Mesoscale eddies in the North Atlantic subtropical gyre: 3D composite structure from satellite altimetry and Argo profile data.

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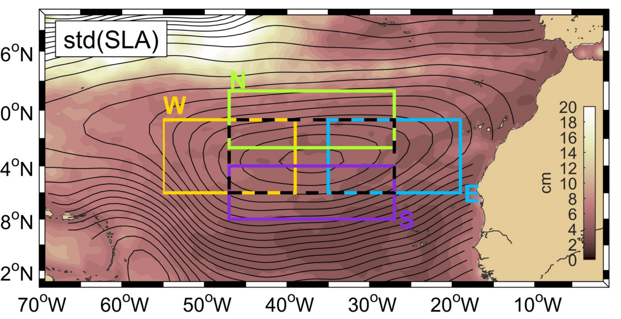
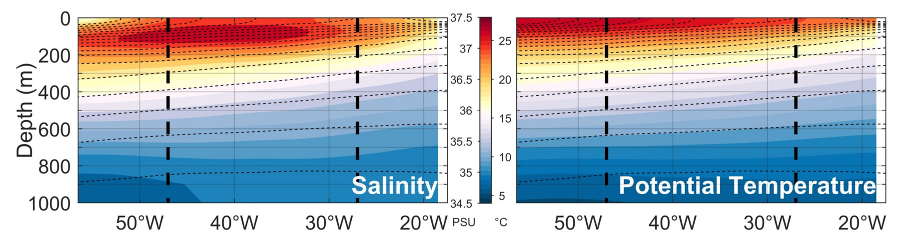
Motivation



Why eddies in the North Atlantic subtropical gyre (NASG)?

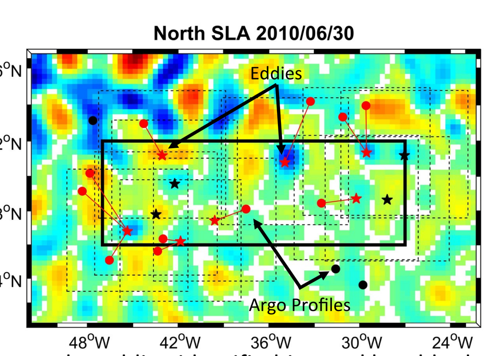
- NASG is an area with low eddy kinetic energy → Weak eddies? → Do they matter for salinity/heat fluxes?
- This area has a Sea Surface Salinity (SSS) maximum → How do eddies contribute to maintaining this quasi-steady-state? What is their relative contribution compared with the excess of evaporation (E) over precipitation (P) in this area?



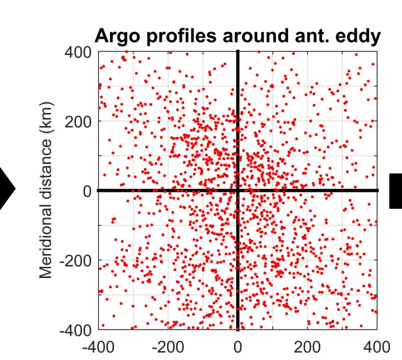
- 4 different areas were defined to take into account the different dynamical properties at each side of the SSS maximum.
- The tilted isopycnals provides the potential energy necessary to generate eddies through baroclinic instability.

Methodology

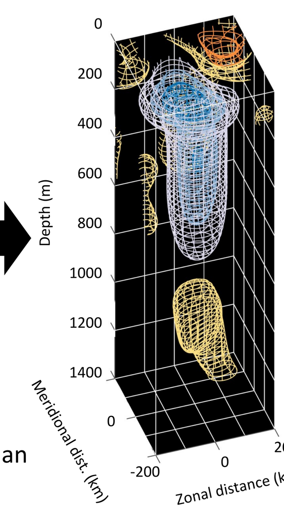
Computing eddy composites



We use the eddies identified in weekly eddy database of Chelton[1] et al. (2011) computed from satellite Sea Level Anomaly and place around them the Argo profile anomalies that took place the same week.



The Argo profile anomalies are placed around an eddy center centered axes.



Observations of salinity, potential temperature and potential density at each individual depth are fitted into 2D Fourier series to get the composite structure characteristic of this region.

A box model for the upper ocean in the subtropical North Atlantic

The equation for the averaged salinity trend inside a defined volume, splitting into mean value and fluctuations, is given by

$$\frac{1}{V}\int_V \frac{\partial \overline{S}}{\partial t}\,dV = -\frac{1}{V}\int_A \overline{S}\,\overline{\mathbf{u}}\cdot d\mathbf{A} - \boxed{\frac{1}{V}\sum_{i=1}^{4}\int_{A_i}\overline{S'\mathbf{u}_\mathbf{h}'}\cdot d\mathbf{A}_{h_i}} + \frac{1}{V}\int_{A_b}\overline{S'\,w'}\,dA_b + \boxed{\frac{1}{V\,H}\int_{A_s}(E-P)\left[\int_{-H}^{0}\overline{S}\,dz\right]dA_s}$$

Averaged eddy salinity trend — Averaged E-P salinity trend

Two ways of computing the eddy fluxes through the lateral boundaries:

1. Counting eddies in the eddy dataset and place the 3D eddy fluxes at each eddy center.
2. Assuming that eddies are densely packed → there is a succession of eddies with different polarities. Count the number of eddies that fit into the length of the boundary.

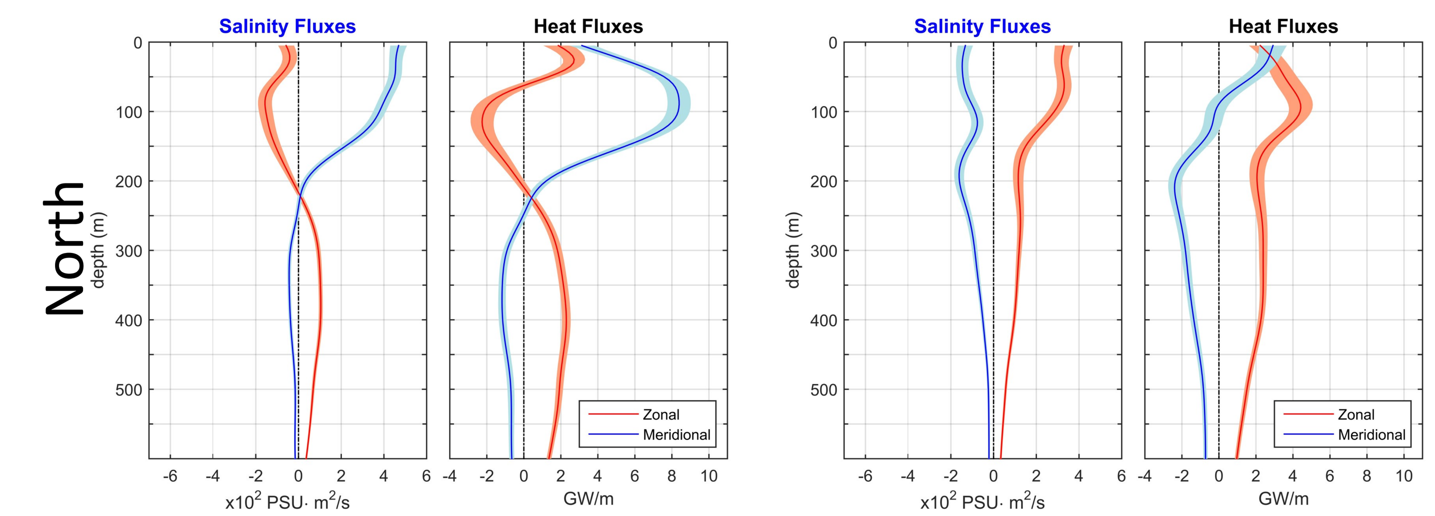
[1]Chelton, D. B., M. G. Schlax, and R. M. Samelson (2011), Global observations of nonlinear mesoscale eddies, Progress in Oceanography, 91 (2), 167-216, doi: 10.1016/j.pocean.2011.01.002.

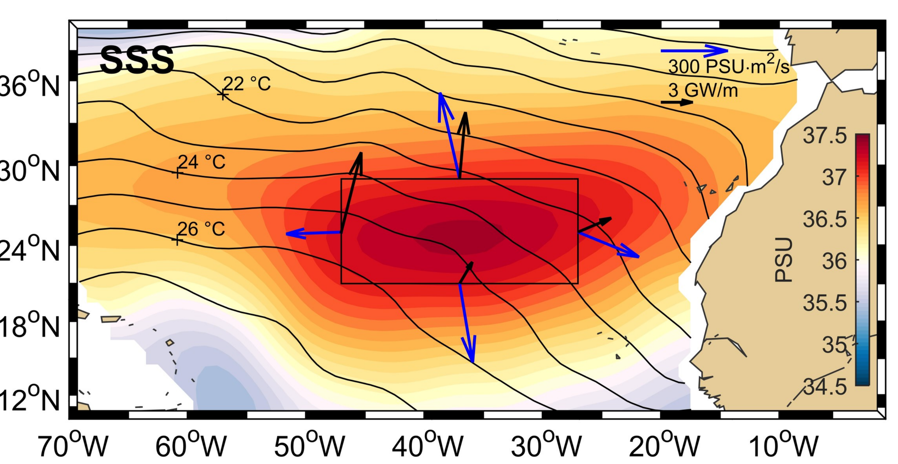
Eddy Composite Fluxes

The fluxes were computed as

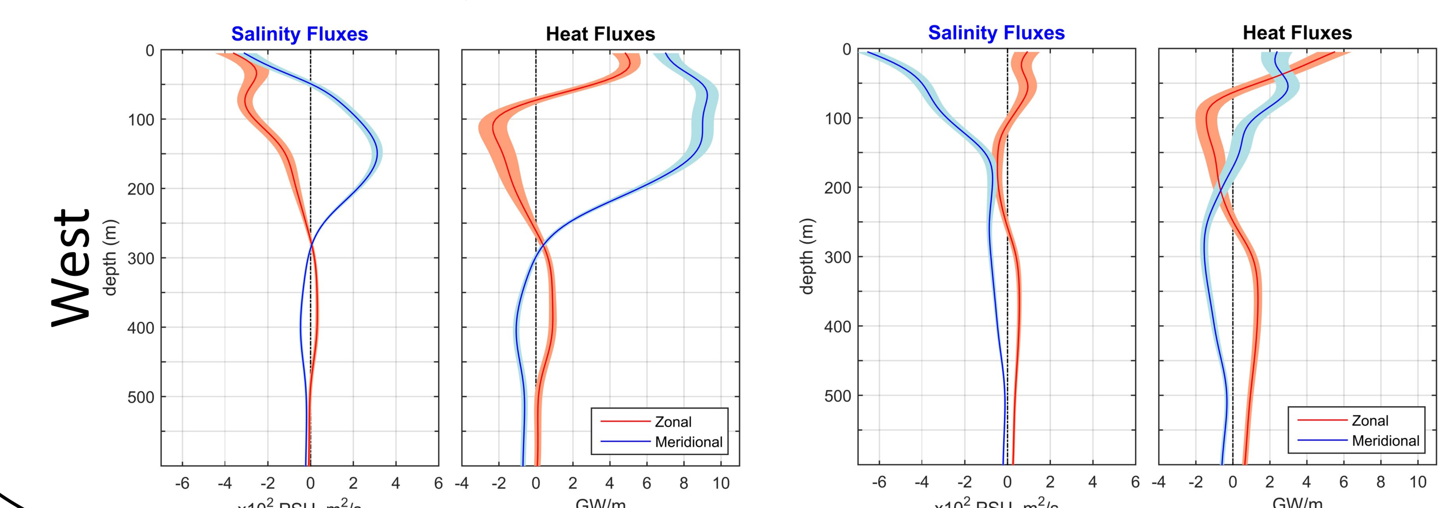
$$Flux_{zonal}(z) = A(z)\cdot\int_{-L}^{L} u'(x=0,y,z)\cdot f'(x=0,y,z)\,dy$$
$$Flux_{meridional}(z) = A(z)\cdot\int_{-L}^{L} v'(x,y=0,z)\cdot f'(x,y=0,z)\,dx$$

where f' can be $\begin{cases} S' \text{ with } A(z)=1 \\ \theta' \text{ with } A(z)=C_p\cdot\rho_0(z)\end{cases}$

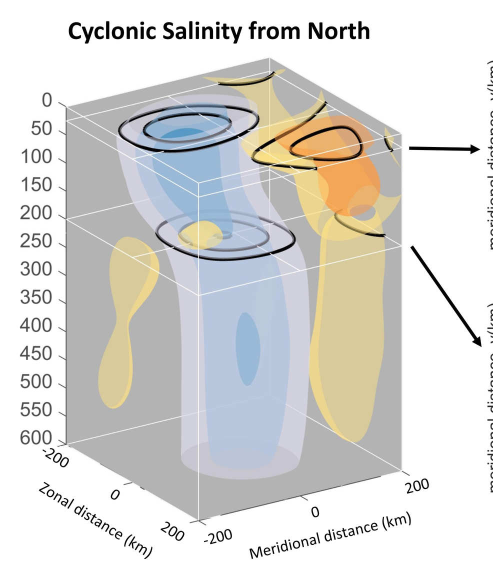


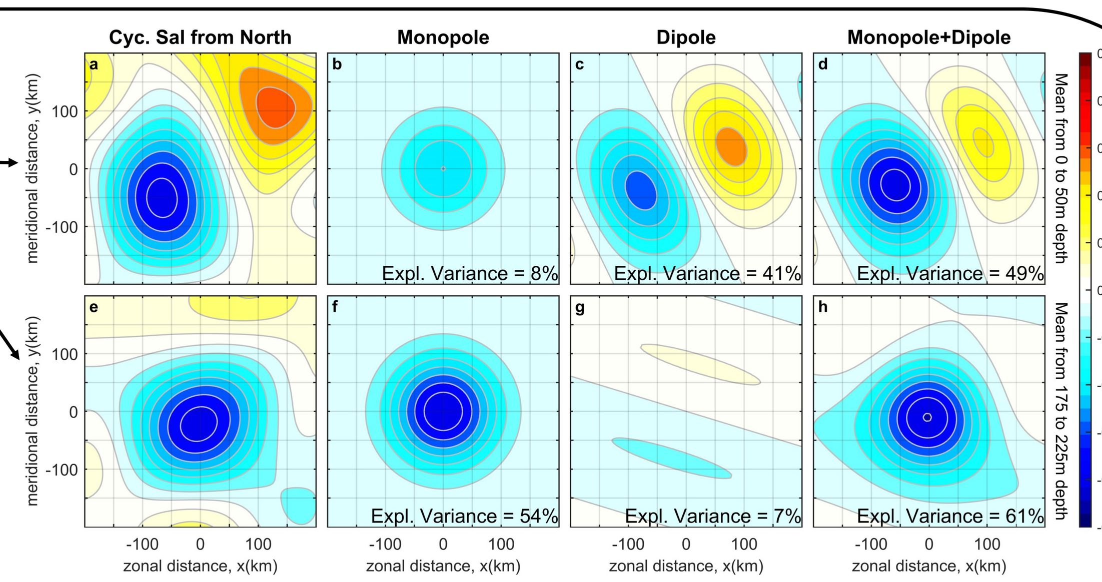


- The phase shifts observed between the salinity/temperature anomalies and velocity anomalies led to transient fluxes → more intense above the thermocline.
- The magnitude is decreasing with depth due to: the reduction of salinity/temperature anomalies, reduction of velocity anomalies and the progressive alignment between them increasing depth.
- The role of the eddies is to remove salinity from the SSS maximum and transport heat northwards.
- The fluxes are following the background gradients, from higher to lower values. They try to homogenize the properties.
- The intensity of the N/S salinity fluxes are comparable to the W/E fluxes.



Horizontal Structure





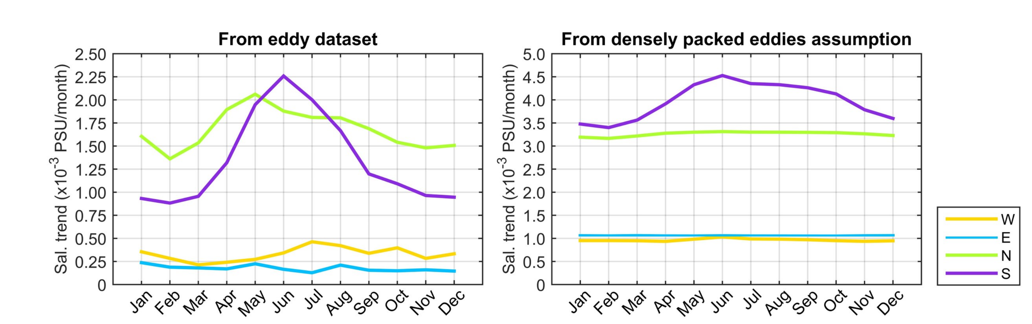
- The horizontal structure in the shallower layers is driven by the salinity and temperature advection caused by the rotational velocity of the eddy.
- This advection is translated into a dipole structure which appears when the eddy currents advect the background gradient around the eddy center.
- The horizontal and vertical structures are explained with two mechanisms: the sinking/lifting (monopole pattern) and the horizontal advection of water (dipole pattern). The relative contribution of each one is analyzed by fitting

$$f(x,y) = \underbrace{monopole(x,y)}_{A_m\cdot e^{-a_m\cdot(x^2+y^2)}} + \underbrace{dipole(x,y)}_{A_d\cdot e^{-(a_{d_x}\cdot x_r^2+a_{d_y}\cdot y_r^2)}\cdot sin\left(\frac{\pi}{T}\cdot x_r\right)}$$

$$x_r(x,y) = x\cdot cos(\alpha) - y\cdot sin(\alpha)$$
$$y_r(x,y) = x\cdot sin(\alpha) + y\cdot cos(\alpha)$$

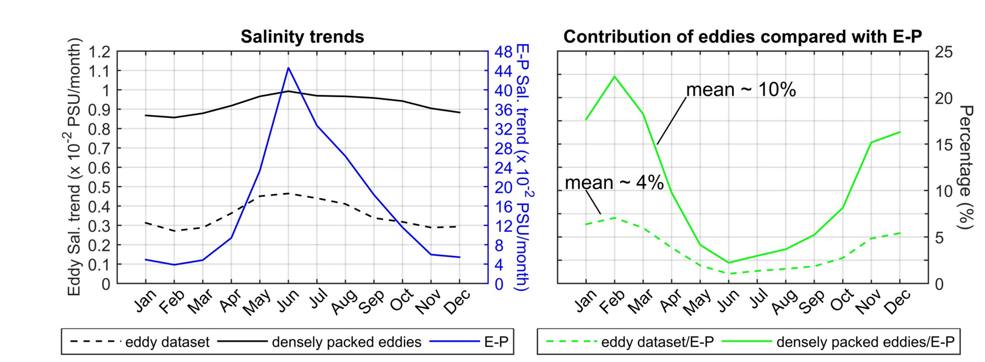
- In the shallower layers, the dipole completely dominates the horizontal structure of the eddy composite.
- Just below the thermocline, the monopole explains the largest part of the variance.
- This result shows that above the thermocline, the horizontal advection is the most important process, and below it, the sinking/lifting dominates.

Box Model

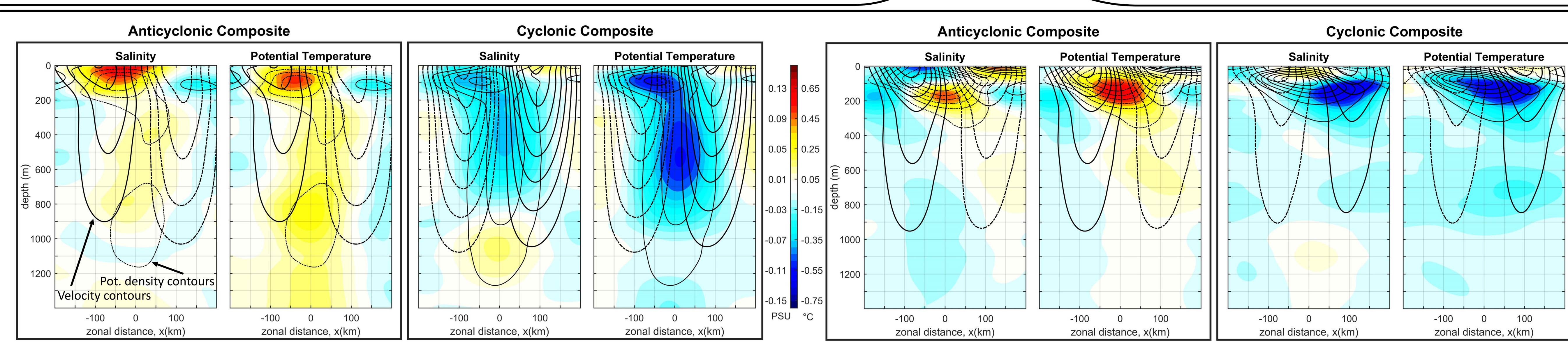


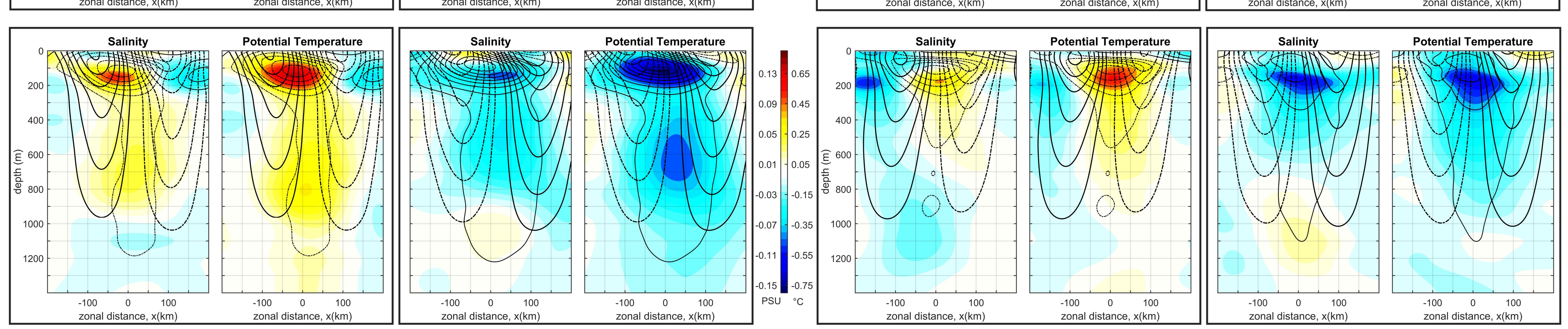
- The eddy salinity trend values from eddy data set are half of the values from densely packed eddies assumption:
  - ⇒ The first one underestimates the number of eddies.
  - ⇒ The second one overestimates the number of eddies, their amplitude and their fluxes.
- Both methods show two groups: N/S and E/W → This only reflects the different size of the boundaries.
- The southern region present a maximum in summer:
  - ⇒ From eddy dataset → larger amplitudes and shallower mixed layer depth in this season.
  - ⇒ From densely packed eddies → shallower mixed layer depth in summer.

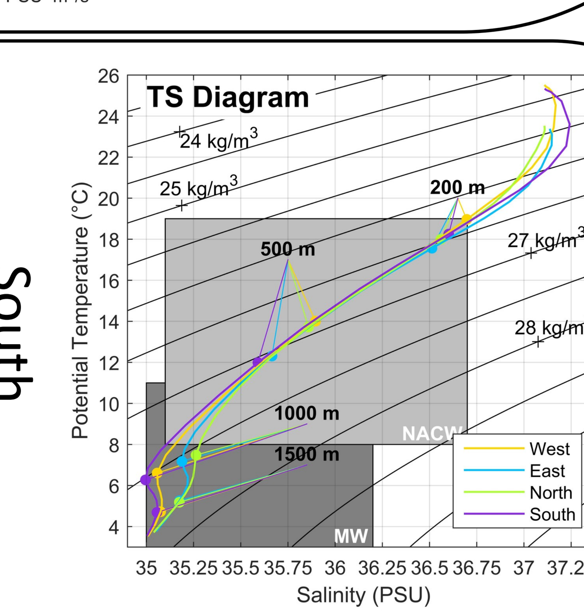
- The total eddy salinity trend estimated from the densely packed eddies assumption (considered the upper boundary; dashed black line) was between 2 and 3 times larger that the eddy salinity trend estimated from the real position of the eddies (the lower boundary; solid black line).
- Both present a maximum in summer due to the contribution of the southern boundary.
- The scale for the eddy salinity trend is 40 times smaller than the scale for the E-P salinity trend.
- The E-P curve was heavily influenced by the MLD → Its maximum coincides with the MLD minimum (~25 m) and vice versa (~95 m).
- The relative contibution:
  - ⇒ Highly influenced by the MLD. Minimum in June; maximum in February.
  - ⇒ Eddies could balance between 4% and 10% of the E-P.



Eddy Composites







- The vertical structure is explained through the TS diagram and taking into account that an anticyclonic (cyclonic) eddy generates downwards (upwards) water movements.
- The positive (negative) salinity anomaly observed around 1000 m depth in the cyclonic (anticyclonic) composites reflects the presence of Mediterranean waters.
- In longitude (from negative to positive zonal distance), the anomaly near the center is surrounded by anomalies of the opposite sign → densely packed eddies.
- Potential density anomalies are mainly driven by potential temperature

Conclusions

- Eddy composites, their salinity and heat fluxes, and their contributions to the salinity maximum in the North Atlantic subtropical gyre were computed directly from observations.
- It has been shown that eddies in this area, despite their low signal in satellite sea level anomaly maps, reach depths deeper than 1000 m .
- Their vertical structure can be understood through the TS diagram for each region. Their horizontal structure changes with depth, from a dipole in the shallower layers (major horizontal advection) to a monopole below the thermocline (major water lifting/shrinking).
- The shifts observed between salinity/temperature and the velocity field result in transient fluxes, that are more important in the upper layers.
- The zonal fluxes have similar magnitude than the meridional fluxes.
- It has been shown that eddies could compensate between 4 to 10% of the excess of evaporation over precipitation in this area. This computation is highly influenced by the mixed layer variability. If the MLD is fixed to 50m (annual mean), this variability disappears but the mean contribution only increases to 6 and 15%, respectively.

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