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Energy Balance Models of planetary climate as a tool for investigating the habitability of terrestrial planets and its evolution

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The study of the habitability and potential for life formation of terrestrial planets requires a considerable work of modelization owing to the limited amount of experimental constraints typical of this type of research. As an example, the paucity of experimental Archean data severely limits the study of the habitability of the primitive Earth at the epoch of the origin of life. In the case of exoplanets the amount of experimental information available is quite limited and the need for modelization strong.

Here we focus on the modelization of the surface planetary temperature, a key thermodynamical quantity used to define the habitability. Energy Balance Models (EBM) of planetary climate provide a simple way to calculate the temperature-latitude profile of terrestrial planets with a small amount of computing resources. Thanks to this fact EBMs offer an excellent tool to exploring a wide range of parameter space and therefore testing the effects of variations of physical/chemical quantities unconstrained by experimental data. In particular, one can easily probe possible scenarios of habitability at different stages of planetary evolution.

We have recently implemented one-dimensional EBMs featuring the possibility of probing variations of astronomical and geophysical parameters, such as stellar luminosity, orbital semi-major axis and eccentricity, obliquity of the planetary axis, planet rotational velocity, land/ocean surface fractions and thermal capacities, and latitudinal heat diffusion. After testing our models against results obtained in previous work (Williams & Kasting 1997, Icarus, 129, 254; Spiegel et al. 2008, ApJ, 681, 1609), we introduced a novel parametrization of the diffusion coefficient as a function of the stellar zenith distance. Our models have been validated using the mean temperature-latitude profiles of the present Earth and its seasonal variations; the global albedo has been used as an additional constraint.

In this work we present specific examples of application of our EBMs to studies of habitability of terrestrial planets. In the first part we focus on the primitive Earth, taking into account the effects of the higher speed of Earth rotation and reduced solar luminosity at the epoch of life formation. In the second part we provide examples of habitability studies of planetary systems discovered in surveys of exoplanets. These examples allow us to critically discuss the concept of circumstellar habitable zone.