Northwest Atlantic Fisheries Organization

Serial No. N5080 **NAFO SCR Doc. 05/5**

SCIENTIFIC COUNCIL MEETING – JUNE 2005

An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2004

B. Petrie, R. G. Pettipas and W. M. Petrie

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

ABSTRACT

A review of meteorological, sea ice and sea surface temperature conditions in the Northwest Atlantic in 2004 is presented. During 2004, the winter NAO index was below normal (~9 mb) for the fourth consecutive year and close to the 2001 value. A negative NAO index implies weakened winds, higher air temperatures and reduced heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. Because of the important role that southward advection plays on the Canadian Atlantic seaboard, the effects of a negative (positive as well) NAO index, particularly four successive years of negative values, are eventually felt throughout the region. Annual average air temperatures were above normal by ~1.2°C over the Labrador Sea and Shelf, the Newfoundland Shelf and the Gulf of St. Lawrence; Scotian Shelf and Gulf of Maine air temperatures were about 0.4°C below normal. The winter wind anomalies over the Labrador Sea were generally towards the northwest at about 1-2 m/s, consistent with the negative NAO index and implying reduced heat flux from the ocean to the atmosphere. The Newfoundland ice coverage was the 2nd lowest in 42 years and its duration was generally less than average; the Gulf of St. Lawrence coverage was also less than normal ranking 11th of 42 years and its duration was typically less than average; on the other hand, the Scotian Shelf, where most of the ice is the result of export form the Gulf, featured unexceptional coverage (rank 19th of 43 years) with ice duration slightly longer than normal. The 262 icebergs that reached the Grand Bank was considerably less than the 927 in 2003 and the 5th lowest since 1985, when more accurate counts became available. The analysis of satellite data indicates a north-south gradient of sea surface temperatures similar to the air temperature distribution. The Labrador Sea and Shelf, the northern Newfoundland Shelf and northern Grand Bank, featured sea surface temperature anomalies that were 0.2-0.5°C above normal. Southeast Shoal and St. Pierre-Green Bank temperatures were slightly below normal. Above normal sea surface temperatures were seen in the northeastern Gulf of St. Lawrence but the rest of the Gulf had values slightly below normal. Sea surface temperatures on the Scotian Shelf and in the Gulf of Maine were 0.3-1.1°C below normal.

INTRODUCTION

This paper examines the meteorological, sea ice and sea surface temperature conditions during 2004 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). It complements the oceanographic reviews of the waters in and around the Gulf of St. Lawrence, Newfoundland and Labrador, and the Scotian Shelf and Gulf of Maine, which together constitute the annual physical environmental overviews to the Fisheries Oceanography Committee (FOC). 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 or normal, and where the data permit, the latter have been standardized to a 30-year base period (1971-2000). This is in accordance with the convention of North American meteorologists and the recommendations of both the Northwest Atlantic Fisheries Organization (NAFO) and the FOC. A standardized base period allows direct comparison of anomalies between sites and between variables.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The German Weather Service publishes monthly air temperature anomalies relative to the 1961-1990 means for the North Atlantic Ocean in the publication *Die Grosswetterlagen Europas* (e.g., Deutscher Wetterdienstes, 2002). Slightly warmer-than-normal temperatures of about 1°C dominated over most of eastern Canadian waters during 2004 (Fig. 2A). Negative annual anomalies were less than 1°C below normal and were limited to the St. Lawrence Estuary, western Magdalen Shallows, Scotian Shelf and Gulf of Maine. The monthly maps of air temperature anomalies indicate that the Labrador Sea had generally warmer-than-normal temperatures throughout the year with the exceptions of March and December (Fig. 2C, D). The Grand Banks featured above average temperatures except for May and June. Conditions were more variable for the Gulf of St. Lawrence and the Scotian Shelf. The Gulf experienced warmer-than-normal temperatures in February, April, and July-October. The Scotian Shelf-Gulf of Maine region showed patches of both above and below average temperatures for most months except for January, June and November which were colder-than-normal, and December, which was warmer-than-normal.

Monthly air temperature anomalies for 2003 and 2004 relative to their 1971-2000 mean at eight sites, from Nuuk 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, 2004). In 2004, there was a systematic latitudinal variation from generally above normal temperatures in the north, Newfoundland and the Gulf of St. Lawrence; generally slightly below normal temperatures were observed at Sable Island, a mixture of positive and negative anomalies at Boston, and mostly above normal values at Cape Hatteras.

The mean annual air temperature anomalies for 2004 were calculated at all sites (Fig. 4). A strong latitudinal variation was evident with the largest above normal anomalies in the north and below average temperatures in the south: Nuuk (1.42°C), Iqaluit (0.84°C), Cartwright (2.04°C), St. John's (0.83°C), Magdalen Islands (0.61°C), Sable Island (-0.23°C), Boston (-0.51°C), Cape Hatteras (0.11°C). In 2003, the pattern was very similar with anomalies ranging from a high of 2.33°C at Nuuk to a low of -0.83°C at Boston.

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to large-scale pressure patterns and atmospheric circulation. Monthly mean atmospheric 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 2004, relative to the 1971-2000 means, are shown in Fig. 5. Winter includes December 2003 to February 2004, spring is March to May, summer is June to August and autumn is September to November.

In winter, an extensive anomalous low covered eastern Canada with its centre (~4 mb below normal) located southeast of Newfoundland. The system extended northwards to Labrador and eastwards to the Mediterranean. A high pressure anomaly (to 8 mb above normal) was situated over and to the east of Greenland. The winter pressure anomalies in 2004 indicate weaker-than-normal Iceland Low and Azores High, i.e. a reduction in the strength of the large-scale atmospheric circulation, similar to but greater than in 2003.

The spring of 2004 featured a negative pressure anomaly trough (minimum about -3 mb) stretching from the Canadian Archipelago across southern Greenland to Iceland. This anomaly was flanked by a weak, higher-than-normal pressure southeast of Newfoundland and another positive anomaly running from northern Greenland to western Europe.

The pressure anomaly field during the summer of 2004 featured a weak negative anomaly (minimum -2 mb) in the central North Atlantic. There was a positive anomaly (~2 mb maximum) over western Greenland.

In the autumn, the pattern was dominated by an intense positive anomaly over Greenland (to ~6 mb) and a secondary cell in the mid-Atlantic.

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 a deepening of the Icelandic Low and a strengthening of the 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 2004, the NAO index was below normal (-9.0 mb) for the fourth year in a row (2001-2004); its magnitude was considerably greater than in 2003 (-3.3 mb). If we order the anomalies from negative to positive, 2004 ranks 22nd of 108 years and was 1.1 standard deviations below normal based on the standard deviation for 1971-2000. There were 4 other periods, 1899-1902, 1962-1966, 1968-1971, 1977-1980 and 1985-1988 that had at least 4 years of negative NAO anomalies. As indicated, a negative NAO is usually accompanied by warm air temperatures over the Labrador Sea in winter. This is consistent with air temperature anomalies which were 0.61-2.04^{o}C above normal for the 5 northern sites (Fig. 4).

Winds

The re-analyzed NCEP (National Centre for Environmental Prediction) – NCAR (National Center for Atmospheric Research) winds (Kistler et al., 2001) are available from the International Research Institute of the Lamont-Doherty Earth Observatory at Columbia University. Based upon correlations with observed winds, the vector components of the NCEP winds capture most of the observed variability in the wind field. They represent winds measured at a height of 10 m and are gridded at intervals of 1.88° longitude and 1.90° 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 magnitude of the wind anomalies tends to be larger in the north, hence for presentation purposes, we show the Labrador Sea separately from regions farther south.

The anomalies of the mean winter winds during 2004 were to the northwest over the Labrador Sea and to the south over the Labrador Shelf (Fig. 8). Over Atlantic Canada, winter wind anomalies had a cyclonic pattern with the centre located south of the Avalon Peninsula (Fig. 9). The anomalous winds in the spring were weak and generally from the southeast in the Labrador Sea; in the southern area, the only appreciable wind anomalies were over the Northeast Newfoundland Shelf. The pattern changed again in summer, with an anticyclonic anomaly pattern over the Labrador Sea, centered off the southern tip of Greenland. The Grand Banks had the largest anomalies, predominantly to the southeast, in the southern region. The autumn wind anomalies over the Labrador Sea were predominantly from the south; those over Atlantic Canada were generally to the southwest.

SEA ICE OBSERVATIONS

The locations and concentrations of sea ice are 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%) are based on the 1971-2000 data (Canadian Ice Service, 2002). The ice edge can vary rapidly over short periods of time (~days) due primarily to changes in the winds. 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 for the Newfoundland region (Peterson and Prinsenberg, 1990) and for the Gulf of St. Lawrence and the Scotian Shelf (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, and the duration of ice were determined for these areas. The data begin in the early 1960s and continue to the present. Long-term means (1971-2000) of each variable were determined (using only data from years ice was present) and were subtracted from the 2004 values to obtain anomalies.

Newfoundland and Labrador

Sea-Ice. At the beginning of 2004, the only sea ice present lay off the southern Labrador coast in the vicinity of Hamilton Inlet (Fig. 10A). This coverage was less than the long-term median for the beginning of the year. By mid-January, ice had spread south in a narrow coastal band to the Strait of Belle Isle, substantially less than the long-term median coverage. The distribution was relatively unchanged by February 1 and was less than the minimum coverage for this time of the year. By March 1, ice coverage was slightly greater than the long-term minimum. On the first of April and May, the coverage was approximately equal to the median (Fig. 10B). A small amount of ice was present on May 31 in the northwest corner of the area; by July all ice had vanished from the analysis region.

Ice appeared along the southern Labrador coast about January 1, 2004 (day 0, Fig. 11), and gradually spread southward to northeastern Newfoundland waters by late February (day 60). It reached the northern Grand Bank by late March (day 90). Relative to the long-term mean, ice typically appeared much later than normal over most of the region (Fig. 11). It began to disappear from the area just north of Grand Bank in early April (day 105; Fig. 12). It did not begin to retreat from northern Newfoundland waters and southern Labrador until early to mid-May (day 120-135). Ice persisted in the Hamilton Bank region to the end of May (day 150). Over much of the Labrador Shelf, it disappeared about 2 weeks earlier than normal (negative anomaly). Ice remained about 2 weeks longer than average over the outer shelf east of the Strait of Belle Isle.

The duration of sea ice is the number of days that ice, at a minimum concentration of 10%, is present. It is not simply the date of the first presence minus the last presence because the ice may disappear for a time and then reappear. Duration ranged from <30 days north of Grand Bank to over 170 days along the Labrador coast (Fig. 13). The ice duration was less-than-normal over most of the Newfoundland and Labrador Shelves by as much as 50 days.

The time series of the monthly ice coverage on the Newfoundland and southern Labrador shelves (45-55^{o}N; I. Peterson, pers. comm., Bedford Institute) show that the peak extent during 2004 was one of the smallest on record (Fig. 14A). For the total ice cover from December to July (mean coverage ~1,000,000 km^2), 2004 had the second lowest coverage, 320,000 km^2; only 1966 had less ice. The 2004 coverage was 2 standard deviations below normal. Relative to 2003, the average ice area decreased during advancement (January to March) and retreat (April to June). The monthly means of ice area show that the 2004 seasonal coverage was less than that of 2003 from December to May. In summary, 2004 overall was one of the lightest ice years on the Labrador and Newfoundland shelves over the length of the record, 1963-2004. Although no estimates of ice volume were made for 2004, studies in the Gulf of St. Lawrence (Drinkwater *et al*., 1999) suggest that the temporal variability of the ice volume would be similar to that of the ice area.

The co-occurrence of the light ice year, higher than average air temperatures in the Labrador-Newfoundland region and a negative NAO anomaly encouraged some further analysis. A linear regression of the ice area summed for the December to July period on the December-March air temperature anomaly at Cartwright and the NAO index shows strong relationships (Fig. 14B). The multiple linear regression accounts for 70% of the variability of the summed sea ice cover.

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). The 1985-2004 period is considered to have reliable SLAR measurements. During the 2003/2004 iceberg season (October 2003 to September 2004), a total of 262 icebergs were detected south of 48^{o}N, a decrease from the 927 recorded in 2003. The first icebergs of 2004 were seen south of 48^{o}N in April. The monthly totals for April to July were 24, 114, 117 and 7 (Fig. 16). For 1985-2004, 4 years (1986,1988,1999 and 2001) had fewer icebergs; for 1890-2004, 2004 ranked 56th out of 125 years when the counts are ordered from lowest to highest (Fig. 16).

Gulf of St. Lawrence

The locations of the ice edge within the Gulf of St. Lawrence during the 2003-2004 winter season are shown in Fig. 17. Ice first appeared in mid-December as small patches in the Estuary. Coverage increased but was less than the median throughout the year. By early March most of the Gulf was covered with ice with the exception of the southeastern area near Cabot Strait. By April 1, the Estuary was clear of ice but coverage along the north shore and in Magdalen Shallows was significant. Small amounts of ice were found in the northeastern Gulf in late April.

The times of first appearance of ice in the Gulf of St. Lawrence were generally 0-15 d earlier than normal in the Estuary, the northwest Gulf, along the north shore and in the western Magdalen Shallows (Fig. 11). Ice appearance was up to about 30 days later than normal in the rest of the Gulf. Figure 11 implies that all areas of the Gulf were covered in 2004. However, this can arise because of the coarse resolution of the ice grid (0.5^o latitude by 1^o longitude); in fact, Ice Central has identified an area off St. Georges Bay, southwestern Newfoundland, as ice free in 2004. The last presence of ice varied from early to mid-April; this was about normal for the entire Gulf (Fig. 12). Ice duration varied from less than 30 to 130 d; ice duration was less than the long-term mean in a broad area from about 47^{o}N northward and from about 64^{o}W eastward. Duration in the Estuary and the southern and western Magdalen Shallows was slightly longer than normal.

We have estimated the monthly mean area of the Gulf covered by ice. The time series shows that in 2004 the peak areal coverage decreased by an average monthly value (December-June) of about 25,000 km^2 compared to 2003; the largest differences, 57,000 and 53,000 km^2, were in February and March (Fig. 18). Ice coverage for the entire 2004 ice season was about 30% smaller than the 1971-2000 average, about 1.2 standard deviations below normal. The 2004 ice season ranked 11th in 42 years, ordering from least to greatest cover. Estimates of the duration of ice showed that on average, the 2004 season was the 12th shortest in 42 years, it was 8 d shorter than the 1971-2000 average duration, 0.5 standard deviations below normal. To summarize, 2004 featured below normal ice coverage and a slightly shorter than normal duration in the Gulf of St. Lawrence.

Scotian Shelf

Sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwesterly winds and ocean currents. In 2004, ice first appeared seaward of the Strait during mid to late January, which is slightly earlier-than-usual (Fig. 11). By early March, the ice had moved along the coast nearly reaching Halifax. It maintained a relatively constant presence in the Cabot Strait area until mid-April; the duration in Sydney Bight was about 10-20 d longer than normal (Fig. 12, 13, 17). The duration of ice in 2004 ranked 30th of 43 years (ordering shortest to longest), was 12 d or 0.6 standard deviations longer than normal (Fig. 19, 20). The ice coverage on the Scotian Shelf was unexceptional; overall 2004 ranked 19th in 43 years, ordering from least to greatest cover.

Remotely-Sensed Sea Surface Temperature

We maintain the 9 km resolution Pathfinder sea surface temperature data in a public database at BIO. In the following analysis, we substituted the 18 km resolution MCSST data for the Pathfinder observations in 1999 because we noticed serious degradation of the latter, particularly towards the end of the year. This deterioration of the Pathfinder data was not evident in other years nor was it found for the MCSST data. The Pathfinder dataset had a major revision in 2004; however, the BIO database has not been updated since June, 2003. To provide data for June, 2003 to present, we used the sea surface temperature data (1997-present) downloaded by the remote sensing group in the Biological Sciences Section (BOS). Comparison of the Pathfinder and BOS temperatures during the common time period indicated that the latter was on average 0.6^{o}C lower than the former. We adjusted the BOS observations to bring them in line with the longer Pathfinder series.

Annual anomalies for 23 subareas, stretching form the Labrador Sea to the Gulf of Maine (Fig. 21), were determined from the averages of monthly anomalies. The results are shown as annual temperature anomalies in Fig. 22 where data are plotted from north to south. In 2004, there was a general pattern of small positive anomalies in the north, small negative ones in the south. The Labrador Sea and Shelf had sea surface temperatures 0.3-0.4^{o}C above normal. The Newfoundland Shelf had above normal temperatures by 0.2-0.5^{o}C except for Southeast Shoal and St. Pierre-Green Banks where the anomalies were slightly negative. The warmer anomalies penetrated through the Strait of Belle Isle to the northeastern Gulf, but the rest of the Gulf had sea surface temperatures that were slightly below normal. The Scotian Shelf and the Gulf of Maine featured temperatures that were below normal by 0.3-1.1^{o}C, with the largest anomaly observed for Georges Bank.

SUMMARY

During 2004, the NAO index was below normal (~9 mb) for the fourth consecutive year and close to the 2001 value. A negative NAO index implies weakened winds, higher air temperatures and reduced heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. Because of the important role that southward advection plays on the Canadian Atlantic seaboard, the effects of a negative (positive as well) NAO index, particularly four successive years of negative values, are eventually felt throughout the region. Annual average air temperatures were above normal by ~1.2^{o}C over the Labrador Sea and Shelf, the Newfoundland Shelf and the Gulf of St. Lawrence; Scotian Shelf and Gulf of Maine air temperatures were about 0.4^{o}C below normal. The winter wind anomalies over the Labrador Sea were generally towards the northwest at about 1-2 m/s, consistent with the negative NAO index and implying reduced heat flux from the ocean to the atmosphere. The Newfoundland ice coverage was the 2nd lowest in 42 years and its duration was generally less than average; the Gulf of St. Lawrence ice coverage was also less than normal ranking 11th of 42 years and its duration was typically less than average; on the other hand, the Scotian Shelf, where most of the ice is the result of export form the Gulf, featured unexceptional coverage (rank 19th of 43 years) with ice duration slightly longer than normal. The 262 icebergs that reached the Grand Bank was considerably less than the 927 in 2003 and the 5th lowest since 1985, when more accurate counts became available. The analysis of satellite data indicates a north-south gradient of sea surface temperatures similar to the air temperature distribution. The Labrador Sea and Shelf, the northern Newfoundland Shelf and northern Grand Bank featured sea surface temperature anomalies that were 0.2-0.5^{o}C above normal. Southeast Shoal and St. Pierre-Green Bank temperatures were slightly below normal. Above normal temperatures were seen in the northeastern Gulf of St. Lawrence but the rest of the Gulf had values slightly below normal. Sea surface temperatures on the Scotian Shelf and in the Gulf of Maine were 0.3-1.1^{o}C below normal.

ACKNOWLEDGEMENTS

We thank all those who provided data, especially Ingrid Peterson of the Bedford Institute for the monthly areal ice extent data for the Newfoundland region. We also thank Eugene Colbourne and Denis Gilbert for reviewing the document.

REFERENCES

Canadian Ice Service. 2002. Sea ice climatic atlas: Northern Canadian waters 1971-2000. Environment Canada, Ottawa. 249 p.

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.

Deutschen Wetterdienstes. 2002. *Die Grosswetterlagen Europas*. Vol. 55. Offenbach, Germany.

Drinkwater, K.F. 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early-1990s. J. Northw. Atl. Fish. Sci. 18: 77-97.

Drinkwater, K.F., R.G. Pettipas, G.L. Bugden and P. Langille. 1999. Climatic data for the Northwest Atlantic: A sea ice database for the Gulf of St. Lawrence and the Scotian Shelf. Can. Tech. Rept. Hydrogr. Ocean Sci. 199: 134 p.

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne AND M. Firoino. 2001. The NCEP-NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull. Amer. Meteorolog. Soc.*, 82: 247-267.

NOAA. 2004. *Monthly climatic data for the world*. Vol. 56. National Climate Data Center, Asheville, North Carolina.

Peterson, I. K. and S. J. Prinsenberg. 1990. Sea ice fluctuations in the western Labrador Sea (1963-1988). Can. Tech. Rep. Hydrogr. Ocean Sci. 123: 130 p.

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.

Thompson, K.R. and M.G. Hazen. 1983. Interseasonal changes in wind stress and Ekman upwelling: North Atlantic, 1950-80. Can. Tech. Rep. Fish. Aquat. Sci. 1214, 175 p.

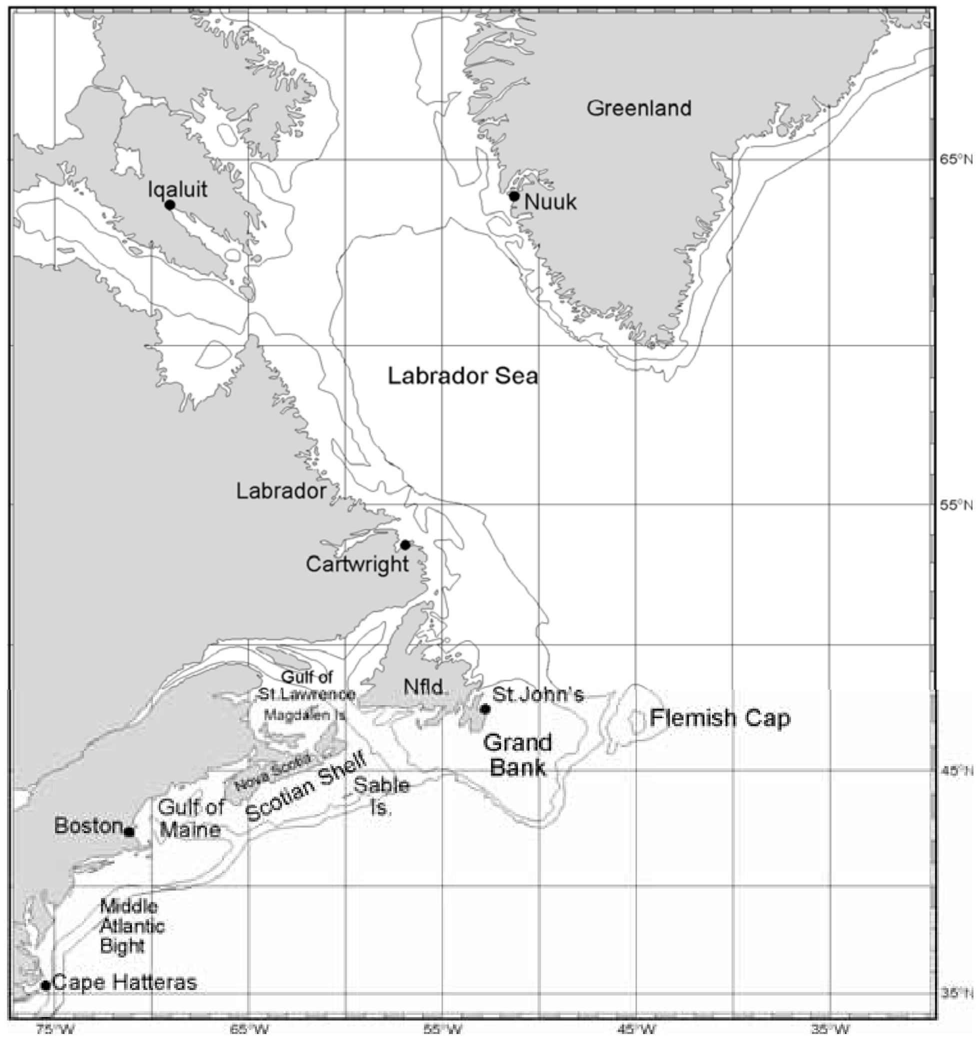

Fig. 1. Northwest Atlantic showing coastal air temperature stations. The thin lines denote the 200 m and 1000 m isobaths.

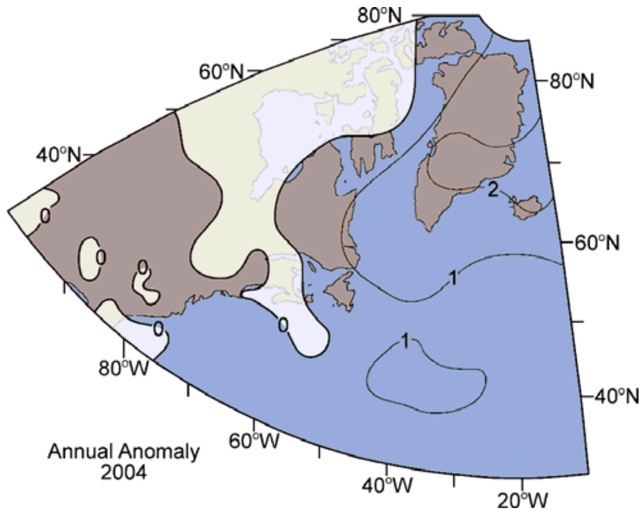

Fig. 2A. The 2004 annual anomaly of air temperature (°C) over the Northwest Atlantic relative to the 1961-1990 means. The light shaded areas are colder than normal. (Redrawn from Grosswetterlagen Europas).

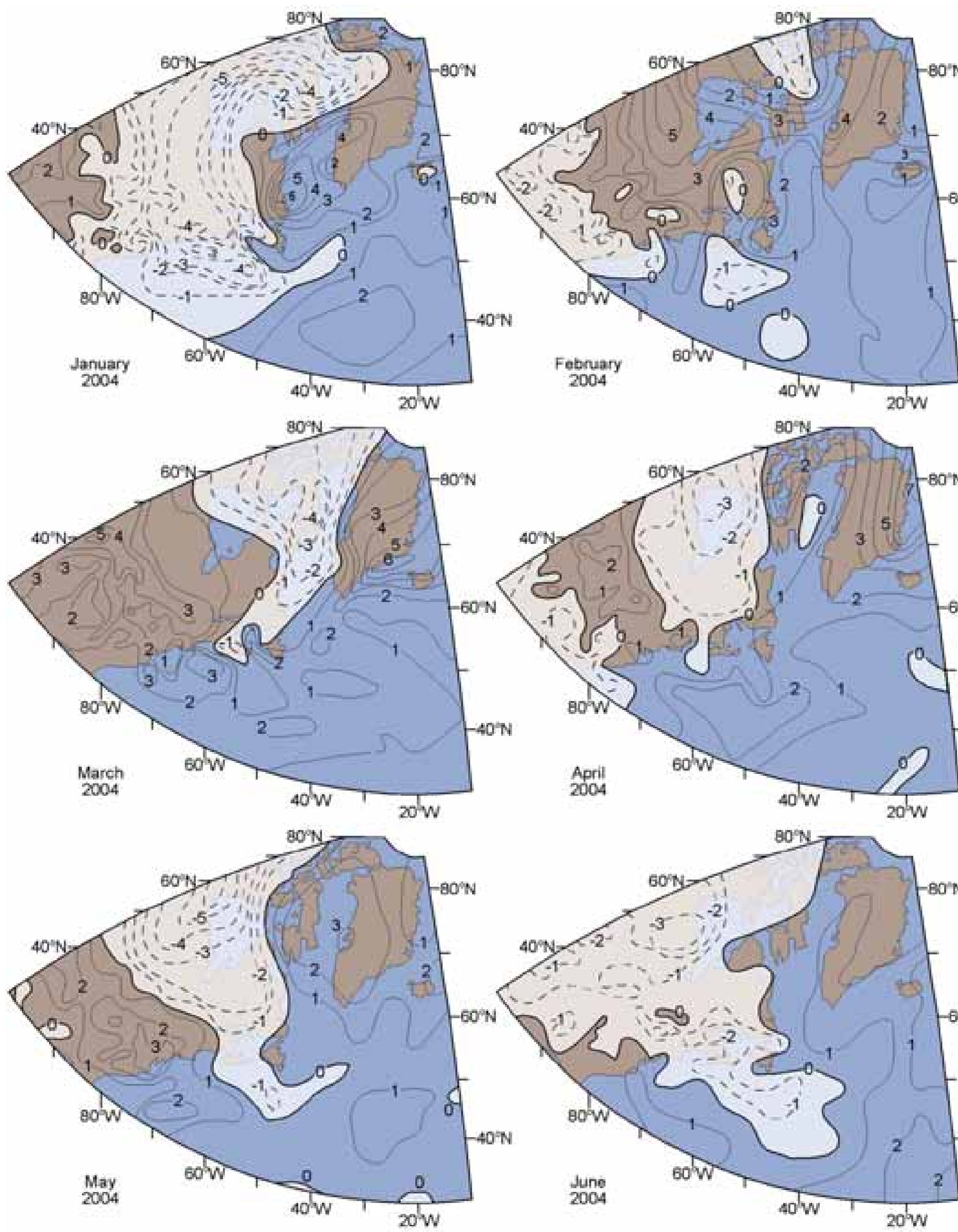

Fig. 2B. Monthly air temperature anomalies (°C) over the Northwest Atlantic from January to June of 2004 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

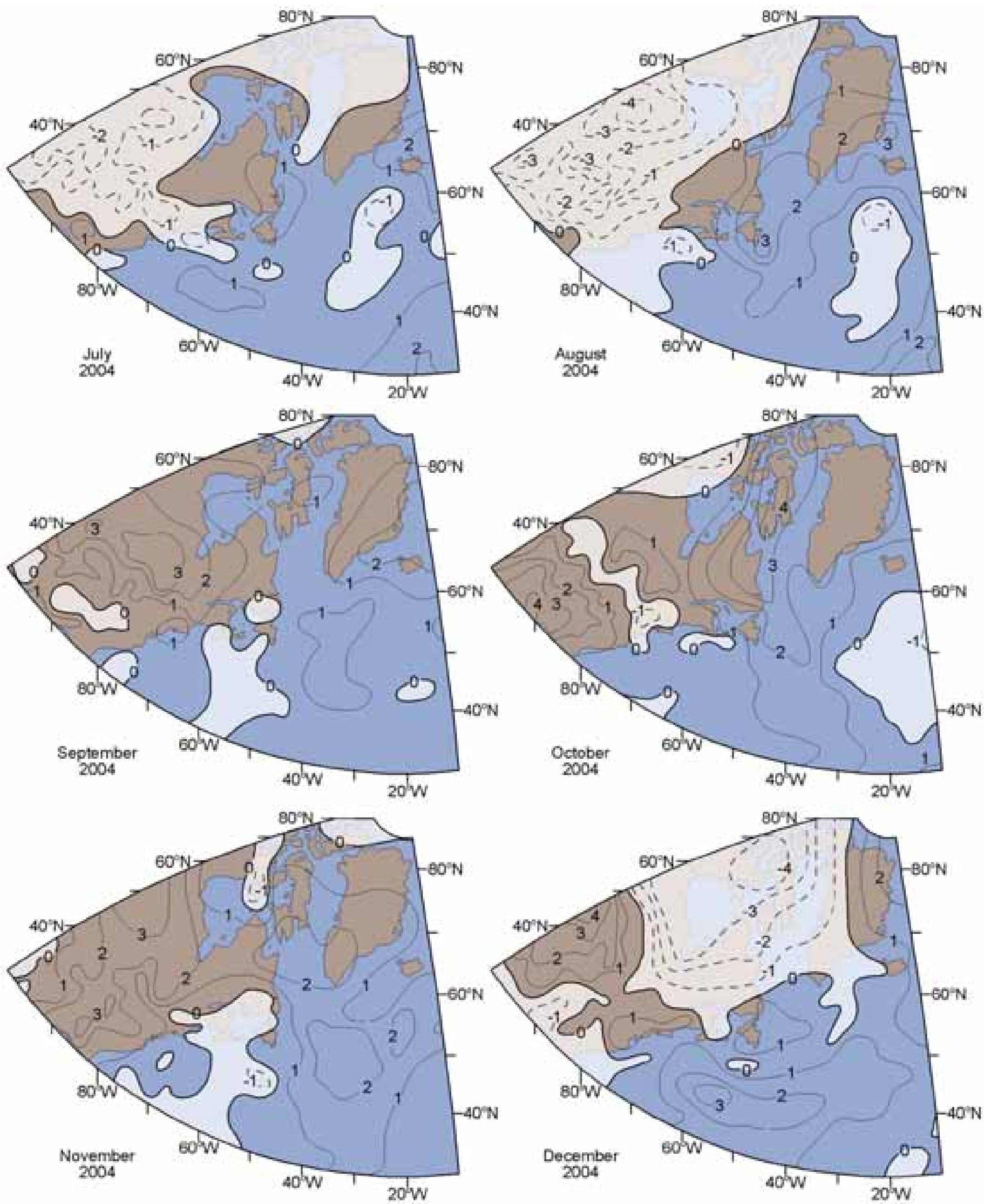

Fig. 2C. Monthly air temperature anomalies (°C) over the Northwest Atlantic from July to December of 2004 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

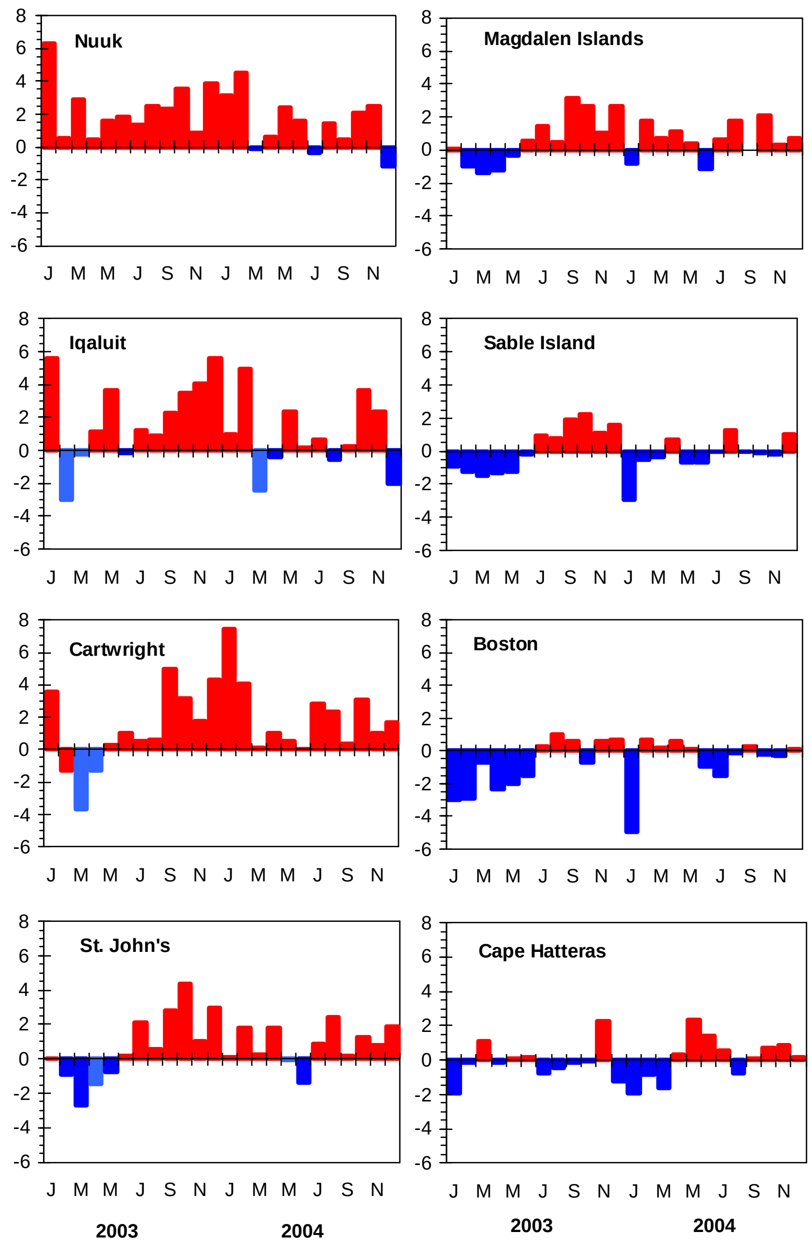

Fig. 3. Monthly air temperature anomalies in 2003 and 2004 at selected coastal sites (see Fig. 1 for locations).

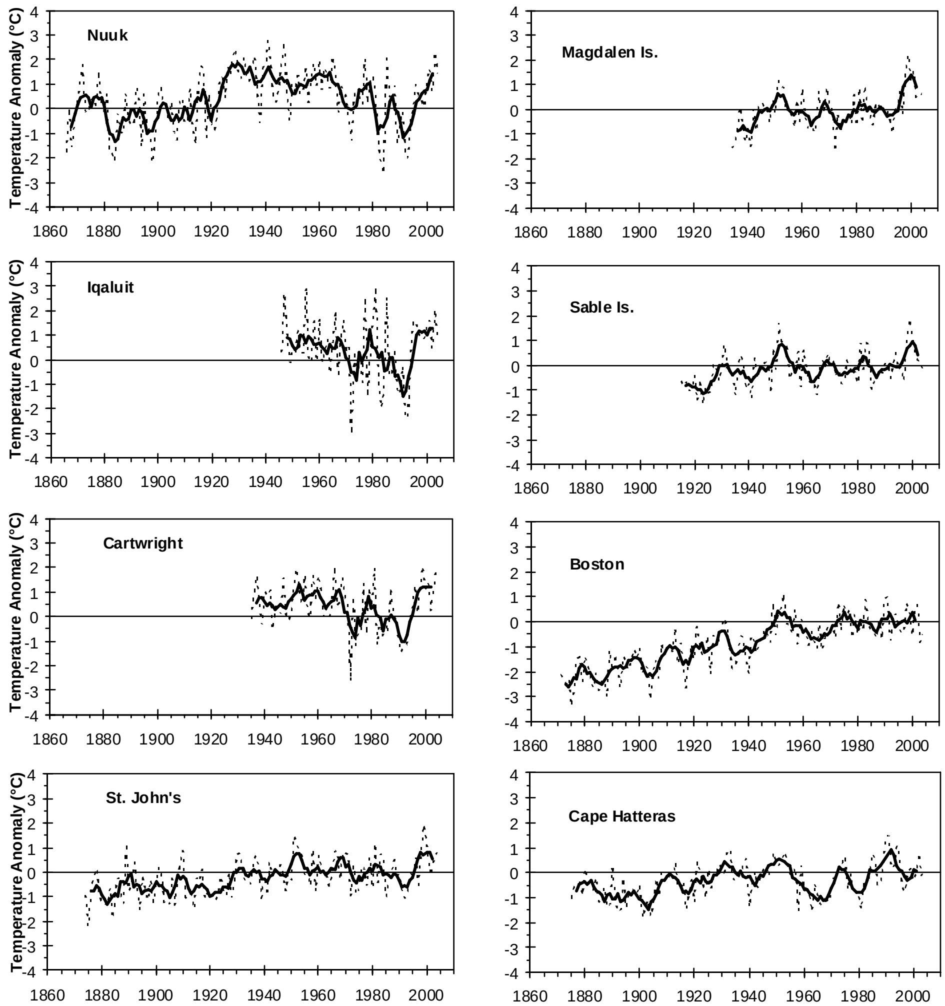

Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

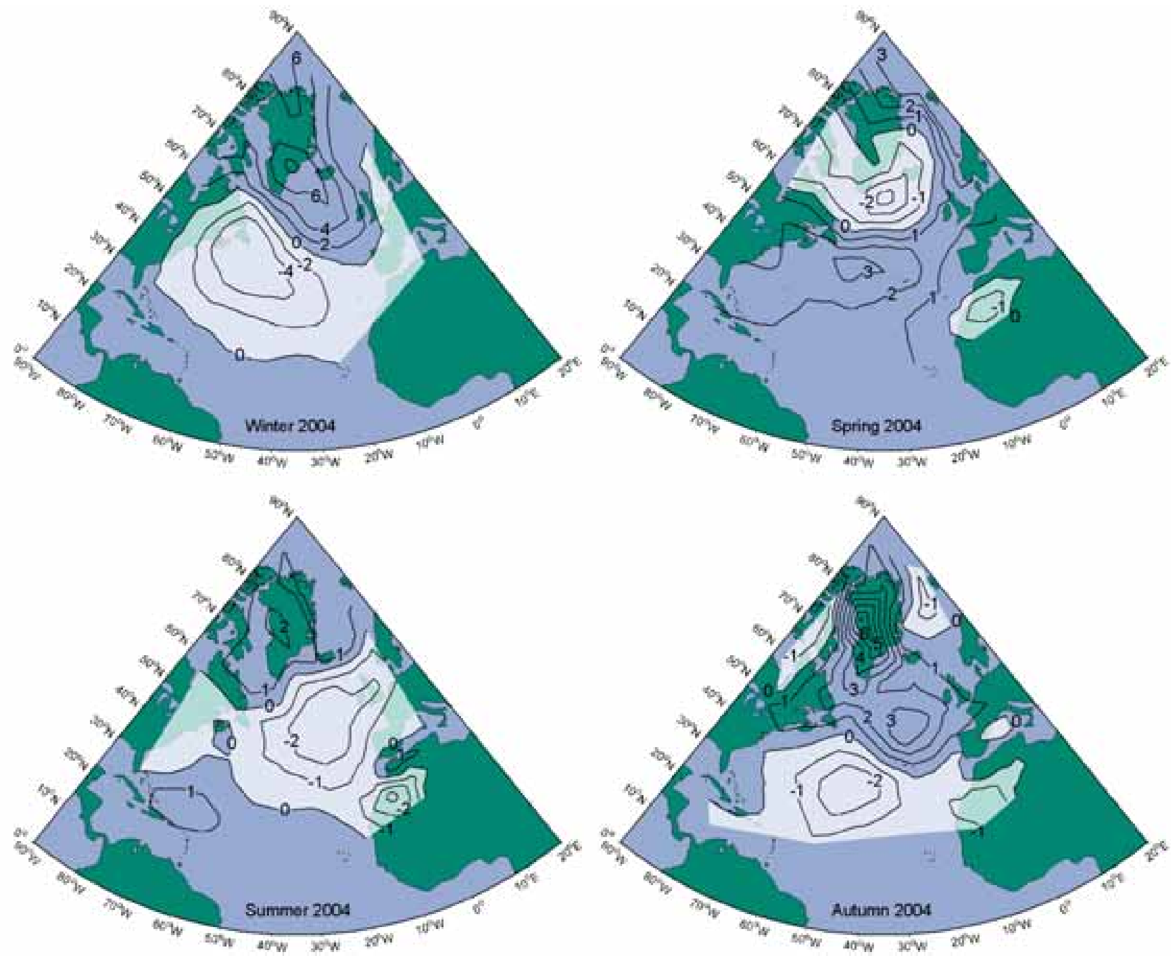

Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2004 relative to the 1971-2000 means.

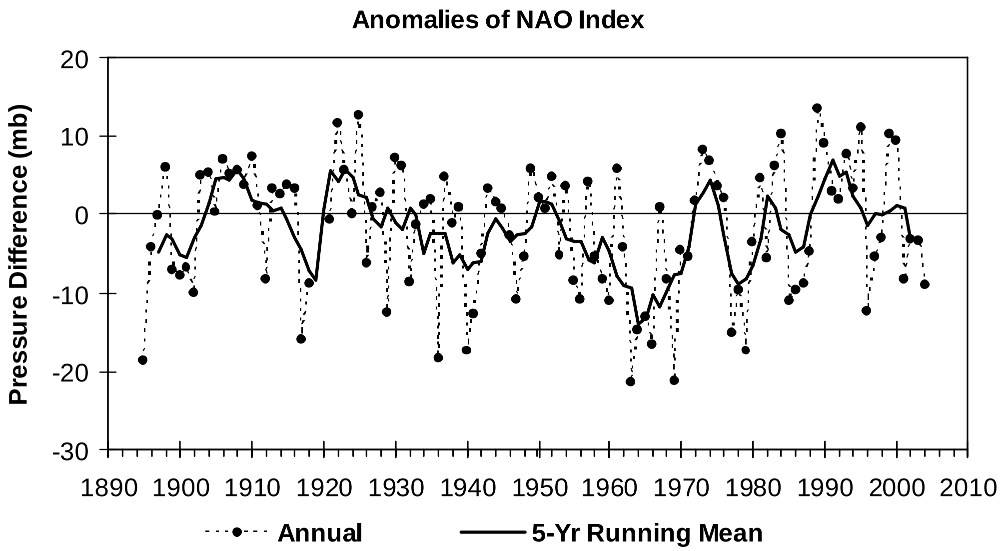

Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

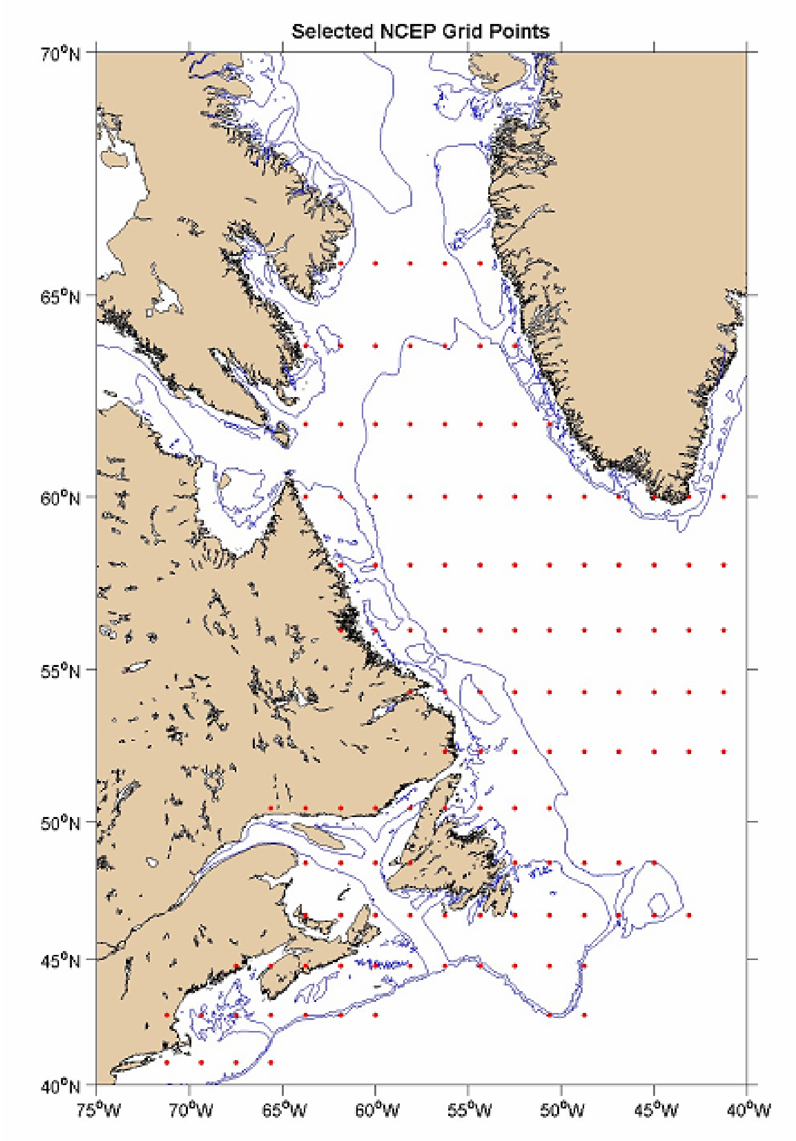

Fig. 7. The Northwest Atlantic showing the NCEP wind grid used in our study.

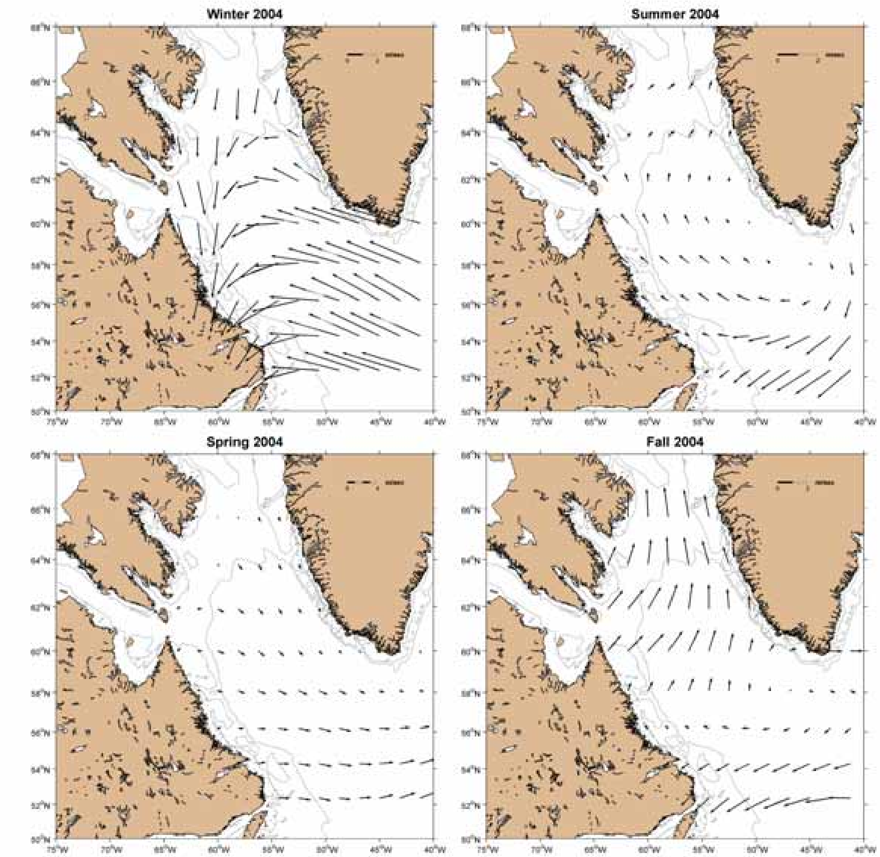

Fig. 8. The seasonal wind anomalies for the northern region during 2004.

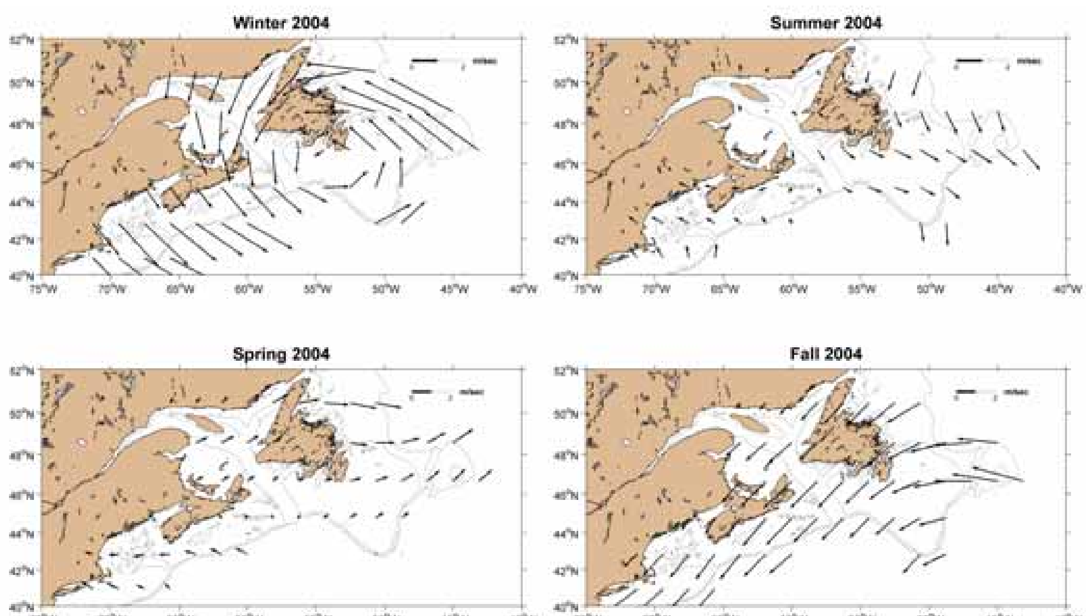

Fig. 9. The seasonal wind anomalies for the southern region during 2004.

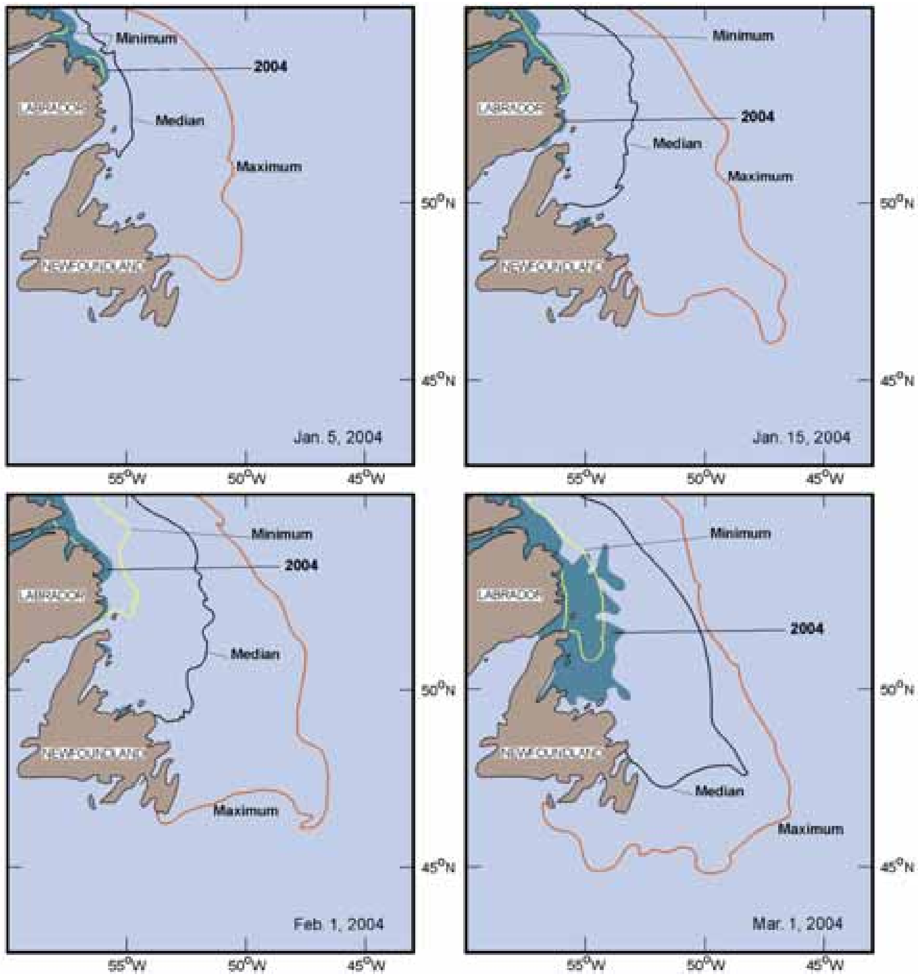

Fig. 10A. The location of the ice (shaded area) between January and March 2004 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

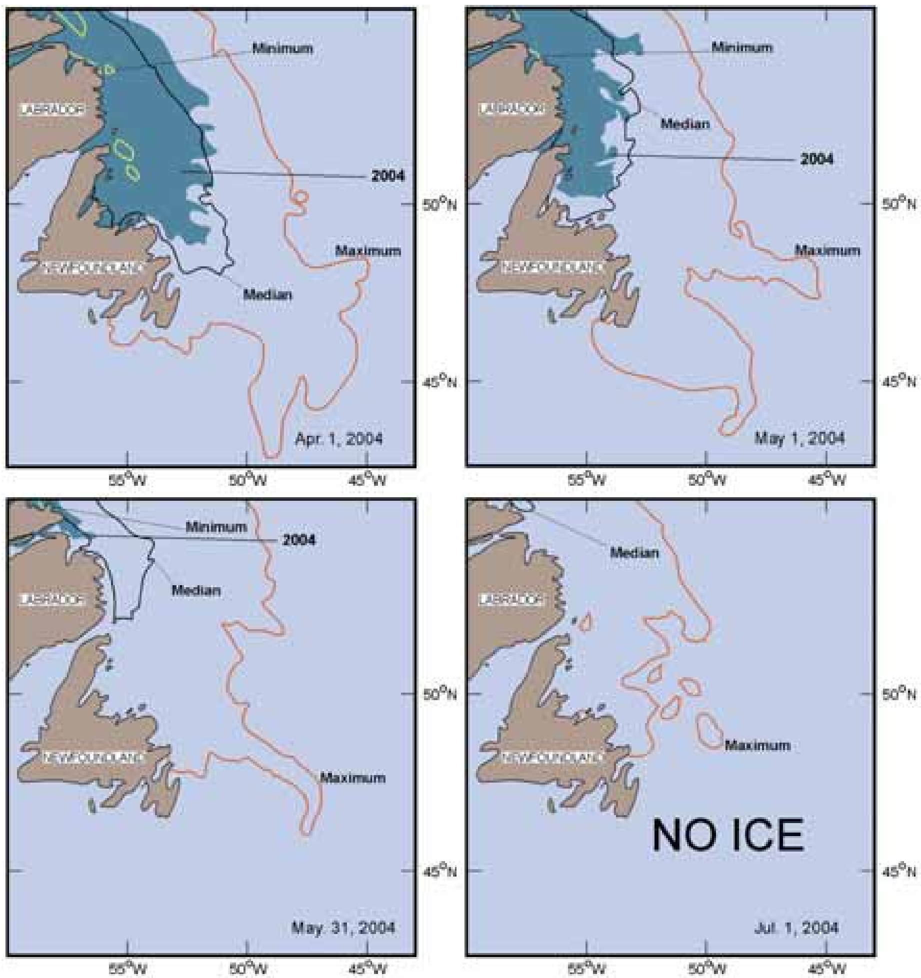

Fig. 10B. The location of the ice (shaded area) between April and July 2004 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

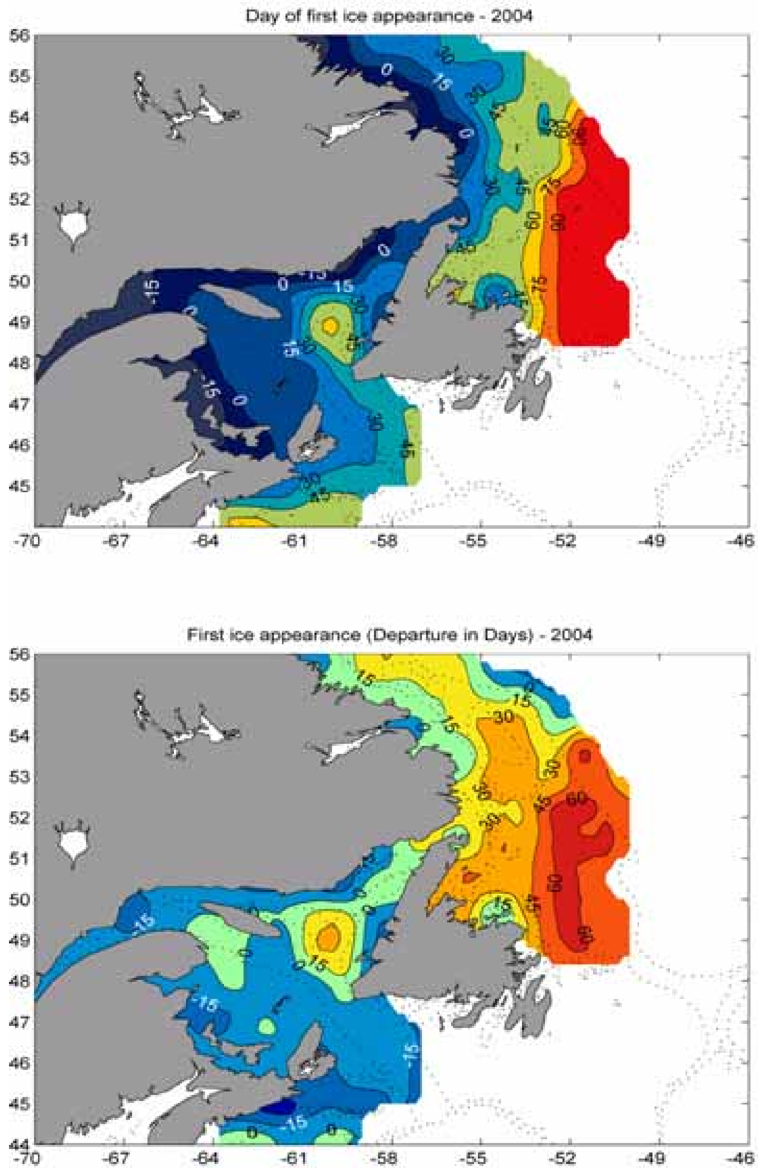

Fig. 11. The time when ice first appeared during 2004 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative (positive) anomalies indicate earlier than normal appearance.

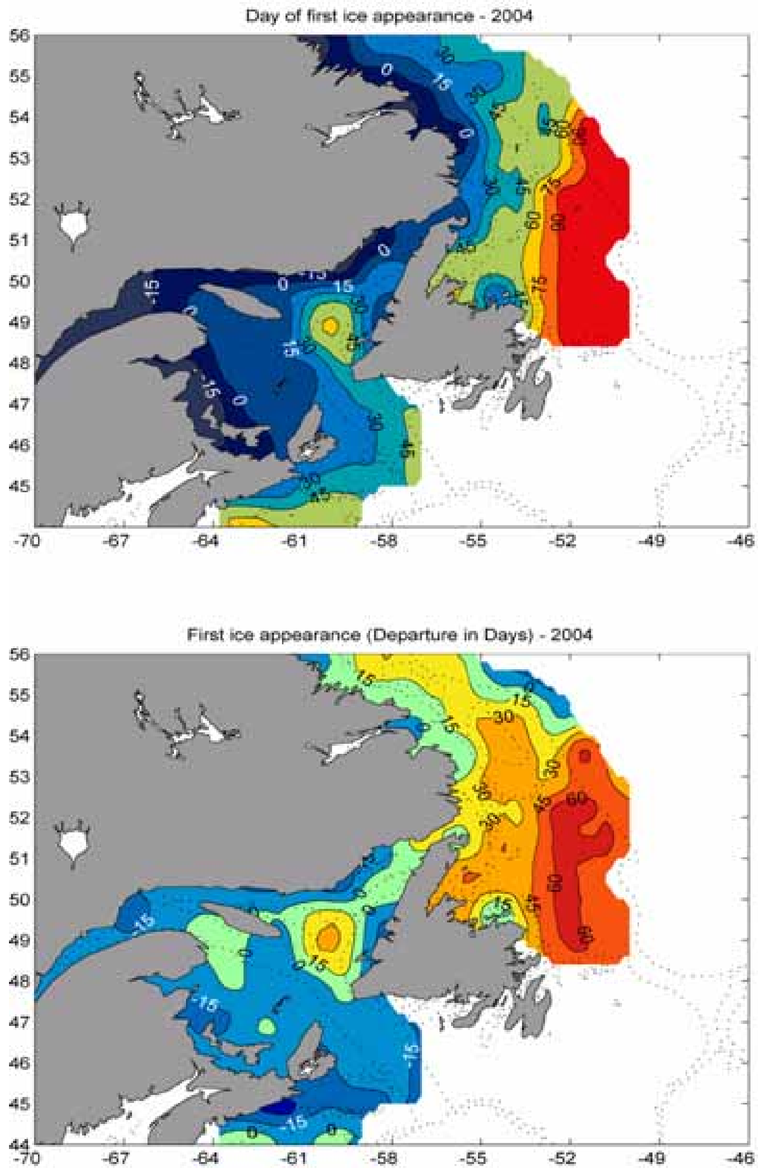

Fig. 12. The time when ice was last seen in 2004 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance.

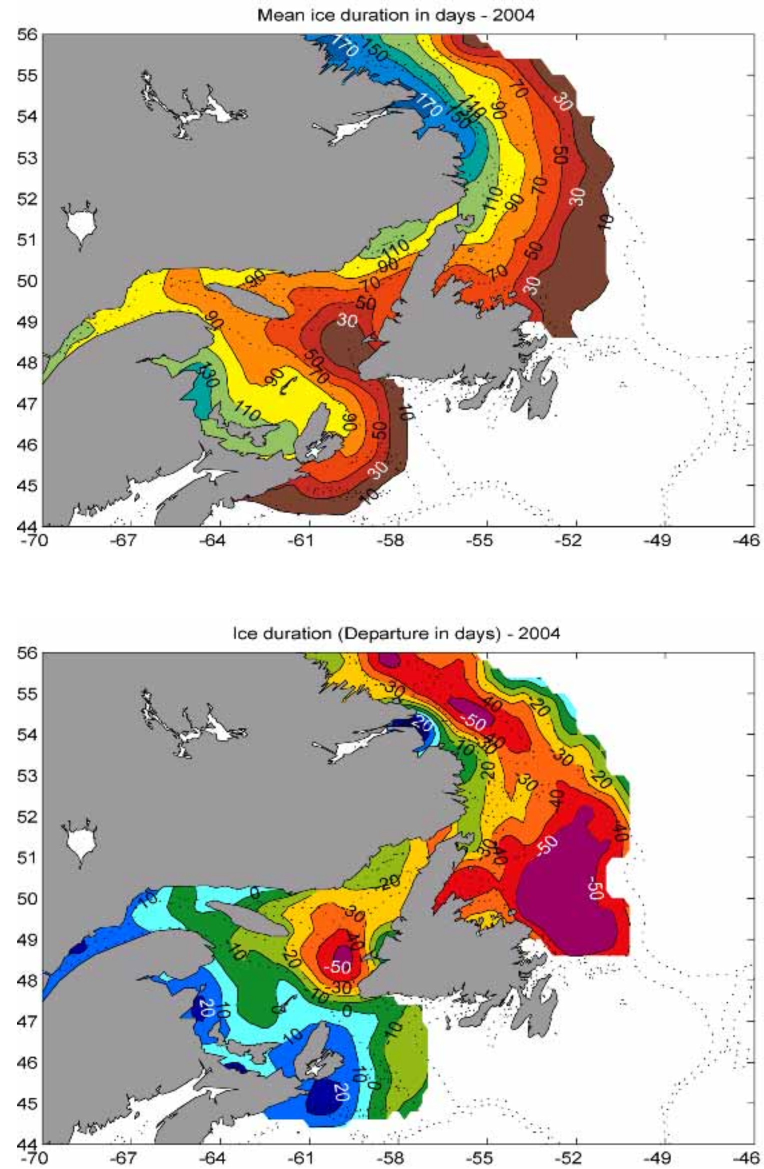

Fig. 13. The duration of ice in days (top panel) during 2004 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

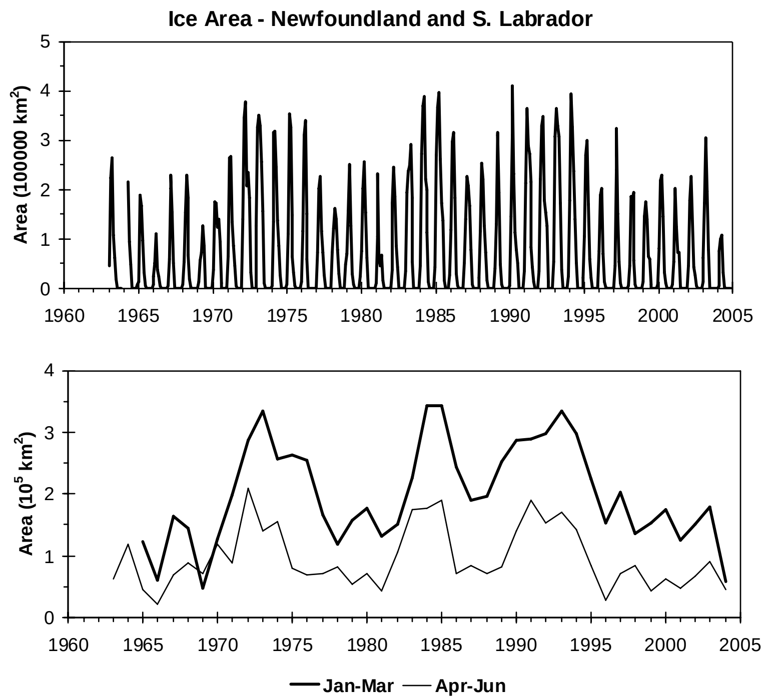

Fig. 14. (A)Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (bottom panel).

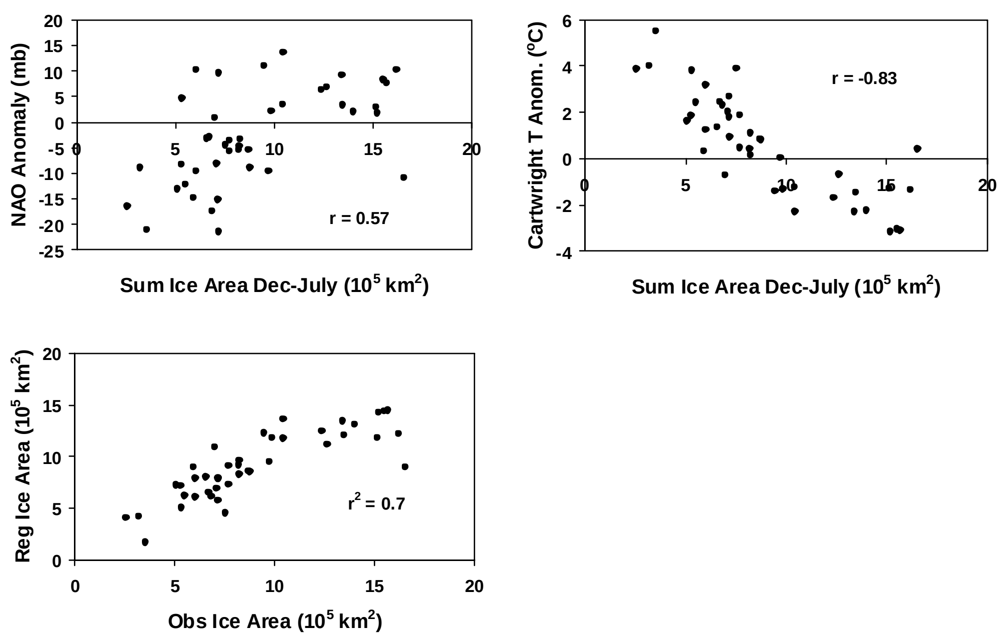

Fig. 14. (B) Comparison of time series of the December-July summed ice area off Newfoundland and Labrador between 45°N-55°N and the NAO anomaly and Cartwright December-March air temperature anomaly. The last panel shows the comparison of the observed, December-July ice cover and the cover calculated from the regression of ice cover on the NAO and Cartwright air temperature anomalies. For the linear regression, the independent variables were normalised by the standard deviations of the anomalies from the 1971-2000 period.

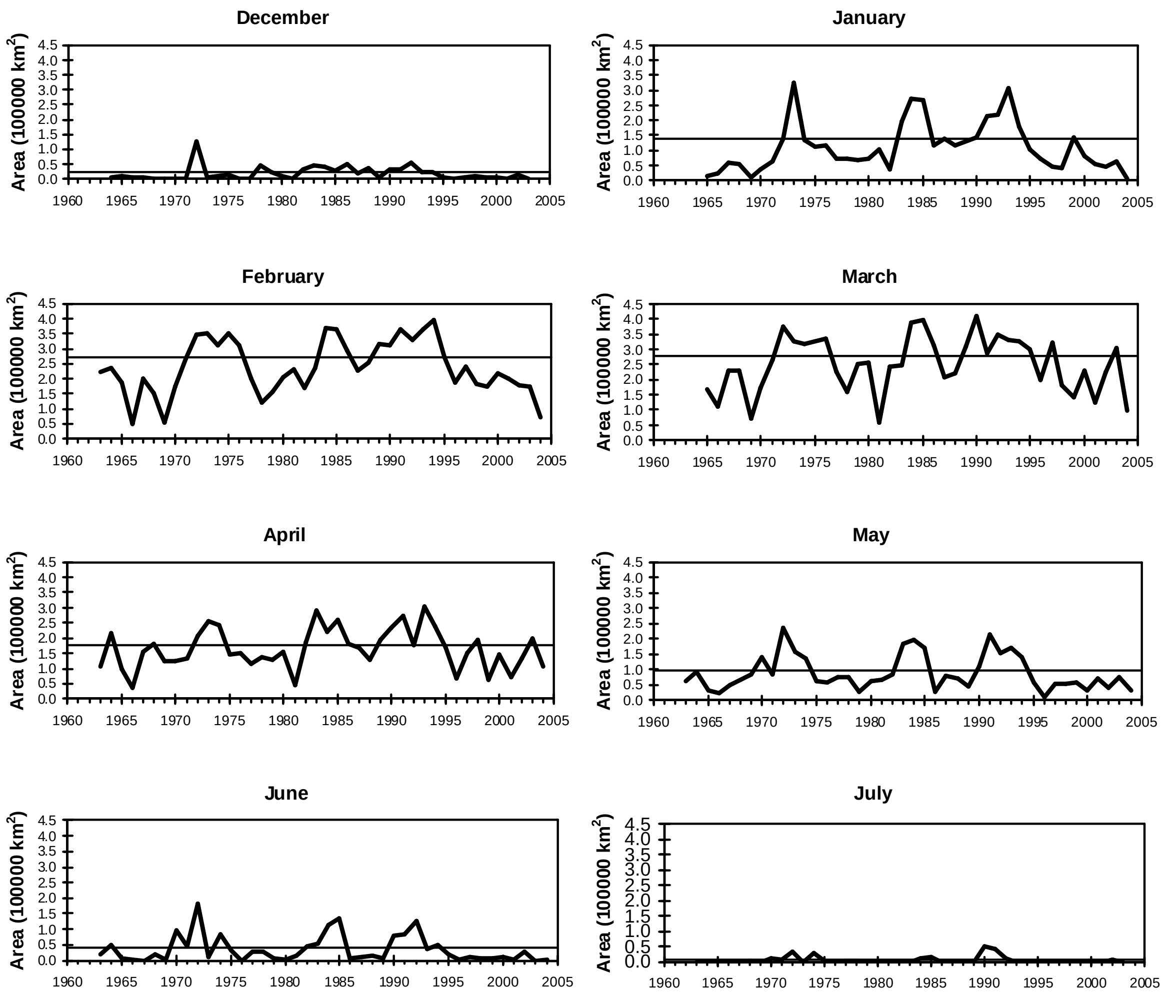

Fig. 15. The time series of ice area off Newfoundland and Labrador by month is presented. The horizontal lines represent the long-term (1971-2000) means.

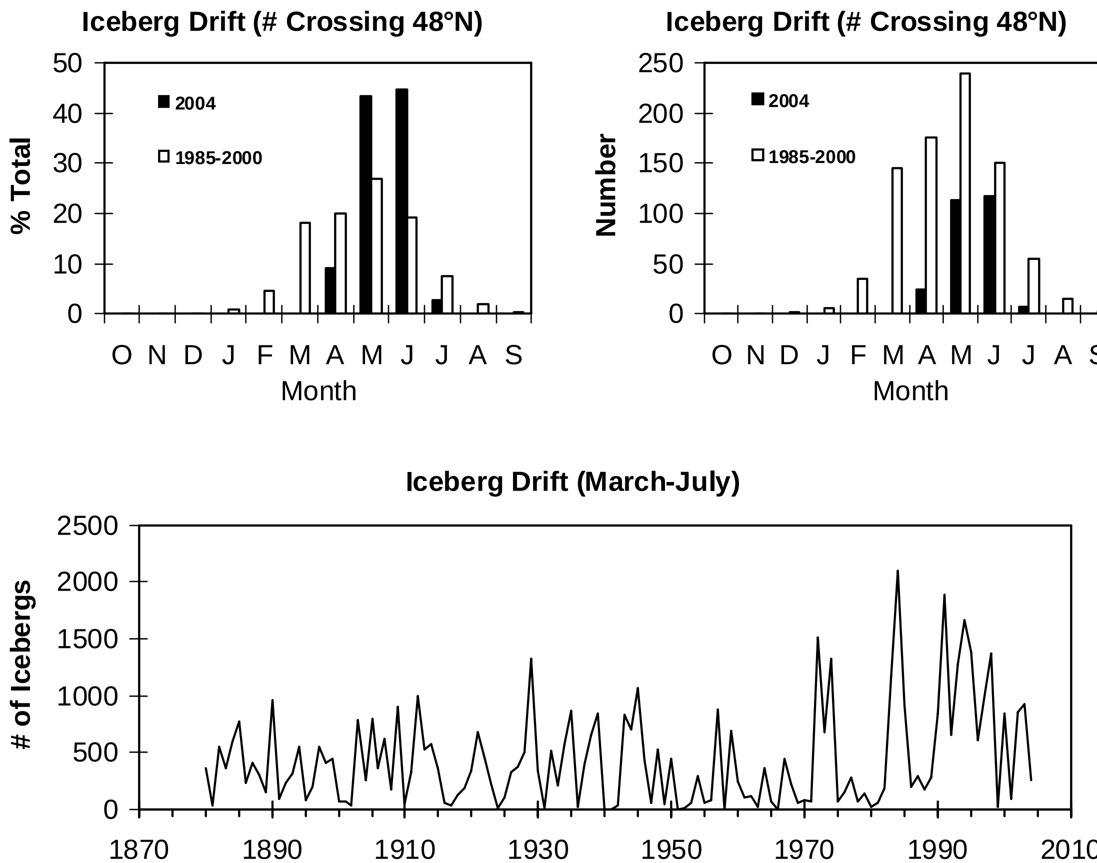

Fig. 16. The number of icebergs crossing south of 48°N during the iceberg season 2003/2004 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2000, the years SLAR has been used (top panel), and the time series of total number of icebergs observed during March to July (bottom panel).

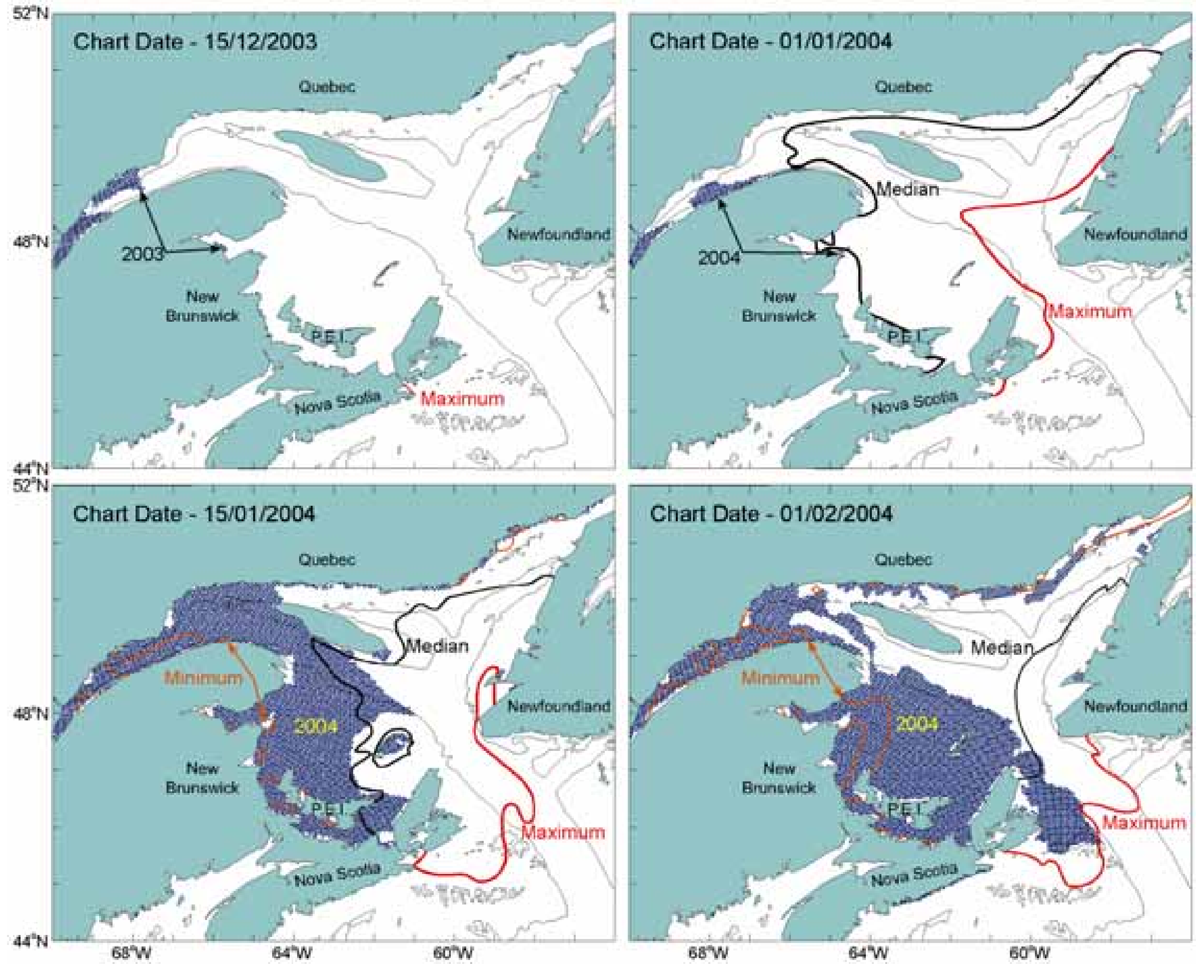

Fig. 17. The location of the ice (shaded area) between December 2003 and February 2004 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

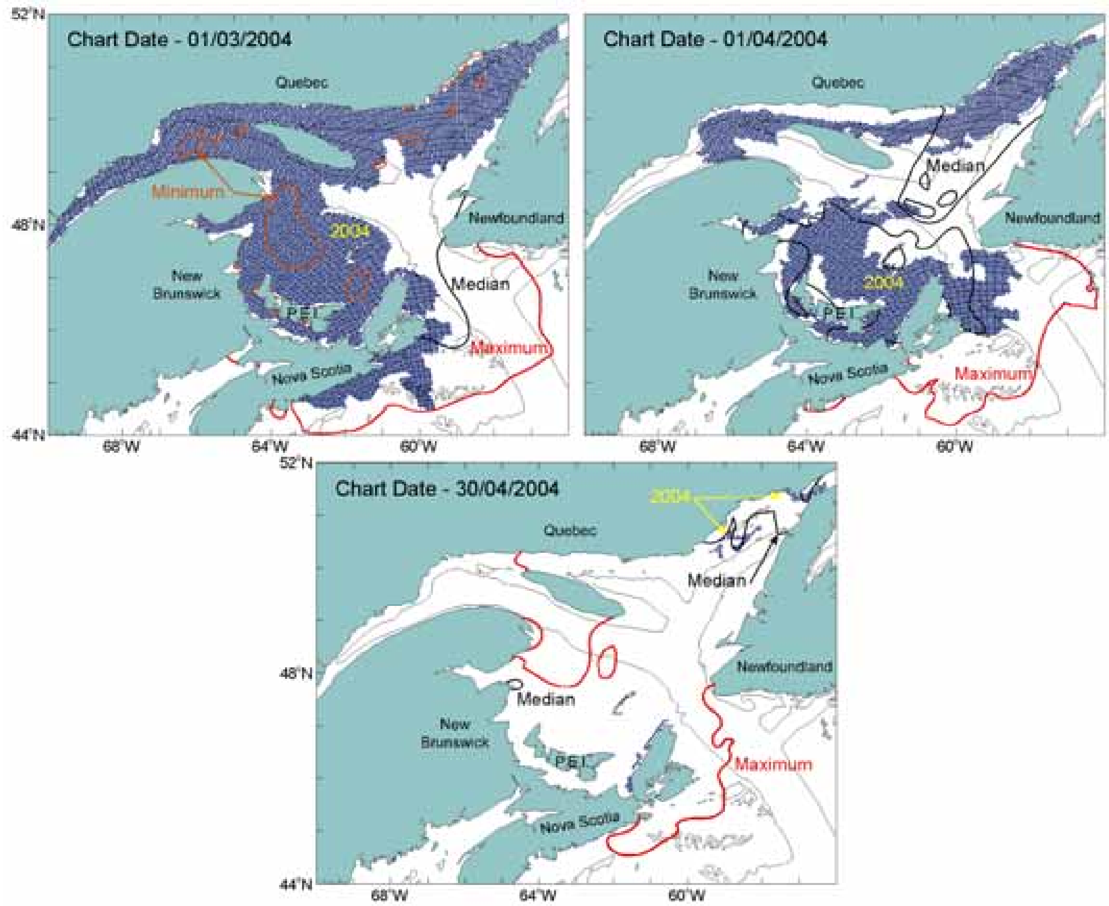

Fig. 17. Continued. The location of the ice (shaded area) between March and April 2004 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

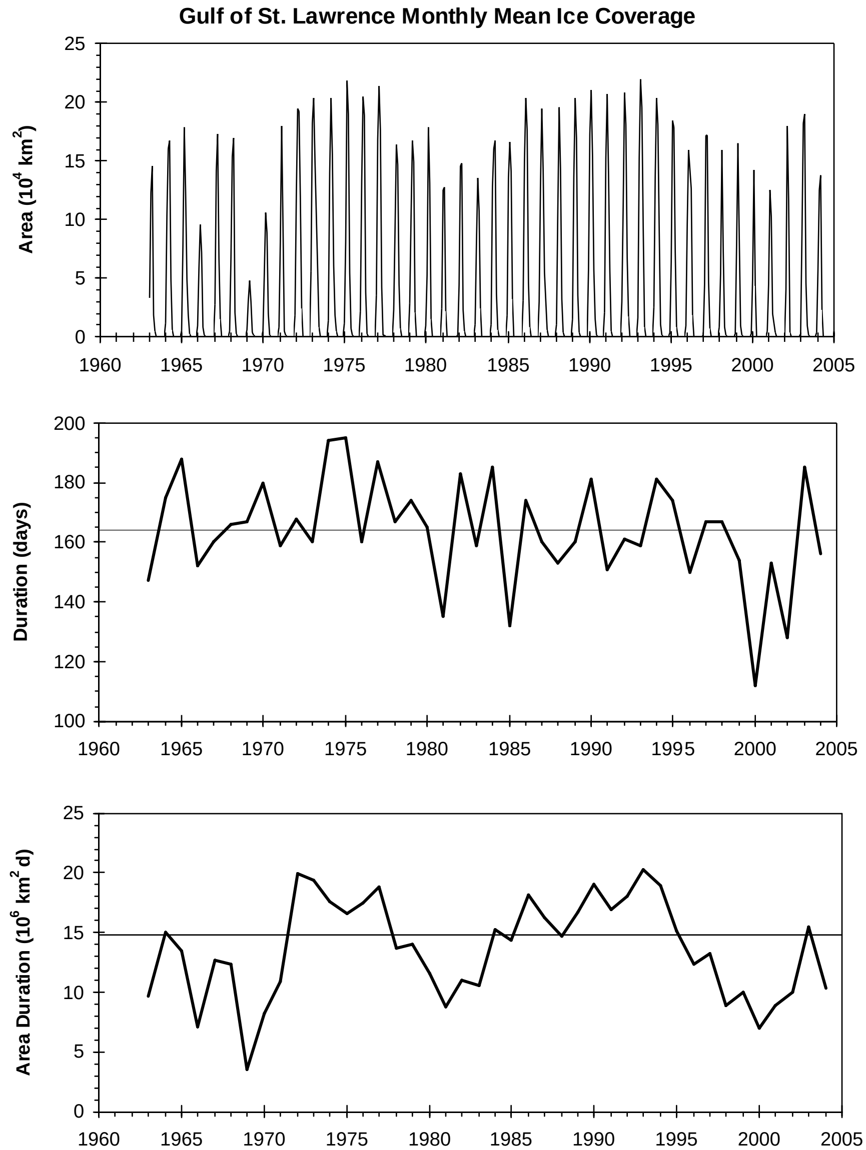

Fig. 18. For the Gulf of St. Lawrence, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

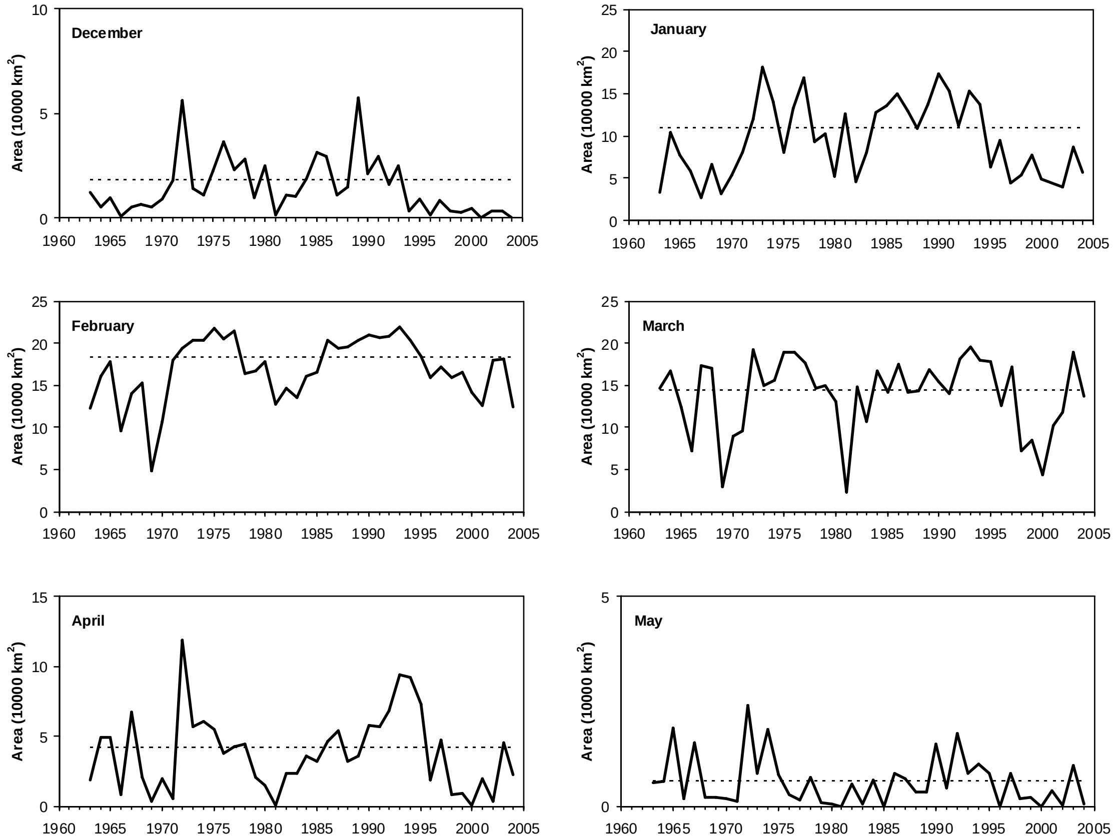

Fig. 18, continued. The time series of ice area in the Gulf of St. Lawrence by month is presented. The horizontal lines represent the 1971-2000 means.

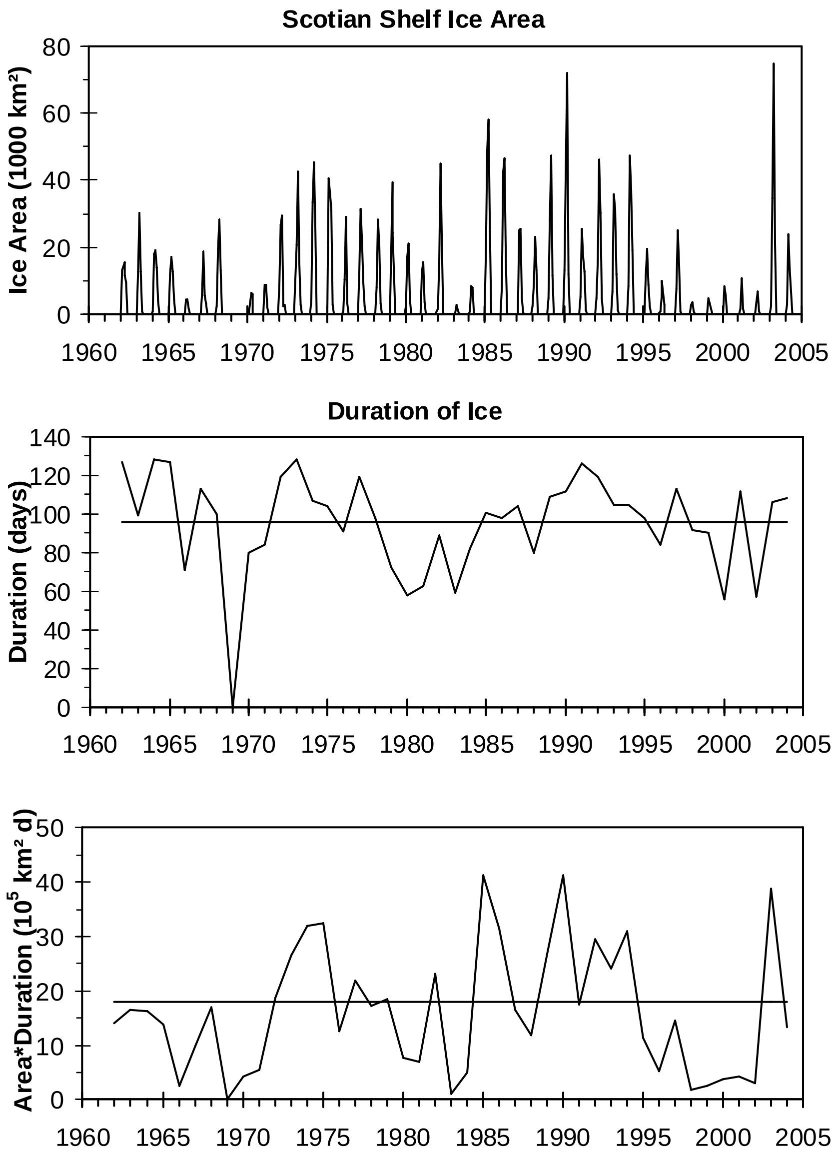

Fig. 19. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

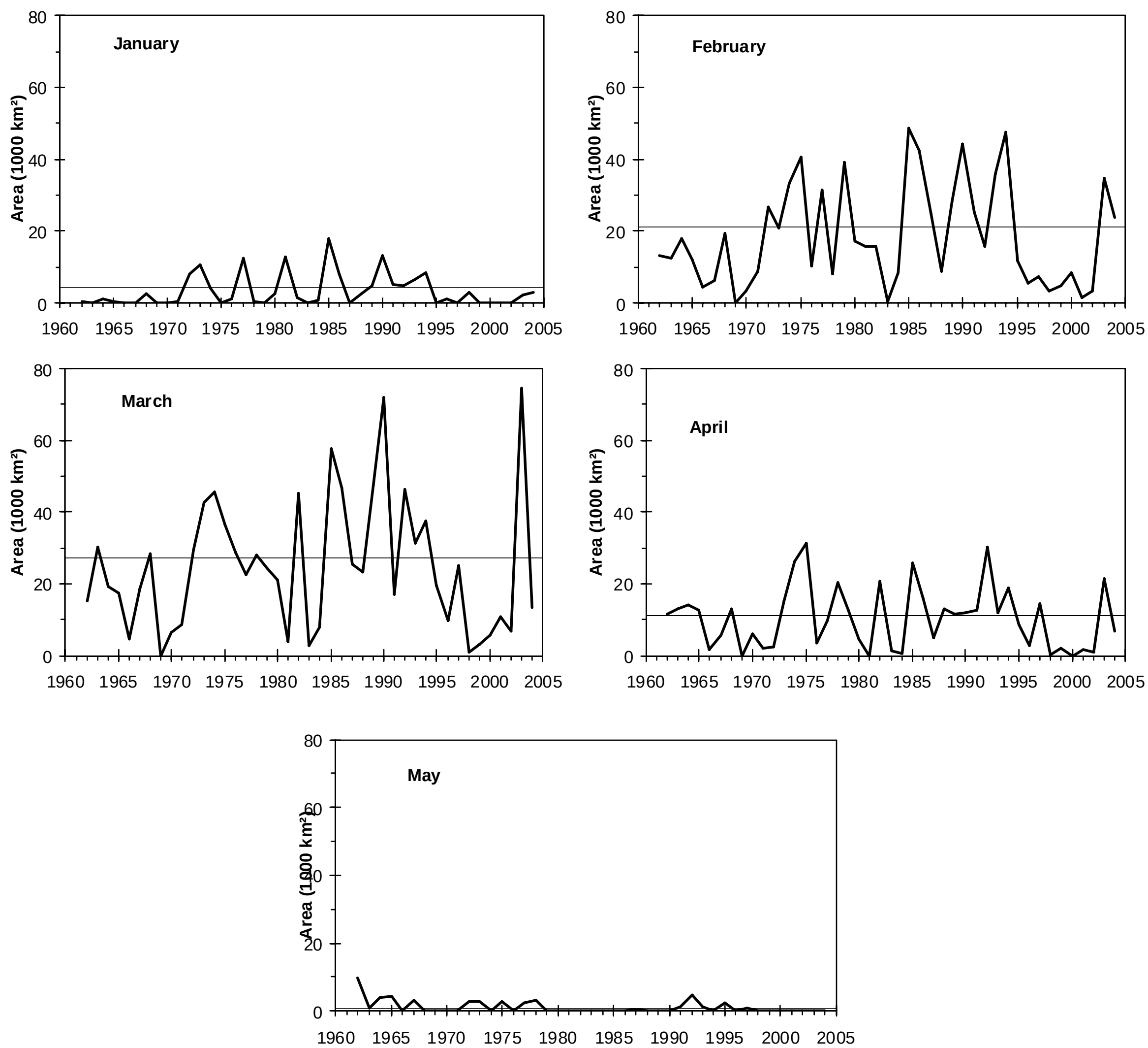

Fig. 20. The time series of ice area seaward of Cabot Strait by month is presented. The horizontal lines represent the 1971-2000 means.

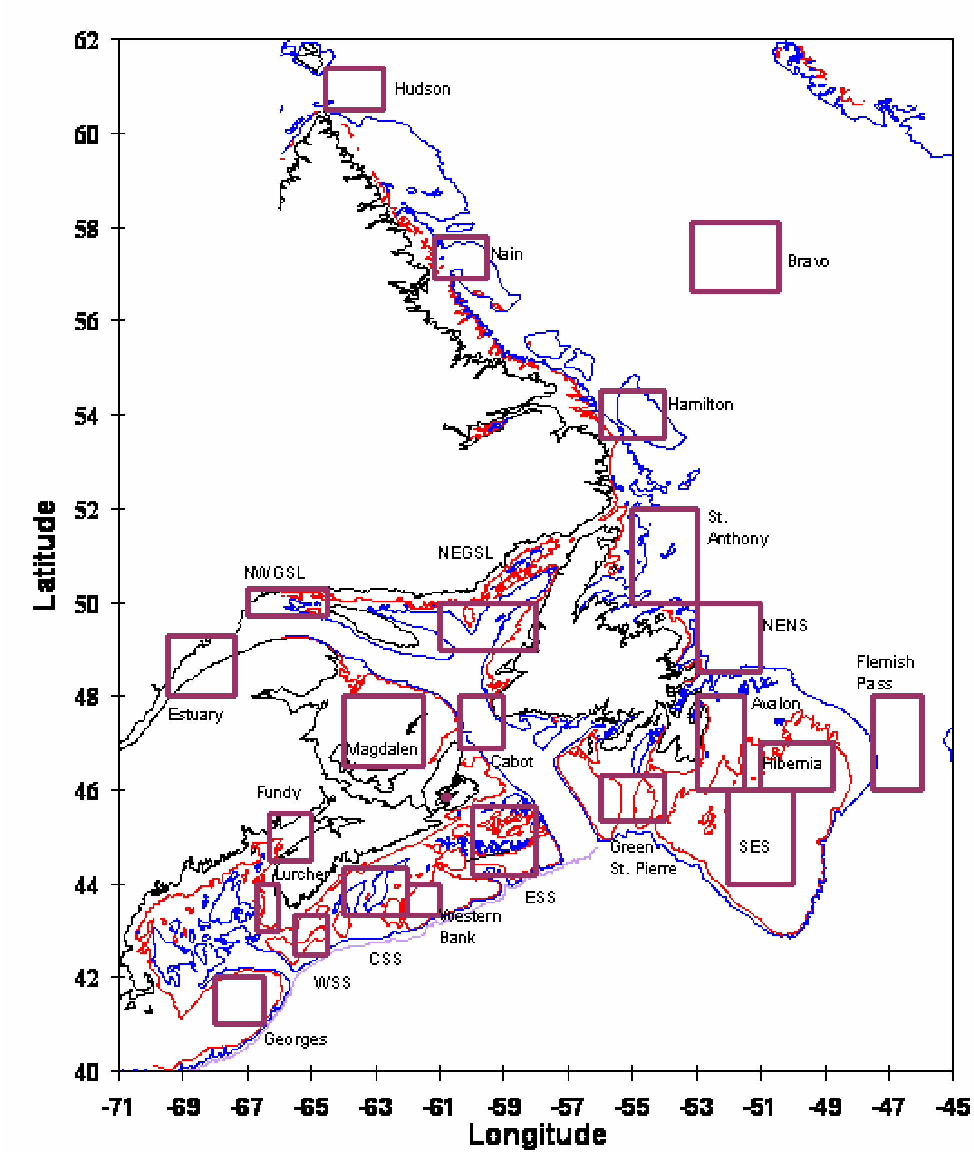

Fig. 21. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

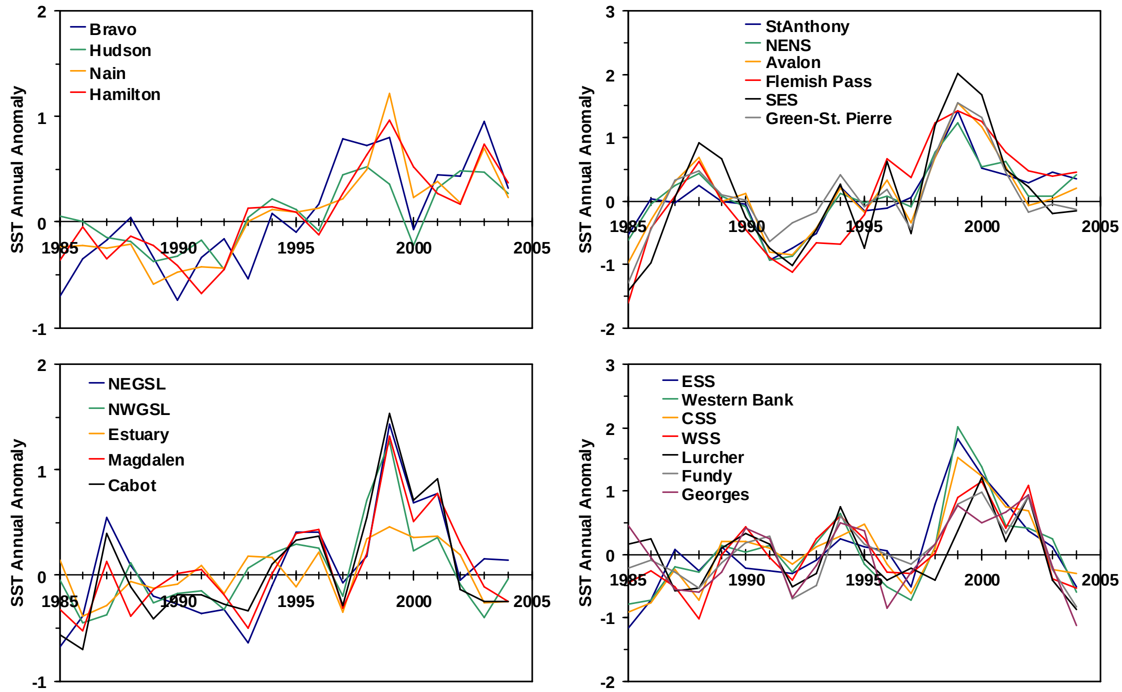

Fig. 22. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2004 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences Division at BIO. These values were adjusted upward by 0.6°C after a comparison between them and overlapping Pathfinder data.