EPSC Abstracts
Vol. 11, EPSC2017-378, 2017
European Planetary Science Congress 2017

Survival of perennial carbon dioxide ice caps on Mars

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1. Introduction

The southern residual ice cap (SRC) of Mars is composed in-part of high-albedo solid CO_2 [1]. It buffers the current atmosphere and probably stabilizes a buried CO_2 reservoir [2] at least 20 times its size. Yet this critical deposit is apparently being eroded at a prodigious rate calling into question the stability of the current martian climate [3]. Here, we tie observations of the SRC surface and overlying atmosphere by Mars Reconnaissance Orbiter (MRO) together with landscape evolution models that predict, not a stable cap, but rather one that waxes and wanes over timescales of ~10^2 years. Our results imply large dust storms provide a mechanism that allows regrowth of the cap and so play a crucial role in stabilizing the current climate.

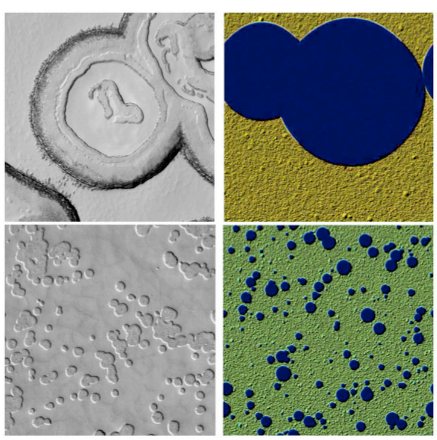

Figure 1. All panels are 1 km^2 and illuminated from the right. (Left) Two examples of SRC terrain with pit densities of ~1 and ~100 km^{-2}. (Right) DTMs (elevation scale in Fig. 2) of model results for higher (top) and lower (bottom) smoothing efficiencies.

CO_2 ice slabs within the SRC vary from 2-10 m thick [4-5]. The SRC has areas at its margins and in its interior where underlying water ice shows through [4-7]. It contains abundant flat-floored, quasi-circular pits (Figure 1) with a wide range of spatial densities [8]. The inclined walls of these pits retreat by several meters each year [3,5,9] leading [3] to suggest that the SRC is in the process of disappearing. However, a changing climate is unexpected as the orbit of Mars changes on much longer timescales. In contrast, other sections of the SRC lack these pits and show little change, but may be accumulating or ablating vertically. Only small changes in SRC extent have occurred in recent decades [10].

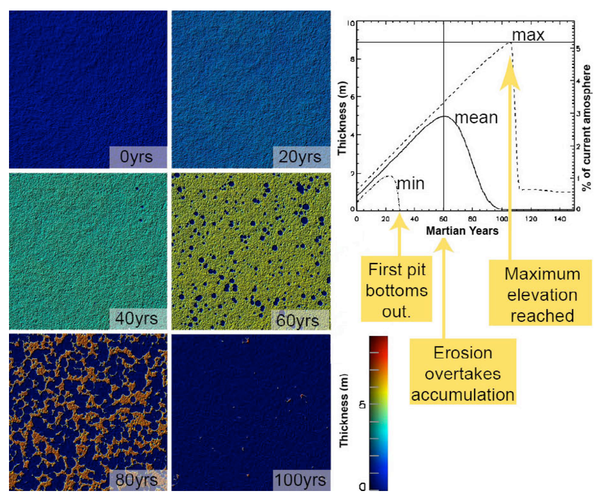

Figure 2. DTMs at times indicated of a typical model run of a CO_2 landscape. (Right) minimum, mean and maximum CO_2 ice thicknesses as a function of time.

2. Observations and Model Results

In our landscape evolution model CO_2 ice elevation falls or rises via ablation or condensation due to imbalances in surface energy budgets. In a typical model run (Figure 2), ice accumulation begins on a low-roughness surface; however, roughness increases with time. After about 30 years, pits begin to form and grow down to the water-ice basement. Over the following decades these pits expand laterally (by a few m/yr as observed [9]) even while the intervening flat surfaces continue to accumulate mass vertically. As the accumulation area (mesa-tops) shrinks, and the ablation areas (pit perimeters) grow, the landscape as a whole passes from a net-accumulation to a net-ablation regime (Figure 2). Many SRC locales are close to the final state shown, where only isolated (and shrinking) mesas remain. This overall behavior is an inevitable consequence of starting with a surface that is not perfectly flat; CO_2 ice caps can never be stable indefinitely. Summertime exposure of the underlying water ice results in heat-storage and an inability for a perennial cap to recondense [11].

Understanding that surface roughness governs pit-initiation resolves how differing pit concentrations (Figure 1) occur. CO_2 snowfall up to a few tenths of the total seasonal surface CO_2 has been detected here by the Mars Climate Sounder [12]. In our model, recently-condensed surficial CO_2 ice can be mobilized by wind and is capable of infilling small-scale roughness (treated mathematically as diffusion). Some parts of the SRC are windier leading to more smoothing and larger pit-spacing (Figure 1).

To allow a new SRC to form, interannual variability (specifically additional CO_2 condensation or snowfall) is required. We have observed refrosting of dark SRC areas after the MY28 summer global dust storm [13]. A similar, more-extreme, refrosting was observed by Mariner 9 and Viking after the Mars Year 9 global storm. We suggest atmospheric dust drives enhanced snowfall the winter following a large storm, both by providing condensation nuclei to a sub-saturated atmosphere and cooling the atmosphere (dust is a much more effective emitter of heat than CO_2 gas). Additional surface CO_2 ice can offset heat stored in subsurface water ice and allow perennial CO_2 to begin growing again. This new perennial cap will accumulate and be in-turn destroyed by expanding pits in a cyclic process. Each cap differs in exact form, but has identical overall behavior (Figure 3).

3. Summary and Conclusions

No climate change is necessary to explain the current erosion of the SRC; expanding pits exist at all phases of its life cycle. As different parts of the cap are at different stages of this cycle no systematic atmospheric pressure changes are predicted. Interannual variability in the form of winters with above-average condensation/snowfall is required to explain a recurring SRC. Historical and MRO data suggest that these winters are preceded by large dust storms.

References

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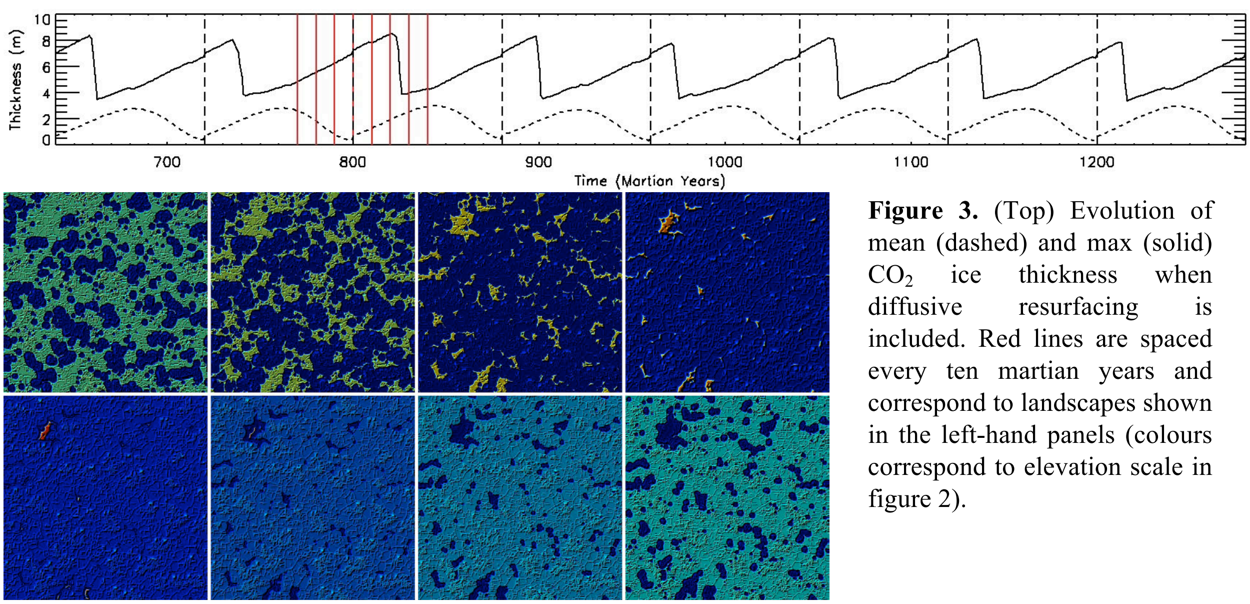

Figure 3. (Top) Evolution of mean (dashed) and max (solid) CO_2 ice thickness when diffusive resurfacing is included. Red lines are spaced every ten martian years and correspond to landscapes shown in the left-hand panels (colours correspond to elevation scale in figure 2).