THE LATEST (VERSION 4.3) MARS CLIMATE DATABASE. E. Millour[1], F. Forget[1], F. González-Galindo[1], A. Spiga[1], S. Lebonnois[1], L. Montabone[1,2], S.R. Lewis[2], P.L. Read[3], M.A. López-Valverde[4], G. Gilli[4], F. Lefèvre[5], F. Montmessin[5], M.-C. Desjean[6], J.-P. Huot[7] and the MCD/GCM development team. [1]Laboratoire de Météorologie Dynamique du CNRS, IPSL, Paris, France (millour@lmd.jussieu.fr), [2]Department of Physics and Astronomy, The Open University, Milton Keynes, UK, [3]Atmospheric, Oceanic & Planetary Physics, University of Oxford, UK, [4]Instituto de Astrofísica de Andalucía, Granada, Spain, [5]Service d'Aéronomie, IPSL, Paris, France, [6]Centre National d'Etudes Spatiales, Toulouse, France, [7]European Space Research and Technology Centre, European Space Agency, Noordwijk, Netherlands.

Introduction: 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.

Current applications of the MCD: Since 2005 MCD version 4.1 and 4.2 have been distributed to over a hundred teams around the world; the latest upgrade (version 4.3) was released in May 2008 and includes all the features of its predecessors along with improved variability models and extra documentation.

Current applications include entry descent and landing (EDL) studies for future missions (ExoMars, MSL), investigations of some specific Martian issues (via coupling of the MCD with homemade codes), analysis of observations (Earth-based as well as with various instruments onboard Mars Express and Mars Reconnaissance Orbiter),...

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.

Representation of variations and variability of variables in the MCD: The Martian atmosphere is well known to be highly variable. 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.
  - A **cold** scenario (dust opacity τ = 0.1), corresponding to an extremely clear atmosphere.
  - A **warm** scenario, corresponding to a rather dusty atmosphere (but not a global dust storm).
  - 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:
  - Standard deviations of main variables (surface pressure, surface temperature, dust opacity, atmospheric density, pressure, temperature and winds) are supplied.
  - 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.

Illustration of the MCD low/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.

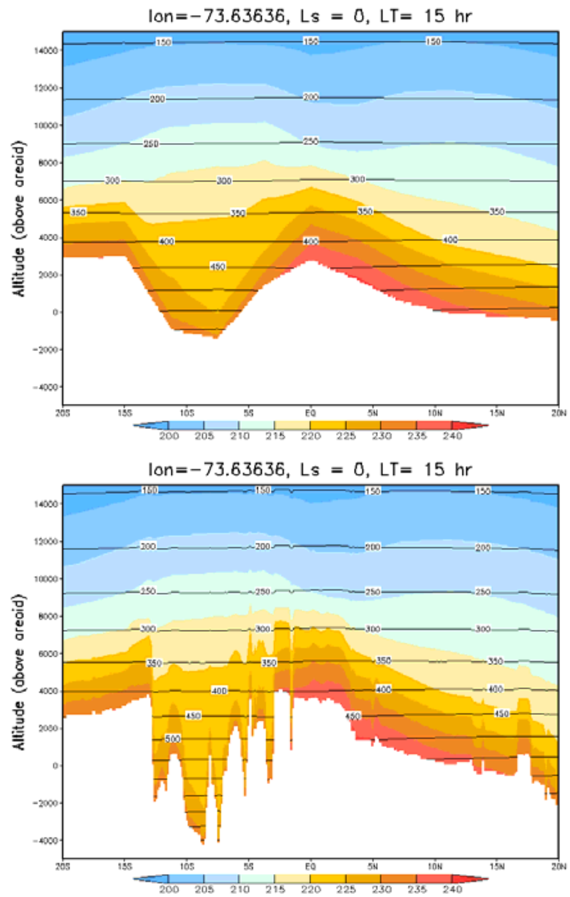

Figure 4: Example of low/high resolution outputs: sections of atmospheric temperature, in the early afternoon at Northern Hemisphere Spring equinox, above Valles Marineris, at low (top) and high (bottom) resolution. Note that there is an order of magnitude between horizontal and vertical scales in these plots; what appear as sharp spikes are in fact much smoother, as plots using commensurate axes would show.

Validation of the MCD climatology: The MCD has been validated using available data, from TES, onboard MGS (see Figure 1 for an example), 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 realized using Viking Lander measurements (see Figure 5).

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

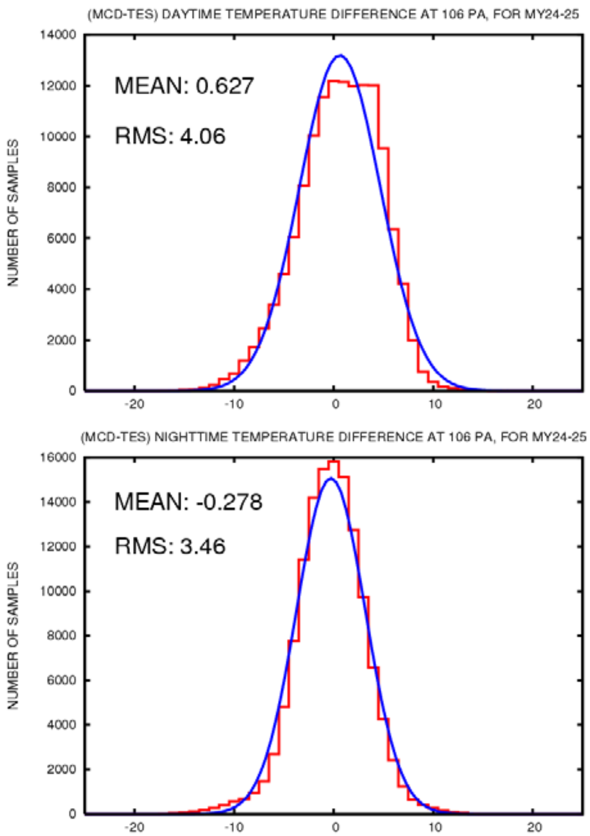

Figure 1: Comparisons between MCD data predictions of atmospheric temperatures and measurements by the Thermal Emission Spectrometer (TES) onboard Mars Global Surveyor (data kindly provided by M.D. Smith). Distributions of binned temperature differences (using bins of 1K) between MCD MY24 predictions and TES measurements (at 2am for the top plot and 2pm for the bottom one) 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 and RMS.

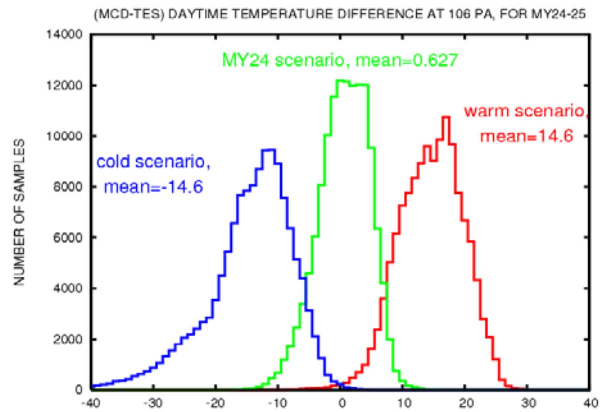

Figure 2: Distributions of binned daytime (i.e. 2pm) atmospheric temperatures differences between MCD and TES, as shown in Figure 1, but using different MCD dust scenarios (the cold, baseline MY24 and warm scenarios).

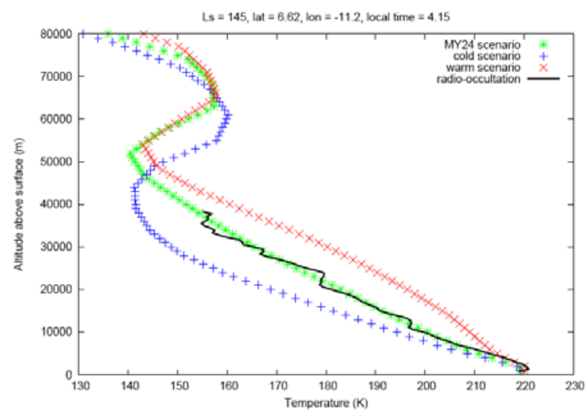

Figure 3: A typical temperature profile obtained by MGS radio occultation in May 1999, compared to profiles predicted by the MCD at the same time and location using various dust scenarios. Profiles obtained using the MY24 scenario are usually close to the MGS observations, whereas those obtained using the warm (dusty) and cold (clear sky) scenarios are typically respectively warmer and colder.

Representation of the variability of the Martian weather using the MCD variability models: Some illustrative examples of use of the provided day-to-day RMS or perturbation models to reconstruct the variability of the Martian weather are given in Figure 5 and Figure 6 which respectively display comparisons between MCD-predicted surface pressure and measurements at Viking Lander 2 and Phoenix sites.

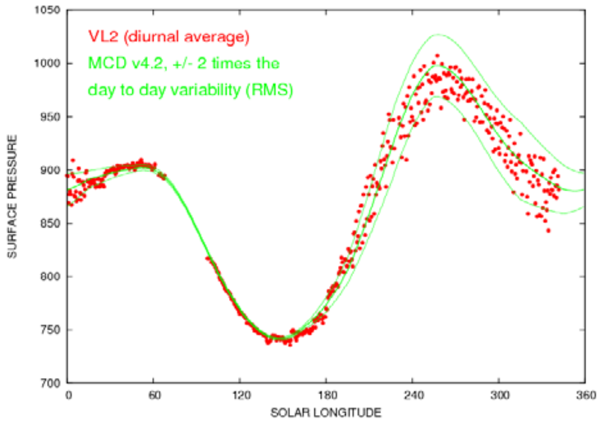

Figure 5: Surface pressure cycle over a Martian year, as predicted by the baseline **MY24** scenario at Viking Lander 2 site, with an envelope of twice its standard deviation, compared to recorded values.

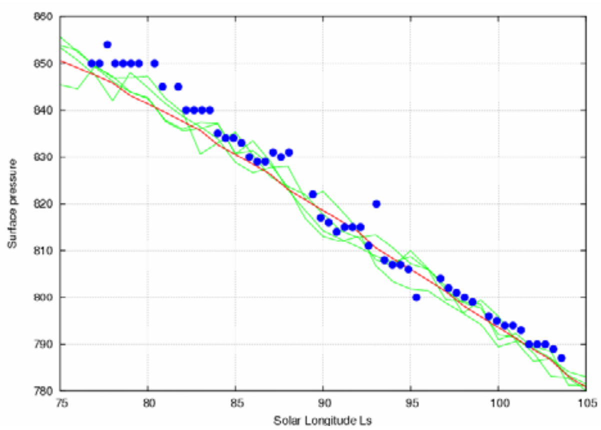

Figure 6: Measured surface pressure at Phoenix Lander site (blue dots) over the first 60 sols of the mission (data taken from the CSA Martian Weather Report webpage) compared to MCD predictions (using the MY24 dust scenario), either without perturbation (red line) or including added large scale perturbations (4 green lines, each corresponding to a different random initial condition).

Obtaining and using the MCD: The Mars Climate Database is freely distributed and available in two different forms.

For moderate needs: the WWW interface (which is based on a Live Access Server) is available at http://www-mars.lmd.jussieu.fr and gives access to:

- All scenarios and main variables.
- A choice between 3 different vertical coordinates (pressure levels, altitude above areoid or above surface).
- A wide range of output formats: Images (gif or postscript files), NetCDF data files, various formats of text files.
- Computation of user-defined variables (averages, minimum or maximum values,…).
- An Earth date to Mars date (value of solar longitude Ls) converter.

For intensive and precise work: The MCD is freely available on a DVD-ROM which contains:

- The MCD documentation: a **user guide**, along with a **validation document** which details comparisons of MCD outputs with available measurements and a **detailed design document** which describes the technical aspects of how the data is stored and processed.
- The data files (in NetCDF format).
- Access software (Fortran 77 subroutine “call_mcd”) which does all the necessary post-processing to include and account for sub-grid scales, day to day variability, ... It has been developed on Unix but can be ported to Windows.
- Examples of IDL, Matlab, Scilab, C and C++ interfaces to the MCD.
- A lighter standalone high resolution surface pressure predictor, “pres0”.

Just contact francois.forget@lmd.jussieu.fr and/or ehouarn.millour@lmd.jussieu.fr to obtain a free copy.

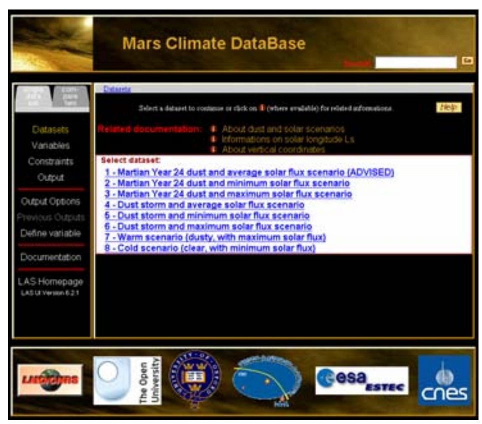

Figure 7: Front page of the Live Access Server of the online version of the Mars Climate Database, available at http://www-mars.lmd.jussieu.fr

References: [1] Forget F. et al. (1999) *JGR*, 104, E10. [2] Lewis S. R. et al. (1999) *JGR*, 104, E10. [3] Lefèvre F. et al. (2004) *JGR*, 109, CiteID E07004. [4] Montmessin F. et al. (2004) *JGR*, 109, E10, CiteID E10004. [5] Angelats I Coll et al. (2005) *Geophys. Res. Lett.*, 32, 4, CiteID L04201. [6] Gonzalez-Galindo F. et al. (2005) *JGR.*, 110, E9, CiteID E09008. [7] Montabone L. et al. (2006) *2nd Int. Workshop on Mars Atmosphere Modeling and Observations*. [8] Clancy R.T. et al. (2000) *JGR*, 105, E4.