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Global climate models and extreme habitability

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1. Introduction

As It not easy to define life and what is needed for it, drawing a line between "habitable" and "not-habitable" is difficult. We usually postulate that "habitable = liquid water available" because liquid water seems required for life as we can imagine it, and because life on Earth has proven to thrive as long as some liquid water is available. Within that context, finding habitable environments is a matter of obtaining the right pressure and temperature conditions at the surface or in the interior of planets, in presence of H_2O. Surface habitability is thus primarily a problem of climate.

To first order, a planetary climate primarily depends on 1) The incident stellar flux; 2) The tidal evolution of the planetary spin (which can notably lock a planet with a permanent night side), and, 3) last but not least, the atmospheric composition and the volatile inventory. Assuming that the atmosphere and the other parameters are known, we can try to explore the possible environments using numerical climate model

2. A new generation of 3D climate models

In the past 20 years, on the basis of the Global Climate Models (GCMs) originally developed for the Earth, it has been possible to develop GCMs for the other terrestrial environments in our solar system: Venus, Mars, Titan, Triton, Pluto. This experience has suggested that realistic 3D climate simulators can be developed by combining components like a “dynamical core”, a radiative transfer solver, a parametrisation of subgridscale turbulence and convection, a thermal ground model, and a volatile phase change code. On this basis, our team and others around the world have undertaken to build realistic "generic" climate models able to predict the environment on any terrestrial planets that we can imagine, with any given atmosphere, around any star etc.

3. Extreme surface habitability

Such 3D climate models have been used to explore a wide range of exotic cases, including the surprising configurations that have been revealed when detecting extrasolar planets. These studies have shown that liquid water may be present on a wide range of worlds, sometime very different than the Earth. The possible configurations are countless: planet around stars very different than our Sun ; planet completely covered by an ocean, or, on the opposite, arid planets able to keep liquid water only around their poles ; planet with very thick atmosphere enabling a strong greenhouse effect and possibly hot oceans; tidally locked planet with a permanent nigh side and a permanent day side, etc.

We will describe some of these cases, and show that, whatever the accuracy of the models, predicting the actual climate regime on a specific planet remains challenging because climate systems are affected by strong positive feedbacks. They can drive planets with very similar forcing and volatile inventory to completely different states. For instance the coupling between temperature, volatile phase changes and radiative properties results in instabilities such as runaway glaciations and runaway greenhouse effect. Furthermore, our imagination is probably too limited when we try to predict the possible atmosphere that may be present on exoplanets. The atmospheric composition and mass depends on complex processes, which are even more difficult to model than climate itself: origins of volatiles, atmospheric escape, geochemistry, photochemistry, etc. Our theoretical knowledge is insufficient and our solar system experience is too limited. For this, observations are needed.

Short Summary

The possible climates on exoplanets can be explored using 3D Global Climate Models analogous to the ones developed to simulate the Earth and the other planets in the solar system.Such 3D models have shown that liquid water may be present on a wide range of worlds, sometime very different than the Earth.