Mapping the Transition to the Stagnant-lid Regime in Variable Core Size Spherical Shell Convection with a Temperature-Dependent Viscosity

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Many features of the behaviour of mantle convection in the terrestrial planets are dependent on the relative sizes of the core and planet surface areas. In previous studies implementing Cartesian geometry models, convection in strongly temperature-dependent viscosity fluids was investigated for a range of viscosity contrasts and Rayleigh numbers. The viscosity contrasts give rise to convective regimes widely described as mobile-lid, transitional (or sluggish)-lid, and stagnant-lid. For systems with small core-to-planet radii ratios, f, the combinations of Rayleigh number and viscosity contrast required for stagnant-lid convection differ substantially from what is found for f values greater than 0.5. Accordingly the first challenge in modelling stagnant-lid convection with small cores is to find parameter combinations that will yield surface stagnation. In the present study, a series of isoviscous convection calculations with rigid top boundary conditions were performed, to model the steady state characteristics of stagnant-lid convection in a spherical annulus. Utilizing existing parameterizations, the mean temperatures of these calculations are then used to predict surface Rayleigh number and viscosity contrast parameters for the stagnant-lid regime as a starting point for a search for finding the parameters (surface Rayleigh number and viscosity contrast) associated with the delineation of mobile surface and stagnant-lid convection in small core planets ($f < 0.5$). Geotherms are used to distinguish between convective regimes characterized by a stagnant-lid versus mobile systems. Findings from several full 3D spherical shell calculations are compared to the 2D model results to test whether our method of determining the appropriate viscosity contrast and Rayleigh number is accurate.