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 aerosols and the surface (polar 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 fog. 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 poster, 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 to test the sensitivity of the MGCM to the distribution and properties of dust (2003 and 2005 dust schemes) used in the MGCM.

Effects of water ice clouds in MGCM simulations
It is known that cirrus clouds in the Earth’s atmosphere can scatter and absorb the sun’s radiation, and alter the temperature of the surface. Similarly, in the Martian atmosphere, aerosols can also influence the radiation budget, and affect the surface temperature.

The current LMD MGCM [9] 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-orienting cloud belt forms [8]. As can be seen in Figure 1, it appears as though the downward intra-rad 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, we have run simulations of the Martian atmosphere using 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 with the other simulations, both simulations used identical initial conditions.

Plots of the meridional mass streamfunction (MMS) averaged over an entire Martian year are shown in Figure 2. The MMS shows the location of dust episodes and dust transport in the Martian atmosphere. The results from the MCD are not as strong as that from the assimilation. None of the plots accurately portray the southerly circulation that is present in the northern hemisphere dust transport. 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.

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. We compared the model results with the MCD data 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:

Figure 1. (a) Seasonal evolution of zonally averaged equatorial temperature bias over the course of the MGS mapping mission; (b) MY24 simulation with 2003 dust scheme; (c) MY24 simulation with 2005 dust scheme; and (d) MY25 assimilation using TES dust and thermal retrievals.

Figure 2. Difference in dust vertical opacity between simulations run with different TES dust schemes (2003 – 2005), averaged over longitude 120° W – 150° W.

Figure 3. Difference in temperature between simulations run with different TES dust schemes (2003 – 2005), averaged over MY24.

Figure 4. Plots of the meridional mass streamfunction (10° lat) zonally and time-averaged over a Martian year for (a) modelled data from the MCD; (b) MY24 simulation with 2003 dust scheme; (c) MY24 simulation with 2005 dust scheme; and (d) MY25 assimilation using TES thermal and dust retrievals.

Figure 5. Mean vertical profiles of temperature at varying latitudes from: (a) MY25 simulation using 2005 dust scheme; (b) MY24 simulation using 2003 dust scheme; (c) modelled data from the MCD; and (d) modelled data from the MCD v3. (Panels (d) and (e) are from [6]).

Figure 6. Daytime and night time temperature profiles for southern hemisphere mid-winter from: (a) modelled data from the MCD; (b) MY24 simulation using 2005 dust scheme; (c) MY25 assimilation using TES dust and thermal retrievals; and (d) MCS limb retrievals with mean local times 09.00 LST and 15.30 LST. (Panel (e) from [8]).

Figure 7. Mean vertical profiles of temperature at varying latitudes from: (a) MY24 simulation using 2005 dust scheme; (b) MY24 simulation using 2003 dust scheme; and (c) modelled data from the MCD; and (d) modelled data from the MCD v3. (Panels (d) and (e) are from [6]).