Modelling Radiatively Active Water Ice Clouds in the Martian Water Cycle

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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 the ice clouds 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, ice caps, clouds and ground fogs. The largest spatial distribution of clouds belongs to the aphelion cloud belt, which apparently occurs 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 (MGCMA) and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilation of Thermal Emission Spectrometer (TES) retrievals to validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCMA 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 atmospheric structure [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 MGCMA.

The current LMD MGCMA [9] 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 MGCMA radiation scheme, so absorption of visible/near 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-encircling cloud belt forms [8]. As can be seen in Figure 1, it appears as though the downward intra-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 MGCMA to the diurnal zonal distribution of dust, a series of simulations has been run using the UK version of the LMD MGCMA.

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 denoted as 2003 and 2005 dust schemes. As the two schemes, both simulations used identical initial conditions.

Discussion

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

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 MGCMA. 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) MY25 assimilation using TES dust retrievals; and (d) modelled data from the MCD v3.

Figure 3 shows the effect of this increased dust opacity on the atmospheric temperature. 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.

Conclusion

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 MGCMA, 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 entire period of the mission. A series of diagnostic studies will be made, to characterise the climate and synoptic meteorology of Mars over seasonal and interannual timescales, including detailed case studies of events such as the formation of cyclogenetic weather systems.

Acknowledgements

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References


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