Geophysical Research Abstracts
Vol. 20, EGU2018-4552-1, 2018
EGU General Assembly 2018

Outgassing of stagnant-lid Super-Earths

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We explore volcanic outgassing on purely rocky, stagnant-lid exoplanets of different interior structures, compositions, thermal states and age. We focus on planets in the mass range of 1–8 M_{Earth}. We derive scaling laws to quantify first- and second-order influences of these parameters on volcanic outgassing.

Given commonly observed astrophysical data of super-Earths, we identify a range of possible interior structures and compositions that represent our anticipated diversity of Super-Earths. The identified interiors are subsequently used as input for two-dimensional (2-D) convection models to study partial melting, depletion, and outgassing rates of CO_2 assuming stagnant-lid convection.

In total, we model depletion and outgassing for an extensive set of more than 2300 different super-Earth cases. We find that there is a mass range for which outgassing is most efficient ($\sim$2–3 M_{Earth}, depending on thermal state) and an upper mass where outgassing becomes very inefficient ($\sim$5–7 M_{Earth}, depending on thermal state). At small masses (below 2–3 M_{Earth}) outgassing positively correlates with planet mass, since it is controlled by mantle volume. At higher masses (above 2–3 M_{Earth}), outgassing decreases with planet mass, which is due to the increasing pressure gradient that limits melting to shallower depths. In summary, depletion and outgassing are mainly influenced by planet mass and thermal state. Interior structure and composition only moderately affect outgassing. The majority of outgassing occurs before 4.5 Gyrs, especially for planets below 3 M_{Earth}.

Despite the anticipated and large variability of various interior parmeters, we confirm that there is (1) a mass range for which outgassing is most efficient and (2) an upper mass limit, above which no significant outgassing can occur. We quantified the secondary influence of compositional and structural properties on outgassing using scaling laws. Our scaling laws are partly based on thermal boundary layer theory.

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). We present a comprehensive study on the outgassing of stagnant-lid super-Earths of different mass, structure, composition, thermal states, age, viscosity and others. Our scaling laws describing outgassing are a helpful tool for the interpretation of astrophysical data from super-Earths atmospheres.