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An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2006

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 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^{o}C over the Labrador Sea and Shelf, 1.7^{o}C over the Newfoundland Shelf, 2.3^{o}C in the Gulf of St. Lawrence, 1.4^{o}C over the Scotian Shelf and 0.8-1.3^{o}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. The Gulf of St. Lawrence ice cover (Dec-Apr) 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 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 0.05^{o}C (Georges Bank) to 2.04^{o}C (eastern Grand Bank).

RÉSUMÉ

Après quatre années consécutives (2001-2004) de valeurs sous la normale et une légère valeur au-dessus de la normale en 2005, l’indice d’oscillation nord-atlantique (ONA) est revenu à une valeur légèrement inférieure à la normale (-3,3 mb) en 2006. Un indice ONA négatif correspond à des vents plus faibles soufflant du nord-ouest, à des températures de l’air plus chaudes et à une perte de chaleur moins 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. Les températures de l’air ont été plus chaudes que la normale dans toute la région : les valeurs annuelles moyennes dans les zones de la mer et du plateau du Labrador ont été de 1,8 à 3,1 ^{o}C au-dessus de la normale, celles du plateau de Terre-Neuve, de 1,7 ^{o}C, celles du golfe du Saint-Laurent, de 2,3 ^{o}C, celles de la plate-forme Néo-Écossaise, de 1,4 ^{o}C et celles du golfe du Maine, de 0,8 à 1,3 ^{o}C. À Terre-Neuve, la couverture de glace (déc. à juin) a été la 2^{e} moins étendue en 37 ans et la saison des glaces a duré de 20 à 60 jours de moins que la moyenne, selon l’endroit. Dans le golfe du Saint-Laurent, en 2006, la couverture de glace (déc. à avril) a été la plus basse en 38 ans et la saison des glaces a été la 2^{e} plus courte en 38 ans. Sur la plate-forme Néo-Écossaise, les conditions ont également été inférieures à la normale : la couverture de glace (de janv. à avril) était la 3^{e} moins étendue en 38 ans et la saison des glaces a duré de 40 à 50 jours de moins que la normale. Aucun iceberg n’a atteint les Grands Bancs en 2006, deuxième année seulement où cette situation se produit depuis 1880. L’analyse des données satellitaires indique un gradient nord-sud des températures de surface de la mer (TSM) qui va de pair avec la répartition des températures de l’air. En 2006, a observé des anomalies positives des TSM annuelles et ce, depuis la station Bravo, située dans la mer de Labrador et du détroit d’Hudson sur la partie nord du plateau du Labrador, jusqu’au banc Georges et à la baie de Fundy. Ces anomalies annuelles allaient de 0,05 ^{o}C (banc Georges) à 2,04 ^{o}C (est du Grand banc).

INTRODUCTION

This paper examines the meteorological, sea ice and sea surface temperature conditions during 2006 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. (2007), Galbraith et al. (2007), Petrie et al. (2007)). 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 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 both the Northwest Atlantic Fisheries Organization (NAFO) and the Fisheries Oceanographic Committee, the Department of Fisheries and Oceans group that requested and reviewed these documents 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 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). Warmer-than-normal temperatures prevailed over the entire region in 2006 with the annual average values increasing from >1°C in the south to 3°C over western Baffin Bay (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 August (Fig. 2B, C). February-June temperatures were exceptional, anomalies were as much as 6°C above normal over the northern Labrador Sea. The Grand Banks featured above average temperatures throughout the year. Similar conditions prevailed for the Gulf of St. Lawrence, the Scotian Shelf and the Gulf of Maine.

Monthly air temperature anomalies for 2005 and 2006 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, 2006). In 2006, generally above normal temperatures prevailed in the entire region, from Nuuk and Iqaluit in the north to Sable Island in the south. Near normal temperatures were recorded at Boston.

The mean annual air temperature anomalies for 2006 (Fig. 4) varied latitudinally, with the largest above normal anomalies in the north (Iqaluit and Cartwright) and the smallest in the south (Boston and Cape Hatteras): 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), Boston (0.81°C), Cape Hatteras (-0.10°C). Yarmouth (not shown) had an annual temperature anomaly of 1.30°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.

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 2006, relative to the 1971-2000 means, are shown in Fig. 5. Winter includes December 2005 to February 2006, 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 eastern North Atlantic with its centre (~6 mb above normal) located off Norway. The winter pressure anomalies in 2006 indicate weaker-than-normal Iceland Low and Azores High, i.e. a decrease in the strength of the large-scale atmospheric circulation compared to 2005.

The spring of 2006 featured a negative SLP anomaly (minimum about -4 mb) in the central North Atlantic giving way to a positive anomaly centred over southern Greenland 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 2006 was extremely weak. In the autumn, the pattern was dominated by an intense positive anomaly over Greenland (to ~7 mb) and a similar negative one south of Iceland.

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 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. 6). 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^{o}C (Nuuk, the only negative value) to 6.87^{o}C (Iqaluit) for the 5 northern sites (Fig. 4). It is also consistent with the March to June temperatures at the 3 northernmost sites where the average monthly anomaly was 2.44^{o}C and the maximum value was 6.55^{o}C (Iqaluit).

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 2006 were to the north and northwest over the Labrador Sea and Shelf (Fig. 8). Over Atlantic Canada, winter wind anomalies were predominantly to the north (Fig. 9). This wind anomaly pattern is consistent with the winter air temperatures over the region and with the simple representation of the wind field by the NAO anomaly. The anomalous winds in the spring were generally from the southeast in the Labrador Sea; over Atlantic Canada, the wind anomalies were weaker than over the Labrador Sea and were generally from the northeast. The pattern changed in summer, with wind anomalies from the south dominating the northern and southern regions. The fall wind anomalies were the weakest of the year over the Labrador Sea and were predominantly from the east; over Atlantic Canada the anomalous winds were generally from the south.

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 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 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 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. Figure 10 compares ice cover and ice volumes estimates, both variables summed over the months indicated in the captions. Since volumes are strongly dependent on the ice cover, it is not too surprising that the squared correlations are high: 0.84 (Newfoundland-Labrador), 0.86 (Gulf of St. Lawrence) and 0.92 (Scotian Shelf). In addition to the correlations, we derived the average ranking difference, i.e. the absolute difference of the ranking based on ice cover and ice volume for 1970 to 2006 for Newfoundland-Labrador and the Gulf of St. Lawrence and for 1969 to 2006 for the Scotian Shelf. The results were 4.1 (Newfoundland-Labrador), 2.5 (Gulf of St. Lawrence and 2.1 (Scotian Shelf). For the top and bottom 10 values, they were somewhat better overall at 4.3 (Newfoundland-Labrador), 1.9 (Gulf of St. Lawrence and 1.4 (Scotian Shelf). The high correlations and the small differences in ranking mean that the interpretations of the two series would lead to essentially the same conclusions: above normal conditions in one series would also be above normal in another and vice versa.

Newfoundland and Labrador

Sea Ice. At the beginning of 2006, sea ice was found off the southern Labrador coast south to the mouth of the Strait of Belle Isle (Fig. 11A), but was 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, again less than the long-term median coverage. The distribution advanced to Baie Verte Peninsula (~49.5^{o}N) by February 1. Both the southern and offshore extent of the ice was less than the median cover. By March 1, ice cover was less than the long-term median over the Newfoundland Shelf but equal to the median cover off Labrador. By April 1, the ice had retreated to the northern coastal areas of Newfoundland; ice cover was substantially less than the long-term median (Fig. 11B). On May 1, the most southerly ice extended just to northern Hamilton Bank on the southern Labrador Shelf (~53.5^{o}N).

Ice appeared along the Labrador coast and at the mouth of Belle Isle Strait by January 1, 2006 (day 0, Fig. 12); it reached the northern Avalon Peninsula by late February (day 60). Relative to the long-term mean, ice appearance typically was late by ~15 days over most of the Newfoundland Shelf region (Fig. 12). Ice began to disappear from the area just north of Grand Bank in mid-March (day 75; Fig. 13). It did not begin to retreat from northern Newfoundland waters and southern Labrador until mid-April to early May (day 105-120). 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 typically a month earlier than normal over the Newfoundland Shelf.

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 2006, the duration ranged from <30 days north of Grand Bank to over 170 days along the Labrador coast (Fig. 14). The 2006 pattern is in fact quite similar to the one in 2005 for the entire region but the ice is confined more closely to the coast. In the entire area, the ice duration was less-than-normal by typically 20-60 days.

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 extent during 2006 was less than in 2005, and the second least December-June cover in 37 years (Fig. 15A). 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 (Fig. 15A, 16). Neither year had ice cover in June or July. 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.

The co-occurrence of the light ice year, higher than average air temperatures in the Labrador-Newfoundland region and a negative NAO anomaly encouraged further analysis in 2004 of the relationships among these variables. This analysis has been extended by incorporating the 2006 data. Moreover, the revised ice areas prompted a re-analysis of the relationships. The linear regressions of the ice area summed for the December to July period on the December-March air temperature anomaly at Cartwright (r=-0.84) and the NAO index ((r=0.42) show strong relationships, little changed from 2005 (Fig. 15B). The multiple linear regression accounts for 70% of the variability of the integrated sea ice cover with most attributable to air temperature. Though Cartwright air temperature alone accounts for nearly the same amount of variance, linear or multiple regression 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 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 is the first occasion in the 1985-2005 period.
Since 1880, the only other year with no bergs sighted was 1966 (Fig. 17).

Gulf of St. Lawrence

The locations of the ice edge within the Gulf of St. Lawrence during the 2005-2006 winter season are shown in Fig. 18. Ice first appeared in late December as very small patches in the Estuary. Over the next month, ice cover increased slowly and was substantially less than the median. By March 1, most of the northwestern and northeastern Gulf and the Magdalen Shallows were covered with ice but the cover was still less than the long-term median. By April 1, ice was confined to the north shore of the Gulf near the Strait of Belle Isle. No ice was evident on May 1.

The times of first appearance of ice in the Gulf of St. Lawrence were generally normal in the Estuary, along the north shore and in the western Magdalen Shallows (Fig. 12). Ice appearance was up to 30 days later than normal in the rest of the Gulf. Figure 12 implies that all areas of the Gulf were ice-covered in 2006. 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 typically 15-30 days earlier than normal (Fig. 13). Ice duration varied from less than 10 to 110 d (Fig. 14); ice duration was less than the long-term mean everywhere in the Gulf by as much as 60 days.

We have estimated the monthly mean ice area of the Gulf (Fig. 19). The time series shows that in 2006 the December-April cover was the lowest in 38 years and 2.8 standard deviations below normal. The product of ice cover times the duration for the entire 2006 ice season was about 34% of the 1971-2000 average, 2.74 standard deviations below normal. Estimates of ice duration showed that on average, the 2006 season was the 2nd shortest in 38 years, 39 d shorter than the 1971-2000 average duration, 2.2 standard deviations below normal. To summarize, 2006 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 2006, ice first appeared seaward of the Strait in late January, which is the normal time for first appearance, but was restricted to the eastern shore of Cape Breton (Fig. 12). The ice field moved very slowly to southern Sydney Bight. This was the maximum extent of ice onto the Scotian Shelf. Overall the appearance of ice was later than usual and departed earlier than normal (Fig. 13). The duration of ice cover on the Scotian Shelf was substantially shorter than normal for the Scotian Shelf by 40 to 50 days in Sydney Bight (Fig. 14). The January-April ice cover was the 3rd lowest in the 38 year record, 1.5 standard deviations below normal (Fig. 20, 21).

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. 22), were determined from the averages of monthly anomalies and arranged from north to south (Fig. 23). In 2006, the anomalies ranged from 0.05 ^{o}C over eastern Georges Bank to 2.04^{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°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) 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 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 0.05°C (Georges Bank) to 2.04°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. 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 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 indicating 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. 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 1998-2006 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. 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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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. 2007. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/030.

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, C. Lafleur, P. Larouche, B. Pettigrew, J. Chassé, R.G. Pettipas, and W.M. Petrie. 2007. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/024.

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. 2007. *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. 2007. Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/023.

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.

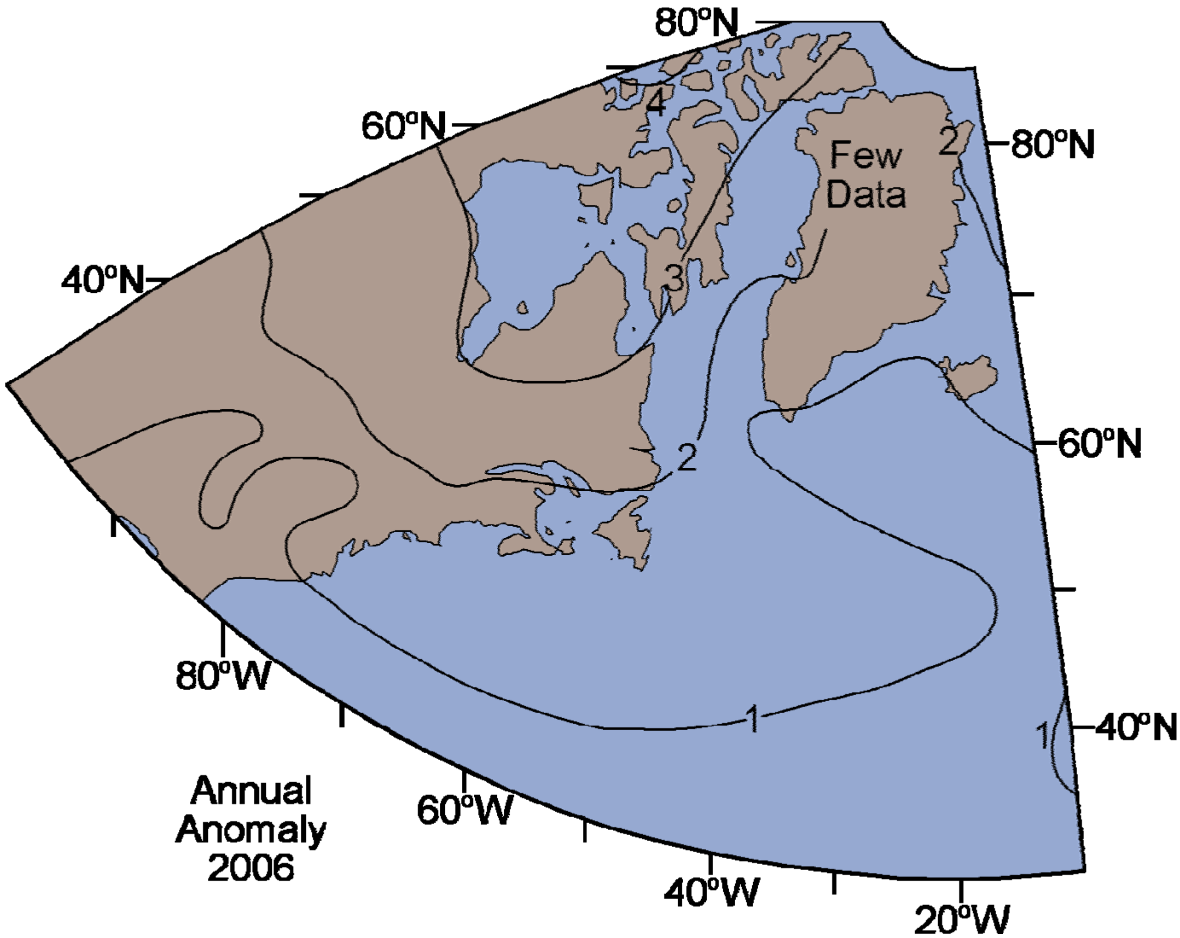

Fig. 2A. The 2006 annual anomaly of air temperature (ºC) over the Northwest Atlantic relative to the 1961-1990 means (Redrawn from *Grosswetterlagen Europas*).

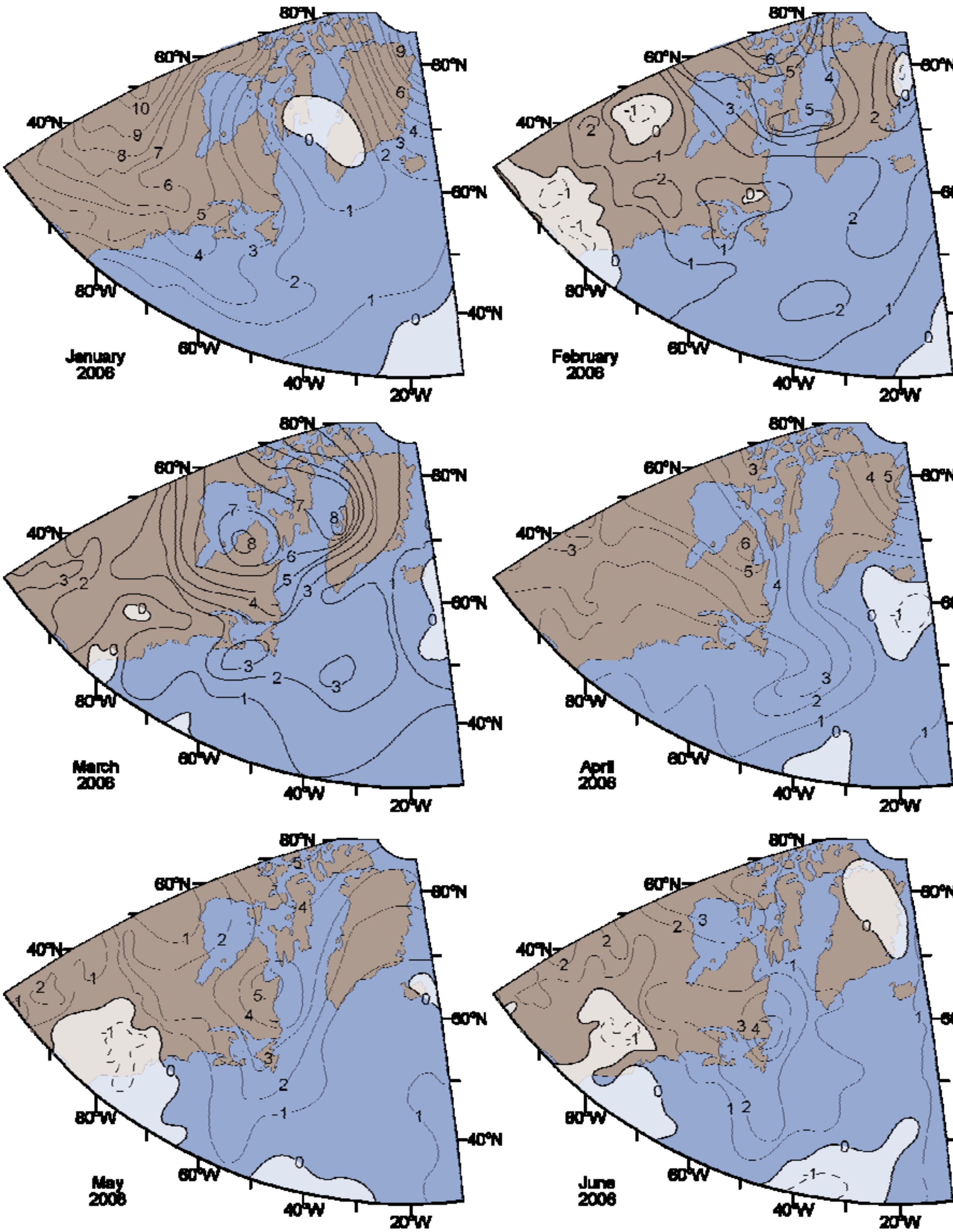

Fig. 2B. Monthly air temperature anomalies (^{o}C) over the Northwest Atlantic from January to June of 2006 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*).

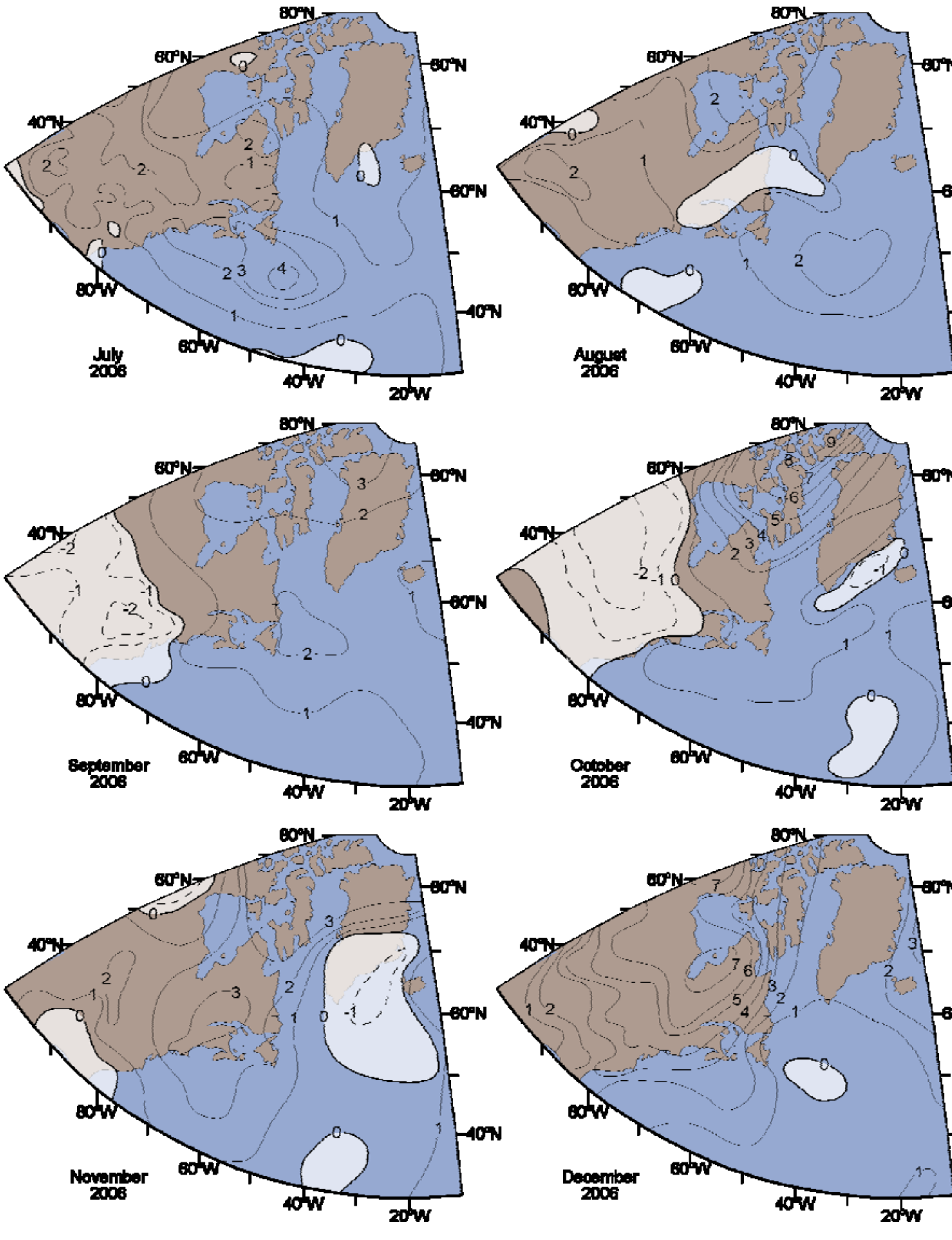

Fig. 2C. Monthly air temperature anomalies (°C) over the Northwest Atlantic from July to December of 2006 relative to their 1961-1990 means. Warmer (colder)-than-normal anomalies are contoured with solid (broken) lines. (Redrawn from *Grosswetterlagen Europas*)

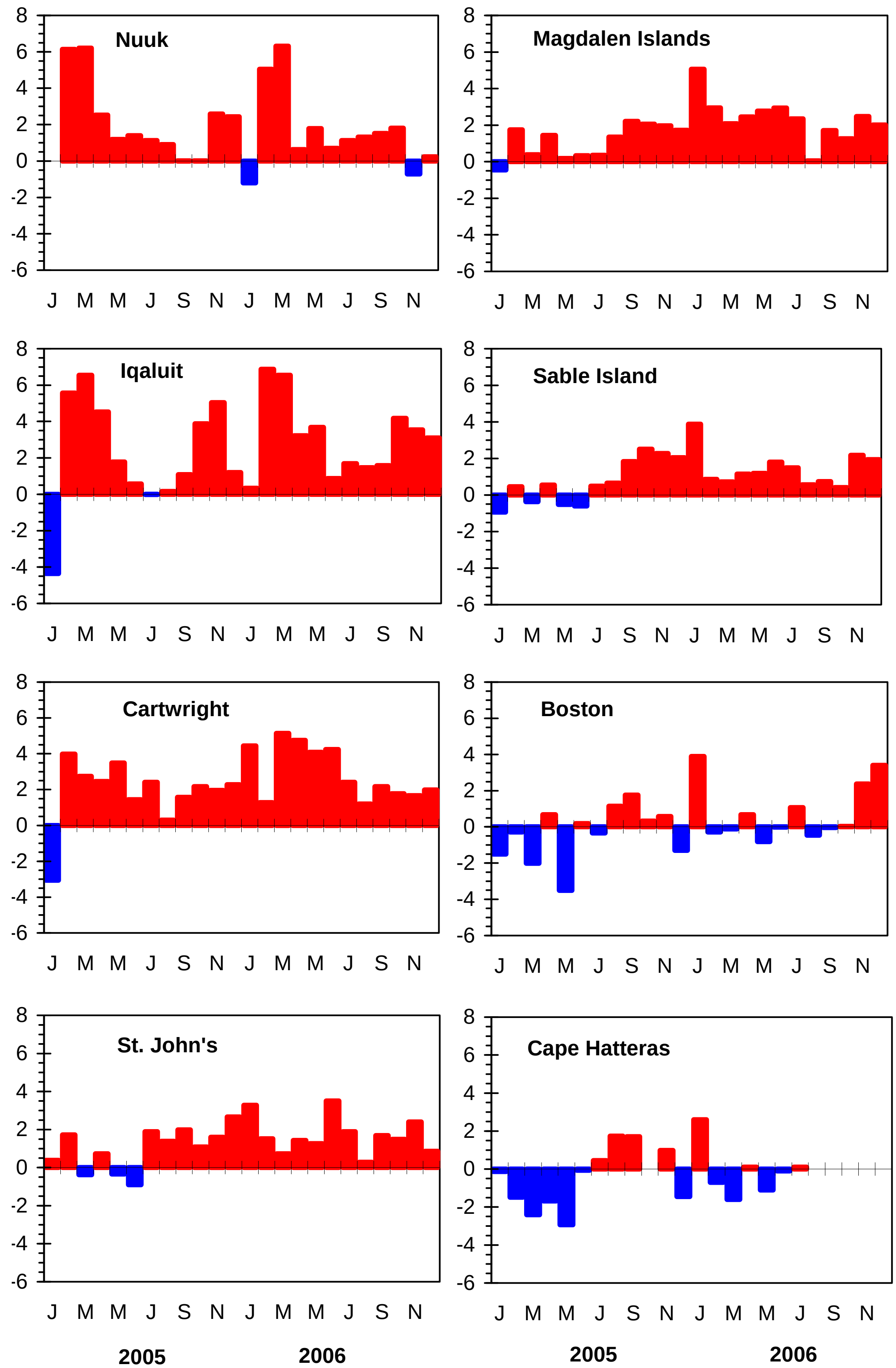

Fig. 3. Monthly air temperature anomalies in 2005 and 2006 at selected coastal sites (see Fig. 1 for locations).

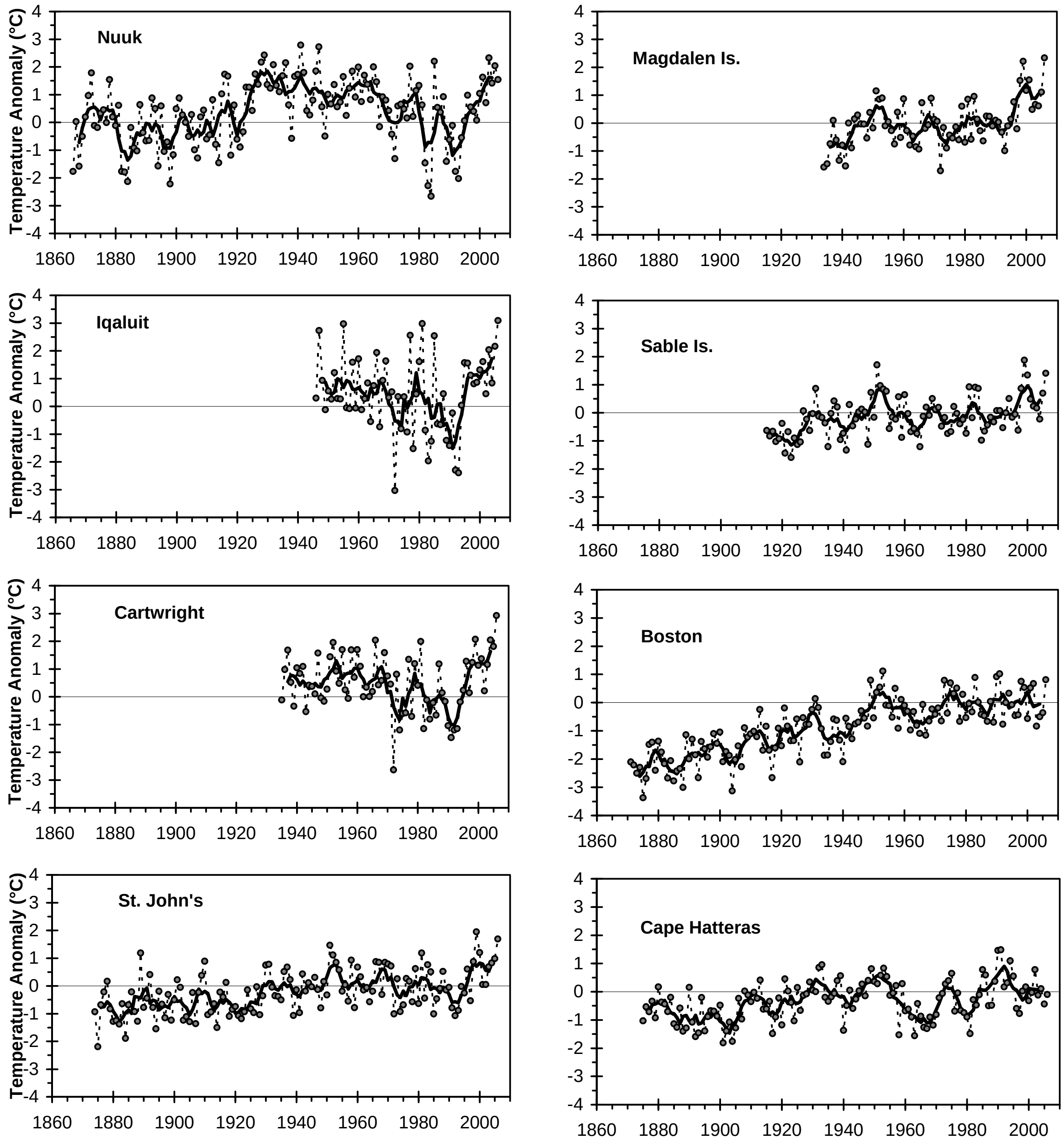

Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

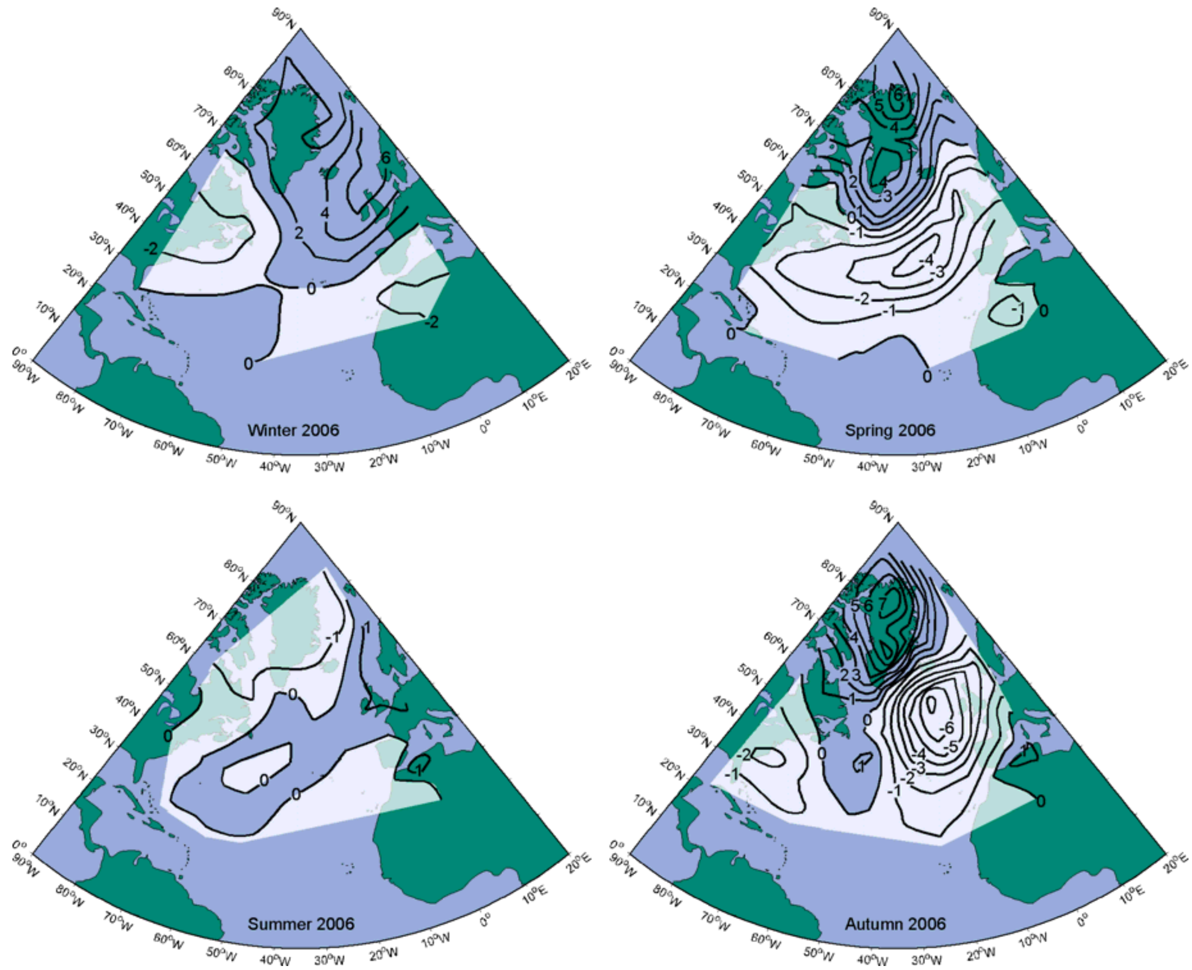

Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 2006 relative to the 1971-2000 means.

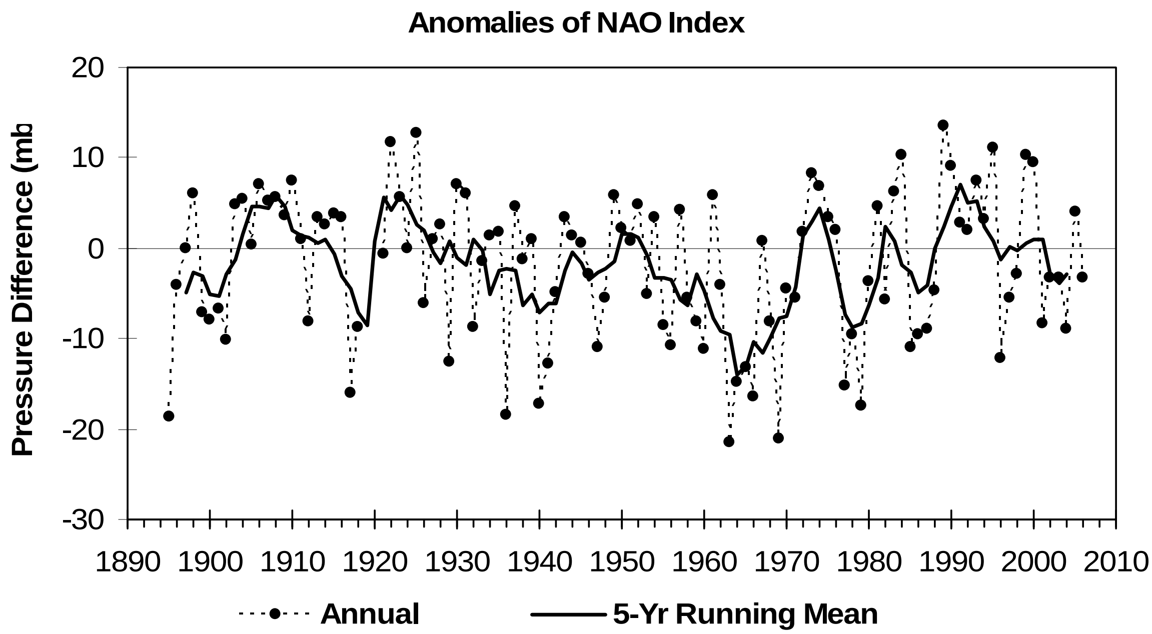

Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean.

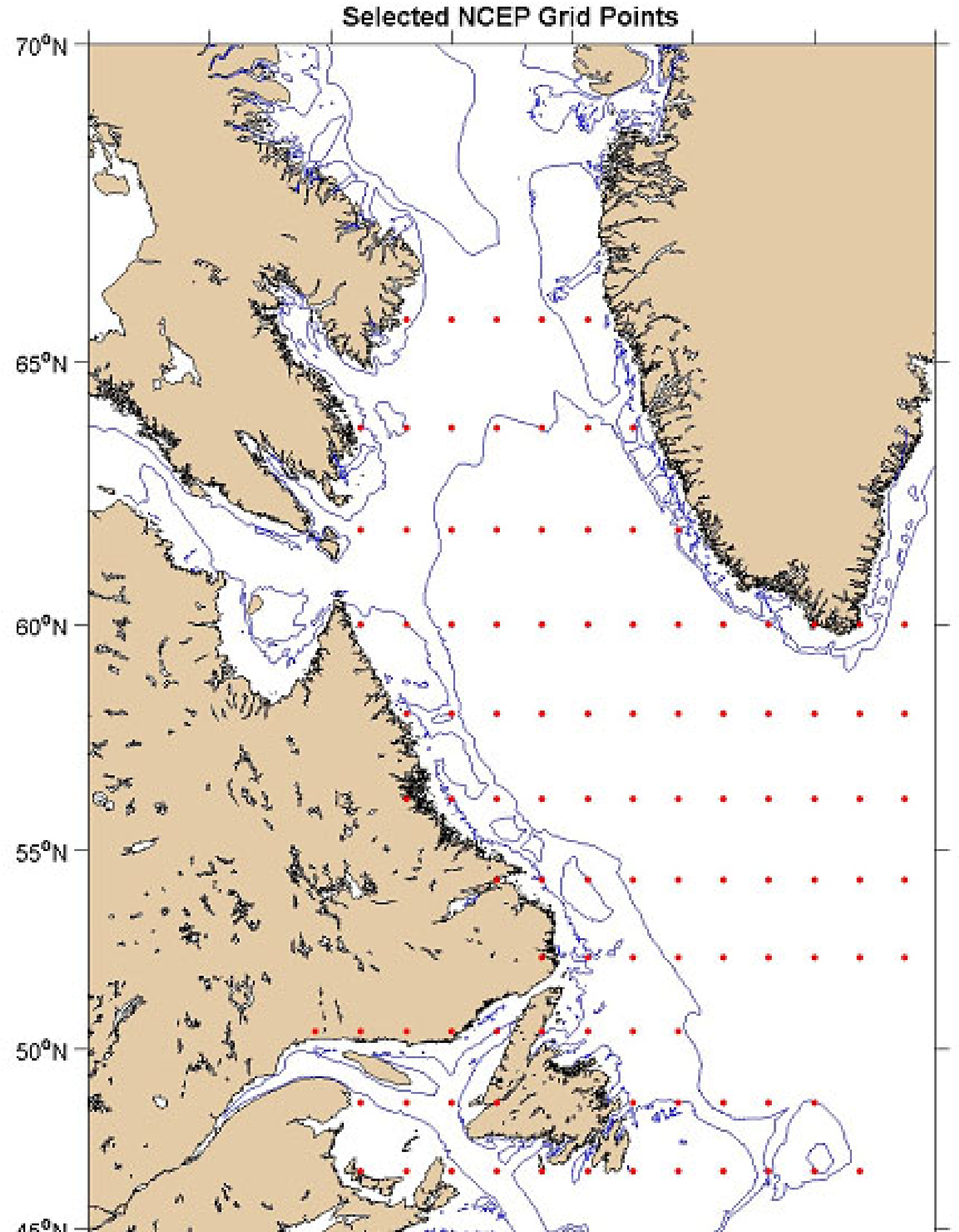

Fig. 7. The Northwest Atlantic showing the NCEP wind grid used in our study.

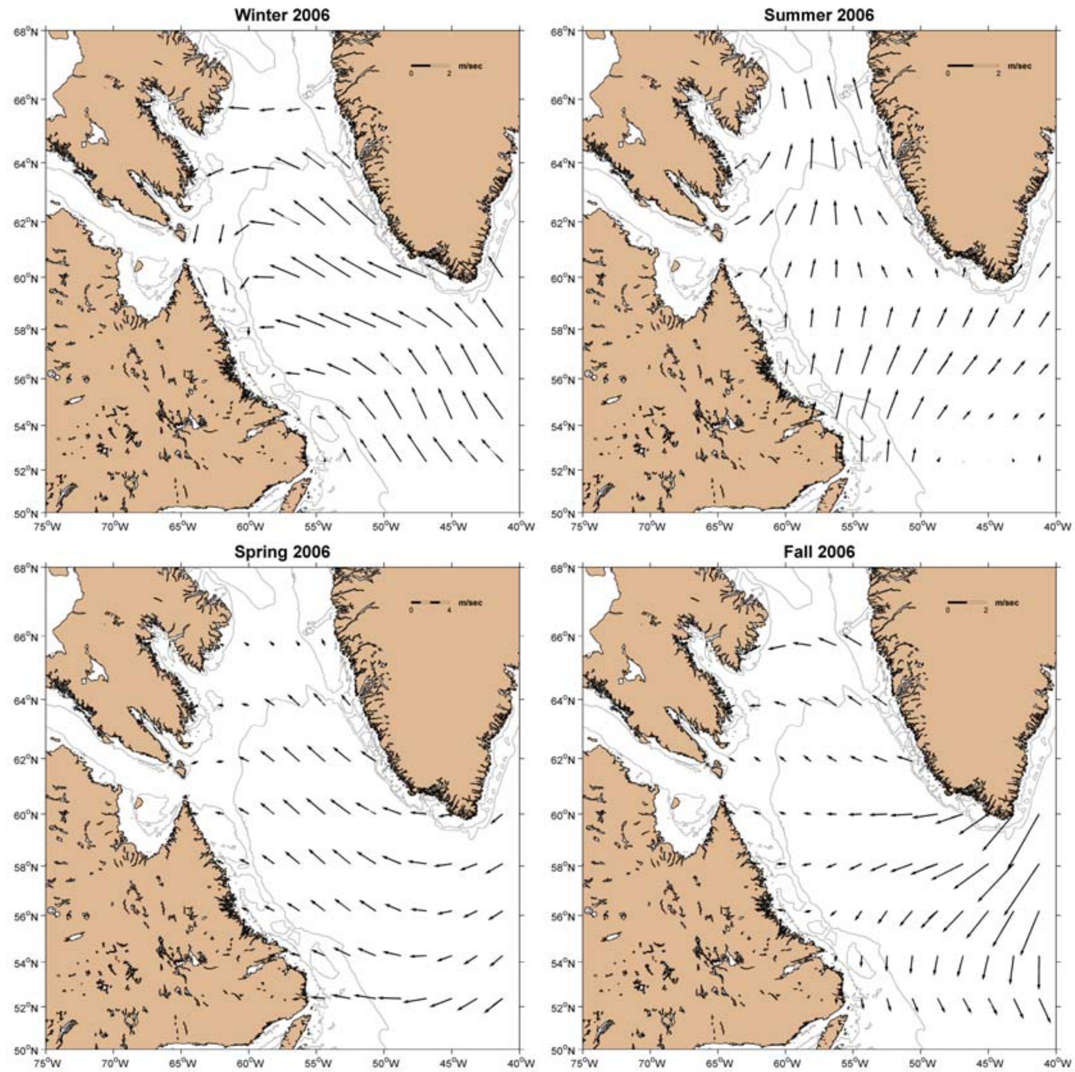

Fig. 8. The seasonal wind anomalies for the northern region during 2006. Note the different scale (0-4 m/s) for spring.

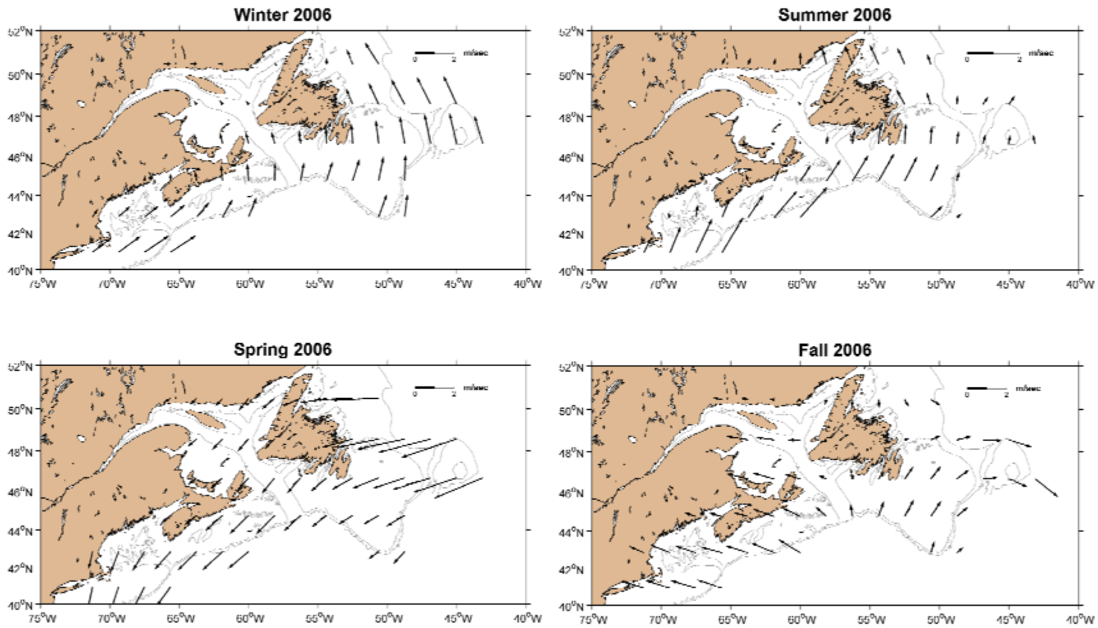

Fig. 9. The seasonal wind anomalies for the southern region during 2006.

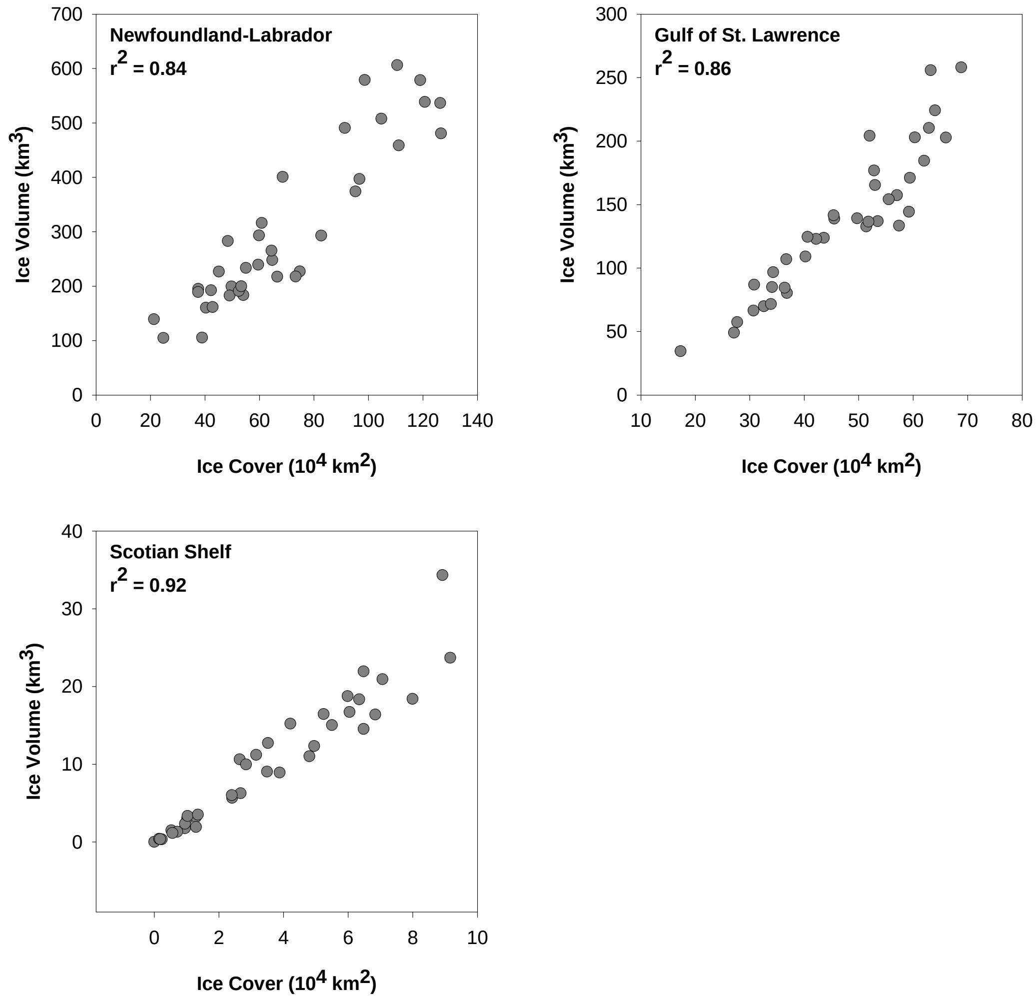

Fig. 10. Comparison of the annual ice cover and ice volume for the Newfoundland-Labrador Shelf summed over the December-June periods, the Gulf of St. Lawrence (December-April) and the Scotian Shelf (January-April).

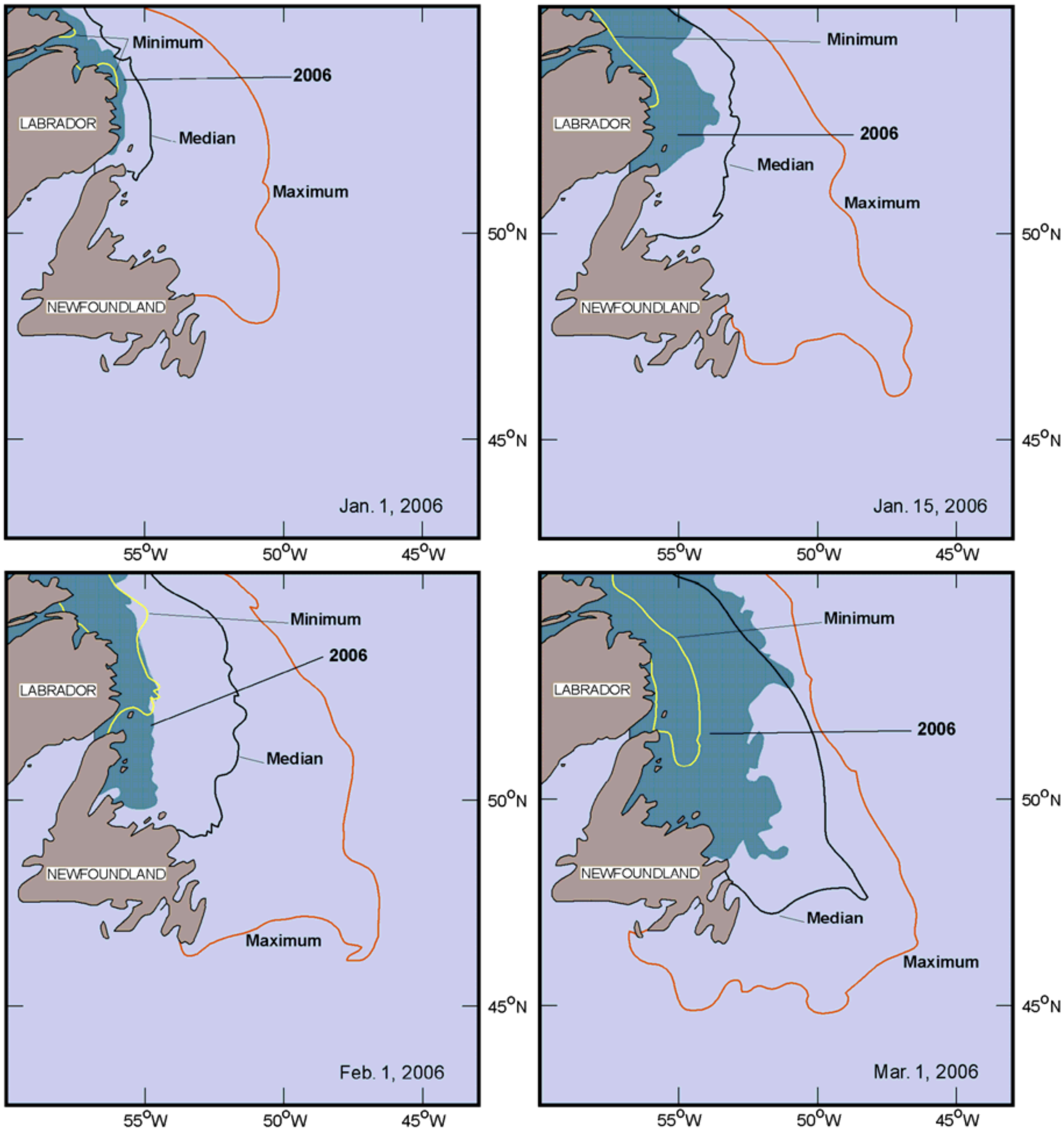

Fig. 11A. The location of the ice (shaded area) between January and March 2006 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

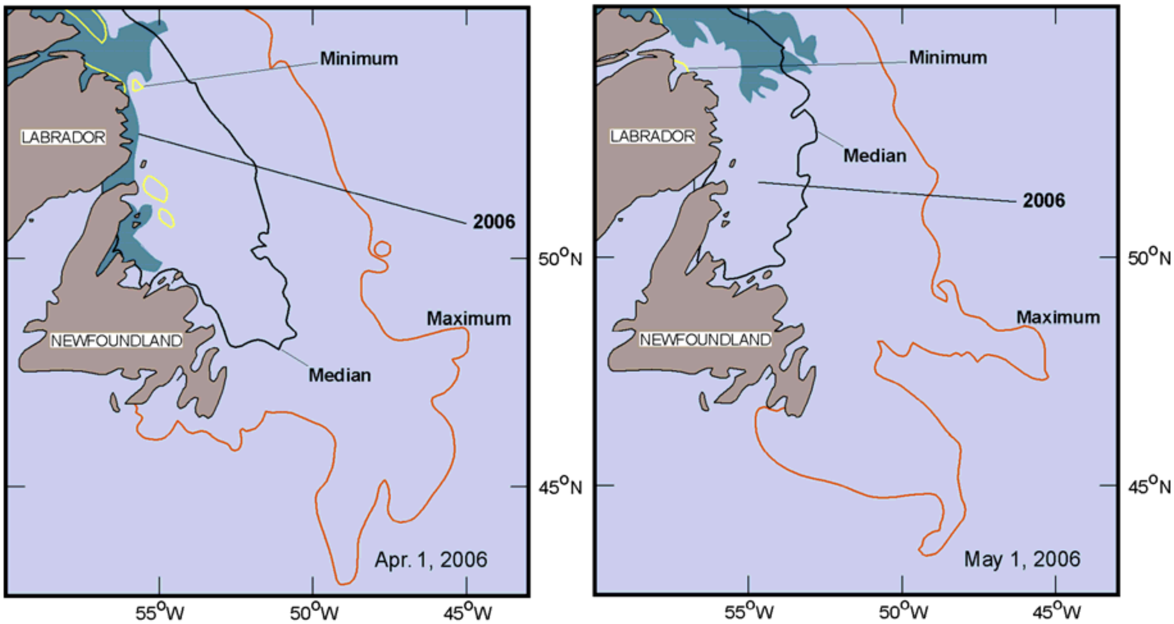

Fig. 11B. The location of the ice (shaded area) between April and May 2006 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

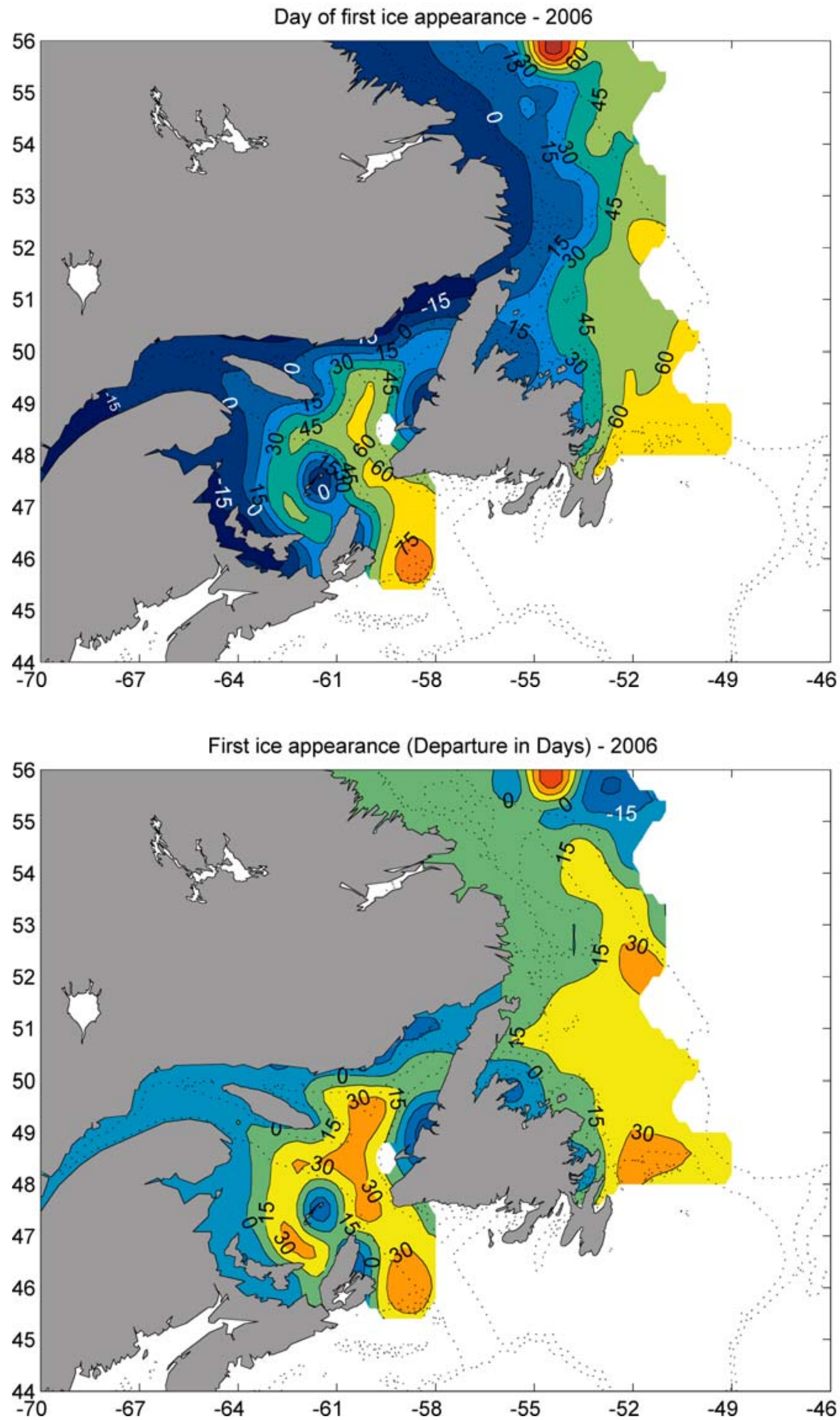

Fig. 12. The time when ice first appeared during 2006 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative (positive) anomalies indicate earlier (later) than normal appearance.

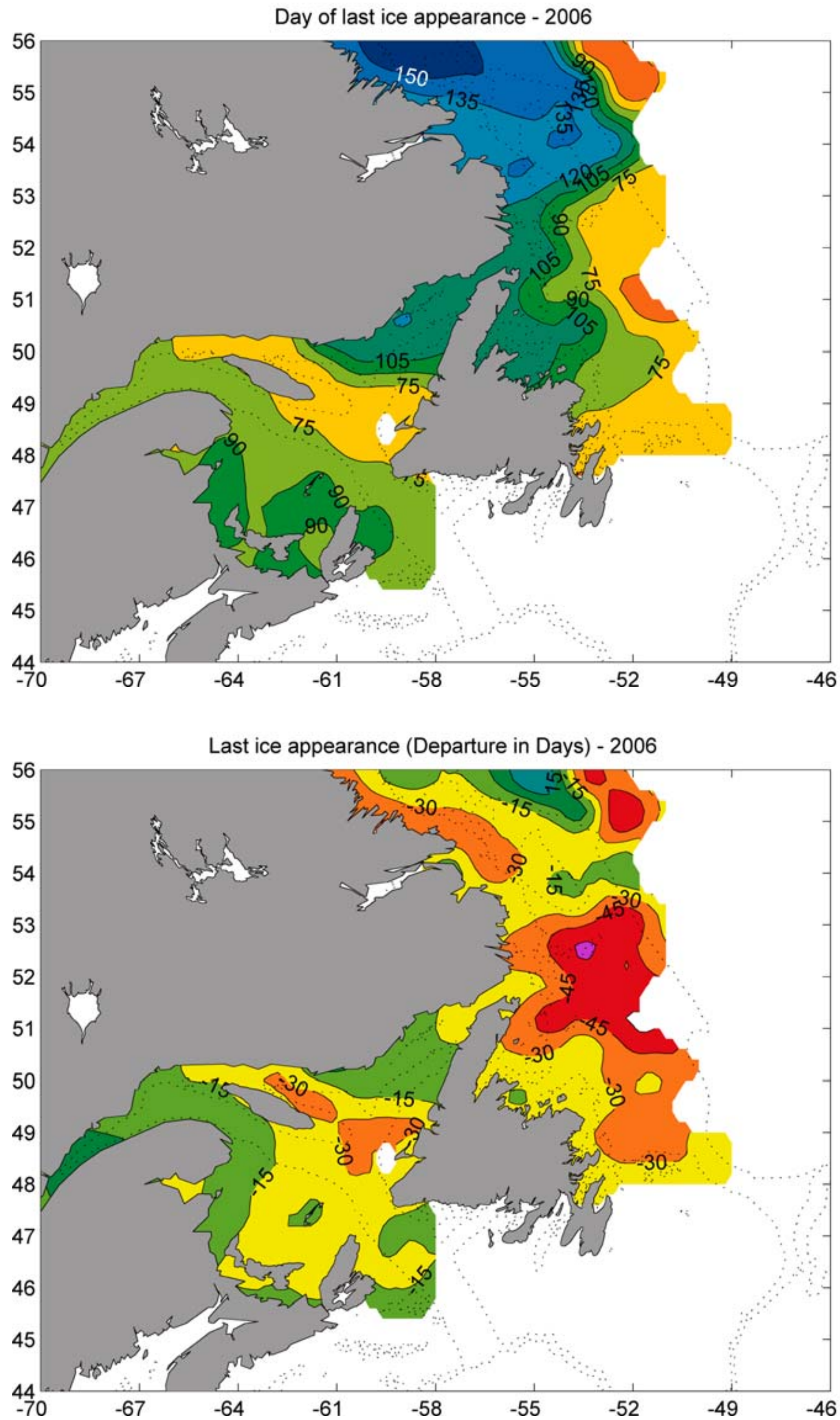

Fig. 13. The time when ice was last seen in 2006 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance.

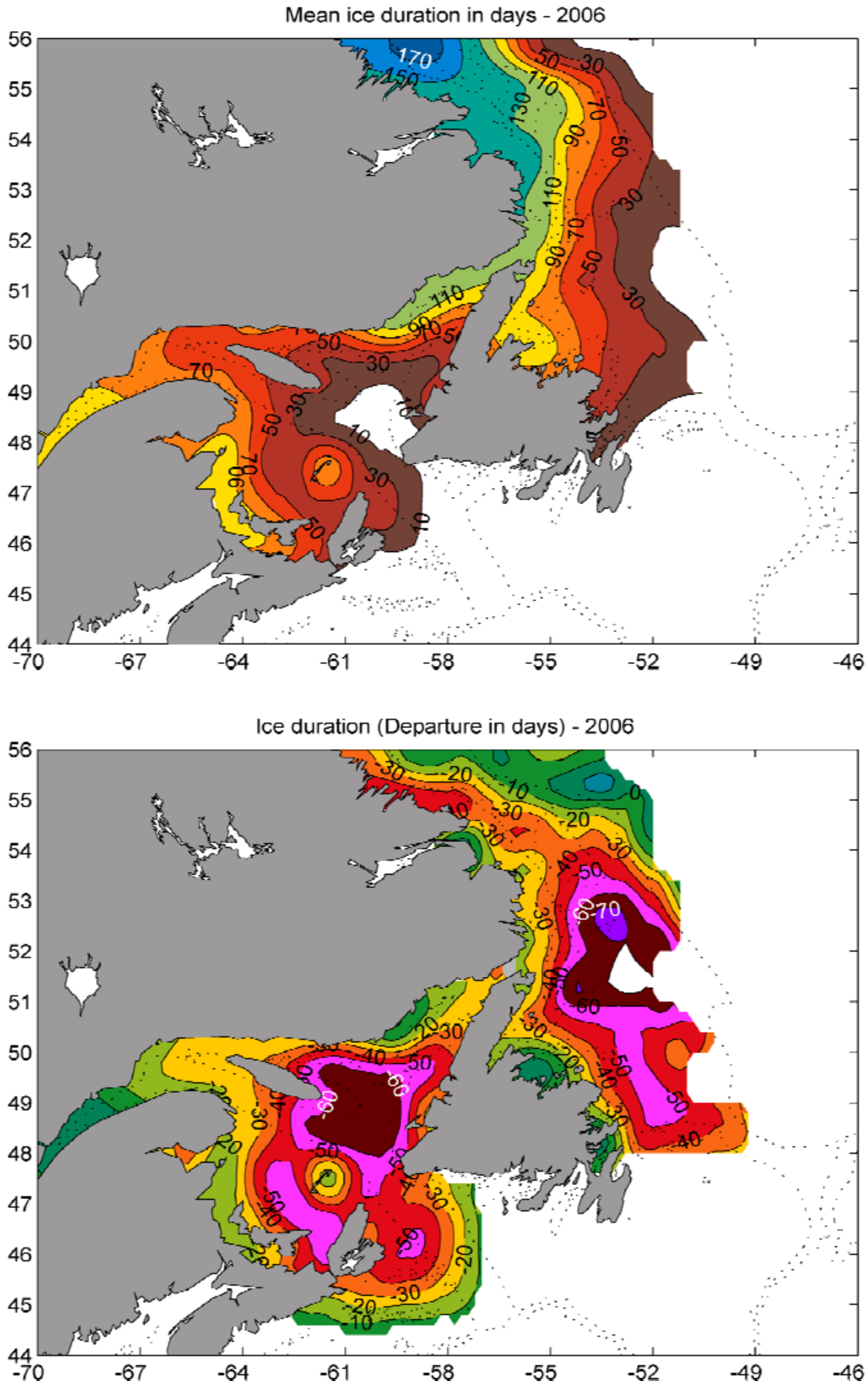

Fig. 14. The duration of ice in days (top panel) during 2006 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

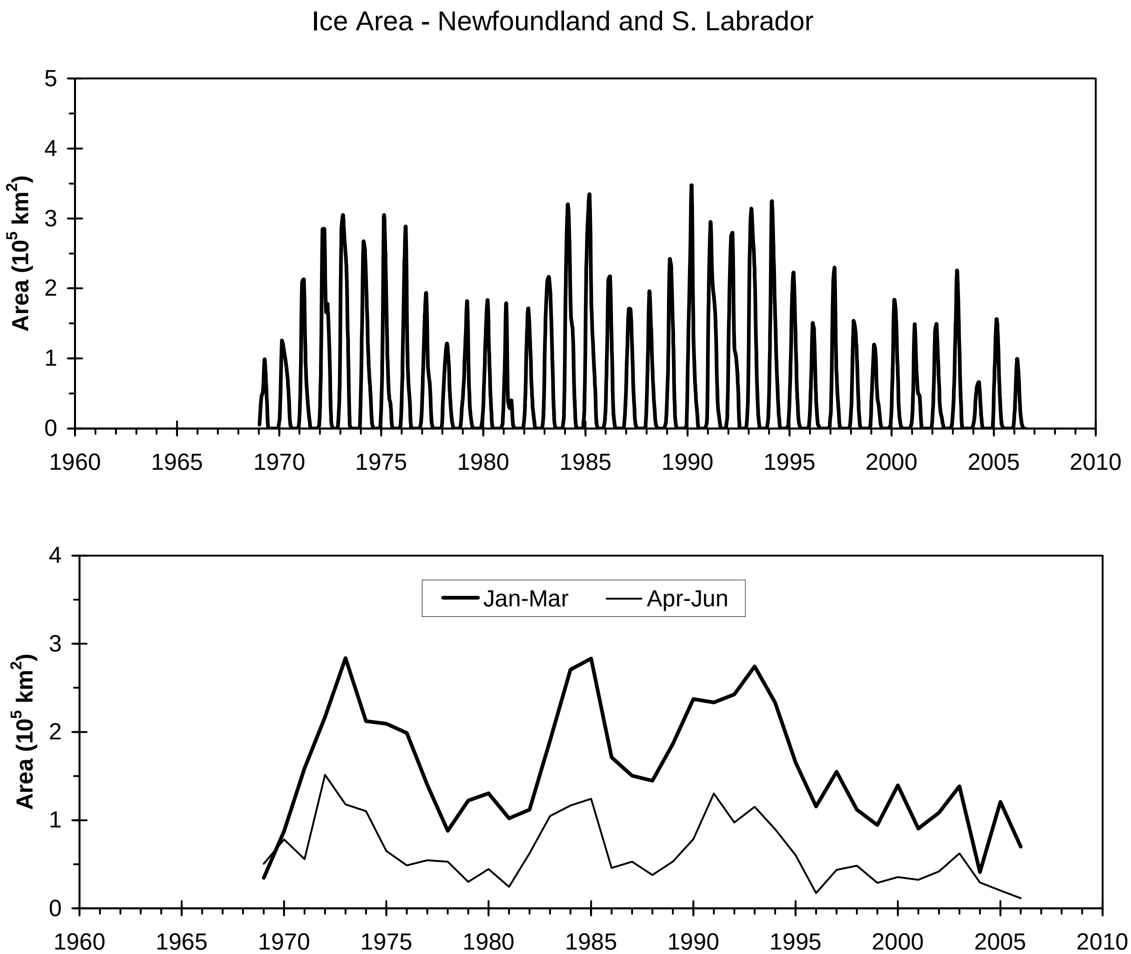

Fig. 15A. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (bottom panel).

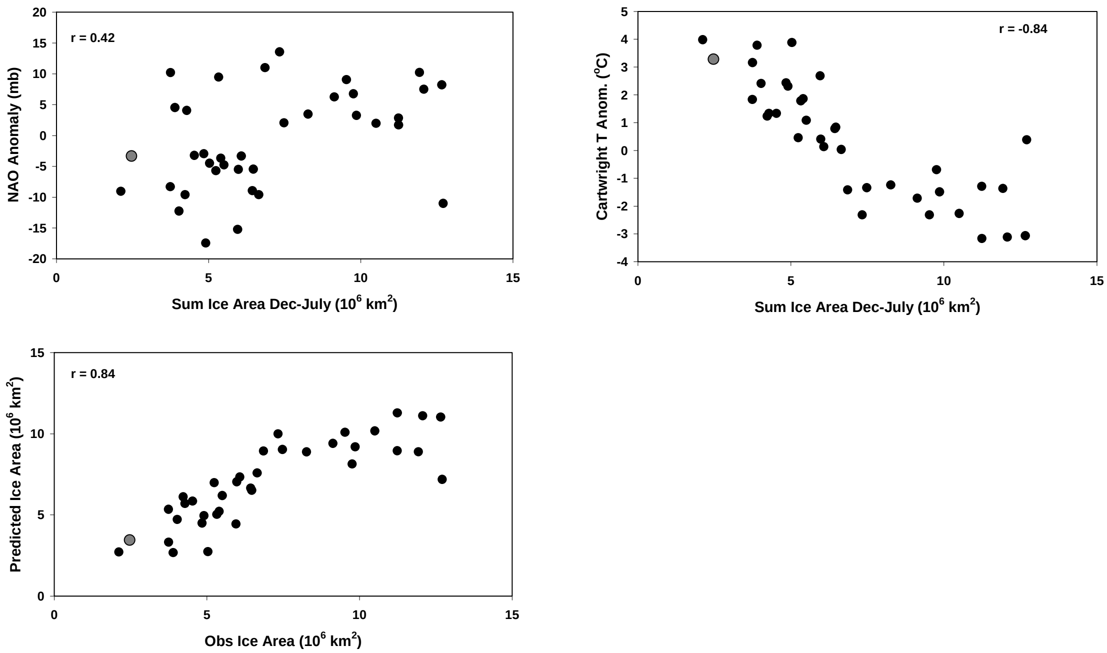

Fig. 15B. Comparison of time series of the December-July summed ice area off Newfoundland and Labrador between 45°N-55°N and the NAO anomaly and Cartwright December-March air temperature anomaly. The last panel shows the comparison of the observed, December-July ice cover and the cover calculated from 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 2006 value is displayed as a larger grey point.

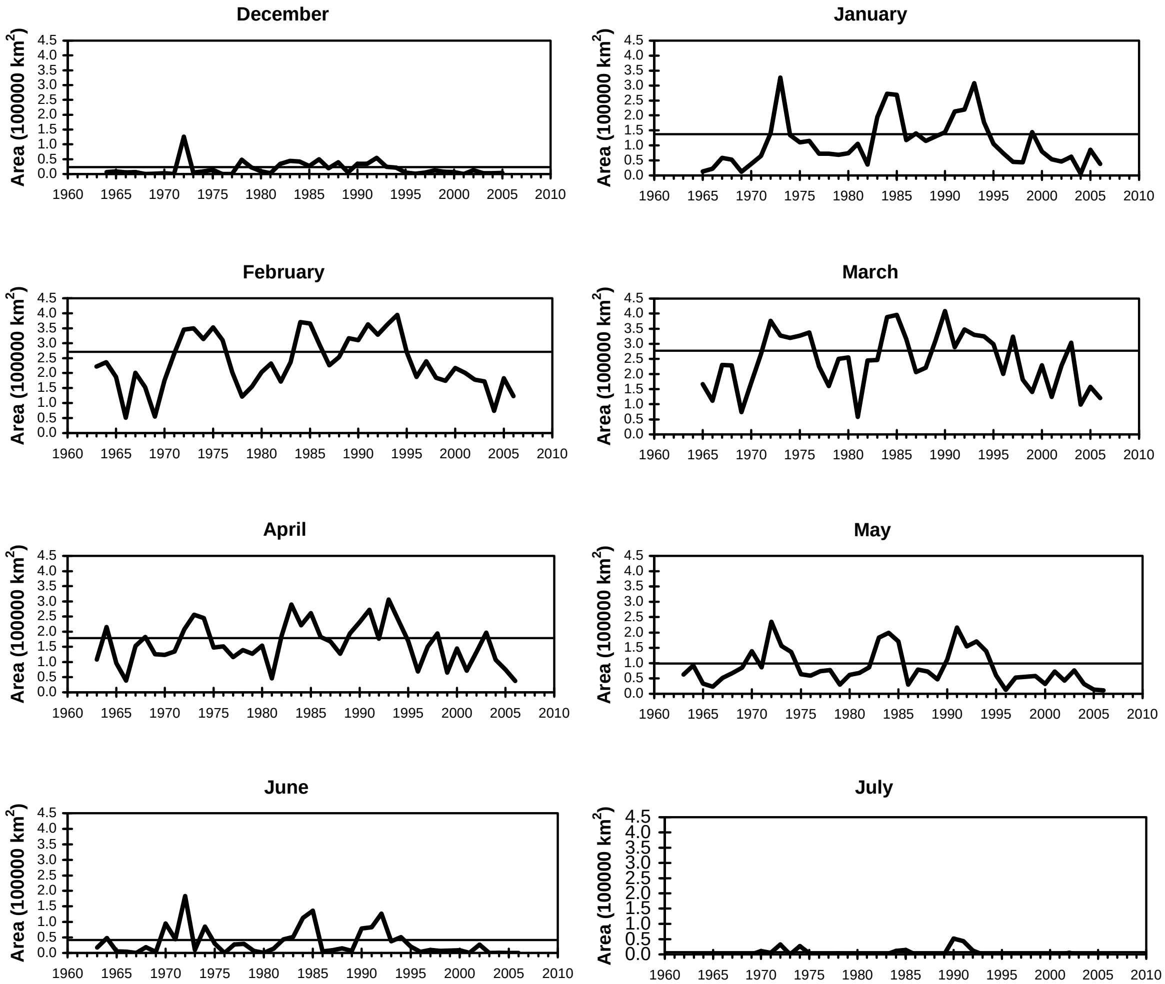

Fig. 16. The time series of ice area off Newfoundland and Labrador by month is presented. The horizontal lines represent the long-term (1971-2000) means.

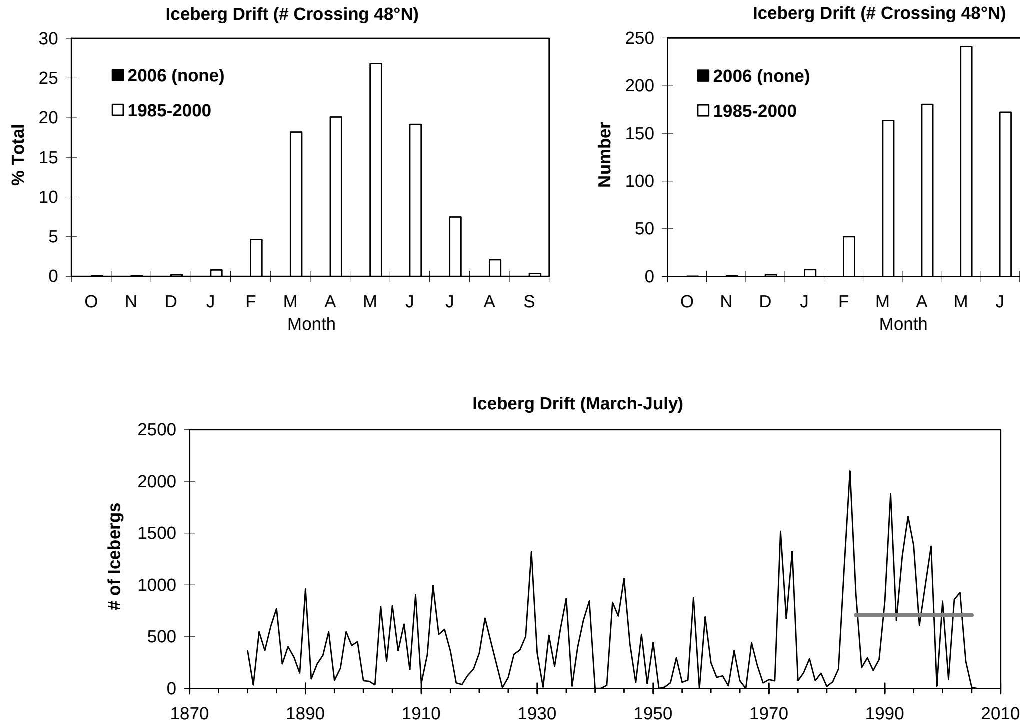

Fig. 17. The number of icebergs crossing south of 48°N during the iceberg season 2005/2006 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2000, the years SLAR has been used (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2006 average number of icebergs.

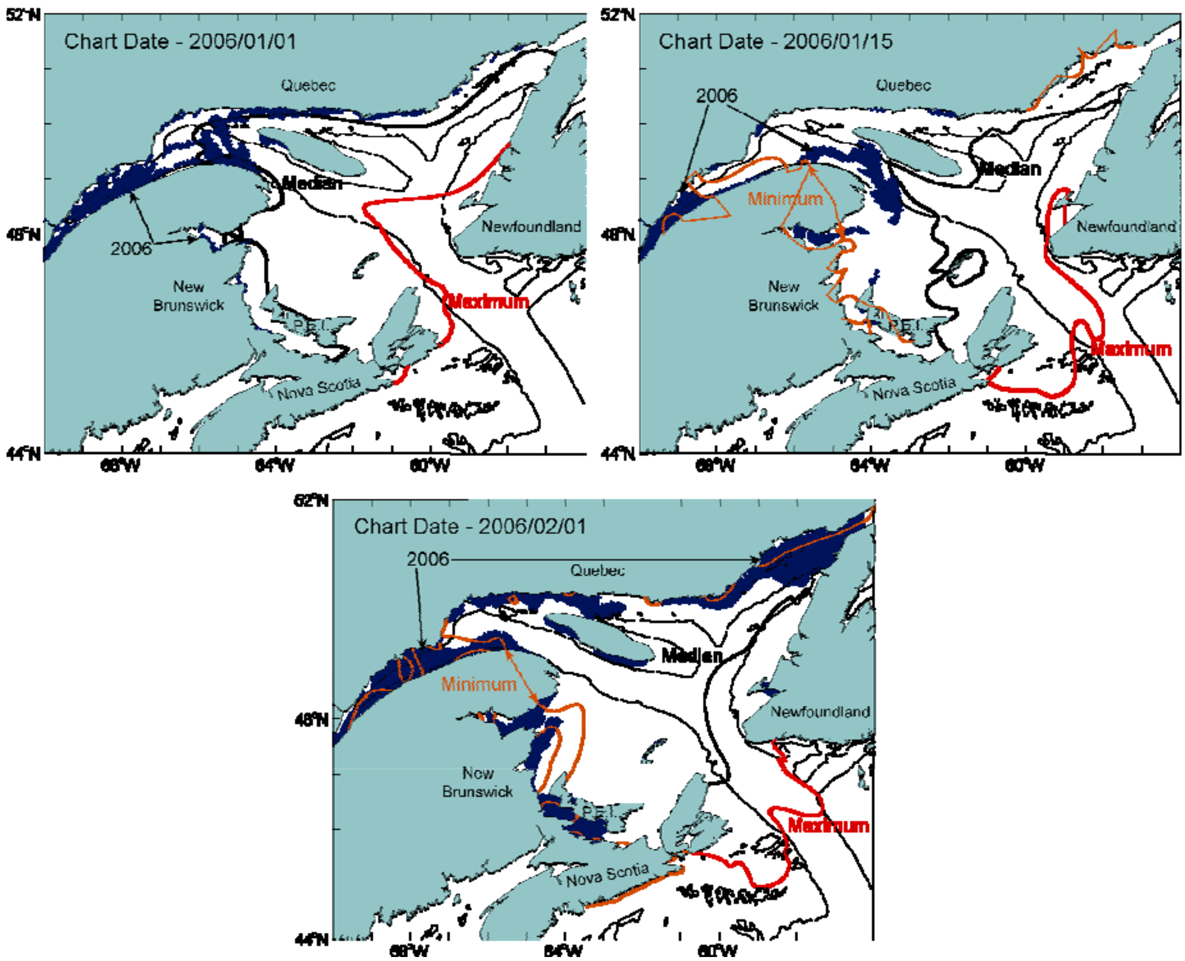

Fig. 18. The location of the ice (shaded area) between December 2005 and February 2006 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

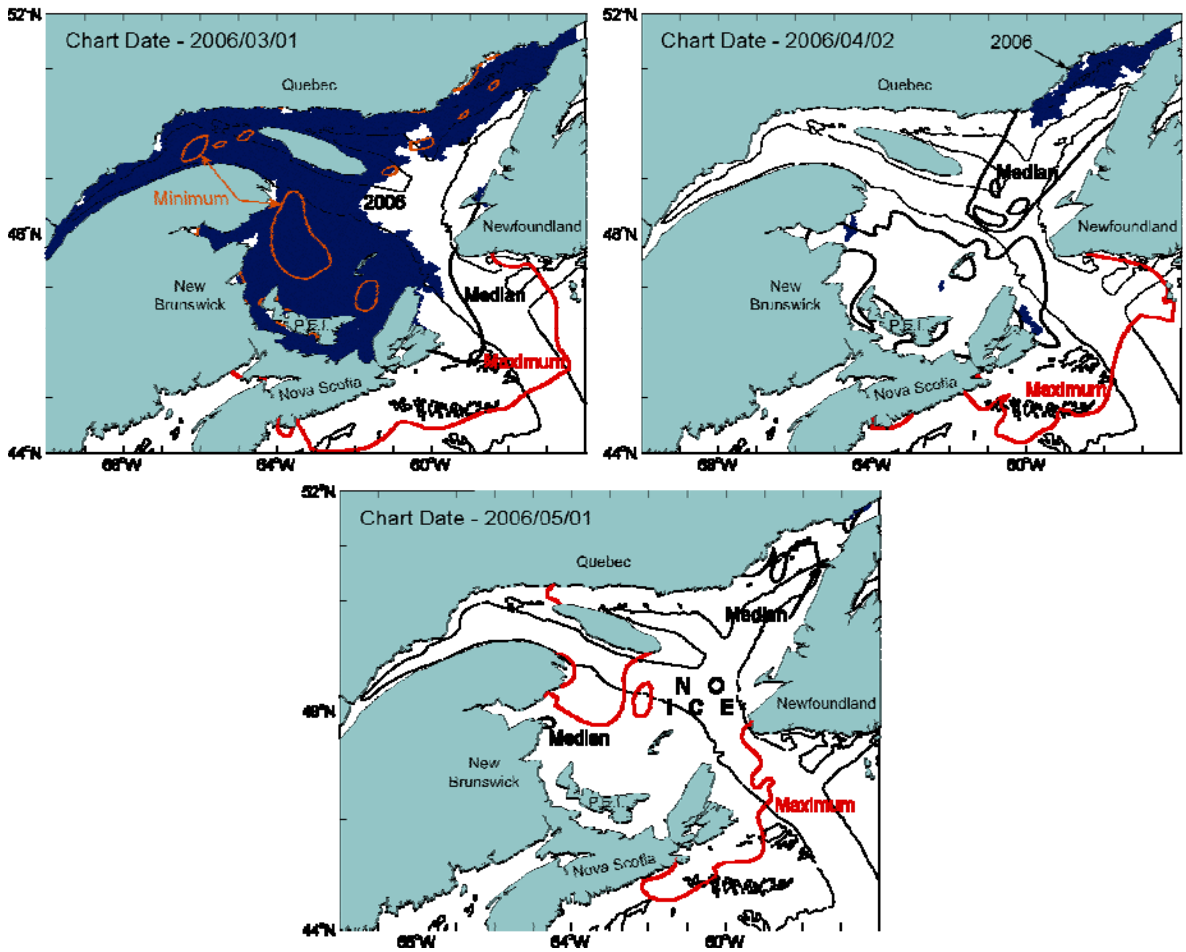

Fig. 18, continued. The location of the ice (shaded area) between March and May 2006 together with the long-term (1971-2000) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

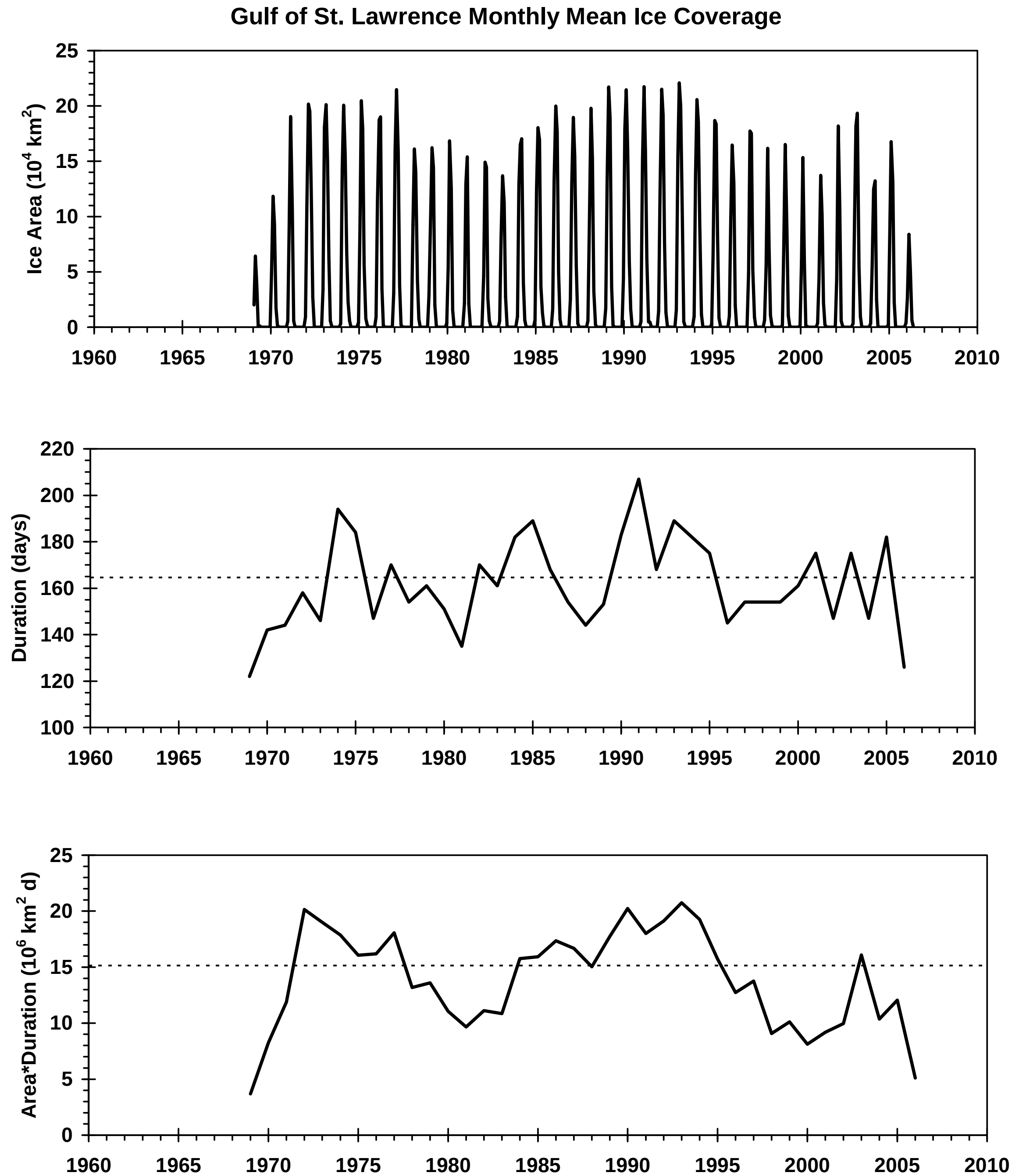

Fig. 19. For the Gulf of St. Lawrence, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

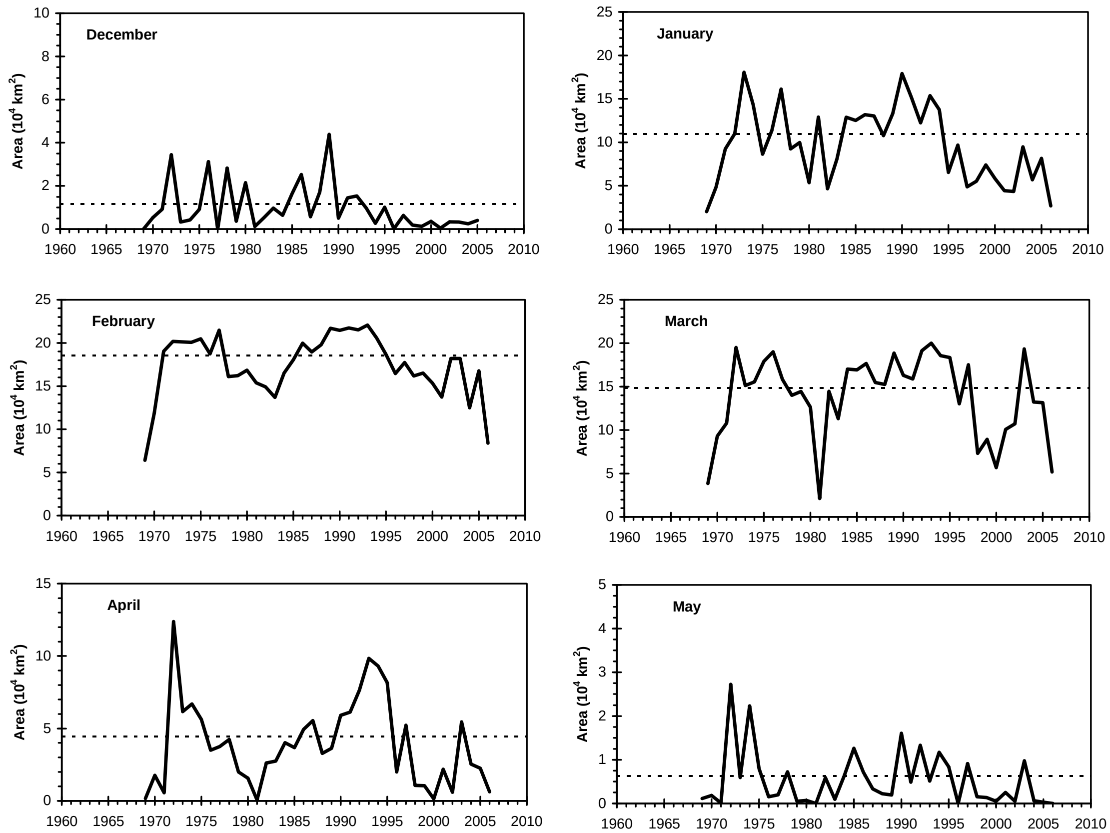

Fig. 19, continued. The time series of ice area in the Gulf of St. Lawrence by month is presented. The horizontal lines represent the 1971-2000 means.

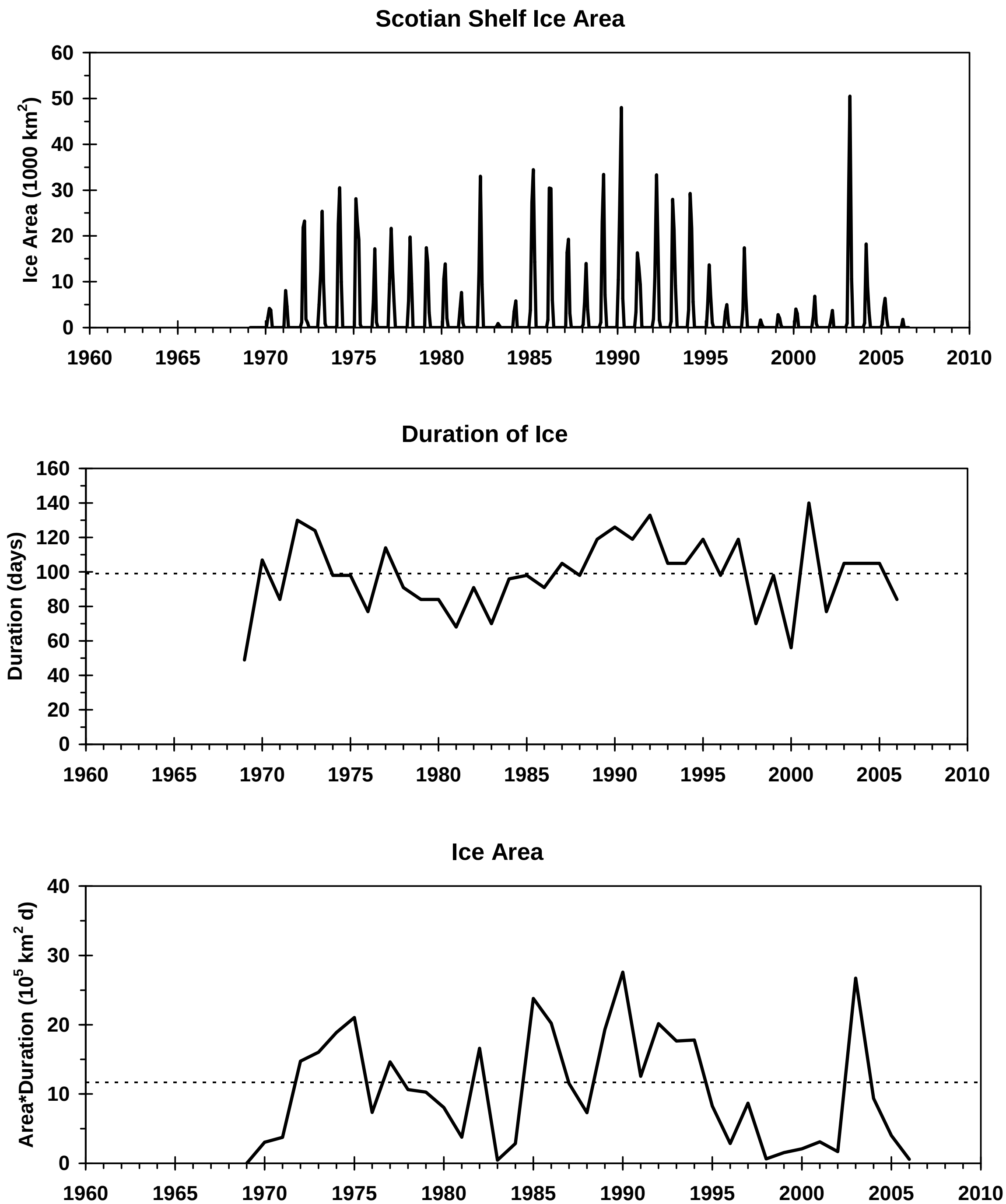

Fig. 20. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1971-2000) means.

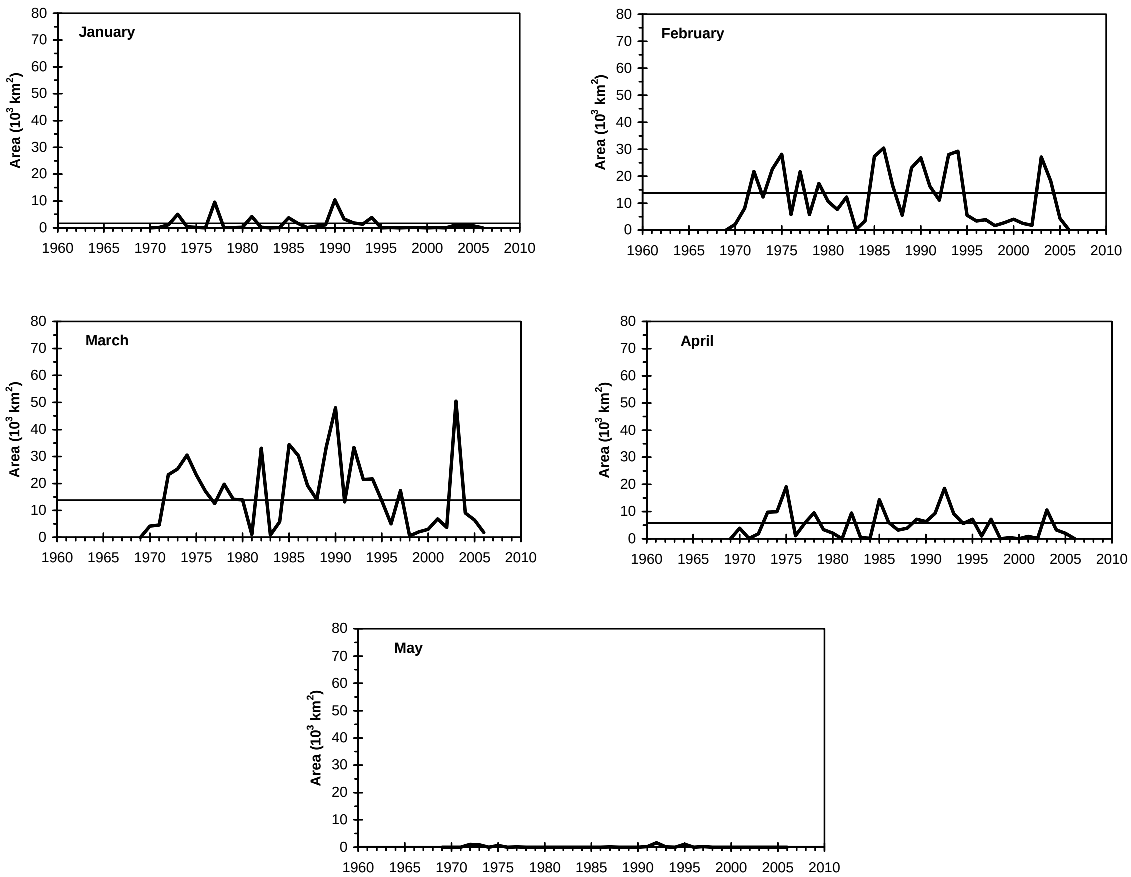

Fig. 21. The time series of ice area seaward of Cabot Strait by month is presented. The horizontal lines represent the 1971-2000 means.

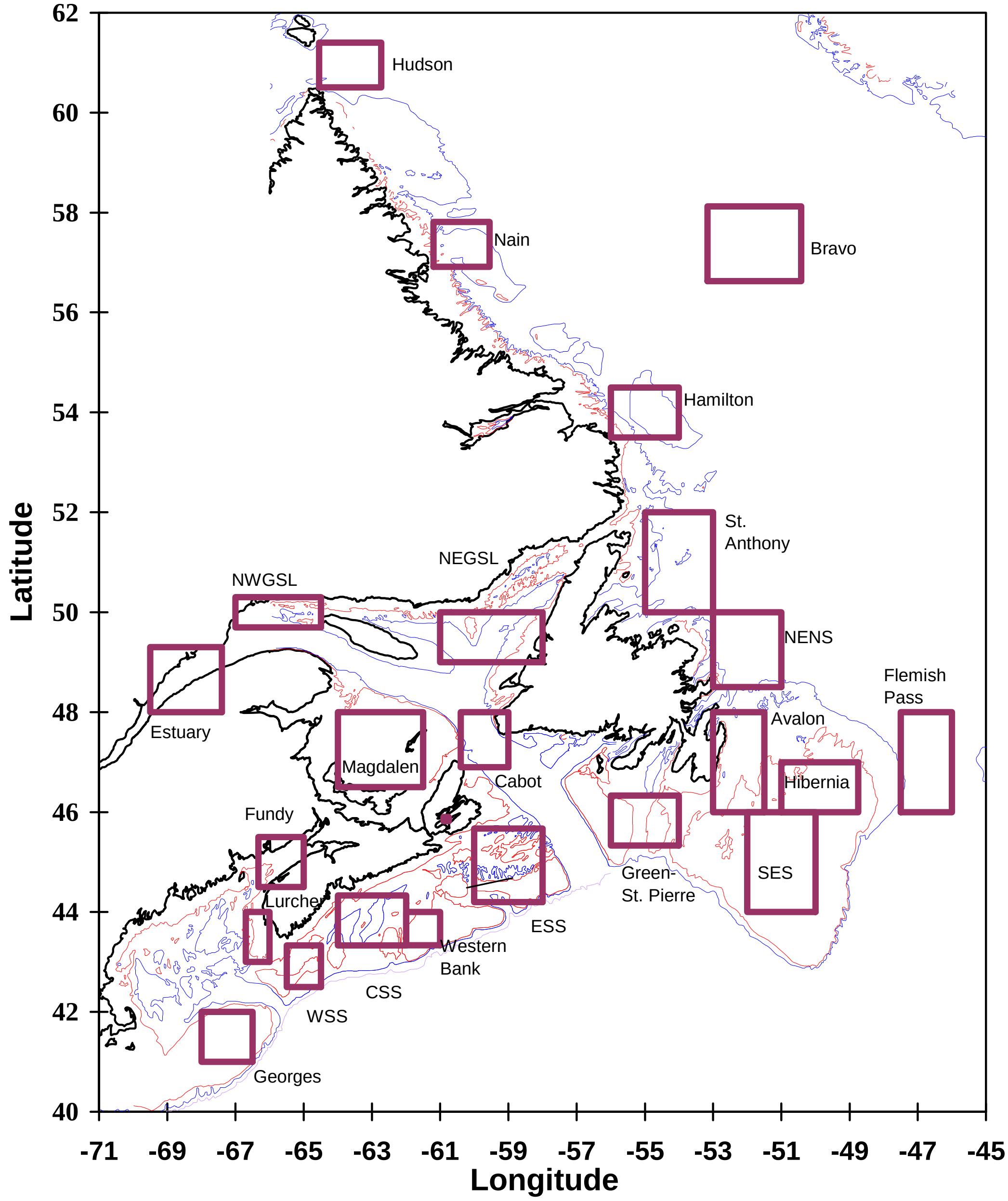

Fig. 22. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

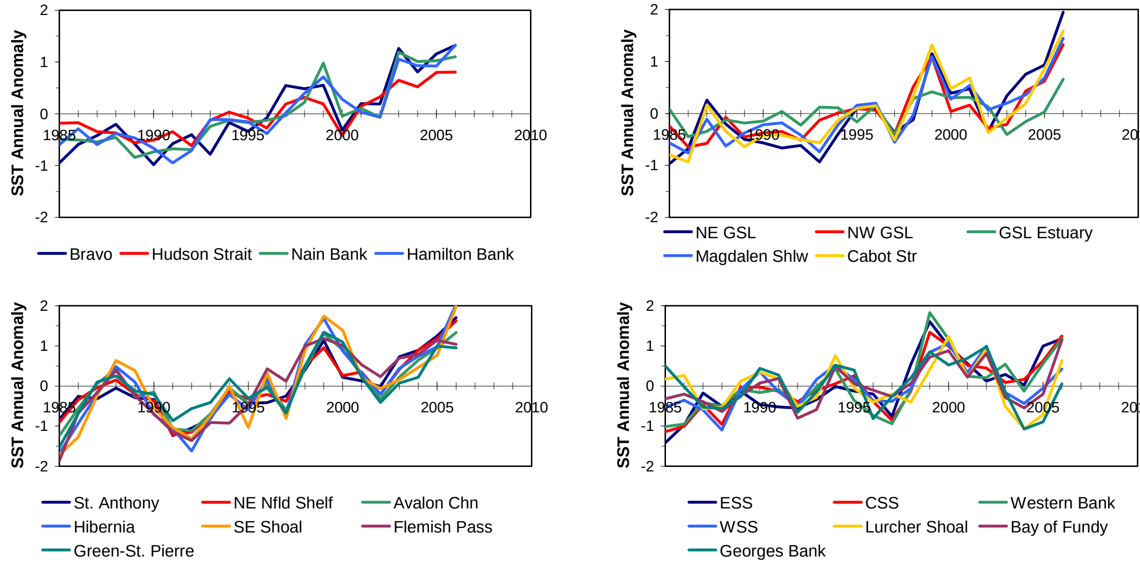

Fig. 23. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985-May 2003. Estimates for June 2003-December 2006 were from the remote sensing laboratory, Biological Sciences Section of the Ocean Sciences 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.

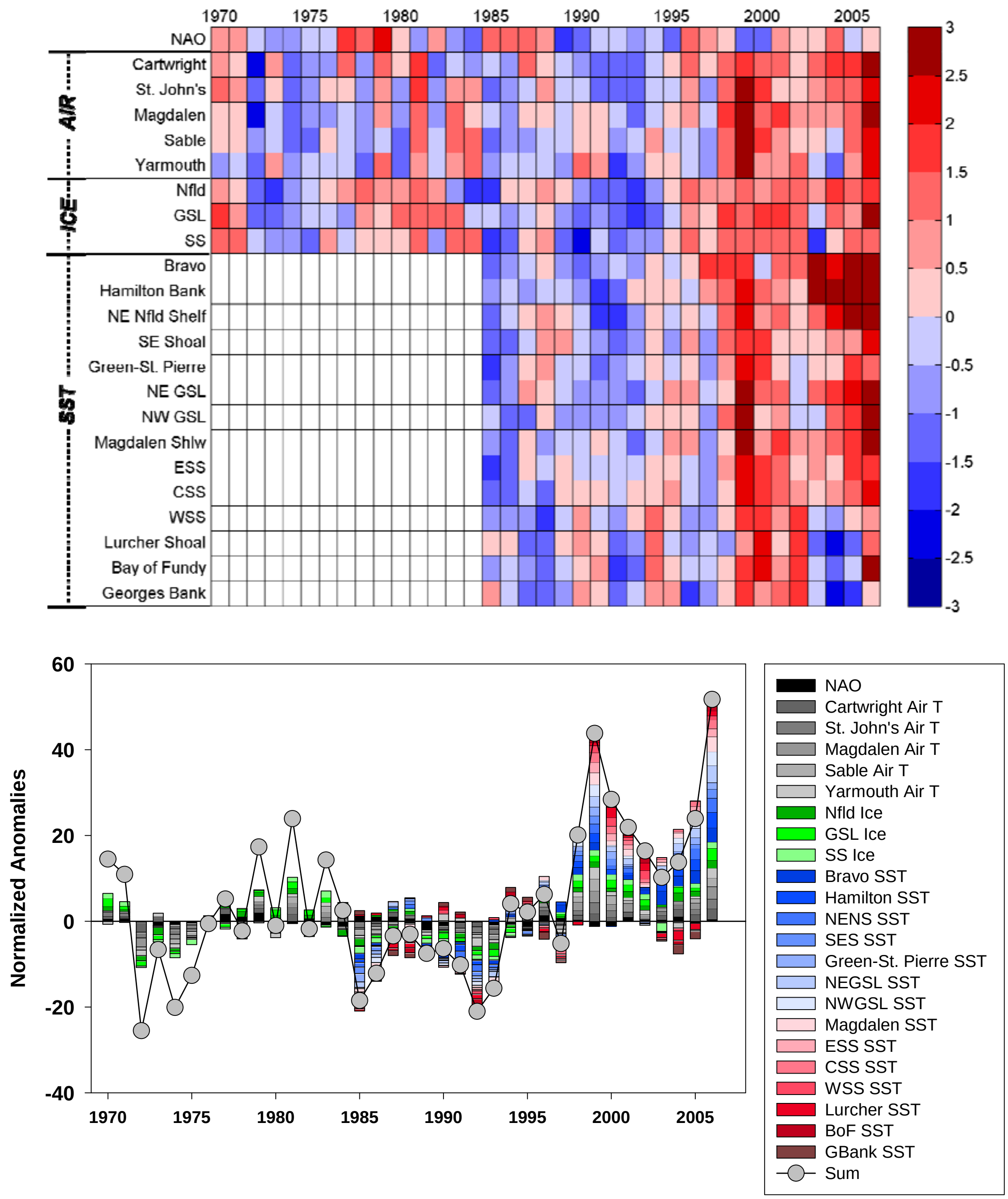

Fig. 24. Normalized annual anomalies of the NAO, air temperatures, ice and sea surface temperatures for the Atlantic region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means (except for SST where all data are used), divided by the standard deviation. The scale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