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Climatic Conditions Around Greenland - 2005

by

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic during winter 2004/2005 indicated 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 anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2004/2005 was positive (+2.03). Air temperature climatic conditions around Greenland continued to be warmer-than-normal. The climatic conditions at Nuuk are inconsistent with the NAO index (positive index = cold climate).

Warmer than normal conditions were observed around Greenland during most of the year 2005 with mean air temperatures at Nuuk indicating positive anomalies (+1.6K). Trend analysis clearly shows a warming trend in the Nuuk air temperature data. Besides harmonic oscillations which explain 61% of the variation, the linear trend incorporated in the 130 years long time series is significant and amounts to a warming rate of 0.007°C/year.

Based on satellite derived ice charts for all months of 2005 it is shown that winter sea ice conditions were favourable during 2005 off West Greenland. Subsurface autumn water temperatures off West Greenland and sea ice cover off Labrador during January-March of the following year, indicate significant negative correlation (r^2 = 0.72). At Fyllas Bank, subsurface warming during 2005 was in the range of the warm 1960s temperatures, but was less than during autumn 2003 when temperatures were 2.44K above normal, and normal for the layer 0-200 m is 2.87°C. Calibration samples from the deep water station Cape Desolation 3 (3 000 m depth) off southwest Greenland reveal harmonic oscillation signals which are most expressed at the 1 500 m depth level (r^2 = 0.85). At 3 000 m depth, in the domain of the Denmark Strait Overflow water mass, the harmonic signal is weaker, and it explains 44% of variation in the calibration data.

Introduction

Since decades, Denmark and Germany perform annual surveys in Greenland waters: The Danish June survey which was initiated in 1950 (Buch, 2000), and the German autumn survey starting in 1963 (Stein, 2004). During October/November 2005 FRV "*Walther Herwig III*" achieved oceanographic observations at NAFO Standard Oceanographic Sections Cape Desolation and Fyllas Bank.

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 fourteenth 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, the air pressure data, the air temperature data, and the sea ice data are taken from sources given under data and methods.

Data and Methods

The pattern of sea level atmospheric pressure anomaly during the winter (December, January, February) of 2004/2005 (Fig. 1b) and of sea level atmospheric pressure (Fig. 1c) 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. 2 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

$$\mathrm{NAO_i} = \frac{p_i - \overline{p}}{\sigma}\Big|PD - \frac{p_i - \overline{p}}{\sigma}\Big|A$$

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 (Fig. 3-7). The climatic mean which the air temperature anomaly charts are referenced to is 1961-1990. Ice charts (Fig. 8-12) 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).

During cruise WH280 of FRV "*Walther Herwig III*", CTD profiles were obtained at each fishing position of the surveyed area (Fig. 1 and 17). Observations on Standard Oceanographic Stations (Stein, 1988) were done at the Cape Desolation Section and the Fyllas Bank Section (Fig. 18 and 19). Salinity readings of the CTD (SeaBird 911+) profiles were adjusted to water samples derived by Rosette water sampler. A mean salinity deviation of +0.009 was applied to all profiles, except for Standard Oceanographic Stations which were calibrated individually. Data analysis and presentation (Fig. 18 and 19) was done using the most recent version of Ocean Data View (Version 3.0, 2005; Schlitzer, 2005). Theta/S sections of Fyllas Bank Section and Cape Desolation Section are displayed in Fig. 18 and 19. Time series of temperature anomaly at Fyllas Bank station 4 is given in Fig. 20. The data comprise observations done during September-November at the station site. Data gaps in our own data base, due to e.g. December observations, were filled with data from the World Data Base. This is the case for 1972, 1978, 1980 and 1981.The time series of salinity calibration samples at NAFO Cape Desolation Station 3 is given in Fig. 21-23.

Results and Discussion

The North Atlantic Oscillation (NAO)

Figure 1b shows the pattern of sea level pressure anomalies over the North Atlantic during the winter of 2004/2005 (DJF). There was a similar pressure pattern recorded during the winters of 1993/94 and 1999/2000.

The recent pattern indicates a dipole pattern with an Icelandic Low pressure anomaly cell shifted to the Greenland Sea (a classical dipole pattern was present in the winters of e.g. 1994/1995 and 1995/1996 when clearly expressed

Icelandic Low and Azores High pressure anomaly cells characterized the winter seasons; in: Stein, 2003).

The sea level atmospheric pressure over the North Atlantic during winter 2004/2005 is given in Fig. 1c. NAO *positive* winters, like 1999, 2000 and 2005, outline a deeper-than-normal Icelandic Low and a stronger-than-normal subtropical Azores High. NAO *negative* winters, like 1998, 2001, 2002, 2003 and 2004 show a weak subtropical high and a weak Icelandic low (for winters prior to 2003/2004 see: Stein, 2003).

The NAO index

The NAO index as given for the last and present decade shows mostly positive values (Fig. 2a, upper panel). The index for winter 2004/2005 (December-February) is positive (+2.03).

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 (Fig. 2b). 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. 2a, upper panel).

The direct influence of NAO on Nuuk winter mean air temperatures is as follows: 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, $p << 0.001$; Stein, 2004). The 2005 mean annual air temperatures at Nuuk reveal, however, that statistical significance being valid for the entire time series of 130 years, must not necessarily mean that this model fits with every year of observation. The NAO index for winter 2004/2005 is among the highest positive values during the past 15 years (Fig. 2a), and the annual mean air temperatures are among the highest values observed during 1876-2005 (see below).

Air Temperature and Climatic means

During 2005, January was the coldest month off West Greenland. While at Egedesminde (Fig. 3) temperatures were above normal, the Nuuk air temperatures reveal colder-than-normal conditions during January. Only at Nuuk, the negative air temperature conditions as observed during December 2004 at the West Greenland sites, were maintained through to January 2005.

Except for September and October, Angmagssalik (Fig. 5) experienced climatic conditions which were above the climatic mean throughout the year.

Climatic Variability off West Greenland

The annual mean air temperature anomaly calculated for 2005 is 1.6K (Fig. 6). This is a continuation of a series of warmer-than-normal years (0.2K to 2.0K) which started in 1996, with the exception of 1999 which was colder-than-normal (-0.3K). During recent times, 2003 was the warmest year with +2.0K. We have to go back to the 1940s to find similar warm years, like 1947 with +2.3K. If we consider West Greenland’s climatic conditions in terms of five-year periods (Fig. 7), the most recent period (2001-2005) reveals anomalous warming (+1.2K). This is the second highest value obtained during the entire time series. Only the period 1926-1930 was warmer (+1.4K). For a scrutinized trend analysis a harmonic model (1) was applied to the data given in Fig. 7. The results as shown in Fig. 8, indicate periods of colder-than-normal conditions prior to 1920, warmer-than-normal conditions thereafter, and a colder-than-normal period from about 1970 onwards. These results are consistent with the warm and cold periods as published by Stein (1995). There is, however, a difference as concerns the trend of the model curve (r^2 = 0.61), and the duration of the cold and warm periods. Fig. 8 clearly shows a warming trend in the Nuuk air temperature data. The linear trend is significant and amounts to a warming rate of 0.007°C/year.

$$(1) \qquad \zeta(t)=A*\sin(2\pi/\tau + \varphi) + \text{lin trend}$$

Similar to Stein (1995) the warm period at West Greenland during the 20th century lasted from about 1920-1970. After that warm period, the five-year period values of the 1970s, 1980s and 1990s indicate colder-than-normal

conditions, whereas from 2000 onwards warmer-than-normal conditions characterize the West Greenland climate. As discussed above, during 1996 warming started. This led to shortening of the cold period which was about 30 years instead of 54 years as proposed by Stein (1995).
Warming in arctic regions has become a more and more frightening scenario in past years (http://cires.colorado.edu/science/groups/steffen/greenland/melt2005/). Warming as observed in our data on West Greenland Current properties (e.g. Stein, 2005), in the climatic data of Nuuk, as indicated above, and in subsurface oceanographic data off West Greenland's fishing banks (see below) support this scenario.

The presentation of decadal air temperature anomalies at 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. 2003 is the warmest year on record for all decades, and 2004 is the warmest "year 4". The year 2005 (+1.6K) is in a similar range as the years 1955 (+1.3K), 1965 (+1.7K) and 1985 (+1.8K).

Ice Conditions around Greenland

Winter sea ice conditions were favourable during 2005 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 end-February off Maniitsoq/Sukkertoppen (Fig. 10), a month earlier than during 2004. Multi-year sea ice, coming from the Arctic Ocean via the East Greenland current to the Cape Farewell area, is called "Storis". During early June, the East Greenland coast was surrounded by sea ice with concentrations ranging from 3-10 tenth (Fig. 12). There was also a tongue of newly formed ice in the Cape Farewell region (Fig. 11). Sea ice formed again in Baffin Bay in the first decade of November (Fig. 13) when 3-10 tenth of ice concentration was observed north off Baffin Island. Off East Greenland first sea ice formation was encountered in the Angmagssalik area and to the north during the third decade of November (Fig. 14). Due to these favourite ice conditions the cruise WH280 of FRV "*Walther Herwig III*" to East and West Greenland waters in October/November 2005 was not affected by any sea ice.

Sea ice off Labrador and water temperatures off West Greenland

Based on the subsurface temperature observations of RV "*Walther Herwig III*" during autumn 1989-2005, and sea ice cover off Labrador in the following winter season (JAN-MAR), statistical correlation was performed for both data sets (V. A. Borovkov, Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia). The results are given in Fig. 15 and 16. Accordingly, the variability of mean water temperatures off West Greenland (bottom depth ≤200 m) measured during autumn, explains 72% of the variation in sea ice off Labrador during the following winter season (JAN-MAR).

Subsurface Observations off West Greenland

There are two salient features in the vertical distribution of temperature which characterize the hydrographic properties between Greenland and arctic Canada (Stein, 2005): The Baffin Island Current and the core of the West Greenland Current (WGC). The Baffin Island Current is a broad current band which exports cold water from Baffin Bay southwards. On the eastern side of the section, the West Greenland Current flows along the shelf break and transports heat into the Baffin Bay.

Vertical distribution of potential temperature and salinity at the NAFO Standard Oceanographic Sections Fyllas Bank and Cape Desolation (Fig. 17) are given in Fig. 18 and 19.

Fyllas Bank Section

The Fyllas Bank Section crosses the WGC-core at the off-slope stations 4 and 5 (Fig. 18). During autumn 2005 observations, core temperatures/salinities amounted to 5.8°C/34.986 PSU at about 225 m depth (station 5), maximum temperature was found at 118 m (6.41°C, 34.920 PSU). The surface layers are dominated by low saline (~33.5 PSU) water of 2.0°C to 3.0°C.

Cape Desolation Section

The Cape Desolation Section station 3 is in the domain of the WGC-core and reveals temperatures (salinities) of 6.0°C (35.024 PSU) at 232 m depth during 5 November 2005 (Fig. 19). At depths of 2 993 m potential temperature of 1.51°C was calculated (*in situ* temperature / salinity: 1.74°C/34.889 PSU).

Temperature time series Fyllas Bank station 4

Based on autumn measurements (September-November) at station 4 of the Fyllas Bank section, the temperature anomaly time series reveals a warming trend which is persistent since 1993 (Fig. 20). Since station 4 of the Fyllas Bank section is situated at the bank slope, it happened in the past decades that cold surface waters from Fyllas Bank were moved westward and influenced the upper 200 m of the water column. This happened during autumn 1983, 1992 and 2002, and these events will be called here "polar events". Subsurface warming during 2005 was in the range of the warm 1960s temperatures, but was less than during autumn 2003 when temperatures were 2.44K above normal, and normal for the layer 0-200 m is 2.87°C. The subsurface warming off West Greenland is analysed in detail in Stein (2005).

Calibration samples

Data on calibration samples taken at CD3, reveal freshening in deep water layers from 1984 onwards (Fig. 22 and 23). During the 2005 cruise, calibration samples were obtained at 500 m, 1 000 m, 1 500 m, 2 000 m, 2 500 m and 3 000 m depth. Model (1) adjusted to the data of 1 500 m, 2 000 m and 3 000 m depth, reveals significant harmonic trends.

They explain 85% of variation at 1 500 m depth (Fig. 21), 81% at 2 000 m depth and 44% at 3 000 m depth. It is suggested here that the values at 1 500 m depth represent climatic changes in the Labrador Sea throughout the time of the 1980s to 2005. At 2 000 m depth, which is the approximate depth of the upper boundary of the saline, low-oxygen layers of the North Atlantic Deep Water (NADW) the model suggests climatic changes which might be forced by the Labrador Sea Water layer, sitting above the NADW (Stein and Wegner, 1990). The bottom water layer at Cape Desolation station 3 is influenced by the Denmark Strait Overflow water. It would appear that the salinity at this depth (3 000 m) points at freshening of this water mass, which obtains its characteristics north of the Denmark Strait in the Greenland Sea.

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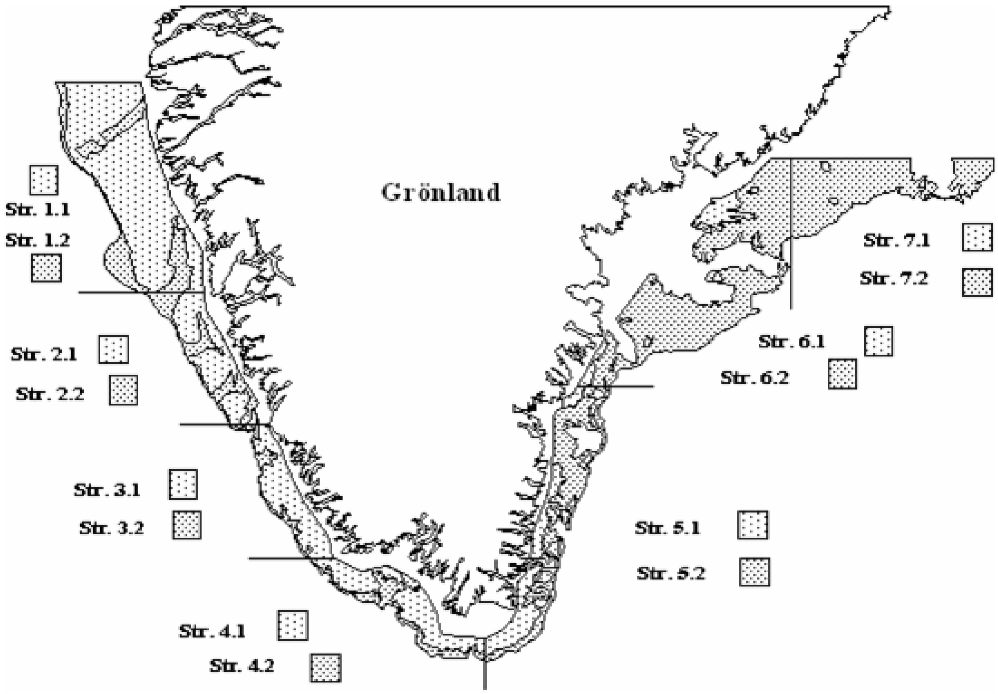

Fig. 1a. Area of investigation during WH 280 (13 October-24 November 2005), and individual survey strata; strata 0-200 m: 1.1, 2.1, 3.1, 4.1, 5.1, 6.1 and 7.1, and 200-400 m: 1.2, 2.2, 3.2, 4.2, 5.2, 6.2 and 7.2 around Greenland.

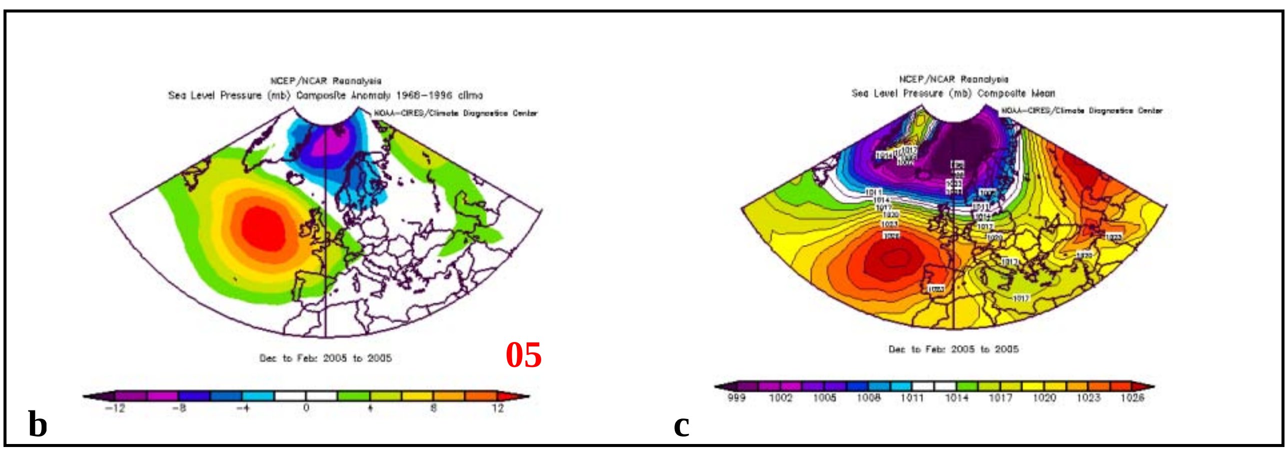

Fig. 1bc. (**b**) The pattern of sea level atmospheric pressure anomaly during the winters (December, January, February) of 2004/2005, red year label denotes positive NAO index. (**c**) The pattern of sea level atmospheric pressure during the same winter as in Fig. 1b.

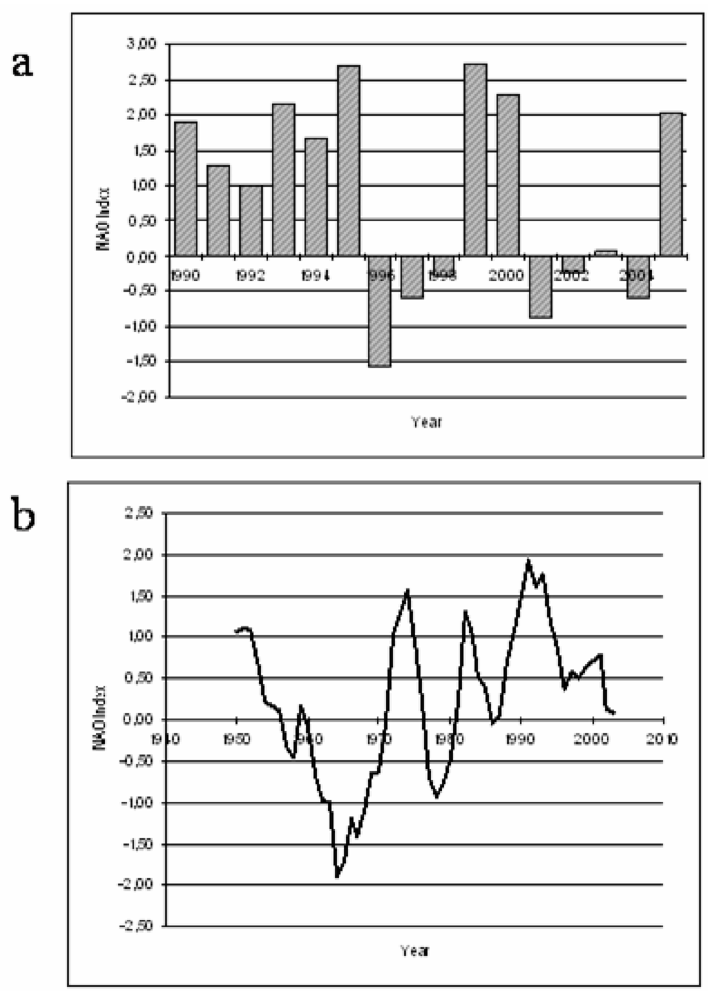

Fig. 2. The winter (DJF) NAO index in terms of the last and present decade (**a**) and the second half of the last century (lower figure **b**, a 5 year running mean has been applied).

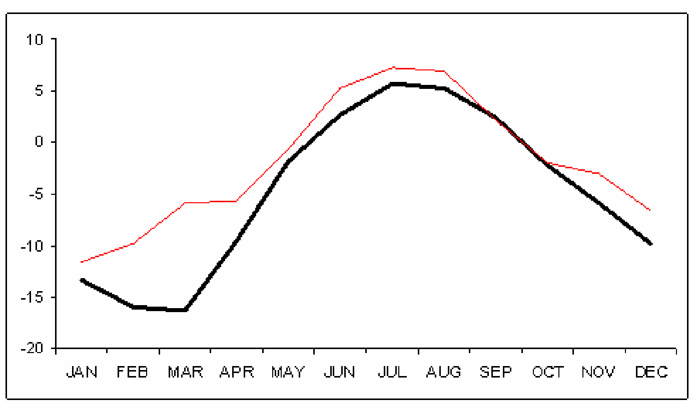

Fig. 3. Monthly mean air temperature [°C] at Egedesminde during 2005 (red, thin line) and climatic mean (1961-1990).

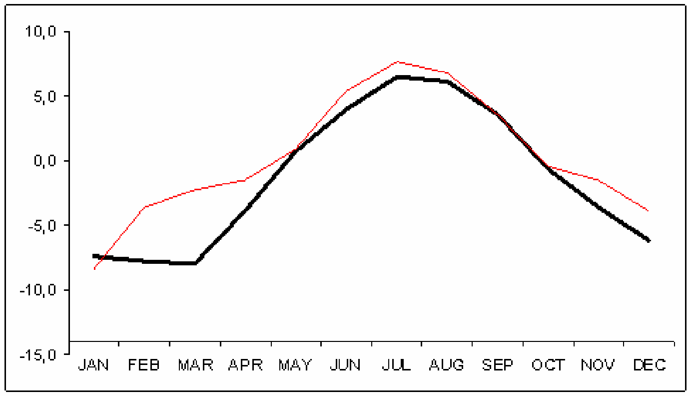

Fig. 4 Monthly mean air temperature [°C] at Nuuk during 2005 (red, thin line) and climatic mean (1961-1990).

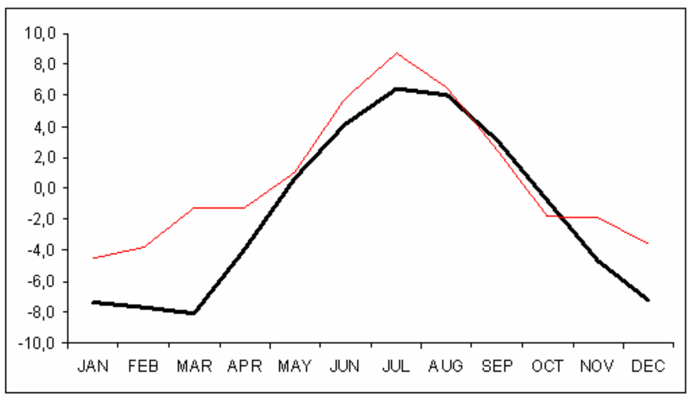

Fig. 5. Monthly mean air temperature [°C] at Angmagssalik during 2005 (red, thin line) and climatic mean (1961-1990).

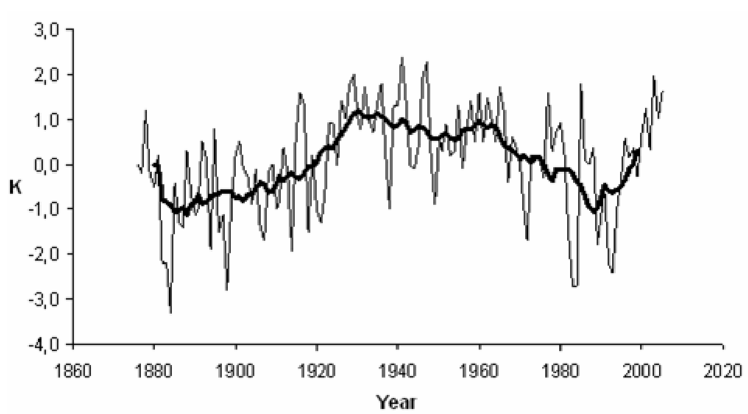

Fig. 6 Time series of annual mean air temperature anomalies at Nuuk (1876-2005, rel. 1961-90), and 13-year running mean.

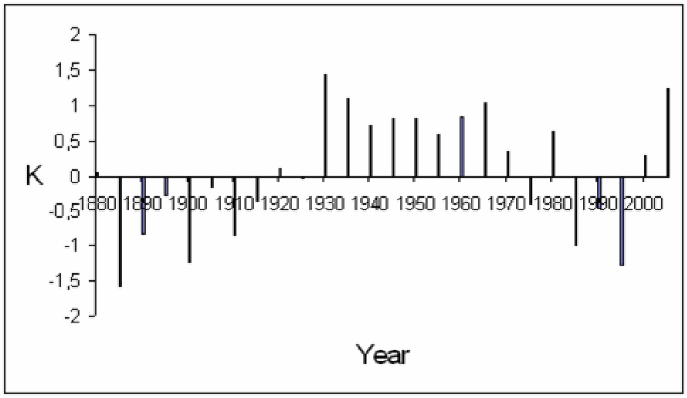

Fig. 7. West Greenland's air temperature anomalies in terms of five-year periods (1876-1880, 1881-1885, …, 2001-2005); data are given in 5-year intervals, starting with 1880, ending with 2005.

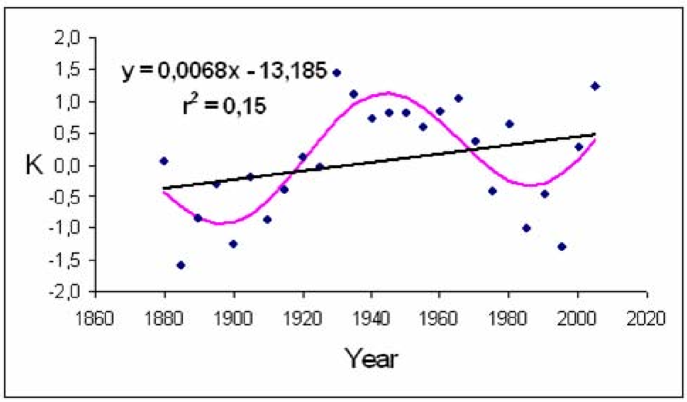

Fig. 8. West Greenland's air temperature anomalies in terms of five-year periods (1876-1880, 1881-1885, …, 2001-2005); harmonic model (1) adjusted to the data (r^2 = 0.61); linear trend of model (r^2 = 0.15) is given.

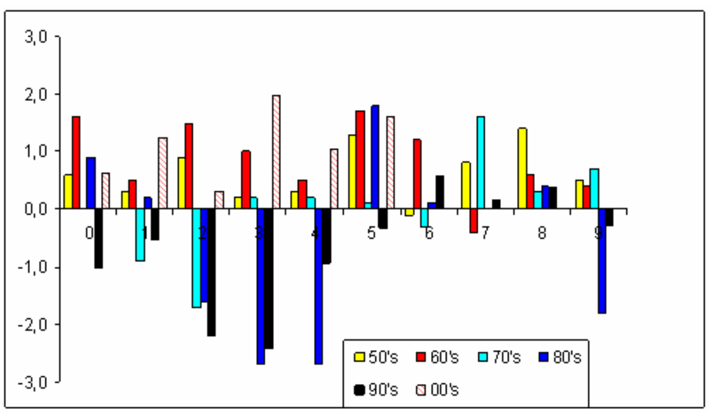

Fig. 9. Composite of decadal air temperature anomalies at Nuuk given relative to the climatic mean of 1961-90 for the decades of the 1950s-1990s and 2000s (dashed column).

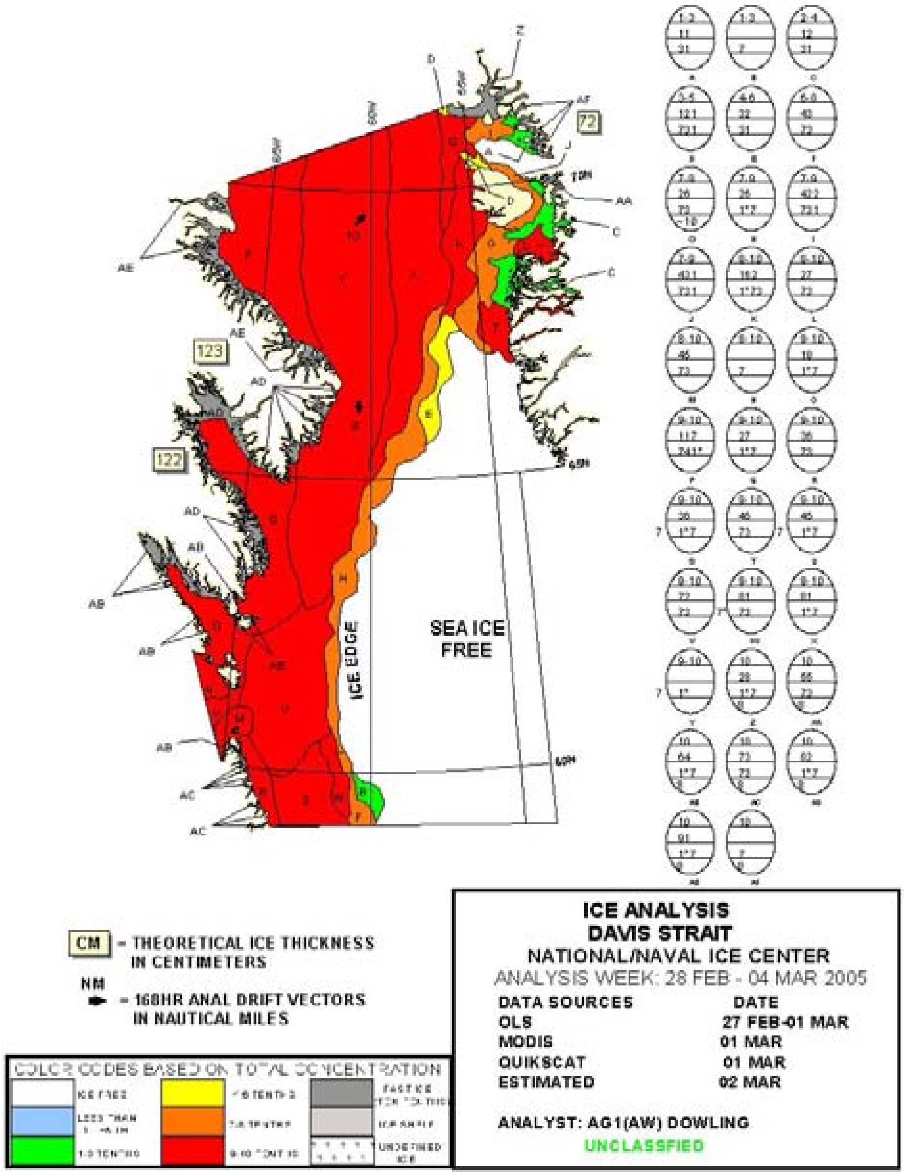

Fig. 10. Ice cover and ice edge during 28 February-04 March 2005 (Davis Strait).

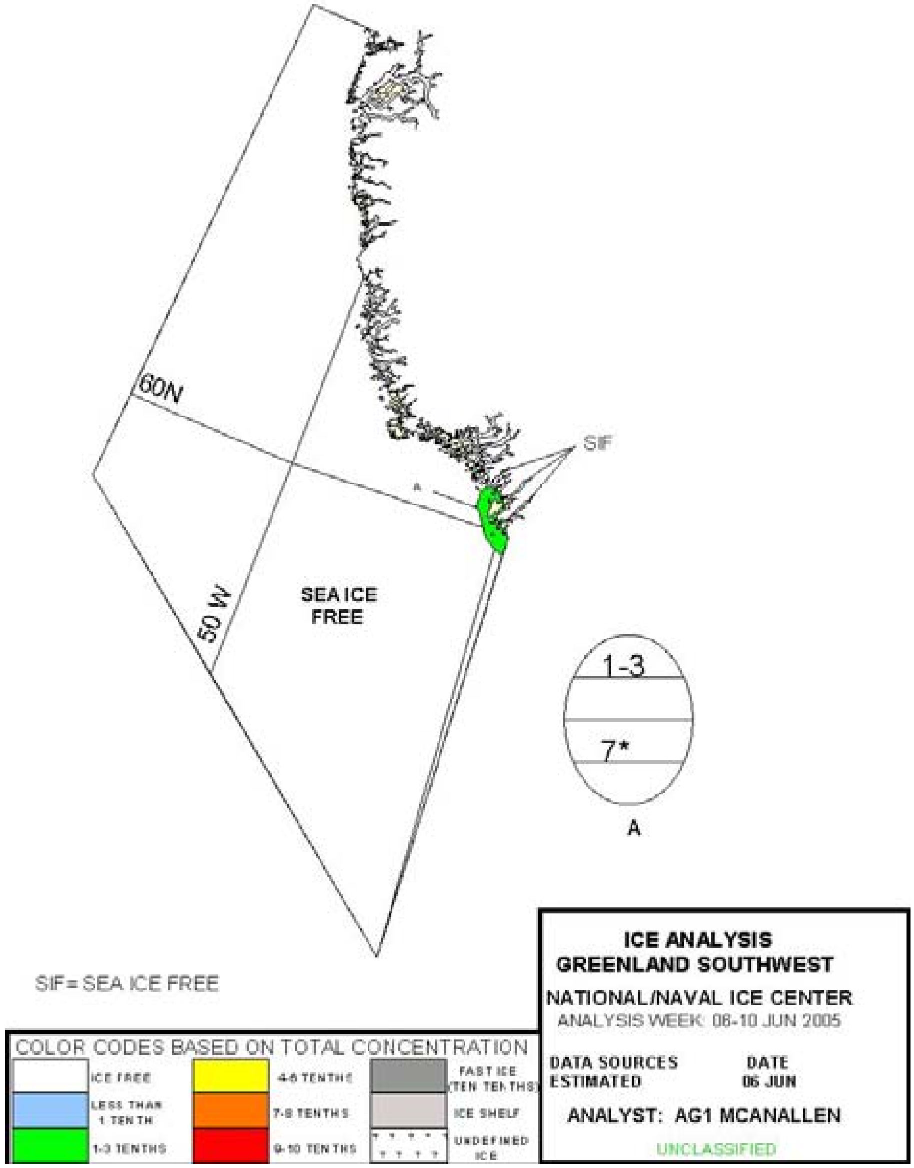

Fig. 11. Ice cover and ice edge during 06-10 June 2005 (Greenland Southwest).

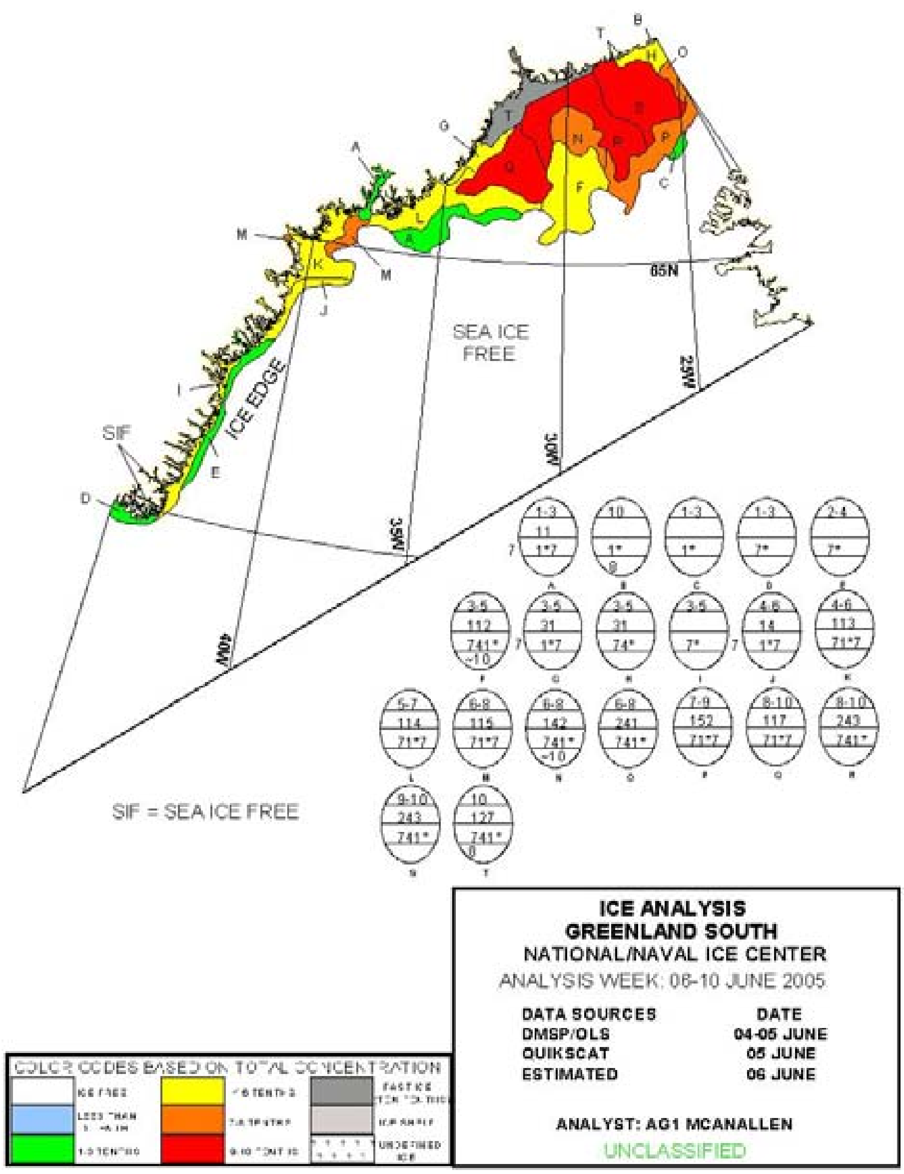

Fig. 12. Ice cover and ice edge during 06-10 June 2005 (Greenland South).

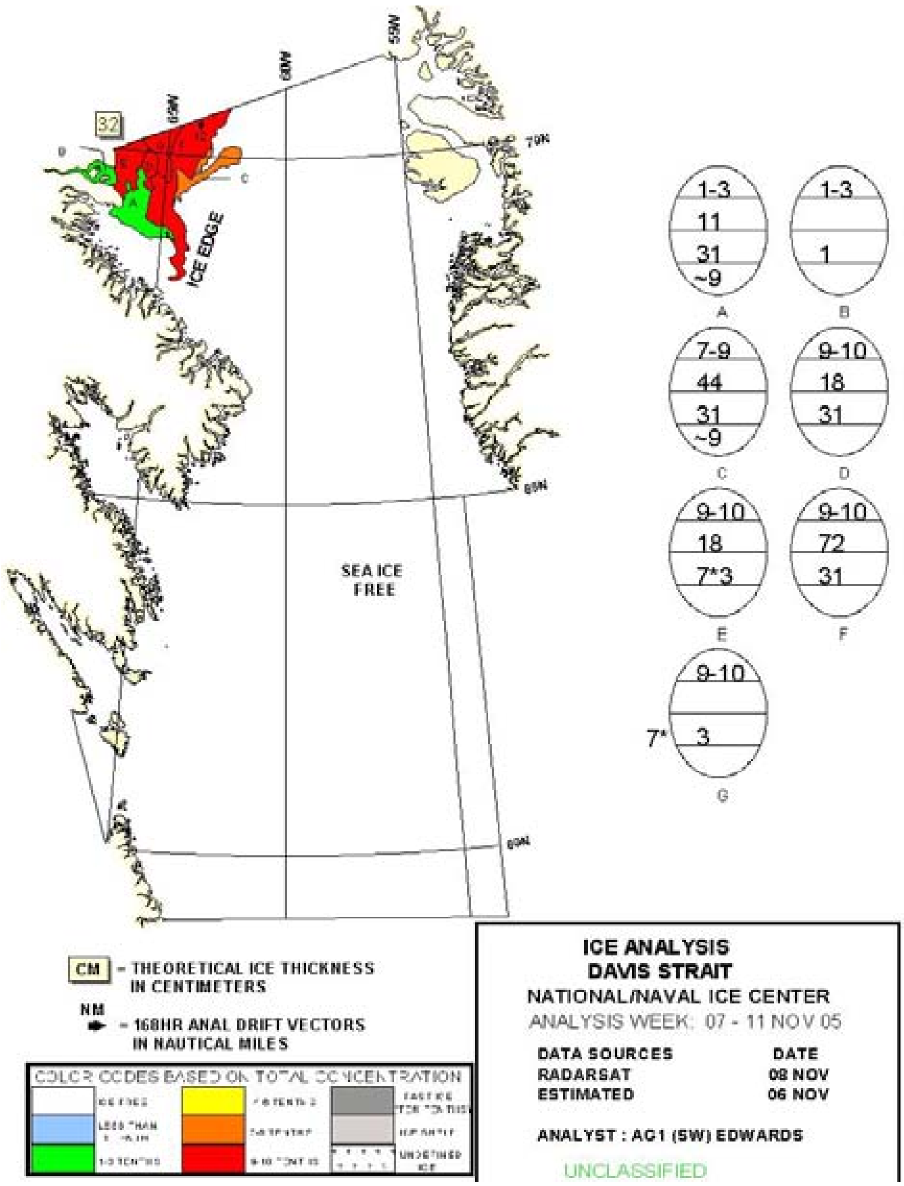

Fig. 13. Ice cover and ice edge during 07-11 November 2005 (Davis Strait).

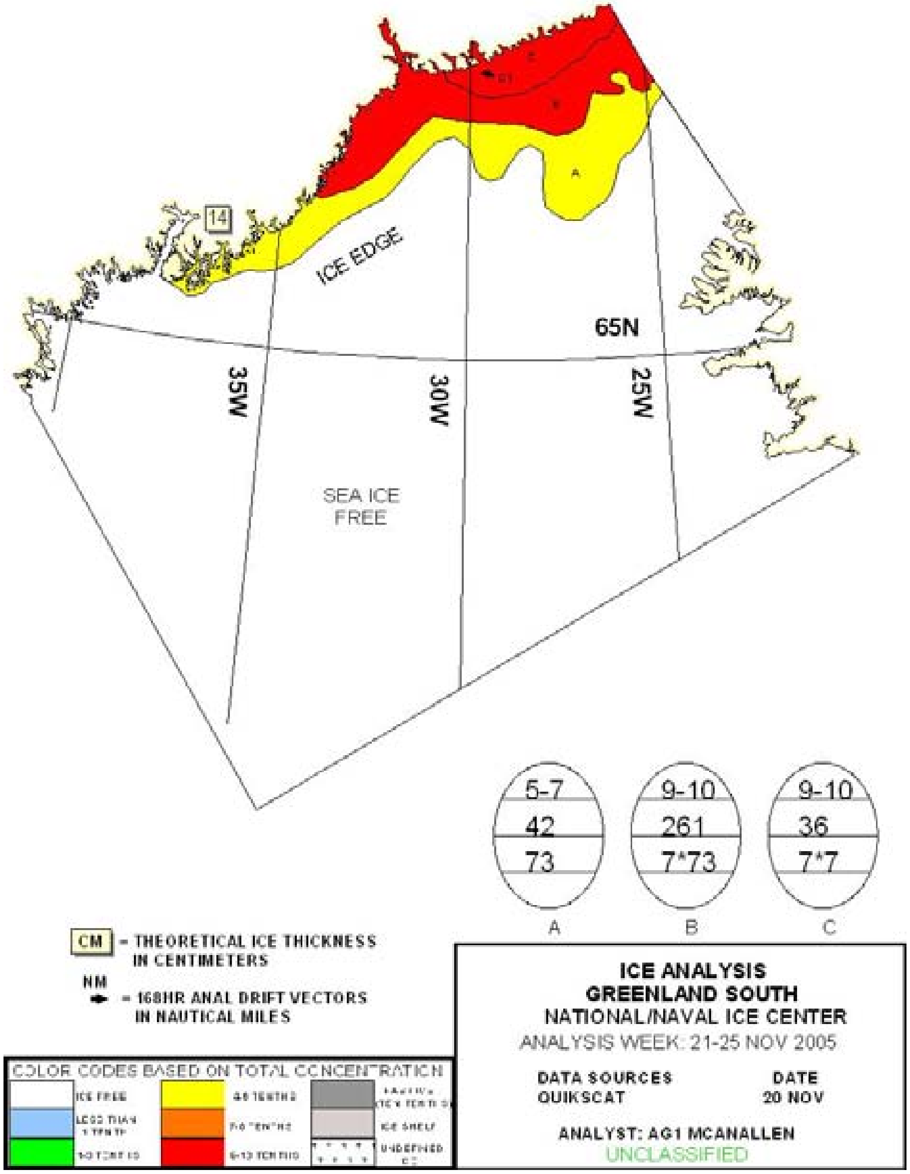

Fig. 14. Ice cover and ice edge during 21-25 November 2005 (Greenland South).

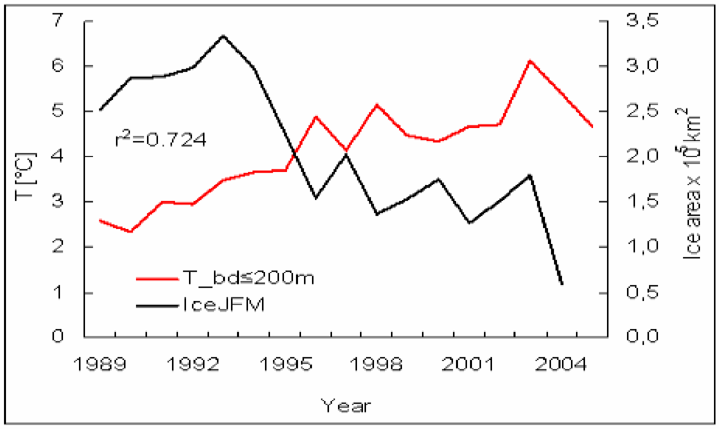

Fig. 15. Mean water temperatures (T_bottom depth ≤200 m) off West Greenland during autumn and sea ice cover off Labrador during JAN-MAR of the following year.

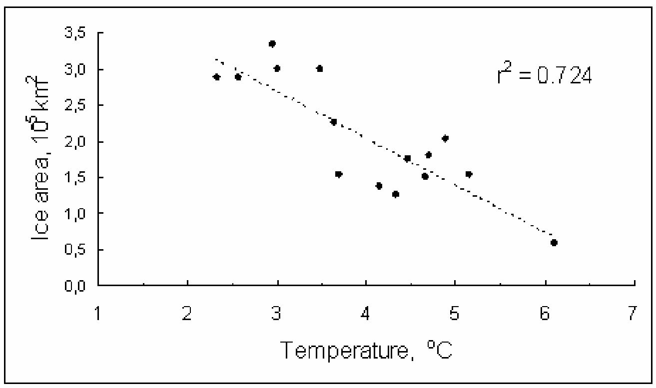

Fig. 16. Linear correlation between mean water temperatures (T_bottom depth ≤200 m) off West Greenland during autumn and sea ice cover off Labrador during JAN-MAR of the following year.

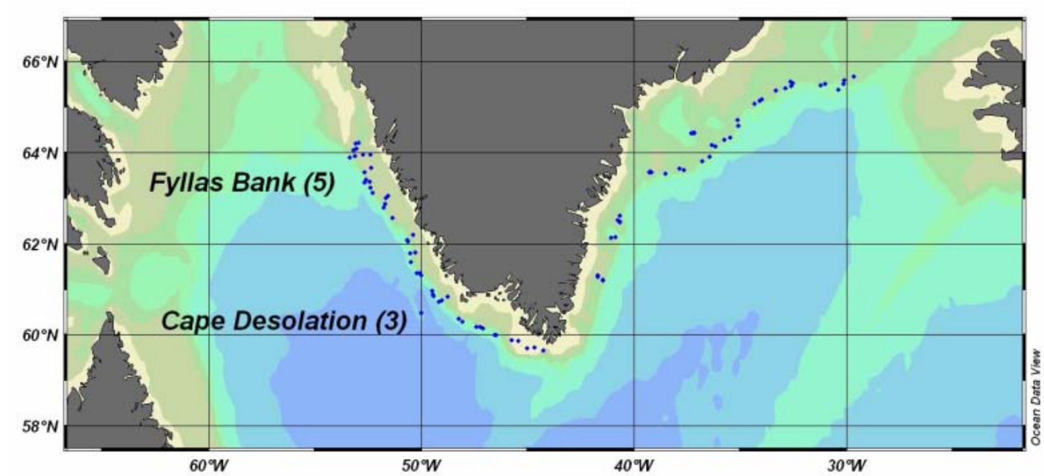

Fig. 17. Positions of fishing stations off East and West Greenland (89), sampled NAFO Standard Sections: Fyllas Bank, Cape Desolation; in brackets: No. of stations.

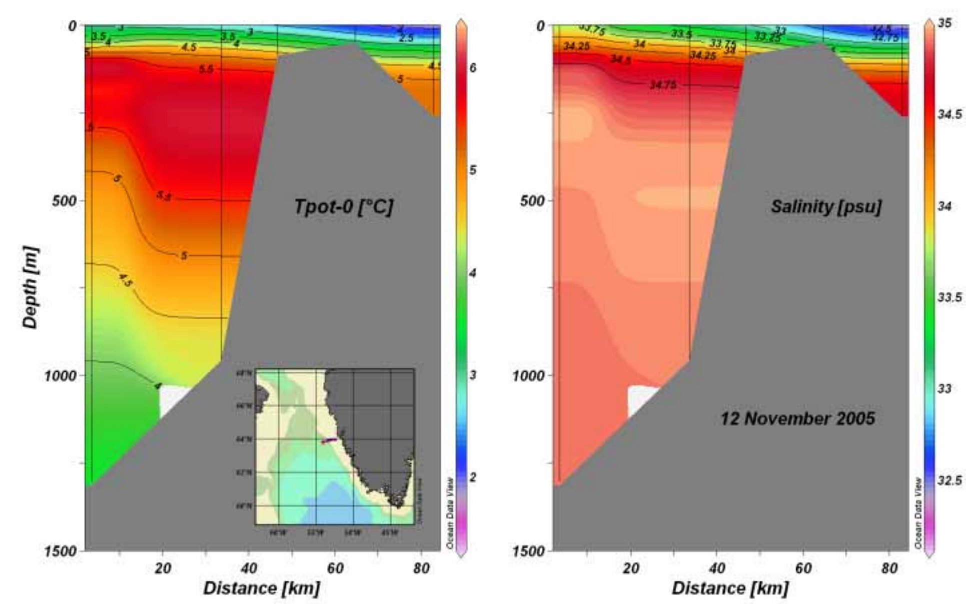

Fig. 18. Potential temperature and salinity along Fylla Bank Section (12 November 2005).

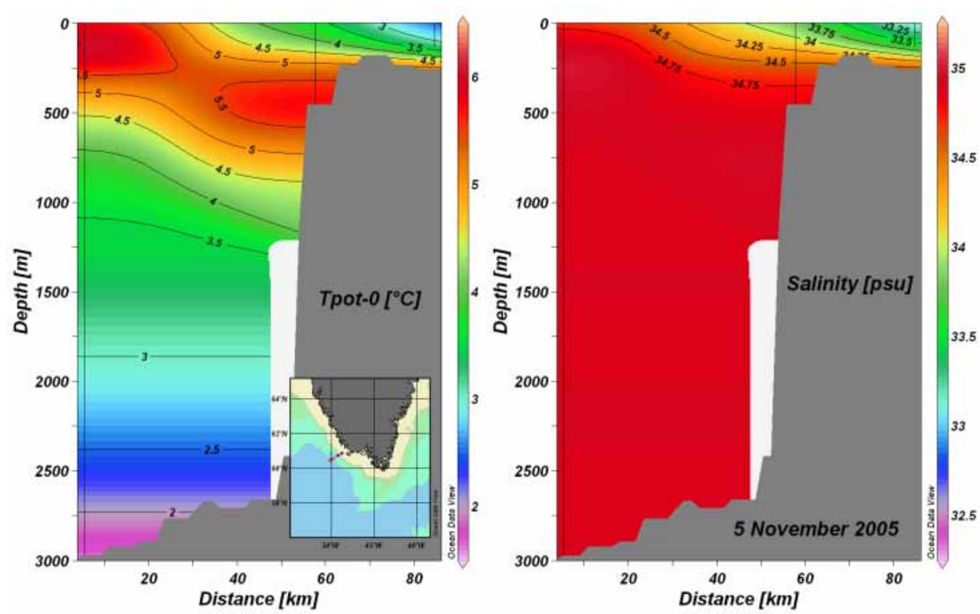

Fig. 19. Potential temperature and salinity along Cape Desolation Section (5 November 2005).

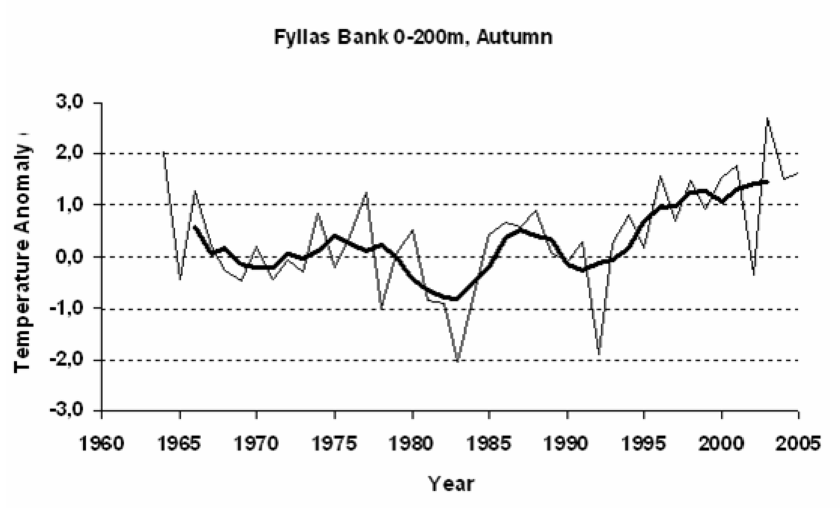

Fig. 20. Mean water temperature anomalies of layer 0-200 m at station 4 of the Fyllas Bank Section during autumn; data: 1964-2005 (thin), 5 yr r.m. (bold); (base period: 1964-1990).

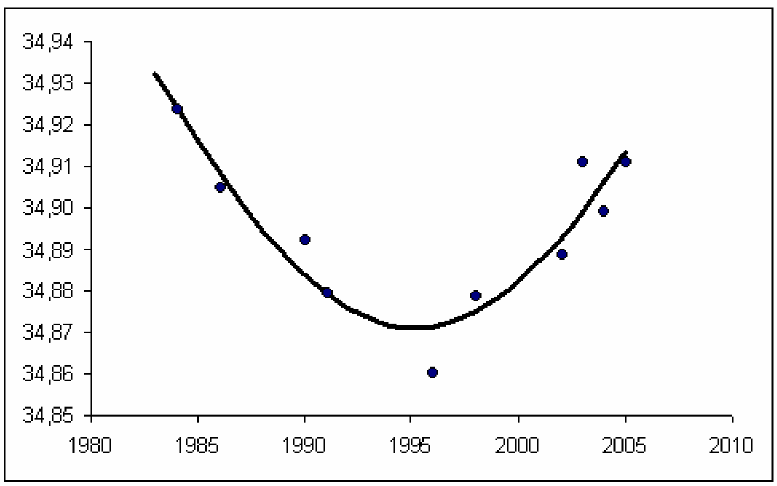

Fig. 21. Salinity of **calibration samples** at Cape Desolation Section station 3, **1 500 m** depth (60°28'N, 50°00'W; data: 1984-2005; harmonic model adjusted to the data; $r^2 = 0.85$).

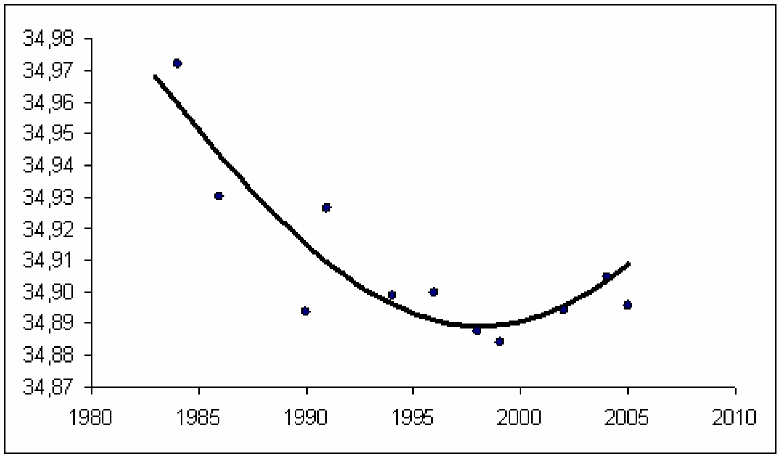

Fig. 22. Salinity of **calibration samples** at Cape Desolation Section station 3, **2 000 m** depth (60°28'N, 50°00'W; data: 1984-2005; harmonic model adjusted to the data; r^2 = 0.81).

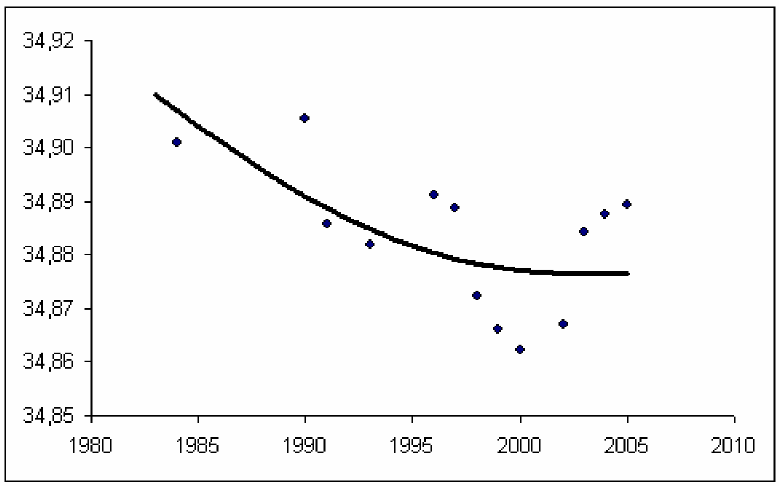

Fig. 23. Salinity of **calibration samples** at Cape Desolation Section station 3, **3 000 m** depth (60°28'N, 50°00'W; data: 1984-2005; harmonic model adjusted to the data; r^2 = 0.44).