Lagrangian Evolution of the Trapping Capacity of Mesoscale Eddies in the Canary Eddy Corridor: A Numerical Modeling Approach

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INTRODUCTION

The **Canary Islands** act as a natural barrier to the **Canary Current**, leading to flow-topography interactions that generate **mesoscale eddies** and enhance the offshore export of coastal upwelling filaments driven by trade winds (Sangrà et al., 2009). The so-called **Canary Eddy Corridor** spans approximately from 22°N to 29°N. Eddies can propagate over 100 km offshore, exporting waters enriched in nutrients and dissolved inorganic carbon (Knoll et al., 2002). Quantifying **eddy-driven transport of volume, heat, and salt** in the oligotrophic Northeast Atlantic remains challenging, as Eulerian methods often underestimate coherent structures and their material retention (Liu et al., 2019). Nonetheless, **it is estimated that the westward eddy transport exceeds one-fourth of the southward flow of the Canary Current**, with associated primary production comparable to that of the entire northwest Africa upwelling system (Sangrà et al., 2009). **This study examines the evolution of the trapping capacity of mesoscale eddies throughout their lifecycle phases** (growth, maturity and decay), **accounting for their vertical structure.** The present analysis focuses on a **representative anticyclonic surface eddy** and demonstrates the **potential of this methodology to be extended to the full census of eddies in the Canary Eddy Corridor**, enabling comparative estimates of eddy retention based on: **(i) Eulerian metrics**, such as the nonlinearity ratio (the ratio between eddy rotational speed and propagation speed), and **(ii) Lagrangian diagnostics**, such as the number of particles retained within the eddy core.

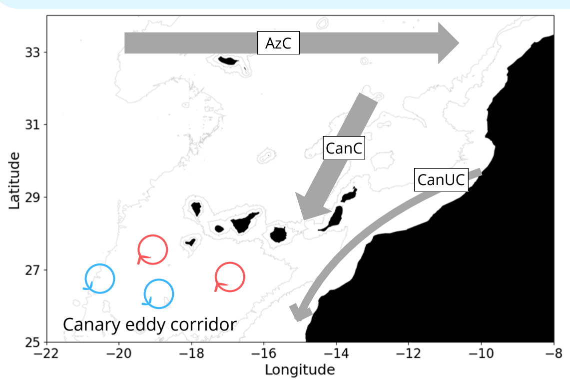

Figure 1 : *Map of the study area showing the major surface currents and the location of the Canary Eddy Corridor. CanC: Canary Current; AzC: Azores Current; CanUC: Canary Upwelling Current.*

DATA AND METHODS

GLORYS12
Reanalysis product
1/12º grid, 50 vertical levels

+

Mesoscale Eddy Trajectory Atlas (META) dataset from AVISO+

Velocity field → **Vector Geometry–Based Eddy Detection Algorithm** (Nencioli et al 2010) Detection parameters: a=4, b=3

Selected eddies detected by satellite altimetry → Vector Geometry–Based Eddy Detection Algorithm

→ **Ocean Parcels** Particle release and tracking, at different depths 1/12º grid

→ **Estimating eddy trapping capacity**

EULERIAN METHOD

Non linearity parameter (NL):
Rotation speed/ Propagation speed
We use the nonlinearity parameter (NL) to determine the **deepest depth at which the eddy is expected to effectively transport water** (NL>1)

VS

LAGRANGIAN METHOD

Percentage of inside particles :
We quantitatively assess the percentage of particles effectively retained at different depths within the eddy. (n of particles at time t / n of initial particles)

Note: Particles that leave the eddy at any point are considered outside for the remainder of the simulation. Particle release occurs every 20 days.

RESULTS AND DISCUSSION

Eddy lifecycle and characteristics

- **Surface-intensified anticyclonic eddy** propagating south of the canary Islands from October 2003 to March 2004 (Fig.1).
- Eddy geometric parameters allow us to **identify three distinct eddy phases** (see dashed vertical lines in Fig. 2).
- **Eddy radius is taken as reference of the eddy's evolution** (Morris er al. 2019).

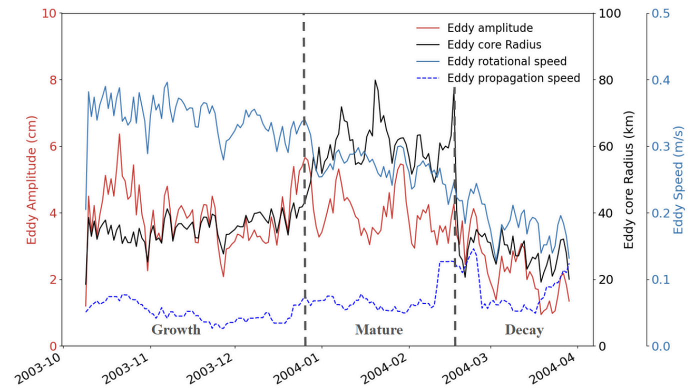

Figure 2 : *Lagrangian evolution of the radius of the eddy core radius (km, black line), amplitude (cm, red line), rotational speed (m s−1, blue line), and daily propagation speed (m s−1, blue dashed line) near surface, derived from the eddy detection algorithm (Nencioli et al., 2010). These eddy geometric properties were derived for a modelled westward-propagating anticyclonic eddy selected as study case.*

Evolution of 3D structure & Eulerian-Based Eddy Transport Capacity

- Eddy **vertical structure changes** significantly throughout the eddy phases (Fig. 3).
- **During the mature phase, relatively strong velocities** (15–20 cm/s) **are visible down to 750–1,000 m,** as compared to 300-400m for the growth and decay phases.
- The **Eulerian-Based Method shows the eddy transport capacity** reaches its highest depth during the mature phase, as compared to the growth and decay phases.
- As a limitation, the **Eulerian-Based Method cannot assess quantitatively** whether the full eddy content, down to the estimated eddy retention depth, is transported along the eddy track.

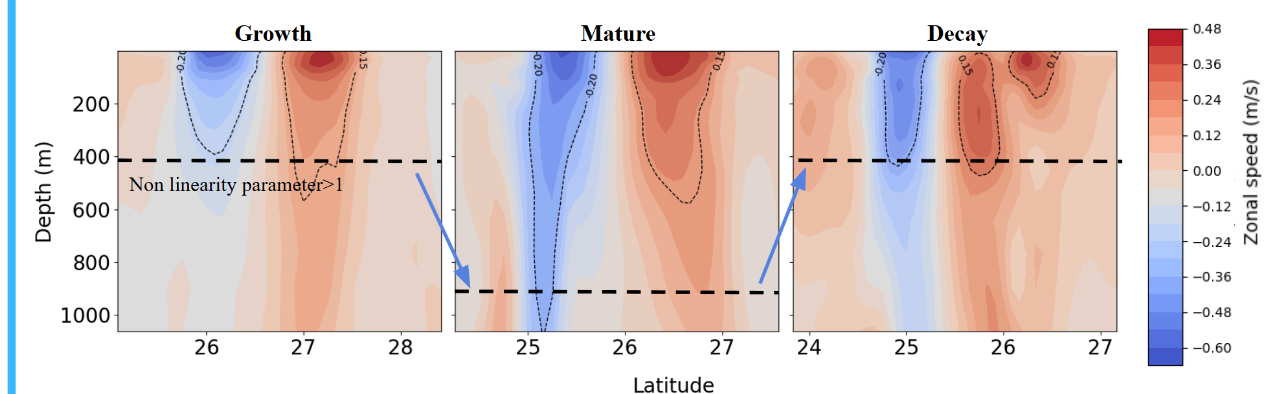

Figure 3 : *Meridional sections of the selected eddy showcasing zonal velocities vs depth at different locations for the beginning of each eddy phase: growth - 09/10/2003 (left), mature- 24/12/2003 (middle), and decay- 01/03/2004 (right).*

Lagrangian-Based Eddy Transport Capacity

- **Trapping efficiency varies with depth (Fig. 4):** Highest retention occurs at 100 m, followed by 200 m, while surface particles are completely expelled by the end of the simulation (Fig.4).
- **Counterintuitively, highest trapping does not occur at the surface (Fig. 5)** of the surface-intensified eddy, contradicting expectations based on the NL parameter.
- **Phase-dependent trapping capacity (Fig. 5):** At surface and 100 m, retention is higher during the eddy's growth phase; at 200 m, maximum trapping occurs during the mature phase.
- This approach provides a quantitative framework to assess eddy transport effectiveness, offering a complementary perspective to the Eulerian-based method.

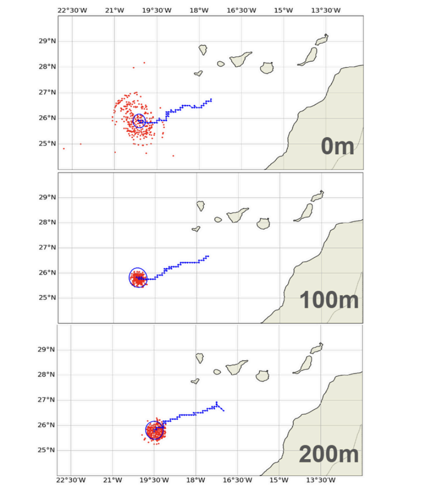

Figure 4: *Snapshot of the particles (red dots) near the eddy during the mature phase (01/02/2004), at different depths : 0m (top), 100m (middle), 200m (down). The shape of the eddy core and its track is shown in blue*

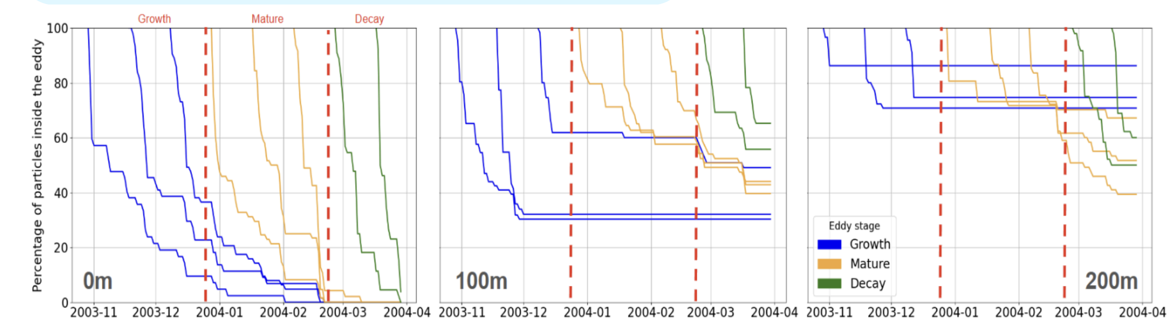

Figure 5: *Evolution of the percentage of particles trapped inside the selected eddy, with new particles being released every 20 days, near the surface (left), at 100m (middle) and at 200m depth (right). The number of particles released is proportional to the eddy radius at that time*

CONCLUSION

- **The eddy's transport capacity peaks during the mature phase**, both in terms of vertical extent (Eulerian method) and particle retention at 200 m (Lagrangian method).
- **Highest particle retention does not occur at the surface** despite the eddy being surface-intensified, highlighting limitations of classical indicators like the NL parameter.
- The **Lagrangian approach** reveals **quantitative depth- and phase-dependent retention patterns**, offering insights beyond those obtained with Eulerian diagnostics.

Future Research: Apply this Lagrangian methodology throughout the full water column to evaluate vertical variability in retention, and **extend it to cyclonic eddies and the entire Canary Eddy Corridor.**

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