

TEMPERATURE DRIVEN TRANSPORT OF LUNAR HYDRATION ON DIURNAL TIMESCALES.

K. L. Laferriere¹, A. M Bramson¹, A. Gleason¹, ¹Purdue University, West Lafayette, IN 47907 (klaferri@purdue.edu).

Introduction: Infrared observations of the lunar surface revealed signatures of hydroxyl and/or molecular water [1, 2, 3]. The observed 3 micron absorption feature is due to the O-H fundamental stretch transition band and/or the overtone of the H₂O vibration band. At the resolution of current orbital data, the contribution to this band from OH versus H₂O is indistinguishable [3]. The absorption feature also cannot distinguish between structural and adsorbed hydration. Based on the observed pattern of hydration with spatial, temporal, and thermal variability [4, 5], it is believed that some of the lunar hydration is structural in grains like agglutinates [6], while some is adsorbed onto the regolith grains [7]. The majority of the observed hydration is believed to be OH with a small contribution from H₂O [5, 8].

Repeat observations of the same geologic region across the course of a lunar day suggest a diurnal (day-time) variability of this hydration feature [4, 5]. Previous modeling of migration of water across the lunar surface suggests that there would be an increased abundance at the morning terminator [e.g., 9]. However, observations lack an elevated hydration signature at this location in comparison to the evening terminator, and actually show the opposite. Recent work has shown that the 3 micron hydration band strength returns to or even exceeds morning values at the evening terminator [5]. It has been proposed that the recovery of hydration over lunar hours is due to localized migration of OH/H₂O, and is ongoing on the lunar surface [4, 5].

Given an activation energy, OH/H₂O molecules can be desorbed from a lunar regolith grain [7]. Once desorbed, these molecules are able to transport across the surface ballistically until they are lost, destroyed, adsorbed or cold trapped. Photo-destruction and deposition are important processes for removing volatiles from

the exosphere during hops [10]. Approaching this problem and considering how the hydration signature would occur on a lunar hourly timescale will allow us to better interpret the observed temporal patterns.

Method: In this work, we apply a Monte Carlo method to a ballistic transport model to understand the patterns of transport and loss on lunar-hour timescales. We initiate our model by creating a random distribution of n particles across the surface of the Moon. Local times are assigned to each particle based on their longitude. Using the Diviner surface temperature averages from Williams et al. (2017) [11], which covers the lunar surface at a resolution of 0.5° by 0.5° and 0.26 lunar hours, we select a temperature for the closest location in the dataset from the particle's position and local time.

The ballistic transport model we use is built upon a simple ballistic transport model for a collision-less atmosphere as is appropriate for an airless body like the Moon [12, 13]. Loss mechanisms like photo-destruction and sputtering are incorporated which can remove entire particles from the system. We model destruction mechanisms as probabilities to occur either in flight or while a particle is on the surface [9, 10, 14; table 1]. We use 1.3×10^{-10} 1/s as the OH sputtering rate [9], and 1.26×10^{-5} 1/s as the OH photolysis rate [10]. We determine the landing position (latitude, longitude, and time of day) based on a randomly selected launch angle and the initial position [15]. We allow particles to sit on the surface for a defined period of time due to adsorption or deposition [9, 14]. We assume that the source is solar wind formation, such that there is a semi-random distribution of particles across the surface.

Recent work has revealed the necessity to include surface temperature variations due to shadowing from surface roughness into models of desorption rate [16].

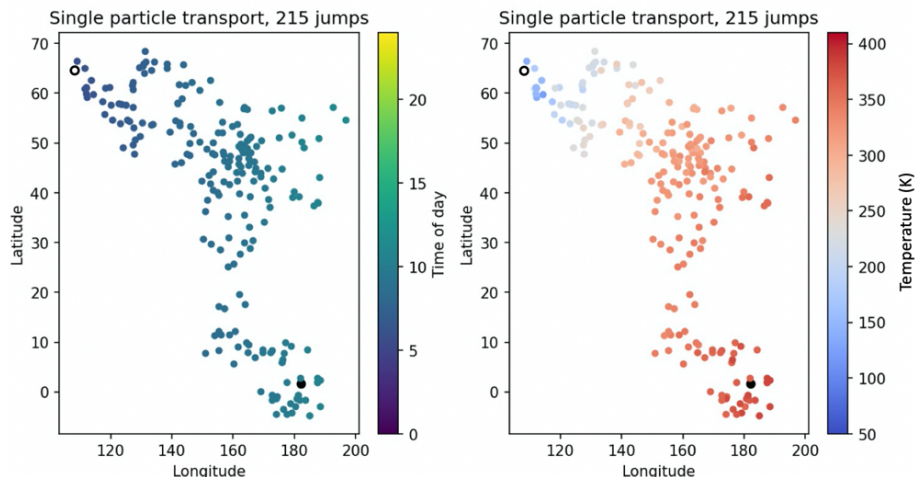


Figure 1: Location (latitude and longitude) for a randomized particle. This particle undergoes 215 jumps before it is lost to photodestruction. The initial location is marked by a black circle, and the final landing location by an open white circle. (Left) Location, color denotes local time of day. (Right) Location with surface temperature.

In this work, we explore two versions of the model. The first is for a ‘smooth’ Moon, which uses the observed temperatures from the [11] dataset. The second version chooses a temperature within a defined range around that from [11], based on the effects of local surface roughness to allow for localized shadowing. This allows us to model anisothermality which occurs within a Diviner pixel, incorporating local cool spots which could assist in localized migration of molecules.

This will allow us to compare to observations and understand the on-going sources and migration over diurnal timescales.

Results: For the smooth moon model, we find that the majority (>90%) of molecules are lost within the first 4 lunar hours. Occasionally (1%), molecules reach the polar regions and are kept for greater than a lunar day due to the low temperatures. From preliminary work, we find that an H₂O molecule undergoes 166 ± 156 ballistically hops for a total of $21.4 \times 10^3 \pm 19.1 \times 10^3$ km during 0.56 ± 0.52 lunar hours of flight, before undergoing photodestruction.

Future work: We will compare the results of the model run for a smooth versus rough Moon to understand how the incorporation of surface temperature variability affects the ability of volatiles to migrate locally. The results from this work will include a detailed analysis of diurnal variability of volatiles, which will aid in the interpretation of previous observations.

In future work, we will include a 1D thermal model to explore how the lunar ice pump [17] can provide an additional loss mechanism (into the subsurface) for surface water molecules. Additionally, we will test the effects of the Moon being inside of Earth’s magnetotail (thus, shielded), as well as diurnal transport of other volatiles detected on the lunar surface previously. Localized migration could explain observations of hydration while in the magnetotail (and thus protected from the solar wind), without having to invoke an additional formation mechanism for OH and H₂O.

Our test of these 4 cases (a smooth moon, rough moon, and in/out of Earth’s magnetotail) will result in a range of results for the transport of volatiles into the PSRs, and it will provide insight into the diurnal patterns of hydration.

Recent work has revealed the importance of seasonal cold trapping [18] and ballistic migration as a source for ice deposits on Mercury [19]. Thus, we can explore how these volatiles could provide a source for ice deposits in permanently shadowed regions (PSRs). The results of diurnal transport to cold traps can be integrated over a lunar year, such that we could model the accumulation rate. We could explore the possibility of frost and sublimation lag formation which could explain the observed patchy ice deposits there today.

References: [1] Pieters, C. et al. (2009), *Sci.*, 326(5952), 568–572. [2] Clark, R. N. (2009), *Sci.*, 326(5952), 562–564. [3] Sunshine, J. M. et al. (2009), *Sci.*, 326(5952), 565–568. [4] Hendrix, A. et al. (2019), *GRL*, 46(5), 2417–2424. [5] Laferriere, K. L. (2022), *JGR Planets*, 127. [6] Liu, Y. et al. (2012), *Nature Geoscience*, 5(11), 779–782. [7] Poston, M. J., et al. (2015), *Icarus*, 255, 24–29. [8] Honniball, C. et al. (2020), *Nature Astronomy*, 5(2), 121–127. [9] Schorghofer, N. (2014), *GRL*, 41, 4888–4893. [10] Grumpe, A. et al. (2019), *Icarus*, 321, 486–507. [11] Williams, J. P. et al. (2017), *Icarus* 283, 300–325. [12] Sori, M. et al. (2017), *Icarus*, 290, 1–13. [13] Butler, A. (1997), *JGR*, 102, 19283–19292. [14] Sarantos, M. and Tsavachidis, S. (2021), *The Astrophysical Journal* 919. [15] Menten, S. M. et al. (2022), *Nature Communications* 13. [16] Davidsson B. J. R., and Hosseini, S. (2021). *MNRAS*, 506, 3421–3429. [17] Schorghofer, N. and Aharonson, O. (2014), *ApJ*, 788. [18] Kloos, J. L. et al. (2019), *JGR Planets*, 124, 1935–1944. [19] Jones, B. M. et al. (2020) *JGR Planets*, 125.

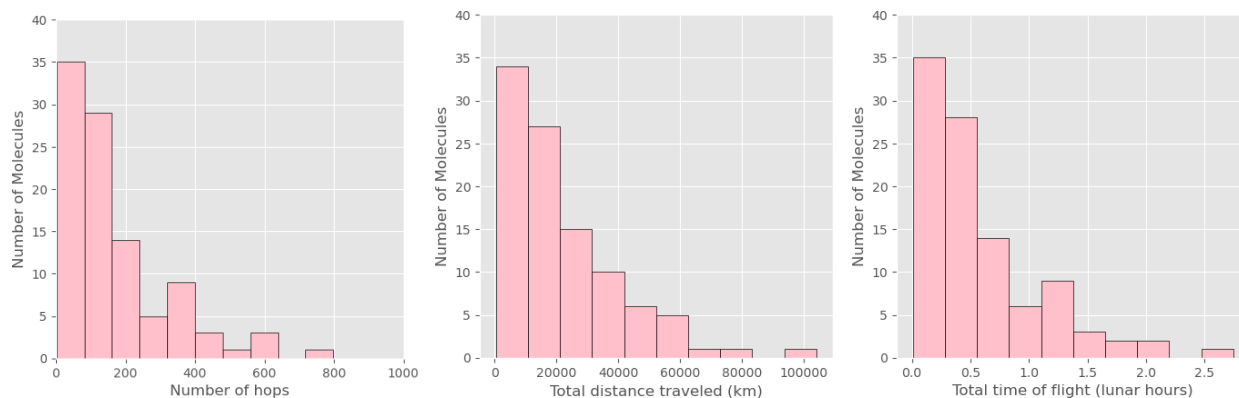


Figure 2: Histograms of results from a model run, 100 H₂O particles initialized at (0°E, 0°N) at local noon. (Left) Number of ballistic hops a particle undergoes before loss. (Middle) Total distance traveled by the molecule. (Right) The total time a particle spends in the ‘air’ during the ballistic hops..