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Mantle Convection in a Spherical Shell: Comparison of Kamenetskii Approximation and Arrhenius Viscosity Law

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Mantle convection in terrestrial planets is strongly influenced by the temperature dependence of its viscosity. This temperature dependence is described by the so called Arrhenius law. Applying the temperature dependent viscosity to model the mantle dynamics shows basically three different regimes depending on the viscosity contrast in the mantle: a mobile lid regime, a transitional regime and a stagnant lid regime. In the first two regimes, surface material can move and is incorporated in the mantle convection, whereas in the third regime a stagnant lid forms on top of the convecting mantle. For realistic rheological mantle parameters all terrestrial planets are actually in the stagnant lid regime unless the lid is prone to break. This latter process can for instance be simulated with a visco-plastic rheology.

For numerical reasons, an approximation of the viscosity is commonly used to model the mantle convection, i.e. the Frank-Kamenetskii approximation. This linearization assumes that the Arrhenius law can be approximated by an exponential law suggesting a viscosity which is many orders of magnitude smaller at the surface. The approximation has been shown to represent only the stagnant lid regime correctly but it is widely used in the literature also for the other regimes.

Here, we show a comparison of the mantle convection using either Arrhenius law or Frank-Kamenetskii approximation for the viscosity with a 3D spherical code, GAIA [Hüttig and Stemmer, 2008 a,b]. A systematic study is presented showing the differences in various control parameters of mantle convection, e.g. degree of convection, Nusselt number, and stagnant lid thickness depending on the used viscosity.

References:

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