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Understanding Mars meteorology using a “new generation” Mars Global Climate Model.

F. Forget (1), J-B. Madeleine (1), E. Millour (1), A. Colaitis (1), A. Spiga (1), L. Montabone (1), J-Y Chaufray (1), F. Lefèvre (2), F. Montmessin (2), Anni Määttänen (2), F. Gonzalez-Galindo (3), M.-A. Lopez-Valverde (3)

(1) Laboratoire de Météorologie Dynamique (LMD°, IPSL, Paris, France (forget@lmd.jussieu.fr),
(2) Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), IPSL, Paris, France
(3) Instituto de Astrofísica de Andalucía, Granada, Spain, ,

1. Introduction

For more than 20 years, several teams around the world have developed GCMs (Mars General Circulation Model or Mars Global Climate) to simulate the environment on Mars.

The GCM developed at the Laboratoire de Météorologie Dynamique in collaboration with several teams in Europe (LATMOS, France, University of Oxford, The Open University, the Instituto de Astrofisica de Andalucia), and with the support of ESA and CNES. is currently used for many kind of applications. It has become a “Mars System Model” which, for instance, includes the water cycle, the dust cycle, several photochemistry cycles, the release and transport of Radon, water isotopes cycles, a therrmosphere and a Ionosphere. It can also be used to explore Mars past climates. Moreover the outputs of the GCM are available to the community and to engineers through the Mars Climate Database, a tool available on a DVD-Rom and used by more than 150 teams around the world.

For all these applications, it is more important than ever that the model accurately simulates the “fundamentals” of the Martian meteorology: pressure, temperature, winds.
However, several recent studies have revealed that to simulate the details of Mars meteorology one must take into account several processes previously neglected like the radiative effect of water ice clouds, complex variations in the vertical distribution of dust including the formation of detached layers of dust, complex coupling in the CO_2 cycle which control the pressure cycle and the temperatures at high latitude, etc.

2. Model improvements.

On this basis, in the past three years, we have worked on including such physical processes and on updating most of the physical parametrizations which are used in our model, in order to simulate and understand the details of Mars meteorology as observed by atmospheric sounders like MGS/TES, MROS/MCS, Mxpress/PFS, Spicam and Omega, as well as radio occultation measurements.

Key improvements include:

- **Improved Dust radiative properties**. We show that using the most recent radiative properties derived by Mike Wolff (Wolff et al. 2006,2009) allows to reconcile predicted temperature of dust laden atmosphere with the observations when using observed dust opacities (Madeleine et al., submitted to JGR, 2011) .
- **Improving the dust vertical distribution and particle size** using a dust transport model (Figure 1; Madeleine et al., submitted to JGR, 2011).
- **Taking water ice clouds radiative effects into account**. This has a very strong impact not only where clouds are observed, but also on the thermal structure of the entire atmosphere and on the seasonal and spatial structure of baroclinic waves (Figure 1)..

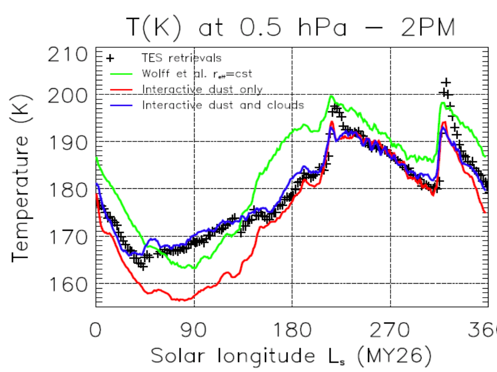

Figure 1. Zonally averaged equatorial temperature at 2 PM for the 0.5 hPa pressure level from TES climatology (crosses; courtesy of M. D; Smith) on martian year 26, and as predicted by the new LMD/GCM for three different cases : a simulation using the new Wolff et al. properties with prescribed dust distribution (green curve) a simulation using a semi-interactive dust transport model to predict dust size and vertical distribution (red curve), and a simulation taking into account the radiative effects of clouds predicted by the GCM (blue curve). Figure from Madeleine et al. [2011]

- **Including the scavenging of dust particles** resulting from by the sedimentation of ice particles within clouds. This process can creates detached layers as observed by the Mars Climate Sounders on MRO (Heavens et al. JGR, 2011). We also account for the corresponding supersaturation resulting from the local decrease of cloud condensation nuclei.

- **A new parameterization of the near surface convection** (see Colaitis et al., this issue) based on a mass flux parameterization of vertical transport. This strongly improves the near surface daytime thermal structure, allows to better simulate the transport and mixing by convection, and affects the strength of the Hadley circulation.
- **An improved CO_2 cycle** for better surface pressures and high latitude temperatures. in addition to the baseline CO_2 condensation/sublimation scheme based on energy balance considerations, the LMD GCM now also includes subsurface water-ice tables in the polar regions, takes into account the impact of CO_2 condensation in the atmosphere (clouds), includes the effect of non-condensable gases and can be guided with the observed solar albedos as recorded by the TES solar band channel.
- **A new map of surface roughness coefficient,** recently derived for the LMD GCM from rock abundance and thermal inertia data (Hebrard et al., 2011; Listowski et al., 2011])
- **In the upper atmosphere**, the GCM includes a new scheme for the **thermal cooling rates**, which handles for the first time the actual atomic oxygen, and introduces a better treatment of radiative transfer in the 15-um bands (see Gonzalez-Galindo et al., this issue) The **solar heating rate model** will also be significantly revised and improved. Finally, the **molecular diffusion scheme** is updated, in order to improve the calculation of the mixing ratio of species like H or H2 above the homopause (see Chaufray et al., this issue).

3. Model tuning, validation and scientific findings.

We are currently tuning the model to produce reference simulations in which all aspects of Mars meteorology will be simulated as accurately as possible. In practice, for each Martian year the model is driven by the observed dust opacities as retrieved by MGS TES, MO Themis, MRO MCS, and by the MER continuous surface measurements. Except for this prescribed dust columns opacity, the GCM is mostly based on universal physical equations. We can nevertheless tune the model to fit key available observations by modifying poorly known parameters such as the effective variance of the ice cloud size distribution, the albedo of CO_2 and H_2O seasonal frost, the composition of the dry material lying above the high latitude subsurface ice (this controls the estimation of the depth of the subsurface water ice, which itself impacts the CO_2 cycle).

In practice we tune 1) the CO_2 cycle to fit the seasonal pressure variations as recorded by the Viking Landers 2) the water cycle to match water vapour observations as retrieved by MGS TES 3) the cloud microphysical properties to obtain cloud opacities in the same range than observed by TES.

The model is then compared with MRO/MCS data. Preliminary results suggest that the new simulations are very close to the observations, although some interesting discrepancies remain. On the one hand, such a model can be used as a reference climatology for future scientific and engineering studies, and will allow to produce a new version of the “Mars Climate Database” (version 5, to be released in late 2011). On the other hand, the new GCM helps explain many meteorological phenomena observed by the atmospheric sounders. At the EPSC-DPS 2011 meeting, we will report in more details on these findings.