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# A complex North Atlantic permanent pycnocline revealed by Argo data

Charlène Feucher

G. Maze & H. Mercier

Laboratoire de Physique des Océans

UMR 6523 CNRS-IFREMER-IRD-UBO



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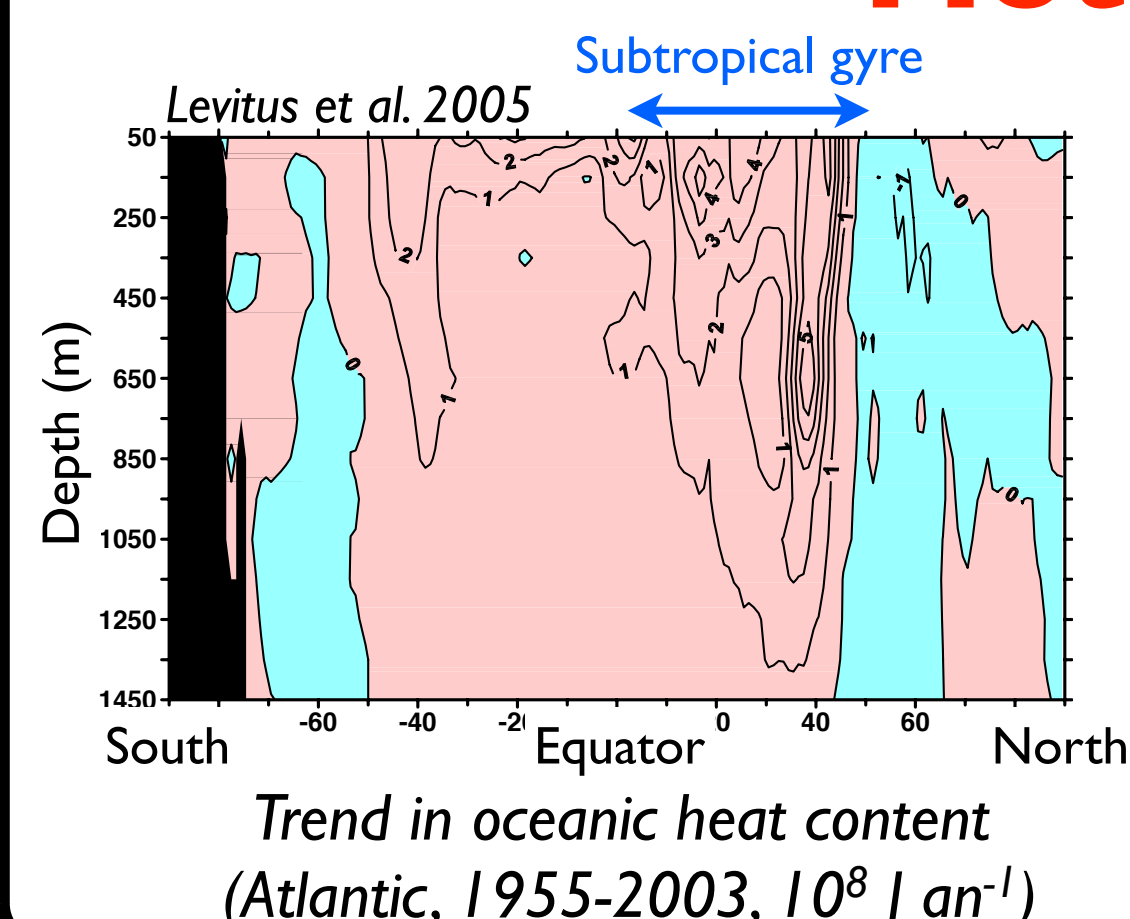


charlene.feucher@ifremer.fr

## Outline

The large scale ocean stratification is a key characteristic of the ocean that plays a role in heat uptake, nutrient supply to the euphotic layer and anthropogenic carbon. Assessing the structure and variability of the permanent pycnocline is of major interest for the understanding of the climate system. Although a key concept of the large scale ocean dynamic, the permanent pycnocline does not have a rigorous definition. Here we propose to define the permanent pycnocline as the layer trapped between two water masses ventilated at different time scales (seasonally and larger time scale) that allows for the development of an original algorithm to characterize it. The algorithm is able to characterize the permanent pycnocline from any profile, whether at low, mid or higher latitudes and along the eastern or western boundaries. A  $0.5^\circ \times 0.5^\circ$  resolution reference state of the permanent pycnocline characteristics based on the 2000-2014 period and the North Atlantic Ocean. It is the first time such a climatology is produced based on *in-situ* observations. It reveals a surprisingly complex structure of the permanent pycnocline with inhomogeneous properties.

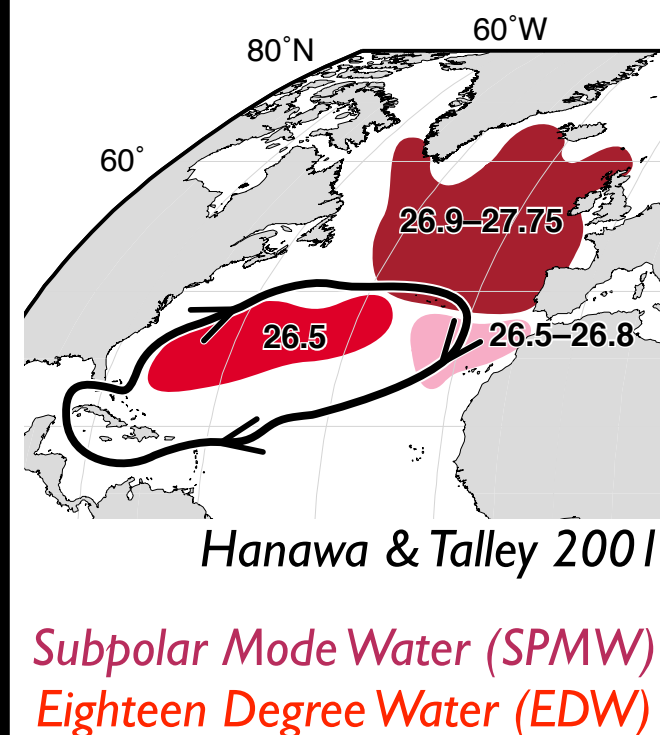
## Motivations



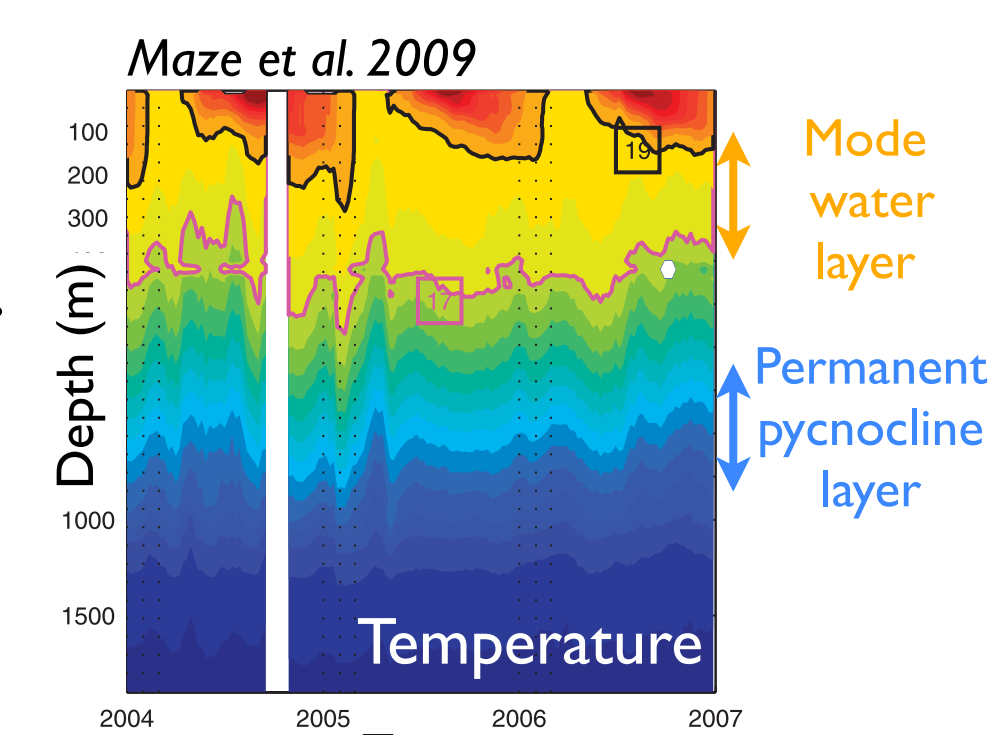
### Global warming of the ocean

It is the most intense in the North Atlantic subtropical gyre and it seems to be constrained by the structure of the permanent pycnocline.

## The pycnocline in the North Atlantic subtropical gyre



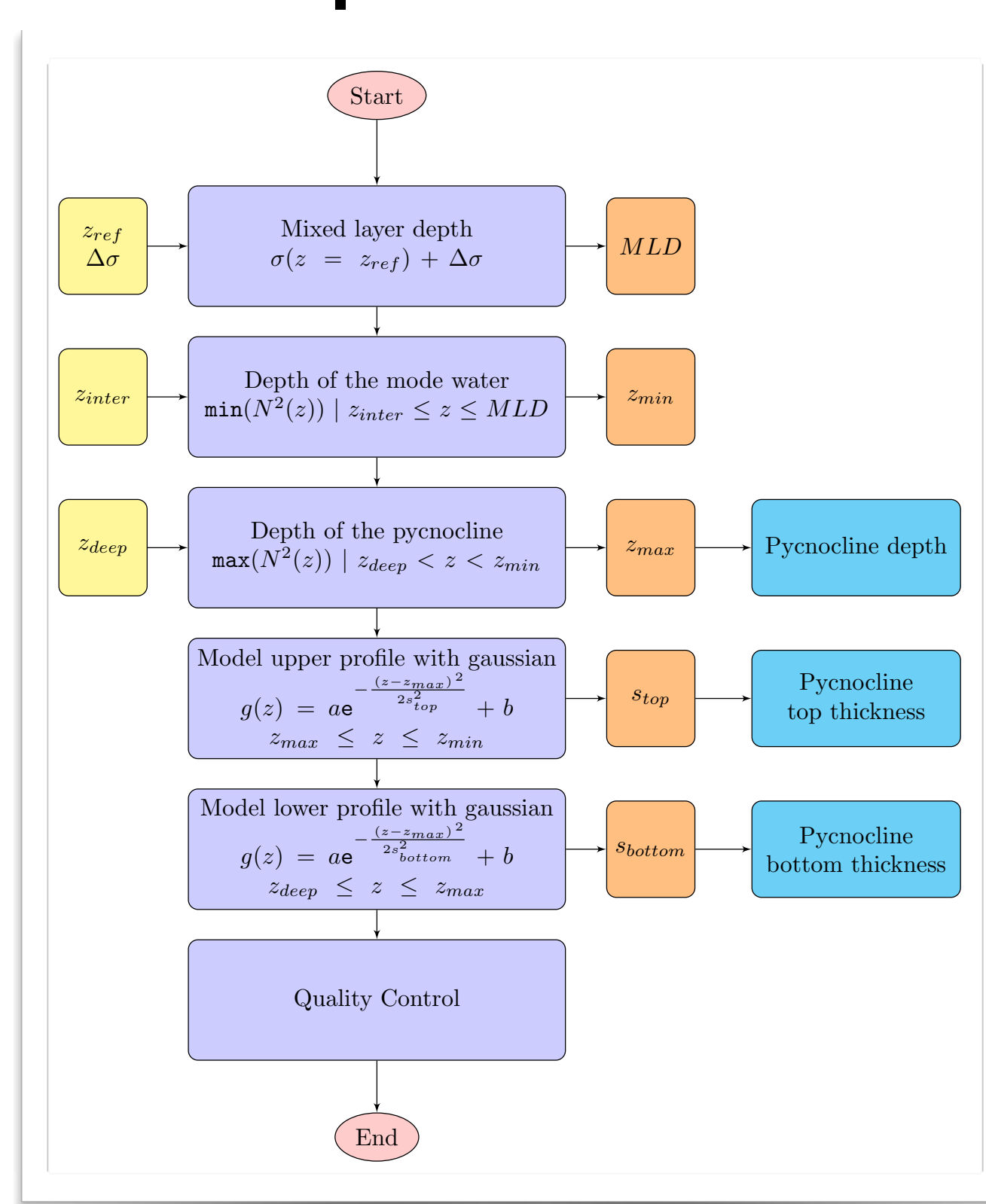
Characterized by a **strong density/temperature gradient**. Found **below a mode water** that seasonally merges with the mixed layer.



## Method to characterize the permanent pycnocline in *in-situ* profiles

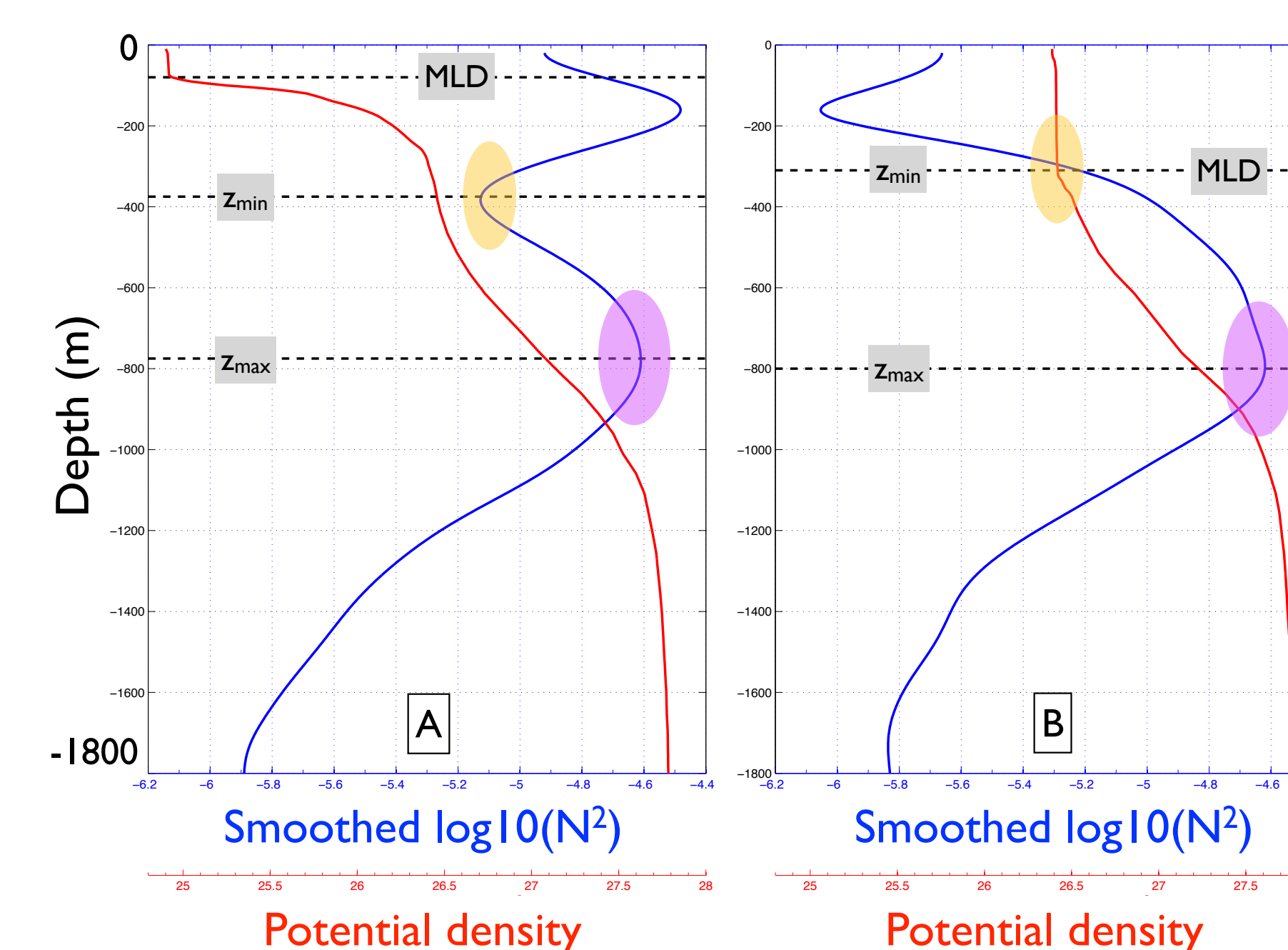
### Process

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



### Pycnocline depth

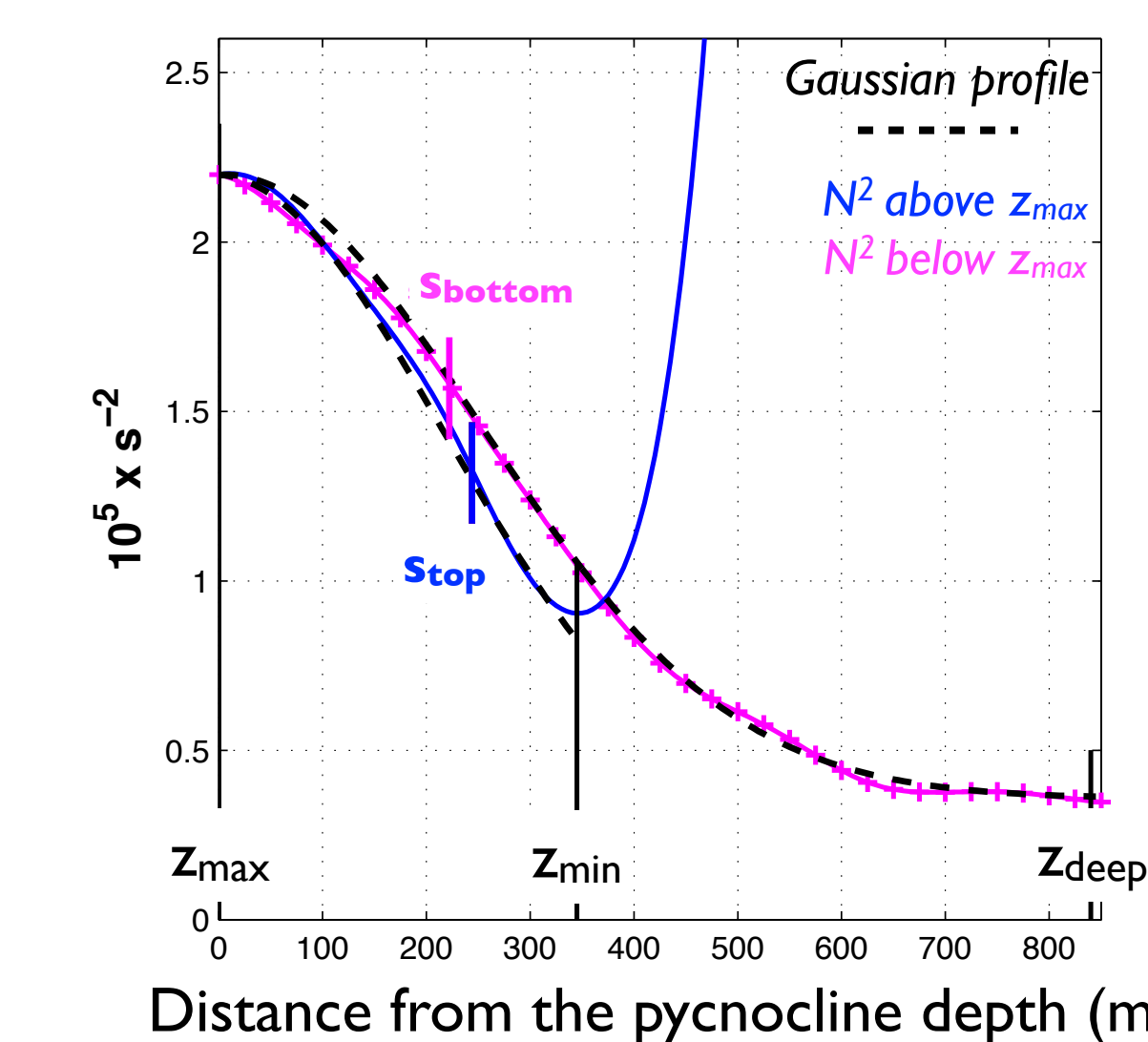
Permanent pycnocline depth (**max of  $N^2$** ) below a mode water (**min of  $N^2$**  below a mixed layer)



Typical subtropical profile in summer (A) and in winter (B) in the North Atlantic subtropical gyre

### Pycnocline thickness

Model  $N^2$  profile with **gaussians**



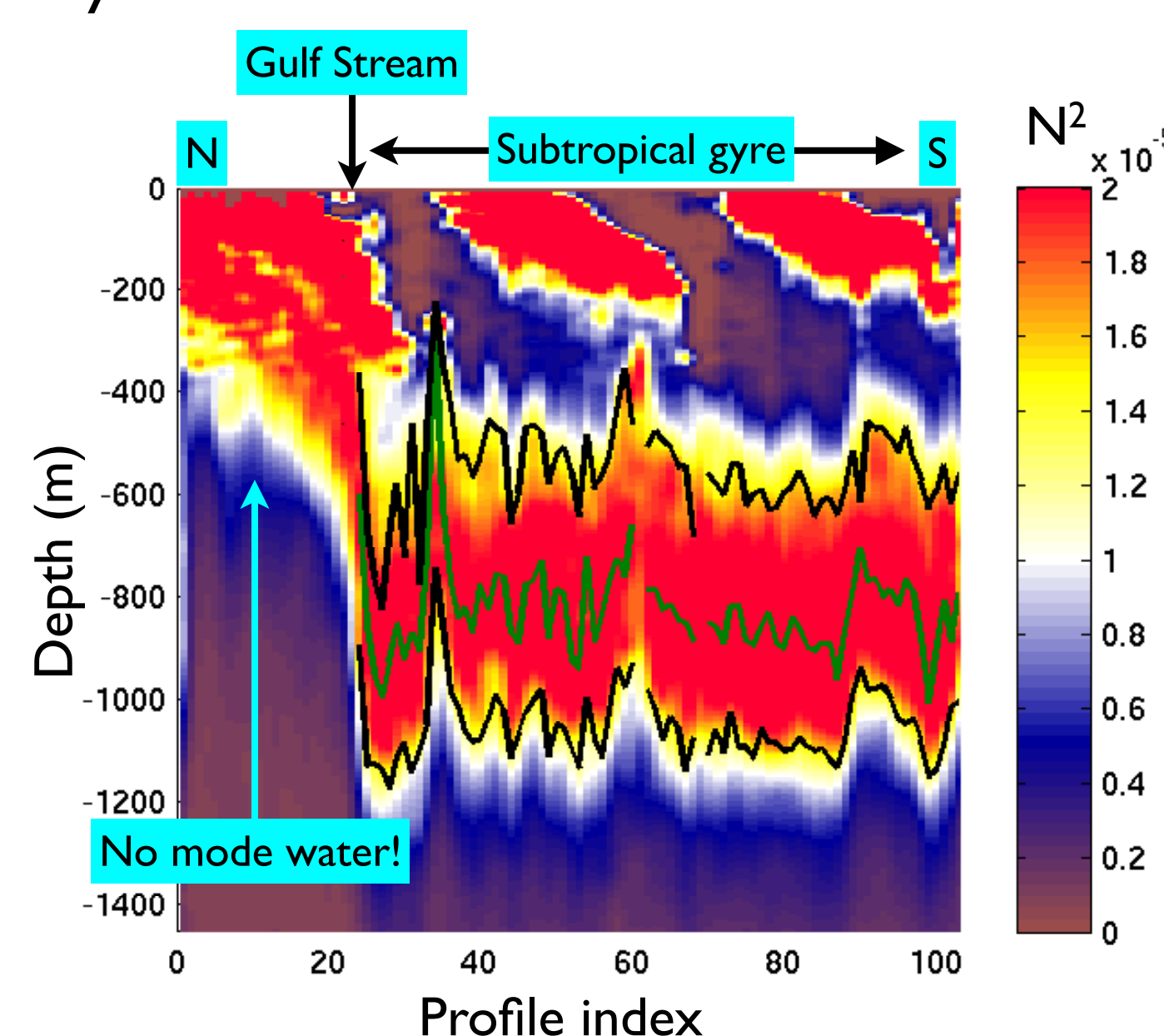
Two gaussians to characterize an **asymmetric** structure around the depth of the permanent pycnocline. The **thickness** is defined by taking the **standard deviation  $s$**  of the gaussians.

## Application to Argo profiles

### The Argo database in the North Atlantic Ocean

147,069 profiles from 1,452 floats  
Time period: May 1998 - December 2014

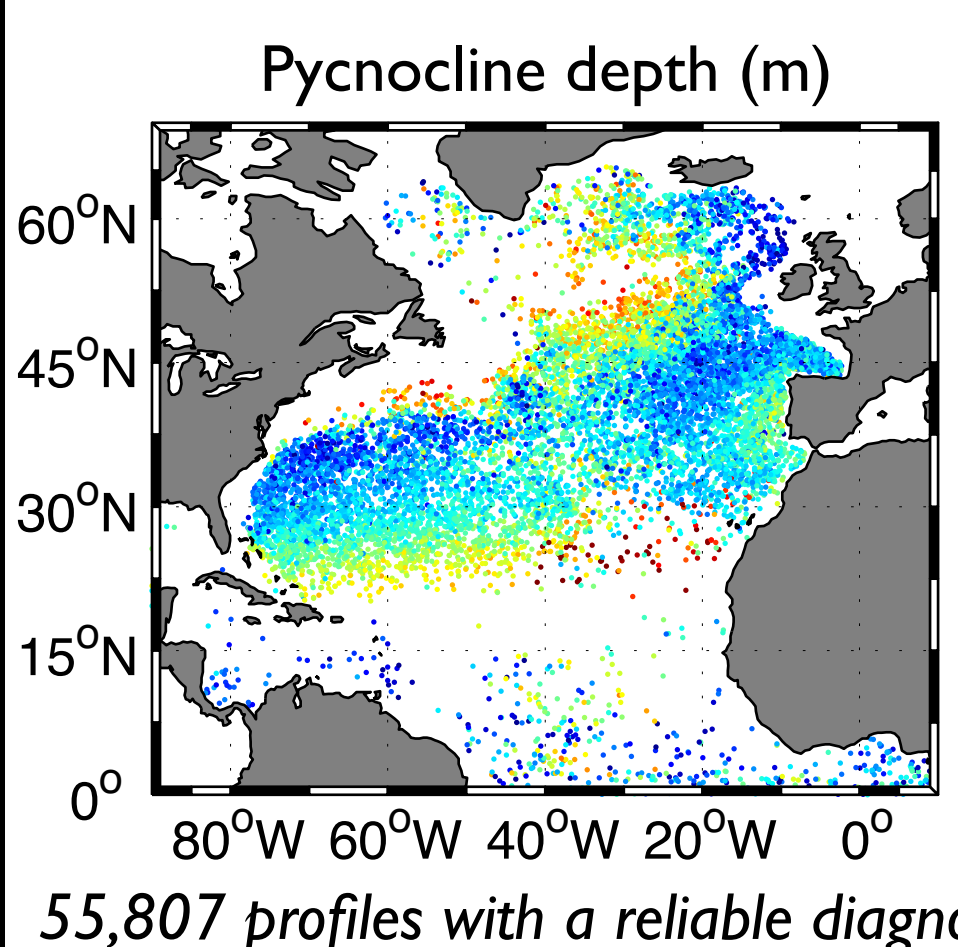
Characterization of the pycnocline layer along an Argo float trajectory



Localization in longitude and latitude of permanent pycnocline depth per profile

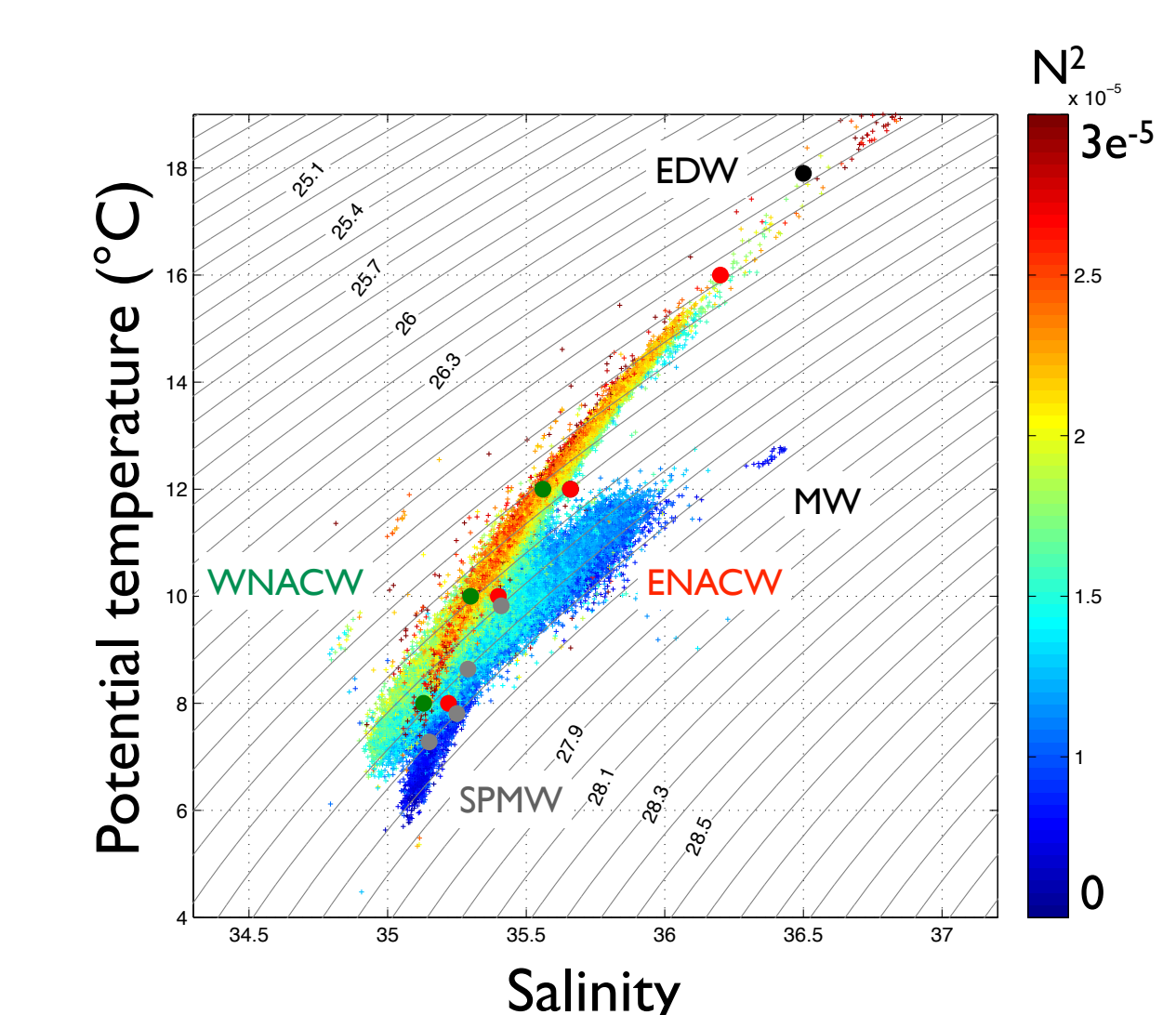
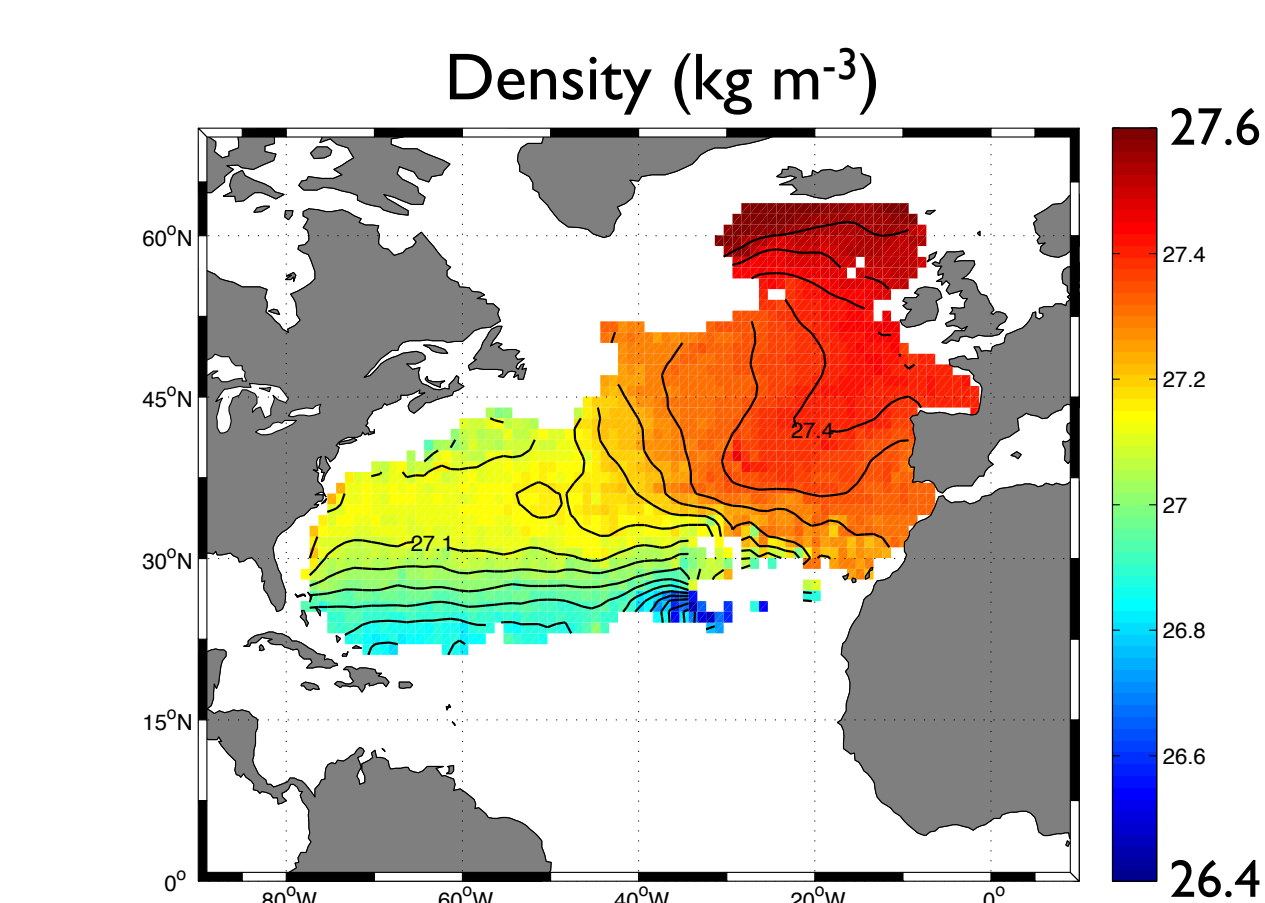
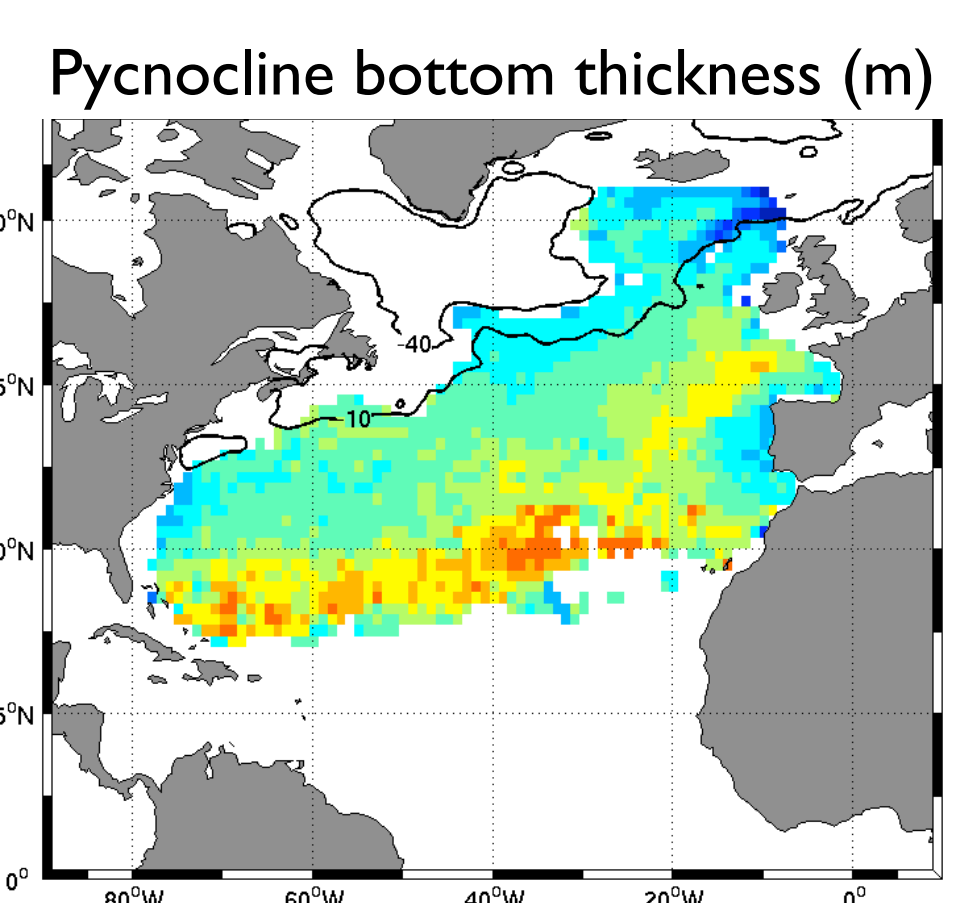
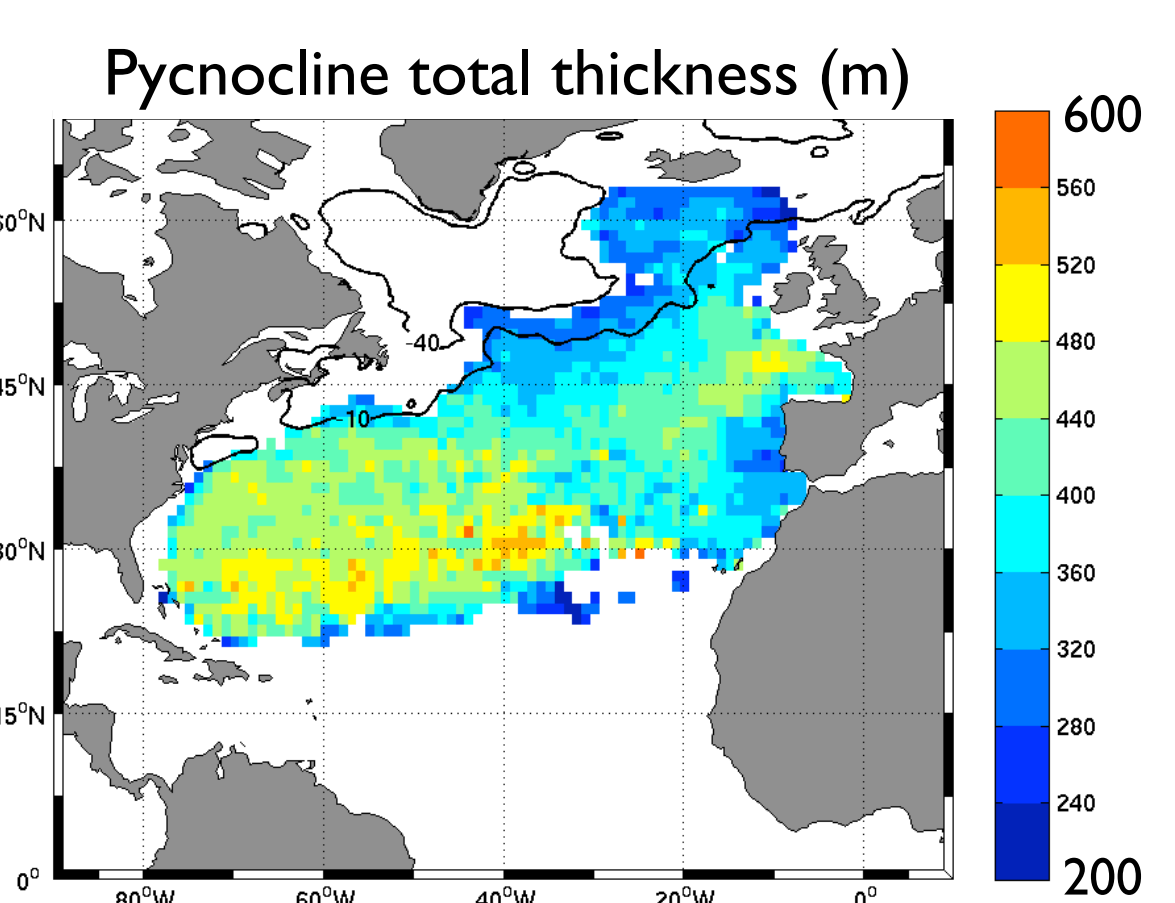
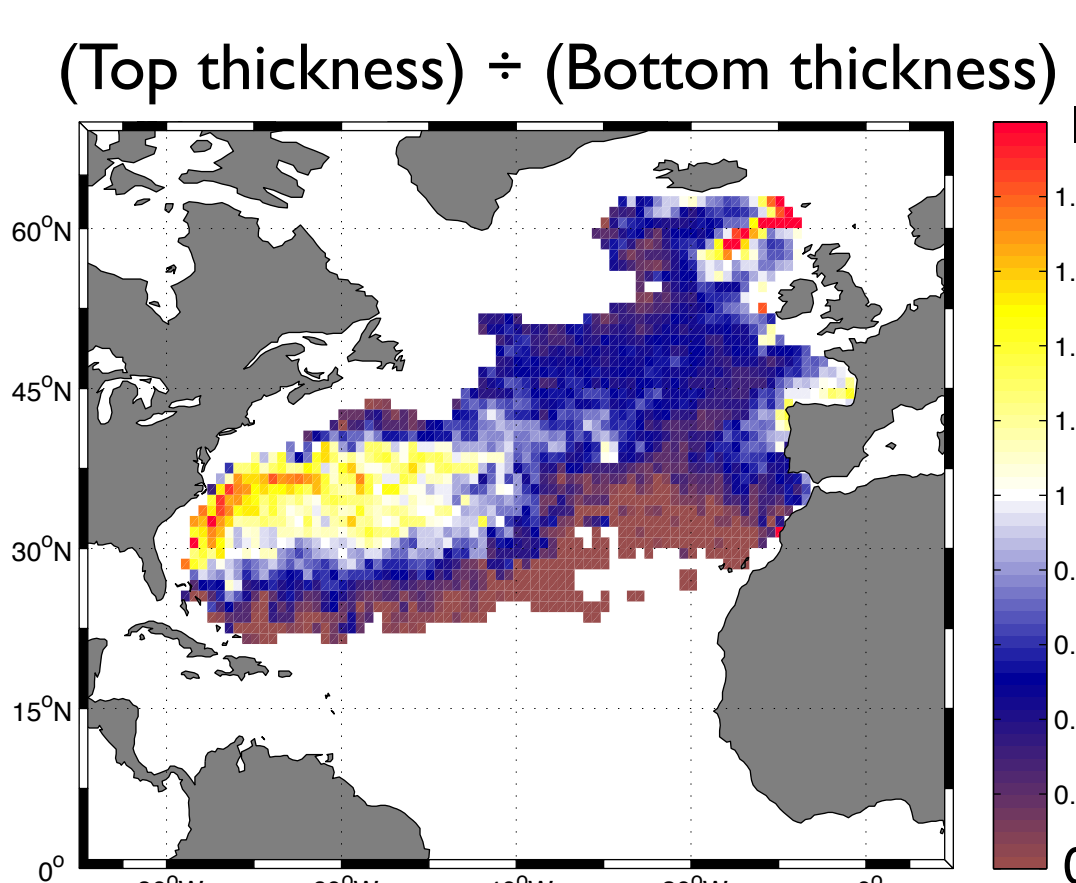
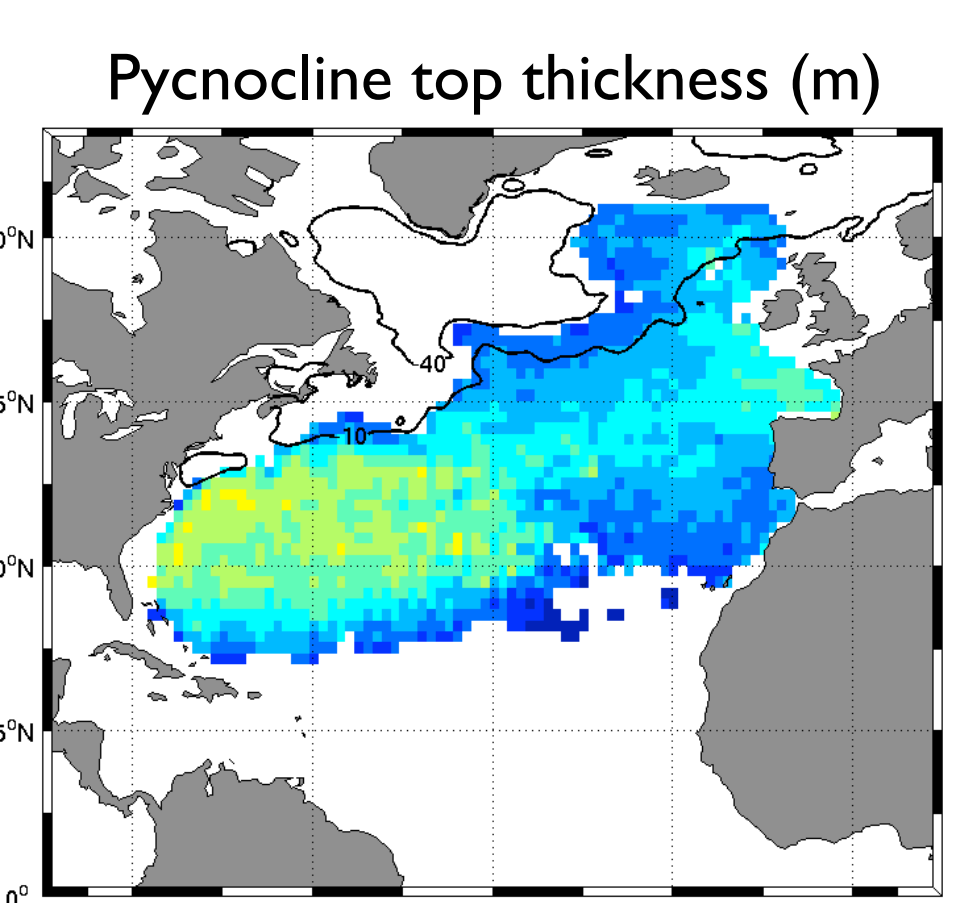
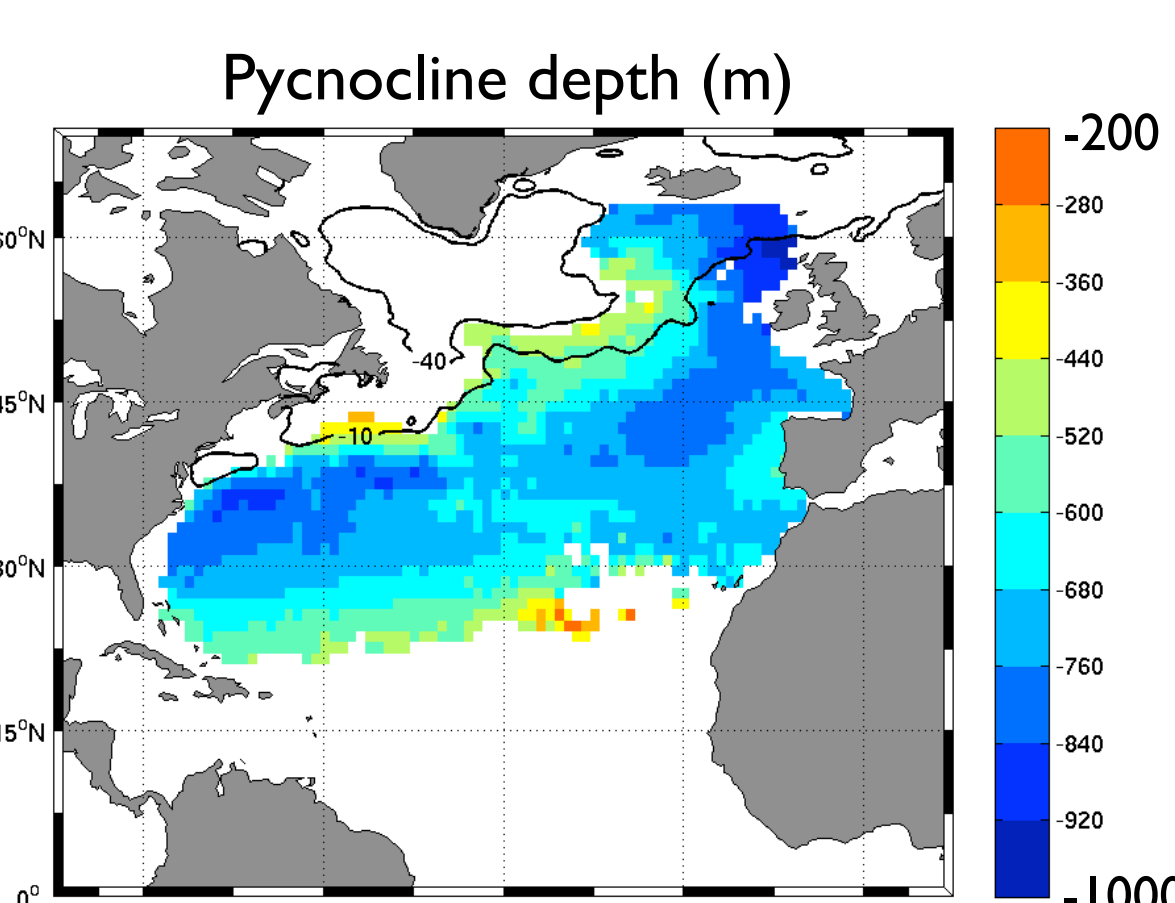
We used an **unsupervised classification** method known as **Gaussian Mixture Model** to remove profiles out of the **subtropical gyre**.

Maze et al. 2015



55,807 profiles with a reliable diagnostic

## Results: permanent pycnocline mean state estimate



### Depth and total thickness

The large scale pattern of the permanent pycnocline reveals the classical **bowl structure**. There are specific structures at **local** and **regional** scales: in the Gulf Stream recirculation region, in the Iceland basin, in the Mediterranean water region and in the bay of Biscay. There is a **transition zone** at about  $40^\circ\text{W}$  with thinning and shoaling of the pycnocline.

### Upper and lower thicknesses

The permanent pycnocline has an **asymmetric structure** around its depth. The upper part is thicker in the western part of the gyre than in the eastern part. The bottom part is thicker at the southern boundary of the gyre and in the bay of Biscay.

### Thermohaline properties

**Central** and **Subpolar Mode Water** are found at the depth of the permanent pycnocline. There are **gradients** in potential density (at southern boundary of the gyre, around  $40^\circ\text{W}$  and in the northeast corner of the gyre). The permanent pycnocline can be approximated by an **isopycne** only on **small areas**. The stratification is stronger in the West than in the East of the gyre.

Feucher et al. 2015, submitted to Journal of Atmospheric and Oceanic Technology