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Climatic Conditions around Greenland - 2009

by

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic during winter 2008/2009 indicated one distinct negative pressure anomaly cell, located over Greenland and the Labrador Sea, and another negative anomaly cell located over Europe and Northern Africa. A strong positive anomaly cells covered Scandinavia and Western Russia, and a slightly weaker positive anomaly cell stretched from the Azores area to the west of the British Isles. As a consequence of this pattern, the North Atlantic Oscillation index for the winter 2008/2009 was weak and negative (-0.08). Warmer-than-normal conditions were observed around Greenland during most of the year 2009 that results in the positive anomaly of the annual temperature of +0.8K at Nuuk. Based on satellite derived ice charts, it is shown that winter sea ice conditions were less favorable during 2009 off West Greenland than during 2008. However, the maximum of ice extension in 2009 was less than the year before. The anomaly of the mean water temperature in the upper 200 m at Fyllas Bank Station 4 increased in comparison with the previous year and reached +1.1K in autumn 2009. Calibration salinity samples from the deep water station Cape Desolation 3 off southwest Greenland reveal harmonic oscillation signals which are most expressed at the 1500m depth level ($r^2 = 0.88$). At 3000m depth, in the domain of the Denmark Strait Overflow water mass, the harmonic signal is weaker, and it explains 48% 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 started in 1963 (Stein, 2010). The oceanographic data obtained during these surveys form the basis for interpretation of the oceanic conditions on the fishing banks around Greenland and at selected NAFO Standard Oceanographic Stations. During October/November 2009 FRV “Walther Herwig III” achieved oceanographic observations in the area of research. This paper is the eighteenth in a series which provides an annual overview on environmental conditions around Greenland starting from 1993 (Stein, 1995).

Data and Methods

The patterns of sea level atmospheric pressure and pressure anomaly during the winter months (December, January, February) of 2008/2009 was taken from NCEP/NCAR Reanalysis data from the NOAA-CIRES Climate Diagnostics Centre <http://www.cdc.noaa.gov/cgi-bin/data/composites/printpage.pl>. The winter NAO Index refers to

the mean of December, January, February indices (DJF). It was taken from http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_index.html.

Data on the air temperature 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 solely given by the Seewetteramt. The climatological or long-term mean of these data is referenced to 1961-1990 and was obtained from the Seewetteramt.

Ice charts were obtained by satellite observations and taken from NOAA websites:

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/.

Sea surface temperature (SST) data were taken from the IGOSS (Integrated Global Ocean Services System Products Bulletin) Data Base <http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/>. The SST climatology is referenced to 1971-2000 (Reynolds and Smith, 1994).

During cruise WH327 of FRV “Walther Herwig III”, CTD profiles were obtained at each fishing position of the survey area (Figures 1a and 1b) using SeaBird911+. Starting off East Greenland in the Dohrn Bank region (stratum 7) on 14 October 2009, 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. Salinity readings of the CTD profiles were adjusted to water samples derived by Rosette water sampler. From 27 October onwards, the ship continued to work in West Greenland waters, including the observations along NAFO Standard Oceanographic sections Cape Desolation and Fyllas Bank (Stein, 1988). On 12 November 2009, FRV “Walther Herwig III” left Nuuk and made her way back to Bremerhaven where the cruise was finished on 20 November 2009.

Data analysis and presentation was done using Ocean Data View Version 3.4.2 (Schlitzer, 2008). Data gaps in our own data base, due to e.g. December observations, were filled with data from the World Ocean Database (WOD, <http://www.nodc.noaa.gov/>). This is the case for 1972, 1978, 1980 and 1981.

Results and Discussion

The North Atlantic Oscillation

The variability of the atmospheric conditions over Greenland and the Labrador Sea is driven by the large scale atmospheric circulation over the North Atlantic, which is normally described in terms of the North Atlantic Oscillation (NAO). During a positive NAO, strong northwest winds bring cold air from the North American continent and cause negative anomalies of air temperatures over Greenland, Labrador Sea, Baffin Bay (Hurrell and Deser, 2010). During a negative NAO the westerlies slacken and the weather is normally milder over the whole region.

In winter 2008/2009, there was one distinct negative pressure anomaly cell, located over Greenland and the Labrador Sea, and another negative anomaly cell located over Europe and Northern Africa (Figure 2a). A strong positive anomaly cells covered Scandinavia and Western Russia, and a slightly weaker positive anomaly cell stretched from the Azores area to the west of the British Isles. As a consequence of this pattern, the North Atlantic Oscillation (NAO) index in winter 2008/2009 was weak and negative (-0.08).

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, e.g. 1998, 2001, 2002, 2003 show a weak subtropical high and a weak Icelandic low (Stein, 2003). The sea level atmospheric pressure over the North Atlantic during winter 2008/2009 (Figure 2b) resembles the conditions during winter 2002/2003 (Stein, 2003).

During the second half of the last century we see that the 1960s were generally “low-index” years while the 1980s, 1990s and 2000s were “high-index” years (Figures 3a and 3b). There was a major exception to this pattern occurring in winter preceding 1995, when the index flipped from being one of its most positive values to its most negative value this century (Figure 3a). The negative NAO index of winter 2008/2009 (December-February) is among the weaker negative indices, similar to those of 1997 and 2003.

Air Temperature and Climatic means

The winter NAO index from NOAA and Nuuk annual air temperature are negatively correlated in time. The correlation between these two time series $r = (-0.57)$ is significant at $p \ll 0.001$. This is comparable with the results of Stein, 2004, who used slightly different NAO index and 130-year time series of both parameters. The 2009 reveal that statistical significance being valid for the entire time series fits with the 2009 observations.

In 2009, monthly mean air temperature at Nuuk station was above its climatological mean for all month, except March and November (Figure 5). Monthly mean temperature curves are similar at Egedesminde and at Nuuk, except for the scaling (Figures 4 and 5). Angmagssalik (Figure 6) experienced warmer than normal conditions the whole year too, with exceptions of February and October, when the monthly air temperature was below its long-term mean.

Climatic Variability off West Greenland

The positive annual air temperature anomaly observed in 2009 is a continuation of a series of warmer-than-normal years (0.2K to 2.0K) which started in 1996, with the warmest air temperature of +2.0K, observed in 2003 (Figure 7). The only exception was 1999 which was colder-than-normal (-0.3K).

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 (Figure 8) 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. The same trend can be seen for the year 2007 (+ 0.8K) which is the same as in 1957. The year 1977 was the warmest “year 7”, and the anomaly amounted to + 1.6K. The year 2008 mean air temperature is in a similar range as the temperatures of the “year 8” of the previous four decades. The year 2009 was the warmest ‘last year’ among all decades since 1950.

Ice Conditions around Greenland

Winter sea ice conditions were not as favourable during 2009 off West Greenland than during the previous year. The sea ice drift has a significant offshore component which is called the “West Ice”. In the beginning of March, Greenland was surrounded by sea ice (Figures 9-11) with an ice concentration of 1 to 3 tenth in the southern part. Multi-year sea ice, coming from the Arctic Ocean via the East Greenland current to the Cape Farewell area, is called “Storis”. During 25-29 May, the East Greenland coast was surrounded by sea ice with concentrations ranging from 9-10 tenth (Figures 12 and 13). There was also a tongue of newly formed ice in the Cape Farewell/Julianehaab Bight region which extended up off Paamiut (Figure 13). Sea ice started to form off East Greenland in the end of October (Figure 14) and in Baffin Bay in the early-November 2009 (Figure 15). This was similar to the sea ice conditions during 2008 (Stein, 2009).

Oceanographic observations off West Greenland

The West Greenland (WGC) and East Greenland (EGC) currents are the boundary currents in the northern part of the North Atlantic sub-polar gyre. EGC transports the fresh and cold Polar Surface Water (PSW) to the south along the eastern coast of Greenland. WGC carries the water northwards on the eastern rim of the Labrador Sea. WGC consists of two components: SPW located on shelf, and saltier and warmer Irminger Sea Water (ISW) located offshore. Since WGC transports water into the Labrador Sea, the variability of the current is important for the Labrador Sea Water formation, which is an essential element of the Meridional Overturning Circulation (MOC).

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

The SST anomaly pattern in 2009 off Greenland is different from those of the previous year. In 2008, anomalous warm conditions were observed off Greenland and in the Labrador Sea throughout the year. In 2009, the stable positive SST anomaly was observed only in the Labrador Sea with September as an exception (Figure 16 and 17). The SST anomaly associated with WGC was negative the first half of 2009, then switched to the positive one, probably because of combined effect of atmospheric heat transport and an intensification of ISW component. At the same time the EGC was associated with a prominent negative anomaly from June 2009 on. The strongest negative SST anomaly of EGC was observed in October. This is consistent with the seasonal maximum of the ice drift from the Arctic.

Cape Desolation Section

At Cape Desolation section the strong surface front separates SPW on the shelf from ISW offshore (Figure 18). In autumn, the temperature of the upper layer is well above zero due to the summer heat accumulation, and hence only the salinity can be used as a tracer of the SPW. The salinity of less than 33 was observed at the shallowest station (Station 199 on Figure 18). The potential temperature of the offshore ISW was slightly above 6°C and its salinity exceeded 35.00 (Figure 18). The core of ISW at the most offshore station (Station 203 on Figure 10) was found at the upper 100 m and it deepened to 500 m water depth toward the shelf (Stations 200 and 201 on Figure 18).

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 in upper 200 m of the water since 1993 (Figure 19). 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”. Mean temperature of the upper layer 0-200m again indicates cooling after 2003 which was the record warm year in the entire time series. In 2009, the temperature of the water layer between 0 and 200 m depth at Fyllas Bank Station 4 was 1.2°C higher than its long-term mean (Figure 19). The main impact on the increased temperature had ISW, which was unusually warm, salty and shallow in 2009 (Figure 20). The temperature and salinity of the PSW, which normally flows in the upper 100 m, were close to their long-term means.

Calibration samples

The time series of salinity calibration samples at NAFO Cape Desolation Station 3 is given in Figures 21 - 23. During the 2009 cruise, calibration samples were obtained at 1500m, 2000m, 2500m and 3000m depth. A model (Eq. 1) adjusted to the data of 1500m, 2000m and 3000m depth, reveals significant harmonic trends.

$$(1) \quad \zeta(t) = A \cdot \sin(2\pi t / \tau + \phi) + \text{lin trend}$$

They explain 88% of variation at 1500m depth (Figure 21), 78% at 2000m depth (Figure 22) and 48% at 3000m depth (Figure 23). It is suggested here that the values at 1500m depth represent climatic changes in the

Labrador Sea throughout the time of the 1980s to 2009. 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 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).

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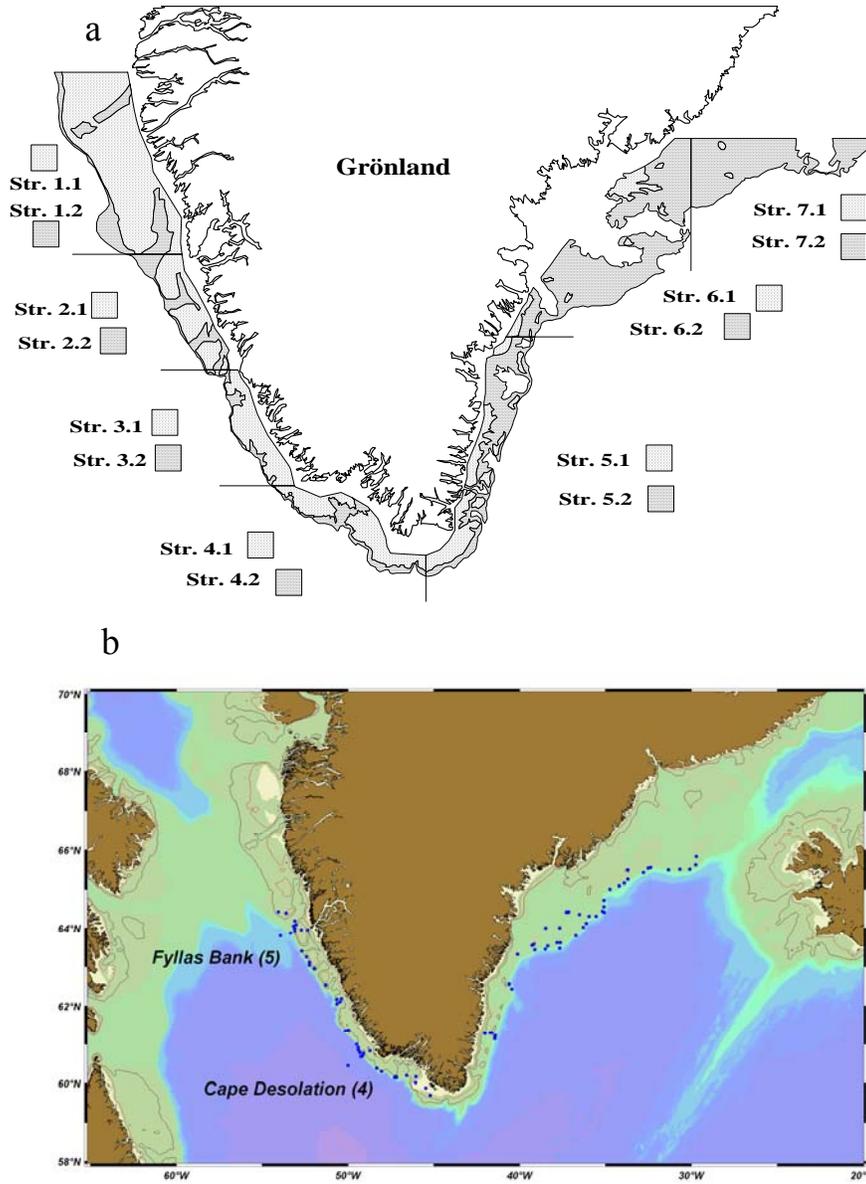
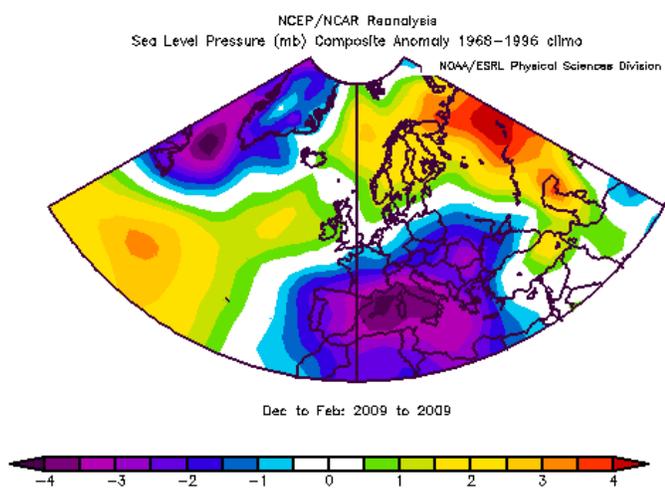


Figure 1. Study region. a) Survey strata. Strata 0-200m depth (1.1, 2.1, 3.1, 4.1, 5.1, 6.1, 7.1) and 200-400m depth (1.2, 2.2, 3.2, 4.2, 5.2, 6.2, 7.2). b) Positions of fishing stations during WH327 cruise in 2009. NAFO standard sections with the number of standard stations in brackets are shown.

a



b

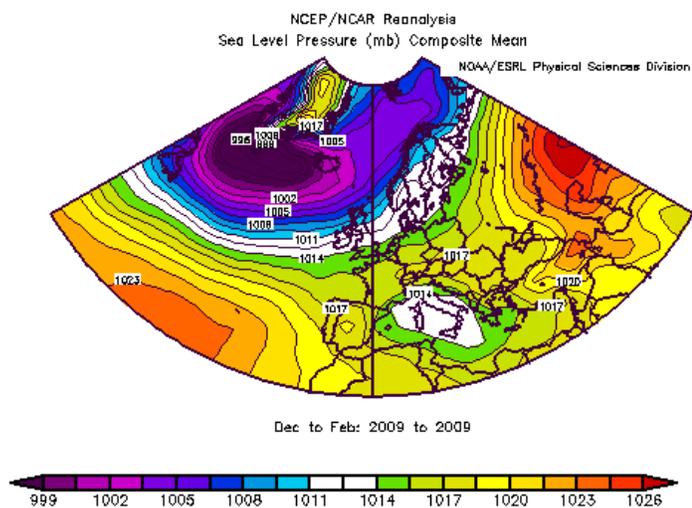


Figure 2. a) Sea level atmospheric pressure anomaly during the winter 2008/2009, related to the long-term mean 1968-1996. b) Pattern of sea level atmospheric pressure during the winter 2008/2009.

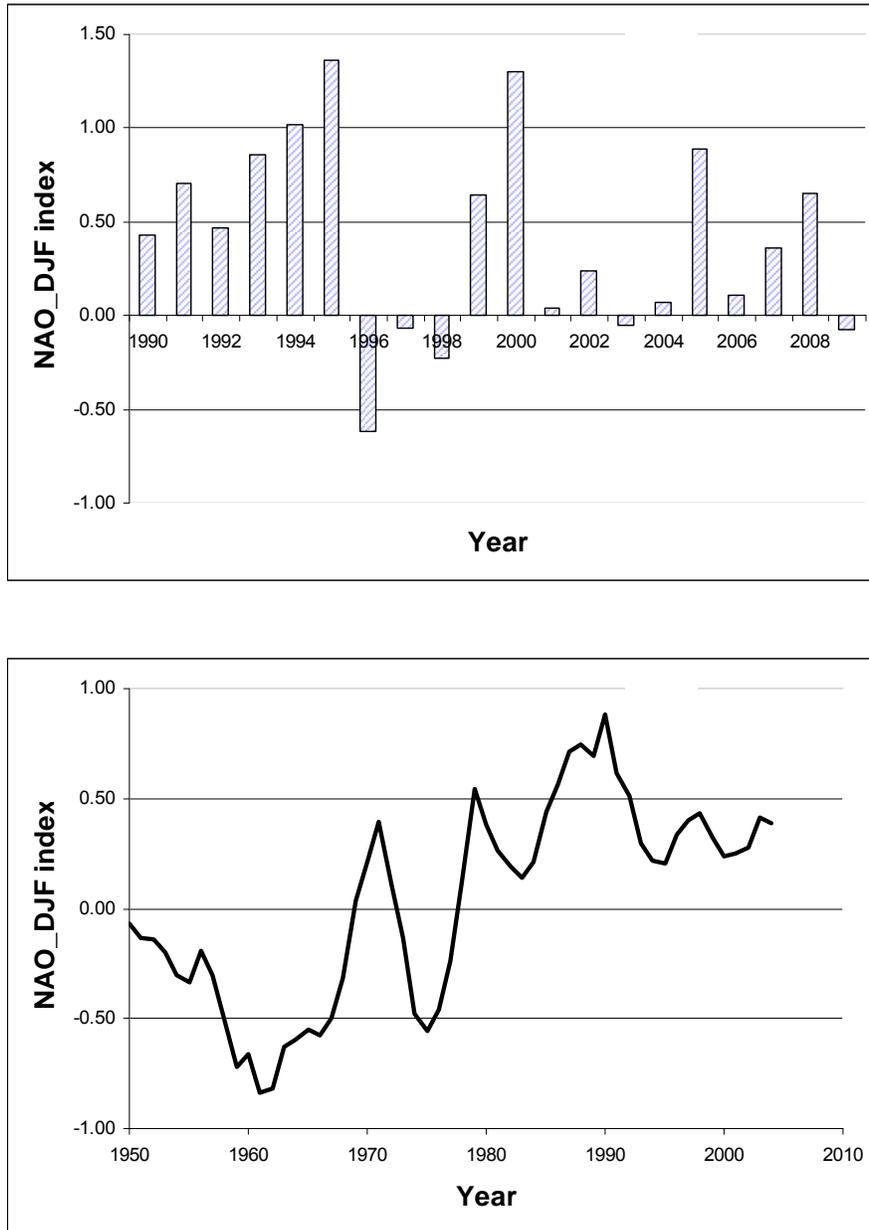


Figure 3. The winter (DJF) NAO index in terms of the last and present decade (a), and the second half of the last century (b). In figure 3b, a 5 year running mean has been applied.

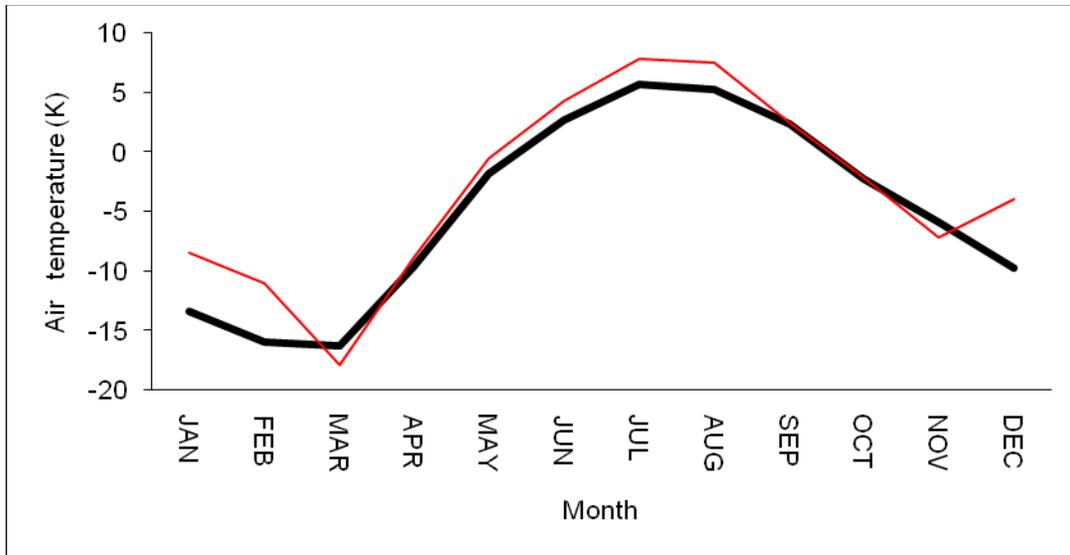


Figure 4. Monthly mean air temperature at Egedesminde. Red line is monthly mean temperature in 2009, black line is climatologically mean of monthly temperature. Climatologically mean of the monthly air temperature is calculated for the period 1961-1990.

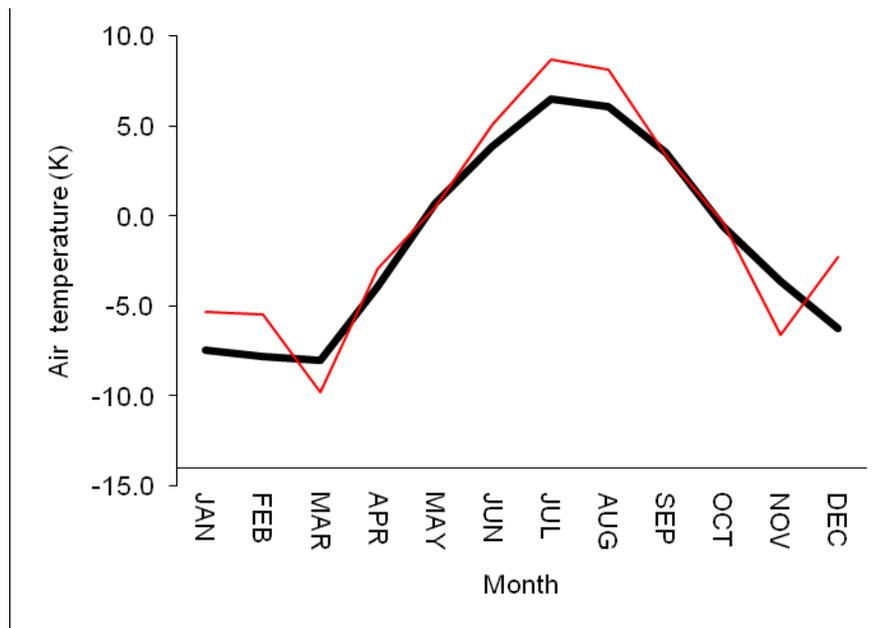


Figure 5. The same as Figure 3, but at Nuuk station.

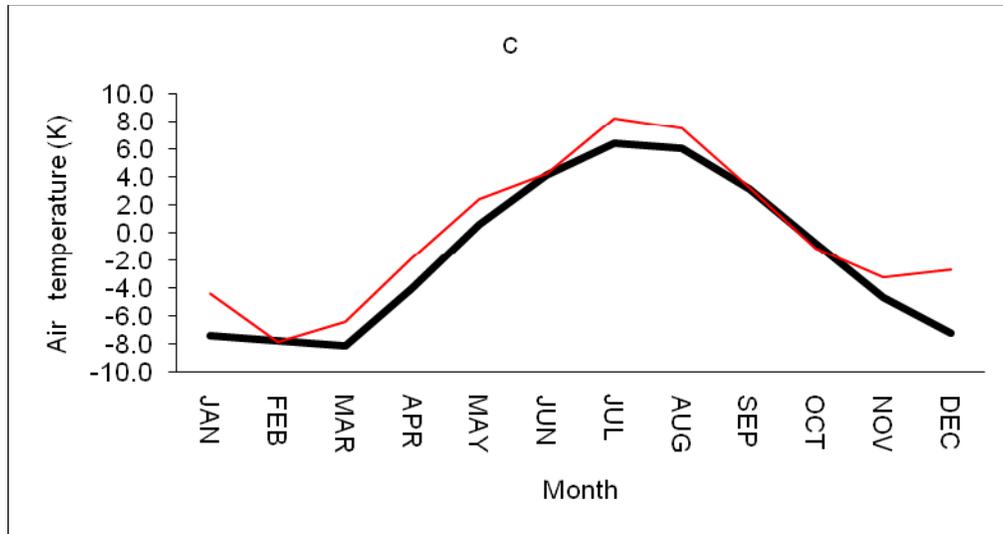


Figure 6. The same as Figure 3, but at Angmagssalik.

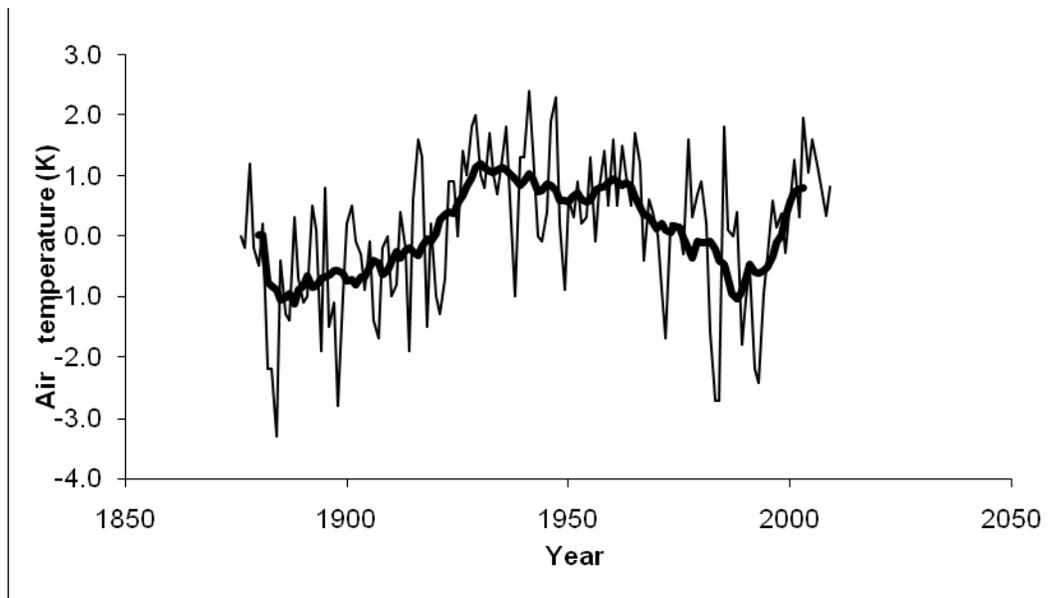


Figure 7. Time series of annual mean air temperature anomalies referenced to 1961-1990 at Nuuk. Thick line shows 13-year running mean.

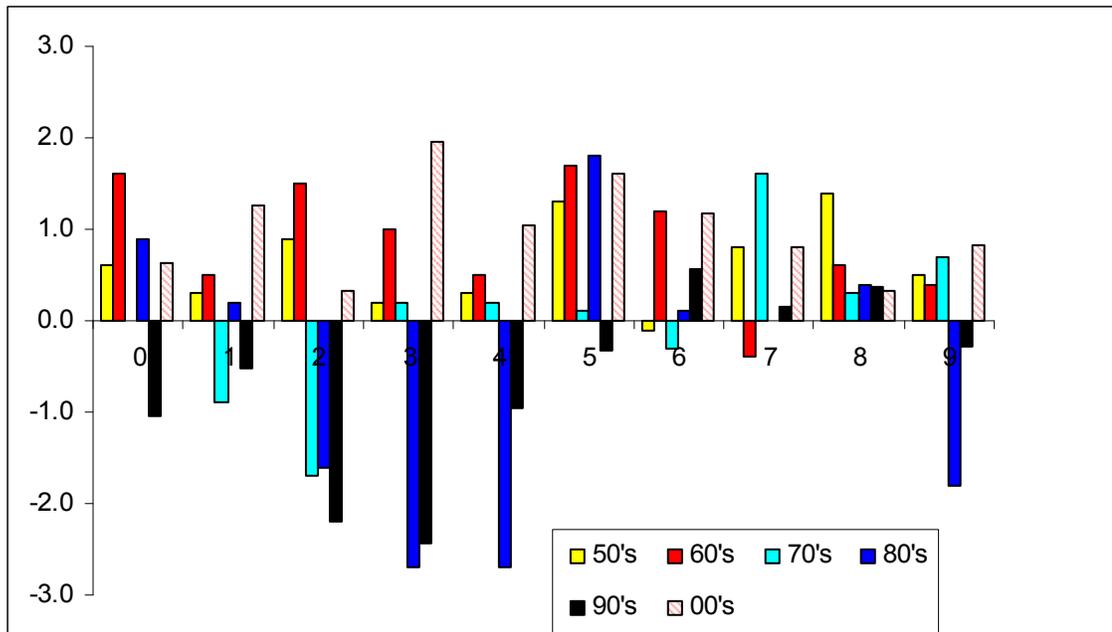


Figure 8. Composite of decadal air temperature anomalies at Nuuk given relative to the climatic mean of 1961-1990 for the decades from 1950s to 2000s

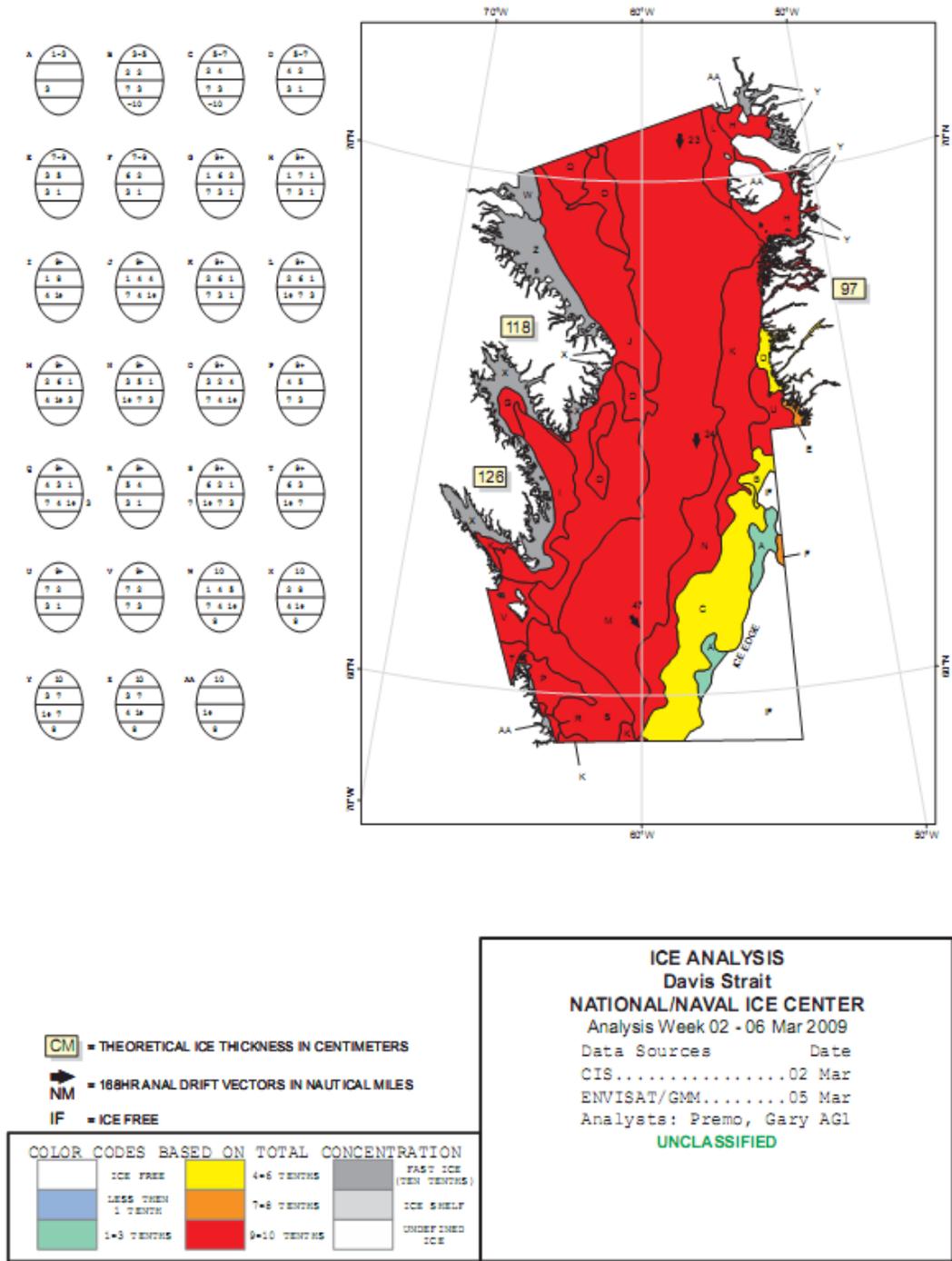


Figure 9. Ice cover and ice edge during 02 - 06 March 2009 (Davis Strait)

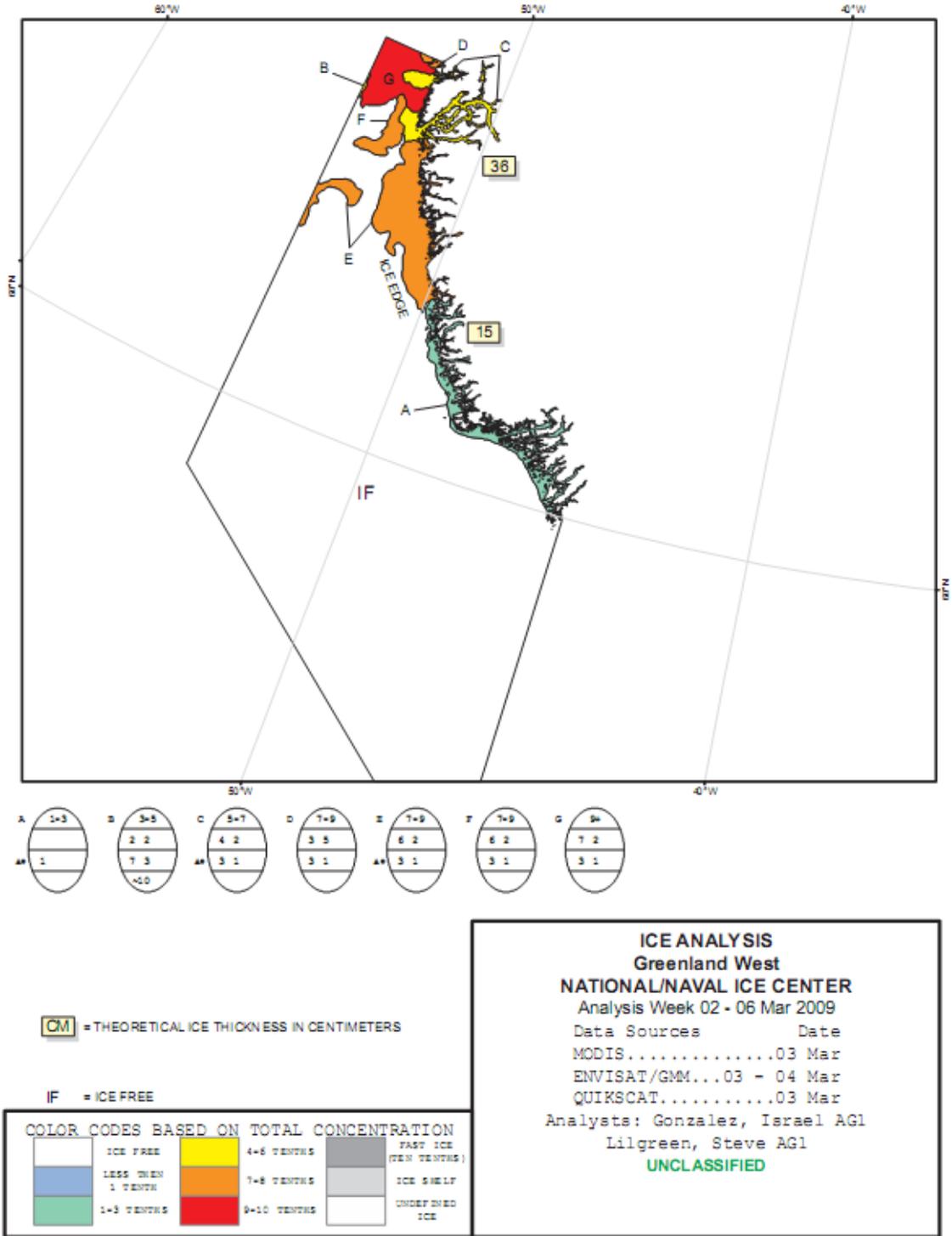


Figure 10. Ice cover and ice edge during 02 - 06 March 2009 (Greenland Southwest)

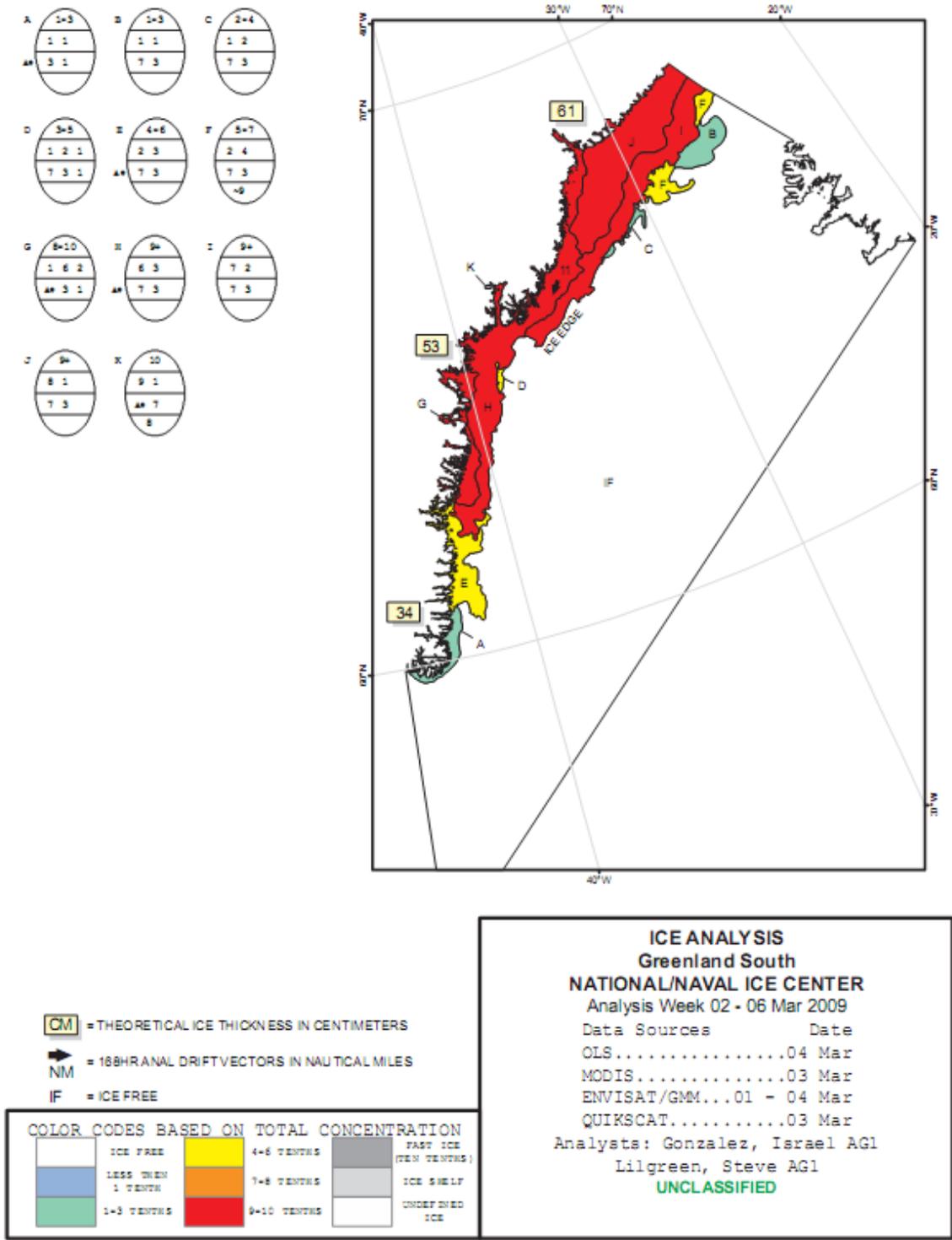


Figure 11. Ice cover and ice edge during 02 - 06 March 2009 (Greenland South).

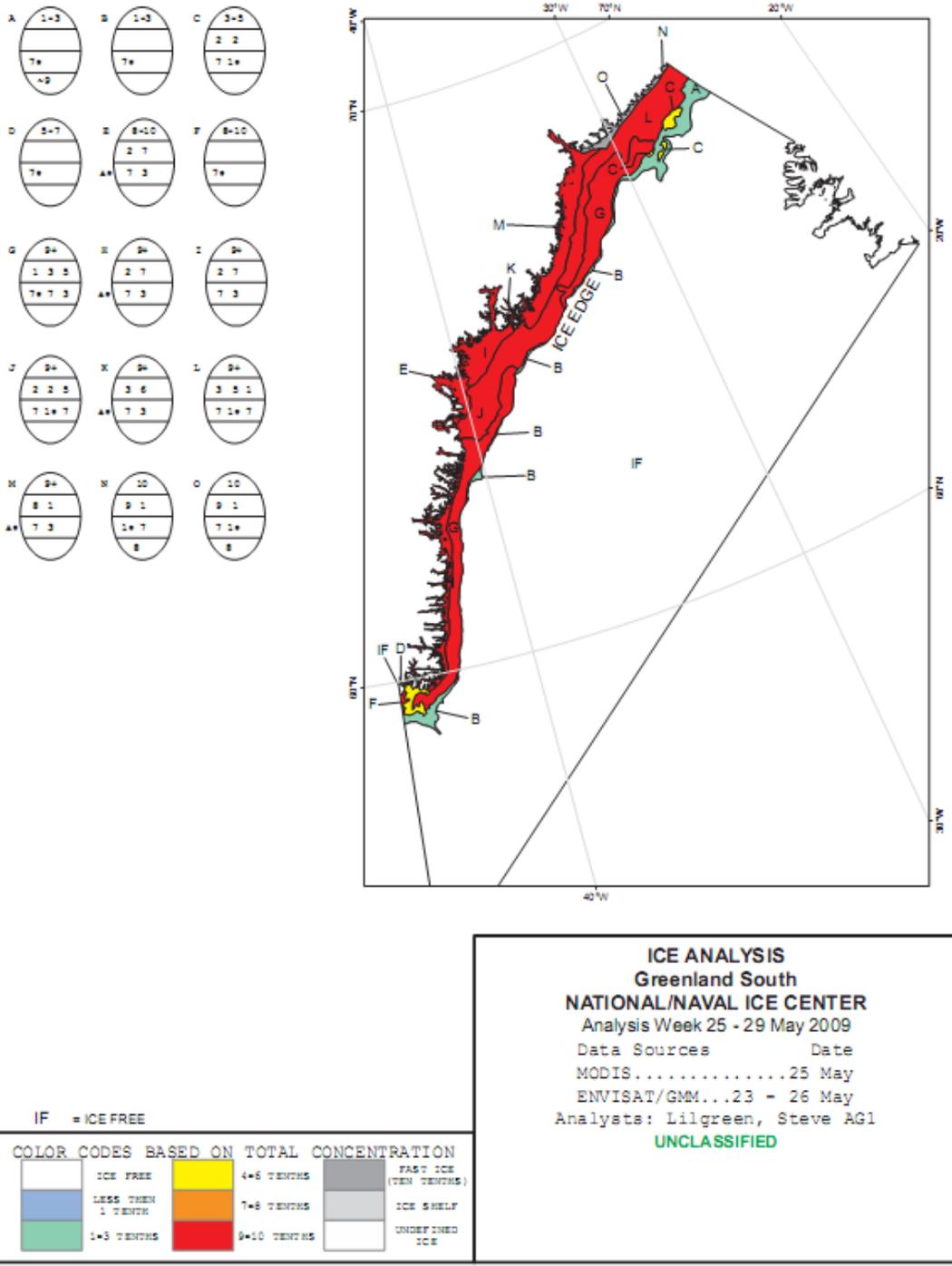


Figure 12. Ice cover and ice edge during 25 - 29 May 2009 (Greenland South).

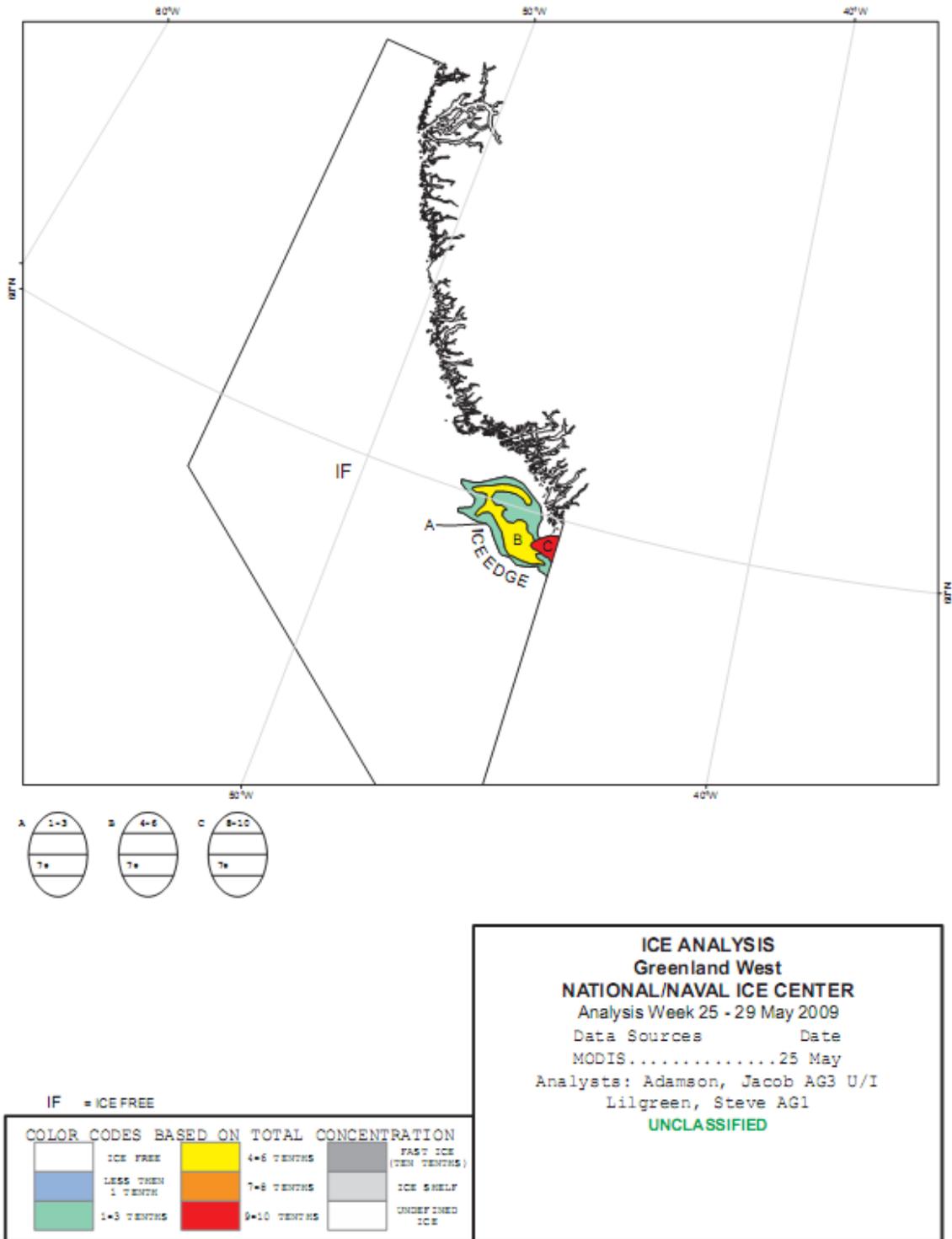


Figure 13. Ice cover and ice edge during 25 - 29 May 2009 (Greenland Southwest).

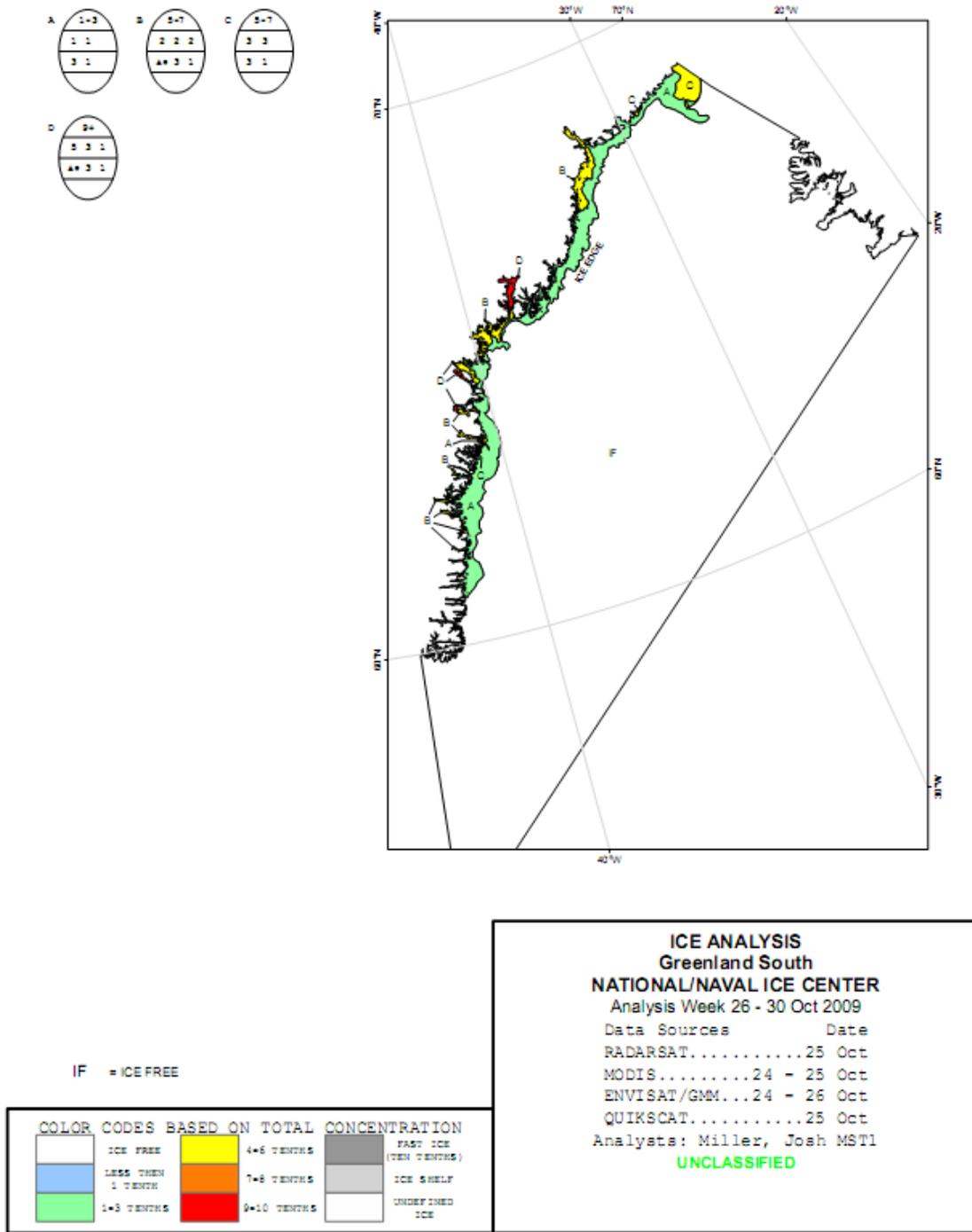


Figure 14. Ice cover and ice edge during 26 -30 October 2009 (Greenland South).

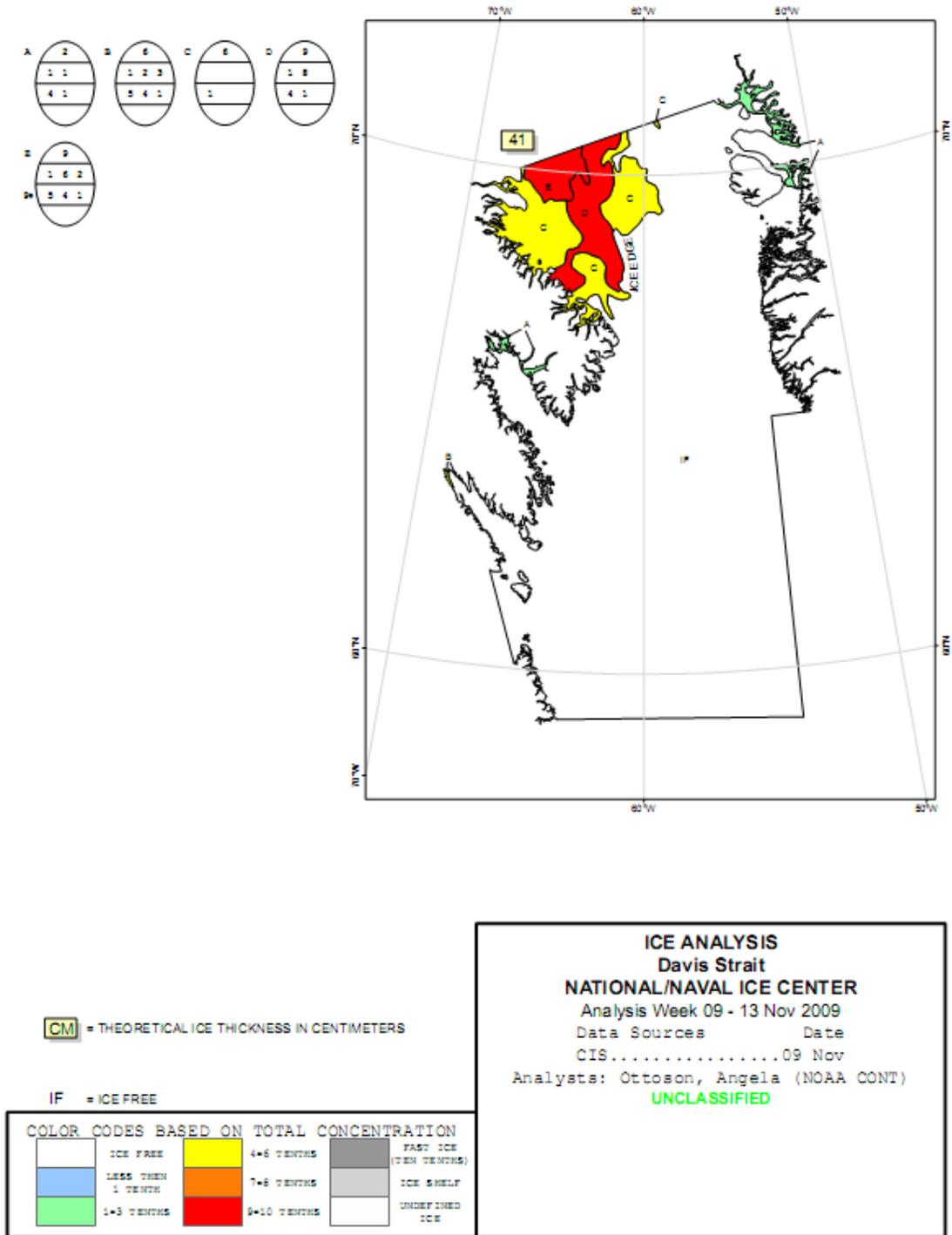


Figure 15. Ice cover and ice edge during 09 - 13 November 2009 (Davis Strait).

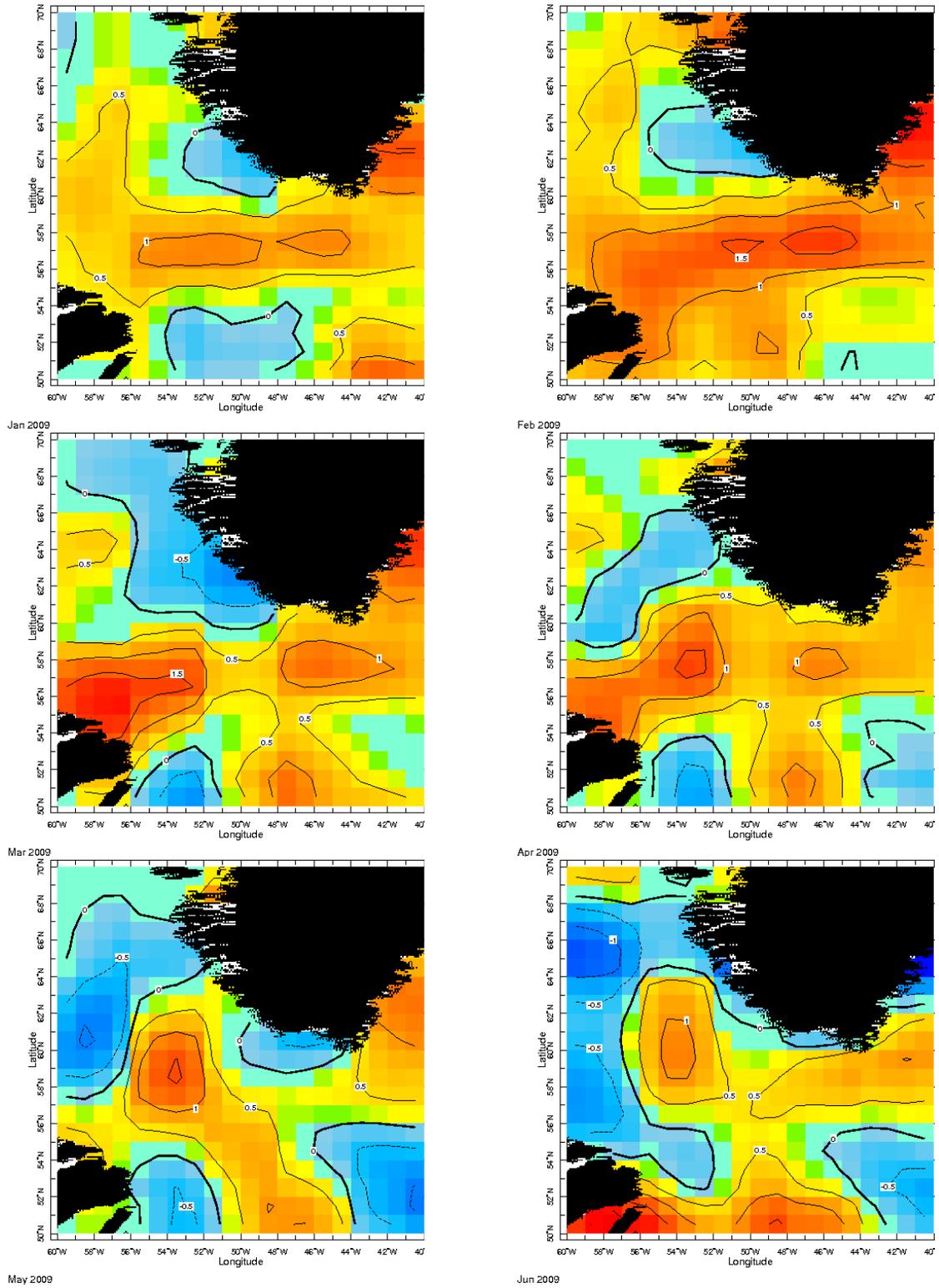


Figure 16. Sea Surface Temperature Anomalies (K) off Greenland and in the Labrador Sea, January-June 2009

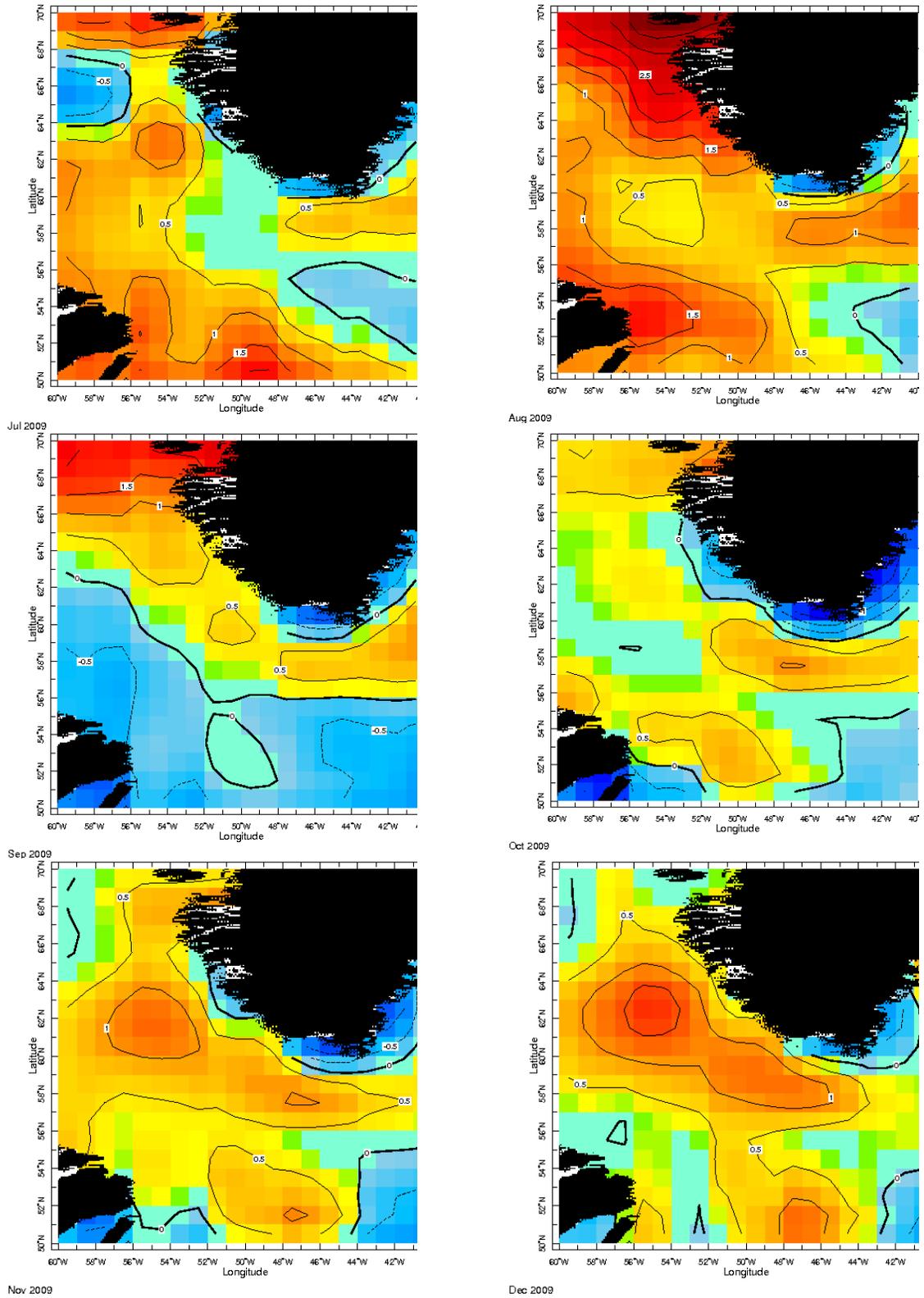


Figure 17. Sea Surface Temperature Anomalies (K) off Greenland and in the Labrador Sea, July- December 2009

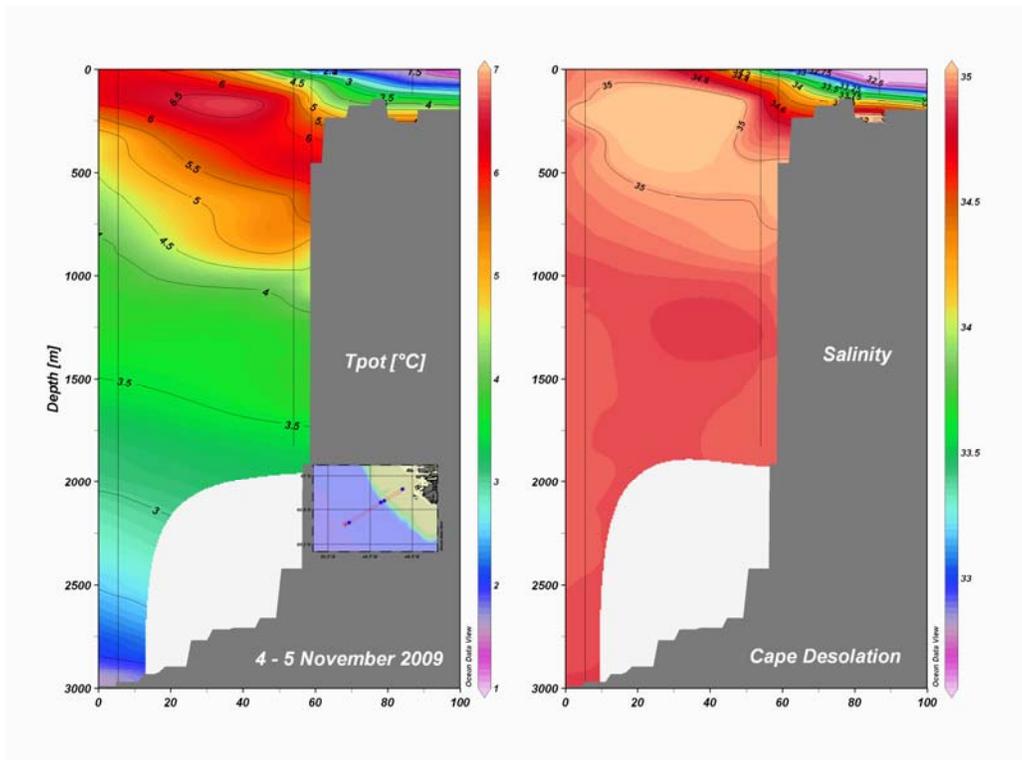


Figure 18. Potential temperature and salinity along Cape Desolation Section (4 – 5 November 2009)

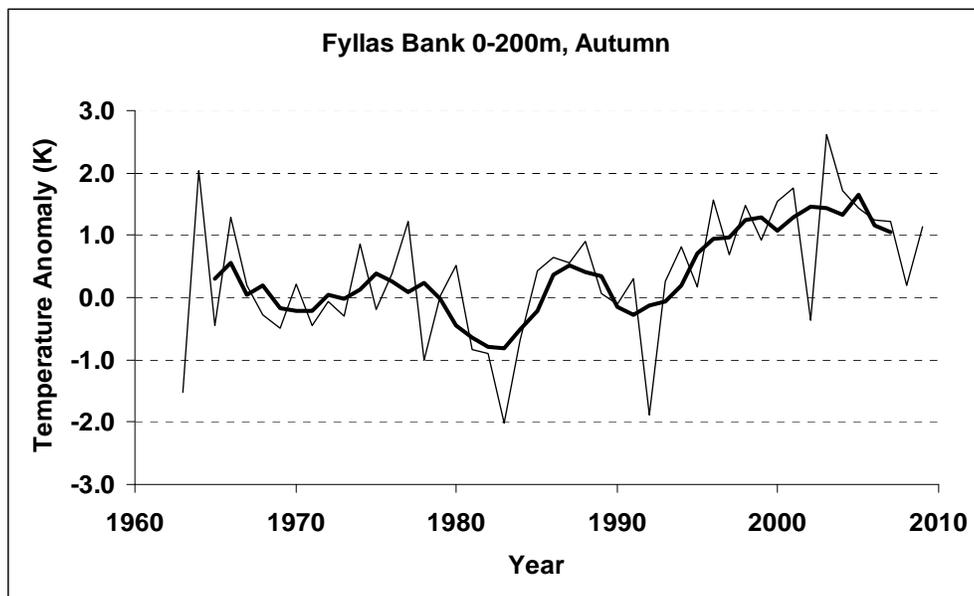


Figure 19 Mean water temperature anomalies of layer 0-200m at station 4 of the Fyllas Bank Section during autumn. Thick line shows the 5-year running mean curve.

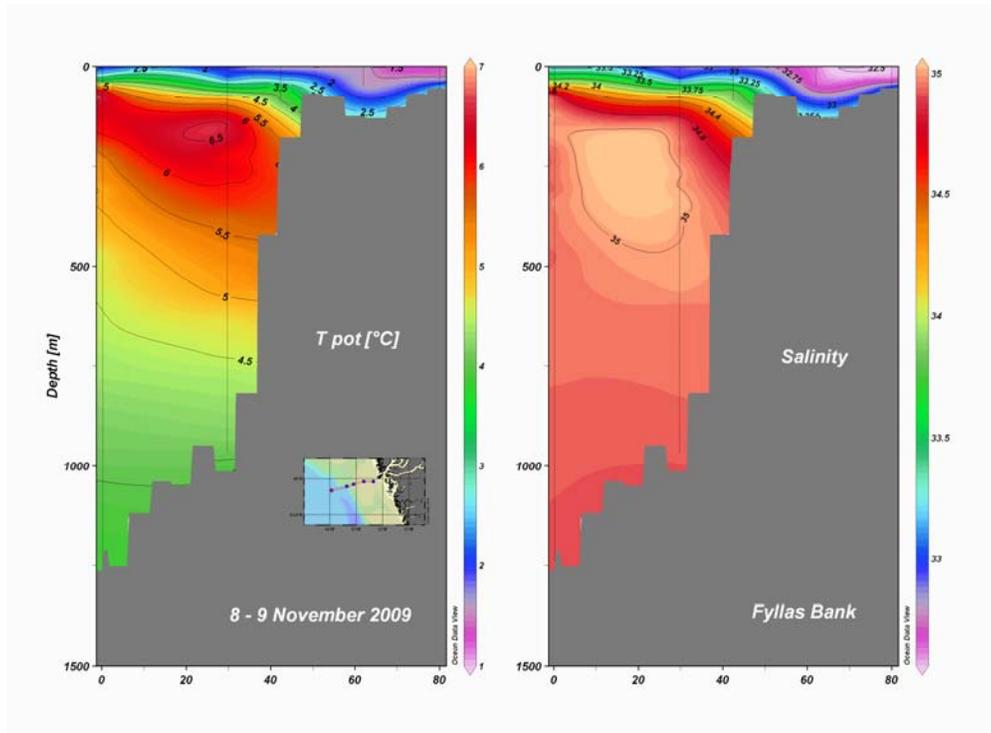


Figure 20. Potential temperature and salinity along Fyllas Bank Section (8 - 9 November 2009)

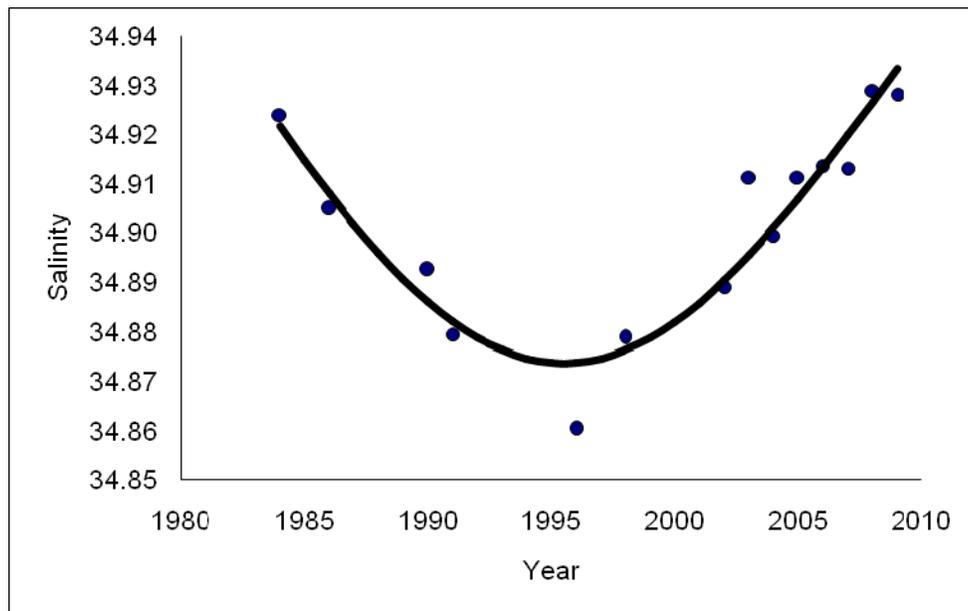


Figure 21. Salinity of calibration samples at Cape Desolation Section station 3, 1500m depth (60°28'N, 50° 00'W). Black points are data, black line is harmonic model adjusted to the data.

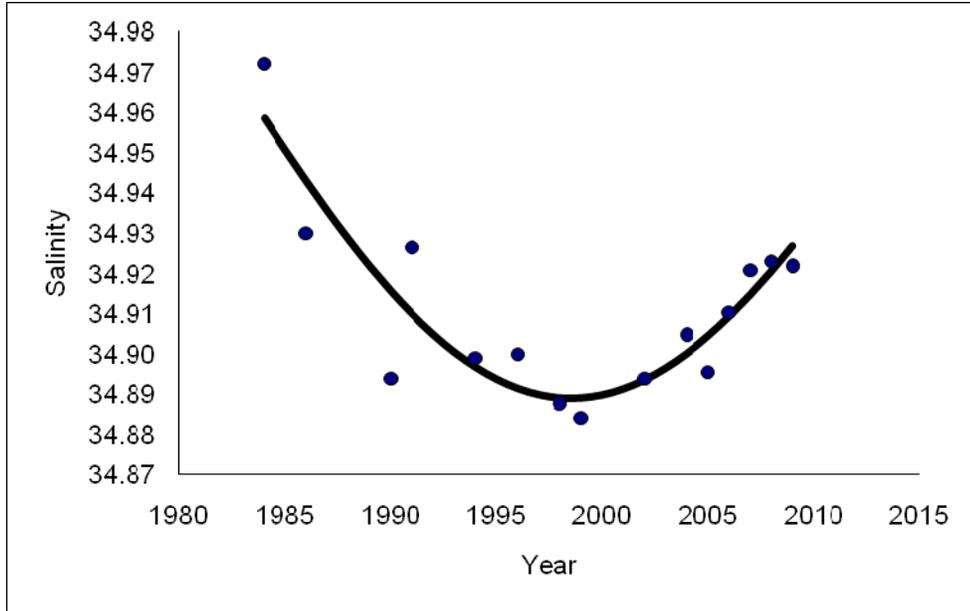


Figure. 22 The same as Figure 21, but at 2000 m depth.

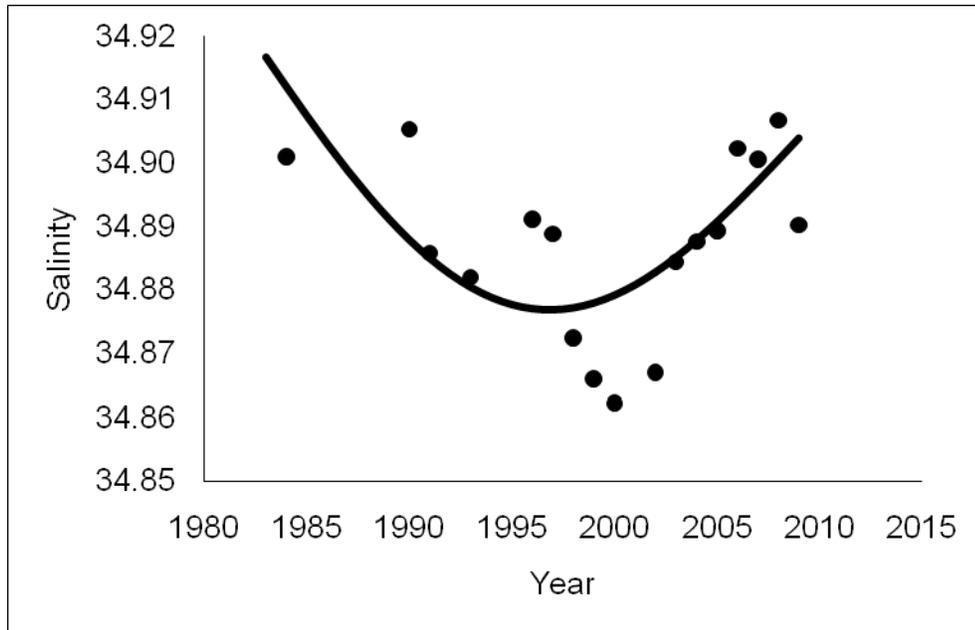


Figure 23. The same as Figure 21, but at 3000 m depth.