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An improved Mars climate database

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AN IMPROVED MARS CLIMATE DATABASE

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Introduction: What is the Mars Climate Database?

The Mars Climate Database (MCD) is a database of meteorological fields derived from General Circulation Model (GCM) numerical simulations of the Martian atmosphere and validated using available observational data. The MCD includes complementary post-processing schemes such as high spatial resolution interpolation of environmental data and means of reconstructing the variability thereof.

The GCM is developed at Laboratoire de Météorologie Dynamique du CNRS (Paris, France) [1,2] in collaboration with the Open University (UK), the Oxford University (UK) and the Instituto de Astrofisica de Andalucia (Spain) with support from the European Space Agency (ESA) and the Centre National d'Etudes Spatiales (CNES).

The MCD is freely distributed and intended to be useful and used in the framework of engineering applications as well as in the context of scientific studies which require accurate knowledge of the state of the Martian atmosphere.

The MCD may be accessed either online (in a somewhat simplified form) via an interactive server available at http://www-mars.lmd.jussieu.fr (useful for moderate needs), or from the full DVD-ROM version which includes advanced access and post-processing software (contact millour@lmd.jussieu.fr and/or forget@lmd.jussieu.fr to obtain a free copy).

Overview of MCD contents:

The MCD provides mean values and statistics of the main meteorological variables (atmospheric temperature, density, pressure and winds) as well as atmospheric composition (including dust and water vapor and ice content), as the GCM from which the datasets are obtained includes both chemistry [3] and full water cycle [4] models.

The database extends up to ~350km, i.e. up to and including the thermosphere[5,6]. Since the influence of Extreme Ultra Violet (EUV) input from the sun is significant in the latter, 3 EUV scenarios (solar minimum, average and maximum inputs) account for the impact of the various states of the solar cycle.

The following values are provided in the MCD:

- Atmospheric density, pressure, temperature and winds (horizontal and vertical),
- Surface pressure and temperature,
- CO_2 ice cover,
- Atmospheric turbulent kinetic energy,
- Thermal and solar radiative fluxes,
- Dust column opacity and mass mixing ratio,
- [H_2O] vapor and [H_2O] ice columns and mixing ratios
- [CO], [O], [O_2], [N_2], [CO_2], [H_2] and [O_3] volume mixing ratios,
- Air specific heat capacity, viscosity and molecular gas constant R.

In order to account for and adequately represent the variability of the Martian atmosphere due to atmospheric dust distribution, the MCD includes 4 different dust scenarios which describe extreme cases (from very clear skies to global planet-wide dust storms) and a baseline scenario for which the dust loading of the atmosphere is that obtained from assimilation of TES observations [7] in 1999-2001. The seasonal variation of variables is provided by the storage of 12 "typical" (average over a month, i.e. 30° of solar longitude) days, and the diurnal variations are provided by the storage of environmental data stored at 12 times of the day for each "typical" day. Using these datasets, values for any given date and time of day are then reconstructed using interpolation.

In addition to these mean climatological values, the wide ranges of scales over which meteorological variables vary are accounted for as follows:

- Year to year variability due to the amount and distribution of suspended dust. 4 dust scenarios are presented:
  - A baseline **MY24** (Mars Year 24) scenario, for which the amount of dust in the atmosphere is that obtained from assimilation of TES observations [7] during Mars Year 24 (following the calendar proposed by R.T. Clancy [8], which starts on April 11, 1955, at Martian solar longitude Ls=0°), a standard Martian year without a global dust

storm and believed to be quite representative of such years.

- o A **cold** scenario (dust opacity τ = 0.1), corresponding to an extremely clear atmosphere.
- o A **warm** scenario, corresponding to a rather dusty atmosphere (but not a global dust storm).
- o A **dust storm** scenario (dust opacity τ = 4), representing Mars during a severe global dust storm when such storms are likely to happen, for Ls ranging from 180° to 369° (northern fall and winter).

- Year to year variability in the thermosphere (~100 km and higher) resulting from Extreme UltraViolet (EUV) input due to the solar cycle: 3 EUV scenarios, minimum, average and maximum solar inputs are considered.
- Day to day variability: Apart from the mean values of meteorological variables, the variability thereof is included in the MCD as follows:
  - o Standard deviations of main variables (surface pressure, surface temperature, dust opacity, atmospheric density, pressure, temperature and winds) are supplied.
  - o Users may reconstruct realistic variability by adding perturbations to mean values; either in the form of large scale perturbations, using Empirical Orthogonal Functions (EOF) derived from the GCM runs, or small scale perturbations, by adding gravity waves of user-defined wavelength.
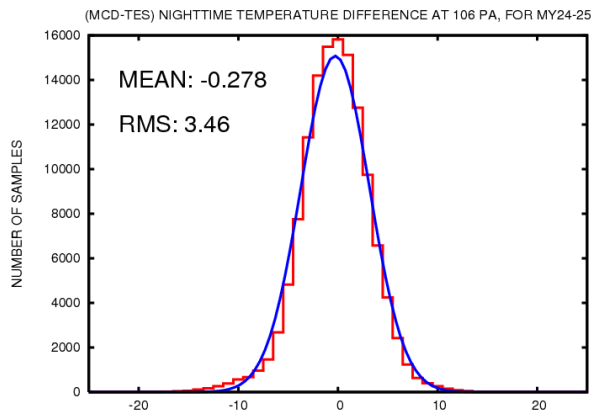
and RMS.

High resolution outputs

The MCD post-processing software includes schemes which combine high resolution (32 pixels/degree) MOLA topography and Viking Lander 1 pressure records with raw "low resolution" MCD surface pressure and reconstructs surface pressure at high resolution. The latter is also then used to reconstruct vertical fields and, within the restriction of the procedure, yield high resolution values of atmospheric variables.

Validation of the MCD climatology:

The MCD has been validated using available data, from TES, onboard MGS (see Figures 1 and 2), for surface and atmospheric temperature, but also from atmospheric temperature retrieved from radio occultation using the ultra-stable oscillator onboard MGS. The assessment of the correctness of the surface pressure predictions was obtained using Viking Lander 2 measurements (see Figure 3).
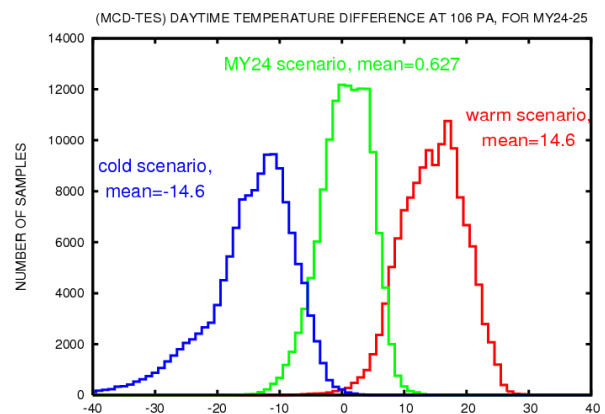

Figure 2: Distributions of binned daytime (i.e. 2pm) atmospheric temperatures differences between MCD and TES, as shown in Figure 1, but using different MCD dust scenarios (the cold, baseline MY24 and warm scenarios).

Figure 1: Example of comparisons between MCD predictions of atmospheric temperatures and measurements by the Thermal Emission Spectrometer (TES) onboard Mars Global Surveyor (data kindly provided by M.D. Smith). Distributions of binned temperature differences (using bins of 1K) between MCD MY24 predictions and TES measurements (at 2am) over Mars Years 24 and 25 (up to Ls=180°, i.e. before the global dust storm) for latitudes ranging from 50°S to 50°N. Displayed MEAN and RMS values are computed from the obtained histograms and the curves correspond to normal distributions of same MEAN
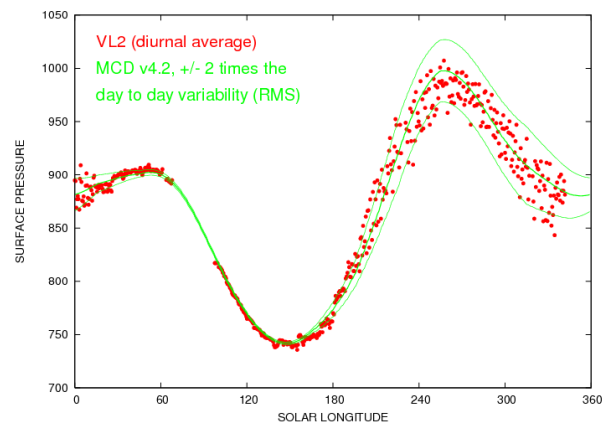
Figure 3: Surface pressure cycle over a Martian year, as predicted by the baseline **MY24** scenario at Viking Lander 2 site, with an envelope of twice its standard deviation,

compared to recorded values.

The MCD includes a **validation document** which reports all the comparisons between MCD outputs and available datasets of measurements.

Obviously, as new measurements are made available, these are compared to the MCD predictions (see Figures 4 and 5 for some illustrative examples).
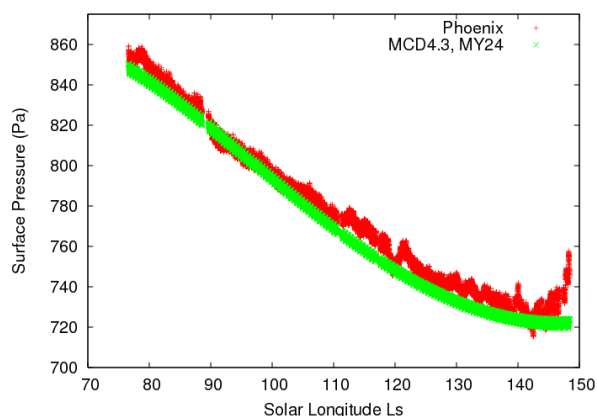

Figure 4: Measured surface pressure at Phoenix Lander site over the 151 sols of the mission (Mars Year 29) compared to the MCD predicted climatology (using the MY24 dust scenario).

Applications of the MCD:

Since its release in May 2008, the full DVD-ROM version of the Mars Climate Database (v4.3) has been distributed to over 130 teams around the world. Typically, the MCD has been used for :

- **Entry descent and landing and spacraft studies** for future planned missions (ExoMars, MSL) and study of "autonomous" landing
  o by all space agencies: ESA ESTEC and ESOC, NASA Langley and Ames, JPL, CNES, DLR, ISRO Sarabhai Space center in India etc);
  o by many of their numerous industrial contractors
  o by Institutes like the Beijing Institute of technology (China), the Center for Planetary Atmospheric Flight Sciences (USA), the Naval Postgraduate School (USA), The Chinese Space science Application Center, etc…
- **The development of future instruments** by, e.g. NASA Langley, Delft University (Netherlands), Aberystwyth University, University of Leicester (UK)**,** Obs. of Capodimonte (Naples, Italy), The Canadian Space Agency**,** Northrop Grumman, (USA) etc.
- **Analysis of observations and retrieval** for most remote sensing instruments including:
  o PFS (by the main team in Roma, at Paris ob-

servatory, at Tohoku University in Japan, at Max Planck Instutute in Lindau, etc),
  o SPICAM (LATMOS , IKI, etc…),
  o TES (JPL, University of Colorado),
  o THEMIS (University of Bristol),
  o OMEGA (IAS, NASA AMes),
  o Hirise (University of Bern)
  o HRSC (DLR, Germany)
  o Entry profile (Boston University)
  o Earth Based observations (NASA Goddard, Paris Observatory, Space Science Institute USA, Australian Center for Astrobiology.
- **Model development** at, for instance, North Carolina State University, NASA Ames, Lancaster University, Shanghai Astronomical Observatory, UC Berkeley, University of Louisville, University of Toronto, Shanghai Astronomical Observatory, Warsaw University, CESR (France), ESTEC, Institute of Atmospheric Physics,, Beijing (China), US Naval Research Laboratory, Royal Observatory in Brussel, Belgium.
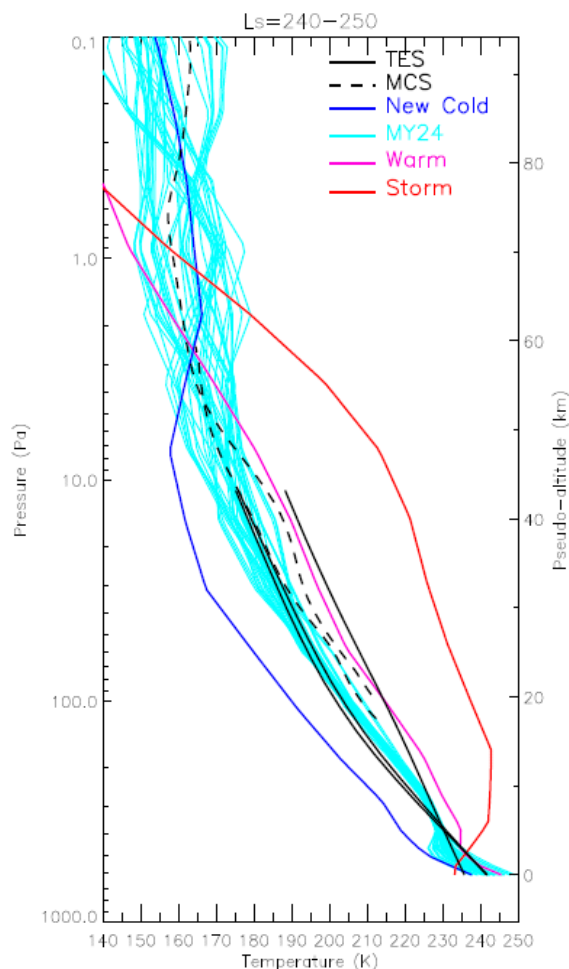- **And many more…**

Figure 5: Comparison among average TES temperature profiles in MY24, 25 and 26, average MCS temperature profiles in MY 28 and 29, and Mars Climate Database v4.3.EXM.1 predictions with dif-

ferent dust scenarios at Exomars' landing site (Meridiani).

To support work by Thales Alenia Space Italy for ESA (and coworkers) on EDL analysis of the ExoMars demonstrator in 2016, specific versions of the MCD (labeled versions 4 .3.EXM.*) have been developed. Added features include extra subgrids-cale variability near the surface and additional specific dust scenarios (aiming at better characterizing the landing site and also focusing on the planned landing period of Ls=240-250, see e.g. Figure 5). As these specificities are only relevant to EDL characterization for the ExoMars 2016 mission, the "official standard" MCD that is routinely delivered to users is version 4.3.

Towards the next version of the Mars Climate Database:

We are currently working on a building a new and improved Mars Climate Database (version 5).

One essential step towards this achievement is running an improved version of the LMD GCM which will include all recent improvements and developments [10]:

- o An improved CO_2 cycle resulting from the inclusion of realistic subsurface water ice tables in the Polar Regions [11].
- o Improved radiative transfer with updated radiative properties of dust, along with the implementation of the radiative effect of water ice clouds [12].
- o An improved water cycle [10,12].
- o An updated chemistry package [13].
- o An improved representation of the non LTE (Local Thermodynamical Equilibrium) phenomena in the thermosphere [14].
- o We plan to update the thermal inertia and albedo maps used by the GCM.
- o We will take into account the recently derived map of surface roughness values [15] (instead of using a fixed value of 1cm everywhere, as we have so far).
- o We are also currently working on implementing the "thermal plume model" [16], a significant improvement to the current convective adjustement scheme in the GCM.

In addition to these technical improvements of the LMD GCM itself, we will include in Mars Climate Database version 5 more dust scenarios, which will include all Mars Years from MY24 to MY29 (as derived by [17]). Again some "extreme" (cold, warm, global dust storm) scenarios will also be provided to bracket reality as best as possible.

We also plan to improve the MCD software with the addition of a subgridscale variability near the surface, which would be an improvement of the coarse scheme developed for the MCD v4.3.EXM.* series, where the nature and amplitude of this added variability would be derived from simulations using the LMD Mars Mesoscale Model [18].

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