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 them is still limited. In particular, interactions involving the surface (solid-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, cryogenic clouds and ground fogs. The largest spatial distribution of clouds belongs to the aphelion cloud belt, which appears during northern hemisphere autumn and spring 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 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 [1-4]. 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 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 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-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 MGMCM to the distribution of dust, we have run experiments of seasonal evolution of zonally averaged temperature bias over the course of the MGS mapping mission; white, red and black contours indicate variable depth of assumed dust distribution, 185° K isotherm and approximate height of cloud condensation level. Figure 2 compares the temperature profile near the south pole in more detail. As can be seen immediately, the profiles from the simulation with the new dust scheme and the assimilation include much stronger southerly circulation than the profiles from the MCD. The MMS from both the simulations and the modelled data shows the dominance of the northerly circulation, though the MMS from the assimilation is not as strong as that from the MCD.

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 MGMCM. 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) MY24 assimilation using TES thermal and dust retrievals; (d) MCS limb retrievals and (e) modelled data from the MCD v3. (Panels (d) and (e) are from [9]).

Effect of water ice clouds

Water ice clouds have been observed at many locations in the Martian atmosphere, it is necessary to take into account their radiative effects in MGCMs. This is to 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 not apparent in the MCS or MCD profiles, as they are too close to the surface to be resolved by the instruments.

As has been seen, the distribution of dust in the MGMCM 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.

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 MGMCM, 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 to date. 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. 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: