An improved LMD GCM water cycle: Applications to paleoclimates.

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Introduction: The Martian water cycle has long been studied, and we can have a good representation for present climate from observations and GCMs (Global Climate Models) [1]. However, less is known about past climates, but the use of a GCM can give some clues about it and its water cycle [2]. It is indeed important to know what effects the water ice clouds could have in different, warmer, wetter conditions due to known past orbital conditions [3] in order to fully picture Mars under different conditions. From that perspective, the modeling of the LMD (Laboratoire de Météorologie Dynamique) Mars GCM water cycle has been improved by implementing meaningful processes, such as radiatively active water ice clouds and a microphysical scheme described in [1] including processes like nucleation, growth of ice particles, sedimentation, coalescence and scavenging of dust nuclei. It is then possible to infer some results about present climate and water cycle and their changes on ~ 100 kyears and millions years timescales.

Modeling used in the LMD GCM:

Dust: Dust is represented via a two-moment scheme of lognormal distributions, allowing the independent transport of both dust mass and number of particles, making able to predict dust particles radius.

Microphysical scheme: The new microphysical scheme includes the nucleation and growth of water ice particles onto dust particles, thus allowing for supersaturation. By doing so, interactions with airborne dust are represented through scavenging, that is to say the redistribution of ice-trapped dust below the clouds after sedimentation.

Radiatively active clouds: Water ice clouds are now radiatively active and interact with radiative transfer processes in both visible and infrared bands [4]. As for dust, ice particles follow a lognormal distribution, so that their radius is not fixed and can vary in both time and location. Scattering properties of ice particles are therefore computed from look-up tables.

Simulation of Mars present day water cycle:

Parameters: Different unknown parameters can be tuned in order to model the present day water cycle. Those are the properties of permanent ice reservoirs in the GCM grid, such as their position, albedo and thermal inertia, but also the effective variance of ice particles distribution for sedimentation flux and the so-called contact angle parameter for heterogeneous nucleation. Recent experimental studies [5],[6],[7] suggest that this angle depends on temperature, so that heterogeneous nucleation of ice is much more difficult for Martian coldest conditions. It turned out that this dependency of nucleation on temperature can change the whole structure of clouds in such a way that perihelion cloud belt vanishes, and thus it has not been not implemented.

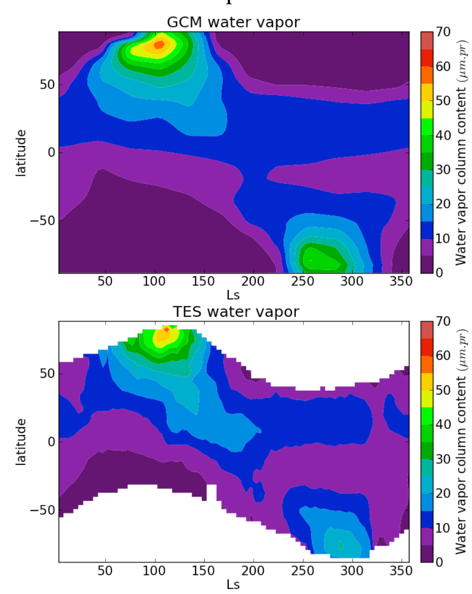

Figure 1: *Zonal mean water vapor column content in microns precipitable from the LMD GCM with radiatively active cloud (top) and as seen from Thermal Emission Spectrometer (TES) for MY26 (bottom)*

The drier water cycle issue: The implementing of clouds radiative effects creates at first a thick polar cloud cover over the Northern hemisphere during Northern summer, decreasing ground temperature by reducing incoming solar flux. As the North pole is the main source of atmospheric water vapor, the resulting water cycle is very dry in comparison to observations and simulations without radiatively active clouds. 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. 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 th use of explicit scheme for nucleation and growth. Others GCMs have faced the same behavior with similar modeling [8], but the use of a shorter integration timestep has not turned out to be a solution. Models intercomparison and the understanding of the nature of this divergence between different GCMs is in progress, and is a crucial point, as it is a very important step for model validation to get the same behavior from different models.

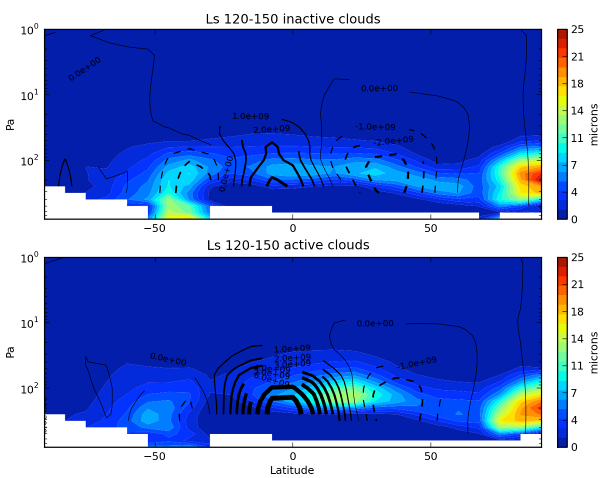

Figure 2: *Zonal mean of ice particle radius in microns without (top) and with (bottom) radiatively active clouds between Ls 120 and 150. Contours indicate the mass stream flux, showing that the Hadley cell is stronger in the latter case. The trap of water in the ascending branch by sedimentation is more efficient with radiatively active clouds, due to bigger particles.*

Results: The present day water cycle can be modeled with good approximation with the use radiatively active water ice clouds. Zonal mean of aphelion cloud belt opacities are well matched, as the sublimation peak of ~ 60 pr.µm of water vapor at North pole. The transport of water vapor from the North pole to tropics is underestimated (Figure 1). The reason is that the trap of water in the ascending branch of the Hadley cell is too much important with the set of parameters used to match opacities. Ice particles are bigger and sequestrated more efficiently by sedimentation [9] (Figure 2).

The presence of radiatively active clouds improves modeled temperatures, by warming the atmosphere above the clouds, in better agreement with observations (Figure 3). This affects the atmosphere not only on a local scale, but on the whole planet, as the global circulation is modified. Indeed, simulations with radiatively active clouds exhibit a stronger Hadley cell [4].

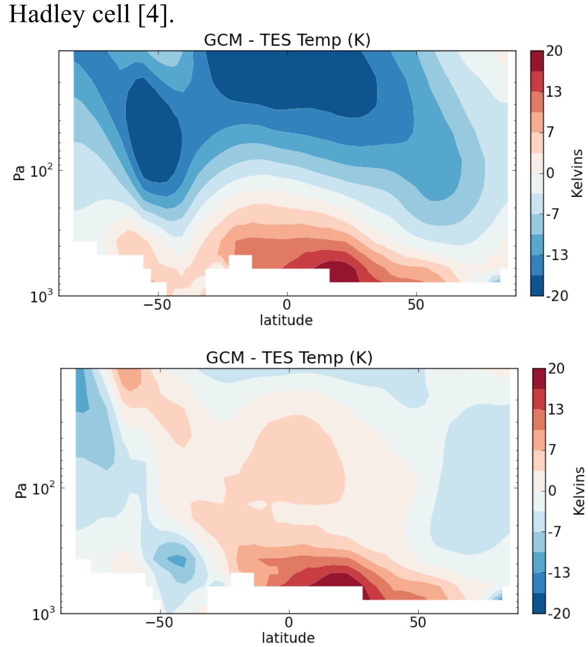

Figure 3: *Differences between simulations and TES observations without (top) and with (bottom) radiatively active clouds for daytime zonal mean temperatures as observed during aphelion cloud belt season (Ls 60-90). The cold bias above the hygropause at 100 Pa can be corrected with the use of radiatively active clouds.*

Supersaturation can also be modeled and is in agreement with SPICAM instrument (Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars) observations at Ls 90-120 [9] in Northern hemisphere, with saturations ratio ranging from 1 to 10 with 25 km above surface. GCM predicts ratios up to 1000 above 40 km, that cannot be observed due to the tiny quantities of water vapor. Modeled supersaturation in Southern hemisphere is less in agreement with observations, probably due to the lack of transport from Northern hemisphere in simulations as mentioned above.

Discussion and model limitations: The amount of permanent water ice reservoirs at the North pole has to bit overestimated to fit water vapor peak release. This could be due to some limitations in the GCM modeling. Indeed, we do not represent finely all sublimation/transport and redeposition processes because we might be underestimating the friction velocity that lifts diffusing water vapor, because the GCM spatial resolution could not be high enough, or because we do not take into account slope exposure to the sun or some other processes, such as the issue of vapor diffusion from the regolith.

Implications for reversed perihelion cases:

Based on those previous results, it is possible to revisit the water cycle under recent past climates. For instance, the date of perihelion, driven by eccentricity and precession, varies on a 42 kyears cycle [3]. The global transport of water between poles over the years is thought to be reversed 21 kyears ago, that is to say from North pole to South pole, when perihelion occurred during northern summer [11]. Simulations with a 'reversed perihelion' were done with a constant dust opacity of 0.2 over the year [12]. As expected, taking into account radiative effects of clouds reduces the transport of water vapor from northern pole to southern pole (Figure 4). Nevertheless, the total budget of deposited ice on surface is found to be more important in the latter case (Table 1), due to more opaque clouds that globally reduce surface temperature over the year, thus preserving ice from being sublimated (Figure 4).

Study	Radiate clouds	No radiative clouds
Present work	220 µm	105 µm
[11]	/	~ 300 µm

Table 1: *Mean ice deposition per year on Southern pole. The difference between this study and previous results from [11] could be accounted for the use of a new microphysical scheme.*

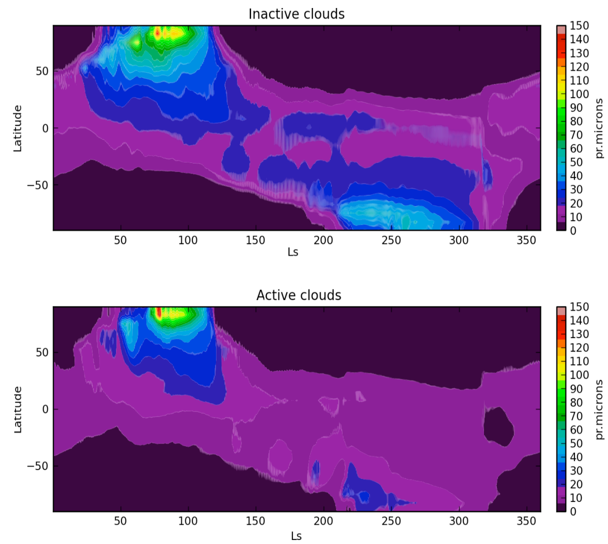

Figure 4: *Differences in zonal simulated water vapor column (pr.µm) with a reversed perihelion without (top) and with (bottom) radiatively active clouds. Water vapor is less transported towards southern latitudes with radiatively active cloud, and less water vapor is released into the atmosphere at South pole during summer.*

Conclusions:

The use of GCMs with radiatively active clouds has changed the way we model the water cycle and thus we have to address the issue of how ice clouds could interact with the whole atmosphere. With the use of 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. A lot of issues are still 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 perihelion cloud belt. Also, It would be important to have a fine spatial modeling of Northern pole permanent ice reservoirs, and what they can tell us about their stability or physical processes at work that could be a source of atmospheric vapor. The use of a new microphysical scheme requires more studies to know what is its mere impact [13], and how taking into account dust scavenging modifies dust profiles and others atmospheric fields.

Moreover, GCM modeling for past climates reveals different behaviors [13] of the water cycle: drier, more complex and more uncertain than previous studies with radiatively inactive clouds.

References:

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