SIMULATING THE MARS CLIMATE WITH THE LMD MARS GLOBAL CLIMATE MODEL: VALIDATION AND ISSUES.

F. Forget, E. Millour, A. Spiga, J-B. Madeleine, A. Pottier, T. Navarro, L. Montabone, A. Colaitis, L. Kerber *Laboratoire de Météorologie Dynamique, IPSL, Paris, France* (forget@lmd.jussieu.fr), **F. Lefèvre, F. Montmessin, J-Y Chaufray** *Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), IPSL, Paris, France* **F. Gonzalez-Galindo, M.-A. Lopez-Valverde,** *Instituto de Astrofísica de Andalucía, Granada, Spain*, **S. R. Lewis,** *Department of Physics and Astronomy, The Open University, Milton Keynes, UK*, **P.-L. Read,** *Atmospheric, Oceanic & Planetary Physics, University of Oxford, UK.*

Introduction: The Mars atmosphere Global Climate Model (GCM) developed at the Laboratoire de Météorologie Dynamique in collaboration with several teams in Europe (LATMOS, 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. Our primary objective is to predict all details of the Mars Climate system, including the dust, water, CO_2 and photochemical cycles from the surface to the exobase, yet only on the basis of universal equations. In practice, to simulate a given year, we still have to assume a daily map of column dust opacity (See Montabone et al., this issue), but otherwise the model is almost free of other forcing (including to predict the dust vertical distribution).

2013 was an important milestone for the project since it concluded a long series of model development defined on the basis of the analysis of the Mars Climate Database version 4, released in 2005 using a previous version of our GCM (Forget et al. 2006).

Key improvements

As documented in the previous edition of the Mars Atmosphere Modeling and Observation Workshop, and in the per-review literature:

- **Improved dynamical core for the polar atmosphere**
- **Improvements of Mars surface fields** (albedo and thermal inertia map)
- **Inclusion of subsurface water ice in the CO_2 ice cap energy balance, and improved tuning of the CO_2 cycle**
- **Improved parametrizations of convection and near surface turbulence,** using a thermal plume model This thermal plume model is coupled to surface layer parameterizations taking into account stability and turbulent gustiness to calculate surface-atmosphere fluxes (Colaitis et al. 2013)
- **Improvement of the representation of the airborne dust** (Madeleine et al. 2011) based on a "semi-interactive" two moments dust transport scheme to predict the dust vertical distribution and the 3D variation of dust particle radii, coupled to improved radiative transfer calculations using Wolff et al. (2009) improved dust scattering properties.
- **Parametrisation of cloud radiative effects** taking into account 3D variations of ice particle radii (Madeleine et al. 2012)
- **A improved water cycle based on a detailed cloud microphysics** with dynamic condensation nuclei (as well as a better implementation of perennial surface water ice). The cloud microphysical scheme notably permits supersaturation above the hygropause in line with SPICAM observations (Maltagliatti et al. 2013) and scavenging of dust by water ice clouds (Navarro et al., this issue and submitted to JGR)
- **Improvements of the upper atmosphere / Thermosphere model** radiative balance(Lopez-Valverde et al. 2011, See Gonzalez-Galindo et al., this issue):
  - A new NLTE model to compute thermal cooling rate by CO_2 at 15 μm
  - A new parameterization of the NLTE solar heating by CO_2
  - For both scheme, the large variations of atomic oxygen (which controls the vibrational states of the CO_2 molecule) are now taken into account based on a detailed photochemical scheme.
  - In the far IR, a new type of cooling process, the cooling by atomic oxygen has been parameterized.

Model validation and observation analysis.

During its development, the model has been mostly tuned and validated using MGS/TES measurements of temperature, water vapor and cloud as provided by Michael Smith. On this basis, it is interesting to compare the GCM prediction with new datasets, in particular from the MRO/Mars Climate Sounder (McClees et et al. 2010) and Mars Express. We will present the outputs of a detailed comparison with these datasets (e.g. Fig 1-3).

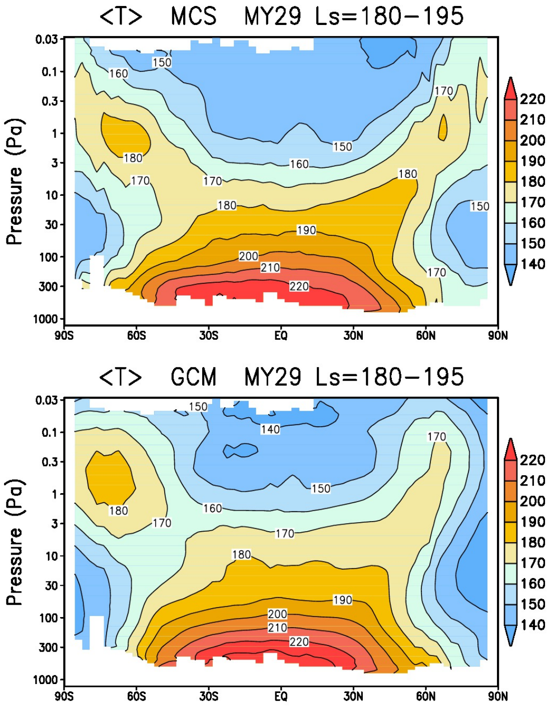

Figure 1: An example of the zonal mean, day-night average of the temperature structure observed by the MRO Mars Climate Sounder (MCS) with the LMD GCM prediction

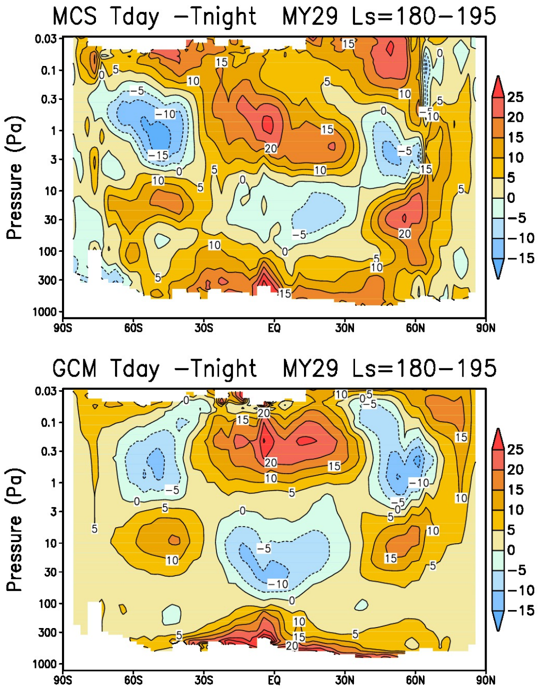

Figure 2: Same as figure 1, but showing the average temperature differences between dayside (around 3pm local time) and nightside (~3am), illustrating the signature of thermal tide waves.

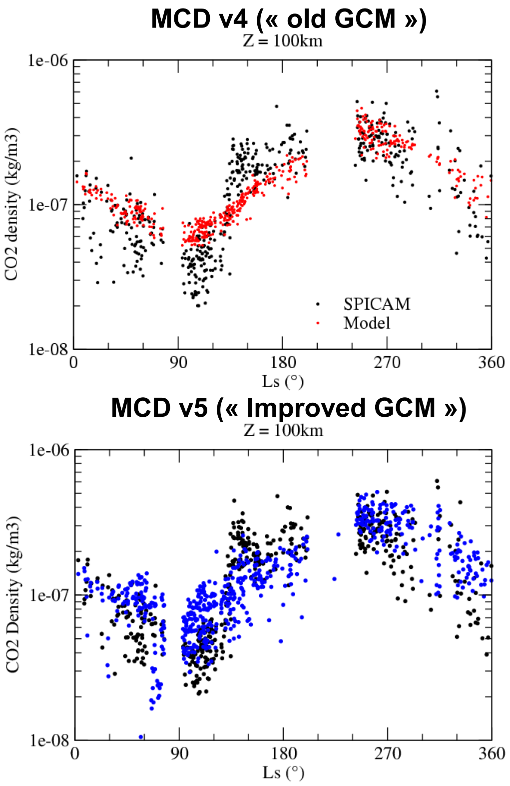

Figure 3 : CO_2 density as a function of season at 100 km above the Mars zero datum (areoid) as observed by Mars Express/SPICAM using stellar occultation on Martian Year 27 (black dots; Forget et al. 2009) compared to GCM prediction at the same location and time (colored dots) : **Top**: prediction from the 2005 LMD GCM (MCD v4). **Bottom**: prediction from the 2013 LMD GCM (MCD v5) using the MY27 dust scenario and an improved upper atmosphere radiative cooling (see text).

Remaining issues and plans for the future.

The GCM is quite successful to predict many aspects of the observed thermal structure, water vapor variations, dust vertical distributions, and ice cloud. However, several problems remain to be solved:

1. The GCM does not simulate the "detached' maximum in dust mass mixing ratio at 15–25 km above the surface notably observed during northern spring and summer by MCS (e.g. McCleese et al. 2010). In particular our parametrization of scavenging of dust particle by condensing clouds – a process thought to be at the origin of the detached dust layers- fails to create the dust distribution observed by MCS. We are now developing a new parametrisation inspired by the "Rocket dust storm" processes which have been predicted when performing meso-scale simulation of local dust storms, and which are likely to create the observed dust detached layers (Spiga et al. 2013).
2. The thermal structure of the mesosphere be-

tween the 1 Pa and 0.01 Pa pressure levels as observed by MCS remains challenging to accurately predict with the GCM, in particular in the polar regions It is found that this thermal structure is controlled by subtle wave mean-flow interactions, and extremely sensitive to most model parameters.

3. As detailed in Navarro et al. (This issue; submitted to JGR, 2013), Radiatively active clouds has changed the way we model the Martian water cycle. They induce a strong coupling between water cycle, clouds, and temperature. Tuning the water cycle has become challenging. Nevertheless, atmospheric temperatures are better represented thanks to the interactions between clouds and radiation. Many issues remain to be addressed, such as the cross-equatorial transport of water and the role of supersaturation that allow vapor to pass the trap of the aphelion cloud belt. We now plan a new phase of model development to improve several aspects of the water vapor and cloud cycles, using all data available (water vapor, cloud, surface frost). In particular, in the future we shall include in the GCM subgrid scale cloud fractions, an improved frost model, and detailed interaction with the regolith.
4. As described in Pottier et al. (this issue), the comparison of water ice cloud observation from MCS with the GCM prediction show large discrepancies. The cloud structure predicted by the model is certainly inaccurate in many locations, possibly because of the inaccurate dust vertical distribution. However, we also understand that such a comparison is made difficult by the very high sensitivity of MCS, which thus cannot observe thick clouds when they are present. The GCM/MCS comparisons thus require a specific strategy to compare the same information.

References

Colaïtis, A., A. Spiga, F. Hourdin, C. Rio, F. Forget, and E. Millour. A thermal plume model for the Martian convective boundary layer. Journal of Geophysical Research (Planets), 118:1468-1487, (2013)

Forget et al. The new Mars climate database. Mars Atmosphere Modelling and Observations 2 128. Available at http://www-mars.lmd.jussieu.fr/granada2006/abstracts/Forget2_Granada2006.pdf

Forget F., F. Montmessin, J.-L. Bertaux, F. González-Galindo, S. Lebonnois, E. Quémerais, A. Reberac, E. Dimarellis, and M. A. López-Valverde. Density and temperatures of the upper Martian atmosphere measured by stellar occultations with Mars Express SPICAM. *Journal of Geophysical Research (Planets)*, 114:1004 (2009)

LopezValverde, M. A., F. GonzalezGalindo, and M. LopezPuertas (2011). Revisiting the radiative balance of the mesosphere of Mars, in Proceedings of the Mars Atmosphere: Modelling and Observation, edited by F. Forget, and E. Millour, pp. 359362, Paris, France.

Madeleine, J.-B. F. Forget, E. Millour, L. Montabone, and M. J. Wolff. Revisiting the radiative impact of dust on Mars using the LMD Global Climate Model. *Journal of Geophysical Research (Planets)*, 116:11010 (2011).

Madeleine, J.-B., F. Forget, E. Millour, T. Navarro, and A. Spiga. The influence of radiatively active water ice clouds on the Martian climate. *Geophysical Research Letters*, 39:23202 (2012).

Maltagliati, L., F. Montmessin, A. Fedorova, O. Korablev, F. Forget, and J.-L. Bertaux. Evidence of Water Vapor in Excess of Saturation in the Atmosphere of Mars. *Science*, 333:1868 (2011).

McCleese, D. J., et al. (2010), Structure and dynamics of the Martian lower and middle atmosphere as observed by the Mars Climate Sounder: Seasonal variations in zonal mean temperature, dust, and water ice aerosols, J. Geophys. Res., 115, E12016, doi:10.1029/2010JE003677.

Spiga A., J. Faure, J.-B. Madeleine, A. Määttänen, and F. Forget. Rocket dust storms and detached dust layers in the Martian atmosphere. *Journal of Geophysical Research (Planets)*, 118:746-767 (2013).

Wolff, M. J., Smith, M. D., Clancy, R. T., Arvidson, R., Kahre, M., Seelos, F., Murchie, S., and Savijarvi, H. Wavelength dependence of dust aerosol single scattering albedo as observed by the Compact Reconnaissance Imaging Spectrometer. *Journal of Geophysical Research (Planets)*, 114, E13 (2009).