Submesoscales variability from surface drifter and HF radar measurements: scale and wind dependence of kinematic properties

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The dynamics of the near-surface ocean currents result from the nonlinear interaction of simultaneous mechanisms at different scales. Of these, the submesoscale range (a few hundred meters to 10 km, hours to a few days) remains particularly challenging to observe directly, due to the high variability in both time and space. In this study, the scale-dependence of kinematic properties (divergence, vorticity and strain) in the submesoscale range, as well as their response to atmospheric forcing, is investigated in two distinct geographic regions: the Ligurian (NW-Mediterranean) Sea and the Northern Gulf of Mexico. The two applications are characterized by different dynamics, and the estimates of kinematic properties are derived from distinctly different observational approaches: in situ GPS drifters observations and remote HF radar data.

The Ligurian Sea application is based on HF radar measurements obtained for the JERICO-NEXT (Joint European Research Infrastructure network for Coastal Observatory - Novel European eXpertise for coastal observaTories) and IMPACT (Port Impact on Protected Marine Areas: Cooperative Cross-Border Actions) projects. Surface current measurements span 40 km off the coast with 1.5 km resolution, available every hour. The velocity fields are used to estimate the kinematic properties with an Eulerian approach, which allows the identification of structures such as eddies and jets of the order of a few km. We focus in particular on the response of the submesoscales to an extreme wind event that was captured by the observations. The deformation of the spatial structures suggests nonlinear interactions with the wind forcing, and the kinematic properties' magnitudes are almost doubled (exceeding the Coriolis parameter, f).

In the Gulf of Mexico, velocity observations are available from a series of massive, nearly simultaneous drifter releases conducted by CARTHE (Consortium for Advanced Research of Transport of Hydrocarbons in the Environment). Drifter triplets are analysed to estimate the kinematic properties of the flow at scales between 100 m and 5 km over a time scale of a day.
Results show that the mean kinematic properties increase in magnitude with decreasing scales, with winter values generally higher than summer ones. For winter flows, vorticity and divergence distributions have more substantial tails of values multiple times the Coriolis parameter \( f \) at scales up to 2 km, while in the summer such large values are restricted to smaller scales (100-500 m).

The Lagrangian estimates of kinematic properties obtained in the Gulf of Mexico were also compared to Eulerian estimates from concurrent X-band radar measurements, showing good correlation and validating the comparison across observational methods. Moreover, the scale-dependence of the kinematic properties from drifter triplets was found to be consistent with turbulence scaling laws evaluated as two-particle statistics. We conclude that the kinematic properties metric provides a robust complementary methodology to characterize submesoscales and can be used both with Lagrangian and Eulerian observations.