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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 these aerosols in the atmosphere (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 forms, such as polar hood clouds, ice anfractue 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 around 10°N and 30° N [1, 2].

In this poster, 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 data from the Mars Environmental Spectrometer (TES) instruments and validate the model against Mars Climate Sounder (MCS) observations.

Effects of water ice clouds in MGCM 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 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 intra-red radiation emitted by the aphelion cloud belt is introducing a warming of the atmosphere not accounted for in the model.

Figure 1. (a) Seasonal evolution of zonally averaged equatorial temperature bias over the course of the MGCM mapping mission. White, red and black patches at 40°S denote dust distribution, 180°K isotherm and approximate height of cloud condensation at 40°S. (b) Seasonal evolution of zonally averaged temperature bias at 0.5 hPa [8].

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, the two dust schemes have been run using the UK version of the LMD MGCM.

The two dust schemes used in the independent experiments are derived from assimilations of TES dust total optical depth. They are based on earlier and revised retrievals, henceforth donated as 2003 and 2005 dust schemes. As can be seen in the schemes, both simulations used identical initial conditions.

Sensitivity of the model to dust distribution

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 Mars Climate Database (MCD). Figure 5 shows mean vertical profiles of temperature at varying latitudes from: (a) KY24 simulation using 2003 dust scheme; (b) KY24 simulation using 2005 dust scheme; (c) MCD 2003 dust scheme; and (d) modelled data from the MCD v3. (Panels (d) and (e) are from [9].)

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

Figure 3. Difference in temperature between simulations run with different TES dust schemes (2003 – 2005), averaged over MY 24.

Above around 40 km, there is no data from the TES, and so the profiles are less accurate. Even so, it can be seen that the assimilation of volatiles improves the output of the MCD. This can 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 MCD or MCM profiles, as they are too close to the surface to be resolved by the instruments.

Figure 6. Daytime and night time temperature profiles for southern hemisphere mid-winter from: (a) modelled data from the MCD; (b) KY24 simulation using 2005 TES dust scheme; (c) KY24 assimilation using TES dust and thermal retrievals; and (d) MCS results retrieved with mean local times 09:16 LST and 15:36 LST. (Panel (d) from [9].)

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 new LMD physics routines. A unique data assimilation system [10] will be used to obtain a complete, dynamically self-consistent reconstruction of the extraterrestrial circulation for the complete period of the MCD mission to date. A series of diagnostic studies will be made to characterise the climatological and synoptic meteorology of Mars over seasonal and interannual timescales; including detailed case studies of events such as the formation of cyclopes ice spiders. 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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