Modeling the evolution of climates over long period: the Planetary Evolution Model

R. Vandemeulebrouck, F.Forget, L.Lange, E.Millour, A.Spiga, A.Bierjon, A.Delavois, J.Naar, *Laboratoire de Météorologie Dynamique, Institut Pierre-Simon Laplace (LMD/IPSL), Sorbonne Université, Centre National de la Recherche Scientifique (CNRS), École Polytechnique, École Normale Supérieure (ENS), Paris, France romain.vandemeulebrouck@lmd.ipsl.fr.*

Introduction:

Studies show that the variation of orbital parameters can deeply impact the climate [Hays et al., 1976]. On Earth, small variations of ±1.3° of obliquity are responsible for ice ages [Imbrie and Imbrie, 1979]. Laskar et al. [2004] indicate that the obliquity of Mars can vary between 0° and 60°, this suggests that huge climatic variations could have happen on Mars in the last Myr.

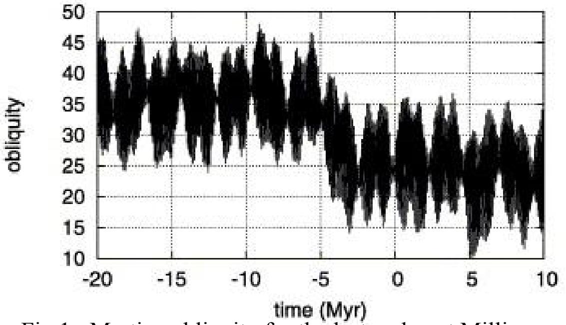


Fig.1 : Martian obliquity for the last and next Millions of years (Laskar et al. [2004])

The usual tool to model and study Mars climate is a Global Circulation Model (GCM here the LMDZ). It is able to adequately simulate a vast impact of phenomenon with a good precision. However, the drawback of this accuracy is that it requires a relatively long computing time. For a low resolution simulation of a martian year it can take up to 2 hours. Therefore it is impossible to study the long timescale variation of orbital parameters (order of magnitude Myr). The new and innovative way to couple physical processes with very different timescale (cloud microphysics, atmospheric dynamics, evolution of glacier accumulation, atmospheric collapse) is a new "asynchronous-coupling" model called **Planetary Evolution model (PEM)**

Philosophy of the PEM:

The idea of the PEM is to take as input different tendencies from the GCM and extrapolate them. It would be able to simulate long variation and should not consider subyear on interannual variability. There is two possibility of use of the PEM :

- Find a steady state for a given external forcing (example : perineal ice reservoir at a given obliquity)
- Realistic simulation of climate and fate of volatiles for thousands of years

Concretely, the GCM is used as a subroutine of the PEM. The GCM is called for two martian years (only one year is also tested for validation), it simulates Mars precisely using a vast variety of physical processes. From these two years, different information can be extracted at a given frequency; such as sublimation and condensation of water and CO_2 ice, precipitation, volume mixing ratio of the atmosphere component etc… Given these informations we are able to compute tendencies. These tendencies can be applied to the output state of the GCM. Once we have applied them, we use this new state as the initial state of the GCM and continue like this for as long as necessary.

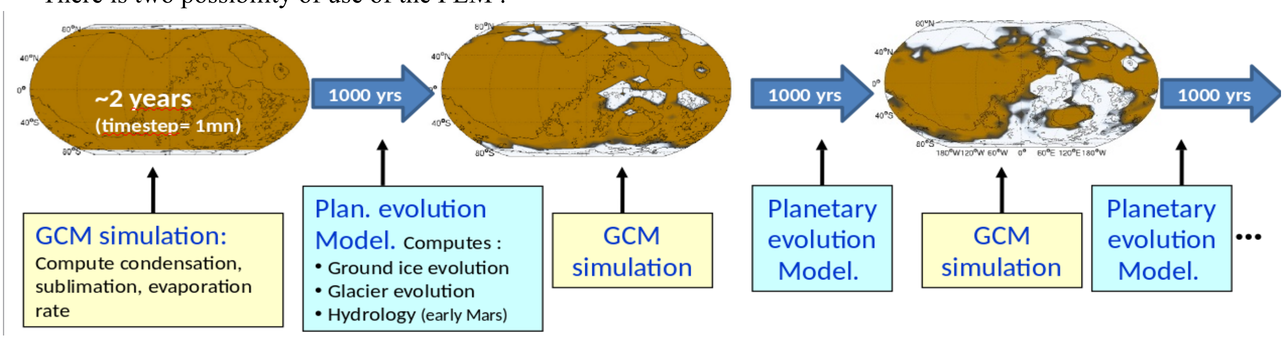
To illustrate, we present the first two kinds of processes that have been implemented : the evolution of water and CO_2 ice.

We are only interested in perennial ice. For each point we compute the minimum of ice over each year; the difference gives the tendency. One has to carefully take into account the change of mass of the atmosphere as the martian atmosphere is mainly composed of CO2. This change of pressure is taken back into account as a feedback on the tendency as the condensing temperature depends on the pressure and volume mixing ratio. We also assume the relative humidity to be constant.

The extrapolation of the tendency is valid until the climate has changed too much. We created a stopping criterion that is supposed to characterize the amplitude of the change of climate. This stopping criterion depends on the surface of ice sublimating that disappeared and the global average pressure, it can be adapted.

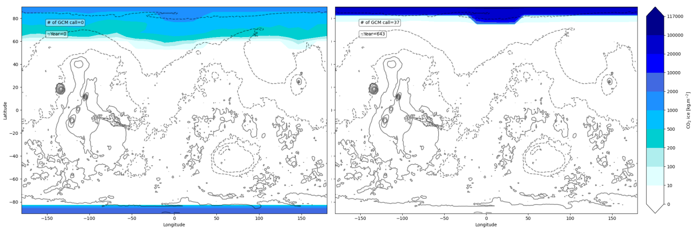
This configuration has been validated by some experiments.

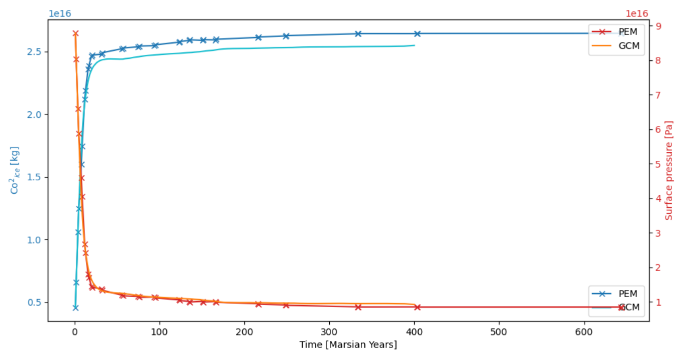
Fig.2 Schematic view of the PEM



Validation:

A run at 5° obliquity has been performed, the opacity of the atmosphere is fixed, and we only consider two tracers in the atmosphere: one called *CO2* and the other one called *noCO2*. Water is not modeled here. We assume that the CO2 ice thickness can not exceed 10 m on slopes, and must flow if this thickness is reached. Values of albedo, emissivity for CO2 and H2O ices, as well as ice tables are set to the current values used in the LMD GCM. The resolution is 3.75° latitude, 5.625° longitude. The PEM is compared to the GCM.



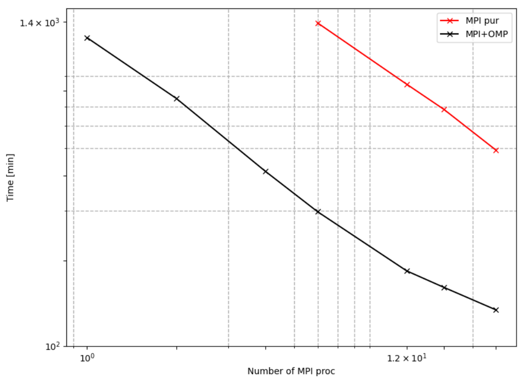


First we can conclude that the PEM behaves as expected and follows the GCM run very nicely. It often calls the GCM in the first moment of the simulation as expected since this is the time where the climate changes the most and the most rapidly. Then, it does longer time steps and extrapolates tendencies for longer which will be very useful to do longer run.

Secondly we see that the evolution seems realistic as the atmosphere condens as co2 ice. The ice is mainly present near the North pole as it should theoretically be at 5° of obliquity.

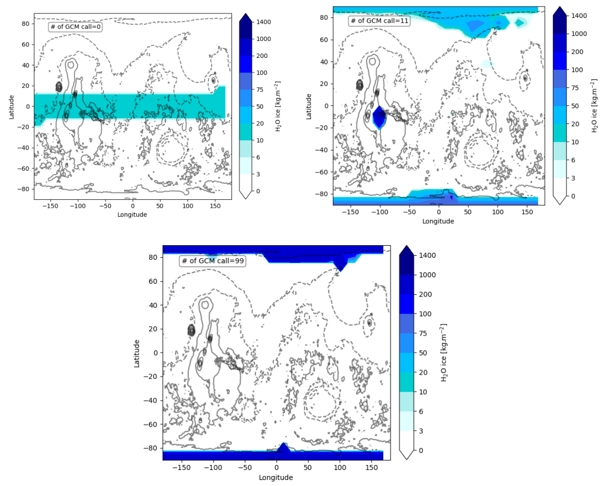
Computing time acceleration:

Another possible way to accelerate the running time is to accelerate the time needed to run the GCM. This has been achieved by using mix MPI-OMP parallelism. Results and performance can be seen in Fig. 4



Preliminary applications to the study of ice evolution:

Another work has been performed most focused on H2o ice. We start from an aritrary initial state : all the water ice form a patch around the equator. We take present day Mars configuration and let the PEM run. We expect to see the ice progressively move to the present ice patch that we observe on Mars. This is exactly what happen and first the ice increase along Tharsis before moving to the poles.



Ongoing work and perspective:

Next part of the work will be to implement a subslope parametrisation in order to accurately simulate glaciers flow and all the physical processes taking place on slope such as the different radiative transfer according to the North-South orientation of the slope.

Then it will also be possible to simulate a variation of orbital parameters such as a descent of obliquity.

Reference:

Hays, J. D., Imbrie, J., and Shackleton, N. J. (1976). Variations in the earth's orbit: Pacemaker of the ice ages. Science, 194(4270):1121–1132.

Imbrie, J. Z. and Imbrie, K. P. (1979). Ice ages: Solving the mystery

Forget, F., Hourdin, F., Fournier, R., Hourdin, C., Talagrand, O., Collins, M., Lewis, S. R., Read, P. L., and Huot, J.-P. (1999). Improved general circulation models of the Martian atmosphere from the surface to above 80 km. , 104(E10):24155–24176.

Laskar, J., Correia, A., Gastineau, M., Joutel, F., Levrard, B., and Robutel, P. (2004). Long term evolution and chaotic diffusion of the insolation quantities of mars. Icarus, 170(2):343–364.

Acknowledgement :

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 835275).