

Intense ocean frontogenesis inducing submesoscale processes and impacting biochemistry

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48th Liège Colloquium
23-27 May 2016, University of Liège, Belgium



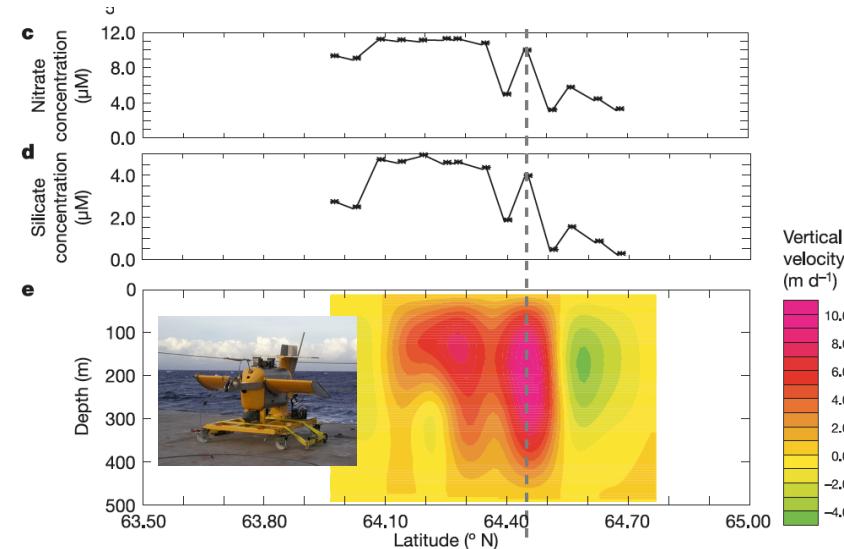
Balearic Islands
Coastal Observing
and Forecasting
System



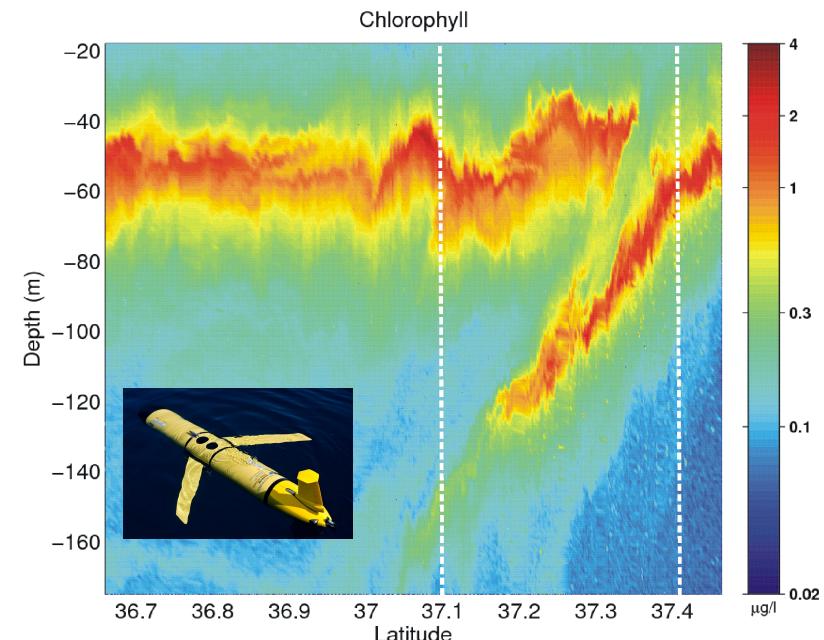
Scientific motivation:

Improve our understanding of meso and submesoscale processes and their impacts on biogeochemistry:

- Carbon export
- Supply of nutrients to upper ocean

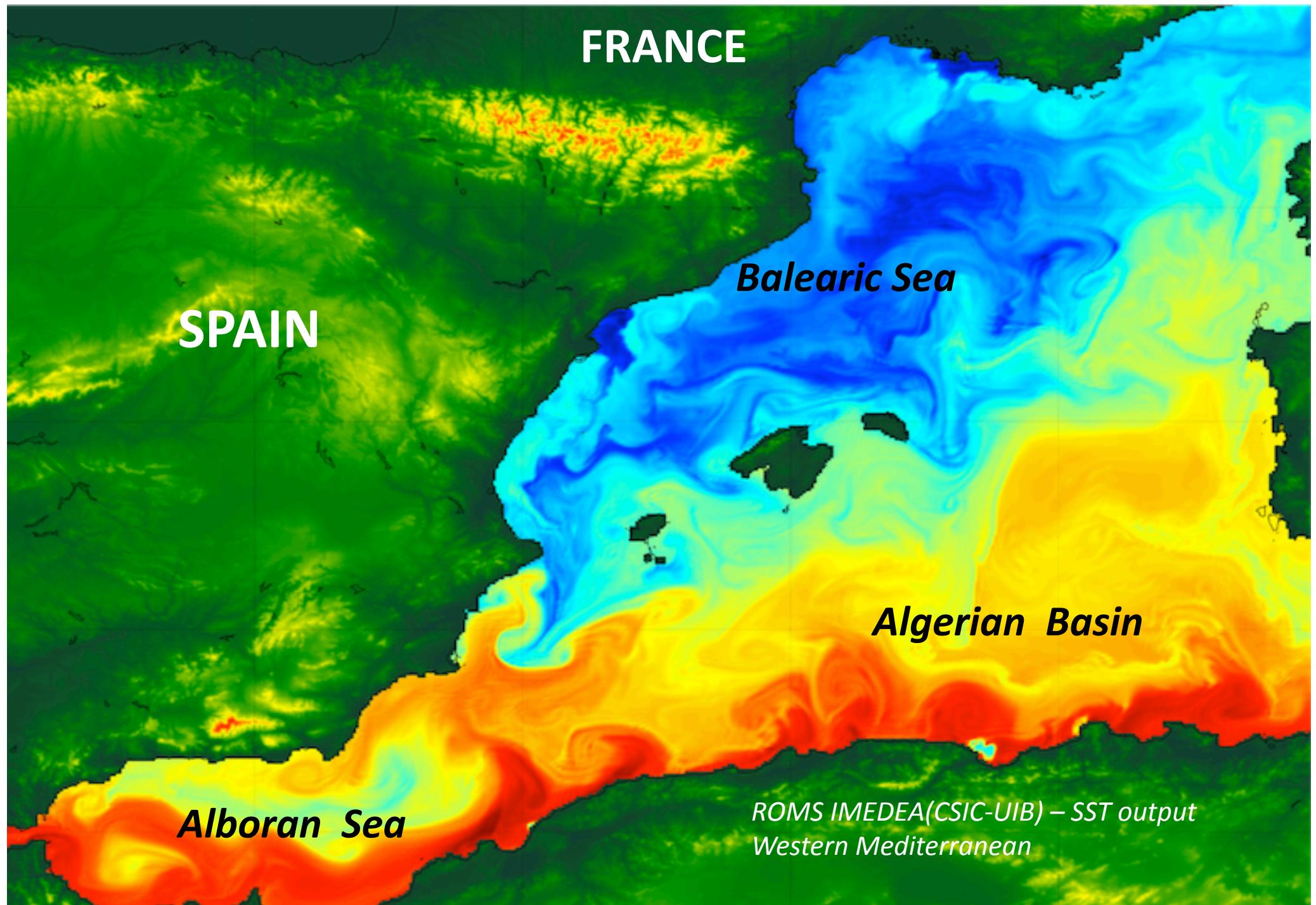


Nitrate, silicate and vertical velocity
(Iceland-Faeroes front)
Allen et al. (2005), Nature



Vertical section of chlorophyll from glider data in the Eastern
Alboran Sea (Western Mediterranean)
Ruiz et al. (2009), GRL

Western Mediterranean Sea



ALBOREX multi-platform and interdisciplinary experiment

High resolution observations

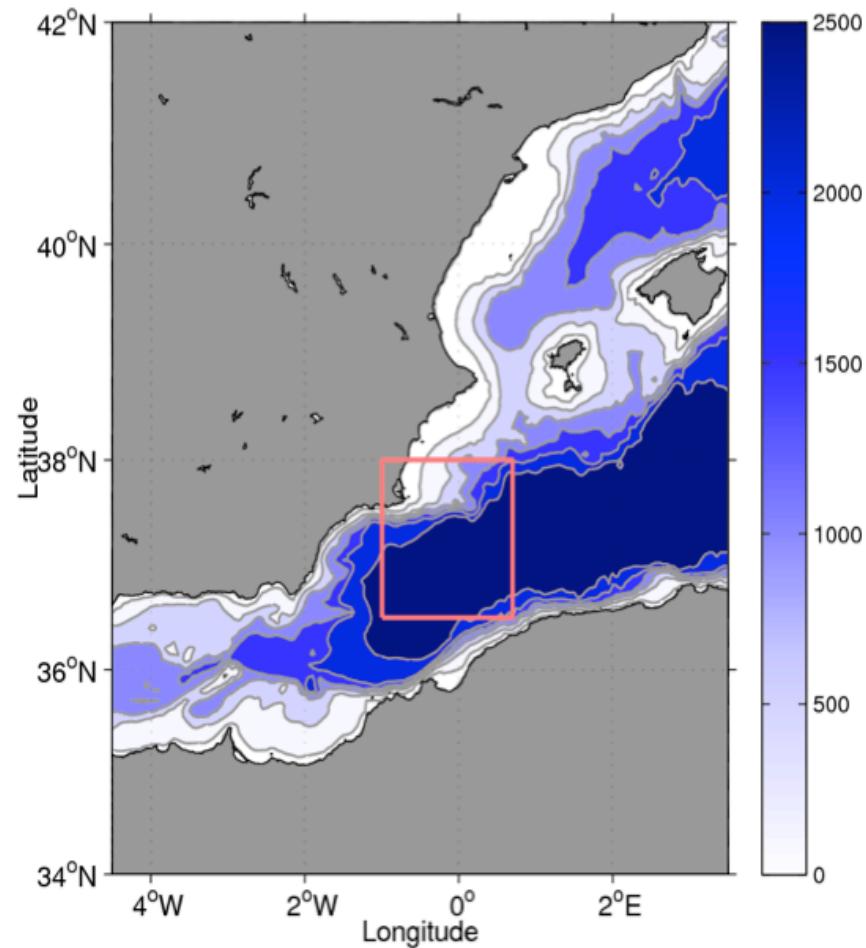


Dates: 24 May – 2 June 2014

Area: Eastern Alboran Sea

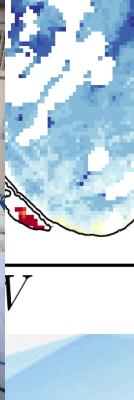
Ship: R/V SOCIB

- 25 drifters
- 2 gliders
- 3 Argo floats
- Continuous ADCP
- Thermosalinograph
- 80 CTDs
- 500 water samples
- Nutrients (Nitrates, phosphates, silicates)
- Chlorophyll
- Remote sensing
- Modeling



Lead by IMEDEA with strong involvement from
SOCIB, OGS, CNR, WHOI, McGill U.

ALBOREX



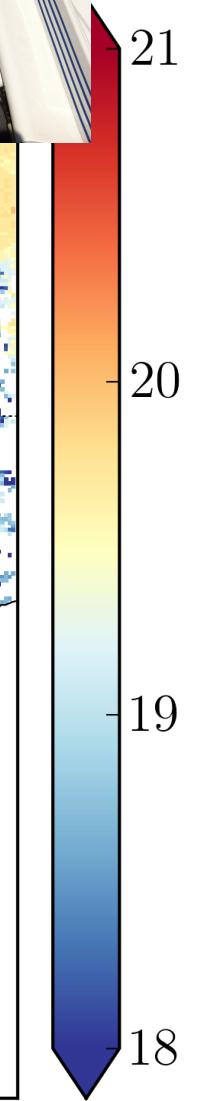
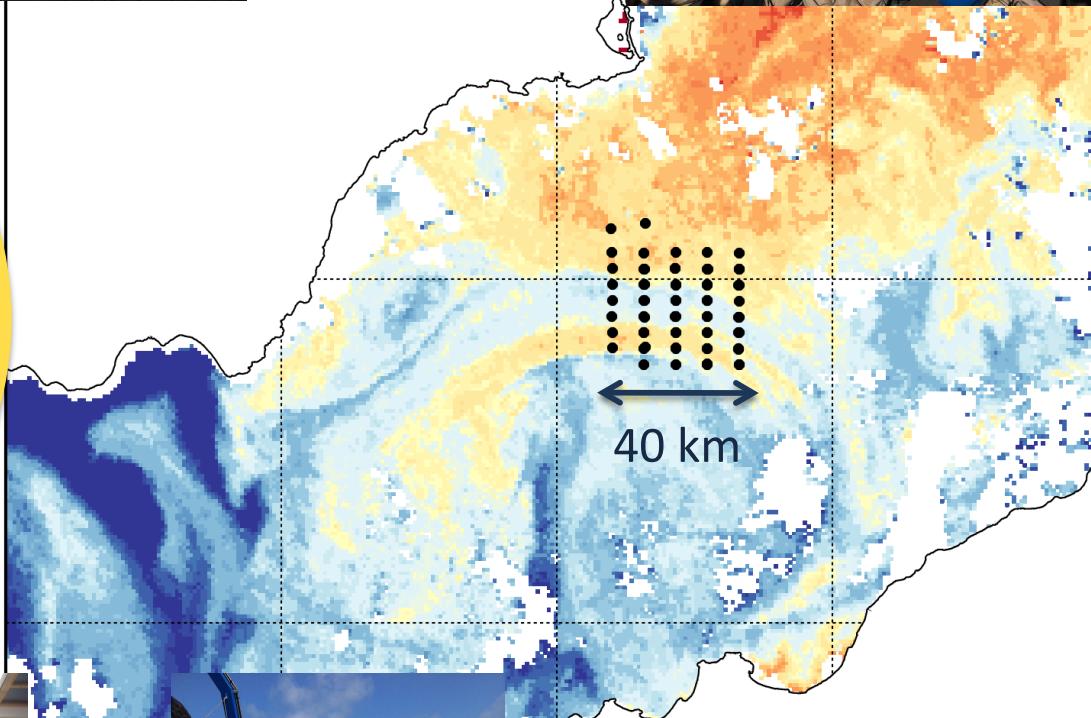
V



1°W

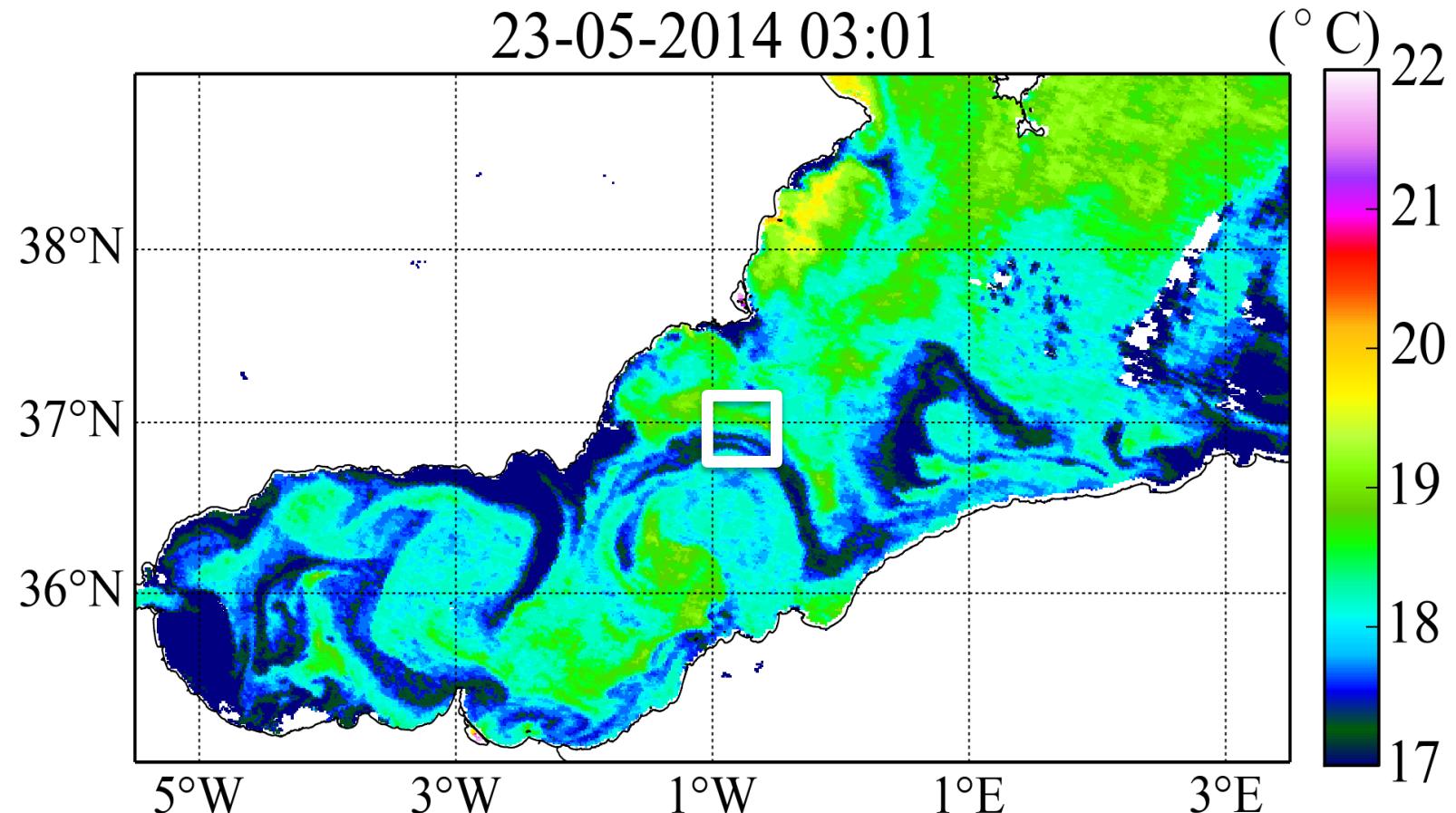


2014-05



Oceanographic context from satellites

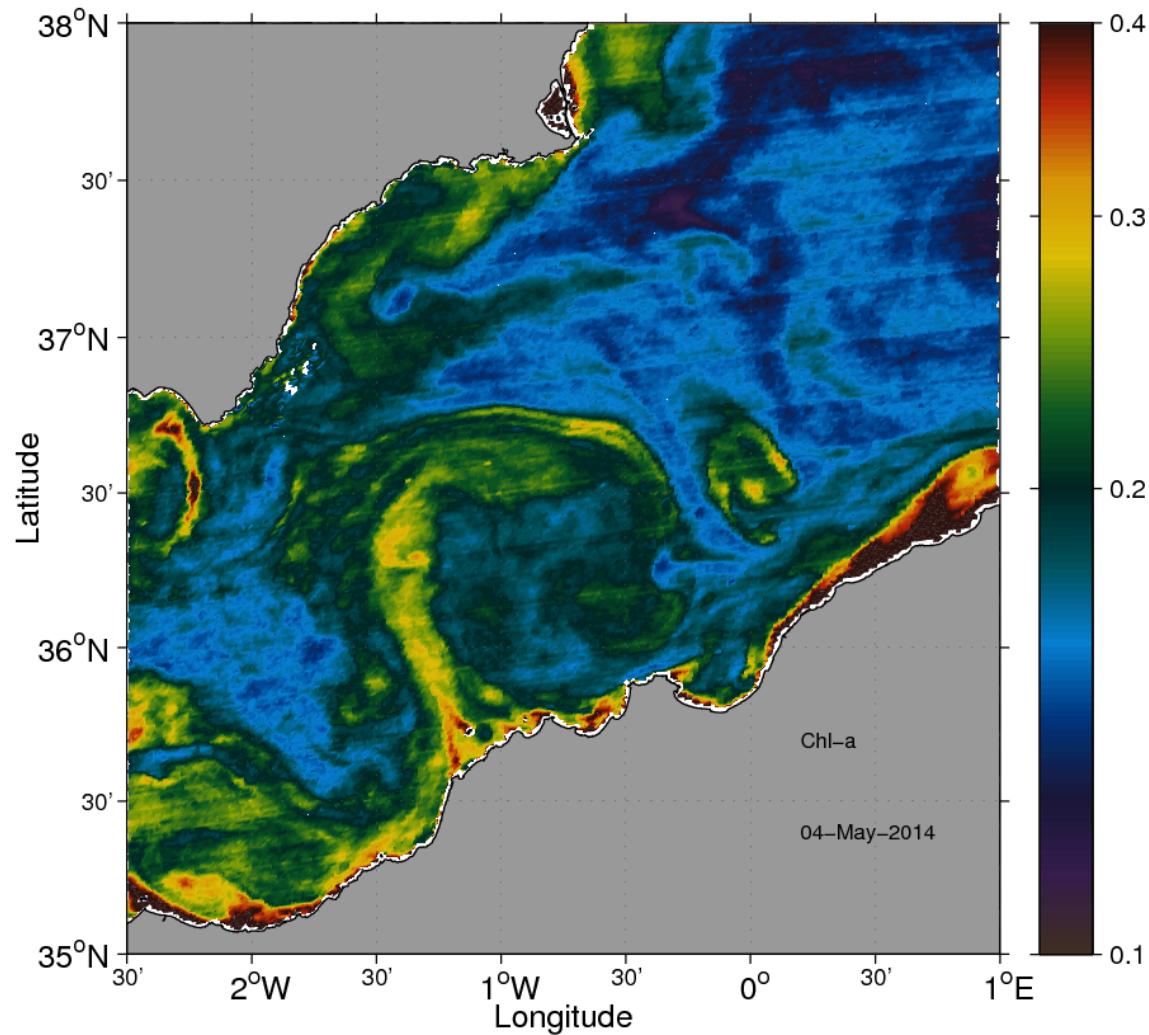
SST



Modis SST - 23 May 2014

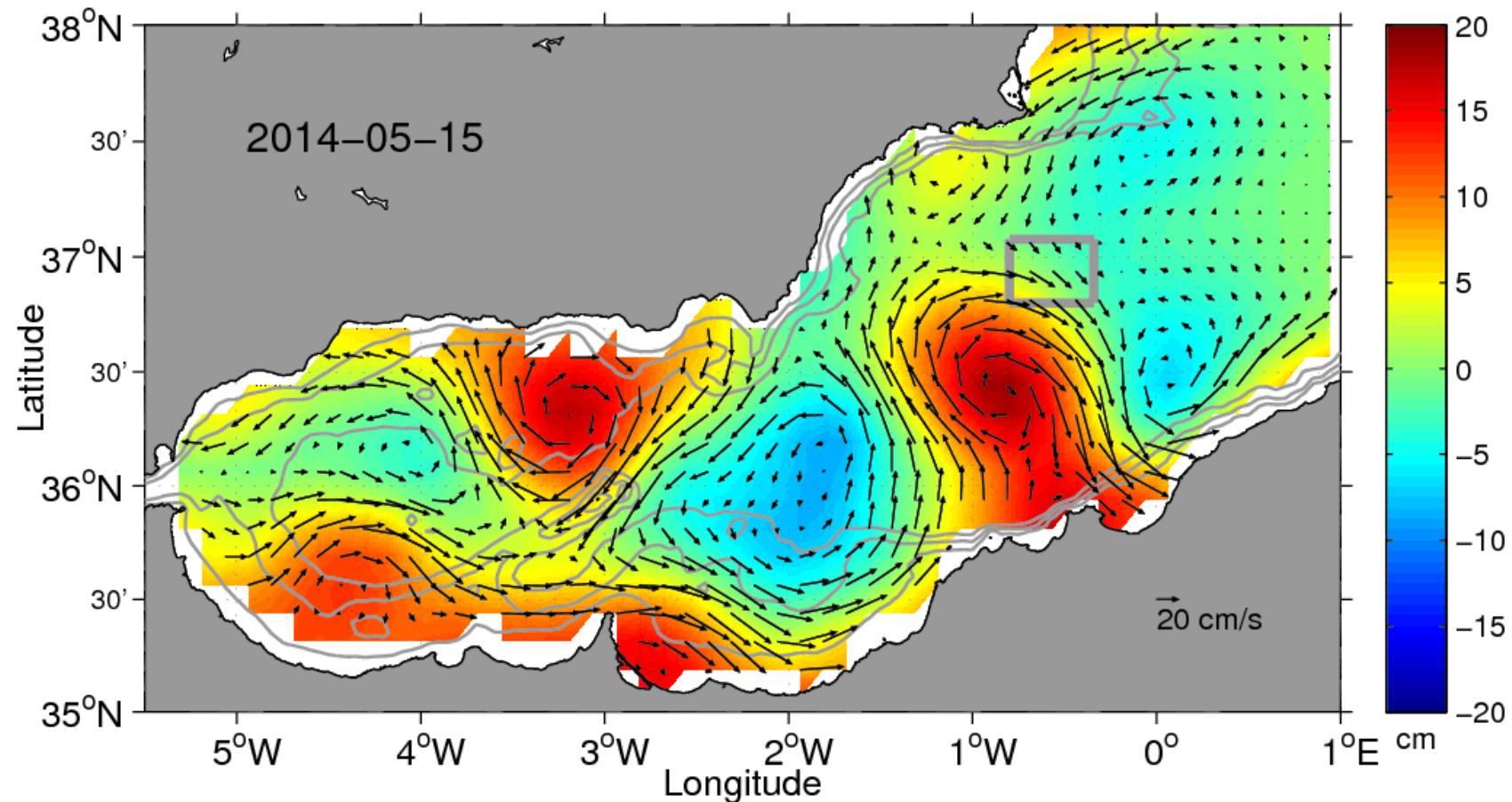
Oceanographic context from satellites

OCEAN COLOR



Oceanographic context from satellites

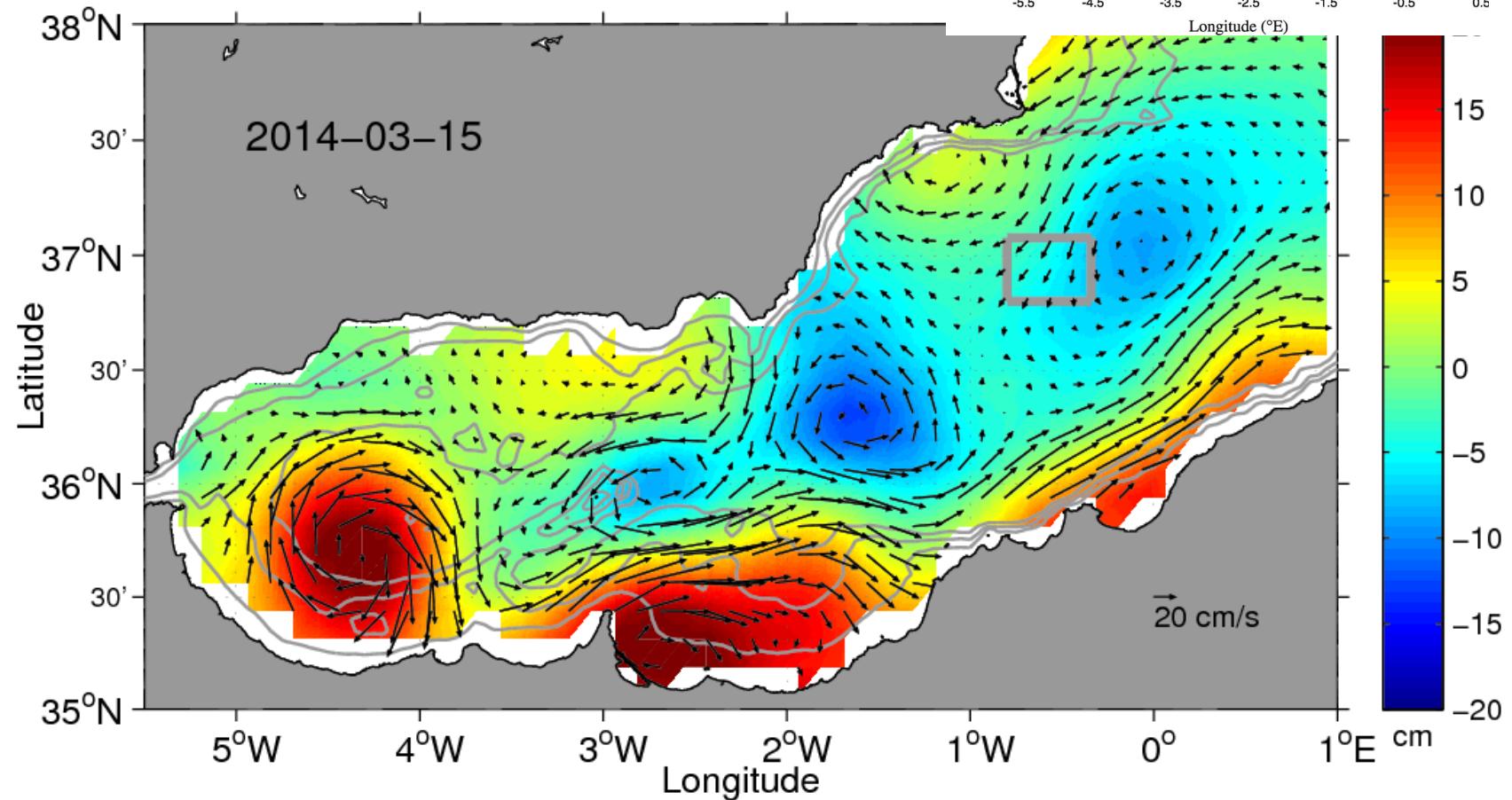
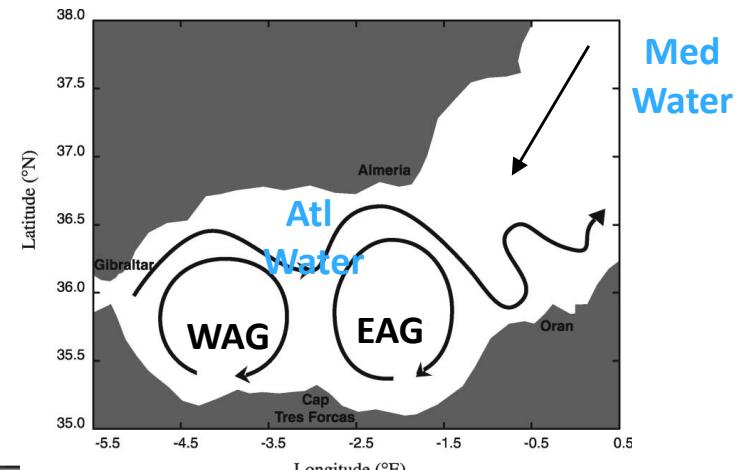
ALTIMETRY



Absolute Dynamic Topography and geostrophic altimeter fields from AVISO

Oceanographic context from satellites

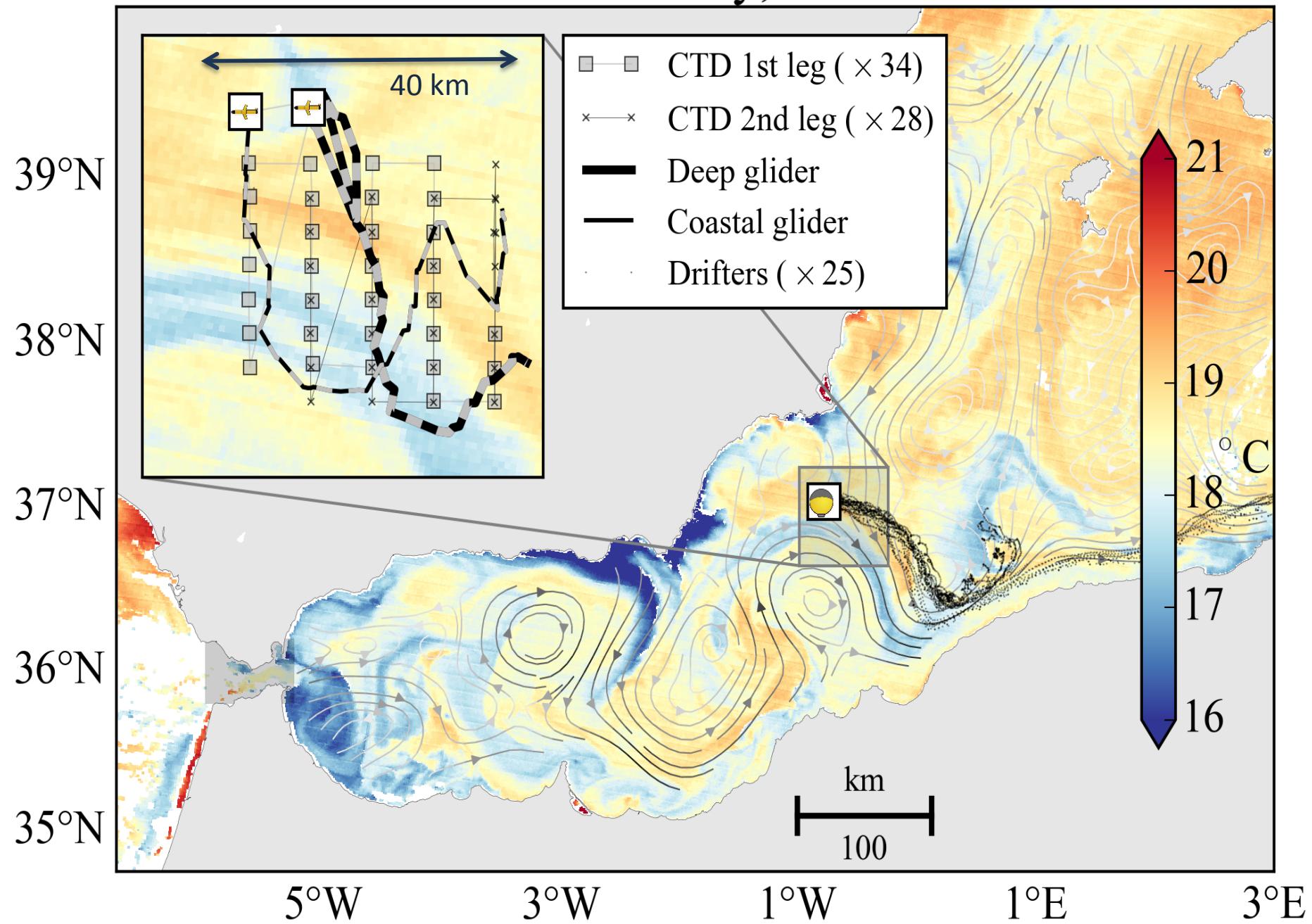
ALTIMETRY



Absolute Dynamic Topography and geostrophic altimeter fields from AVISO

ALBOREX

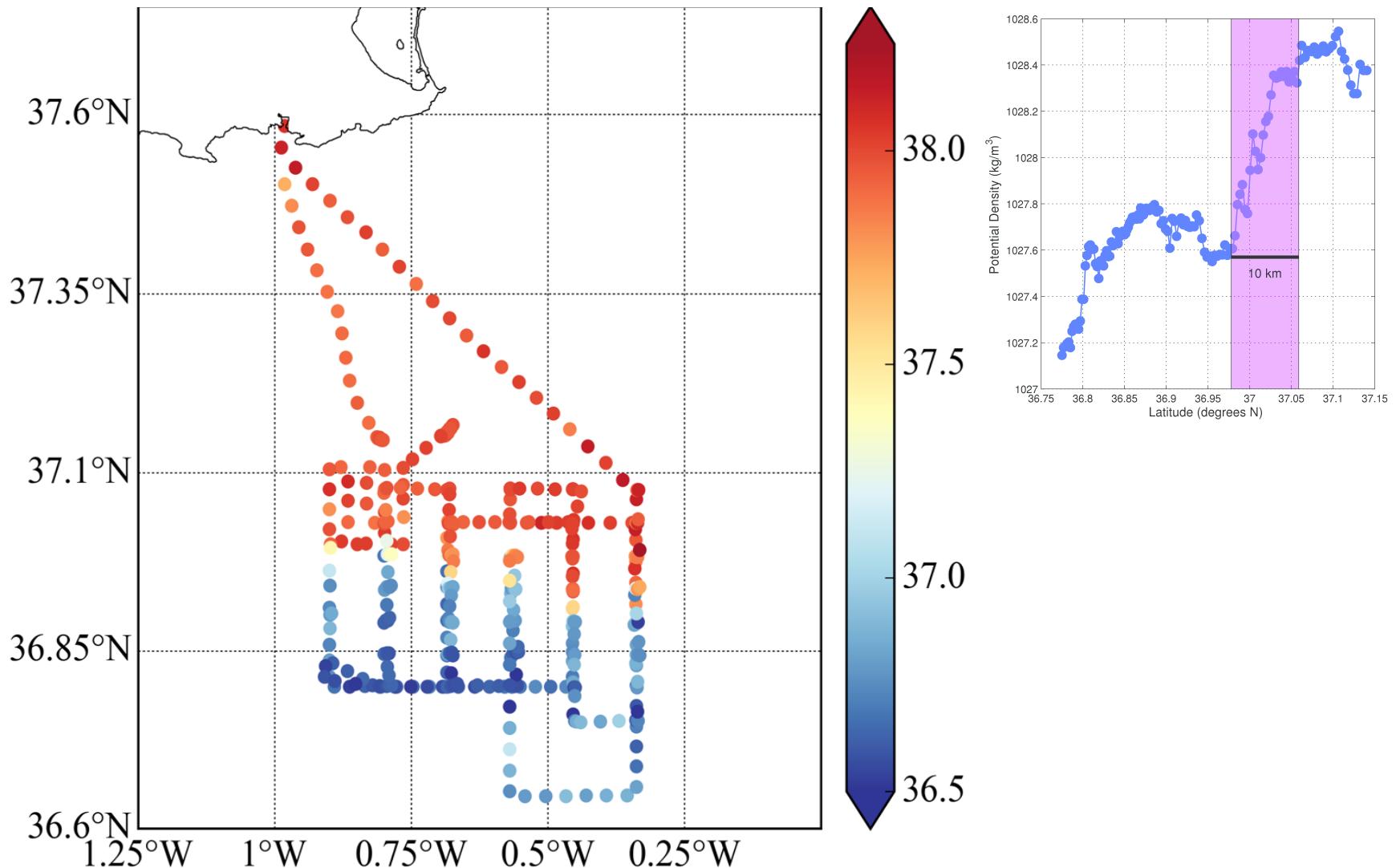
25–31 May, 2014



THERMOSALINOGRAPH and CTD/GLIDER

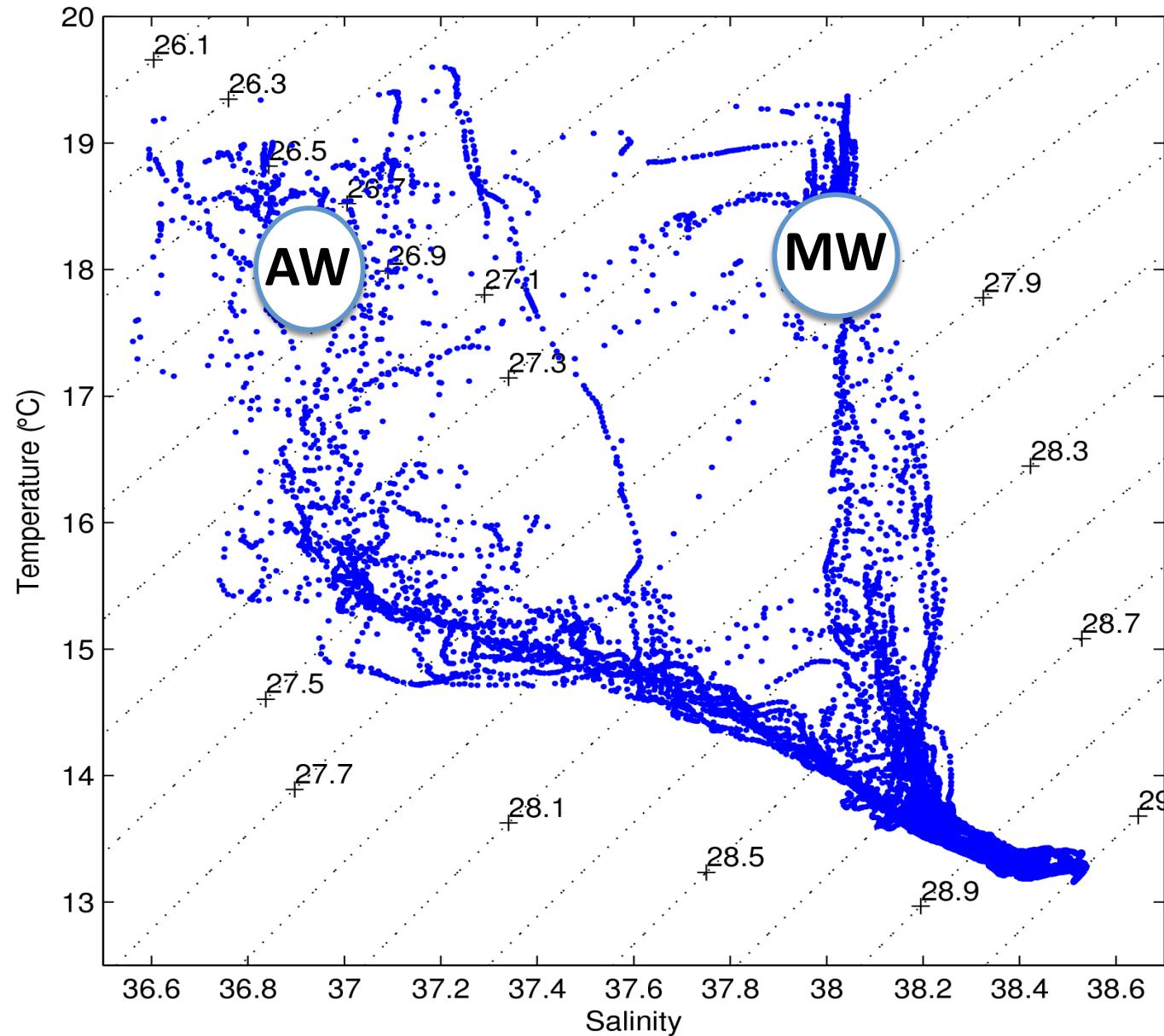
Surface salinity front (change of 1.4 in 5 km)

Surface density front (change of ~1 kg/m³ in 10 km)



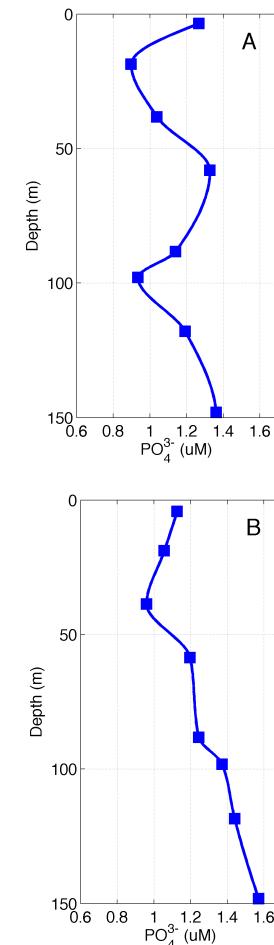
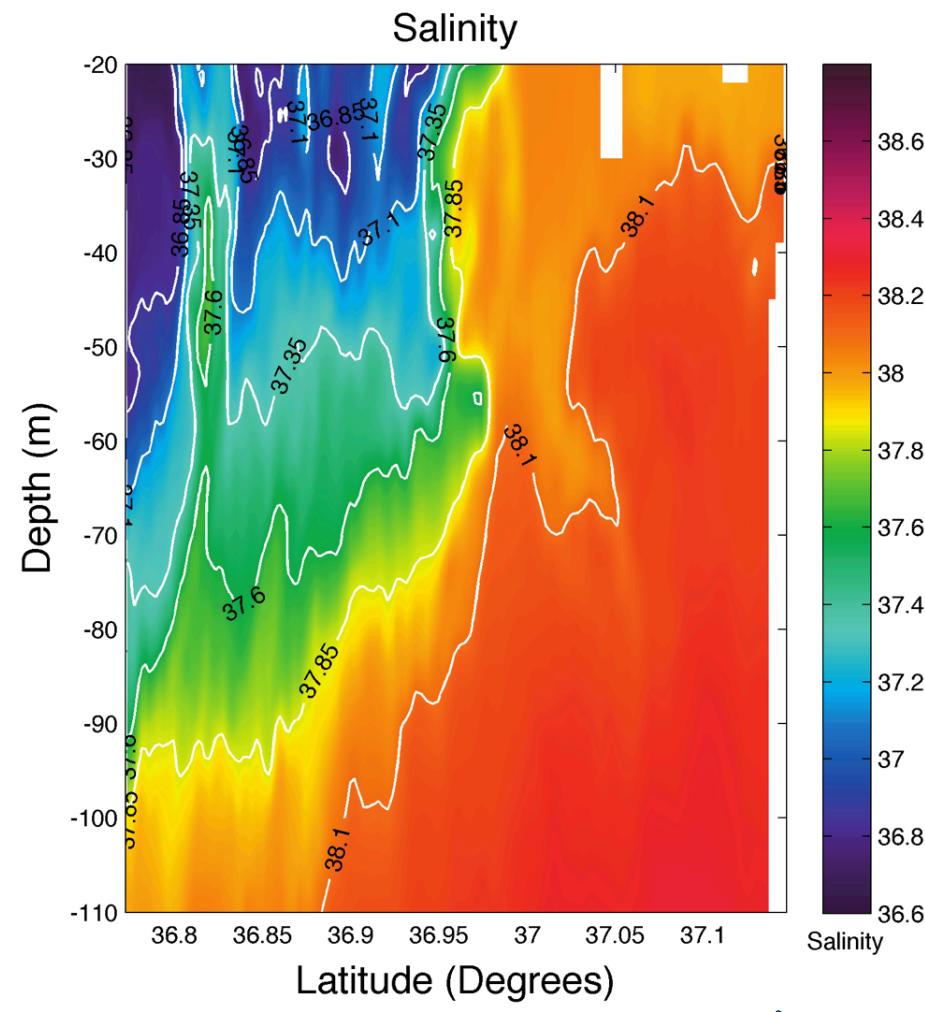
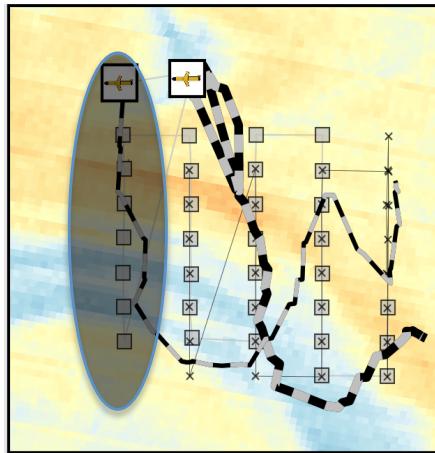
T-S diagram: CTD

Atlantic and Mediterranean waters



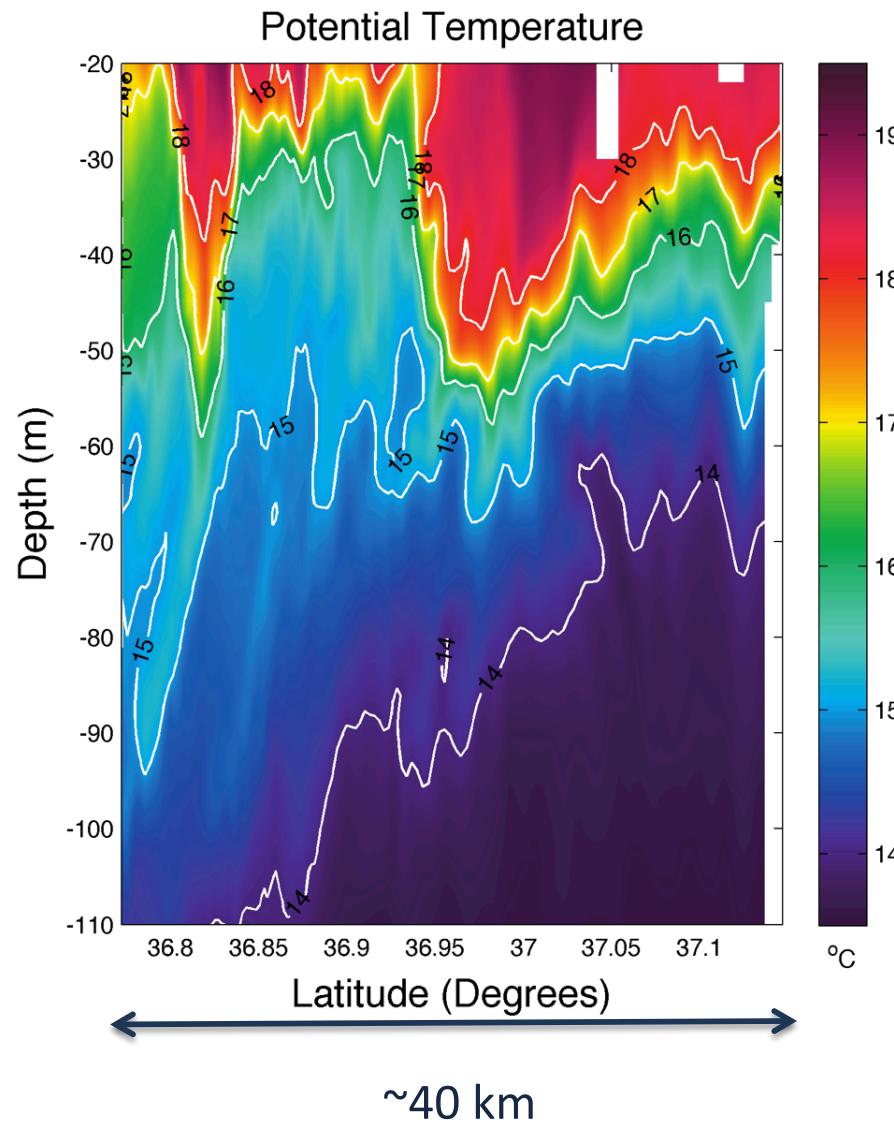
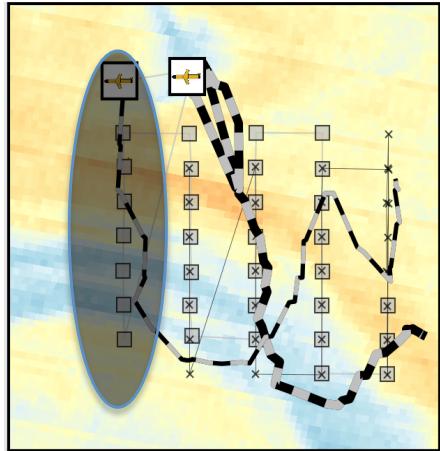
ALBOREX - GLIDER

SALINITY – (400 m resolution) and phosphate from water samples

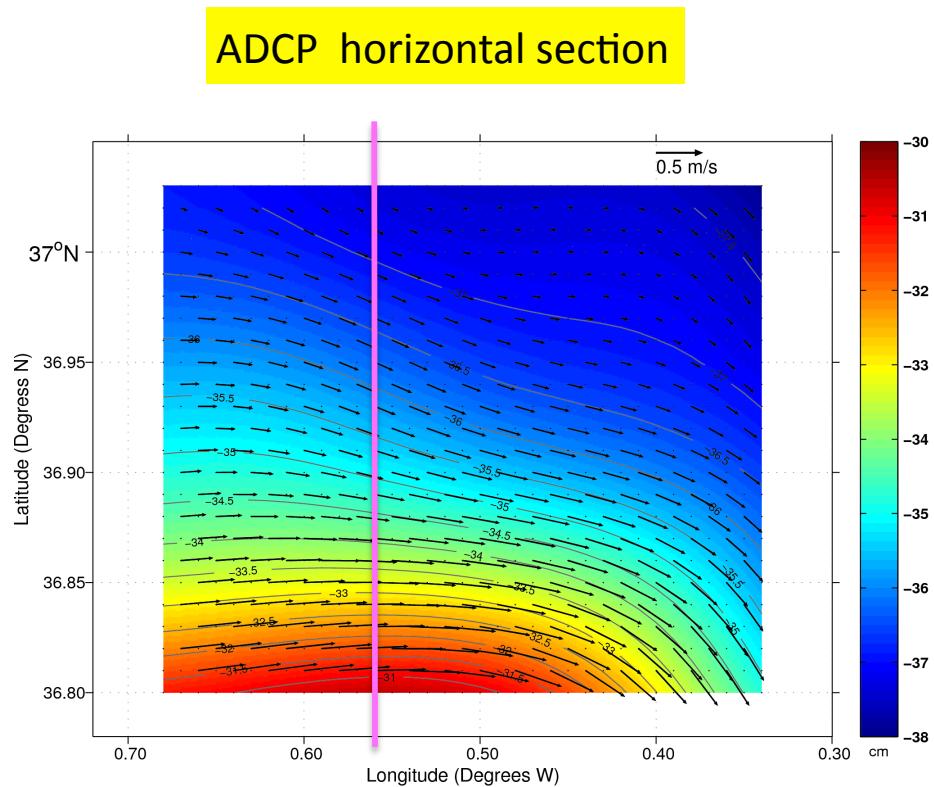


\sim 40 km

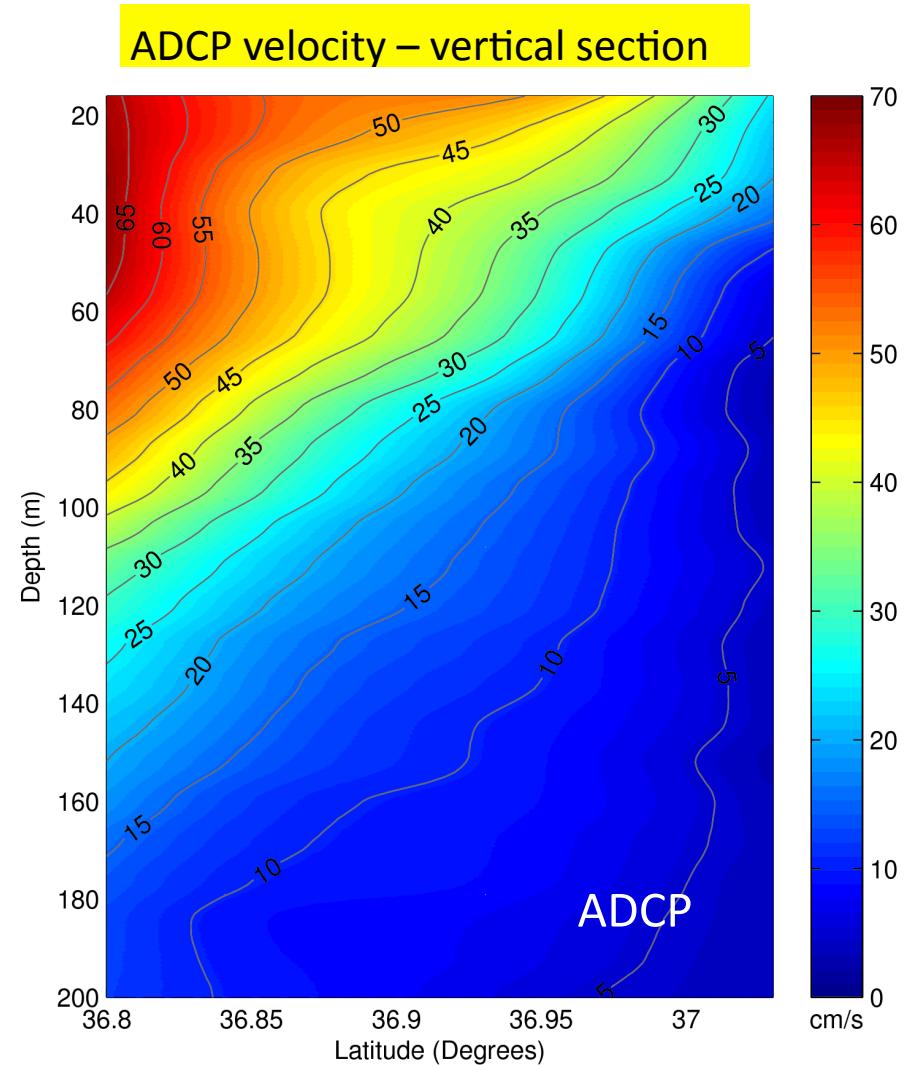
ALBOREX - GLIDER POTENTIAL TEMPERATURE



ADCP velocities and geostrophic Max. surface currents from ADCP of 70 cm/s



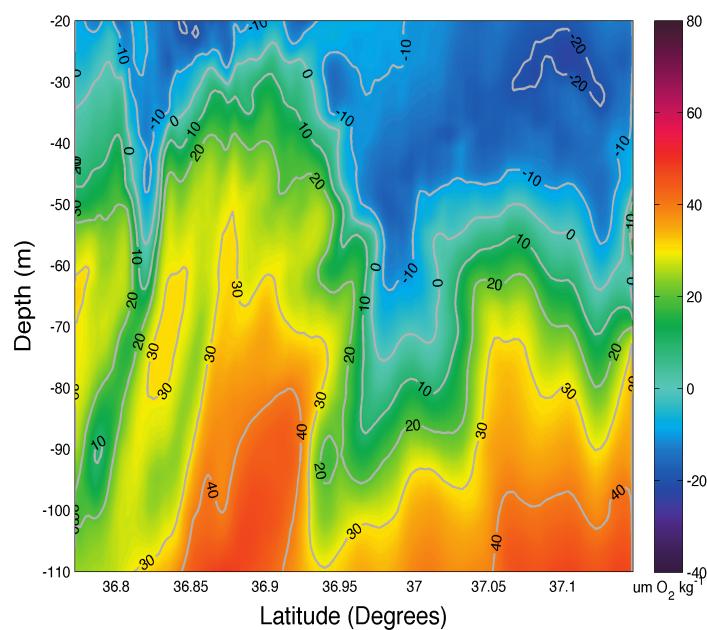
Max. Geostrophic velocity \sim 50 cm/s



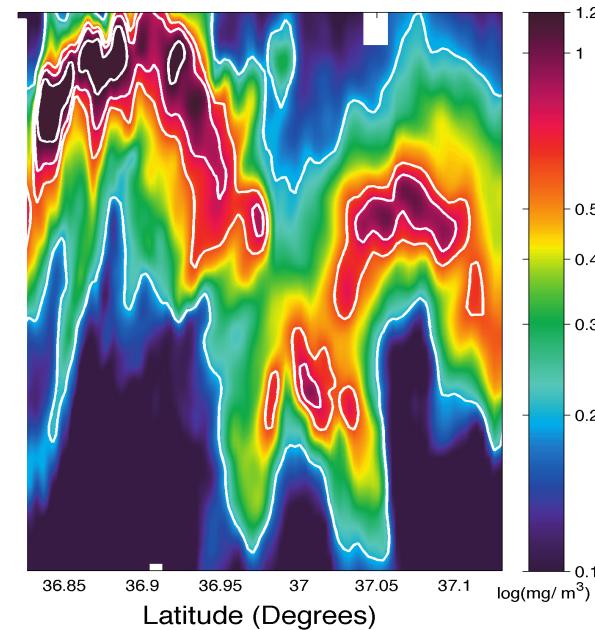
ALBOREX

AOU and Chl-a from glider observations

Apparent Oxygen Utilization



Chlorophyll-a



- Oxygen: regions showing oversaturation
- Importance of carbon export driven by submesoscale

Further details in Olita et al. (talk on Friday)

Meso and submesoscale dynamics

Mesoscale Dynamics

$$R_o = \frac{U}{fL} = \frac{\zeta}{f} = \mathcal{O}(0.1 - 0.01)$$

Submesoscale Dynamics

$$R_o = \frac{\zeta}{f} = \mathcal{O}(1)$$

R_o : Rossby number

U : horizontal velocity

f : Coriolis parameter

L : characteristic scale

ζ : relative vorticity

Potential mechanisms vertical motion:

Quasi-Geostrophic Dynamics

Omega Equation (Vector-Q formulation)

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

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

(U, V) : geostrophic velocity components

w : quasi-geostrophic vertical velocity

N : Brunt-Vaisala frequency

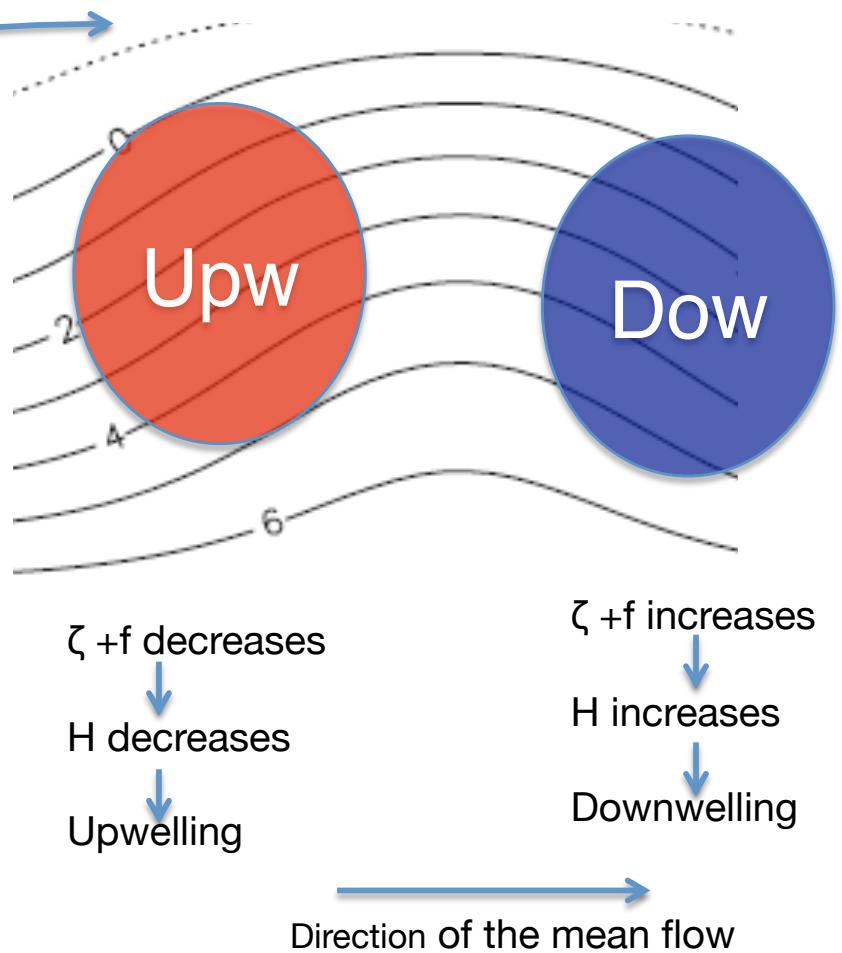
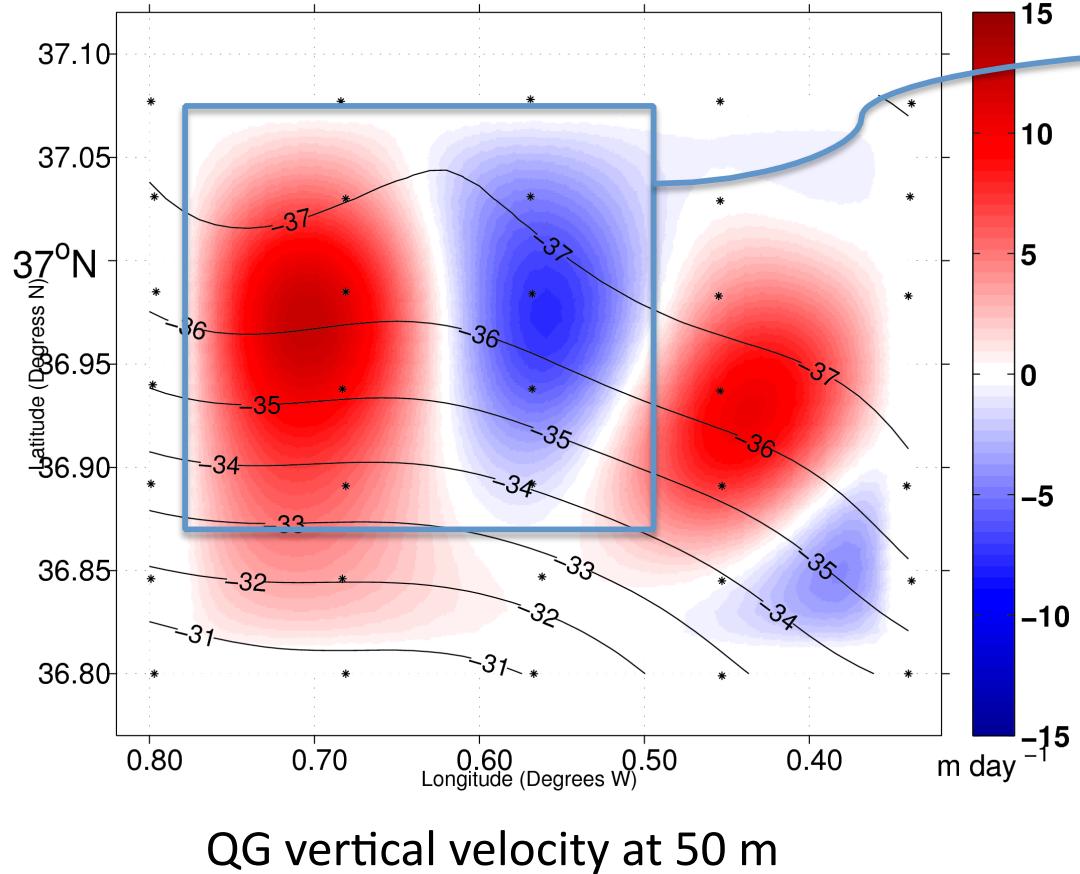
$$R_o \ll \mathcal{O}(1)$$

$$w \sim 1-10 \text{ m/d}$$

Hoskins et al. (1978)
 Tintoré et al. (1991)
 Pollard and Regier (1992)
 Pascual et al. (2004)

ALBOREX:

Quasi-Geostrophic vertical velocity



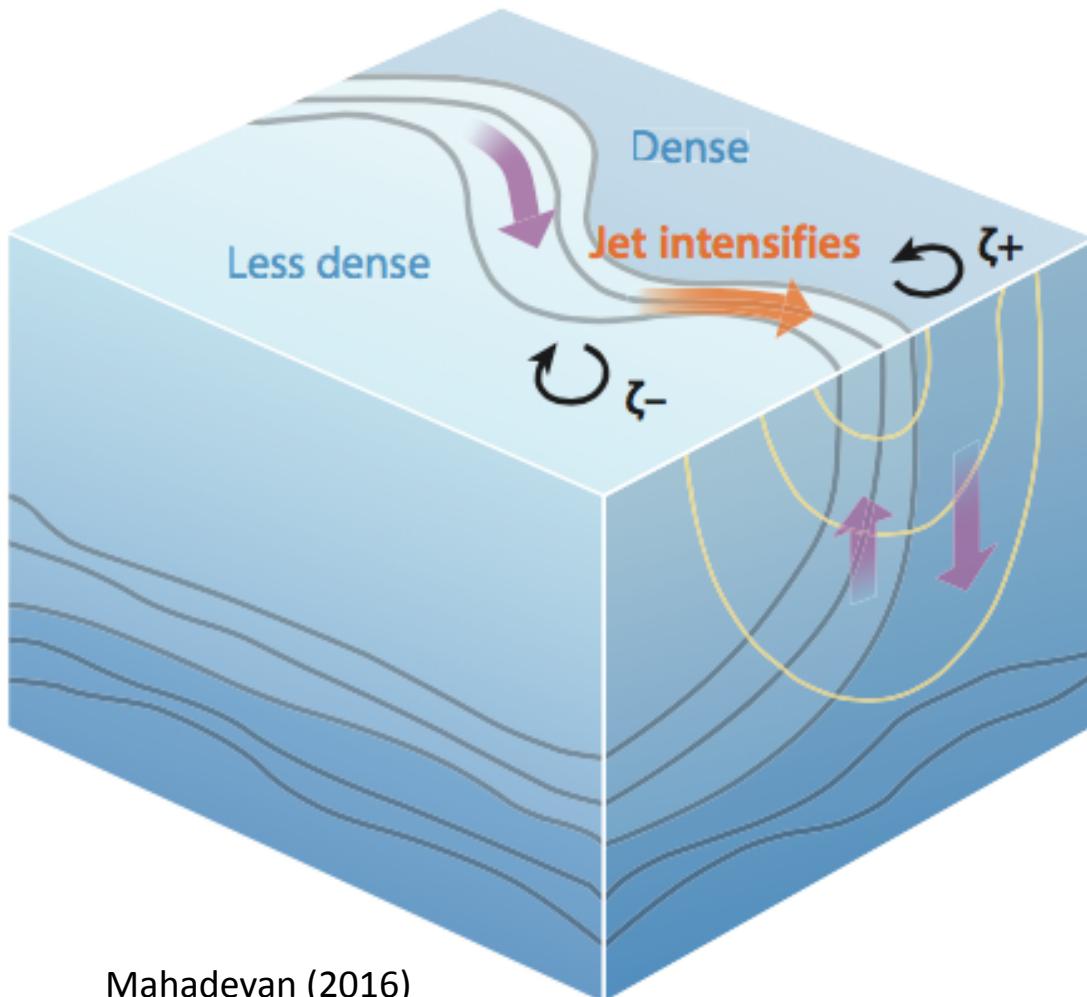
About ± 15 m/day.

QG-w patterns are consistent with those predicted by QG theory.

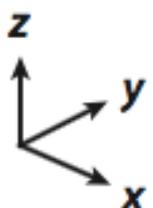
Filtering of scales < 20 km

$Ro \ll 1$

Frontogenesis



Mahadevan (2016)



Buoyancy

$$b = -g \frac{\rho'}{\rho_o}$$

Conserved in the absence of forcing

$$\frac{Db}{Dt} = 0$$

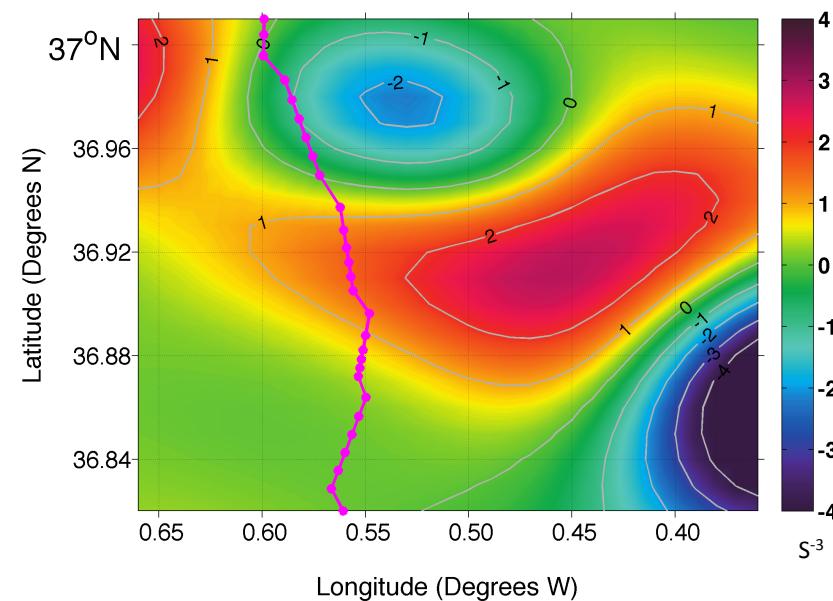
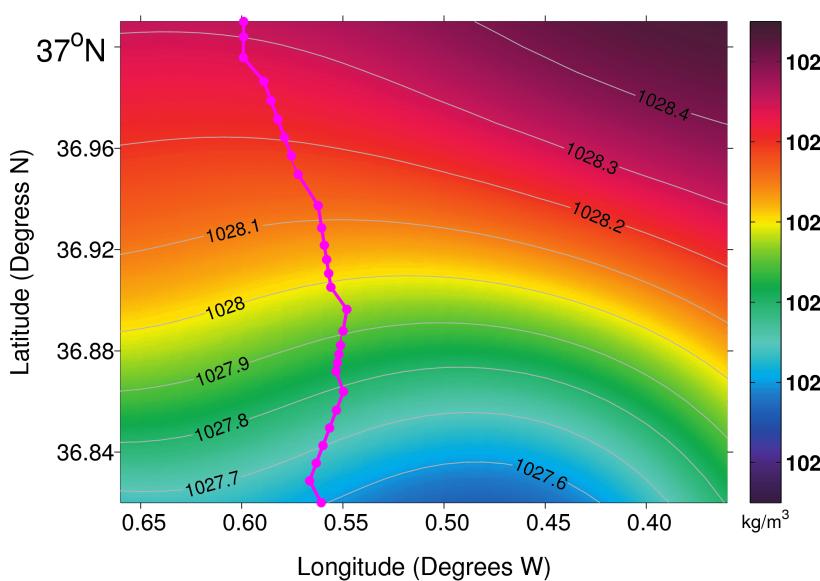
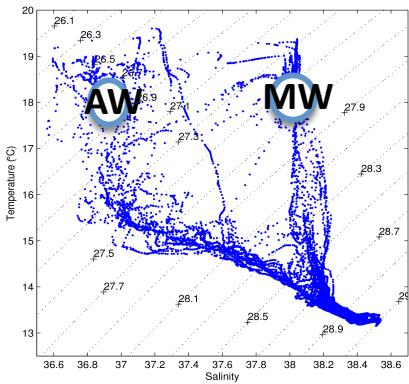
Front intensifies and buoyancy gradients and relative vorticity increase

$$R_o \sim \mathcal{O}(1)$$

$$w \sim 100 \text{ m/d}$$

Submesoscale Dynamics

Frontogenesis

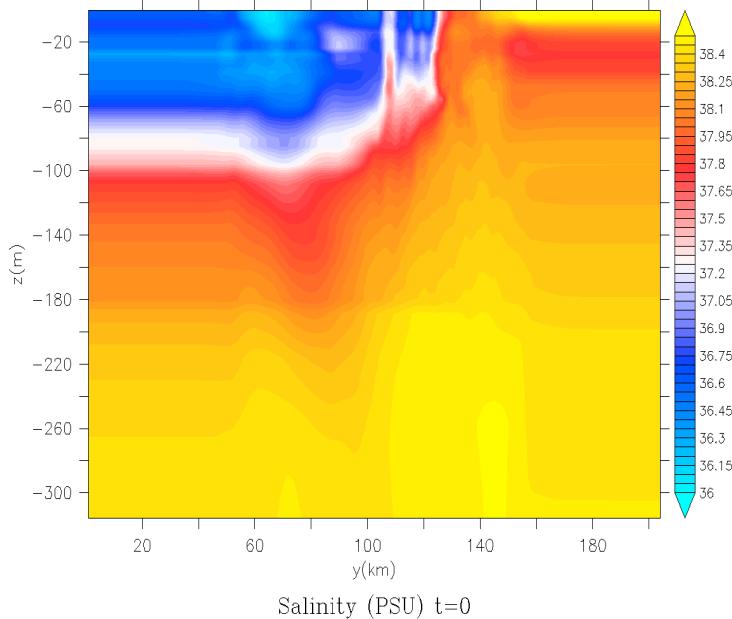


Frontogenesis mechanism due to the confluence of two very difference water masses can trigger submesoscale structures observed by gliders

Potential mechanisms of vertical motion

Frontogenesis - numerical simulation

Process Ocean Study Model (PSOM, <https://github.com/PSOM>, Mahadevan et al. 1996, Oman et al., Science 2015) used to isolate the impact of frontal dynamics in vertical transport.



Vertical section of salinity used to initialize the model.

Atmospheric forcing is not included

Flow remains statically, inertially, and symmetrically stable during the time period of analyses.

Domain is a periodic channel along the zonal direction (120km) meridional dimension (200km), lateral resolution (500m)
The vertical extent is 550m.

Front defined by the encountering of Mediterranean and Atlantic waters is initialized in thermal-wind balance using a hydrographic glider section extended with 2km-resolution output from the Western Mediterranean Operational Model.

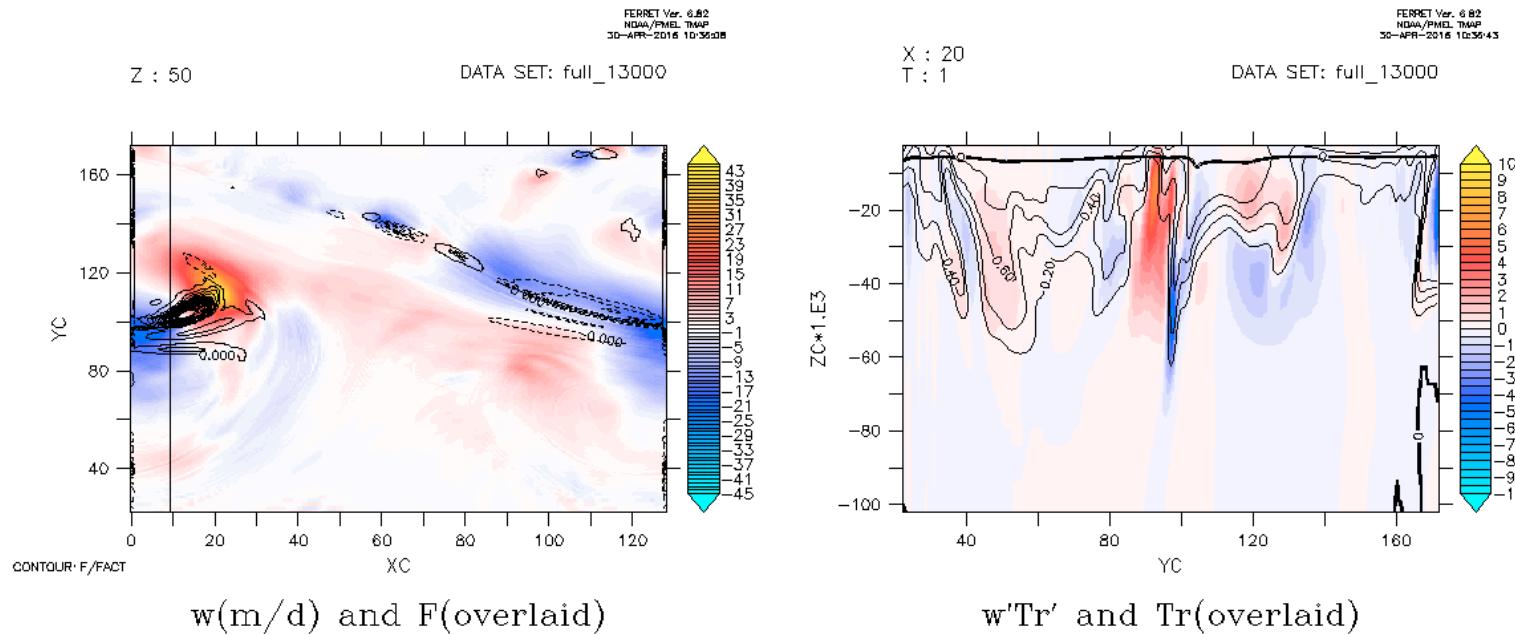
A passive tracer is implemented homogeneous within the mixed layer, which depth is defined by a density criteria, in order to investigate vertical intrusions and subduction events below it.

Visit poster by Claret et al.

“Submesoscale vertical transport at the Eastern Alboran Front’

Potential mechanisms of vertical motion

Frontogenesis - numerical simulation



- Vertical velocities of about 45 m/day ($x3$ w diagnosed by mesoscale QG)
- Modelling results support that front can trigger submesoscale dynamics.
- Vertical velocities associated to these submesoscales structures can explain subductions observed by gliders in regions where frontogenesis occurs.

Summary

- Multi-platform experiment sampling a sharp salinity front. Density gradient of about **1 kg/m³** in 10 km, **observational evidence for submesoscale structures** from gliders.
- **Quasi-geostrophic theory:** Vertical Velocity of the order of **15 m/day** at 50 m depth. It fails due Rossby Number $O(1)$.
- **Frontogenesis:** Lateral buoyancy gradients from observations suggest that mesoscale front can trigger baroclinic instabilities at submesoscale.
- Modelling results support this role of frontogenesis mechanism.
Vertical velocity > 45 m/day from high-resolution numerical simulation
(x3 w diagnosed by mesoscale QG).
- Vertical velocities associated with these submesoscales structures can explain subductions observed by gliders in regions where frontogenesis occurs.

Thank you

Gracias

