Anisotropic high-wavenumber constraints on energy in rotating and stratified flows

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Abstract

Rapidly rotating, stably stratified three-dimensional inviscid flows conserve both energy and potential enstrophy. We show that in such flows, the forward cascade of potential enstrophy imposes anisotropic constraints on the wavenumber distribution of kinetic and potential energy. The horizontal kinetic energy is suppressed in the large, nearly horizontal wave modes, and should decay with the horizontal wavenumber as k_h^{-3}. The potential energy is suppressed in the large, nearly vertical wave modes, and should decay with the vertical wavenumber as k_z^{-3} . These results augment the only other exact prediction for the scaling of energy spectra due to constraints by potential enstrophy obtained by Charney (J. Atmos. Sci. 28, 1087 (1971)), who showed that in the quasi-geostrophic approximation for rotating stratified flows, the energy spectra must scale isotropically with total wavenumber as k^{-3}. We test our predicted scaling estimates using resolved numerical simulations of the Boussinesq equations in the relevant parameter regimes, and find reasonable agreement.