Modelling Radiatively Active Water Ice Clouds in the Martian Water Cycle

How to cite:

For guidance on citations see FAQs.

© 2011 The Authors

Version: Version of Record

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. Steele, S. R. Lewis, M. R. Patel and R. J. Wilson

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 on the surface (polar 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, cirriform 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 (MGCN), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of Thermal Emission Spectrometer (TES) retrievals and validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCN 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 MGCN simulations.

The current LMD MGCN [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 MGCN 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-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.

Figure 1. (a) Seasonal evolution of zonally averaged equatorial temperature bias over the course of the MGS mapping mission; (b) Northern and Southern Hemisphere dust distribution (black); (c) Northern and Southern Hemisphere dust distribution (blue). 185° K isotherm and approximate height of cloud condensation level respectively. (b) Seasonal evolution of zonally averaged temperature bias at 0.5 hPa [6].

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 MGCN to the total dust distribution, a series of simulations with altered dust distribution, 185° K isotherm and approximate height of cloud condensation level respectively. (c) Seasonal evolution of zonally averaged temperature bias at 0.5 hPa [6].

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

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

Figure 2. 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 globally, particularly in the southern hemisphere poleward of around 40° S.

Figure 2. Difference in dust column visible opacity between simulations run with different TES dust schemes (2005–2003), averaged over Mars month 5.

As well as comparing the two schemes 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) MY24 simulation using 2005 dust scheme; (b) MY24 simulation using 2003 dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; (d) MCS limb retrievals and (e) modelled data from the MCD v3. (Panels (d) and (e) are from [6].

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

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 MGCN. This is to be expected at 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 too close to the surface to be resolved by the instruments.

Figure 4. Plots of the McMurdo mass streamfunction (10^11 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.

As has been seen, the distribution of dust in the MGCN 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 6. Daytime and night time temperature profiles for southern hemisphere mid-winter from: (a) modelled data from the MCD; (b) MY24 simulation using 2005 dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; (d) MCS limb retrievals with mean local times 09:16 LST and 15:18 LST. (Panel (d) from [6].

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 climate for the complete period of the MGS mission data. 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 cyclonic 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. Muhiold for their assistance with the model simulations.

References: