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 these aerosols 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 forms, such as polar hood clouds, icy orographic 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 Thermal Emission Spectrometer (TES) retrievals 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 assumption of radiation has been identified as being potentially significant in the equatorial middle atmosphere of Mars around aphelion, when the planet-mean cloud belt forms [8]. As can be seen in Figure 1, it appears as though the downward infrared 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 LMD MGCM to the temporal distribution of dust, simulations with different dust schemes have been run using the UK version of the LMD MGCM.

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

Figure 3 shows the effect of this increased dust opacity on the atmospheric temperature. The colder cloud scheme results in increased middle atmosphere warming, particularly over the poles, and especially over the north pole. The increased temperature can be attributed to the adiabatic warming of the air that is sinking over the poles. The increased dust in the atmosphere from the 2005 scheme leads to stronger meridional circulation, and hence increased polar warming.

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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 extratropical circulation for the complete period of the MCS mission data. A series of diagnostic studies will be made to characterise the climatological and synoptic meteorology of Mars over seasonal and interannual timescales, including detailed case studies of events such as the formation of Martian cyclones. 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.

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References: