IS IT POSSIBLE TO NEGLECT THE EFFECTS OF LIFE WHEN CALCULATING THE BOUNDARIES OF HABITABILITY?

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In brief

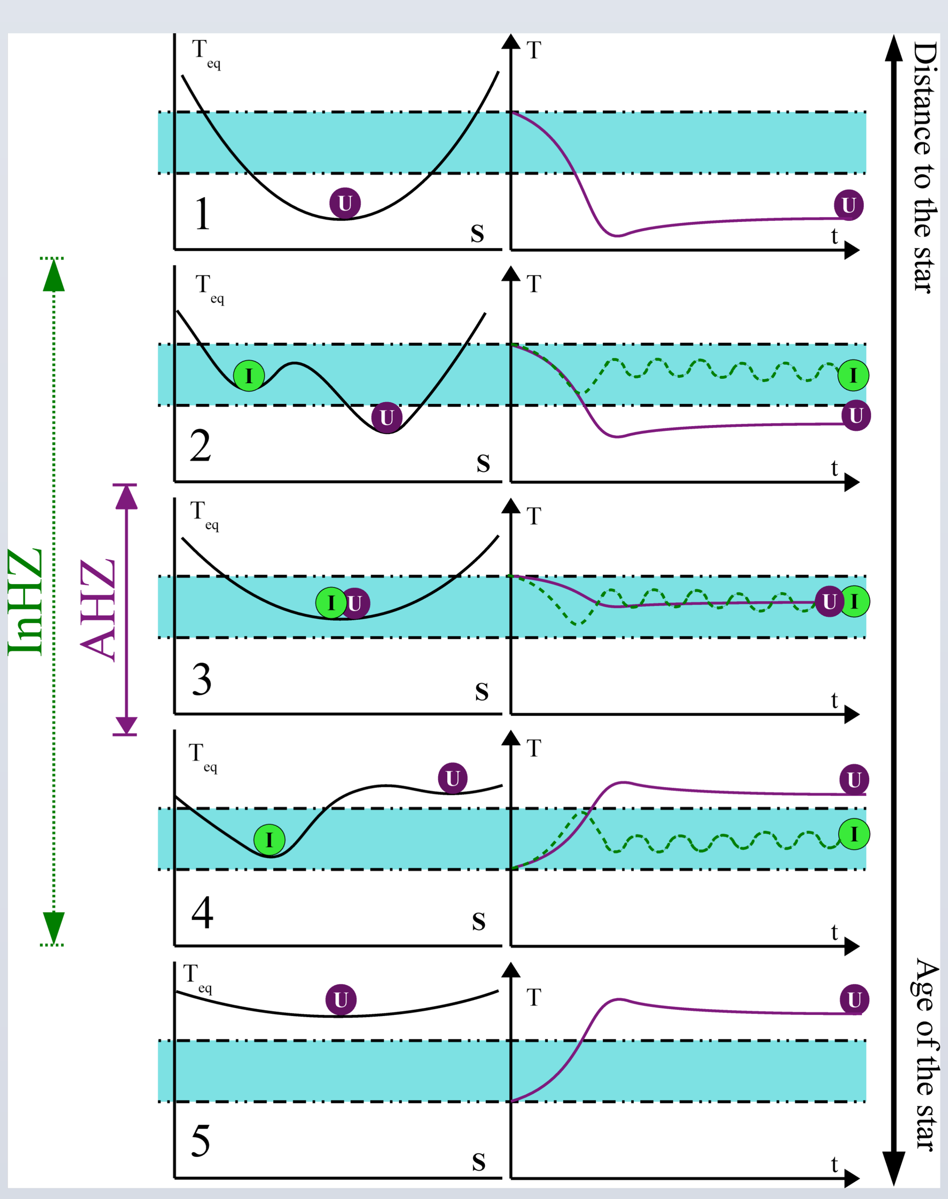
Habitability is traditionally defined as an abiotic prerequisite for life. But **life is a major environmental force**. While we better know our planet and the complex interaction between the biota and its environment, we are more convinced that **the Earth will be a different planet if uninhabited**. Habitability is actually an emergent property of a complex system involving the interaction of biotic and abiotic components. If our ultimate goal is to find inhabited planets **we should stop disregarding the effect of life when defining the boundaries of the habitable zone**. We develop here the hypothesis that life cannot be excluded when defining and calculating the physical boundaries of habitability. We test our hypothesis using numerical simulations of biota-environment interactions in hypothetical inhabited worlds. We compare the results of these simulations with those obtained for uninhabited planets. We find that **under general assumptions, inhabited planets may support habitable environments under a wider range of conditions**, as compared to similar planets lacking the power of biotic feedbacks. We present a planetary environment model (`Earth1.5`) able to incorporate the effect of a widespread biota when modeling the equilibrium states of an **Inhabited Habitable World**.

Bottom line

1. Biota-environment feedbacks are likely to (substantially) alter the environment of an inhabited planet.
2. The equilibrium state of a complex system cannot be predicted while neglecting one of its (major) components.
3. Living phenomena have (unique) properties able to drive the environment to (otherwise) unstable physical states.

Key properties of (any) biota as a major environmental force

1. **BIOTA FEEDBACKS**. Life alters the environment by taking and excreting energy and waste products giving rise to (powerful) feedbacks on the enviroment (Lenton, 1998).
2. **MULTIPLICATION**. Organisms (exponentially) multiply amplyfying biota feedbacks (Lenton, 1998).
3. **OPTIMUM**. There is a range for each environmental variable where organisms grows at a maximum rate. This gives rise to feedbacks around the optimum values of the environmental variables (Lenton, 1998).
4. **ENTROPY PRODUCTION**. Life tends maintain a steady state at which entropy production is maximized (Schrödinger 1992; Kleidon and Lorenz 2005).
5. **ORDERLINESS AND COMPETITION**. Orderliness in life (which is incomparably higher than that of the surrounding environment) is supported in a way unprecedented in the inanimate world: via competitive interaction (Gorshkov et al. 2004).
6. **FREE ENERGY**. Life (in particular photosynthetic organisms) generates substantial amounts of chemical free energy skipping limitations and inefficiencies with the transfer of power (Kleidon 2010).

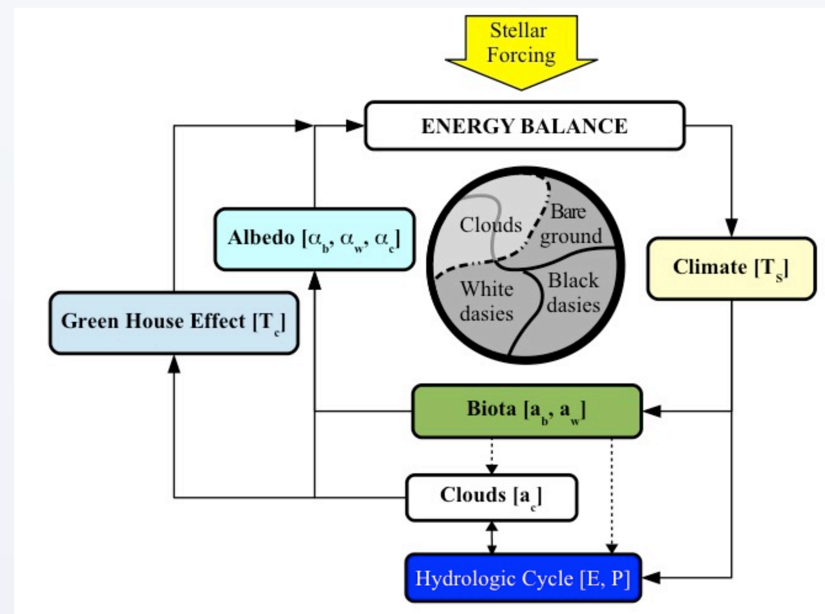


If life can alter the equilibrium state of a planet, the "landscape" of habitability could be modified leading to different boundaries for habitability

The Habitable Zone of Inhabited Planets (InHZ)

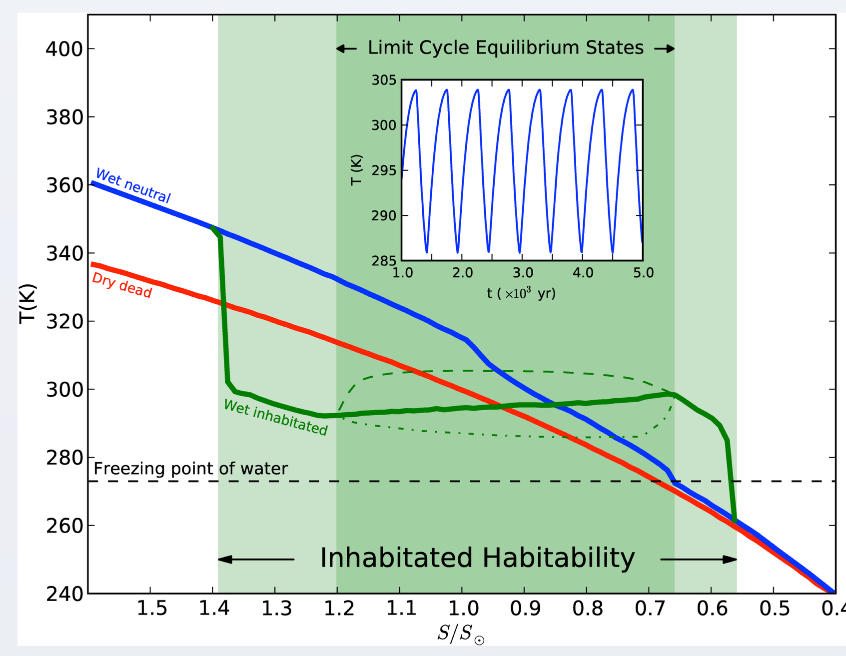
*The InHZ is the region (in space and time) where the complex interaction between life and its abiotic planetary environment is able to produce **plausible equilibrium states** with the necessary physical conditions for the existence and persistence of life itself.*

The "toy" model

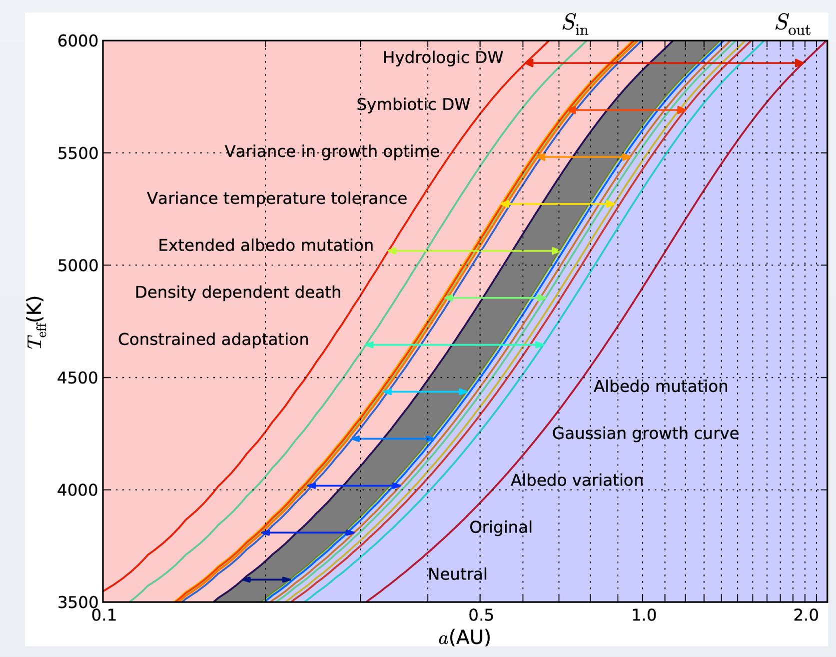


We have tested our hypothesis using a popular toy model, **the Daisworld (DW)**. We applied a variant of the DW that incorporates the key role of the Hydrological Cycle (Hydrologycal Daisyworld, HDW) (Salazar & Poveda, 2011).

In the HDW, an inhabited planet maintains habitable temperatures under a wider range of insolation conditions. Habitable equilibrium states are generally limit cycles rather than fixed points.



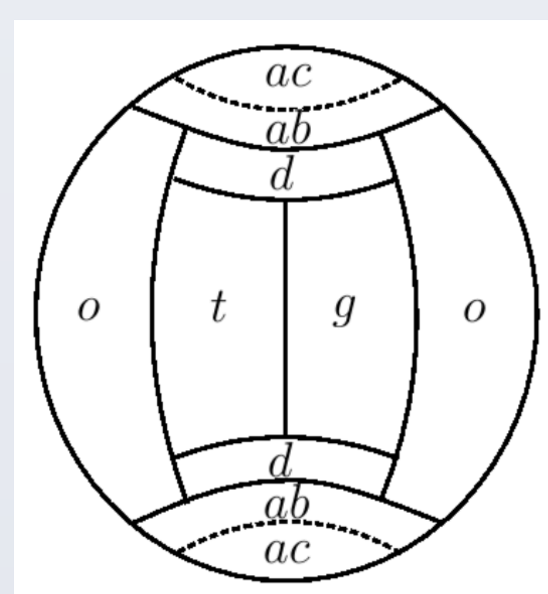
Global equilibrium temperature as a function of solar insolation in an inhabited HDW (green lines) and uninhabited planets (blue and red lines). The range of Habitable conditions (T = 273 - 300 K) in inhabited planets are extended to a wider range of insolations as compared to dead planets (Zuluaga et al. 2014)



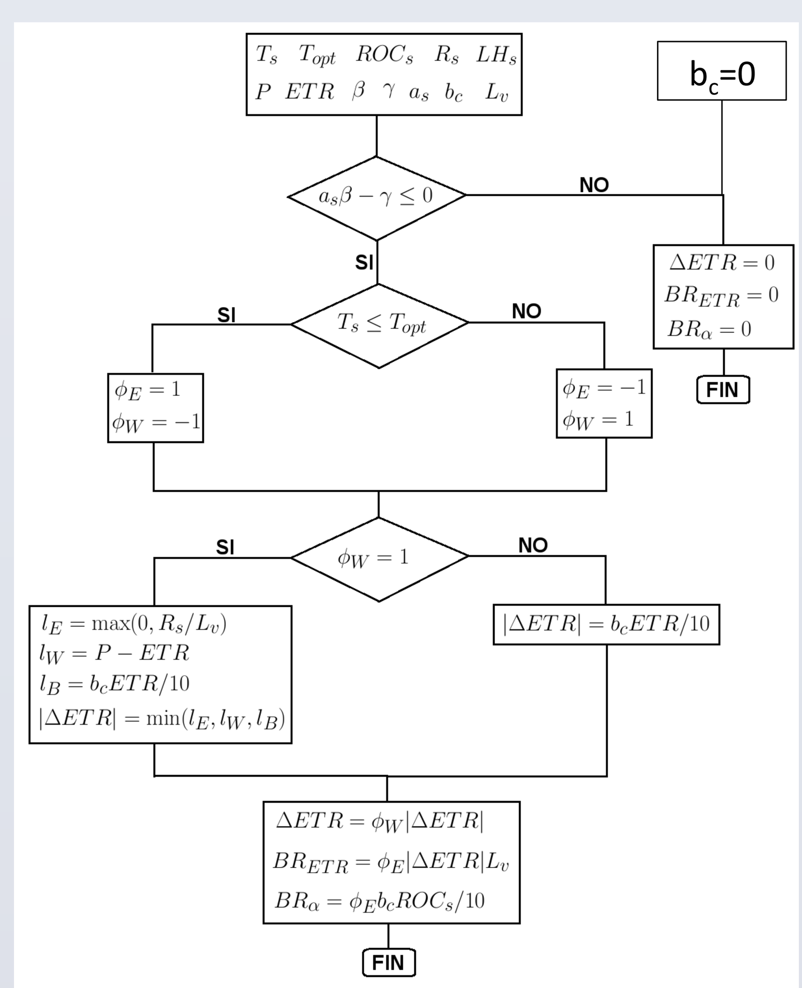
Boundaries of the Habitable Zone for Inhabited Planets (InHZ) as calculated using different DW variants including HDW (red line). In all cases the width of the InHZ is stretched in one direction or another with respect to the traditional abiotic HZ (Zuluaga et al. 2014)

`Earth 1.5`

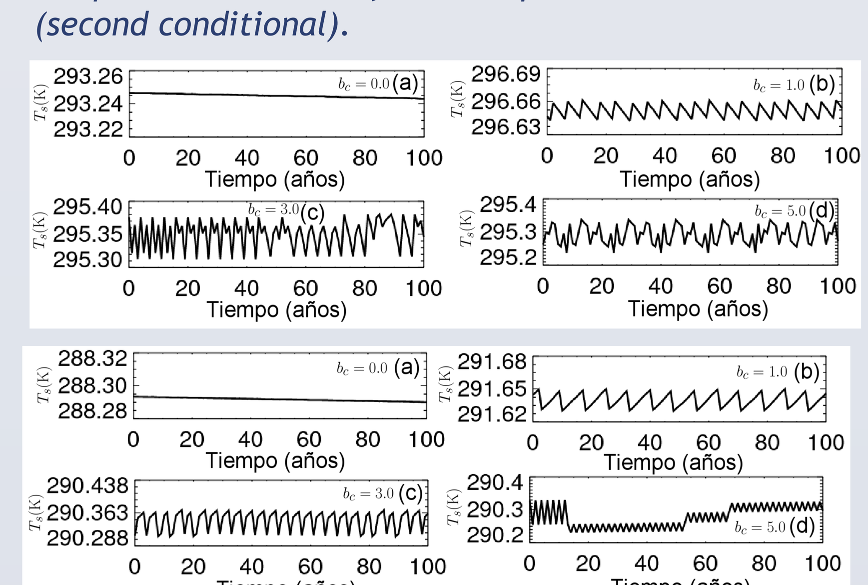
Download an alpha version at: `http://github.com/seap-udea/Earth1.5`



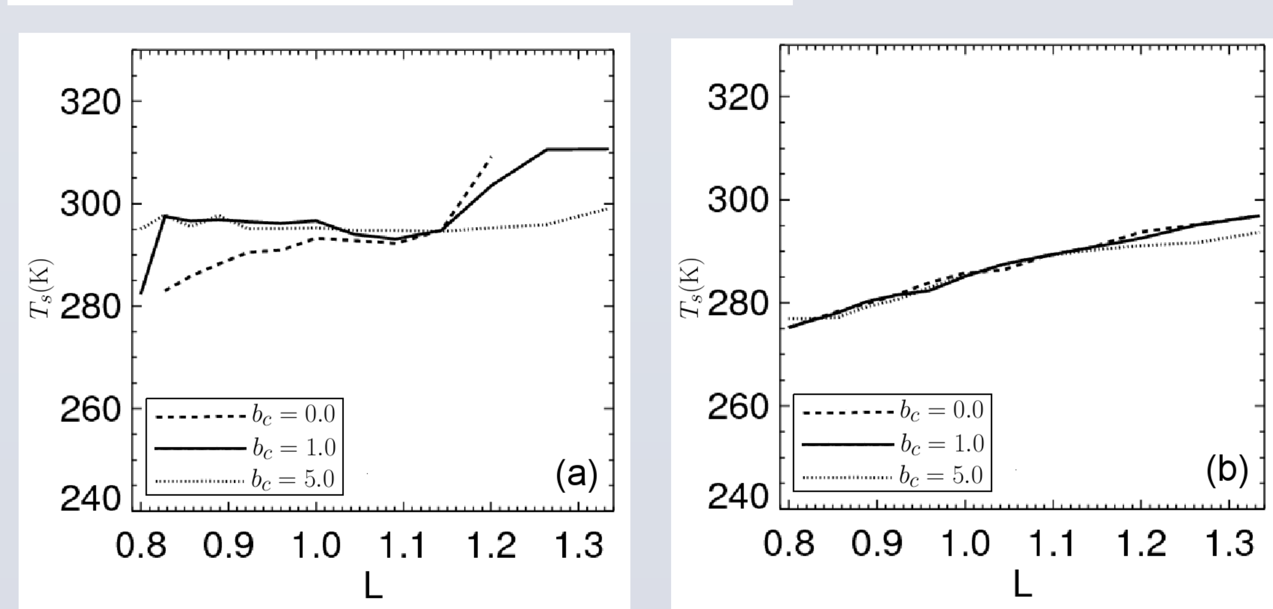
`Earth 1.5` is a simplified (albeit realistic) Global Environmental Model including two types o biota: forests (trees, t) and sabana-like areas (grass, g). The model implements the Dynamical Area Fraction formalism by Nordstrom et al. (2004). In contrast to a zero-dimensional model like DW, this model is "1.5"-dimensional: fluxes area calculated along the atmospheric column and partially along longitude and latitude.



The effect of life on Earth 1.5 is implemented using a "biotic regulation" algorithm that alters the evapotranspiration rate in response to environmental changes ONLY If: (1) the growth rate is negative (first conditional) and (2) surface temperature deviates from its optimum value (second conditional).



Surface temperature on the forest (up) and Sabana for the last centurry of a typical run of the model. The equilibrium state when biotic regulation (bc) is turned on is a limit cycle.



Interestingly, In contrast with the HDW result, life tends to regulate the local surface and atmospheric temperature (left) while having a minor effect on the global average temperature (right). This seems to imply that regions where life thrives are fresher than the uninhabited areas that ultimately determines the average. If the inhabitade areas where larger, local regulation may lead to global regulation

TO KNOW MORE

Salazar & Poveda, Tellus B (2009), doi: 10.1111/j.1600-0889.2008.00411.x

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