# Deep Argo deployment strategy

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# Objectives of the Deep Argo program

**Operational application**:

- Improve global ocean reanalysis and coupled ocean-atmosphere forecasting systems below 2000m

**Climate change:**

- Improvement of global heat and freshwater budget
- Improvement of regional sea level budget and quantification of the causes of sea level changes
- Track planetary energy budget in real time

**Other research topics**

- Quantify mean state and variability of deep ocean circulation
- Investigate relationship between circulation and topography
- Deep mixing and convection
- ….

..

# Hypothetical Deep-Argo array proposed by Johnson and Purkey, JAOT, 2015

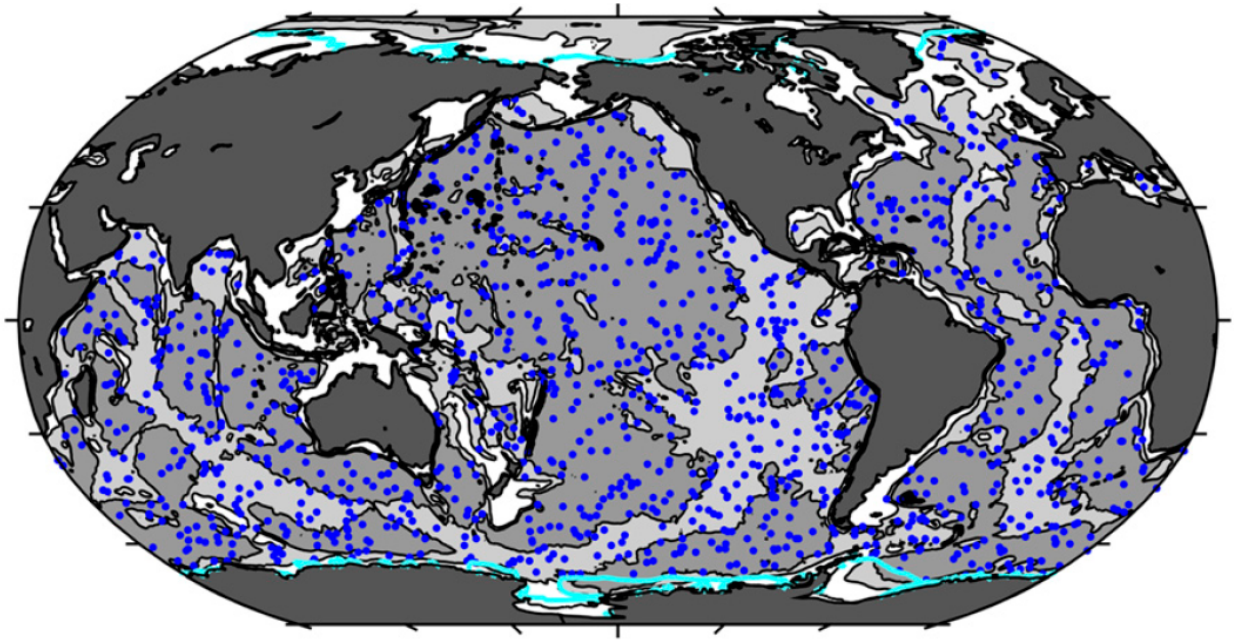
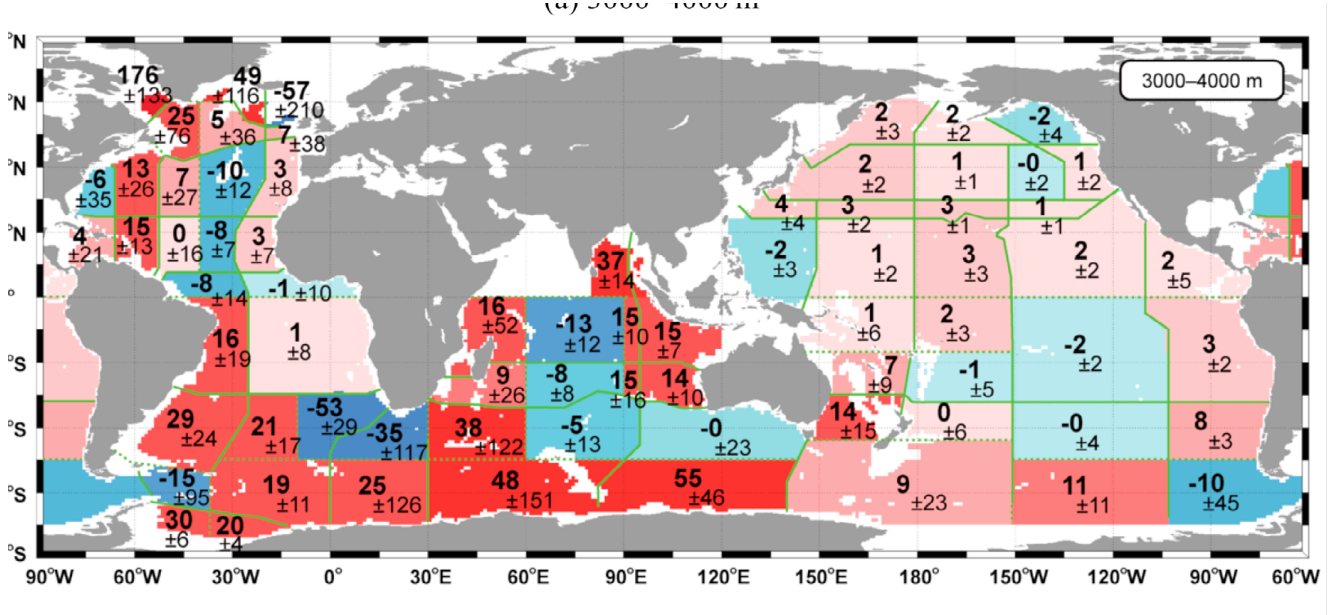


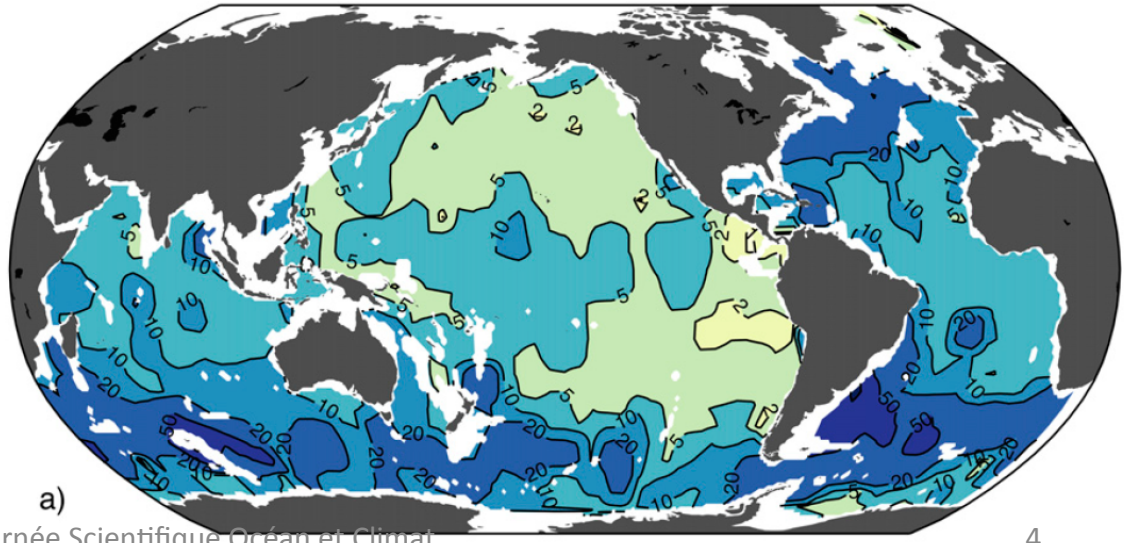
FIG. 1. Straw-plan of a nominally 5° × 5° distribution of 1228 Deep Argo floats (blue dots) randomly populating the global ocean excluding areas shallower than 2000 m (white areas), and areas with mean 1981–2010 ice concentrations >75% (poleward of thick cyan contours). Lightest gray areas indicate bottom depths between 2000 and 4000 m, darker gray areas indicate bottom depths exceeding 4000 m, and darkest gray areas indicate land.

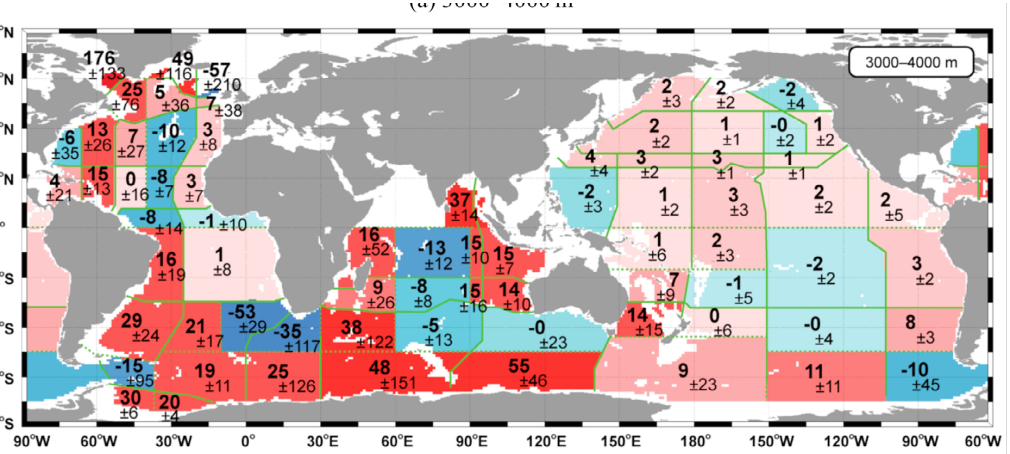
- 5° latitude x 5° longitude x 15-day cycle
- About 1200 floats (~30% of the current Argo array)
- Only plan proposed, not yet endorsed

# Temperature trends in m°C/decade from the 1990s to the 2000s (Kouketsu et al, 2011)

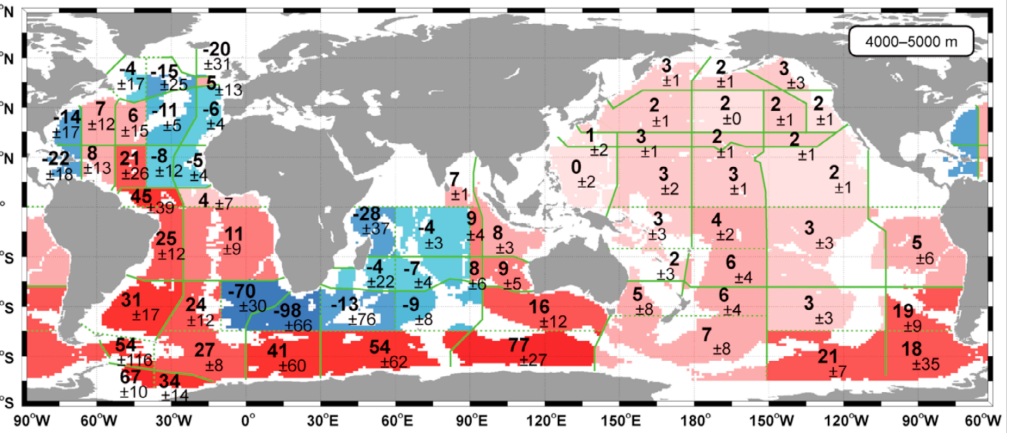



**Estimated temperature trend standard errors in m°C per decade at 3000m with the Deep-Argo array design proposed by Johnson and Purkey 2015.**

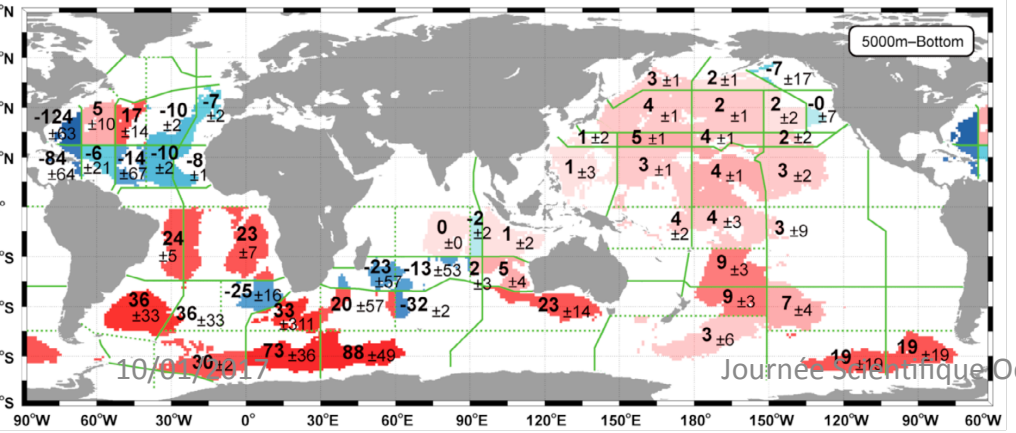





(b) 4000–5000 m



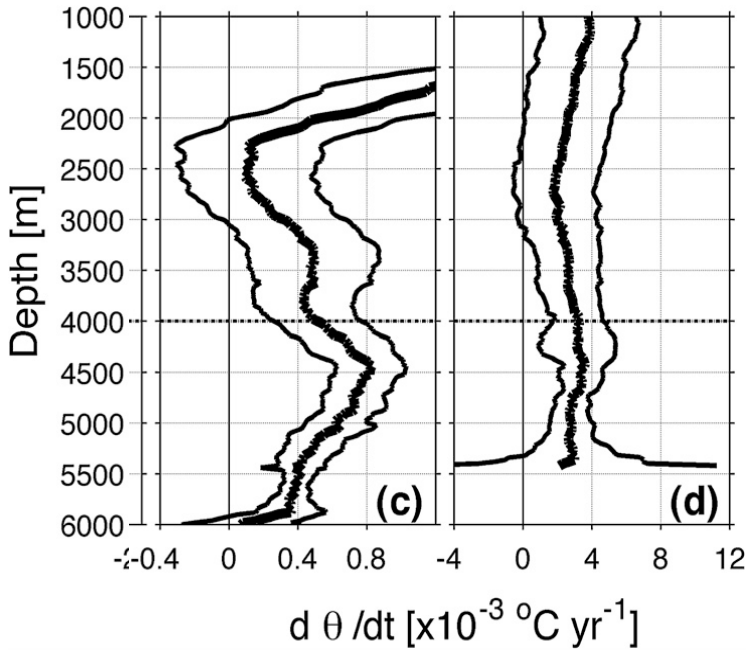

(c) 5000 m–bottom




**Temperature trends in m°C/decade from the 1990s to the 2000s (Kouketsu et al, 2011; Purkey and Johnson, 2010)**

Mean temperature trend

Global Southern Ocean



# Decadal variability in decadal temperature trend (Desbruyères et al, 2014)

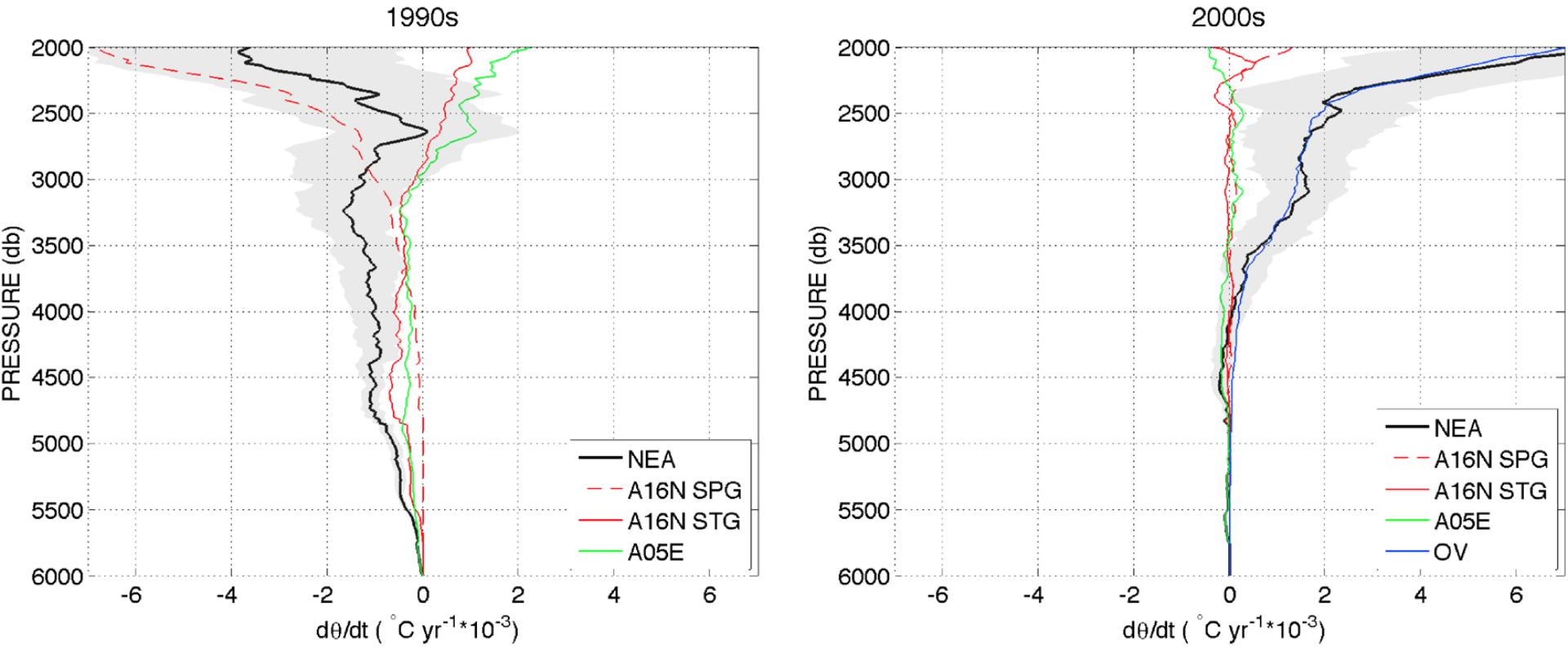
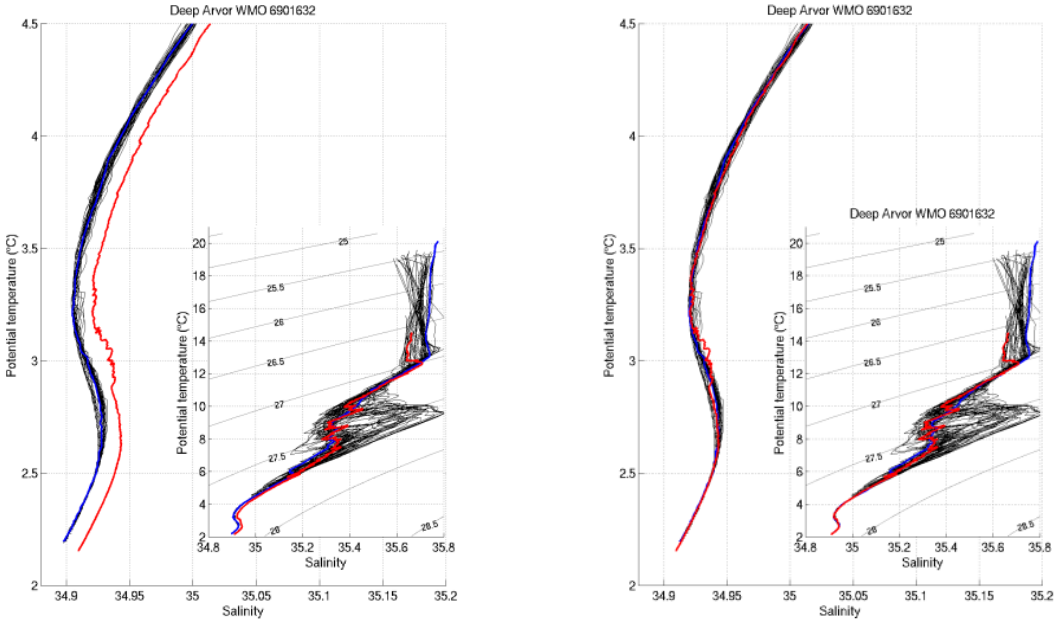


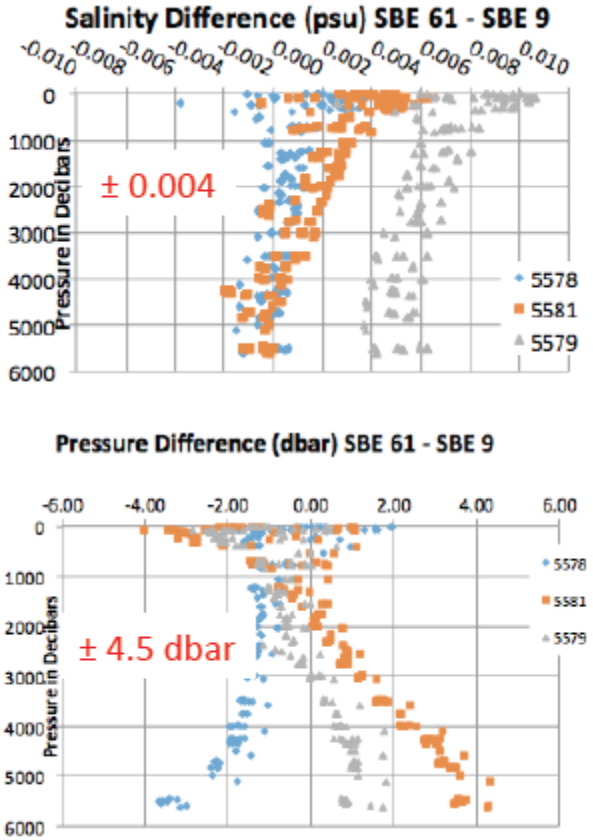

**Figure 3.** Basin-mean vertical profile of temperature trend below 2000 m depth (black) and length-weighted contributions of A16N (red), A05E (green), and
A25-Ovide (blue) during (a) the 1990s and (b) the 2000s. Grey shading indicates 95% confidence intervals (see text for details). Units are ◦C yr−1.

# Sensor accuracy

- Aspirational accuracies are pressure: ± 3 dbar, temperature ± 0.001°C and salinity ± 0.002, not yet achieved
- On-going work with manufacturers to resolve current sensors issues

SBE41-CP




Le Reste et al, 2016, JAOT

# Some thoughts about deployment strategy

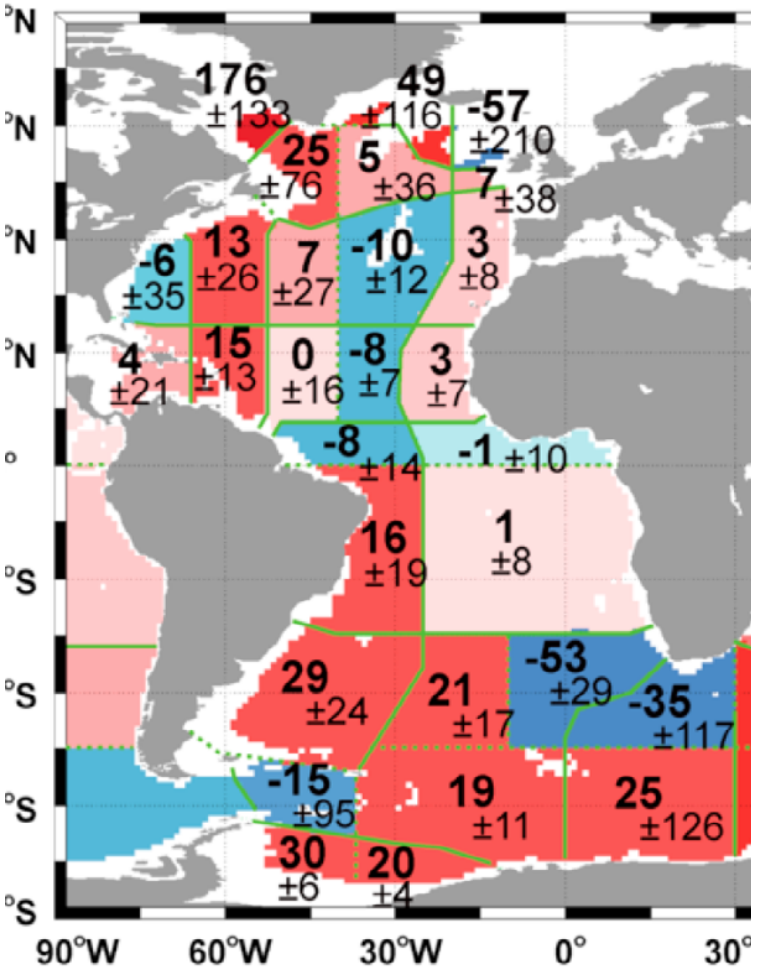
- Considering the amplitude of the signal and the expected standard errors, reliable and significant decadal temperature trends will be provided by a Deep-Argo array at best in 10-15 years from now
- In the meantime, we need to solve the technological issues we are facing (float reliability, sensors accuracy)
- To be able to demonstrate in few years (funding agencies, Ocean Obs 19, ..) the value of Deep Argo data, we have to deploy floats where high-frequency signals (<10 years) exist
- To better interpret the data and understand the quality of the data, we have to deploy floats in areas where other observational programs exist
- For those two reasons, we have to focus deployment in specific areas and avoid sparse deployments

➔ This strategy corresponds to that of the Euro-Argo ERIC who will focus deployment in the North-Atlantic, Med Sea, Southern Ocean

➔ We will focus our deployments in the Subpolar Gyre of the North-Atlantic ocean

# Why a focus on the North-Atlantic Ocean ?

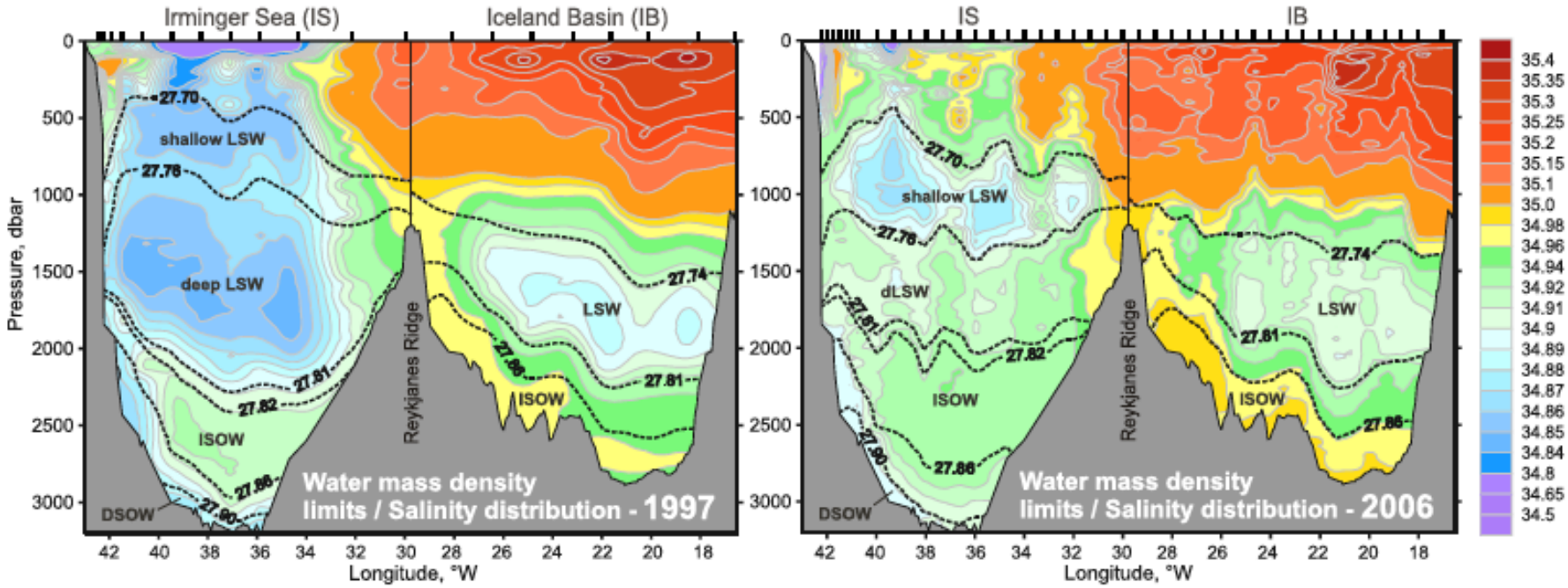
- Large spatial and interannual variability of the decadal temperature trend
- On the long-term those deployments will help reduce uncertainty in heat and freshwater budget in this basin




**Temperature trends in m°C/decade from the 1990s to the 2000s (Kouketsu et al, 2011)**

# Why a focus on the North-Atlantic Ocean ?

- Very dynamically active regions in the subpolar and subtropical gyres with large signal of variability in the deep layers assuring a scientific interest of the data on the short term, despite uncertainties on the data quality (correctable fresh bias)

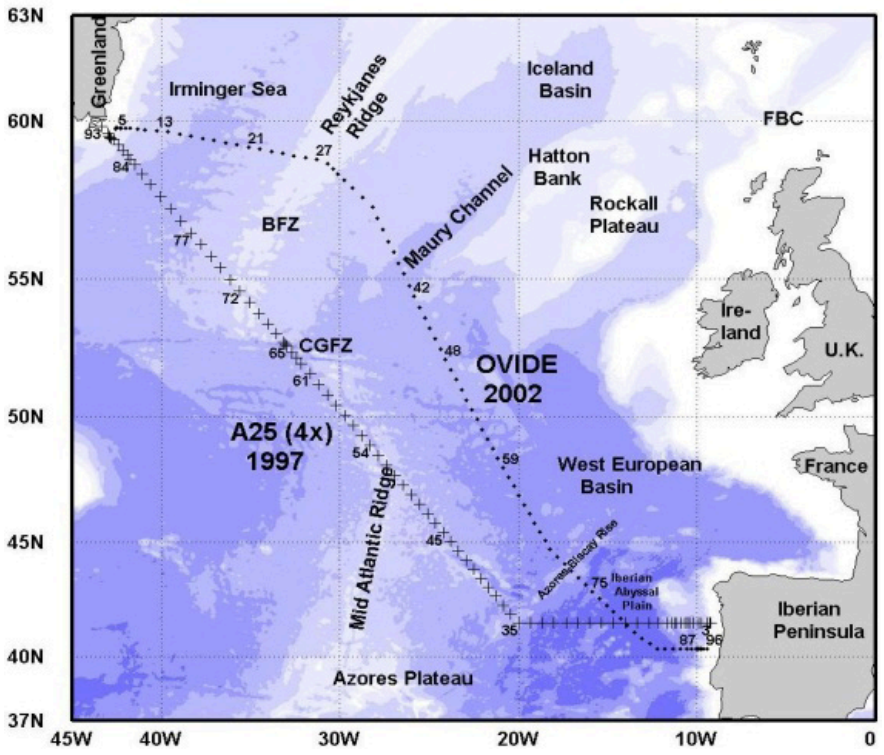


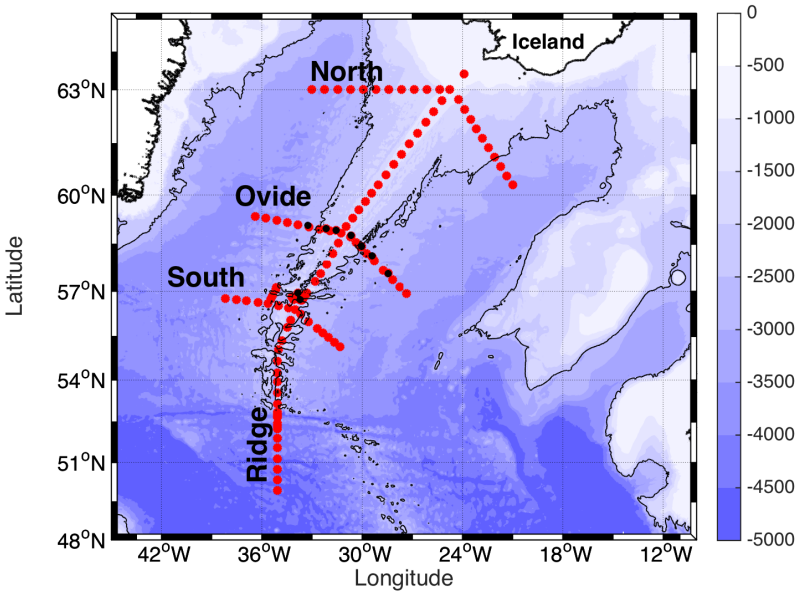

Sarafanov et al, 2007

- Very stable deep-water masses in the North-East Atlantic Ocean allowing an assessment of the sensor quality and sensor long-term stability

# Why a focus on the North-Atlantic Ocean ?

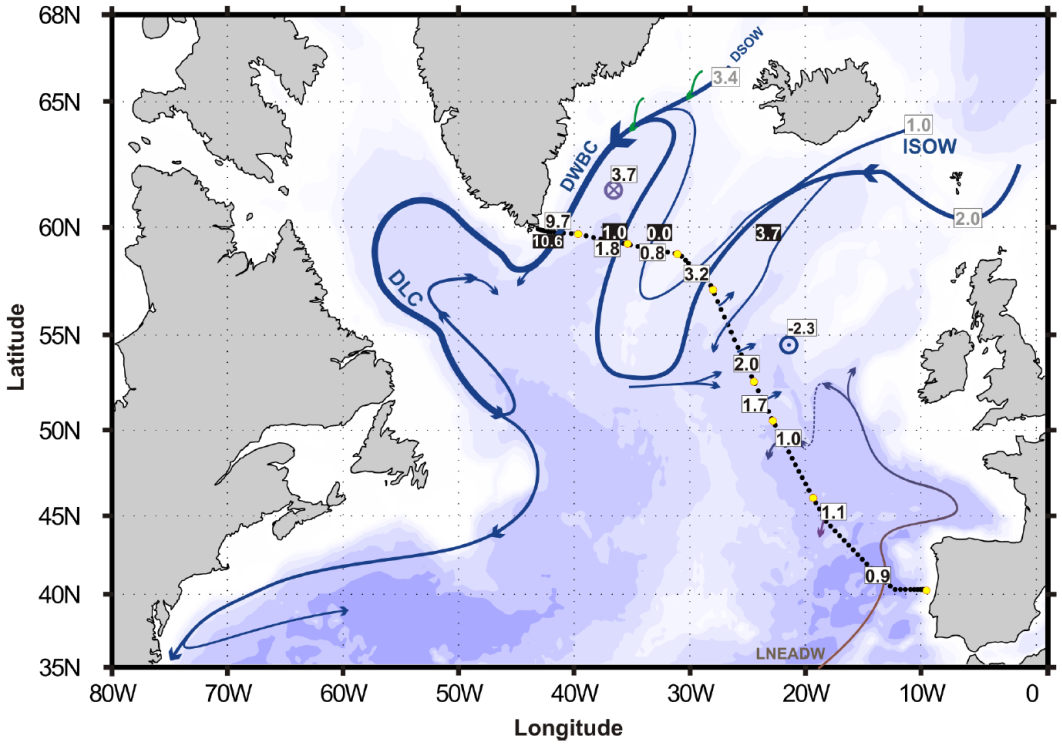
- Existence of complementary observing programs (OVIDE, RREX, etc) that will allow the deployment of the floats (and maybe their recovery), the interpretation and the qualification of the data



# Some scientific questions that will be addressed: ISOW pathways and deep mixing

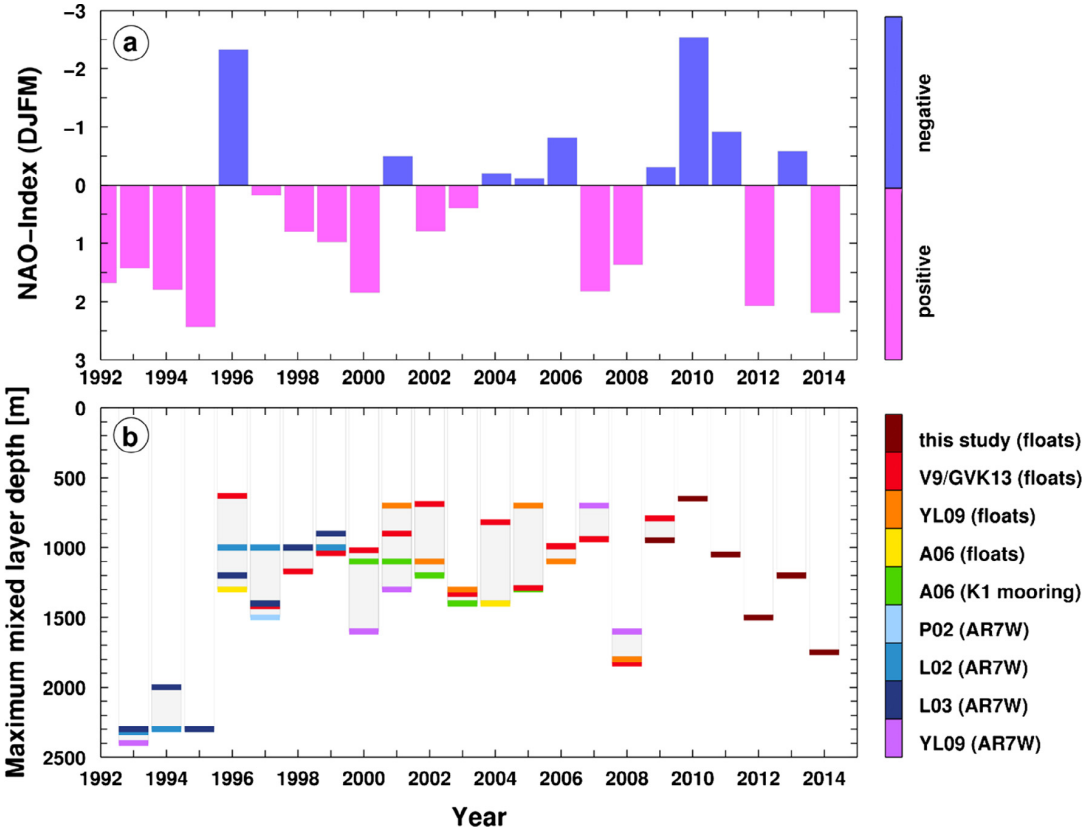
Circulation scheme in the deep layers (σ0=27.8), (Daniault et al. 2016)




➔ See Virginie R. presentation

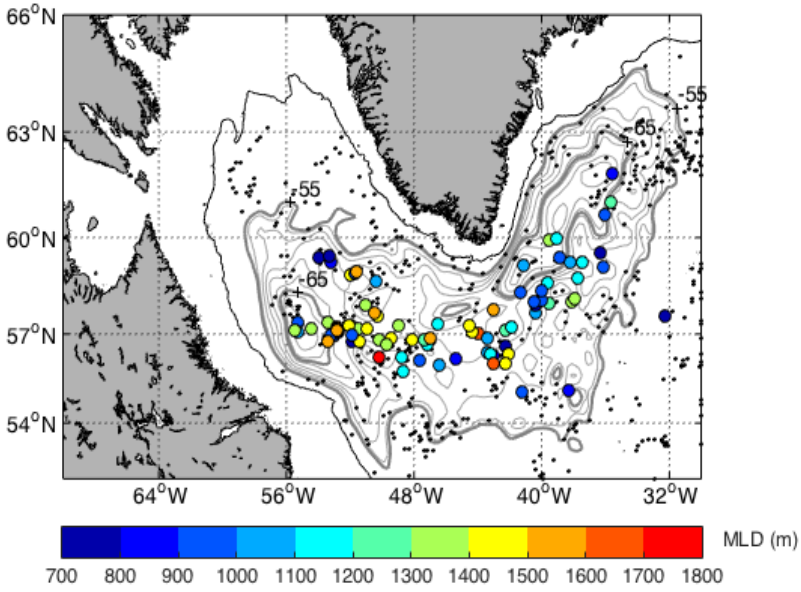
- Mixing in fracture zones, downstream of the Denmark strait, in the Labrador Sea
- Fate of the 3 branches of ISOW in the Island Basin and downstream of Bight and Charlie-Gibbs Fracture Zones, Interior pathways of DWBC …

# Monitoring deep convection in the Subpolar Gyre




Kieke and Yashayaev, 2015

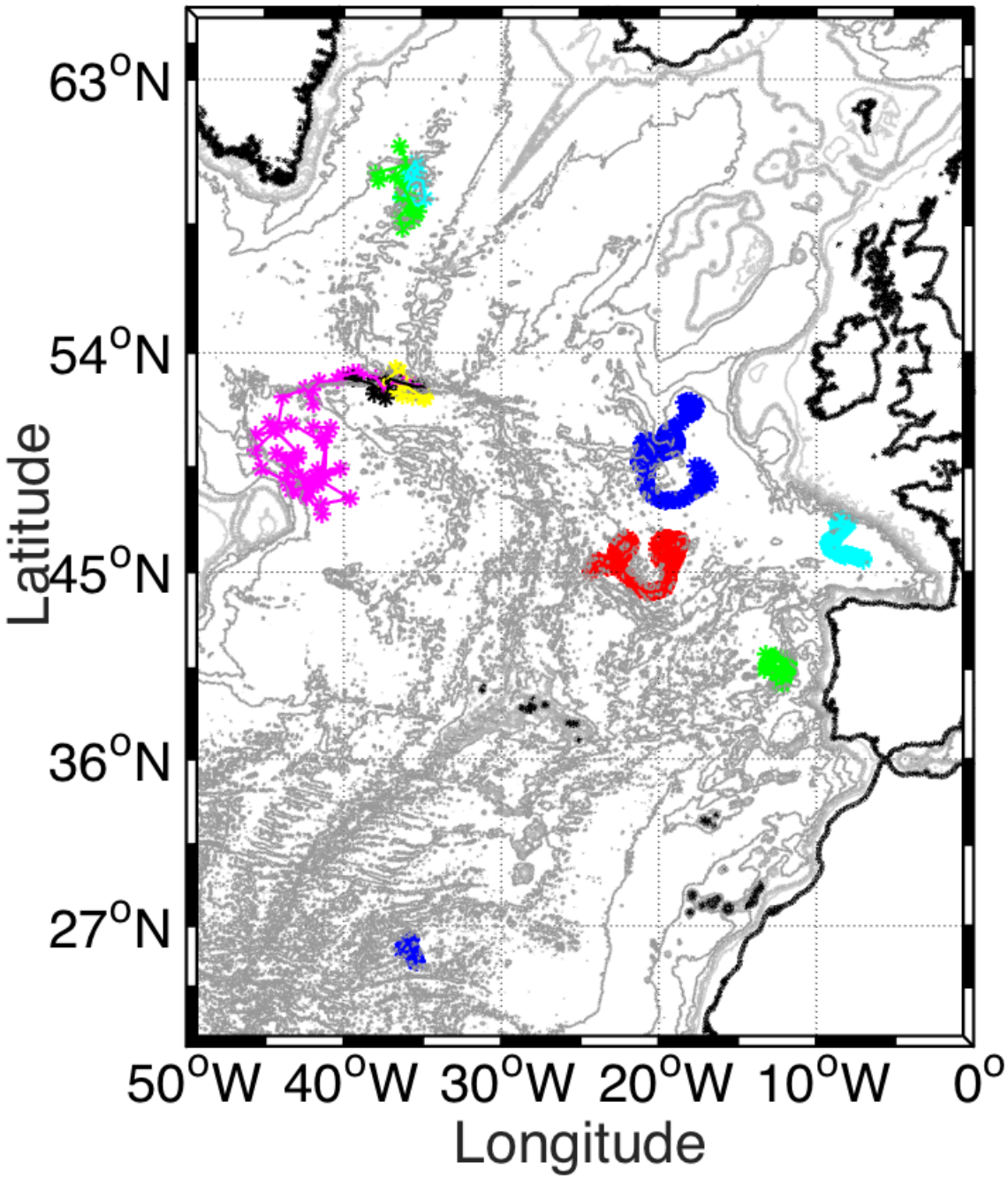
Winter 2014-2015 MLD



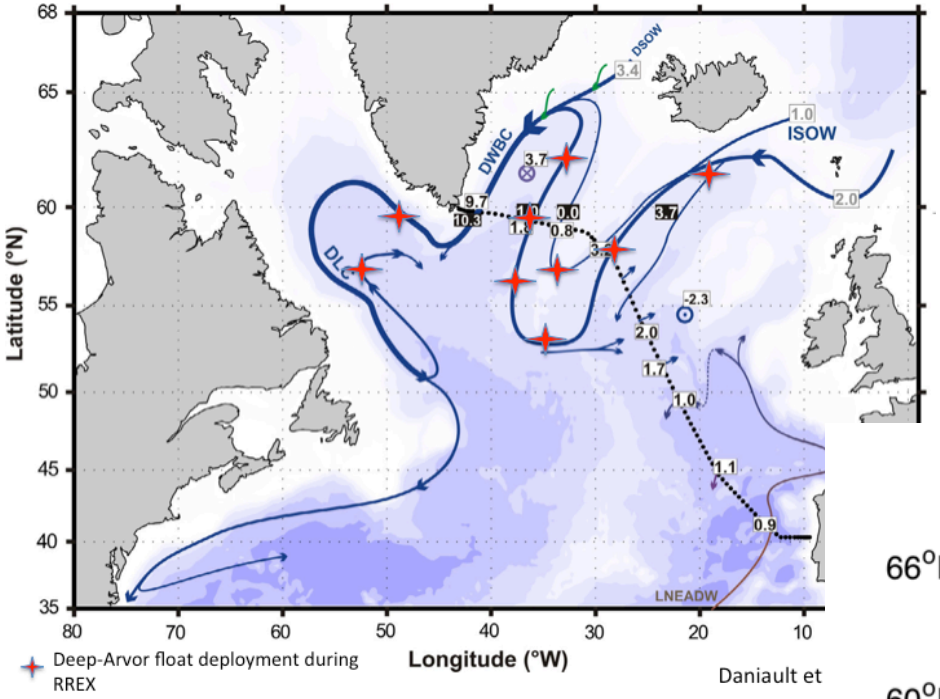

Piron et al, 2017

# Float availability

| | | North Atlantic | Southern Ocean | Elsewhere |
|---|---|---|---|---|
| 2012 | 2 Prototypes | North-East Atlantic | | |
| 2014 | 2 Pre series | North-East Atlantic | | |
| 2015 | 4 NAOS lot 1 | 3 in CGFZ +1 in Iceland basin | | |
| 2016 | 2 NAOS lot 1 | 2 in Irminger Sea | | |
| 2017 | 5 NAOS lot 1<br>11 NAOS lot 2<br>4 Euro-Argo (AtlantOS) | Irminger Sea, Iceland Basin, CGFZ, Labrador Sea | 3 (JB Sallée) | |
| 2018 | 15 CPER Euro-Argo | 15 along OVIDE + Labrador Sea | | |
| 2019 | 15 CPER Euro-Argo | X | ? | ? |
| 2020 | 15 CPER Euro-Argo | 15 along OVIDE + Labrador Sea | ? | ? |
| 2021 | 15 CPER Euro-Argo | X | ? | ? |

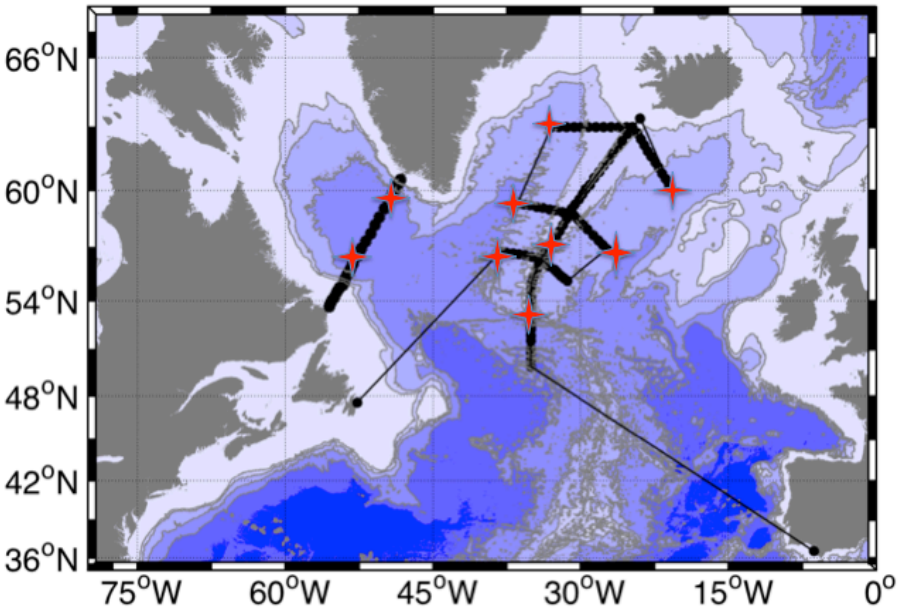

63°N
54°N
45°N
36°N
27°N
Latitude
50°W
40°W
30°W
20°W
10°W
0°
Longitude

# 2017 float deployment




Deep-Arvor float deployment during RREX

Daniault et




Deep-Arvor float deployment

# Sampling frequency, sampling depth and other questions

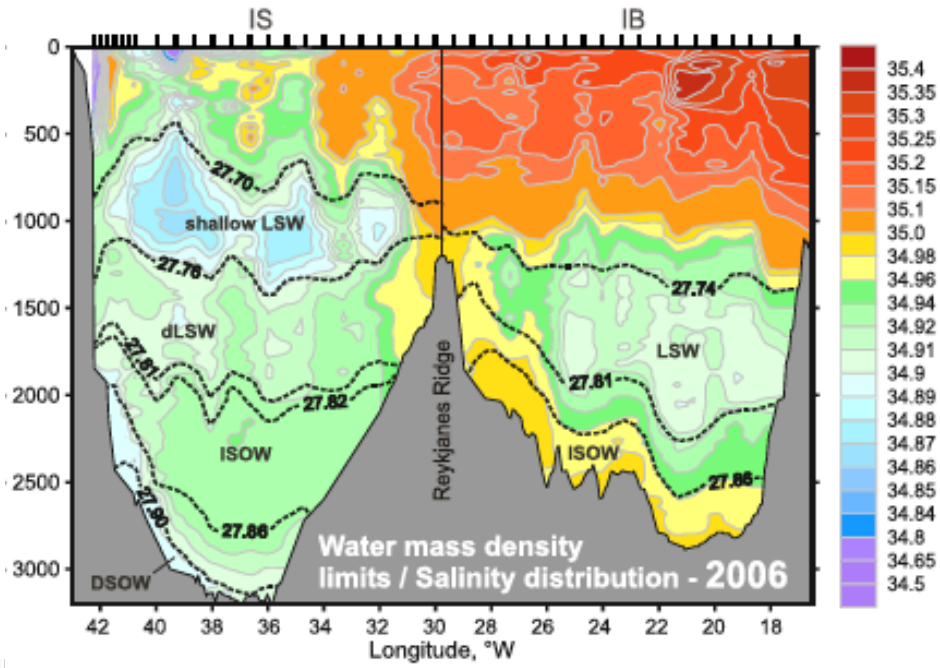
**Sampling frequency**

- 10 day, as for the core Argo array

**Sampling depth**

- 1000 m for the first floats, as for the Argo core array
- 2750 m for the 3 floats in the CGFZ to follow ISOW
- 2100 m for the 2 floats in the Irminger Sea to follow ISOW also !

➔ If we want to investigate deep circulation, we certainly need to have different sampling depth for different region. This has to be defined.

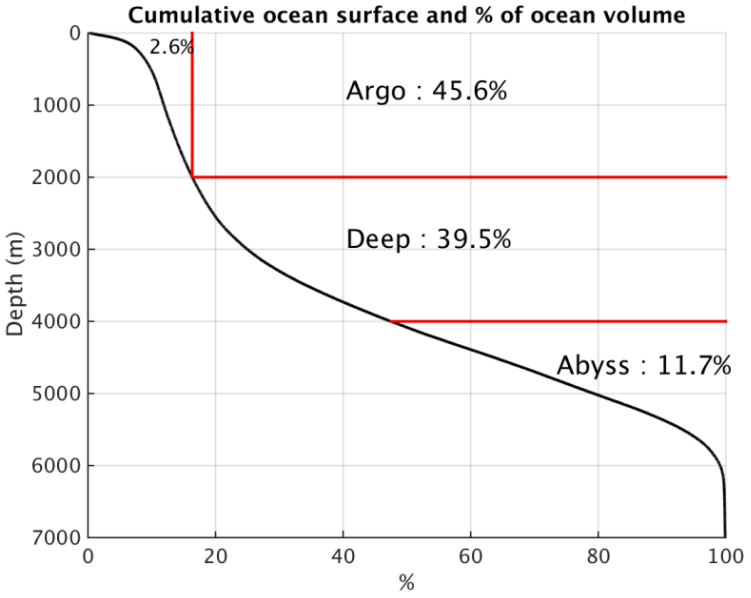



**Other questions**

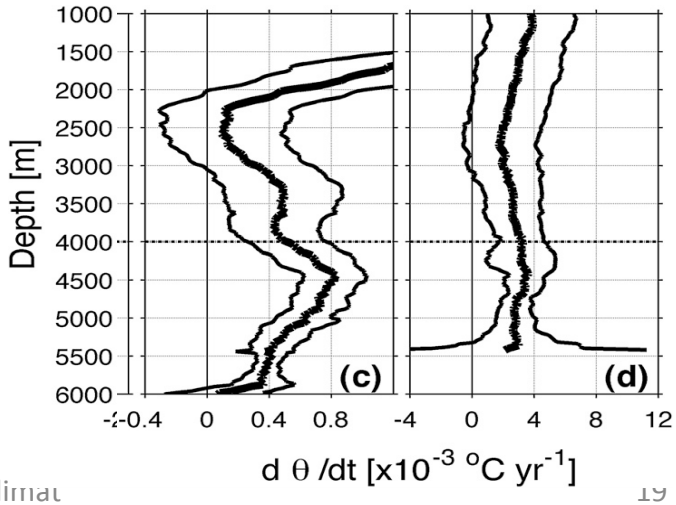
- New development: implement SBE61 instead of SBE41
- Should we go deeper ?

# Conclusion

- Euro-Argo plans to contribute to ~1/4 of the Deep-Argo array: ~250 floats and ~50 floats deployed/year
- Number will be refined based on the agreed Deep-Argo array design, the cycling period, the life-time of the floats
- We need to precise the number of 4000m floats vs 6000m floats
- Most of the floats will be deployed in the North-Atlantic, which will be the main European contribution to Deep-Argo in the coming years.
- Deployment in the Mediterranean Sea and in the Southern Ocean, which are regions of scientific interest for Euro-Argo members and of large signal in the deep layers (deep water mass formation), will also be done



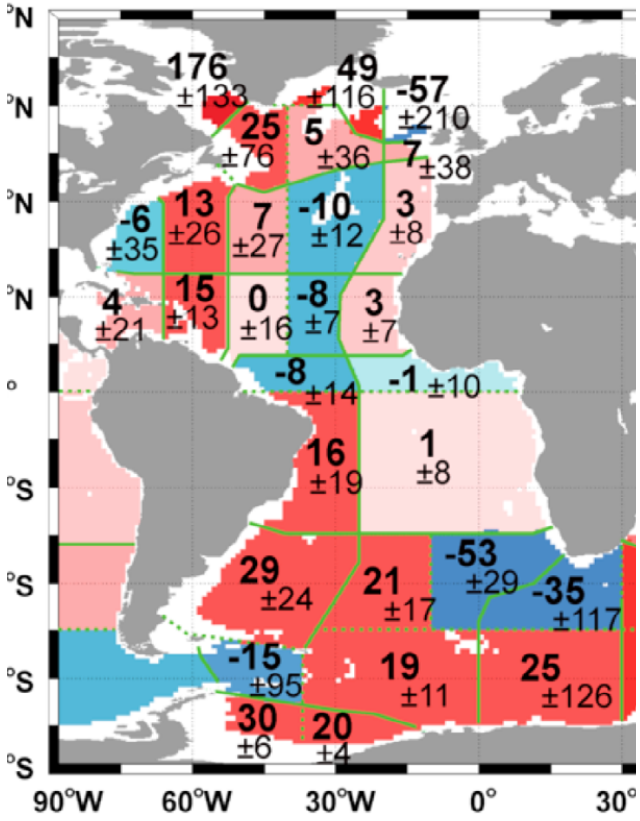

Le Reste et al, 2016, in press, JAOT



# Conclusion

Why the North-Atlantic Ocean ?

- Large signal (in temperature and salinity) in subpolar and subtropical gyres allowing the use of the data despite the uncertainties of the data accuracy.
- Short-term scientific objectives: deep convection, ISOW pathways, deep mixing; expected rapid publication to demonstrate the value of those data (funding agencies, Ocean Obs 19)
- Large scale, interannual, scientific context provided by complementary observing programs (RAPID, OVIDE, etc)
- Very stable deep water masses in eastern part of the basin allowing sensor evaluation
- On the longer term, data will allow to refine the heat budget in that basin characterized by large variability of the temperature trend at spatial and interannual time scales



# European contributions

- Euro-Argo plans to contribute to ~1/4 of the Deep-Argo array: ~250 floats and ~50 floats deployed/year
- Number will be refined based on a agreed Deep-Argo array design, the cycling period, the life-time of the floats, feedback from pilot arrays
- Ratio between 4000 and 6000m models needs to be defined too

# European contributions to Deep-Argo

- Contribute to the global Deep-Argo array by focusing deployments in the North-Atlantic Ocean

- Additional deployments planned in the Mediterranean Sea and envisioned in the Southern Ocean depending on scientific opportunities

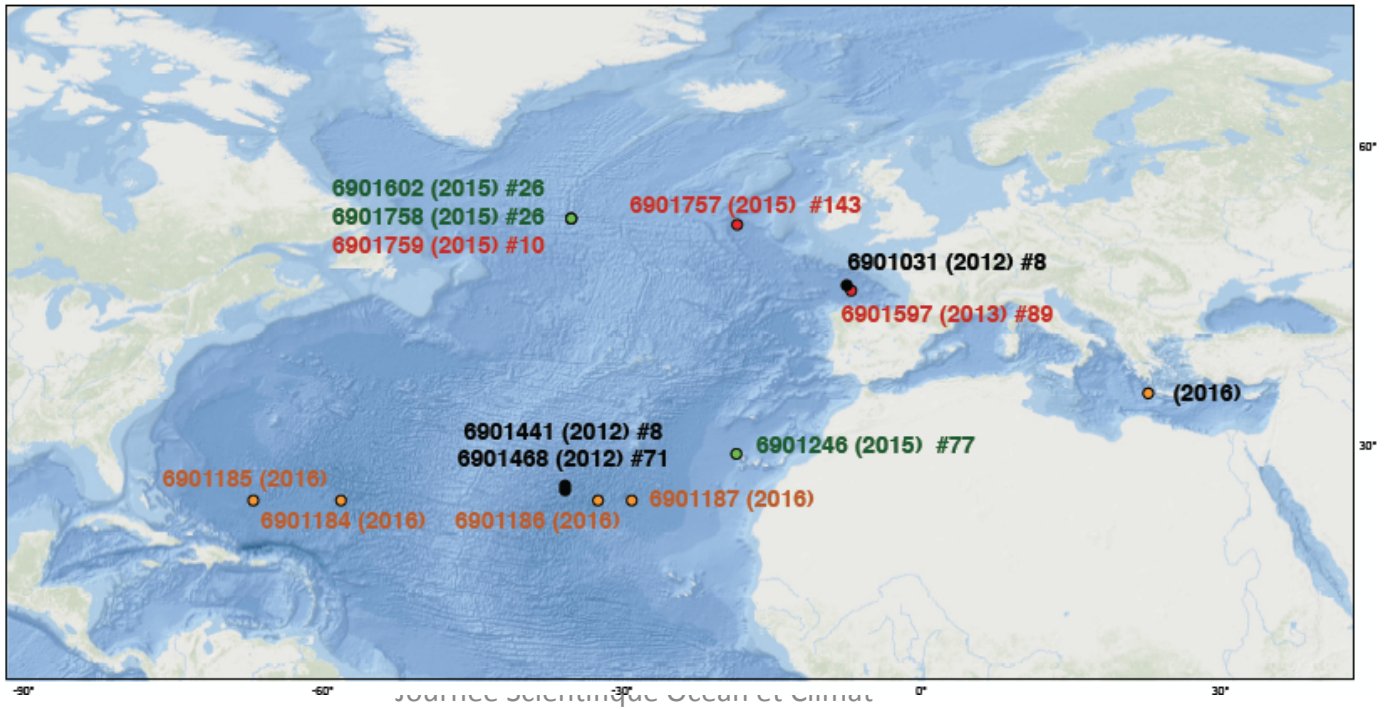
# Context

- Temperature trend is in the range ± 1 - ± 50 m°C/decade
- Based on the Johnson and Purkey Deep-argo array design, standard error on temperature trend estimates is of the same order of magnitude as the temperature trend itself in all basins
- Clear warming signal below 4000 m depth
- Sign and amplitude of the temperature trend is uncertain in the 2000-4000 m due to large regional differences and uncertainties:
- Decadal variability of the temperature trend value
- Aspirational accuracies are pressure: ± 3 dbar, temperature ± 0.001°C and salinity ± 0.002, not yet achieved

# Conduct the North-Atlantic Deep pilot array

- Technological issue: Float and sensor evaluations
- Strategy assessment : density, parking depth, cycling period, cost
- Demonstration of data value on a short term
- Initiate Deep-Argo time series to address the Deep-Argo objectives in 10 or 20 years from now.

- 13 floats already deployed, ~500 deep profiles



# Conduct the North-Atlantic Deep pilot array

| Program | Project | Float type and numbers | Deployment | Region |
|---|---|---|---|---|
| Argo-France | NAOS<br>V. Thierry | 19 Deep-Arvor | 2016 and 2017 | Subpolar gyre<br>Maybe 3 in Southern Ocean |
| Argo-Italy | PM. Poulain | 1 Deep-Arvor | 2016 | Mediterranean Sea |
| Euro-Argo | AtlantOS | 7 Deep-Arvor | 2017 | North-Atlantic |
| Argo-France | CPER Euro-Argo (Brittany) | 15 Deep-Arvor/ year (5 years) | 2017-2021 | North-Atlantic |
| Argo-UK | | ? | 2017 | |
| + Argo-US contribution | | | | |