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► **To cite this version:**

Joseph Naar, F Forget, E Vos, E Millour, C Segonne, et al.. New High Obliquity Climate Simulations Reconcile Climate Scenarios with Geological Evidences of Very Recent Ice Ages on Mars. 8th International Conference on Mars Polar Science and Exploration, Jul 2024, Whitehorse, Yukon, Canada. pp.LPI Contribution No. 3064, 2024, id.6046. insu-04688492

**HAL Id: insu-04688492**

**<https://insu.hal.science/insu-04688492v1>**

Submitted on 5 Sep 2024

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**NEW HIGH OBLIQUITY CLIMATE SIMULATIONS RECONCILE CLIMATE SCENARIOS WITH GEOLOGICAL EVIDENCES OF VERY RECENT ICE AGES ON MARS.** 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:** Compelling geological evidence suggests that Mars is covered in both hemispheres by a “Latitude-Dependent Mantle” (LDM) of buried ice-rich material, likely of climatic origin [1]. The corresponding climate regime is attributed to high obliquity excursions, during which the insolation over the Northern Polar Cap (NPC) induces mass loss and the stability regions of surface ice are shifted equatorward. Over the years, several Global Climate Model (GCM) studies investigated the high obliquity Martian climate and established the following paradigm. At first, when increasing Mars’ obliquity in GCMs, the global water cycle is intensified but ice remains stable only in the polar regions until an obliquity of 40° is reached. Then, surface ice becomes unstable in the North Pole and accumulates in the tropical regions on the flanks of Tharsis volcanoes [2]. Finally, decreasing the obliquity in those simulations destabilize the tropical glaciers and surface ice accumulates in the mid-latitudes [3]. However, this climate scenario involves obliquity variations occurring more than 5 million years ago [4], whereas the inferred emplacement age of the LDM is a few hundred thousand years [1,5]. As part of the *Mars Through Time* ERC project, we have conducted a set of implementations and improvements of the Mars Planetary Climate Model (previously Mars LMD-GCM) dedicated to paleoclimate studies, which we use to address the apparent paradox described above.

**Radiatively active clouds:** Previous work regarding the modeling of high obliquity Martian climate showed that the radiative effect of clouds dramatically affect the global water cycle [6]. However, this aspect is quite challenging even in the present-day climate because of the intricate retroactions with the entirety of the Martian climate system. We have updated the cloud microphysics and its numerical scheme for stability, accuracy and increased physical realism at higher obliquity.

**Latent heat of ground ice sublimation:** The latent heat cooling associated with ground ice sublimation is usually neglected in Martian GCMs. In the present-day climate, this is because the NPC is cold and the seasonal ice mantle is extremely thin, resulting in small energy fluxes. However, this is not the case

anymore in the high obliquity climate regime and this physical process must be considered. We find that it has a strong, twofold impact in our simulations, both limiting sublimation over the NPC and favoring the persistence of mid-latitude ice.

**Seasonal water ice mantle:** At present, the seasonal water frost on Mars is only a few microns thick. It is formed by direct atmospheric condensation of ambient humidity in the winter hemisphere. In our high obliquity simulations, increased insolation over the NPC leads to a more humid climate regime where cloud activity is amplified. The seasonal water ice mantle may thus be tens of millimeters thick and is formed by aerial deposition. Its physical properties may thus differ from its present-day counterpart, specifically regarding its albedo and thermal inertia.

**High obliquity simulations:** With the updated physics of the Mars PCM, we have conducted a series of numerical experiments at high obliquity. We find that the predicted climate regimes allow for the straightforward depositions of meters-thick mid-latitude ice, without ad-hoc parameterizations, as shown in figure 1. This holds for a wide range of orbital configurations, including some encountered in the last few hundred thousand years and thus provides an updated climate scenario for the recent emplacement of the LDM, in agreement with the existing geological records [1].

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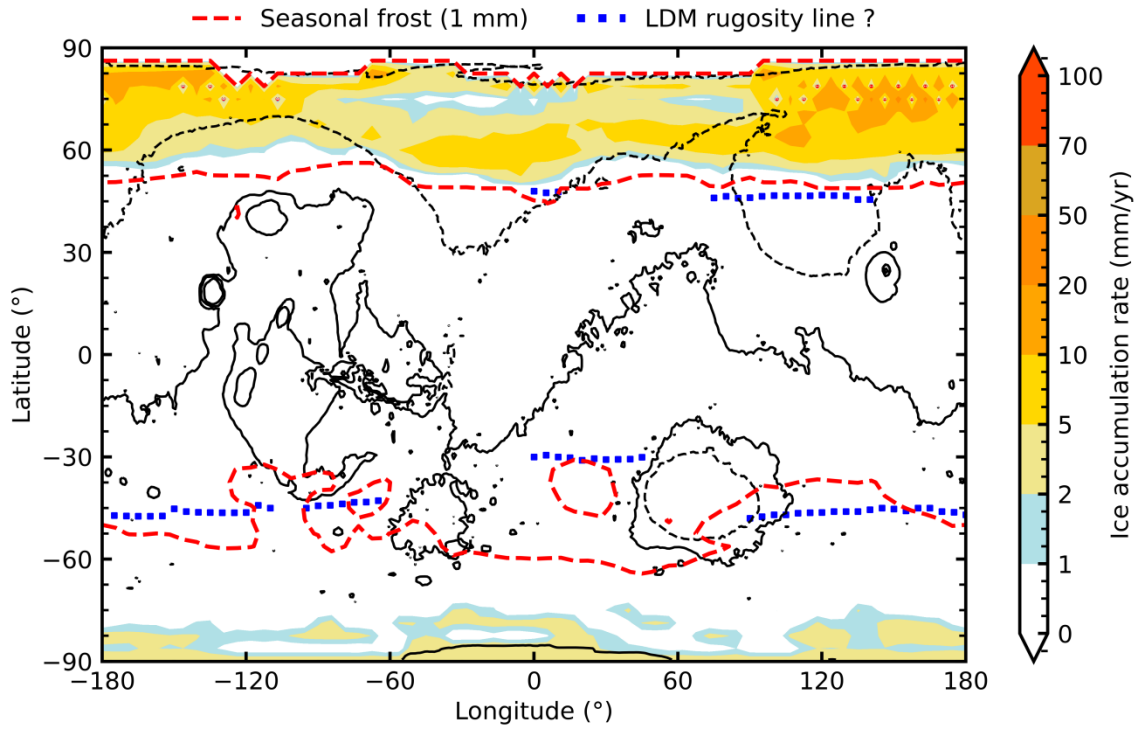


Figure 1 : Inter-annual ice accumulation rate after the 10<sup>th</sup> year of simulation for Mars at 35° obliquity,  $L_p=270^\circ$  and eccentricity=0.08, with the discussed physical parameterizations and a seasonal surface albedo of 0.7.