AN IMPROVED MODEL OF WATER ICE SUBLIMATION ON MARS: VALIDATION AT THE PHOENIX LANDING SITE

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Introduction:

While numerous authors [e.g., 1, 2] have modeled the sublimation rate of exposed H_2O ice at the surface of Mars, these models have not been directly validated with in-situ data. Furthermore, although analog studies of martian ice have been performed [3, 4], these studies fail to accurately replicate martian ice conditions in terms of dust content, physical scale and boundary layer atmospheric conditions.

Here we present results from a one-dimensional atmospheric surface layer model that calculates turbulent fluxes over planetary surfaces to predict the sublimation rates of ices (CO_2, H_2O, CH_4 etc.). We have validated our model against terrestrial and martian in-situ data. We have compared our results with the predictions of [1], which are commonly used by martian ice studies today.

Methods: We have developed a model of the atmospheric surface layer that is based on previous terrestrial/martian atmospheric surface layer work [5, 6]. The model requires the following input data: (1) surface pressure, (2) surface roughness, (3) temperature (at two heights), (4) relative humidity (at two heights) and (5) wind speed. To validate the model, we used the only martian in-situ measurements of martian H_2O ice available at present, from the Phoenix mission, which landed in Utopia Planitia (68.2°N, 125.8°W) in 2008. The lander's robotic arm dug trenches around the lander to excavate buried H_2O ice present a few centimeters below the surface [7]. This trenching revealed light-toned, friable H_2O ice on sol 20 of the mission (Fig. 1), with an albedo matched by 350 μm H_2O snow with 0.015% dust in it [8].

This ice was left undisturbed for the remainder of the mission. Within the first four days (between sols 20 and 24), a few 1.5 - 2 cm sized, light-toned clods sublimated away (yellow ellipse in Figure 1). The light-toned patches sublimated far more slowly, with shadow measurements indicating losses of ~3 mm over 42 sols [7]. However, no measurements of temperature were made of the ice itself, and the lower atmospheric temperature measurements were impacted by the lander itself (but not at the 2 m height; [9]). Thus, to validate our model, we simulated temperatures at the surface of the ice by using the Mars Climate Database (MCD; [10, 11]).

To do so, we ran the MCD for the Phoenix mission landing site (with properties similar to [12]) to obtain 2 m air temperatures (black curves in Figure 2) and also soil surface temperatures (blue curves). We then added the mean temperature difference between the MCD surface and MCD 2 m temperatures to the 2 m air temperatures measured by the lander (red curves) to obtain simulated soil surface temperatures (green curves).

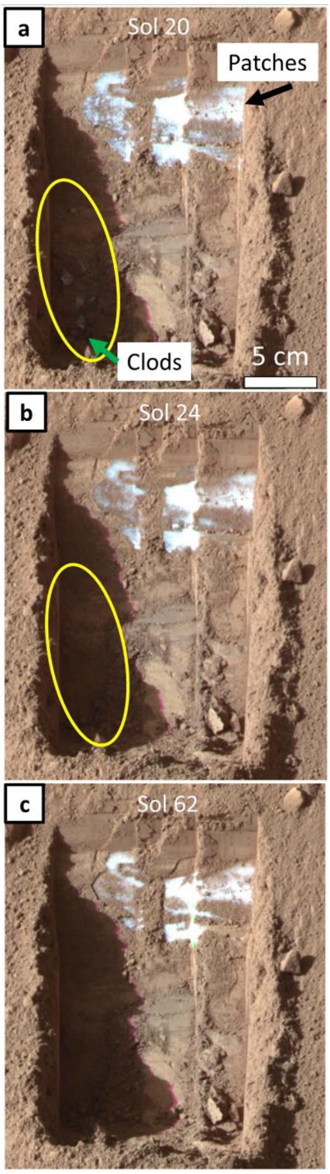

Figure 1. *Evolution of ice exposed at the Phoenix landing site over 42 sols (adapted from [7]).*

We assumed that these simulated soil surface temperatures are representative of the ice clods' surface/skin temperatures, despite the differences in albedo and thermal inertia, due to their small size and the radiating nearby trench walls resulting in enhanced warming. Relative humidity at the surface of the ice was assumed to be equal to 100% and interpolated values of relative humidity measured by the lander were used at ~2 m. The wind speed was assumed to be 4 m/s throughout [13]. The sensitivity of the modeled net sublimation was also analyzed.

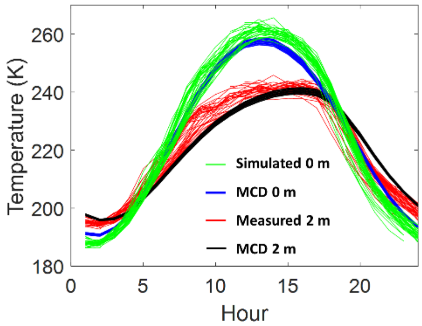

Figure 2. *Temperatures between sols 20 and 62 at 0 m (simulated; green, and modeled by MCD; blue) and 2 m (measured; red, and modeled by MCD; black).*

Results and Discussion:

Our Model Results

The modeling results for the base case (~0.7 cm; black triangles in Figure 3) are within a factor of two of the observed sublimation of the 1.5 - 2 cm clods over four sols (dashed red lines). Our sensitivity analysis indicates that higher values of surface roughness and surface temperatures (due to the ~13 cm deep trench walls near the clods) would increase the net sublimation during this period, whereas lower wind speeds caused by the trench walls obstructing the local airflow would reduce sublimation.

To model the light-toned patches (shallow portion of the trenches, Fig. 1), we ran KRC, a planetary thermal model [14] using the ice's measured albedo and calculated thermophysical properties. Due to their small areal extent, we assumed that the atmospheric properties above the interfacial sublayer immediately adjacent to the ground are the same above the patches as for the surrounding terrain. The resultant net modeled sublimation was significantly lower than for the clods, which is consistent with the observed ~3 mm sublimation over 42 sols. The lower rate of sublimation for the patches relative to the clods is likely due to colder surface temperatures, lower surface roughness and less exposed surface area.

Comparison with Commonly Used Martian Ice Sublimation Model Predictions [1]

Almost all existing models that simulate the stability and sublimation rate of exposed ice on Mars use versions of equations similar to those presented by [1]. These equations ignore the important effects of atmospheric stability and assume neutral atmospheric stability under sheared ("forced" convection conditions, leading to errors in the resulting fluxes of sensible and latent heat of up to a factor of three depending on the stability of the atmosphere [5]. Additionally, thus far, these equations have not been validated/tested using in-situ data on Mars.

Figure 3 shows that these equations consistently underestimate (black dashed lines) the net sublimation of the 1.5 – 2 cm ice clods observed at the Phoenix landing site. No set of conditions we tested in our sensitivity analyses was able to match the observed sublimation.

Thus, our improved model of ice sublimation represents a step forward in martian ice modeling studies, building on past work. We are in the process of applying this model to other exposures of ice on Mars, such as within the mid-latitude mantle (e.g., [15]).

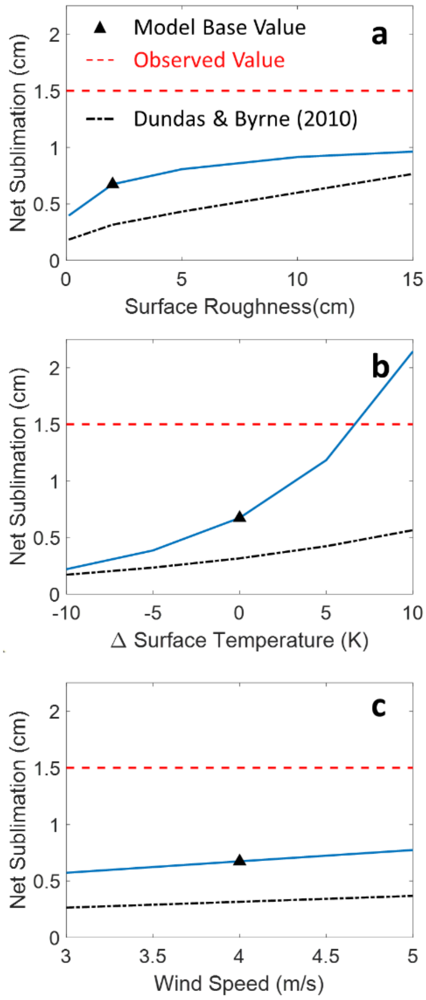

Figure 3. *Sensitivity of the net sublimation (blue curves) over the four sols during which the 1.5-2 cm clods disappeared (dashed red lines) to: a) surface roughness, b) the simulated surface temperature relative to the base value and c) the wind speed at 2 m. The predictions of [1] for the same inputs are shown as black dashed lines for comparison.*

References: [1] Dundas, C. M. and Byrne, S. (2010). *Icarus*, *206*(2), 716-728. [2] Ivanov, A. B. and Muhleman, D. O. (2000). *Icarus*, *144*(2), 436-448. [3] Douglas, T. A. and Mellon, M. T. (2019). *Nature comm.*, *10*(1), 1-9. [4] Chittenden, J. D. et al. (2008). *Icarus*, *196*(2), 477-487. [5] Brutsaert W. (1982) *Springer 1567-7419* [6] Clow G. & Haberle R. (1990) *Mars, 14-91, 111*. [7] Smith, P. H. et al. (2009). *Science*, *325*(5936), 58-61. [8] Khuller, A. R. et al. (2021). *JGR*, *126*(9), e2021JE006910. [9] Davy, R. et al. (2010). *JGR*, *115(E3)*. [10] Forget, F. et al. (1999). *JGR*, *104*(E10), 24155-24175. [11] Millour, E. et al. (2018). *MEEMA*, *68*. [12] Savijärvi, H. and Määttänen, A. (2010). *QJRMS*, *136*(651), 1497-1505. [13] Holstein-Rathlou, C. et al. (2010). *JGR*, *115(E5)*. [14] Kieffer, H. H. (2013). *JGR*, *118*(3), 451-470. [15] Khuller, A. R and Christensen, P. R. (2021). *JGR*, *126*(2), e2020JE006539.

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