DIVINER-BASED PREDICTIONS OF SUBSURFACE WATER ICE THERMAL STABILITY ZONES AT THE LUNAR POLES.
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Introduction: The origin of lunar polar volatiles is a long-standing mystery in planetary science, especially as these volatiles may hold a key to understanding volatile delivery, composition, and timing to Earth and/or be a laboratory for understanding the effect of volcanism on rocky planet interior degassing. Direct measurements and inferences from remote sensing have indicated that water ice and other volatiles exist in the near-subsurface of the lunar south polar region (e.g., [1-6]), with a plethora of additional areas where volatiles could be thermally stable in the present day on the surface [7]. Neutron data suggest hydrogen enhancement at both poles (e.g., [8]), consistent with the presence of buried water ice or hydrated minerals in the upper ~1 m of the surface. Buried water ice has been suggested to explain trends in lunar crater depth-to-diameter ratios with latitude [9] and could record previous lunar polar orientations [10]. One outstanding issue is how that buried hydrogen could have been delivered to the subsurface and when.

This work aims to address one aspect of the buried lunar hydrogen problem: Are predictions of the thermal stability of buried water ice within the ~1 m of the surface from Diviner data consistent with the hydrogen distribution observed in the present day? If not, where do they differ and by how much? We present initial results in processing the Diviner data and using a minimal thermal model to refine predictions of subsurface temperature and buried water ice stability.

Data: We use two Diviner-derived data sets: maximum temperature and annual average temperature over the course of 10 Draconic years. Ultimately, we will use the latitude range of 60-90° to be able to apply the smaller Diviner footprint (~300 m) to the larger regional-scale footprints from neutron instruments like the one on Lunar Prospector [e.g., 11]. Here, we present a narrower latitude range as proof of concept.

We use the maximum temperature maps of [7] and calculate annual average temperature by averaging the data in bins of ~1 lunar day (360 bins/year) in order to reduce the effect of noise in the radiance measurements on the final bolometric temperature calculations, following the techniques described in [1]. We average each of the 360 resulting bolometric temperature maps together to generate the yearly maps. This reduces the number of time bins used in previous work [12], though the final annual average bolometric temperatures and temperature distributions at the south pole are generally in good agreement. An initial annual average temperature map for the south pole is shown here (Figure 1). Our next steps are to refine this map is to add day/night observation bins to further reduce noise in the averaged radiance values before calculating bolometric temperatures, and expanding the latitude range. We will repeat the same process for the north pole.

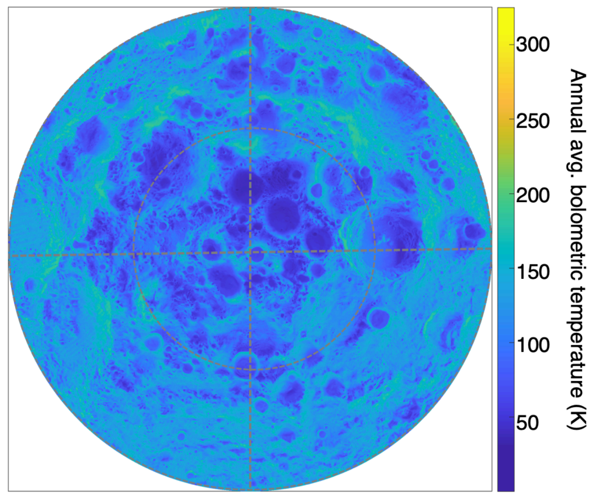

Figure 1. *Annual average bolometric temperature for the lunar south pole from 80-90° using 360 time bins per year, derived from Diviner radiance data. Concentric circles indicate each 5° of latitude.*

Minimal thermal model: Rather than assuming that annual average temperature is fully representative of temperatures in the upper ~1 m of the lunar subsurface or constructing a 3d thermal model, we modeled the temperature decay in the subsurface using a simple model. This provides a data-reliant method for calculating temperatures (and therefore water vapor loss) especially for regions where water ice may be stable near or within the diurnal skin depth (e.g., ~4-7 cm, though in some places closer to ~10 cm [13]).

We assumed that the subsurface annual temperature curve could be calculated by setting the top of the surface to the maximum temperature and that at some large depth (z), the temperature would equilibrate to the annual average surface temperature. We assumed an energy balance for the overall temperature at depth that included the exponential decay of the surface temperature, the annual average temperature, and geothermal heat flux. A schematic of our assumed temperature decay with depth is shown in Figure 2.

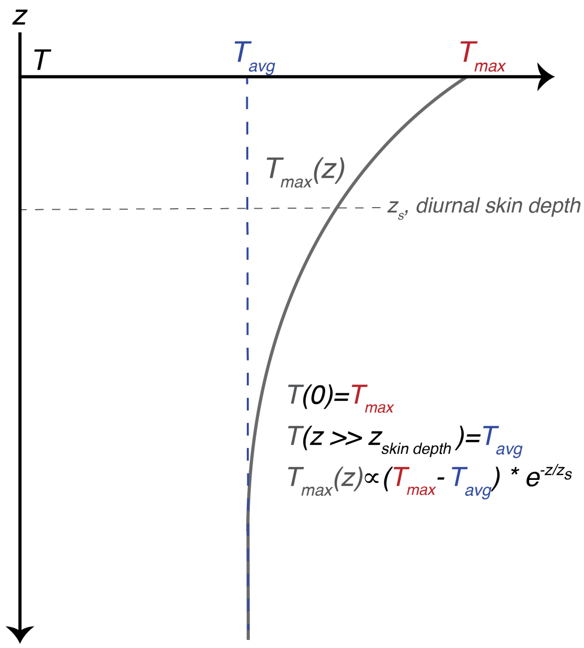

Figure 2. *Schematic showing our assumptions behind calculating lunar subsurface temperature. This temperature calculation is used to determine the predicted vapor flux of a water ice deposit at this location, and therefore its long-term stability.*

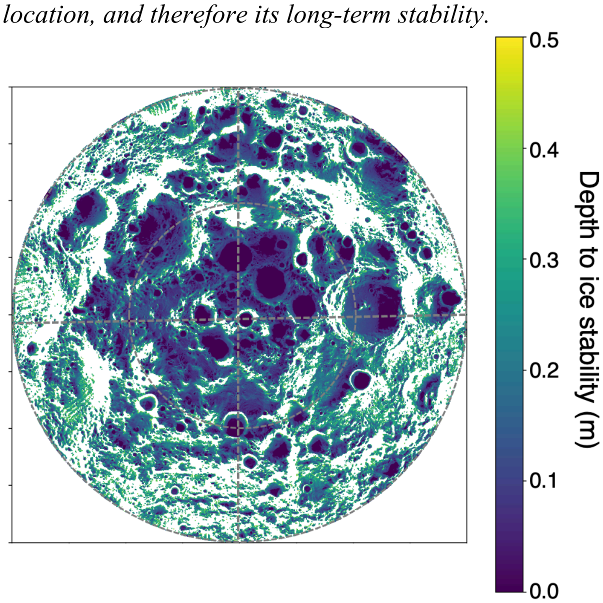

Figure 3. *Results for depth to ice calculations from annual maximum Diviner temperatures [7] and the 360 bins/year annual average temperature data (Figure 1) using our minimal thermal model and Knudsen vapor diffusion. Particle diameter of 75 microns assumed. Concentric circles indicate each 5° of latitude.*

In order to find the depth at which water ice would be stable, we use a Newton root finding method to calculate where the predicted vapor loss (using Knudsen diffusion, e.g., [14]) is less than ~1 mm/Gyr. Preliminary results from this combined thermal and vapor diffusion model are shown in Figure 3.

Notable is that our initial modeling finds buried water ice stability zones much closer to the surface than previous work, e.g., [1]. We are currently investigating why this difference exists, and in particular if the initial assumptions about the surface temperatures have changed significantly now that Diviner has returned substantially more data than in 2010.

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