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Climatic Conditions Around Greenland - 2002

by

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic was anomalous during winter 2001/2002. In contrast to previous winters (1999-2001), the pressure anomaly fields during this winter differed considerably from a dipole pattern which is usually present in the North Atlantic region, with two pressure anomaly cells, one in the Icelandic Low area, the other in the Azores High area. As a consequence of this unusual anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2001/2002 was weak and negative (-0.24). Air temperature climatic conditions around Greenland continued to be warm. The climatic conditions at Nuuk are consistent with the NAO index (negative index = mild climate).

Warmer than normal conditions were observed around Greenland during most of the year 2002 with mean air temperatures at Nuuk indicating positive anomalies (+0.3K). Based on satellite derived ice charts and sea-surface temperature (SST) anomaly maps for all months of 2002 it is shown that the distribution of ice in the southwestern area off West Greenland, and especially in the Julianehaab Bight, is reflected in the SST anomalies. Except for December, during all months in 2002 the surface waters in the southwestern area off West Greenland were colder than normal. During winter and spring SST anomalies indicate considerable warming which exceeded +3.5K in the central Labrador Sea. Colder than normal SSTs in the region of Fyllas Bank during most of the second half of 2002 were confirmed by measurements along the NAFO Standard Section Fyllas Bank, performed from board the German RV "*Walther Herwig III*". Subsurface oceanographic data from Fyllas Bank reveal considerable cooling in the upper 200 m during autumn 2002. Irminger Water was not found at Fyllas Bank during autumn 2002. In the near-bottom water layer off Cape Desolation/West Greenland, at about 3 000 m depth, freshening of the Denmark Strait Overflow water mass was observed.

Introduction

There are two annual Greenland surveys which are ongoing since decades in the waters adjacing this island: The Danish June survey (Buch, 2000), and the survey performed by Germany in autumn. During October/November 2002 FRV "*Walther Herwig III*" achieved oceanographic observations at NAFO Standard Oceanographic Sections Cape Desolation and Fyllas Bank as part of the annual autumn groundfish survey to East and West Greenland waters performed by Germany since 1963. The oceanographic data obtained during these surveys form the basis for interpretation of the oceanic climate on the fishing banks around Greenland and at selected NAFO Standard Oceanographic stations.

Starting in 1993 with a compilation of climatic conditions in the northwestern North Atlantic area (Stein, 1995), this paper is the tenth in a series which provides an annual overview on environmental conditions around Greenland. Whereas the subsurface oceanographic data originate from FRV "*Walther Herwig III*" observations and from the World Ocean Database, the air pressure data, the air temperature data, sea ice data and the sea surface temperature anomalies are taken from sources given under data and methods.

Data and Methods

The pattern of sea level atmospheric pressure anomaly during the winters (December, January, February) of 1990 to 2003 (Fig. 2a-c) and of sea level atmospheric pressure (Fig. 2d) was taken from NCEP/NCAR Reanalysis data from the NOAA-CIRES Climate Diagnostics Centre: http://www.cdc.noaa.gov/Composites.

The NAO Index as given in Fig. 3 refers to the mean December, January, February (DJF) sea level pressure (SLP) from the Azores (Ponta Delgada, PD) and from Iceland (Akureyri, A). The individual SLP's are standardized to 1961-90 base period, and calculated using

$$\text{NAO}_i = \frac{p_i - \overline{p}}{\sigma}\Big|PD - \frac{p_i - \overline{p}}{\sigma}\Big|A$$

with $_i$ = year, p_i = SLP of the given year from PD or A, p = mean SLP of the 1961-90 base period from PD or A, σ = standard deviation of the 1961-90 base period. DJF pressures for 1998/99 and 1999/2000 for Ponta Delgada were defined by regression (Loewe and Koslowski, 1998).

Data on the atmospheric climate of Greenland were sampled by the Danish Meteorological Institute at Nuuk (64°11'N, 51°44.5'W), Egedesminde (68°42.5'N, 52°53'W) and Angmagssalik (65°36'N, 37°40'W). Whereas the first data set was mutually supplied by the Danish Meteorological Institute in Copenhagen and the Seewetteramt, Hamburg, the latter data sets were given by the Seewetteramt, Hamburg. The climatic mean which the air temperature anomaly charts are referenced to is 1961-1990. Ice charts (Fig. 11-16) were taken from:

http://www.natice.noaa.gov/pub/East_Arctic/Baffin_Bay/Davis_Strait/;
http://www.natice.noaa.gov/pub/East_Arctic/Greenland_Sea/Greenland_Sea_southwest/;
http://www.natice.noaa.gov/pub/East_Arctic/Greenland_Sea/Greenland_Sea_South/.

They originate from NOAA satellite ice observations. Analysis of ice conditions is grouped in sub areas which are denoted in the above given internet links (Baffin Bay/Davis Strait, Greenland Sea southwest, Greenland Sea South).

Sea surface temperature anomaly data (Fig. 17, 18) for the region between Greenland and Labrador were taken from the IGOSS Data Base http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS .

During cruise WH244 of FRV "Walther Herwig III", CTD profiles were obtained at each fishing position of the surveyed area (Fig. 1). Observations on Standard Oceanographic Stations (Stein, 1988) were done at the Cape Desolation Section and the Fyllas Bank Section (Fig. 19). Salinity readings of the CTD (SeaBird 911+) profiles were adjusted to water samples derived by Rosette water sampler. A mean salinity deviation of -0.001 was applied to all profiles. Data analysis and presentation was done using the most recent version of Ocean Data View (mp-Version 1.4-2003). Theta/S sections of Cape Desolation Section and Fyllas Bank Section are displayed in Fig. 20 and 21, the θS-water mass diagram is given in Fig. 22. Time series of temperature anomaly at Fyllas Bank station 4 is given in Fig. 24 and 25, and the time series of salinity calibration samples at NAFO Cape Desolation Station 3 is given in Fig. 23.

Water mass analysis was done using the "patch" option in Ocean Data View for Irminger Water (4°C < Theta < 6°C, 34.95 < S < 35.1) for the autumn observations (Fig. 26). Historic data for this analysis was taken from the World Ocean Database (WOD98, WOD01) and the World Ocean Atlas 1994. These historic data from Fyllas Bank Section station 4 were mainly sampled by Denmark and Germany. For this site there is also information available in the World Databases measured by vessels from Canada, USA, Norway, UK and Russia. The time period covered in this paper is 1946-2002.

Results and Discussion

The North Atlantic Oscillation

General considerations

The North Atlantic Oscillation is a large scale alternation of atmospheric mass with centres near the Icelandic Low and the Azores High. It is most pronounced during winter. One of the earliest known writings of what we now call the North Atlantic Oscillation (NAO) is by Hans Egede, known as "The Apostle of Greenland" because of his missionary work there which began in 1721 and continued for fifteen years. In his diaries Egede wrote: "In Greenland all winters are severe yet they are not all alike. The Danes have noticed that when the winter in Denmark was severe, as we perceive it, the winter in Greenland in its manner was mild, and conversely" (van Loon and Rogers, 1978; Wanner *et al*., 2001).

The pressure difference calculated, as given under Data and Methods, is the NAO index. The red/blue year labels in Fig. 2 denote a positive/negative NAO index for the respective winter. The *positive* NAO index phase shows a stronger-than-normal subtropical high pressure center and a deeper-than-normal Icelandic low. The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track. This results in warm and wet winters in Europe and in cold and dry winters in northern Canada and Greenland. The eastern US experiences mild and wet winter conditions.

The *negative* NAO index phase shows a weak subtropical high and weak Icelandic low. The reduced pressure gradient results in fewer and weaker winter storms crossing on a more west-east pathway. They bring moist air into the Mediterranean and cold weather to northern Europe. The US east cost experiences more cold air outbreaks and hence snowy winter conditions. Greenland, however, will have milder winter temperatures.

The NAO during the 1990s and early-2000s

The pattern of sea level atmospheric pressure anomalies over the North Atlantic during the winters (December, January, February) of 1990 to 2001 is given in Fig. 2a, b. Winter seasons with classical pressure dipole patterns are 1993, 1994, 1995, 1999 and 2000, with negative anomalies in the Icelandic Low area and positive anomalies in the Azores High area. There are two winter seasons which show pressure dipole patterns, however of different signs, 1996 and 2001. During these two winter seasons the sea level pressure anomalies were positive in the region of the Iclandic Low and negative in the region of the Azores High. In both cases (see Fig. 2a and b) the previous winters, 1995 and 2000, showed classical pressure dipole patterns, however of different signs.

Figure 2c shows the pattern of sea level pressure anomalies over the North Atlantic during the winters of 2002 and 2003. There was no similar pressure pattern recorded during the winters of the 1990s and early-2000s as during these two recent winters.

Air pressure dipole patterns

Around the turn of the century, during the last six years, Figs. 2b and c show three pressure dipole patterns (1999, 2000 and 2001), and three patterns which differ considerably from a dipole pattern (1998, 2002 and 2003). These patterns reveal four or less centres of pressure anomaly. During the winter of 1998 a positive anomaly cell is found stretching from eastern Canada to Spitsbergen, another positive cell is situated over Europe, and a negative anomaly cell is embedded between both cells with centres of anomaly northwest of the Azores and over Russia. The 2002 winter anomaly pattern reveals two major pressure cells, a positive cell over Spain and France and a negative cell over Eastern Europe. In the west there are two cells, a positive one over Iceland and a negative one between Newfoundland and the Azores. The 2003 situation indicates a complete change from a north-south oriented dipole structure (e.g. 1999, 2000 and 2001) to an east-west oriented dipole structure. The latter reflects the long-lasting flow of cold air masses from Scandinavia and Russia to Western Europe during the winter of 2003.

The sea level atmospheric pressure over the North Atlantic during these six years is given in Fig. 2d. NAO *positive* winters, like 1999 and 2000, outline a deeper-than-normal Iclandic Low and a stronger-than-normal subtropical Azores High. NAO *negative* winters, like 1998, 2001, 2002 and 2003 show a weak subtropical high and a weak Icelandic low.

The NAO index

The NAO index as given for the last and present decade shows mostly positive values (Fig. 3, upper panel). The index for winter 2001/2002 (December-February) is, however, negative (-0.24).

During the second half of the last century we see that the 1960s were generally "low-index" years while the 1990s were "high-index" years. There was a major exception to this pattern occurring between the winter preceding 1995 and the winter preceding 1996, when the index flipped from being one of its most positive values to its most negative value this century (Fig. 3 upper panel).

The direct influence of NAO on Nuuk winter mean air temperatures can be seen in Fig. 4: A "low-index" year corresponds with warmer-than-normal years. Colder-than-normal climatic conditions at Nuuk are linked to "high-index" years. This indicates a negative correlation of Nuuk winter air temperatures with the NAO. Correlation between both time series is significant ($r = -0.73$, $p << 0.001$).

Air Temperature and Climatic means

Similar to previous years conditions (Stein, 2001), February was the coldest month off West Greenland, and the positive air temperature conditions as observed during December 2001 at the West Greenland sites, were maintained through to January 2002.

The annual air temperature curves referenced to the climatic means at the three observation sites off West and East Greenland, are given in Fig. 5 to 7. Egedesminde's air temperatures during 2002 were mostly at or above the climatic mean, with colder than normal conditions being encountered at this site during February (Fig. 5). Nuuk experienced colder than normal conditions during February, March and April (Fig. 6). Air temperature anomalies (in brackets: mean temperature of the month) during February were -3K at Egedesminde (–19°C), and –3.7K Nuuk (–11.5°C). Angmagssalik (Fig. 7) experienced climatic conditions which were near or above the climatic mean throughout the year, except for February when air temperature anomalies were –1.3K and monthly mean temperature was –9°C.

Climatic Variability off West Greenland

The annual mean air temperature anomaly calculated for 2002 is 0.3K (Fig. 8). This is a continuation of a series of warmer-than-normal years (0.2K to 1.3K) which started in 1996, with the exception of 1999 which was colder-than- normal (-0.3K). The presentation of decadal air temperature anomalies Nuuk (Fig. 9) reveals much variability during the first year of each decade: whereas the years 1950 and 1960 were warmer-than-normal, 1970 about normal, the years 1980 and 1990 indicated considerable positive/negative anomalies, and the year 2000 conditions were similar to 1980. The year 2001 was the warmest "year 1" since the 1950s, and 2002 is the first warmer-than-normal "year 2" after three decades. The long-term trend of Nuuk air temperature anomalies (the 13-year running mean as well as the 5-year running mean) is, as emphasised by Stein (1999, 2000) pointing at intermediate warming, a feature which was also observed during the 1970s and 1980s (Fig. 10).

Ice Conditions around Greenland

Winter sea ice conditions were favourable during 2002 off West Greenland. The sea ice drift has a significant offshore component which is called the "West Ice". The southernmost location of the ice edge of "West Ice" was found around 20 March in the off-slope region of the Fyllas Bank (Fig. 11 and 12). Multi-year sea ice, coming from the Arctic Ocean via the East Greenland current to the Cape Farewell area, is called "Storis". During mid-March, the East Greenland coast was surrounded by sea ice with the concentration of 9-10 tenth. There was also a tongue of newly formed ice in the Cape Farewell region (Fig. 13). Maximum extension of "Storis" off West Greenland was found in the southwestern bight of Greenland (Julianehaab/Qaqortoq) around mid-June (Fig. 14). Sea ice formed again off West Greenland in late November (Fig. 15) when 4-6 tenth of ice concentration was observed in the Disko Bight area. Off East Greenland first sea ice formation was encountered in the Angmagssalik area during late November (Fig. 16). Due to these favourite ice conditions the cruise WH244 of FRV "*Walther Herwig III*" to East and West Greenland waters in October/November 2002 was not affected by any sea ice.

Sea Surface Temperature Anomalies

Similar to previous years, colder than normal conditions in sea surface temperatures (SSTs) were encountered during most of the year in the Julianehaab Bight/Southwest Greenland where temperatures dropped –2.5K below the norm (Fig. 17, 18). During winter and spring season a patch of warmer-than-normal water is seen to remain in the centre of the Labrador Sea. As in previous years, during the months of February to May core temperature anomalies of more than +3.5K were found in a warm pool of surface water at about 60°N, 55°W. During the second half of 2002, SSTs anomalies indicate cooling in the area of Fyllas Bank and to the south (Fig. 18, between about 51°W and 55°W). This surface water cooling was also observed by CTD profiles taken along the Fyllas Bank section on 8 November 2002. Maximum warming off West Greenland was observed during the month of December (Fig. 18).

Subsurface Observations off West Greenland

Vertical distribution of potential temperature and salinity at the NAFO Standard Oceanographic Sections Cape Desolation and Fyllas Bank (Fig. 19) are given in Fig. 20 and 21. They reveal the typical distribution of cold, low saline waters on the banks and warm saline waters at the slope region.

The water mass characteristics potential temperature θ, potential density (σθ) and salinity (S) for these sections are given in Fig. 22. Starting in the lower left corner of the diagram, the cold, diluted surface waters emerge from the picture showing potential densities of σθ = 25.5 to 26. In the deeper parts of the profiles, centered near σθ = 27.5, the domain of the warm Irminger Water is visible with temperatures exceeding 6°C and salinities near 35. Below the warm water the θ S-diagram is rather uniform showing temperatures less than 2°C at the lower end of the diagram. These θS-characteristics document the thermohaline conditions of the near-bottom water layer at about 3 000 m depth at station 3 of the Cape Desolation Section (CD3). This deep layer is influenced by the Denmark Strait Overflow water mass (Swift, 1984; Stein and Wegner, 1990).

Data on calibration samples taken at CD3, reveal freshening in deep water layers from 1984 onwards (Fig. 23). The freshening trend is significant at all observed depths (1 500 m, 2 000 m, 2 500 m, 3 000 m). The statistics for the linear trends are given in Table 1.

Time series of temperature measurements from Fyllas Bank Station 4 are given in Fig. 24 and 25. The data are referenced to the 1963-90 climatic mean. The surface layers 0-50 m (Fig. 24) and 0-200 m (Fig. 25) reveal considerable cooling during 2002. This surface water cooling is in the range from –0.36K (0-200 m) to –0.69K (0-50 m). A similar amount of cooling is documented in the SST anomalies for November 2002 (Fig. 18).

The dashed curves in Fig. 24 and 25 denote the time series of the NAO winter index (1980-2002). There is ***no*** significant correlation between variations of water temperature anomalies and variations of NAO index. The correlation found is negative and the correlation coefficients are r = –0.32 for the 0-50 m layer, and r = –0.34 for the 0-200 m layer.

The major heat input to the water column off West Greenland is derived by advection, i.e. the warm Irminger component of the West Greenland Current. A total of 40 oceanographic stations were performed during the West Greenland part of cruise WH244 of FRV "*Walther Herwig III*". Among these there are profiles which were obtained along two NAFO Standard Oceanographic Sections, Cape Desolation and Fyllas Bank (Fig. 19). These temperature/salinity profiles show the presence of Irminger Water during autumn 2002 only at stations 2 and 3 of the Cape Desolation section at depths between 600 m and 900 m. At Fyllas Bank, the characteristic parameters of Irminger Water (4°C < Theta < 6°C, 34.95 < S < 35.1; Fig. 22) were slightly missed by the profiles obtained at station 4 (Theta=5.32°C, S=34.945) and station 5 (Theta=5.22°C, S=34.935).

An analysis on the presence of Irminger Water at Fyllas Bank station 4 during autumn, reveals that this water mass is mostly found at depths between 400 and 800 m (Fig. 26). The data indicate that Irminger Water was not found during all years at this site. There are some observations on the presence of Irminger Water at Fyllas Bank station 4 in the 1960s, in the second half of the 1980s, the early-1990s, during 1999 and 2000 (Fig. 26).

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Table 1. Correlation coefficient r and r² of linear trends incorporated in the calibration time series as given in Fig. 23.

Depth [m]	r^2	r
1 500	0.48	0.69
2 000	0.68	0.83
2 500	0.46	0.68
3 000	0.41	0.64

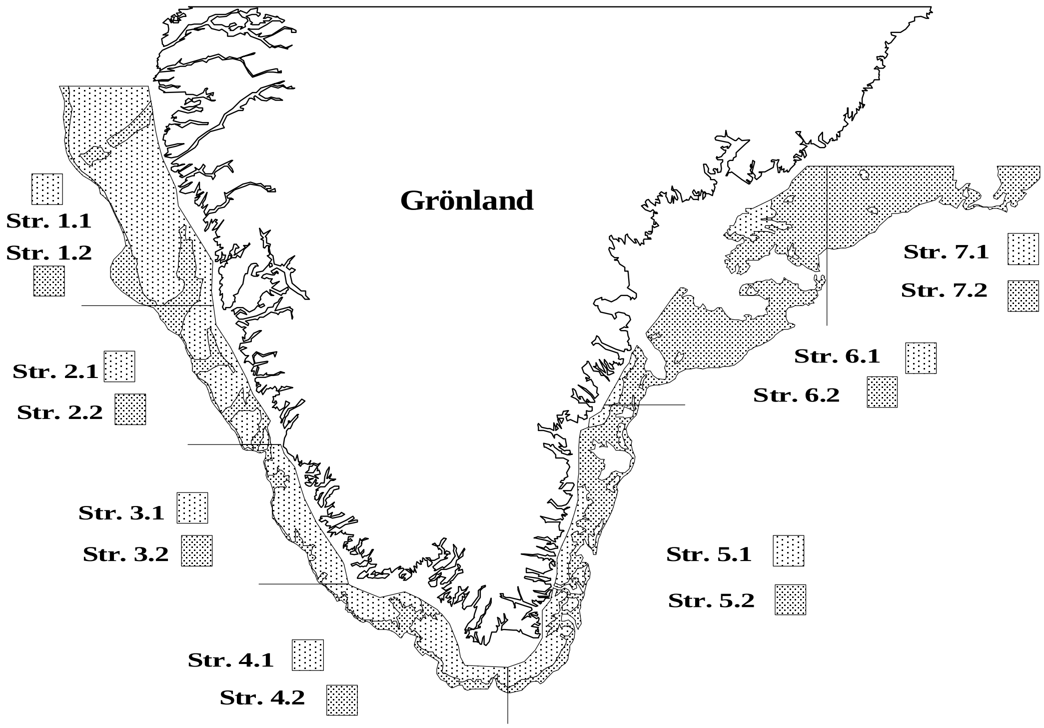

Fig. 1 Area of investigation during WH 244 (11 October-21 November 2002), and individual survey strata; strata 0-200 m: 1.1, 2.1, 3.1, 4.1, 5.1, 6.1 and 7.1, and 200-400 m: 1.2, 2.2, 3.2, 4.2, 5.2, 6.2 and 7.2 around Greenland

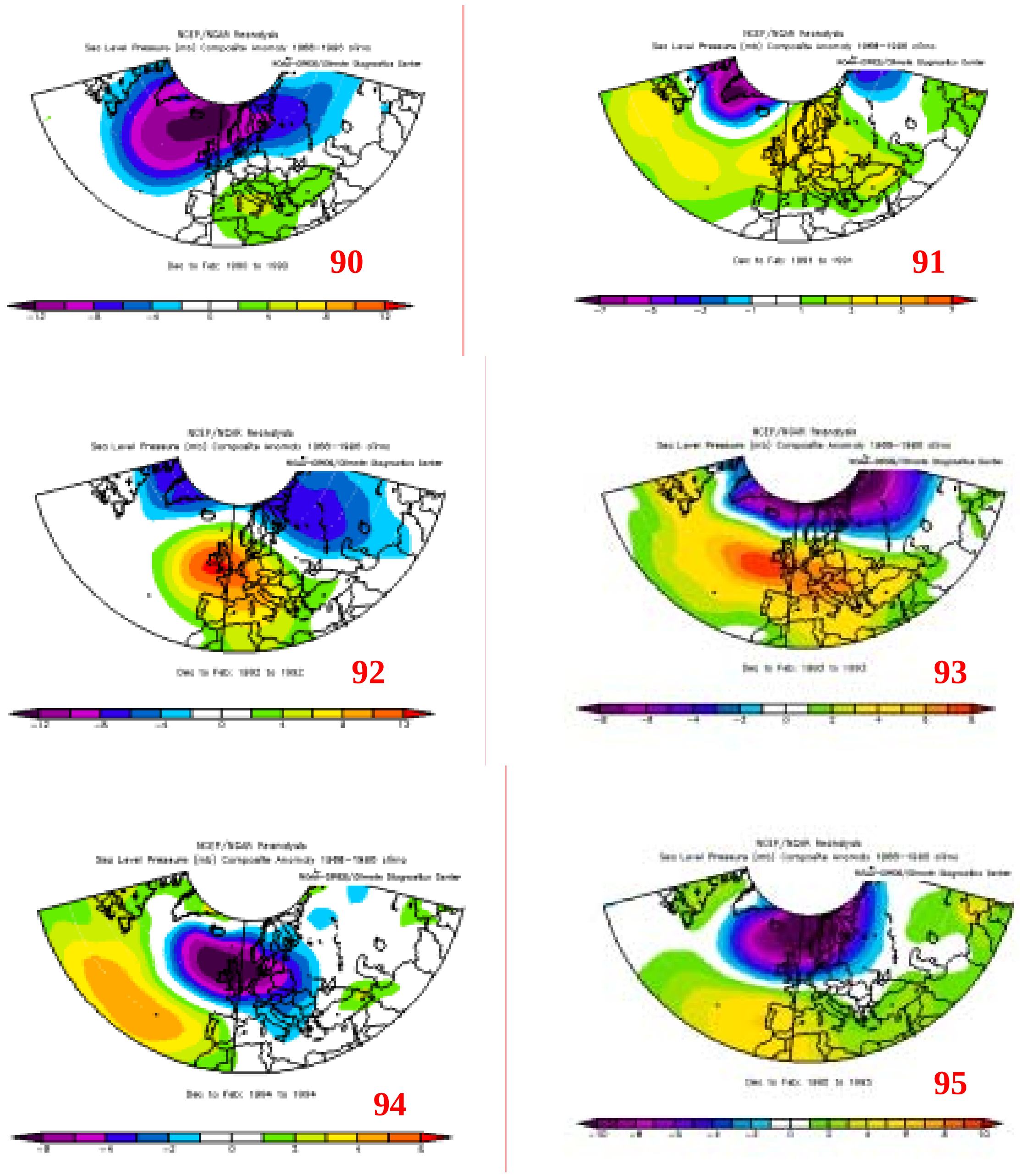

Fig. 2a. The pattern of sea level atmospheric pressure anomaly during the winter (December, January, February) of 1990 to 1995 from which the NAO index is calculated (Iceland to the Azores); red/blue year label denotes positive/negative NAO index.

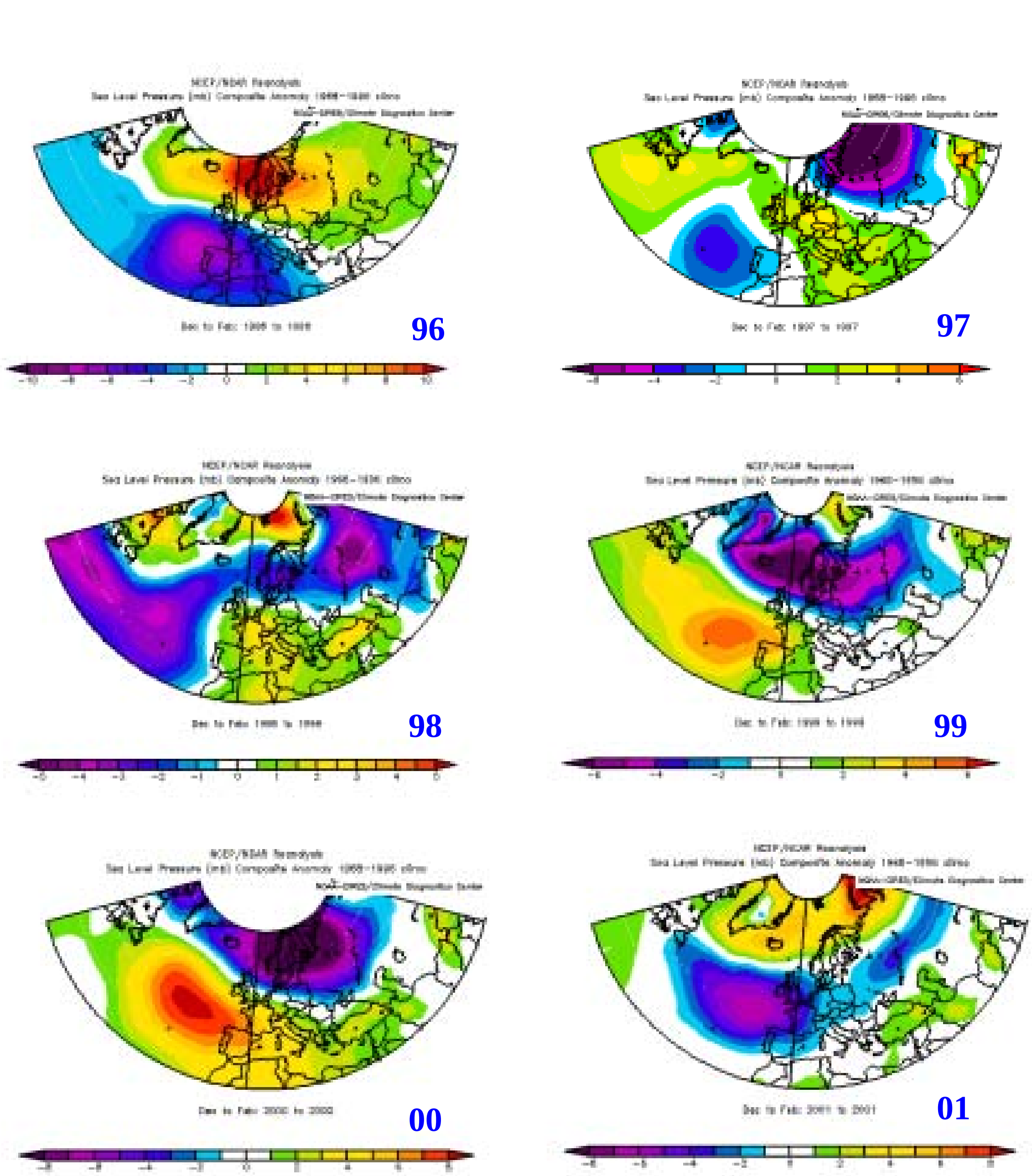

Fig. 2b. The pattern of sea level atmospheric pressure anomaly during the winter (December, January, February) of 1996 to 2001 from which the NAO index is calculated (Iceland to the Azores); red/blue year label denotes positive/negative NAO index.

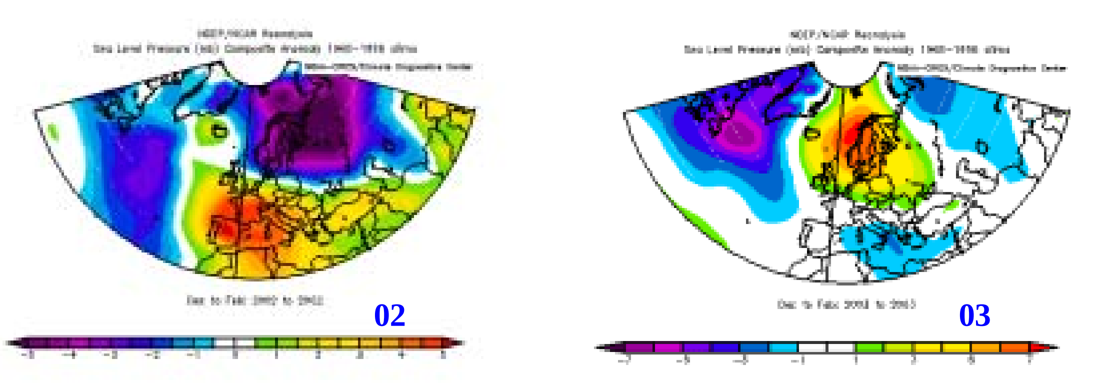

Fig. 2c. The pattern of sea level atmospheric pressure anomaly during the winters (December, January, February) of 2002 to 2003; red/blue year label denotes positive/negative NAO index.

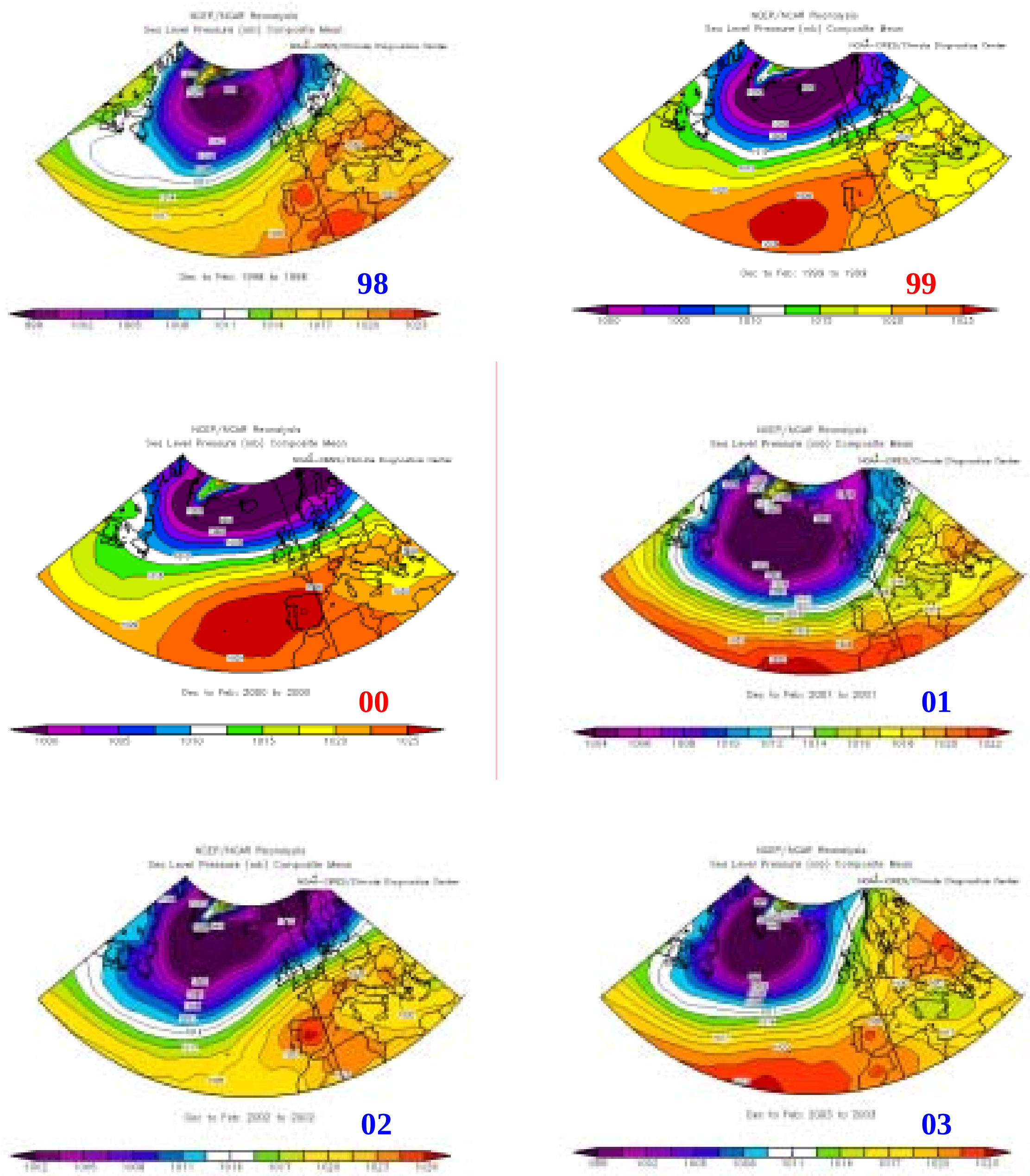

Fig. 2d. The pattern of sea level atmospheric pressure during the winters (December, January, February) of 1998 to 2003; red/blue year label denotes positive/negative NAO index.

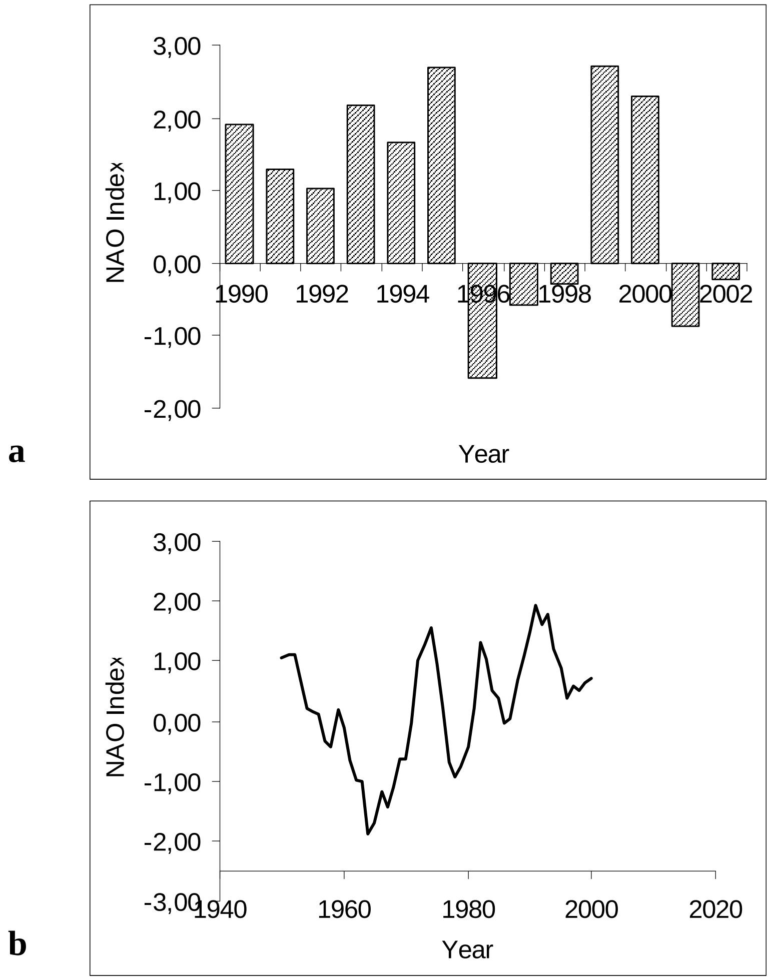

Fig. 3. The winter (DJF) NAO index in terms of the last and present decade (a) and the second half of the last century (lower Figure b, a 5-year running mean has been applied)

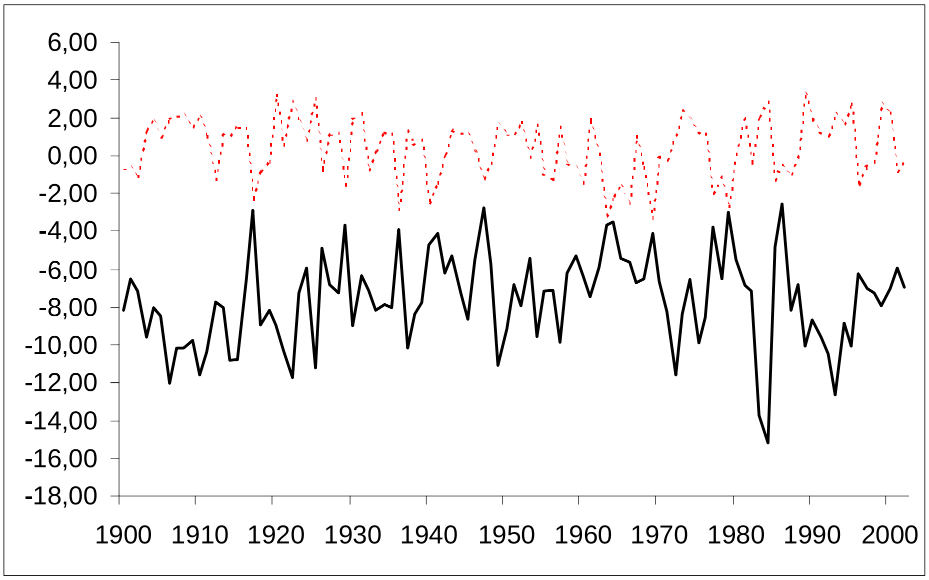

Fig. 4. The winter (DJF) NAO index in terms of the last century and during the first years of the 2000s decade (upper curve, dashed) and the winter (DJF) mean air temperatures at Nuuk.

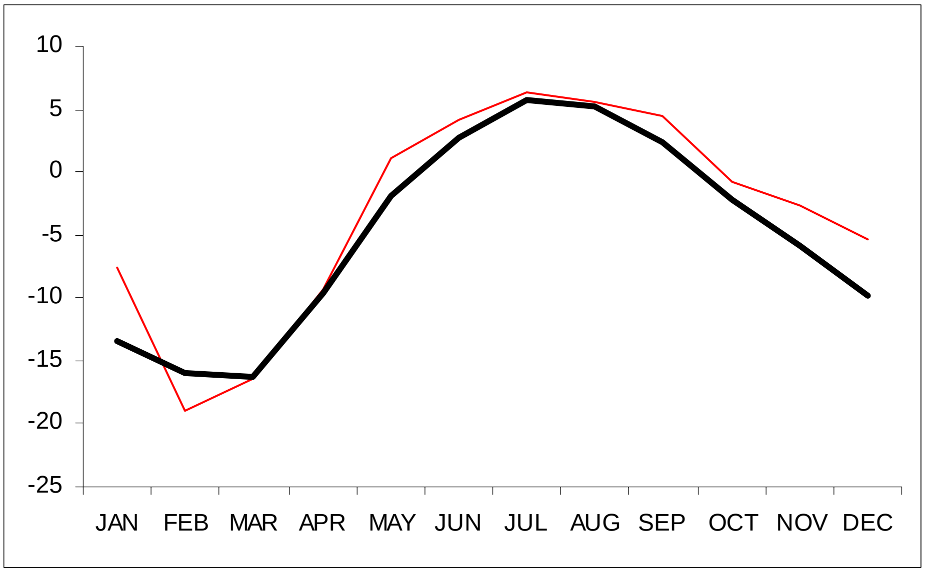

Fig. 5. Monthly mean air temperature [°C] at Egedesminde during 2002 (red, thin line) and climatic mean (1961-1990).

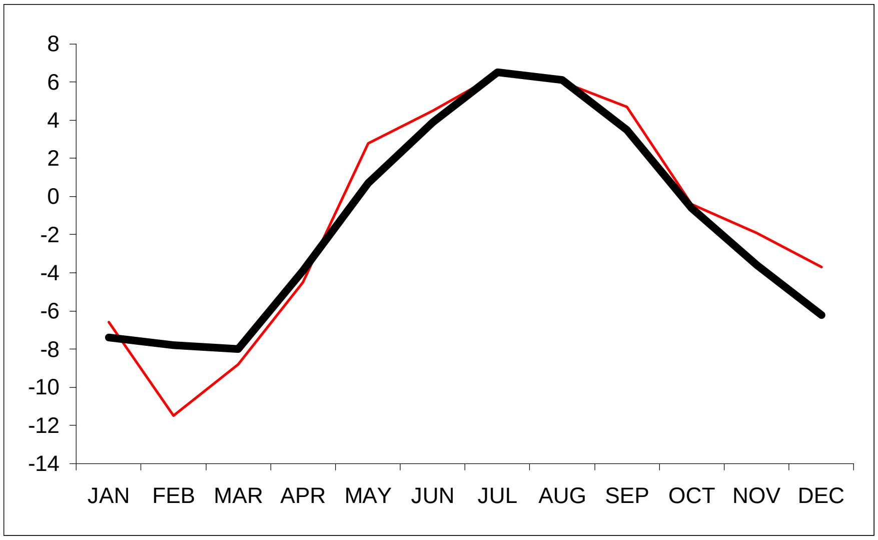

Fig. 6. Monthly mean air temperature [°C] at Nuuk during 2002 (red, thin line) and climatic mean (1961-1990).

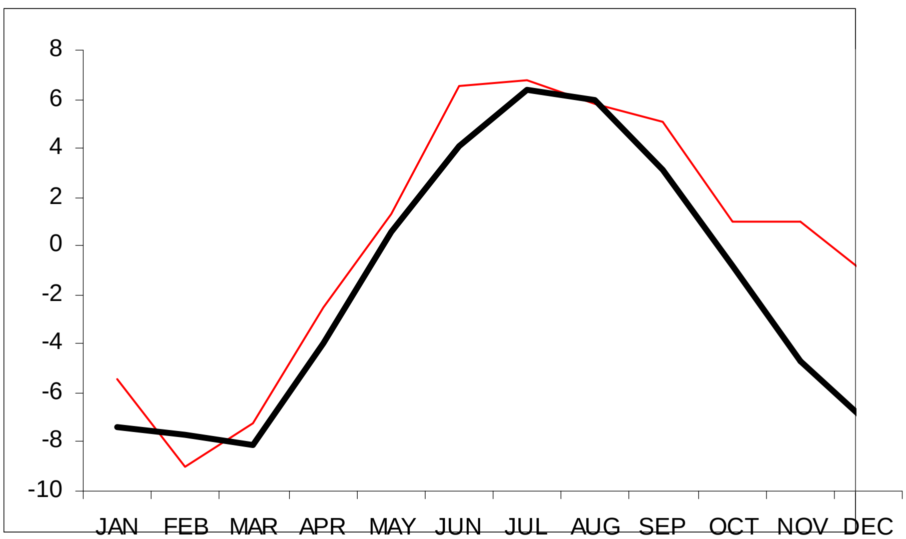

Fig. 7. Monthly mean air temperature [°C] at Angmagssalik during 2002 (red, thin line) and climatic mean (1961-1990).

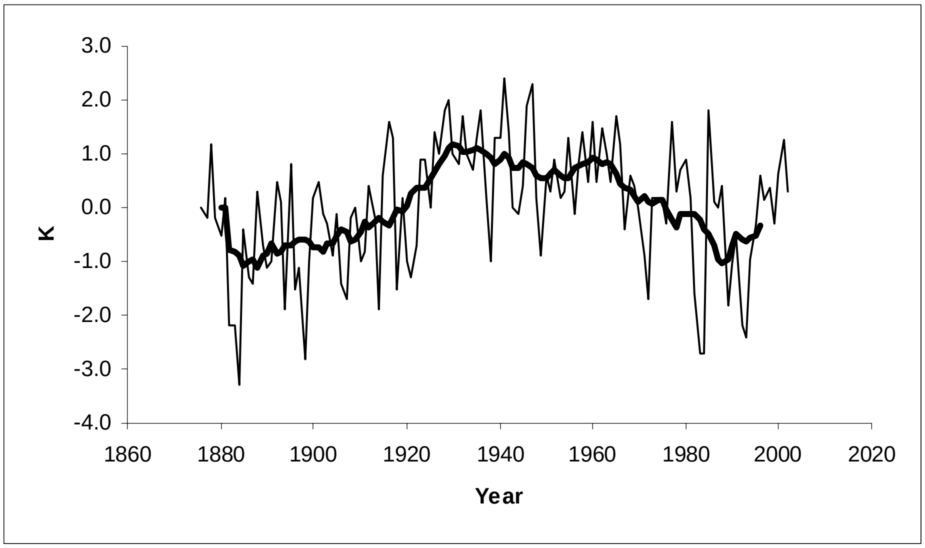

Fig. 8. Time series of annual mean air temperature anomalies at Nuuk (1876-2002, rel. 1961-90), and 13-year running mean.

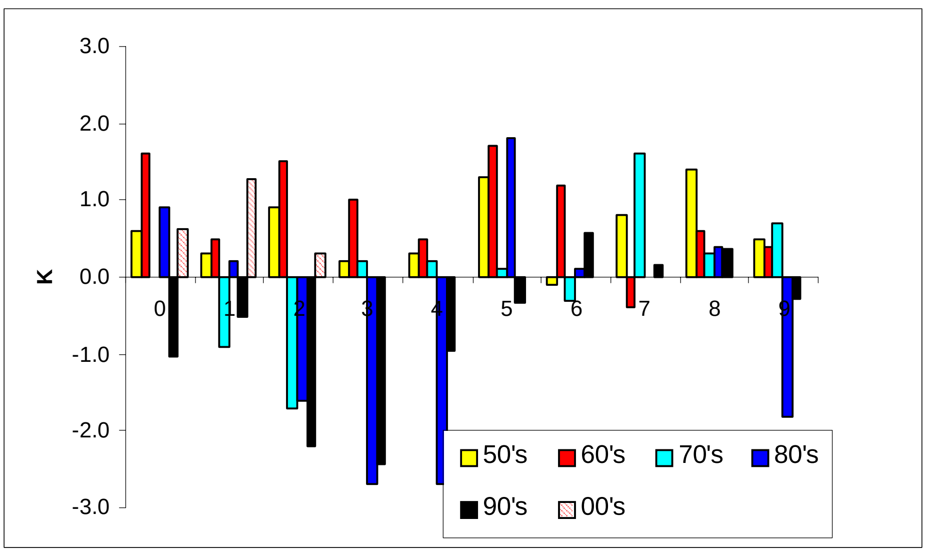

Fig. 9. Composite of decadal air temperature anomalies at Nuuk given relative to the climatic mean of 1961-90 for the decades of the 1950s- 1990s and 2000s (dashed column).

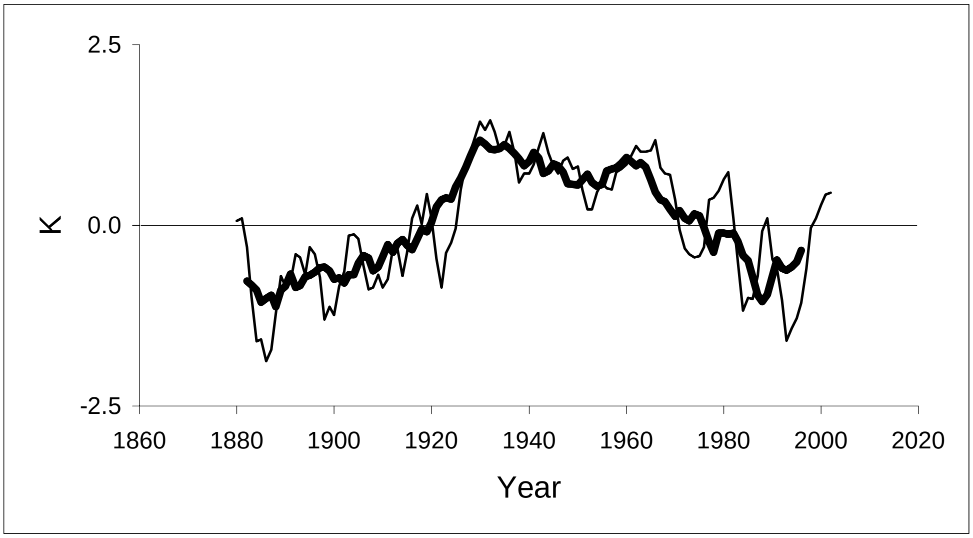

Fig. 10. Time series of annual mean air temperature anomalies at Nuuk; 5-year (thin: 1880-2002), and 13-year (bold: 1882-1996) running mean; both time series rel. to climatic mean 1961-90

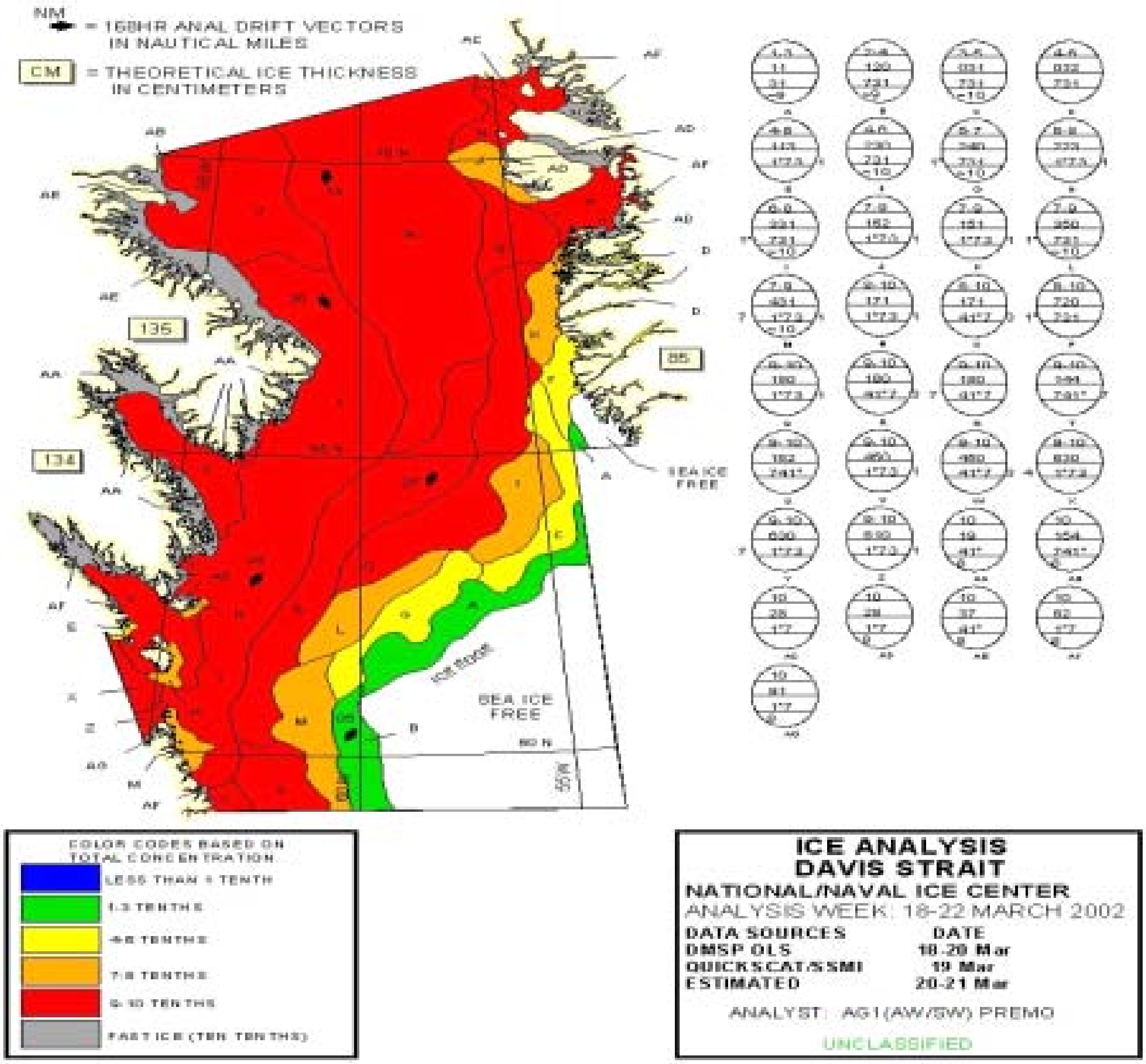

Fig. 11. Ice cover and ice edge during 18-22 March 2002 (Davis Strait).

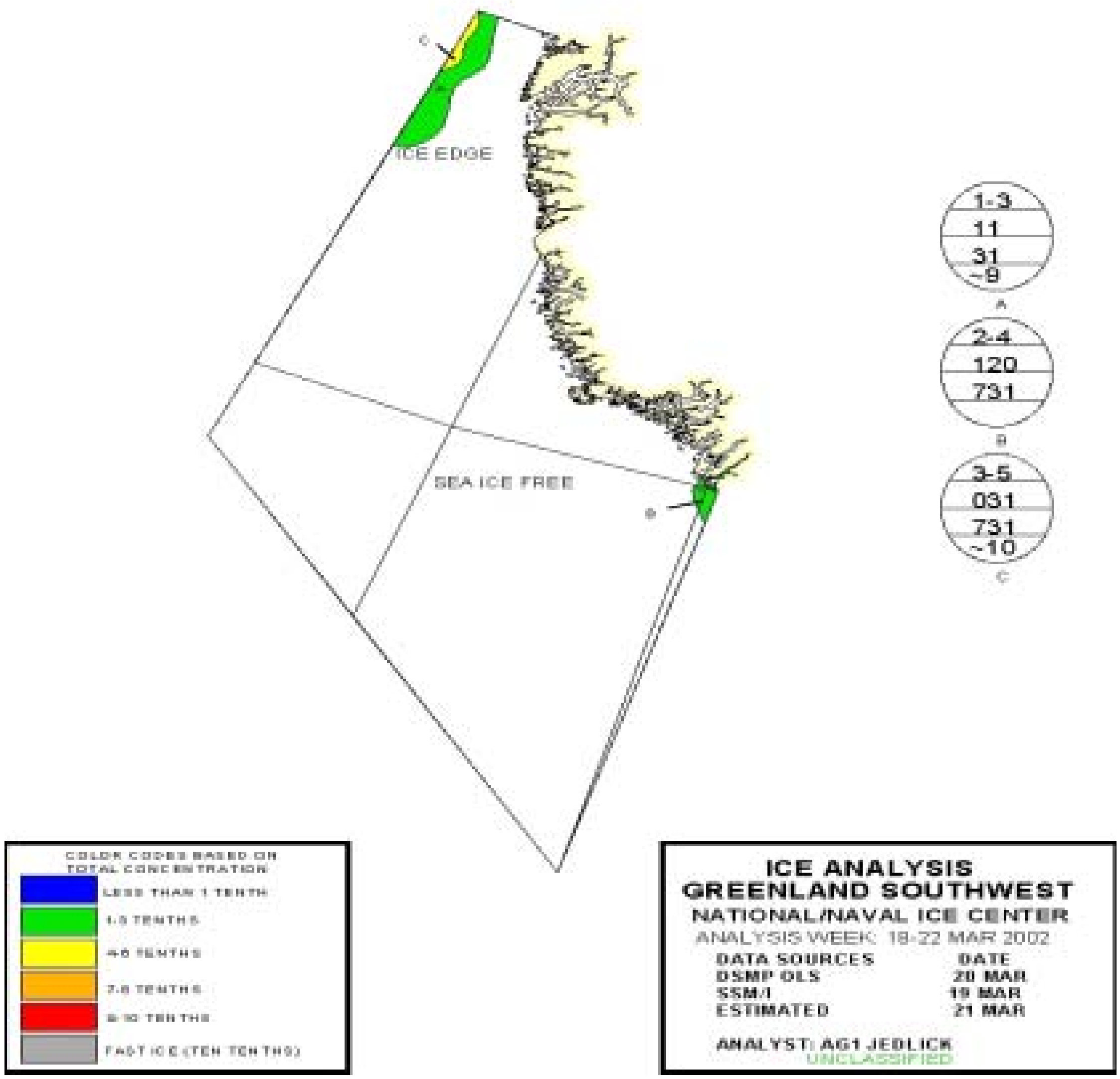

Fig. 12. Ice cover and ice edge during 18-22 March 2002 (Greenland Southwest).

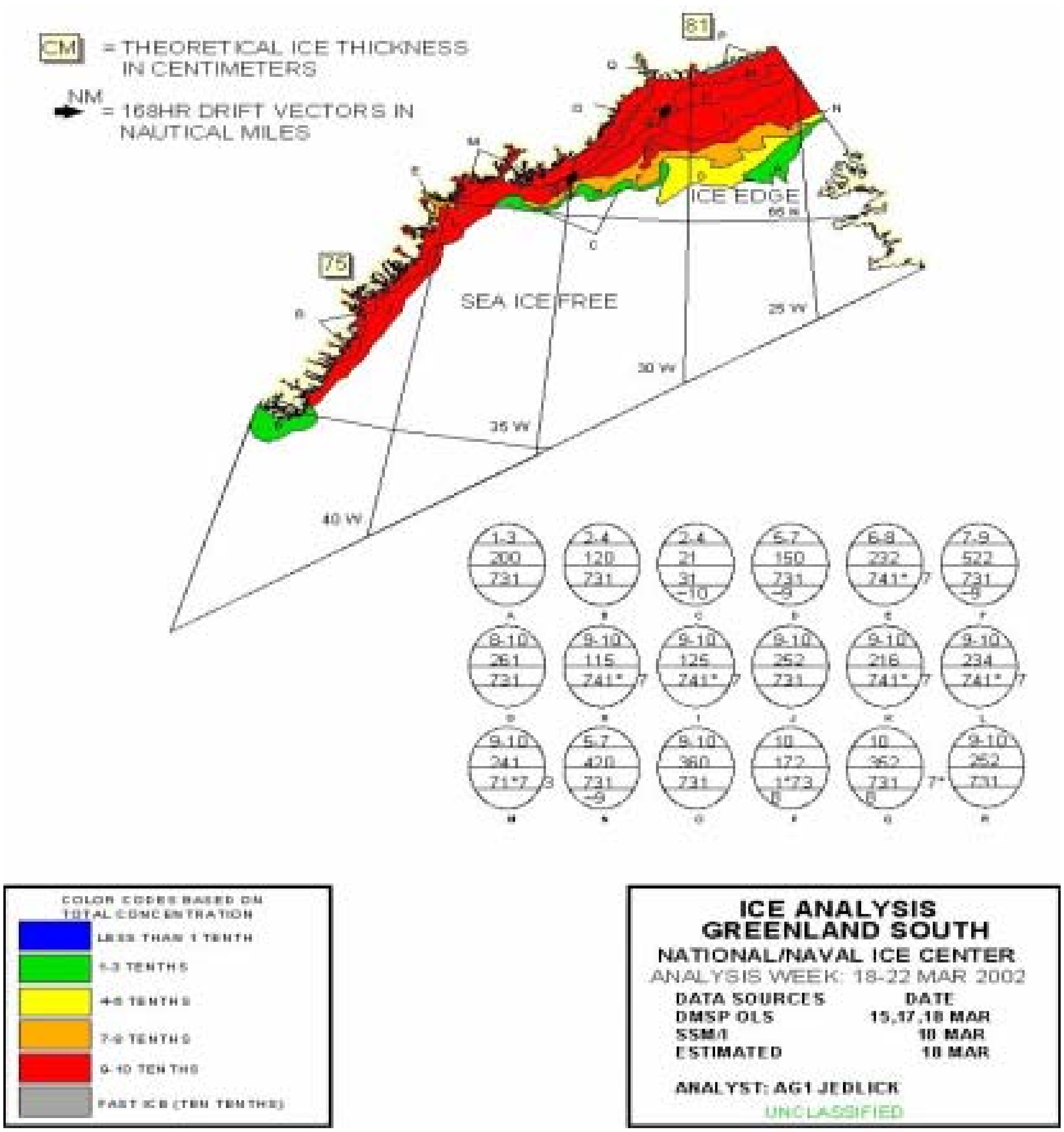

Fig. 13. Ice cover and ice edge during 18-22 March 2002 (Greenland South).

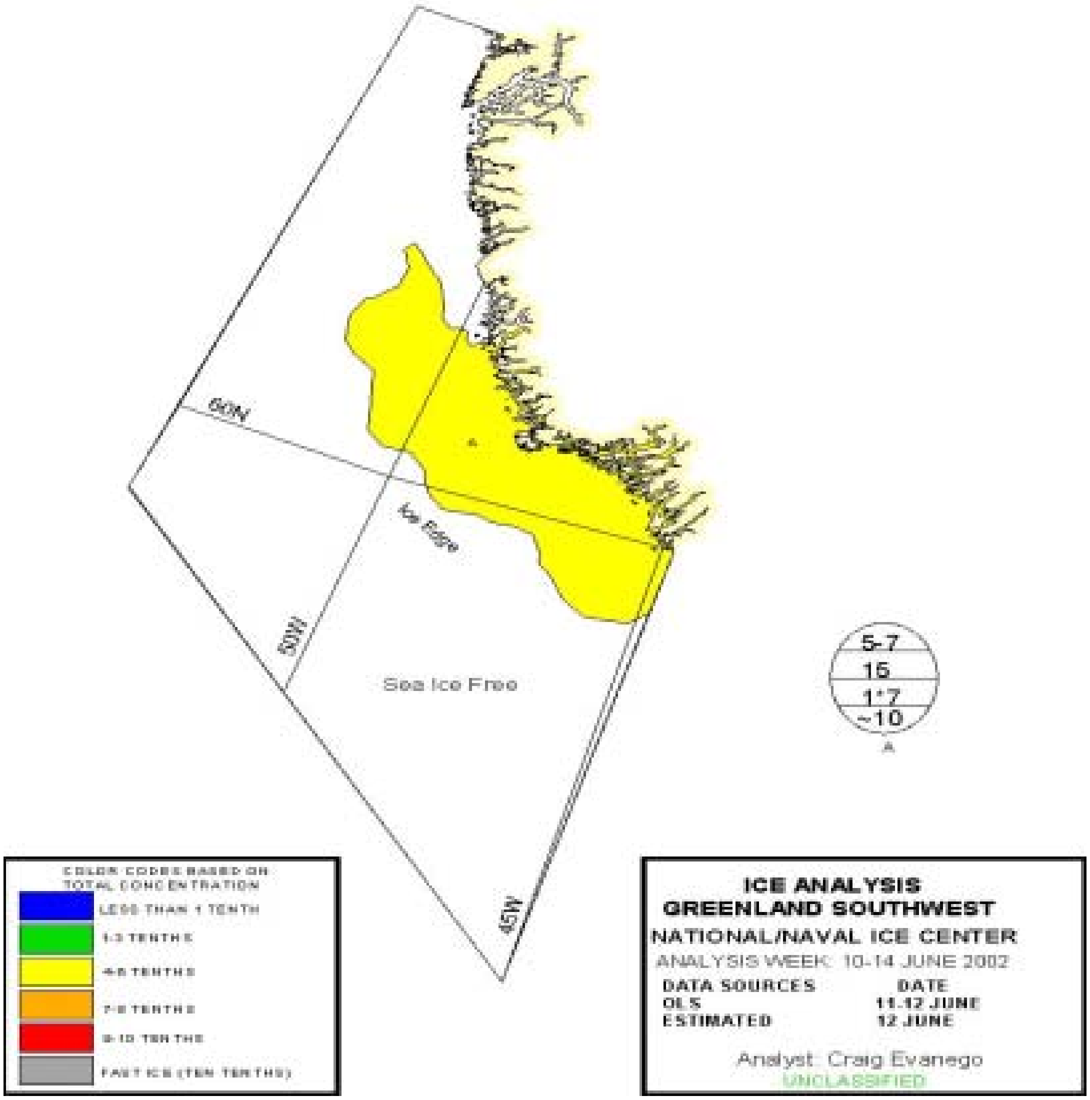

Fig. 14. Ice cover and ice edge during 10-14 June 2002 (Greenland Southwest).

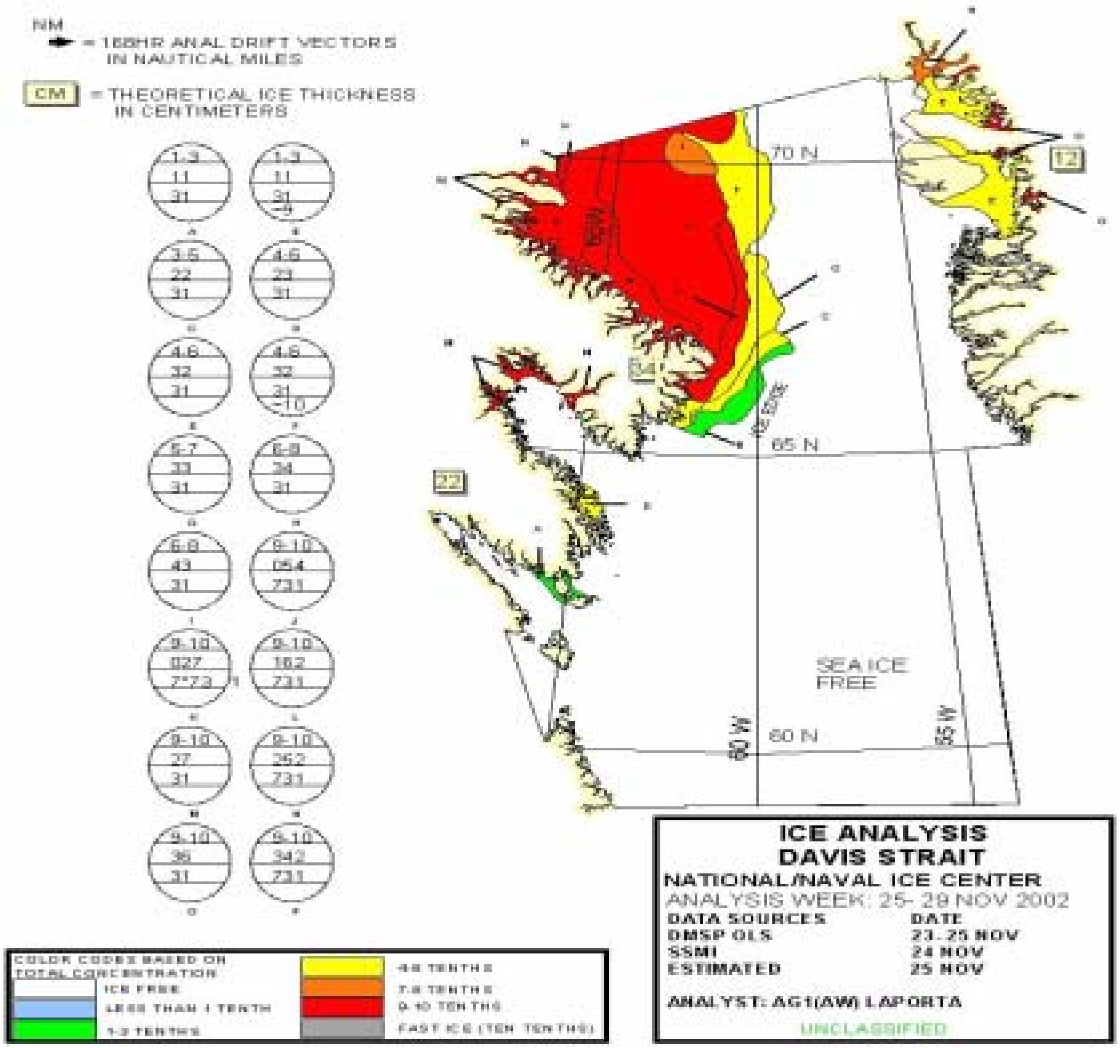

Fig. 15. Ice cover and ice edge during 25-29 November 2002 (Davis Strait).

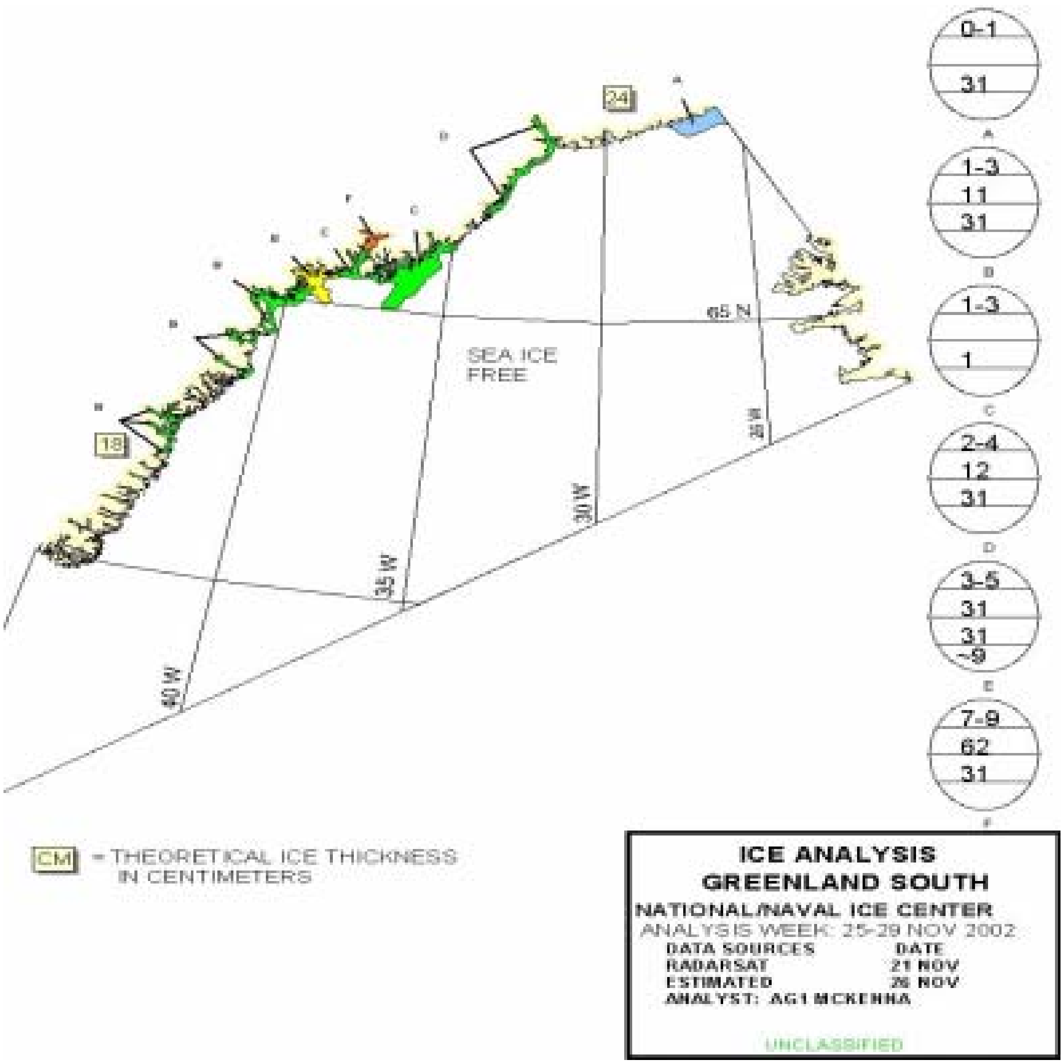

Fig. 16. Ice cover and ice edge during 25-29 November 2002 (Greenland South).

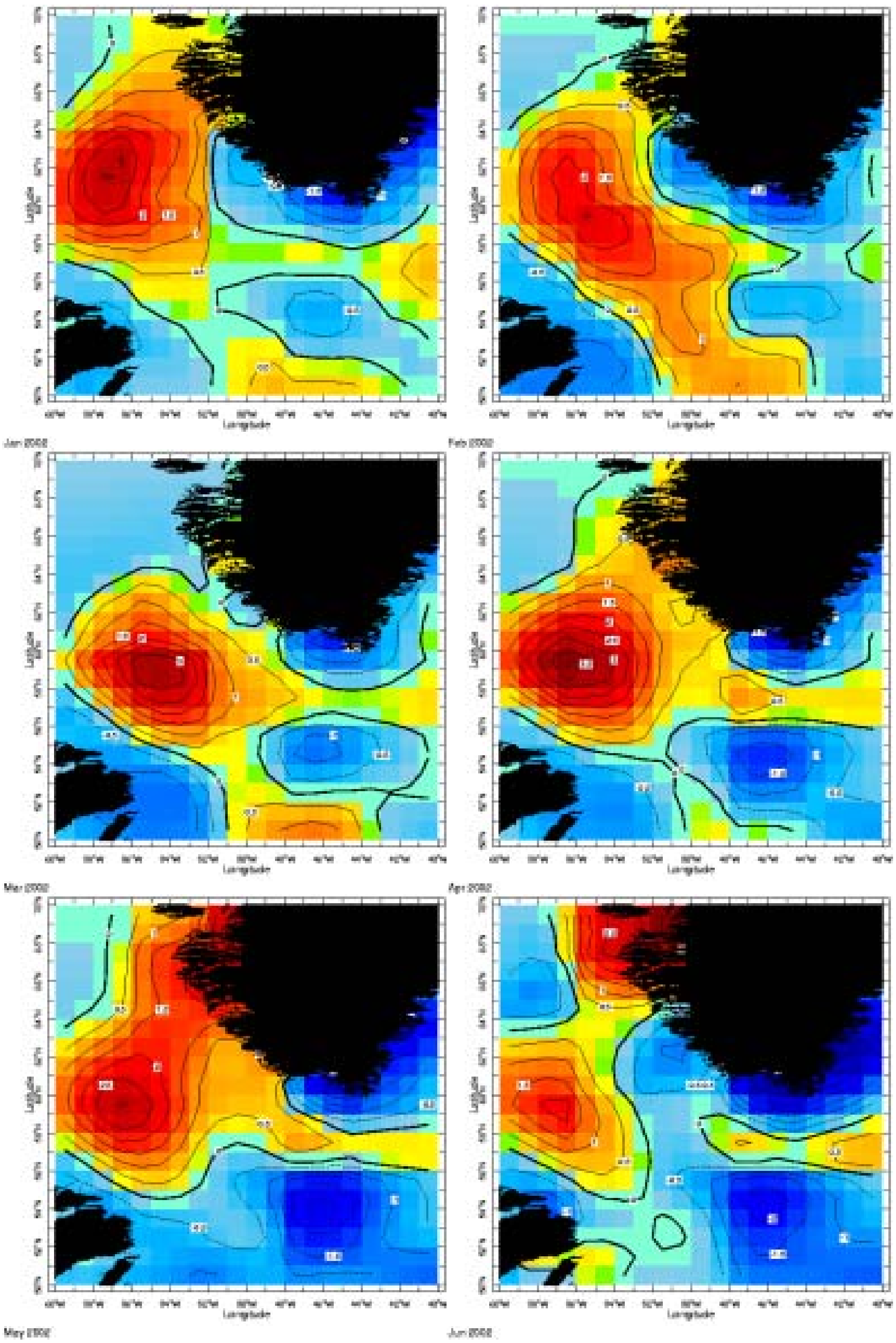

Fig. 17. Sea-surface Temperature Anomalies during January-June 2002.

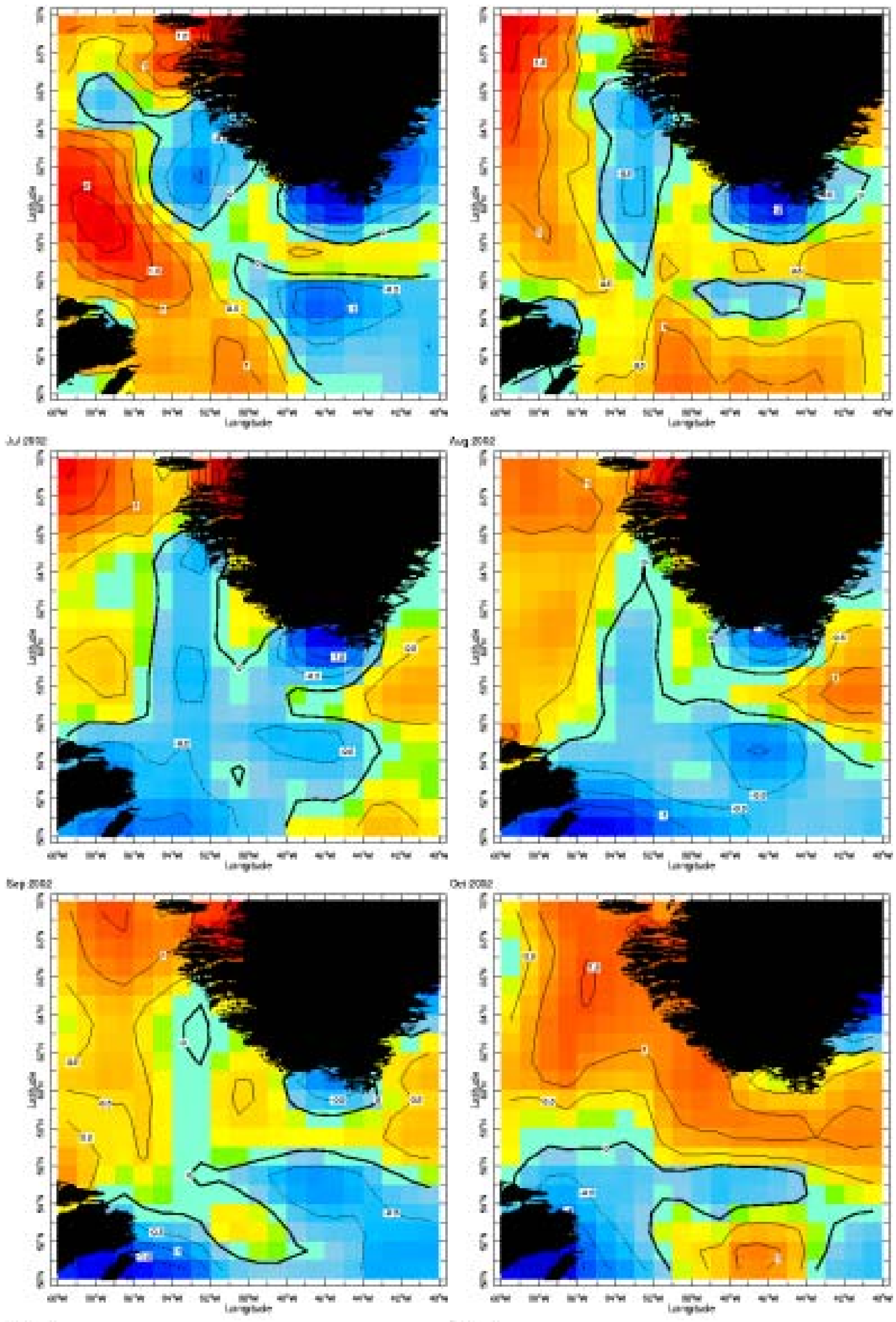

Fig. 18. Sea-surface Temperature Anomalies during July-December 2002.

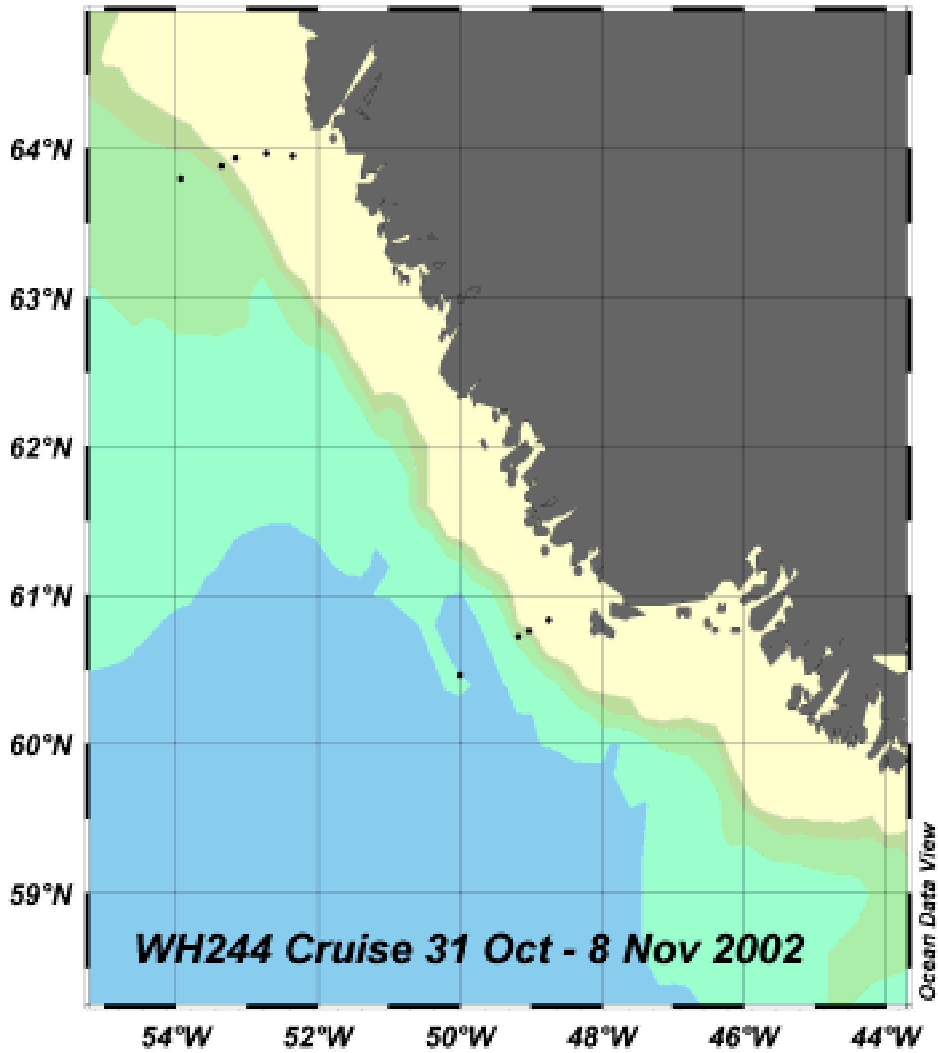

Fig. 19. Positions of sampled NAFO Standard Stations and Sections (31 Oct – 8 Nov 2002).

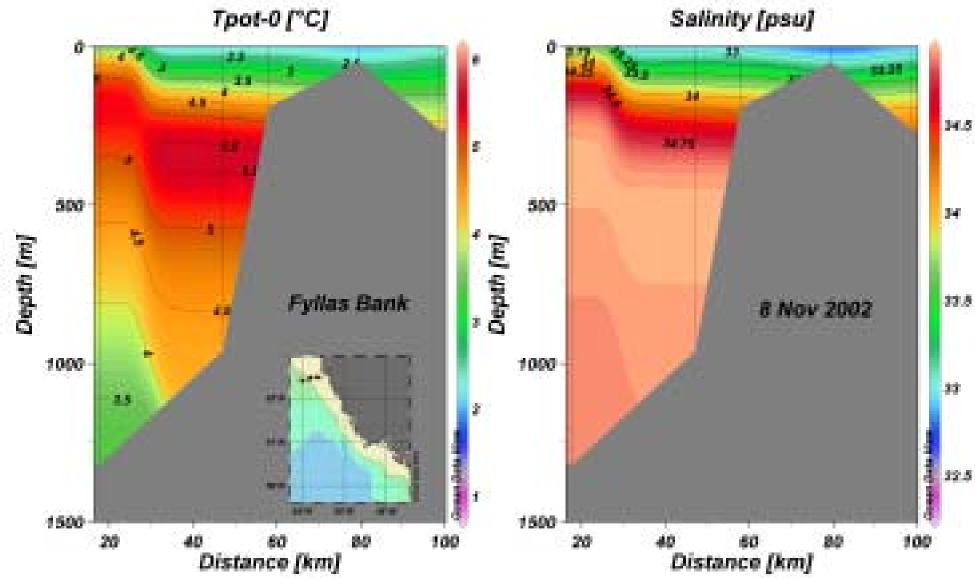

Fig. 20. Potential temperature and salinity along Fylla Bank Section (8 November 2002).

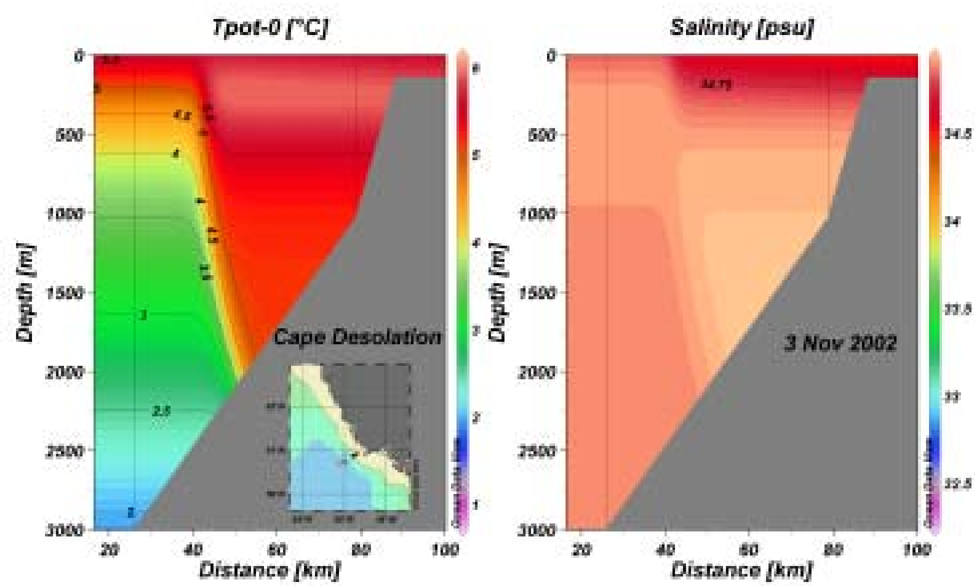

Fig. 21. Potential temperature and salinity along Cape Desolation Section (3 November 2002).

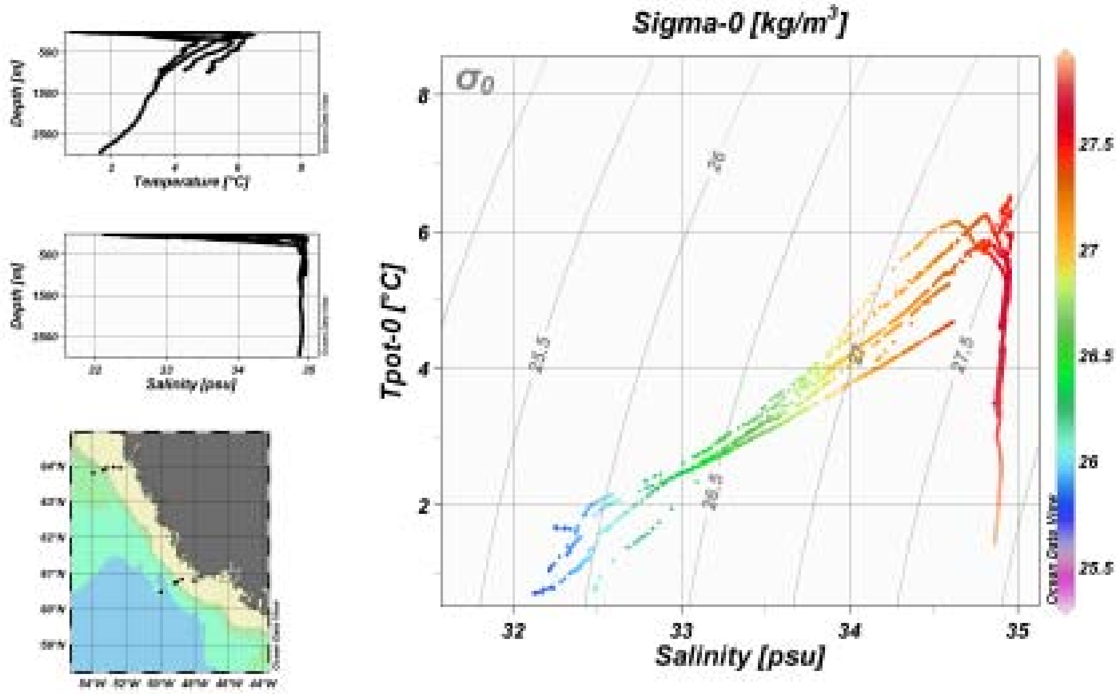

Fig. 22. Theta/S diagram of station profiles indicated in Fig. 19.

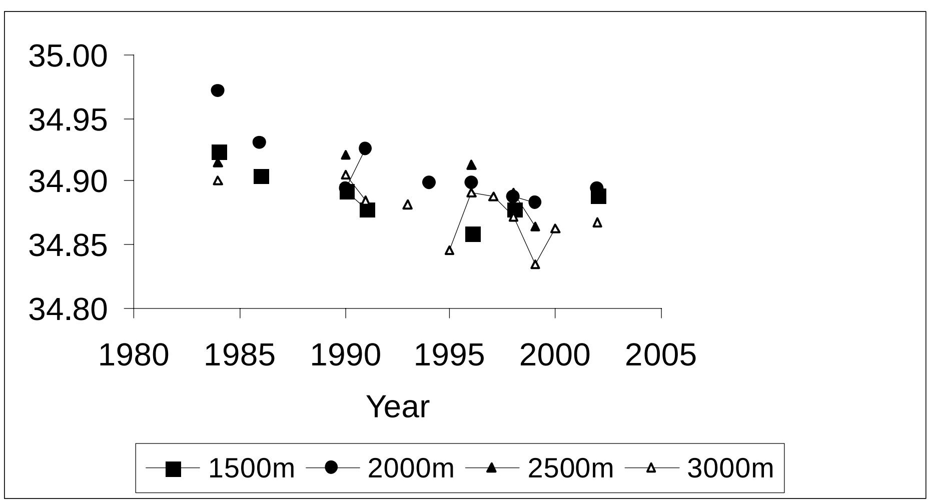

Fig. 23. Salinity of calibration samples at Cape Desolation Section station 3 (60°28’N, 50° 00’W).

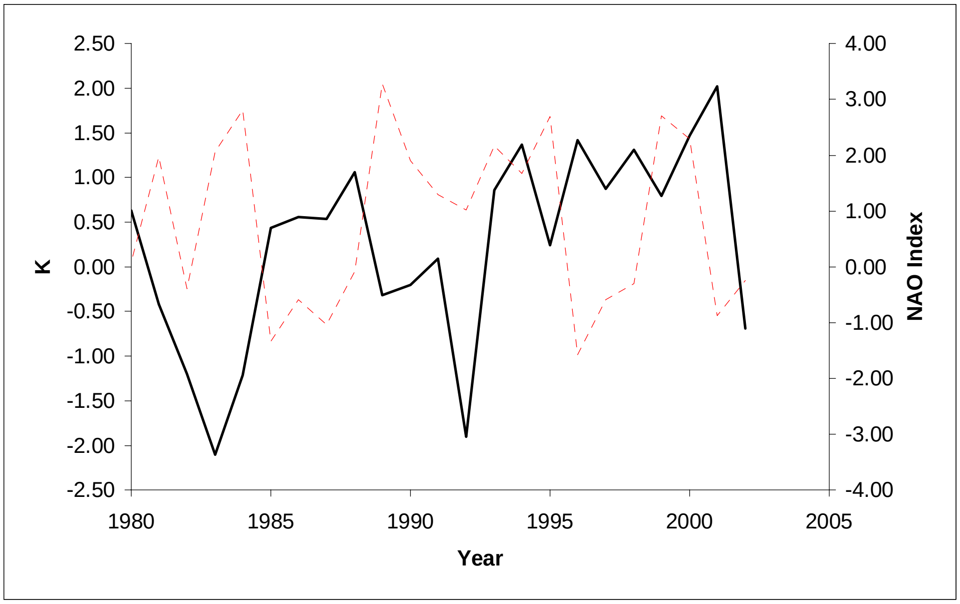

Fig. 24. Mean temperature anomalies of water layer 0-50 m at station 4 of the Fyllas Bank Section; data 1980-2002 (dashed: NAO Index).

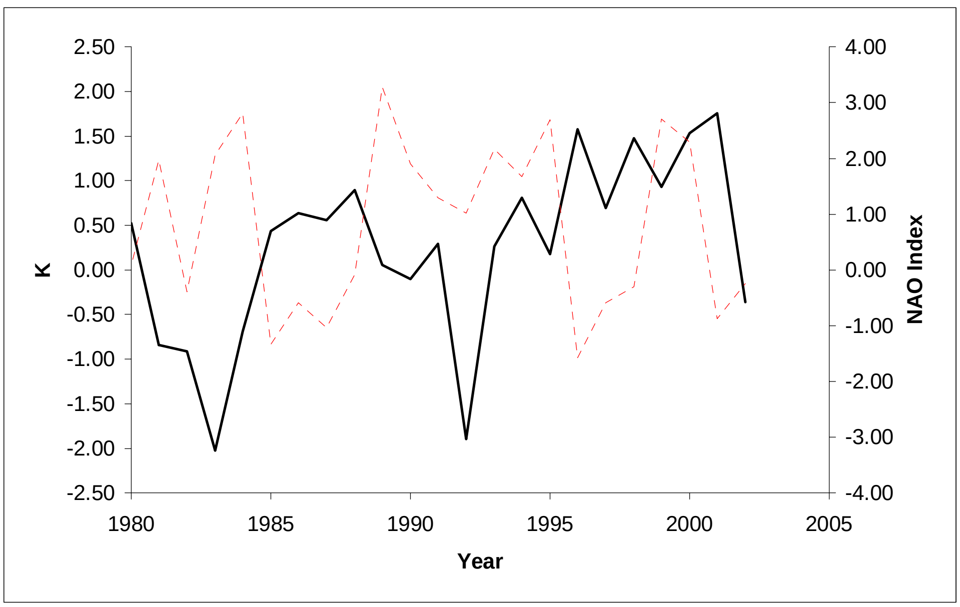

Fig. 25. Mean temperature anomalies of water layer 0-200 m at station 4 of the Fyllas Bank Section; data 1980-2002 (dashed: NAO Index).

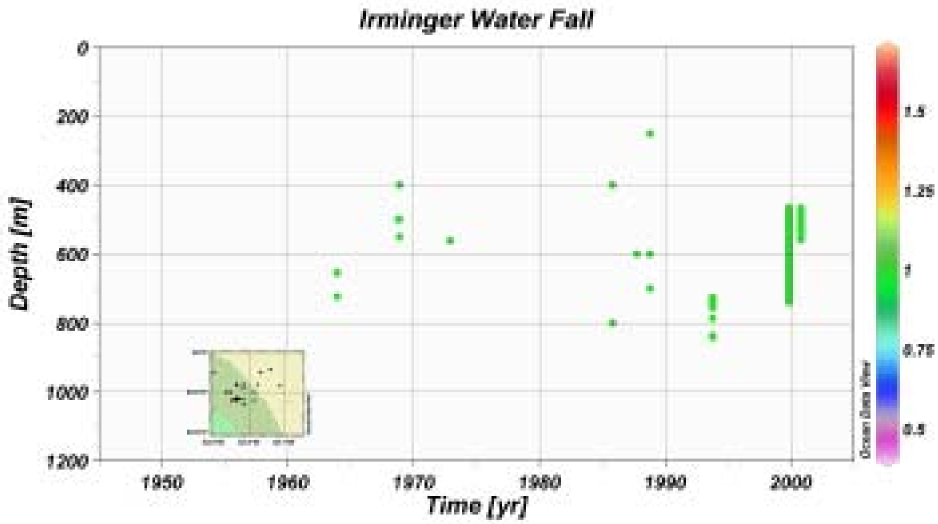

Fig. 26. Presence of Irminger Water at Fyllas Bank Station 4 during 1946-2002.