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Modelling radiatively active water ice clouds in the Martian water cycle

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Introduction

Aerosols, both water ice and dust, play a key role in the Martian climate. However, our understanding of the interactions between dust and water ice clouds, and the distribution and properties of dust is currently incomplete.

Water ice clouds have been observed at many locations in the Martian atmosphere, and they occur in many different guises, such as polar night clouds, equatorial clouds and ground fogs. The largest spatial distribution of clouds belongs to the aphelion cloud belt, which appears during northern hemisphere spring and summer each year in a zonal band between around 10° S and 30° N [1, 2].

In this paper, we demonstrate the potential impact of water ice clouds on a Mars Global Circulation Model (MGCM), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of Mars Climate Sounder (MCS) observations to test the sensitivity of the model to the atmospheric temperature, and to validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCM simulations

It is known that cirrus clouds in the Earth’s atmosphere can scatter and absorb incoming solar radiation, and absorb and emit thermal infrared radiation, causing a warming of the atmosphere [3, 4]. Therefore, due to the presence of water ice clouds in the Martian atmosphere, it is necessary to take into account their radiative effects in MGCMs.

The current LMD MGCM [5] run in the UK uses a spectral dynamical core, and includes a simplified water cycle in which there is atmospheric transport of water vapour and ice, a bulk cloud scheme, and interaction with the Martian regolith [5, 6]. However, in the model run in the UK, the water ice opacity is not yet coupled with the MGCM radiation scheme, so absorption of visible/infrared radiation by the water ice clouds is not taken into account. This absorption of radiation has been identified as being potentially significant in the equatorial middle atmosphere of Mars around aphelion, when the planet-circling cloud belt forms [8]. As can be seen in Figure 1, it appears as though the downward infra-red radiation emitted by the aphelion cloud belt is introducing a warming of the atmosphere not accounted for in the model.

Sensitivity analysis of the model to dust distribution

Due to the radiative effects of dust, its temporal and spatial distribution will have a large effect on other atmospheric properties. To test the sensitivity of the MGCM to the distribution of dust, two simulations have been run using the UK version of the LMD MGCM.

The two dust schemes used in the independent simulations are derived from assimilations of TES dust total-day photography. They used identical initial conditions. None of the plots accurately portray the southerly circulation of clouds, though such simulations have not yet been carried out.

Above around 40 km, there is no data from the TES, and so the profiles are less secure. Even so, it can be seen that the assimilation of volatiles improves the output of the MGCM. This may be expected as the assimilation includes the radiative effects of clouds, unlike the current UK version of the model. Strong temperature inversions can be seen close to the ground in the model simulations, but these are not apparent in the MCS or MCD profiles, as they are too close to the surface to be resolved by the instruments.

As has been seen, the distribution of dust in the MGCM has a large impact on atmospheric temperature. It would also therefore be expected to influence the temporal and spatial distribution of clouds, though such simulations have not yet been carried out.

As well as comparing the two simulations with each other, we have also carried out comparisons with observations from the MCS and modelled data from the MCD, which is used as a convenient summary of model experiments from the LMD MGCM. Figure 5 shows mean vertical profiles of temperature at varying latitudes from; (a) MY25 simulation using 2003 dust scheme; (b) MY24 simulation using 2005 dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; and (d) modelled data from the MCD v3. (Panels (d) and (e) are from [9]).

Sensitivity of the model to dust distribution

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Figure 1. (a) Seasonal evolution of zonally averaged equatorial temperature bias over the course of the MGS mapping mission; (b) 120°E, 150°E and 180°E meridional cross sections of dust distribution, 185°K isotherm and approximate height of cloud condensation level respectively. (b) Seasonal evolution of zonally averaged temperature bias at 0.5 KPa [8].

Figure 2. Difference in dust column visible opacity between simulations run with different TES dust schemes (2005 – 2003), averaged over L= 120°E, 150°E.

Figure 3. Difference in temperature between simulations run with different TES dust schemes (2005 – 2003), averaged over MY24.

Figure 4. Plots of the meridional mass streamfunction (MMS) averaged over an entire Martian year are shown in Figure 4. The MMS from both the simulations and the modelled data from the Mars Climate Database (MCD) shows the dominance of the northerly circulation, though the temperature bias from the MCD is not as strong as that from the assimilation.

Figure 5. Mean vertical profiles of temperature at varying latitudes from; (a) MY25 simulation using 2003 dust scheme; (b) MY24 simulation using 2005 dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; and (d) modelled data from the MCD v3. (Panels (d) and (e) are from [9]).