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Modelling sublimation of impact-exposed ice in the Martian mid-latitudes: Implications for ground ice properties

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Abstract

Images from the High Resolution Imaging Science Experiment (HiRISE) camera reveal that new craters in the Martian mid-latitudes have exposed ice in the shallow subsurface at several sites [1] (Fig. 1). This ice is observed to fade to match the regolith over a period of several months. Surface ice is not stable at the latitudes of the craters, so it is likely that sublimation plays a major role in the fading of the ice and the accumulation of an opaque lag deposit. We have modelled the sublimation of ice exposed at these sites. Our model results suggest that over a millimetre of sublimation occurred before the ice faded from view. This is consistent with relatively pure ice that does not simply fill the pore space of the regolith. This pure ice likely occurs in a relatively thin layer, which may overlie pore-filling ice.

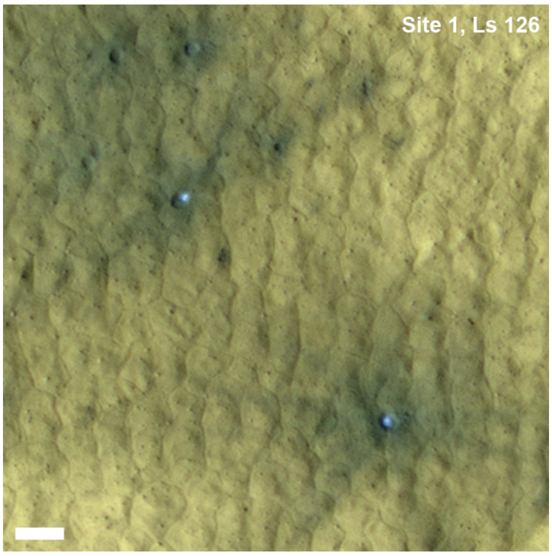

Figure 1: False-color subsection of HiRISE image of the first exposures observed (site 1), PSP_009978_2265. Scale bar is 10 m. Light is from the left and north is up.

Model

We use a one-dimensional thermal model to calculate the ice surface temperature. This model incorporates solar insolation, conduction between layers, atmospheric thermal radiation, and latent and sensible heat. We are able to consider multiple material layers. The model can incorporate topographic shading, such as on crater floors where some ice exposures occur. We also estimate lateral heat conduction for some cases. We calculate sublimation by both free [2, 3] and forced [4] convection, similar to [5]. Following Mills [3], we incorporate temperature as well as water vapour content in our calculation of buoyancy for free convection. We previously considered using the average of the ice and surface temperatures to set the saturation pressure for sublimation [6], but use the ice surface temperature here.

Model Scenarios

Ice has been observed at the five northernmost new impact sites imaged by HiRISE. We have modelled a variety of scenarios for each site. We begin our model by running with ice buried under a layer of desiccated regolith in order to set up an accurate thermal profile and remove the effects of initial conditions. Impact times are constrained by before-and-after images, and we test several times within the possible window for each site to examine the variation. We use the appropriate albedo [7], thermal inertia [8] and depths to ice [1] for the initial scenario at each site.

For the first site imaged (Fig. 1), the ice exposures are on crater floors. We initiate the sublimation model using the initial temperature profile from the ice, assuming that the overlying regolith was removed by the impact. (Ice has a high thermal conductivity, so a small amount of excavation will

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have little effect.) We consider the topographic shading from the crater in calculating the insolation. Other sites have more complex geometries, with ice exposed in crater walls and ejecta. For these sites we consider exposed ice as for site 1, but without shading. We also model cases assuming ice was emplaced on top of the original profile, as in crater ejecta. We considered variations in the initial ice albedo, which we vary linearly with time. We also tested wind speeds of 0, 2.5 and 7.5 m/s; the intermediate value is typical of the Viking 2 Lander site [9], at similar latitude. We estimated atmospheric water vapour content from [10], although this may be too high [11].

Results

For all five sites, intermediate values in parameter space suggest over a millimetre of sublimation by the time of the last HiRISE image showing ice, or the time of ice fading for site 1. For instance, 1.7 mm of ice sublimates at site 1 if the ice albedo fades from 0.4 to 0.2 between L_s 96 and L_s 171. For several sites, the minimum sublimated thickness in any case considered was close to a millimetre, and sublimated thicknesses of several millimetres are possible. Forced convection sublimation plays a significant role, and zero-wind cases give low sublimated thicknesses. The ice albedo and the impact time were found to have moderate effects on the total sublimation. An infinite ice table showed little difference from a five meter layer of ice underlain by regolith.

Discussion

Most (although not all) of our assumptions are deliberately conservative with respect to the calculated sublimation. This makes it most likely that we underestimate the sublimated thickness, and overestimate the dust content of the ice. Despite this, we find that at each of the five sites, it is likely that over a millimetre of ice sublimated during the interval when ice was visible. The dust thickness required to make an opaque lag is 40-400 microns (0.04-0.4 mm), depending on layer properties, and may be less at short wavelengths [12, 13]. If sublimated thicknesses were close to these values, pore-filling ice might be likely; however, only the most extreme cases from our parameter space give values comparable to the highest of these values. Therefore, our results suggest that these craters have exposed ice that is relatively pure rather than pore-filling.

One significant complication is the geometry of the sites. We have assumed flat-lying ice, shaded by topography for site 1. Several other sites have ice exposed in crater ejecta and may reasonably be approximated as flat; however, in at least one site (HiRISE image PSP_010585_2255) the major ice exposures are in crater walls, and so our one-dimensional model is likely oversimplified there.

Gamma ray spectrometry suggests high volumetric ice contents in Martian ground ice [14]. The Phoenix Lander also observed relatively pure ice [15], which faded under a lag on a timescale of months, similar to the impact exposures considered here. This pure ice may comprise a relatively thin layer above pore-filling ice [16], which is consistent with our observations. Our results support the idea that relatively pure ice is common in the shallow Martian subsurface and suggest that it extends to lower latitudes than previously thought.

Acknowledgements

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