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**MARS AT LOW OBLIQUITY** L.Lange<sup>1,\*</sup>, F.Forget<sup>1</sup>, J.B.Clément<sup>1</sup>, E.Millour<sup>1</sup>, E.Vos<sup>1</sup>, A.Grau Galofre<sup>2</sup>, S.Conway<sup>2</sup>, L.Roelofs<sup>3</sup>, <sup>1</sup>Laboratoire de Météorologie Dynamique, Institut Pierre-Simon Laplace (LMD/IPSL), Sorbonne Université, CNRS, Paris, France; <sup>2</sup>Laboratoire de Planétologie et Géosciences, CNRS UMR 6112, Nantes, France; <sup>3</sup>Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands \*lu-cas.lange@lmd.ipsl.fr.

**Introduction:** The obliquity of Mars reached values of nearly 15° 800,000 years ago, and probably few degrees less during the Amazonian era [1]. Under these conditions, Mars was probably completely different world from the one we observe today. Yet, this 'exotic' has been poorly documented.

At low obliquity, Mars' poles become cold traps. As a result, a significant portion of the atmosphere condenses at these points: this is known as atmospheric collapse [2-8]. For example, [7] predicted, using a 3D climate model, a residual atmosphere of 350 Pa at 15° of obliquity, and 40 Pa at 5°. [6] demonstrated using a radiative equilibrium model that condensation of CO<sub>2</sub> would not necessarily take place at the poles, but preferentially at high latitudes on pole-facing slopes facing the poles, forming massive CO<sub>2</sub> glaciers « flowing » on the surface. On the opposite, [9] have demonstrated that the regolith desorbs during periods of low obliquity, reinjecting CO<sub>2</sub> gaseous into the atmosphere. However, all of these studies do not consider the negative feedback from subsurface water ice, an essential element for quantifying the mass of CO<sub>2</sub> that condenses on the surface in the present-day climate [10].

Consequently to the atmospheric collapse, the residual atmosphere should be depleted of CO<sub>2</sub>, and be mainly composed of Ar/N<sub>2</sub> (and possibly CO). Another consequence of this pressure drop is the decrease in the thermal conductivity of the regolith, which could lead to a subsurface warming of more than 20-30 K [11-12], possibly accelerating CO<sub>2</sub> exchanges between the subsurface and the atmosphere, and potentially melting subsurface ice. Finally, because of the lower surface winds and pressure, dust lifting is less likely to occur, and the dust storm activity is expected to be weaker. Similarly, the atmosphere is expected to be drier, with most of the water vapor condensing in the poles.

Experiments leading to our knowledge on Mars at low obliquity are still limited: most are based on simplified 1D or 3D models, and do not take into account the feedback from water ice buried in the subsurface, while this has a crucial effect when quantifying the magnitude of the collapse. We will describe during the conference Mars' climatic variations and the evolution of surface and subsurface ice reservoirs during a descent in obliquity, using the Mars Planetary Climate

Model and the Mars Planetary Evolution Model.

**The Mars Planetary Climate Model (PCM):** Climate simulations are performed using the Mars PCM. This model has been widely used to simulate the present and past climates of Mars. To simulate the condensation of CO<sub>2</sub> on slopes, we have added a slope parameterization in the model [13]. This parameterization enables to model the microclimate on local slopes and thus the formation of CO<sub>2</sub>/H<sub>2</sub>O glaciers. It has been tested and validated for present-day climate using the current observations of ice deposits on pole-facing slopes [14]. The effect of subsurface ice on the surface energy budget is included by using a soil-conduction scheme which includes the possibility of varying the thermal properties in the subsurface. A more complete description of the PCM can be found in [13].

**The Mars Planetary Evolution Model (PEM):** Simulation of past Martian climates with the PCM is challenging as one must couple physical processes with very different timescales, ranging from clouds microphysics (~seconds) to the slow evolution of glaciers (~thousand of years). We have designed an asynchronous model, the Planetary Evolution Model (*Clement et al., this issue*) to enable such long simulations. In short, tendencies (e.g. mean precipitations of CO<sub>2</sub>, H<sub>2</sub>O snows, sublimations, dust deposition rates, etc.) are extracted from multi-annual runs of the Mars PCM. Tendencies obtained from the PCM are then extrapolated in the PEM over hundreds of years, taking into account the main physical processes described below:

**Glacier Flow** We use a simplified glacier flow model for CO<sub>2</sub> and H<sub>2</sub>O ices. Here, we assume that a glacier on a Mars PCM subgrid-slope cannot exceed a critical thickness, in which case the excess ice is transferred into the adjacent sub-slope. To provide an estimate of this critical thickness, we derive the characteristic driving stress of CO<sub>2</sub> ice with parameters taken from [15,16] by adapting a well-established scaling balance from terrestrial glaciology to the flow of CO<sub>2</sub> ice [17,18]. Using the flow law parameters given by [15,16], we derive a characteristic driving stress of about ~10<sup>3</sup> Pa (compared to ~10<sup>5</sup> for water ice), which translates to critical ice thicknesses on the order of ~1

m to start ice flow on a 30° slope.

**Subsurface Ice:** For each grid mesh of the PCM, we put subsurface ice in a soil layer if the yearly average vapor pressure over ice in a soil layer (function of Tsoil) is lower than the yearly average near-surface humidity, a common criterion used in most models (e.g., [19-20]). When subsurface ice sublimates, the PEM releases the corresponding amount of water vapor in the atmosphere. We only model here equilibrium ice table. A complete dynamic model of subsurface ice is currently under development (Vos *et al.*, Clément *et al.*, *this issue*)

**Soil Properties:** In the absence of subsurface ice, the soil is represented as in [11], i.e., with a regolith layer that is ~10m thick, ~1km of breccia, and then indurated rock. Regolith and breccia conductivities vary with the pressure following the relationship from [21].

**Adsorption/Desorption:** We compute simultaneously the adsorption of CO<sub>2</sub> and H<sub>2</sub>O using the method of [22]. We assume here that the amount of CO<sub>2</sub>, H<sub>2</sub>O adsorbed is in equilibrium with the atmosphere, and the full dynamic of adsorption/desorption is not modeled.

**Preliminary results:** We have performed first simulations and validations with the PEM setting the obliquity of Mars at 5°. Preliminary results suggest that the atmosphere condenses on the Poles, forming massive (> 10m thick) glaciers at high latitudes (Figure 1), leaving a residual atmosphere mainly composed of Ar/N<sub>2</sub>. Updated results with a finer resolution and a real descent of obliquity will be presented at the conference.

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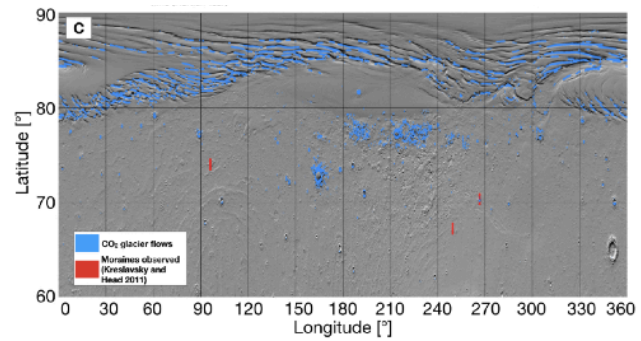


Fig. 1: Representation of the sloped terrains where thick CO<sub>2</sub> deposits are predicted (blue) and where CO<sub>2</sub> moraines are observed (red).

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