OCEAN SCIENCES MEETING | NEW ORLEANS LOUISIANA
18-23 FEBRUARY 2024

Improving the frontal zone detection in the southern Bay of Biscay by a combination of remote sensing and Lagrangian measurements of surface current velocities

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S. Bertin[1], A. Rubio[2], I. Hernandez-Carrasco[3], L. Solabarrieta[2], I. Ruiz[2], A. Orfila[3], A. Sentchev[1]

[1] Université du Littoral - Côte d'Opale Laboratoire d'Océanologie et de Géosciences, UMR 8187- LOG, Wimereux (France)
[2] AZTI BRTA, Pasaia, Gipuzkoa (Spain)
[3] Institut Mediterrani d'Estudis Avançat (IMEDEA), Esporles, Illes Balears (Spain)

https://lamarca-project.eu/

Grant PID2021-123352OB-C31, C32 and C33 funded MCIN/AEI/10.13039/501100011033 and by ERDF A way of making Europe

BACKGROUND

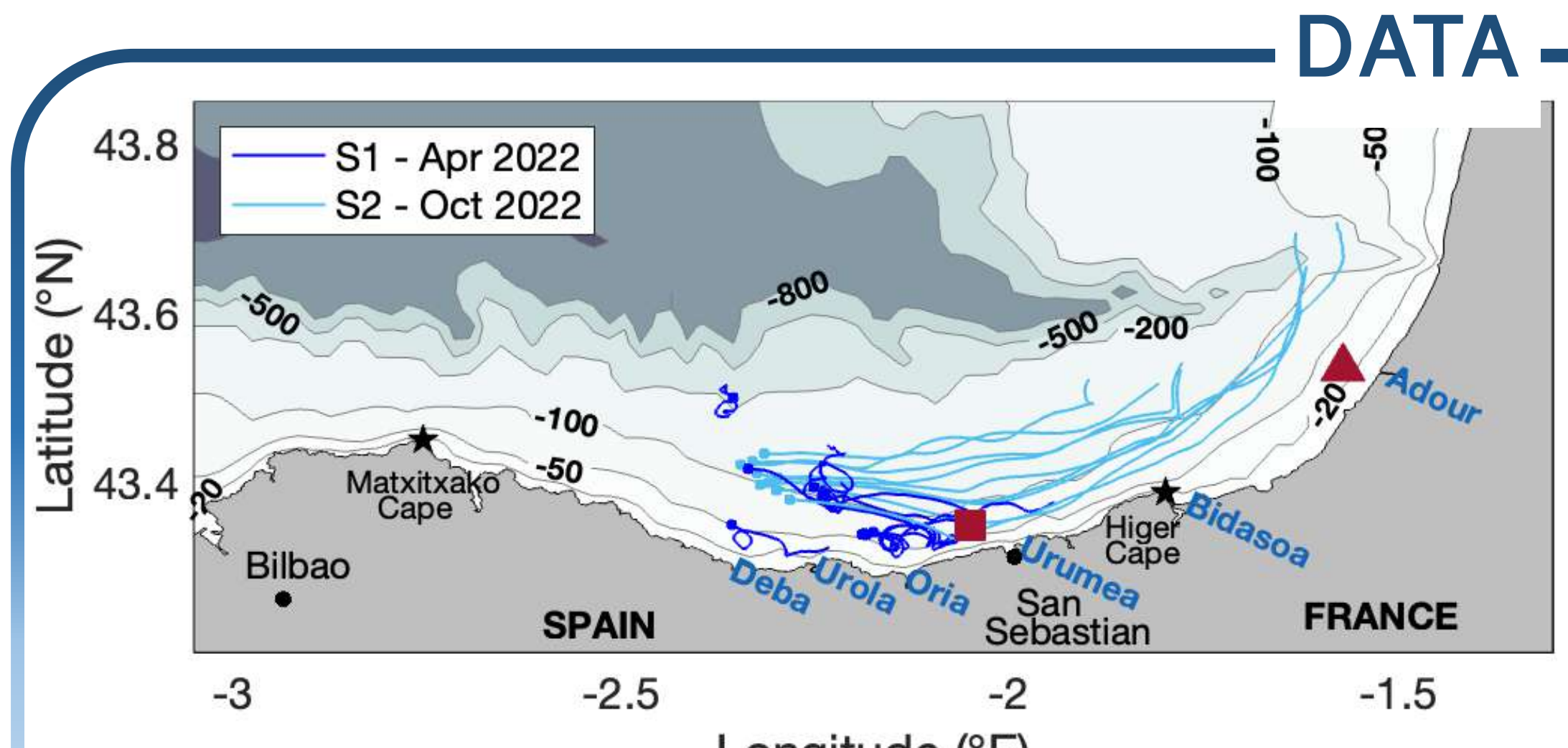
The southeastern Bay of Biscay has been described as "dead end" for floating marine litter. Marine litter accumulation along linear streaks, observed in this area, appears to be a recurrent process. Enhancing our understanding of small-scale processes behind these aggregations is essential to better quantify and to help mitigate marine litter pollution. An optimization method was developed and applied to HF radar surface velocity measurements, using the data from two 3-day long in-situ surveys, conducted in April and October 2022. Surface current fields and drifter velocities were optimally interpolated in space and time. Adopting a Lagrangian point of view, Finite Size Lyapunov Exponents (FSLE) were used to identify Lagrangian Coherent Structures in the study area, highlighting the location of coastal Current Convergence Structures (CCS). CCS, representing converging Lagrangian trajectories, are structures where larger concentration of marine litter is likely to occur.

STUDY AREA

Bay of Biscay

- Iberian Poleward Current creating anticyclonic eddies
- Dynamics affected by geostrophic current, winds, inertial oscillation (~18 hours period), and tides
- Freshwater inputs from French and Spanish rivers.

DATA



Modeled outputs

U and V velocities from 3-D NEMO model in Iberia-Biscay-Ireland (IBI).

Space-time resolution: ~3.5 km - 15 min

Satellite data

Sentinel-3 OLCI Chl-a concentration estimation

Space-time resolution: 300 m - 1 day

Observations

- Survey1 (S1): 13 surface drifters (z~1 m)
- Survey2 (S2): 9 surface drifters (z~1 m)
  → 40 hours observations, 15 min temporal resolution

- Gap-filled surface currents from euskoos HFR (https://info.euskoos.eus/en/) using:
  → OMA fields (Kaplan and Lekien, 2007)
  Space-time resolution: 5 km - 1 h
  → 2dVar fields (Yaremchuk and Sentchev, 2009)
  Space-time resolution: 2.5 km - 1 h

METHODS: LAGRANGIAN ERROR & FSLE

Lagrangian error index – *L* 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

FSLE (Hernández-Carrasco et al., 2011; LaCasce, 2008) estimated as the 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, and is expressed at position ***x*** and time *t* as

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

Parameters: $\delta_0 = 0.4$ km ; $\delta_f = 3.2$ km (using an amplification factor $\alpha = \delta_f/\delta_0 = 8$) ; computed backward in times over 15 days of integration.

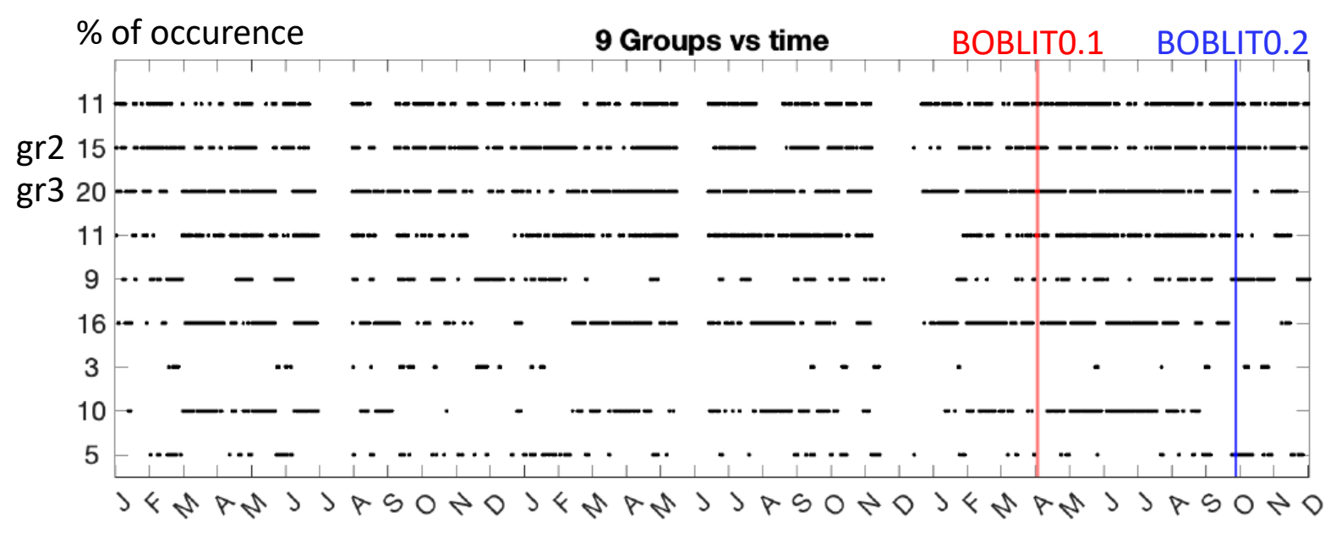
METHODS: OPTIMAL INTERPOLATION

Improvement of 2dVar fields (hereinafter 2dVar-opt) by the linear combination of the weighted differences between the 2dVar and observed velocities from drifters (Gandin, 1963; Sentchev and Yaremchuk, 2015):

$$u_{OI} = \underbrace{u_m}_{\text{Initial 2dVar velocity}} + \underbrace{\sum_{ij} BH_j^T \left(H_i B H_j^T + R_{ij}\right)^{-1}}_{\text{Dynamic interpolator Combination of 2dVar and drifter observations covariances}} \underbrace{\left(H_i u_m - u_i^*\right)}_{\text{Interpolated differences between 2dVar and observations}}$$

$B = \langle u_m(x,t) u_m(x',t') \rangle$	2dVar's space-time covariance matrix
$R_{ij} = \langle u_i^* u_j^* \rangle$	Drifter observations' space-time covariance matrix
u_M ; u_i^* ; u_{OI}	2dVar, observed (drifter) and optimized velocities
H_i	Projection operator

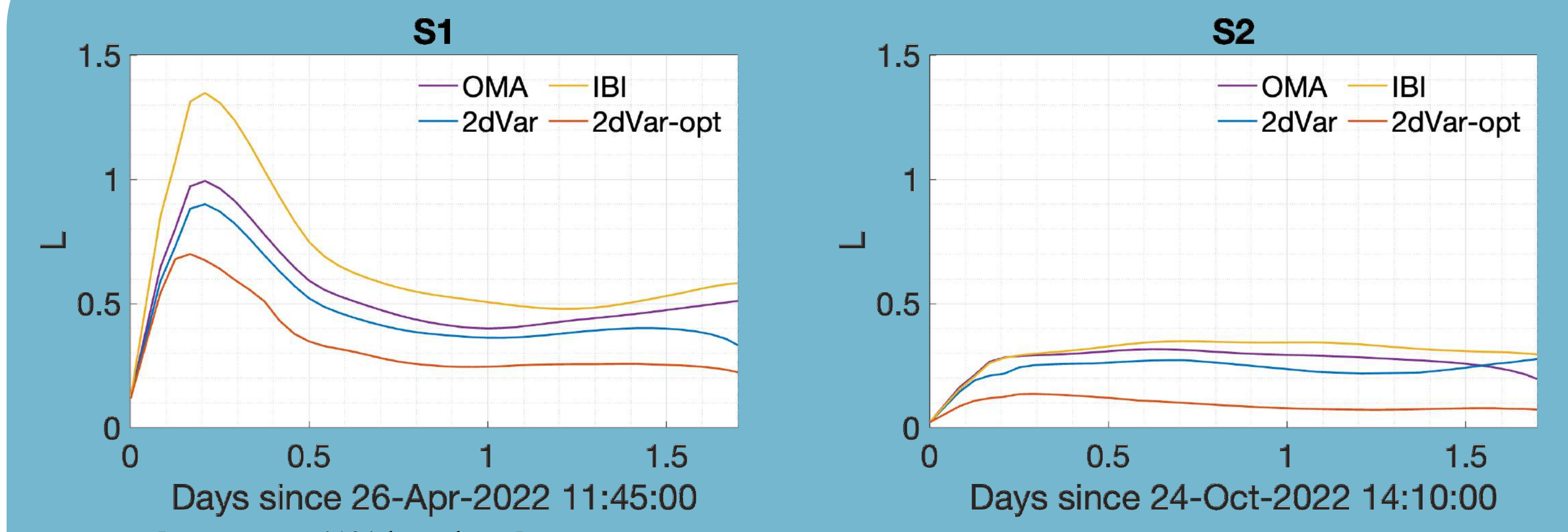
K-Means clustering method (Solabarrieta et al., 2015) using velocities from 2dVar for extraction of ensemble members required for the covariance matrix calculation:



Extraction of ensemble members displaying the same groups of surface current variability in the similar order of magnitude.

RESULTS

L index: 2dVar-opt showed the best performance compared to the other fields, followed by 2dVar



→ $L_{2dVar-opt}$ 41% less than L_{OMA} on average
→ $L_{2dVar-opt}$ 52% less than L_{IBI} on average
→ $L_{2dVar-opt}$ 31% less than L_{2dVar} on average

→ $L_{2dVar-opt}$ 65% less than L_{OMA} on average
→ $L_{2dVar-opt}$ 70% less than L_{IBI} on average
→ $L_{2dVar-opt}$ 62% less than L_{2dVar} on average

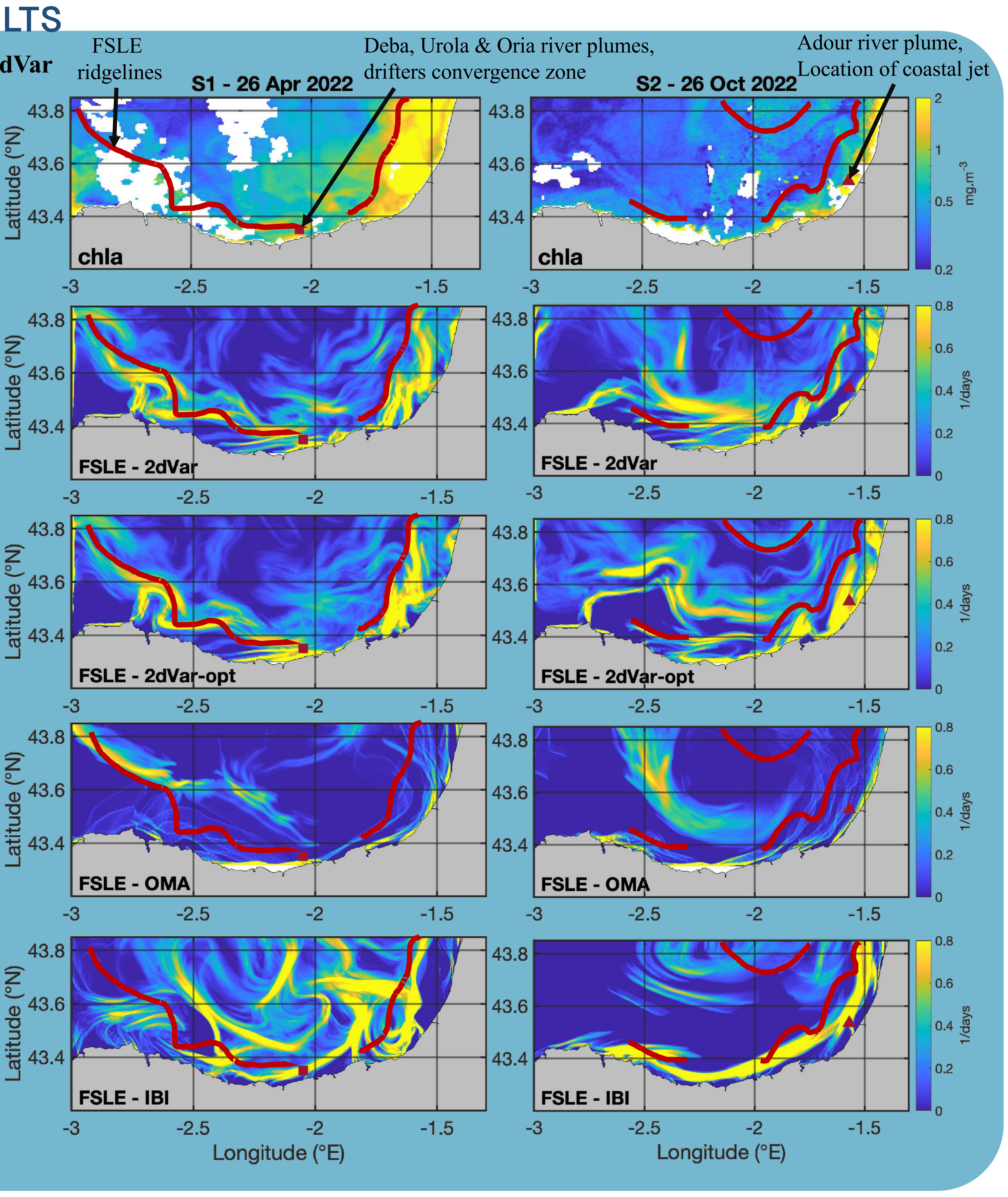
FSLE and Chl-a maps: Best performance of 2dVar-opt, during S1 and S2, with FSLE ridgelines matching CCS location and delimiting the spatial distribution of high Chl-a concentration

During S1

- Large values of Chl-a around river plumes (red square) and around the French coast.
- 2dVar and 2dVar-opt FSLE ridgelines **aligned with Spanish and French coast**, CCS visible in a zone of converging drifters (red square), also corresponding to Deba, Urola and Oria river plumes. FSLE ridgelines match the limit of high concentration of Chl-a.
- OMA and IBI FSLE ridgelines are not specifically linked with the Chl-a spatial distribution.

During S2

- Large values of Chl-a concentration located around Adour river plume (red triangle).
- 2dVar **alongshore FSLE ridgelines** matches well the Chl-a distribution but does not represent the strong coastal jet present during S2.
- 2dVar-opt **alongshore FSLE ridgelines** matches well the Chl-a distribution, repositioning and accounting better for the **coastal jet** (red triangle).
- OMA underestimates the coastal jet whereas IBI overestimates it and place it too far away from the coast.


FSLE ridgelines

Deba, Urola & Oria river plumes, drifters convergence zone

Adour river plume, Location of coastal jet

CONCLUSIONS

- Coastal dynamics in the southeastern Bay of Biscay is complex, with small-scale structures that efficiently aggregate passive particles and tracers at short time scales.
- The effectiveness of Optimal Interpolation for drifter and HF radar data fusion is demonstrated, highlighting its potential both in research and operational identification of CCS.
- FSLE are valuable for studying CCS, however their effectiveness is highly reliant on the underlying Eulerian fields.
- Backward-in-time FSLE ridgelines applied to optimized fields locate CCS parallel to the coast, showing a good agreement with spatial distribution of Chl-a and presence of river plumes.

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This work has been financially supported by the Structure Fédérative de Recherche (SFR) Campus de la Mer, by the French National program LEFE (Les Enveloppes Fluides de l'Environnement) and the Spanish LAMARCA project (PID2021-123352OB-C31, C33) funded by MCIN/AEI/10.13039/501100011033 and by ERDF A way of making Europe and #ebegi project, funded by the Directorate of Agriculture, Fisheries, and Food Policy of the Department of Economic Development, Sustainability, and Environment of the Basque Government.