Assessing Objective Eulerian Coherent Structures in the sea surface during the Gloria Storm

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Abstract

A rigorous global variational theory of the Objective Eulerian Coherent Structures (OECSs) has been developed in recent years [1, 2]. This Eulerian, frame-invariant, method reveals the instantaneous structures that act as barriers or organizing structures for an unsteady flow. The ocean circulation is inherently unstable and chaotic, so small errors or perturbations in the velocity field and the sensitive dependence on initial conditions can propagate and amplify rapidly over time. Therefore, this approach is a complementary tool to Lagrangian approaches, allowing the identification of coherent structures from the instantaneous velocity field derived from observations of models [3]. Whereas the Lagrangian Coherent Structures (LCSs) provide a time-dependent flow description by temporal integration of a set of ordinary differential equations, the OECSs highlight an instantaneous snapshot of the coherent structures.

The concept of stretching fluid parcels is the basis of the Lagrangian approach formulated in [4]. It introduces in a natural way concepts such as the Cauchy-Green tensor $\mathcal{C}$ and the Finite-Time Lyapunov exponents (FTLE). Performing a Taylor expansion on time [2] and neglecting second-order terms, it is possible to relate $\mathcal{C}$ to the symmetric part of ∇v ($\mathcal{S}$, the rate-of-strain-tensor) or the largest FTLE to the concept of Instantaneous Rate of Separation (IROS). Similarly, the smallest FTLE in the infinitesimal limit forward in time defines the Instantaneous Rate of Attraction (IROA). The IROS concept has already been used in [5] to identify areas of enhanced particle dispersion during the Gloria storm (19-24 January 2020) in the Ebre Delta (northwestern Mediterranean). However, although IROS/IROA are useful tools, they are not OECSs. The attracting (repelling) hyperbolic OECS are instantaneous curves and transport barriers that maximize short-term normal attracting (repelling) of nearby parcels in the flow. They are equivalent to LCS in the limit of the integration period approaching zero. The attracting OECSs at a given time (i.e. Transient Attracting Profiles or TRAPs for short,[6]) are tangent to the $\mathcal{S}$ eigenvector associated with the higher eigenvalue ($\vec{S}^{+}$). Moreover, their cores are located at the minima of the smallest eigenvalue field (s^{-}).

The data source used to compute the OECS is the output of a high-resolution simulation (CROCO model at 650 m), nested to the daily CMEMS Mediterranean Sea Physics Reanalysis product (MEDSEA) at 1/24°. The hourly ERA5 reanalysis product provides the atmospheric forcing. To account for anomalous storm-related river discharges along the coast, measured discharges of 17 of the most important rivers in the northwestern Mediterranean are used.

Although the storm affected a large offshore area, the model simulations show that the major changes in transport barriers are concentrated near the coast. The attraction and separation strengths are more than 20 times higher at some points during the storm (figure 1 left), severely punishing coastal areas. Moreover, during the storm, the OECS (the TRAPS) are almost perpendicular to the coast (figure 1 right). This may indicate that particles are lost in certain areas of the coast where they are transferred towards the attracting barriers. This phenomenon, together with the strong waves that occurred, could be responsible for the disappearance of large quantities of sand in the central part of the Barra del Trabucador and other coastal areas. Finally, we present the energy dissipation during the Gloria episode in terms of the kinetic energy dissipation rate density and its relationship with the IROS and IROA quantities.

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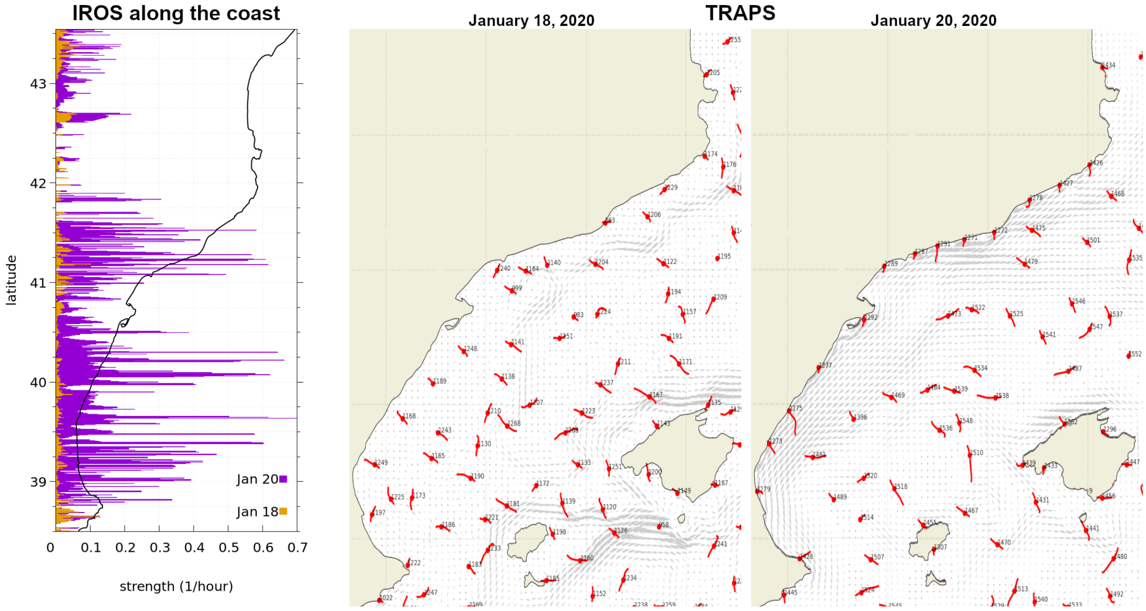

Figure 1: IROS and TRAPs, computed from CROCO model, before and during the Gloria episode (January 18 and January 20 respectively). Left: IROS along the Valencian, the Catalan, and the southern French coast. Center and right: Daily TRAPs (OECSs). The red dot in the middle indicates the TRAP core, and the red line is the TRAP curve.

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