UPDATED ASSIMILATION OF DUST IN A MARTIAN GLOBAL CLIMATE MODEL

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Introduction:

Dust activity is a key component of the Martian atmosphere, and it can greatly change the atmospheric circulation during significant dust events. Measurements of atmospheric temperature and dust extending over nearly 8 Mars years (MY) are now available with unprecedented spatial coverage, thanks to various spacecraft in orbit around Mars since 1997. These include Mars Global Surveyor (MGS), Mars Odyssey (MO) and Mars Reconnaissance Orbiter (MRO). Those observations have already helped scientists to improve our understanding of the weather and climate on Mars. However, the intermittent nature of the measurements still restrains our ability to study the full details of the circulation, especially for those aspects related to dust activity. On the other hand, a numerical model can provide four-dimensional simulated data with high temporal and spatial resolution, but can scarcely represent the full variability of the dust cycle. In this context, a data assimilation system is an alternative approach to providing a four-dimensional solution consistent with both observations and modelled physical constraints.

The MGCM we use combines a spectral dynamical solver, a tracer transport scheme and dust lifting routines, developed in the UK, with a full range of physical parameterizations developed by the Laboratoire de Météorologie Dynamique (LMD; Paris, France) in collaboration with Oxford University, The Open University and the Instituto de Astrofisica de Andalucia (Granada, Spain). Based on this MGCM, previous attempts at data assimilation for Mars have been conducted without explicitly advecting a dust tracer field, mainly because the Thermal Emission Spectrometer (TES) on board MGS did not provide information on the vertical dust distribution. This data assimilation scheme has been applied in several studies [Lewis et al., 2005; Montabone et al., 2005; Montabone et al., 2006a; Montabone et al., 2006b; Lewis et al., 2007; Rogberg et al., 2010; Ruan et al., 2011] as an effective tool with which to analyze spacecraft observations and phenomena (e.g., atmospheric tides, dust distribution, weather predictability, etc.) in the Martian atmosphere.

Updated Data Assimilation System:

As the newly-available data from Mars Climate Sounder (MCS; carried on MRO) provides relatively detailed information on the vertical dust distribution, we have updated the data assimilation system to incorporate dust transport and dust lifting into the full assimilation of temperature and dust measurements. The assimilation of temperature profiles is followed by the assimilation of column integrated dust opacity, and then the assimilation of dust profiles. Through assimilating the temperature profiles (MCS retrievals), column integrated dust opacity (THEMIS retrievals; carried on MO) and dust profiles (MCS retrievals) the assimilation has been conducted for the period from solar longitude (L_s) $L_s = 110°$ of Martian Year (MY) 28 to $L_s = 330°$ of MY 29.

Overview of the Dust Opacity in the Assimilated Results:

Figure 1 shows the seasonal and latitudinal evolution of dust opacity from the assimilated results. Within a MY, the dust opacity is higher on a global scale during the second half of the year ($L_s = 180° - 360°$), while it is relatively "quiet" for the dust activities during the first half of the year ($L_s = 0° - 180°$). The interannual variability shown in the assimilated results is found to be essentially the same as the pattern found in the observations, and the initialization and duration of the planet-encircling dust storm that occurred around $L_s \approx 265° - 310°$ are both consistent with the THEMIS retrievals [Smith, 2009].

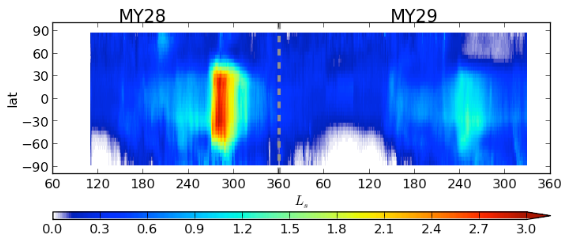

Figure 1 Seasonal and latitudinal evolution of the zonal averaged dust opacity from the assimilated results. The column-integrated dust opacity is rescaled to 610 *Pa* to remove the effect of topography.

Comparison against "Spirit" Pancam:

The measurements at the wavelength of 880 *nm* are rescaled to the reference pressure 610 *Pa*, and compared directly with the modeled sol-averaged total dust opacity (named *tauref*, also rescaled to 610 Pa). During the relatively "quiet" season for dust activity ($L_s = 0° - 180°$), the Spirit Pancam observations show that *tauref* is normally below 0.3 (Figure 2). A free-run simulation without data assimilation is run parallel with completely the same dynamics and physics parameters as those in the assimilation. During this season, the free-run simulation exhibits reasonable agreement with the "Spirit" Pancam data, especially in the "quiet" season of MY 29, but the assimilation shows more realistic overall variability. Dust events are more evident during the dusty season ($L_s = 180° - 360°$), and a planet-encircling dust event is observed in MY 28 when *tauref* exceeds 3.5 at the "Spirit" landing site, Gusev Crater. In the following MY 29, the dusty season was relatively mild. The free-run simulation generates high dust loadings in both dusty seasons with similar magnitude. In MY 28, the high dust loadings at Gusev Crater in the free-run simulation started earlier than in the "Spirit" Pancam observations, and the settling out of the dust loading took longer. The free-run simulation fails to reproduce the interannual variability in the following dusty season of MY 29. In the assimilation, the modeled high dust loading has a better agreement with the observations, and can capture the variability of *tauref* at Gusev Crater in both "quiet" and dusty seasons. The assimilation is able to reproduce the simultaneous initialization and decay of the episodes of high dust loading during the MY 28 planet-encircling dust storm, and it also models a less intense dusty season in MY 29.

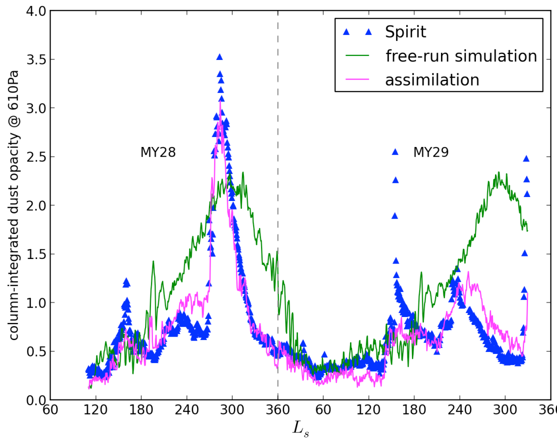

Figure 2 The comparison of modeled sol-averaged column integrated dust opacity against the obserbaion of "Spirit" Pancam. The column integrated dust opacities from observation and model are all rescaled to 610 Pa to remove the effect of topography.

Zonal Average of Dust Opacity:

The results of the assimilation, which are described here, show the ability to capture many aspects of the evolution of dust storms and to obtain a better agreement with the observed dust vertical distribution [Ruan et al., 2012]. Figure 3 demonstrates, for instance, that the assimilation of dust profiles can capture the presence of detached dust layers which was described by Heavens et al. [2011] using the MCS dataset and discussed by Spiga et al. [2013] in the context of simulations by a Mars mesoscale model.

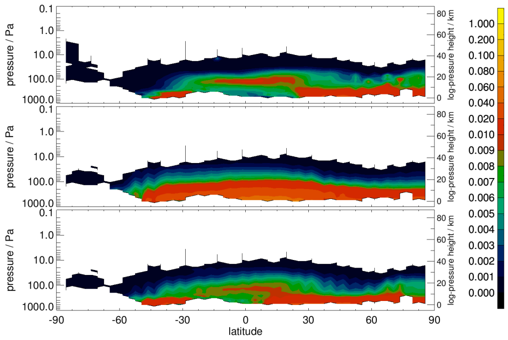

Figure 3 Zonal average of dust opacity (km^{-1}) at each retrieved level during night time (between local time 18:00 and 6:00). Top panel is for the MCS observations, middle panel is for the free-running simulation, and the bottom panel is for the assimilation. All the values are averaged over a 5° solar longitude time window (centered at $L_s = 122.5°$), and the model results are interpolated onto the same horizontal grid and vertical levels as the MCS retrievals before sampling at the retrievals' locations.

Summary and Conclusions:

The assimilation of column dust opacities with full dust transport is able to recover the spatio-temporal variability of dust opacity, especially in providing a reasonable magnitude of dust loadings during planet-encircling dust storm periods. This gives us some confidence in using the data assimilation system for the period in which only the measurements of column dust opacity are available. The assimilation of dust profiles enables the model to capture some of the details of the dust vertical distribution, especially the detached dust layers. Since data coverage is poor in the lower part of the atmosphere, assimilating the dust profiles together with a measure of column dust opacity can contribute to improving the agreement with dust observations. On comparison against independent rover data from "Spirit" Pancam, the assimilation is able to reproduce the seasonal and interannual variability of dust loadings observed at Gusev Crater. A full validation beyond the scope of this abstract shows that the reanalysis from this updated data assimilation system greatly reduces the model uncertainty of dust estimates.

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