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Air Temperature, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2007

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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°C over the Labrador Sea and Shelf, 0.3°C over the Grand Banks, and ~1°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°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. Below normal ice conditions (-0.8 SD) 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°C) to the northeast and below normal values (-0.6°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°C (western Scotian Shelf) to 1.5°C (Labrador Shelf).

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, the North Atlantic Oscillation (NAO) winter index, sea ice cover, iceberg drift and sea surface temperatures. 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 as standardized anomalies (anomaly/standard deviation). 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 the Northwest Atlantic Fisheries Organization (NAFO) and the Fisheries Oceanographic Committee, the Department of Fisheries and Oceans. A standardized base period allows direct comparison of anomalies between sites and between variables.

Meteorological Observations

Air Temperatures

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. 2 (see Fig. 1 for locations). The anomalies are presented in 2 ways: the heights of the bars represent the anomalies in °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. 3) 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..

NAO Index

The North Atlantic Oscillation winter 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 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. 4). 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.

Sea Ice Observations

The spatial distribution and concentrations of sea ice are available from the daily ice charts published by Canadian Ice Service of Environment Canada in Ottawa. We compare the current year's ice statistics with the long-term values 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. A detailed 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) is given by Petrie et al. (2008). The weekly concentration and types of ice within 0.5° latitude by 1° longitude areas were recorded during the ice season. 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. The time series of the monthly ice cover on the Newfoundland and southern Labrador shelves (45-55°N) 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. 5A, B). 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. 5C). 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 48°N 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°N, an increase from 2006, when none were observed but substantially less than the 1985-2007 mean (Fig. 6).

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. 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. The duration of ice cover on the Scotian Shelf was slightly longer than normal. The January-April ice cover was 0.8 SD below normal, the 15th lowest in the 39 year record (Fig. 7A). Sea ice volume was 1.1 SD below normal, the 12th lowest in the 39 year record (Fig. 7B).

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, an earlier lower spatial resolution product, 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 series. Anomalies were based on 1985-2007 data.

Annual anomalies for 23 subareas, stretching from the Labrador Sea to the Gulf of Maine (Fig. 8), were determined from the averages of monthly anomalies and arranged from north to south (Fig. 9). 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. 10, 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. 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. 10, 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 time series.

Acknowledgements

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

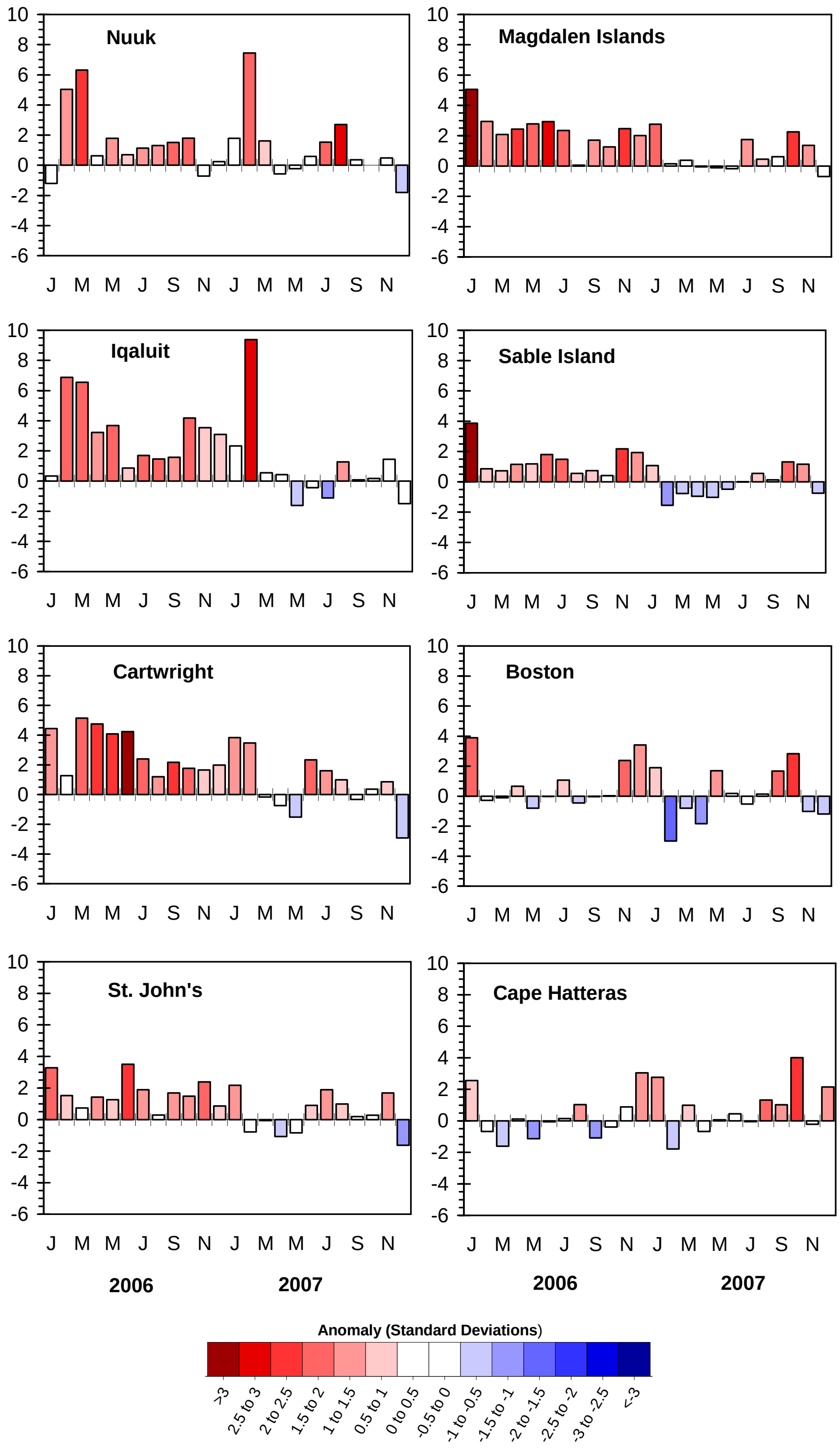

Fig. 2. Monthly air temperature anomalies in 2006 and 2007 at selected coastal sites (see Fig. 1 for locations). Temperature anomallies are colour-coded in terms of the monthly standard deviations with blue representing below normal observations and red representing above normal ones.

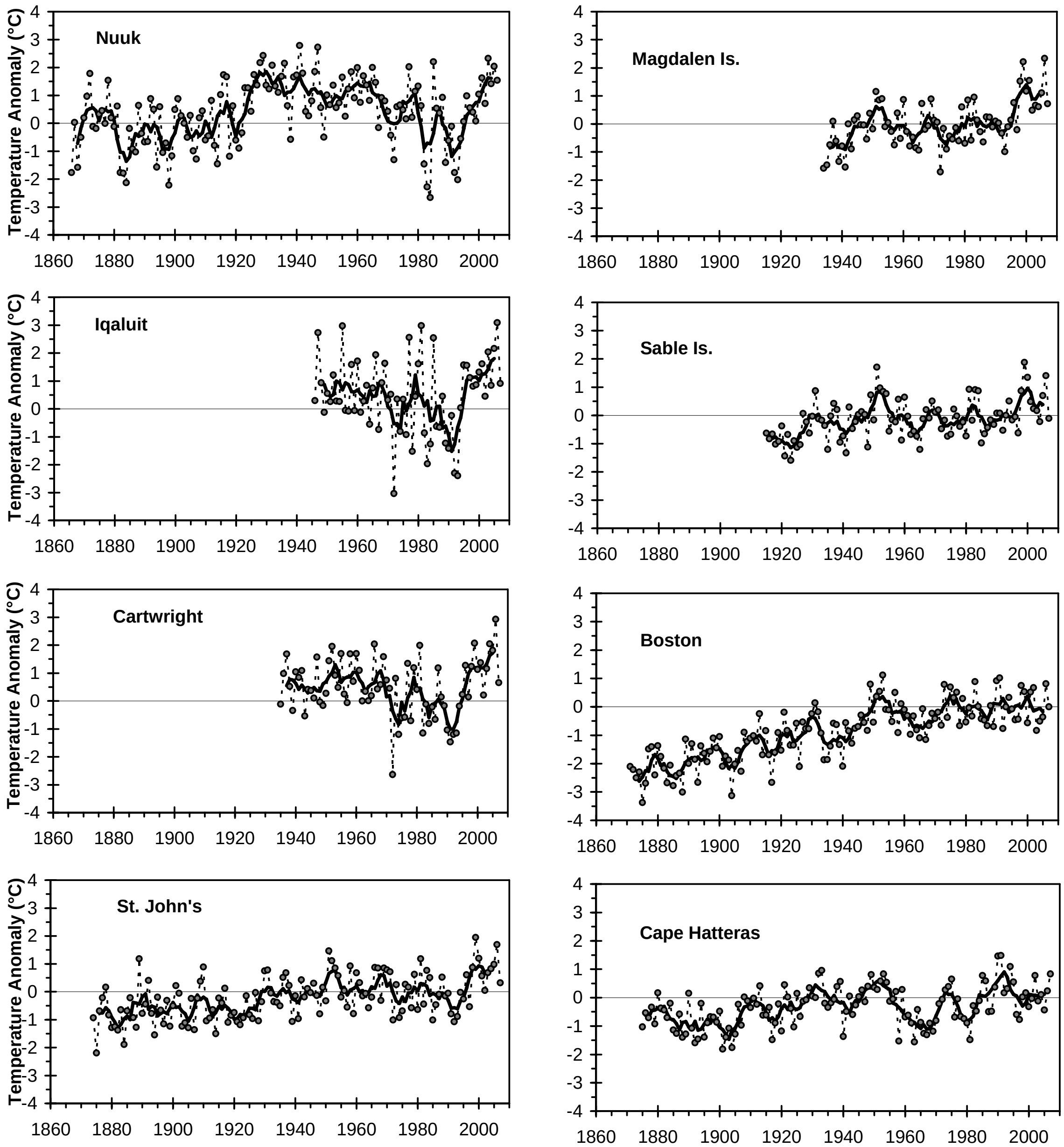

Fig. 3. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

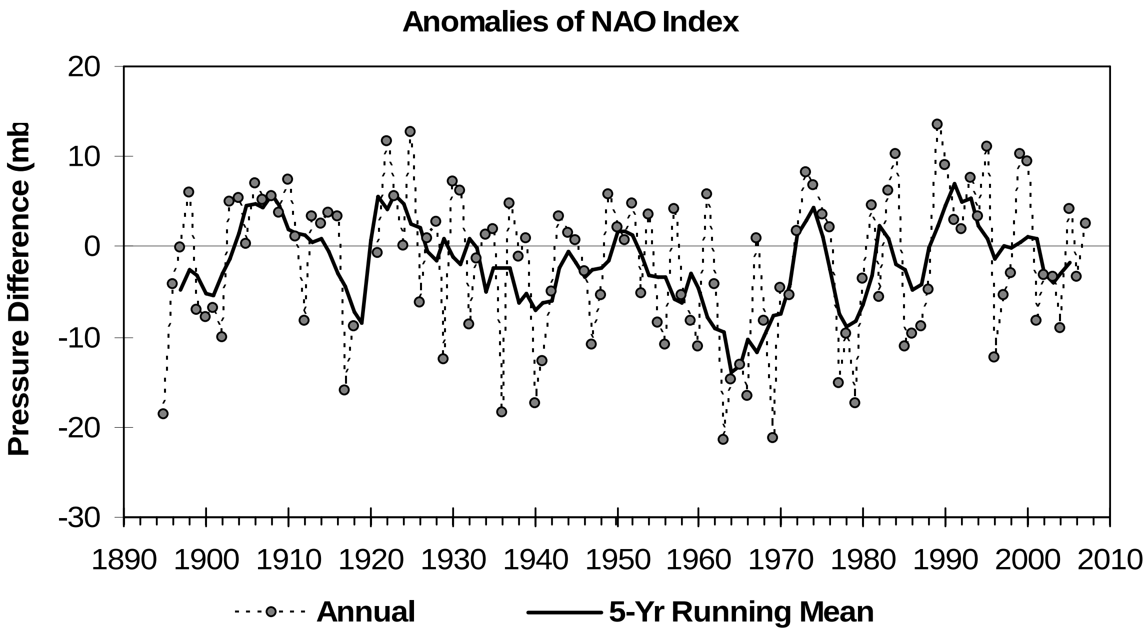

Fig. 4. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

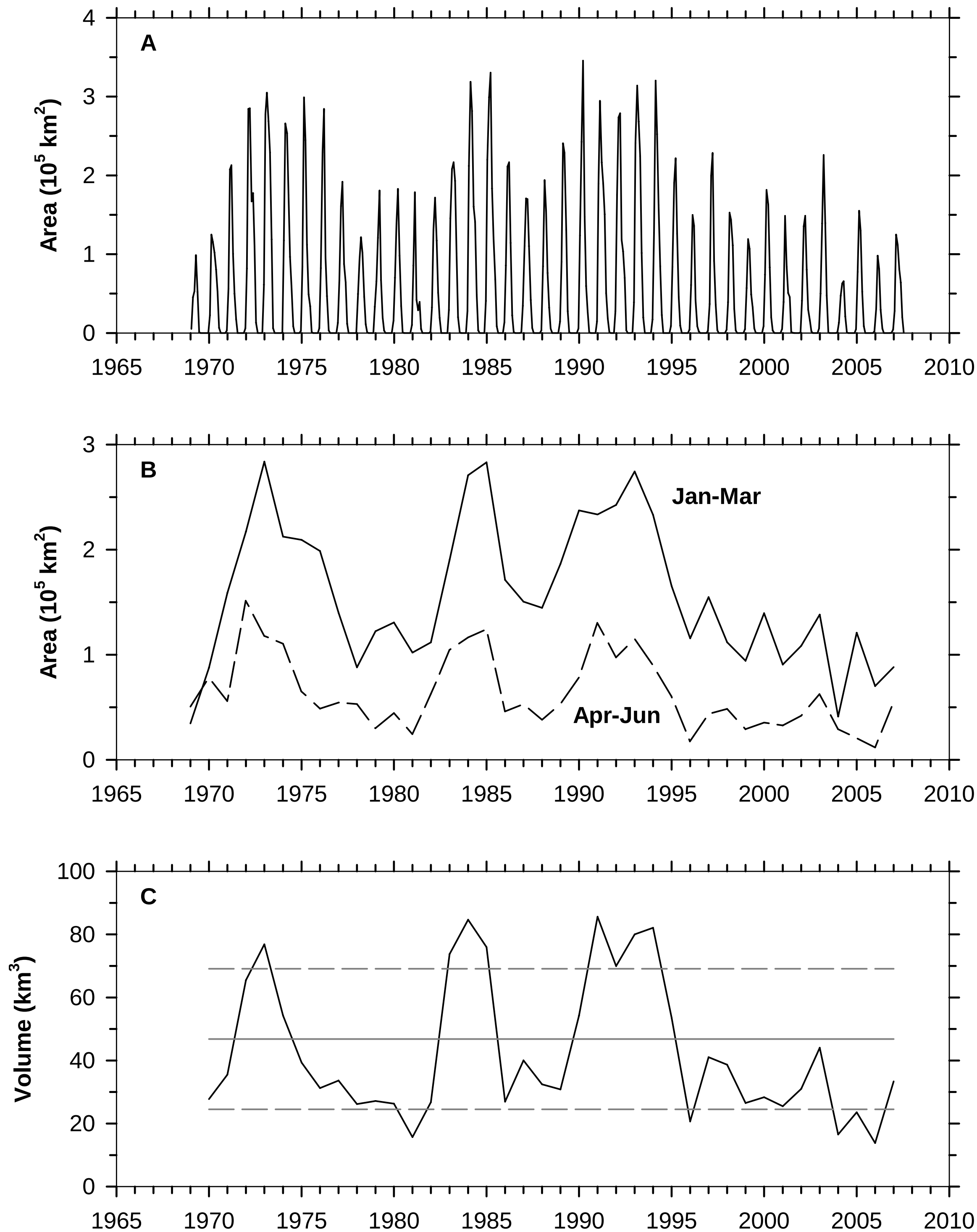

Fig. 5. Time series of **(A)** the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N, **(B)** the average ice area during the usual periods of advancement (January-March) and retreat (April-June) and (C) Dec-June average ice volume (horizontal solid line is 1971-2000 mean volume, broken lines are the mean ± 1 standard deviation).

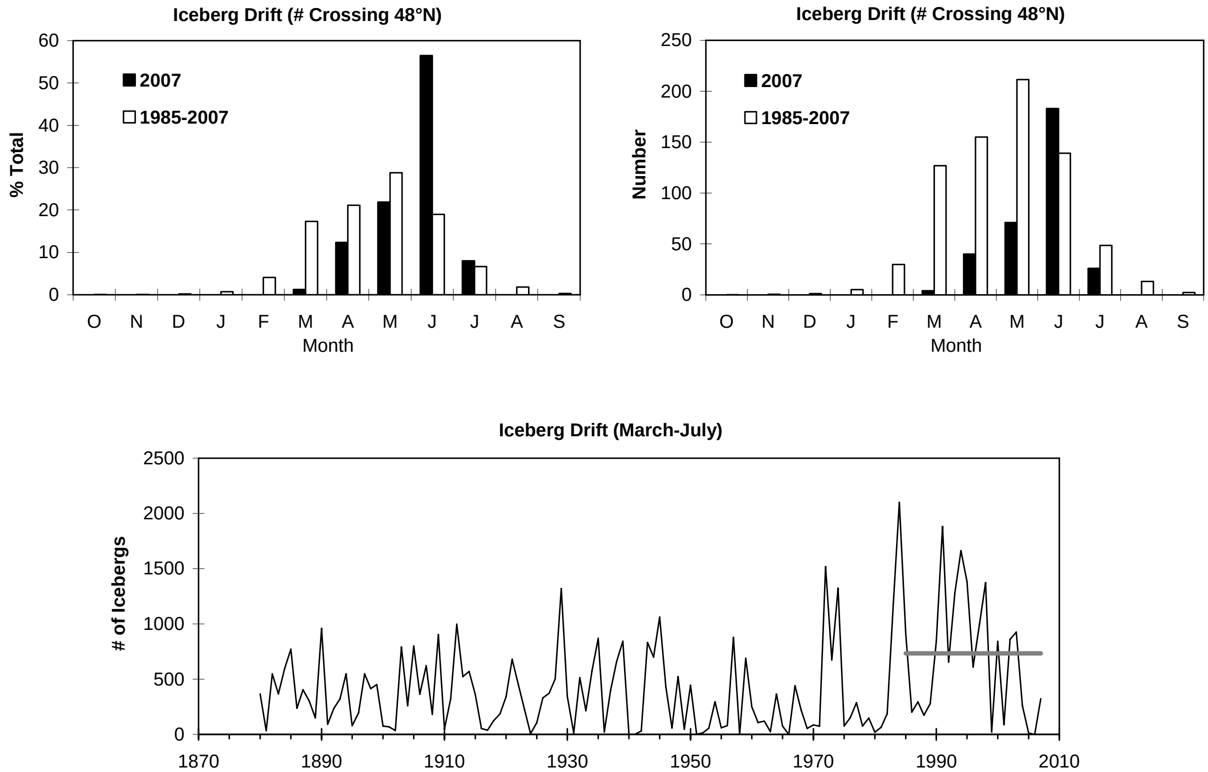

Fig. 6. The number of icebergs crossing south of 48°N during the iceberg season 2006/2007 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2007, the years SLAR has been used (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2007 average number of icebergs.

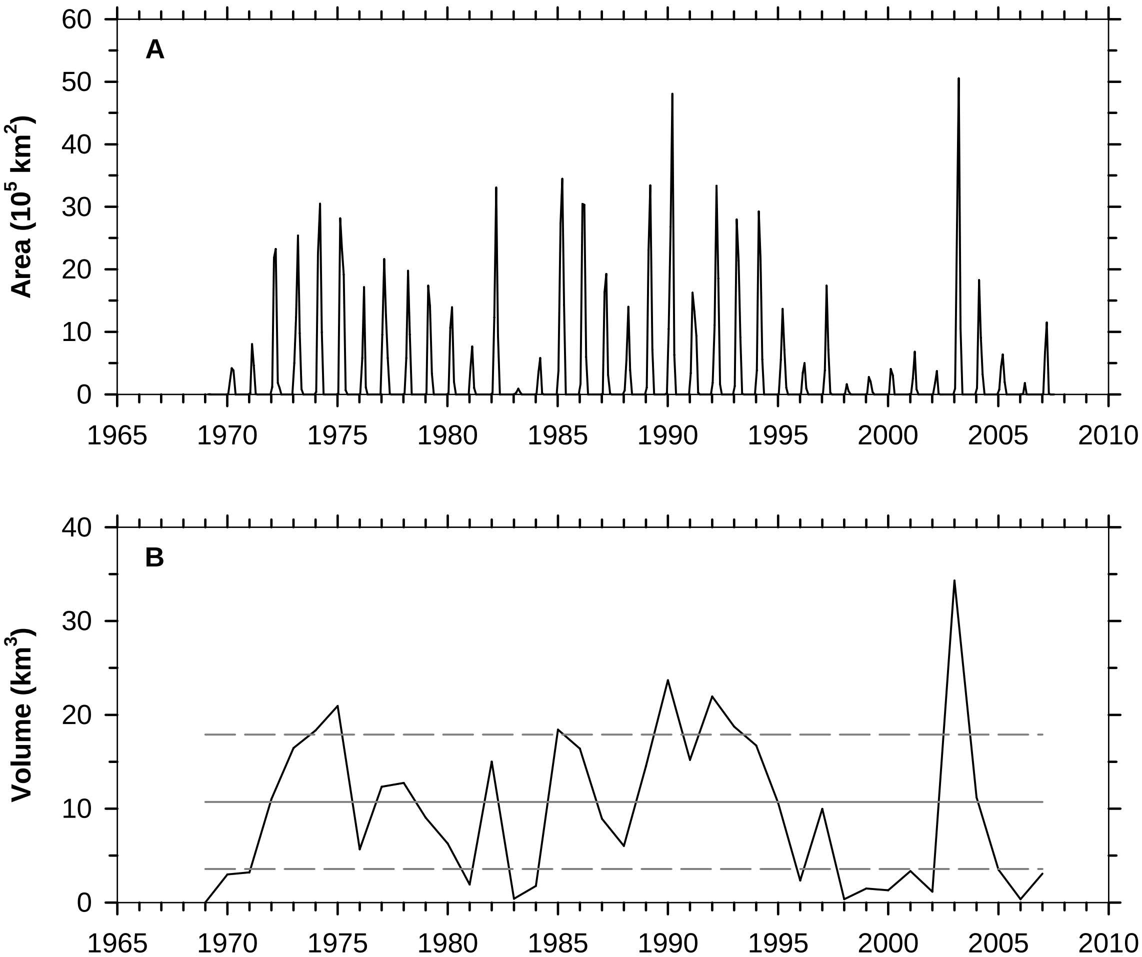

Fig. 7. For the region seaward of Cabot Strait, the time series of the **(A)** monthly mean ice area and **(B)** Jan-April ice volume (bottom). The solid horizontal line represents the long-term (1971-2000) mean and the broken lines represent the mean ± 1 standard deviation.

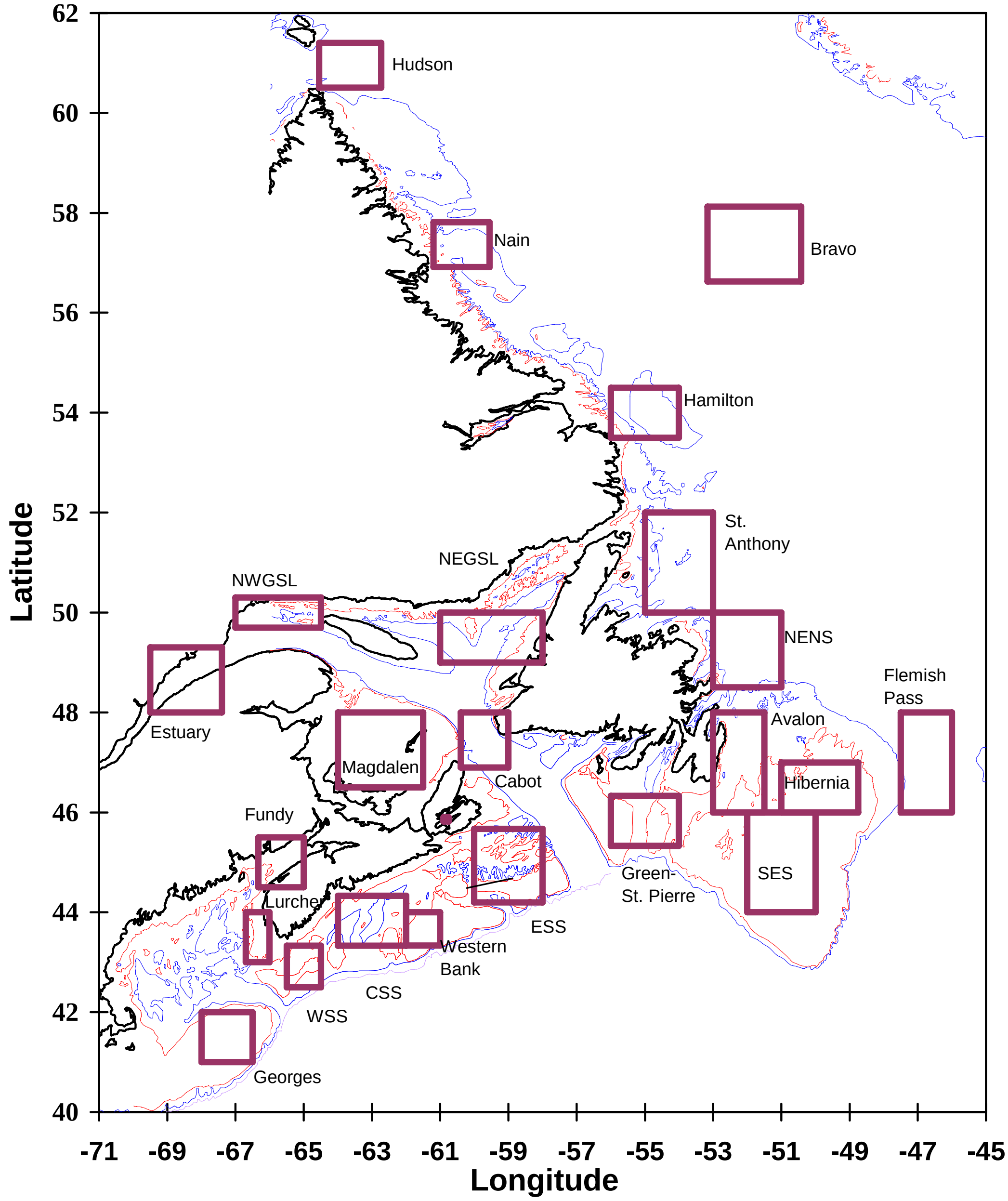

Fig. 8. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

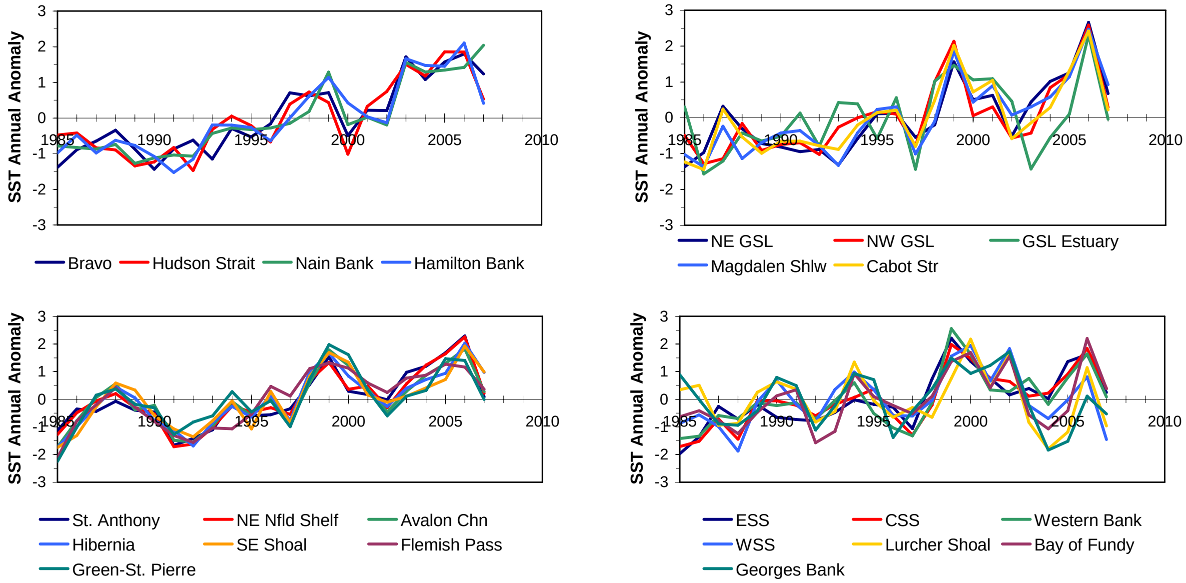

Fig. 9. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2007 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences 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.

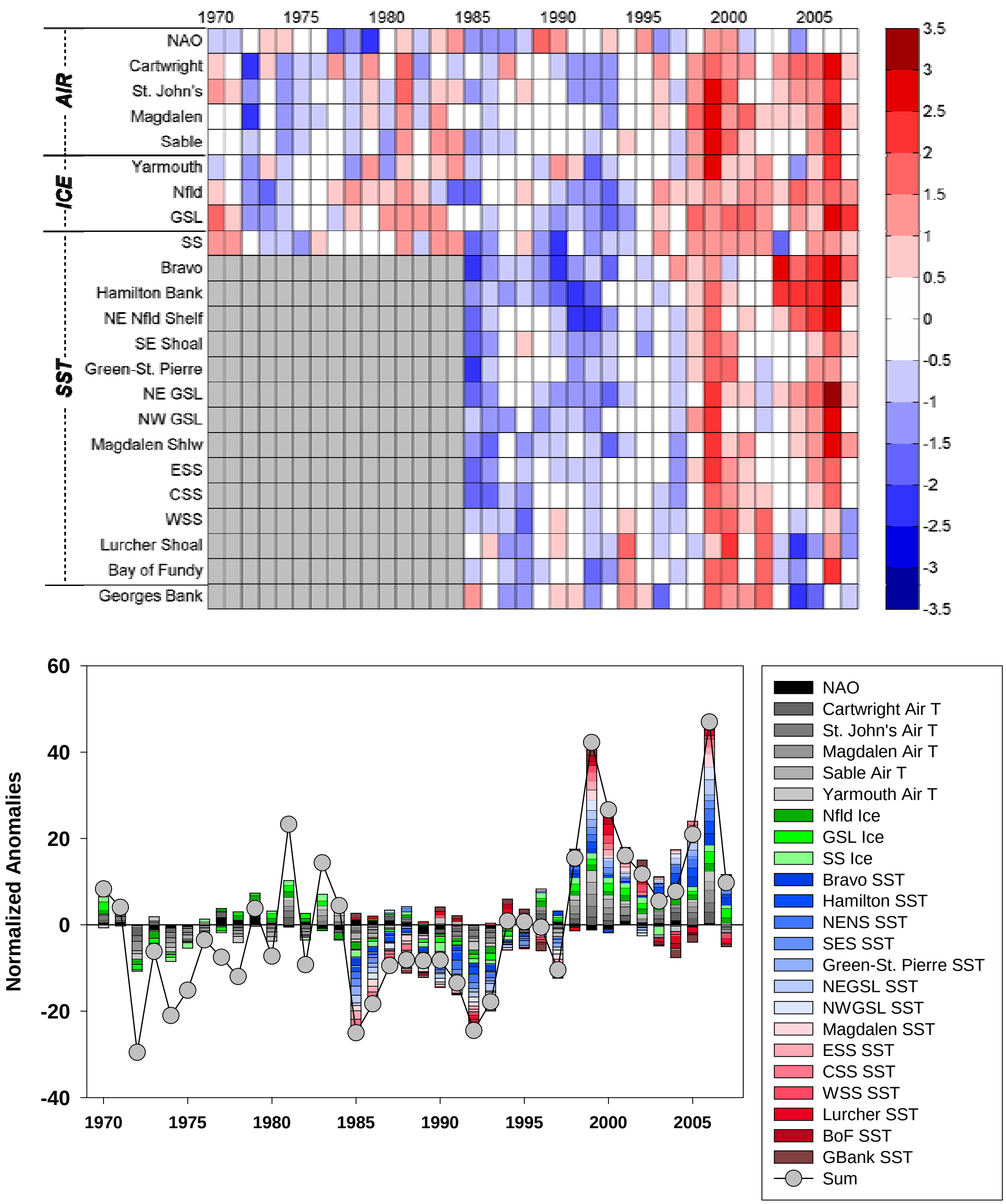

Fig. 10. Normalized annual anomalies of the NAO, air temperatures, ice and sea surface temperatures for the Atlantic region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means (except for SST where all data are used), divided by the standard deviation. The scale 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).