SEASONAL FROST AS SOURCE OF LIQUID WATER ON MARS. N. Schorghofer[1], J. S. Levy[2], and T. A. Goudge[3] [1]Planetary Science Institute, Tucson AZ and Honolulu HI, USA (norbert@psi.edu), [2]Department of Geology, Colgate University, Hamilton NY, USA, [3]Jackson School of Geosciences, University of Texas, Austin, TX, USA.

Introduction: The possible occurrence of liquid water on present-day Mars has long been of primary interest to planetary scientists and the public. Liquid water is considered an agent for many surface processes, e.g. [1-3] and it also is a universal prerequisite for microbial activity [4]. Recurring Slope Lineae (RSL) form during the warm season on Mars and may be caused by liquid water [2,5-8], although dry mechanisms have also been suggested [15]. The source of the water (aquifers, ground ice, deliquescence, seasonal frost, or other) remains unknown and the physical mechanism of how ice can melt, under adverse physical conditions, remains obscure.

RSL are narrow, relatively dark-toned, martian surface features that form on steep slopes (Figure 1, top), and that appear in early spring, grow longer in the downslope direction during spring and summer, and fade during autumn and winter [2]. Under the physical conditions of present-day Mars, it is difficult to form or maintain liquid water [9,10]. The partial pressure of H_2O in the atmosphere of Mars is presently about 0.15 Pa, about 4,000 times lower than the vapor pressure at the melting point of pure ice (611 Pa). Moreover, the total pressure of the atmosphere is comparable to the triple point pressure, so that any ice that approaches 0°C will begin to sublimate so rapidly that evaporative cooling becomes significant [9,11]. This is known as the "evaporative cooling problem". The rapid sublimation rates have another and perhaps even more detrimental consequence: any slow transition from cold conditions, where ice is stable (<200K), to hot conditions, where ice can melt (~273K), involves significant ice loss, and hence near-surface ice is depleted over time periods of orbitally-driven climate change (the "source problem").

We quantitatively evaluate one potential pathway for the formation of liquid water on present-day Mars: Melting of seasonal water frost in alcoves.

Seasonal CO_2 and H_2O frost has been identified at many places on Mars, including isolated locations at low- and mid-latitudes [12-14]. Seasonal frost is a recurrent source of water. In areas within alcoves that are seasonally shadowed, water frost will accumulate, and when the sun rises again, temperature increases rapidly and may melt the frost. A rapid transition from cold to hot conditions will involve little sublimation loss. This may indeed occur in an alcove, where topography causes shadowing, but solar incidence angles are steep after the sun rises. Evaporative cooling can be overcome with a thin overlying layer. Such a layer could form as sublimation lag (from material that was incorporated into the frost) or by mass wasting. If this layer is on the order of a few mm thick, evaporation is strongly suppressed while peak temperatures are barely attenuated. Our goal is to quantitatively assess the full cycle of frost accumulation, warming, and melting in alcoves.

Model: We use HiRISE-stereo derived digital elevation models (DEMs) and three-dimensional modeling of shadows, surface temperature, near-surface temperatures, and sublimation in RSL alcoves to evaluate this hypothesis quantitatively.

Sublimation is a temperature-sensitive process, so we have developed a multi-grid accelerated model of alcove temperatures that incorporates shadowing geometry, radiation geometry, and subsurface conduction. A multi-grid method uses a coarser grid at large distance from the point of interest, which results in significantly faster numerical calculations. The steepest slopes occur at the finest resolution, and horizons from far away affect the shadowing, so thermal modeling needs to consider DEMs with large pixel dimensions. The model code has also been parallelized for use on a computer cluster. The horizons and other geometric information are pre-calculated. The part of the model which carries out the thermal calculations as the sun moves through the sky during a Martian year has been designed for use on multi-core and shared-memory architectures [16].

Another component of the model is the quantification of gain and loss of H_2O frost. We updated the well-known equation for the evaporative cooling from free convection in the Mars atmosphere by Ingersoll [11]. This literature study also provided modifications of the formula for an inclined surface and for high H_2O/CO_2 mixing ratio. This effort is part of the task to better represent the relevant physics for the behavior of volatiles in an alcove.

Results: Figure 1 (middle) shows the results of quantitative model calculations at one study site. Small parts of the alcoves are seasonally shadowed. These areas are cold enough even for CO_2 frost to condense (~145K). Hence, both types of frost, H_2O and CO_2, will accumulate over many months. Once the sun rises, or alternatively mass wasting moves the ice into sunlight, the CO_2 ice begins to sublimate, but the CO_2-H_2O ice mixture cannot warm until all of the CO_2 ice has disappeared. By this time, the insolation will be even more intense. After this point, the H_2O frost, almost none of which has yet been lost to the atmosphere, will experience rapid warming.

At one location near a seasonally shadowed area, our model calculations show that on the first day without CO_2 ice, temperature abruptly rises from 145K to 280K within one day. Sublimation cooling will delay this rapid temperature rise, but the sudden increase suggests little frost will be lost by the time melting temperature is reached. We continue to quantitatively evaluate this process and try to identify the most favorable locations where melting could occur. It is already apparent that the azimuthal direction of the source region is of prime importance.

The area where seasonal CO_2 frost accumulates is almost as large as that for H_2O frost accumulation, and both extend considerably beyond the area of seasonal shadow. Very small areas even remain below the frost point (~200K) all year, and hence accumulate water frost continually. These areas never experience high temperatures, but it is plausible that avalanching of thick frost deposits could occur after multiple years of frost buildup.

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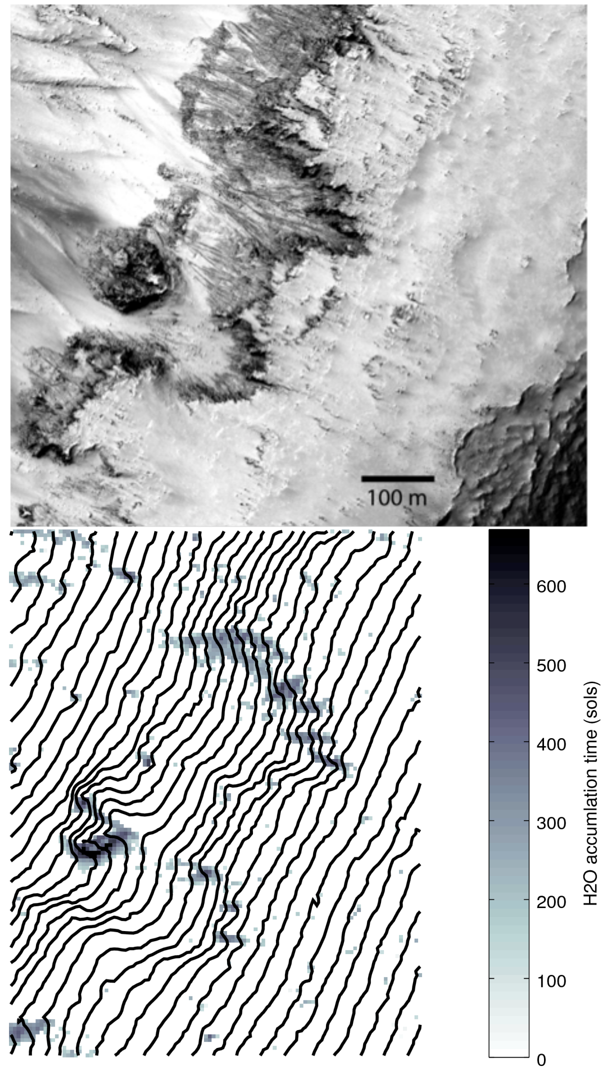

Figure 1. a) RSL emanating from steep slopes in the alcoves at 42°S, 158°W at Palikir Crater. b) Model results for the duration of uninterrupted water frost buildup. Contours are topography. North is up (equator-facing). The thermal inertia at this site is 200 tiu [17].