

European contributions to Deep Argo and scientific objectives

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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

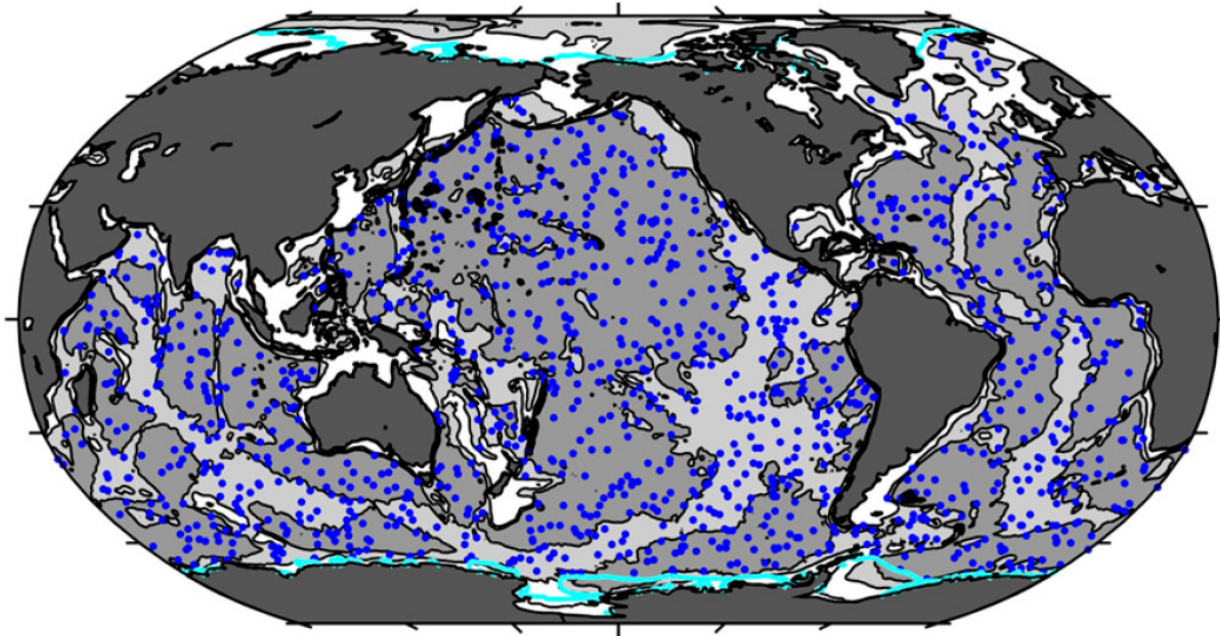


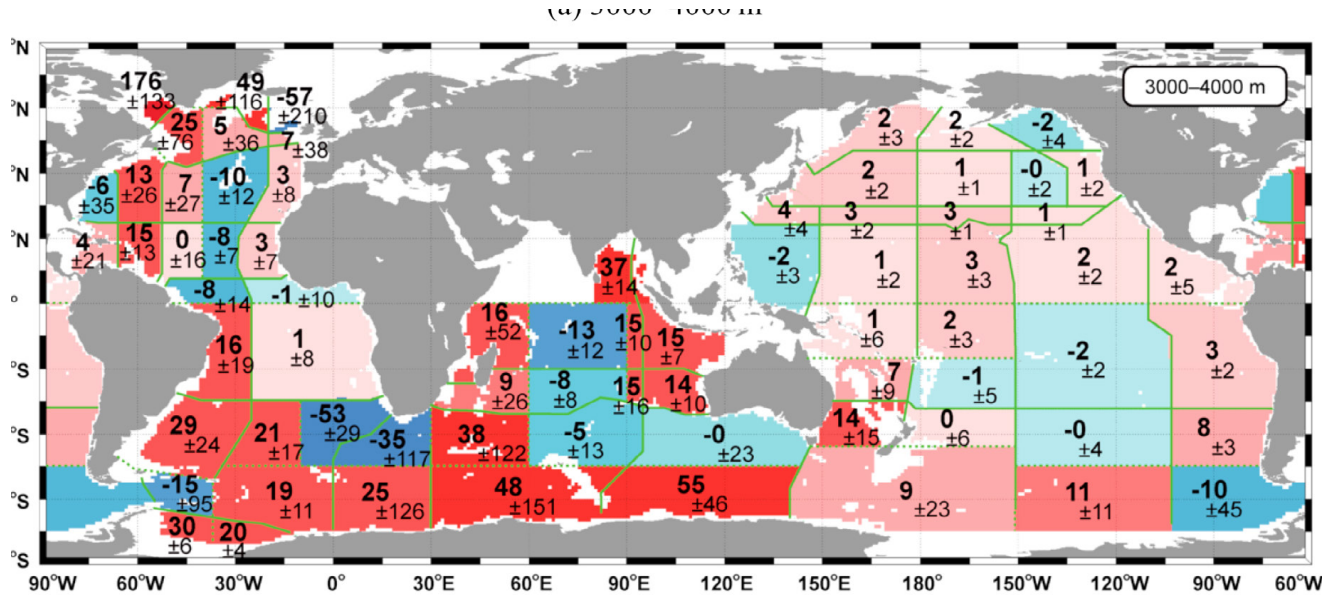
FIG. 1. Straw-plan of a nominally $5^\circ \times 5^\circ$ distribution of 1228 Deep Argo floats (blue dots) randomly populating the global ocean excluding areas shallower than 2000 m (white areas), and areas with mean 1981–2010 ice concentrations $>75\%$ (poleward of thick cyan contours). Lightest gray 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 ($\sim 30\%$ of the current Argo array)
- Only plan proposed, not yet endorsed

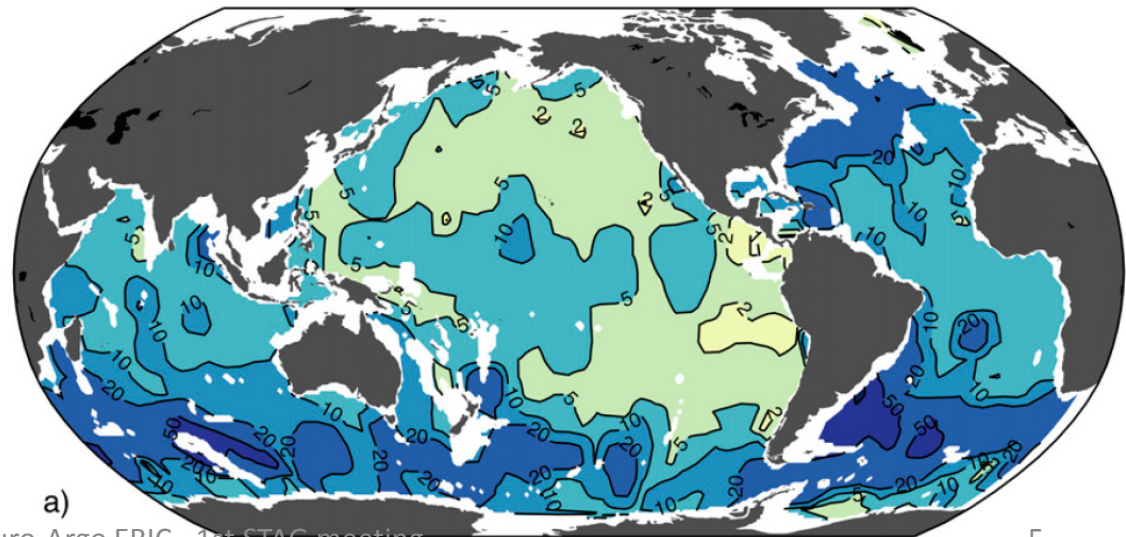
European contributions

- Euro-Argo plans to contribute to $\sim 1/4$ 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

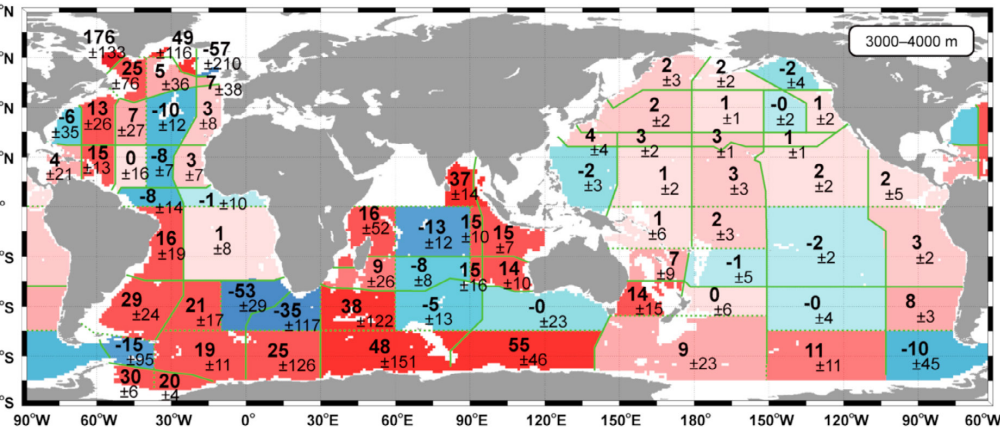
Temperature trends in $m^{\circ} C/decade$ from the 1990s to the 2000s (Kouketsu et al, 2011)



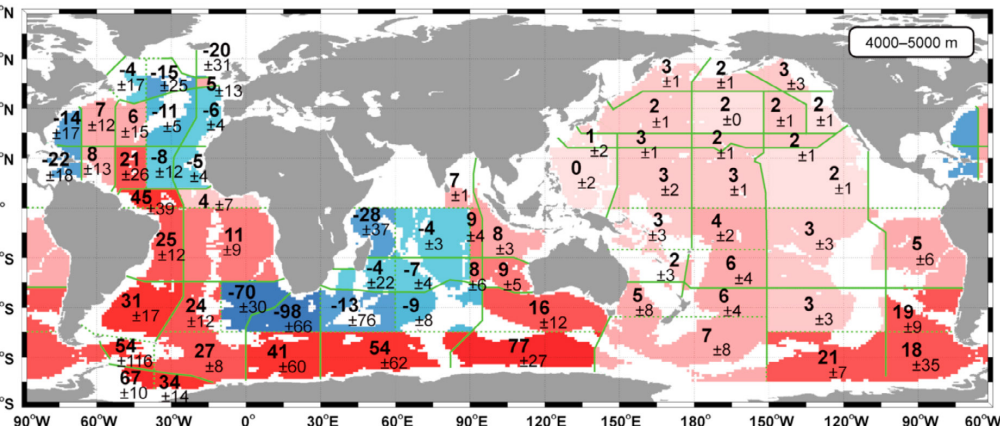
Estimated temperature trend standard errors in $m^{\circ} C$ per decade at 3000m with the Deep-Argo array design proposed by Johnson and Purkey 2015.



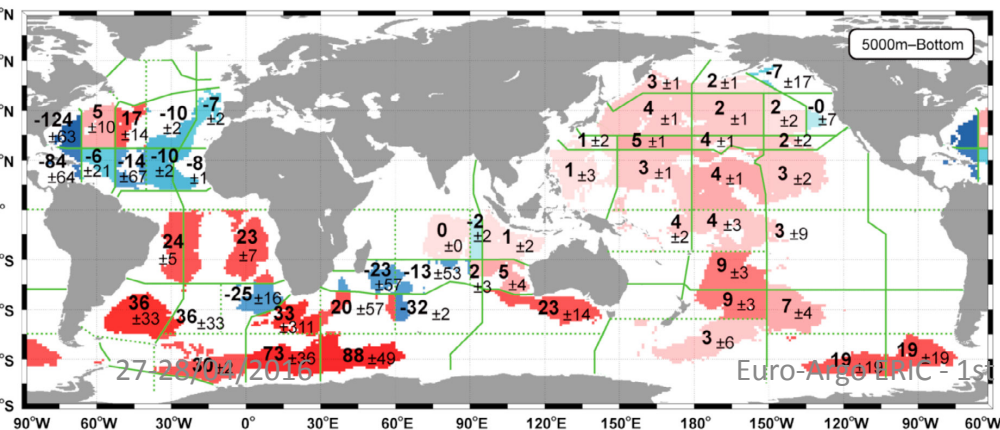
Temperature trends in m° C/decade from the 1990s to the 2000s (Kouketsu et al, 2011; Purkey and Johnson, 2010)



(b) 4000–5000 m



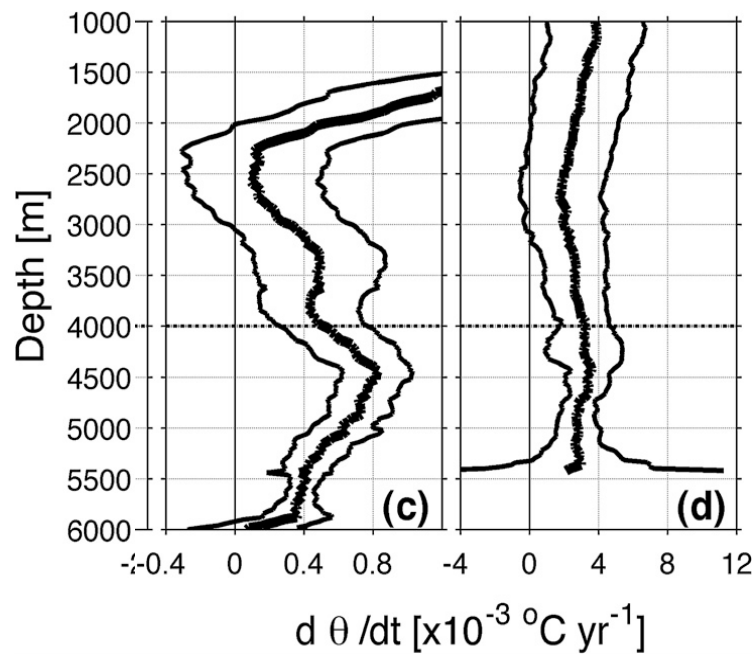
(c) 5000 m–bottom



Mean temperature trend

Global

Southern Ocean



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

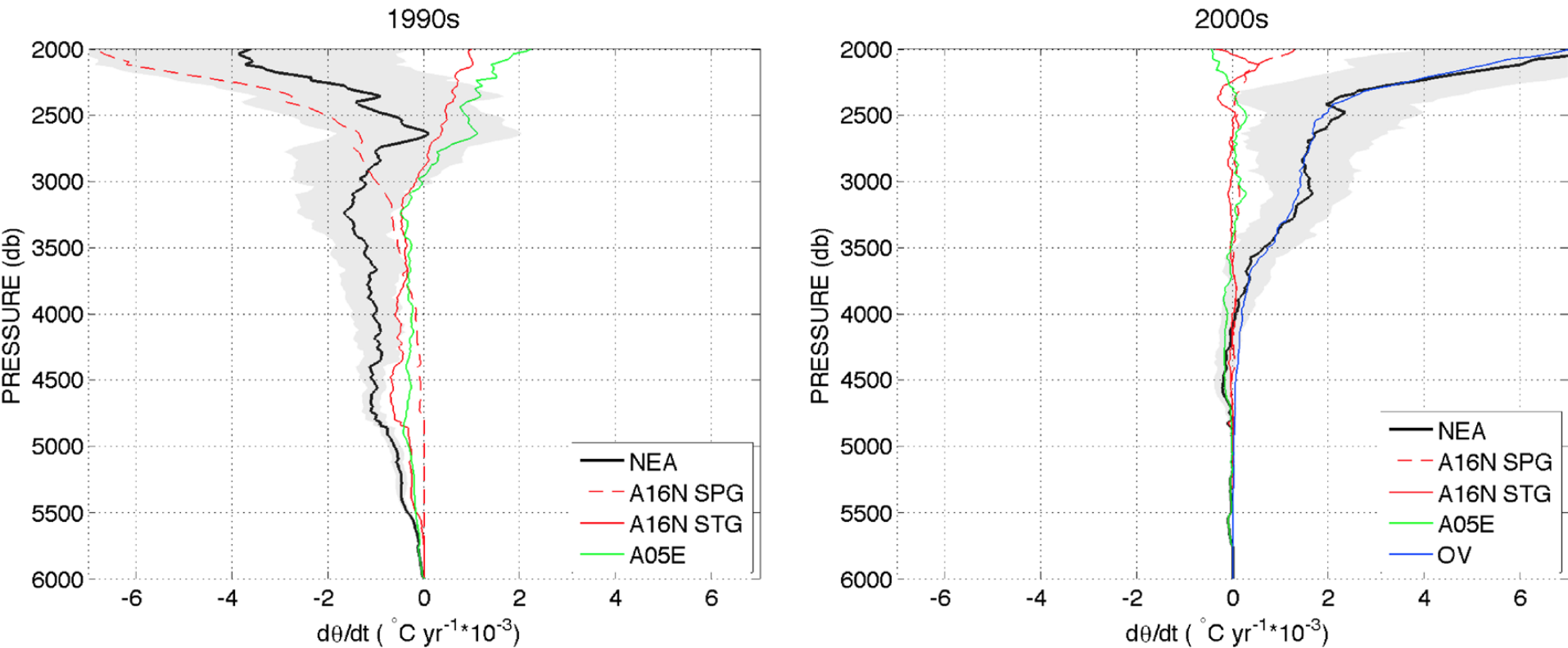
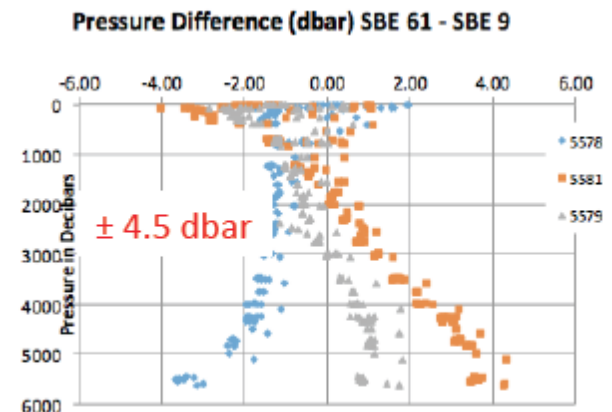
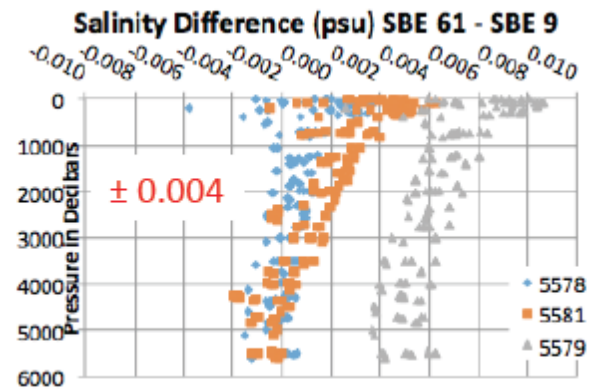
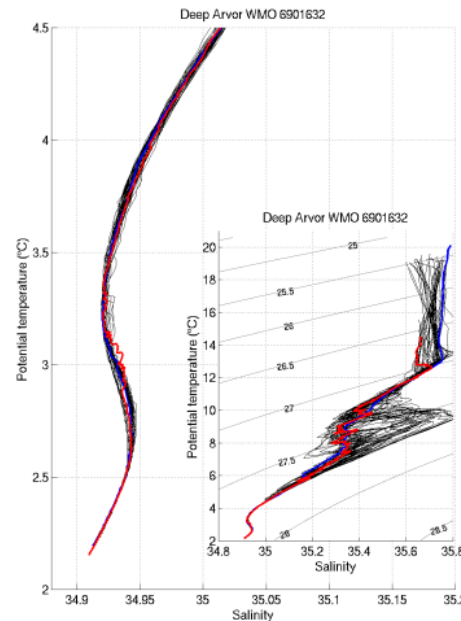
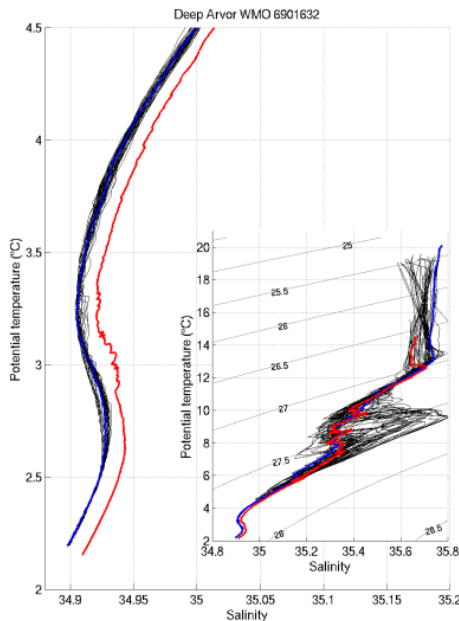


Figure 3. Basin-mean vertical profile of temperature trend below 2000 m depth (black) and length-weighted contributions of A16N (red), A05E (green), and A25-Ovide (blue) during (a) the 1990s and (b) the 2000s. Grey shading indicates 95% confidence intervals (see text for details). Units are $^{\circ}\text{C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

Sensor accuracy

- Aspirational accuracies are pressure: ± 3 dbar, temperature $\pm 0.001^\circ$ 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, in press, JAOT

Some thoughts about deployment strategy

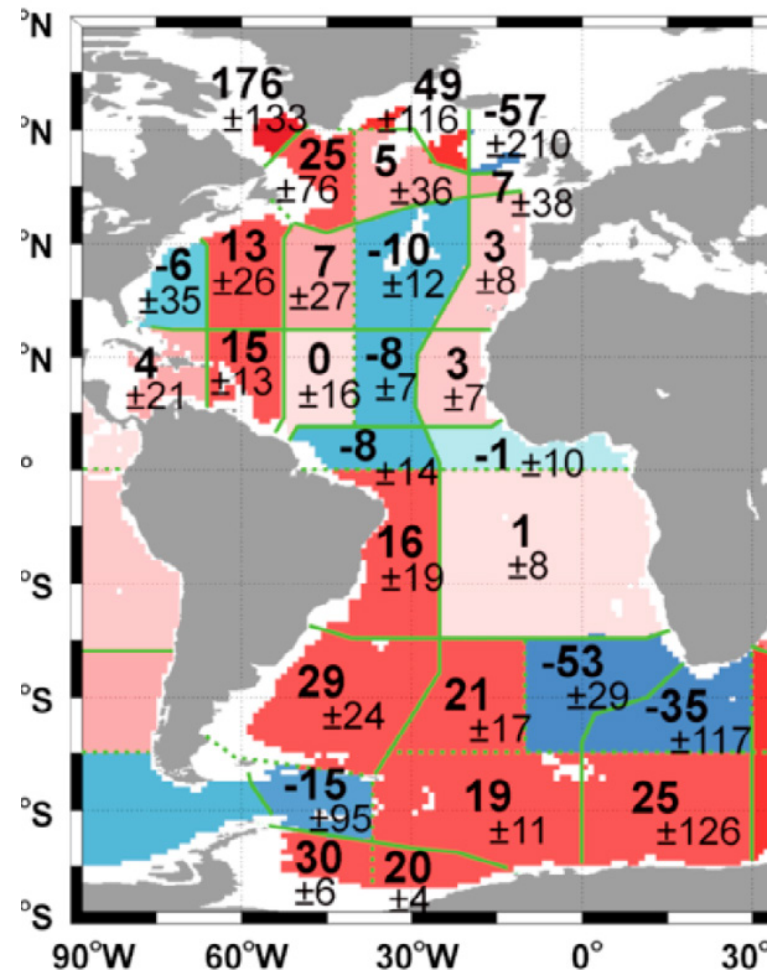
- Considering the amplitude of the signal and the expected standard errors, reliable and significant decadal temperature trends will be provided by a Deep-Argo array at best in 10-15 years from now
- In the meantime, we need to solve the technological issues we are facing (float reliability, sensors 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

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

Why a focus on the North-Atlantic Ocean ?

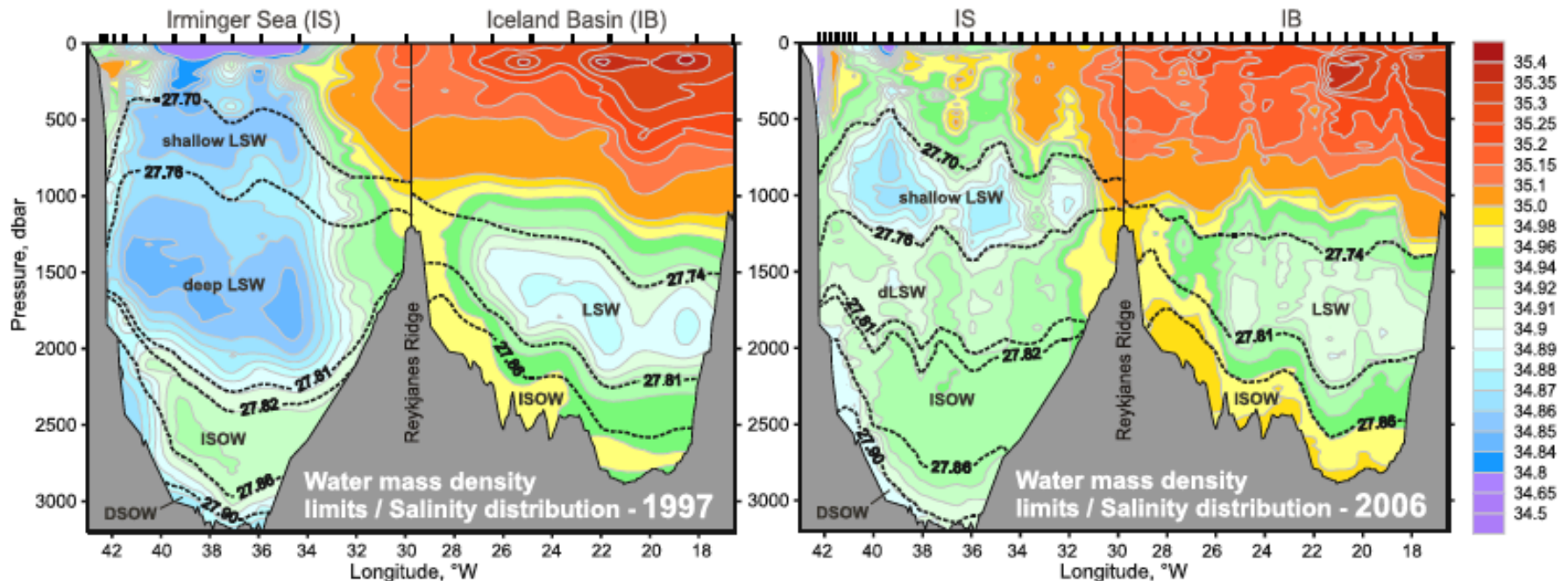
- Large spatial and interannual variability of the decadal temperature trend
- On the long-term those deployments will help reduce uncertainty in heat and freshwater budget in this basin



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)

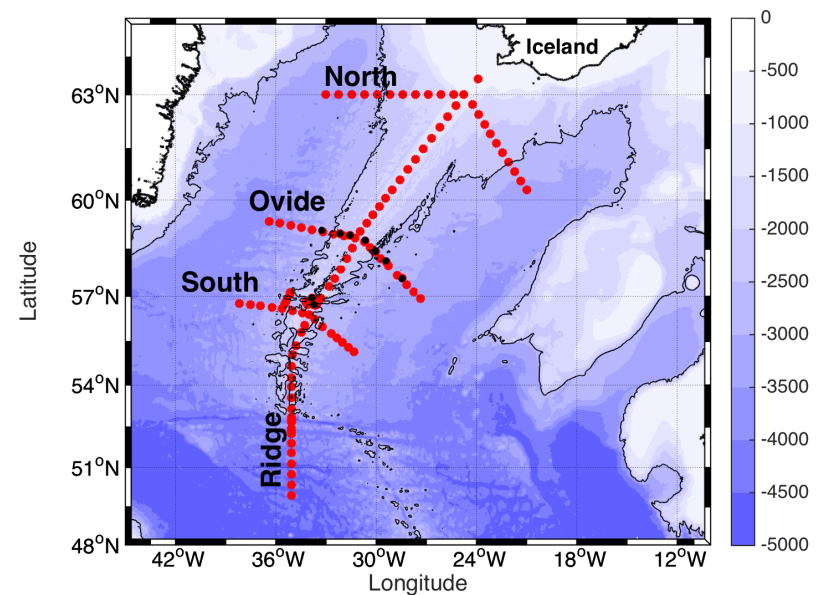
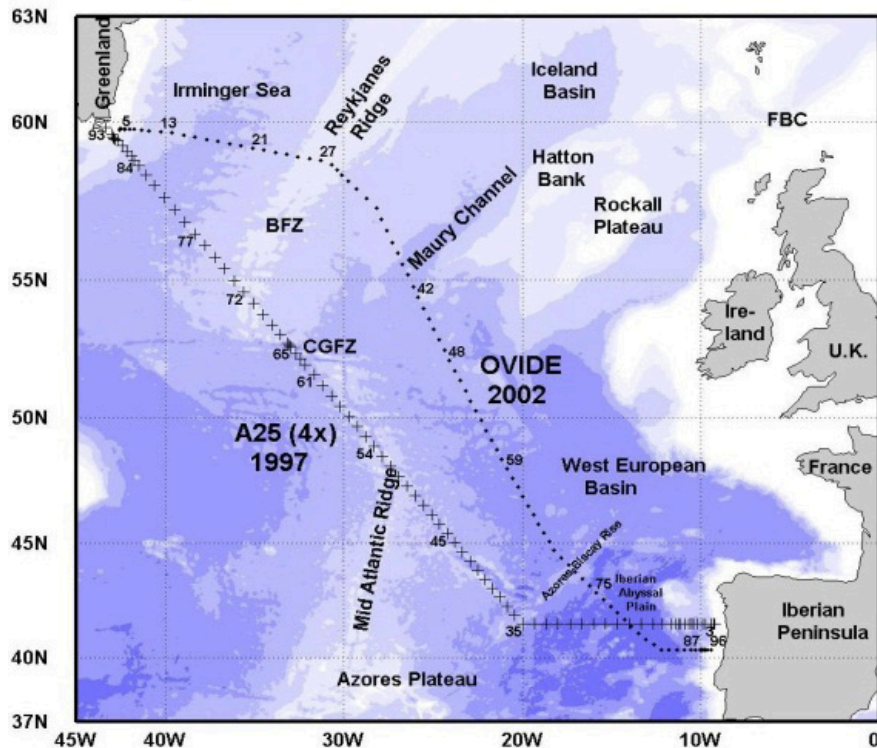


Sarafanov et al, 2007

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

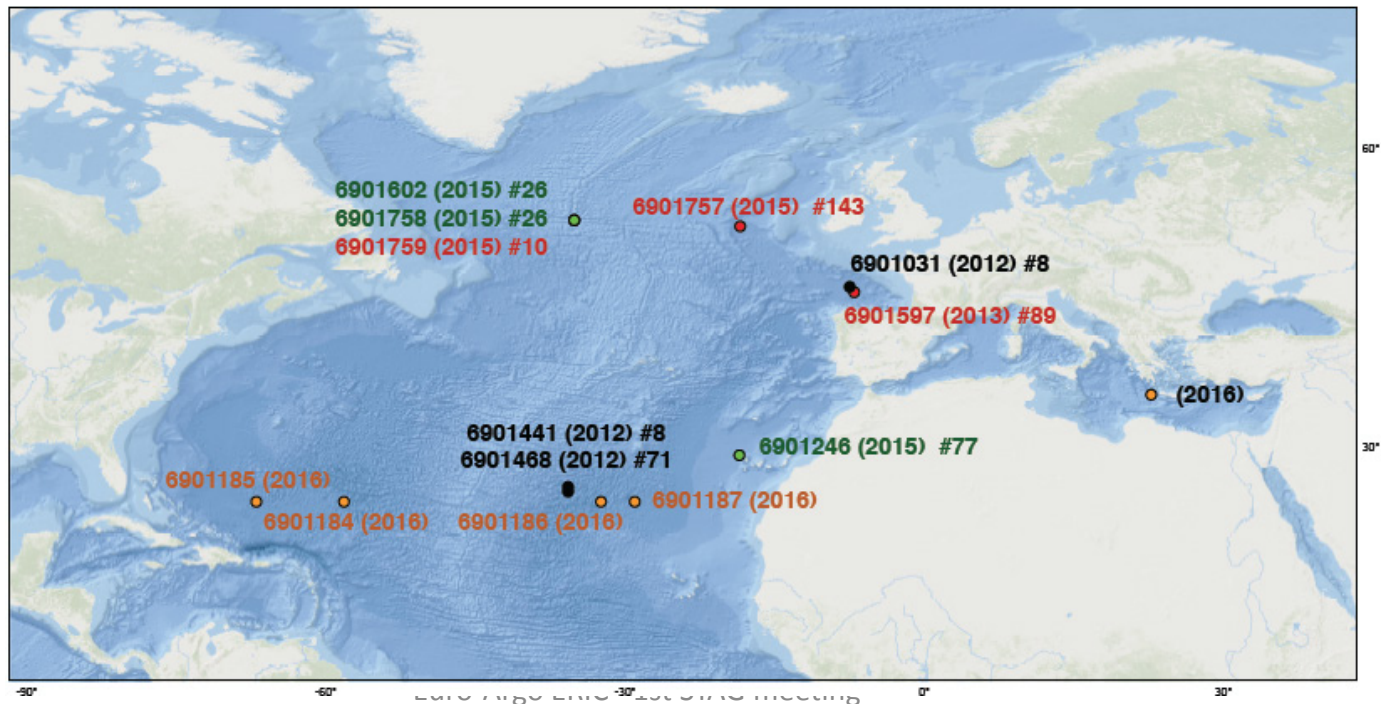
Why a focus on the North-Atlantic Ocean ?

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



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

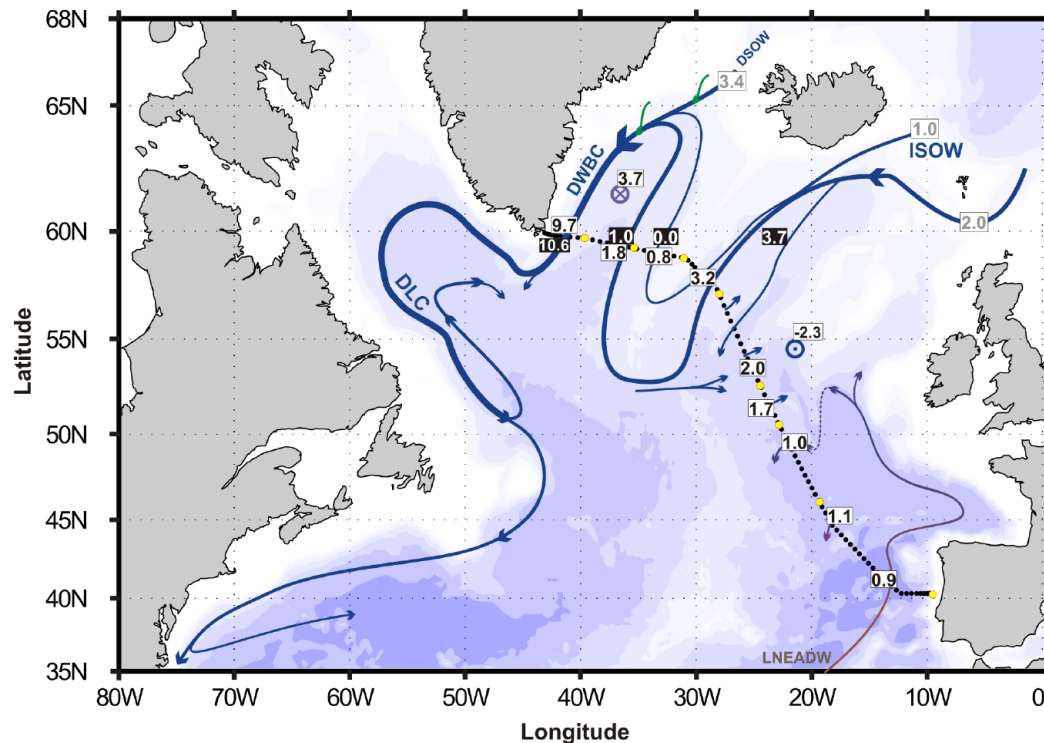


Conduct the North-Atlantic Deep pilot array

Program	Project	Float type and numbers	Deployment	Region
Argo-France	NAOS V. Thierry	19 Deep-Arvor	2016 and 2017	Subpolar gyre 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				

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

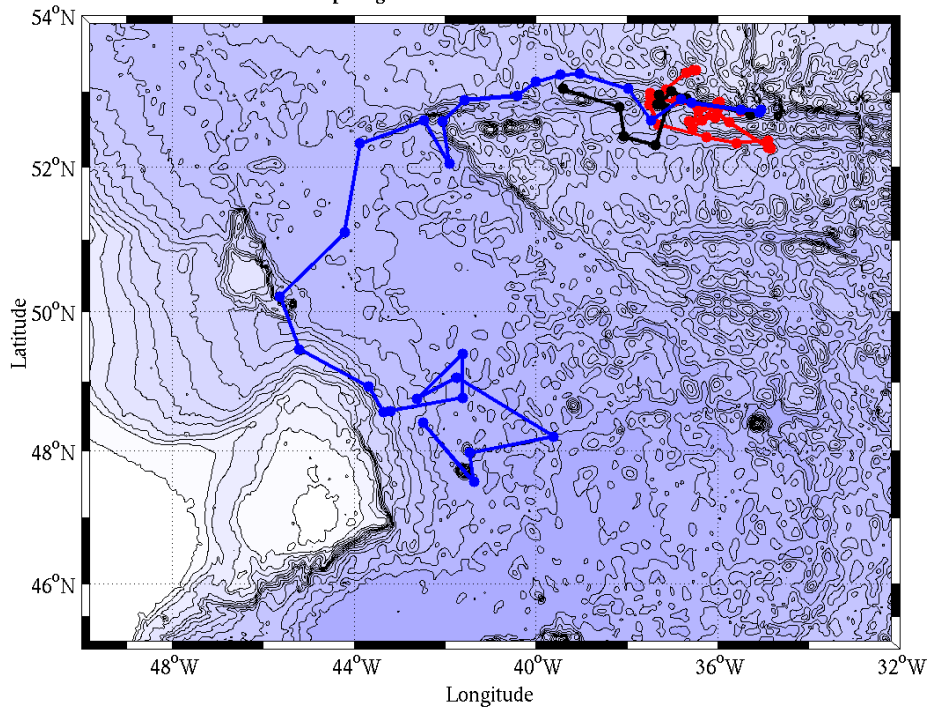
Circulation scheme in the deep layers ($\sigma_0=27.8$), (Daniault et al. 2016)



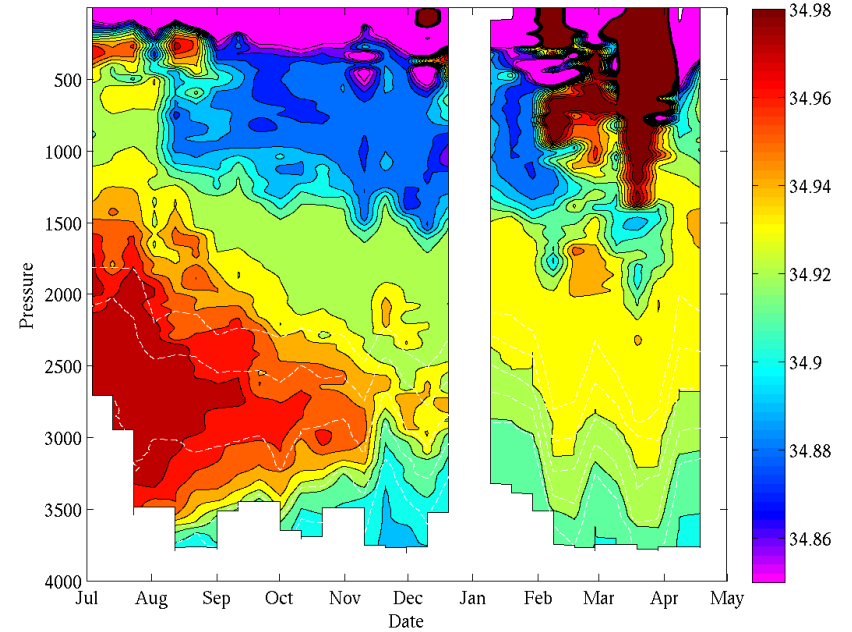
- Mixing in fracture zones, downstream of the Denmark strait, in the Labrador Sea
- Fate of the 3 branches of ISOW in the Island Basin and downstream of Bight and Charlie-Gibbs Fracture Zones, Interior pathways of DWBC ...

ISOW pathways

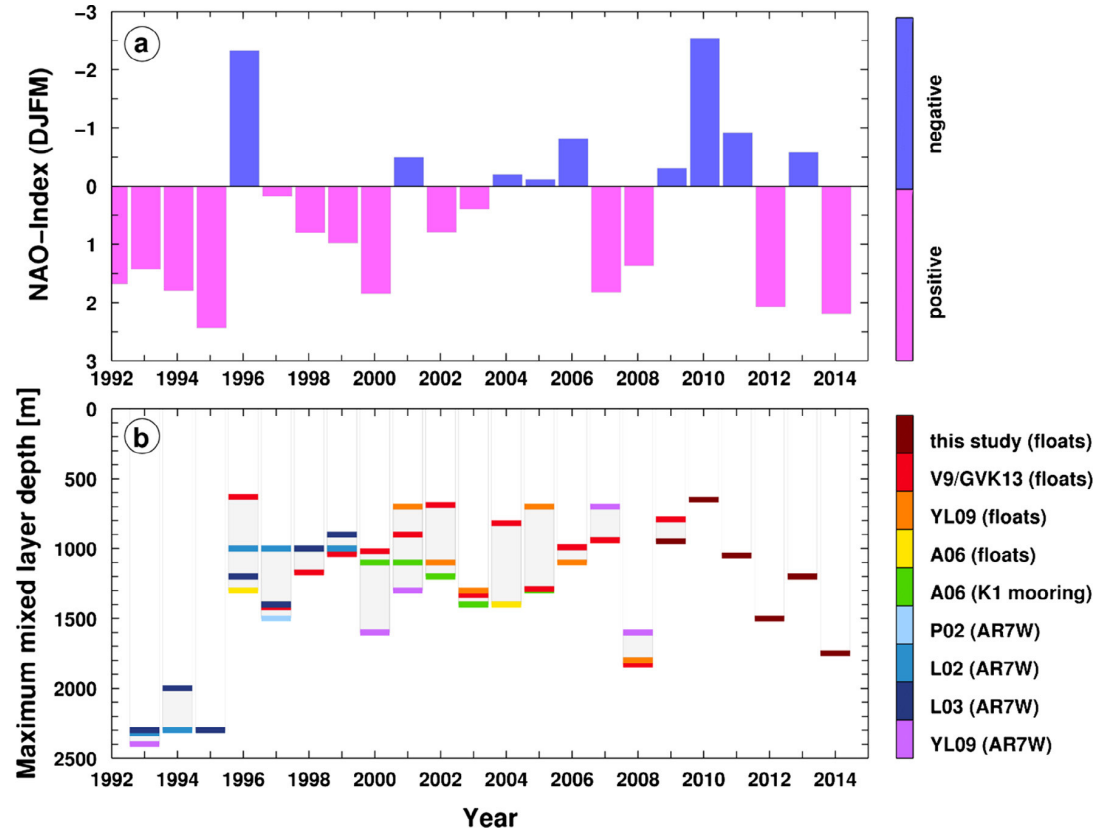
Deep Argo Floats Launched in the CGFZ



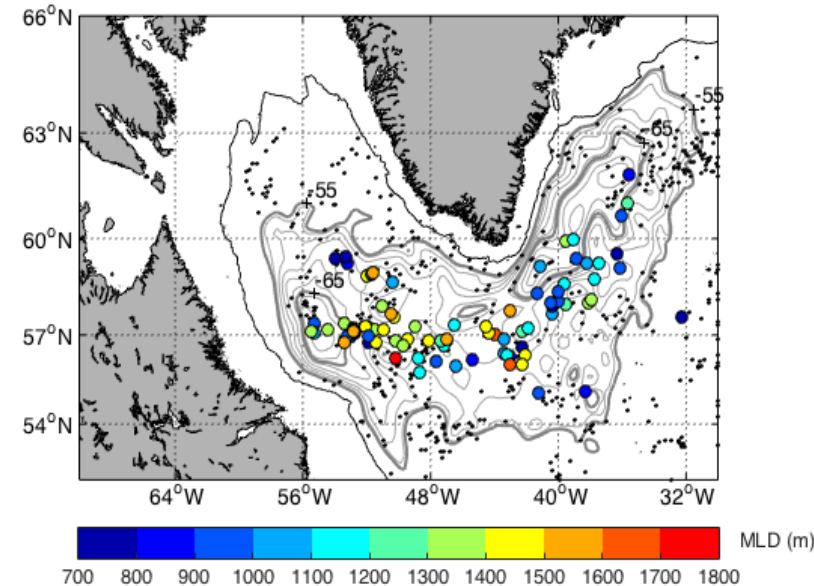
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Monitoring deep convection in the Subpolar Gyre



Winter 2014-2015 MLD

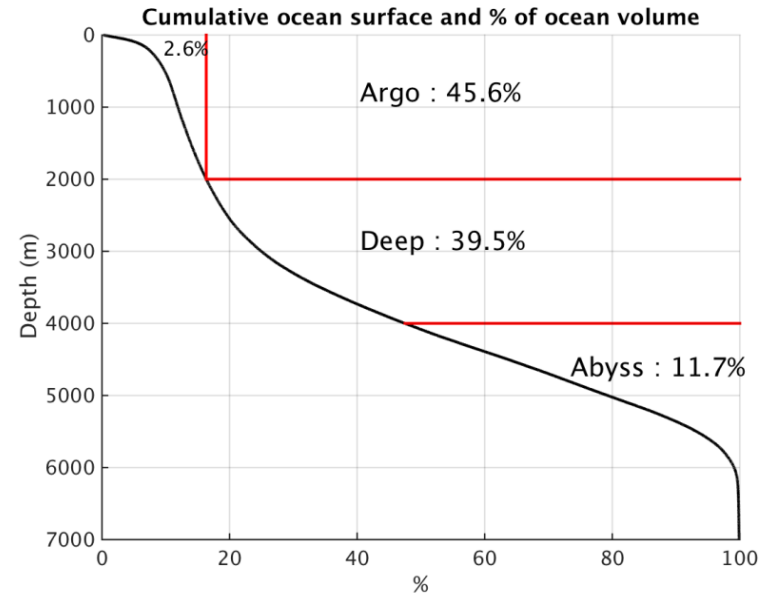


Piron et al, 2016, to be submitted

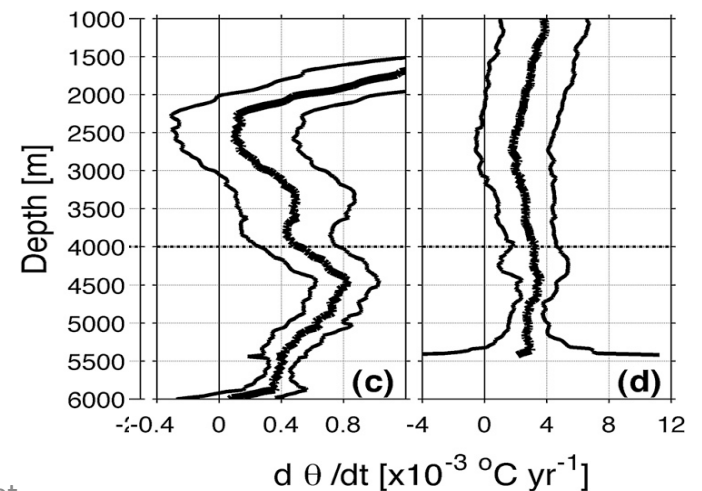
Kieke and Yashayaev, 2015

Conclusion

- Euro-Argo plans to contribute to $\sim 1/4$ 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

