SUBLIMATION AT THE BASE OF A SEASONAL CO_2 SLAB ON MARS. Oded Aharonson, *Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena CA 91125, USA (oa@caltech.edu).*

Motivation and Goal

A host of new observations of defrosting features appearing during the sublimation of polar CO_2 ice on Mars have been reported [e.g. 1–3]. The development of some of these features, from vents, to plumes, and eventually spider landforms has been linked to exhausting of a pressurized gas layer trapped between a CO_2 slab and the underlying ground, being heated from above from solar insolation [2]. This mechanism relies on the slab's being sufficiently transparent to sunlight to allow heating to occur at the base of the slab, which may be about 1 m thick [4].

A self-cleaning mechanism of the slab resulting from heating of dust particles by the sun has been proposed [3]. Here we consider the role of subsurface heat conduction in the energy balance at the base of the slab, and show that sublimation results from this process alone, which may explain the early onset of surface features. There are certainly additional lines of evidence which argue an annealed CO_2 slab (termed "cryptic terrain") may develop both in the north and south seasonal caps [5, 6] based on visible and thermal properties, and indeed spider forms appear geographically correlated with such areas[2]. We aim to evaluate another mechanism, that may act in addition to ones previously suggested. As will be shown, the hypothesis of heat conduction is particularly attractive for explaining venting activity that appears during the earliest parts of the spring season, before the sun has risen sufficiently high above the horizon to supply significant heat and clean the slab of impurities. Figure 1 shows a portion of a Mars Orbiter Camera [1] image, collected during an areocentric solar longitude of $L_s = 174.3^\circ$, at a latitude of 86.5°S, in polar twilight. The image shows numerous dark spots of the type that are seen to develop into plumes.

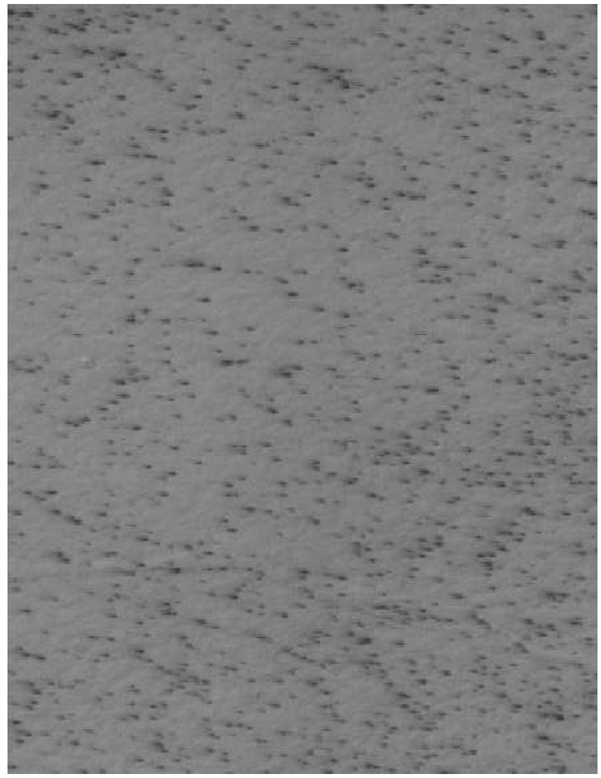

Figure 1: A portion of MOC image M03-03982, taken in polar twilight. The region is centered at about 225.0°E 86.5°S, was imaged at $L_s = 174.3^\circ$, and is approximately 3 km across. Numerous dark spots are visible, even at this early season.

Model

A simple 1-dimensional thermal diffusion model is numerically solved according to

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k \frac{\partial}{\partial z} T\right) \quad (1)$$

subject to the boundary condition,

$$Q_{\text{solar}} + Q_{\text{IR}} + k \left.\frac{\partial T}{\partial z}\right|_{z=0} = \sigma T^4 + L \frac{\partial m_{CO_2}}{\partial t} \quad (2)$$

at the top surface, and

$$k \left.\frac{\partial T}{\partial z}\right|_{z=z_0} = Q_{\text{geothermal}} \quad (3)$$

at the bottom of the domain ($z = z_0$), where ρ is the ground density, c is the heat capacity, T is temperature, k is thermal conductivity, Q_{solar} is the absorbed solar flux, Q_{IR} is the infrared flux assumed to be 4% of the peak noon-time insolation [7], σ is Boltzmann's constant, $L = 590$ kJ/kg is the latent heat of CO_2 fusion, $Q_{\text{geothermal}} = 28$ mW m^{-2} is the geothermal heat flux [8], and m_{CO_2} is the mass per area of CO_2 cover. The requisite orbital parameters of Mars are evaluated according to [9]. The model is numerically integrated using an implicit Crank-Nicholson time stepping scheme, and is initialized by running over many annual cycles at the beginning of the simulation.

The temperature of the CO_2 slab (if present) is assumed constant throughout the slab at the mean CO_2 frost point of 148 K, an approximation which implies gas pressure beneath the slab is never elevated to a point where it affects the equilibrium temperature. Energy balance is then satisfied by independently accounting for solid CO_2 mass fluxes at the top and bottom of the slab, F_{top} and F_{bot}, respectively, while keeping the temperature constant when CO_2 is present. The model is shown heuristically in Figure 2, where the various heat sources and sinks are indicated, as well as example subsurface tempertaure profiles.

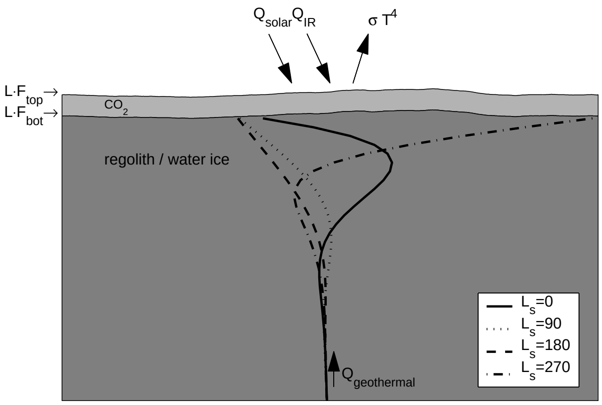

Figure 2: A heuristic cartoon summarizing the model. Solar, infrared, blackbody radiation, and geothermal heat sources are indicated, as well as the latent heat of CO_2 sublimation at the two boundaries of a slab. Four temperature profiles are shown, three examples delivering heat to the base of the slab, and one example away from it.

Results

The results of a calculation for a flat surface at latitude 85°S, with albedo $A = 0.29$, $\rho c = 2 \times 10^6$ J K^{-1}m^{-3}, and four different thermal inertias in the range from that appropriate for dust (250 J m^{-2}s$^{-1/2}$K^{-1}) to that for water ice (2000 J m^{-2}s$^{-1/2}$K^{-1}), are shown in Figure 3.

The heat deposited in the exposed ground during the summer season is delivered up to the slab during the winter months, and can account for several kg m^{-2} sol^{-1} of sublimation, as seen in the peak mass flux in the top panel. During the winter when the sun is below the horizon this accounts for 100% of the sublimation budget, and in the spring it still represents an appreciable heat source accounting for several to tens of percent of the mass loss (bottom panel). The integrated amount of mass per area sublimated by conduction at the base of the slab during the season can reach several hundreds of kg m^{-2}, again a non-negligible fraction of the total slab mass (bottom panel). The calculations confirm that the conduction effect becomes more important when the ground thermal inertia is high. Measured thermal inertias are typically low in the vicinity of the south polar cap, but the relevant quantity is the inertia on seasonal timescales, while the observations are of the diurnal fluctuations.

We have shown conduction provides a non-negligible contribution to the heat-, and therefore mass-, balance at the base of a seasonal CO_2 slab. Sublimation beneath an ice cover during the winter months can lead to enhanced gas pressure and venting that could be, in part, responsible for observed surface features.

Acknowledgments

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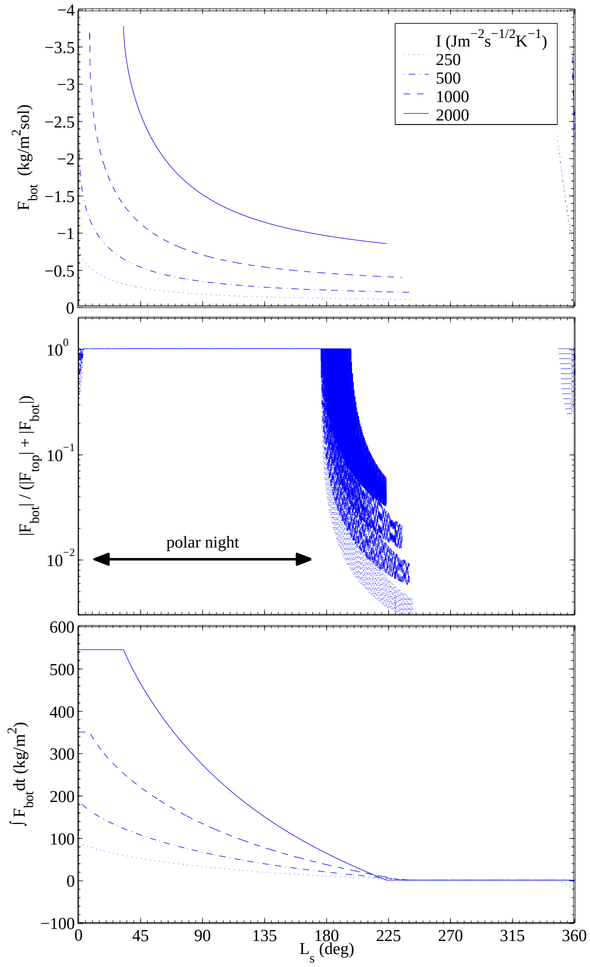

Figure 3: Model calculation showing solid CO_2 mass flux at the bottom boundary of a slab at 86°S for thermal inertias of the underlying ground. Shown are the rates of mass sublimated per unit area at the base of the slab in absolute units (top panel) and as fraction of the total sublimation budget excluding condensation at the top surface (middle panel). The integrated mass per area sublimated during a season is also shown with the zero level chosen such that it corresponds to a time with no CO_2 cover (bottom panel).

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