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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 surface (oceanic 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, convection 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 (MGMCM), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of the Mars Climate Sounder (MCS) retrievals and validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGMCM 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 MGMCMs.

The current LMD MGMCM [5] run in the UK uses a spectral dynamical core, and it 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 to the MGMCM 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-averaging 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 MGMCM to the distribution of dust, simulations have been run using the UK version of the LMD MGMCM.

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 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.

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 has increased opacity, 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 newer dust scheme results in increased middle atmosphere warming, particularly over the poles, and especially over the north pole. The increase in 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.

Figure 4 shows the effect of this increased dust opacity on the atmospheric temperature. The newer dust scheme results in increased middle atmosphere warming, particularly over the poles, and especially over the north pole. The increase in 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.

Figure 5 shows the effect of this increased dust opacity on the atmospheric temperature. The newer dust scheme results in increased middle atmosphere warming, particularly over the poles, and especially over the north pole. The increase in 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.

Figure 6 shows the difference in dust opacity between simulations run with different TES total dust schemes (2003 - 2005), averaged over L = 120°, 150°.

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