MAPPING THE MARTIAN DUST CYCLE FROM ASSIMILATION OF SPACECRAFT OBSERVATIONS.

P. L. Read[1], Tao Ruan[1], A. Valeanu[1], R. M. B Young[1], S. R. Lewis[2] and L. Montabone[3].
[1]University of Oxford, UK (Atmospheric, Oceanic & Planetary Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, UK; peter.read@physics.ox.ac.uk), [2]The Open University, UK; [3]Space Sciences Institute, USA.

Introduction: The atmosphere and near-surface environment of Mars exhibits a highly dynamic climate and circulation on all space and time scales. Remote sensing observations of variables such as atmospheric and surface temperature, cloud aerosol and dust opacity provide information with global coverage and moderate resolution in space and time, but cannot resolve variations on horizontal scales < 100 km or close to the surface. In situ instrumentation on lander spacecraft provide much local detail, but lack the broader meteorological context. Both sources of data are fundamentally incomplete, however, since certain variables, such as surface pressure or vertical velocity, are difficult or impossible to derive directly from the measurements.

An alternative approach to the determination of the Martian climate has emergd recently with the application of meteorological data assimilation methods. Such an approach builds on techniques originally developed by the Earth meteorology and climate community, and seeks to combine sets of incomplete and noisy observations with comprehensive numerical simulations of the Martian atmospheric circulation and near-surface environment. The model simulation is typically constrained to evolve its atmospheric state to remain statistically consistent with available observations to within reasonable uncertainties.

Several groups in Europe and USA have recently deployed this approach successfully, using data from infrared sounding instrumentation on NASA's Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) spacecraft[1,2]. The results demonstrate the ablity of assimilation to capture accurately the day by day meteorological variability of the Martian meteorology, at least on large "synoptic" scales, allowing the compilation of a global climatology for Mars covering a number of Mars years. This has even led to the publication of a publicly accessible climae record for the whole of Mars, known as MACDA[3]. This approach is now being extended in Oxford and at the Open University in the UK to cover dust and water ice[4,5].

Dust Cycle: Dust storms and other processes lifting dust into the atmosphere are a major source of atmospheric variability on Mars at certain seasons of the year. The atmospheric dust loading is highly variable and needs to be taken into account in compiling an accurate climate record. Observations of dust opacity have been obtained from Mars orbit by infrared instruments on MGS, MRO and Mars Odyssey (MO).

Updated Data Assimilation System: In recent work at Oxford, we have extended our earlier Analysis Correction assimilation scheme[6] to include dust column opacity (from the THEMIS instrument on MO) and limb profile measurements (from the Mars Climate Sounder (MCS) on MRO) in assimilations that combine temperature and dust opacity retrievals using the UK version of the LMDGCM numerical model. The model is run with an active dust cycle that transports a radiatively active dust, whose concentration is updated by observational increments whenever these become available.

Through assimilating temperature profiles (from MCS retrievals), dust profiles (also from MCS retrievals) and column integrated dust opacity (obtained from THEMIS retrievals; carried on MO), the assimilation has been conducted for the period from solar longitude (L_s) $L_s = 110^\circ$ of Martian Year (MY) 28 to $L_s = 330^\circ$ of MY 29. This period includes coverage of some regional dust storm events as well as a major planet-encircling storm in MY28.

Overview of Dust Opacity Assimilated: Figure 1 shows the seasonal and latitudinal evolution of dust opacity from the assimilated results. Within a Martian year (MY), dust opacity is generally higher on a global scale during the second half of the year ($L_s = 180^\circ - 360^\circ$), while it is relatively clear for the first half of the year ($L_s = 0^\circ - 180^\circ$). 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 Global Dust Storm (GDS) that occurred around $L_s = 280^o – 300^o$ in MY28 are both consistent with the THEMIS retrievals [7].

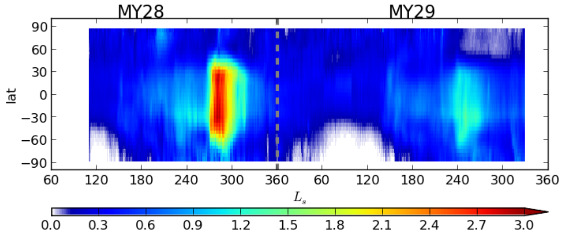

Figure 1 Seasonal and latitudinal evolution of the zonal averaged dust opacity from the assimilated results. The column-integrated dust opacity is rescaled to 610 Pa to remove the effect of topography.

Comparison with “Spirit” Pancam: The measurements from the Pancam instrument on the Spirit rover at a wavelength of 880 nm are rescaled to the reference pressure 610 Pa, and compared directly with the modeled and assimilated, sol-averaged total dust opacity (named $tauref$, also rescaled to 610 Pa). During the relatively “quiet” season for dust activity ($L_s = 0^\circ - 180^\circ$), the Spirit Pancam observations show that $tauref$ is normally below 0.3 (Figure 2). During this season, a free-running simulation for this period exhibits reasonable agreement with the “Spirit” Pancam data, especially in the “quiet” season of MY 29, but the assimilation shows much more realistic overall variability. Individual dust events are more evident during the dusty season ($L_s = 180^\circ - 360^\circ$), and a GDS is observed in MY 28 when $tauref$ exceeded 3.5 at the “Spirit” landing site in Gusev Crater. In the following year, MY 29, the dusty season was relatively mild. The free-running simulation for this period generates high dust loadings in both dusty seasons of similar magnitude. In MY 28, the high dust loading at Gusev Crater in the free-running simulation started earlier than in the “Spirit” Pancam observations, and the settling out of the dust loading took longer. The free-run simulation failed to reproduce the interannual variability in the following dusty season of MY 29. In the assimilation, the analysed high dust loading exhibits much better agreement with the surface observations, and captured the variability of $tauref$ at Gusev Crater in both “quiet” and dusty seasons. The assimilation is seen to reproduce the simultaneous initiation and decay of several episodes of high dust loading during the MY 28 GDS, and it also recovers a less intense dusty season in MY 29.

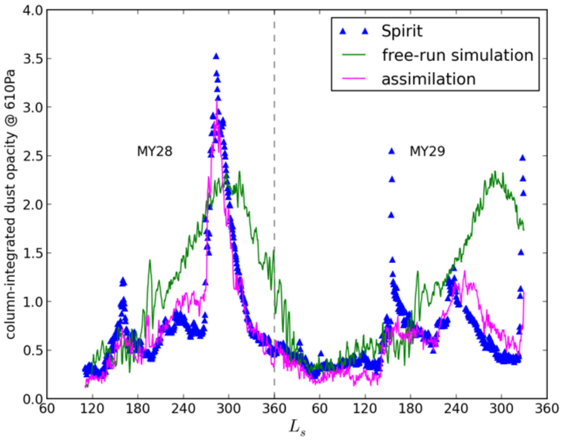

Figure 2 The comparison of modeled sol-averaged column integrated dust opacity against the obserbaion of “Spirit” Pancam. The column integrated dust opacities from observation and model are all rescaled to 610 Pa to remove the effect of topography.

Elevated dust layers: 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 much better agreement between the model and the observed dust distribution [5]. 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. [8] using MCS observations. Such elevated layers have proved very difficult to reproduce in free-running GCMs, although similar features may be captured using models at mesoscale resolution [9].

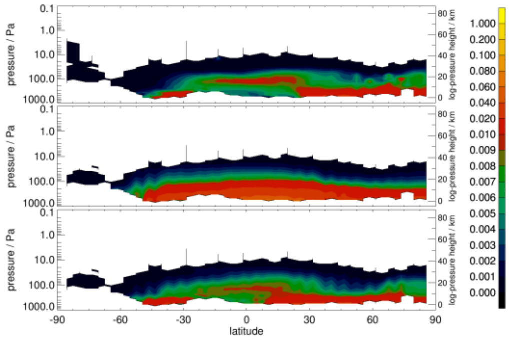

Figure 3 Zonal average of dust opacity (km^{-1}) at each retrieved level during night time (between local time 18:00 and 6:00). Top panel is for the MCS observations, middle panel is for the free-running simulation, and the bottom panel is for the assimilation. All the values are averaged over a 5° solar longitude time window (centered at $L_s = 122.5^\circ$), 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: In this presentation we will give an overview of the extended dust assimilation scheme and present some case studies which demonstrate its effectiveness in recovering the synoptic evolution of dust features in regional and larger dust storm events. We show that assimilation of column and limb dust opacities with full dust transport is able to recover the spatio-temporal variability of dust opacity, even when observational coverage of retrievals is incomplete. We also outline future plans to extend the analysis to cover the full MRO period and to include observations from ESA’s Trace Gas Orbiter.

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