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Supercriticality and inverse cascades in the primitive equations

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The equilibration of baroclinic eddies and their effects on the mean flow remain an outstanding problem in atmospheric dynamics. Roughly speaking, theories fall in or between two classes: so-called adjustment theories, and diffusive theories. In the former, the mean flow adjusts to some preferred equilibrium that is typically only slightly supercritical (in some appropriate sense) and the eddy fluxes then adopt whatever value is required to maintain this. In diffusive theories, the fluxes are a smooth function of the mean state, which implies that the mean state must vary continuously with the forcing.

In the simplest case – quasi-geostrophic turbulence in two layers – theory suggests that a diffusive theory may approximately hold, with a diffusivity that increases rapidly with supercriticality, so resembling in some ways an adjustment. Although detailed predictions of the theory have not been verified, a robust result is the presence of an inverse cascade, producing eddies that are larger than the deformation radius. However, in non-quasi-geostrophic flows, for example in the primitive equations, an inverse cascade is not always present. For example, in the earth's atmosphere the eddy scale is barely larger than the deformation scale and an inverse cascade, if it exists at all, is evidently of limited extent. It is not clear whether this is a general result, or is particular to a certain set of parameters, including those of the Earth's atmosphere.

We have investigated this problem in perhaps the simplest framework possible, a two-level primitive-equation model on the beta plane. The model used permits adjustments in the static stability (and these are found to be important), but is otherwise most sim-

ilar to quasi-geostrophic models. A convenient feature of the model is that the mean Coriolis parameter and its gradient can be changed independently. Our results suggest that quasigeostrophic theory works reasonably well, at least in some parameter regimes, provided that the stratification is diagnosed from the primitive-equation model. In particular, for some parameter regimes the mean flow is found to be supercritical and eddies are considerably larger than the deformation radius, suggesting a vigorous inverse cascade. We will present the results of various simulations, and suggest a conceptual framework for their understanding.