Backward and forward Lagrangian dispersion in forced and dissipated Surface Quasi-Geostrophic turbulence

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Résumé

Surface Quasi-Geostrophy (SQG) serves as a model of ocean surface dynamics under the hypothesis of strong rotation and stratification. The resulting two-dimensional (2D) equations, describing the transport of the surface temperature, are known to share formal similarities with the incompressible three-dimensional Navier Stokes equations (3D-NS). The analogy is formally mediated by the scalar gradient, which undergoes stretching along Lagrangian trajectories, akin to the vortex stretching constitutive of 3D-NS. Moreover, recent studies have also pointed out that, when subject to suitable large-scale forcing and small-scale dissipation, SQG settles into a statistical steady state displaying hallmark signatures of canonical 3D homogeneous isotropic turbulence, namely: (i) a direct cascade of kinetic energy, (ii) intermittent statistics, and (iii) extreme unpredictability at both Lagrangian and Eulerian level. Beyond its relevance to geophysics, the study of SQG flows thus falls within a more fundamental context; the statistical study of hydrodynamical turbulence.

This work, based on highly-resolved direct numerical simulations, aims to challenge this analogy by investigating particle dispersion in SQG steady turbulence. The focus is on the evolution of particle pairs, their dependence on the initial separations, and differences between their backward and forward dynamics.

Primarily, our numerics substantiate that the mean-squared separations follow the Richardson-Obukhov law both backward and forward in time, although the Eulerian statistics of the velocity fields are known to lack of classical scaling properties. Yet, the forward dispersion increases nearly twice as fast as its backward counterpart. This contrasts with the classical phenomenology of 3D-NS turbulence, but accounts in our view for the positive skewness of longitudinal velocity increments in SQG. Finally, an additional and new backward-forward asymmetry for the Lagrangian flow is evidenced in SQG from the higher-order moments of the separations. Although the anomalous power laws observed for the backward dynamics match the Eulerian statistics through the bridge relation, the forward exponents deviate more strongly from the similarity prediction.

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