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An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada During 2001

by

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ABSTRACT

A review of meteorological, sea ice and sea-surface temperature conditions in the Northwest Atlantic during 2001 is presented. Annual mean air temperatures throughout most of the northwest Atlantic were warmer-than-normal. They generally increased relative to 2000 but were below the record setting temperatures of 1999. The North Atlantic Oscillation (NAO) index was below normal and fell compared to its 2000 value. It was similar to the values of 1996-1998 and well below the levels seen in the cold period of the early-1990s. The high index means that the large-scale atmospheric circulation, including the Icelandic Low and Azores High, weakened in 2001. The Labrador Sea experienced predominantly more easterly winds than usual throughout most of the year. Sea ice on the southern Labrador and Newfoundland shelves generally appeared late and left early, resulting in a shorter duration of ice than usual. The ice coverage in these areas was lower than average. The number of icebergs reaching the Grand Banks in 2001 was only 89, almost a 10-fold decrease from the 843 icebergs observed in 2000. In the central Gulf of St. Lawrence, sea ice appeared late and disappeared early while the opposite (early arrival and late departure) was observed in the southwestern (inner Magdalen Shallows) and northeastern (Strait of Belle Isle) Gulf. Less ice than usual reached the Scotian Shelf while the areal coverage of ice in the Sydney Bight area off eastern Cape Breton was normal to less-than-normal. Sea-surface temperature anomalies throughout eastern Canadian waters were positive in 2001.

INTRODUCTION

This paper examines the meteorological, sea ice and sea-surface temperature conditions during 2001 in the Northwest Atlantic (Fig. 1). Specifically, it discusses air temperature trends, atmospheric sea level pressures, winds, sea-ice coverage, iceberg drift and sea-surface temperatures (SST). This paper complements the oceanographic reviews of the waters in and around Newfoundland and the Scotian Shelf and Gulf of Maine, which together constitute the annual physical environmental overviews to NAFO Fisheries Oceanography Committee (Colbourne, 2002; Drinkwater and Petrie, 2002). Environmental conditions are compared with those of the preceding year as well as to the long-term means. The latter comparisons are usually expressed as anomalies, i.e. deviations from their long-term mean, and where the data permit, the latter have been standardized to a 30-yr base period in accordance with the convention of meteorologists and the recommendations of the Northwest Atlantic Fisheries Organization (NAFO). Also as recommended, the 30-yr period has been updated from 1961-1990 used by Drinkwater *et al.* (2001) and their predecessors to 1971-2000, where possible. Having a standardized base period allows direct comparison of anomaly trends both between sites and between variables.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The German Weather Service publishes monthly air temperature anomalies relative to the 1961-90 means for the North Atlantic Ocean in their publication *Die Grosswetterlagen Europas* (Deutscher Wetterdienstes, 2001). Warmer-than-normal temperatures dominated over most of eastern Canada and its coastal waters during 2001 (Fig. 2). However, the year began with predominantly cold air covering most of the continental shelves from northern Labrador through to the southern United States, with a maximum positive anomaly (>4°C) located in the central Labrador Sea. A region of weak negative temperature anomalies (0° to -1°C) continued to cover most of the northern region including the Gulf of St. Lawrence during February but rose slightly above normal off Nova Scotia, in the Gulf of Maine and on the MIddle Atlantic Bight. By March, almost the entire area of the Northwest Atlantic was warmer-than-normal with the maximum anomaly of >8°C above Ungava Bay and anomalies of >2°C over the entire Labrador Sea. The only exceptions were over the Gulf of Maine and the Middle Atlantic Bight where there were below normal temperatures (generally less than -1°C). In April, temperatures were near to or slightly below normal throughout most of our area of interest. By May, however, warmer-than-normal temperatures covered all of coastal regions with the exception of eastern Newfoundland and the Grand Banks. In the offshore areas of the Scotian Shelf and in the parts of the Labrador Sea air temperature anomalies were near to or slightly below normal. From June to November, warm anomalies dominated throughout the region with the exception of July. In that month, most of the Scotian Shelf, the Gulf of Maine and the Middle Atlantic Bight as well as off Newfoundland and southern Labrador were below normal (between 0° and -2°C). During August to November the warm anomalies tended to be between 0° and 2°C and occasionally up to 3°C.

Monthly air temperature anomalies for 2000 and 2001 relative to their 1971-2000 mean at eight sites in the northwest Atlantic from Nuuk (Godthaab) in Greenland to Cape Hatteras on the eastern coast of the United States are shown in Fig. 3 (see Fig. 1 for locations). Data from the Canadian sites were available from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA, 2001). At the time of writing data for December were not available at Cape Hatteras. The predominance of warmer-than-normal air temperatures over most of eastern Canadian waters during 2001, noted above, is clearly evident (Fig. 3). On the Magdalen Islands, all months but one (April), at Iqaluit all but two (January and November), and at Cartwright and St. John's all but three (January and April at both sites, July at Cartwright and February at St. John's) were above normal, on the Magdalen Islands and St. John's, all months but one (May and December, respectively), and at Cartwright all but two (May and October). On Sable Island, February through April saw slightly colder than normal air temperatures but the remaining months were warmer-than-usual. While Nuuk and Boston also displayed warm conditions in 2001, Cape Hatteras on the other hand had the majority of months with colder-than-normal temperatures. Note, that the last couple of months of 2001 were very warm throughout the entire Northwest Atlantic.

The mean annual air-temperature anomalies for 2001 were also calculated at all eight sites. For Cape Hatteras, the annual anomalies were the average of the available 11 monthly anomalies. For all sites except Cape Hatteras, the annual anomalies were above normal. The maximum annual anomalies were recorded in the north at Nuuk and Iqaluit and on the Magdalen Islands where they were over 1.5°C. Around the Labrador Sea annual means rose compared to 2000. They also rose on the Magdalen Islands, Boston and at Cape Hatteras but declined at St. John's and Sable Island. The time series of the annual anomalies are shown in Fig. 4. The generally positive air temperature anomalies in 2001 are clearly evident. Note that the interannual variability in air temperatures since 1960 at Nuuk, Iqaluit, Cartwright, and, to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with minima in the early-1970s, early- to mid-1980s and the early-1990s, suggesting a quasi-decadal period. Indeed, the recent rise in temperature at most of these sites is consistent with a continuation of this near decadal pattern. Monthly temperature anomalies at the Magdalen Islands and Sable Island contained quasi-decadal fluctuations with minima in the early-1970s (both sites), the mid-1980s (Sable Island only) and in the 1990s (Magdalen Islands only). Air temperatures at Boston and Cape Hatteras have generally been out of phase with the temperature fluctuations in the Labrador region. Thus, for example, when the temperatures were very cold in Labrador during the early-1990s, they were relatively warm along the US seaboard (Fig. 5). Also note that all sites where data are available, cold conditions (relative to the 1971-2000 mean) existed throughout the late-1800s and early-1990s. Temperatures rose to above normal values between the 1910s and 1950s, the actual timing being site-dependent.

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale pressure patterns and atmospheric circulation. Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas*. The long-term seasonal mean pressure patterns are dominated by the Icelandic Low centred between Greenland and Iceland and the Bermuda-Azores High centred between Florida and northern Africa (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 2001, relative to the 1971-2000 means, are shown in Fig. 5. Winter includes December 2000 to February 2001, spring is March to May, summer is June to August and autumn is September to November.

In winter, a dipole pattern was established with negative air pressure anomalies in the central North Atlantic and positive anomalies to the north. The largest negative anomalies (below -4 mb) were located west of Europe and the largest positive anomalies (>6 mb) were centred over eastern Greenland. The highest anomalies were on the eastern side of the Atlantic, which continue a wintertime pattern that has persisted for the past several years. The winter pressure anomalies in 2001 indicate a weakening of both the Iceland Low and the Azores High, i.e. a reduction in the strength of the large-scale atmospheric circulation. The pressure data also suggest anomalous easterly to southeasterly winds over the Labrador Sea and weaker northerly to northwesterly winds over the Maritime Provinces and the northeastern United States. The spatial pattern of the pressure fields in 2001 was opposite to that in 2000, i.e. during 2000 there had been an intensification of the atmospheric circulation patterns.

In the spring of 2001, the pattern of anomalous pressures was similar to that observed in winter. There was a strong negative pressure anomaly over the most of North Atlantic. It was oriented southwest to northeast, with its maximum value (below -5 mb) in the central north Atlantic. A weaker positive anomaly (upwards of 3 mb) formed off northeastern Greenland. In eastern Canada, the geostrophic winds associated with these anomaly pressure fields are predominantly northeasterly.

As is typical in most years, the pressure anomaly field during the summer of 2001 was weaker than in the other seasons. A broad band of negative anomalies stretched across the northern North Atlantic with the maximum (>1 mb) located to the west of Ireland. Weak positive anomalies (<2 mb) were observed to the north and south of this band of negative anomalies. The geostrophic winds off eastern Canada which accompany this pressure anomaly field are also relatively weak and predominantly from the west.

In the autumn, the pattern switched to predominantly positive anomalies across the North Atlantic. The maximum anomaly was 3 mb and was located in the central North Atlantic. Negative anomaly regions lay to the north and south of this band with maximum values up to –2 mb and –1 mb, repectively. Over eastern Canada, the winds associated with this pressure system were predominantly from the west and the north.

NAO Index

The North Atlantic Oscillation (NAO) Index is the difference in winter (December, January and February) sea level atmospheric 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). A high NAO index corresponds to an intensification of the Icelandic Low and Azores High. Strong northwest winds, cold air and sea temperatures and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index (Colbourne *et al*., 1994; Drinkwater, 1996). The opposite response occurs during low NAO years. The annual NAO index is derived from the measured mean sea level pressures at Ponta Delgada (up to 1997) or Santa Maria (since 1997) in the Azores minus those at Akureyri in Iceland. The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1971-2000 mean.

In 2001, the NAO index was below normal (+8.3 mb anomaly) and dropped significantly (by 17.8 mb) from its 2000 value (Fig. 6). It was similar to the low levels observed during the mid-1990s and well below the higher-than-average indices registered during the past few years. This change in the NAO index fits the pattern of quasi-decadal variability that has persisted since the 1960s. As alluded to above, low NAO is usually accompanied by warm air temperatures over the Labrador Sea in winter. This is consistent with observations in 2001. However, as described last year (Drinkwater *et al*., 2001), warm air temperatures accompanied high NAO indices during the past three years. The latter was a result of the eastward shift in the location of the anomalous winter pressure field was with weaker gradients over the Northwest Atlantic and the Azores High extending into southeastern Canada in winter, which produced more southerly winds with accompanying warm air.

Winds

The re-analyzed NCEP (National Centre for Environmental Prediction) – NCAR (National Center for Atmospheric Research) winds are available from the International Research Institute of the Lamont-Doherty Earth Observatory at Columbia University. Based upon correlations with measured data, the vector components of the NCEP winds capture most of the observed variability in the wind field. They are representative of 10 m winds and are gridded at intervals of 1.875° longitude and approximately 1.905° latitude. We have averaged the winds seasonally and obtained anomalies for the gridded wind data covering an area approximately from 40°-68°N and 40°-75°W (Fig. 7). The strength of the wind anomalies tend to be larger in the north, hence for presentation purposes, we split the data to show the Labrador Sea separately from regions further south.

The winter winds during 2001 in the Labrador Sea reflect the air pressure anomalies (Fig. 5) and are primarily easterly and onshore towards the Labrador coast (Fig. 8). In the northern Labrador Sea the wind shifts slightly southeasterly due to the anomalous high pressure over Greenland while in the southern Labrador Sea they turn northeasterly due to the anomalous low in the central North Atlantic. This low results in variable anomalous wind directions, being northerly off northern Newfoundland to westerly off the Middle Atlantic Bight and on the southeastern Scotian Shelf. The anomalous winds in the spring are dominated by north to northeasterlies, again reflecting the anomalous low pressure in the northern North Atlantic. In the summer, the anomalous winds in the Labrador Sea are easterly while those to the south are very weak, indicating near normal winds. The reduced amplitudes south of Newfoundland result in highly variable wind directions. The autumn winds over the Labrador Sea are again predominantly from the east. In the Gulf of St. Lawrence, the Grand Banks and the Scotian Shelf they are northeasterly but of reduced amplitude to those over the Labrador Sea. The pattern of anomalous winds in summer and the fall also reflect the pressure fields (Fig. 5) through geostrophy.

SEA ICE OBSERVATIONS

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 median, 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) (Fig. 9). These daily charts represent snap shots of the ice and it must be remembered that the ice edge can vary rapidly over short periods of time. We also include an analysis of the time of onset, duration and last presence of sea ice based upon the sea-ice database maintained at the Bedford Institute of Oceanography (Drinkwater *et al*., 1999). The weekly concentration and types of ice within 0.5° latitude by 1° longitude areas were recorded through the ice season. The dates of the first and last appearance of ice within these areas, as well as the duration of ice, were determined. The database begins in the early-1960s and continues to the present. Long-term means (30-years, 1971-2000) of each variable were determined (using only data during the years ice was present) and subtracted from the 2001 values to obtain anomalies.

Newfoundland and Labrador

At the end of 2000, sea ice lay off the southern Labrador coast in the vicinity of Hamilton Inlet and a small patch of ice was in Notre Dame Bay along the northern coast of Newfoundland. This was an areal coverage that was close to the long-term minimum for the beginning of the year (Fig. 10a). By mid-January, colder temperatures spread the ice past southern Labrador to the northern tip of Newfoundland, although the ice that had been in Notre Dame Bay disappeared. Continuing cold temperatures in the latter half of the month lead to further spreading of ice so that by 1 February ice was near its long-term median position. The ice edge remained close to its median position throughout February and into early March. However, strong easterly winds later in the month pushed the ice towards the Newfoundland coast and by 1 April, the ice edge again lay well shoreward of it usual position (Fig. 10b). During April, the ice began to retreat and on 1 May was close to its usual location. It continued to retreat slightly more rapidly than normal during the month due to the warmer-than-usual temperatures. This resulted in the ice edge being north of its median position on 1 June, except for a patch of ice located in White Bay. The ice continued to retreat but did not disappear from southern Labrador until late June.

The time series of the areal extent of ice on the Newfoundland and southern Labrador shelves (between 45-55°N; I. Peterson, personal communication, Bedford Institute) show that the peak extent during 2001 was slightly below that observed in 2000 (Fig. 11). Relative to 2000, the average ice area fell slightly during advancement (January to March) and retreat (April to June). During both periods, the average ice area was below the long-term mean and was much less than the early-1990s. The monthly means of ice area show that the 2001 coverage was below that of 2000 throughout the ice season except in May (Fig. 12). In all months, the ice area was below the long-term average (1971-2000). In summary, 2001 was generally a lighter-than-average ice year on the Labrador and Newfoundland shelves. Although no estimates of ice volume were made for 2001, based upon studies in the Gulf of St. Lawrence (Drinkwater *et al*., 1999), the temporal variability of the ice volume is expected to be similar to that of the ice area.

An analysis of the first and last presence of ice was also carried out. In 2001, ice appeared along the southern Labrador coast in late December, and gradually spread southward to northeastern Newfoundland waters by mid-February (around day 45; Fig. 13). Only small quantities of ice reached the northern Grand Bank. Relative to the long-term mean, ice generally appeared later-than-normal off Labrador and the northern tip of Newfoundland (Fig. 13). On the inner half of the shelf, it was over 15 days late. Ice began to disappear from the offshore and southern sites in March (day 60-90; Fig. 14). It did not began to retreat from northern Newfoundland waters and southern Labrador until mid-May (day 135) but lasted in the region north of Hamilton Inlet until near late-June. Over most of the region, ice disappeared earlier-than-normal (negative anomaly, generally associated with warm conditions), more than 45 days early over large sections of the outer shelf off northeastern Newfoundland (Fig. 14). In the inshore regions of Newfoundland, however, ice departed slightly later-than-usual. The duration of the ice season ranged from less than 20 days on the northern Grand Banks to over 170 days north of Hamilton Inlet on the southern Labrador (Fig. 15). Note that the duration is not simply the date of the first presence minus the last presence because the ice may disappear for a time and then reappear. The ice duration was shorter-than-normal (negative anomaly) over almost all of the Newfoundland and Labrador Shelf. Off large portions of the central shelf, the duration was over 50 days shorter-than-usual and in some cases 60 days shorter. The only region where the duration longer-than-normal was in Bonavista Bay, where it remained upwards of 10 days longer than usual.

Icebergs

The International Ice Patrol Division of the United States Coast Guard monitors the number of icebergs that pass south of 48°N latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1999/2000 iceberg season (October 2000 to September 2001), a total of 89 icebergs were spotted south of 48°N. The monthly totals for February to June were 4, 31, 31, 19 and 4, respectively (Fig. 16). No icebergs were spotted between October 2000 and January 2001, inclusive, or in July to September 2001. In 2001, 96% of the icebergs were observed during the primary iceberg season of March to July, which is higher than the 1985-2000 mean of 91.7%. The 1985-2000 period is considered to represent reliable SLAR measurements. A higher percentage of the icebergs in 2001 arrived in March and April than usual and a lower percentage in May and later. The total number of icebergs was down dramatically from the 843 icebergs recorded in 2000 and was the 34th lowest number recorded in 122 years of data (Fig. 16).

Gulf of St. Lawrence

The location of the ice edge within the Gulf of St. Lawrence at various times during the 2000-2001 winter season is shown in Fig. 17. These again represent snap shots and the reader is reminded that the ice edge can vary rapidly over short periods of time. In the latter half of December 2000, strong winds and warm air temperatures caused destruction of the ice that had formed earlier in the month and also slowed ice formation. There was generally less ice than usual at the end of the 2000 and the ice that had formed was restricted to the coastal regions of the Shallows, especially in Northumberland Strait and vicinity. By mid-January the ice coverage was near normal in Northumberland Strait and along the north shore of Quebec but less than normal elsewhere due to mild air temperatures and the passage of a series of storms. The northern region of the Shallows and off northern Prince Edward Island became ice-covered by the end of January but the southern region remained open. Usually at this time of the year, the entire Magdalen Shallows are covered with ice. Due to persistent north to northwesterly winds and below normal temperatures, ice drifted rapidly southeastward during the second half of February such that the Gulf was essentially covered by 1 March. With frequent storms during March, the ice began to break and by 1 April ice had disappeared from most of the Gulf. There was less ice than usual except in the Strait of Belle Isle where it was near normal. The ice continued to break up and melt and by 1 May ice was only in the Strait of Belle Isle region. Small amounts of ice remained in this area until early June.

The times of first presence show ice formed initially in the St. Lawrence Estuary, along the coastal regions of the Magdalen Shallows and the northern shore of Quebec (Fig. 18). By mid-January, ice had covered most of Gulf for at least some period of time. Subtracting the long-term (1971-2000) mean, indicates that the time of first ice was earlier than normal over large sections of the Magdalen Shallows and in the northeastern Gulf, especially along the north shore of Quebec. (Fig. 18). The last presence of ice varied from late March to late May, with the result that it disappeared earlier than normal in the central region of the Gulf by up to 15 days off southwestern Newfoundland (Fig. 19). On the Magdalen Shallows and in the northeastern Gulf ice disappeared later than normal. The duration of sea ice is the number of days ice was present. It is not the simple difference between the dates of first presence and last presence since the ice may appear and disappear during the ice season. On the Shallows the duration varied from a high of over 130 days in the southwestern and northeastern regions of the Gulf to just 10 days off southwestern Newfoundland (Fig. 20). This resulted in durations that were up to 50 days less than normal off southwestern Newfoundland to 20 days longer than normal in Northumberland Strait and Miramichi Bay (Fig. 20).

Scotian Shelf

Sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwest winds and ocean currents. In 2001, ice first appeared seaward of Cabot Strait during late-January (Fig. 13), which is slightly earlier-than-usual (Fig. 13). It maintained a relatively constant presence through into late-March off northeastern Cape Breton. Ice was primarily in the Sydney Bight area but some ice reached the Scotian Shelf proper. This ice had disappeared by mid-March, a departure time that was near normal (Fig. 14). The duration of ice south of Cabot Strait was up to 50 days off northern Cape Breton Island. This was near the long-term mean duration in the coastal regions of eastern Cape Breton but elsewhere the durations were shorter-than normaly, by 30-40 days in the Laurentian Channel and 10-30 days on the Scotian Shelf proper (Fig. 15). Note that durations of less than 10 days are not plotted.

The monthly estimates of the ice area seaward of Cabot Strait since the 1960s show that only small amounts were transported onto the Scotian Shelf during 20001 compared to the long-term mean (Fig. 18, 19). The ice area was, however, slightly larger in magnitude than the ice area observed in 2000. There were significantly more days than usual with ice present seaward of Cabot Strait, and well above the last few years. In spite of the long duration, the integrated ice area (summation of the area times the number of days) was similar to last year and remained well below the long-term average (Fig. 18). Indeed, it was the seventh lowest on record. This was the fourth consecutive year of very light ice conditions seaward of Cabot Strait. Note that based upon data collected since the 1960s, the furthest south that the ice penetrates is along the Atlantic coast of Nova Scotia to just past Halifax. Historical records prior to 1960 suggest that during heavy ice years, it occasionally penetrated much further south, for example in the 1880s sea ice was observed in the southwestern Scotian Shelf (A. Ruffman, Geomarine Associates Ltd., Halifax, personal communication).

Remotely-Sensed Sea Surface Temperature

Estimates of sea-surface temperature (SST) from satellite observations made by the Jet Propulsion Laboratory are archived by the Bedford Institute. The data provide broad coverage of SSTs from late-1981 to present. Discussions of their accuracy and utility as a climate indicator were provided by Mason *et al*. (1999) and Petrie and Mason (2000). Unfortunately in 2001, two factors contributed to the reduction of the satellite-derived estimates of sea-surface temperature (JPLSST). First, there was a degradation of the data beginning in the fall of 2000 and secondly, funding for the JPLSST dataset was discontinued in early-2001. Essentially no JPLSST estimates are available for the region after November 2000.

From the semi-monthly composite images on the Bedford Institute OSD website it appears that a false field representing cold temperatures started in the northern portion of the region in October 2000 and had a southern limit of roughly 48°N. It affected the SST estimates in the Gulf of St. Lawrence and over the NE Newfoundland Shelf. By the second half of October, it had moved to about 46°N and affected the northern half of the Magdalen Shallows, the northern half of St. Pierre Bank and the Grand Bank. By November 1-15, it encompassed the Gulf of Maine and Scotian Shelf, St. Pierre Bank, and retreated to the north somewhat over Grand Bank to about 47°N. For November 16-30, it covered the entire shelf region of Atlantic Canada. By February 2001, the SST images seemed to be free of this anomalous structure. However, comparisons with Station 2 off Halifax and Station 27 off St. John's indicate that SST from the satellite may be too low up to and including April 2001. Images processed and displayed by The Johns Hopkins University Applied Physics Laboratory show (erroneous) low temperatures during the fall period and extensive cloud cover from January 2001 to mid-April 2001. To be safe, anomalies for 2001 will include only May-December 2001.

In order to examine the variations in SST in 2001 from the region, we have used the estimates from the data downloaded at Bedford Institute. A comparison of the overlapping data (1997-2000) from JPL and BIO for the 23 AZMP sites (Fig. 20) show r^2=0.98 and a linear regression given by SST(BIO)=-0.575+1.0083*SST(JPL). However, when anomalies were created for both datasets using the long-term monthly means based on JPL data (1981-2000), r^2=0.50 and the regression was SST_{anom}(BIO)=-0.28+0.7387*SST_{anom}(JPL). It therefore was not appropriate to link the 2001 anomalies from BIO with the pre-2001 anomalies from JPL.

In order to determine the large spatial scale changes of SST during 2001, we proceeded as follows. Using the BIO estimates, we derived monthly (May to December) temperature changes for each of the 23 AZMP boxes from SST(month, 2001)-SST(month, average(1997-2000)) (Fig. 21). Annual anomalies were calculated from the May-December monthly anomalies. The results (shown as circles) indicate that from the mid-Labrador Shelf southward over the Grand Banks sea-surface temperatures were 0.2 to 0.8 lower than for the 1997-2000 period. The contiguous area consisting of Cabot Strait, the NE Gulf of St. Lawrence, the Magdalen Shallows, the eastern and central Scotian Shelf have SST anomalies for 2001 that did not change from the 1997-2000 period or increase by about 0.6°C (Magdalen Shallows). The western Scotian Shelf, Lurcher, and Bay of Fundy show a decrease. However, the 1997-2000 period was generally above normal by as much as 2°C from the JPL long-term time series. To give the limited duration of the BIO series more context, we have subtracted the change in temperature from the average JPL anomalies (1997-2000) and find that in general while temperatures decreased in 2001, they were generally still above normal (triangles in figure).

SUMMARY

During 2001, the NAO index was low and declined relative to 2000. Air temperatures over most of the northwest Atlantic region were above normal and most increased compared to 2000. The exception to the warm conditions was at Cape Hatteras where available air temperatures indicate colder-than-normal conditions but still warmer than in 2000. Anomalous easterly and northeasterly winds dominated the Labrador Sea region during 2001 while to the south they were more variable. The relatively warm winter temperatures in eastern Canada resulted in less ice than normal off Newfoundland and Labrador, and in the Gulf of St. Lawrence. Ice generally arrived late or on schedule but left early, causing fewer days of ice in most areas. The exceptions were in the coastal regions around the Magdalen Shallows and in the vicinity of the Strait of Belle Isle. Little ice reached the Scotian Shelf proper and seaward of Cabot Strait the amount of ice was the 7th lowest in the 40-year record. The number of icebergs that reached the Grand Banks was 89, significantly lower than 2000 when 843 bergs were spotted on the Banks. The analysis of satellite-derived sea-surface temperature indicates that the entire region experienced above normal values in 2001.

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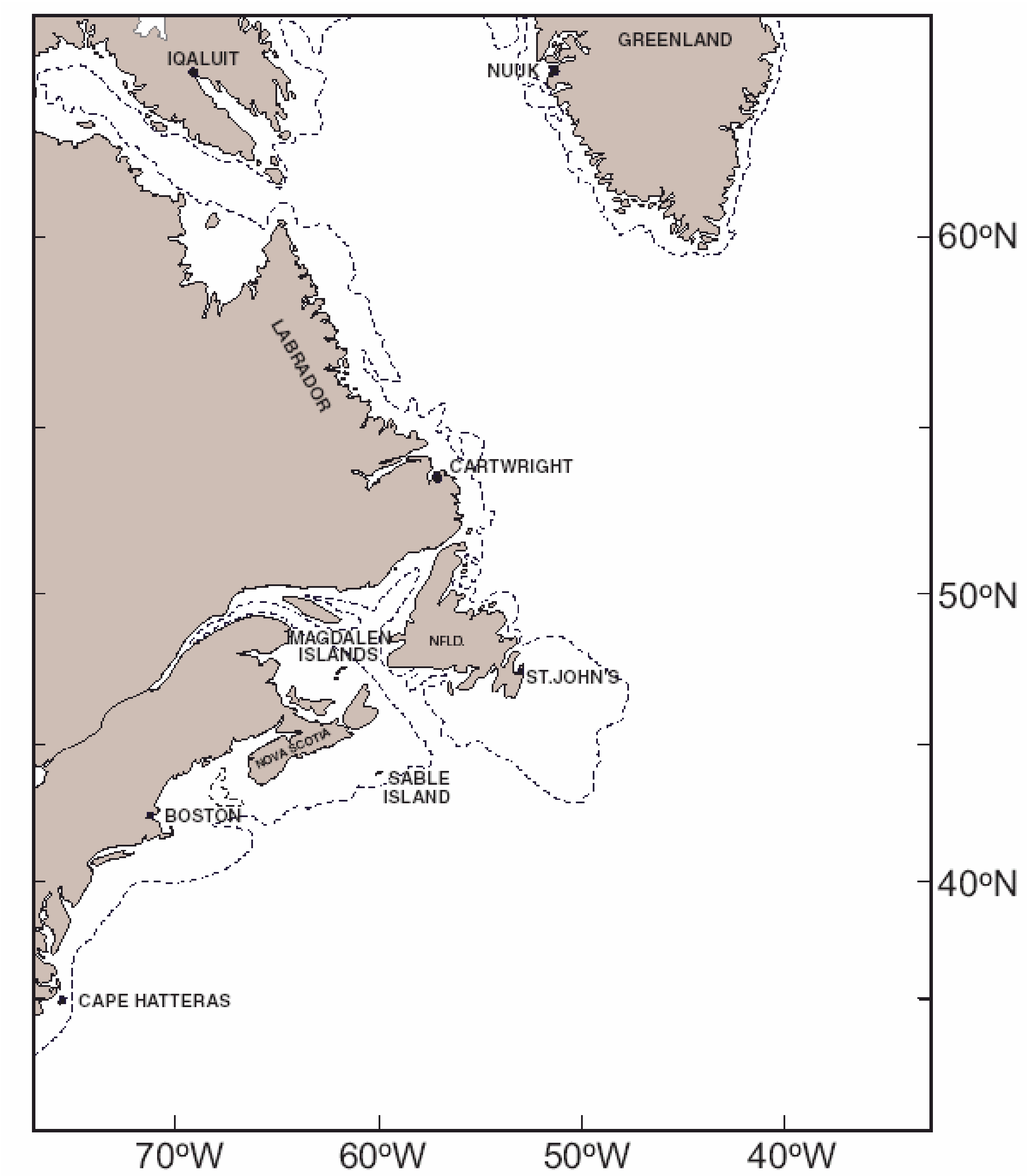


Fig. 1. Northwest Atlantic showing coastal air temperature stations. The dashed line denotes the 200 m isobath.

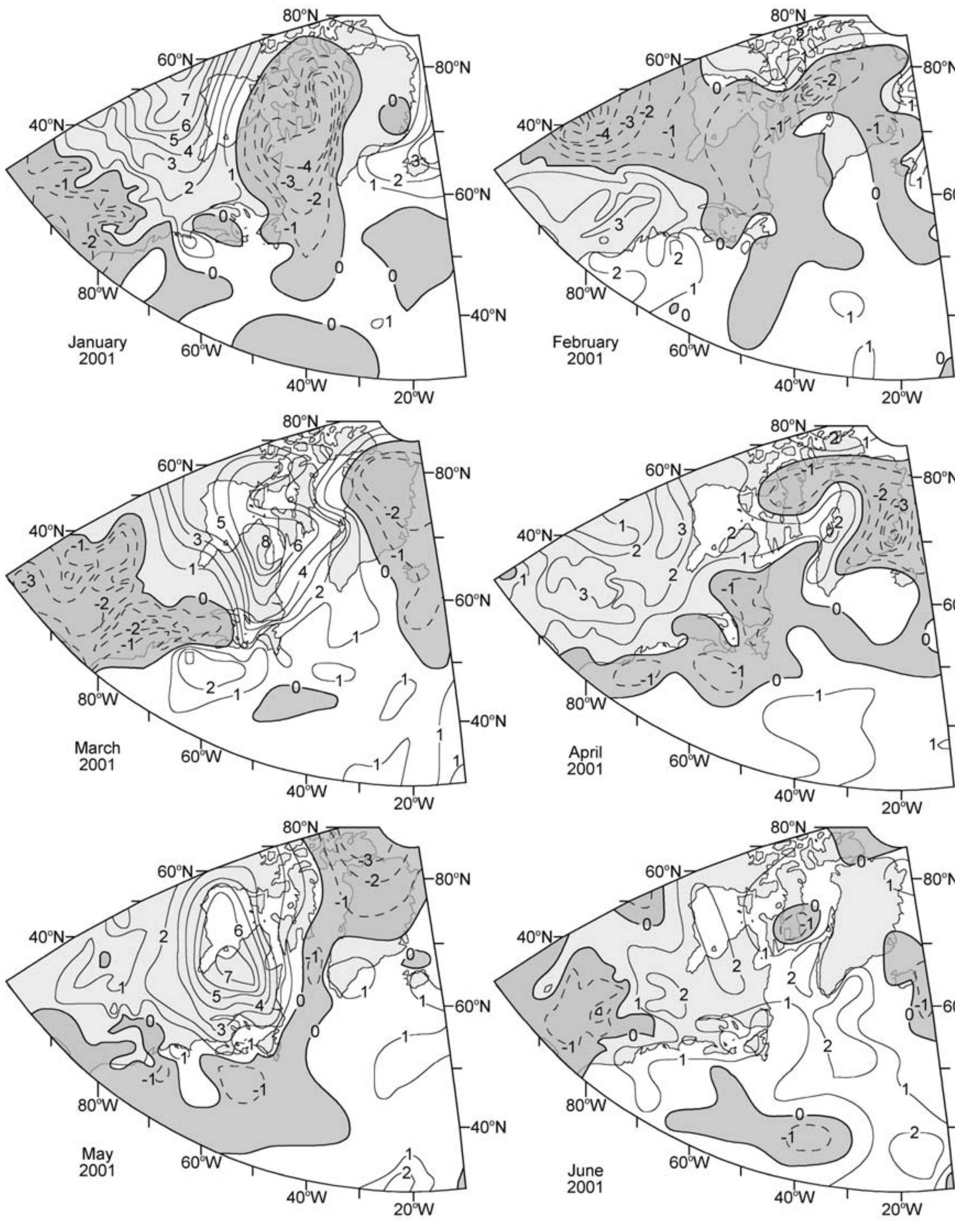


Fig. 2. Monthly air temperature anomalies (°C) over the Northwest Atlantic and eastern Canada in 2001 relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*).

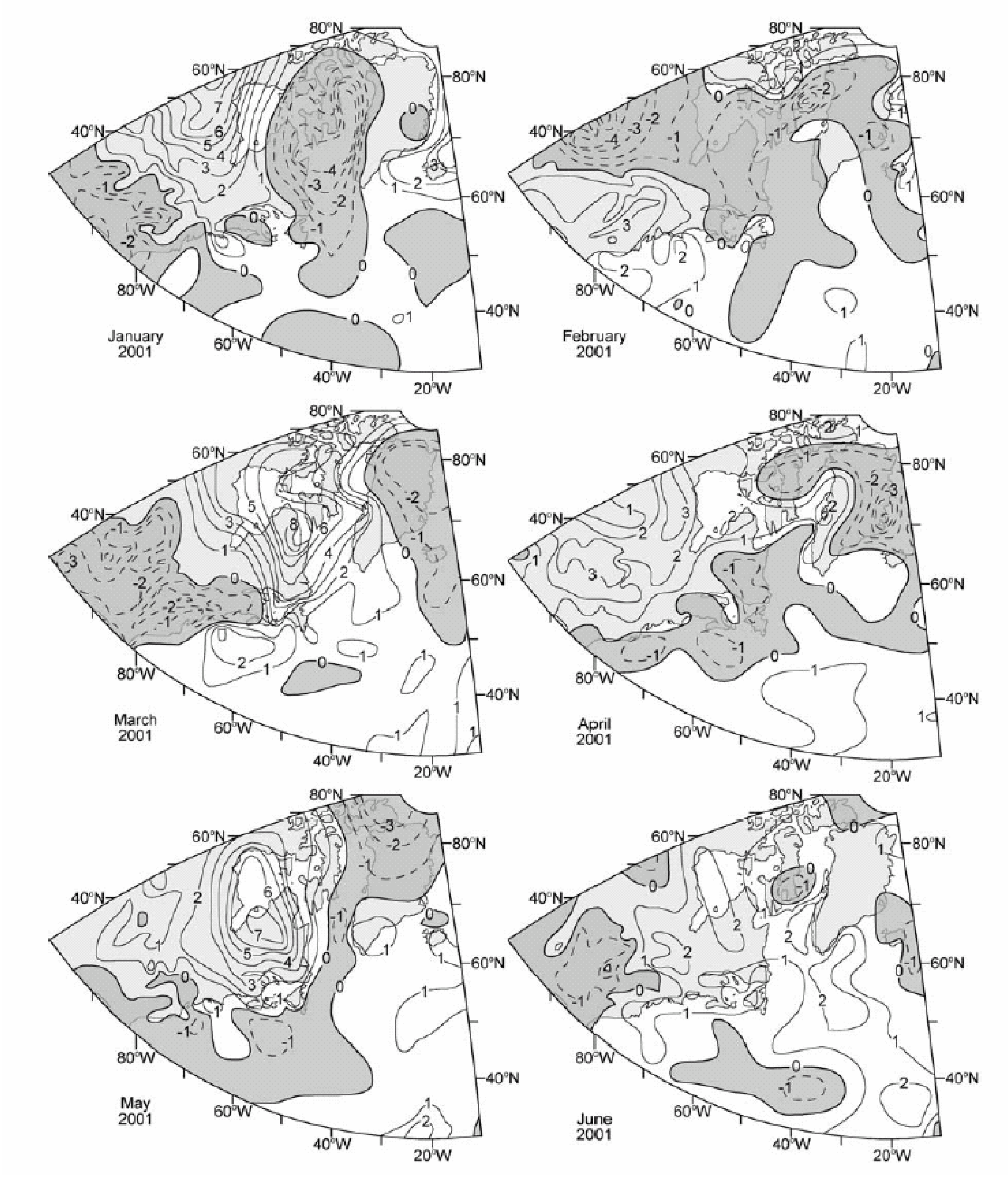


Fig. 2 (continued). Monthly air temperature anomalies (°C) over the Northwest Atlantic and eastern Canada in 2001 relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*).

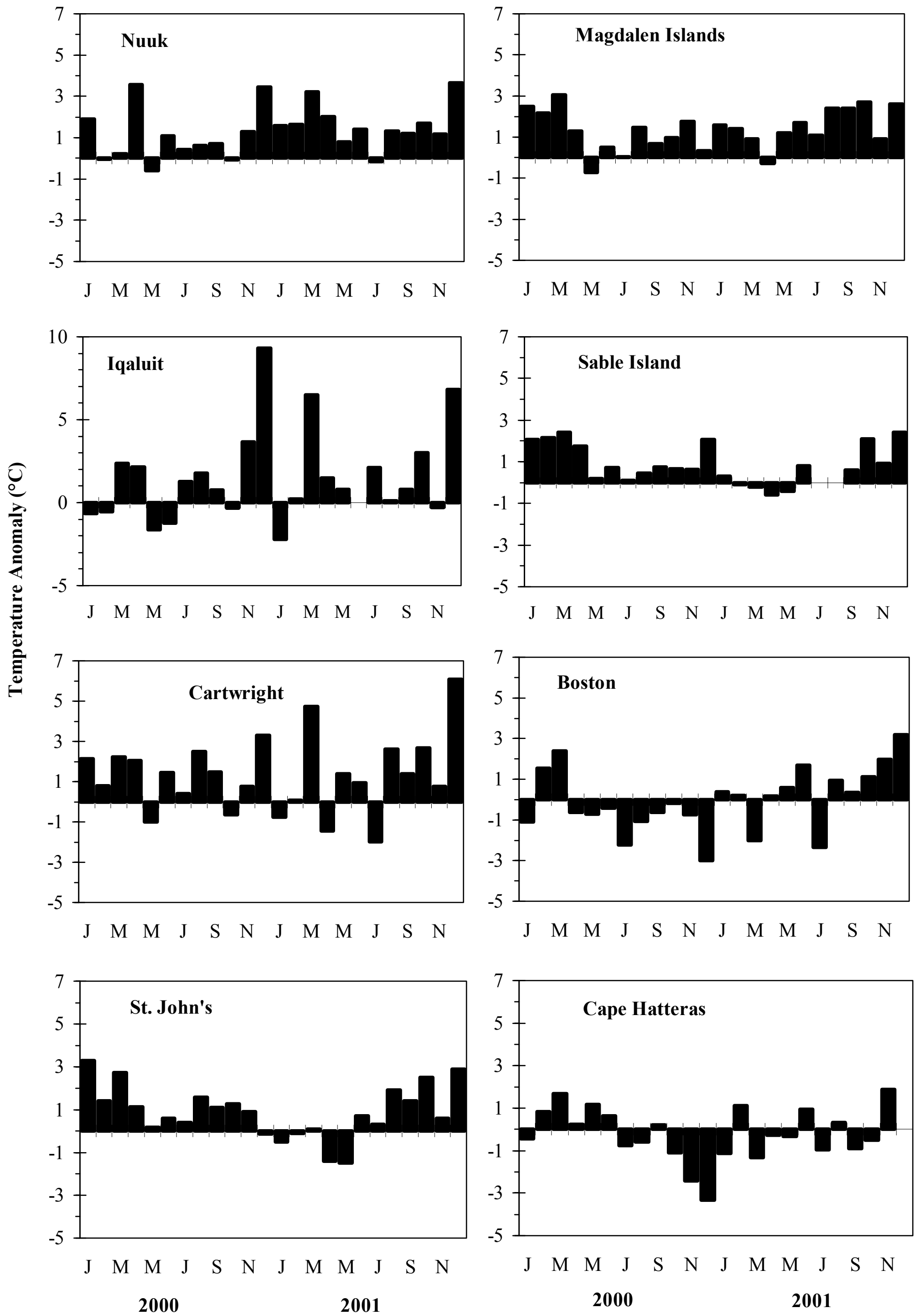


Fig. 3. Monthly air temperature anomalies in 2000 and 2001 at selected coastal sites (see Fig. 1 for locations).

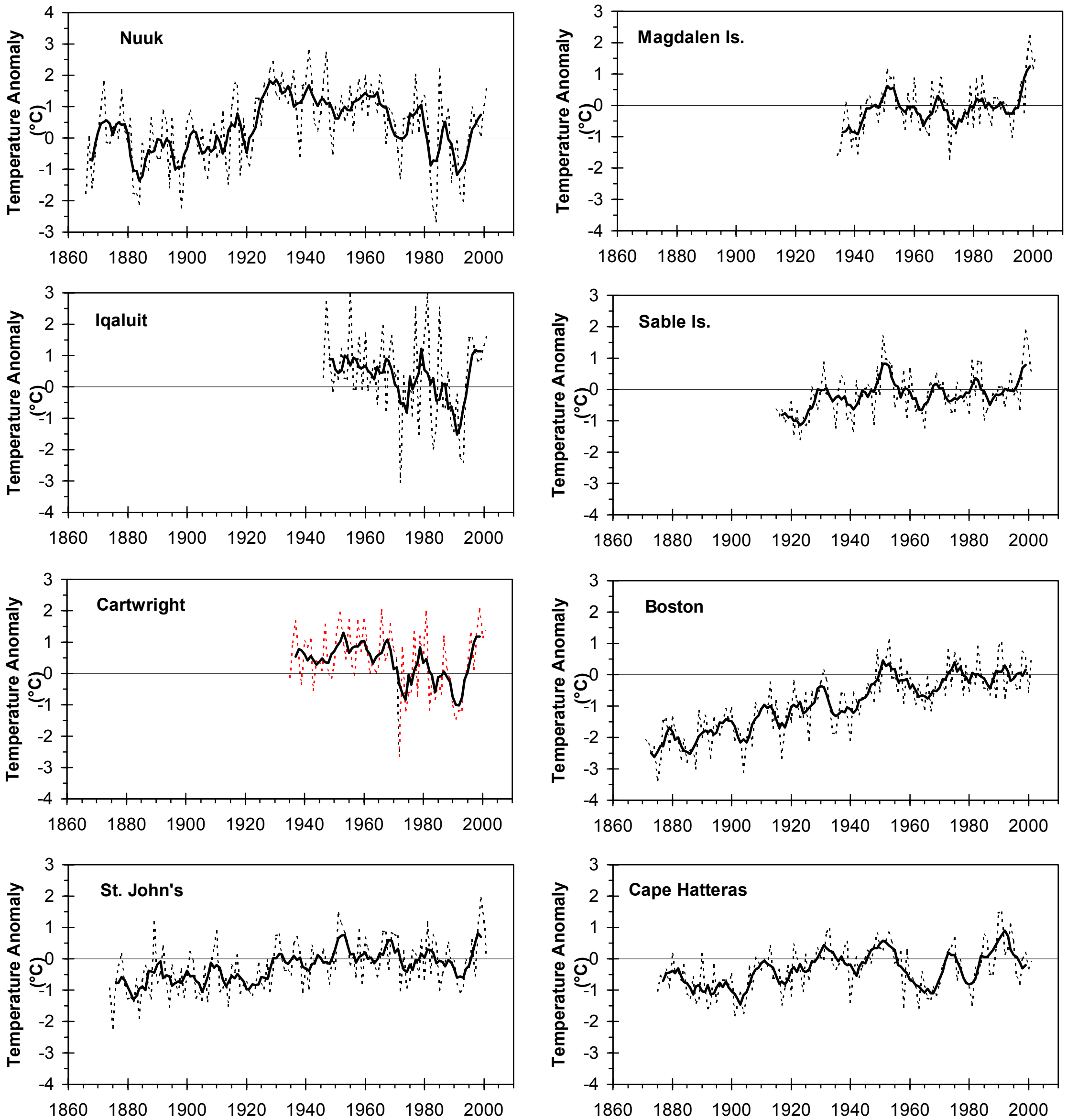


Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

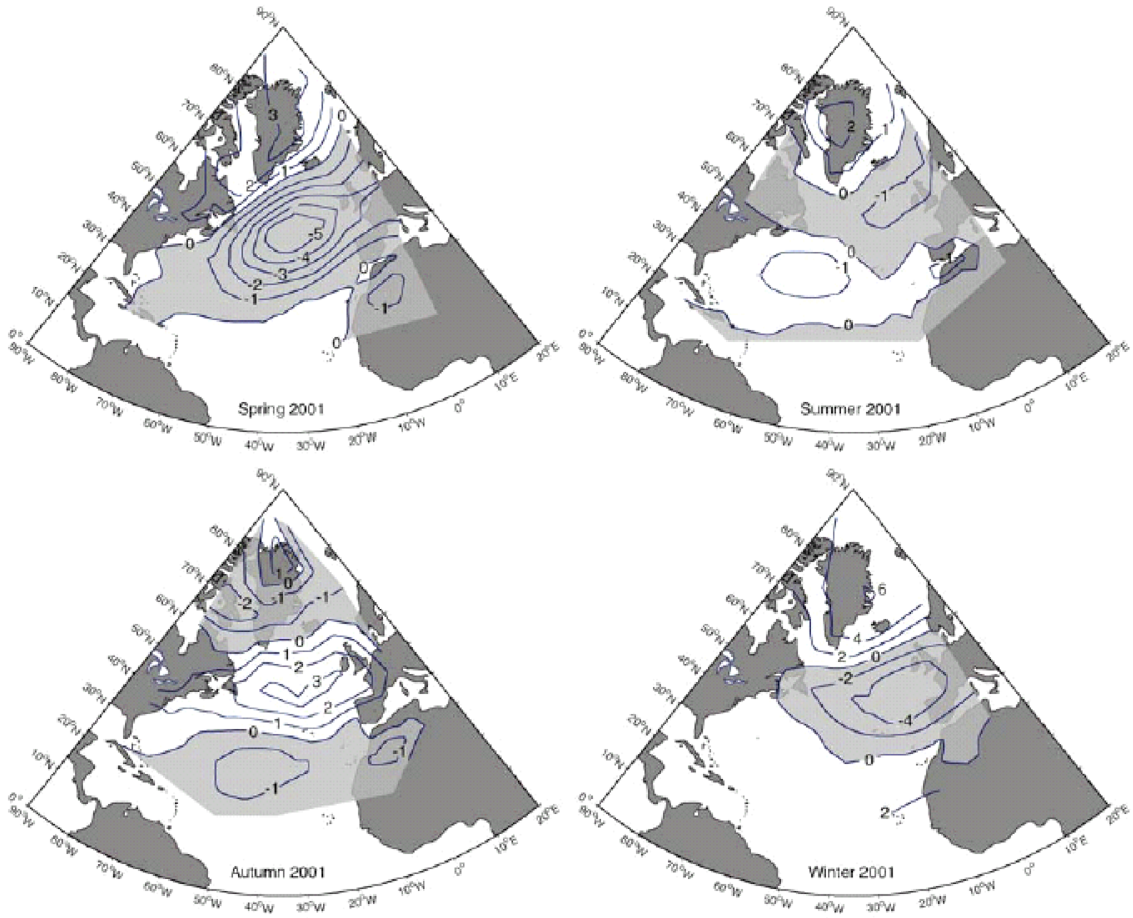


Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2000 relative to the 1961-90 means.

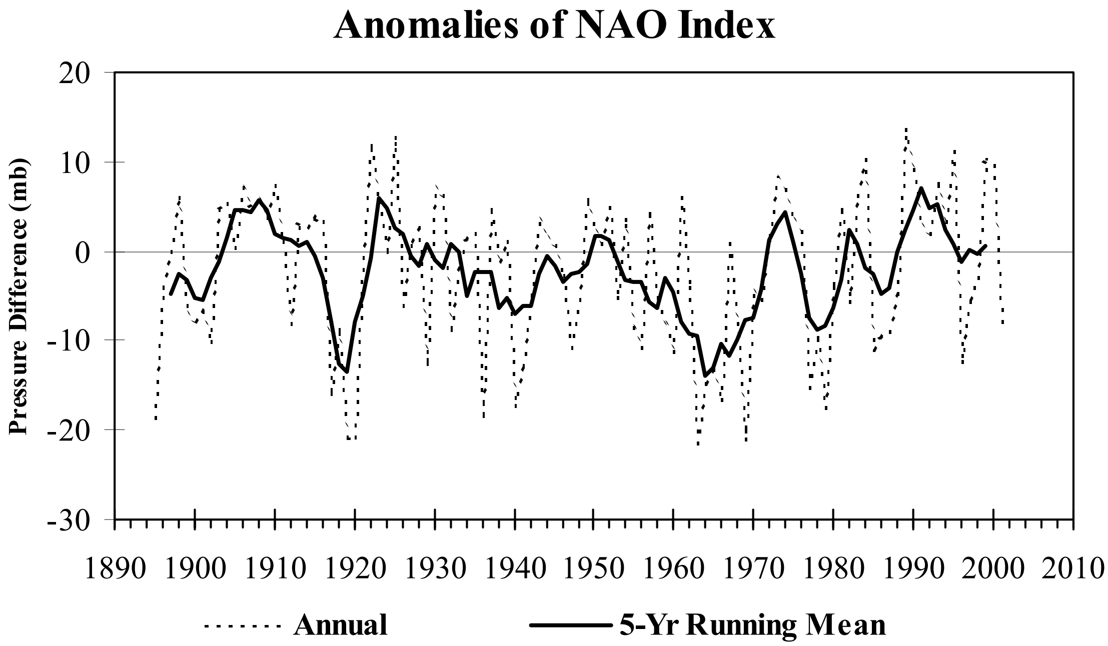


Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1961-90 mean.

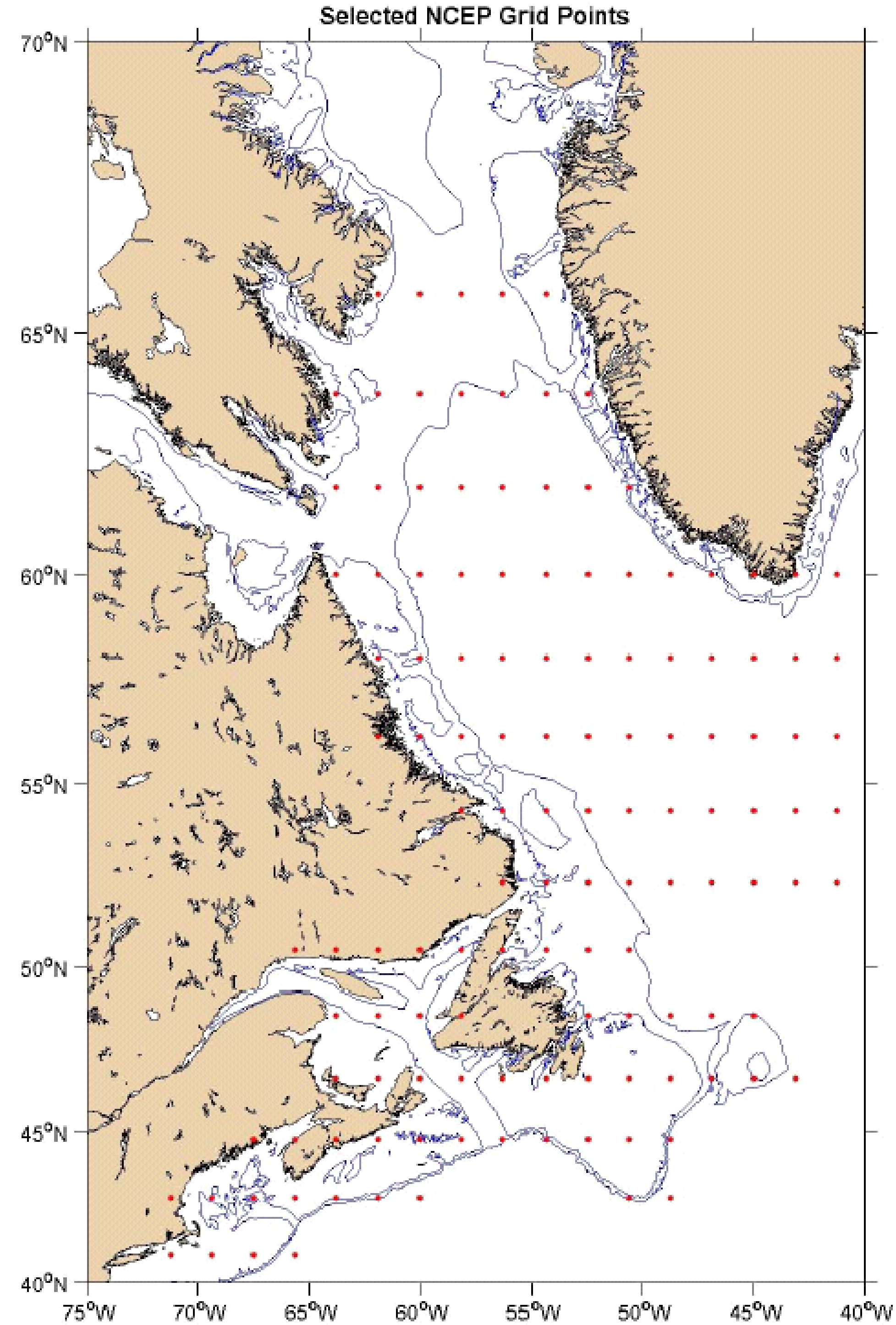


Fig. 7. The Northwest Atlantic showing the NCEP wind grids used in our study..

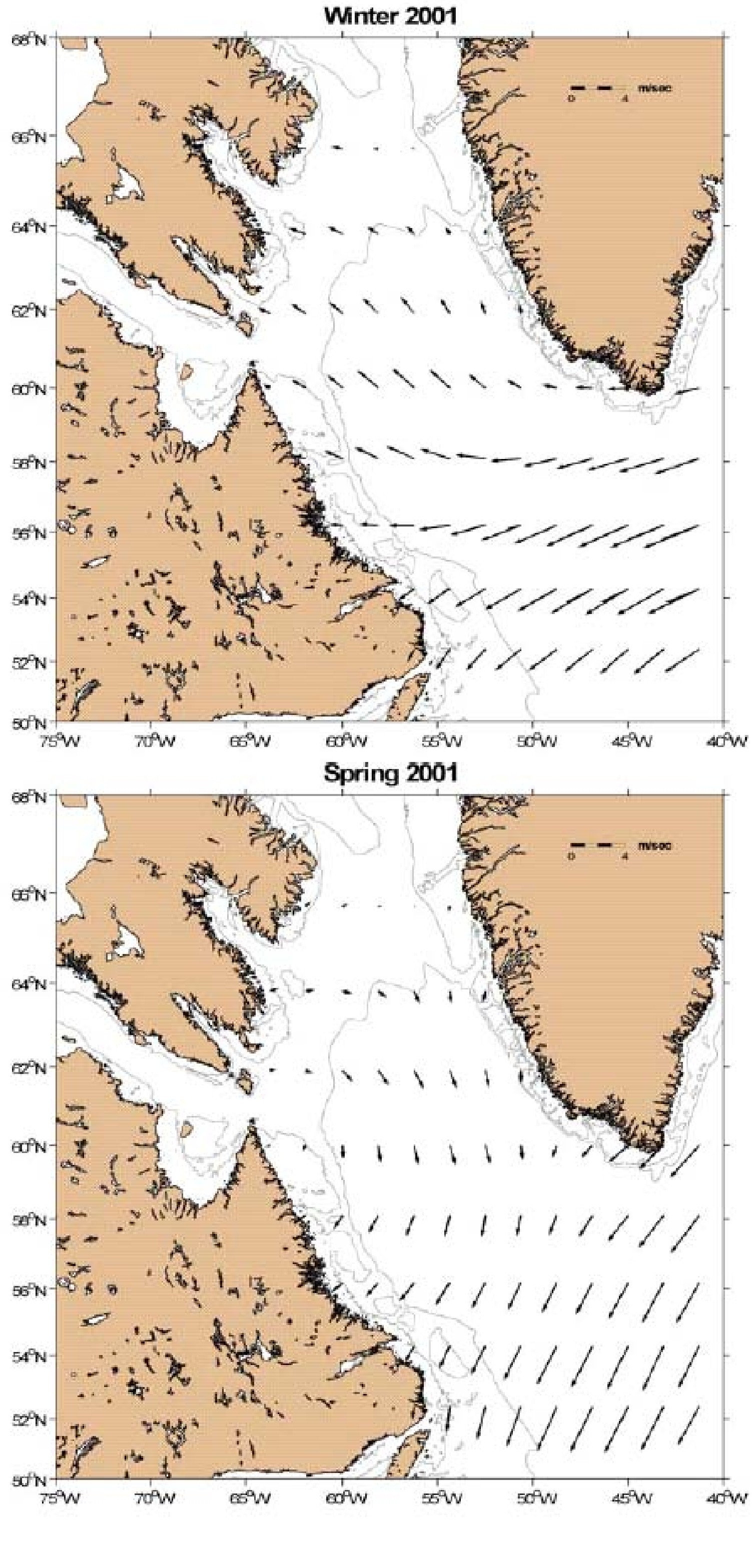


Fig. 8. The wind anomalies.

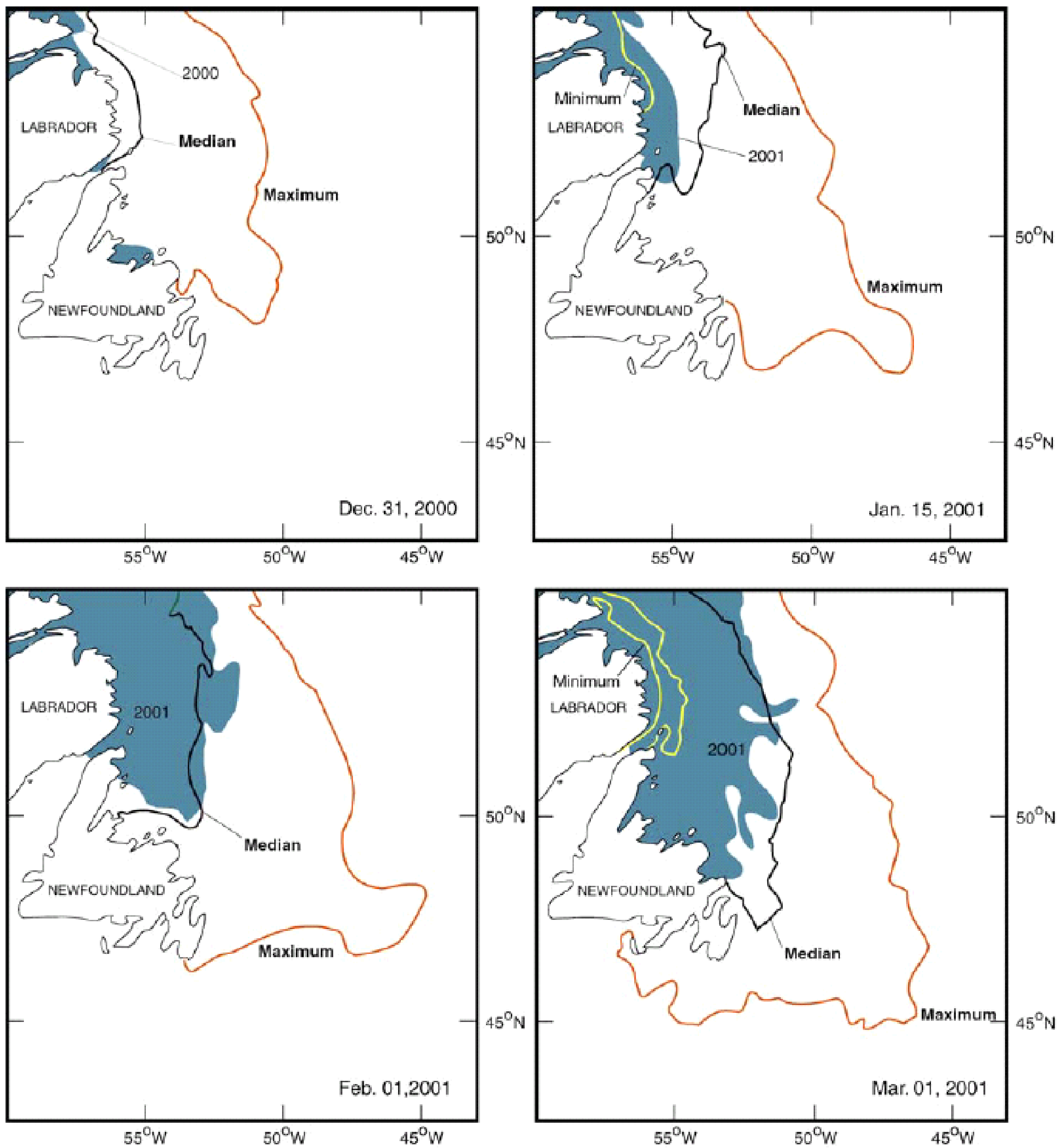


Fig. 10a. The location of the ice (shaded area) between December 2000 and March 2001 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

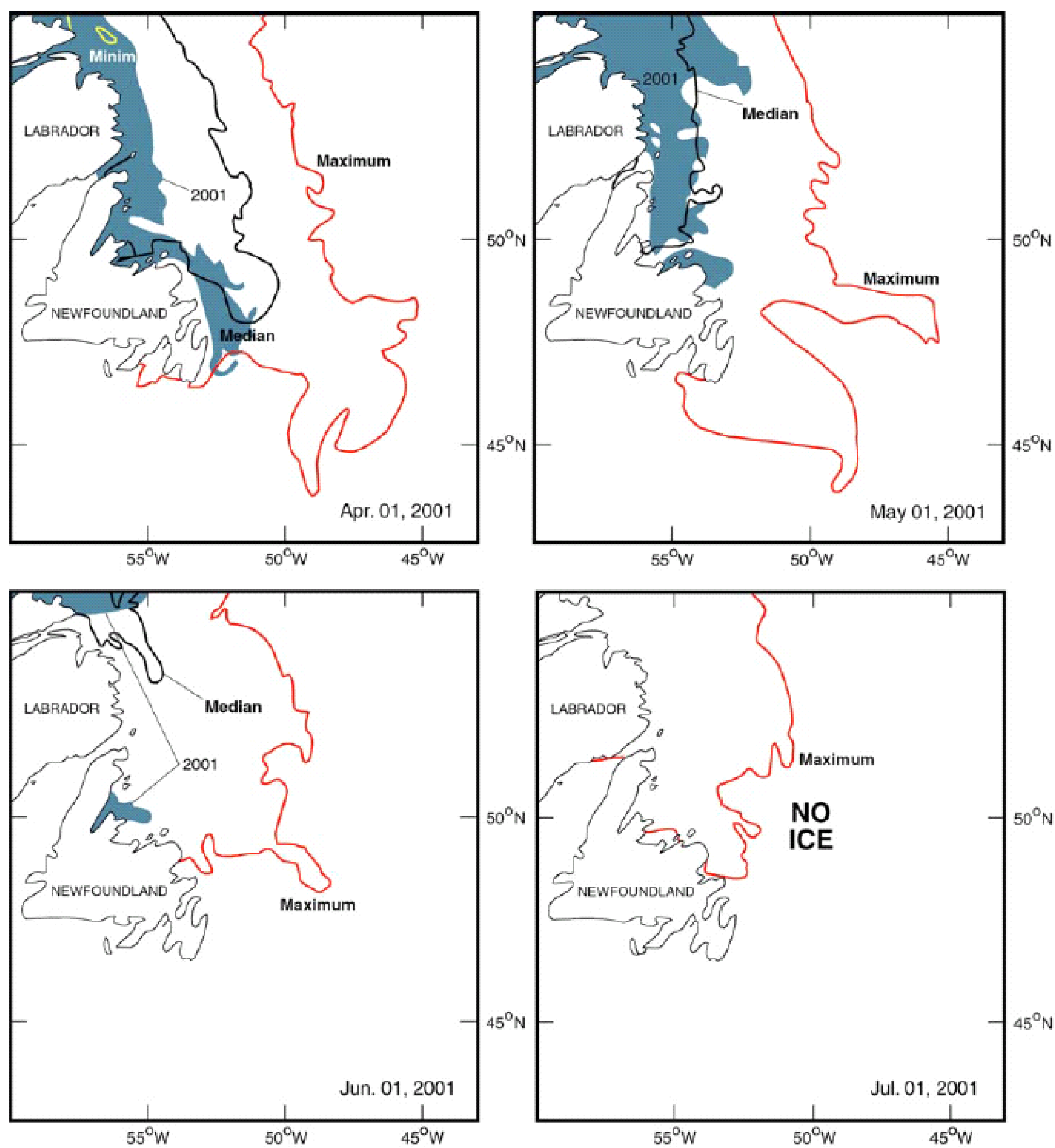


Fig. 10b. The location of the ice (shaded area) between April and July 2001 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

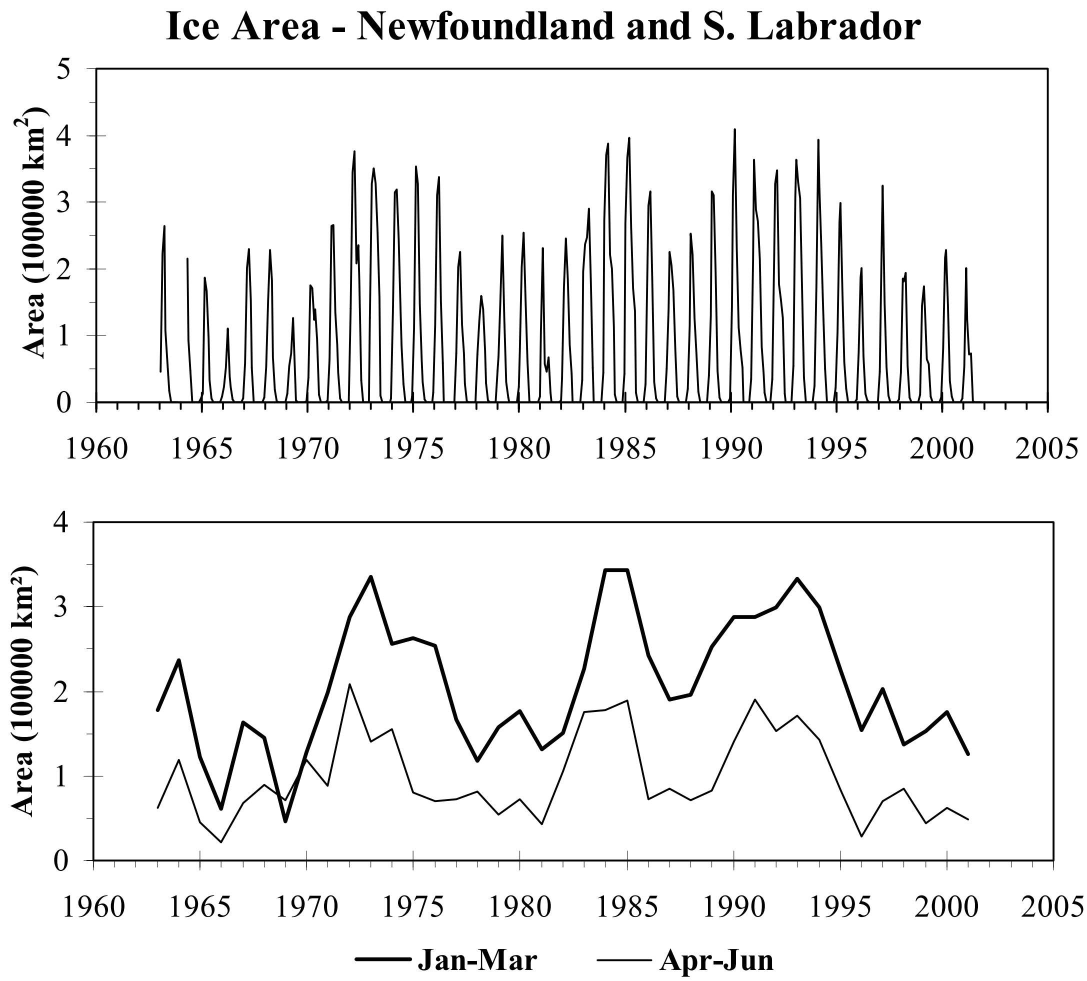


Fig. 11. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

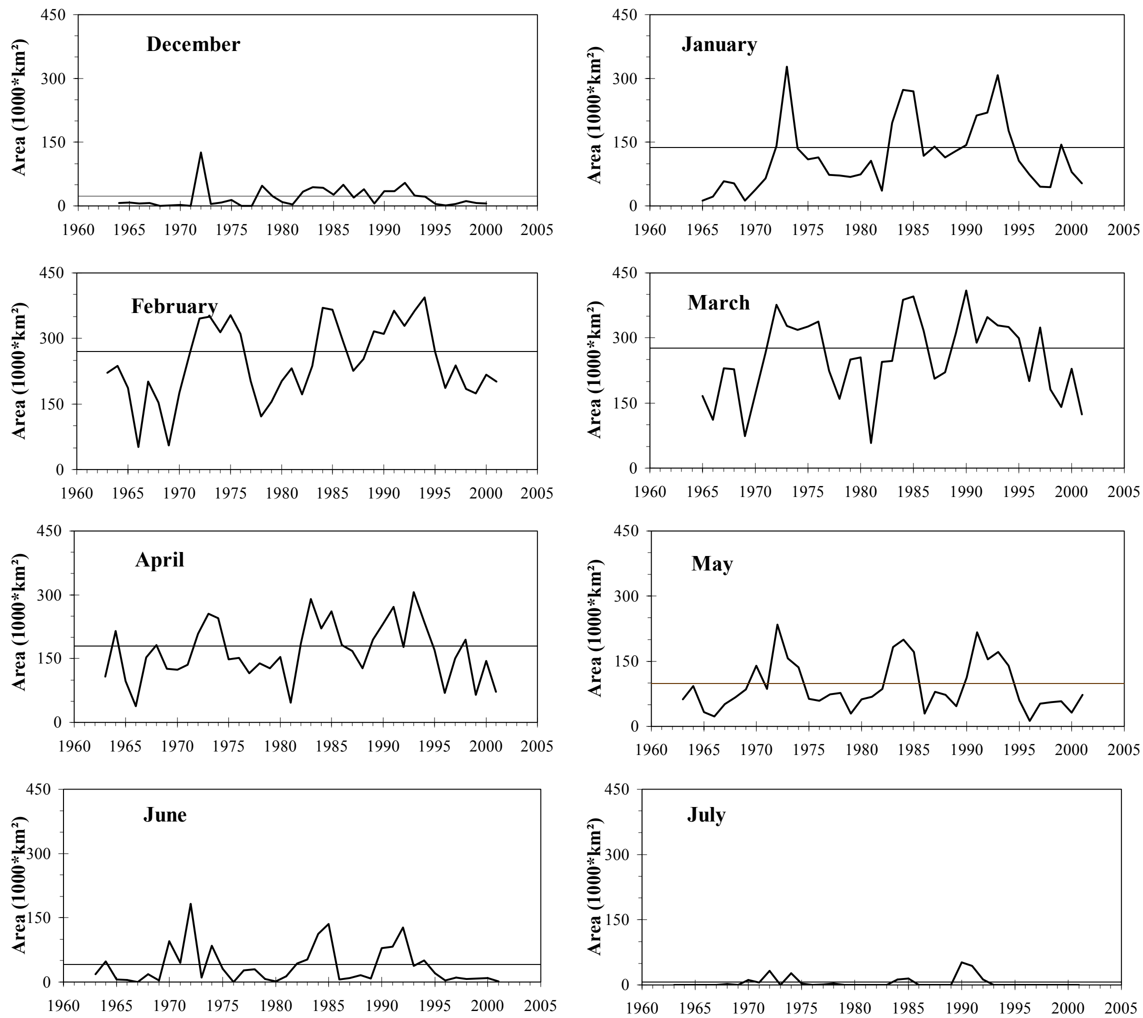


Fig. 12. The time series of ice area off Newfoundland and Labrador, by month. The horizontal lines represent the long-term (1971-2000) means.

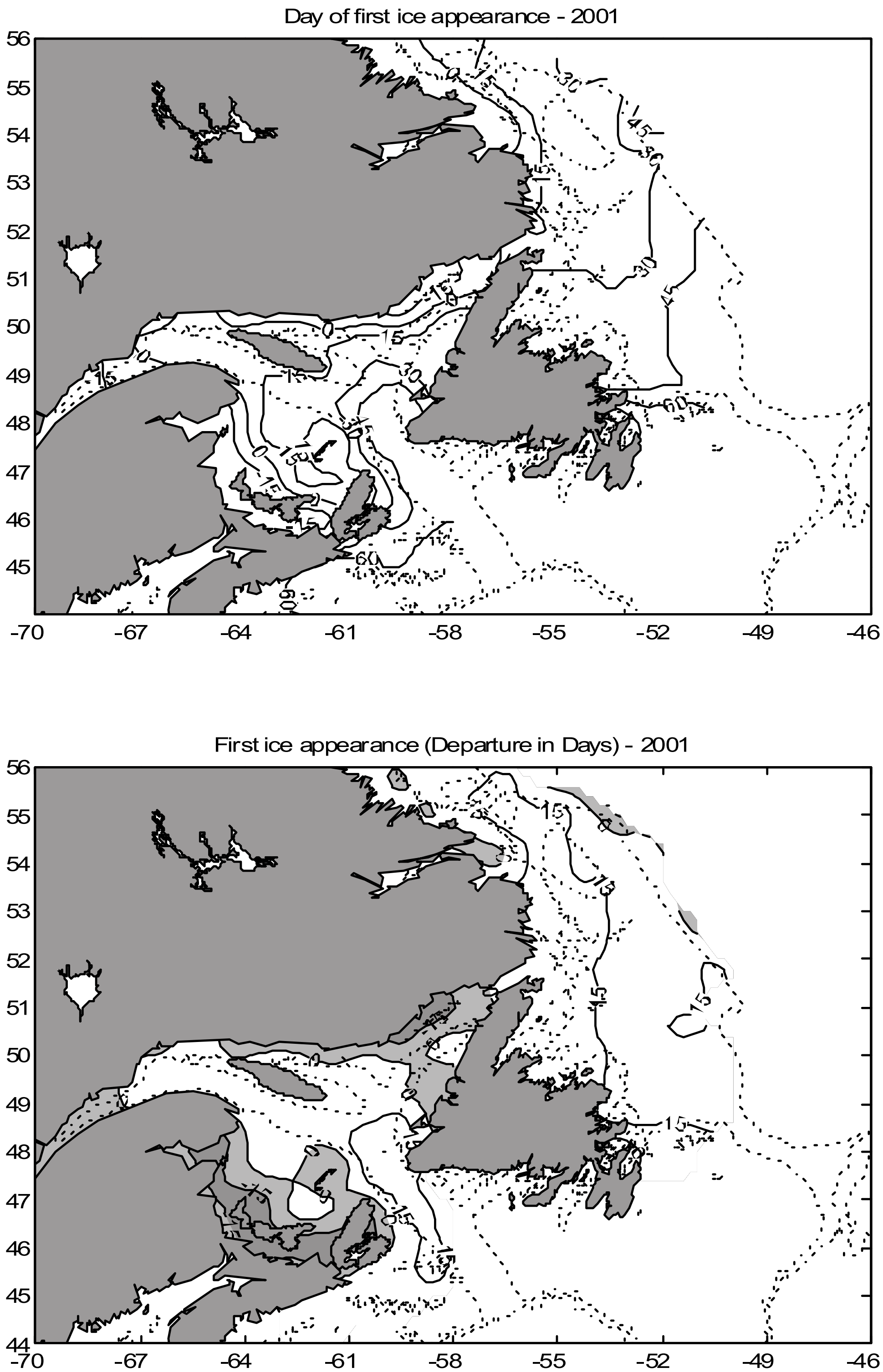


Fig. 13. The time when ice first appeared during 2001 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative anomalies indicating earlier than normal appearance are shaded.

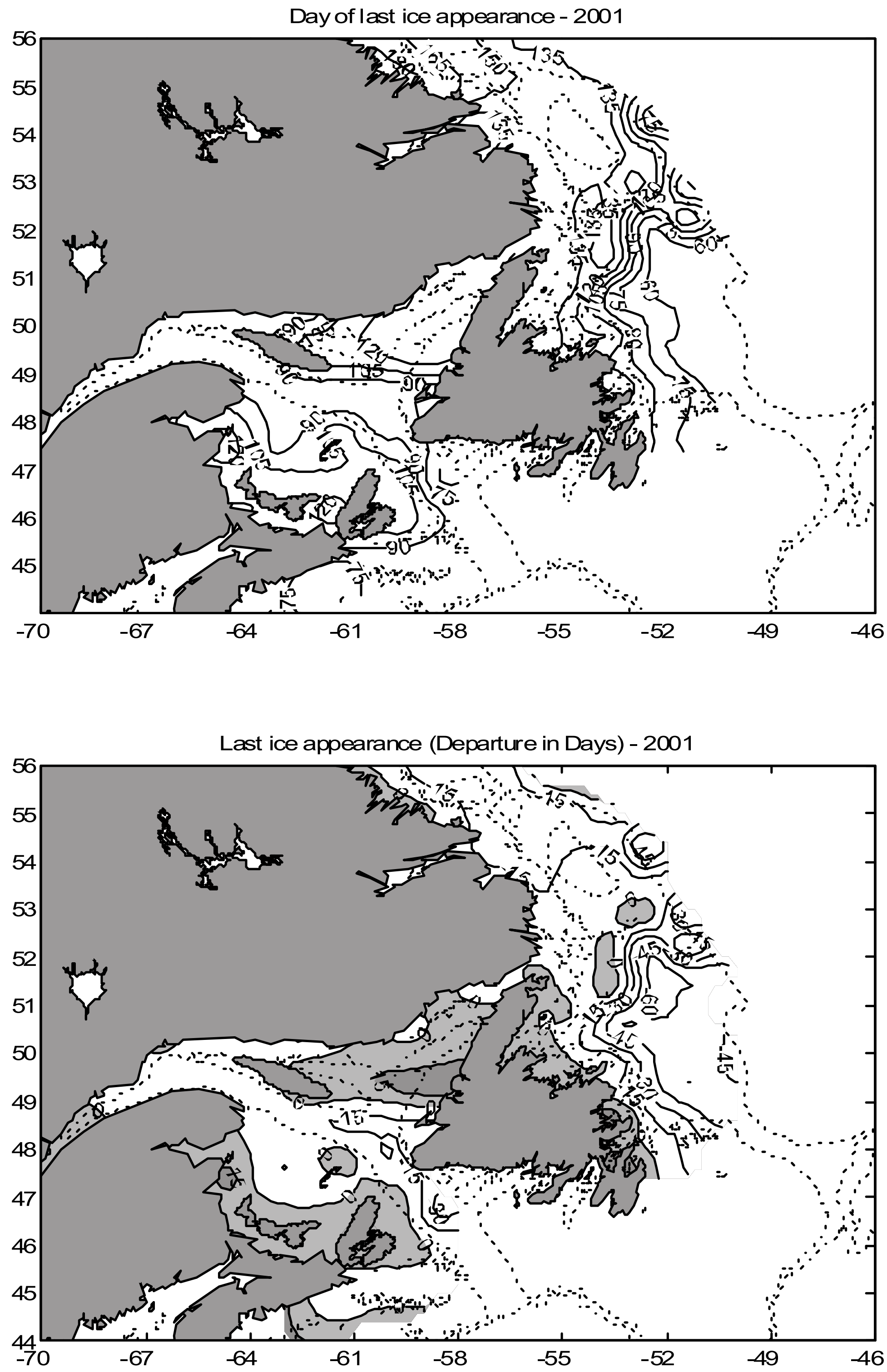


Fig. 14. The time when ice last appeared during 2001 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative anomalies indicating later than normal disappearance are shaded.

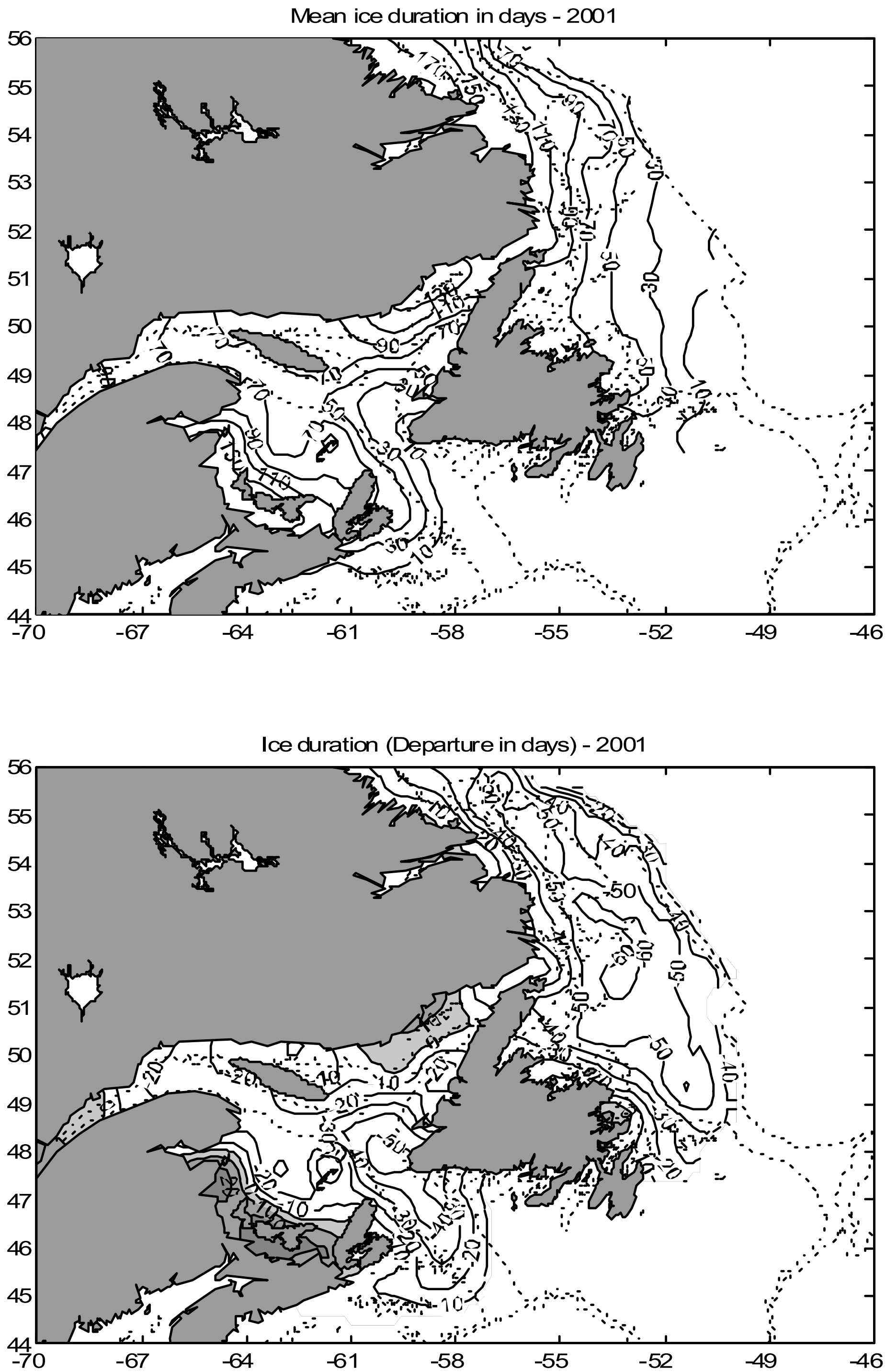
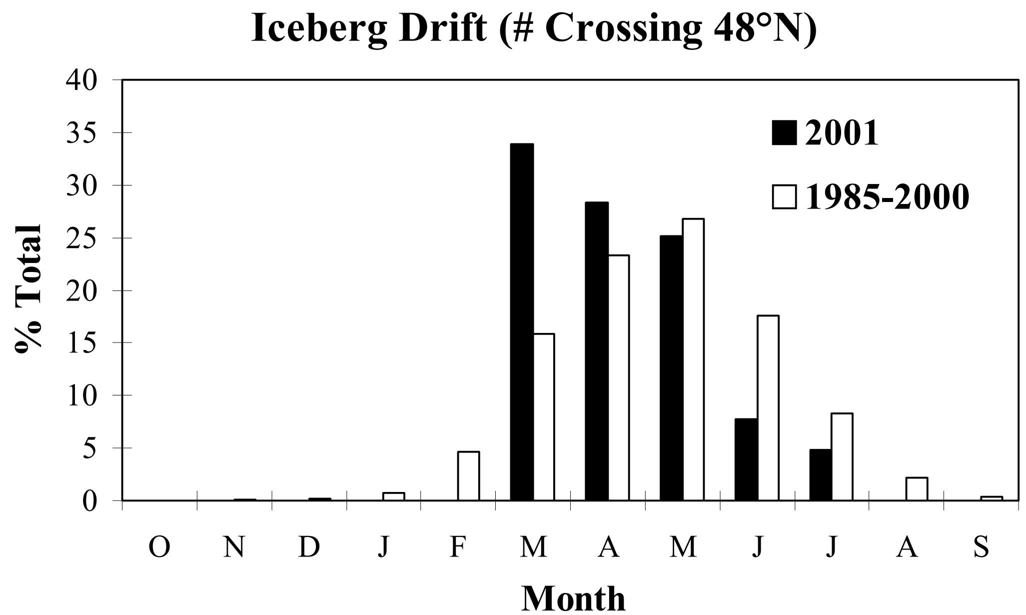


Fig. 15. The duration of ice in days (top panel) during 2001 and their anomaly from the 1971-2000 mean in days (bottom panel). The positive anomalies, which indicate a duration longer than the mean, are shaded.



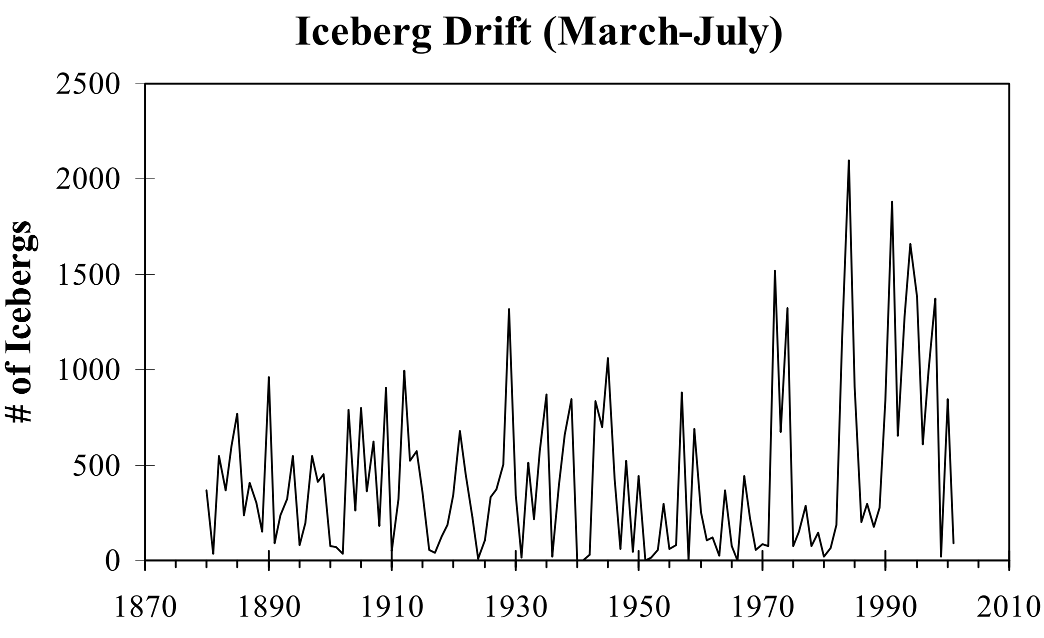


Fig. 16. The number of icebergs crossing south of 48°N during the iceberg season 2000/2001 expressed as a percent of the total by month compared to the mean during 1985-2000, the years SLAR has been used (top panel) and the time series of total number of icebergs observed during March to July (bottom panel).

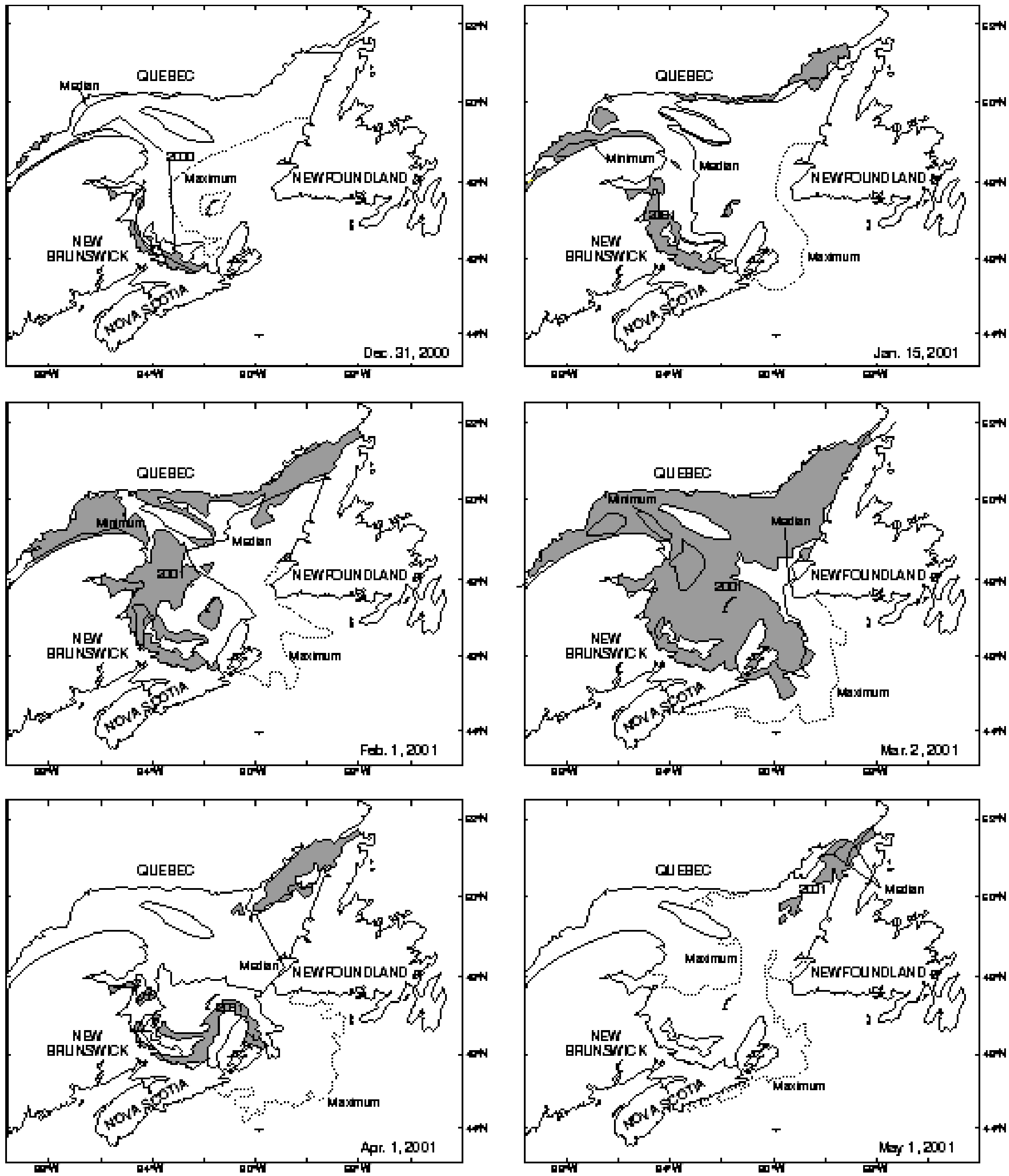


Fig. 17. The location of the ice (shaded area) between December 2000 and May 2001 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

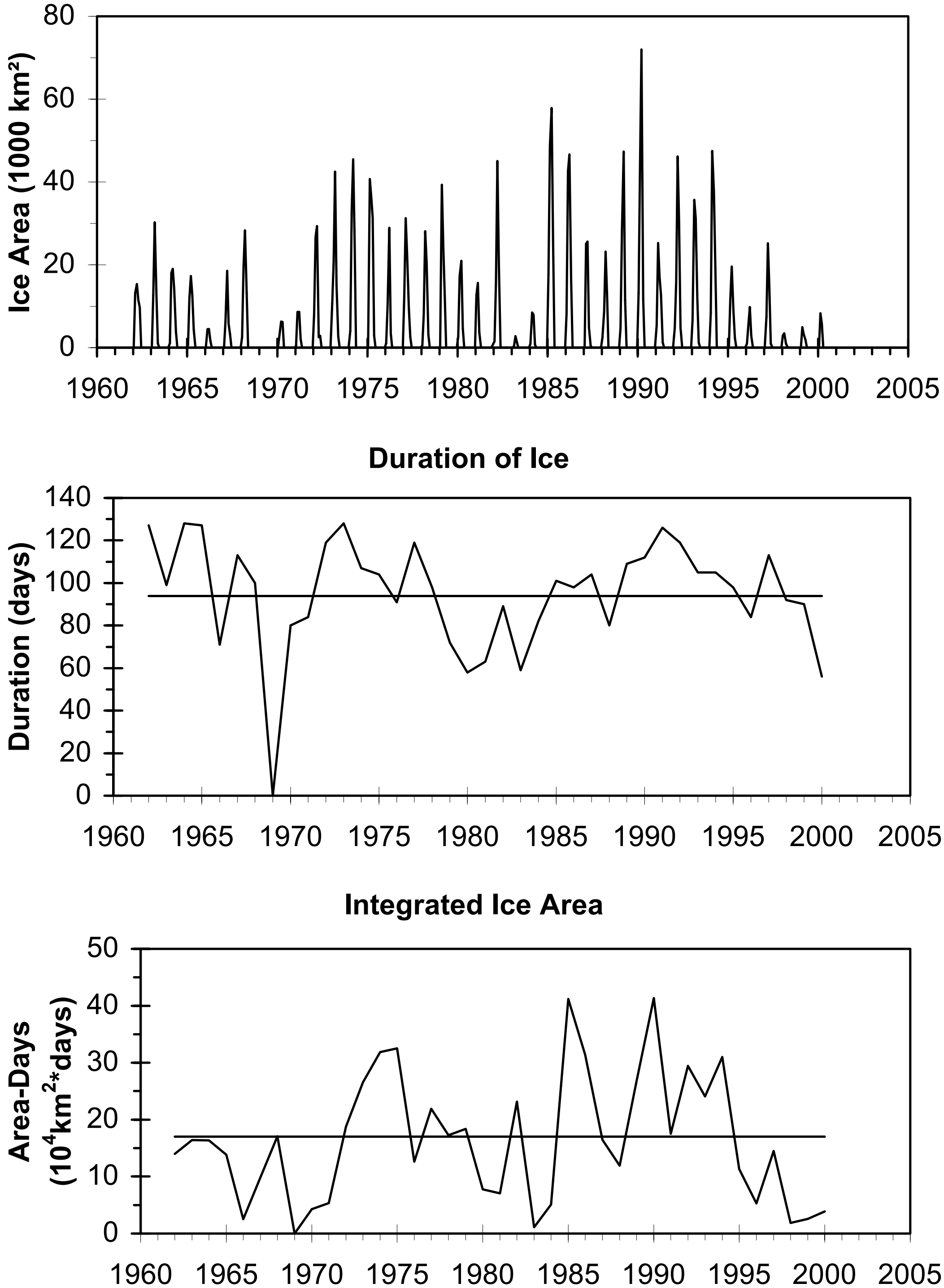


Fig. 18. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

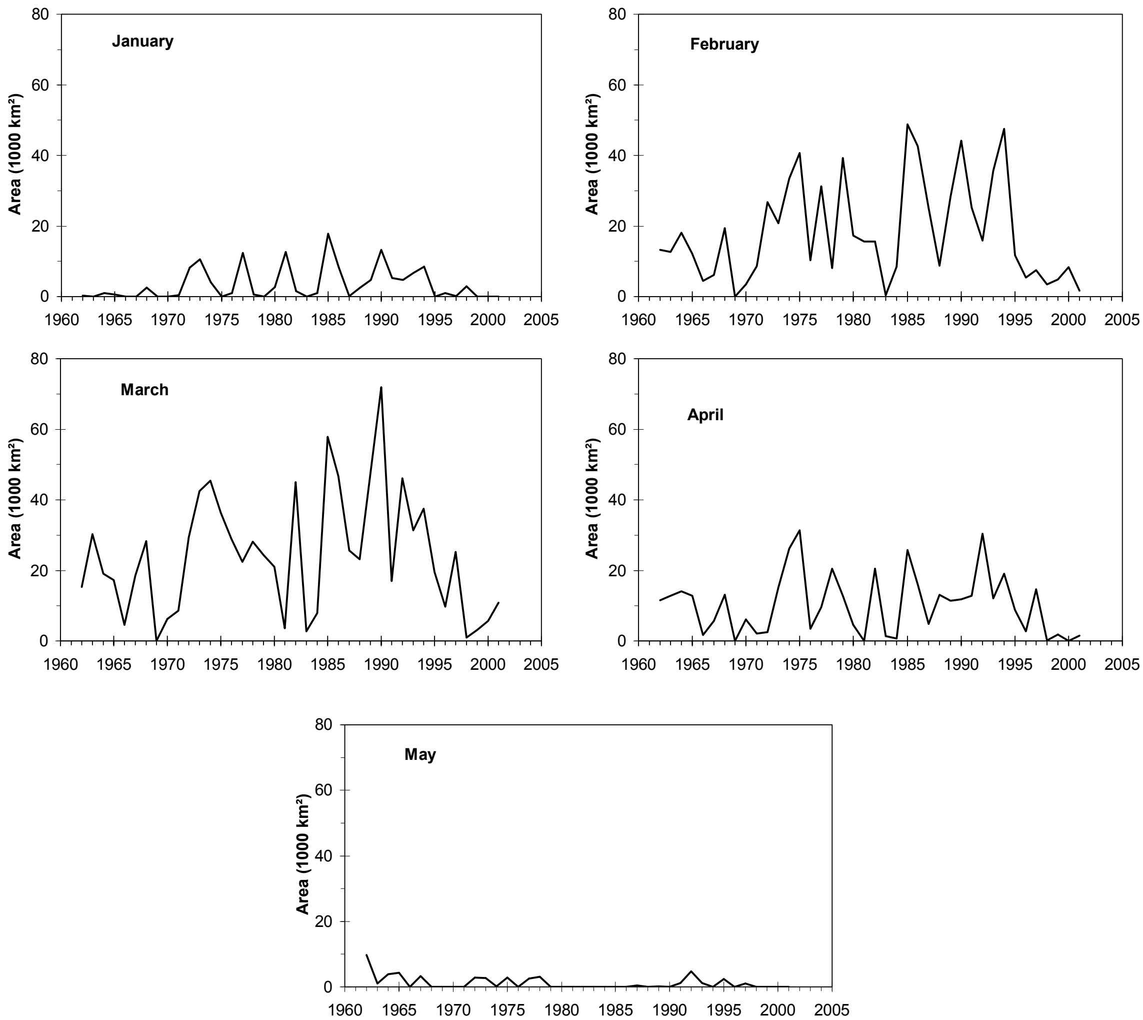


Fig. 19. The time series of ice area seaward of Cabot Strait, by month. The horizontal lines represent the long-term (1962-1990) monthly means.

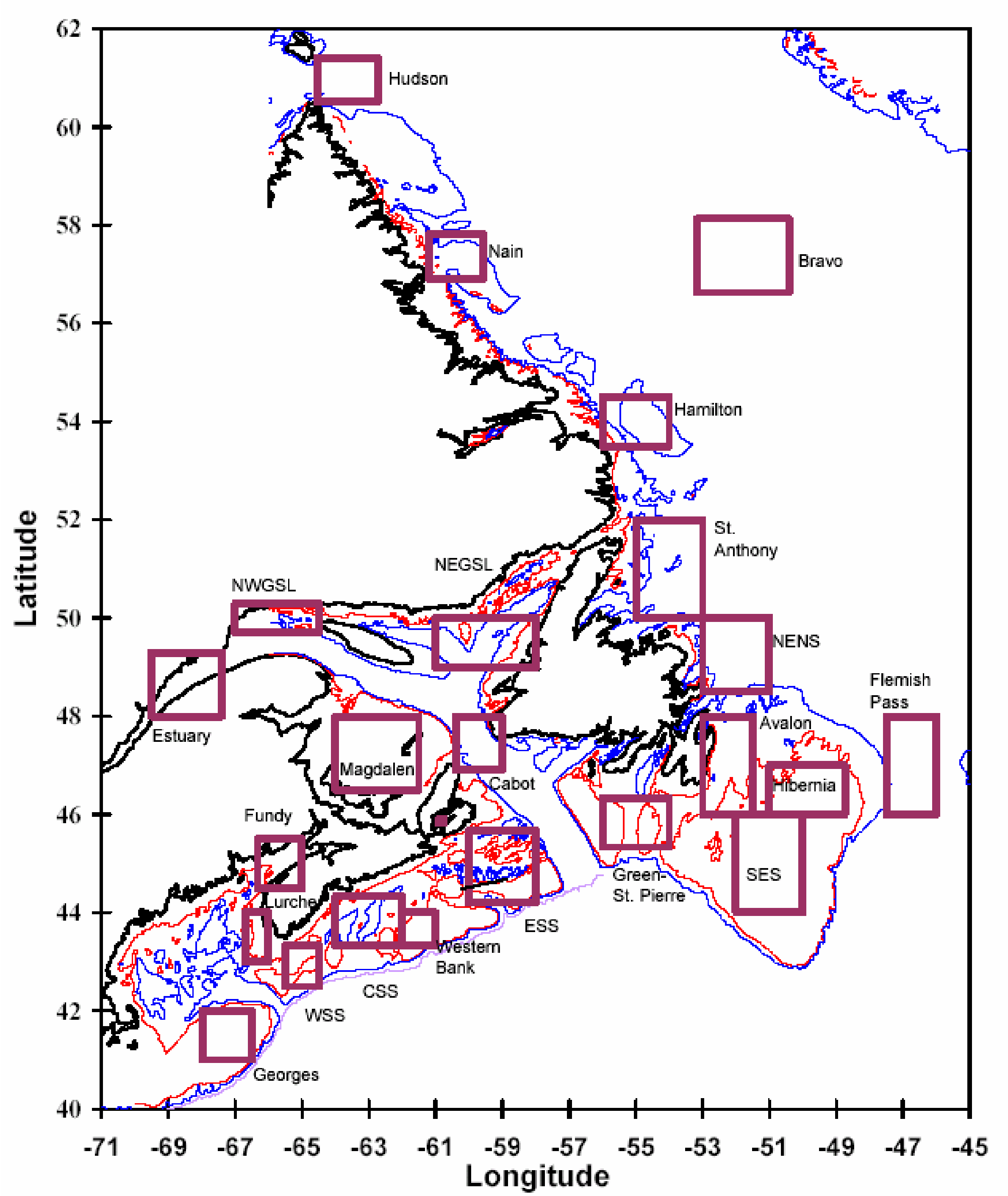


Fig. 20. The areas in the northwest Atlantic used for extraction of sea-surface temperature.

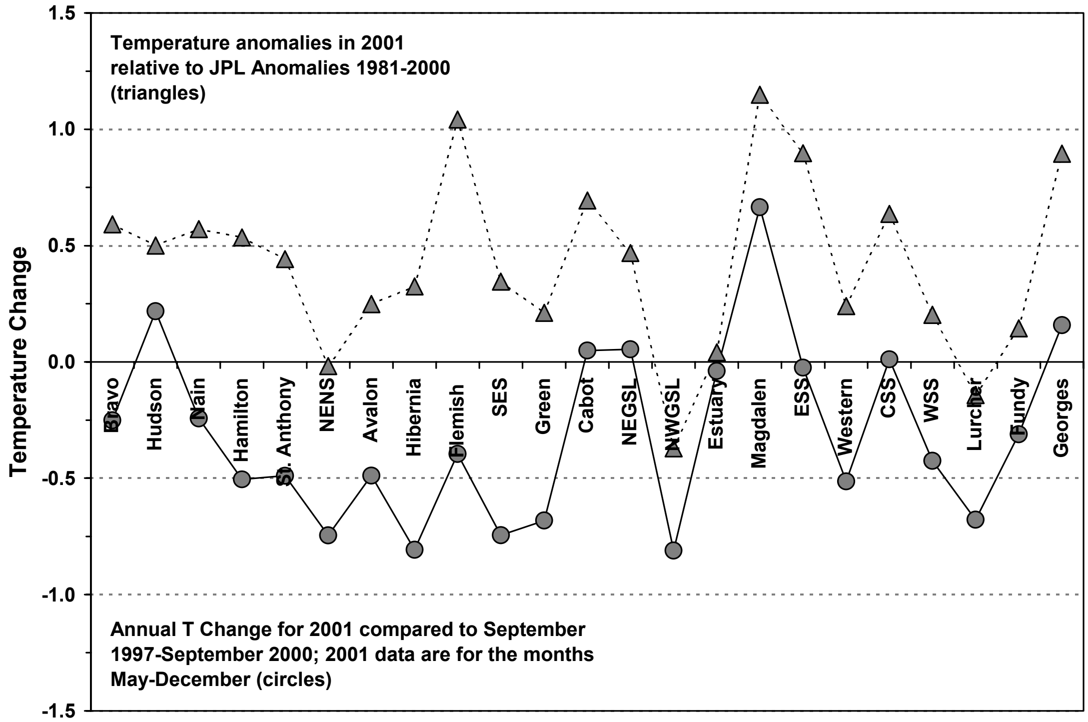


Fig. 21. The sea-surface temperature anomalies derived from satellite imagery in 2001 based upon the months May to December (triangles) and the change in 2001 compared to September 1997-2000 (circles).