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Hydrographic conditions off West Greenland in 2014

Boris Cisewski, Thünen Institute of Sea Fisheries, Germany

Abstract

An overview of the atmospheric and hydrographic conditions off West Greenland in autumn 2014 is presented. In winter 2013/2014, the NAO index was positive (3.1) describing anomalous strong westerlies over the North Atlantic Ocean. The annual mean air temperature at Nuuk Weather Station in West Greenland was -0.6°C in 2014, which was 0.8°C above the long-term mean (1981-2010). The core properties of the water masses of the West Greenland Current (WGC) are monitored at two standard NAFO/ICES sections, which span across the western shelf and continental slope of Greenland near Cape Desolation and Fyllas Bank. The properties of the Irminger Sea Water (ISW) are monitored in the 75-200 m layer at Cape Desolation Station 3. In 2014, the temperature and the salinity of the ISW was 6.27°C and 34.89, which was 0.55°C above the long-term mean and 0.03 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, both temperature and salinity were decreasing and reached their minimum in 1998 and 1997, respectively. After that, the temperature of the NADW revealed a positive trend until 2014. The salinity showed a strong increase until 2007 and a rather stagnation between 2007 and 2014. The water properties between 0 and 50 m depth at Fyllas Bank Station 4 are used to monitor the variability of the fresh Polar Water component of the West Greenland current. In 2014, the temperature and the salinity of this water mass was 3.38°C and 33.58, which was 0.74°C and 0.42 above its long-term mean, respectively.

Introduction

The water mass circulation off Greenland comprises three main currents: Irminger Current, West Greenland and East Greenland Currents (Figure 1). The East Greenland Current (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 Irminger Current (IC) is a branch of the North Atlantic Current. Figure 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 Irminger Sea Water (ISW) southward along the eastern continental slope of Greenland. It makes a cyclonic loop in the Irminger Sea. 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 Irminger Sea Water (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 (Figure 3).

Materials and Methods

The German groundfish survey off Greenland is conducted since 1981, aiming at monitoring groundfish stocks in particular of cod and redfish. The monitoring is carried out by the Thünen-Institute of Sea Fisheries (TI-SF) from board of R.V. 'Walter Herwig III' and reveals significant interannual and long-term variability of both components of the WGC. CTD profiles were conducted with a Sea-Bird 911plus sonde attached to a 12-bottle water sampler. The hydrographic database consisted of 60 hydrographic stations sampled between October 14 and November 4, 2014, from R.V. 'Walther Herwig III'. Study area and station locations are shown in Figure 3. For in-situ calibration, salinity samples were analysed with a Guildline Autosal-8400A salinometer immediately after the cruise. The collected data was interpolated to a 1 m grid in the vertical. If data was missing at the top of a profile, we assumed constant properties from the first measurement (normally 2–5 m) 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; available at http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html), 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 (Table 1) on the western coast of Greenland was used to characterize the atmospheric conditions in 2014. Annual and monthly mean values were obtained from the Danish Meteorological Institute (Cappelen, 2013).The climatological mean of this time series were 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 2014

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. According to ICES standards, I use in this study the Hurrell winter (DJFM) NAO index, which is available at *http://www.cgd.ucar.edu/cas/jhurrell/indices.html*. In winter 2013/2014, the NAO index was positive (3.1) describing anomalous strong westerlies over the North Atlantic Ocean (Figure 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 increased pressure difference over the North Atlantic sector than normal during winter 2013/2014 (Figure 5b). The resulting negative anomalies in the north and the positive in the south reveal a positive NAO character (Figure 5c). Air temperature at Nuuk was used to characterize the atmospheric conditions in 2014. Annual and monthly mean values were obtained from the Danish Meteorological Institute (Cappelen, 2013). In 2014, the monthly mean air temperatures were higher than the long-term mean except for the months March, April and December (Figure 6). The resulting annual mean temperature at Nuuk was -0.6°C in 2014, which was 0.8°C above the long-term mean (1981-2010) (Figure 7).

Hydrographic Conditions in 2014

Here a short overview of the hydrographical condition west off Greenland during autumn 2014 is presented. The core properties of the water masses of the WGC are formed in the western Irminger Basin where the EGC meets the Irminger current (IC). The EGC transports fresh and cold PSW of Arctic origin. The IC is a northern branch of the Gulf Stream, which makes a cyclonic loop in the Irminger Sea 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 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 2014 indicate positive anomalies in the Northwestern Atlantic with highest values occurring northeast of Iceland (Figure 8), whereas negative anomalies were observed in the central area of the North Atlantic.

Standard Cape Desolation and Fyllas Bank sections span across the shelf and the continental slope off West Greenland. The Cape Desolation section is situated 300 km northwest from the southern tip of Greenland. At this section a strong surface front separates PSW on the shelf from ISW offshore (Figure 9). In autumn, the temperature of the upper layer is well above zero (θ_{Min} = 2.15°C) due to the summer heat accumulation, and hence only the salinity can be used as a tracer of the SPW (Figure 9a). A salinity of less than 32.5 was observed at station 920 (Figure 9b). The most offshore station of the section done in 2014 (Station 923) corresponds to the standard Cape Desolation Station 3, which was reported in ICES WGOH since 2001 (Stein, 2010). In 2014, the water temperature and the salinity of the upper 100 meters were lower than their long-term mean, whereas both properties reveal positive anomalies between 100 and 700 m water depth (Figures 10a, b).

In 2014, the water temperature and the salinity in the 75-200 m layer at Cape Desolation Station 3 was 6.27°C (Figure 11a) and 34.89 (Figure 11b), which was 0.55°C above and -0.03 below the long-term mean, respectively. This finding agrees with previous studies e.g. Myers et al., 2009 who used summer observations off West Greenland. The observed warming of the ISW in the WGC coincides with a 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; Hátún et al., 2009).

The properties of the North Atlantic Deep Water 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 (Figure 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. The salinity showed a strong increase until 2007 and a rather stagnation between 2007 and 2014. In 2014, the temperature increased and salinity decreased, and was 0.17°C and 0.007 above the long-term mean, respectively (Figures 12a and b).

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). In 2014, fresh PSW was seen in uppermost 100 m over the entire section (Figure 13) and it spread at least 100 km away from the shelf. The core of ISW (θ >5 °C, S>34.9) was found between 328 and 665 m water depth at station 959, which corresponds to standard Fyllas Bank Station 4 (e.g. ICES, 2002; ICES, 2004). This station reveals positive potential temperature anomalies within the upper 700 m except from the depth range between 50 to 150 m, where negative anomalies occur. While negative salinity anomalies are restricted to the upper 300 m, positive anomalies are found between 300-700 m (Figures 14 a and b). The water properties between 0 and 50 m depth at Fyllas Bank Station 4 are used to monitor the variability of the fresh Polar Water component of the West Greenland current. In 2014, the temperature of this water mass was 3.38°C, which was 0.74°C above its long-term mean (1983-2010). While the Polar Water reveals strong negative salinity anomalies between 2012 and 2013, the salinity increased in 2014 and was 0.42 above its long-term mean (Figure 15a and b).

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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).

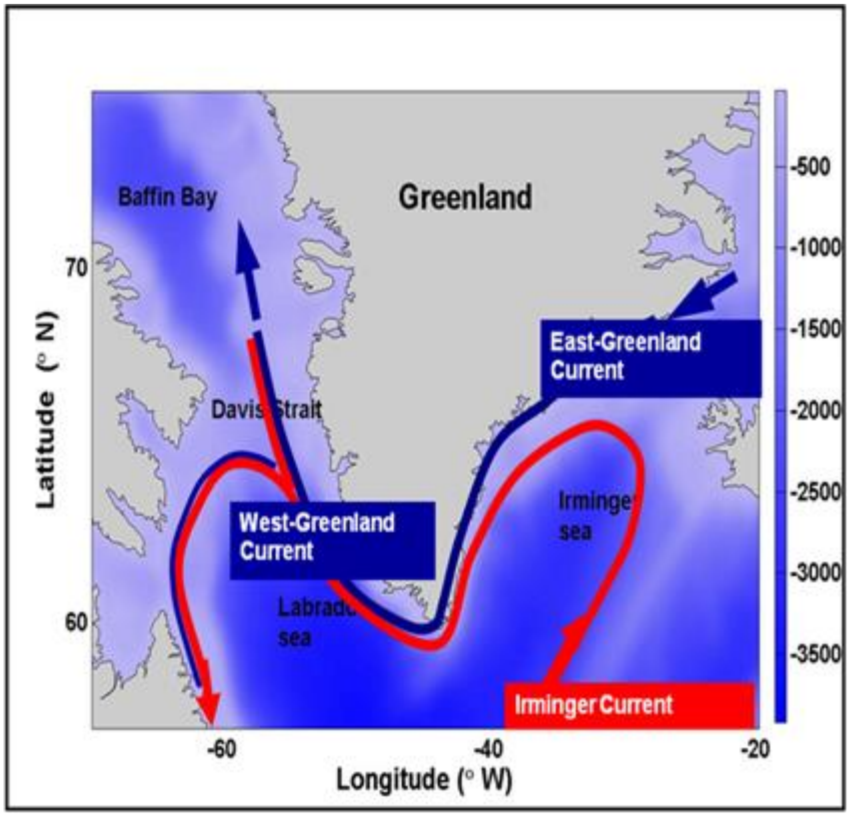


Figure 1. Scheme of the upper ocean circulation in the study area. Red and blue curves show the trajectories of warm Irminger Sea Water and cold Surface Polar Water, respectively.

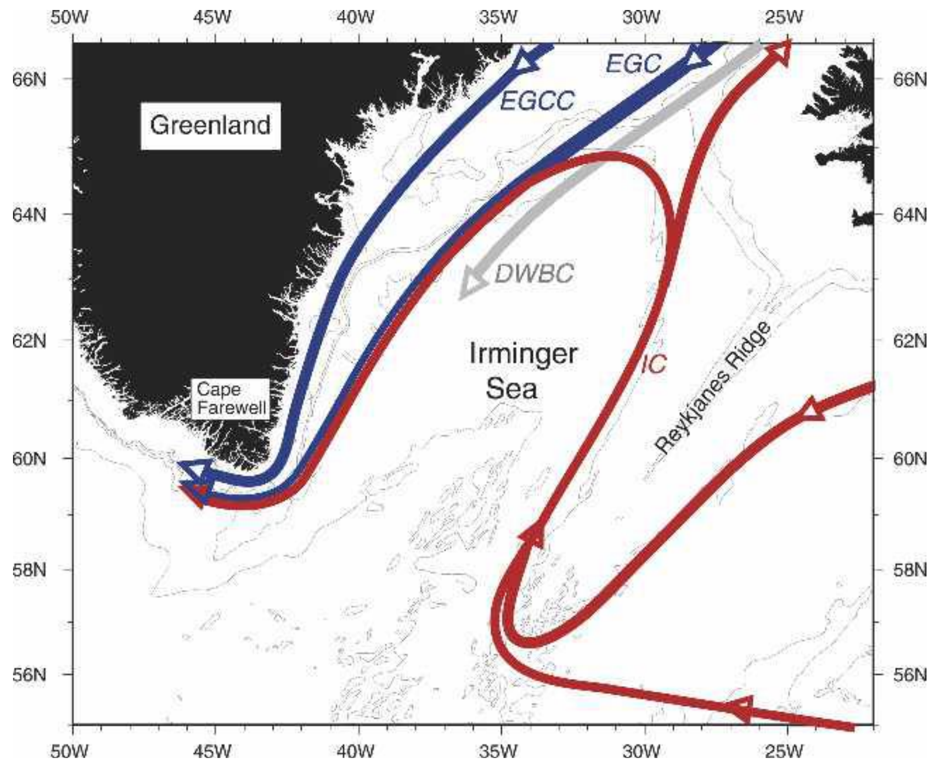


Figure 2. Schematic of the boundary currents of the Irminger Sea (depicted from Pickart et al., 2005)

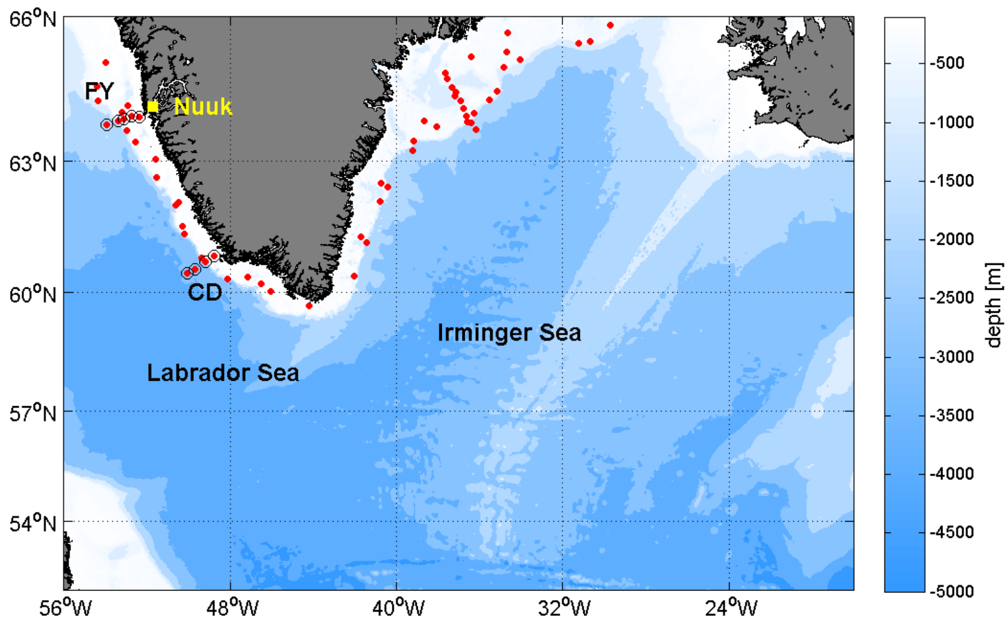


Figure 3. Map and bathymetry of the study region. Meteorological station location is shown in yellow. Red dots show the location of the hydrographic stations, conducted during the survey in 2014. Gray edged dots show the two ICES/NAFO standard sections (CD – Cape Desolation section, FY – Fyllas Bank Section; geographic coordinates are given in Table 1).

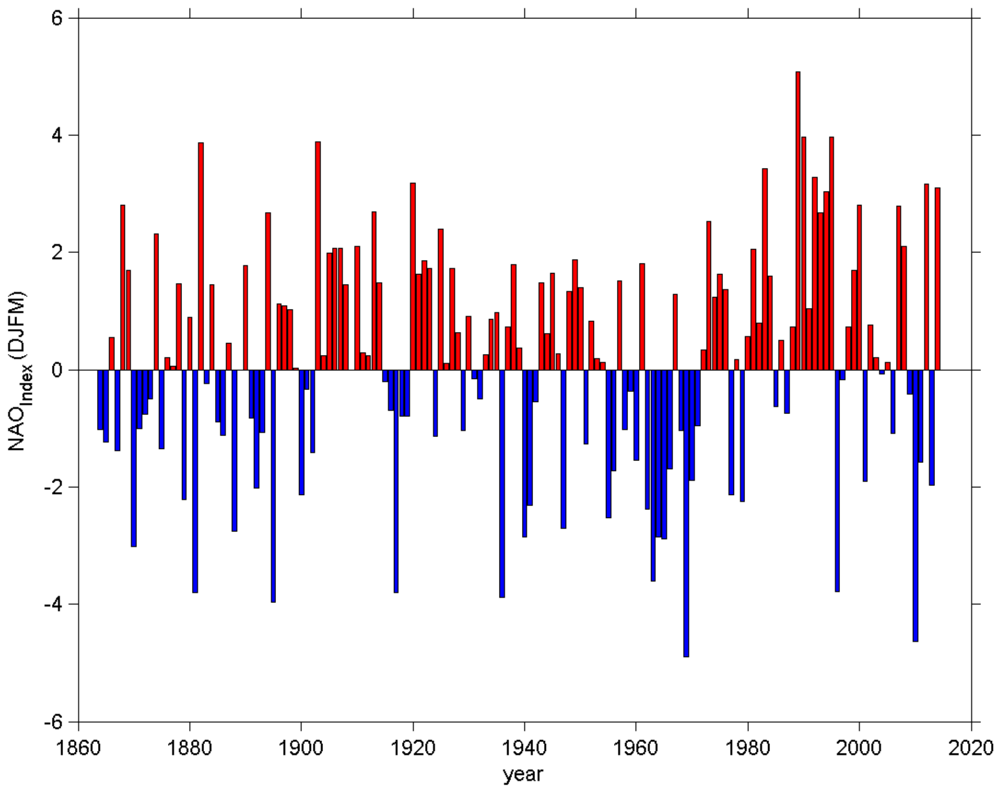


Figure 4. The Hurrell winter (DJFM) NAO index.

Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.

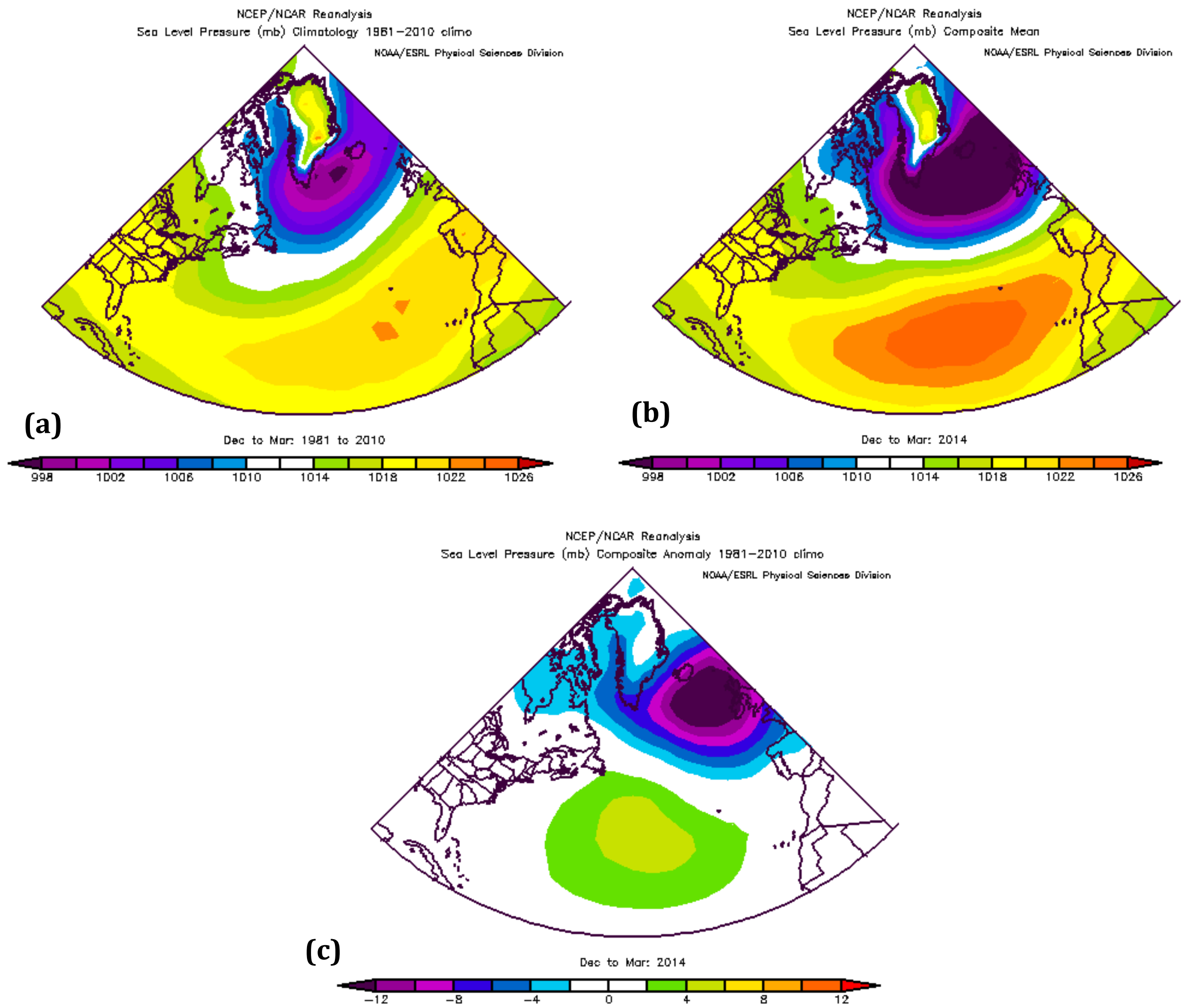


Figure 5. Maps of winter 1981-2010 (DJFM) mean sea level pressure (SLP) **(a)**, winter 2014 SLP **(b)**, and resulting SLP anomaly **(c)** over the North Atlantic. *Images are provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*

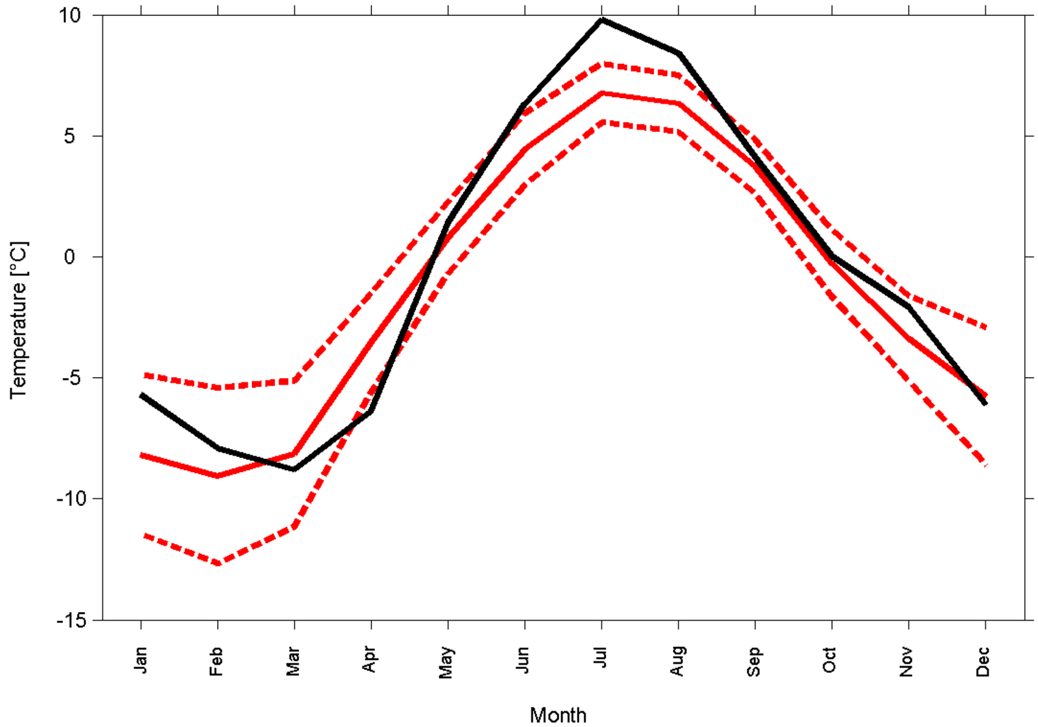


Figure 6. Monthly mean temperature at Nuuk station in 2014 (black line), long-term monthly mean temperature (red solid line) and one standard deviation (red dashed lines) are shown. Reference period is 1981 to 2010. Data source: Danish Meteorological Institute (DMI)

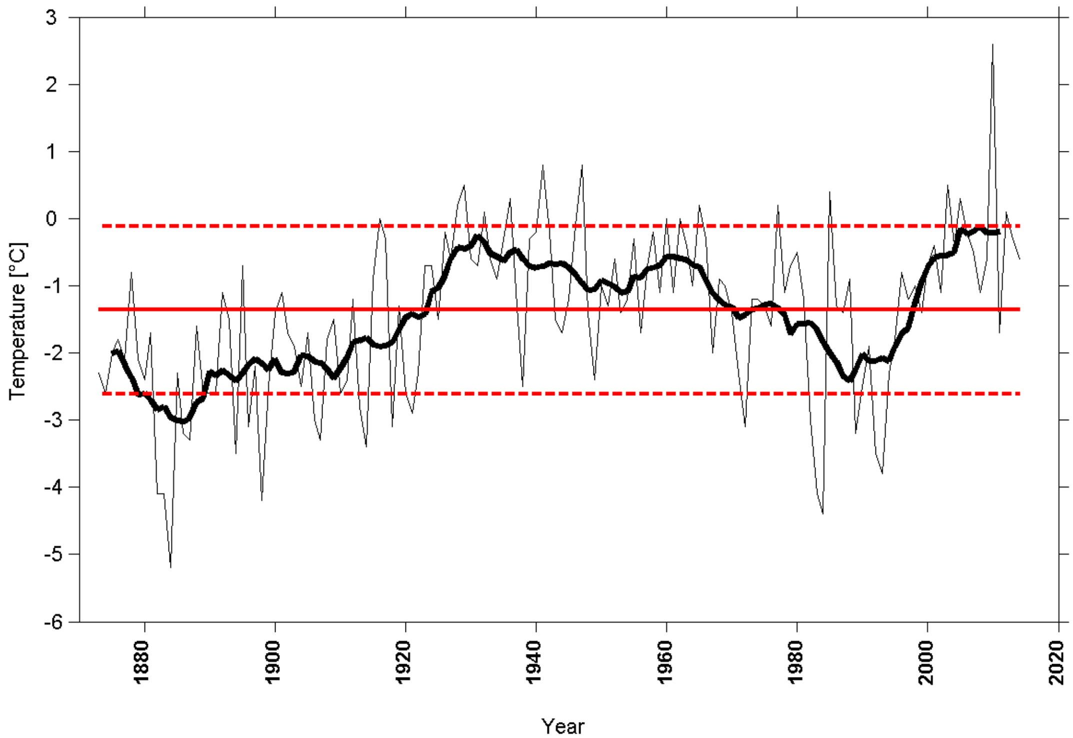


Figure 7. Annual mean air temperature at Nuuk station. Thick black line shows the 5-year smoothed data. Red solid line indicates the long-term mean temperature, referenced to 1981-2010. Dashed red lines mark corresponding standard deviations. Data source: Cappelen, J. (ed.), 2013: Greenland - DMI Historical Climate Data Collection 1873-2012 – with Danish Abstracts. DMI Technical Report 13-04. Copenhagen.

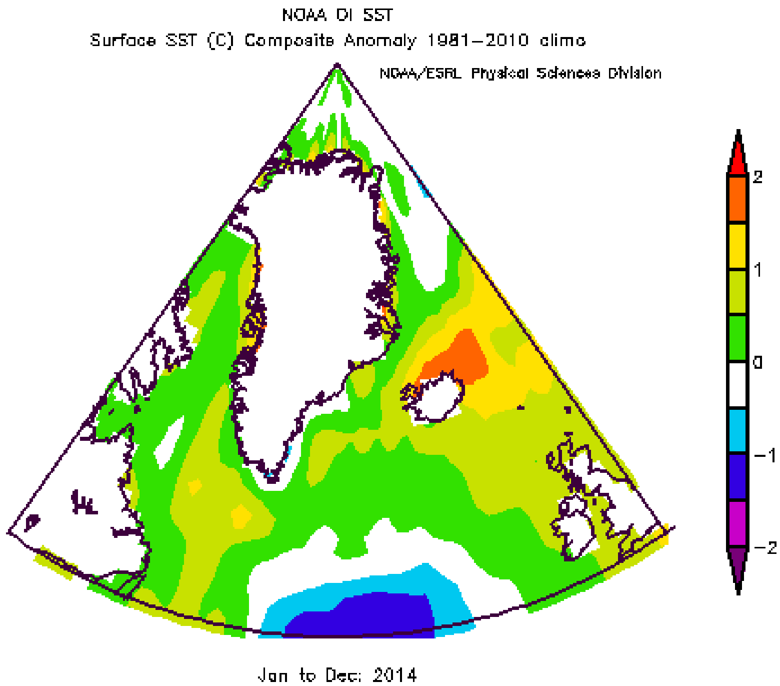
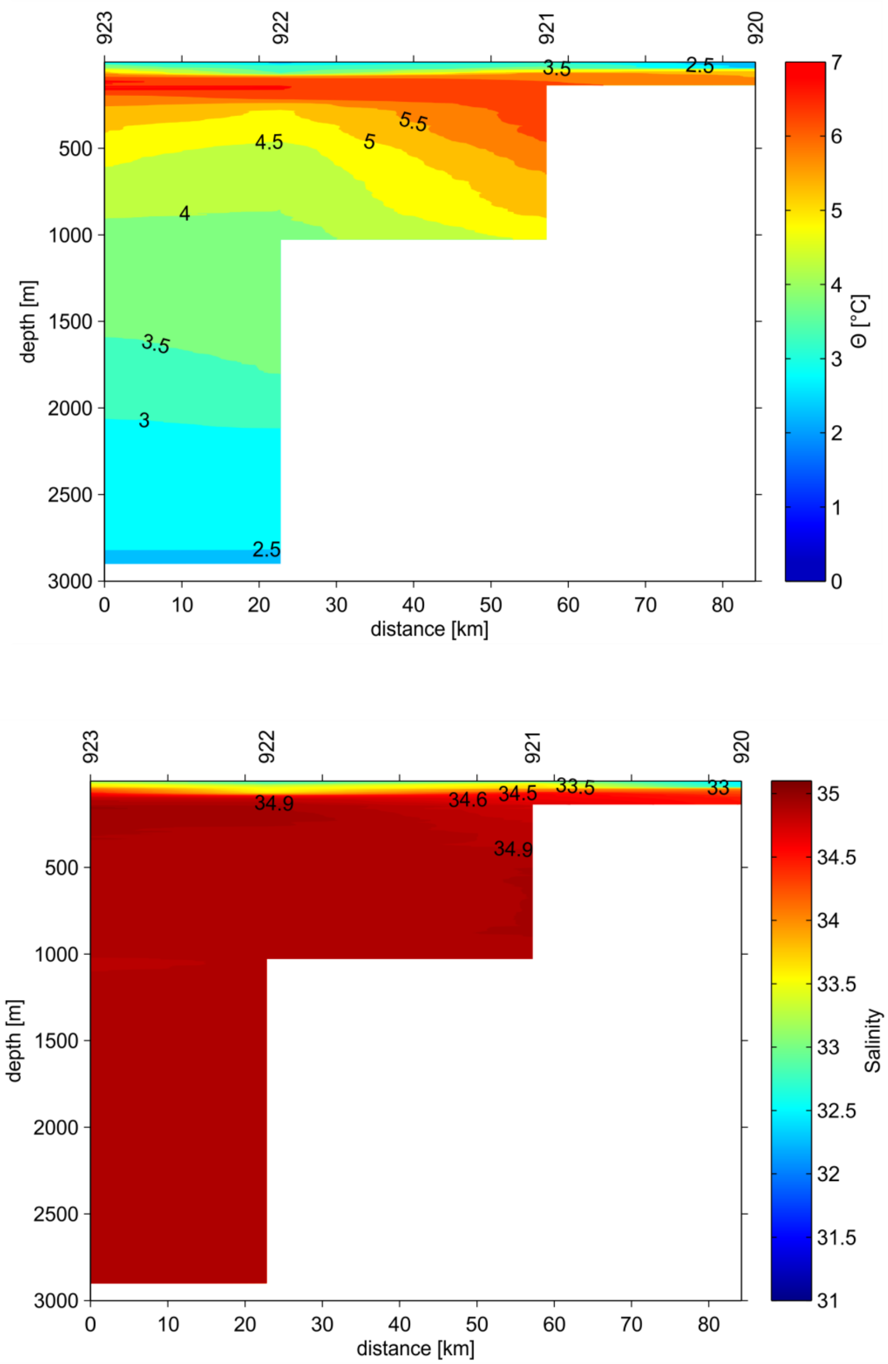


Figure 8. Map of 2014 annual sea surface temperature (NOAA OI SST) anomalies in the study region. The long-term mean corresponds to 1981-2010. *Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*



(a)

(b)

Figure 9. Vertical distribution of potential temperature **(a)** and salinity **(b)** along the Cape Desolation section in 2014.

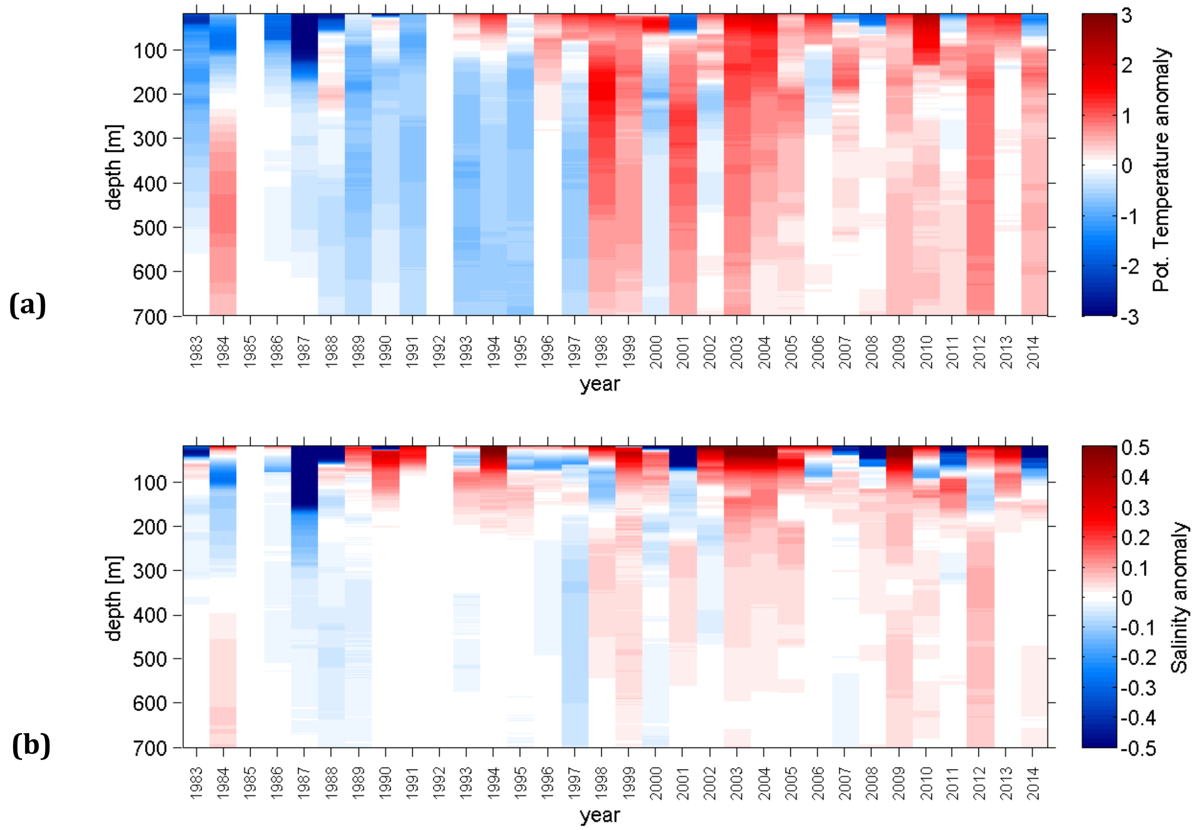
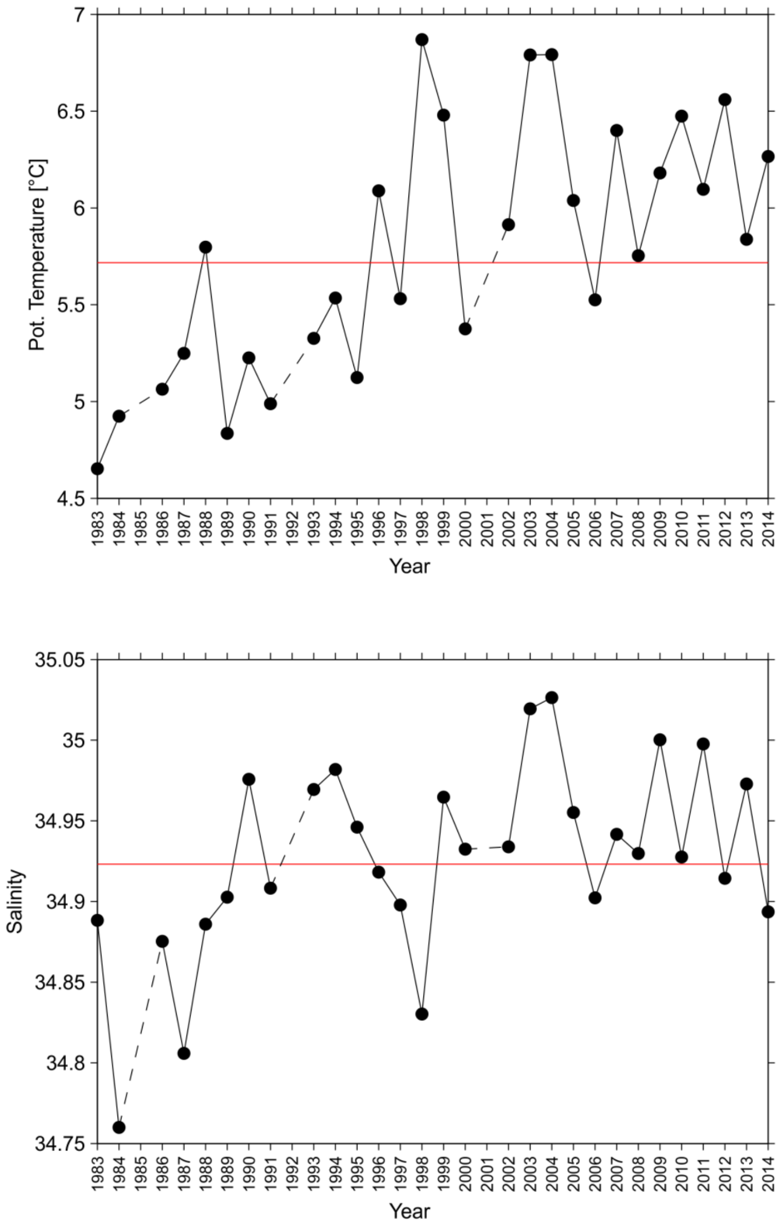


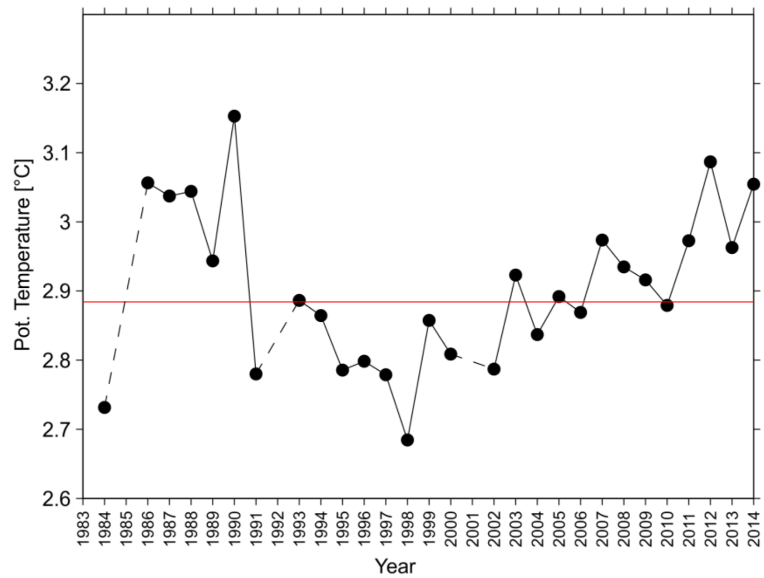
Figure 10. Hovmoeller diagram of the potential temperature anomalies **(a)** and salinity anomalies **(b)** in the upper 700 m at Cape Desolation Station 3. Reference period is 1983-2010.



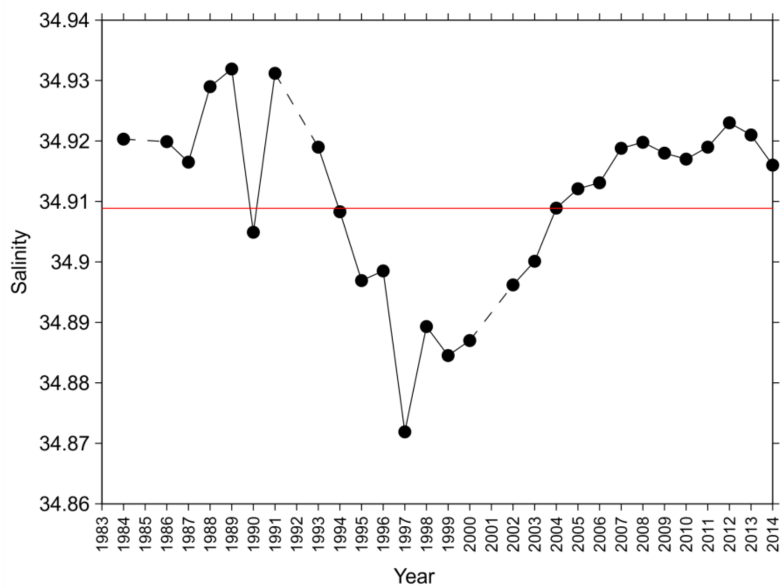
(a)

(b)

Figure 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.

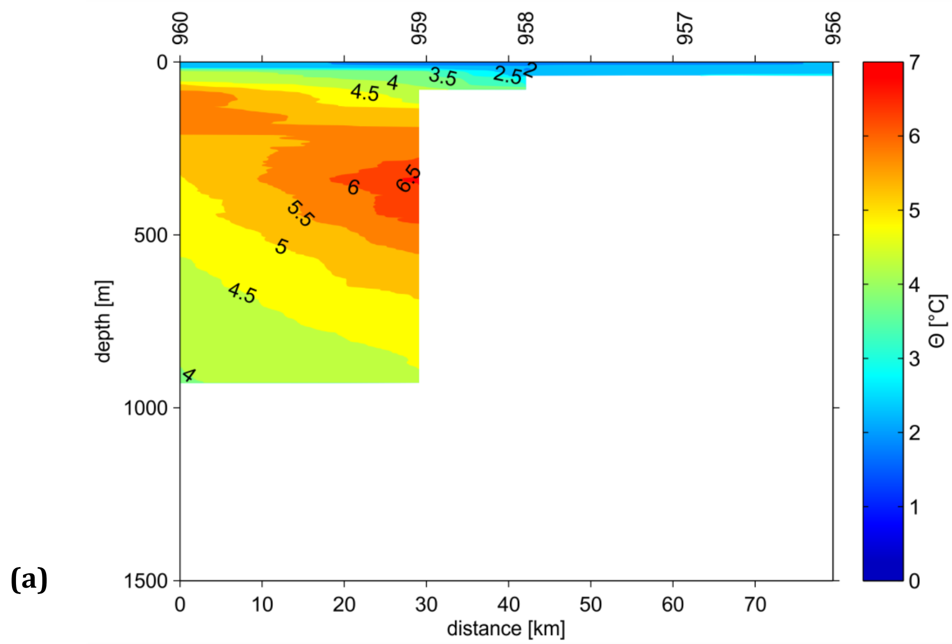


(a)



(b)

Figure 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.



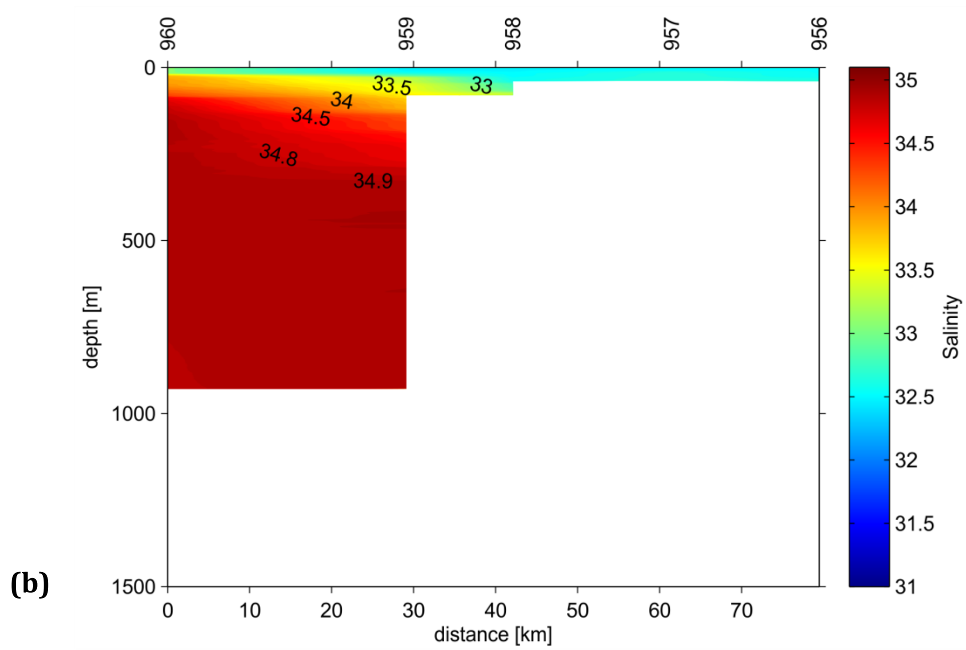
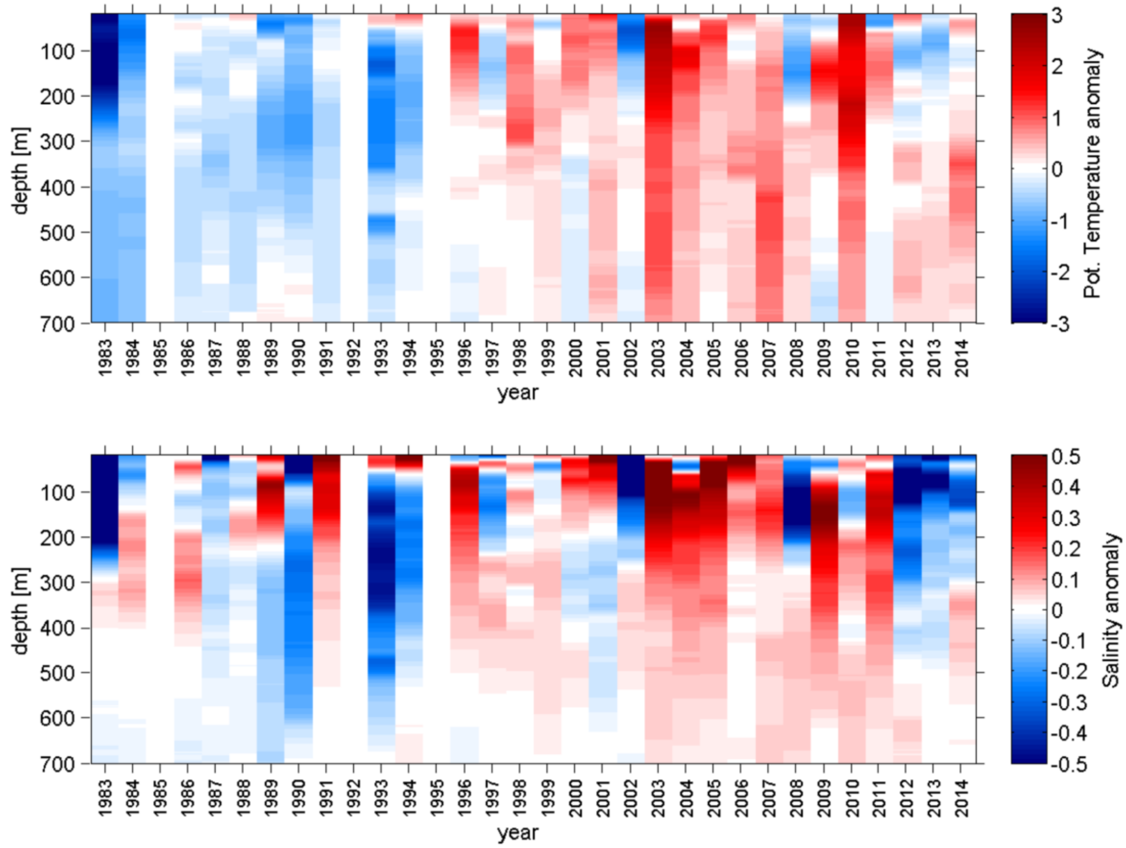


Figure 13. Vertical distribution of potential temperature **(a)** and salinity **(b)** along Fyllas Bank section (Figure 8) in 2014.

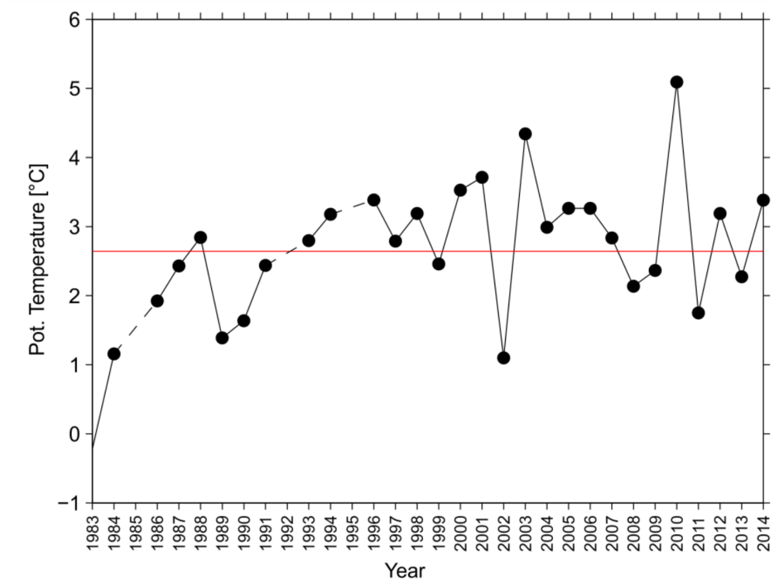


(a)

(b)

Figure 14. Hovmoeller diagram of the potential temperature anomalies **(a)** and salinity anomalies **(b)** in the upper 700 m at Fyllas Bank Station 4. Reference period is 1983-2010.

(a)



(b)

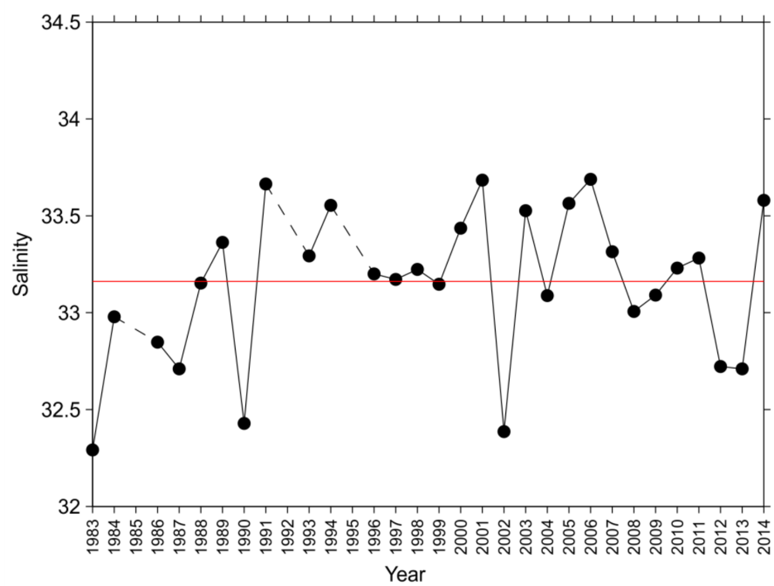


Figure 15. Mean potential temperature **(a)** and salinity **(b)** in the 0-50 m water layer at Fyllas Bank Station 4 (63.88°N, 53.37°W). Red lines indicate the long-term mean potential temperature and salinity, referenced to 1983-2010.