Modelling Radiatively Active Water Ice Clouds in the Martian Water Cycle

How to cite:

Link(s) to article on publisher’s website:

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.

oro.open.ac.uk
Modelling radiatively active water ice clouds in the Martian water cycle

L. Steele1, S. R. Lewis2, M. R. Patel2 and R. J. Wilson3

1Department of Physics & Astronomy, The Open University, MK7 6AA, UK
2Planetary and Space Sciences Research Institute (PSSRI), The Open University, MK7 6AA, UK
3Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA

Email: L.Steele@open.ac.uk

Introduction

Aerosols, both water ice and dust, play a key role in the Martian climate. However, our understanding of the interactions between these two components is incomplete, especially as far as the surface (Solar ice caps, frost) in the atmosphere (vapour, ice clouds), and the distribution and properties of dust is currently unknown.

Water ice clouds have been observed at many locations in the Martian atmosphere, and they occur in many different forms, such as polar hood clouds, cirrus clouds and ground fog. 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 poster, we demonstrate the potential impact of water ice clouds on a Mars Global Circulation Model (MGCMM), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of Mars Climate Sounder (MCS) retrievals and validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCMM 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 MGCMMs.

The current LMD MGCMM [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 middle atmosphere of Mars around aphelion, when the planet-venying 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 MGCMM to the dust distribution, two simulations with different dust distributions have been run using the UK version of the LMD MGCMM.

The two dust schemes used in the independent simulations are derived from assimilations of TES dust total dust opacity. They are based on earlier and revised retrievals, and have been run using the UK version of the LMD MGCMM.

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 MGCMM to the dust distribution, two simulations with different dust distributions have been run using the UK version of the LMD MGCMM.

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 Mars Climate Database (MCD). Figure 5 shows mean vertical profiles of temperature at varying latitudes from (a) MY24 simulation using 2003 dust scheme; (b) MY24 simulation using 2005 dust scheme; (c) MCD; (d) modelled data from the MCD v3. (Panels (d) and (e)) are from [9].

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 MGCMM. This can 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.

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 MCD. The lower temperature close to the pole in the simulation are apparent, but the middle atmosphere warming agrees well with the MCS plot.

As has been seen, the distribution of dust in the MGCMM 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.

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 MGCMM, 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 entire global circulation for the entire period of the MCD mission. A series of diagnostic studies 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 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. Muilholland for their assistance with the model simulations.

References:

Figure 1. (a) Seasonal evolution of zonally averaged equatorial temperature bias over the course of the MGS mapping mission; (b) northern and southern hemispheres; (c) assumed dust distribution; 185° K isotherm and approximate height of cloud condensation. (d) Seasonal evolution of zonally averaged temperature bias at 65.6 Pa [9].

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

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

Figure 4. 3. Plots of the meridional mass streamfunction (10^14 kg/s), zonally and time-averaged over a Martian year for (a) modelled data from the MCD; (b) MY24 simulation with 2003 dust scheme; (c) MY24 simulation with 2005 dust scheme; and (d) MY25 assimilation using TES thermal and dust retrievals.

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

Figure 6. Daytime and night time temperature profiles for southern hemisphere mid-winter from: (a) modelled data from the MCD; (b) MY24 simulation using 2005 TES dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; and (d) MCD with retrievals mean local times 03:16 LST and 15:36 LST. (Panel (d) from [9]).