EIGHT MARTIAN YEARS OF DUST CLIMATOLOGY RECONSTRUCTED FROM SPACECRAFT OBSERVATIONS

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Introduction:

The dust cycle is currently considered as the key process controlling the Martian climate variability at interseasonal and interannual time scales, as well as the weather variability at much shorter time scales. The atmospheric thermal and dynamical structures, as well as the transport of aerosols and chemical species, are all strongly dependent on the dust spatio-temporal distribution, particle sizes, and optical properties. -In particular, local, regional and planet-encircling dust storms strongly affect the variability on a range of spatial and temporal scales. The enhanced absorption of solar radiation during a dust storm induces a local thermal forcing. This forcing (depending on its magnitude, extension, and location) can alter the dynamical state of the atmosphere, producing effects locally and remotely.

The knowledge of the spatio-temporal distribution of dust opacity is, therefore, of primarily importance to study the impacts on the atmospheric dynamics on Mars at short and medium time scales (the “weather”), as well as at long time scales (the “climate”). This knowledge can be acquired by reconstructing the long term climatology of the dust on Mars using all available observations.

In this paper, we describe the way by which the climatology of the column dust optical depth has been reconstructed for eight Martian years using most of the available spacecraft observations.

Reconstructed dust climatology:

We have reconstructed a multiannual climatology of airborne dust from Martian years (MY) 24 to 31 using multiple datasets of retrieved dust optical depths. The retrievals are based on observations of the Martian atmosphere from April 1999 to July 2013 by different orbiting instruments: the Thermal Emission Spectrometer on board Mars Global Surveyor (TES/MGS), the Thermal Emission Imaging System on board Mars Odyssey (THEMIS/MO), and the Mars Climate Sounder on board Mars Reconnaissance Orbiter (MCS/MRO). See Smith (2004) for TES retrievals, Smith et al. (2003), Smith (2009) for THEMIS retrievals, and Kleinboehl et al. (2009) for MCS retrievals.

The procedure we have adopted consists in gridding the available retrievals of column dust optical depth from nadir observations (TES and THEMIS), as well as the estimates of this quantity from limb and off-nadir observations (MCS). Our gridding method calculates averages on a regular but likely incomplete spatial grid for each sol, using weights in space, time, and retrieval uncertainty. In order to evaluate strengths and weaknesses of the resulting gridded maps, we associate values of weighted standard deviation to every grid point average, and compare to independent observations of column dust optical depth by Pancam cameras on board the Mars Exploration Rovers (MERs) ``Spirit" and ``Opportunity" (Lemmon et al., 2013), and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on board MRO (Wolff et al., 2011).

The application of the weighted gridding technique has the advantage of 1) combining available dust optical depth observations from several different instruments, including sparse observations like those from THEMIS, and 2) providing an estimate of uncertainties for each grid point.

The maps produced with the gridding technique are likely to have spatial and temporal gaps because of lack of observations. In order to produce complete gridded maps, we have spatially interpolated the incomplete maps using a kriging method under stated assumptions. These complete maps are used as dust scenarios in the Mars Climate Database (MCD) version 5.1 (Millour et al., 2013, this issue), and should be useful for many other applications.

A complete description of the methodology (including the validation), and an overview of the interannual variability of dust distribution is available, together with version 1.0 of the maps (Montabone et al., 2014).

Open access to the dust climatology:

The reconstructed dust climatologies based on weighted gridding and gridding+kriging are publicly available with open access, under Creative Commons Attribution-ShareAlike 3.0 Unported License.

This is an ongoing project at the Laboratoire de Météorologie Dynamique in Paris (France). The reconstructed maps of column dust optical depth are likely to be updated as long as new observations become available, old observations are reviewed, and gridding techniques are improved.

The latest available reconstructed dust climatology (now v1.0) can be downloaded from: http://www-mars.lmd.jussieu.fr/mars/dust_climatology/

Eight-years of dust inter-annual variability: Figure 1 shows zonal means of equivalent visible column dust optical depth normalized at the reference pressure level of 610 Pa, as a function of latitude and solar longitude for all eight available Martian years (MY 24-31). These zonal means are calculated from the daily maps of gridded column dust optical depths from TES, THEMIS, and MCS observations (using v1.0 beta). From these incomplete maps, complete maps can be obtained by using interpolation methods such as kriging (Figure 2 shows the zonal means of the complete kriged maps, v1.0 beta). We have to make few assumptions in order to fill some of the data gaps. Data assimilation using a dust transport model would allow calculating dynamically consistent dust distributions even during data gaps, although the Analysis Correction scheme, for instance, would not able to provide uncertainties on the gridded values. Even more sophisticated schemes, such as the Ensemble Kalman Filters, have to rely on the free-running model when the data gaps have a large spatial extension or long temporal interruption.

These zonal mean plots show a strong inter-annual variability in the dust distribution, which makes it difficult to define a "typical" or "average" dust scenario. This is the reason why the variability of the MCD is now built using dust scenarios from all available years, excluding the periods in MY 25 and MY 28 when planet-encircling dust storms occurred. Nonetheless, there are repeatable features in the zonal means plots, which characterize every Martian year during the perihelion season. These features, also mentioned in Wang et al. (2013) are:

1) the presence of an early equinoctial peak mostly created by dust lifted at the edge of the retrieving southern polar cap (southern baroclinic waves play a determinant role at this time of year);
2) A main peak of dust between L_s~220°-260°, originating from dust storms developing in the southern hemisphere or from cross-equatorial "flushing storms";
3) A "solsticial pause" around perihelion, when the dust loading substantially decreases and new dust storms become less likely (particularly the flushing storms, which are suppressed by the pause in northern baroclinic wave activity at low altitudes);
4) The presence of a late peak of dust opacity between L_s~320°-340°, mostly linked to the recovery of baroclinic wave activity and corresponding flushing storms.

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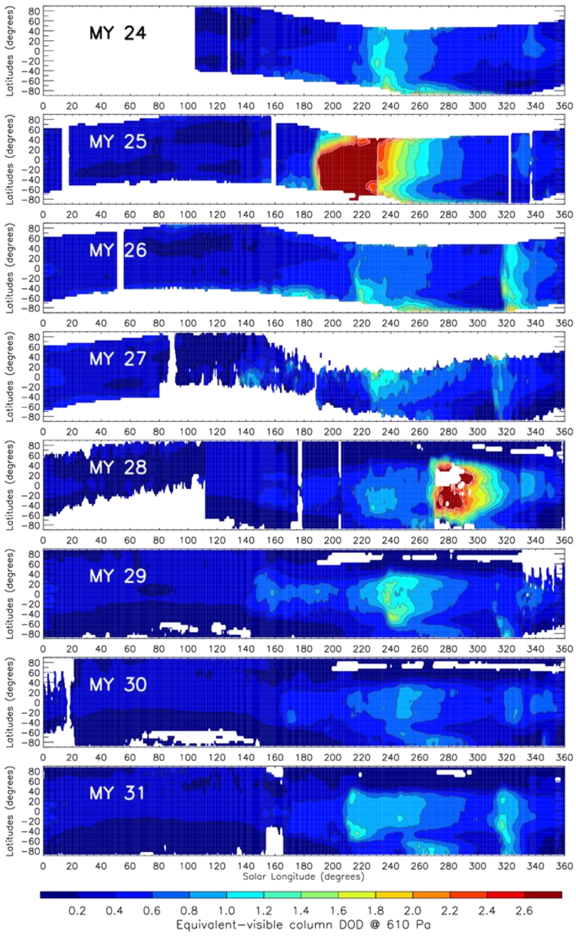

Figure 1: Zonal means of (equivalent visible) column dust optical depths at the reference pressure of 610 Pa using gridded maps (v 1.0 beta).

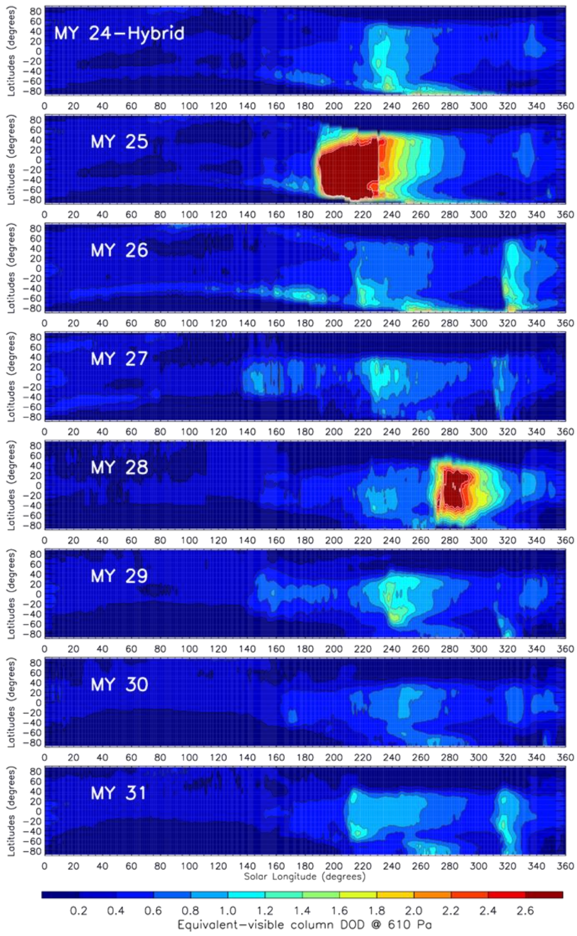

Figure 2: Zonal means of (equivalent visible) column dust optical depths at the reference pressure of 610 Pa using gridded+kriged maps (v 1.0 beta).