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Modeling of the Martian water cycle with an improved representation of water ice clouds

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1. Introduction

The Martian water cycle has been studied for a long time thanks to remote observations and the use of GCMs (Global Climate Model). Thanks to GCMs, the comprehension of the water cycle has been improved, revealing for instance the importance of clouds in the global water transport [5] with implications for atmospheric dynamics, paleoclimates. From that perspective, the modeling of the Martian water cycle by the LMD (Laboratoire de Météorologie Dynamique) Mars GCM has been improved by implementing significant processes, such as radiatively active water ice clouds and a microphysical scheme described in [4], including processes such as nucleation, growth of ice particles, sedimentation, coalescence and scavenging of dust nuclei.

2. Model description

Various recent improvements in LMD Mars GCM impact on the water cycle. Dust is represented via a two-moment scheme of lognormal distributions, allowing the independent transport of both dust mass and particles number, enabling dust particles radius prediction. Additionally, a new microphysical scheme includes the nucleation and growth of water ice particles onto dust particles, and thus enables supersaturation. Interaction with airborne dust is thus represented through scavenging, that is to say the redistribution of ice-trapped dust below the clouds after sedimentation.

Moreover, water ice clouds are now radiatively active and interact with radiative transfer processes in both visible and infrared bands [2]. As for dust, ice particles are accounted for using a lognormal distribution, i.e. their radius is not fixed and can vary in both time and location.

3. Simulation of the water cycle

3.1 The drier water cycle issue

Implementation of clouds radiative effects generates a thick polar cloud cover over the Northern hemisphere during Northern summer, decreasing ground temperature by reducing incoming solar flux [1]. As the North pole is the main source of atmospheric water vapor, the resulting water cycle is then very dry in comparison to observations and simulations without radiatively active clouds (RAC). The reason of the formation of such thick polar clouds during polar day has been identified as the consequence of retroactive processes between local temperature and both nucleation and growth of ice particles, driven by the use of an explicit scheme for nucleation and growth. This issue has been solved by the use of a smaller integration timestep for microphysical processes, in the integration of nucleation and ice growth explicit schemes.

3.2 Parameters

Once a North pole free of clouds during summer solstice obtained in GCM simulations, further unknown parameters have to be tuned in order to adequately model the Martian water cycle. These are the properties of permanent ice reservoirs in the GCM grid, (i.e. their position, albedo and thermal inertia), but also the effective variance of ice particles distribution for sedimentation flux and the contact angle parameter for heterogeneous nucleation.

3.3 Results

The water cycle is modeled with the use of RAC. Zonal mean of aphelion cloud belt opacities are well matched. However, the transport of water vapor from the North pole to tropics is underestimated while the sublimation peak during Northern solstice is overestimated (Figure 1). The reason is that the trap of water in the ascending branch of the Hadley cell is more significant with RAC given the set of parameters used to match observed cloud opacities (Figure 2). Including RAC improves modeled temperatures, by warming the atmosphere above the clouds, in better agreement with observations [2]. This affects the atmosphere not only on a local scale, but on the whole planet, as the global circulation is modified. Supersaturation is modeled and compared to observations [6] with predictions of ratios up to 1000 above 40 km, that cannot be observed due to the tiny quantities of water vapor. Dust scavenging by clouds enhances the formation of dust detached layers in rare and very localized areas and periods, but generally fails to explain the global distribution of detached layers observed from orbit [3].

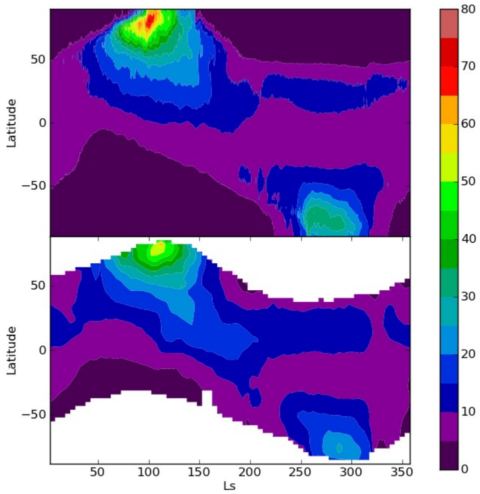

Figure 1: Atmospheric vapor as modeled with the GCM with RAC and microphysics (top) and observed by TES (bottom)

4. Summary and conclusions

The use of GCMs with RAC has changed the way we model the Martian water cycle and thus we have to address the issue of how ice clouds interact with the whole atmosphere. With the use of microphysics with a smaller integration timestep we could fix the issue of the dry water cycle, and then simulate water vapor quantities and water ice opacities in better agreement with observations. Atmospheric temperatures are better represented thanks to the interactions between clouds and heating rates they yield. Many issues remain to be addressed, such as the cross-equatorial transport of water and the role of supersaturation that allow vapor to pass the trap of the aphelion cloud belt. It is noticeable that dust scavenging by water ice clouds cannot explain the observed detached dust layers. Also, it would be important to have a fine spatial modeling of Northern pole permanent ice reservoirs, and what it can tell us about their stability and the possible need for additional sources of atmospheric vapor, such as the regolith.

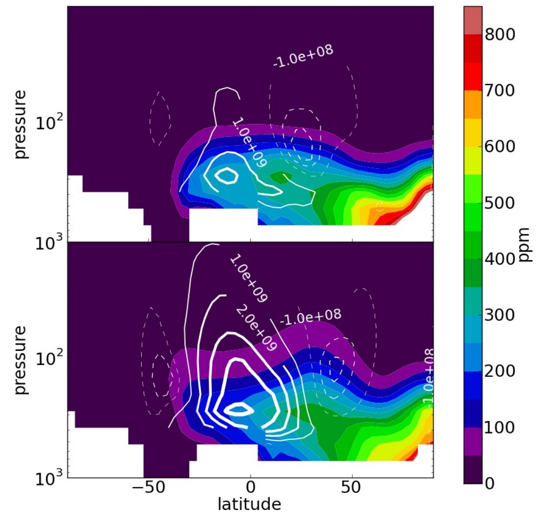

Figure 2: Zonal mean of water vapor (shaded) and Hadley circulation (contours) during Ls=120-150 with RAC (bottom) and without (top)

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