

A complex North Atlantic permanent pycnocline revealed by Argo Data

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5th Euro-Argo user Workshop
Brest, March 16-17 2015



Scientific context

Global warming of the ocean

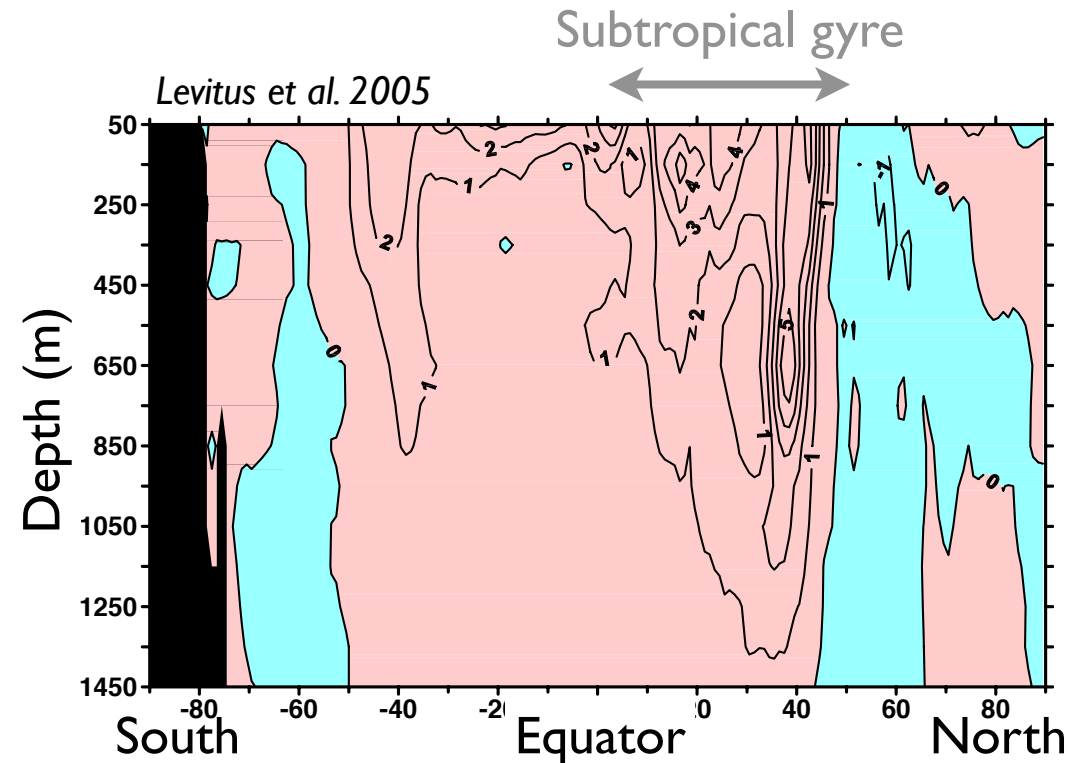
- The most intense in the North Atlantic
- Seems to be constrained by the structure of the permanent pycnocline



Need to characterize and monitor the structure of the permanent pycnocline



How is the excess of heat stored?



Method

How to characterize the permanent pycnocline in subtropical gyres ?

Pycnocline: strong temperature/
density gradient with depth

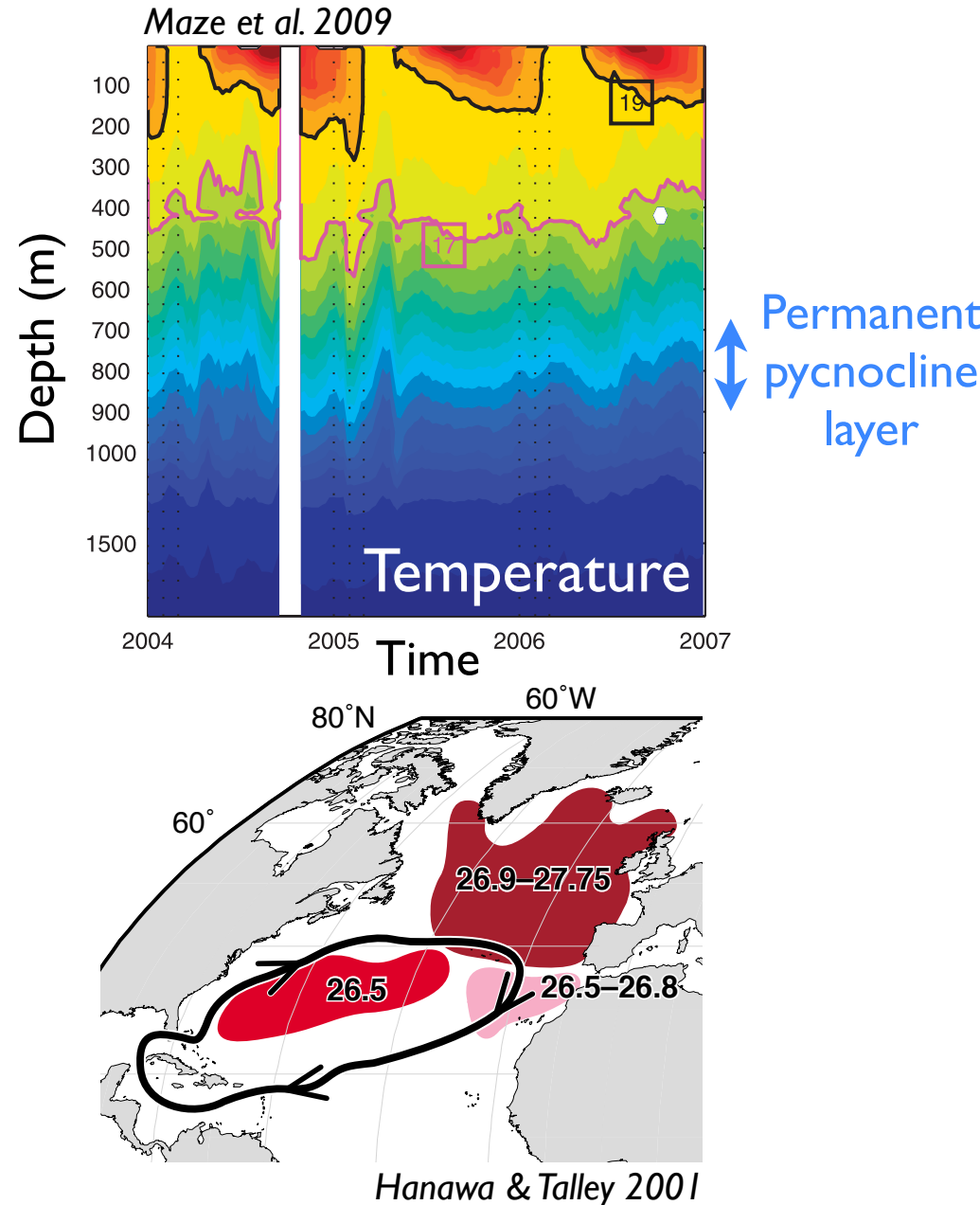
**The subtropical
permanent pycnocline is
found below a mode water**

The mode water seasonally
merged with the mixed layer

North Atlantic Ocean



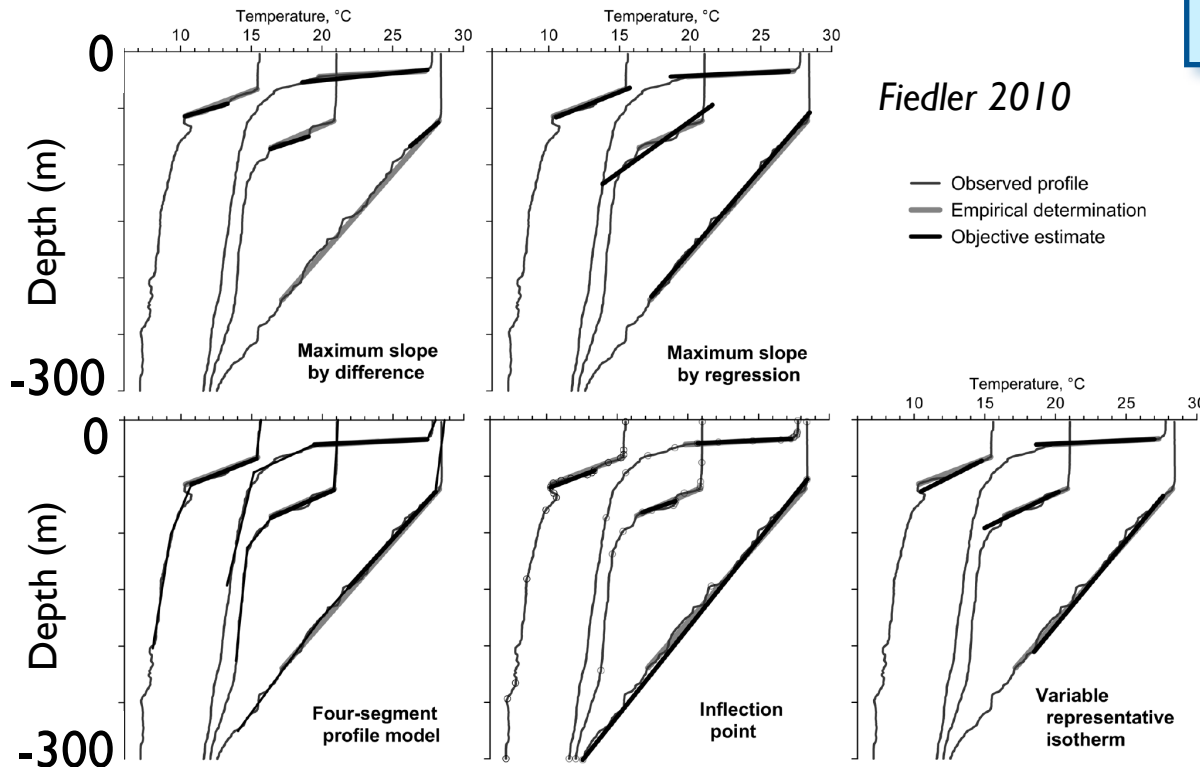
Subpolar Mode Water (SPMW)
Eighteen Degree Water (EDW)



Method

How to characterize the permanent pycnocline in subtropical gyres?

Temperature profiles



Fiedler 2010

Methods up to date are applied locally in equatorial regions

The maximum temperature gradient is below the mixed layer

- Model with segments
- Approximation by isotherms

Limits

- Segments suppose linear density variation with depth
- Temperature/density variation at the depth of the pycnocline at large scale

Need a robust method to characterize the **permanent pycnocline** at **large scale**

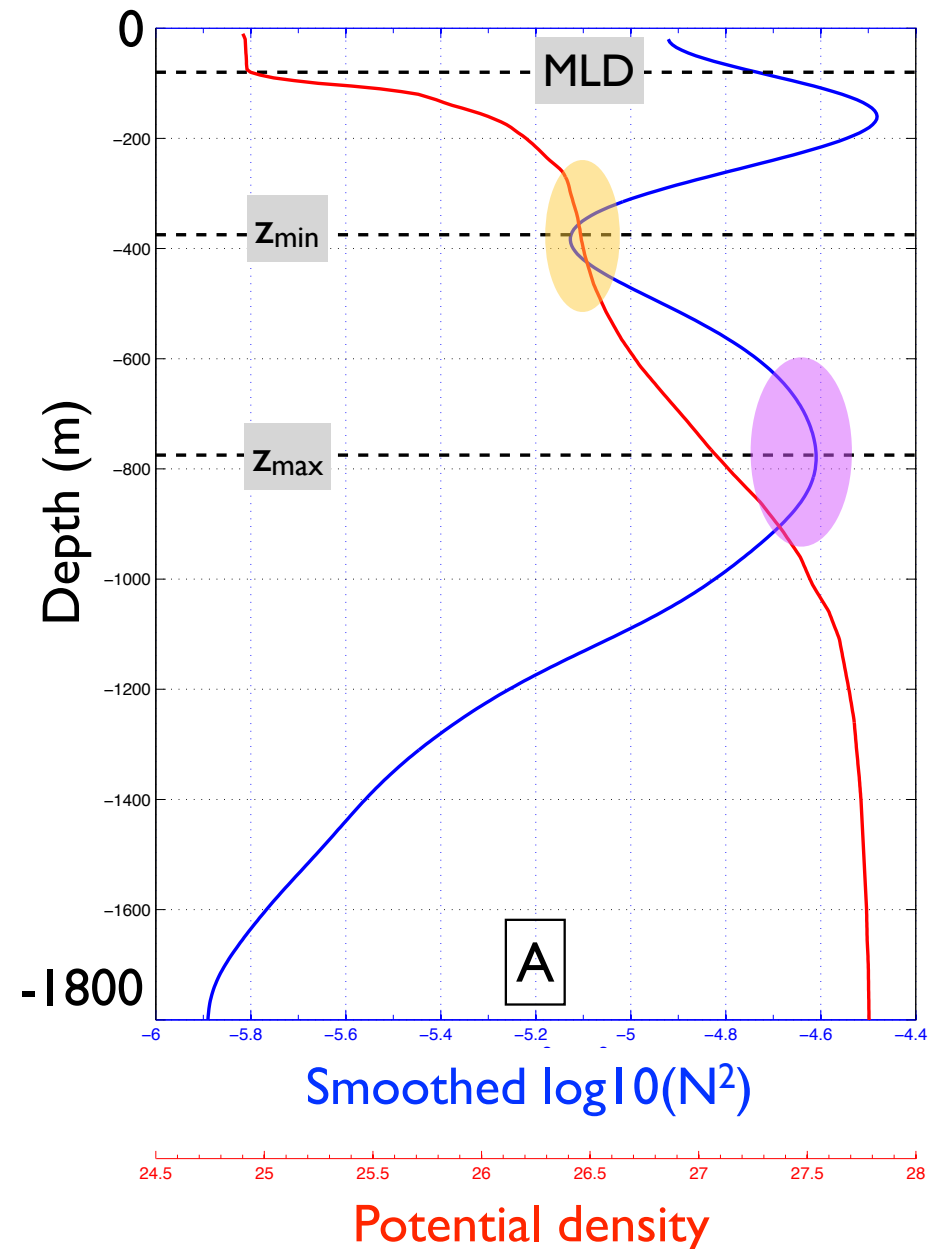
Method

An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Typical subtropical profile
in the North Atlantic
subtropical gyre:

A **mode water**
(**minimum in stratification**)
trapped between
the **mixed layer**
and the
permanent pycnocline
(**maximum of stratification**)

Characterization of the
permanent pycnocline in
terms of **depth** and **thickness**

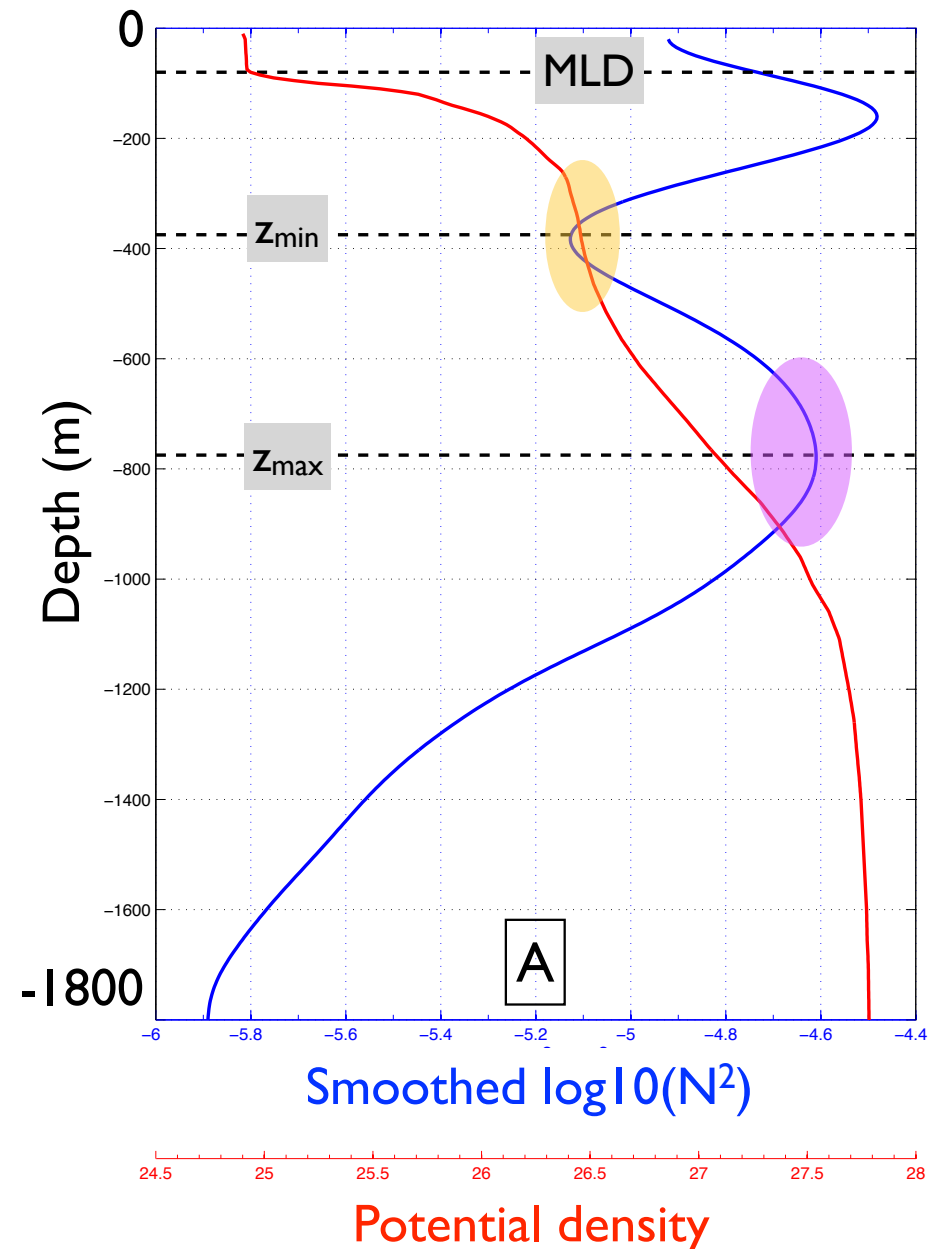


Method

An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Characterization of the permanent pycnocline depth

1. Depth of the local minimum of the stratification below the mixed layer (Z_{\min})
2. Depth of the local maximum of the stratification below the mode water (Z_{\max})



Method

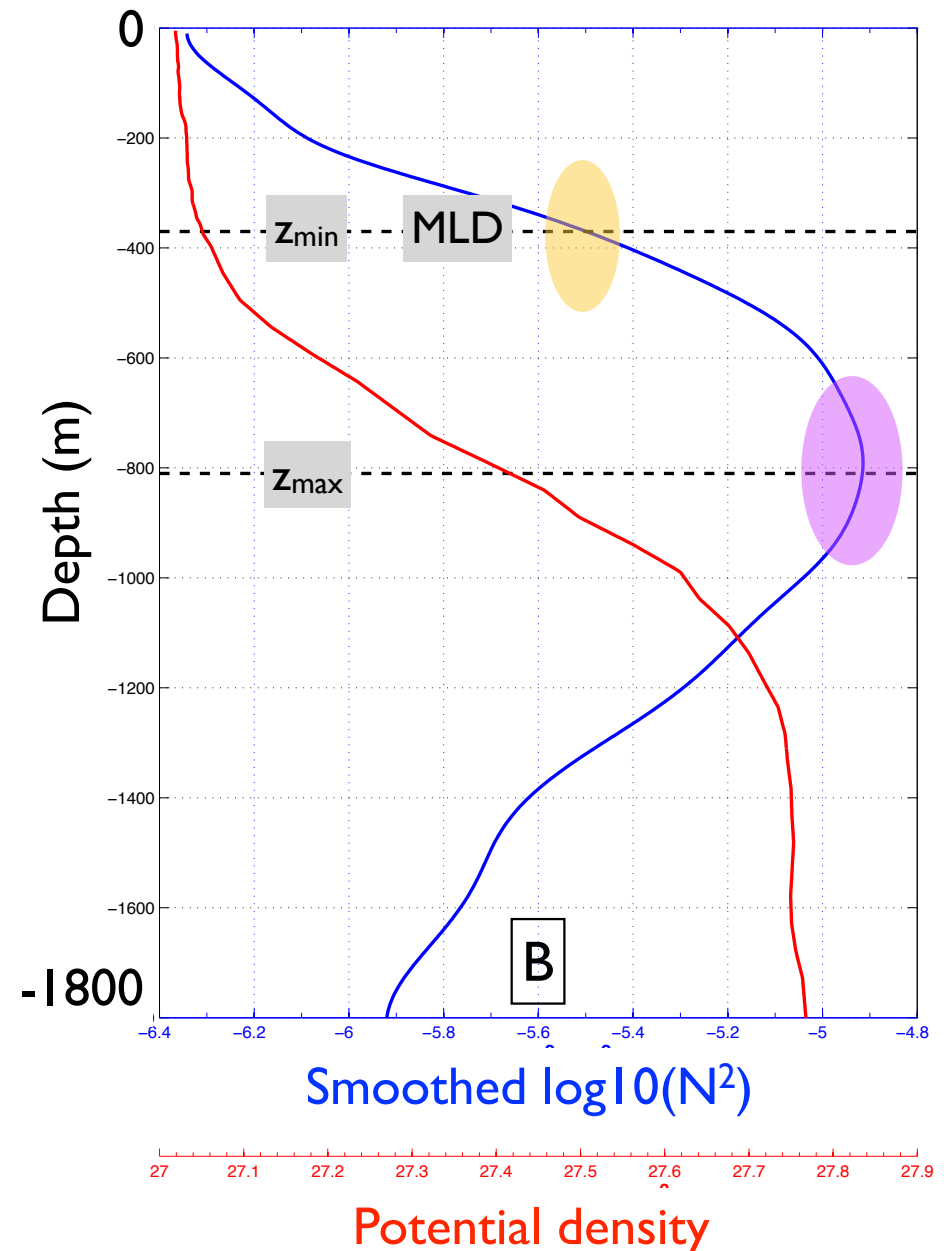
An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Characterization of the permanent pycnocline depth

1. Depth of the local minimum of the stratification below the mixed layer (Z_{\min})
2. Depth of the local maximum of the stratification below the mode water (Z_{\max})

Seasonality of the mode water

$$Z_{\min} = \text{MLD}$$



Method

An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Characterization of the permanent pycnocline thickness

Choice of a model:

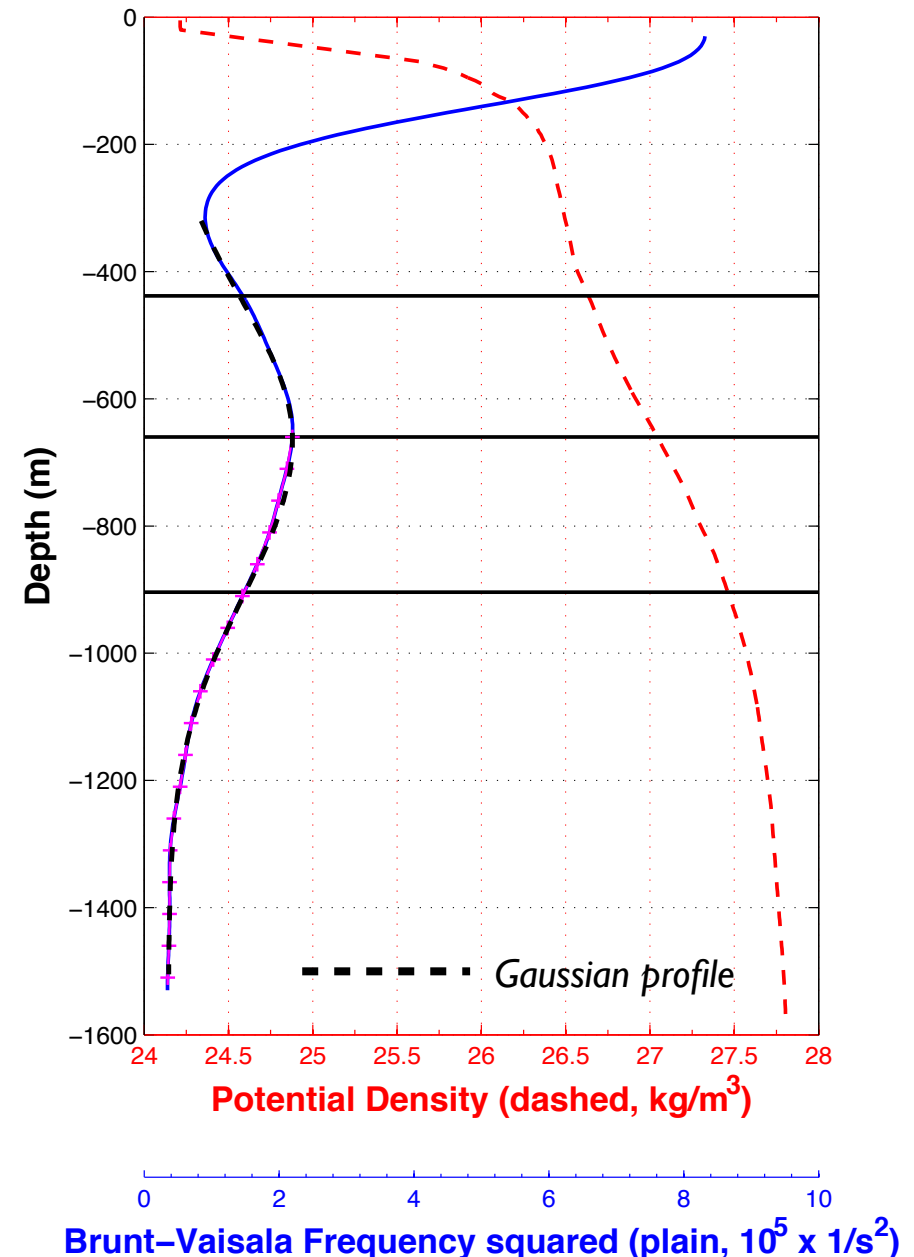
Density profile: erf function

N^2 profile: gaussian distribution

diffusive balance between two homogeneous reservoir (mode water-abyssal water)

Asymmetric structure of the pycnocline around its depth:

Two half gaussians centered at the depth of the permanent pycnocline



Method

An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Characterization of the permanent pycnocline thickness

Choice of a model:

Density profile: erf function

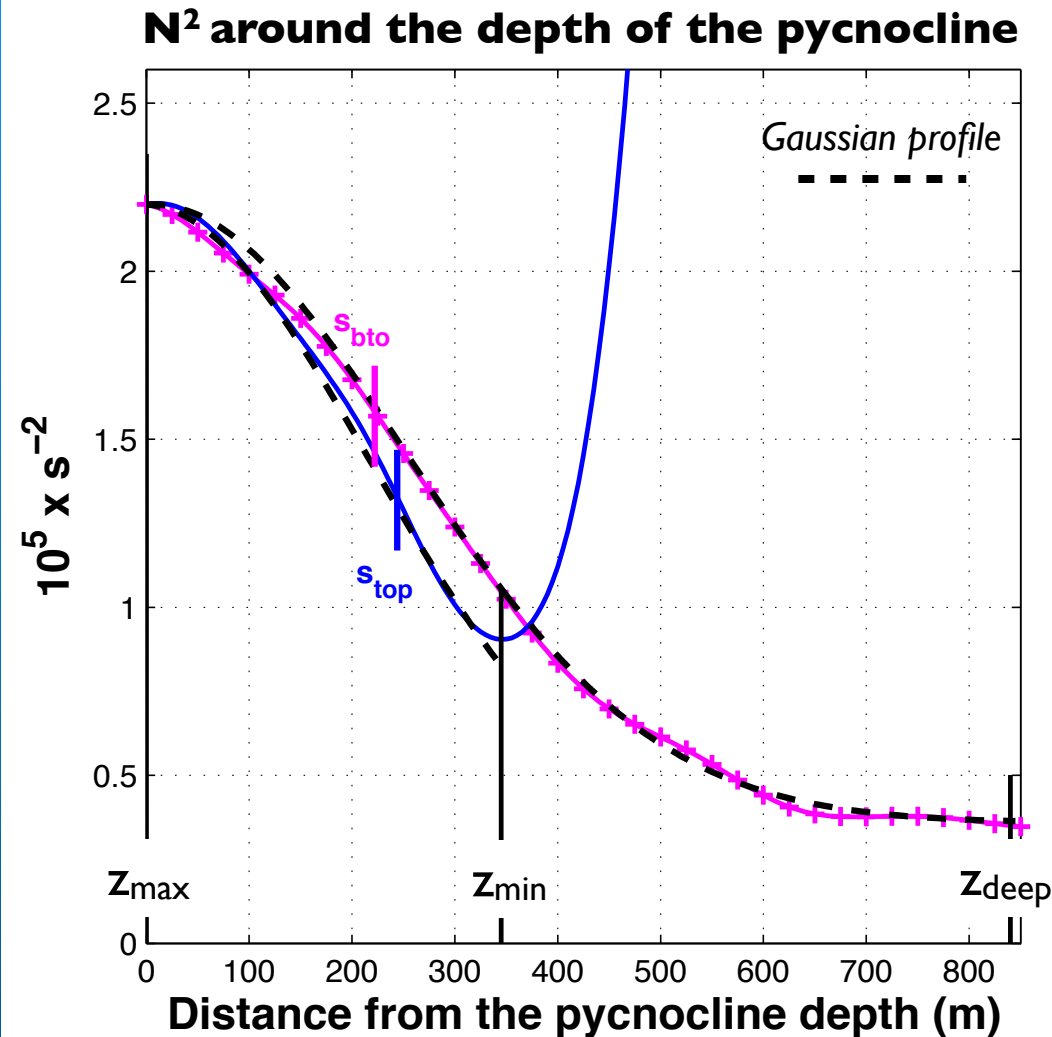
N^2 profile: gaussian distribution

diffusive balance between two homogeneous reservoir (mode water-abyssal water)

Asymmetric structure of the pycnocline around its depth:

Two half gaussians centered at the depth of the permanent pycnocline

Pycnocline top and bottom thicknesses:
standard deviation of the gaussians



Method

An Objective Algorithm for the Characterization of the Permanent Pycnocline (OAC-P)

Quality Control

Check if differences with typical subtropical profiles

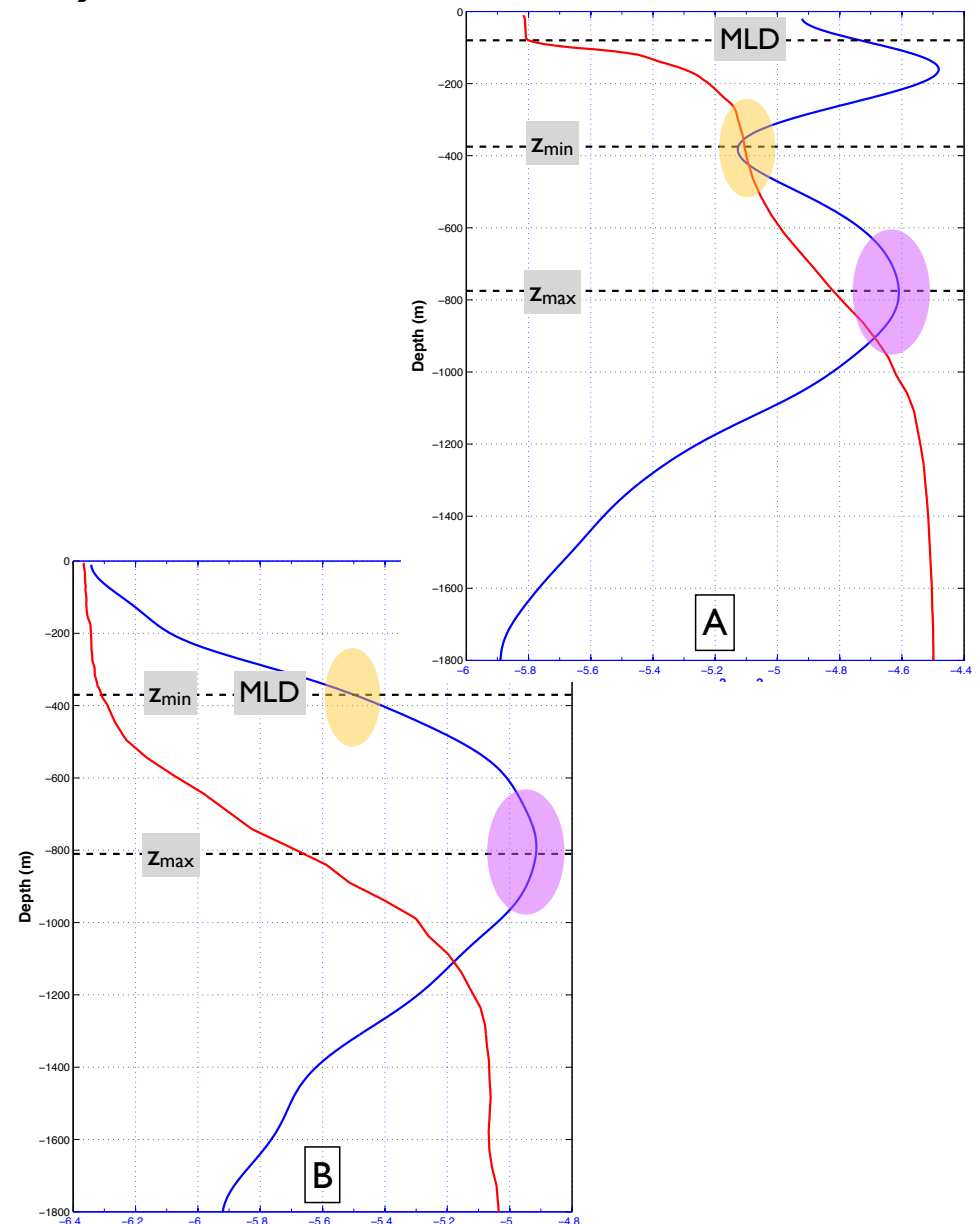
Permanent pycnocline below a mode water

=

Profile with a **minimum** below the mixed layer followed by a **maximum** in the stratification

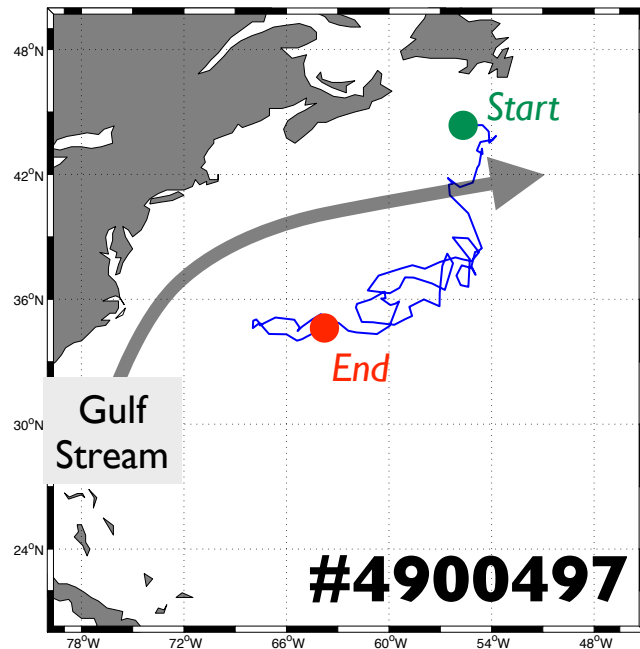


Discard profiles that do not correspond to this definition

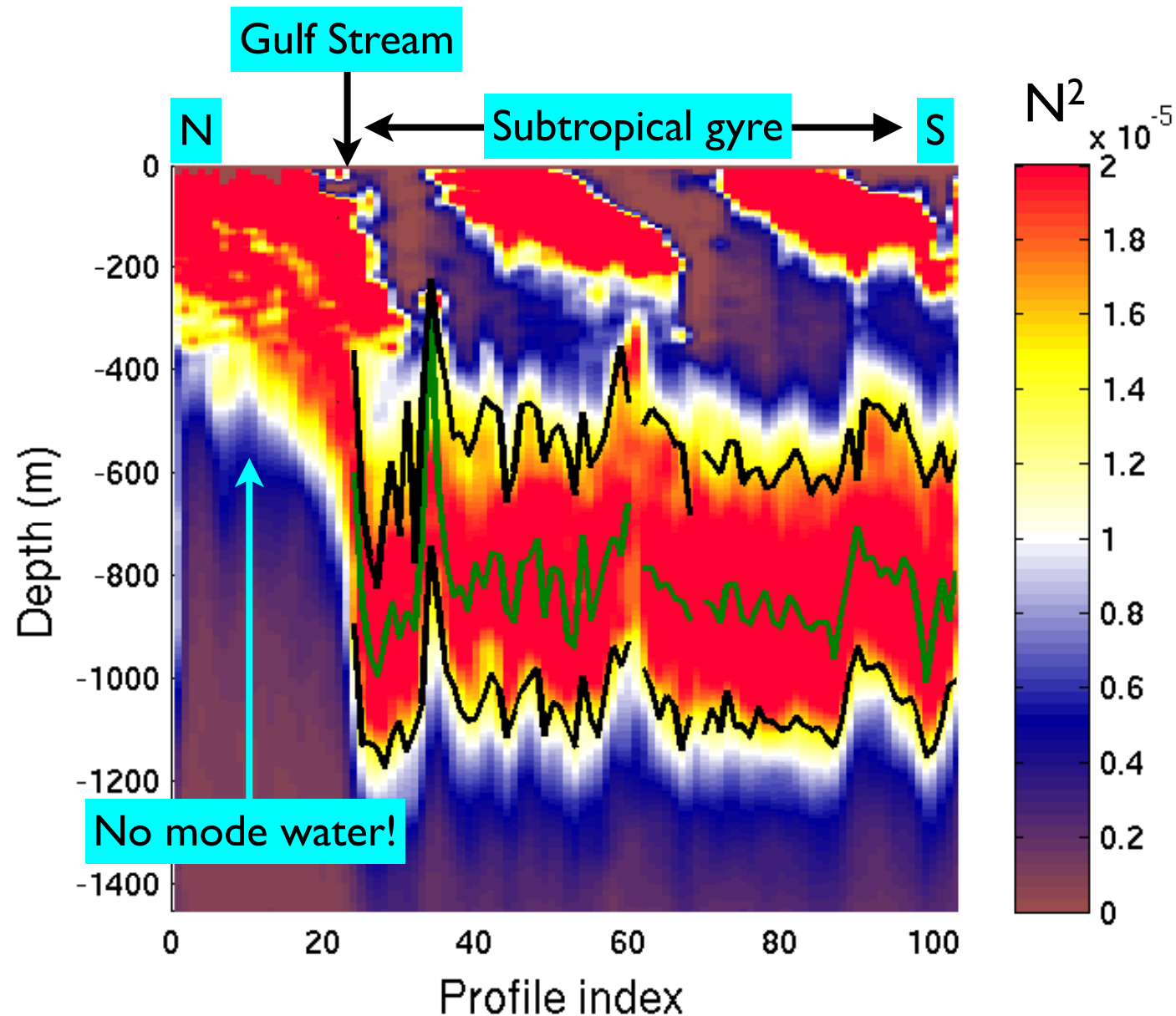


Method

OAC-P on Argo data

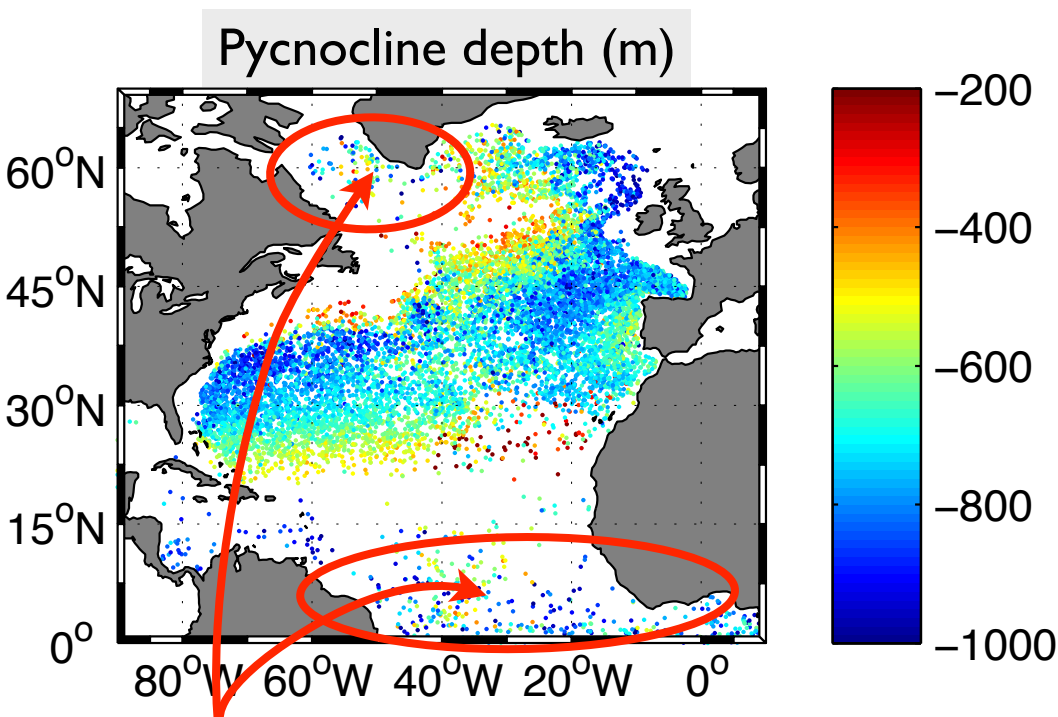


- Interpolate profiles onto a regular grid
- Smooth N^2 profiles (scale < 50 m)



OAC-P on Argo data

Profiles where the pycnocline is characterized



Detection at subpolar and equatorial regions

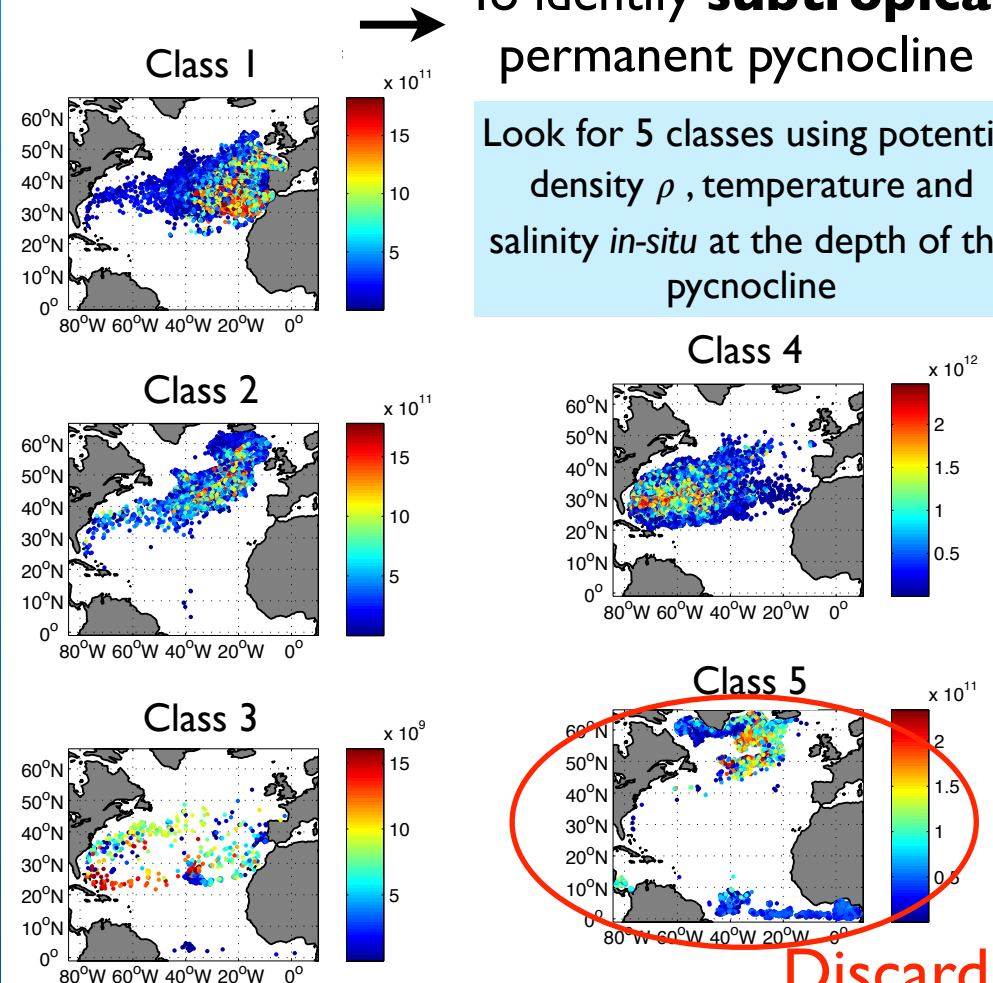
Filtering the database

Unsupervised classification
Gaussian Mixture Model (GMM)

Maze et al. 2015, submitted

To identify **subtropical** permanent pycnocline

Look for 5 classes using potential density ρ , temperature and salinity *in-situ* at the depth of the pycnocline

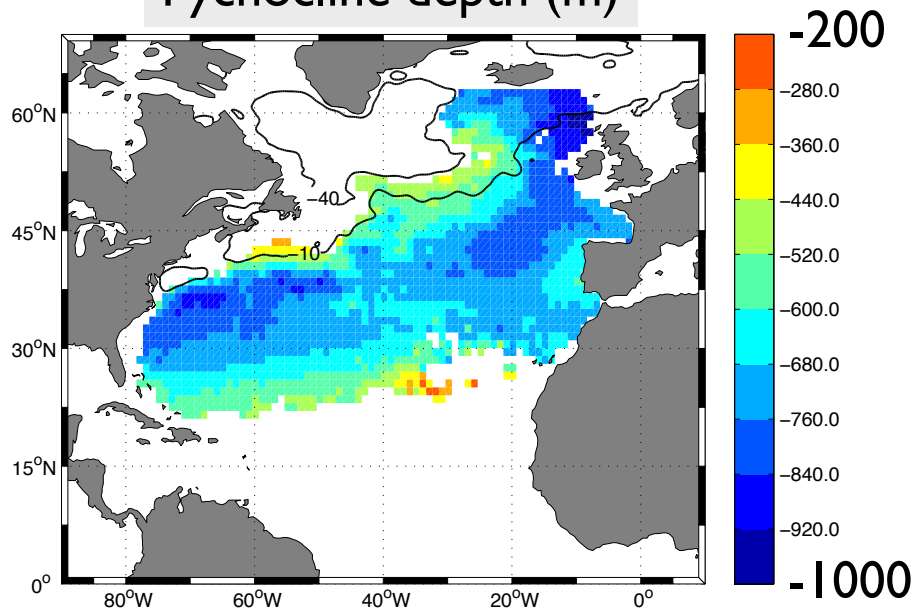


Discard!

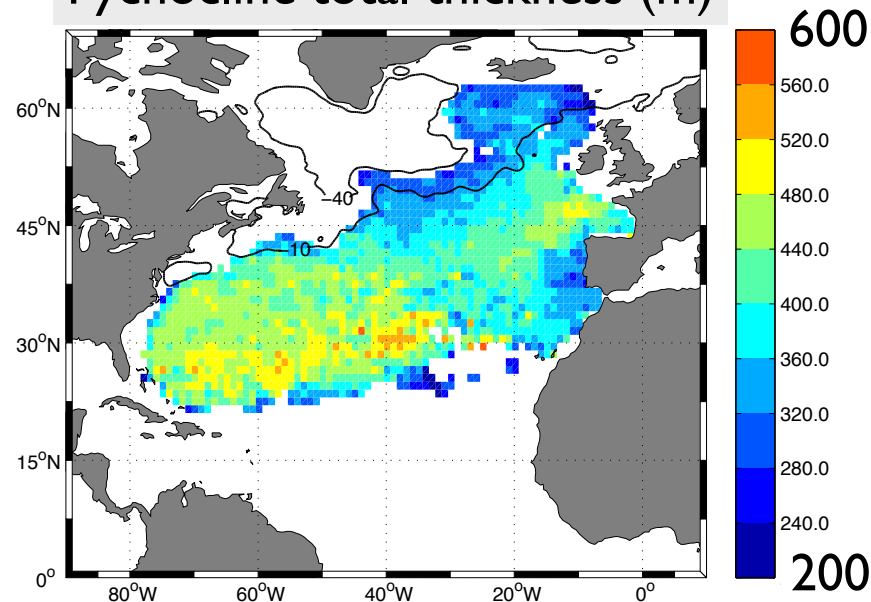
Color: probability for each profile to belong to the class

Results

Pycnocline depth (m)



Pycnocline total thickness (m)



Contours: SSH mean field (2000-2012)

Northern boundary

- Gulf Stream (GS)
- North Atlantic current (NAC)

Large scale: classical bowl structure

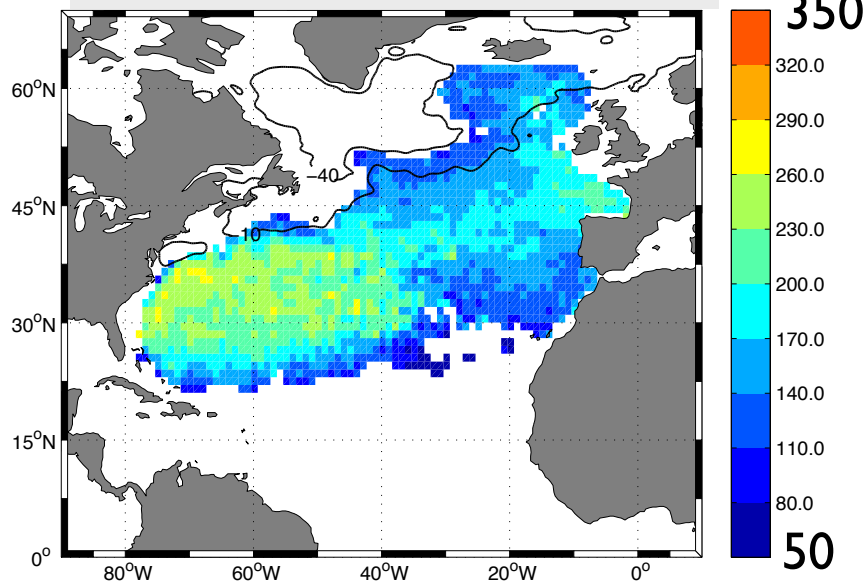
- Deep (800 m) and thick (450 m) in the core
- Shoaling (400 m) and thinning (200 m) at the boundaries
- Strong gradients across the GS and the NAC

Regional and local patterns

- West: deepest in the GS recirculation (900 m) and thickest locally in the southward (500 m)
- North-East: deepest (950 m) and thinnest (200 m) in the Iceland basin
- Deepest where there are mode waters: EDW and SPMW
- East: deep (800 m) and thick (450 m) in the Bay of Biscay
- Transition zone at 40°W: shoaling (700 m) and thinning (400 m)
- Mediterranean water: shoaling (300 m) and thinning (700 m)

Results

Pycnocline top thickness (m)



Asymmetric structure

- Top: East/West
- Bottom: North/South

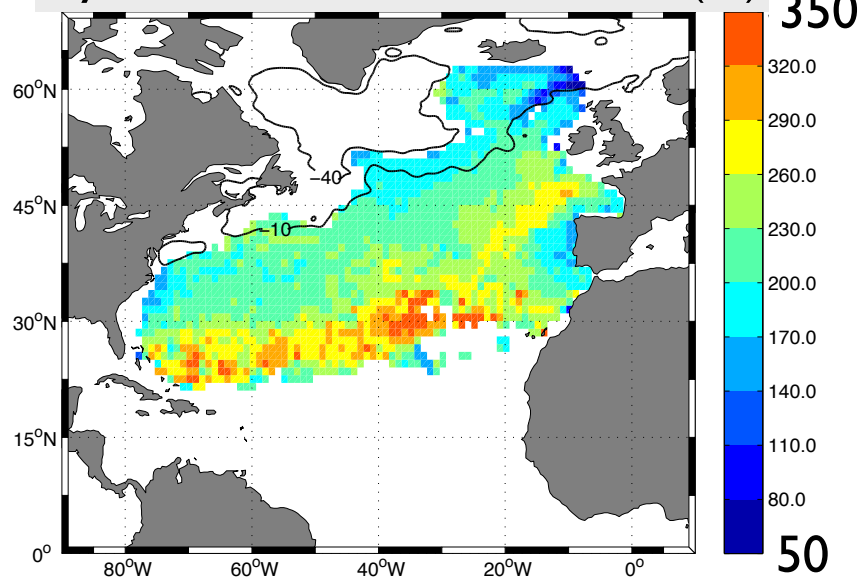
Top thickness

- West: thick (250 m)
- East: thin (170 m)
- Thinning at the boundaries
- Thinning at 40°W

Bottom thickness

- Iceland basin: thinner (250 m)
- South: thickest (270 m)
- Thinning of the bottom thickness in the Mediterranean water region

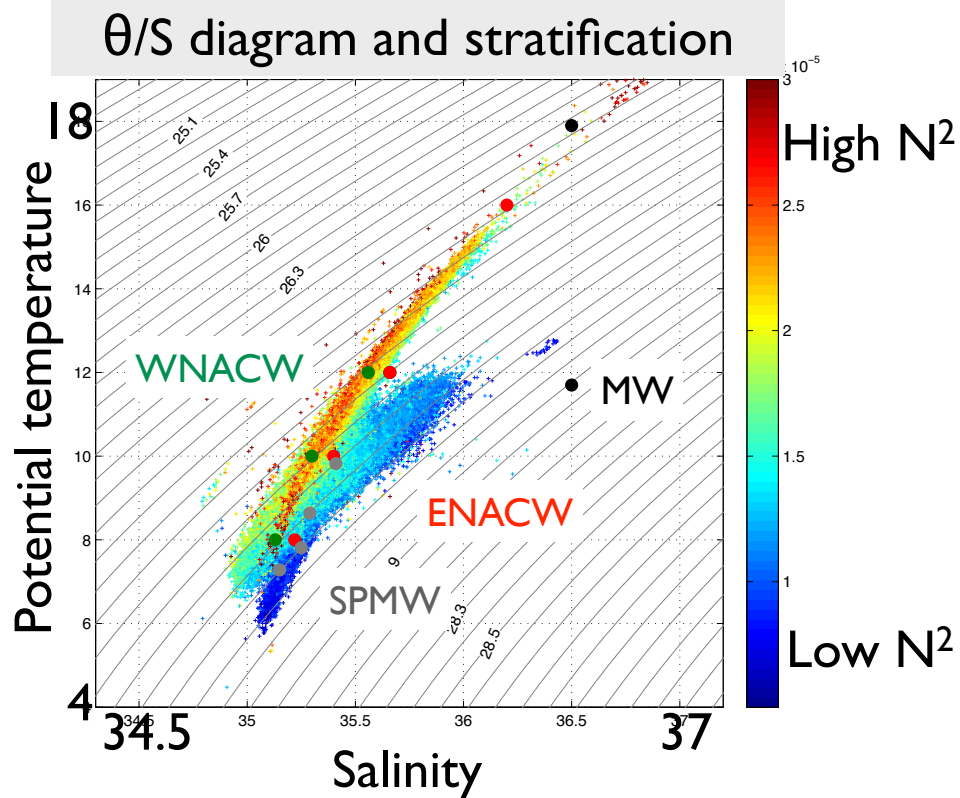
Pycnocline bottom thickness (m)



Contours: SSH mean field (2000-2012)

Results

Hydrographic properties at the depth of the permanent pycnocline



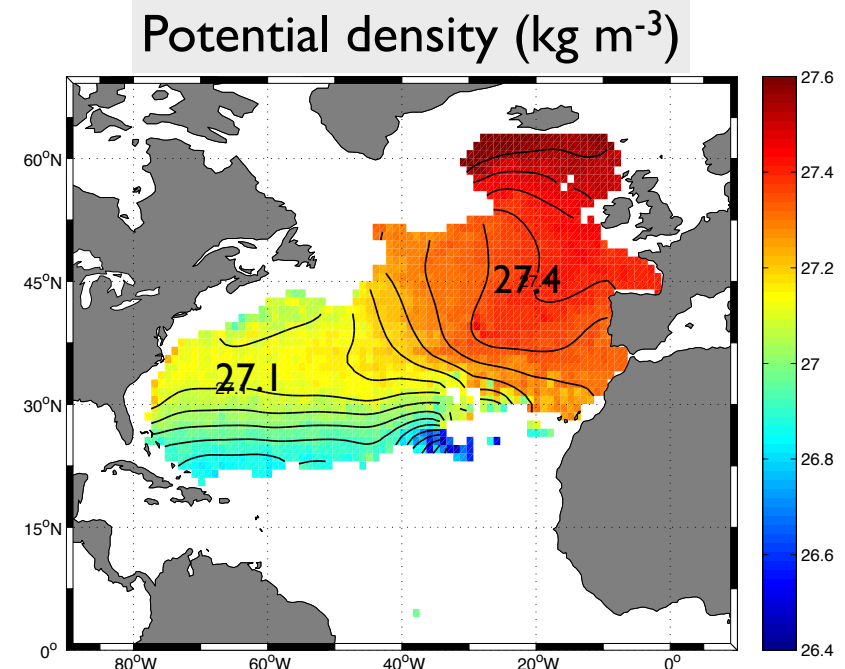
Gradients at the southern boundary of the gyre

Gradient across 40°W

Approximation by an isopycne only locally, in the Gulf Stream recirculation region and in the eastern part of the gyre

Diversity in water masses:
Central and Subpolar Mode Waters

Strongest stratification in the
West than in the East



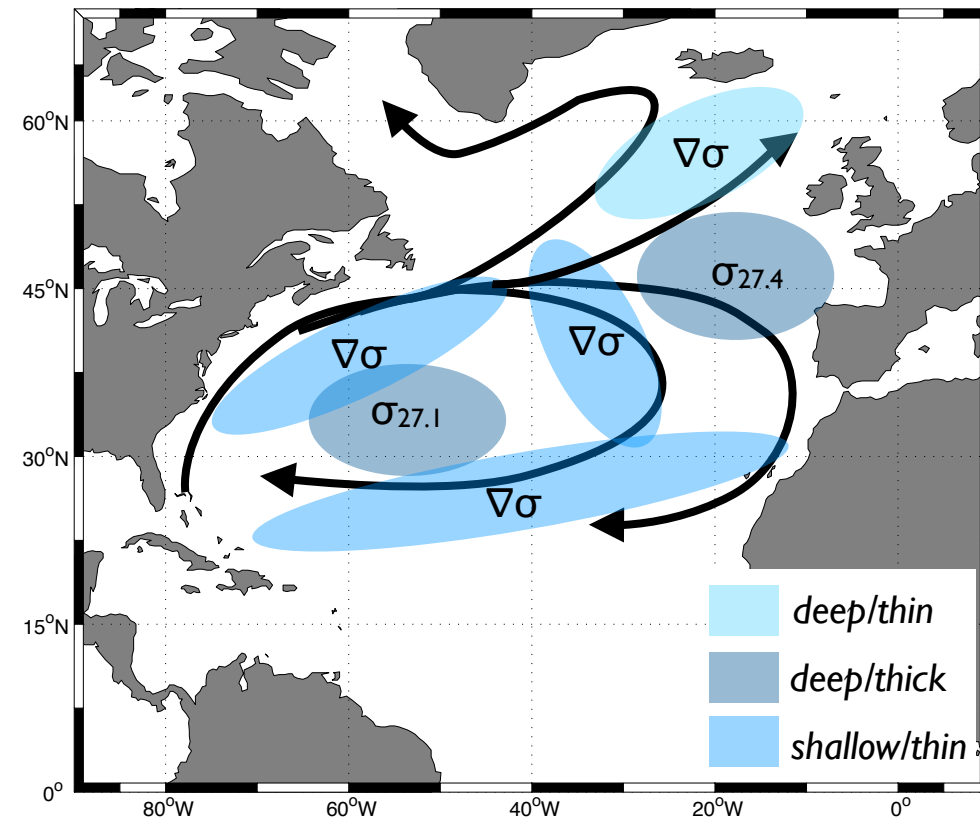
Conclusion and perspectives

- An objective algorithm to characterize the permanent pycnocline in subtropical gyre
- Application to the North Atlantic with Argo data: 77.3% of permanent characterized in the subtropical gyre among 74106 profiles
- Structure of the permanent pycnocline
- Thermohaline properties of the permanent pycnocline

Feucher et al. 2015, submitted to JAOT 2015

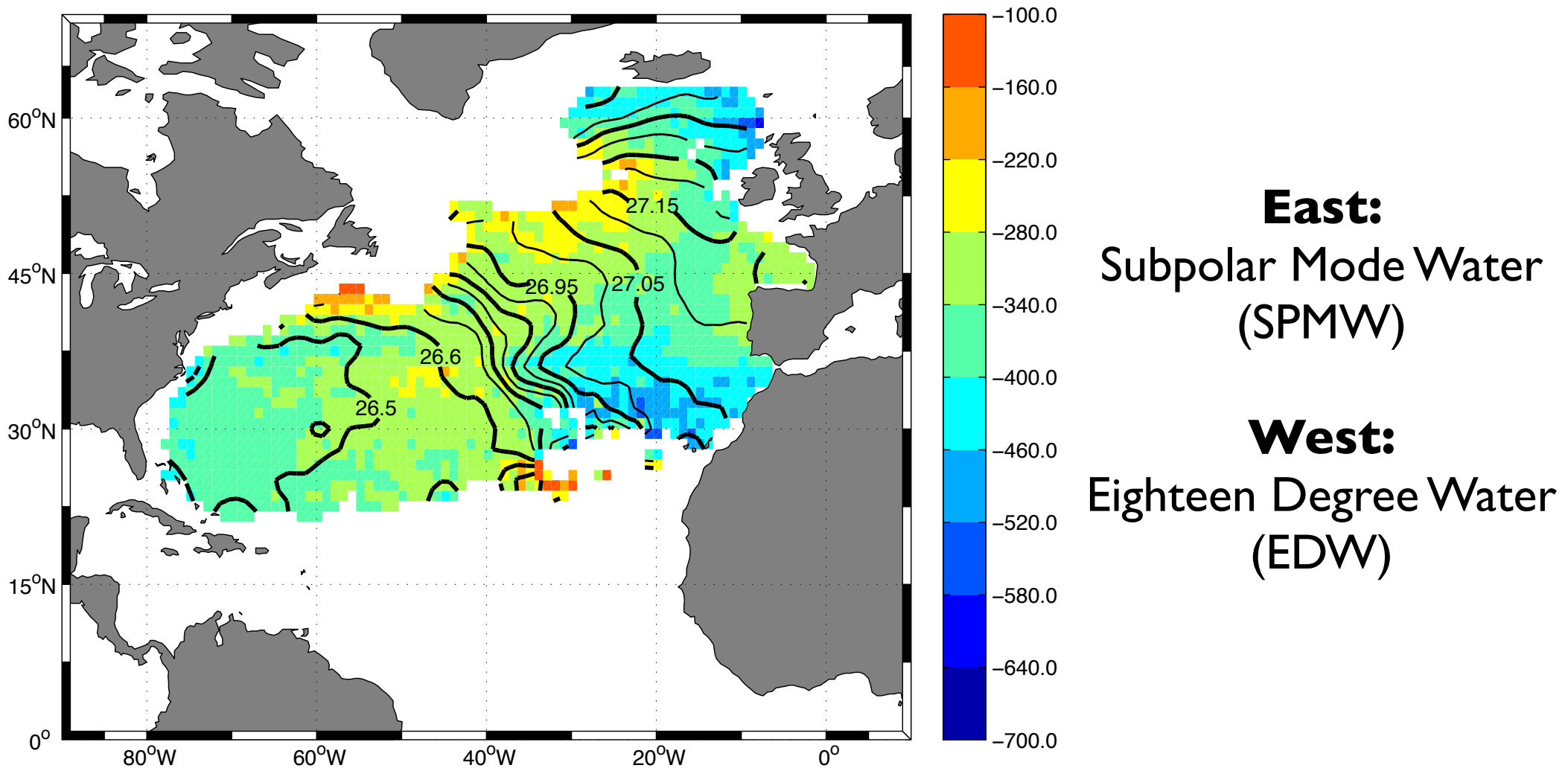
Ongoing work ...

- Interannual variability of the permanent pycnocline
- Role of the permanent pycnocline in oceanic heat storage



Mode water depth (z_{\min})

Mode water depth and contours of potential density



OAC-P performance

Application to the North Atlantic subtropical gyre with Argo data (74106 profiles)

- 77.3% of profile with a permanent pycnocline characterized
- 21.1% for which no mode water has been characterized
- 1.6% with a bad permanent pycnocline characterization

