INVESTIGATING THE ROLE OF ADVECTION PROCESSES IN IMPROVED MARTIAN DUST ASSIMILATION TECHNIQUES FOR EXOMARS

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Introduction:

Mineral dust is a vital component of the martian weather and climate system. Its presence heats the atmosphere, at the same time causing cooling at the surface. While dust storms occur on Earth as well, Mars' lack of oceans and significantly lower thermal inertia means that the storms there can last up to weeks, rapidly reach global scale, and cause greater temperature variations (Haberle, Conway, & Pollack, 1982) (Read, Lewis, & Mulholland, 2015). Understanding martian dust's characteristics and transport is therefore key for planning and conducting future activity on Mars.

A valuable new source of dust observations will be soon be available following the successful orbital insertion of ExoMars' Trace Gas Orbiter (TGO), which will begin its science phase in March 2018. TGO will provide higher resolution vertical profiles of the atmosphere in general, and of atmospheric dust opacity in particular, especially from the ACS and NOMAD instruments. These observations will be integrated with the Open University's existing Mars General Circulation Model (MGCM) using a technique called data assimilation, which can constrain the model and help obtain the best possible representation of the Martian atmosphere (Lahoz, Khattatov, & Menard, 2010). Fig.1 illustrates the power of this technique in reconstructing atmospheric states from irregular data. Data assimilation techniques will be tested and validated using existing observations from the Mars Climate Sounder (MCS), in preparation for use with TGO data.

Previous work:

Current data assimilation schemes use observations from the Thermal Emission Spectrometer (TES), the Thermal Emission Imaging System (THEMIS), and the Mars Climate Sounder (MCS). Fig. 2 is an example of results from an assimilation of TES dust optical depth, assimilated with an analysis correction scheme adapted from the Met Office (Lorenc, Bell, & Macpherson, 1991) and using persistence forecasting, in which the dust field is kept constant when no direct observations are available (Lewis et al., 2007). Even with the irregular coverage and observations from the aerobraking phase of TES, with its orbital period of a day, data assimilation allows for the creation of a globally self-consistent atmospheric model, and therefore for the inference of non-observed variables such as wind speed. A further example of this is Fig. 3, which demonstrates a verti-

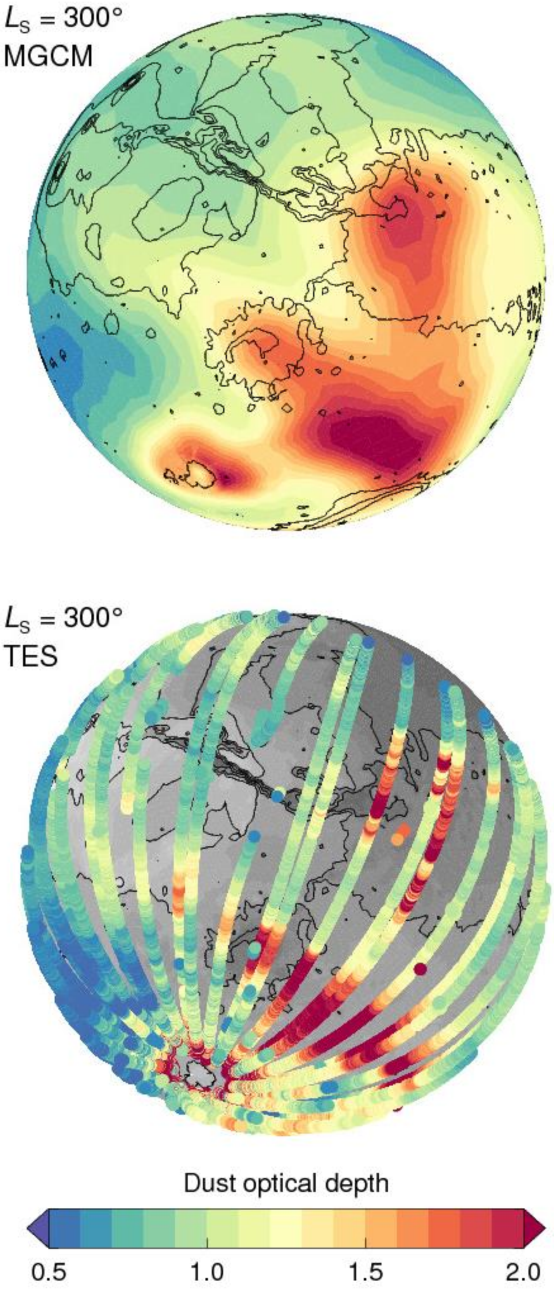

Figure 1: Top panel: total dust visible optical depth output for MGCM with TES dust data assimilated over a 5-sol period centred on L_s = 300, MY 26. Bottom panel: total dust visible optical depth observations from TES over the same period. The grey shading indicates topography.

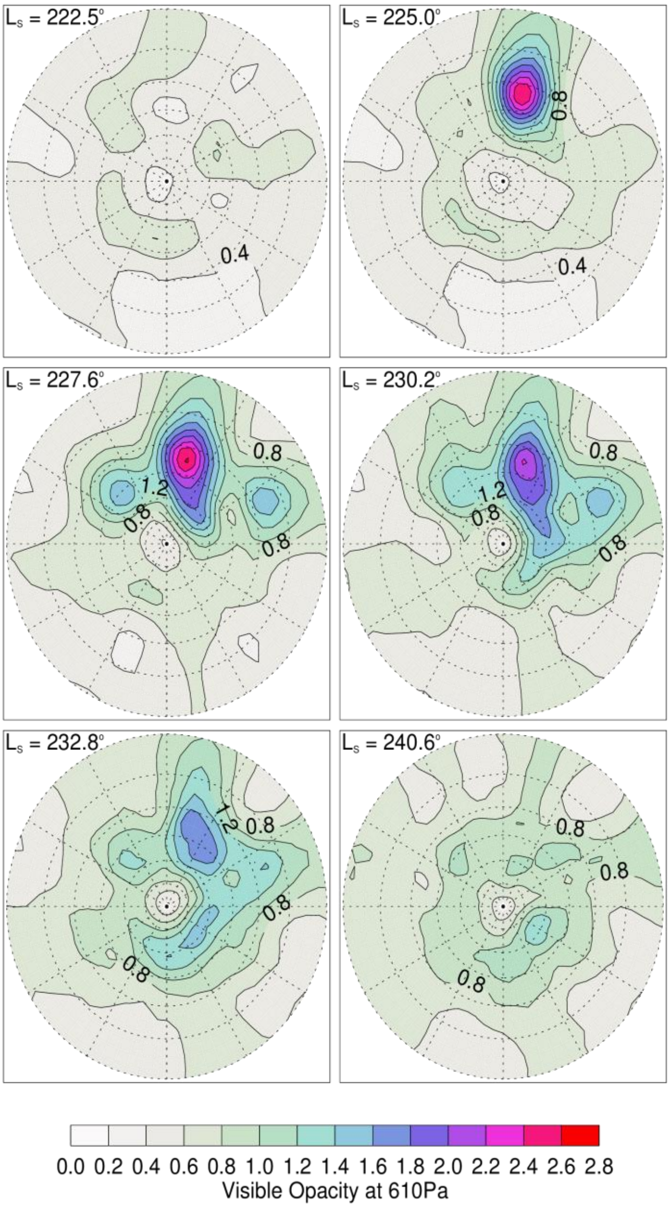

Figure 2: Total dust visible optical depth from the model assimilation, normalized to 610 Pa to remove topographic effects, for a sequence surrounding the onset and decay of the Noachis dust storm. Reading from upper left to lower right the intervals between the plots are 4, 4, 4, 4 and 12 sols. The plots are polar stereographic with the south pole at the centre, the equator at the edge, the prime meridian pointing upward and a grid spacing of 15 in latitude and 30 in longitude. (Lewis et al., 2007)

cal dust profile constructed by allowing dust transport in the MGCM but scaling the results to match total dust visible optical depths observed by TES and THEMIS. While TES/THEMIS data itself only gives a patchwork of total dust opacities, using the data to constrain dust transport can reproduce some important features of the Martian climate; for example, the collar of low dust density at approximately 60 degrees latitude matches where the south to north meridional circulation descends to the surface (Read, Lewis, and Mullholland, 2015).

While valuable, TES observations have limitations in the vertical which restrict the use of more realistic dust transport schemes. Currently, only MCS conducts significant limb observations from which vertical profiles can be reconstructed, but they often lack valid values for dust opacity near the Martian surface (Montabone et al., 2015). This relative paucity of vertical dust distribution measurements contributes to the fact that most assimilation schemes and dust scenarios are 2D only, working with the horizontal distribution of column dust optical depth (CDOD) and using the standard Conrath distribution to model vertical opacity, which assumes well-mixed dust (Conrath, 1975). However, observations from TES and MCS have confirmed the existence of discrete dust layers of enhanced opacity, suggesting that the well-mixed assumption does not necessarily hold (Guzewich at al., 2013).

In addition, to date dust advection has been treated simply in attempts to assimilate Martian data. For example, the current Mars Analysis Correction Data Assimilation Database (MACDA), as well as analytically prescribing vertical dust distribution, does not use the MGCM's ability to lift and transport dust to assimilate observations. Instead, it uses a persistence forecasting approach for the dust field (Montabone et al., 2014). Montabone et al.'s 2015 dust climatology uses spatial kriging with a time-dependence to represent possible dust motion during delays between observation times, but likewise does not include a dust transport model (Montabone et al., 2015). Greybush et al. conducted a an ensemble-based reanalysis of TES thermal profile data, but using a dust field prescribed to vary seasonally rather than by fully assimislating dust opacities from TES (Greybush et al., 2012). Navarro et al. successfully reproduced detached dust layers without relying on the Conrath assumption; however, dust distributions were estimated by assimilating thermal profile observations (Navarro et al., 2014).

Proposed work:

Some work has already been done by Ruan et al. using 2-D data assimilation with full transport of the dust mass mixing ratio, yielding improved representation of the top of the atmospheric dust layer (Ruan, Montabone, Read, & Lewis, 2012). Further work by Ruan et al. explicitly advects dust while using MCS vertical profile data to track dust storms, yielding new results not apparent from the data or MGCMs alone; for example, the ability of storms to transport dust up to 30 km during their evolution (Ruan et al., this meeting). While simple statistical methods for assimilation such as gridding may be easier and more generally applicable (Montabone et al., 2015), the results from Ruan and others suggest that more realistic dust advection schemes are a promising avenue for further research; especially in preparation for new TGO data, and to replicate results such as detached dust layers in the upper atmosphere.

However, the question of how exactly to fully couple winds and dust distribution remains an area open for investigation. Some possible methods of modelling dust transport and coupling dust metrics/parameters to wind will be tested on the MGCM and compared with existing assimilation schemes and free-running simulations, with an eye (following Ruan) to a fully 3-D dust assimilation. This would allow for the full exploitation of current and future vertical profiles. A further aim for this project would be to extend the wind-dust coupling to predict dust lifting through surface wind stress and/or dust devil activity. Model uncertainties and robustness can be estimated through ensemble forecasting. A realistic, coupled advection scheme for dust data assimilation combined with greater observational coverage could offer new insights into Martian dust transport and atmospheric behavior.

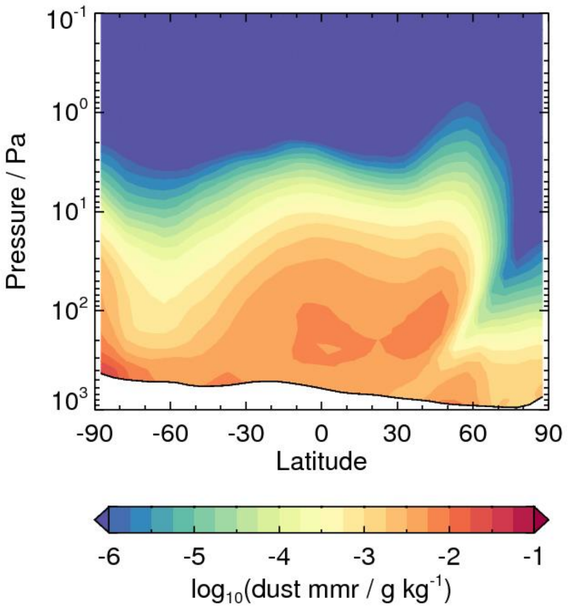

Figure 3: Zonal- and temporal-mean dust mass mixing ratio (averaged over same time period as Fig. 1), taken from an MGCM in which dust is transported but scaled to match the TES/THEMIS dust optical depth maps of Montabone et al. (2015). The black line at the bottom of the plot indicates the zonal-mean surface pressure.

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