EVOLUTION OF THE GLOBAL TERRESTRIAL HABITABILITY DURING THE LAST CENTURY.
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Introduction: Climate change will have an impact on life on Earth [1]. The distribution, abundance and diversity of primary producers in land and ocean environments might be altered thus changing the biosphere's capacity to compensate for carbon emissions and recover from climate change. Estimates show that the primary productivity of terrestrial vegetation has increased in the last two decades [2]. The potential for life or our biosphere, its habitability, could be changing. However, there are no standard frameworks to quantify these habitability changes of our biosphere.

The main goal of this study is to evaluate the evolution of the global terrestrial habitability during the last century. Seasonal and annual habitability was calculated from the Quantitative Habitability Theory (QH Theory) [3]. Ground and satellite data was used to define a biophysical quantity, the Standard Primary Habitability (SPH), which describes the environmental requirements for primary productivity. The SPH was used to estimate the spatial and temporal variation of terrestrial habitability and primary productivity. A Planetary Habitability Classification (PHC) was constructed to characterize planetary habitable zones and establish a terrestrial-based standard for future comparisons with other planetary bodies including extrasolar planets.

The Standard Primary Habitability (SPH): The SPH is a climatology measure of the habitability of a region for most primary producers (i.e. plants) [4]. It is a normalized scale where values close to one represent environments with the best conditions for metabolic activity while values close to zero are unfavorable. The evaluation presented in this paper is limited to the simplest form of the SPH, one based on temperature and relative humidity alone, two variables that are easy to measure by ground or satellite observations. The SPH is defined as:

$$\mathrm{SPH} = H_T(T) \cdot H_{RH}(RH) \qquad (1)$$

where T is temperature, RH is relative humidity, H_T and H_{RH} are the thermal and relative humidity habitability, respectively. Both the H_T and H_{RH} functions are based of ecophysiology parameters that describe the environmental limits of the specific primary producer under consideration.

Net Primary Productivity (NPP) is related to the SPH a can be approximated as:

$$\mathrm{NPP} = \mathrm{NPP}_{\mathrm{max}} \cdot \mathrm{SPH} \qquad (2)$$

where $\mathrm{NPP}_{\mathrm{max}}$ is the maximum NPP allowable by the environment (carrying capacity). Eq. 2 was fitted to data from seven years monthly NPP (MODIS V5.1 MOD17A2 and MOD17A3), and temperature and relative humidity (CRU TS 3.0) to estimate the best parameters that describe the natural environment requirements of plants (Table 1). Many other variables contribute to the productivity of vegetation. The values calculated from Eq. 2 represent upper limits or a potential climate-driven productivity.

Table 1: Parameters of the Arecibo Model (Eq. 2). They include the general temperature and relative humidity productivity limits for most terrestrial vegetation and their potential maximum NPP.

Variable	min	opt	max
Temperature (°C)	-0.6	22.0	43.6
Relative Humidity (%)	0.0	> 93.1	—
NPP (gC/m^2/month)	—	—	90.3

The NPP derived from the SPH, or Arecibo Model, has some similarities with the Miami or Madison Models, which estimates NPP from mean annual temperature and precipitation [5]. However, the Arecibo Model can be used to estimate productivity at any temporal resolution and can be easily adapted to different vegetation types. The Arecibo Model was compared with other models and validated with ground NPP measurements (Fig. 1).

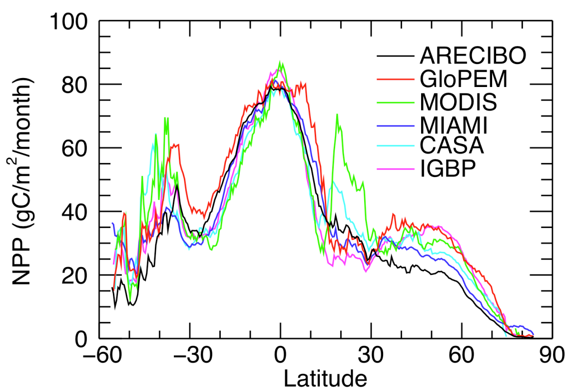

Figure 1: Latitudinal comparison of the Arecibo model with the GloPEM, MODIS, Miami, CASA, and the IGBP models. All models were also correlated with GPPDI NPP field measurements and the ARECIBO and MIAMI models are comparable (r = 0.8).

A Planetary Habitability Classification (PHC) was constructed based on the SPH values. The PHC has some correlation with other climate-driven classifications like the Köppen Climate Classification and Holdrigde Life Zones (Table 2). However, the PHC reflects the seasonal dynamic nature of the habitability of the environments (Fig. 2 to 4). It also can be used to classify entire planetary bodies based on their mean global habitability. The global evolution of the SPH was calculated for 105 years from CRU TS 3.0 data (Fig. 5). The data shows a generally increase in SPH with a relatively steady period between 1950 and 1990.

Table 2: Planetary Habitability Classification (PHC).

Zone	H	Vegetation Type	Name
A	> 0.8 — 1.0	Dense Vegetation	Amazonian
B	> 0.6 — 0.8	Mixed Vegetation	Serengetian
C	> 0.4 — 0.6	Shrublands	Mediterranean
D	> 0.2 — 0.4	Grasslands	Pampian
E	> 0.0 — 0.2	Sparsely Vegetated	Saharan
F	= 0.0	None	Dead

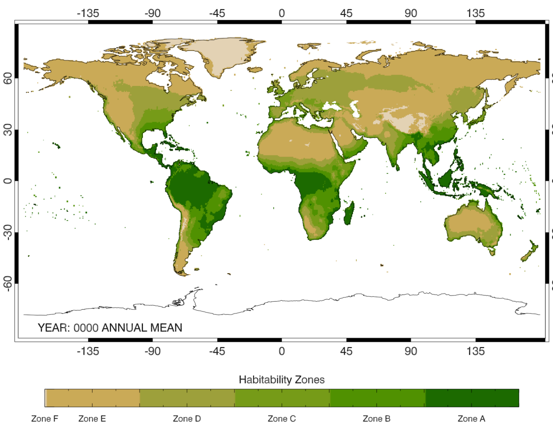

Figure 2: Mean global habitability map for vegetation. The diagram shows the regions that are more habitable for plants in scale from A (best) to F (worst). These are dynamic zones that correlate well with the actual seasonal distribution of vegetation.

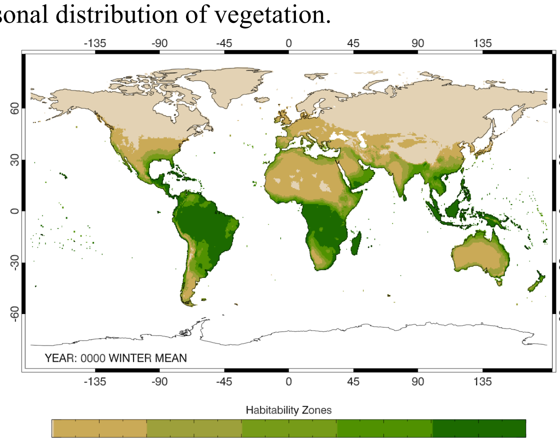

Figure 3: Habitability map for vegetation during northern winter (JAN-FEB-MAR). This is the least habitable season of our global biosphere (SPH = 0.31).

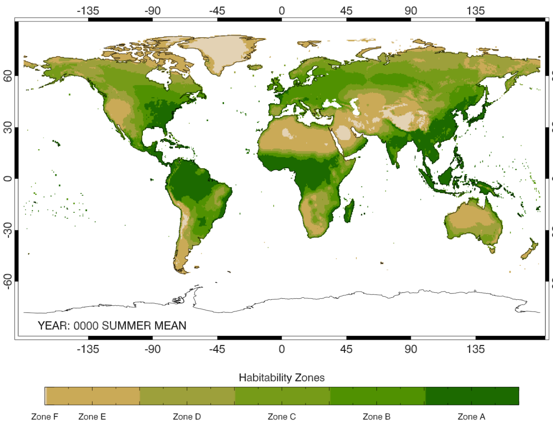

Figure 4: Habitability map for vegetation during northern summer (JUL-AUG-SEP). This is the most habitable season of our global biosphere (SPH = 0.50).

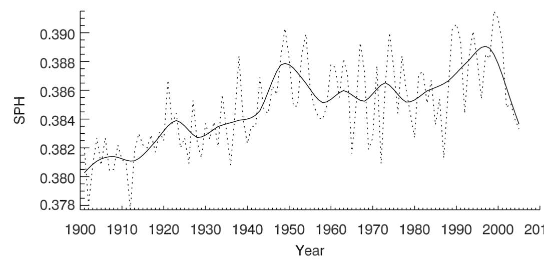

Figure 5: Mean annual global SPH from 1901 to 2005.

Conclusion: Terrestrial habitability has been generally increasing during the last century even long before the last decades of global warming. It represents a century change of 1.5 PgC and 0.5 PgC in the last two decades. Global variations of temperature and humidity account for only 15% of the increase of terrestrial productivity in the last two decades (3.4 PgC [2]).

The SPH is a practical biophysical quantity that can be extended to other variables like pCO2 and light. Habitability maps can be constructed for other groups including microbial life. For example, temperature and salinity can be used to calculate a SPH for oceanic phytoplankton. The current mean global terrestrial habitability is 0.39, which makes Earth a Class D planet. Current work is including Antarctica and the oceans in the SPH calculations.

References: [1] Allison, I., *et al.* (2009). The University of New South Wales Climate Change Research Centre (CCRC). [2] Nemani, *et al.* (2003). *Science*, **300**, 1560. [3] Méndez, A. (2009) Under Preparation. [4] Méndez, A. (2009) *LPSC XXXX*, Abstract #2333. [5] Zaks, D. P. M., *et al.* (2007). *Global Biogeochemical Cycles*, **21**, GB3004.

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