MODELING SUBLIMATION OF ICE EXPOSED BY RECENT IMPACTS IN THE MARTIAN MID-LATITUDES.
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Introduction: High latitude ground ice on Mars was inferred in the shallow subsurface by hydrogen measurements using Mars Odyssey's Gamma Ray Spectrometer (GRS) [1]. However, at mid to low latitudes, GRS found only small quantities of hydrogen, consistent with hydrated minerals. Recent observations have shown new small craters [2], and some in the mid-latitudes have exposed water ice at a depth of a few tens of centimeters [3] (Fig. 1). Such ice is unstable in the present climate. We use thermal modeling to examine the evolution of the observed ice and to calculate the ice loss due to sublimation at each site. This provides insight into the significance of changes observed at the impact sites in HiRISE image sequences. Five such sites have been discovered to date; for this abstract, we focus on the first site observed.

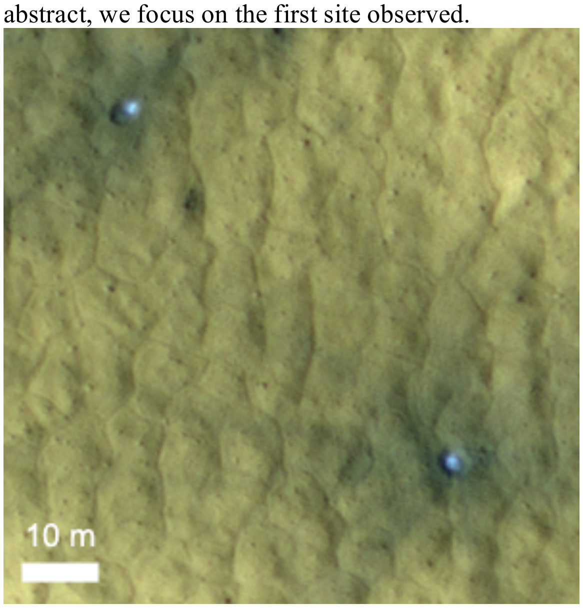

Figure 1: Cutout of HiRISE image PSP_009978_2265 showing a crater cluster with exposed ice at 46° N. Note thermal contraction polygons, indicating past or present ground ice. North is up, illumination from left.

Model: We use a one-dimensional finite-difference thermal model of the shallow subsurface similar to that of Kieffer et al. [4] and many subsequent workers. The thermal model includes solar heating and an estimated atmospheric long-wavelength radiation term equal to 4% of the peak noontime insolation [5] as well as conduction and radiation. We model initial conditions of a layer of dry regolith over ice. Each material layer includes many model layers, increasing in thickness with depth. We set up the model by running it with ice buried until the temperature structure stabilizes. At an L_s appropriate for the timing of the impact, we remove the regolith cover and run the model, tracking the temperature and resulting sublimation. (Due to the high thermal conductivity of ice, excavation of a small amount of ice will have a negligible effect on the temperature structure.) For the exposed ice, we incorporate sensible and latent heat effects into the thermal model.

Sublimation is modeled by both free and forced convection (similar to [6] and [7]), using the free convection equation derived by Ingersoll [8] and a forced convection term from [9]. Sublimation rate is controlled by saturation vapor pressure in a boundary layer above the ice; we also model the regional surface temperature and set the boundary layer temperature to the average of the ice and atmospheric temperature [10], assuming that the local atmospheric temperature is close to that of the regional surface [7].

For our standard case, we assume flat topography. This is oversimplified for the case where ice is exposed on the floor of a small crater; however, it is difficult to model the effects of this topography. Because the crater walls have a range of slopes and are oriented in all directions, the ice receives radiant heat from from surfaces at many temperatures, and a complete solution would require modeling all of these surfaces. We made a simple estimate of the effect of topography by testing a case in which the ice received no insolation when shaded but still emitted to the full sky and received no heat from the walls. In reality, radiation from the walls will raise the peak temperature and increase ice loss.

The impact at the first site observed occurred between L_s 81 and 111 of this year; we take L_s 95 (early northern summer) as our nominal value. We use appropriate regional albedo and thermophysical properties to set up the model with the initial dry overburden. For our baseline case, we assume a constant wind speed of 2.5 m/s, similar to that observed in summer at the Viking 2 landing site [11]. We estimate a surface water vapor partial pressure of 0.36 Pa (based on [12]) and hold this constant over the interval modeled; although the water vapor content of the atmosphere does vary somewhat over this interval, it is generally well below saturation, and so moderate variations have only a minor effect. Since the water vapor contents of [12] may be overestimates [13], we also examined partial pressures as low as 0.09 Pa. Overestimating the vapor pressure will lead to an underestimate for sublimation. We assumed an ice albedo of 0.4 appropriate for clean ice [9]. We examined cases with constant or darkening albedo; darkening increases the sublimation rate, and so constant albedo produces a conservative estimate.

Results: For our nominal case with crater formation at L_s 95, we find that 3.4 cm of sublimation should have occurred by L_s 162 (Fig. 2). In HiRISE image PSP_010901_2265, acquired at that time, the ice patches have faded but are still visible; by L_s 180, they had faded enough to match the background. Reasonable changes to the input parameters can cause moderate variations in this value. Impact occurrence at the earliest and latest possible times give 4.2 and 2.4 cm of sublimation, respectively. Raising the wind speed to 5 m/s (with the impact at L_s 95) gives 4.1 cm sublimation by L_s 162; if the albedo is forced to darken linearly from 0.4 to 0.18 between L_s 95 and 180, the total sublimation is 4.6 cm. Use of lower-temperature ice thermophysical properties also had only a minor effect as did incorporation of shading and lower partial pressures of water. This suggests that several centimeters of ice sublimated before the ice disappeared, likely fading under an accumulating lag. Sublimation rates at the other ice exposure sites are comparable.

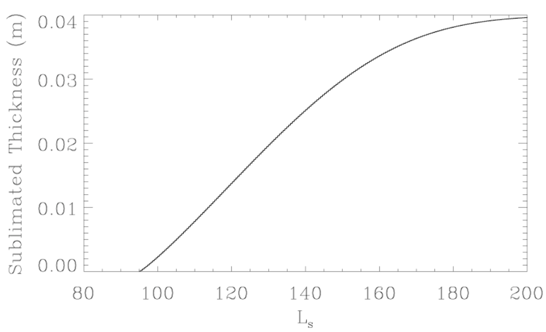

Figure 2: Modeled cumulative sublimation as a function of time for a nominal case with impact at L_s 95.

The sublimation rate is very sensitive to the boundary layer saturation vapor pressure. If this pressure is set by the ice surface temperature rather than the ice and regional average, sublimation is reduced by roughly an order of magnitude; this is likely a lower bound. Using this temperature in a case similar to the nominal, 2.7 mm of sublimation is expected at L_s 162. Experimental results indicate that an averaged boundary layer temperature is more accurate [14], but the method used here for the atmospheric temperature is an approximation and the air temperature may lag behind ground temperature changes [15], which would reduce the sublimation.

Discussion: Pore-filling ground ice would be masked by sublimating a thickness of ice comparable to an optically thick regolith layer. The persistence of the bright patches suggests as much as several centimeters of ice with low dust content. Even values of a few mm of sublimation would suggest that the ice content exceeds typical pore space for reasonable particle sizes; opaque sublimation lags developed at the Phoenix landing site in as little as two sols [16]. Such low dust content would not be expected for atmospheric deposition in soil pore space and suggests another formation process, such as ice lensing by cryosuction or burial of snow or ice. It is possible that this ice has been deformed or brecciated by the impact event; this is unlikely to reduce the dust content. The absence of visible ice within other fresh craters in the cluster could be due to dustier ice, variations in ice depth, or masking by ejecta fallback.

HiRISE observations indicate that ground ice occurs in the midlatitudes, at a depth beyond the reach of GRS detection. The sublimation modeling described here indicates that this ice may be at least several cm thick, and that portions have a relatively low dust content. The extent of this ice is still unknown, as the number of exposures is limited and their distribution affected by geographic biases in the detection of new impacts [2]. However, if the ground ice exposed by these impacts is common in the midlatitudes, it may represent a significant contribution to the Martian global water inventory. It is possible that some of this ice is out of equilibrium in the present climate. The ice exposures are at the fringes of the region where ice is stable at all [3, 17, 18], and occur at very shallow depths. This may indicate that the ice is a remnant from a previous epoch and currently retreating.

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