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Outgassing of stagnant-lid planets

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Little is known about compositional and structural diversity of super Earths. Super-Earths are distinct from mini-Neptunes in terms of the origin of their atmospheres, i.e. which are outgassed from the interior. Modeling the outgassing rates that arise from interior dynamics is key in order to inform the interpretation of data from current and future missions (e.g., James Webb Space telescope). Here, we present a comprehensive study on the outgassing of super-Earths of different mass, structure, composition, and temperature. We emphasize that this study is limited to planets in a stagnant-lid convection regime only.

We model a convection and melting in a 2-D spherical annulus geometry. The convection code solves the conservation equations for mass, momentum and energy. Partial melt occurs where mantle temperature exceeds the solidus melting temperature. If the melt is gravitationally buoyant, we assume that melt rises immediately to the surface, while tracing the melt depletion in the mantle with particles, that advect along the convective stream lines.

The model for convection and melting is applied to planets between 1 and 8 Earth masses. Besides planet mass, we test different aspects that may influence the production of melt and outgassing: (1) core size, (2) mantle composition, especially iron mantle content, (3) upper mantle temperature, (4) amount of radioactive heat sources, (5) temperature jump at the core-mantle-boundary, (6) lithosphere thickness, and (7) model resolution. We present our findings in the form of scaling laws that express the outgassing depending on investigated parameters.

We find that first order effects on outgassing are energy-related parameters such as upper mantle temperature and the amount of radioactive heat sources, as well as planet mass. Interestingly, the composition of the mantle has only second-order effects. However, we note that we use reference profiles for pressure and temperature and hence phase transition depths are set constant over time. Core size has almost no effect on melting in the mantle.

Findings of our study are in agreement with previous work. Our study, however, represents a comprehensive investigation of interior parameters that affect melting and outgassing. We provide scaling laws of outgassing that are helpful for the interpretation of astrophysical data from super-Earths atmospheres.