Incorporating the "runaway greenhouse" phenomenon of extremely warm climates into the climate model of the educational software SimClimat.

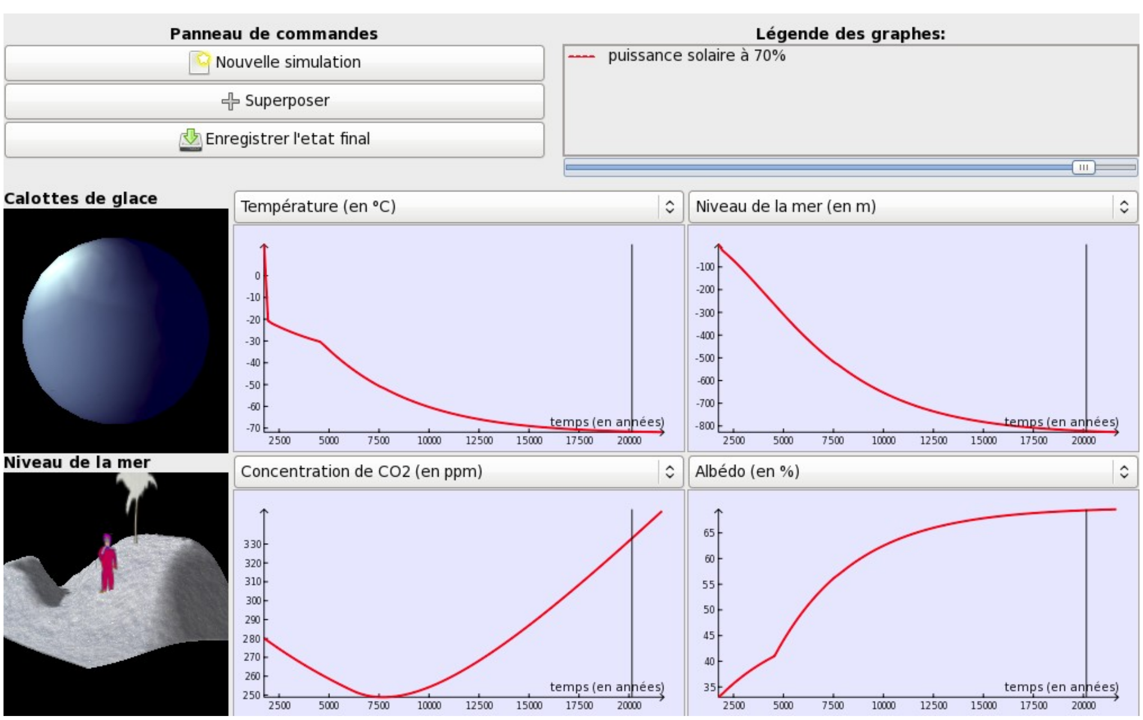
The other planets of the solar system have very different climates from ours: their atmospheres does not have the same composition, their surfaces are not of the same type, the temperature and pressure are different, etc. The earth climate also was very different from today a few million years ago, and will change again in the future.

For the study of these extreme climates and other planets climates, computer models adapted from earth climate models are generally used.

The internship is based on the highly simplified climate model from the educational software SimClimat. This software is usually used to study a given range of earth climates, from extremely cold ("snowball" Earth) to current climate and hot climates. But it is not able to simulate an extremely hot climate in a realistic way.

For this internship, we will focus on the "runaway greenhouse" effect: this phenomenon appears when the temperature reaches a value around 1000°C, and describes the behavior of a planet emission to space at this temperature. The mechanisms at stake are very different from the ones currently leading our climate; this explains why the model equations must be adapted in order to simulate this phenomenon.

The main objective is that after this internship we could use the SimClimat software for planetology classes. Besides, in addition to the runaway greenhouse linked theory, the student will discover some aspects of climate modeling, especially of developing a model designed for an educational purpose. This implies to think about: (1) how to turn complex mechanisms into simple equations keeping a physical meaning, (2) why a given model works well only in a limited range of temperatures and how to remedy it, (3) how to guide the approach according to the model purpose (understanding, or reproducing).



Supplementary notes for the supervisor

Reference papers:

Kasting, J. F., 1988: Runaway and Moist Greenhouse Atmospheres and the Evolution of Earth and Venus. *ICARUS*, 74, 472-494, doi: 10.1016/0019-1035(88)90116-9.

Pierrehumbert, R. T., 2010: *Principles of Planetary Climate*. Cambridge University Press.

Main concept to be explained to the student: the runaway greenhouse effect

(A) The temperature rises: more and more longwave radiation is emitted from the surface and the atmosphere.

(B) All the longwave radiation emitted from the surface is absorbed by the atmosphere. The atmosphere keeps on warming but it also thickens; both effects compensate so that the outgoing longwave radiation (F_{IR}) is stable.

(C) The planet is so hot that it emits within near-visible wavelengths, which the atmospheric water vapor does not absorb. Consequently the outgoing longwave radiation can increase again.

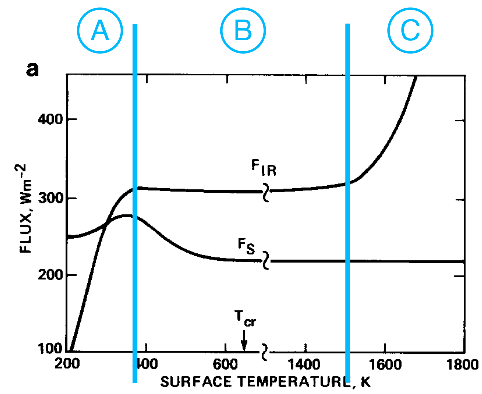


FIG. 7. Radiation fluxes and their derived functions versus temperature at the Earth's surface: (a) Net outgoing infrared flux FIR and net incident solar flux Fs.

Kasting 1988

The runaway greenhouse in SimClimat at the current state:

Related equations (see the model documentation for explanations (in french): http://www.lmd.jussieu.fr/~crlmd/simclimat/logiciel_documentation.pdf):

Radiative Budget: $1-\alpha F_{TOA}^{in} = 1-G\sigma T^4$

with G the greenhouse effect: $G = G_0 + G_{H2O} + G_{CO2}$

with $G_{H2O} = -Q.G_0(1-R_{H2O}(t)p)$, where $R_{H2O} = psat(T)psat(T_{ref})$

and $G_{CO2} = 1.8 \bullet 10^{-2} \ln(CO_2(t)CO_{2ref})$

The model thus does not simulate the runaway greenhouse. Indeed, these equations are adapted for a current range of temperatures; they do not represent the fact that the planet does not emit far-infrared at high temperatures but near-visible radiation, neither that there is a limited quantity of water on Earth.

However, there is an important equation in the model which is not mentioned in the documentation and which gives a limit to the greenhouse effect due to water vapor:

for $R_{H2O} > 10^{-5}$, G_{H2O} is actually given by $G_{H2O} = -Q.G_0(1-R_{H2O}(t)p)(0.3e^{-R_{H2O}-1110}+0.7)$

Consequently, the model behaves as follows. For example if a 10,000 years simulation is launched with "the world in 2007" as the initial state, the temperature first increases till reaching 50-60 °C after 5,000 years. From this point, it rises very abruptly to reach 2,250 °C within 1,000 years only. After this abrupt transition, the system is in an equilibrium state at 2,250 °C.

This behavior is due to the water vapor greenhouse effect, and the goal of the internship is to make it more realistic and to give it more physical meaning.

Table of correspondences between the variables names in the documentation and in the code:

Documentation	Code
p	*pow_H2O*
GH2O ou GH2Oserre	*forcage_serre_H2O*
Q	*q_H2O*
$(1-G_0)$	*G0*
$-Q.G_0$	*a_H2O*

Approximate stages of the internship:

- Introducing the software, and the theoretical concepts (see previous section).
- Introducing the related equations of the SimClimat model (see the previous section).
- The study in itself. The goal will be to turn the runaway greenhouse complex mechanisms into simple equations still keeping a physical meaning. As mentioned in the subject description, this also implies a reflection on the following points:
    - Understanding why our model works well only in a limited range of temperatures (to find out how to remedy it). An idea could be to draw the analytic equations of the model and test them with arbitrary limits.
    - Guiding the approach according to the model purpose, which is in our case educational. Then, we will try to reproduce the runaway greenhouse rather than to use its exact physical equations.

In order to find good limits and approximation, the student could estimate the whole quantity of water vapor - and possibly CO_2 - available on Earth.