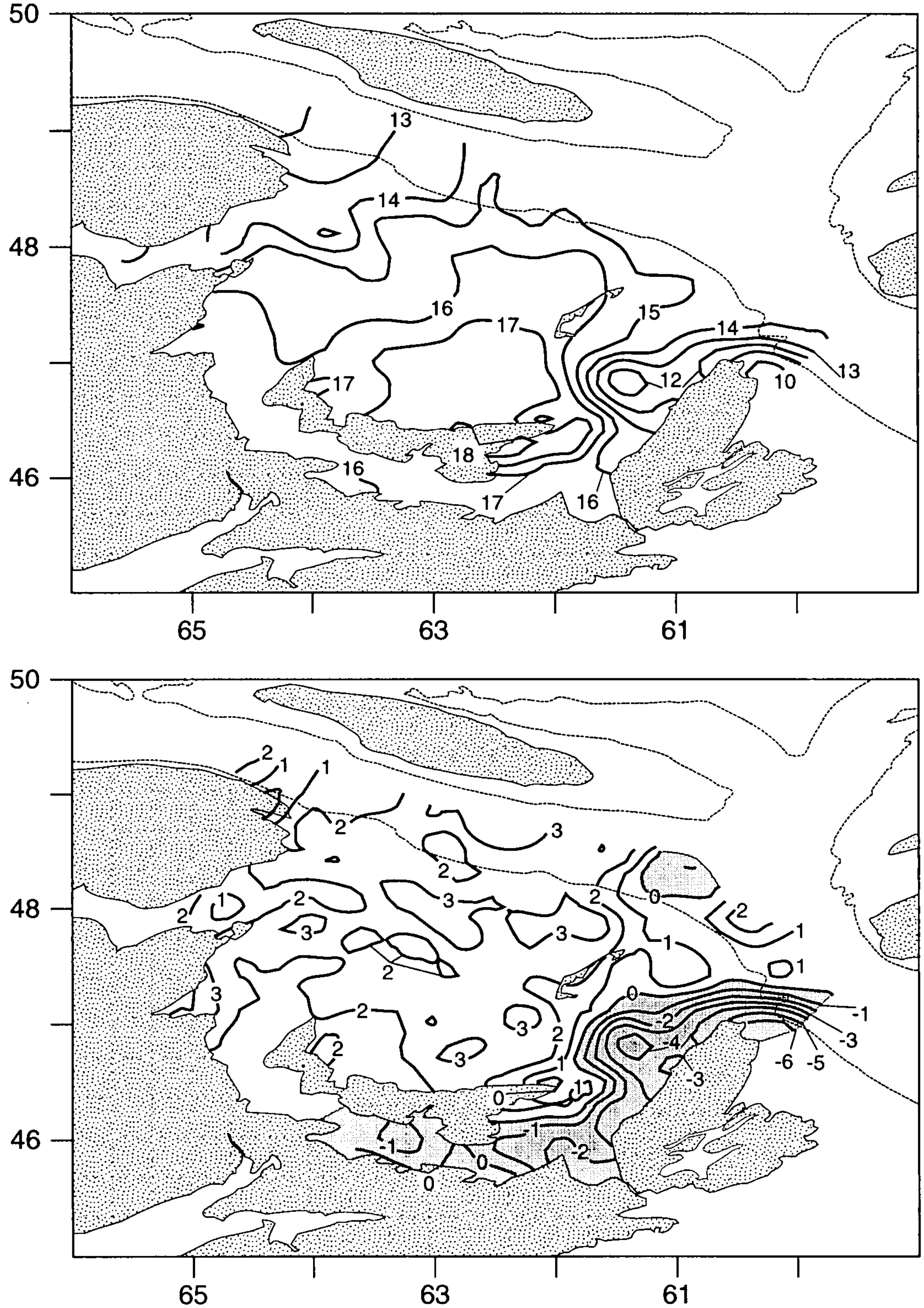


Fig. 18 Temperatures and temperature anomalies at the surface during the September groundfish survey.