Northwest Atlantic Fisheries Organization

**Serial No. N5360** **NAFO SCR Doc. 07/13**

**SCIENTIFIC COUNCIL MEETING – JUNE 2007**

# Air Temperature, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2006

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## Abstract

After 4 consecutive years (2001-04) of below normal anomalies and a small positive value in 2005, the NAO index returned to a slightly, below normal value (-3.3 mb) in 2006. A negative index implies weaker winds from the northwest, warmer air temperatures and reduced oceanic heat loss during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. The air temperatures were warmer than normal throughout the area: annual average values were above normal by 1.8 to 3.1°C over the Labrador Sea and Shelf, 1.7°C over the Newfoundland Shelf, 2.3°C in the Gulf of St. Lawrence, 1.4°C over the Scotian Shelf and 0.8-1.3°C in Gulf of Maine. The Newfoundland sea ice cover (Dec-June) was the 2nd lowest in 37 years and its duration was 20 to 60 days less than average depending on location. Below normal conditions also prevailed on the Scotian Shelf: the ice cover (Jan-Apr) was the 3rd least in 38 years and its duration was 40-50 days less than normal. No icebergs reached the Grand Banks in 2006, only the second year since 1880 when none were reported. The analysis of satellite data indicates a north-south gradient of sea surface temperatures (SST) anomalies similar to the air temperature distribution. In 2006, there were positive annual SST anomalies from Bravo in the Labrador Sea and Hudson Strait on the northern Labrador Shelf to eastern Georges Bank and the Bay of Fundy. Annual anomalies ranged from 0.1°C (Georges Bank) to 2°C (eastern Grand Bank).

## Introduction

This document examines the meteorological, sea ice and sea surface temperature conditions during 2006 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 2005 and 2006 relative to their 1971-2000 mean at eight sites, from Nuuk in Greenland to Boston on the eastern coast of the United States, are shown in Fig. 2 (see Fig. 1 for locations). Data from the Canadian sites were from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA, 2006).

The mean annual air temperature anomalies for 2006 (Fig. 3) varied latitudinally, with the largest above normal anomalies in the north (Iqaluit and Cartwright) and the smallest in the south (Boston): Nuuk (1.84°C), Iqaluit (3.09°C), Cartwright (2.93°C), St. John's (1.69°C), Magdalen Islands (2.34°C), Sable Island (1.41°C), Yarmouth (1.30°C) and Boston (0.81°C). In 2005, the pattern was very similar with anomalies ranging from a high of 2.16°C at Iqaluit to a low of -0.36°C at Boston.

A further indication of how exceptional 2006 was can be obtained by ranking the annual air temperatures for each site. Temperatures at Nuuk were the 26th warmest of 141 years (i.e. 26/141), Iqaluit 1/61, Cartwright 1/71, St. John's 2/133, Magdalen Islands 1/73, Sable Island 3/93, Yarmouth 4/131 and Boston 5/136.

## 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 2006, the NAO index was below normal (-3.3 mb, -0.39 standard deviations based on the statistics for 1971-2000), down from the 4.1 mb anomaly in 2005 (Fig. 4). As indicated, a negative NAO anomaly is usually accompanied by above normal air temperatures over the Labrador Sea in winter. This is consistent with the December 2005 to February 2006 air temperature anomalies which ranged from -1.21°C (Nuuk, the only negative value) to 6.87°C (Iqaluit) for the 5 northern sites (Fig. 2). It is also consistent with the March to June temperatures at the 3 northernmost sites where the average monthly anomaly was 2.44°C and the maximum value was 6.55°C (Iqaluit).

## 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. (2007). 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 2006 values to obtain anomalies.

Until this year, the ice cover 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 areal cover. Beginning this year, we have accounted for the amount of ice cover. This means that the plots of ice area scale differently than in the past in terms of the absolute magnitude, though 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 measuring ice cover. Some earlier data did not have the information that allowed this revised computation of area which means that the first year a quantitative assessment could be made was 1969.

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. This is not an ideal way to estimate ice volumes however, since observations of ice thickness are not available.

*Newfoundland and Labrador*

*Sea Ice*. The time series of the monthly ice cover and volume on the Newfoundland and southern Labrador Shelves (45-55$^{o}$N) show that the peak extent during 2006 was less than in 2005, and the second least December-June cover in 37 years (Fig. 5). Only 2004 had less ice cover. The 2006 cover was 1.8 standard deviations below normal. The time series of monthly ice area show that the 2006 cover was less than that in 2005 for January to May. Neither year had ice cover in June or July. The summation of the January to June ice volume is highly coherent with the ice extent (Fig. 5); the volume recorded in 2006 was the smallest in the time series, about 1.5 standard deviations below the 1971-2000 normal value. In summary, 2006 was one of the lightest ice years on the Labrador and Newfoundland shelves over the length of the revised record, 1969-2005.

*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 2005/2006 iceberg season (October 2005 to September 2006), no icebergs were detected south of 48$^{o}$N, a decrease from the 11 recorded in 2005. The lack of bergs in 2005/06 season is the first occasion in the 1985-2005 period. Since 1880, the only other year with no bergs sighted was 1966 (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 2006, ice first appeared seaward of the Strait in late January, which is the normal time for first appearance. The ice field moved very slowly to southern Sydney Bight. This was the maximum extent of ice onto the Scotian Shelf in 2006. The January-April ice cover was the 3$^{rd}$ lowest in the 38 year record, 1.5 standard deviations below normal (Fig. 7). Similarly, the ice volume was the 3$^{rd}$ lowest in the 38 year record, 1.45 standard deviations below normal (Fig. 7).

## 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 4 series.

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 2006, the anomalies ranged from 0.1 $^{o}$C over eastern Georges Bank to 2.0$^{o}$C over the eastern Grand Bank. The average anomaly over the Labrador Shelf was 1.1$^{o}$C, 1.5$^{o}$C over the Newfoundland Shelf, 1.4$^{o}$C in the Gulf of St. Lawrence and 1$^{o}$C over the Scotian Shelf.

## Summary

After 4 consecutive years (2001-04) of below normal anomalies and a small positive value in 2005, the NAO index returned to a slightly, below normal value (-3.3 mb) in 2006. A negative index implies weaker winds from the northwest, warmer air temperatures and reduced heat loss from the ocean during winter over the Labrador Sea and partly over the Labrador and Newfoundland Shelf. The air temperatures were warmer than normal throughout the area: annual average air temperatures were above normal by 1.8 to 3.1$^{o}$C over the Labrador Sea and Shelf, 1.7$^{o}$C over the

Newfoundland Shelf, 2.3°C in the Gulf of St. Lawrence, 1.4°C over the Scotian Shelf and 0.8-1.3°C in Gulf of Maine. The Newfoundland sea ice cover (Dec-June) was the 2nd lowest in 37 years and its duration was 20-60 days less than average. The Gulf of St. Lawrence ice cover (Dec-Apr, not shown) in 2006 was the lowest in the 38 year record; the ice season was the 2nd shortest in 38 years. Below normal conditions also prevailed on the Scotian Shelf: the ice cover (Jan-Apr) was the 3rd least in 38 years and its duration was 40-50 days less than normal. No icebergs reached the Grand Banks in 2006, only the second year since 1880 when none were reported. The analysis of satellite data indicates a north-south gradient of sea surface temperatures anomalies similar to the air temperature distribution. In 2006, there were positive annual SST anomalies from Bravo in the Labrador Sea and Hudson Strait on the northern Labrador Shelf to eastern Georges Bank and the Bay of Fundy. Annual anomalies ranged from 0.1°C (Georges Bank) to 2.0°C (eastern Grand Bank).

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 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 past year features all of the variables indicated warmer than normal conditions and 10 of the 22 greater than 2.5 standard deviations greater than average; 2006 was truly an exceptional year on the basis of these series.

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 1998-2006 are apparent. In 2006, this composite index reached its highest value to date. 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. It is heavily weighted towards SST with 14 series; there are 3 ice, 5 air temperature and the NAO 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.

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

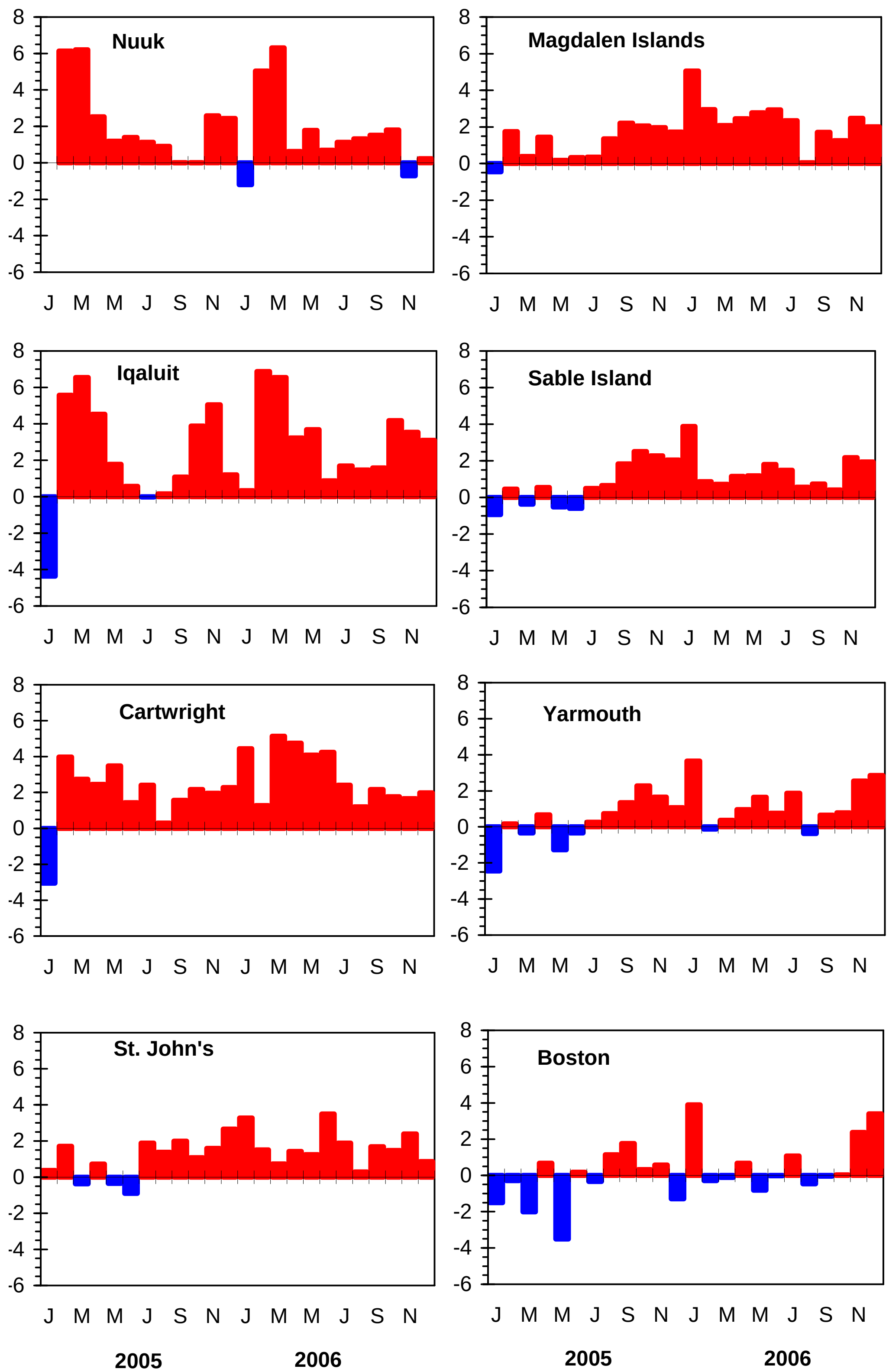



Fig. 2. Monthly air temperature anomalies in 2005 and 2006 at selected coastal sites (see Fig. 1 for locations).

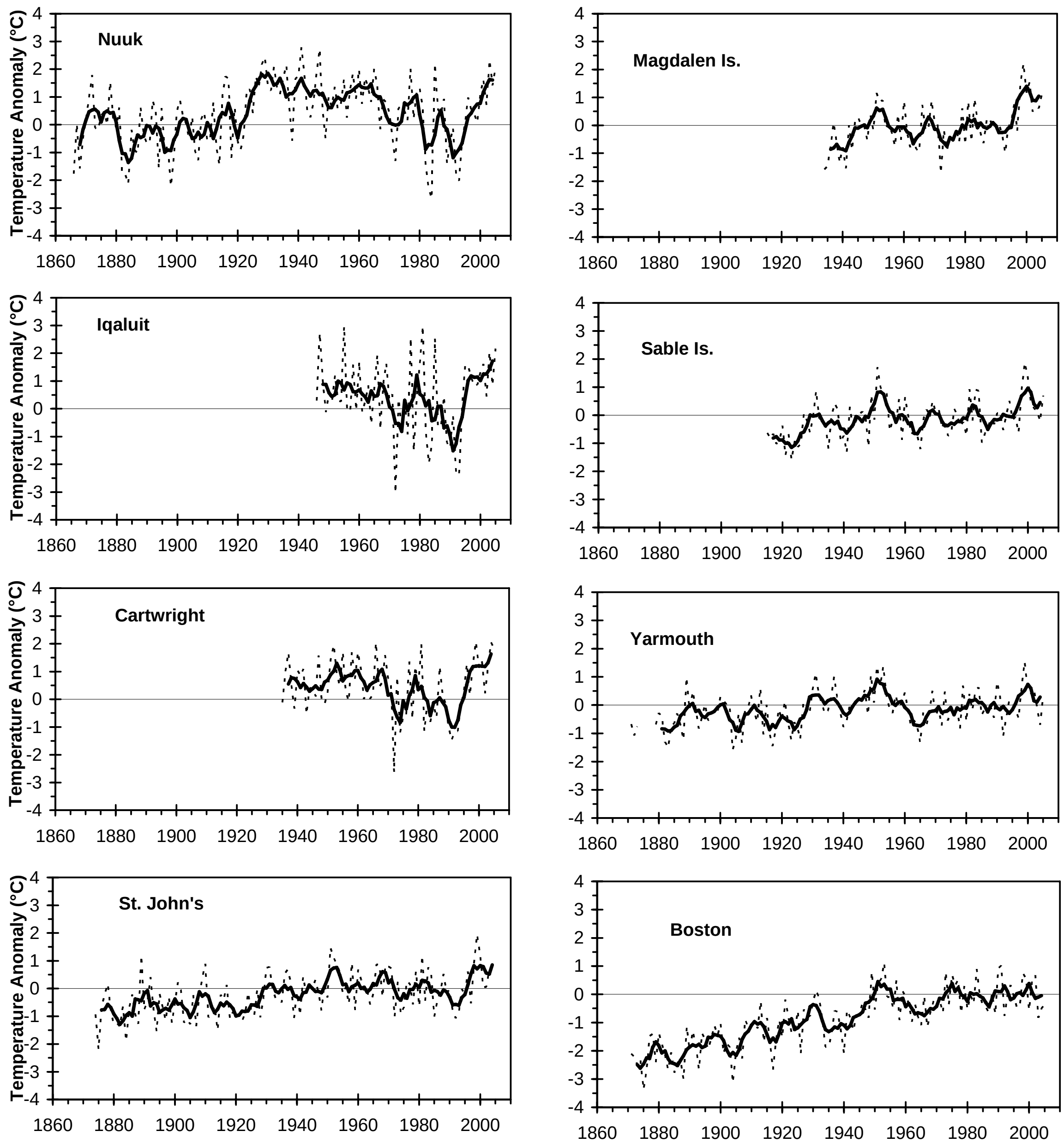



Fig. 3. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

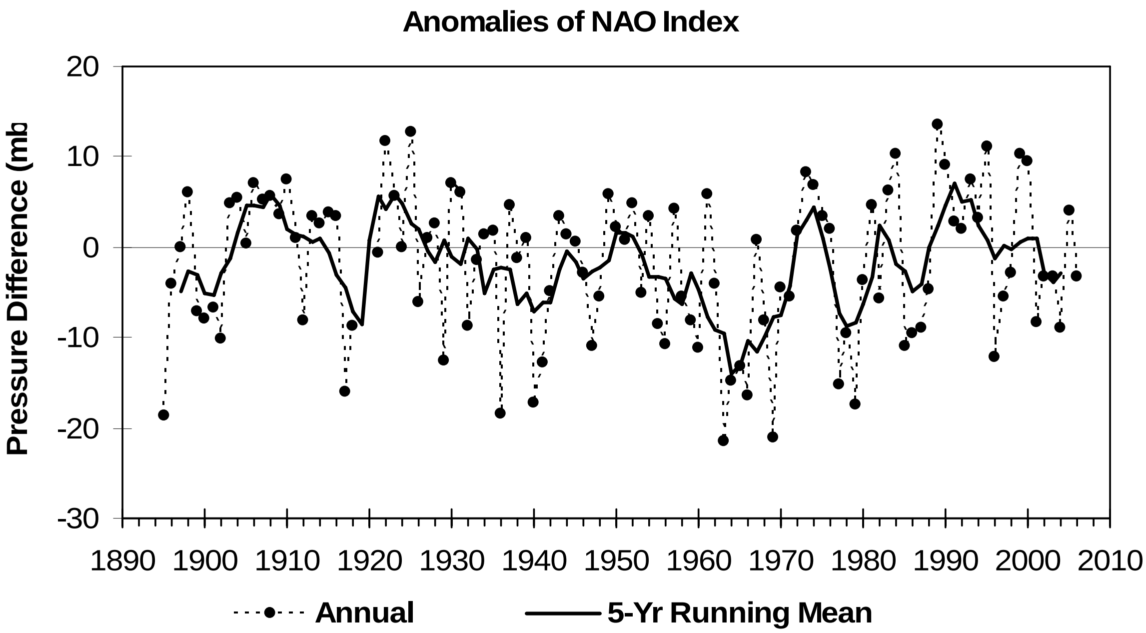



Fig. 4. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

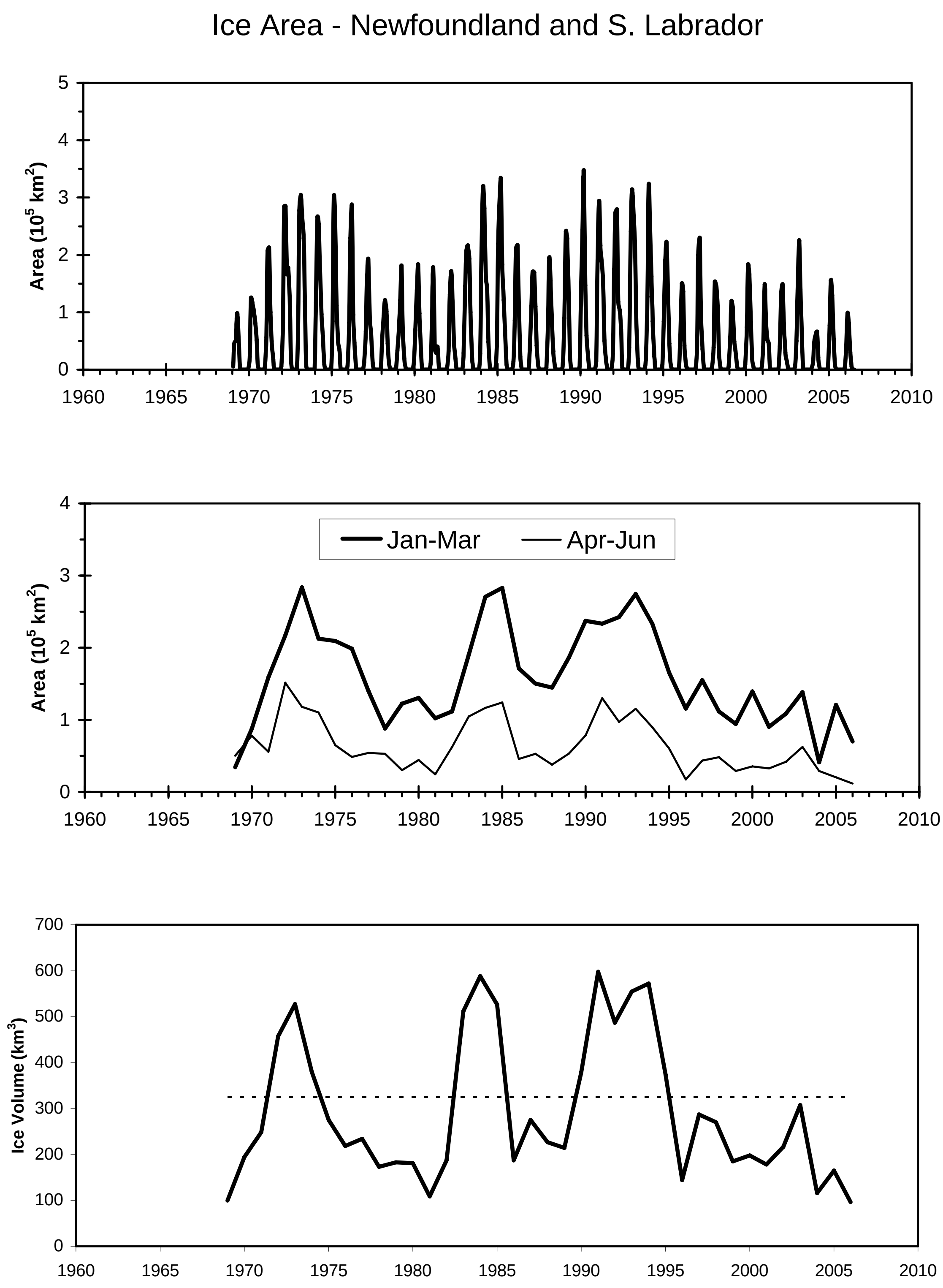



Fig. 5. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel), the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (middle) and Jan-June ice volume (bottom, broken line is 1971-2000 mean volume).

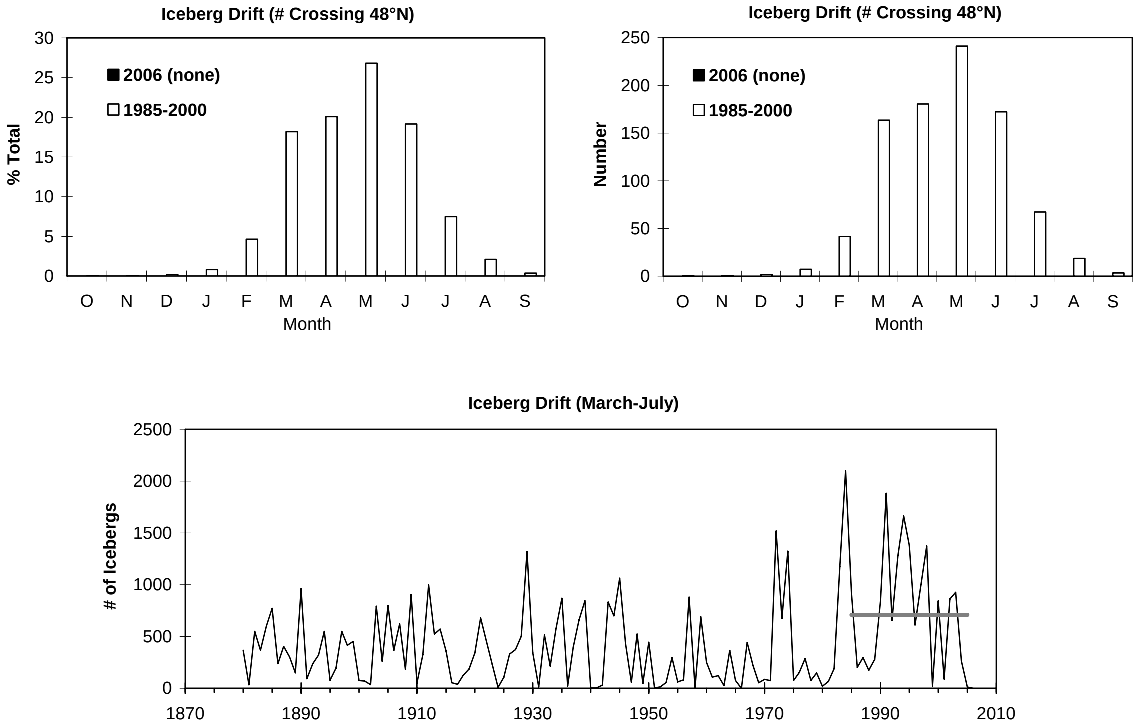
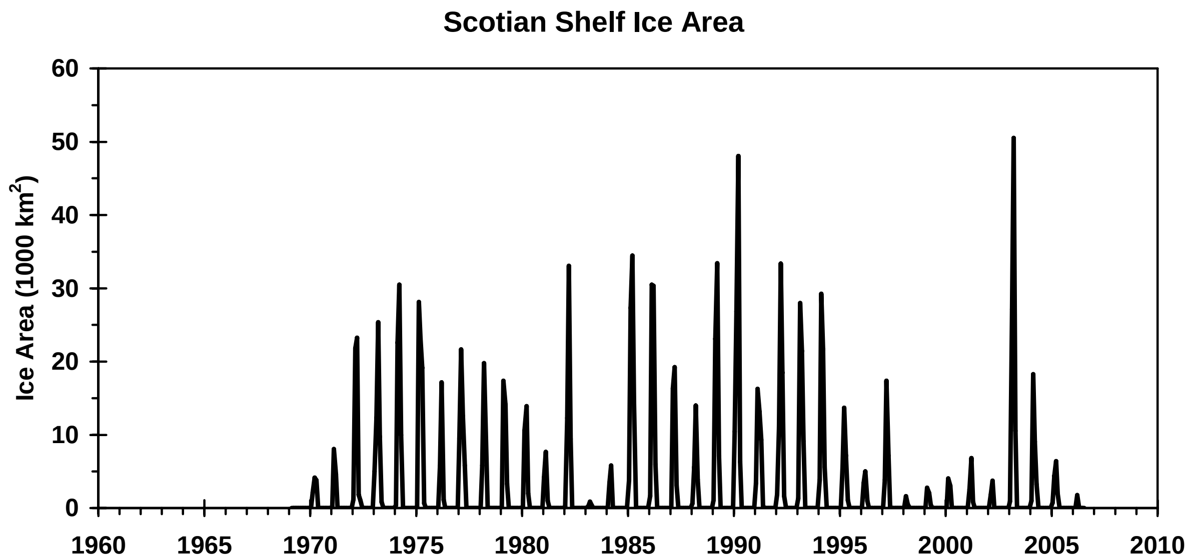



Fig. 6. The number of icebergs crossing south of 48°N during the iceberg season 2005/2006 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2000, the years SLAR has been used (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2006 average number of icebergs.



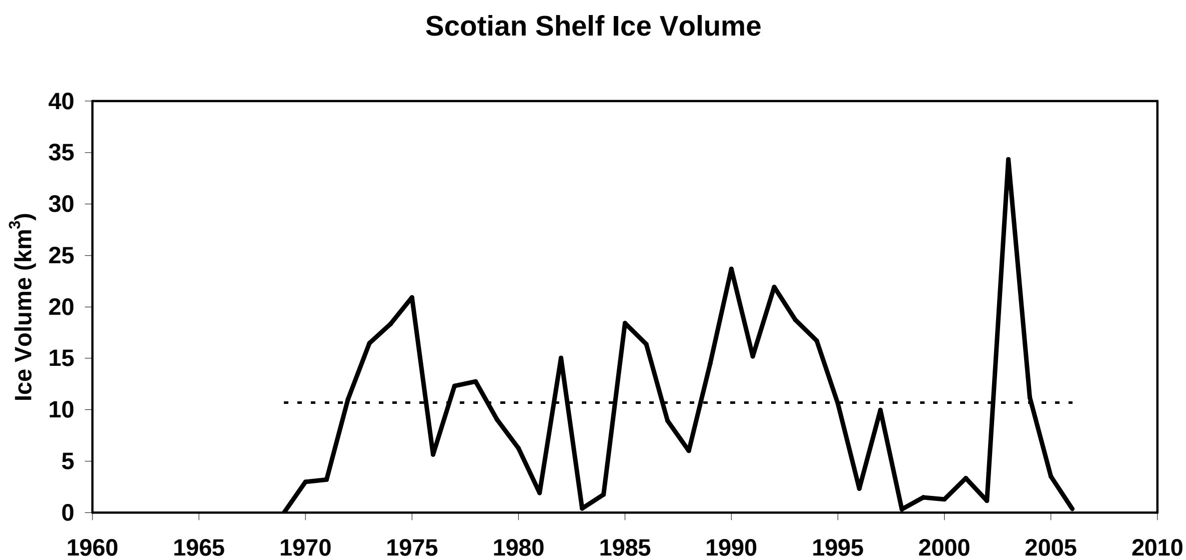




Fig. 7. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top) and Jan-April ice volume (bottom). The horizontal line represents the long-term (1971-2000) mean.

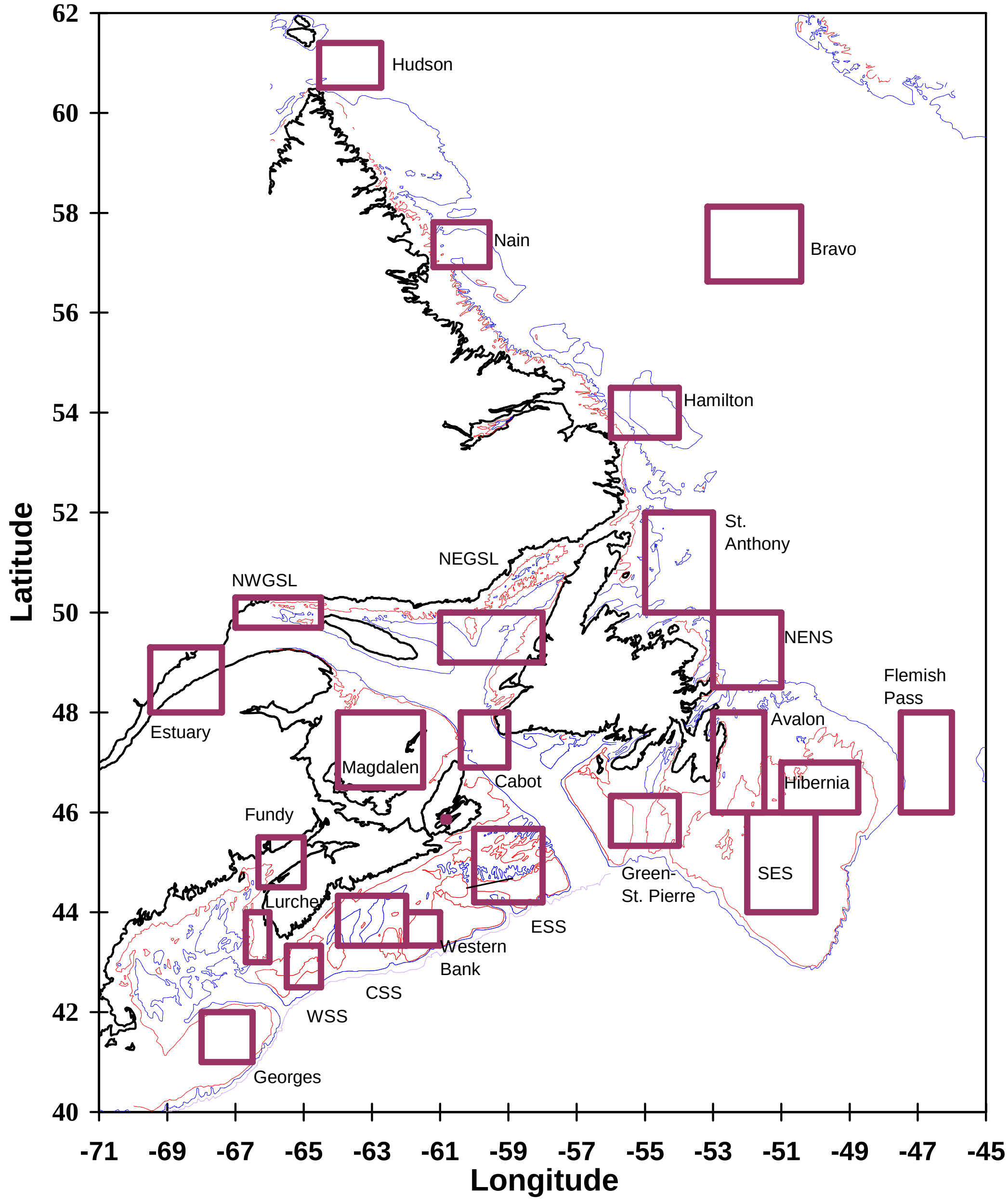



Fig. 8. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

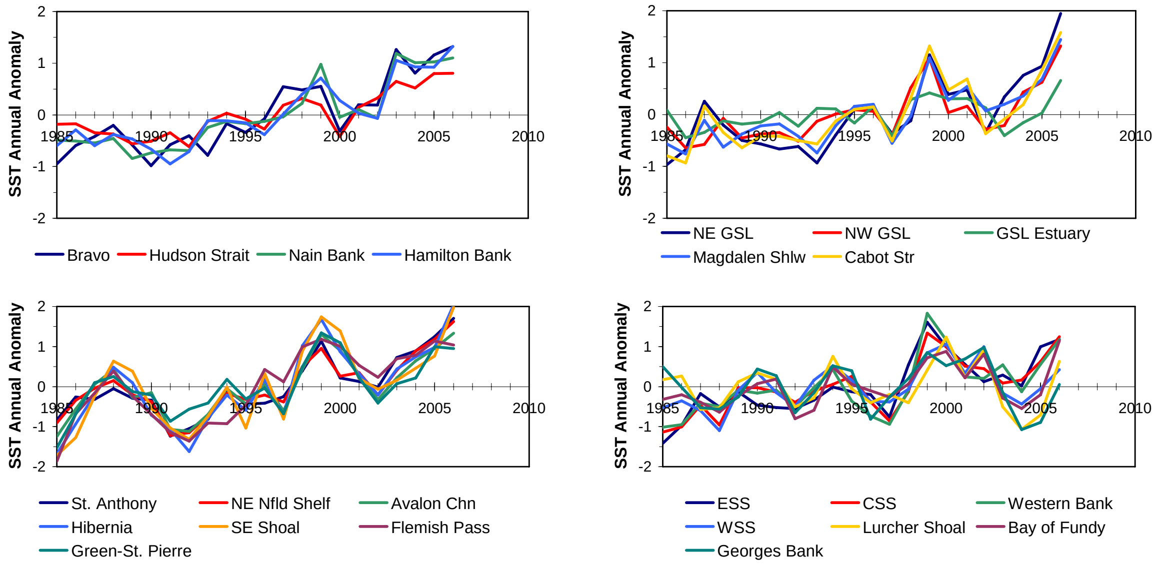



Fig. 9. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2006 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences 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.

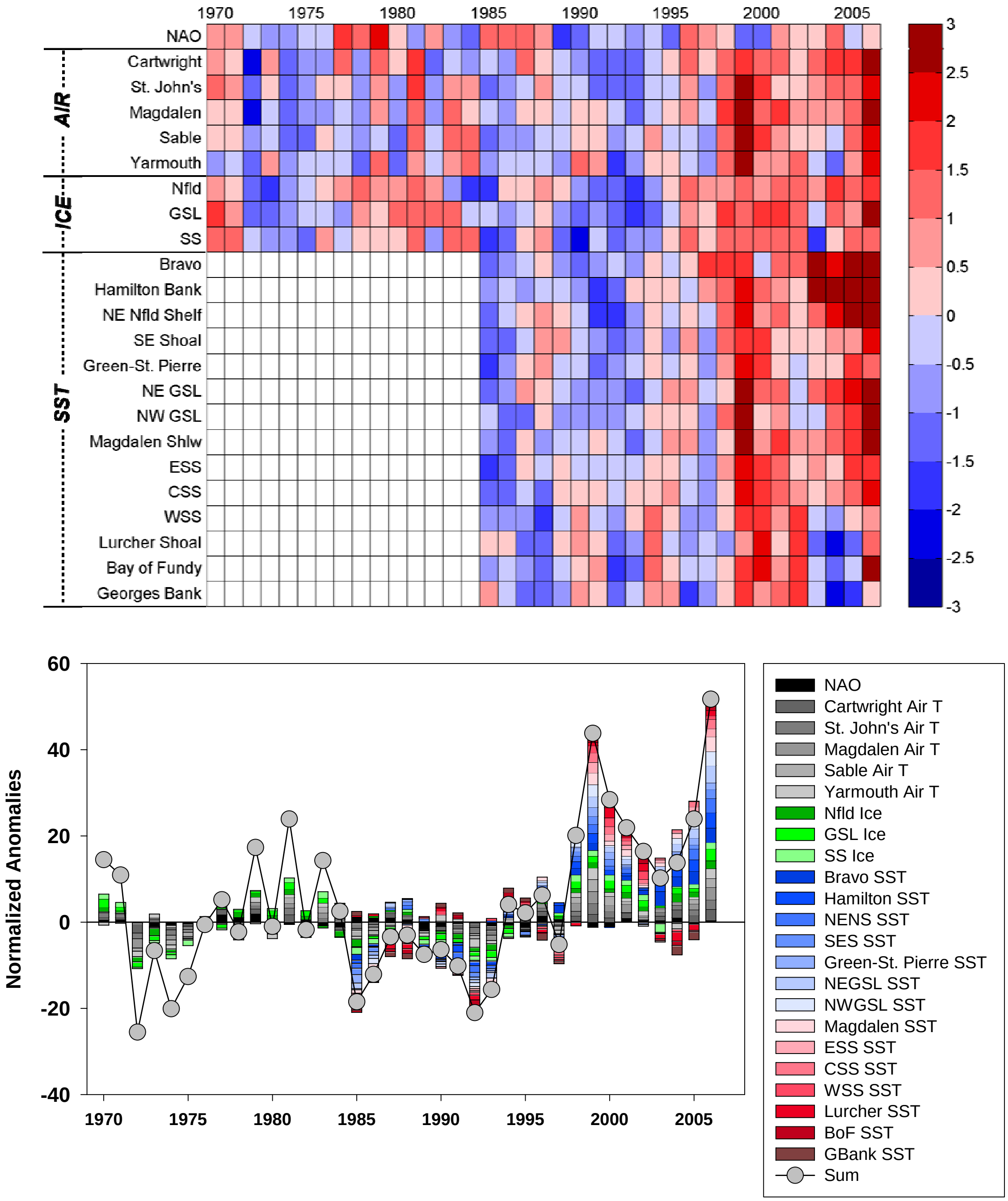



Fig. 10. Normalized annual anomalies of the NAO, air temperatures, ice and sea surface temperatures for the Atlantic region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means (except for SST where all data are used), divided by the standard deviation. The scale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