The circulatory impact of dust from dust profile assimilation

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Introduction: We present results from a reanalysis of temperatures, dust columns and dust vertical profiles focussing on the assimilation, distribution and transport of dust in the martian atmosphere. The assimilation of dust vertical information in particular is a valuable technique which has has been shown to be of vital importace to a successful assimilation of the martian atmosphere [1,2], with the vertical representation of the dust distribution having a critical effect on assimilation results generally [3,4,5].
Atmospheric dust is a key driver of the martian circulation. Dust-induced heating and cooling is a potential feedback mechanism for dust lifting, for example, and can modify the circulation to either enhance or suppress dust storm activity [6]. Accurately representing its complex spatial and temporal distribution is therefore crucial for understanding Mars' atmospheric dynamics and transport.

Model and Assimilation: We use the LMD-UK Mars Global Circulation Model (MGCM), which solves the relevant equations of fluid dynamics and radiative physics to calculate the state of the martian atmosphere [7,8]. The UK version of the MGCM possesses a spectral dynamical core and semi-Lagrangian advection scheme [9], and is a collaboration between The Open University, the University of Oxford, and the Instituto de Astrofisica de Andalucia. The model was run using a spectral resolution of T31, corresponding roughly to grid boxes of 5 degrees latitude by 5 degrees longitude at the equator, and 35 vertical levels extending from 0 to 100 km above the surface (spaced logarithmically).
The assimilation scheme used was a modified version of the Analysis Correction scheme developed at the Met Office [10], adapted for use on Mars [11]. This method has the advantage of being computationally inexpensive and its use of repeated insertion helps counter the issue of relaxation of the atmospheric state.

Retrievals: The retrievals used in this study are from the Mars Climate Sounder (MCS) instrument aboard the Mars Reconnaissance Orbiter (MRO) [12]. MCS retrievals start from 2007, meaning that there is significant overlap with retrievals from instruments on Mars Express. 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 upwards. Retrieval of dust profiles allows MCS to observe the complex vertical dust structure in the atmosphere. The retrieval version used is 5.2, a re-processing using updated 2D geometry [13]. This results in improved retrievals, especially in the polar regions.

Results: To fully investigate the effect of a realistic vertical dust distribution on the circulation, a control assimilation was run using just temperatures and dust columns, with the MGCM being allowed to set the vertical dust distribution ("2D reanalysis"). This was compared to an assimilation of temperatures, dust columns, and dust profiles ("3D reanalysis").
Results show a significant difference between the 3D reanalysis and the 2D reanalysis. An example is presented in Figure 1, which shows temperature and zonal wind speeds for southern winter solstice. Figure 1b shows the difference between the 3D and the 2D reanalyses, revealing significant changes throughout the atmosphere. Most noticeably, tropical to northern high-latitude temperatures between 5 and 45 km are significantly increased in the 3D case, due to the greater representation of atmospheric dust in the MCS retrievals at those altitudes compared to the MGCM. The degree of polar warming above the south pole is also enhanced, as is the westerly jet circumscribing the southern polar vortex. In general, we see a stronger atmospheric circulation, including greater near-surface wind speeds.
The results suggest that the current MGCM underestimates dust quantities above the bottom 10 km of the atmosphere, and that better representation of this distribution has a significant impact on the circulation and transport. In particular, higher-altitude dust acts to meridional mass transport changes due to seasonal obliquity, leading to a consistently longer-lived and stronger tropical Hadley cell in the 3D case. This altered circulation has significant implications for the transport of aerosols and trace gases in the martian atmosphere.

Summary and future: Better model representation of the vertical dust structure has significant impacts on Mars' circulation and atmospheric transport. In particular, dust quantities above the planetary boundary layer are underestimated in the MGCM; a greater dust presence presence above the PBL appears to both enhance the overall circulation and cause complex changes in the meridional transport cell structure. This has implications for tracer transport.

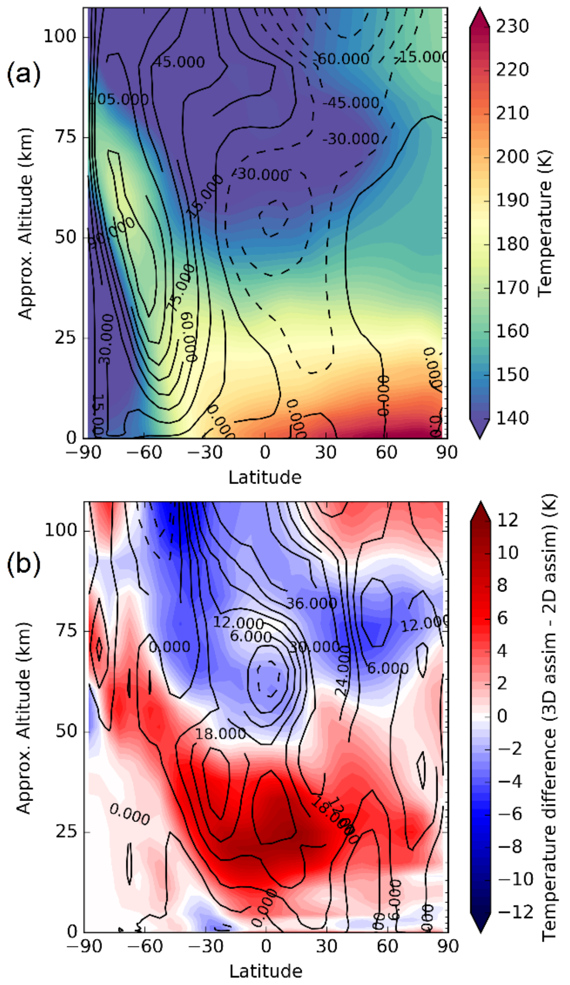

Figure 1: (a) Assimilated zonally averaged temperature and zonal wind speed around L_S 90 for the 3D reanalysis and (b) absolute difference in temperature and zonal wind speed between 3D reanalysis and 2D reanalysis over the same time period.

The NOMAD instrument aboard ExoMars TGO will provide another high-volume source of dust profiles alongside MCS [14], and should return observations with an even higher vertical resolution. In addition, NOMAD will return observations over a range of martian local times, in contrast to MCS's fixed day-night local times. NOMAD retrievals represent a valuable opportunity to further investigate the vertical dust structure of the atmosphere, including the possibility of cross-validation and joint assimilation with MCS to maximise local time and spatial coverage.

References:

[1] Ruan, T., DPhil Thesis, 2015.
[2] Navarro T. et al., ***Earth and Space Sci.***, In Press.
[3] Lewis, S. R. et al., ***Icarus*** *192 (2),* 327-347, 2007.
[4] Rogberg, P. et al., ***QJRMS*** *136,* 1614-1635, 2010.
[5] Greybush, S. J. et al., ***JGR.*** *117,* E11008, 2012.
[6] Newman, C. E. et al., ***JGR*** *107,* 5124, 2002.
[7] Forget, F. et al., ***JGR*** *104,* 24155-24175, 1999.
[8] Madeleine, J.-B. et al., ***JGR (Planets)*** *116,* E11010, 2011.
[9] Newman, C. E. et al., ***JGR*** *107,* 5123, 2002.
[10] Lorenc, A. C. et al., ***QJRMS*** *117,* 59-89, 1991.
[11] Lewis, S. R. et al., ***Icarus*** *192*, 327-347, 2007.
[12] McCleese, D. J. et al., ***J. Geophys. Res.*** *115,* E12016, 2010.
[13] Kleinböhl, A. et al., ***J. Quant. Spectrosc. Radiat. Transfer*** *187,* 511-522, 2017.
[14] Patel, M. R. et al., ***Appl. Opt.*** *56 (10)*, 2771-2782, 2017.

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