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An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2005

Bilan des conditions météorologiques, des conditions de la glace de mer et des températures de surface de la mer au large de la côte Est du Canada en 2005

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ABSTRACT

A review of meteorological, sea ice and sea surface temperature conditions in the Northwest Atlantic in 2005 is presented. After 4 consecutive years of below normal values, the NAO index was above normal (~4.1 mb) in 2005. A positive NAO index implies stronger winds from the northwest, cooler air temperatures and enhanced heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. However, except for January, the observed air temperatures were warmer than normal over the Labrador Sea; furthermore, the NCEP winter wind anomalies were generally towards the north in the Labrador Sea, opposite to our expectations for a positive NAO anomaly. Annual average air temperatures were above normal by 0.7 to 2.2°C over the Labrador Sea and Shelf, the Newfoundland Shelf, the Gulf of St. Lawrence and the Scotian Shelf; Gulf of Maine air temperatures were about 0.4°C below normal. The Newfoundland-Labrador ice coverage was the 5th lowest in 43 years and its duration was generally less than average. The Gulf of St. Lawrence ice coverage in 2005 was also less than normal ranking 15th of 43 years; the ice season was the 6th shortest in 43 years. Both the ice coverage, 13th least in 44 years, and its duration, 17th shortest in 44 years, on the Scotian Shelf were below normal. Only 11 icebergs reached the Grand Banks in 2005, considerably less than the 262 in 2004, and the lowest since 1985, when more accurate counts became available. It was also the 7th lowest count in 126 years. The analysis of satellite data indicates a north-south gradient of sea surface temperatures similar to the air temperature distribution. In 2005, there were positive annual SST anomalies from Bravo in the Labrador Sea to the central Scotian Shelf of 0.6 to 1.3°C, with the exception of the St. Lawrence Estuary which had an anomaly of nearly 0°C. The western Scotian Shelf, Lurcher Shoals, Bay of Fundy and Georges Bank were colder than normal with annual SST anomalies of ~0°C to -0.9°C.

RÉSUMÉ

Le présent rapport fait le bilan des conditions météorologiques, des conditions de la glace de mer et des températures de la surface de la mer (TSM) dans l'Atlantique Nord-Ouest en 2005. Après quatre années consécutives de valeurs sous la normale, l'indice d'oscillation nord-atlantique (ONA) a été au-dessus de la normale (~4,1 mb) en 2005. Un indice ONA positif correspond à des vents plus forts soufflant du nord-ouest, à des températures de l'air plus fraîches et à une perte de chaleur plus élevée des eaux océaniques durant l'hiver dans la mer de Labrador et sur une partie du plateau continental de Terre-Neuve et du Labrador. Cependant, sauf pour les observations faites en janvier, les températures de l'air ont été plus chaudes que la normale dans la mer de Labrador; qui plus est, les anomalies des vents d'hiver du National Centre for Environmental Prediction (NCEP) ont été généralement observées vers le nord de la mer de Labrador, contrairement à ce à quoi nous nous attendions pour une anomalie ONA positive. Les températures de l'air annuelles moyennes dans les zones de la mer et du plateau du Labrador, du plateau de Terre-Neuve, du golfe du Saint-Laurent et du plateau néo-écossais ont été de 0,7 °C à 2,2 °C au-dessus de la normale, alors que les températures de l'air dans le golfe du Maine ont été d'environ 0,4 °C sous la normale. À Terre-Neuve et au Labrador, la couverture de glace a été la 5^{e} moins étendue en 43 ans et la saison des glaces a été généralement plus courte que la moyenne. Dans le golfe du Saint-Laurent, en 2005, la couverture de glace a été également inférieure à la normale, soit la 15^{e} moins étendue en 43 ans, et la saison des glaces a été la 6^{e} plus courte en 43 ans. Sur le plateau néo-écossais, la couverture de glace a été la 13^{e} moins étendue en 44 ans et la saison des glaces a été la 17^{e} plus courte en 44 ans, des valeurs qui sont toutes les deux inférieures à la normale. Seuls 11 icebergs ont atteint les Grands Bancs en 2005. Ce nombre est de beaucoup inférieur aux 262 dénombrés en 2004 et est le plus bas enregistré depuis 1985, année à partir de laquelle on commence à disposer de chiffres plus précis. Ce nombre est aussi le 7^{e} plus bas enregistré depuis 126 ans. L'analyse des données satellitaires indique un gradient nord-sud des TSM qui va de pair avec la répartition des températures de l'air. En 2005, on a observé des anomalies positives des TSM annuelles allant de 0,6 °C à 1,3 °C, et ce, depuis la station Bravo, située dans la mer de Labrador, jusqu'au centre du plateau néo-écossais, à l'exception de l'estuaire du Saint-Laurent où l'on a observé une anomalie de près de 0 °C. L'ouest du plateau néo-écossais, le haut-fond Lurcher, la baie de Fundy et le banc Georges ont été plus froids que la normale; on y a observé des anomalies de TSM annuelles allant de 0 °C à -0,9 °C environ.

INTRODUCTION

This paper examines the meteorological, sea ice and sea surface temperature conditions during 2005 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 for the Atlantic Zone Monitoring Program (AZMP). Environmental conditions are compared with those of the preceding year as well as with the long-term means. The latter comparisons are usually expressed as anomalies, i.e. deviations from their long-term mean or normal. Where the data permit, the long-term means are 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 Fisheries Oceanographic Committee, the Fisheries and Oceans group that requested and reviewed these overviews until 2005. 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). Warmer-than-normal temperatures prevailed over the entire region in 2005: 1-2^{o}C over the Labrador Sea, 1^{o}C over the Gulf of St. Lawrence and 0-1^{o}C over the Scotian Shelf-Gulf of Maine (Fig. 2A). The monthly maps of air temperature anomalies indicate that the Labrador Sea had generally warmer-than-normal temperatures throughout the year with the exception of January (Fig. 2B, C). March and April temperatures were as much as 7^{o}C above normal over the northern Labrador Sea. The Grand Banks featured above average temperatures except for January, May and June. Similar conditions prevailed for the Gulf of St. Lawrence and the Scotian Shelf. In addition to below normal air temperatures in January, May and June, the Gulf of Maine region had slightly below normal values in March.

Monthly air temperature anomalies for 2004 and 2005 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, 2005). In 2005, there was a systematic latitudinal variation from generally above normal temperatures in the north, Newfoundland and the Gulf of St. Lawrence to a mixture of slightly above and below normal temperatures at Sable Island, Boston and

Cape Hatteras.

The mean annual air temperature anomalies for 2005 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 (2.04^{o}C), Iqaluit (2.16^{o}C), Cartwright (1.81^{o}C), St. John's (0.98^{o}C), Magdalen Islands (1.11^{o}C), Sable Island (0.70^{o}C), Boston (-0.36^{o}C), Cape Hatteras (-0.33^{o}C). In 2004, the pattern was very similar with anomalies ranging from a high of 2.04^{o}C at Cartwright to a low of -0.51^{o}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 (SLP) 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 2005, relative to the 1961-1990 means, are shown in Fig. 5. Winter includes December 2004 to February 2005, spring is March to May, summer is June to August and autumn is September to November.

In winter, an extensive, above average SLP pattern dominated the North Atlantic with its centre (~10 mb above normal) located between eastern Canada and Europe. A below normal SLP anomaly (to 8 mb below normal) was situated northeast of Greenland. The winter pressure anomalies in 2005 indicate stronger-than-normal Iceland Low and Azores High, i.e. an increase in the strength of the large-scale atmospheric circulation compared to 2004.

The spring of 2005 featured a negative SLP anomaly (minimum about -5 mb) in the central North Atlantic giving way to a positive anomaly centred between Greenland and Iceland with strong zonal gradients between the two features. This would result in a weaker-than-normal Iceland Low and Azores High.

The pressure anomaly field during the summer of 2005 featured a weak negative anomaly (minimum -1 mb) south of Greenland. In the autumn, the pattern was dominated by an intense positive anomaly over Greenland (to ~6 mb).

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 2005, the NAO index was above normal (4.1 mb) for the first time since 2000, a large change from the -9.0 mb anomaly in 2004 (Fig. 6). If we order the anomalies from negative to positive, 2005 ranks 81st of 109 years and was 0.47 standard deviations above normal based on the statistics for 1971-2000. As indicated, a positive NAO is usually accompanied by below normal air temperatures over the Labrador Sea in winter. This is not consistent with the December 2004 to February 2005 air temperature anomalies which ranged from -0.27 (Iqaluit, the only negative value) to 1.66 (Nuuk) for the 5 northern sites (Fig. 4). Nor is it consistent with the March to June temperatures at the 3 northenmost sites where monthly anomalies were more than 6^{o}C above normal in March at Nuuk and Iqaluit, and 3.5^{o}C above normal in May at Cartwright.

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 2005 were to the north and northeast over the Labrador Sea and Shelf (Fig. 8). Over Atlantic Canada, winter wind anomalies were predominantly from the east (Fig. 9). This wind anomaly pattern is more consistent with the winter air temperatures over the region than the simple representation of the wind field by the NAO anomaly. The anomalous winds in the spring were weak and generally from the southeast in the Labrador Sea; in the southern area, the wind anomalies were stronger than over the Labrador Sea and were generally from the northeast. The pattern changed in summer, with wind anomalies from the west dominating the northern region; while in the south, the anomaly pattern was very weak with wind anomalies mostly from the north. The autumn wind anomalies reverted to the spring pattern over the Labrador Sea, i.e. predominantly from the southeast; over Atlantic Canada the anomalous winds were generally from the south to the southeast.

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 2005 values to obtain anomalies.

Newfoundland and Labrador

Sea-Ice. At the beginning of 2005, sea ice was found off the southern Labrador coast south to the mouth of the Strait of Belle Isle (Fig. 10A), coverage equal to the long-term median. By mid-January, ice had spread farther south past the mouth of the Strait with some ice near the shore of the northern peninsula, again close to the long-term median coverage. The distribution continued to advance and by February 1 reached Cape Bonavista. Thus the southern extent of the ice exceeded the median coverage but the offshore extent was less than the median. By March 1, ice coverage was slightly less than the long-term median except off Labrador. By the first of April, the ice had retreated to the coastal areas of Newfoundland, coverage substantially less than the long-term median (Fig. 10B). On May 1, the most southerly ice extended just beyond the mouth of the Strait of Belle Isle, slightly less than the median. A small amount of ice was present on May 20 mostly in Groswater Bay, in the northwest corner of the area; by June all ice had vanished from the analysis region.

Ice appeared along the Labrador coast and south of Belle Isle Strait by January 1, 2005 (day 0, Fig. 11); it gradually spread southward to Cape Bonavista late January (day 30). It reached the northern Avalon Peninsula by late February (day 60). Relative to the long-term mean, ice typically appeared at its normal time over most of the region from Labrador to Trinity Bay (Fig. 11). It occurred later than usual in part of the offshore region marked by the 1000 m isobath and on northern Grand Bank. Ice began to disappear from the area just north of Grand Bank in mid- March (day 75; 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 most northern part of the analysis region until the end of May (day 150). Over much of the Labrador Shelf, it disappeared about 2 weeks to 1 month earlier than normal (negative anomaly). Ice disappeared at the average time (0 contour) in the region from Fogo Island to the Avalon Peninsula.

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. In 2005, the duration ranged from <30 days north of Grand Bank to over 170 days along the Labrador coast (Fig. 13). The pattern is in fact quite similar to the one in 2004 for the Labrador Shelf but the duration was longer on the NE Newfoundland Shelf. Except for the outer Labrador Shelf, Groswater Bay and Notre Dame to Trinity Bay, the ice duration was less-than-normal over most of the Newfoundland and Labrador Shelves by typically 10-20 days and 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 2005 was greater than in 2004, which was one of the years with the lowest ice coverage on record (Fig. 14A). For the total ice cover from December to July (mean coverage ~1,000,000 km^2), 2005 had the 5th lowest coverage (320,000 km^2) of the 43 years for which there are records. The 2005 coverage was 1.5 standard deviations below normal. The time series of monthly ice area show that the 2005 coverage was greater than that in 2004 for January to March, and less in April and May (Fig. 15). In summary, 2005 overall was one of the lightest ice years on the Labrador and Newfoundland shelves over the length of the record, 1963-2005.

The co-occurrence of the light ice year, higher than average air temperatures in the Labrador-Newfoundland region and a negative NAO anomaly in 2004 encouraged further analysis of the relationships among these variables. This analysis has been extended by incorporating the 2005 data. The linear regressions of the ice area summed for the December to July period on the December-March air temperature anomaly at Cartwright (r=-0.83) and the NAO index ((r=0.54) show strong relationships, little changed from 2004 (Fig. 14B). The multiple linear regression accounts for 70% of the variability of the integrated sea ice cover. We note Cartwright air temperature alone accounts for nearly the same amount of variance; however, linear or multiple regression alone cannot determine the cause of the variability. The fits satisfy a mathematical criterion not a dynamical one.

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 1985-2005 period is considered to have reliable SLAR measurements. During the 2004/2005 iceberg season (October 2004 to September 2005), a total of 11 icebergs were detected south of 48^{o}N, a dramatic decrease from the 262 recorded in 2004. The 11 bergs in 2004/05 season is the lowest total in the 1985-2005 period; only 1999 when 22 bergs were sighted is comparable. The first icebergs of 2005 were seen south of 48^{o}N in March. The monthly totals for March to May were 9, 1and 1 (Fig. 16). For 1890-2005, 2005 had the 7th lowest number of icebergs in the 126 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 2004-2005 winter season are shown in Fig. 17. Ice first appeared in mid-December as very small patches in the Estuary. Over the next month, coverage increased slowly but was substantially less than the median. Between mid-January and early February, most of the northwestern and northeastern Gulf and the Magdalen Shallows were covered with ice; the coverage approached the long-term median for February 1. By March 1, ice had moved through Cabot Strait into Sydney Bight and was encroaching on the eastern Scotian Shelf. The overall coverage was slightly less than the long-term median. Ice was confined mainly to the Magdalen Shallows by April 1 and had small, scattered patches in the northern Gulf. Only a minute patch remained at the mouth of the Strait of Belle Isle on May 1.

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 30 days later than normal in the rest of the Gulf. Figure 11 implies that all areas of the Gulf were ice-covered in 2005. However, this can arise because of the coarse resolution of the ice grid (0.5^o latitude by 1^o longitude); any ice found in a grid rectangle counts for the entire rectangle. The last presence of ice varied from mid-March to mid-April; this was about normal for the entire Gulf with the exception of the northeastern region where the ice left roughly 15 d earlier than normal (Fig. 12). Ice duration varied from less than 30 to 130 d (Fig. 13); ice duration was less than the long-term mean in a broad area from western Cabot Strait to Anticosti to the north shore of the Gulf. Duration in the Estuary and the Magdalen Shallows was from 0 to 10 d longer than normal.

We have estimated the monthly mean area of the Gulf covered by ice (Fig. 18). The time series shows that in 2005 the peak areal coverage increased by an average monthly value (January-April) of about 2,600 km^2 compared to 2004. The product of Ice cover times the duration for the entire 2005 ice season was about 23% smaller than the 1971-2000 average, 0.9 standard deviations below normal. The 2005 ice season had the 15th least (ice cover)*duration in 43 years. Estimates of the duration of ice showed that on average, the 2005 season was the 6th shortest in 43 years, it was 18 d shorter than the 1971-2000 average duration, 0.9 standard deviations below normal. To summarize, 2005 featured below normal ice coverage and a 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 2005, ice first appeared seaward of the Strait during mid- to late January, which is the normal time for first appearance (Fig. 11). On January 27th, Ice Central reported ice in the very nearshore (within ~10 km) along the Scotian Shelf from Cabot to Halifax. Concentrations from Canso to Halifax were as high as 6 tenths but were less than 1 tenth from Cabot to Canso. By the end of January, 6 tenths ice cover was reported to just past 65°W, again confined to a narrow coastal band. Concentrations in this band decreased to less than 1 tenth by February 4th. The next incursion of ice concentrations greater than 1 tenth south of Sydney Bight did not occur until February 22. By the end of March, ice concentrations greater than 1 tenth had moved no farther westward than Canso. The duration of ice cover on the Scotian Shelf was normal or slightly longer than normal in the coastal zone from Cabot Strait to Halifax and shorter than normal over the Laurentian Channel and eastern Scotian Shelf (Fig. 13). The overall duration of ice in 2005 was the 17th shortest in 44 years, 4 d or 0.2 standard deviations shorter than normal (Fig. 19, 20). The ice coverage on the Scotian Shelf was below normal in 2005, the 13th least coverage in 44 years.

Remotely-Sensed Sea Surface Temperature

We maintain the 9 km resolution Pathfinder 4 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 there was 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 4 dataset runs to June, 2003 when this version of the data series was terminated. 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 Oceanography Section (BOS). Comparison of the Pathfinder and BOS temperatures during the common time period led to a conversion given by the equation SST(Pathfinder) = 0.976*SST(BOS)+0.46 with an r^2=0.98. We adjusted the BOS observations to bring them in line with the longer Pathfinder 4 series.

Annual anomalies for 23 subareas, stretching from the Labrador Sea to the Gulf of Maine (Fig. 21), were determined from the averages of monthly anomalies and are shown in Fig. 22 arranged from north to south. In 2005, there was a general pattern of positive anomalies in the regions from Bravo in the Labrador Sea to the central Scotian Shelf of 0.6 to 1.3^{o}C, with the exception of the St. Lawrence Estuary which had an anomaly of nearly 0^{o}C. The western Scotian Shelf, Lurcher Shoal, Bay of Fundy and Georges Bank were colder than normal with annual SST anomalies from ~0^{o}C to -0.9^{o}C.

SUMMARY

After 4 consecutive years of below normal anomalies, the NAO index was above normal (~4.1 mb) in 2005. A positive NAO index implies stronger winds from the northwest, cooler air temperatures and enhanced heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. However, except for January, the air temperatures were warmer than normal over the Labrador Sea; furthermore, the NCEP winter wind anomalies were generally towards the north in the Labrador Sea, opposite to our expectations for a positive NAO anomaly. Annual average air temperatures were above normal by 0.7 to 2.2^{o}C over the Labrador Sea and Shelf, the Newfoundland Shelf, the Gulf of St. Lawrence and the Scotian Shelf; Gulf of Maine air temperatures were about 0.4^{o}C below normal. The Newfoundland ice coverage was the 5th lowest in 43 years and its duration was generally less than average. The Gulf of St. Lawrence ice coverage in 2005 was also less than normal ranking 15th of 43 years; the ice season was the 6th shortest in 43 years. Both the ice coverage, 13th least in 44 years, and its duration, 17th shortest in 44 years, on the Scotian Shelf were below normal. Only 11 icebergs reached the Grand Banks in 2005, considerably less than the 262 in 2004, and the lowest since 1985, when more accurate counts became available. It was also the 7th lowest count in 126 years. The analysis of satellite data indicates a north-south gradient of sea surface temperatures similar to the air temperature distribution. In 2005, there were positive annual SST anomalies from Bravo in the Labrador Sea to the central Scotian Shelf of 0.6 to 1.3^{o}C, with the exception of the St. Lawrence Estuary which had an anomaly of nearly 0^{o}C. The western Scotian Shelf, Lurcher Shoals, Bay of Fundy and Georges Bank were colder than normal with annual SST anomalies of ~0^{o}C to -0.9^{o}C.

A graphical summary of many of the time series already shown indicates that the periods 1972-1975 and 1985-1993 were predominantly colder than normal and 1998-2005 was warmer than normal (Fig. 23, upper panel). In this figure, annual anomalies based on the 1971-2000 means have been normalized by dividing by the 1971-2000 standard deviations for each variable. For the sea surface temperature series, the long-term means and standard deviations were calculated using all available data. The results are displayed as the number of standard deviations above (red) and below (blue) normal. Since negative NAO and ice anomalies generally represent warmer than normal conditions, the signs of these series were reversed before plotting. During predominantly warmer or colder than normal periods, there are sometimes systematic exceptions to the overall pattern. For example, from the western Scotian Shelf to Georges Bank, sea surface temperatures from 2003 to 2005 were below normal whereas most other variables were above normal. The mosaic plot can be summarized as a combination bar and line-scatter plot (Fig. 23, lower panel). The bar components are colour coded by variable so that for any year the contribution of each variable can be determined and systematic spatial variability seen. The height of each variable's contribution to the bar depends on its magnitude. The positive components are stacked on the positive side, the negative components on the negative side. The sum of the normalized anomalies (difference between the positive and negative stacks) is shown as a black line connecting grey circles. (Note that the sum for the SST variables for 1970-1984 was estimated from the linear regression between the SST sum and the sum of the other variables for the 1985-2005 period (r^2=0.73).) This is a measure of whether the year tended to be colder or warmer than normal and can serve as an overall climate index. The cold periods of 1972-1975 and 1985-1993 and the warm period of 1998-2005 are apparent. Systematic differences from the overall tendency as noted above are also apparent. This last plot is an attempt to derive an overall climate index for the area, a draft index you might say. In the manifestation presented in Fig. 23, it is heavily weighted towards SST with 14 series; there are 3 ice, 5 air temperature and the NAO series. It may be that some of the series having the same variable should be consolidated before combining with others. We shall continue to experiment with developing an overall climate index over the next year.

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

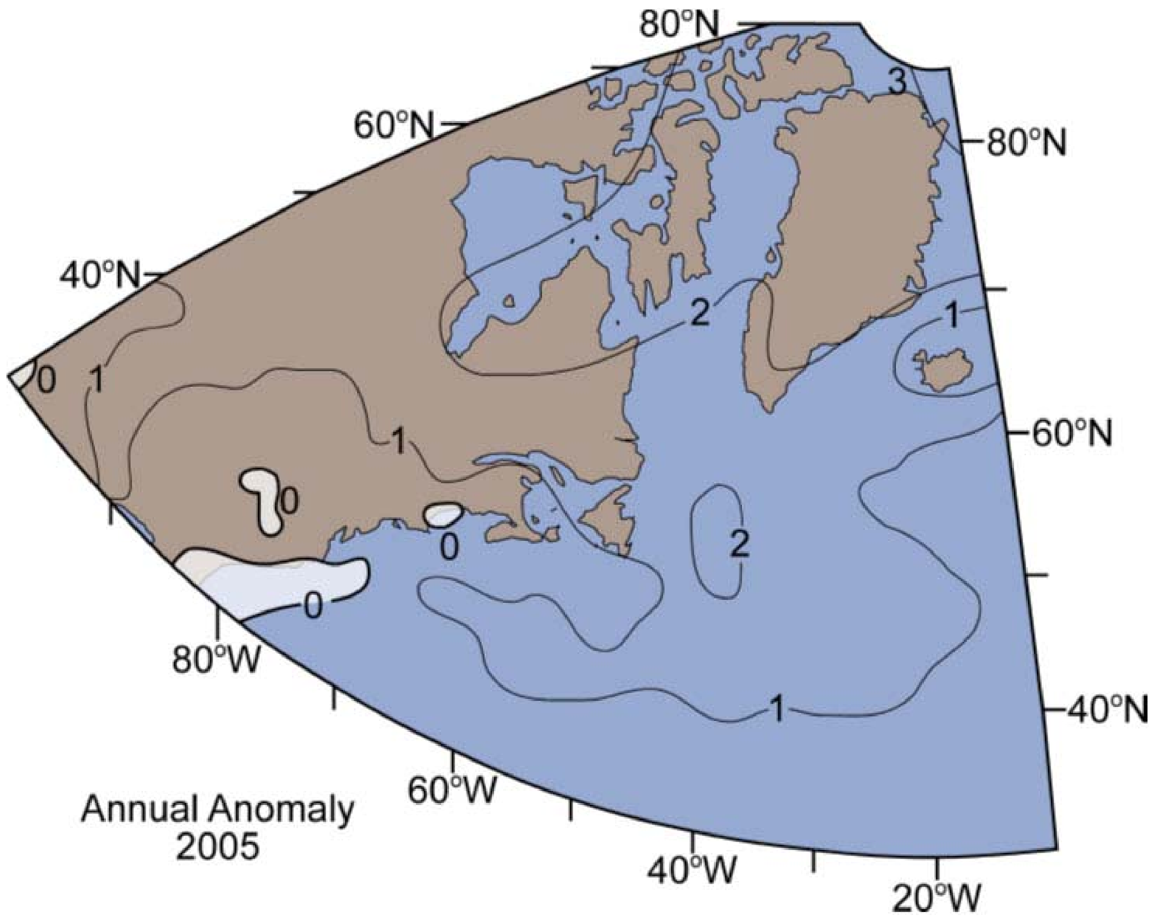

Fig. 2A. The 2005 annual anomaly of air temperature (ºC) over the Northwest Atlantic relative to the 1961-1990 means. The light shaded areas are colder than normal. (Redrawn from Grosswetterlagen Europas).

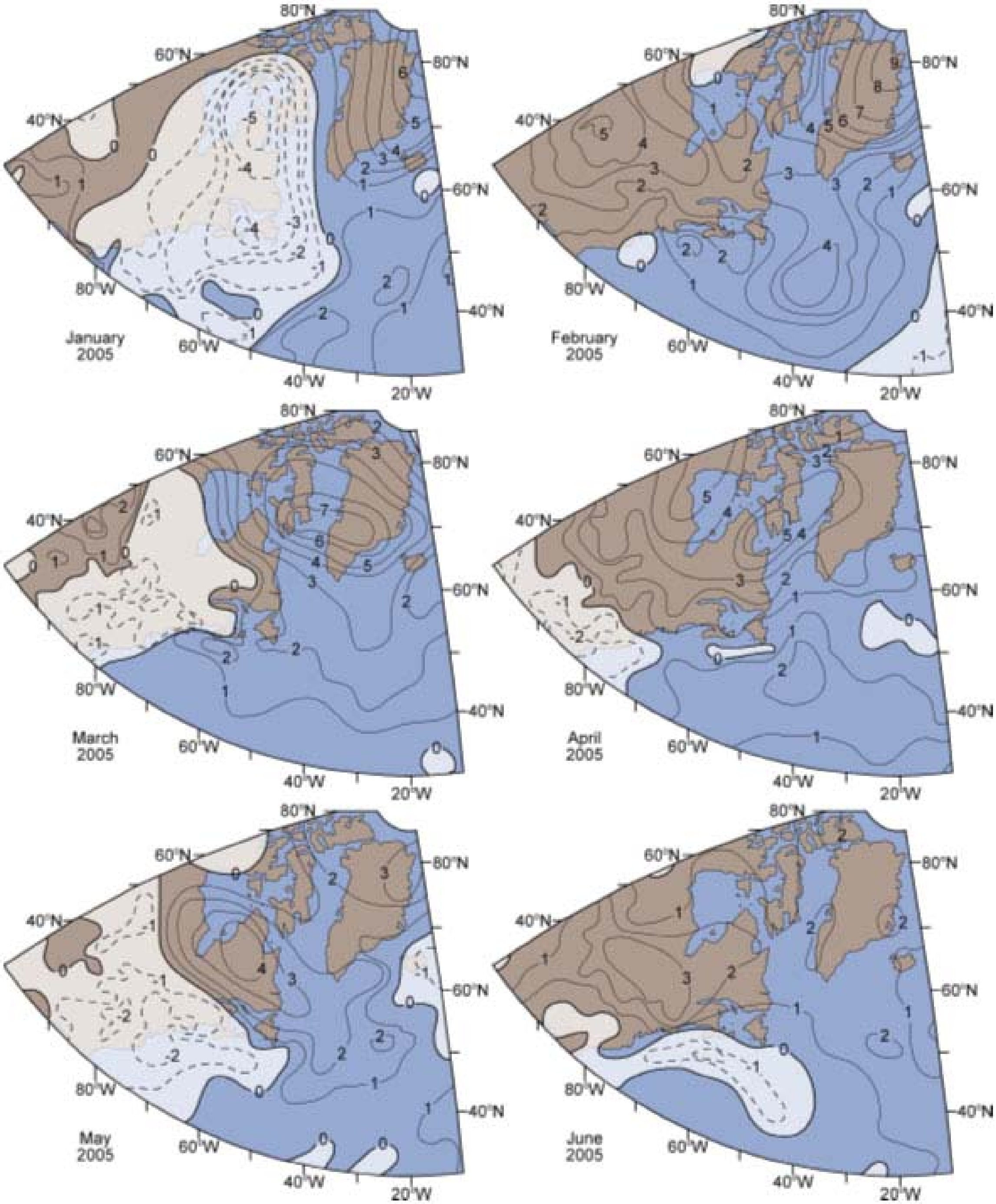

Fig. 2B. Monthly air temperature anomalies (°C) over the Northwest Atlantic from January to June of 2005 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

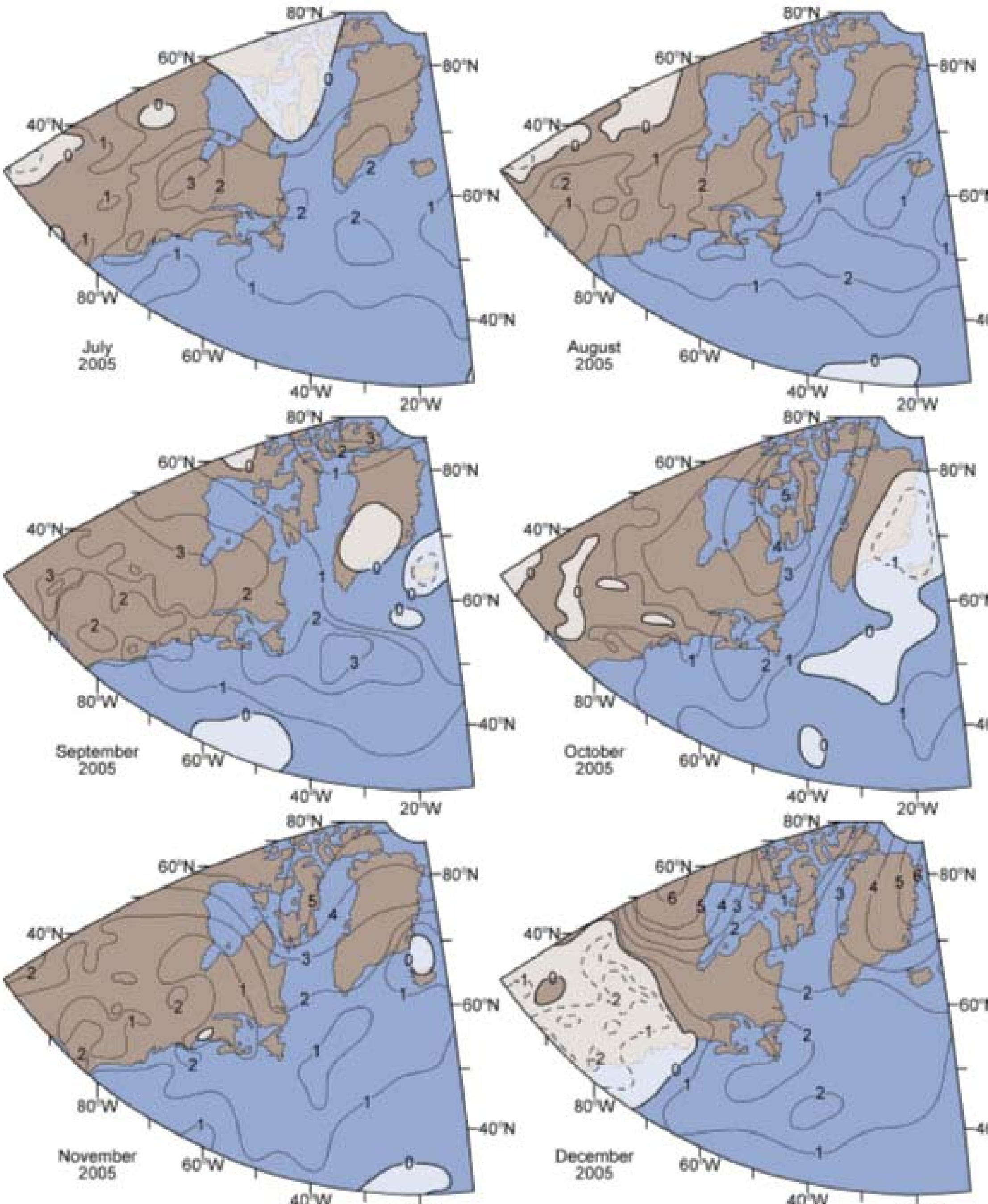

Fig. 2C. Monthly air temperature anomalies (^oC) over the Northwest Atlantic from July to December of 2005 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

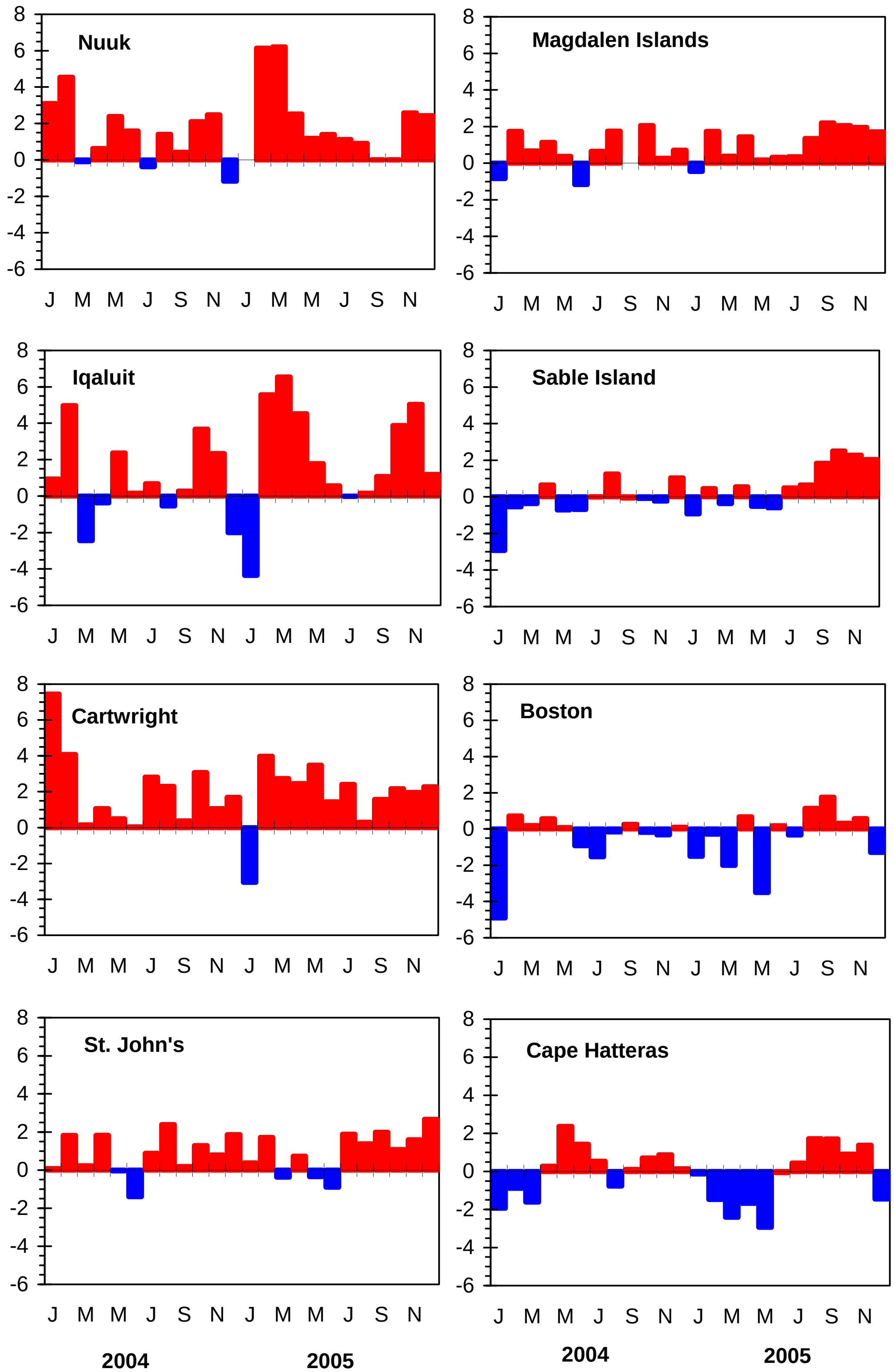

Fig. 3. Monthly air temperature anomalies in 2004 and 2005 at selected coastal sites (see Fig. 1 for locations).

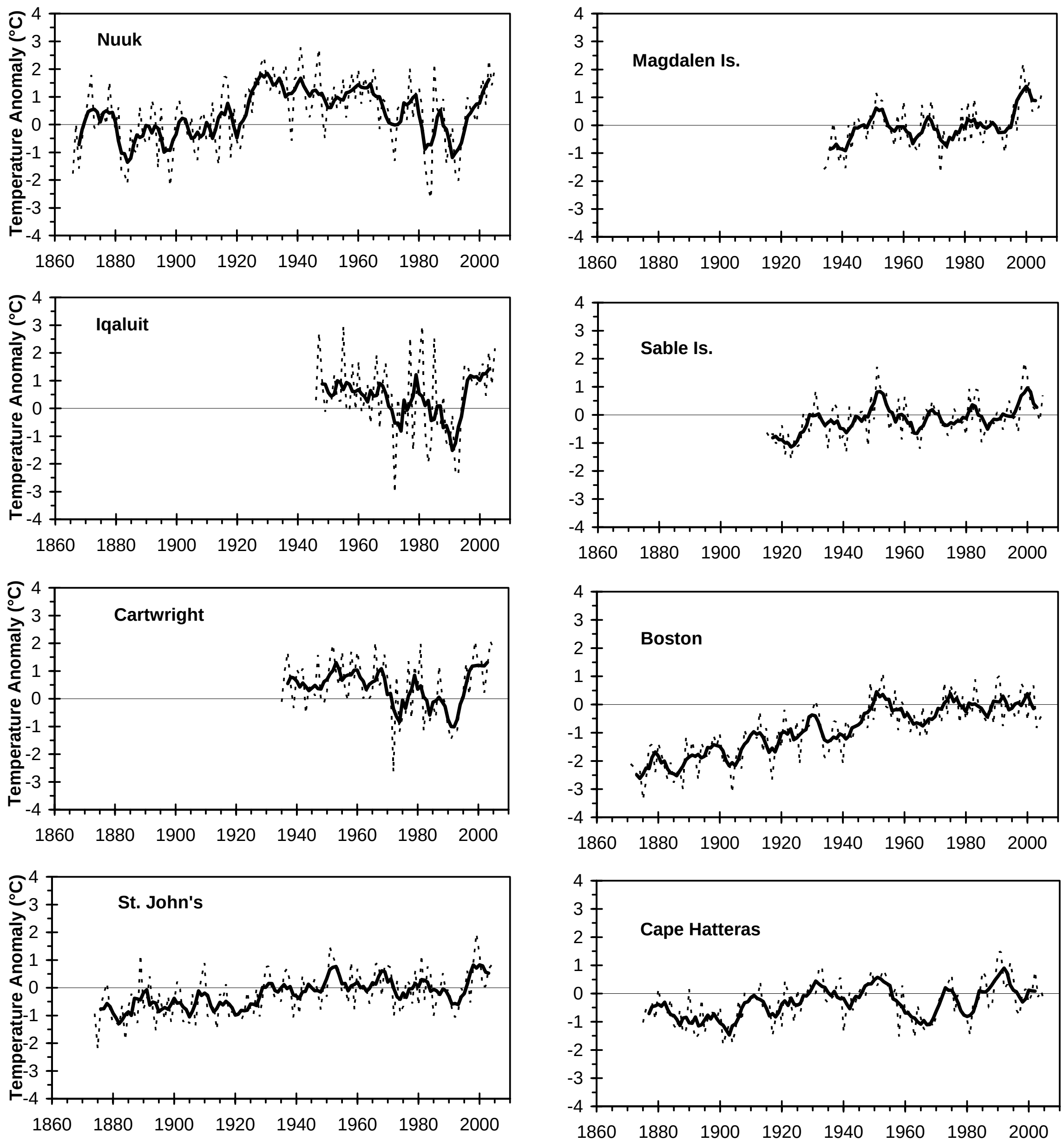

Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

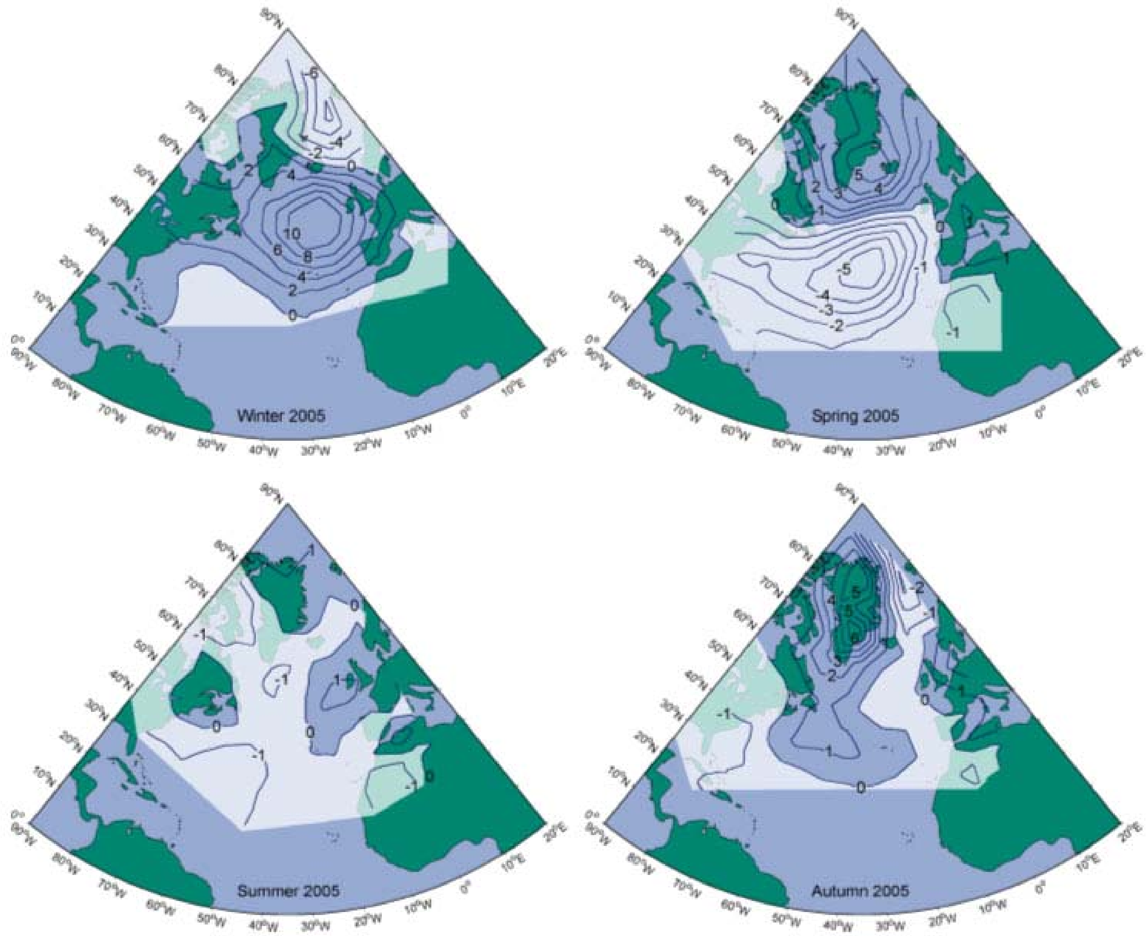

Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2005 relative to the 1971-2000 means.

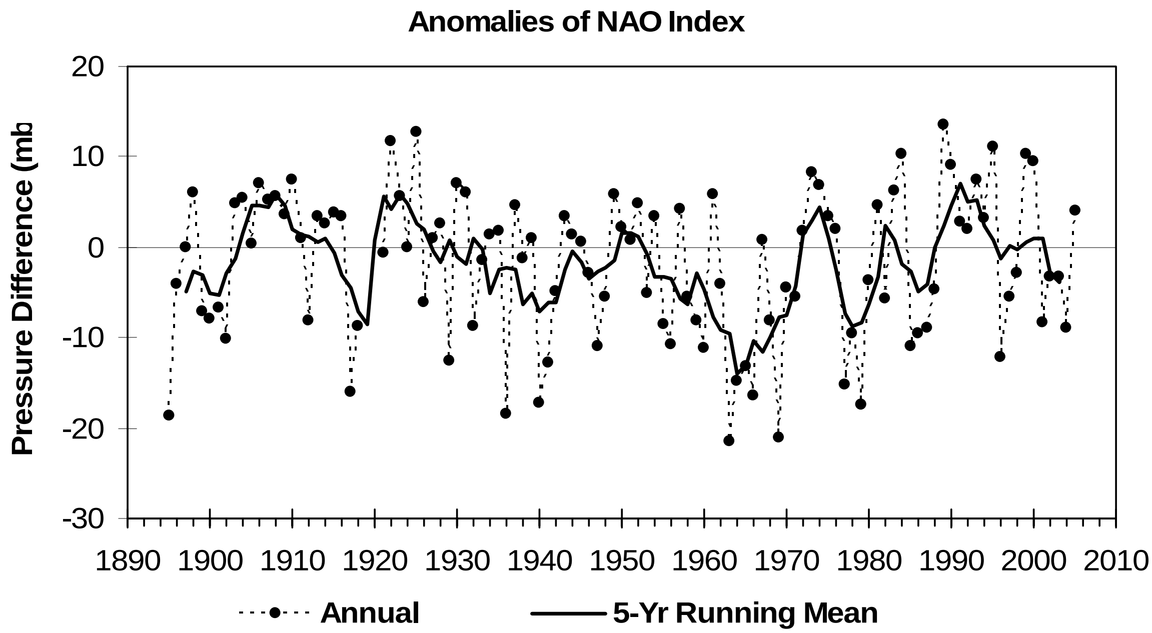

Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

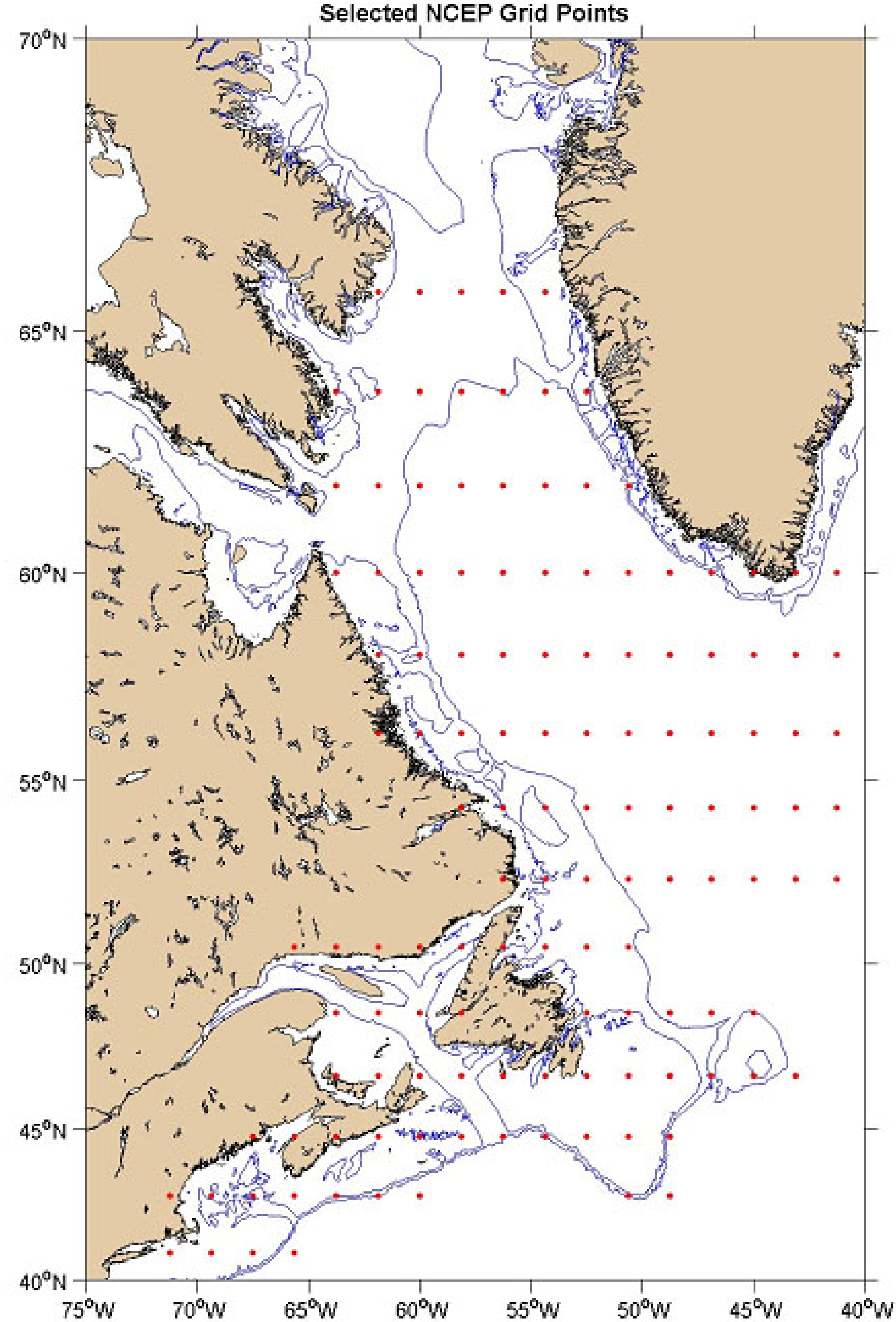

Fig. 7. The Northwest Atlantic showing the NCEP wind grid used in our study.

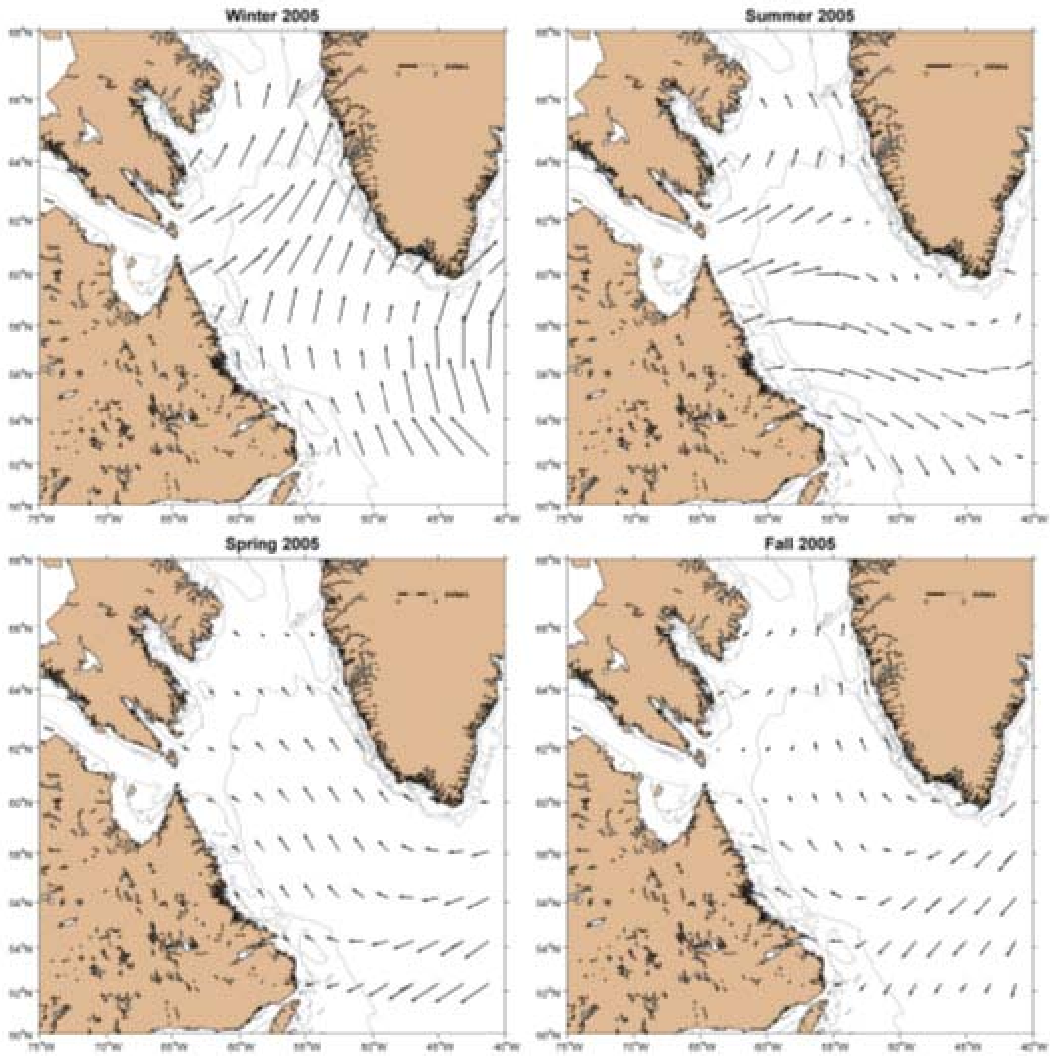

Fig. 8. The seasonal wind anomalies for the northern region during 2005. Note the different scale (0-4 m/s) for spring.

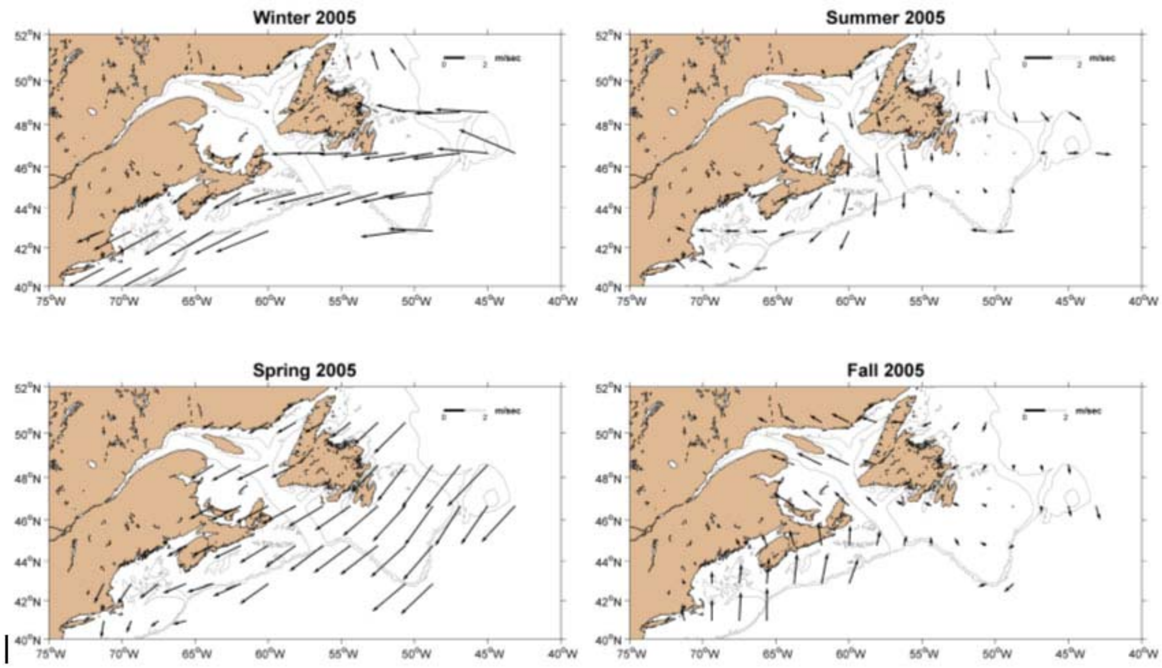

Fig. 9. The seasonal wind anomalies for the southern region during 2005.

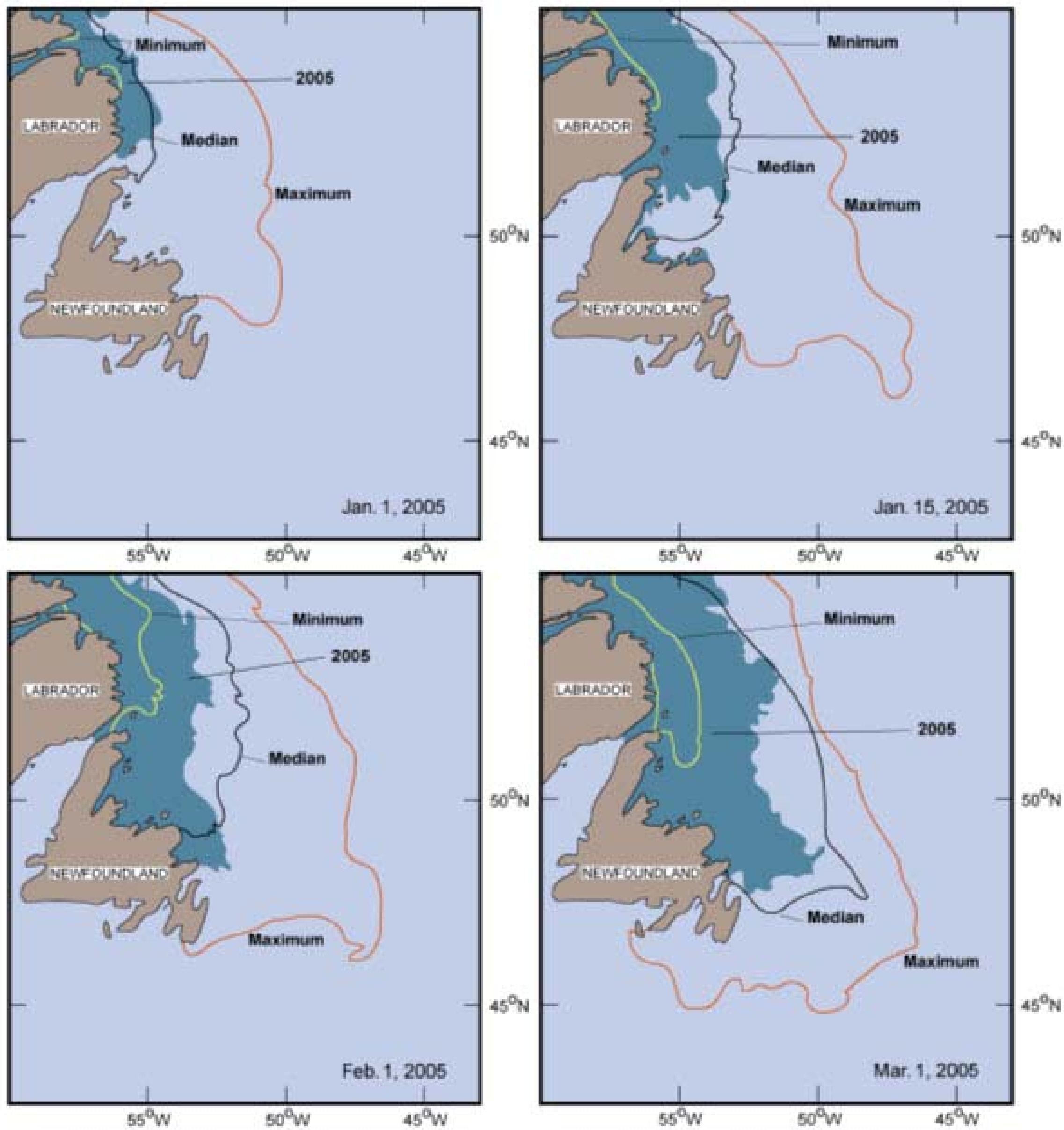

Fig. 10A. The location of the ice (shaded area) between January and March 2005 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

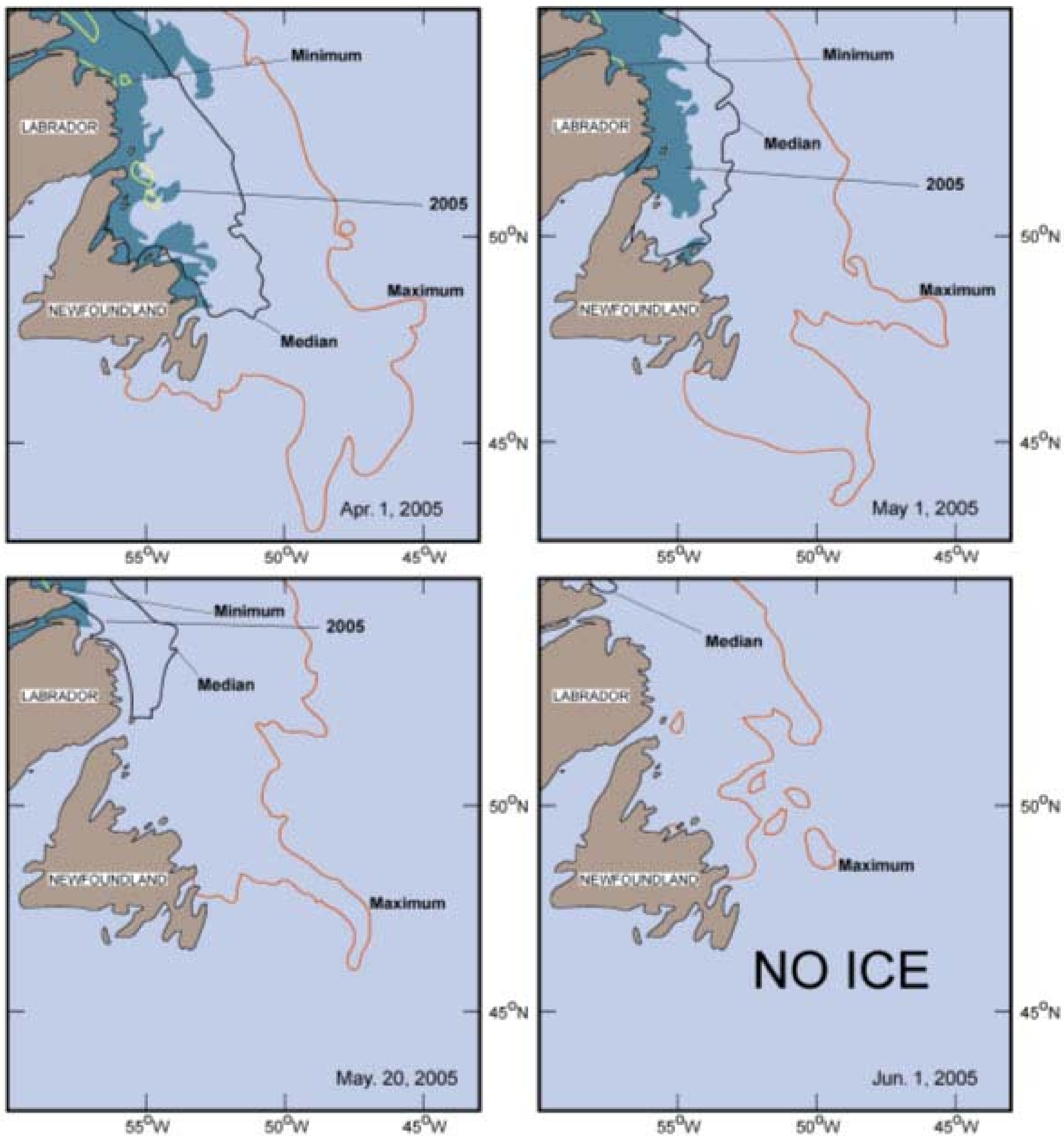

Fig. 10B. The location of the ice (shaded area) between April and July 2005 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

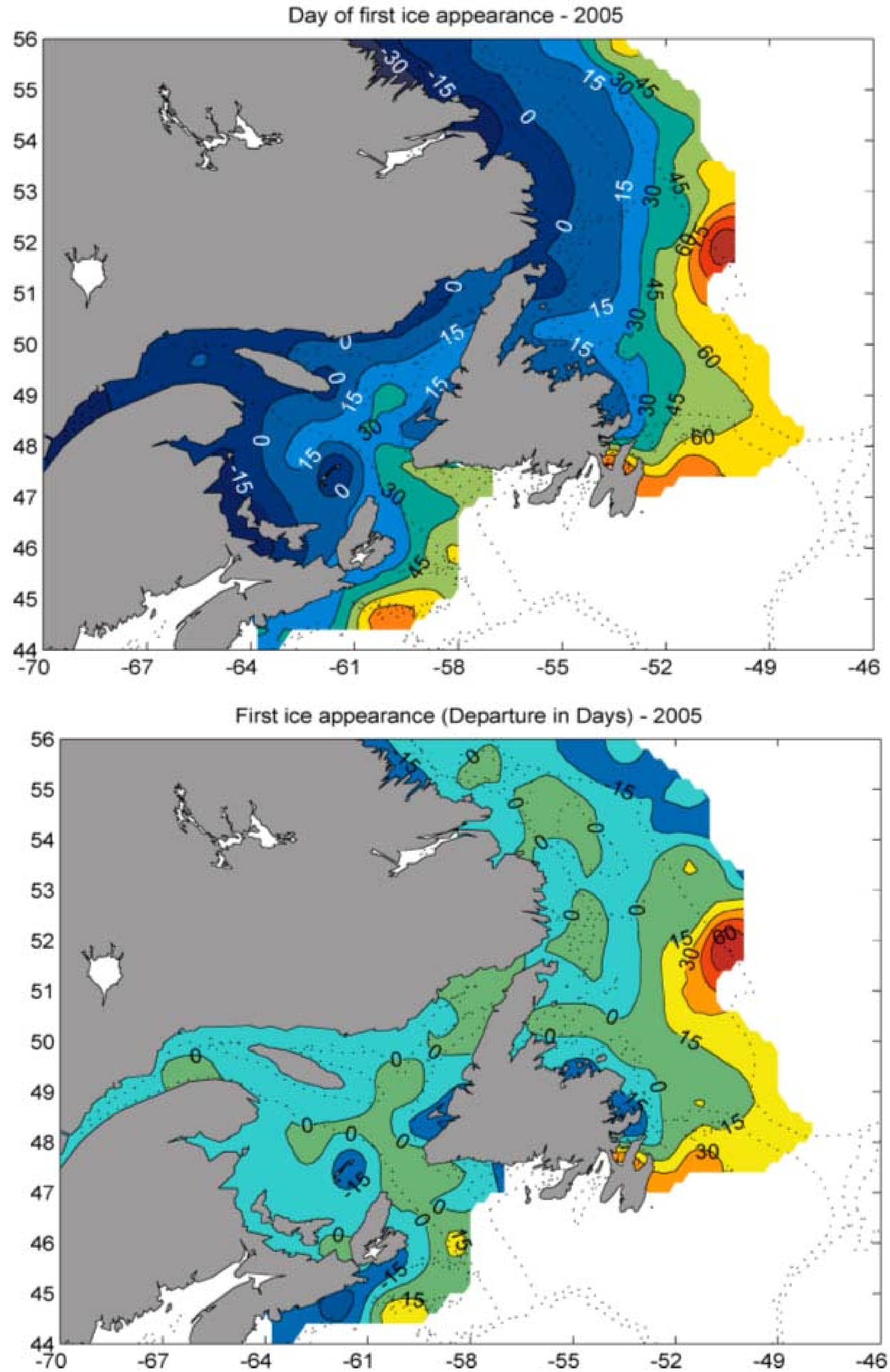

Fig. 11. The time when ice first appeared during 2005 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative (positive) anomalies indicate earlier (later) than normal appearance.

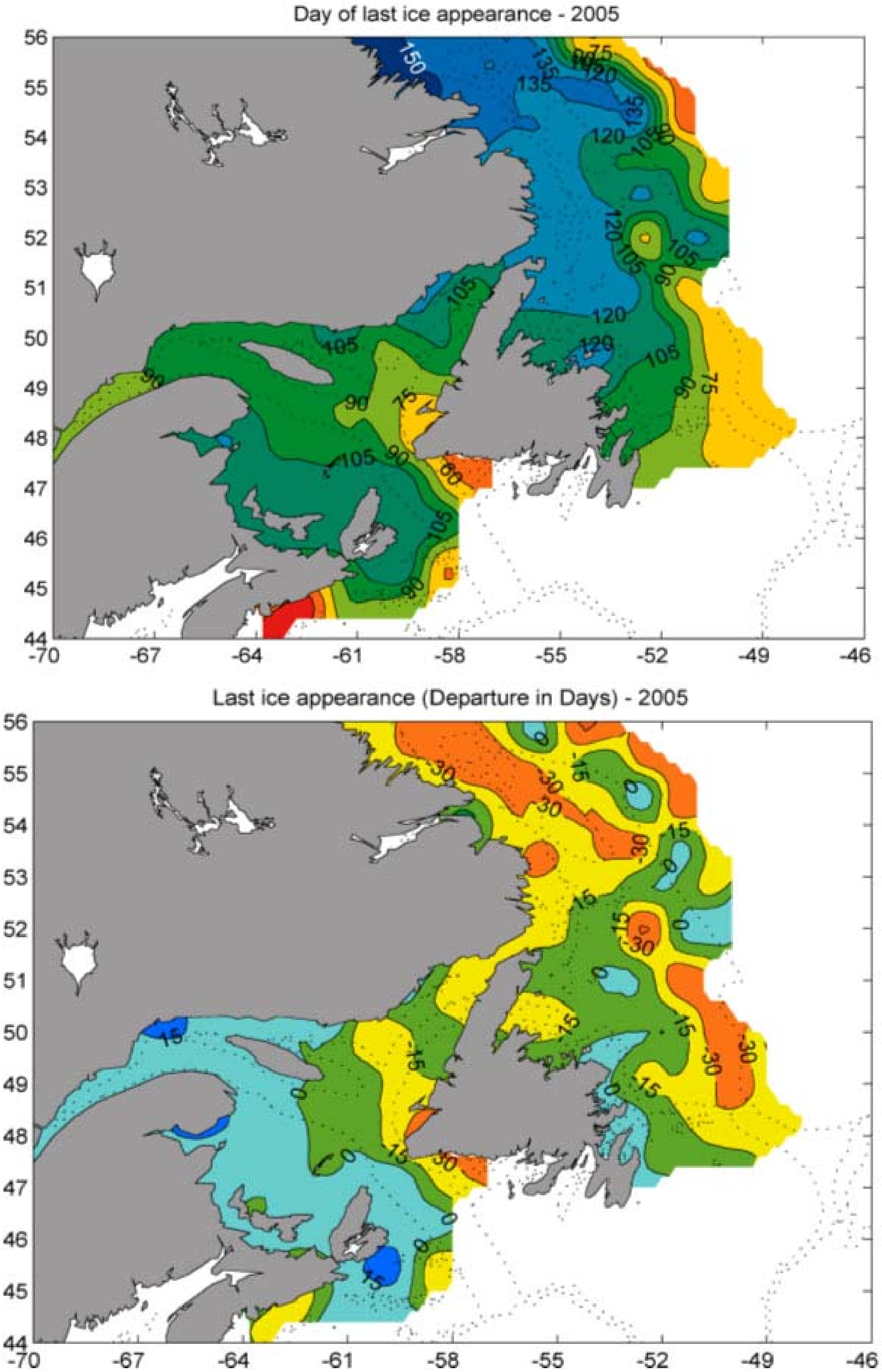

Fig. 12. The time when ice was last seen in 2005 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance.

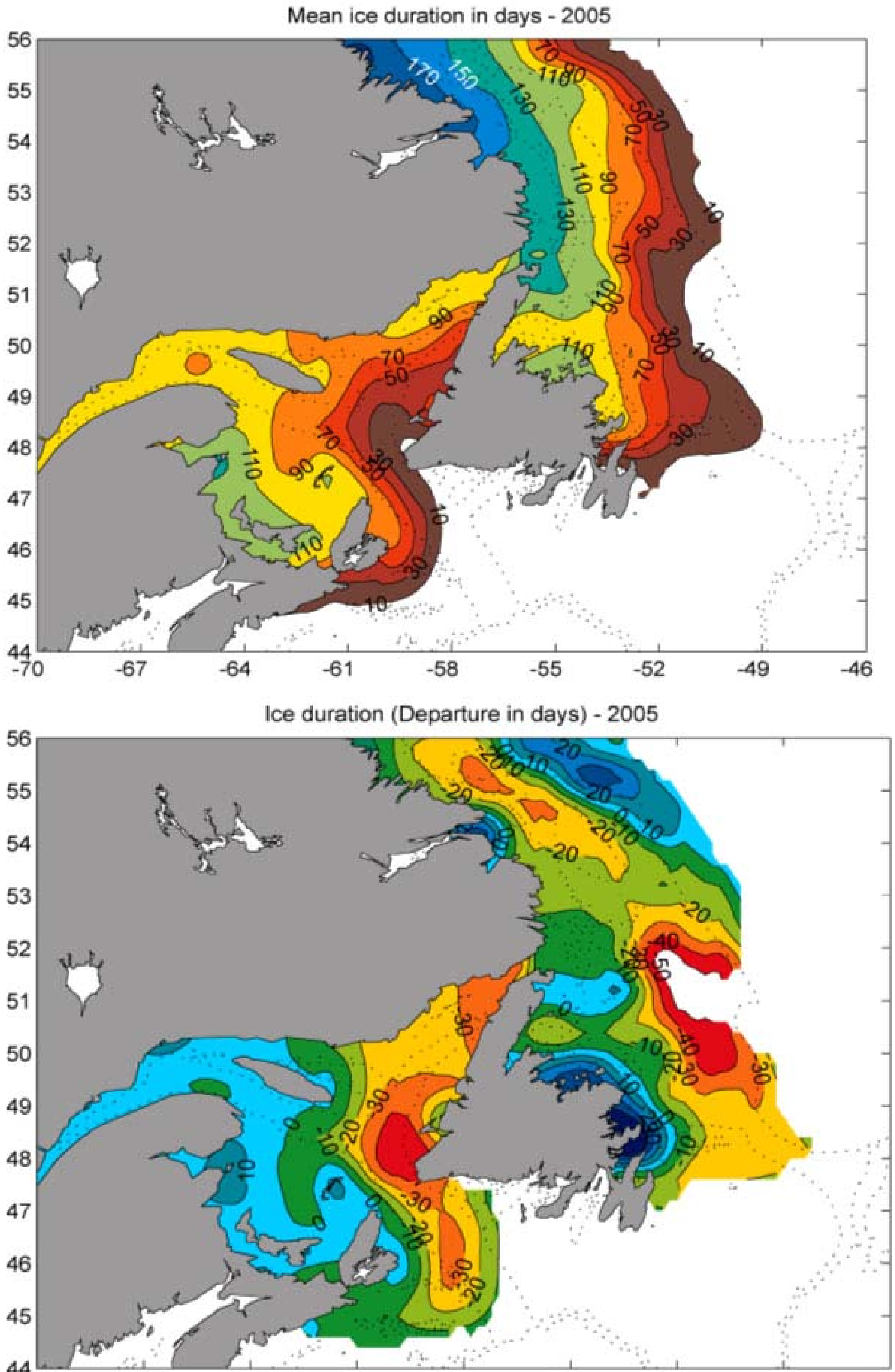

Fig. 13. The duration of ice in days (top panel) during 2005 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

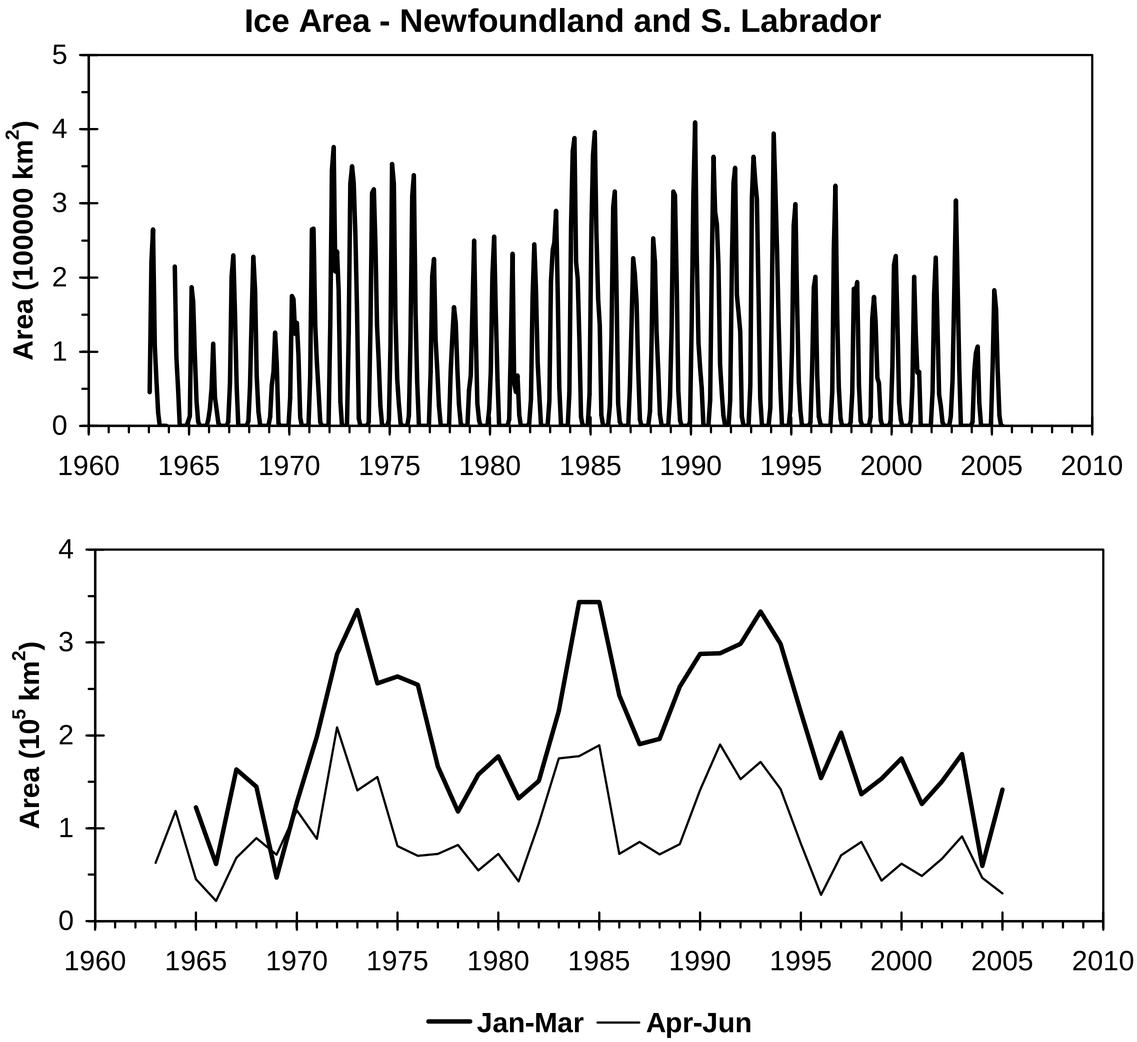

Fig. 14A. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (bottom panel).

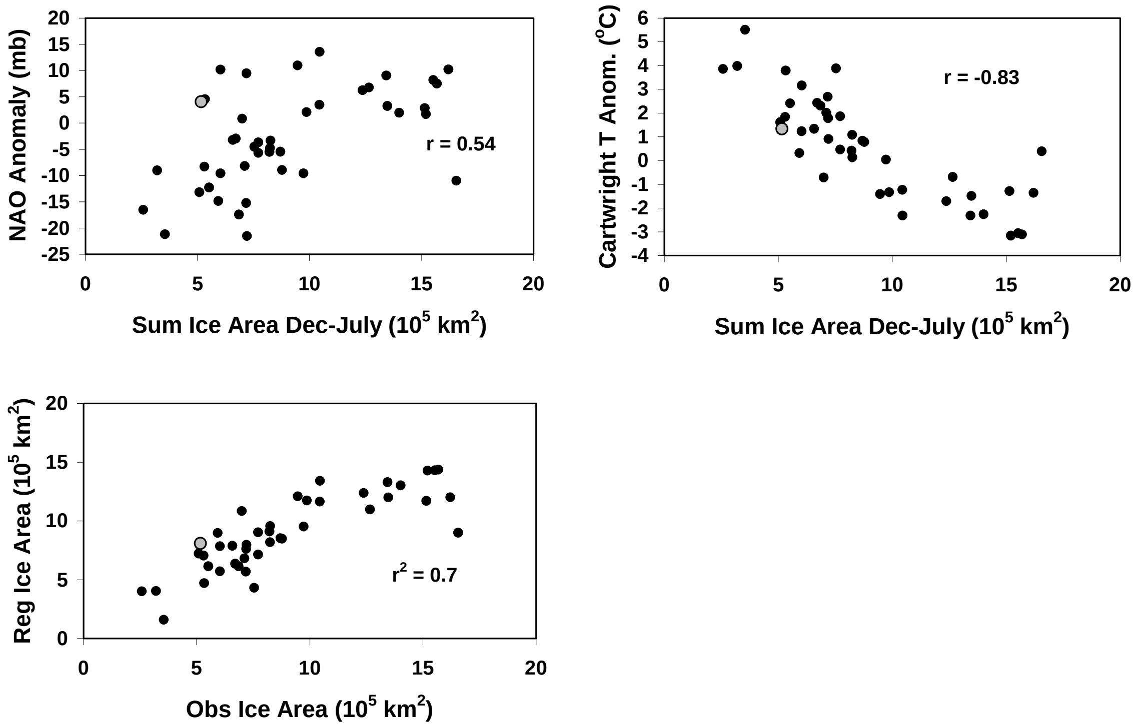

Fig. 14B. Comparison of time series of the December-July summed ice area off Newfoundland and Labrador between 45°N-55°N and the NAO anomaly and Cartwright December-March air temperature anomaly. The last panel shows the comparison of the observed, December-July ice cover and the cover calculated from 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. The 2005 value is displayed as a larger grey point.

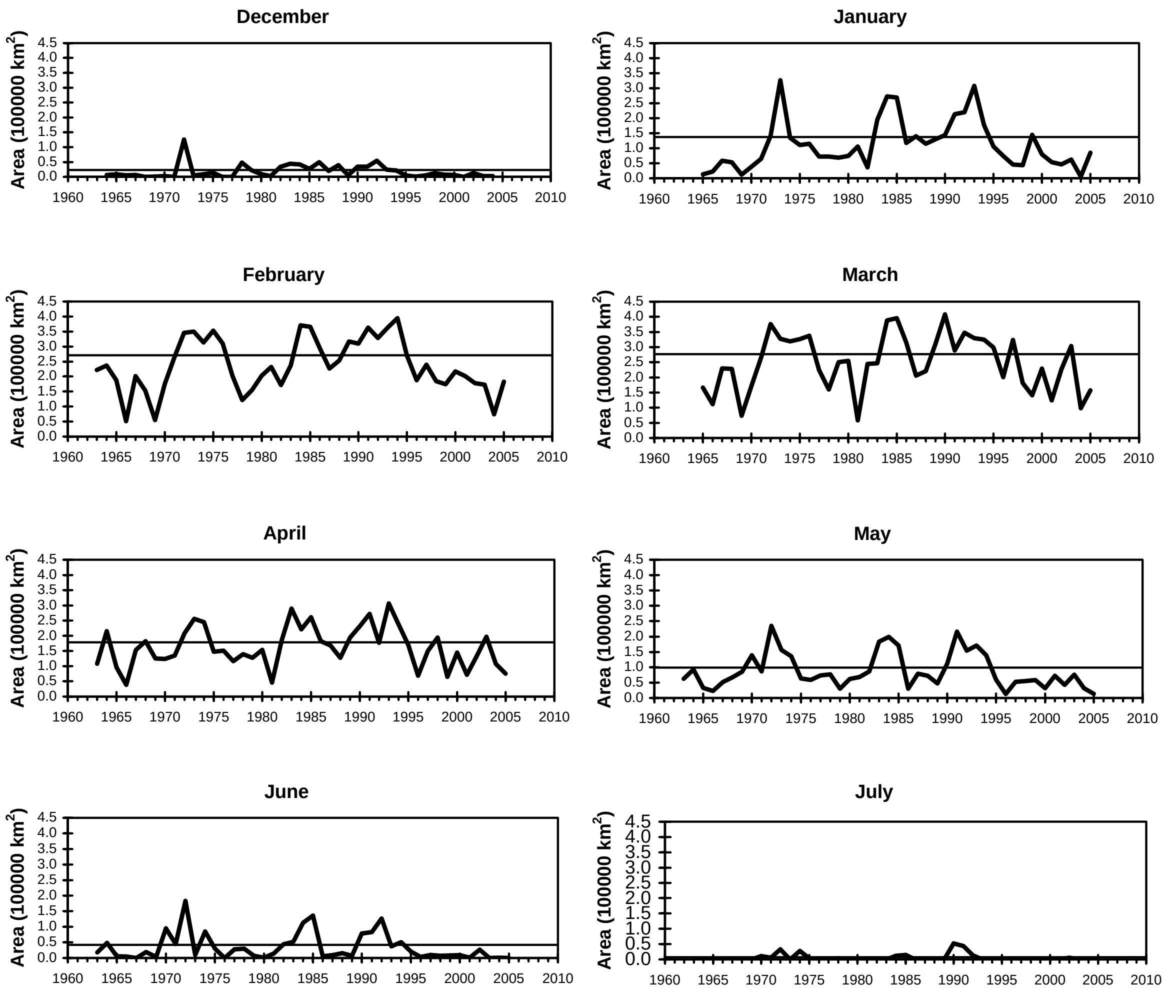

Fig. 15. The time series of ice area off Newfoundland and Labrador by month is presented. The horizontal lines represent the long-term (1971-2000) means.

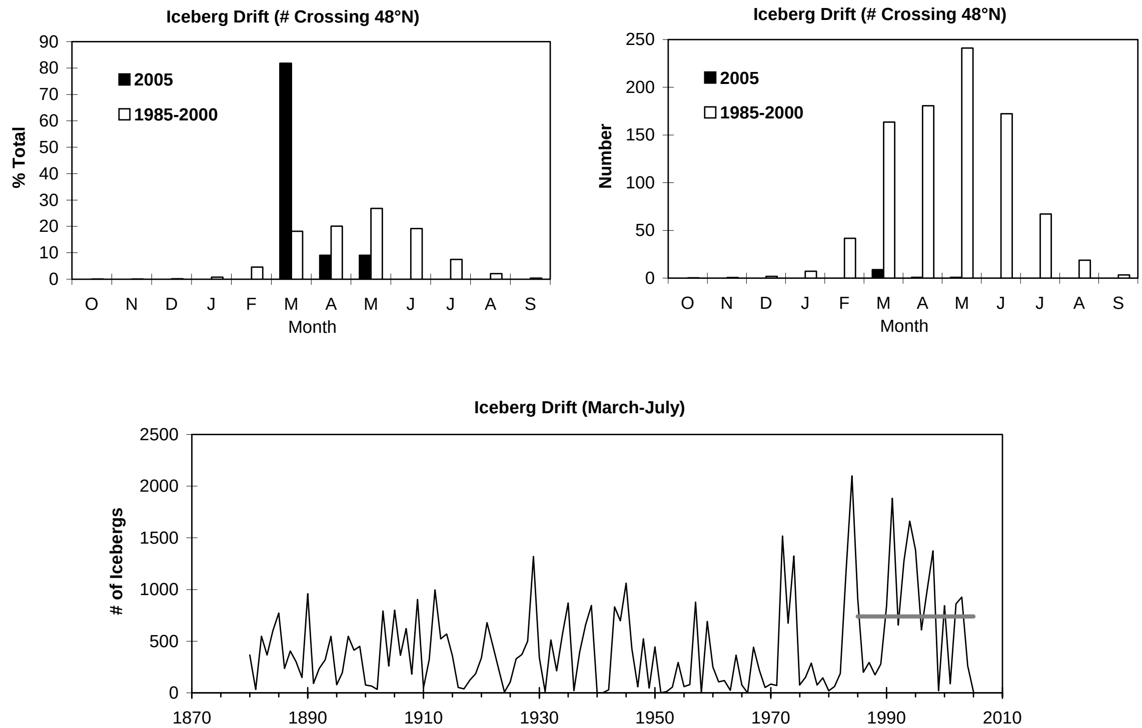

Fig. 16. The number of icebergs crossing south of 48°N during the iceberg season 2004/2005 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2000, the years SLAR has been used (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2005 average number of icebergs.

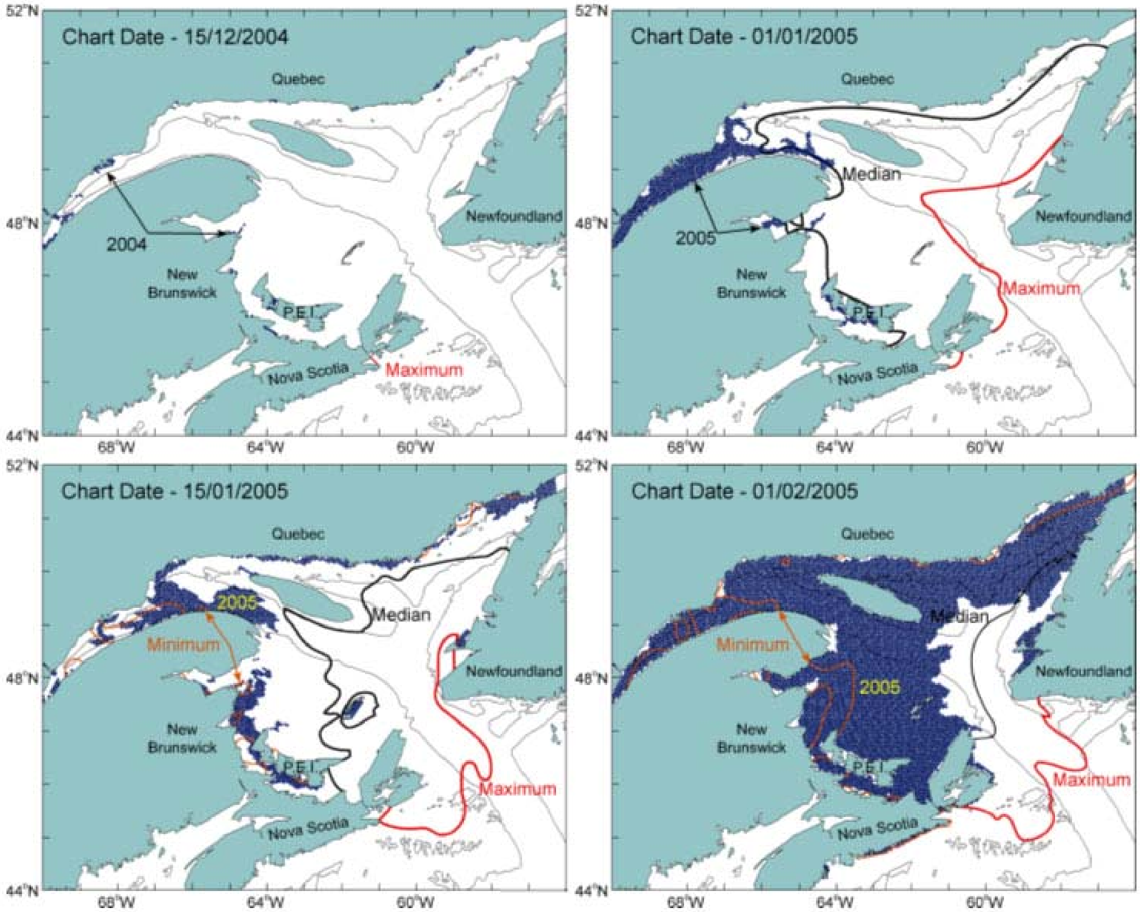

Fig. 17. The location of the ice (shaded area) between December 2004 and February 2005 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

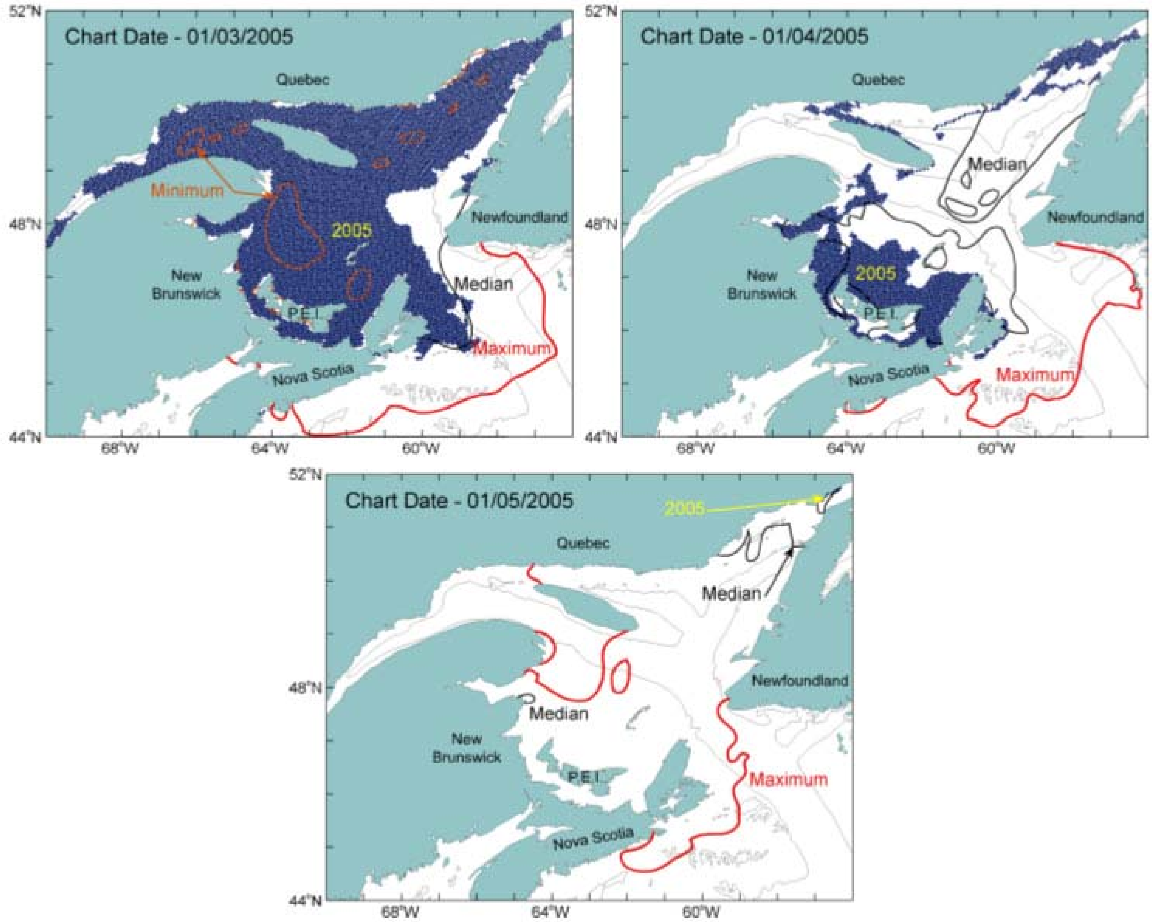

Fig. 17, continued. The location of the ice (shaded area) between March and May 2005 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

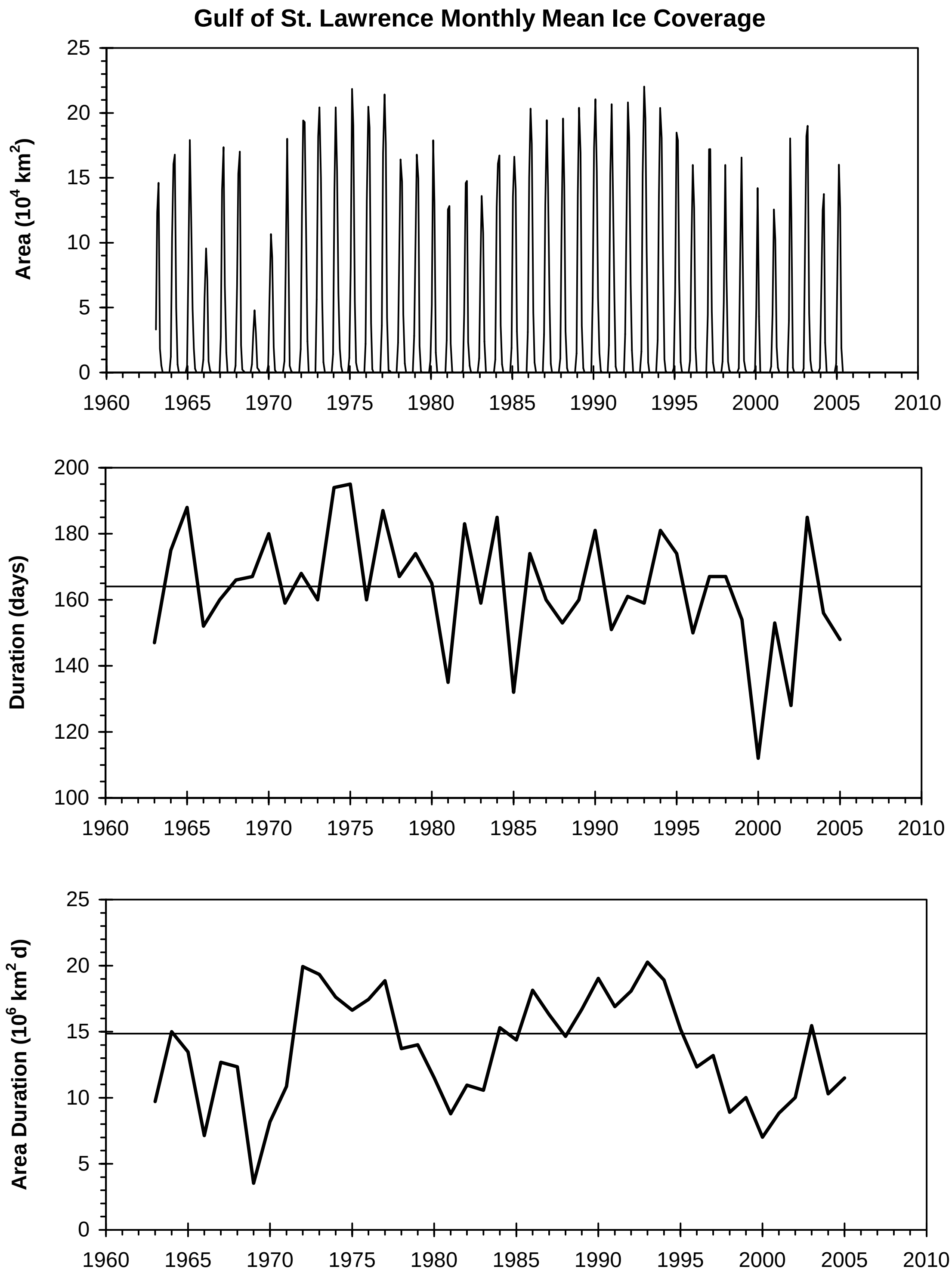

Fig. 18. For the Gulf of St. Lawrence, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

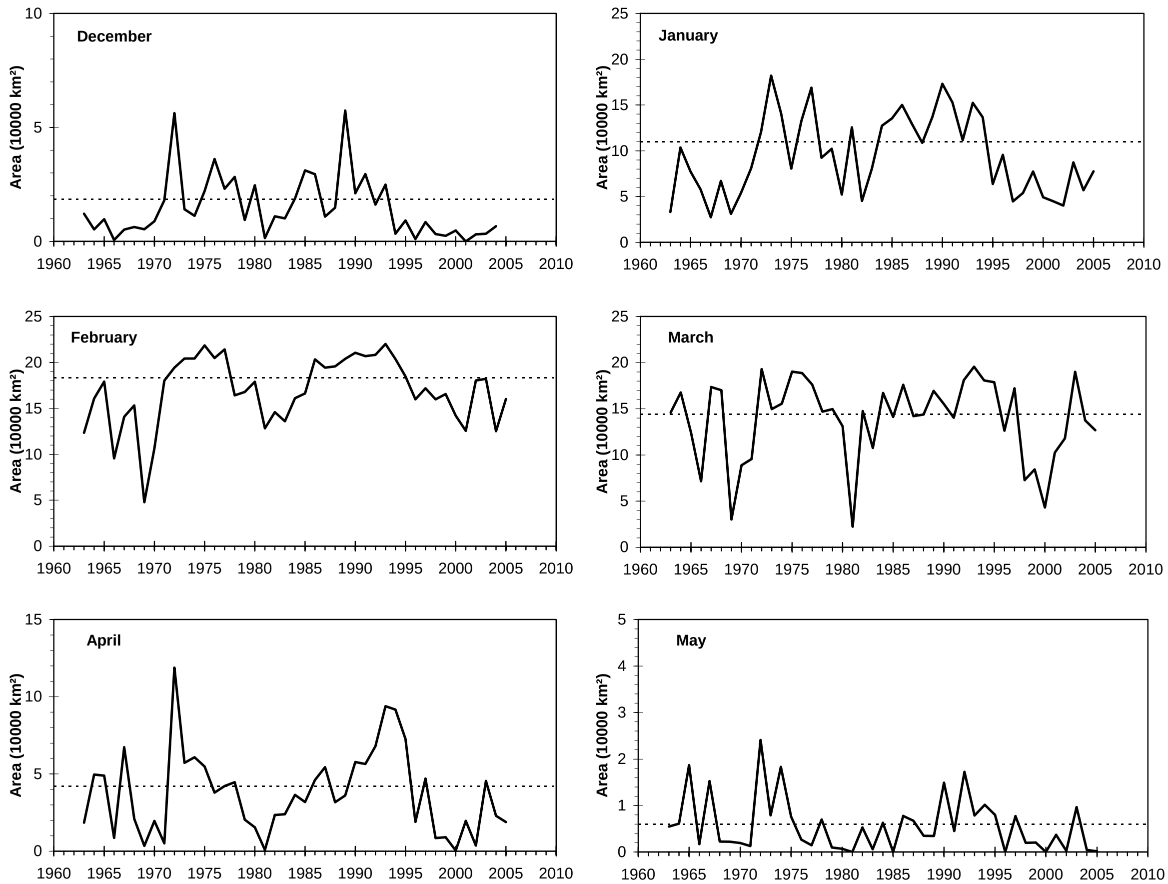

Fig. 18, continued. The time series of ice area in the Gulf of St. Lawrence by month is presented. The horizontal lines represent the 1971-2000 means.

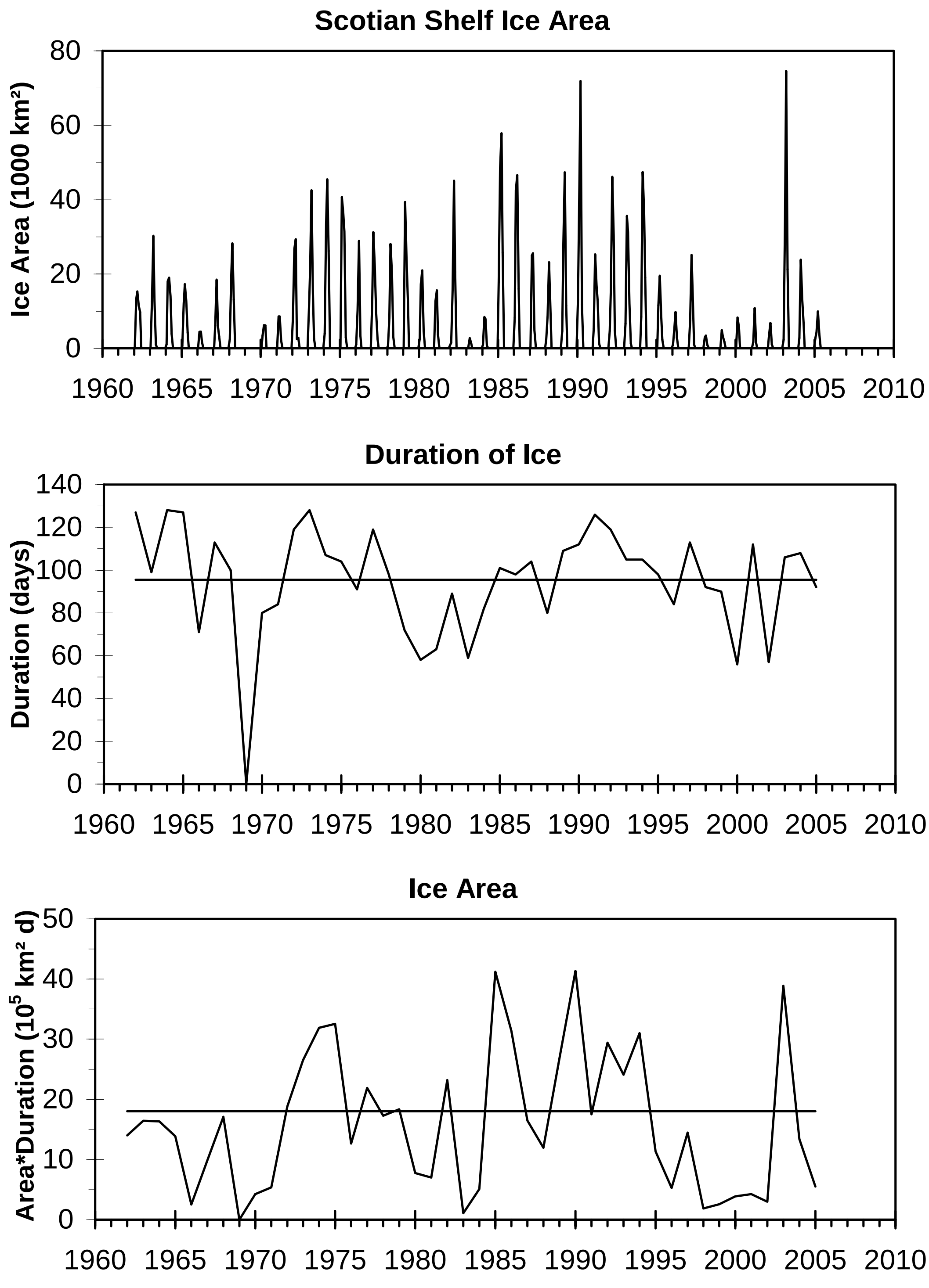

Fig. 19. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

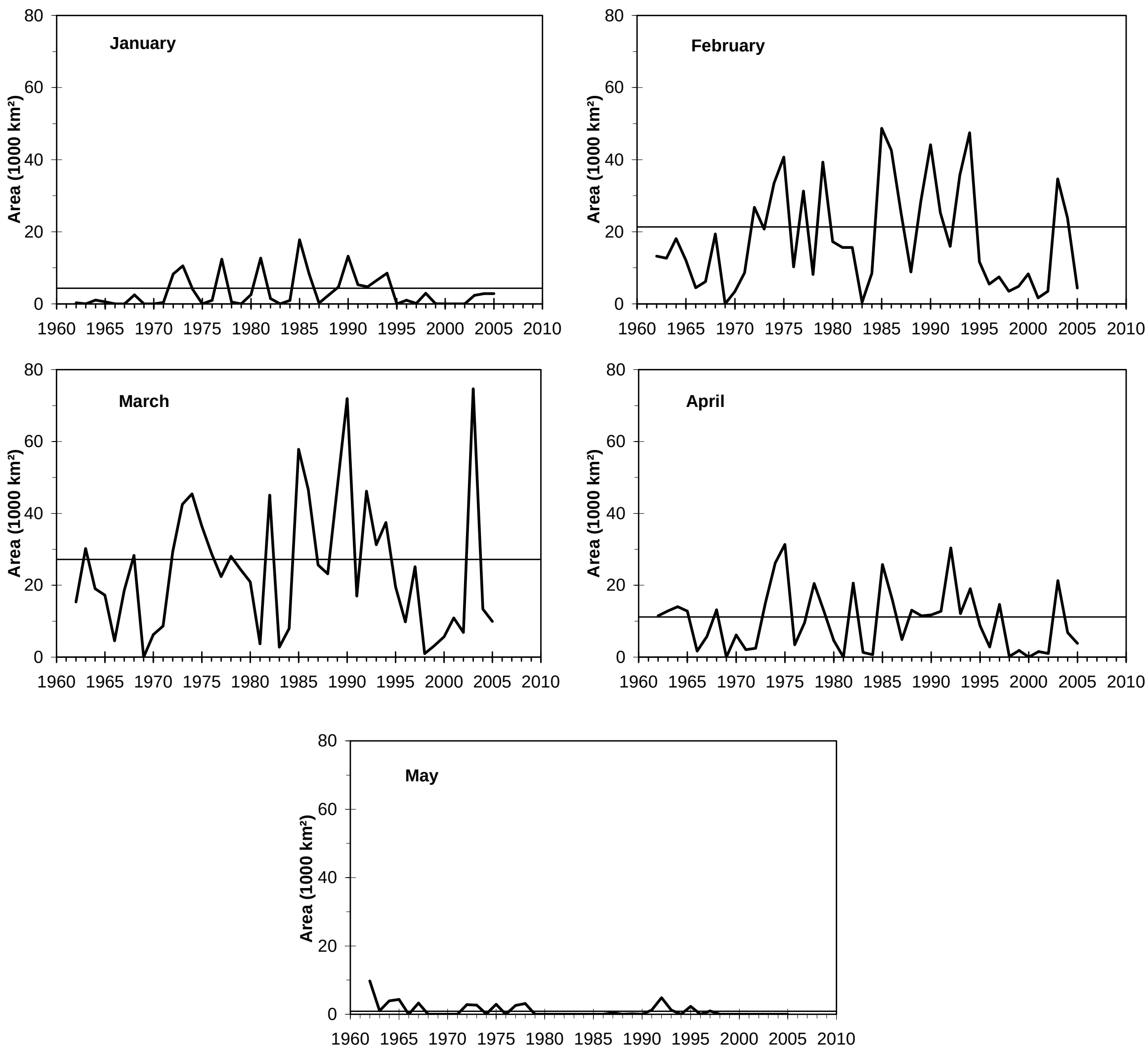

Fig. 20. The time series of ice area seaward of Cabot Strait by month is presented. The horizontal lines represent the 1971-2000 means.

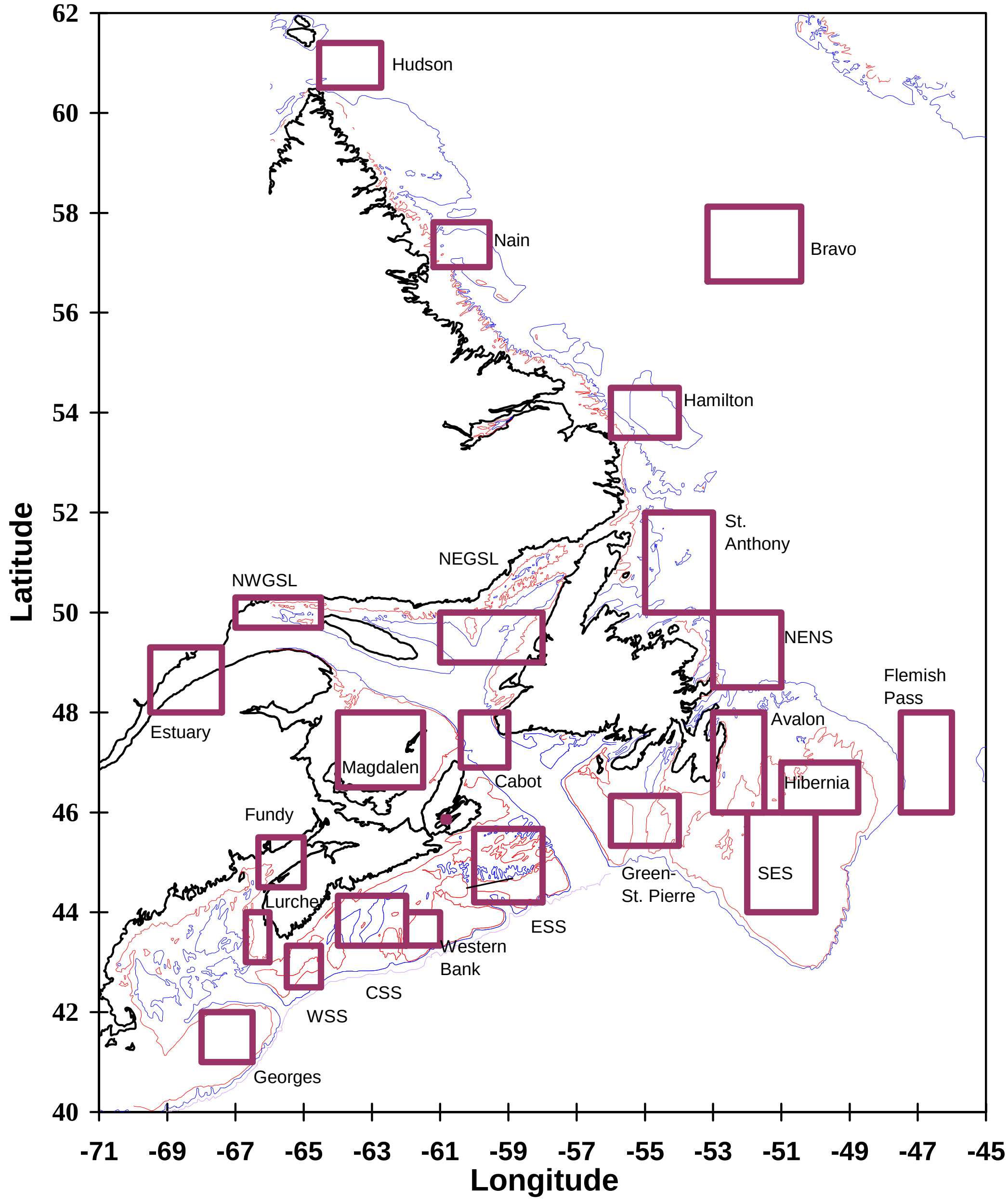

Fig. 21. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

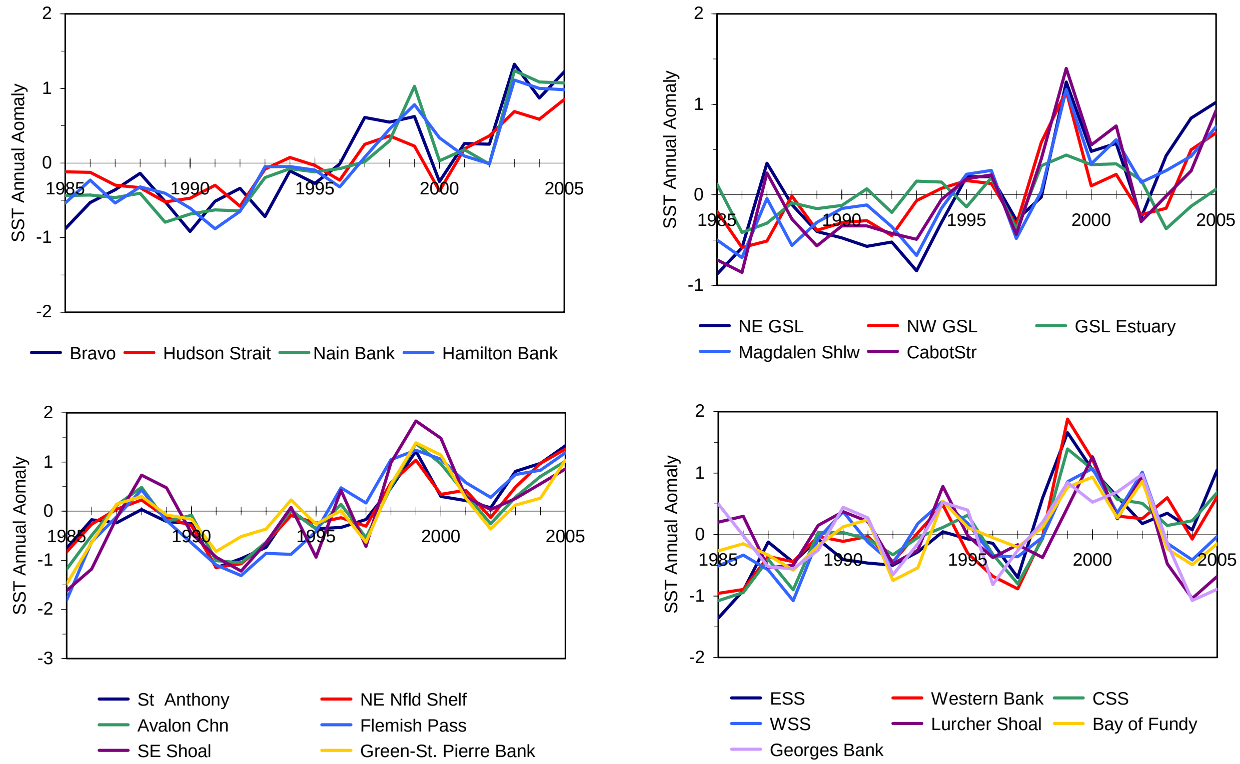

Fig. 22. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2005 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences Division at BIO. These values were adjusted by the regression Pathfinder=0.976*BOS+0.46 based on a comparison between overlapping Pathfinder-BOS data.

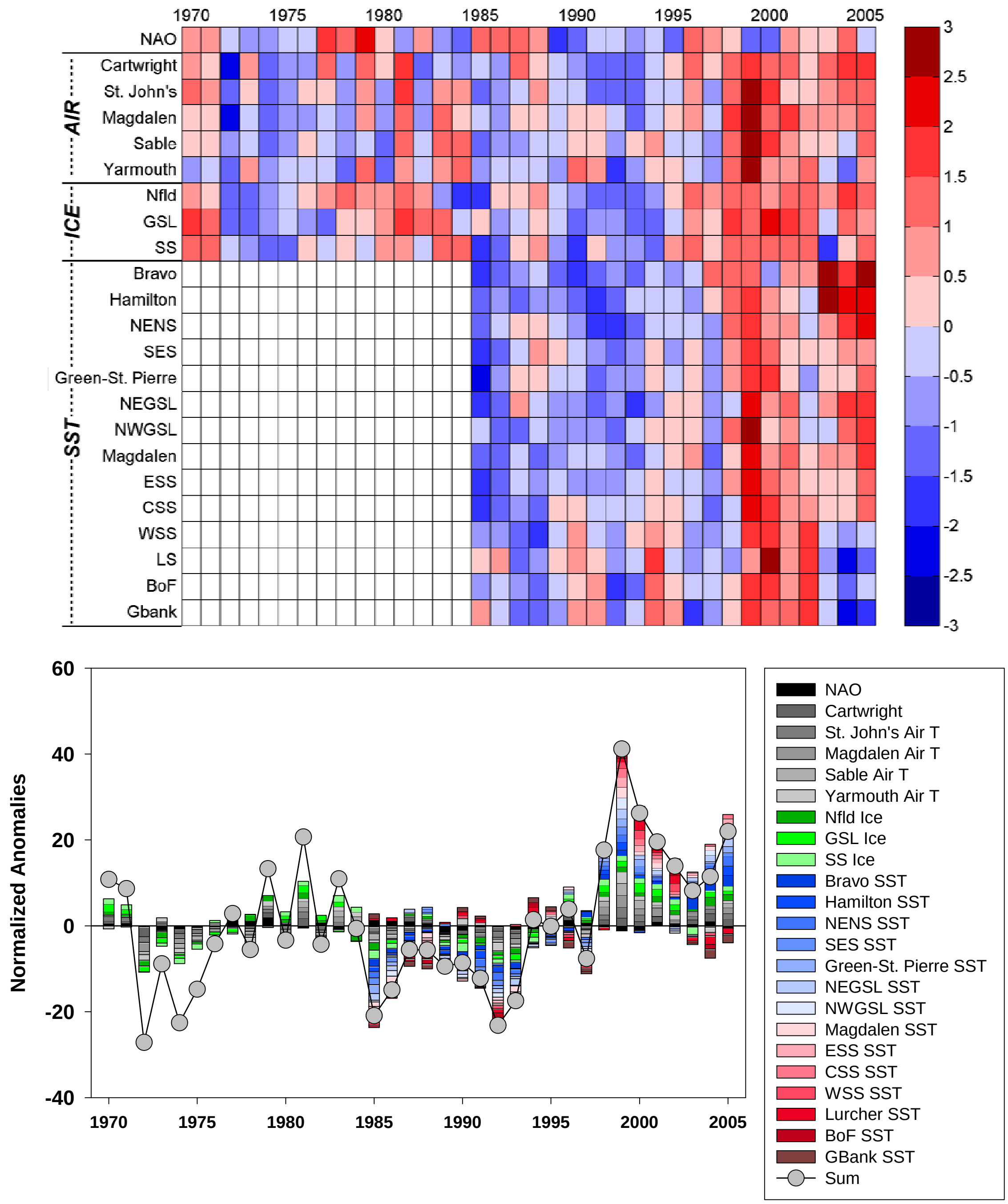

Fig. 23. Normalized annual anomalies of the NAO, air temperatures, ice and sea surface temperatures for the Atlantic region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means (except for SST where all data are used), divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal. The signs of the ice and NAO have been reversed before plotting since reduced ice cover and a negative NAO represent warmer than normal conditions. The contributions of each of the normalized anomalies are shown as a bar chart and their summation as a time series (grey circles, black line; lower panel).