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Relative dispersion in a model of stratified upper-ocean turbulence

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Turbulence in the upper ocean in the submesoscale range (scales smaller than the deformation radius) plays an important role for the heat exchange with the atmosphere and for oceanic biogeochemistry. Its dynamical features are thought to strongly depend on the seasonal cycle and the associated mixed-layer instabilities. The latter are particularly relevant in winter and are responsible for the fomation of energetic small scales that are not confined in a thin layer close to the surface, as those arising from mesoscale-driven processes, but extend over the whole depth of the mixed layer. The knowledge of the transport properties of oceanic flows at depth, however, is still limited, due to the complexity of performing measurements below the surface. Improving this knowledge is essential to understand how the surface dynamics couple with those of the ocean interior.

By means of numerical simulations, here we explore the dispersion properties of turbulent flows in a quasi-geostrophic model system made of two coupled fluid layers (aimed to represent the mixed layer and the thermocline) with different stratification. Such a model has been previously shown to give rise to dynamics that compare well with observations of wintertime submesoscale flows. We examine the horizontal relative dispersion of Lagrangian tracers by means of both fixed-time and fixed-scale statistical indicators, at the surface and at depth, in the different dynamical regimes occurring in the presence, or not, of a mixed layer. The results indicate that, when mixed-layer instabilities are present, the dispersion regime is local (meaning governed by eddies of the same size as the particle separation distance) from the surface down to depths comparable with that of the interface with the thermocline. By contrasting this picture with what happens in the absence of a mixed layer, when dispersion quickly becomes nonlocal (i.e. dominated by the transport by the largest eddies) as a function of depth, we identify the origin of this behavior in the existence of fine-scale energetic structures due to mixed-layer instabilities. Finally, we discuss the effect of vertical shear on the tracer spreading process and address the correlation between the dispersion properties at the surface and in deeper layers, which is relevant to assess the possibility of inferring the dynamical features of deeper flows from the more accessible surface ones.