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VIII Encuentro Oceanografía Física

Operational observations of coastal current convergence structures driving floating marine litter aggregations in the southeastern Bay of Biscay

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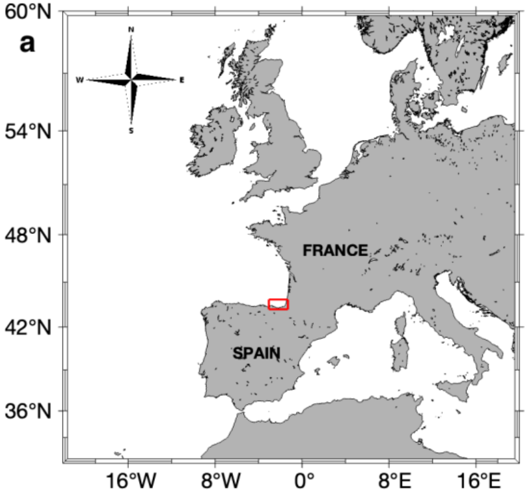
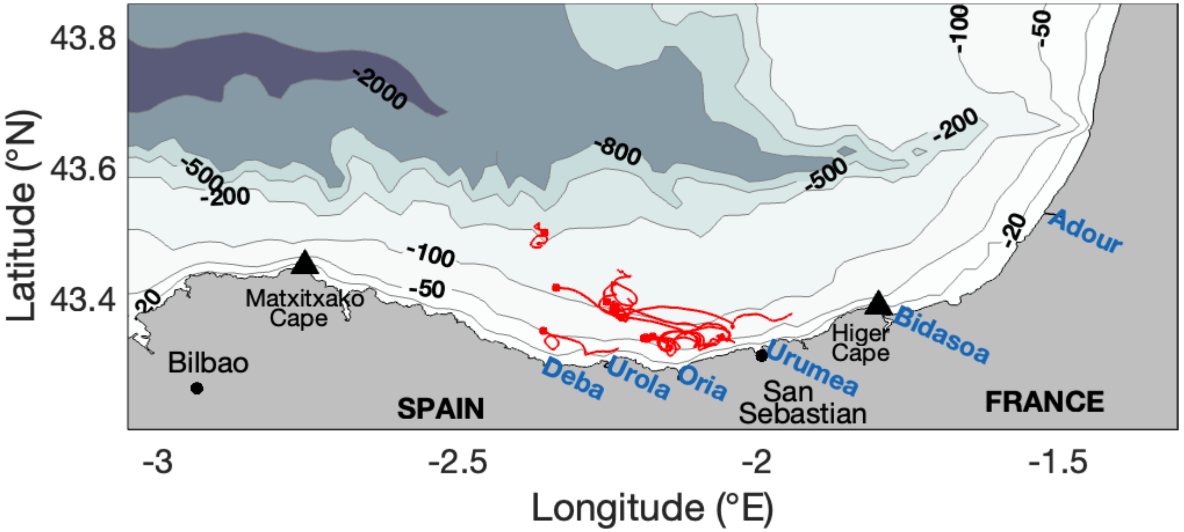
Frontal accumulation of marine litter is observed in the southeastern Bay of Biscay.





Study region

- Iberian Poleward Current creating anticyclonic eddies
- Dynamics affected by geostrophic current, winds, inertial oscillation (~17 hours period), and tides
- Freshwater inputs from French and Spanish rivers
- Region identified as accumulation zone of marine litter, and where litter aggregation is observed along frontal structures

Observations

- Survey: 13 surface drifters with 1 m drogue
  → 40 hours observations with 15 min temporal resolution

- HFR radials from Euskoos system
  → 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

Modeled outputs

U and V velocities from 3-D NEMO model in Iberia-Biscay-Ireland (IBI) $\Delta_{x,y} = 3.5\ km$ - $\Delta_t = 15\ min$

Surface drifter data constrain HF radar surface current field through the Optimal Interpolation (OI) method. K-Means algorithm is used to select the ensemble members composing the OI covariance matrix.

<u>Linear combination of the weighted differences between the modeled and observed velocities</u>:

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

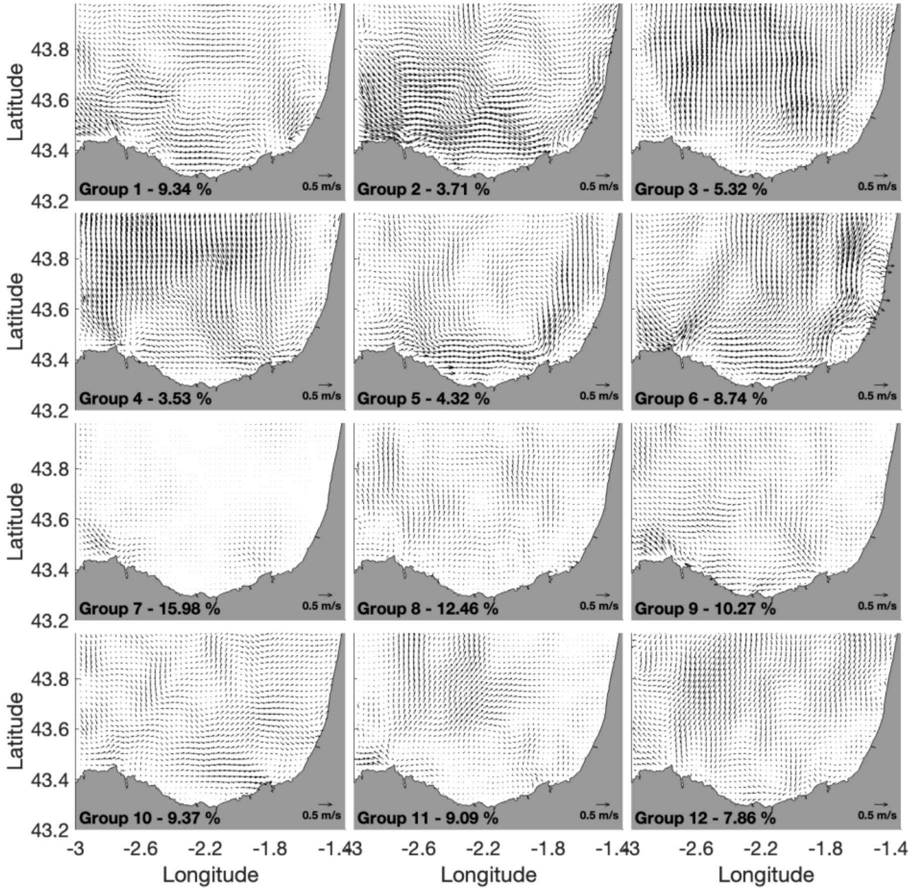
$B = \langle u_m(x,t) u_m(x',t') \rangle$ Model's space-time covariance matrix

$R_{ij} = \langle u_i^* u_j^* \rangle$ Observations' space-time covariance matrix

u_M ; u_i^* ; u_{OI} Modeled, observed and optimized velocities

H_i Projection operator

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:



The Lagrangian Error enable to evaluate the performance of the available surface current fields: 2dVar, 2dVar-opt, OMA and IBI

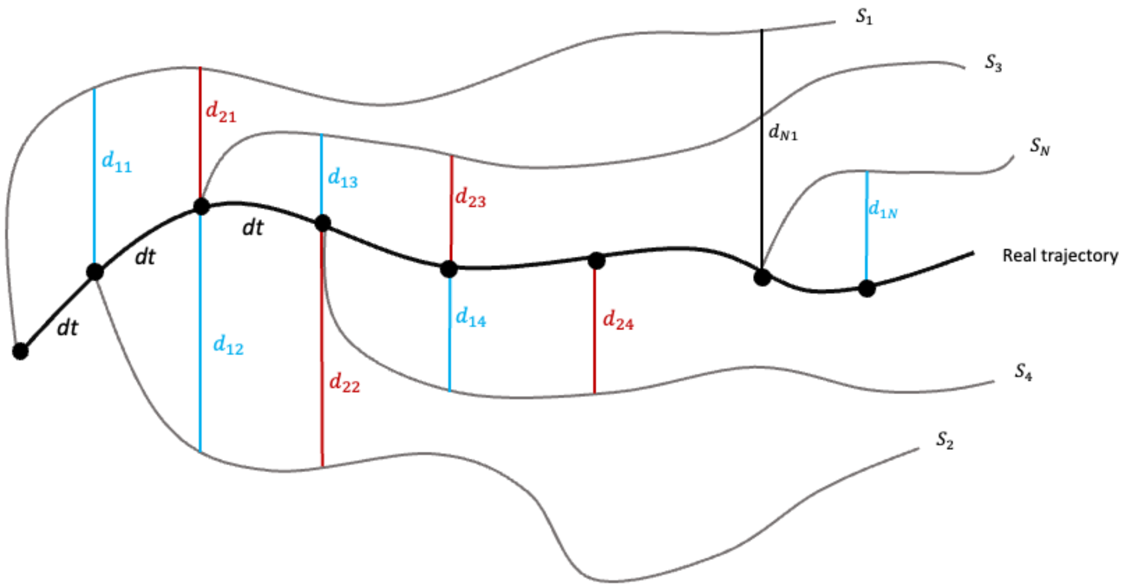
Lagrangian error index (Ruiz et al., 2022):

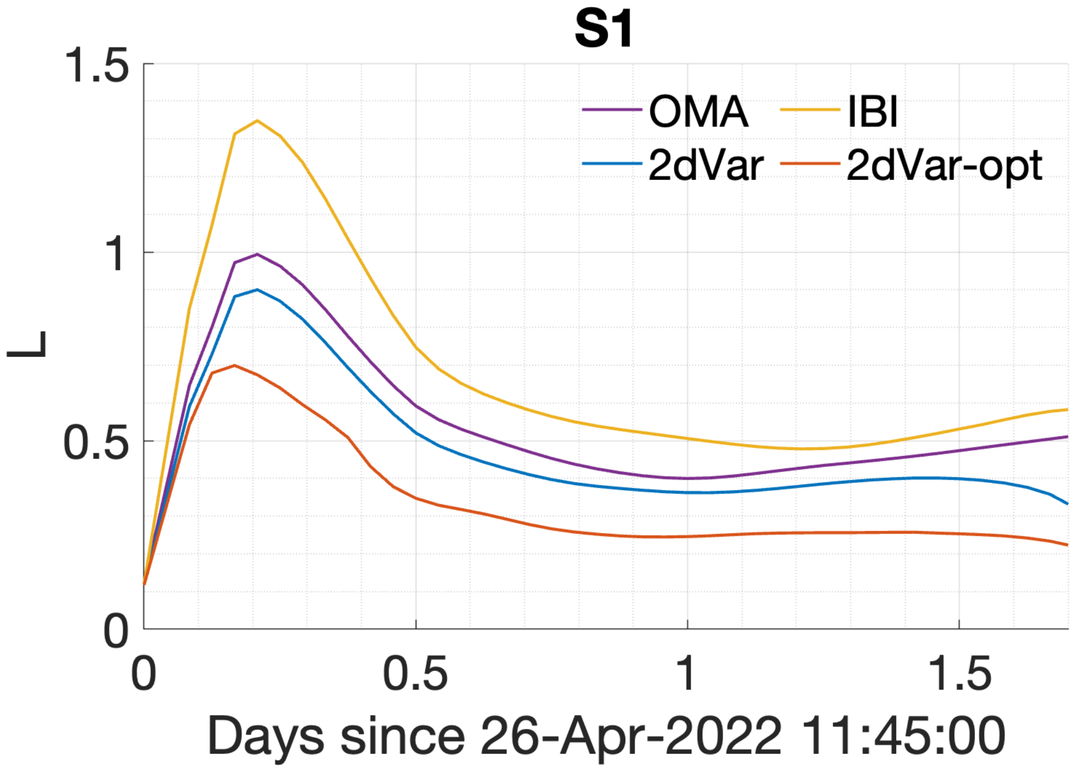
$$L(t) = \langle \sum_{t=1}^{N} \sum_{k=1}^{N-(t+1)} \frac{d_{tk}}{N-(t+1)} \rangle / \overline{D}$$

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

$\overline{D}$: mean drift distance of the real drifters

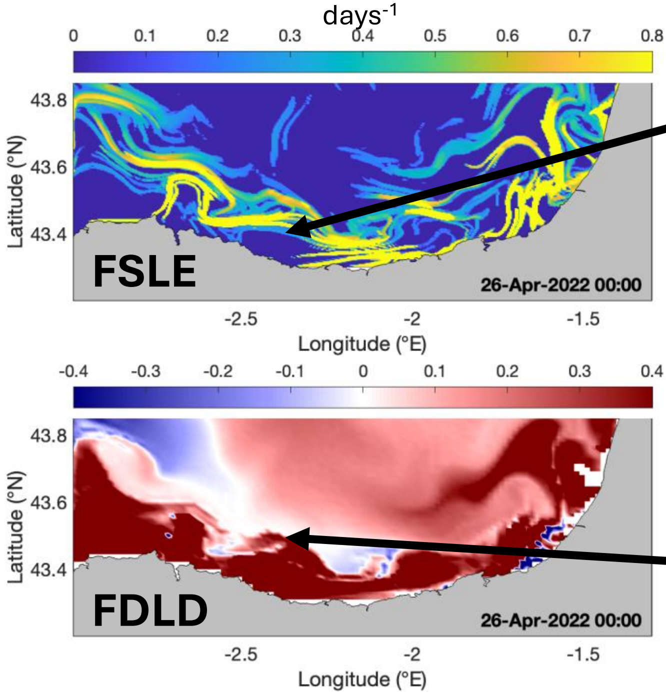




Finite-Size Lyapunov Exponents (FSLE) and Finite-Domain Lagrangian Divergence (FDLD) are used to identify Current Convergence Structures (CCS), likely to accumulate marine litter.

FSLE: inverse of the time $\tau(\boldsymbol{x})$ required for two particles of fluid to separate from an initial distance δ_0 to a final distance δ_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): $FDLD(x_0, y_0, t_0, t_f) = \frac{1}{t_f - t_0} \int_{t_0}^{t_f} \nabla_H . \mathbf{v}(x(t), y(t), t) dt$



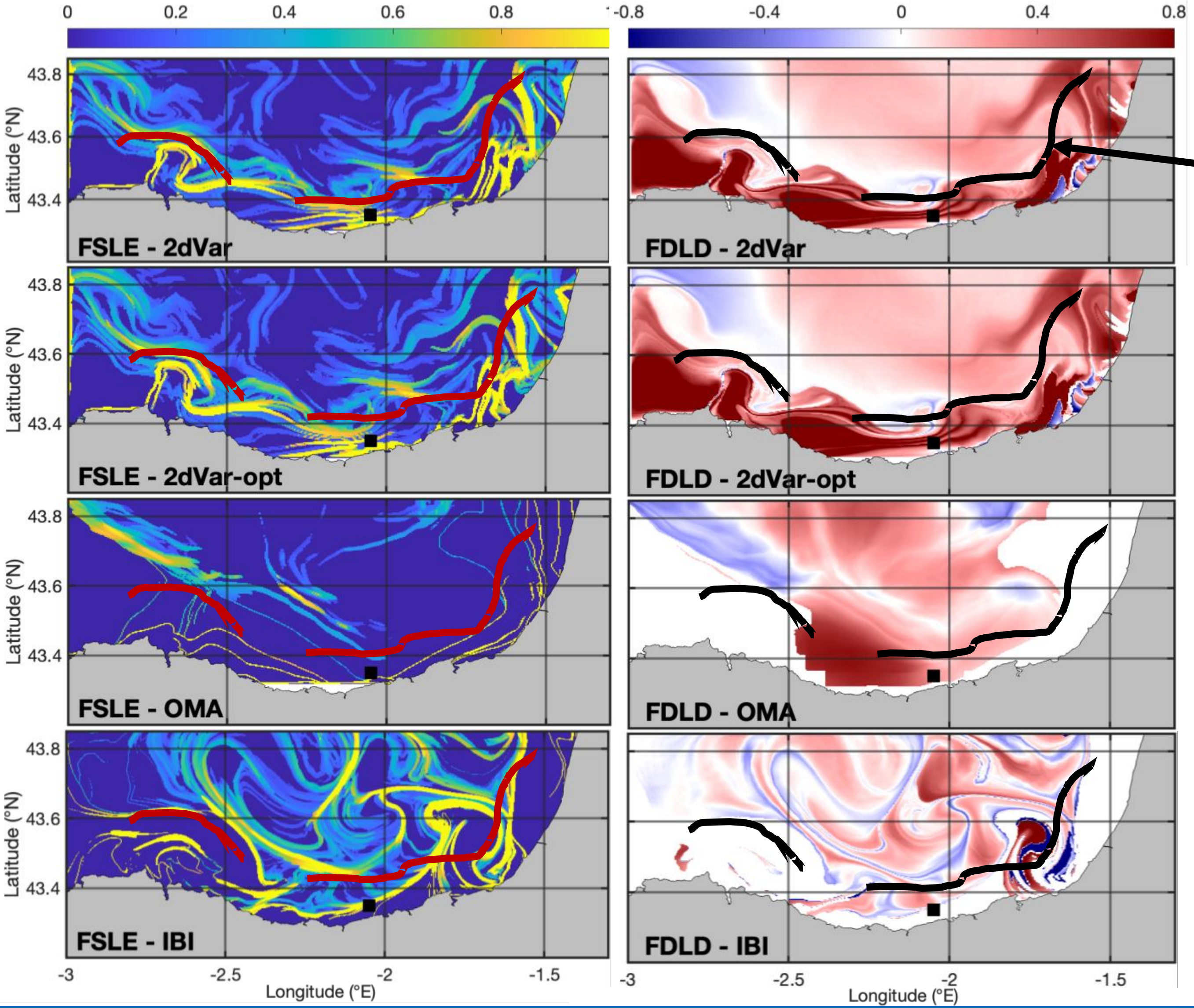
ridgeline

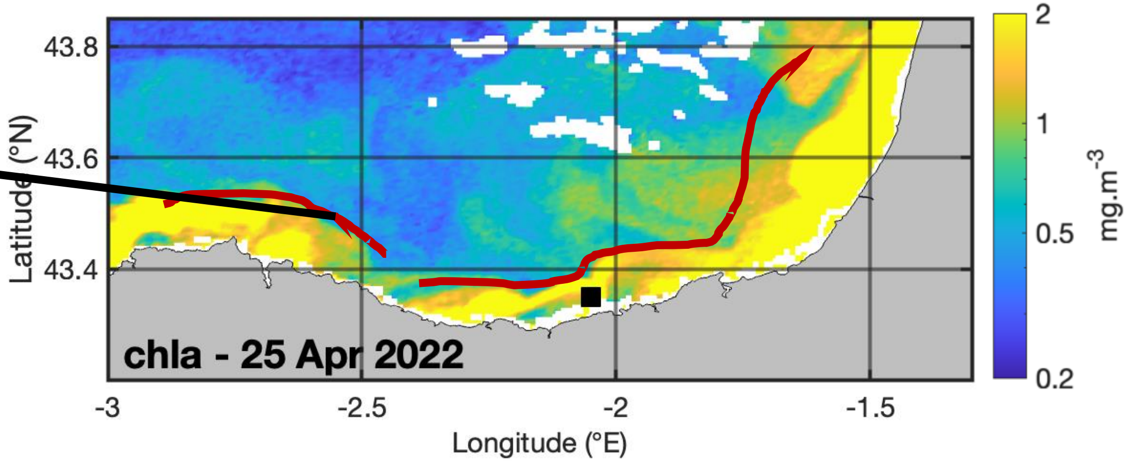
Convergence lines given by **maximum ridgelines in FSLE field** and **minimum ravines in FDLD field** identify attractive Lagrangian Coherent Structures.

→ Revealing dynamical structures that affect transport
→ Likely to accumulate floating material such as marine litter

ravine (important gradient)

Better performance of 2dVar and 2dVar-opt, with FSLE ridgelines and FDLD ravines matching CCS location and delimiting the spatial distribution of Chl-a.

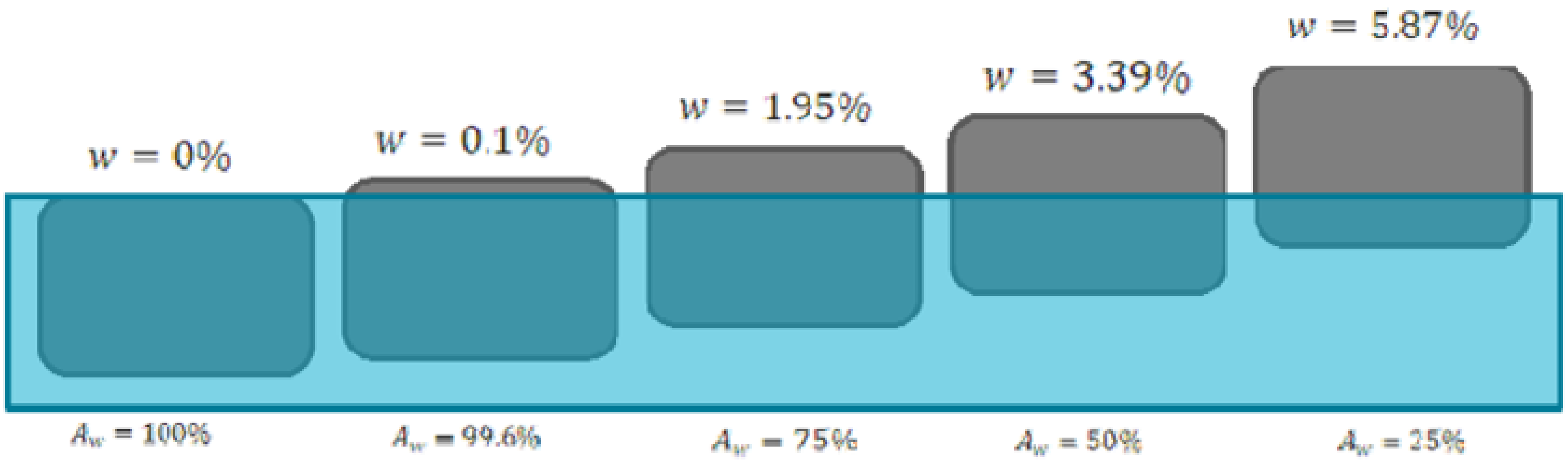




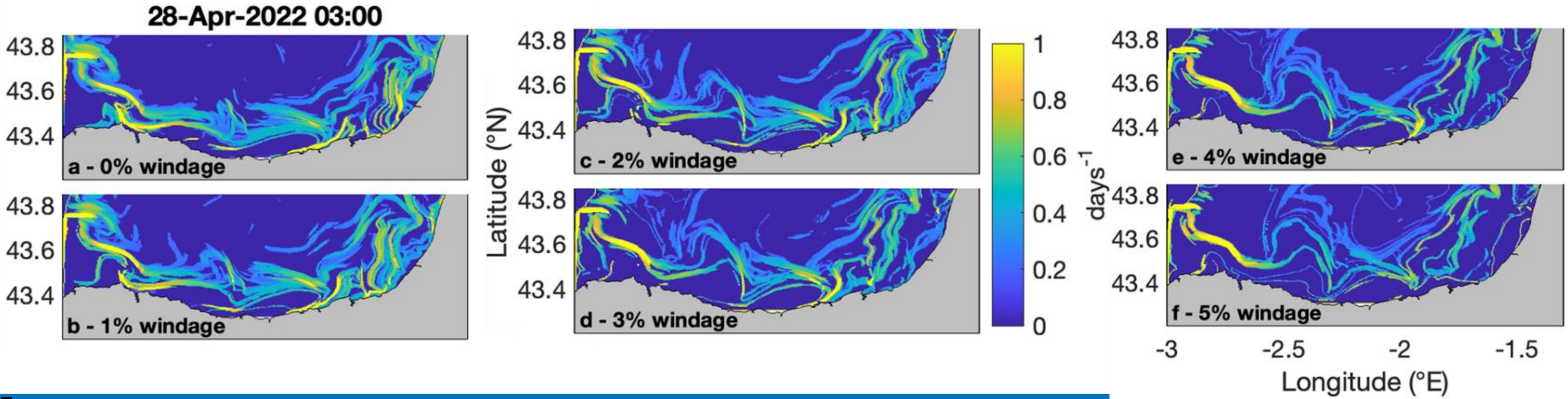
- Large values of Chl-a around river plumes (black square) and around the French coast.
- 2dVar and 2dVar-opt FSLE ridgelines and FDLD ravines **aligned with the coast**
- CCS visible in a zone of converging drifters (red square), also corresponding to Deba, Urola and Oria river plumes.

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?



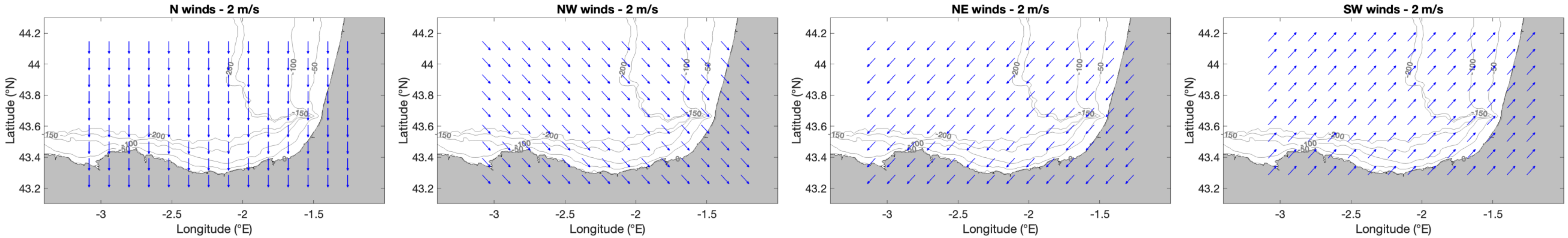
Saint-Rose et. al., 2016



To estimate the impact of windage, a fraction of wind speed was added to surface currents to compute transport, FSLE and FDLD. Four typical wind regimes were tested.

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



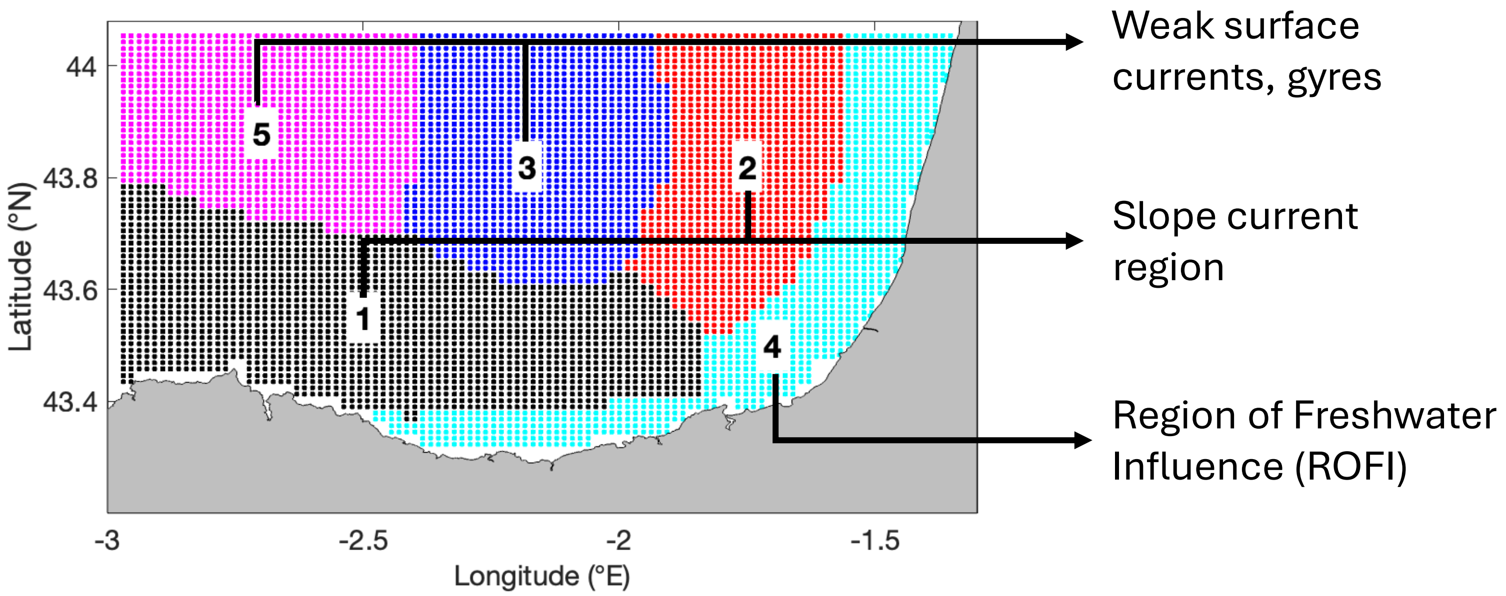
Breivik et. al., 2011
Shipping container → 1.4%
Oil drum → 0.8%

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

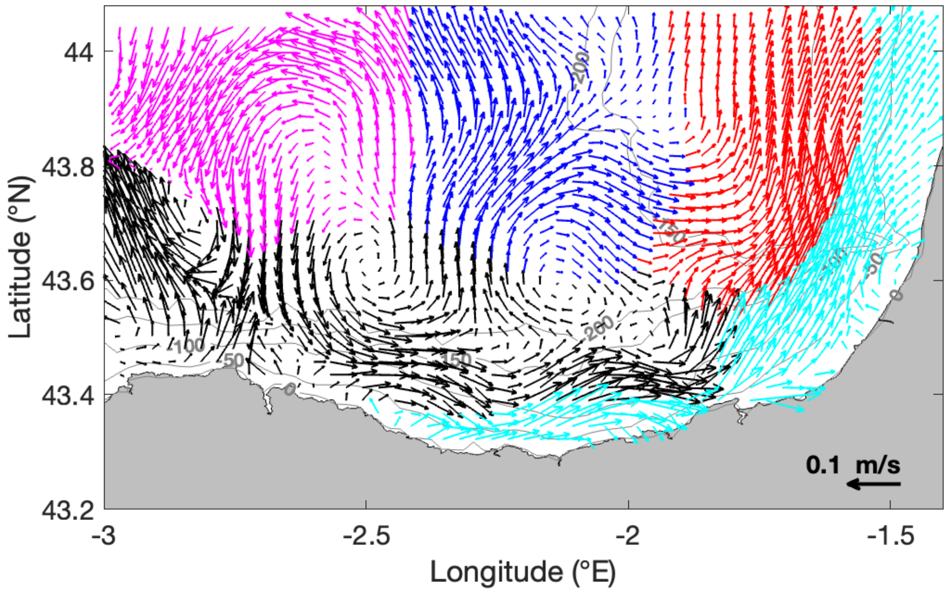
$$\mathbf{0 < C_x < 4\%}$$

Transport: Self-Organizing Maps (SOM) are used to distinguish regions with different dynamical regimes in the area and deploy virtual particles as clusters.

SOM technique applied in the temporal domain (Kohonen, 1998) to 3-years of HF radar velocity with 2dVar interpolation method.
→ Distinguish 5 regions with distinct dynamical behaviors

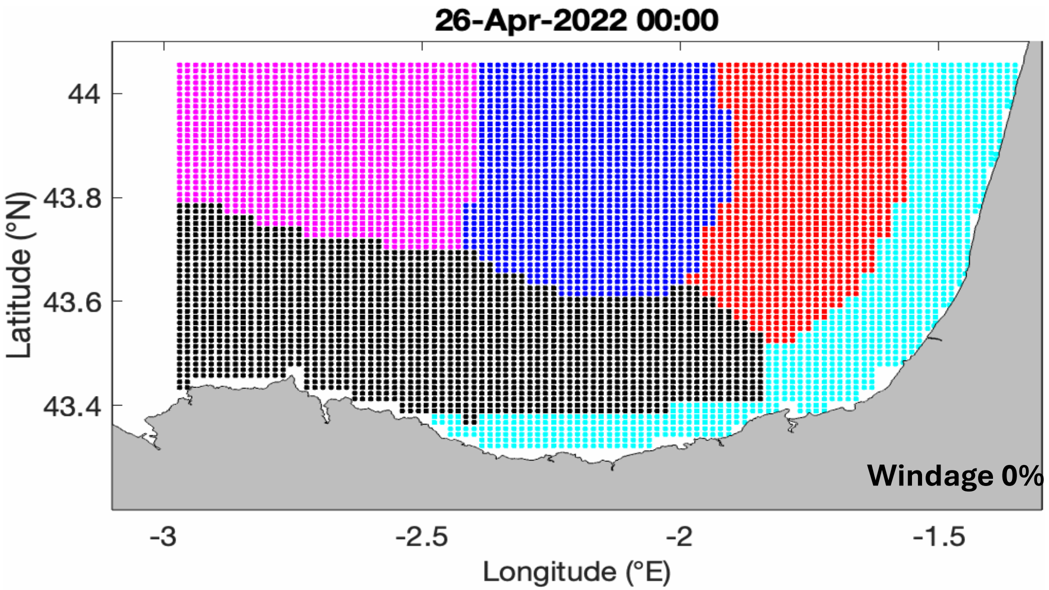


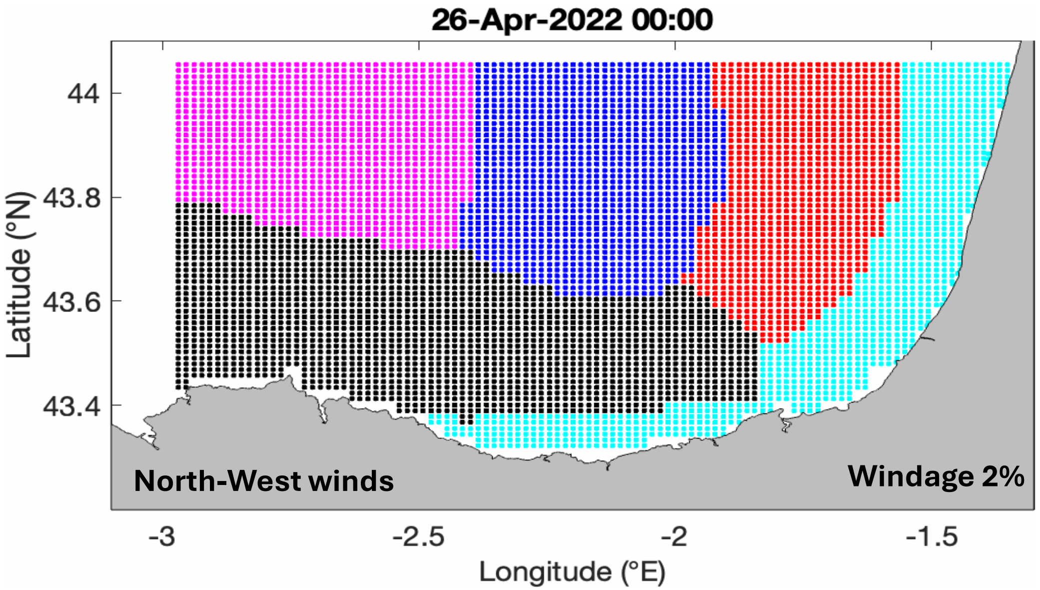
Survey: mean surface current velocity

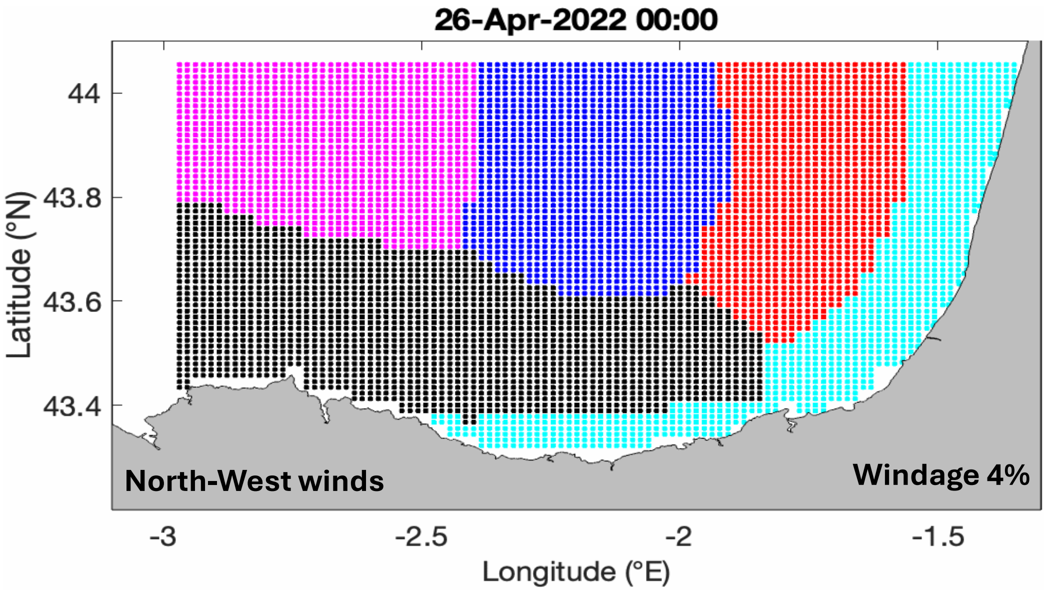


Transport: Virtual particles were deployed using OpenDrift (Jones et al., 2016) during 6 days.

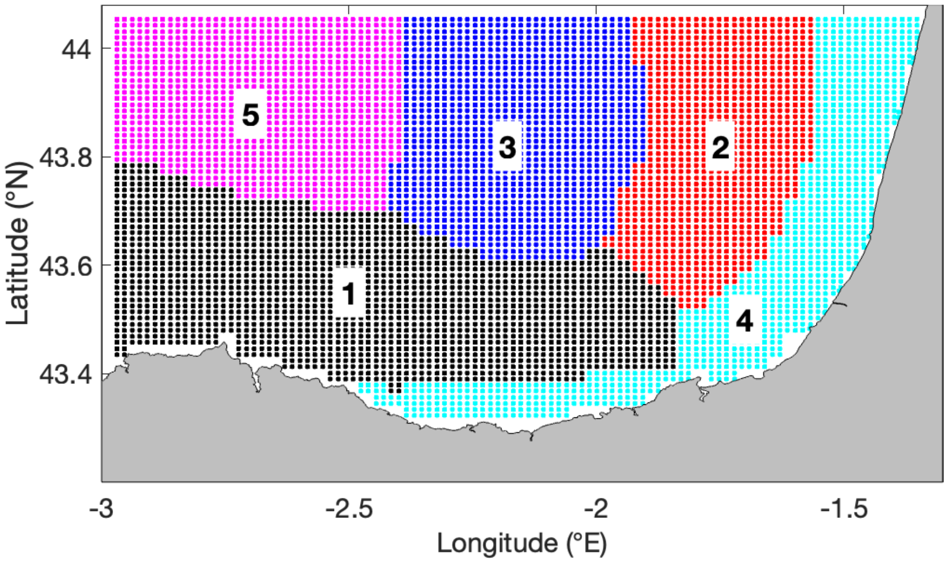
NW winds

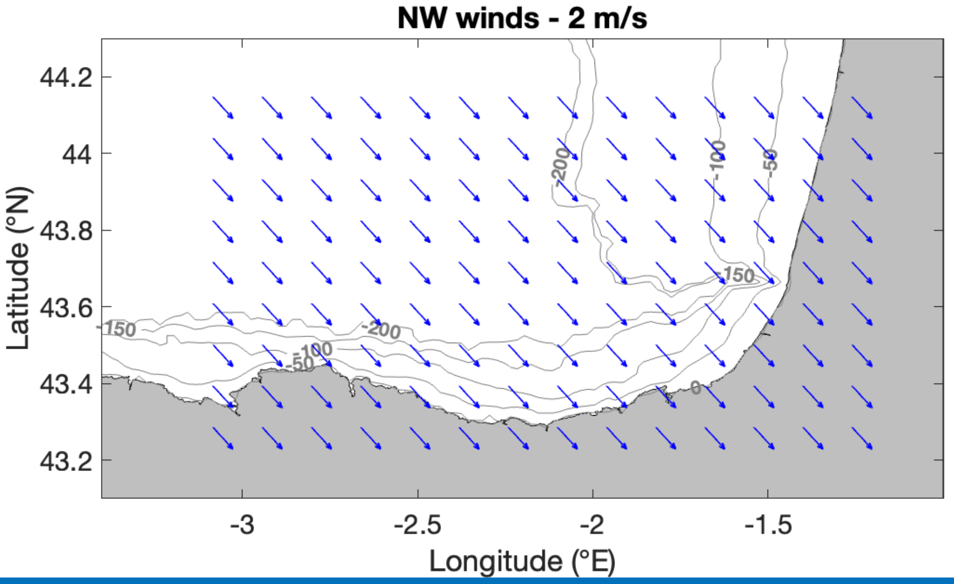


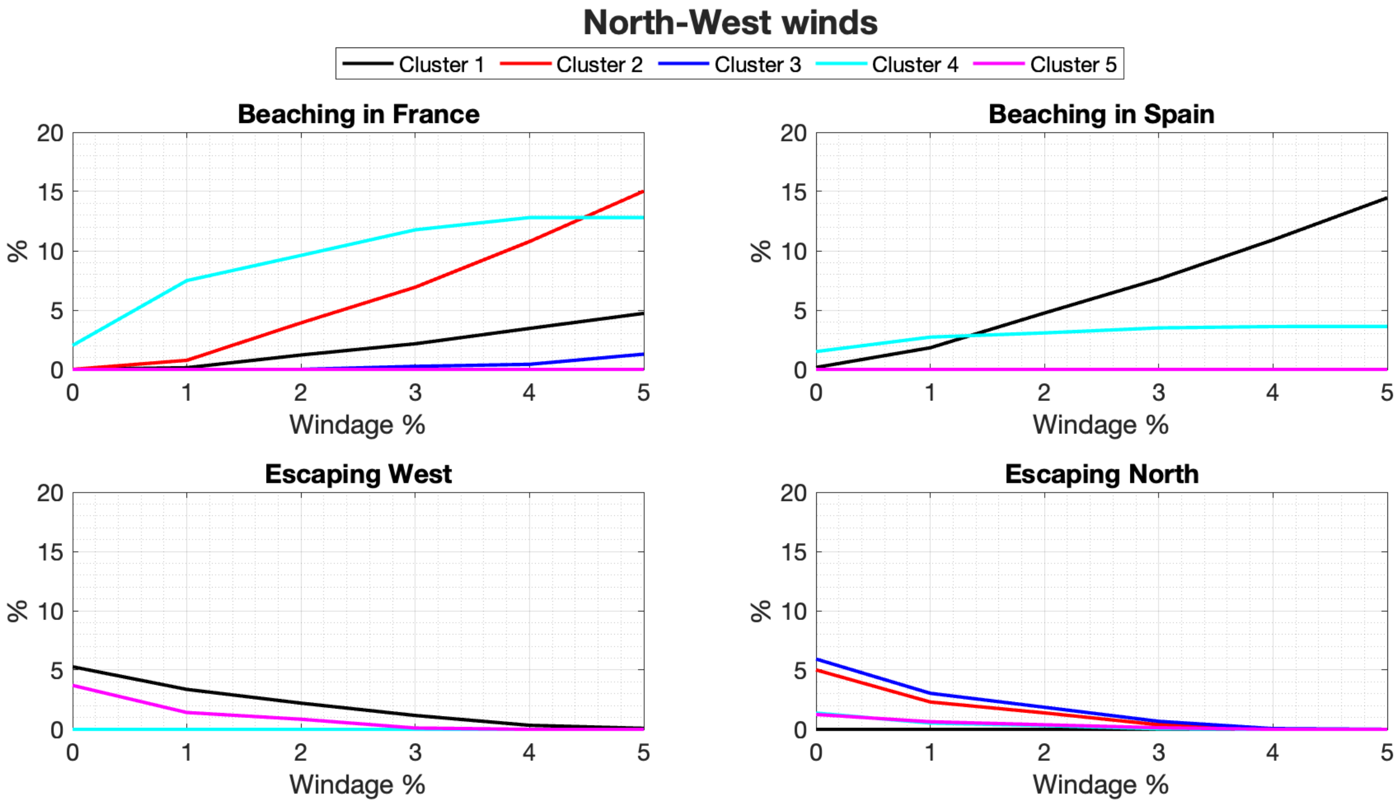




Transport: The rates of escaping and beaching were computed depending on the windage coefficient and on the wind direction.

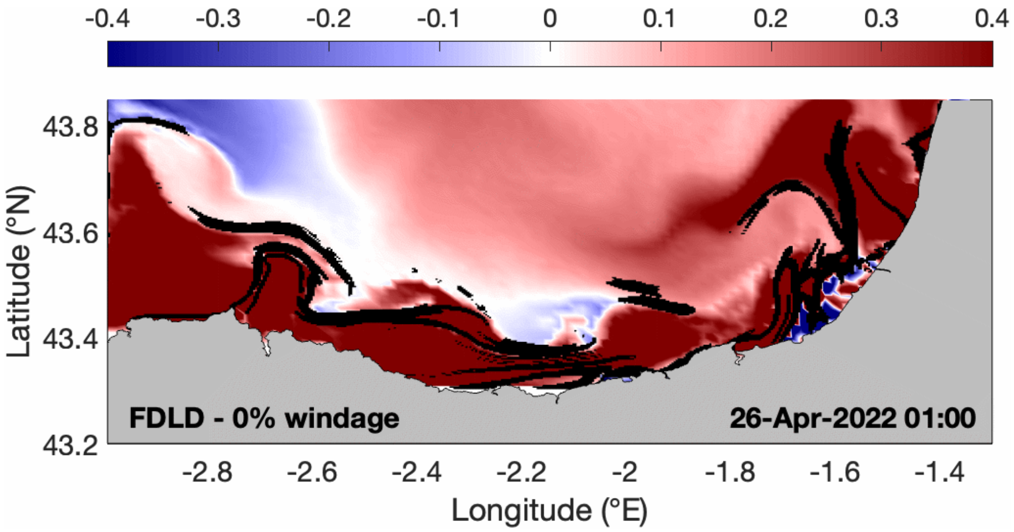




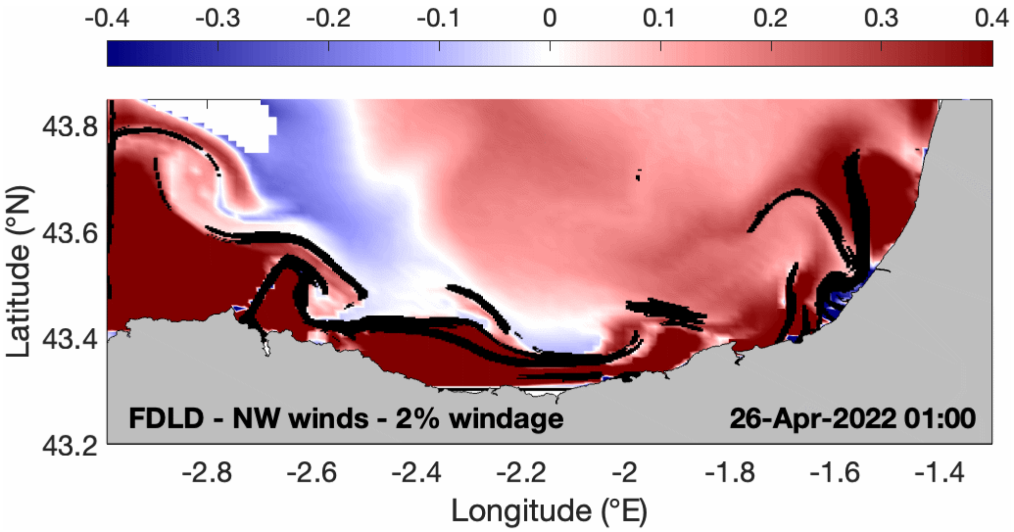


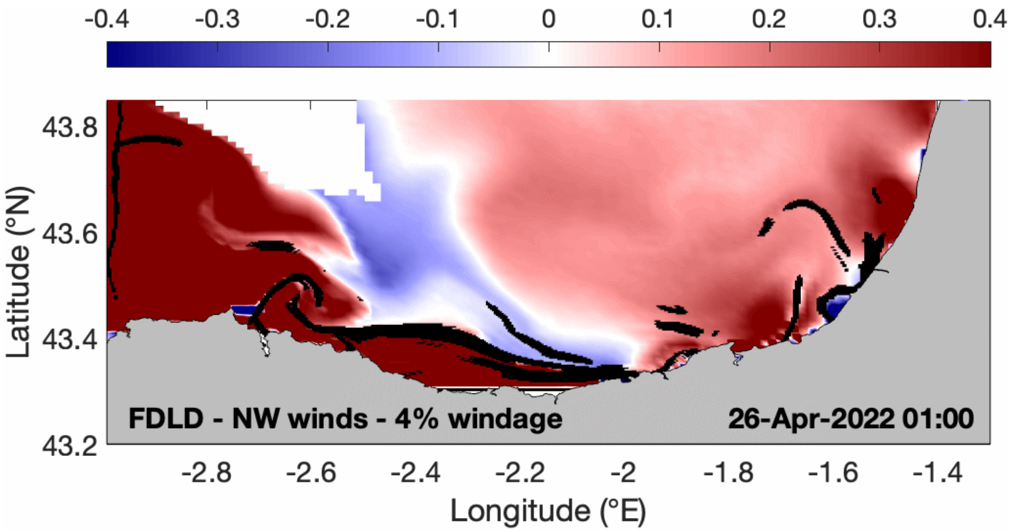
FDLD superimposed with FSLE ridgelines reveal structures affecting the transport of particles subject to different windages. FDLD unveil strong divergence in coastal area.

NW winds



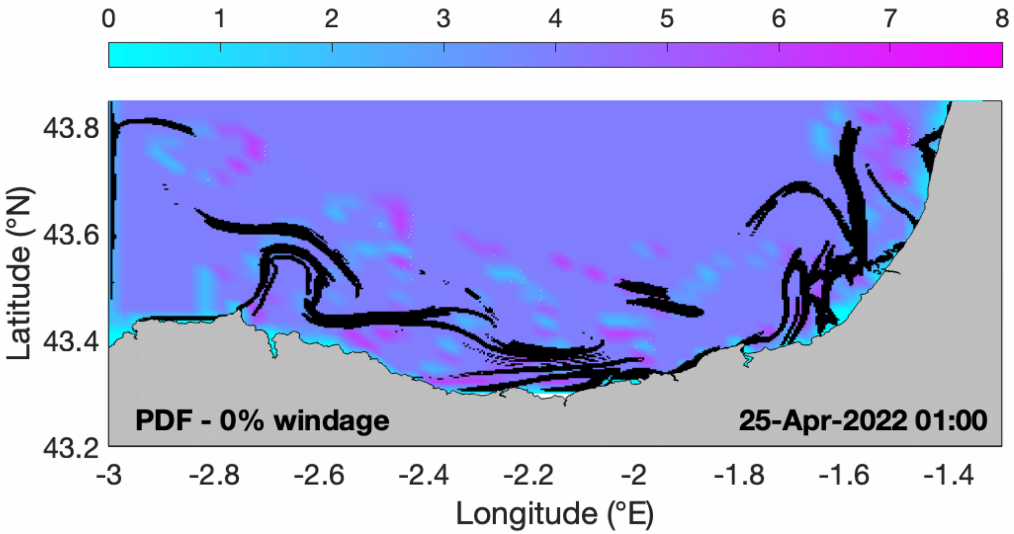
Bertin et al. (in prep)





PDF superimposed with FSLE ridgelines show that LCS structures well the passage of particles subject to different windages.

NW winds



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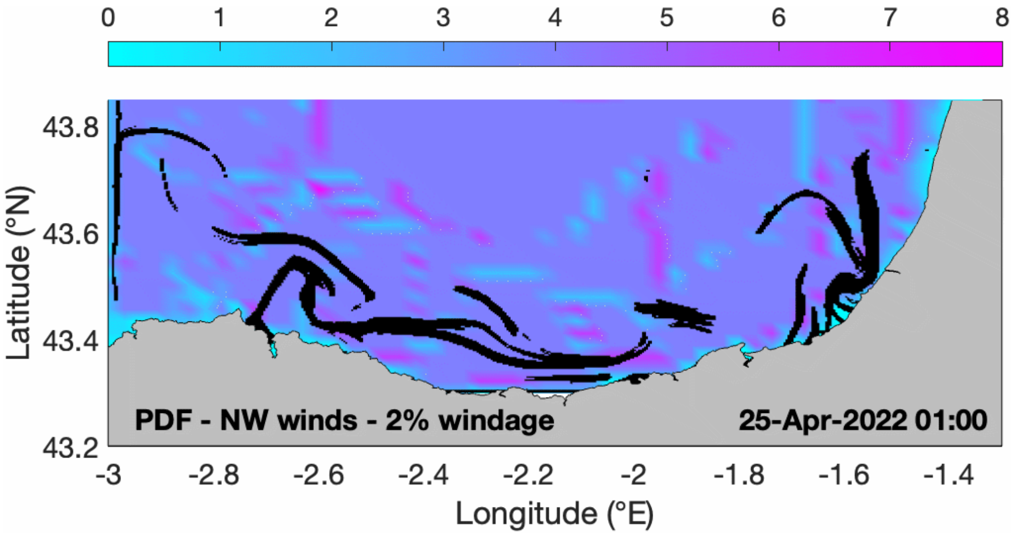
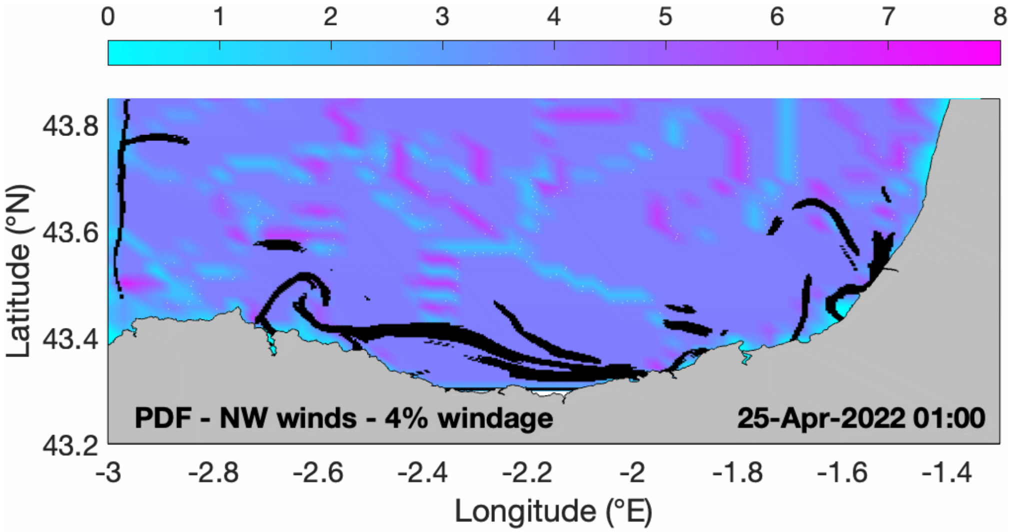
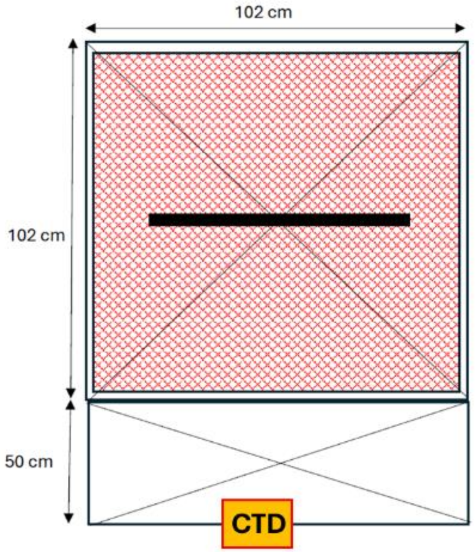


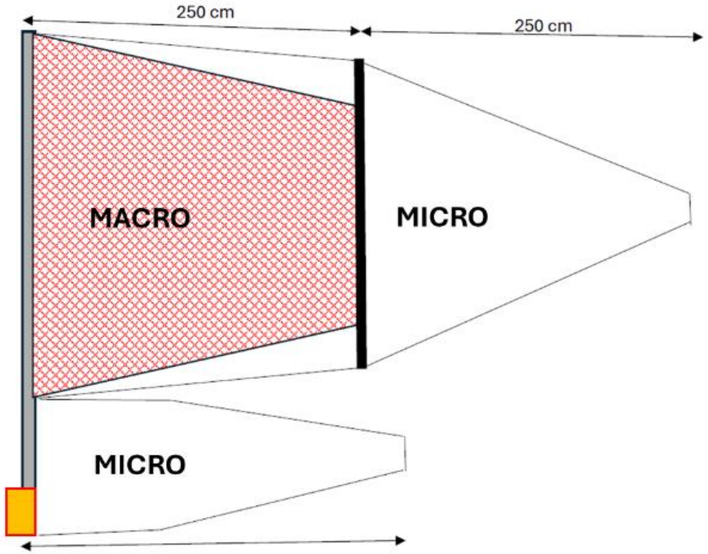


Highlights

- Coastal dynamics in the southeastern Bay of Biscay is complex, with small-scale structures that efficiently aggregate passive particles at short time scales.
- The effectiveness of Optimal Interpolation for drifter and HFR data fusion is demonstrated, highlighting its potential both in research and operational identification of CCS.
- 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.
- Below 2-3% windage, aggregation structures are shifted in the direction of currents and winds. Above 3% of windage, beaching and escaping rates are increasing and fewer aggregation structures are observed.
- The intense FML passage zones observed are generally located in similar areas, regardless of wind direction. FML origin and characteristic in aggregation zones may be very different depending on how much they are influenced by windage.

In progress… sampling along frontal lines with a net designed *ad hoc*





Thank you for your attention!

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