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Modelling radiatively active water ice clouds in the Martian water cycle

L. Steele1, S. R. Lewis1, M. R. Patel2 and R. J. Wilson3

1Department of Physics & Astronomy, The Open University, MK7 6AA, UK
2Planetary and Space Science Research Institute (PSSRI), The Open University, MK7 6AA, UK
3Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA

Email: L.Steele@open.ac.uk

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 forms, such as polar hood clouds, ice caps, ground fog and cloud belts. The largest spatial distribution of dust 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 (MGCM), and test the sensitivity of the model to varying dust opacity. We use independent model experiments and assimilations of data from the Thermal Emission Spectrometer (TES) experiments 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-facing 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.

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 two simulations with different dust distributions. 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 globally, particularly in the southern hemisphere poleward of around 40°S.

Figure 2. 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 globally, particularly in the southern hemisphere poleward of around 40°S.

Figure 3 shows the effect of this increased dust opacity in the atmosphere. As can be seen from the assimilation that 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.

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 MGCM 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.

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 extraterrestrial circulation for the whole period of the MCD mission. A series of diagnostic studies will be made to characterise the climatological and dynamical properties of the water cycle, including detailed case studies of events such as 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