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Anisotropic β-plane turbulence and zonal jets

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Results of systematic studies of two-dimensional (2D) turbulence on the surface of a rotating sphere will be presented. It is shown that the kinetic energy spectrum develops strong anisotropy. For the zonal modes, a steep spectral distribution, $E(k) = C_Z(\Omega/R)^2k^{-5}$, is established, where C_Z is a non-dimensional coefficient, Ω is the angular velocity and R is the radius of the sphere, respectively. For all other, non-zonal modes, the classical, Kolmogorov-Batchelor-Kraichnan, $-5/3$ spectral law is preserved. A parameter range in which the flow regime with the anisotropic (-5, $-5/3$) spectrum can develop is identified.

Natural rotating flows with β-effect, strong spatial anisotropy (caused by the geometrical constraints, stable stratification, rotation, etc.), and small Burger number are good candidates for realization of this flow regime on large scales. Recent experiments (Read et al., GRL, 2004) using the Coriolis turntable in Grenoble with the topographic β-effect have confirmed the mechanism of zonation and both spectral laws, $-5/3$ and -5. Spectral analysis of zonal flows on the outer planets also confirms the development of a strongly anisotropic spectrum with the -5 law for the zonal component. The available data is not sufficient to estimate the non-zonal spectrum. Recent eddy-permitting simulations of general oceanic circulation have revealed the presence of systems of narrow zonal jets throughout all major oceans. Analysis of the circulation patterns points to strong spectral anisotropization and the establishment of the $-5/3$ and -5 spectral laws for non-zonal and zonal components. The evidence of the presence of narrow alternatingzonal jets in the ocean has also emerged from several long-term monitoring studies conducted throughout various cross-sections of the global ocean. The non-dimensional coefficient C_Z in the -5 spectral law was found to be invariant, $C_Z \simeq 0.5$, in a variety of simulated and natural flows.