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Stochastic structural stability of a barotropic flow

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Turbulent, geophysical flows are often observed to be organized into large scale jets that are maintained by the very turbulence they support. Spontaneous emergence of these jets in a wide variety of geophysical settings implies that the mechanism for jet formation and maintenance is generic. Previous theoretical studies either invoked an anisotropic inverse energy cascade that is local in wavenumber space, or a non-local energy transfer mechanism such as modulational instability of Rossby waves, or upgradient eddy momentum flux through shear straining, as essential elements of the jet formation dynamics. A novel theory for the interaction of jets with turbulence has been developed recently called Stochastic Structural Stability Theory (SSST). According to SSST, the distribution of eddy momentum fluxes associated with a given jet structure is obtained using a linear model of stochastic turbulence. The resulting momentum flux distribution is then coupled with the mean zonal momentum equation to produce a closed set of eddy-mean flow equations. In this work we apply the tools of SSST in a barotropic beta plane model of a fluid subjected to homogeneous stochastic forcing. The goal is to investigate the role of the eddy-mean flow feedbacks and the beta effect in the structural instability of the eddy-mean flow equilibria giving rise to zonal jets. We show that the structural instability of the equilibrium state with no mean flow is governed by two competing mechanisms: shearing of the eddies that produces upgradient fluxes and is jet forming and advection of the vorticity gradient of the infinitesimal jet by the eddies that produces downgradient fluxes and hinders the formation of the mean flow. The presence of beta is found to mainly weaken the stabilizing downgradient fluxes, enhancing the driving mechanism for jet formation and the resulting structural instability. We also find that it stabilizes the emergent jets with respect to small eddy perturbations leading to strong finite amplitude jets.