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# Integrated and multidisciplinary observational approach to (sub-)mesoscale coastal dynamics in the southeast Bay of Biscay

Anna Rubio, AZTI

# CEOO: COASTAL ENIGINEERING AND OPERATIONAL OCEANOGRAPHY GROUP

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**Physical oceanography, coastal morphodynamics & climate**

**Real-time monitoring systems** and numerical applications providing predictions on the future behavior of the sea, to improve **safety** and **efficiency** in all sectors of the maritime and coastal economy.

- **Operational Observation**
- **Numerical Modeling**
- **Operational applications**

_ **EUSKOOS: BASQUE COASTAL OPERATIONAL OCEANOGRAPHY SYSTEM**

_ **KOSTASYSTEM**

_ **CLIMATE IMPACTS ON COASTAL AREAS**

_ **MODELLING OF OCEAN-METEOROLOGICAL PROCESSES AND PARAMETERS**

_ **SATELLITE OCEANOGRAPHY APPLIED TO THE FISHING OF PELAGIC FISHERY RESOURCES**

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_ **ALERT SYSTEMS (EXTREME, TEMPORARY EVENTS)**

_ **CONTINGENCY PLANS AND RESPONSE TO ACCIDENTAL SPILLS**

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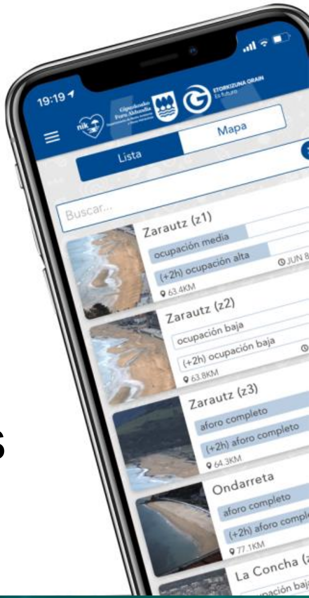


# EUSKOOS

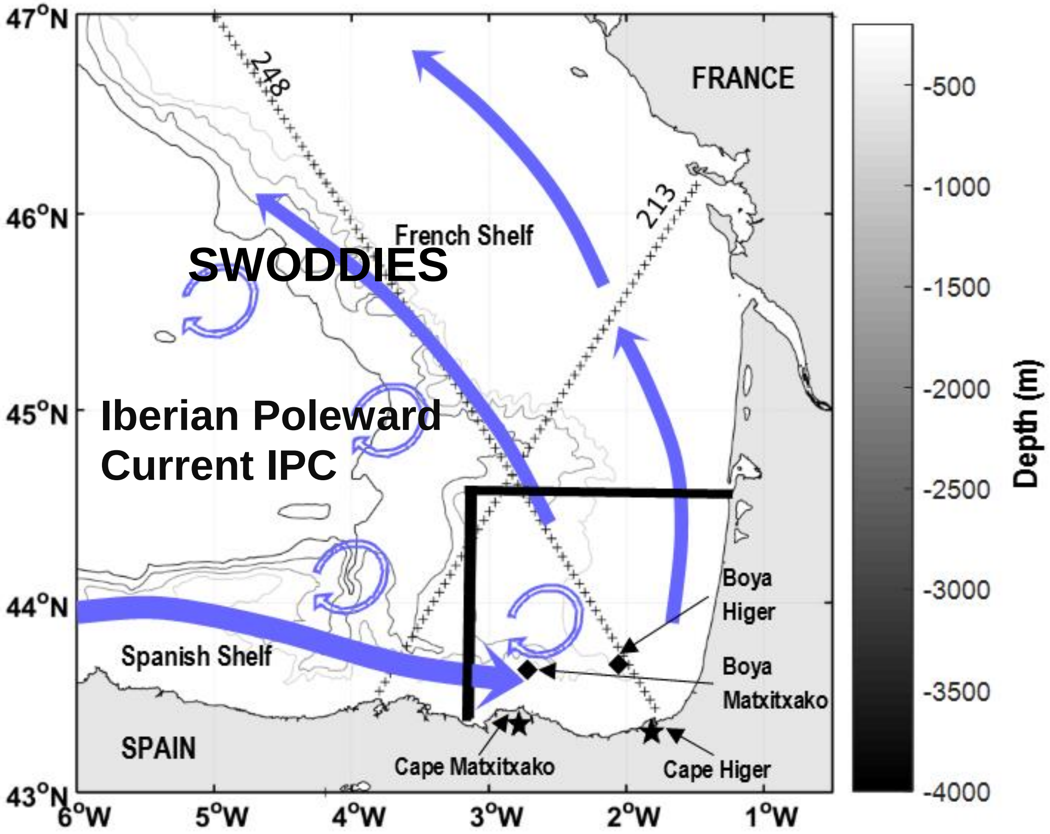
## The operational coastal observatory of the SE Bay of Biscay



euskoos

Euskadiko Ozeanografia Operazional Sistema
Sistema de Oceanografía Operacional de Euskadi
Basque Operational Oceanography System
Système d'Océanographie Opérationnelle d'Euskadi

euskalmet
agencia vasca de meteorología
euskal meteorologia agentzia




# EUSKOOS

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Euskalmet

**2001**

**2 Coastal stations**

- Temperature
- Hs,Tp,thtp
- Currents

**2006**

**40 KOSTASystems**

- Coastline
- Risks
- Currents
- Morphology
- User density
- Overtoppings

**2007**

**2 offshore buoys**

- Meteo
- Hs,Tp,thtp
- 1 ADCP
- 7 CT

**2009**

**2 HF radars**

- Currents

**2013**

**6 tide-gaudes**

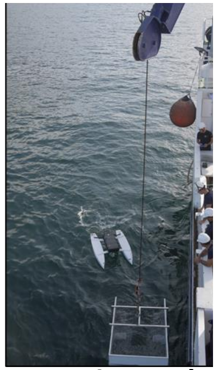
- Tide level
- Agitation

**2021**


**2 gliders**

- PLD1
- PLD2
- PLD3

**2023**



**2 ASV-Ranger (6m)** **Itsasdrone (2m)**

- Echosounders
- ADCP

**2024-on: EUSKOOS-RI**

External acces to euskoos infrastructure for R+D+i

# EUSKOOS PORTAL

https://euskoos.eus/mapv2/
https://info.euskoos.eus/

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Euskalmet

## The operational coastal observatory of the SE Bay of Biscay


Tue 21 May | Wed 22 May | **Thu 23 May** | Fri 24 May | Sat 25 May

| | 03:00 | 04:00 | 05:00 | 06:00 | 07:00 | 08:00 | 09:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Height (m) | 1.53 | 1.61 | 1.61 | 1.60 | 1.62 | 1.67 | 1.73 | 1.81 | 1.90 | 1.96 | 1.97 | 1.95 | 1.92 | 1.90 | 1.89 | 1.86 | 1.83 | 1.81 | 1.78 | 1.75 | 1.72 |
| Direction (deg) | 292 ° | 291 ° | 292 ° | 292 ° | 292 ° | 293 ° | 293 ° | 293 ° | 293 ° | 294 ° | 295 ° | 297 ° | 299 ° | 300 ° | 301 ° | 302 ° | 303 ° | 303 ° | 304 ° | 305 ° | 306 ° |
| Direction | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ |
| Peak Period (s) | 5.7 | 5.7 | 6.3 | 11.2 | 11.2 | 11.2 | 11.2 | 11.2 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 |

# EBEGI

## Augmented Observatory of the Bay of Biscay: comprehensive ecosystemic and multi-platform observations

https://aztidata.es/ebegi/

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Euskadi, auzolana, bien común
EUSKO JAURLARITZA GOBIERNO VASCO

Euskalmet

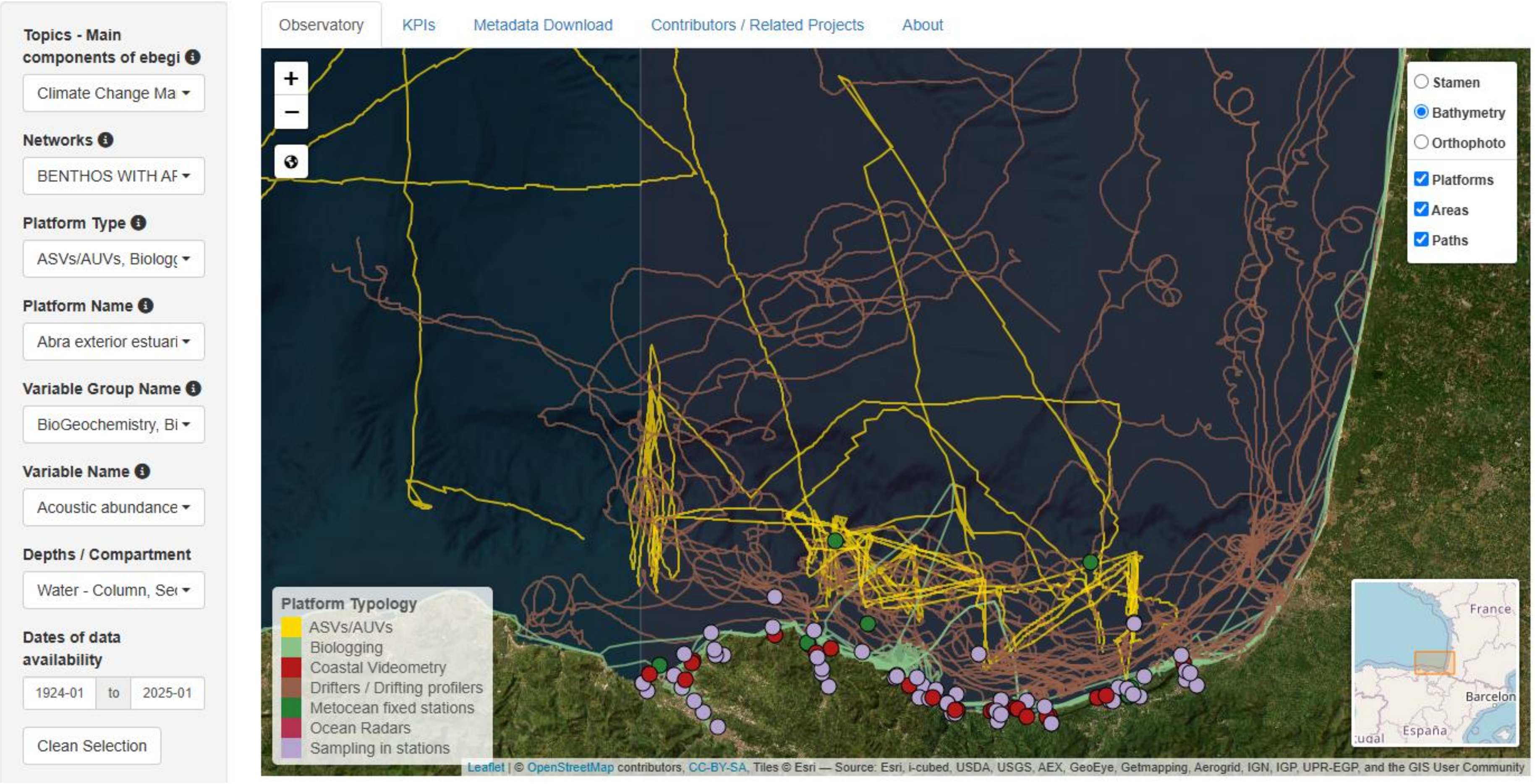
ura
URAREN EUSKAL AGENTZIA | AGENCIA VASCA DEL AGUA

JERICO RESEARCH INFRASTRUCTURE

EuroSea

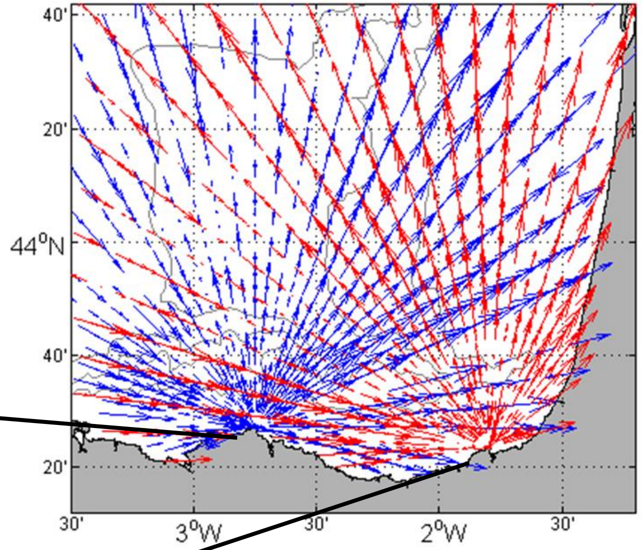
COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE
CMEMS IN SITU TAC

EuroGOOS
European Global Ocean Observing System



# EUSKOOS HF radar

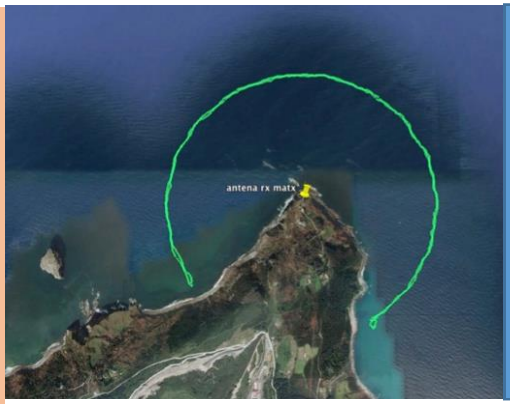





| Radar Freq. (Mhz) | 4.463 |
|---|---|
| Radar Wavelength (m) | 60 |
| Ocean Wavelength (m) | 30 |
| Depth of current (m) | ~ 0-2 |
| Range (km) | ~ 150 |
| Resolution (km) | 5 |
| Bandwidth (kHz) | 30 |
| Upper H1/3 Limit (m) | 25 |

**Major Hardware Failures**

- Jan – May 2010
- May 2015
- Dec 2018
- Several dates in 2019




**Latest APMs**

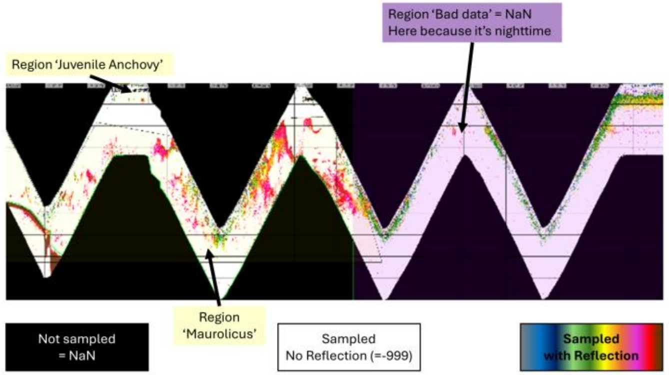
- ✓ June 2015
- ✓ May 2017
- ✓ June 2020
- ✓ May 2023

**15 years of data**

# EUSKOOS GLIDER FLEET

**Pasaia Glider Port**


**5 missions completed**


**2 SEAEXPLORER GLIDERS (2021 and 2024)**
**DRY LABORATORY, BALLASTING POOL, VAUCUM PUMP, DEPLOYMENT FACILITIES, GONIOMETER**


**3 PAYLOADS**

**PAYLOAD 1**

- **CTD** (RBRlegato3)
- Scientific **Echosounder** (Imagenex ES853)

**PAYLOAD 2**

- **CTD** (RBRlegato3)
- **Dissolved Oxygen** (RBRcoda T.ODO.)
- **Chlorophyll-a** @470/695nm + **Turbidity** @700nm + **CDOM** @370/460nm WETLabs ECO Puck FLBBCD
- **Nitrates** (DeepSuna Sea-Bird)

**PAYLOAD 3**

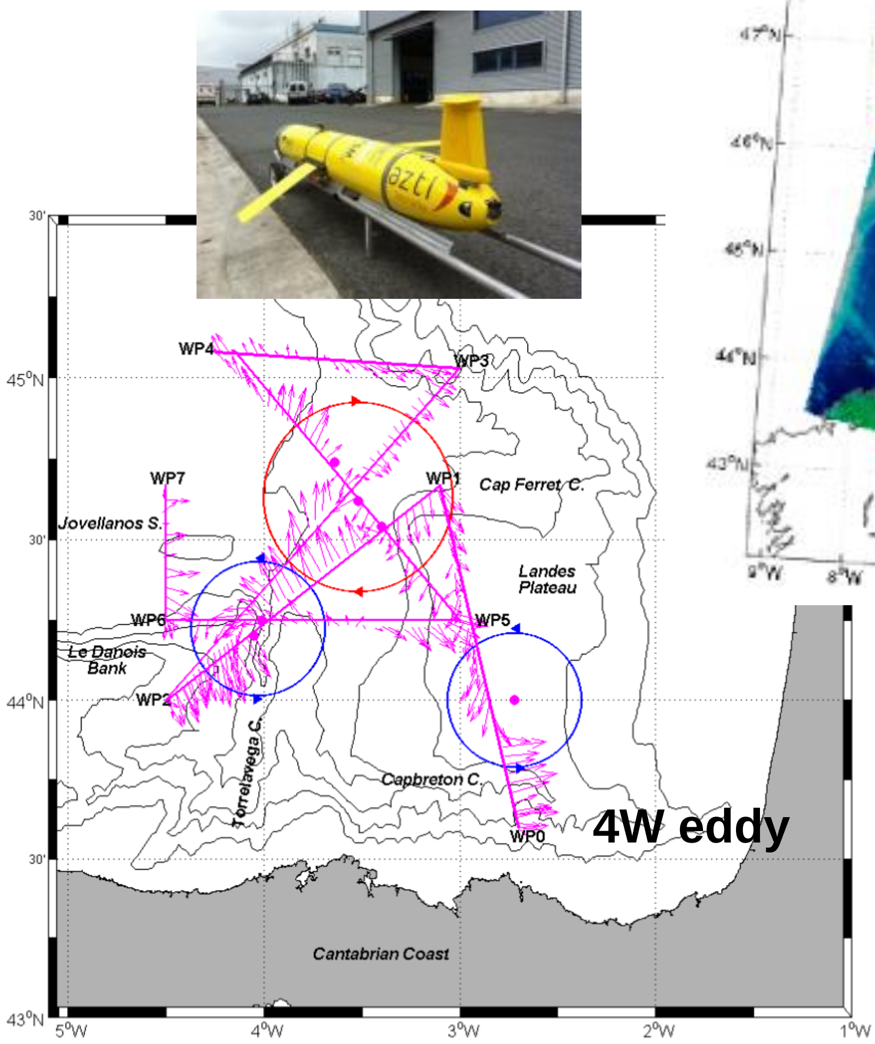
- **CTD** (RBRlegato3)
- **Dissolved Oxygen** (RBRcoda T.ODO.)
- **Chlorophyll-a** @470/695nm + **Turbidity** @700nm + **CDOM** @370/460nm WETLabs ECO Puck FLBBCD

# MESOSCALE EDDIES

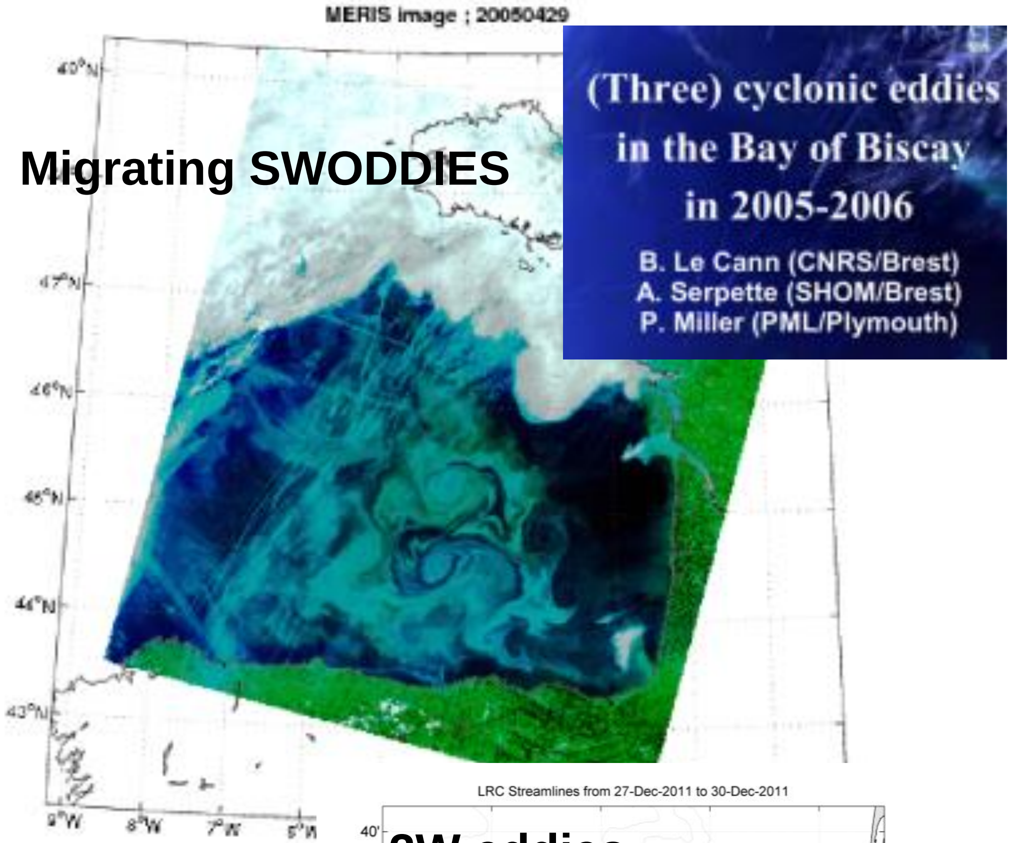
**Migrating SWODDIES.** Seasonal generation: IPC instabilities and bathymetric irregularities (Pingree and Le Cann, 1992).

**Stationary 4W eddy** (Garcia-Soto et al., 2002; **Caballero et al., 2014, 2016)**

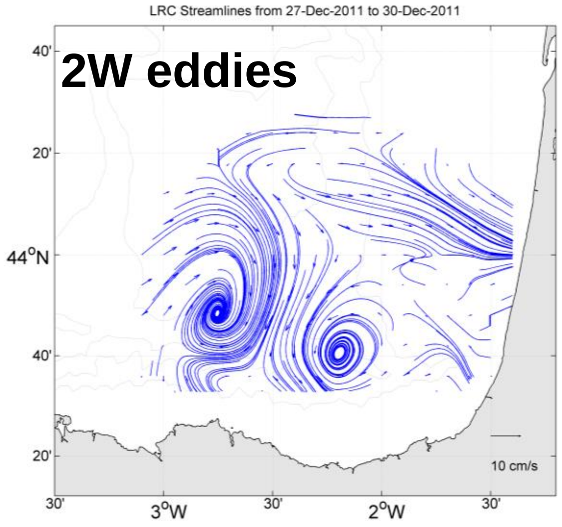
**2W eddies**– identified by HF radar **(Rubio et al. 2013, 2018; Solabarrieta et al 2014, 2015; Manso et al., 2021)**




4W eddy




Migrating SWODDIES




2W eddies

HF RADAR LRC

# 2W EDDIES FROM HFR + Satellite SST

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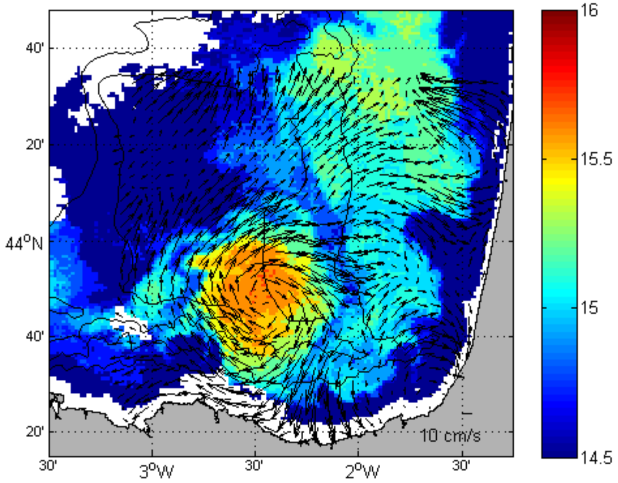
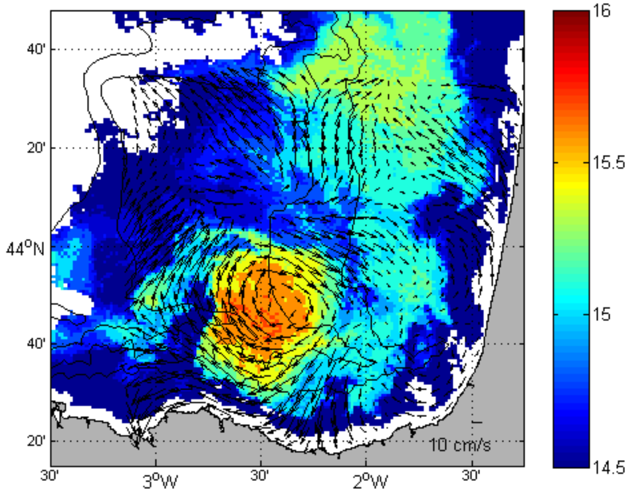
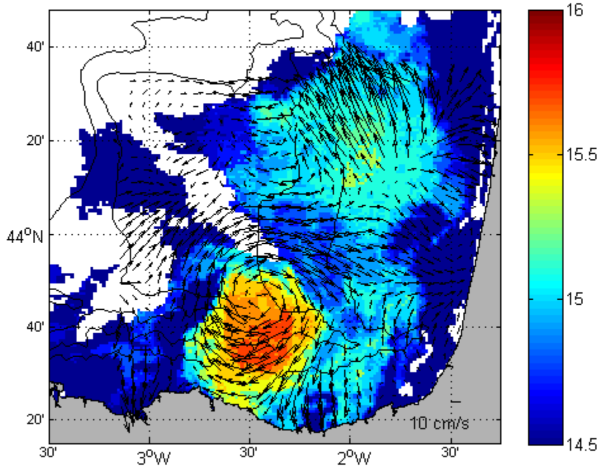
21/12/2014




22/12/2014

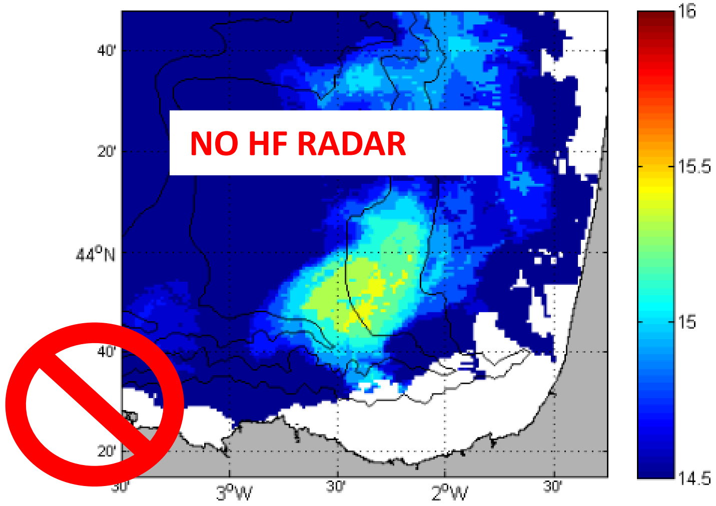



23/12/2014

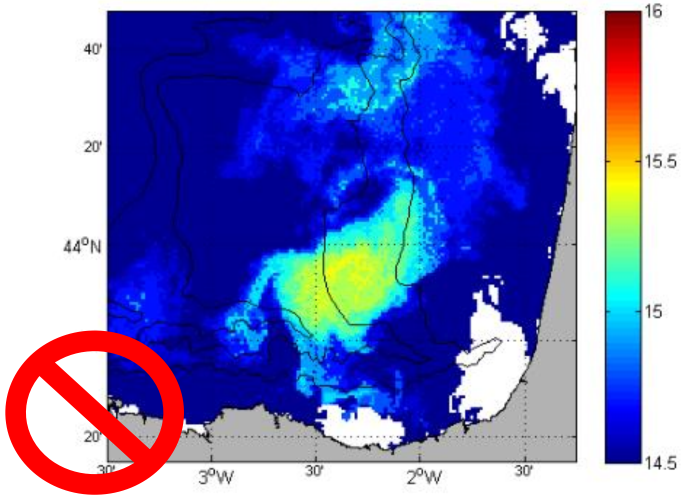



AVHRR SST (ºC)

29/12/2014

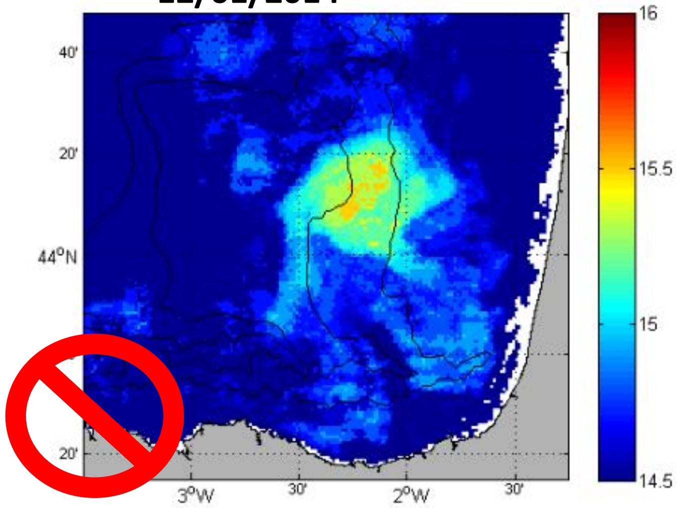



31/12/2014




Rubio et al, 2018 RSE

12/01/2014




*Rubio et al., 2018 RSE doi:10.1016/j.rse.2017.10.037*

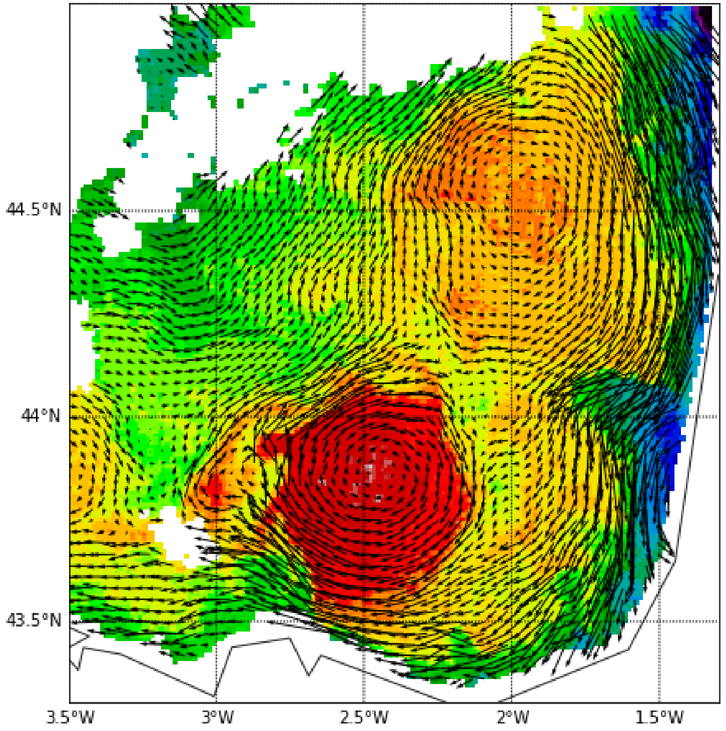
# 2W EDDIES FROM HFR + Satelite SST

## Reconstruction of surface currents from SST & the SQG approximation

*Lapeyre & Klein JPO 2006, Lacasce & Mahadevant JMR 2006, Isern-Fontanet et al. GRL 2006*

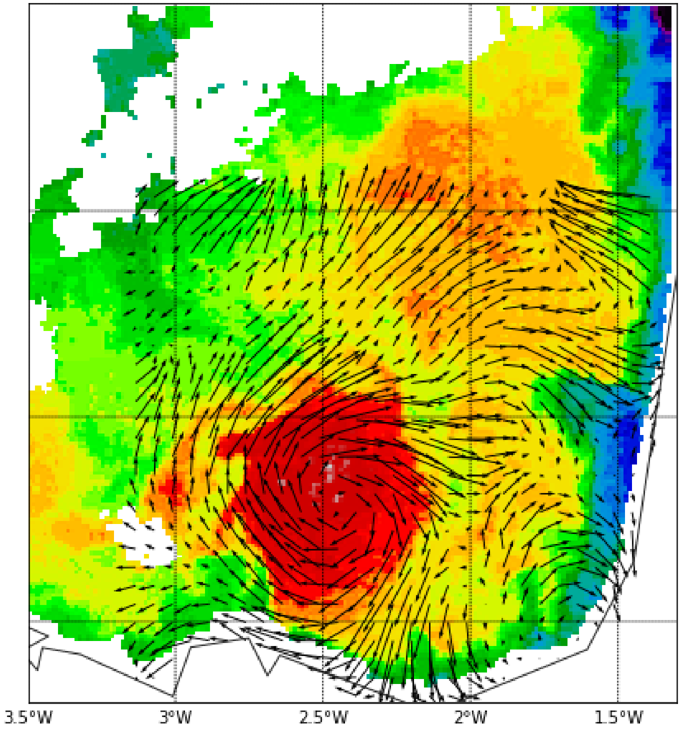
SST + SQG with Lmax = 300 km, Lmin=5 km

20141221.1400.n19.nc



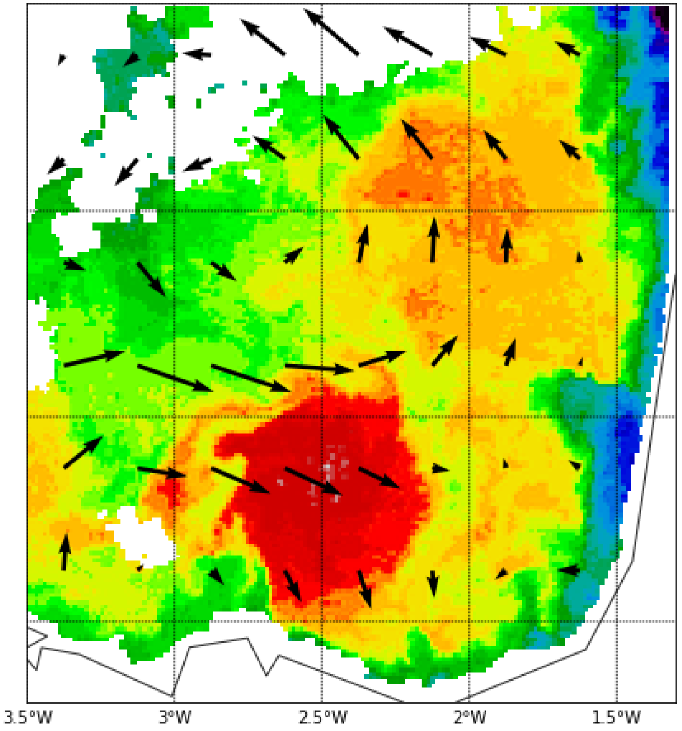

SST + simultaneous velocity field from radar

20141221_140000_radar.nc




SST + altimetry maps

dt_global_allsat_phy_l4_20141221_20180115.nc




**J. Isern- Fontanet**

# 2W EDDIES FROM HFR + Satellite SLA

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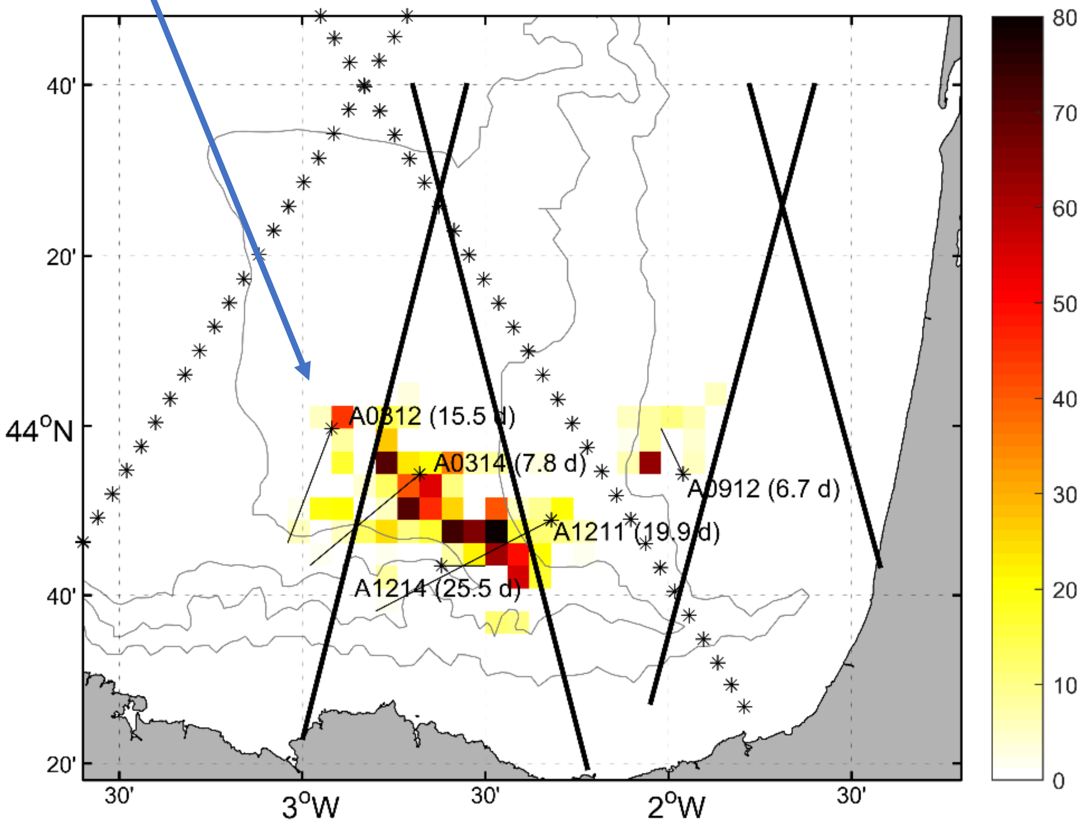
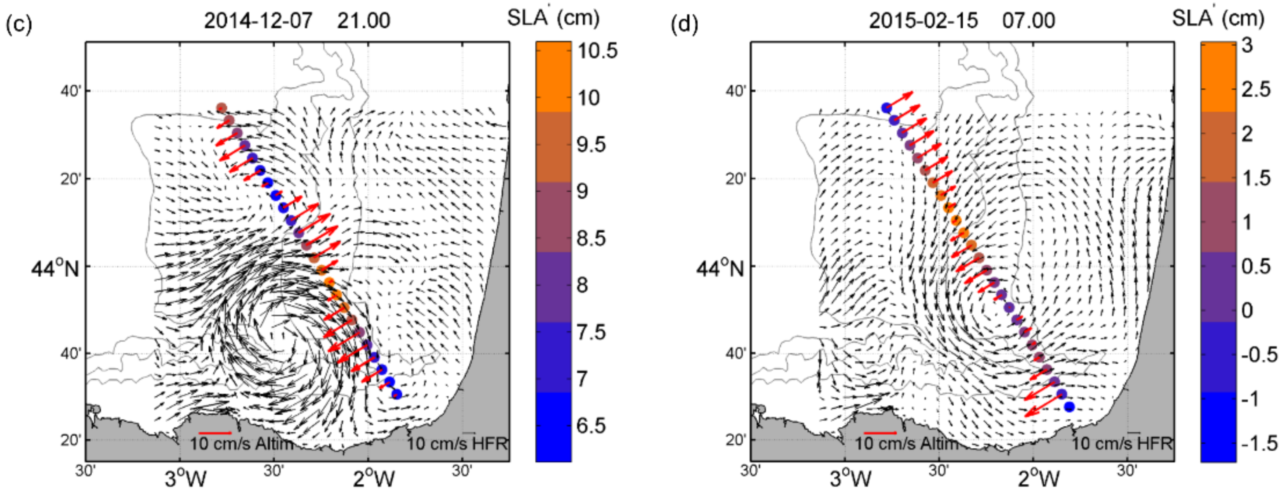
Spatial distribution of the number of anticyclone cores (2011-2014)



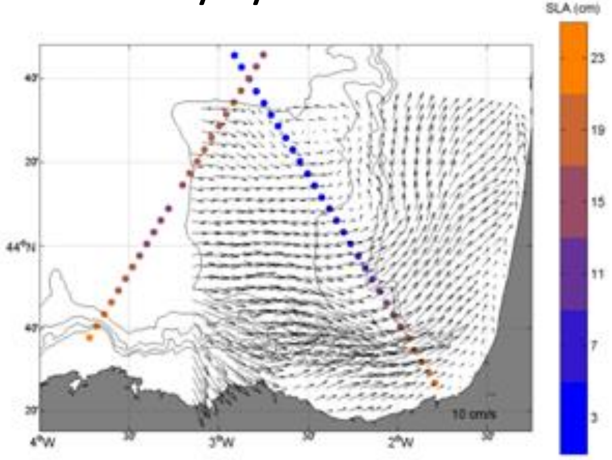

HF radar + along-track SLA (Jason3)

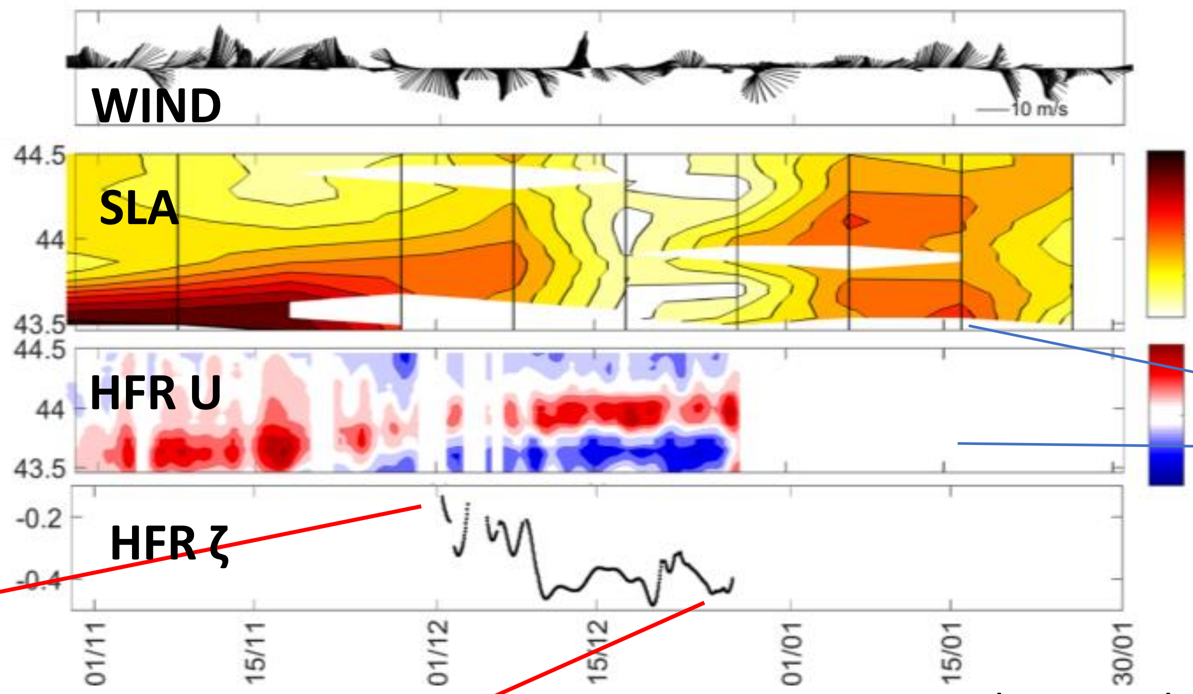


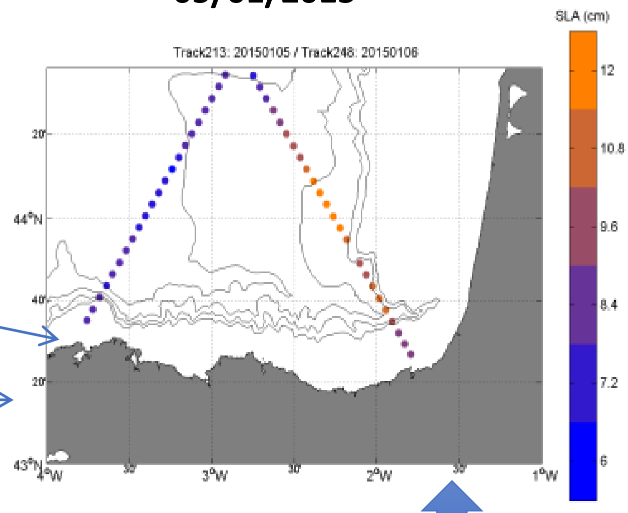

Revisit period: Sentinel 3A: 23days
Jason 3: 10days

*Manso-Narvarte, et al. 2018. Oc.Sci. doi:10.5194/os-2018-33.*

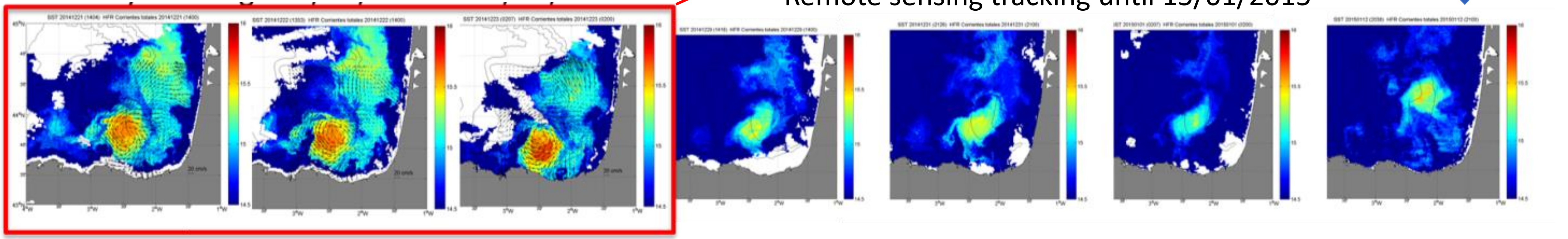
# 2W EDDIES FROM HFR + Satellite SLA + SST



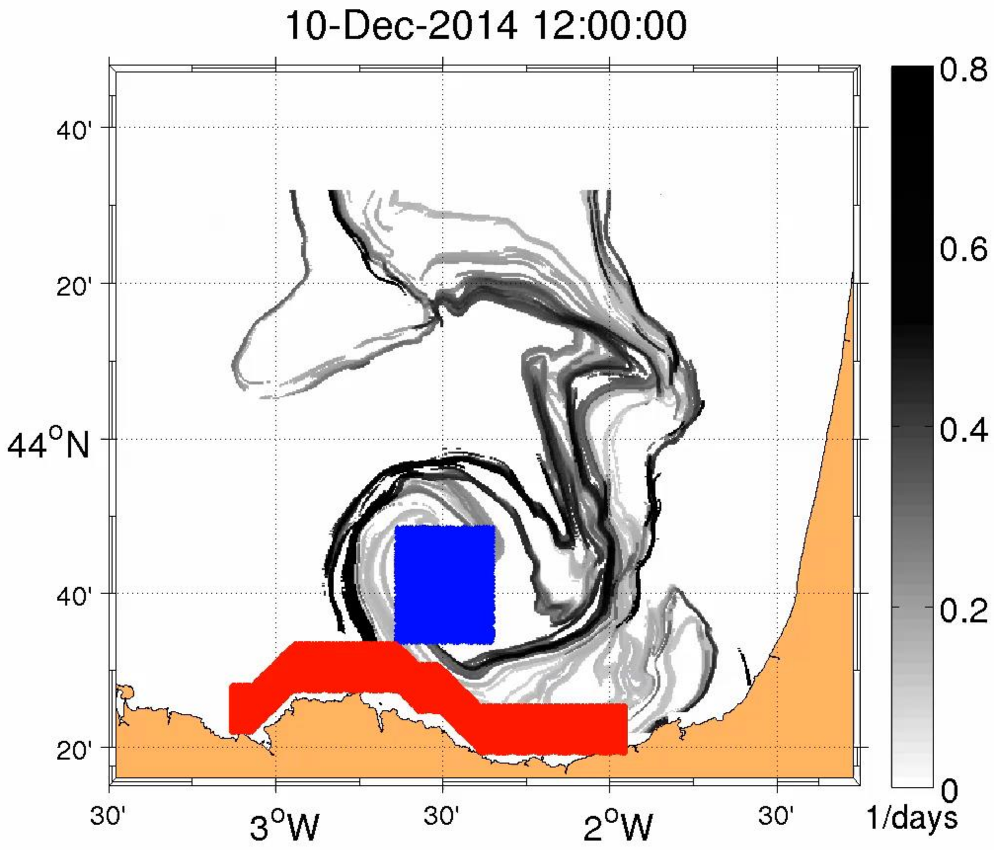



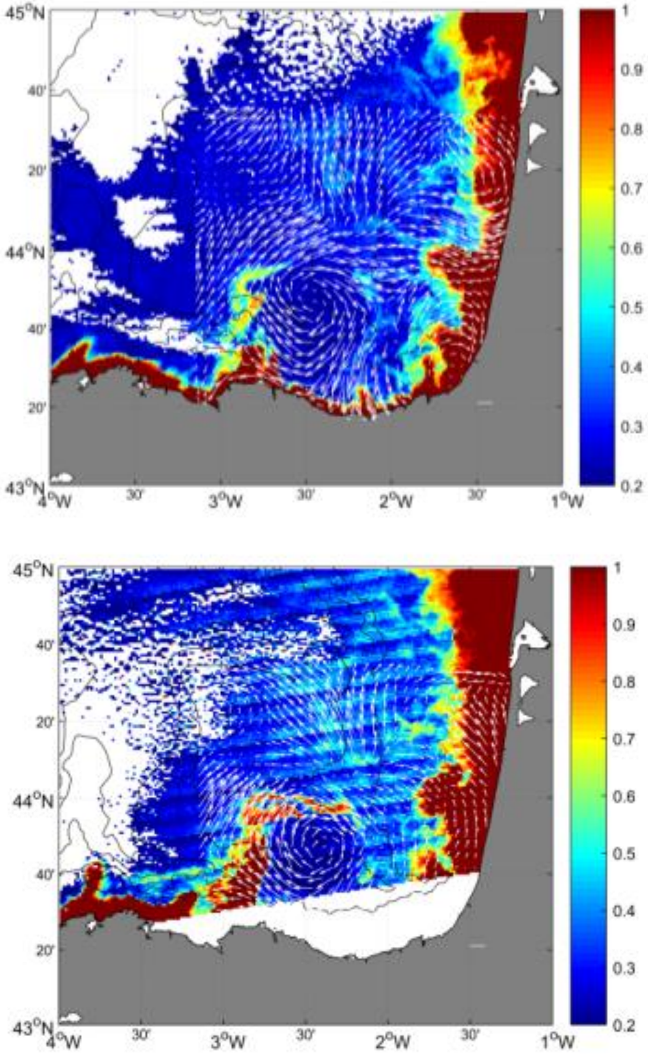

Remote sensing tracking until 15/01/2015



# 2W EDDIES FROM HFR + Satelite Chl-a

MODIS Chl-a 21-22 Dec




**Shelf particles**

**Core partcles**

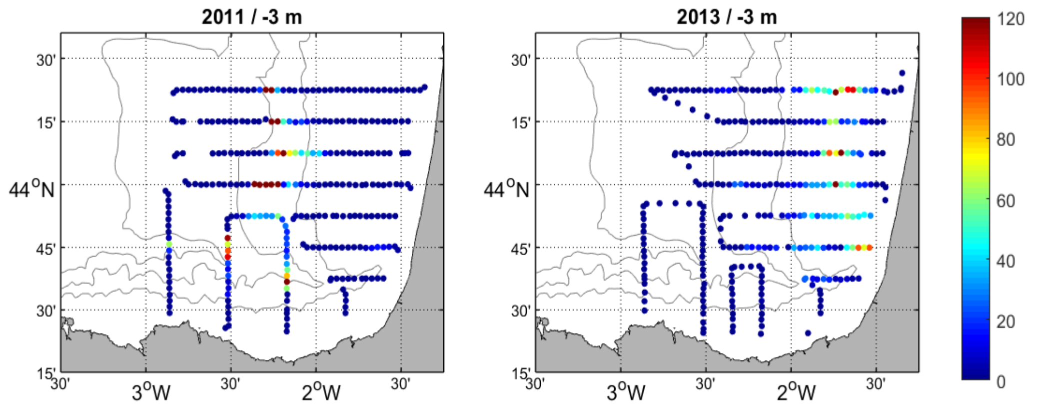
Rubio et al, 2018 RSE

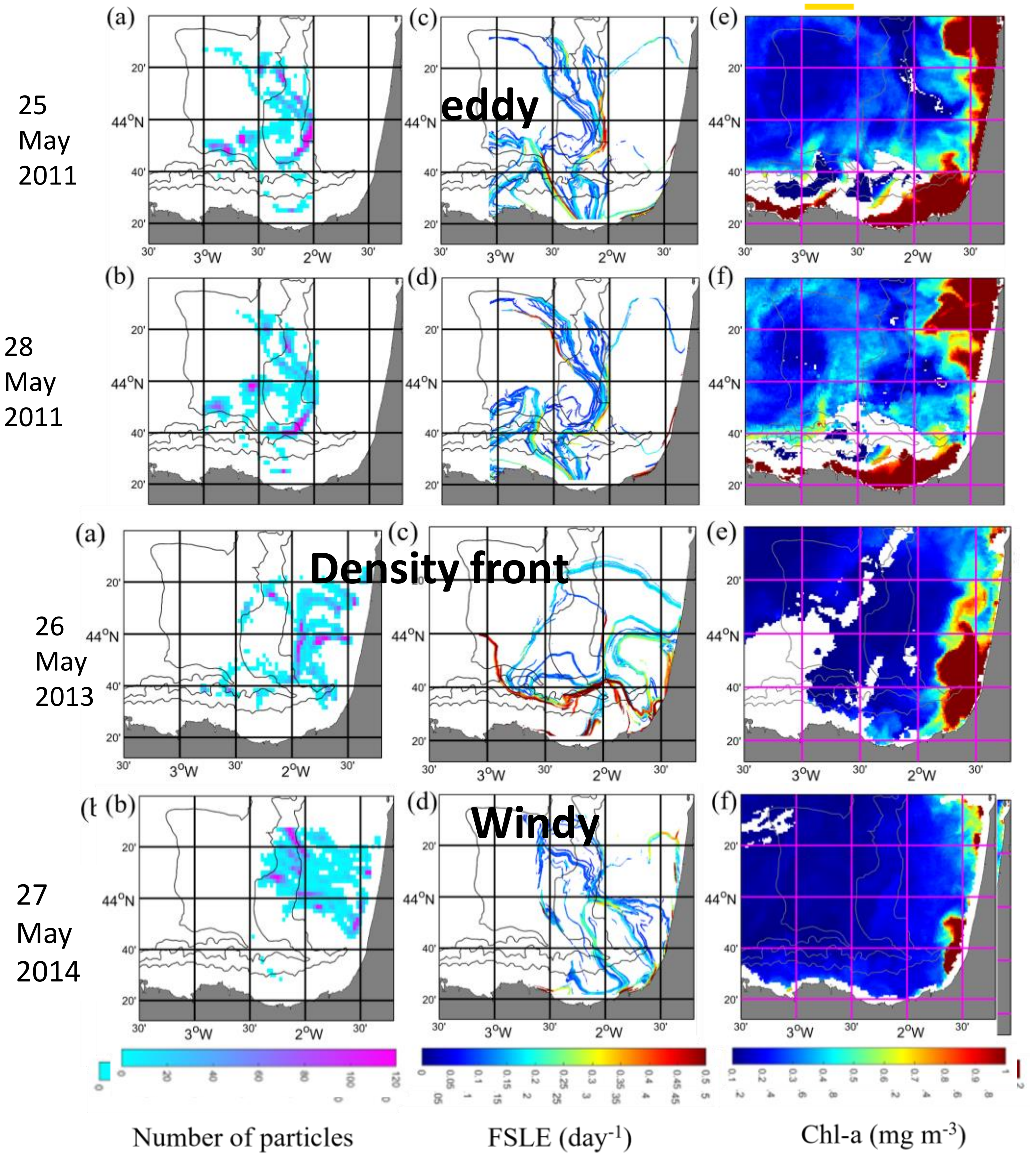


*Rubio et al., 2018 RSE doi:10.1016/j.rse.2017.10.037*

# 2W EDDIES shape ELS anchovies distribution

- BIOMAN (egg-larvae) surveys: 2011-2018
- 10,000 particles released based on the observed distributions and advected using HF radar surface currents
- 30 days (ELS passive tracers)



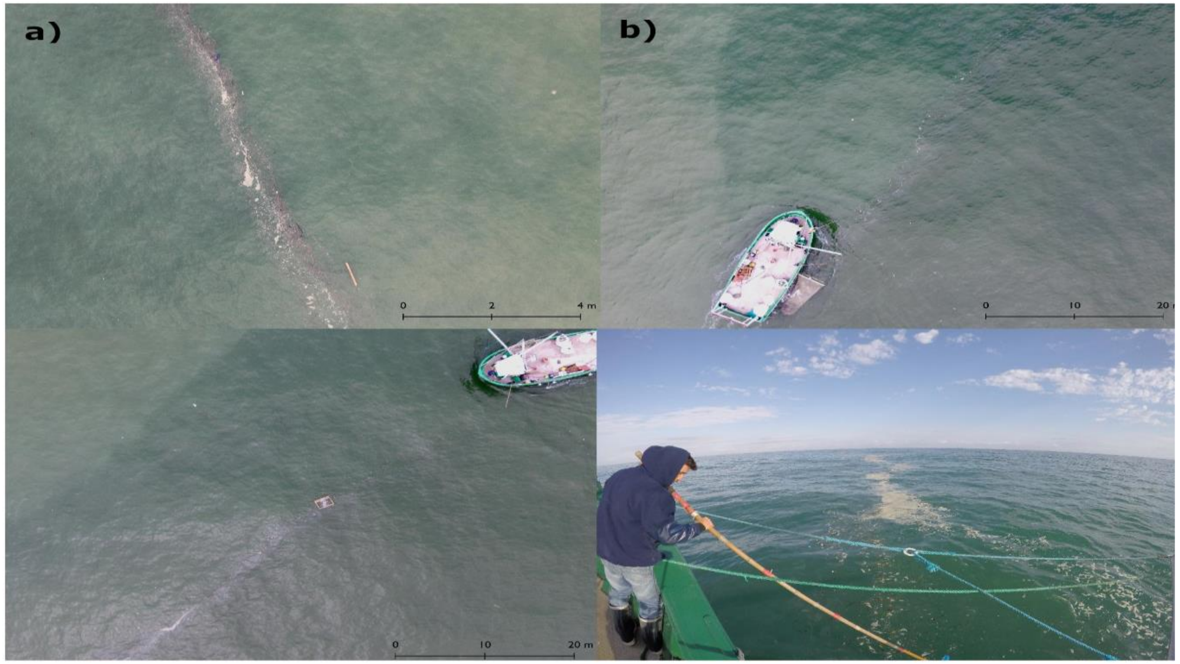



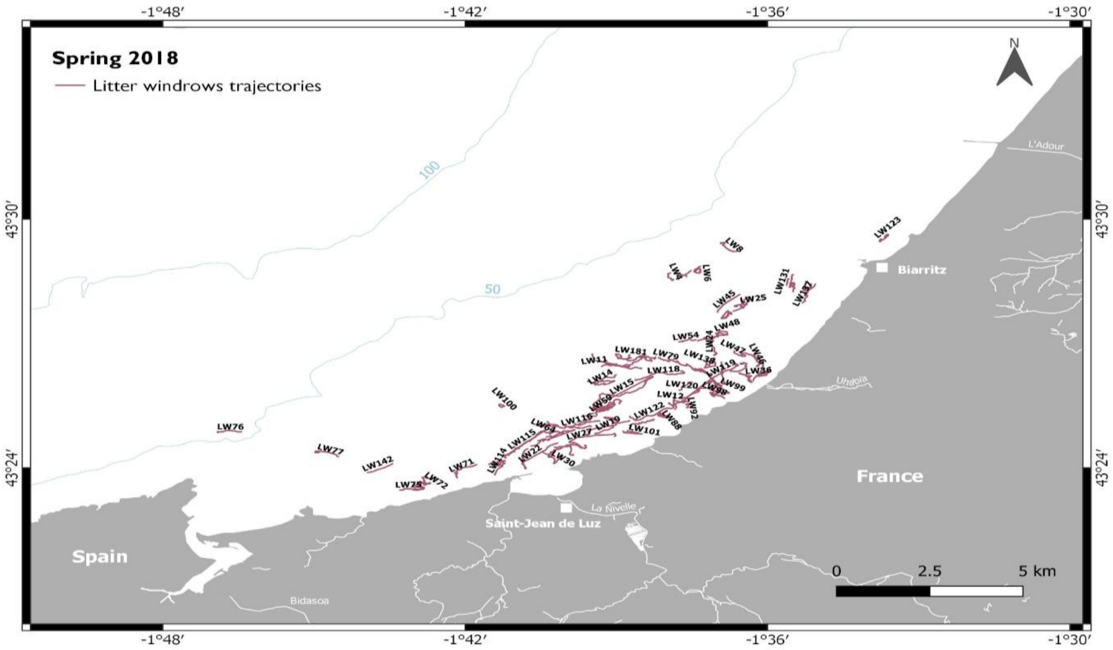

- ➢ Transport patterns: highly influenced by different physical processes, we observe lower retention for eggs spawned over off-shelf areas.
- ➢ Circulation can play a key role in ELS anchovy aggregation within short time scales (20 days).

Manso-Narvarte et al. JMS 2024

# And then…. Plastics came!

# Marine (macro) **litter aggregation is observed along frontal structures** (active fishing for litter)




**Opportunity surveys** (LIFE LEMA project)

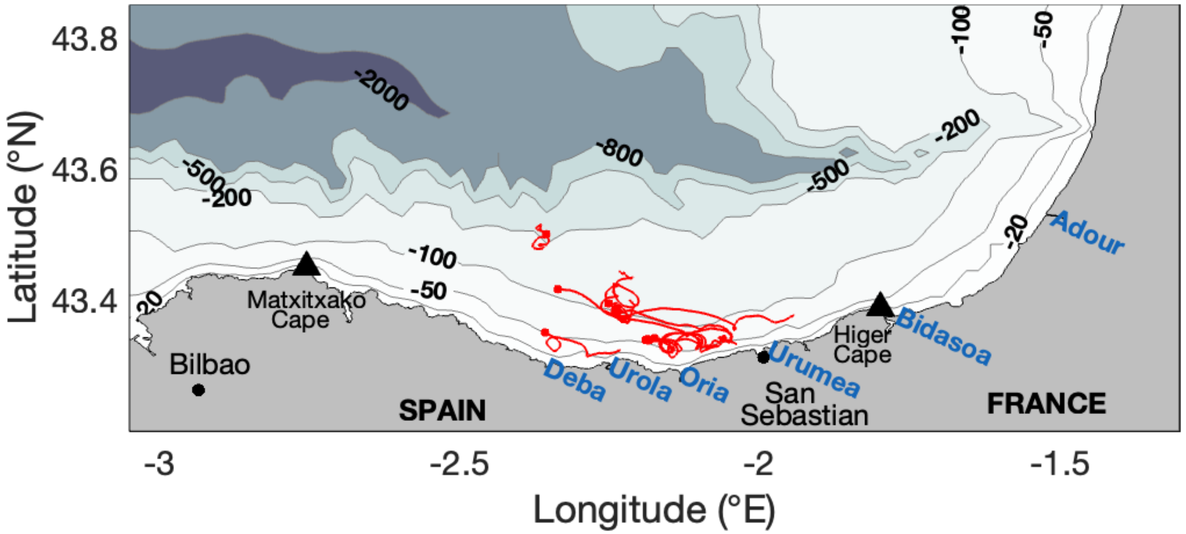
Big difference (x10^4) in marine litter items number **within and out of frontal areas (Ruiz et al. 2020)**

Most of the **litter was from Sea-based sources**

# Frontal accumulation of marine litter

What dynamics, what processes behind? What explains the litter loads?

Sloane BERTIN, phD thesis 2024 "AMÉLIORATION DE LA PRÉVISIBILITÉ DE LA DISPERSION DU MATÉRIEL EN DÉRIVE EN ZONE CÔTIÈRE PAR FUSION D'INFORMATIONS NUMÉRIQUES ET OBSERVATIONNELLES"




**Observations**

- Drifter Survey: 13 drifters 1 m drogue (40 h total, $\Delta_t$= 15')
- HF radar

→ OMA fields (Kaplan and Lekien, 2007) $\Delta_{x,y} = 5\ km$ - $\Delta_t = 1\ h$

→ 2dVar fields (Yaremchuk and Sentchev, 2009) $\Delta_{x,y} = 2.5\ km$ - $\Delta_t = 1\ h$

- Satellite data: Sentinel-3 OLCI Chl-a concentration estimation

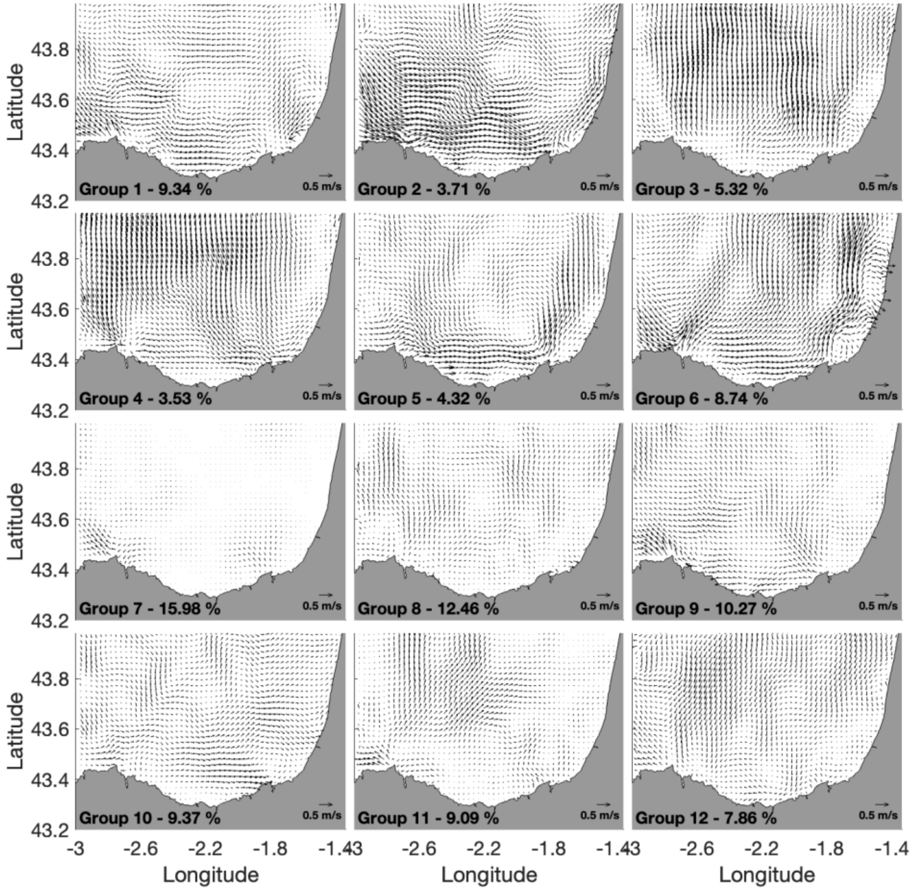
**Model outputs**

U and V from 3-D NEMO $\Delta_{x,y} = 3.5\ km$ - $\Delta_t = 15\ min$

# Surface drifter data constrain HF radar surface current field through the Optimal Interpolation (OI) method.



**K-Means clustering method** using velocities from HF Radar measurement (Solabarrieta et al., 2015) for extraction of ensemble members required for the covariance matrix calculation:




Linear combination of the weighted differences between the modeled and observed velocities:

*Sentchev & Yaremchuk, 2016*

$$u_{OI} = u_m + \sum_{ij} BH_j^T \left(H_i B H_j^T + R_{ij}\right)^{-1} \left(H_i u_m - u_i^*\right)$$

Initial model velocity

Dynamic interpolator
Combination of model and observations covariances

Interpolated differences between model and observations

| | |
|---|---|
| $B = \langle u_m(x,t) u_m(x',t') \rangle$ | Model's space-time covariance matrix |
| $R_{ij} = \langle u_i^* u_j^* \rangle$ | Observations' space-time covariance matrix |
| $u_M$ ; $u_i^*$ ; $u_{OI}$ | Modeled, observed and optimized velocities |
| $H_i$ | Projection operator |

# The Lagrangian Error to evaluate the performance of the available surface current fields



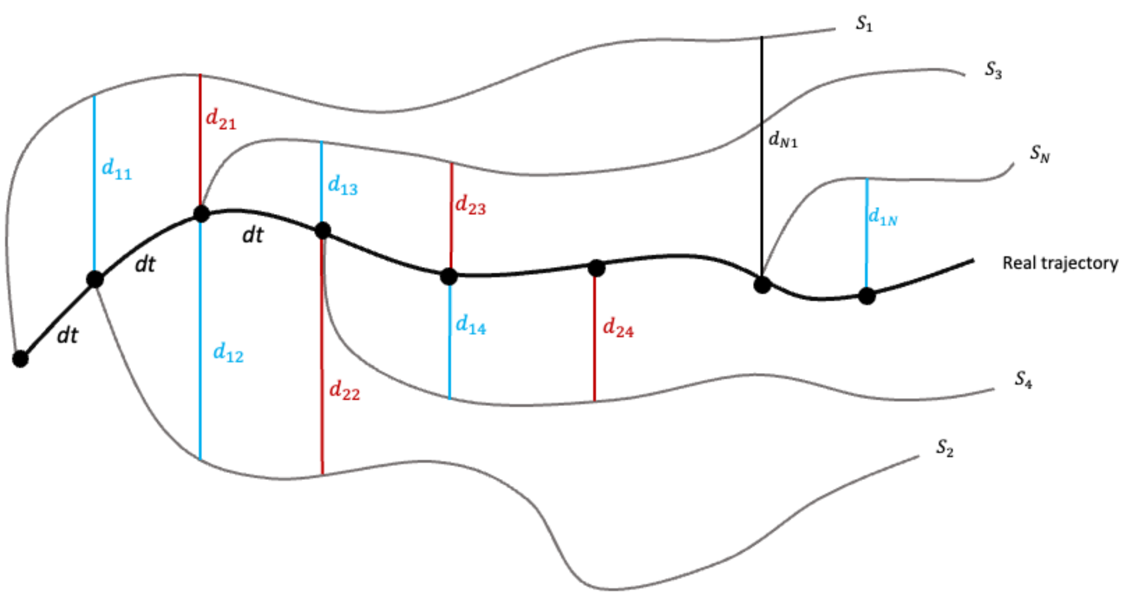
Lagrangian error index (Ruiz et al., 2022):

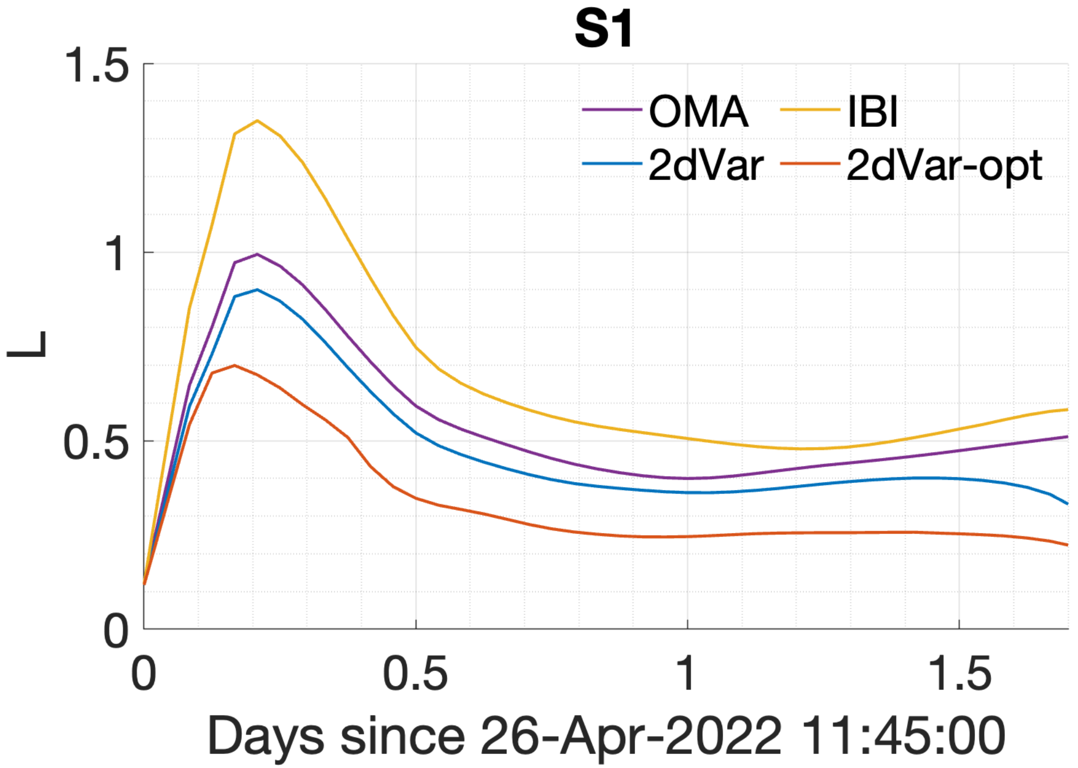
$$L(t) = \langle \sum_{t=1}^{N} \sum_{k=1}^{N-(t+1)} \frac{d_{tk}}{N-(t+1)} \rangle / \overline{D}$$

$d_{tk}$: separation distance between the real and the $k$ simulated trajectory at time step $t$

$N$: maximum number of time steps of drifter displacement, also corresponding to the number of simulated trajectories

$\overline{D}$



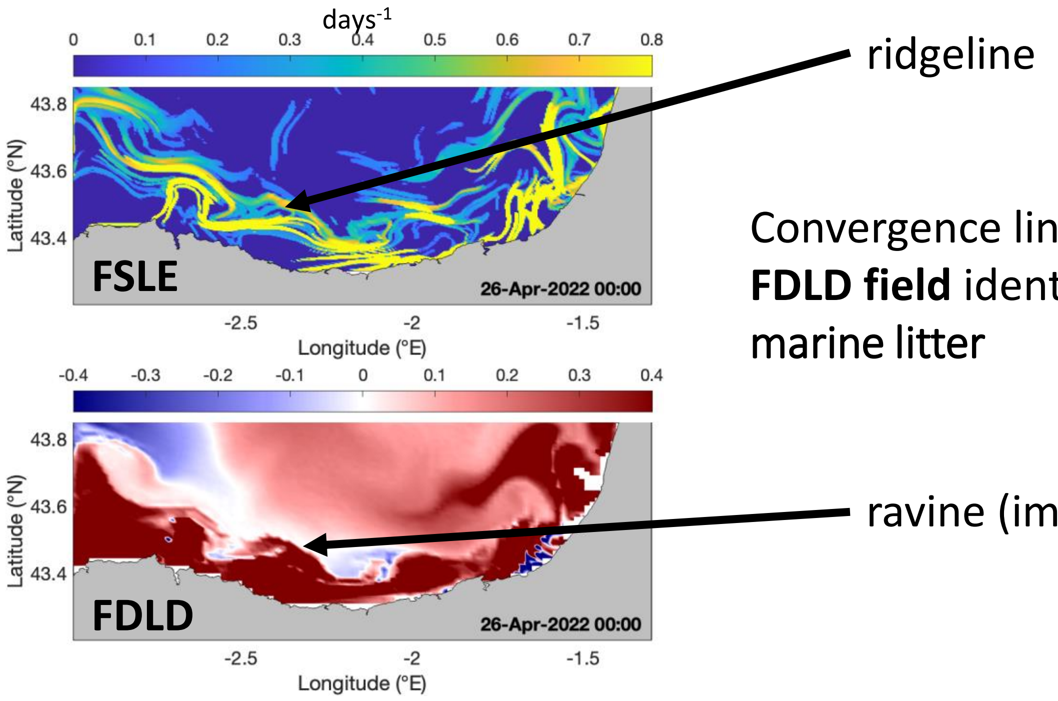




**Bertin et al. 2024, STOTEN**
**https://doi.org/10.1016/j.scitotenv.2024.174372**

# FSLE and Finite-Domain Lagrangian Divergence (FDLD) are used to identify Current Convergence Structures (CCS).

**FSLE**: inverse of the time $\tau(\boldsymbol{x})$ required for two particles of fluid to separate from an initial distance $\delta_0$ to a final distance $\delta_f$ (Hernández-Carrasco et al., 2011; LaCasce, 2008): $\lambda(\boldsymbol{x}, t, \delta_0, \delta_f) = \frac{1}{\tau(\boldsymbol{x})} ln \frac{\delta_f}{\delta_0}$

**FDLD**: assuming that the horizontal divergence accumulates along a trajectory in the finite domain, FDLD values are calculated by integrating horizontal divergence over time (Hernandez-Carrasco et al., 2018): $FDLD(x_0, y_0, t_0, t_f) = \frac{1}{t_f - t_0} \int_{t_0}^{t_f} \nabla_H \cdot \mathbf{v}(x(t), y(t), t) dt$




Convergence lines given by **maximum ridgelines in FSLE field** and **minimum ravines in FDLD field** identify attractive Lagrangian Coherent Structures, likely to accumulate marine litter

$\delta_0 = 0.4\ km$ ; $\delta_f = 3.2\ km$ *(using an amplification factor* $\alpha = \delta_f / \delta_0 = 8$ *) ; computed backward over 5 days of integration*

# 2dVar FSLE ridgelines and FDLD ravines delimiting the spatial distribution of Chl-a.

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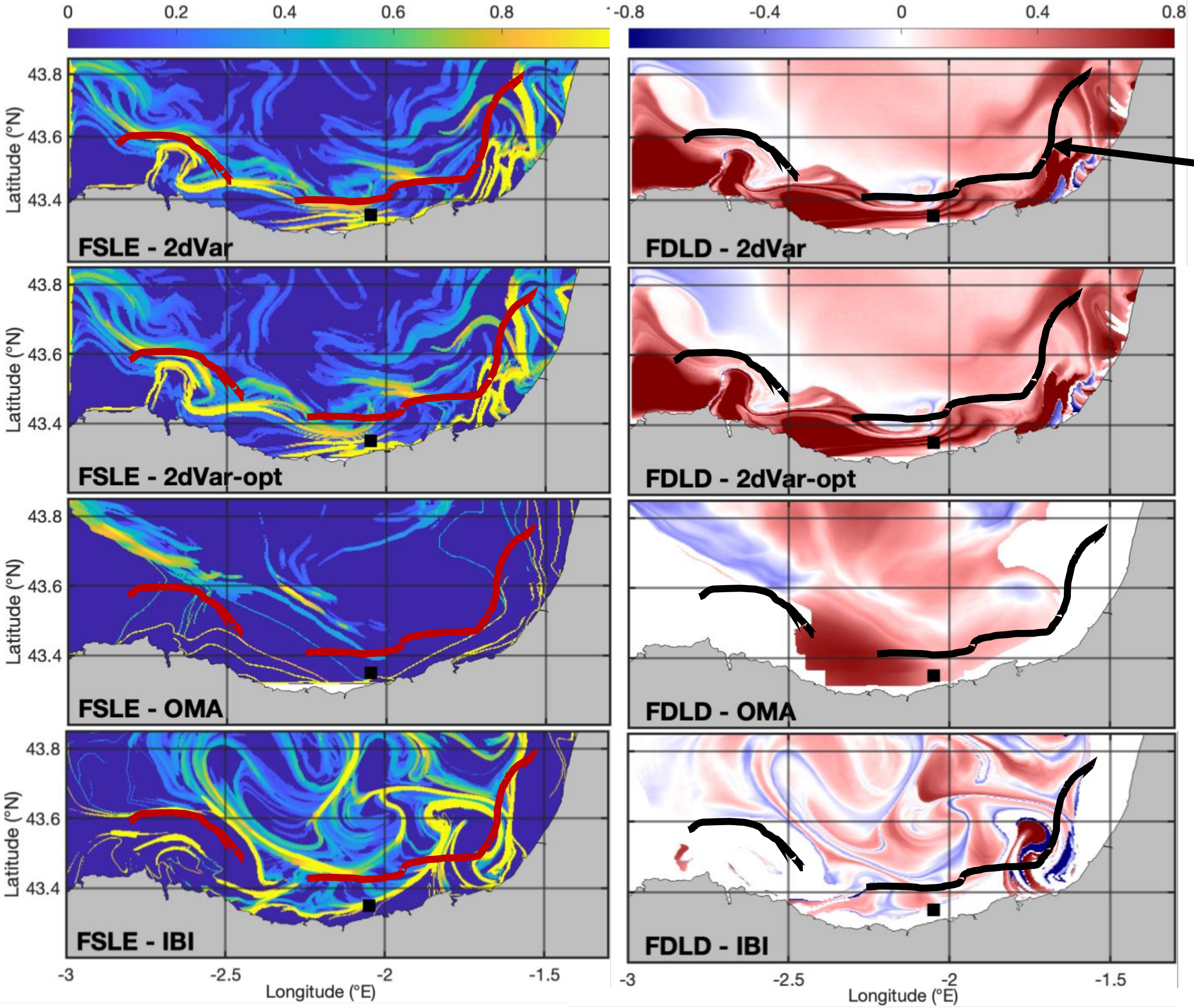
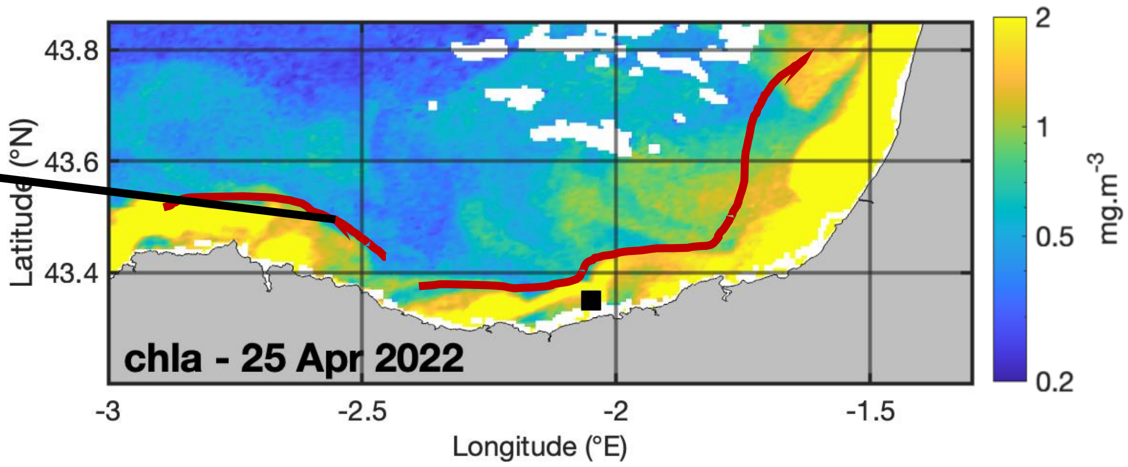


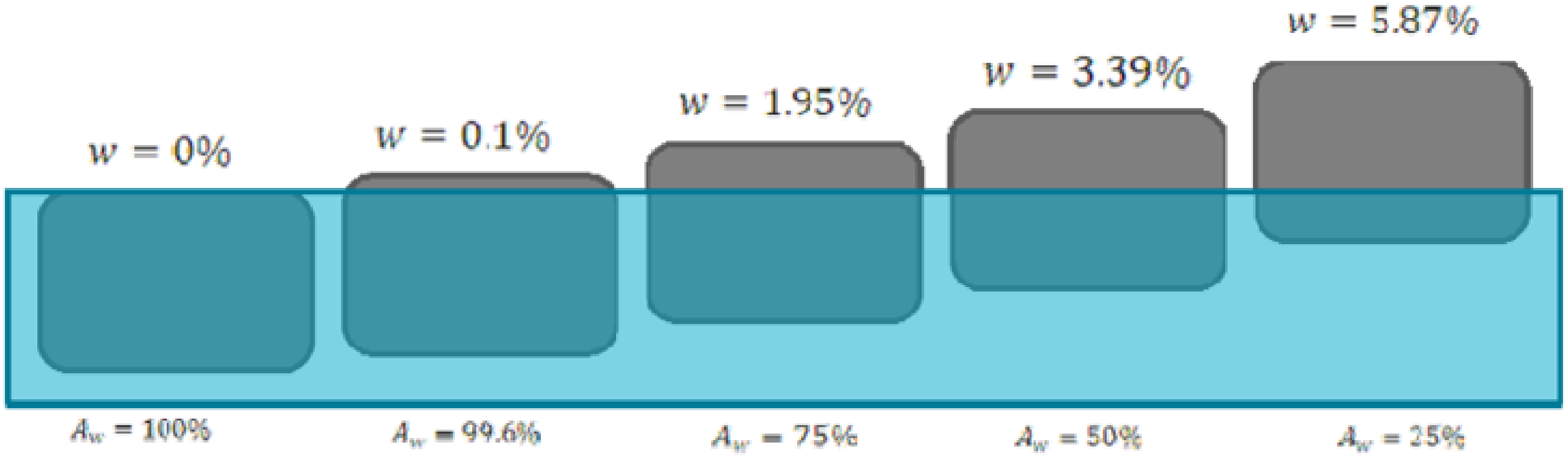




- 2dVar and 2dVar-opt FSLE ridgelines and FDLD ravines **aligned with the coast, coherent with observations of along-shore litter (and drifter) convergence**
- CCS delimitate large values of Chl-a around river plumes

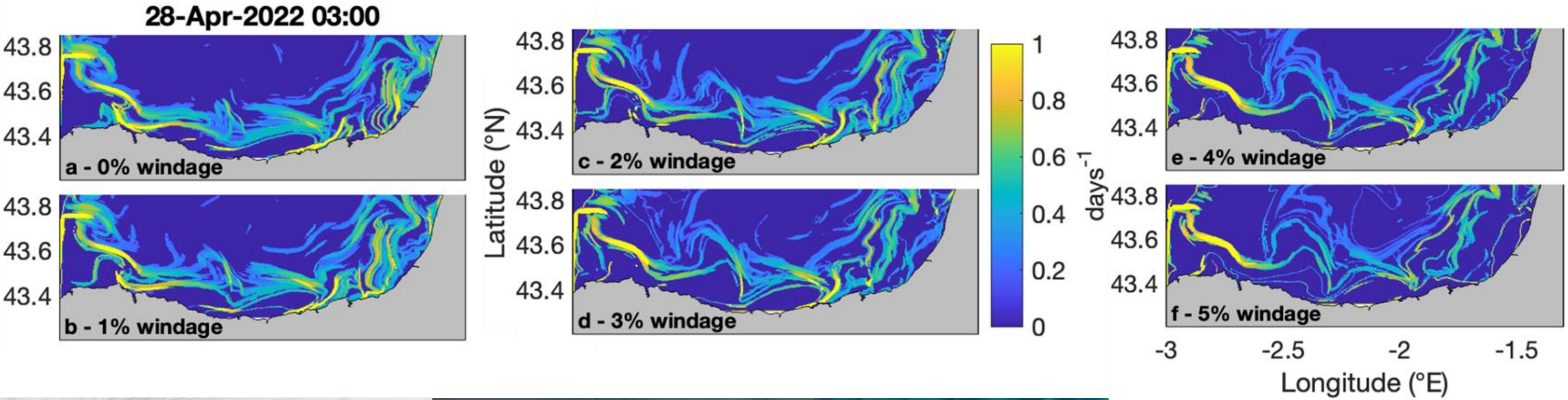
**Bertin et al. 2024, STOTEN**
**https://doi.org/10.1016/j.scitotenv.2024.174372**

# What about marine litter which is affected by direct wind drag?






Saint-Rose et. al., 2016

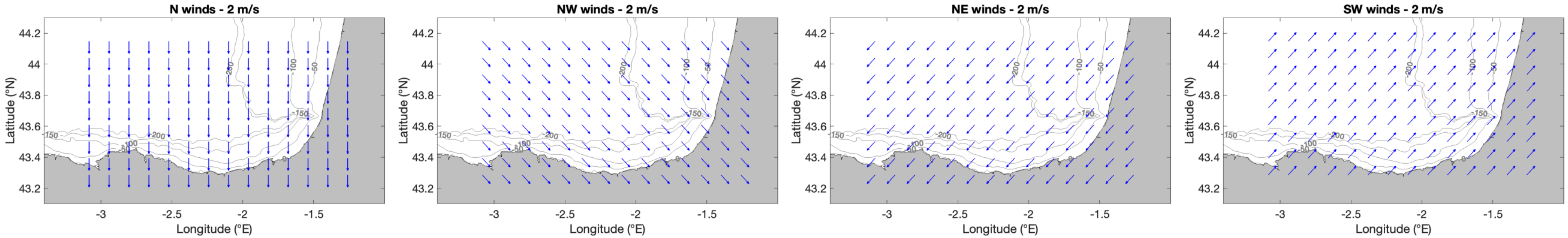


# Windage added to surface currents to compute transport, FSLE and FDLD, under four typical wind regimes



Windage is the force exerted by the wind on the emerged part of an object.
A simplified windage model is used (Yoon et al., 2009), computed as a fraction of the wind velocity at 10-m height: $U_{windage} = C_x U_{10}$

Windage coefficient




**Breivik et. al., 2011**
Shipping container → 1.4%
Oil drum → 0.8%

**Park & Seo, 2021**
Small plastic fragment → 2%
Empty capped plastic bottles, fishing buoys → 4%

$\mathbf{0 < C_x < 4\%}$

# FDLD superimposed with FSLE ridgelines reveal structures affecting the transport of particles subject to different windages.

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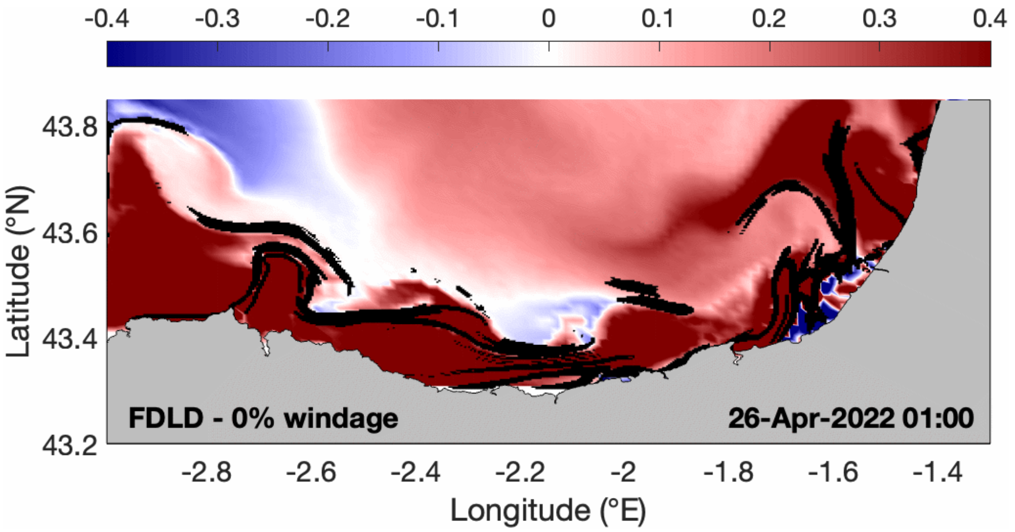
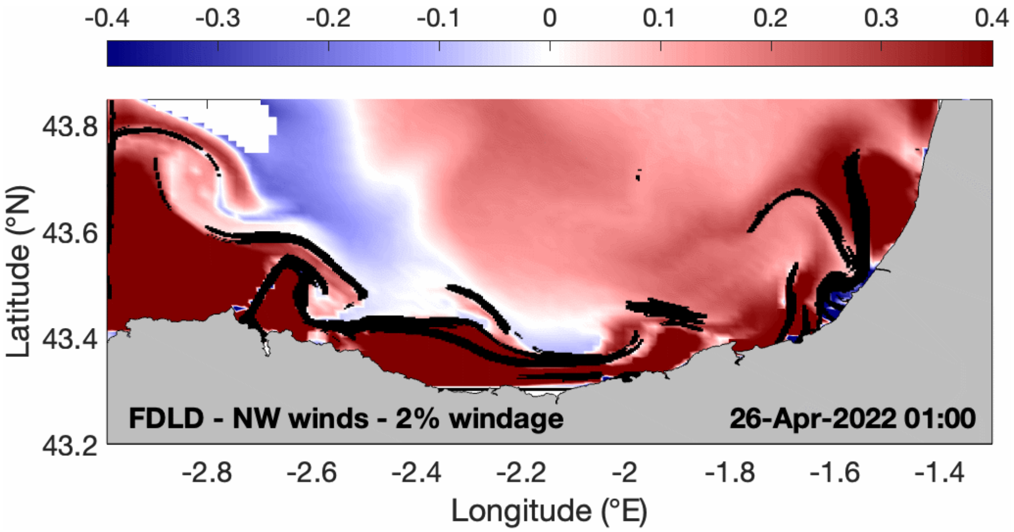
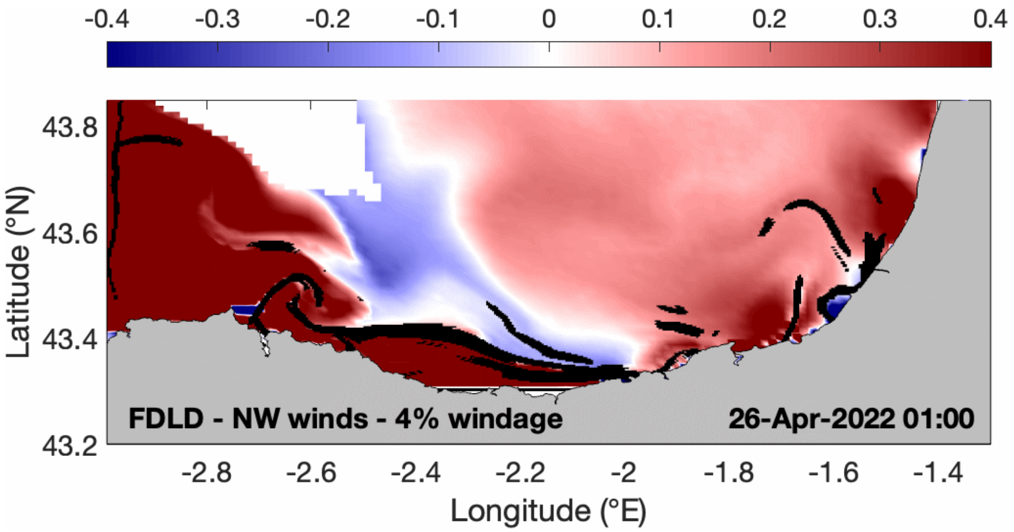
## NW winds




Bertin et al. (under review)



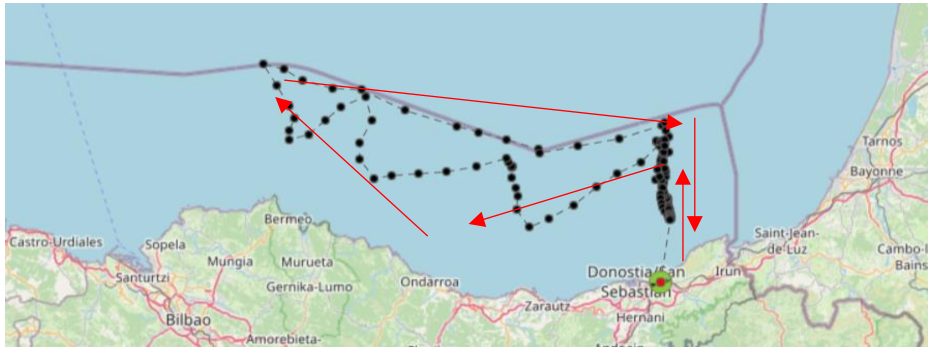



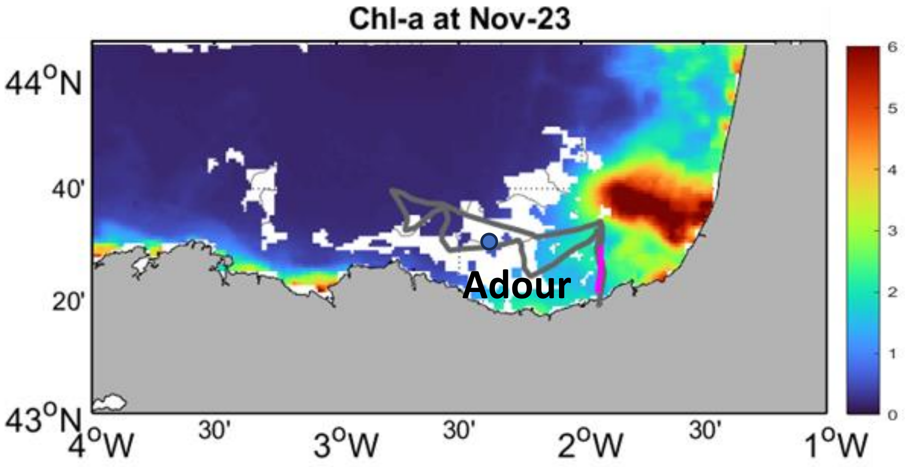
# So, what about river plumes?

# THE BGCD3 GLIDER MISSION

## Designed to cover in-situ stations routinely measured for climate change studies the glider sampled the Adour River plume

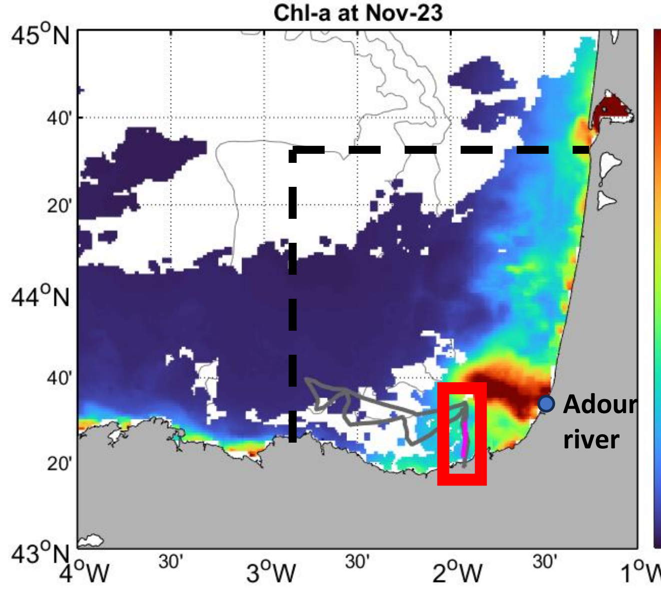
- November 23 to December 4 (2023)
- Mission duration : **11.0 Days**; Distance traveled: 239.63 km;     465 cycles,  0– 950 m depth
- The glider collected:
  - **Integrated Currents +**Hydrography: **T, S**
  - BGC: **turbidity, chlorophyll-a (Chl-a), dissolved oxygen (DO), colored dissolved organic matter (CDOM) and nitrate concentration**
- BGC data QC in progress



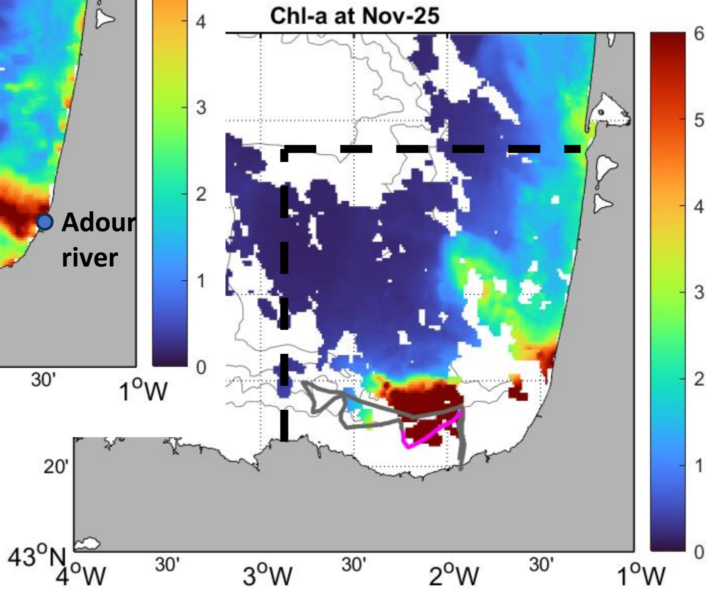



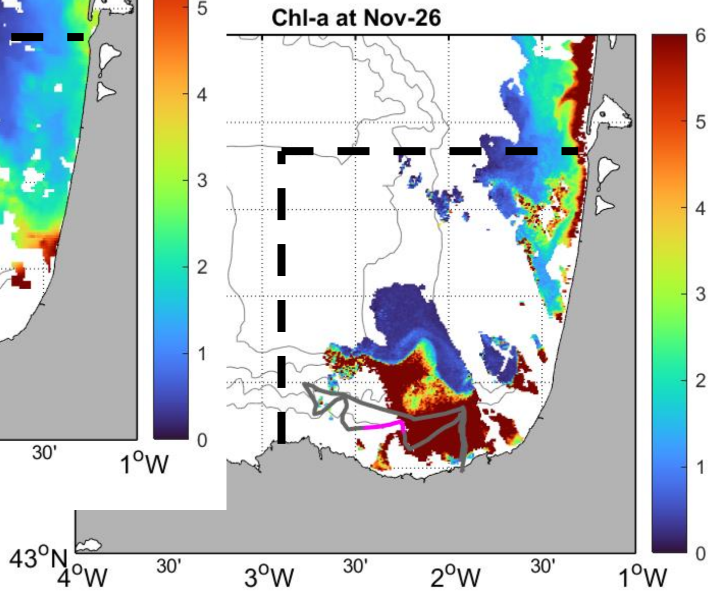
# Adour River Plume Horizontal extension

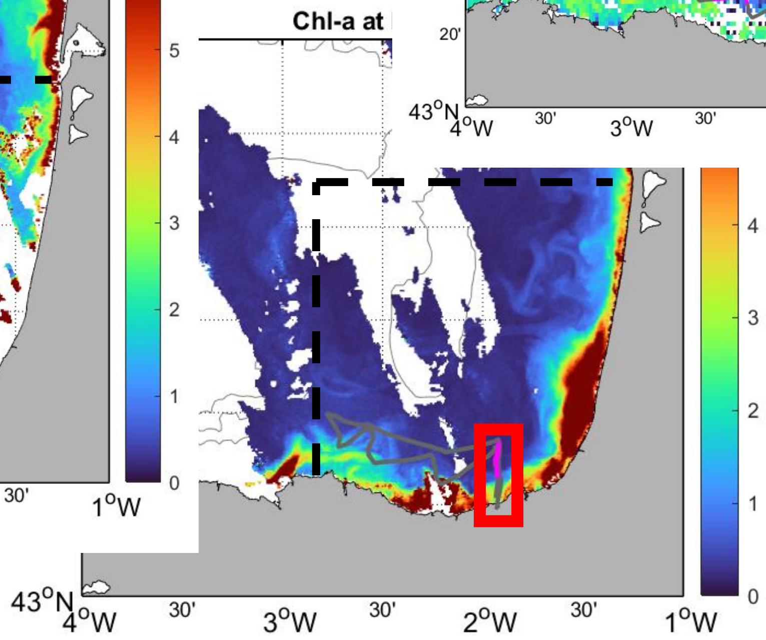
From remote sensing data showed a westward extension along 85 km

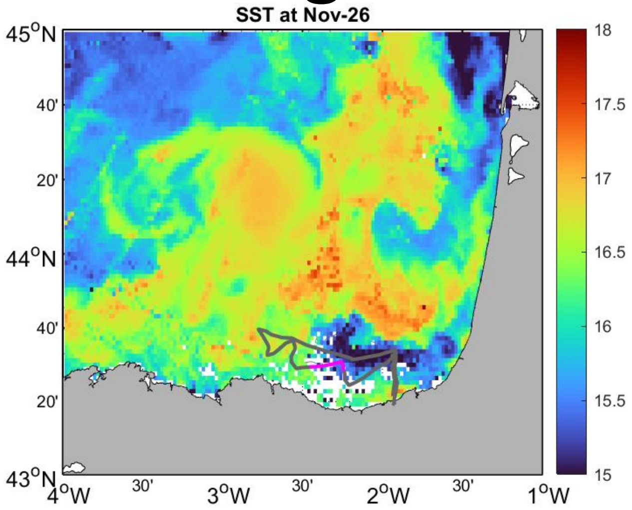



▯ Area **visited by the glider** from Nov 23 to 25 and **revisited** from Dec 2 to 4




**- - - HF radar footprint area**

# Surface currents from glider & radar

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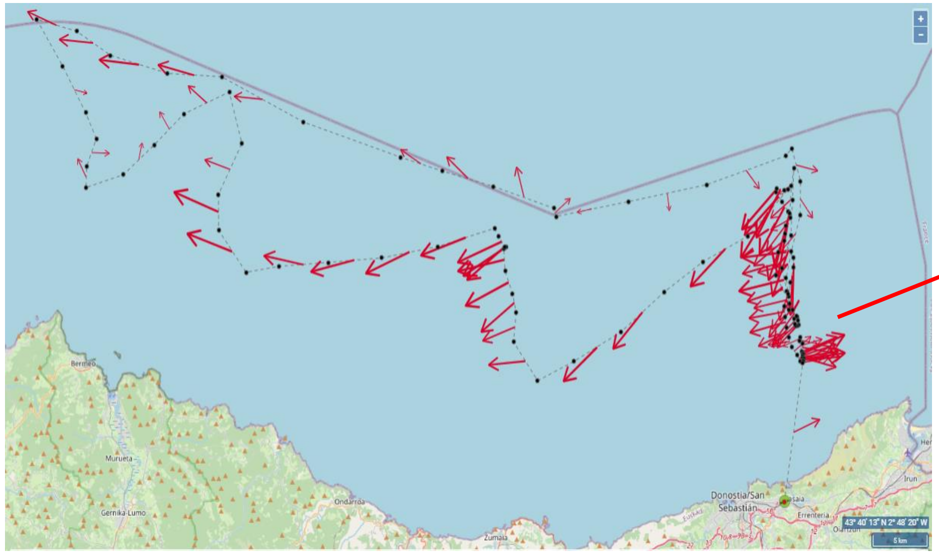
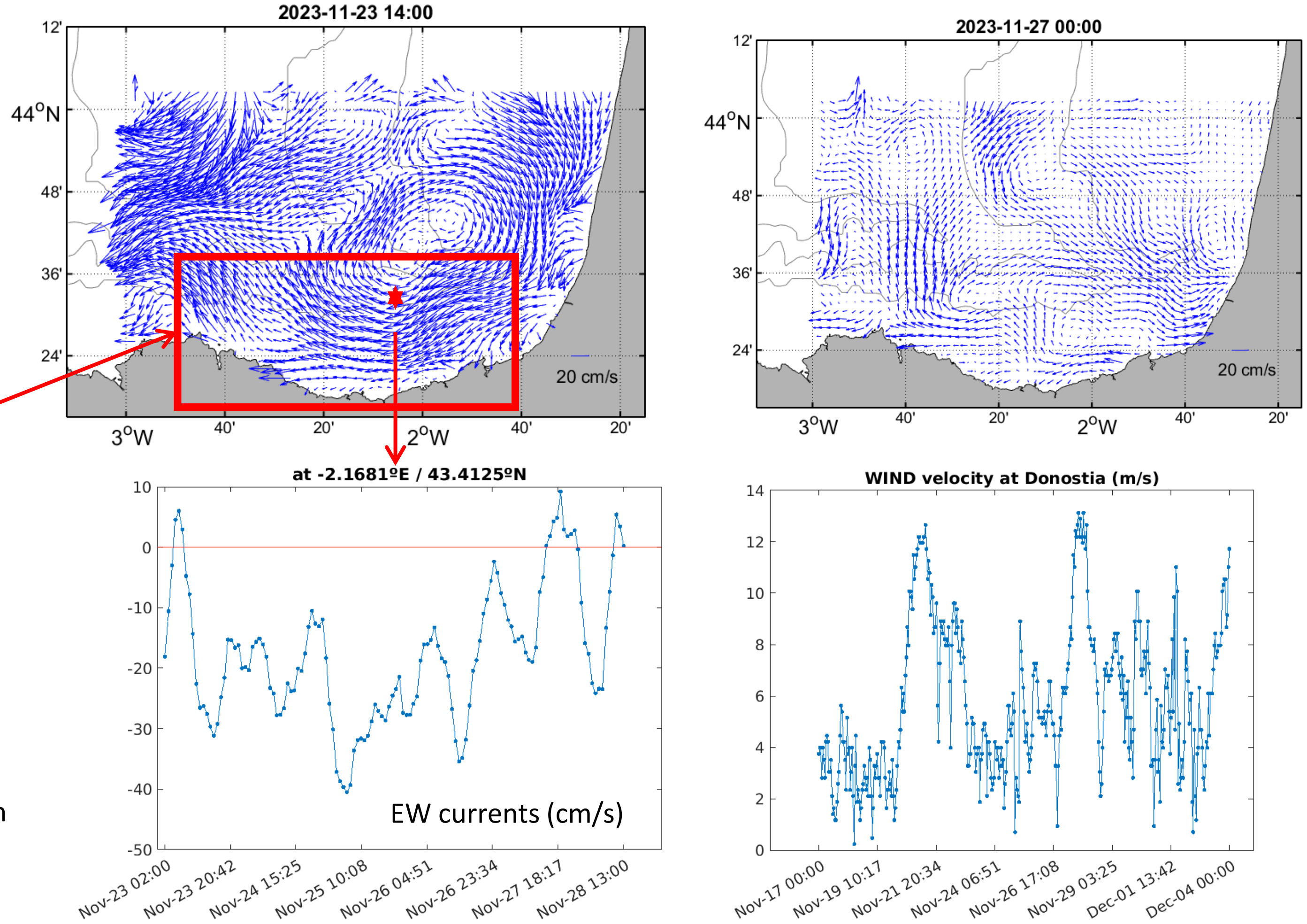
Maximum westward surface currents detected by the HF radar of 50 cm/s while the glider sampled 30 cm/s along the water column

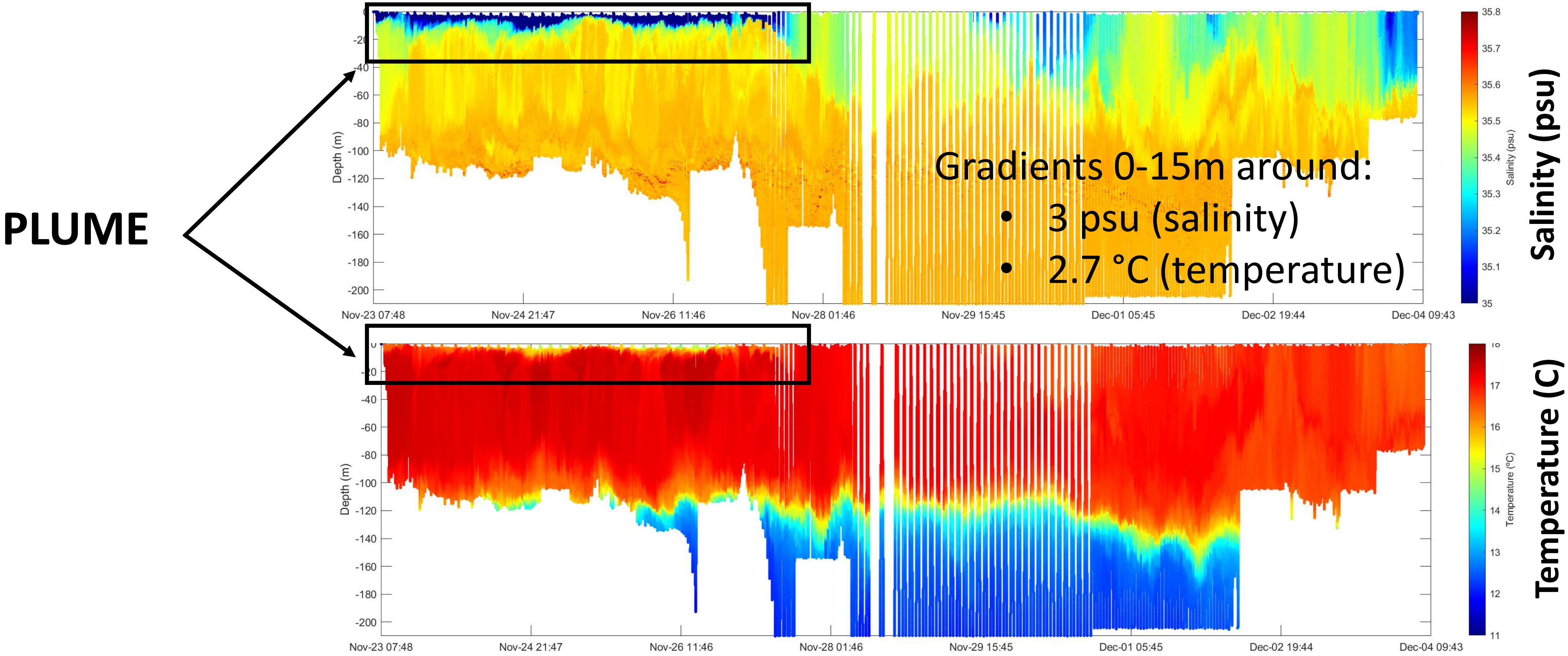





Westward advection relaxed from Nov 27th
N winds gusts (50 km/h), more variable after the 27th

# Adour River Plume vertical extension

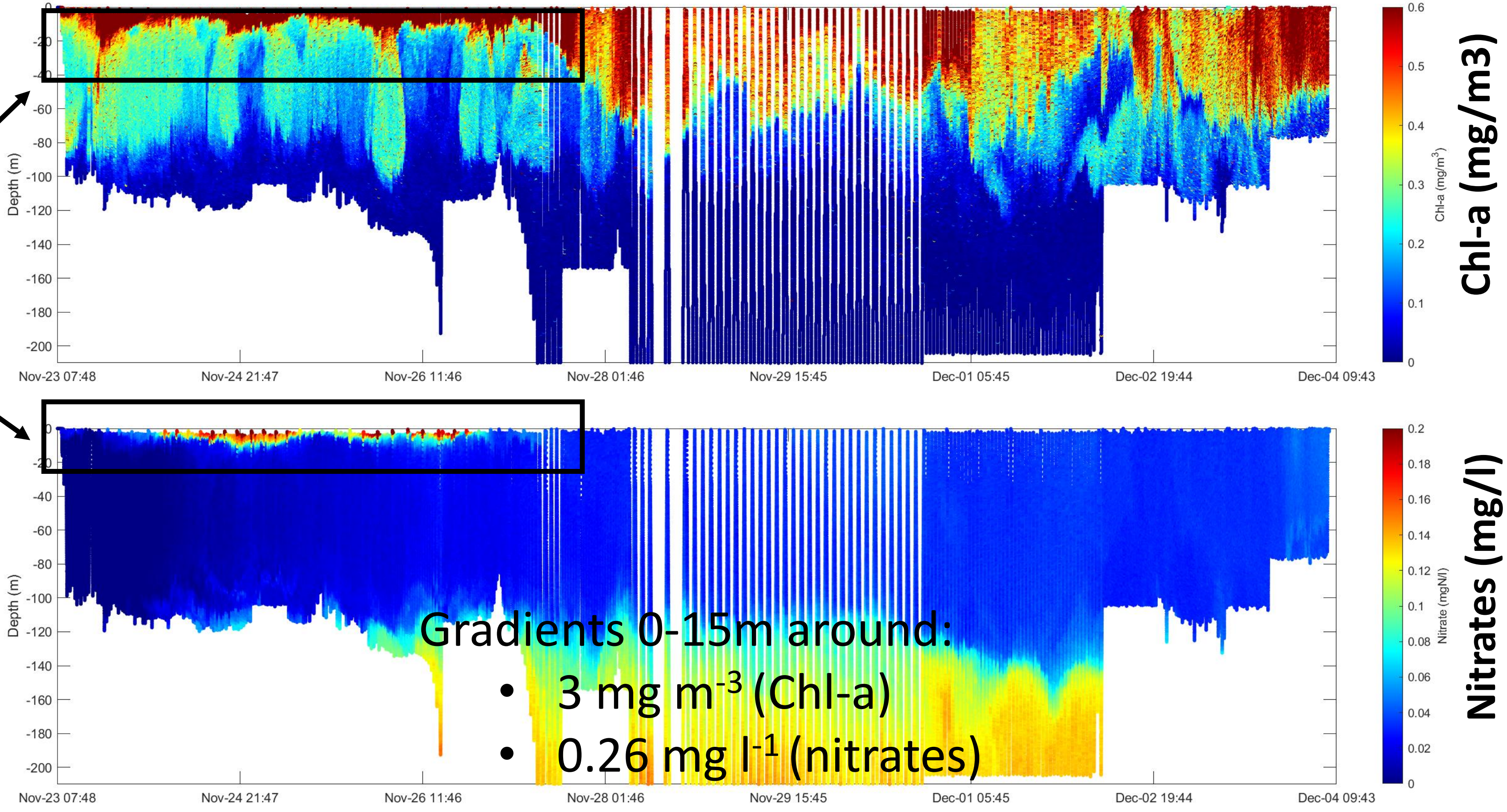
Strong TS anomaly from 0 to 15m depth between 23-27 Nov



# Adour River Plume vertical extension

Strong TS anomaly from 0 to 20m depth between 23-27 Nov

**PLUME**




Gradients 0-15m around:

- 3 mg m$^{-3}$ (Chl-a)
- 0.26 mg l$^{-1}$ (nitrates)

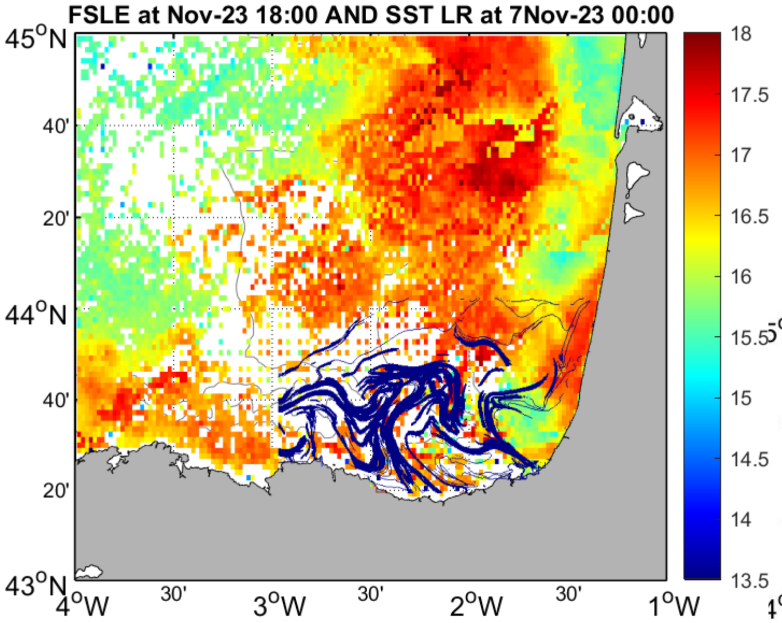
# HF radar FSLE & Chl-a maps from satellite

## FSLEs ridges computed from HF radar delimitate the plume extension

**HF radar 2dVar fields** (Yaremchuk and Sentchev, 2009)
$\Delta_{x,y} = 2.5\ km$ - $\Delta_t = 1\ h$
(validated in Bertin et al. 2024)

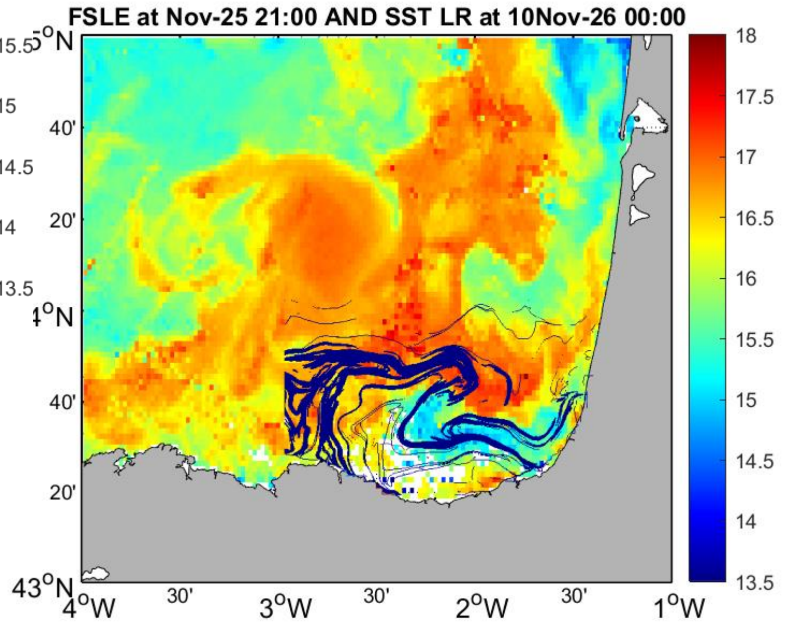
**FSLE**: Inverse of the time $\tau(\boldsymbol{x})$ required for two particles of fluid to separate from an initial distance $\delta_0$ to a final distance $\delta_f$ (Hernández-Carrasco et al., 2011; LaCasce, 2008):

$$\lambda(\boldsymbol{x}, t, \delta_0, \delta_f) = \frac{1}{\tau(\boldsymbol{x})} ln \frac{\delta_f}{\delta_0}$$




*Ridges >0.3 (1/day)*

*At* $bkw = 15\ days$ *,* $\frac{\delta_f}{\delta_0}$*=10*



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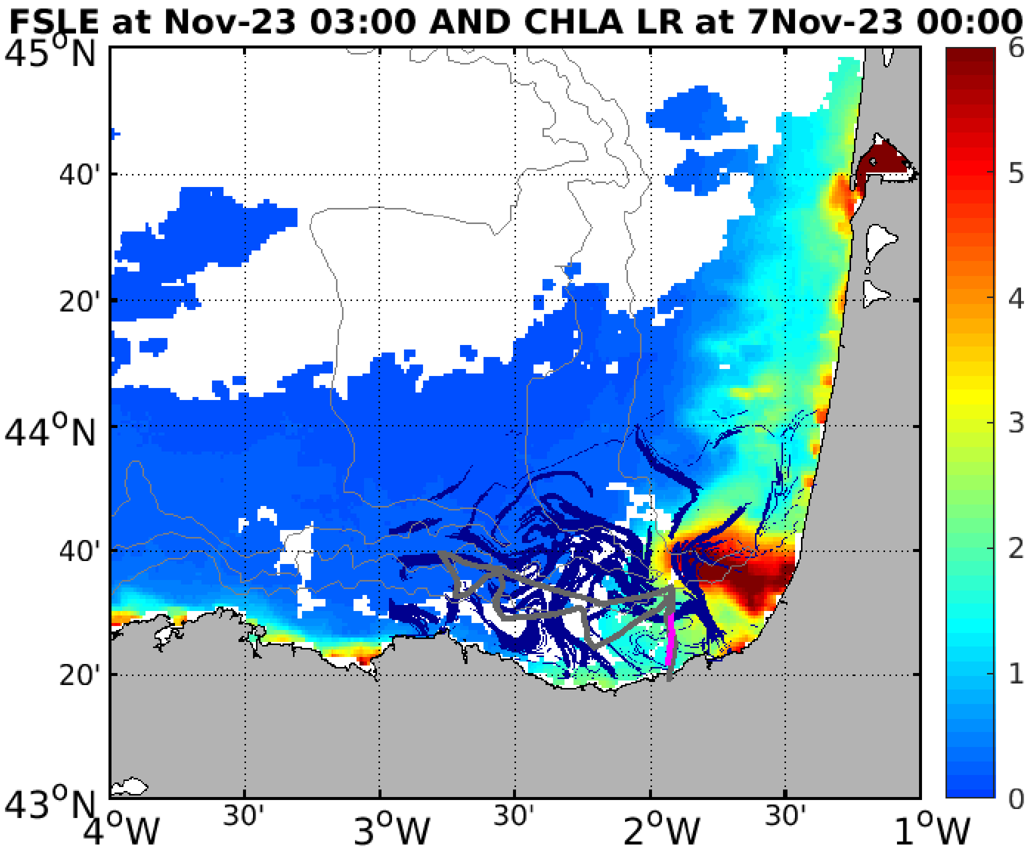
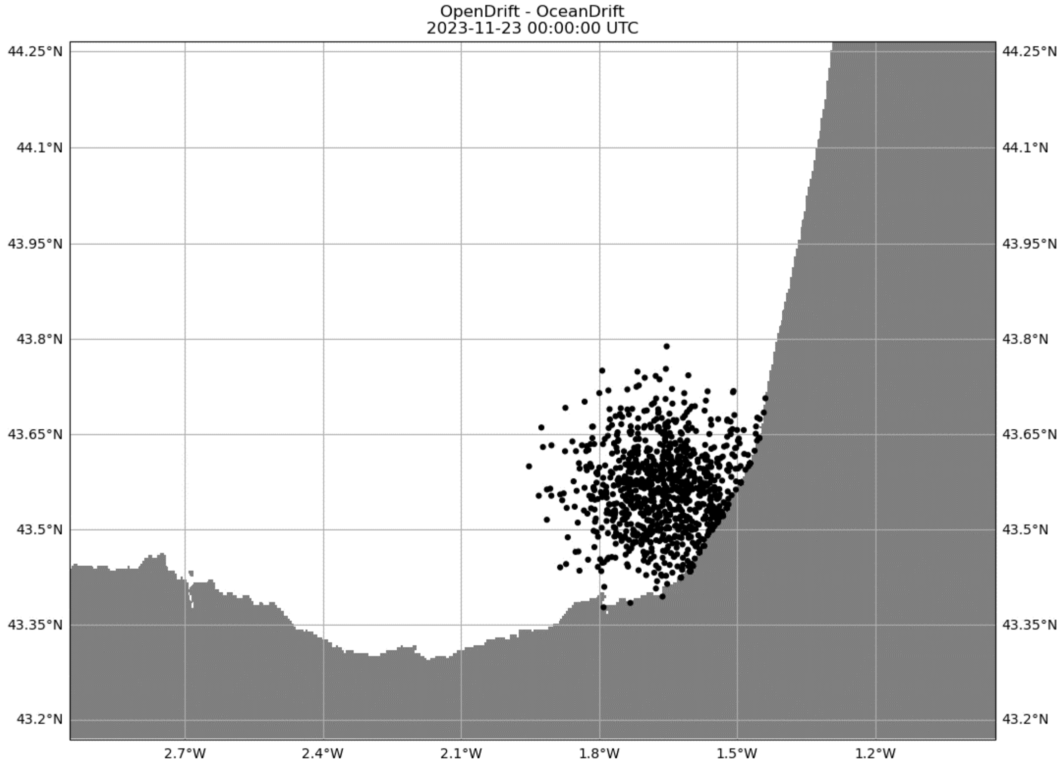
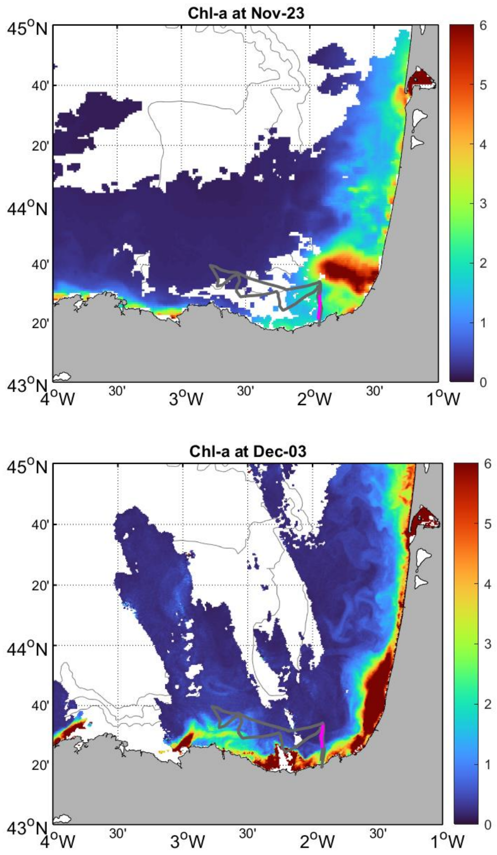


# Surface currents & FSLE

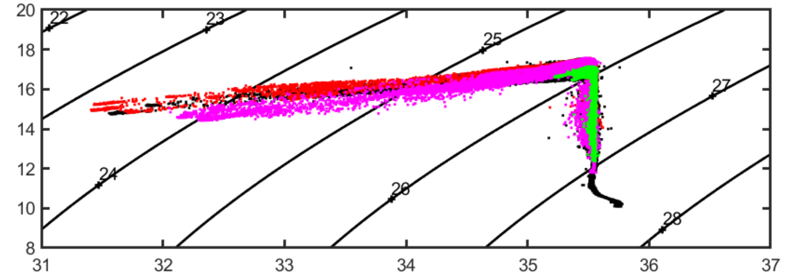
FSLEs ridges computed from HF radar delimitate the plume extension

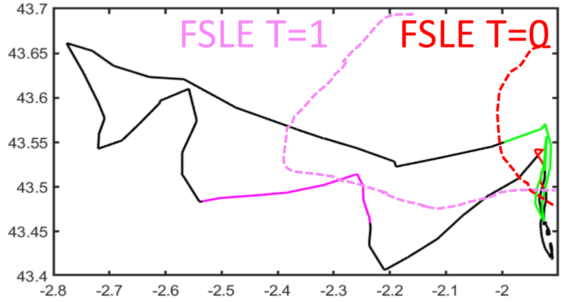


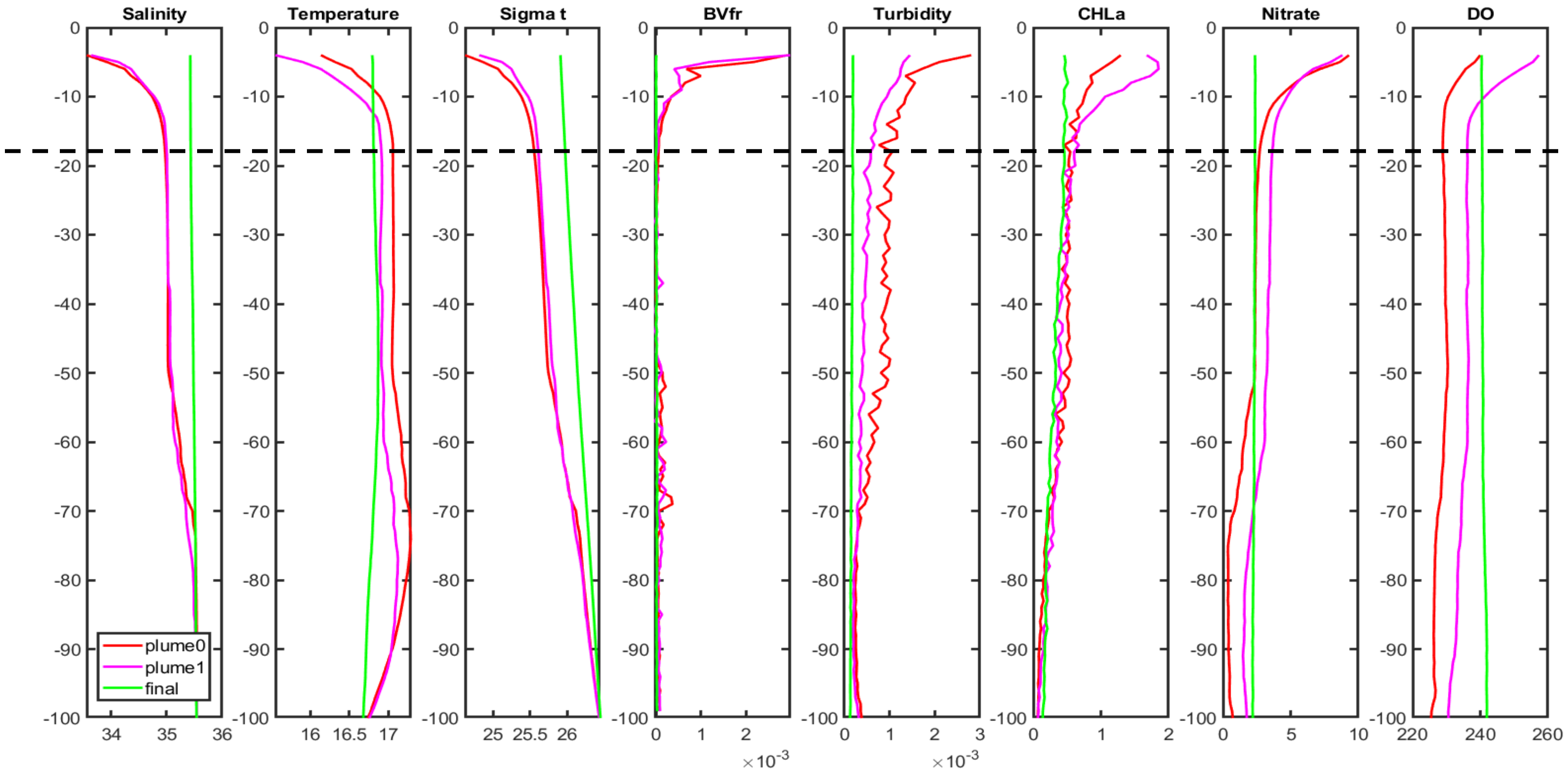



# Vertical mixing vs. advection?

## Evolution of main hydrographic and BGC variables




From T0 to T1:

- Plume gains in extension
- Lower temperature and buoancy
- Increase in PP (phytoplankton dynamics)
- Temporal vs spatial varibility ?
- Advection vs. difussion
- Vertical extension of the plume

Work in progress....

# CONCLUSIONS

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- Coastal dynamics is complex, with small-scale features that efficiently aggregate passive particles at short time scales and may have complex 3D structures.
- The observed processes (eddies, fronts and rapidly evolving river plumes) are recurrent and they impact surface and subsurface transport
- This variability is often missed by traditional observational methods (and models), enhancing the importance of multiplatform coastal observatories
- Backward-in-time FSLE ridgelines and FDLD ravines delimit the spatial distribution of Chl-a and enable to locate CCS, however their effectiveness is highly reliant on the underlying Eulerian fields (potential of HF radar is showcased)
- Future work includes:
  - The **LAMARCA MEDLIT Sea survey in the Ibiza Chanel in July** for studying frontal accumulation of plastics in the area covered by the SOCIB HF radar
  - Work on BGC data processing first, then to advance on the characterization of **Fine-Scale Biogeochemical-Physical Interactions** for Enhanced coastal ocean Monitoring and Forecasting capabilities
  - **Lagrangian diagnostics on** HF radar and model simulations to study **mackerel and anchovy ELS distributions**

# Acknowledgments

https://lamarca-project.eu/

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UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL "Una manera de hacer Europa"
AGENCIA ESTATAL DE INVESTIGACIÓN

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