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Climatic Conditions Around Greenland - 2006

by

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic during winter 2005/2006 indicated a positive pressure anomaly cell stretching from Barents Sea in the east to the south of Greenland, and a weak negative anomaly cell in the Azores High area. As a consequence of this anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2005/2006 was positive (+0.50). 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 2006 with mean air temperatures at Nuuk indicating positive anomalies (+1.2K).

Based on satellite derived ice charts for all months of 2006 it is shown that winter sea ice conditions were favourable during 2006 off West Greenland.

At Fyllas Bank, subsurface warming during 2006 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 0-200m is 2.87°C. Temperature measurements along the Holsteinsborg-Baffin Island Section reveal warming of the northward flowing West Greenland Current (WGC) at depths of 200m-600m by 1K, when compared to measurements obtained a month earlier by the US RV"Knorr". Current speeds of the northward flowing WGC amount to >30 cm/sec, whereas the southward flowing Baffin Current has core velocities around 20 cm/sec. Calibration samples from the deep water station Cape Desolation 3 (3000m depth) off southwest Greenland reveal harmonic oscillation signals which are most expressed at the 1500m depth level (r^2 = 0.87). At 3000m depth, in the domain of the Denmark Strait Overflow water mass, the harmonic signal is weaker, and it explains 38% 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 2006 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 fifteenth 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 2005/2006 (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 (Figs. 3–7). The climatic mean which the air temperature anomaly charts are referenced to is 1961-1990.

Sea surface temperature data for the region between Greenland and Labrador were taken from the IGOSS Data Base http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS . The climatology is referenced to 1971-2000 (Figs. 13, 14).

Ice charts (Figs. 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 WH293 of FRV "Walther Herwig III", CTD profiles were obtained at each fishing position of the surveyed area (Figs. 1 and 15). Observations on Standard Oceanographic Stations (Stein, 1988) were done at the Cape Desolation Section, the Fyllas Bank Section and along the Holsteinsborg-Baffin Island Section (Figs. 16, 17 - 25). Salinity readings of the CTD (SeaBird 911+) profiles were adjusted to water samples derived by Rosette water sampler. Theta/S sections of Cape Desolation Section and Holsteinborg-Baffin Island Section are displayed in Figs. 16, 19 - 20. Time series of temperature anomaly at Fyllas Bank station 4 is given in Fig. 17. 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. 23 - 25. Data analysis and presentation (Figs. 16, 19 - 22) was done using the most recent version of Ocean Data View (Version 3.2.0, 2006; Schlitzer, 2006), including the geostrophic estimates. Where observed depths for adjacent stations did not match, data were interpolated to a set of common depths (ODV uses piecewise linear least squares for the interpolation on a predefined set of standard depths). Dynamic heights at the standard depths were then calculated and the geostrophic velocities between station pairs (at the standard depths) were obtained. Oxygen profile measurements were obtained with the Seabird SBE 43 sensor. Oxygen data are given in [ml/l], and [% saturation]. Turbidity measurements were done with the Seapoint Turbidity sensor which was mounted to the Seabird CTD. The Seapoint Turbidity Meter detects light scattered by particles suspended in water, generating an output voltage proportional to turbidity or suspended solids. The light source wavelength is 880 nm. The sensor was not calibrated against any particles.

Results and Discussion

Fig. 1 shows the area of investigation during cruise WH293. Starting off East Greenland in the Dohrn Bank region (stratum 7) on 20 October 2006, FRV "Walther Herwig III" went southwards along the East Greenland shelf and slope to complete bottom trawl fishing and CTD/Rosette work in stratum 6. Due to adverse weather condition, stratum 5 could not be sampled during autumn 2006. From 27 October onwards, the ship worked in West Greenland waters, doing bottom trawl fishing and CTD/Rosette work, as well as CTD/Rosette observations along oceanographic sections. On 13 November 2006, FRV "Walther Herwig III" left Nuuk and made her way back to Bremerhaven where the cruise was finished on 22 November 2006.

The North Atlantic Oscillation (NAO)

Fig. 1b shows the pattern of sea level pressure anomalies over the North Atlantic during the winter of 2005/2006 (DJF). There was no similar pressure pattern recorded during past winters from 1989/90 onwards (Stein, 2003).
The pattern of sea level atmospheric pressure over the North Atlantic during winter 2005/2006 indicated a positive pressure anomaly cell stretching from Barents Sea in the east to the south of Greenland in the west, and a weak negative anomaly cell in the Azores High area. As a consequence of this anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2005/2006 was positive (+0.50). The sea level atmospheric pressure over the North Atlantic during winter 2005/2006 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 2005/2006 (December-February) is positive (+0.50).

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 2006 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 2005/2006 is among the weak positive values during the past 16 years (Fig. 2a), and the annual mean air temperatures are among the highest values observed during 1876-2006 (see below).

Air Temperature and Climatic means

During 2006, January was the coldest month off West Greenland. While at Egedesminde (Fig. 3) temperatures – except for November - were above normal, the Nuuk air temperatures reveal colder-than-normal conditions during January and November.
Except for July and November, Angmagssalik (Fig. 5) experienced climatic conditions which were at or above the climatic mean throughout the year.

Climatic Variability off West Greenland

The annual mean air temperature anomaly calculated for 2006 is 1.2K (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.

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. 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". The year 2005 (+1.6K) is in a similar range as the years 1955 (+1.3K), 1965 (+1.7K) and 1985 (+1.8K). The year 2006 (+1.2K) is in the same range as the year 1966 (+1.2K) and thus another warmer-than-normal year at Nuuk.

Ice Conditions around Greenland

Winter sea ice conditions were favourable during 2006 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 mid-January off Maniitsoq/Sukkertoppen (Fig. 8), one and a half month earlier than during 2005. Multi-year sea ice, coming from the Arctic Ocean via the East Greenland current to the Cape Farewell area, is called "Storis". During early-July, the East Greenland coast was surrounded by sea ice with concentrations ranging from 3-10 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 third decade of November (Fig. 11) when 3-10 tenth of ice concentration was observed north off Baffin Island. This was two weeks later than during 2005. Off East Greenland first sea ice formation was only encountered in the Angmagssalik area and to the north at Storfjord Deep during the first decade of October (Fig. 12). Due to these favourite ice conditions the cruise WH293 of FRV "Walther Herwig III" to East and West Greenland waters in October/November 2006 was not affected by any sea ice.

Sea Surface Temperature (SST) Observations off Greenland and in the Labrador Sea

The SST anomaly data as given in Figs. 13 and 14 reveal anomalous warm conditions off Greenland and in the Labrador Sea throughout all months of 2006. Maximum warming exceeded 3 K during July (Fig. 14), least warming occurred in December when SSTs were 1.5 K warmer-than-normal.

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 (station 4), Cape Desolation and along the Holsteinsborg-Baffin Island Section (Fig. 15) are given in Figs. 16 to 25.

Cape Desolation Section

The Cape Desolation Section station 3 is in the domain of the WGC-core and reveals temperatures (salinities) of 5.61°C (34.967 psu) at 119m depth during 29 October 2006 (Fig. 16). At depths of 2991m potential temperature of 1.51°C was calculated (*in situ* temperature / salinity: 1.88°C / 34.902 psu).

Fyllas Bank Section

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. 17). 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 200m of the water column. This happened during autumn 1983, 1992 and 2002, and these events will be called here "polar events". Due to time constraints during autumn 2006, only station 4 of the section could be sampled (Fig. 17). Mean temperature of the upper layer 0-200m again indicates cooling after 2003 which was the record warm year in the entire time series. However, being 1.28 K warmer-than-normal, the thermal conditions off Fyllas Bank still indicate similar warm conditions as in the 1960s. Normal for the layer 0-200m is 2.87°C.

Holsteinsborg-Baffin Island Section

The Holsteinsborg-Baffin Island Section which was done by FRV "Walther Herwig III" during 5 - 6 November 2006, crosses the above mentioned two salient features in the vertical distribution of temperature which characterize the hydrographic properties between Greenland and Baffin Island (Fig. 18): The Baffin Island Current and the core of the West Greenland Current (WGC). A month previous to our measurements, the US RV "Knorr" run a similar section along 66° 15'N. Both potential temperature recordings are given in Fig. 19. On the eastern side of the section, the West Greenland Current flows along the shelf break and transports heat (core temperatures > 5.8°C) into the Baffin Bay. According to the US and German results, there is warming in the West Greenland Current core between early-October 2006 and early-November 2006, which amounted to about 1 K. On the western side of the section, the cold Baffin Island Current characterizes the thermal fields of the upper ocean. Whereas the US data indicate minimum temperatures of -1.62 °C, our data yield minimum temperatures of -1.56 °C. During the 2006 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, between stations HUDSON 3 and 4 (c.f. Fig. 18), a remnant of 3°C warm water is visible (Fig. 19). A month prior to our observations, RV "Knorr" of the US observed a sub-surface patch of warm water at this location which had similar thermohaline properties.

Our data were also analysed for geostrophic current components (Fig. 22, lower panel). According to the geostrophic calculation method, the current components are computed for the intermediate point of a station pair. Consequently, this results in only 9 stations which the section presentation is then based upon (Figs. 20 – 22). This explains the slightly different outline of the thermal fields as given in Figs. 19 (lower panel), and Fig. 20 (upper panel). Salinity (lower panel of Fig. 20) reveals a near-surface thin layer of low saline water (< 32 psu) on the western side of the section, and < 32.25 psu water on the eastern side. In the WGC-core at the West Greenland slope, salinities are around 34.92 psu. Oxygen distribution (Fig. 21) reveals highly oxygenated conditions throughout the water column. Only at depths below 600m oxygen values decrease to 5 ml/l (upper panel) and less than 65% oxygen saturation. The measurements done with the turbidity sensor (Fig. 22, upper panel) reveal clear water on top of Davis Strait sill. On the West Greenland shelf and slope there are increased turbidity values which might point at sediments stirred up by bottom near currents.

Compared to mean autumn conditions, the temperatures in the WGC-core and on the West Greenland shelf as measured during autumn 2006, are up to 2K warmer-than-normal.

Calibration samples

Data on calibration samples taken at CD3, reveal freshening in deep water layers from 1984 onwards (Figs. 24 and 25). During the 2006 cruise, calibration samples were obtained at 500m, 1000m, 1500m, 2000m, 2500m and 3000m depth. Model (1) adjusted to the data of 1500m, 2000m and 3000m depth, reveals significant harmonic trends.

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

They explain 87% of variation at 1500m depth (Fig. 23), 80% at 2000m depth (Fig. 24) and 38% at 3000m depth (Fig. 25). It is suggested here that the values at 1500m depth represent climatic changes in the Labrador Sea throughout the time of the 1980s to 2006. At 2000m 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 (DSOW). It would appear that the salinity at this depth (3000m) points at freshening of this water mass, which obtains its characteristics north of the Denmark Strait in the Greenland Sea. Since 2003, data suggest increasing salinities in the bottom water layer at Cape Desolation Station 3. This might be a consequence of previous warming and increasing salinities upstream in the Greenland Sea (Osterhus and Gammelsrod, 1999; Walter, 2004).

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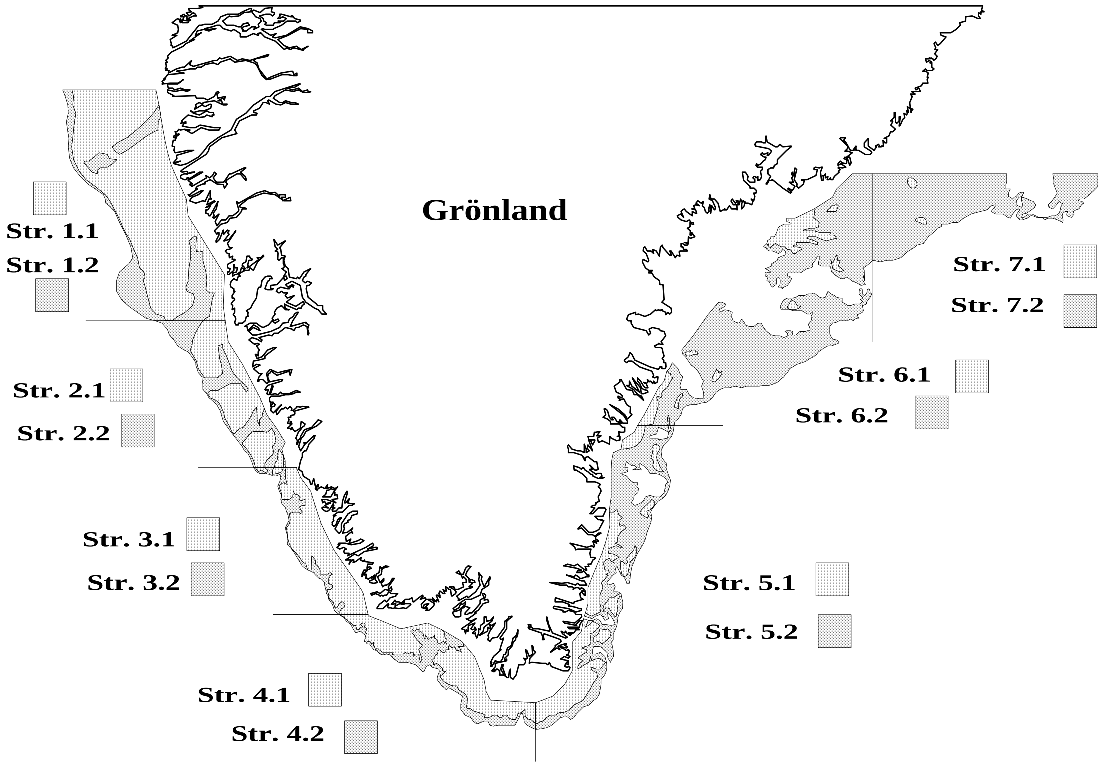


Fig. 1a Area of investigation during WH 293 (12 October – 24 November 2006), and individual survey strata; strata 0-200m: 1.1, 2.1, 3.1, 4.1, 5.1, 6.1 and 7.1, and 200-400m: 1.2, 2.2, 3.2, 4.2, 5.2, 6.2 and 7.2 around Greenland

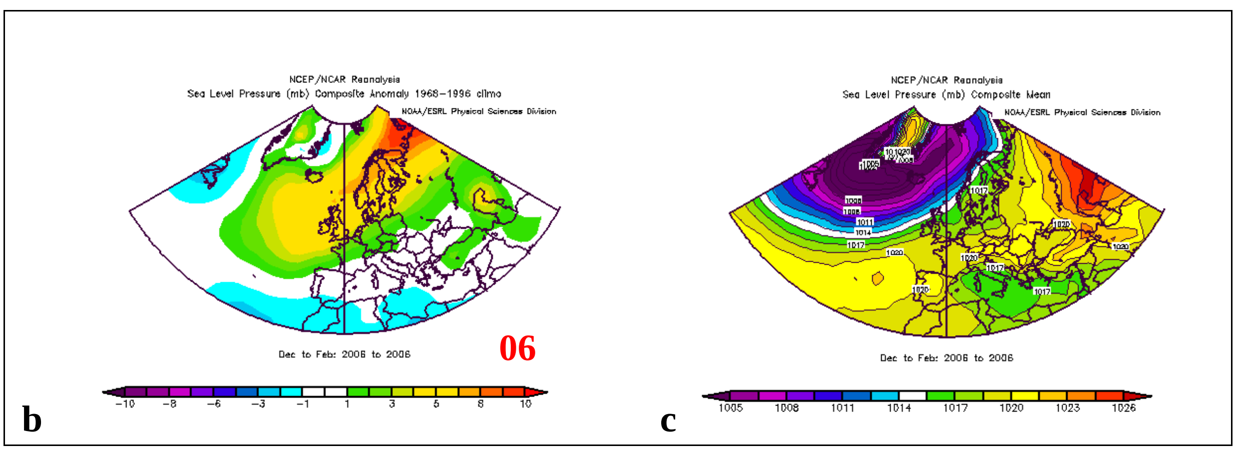
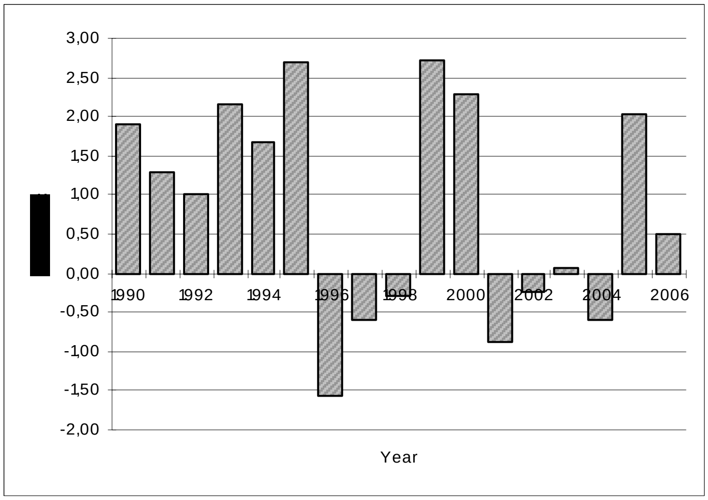


Fig. 1b The pattern of sea level atmospheric pressure anomaly during the winters (December, January, February) of 2005/2006, *red year label denotes positive NAO index.*

Fig. 1c The pattern of sea level atmospheric pressure during the same winter as in Fig. 1b.

a



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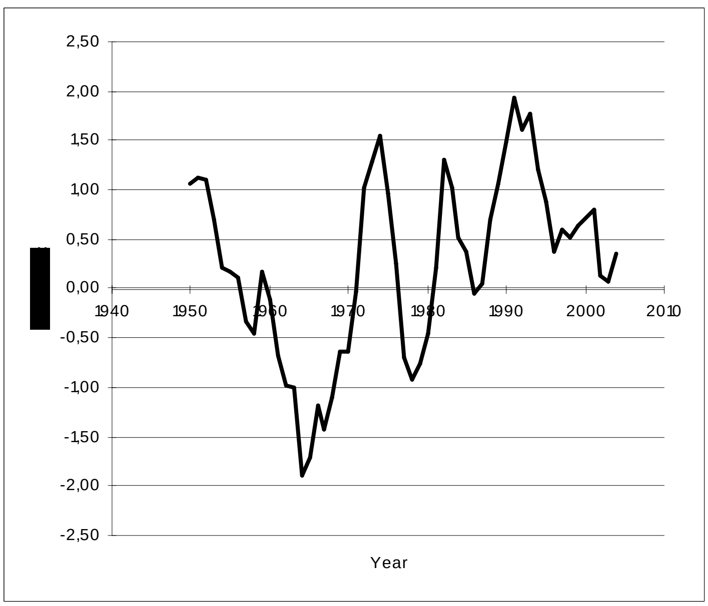


Fig. 2. The winter (DJF) NAO index in terms of the last and present decade (a), and the second half of the last century (lower figure b, a 5 year running mean has been applied)

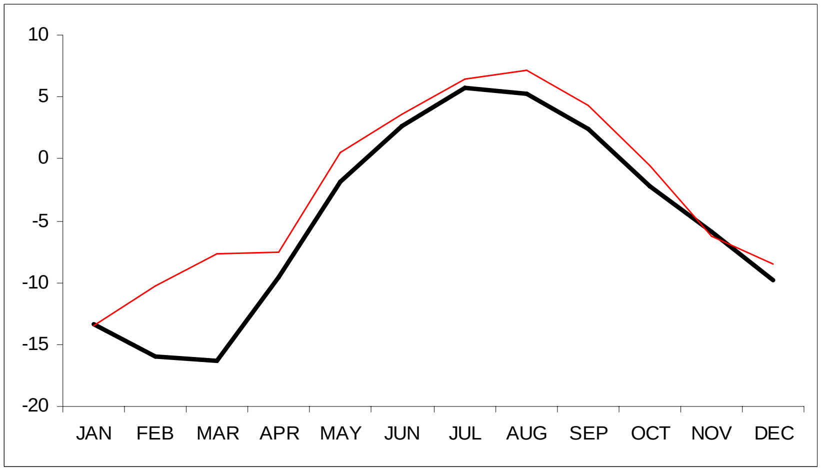


Fig. 3 Monthly mean air temperature [°C] at Egedesminde during 2006 (red, thin line) and climatic mean (1961-1990)

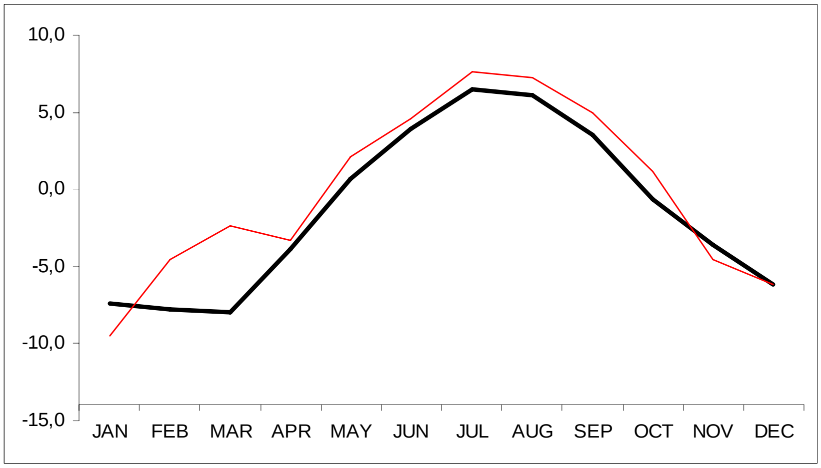


Fig. 4 Monthly mean air temperature [°C] at Nuuk during 2006 (red, thin line) and climatic mean (1961-1990)

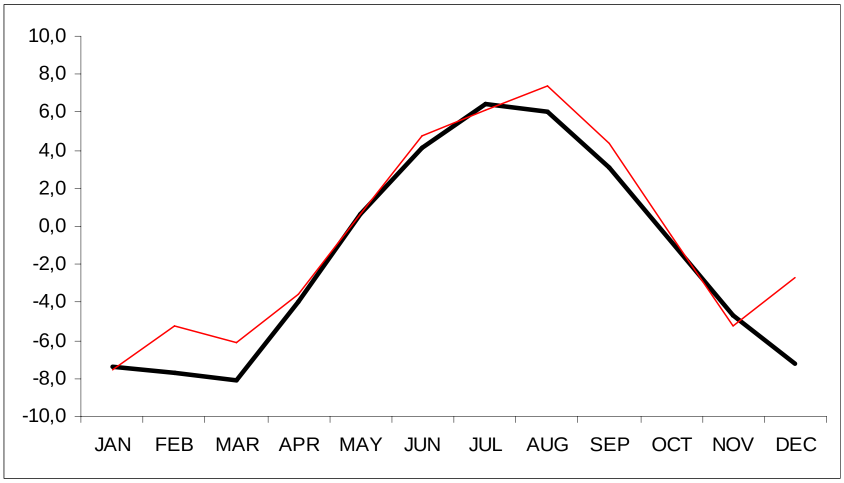


Fig. 5 Monthly mean air temperature [°C] at Angmagssalik during 2006 (red, thin line) and climatic mean (1961-1990)

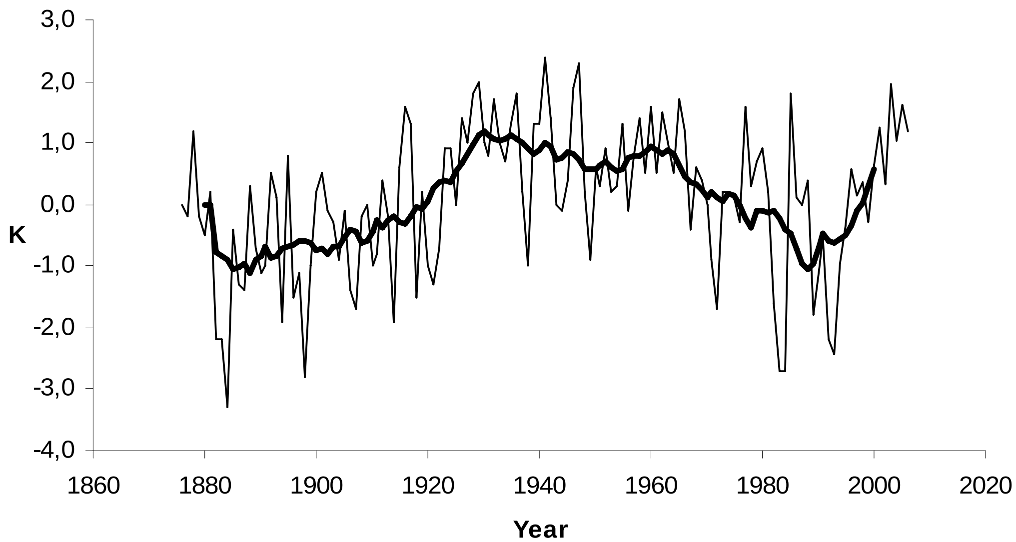


Fig. 6 Time series of annual mean air temperature anomalies at Nuuk (1876-2006, rel. 1961-90), and 13 year running mean

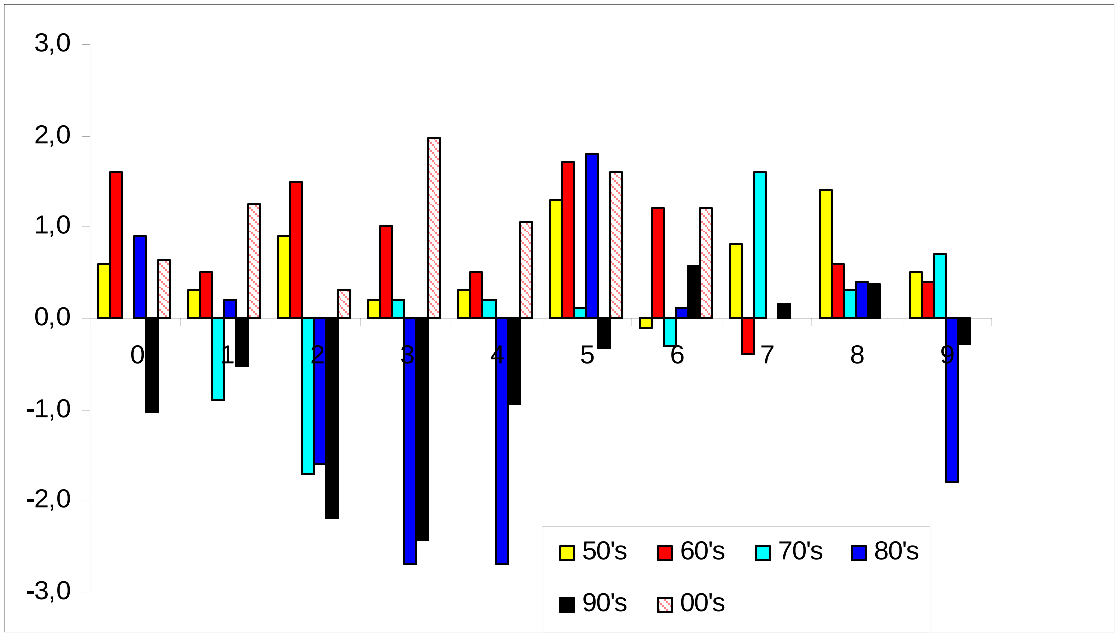


Fig. 7 Composite of decadal air temperature anomalies at Nuuk given relative to the climatic mean of 1961-90 for the decades of the 1950s - 1990s and 2000s (dashed column)

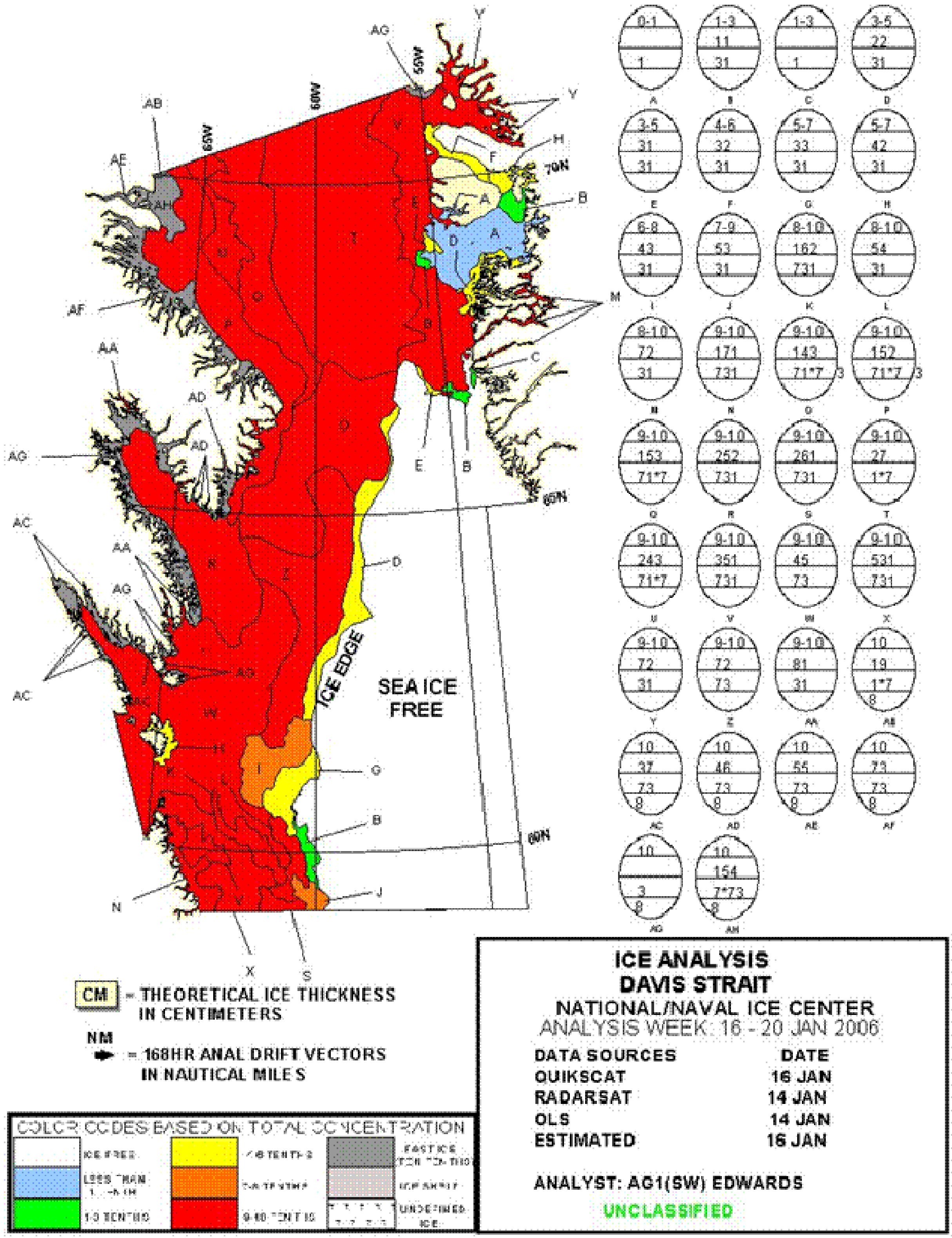


Fig. 8 Ice cover and ice edge during 16 - 20 January 2006 (Davis Strait)

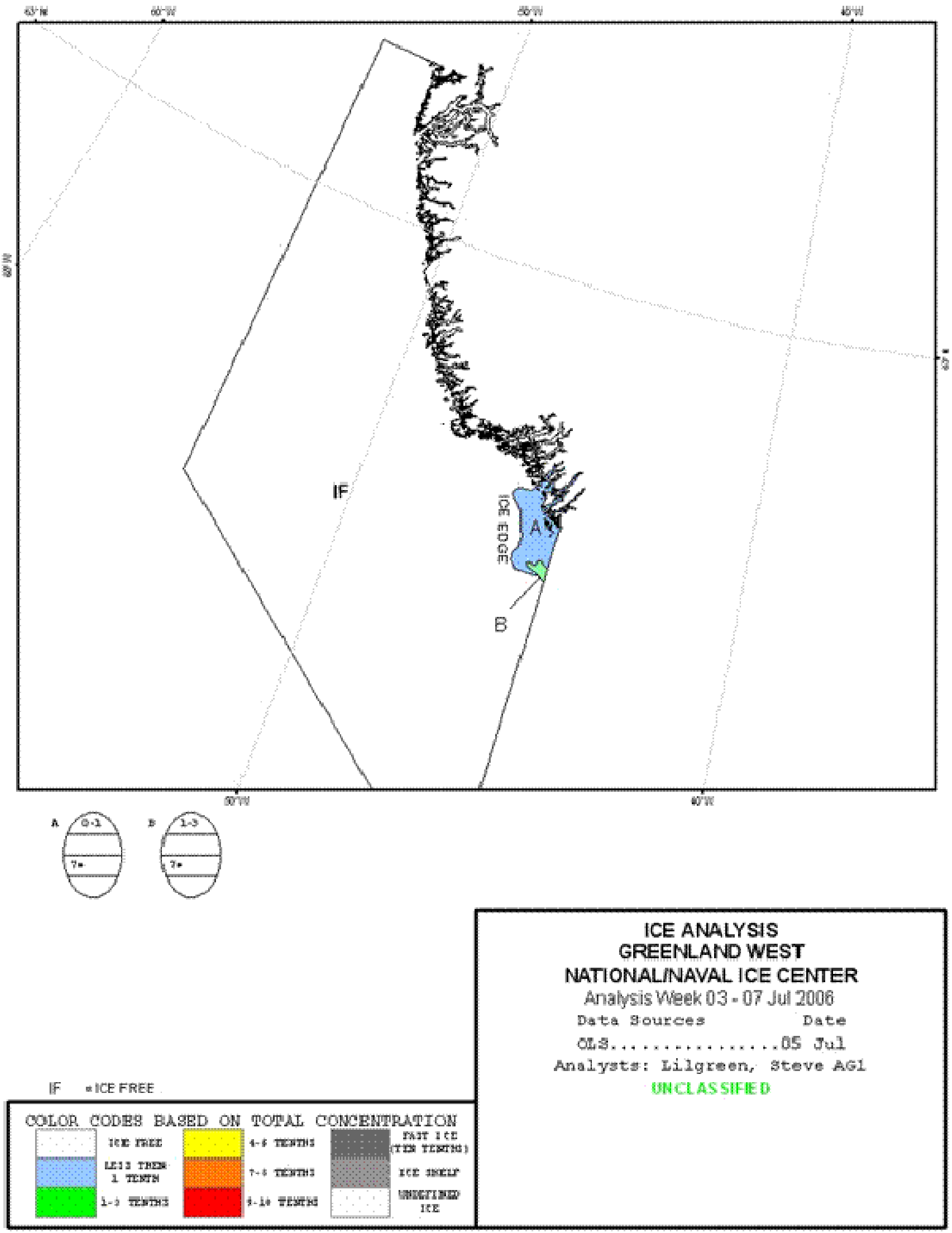


Fig. 9 Ice cover and ice edge during 03- 07 July 2006 (Greenland Southwest)

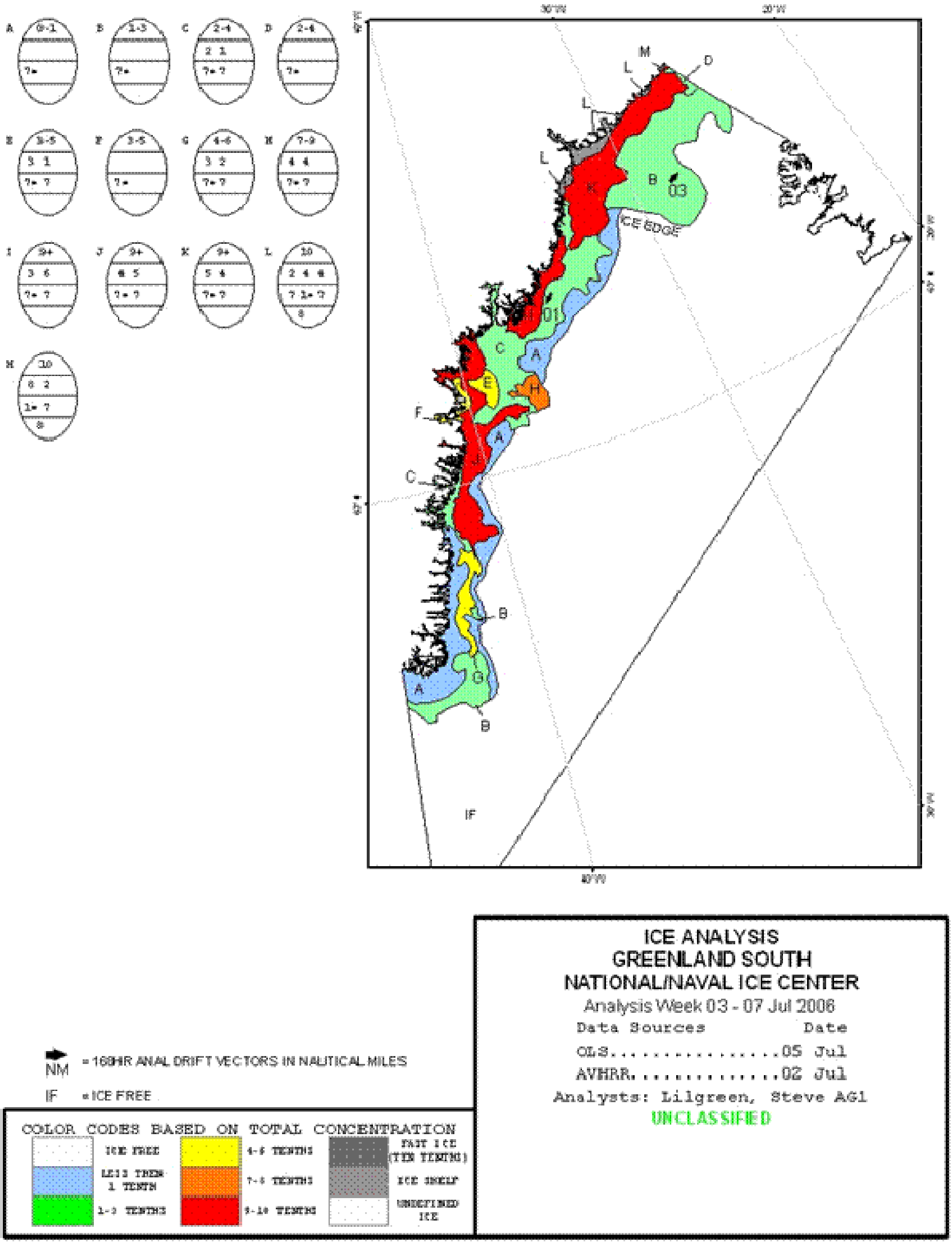


Fig. 10 Ice cover and ice edge during 03- 07 July 2006 (Greenland South)

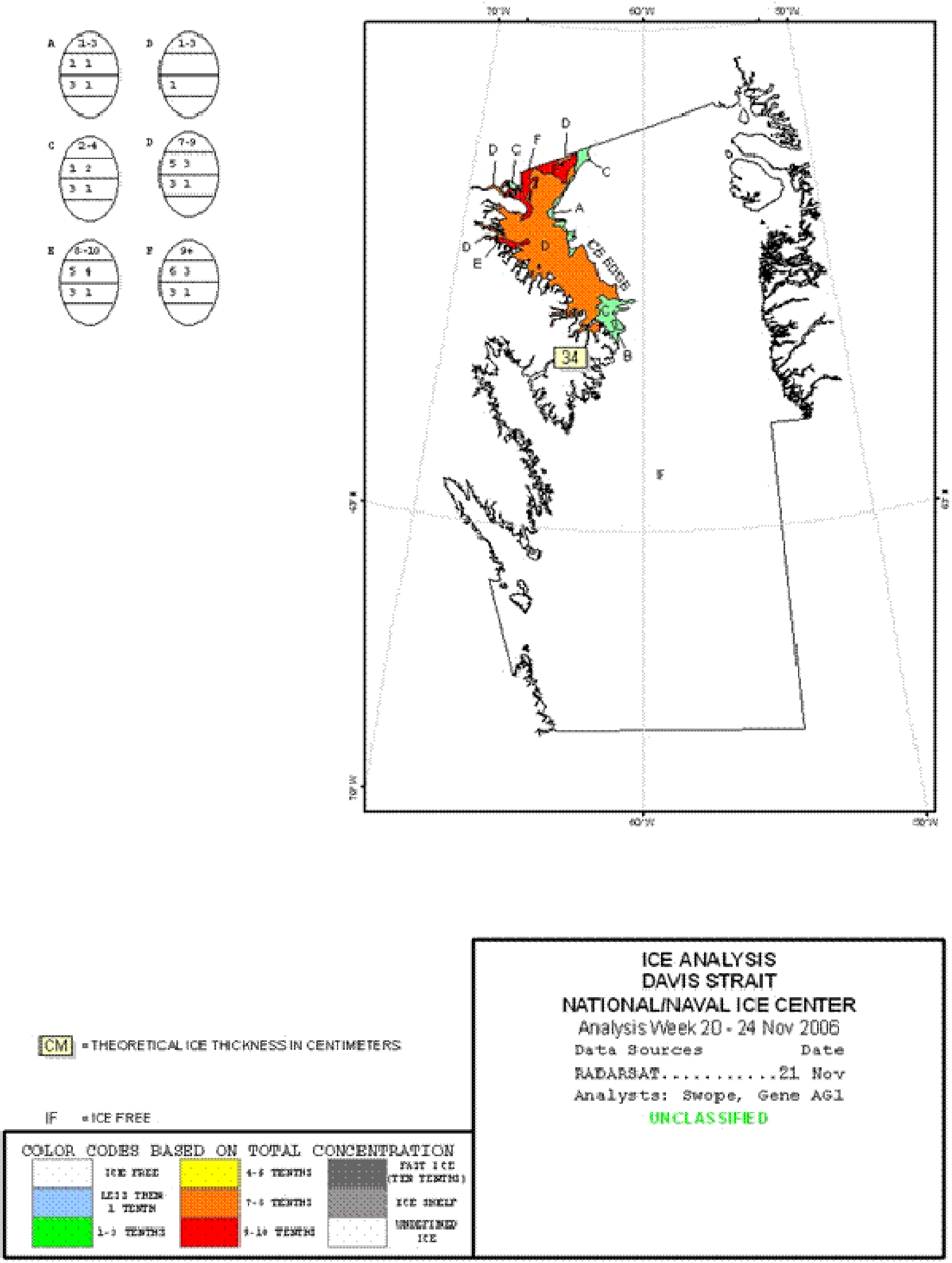


Fig. 11 Ice cover and ice edge during 20 -24 November 2006 (Davis Strait)

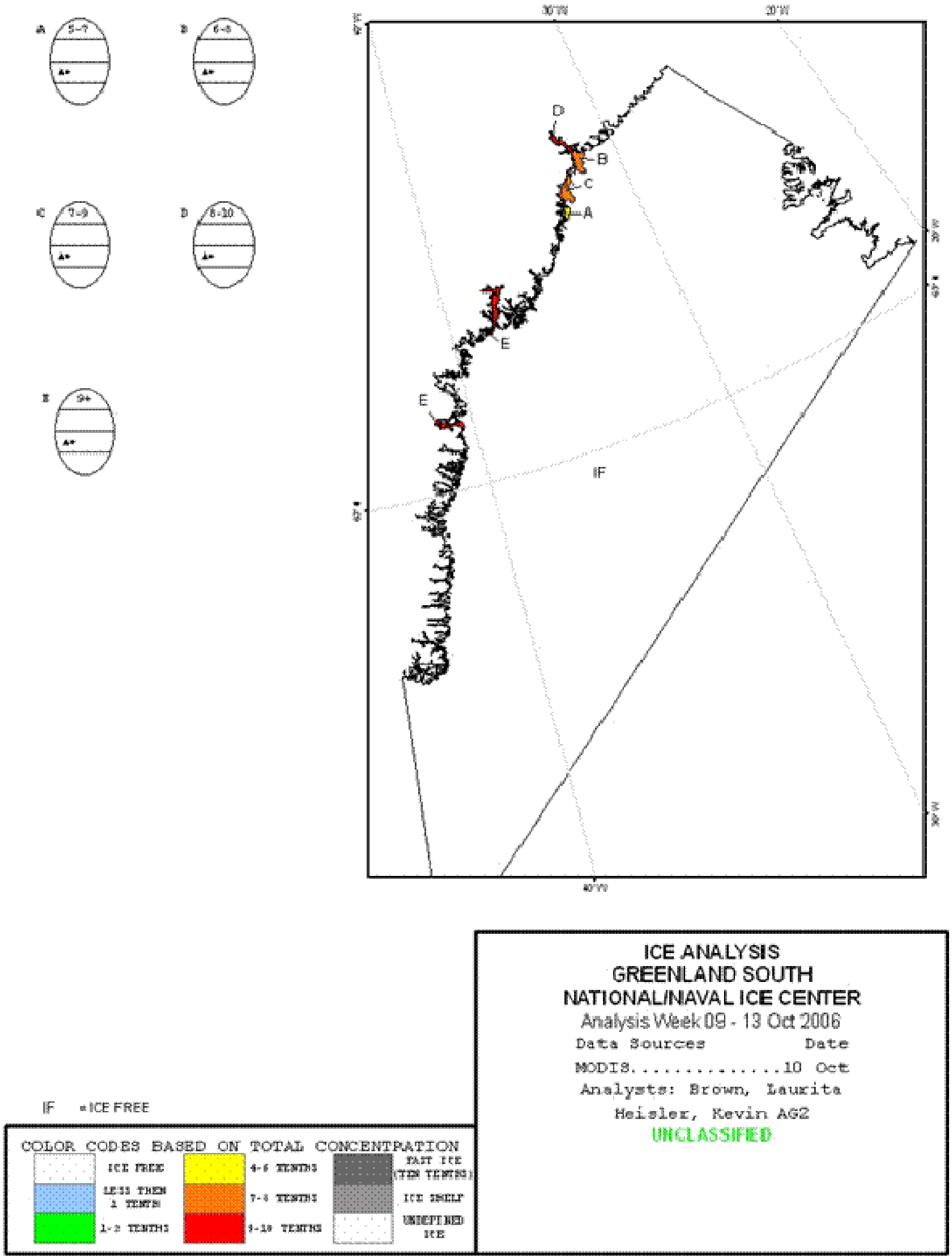


Fig. 12 Ice cover and ice edge during 09 -13 October 2006 (Greenland South)

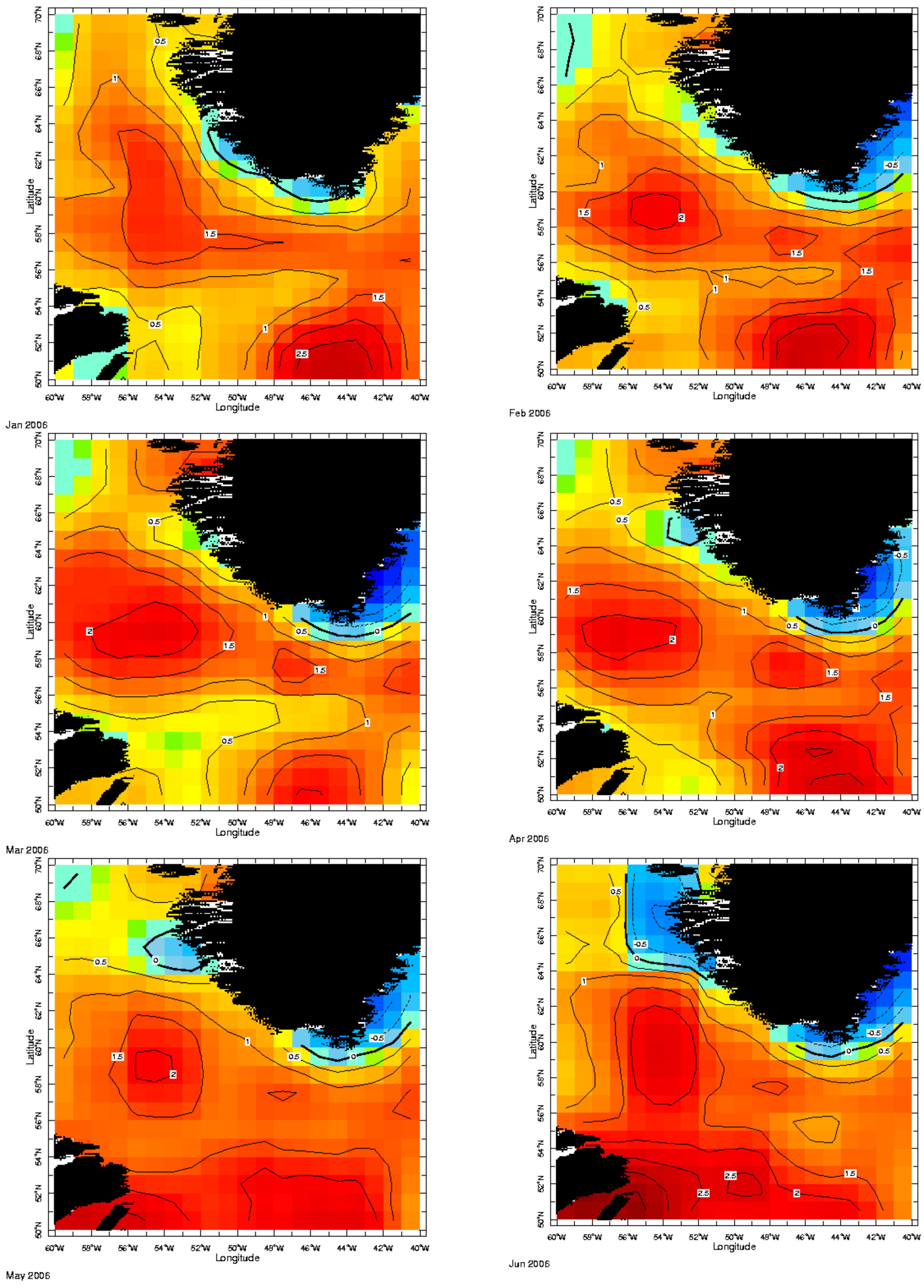


Fig. 13 Sea Surface Temperature Anomalies (K) off Greenland and in the Labrador Sea, January-June 2006

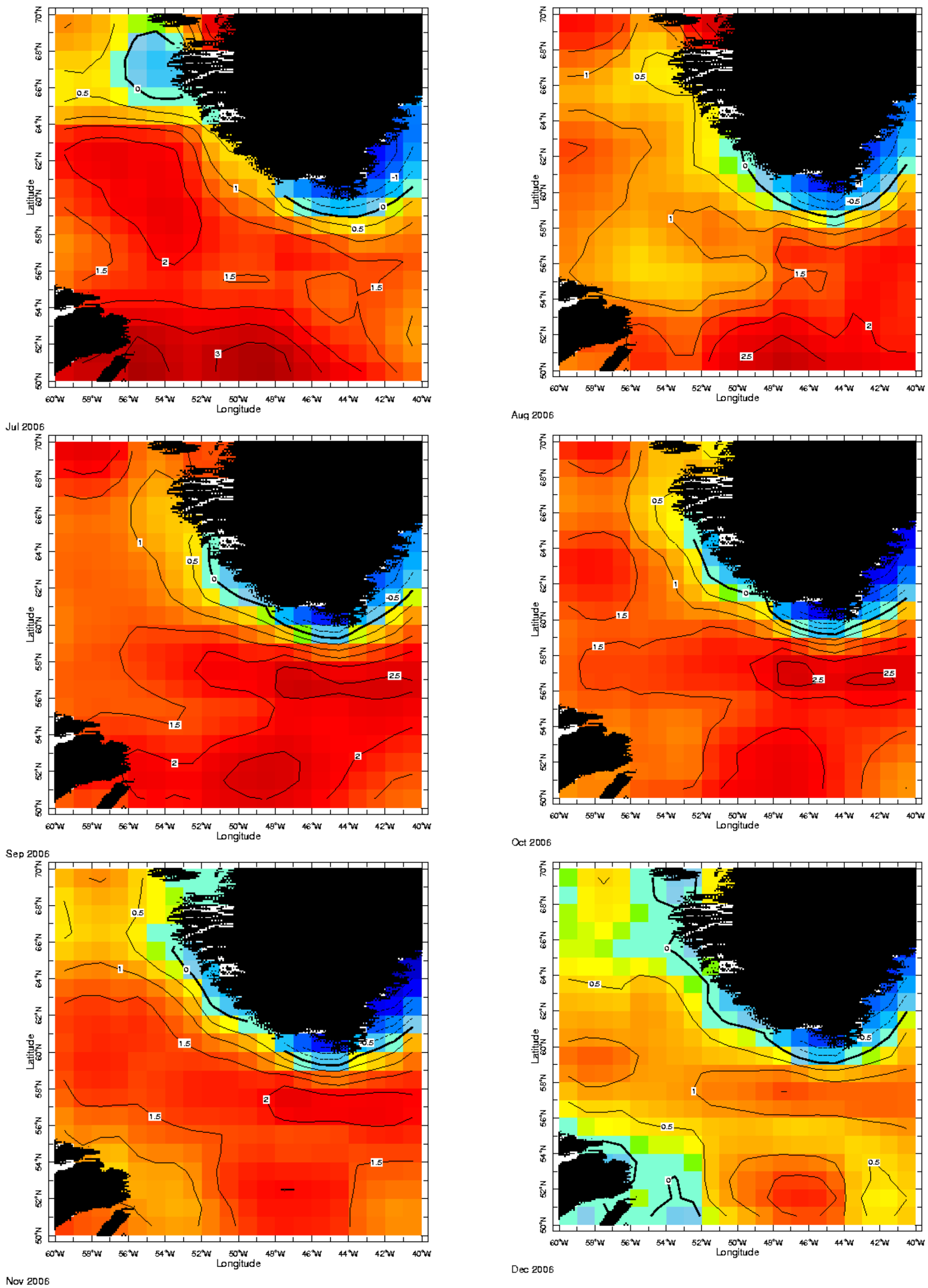


Fig. 14 Sea Surface Temperature Anomalies (K) off Greenland and in the Labrador Sea, July- December 2006

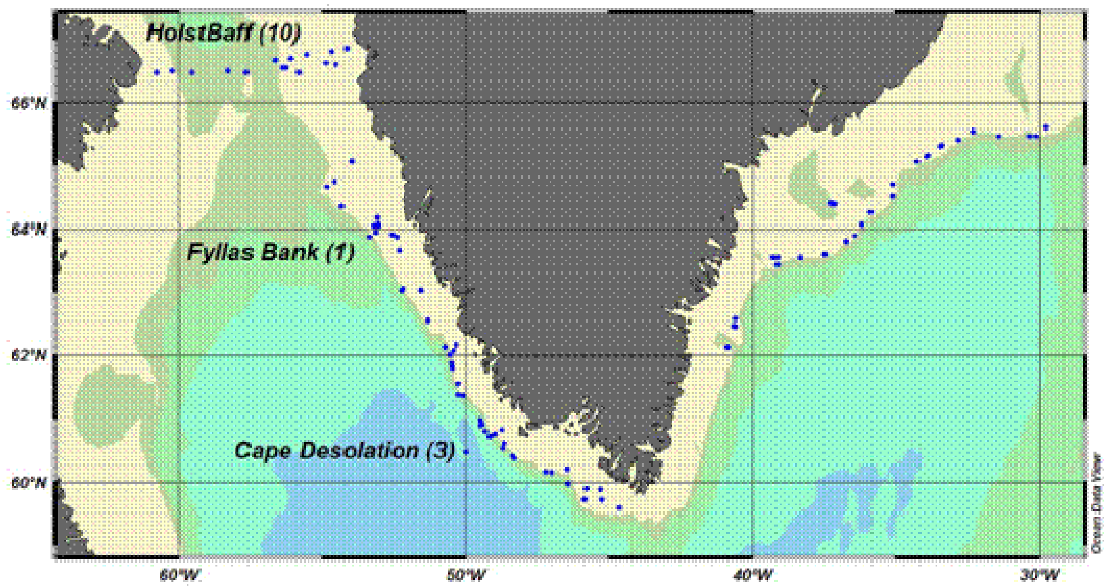


Fig. 15 Positions of fishing stations off East and West Greenland (81), sampled NAFO Standard Sections: Fyllas Bank, Cape Desolation, Holsteinsborg-Baffin Island; in brackets: No. of stations;

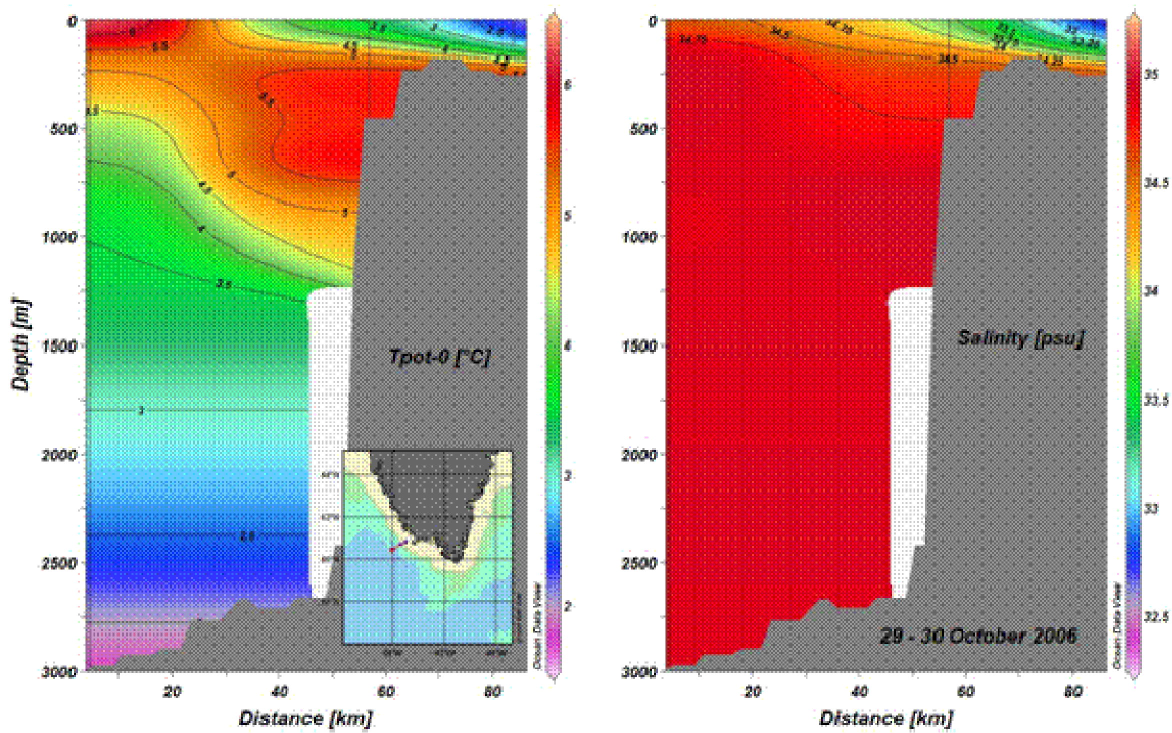


Fig. 16 Potential temperature and salinity along Cape Desolation Section (29 – 30 October 2006)

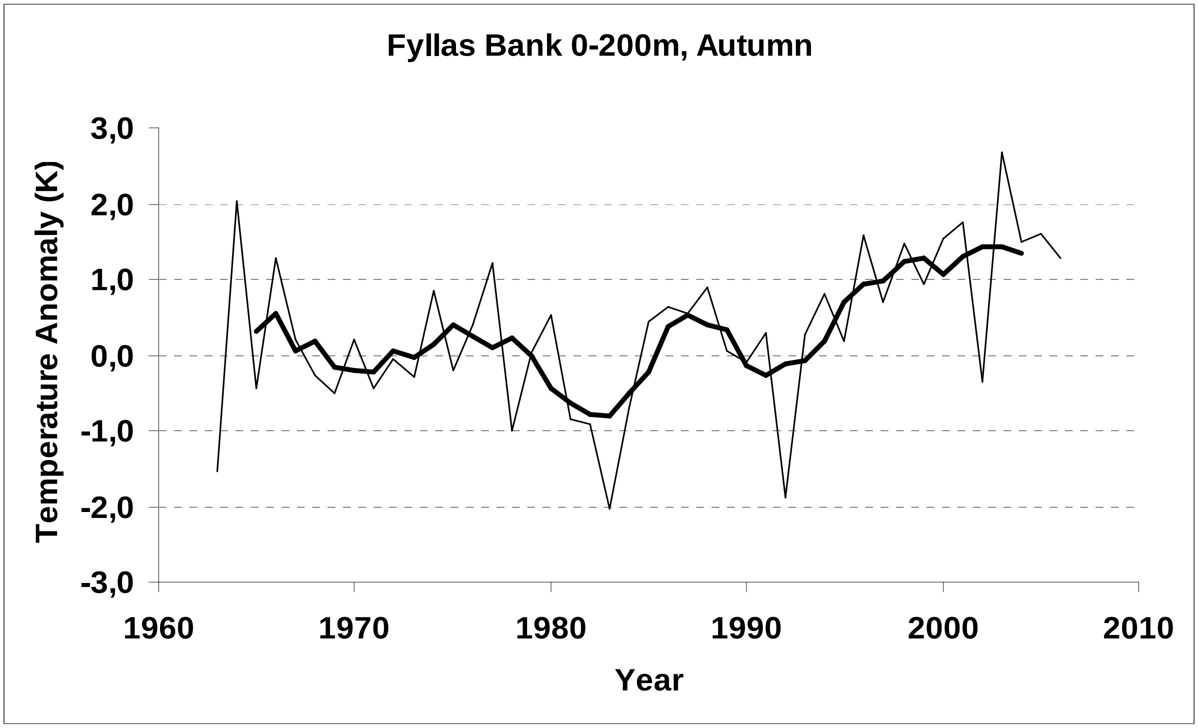


Fig. 17 Mean water temperature anomalies of layer 0-200m at station 4 of the Fyllas Bank Section during autumn; data: 1964-2006 (thin), 5 yr r.m. (bold); (base period: 1964-1990)

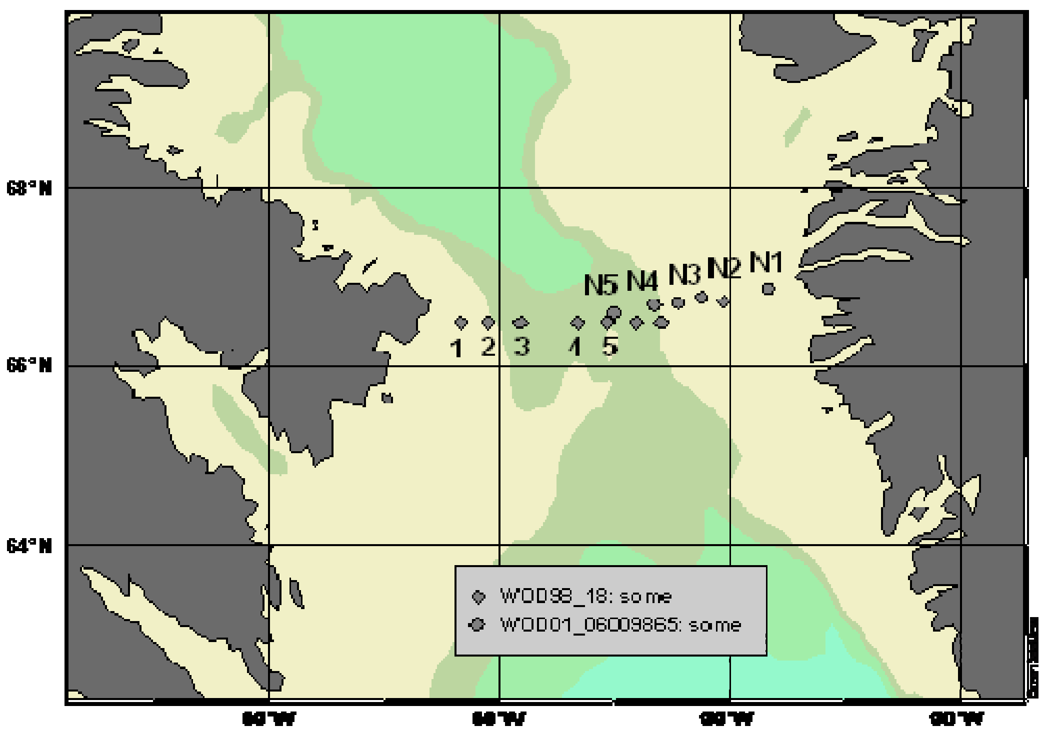


Fig. 18 Positions of the HolstBaff Section; N1 – N5: NAFO Standad Stations;
1 – 5: Historic HUDSON Stations

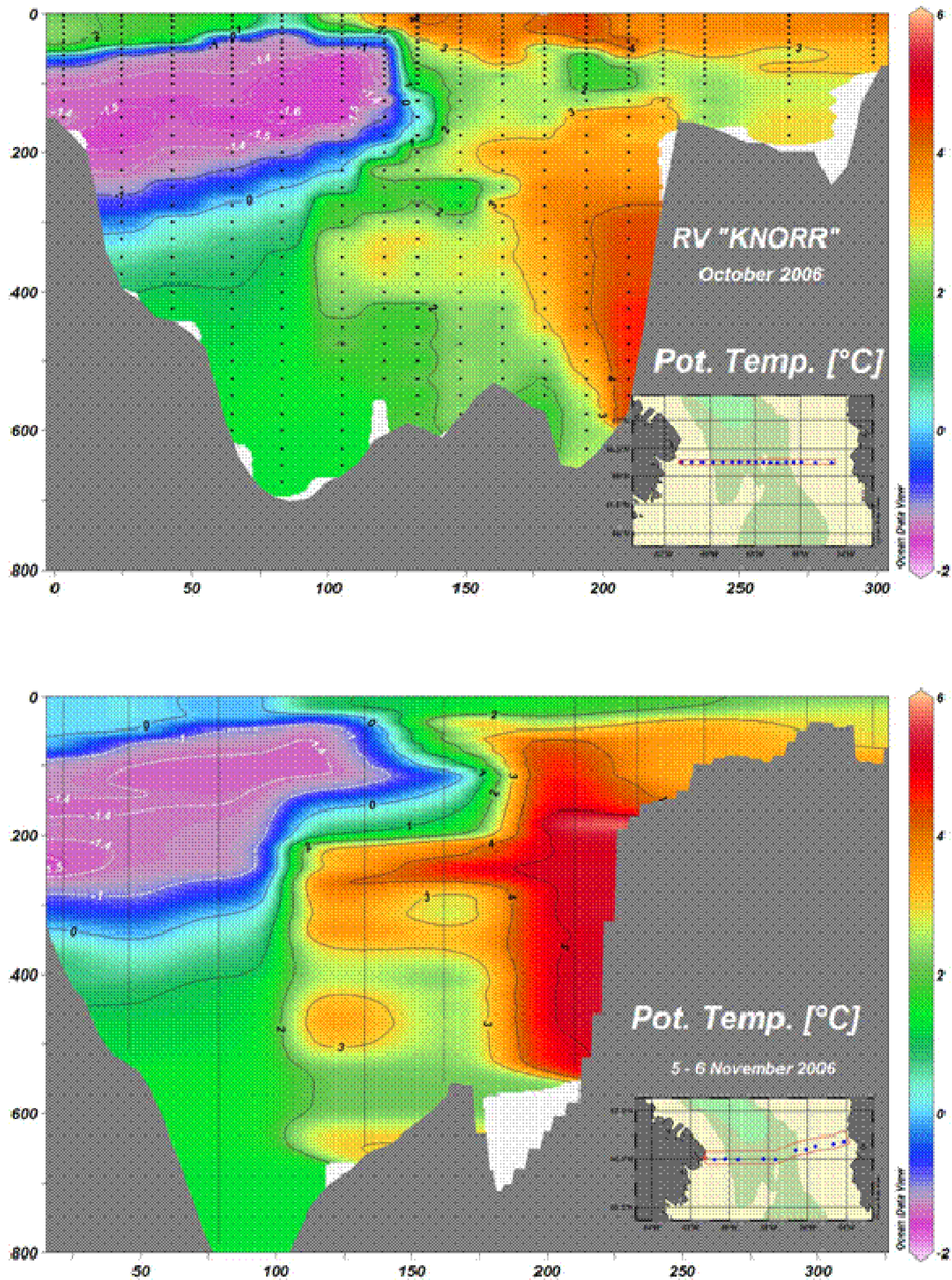
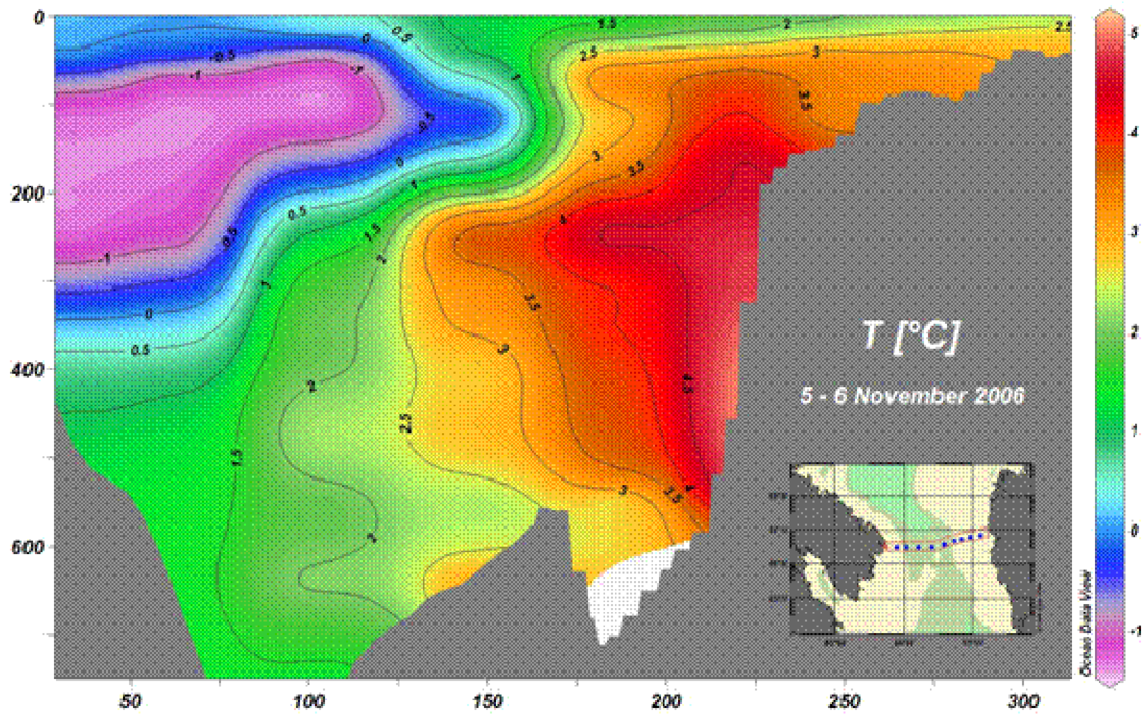


Fig. 19 Potential temperature along 66° 15’N (RV “KNORR”, October 2006; courtesy B. Petrie, Bedford Institute of Oceanography, Dartmouth, Canada), and along Holsteinsborg-Baffin Island Section (5 - 6 November 2006)



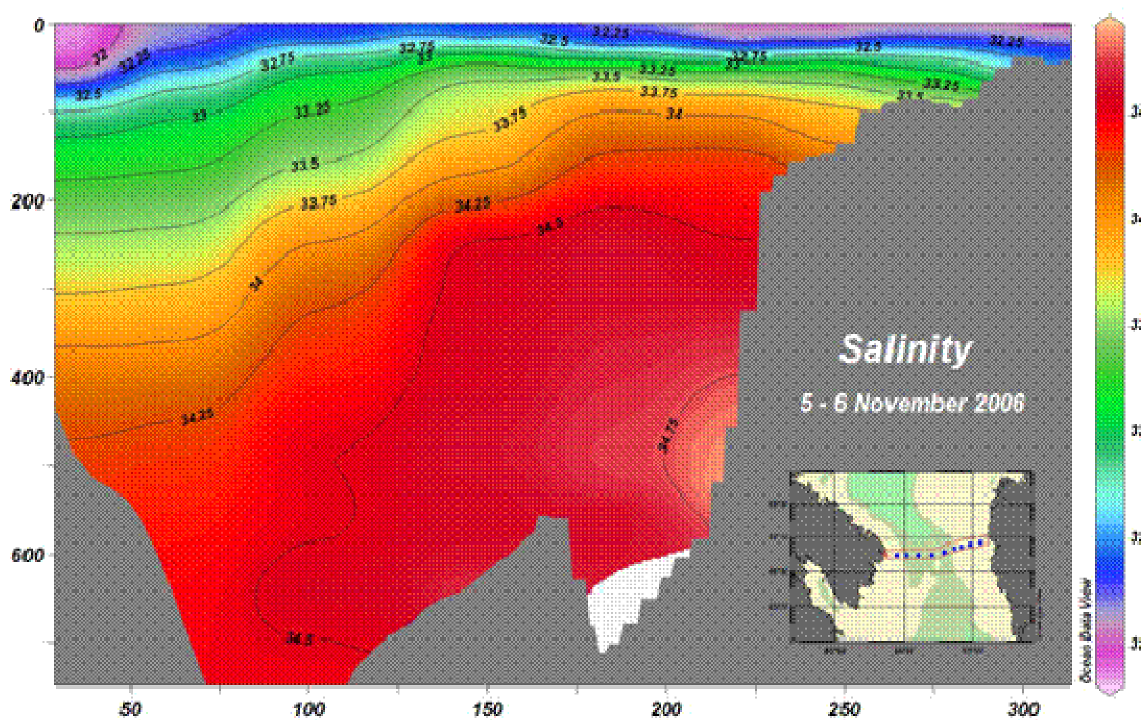
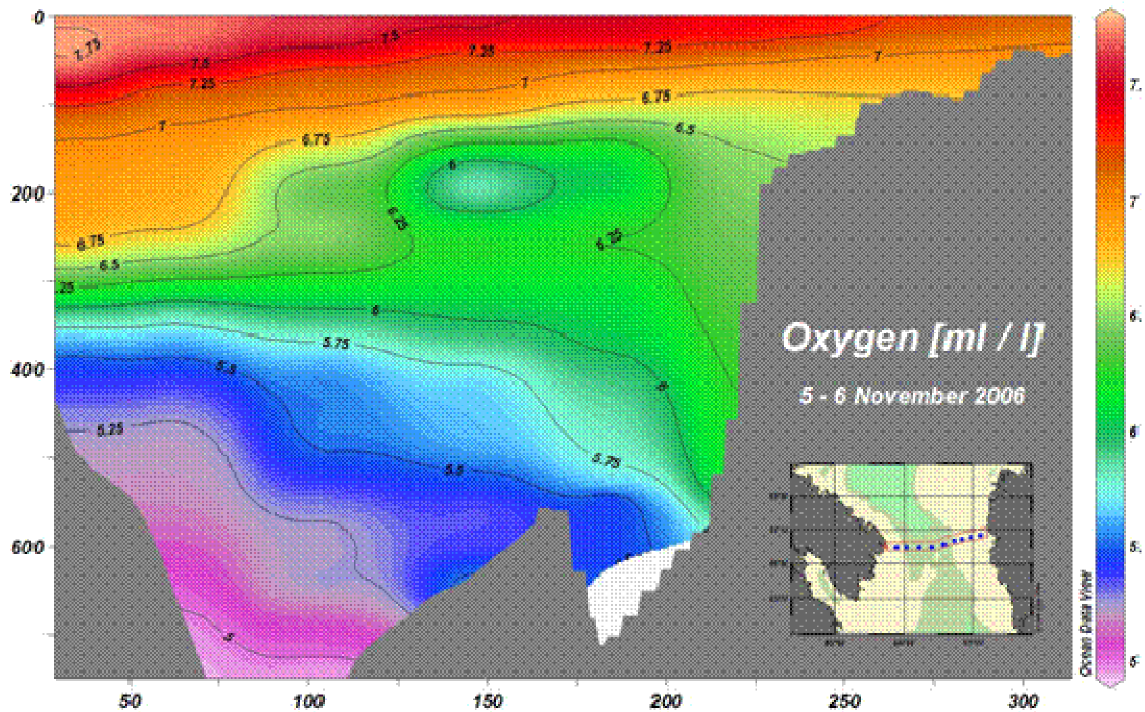


Fig. 20 Temperature and salinity along Holsteinsborg-Baffin Island Section (5 - 6 November 2006); 9 intermediate stations (see chapter on Material and Methods)



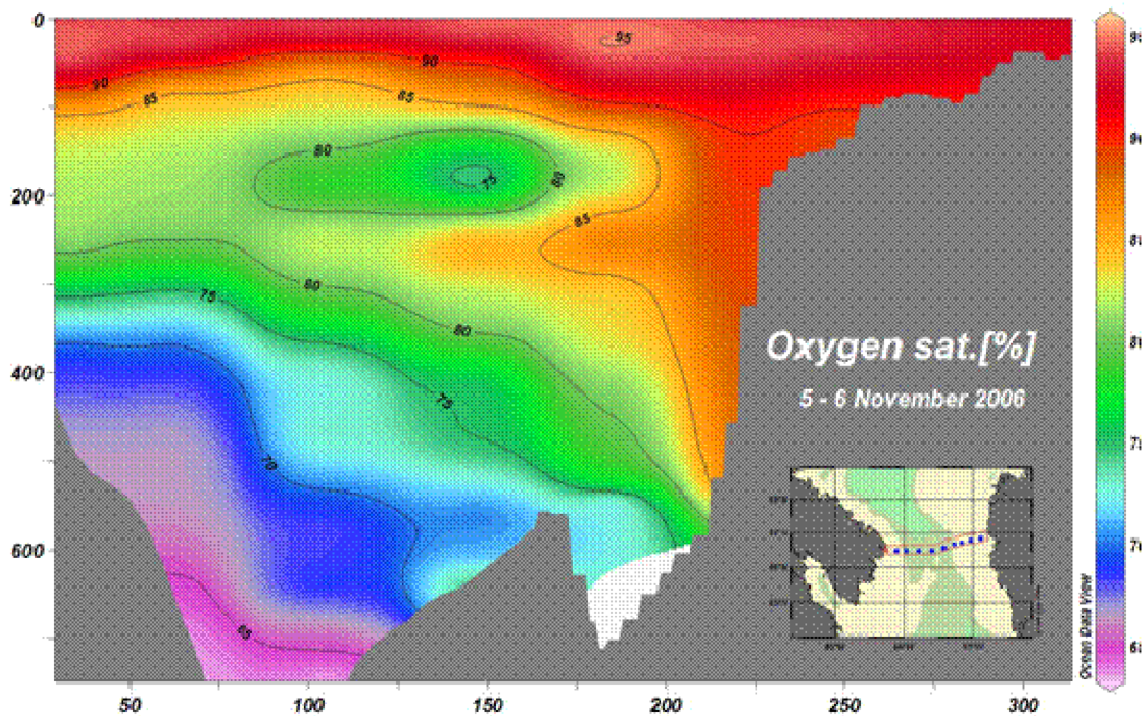


Fig. 21 Dissolved oxygen and oxygen saturation along Holsteinsborg-Baffin Island Section (5 - 6 November 2006); 9 intermediate stations (see chapter on Material and Methods)

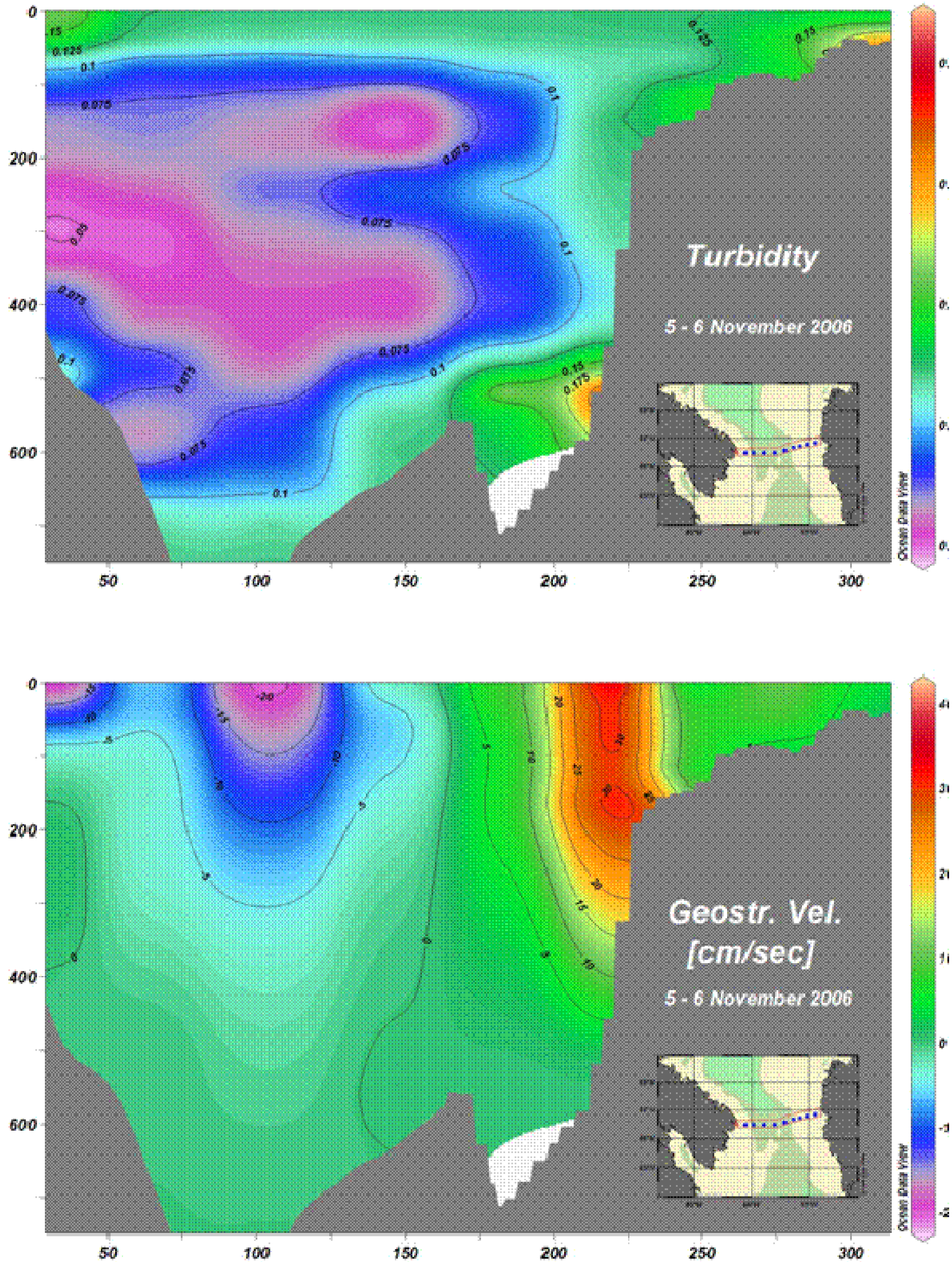


Fig. 22 Turbidity and geostrophic currents (north/south component) along Holsteinsborg-Baffin Island Section (5 - 6 November 2006); 9 intermediate stations (see chapter on Material and Methods)

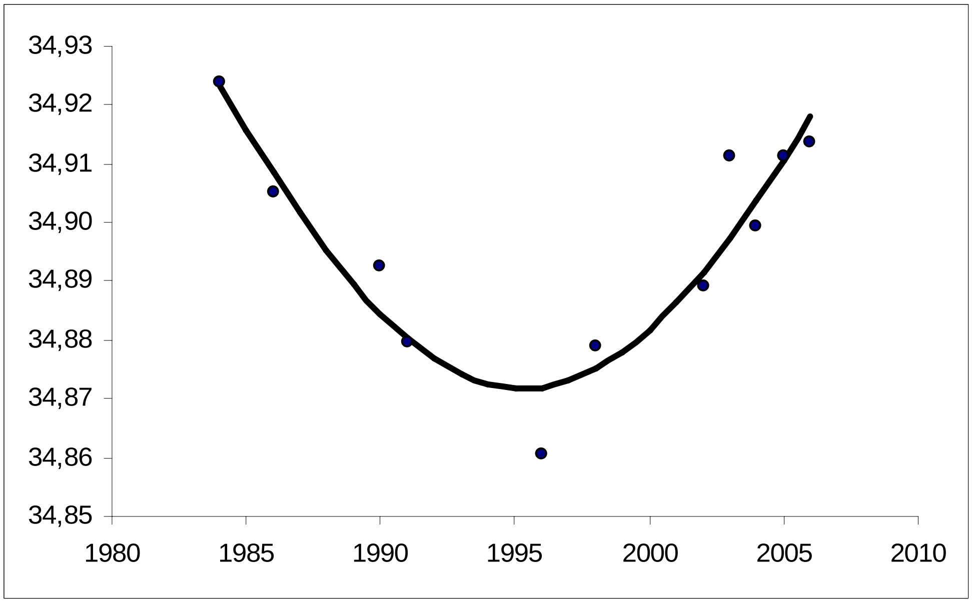


Fig. 23 Salinity of **calibration samples** at Cape Desolation Section station 3, **1500m** depth (60°28'N, 50° 00'W; data: 1984 – 2006; harmonic model adjusted to the data; $r^2 = 0.87$)

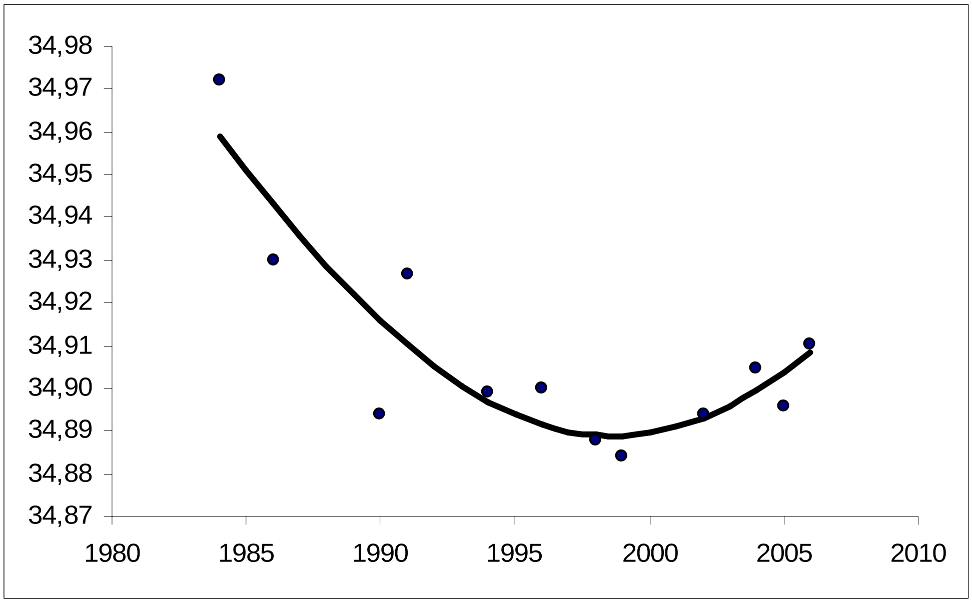


Fig. 24 Salinity of **calibration samples** at Cape Desolation Section station 3, **2000m** depth (60°28'N, 50° 00'W; data: 1984 – 2006; harmonic model adjusted to the data; $r^2 = 0.80$)

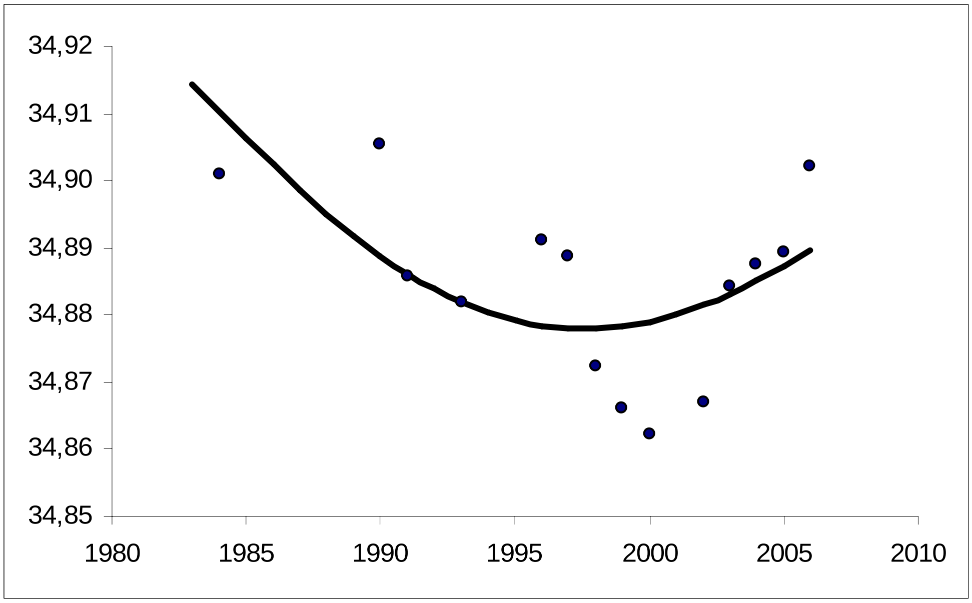


Fig. 25 Salinity of **calibration samples** at Cape Desolation Section station 3, **3000m** depth (60°28'N, 50° 00'W; data: 1984 – 2006; harmonic model adjusted to the data; $r^2 = 0.38$)