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The habitability of terrestrial exoplanets with a time-marching climate model : an educational tool.

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1. Introduction

Using a 1D version of the LMD Global Climate Model, we have developed a new educational tool (figure 1) which provides an accelerated simulation of the climate of terrestrial planets.

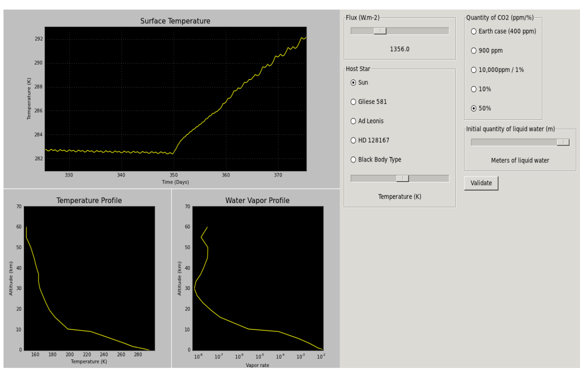

Figure 1 : Graphical User Interface of the 1D LMD GCM tool. It presents the evolution of the surface temperature and the instantaneous vertical profile of temperature and water vapor during a simulation which typically achieve 10 days per CPU seconds on a basic computer. Throughout the simulations, the star insolation (i.e. the distance from the star), the type of star, the amount of CO_2, ... can be modified.

This tool was designed for students to explore the "classical Habitable Zone", defined as the range of orbital distances within which a planet can maintain liquid water on its surface [1].

The inner edge of the Habitable Zone is the limit inside which runaway greenhouse occurs : For Earth-like planets with high stellar flux, surface liquid water tends to evaporate efficiently, releasing high amount of water vapor. This water vapor, which acts as a very strong greenhouse gas, leads to an increase of the surface temperature and thus to more evaporation.

The outer edge of the Habitable Zone is defined by a complete glaciation : For Earth-like planets with low stellar flux, at the limit where surface liquid water starts to freeze, ice forms and surface albedo increases. As a consequence, the amount of energy absorbed by the planet decreases, which reinforces the glaciation effect.

The 3D LMD GCM was previously used to reproduce these "runaway greenhouse" effect [2,3] and "runaway glaciation" effect [4,5,6].

To illustrate these concepts, we developed an educational – easy to use – 1D LMD GCM able to model these two limits and their dependencies with the type of star and the gas composition.

2. Description of the model

The GCM is designed for Earth-like atmospheres made of variable compositions of N_2/O_2/CO_2/H_2O and includes a radiative transfer (correlated k method), a water cycle and a multiple-layers soil model. Wavelength dependency of ice albedo was taken into account according to Joshi et al (2012) [7].

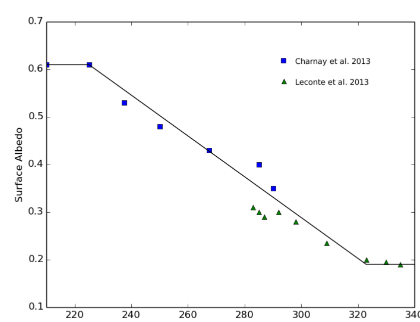

Figure 2 : Effective Surface albedo versus surface temperature. This empirical law was built according to a 3D parameterization of Earth atmosphere including the effects of clouds [2,6].

An empirical law between the global mean effective surface albedo and the global mean surface temperature (figure 2) was built from previous 3D LMD GCM simulations including the effects of clouds [2,6] and used as the surface albedo law for our 1D LMD GCM.

3. Use of the model

The user-friendly GCM tool we developed works with a Graphical User Interface shown on Figure 3. The code, mainly written in Fortran language, but wrapped in Python, is available on my webpage (http://www.lmd.jussieu.fr/~mturbet/). It only requires the GFortran compiler and the WX-python library.

Nonetheless, an online version of the tool will be soon available on http://www.esep.pro/.

4. Abilities of the model

The model faithfully reproduces the classical limits of the Habitable Zone, and their dependencies to the type of star/the gas composition. Furthermore, it provides an "hands on" experience by showing how the surface and atmospheric temperature as well as the profile of water vapor evolves through time when the external forcing (insolation, star spectrum) or the planet (quantity of CO_2, initial amount of water reservoir) is modified.

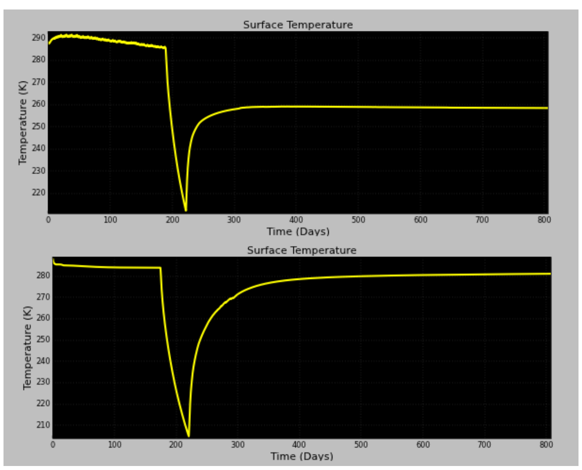

Figure 3 : Surface temperature versus time for a Sun-Earth system (top pannel) and a Mstar-Earth system (bottom pannel). At day 200, we cut the stellar flux. After 20 days, we put back the initial stellar flux.

Figure 3 shows for instance the ability of the model to deal with the runaway glaciation effect. Depending of the type of star, and thus the value of ice albedo, the Earth-like planet can/cannot be locked in a cold state.

The model is able to reproduce the runaway greenhouse effect beyond an insolation threshold of ~360 $W.m^{-2}$ in the case of the Sun-Earth system.

The GCM is also consistent with current Earth surface mean temperature.

Eventually, it would be easy to implement parameters like initial temperature pressure, excentricity/period of the orbit, mass/radius of the planet ... For these purposes, several versions of the tool will be available on my webpage.

The tool will be presented on demand during the poster session.

References

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