Effect of surface-mantle water exchange parameterizations on the prevalence of waterworlds. T.D. Komacek[1] and D.S. Abbot[2], [1]Lunar and Planetary Laboratory, University of Arizona (tkomacek@lpl.arizona.edu), [2]Department of the Geophysical Sciences, University of Chicago (abbot@uchicago.edu).

Introduction:

Why does the amount of surface water matter? The traditional habitable zone relies on surface liquid water being present [1]. However, it also relies on the operation of the continental silicate-weathering feedback, which stabilizes the climate to perturbations in CO_2 concentration [2]. If the surface of the planet is completely covered with water, the silicate-weathering feedback cannot operate [3,4]. Such a "waterworld" state is likely stable [5], though not climatically, as it would likely be trapped in a moist greenhouse [3,5]. As a result, understanding the prevalence of such waterworlds is important, as they are likely to not be conducive for the evolution of Earth-like life.

The deep-water cycle. To understand how common such waterworlds are, we must understand how much of the initial amount of delivered water (which varies over a wide range and can be up to 1% by mass or more [6,7]) is sequestered in the planetary interior. This is reliant on a physical understanding of the processes which regulate the exchange of water between the surface and interior of a planet. The deep-water cycle has been extensively studied on Earth (e.g. [8,9,10]), with the implicit assumption that water cycling depends solely on the heat transfer properties of the mantle. This "temperature-dependent" water cycling paradigm has been applied to super-Earths [11]. [11] found that it is unlikely for super-Earths to be waterworlds, though if the mantle viscosity is small the surface of the planet may be quickly flooded but should be removed over short timescales.

An alternative paradigm for terrestrial planet water cycling ([12]) is that water cycling is solely dependent on the amount of surface water (that is, the pressure at the base of the surface oceans). Parameterizing water cycling as power-laws in seafloor pressure and assuming that water cycling was in steady-state, [12] was able to determine the how planetary water mass fraction at which planets became waterworlds varies with planet mass. However, they found that this waterworld boundary was incredibly sensitive to the assumed power-law dependencies in their water cycling model.

Analytic modeling approach: We have developed a non-dimensional analytic framework in which to understand how various assumptions about water cycling affects the prevalence of waterworlds [13]. In this model, we directly compare the predictions of the temperature and pressure-dependent models, along with developing a hybrid model combining their effects. We find that water cycling reaches a steady-state (or near steady-state) for all relevant parameter choices, and using our non-dimensional framework can vary these paramters to understand how they affect the waterworld boundary.

What determines if a planet will become a waterworld? Figure 1 shows our key result, that the water mass fraction needed to become a waterworld strongly depends on both planet mass and assumptions about water cycling. If water cycling is solely dependent on mantle temperature or seafloor pressure, super-Earths need to be >0.3% water by mass to become waterworlds. However, if the hybrid model is relevant or water cycling does not occur, super-Earths with a total water complement similar to Earth (~0.05%) can become waterworlds. Understanding which model is physically relevant for water cycling will aid in determining the likelihood of clement surface conditions and hence inhabitance on terrestrial exoplanets.

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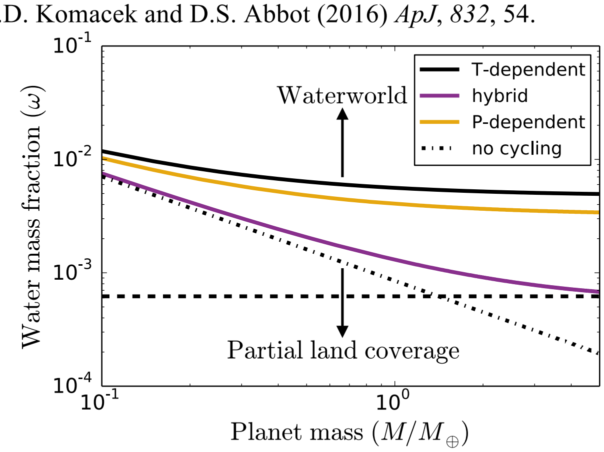

Figure 1: Water mass fraction at which planets become waterworlds as a function of planet mass for various assumptions about how water cycling depends on properties of the planet.