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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 atmospheric circulation and the surface (such as dust ice caps), both 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 cap clouds and ground fog. The largest spatial distribution of clouds belongs to the polar 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 (MGCAM), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of temperature and emission Spectrometer (TES) temperature data and validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCAM 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 MGCAMs.

The current LMD MGCAM [5, 6] 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 MGCAM radiation scheme, so absorption of visible/infrared radiation by the water ice clouds is not taken into account. This absorption of radiation has not been identified as being potentially significant in the equatorial middle atmosphere of Mars around aphelion, when the planet-circling cloud belt forms [8]. As can be seen in Figure 1, it appears as though the downward infra-red radiation emitted by the polar 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 MGCAM to the distribution of dust, we use two different schemes that have been run using the UK version of the LMD MGCAM.

The two dust schemes used in the independent simulations are derived from assimilations of TES dust total column. They are based on earlier and revised retrievals, and are used to simulate dust properties. To test the sensitivity of the MGCAM to the dust distribution, we use 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, 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 MCD and modelled data from the MCD, which is used as a convenient summary of model experiments from the Mars Climate Database. Figure 5 shows mean vertical profiles of temperature at varying latitudes in Mars’ southern hemisphere obtained from: (a) MY24 simulation using 2003 dust scheme; (b) MY24 simulation using 2005 dust scheme; and (c) MCD vertical profiles. The two simulations using the 2003 and 2005 dust schemes do show stronger, southerly circulation than that from the MCD, but it is still weaker than in the assimilation.

Figure 6 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 are in much closer agreement with the MCS observations than the profile from the MCD. The lower temperature close to the pole in the simulation are apparent, but the middle atmosphere warming agrees well with the MCS plot.

As has been seen, the distribution of dust in the MGCAM has a large impact on atmospheric temperature. It would also therefore be expected to influence the temporal and spatial distribution of clouds, although such simulations have not yet been carried out.

Figure 7 shows the difference in vertical dust opacity between simulations using different dust schemes (2005 – 2003), averaged over MY24. The authors thank L. Montabone and D. Mulholland for their assistance with the model simulations.

Background image: MOC view across the Martian surface towards Gusev Crater. Credit: NASA/JPL/Malin Space Science Systems

References: