CROCUS MELTING BEHIND BOULDERS ON MARS. Norbert Schörghofer, Planetary Science Institute, AZ & HI, USA (norbert@psi.edu).

Introduction: Melting is physically difficult to achieve under present-day Martian environmental conditions [1, 2, 3], and the observational evidence for liquid water is ambiguous. If liquid water is present on the surface, it is transient and tied to small-scale topography.

The frost point temperature on Mars (∼200 K) is far below the melting point of pure ice (273 K). Hence, water ice diffuses into the ambient atmosphere long before it reaches the melting point. Moreover, the total pressure of the atmosphere lies near the triple point pressure, so that ice near 0°C sublimates so rapidly that evaporative cooling becomes significant, and in fact exceeds the solar constant [1].

Here, one specific pathway for the formation of liquid water on present-day Mars is evaluated quantitatively: Melting of seasonal water frost in rough terrain. In areas that are seasonally shadowed, water frost accumulates, and when the sun rises again, temperature increases rapidly and may melt the frost. A rapid transition from cold to hot will involve little sublimation loss. A suite of new quantitative models is used to investigate whether melting of seasonal water frost can occur on present-day Mars. Previous model studies investigated the role of dust-covered ice [4], the "dirty snow pack model" [5, 6, 7], radiative cooling in alcove geometries [8], and crocus melting [9]. (The first day of spring without seasonal CO_2 frost is known as "crocus date".)

Updated Formula for Evaporative Cooling: When the water vapor content of the atmosphere is a non-negligible fraction of the total atmosphere pressure, as will be the case near melting, there is a strong buoyancy force that leads to free turbulent convection and strong evaporative cooling. I updated the classical parametrization of the turbulent flux [1] based on more recent literature [10].

Figure 1 compares the classical and the updated parametrization for a specific atmospheric pressure and a common set of material constants. The most significant difference is the divergence of the updated parametrization when the partial H_2O pressure approaches the total atmospheric pressure.

Surface Energy Balance with Three-Dimensional Topography: To evaluate the thermal evolution, a numerical model is used that includes direct insolation, subsurface conduction, horizons (terrain shadowing), and radiative energy exchange between surface elements. As the sun moves through the sky, the surface energy balance is integrated over time at steps of 1/50th of a solar day (sol) for 6 Mars years. Further details are included in the User Guide that accompanies the online code archive [11].

The model site is at a latitude of 30°S, with an albedo of 0.12 and an infrared emissivity of 0.98. The model run assumes a thermal inertia of 400 tiu (the thermal inertia unit, tiu = $Jm^{-2}K^{-1}s^{-1/2}$). The CO_2 frost albedo is 0.65. The albedo of the water frost is assumed to be the ambient albedo, as the frost is easily darkened by a sublimation lag.

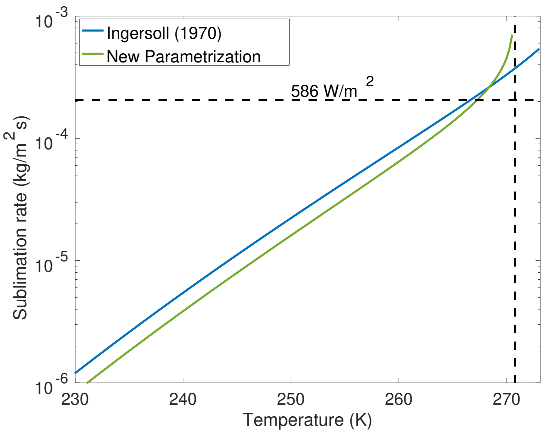

Figure 1: Parametrizations for free turbulent convective heat flux driven by the buoyancy of water vapor in a 500 Pa CO_2 atmosphere. The horizontal dashed line corresponds to the solar constant at Mars' semi-major axis.

For a boulder, idealized as a half-sphere that sticks out from the surface (Figure 2), the situation is favorable. Beyond the southern (poleward) end of the boulder, water frost continuously accumulates for hundreds of sols, decimeters of CO_2 frost accumulate, and peak temperatures are well above the melting point (when evaporative cooling is not considered). Figure 3 shows the time dependence of a location behind the boulder. The location is seasonally shadowed around the winter solstice. After the crocus date, the surface temperature goes from 145 K to 273 K within 1¼ sols.

With evaporative cooling, the surface does not reach the melting point (Fig. 3). On the first full sol after the crocus date, the temperature rises to 256 K and 0.1 kg/m^2 of frost (a 100 μm thick layer) are lost until it first reaches this temperature. The next day, the peak temperature is 260 K and at this point 0.5 kg/m^2 of frost have been cumulatively lost. The evaporative cooling is too strong to allow 273 K to be reached. Melting temperature would be reached, if the loss rate was artificially reduced by a factor of 20.

The Overlying Layer: A layer of dry material overlying the ice acts as a diffusion barrier and reduces mass loss and evaporative cooling. Quantitative calculations

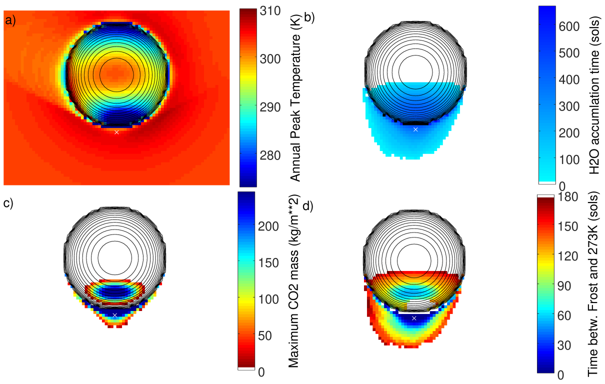

Figure 2: Thermal model results for a boulder at latitude 30°S and thermal inertia 400 tiu. The height-to-diameter ratio is 1:2. North is up and equatorfacing.

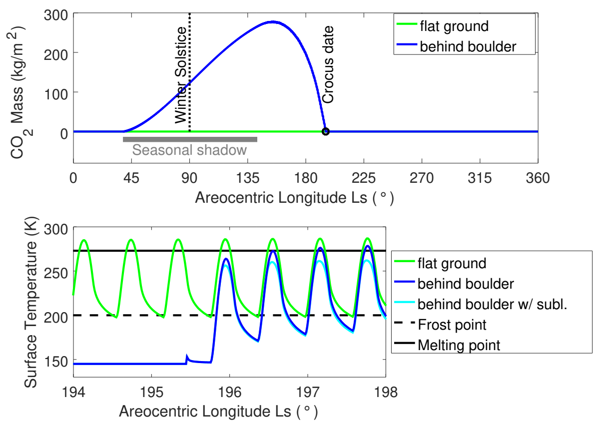

Figure 3: Time dependence of CO_2 mass and surface temperature behind the pole-facing slope of the boulder. The total atmospheric pressure is 1000 Pa.

show that for the dust layer to be a significant barrier to vapor diffusion, its thickness needs to be on the order of a cm, even with micron-sized particles.

An idealized form for the solar flux corresponds to the sun rising at the equator at perihelion. For this energetically favorable situation, Figure 4 shows the surface temperature over a quarter of a sol.

The consequences of evaporative cooling are severe. For all but the most favorable conditions, the melting point is not reached. Peak temperatures within about 10 K of the melting point within one or two sols of the crocus date are realistic.

Discussion: Evaporative cooling prevents temperatures from rising to 273 K, even at an atmospheric pressure as high as 1000 Pa and even with a sublimation lag of several mm of dust. For expected sublimation lag thicknesses, evaporative cooling is not significantly reduced. Overall, melting of pure seasonal water ice is not expected under present-day Mars conditions.

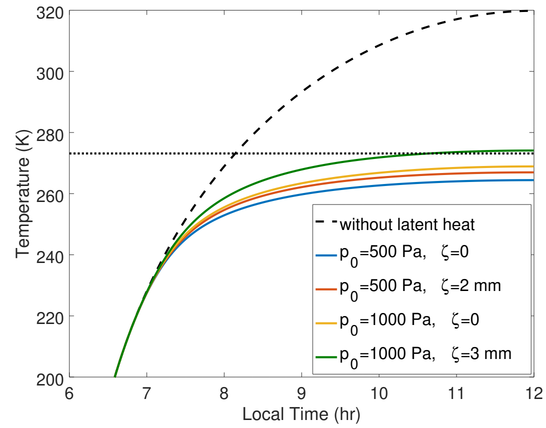

Figure 4: Equilibrium surface temperature from morning until noon with idealized solar energy input. The atmospheric pressure is p_0, and ζ is the thickness of an overlying layer of micron-sized dust particles.

Dark water frost can reach peak temperatures within about 10 K of the melting point, and the loss of ice experienced during the warming phase is no larger than the amount of seasonal water frost that can be expected to be present. For bright water frost (albedo 0.4) peak temperatures within about 15 K of the melting point are realistic. At these temperatures, seasonal water frost can melt on a salt-rich substrate. Hence, crocus melting behind boulders can lead to the formation of brines under present-day Mars conditions. The process will repeat periodically until the salt is depleted. Since the seasonal H_2O frost layer is very thin, the total volume of brine produced is small.

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