Scale invariance and energy spectra in geostrophic convective turbulence

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Abstract

Geostrophic convective turbulence is associated with many fluid phenomena in geophysical and astrophysical systems, such as tropical cyclones and Jovian polar vortices. Convective turbulence subjected to rapid rotation exhibits properties of quasi-two-dimensional turbulence, leading to the formation of large-scale vortices (LSVs) via upscale energy transfer. By introducing a large-scale friction to control the scale of LSVs, we are able to analyze the system in a steady state. We find that the scaling relationship between the LSV radius and the friction coefficient is different from that obtained from the Kraichnan-Leith-Batchelor theory. Additionally, the scaling relationship for the energy spectrum of the 2D manifold during the inverse energy cascade also exhibits a scaling exponent of -3, which differs from -5/3 in the classical 2D turbulence. To account for these deviations, we propose a theoretical framework developed based on the observed scale-invariant coarse-grained vorticity. Within this framework, both the scaling of the energy spectrum and the LSV radius can be explained self-consistently. The circulation and transverse structure functions are examined to validate the scale-invariant statement. This work is supported by the National Natural Science Foundation of China (Grant Nos 12302282, 12232010, 12594530010, 12595302) and the Startup Foundation of Fudan University.

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