LMD-MGCM: THE FIRST GROUND-TO EXOSPHERE GENERAL CIRCULATION MODEL OF THE MARTIAN ATMOSPHERE

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Introduction: Recent observations from different spacecrafts have unveiled some interesting aspects of the Martian upper atmosphere. Mars Global Surveyor aerobraking and electron profiles show a tidal structure in the neutral density, mainly composed of waves 2 and 3, attributed to non-migrating components [1][2][3]. During Mars Odyssey aerobraking maneuvers, a thermospheric polar warming was observed during Norther winter, due to the subsiding branch of a strong interhemispheric circulation cell during solstices [4]. SPICAM on board Mars Express has observed the Martian nightglow, composed of hidrogen and NO emissions. This NO emission, already observed in Venus upper atmosphere, is due to recombination of N and O atoms produced in the dayside thermosphere and transported to the nightside [5]. All these results are signatures of a strong coupling between the upper and lower atmosphere of Mars.

It is therefore important to include all atmospheric regions and the couplings between them when studying the Martian atmosphere. This is the philosophy followed at the Laboratoire de Méteorologie Dynamique (LMD, Paris), where the Martian General Circulation Model developed in the 90s [6], LMD-MGCM, has been extended to the thermosphere becoming the first Martian GCM that can simulate the full atmosphere from the ground to thermospheric heights.

We will describe here the strategy followed in this extension, and we will present some results obtained.

Brief description of LMD-MGCM: The LMD-MGCM, evolved from a terrestrial model, includes the relevant processes near the surface, such as turbulent diffusion, convection, orography and low-level drag. For the energetics, it considers the effects of dust and CO_2 in the IR. CO_2 and water vapor cycles are also realistically included. A detailed description of this model can be found in [7]

Extension to the thermosphere: The extension to the thermosphere of the LMD-MGCM was done in two steps. First, parameterizations and approximations for NLTE processes were included, so that the model could be extended up to the mesosphere, region where these processes are of a great importance. In a second step, the processes relevant for the thermosphere were added. In what follows we will describe these added processes.

-NLTE processes: Corrections to the IR radiative transfer for departures of the situation of Local Thermodynamic Equilibrium are essential above about 80 km. The approximations used in our GCM are based on a detailed non-LTE model of CO_2 for the Martian atmosphere [8], based on the Curtis matrix method. For the NIR solar heating rate, this detailed model has shown that the ratio between LTE and NLTE is basically independent on the thermal structure. A LTE to NLTE NIR solar heating rate conversion table [9] is used. For the 15 um cooling the situation is not so simple, because this term is strongly dependent on the thermal structure and the atomic oxygen concentration. So, for the 15 um cooling the parameterization is based on some simplifications introduced to the full NLTE model, reducing the number of levels and introducing some approximations to the radiative transfer scheme [10]

-UV heating: This process is the main heating source of the Martian thermosphere, so a good representation is very important for reproducing the thermal structure of the Martian upper atmosphere. A parameterization based on a full 1-D UV heating model is used in our GCM [11]. This full model includes the absorption by CO_2, O_2, atomic oxygen, H_2, H_2O, H_2O_2 and O_3 in the UV-visible range. The parameterization is based on a tabulation of the photoabsorption coefficients, integrated in carefully chosen spectral intervals, as a function of the column amount of the species that absorb the radiation in each interval. Corrections to account for the variation of CO_2 cross section with temperature and for the variation of the solar flux during the solar cycle are included.

-Thermal conduction and molecular viscosity: Thermal conduction provides the primary cooling offsetting the peak UV heating at the altitude of its peak [12]. The equation governing this process is solved using an implicit method and a thermal conduction coefficient that is the weighted average of the various thermal conductivities. A similar method is used for the molecular viscosity [13] .

-Molecular diffusion: This is an important process in the upper atmosphere, responsible for the individual scale height of the species above the homopause. The exact theory of multicomponent diffusion is used, instead of the common approximation of monocomponent diffusion. An implicit scheme is used to assure the stability of the calculation [13].

-Photochemistry: A detailed photochemical 1-D model, appropriate for the rarified upper atmosphere of Mars, is at the core of the fast scheme included in the GCM. This detailed model includes the 12 major constituents of the C, O and H families, taking into account 27 reactions between them. The chemical cycles important for the stability of the Martian atmosphere are included. The fast scheme is based on the approximation of photochemical equilibrium for those species with a short lifetime [11].

Validation: Different strategies have been used for the validation of the extension to the thermosphere of the LMD-MGCM.

First, a series of internal consistency tests have been performed. The sensitivity of the results to different kinds of perturbations (e.g. modifications in some input coefficients) or to the absence of certain processes (e.g. photochemistry in fig. 1) has been tested. In all cases the behavior of the model responds to theoretical expectations. Also a qualitative comparison with previously published results from other models of the Martian thermosphere has been made, showing a good agreement in results such as the thermal balance (fig. 2) or the thermal structure of the upper atmosphere.

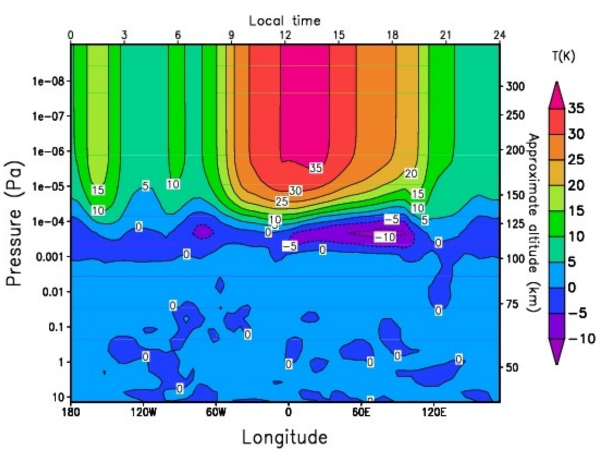
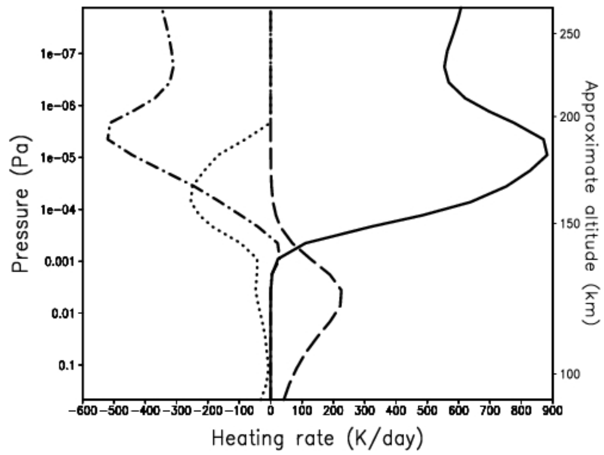


Fig.. 1. Difference of temperature between a simulation without photochemistry and a simulation with photochemistry.



Fig, 2 Thermal balance obtained by the LMD-MGCM at noon. Solid line; UV heating; Dotted line: 15 um cooling; Dashed line; NIR heating; Dash-Dot line: Thermal conduction

Second, an intercomparison campaign between the LMD-MGCM and the Mars Thermospheric GCM has been made. This MTGCM, developed at NCAR and nowadays maintained at Michigan University, is the reference model for the Martian thermosphere. Nowadays it is coupled to the NASA-AMES GCM to capture the upward propagating waves generated in the lower atmosphere [12]. The intercomparison campaign was designed to test the thermal and wind structure of the Martian upper atmosphere, as well as its seasonal variability. The results are very encouraging, as both models give very similar general structure and values for temperature and winds (in spite of some local differences) when the same inputs are used.

And third, a series of comparisons with different data from spacecrafts have been and are being performed. The LMD-MGCM reproduced successfully the tidal structure in the neutral densities observed by MGS (fig. 3), and allowed for a better interpretation of the data, confirming the role of wave-topography and wave-wave non linear interactions in the excitation of some of the tidal components observed [2]. SPICAM temperature and density profiles in the lower thermosphere are being also used to compare with results from the model (Forget et al. presentation in this conference).

Future work: Many different studies can be done with this ground-to-thermosphere model. Specially interesting would be the study of phenomena that imply a coupling between different atmospheric layers. Some examples are described below:

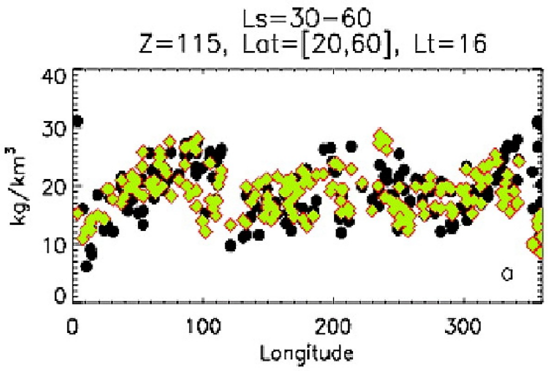


Fig. 3. MGS (black) and LMD-MGCM (green) neutral density at 115 km.

-SPICAM NO nightglow: N and O atoms are produced in the nightside thermosphere. Transport to the nightside and downwelling complete the picture. A proper simulation of this process has to include chemical, energetical and dynamical processes at different altitudes. We are currently working on including Nitrogen chemistry in the LMD-MGCM for a complete simulation of this nightglow with our model.

-Thermospheric polar warming observed by Mars Odyssey is also a signature of coupling between layers. It has been shown the importance of the variations of dust amount in lower layers for the intensity of the warming [4]. We will use our model to confirm these results and for a better insight of this warming.

-OMEGA CO2 emissions: OMEGA on board Mars Express has observed strong CO_2 mesospheric emissions, with a high variability in both the intensity and altitude of the peak emission. We plan to use our model for a better interpretation of these variations.

Given the similarities between the upper atmospheres of Mars and Venus, we plan to use our experience in the development of this thermospheric model in the extension to the thermosphere of a GCM of the Venus atmosphere developed at the LMD. A similar two step process will be followed, and some of the fast schemes developed for Mars will be easily adapted to Venus

Conclusions: The LMD-MGCM has been successfully extended to the thermosphere, becoming the first ground-to-exosphere GCM of the Martian atmosphere. It has been validated against other models and against different data, showing a reasonable agreement in all cases. This model will be used in the future to analyze some data concerning the upper atmosphere. A similar extension for a Venus GCM is envisaged.

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