On the Problem of the Propensity of Plate Tectonics on Super-Earths

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The last decades of astronomical observation have opened the new interdisciplinary field of extra-solar planetary research. Up to this date around 500 exoplanets were detected, most of them with masses in the range of Jupiter. With improved technology the mass detection limit has been reduced to planets consisting of a few Earth masses. Planets with a structure similar to Earth but being more massive are called Super-Earths, such as Corot-7b (approx $5M_E$ and $1.6R_E$, *Queloz et al. 2009*). Recently, questions have been raised about the ability of Super-Earths to sustain active plate tectonics, similar to Earth. *Valencia et al 2007* and *O'Neill and Lenardic 2007* have investigated the ability of Super-Earths to overcome lithospheric stresses and to deform plates, but both derived opposite conclusions.

Both models were using a pressure-independent rheology, which is not suitable to describe the mantle convection of Earth and Super-Earths as shown in *Stamenkovic et al 2010 a)* and *b)*.

Nonetheless to test the robustness of their findings, we at first investigate a pressure independent rheology (with activation volume V^*=0), using a parameterized 1D thermal boundary layer model similar to *Valencia et al 2007*. We define a driving propensity of plate tectonics for every planet in relation to a test planet with one Earth mass for every time step. The driving propensity describes for every planet at a given time the ratio of convective stresses versus the yielding stresses below the planetary lid in relation to a one Earth mass planet. We test the sensitivity of the results in dependence to the choice of the two main scaling parameters of the model, namely the Nusselt-Rayleigh scaling exponent β and the scaling Rayleigh number Ra ($\mathrm{Nu} \propto \mathrm{Ra}^{\beta}$).

For isoviscous convection boundary layer theory predicts that β depends on the type of heating (internal or bottom) and on the boundary conditions (free-slip or no-slip). Ideally, in the case of free-slip conditions, β=¼ for internal, and β=⅓ for bottom heating respectively. 3D and 2D calculations have shown that for isoviscous and non-isoviscous convection with varying boundary conditions and mixed heating β<⅓ and is actually closer to β≈¼ for any kind of heating mode (*Choblet and Parmentier, PEPI 173, 2009; Iwase and Honda, GJI 180,1997; Sotin and Labrosse, PEPI 173, 1998*). We observe that for V^*=0 we only obtain increasing driving propensities with increasing planetary mass for Super-Earths, as observed by *Valencia et al 2007*, if β>0.32, which is not realistic for mixed heating.

Parameterized Boundary Layer Models use the Rayleigh number as their scaling parameter. The Rayleigh number Ra depends on values that change with depth in planetary mantles, which we derive in *Stamenkovic et al 2010 a)* for phononic contributions:

- Density **increases** with depth
- Thermal expansivity **decreases** with depth

- Thermal diffusivity **increases** with depth

The Rayleigh number is used to scale the whole depth-dependent, compressible system. Note that *Valencia et al 2007* has inconsistently used an upper mantle thermal expansivity and a upper mantle thermal diffusivity but kept an average mantle density. For a depth-dependent system with "local" Rayleigh numbers strongly varying it comes to hand to describe the convective system with a Rayleigh number defined with all average mantle values. In this case, the driving propensity decreases for more massive Super-Earths. We further find that in an as well consistent model with only upper mantle values, the driving propensity would remain almost unaffected by the planet's mass.

In both cases we can show that the results obtained by *Valencia et al 2007* are crucially depending on the unrealistic model assumptions and by far not rubust. For Super-Earths our results tend to agree well with the findings of *O'Neill and Lenardic 2007*, where the driving propensity of plate tectonics is decreasing with planetary mass, but our results disagree for planets smaller than Earth, where we observe a lower driving propensity at all times and for the whole parameter range in comparison to a one Earth mass reference planet.

The results so far were for $V^*=0$, which is not realistic for planets as large as or larger than Earth. In *Stamenkovic et al 2010 a)* we derived a more realistic viscosity law, suitable for Earth and Super-Earths with $V^*\neq 0$. We discuss the implications of this pressure-dependent viscosity for our results and show that it most likely leads to a further decrease of driving plate tectonics propensity on Super-Earths, as already observed for $V^*=0$.

References:

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