Observational and numerical evidence for ocean frontogenesis inducing submesoscale processes and impacting biochemistry

Simón Ruiz[1], Mariona Claret[2], Ananda Pascual[1], Antonio Olita[3], Amala Mahadevan[4], Antonio Tovar[1], Charles Troupin[5], Arthur Capet[6], Joaquín Tintoré[1,5]

[1]IMEDEA (CSIC-UIB), Esporles, Spain – [2]McGill University, Canada – [3]CNR, Oristano, Italy – [4]WHOI, Woods Hole, USA, - [5]SOCIB, Palma de Mallorca, Spain - [6]OGS, Trieste, Italy

contact: simon.ruiz@imedea.uib-csic.es

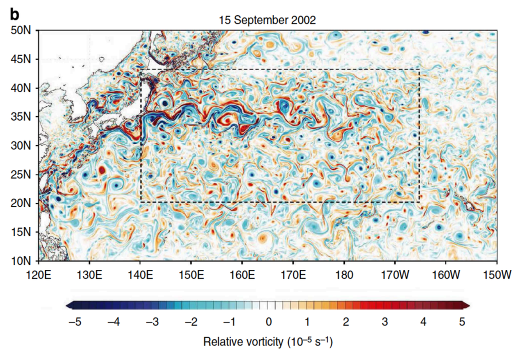
PO24B-2929

Abstract ID: 88794

1. Motivation and field experiment

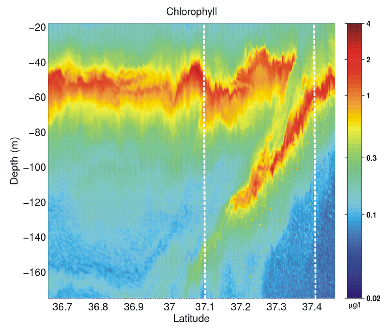
Scientific motivation: Capture the intense but transient vertical exchanges associated with mesoscale and submesoscale features, in order to fill gaps in our knowledge connecting physical process to ecosystem response.

Numerical simulations



Surface relative vorticity in the Northwestern Pacific, 15 September 2002 (Sasaki et al., 2014)

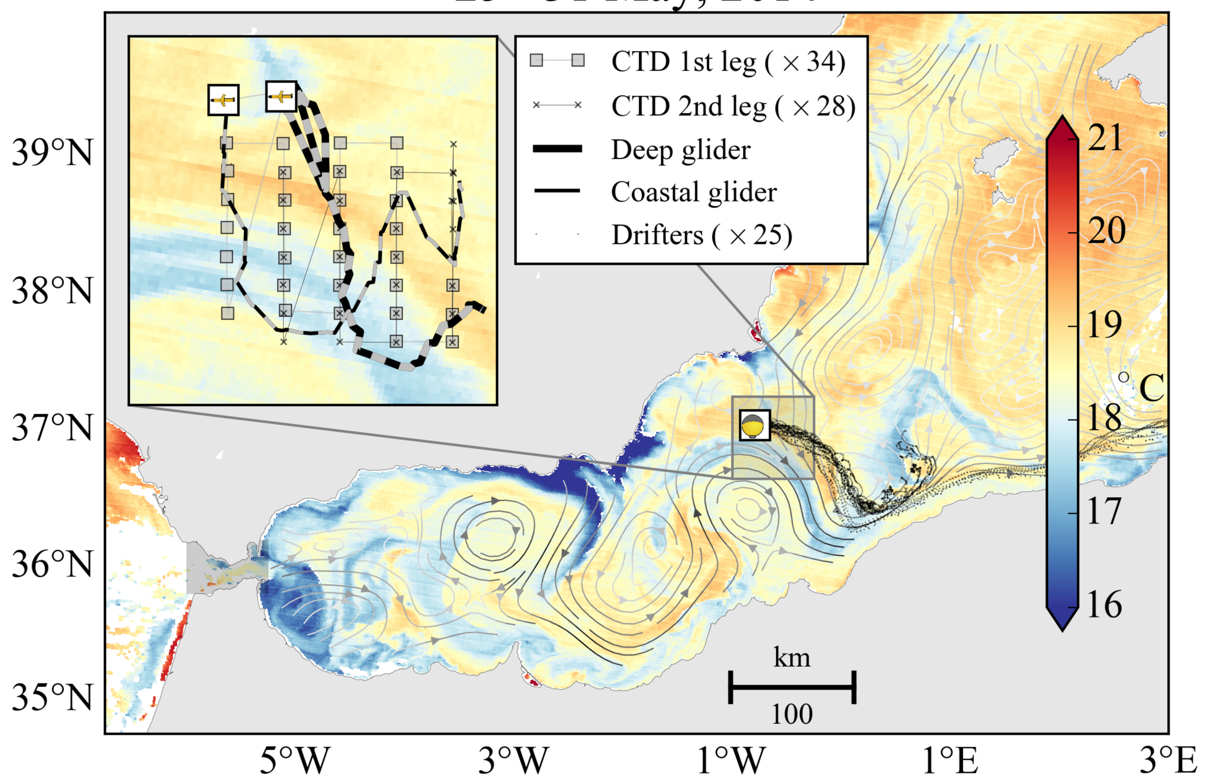
In-situ observations



Vertical section of chlorophyll from glider data (Ruiz et al. 2009)

Need for high-resolution observations (both in situ and satellite) and multi-sensor approaches in synergy with numerical simulations

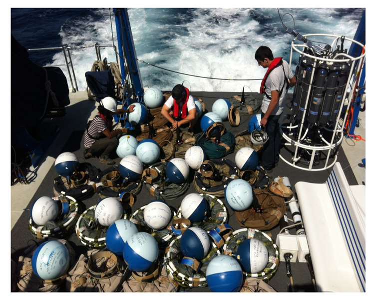
25–31 May, 2014



ALBOREX EXPERIMENT- OBJECTIVE

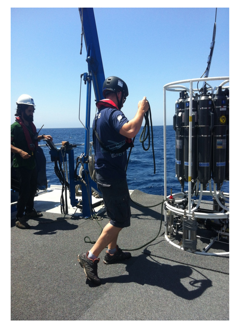
Improve our understanding of meso and submesoscale processes and their impacts on biogeochemistry in an area characterized by intense horizontal gradients (Eastern Alboran Sea, Western Mediterranean)

3 Argo floats



25 SVP drifters

Chl and nutrients

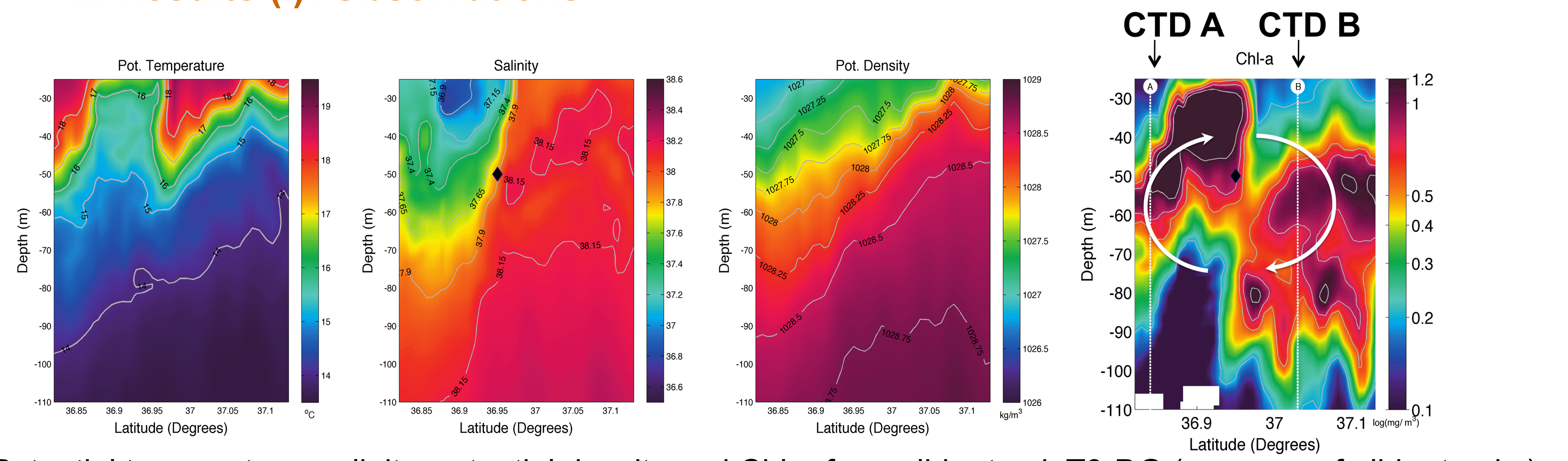


80 CTDs

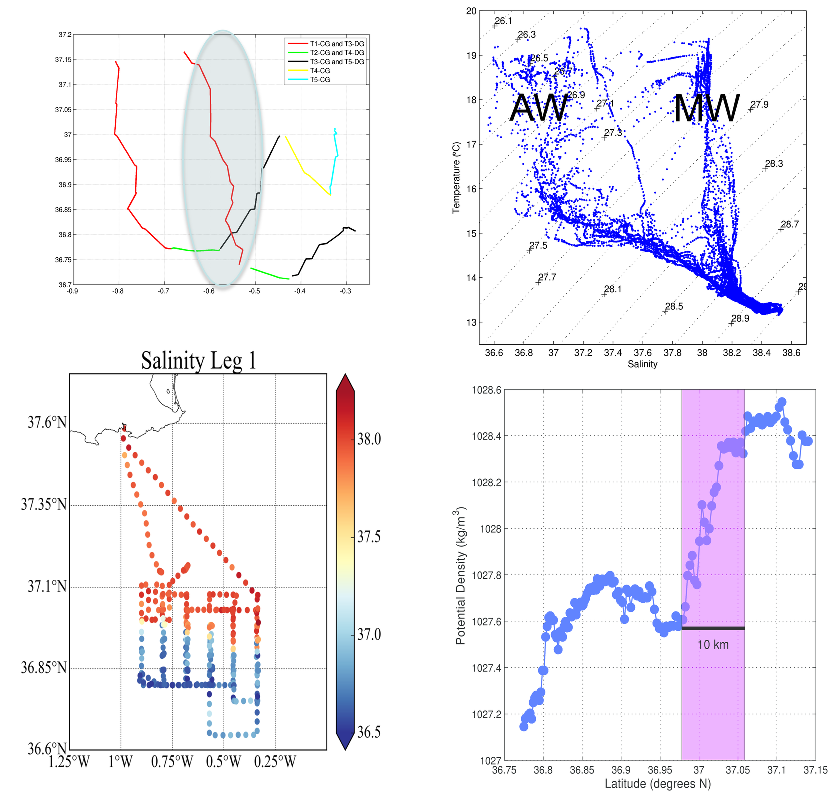
2 gliders

and VM-ADCP, Remote Sensing and Modelling

2. Results (I): Observations

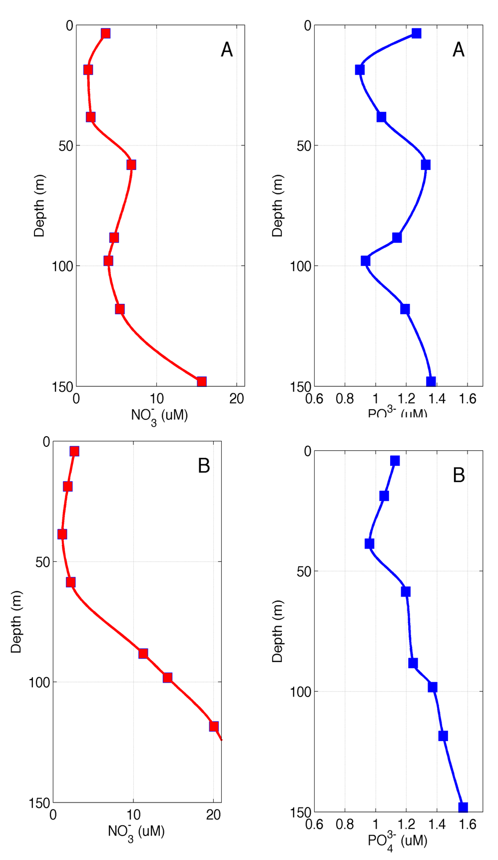


Potential temperature, salinity, potential density and Chl-a from glider track T3-DG (see map of glider tracks).



Top: Map of glider tracks (left) and T/S diagram from CTDs (right). Bottom: Surface salinity from thermosalinograph (left) and surface (20 m) potential density from glider (right) (Ruiz et al., 2015).

Scenario of strong confluence of fresh Atlantic Water (AW) and resident more saline Mediterranean Water (MW)



Vertical profiles of nutrients at CTD stations A and B.

Mechanisms driving vertical motion:

1. Quasi-geostrophic **mesocale dynamics**: (Tintoré et al., 1991)

$$\nabla_h^2\left(N^2 w\right)+f^2\frac{\partial^2 w}{\partial z^2}=2\nabla_h\cdot\vec{Q}$$

$$\vec{Q}=\left[f\left(\frac{\partial V}{\partial x}\frac{\partial U}{\partial z}+\frac{\partial V}{\partial y}\frac{\partial V}{\partial z}\right),-f\left(\frac{\partial U}{\partial x}\frac{\partial U}{\partial z}+\frac{\partial U}{\partial y}\frac{\partial V}{\partial z}\right)\right]$$

(U,V): geostrophic velocity components
N: Brunt-Vaisala frequency
f: the Coriolis parameter

2. Frontogenesis: Horizontal gradients in buoyancy can play an important role in **submesoscale dynamics.** Considering the advection of buoyancy:

$$\frac{Db}{Dt}=b_t+u\,b_x+v\,b_y=0$$

The change of the gradient of *b* can be expressed as follows:

$$\frac{1}{2}\frac{D}{Dt}\left|\nabla_h b\right|^2=-b_x\left(u_x b_x+v_x b_y\right)-b_y\left(u_y b_x+v_y b_y\right)$$

$$b\equiv(-g/\rho_o)\rho'$$

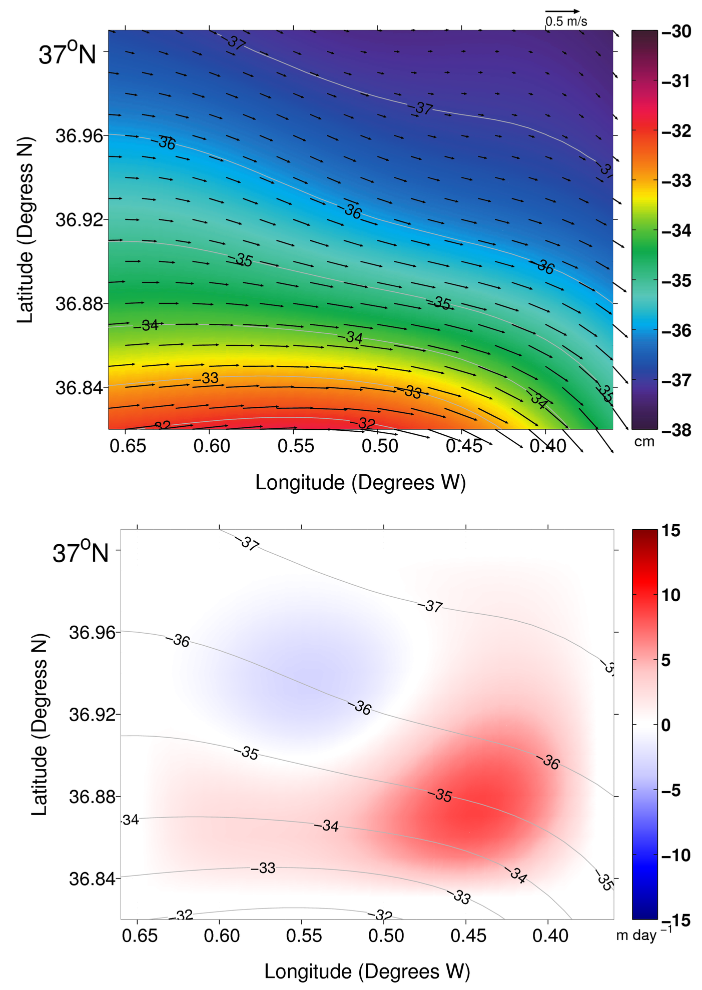
Hoskins (1982)

3. Ekman pumping (linear):

$$W_E=\frac{\nabla\times\tau}{\rho_o f}\qquad \tau=\rho_a C_D u_{rel}\left|u_{rel}\right|\qquad u_{rel}=u_a-u_o$$

Assuming u_a constant over the studied domain u_{rel} is proportional to relative vorticity with a change of sign and a factor scale (C_D ~10^{-3}, Gaube et al. (2013); Foreman and Emeis (2010))
W_E~0.5 m/day.

3. Results (II): Observations

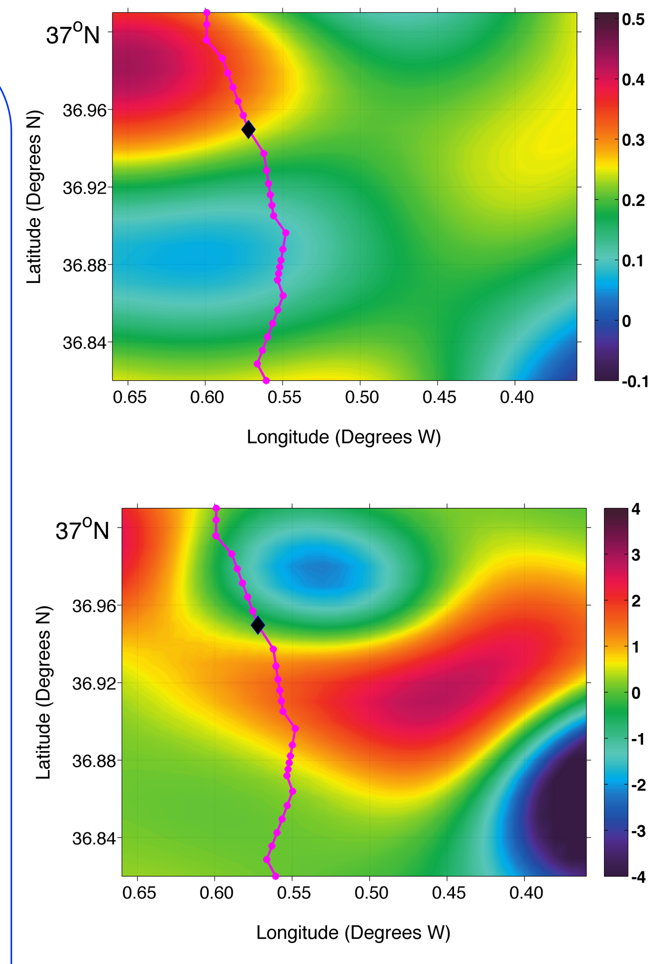


Top: Dynamic height and geostrophic velocity at 50 m depth. Bottom: Quasi-geostrophic vertical velocity (m/day) at 50 m depth. Analysis based on ship-CTD and Optimal Statistical Interpolation (OSI).

QG-theory reports maximum **W_{qg}~20 m/day**. This theory assumes R_o<<1 and does not resolve submesoscale processes.

Frontogenesis: Relative vorticity increases on either side of the front and it becomes as large as planetary vorticity, R_o=O(1) (see figure). The loss of geostrophic balance produces an ageostrophic secondary circulation (Mahadevan, 2016)

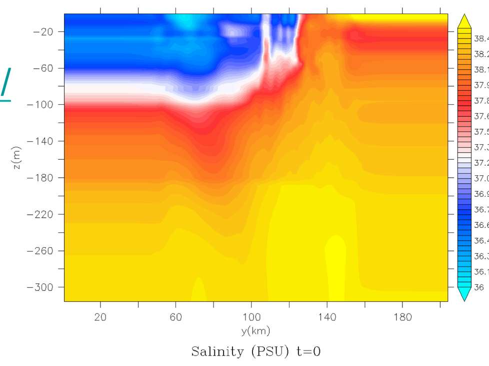
Scaling W_F~$R_o\delta U$, we estimate **W_F> 100 m/day** with U~0.15 m/s; Ro~1; δ=D/L~10^{-2}

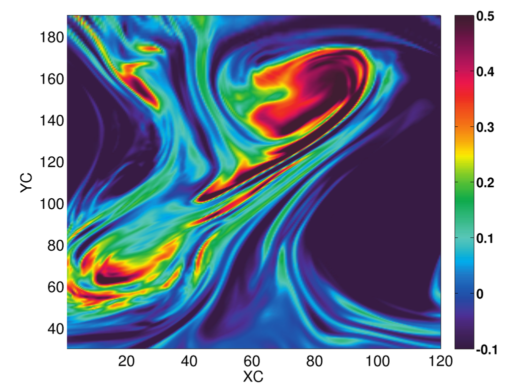


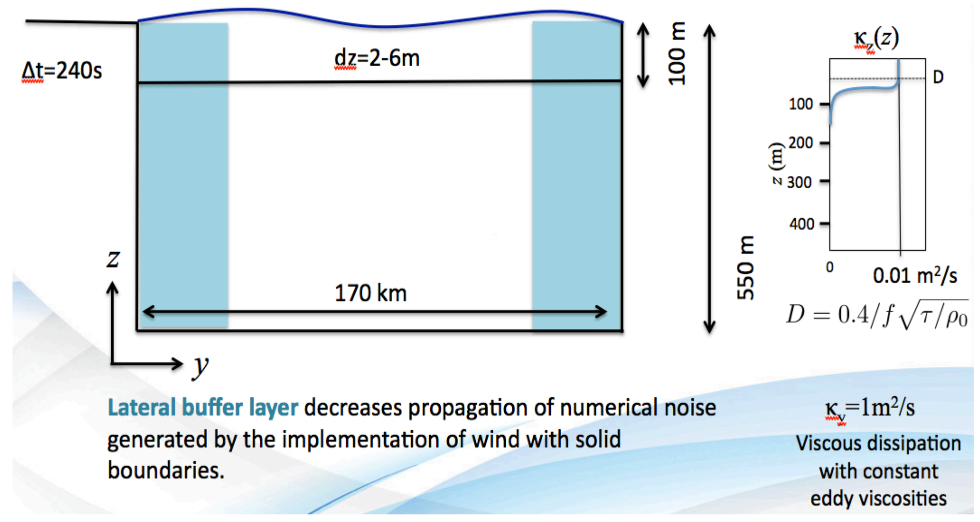
Top: Actual (ADCP) relative vorticity (normalized by *f*).
Bottom: Frontogenetic term (x10^{-18}) at 50 m depth from CTD survey. Magenta line corresponds to glider track T3-DG.

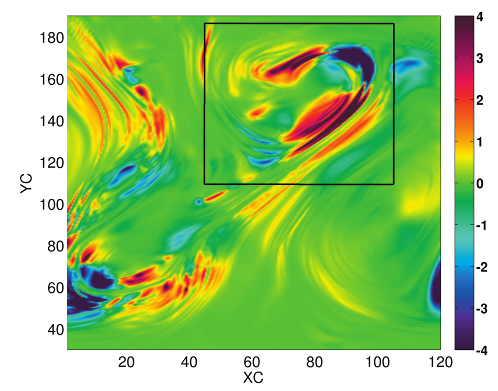
3. Results (III): Numerical simulations

Process Ocean Study Model (PSOM, https://github.com/PSOM, Mahadevan et al. 1996, Omand et al. 2015) used to explore the role of submesoscale processes in enhancing vertical transport at the front.









Top/left: Vertical section of salinity used to initialize the model.

Top/Right: Horizontal section of relative vorticity (normalized by *f*).

Bottom: Horizontal section of Frontogenetic term (x10^{-17}) at 47 m.

4. Summary

- Detection and sampling of an intense front: change in potential density of **1 kg/m³** in 10 km and evidence of vertical motions.
- **Quasi-geostrophic theory:** Vertical Velocity of the order of **20 m/day** at 50 m depth. Does not resolve submesoscale processes and not valid with Rossby Number *O*(1).
- **Linear Ekman pumping theory:** Low vertical velocity of about **0.5 m/day.**
- **Frontogenesis:** Relative vorticity increases on either side of the front and becomes as large as planetary vorticity. We have estimated local R_o=O(1) and vertical velocity > **100 m/day** that can explain vertical motion suggested by high-resolution observations from autonomous ocean gliders. These findings based on observations are consistent with numerical simulations.

Acknowledgments: This study has been done in the framework of PERSEUS EU-funded project. We would like to thank all the crew and scientific staff on board R/V SOCIB for their efficient collaboration during the ALBOREX experiment. For a complete list of references cited in this poster, please contact first author.