The Mars Climate Database

Conference or Workshop Item

THE MARS CLIMATE DATABASE.

S. J. Bingham, **S. R. Lewis, P. L. Read,** *Atmospheric, Oceanic & Planetary Physics, University of Oxford, UK (bingham@physics.ox.ac.uk)*, **F. Forget, F. Hourdin, O. Talagrand, Y. Wanherdrick, M. Angelats I Coll,** *Laboratoire de Météorologie Dynamique du CNRS, Université Paris 6, Paris, France,* **M. Lopez-Valverde, M. Lopez-Puertas,** *Instituto de Astrofisica de Andalucia, Granada, Spain*, **J-P. Huot,** *European Space Research and Technology Centre, European Space Agency, Noordwijk, Netherlands.*

Introduction:

The Mars Climate Database (MCD) [1] is a database of statistics describing the climate and environment of the Martian atmosphere. It was constructed directly on the basis of output from mulitannual integrations of two general circulation models (GCMs) developed by Laboratoire de Météorologie Dynamique du CNRS, France, the University of Oxford, UK, and Instituto de Astrofisica de Andalucia, Spain, with support from the European Space Agency (ESA) and Centre National d'Etudes Spatiales (CNES).

A description of the MCD is given along with a comparison between spacecraft observations of Mars and results predicted at similar locations and times in the MCD.

The MCD can be used as a tool for mission planning and has been applied to prepare for several missions in Europe and the USA. It also provides information for mission design specialists on the mean state and variability of the Martian environment from the surface to above 120km. The GCMs on which the database is founded, include a set of physical parameterizations (radiative transfer in the visible and thermal infrared ranges, turbulent mixing, condensation-sublimation of CO_2 , thermal conduction in the soil and representation of gravity waves) and two different codes for the representation of large scale dynamics: a spectral code for the AOPP version and a grid-point code for the LMD version. The GCMs correctly reproduce the main meteorological features of Mars, as observed by the Mariner 9 and Viking orbiters, the Viking landers, and Mars Global Surveyor (MGS). As well as the standard statistical measures for mission design studies, the MCD includes a novel representation of large-scale variability, using empirical eigenfunctions derived from an analysis of the full simulations, and small-scale variability based on parameterizations of processes such as gravity wave propagation. The database allows the user to choose from 5 dust storm scenarios including a best guess, default scenario, deduced from recent MGS observations, an upper boundary for an atmosphere without dust storms, as observed by Viking the landers, and a clear, cold, lower boundary scenario, as observed by Phobos 2 and from Earth.

The full version of the MCD is available on CDROM (for UNIX systems and PCs) and is also accessible through an interactive WWW interface at http://www-mars.lmd.jussieu.fr/.

Development of the database:

First, the current state of knowledge of the Martian environment was reviewed, and two extant Mars GCMs were updated with various new parameterization schemes, validated wherever possible using observations. This task is described in [2]. Second, the GCMs were integrated over several annual cycles, using different dust distributions, and the output was collected and summarized in the form of a database. The mean atmospheric diurnal and seasonal cycles were captured by storing model fields at 12 times of day for each season, with the Martian year split into 12 seasons. Multiannual experiments were conducted for each dust scenario, and a separate set of statistics was accumulated in each case. These statistics give the climatological mean and variance for each field of interest, but it is also desirable for some purposes to be able to produce a realistic ensemble of individual profiles representing plausible instantaneous atmospheric states. This is achieved in the MCD by the application of statistical-dynamical models of the large-scale, day-to-day GCM variability within each season, for example, owing to weather systems, and the small scale motions which are often parameterized in a GCM, for example, vertically propagating gravity waves.

Database structure:

The variables stored in the database are: atmospheric temperature, zonal wind, meridional wind, atmospheric density, turbulent kinetic energy, surface pressure, surface temperature, surface emmisivity, CO_2 ice cover, and radiative fluxes. The database also includes time invariant fields of surface topographic height and subgrid-scale topographic standard deviation.

Temporal structure.

Some temporal averaging of the model output was performed in order to reduce the mass storage requirement. To resolve the large annual cycle observed in many variables such as surface pressure, the Martian year was split into 12 seasons of equal length in areocentric longitude, L_s , described in [1]. Within each season, mean values of each variable are stored at 12 universal times, in order to resolve the large Martian diurnal tide. Also, the diurnally averaged standard deviation of every variable is stored for each season in order to represent all the variability not associated with the mean diurnal cycle. Such variability is due both to the passage of weather systems and to any intraseasonal trend, for example, pressure variations resulting from the CO_2 condensation cycle.

Horizontal structure.

Variables in the database are written on a horizontal grid of 72 longitude points by 36 latitude points equally spaced by 5° in each direction. Surface topography is based on data from the Mars Orbiter Laser Altimeter (MOLA) aboard the MGS spacecraft.

Vertical Structure.

The database vertical coordinate, is based on the terrain-following σ coordinate, defined as $\sigma = p/p_*$, where p is the atmospheric pressure and p_* is the surface pressure. When using the database software, σ is converted to either pressure or geometric height using the surface pressure and integration of the hydrostatic equation using the local temperature profile. There are currently 32 vertical levels in the database.

Dust distribution scenarios:

The interannual variability in the Martian atmosphere is mainly related to the amount and distribution of suspended dust. Multiannual experiments were conducted to give statistics for all 12 seasons from several different years and multiannual model integrations were carried out for the database under three main dust scenarios: (1) the default, best guess, modeled on MGS observations, (2) seasonally varying dust, modeled on that observed during the Viking Lander years [3] but with large dust storms removed, and (3) low, uniform dust, appropriate to a clearer, colder Mars. The Viking dust scenario and the low-dust scenario provide the database with warm and cold extremes.

In addition to the full annual data sets, scenarios were conducted for several seasons with much higher dust loadings, appropriate to moderate and heavy dust storm conditions. There is good evidence [4] that the dust optical depth may exceed $\tau = 2$ during dust storms and reach $\tau = 5$ or greater; hence the inclusion of these scenarios in the database. The moderate, global dust storm scenario was conducted using parameters similar to those of the Viking scenario, with double the optical depth, peaking at $\tau = 2$. The heavy, global dust storm, was conducted as the $\tau = 2$ storm scenario but with the Viking scenario dust optical depth multiplied by five, to peak at $\tau = 5$.

Variability:

Large-scale variability model.

Mean fields in the MCD are stored once a season, a season being typically 50-70 days long. Although the component of the variability which is due to the diurnal cycle is largely captured by storing the seasonally averaged fields at 12 times of day, there may still be significant variation about the mean owing to, for example, motions of baroclinic weather systems. This large-scale, or model-resolved, variability is represented in the database using a novel approach based on empirical orthogonal function (EOF) analysis, for example used by [5]. This involves finding the eigenvalues and eigenvectors of the covariance matrix of a set of data vectors. The eigenvectors, or EOFs, form a linear basis for the data such that those with the largest eigenvalues account for the most variance. The "variance compression" nature of the EOFs means that one can reconstruct the main characteristics of the original data from a limited set of EOFs and corresponding time coefficients, sometimes called principal components (PCs). In the special case of data contaminated with uncorrelated noise, the EOFs separate the "signal" from the "noise".

It was necessary to compute multivariate EOFs of the main atmospheric variables: surface pressure, atmospheric temperature, zonal and meridional wind, and density. There is significant cross correlation between dynamical variables because the processes which generate such variability are often large-scale features, such as baroclinic waves with wave numbers in the longitudinal direction of typically one, two, or three. The two-dimensional, multivariate EOFs are computed within ranges of latitude grouped into 9 bins. Examples of simulated profiles and further details about this technique are described in [1], although the current 3.1 version of the database allows the variability to be represented with horizontal, as well as vertical, correlations.

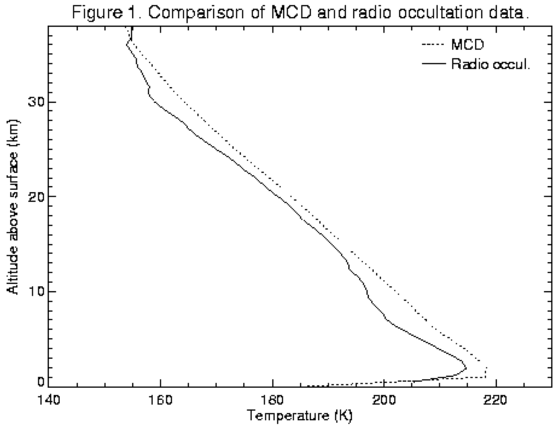
Small-scale variability model.

Small-scale vertically propagating inertia-gravity waves, can feed back on the large-scale circulation of the atmosphere and so a parameterization of these effects was introduced in the Mars GCM used to generate the database [2] [6]. A model was developed which simulates perturbations of density, temperature, and wind due to the upward propagation of small-scale gravity waves. The model is based on the parameterization scheme used in the GCM. More details can be found in [1].

Comparison with observations:

A comparison has been made between new spacecraft observations of Mars with results predicted by the MCD. Figure 1 shows an example of a radio occultation temperature profile from MGS observations in May 1999, $L_s = 137$, at 4:00 Mars local time, 29°N and 89°E, along with the MCD mean prediction using the default, MGS dust scenario. This figure shows a remarkably good correlation between the MCD results and the radio occultation data.

Figure 1. Comparison of MCD and radio occultation data.



Summary:

The MCD is a database used to predict the atmosphere and near-surface environment of Mars, used by both scientists and engineers. It contains a fully-consistent collection of statistics from an ensemble of multiannual simulations using a well verified model. The MCD includes a novel representation of large-scale variability and 5 dust storm scenarios. The database has been compared with a representative range of new spacecraft observations.

References:

[1] Lewis, S. R., *et al.* A climate database for Mars *J. Geophys. Res.*, 104, E10, pp 24,177-24,194, 1999.

[2] Forget, F., *et al.* Improved general circulation models of the martian atmosphere from the surface to above 80km *J. Geophys. Res.*, 104, E10, pp 24,155-24,176, 1999.

[3] Zurek, R. W., Martin, L. J. Interannual variability of plant-encircling dust storms on Mars *J. Geophys. Res.*, 98, pp 3247-3259, 1993.

[4] Zurek, R. W., *et al.* Dynamics of the atmosphere of Mars, in *Mars*, edited by Kieffer, H. H., *et al.*, pp 835-933, Univ. of Ariz. Press, Tucson, 1992.

[5] Mo, K. C., Ghil, M. Statistics and dynamics of persistent anomalies, *J. Atmos. Sci.*, 55, 877-901, 1987.

[6] Collins. M., *et al.* Gravity wave drag in a global circulation model of the Martian atmosphere: Parameterization and validation, *Adv. Space Res.,* 19(8), pp 1245-1254, 1997.