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Validation of a new Mesoscale Model for MARS

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Abstract. The study of Mars planet is very important because of the several similarities with the Earth. For the understanding of the dynamical processes which drive the martian atmosphere, a new Martian Mesoscale Model (MARS-MM5) is presented. The new model is based on the Pennsylvania State University (PSU)/National Centre for Atmosphere Research (NCAR) Mesoscale Model Version 5 (Dudhia 1993; Grell & al. 1994). MARS-MM5 has been adapted to Mars using soil characteristics and topography obtained by Mars Orbital Laser Altimeter (MOLA). Different cases, depending from data availability and corresponding to the equatorial region of Mars, have been selected for multiple MARS-MM5 simulations. To validate the different developments Mars Climate Database (MCD) and TES observations have been employed: MCD version 4.0 has been created on the basis of multi annual integration of Mars GCM output. The Thermal Emission Spectromter observations (TES) detected during Mars Global Surveyor (MGS) mission are used in terms of temperature. The new, and most important, aspect of this work is the direct validation of the newly generated MARS-MM5 in terms of three-dimensional observations. The comparison between MARS-MM5 and GCM horizontal and vertical temperature profiles shows a good agreement; moreover, a good agreement is also found between TES observations and MARS-MM5.

Key words. Mesoscale – Mars Climate Database – MGS

1. Introduction

In the last years, the availability of some information on the Mars atmosphere triggered the interest of the earth atmospheric scientific community in understanding the Mars physics and dynamics. The Earth atmosphere general circulation models were changed to correctly reproduce the Mars atmosphere. Forget et al. (1999) successfully developed a general circulation model which was used to produce a climate data base for Mars (Lewis et al. 1999). More recently, to better reproduce local features Toigo & Richardson (2002) adapted the MM5 model from the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR), used for reproducing mesoscale feature of the earth atmosphere, to the Mars atmosphere. In their work the authors showed model simulations for a few cases of the Mars atmosphere. Similarly, in this paper a newly developed Martian Mesoscale Model (MARS-MM5) at Cetemps-University of L'Aquila based on the MM5V5 from PSU/NCAR (Dudhia 1993; Grell & al. 1994) is presented. The new, and most important, aspect of this work is the use of three-dimensional observations (from sur-

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face to 35 kilometers) both to adapt the model to Mars and to validate the model results. The use of MARS-MM5 at high resolution will permit the study of Boundary Layer of Mars and its employment will be handy for meteorological forecast around areas of landing of Landers site. The Mars Orbital Laser Altimeter (MOLA) (Kreslavsky & Head 1999, 2000) data has been used to define the topography into the model; whereas the albedo and thermal capacity are derived by the Thermal Emission Spectrometer experiments (TES)(Christensen et al. 2001). The MARS-MM5 results are compared with the GCM developed by Lewis et al. (1999) and the Climate Mars data base is used to this aim. A preliminary tuning of the PBL is performed and the comparison allowed to correctly design the PBL, which is one of the most important parameterization for Mars atmosphere. Also the radiative scheme plays a major role because of the difference in the atmospheric constituents: the radiative effects through the Martian atmosphere may be conditioned by a massive presence of carbon dioxide, dust and a minor presence of water vapor and ozone.

2. MARS-MM5

The MM5V3 version 5 from PSU/NCAR by Dudhia (1993); Grell & al. (1994) has been adapted to Mars planet. The original MM5 is a non-hydrostatic model at the primitive equations using the sigma vertical coordinate, which is a terrain following one. The horizontal grid uses an Arakawa B-staggering: the scalars (T, q, etc) are defined at the centre of the grid square, while the eastward (u) and northward (v) velocity components are situated at the corner. The model may use three different types of map projection: Lambert Conformal is suitable for mid-latitude, Polar Stereographic for high latitude and Mercator for low latitude. The MM5 model has the feasibility of several physical parameterizations: the PBL, the cumulus convection and the radiative transfer scheme. The MARS-MM5 retains most of these characteristics, but the conversion to a Mars atmosphere required several modifications, the most important ones involving:

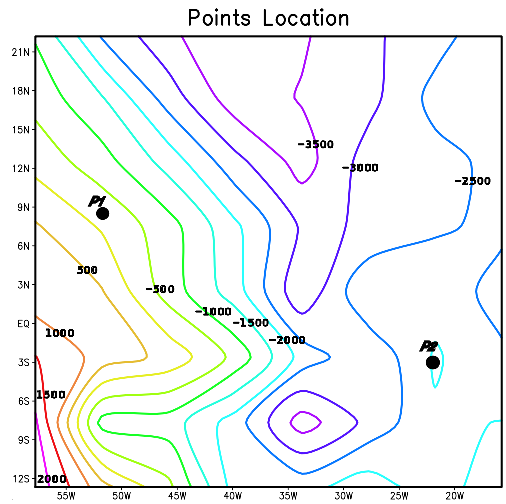

Fig. 1. Model topography and observation distribution in MM5 grid domain; Pi=(latitude,longitude),P1=(8°,-51°), P2=(-3°,-21°)

- Geography and topography characteristics
- Thermodynamics
- PBL parametrization
- Radiative parametrization

2.1. Model Setup

The MARS-MM5 configuration (horizontal domain and vertical levels) used for this study is showed on Fig.1. The main purpose of this experiment is to verify MARS-MM5 against GCM, consequently the same configuration is chosen. The model domain is 35°x40° and has a resolution of 300 Km (~5°). The location points are relative to Ls=38.9° at local time LT= 02:00 for points P1 Ls=41.8° at LT= 14:00 for points P7. The selected data for the simulations are daily data taken every 2 hours. Since this area is on the equatorial region, the Mercator projection is used for the simulations. According to GCM configuration, 20 vertical sigma levels are used from 6 Pa (surface pressure) to 0.01 Pa (~50 Km) at the top. The newly upgraded versions of both the MRF and RRTM parametrization are applied to respectively the planetary boundary layer and radiative transfer; a Simple parametrization is used, to describe the explicit moisture and hydrometeor scheme. No cumulus convection parametrization is used because this effect is negligible. The initial and boundary conditions are provided by the GCM (Lewis et al. 1999).

With improving the PBL, a simple parametrization of optical dept in term of Mars dust is developed: originally, MM5 model transfers cloud fraction to RRTM array, computing cloud optical depth as the product of cloud liquid water path and cloud mass absorption coefficient in the model, which is a combination of liquid and ice absorption coefficients. On Mars, the impact of cloud liquid water is expected to be negligible compared to the dust produced by turbulence at the lower layer. Therefore in MARS-MM5 a new simple parametrization of optical depth (tau) has been assumed: tau is a linear function of u and v components of the wind. Several experiments are performed using different PBL schemes, with and without the tau parametrization and different values of Landuse.

3. Results

For the validation of MARS-MM5, both the GCM results and the TES data are used. The statistical approach is used only to objectively compare both MARS-MM5 and GCM results with experimental measurements by means of the mean error M or Bias and the RMS (R) for temperature T for each point. The statistical parameters are defined as:

$$M = \frac{\sum_{j=1}^{N}(OBS_j - OU_j)}{N} \tag{1}$$

$$R = \sqrt{\frac{\sum_{j=1}^{N}(OBS_j - OU_j)^2}{N}}$$

where OBS is the observation (TES data) and OU is the model output (MARS-MM5 or GCM) at the i-th point location. N is the total number of vertical levels. To the aim of validating MARS-MM5 the GCM results are used as reference. The RMS for temperature T for each level is computed for MARS-MM5 and GCM. The correlation coefficient for pairs of vertical profile (x_i, y_i), i = 1, . . . N, is defined as:

$$r = \frac{\sum_{i=1}^{N}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{N}(y_i - \overline{y})^2}} \tag{2}$$

where $\overline{x}$ is the mean of the x_i's, $\overline{y}$ is the mean of the y_i's. The value of r lies between -1 and 1, inclusive. The comparison between the temperature field produced by MARS-MM5 and CGM is performed both horizontally and vertically. For the horizontal comparison, three levels are selected: the first at 200 meters, the second at 900 meters and the third at 14.2 kilometers from surface. The levels are chosen in order to eventually highlight discrepancies at the lower and upper levels. The vertical comparison between the theoretical vertical temperature profiles (MARS-MM5 and GCM) and the experimental data (TES) at the two locations (Fig.1) will be presented. The variability range of vertical profiles extended from surface to around 45 kilometers, because above this level the TES data could be affected by a large error (Conrath et al. 2000).

3.1. Horizontal and Vertical Comparison

Based on the tuning results, the validation is now performed using a previous configuration. In what follows, the comparison is performed between the horizontal temperature fields of MARS-MM5 and GCM. The comparison between MARS-MM5 and GCM temperature fields relative to Ls=38.9° and Lt= 02.00 shows a very good agreement between MARS-MM5 and GCM temperatures (Fig.2), either for the absolute values or for area distribution. A better agreement is found at 200 meters (Fig. 2a-2b), above the PBL and no differences are detectable at 14.2km. Similar results are also obtained for the other day(Ls=41.8°) at every time step and every vertical level. The comparison between horizontal temperature field shows that the differences are very small. In summary, the previous results show negligible discrepancies between the two models in reproducing the PBL. The vertical temperature profiles for MARS-MM5 (dashed line), GCM (continuous line) and TES (grey line),

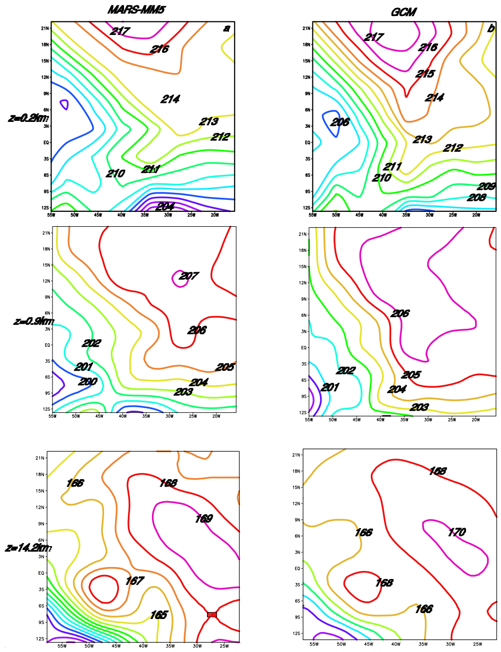

Fig. 2. Temperature (k) for MARS-MM5 (first column) and CGM (second column) at tree different levels: at 200m on the first line, at 900m on the second line and at 14.2km on the third line.

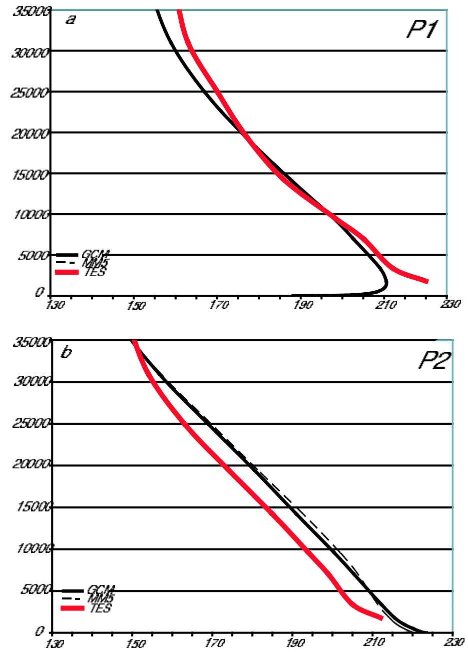

Fig. 3. The temperature vertical profiles for MARS-MM5 (black solid line), CGM (black dashed line) and TES (red line) for the 2 points in Fig.1

Table 1. Bias values for two points: M_1 and R_1 refer to comparison between GCM and TES, while M_2 and R_2 refer to comparison between MM5 and TES.

P_i	$M_1(K)$	$M_2(K)$	$R_1(K)$	$R_2(K)$
P_1	−3.0	−2.8	4.2	4.2
P_2	4.2	4.1	5.1	5.8

for each observing point, show a generally good agreement between MARS-MM5 and GCM, suggesting that the newly developed MARS-MM5 is able to reproduce the Mars atmosphere. Moreover, MARS-MM5 shows a cold bias compared to GCM up to 38km (not shown). Noteworthy, the MARS-MM5 lapse rate is in very good agreement with the GCM one. The comparison between MARS-MM5 and TES clearly confirm the good ability of MARS-MM5 to reproduce the Mars atmosphere. Generally, the vertical temperature profiles from MARS-MM5 well agree with TES, except for the lower layers, where it is known that the observation uncertainties are large (Conrath et al. 2000)(Fig. 3a-b): is possible to note that, in correspondence to the mid layer (from 5 Km to 35 Km), both MARS-MM5 and GCM show a good agreement to TES vertical profiles. Below 2 Km and above 35 Km the comparison shows some discrepancies probability because at these levels the instrumental error is more relevant. The statistical analysis allows to better understand the previous results; the bias and RMS (R) values for the selected points are reported in Tab. 1: index 1 refers to the differences between GCM and TES, while index 2 refers to those between MM5 and TES. The bias is computed following equation (1) while in this case OBS is the TES observation, OU is the output model (MM5 or GCM), and N is the total number of points. Negative values of bias implies an overestimation of the model compared to experimental data. The results show that in all cases the bias between MARS-MM5 and TES is smaller or equal than the one between GCM and TES; RMS shows similar results. To further explore the previous findings the correlation coefficient is also used. In Ttable 2 the correlation coefficients is computed for each point, as before index 1 is used for comparing GCM and TES, whereas index 2 for MARS-MM5 and TES. As previously found, in two cases, the correlation between MARS-MM5 and TES is slightly larger or equal than the one obtained by the comparison between GCM and TES: this result largely agrees with what shown in Table 2. This implies that the vertical temperature profiles produced by MARS-MM5 are compatible with experimental data, and that in all cases the MARS-MM5 profiles are as good as those obtained with GCM.

Table 2. Correlation coefficients for two points: r_1 refers to comparison between GCM and TES while r_2 refers to comparison between MM5 and TES.

P_i	r_1	r_2
P_3	0.99	0.99
P_7	0.99	0.99

4. Conclusion

A newly developed mesoscale model validation for the Martian atmosphere adapting MM5V3 from PSU/NCAR is presented. Several changes are applied to the Earth MM5 to correctly reproduce the Martian atmosphere. Both the PBL model, concerning the calculation of surface temperature and heat fluxes, and the radiative transfer scheme are modified. To validate the newly developed MARS-MM5 the results are verified against a CGM and TES observations. Both the horizontal and vertical structure of temperature field are used to verify MARS-MM5. The comparison between the MARS-MM5 and GCM temperature field at three different levels suggest a good agreement between the two models; moreover, the correlation coefficient computed for MARS-MM5 and GCM in comparison to TES data confirm the previous outcome. These preliminary results are encouraging and they suggest further improving MARS-MM5. Moreover, they support the need of having a mesoscale model for the Martian atmosphere.

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