THE ROLE OF TOPOGRAPHY IN MODULATING CLIMATES OF HABITABLE WORLDS.

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Introduction: The surface features of distant potentially habitable worlds are currently unknown, and it may be some time before a technique such as spin-orbit tomography permits us to retrieve even basic 2-D information [1]. Within the Solar System, the original surfaces of Paleo-Earth (>2 Gyr) and paleo-Venus have long since been altered by tectonics and/or eruption events [2, 3]. As a consequence, 3-D general circulation model (GCM) simulations of the climates of these worlds typically utilize an aquaplanet configuration (no emergent land) [e.g. 4], which has the benefit of simplifying assumptions but may limit the assessment of planetary habitability. We highlight here the differences in simulated climates that are produced when using realistic, reconstructed, or idealized continental distributions.

Approach: We employed the latest versions of NASA's coupled ocean atmosphere Earth System Model [5] and NASA's newest planetary GCM, ROCKE-3D [6] for the simulations discussed. Paleo-Earth simulations, which did not require special radiative transfer capabilities but did benefit from running at higher resolution (2˚x2.5˚x40L atmosphere, 1˚x1.25˚x32L ocean) for purposes of checking against proxy data from the geologic record, were run with the regular Earth System Model. Paleo-Venus, Early Earth and various exoplanet simulations were run with ROCKE-3D to take advantage of expanded radiative transfer and stellar spectral capabilities in conjunction with slightly coarser resolution (4˚x5˚x20L or 40L atmosphere, 4˚x5˚x13L ocean) for improved computational speed.

Habitable world scenarios:

Paleo-Earth: A range of habitable states exists throughout the last two billion years of Earth history, including periods that are representative of both inner and outer edge environments, i.e., Snowball Earth and the Cretaceous Greenhouse [7]. There is high confidence in continental reconstructions with emergent land back to ~300 Myr, with moderate confidence reconstructions dating to at least 1 Gyr. Using reconstructed land/ocean distributions with the GCM permits us to test hypotheses based on conceptual models (does a supercontinent at tropical latitudes encourage global cooling via albedo feedbacks?) as well as explore far-field climate teleconnections that may explain enhanced habitability (does the closing of an equatorial seaway drive increased heating in polar regions?). These runs have the added benefit of being evaluatable against known climate states of the past.

Paleo-Venus: Using current Venus topography as a proxy for paleo-Venus landscapes, and a slow rotation rate, we have shown that having a large land fraction in the tropics combined with modest amounts of water actually limits the amount of planetary warming to habitable levels, moreso than aquaplanets – or even a modern Earth topography – given the equivalent solar flux [8]. This result suggests that more surface water is not necessary "better" for habitability under certain circumstances, and also shows that the inner edge of the HZ is more transitional than previously described.

Early Earth/Exoplanets: A series of idealized continents simulations, varying the total global land fraction from 75% to 6.25%, and varying the location of continents from polar-centered positions to scattered rectangular continents produces as much as a 20˚C difference in global mean annual temperature for otherwise identical simulations (same solar/GHG forcings).

A synchronously rotating exoplanet such as Proxima Centauri b, modeled both as an aquaplanet and with modern Earth topography [9], shows how land barriers to zonal water/heat transports result in a global mean annual surface temperature that is ~10˚C colder than the equivalent aquaplanet scenario. Ice and snow cover increases by roughly a factor of two when land is beneath the substellar point, rather than ocean – an outcome with ramifications for the area of habitable space available.

Future research and challenges: We recognize that introducing topography adds complexity and time to the creation and running of GCM simulations, and that the parameter space to explore is potentially quite broad. However, we feel that there are clear benefits to including some emergent land fraction experiments along with aquaplanets, in terms of the diversity of habitable planetary environments that can be identified.

References: [1] Fujii Y. and Kawahara H. (2012) *ApJ 755*, 101. [2] Harrison T. M. (2009) *Ann. Rev. Earth Planet. Sci. 37*, 479-505. [3] Bjonnes E. E. et al. (2012) *Icarus 217*, 451-461. [4] Noda S. et al. (2017) *Icarus 282*, 1-18. [5] Miller R. L. et al. (2014), *J. Adv. Model. Earth Syst.,* 6, 441-477. [6] Way M. J. et al. (2017) *ApJSS, 231*, 12. [7] Sohl et al. (2015) *AbSciCon 2015*, abstract 7645. [8] Way M. J. et al. (2016) *GRL, 43*, 8376-8383. [9] Del Genio A. D. et al. (2017) Subm. to *Astrobio*.