# An Astro-ecological Model for Characterizing Exoplanet Habitability

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## Introduction

The field of astrobiology aims to explore the relationship between alien environments and carbon-based life, with the goal of identifying habitable planets. Based on the habitability of the Earth, life as we know it is largely dependent upon environmental temperature. This is because the metabolic rate of living organisms is a function of temperature. Thus, to understand the relationship between extraterrestrial environments and telluric life, it is essential to investigate the climates of ideal candidates for habitability.

The ideal candidate for detectable habitability is a rocky planet in the circumstellar habitable zone (CHZ) with a protective atmosphere. Atmospheric climate, thus temperature, is directly influenced by the received stellar insolation which is a function of orbital parameters including obliquity, eccentricity, and rotation period. Thus, all things being equal, an Earth-like exoplanet with different or more variable orbital parameters would alter time-dependent habitability.

Exoplanet climates are regularly examined with the use of General Circulation Models (GCMs), which take as inputs key orbital parameters to simulate probable exoplanet environments. In this research, a modeling approach is outlined for which output data of the GCM Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments (ROCKE-3D, **Figure 1**) [1] will serve as input for a newly developed astro-ecology model. This astro-ecology model considers exoplanet environmental data as well as terrestrial physiological data (The biokinetic spectrum for temperature, **Figure 2**) [2] to study the habitability of known exoplanets.

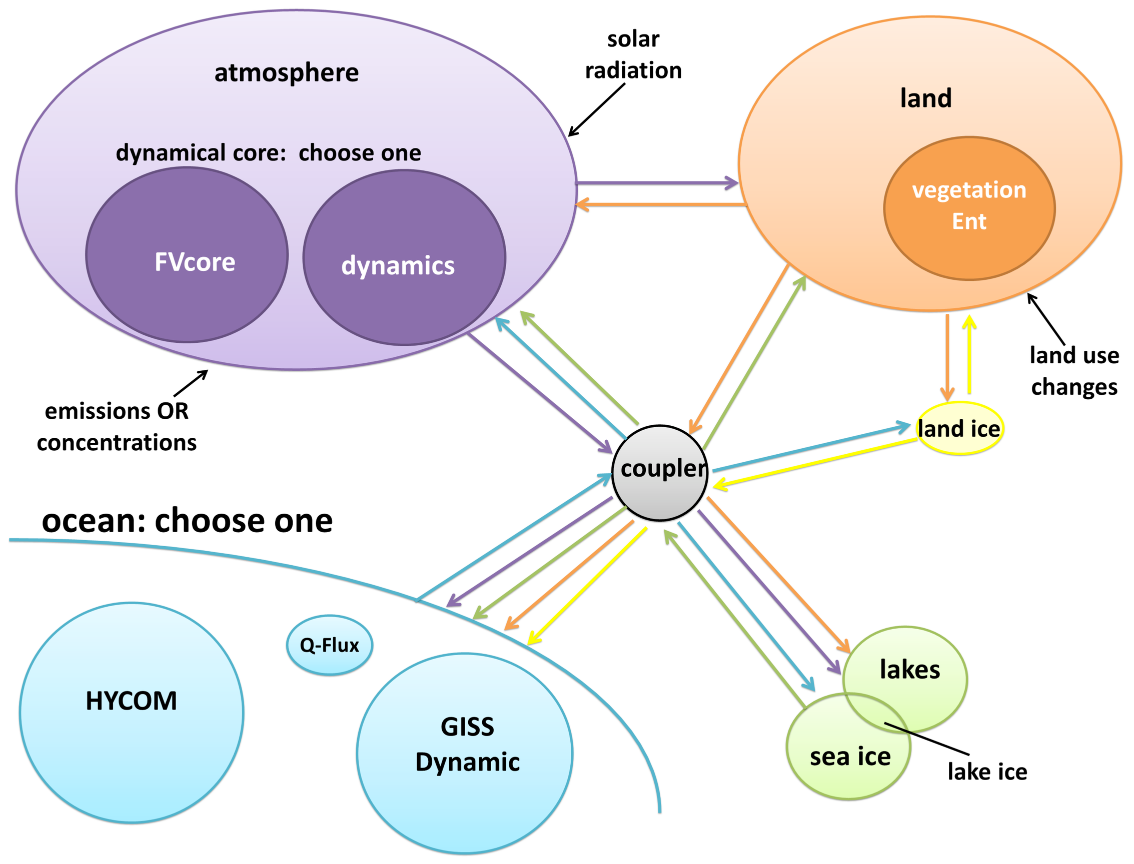
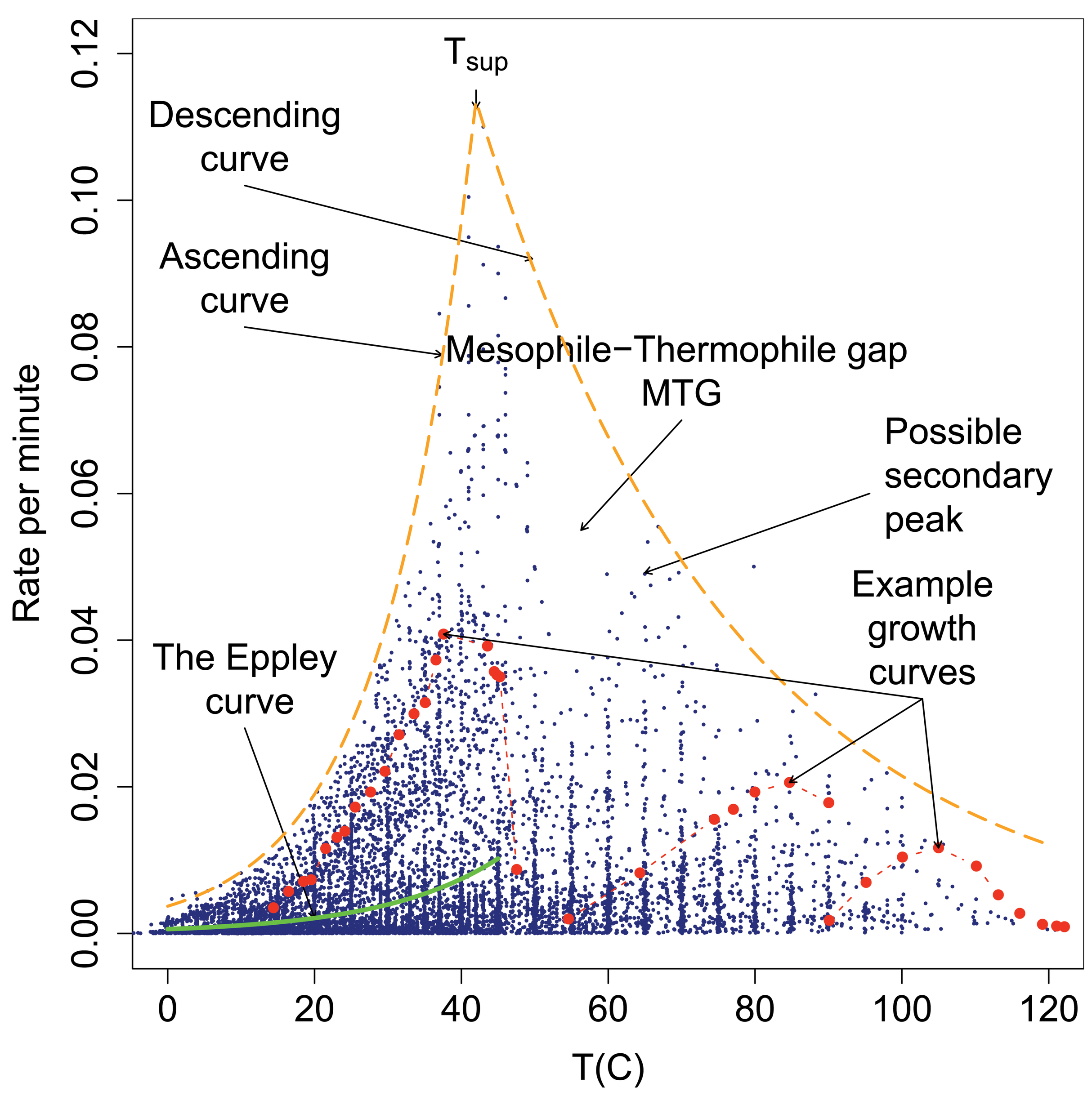



**Figure 1. The global circulation model ROCKE-3D.** ROCKE-3D is a fully-coupled 3-dimensional oceanic-atmospheric climate model developed at the NASA Goddard Institute for Space Studies. The GCM features interactive atmospheric chemistry, aerosols, the carbon cycle, and other tracers, as well as the standard ocean, sea ice, and land surface components. It has been used to successfully model Earth, Mars, ancient Venus, TRAPPIST-1, and Proxima Centauri b, among others. [1] (Image credit: Kaitlyn Alexander and Steve Eastbrook)

**Figure 2. The biokinetic spectrum for temperature.** The biokinetic spectrum for temperature is defined as the distribution of temperature-dependent growth rates for life on Earth. This spectrum arises from a meta-analysis of individual growth rate thermal performance curves gathered from numerous empirical studies. The data includes 1627 cell strains from different species representing all three Domains, all six Kingdoms, and forty-three of the fifty-five Phyla. The sample is also representative of all types of cellular respiration and modes of energy acquisition. [2] Clearly, terrestrial biodiversity is comprehensive in the spectrum.




## Methods

Ecosystem studies often employ the use of ecological models to explore the responses of individual organisms to their environment. Here, a simple astro-ecology model is implemented in the program NetLogo [4] to assess the habitability of an exoplanetary environment based upon its thermal ability to sustain terrestrial life (**Figure 3**). Environmental temperature data will be derived from ROCKE-3D simulations (e.g. **Figure 4**), and individual thermo-physiology responses will be derived from the biokinetic spectrum for temperature (e.g. **Figure 5**). This model will be applied to confirmed rocky CHZ exoplanets.

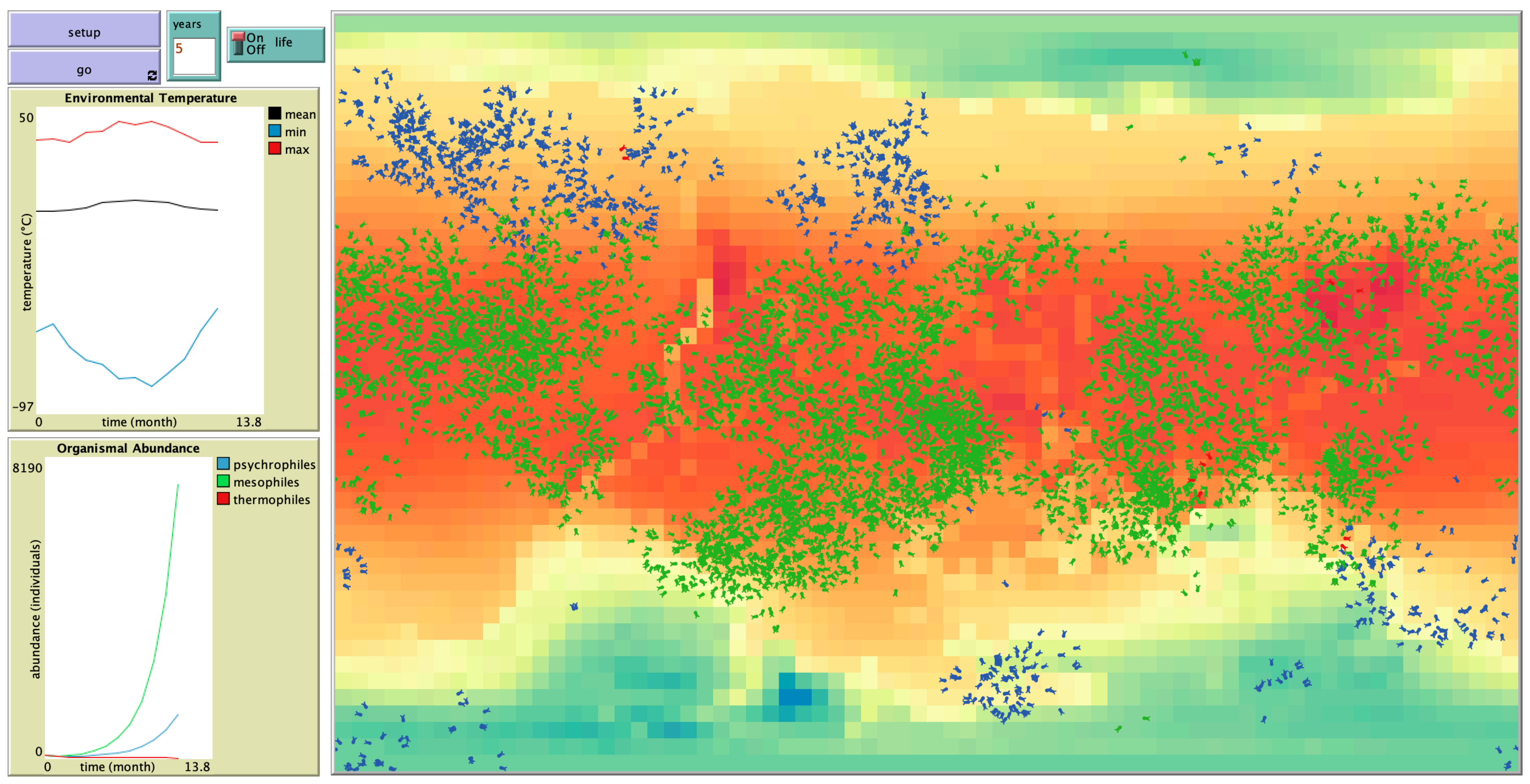



**Figure 3. An astro-ecology model to characterize physiology dependent exoplanet habitability.** In this agent-based model, individual organisms analyze and respond to their environmental temperature ($T_E$) based upon maximum and minimum thermal tolerances ($T_{max}$ and $T_{min}$) according to two rules: 1. If $T_{max} > T_E > T_{min}$, cell development proceeds and life is sustainable, and 2. If $T_E < T_{min}$ or $T_E > T_{max}$, cell development does not occur, and life is non-sustainable.

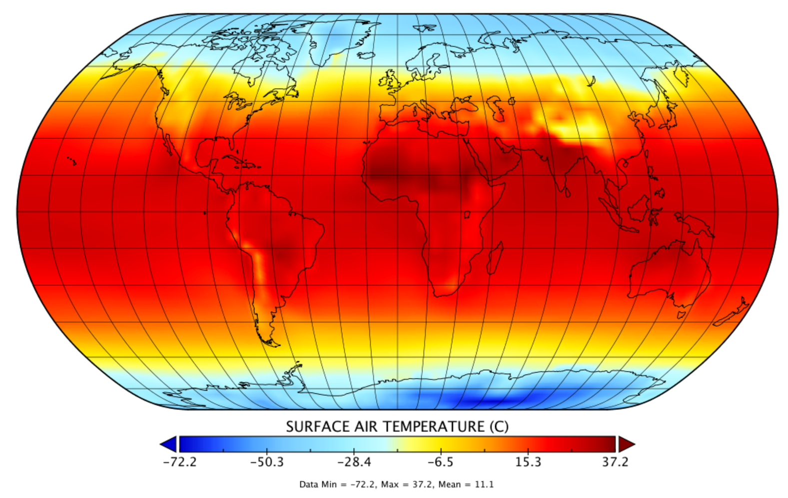



**Figure 4.** ROCKE-3D surface temperature profile for an Earth-like planet on a 0° obliquity orbit. [3]

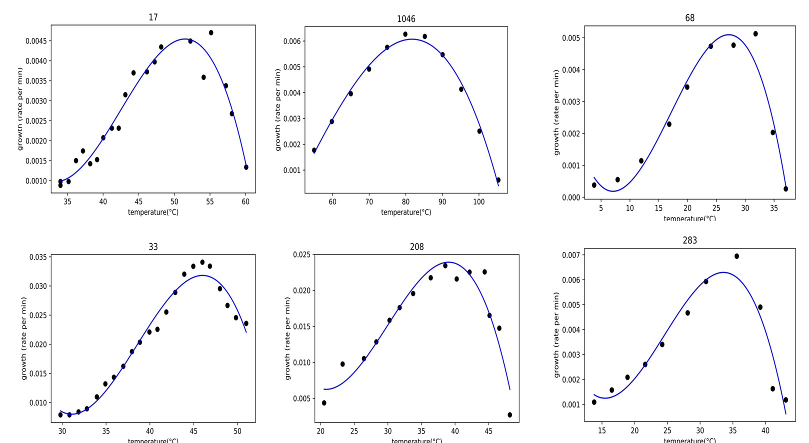


**Figure 4.** Individual thermal performance curves of growth rate drawn from the biokinetic spectrum for temperature. Plot title indicates species ID.

## Discussion

There exist thousands of known exoplanets, some of which are potentially habitable. Thousands more await to be discovered in the era of the *Transiting Exoplanet Survey Satellite*. The described project presents an integrative approach between exoplanet science and ecophysiology to explore the relationship between extraterrestrial environments and life as we know it.

The applied methodology will identify exoplanets with the highest probability of being habitable to life with Terran-based thermophysiological profiles. These planets will be recommended as high-priority targets for future survey missions (e.g. *James Webb Space Telescope*). Confirmed CHZ exoplanets found to be suitable for terrestrial organisms are termed habitable (concerning only temperature and liquid water). This analysis will also qualify known metabolic byproducts to identify potentially observable biosignatures in the search for life on probably habitable exoplanets.

### References

[1] Way M.J. et al. (2017) *ApJ*, 231, 12-34. [2] Corkrey R. et al. (2016) *Plos One*. [3] Way M.J. et al. (2018).