MODELLING THE PAST MARS CLIMATE AND WATER CYCLE WITH A THICKER CO_2 ATMOSPHERE

R. D. Wordsworth *(rwlmd@lmd.jussieu.fr)*, **F. Forget, E. Millour, J.-B. Madeleine, B. Charnay,** *Laboratoire de Métérologie Dynamique, CNRS/UPMC/IPSL, Paris, France*, **R. Haberle**, *NASA/Ames Research Center, Moffett Field, CA 94035-1000, USA*.

Introduction:
Abundant geological evidence, both chemical and morphological, now exists for the presence of liquid water on Mars in the Noachian and Hesperian eras. Where did this water come from? Was it the consequence of an early climate that was warmer over an extended period, or of episodic, possibly catastrophic events? If the climate was warmer, what was the cause, given that the young Sun was around 25 % weaker at this time?
To address these long-standing questions, we have performed three-dimensional simulations of Mars with a denser CO_2 atmosphere, as is believed to have existed in the Noachian era. We have investigated the Martian climate and water cycle under a faint young Sun for a range of atmospheric pressures, in order to better understand the possible conditions in this era. We are particularly interested in a) investigating if a steady-state warm, wet early Martian climate is possible b) determining the conditions that lead to significant precipitation (rain or snow) over the equatorial valley networks, and c) assessing the plausibility of an ancient northern ocean.

Method:
We use the new LMD Terrestrial Climate Model, which has been specifically developed for the study of a diverse range of atmospheres, including the Martian paleoclimate. The model combines the LMDZ dynamical core and basic physics parameterizations (boundary layer scheme, soil physics, dry convection etc.) with a new generalized radiative transfer scheme based on the correlated-*k* method. The model uses gas absorption data generated directly from high resolution spectra, which allows a diverse range of atmospheres to be simulated accurately using the same techniques. We model the collision-induced absorption of CO_2 using an improved parameterization that predicts a slightly reduced greenhouse effect [4]. The radiative effects of clouds (CO_2 and H_2O for Early Mars) and aerosols are included via the Toon et. al (1989) scheme [1], with Mie theory used to calculate their radiative properties. Finally, we include a water cycle in the model. Both water vapour and ice are treated as active tracers with radiative effects, and moist convection, latent heat changes and precipitation microphysics are taken into account. Surface albedo changes due to ice / water are included, and surface hydrology is treated using a simple bucket scheme.

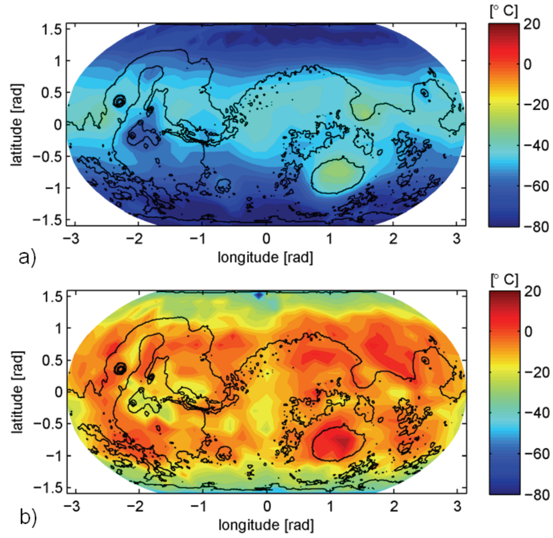

Figure 1: a) Annual mean and b) annual maximum temperature on a dry Mars with a 0.5-bar CO_2 atmosphere and 25° obliquity.

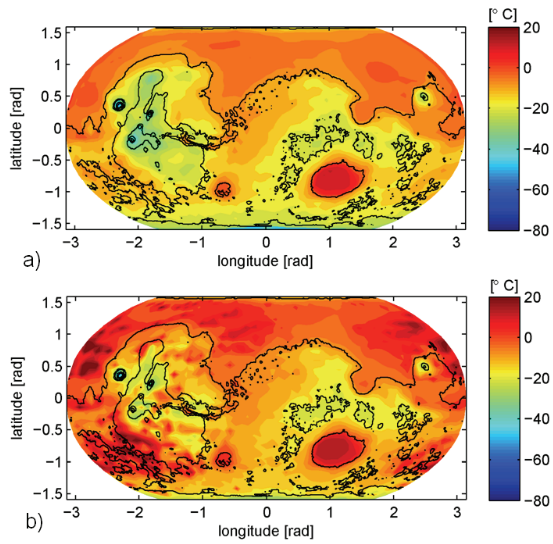

Figure 2: a) Annual mean and b) annual maximum temperature on a dry Mars with a 5-bar CO_2 atmosphere and 25° obliquity.

Results:
Radiative effects of clouds and vapour.
CO_2 clouds have been debated as a possible source of warming in the denser early Martian atmosphere [2-3]. We model their formation, evolution and radiative effects in 3D, including simplified cloud microphysics. We find that using reasonable assumptions on the cloud particle sizes and micro-

physics, 2-5 bars CO_2 is necessary to warm the (dry) planet up to the melting point of water. When the radiative effects of water are included, the moderate cooling effect of low altitude H_2O clouds is more than compensated by the greenhouse effect of H_2O vapour, resulting in higher overall temperatures for a given CO_2 pressure.

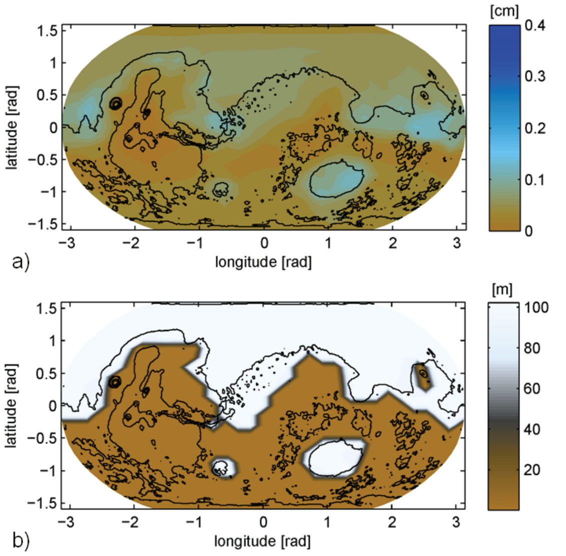

Figure 3: Snowball Mars. a) Annual mean water column amount and b) surface ice coverage after 5 years for a Mars simulation starting with a northern ocean, 2-bar CO_2 atmosphere, and 25° obliquity.

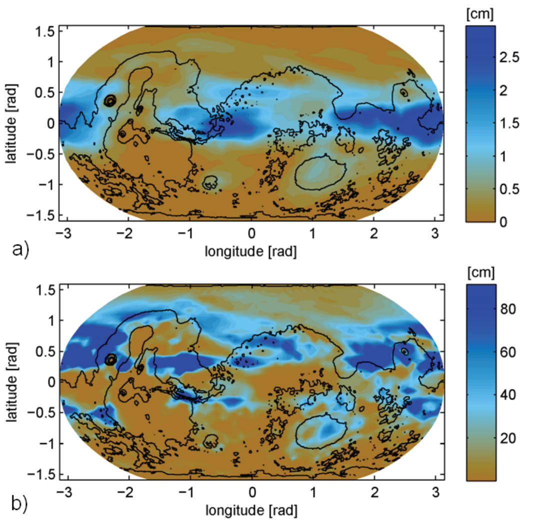

Figure 4: Warm, wet Mars. a) Annual mean water column amount and b) annual total rainfall after 5 years for a Mars simulation starting with a northern ocean, 5-bar CO_2 atmosphere, and 25° obliquity.

Constraints on the global water cycle.
In our simulations that include a water cycle, we find the amount of precipitation over the valley network regions depends strongly on the local distribution of water sources. If a stable northern ocean exists, transport of water to the valley highlands is relatively easy to achieve, while placing surface water sources only at the poles results in dry equatorial regions. We are currently investigating the possibility that even without a northern ocean, a local source of water from e.g., Hellas basin would still allow sufficient precipitation in the equatorial highlands.

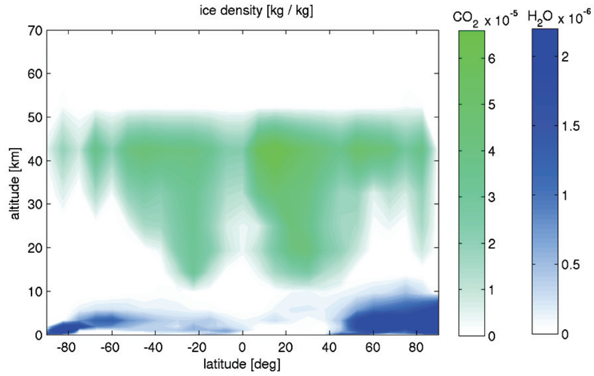

Figure 5: Annual and longitudinal mean of H_2O and CO_2 cloud mixing ratio for a 2-bar CO_2 atmosphere with water sources at the poles.

Snowball Mars. Including surface albedo changes due to CO_2 / H_2O ice allows us to study the likelihood of snowball Mars scenarios. We find that starting with a northern ocean leads to a strong ice-albedo feedback below a few bar CO_2, resulting in runaway glaciation and an ice-covered Early Mars. This effectively poses strong constraints on the existence of an early northern ocean.

Discussion:
We are currently testing the sensitivity of our results to the underlying microphysical assumptions and studying the long-term precipitation patterns for a range of surface water distribution and atmospheric pressures. In the future, we plan to test the effects of dust on the Early Martian climate (collaboration with I. Halevy) and improve the treatment of hydrological processes (runoff, subsurface flow etc.) in the model.

[1] O. B. Toon, C. P. McKay, T. P. Ackerman, and K. Santhanam, "Rapid calculation of radiative heating rates and photodissociation rates in inhomogeneous multiple scattering atmospheres," Journal of Geophysical Research, vol. 94, pp. 16287–16301 (1989)
[2] F. Forget, R. Pierrehumbert, "Warming Early Mars with Carbon Dioxide Clouds That Scatter Infrared Radiation", Science, vol. 278, pp. 1273 (1997)
[3] A. Colaprete, O. B. Toon, "Carbon dioxide clouds in an early dense Martian atmosphere", Journal of Geophysical Research (Planets), vol. 108, pp. 6-1 (2003)
[4] R. Wordsworth, F. Forget, and V. Eymet, "Infrared collision-induced and far-line absorption in dense CO_2 atmospheres", Icarus, vol. 210, pp. 992-997 (2010)