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On the Problem of Deriving Scaling Laws for Plate-Tectonics on Terrestrial-Like Exoplanets

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Space missions like Kepler and CoRoT led to a fast growing number of detected rocky exoplanets up to 10 Earth masses, and a large effort is done in simulating the interior processes of these planets including the atmosphere, surface processes, mantle convection and core dynamos. These investigations help to find specific constraints on the habitability of these planets (e.g. the likeliness of plate tectonics or the amount of outgassed volatiles) and select candidates for future space missions which can observe only a limited amount of planetary candidates (EChO for example can only observe 100 exoplanets [0]).

Studies that try to investigate the likeliness of plate tectonics on exoplanets typically extrapolate their results obtained for convection simulations of smaller planets or of planets with a stiffer mantle (using higher reference viscosities) to obtain a general conclusion about how larger planets would evolve with time. Further, parameterized model are often used to investigate large parameter spaces. However, these models are based on scaling laws, which are typically derived for small Rayleigh numbers and predefined viscosity contrasts (typically 10^5 to guarantee a stagnant lid), and hence may fail to yield realistic results if applied to exoplanets.

In this study, we therefore concentrate on the dependence of the scaling laws on the large-Rayleigh-number regime and the viscosity contrast (influenced either by a change in surface temperature, activation energy or viscosity approximation). First results of our parameter study show already that the scaling of convective stress below the lid, root-mean-square velocity and Nusselt number leads to different scaling parameters depending on the viscosity contrast, which has important consequences for plate-tectonics simulations performed by parameterized models. A formulation following

$$Nu = \theta^\alpha Ra^\beta$$

for varying viscosity contrasts (with $\theta = ln(\eta_{surf}/\eta_{CMB})$) and Rayleigh numbers but fixed exponents α, β does not hold. The exponent of the Rayleigh number itself depends on the viscosity contrast ($\beta(\theta)$). We determine a universal scaling that fits to all viscosity contrasts investigated.

We further compare the scaling exponent for different geometries (sphere vs. box [1]) and different ratios of core radius to planet radius. Finally, the scaling laws for the convective stress are compared to plate tectonics simulations, where a specific factor (i.e. surface temperature or mantle thickness) is varied, to verify of our new scaling laws.

References

[0] EChO Science Requirements Document (2011). SRE-PA/2011.037, ESA.
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