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Hydrographic conditions off West Greenland in 2016

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Abstract

An overview of the atmospheric and hydrographic conditions off West Greenland in autumn 2016 is presented. In winter 2015/2016, the NAO index was positive (0.98). The annual mean air temperature at Nuuk weather station in West Greenland was 0.6°C in 2016, which was 2.0°C above the long-term mean (1981-2010). The core properties of the water masses of the West Greenland Current (WGC) are monitored annually at two standard NAFO/ICES sections across the western shelf and continental slope of Greenland near Cape Desolation and Fyllas Bank. However, the Fyllas Bank Section had to be abandoned due to severe weather conditions in autumn 2016. The properties of the Irminger Sea Water (ISW) are monitored in the 75-200 m layer at Cape Desolation Station 3. In 2016, the water temperature and the salinity of the ISW was 5.44°C and 34.84, which was 0.27°C and 0.08 below the long-term mean, respectively. The properties of the North Atlantic Deep Water (NADW) in the Deep Boundary Current west of Greenland are monitored at 2000 m depth at Cape Desolation Station 3. Since the beginning of the 1990s, temperature and salinity were decreasing and reached their minimum values in 1998 and 1997, respectively. After that, the temperature of the NADW revealed a positive trend until 2014, whereas its salinity rather

stagnated between 2007 and 2014. In 2016, the temperature increased and salinity stagnated, and were 0.1°C and 0.02 above the long-term mean.

Introduction

The water mass circulation off Greenland comprises three main currents (Fig. 1): Irminger Current (IC), West Greenland (WGC) and East Greenland Currents (EGC). The EGC transports ice and cold low-salinity Surface Polar Water (SPW) to the south along the eastern coast of Greenland. On the inner shelf the East Greenland Coastal Current (EGCC), predominantly a bifurcated branch of the EGC, transports cold fresh Polar Water southward near the shelf break (Sutherland and Pickart, 2008). The IC is the northward flowing component of the North Atlantic subpolar gyre. It transports relatively warm water that mixes with colder water transported by the EGC from the Arctic Ocean. Fig. 2 reveals warm and salty Atlantic Waters flowing northward along the Reykjanes Ridge. South of the Denmark Strait (DS) the current bifurcates. While a smaller branch continues northward through the DS to form the Icelandic Irminger Current, the bulk of the current recirculates to the south and transports salty and warm ISW southward along the eastern continental slope of Greenland. South of Greenland both currents bifurcate and spread northward as a single jet of the West Greenland Current (WGC). The WGC carries the water northward and consists of two components: a cold and fresh inshore component, which is a mixture of the SPW and melt water, and a saltier and warmer ISW offshore component. The WGC transports water into the Labrador Sea, and hence is important for Labrador Sea Water formation, which is an essential element of the Atlantic Meridional Overturning Circulation. The dynamics of the current is monitored yearly in autumn at two standard ICES/NAFO oceanographic sections across the slope off West Greenland (Fig. 3).

Materials and Methods

The German groundfish survey off Greenland has been conducted since 1981, aiming at monitoring groundfish stocks, cod and redfish in particular. The monitoring is carried out by the Thünen-Institute of Sea Fisheries (TI-SF) and reveals significant interannual and long-term variability of both components of the WGC. Hydrographic profiles were collected with a Sea-Bird 911plus CTD attached to a 12-bottle water sampler. The hydrographic database consisted of 36 hydrographic stations sampled between October 22 and November 11, 2016, from R/V *Walther Herwig III*. Study area and station locations are shown in Figure. 3. For in-situ calibration, salinity samples were analyzed with an OPTIMARE Precision Salinometer (OPS) immediately after the cruise. The CTD data were averaged to 1 m depth bins. If CTD data were missing from the near the surface of a profile, constant properties were assumed from the first measurement (normally 2–7 m) 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, Hurrell's winter (December through March) station based index of the North-Atlantic Oscillation was used (Hurrell, 1995). This index based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Reykjavik, Iceland since 1864 and is available at https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based.

Air temperature at Nuuk station (Table 1) on the western coast of Greenland was used to characterize the atmospheric conditions in 2016. Annual and monthly mean values were obtained from the Danish Meteorological Institute. The climatological mean of this time series was referenced to 1981-2010. Information about sea surface temperature anomalies was provided by

NOAA/ESRL Physical Science Division, Boulder, Colorado, based on objective interpolation product (NOAA OI SST, Reynolds *et al.*, 2002).

Results and Discussion

Atmospheric conditions in 2016

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 the air temperatures over Greenland, Labrador Sea and 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 2015/2016, the NAO index was positive (0.98) for the third consecutive winter but was weaker than these 2 preceding winters (Fig. 4). Figure 5a shows the winter sea level pressure (SLP) averaged over 30 years (1981-2010), mainly dominated by the Iceland Low and the Azores High. Both the Icelandic Low and the Azores High were strengthening, resulting in an greater than normal increase in pressure difference over the North Atlantic sector during the winter of 2015/2016 (Fig. 5b). The resulting negative anomalies in the north and the positive in the south reveal characteristics typical of a positive NAO (Fig. 5c). Air temperature at Nuuk was used to characterize the atmospheric conditions in 2016. Annual and monthly mean values were obtained from the Danish Meteorological Institute (Cappelen, 2013). In 2016, the monthly mean air temperatures between January and August were higher than the long-term mean (Fig. 6). Greenland witnessed its highest June temperature ever recorded on June 9 2016 when the daily air temperature at Nuuk reached 24°C. The resulting annual mean temperature at Nuuk was 0.6°C in 2016, which was 2.0°C above the long-term mean (1981-2010) (Fig. 7).

Hydrographic Conditions in 2016

The core properties of the water masses of the WGC are formed in the western Irminger Basin where the EGC meets the IC. The EGC transports fresh and cold SPW of Arctic origin. The IC is the northward flowing component of the North Atlantic subpolar gyre and circulates cyclonically around the Iceland Basin and carries warm and saline ISW. After the currents converge, they turn around the southern tip of Greenland, form the WGC and propagate northward along the western coast of Greenland. During this propagation considerable mixing between two water masses takes place and the ISW gradually deepens (Clarke and Gascard, 1983; Myers *et al.*, 2009). There is more than one definition of the water masses carried by the WGC (Clarke and Gascard, 1983; Stein, 2005; Schmidt and Send, 2007; Myers *et al.*, 2009). Here I consider the upper layer down to 700 m water depth and define SPW and ISW following the nomenclature of Myers *et al.*, 2009 (Table 2). The annual sea surface temperature (NOAA OI SST) anomalies for 2016 indicate positive anomalies in the Northwestern Atlantic with highest values occurring northeast of Iceland and along the coast of East Greenland (Fig. 8), whereas negative anomalies were observed in the central area of the North Atlantic.

The core properties of the water masses of the West Greenland Current (WGC) are monitored at a standard NAFO/ICES section across the western shelf and continental slope of Greenland near Cape Desolation. The Cape Desolation section is located 300 km northwest from the southern tip of Greenland. At this section a strong surface front separates PSW on the shelf from ISW offshore (Fig. 9). In autumn, the temperature of the upper layer is well above zero (Θ_{Min} = 2.88°C) due to the summer heat accumulation, and hence only the salinity can be used as a tracer of the SPW (Fig. 9a). A surface salinity of about 31 was observed at station 540 (Fig. 9b). The most offshore station of the section done in 2016 (Station 537) corresponds to the standard Cape Desolation Station 3, which was reported in ICES WGOH since 2001 (Stein, 2010). In 2016, the water temperature of the upper 700 meters was lower than its long-term mean, whereas the salinity reveals strong negative anomalies between 20 and 150 m water depth (Figs. 10a, b). In 2016, the water temperature and the salinity in the 75-200 m layer at Cape Desolation Station 3 was 5.44°C (Fig. 11a) and 34.84 (Fig. 11b), which was 0.27°C and 0.08 below the long-term mean, respectively. The properties of the North Atlantic Deep Water (NADW) in the deep boundary current west of Greenland are monitored at 2000 m depth at Cape Desolation Station 3. The temperature and salinity of this water mass underwent strong interannual variability during the 1980s (Fig. 12). Since the beginning of the 1990s, both characteristics were decreasing and reached their minimum values in 1998 and 1997, respectively. After that, the temperature of the NADW revealed a positive trend until 2014, whereas its salinity rather stagnated between 2007 and 2014. In 2016, the temperature increased and salinity stagnated, and were 0.1°C and 0.02 above the long-term mean (Fig. 12a and b).

Tables

Table 1. Details on the times series, analysed in this study.

Name	Lat (°N)	Lon (°W)	Type	Source
Nuuk (4250)[1]	64.17	51.75	Weather station	DMI
Nuuk airport (4254)[1]	64.20	51.68	Weather station	DMI
Cape Desolation Station 3	60.47	50.00	Oceanographic station	TI-SF
Fyllas Bank Station 4	63.88	53.37	Oceanographic station	TI-SF

Table 2. Water mass characteristics in the study area.

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)	$\theta \geq 4.5$	$S \geq 34.95$

[1] In recent years, Nuuk air temperature was taken from the Nuuk airport synop station 04254 due to a failure on Nuuk synop station 04250 (Cappelen, 2013).

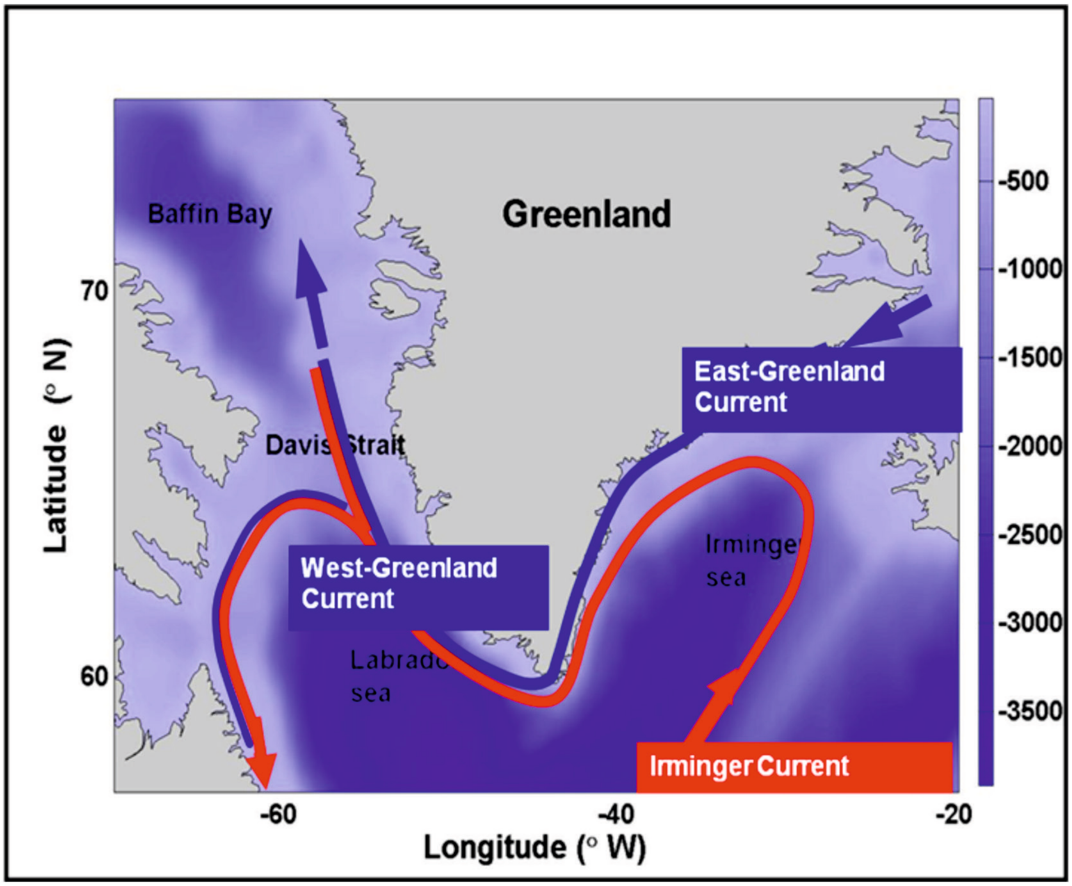


Fig. 1 Scheme of the upper ocean circulation in the study area. Red and blue curves show the trajectories of warm Irminger Sea Water and cold Surface Polar Water, respectively.

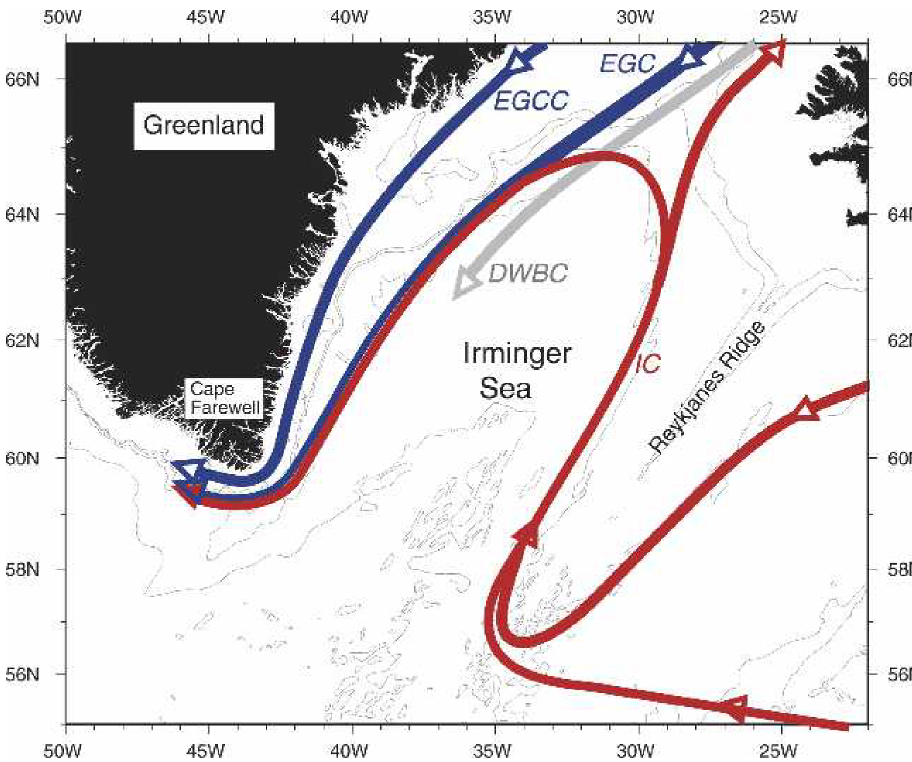


Fig. 2 Schematic of the boundary currents of the Irminger Sea (depicted from Pickart et al., 2005)

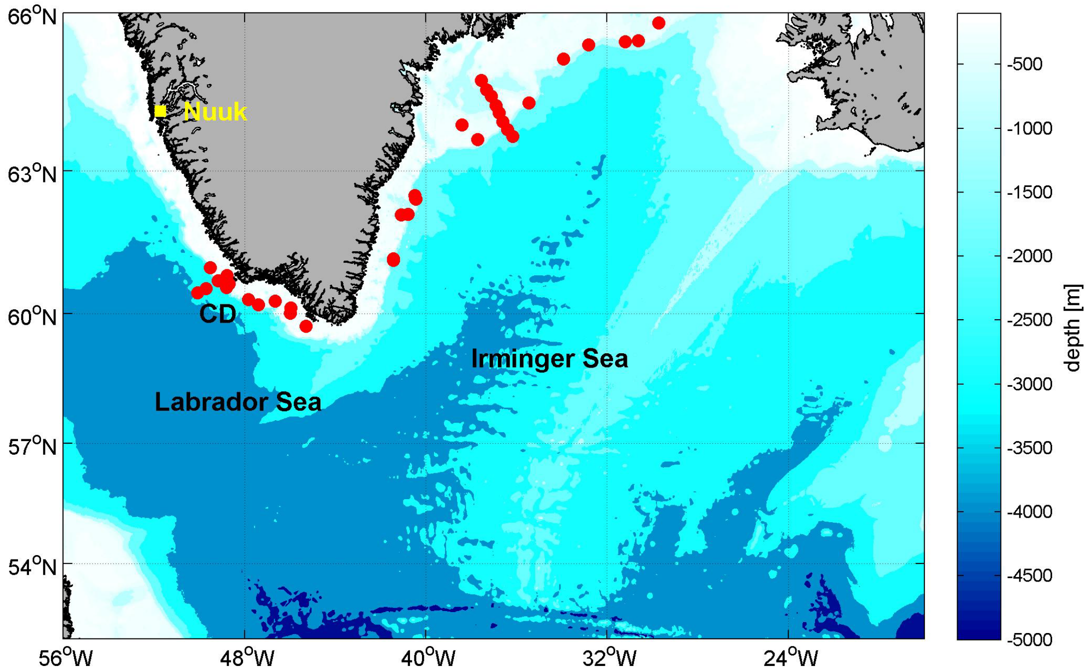


Fig. 3 Map and bathymetry of the study region. Meteorological station location is shown in yellow. Red dots show the location of the CTD stations, conducted during the survey in 2016. The Fyllas Bank Section had to be abandoned due to severe weather conditions (geographic coordinates are given in table 1).

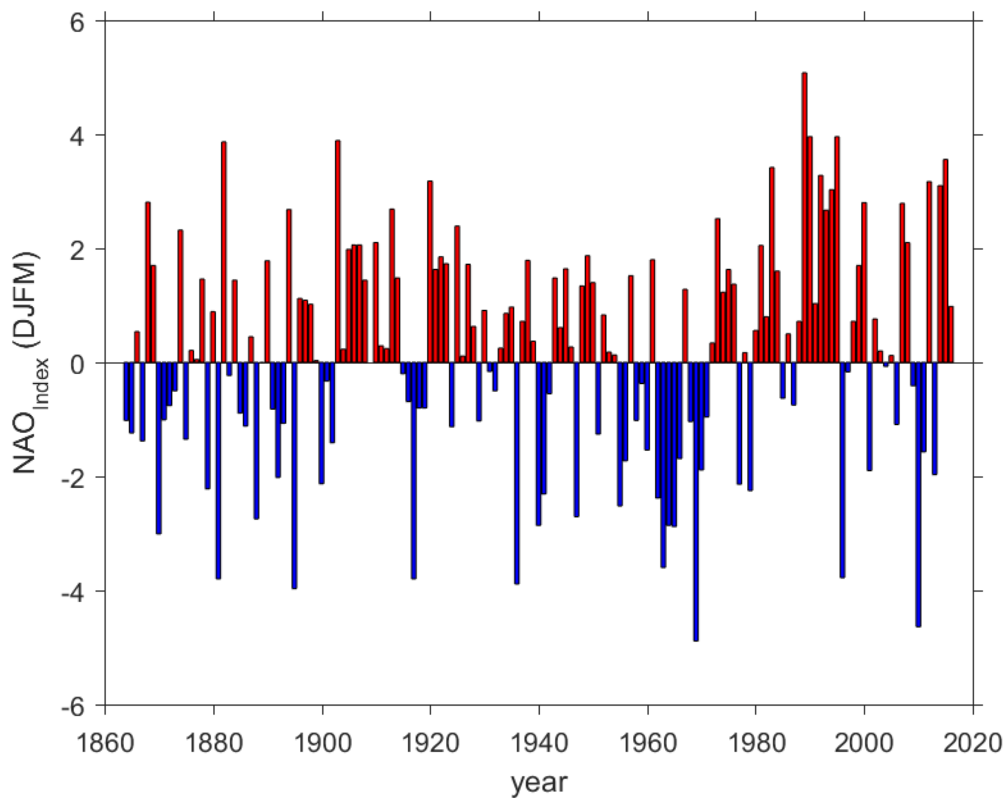


Fig. 4 The Hurrell winter (DJFM) NAO index.

Data source: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based

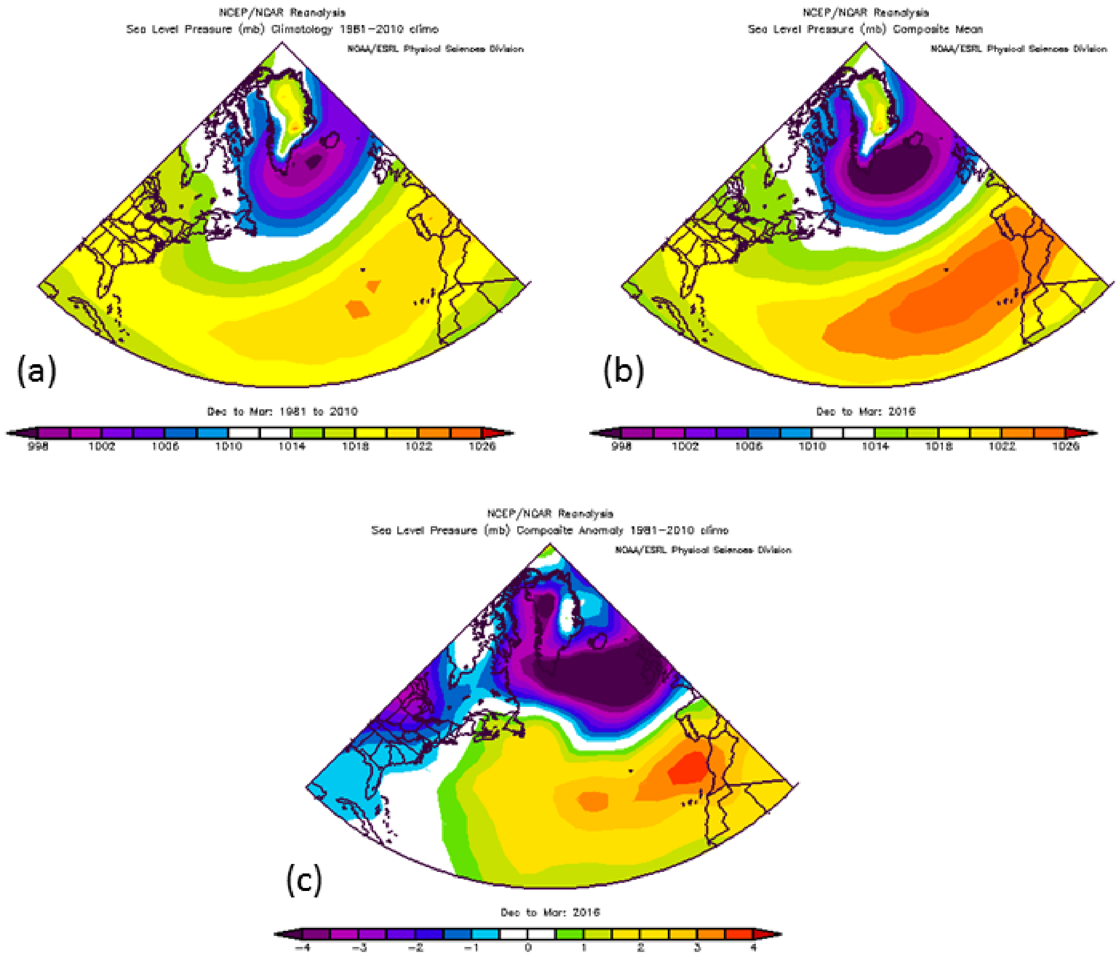


Fig. 5 Maps of winter 1981-2010 (DJFM) mean sea level pressure (SLP) **(a)**, winter 2016 SLP **(b)**, and resulting SLP anomaly **(c)** over the North Atlantic. *Images are provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*

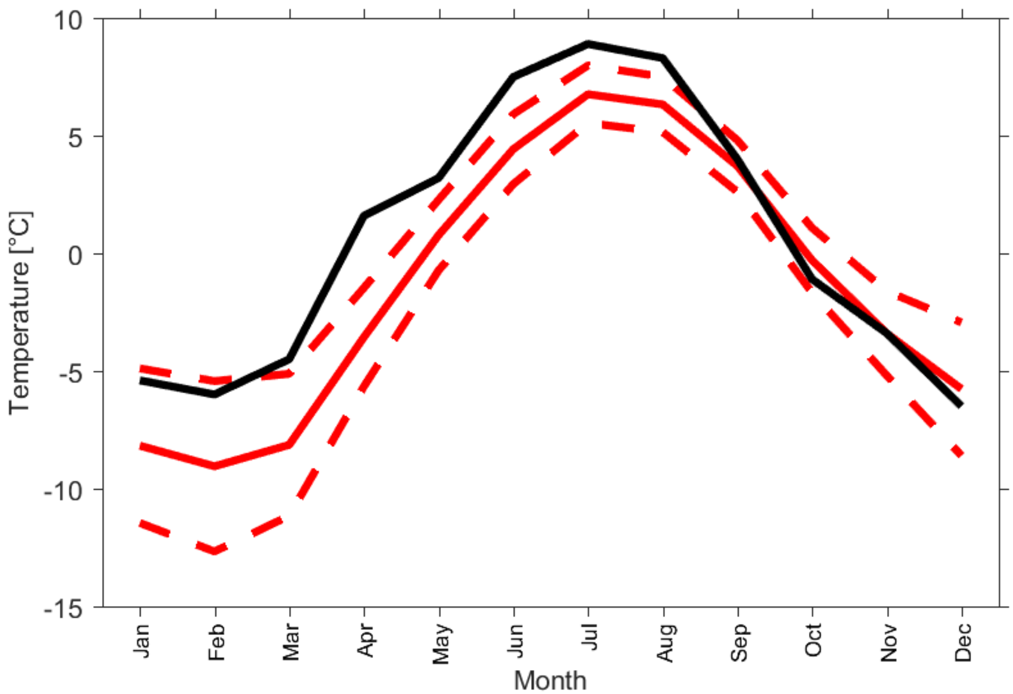


Fig. 6 Monthly mean air temperature at Nuuk station in 2016 (black line), long-term monthly mean temperature (red solid line) and one standard deviation (red dashed lines) are shown. Reference period is 1981 to 2010. Data source: Danish Meteorological Institute (DMI)

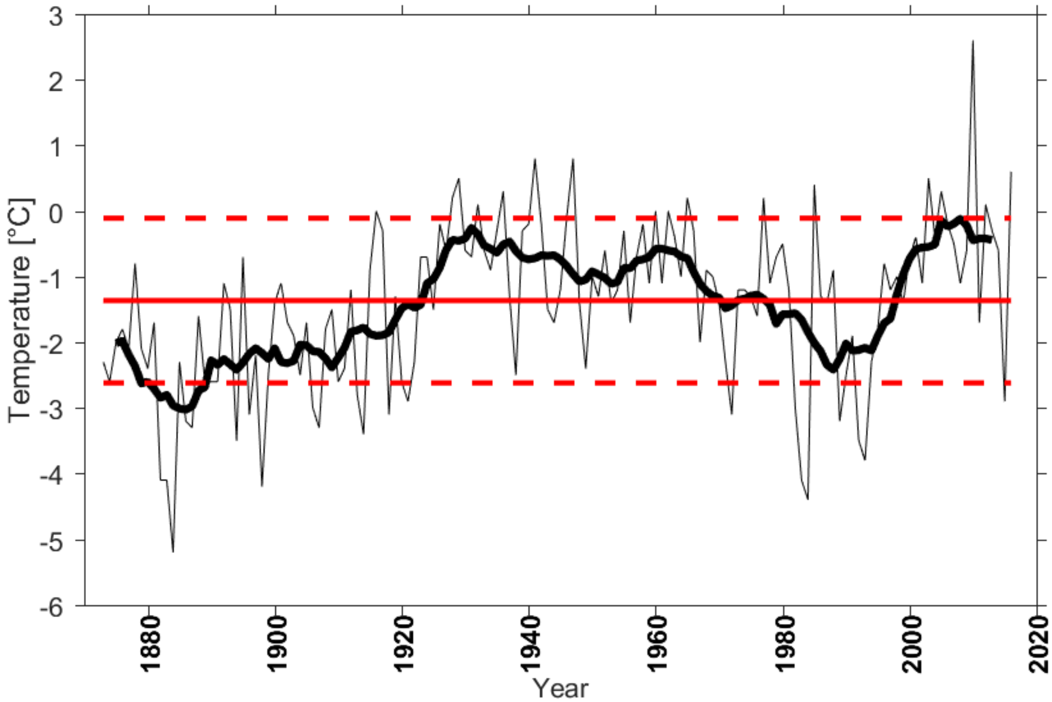


Fig. 7 Annual mean air temperature at Nuuk station. Thick black line shows the 5-year smoothed data. Red solid line indicates the long-term mean temperature, referenced to 1981-2010. Dashed red lines mark corresponding standard deviations. Data source: Danish Meteorological Institute (DMI)

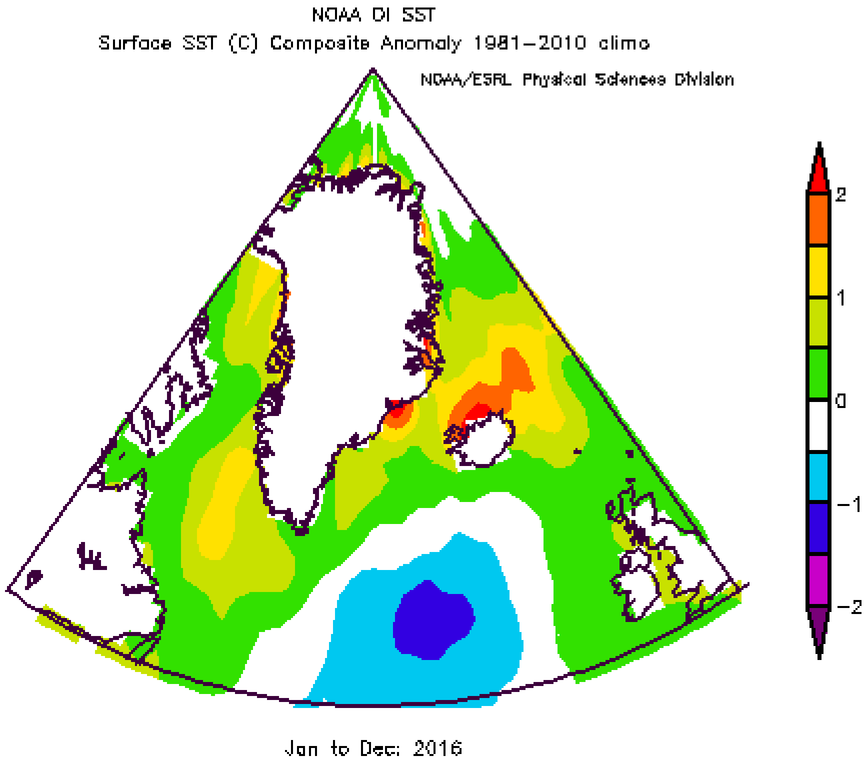
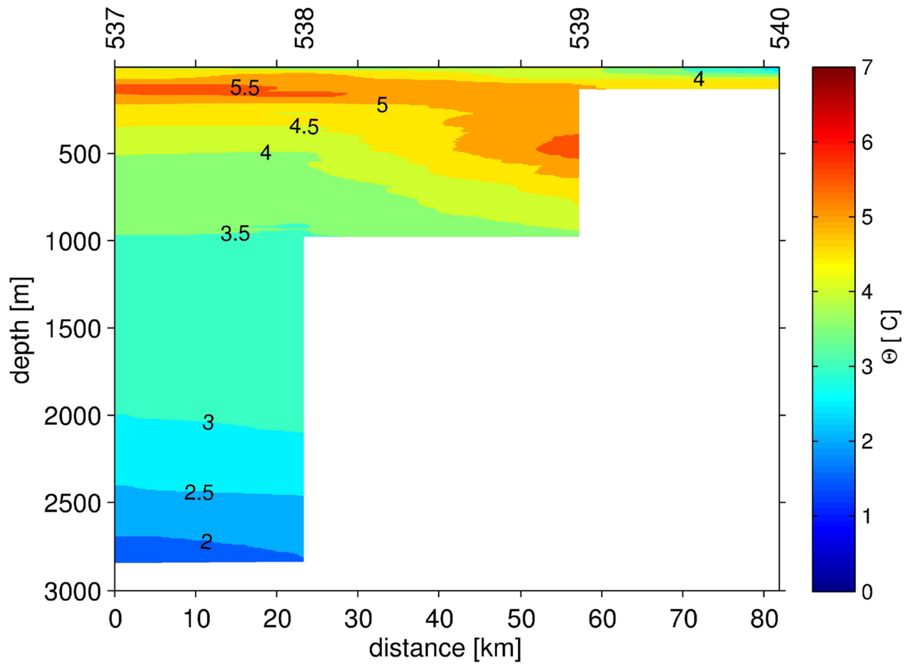
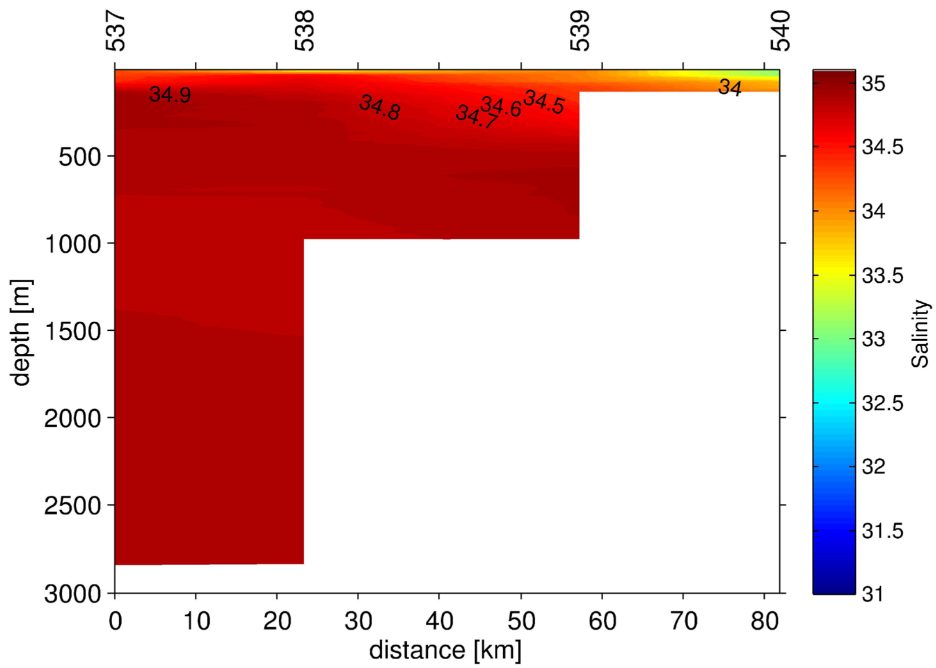


Fig. 8 Map of 2016 annual sea surface temperature (NOAA OI SST) anomalies in the study region. The long-term mean corresponds to 1981-2010. *Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*



(a)



(b)

Fig. 9 Vertical distribution of potential temperature **(a)** and salinity **(b)** along the Cape Desolation section in 2016.

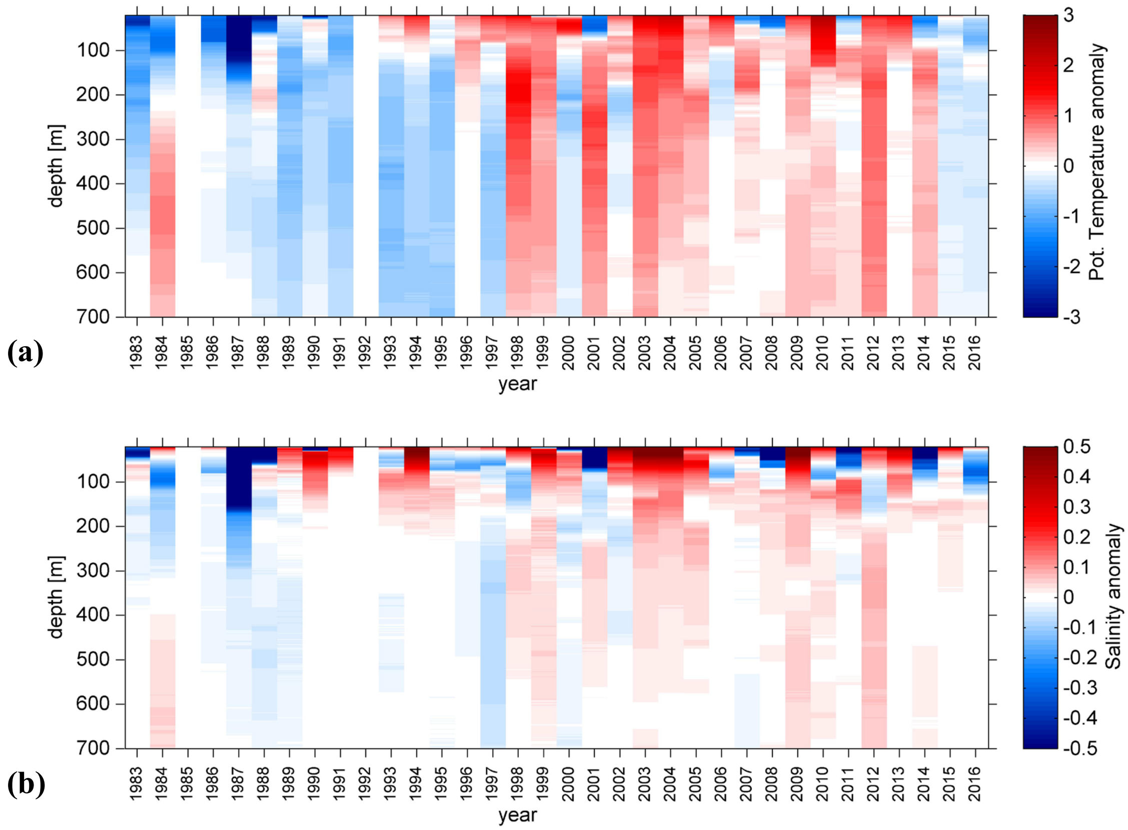
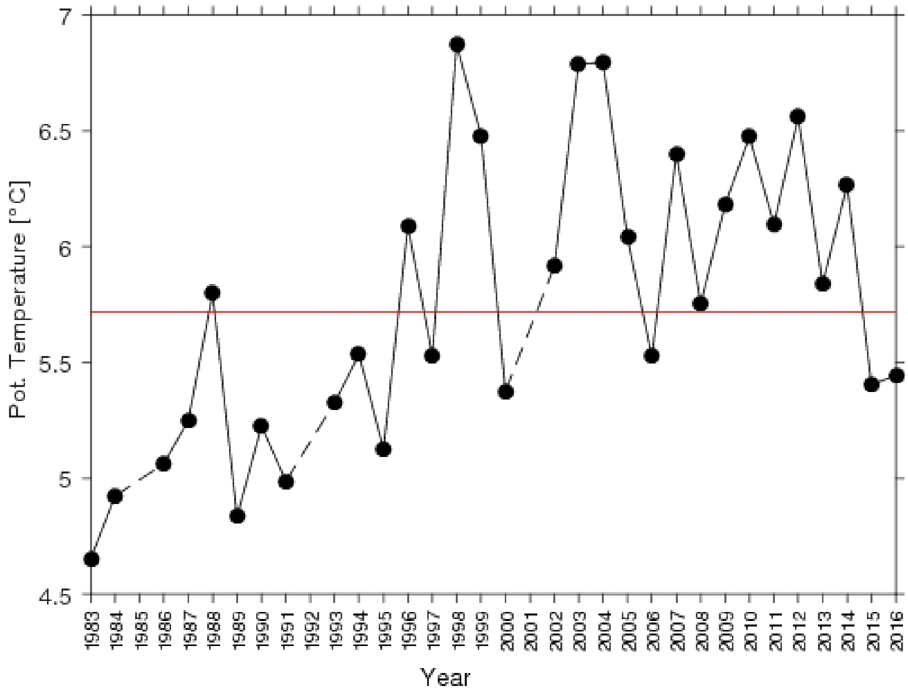
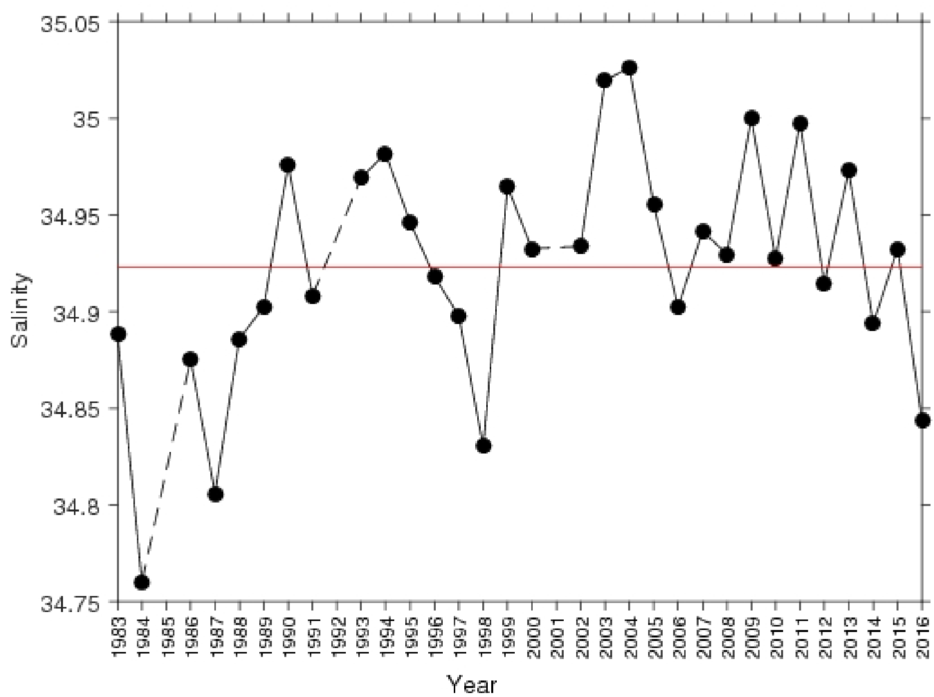


Fig. 10 Hovmoeller diagram of the potential temperature anomalies **(a)** and salinity anomalies **(b)** in the upper 700 m at Cape Desolation Station 3. Reference period is 1983-2010.

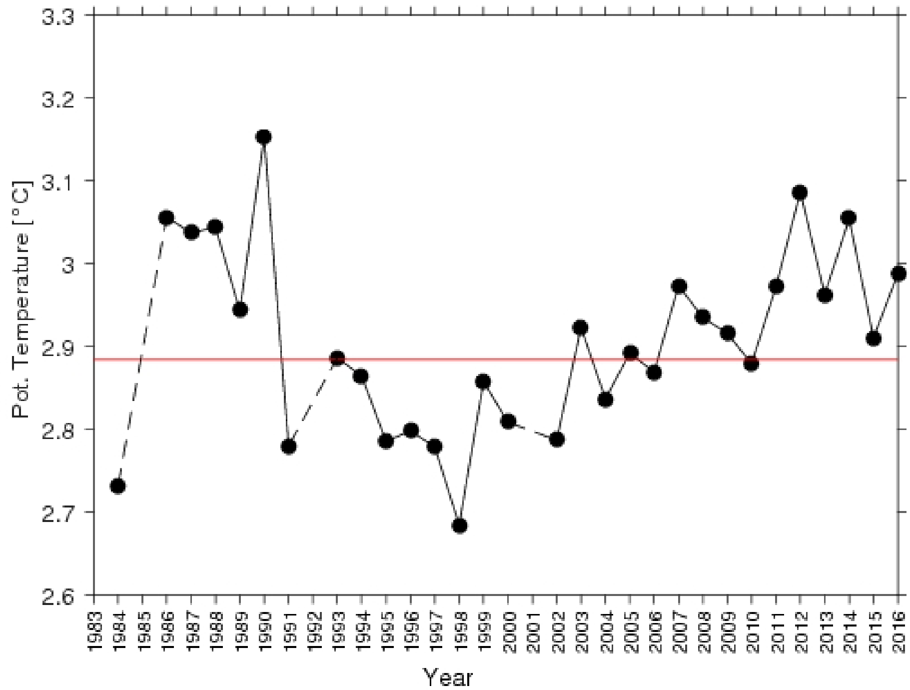


(a)

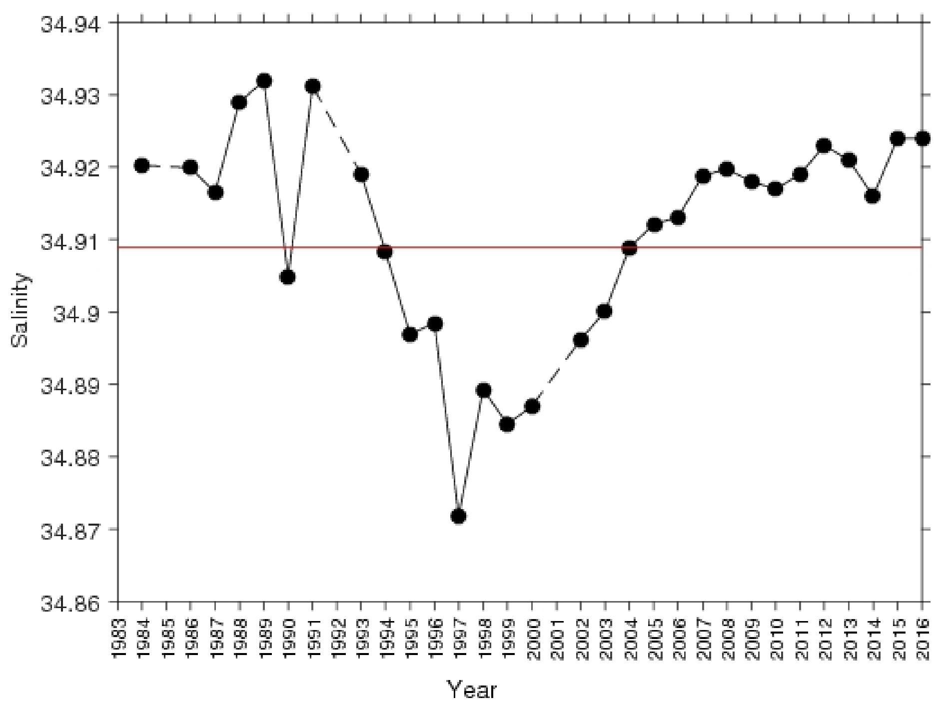


(b)

Fig. 11 Potential temperature **(a)** and salinity **(b)** in 75-200 m water layer at Cape Desolation Station 3 (60.47°N, 50°W). Red lines indicate the long-term mean potential temperature and salinity, referenced to 1983-2010.



(a)



(b)

Fig. 12 Potential temperature **(a)** and salinity **(b)** at 2000 m water depth at Cape Desolation Station 3 (60.47°N, 50°W). Red lines indicate the long-term mean potential temperature and salinity, referenced to 1983-2010.

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