Laboratoire d'Océanographie Physique et Spatiale
UMR6523 – CNRS-IFREMER-IRD-UBO
http://www.umr-lops.fr

Contribution to the ICES Working Group on Oceanic Hydrography

National report: France, Juin 2016

N. Kolodziejczyk[1], F. Gaillard[1], G. Reverdin[2], T. Cariou[3], Y. Bozec[3], and P. Morin[3]

[1] LOPS, UMR 6523, Ifremer-CNRS-IRD-UBO, Brest, France

[2] LOCEAN, CNRS, Paris, France

[3] Observatoire Océanologique de Roscoff, CNRS-Sorbonne Universités

LOPS - Campus Ifremer – ZI de la Pointe du Diable – CS10070 – 29280 Plouzané

Tél 33 (0)2 98 22 48 50 – Fax 33 (0)2 98 22 44 96

IUEM, Rue Dumont d'Urville, 29280 Plouzané

Rapport : LOPS-WGOH-2016-01

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 repeat stations and sections collected mostly at the periphery of the basin by the partners of the ICES Working Group on Ocean Hydrography (WGOH).

1.1 *ISAS: gridded temperature and salinity fields*

Temperature and salinity fields are estimated on a regular half degrees (Mercator scale) grid using the In Situ Analysis System (ISAS), (*Gaillard et al.*, 2016). The dataset 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, gliders, CTDs. However, the ARGO dataset remains the main contributor in the open ocean. The last years of the analyzed series uses the Near Real Time dataset prepared by Coriolis at the end of each month from real time data. Delayed mode data are progressively taken into account for the previous years, replacing the NRT data.

Data are pre-processed before entering the analysis. First we perform a climatological test to detect outliers then we vertically interpolate the profiles on 152 standard levels between the surface and 2000m. The analysis to produce gridded fields is performed at each standard level independently. The method is based on optimal estimation principles and includes a horizontal smoothing through specified covariance scales. The results presented here were produced with version 6 of ISAS (*Gaillard*, 2012). The reference state was computed as the mean of a 2004-2010 analysis (D2CA1S2) and the a priori variances were computed from the same dataset. The period 2002-2012 was fully reprocessed to take into account new delayed mode data and flags. Near-Real Time (NRT) temperature and salinity fields provided by Coriolis Center (Ifremer) are used to complete the time series from 2013 to 2015. Over this period, data are interpolated using ISAS v6 including only Real Time mode data (i.e. only from automatic QC processing).

1.2 *Surface layers*

During winter 2015, the near surface waters were anomalously cold and fresh in the middle of subpolare gyre. The cold temperatures in the Labrador Sea were associated with a strengthening of North-easterly winds (Fig. 1). Further South, 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 is also observed.

This subpolar cold anomaly persistes and increases troughout the year 2015 (Fig. 1). Summer 2015 has been anomalously cold over most of the subpolar basin, north of 40°N. South of 40°N, a strong warm anomaly is persistent over the whole subtropical gyre.

During summer fresh salinity anomalies north of 40°N is also more intense than during the winter period and correlated with temperature anomalies. Waters were very salty in the Greenland Sea/Norvegian Sea and along the East Greenland coast. They were fresh along the western boundary: starting from the West Greenland coast, following the North American coast and from there, extending toward the west.

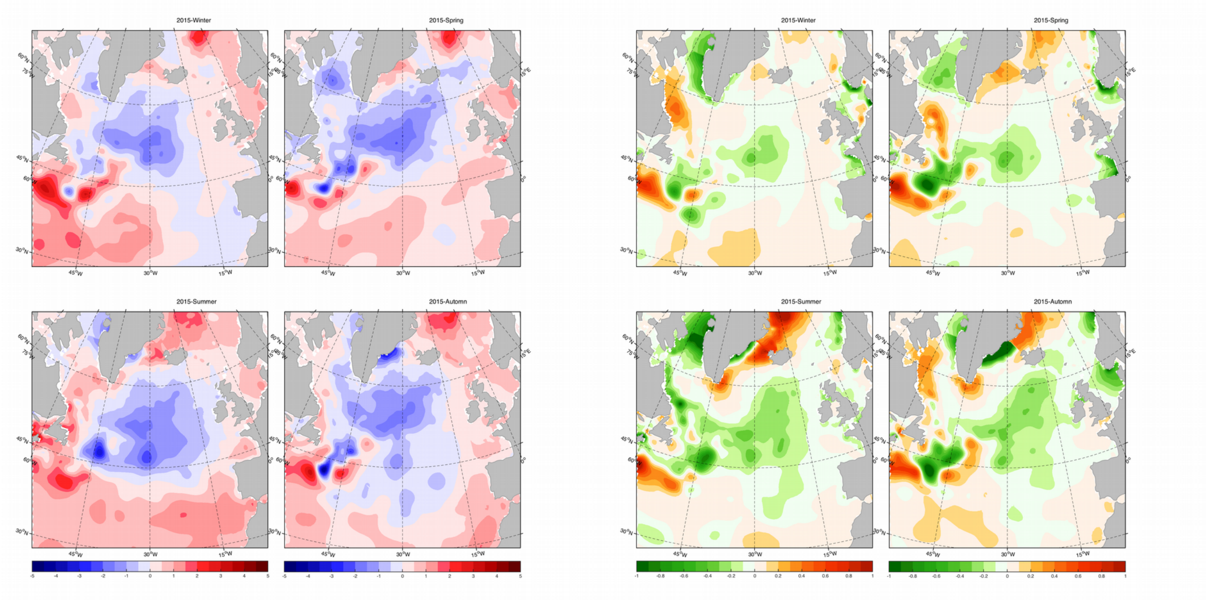
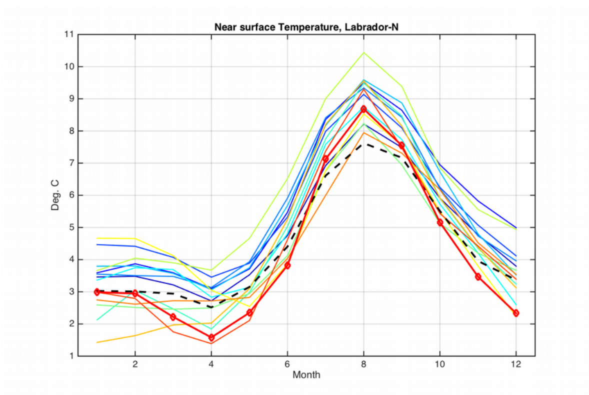
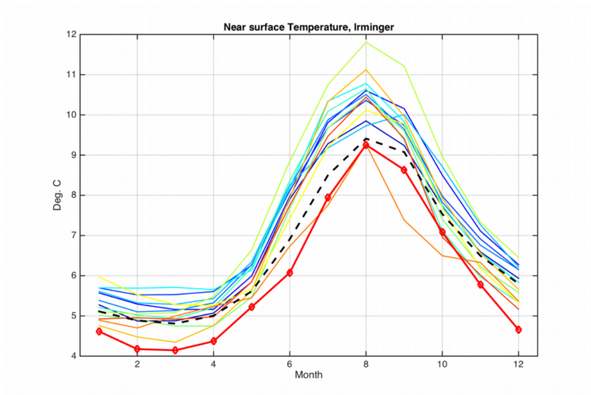


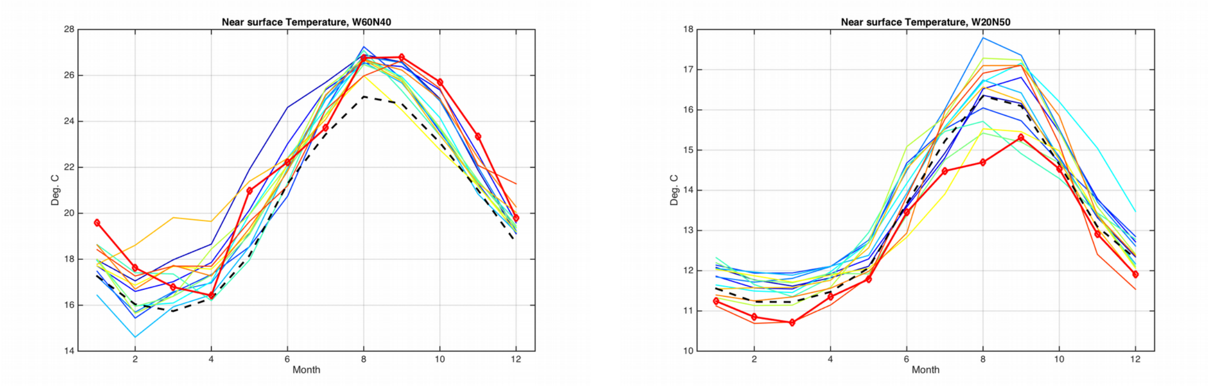
Figure 1: Near surface (10 meter) temperature (left) and salinity (right) averaged over Winter (JFM), Spring (AMJ), Summer (JAS) and Autumn (OND) 2015. The anomalies are shown relative to the World Ocean Atlas (WOA-05).



a)

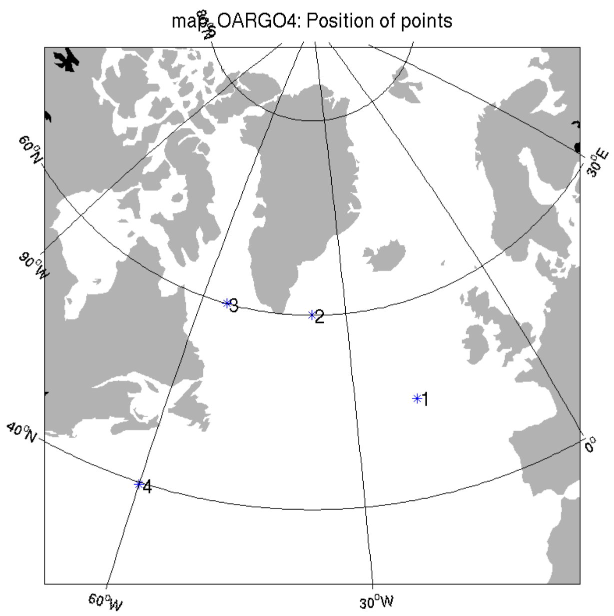


b)



c) d)

Figure 2: Seasonal cycle for temperature at 4 points in the North Atlantic basin (see the map below). In heavy red the year 2015, in dashed black the WOA05 climatology, other curves show the years 2002-2014.



The year 2015 appears as an extremum in the 2002-2015 decade for the cold winter observed in the Labrador Sea and the Irminger Sea, (Fig. 2ab) where temperatures went well below the climatological mean (nearly 2° lower in the Irminger Sea) and the warm temperature in early winter in the south-west part of the basin (Fig. 2c). North of 40°N, the cold temperatures persists during the summer especially in the Irminger Sea and in the Eastern basin off European coasts (Fig. 2bd). In contrast, the warm summer that extends south of 40°N shows extrem values in the Eastern basin (Fig. 2c).

Winter surface conditions determine the mixed layer properties. In order to compare all areas over the decade, we adopt a simple definition for the mixed layer depth, using the level at which temperature changes by more than 0.5°C with respect to the 10 meter depth. The month of February is selected as the common period for maximum mixed layer depth. This is not perfectly true since the time of the deepest mixed layer may vary from year to year at a single location and does not occur at the same time over the whole basin.

During the year 2015 the area covered by a deep mixed layer (deeper than 900 m) is more extended than usual in the North of the basin (even more than during the 5 previous winters since 2010), extending from the Labrador Sea to the Irminger Sea (Fig. 3). This deeper than usual mixed layer may reflect strong winter convection in both Labrador and Irminger basin. Unusual deep mixed layer is also observed in the eastern side of the basin off Scotland and Ireland coasts. In the South-East of the basin, the deep mixed layer extension stops around 48/50°N such that only moderate mixed layer depths are observed along the shelf in the Bay of Biscay contrary to the 2009, 2010 and 2011 winters. Note that the deep mixed layer anomaly centered at 45°N-20°W in 2014 is likely an artifact due to Near Real Time data in use of this period. Additional quality control and analysis is needed for this period.

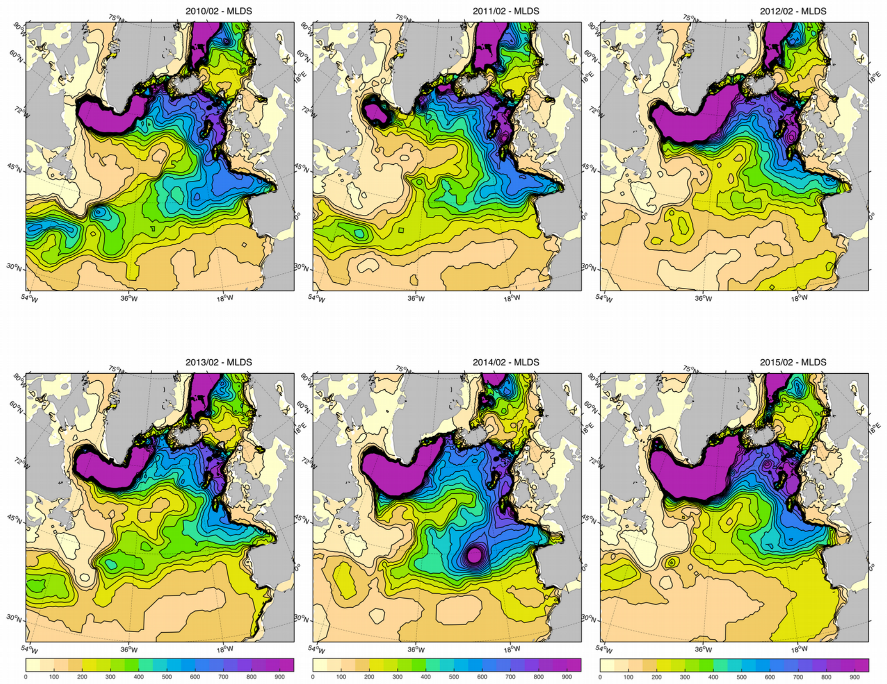
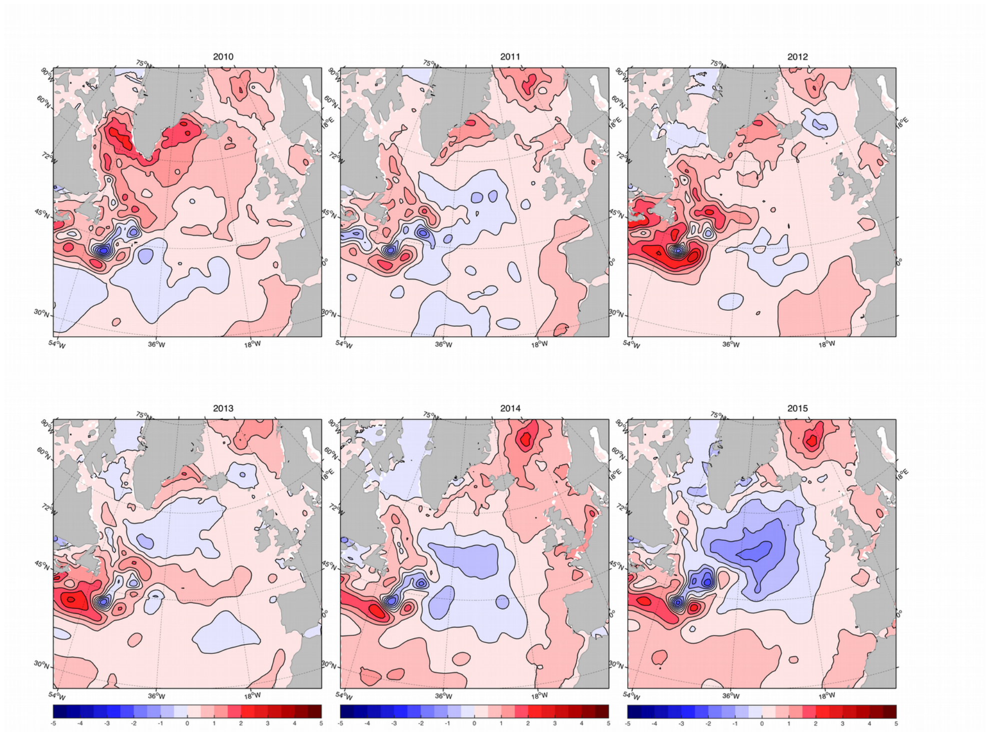


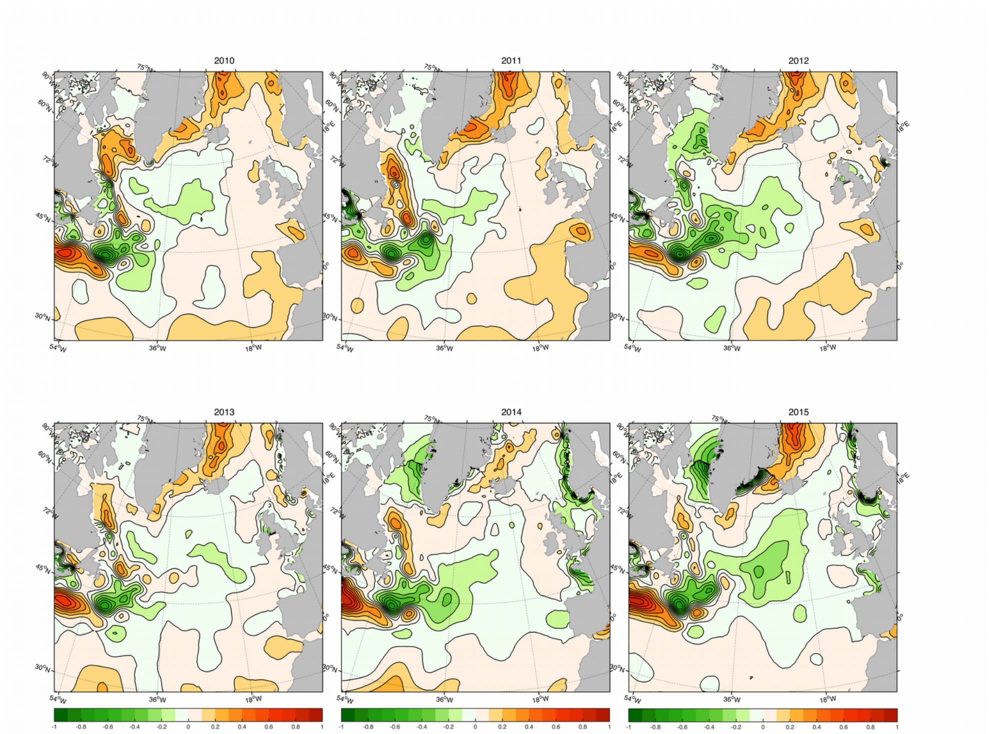
Figure 3: North Atlantic mixed layer depth in February from 2010 to 2015. The mixed layer is defined as the depth at which the temperature has decreased by more than 0.5° from the temperature at 10 m. This criterion is not suitable for areas of salinity compensation or very week stratification.

The most salient feature of the 2015 annual mean temperature is an intense cold anomaly (persistant and increasing since 2013) over the subpolar basin from the tip of Greenland to 40°N and the persistence of a moderately warm anomaly over the Greenland Sea and along the East Greenland coast (Fig. 4a).

Since 2013, the structure of the salinity anomaly appears correlated with the temperature anomalies with cold/fresh anomaly in the subpolare gyreand the Labrador Sea (Fig. 4b); and warm/salty anomaly over the Greenland Sea. In 2015, the most remarkable feature is the large cold/fresh anomaly, 2°C/0.2 pss below the ‘normal’ WOA05 conditions, is observed in the subpolar gyre and Labrador Sea.

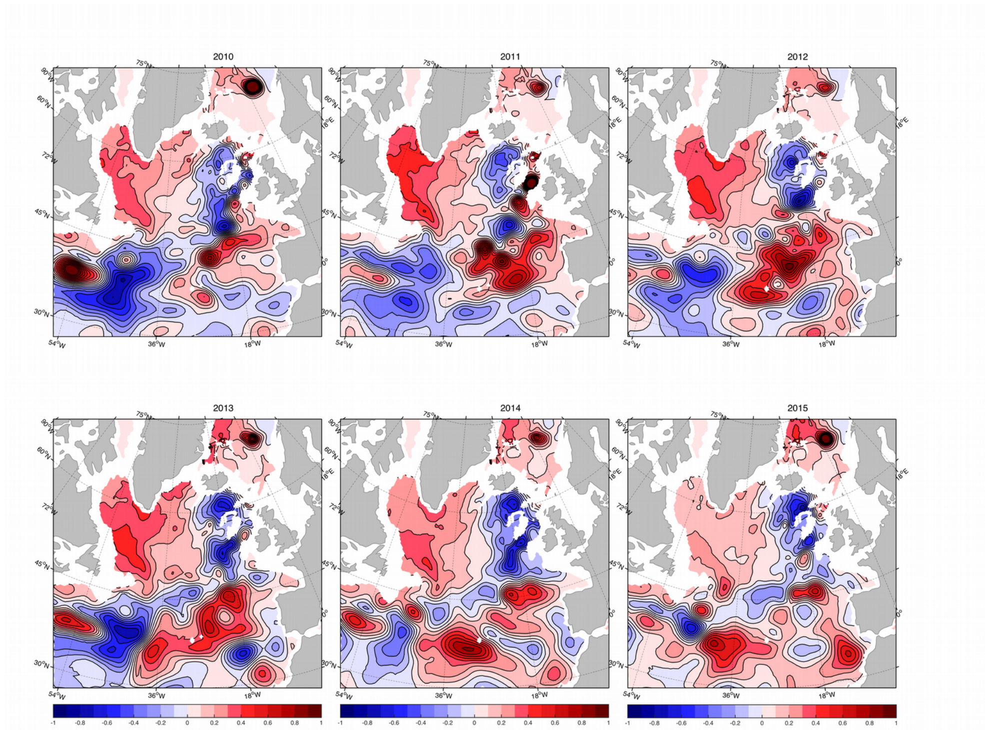


a)

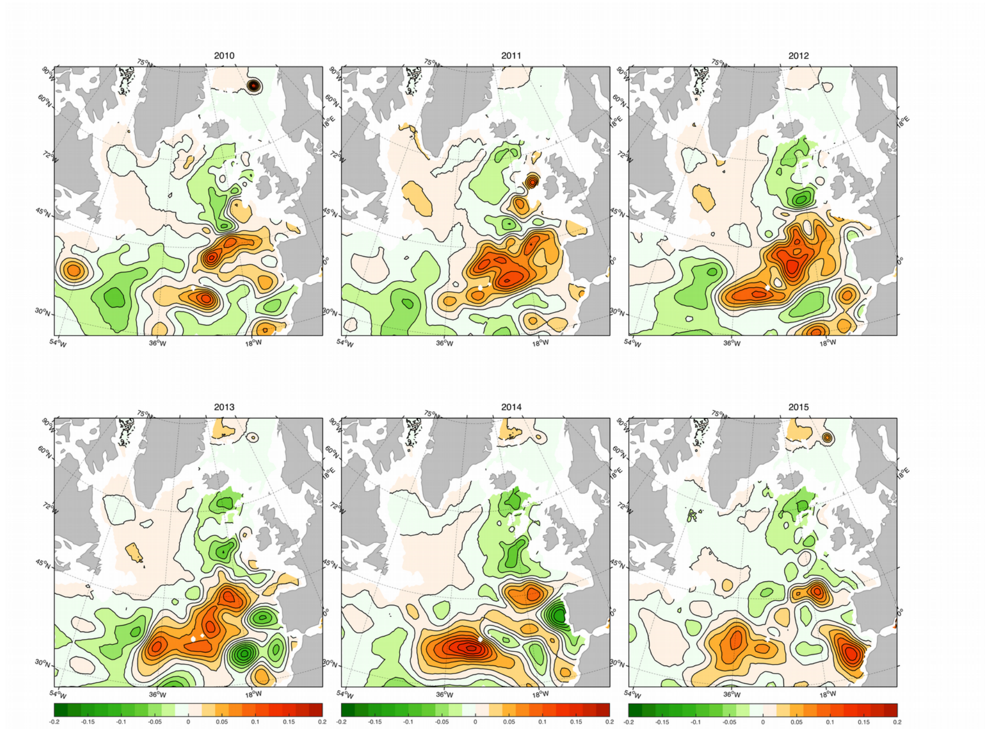


b)

Figure 4: Annual average temperature (a) and salinity (b) anomalies at 10 m during 2010-2015



a)



b)

Figure 5: Annual average temperature (a) and salinity (b) anomalies at 1000 m during 2010-2015.

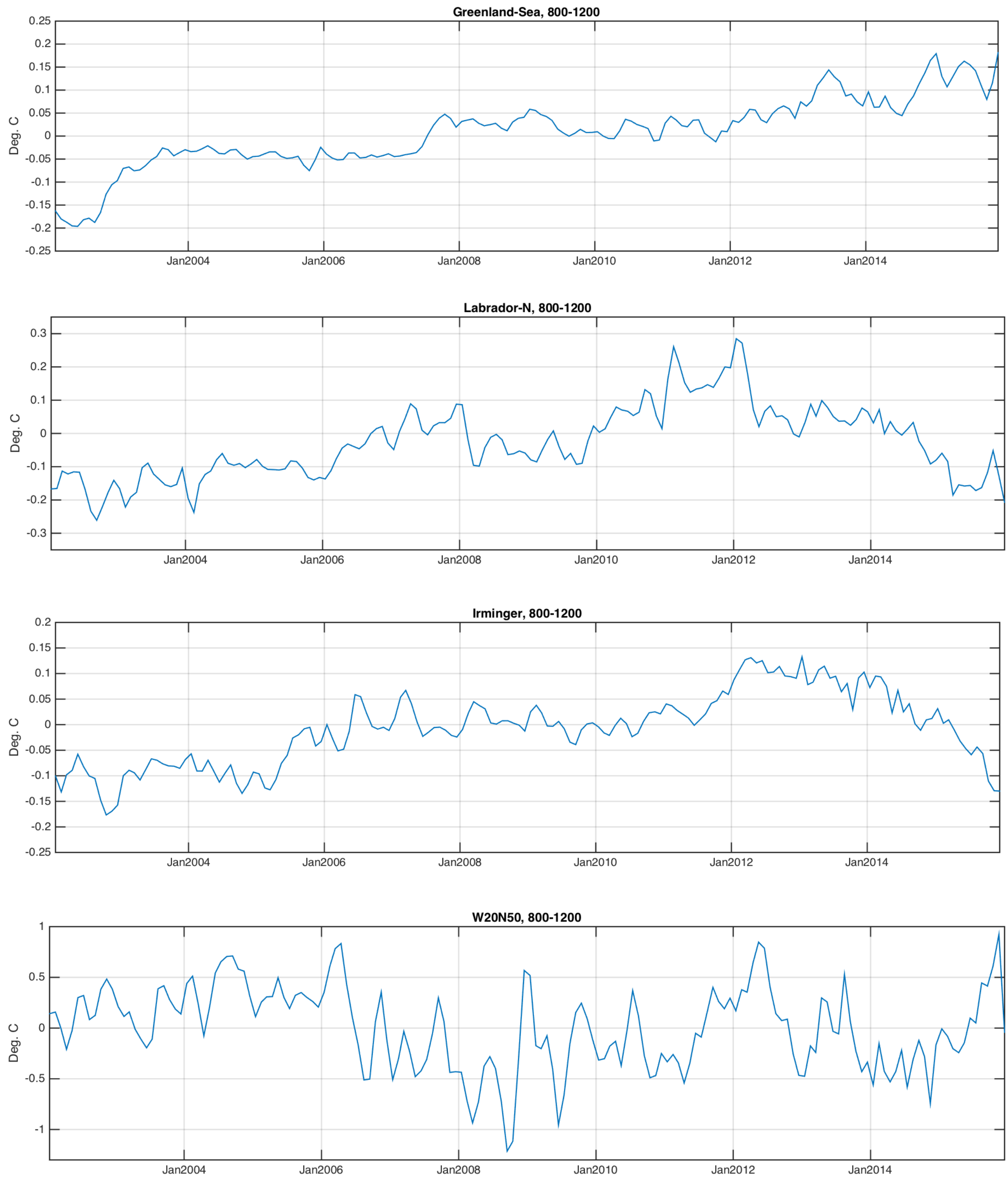


Figure 6: Time series of temperature anomalies averaged over the 800-1200m layer over 2002-2015 period.

1.3 Deep layers

At 1000 m (Fig. 5) :

- The Labrador Sea and the Irminger Sea are warmer than normal, but the warming tendency observed since 2002 is interrupted since 2012 as seen in the time series (Fig. 6). However, deep Greenland Sea keeps on warming (Fig. 6).

- The Mediterranean Outflow water seems warmer and saltier south of 40°N and off Gibraltar straight. The salt increase seems to extend over the basin.
- A cold and fresh anomaly stands from the South of Iceland down to Rockall Trough
- A warm and salty anomaly is observed south of the Gulf-Stream and Azores current (subtropical gyre).

1.4 References

Gaillard, F., 2012. ISAS-Tool Version 6: Method and configuration. Rapport LPO-12-02, http://archimer.ifremer.fr/doc/00115/22583/

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.

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

The two shipping routes along which surface sampling was continued were (Fig. 7) lines AX2 (since mid-1993; in 2015, MV Skogafoss) between southern Newfoundland and Reykjavik; and AX1 (since mid-1997; in 2015, MV Nuka Arctica) between Denmark and west Greenland. 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 pCO2 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, the nominal AX1 route was not often followed during these seasons. Both ships also experienced frequent failures of their water circuit resulting in loss of data from the thermosalinograph.

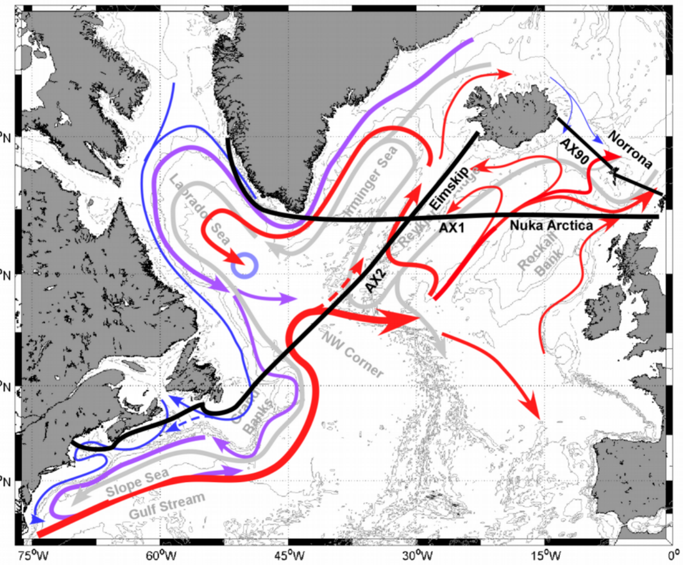


Figure 7 : AX1 and AX2 ship of opportunity lines equipped with Thermosalinograph and XBT launcher. Surface (red arrows) and deep (bleu and purple arrrow) main currents are indicated.

We present Hövmuller diagrams of SSS as a function of latitude (AX2) (Fig. 8) and longitude (AX1) (Fig. 9). For AX2, only the part of the section between the shelf break off Cape Farewell and the approaches of Scotland is presented. To complement the TSG measurements, we also use nearby ARGO 5m depth data.

We will fist comment the AX2 section (Fig. 8). In early 2015, SSS is anomalously low both on the shelf and on the region north of it until 54°N. This anomaly already seen in this region intermittently since 2011, persists until the end of 2015. Further north, the weak positive anomalies at the end of 2014 diminish or become slightly negative north of 60°N. These differences between the two regions are commonly witnessed in this time series, except in 1994-early 1996, when both experienced mostly large negative anomalies. This indicates that in 2015 there were larger meridional contrasts around 54°N, in the region separating mostly eastward flow of the southern limb of the subpolar gyre and the anticyclonic circulation around the Reykjanes Ridge (much more salty).

We will now comment the AX1 zonal section (along 59°N, the most sampled latitude band) (Fig. 9). On this section, there are rather different anomalies east of the Reykjanes Ridge in the Iceland Basin (15-30°W) and west of it (interestingly, AX2 cuts this section very close to the 0-anomaly). Since 2011, there is a negative anomaly east of Reykjanes Ridge, which became very large throughout 2015. Interestingly at 10°W or further east, anomalies were on the other hand small or slightly positive. Such patterns suggest reinforced fronts near 15°W, close to a branch of the NAC, something also noticed on the XBT sections collected by Nuka Arctica, and by Argo floats.

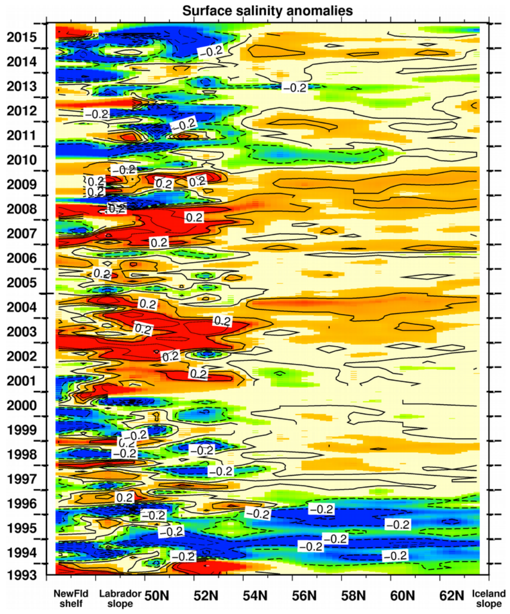


Figure 8: Monthly salinity anomalies from the Eimskip along AX2 between Reykjavik and Southern Newfoundland between 1993 and 2016.

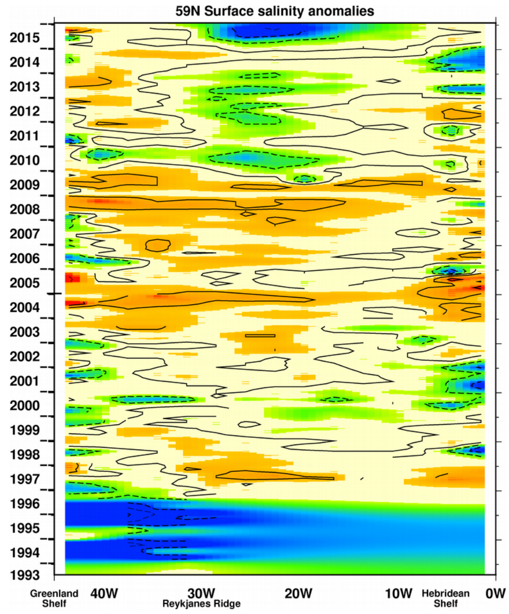


Figure 9: Monthly salinity anomalies from the Nuka Arctica along 59°N from the shelf break south-east of Cape Farewell to the north-west of Scotland between 1993 and 2016.

3 South western Channel: Astan and Estacade time series

3.1 The year 2015 vs Climatology

Here, we present measurements collected twice a month at two stations located on the north coast of Brittany in France. The Estacade site is located at the end of a pier (3°58'58°W and 48°43'56°N) (Fig. 10) in the city of Roscoff (France) where the bottom depth varies from 3 to 12 m depending on the tides. Measurements began in 1985 and are collected at 1 m depth. The Astan site (3°56'15°W; 48°46'40°N) is located 3.5 kilometers offshore from the Estacade site (Fig. 10) and measurements began in 2000. Seawater biogeochemical properties at this site are typical of the Western Channel waters. Bottom depth is about 60 m depth and the water column is well mixed for most of the year. More details can be found at http://somlit.epoc.u-bordeaux1.fr/fr/ and http://www.sb-roscoff.fr/en/coastal-observatory/marine-system-hydrological-parameters-offshore-roscoff. The Western Channel is connected to the eastern boundary current and linked to the North Atlantic drift. The climatic conditions are impacted by the westerlies blowing over the Atlantic basin which transport heat and moisture towards the Western Europe. These conditions explain the typical weather conditions observed in the Roscoff area: Winter precipitations generate intensive weathering of the soils loaded with important nutrients amounts from intensive agriculture. River discharges contribute to influence the salinity cycles and to feed the stocks of nutrients in coastal waters. Salinity of this coastal waters remained close to 35.5, a typical value of the waters adjacent to the North Atlantic Ocean. This system can be considered as a coastal system.

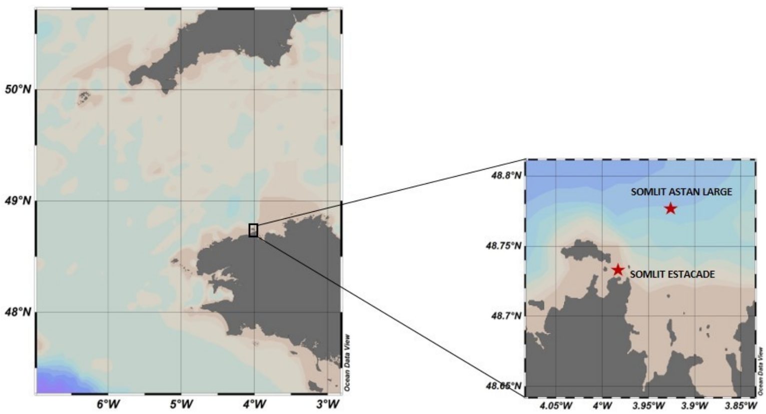
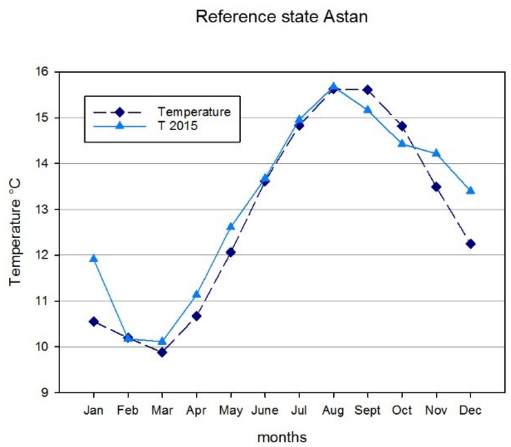


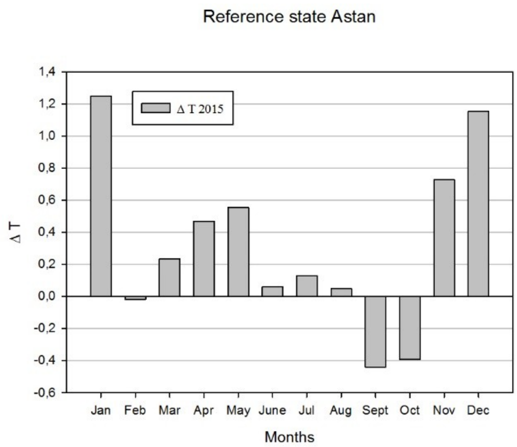
Figure 10: Localisation of Estacade and Astan large sites.

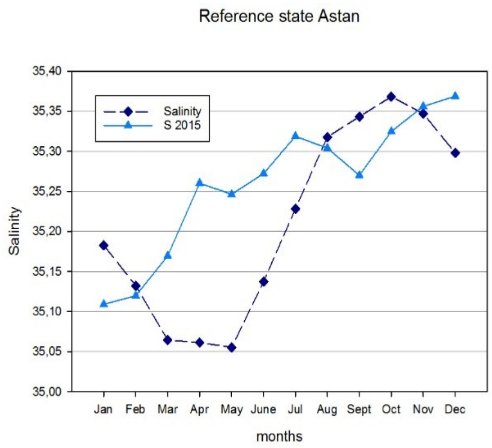
Figures 11 and 12 display the 2015 cycle of temperature, salinity and nitrate in relation to the mean annual cycle at the Astan and Estacade stations. The temperature cycles show different dynamic between the 2 studied stations: At Astan station, for the year 2015, temperatures are higher than the climatology values for the winter, spring, summer (from 1.25°C to 0.05°C) and lower for September and October (respectively -0.44 °C and -0.39°C). Temperature values become higher again in November and December (+0.73°C and +1.15°C). At Estacade station, temperatures are higher than climatology values for the winter and at the beginning of spring (from +1.58°C to +0.48°C) but become lower from June to October with a maximum deviation equal to -0.97°C in July. In the two stations, we can observe that the temperature values become suddenly higher in November and December predicting a warmer 2015-2016 winter than the global average values of this season. The annual average and global values are given in Tables 1 and 2.

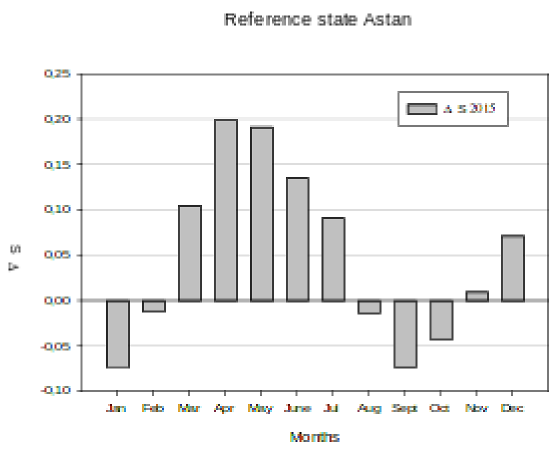
The mean Salinity cycles at the two stations are characterized by an important seasonality with minimum values in spring and maximum in fall. The salinity seasonal cycle is starts one month earlier at the Astan station compared to the Estacade station. In 2015, the salinity cycle is atypical in comparison with the global average cycle. Indeed, there are no low values in winter and spring and we can observe a constant increase all along the year (we observed a maximum deviation in salinity equal to +0.265 at Estacade and +0.199 at Astan, in April). Salinity values are just lower than the average for August, September and October. Minimum salinity values weren't observed in 2015 because of a dry winter with low water precipitations reducing the river inputs in the Western Channel. We have observed the same kind of cycle with no spring salinity low values in 2005, 2007 and 2012.

During 2015, at Astan station, nitrate concentrations were significantly lower than the averaged values excepted from August to October where they are close to the mean values. At the Estacade station, we observed a different evolution than in the Astan station. Nitrate concentrations were almost totally exhausted at Estacade contrary to Astan where the nutrients stock is spread over the well-mixed water column and not totally consumed by the phytoplankton development. The low levels of nitrate concentrations are linked to the high levels of salinity for 2015. The weaker river inputs contributed less to the nutrients supplies.









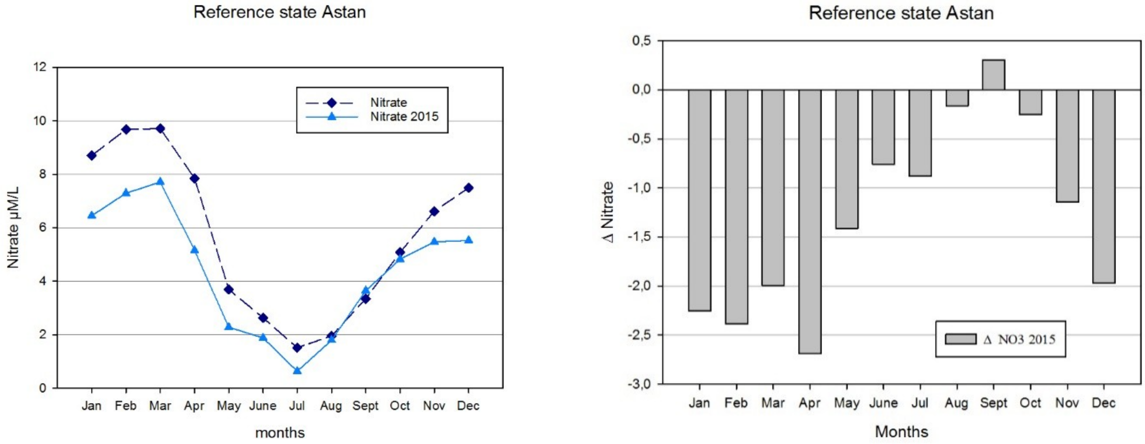
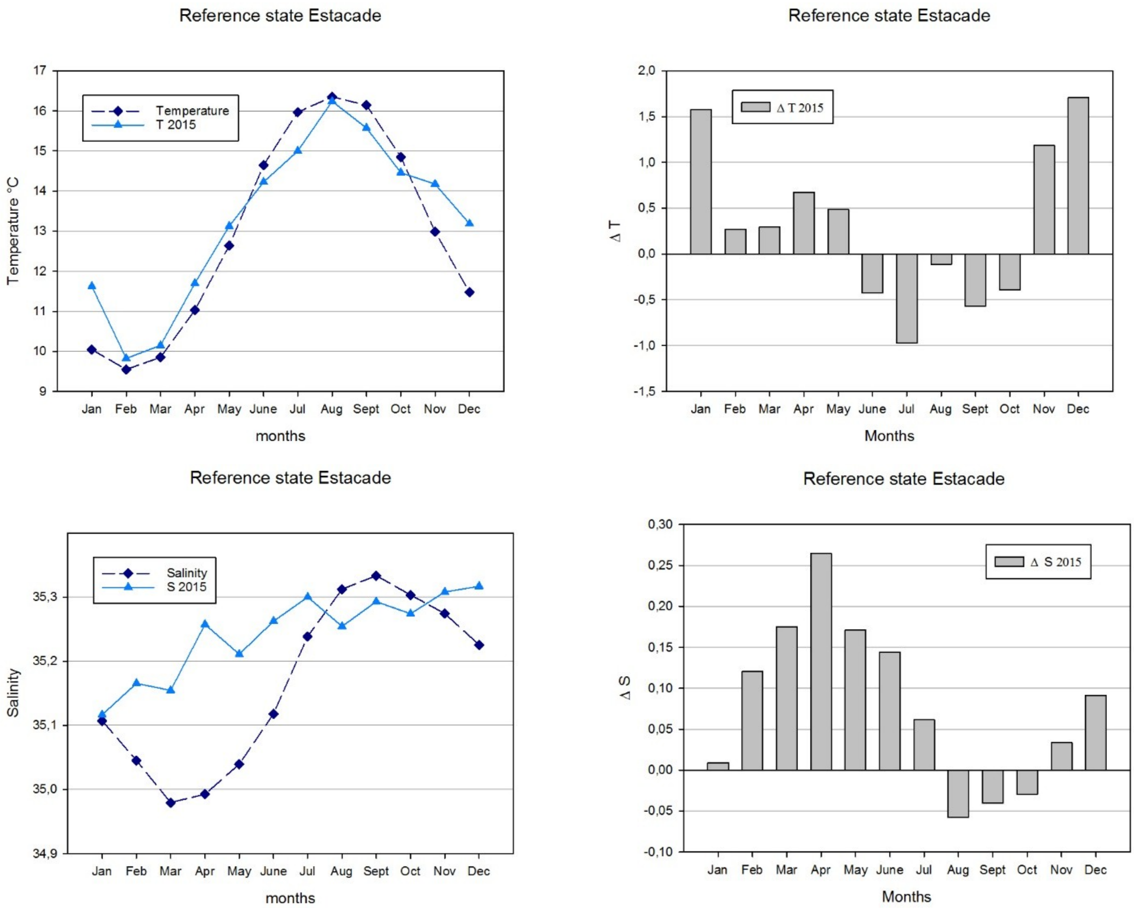


Figure 11: comparison between time series of temperature (upper), salinity (middle) and nitrate (lower) at Astan site in 2015 with the climatological cycle (average over the 2000-2015 period). (Left panels) Dark blue line represents the mean annual cycle and the light blue line represent 2015 data. (Right panels) 2015 deviation to mean values.



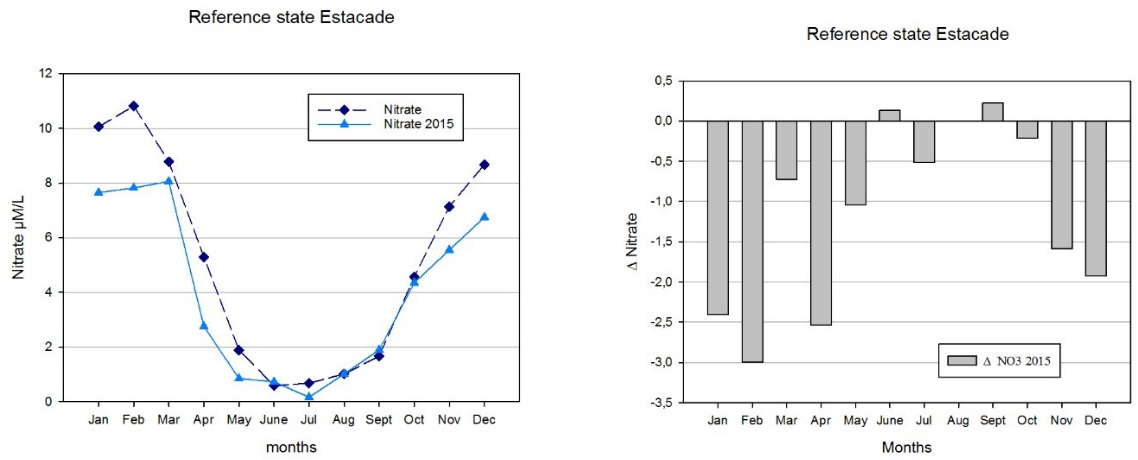


Figure 12: comparison between time series of temperature (upper), salinity (middle) and nitrate (lower) at Estacade site in 2015 with the climatological cycle (average over the 2000-2015 period). (Left panels) Dark blue line represents the mean annual cycle and the light blue line represent 2015 data. (Right panels) 2015 deviation to mean values.

Estacade	Temperature (°C)	Salinity	Nitrate (µmole/l)
Global average	12.94	35.171	5.1
2015	13.27	35.243	3.9

Table 1: Global mean for the period 1985-2015 and 2015 values at Estacade station.

Astan	Temperature (°C)	Salinity	Nitrate (µmole/l)
Global average	12.83	35.211	5.6
2015	13.12	35.260	4.4

Table 2: Global mean for the period 2000-2015 and 2015 values at Astan station.

3.2 Water column properties

As usually observed in this area, the Western Channel waters were well-mixed over the entire water column during the whole year with no significant gradient observed between the surface and the bottom (Fig. 13). The low vertical temperature gradient observed episodically in late summer (late august- early September) during low wind-neap tides period was not observed in 2015. As for temperature Western Channel waters were generally well-mixed over the entire water column since no salinity differences between surface and bottom waters were observed even during the late summer surface heating.

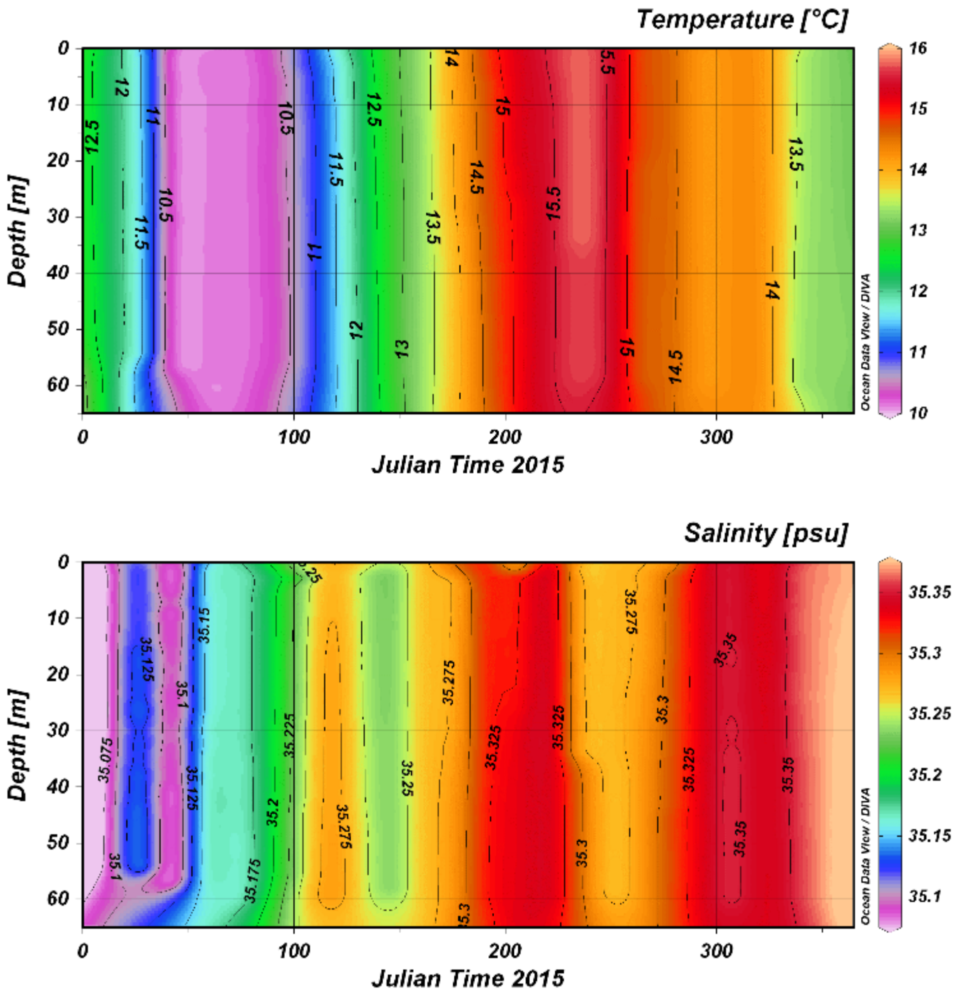
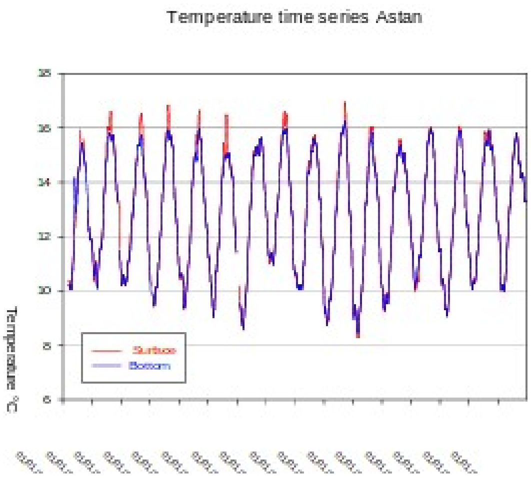


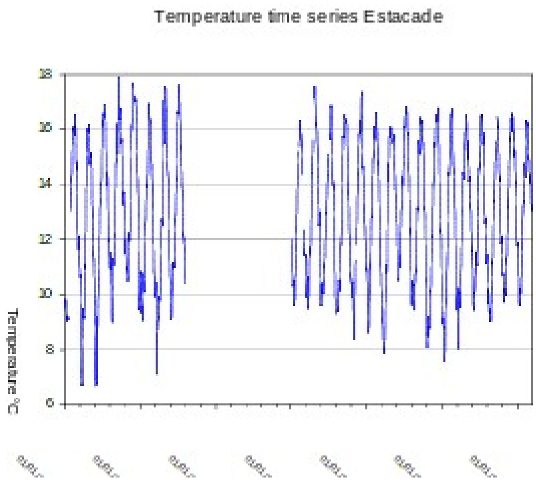
Figure 13: vertical distributions of temperature (top) and salinity (bottom) at Astan site during 2015 (bimonthly CTD profiles). Well-mixed waters were observed during the whole year due to an enhanced vertical mixing by tidal currents.

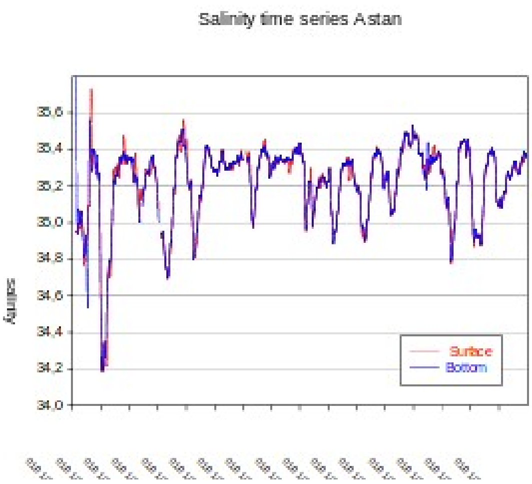
3.3 *Long-term trends*

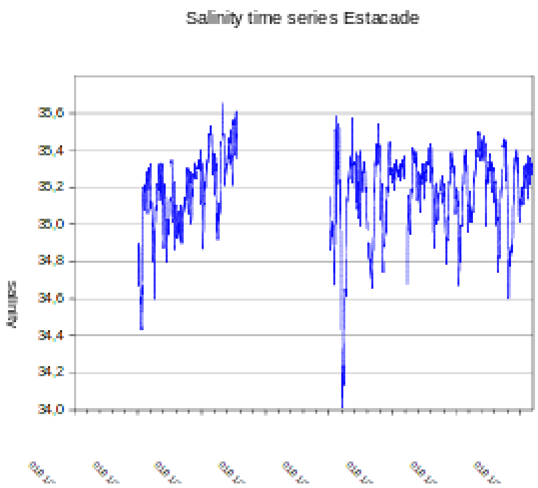
Figure 14 shows the time series of temperature, salinity and nitrate at Astan over the period 2000-2015 and at Estacade over the period 1985-2015 with a large gap from 1992 through 2000 for salinity and nitrate measurements. At the Astan and Estacade sites, winter 2015 minimum temperature were significantly higher than the global mean calculated over the time series.

In 2015, salinity cycle is characterized, as mentioned above, by higher values than those usually observed in this area, especially in winter. Means annual salinity at Astan and Estacade are slightly higher than the global average values. The differences are more important during winter explaining the low values of nitrate in the first part of the year. Usually, nitrate concentrations, as salinity and temperature, present a large interannual variability particularly in the winter maximum values which is linked to the interannual variability in the oceanic influence in the Channel waters. Maximum nitrate winter concentrations (7.7 µM/l at Astan and 8.1 µM/l at Estacade) were significantly lower than average winter values due to the reduced influence of the low salinity waters in the Western Channel. The monthly mean nitrate concentrations were the third minimum concentrations observed between January and April since 2000 at Astan. Nitrate winter and early spring stock for the spring phytoplankton development was reduced in 2015 when compared to the previous years. Residual nitrate values (C = 0.6 µMole/l at Astan and C = 0.2 µMole/l at Estacade) observed in summer 2015 are the second lowest measured values since 2000 at the two stations. The available nutrient amounts for the phytoplanktonic production weren't totally exhausted which may be explained by less favorable meteorological conditions.









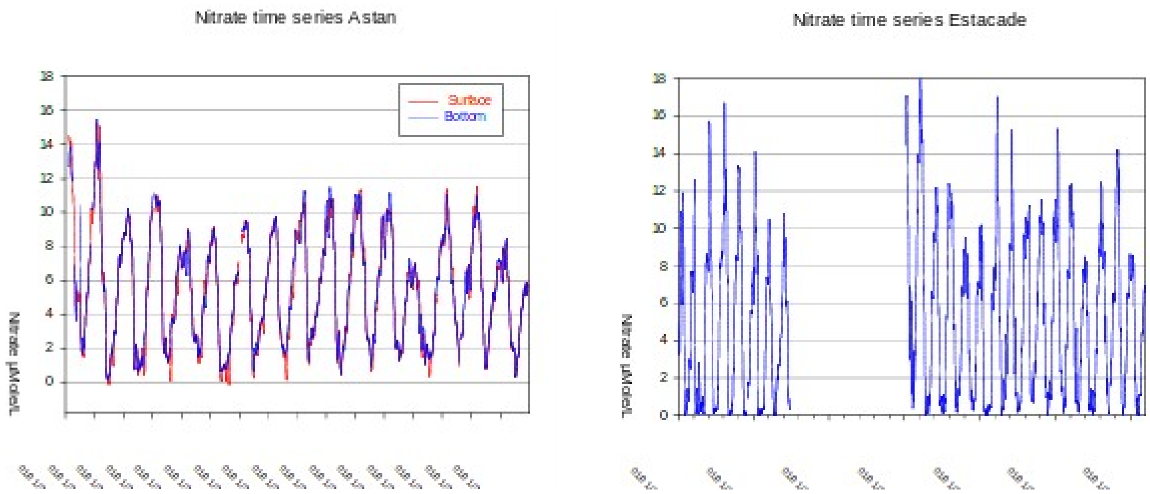


Figure 14: Interannual variability of the temperature, salinity and nitrate at Astan site over 2000-2015 (left panels) and at Estacade site over 1985-2015 (right panels).

We calculated the trends over the time series for the 2 periods mentioned above: At Astan station, we observed an increase of SST (+0.004°C/year), an increase of the SSS (+0.007 pss/year) associated to a decrease of the nutrient concentrations (-0.04 µmole/year).

At Estacade station, we observed an increase of SST (+0.001°C/year), an increase of the SSS (+0.001 pss/year) and an increase of the nutrient concentrations (+0.009 µmole/year). This last result, we would expect that the variation of the nutrient concentrations should be anti-correlated with the salinity variation as at Astan station. Therefore, more statistical and in depth analysis of these time-series will be need to understand the key processes influencing the long-term trends at these 2 coastal sites.