# The Sellers Exoplanet Environments Collaboration

# Land Planets: Foundations for Understanding the Distribution of Surface Habitability and Life Inside the Habitable Zone


**Team: (June 2018 – September 2019)**

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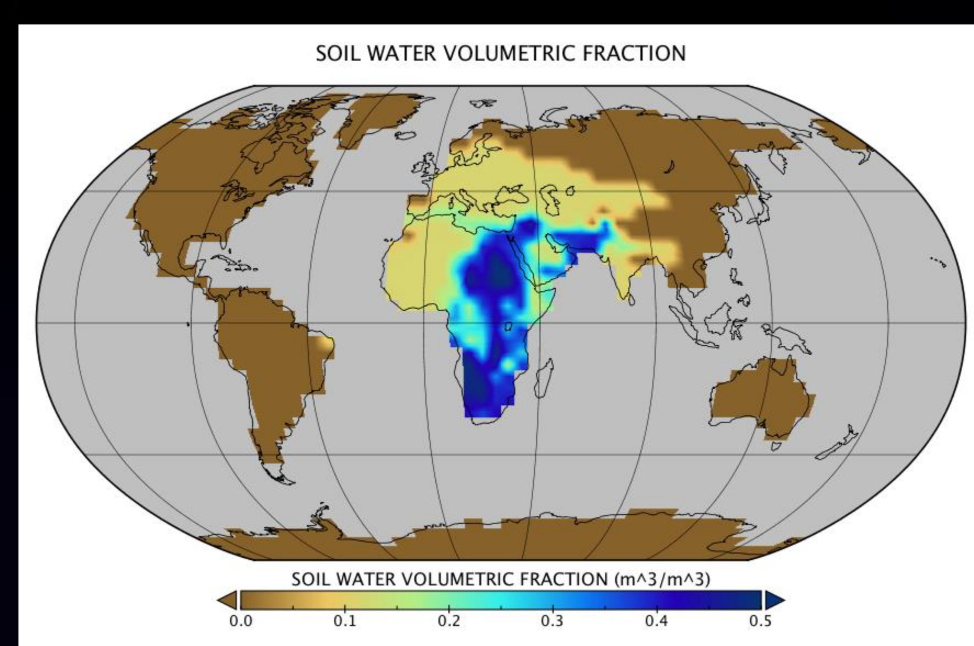



Tidally locked Proxima b

Del Genio et al. accepted.

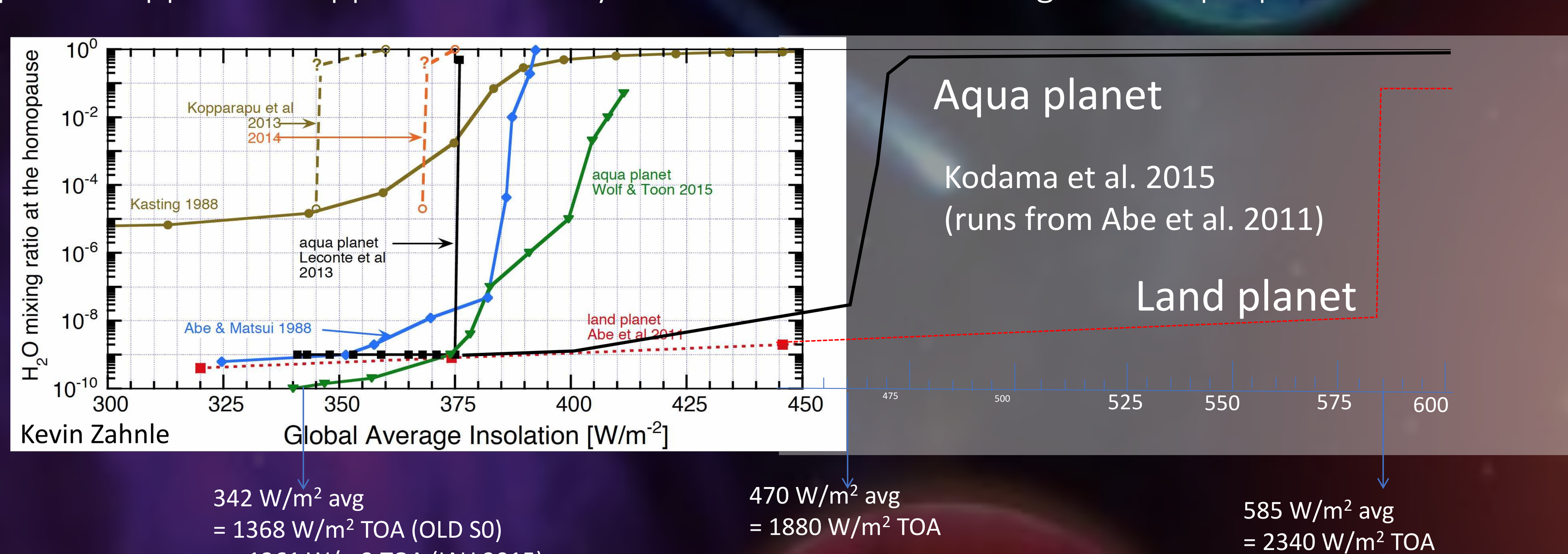
**Key Problem:** Life is heterogeneously distributed over a planet's surface due to the variety of climate regimes a planet will host. A planet may therefore be fractionally habitable to super-habitable.

**Objective:** We aim to establish foundations for classically understood behavior of

1) the sensitivity of planetary climates to other stellar types, orbital characteristics, and surface configurations;
2) the extent to which feedback by biota may alter the climate;
3) how that sensitivity and feedback could affect the detectability of biosignatures.

**Focus on Land:** Although life might begin in the ocean, land surfaces are where biomass can build up to high density to produce surface biosignatures amenable to direct telescope detection, such as the vegetation red edge. Land surfaces are also required to enable weathering to support a carbonate-silicate cycle for the stability of the planet's climate. Planets dominated by land also may allow for a more extensive continuous habitable zone than an aqua planet (Figure 1).

Figure 1. Idealized Aqua vs. Land planets: Limits of habitability. The plot below shows the moist greenhouse limits of Earth-like, aqua, and land planets estimated by a variety of studies. Land planets appear to support habitability at a wider instellation range than aqua planets.




**Understanding Land Planet Habitability with 3D General Circulation Models:** Simulations of 3D dynamics of planetary climates with GCMs are now accepted as important to constrain planetary habitability and super-habitability. However, thus far, the majority of climate modeling efforts have sought to delineate the edges of the habitable zone (HZ), or GCM and biosignature detection modeling efforts to date have focused mostly on conditions around M stars, and utilized a narrow set of idealized specifications of a planet's surface: all ocean, or modern Earth continents, and few all-land studies. Life is less likely to be detectable at the extreme edges of the habitable zone; the long-term habitability of M star and ocean planets is questionable; and the effect of surface configuration is a very unexplored problem. Exploring the parameter space where life is more likely to persist and be detectable rather than at its extreme limits is necessary to fill in knowledge gaps about exoplanet climate characteristics and constrain confidence in interpreting observations for the presence or absence of life.

**WHERE WILL THE WATER BE? ROCKE-3D GCM, ABIOTIC PLANET:**. We will use the NASA Goddard Institute for Space Studies (GISS) Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) GCM to perform perturbed parameter ensemble (PPE) planetary climate simulations to characterize how liquid water may be distributed over land planets. We will use a Latin hypercube sampling (LHS) experimental design to explore the parameter space of stellar type (M, K, and G stars), instellation, planet size, surface pressure, rotation rate, obliquity, atmospheric CO2 and N2, land albedo, soil texture, and initial water content. We leverage prior ROCKE-3D simulations to populate the parameter space. Observed stars and planets provide benchmarks.

Earth-size land planet
10 variables
110 LHS experiments + 4 known planets through time
Stars: 8 spectral types – M, K, G
Instellation: Mars to Early Venus
Rotation: fast to slow, tidally locked, 3:2 spin-orbit resonance
Obliquity: 0 to 90 degrees
(Eccentricity: None)
Atmosphere: $N_2/CO_2$, low to high CO2
Pressure: 0.5-2 bar
Surface Albedo: basalt to sand
Surface Roughness: Mars 0.001 to > Earth global bare soil 0.7
Soil texture: minimum to maximum relative water holding capacity

Initial conditions:
Initial $H_2O$: in soil, 20-70 cm; in atmosphere, uniform
Initial temperature: uniform

Idealized known planets as land planets:
Earth, Mars, Venus, Proxima b

**BIOTIC PLANET: SEEK THE WATER.** After characterizing habitability of abiotic planets, we will explore potential biological homeostatis with climate by introducing within the GISS GCM's existing land biosphere model a generic surface life form, an "Exo-plant", that "seeks the water." Like land biota on Earth, this idealized surface life type will alter **surface albedo** and **water conductance**, feeding back to climate.

**OBSERVATION SIMULATION:** Diagnostic outputs of the GCM will provide snapshots of planetary states relevant to telescope observations for analysis with the observation system simulation experiment (OSSE) tools of the NASA Astrobiology Institute (NAI) Virtual Planetary Laboratory (VPL) team, and the NASA Planetary Spectrum Generator (PSG).

**Foundations for understanding.** This project starts the investigation with idealized all-land abiotic planets, then couples in a surface life form, to lay foundations eventually for understanding the spatial distribution of surface habitability (liquid water availability) and biota on rocky exoplanets with more complex surfaces and land/ocean configurations