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Hydrographic conditions off West Greenland in 2010 in context of interannual and long-term variability.

by

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Abstract

Atmospheric and hydrographic conditions off West Greenland in 2010 are presented based on the CTD (temperature-conductivity-depth) data from German ground fish surveys and satellite observations. North-Atlantic Oscillation index is normally used to describe the atmosphere circulation pattern over the North Atlantic and was strongly negative in 2010. This resulted in extreme warm atmospheric conditions over the whole western North Atlantic. The mean air temperature at Nuuk station in west Greenland was 4.6 °C above its climatological mean and reached its highest value in the whole series of observations since 1876. Based on the satellite data, the sea surface temperature showed positive anomalies up to 4°C over the Greenland shelf and in the Labrador Sea, following the warm atmospheric conditions. The long term trend of the sea surface temperature over the Greenland shelf is found to be almost 0.5°C for the period 1982-2010. Similar positive trend can be seen in the temperature of the subsurface shelf waters, whereas the salinity of these waters shows no significant trend, but strong interannual variability. The salinity and temperature of the Irminger Sea Water component of the West Greenland Current were high in 2010, which can be explained by continued slow phase of the Subpolar Gyre, started mid 1990s.

Introduction

The water circulation pattern off Greenland comprises three main currents: Irminger current, West Greenland and East Greenland currents (Figure 1). The East Greenland current transports fresh and cold Surface Polar Water (SPW) to the south along the eastern coast of Greenland. The Irminger current is a branch of the North Atlantic current. It makes a cyclonic loop in the Irminger Sea and transports salty and warm Irminger Sea Water (ISW) southward along the eastern continental slope of Greenland. South of Greenland both currents bifurcates and spread northward as a single jet of the West Greenland Current. Dynamically the West Greenland Current has a single core near the shelf break, but it is often divided into two components, based on the water properties (*Fratantoni and Pickart*, 2007). The variability of the cold and fresh inshore component is driven by the variability of the SPW and ice transport from the Arctic Ocean, atmospheric heat flux and ice melt (*Holfort et al*., 2008). The temperature and salinity of the ISW offshore component follows those of the Irminger Current and therefore is subject to variations within the Subpolar Gyre. The SPG is known to be weakening since mid 1990s that resulted in substantial warming and salinification of the eastern North Atlantic (*Hatun et al, 2005*). The coinciding increase of the temperature, volume and salinity of the ISW off West Greenland was reported by *Myers et al*., 2007, based on the summer observations.

In this study I report on the atmospheric and hydrographic conditions west off Greenland, observed during the autumn ground fish survey in 2010 and put them in context of interannual and long-term variability. My mainly concern is the water properties over the West Greenland shelf, since they comprise the environment for the demersal fish stocks and are essential for the understanding of the stocks dynamics, and the properties of the warm Irminger Sea Water, which plays an important role in the water temperature variability west off Greenland.

Data

Since 1963 German Institute of Sea Fisheries has carried out autumn ground fish surveys on the western and eastern Greenland shelves (*Stein*, 2010). The oceanographic data collected during these surveys form the basis for interpretation of the oceanic conditions off West Greenland. In October-November 2010 66 unevenly distributed CTD casts were obtained west off Greenland (Figure 1). Standard Cape Desolation and Fyllas Bank sections were occupied on 25th and 27th of October 2010. A SeaBird911+ profiler (www.seabird.com) were used, the salinity samples were taken to calibrate salinity values by means of OSIL Autosal 8400B (www.osil.co.uk). The CTD profiles were averaged into 1-m depth bins. If data was missing at the top of a profile, we assumed constant properties from the first measurement (normally shallow than 15 m depth) up to the surface.

The sea level pressure (SLP) and its anomalies during the winter months (December through March) were taken from NCEP/NCAR Reanalysis data available from the NOAA-CIRES Climate Diagnostics Centre (http://www.cdc.noaa.gov/). To describe the pattern of SLP over the North Atlantic I used Hurrell winter North-Atlantic Oscillation index (NAO), which is based on the principal component (PC) time series of the leading EOF of seasonal (December through March) SLP anomalies over the Atlantic sector (20-80°N, 90W-40°E, *Hurrell*, 1995).

Air temperature at Nuuk station (Figure 2) on the western coast of Greenland was used to characterize the atmospheric conditions in 2010. Monthly mean values were obtained from Goddard Institute for Space Studies of National Aeronautics and Space Administration (NASA), accompanied by the data from the Danish Meteorological Institute. The climatological mean of this timeseries were referenced to 1971-2000.

Sea surface temperature (SST) data were taken from NOAA Optimum Interpolation (OI) SST (Reynolds et al., 2002). The monthly data with 1-degree resolution was provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/ (date of access is 8th of June 2011) and the daily 0.25-degree resolution data (*Reynolds et al*., 2007) were taken from National Climatic Data Center (NCDC, http://www.ncdc.noaa.gov).

Results and Discussion

Atmospheric Conditions

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 NAO. During positive NAO phase, 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 negative NAO phase the westerlies slacken and the weather is normally milder over the whole region.

In winter 2009/2010, the low pressure cell was centered south of Greenland between Irminger and Labrador Basins and was strongly shifted southwest in comparison with its long term position (Figure 3). A similar southwestern replacement was observed for the high pressure cell, normally located over Azores. Both high and low pressure cells were weak in comparison with their long-term means. As a consequence of this pattern, the winter NAO index in 2010 was strongly negative (-4.64). It was the second strongest negative index through the whole time series starting in 1899 (Figure 4).

I would like to notice, that in this study I use PC-based NAO instead of station-based indices, associated with the SLP differences between fixed stations. An advantage of using PC-based indices is that they adequately represent the NAO spatial pattern that becomes important given movements of pressure cells in space, as was observed, for example, in 2010. Furthermore, using PC-based indices allow one to avoid small-scale meteorological events, which affect individual pressure stations. For a detailed discussion of this issue please see *Hurrell and Deser*, 2009.

Following the strong negative winter NAO phase in 2010, the air temperature over the whole Northwest Atlantic was well above its long-term mean (Figure 5). The air temperature at Nuuk (64.36°N, -51.75°W) was 4.6°C above its climatological mean (1971-2000) and reached its record high value since 1876 (Figure 6a). The whole 2010 was warmer than normal, particularly warm were the winter months (Figure 6b).

Water properties over West Greenland shelf

Satellite data indicates strong positive anomalies of the SST around Greenland through all months in 2010 (Figure 7). The negative anomalies were observed only during the summer months along eastern coast of Greenland and associated the East Greenland current. High SST in 2010 was consistent with the above normal air temperature in the region.

To describe the temporal variability of the SST of the shelf waters, I calculated the monthly mean SST over the shelf area bounded by 500m isobath (Figure 8). As one can see from the time series, 2010 as whole and particular in summer was characterized by extremely high SST over the west Greenland shelf, which has been never observed since the beginning of the timeseries in 1982. Generally, the SST shows positive trend of about 0.5°C for the period 1982-2010.

The interannual variability of the bottom water properties over the shelf is believed to play an important role in dynamics of demersal fish stocks west off Greenland (*Stein and Borovkov*, 2004; *Fock*, 2008). Therefore I perform here the analyses of the shelf water temperature and salinity, based on the unevenly distributed CTD data, collected during the German ground fish survey since 1991. Years previous to 1991 were excluded because of their insufficient spatial coverage. The bottom water potential temperature and salinity for each cast are found as the means in 20m-thick layer above the bottom. Based on the similarity of the water properties and their interannual variability, individual stations were combined into two groups: shallow shelf stations with the depth less than 200 m and deep shelf stations with the depth between 200 and 500 m. Such division agrees well with the one, applied by *Rätz*, 1996 to analyze the cod stock in West Greenland water. The interannual variability of the water properties within these two groups is depicted in Figure 9 and discussed below.

Shelf waters off West Greenland are pure SPW above approximately 200 m water depth and a mixture of SPW with mode Irminger Sea Water (mISW) below (Table 1). The water temperature on the shelf increases with the depth that hints to an importance of the subsurface mISW as a heat source. The time series of the bottom temperatures in both layers show significant warming trend (Figure 9a). The bottom water temperature in 2010 didn't exceed the peak, observed in 2003 in contrast to the SST, which was the highest in 2010 (Figure 8). Salinity of the bottom water show significant interannual variability with almost no trend (Figure 9b). The bottom salinity within upper 200 m was 33.6, which is one of the lowest values during the whole series of the observations. It is probably a consequence of the intense ice melting due to the warm atmospheric conditions, described above.

Variability of Irminger Sea Water component of West Greenland Current

The variability of the ISW is monitored normally at Cape Desolation and Fyllas Bank sections, which span across the shelf and the continental slope off West Greenland (Figure 2). The Cape Desolation section is situated 300 km northwest from the southern tip of Greenland. The Fyllas Bank section is situated further to the north over the broad shallow Fyllas Bank that affects strongly the structure of the West Greenland Current (Myers et al., 2009).

To describe the variability of the warm and saline ISW, we considered the water properties at the most offshore stations within each section (Figure 10 and

Figure 11). Observations along both sections show a continuous increase of ISW temperature and salinity started mid 1990s. This finding agrees with the previous studies of *Yashayaev, 2007* and *Myers et al., 2007* who used summer observations off West Greenland. The observed warming of the ISW in the WGC coincides with temperature increase at other locations within Subpolar Gyre (e.g. Irminger Current south of Iceland, see *Hátún et al.*, 2005) and is believed to be cause by weakening of the Subpolar Gyre started a decade and a half ago (*Häkkinen and Rhines*, 2004; *Hátún et al.*, 2005). In 2010, the Subpolar Gyre was still slow (Figure 12, H.Hatun, *pers. communication*) that resulted in warmer and more saline ISW in comparison with its long-term mean, calculated for the whole period of observations (Figure 13).

Summary

The general conclusions about the atmospheric and oceanic conditions west off Greenland in autumn 2010 are follows. The NAO was strongly negative in winter 2010. Consequently the air temperature was unusual high during the whole year, and the annual air temperature was the highest since 1876. The SST over the west Greenland shelf was the highest since the beginning of observations in 1982. The potential temperature and salinity of ISW was lower than in 2009, but continued the warm and salty phase started in early 1990s. This warm phase is associated with the slow phase of the Subpolar Gyre, which has continued in 2010.

Acknowledgements

I would like to acknowledge I. Nunez-Riboni for a fruitful discussions, H. Hatun for providing Subpolar Gyre index, crew of RV ”Walther Herwig 3”, scientific group of Institute of Sea Fisheries and particular Heino Fock for gathering the data.

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Table 1. Water mass properties in the area of research.

The water masses in the area	Potential temperature (θ)	Salinity (S)
Surface Polar Water (SPW)	$\theta \leq 0$	$S \leq 34.4$
Irminger Sea water (ISW)	$\theta \geq 4.5$	$S \geq 34.95$
Modified ISW (mISW)	$3.5 \leq \theta \leq 5$	$34.88 < S < 34.95$

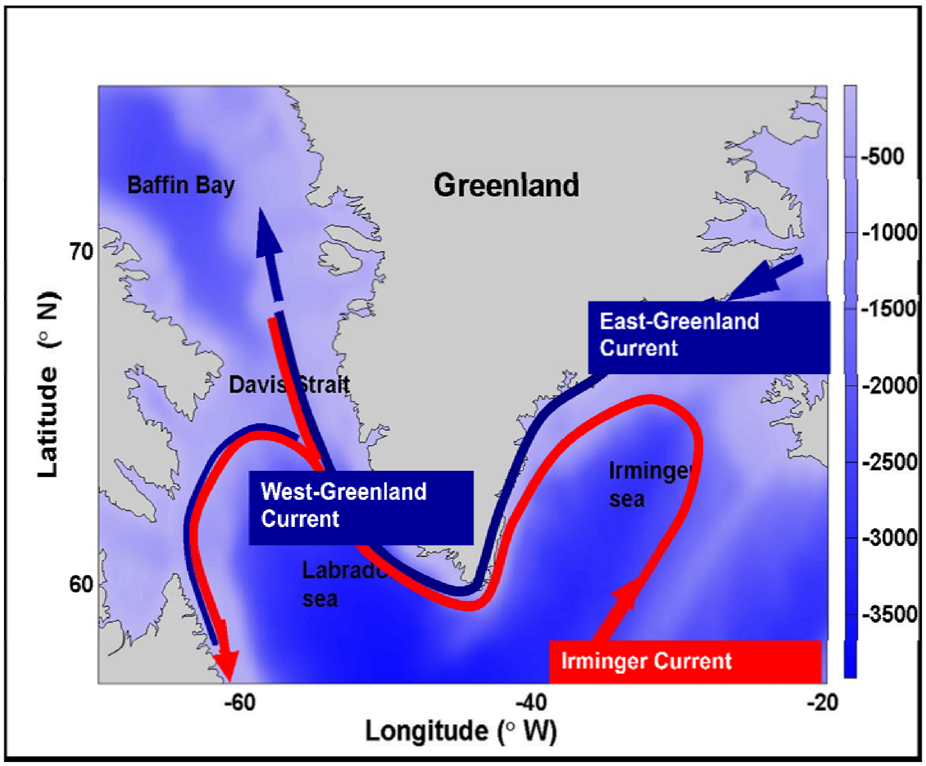

Figure 1. Scheme of the upper ocean circulation in the area of research. Red and blue curves show the trajectories of Irminger Sea Water and Surface Polar Water correspondingly.

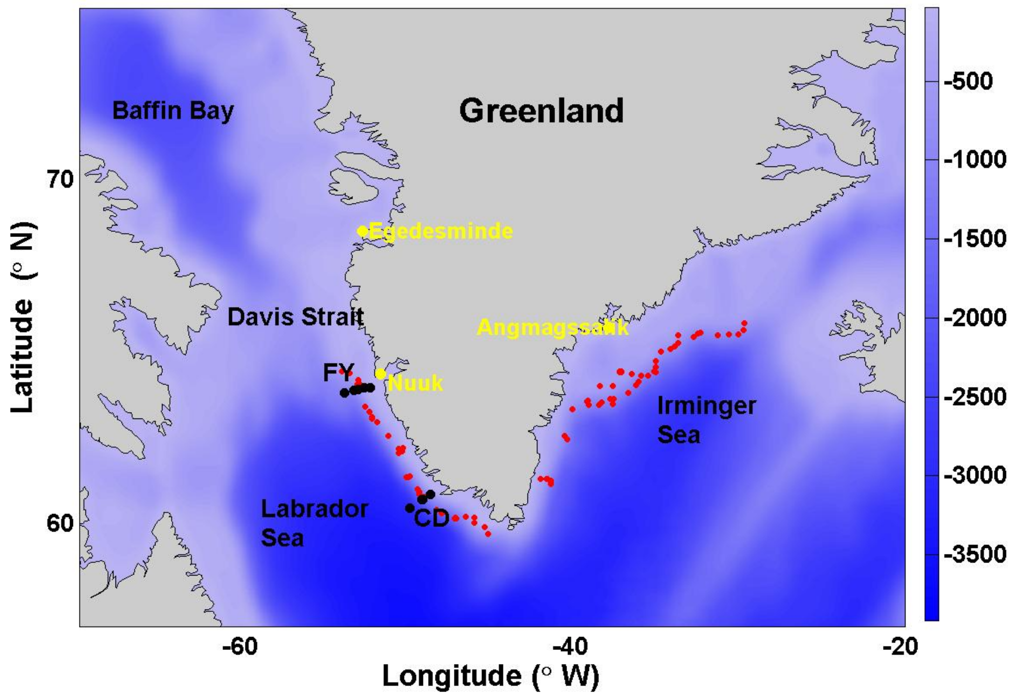

Figure 2. Map and bathymetry of the study region. Meteorological stations are shown in yellow. Red dots mark CTD stations, occupied during the survey in 2010. Black dots show two standard NAFO sections (CD – Cape Desolation section, FY – Fyllas Bank Section).

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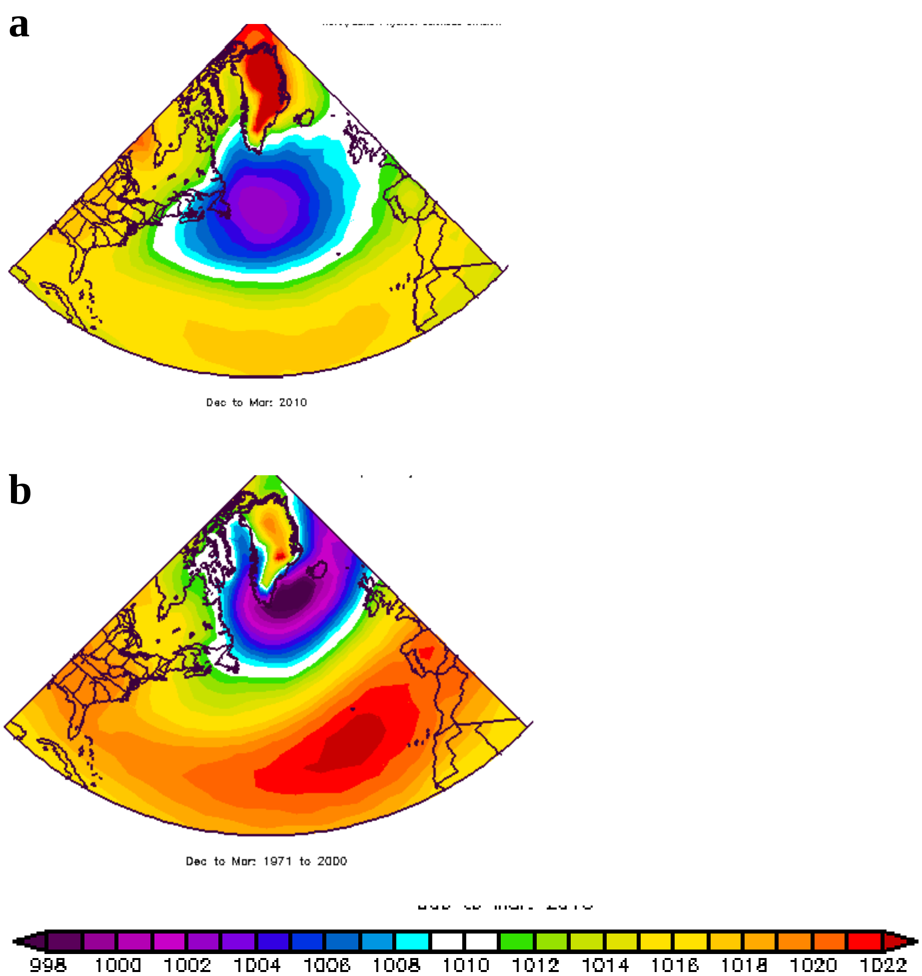

Figure 3 Sea level pressure in winter (December through March) 2010 and long-term (1971 to 2000) mean sea level pressure, as derived from NCEP/NCAR reanalyzes.

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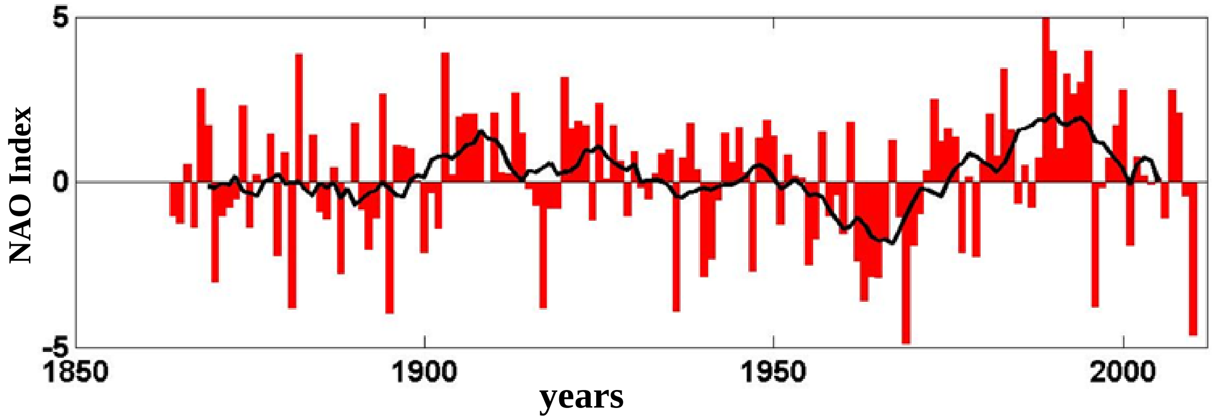

Figure 4. Hurrel winter NAO Index from 1899 to 2010, based on the principal component time series of the leading EOF of seasonal (December through March) sea level pressure anomalies over the Atlantic sector (20-80°N, 90°W-40°E). Red bars show the index, black line shows 5-year running mean.

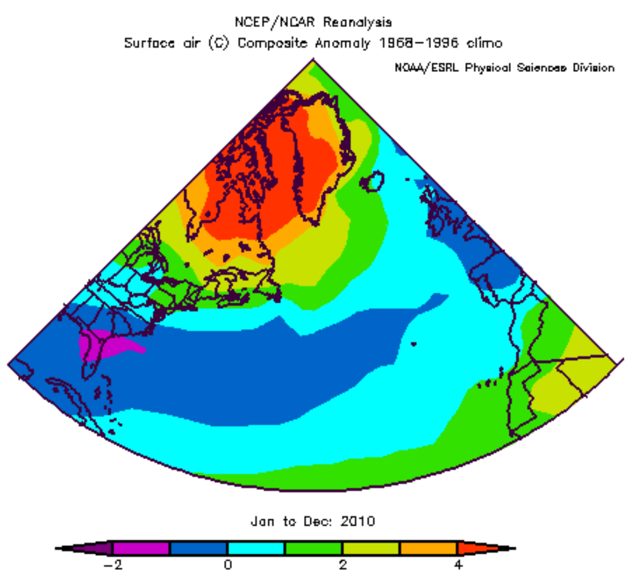

Figure 5. Annual air temperature anomalies in 2010 referenced to period 1968-1996, as derived from NCEP/NCAR reanalyzes.

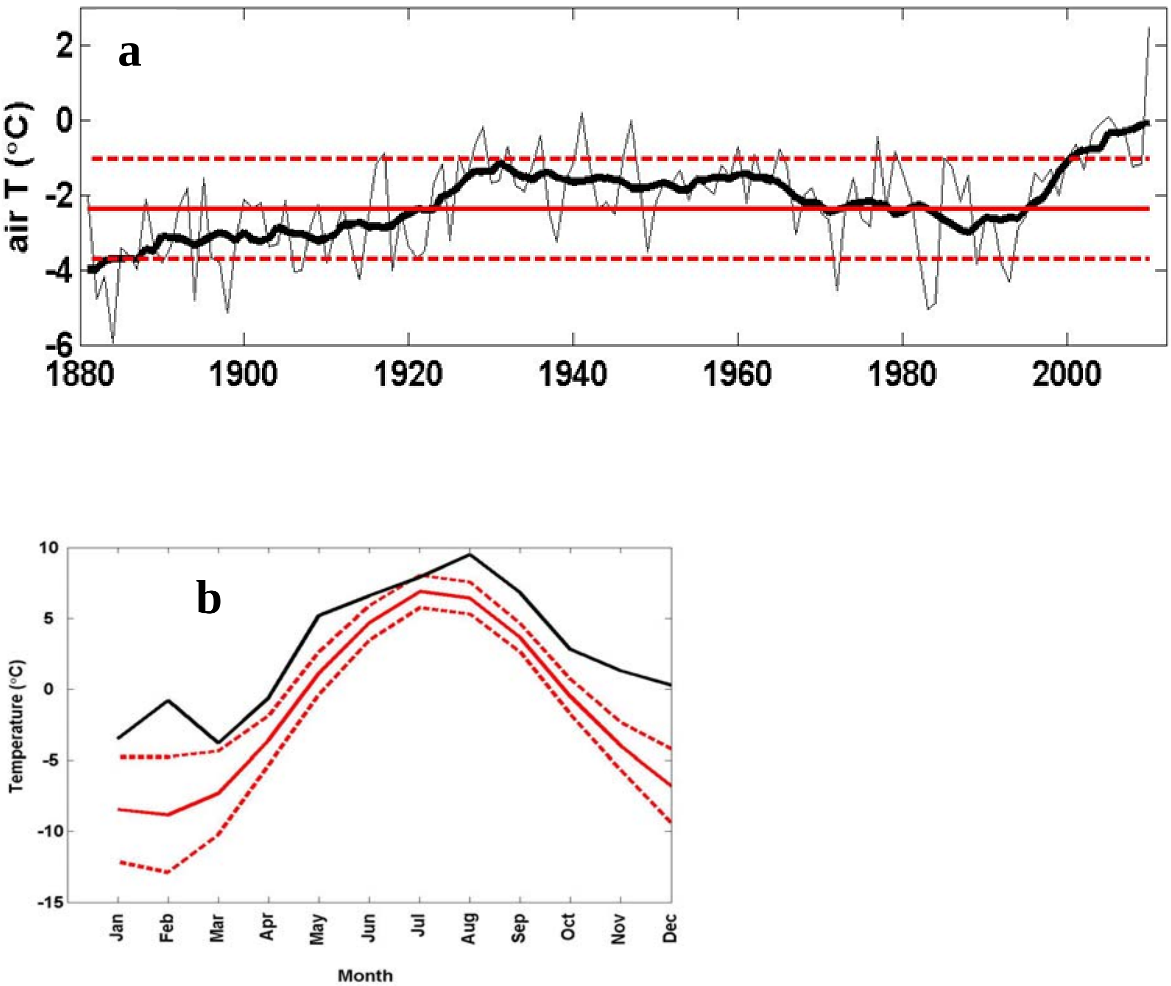

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Figure 6. Air temperature at Nuuk station (Figure 2). Panel *a* illustrates the annual mean temperature (thin black curve), 13-year running mean (thick black curve), The seasonal circle of the air temperature in 2010 is shown on panel *b* by black curve. On both panels red solid curves show long-term mean (1971-2000) and red dashed curves mark one standard deviation.

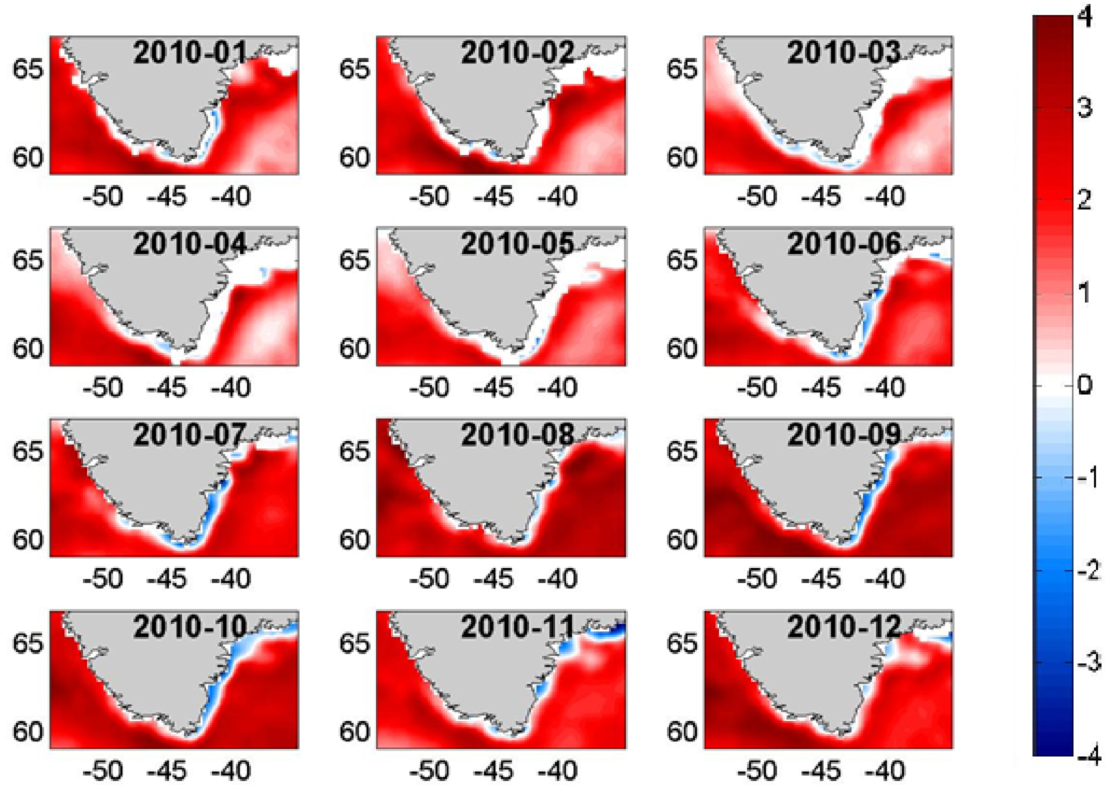

Figure 7. Monthly mean sea surface temperature anomalies around Greenland in 2010. Daily Optimal Interpolation SST (OISSTv2) with the spatial resolution of 0.25° is used. The anomalies are referenced to period 1971-2000.

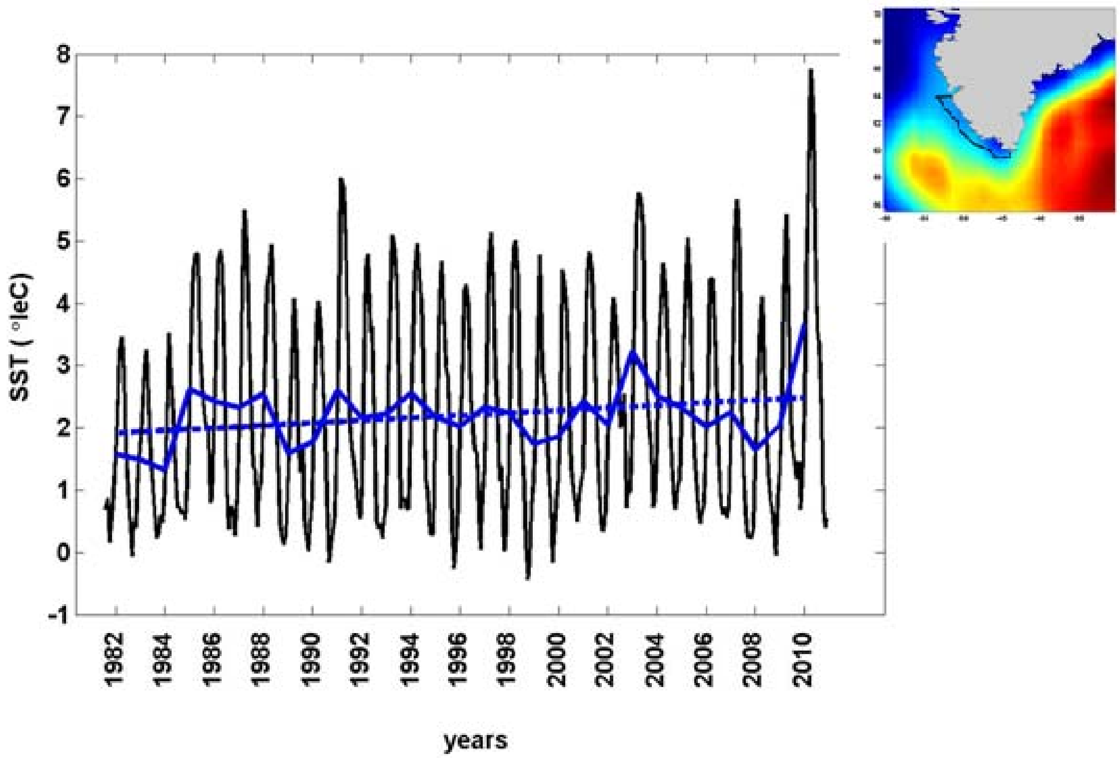

Figure 8. Monthly mean (black curve) and annual mean (blue solid curve) sea surface temperature over the shelf of West Greenland. The area of data averaging is shown by black curve on the inset panel. The blue dashed line depict the linear trend. Monthly Optimal Interpolation SST (OISSTv2) with the spatial resolution of 1° is used.

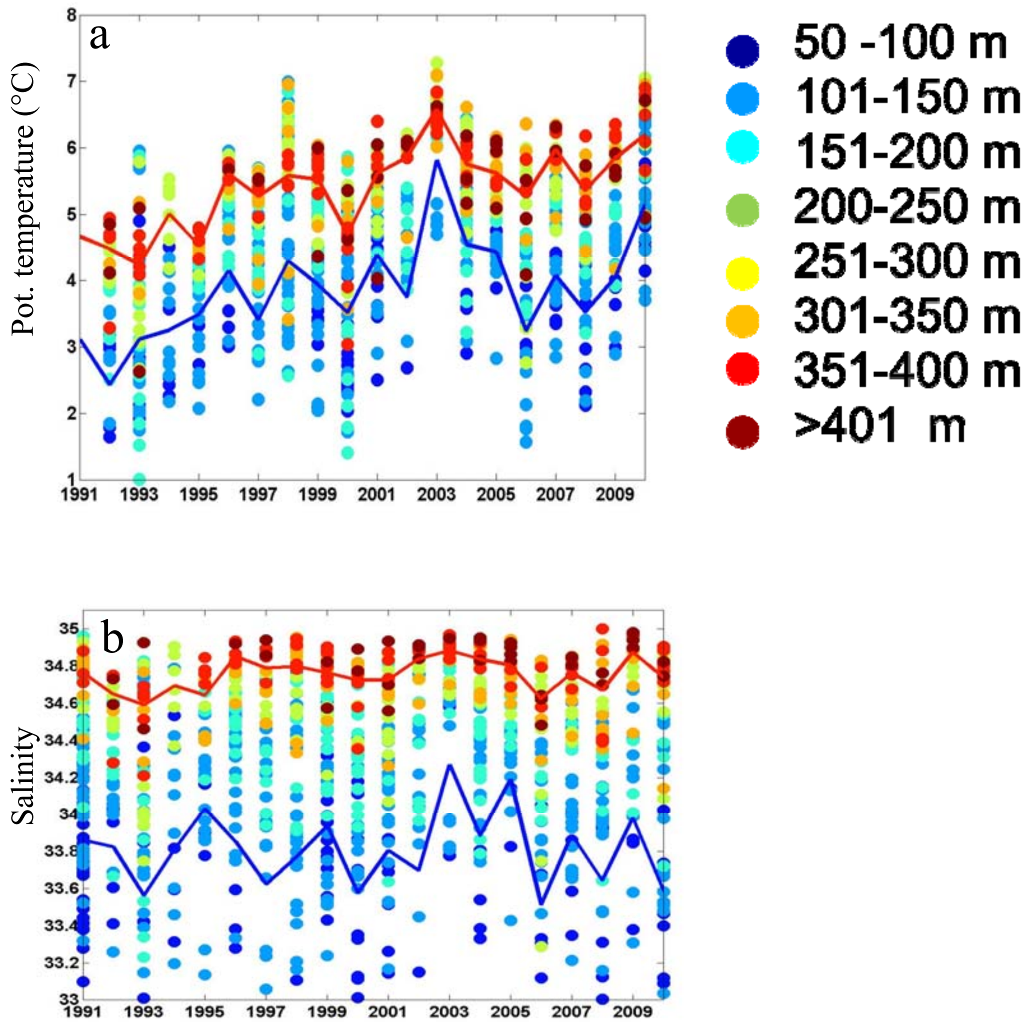

Figure 9. Potential temperature (*a*) and salinity (*b*) of the bottom waters over the West Greenland shelf. Circles mark the individual casts, the color of the circles codes the maximal observed water depth. Blue curves on both panels show the properties of the water shallower than 200 m water depth, red curves show the mean properties of the bottom water between 200 and 500 m water depth.

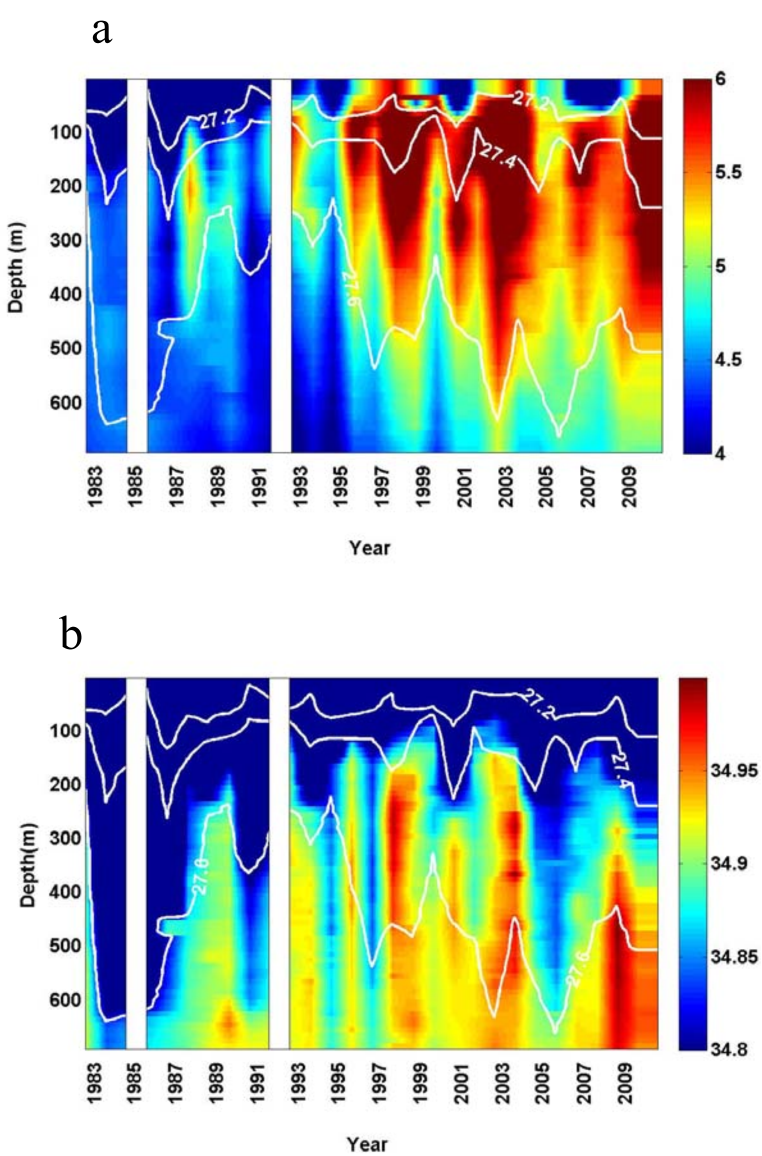

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Figure 10. Hovmoeller diagram of potential temperature (*a*) and salinity (*b*) in the upper 700 m along Cape Desolation section in 1983-2010. The temperature and salinity are isobaric averaged over two offshore stations. White curves show the potential density.

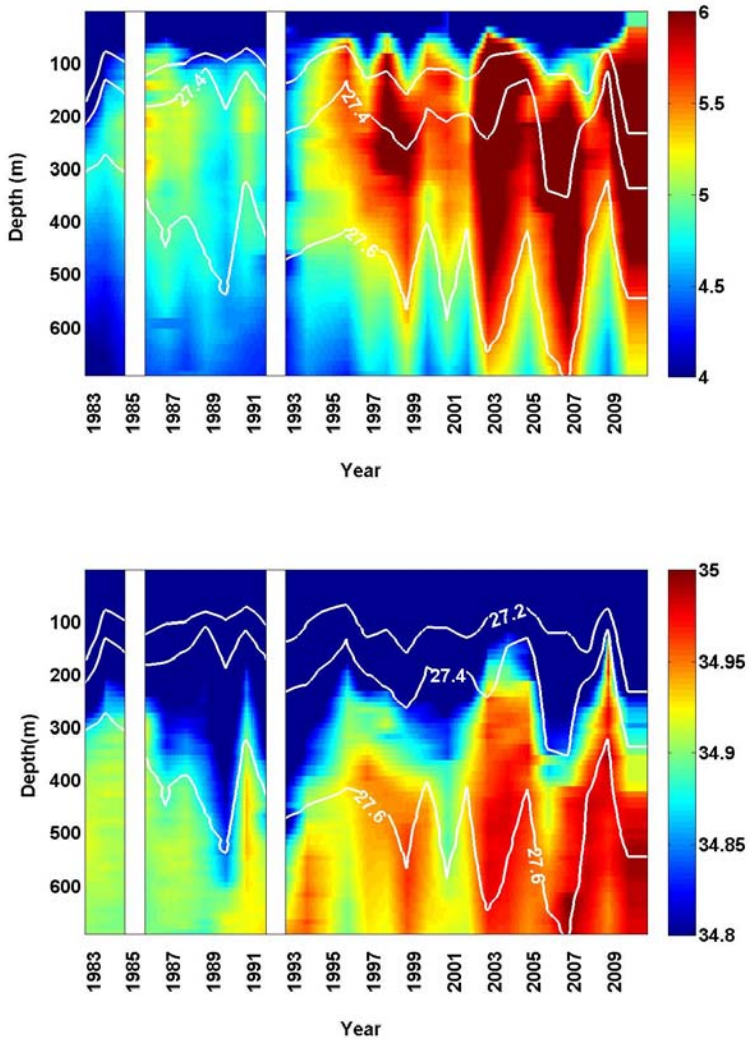

Figure 11. The same as Figure 10, but for the Fyllas Bank Section.

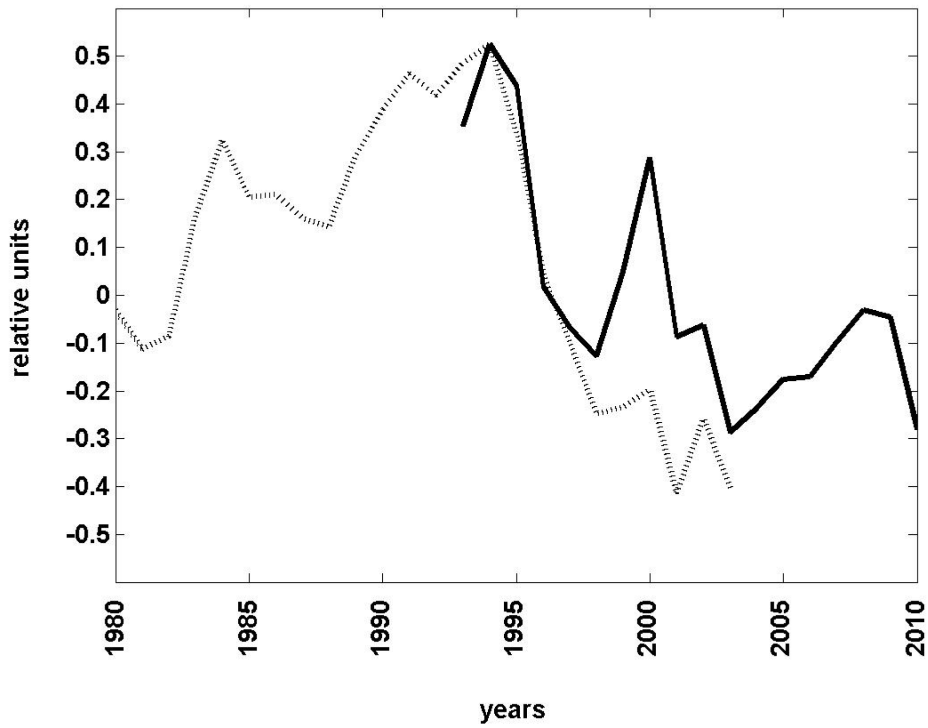

Figure 12 Observed (solid line) and modeled (dashed line) Subpolar Gyre Index, associated with principal component of the leading North-Atlantic sea surface height mode (H.Hatun, pers. communication). For more detail please see *Hátún et al.*, 2005

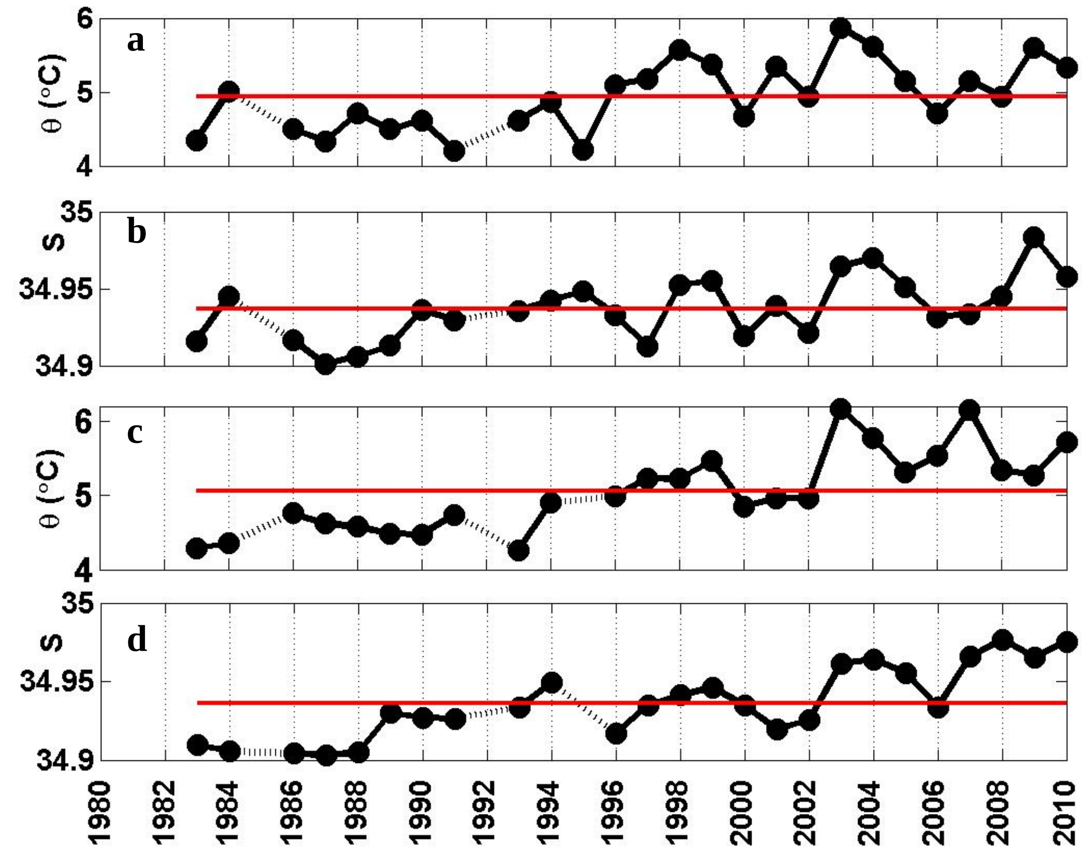

Figure 13. Mean potential temperature and salinity of Irminger Sea Water at Cape Desolation section (panels *a*, *b*) and Fyllas Bank section (panels *c*, *d*). Irminger Sea Water is defined as in Table 1. Red lines show long-term means of characteristics for the whole period of observations (1983-2010).