DNS of reduced equations for rotationally constrained nonhydrostatic flows

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Using DNS, we investigate the solution to a reduced system of nonlinear PDEs for rapidly rotating convection: non-hydrostatic quasi-geostrophic equations (NHQGE). The NHQGE are derived asymptotically in the limit of small Rossby number from the Navier-Stokes equations under the Boussinesq approximation. Two distinct vertical scales are present: a small-scale occurring as a consequence of rotational alignment and large-scale due to convective forced motions. The resulting equations filter fast inertial waves and relax the need to resolve Ekman boundary layers, and are potentially applicable to deep-ocean turbulent convection, which, under thermal forcing, is characterized by thermal and vortical coherent structures that span the layer depth. We examine flow morphology (plumes and Taylor columns) as a function of scaled Rayleigh number and compare results from a single-mode theory. We also investigate the dynamics of the vortical structures and their effect on lateral mixing. Representative results for temperature are shown below for Prandtl number 7 and scaled Rayleigh numbers of 40 (left) and 80 (right).

Figure 1: Snapshots of volume-rendered temperature anomaly $\theta'$ for $Pr = 7$ and $\tilde{Ra} = 40$ (left) and $\tilde{Ra} = 80$ (right). Color tables are on the left of each figure; black regions indicate field values with zero opacity.