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# Fresh Perspective on High Obliquity Recent Martian Paleoclimates Under Dramatic Cloud-Induced Greenhouse Effect

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**FRESH PERSPECTIVE ON HIGH OBLIQUITY RECENT MARTIAN PALEOCLIMATES UNDER DRAMATIC CLOUD-INDUCED GREENHOUSE EFFECT.** J. Naar<sup>1, 2</sup>, F. Forget<sup>1</sup>, E. Vos<sup>1</sup>, E. Millour<sup>1</sup>, C. Segonne<sup>1</sup>, L. Lange<sup>1</sup>, J.-B. Clément<sup>1</sup>, F. Montmessin<sup>2</sup>, <sup>1</sup>Laboratoire de Météorologie Dynamique, UMR CNRS 8539, Institut Pierre-Simon Laplace, Sorbonne Universités, UPMC Univ Paris 06, 4 place Jussieu, 75005, Paris, France. ([joseph.naar@lmd.ipsl.fr](mailto:joseph.naar@lmd.ipsl.fr)) <sup>2</sup> Laboratoire atmosphères et observations spatiales, UMR CNRS 8190, Institut Pierre-Simon Laplace, Sorbonne Universités, UPMC Univ Paris 06, 4 place Jussieu, 75005, Paris, France.

**Introduction:** The recent geological history of the planet Mars is complex and indicative of climatic regimes different from the cold and arid Mars we know today. These diverse climatic regimes are associated with variations in the planet's orbital parameters, particularly its obliquity [1]. In particular, over the past 5 million years, Mars has experienced variations in obliquity of 10° around its current value of 25°, with a shift beyond that to an average value of 35° [2]. In these exotic configurations, increased insolation on the Northern Polar Cap (NPC) promotes the sublimation of water vapor into the atmospheric reservoir, resulting in a climate that is wetter and richer in clouds. While these climates have been investigated by several teams [3, 4, 5, 6], all have overlooked the radiative effect of clouds (notoriously difficult to model), which is negligible in the current climate but significant at higher obliquity with ubiquitous clouds. Using the Mars Planetary Climate Model (PCM), we have built upon pioneer work [7] and updated the cloud scheme to properly model the radiatively active clouds (RACs). Here, we present the results of new climate simulations at high obliquities ranging from 30° to 45° with radiatively active clouds that challenge the paradigm of recent climatic variations on Mars.

**The global atmospheric water cycle:** In the present-day Martian climate, the scarcity of clouds results in a low magnitude radiative effect [8]. Previous high-obliquity climate simulations without RACs show that the mere increase of northern insolation drives an increase of atmospheric water content by an order of magnitude. In our simulations, the additional sublimation caused by the greenhouse effect of clouds leads to an even more intense sublimation of the NPC: this result in atmospheric water content up to two orders of magnitude more than present-day value. Furthermore, we find that this is not only sensitive to obliquity, but also to the other orbital parameters (eccentricity and timing of perihelion), as radiatively active clouds are responsible for internal climate forcing.

**Greenhouse effect of clouds:** The accumulating clouds have a strong greenhouse effect throughout the year. On average, in our most humid simulations, sur-

face temperatures may be increased of 30K compared to present-day climate. The thermal structure of the atmosphere is also modified, which strongly enhances the hemispheric circulation and elevates the hygropause. We also find that despite the emphasis of the polar nights during which a fraction of the atmosphere condenses, the strong greenhouse effect dampens the seasonal CO<sub>2</sub> cycle, or even stops it completely, as opposed to previous findings [3].

**Fate of ground ice reservoirs:** The NPC is the main reservoir for atmospheric water in our model. In the present-day climate, sublimation of ground ice occurs at low temperatures, even around the summer solstice. At high obliquity, under the dramatic greenhouse effect of clouds, the temperature of ground ice rises and the latent heat of sublimation, previously neglected, must be computed. We find that it has a strong effect on the stability of the NPC, where the latent heat cooling halves the summertime sublimation. In addition, we have refined our representation of seasonal water ice mantle in the winter hemisphere. This frost is formed through direct condensation of humidity at the surface in our present-day simulations and is a few microns thick at most. With the intensified water cycle at high obliquity, the seasonal water ice mantle is now formed via snowfall and may be centimeters-thick. We account for its expected increase of albedo and thermal inertia. We find that in our simulations these effects, combined with the latent heat cooling of sublimation, allow for the seasonal ice mantle to survive summertime sublimations in a wide range of orbital configurations, as shown in figure 1. This provides a straightforward climatic explanation for the geological findings suggesting the emplacement of the recent Martian “Ice Ages”, even for young age of a few hundred thousand years [1,9], corresponding to a mere 30° obliquity excursion.

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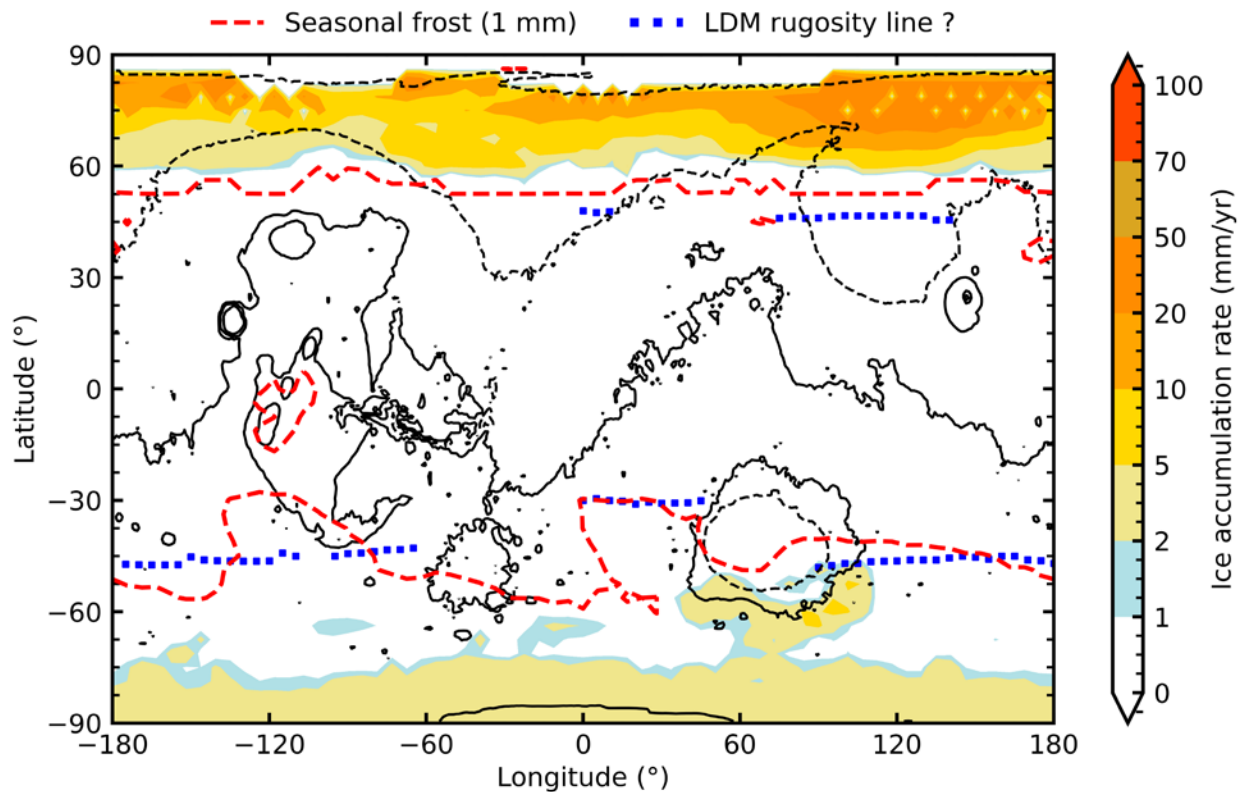


Figure 1 : Inter-annual ice accumulation rate after the 10<sup>th</sup> year of simulation for Mars at 35° obliquity,  $L_p=90^\circ$  and eccentricity=0.08, with the discussed physical parameterizations and a seasonal surface albedo of 0.7 with increased thermal inertia of seasonal ice.