Relation among zonal flow, Rossby radius, and triple cascade in two-dimensional equivalent barotropic vorticity turbulence

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Various characteristic scales of zonal flow, waves, vortices and dissipation exist in geophysical turbulence. These scales vary from latitude to latitude and planet to planet. Two-dimensional barotropic turbulence, one of the simplest models of geophysical turbulence, shows rich phenomena depending on magnitude relationship among the scales. Turbulence properties are generally determined by the cascades of invariants. It is essential to reveal the relation among zonal flow, the Rossby radius and cascades of invariants. We focus on the dependence of turbulence properties on magnitude relation between the Rhines scale R_h and the Rossby deformation radius R_o.

As R_o decreases from infinity while fixing R_h, the characteristic flow profile changes from zonal flow to quasi-crystalline structure, Formation of large-scale structures are often explained in relation to the inverse energy cascade. Since the zonal flow has strong anisotropy, scalar energy flux used in isotropic turbulence should be generalized to quantify anisotropic transfer in wavenumber space, which led to the idea of local flux vectors (LFVs).[1,2] The LFVs of energy for three representative R_o's are drawn in Fig. 1, which are shown only in the first quadrant of the small-wavenumber range to increase visibility, taking advantage of their mirror symmetry with respect to each coordinate axis. For the large R_o, the inversely cascaded energy turns to surround the dumbbell spectrum on the Rhines wavenumber, $1/R_\mathrm{h}$, and converges to zonal wavenumber modes on the k_y-axis, consistent with the critical balance[3] (Fig. 1 (a)). For the small R_o, the inversely cascaded energy is isotropically blocked on the Rossby wavenumber, $1/R_\mathrm{o}$ (Fig. 1 (c)). When R_o is comparable with R_h, Fig. 1 (b) has an intermediate structure. In the presentation, we will also discuss LFVs of enstrophy and zonostrophy to investigate the relation with vortex structure and zonal flow.

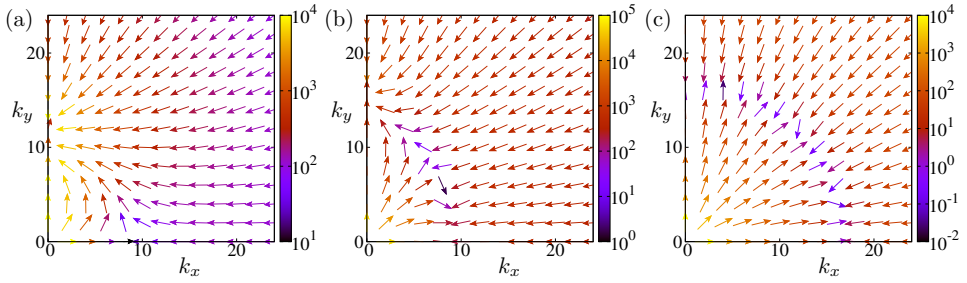

Figure 1: LFVs of energy in the first quadrant of the small-wavenumber range (a) for large Rossby radius, (b) for medium Rossby radius, and (c) for small Rossby radius.

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[1] Yokoyama and Takaoka, *J. Fluid Mech.* **907** A17 (2021)
[2] Takaoka et al., *Phys. Rev. Fluids* **7** L012601 (2022)
[3] Nazarenko and Schekochihin, *J. Fluid Mech.* **677** 134 (2011)