Assimilation of Mars Climate Sounder Dust Observations: Challenges and Ways Forward

Conference or Workshop Item

ASSIMILATION OF MARS CLIMATE SOUNDER DUST OBSERVATIONS: CHALLENGES AND WAYS FORWARD

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Introduction: Atmospheric dust is ubiquitous on Mars, and as a result of its absorption and scattering of radiation, is the key driver of the martian circulation. Accurately representing the complex spatial and temporal distribution of dust is therefore crucial for understanding Mars' atmospheric dynamics. In particular, the vertical representation of the dust distribution in Mars' atmosphere has been shown to have a significant effect on results from modelling and assimilation [1,2,3]. With the goal of more accurately representing this distribution, the assimilation of dust vertical information is a valuable technique which is being increasingly explored [4,5]. However, it brings with it its own challenges and methodological questions to be explored.

Model and assimilation details: We use the LMD-UK Mars Global Circulation Model (MGCM), which solves the meteorological primitive equations of fluid dynamics, radiative and other parameterised physics to calculate the state of the martian atmosphere [6,7]. The UK version of the MGCM possesses a spectral dynamical core and semi-Lagrangian advection scheme [8], and is a collaboration between the Laboratoire de Météorologie Dynamique, The Open University, the University of Oxford, and the Instituto de Astrofisica de Andalucia. The model was run using a range of spectral and vertical resolutions, the latter spaced logarithmically. The assimilation scheme used was a modified version of the Analysis Correction scheme developed at the Met Office [9], adapted for use on Mars [10]. This method has the advantage of being computationally inexpensive, and its use of repeated insertion, weighted over a time window of about six hours, helps counter the issue of relaxation of the atmospheric state – an especially significant problem given the low thermal inertia of Mars' atmosphere.

Retrievals: The retrievals used in this study are from the Mars Climate Sounder (MCS) instrument aboard the Mars Reconnaissance Orbiter (MRO) [11], which now has amassed over five full martian years' worth of data. For this study, the assimilated MCS variables were temperature and dust profiles. Temperature profiles extend from the surface to approximately 100 km, and dust profiles from as low as 10 km above the surface up to a maximum height of approximately 50 km. Retrieval of dust profiles allows MCS to observe the complex vertical dust structure in the atmosphere. The retrieval version used is 5.2, a reprocessing using updated 2D geometry [12]. This results in improved retrievals, especially in the polar regions.

While not used in this study, the NOMAD instrument aboard ExoMars TGO will soon provide another high-volume source of dust profiles alongside MCS [13], and should return observations with an even higher vertical resolution.

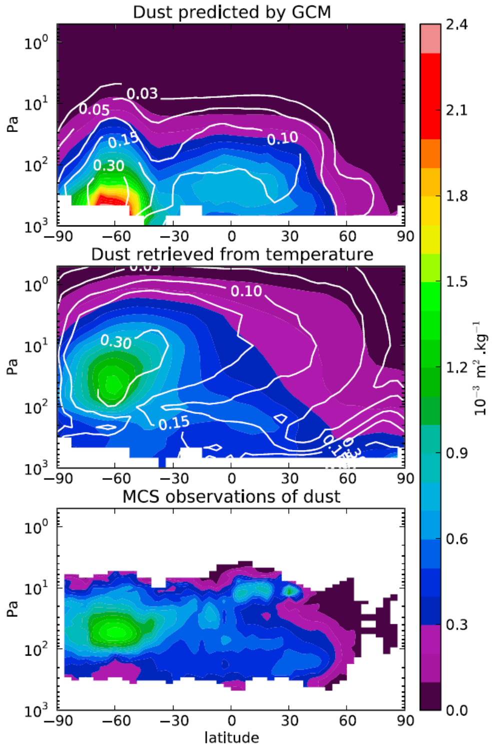

Figure 1: Model density-scaled dust opacity (DSO) at MY 29 between sols 587-590 in an assimilation of MCS data with (top) prescribed dust scenario and (middle) indirectly assimilating dust from its temperature signature, as compared to (bottom) nightside MCS retrievals [14].

Discussion: The assimilation of MCS dust profiles poses unique technical challenges, but presents the opportunity of representing Mars' vertical dust distribution with unprecedented spatial and temporal accuracy within a GCM. Some outstanding questions for further experimentation and discussion include:

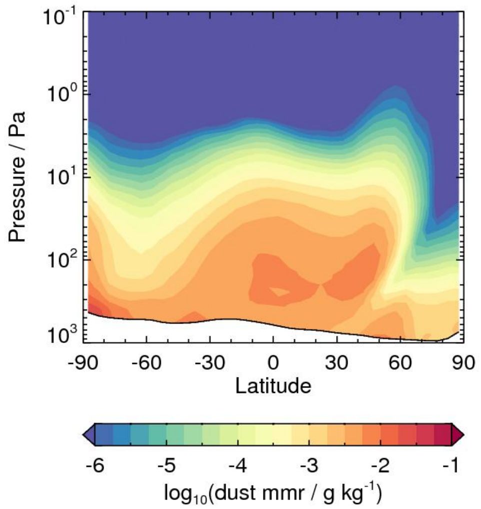

Figure 2: Zonal- and time-mean dust mass mixing ratio averaged over 5 sols around Ls 300 of MY26, from an assimilation of TES dust column optical depth. Dust is freely transported but scaled to match TES column values [15].

What are the optimal spatial and, in particular, vertical model resolutions for assimilation of this data?

Can dust profile assimilation aid in forecasting? Previous indirect assimilation of vertical dust via its MCS temperature signature has yielded a forecast time of 10 sols [5]; how dependent is this on the assimilation scheme and the choice of assimilating variables?

How should we approach the bimodal nature of MCS local times? Should we give higher weighting to nightside dust observations, which tend to have better vertical coverage due to reduced scattering? And how much can we validly infer from the high day-night variability seen in MCS dust profiles?

What are the best heuristics for filtering spurious opacities which could disrupt the assimilation, for example due to CO_2 ice or surface reflectance [16])?

What are the optimal ways of dealing with spatial and temporal gaps in the dataset?

How can we best represent the dust distribution beyond the range of MCS, especially in the lowest 5-10 km of the atmosphere?

What are the advantages and disadvantages of directly assimilating the dust field vs indirectly updating the dust field via its temperature signature, as seen in Fig. 1?

Dust profile assimilation has been used to track individual dust storm events [4]; what can this tell us about storm formation and evolution, and can it be used for storm forecasting?

How can we best constrain and validate the column optical depths of MCS dust profiles?

Some ways forward regarding these questions will be explored, including comparative reanalyses and validation against different orbital datasets. Comparisons against MCS and other retrievals (such as NOMAD) should provide insight into the advantages of various in-model representations of features such as the dust distribution as well as the possible advantages or disadvantages of pruning the assimilated dataset. Meanwhile, alternate orbital or even ground-based sources of column opacity (such as Mars Express and MSL) could help better constrain the distribution of dust not seen by MCS and offer clues how best to proceed in periods when MCS data is missing or limited. Some results of intercomparisons will be presented with the aim of fostering a more general discussion on MCS assimilation techniques.

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