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Climatic Conditions Around Greenland - 2004

by

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic was anomalous during winter 2003/2004. 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 2003/2004 was weak and negative (-0.60). Air temperature climatic conditions around Greenland continued to be warmer-than-normal. 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 2004 with mean air temperatures at Nuuk indicating positive anomalies (+1.1K). Based on satellite derived ice charts for all months of 2004 it is shown that winter sea ice conditions were favourable during 2004 off West Greenland. Compared to mean autumn conditions derived from the Holsteinsborg section, the temperatures in the West Greenland Current core and on the West Greenland shelf, as measured during autumn 2004, are up to 2K warmer than normal. At Fyllas Bank, subsurface warming during 2004 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.

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 2004 FRV "*Walther Herwig III*" achieved oceanographic observations at NAFO Standard Oceanographic Sections Cape Desolation, Fyllas Bank and along a new oceanographic section line between Greenland and Canada. This section followed NAFO Standard Section Holsteinsborg (Stein, 1988), and historic stations performed by the Canadian RV "*Hudson*" during autumn 1965. Details on the flow of water masses across the Davis Strait sill and the West Greenland shelf which is a 330 km wide gap between West Greenland and Baffin Island/Canada is given in Stein (2005).

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 thirteenth 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, 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 2003/2004 (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 WH268 of FRV "*Walther Herwig III*", CTD profiles were obtained at each fishing position of the surveyed area (Figs. 1 and 13). Observations on Standard Oceanographic Stations (Stein, 1988) were done at the Holsteinsborg/Baffin Island Section, Cape Desolation Section and the Fyllas Bank Section (Fig. 13-21). Salinity readings of the CTD (SeaBird 911+) profiles were adjusted to water samples derived by Rosette water sampler. A mean salinity deviation of -0.006 was applied to all profiles. Data analysis and presentation (Fig. 13-19) was done using the most recent version of Ocean Data View (Version 2.1, 2004; Schlitzer, 2004). Theta/S sections of Holsteinsborg-Baffin Island Section, Fyllas Bank Section and Cape Desolation Section are displayed in Fig. 14-16, the θS-water mass diagram of the section stations is given in Fig. 17-19. 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.

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 2003/2004 (DJF). There was no similar pressure pattern recorded during the winters of the 1990s and early-2000s as during this recent winter.

The recent pattern differs considerably from a classical dipole pattern (a 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 2003/2004 pattern reveals three centres of pressure anomaly: A positive anomaly cell is found stretching from Greenland to Spain, a negative cell is located to the south of the positive anomaly, reaching from Newfoundland in the west to the region of the Azores, and another negative cell is situated over Scandinavia and West Russia.

The sea level atmospheric pressure over the North Atlantic during winter 2003/2004 is given in Fig. 1c. 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, 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 2003/2004 (December-February) is, however, negative (-0.60).

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 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, $p \ll 0.001$; Stein, 2004).

Air Temperature and Climatic means

During 2004, March was the coldest month off West Greenland. While at Egedesminde (Fig. 3) temperatures were mostly above normal, the Nuuk air temperatures reveal colder-than-normal conditions during March, July and December. The positive air temperature conditions as observed during December 2003 at the West Greenland sites, were maintained through to January 2004.

Air temperature anomalies (in brackets: mean temperature of the month) during March were +2.5K at Egedesminde (–13.8°C), and –0.8K Nuuk (–8.8°C). Angmagssalik (Fig. 5) experienced climatic conditions which were mostly above the climatic mean throughout the year, except for December when air temperature anomalies were –0.3K and monthly mean temperature was –7.5°C.

Climatic Variability off West Greenland

The annual mean air temperature anomaly calculated for 2004 is 1.1K (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. The presentation of decadal air temperature anomalies Nuuk (Fig. 7) 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".

Ice Conditions around Greenland

Winter sea ice conditions were favourable during 2004 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-March off Maniitsoq/Sukkertoppen (Fig. 8). 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 7-10 tenth (Fig. 10). There was also a tongue of newly formed ice in the Cape Farewell region (Fig. 9). Sea ice formed again in Baffin Bay in the first decade of November (Fig. 11) when 4-10 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. 12). Due to these favourite ice conditions the cruise WH268 of FRV "*Walther Herwig III*" to East and West Greenland waters in October/November 2004 was not affected by any sea ice. This was especially the case with the Holsteinsborg-Baffin Island Section (Fig. 13, 14) which was done on 31 October and 1 November, 2004: Only a week after we finished our measurements off Cape Dyer/Baffin Island, sea ice formation started at the coast, and from 20 November onwards half of the Davis Strait was closed by sea ice with concentrations ranging from 4-8 tenth (see: http://www.natice.noaa.gov/pub/East_Arctic/Baffin_Bay/Davis_Strait/2004/davi041122color.jpg).

Subsurface Observations off West Greenland

Vertical distribution of potential temperature and salinity at the NAFO Standard Oceanographic Sections Holsteinsborg-Baffin Island, Fyllas Bank and Cape Desolation are given in Fig. 14-16.

Holsteinsborg-Baffin Island Section

There are two salient features in the vertical distribution of temperature (upper panel in Fig. 14) which characterize the hydrographic properties between Greenland and Baffin Island: 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 (core temperatures <-1.64°C) from Baffin Bay southwards. On the eastern side of the section, the West Greenland Current flows along the shelf break and transports heat (core temperatures >5.9°C) into the Baffin Bay. During the 2004 observations, both currents meet and mix intensively between the two innermost stations of the section. There is a sub-surface tongue of warm West Greenland Current water (>3°C) located under the cold Baffin Island Current which extends westward from the WGC-core. Further west, at station HUDSON 3, a remnant of 2°C warm water is visible (Fig. 14). A month prior to our observations, RV "*KNORR*" of the US observed a sub-surface patch of warm water at this location which had thermohaline properties of WGC-water (Petrie, *pers. comm.*). Salinity (lower right panel of Fig. 14) reveals a near-surface thin layer of low saline water (<32 PSU) on the western side of the section, and <33 PSU water on the eastern side. In the WGC-core at the West Greenland slope, salinities are around 34.94 psu. Similar to the vertical temperature distribution along this section there is a remnant of saline water (>34.5 PSU) below the Baffin Island Current water.

Compared to mean autumn conditions, the temperatures in the WGC-core and on the West Greenland shelf as measured during autumn 2004, are up to 2K warmer than normal.

Fyllas Bank Section

The Fyllas Bank Section crosses the WGC-core at the off-slope stations 4 and 5 (Fig. 15). During autumn 2004 observations, core temperatures/salinities exceeded 6.6°C / 34.981 PSU at about 135 m depth (station 5), maximum temperature was found at 71 m (7.11°C, 34.900 PSU). The surface layers are dominated by low saline (<33.5 PSU) water of 3.0°C to 4.0°C.

Cape Desolation Section

The Cape Desolation Section station 3 is in the domain of the WGC-core and reveals temperatures (salinities) of 7.06°C (34.962 PSU) at 27 m depth during 25 October 2004. At depths of 2 994 m potential temperature of 1.34°C was calculated (*in situ* temperature / salinity: 1.56°C / 34.867 PSU).

Temperature/Salinity diagrams

Figures 17-19 display the θS-diagrams of the transect stations. Along the *Holsteinsborg-Baffin Island section*, the on-shelf stations 352-355 (Fig. 17) show the thermohaline properties on the West Greenland shelf. The deepest on-shelf station, station 355, is 175 m deep and reveals temperatures/salinities of 2.08°C / 32.364 PSU at the surface and 3.71°C / 34.245 PSU at the bottom. Station 356 is in the domain of the WGC branch and shows a θS-curve which differs completely from the other θS-curves on the "Greenland" side of the section. At the sea surface 2.57°C / 32.636 PSU were observed, warmest conditions were encountered at 255 m depth with temperatures/salinities of 5.94°C / 34.927 PSU. Bottom temperatures/salinities were observed as 5.32°C / 34.950 PSU.

Of completely different shape are the θS-curves of stations 357-361. They are the thermohaline expressions of the cold, arctic waters of the Baffin Island Current. The surface θS-characteristics are in the lower left part of Fig. 17, indicating values of 0°C to –1°C and salinities below 32 PSU. Lowest temperatures (-1.64°C) are observed around 100m depth, salinities range between 33.0 and 33.5 PSU. At depths of 421 m (station 358), warmest conditions are measured, 3.43°C and 34.629 PSU. The "Baffin Island Current" shaped θS-curves follow more or less this structure of θS-properties from top to bottom of the water column, with the exception of station 361 which has no "Warm Deep Water" signal.

At the *Fyllas Bank section*, the innermost stations (391-389) have a linear shape θS-curve (Fig. 18). Station 388 (slope station of the section, Standard Station 4, 950 m deep), and the 1 300 m deep station 387 reveal θS-curves which document a "Warm Deep Water" layer of WGC thermohaline properties. Core temperatures/salinities of station 387 are 7.11°C/34.900 PSU. Near the bottom, temperatures/salinities of 3.62°C/34.897 PSU were observed.

Station 322 of the *Cape Desolation section* is positioned on the West Greenland shelf (Fig. 19). The θS-curve has a linear shape. The θS-curve of station 321 reveals the presence of WGC water with temperatures above 5°C in the "Warm Deep Water" layer, 6.6°C/34.961 PSU at 261 m depth. Being warmer than 7°C and more saline than 35 PSU, station 320 is in the domain of the WGC. Maximum salinities (35.061 PSU) were found at 143 m depth. The bottom layer thermohaline properties were observed as 1.56°C/34.867 PSU at depths of 2 994 m (θ = 1.34°C).

Temperature time series Fyllas Bank station 4

Based upon 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. 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 2004 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. 21). During the 2004 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. A linear trend line, applied to the data of 2 000 m, 2 500 m and 3 000 m depth, reveal significant negative trends. They amount to –0,003 (r = 0.74) at 2 000 m, to -0,002 (r = 0.56) at 2 500 m, and to –0,002 (r = 0.42) at 3 000 m depth. A quadratic polynomial regression applied to the data (Fig. 21, lower panel) observed at 1 500 m depth, yields significant correlation (r^2 = 0.84). 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 2004. 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 it's characteristics north of the Denmark Strait in the Greenland Sea.

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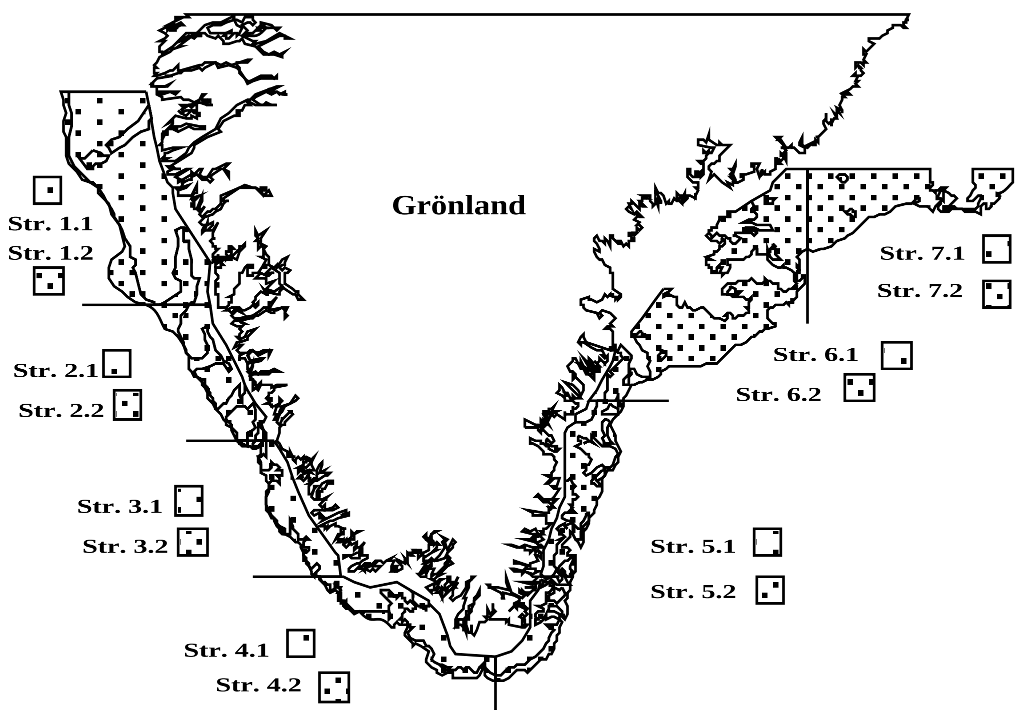

Fig. 1a. Area of investigation during WH 268 (5 October – 18 November 2004), and individual survey strata; strata 0-200 m: 1.1, 2.1, 3.1, 4.1, 5.1, 6.1 and 7.1, and 200-400 m: 1.2, 2.2, 3.2, 4.2, 5.2, 6.2 and 7.2 around Greenland

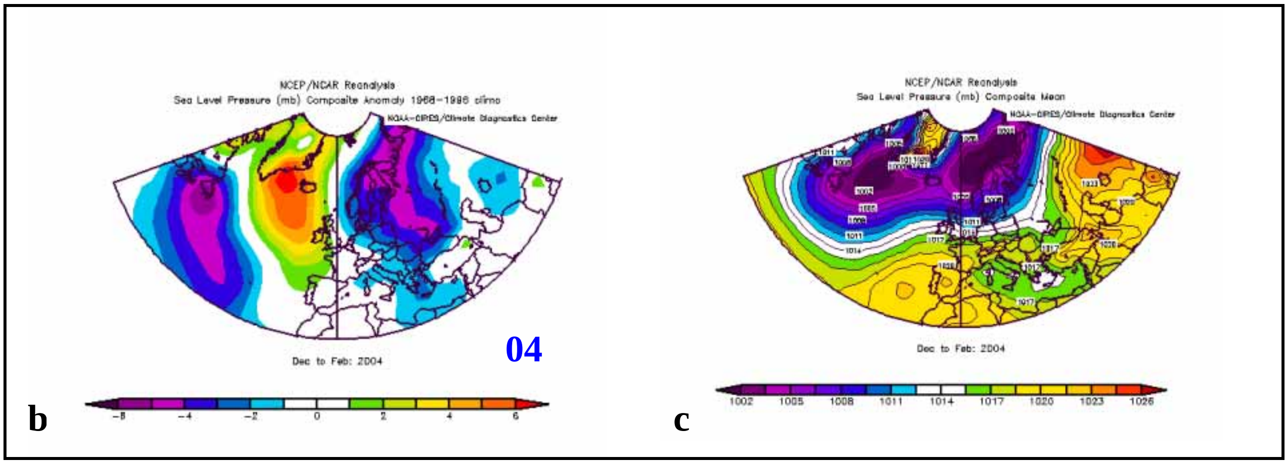

Fig. 1. (b) The pattern of sea level atmospheric pressure anomaly during the winters (December, January, February) of 2003/2004, blue year label denotes negative NAO index and (c) The pattern of sea level atmospheric pressure during the same winter as in Fig. 1b.

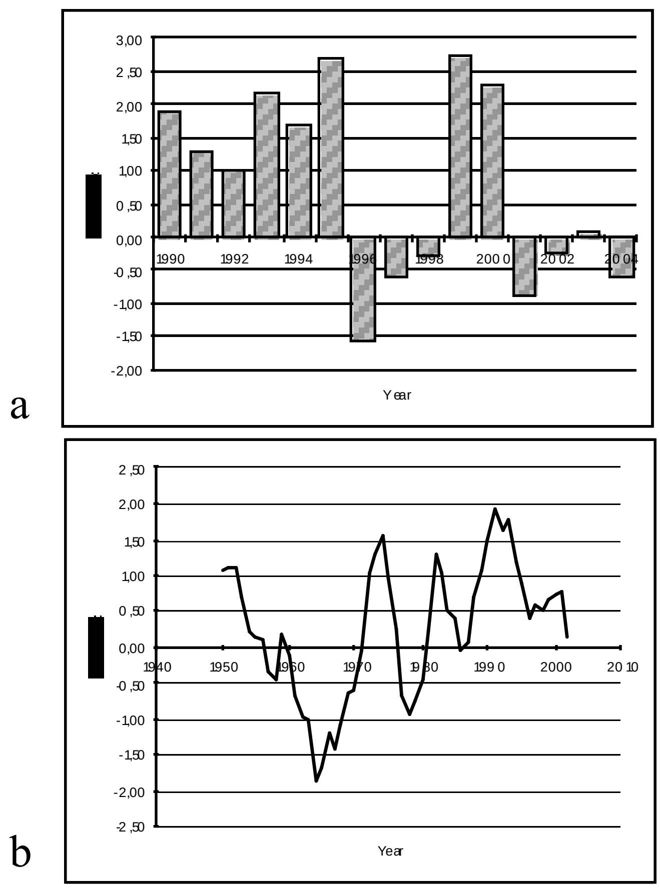

Fig. 2. The winter (DJF) NAO index in terms of the last and present decade (a) and the second half of the last century (lower Fig. b, a 5-year running mean has been applied).

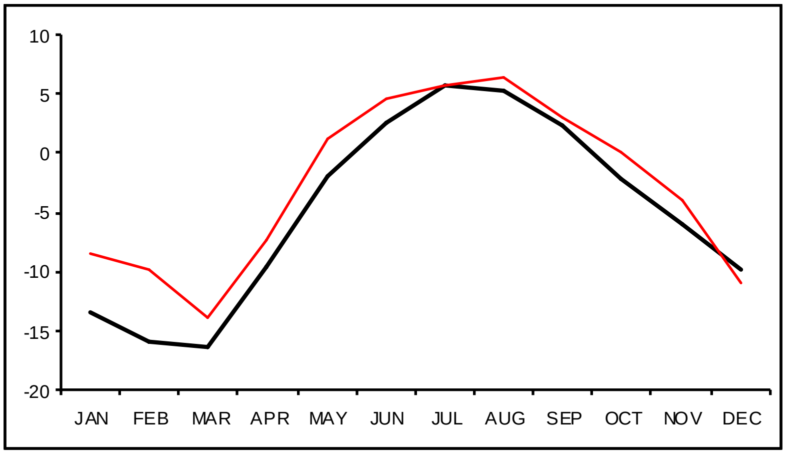

Fig. 3. Monthly mean air temperature [°C] at Egedesminde during 2004 (red, thin line) and climatic mean (1961-1990).

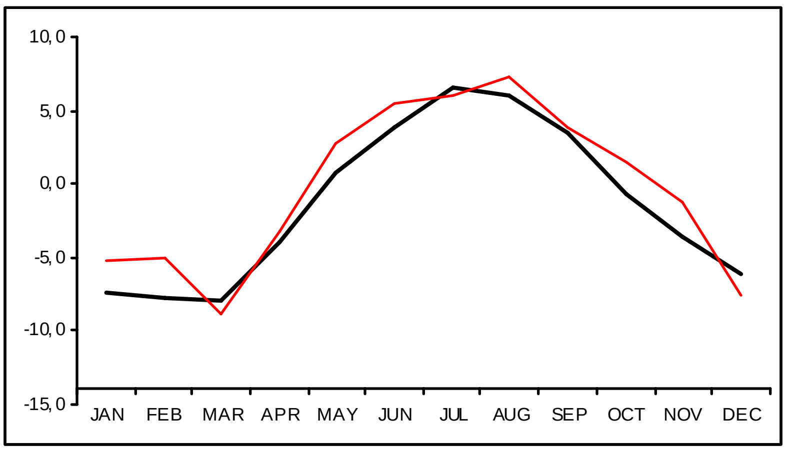

Fig. 4. Monthly mean air temperature [°C] at Nuuk during 2004 (red, thin line) and climatic mean (1961-1990).

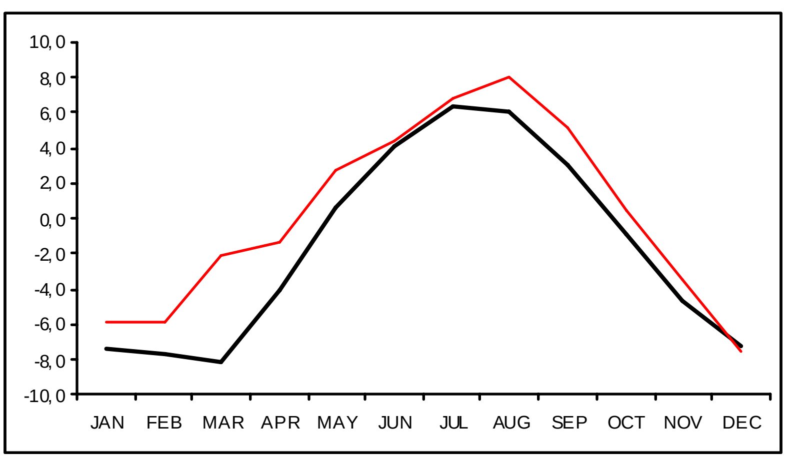

Fig. 5. Monthly mean air temperature [°C] at Angmagssalik during 2004 (red, thin line) and climatic mean (1961-1990).

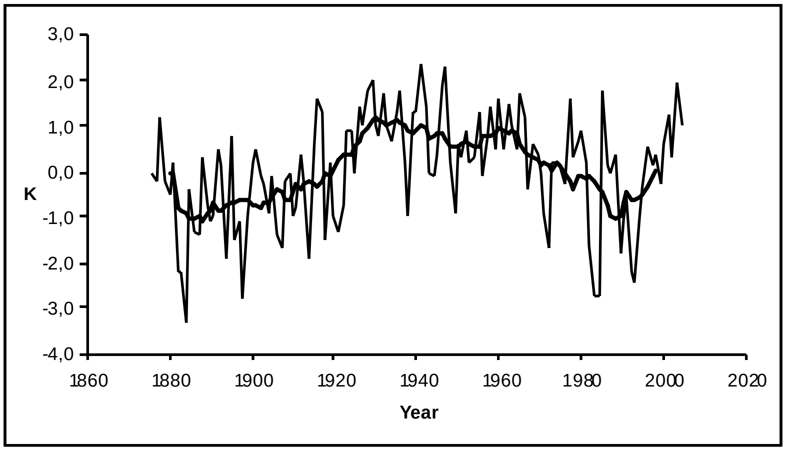

Fig. 6. Time series of annual mean air temperature anomalies at Nuuk (1876-2003, rel. 1961-90), and 13-year running mean.

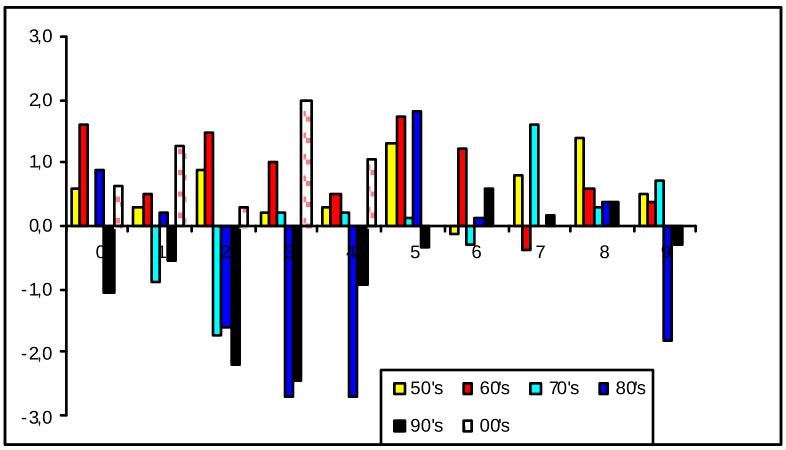

Fig. 7. Composite of decadal air temperature anomalies at Nuuk given relative to the climatic mean of 1961-90 for the decades of the 1950s-1990s and 2000s (dashed column).

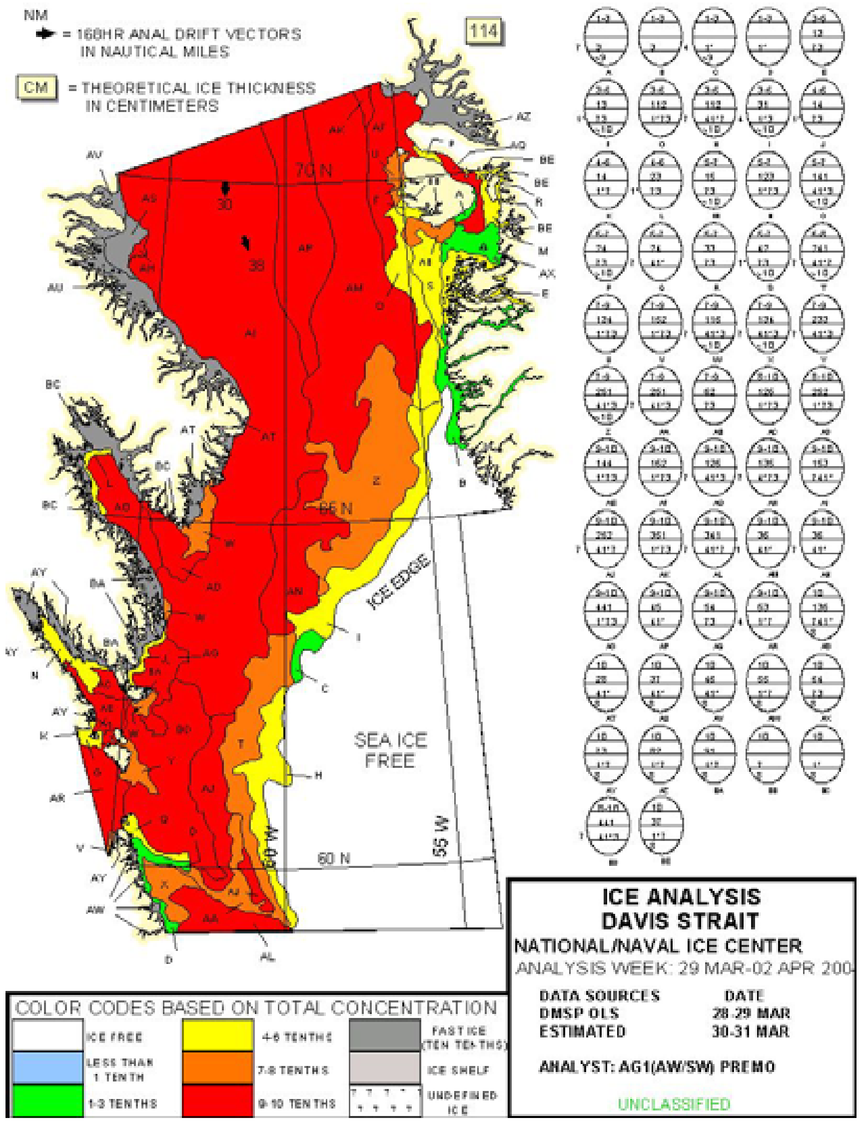

Fig. 8. Ice cover and ice edge during 29 March -02 April 2004 (Davis Strait).

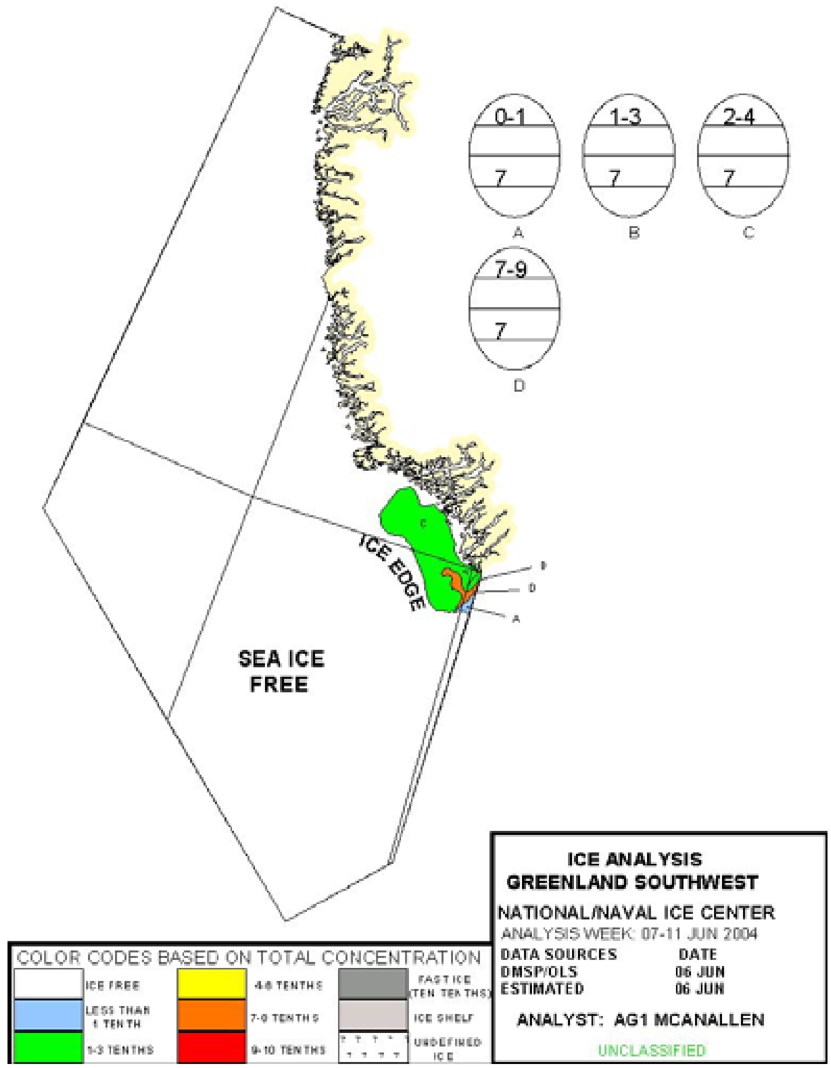

Fig. 9. Ice cover and ice edge during 07-11 June 2004 (Greenland Southwest).

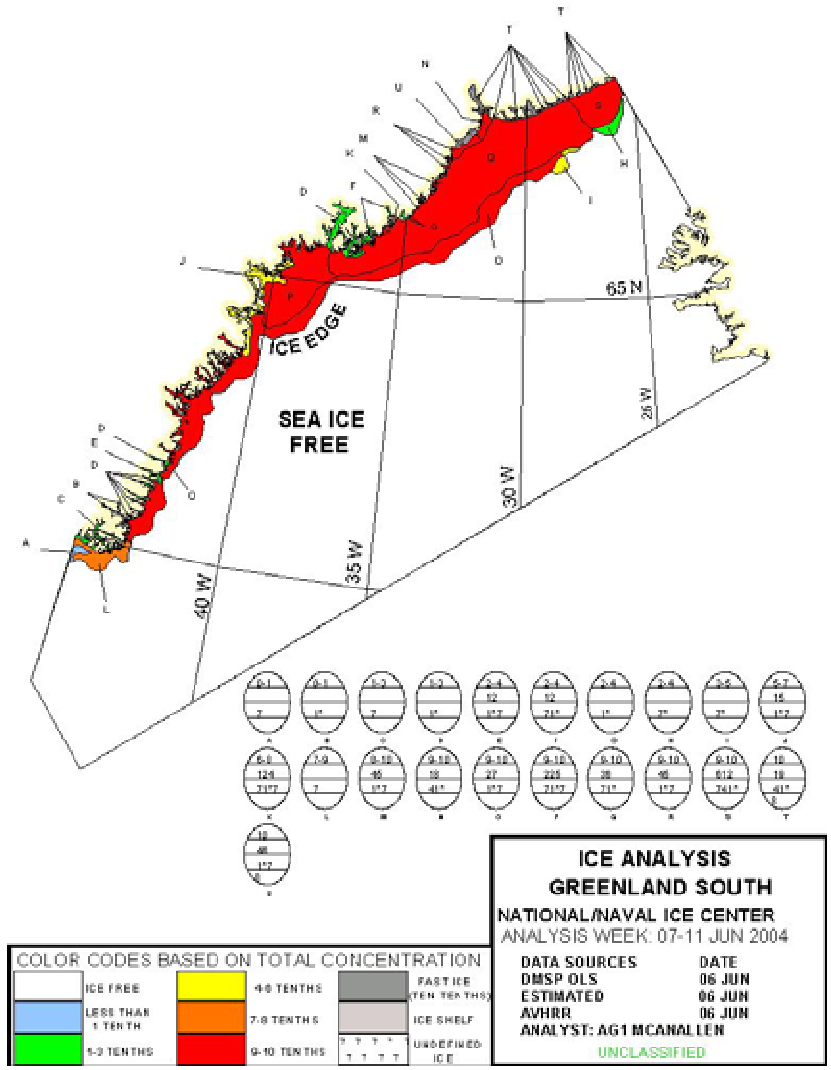

Fig. 10. Ice cover and ice edge during 07-11 June 2004 (Greenland South).

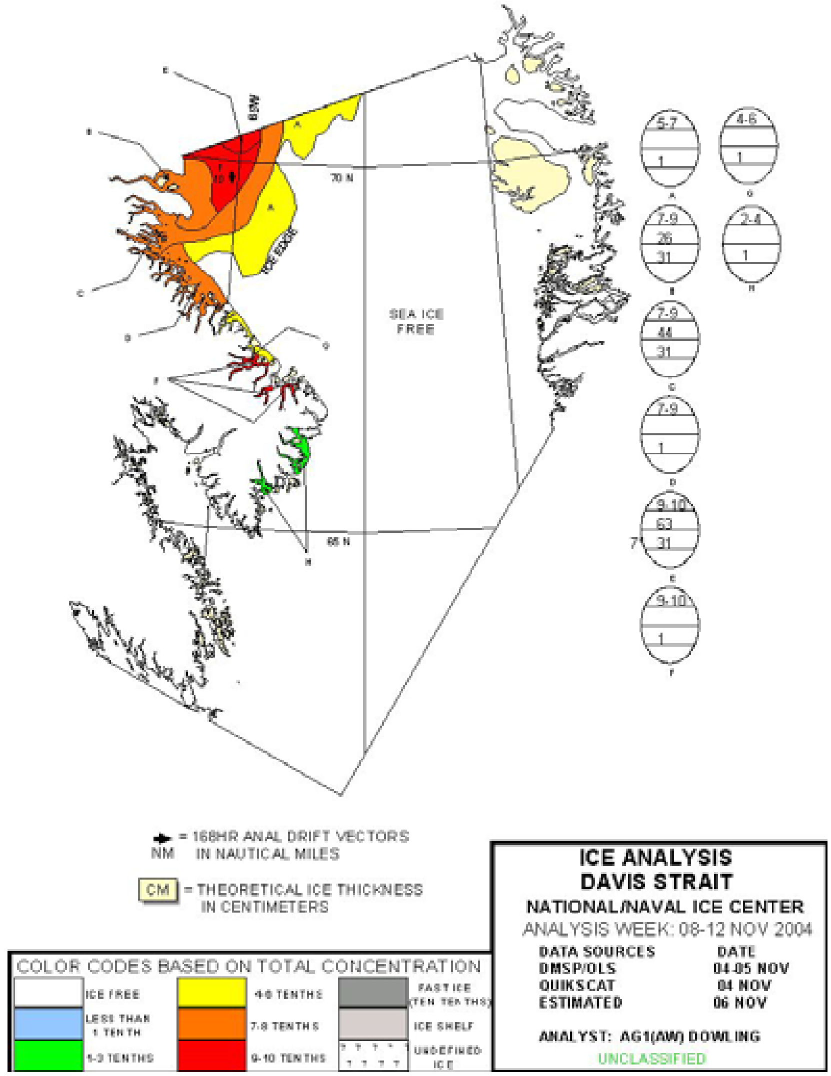

Fig. 11. Ice cover and ice edge during 08-12 November 2004 (Davis Strait).

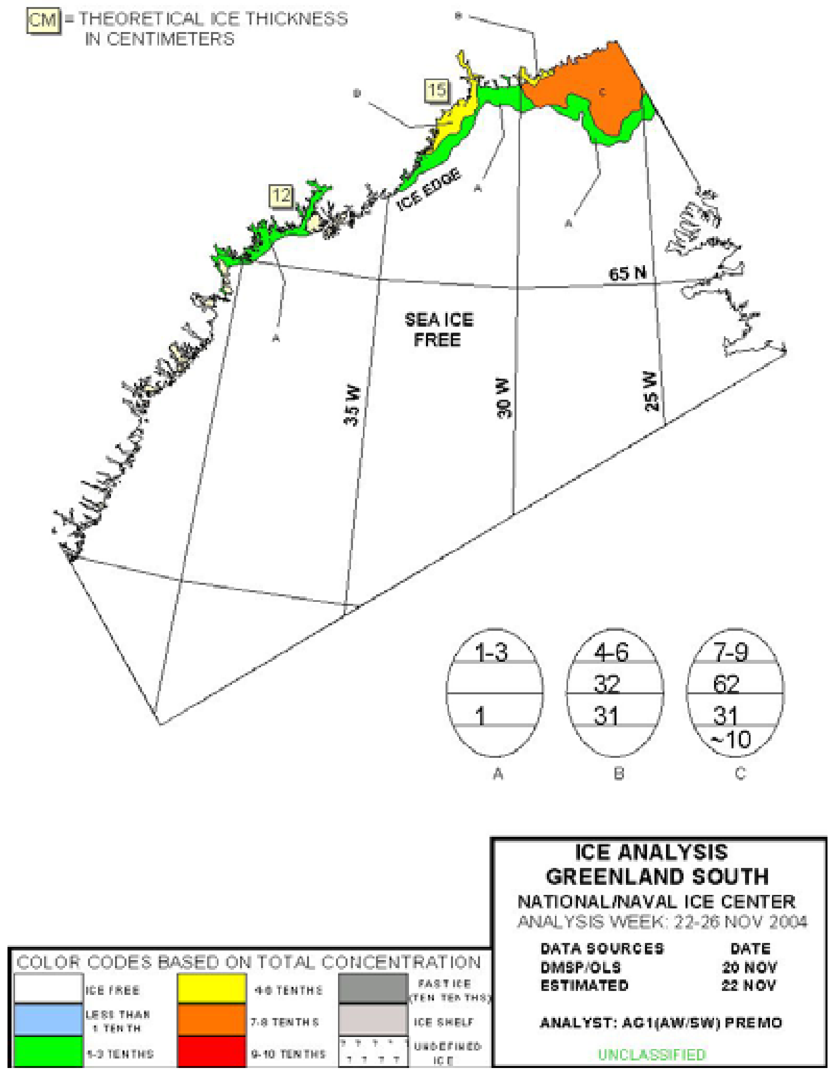

Fig. 12. Ice cover and ice edge during 22-26 November 2004 (Greenland South).

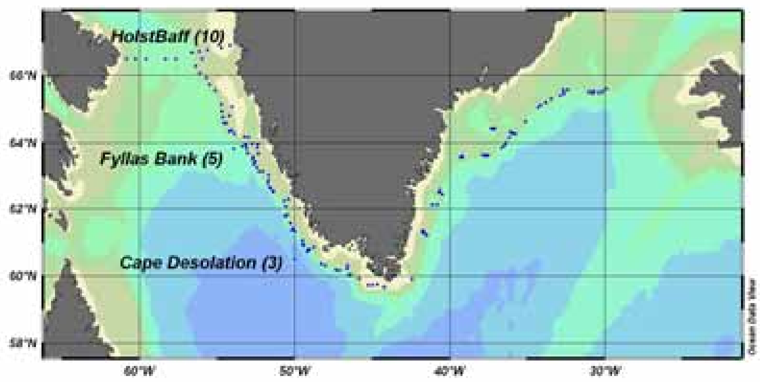

Fig. 13. Positions of fishing stations off East and West Greenland (123), sampled NAFO Standard Sections: Holsteinsborg-Baffin Island (HolstBaff), Fyllas Bank, Cape Desolation; in brackets: No. of stations sampled.

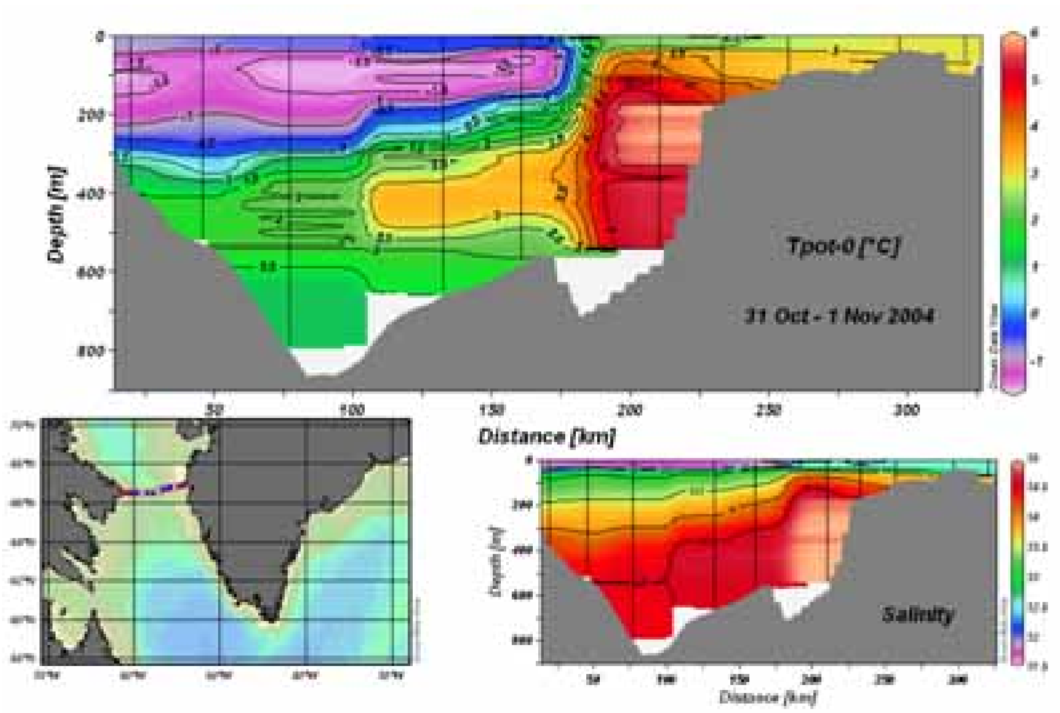

Fig. 14. Vertical distribution of potential temperature and salinity along the Holsteinsborg-Baffin Island section; data: 31 October – 1 November 2004.

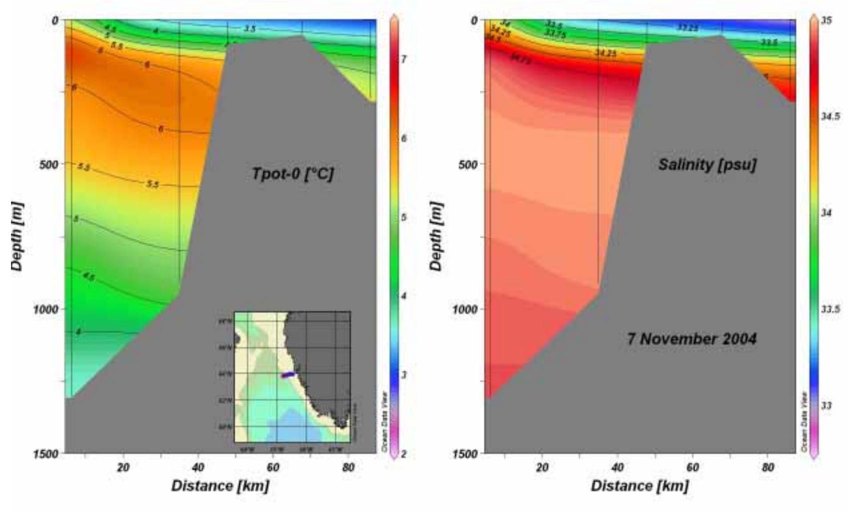

Fig. 15. Potential temperature and salinity along Fylla Bank Section (07 November 2004).

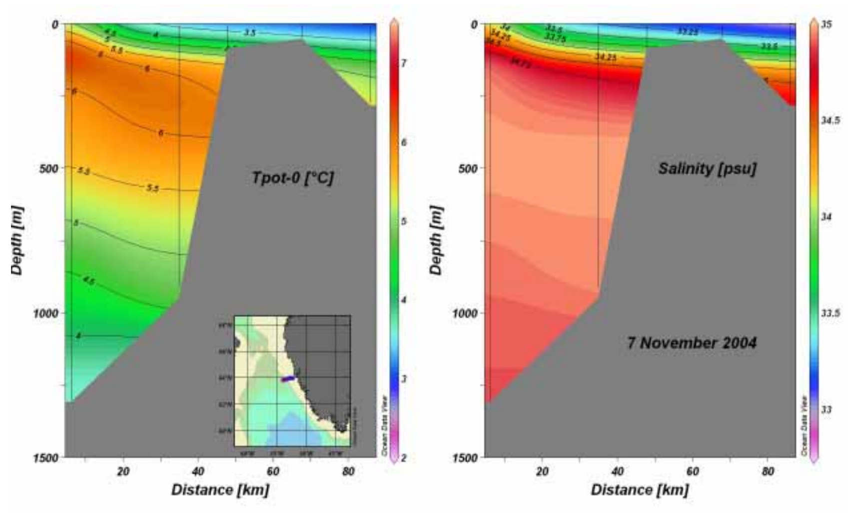

Fig. 16. Potential temperature and salinity along Cape Desolation Section (25 October 2004).

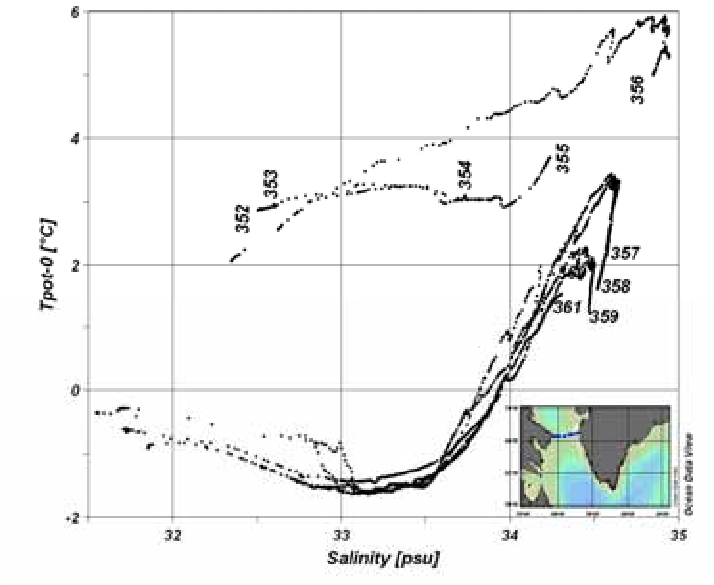

Fig. 17. Theta/S diagram of Holsteinsborg-Baffin Island Section (see Fig. 14).

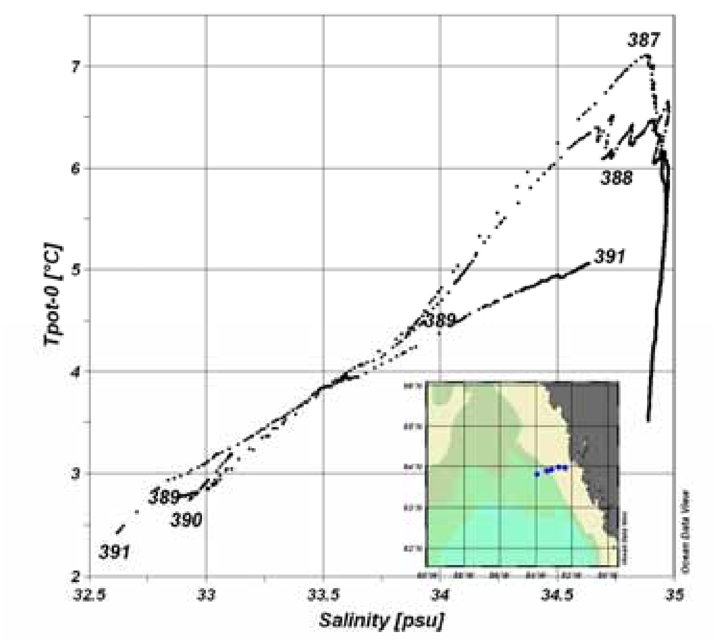

Fig. 18. Theta/S diagram of Fyllas Bank Section (see Fig. 15).

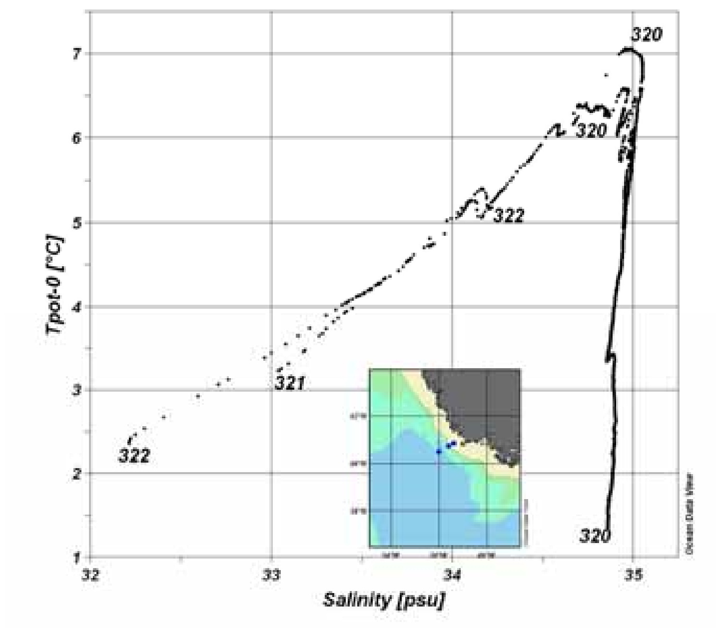

Fig. 19. Theta/S diagram of Cape Desolation Section (see Fig. 16).

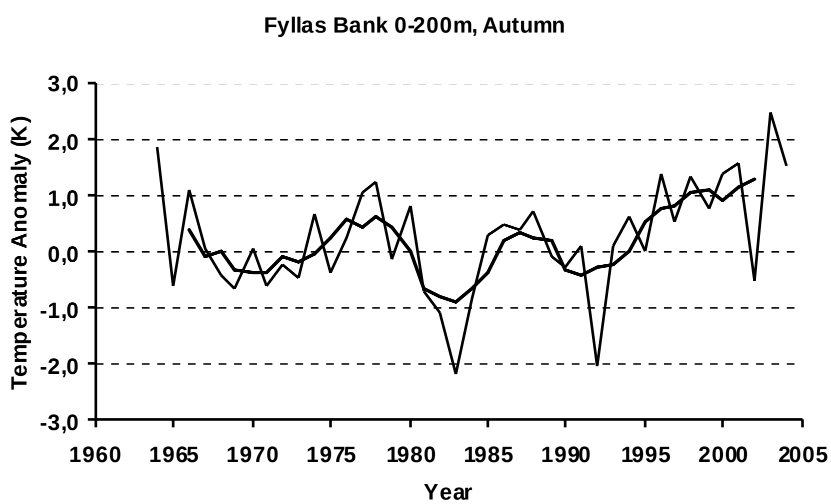

Fig. 20. Mean water temperature anomalies of layer 0-200 m at station 4 of the Fyllas Bank Section during autumn; data: 1964-2004 (thin), 5 yr r.m. (bold); (base period: 1964-1990).

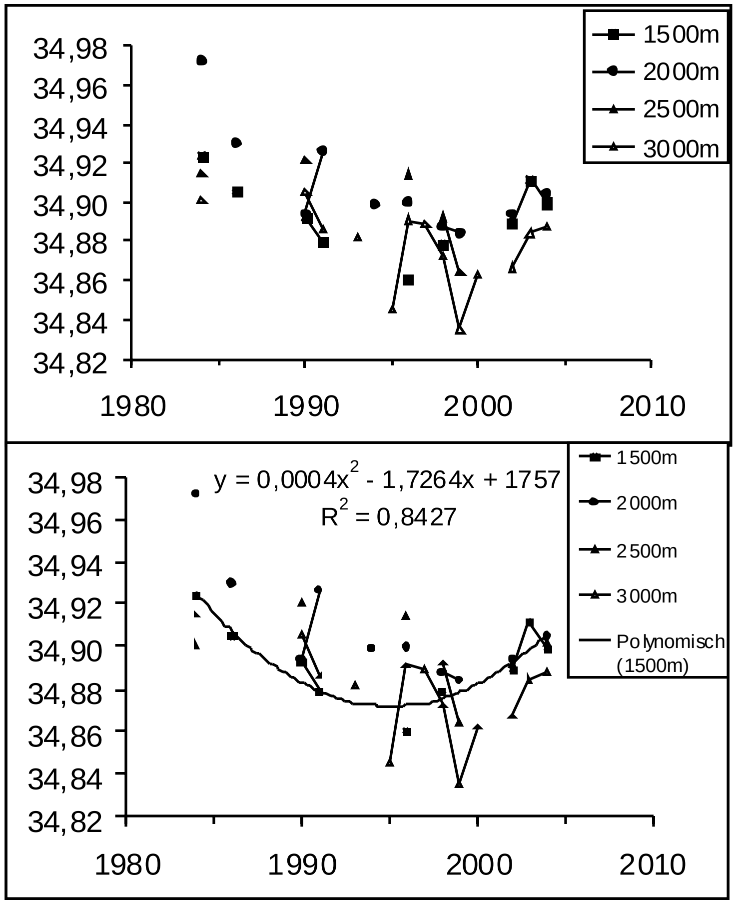

Fig. 21. Salinity of **calibration samples** at Cape Desolation Section station 3 (60°28’N, 50° 00’W; data: 1984 - 2004).