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 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, ice-grown 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 the Mars Climate Sounder (MCS) measurements 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 [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 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-encircling 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 dust distribution, a series of experiments 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 dust total opacities, and henceforth denoted as 2003 and 2005 dust schemes. As can be seen in the table, the two schemes used identical initial conditions.

Figure 2 shows the difference in visible dust opacity averaged over March month 5 for both dust schemes. As can be seen, the 2005 dust scheme shows increased opacity at mid-latitudes, 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. 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.

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 would 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 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 spatial and temporal distribution of clouds, though such simulations have not yet been carried out.