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Contribution to the ICES Report on Ocean Climate : North Atlantic Ocean in 2020

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1 Argo gridded temperature and salinity fields

1.1 ISAS: gridded temperature and salinity fields

The ARGO network of profiling floats has been set up to monitor large-scale global ocean hydrological variability (http://www.argo.ucsd.edu). Argo data are transmitted in real time and rapidly made available by the two Global Data Assembly Centres (Argo-GDAC). Delayed-mode data undergo expert calibration and are delivered later, on average with a delay between one and several years. In the North Atlantic, temperature and salinity conditions have been adequately described over the upper 2000 m since 2002, when the Argo network started to be implemented. The dataset is thus suitable for an overview of deep sea oceanographic conditions in this basin and provides the general context for the data collected at stations and sections, mostly located at the periphery of the basin.

Temperature and salinity gridded fields are estimated on a regular 0.5° 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[1]. It should be noted that Coriolis assembles many types of data transmitted in real time, merging the Argo dataset with data collected by the Global Telecommunications System[1] (GTS), such as data from moorings and CTDs, and data on marine animals. However, the Argo dataset remains the main contributor to the ISAS gridded fields in the open ocean. The ISAS optimal interpolation (OI) procedure is as follows: the *in-situ* temperature and salinity 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 an optimal estimation algorithm and includes a horizontal smoothing through specified covariance scales. The results presented here were produced with the last version of ISAS. The reference state used in the OI process 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 temperature and salinity products are used:

- For the period 2002–2015, ISAS15 product is used (Kolodziejczyk *et al.*, 2017; using ISASv7 tool). For this period, only delayed mode *in situ* and preprocessed, and extra quality control is applied to *in situ* profiles delayed mode and remaining real time data before they are included in the analysis. ISAS15 product is the highest quality product in Delayed Mode.
- The last years of the analyzed series, i.e. 2016–2020, use the Near Real Time (NRT) dataset prepared by Coriolis at the end of each month from real-time data. For this period, data are

1 https://www.wmo.int/pages/prog/www/TEM/GTS/index_en.html

interpolated using ISASv6 tool including only real-time mode data (i.e. only from automatic QC processing). Because Argo salinity data require advanced quality checks and validation, NRT salinity fields have to be used with caution. Therefore, time-series of monthly salinity anomalies are not considered herein, and the focus is rather made on their seasonally averaged and annually averaged patterns.

The ISAS interpolated fields are used to compute seasonal to interannual maps of temperature and salinity anomalies averaged within an upper layer (0–100 m depth), intermediate and deep layers (700 - 1000m; 1000-1500m; 1500-2000 m depth). Note that the temperature and salinity anomalies throughout this section are computed using the climatological ISAS15 fields (2006–2015). In order to compute temperature and salinity anomalies, the climatological monthly temperature and salinity fields are removed from each monthly ISAS field over the period 2002–2020. Note that the temperature and salinity fields are blanked in regions with water depths deeper than 1000 m, where the Argo coverage is either too sparse or unavailable. The seasonal time-windows are defined as winter (DFM), spring (AMJ), summer (JAS), and autumn (OND). The seasonal and interannual variability is monitored in selected area (Fig. 1) representative of the North Atlantic Polar, Subpolar, and Subtropical variability, named: Greenland Sea; Labrador Sea; Irminger basin; Eastern Atlantic region (Iceland and Rockall basin); Gulf Stream Region; and Azores region. Within each selected area the number of temperature and salinity profiles used in monthly objective analyses is showed in Figure 2. This provides an assessment of the robustness of the temperature and salinity timeseries in each area.

1.2 Highlights of 2020

- In 2020, the surface Subpolar Gyre is moderately colder than 2006-2015 climatology but exhibits a warming tendency since 2016. The Subtropical Gyre remains warmer than average conditions (2006-2015) (Fig. 3, 4, 5).
- In 2020, the intermediate layers of the Nordic Seas and Subtropical basins have continued to warm up. In the Subpolar Gyre, the significant cooling trend of intermediate layers observed since 2012 has come to an end in the Labrador Sea and is slowing down in the Irminger Sea (Fig. 8 and 9).

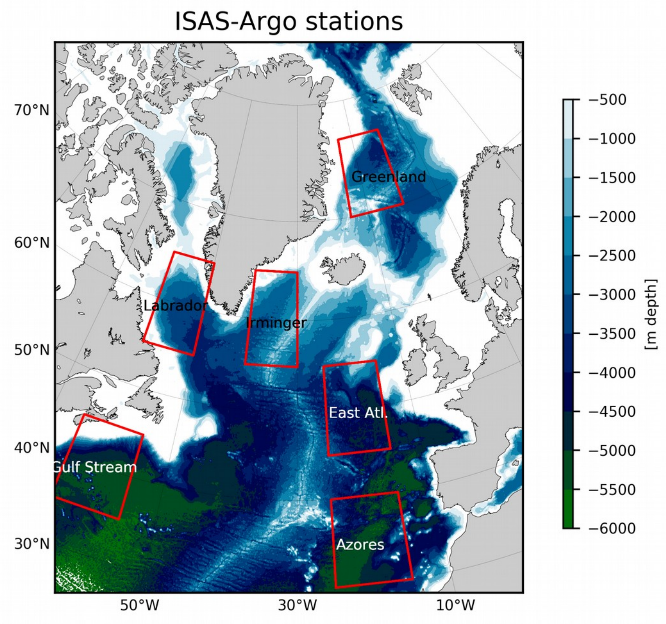

Figure 1: Location of the six areas in the North Atlantic: Azores, Gulf Stream region, Eastern Atlantic (Iceland and Rockall basin), Irminger Sea, Labrador Sea, and Greenland Sea. Those areas are used for compute averaged temperature and salinity profile time-series.

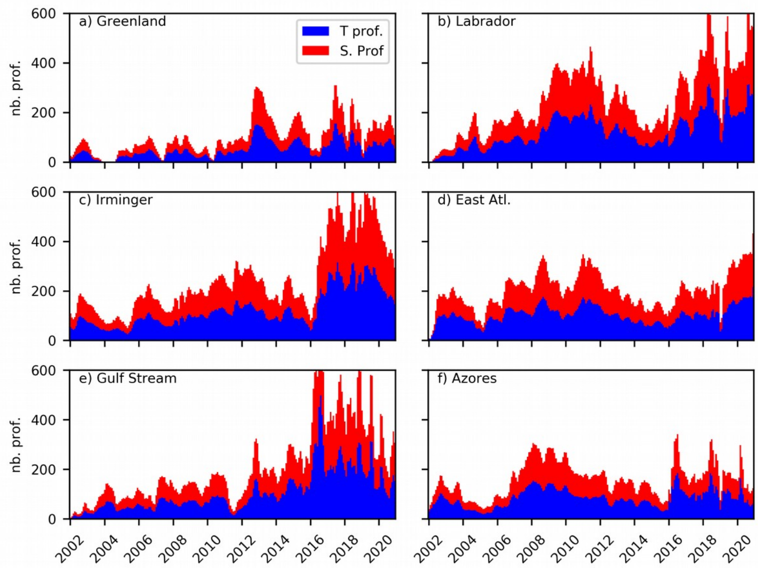

Figure 2: **Number of temperature (blue) and salinity (red) profiles** used in monthly objective analysis between 2002-2020 in each selected area from Figure 1. a) Greenland Sea; b) Labrador Sea; c) Irminger basin; d) Eastern Atlantic region (Iceland and Rockall basin); e) Gulf Stream Region; and f) Azores region.

1.3 Surface layers

Seasonal patterns of T/S 2020 anomaly

The broad pattern of temperature and salinity anomalies in 2020 (with respect to the 2006–2015 climatological mean) shows a relatively warm and salty Subtropical region, a relatively cold and fresh Subpolar region, and contrasted conditions in Nordic seas (Fig. 3). However, there were significant subregional and intra-annual changes in each of these regions. The warm Subtropical anomalies appear to spread over the width of the basin from east (in JFM) to west (in OND), while a cold and fresh anomaly is observed off Newfoundland (~45°N) in JFM before likely propagating northeastward along the North Atlantic Current (NAC) up to 20°W in OND. In the Subpolar region, negative temperature and salinity anomalies are observed in the Irminger Basin during JFM. This pattern is sustained over the years. In contrast, the Labrador Sea is warmer and saltier than usual around its northern (during JFM and AMJ) and eastern (JAS and OND) boundary. The warm and salty anomaly was probably advected southward by the Labrador Current along the upper North American US continental slope. In the Nordic Seas, warm and salty anomalies primarily developed within the western portion of the domain (Iceland and Greenland Seas), while cold anomalies developed along the eastern margin (Norwegian Sea). This asymmetric pattern is less visible for salinity, but still present (salty in the west and fresh in the east). Note that the situation in 2020 remains comparable to the 2019 situation.

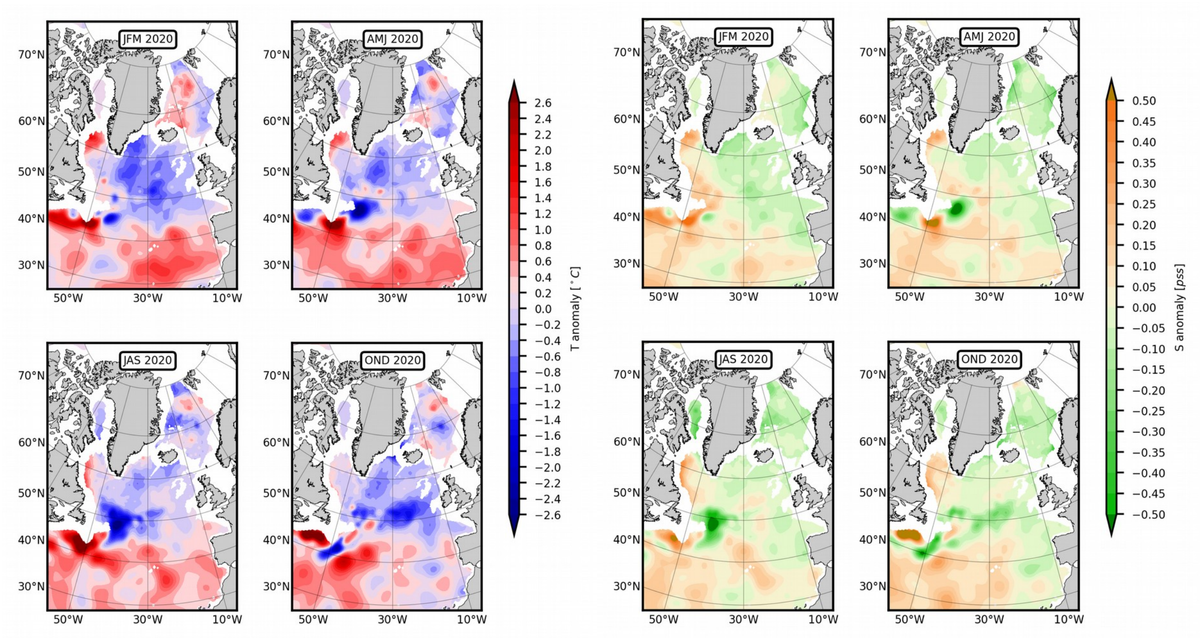

Figure 3: Near surface temperature (left) and **salinity** (right) **anomalies** (0-100 m average) averaged over Winter (JFM), Spring (AMJ), Summer (JAS) and Autumn (OND) 2020. Anomalies are the differences between the ISAS monthly mean values and the reference climatology ISAS15 2006–2015. Data prepared from the Coriolis, ISAS monthly analysis of Argo data.

Seasonal cycle and monthly anomalies

The 2020 seasonal cycles of temperature anomalies, averaged within the six areas representative of the main sub-basins of the North Atlantic domain (Fig. 1), are depicted in Figure 4. The 2006-2015 climatology (solid) and the spread (dashed) over the period 2002-2020 is also shown in Figure 4.

- In 2020, the surface layer in the Greenland Sea (Fig. 4a) was warmer than the reference period 2006–2015 during the winter months (JFMA), then it remains mostly colder than usual during the rest of the year (spring-summer-fall).
- The surface layer of the Labrador Sea (Fig. 4b) was warmer than normal over the whole seasonal cycle.
- In the Irminger Sea (Fig. 4c), the surface layer was colder than normal throughout the year, especially during winter.
- In the Eastern Atlantic (Fig. 4d), the 2020 surface layer exhibited colder temperature than the 2006–2015 average, excepted during summer (JJA) where temperature were not significantly higher than usual.
- The surface layer of the Gulf Stream and Azores region, *i.e.* western and eastern Subtropical Gyre, respectively (Fig. 4e and f) was warmer than normal over the whole seasonal cycle.

In conclusion, the observed seasonal cycle of temperature in the main North Atlantic sub-basins reveals a year 2020 warmer than usual for the Western Subpolar basin (Labrador), while the eastern Subpolar basin (Irminger, Iceland and Rockall basins) remain colder than usual most of the year. The Greenland Basin, is in contrast warmer only for the winter period. The Subtropical Gyre also shows a sustained warmer anomaly over the whole seasonal cycle.

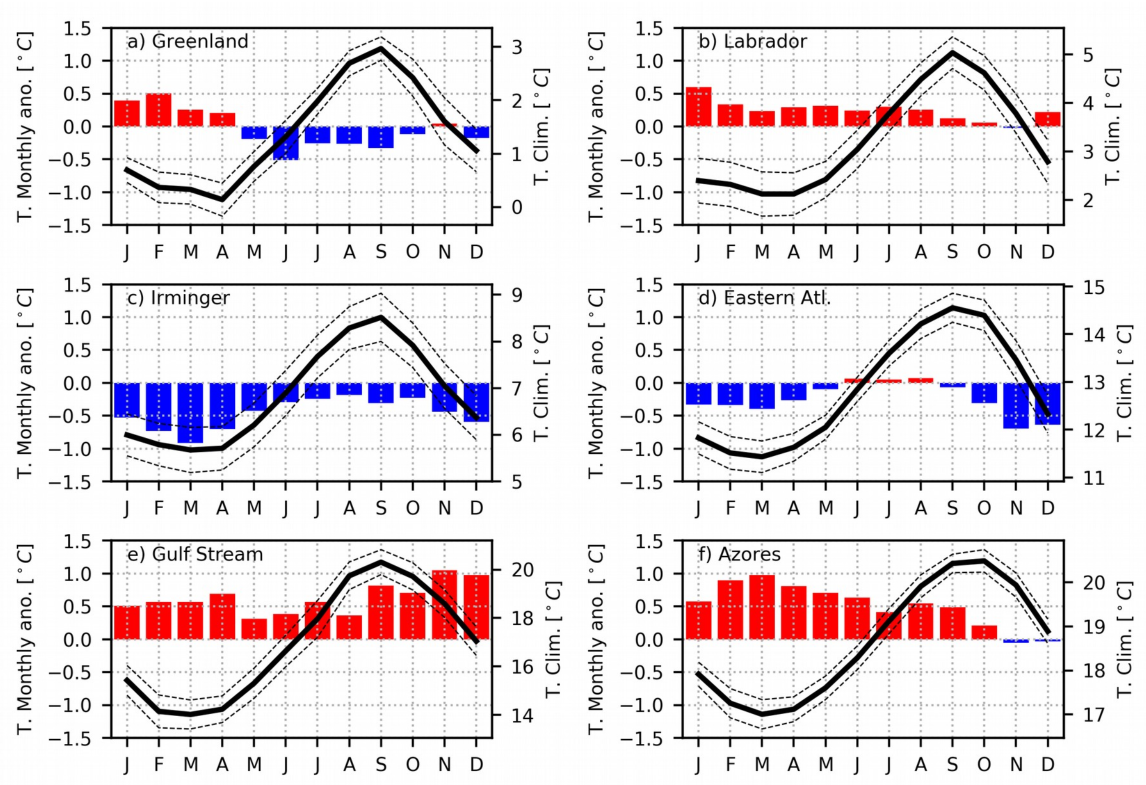

Figure 4: 2020 near surface temperature (0-100 m average) **monthly anomalies** (bars) and climatological seasonal cycle (thick line) and standard deviation (dashed lines) over the period 2006-2015. Anomalies are the differences between the ISAS monthly mean values and the reference climatology ISAS15 2006–2015. Data prepared from the Coriolis, ISAS monthly analysis of Argo data.

Interannual variability and long-term tendency

The interannual variability of upper layer (0–100 m) temperature anomaly (relative to 2006-2015) over the period 2002-2020 in the six North Atlantic areas is depicted in Figure 5. The Greenland Sea region, warmer than average over the last five years, shows a continued cooling tendency since 2018, to reach the average 2006-2015 surface temperature conditions in 2020 (Fig. 5b). In 2020, the Labrador basin (Fig. 5b) remained warmer than usual, due to a warming trend since 2018 and which is now mainly observed along the western boundary of the basin (Fig. 3). This recent warming event in the Labrador basin occurs after a decade (since 2008) that was slightly colder than usual, except for the remarkable 2010 warm event. Although the Irminger basin (Fig. 5c) exhibits similar relative warming events since 2018, the 2020 year remains colder than usual. This is due to an unabated cooling observed since 2008, in spite of the 2010 exceptional warming event. The Eastern Atlantic region (Iceland and Rockall basins; Fig. 5d), shows similar upper ocean temperature decrease, but 2020 remain within the 2006-2015 average.

When compared to the long-term 2006–2015 mean, the Subtropical region was generally warmer in recent years, with warming being particularly significant over the Gulf Stream region (Fig. 5e) since 2015.

In the Eastern Subtropical Gyre (Azores; Fig. 5f), although 2019-2020 was warmer than usual, similarly to 2017 warm events, no long-term tendency was observed since 2002. However, 2020 shows up the warmer surface temperature since 2002 in this region.

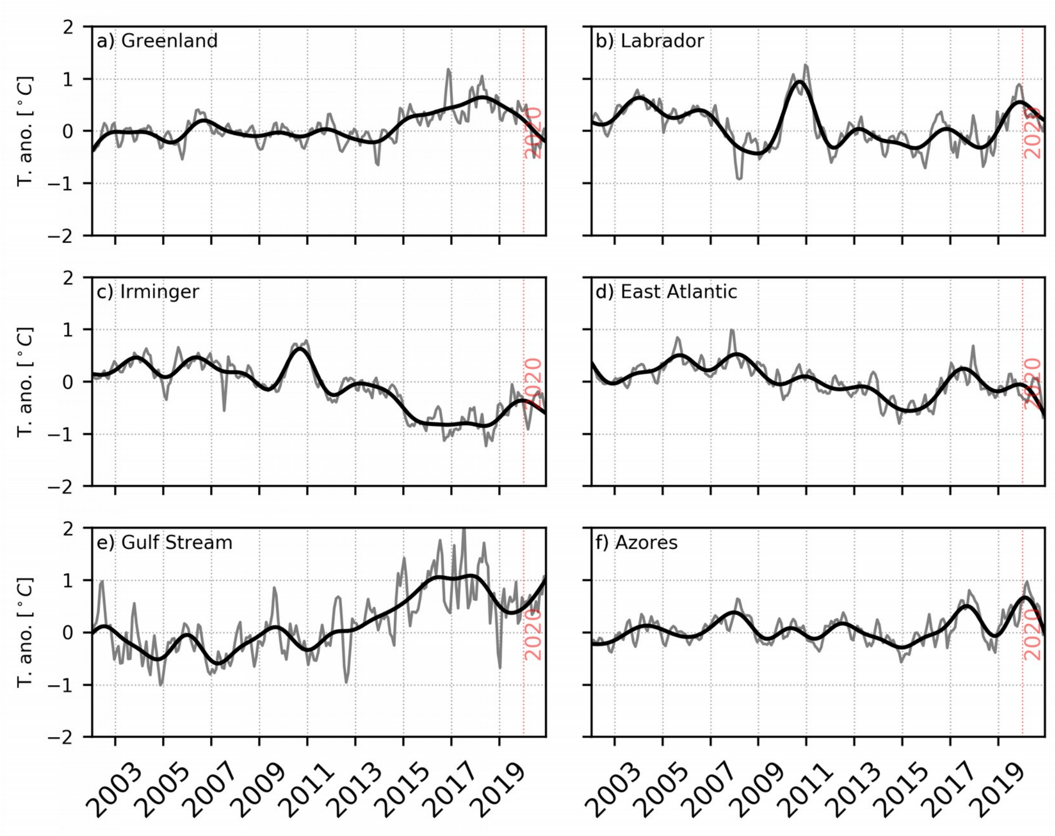

Figure 5: Upper ocean (0-100 m depth) temperature interannual anomalies (reference climatology: 2006-2015) over 2002-2020 period (19 years) in the basin areas defined in Figure 1. a) Greenland Sea; b) Labrador Sea; c) Irminger basin; d) Eastern Atlantic basin (Iceland and Rockall basin); e) Gulf Stream region; and f) Azores regions. The thin gray line represents the monthly interannual anomaly. The thick black curve is the 24-months low pass filtered (with a Butterworth filter) timeseries.

Mixed layer depth

The mixed-layer depth (MLD) is an indicator of winter convection intensity in the North Atlantic and Nordic Seas. Winter heat and freshwater fluxes control the sea surface buoyancy loss (increase of density) of the ocean surface layers and trigger deep convection. In order to compare all areas throughout the decade, the MLD is defined here as the level at which density changes by more than 0.03 kg m^{-3} with respect to the 10-m depth value. This is a common criterion used for the global ocean (de Boyer Montegut *et al.*, 2004). Given the difference of stratification over the North Atlantic and Nordic seas, it is probably not the optimal criterion to define the MLD in this region. However, adopting this definition allows the comparison of the relative winter MLD across multiple years. To compute 2006-2015 average and 2020 anomaly of MLD (Fig. 6), the month of March has been chosen as being the common period for maximum MLD, at the end of the winter season, and comes before spring re-stratification. However, this is not always true, since the time-point when the deepest mixed layer occurs can vary from year-to-year at a single location and might not occur at the same time of year across the whole basin (generally between February and March in the North Atlantic; Fig. 7). Therefore, in order to compute the interannual MLD time series (Fig. 7), i) we here focus on specific winter convection area in North Atlantic, which were chosen from the climatological March MLD over the period 2006-2015 (Fig. 6). Note that the selected deep convection areas differ from the ones in Figure 1 (see figure 6). Six regions are selected: Greenland convection zone in Nordic Seas; Western and Eastern Labrador area; Irminger basin convection zone, and Iceland and Rockall region in the eastern Subpolar Gyre (Fig. 6). ii) For each year since 2002, we have plotted the MLD corresponding to the month of the deepest MLD (color code; Fig. 7).

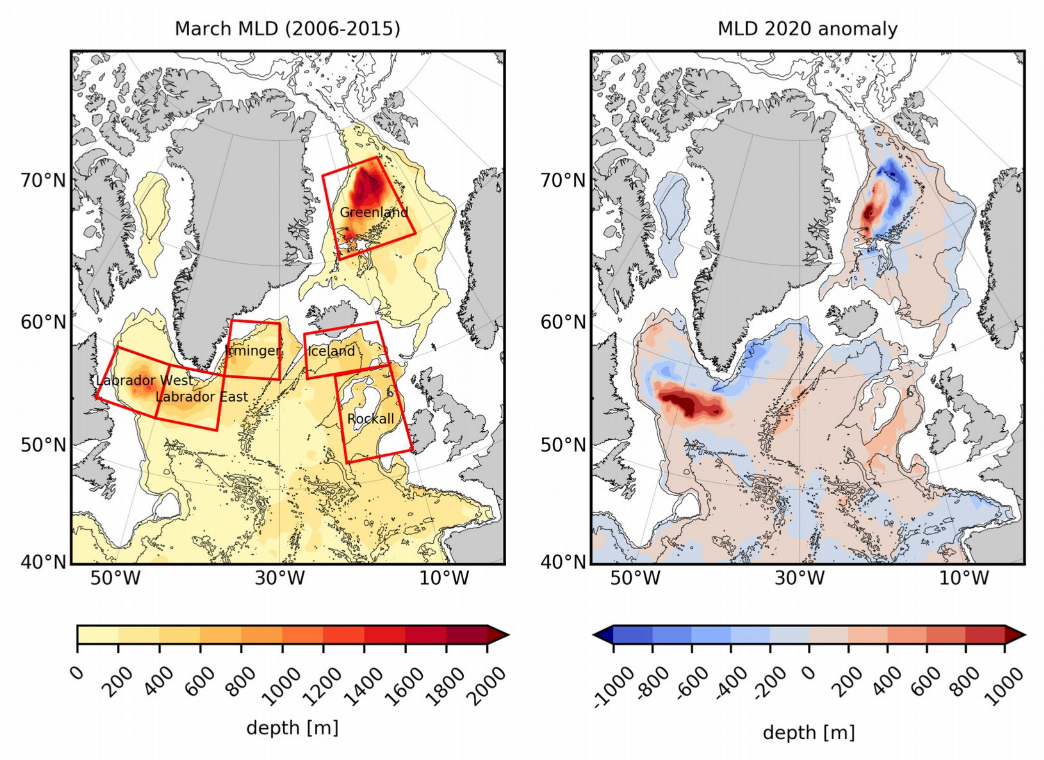

Figure 6 : (Left) **climatological March Mixed Layer Depth (MLD)** for the winter 2006-2015. The selected areas to compute the yearly deepest MLD time series in Figure 7 are as follows : Western and Eastern Labrador sea, Irminger, Greenland, Iceland and Rockall basin. (Right) **The 2020 March MLD anomaly** (in m). Isobath 1000 m, 2000 m and 4000 m depth are plotted. Region shallower than 1000 m depth are blanked.

The 2020 winter (Fig. 6) was characterized by a noticeable increase in MLD in both the Labrador and Greenland seas. However, in the Labrador basin the center of the deepest MLD anomaly are shifted eastward, while the Irminger basin presents shallower MLD than usual (Fig. 6). Interestingly, on the northern and western boundary of the Labrador Sea deeper than usual MLD is observed. In the Greenland Sea, the deep convection area appears smaller but deeper than usual and confined to the eastern part of Greenland Gyre. In 2020, in the Irminger and North Iceland basin, the March MLD is shallower than usual, while in the Southern Iceland and Rockall basin, it appears deeper than usual.

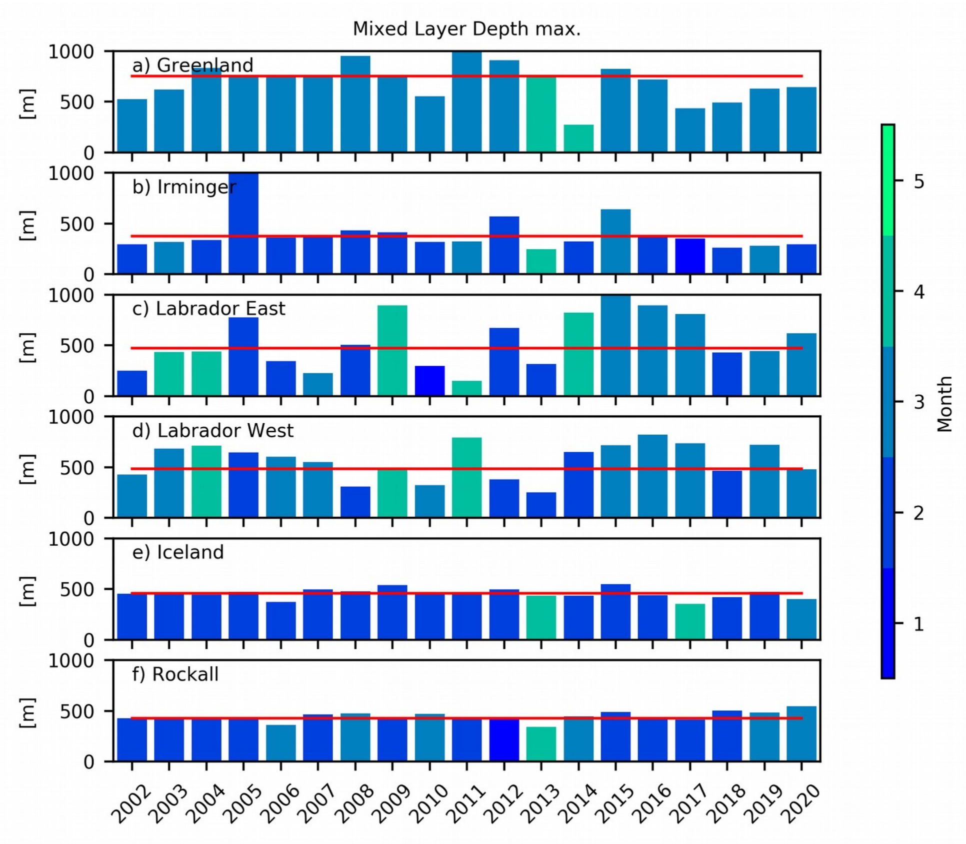

Figure 7: Yearly deepest MLD over the period 2002-2020 averaged in the selected area from Figure 6: a) Greenland sea; b) Irminger basin; c) Eastern and d) Western Labrador Sea; e) Iceland basin; f) Rockall basin. Colorbar indicates the winter month of the year when occurs the deepest MLD (between January and April).

The Figure 7 shows the deepest MLD averaged in the different regions depicted in Figure 6 over the period 2002-2020. In the Greenland Sea, the deepest MLD generally appears during March (Fig. 7a). In 2020, the MLD is recovering deeper convection events since the last minimum event in 2018, but still below average. In the Irminger Basin (Fig. 7b), maximum MLD is still lower than usual since its 2015 maximum. In 2020, in the Labrador Sea, the MLD is deeper in the Eastern Labrador region (Fig. 7c) than in the Western Labrador region (Fig. 7d). This is explained by deeper convection slightly shifted in the eastern part of the Labrador basin (Fig. 6). In contrast, the previous 2019 year, the deep convection was mainly located in Western Labrador basin (Fig. 7d). In 2020, the deep convection in Labrador Sea is recovering a level slightly larger than average, but not at the level of deepest events observed during the period 2014-2017 (Fig. 7cd). Interestingly the deepest MLD in the Eastern Labrador basin were less common before 2014 (1/3 of the events). In 2020, and since 2016 the Iceland basin presents shallower MLD than usual. In contrast, the Rockall region presents deepest MLD than usual.

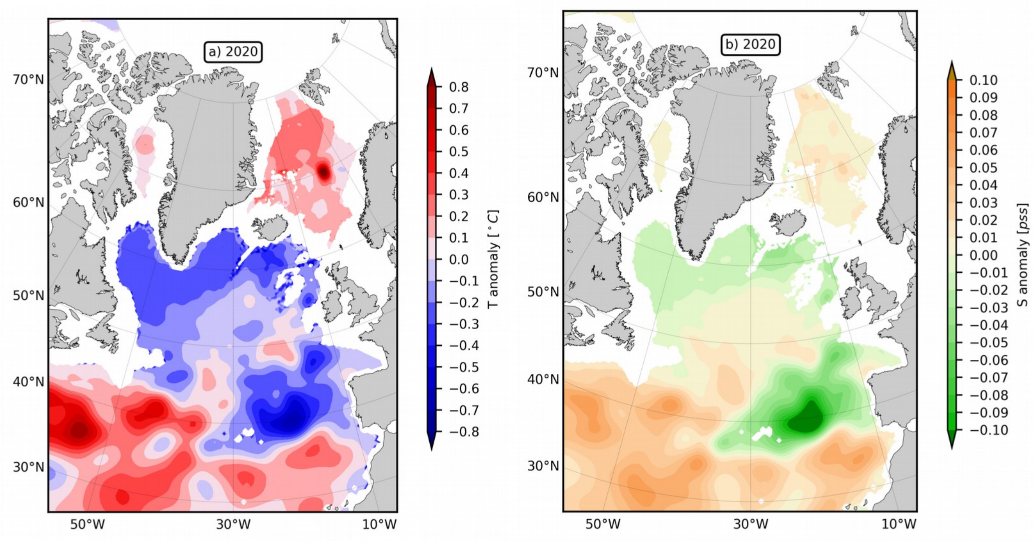

Figure 8: **2020 maps of annual a) temperature and b) salinity anomalies averaged within 700–1500 m** in the North Atlantic. Anomalies are the differences between the ISAS monthly mean values and the reference climatology ISAS15 2006–2015. Data prepared from the Coriolis ISAS monthly analysis of Argo data.

1.4 Intermediate and deep layers

The map of 2020 interannual anomalies of temperature anomalies and salinity in the intermediate layer (700–1500 m) of the North Atlantic is shown in Figure 8. Figure 9 shows time-series of temperature anomalies in the intermediate and deep layers averaged in each area (Figure 1) for the period 2002–2020. In 2020, the overall spatial pattern is one of a relatively warm Subtropical region, a relatively cold Subpolar region, and relatively warm Nordic seas (when compared to the 2006–2015 climatological period; Fig. 8a). This tripole pattern characterizing the intermediate layer, which was already observed the preceding year, appears to have sustained in 2020. The strongest centers of action are located in the western Subtropical Gyre, where the Gulf Stream/NAC area are found, in the Irminger and Labrador Seas, and in the Greenland Sea. The North Atlantic intermediate salinity anomalies show a similar pattern with saltier anomaly in Subtropical Gyre and Nordic Seas, and fresher Subpolar Gyre (Fig. 8b). Note that, the cold anomaly pattern observed at 40°N off Iberic Peninsula, is associated with a similar pattern of fresh anomaly (Fig. 8ab). This is probably due to the southward shift of the warm and salty Mediterranean water panache at intermediate depth.

The contrasting interannual behavior of temperature in those regions is striking (Fig. 9). Since 2012, the Gulf Stream area has warmed nearly 0.05°C in deep layers (in 1500-2000 m), 0.1°C (in 1000-1500 m) and 0.5°C (in 700-1000 m) in intermediate layers (Fig. 9e). The Subpolar area (Labrador and Irminger seas) has cooled around 0.3°C in intermediate layers (700-1500 m depth; Fig. 9bc). In the Labrador Sea, even the deepest layers (1500-2000 m depth) have cooled by nearly 0.1°C during the same period. Interestingly, since 2016, the intermediate layer cooling trend seems to be halted in the Labrador Seas (Fig. 9b), and since 2019 in the Irminger Sea (Fig. 9c). In contrast to those two latter regions, temperatures in the intermediate and deep layer of the Greenland Sea (Fig. 9a) have been characterized by an unabated positive trend (increase between 0.1°C and 0.3°C since 2002 for deep and intermediate layer, respectively). In Eastern Subtropical Gyre (Fig. 9d), in spite of a very large interannual variability, intermediate layers (700-1500 m depth) appears to have slightly cooled since 2012. In contrast, deep layer reveals a warming trend (0.15°C) for 2002-2017 and relatively stable conditions afterwards.

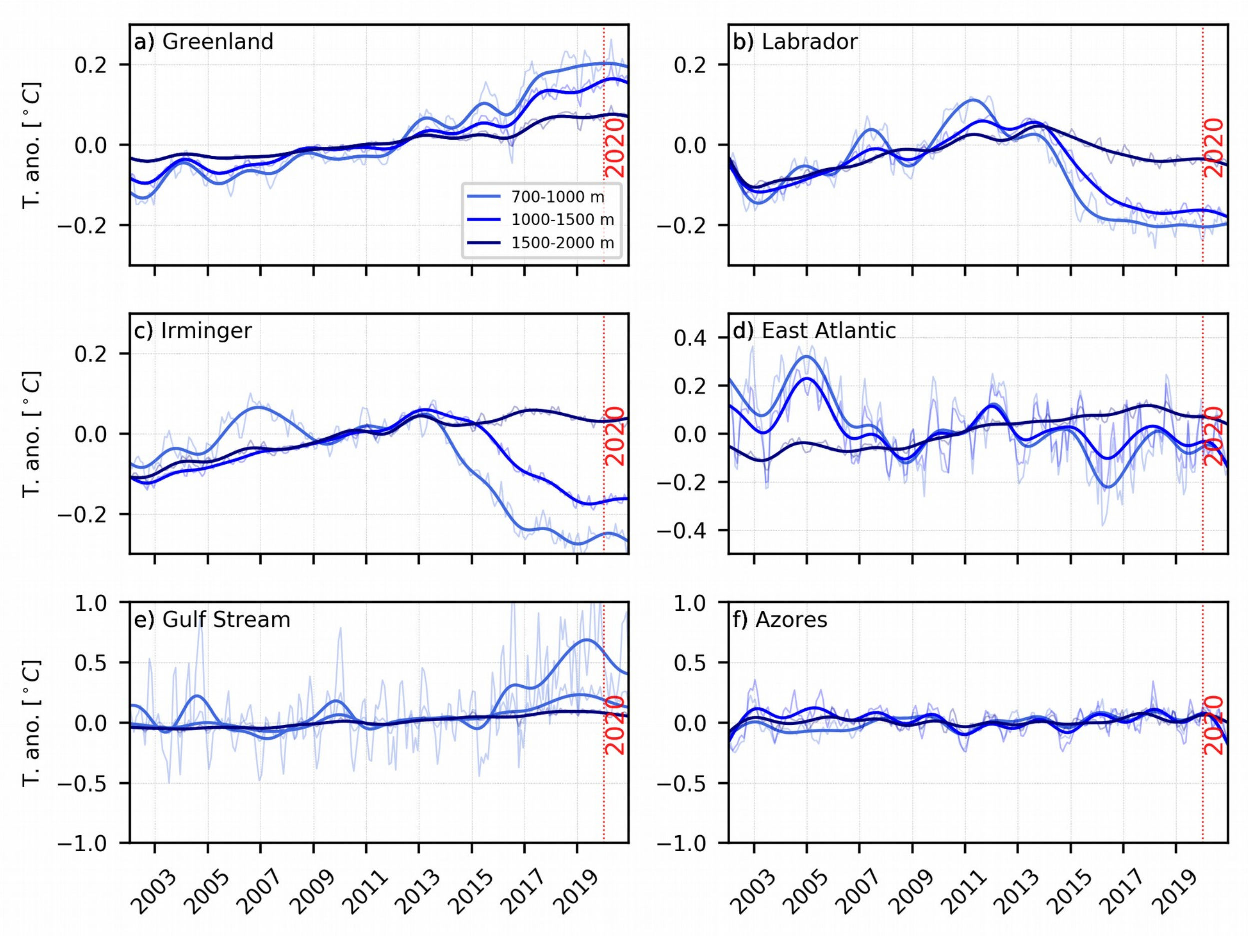

Figure 9: Time-series of temperature anomalies (using 2006–2015 as reference) averaged over the 700–1000 m (light blue), 1000-1500 m (blue) and 1500-2000 m (dark blue) layer and in (a) Eastern Atlantic, (b) Irminger Sea, (c) Labrador Sea, (d) Greenland Sea, (e) Gulf Stream region, and (f) Azores region over the period 2002–2020. The thin lines are monthly anomalies and the 24-month low pass filtered (with Butterworth filter) time series of monthly anomalies is plotted in thick lines.

2 References and dataset

Argo (2019). Argo float data and metadata from Global Data Assembly Centre (Argo GDAC). SEANOE. https://doi.org/10.17882/42182

de Boyer Montégut, C., Madec, G., Fischer, A. S., Lazar, A., & Iudicone, D. (2004). Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology. *Journal of Geophysical Research C: Oceans*, *109*(12), 1–20. https://doi.org/10.1029/2004JC002378

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