The Challenge of Modelling the Recent Evolution of the Martian Environment at other Obliquities and Orbits

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For more than 20 years, numerical Global Climate Models (GCM) adapted to the present-day Mars have been used to explore the possible environments when Mars's obliquity or orbit varied throughout the Amazonian. These studies, conducted notably by our team at LMD, have mostly made the "thought experiment" of taking the Martian Climate System as it is today, but with a different obliquity, eccentricity and/or season of perihelion. However, we now understand that all these results were incomplete and often erroneous for two reasons:

1) Firstly, the models did not simulate well all the physical processes at work when the change in the insolation parameters induced different climate. For instance, the radiative effects of clouds and water vapor, the role of latent heat and snow albedo have often been neglected or oversimplified (as often done on present-day Mars). This is found to be incorrect because at high obliquity there is significantly more water injected into the climate system than there is today. As a result, the radiative effect of clouds is considerable, which affects the temperature and the ice deposition. Conversely, at low obliquity CO_2 can condense in massive glaciers but modelling such glacier and the behavior of such a CO_2-depleted atmosphere requires to develop specific modelling tools.

2) Secondly, as traditional global climate models simulations are limited to durations of few decades, they have often used the present-day or artificially prescribed locations of volatile reservoirs such as CO_2 or H_2O glaciers, or subsurface reservoirs. In reality, water tends to accumulate in specific places like cold-traps. Very unrealistic results are obtained with prescribed reservoirs. **volatile surface and subsurface reservoirs must be modeled, not prescribed.** Moreover, calculating where the water (e.g., glacier, lakes) and CO_2 ice reservoir reach a stable equilibrium is not sufficient to understand the geological records. It is the destabilization of the volatile reservoirs that induces activity. For instance, the growth of the northern polar layered deposits is the consequence of such a destabilization in glaciers induced by the changes in obliquity and orbit.

New models.

Within the context of the *Mars Through Time* project, supported by the European Research Council, we have been aiming at developing new numerical models to simulate the past environments of Mars.

A completely new "***Mars Evolution Model***" (see *Clement et al.*, this issue) has been created by asynchronously coupling glacial accumulation (for H_2O and CO_2 ice) and ground ice models with a new generation 3D Planetary Climate Model (PCM). It allows to simulate the evolution of the Martian Surface and the formation of all kinds of layered deposits and erosional features over up to several million years

The updated 3D **Mars Planetary Climate Model** PCM (formally known as the LMD Mars Global Climate Model) is derived from the one that we have previously designed to simulate present day Mars, but we are improving it to represent the details of the surface as well as all the processes that affected Mars when its environment evolved because of the oscillations of its orbit and obliquity (atmospheric collapse in CO_2 glaciers at low obliquity, intense water cycle with thick clouds at high obliquity, etc.) The present-day Mars model now includes a representation of the microclimates that can occur on local slopes and their effect on the thermodynamics of ices on the surface and in the subsurface. We are also building a new model of the dust cyle (*Pierron et al.* this issue) with the objectives of independently simulating realistic dust lifting, transport and sedimentation. Such a model will allow to explore the nature of the dust cycles in the past.

These new tools address numerous enigmas found in Mars sciences. They also offer a new platform to study specific processes such as the atmospheric escape and aeronomy through time (*Luo et al.*, this issue) or the chemical alteration of the soil. Furthermore, the project tests our capacity to model planetary environments and climate changes, as well as provide lessons on the evolution of terrestrial planets and the possibility of life elsewhere.

At the conference, We will focus on the challenge that we face in this ambitious exploration of the recent Mars Climates, and present selected recent results obtained with our suite of models.

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