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Contribution to the ICES Report on Ocean Climate : North Atlantic Ocean in 2017

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Summary

1 Argo gridded temperature and salinity field

The ARGO network of profiling floats has been set up to monitor the large-scale global ocean variability (http://www.argo.ucsd.edu/). Argo data are transmitted in real time and hastily made available by the two Global Data Assembly Centres (Argo-GDAC). Delayed mode data undergo expert calibration processes and are delivered later. In the North Atlantic, the temperature and salinity conditions of the upper 2000 m are adequately described since 2002. This dataset is thus suitable for an overview of the oceanographic conditions in this basin, giving the general context for the repeated stations and sections collected mostly at the periphery of the basin by the partners of the ICES Working Group on Ocean Hydrography (WGOH).

Note that, in this Section, the temperature and salinity anomalies are compute using World Ocean Atlas-2005 climatology (WOA05; https://www.nodc.noaa.gov/OC5/SELECT/woaselect/woaselect.html), that mainly reflects the mean oceanic conditions of the *pre-Argo* period, *i.e.* before 2000's. Thus, temperature and salinity anomalies reflect change in comparison to this period.

1.1 ISAS: gridded temperature and salinity fields

Temperature and salinity gridded fields are estimated on a regular half degrees grid using the In Situ Analysis System (ISAS), (*Gaillard et al.*, 2016). The dataset used for generating ISAS gridded fields is downloaded from the Coriolis Argo GDAC (http://www.coriolis.eu.org/). It should be noted that Coriolis assembles many types of data transmitted in real time, merging the ARGO data set with data collected by the GTS such as mooring data, marine animals, CTDs. However, the ARGO dataset remains the main contributor in the open ocean.

The optimal interpolation procedure is the following : First the in situ T and S profiles are vertically interpolated on 152 standard levels between the surface and 2000 m depth. The horizontal mapping to produce gridded fields is performed at each standard level independently. The mapping method is based on optimal estimation principles and includes a horizontal smoothing through specified covariance scales. The results presented here were produced with last version of ISAS. The reference state was computed as the mean of a 2005-2012 analysis (using ISAS13; *Gaillard et al.*, 2016) and the a priori variances were computed from the same dataset.

Two ISAS gridded T and S products are used:

i) Over the period 2002-2015, ISAS15 product is used (*Kolodziejczyk et al.*, 2017; doi: http://doi.org/10.17882/52367). ISAS15 product constitutes the highest quality products in Delayed Mode since only delayed mode in situ data are used. Moreover, data are pre-processed and extra-QC dedicated to the ISAS15 analyses was performed on in situ profiles before entering the analysis.

ii) The last years of the analyzed series, *i.e.* 2016-2017, use the Near Real Time dataset prepared by Coriolis at the end of each month from real time data. Over this period, data are interpolated using ISAS v6 including only Real Time mode data (i.e. only from automatic QC processing). Delayed mode data are progressively taken into account for the previous years, replacing the NRT data.

1.2 *Surface layers*

<u>*Seasonal cycle*</u>

During winter 2017, in the middle of subpolare gyre (north of 45°N) and in the Labrador Sea, the near surface waters (10 m depth) were anomalously colder and fresher than the WOA05 pre-Argo (before 2002) climatological winter (Fig. 1.1; left). Further South, near surface waters were extremely warm and salty in the western basin south of 40°N, indicating a northward shift of the Gulf Stream. A warmer than normal subtropcial gyre (south of 45°N) is also observed.

This subpolar gyre cold anomaly has persisted but has decreased throughout the year 2017 (Fig. 1.1). However, during summer 2017 Labrador and Greenland basin have been anomalously warmer than the pre-Argo climatological conditions.

During the 4 seasons remarkable fresh salinity anomalies (Fig. 1.1; right) have been reported along the northeastern and northwestern Greenland coast, while sea surface is saltier in the Labrador Sea along the Canadian coasts and in the Greenland Sea, north of Iceland.

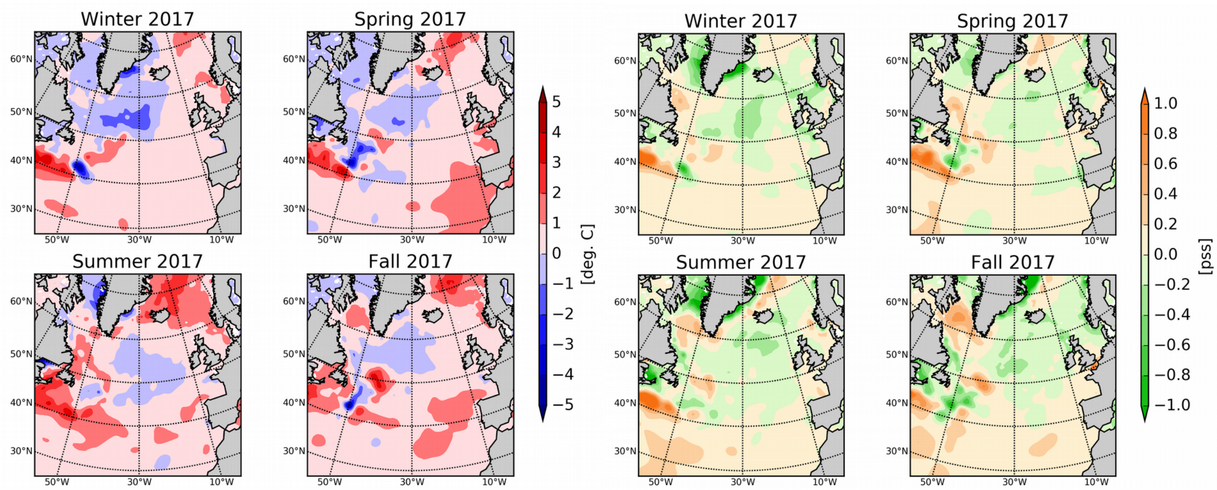


Figure 1.1: Near surface (10 m depth) temperature (left) and salinity (right) averaged over Winter (JFM), Spring (AMJ), Summer (JAS) and Autumn (OND) 2017. The anomalies are shown relative to the World Ocean Atlas (WOA05), i.e. pre-Argo seasonal climatology (before 2002).

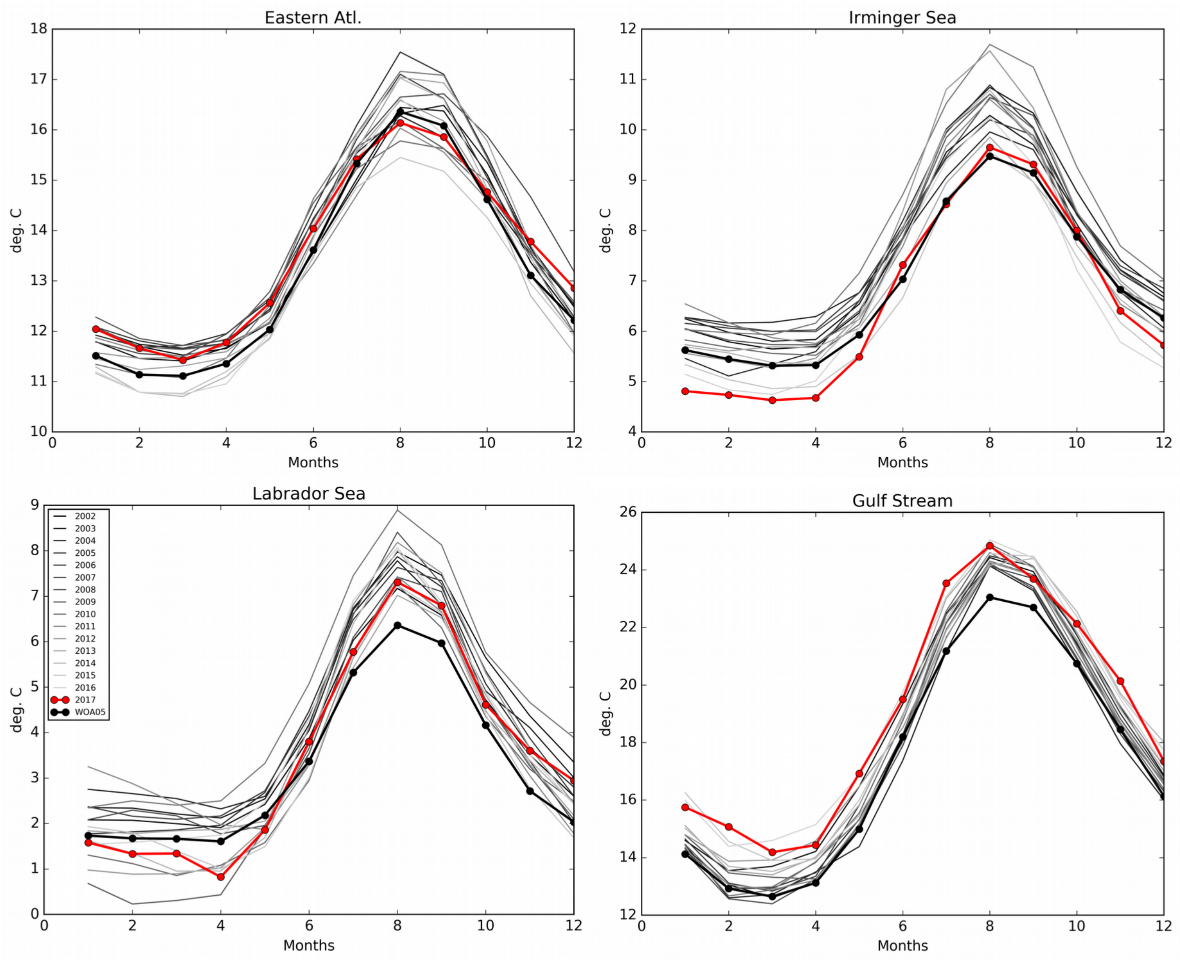
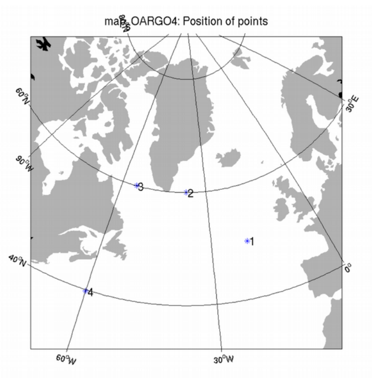


Figure 1.2: Seasonal cycle for near surface temperature (10 m depth) at 4 points in the North Atlantic basin (see stations in the map below), *i.e.* : a) Eastern Atlantic (1); b) Irminger Sea (2); c) Labrador Sea(3) and d) Gulf Stream region (4). In heavy red the year 2017, in dashed black the WOA05 climatology, other curves show the years 2002-2016.



In the Irminger Sea, the winter 2017 appeared to be the coldest winter over the 2002-2017 period (thick red circle; Fig. 1.2b), where near surface temperature went well below the pre-Argo seasonal climatology (thick black circle). The near surface temperature in the Labrador Sea (Fig. 1.2c), also presented condition of extreme cooling. Since 2014, these conditions contrasted with the general trend of warmer conditions than pre-Argo climatology that have been observed over the last decade in the Irminger and Labrador Sea. During summer period, near surface temperature also showed coolest temperature measured since 2002.

In contrast the near surface temperature seasonal cycle in the Gulf Stream region (Fig. 1.2d) confirms the warm shift observed this last few years. Both winter and summer temperature exhibited maximum values, more than 1°C above the pre-Argo period.

Off the European coasts in the Eastern Atlantic (Fig. 1.2a), near surface temperature presented normal seasonal values relative to the period 2002-2017, not significantly different from the pre-Argo period.

Mixed layer depth

Winter heat and fresh water fluxes control the buoyancy loss (increasing of density) of the ocean surface layers and the winter convection in North Atlantic. The mixed layer depth is an indicator of the winter convection intensity in the North Atlantic. In order to compare all areas over the decade, we adopt a definition for the mixed layer depth, using the level at which density changes by more than 0.03 $kg.m^{-3}$ with respect to the 10 meter depth. The criteria on density is more accurate because is sensitive to both temperature and salinity stratification. The month of March is selected as the common period for maximum mixed layer depth at the end of winter season before the spring re-stratification. However, this is not perfectly true since the time of the deepest mixed layer may vary from year to year at a single location and might not occur at the same time over the whole basin (between February and March in North Atlantic).

In the North of the basin extending from the Labrador Sea to the Irminger Sea, in spite of the exceptional winter 2015 and 2016, during late winter 2017, the area covered by a deep mixed layer (deeper than 2000 m) was the third most extended (Fig. 1.3). This was noticeably due to deeper late winter mixed layer in the Irminger basin during the winter 2015, 2016 and 2017 than in the 2013 and 2014 winter. This deep mixed layer may reflect strong winter convection in both Labrador and Irminger basin.

In the eastern side of the basin off Scotland and Ireland coasts shallower mixed layer depth (less than 800 m) were observed in March 2017 contrasting with the deeper mixed layer (>800 m) during the late winter of the 2012-2016 period. In the Bay of Biscay, the 2017 March mixed layer depth has remained shallower (<600 m) than the exceptional winter 2014 and 2015 (>600 m).

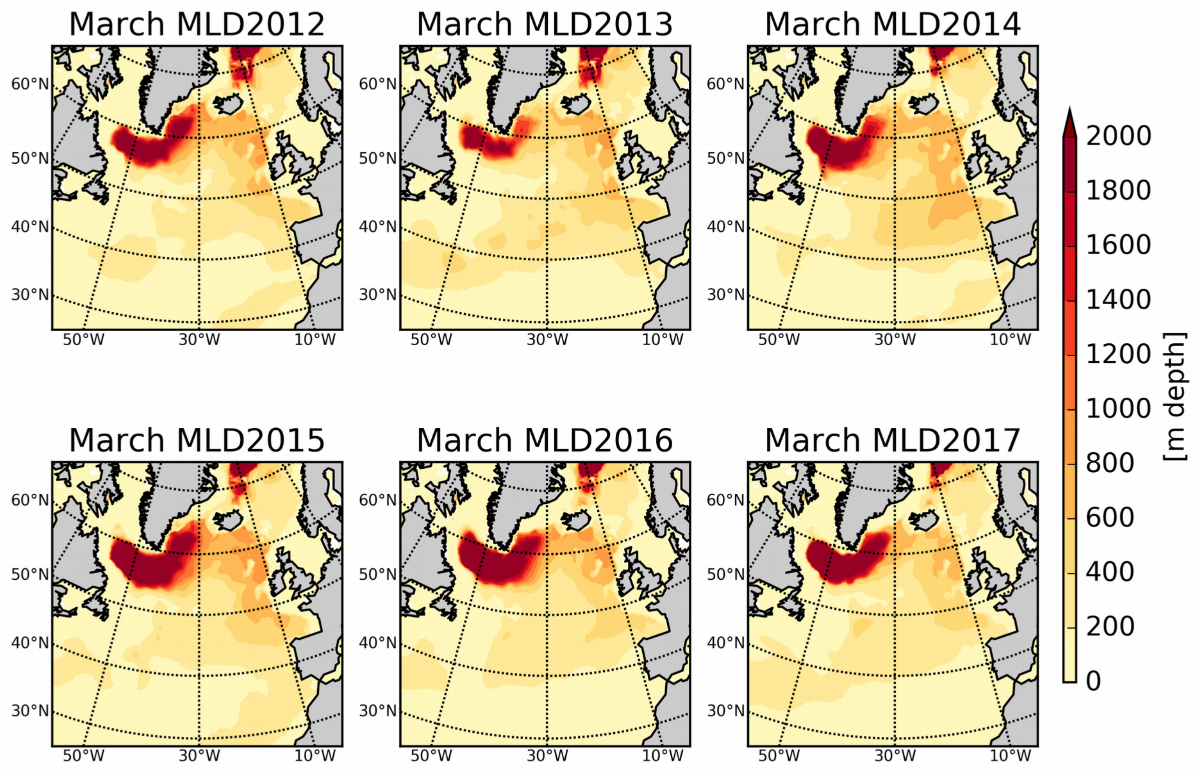


Figure 1.3: North Atlantic mixed layer depth in March from 2012 to 2017. The color bar is limited to Argo profile range: between 0 and 2000 m depth.

Interannual variability

In 2017, in North Atlantic, the most salient feature observed in the annual near surface temperature anomaly (using WOA05 as reference climatology), is the persistence of a coherent cold anomaly over the subpolar gyre (Fig. 1.4a). This subpolar cold anomaly has grown from 2013 to 2015 where minimum temperature anomalies (<-2°C) where observed. Since 2016, this cold anomaly appeared to diminish in intensity (1°C) and extension in the subpolare gyre.

In contrast, since 2012 Nordic Seas (>65°N) exhibited persistent warm anomalies (>2°C) of near surface temperature over the Greenland Sea and along the Eastern Greenland coast (Fig. 1.4a).

In the subtropical gyre, the surface condition remained warmer in 2017, especially in the Gulf Stream region, where northward shift of the subtropical front may explain the warm extreme anomalies (>3°C).

Over the 2012-2017 period, in the subpolare gyre, the persistent large scale cold near surface temperature anomaly was concomitant to a fresh near surface salinity anomaly (about 0.4 pss). More precisely, in 2012 a fresh anomaly (0.4 pss) was observed in the western Atlantic basin around 45°N, then the fresh near surface water anomaly have translated across the subpolare gyre toward the eastern North Atlantic. The fresh anomaly enters the Irminger basin in 2016 (Fig. 1.4b).

Around the Greenland coast, since 2014, noticeable strong near surface salinity negative anomaly was also observed both in the Labrador and Irminger basin. In this region, the fresher near surface water may be likely explained by increase of the fresh water flux originated from atmosphere, ocean or Greenland ice sheet melt.

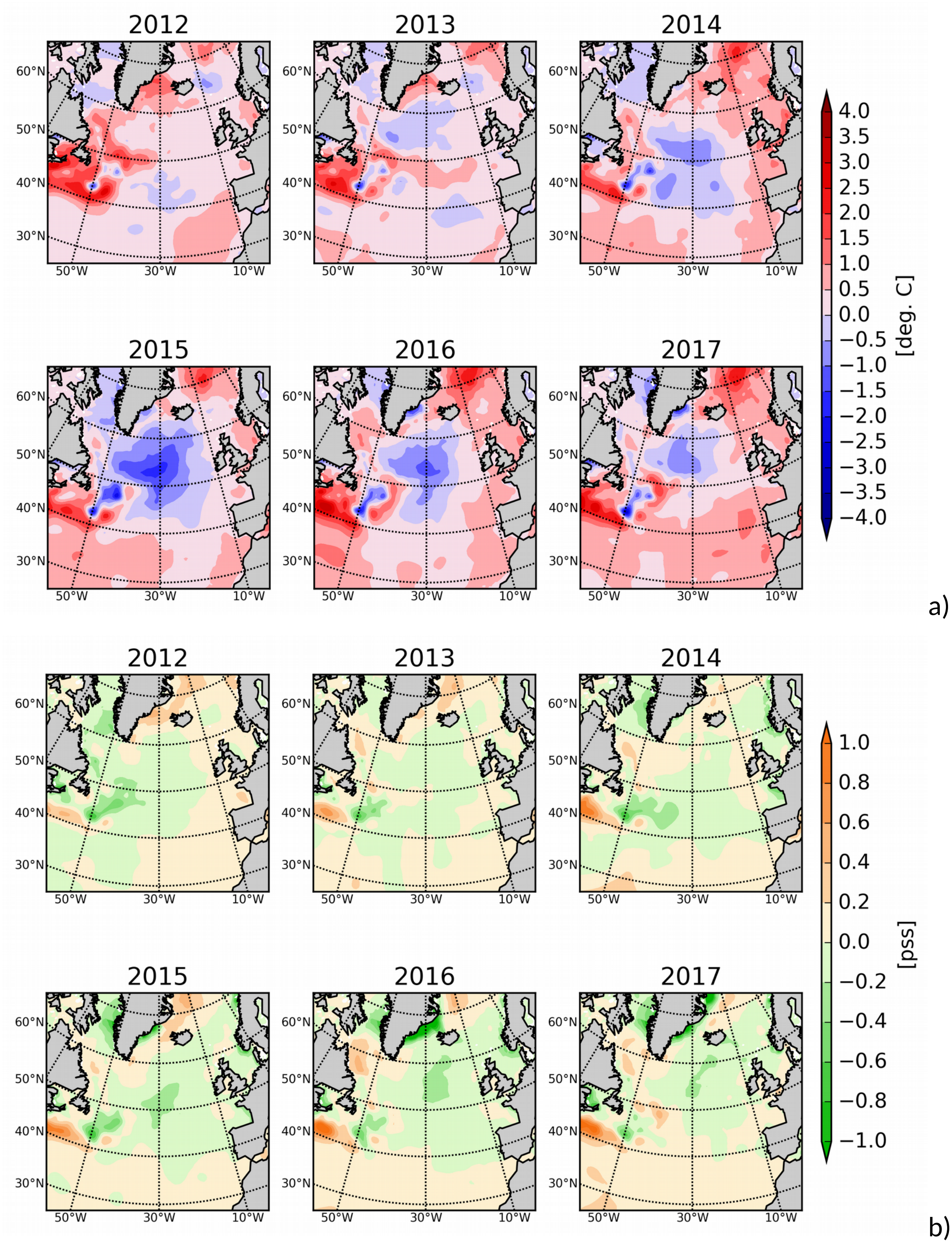


Figure 1.4: Annual average temperature (a) and salinity (b) anomalies at 10 m depth during 2012-2017

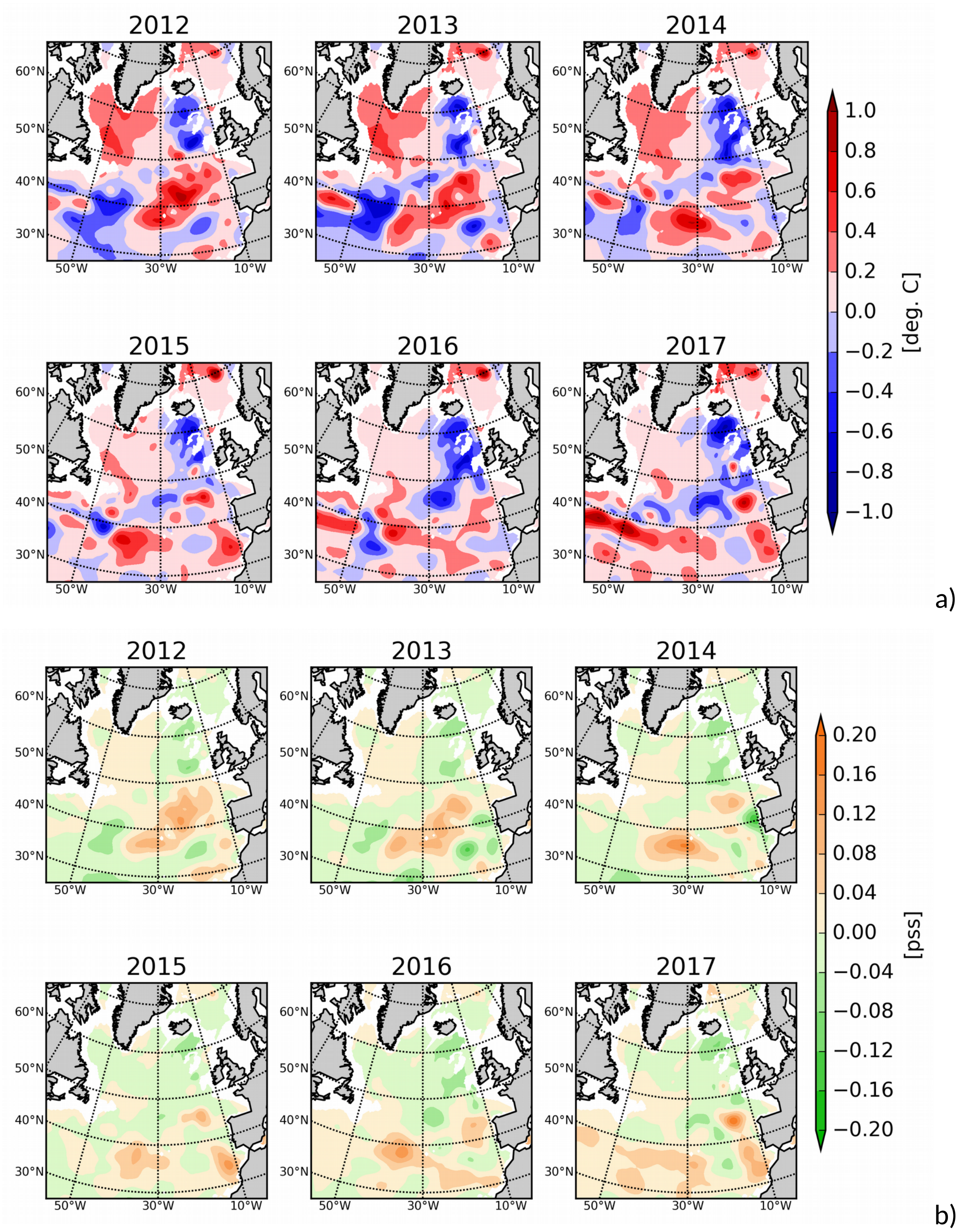


Figure 1.5: Annual average temperature (a) and salinity (b) anomalies at 1000 m depth during 2012-2017.

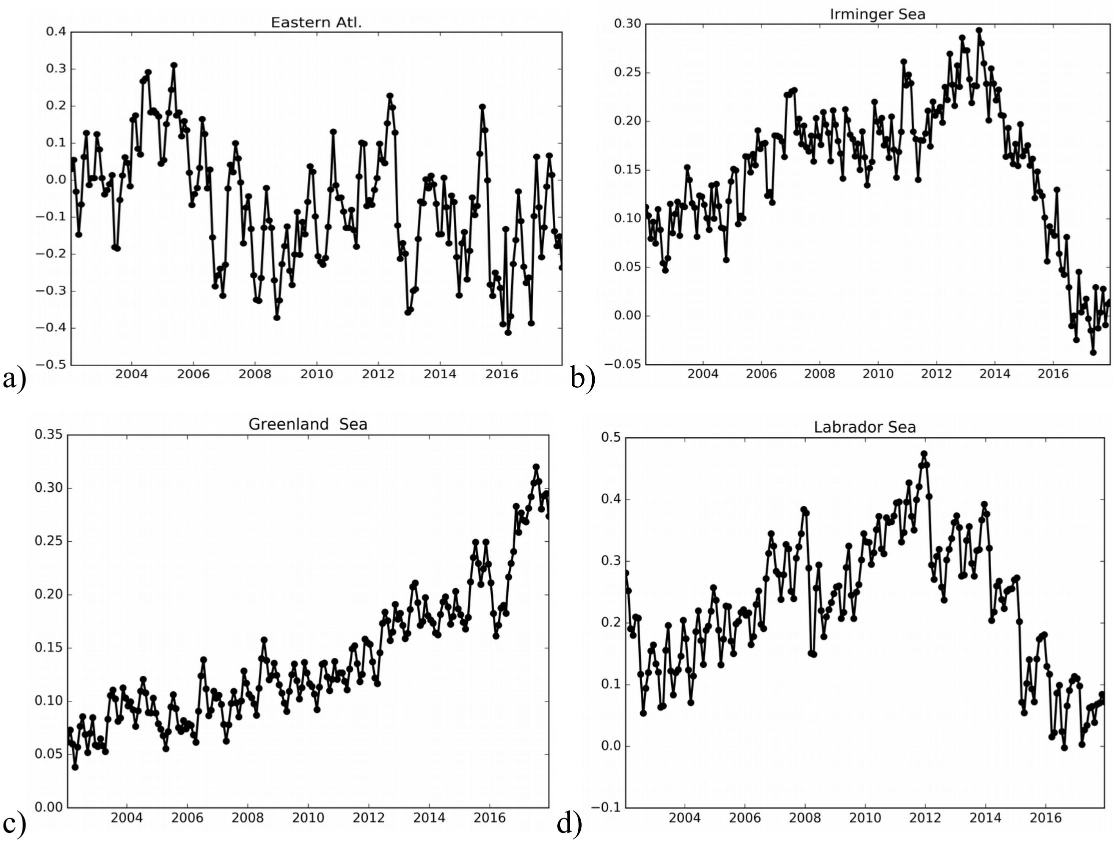


Figure 1.6: Time series of temperature anomalies (using WOA05 as reference) averaged over the 800-1200m layer and in a) Eastern Atlantic region [25°W, 15°W, 45°N, 55°N] ; b) Irminger Sea [40°W, 30°W, 55°N, 65°N]; c) Greenland Sea [15°W, 5°W, 65°N, 75°N] and d) Labrador Sea [60°W, 50°W, 55°N, 65°N], over the period 2002-2017.

1.3 Deep layers

At 1000 m (Fig. 1.5a), until 2014, in the subpolare gyre, the Labrador Sea and the Irminger Sea were warmer than the pre-Argo condition (0.4°C). In contrast since 2015, the warming tendency of was no more observed (~0°C anomaly) and may reflect conditions more comparable to the pre-Argo period. The time series of temperature averaged between 800-1000 m depth confirms the tendency since 2002 (Fig. 1.6bd). The deep temperature in both Labrador and Irminger basin has increased since 2002 until 2011 (+0.4°C) and 2013 (+0.3°C), respectively. Then, the temperature has collapsed until 2016-2017 (Fig. 1.6bd). This reflects colder condition in the subpolare gyre over the water column in this both basin after 2012 respective to the 2002-2012 period. Note that in the Eastern Subtropical gyre between Iceland and Ireland, persistent cold condition (and colder than the pre-Argo condition) were observed between 2002-2017.

The deep Greenland sea has warmed up over the period 2002-2017 with an amplitude of 0.3°C (Fig. 1.5a and 1.6c).

At 1000 depth, The Mediterranean Outflow water was warmer and saltier south of 40°N and off Gibraltar straight. From 2012 to 2017, the salty (>0.04 pss) and warm anomaly increase seems to have extended westward in the subtropical basin (Fig. 1.5b). In contrast, a cold and fresh anomaly have stood from the South of Iceland down to Rockall Trough, and is intensified in 2016 and 2017 (Fig. 1.5b).

1.4 References

Gaillard, F., T. Reynaud, V. Thierry, N. Kolodziejczyk and K. von Schukmann , 2016 : In Situ–Based Reanalysis of the Global Ocean Temperature and Salinity with ISAS: Variability of the Heat Content and Steric Height, *J. Clim.*, 29, 1305-1323.

Kolodziejczyk N., A. Prigent-Mazella, F. Gaillard (2017). ISAS-15 temperature and salinity gridded fields. SEANOE. http://doi.org/10.17882/52367

2 Surface sampling along AX1 and AX2 (North Atlantic subpolar gyre)

The two shipping routes along which surface sampling was continued were (figure 1) lines AX01 (since mid-1993 until June 2016) between southern Newfoundland and Reykjavik and AX02 (since mid-1997, MV Nuka Arctica) between Denmark and west Greenland (Fig. 1). Both ships were equipped with thermosalinograph and XBT launchers, and are part of a concerted multi-disciplinary effort, including the measurement of the current with a ship-ADCP on Nuka Arctica (Univ. Bergen) and fCO2 measurements on Skogafoss (NOAA/AOML) and Nuka Arctica (Univ. Bergen). Because of large sea ice extent in late winter and early spring, as well as numerous winter storms in the winter and early spring 2015, and 2016, the nominal AX01 route was not often followed during these seasons. In June 2016, the TSG on AX01 was discontinued, but seasonal sampling has continued with a ship rider.

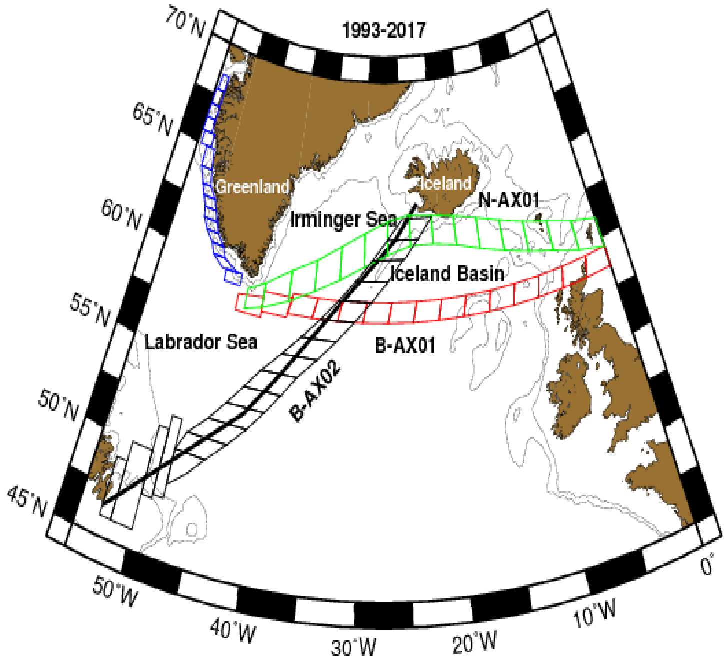


Figure 2.1 : Map of the bins along B-AX01 (black), B-AX02 (red), G-AX02 (blue), and N-AX01 (green). A typical example of ship track is shown along B-AX02.

We present Hövmuller diagrams of SST and SSS as a function of latitude (B-AX01) (Fig. 2) and longitude (B-AX02) along nominal lines (Fig. 3). For B-AX02, only the part of the section between the shelf break off Cape Farewell and the north-east of Scotland is presented (see Fig. 1). The average seasonal cycle has been removed and thus this is a mapping of the deviations from this average seasonal cycle which is presented. To complement the TSG measurements, we also use nearby ARGO 5m depth data. We will fist comment the B-AX01 plots (left hand-side of Fig. 2). There is usually a large change in the anomalies (in particular for S) happening near 53°N, at the northern reach of the northwest corner region (and latitude of Charlie-Gibbs fracture zone). This difference is not really observed in 2017. 2017 seemed anomalously salty on the Newfoundland shelf, but near neutral (or slightly negative) in the deep waters further north until 58°N. In the northern part of the section fresh anomalies are present, continuing what was already sensed by mid-216. The year was also colder than average, in particular in its second half, but not as much as the exceptional 2015.

Along B-AX01 (right hand-side of Fig. 2), the very fresh anomalies observed since mid-2015 in the Iceland Basin east of the Reykjanes Ridge (and until 15°W) were still present, although a little bit less strong, and spreading both eastward and westward in the Irminger Sea. Temperature anomalies were negative in the central and western parts of the section, whereas positive anomalies returned to the east. Both for salinity and temperature, the recent anomalies have been on a magnitude comparable to the ones observed in the first year of the record.

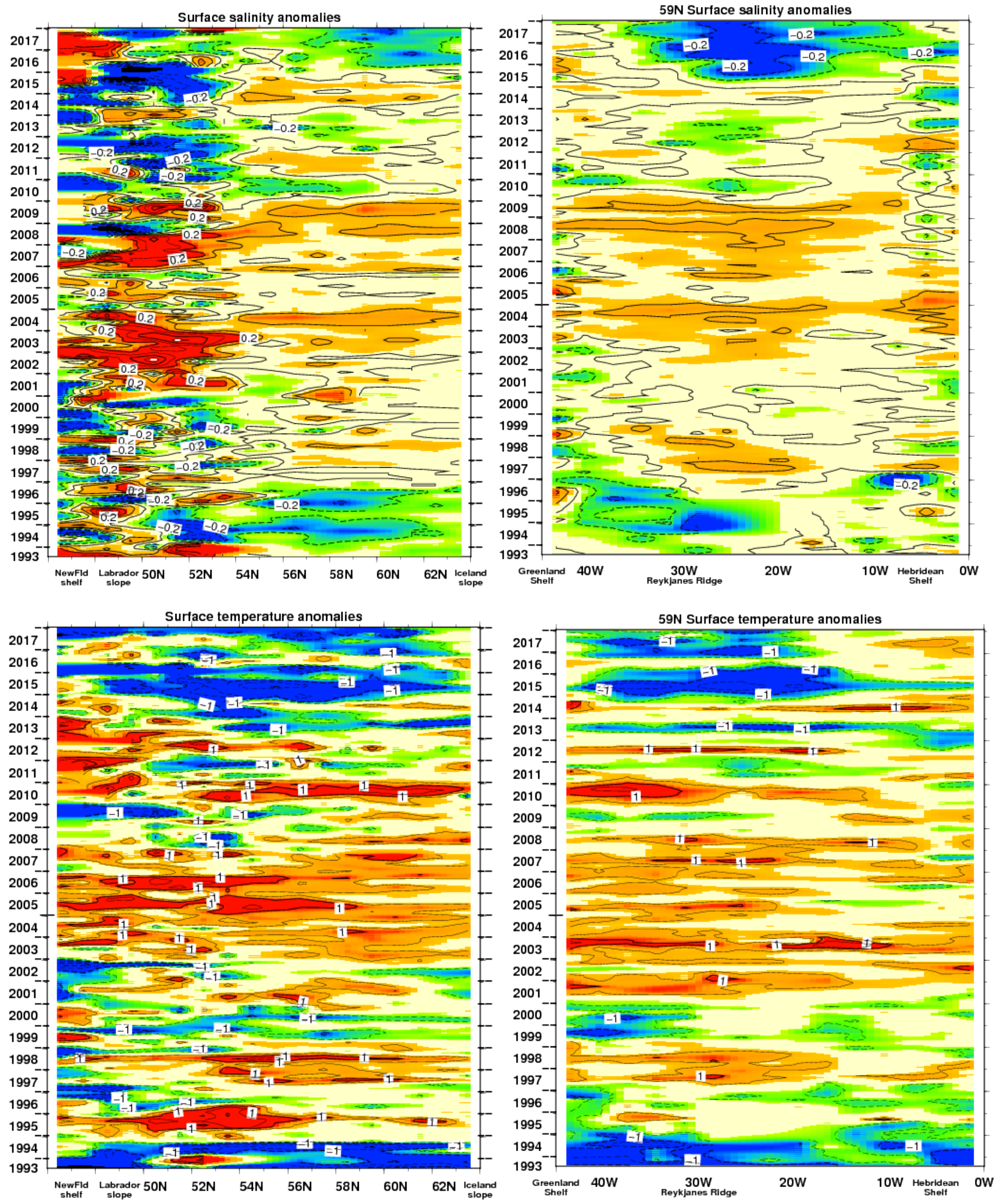


Figure 2.2: B-AX02 (left) and B-AX01 (right) Hoevmoller diagrams of deviations from an average seasonal cycle. Salinity (top with vertical lines indicative of the crossing of the two lines), temperature (lower panel). See Figure 1 for the positions of the lines.