MODELING THE FORMATION OF CO_2 FROST HALOS ON THE SOUTH POLAR RESIDUAL CAP OF MARS P. Becerra[1], S. Byrne[1], and the HiRISE Team, [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, becerra@lpl.arizona.edu.

Introduction: The south polar residual cap of Mars (SPRC), composed in part of high-albedo CO_2 ice, displays morphological features that are shaped by recent surface-atmosphere interactions. Investigating these features can help constrain the mass balance of the cap, leading to a better understanding of the relationship between the martian atmosphere and surface.

A spectacular example of some of the morphology within the SPRC is the "swiss cheese terrain", which is composed of quasi-circular pits and curved scarps that cut through the 2-8 m thick CO_2 ice sheet. Models of the formation of these depressions exist [1], however, the broad spectrum of features that these pits exhibit, and the role they play in setting the overall mass balance of the SPRC, are not yet well understood.

MRO's HiRISE and CTX instruments photographed these regions and found that a large number of the scarps exhibit a bright halo around their edges (Fig.1a,c). Here we investigate the formation of these halos by means of a model of the mass budget of CO_2 ice on surfaces near the martian south pole. We propose that the halos are formed from differences between the sublimation rates of surfaces adjacent to the edges of the scarps and more distant surfaces. These differences are driven by an increase in the partial pressure of CO_2 in the local atmosphere, produced by higher ablation off the sloped walls of the pits.

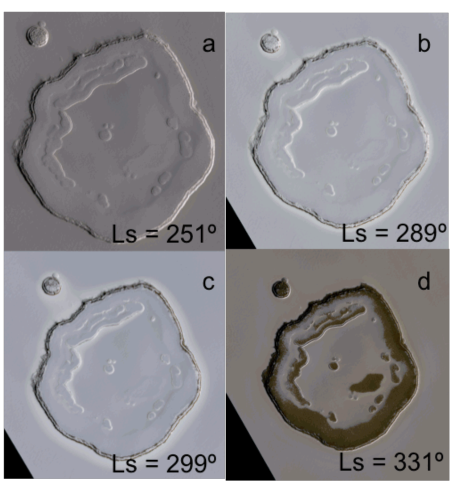

Fig. 1. Portion of four HiRISE images showing the same swiss cheese pit at different times. In images b and c, a bright halo of frost is clearly visible around the edge of the pits.

Observations: We have examined nearly 170 images taken throughout southern summer (~Ls 270-330). About 30% of the total number of images examined (CTX and HiRISE) were found to have halos around the edges of SPRC scarps, the majority between Ls 285-305. No halos were seen before Ls 280 or after Ls 320. The halos mostly appear in scarps closer to the southernmost latitudes of the residual cap (~85º-90º). The appearance of the halos coincides with the darkening of the pit walls (see Fig. 1), indicating that the formation of halos is a highly seasonal process.

HiRISE shows an 8% albedo difference between the halos and the surrounding material. Concurrent CRISM observations reveal a uniform cover of CO_2 ice, thus ruling out spatial variations in dust or water frost as constituents responsible for the halos.

Hypothesis: Brown et al. [2] reported a decrease in CO_2 grain sizes from ~7cm to ~5mm in one martian season. We constructed a Hapke reflectance model [3] and found that there is a ~10% albedo difference between 7cm grains and freshly deposited 1μm grains. This leads us to infer that the halos are exposures of fresher, fine-grained CO_2 ice that is brighter than the older surrounding ice. Our hypothesis (Fig. 2) is that there is condensation, or slower sublimation of CO_2 ice occurring in the regions near the walls of the scarps. This effect is caused by the increased partial pressure of CO_2 gas in the local atmosphere, supplied by a faster sublimation rate from the sloped walls that receive sunlight at lower incidence angles. The enhancement is diminished as one moves away from the walls, through the diffusion and dilution of the extra CO_2 gas into the surrounding atmosphere.

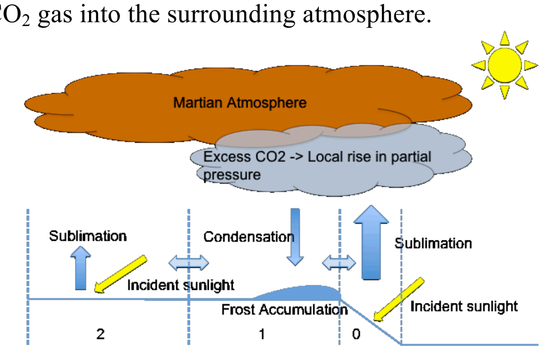

Fig. 2. Schematic of our theory/model for the formation of the bright halos on the edges of south polar scarps. The model surfaces/cells are labeled as follows: 0 – slope, 1 – adjacent, 2 – distant.

Model: The objective of our model is to describe the annual cycle of accumulation and ablation of CO_2 ice on a model surface like the one shown on fig. 2, and track the diffusion of the excess CO_2 sublimated from the sloped surface (cell 0 in fig. 2), in order to expose the differences between the accumulation rates of a flat surface adjacent to the scarp (cell 1 in fig. 2), and one distant from the scarp (cell 2 in fig. 2). We assume no radiation or sensible heat exchange between the atmosphere and the surface, and we set the atmosphere to follow the pressure curves measured by the Viking landers scaled to south polar altitudes.

We first calculate the sublimation rate and mass of CO_2 accumulated at each surface using the following energy balance equation:

$$\frac{dm}{dt}L = \left(\frac{S_0}{r^2}\right)(1-A)\cos(i) - \varepsilon\sigma T^4$$

The first term on the right side represents insolation; the second term represents the energy radiated by the surface (L=Latent heat of sublimation of CO_2, S_0=solar constant, r=solar distance, A=geometric albedo, i=incidence angle, ε=emissivity, σ=Stefan Boltzmann constant, T=surface temperature). We set the albedo of the flat surfaces to vary according to equation 1 in [4], The slope's albedo changes from 0.74 to 0.3 at ~Ls 290 to match the observed darkening of the pit walls. The surface temperature varies according to the partial pressure of CO_2 above the corresponding surface cell. The obtained thickness of CO_2 accumulated in flat and sloped surfaces is compared in fig. 3.

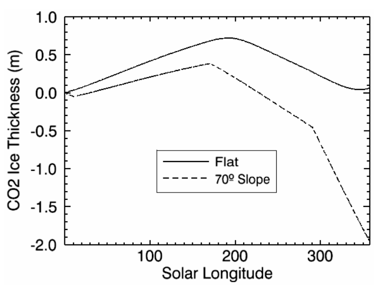

Fig. 3. CO_2 ice thickness for two surfaces at 87ºS for a martian year. The dashed line represents a surface with a north-facing slope of 70º (surface 0 in fig. 2).

We then calculate the partial pressure of CO_2 above each surface cell, considering the sublimated CO_2 at each cell and the flux due to the diffusion of this excess CO_2 with the above atmosphere and with the adjacent cells. With this information we recalculate the ice temperature and repeat the process for a full year.

Preliminary Results: The difference in thickness of deposited frost between surfaces 1 and 2 of figure 2 is shown in fig. 4. This plot reveals that a number of different scenarios occur throughout the year. At the onset of winter (~Ls 350-10) the sun is very low in the sky, so the slope receives sunlight at a much lower incidence angle than the flat surfaces, resulting in sublimation from the slope and condensation onto the plateau. During polar night (~Ls 10-170) there is net condensation on all surfaces. At the onset of spring (~Ls 170-190) the situation is identical to that at the onset of winter. Finally, during summer, when the sun is higher in the sky, surface 0 has a higher sublimation rate than surfaces 1 and 2, but the atmosphere is nearly saturated. This reduces the effect significantly, making the deposition difference between surfaces 1 and 2 very small at this time of year.

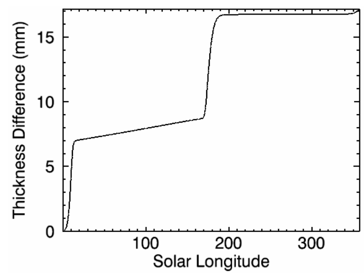

Fig. 4. Difference in frost thickness between a surface adjacent to the slope (1), and one distant from it (2).

The grain sizes observed by [2] during midsummer are ~2.5-7.5mm, and our Hapke model tells us that there is a 4% albedo difference between these grains and fresh frost (1μm). This means that a difference in thickness of frost can in fact translate into an albedo difference due to ice grain growth. Nevertheless, the difference in frost thickness produced by the model during midsummer is too small to expose ice old enough to match the observed albedo difference.

Preliminary Conclusions: (a) The halos are composed of fresh CO_2 and are not compositionally different than their surroundings. (b) The albedo difference is most likely due to a difference in the grain sizes of exposed ice. (c) The seasonal occurrence of the halos is connected to the increased sublimation rate from the slopes. (d) The time at which the halos disappear (~Ls 320) suggests that they get buried by uniform condensation of CO_2 at the beginning of winter.

Future Work: We have begun work on coupling a model for grain growth with our Hapke reflectance model. This will allow us to determine how much grain growth is required to produce the observed albedo differences. We must also extend our current frost accumulation model to include multiple surface scattering and atmospheric emission, in order to more accurately simulate the radiation balance. Our ultimate goal is to explain the importance of this process in setting the overall mass balance of the SPRC.

References: [1] Byrne S. and Ingersoll P. (2003) *Science* 299, 1051-1053. [2] Brown et al. (2010) *JGR* 115, E00D13. [3] Hapke, B. (1993) Theory of Reflectance and Emittance Spectroscopy, *Cambridge U. Press.* [4] Guo X. et al. (2010) *JGR* 115, E04005.