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 the atmosphere and the surface (solar ice caps, frost) in the atmosphere (vapour, 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 hood clouds, cirrus 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 around 10° S and 30° N [1, 2].

In this poster, we demonstrate the potential impact of water ice clouds on a Mars Global Circulation Model (MCMG). We use independent model experiments and assimilations of TES data to evaluate the modelled meteorological processes and 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 [6,7]. 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 and middle latitudes of Mars around aphelion, when the planet-clouding 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 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 and water ice clouds, two simulations have been run using the UK version of the LMD MGCM.

The two dust schemes used in the independent experiments are derived from assimilations of TES total dust opacity. They are based on earlier and revised retrievals, henceforth denoted as 2003 and 2005 dust schemes. As opposed to the initial schemes, both simulations used identical initial conditions.

Figure 2 shows the difference in visible dust opacity averaged over Mars month 5 for both dust schemes. As can be seen, the 2005 dust scheme shows increased opacity, especially at southern latitudes, partly due to the increased dust opacity, mainly at southern latitudes, derived from the new, 2005 dust scheme.

Above around 40 km, there is no data from the TES, and so the profiles are less accurate. Even so, it can be seen that the assimilation of volatiles improves the output of the MGCM. This will be supported by the assimilation of the radiative effects of dust, unlike the current UK version of the model. Strong temperature inversions can be seen close to the surface 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.

Figure 6 compares the temperature profile near the south pole in more detail. As can be seen immediately, the profiles from the simulation with the new dust scheme and the assimilation are in much closer agreement with the MCS observations than the profile from the model. The lower temperature close to the pole is not apparent in the simulation, but the middle atmospheric warming agrees well with the MCS plot.

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.

Figure 3. Difference in temperature between simulations run with different TES dust schemes (2005 – 2003), averaged over MY 24, for a zonal average at 5° S and 30° N.

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 dynamics of the atmosphere, though the increased polar warming from the MCD is not as strong as that from the assimilation. None of the plots accurately portray the southerly circulation that is present in the assimilation as a result of the increased dust opacity. The two simulations using the 2003 and 2005 dust schemes do show stronger, southerly circulation than that from the MCD, but it is still weaker than in the assimilation.

Project aims

The project will model the Martian water cycle, including radiatively active water ice clouds, to interpret new observations from MCS. We will be using the latest version of the LMD MGCM, which includes the new LMD physics routines. A unique data assimilation system [10] will be used to obtain a complete, dynamically self-consistent reconstruction of the extraterrestrial circulation for the complete period of the MCM mission. A further diagnostic study will be made to characterise the climatology and synoptic meteorology of Mars over seasonal and interannual timescales, including detailed case studies of events such as the formation of cyclogenetic weather systems. The assimilation results can be used to test the validity of the new cloud schemes introduced to the model, improving our understanding of the Martian water cycle.

Acknowledgements

The authors thank L. Montabone and D. Muhiollad for their assistance with the model simulations.

References: