Fisheries and Oceans Canada — Pêches et Océans Canada
Science — Sciences

C S A S — **S C C S**

Canadian Science Advisory Secretariat

Secrétariat canadien de consultation scientifique

Research Document 2008/016

Document de recherche 2008/016

Not to be cited without
Permission of the authors *

Ne pas citer sans
autorisation des auteurs *

An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2007

Vue d'ensemble des conditions météorologiques, des conditions de glace de mer et des températures à la surface de la mer au large de l'est du Canada en 2007

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

ISSN 1499-3848 (Printed / Imprimé)

ABSTRACT

In 2007, the NAO index returned to a positive value, but only slightly above normal (2.5 mb, 0.3 SD). A positive index implies stronger winds from the northwest, cooler air temperatures and increased heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. The mean annual air temperatures decreased at selected sites from the northern Labrador Sea to the Gulf of Maine except Cape Hatteras, but still remained above normal by ~1^{o}C over the Labrador Sea and Shelf, 0.3^{o}C over the Grand Banks, and ~1^{o}C over the Gulf of St. Lawrence. On the other hand, annual air temperatures over the Scotian Shelf and Gulf of Maine were about 0.2^{o}C below normal. The average December-June Newfoundland and Labrador sea ice cover and ice volume were 1.2 and 0.6 SD below normal respectively. However, ice persisted on the east coast north of Cape Bonavista for longer than it has in recent years. The Gulf of St. Lawrence ice cover (Dec-Apr) in 2007 was the second lowest in the 38 year record with only 2006 having less cover. Below normal ice conditions (-0.8 SD) also prevailed on the Scotian Shelf with ice cover (January-April) the 15th least in 39 years. Three hundred twenty-four icebergs reached the Grand Banks in 2007, a substantial increase from 2006 when none were observed but still well below the long-term mean. The analysis of satellite data indicates a northeast to southwest gradient of sea surface temperature anomalies similar to the air temperature anomaly distribution, i. e., generally above normal SST (by ~0.7^{o}C) to the northeast and below normal values (-0.6^{o}C) over the western Scotian Shelf, Lurcher Shoals and Georges Bank. Eighteen of twenty-three areas had positive annual SST anomalies; values ranged from -0.8^{o}C (western Scotian Shelf) to 1.5^{o}C (Labrador Shelf).

RÉSUMÉ

En 2007, l'indice d'ONA est revenu à une valeur positive, mais n'a été que légèrement supérieur à la normale (2,5 mb, écart-type de 0,3). Lorsque l'indice est positif, les vents du nord-ouest sont plus intenses au-dessus de la mer du Labrador et d'une partie du plateau continental de Terre-Neuve et du Labrador, les températures de l'air plus fraîches et les pertes de chaleur accrues en hiver. Les températures de l'air annuelles moyennes ont diminué à certains sites répartis entre le nord de la mer du Labrador et le golfe du Maine, sauf à cap Hatteras, mais sont toujours demeurées supérieures à la normale d'environ 1 ^{o}C au-dessus de la mer du Labrador et du plateau continental, de 0,3 ^{o}C au-dessus du Grand Banc et d'environ 1 ^{o}C au-dessus du golfe du Saint-Laurent. Par contre, les températures de l'air annuelles au-dessus du plateau néo-écossais et du golfe du Maine ont été d'environ 0,2 ^{o}C sous la normale. La couverture de glace et le volume moyen des glaces à Terre-Neuve et au Labrador entre décembre et juin ont été respectivement de 1,2 et 0,6 écart-type sous la normale. Cependant, comparativement aux dernières années, la glace a persisté plus longtemps sur la côte est, au nord du cap Bonavista. En 2007, le couvert de glace dans le golfe du Saint-Laurent (décembre-avril) a été le deuxième plus petit en importance depuis 38 ans, tout juste après celui de 2006. Des conditions de glace sous la normale (écart-type de -0,8) ont également été observées sur le plateau néo-écossais, le couvert de glace (janvier-avril) étant le 15e plus petit en importance depuis 39 ans. Trois cents vingt-quatre icebergs ont atteint le Grand Banc en 2007, ce qui est une augmentation considérable par rapport à 2006 où aucun iceberg n'a été observé, mais ce nombre demeure toujours bien en-dessous de la moyenne à long terme. L'analyse des données satellites indique un gradient nord-est sud-ouest des anomalies des températures à la surface de la mer (TSM) similaire à la distribution des anomalies des températures de l'air, c.-à-d. des TSM généralement au-dessus de la normale (d'environ 0,7 ^{o}C) au nord-est et inférieures à la normale (de -0,6 ^{o}C) au-dessus du secteur ouest du plateau néo-écossais, du haut-fond Lurcher et du banc Georges. Dix-huit des vingt-trois sites ont affiché des anomalies positives des TSM; les valeurs se sont échelonnées de -0,8 ^{o}C (ouest du plateau néo-écossais) à 1,5 ^{o}C (plateau continental du Labrador).

INTRODUCTION

This document examines the meteorological, sea ice and sea surface temperature conditions during 2007 in the Northwest Atlantic (Fig. 1). Specifically, it discusses air temperature trends, atmospheric sea level pressures, winds, sea ice cover, 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; see Colbourne et al. (2008), Galbraith et al. (2008), Petrie et al. (2008)). Environmental conditions are compared with the long-term means and in some cases, to 2006 values. These comparisons are often expressed as anomalies, which are the deviations from the long-term means, or as standardized anomalies, i. e. the anomaly divided by the standard deviation (SD). Where the data permit, the long-term means and standard deviations are calculated for the 30-year base period, 1971-2000. This is in accordance with the convention of North American meteorologists and the recommendations of the Northwest Atlantic Fisheries Organization (NAFO) and the Fisheries Oceanographic Committee of the Department of Fisheries and Oceans. The use of standardized anomalies and the same base period allow direct comparison of anomalies among sites and variables.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The German Weather Service publishes monthly surface 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). The annual anomaly map was not available for 2007, however, the monthly maps were and are discussed below. In place of their annual map, we show the equivalent NOAA product which features warmer-than-normal temperatures over the Labrador Sea and Shelf, decreasing from >2^{o}C over Davis Strait to 1^{o}C over Hamilton Bank (Fig. 2A). The southern half of the Gulf of St. Lawrence, the Scotian Shelf and the Gulf of Maine had weak anomalies ranging from 0 to -0.5^{o}C. The monthly maps of air temperature anomalies indicate that the Labrador Sea and Shelf had generally warmer-than-normal temperatures throughout the year with the exception of May and December (Fig. 2B, C). The Grand Banks and Gulf of St. Lawrence featured anomalies of ~±1^{o}C throughout the year, with an overall positive tendency. Similar conditions prevailed over the Scotian Shelf and the Gulf of Maine but with a greater prevalence of negative anomalies.

Monthly air temperature anomalies for 2006 and 2007 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). The anomalies are presented in 2 ways: the heights of the bars represent the anomalies in ^{o}C; the colours of the bars represent the number of standard deviations the anomalies differ from their long-term means. Data from the Canadian sites were from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA, 2007). In 2007, monthly temperature anomalies were variable among sites in contrast to 2006, when large positive anomalies dominated at the 6 northernmost sites.

The mean annual air temperature anomalies for 2007 (Fig. 4) decreased at all sites except Cape Hatteras compared to 2006. The 2007 annual anomalies and their changes from 2006 were: Nuuk (anomaly, 1.3^{o}C; change, -0.3^{o}C), Iqaluit (0.9^{o}C; -2.2 ^{o}C), Cartwright (0.7^{o}C;

-2.3 ^{o}C), St. John's (0.3^{o}C; -1.4 ^{o}C), Magdalen Islands (0.7^{o}C; -1.6^{o}C), Sable Island (-0.1^{o}C; -1.5^{o}C), Boston (0.0^{o}C; -0.8^{o}C), Cape Hatteras (0.8^{o}C; 0.6^{o}C). Yarmouth (not shown) had an annual temperature anomaly of -0.2^{o}C, a decrease of -1.5^{o}C from 2006. Overall, the anomalies are closer to normal values, i. e., within 0.5 standard deviations (SD), over the Scotian Shelf and Gulf of Maine (Sable Island, Yarmouth and Boston). The annual standardized anomalies at Nuuk, Iqaluit, Cartwright, St. John's, the Magdalen Islands and Cape Hatteras were 1, 0.6, 0.6, 0.4, 0.9 and 1.2 SD above normal respectively.

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 2007, relative to the 1971-2000 means, are shown in Fig. 5.

In winter, an extensive, below average SLP pattern dominated the western North Atlantic with its centre (~6 mb below normal) located off Labrador. The winter pressure anomalies in 2007 indicate slightly stronger-than-normal Iceland Low and Azores High, i. e. a small increase in the strength of the large-scale atmospheric circulation compared to 2006.

The spring of 2007 featured a negative SLP anomaly (minimum about -4 to -5 mb) in an elongated trough extending from Barents Sea to off Iceland giving way to a positive anomaly (~3 mb) centred east of the Azores with strong zonal gradients between the two features. This would result in a stronger-than-normal Iceland Low and Azores High.

The pressure anomaly field during the summer of 2007 was robust and a near reversal of the spring pattern. Positive anomalies (to ~3 mb) were found over Greenland with strong gradients to the south, especially towards Iceland. Negative anomalies (-3 mb) stretched southwestward from the North Sea into the Atlantic Ocean. In the autumn, the pattern was dominated by an intense positive anomaly over Ireland (to ~8 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 years with a negative NAO index. The annual NAO index is the difference of the observed sea level pressures at Ponta Delgada (up to 1997), Santa Maria (1998-2005) or Lajes (since 2006) in the Azores, and 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 2007, the winter NAO index was normal (2.5 mb, 0.3 SD above normal), an increase from the -3.3 mb anomaly in 2006 (Fig. 6). Five of the last 6 years have featured weak anomalies, i. e. within 0.5 SD of the long-term mean; negative anomalies have occurred for 5 of the last 7 years. As indicated, a negative NAO anomaly is usually accompanied by above normal air temperatures and weaker winds over the Labrador Sea in winter. Moreover, the Labrador Sea retains a memory of the past atmospheric conditions over several years. The early winter air temperature anomalies ranged from 9.4^{o}C (Iqaluit) to -0.8^{o}C (St. John's, only negative value, February) for the 5 northern sites (Fig. 4). Anomalies at these sites became generally negative from March to May.

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 2007 were to the west over the Labrador Sea and to the south over the Labrador Shelf (Fig. 8). Over Atlantic Canada, winter wind anomalies were predominantly to the east (Fig. 9). The anomalous winds in the spring were generally to the southwest and weak over the Labrador Sea; over Atlantic Canada, the wind anomalies were stronger than over the Labrador Sea and were generally to the southeast. The pattern changed in summer, with wind anomalies to the northwest dominating the northern area and to the north prevailing over the southern regions. The fall wind anomalies were generally southward over the Labrador Sea and were weak and variable over Atlantic Canada.

SEA ICE OBSERVATIONS

The spatial distribution and concentrations of sea ice are available from the daily ice charts published by the Canadian Ice Service of Environment Canada in Ottawa. We compare the current year's ice statistics with the long-term median, maximum and minimum positions of the ice edge (concentrations above 10%) 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 during 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 when ice was present) and were subtracted from the 2007 values to obtain anomalies.

Until 2006, the ice extent for Newfoundland-Labrador and the Scotian Shelf were defined as the area enclosed by ice with at least one tenth coverage. A given area with one or nine tenths ice was recorded as the same ice extent. Beginning with the 2007 research documents, we have accounted for the amount of ice cover and report the ice area or cover, not the ice extent. This means that the current plots of ice area scale differently than in the past presentations of ice extent in terms of the absolute magnitude; however, correlations of the new with the old time series are extremely high ($r^2 > 0.98$). Therefore, the interpretation of past variability does not change given the new way of reporting ice cover. Some early years did not have the data in a format that allowed revised computations of area; this means that 1969 is the first year for which a quantitative assessment of ice area can be made.

Ice cover can be estimated well by remote sensing; moreover, it provides an index that can be related to the initiation and maintenance of the spring phytoplankton bloom. On the other hand, identical ice cover but differing ice thickness, leading to different ice volumes, could distinguish a winter with above or below normal heat losses. Ice volumes have been estimated for the three regions using a look up table that assigns characteristic thicknesses to particular ice types, since observations of ice thickness are not available. While this is not an ideal way to estimate ice volumes, it does provide a basic assessment that can be used as an additional climate index and a reference point for testing ice models. The Canadian Ice Service does not generally compute ice volume estimates for Canadian Waters. They give two main reasons for this (S. McCourt, pers. comm; steve.mccourt@ec.gc.ca): "1. Ice types are reported in terms of "stage of development" which have an associated range of thickness. For example "first-year ice" has an associated range of thickness of 30cm to 120cm. It is therefore difficult to assign a "typical" thickness and in the case of first-year ice, the value assigned will vary from area to area (i.e. first-year ice in the Gulf would have a different thickness than first-year ice in the Arctic). 2. Old ice in particular is extremely difficult to estimate thickness and subsequent volume, however, for the Gulf of St Lawrence this should not be a limiting factor."

Newfoundland and Labrador

Sea Ice. At the beginning of 2007, sea ice was found off the southern Labrador coast south to the mouth of the Strait of Belle Isle (Fig. 10A), slightly less than the long-term median. By mid-January, ice had spread farther south past the mouth of the Strait but just to the tip of the Northern Peninsula. Both the southern and offshore extent was less than the long-term median coverage. The distribution advanced to Baie Verte Peninsula (~49.5^{o}N) by February 1 with the cover still less than the median. By March 1, ice cover remained north of Avalon Channel and the Grand Bank, less than the long-term median over the Newfoundland-Labrador Shelf. The ice was essentially equal to the long-term median distribution on April 1 (Fig. 10B). By May 1, the southern ice extent remained the same but the offshore extent decreased compared to April 1. Ice was found along most of the coast north of Cape Bonavista on June 1, exceeding the median distribution by a considerable amount. The ice had retreated north of the Strait of Belle Isle by June 15.

Ice appeared along the Labrador coast and at the mouth of Belle Isle Strait by January 1, 2007 (day 0, upper panel Fig. 11); it reached the northern Avalon Peninsula by late February (day 60). Relative to the long-term mean, ice appearance typically varied from normal (0 contour, lower panel Fig. 11) to ~15 days later than normal over most of the Newfoundland and Labrador Shelf region. 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 late May to early June (day 150-165). Ice persisted in the most northern part of the analysis region until the end of June (day 180). Over much of the Newfoundland and Labrador Shelf, it disappeared about 2 weeks to 1 month later than normal (positive anomaly, Fig. 12, lower panel).

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 from an area for a time and then reappear. In 2007, the duration ranged from <30 days north of Grand Bank to over 210 days along the Labrador coast (Fig. 13, upper panel). The 2007 pattern, with ice present for generally 10-20 days longer than normal (Fig. 13, lower panel), is quite different from the durations in 2006 and 2005, which were 20-60 days shorter than normal.

The time series of the monthly ice cover on the Newfoundland and southern Labrador shelves (45-55^{o}N; I. Peterson, pers. comm., Bedford Institute) show that the peak ice area during 2007 was slightly more than in 2006, and the 9th least December-June cover in 38 years (Fig. 14, 15). The 2007 cover was 1.2 SD below normal. On the other hand, the ice lingered in significant amounts on the shelves through May and June; the ice cover in these months was the greatest since 1994 and caused coastal fishing vessels to become locked in ice during the sealing season (E. Colbourne, pers. comm.). Ice volume (Dec-June) for 2007 was below normal by 0.6 SD, the twelfth year with less than average volumes (Fig. 16). This places the past year in the centre of the ice volume distribution, with 2007 ranking the 19th least volume in 38 years.

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 1985-2007 period is considered to have reliable SLAR measurements. During the 2006/2007 iceberg season (October 2006 to September 2007), 324 icebergs were detected south of 48^{o}N, an increase from 2006, when none were observed but substantially less than the 1985-2007 mean (Fig. 17).

Gulf of St. Lawrence

The locations of the ice edge within the Gulf of St. Lawrence during the 2006-2007 winter season are shown in Fig. 18. Ice first appeared in late December as very small patches in the Estuary and on the New Brunswick coast. Over the next 15 days, ice cover increased very little and was substantially less than the median. By February 1, ice cover increased substantially and covered the Estuary, the north shore of the Gulf and most of the Magdalen Shallows; however, the cover was still less than the long-term median. By April 1, for the greater part, ice was confined to the northeastern Gulf southeast of the Strait of Belle Isle, and the Magdalen Shallows. From April 1 to June 1, ice was mostly confined to the northeastern Gulf.

Ice first appeared in the Gulf of St. Lawrence in January and generally within 15 days of normal (Fig. 11). The last presence of ice varied from mid-March to the end of May; this was typically 0-15 days earlier than normal in the Magdalen Shallows but up to 30 days later than normal in the northeastern Gulf (Fig. 12). Ice duration varied from less than 30 days off southwestern Newfoundland to 150 days in the northeastern Gulf (Fig. 13); ice duration was less than the long-term mean by about 20-30 days everywhere in the Gulf with the exception of the northeastern region, where ice remained slightly longer than normal by ~10 days.

We have estimated the monthly mean ice areas in the Gulf as continuous time series (Fig. 19A, upper panel) and as time series for individual months (Fig. 19B). The time series shows that in 2007 the December-April cover was the second lowest in 38 years (1970-2007) and 2.2 standard deviations below normal. Only the 2006 ice cover was less. Estimates of maximum ice duration showed that on average, the 2007 season was 10 days longer than the 1971-2000 average maximum duration (Fig. 19A, middle panel). However, this was confined to a small area in the northeastern Gulf; Fig. 13 indicates that for most of the Gulf, the duration was shorter than normal. The product of ice cover times the duration for the entire 2007 ice season was about 49% of the 1971-2000 average, 2.1 standard deviations below normal (Fig. 19A, lower panel). To summarize, 2007 featured below normal ice cover 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 2007, ice first appeared seaward of the Strait in early February, which is approximately the normal time for first appearance (Fig. 12). In fact, some ice appeared on January 26 but was less than one tenth cover and was restricted to the eastern shore of Cape Breton. The first concentrations of ice greater than one tenth were observed on February 6, when concentrations of three tenths moved from the Gulf to Sydney Bight. By February 10, ice had filled all of Sydney Bight. The maximum extent of ice on the Scotian Shelf occurred between late February and mid-March. Overall the last presence of ice was about normal (Fig. 13). The duration of ice cover on the Scotian Shelf was slightly longer than normal (Fig. 14). The January-April ice cover was 0.8 SD below normal, the 15th lowest in the 39 year record (Fig. 20, 21).

Remotely-Sensed Sea Surface Temperature

A 9 km resolution Pathfinder sea surface temperature database is maintained at BIO. In the following analysis, we substituted the 18 km resolution Multi-Channel Sea Surface Temperature (MCSST) data, an earlier, lower spatial resolution product, from 1999 for the Pathfinder observations from that year because there was serious degradation of the latter, particularly towards the end of the year. This deterioration of the Pathfinder data quality was not evident in other years nor was it found for the MCSST data. The Pathfinder 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 from the satellites 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 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 series. Anomalies were based on 1985-2007 data.

Annual anomalies for 23 subareas, stretching from the Labrador Sea to the Gulf of Maine (Fig. 22), were determined from the averages of monthly anomalies and arranged from north to south (Fig. 23). In 2007, anomalies ranged from -0.8 ^{o}C (-1.5 SD) over the western Scotian Shelf to 1.5^{o}C (2.0 SD) over the Labrador Shelf. Eighteen of the twenty-three areas had positive anomalies, but only 7 were greater than 0.5 SD. Of the 5 areas that had negative anomalies, 3 had values <-0.5 SD. The average anomaly over the Labrador Shelf was 0.7^{o}C, 0.4^{o}C over the Newfoundland Shelf, 0.5^{o}C in the Gulf of St.

Lawrence and -0.3^{o}C over the Scotian Shelf. The eastern and central Scotian Shelf were 0.3^{o}C above normal, while the western shelf and Lurcher Shoals were 1.2^{o}C below normal.

SUMMARY

In 2007, the NAO index returned to a positive value, but only slightly above normal (2.5 mb, 0.3 SD). A positive index implies stronger winds from the northwest, cooler air temperatures and increased heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. The mean annual air temperatures decreased at all sites except Cape Hatteras in 2007, but still remained above normal by ~1^{o}C over the Labrador Sea and Shelf, 0.3^{o}C over the Grand Banks, and ~1^{o}C over the Gulf of St. Lawrence. On the other hand, annual air temperatures over the Scotian Shelf and Gulf of Maine were about 0.2^{o}C below normal. The average December-June Newfoundland and Labrador sea ice cover and ice volume were 1.2 and 0.6 SD below normal respectively. However, ice persisted on the east coast north of Cape Bonavista for longer than it has in recent years. The Gulf of St. Lawrence ice cover (Dec-Apr) in 2007 was the second lowest in the 38 year record with only 2006 having less cover. Below normal conditions (-0.8 SD) also prevailed on the Scotian Shelf with ice cover (January-April) the 15th least in 39 years. Three hundred twenty-four icebergs reached the Grand Banks in 2007, a substantial increase from 2006 when none were observed but still well below the long-term mean. The analysis of satellite data indicates a northeast to southwest gradient of sea surface temperature anomalies similar to the air temperature anomaly distribution, i. e., generally above normal SST (by ~0.7^{o}C) to the northeast and below normal values (-0.6^{o}C) over the western Scotian Shelf, Lurcher Shoals and Georges Bank. Eighteen of twenty-three areas had positive annual SST anomalies; values ranged from -0.8^{o}C (western Scotian Shelf) to 1.5^{o}C (Labrador Shelf).

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 1998-2006 was warmer than normal (Fig. 24, 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 the past year, 10 of the 23 series had anomalies that were within 0.5 SD of normal, 10 had anomalies that were greater than 0.5 SD above normal, and 3 had values less than -0.5 SD of normal. This represents a very large change since 2006, the warmest year on record based on these indexes.

The mosaic plot can be summarized as a combination bar and line-scatter plot (Fig. 24, 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 1998-2007 are apparent. In 2007, this composite index was slightly positive, a significant decrease from 2006 when it had its highest value. The decrease from 2006 to 2007 is the greatest change in the times series.

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 Peter Galbraith 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.

Colbourne, E., J. Craig. C. Fitzpatrick, D. Senciall, P. Stead and W. Bailey. 2008. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2007. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/020, 17 p.

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.

Galbraith, P. S., D. Gilbert, R.G. Pettipas, J. Chassé, C. Lafleur, B. Pettigrew, P. Larouche and L. Devine. 2008. Physical oceanographic conditions in the Gulf of St. Lawrence in 2007. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/001, 55 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. 2008. *Monthly climatic data for the world*. Vol. 59. 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.

Petrie, B., R.G. Pettipas, W.M. Petrie and V. Soukhovtsev. 2008. Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2007. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/017, 44 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 shading differences denote the 200 m and 1000 m isobaths.

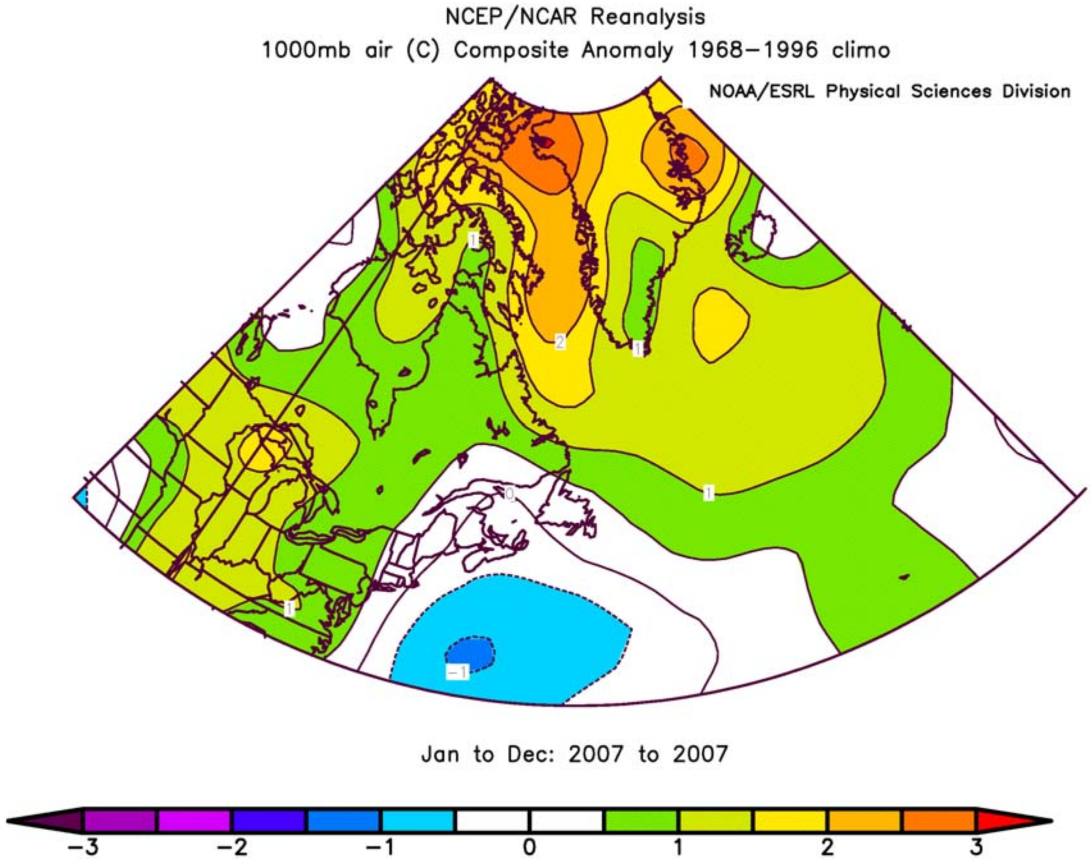

Fig. 2A. The 2007 annual air temperature anomaly (ºC) over the Northwest Atlantic relative to the 1968-1996 means from http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl

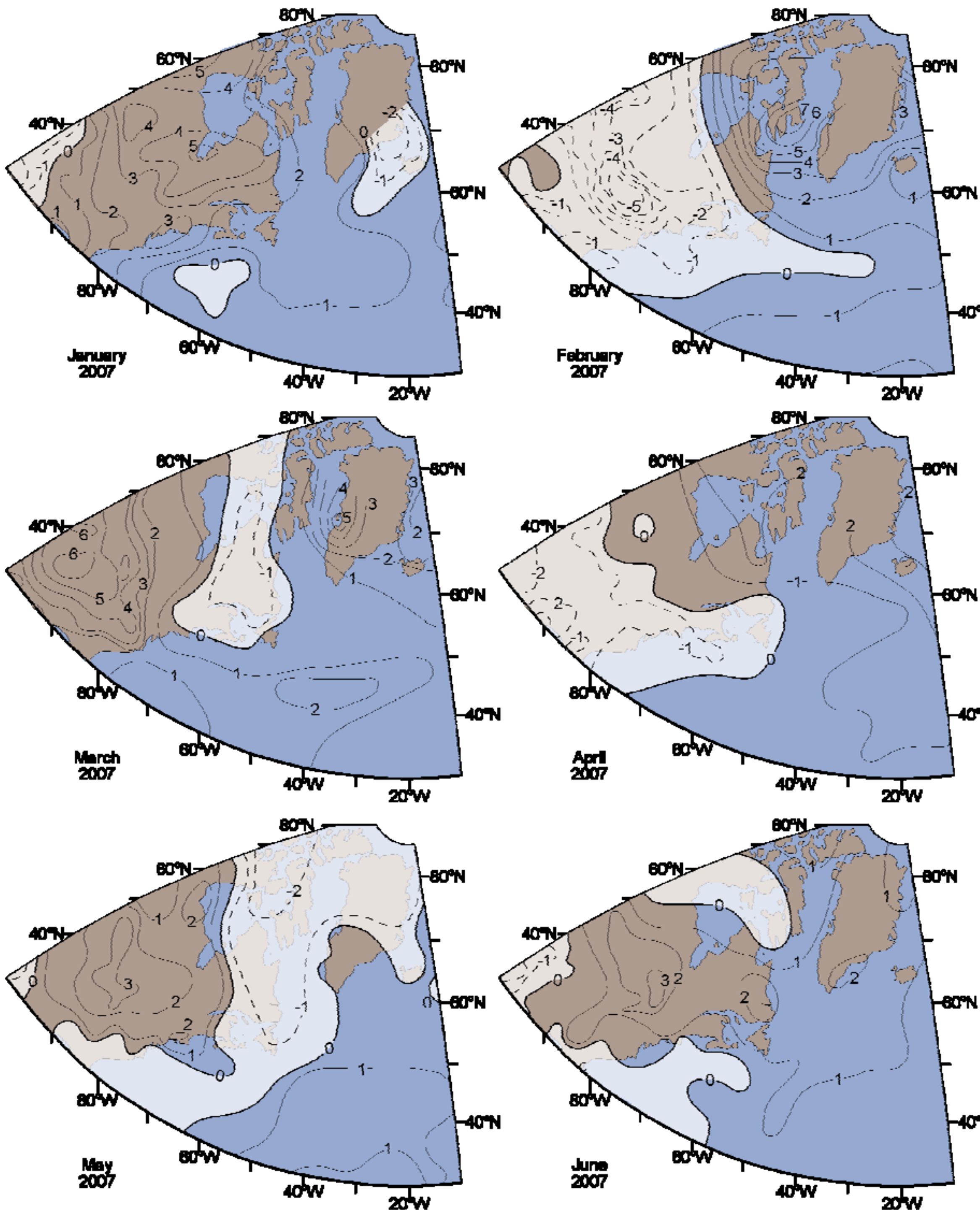

Fig. 2B. Monthly air temperature anomalies (°C) over the Northwest Atlantic from January to June of 2007 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

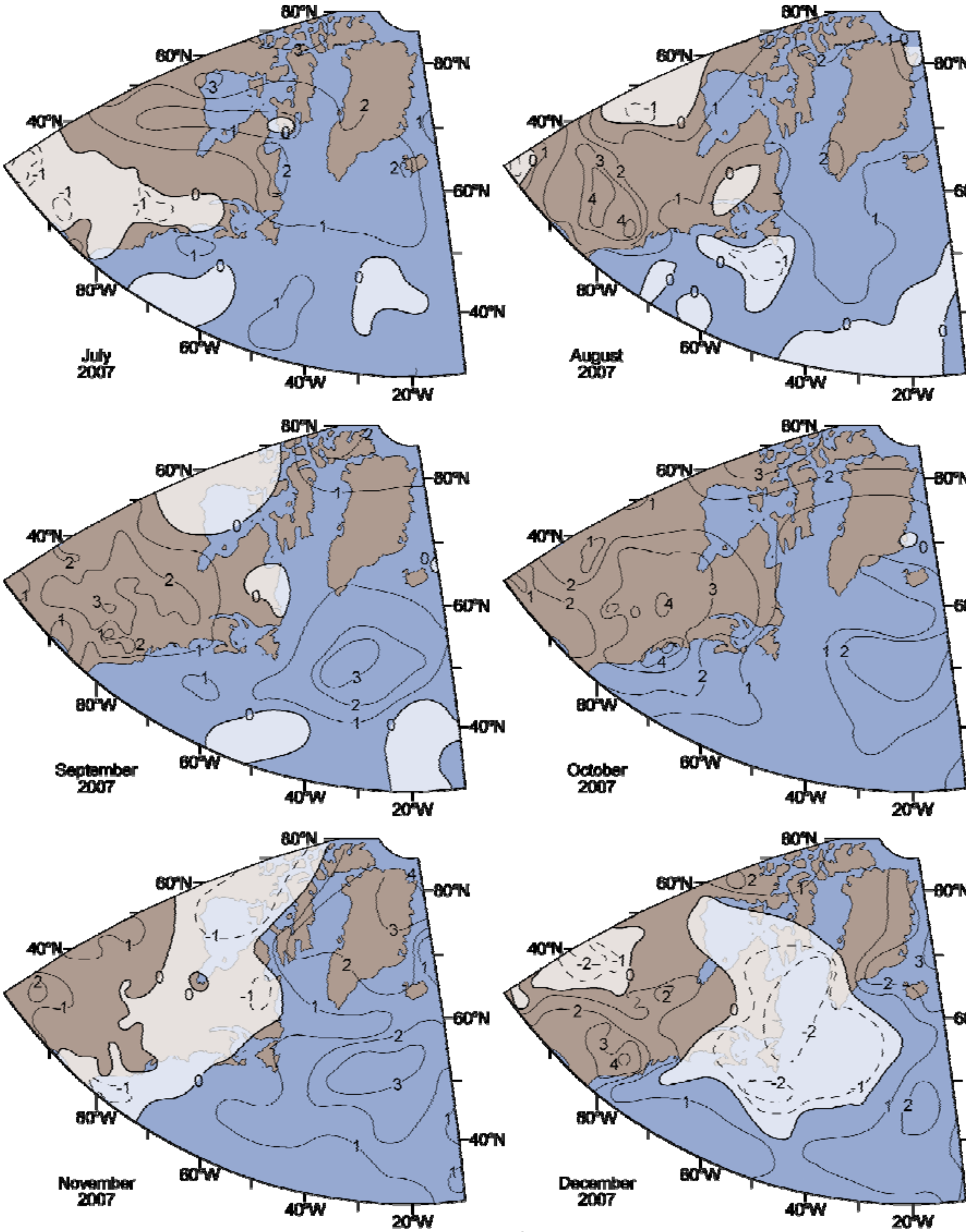

Fig. 2C. Monthly air temperature anomalies (°C) over the Northwest Atlantic from July to December of 2007 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

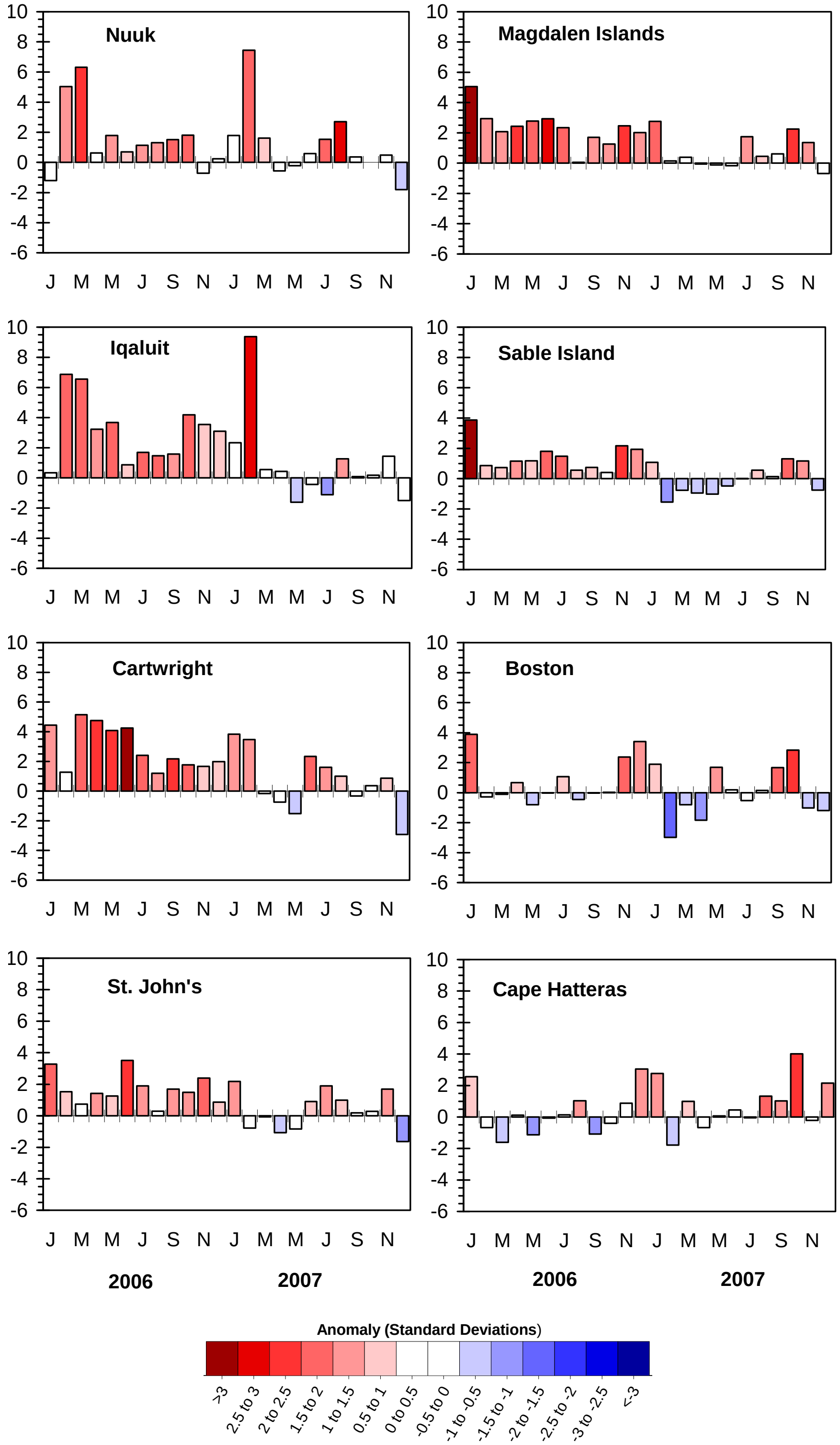

Fig. 3. Monthly air temperature anomalies in 2006 and 2007 at selected coastal sites (see Fig. 1 for locations). Anomalies are colour coded in terms of the numbers of SD above or below normal.

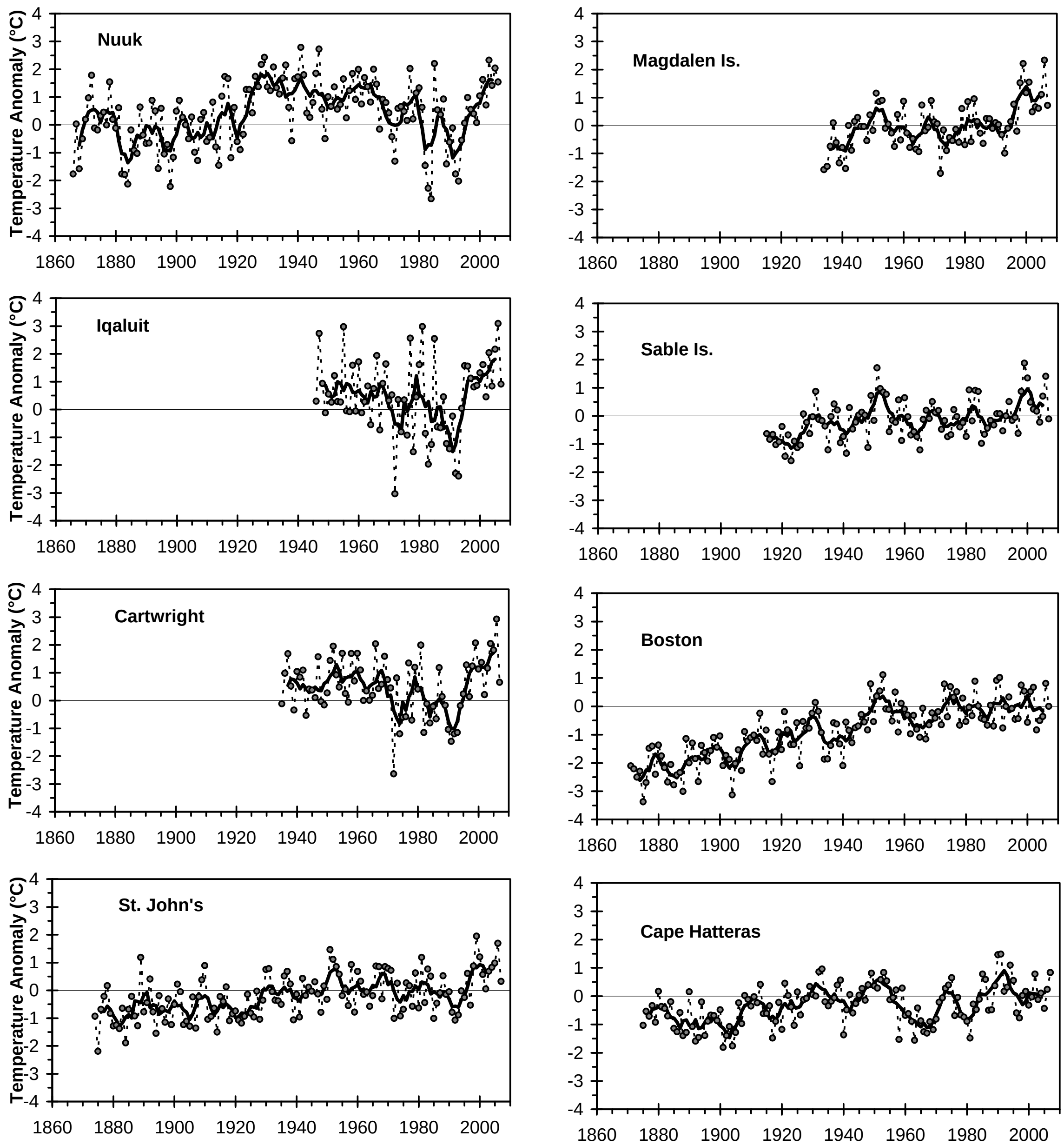

Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

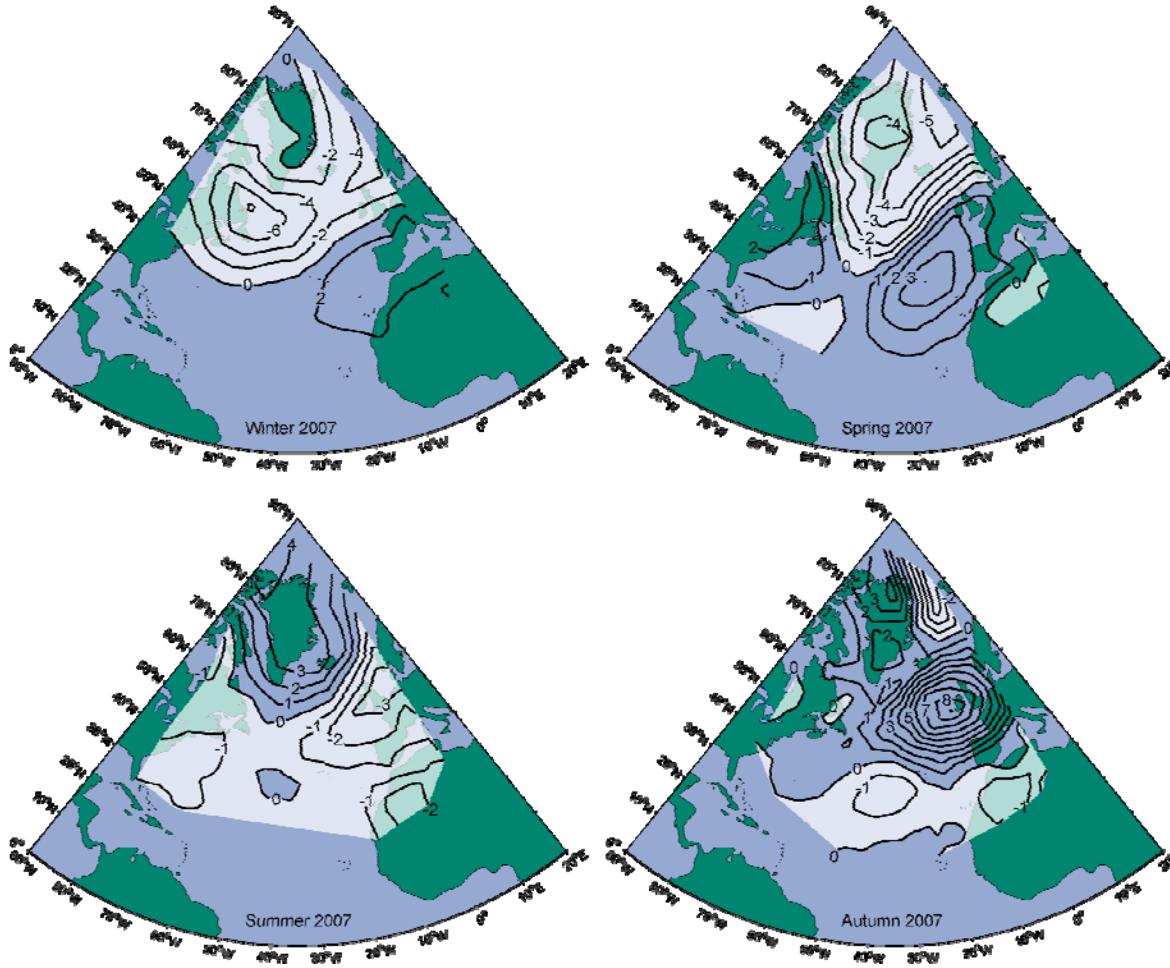

Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2007 relative to the 1971-2000 means. Winter includes December 2006 to February 2007, spring is March to May, summer is June to August and autumn is September to November.

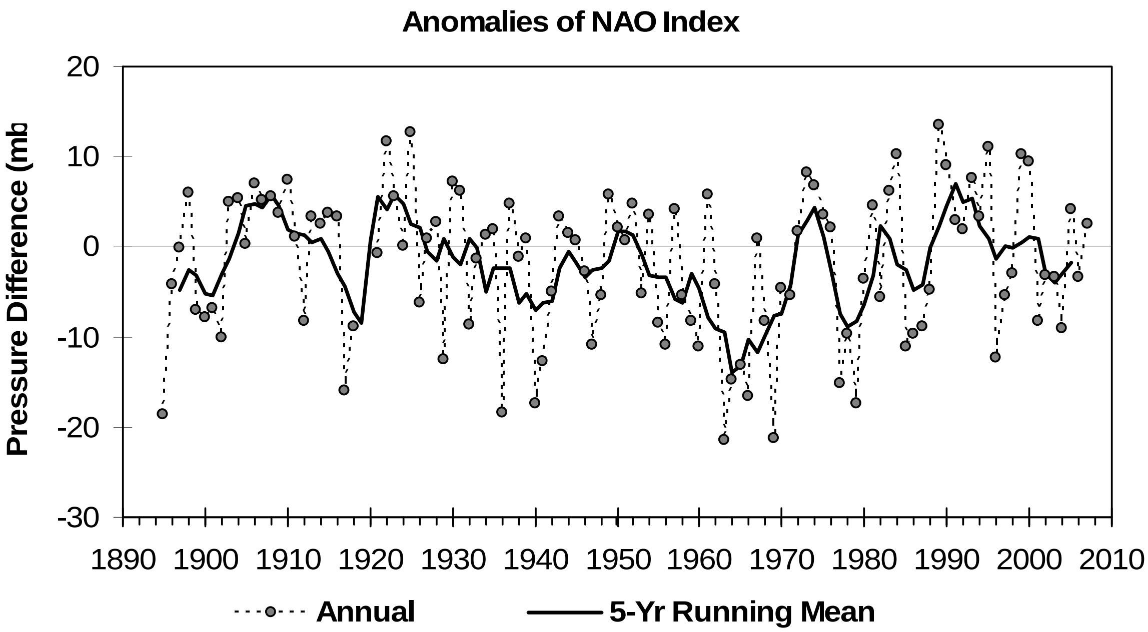

Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

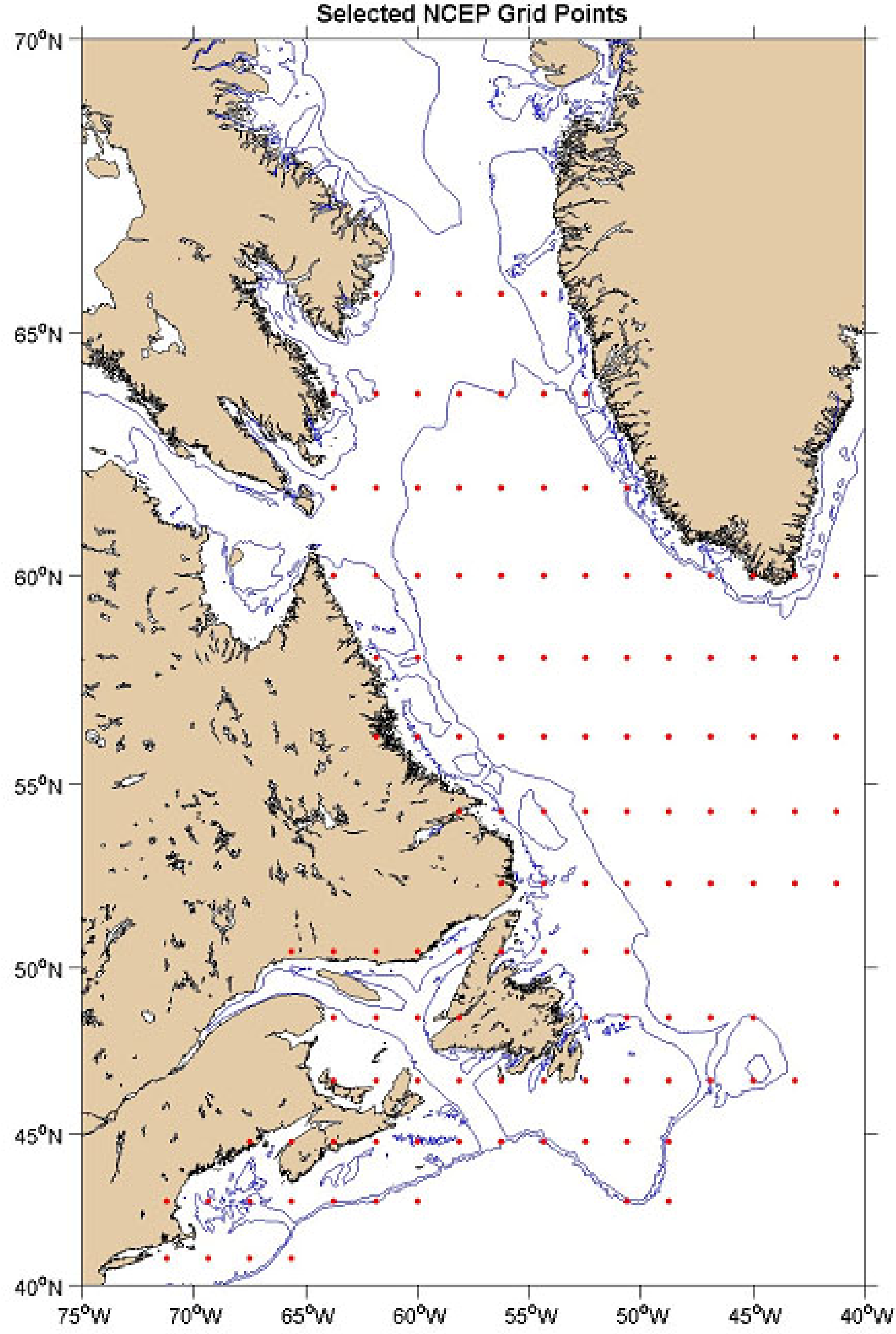

Fig. 7. The Northwest Atlantic showing the NCEP wind grid used in our study.

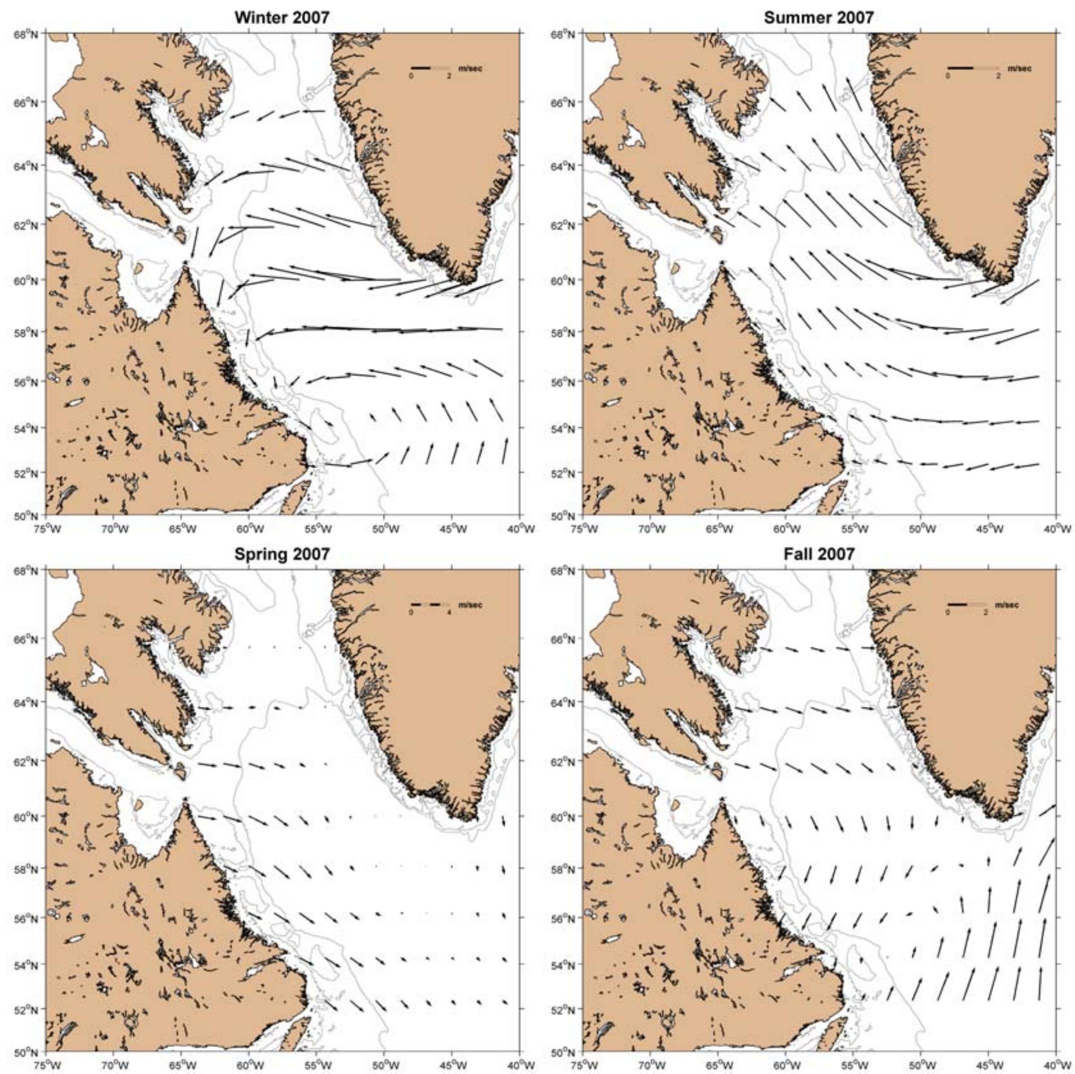

Fig. 8. The seasonal wind anomalies for the northern region during 2007. Note the different scale (0-4 m/s) for spring.

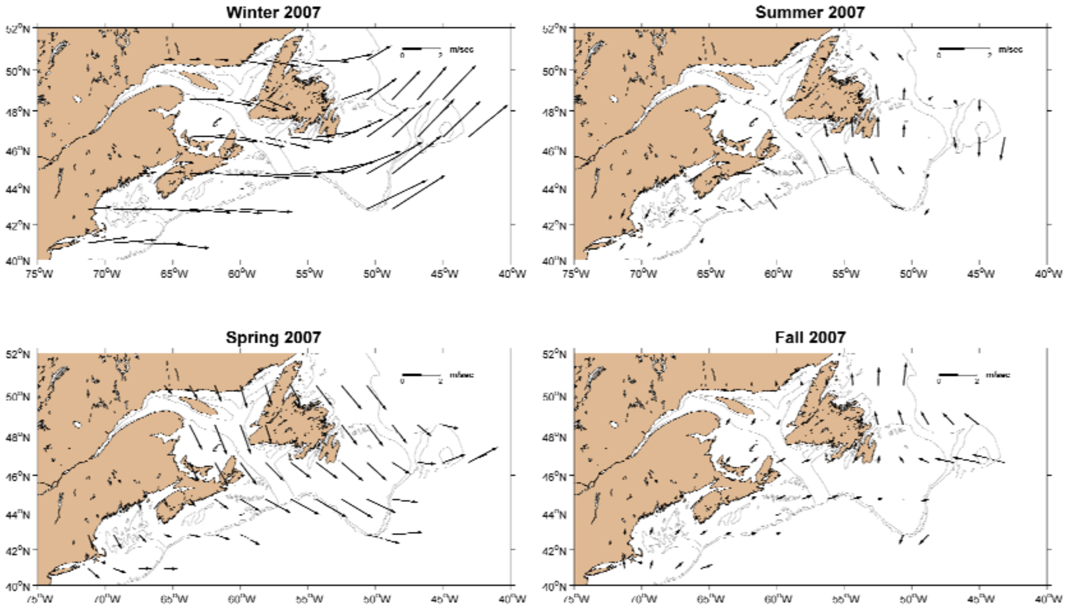

Fig. 9. The seasonal wind anomalies for the southern region during 2007.

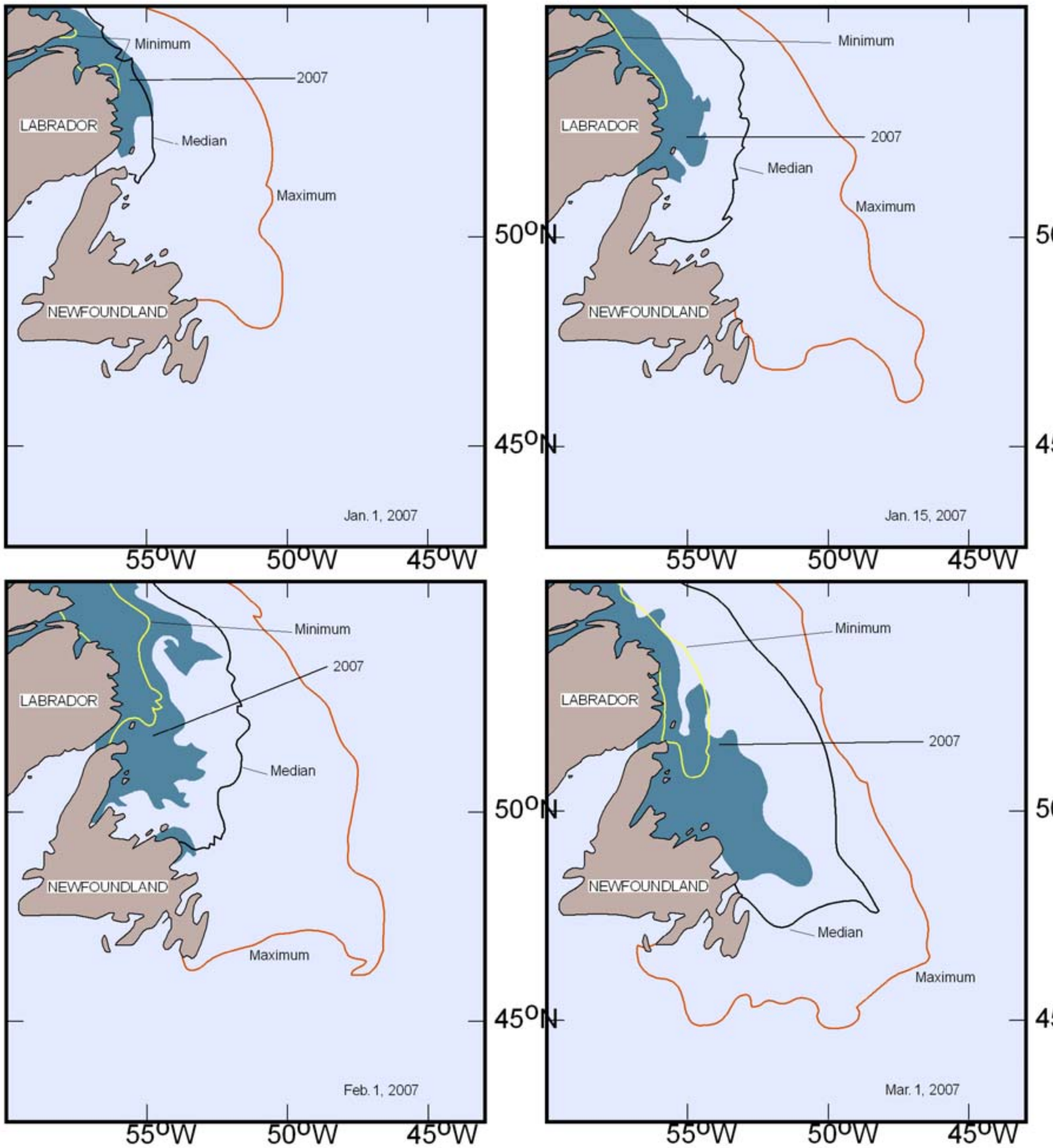

Fig. 10A. The location of the ice (shaded area) between January and March 2007 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off the coasts of Newfoundland and Labrador. The positions of the ice edge in the Gulf of St. Lawrence are omitted in this figure.

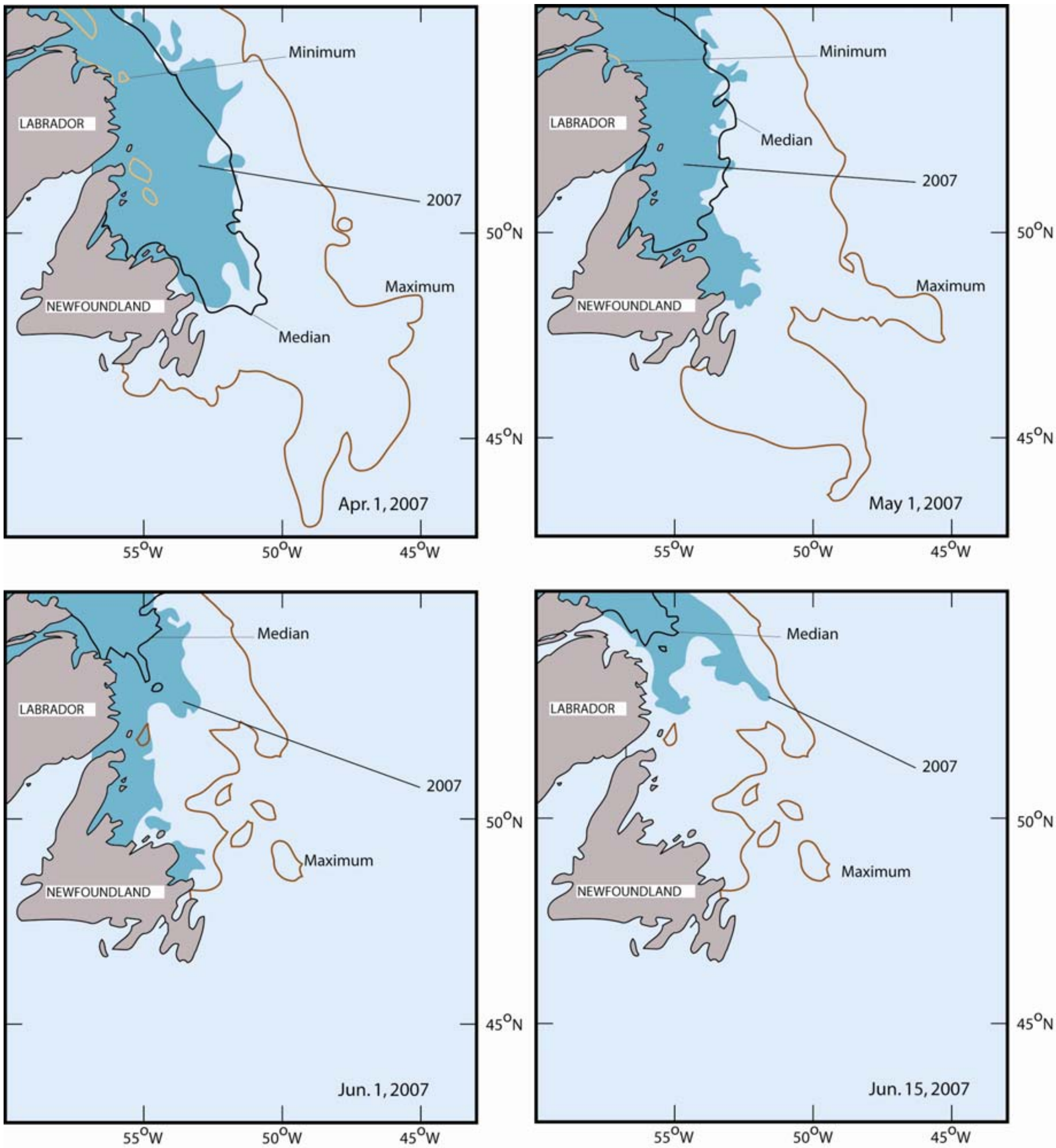

Fig. 10B. The location of the ice (shaded area) between April and June 2007 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador. The maximum extent for June 1 is shown for the June 1 and 15 maps.

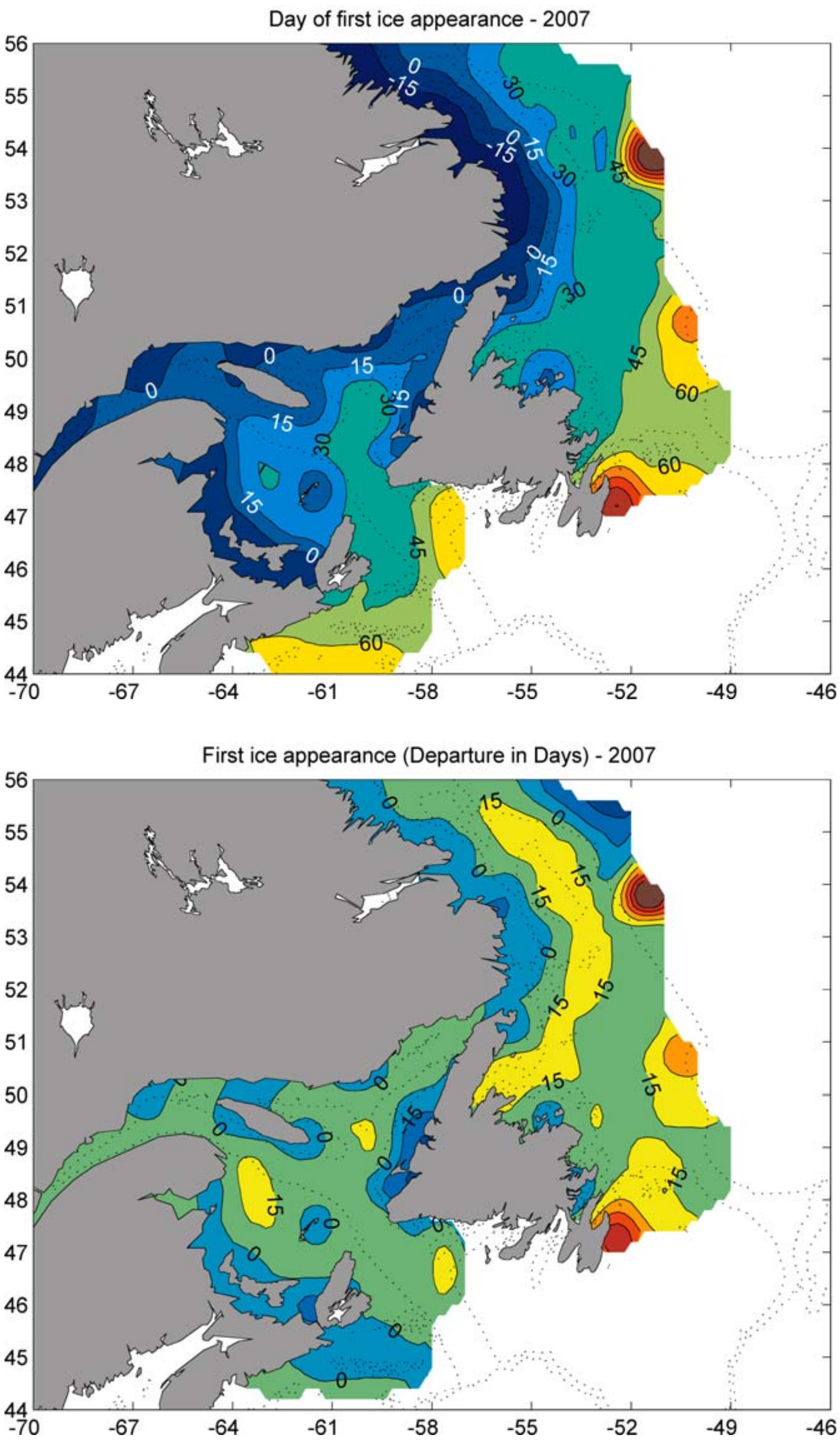

Fig. 11. The time when ice first appeared during 2007 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative (positive) anomalies indicate earlier (later) than normal appearance.

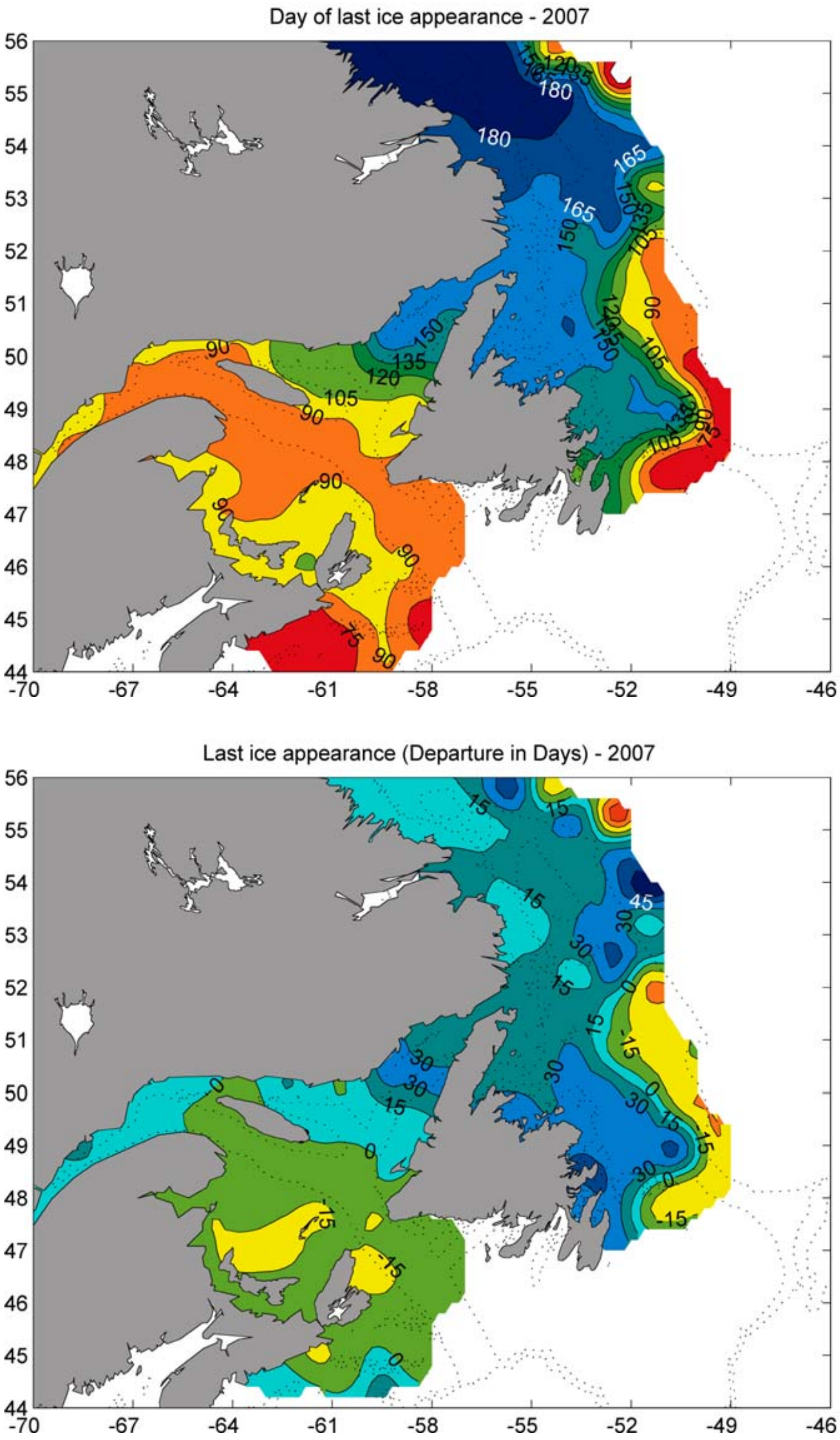

Fig. 12. The time when ice was last seen in 2007 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance.

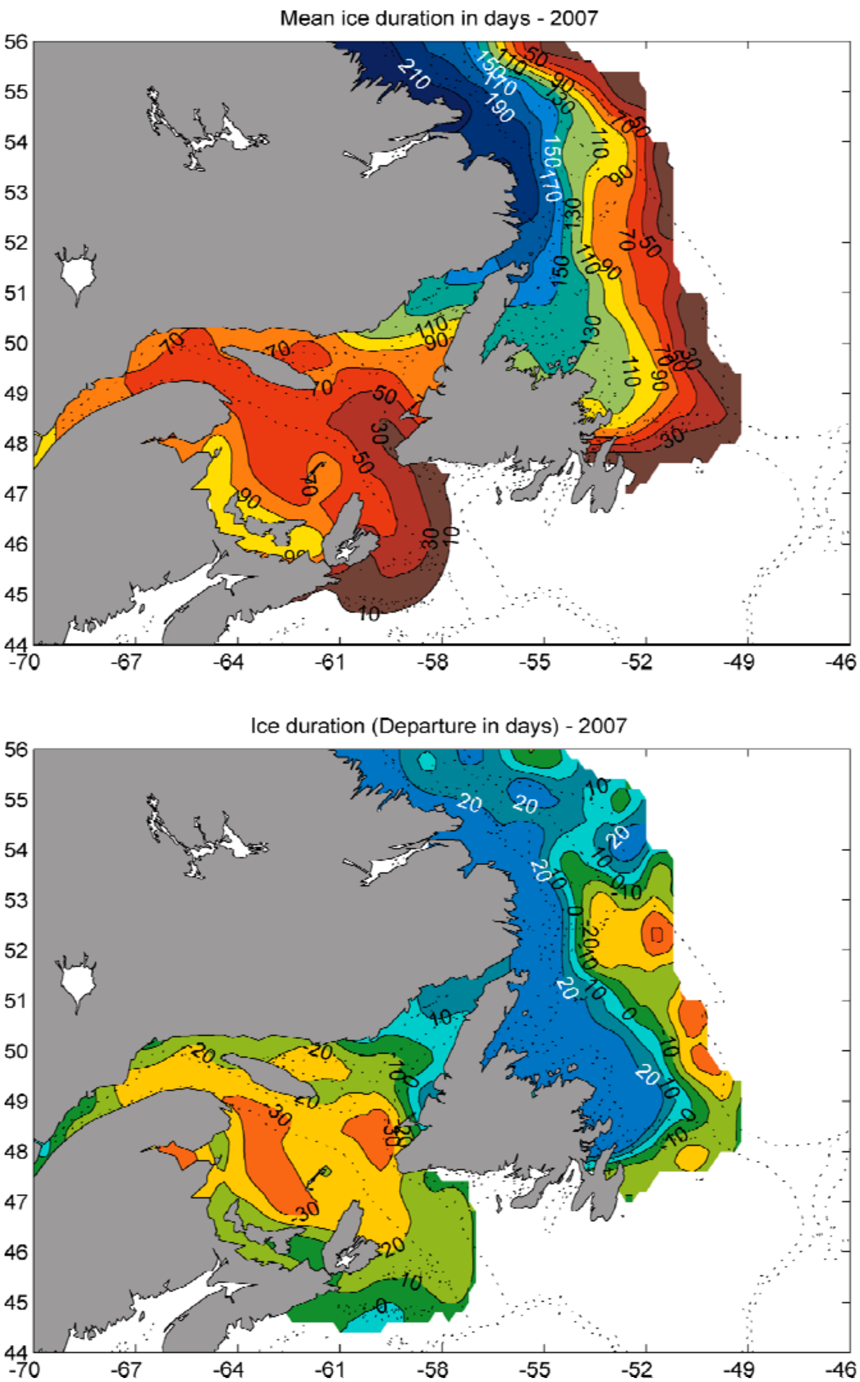

Fig. 13. The duration of ice in days (top panel) during 2007 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

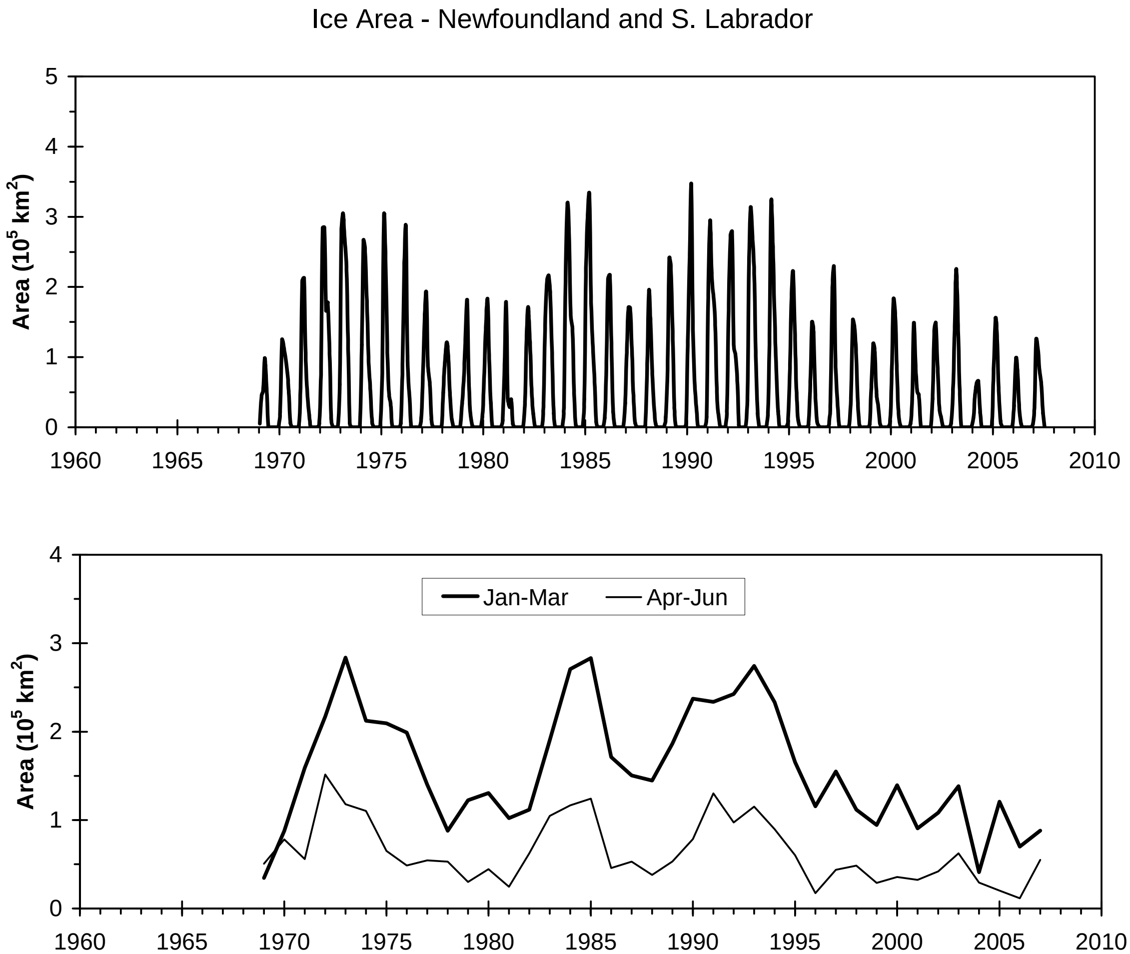

Fig. 14. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (bottom panel).

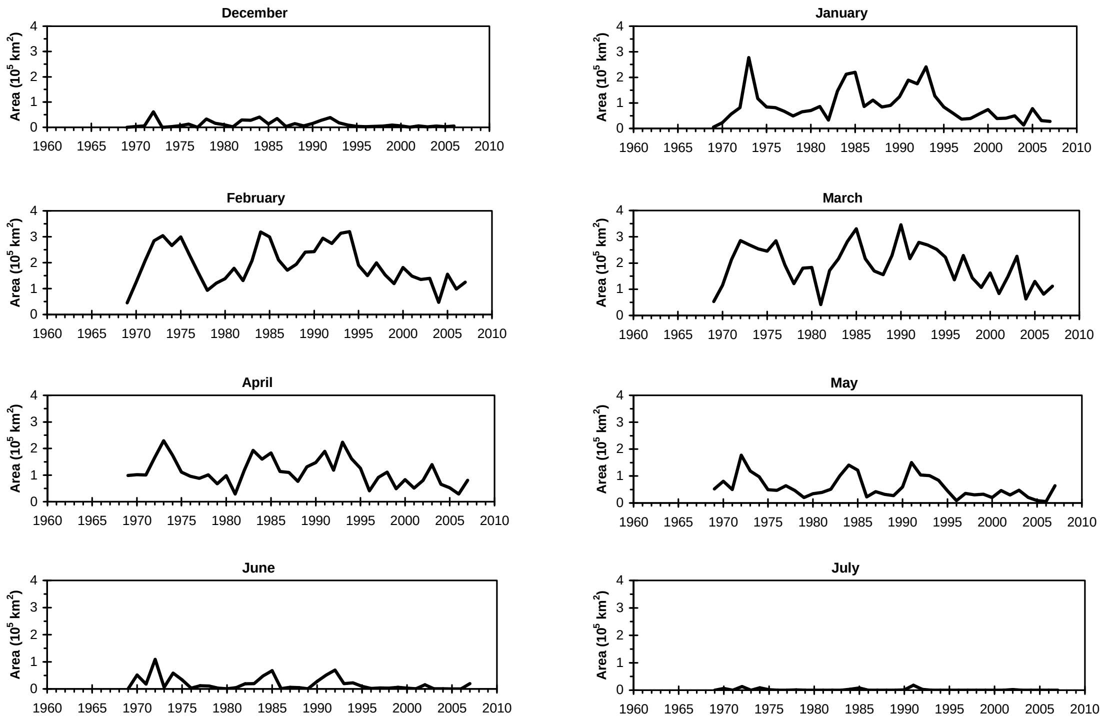

Fig. 15. Time series of ice area off Newfoundland and Labrador by month.

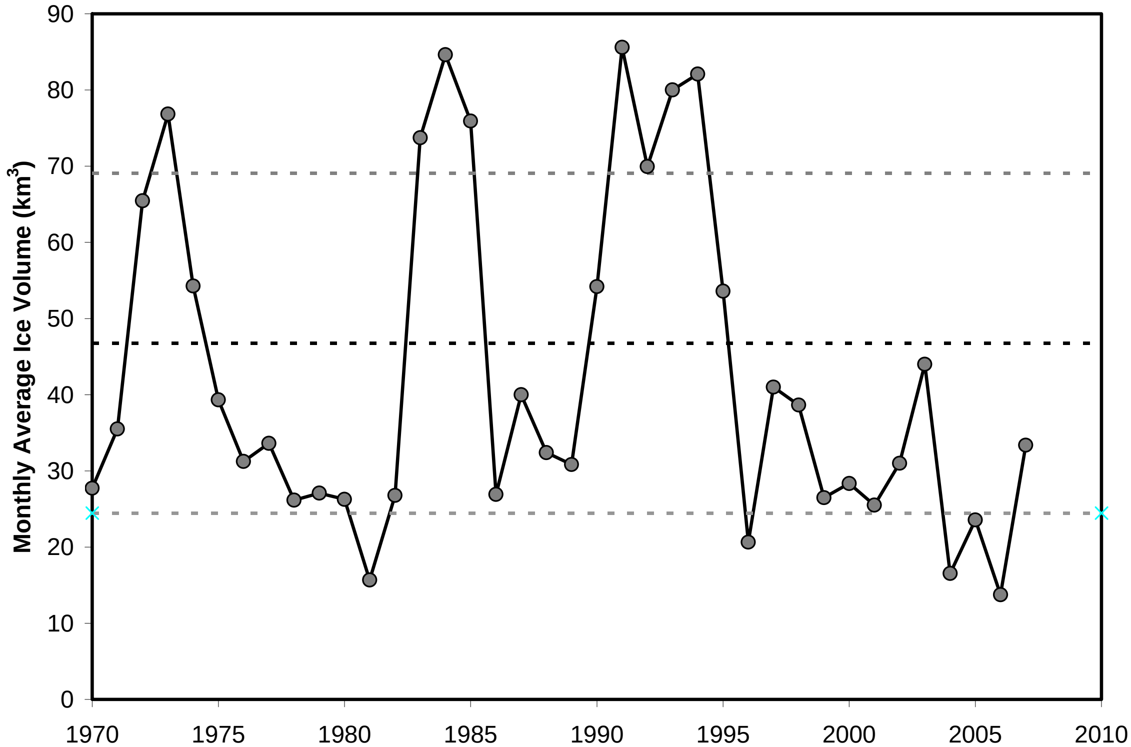

Fig. 16. Time series of the December-June monthly average ice volume off Newfoundland and Labrador between 45°N-55°N. The mean (black, dashed line) and mean ± 1 SD (grey dashed lines) are based on the 1971-2000 period.

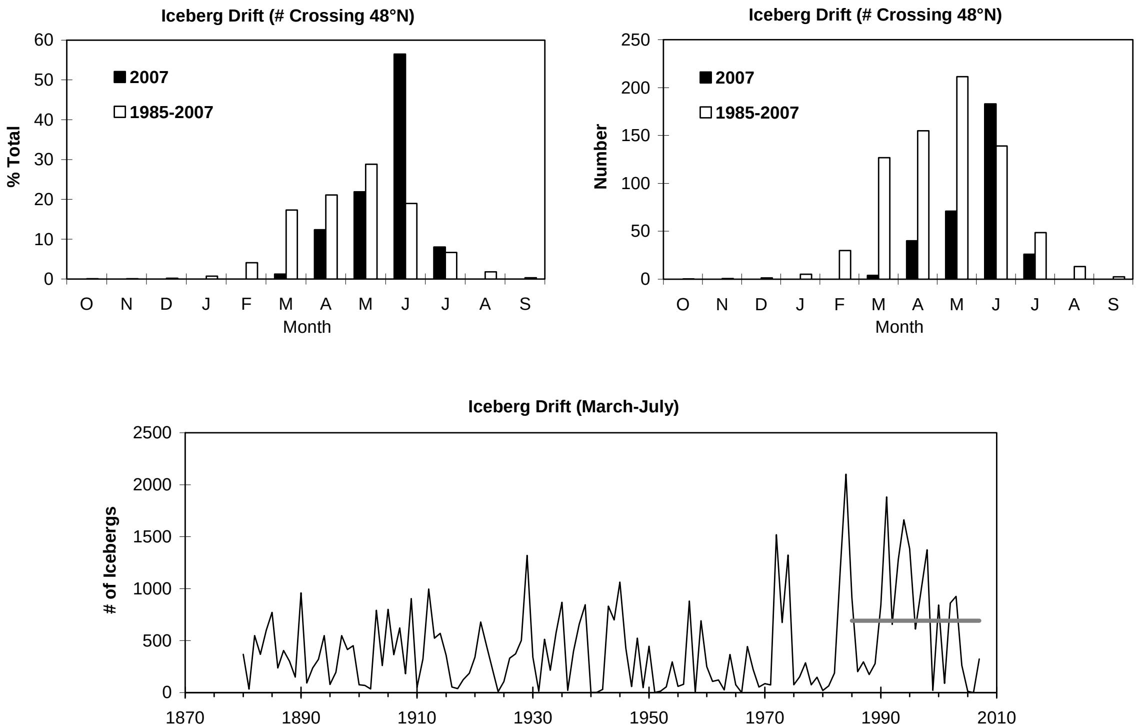

Fig. 17. The number of icebergs crossing south of 48^{o}N during the iceberg season 2006/2007 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2007 (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2007 average number of icebergs.

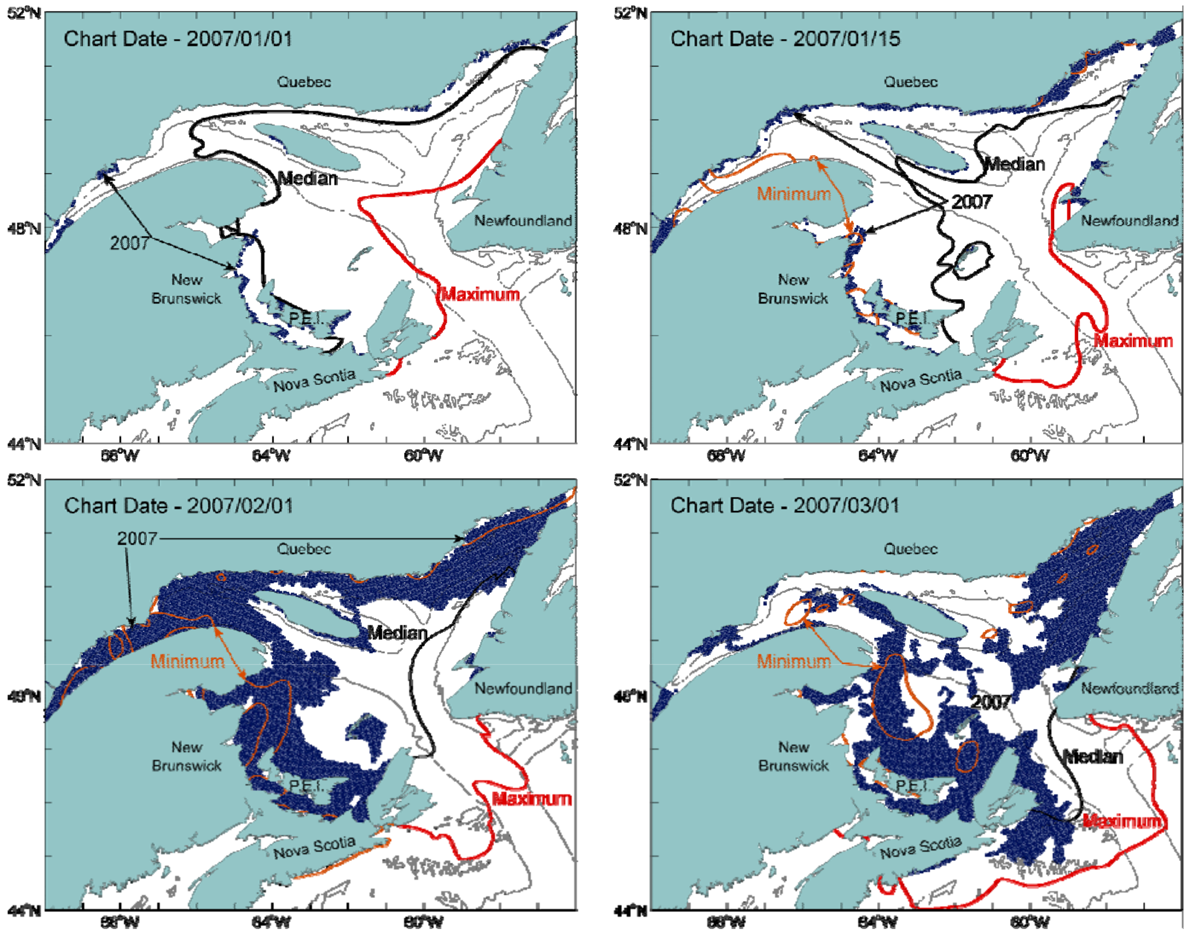

Fig. 18. The location of the ice (shaded area) between December 2006 and March 2007 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

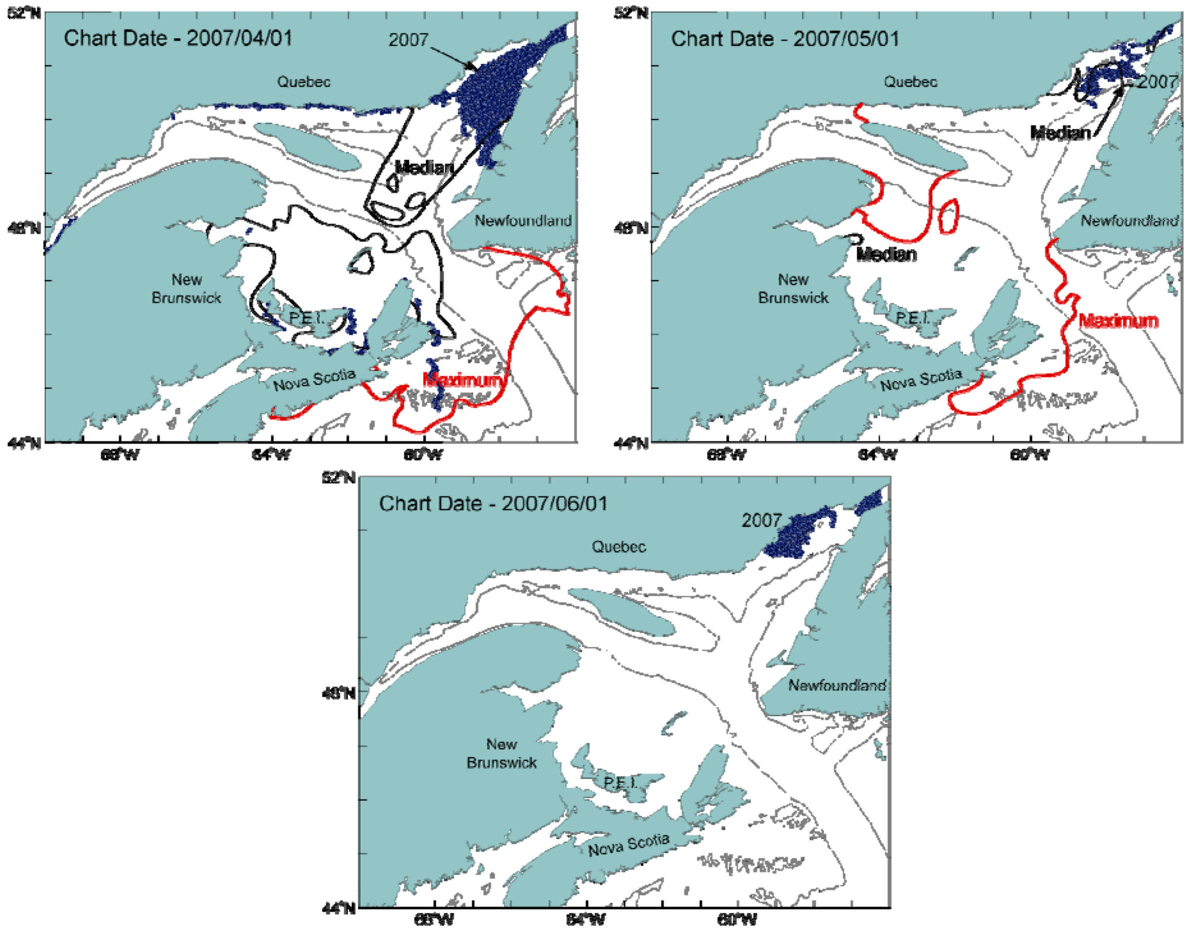

Fig. 18 (continued) The location of the ice (shaded area) between April and June 2007 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

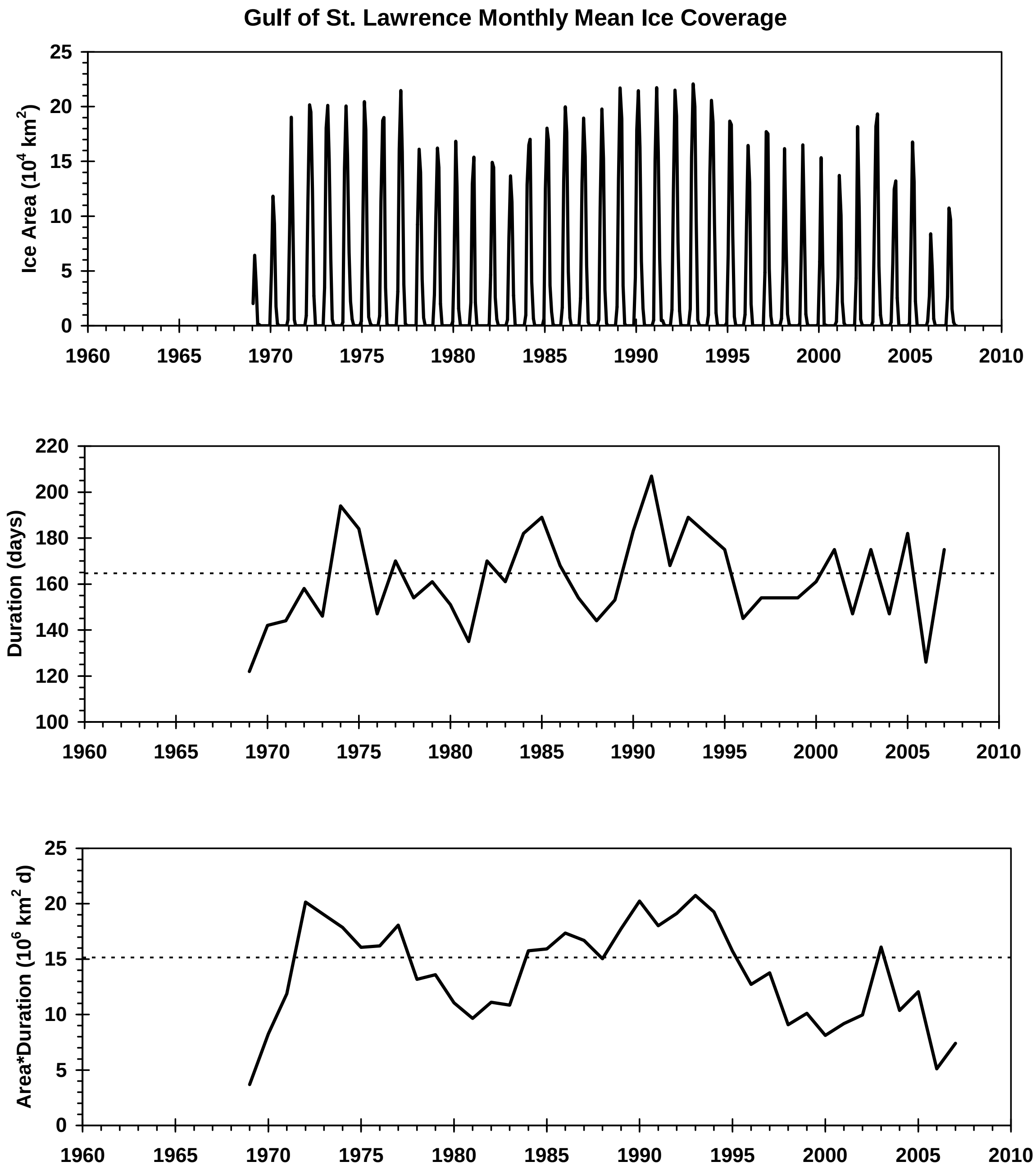

Fig. 19A. For the Gulf of St. Lawrence, the time series of the monthly mean ice area (top), the maximum duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

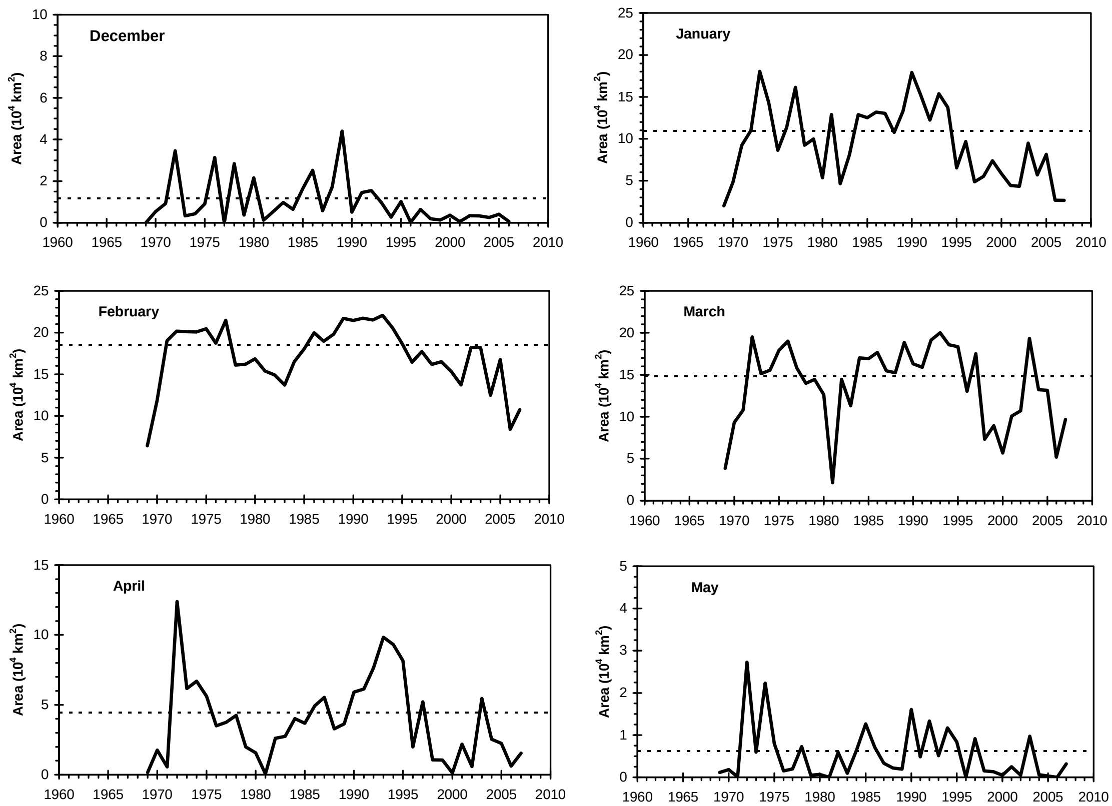

Fig. 19B. The time series of ice area in the Gulf of St. Lawrence by month. The horizontal lines represent the 1971-2000 means.

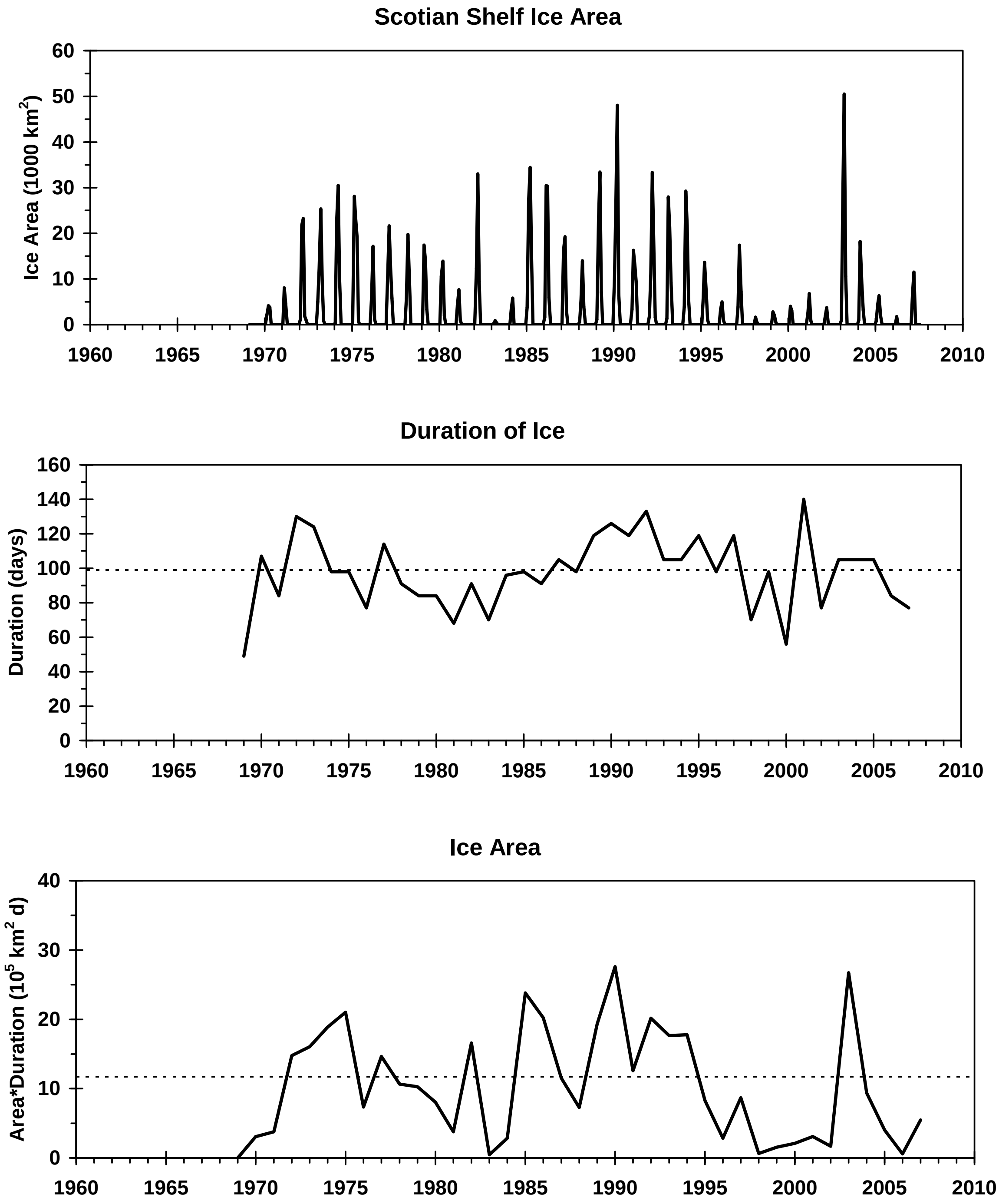

Fig. 20. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

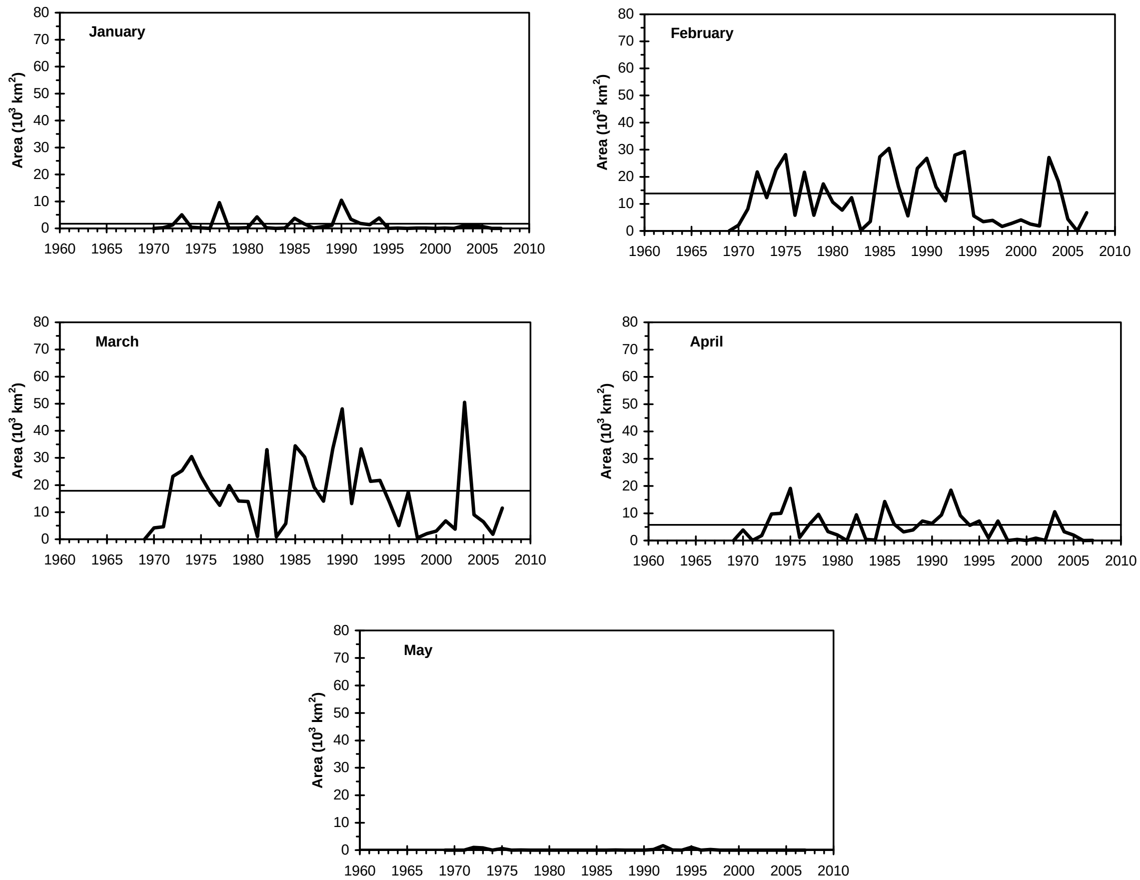

Fig. 21. The time series of ice area seaward of Cabot Strait by month is presented. The horizontal lines represent the 1971-2000 means.

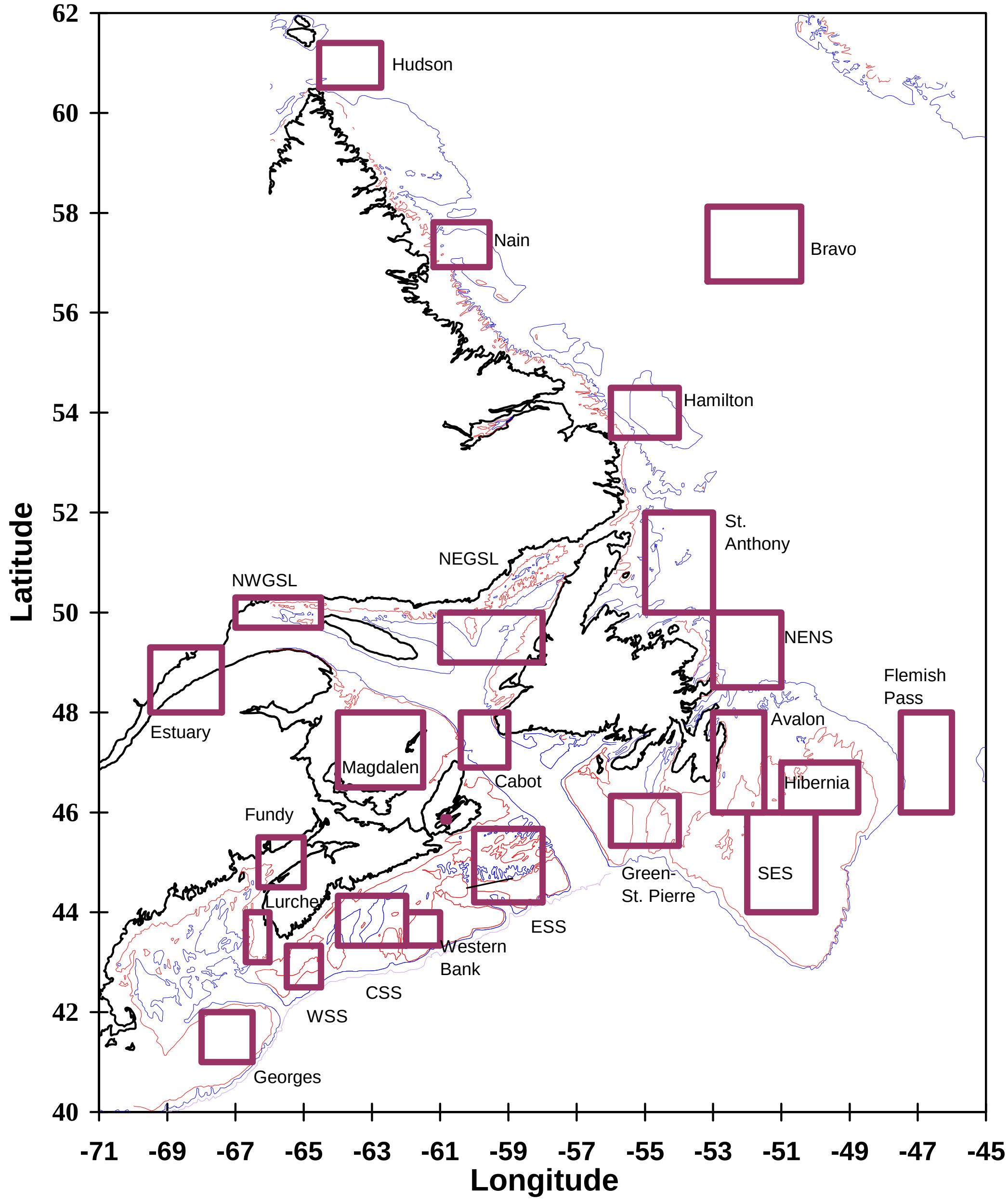

Fig. 22. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

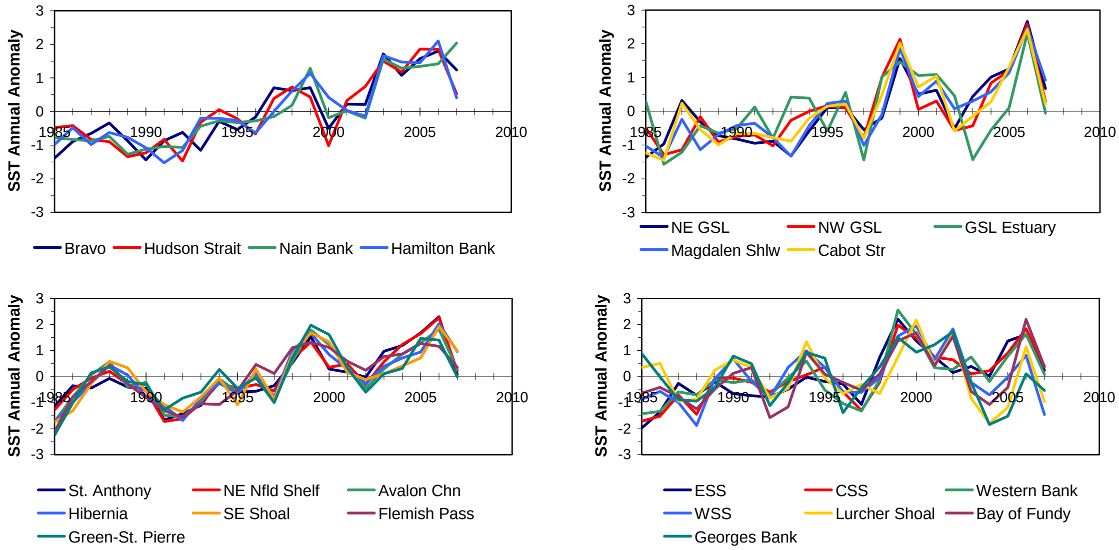

Fig. 23. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2007 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences 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.

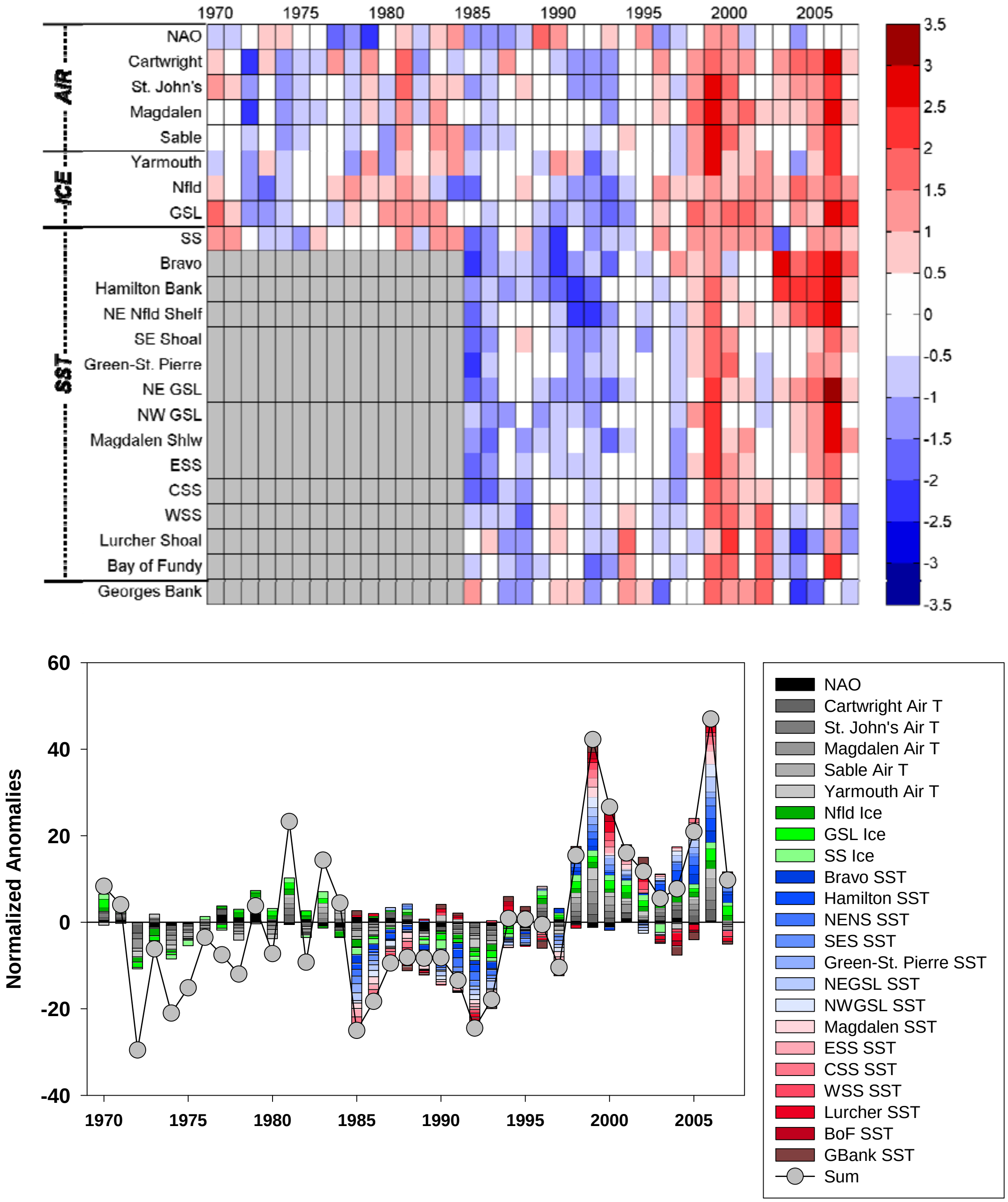

Fig. 24. Normalized annual anomalies of the NAO, air temperatures, ice and sea surface temperatures for the Atlantic region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means (except for SST where all data are used), divided by the standard deviation. The scale 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).