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Vortex cores, circulation cells, and filaments in 2D and 3D quasi-geostrophic turbulence

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The structure of three-dimensional quasi-geostrophic (3D QG) turbulence is quantitatively different from two-dimensional (2D) barotropic turbulence. This is shown by separating the potential vorticity fields into three components: vortex cores; the circulation cells surrounding the cores; and the background, which contains filaments. Even though the background contains 85% of the gridpoints, the vortex cores induce five times the energy as the background in 2D. In 3D QG the background plays a more dominant roll in the dynamics, and induces the same amount of energy as the vortex cores.

The probability density function (PDF) of velocity due to the total vorticity field is nearly Gaussian in 3D QG (kurtosis=3.08), but less Gaussian in 2D (kurtosis=3.95). In both 2D and 3D QG the velocity PDFs due to the vortex cores and the circulation cells are non-Gaussian. In 3D QG the total velocity PDF is more strongly influenced by the background, while in 2D the vortex cores are more influential. In both 2D and 3D QG turbulence, the enstrophy spectrum of the background fits the Kraichnan k^{-1} slope for isotropic 2D turbulence.

Our conclusion is that filamentous structures play a more dominant role in 3D QG dynamics than in 2D turbulence. In addition, two traditional measures used to quantify vorticity, the Okubo-Weiss parameter and λ_2, are shown to be equivalent to each other for 2D and 3D QG fields. A point vortex model for 3D QG is derived in order to show that a collection of point vortices has a non-Gaussian probability density function, which matches the results of the numerical model.