Scaling of temperature- and pressure-dependent viscosity convection

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Abstract

In a series of three-dimensional spherical simulations the effects of purely internally heated convection was studied to yield updated scaling laws for parameterized mantle convection models similar to 2D boxed approaches as [1], [2]. The upper Rayleigh number, the viscosity contrast due to temperature and pressure were varied in over 88 cases to study the influence of these parameters on the quasi steady-state. A viscosity contrast up to the order of 10^9 was observed. The simulations were carried out using the GAIA framework, consisting of a highly parallel solver for mantle convection in arbitrary geometries. Updated values for the Nusselt – Rayleigh scaling are presented together with a mobility criterion to specify the stagnant lid regime. Furthermore, the parametric ranges of degree-one convection are presented along with a new spectral scaling that allows the determination of the internal Rayleigh number from dominant spherical harmonic modes of convective systems.

If the viscosity contrast within the system reaches a certain limit, the style changes to stagnant lid convection. In the regime of stagnant lid convection, the dominant mode increases if the internal Rayleigh number is increased as well, while in the non-stagnant lid regime the modes stay low (bifurcation), as shown in figure 1.

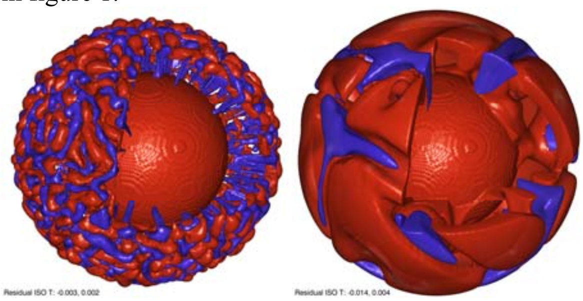

Fig. 1 Residual iso-surface of temperature with approximately similar internal Rayleigh number, left: convection under a stagnant lid; right: whole-mantle convection.

Comparing the results to those previously published ([1], [2], [3], [4]) in the same parameter range in 2D and 3D boxes exposed an interesting increase of the γ parameter relating the transition to the stagnant lid regime. It seems that 2D or 3D boxed runs produce a stagnant lid while in a sphere fall into degree-one convection without a stagnant lid. A transitional or sluggish regime could not be observed. The viscosity contrast at which stagnant lid convection occurs could be pin-pointed to 2.96e4 with a confidence interval of less than +/-2.7e3. Spectral analysis revealed also that stagnant lid convection cannot happen below a degree-four pattern and that degree-one convection is not possible for iso-viscous convection because the range in which degree-one convection would occur leads to a Rayleigh number not high enough to enable convection.

The newly derived spectral scaling law was applied to gravity field observations of Venus to constrain and compare internal parameters such as viscosity and temperature at the convecting interior with previously published values.

References

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