WHAT DEFINES A MARTIAN GLACIAL STATE? ANALYSIS OF THE MARS CLIMATE SYSTEM UNDER PAST CONDITIONS USING THE NEW LMD GLOBAL CLIMATE MODEL.

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Under various latitudes, the Martian surface shows evidence for glacial cycles in the last hundreds of millions of years of the planet's history (see [1] and references therein). The LMD Global Climate Model (GCM) was able to explain the origin of many glacial deposits [2,3], but some widespread features, such as the Latitude Dependent Mantle [4], are still unexplained. Thanks to the observations of the last decade, the LMD/GCM has evolved toward a much higher level of complexity, and is giving new insights into the present-day and past climate of the planet. This study aims at a better characterization of the Martian glacial and interglacial states by using the new version of the LMD/GCM. To do so, we will study the response of the Mars climate system to changes in the orbital conditions, and look at the ice ages through the lens of the water cycle and global radiation budget of the planet. The different simulations performed for this sensitivity study are summarized in Table 1.

Simulation	#1	#2	#3	#4	#5	#6
Obliquity (°)	15	25.19	35	45	45	45
Dust opacity	0.2	MY26	0.2	0.2	0.2	**1**
RAC	On	On	On	On	**Off**	On
T_s (K)	206	205	224	241	200	230
WV col. (pr.µm)	4	9	490	3037	78	788
Ice col. (pr.µm)	0.3	1	65	391	9	124

Table 1: Global mean annual surface temperature, water vapor column and cloud column for all the simulations analyzed in this abstract. Simulation #2 is performed under present-day conditions, using the dust scenario of Martian Year 26. RAC stands for Radiatively Active Clouds.

The new version of the LMD/GCM [5] includes a semi-interactive dust scheme [6] and radiatively active clouds [7], a new cloud microphysics scheme [8], a parameterization of the thermals in the boundary layer [9] and the ice - thermal inertia feedback [3].

Results: In this study, we assume that the only source of water is the north polar cap, and the obliquity is increased from 15° to 45°. The amount of dust in the atmosphere is also varied (visible dust opacity of 0.2 or 1, see Table 1), and the sensitivity of the climate to radiatively active clouds is also assessed.

Water cycle: When the obliquity is increased, the atmosphere goes from a dry state to a very humid state (see Table 1, simulations #1,2,3,4). Figure 1 shows the annual evolution of the water vapor (WV) column in pr.µm for simulation #2 and 4. The significant increase in atmospheric WV is apparent in the lower panel, and the WV column is two to three orders of magnitude higher than under present-day conditions. This trend is due to increasing insolation over the north polar cap as obliquity is increased, and is further amplified by radiatively active clouds (compare simulation #5 and 4, Table 1).

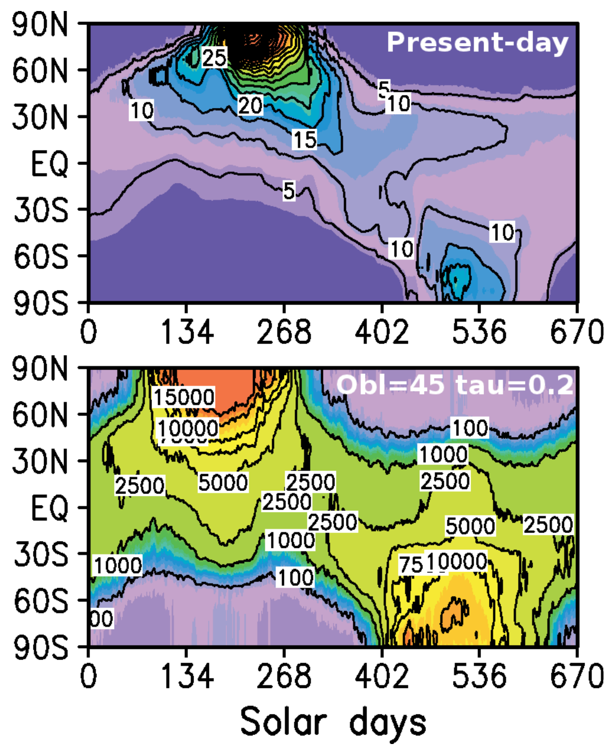

Figure 1: Annual evolution of the zonal-mean water vapor column (pr.µm) for simulations #2 and 4 of Table 1 (different color scales, see the labeled contours).

Indeed, the amount of WV that is sublimed from the north polar cap when clouds are active is three times that sublimed when clouds are not active. Moreover, clouds tend to warm on average the atmosphere itself (increase of ~ 40 K at the 20 km level on average between simulations #2 and 4) and to increase the meridional circulation [7], which results in a higher WV holding capacity of the atmosphere and greater meridional water transport.

Radiation budget: In the polar regions, the net effect of radiatively active clouds is a warming of the surface, which intensifies the sublimation of the polar cap (see Figure 1 and Table 1). Figure 2 shows the surface and TOA (Top Of Atmosphere) shortwave (SW) and longwave (LW) fluxes for simulations #2 and 4. The black line shows the incoming SW radiation, which is equal to ~ 148 W m^{-2} on average. Obliquity changes the latitudinal distribution of the incoming solar radiation, but not its global mean value. Eccentricity, however, changes the global mean insolation, which explains the difference in incoming SW radiation between the upper and lower panel of Figure 2 (eccentricity of 0.093 and 0, respectively).

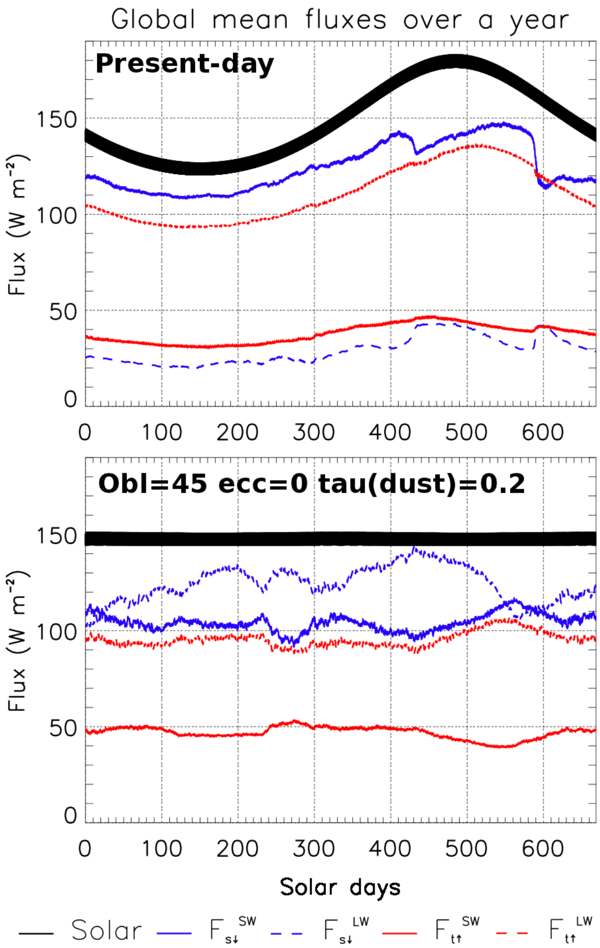

Figure 2: Global mean area-weighted surface (blue) and TOA (red) fluxes in the SW (plain) and LW (dashed) domains for simulations #2 and 4.

Under present-day conditions (upper panel of Figure 2), the variations in the SW and LW fluxes are mostly controlled by dust, rather than atmospheric gases or water-ice clouds. The surface receives around 10 W m-2 of LW radiation due to emission in the 15 µm band of CO_2, but most of the remaining energy (between 10 and 30 W m^{-2}) comes from the dust particles. The picture is very different at high obliquity (Figure 2). In this case, the radiation budget is mostly controlled by clouds and a strong greenhouse effect is predicted (see the LW flux received at the surface in Figure 2), with a warming of the surface of ~ 40 K (compare T_s for simulations #4 and 5 in Table 1). When the dust opacity is increased from 0.2 to 1, the surface temperature of the cap during northern summer is decreased, the sublimation is reduced and another equilibrium is reached. The climate is in this case dryer, with less clouds and less warming of the surface (see simulation #6 in Table 1). The climate system is therefore strongly controlled by the positive feedback loop formed by the couplings: sublimation → water vapor, water vapor → clouds, clouds → greenhouse effect, greenhouse effect → sublimation.

Surface ice: At high obliquity, the predicted clouds are much thicker than under present-day conditions (Table 1), leading to strong seasonal precipitation and to the formation of an ice mantle in the winter hemisphere that can be up to 10 cm thick. This mantle was not present when clouds were not radiatively active. However, summer temperatures are also higher when clouds are active, and this mantle is sublimed from one year to another. Only a few regions show a net annual accumulation of ice, such as Tharsis, Alba Patera, Elysium, and western and eastern Hellas.

Perspectives: More simulations are underway, and the relative contributions of CO_2 gas, dust and clouds to the global radiation budget are being quantified to establish detailed energy diagrams of the different climate states. The different water cycles are also being further analyzed. This study will allow us to better understand recent climate changes and the origin, duration and age of the identified glacial features [1]. The next step is to understand the details of the deglaciation stage that led to the cold and dry interglacial state we see today.

References: [1] J. W. Head and D. R. Marchant (2008) 39th LPSC Conference Abstract 1295. [2] F. Forget et al. (2006) Science 311:368. [3] J.-B. Madeleine et al. (2009) Icarus 203:390. [4] J. W. Head et al. (2003) Nature, 426:797-802. [5] F. Forget et al. (2011) EPSC-DPS Joint Meeting p:1568. [6] J.-B. Madeleine et al. (2011) JGR Planets, 116:E11010. [7] J.-B. Madeleine et al. (2012) GRL 39:L23202. [8] T. Navarro et al. (2012) Mars Recent Climate Change Workshop. [9] A. Colaitis et al. (2011) EPSC-DPS Joint Meeting p:1061.