The water cycle in the northern polar region of Mars: Improved modeling using the LMD Global Climate Model.

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It has become apparent in recent years that the thermal structure of the martian atmosphere cannot be explained without accounting for the radiative effect of water-ice clouds. Many efforts have been made to implement radiatively active clouds (RAC) in Global Climate Models (GCMs) of the martian atmosphere [1, 2, 3, 4, 5, 6]. Including RAC in the LMD/GCM significantly improves the simulated temperatures on one hand (see Fig. 4 of [7]), but on the other hand tends to dry out the whole water cycle (see Fig. 1 below as well as Fig. 2 of [8]).

The northern polar region is key to accurately simulate the water cycle, and this drying out suggests that some polar climate processes may not be well reproduced or even missing in our model. For example, between $L_s = 90°$ and $L_s = 120°$, a warm bias occurs in the GCM near the pole at an altitude of around 30 km, and this warm bias is mainly explained by the radiative effect of clouds forming at this altitude. These clouds are probably thinner in reality than in the model, which might be due to the scavenging of dust nuclei by water-ice clouds.

To improve the simulation of the water cycle when clouds are radiatively active, the scavenging of dust particles by water-ice clouds is implemented in our model and the representation of the north residual ice cap (NRIC) is refined. These new developments are described below.

New GCM developments

Interactive aerosols: The scavenging of dust particles is made possible by the semi-interactive dust scheme described in [9] and its coupling to the water cycle scheme. The semi-interactive dust transport scheme predicts the spatial and size distributions of dust. It is called "semi-interactive" because the predicted dust profiles are scaled so that the total column opacity matches the dust opacity observed by TES (for more information, see [10] and [7]). These dust particles serve as condensation nuclei for water-ice cloud formation. The fraction of dust particles involved in cloud formation depends on local temperature, absolute humidity and size of the dust particles. The nucleation rate calculation follows the method of [11] and depends on the contact parameter $m = \cos(\theta)$, where θ is the contact angle. m is quite unknown, and therefore used as a tuning parameter of our model. The mass mean radius of the ice particles r_c computed by the microphysical scheme (see the paragraph 28 of [12]) is then used to compute the effective sedimentation radius, $r_{\text{sed}} = r_c \ (1 + \nu_{\text{eff}})^3$, where ν_{eff} is the effective variance of the lognormal distribution, which is also a tunable parameter. These two parameters m and ν_{eff} are adjusted so that the simulated cloud properties are consistent with the observations.

It is also worth reminding that the radiative effect of dust and water-ice particles depends on the size of the particles, and the single scattering properties are constantly updated in the GCM as the dust layer and clouds evolve [7].

Scavenging of dust particles by water-ice clouds: Direct scavenging of dust particles by water-ice crystals is simulated by adding the cloud condensation nuclei (CCN) to the GCM tracers. Below-cloud scavenging is neglected. Indeed, the mass flux due to this process can be assessed following [13] and is 2 to 3 orders of magnitude lower than the sedimentation flux. A two-moment scheme is used, and the size of the CCN is therefore known. As nucleation occurs in the air parcel, dust particles are integrated into the ice crystals and the number of remaining dust particles decreases. The CCN are then released when the ice crystals sublimate. The effect of dust scavenging on the formation of the northern polar clouds will be further analyzed during the conference.

Representation of the NRIC: The simulated water cycle is very sensitive to the extent and surface properties (mainly albedo and thermal inertia) of the NRIC. The NRIC is represented in our model by a circular area above 84°N where sublimation of surface water-ice can always occur. Then, the model reaches its own hydrological equilibrium and perennial ice deposits can be formed outside of the 84°N latitude circle. In order to better understand the water cycle in the northern polar region, we performed mesoscale simulations where the above mentioned circular area is replaced by the observed NRIC. These simulations show that a significant fraction of the water vapor injected during northern summer comes from the NRIC outliers, as depicted in Fig. 3

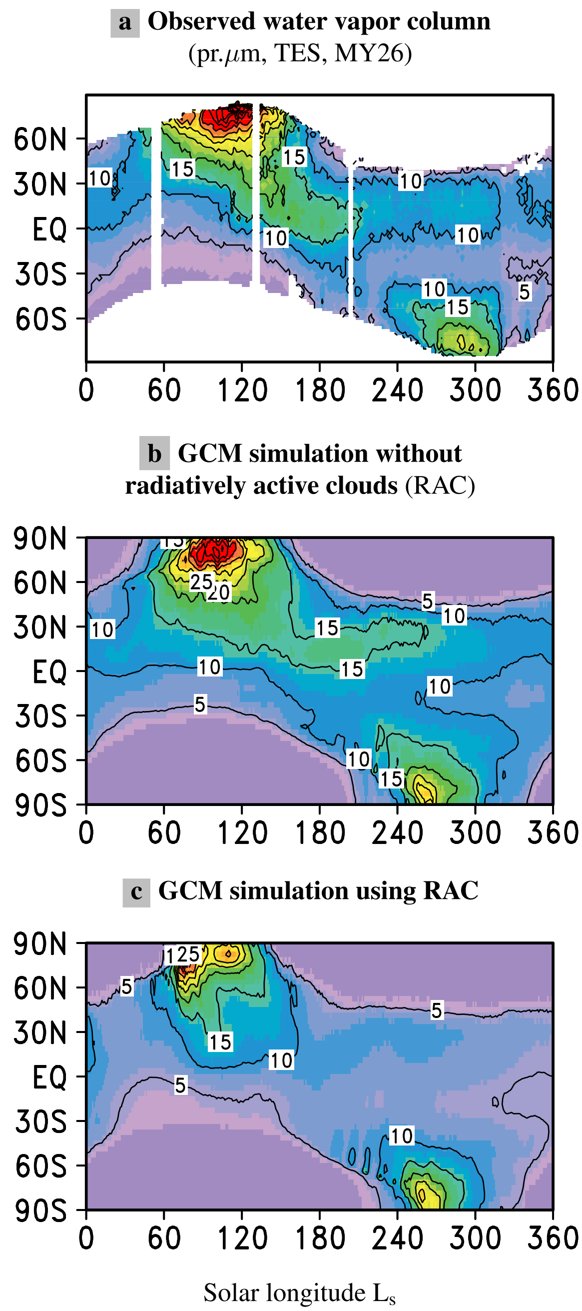

Figure 1: Annual evolution of the zonal mean water vapor column (pr.μm) as retrieved by TES (panel a.) and as simulated by the LMD/GCM when ignoring (panel b.) and using (panel c.) radiatively active clouds (MY26). The drying out of the whole water cycle when clouds are radiatively active is apparent in panel c.

of [14]. The latitude of these outliers is lower than 84°N, and part of the drying out observed when clouds are radiatively active may come from the fact that they are not well represented at coarser resolution in the GCM. We are therefore developing a subgrid scale parameterization for the GCM which accounts for the observed spatial variability of the NRIC, while keeping the area of sublimation consistent with the observations.

Perspectives

During the conference, the results of this new model will be analyzed, with a particular focus on the role of radiatively active clouds, dust scavenging and NRIC sublimation in establishing an abundant and stable water cycle.

References

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