THE INFLUENCE OF LOCAL GEOMETRIC EFFECTS ON MARS POLAR PROCESSES.

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Introduction: Using simple, qualitative heat balance models, this paper addresses textures and structures that will result from the evolution of volatile layers by accretion and by ablation. Such phenomena may have global implications that are not apparent when only flat or sloped surfaces are modeled.

In general, structures such as mounds or depressions formed out of volatile materials will evolve in shape such that the growth or retreat of any particular surface will be maximized. It can be shown that the local radius of curvature is proportional to the growth or retreat rate. For example, icy surfaces will tend to form facets that face the dominant sun direction. Two such cases are evaluated:

a) Features associated with condensation of volatiles, include coldtrapping and redistribution, such as the concentration of frost around the Viking 2 lander [1]. Here I will focus on textures that likely result from the formation of seasonal CO_2 deposits.

b) Features associated with sublimation of volatiles, such as those described by Ingersoll et. al. [2] result in textured surfaces that affect both the apparent emissivity and albedo. Similar calculations have been performed with respect to the "Swiss cheese" features on the South Polar Cap [3]. Here, I evaluate the likely sublimation rates from optimal ice scarp structures and their implications for the long-term evolution of the polar caps and formation of layered terrain.

CO_2 condensation: The thickness of the seasonal CO_2 cap has been measured by multiple techniques [4], and can be approximately modeled simply by balancing the radiative loss to space and the latent heat of condensation from the atmosphere.

Since the solid CO_2 surface itself is at a uniform temperature, ~148K, in the absence of precipitation CO_2 will only condense in locations that are radiating to the sky. If a small depression forms randomly, the surface within the depression will radiate to a smaller solid angle and will therefore accumulate at a slower rate than the surrounding surface. It is shown here that this positive feedback results in heavily perforated surface on the scale of ~10 cm.

Figure 1 shows a one-dimensional (cylindrically symmetrical) radiative balance model of the evolution of such a frost layer from a modulated, 1-cm thick surface. The starting condition included a depression of the shape $(1-\cos\theta)/2$ spanning the entire period from $-\pi$ to π. Periods of 10, 25, 50, and 100 cm are shown. The simulation ran in 10-hour steps for 5000 hours, on the scale of a polar night. At each time step, the surface was allowed to grow in a direction normal to its local slope at a rate proportional to the apparent emissivity (i.e. the solid angle of visible sky). The original grid was then restored by interpolation. The endpoints are constrained to be horizontal and unshadowed. For display purposes, a density of 1 g/cm^3 was assumed.

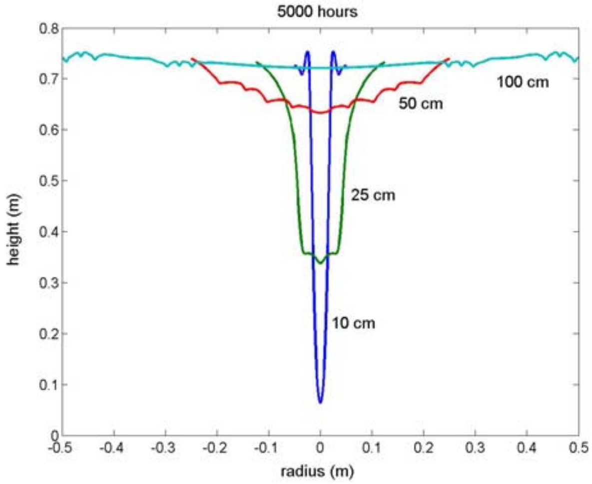

Figure 1: Perforations develop in a condensing CO_2 frost layer as a result of nonuniformities which modify the radiation environment. The depth of the perforation is greatest for the narrowest nonuniformities.

It should be noted that the calculation is scale-independent and hence intrinsically unstable with respect to roughening. Any discrete offset between adjacent points is equivalent to a vertical scarp and will induce formation of an annular trench. To simulate natural processes that limit the scale of roughness (e.g. heat conduction), a 1-cm smooth was applied at each 10-hour time step. In addition, the evolution of sidelobes was suppressed.

The most common feature of the simulation is the appearance of perforations, a few centimeters in diameter, that pierce the entire blanket of frost. Depending on the competence of the remaining material, this phenomenon could alter the effective density of the frost layer (and hence the thickness) by a factor of ~2.

The resulting structure may explain a number of mysteries about the nature of CO_2 frost on Mars. For example, by comparing MOLA heights and GRS column mass results, Aharonson et al [5] recently concluded that the polar CO_2 deposits were of surprisingly low density, ~0.5 g/cm^3. This result could readily be explained by a denser blanket of perforated material. Recently, Ivanov [6] reported on apparent enhancement in the definition of surface features in the presence of CO_2 ice. This enhancement could be due to a tendency of the CO_2 to dramatically accentuate the surface relief by condensing preferentially on exposed surfaces. Finally, perforated CO_2 structures are a possible alternate explanation for the apparent visible transparency of CO_2 layers identified as slab ice by their thermal signatures [7].

Polar water ice sublimation: The sublimation rate of polar ice varies strongly with orbital parameters and can result in macroscopic changes to the shape and character of the polar surface. As a reference for subsequent discussion, a qualitative estimate of the variation in the sublimation rate can be inferred by determining the temperature resulting from radiative balance, and the corresponding evaporation rate for pure ice [8]. such a model is shown in Figure 1 over the next precessional period (not obliquity), using orbital periods from Ward [9]. The result, which peaks at nearly 7 cm/year, is overstated in that it does not consider seasonal redeposition, heat storage in the surface, or large scale atmospheric heat transport. Nonetheless it is apparent that we are currently very much at a minimum sublimation rate for the North Pole.

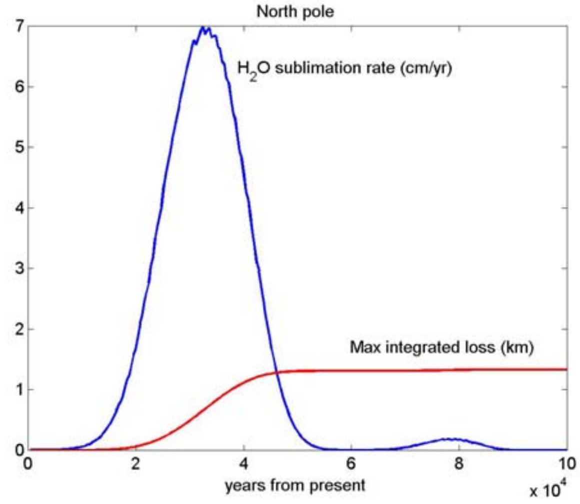

Figure 2: Qualitative estimate of sublimation rate from the North Pole over the next precessional cycle. The integrated loss rate assumes no redeposition or quenching of sublimation by lag buildup.

On the margins of the polar cap, however, a very different situation would obtain. A volatile surface shaped by sublimation will facet on some spatial scale to maximize the erosion rate. The low polar sun would thus imply near-vertical facets covering a net area up to 10% of the total polar surface area, depending on the degree of undulation of the margin. Moreover, on a larger scale, the horizontal cross section will tend to form scallop shapes to minimize radiation to the sky, lowering the apparent emissivity.

As a first estimate of the *relative* impact of this phenomenon, figure 3 uses radiative balance to calculate the peak equilibrium temperature of a flat surface compared to a steep scarp, and the same scarp with a semicircular profile. For the sloped surfaces, the peak temperature was estimated by assuming a sinusoidal diurnal variation in heat flux with a thermal inertia of 900. It was further assumed that surfaces only radiate to the sky. If latent heat were included, the temperature would never exceed ~273K, but the evaporation rate would increase in the "warmer" locations. Note also that, heat storage is ignored.

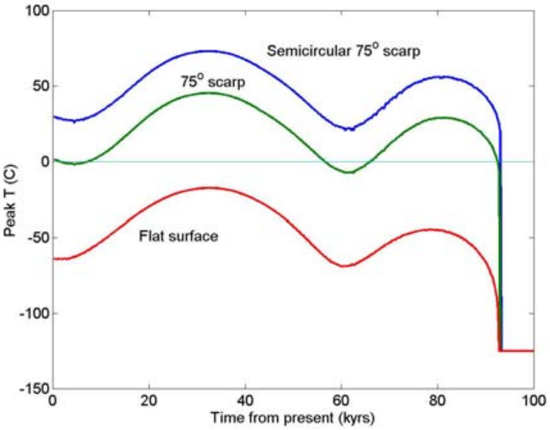

Figure 3:"Moon-like" approximation for North Pole (radiative balance and CO_2 latent heat only), with albedo 0.4 and emissivity 0.9 for water ice, albedo 0.65 and emissivity 0.85 for CO_2 frost respectively. .

It follows from that horizontal erosion from the polar cap margins could be significantly more rapid than erosion from the top surface, consistent with the formation of features such as Chasma Boreale. Moreover, the formation of a sublimation lag would be less likely on near-vertical surfaces, and horizontal erosion would continue over the entire the orbital cycle.

References: [1] Svitek T. and Murray B. (1990) *J. Geophys. Res. 95*, 1495-1510. [2] A. P. Ingersoll, T. Svitek, B. C. Murray (1992), *Icarus 100*, 40-47. [3] Byrne, S. and Ingersoll, A..P. , *Science* **299**, 1051-1053 (2003). [4] Mitrofanov I. G. et al. (2003) *Science 300*, 2081-2084 [5] Aharonson O. et al. (2004) *J. Geophys. Res. 109*, *E05004* [6] Ivanov A.B. (2004), *Eos Trans. AGU 85(47), Fall Meet. Suppl. Abstract P13A-0978.* [7] Titus T.N. et al. (2001) *J. Geophys. Res. 106,* 23,181-23,196. [8] Fanale F.P. et al. (1986), *Icarus 67*, 1-18. [9] Ward W.R. (1974), *J. Geophys. Res. 79*, 3375-3386.