OSTST2015 meeting Reston (Virginia) · US 20 October 2015

ALBOREX: a multi-platform interdisciplinary view of Meso and Submesoscale processes

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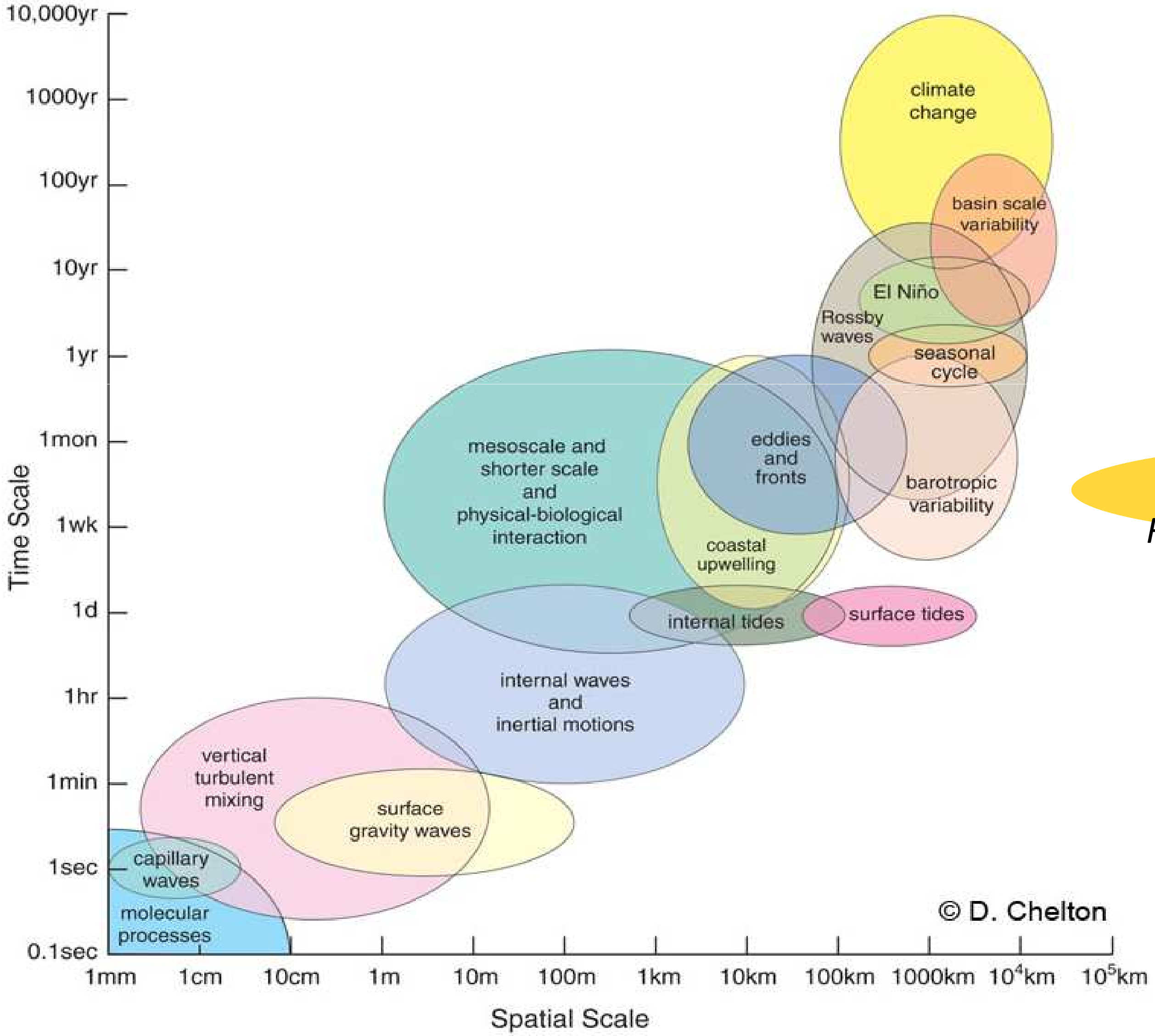
[4] McGill U, Canada; [5] WHOI, US[6]; OGS, Italy

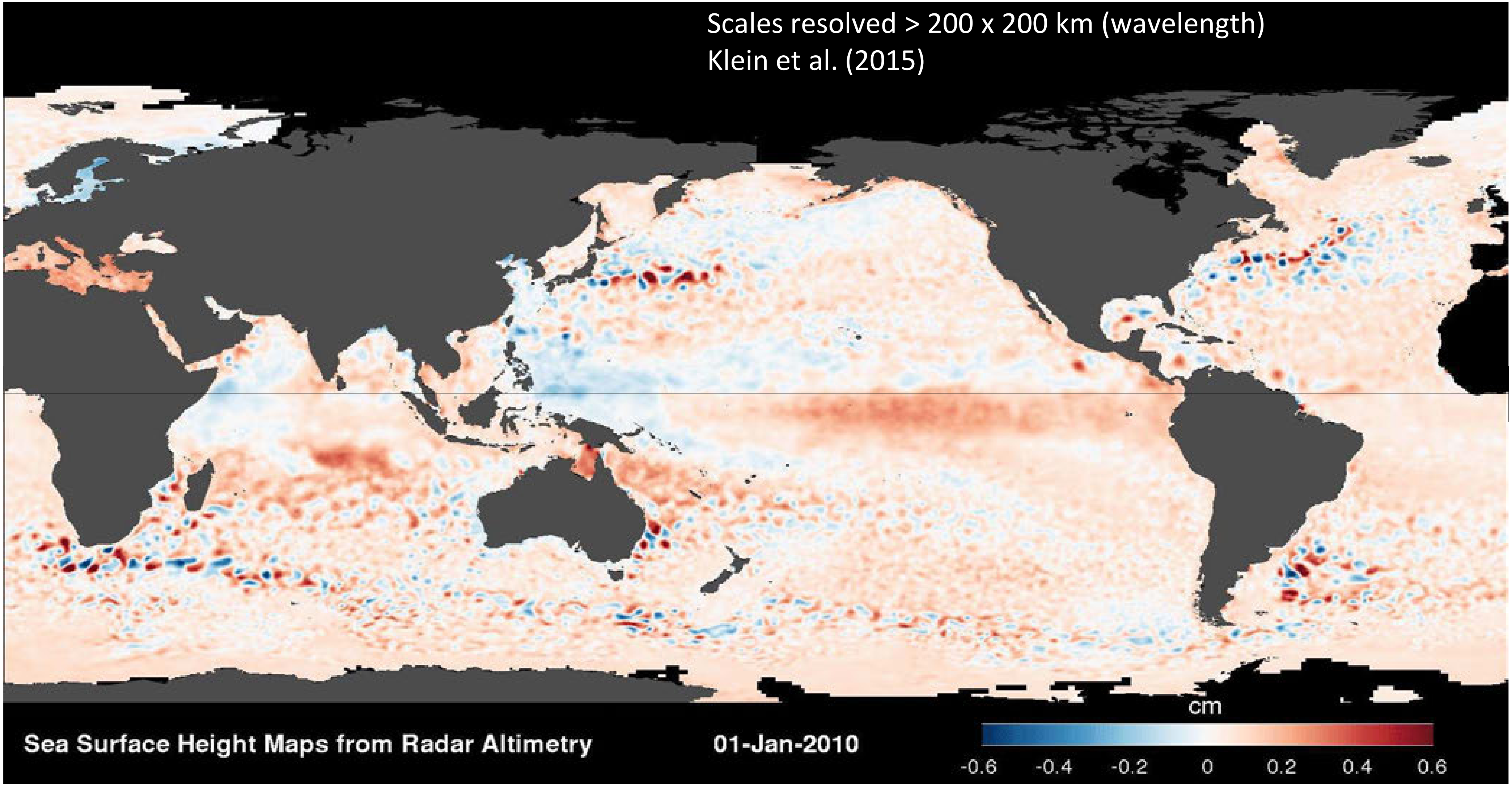
The ocean is a complex system with multiple processes and scales



Mesoscale and Submesoscale

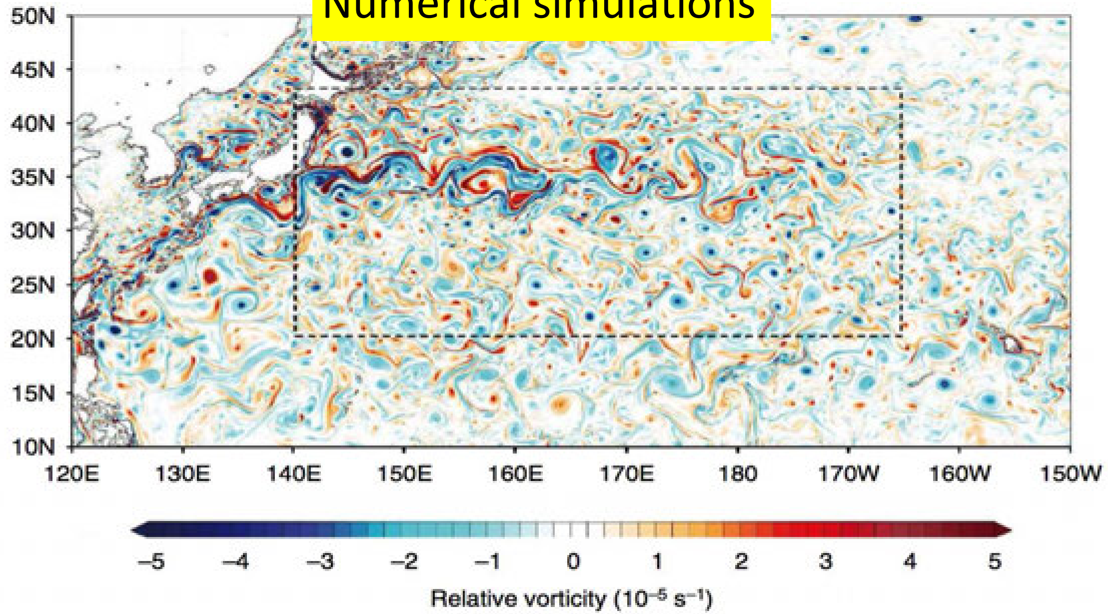
From a few km to hundreds of kms

From days to several months


Scales resolved > 200 x 200 km (wavelength)
Klein et al. (2015)
Sea Surface Height Maps from Radar Altimetry
01-Jan-2010
cm
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

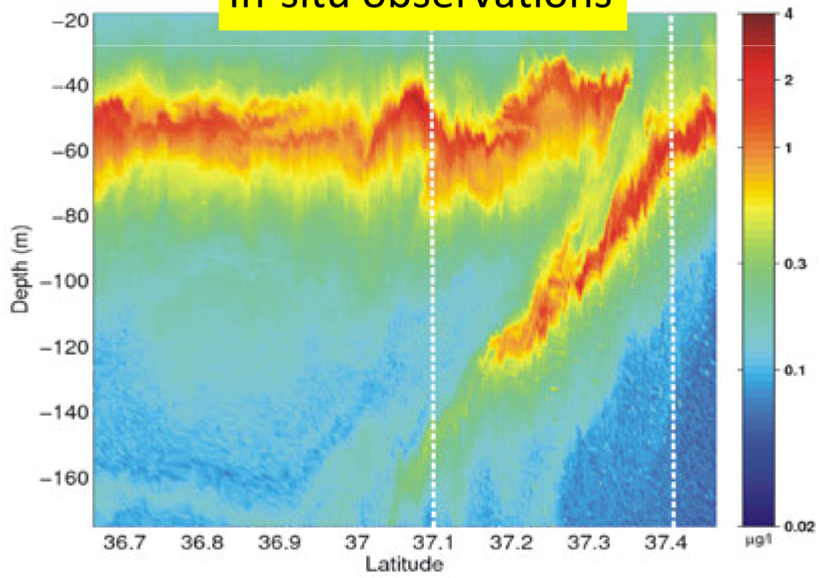
Scientific motivation:
Improve our understanding of meso and sub-mesoscale processes and their impacts on biogeochemistry

Numerical simulations



Relative vorticity from primitive equations numerical simulations
Sasaki et al. (2014)

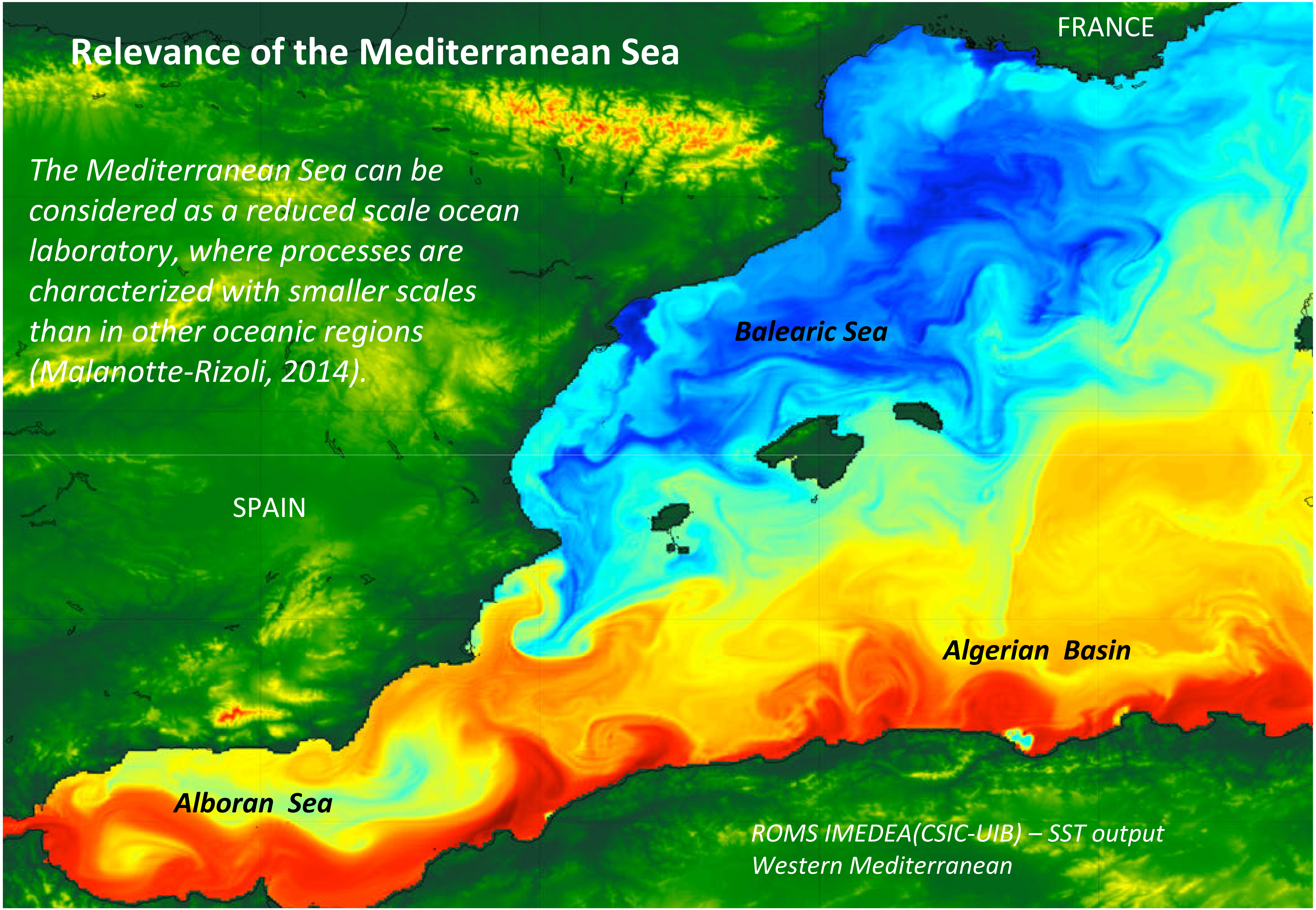
In-situ observations



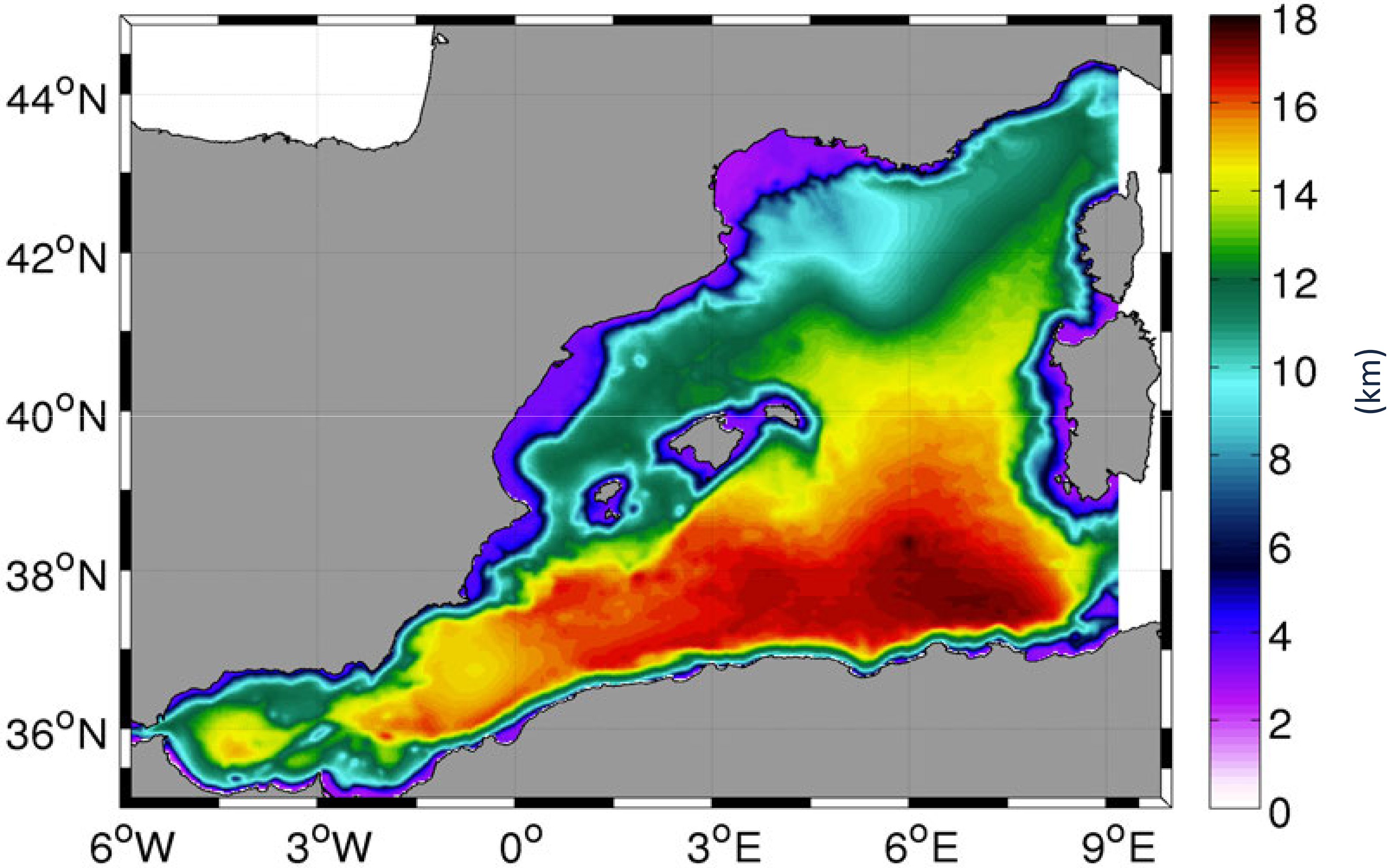
Vertical section of chlorophyll from glider data in the Eastern Alboran Sea (Western Mediterranean)
Ruiz et al. (2009)

Relevance of the Mediterranean Sea

The Mediterranean Sea can be considered as a reduced scale ocean laboratory, where processes are characterized with smaller scales than in other oceanic regions (Malanotte-Rizoli, 2014).

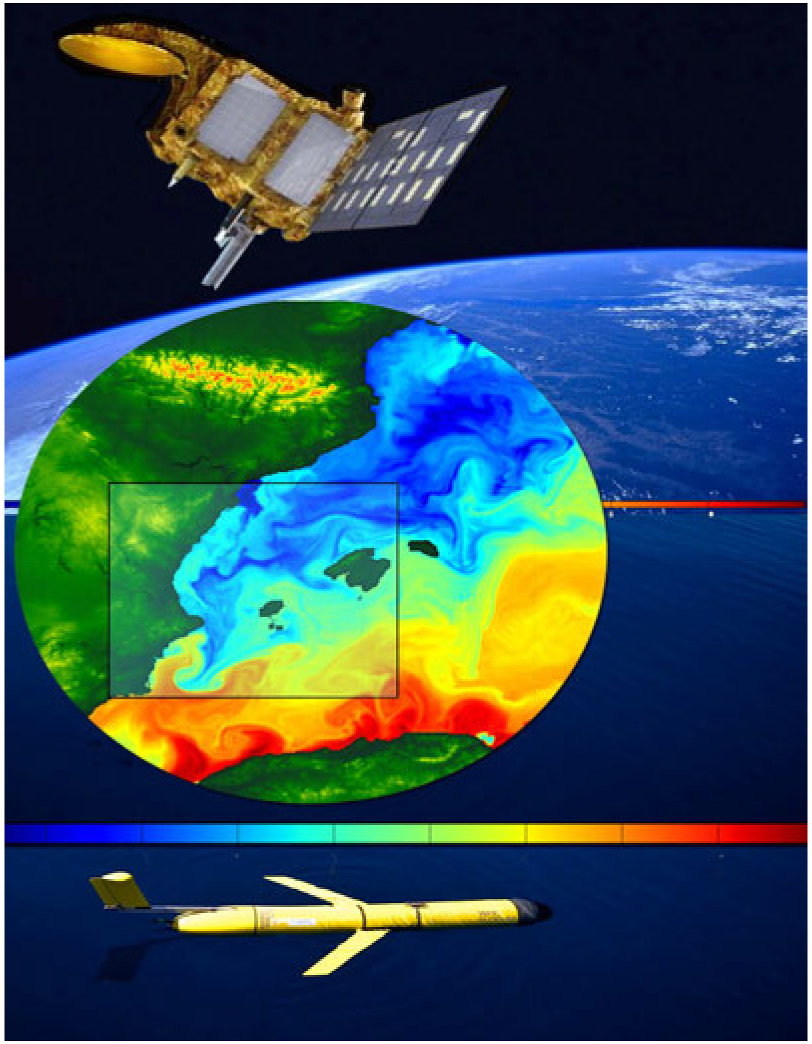


The Mediterranean Sea is characterized by fine-scale structures



First Rossby radius of deformation from a numerical simulation (1/32°) . Escudier et al. (2015)

Multi-sensor experiments



- Multi-sensor experiments (gliders, drifters, ship, radar, argo, satellite)
- Sustained monitoring of the Mallorca and Ibiza channels
  - Bouffard et al. (2010, 2012)
  - Escudier et al. (2013)
  - Heslop et al. (2013)
  - Ruiz et al. (2009a,b, 2012)
  - Pascual et al. (2010, 2013, 2015)
  - Tintoré et al. (2013)
  - Troupin et al. (2015)

60 glider missions
From 2006 to 2015 in the Wmed
updated 13/Oct/2015

IMEDEA CSIC Universitat de les Illes Balears

SOCIB Balearic Islands Coastal Observing and Forecasting System

12753 nautic miles - 1081 days
33069 full CTD casts
+ oxygen, chlorophyll, turbidity
(from surface to 200m or 1000 m)

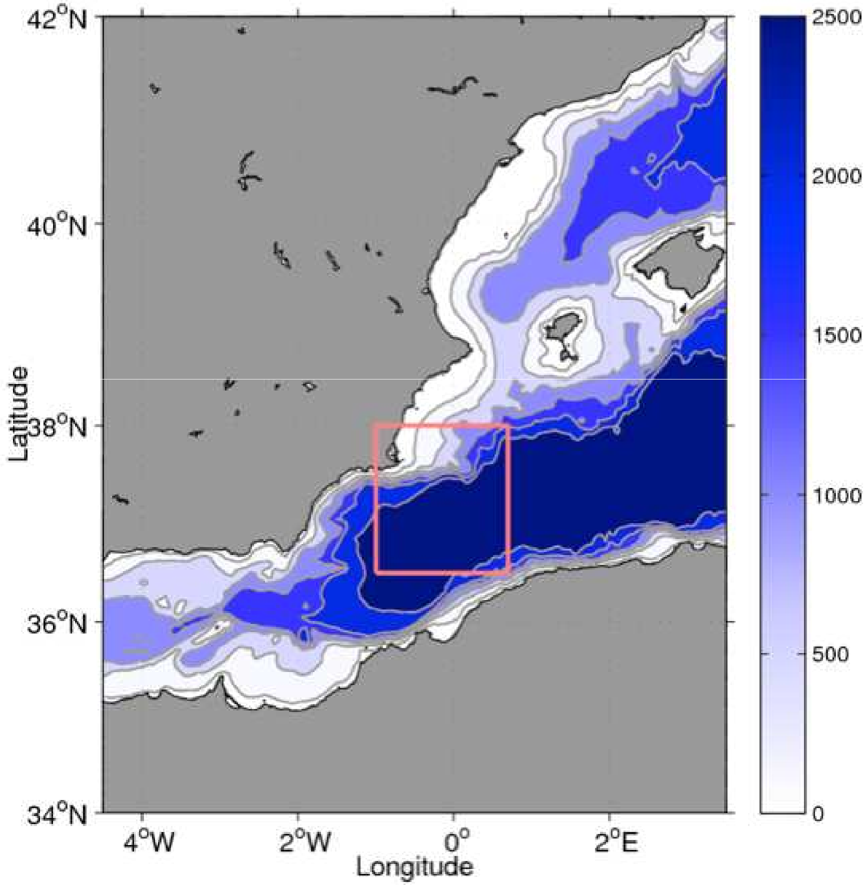
ALBOREX multi-platform and interdisciplinary experiment

High resolution observations

Dates: 24 May – 2 June 2014

Area: Eastern Alboran Sea
Ship: R/V SOCIB

- 25 drifters
- 2 gliders
- 3 Argo floats
- ADCP
- Thermosalinograph
- 80 CTDs
- Nutrients
- Chlorophyll
- Remote sensing
- Modeling

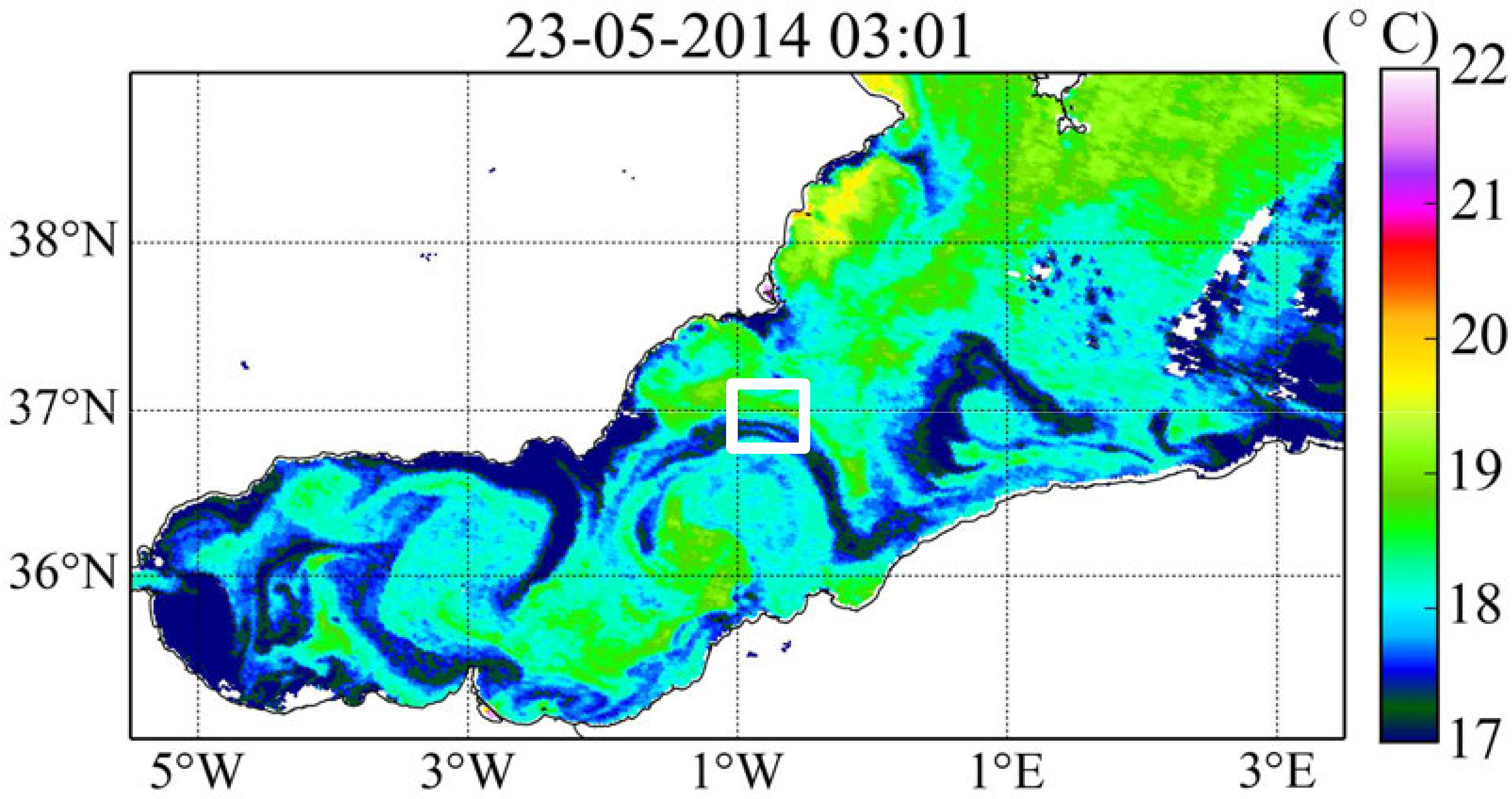


Lead by IMEDEA with strong involvement from SOCIB, OGS, CNR, WHOI, McGill U.

OBJECTIVE

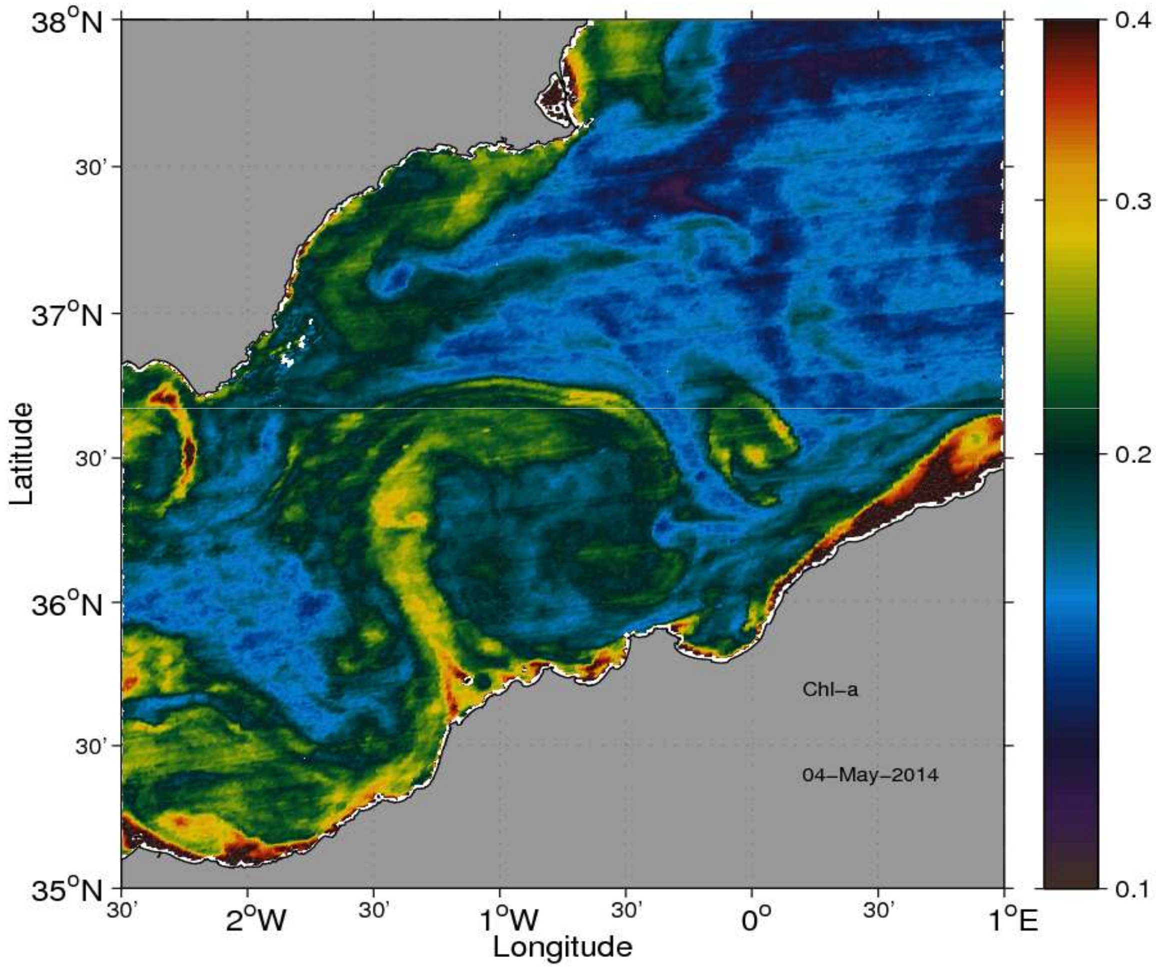
Improve our understanding of meso and sub-mesoscale processes and their impacts on biogeochemistry in an area characterized by intense gradients

Oceanographic context from satellites
SST



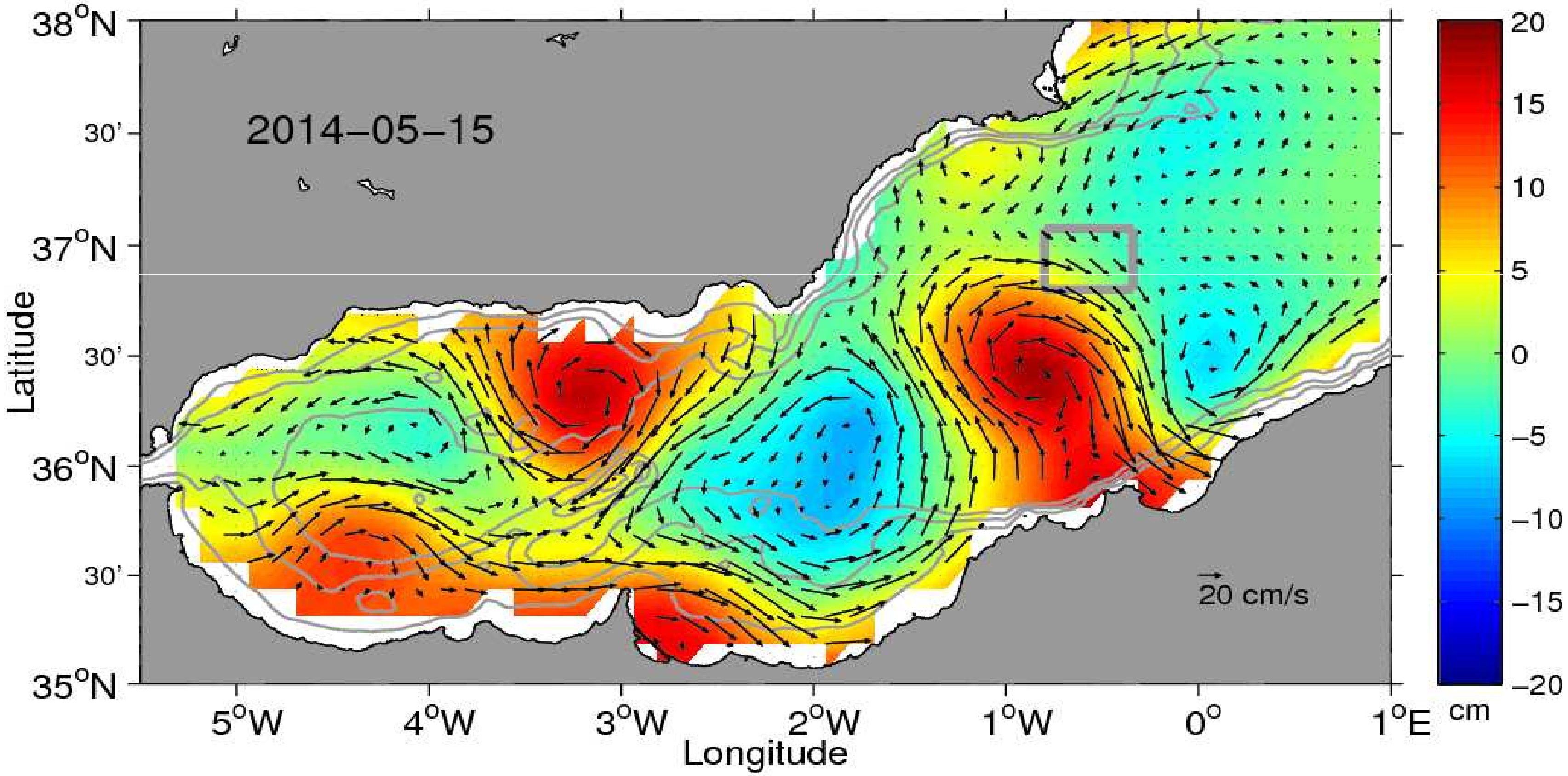
Modis SST - 23 May 2014

Oceanographic context from satellites
OCEAN COLOR



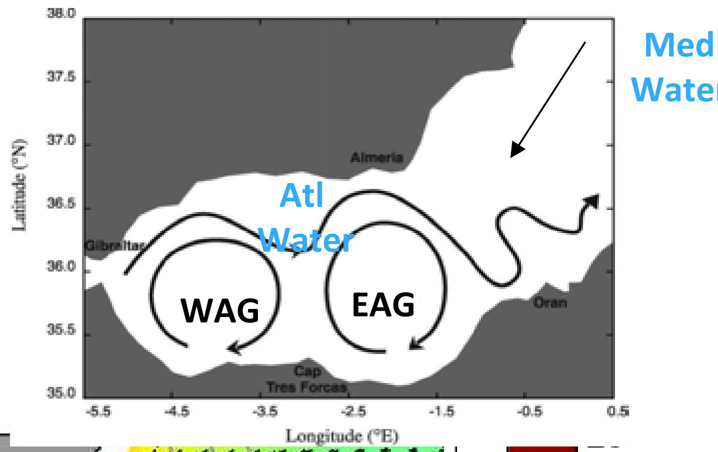
Modis Chl-A 4 May 2014

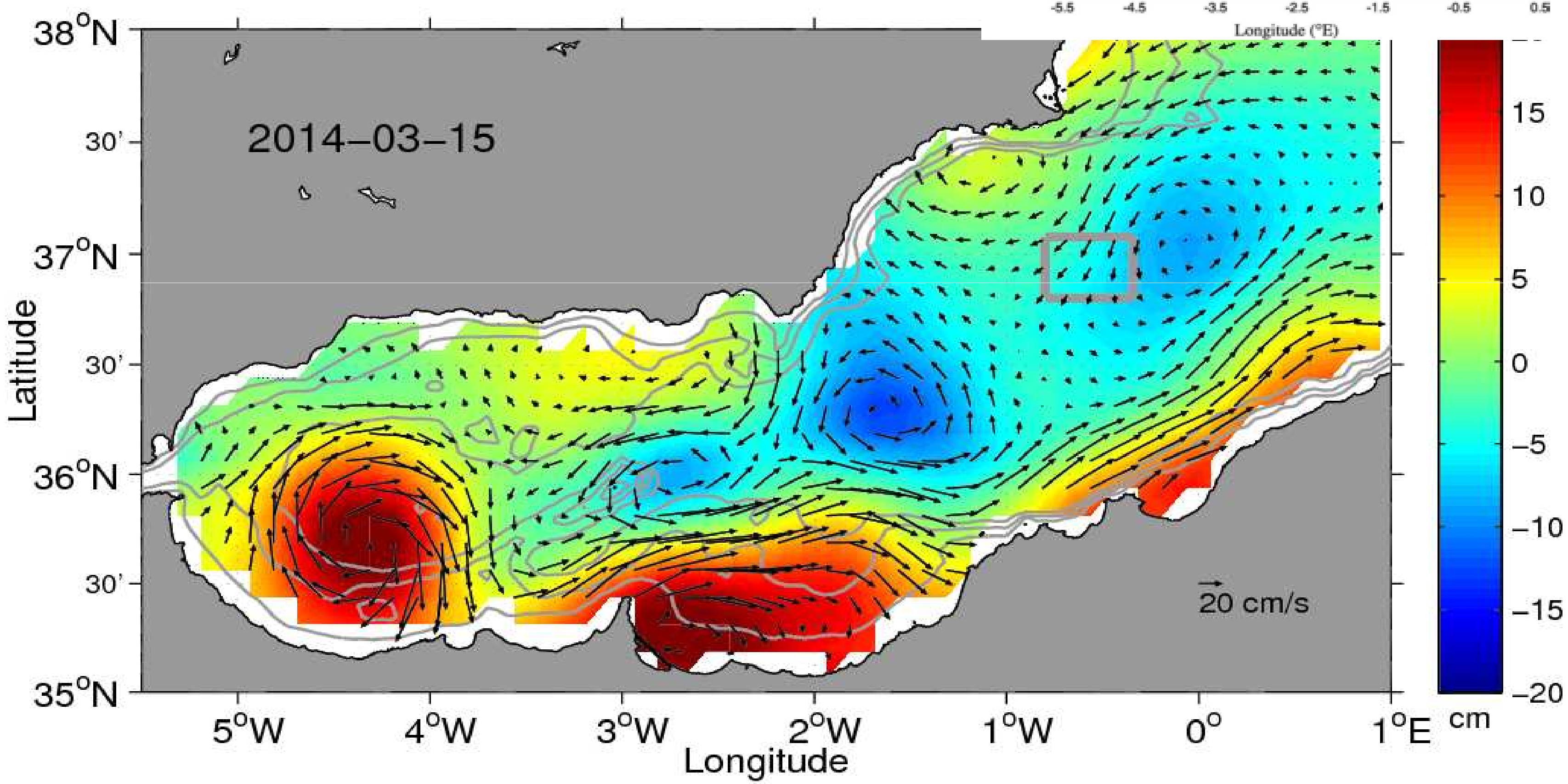
Oceanographic context from satellites
ALTIMETRY



Absolute Dynamic Topography and geostrophic altimeter fields from AVISO

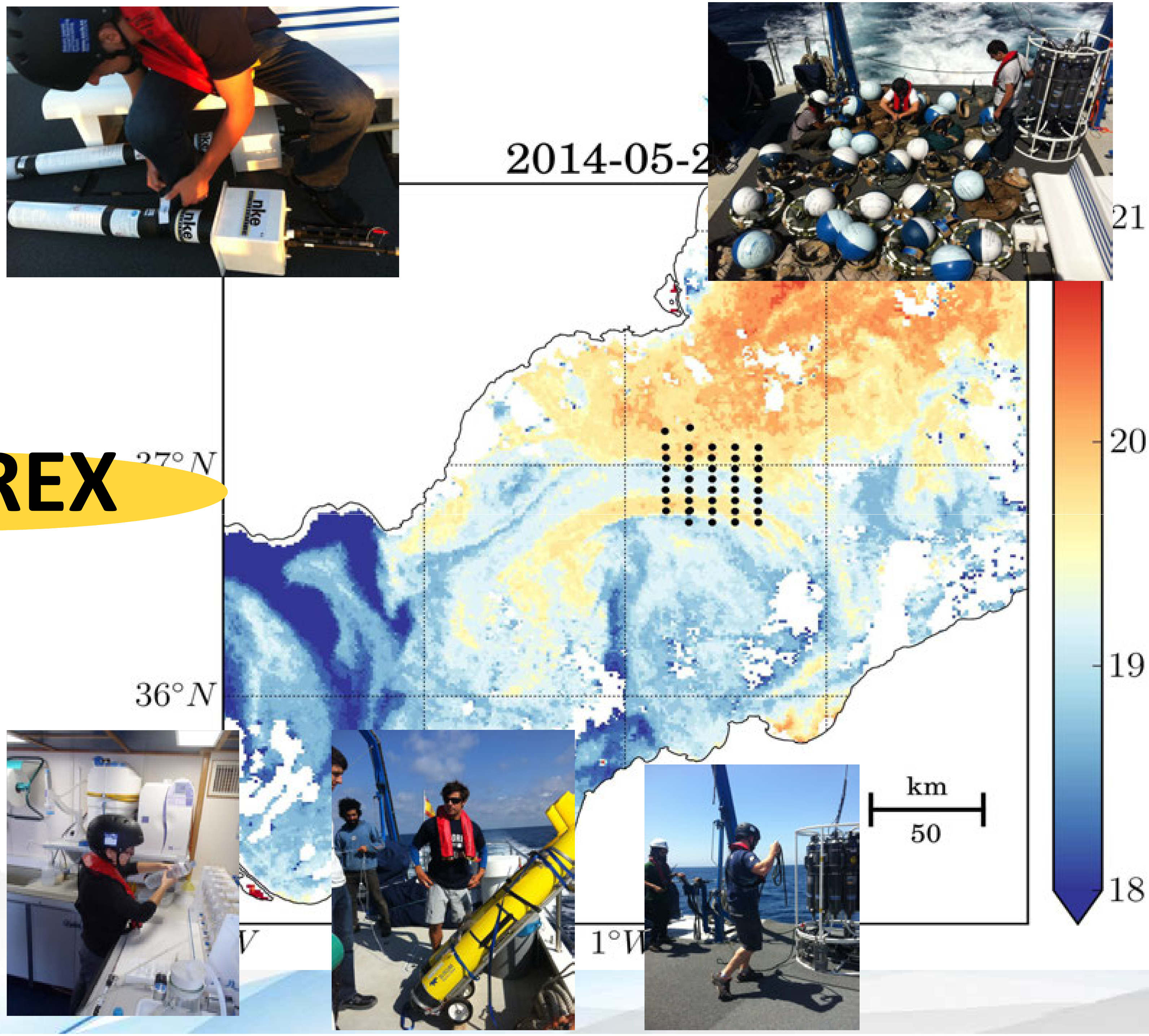
Oceanographic context from satellites
ALTIMETRY



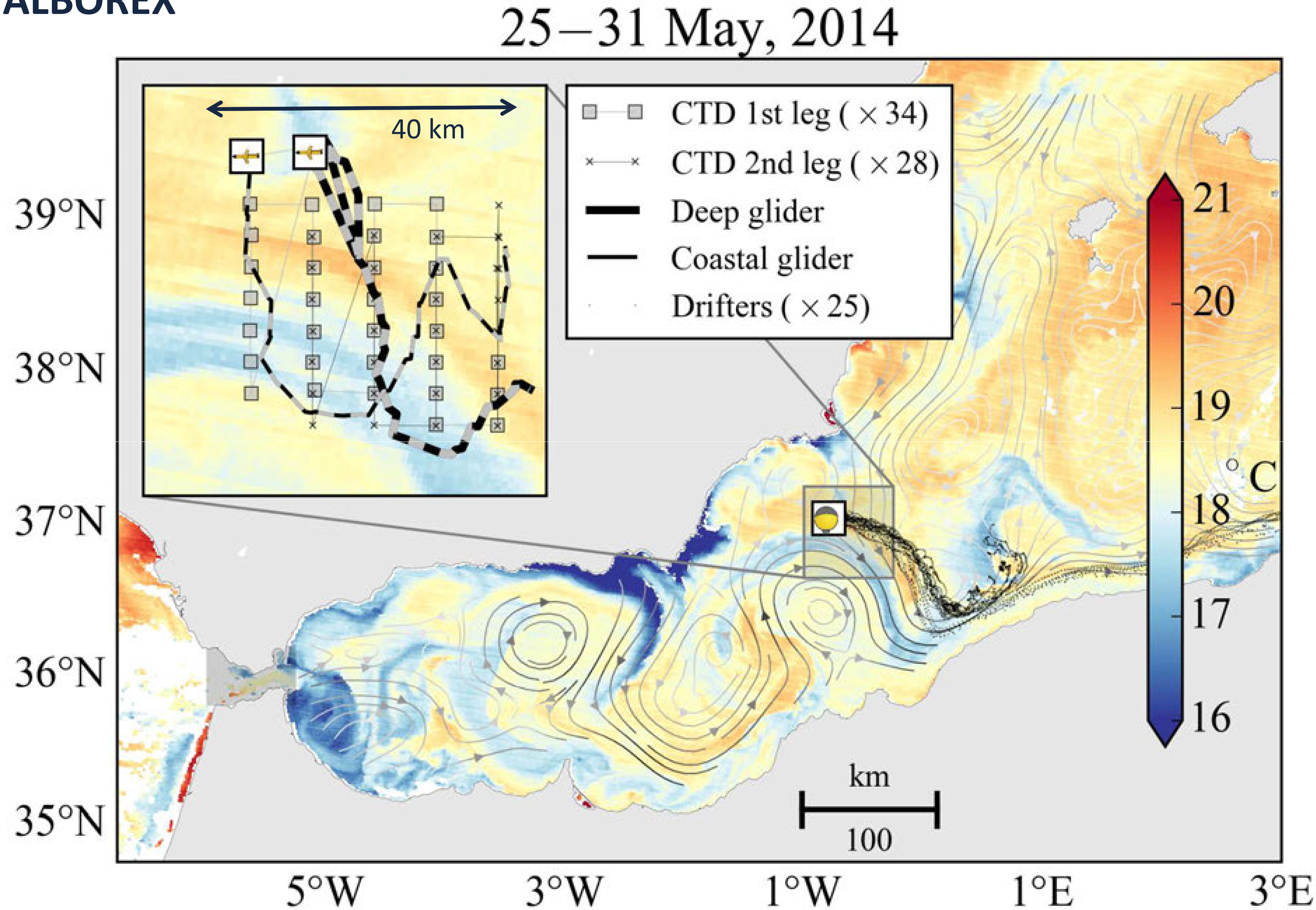


Absolute Dynamic Topography and geostrophic altimeter fields from AVISO

ALBOREX

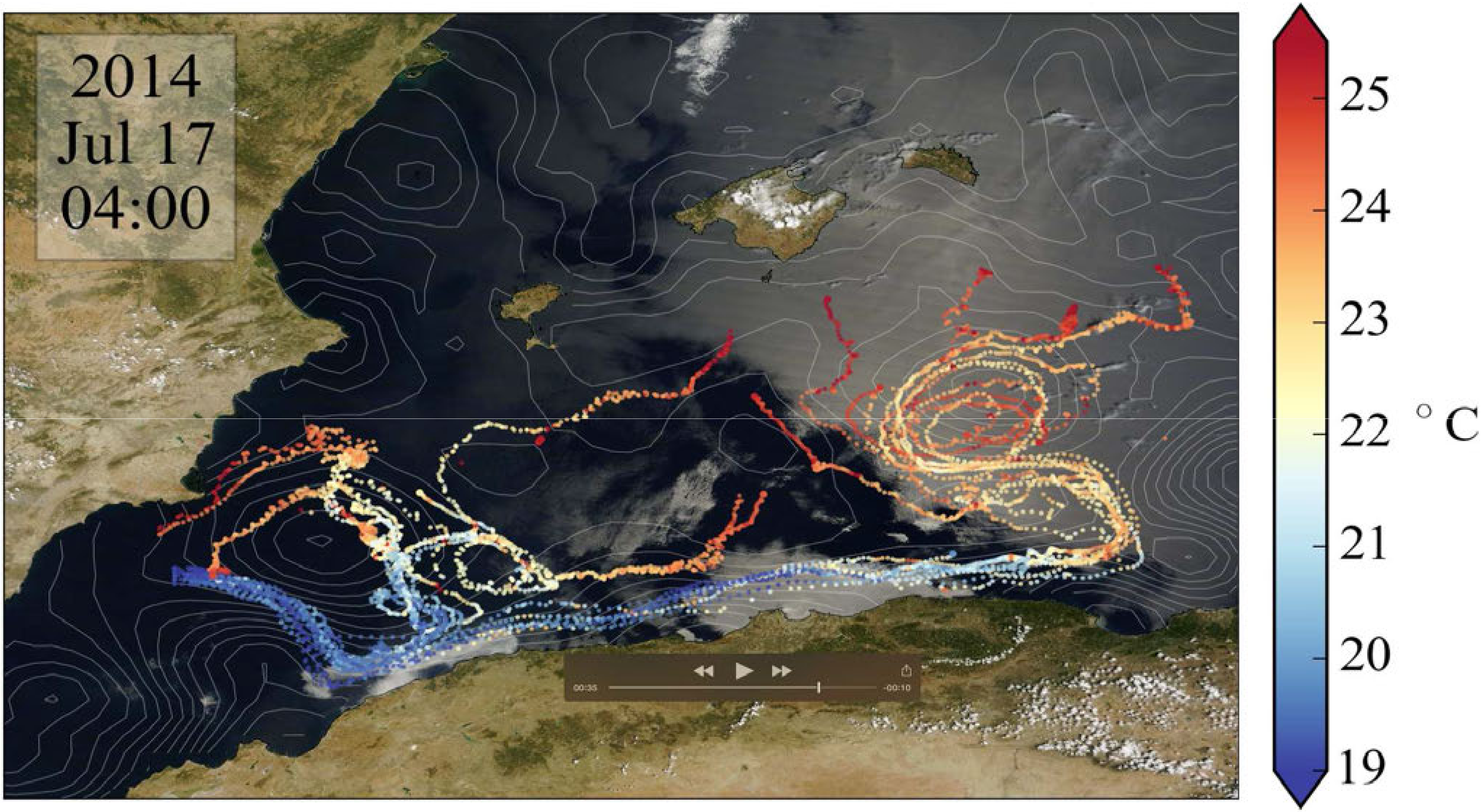


ALBOREX



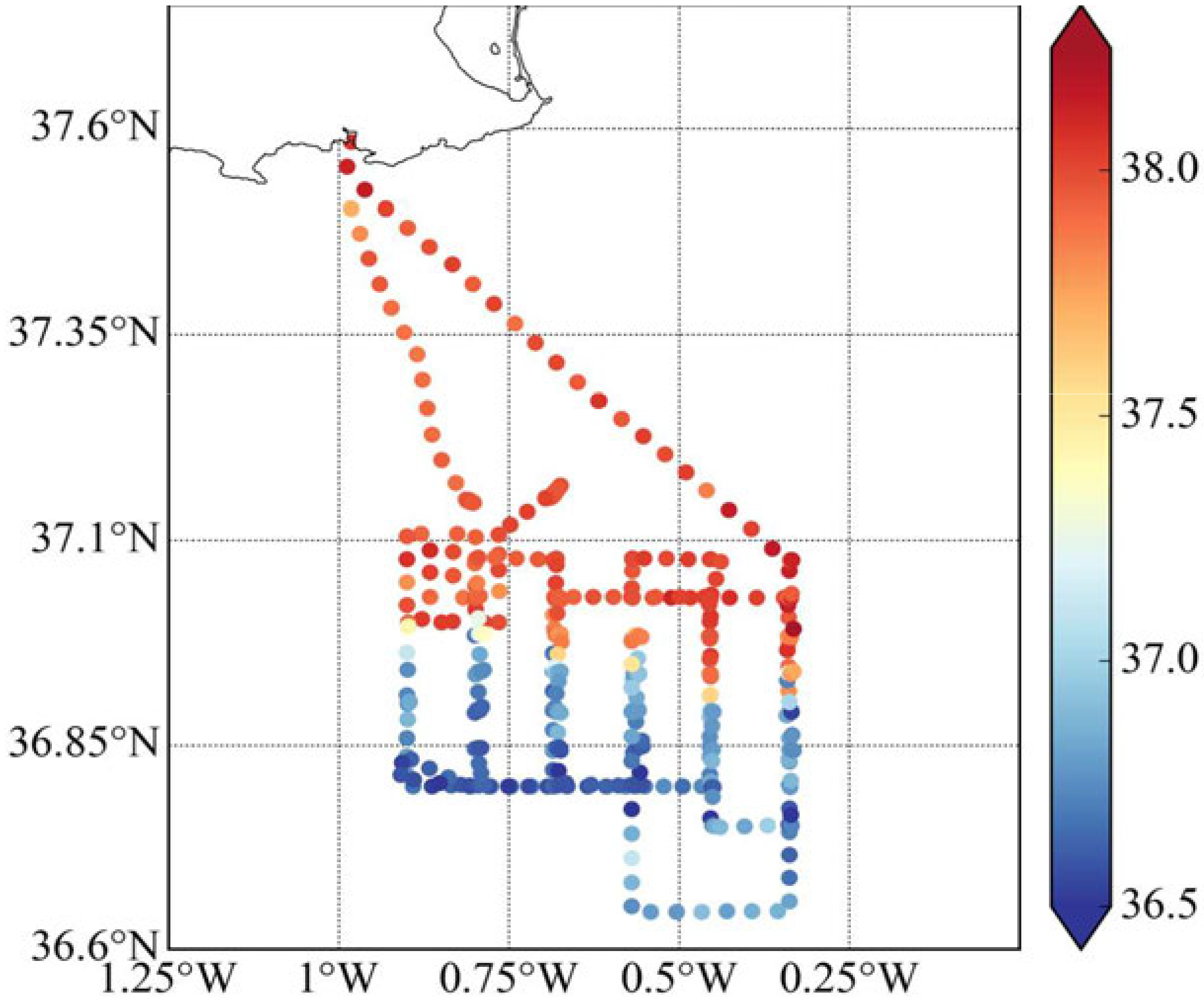
25–31 May, 2014
40 km
CTD 1st leg (× 34)
CTD 2nd leg (× 28)
Deep glider
Coastal glider
Drifters (× 25)
39°N
38°N
37°N
36°N
35°N
5°W
3°W
1°W
1°E
3°E
21
20
19
18
17
16
°C
km
100

DRIFTERS

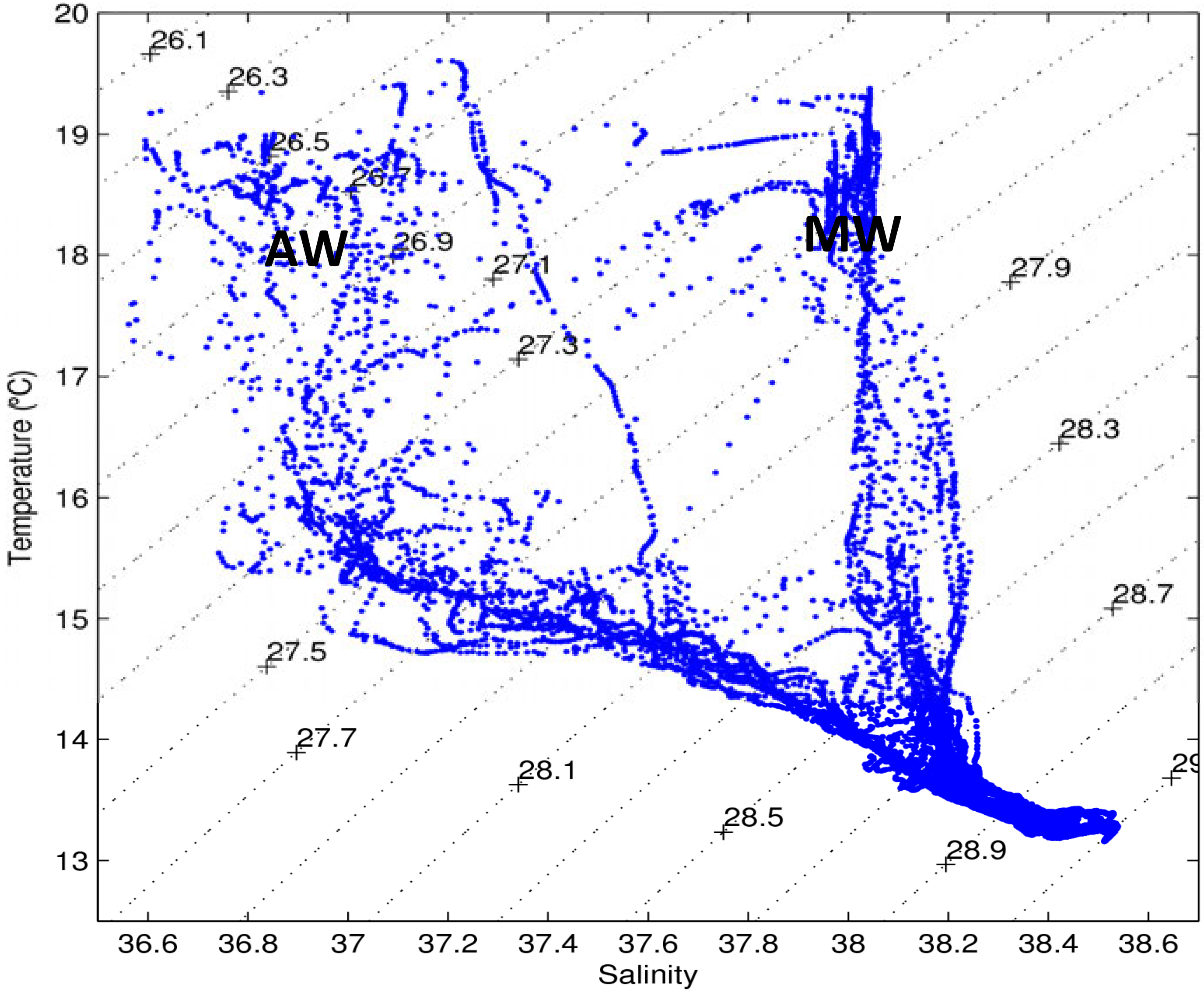


SVP drifter tracks between 25 May 2014 and 14 July 2014.

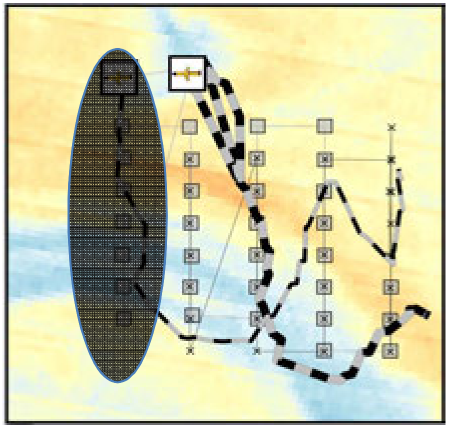
THERMOSALINOGRAPH
Surface salinity front (change of 1.4 in 5 km)

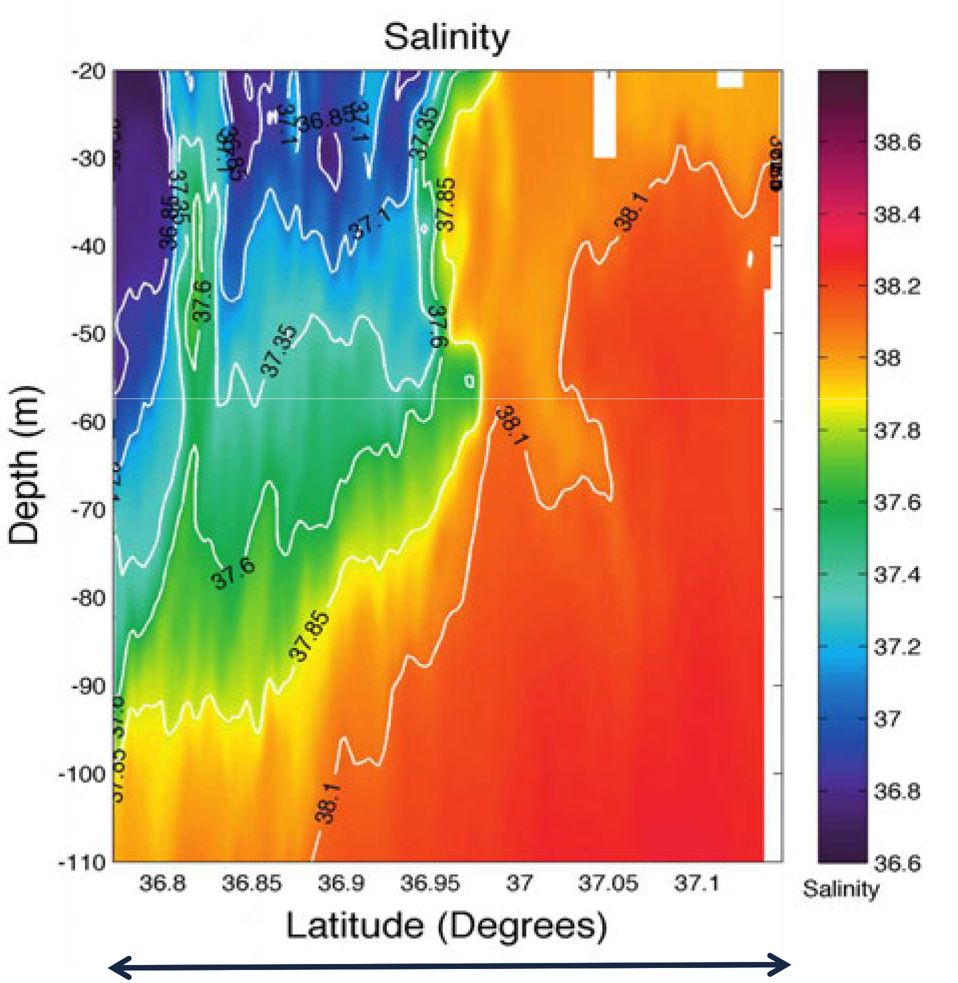


T-S diagram: CTD
Atlantic and Mediterranean waters



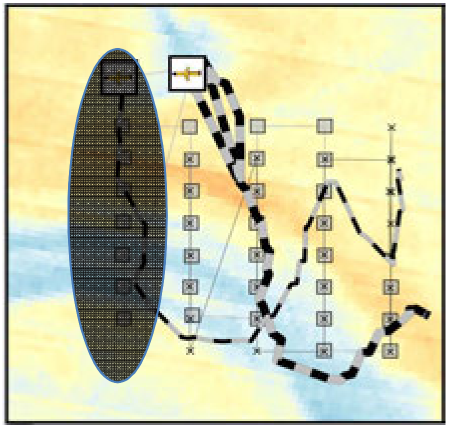
ALBOREX GLIDER
SALINITY – (400 m resolution)

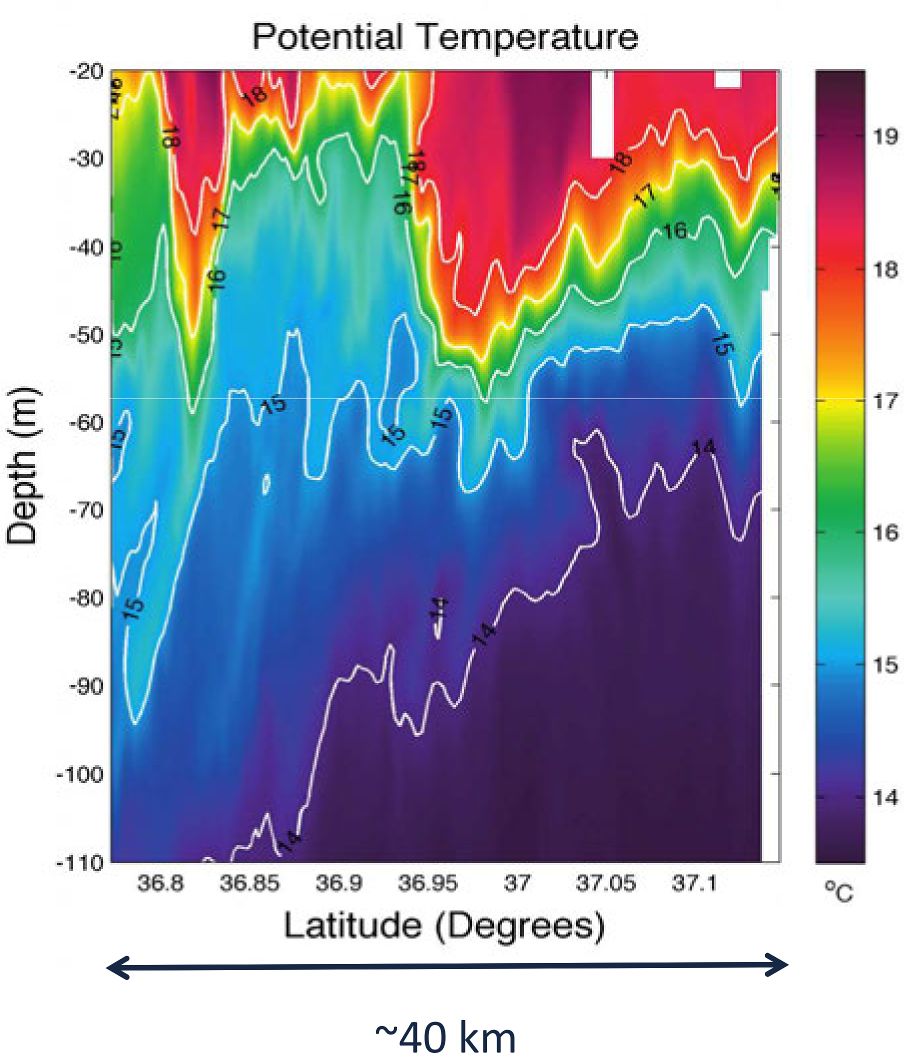




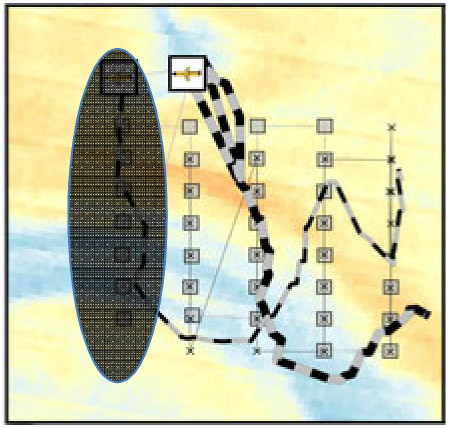
~40 km

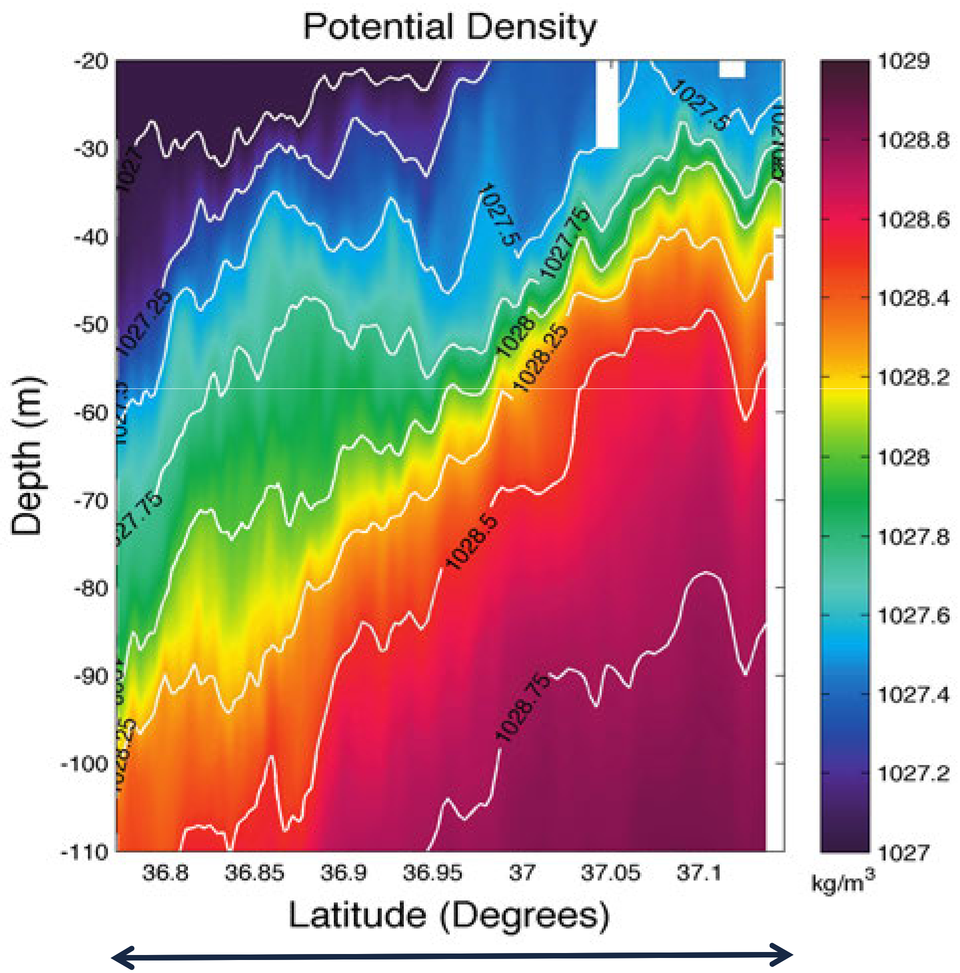
ALBOREX GLIDER
POTENTIAL TEMPERATURE – (400 m resolution)





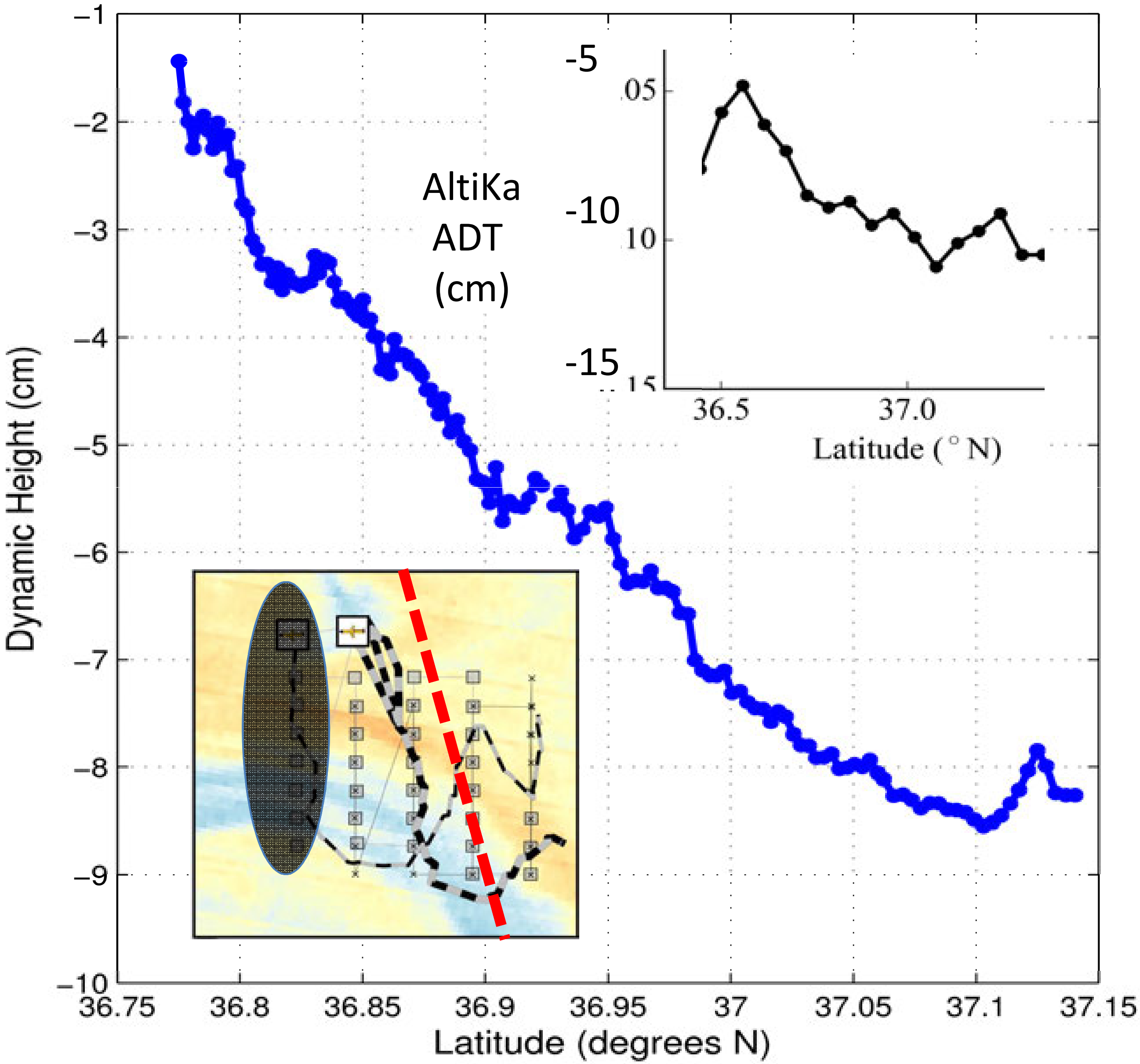
ALBOREX GLIDER
POTENTIAL DENSITY





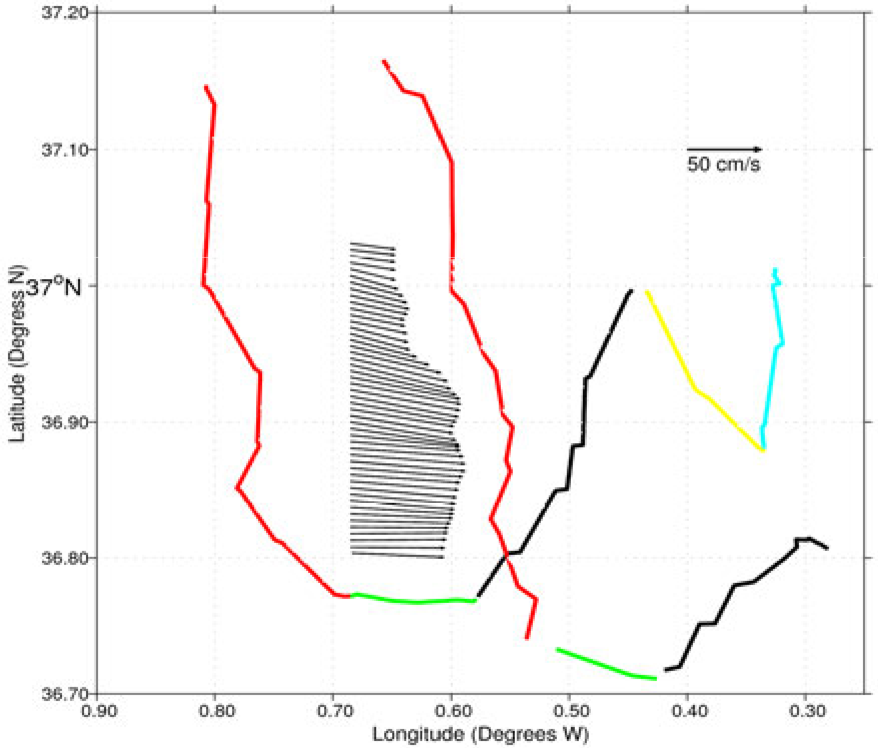
~40 km

DH glider / ADT altimetry

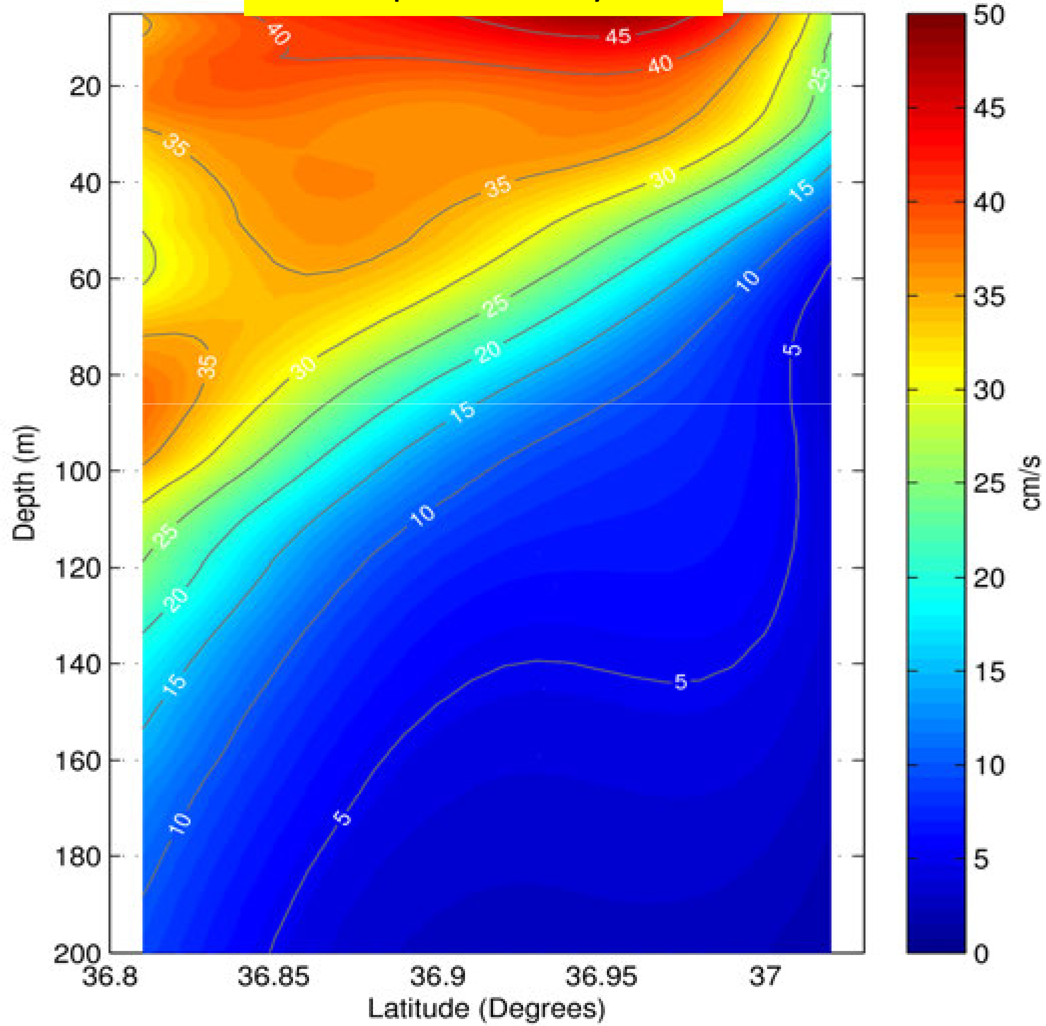


Geostrophic and ADCP velocities
Max. surface currents from ADCP of 70 cm/s

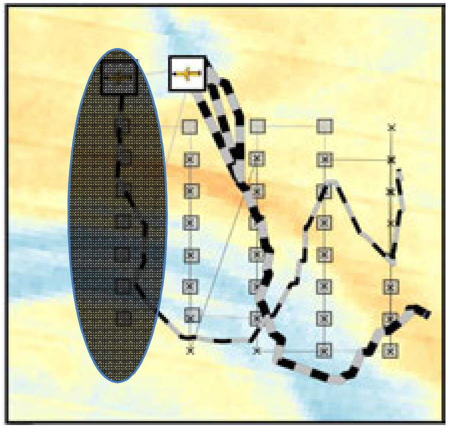
ADCP between Glider transects

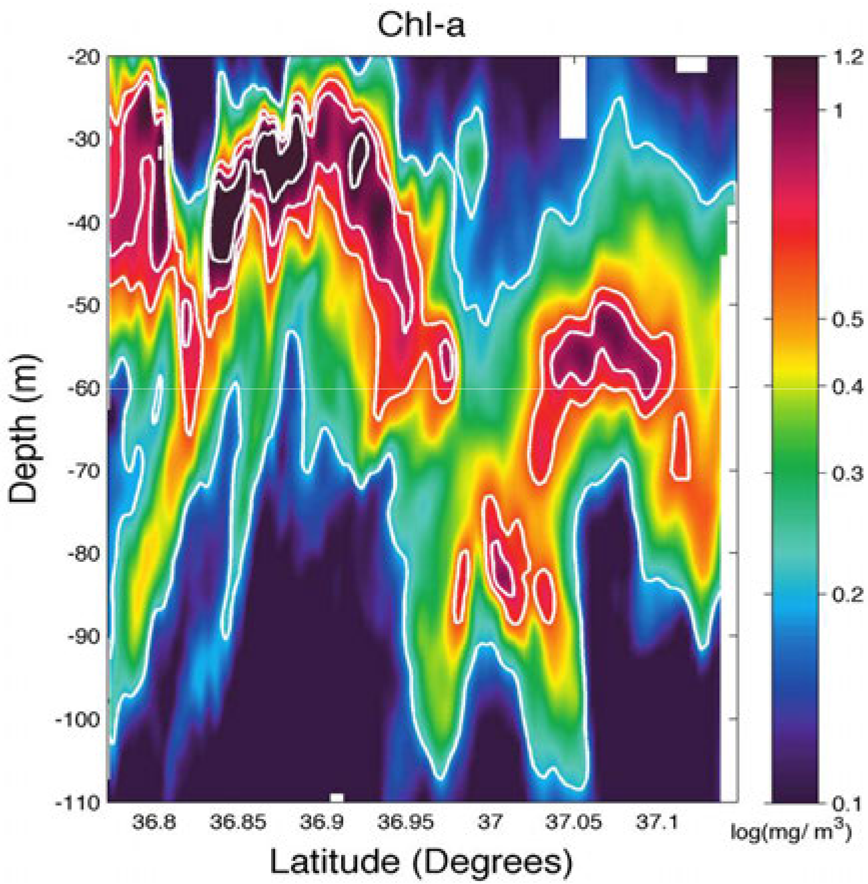


Geostrophic velocity



ALBOREX GLIDER
CHLOROPHYLL (400 m resolution)





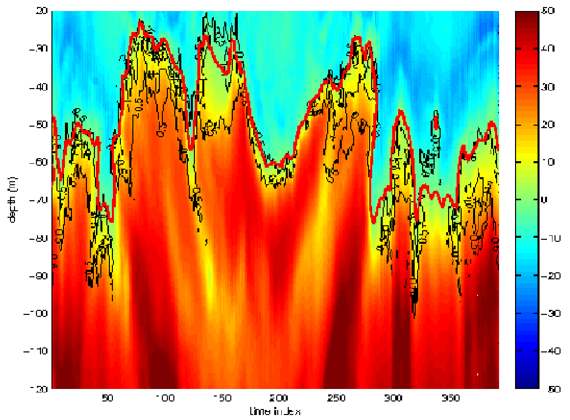
Upwelling?

Vertical subduction?

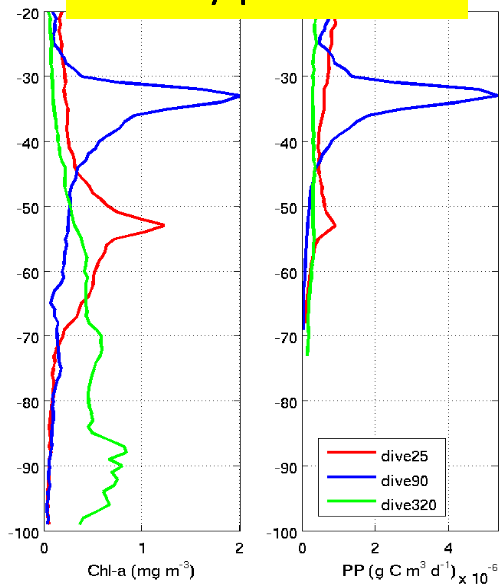
~40 km

Fine-scale features in biochemistry

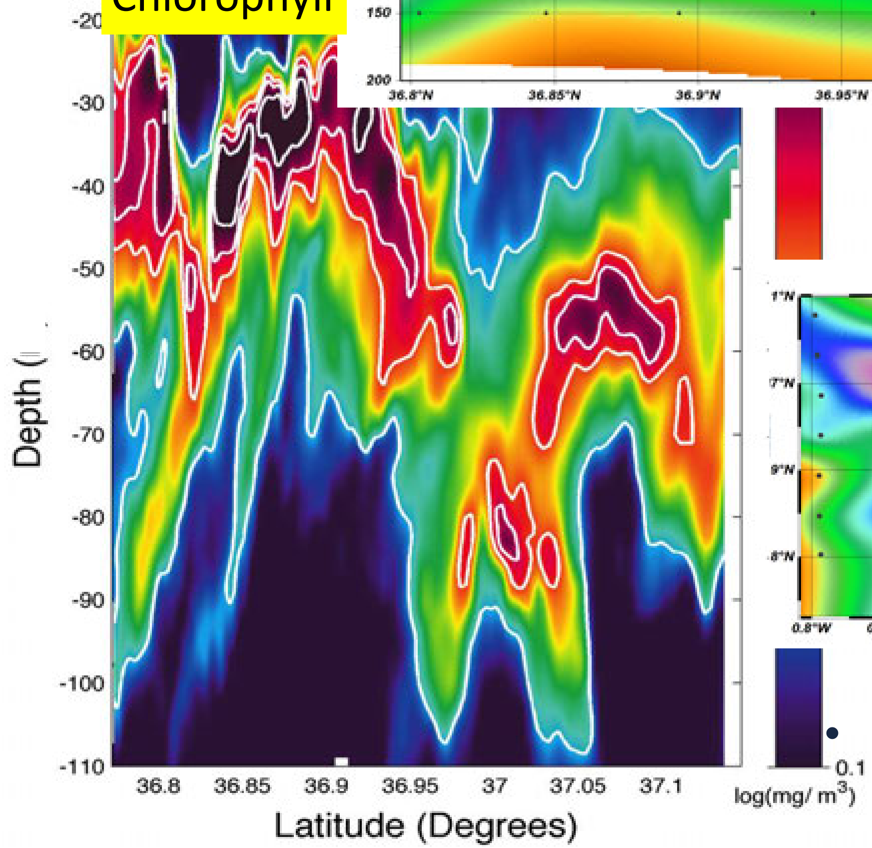
Oxygen - AOU



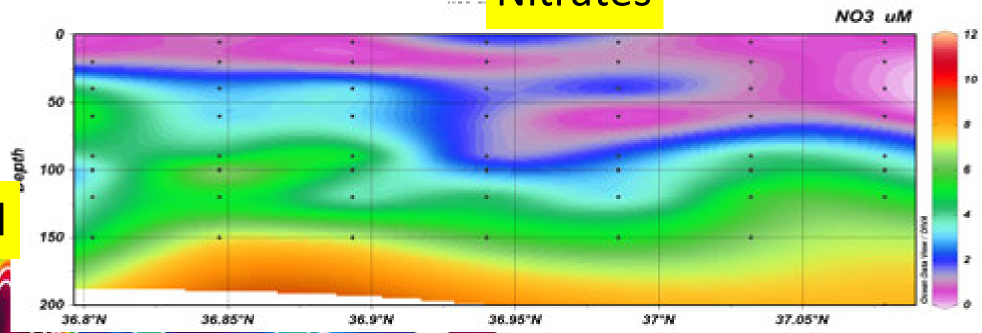
Primary production



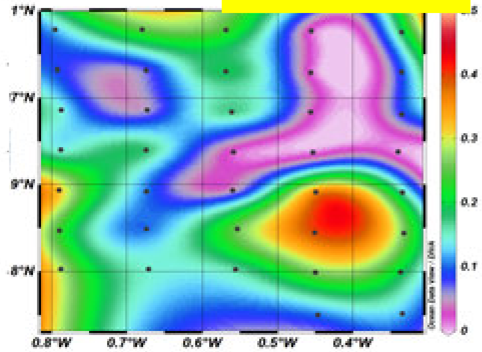
Chlorophyll



Nitrates



Phosphates



- Role of meso and submesoscale dynamics?
- Vertical fluxes?

Meso and submesoscale dynamics

Mesoscale Dynamics

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

Submesoscale Dynamics

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

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*

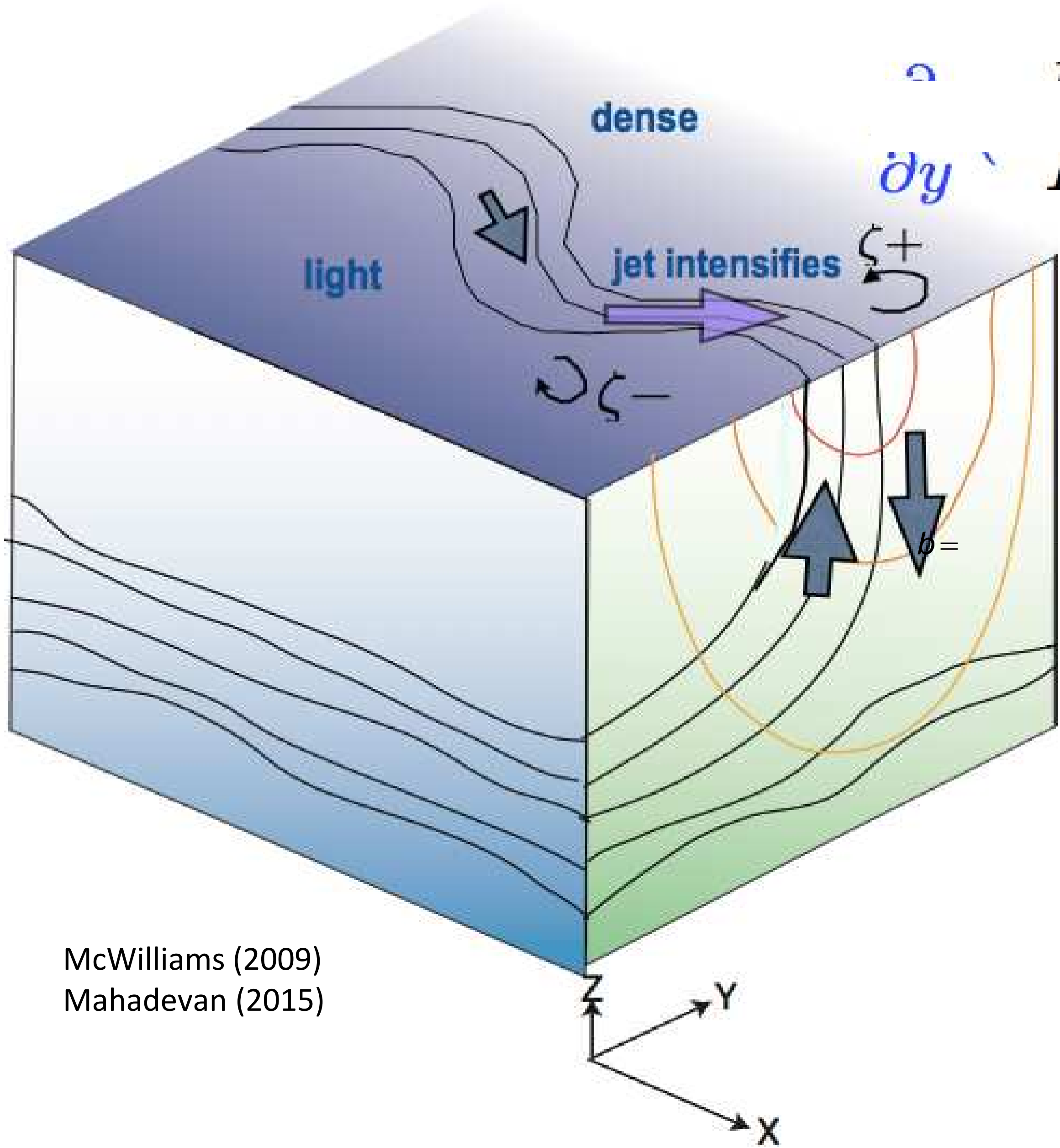
N: *Brunt-Vaisala frequency*

$$R_o << O(1)$$

Mesoscale Dynamics

Hoskins et al. (1978)
Tintoré et al. (1991)
Pollard and Regier (1992)
Pascual et al. (2004)
Ruiz et al. (2009)
Pascual et al. (2015)

Ocean frontogenesis



McWilliams (2009)
Mahadevan (2015)

Buoyancy

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

$$\frac{Db}{Dt} = \frac{\partial b}{\partial t} + u b_x + v b_y = 0$$

Conserved in the absence of forcing

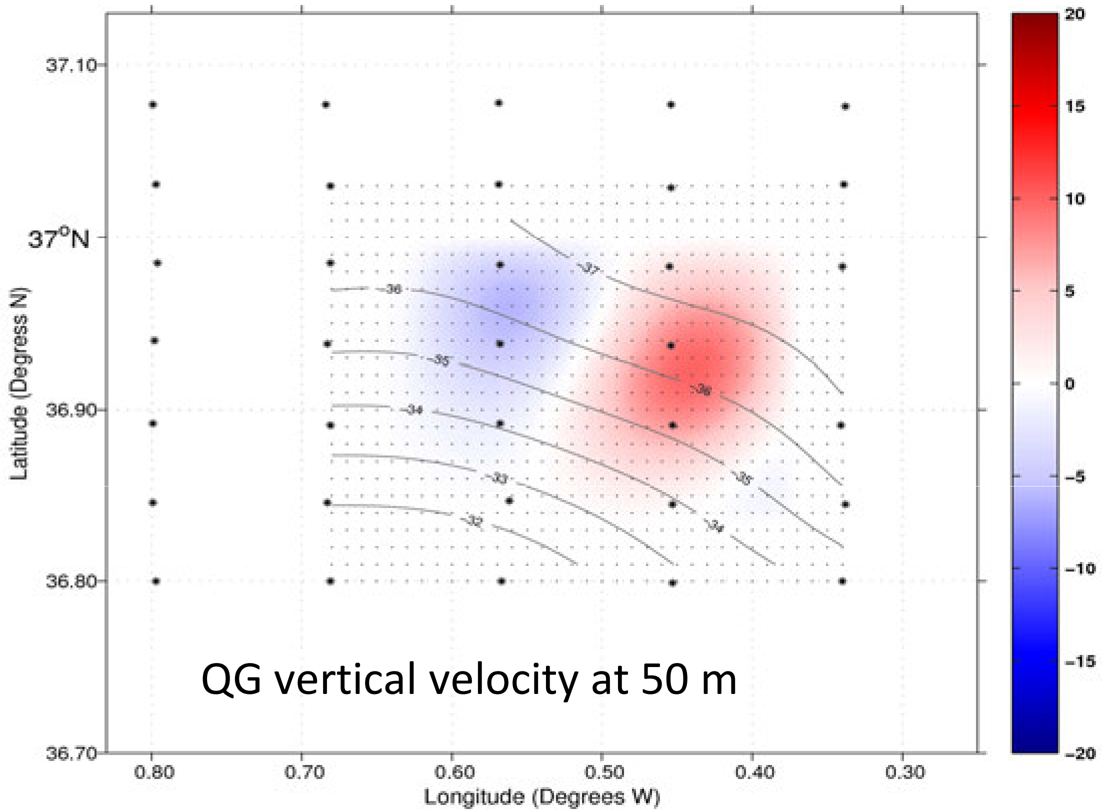
$$\frac{Db}{Dt} = 0$$

Front intensifies and buoyancy gradients and relative vorticity increase

$$R_o = \zeta/f = O(1)$$

Submesoscale Dynamics

ALBOREX:
Quasi-Geostrophic vertical velocity



ζ +f increases → H increases → Downwelling

ζ +f decreases → H decreases → Upwelling

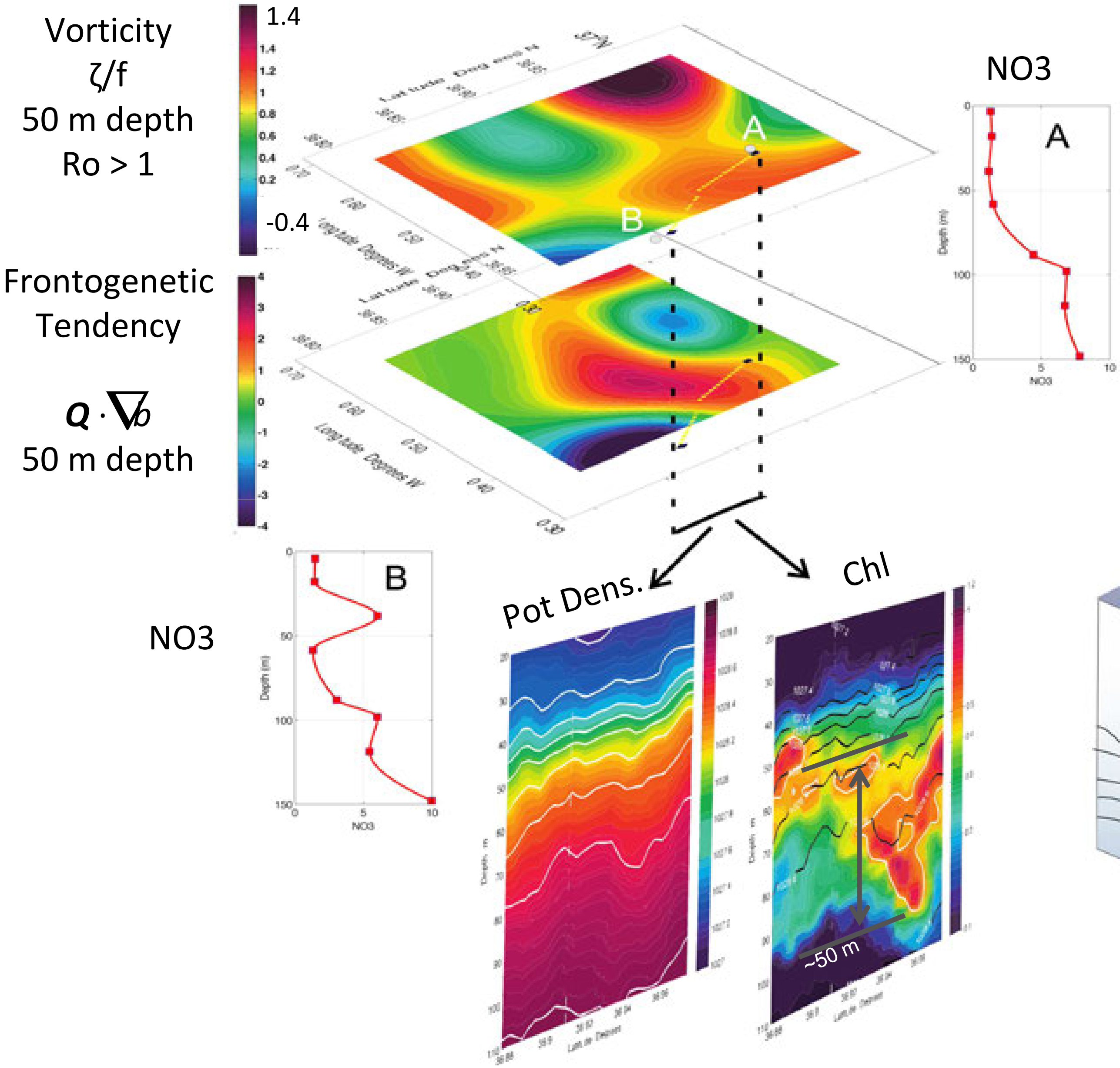
Order 10 m/day

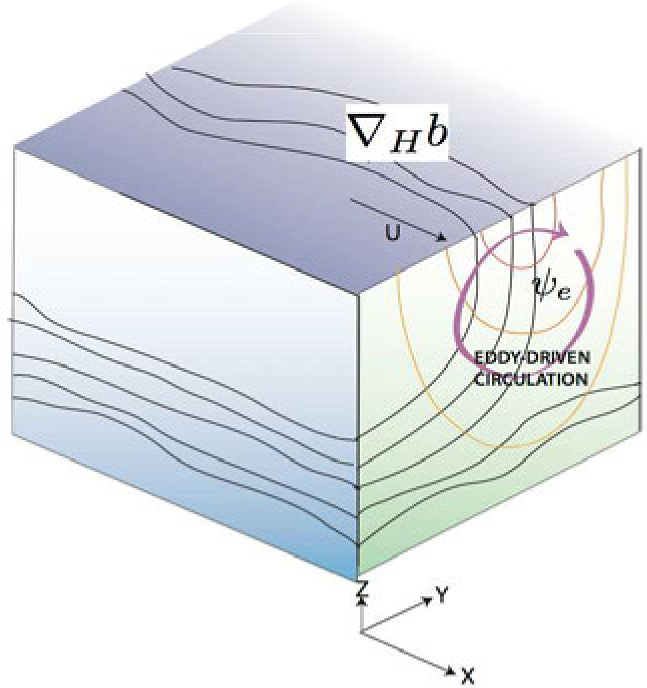
QG-w patterns are consistent with those predicted by QG theory.

Filtering **<u>of scales <20 km</u>**

Ro << 1

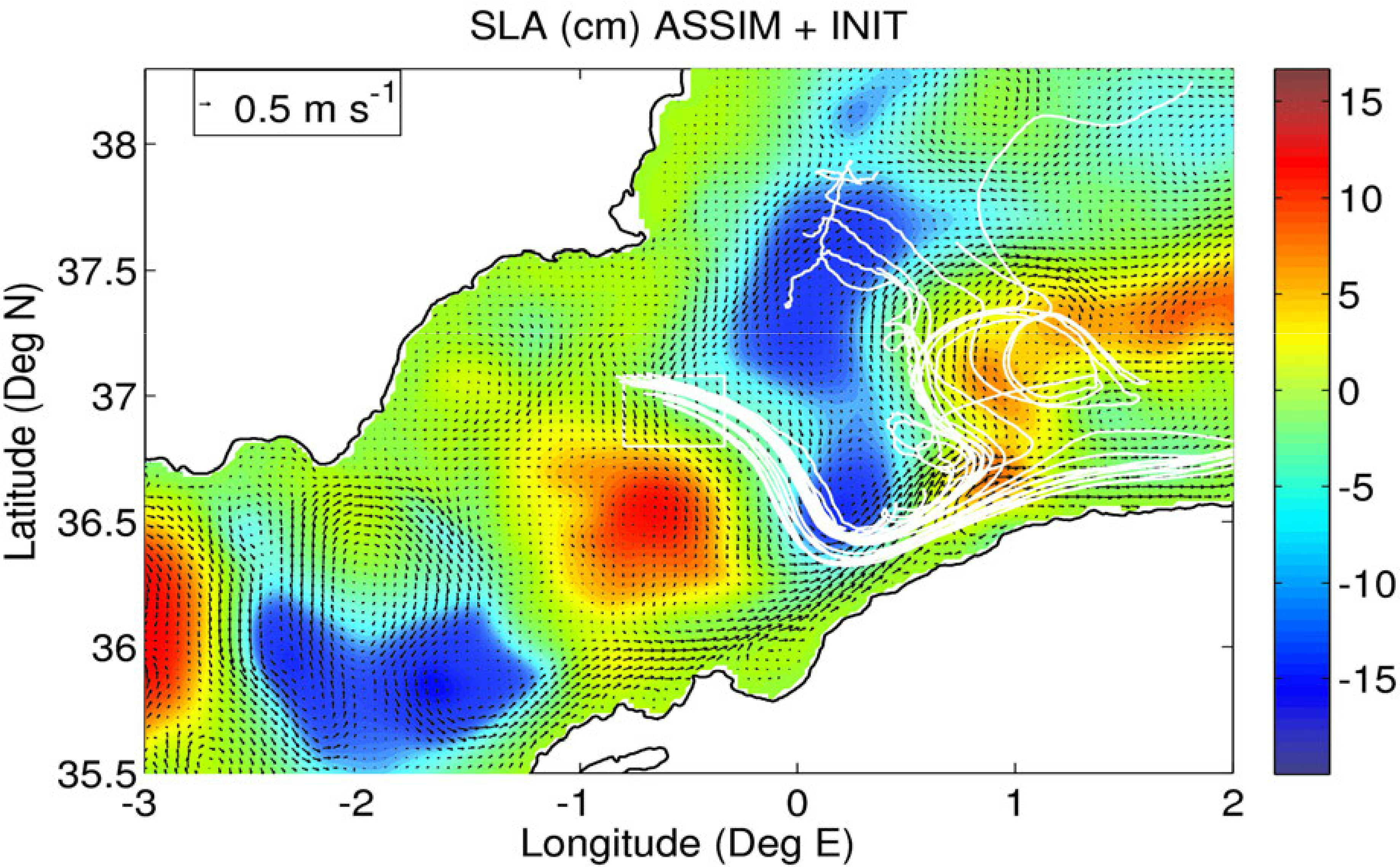
Ocean frontogenesis: evidences from ALBOREX observations



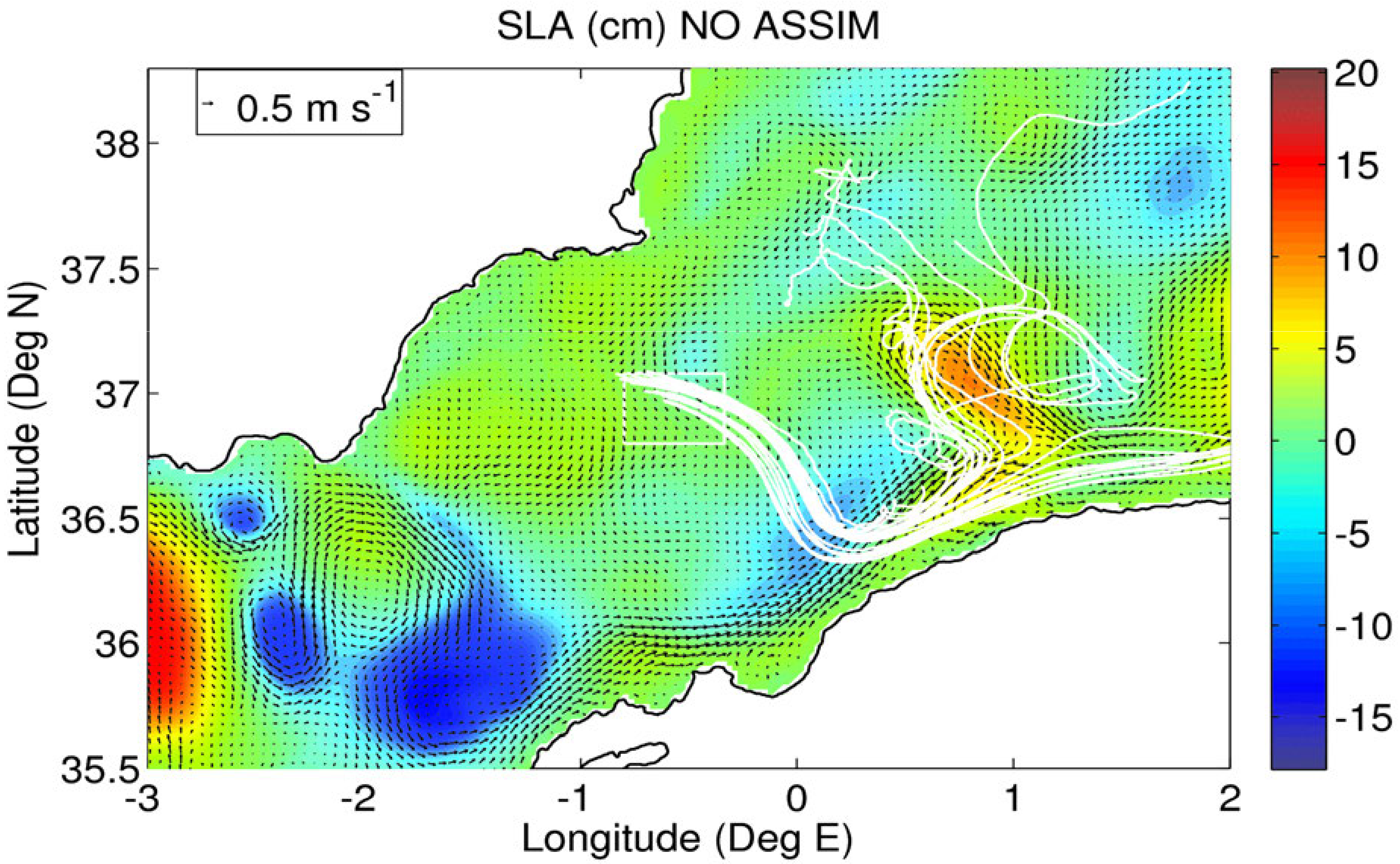


Observations complemented with numerical simulations

(WMOP operational model – 2 km – assimilation of ALBOREX OBS + SST + SLA)



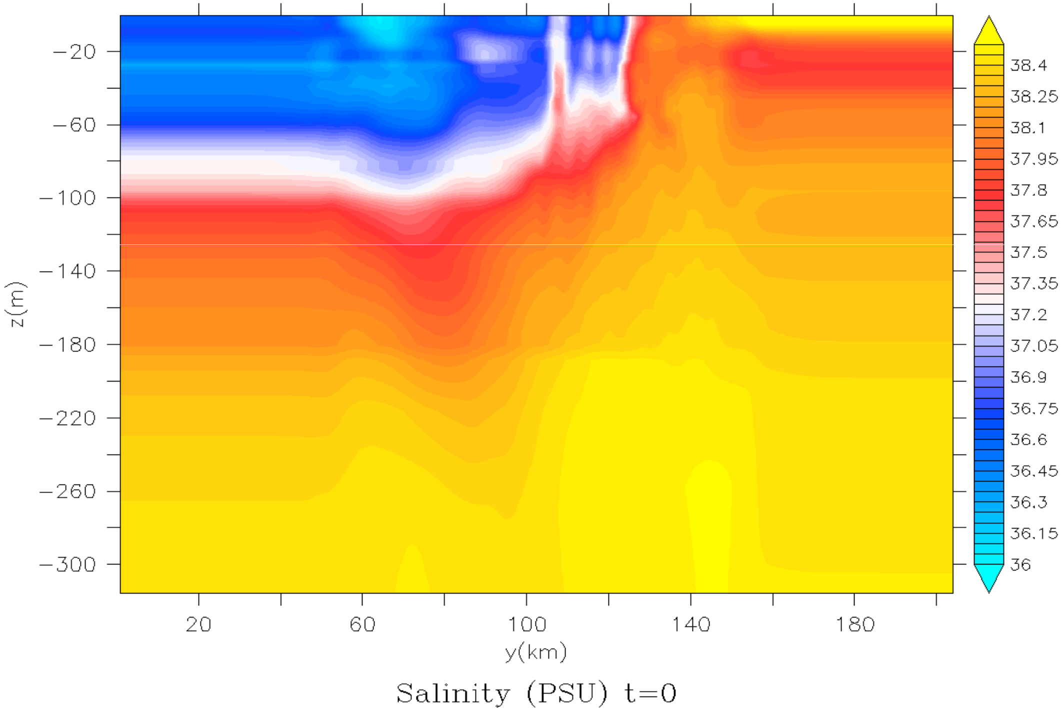
Observations complemented with numerical simulations
(WMOP operational model – 2 km - free run)

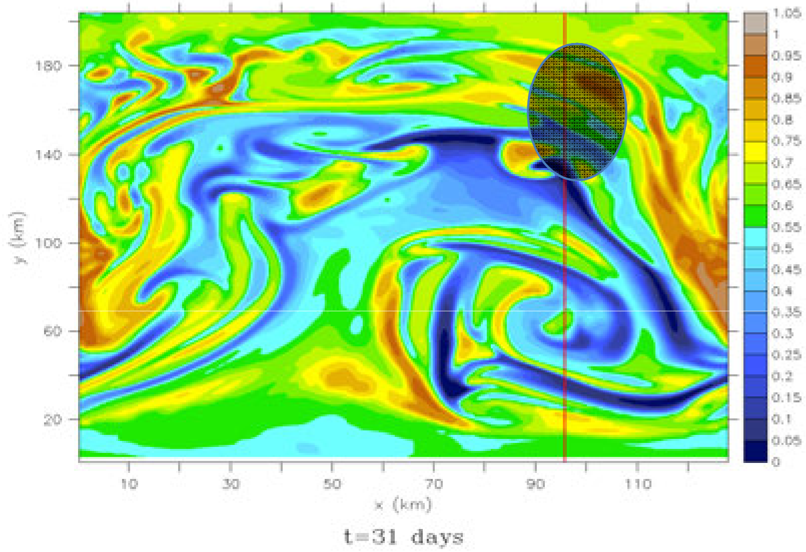


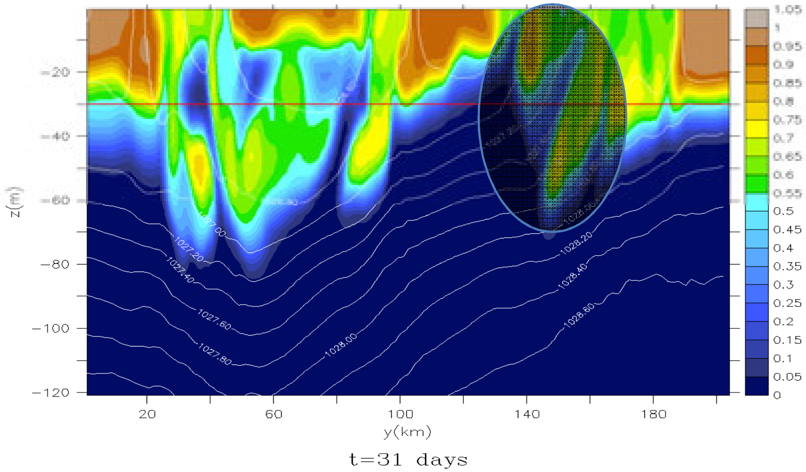
Potential mechanisms of vertical motion

Frontogenesis - numerical simulation

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: Vertical section of salinity used to initialize the model.
Right: tracer after 31 days of simulation (30 m). Contours correspond to isopycnals. Resolution 500 m.

Summary

- The Alboran Sea is an ideal test site for studying 3D meso and submesoscale processes
- Intense fronts with impacts on biochemistry
- Numerical and observational evidences of ocean frontogenesis in ALBOREX

Challenges and Requirements

- Multi-platform and interdisciplinary approach
- Satellite component is crucial
- SWOT will make an unprecedented contribution
- Integration with modelling
- Critical mass
- National and international cooperation

COLLOQUIUM

Submesoscale Processes: Mechanisms, Implications And New Frontiers

The 48th International Liège Colloquium on Ocean Dynamics

Liège, Belgium
23rd - 27th May 2016

Wallonie

Université de Liège

Intergovernmental Oceanographic Commission

SOCIB Balearic Islands Coastal Observing and Forecasting System

http://modb.oce.ulg.ac.be/colloquium/

Place of the Conference: University of Liège - Place du 20-Août, 7 - 4000 Liège - Belgium

cnes   esa   NASA

Deadline for abstract submission:
30th January 2016

Acknowledgements

– Co-authors and contributors (scientists, engineers, technicians, postdocs, PhD and master students, …)

– EU commission (PERSEUS project)

– Spanish Ministry of Economy (E-MOTION project)

If you want to go fast,

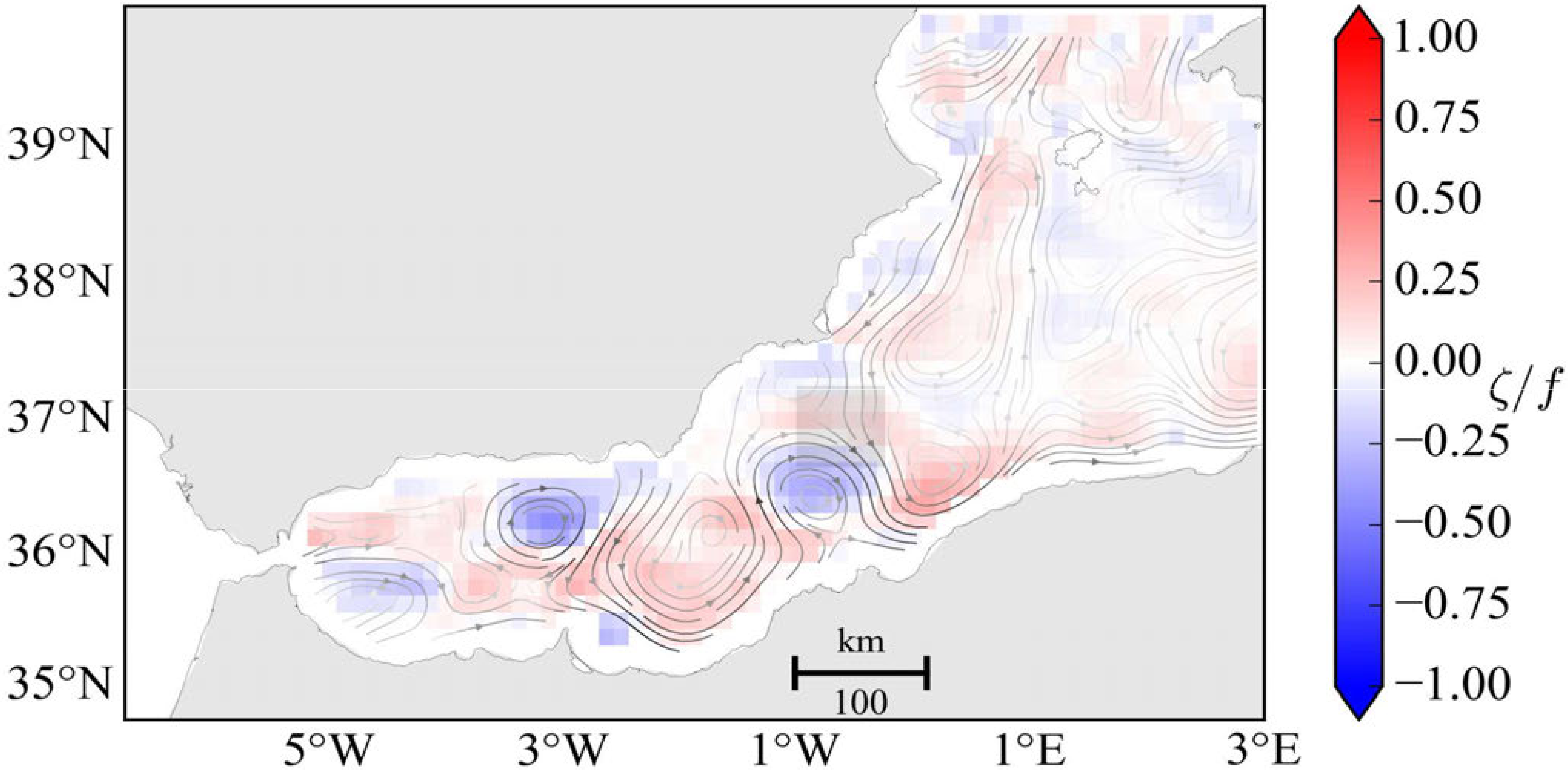
go alone.

If you want to go far,

go together.

- African Proverb -

Oceanographic context from satellites
ALTIMETRY



ALBOREX data assimilation experiment

Data assimilation approach:

Local Multimodel Ensemble Optimal Interpolation

Ensemble anomalies sampled from three 2009-2014 WMOP hindcast simulations.

The anomalies are considered within the same season as the analysis date after having removed the seasonal cycle.

Multivariate, inhomogeneous and anisotropic model error covariances characteristic of the mesoscale variability of the season under consideration.

→ Localization radius = 280km

→ 80 ensemble members

Assimilated data

One single analysis on 27 May 2014 00:00, assimilating:

→ Gridded Sea Level Anomaly (AVISO)

→ Satellite-derived interpolated Sea Surface Temperature (GHRSST-JPL)

→ ARGO TS profiles (5-day window)

+ dense ALBOREX CTDs data
(considered as synoptic over the 24-hour sampling period)

ONCE WE HAVE A PAR VARIABLE TO GLIDER DATA WE MAY DIAGNOSE PRIMARY PRODUCTION FROM CHL AND LIGHT, THROUGH A BIO-OPTICAL MODEL.

$$P(z,t,\lambda) = 12 \ \ Chl(z,t) \ \ a^*(z,t,\lambda) \ \ PAR(z,t,\lambda) \ \ \varphi_\mu(z,t,\lambda)$$

Bannister 1974; Morel 1991; Antoine 1996...etc

- P is the istantaneous assimilation rate in g C m-3 s-1
- a* is the chlorophyll specific absorption coefficient (m^2 (g Chl)-1)
- phi is the yield of transformation (dimensionless)
- PAR is the light along water column in mol quanta m-2 s-1
- Chl is expressed in g m-3
- 12 is the conversion ratio from moles quanta to g of Carbon

$$a^*_{\max} = 40.3(Chl)^{-0.33}$$

Bricaud et al. 1995
Good estimation for oligotrophic waters

$$\varphi_{\mu\max} = 0.05[(Chl)^{0.66}/(0.44 + (Chl)^{0.66})]$$

Wozniak et al. 1992