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 dust, water ice, 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, 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 (MGCMM) and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of thermal infrared emission (TES) spectrometer data to validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCMM 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]. 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 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 distribution of dust, simulations with varying dust schemes are derived from assimilations of TES total dust distribution, 185° K isotherm and approximate height of cloud tops from the Mars Climate Database (MCD) shows the distribution of dust column visible opacity between simulations run with different TES dust schemes (2005 – 2003), averaged over L.s = 120°S – 150°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 MCS plot.

Results

Plots of the meridional mass streamfunction (MMS) averaged over an entire Martian year are shown in Figure 4. The MMS from both the simulations and the modelled data from the Mars Climate Database (MCD) shows the distribution of dust column visible opacity between simulations run with different TES dust schemes (2005 – 2003), averaged over L.s = 120°S – 150°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 MCS plot.

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 global circulation for the entire Martian year. 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.

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