CHALLENGES IN MARS CLIMATE MODELLING WITH THE LMD MARS GLOBAL CLIMATE MODEL, NOW CALLED THE MARS "PLANETARY CLIMATE MODEL" (PCM)

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Introduction:

The Mars atmosphere Global Climate Model (GCM) developed at the Laboratoire de Météorologie Dynamique [1] in collaboration with several teams around the world (LATMOS, the Instituto de Astrofisica de Andalucia, UAE University, University of Oxford, The Open University), and with the support of ESA and CNES is currently used for many kinds of applications. It simulates Mars from the subsurface to the top of the thermosphere and includes the cycles of dust, water and CO_2 that control the current Martian climate as well as a photochemical/ionospheric module.

The aim of this modeling is high: ultimately to build a numerical simulator based only on universal equations, yet able to consistently reproduce available observations. The goal is to create a realistic virtual planet on which all observed phenomena and climate-induced geological landforms arise naturally. Like for the other similar models in the community, this specific goal is a scientific endeavour by itself.

Such a GCM can also provide useful environmental predictions that can be used to process observations or prepare space missions. For this purpose our teams have produced the ***Mars Climate Database*** (See *Millour et al.*, this issue) which provides climatologies derived from GCM simulations completed by dedicated tools. The GCM is also used to perform meteorological data assimilation to create an optimal description of the Martian environment obtained by combining observation and model simulations (See e.g. *Young et al.*, *Read et al.*, *Holmes et al.*, this issue).

A new name: The Mars PCM

The different planetary version of the LMD GCM (for Mars, Venus, Titan, Pluto, Triton, giant planets, and a "generic" version for exoplanets and primitive atmospheres) are more and more used and co-developed by other teams around the world. Within that context, we wish to use new model names and specifically a new naming convention to designate the LMD GCM. We now (very simply) call it the "**Planetary Climate Model (PCM)**", preceded by the name of the planet and -if needed- followed by the name of the dynamical core used to solve the fluid dynamical equations to compute the atmospheric circulation and transport. For instance : the "*Mars PCM-Dynamico*"

In the case of our Mars PCM, 4 different dynamical cores are available (all using the same kind of physical parameterizations to model radiative transfers, surface and subsurface physic, clouds, dust, subgrid-scale dynamical processes, chemistry, etc…):

- **LMDZ**: the baseline latitude-longitude grid "dynamical core", notably used to produce the Mars Climate Database version 5 and 6 (See *Millour et al.*, this issue).
- **UK-spectral** : a spectral dynamical core (originally developed at the University of Reading [2] and adapted to Mars at the University of Oxford and the Open University) combined with a semi-Lagrangian advection scheme (e.g. *Holmes et al.*, *Read et al.* this issue).
- **Dynamico**: a new, state of the art energy-conserving finite differences model on a quasi-uniform icosahedral-hexagonal grid (developed at LMD and IPSL [3]). The hexagonal mesh is much more uniform than the regular latitude-longitude grids adopted in our previous Global Climate Models and avoids the pole singularity problem.
- **WRF**. The dynamical core of the Weather Research and Forecasting (WRF [4]) Model is used in combination with the Mars PCM physic to create a meso-scale and micro-scale/Large Eddy Simulation (LES) model [5].

Current challenges.

In this talk, we will present the major challenges and remaining enigmas that we currently face when modeling the Martian climate. In the lower atmosphere, key challenges are

- **Dust cycle.** Even in the version where dust lifting is driven by the observed climatology, it is not easy to predict a 4D dust distribution that matches the available observations, and in particular the Mars Climate Sounder observations. Creating the detached dust layers observed throughout the year remains a challenge, in spite of our effort to parametrize the effect of "Rocket dust sorms" and "Mountain top flows" (See *Bierjon et al.*, this issue). It is notably difficult to create detached dust layers at the observed altitudes.

- **Mean temperatures.** When the dust vertical extension seems to match the MCS observations, the mean atmospheric temperatures appear to be overestimated when compared to observations. Even after paying a particular attention to the dust optical properties at various wavelengths, this discrepancy is not easy to solve. It is possible that we are missing a physical process, or that we do not understand well the observations. The modeled variations of mean temperature with latitude, altitude and season can be significantly improved when taking into account and tuning the effect of gravity waves (See *Liu et al.*, this issue).

- **Thermal tides.** The phase of the modeled thermal tides seem systematically slightly different than what is observed by MCS, TGO/ACS/TIRVIM and EMM/EMIRS (see *Fan et al.*, this issue), probably for a fundamental reason that we have not yet identified. The amplitude and the phases of the tides is nevertheless improved when taking into account and tuning the effect of gravity waves (*Liu et al.*, this issue).

- **Water cycle and clouds.** In the past years we have conducted many studies to improve our modeling of the water cycle. It is found to be sensitive to complex couplings between microphysics, radiative transfer (heating and cooling of the ice particles and their radiative effect), mixing by the convective and turbulent motions, gravitational sedimentation, and scavenging by CO_2 ice condensation in the polar night. These coupling result in a significant sensitivity to the GCM physical timestep. By exploring the sensitivity of the modeled water cycle to some of the poorly known parameters that control this cycle, we can set the model to simulate a realistic water/cloud cycle. However it remains very sensitive to model parameters (positive feedbacks) and in particular it is difficult to simulate realistic water vapour columns at low and mid latitudes without predicting a northern summer pole water vapour column higher that observed (i.e. 70-80 pr-µm instead of ~50 pr-µm.

Modelling Mars Through Time.

The Mars PCM is also used to explore the possible climate on Mars in the past, in particular when the obliquity was different (see *Lange et al., Vos et al., Aharonson et al.* this issue). These developments are notably achieved with the support of the European Research Council (ERC) within the context of advanced grant project "*Mars Through Time*" [5]

For this purpose, we have included several improvements in the PCM, and in particular a new parametrizations to model micro-climates on subgrid scale slopes (*Lange et al.* this issue). This allows us to better understand the formation of glaciers (H_2O and CO_2) and subsurface ice deposits on possible slopes anywhere on past or current Mars.

In addition, to simulate where the different volatile reservoirs stabilize and how they evolve over tens of thousands of years as the orbital and spin parameters evolve, we are developing a new kind of model, the Mars **Planetary Evolution Model** (**PEM**) (See *Vandemeulebrouck et al.*, this issue). It calls the much slower Planetary Climate Model (PCM) regularly to update the local condensation and sublimation rates as well as the surface temperatures, and use this information to extrapolate the evolution of glaciers, sub-surface ice, etc. Ultimately, this will allow us to realistically simulate the environment on Mars at low and high obliquity, and the formation of periglacial landforms such as the Northern Polar Layered deposits.

References

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