MODELING THE FORMATION OF \( \text{CO}_2 \) FROST HALOS IN THE SOUTH POLAR RESIDUAL CAP OF MARS

P. Becerra\(^1\) and S. Byrne\(^1\), \(^1\)Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, becerra@lpl.arizona.edu.

Introduction: The “swiss cheese” features on the south polar residual ice cap (SPRC) of Mars are one of the most fascinating formations on the planet. These near circular pits have diameters that range from meters to hectometers, and depths that cut through the 2-8m thick \( \text{CO}_2 \) ice sheet of the SPRC. The steepness of the walls of the pits varies greatly throughout the SPRC, sometimes up to the point where there is material overhanging into the pits. Analyses of the formation and growth of these depressions have been done in the past [1,2]. However the broad spectrum of physical characteristics that these pits exhibit, and the processes that shape them are not yet well understood.

MRO’s High Resolution Imaging Science Experiment (HiRISE) [3] has imaged these features extensively and found that some exhibit a bright halo around their edges on the flat floors of the plateau of \( \text{CO}_2 \) ice surrounding them (Fig.1). Here we investigate the formation of these halos by means of a model for the accumulation and ablation of \( \text{CO}_2 \) ice on a surface near the martian south pole. We propose that the process responsible for forming the bright rings is most likely condensation driven by increased levels of \( \text{CO}_2 \) gas in the local atmosphere produced by ablation of the sloped walls of the pits.

Images: Out of about 30 images examined, only 4 were found to have halos around the swiss cheese depressions. This suggests that the process that forms them is a seasonal one, in fact occurring only at specific times during martian southern summer (~Ls 295º - 300º). Further image analysis will be done to better constrain this seasonality.

Physical Model: The halos are most likely composed of a thin bright layer of frost. Their location around the edges of the pits suggests that their formation is in someway related to the sublimation and condensation of \( \text{CO}_2 \) near the rims.

Our hypothesis (Fig. 2) is that extra \( \text{CO}_2 \) gas in the local atmosphere, supplied by ice sublimating at a faster rate from the sloped walls than from the flat plateau, drives frost condensation in areas adjacent to the walls. This difference in ablation rates emerges from the fact that, during southern summer, a sloped surface near the pole receives sunlight at lower incidence angles than a flat surface, therefore increasing the energy input and sublimation rate of the ice. The extra \( \text{CO}_2 \) sublimed into the atmosphere at the walls, raises the local partial pressure of \( \text{CO}_2 \) and thus the local condensation temperature of \( \text{CO}_2 \) ice. This results in frost condensing onto the adjacent colder surfaces. This effect is diminished as one moves away from the walls, through the diffusion and dilution of the extra \( \text{CO}_2 \) gas into the surrounding atmosphere.

Fig. 2. Schematic of our theory for the process governing the formation of the bright halos around swiss cheese features.

Numerical Model: We model the accumulation and ablation of \( \text{CO}_2 \) ice on smooth surfaces near the south pole (87º S) and the diffusion of the extra \( \text{CO}_2 \) input into the atmosphere by a surface with a 30º north-facing slope.

\( \text{CO}_2 \) Ice Thickness Model: The \( \text{CO}_2 \) ice thickness for an entire martian year was calculated using the following equation for the change in \( \text{CO}_2 \) ice mass with time (an ice density of 1600 kg/m\(^3\) was assumed):

\[
\frac{dm}{dt} = \left( \frac{S_i}{r^4} \right) (1 - A) \cos(i) - \epsilon \sigma T^4
\]

The first term on the right side represents the solar radiation incident on the surface, and the second term...
represents the blackbody energy radiated by the surface \( L = \text{Latent heat of sublimation of CO}_2, S_0 = \text{solar constant}, r = \text{solar distance}, \ A = \text{geometric albedo}, \ i = \text{incidence angle}, \ e = \text{emissivity}, \ \sigma = \text{Stefan Boltzmann constant}, \ T = \text{surface temperature} \). We assumed a constant geometric albedo of 0.72, and an emissivity of 0.95. The solar distance, incidence angle and surface temperature vary throughout the year. Equilibrium temperature values were obtained by scaling the pressure curves measured by Viking [4] to the south polar altitudes, and assuming a constant CO\(_2\) mixing ratio. We solved the above equation for a flat and for a sloped surface, and obtained the results shown in Figure 3.

![Figure 3](image)

**Fig. 3.** Seasonal CO\(_2\) ice thicknesses for two surfaces at 87ºS for a whole martian year. The red plot represents a flat surface and the blue plot represents a surface with a north-facing slope of 30º.

Our results clearly indicate that the ablation of the surface during southern spring and summer (Ls 180º - 360º) is greater for a sloped surface (blue) than for a flat surface (red).

**Diffusion Model:** Once the mass balance has been calculated, we use these values as a surface boundary condition in a model of local atmospheric composition. We solved the diffusion equation for the partial pressure of CO\(_2\) using the forward-time-centered-space method. We used a 100m x 100m square grid (grid point = 1m\(^2\)), in which the bottom boundary represents the flat surface, and its middle grid point, the 30º slope. The other three boundaries were set to the Viking pressure curves. The molecular diffusivity was calculated using equation 11 in [5]. The interdiffusivity of CO\(_2\) through CO\(_2\) was interpolated from interdiffusivities of different vapors through CO\(_2\), which were measured in [6]. The solutions to the diffusion equation for a martian year were visualized via animations (Fig. 4.). There is a clear offset between daily oscillations in CO\(_2\) partial pressure near a sloped surface and near a flat surface. The animations also indicate that the CO\(_2\) partial pressure differences due to sublimation at the slope diffuse outward rapidly, which provides an explanation for the restricted size of the halos.

![Animation Frame](image)

**Fig. 4.** Frame from the diffusion animation at Ls=227.18º. Whiter and darker pixels represent high and low pressures respectively. The white point in the center of the bottom boundary represents the slope, the rest of the pixels in this boundary are flat surface pixels. The other three boundaries are set to the Viking pressure curve values.

**Preliminary Conclusions:** (a) A sloped surface of carbon dioxide ice near the south pole results in more ablation during the summer than a flat surface. (b) There is a clear offset between daily variations in CO\(_2\) partial pressure near a slope and near a flat surface. (c) The model shows that pressure differences at the slope diffuse quickly, which accounts for the thinness of the halos relative to the size of the pits.

**Future Work:** A more complete treatment of the radiation balance incorporating multiple surface scattering and atmospheric emission will be developed. In order for the formation of halos to come directly from our model, we will link ice equilibrium temperatures to local (rather than global) partial pressure variations. Using the widths of our model halos and comparing them to the real widths seen by HiRISE, we will investigate if molecular diffusion or turbulent diffusion is the dominating process.

**References:**