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Jet Formation Mechanisms in the presence of Topography

Emma Boland (1), Peter Haynes (2), and Emily Shuckburgh (1)

(1) British Antarctic Survey, Cambridge, United Kingdom (emmomp@bas.ac.uk), (2) The University of Cambridge, DAMTP, Cambridge, United Kingdom

Despite over 35 years of discussion, there still remain a range of theories describing the formation of jets on a beta plane. One such theory, first proposed by Rhines (1975), is that jets form as a result of an inverse cascade of energy that is halted by the excitation of Rossby waves. We present the results of an investigation in which we attempt to apply this theory to the case of tilted jets forming over a uniform slope in bottom topography in a quasi-geostrophic, two-layer, doubly periodic model. The forms of the Rossby wave frequencies of this system depend on the Rossby deformation radius, and have two limits: a shortwave limit in which the two frequencies are the equivalent layer-wise frequencies, and orientated with the layer-wise PV gradients; and a longwave limit in which the two frequencies are barotropic- and baroclinic-like, and orientated with the barotropic PV gradient. Freely decaying simulations of the system show that the anisotropy of the frequencies successfully predicts the orientation of the jets that form, which are found to be decoupled and follow layer-wise PV gradients in the shortwave limit, and to be coupled and follow the barotropic PV gradient in the longwave limit. Introducing shear and bottom friction does not change the qualitative form of the Rossby wave frequencies, but due to the forcing by baroclinic instability occurring close to the deformation radius, all such quasi-equilibrated simulations are in the longwave limit and jets follow the barotropic PV gradient. However, only some simulations demonstrate the predicted inverse cascade and associated cascade barrier. Other simulations do not have a well developed inverse cascade, and yet still show jet formation. Previous studies have also shown that significant non-local transfers of energy occur in quasi-geostrophic systems with jets, which suggests a richer picture of jet formation. We thus propose that Rossby waves provide a barrier to further energy transfer, and their anisotropy predicts the jet orientation, but that the energy transfer does not necessarily take the form of an inverse cascade. This work is a significant step towards understanding the formation of jets in quasi-geostrophic turbulence, and is also of relevance to the regions of the ocean where strong non-zonal jets are present.