On the Possibility of Melting Water Ice to Initiate/Promote Gully Activity during the Recent Past of Mars.

Luca Lange* and Francois Forget. *Laboratoire de Météorologie Dynamique (LMD), Sorbonne University, Centre National de la Recherche Scientifique, Paris, France. (* Now at Jet Propulsion Laboratory, USA)*

The potential for liquid water formation on Mars during the late Amazonian period has sparked considerable scientific debate, driven by the presence of young landforms such as gullies, Recurring Slope Lineae (RSL), and channels that resemble water-formed features on Earth [see review in 1]. While some studies support the possibility of surface or subsurface ice melting as a source of liquid water [e.g., 2-3], others argue it is thermodynamically implausible under current Martian conditions ice [e.g., 4-5]. This presentation reviews the literature, identifies limitations in studies supporting meltwater, and employs advanced modeling to show that recent melting of water ice on Mars is highly improbable.

Why is it difficult to melt ice on Mars?

Numerous studies have shown that water ice is abundant on Mars at the surface or in the ground. Furthermore, thermophysical conditions that allow liquid water to be present (above the triple point pressure and freezing temperatures) are common during most of summer's afternoon on Mars [6]. Hence, one may suggest that ice can melt. Yet, two mechanisms, often neglected, prevent to reach such conclusions:

Water ice/frost forms in cold trap, like pole-facing slopes on crater's rims, rather than warm places. When ice/frost is heated and warms, it generally disappears quickly before reaching 273.15 K as the sublimation flux is growing exponentially with ice temperature.

When ice approaches the temperature of melting, the sublimation cooling induced by the release of latent heat surpasses the solar and thermal infrared heating, forcing the ice to cool and thus preventing it to reach 273.15 K.

Several studies have suggested that the sublimation fluxes and latent heat cooling could be significantly reduced by: i) A high humidity in the atmosphere, likely during period of high obliquity; which would reduce the gradient of humidity between the near-surface atmosphere and the ice subliming, and thereby the sublimation flux; and ii) the presence of a thin dry-regolith layer above the ice, acting as a sublimation barrier. Yet, as we show below, such mechanisms are not efficient enough to allow melting.

Melting ice at the surface

Using the Mars Planetary Climate Model (PCM) and its representation of slope-microclimates [7], we test whether frost/ice at the surface can melt at an obliquity of 35°, when the humidity was the highest in the last 5 million years. The modeled distribution of frost at these epochs are shown in Figure 1, along with the maximum temperature of these deposits. For all simulations, no ice deposits can melt (maximum temperature of 272 K), again because of the significant sublimation cooling.

Melting ground ice

To check whether ground ice can melt, we first compute the depth at which water ice would be present based on vapor-exchange theory [8] for present-day and obliquity 35° (Figure 2). We then retrieve the maximum temperature of this ice (Figure 2). In all cases, we find that subsurface ice does not reach the melting temperature (maximum temperature of 260 K). Indeed, ice is generally stable at depth too large to be sufficiently heated to melt.

The best case: bring ground ice closer to the surface

As shown previously, ice at the surface cannot melt because of the latent heat cooling. Stable ground ice is too deep to be warmed enough and melt. Thus, the most favorable scenario for melting buried near-surface ice on Mars in the recent past would be to destabilize it by bringing it closer to the surface, allowing sufficient heating to reach melting while minimizing cooling from latent heat loss. This process is currently being observed on Mars: during the active period of a gully, part of the surface material is removed (most likely because of by CO_2 ice sublimation, [9]), bringing the ice buried beneath these slopes closer to the surface, sometimes even exposing it on the surface [10]. We use a 1D version of the Mars PCM to simulate the evolution of such ice after an event that eroded the surface. Almost none of our simulations with realistic thermophysical properties of the regolith/ice allows the melting for present-day and recent past, suggesting that recent melting on Mars is highly unlikely.

Effects of salts

Salts are well known to reduce the temperature needed to melt ice. However, the quantity of salts needed to significantly reduce this temperature is too high compared to typical abundance measured at the surface [5]. Hence, we suggest that the formation of brine through the melting of salty ice is unlikely in the recent past of Mars.

Melting Ice Through the Solid-State Greenhouse Effect Some studies [e.g., 3, 11] have suggested that dusty snowpack can melt on Mars because of a greenhouse effect generated by the absorption of solar radiation by dust grains within the ice. While this mechanism is the most credible to date to allow melting and might happens today on dusty-ice exposure [e.g., 10], it remains uncertain whether this is a widespread phenomenon, especially given the uncertainty on the dust cycle and dust deposition with the ice during periods of higher obliquity.

References: [1] Conway et al. (2021), *Mars Geological Enigmas*. [2] Costard et al. (2002), *Science,295 (5552)*. [3] Christensen (2003), *Nature, 422 (6927).* [4] Ingersoll (1970), *Science, 168 (3934).* [5] Mellon et al. (2001), *JGR-Planets, 106 (E10)*. [6] Haberle et al. (2001), *JGR-Planets, 106 (E10).*[7] Lange et al. (2023*), JGR-Planets, 128 (10).* [8] Schorghofer & Aharonson (2005), *JGR-Planets, 110 (E5).* [9] Pilorget & Forget (2016), *Nature Geoscience, 9, 65-69*. [10] Khuller & Christensen (2021) , *JG R-Planets*, *126* (2). [11] Clow (1987), *Icarus, 72 (1).*

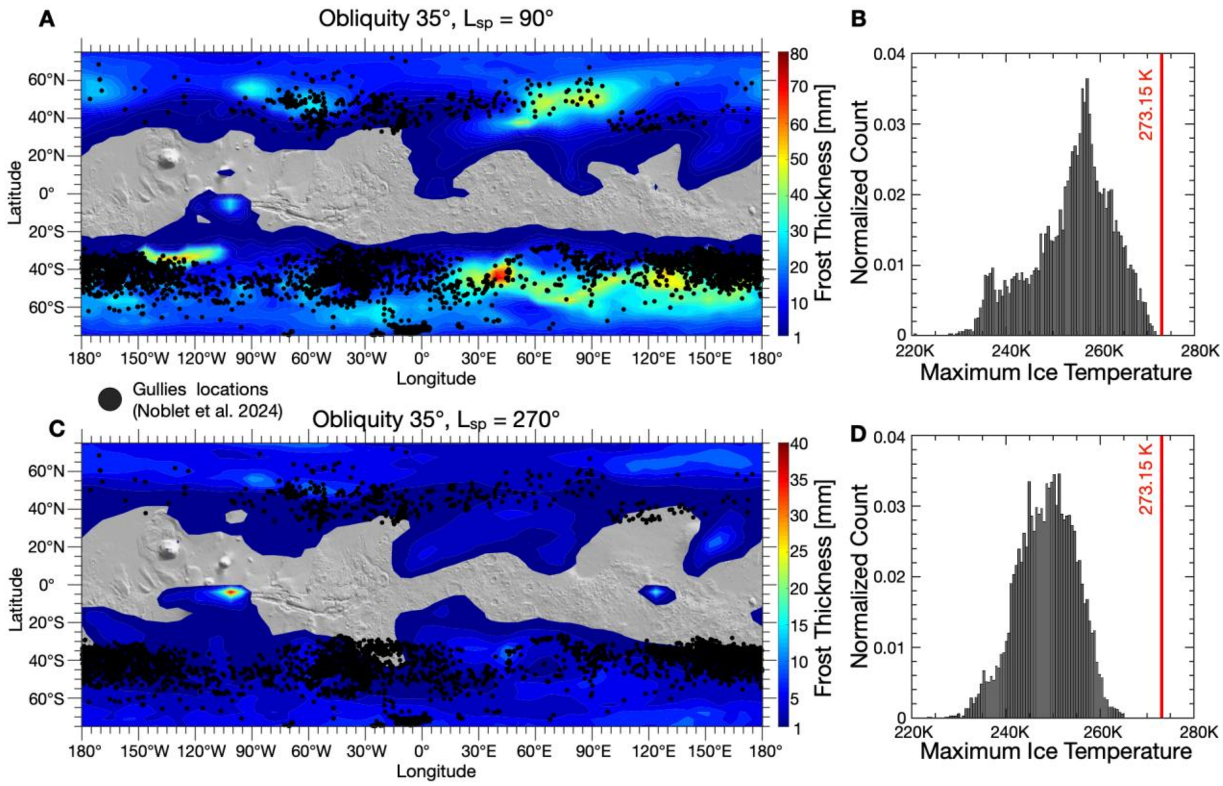

Figure 1: Maximum thickness of seasonal frost on 30° pole-facing slopes for an obliquity of 35° and perihelion coincident with the Northern summer (a), and the Southern summer (c). Gully's locations are reported by the grey dots. Maximum temperatures of these deposits are shown in (b,d).

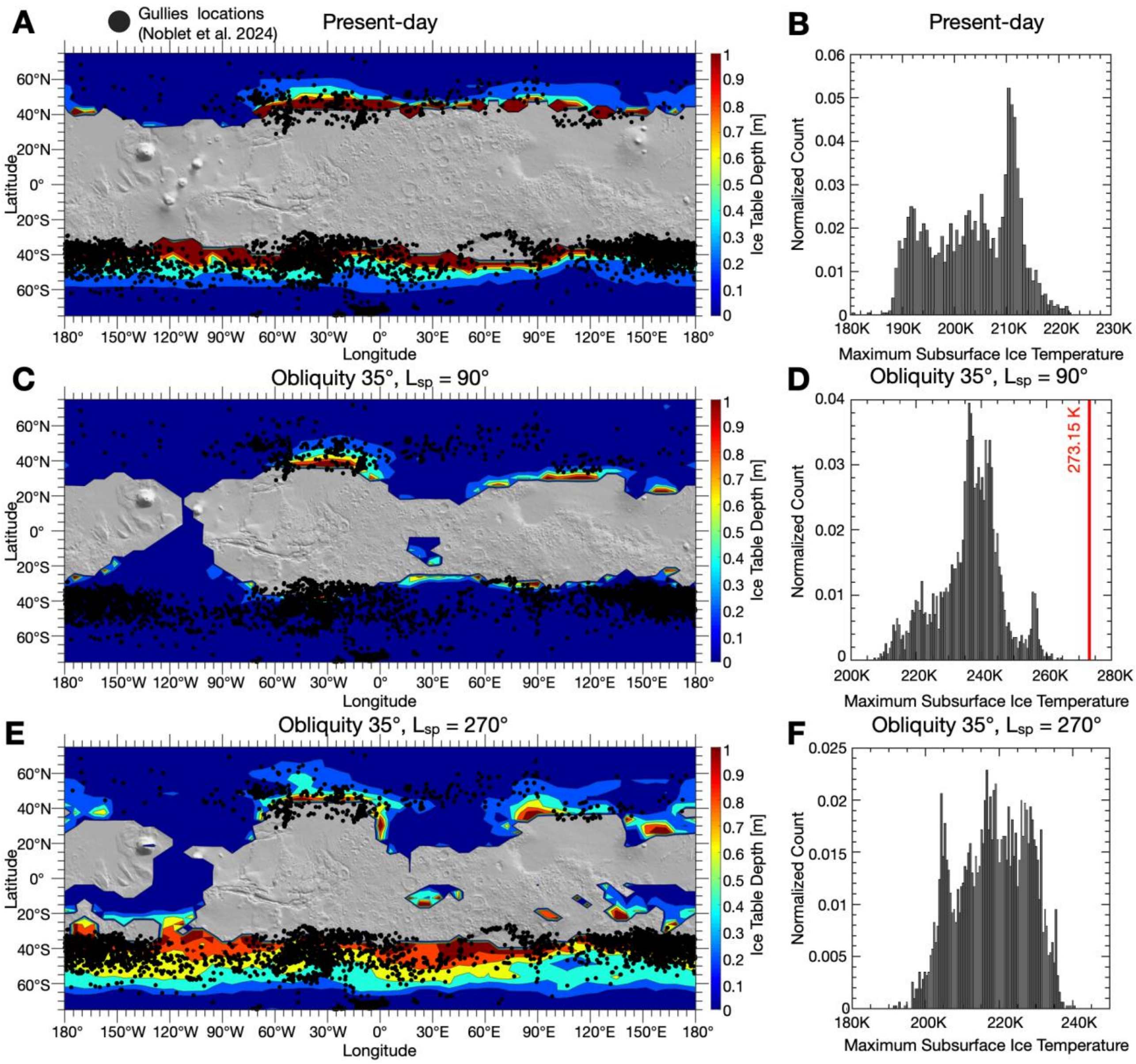

Figure 2: (a,c,e) Depth at which water ice can be stable beneath 30° pole-facing slopes for present-day and recent past, along with the maximum temperatures of these ice (b,d,f)