Atmosphere-Interior Coupling: outgassing effects on Runaway Greenhouse desiccation timescales

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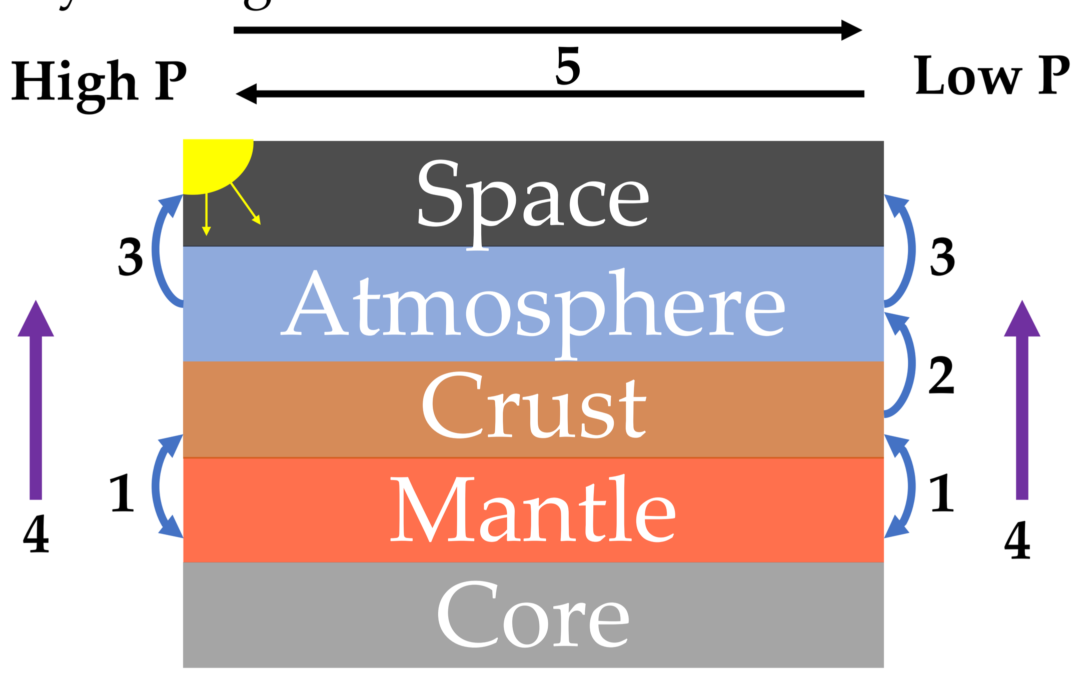
VPLanet can be found on Github at: https://github.com/VirtualPlanetaryLaboratory/vplanet

Motivation

- Outgassing is a key surface-interior interaction, but is often not considered in the context of larger-scale planetary processes, especially atmospheric escape

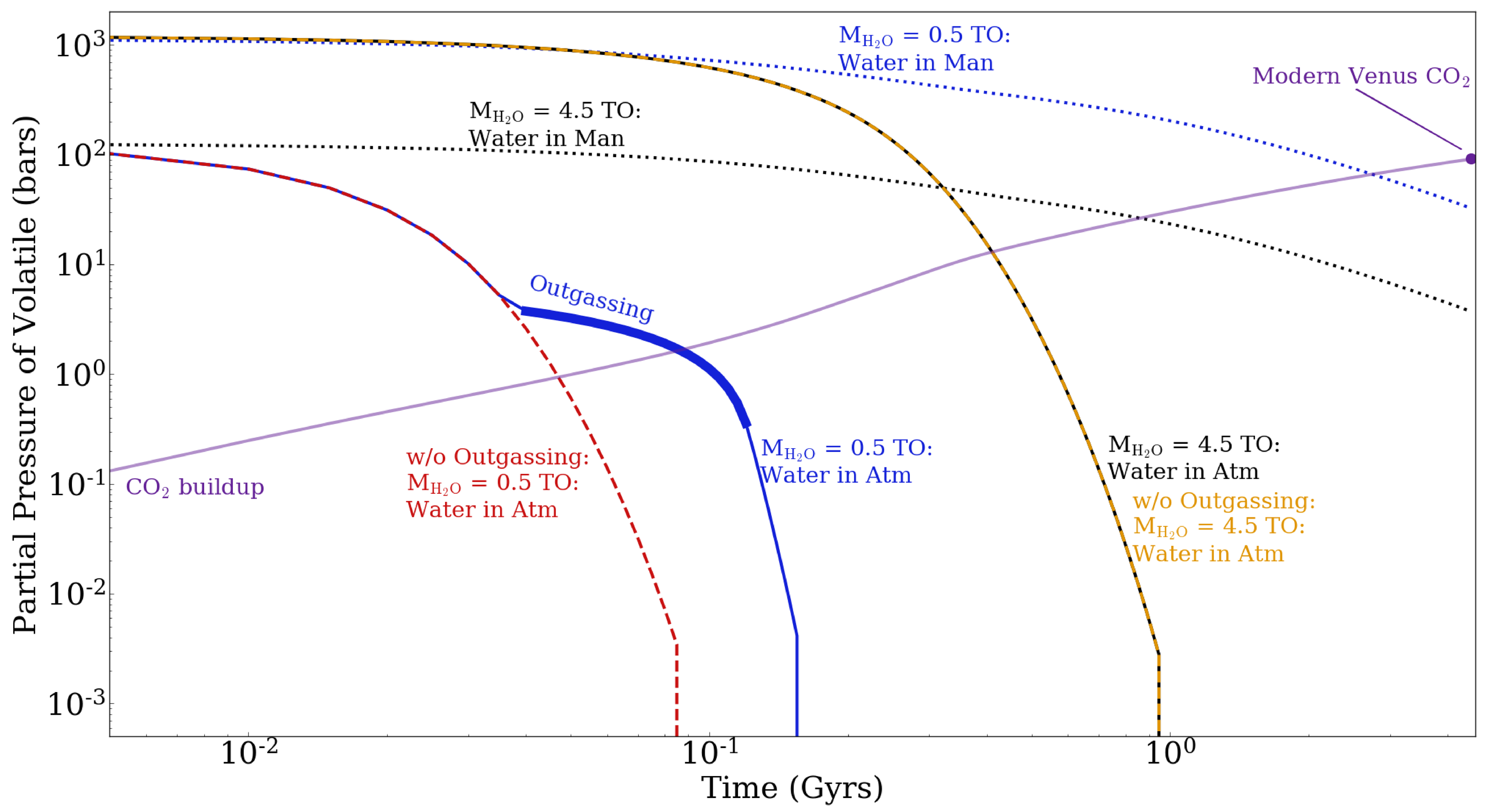
Method

- We coupled pressure-dependent outgassing to atmospheric escape to explore the lifetime of water vapor on Venus around the Sun.
- Our model utilizes VPLanet, a software suite that couples a variety of physical processes, including stellar evolution, atmospheric escape, thermal interior evolution, and dynamo generation



1. H_2O in the melt extrusively erupts from the mantle to form the crust Crustal H_2O returns to the mantle at a rate proportional to the melt production rate (the recycling efficiency) which is calculated via a thermal interior model [1]
2. At low pressure, the melt is supersaturated with H_2O at surface pressure and outgasses H_2O to the atmosphere [2] This does not occur at high pressure
3. The H_2O in the atmosphere is photolyzed by an evolving XUV flux and the resulting hydrogen escapes to space [3]
4. CO_2 is continuously outgassed to the atmosphere based on the redox state of the mantle [2] This process does not depend on the surface pressure
5. Atmospheric escape lowers the surface pressure, outgassing increases the surface pressure

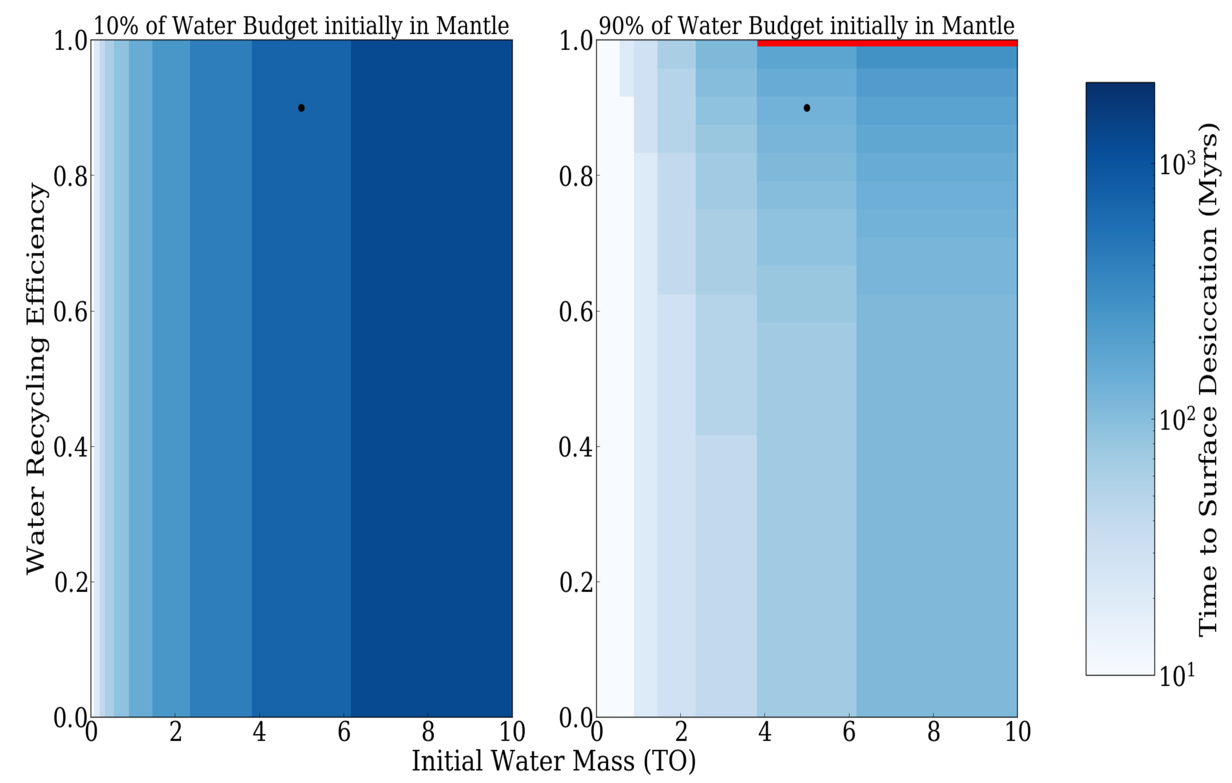
High surface **pressures suppress outgassing**, but **atmospheric escape reduces pressure, facilitating outgassing** and **extending the runaway greenhouse state** on terrestrial planets around Sun-like stars



Solid lines show the amount of volatiles in the atmosphere calculated from a model combining atmospheric escape and interior outgassing. Dashed lines show volatile amounts calculated with only atmospheric escape. In both cases the total initial water mass is 5 terrestrial oceans (TO) with either 0.5 or 4.5 TO sequestered in the mantle and the recycling efficiency is 0.9. We find that to reproduce Venus' 92 bar CO_2 atmosphere, the mantle redox state must be 2.76 above the iron-wustite (IW) buffer. Atmospheric desiccation times are higher when outgassing is included in the model, though outgassing is irrelevant when a majority of the initial water budget is initially in the atmosphere.

Key Takeaways

- We found that atmospheric escape and outgassing counter each other, explaining planetary evolution in a way that neither process does alone
- We found that crustal recycling and a majority of water being initially sequestered in the mantle are both required for outgassing to occur
- We found that high crustal recycling rates do not reproduce Venus as the planet would maintain a geodynamo
- Our simplified model suggests that a mantle redox state of IW + 2.76 can reproduce Venus' atmosphere



Parameter space exploration of desiccation times, with black points corresponding to simulations in the central figure. The red region maintains a geodynamo, which is not observed on Venus.

References

[1] Driscoll and Bercovici (2014). *Physics of the Earth and Planetary Interiors*. **236** p. 36-51.
[2] Grott et al. (2011). *Earth and Planetary Science Letters*. **308** pg. 391-400.
[3] Luger and Barnes (2015). *Astrobiology*. **15** pg. 119-143.