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Lagrangian pair dispersion in upper-ocean turbulent flows with mixed-layer instabilities

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Oceanic motions at scales larger than few tens of km are quasi-horizontal due to seawater stratification and Earth's rotation and are characterized by quasi-two-dimensional turbulence. At scales around 300 km (in the mesoscale range), coherent vortices contain most of the kinetic energy in the ocean. At scales around 10 km (in the submesoscale range) the flow is populated by smaller eddies and filamentary structures associated with intense gradients (e.g. of temperature), which play an important role in both physical and biogeochemical budgets. Such small scales are found mainly in the weakly stratified mixed layer, lying on top of the more stratified thermocline. Submesoscale dynamics should strongly depend on the seasonal cycle and the associated mixed-layer instabilities. The latter are particularly relevant in winter and are responsible for the generation of energetic small scales that are not trapped at the surface, as those arising from mesoscale-driven processes, but extend down to the thermocline. The knowledge of the transport properties of oceanic flows at depth, which is essential to understand the coupling between surface and interior dynamics, however, is still limited.

By means of numerical simulations, we explore Lagrangian pair dispersion in turbulent flows from a quasi-geostrophic model consisting in two coupled fluid layers (representing the mixed layer and the thermocline) with different stratification. Such a model has been previously shown to give rise to both meso and submesoscale instabilities and subsequent turbulent dynamics that compare well with observations of wintertime submesoscale flows. We focus on the identification of different dispersion regimes and on the possibility to relate the characteristics of the spreading process at the surface and at depth, which is relevant to assess the possibility of inferring the dynamical features of deeper flows from the experimentally more accessible (e.g. by satellite altimetry) surface ones.

Using different statistical indicators, we find a clear transition of dispersion regime with depth, which is generic and can be related to the statistical features of the turbulent flows. The spreading process is local (namely, governed by eddies of the same size as the particle separation distance) at the surface. In the absence of a mixed layer it rapidly changes to nonlocal (meaning essentially driven by the largest eddies) at small depths, while in the opposite case this only occurs at larger depths, below the mixed layer. We then identify the origin of such behavior in the existence of fine-scale energetic structures due to mixed-layer instabilities. We further discuss the effect of vertical shear and address the properties of the relative motion of subsurface particles with respect to surface ones. In the absence of a mixed layer, the properties of the spreading process are found to rapidly decorrelate from those at the surface, but the relation between the surface and subsurface dispersion appears to be largely controlled by vertical shear. In the presence of mixed-layer instabilities, instead, the statistical properties of dispersion at the surface are found to be a good proxy for those in the whole mixed layer.