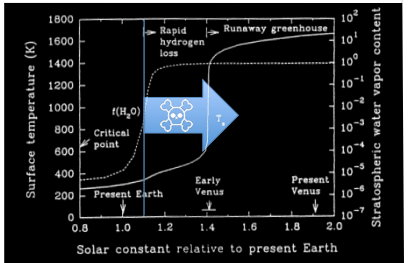
Revisiting and Revising the Habitable Zone: Haze and Ocean Albedo Effects

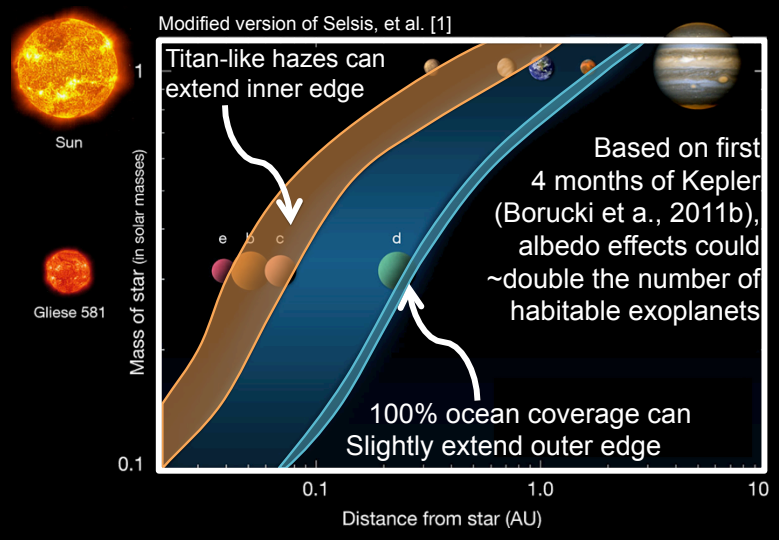
Shawn D. Domagal-Goldman[1,2] (email: sgoldman@astro.washington.edu), Victoria S. Meadows[2, 3]
[1]NASA Headquarters, Washington, DC; [2]Virtual Planetary Laboratory at the University of Washington, a NASA Astrobiology Institute Lead Team; [3]University of Washington Astronomy

Inner Edge: Haze Effects

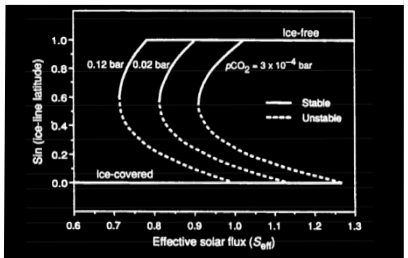


RUNAWAY GREENHOUSES [2] form if a planet receives too much energy from its star: a steam-filled stratosphere leads to rapid loss of water to space (through H escape). Further insolation increases cause the planet's surface to absorb more radiation than it can radiate, creating a runaway condition and Venus-like surface temperatures. Hazes, similar to those on the ancient Earth, could prevent this.

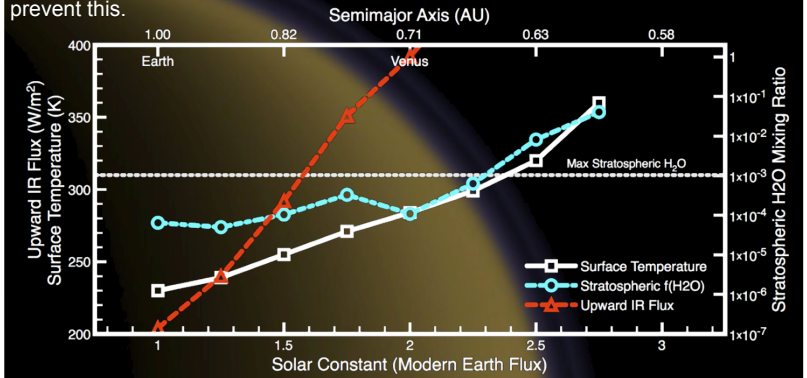
Modified version of Selsis, et al. [1]



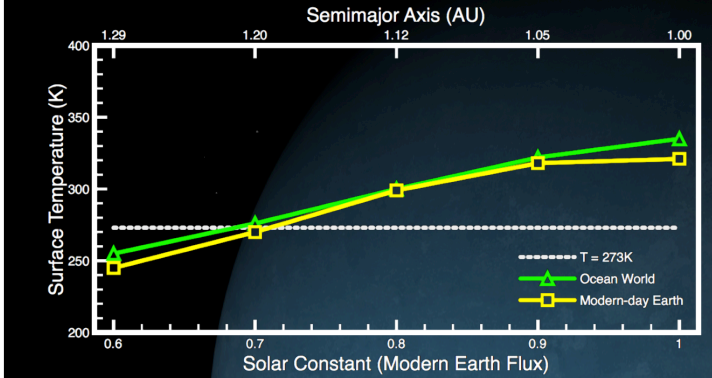
Outer Edge: Albedo Effects



SNOWBALL GLACIERS [3] form if a planet does not receive enough energy from its star, causing a runaway feedback: cold temperatures lead to more ice, higher surface albedo, and even lower surface temperatures. The distance from a star at which this feedback is triggered can be increased if ocean coverage is greater, or if orbital dynamics lead to periodic melting of the ice.



Thick hazes significantly impact the habitable zone. We predict surface temperature (white, left y-axis), upwards IR flux (red, left y-axis), and tropopause H_2O concentration (cyan, right y-axis) as a function of solar constant (bottom x-axis, semimajor axis on top x-axis). This simulation had CO_2 concentrations at the lower limit for photosynthesis (10ppm), and CH_4 fluxes at 2 times modern-day values. The dashed line is the habitability limit imposed by stratospheric H_2O concentrations (teal line). Hazes extend the inner edge of the habitable zone inwards to ~0.6 AU; this represents a significant extension.



Surface albedo slightly impacts the habitable zone. This figure shows predictions of surface temperature (y-axis) as a function of solar constant (bottom x-axis, semimajor axis on top x-axis). The yellow line is for a planet with the same albedo (clouds and ocean coverage) as Earth. The green line is for a planet with 100% ocean coverage and no clouds. Both model runs had 0.3 bars of CO_2, 0.03 bars of CH_4, and concentrations of other species consistent with those values. The dashed line is the habitability limit imposed by snowball Earth conditions (grey line). These albedo effects slightly extend the outer edge of the HZ.

Conclusions:

- Thick hazes extend HZ
- Needs high CH_4/low O_2
- GJ581c may be in HZ

WE ACKNOWLEDGE:
This work was made possible by funding from the Virtual Planetary Laboratory, an NAI lead team.

References:

[1] Selsis FJ, *et al.* (2007) Habitable planets around the star Gl581? *Astronomy and Astrophysics*: 476, 1373-1387.
[2] Kasting, JF. (1996) Habitable Zones Around Low Mass Stars and the Search for Extraterrestrial Life. *Origins of Life and the Biosphere*: 27:291-307.
[3] Caldiera K and Kasting JF. (1993) Susceptibility of the Early Earth to Irreversible Glaciation Cause by Carbon Dioxied Clouds. *Nature*: 359:226-228.

Conclusions:

- Oceans can extend HZ
- Not a huge effect
- Obliquity is important