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Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2000

Aperçu des conditions de la météo et de la glace de mer et des températures de la surface de la mer au large de l'est du Canada en 2000

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ABSTRACT

A review of meteorological, sea ice and sea-surface temperature conditions off eastern Canada during 2000 is presented. Annual mean air temperatures throughout most of the northwest Atlantic were warmer than normal, although from southern Labrador to the eastern Gulf of Maine, they declined relative to the record setting temperatures of 1999. The North Atlantic Oscillation (NAO) index was above normal and similar to 1999. It was well above the values of 1996-1998 but similar to 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, was more intense than normal in 2000. Sea ice on the southern Labrador and Newfoundland shelves generally appeared on schedule but left early, resulting in a shorter duration of ice than usual. The ice coverage in these areas was lower than average but higher than in 1999. The number of icebergs reaching the Grand Banks in 2000 was 843, compared to only 22 observed in 1999, but lower than the numbers recorded through most of the 1990s. In the Gulf of St. Lawrence, sea-ice also appeared late or on schedule but disappeared much earlier-than-normal. Little to no ice reached the Scotian Shelf and the areal coverage of ice in the Sydney Bight area off eastern Cape Breton was much less-than-normal. Sea-surface temperatures throughout eastern Canadian waters were warmer-than-normal in 2000.

RÉSUMÉ

Le bilan des conditions de la météo et de la glace de mer au large de l'est du Canada en 2000 est présenté. Les températures annuelles moyennes de l'air dans presque tout le territoire de l'Atlantique Nord-Ouest ont été plus chaudes que la normale, bien qu'entre le sud du Labrador et l'est du golfe du Maine, elles aient baissé par rapport aux températures records de 1999. L'indice d'oscillation nord-atlantique (NAO) a été supérieur à la normale et similaire à celui de 1999; il a été bien au-dessus des chiffres des années 1996 à 1998, mais semblable à ceux observés pendant la période froide qui a sévi au début des années 1990. Le fait que l'indice soit élevé signifie que la circulation atmosphérique à grande échelle, y compris la dépression d'Islande et l'anticyclone des Açores, a été plus intense que la normale en 2000. La glace de mer s'est généralement formée tardivement ou à la même période sur les plates-formes du sud du Labrador et de Terre-Neuve, mais elle a vite disparu, ayant pour résultat de raccourcir la durée de sa présence habituelle. La couverture de glace y a donc été inférieure à la moyenne. En 2000, 843 icebergs ont atteint les Grands Bancs de Terre-Neuve, un nombre bien supérieur à celui observé en 1999 (22), mais inférieur à ceux enregistrés pendant la plupart des années 1990. Dans le golfe du Saint-Laurent, la glace de mer est également apparue tard ou à la période habituelle, mais a aussi fondu bien plus tôt que la normale. Il n'y a pas eu de glace pour ainsi dire sur la Plate-forme Scotian. De plus, la superficie glacée dans le secteur de la baie Sydney, au large de l'est du cap Breton, a été bien moins grande que la normale. Les températures de la surface de la mer dans l'ensemble des eaux de l'Est canadien ont été plus chaudes que la normale en 2000.

INTRODUCTION

This paper examines the meteorological and sea ice conditions during 2000 off eastern Canada (Fig. 1). Specifically, it discusses air temperature trends, atmospheric sea level pressures and their associated winds, sea ice coverage and iceberg drift. New this year, we are providing information on sea surface temperature (SST) and measured winds. The paper complements the oceanographic reviews of the waters in and around Newfoundland, the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine, which together constitute the annual physical environmental overviews to DFO's Fisheries Oceanography Committee (Colbourne, 2001a,b; Drinkwater et al., 2001). 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 (1961-90) base period in accordance with the convention of meteorologists and the recommendations of the Northwest Atlantic Fisheries Organization (NAFO). 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, 2000). Above average temperatures dominated over most of eastern Canada and its coastal waters during 2000 (Fig. 2). In January, warmer-than-normal air covered the continental shelves from southern Labrador through to the southern United States, with a maximum positive anomaly (>3°C) located well offshore of the Gulf of Maine and the Grand Banks. In contrast, over the Labrador Sea and Baffin Bay, air temperatures in January were below normal by upwards of 3°C. Mild conditions continued for the remainder of the winter over the region south of Labrador to the Middle Atlantic Bight with positive anomalies between 2°-3°C during February and 2°-5°C in March. In February, the majority of the Labrador Sea was again covered by a colder-than-normal air mass but gave way to warm conditions on the Canadian side in March. Air temperatures off southwest Greenland remained colder-than-normal. Temperatures over most marine areas of the northwest Atlantic in April were above normal with the warmest anomalies over Baffin Bay (>5°C). In May and June slightly colder-than-normal conditions returned to the Labrador Sea region. Through the summer, warmer-than-normal conditions were observed in most marine areas. An exception was the Middle Atlantic Bight where cold temperature anomalies prevailed. These conditions on the Bight extended into the autumn. While air temperature anomalies over southeastern Canadian waters varied through the fall, those over the Labrador Sea and Baffin Bay were warm during both November and December. The latter reached upwards of 5°C in Baffin Bay and up to 9°C on southern Baffin Island.

Monthly air temperature anomalies for 1999 and 2000 relative to their 1961-90 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, 2000). The predominance of warmer-than-normal air temperatures over most of eastern Canadian waters during 2000, noted above, is clearly evident (Fig. 3). At Sable Island, all months 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 were above normal (May and October). Cape Hatteras also experienced generally warmer-than-normal conditions with only three of the available ten months below normal (June, July and October). Iqaluit, while recording below normal temperatures in 5 months, also had predominantly warm conditions and the highest temperature anomaly on record (>9°C) in December. Note that at the sites with a predominance of above normal temperatures, anomalies of +1° to +3°C were common but were generally lower than those in 1999. In contrast to these warm conditions, Boston experienced colder-than-normal temperatures.

The mean annual air-temperature anomalies for 2000 were also calculated at all eight sites. For Boston and Cape Hatteras, the annual anomalies were the average of the available monthly anomalies. For all sites except Boston, the annual anomalies were above normal. The maximum anomaly was recorded on Sable Island (1.3°C) with values above +1°C from the Scotian Shelf to the southern Labrador. At the southern (Cape Hatteras) and northern extremes (Nuuk and Iqaluit) annual means rose compared to 1999. Elsewhere they declined but at these sites, 1999 set all time historic records. The time series of the annual anomalies are shown in Fig. 4. The generally positive air temperature anomalies in 2000 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. 4). Also note that all sites where data are available, cold conditions (relative to the 1961-90 mean) existed throughout the late 1800s and early 1990s. Temperatures rose to above normal values around the 1920s at the northern most sites and between the 1910s and 1950s elsewhere.

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 2000, relative to the 1961-90 means, are shown in Fig. 5. Winter includes December 1999 to February 2000, spring is March to May, summer is June to August and autumn is September to November.

In winter, a strong dipole pattern was established with negative air pressure anomalies in the northern North Atlantic and positive anomalies to the south. The largest negative anomalies (below -10 mb) were located west of Norway and the largest positive anomalies (>10 mb) were centred over the central Atlantic. These high anomalies extended across the entire width of the Atlantic Ocean. This pattern indicates a strengthening of the atmospheric circulation with an intensification of both the Iceland Low and the Azores High. Strong westerly winds across the northern North Atlantic accompany this pressure pattern with the maximum wind anomalies over Western Europe. Over the Labrador Sea the pressure field also implied slightly stronger-than-normal westerly winds. Southeastern Canada came under the influence of the Azores High producing more southerly winds, which carried relatively warm air into the region. The spatial pattern of the pressure fields in 2000 was similar to that in 1999 but they were more intense. As observed in 1999, the centres of the large amplitude changes were located further eastward than usual.

In the spring of 2000, a relatively strong positive pressure anomaly (> 3 mb) developed over the northwestern Atlantic, with its center to the north of Greenland. Two smaller and weaker negative anomalies also formed, one off the eastern United States and another over the eastern Atlantic and Europe. In eastern Canada, the geostrophic winds associated with these pressure fields would be predominantly from the south and east.

As is typical in most years, the pressure anomaly field during the summer of 2000 was generally weaker than in the other seasons. Slightly higher pressures than normal covered the northwest Atlantic with the maximum (>2 mb) over Greenland and Iceland. There were several local maxima, all of which were slightly above 2 mb. The geostrophic winds accompanying this pressure field were also relatively weak.

In the autumn, there was a return to the wintertime pattern with an intensification of the Icelandic Low and Azores High, with a particular strong negative anomaly centred over Scotland. The northwestern Atlantic was covered by weak negative anomalies in sea level pressure. Over eastern Canada, the winds associated with this pressure system were predominantly easterly.

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 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 1961-90 mean.

In 2000, the NAO index was above normal (+13.6 mb anomaly) but dropped slightly from its 1999 value (Fig. 6). It was similar to levels observed during the first half of the 1990s and well above the lower-than-average indices registered in 1996 and 1997. These recent changes in the NAO index fit the pattern of quasi-decadal variability that has persisted since the 1960s. As described above, high NAO is usually accompanied by cold conditions over the Labrador Sea in winter. However, in 2000 air temperatures in the region were above normal in spite of the high NAO index. A similar situation occurred during 1999. Two possible causes of the break down in the relationship between the NAO and air temperatures in the Labrador-Newfoundland area are apparent. First, most of the activity in the anomalous winter pressure field was over the eastern North Atlantic with weaker gradients over the Northwest Atlantic (Fig. 5). Weaker gradients lead to weaker winds. Second, the Azores High extended into southeastern Canada, especially in winter (Fig. 5). This brought more southerly winds into the region with accompanying warm air.

Winds

During 2000, we obtained from the Atmospheric Environment Service of Environment Canada a new set of wind estimates for the northern hemisphere derived from a combination of geostrophic estimates, station and ship observations and model results. These only extend to 1998 and have not yet been updated. For this report we obtained wind data from Sable Island and the Magdalen Islands but unfortunately, the latter were questionable and so we have not included them. The monthly mean anomalies of the Sable Island wind speeds in 2000 varied greatly although the annual means were near normal (Fig. 7). Wind speeds declined from the 1970s through to the early 1990s, before returning to normal by 1999. An extended period of low wind speeds was observed from the late 1980s to the late

1990s. Negative anomalies in the u and v components of the winds were also observed during this period.

SEA ICE OBSERVATIONS

Information on the location and concentration of sea ice is available from the daily ice charts published by the Canadian Ice Service of Environment Canada in Ottawa. These daily charts represent snap shots, however, and it must be remembered that the ice and the location of the ice edge can vary rapidly over short periods of time. The long-term median, maximum and minimum positions of the ice edge (concentrations above 10%) are included for comparison. These are based on the composite for the years 1962 to 1987 and are taken from Coté (1989). 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, 1964-1993) of each variable were determined (using only data during the years ice was present) and subtracted from the 2000 values to obtain anomalies.

Newfoundland and Labrador

At the end of 1999, sea ice lay off the southern Labrador coast in the vicinity of Hamilton Inlet resulting in an areal coverage that matched closely the long-term median for that time of the year (Fig. 8a). This was aided by below normal air temperatures and strong northwest winds during the latter half of December as reported by the Canadian Ice Service. By mid-January, the ice had spread past the southern tip of Labrador and onto the northern Newfoundland coast, which was a little further south than its long-term median position. Elsewhere, however, the ice edge was near its median position. During the latter half of January light west to northwest winds prevailed and air temperatures were generally 1°-3°C above normal. As a result, by the first of February the ice edge extended south to Notre Dame Bay and the extent and thickness of the ice were near normal. By 1 March, the southern most ice edge still lay close to the long-term median position, however, there was a less-than-normal ice extent. This was largely due to the persistent northeast winds during the second half of February, which pushed the ice shoreward. Winds from the southwest and above normal air temperatures during most of March resulted in an early retreat of the ice and by 1 April, the ice edge was inshore of its long-term median position on the northern Newfoundland shelf, although near it off southern Labrador (Fig. 8b). Warm air temperatures continued throughout April with the result that the ice continued to retreat faster-than-normal. By 1 May, the ice was restricted to the nearshore areas off northern Newfoundland and the inner Labrador Shelf. The ice edge lay well inshore of the long-term median location. On 1 June, the ice had retreated to the Labrador Shelf region north of Hamilton Inlet. The ice edge was near its normal position but the ice thickness was less than normal. By 1 July all traces of ice had disappeared from southern Labrador.

The time series of the areal extent of ice on the Newfoundland and southern Labrador shelves (between 45-55^{o}N; I. Peterson, personal communication, Bedford Institute) show that the peak extent during 2000 was slightly above that observed in 1999 (Fig. 9). Relative to 1999, the average ice area rose 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 2000 coverage was above that of 1999 in February to April but below for January and May (Fig. 10). In the remaining months the ice area was similar to the previous year. In all months, the ice area was below the long-term average (1963-1990). In summary, 2000 was generally a lighter-than-average ice year on the Labrador and Newfoundland shelves. Although no estimates of ice volume were made for 2000, 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 2000, ice appeared along the southern Labrador coast in late December, and gradually spread southward to northeastern Newfoundland waters by mid-March (around day 75; Fig. 11). Only small quantities of ice reached the northern Grand Bank. Relative to the long-term mean, ice generally appeared slightly earlier-than-normal on the inner shelf off Labrador and the northern tip of Newfoundland (Fig. 12). Over the offshore regions and off most of Newfoundland ice arrived later-than-usual. Ice began to disappear from the offshore and southern sites by late March to early April (day 90-105; Fig. 11). Ice did not began to retreat from northern Newfoundland waters and southern Labrador until May but lasted in the region north of Hamilton Inlet until near mid-June. Over most of the region, ice disappeared earlier-than-normal (negative anomaly, generally associated with warm conditions), more than 30 days early over large sections of Northern Newfoundland (Fig. 12). The only regions where ice departed later-than-usual was at the shelf edge. The duration of the ice season ranged from less than 10 days on the northern Grand Banks and off the shelf edge to over 170 days north of Hamilton Inlet on the southern Labrador (Fig. 13). 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 most of the Newfoundland Shelf and south of Hamilton Inlet on the Labrador Shelf. Off northern Newfoundland, the duration was 20-40 days shorter-than-usual. Those small regions where the duration was longer-than-normal, it was still within a few days of normal.

Icebergs

The International Ice Patrol Division of the United States Coast Guard monitors the number of icebergs that pass south of 48ºN latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1999/2000 iceberg season (October 1999 to September 2000), a total of 843 icebergs were spotted south of 48°N. The monthly totals for March to July were 286, 239, 212, 65 and 41, respectively (Fig. 14). No icebergs were spotted between October 1999 and February 2000, inclusive, or in August or September 2000. In 2000, all 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 is considered to represent the period of reliable SLAR measurements. A higher percentage of the icebergs in 2000 arrived in March and April than usual and a lower percentage in June and July. The total number of icebergs was up dramatically from the 22 recorded in 1999 and although the 2000 numbers were higher than average, there were less icebergs than in most of the years of the 1990s (Fig. 14).

Gulf of St. Lawrence

The location of the ice edge within the Gulf of St. Lawrence at various times during the 1999-2000 winter season is shown in Fig. 15. At the end of December light to moderate winds and typical air temperatures in the latter half of the month resulted in near normal ice conditions. Ice was located in the nearshore regions of the southern Gulf of St. Lawrence and the northeastern Gulf. By mid-January the ice coverage and ice thickness were below normal due to warmer-than-normal air temperatures over the region. Near normal temperatures in the latter half of the month resulted in an increase in ice coverage by 1 February, especially over the Magdalen Shallows, but the ice area still remained below normal. Ice coverage continued to spread through February, eventually covering most of the Gulf. By 1 March only small coastal areas of the Shallows had open waters along with the St. Lawrence Estuary and off the west coast of Newfoundland. This open water was due to offshore winds and was only temporary. Warmer-than-normal temperatures during March led to rapid ice melt over the Gulf in the second half of the month. Only small patches of ice were found on the Shallows and off the northeastern Gulf by 1 April and all of the ice disappeared by the middle of April.

During the 1999-2000 ice season in the Gulf, the first appearance of ice ranged from late December in the St. Lawrence Estuary and along the coastal regions of the Magdalen Shallows and the north shore of Quebec to mid February (day 45) off southwestern Newfoundland (Fig. 11). Although generally within 10 days of the typical date, ice appeared earlier-than-normal over much of the Magdalen Shallows, around Anticosti Island and on the north shore of Quebec from Anticosti to the Strait of Belle Isle (Fig. 12). The date of last appearance shows the standard pattern with ice lasting longest over the southern Magdalen Shallows and along the north shore of Quebec through to the Strait of Belle Isle (Fig. 11). In 2000, ice left the Gulf early except in the Estuary (Fig. 12). Ice left the

Magdalen Shallows 1-2 weeks early and the eastern Gulf 2-4 weeks early. The duration of ice ranged from 10 days off southwestern Newfoundland to over 90 days in the Strait of Belle Isle (Fig. 13). Relative to the long-term mean, using only years when ice was present, ice duration was less than normal throughout the Gulf. The largest anomalies were in the northwest where there were 30 to over 60 fewer days of ice than usual.

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 2000, ice first appeared seaward of Cabot Strait during early February (Fig. 11), which is later-than-usual (Fig. 12). It maintained a relatively constant presence through into early March off northeastern Cape Breton. This ice was primarily restricted to the Sydney Bight area with little ice reaching the Scotian Shelf proper. This ice had disappeared by the end of March (Fig. 11), a departure about 2 weeks earlier-than-normal (Fig. 12). The duration of ice south of Cabot Strait was up to 50 days off northern Cape Breton Island. This was less than the long-term mean in most areas, 30 to over 40 days off the northeastern Scotian Shelf (Fig. 13). Note that durations of less than 10 days are not plotted in Fig. 13.

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 2000 compared to the long-term mean (Fig. 16, 17). The amount in 2000 was, however, slightly larger in magnitude than the ice area observed in 1999. There were fewer days than usual with ice present seaward of Cabot Strait, the second lowest in the 39-year record. The integrated ice area (summation of the area times the number of days) rose slightly but remained well below the long-term average. Indeed, it was the sixth lowest on record (Fig. 16). This was the third 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, albeit incomplete, 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. A discussion of their accuracy and utility as a climate indicator is provided by Mason et al. (1999) and Petrie and Mason (2000). The latter showed that the data from a number of locations could be reduced to a couple of time series that capture most of the variance in the annual temperature anomalies.

Temperature estimates were extracted from the BIO SST database for 23 areas that cover the Canadian Atlantic coast from Hudson Strait to Georges Bank (Fig. 18). Monthly means were determined for each area, monthly temperature anomalies calculated, and annual temperature anomalies computed from the monthly anomalies. The resulting 23 time series covering 18 years are analyzed using empirical orthogonal functions. This technique reduces the data into a smaller number of time series called modes, determined from the correlation matrix of the 23 time series.

The results indicate that 58.3 percent of the overall variance in the 23 series can be accounted for by mode 1, and an additional 15.1% by mode 2; i.e., about 73% of the overall variance can be accounted for by two functions. This means that there is broad-scale coherence over the region due to similar solar heating and cooling. The amplitude of mode 1 is almost constant for the sites from Hamilton Bank to Georges Bank, except for the St. Lawrence Estuary where the amplitude is reduced, and is low for Bravo (Labrador Sea), Hudson Strait, and Nain Bank (Fig. 19a). Mode 1 accounts for between about 50-95% of the temperature variance for the sites from Hamilton Bank to Georges Bank except for the Estuary and the Bay of Fundy where 15% and 36% is captured (Figure 19b). Mode 2 captures about 50-70% of the temperature variance from the 3 northernmost sites and about 30% from Hamilton Bank and St. Anthony (Fig. 19a,b). It accounts for little of the variance at the other sites.

The 17 times series with significant variance accounted for by mode 1, the 5 captured by mode 2 and the remaining 3 time series from the Gulf of St. Lawrence are grouped together in Fig. 20a-c. The correspondence among the observations is evident in each plot. The mode 1 group exhibits more short term variability than the other 2 groups with annual temperatures 1-2^{o}C above normal the past 2 years; a longer trend is apparent in the mode 2 group comprised of the most northerly sites on the Labrador-Newfoundland Shelf and in the Labrador Sea. There the temperature anomaly has been about 1^{o}C above normal for the past 3 years except for Hudson Strait where the temperature was about normal in 2000. The Gulf of St. Lawrence group comprised of the Estuary, the Northwest Gulf and the Magdalen Shallows resembles the mode 1 group more than the northern sites but with temperatures about 0.5^{o}C above normal in 2000.

SUMMARY

During 2000, the NAO index was high, similar to 1999 but well above the levels of the previous 3 years. Air temperatures over most of the northwest Atlantic region were above normal but declined relative to the 1999 record setting temperatures from southern Labrador to eastern Gulf of Maine. The exception to the warm conditions was at Boston where available air temperatures indicate colder-than-normal conditions. The relatively warm winter temperatures 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 these areas. Little ice reached the Scotian Shelf proper and seaward of Cabot Strait the amount of ice was the 6th lowest in the 39-year record. The number of icebergs that reached the Grand Banks was 843, significantly higher than 1999 when only 22 bergs were spotted on the Banks.

Past studies have shown that high NAO years usually bring cold air temperatures and extensive ice off Newfoundland and Labrador (Colbourne et al., 1994; Drinkwater et al., 1996). This was not the case in 2000, or in 1999. In these years, warm conditions over much of eastern Canada, especially in winter, was due to the extended influence of the Azores High and its associated southerly winds.

The analysis of satellite-derived sea-surface temperature has shown that on the annual time scale, there is broad-scale, coherent variability from the Gulf of Maine to the Labrador Shelf with generally above normal temperatures in 2000. The region divides into 2 distinct sea-surface temperature patterns, one that stretches from Hamilton Bank to Georges Bank, the other from Hudson Strait to St. Anthony with overlap on the southern Labrador and northern Newfoundland Shelf.

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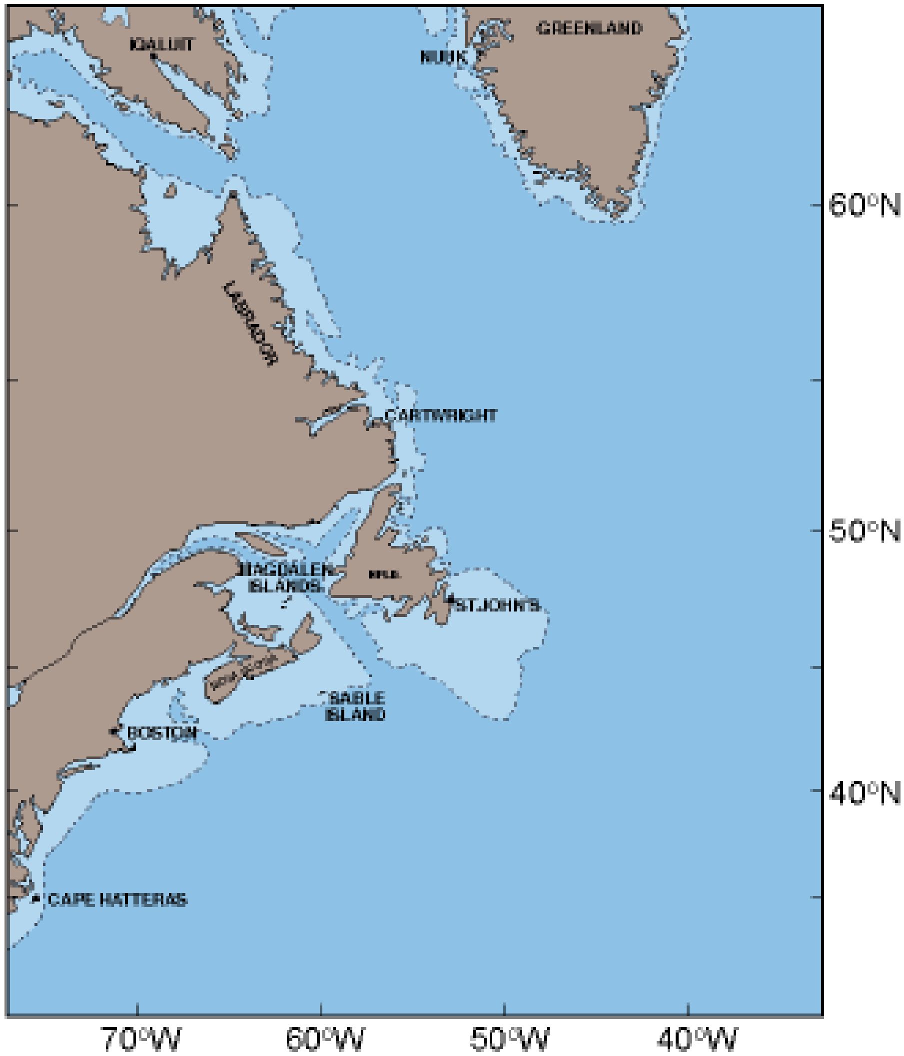

Fig. 1. Northwest Atlantic showing coastal air temperature stations. The dashed line denotes the 200 m isobath.

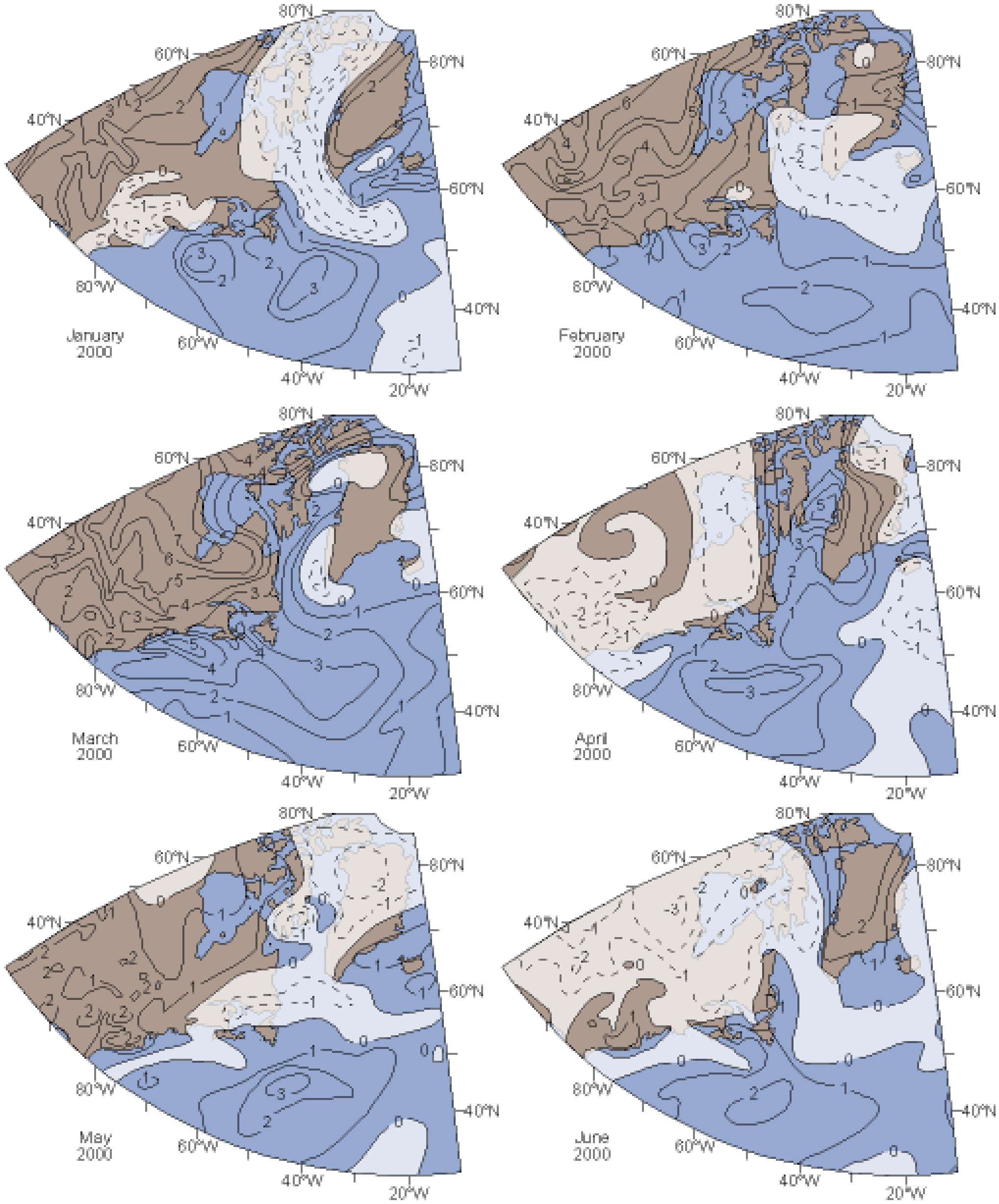

Fig. 2. Monthly air temperature anomalies (^oC) over the Northwest Atlantic and eastern Canada in 2000 relative to the 1961-90 means. The light shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

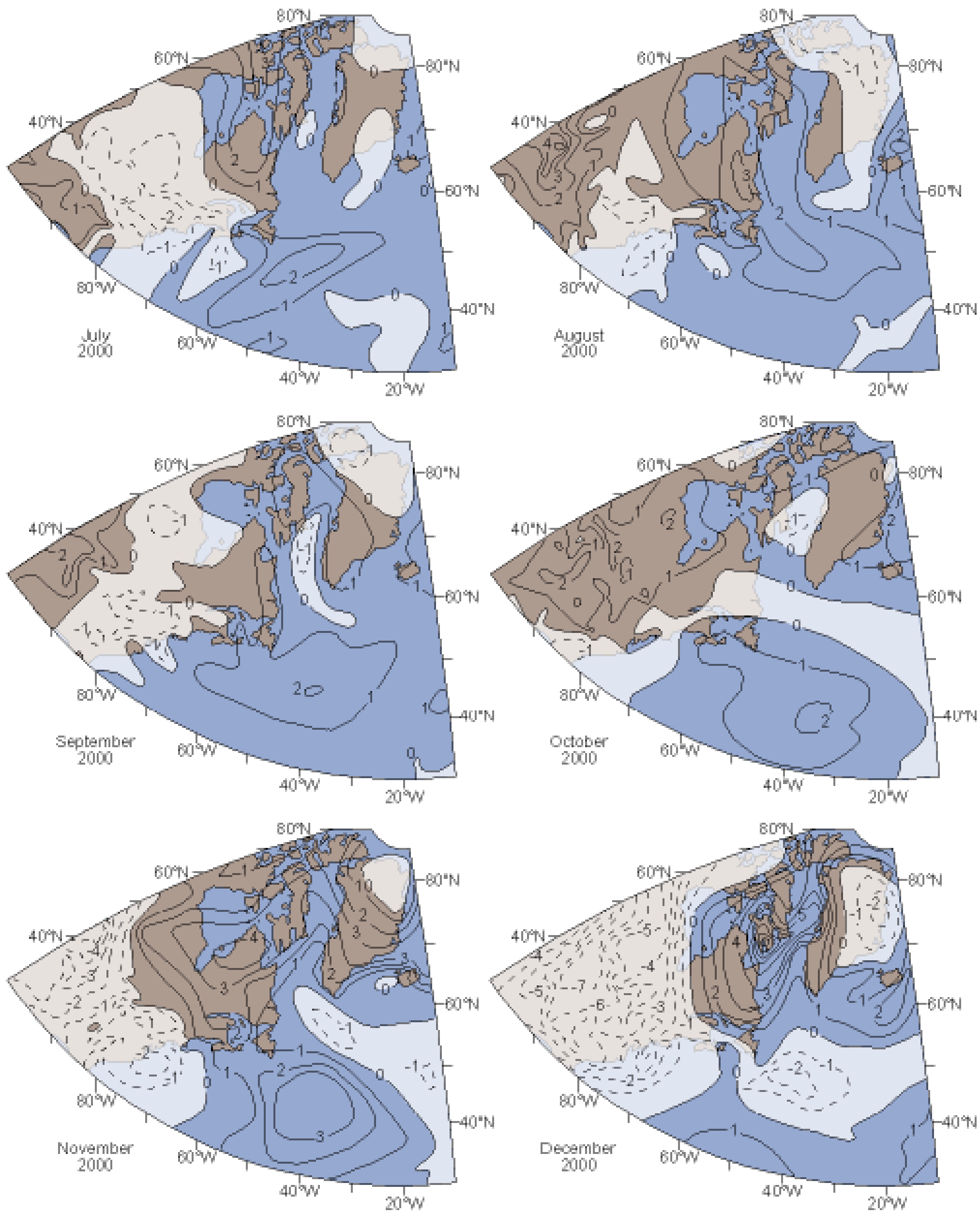

Fig. 2 (continued). Monthly air temperature anomalies (^oC) over the Northwest Atlantic and eastern Canada in 2000 relative to the 1961-90 means. The light shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

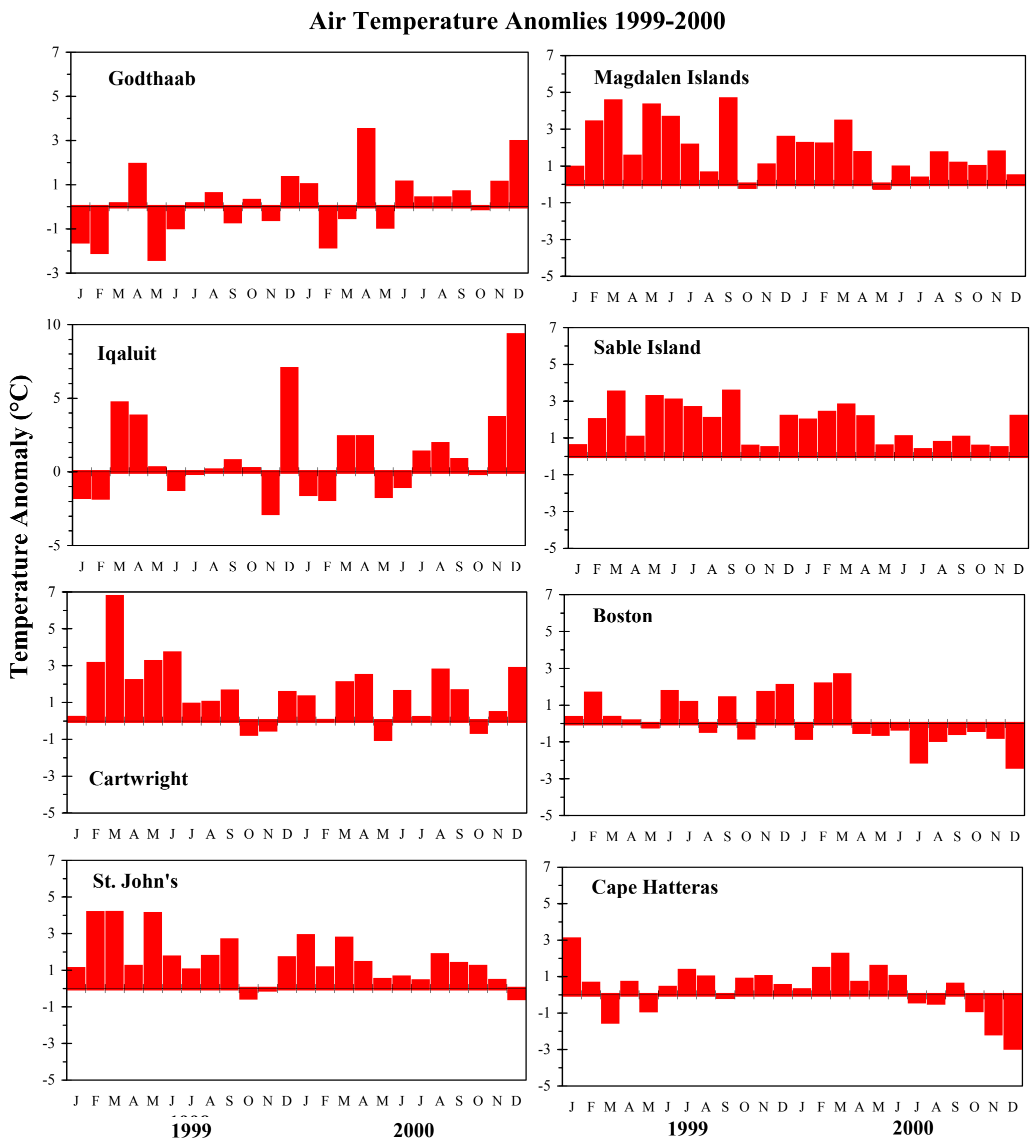

Fig. 3. Monthly air temperature anomalies in 1999 and 2000 at selected coastal sites (see Fig. 1 for locations).

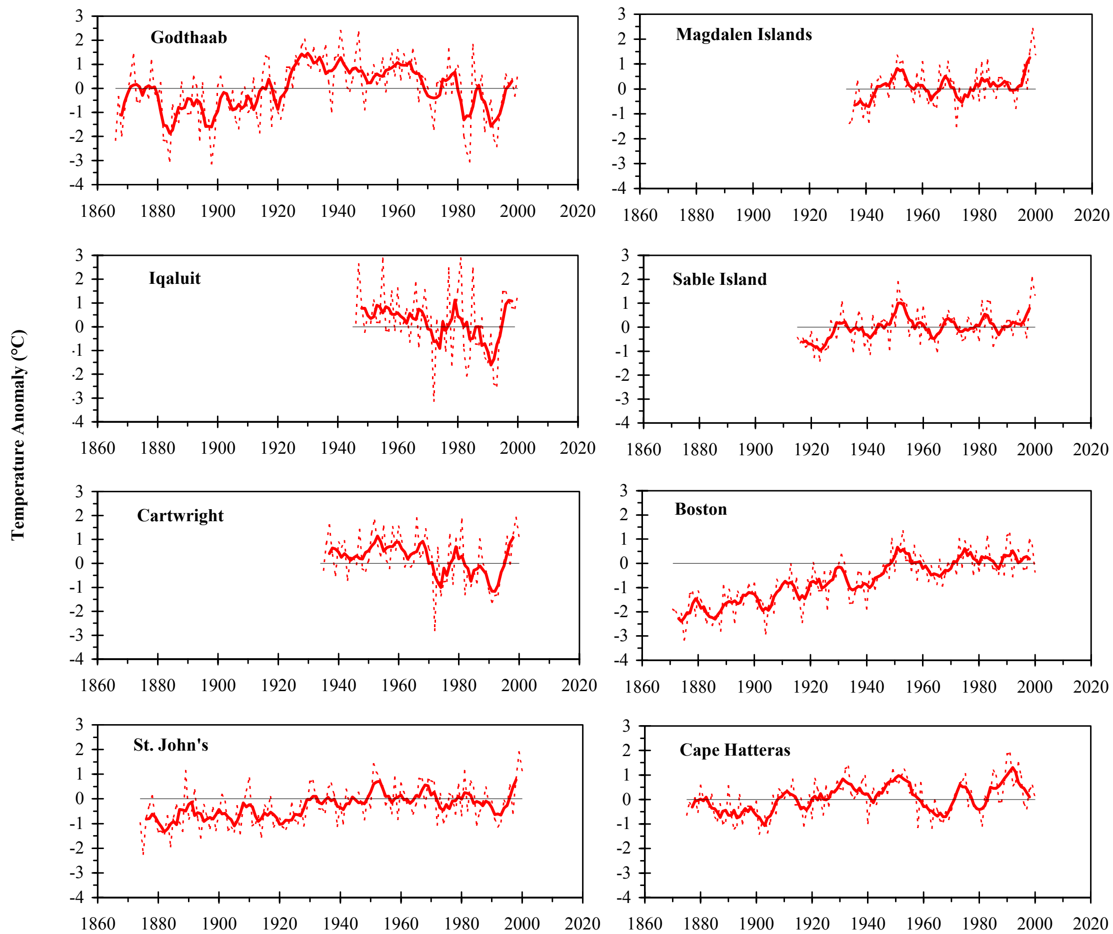

Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

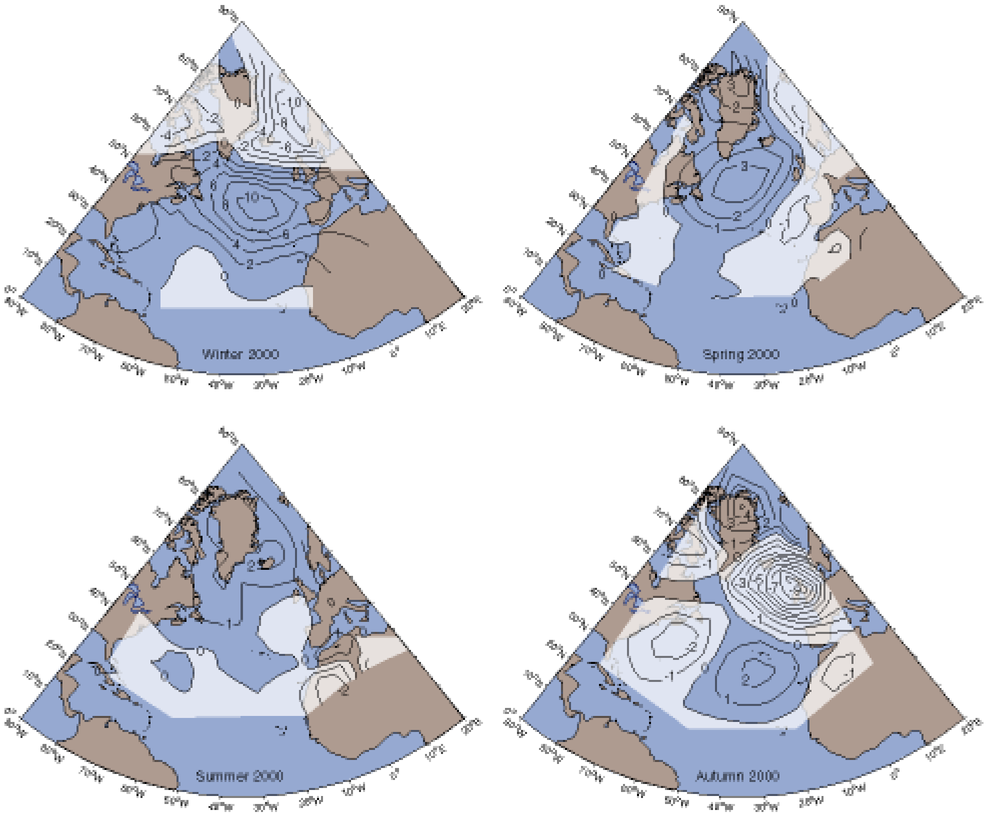

Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2000 relative to the 1961-90 means.

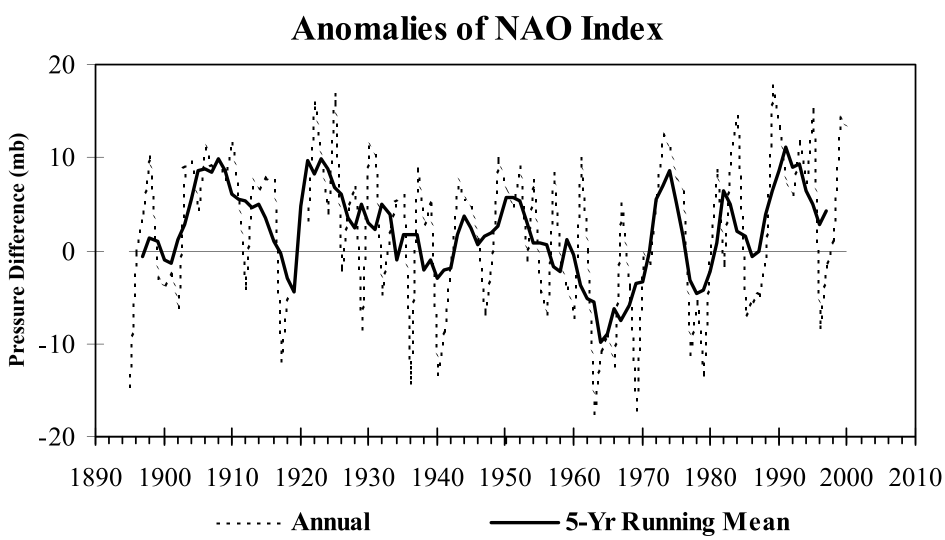

Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1961-90 mean.

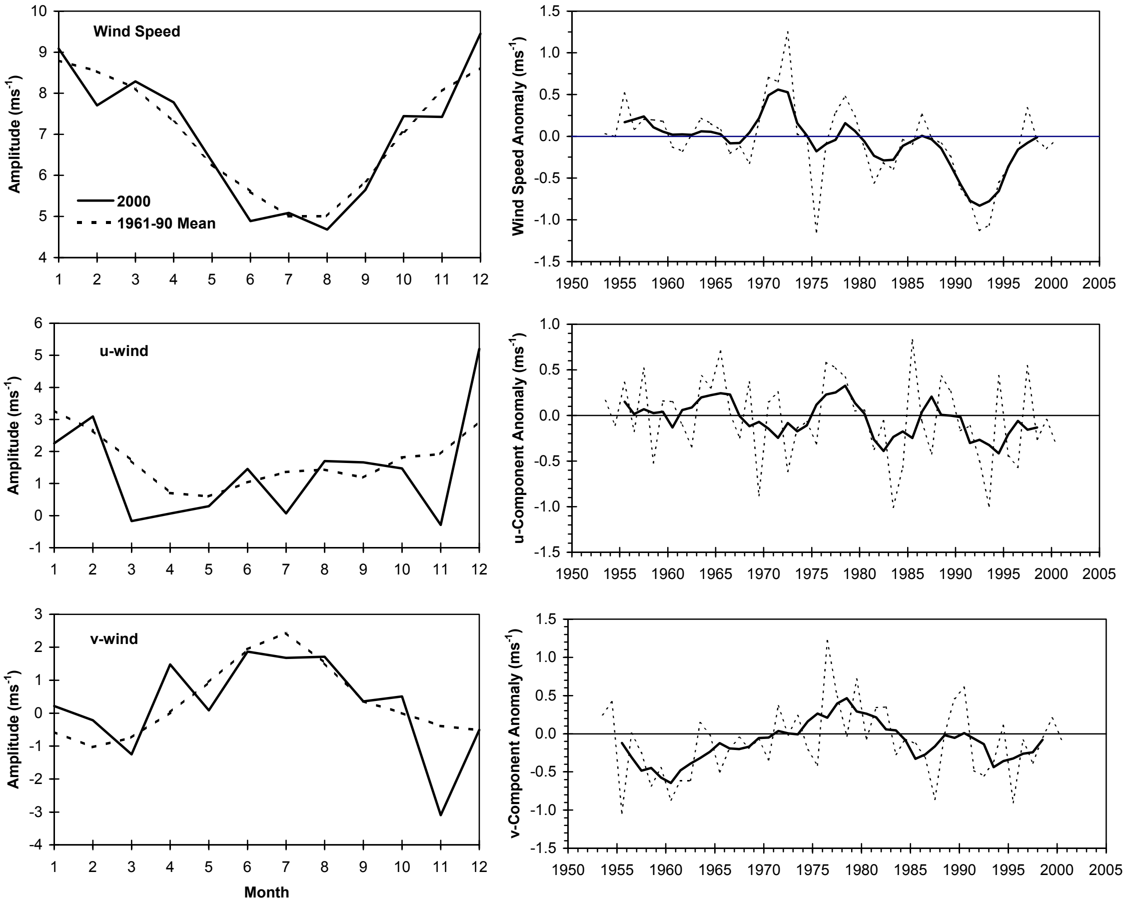

Fig. 7. The annual anomalies in the mean wind speed (top panel), the u-component (positive eastward; middle panel) and the v-component (positive northward; bottom panel) of the wind at Sable Island.

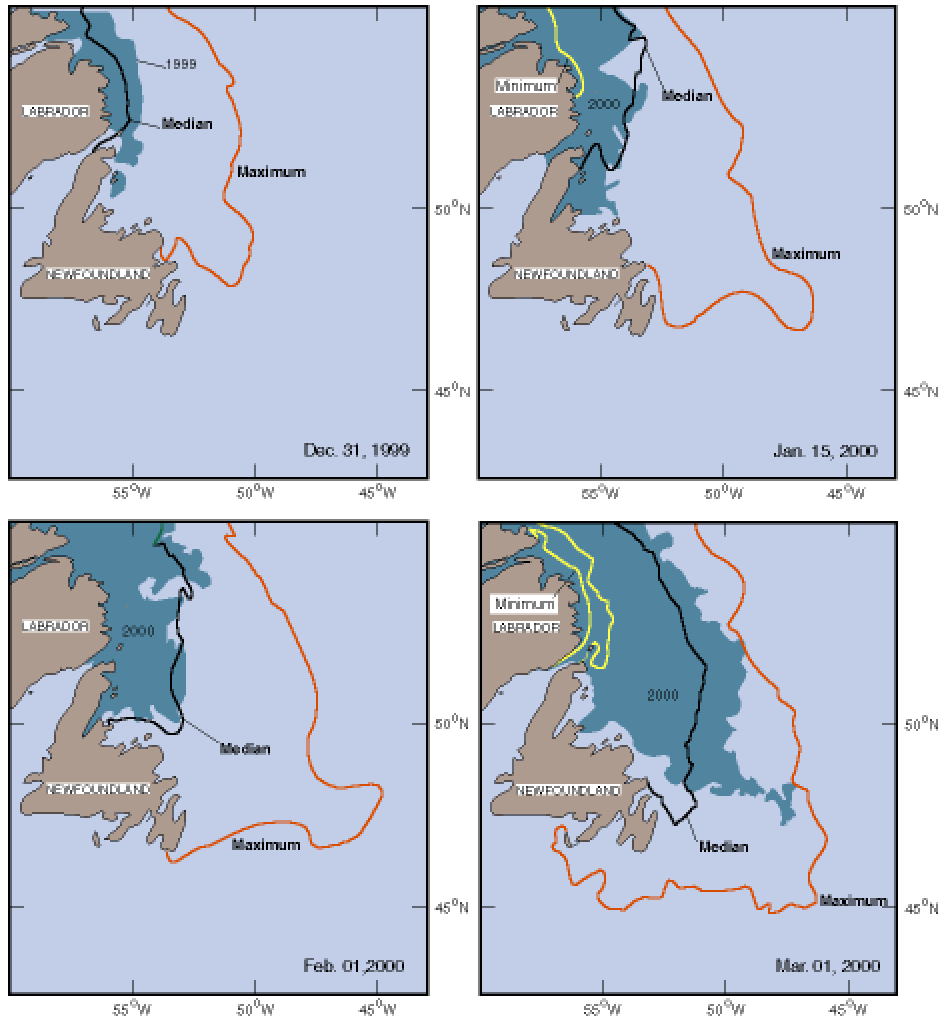

Fig. 8a. The location of the ice (dark shaded area) between December 1999 and March 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

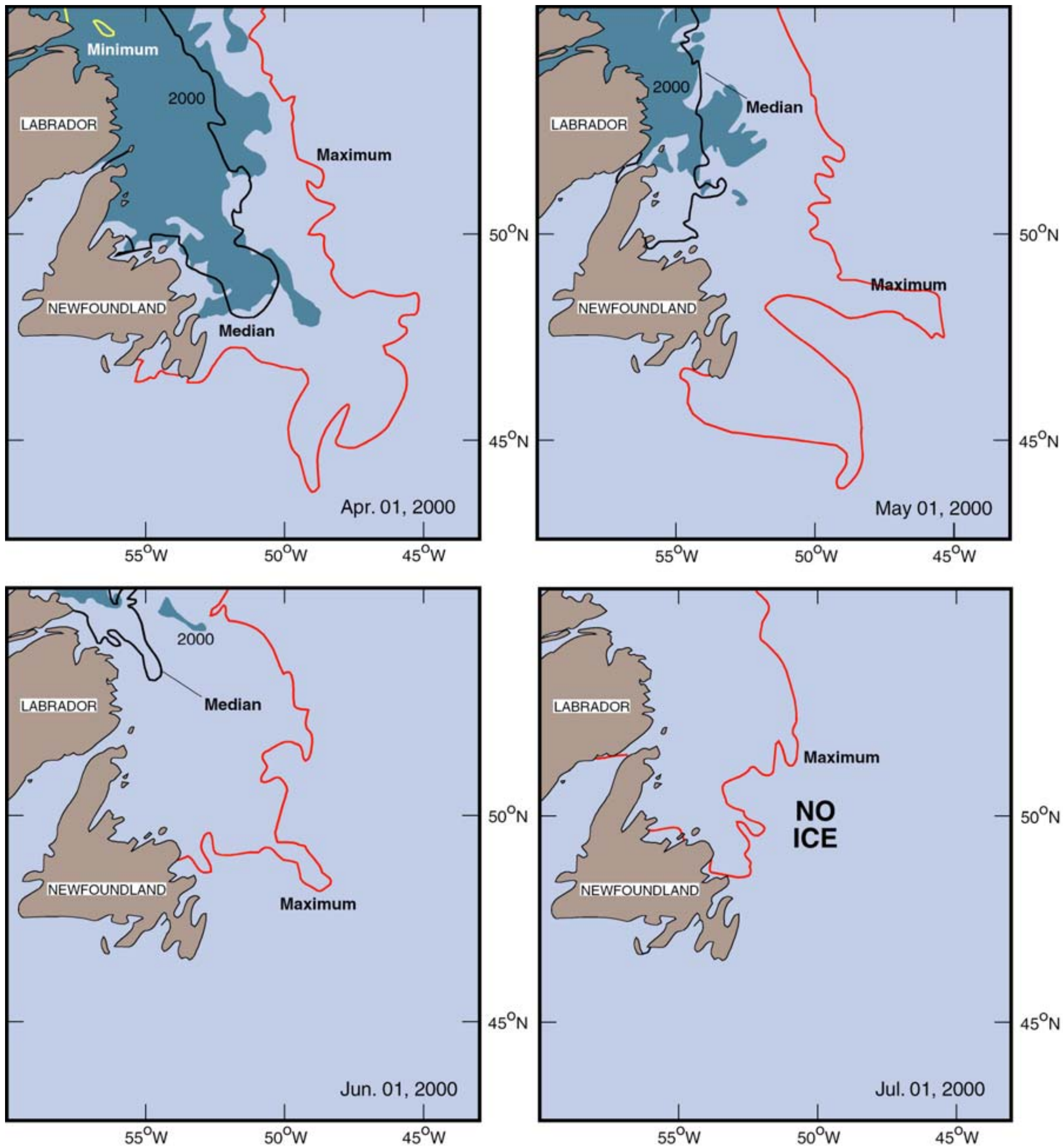

Fig. 8b. The location of the ice (dark shaded area) between April and July 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

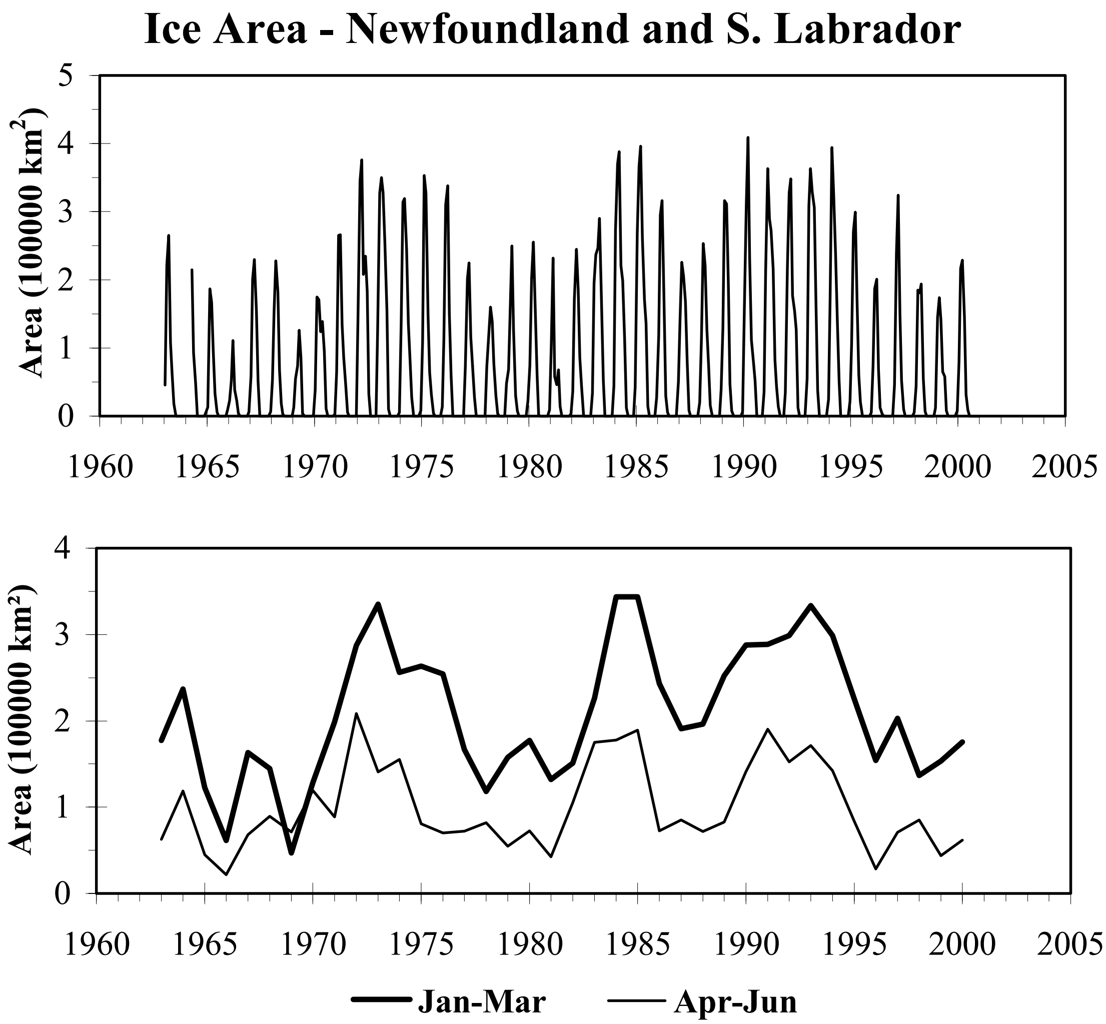

Fig. 9. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

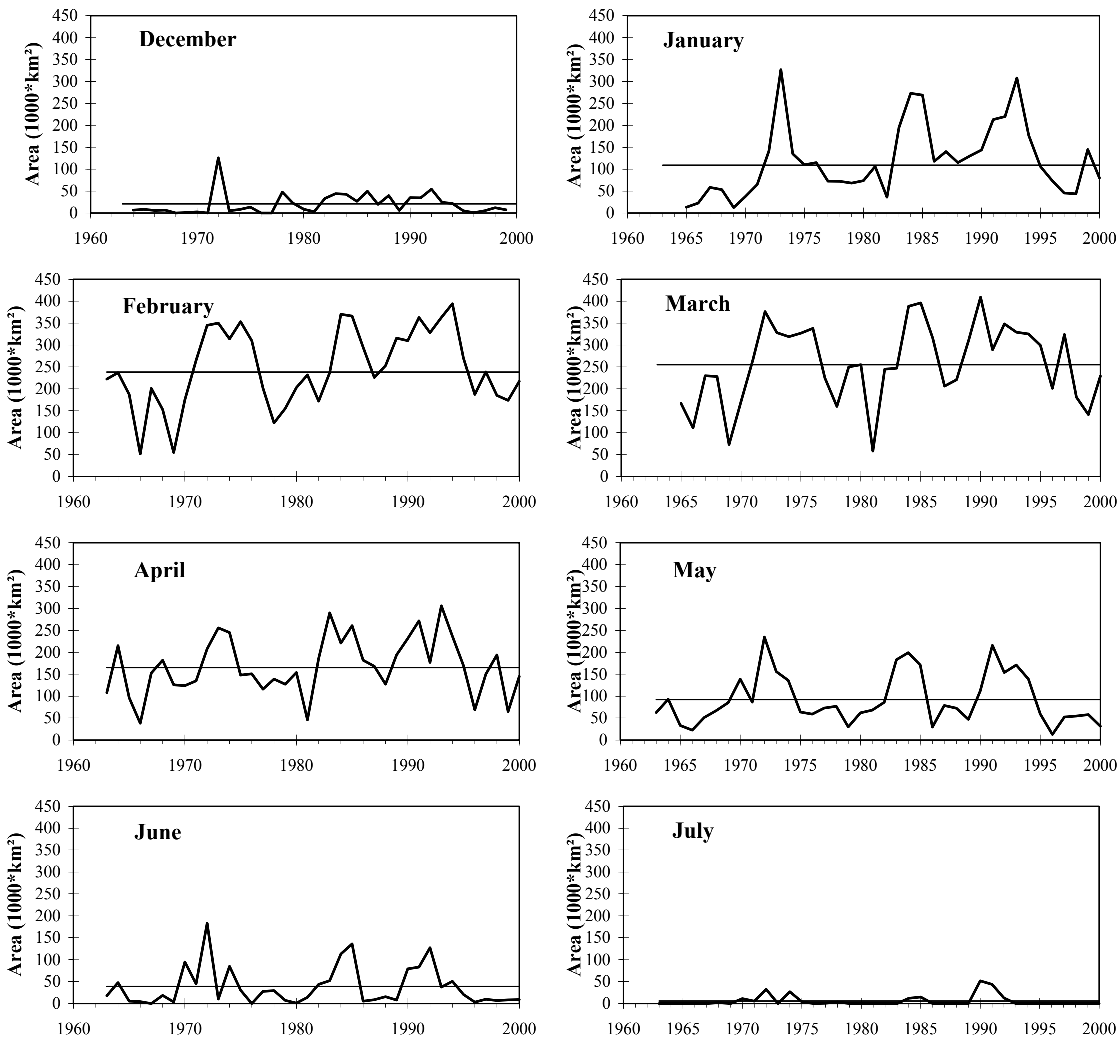

Fig. 10. The time series of ice area off Newfoundland and Labrador, by month. The horizontal lines represent the long-term (1963-90) means.

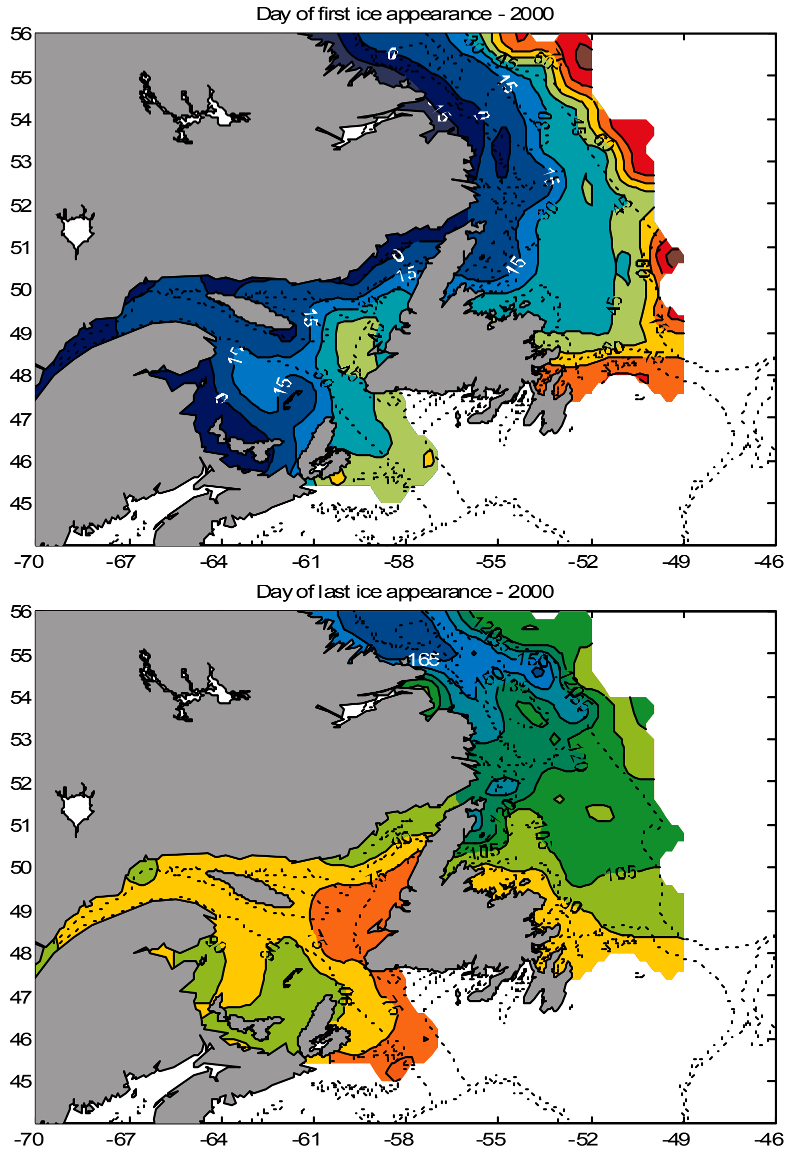

Fig. 11. The time when ice first appeared (top panel) and last appeared (bottom panel) during 2000 in days from the beginning of the year.

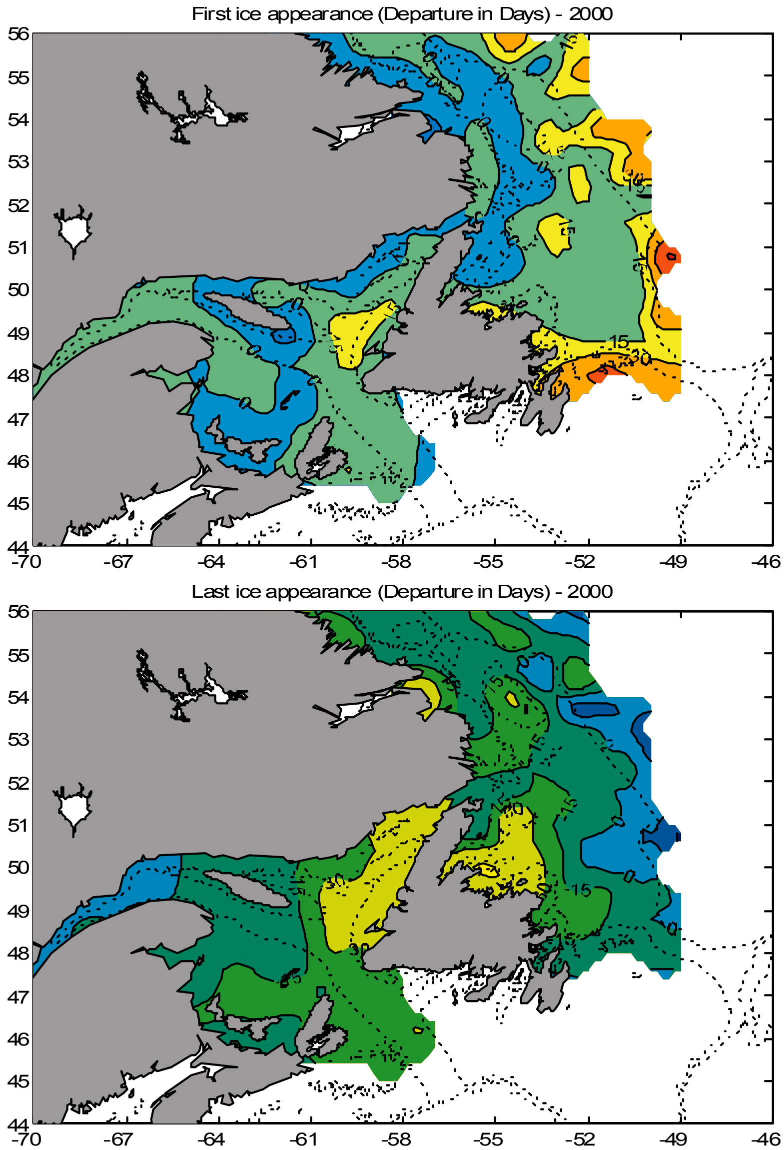

Fig. 12. The anomaly of the time when ice first appeared (top panel) and was last reported (bottom panel) during 2000 in days from the beginning of the year. Negative anomalies indicate earlier-than-normal and positive are later-than-normal.

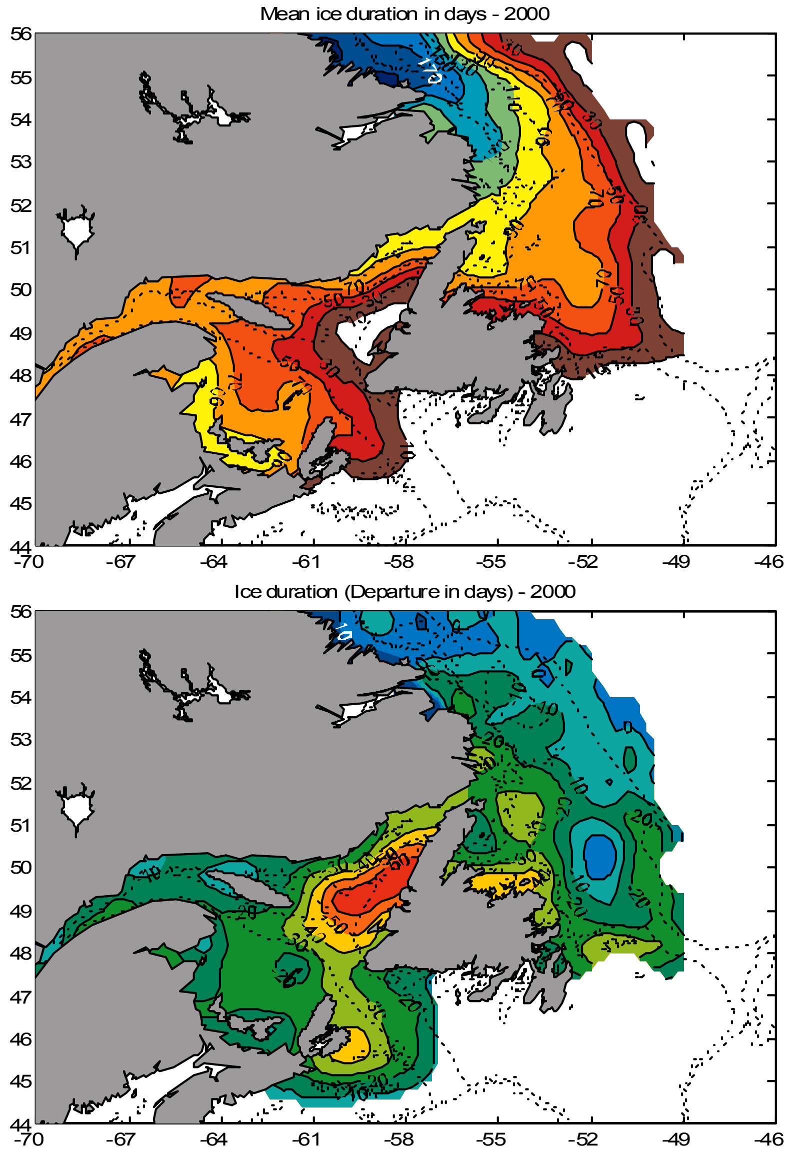

Fig. 13. The duration of ice in days (top panel) during 2000 and their anomaly from the long term mean in days (bottom panel). The positive anomalies (blues) indicate durations longer than the mean, which are generally associated with a cold year. Most of 2000 saw negative anomalies (greens to reds) where the ice duration was less than normal.

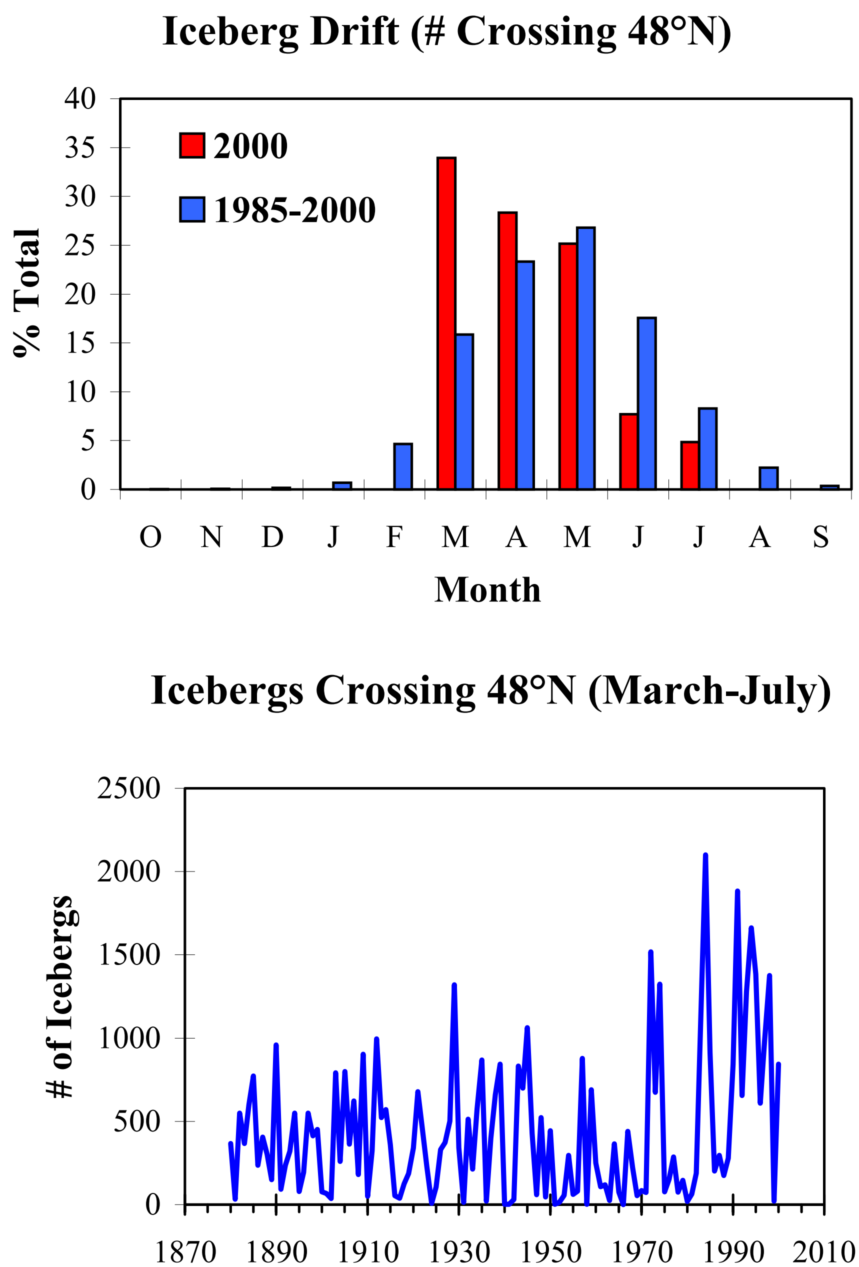

Fig. 14. The number of icebergs crossing south of 48^{o}N during the iceberg season 1999/2000 expressed as a percent of the total by month compared to the mean during 1985-2000, the years SLAR has been used (top panel) and the time series of total number of icebergs observed during March to July (bottom panel).

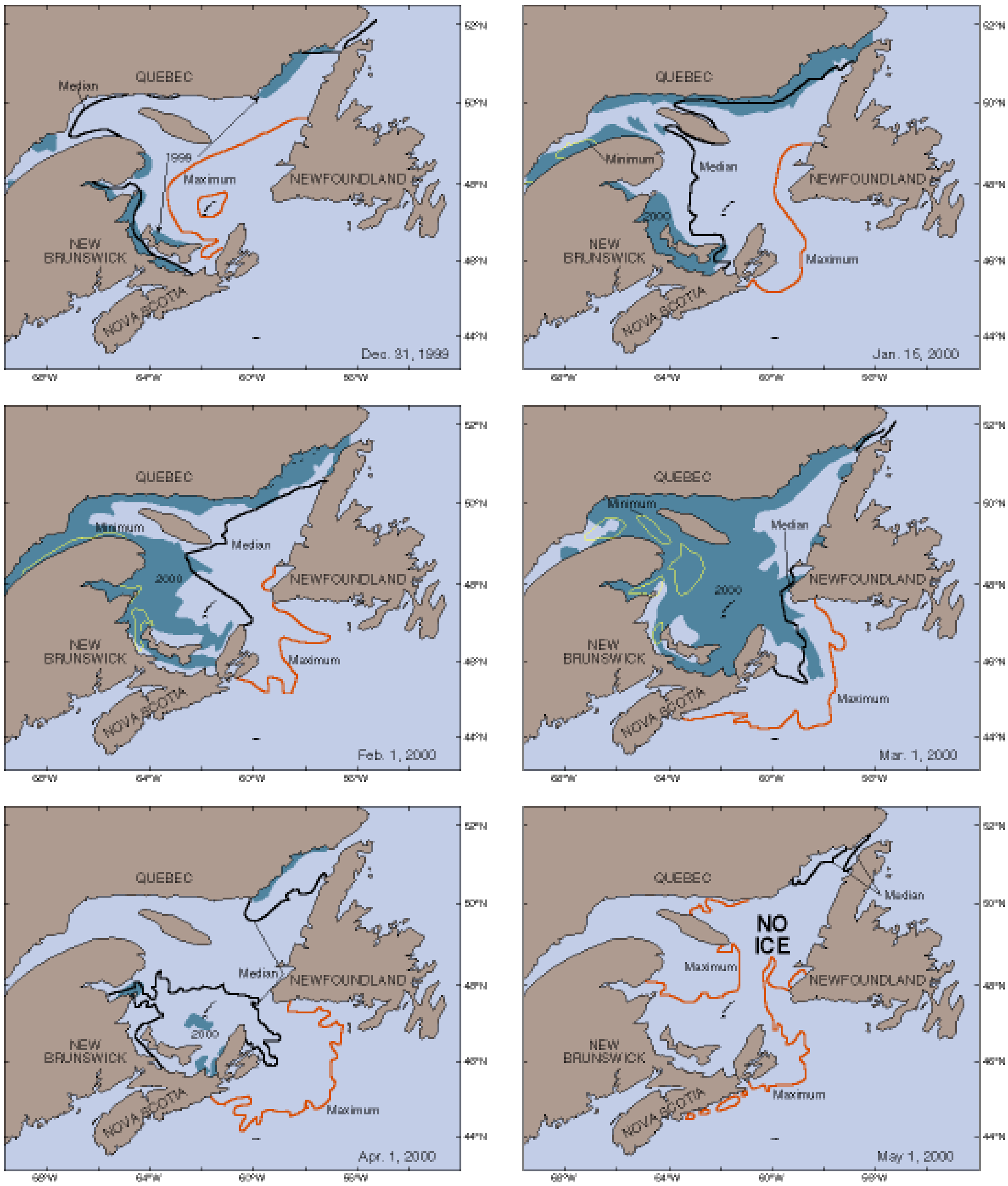

Fig. 15. The location of the ice (dark shaded area) between December 1999 and May 2000 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

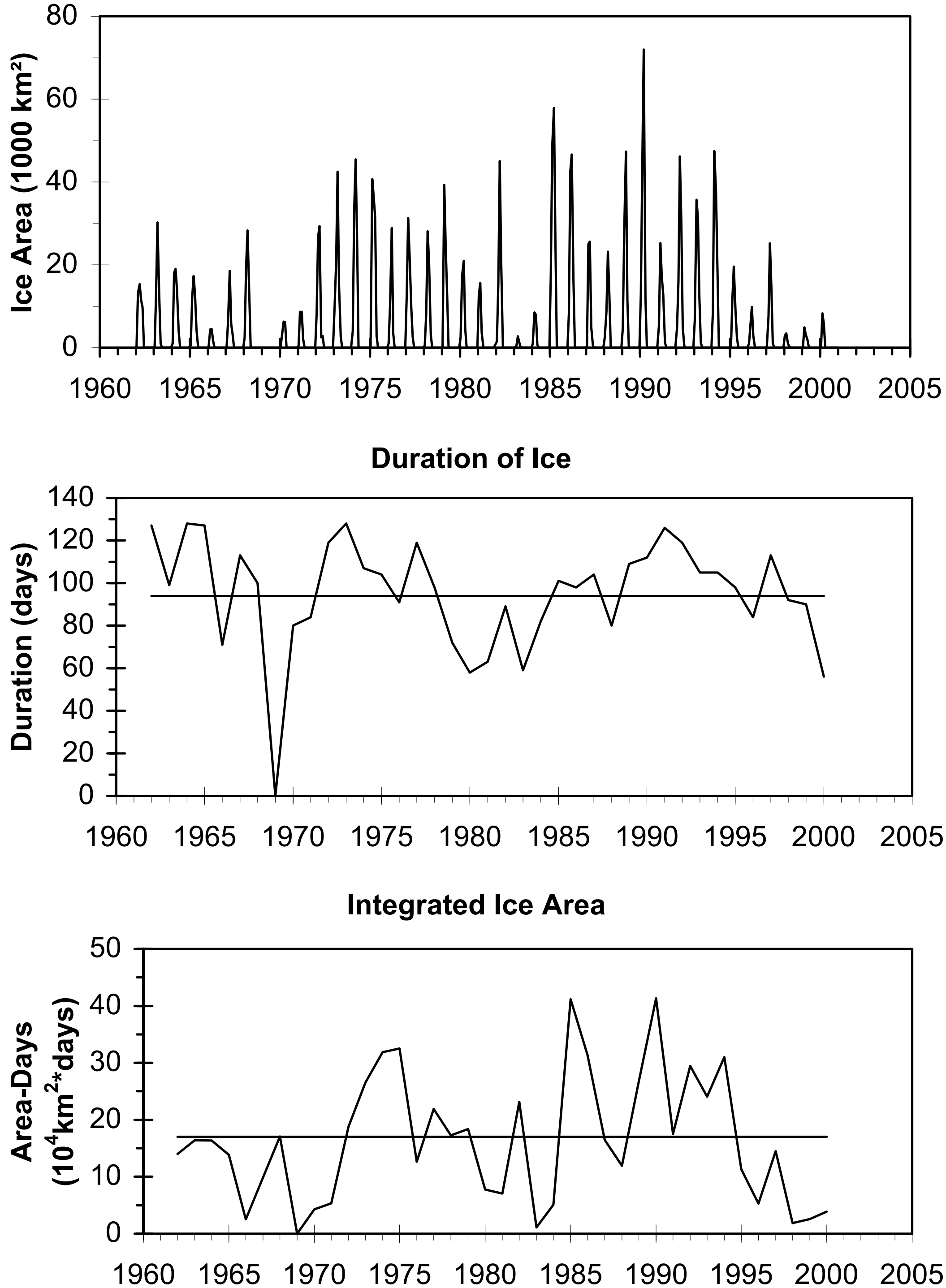

Fig. 16. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1962-1990) means.

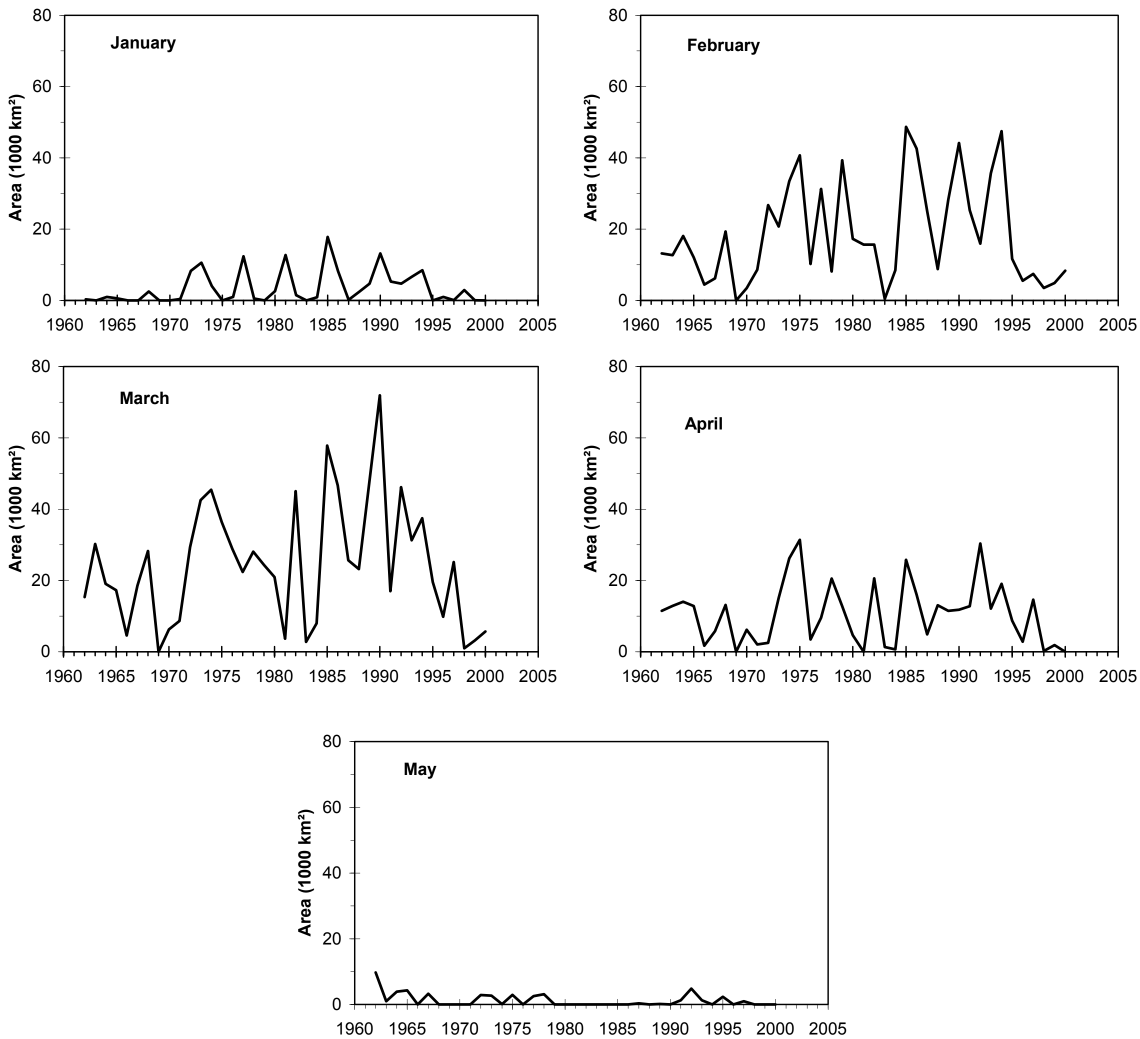

Fig. 17. The time series of ice area seaward of Cabot Strait, by month. The horizontal lines represent the long-term (1962-1990) monthly means.

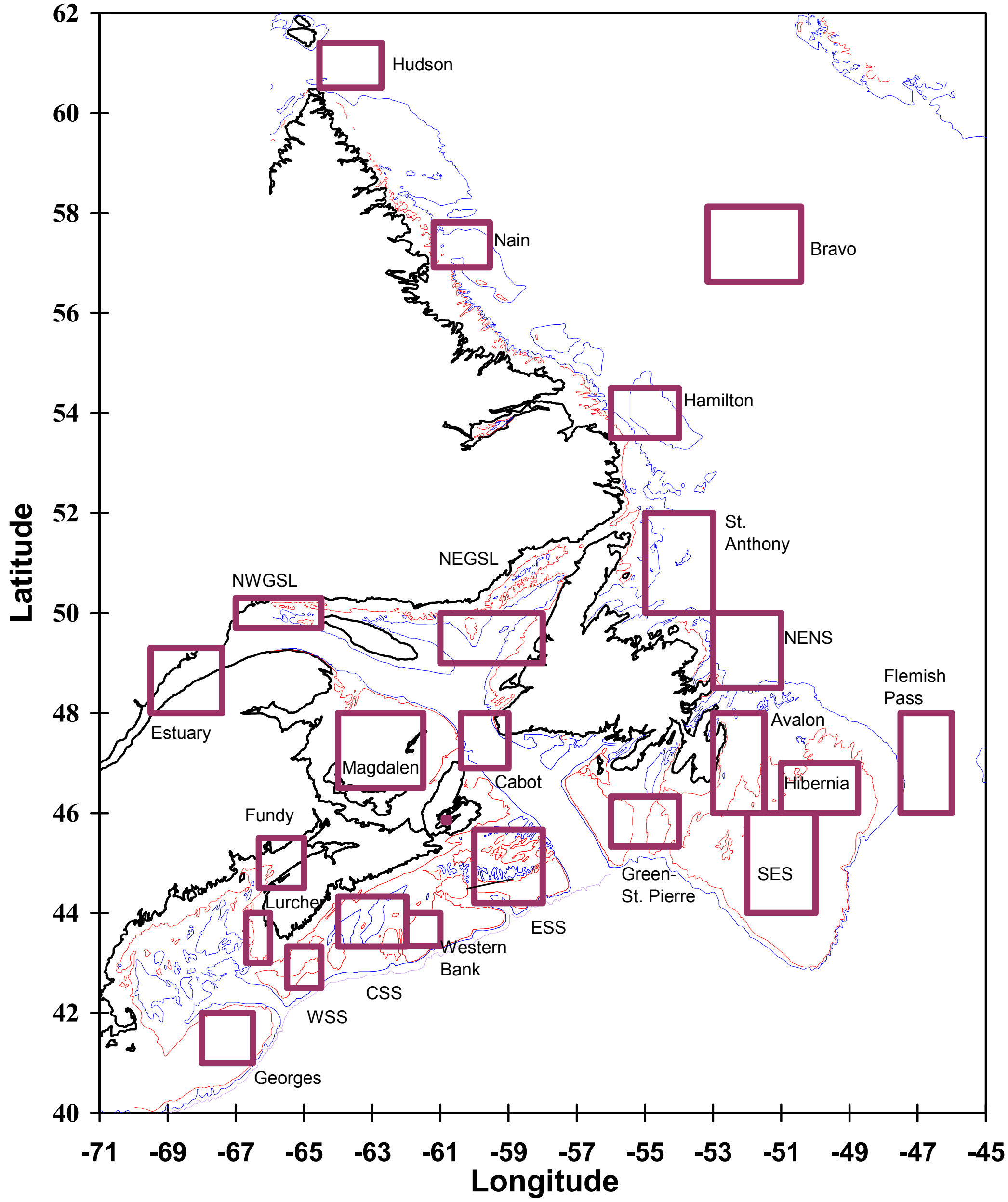

Fig. 18. The areas in the northwest Atlantic used for extraction of sea-surface temperature.

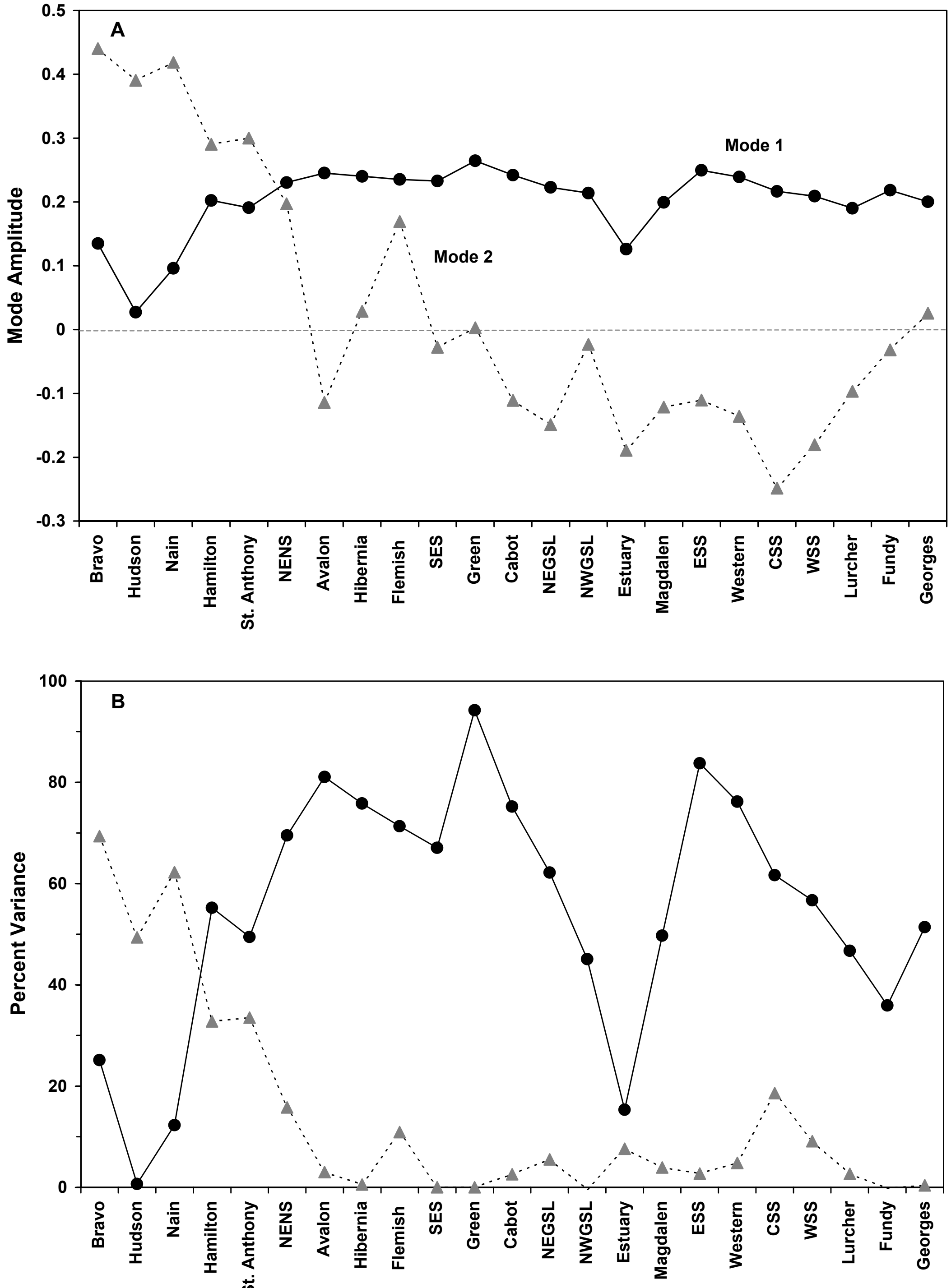

Fig. 19. (A) The amplitudes of modes 1 and 2 at each site.
(B) The percent variance accounted for by modes 1 and 2 at each site.

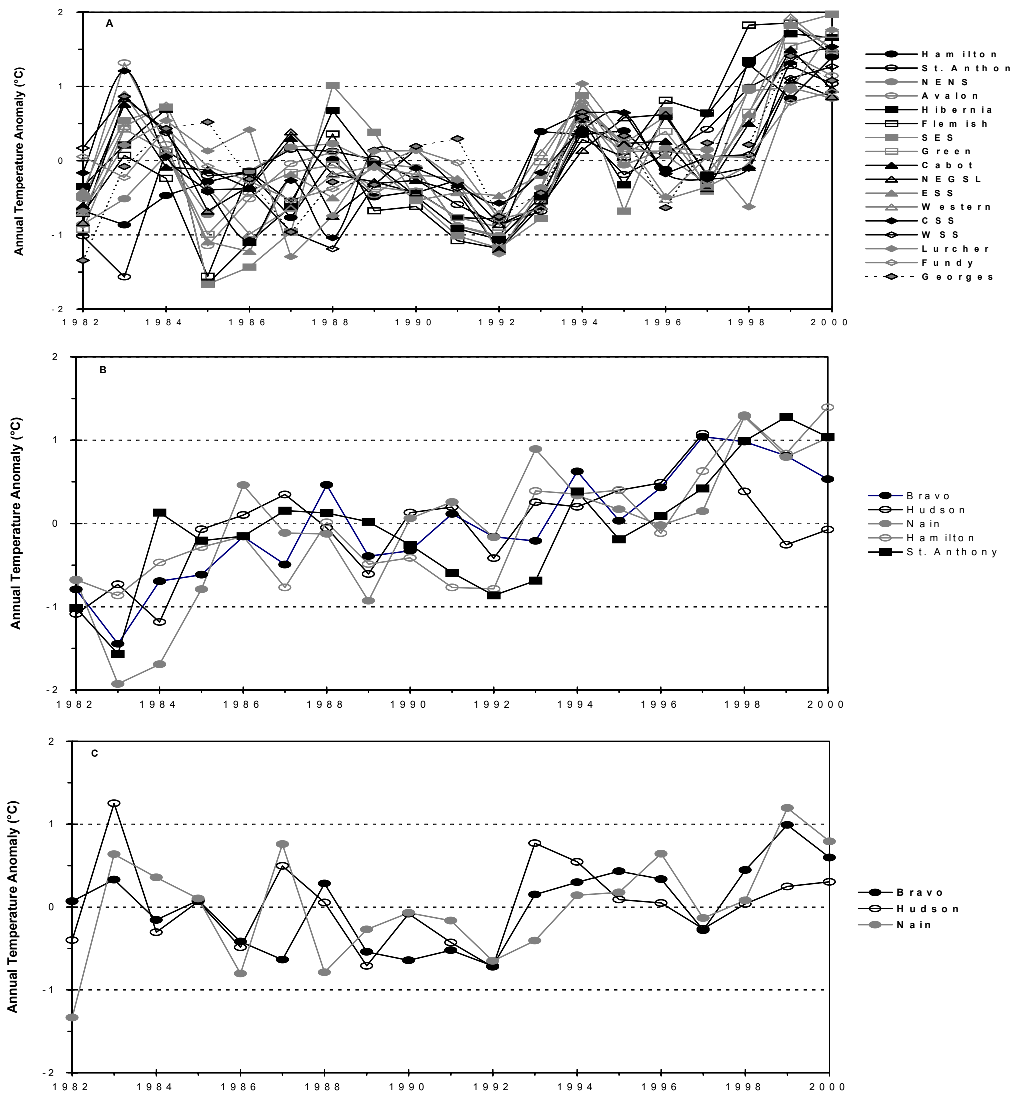

Fig. 20. Time series of annual sea-surface temperature anomalies for (a) Newfoundland Shelf, Scotian Shelf and Gulf of Maine, (b) northern sites, and (c) Gulf of St. Lawrence.