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Transient Bright Halos on the South Polar Residual Cap of Mars: Implications for Mass Balance

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Abstract

The CO_2 ice South Polar Residual Cap (SPRC) on Mars may be a sensitive indicator of inter-annual climate variability. Imaging by HiRISE [1], and CTX [2] found that many scarps and pits [3] on the SPRC exhibited a bright "halo" around their edges (fig. 1). These halos appeared during southern summer in Mars Year 28 (MY28, [4]), and have been observed in only one of eight MY for which observations at high enough resolution exist. We hypothesize that the formation of these features is linked to the late-summer global dust storm of MY28 and report on observations, formation models, and implications for mass balance of the SPRC. The transient nature of the halos proves that the flat surfaces of the SPRC have a positive mass balance during most years.

1. Observations

We surveyed data from HiRISE, CTX, and CRISM [5] to constrain the optical properties and composition of the halos, as well as their time of appearance and location. The halos appeared throughout most of the SPRC between L_s 280º and 330º in MY28 (fig. 2). The widest halos occurred adjacent to north-facing walls, and the brightest to sun-facing walls, which points to a connection between insolation and halo appearance. CRISM spectra ruled out water ice as a factor in the halos' appearance. These data also show CO_2 ice grain sizes where the bright halos were seen were not systematically smaller, which are normally associated with higher albedos [6]. Thus, we were able to rule out CO_2 ice grain size differences as the cause for the halos. This remaining possibility is that the halos appeared due to dust content differences between terrain adjacent to the pit walls and the surrounding ice. HiRISE BG/RED color ratios show halos are bluer than surrounding ice and so support this formation mechanism.

2. Reflectance Modeling

We constructed a Hapke [7] surface reflectance model in which the CO_2 ice grain size, dust volumetric content and dust particle size were free parameters. We used the instrument band-pass coefficients to simulate HiRISE albedo and CRISM spectra, and attempted to match the observations. A self-consistent set of CO_2 ice grain sizes and dust contents can explain the halos (fig. 3). As the halos have larger grains, small dust deficiencies in the halos explain their brighter appearance. Our model results constrain the composition of the ice to a small range of parameter space (10 – 20 μm dust grains at ~ 300 (halos) – 600 (surroundings) ppm, in ~8 mm CO_2 ice grains), and show that small differences in dust content are responsible for the halos.

3. Conceptual Model

A plausible formation mechanism could be that an outward flow of gas caused by the higher sublimation rate from the pit walls deflects settling dust particles, effectively keeping these areas clean of dust and causing them to appear brighter (fig. 4). This indicates that it was the cap that darkened rather than the halos brightening. The timing of the halos' disappearance (~L_s 330º) coincides with the end of southern summer. Therefore, it is likely that condensing CO_2 frost at the onset of winter covered the halos and adjacent terrain.

4. Implications for Mass Balance

Small changes in SPRC albedo can have large effects on the cap's stability, and may make the difference between net accumulation and net ablation for a year. HiRISE confirmed that after the halo occurrence at the end of summer in MY28, the residual cap defrosted more extensively than usual (fig. 5).

What do the halos tell us about the mass-balance of the SPRC? Their timing indicates that they were buried by seasonal frost by the end of MY 28. Since they were not exhumed during late summer of MY 29, or in any subsequent year we can assume that flat surfaces in the SPRC underwent net accumulation during over MY 29-31. Thus the situation on the SPRC in non dust-storm years appears to be one of net accumulation on flat surfaces even while the steeply inclined walls of the pits retreat several meters per year through ablation.

4. Conclusions

1. In order for halos to form on the SPRC, special conditions must be met that require the presence of an unusual amount of dust in the atmosphere at the correct time of year. This not only darkens the cap through the settling of dust, but it also increases the sublimation rates through an increase in atmospheric heating [8].
2. The single-time, ephemeral occurrence of halos indicates that the layer of ice that darkened as a result of the dust storm and surrounded the halos, was not exhumed in subsequent years, implying a positive mass balance for flat surfaces on the SPRC during MY29, and net positive mass balance from the end of MY28 through the end of MY31.

4. Figures

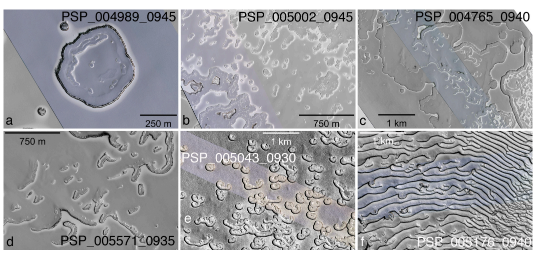

Fig. 1. Examples of sites on the SPRC that displayed halos during MY 28.

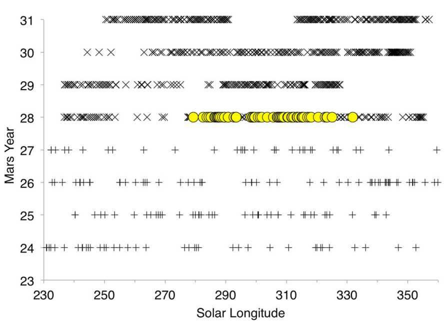

Fig. 2. Temporal distribution over MY and L_s of all HiRISE and MOC images examined. The yellow dots represent those images in which halos were seen.

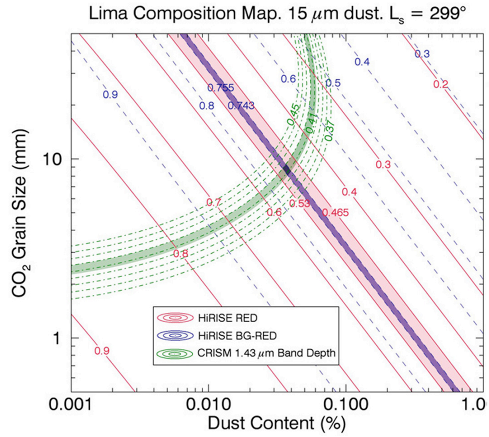

Fig. 3. Example of a contour map of surface photometric properties from our Hapke reflectance model. The shaded regions indicate the observed values (RED, BG/RED, 1.43 mm band depth) for this time of year (Ls 299º). The intersection of the shaded regions limits the composition of the surface to a particular combination of CO_2 grain size, dust content, and dust grain size.

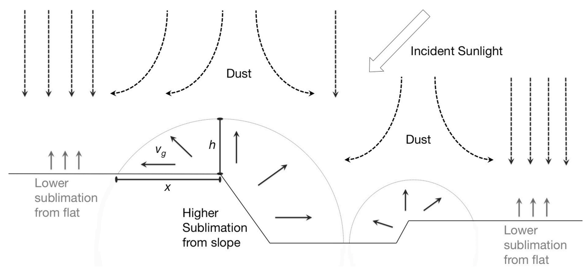

Fig. 4. Schematic of our model for the formation of SPRC halos. The higher sublimation rate on a slope raises the local partial pressure of CO_2 creating a "sublimation-wind" that blows settling dust grains away from the slope and keeps near-pit areas relatively dust-free.

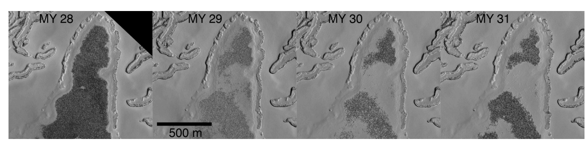

Fig. 5. Section of the SPRC at a halo site during four different MY. Defrosting after MY 28 was more pronounced than in later years, meaning that the cap recovered from a year with stronger than usual sublimation.

References

[1] McEwen et al. JGR 112, (2007). [2] Malin et al., JGR 112, (2007). [3] Thomas et al., Icarus 203, (2009). [4] Clancy et al., JGR 105, (2000). [5] Murchie et al., JGR 112 (2007). [6] Brown et al., JGR 115, (2010). [7] Hapke, B., Cambridge Univ. Press, (2012). [8] Bonev et al., Planet. Spac. Sci. (2008).