LADEE NMS OBSERVATIONS OF EXOSPHERIC WATER EVENTS AT THE MOON. D. M. Hurley[1] , M. Benna[2], T. J. Stubbs[2], P. R. Mahaffy[2], and R. C. Elphic[2], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel MD 20723, USA (dana.hurley@jhuapl.edu), [2]NASA Goddard Space Flight Center, Greenbelt MD 20771, USA, [3]NASA Ames Research Center, Mountain View CA 94035, USA.

Introduction: Water on the Moon is a resource for both scientific understanding of volatile inventories in the inner solar system and fueling exploration of the inner solar system. Although great progress has been made in the identification of water and other volatiles on the Moon and measuring their spatial distribution [e.g., 1-9], much work remains to determine the relative importance of the sources, the mechanisms and efficiency of redistribution, and relevant loss processes. In this work, we focus on ongoing sources of water to Moon including meteoroids and solar wind. We determine the relationship between the mass influx of meteroids and the mass of water introduced into the exosphere from meteoroid impacts. In addition, we examine the efficiency of migration by examining the steady state water content of the exosphere. These are inputs into the examination of the delivery efficiency of ongoing sources to lunar cold traps.

LADEE Data: The Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft was a mission to measure the Moon's atmosphere and dust environment and dynamics [10]. The Neutral Mass Spectrometer (NMS) used a quadrupole mass analyzer to determine the density of the lunar exosphere in situ as LADEE traversed on a retrograde orbit about the Moon [11]. For inert species such as the noble gases, NMS mapped the spatial profile of constituents along its trajectory [12]. However, for water, it was found that the instantaneous external density of could not be measured owing to interactions between water and the surface of the instrument. Instead, the integrated water encountered along the LADEE trajectory while NMS was not operating can be measured. The median integration time is 129 minutes, which is roughly the same as the orbital period of LADEE. Thus spatial information is removed from the measurement. In total, NMS acquired 743 measurements of integrated exospheric water content over the 5 months of the mission, of which 684 are significant, defined as being above 1 standard deviation determined by counting statistics.

The water measurements throughout the mission show sporadic water events in the lunar exosphere. The timing of the most intense events matches the timing of known meteoroid streams that the Moon encounters [13]. This association strongly suggests that meteoroid impacts are an important mechanism releasing water into the Moon's exosphere.

Simulations: Because meteoroid impacts are a stochastic process and there is no way to determine the exact time, location, and size of each individual impactor on the Moon with existing data, we approach the problem using a Monte Carlo model. The goal is to reproduce the distribution and magnitude of the observed water events by creating a model lunar exosphere produced by a representative set of meteoroids.

We have modeled the propagation of water through the lunar exosphere from a single impact of a meteoroid [14]. This model is scaled by the mass of water released and can be sampled as NMS would fly through the atmosphere. The relative timing and position is not known, so we use a probability function to select a value for the atmospheric contribution sensed by NMS for each meteoroid (Fig. 1).

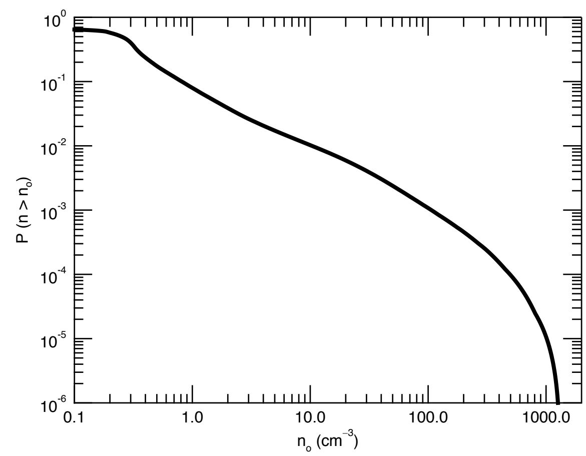

Figure 1. The probability of encountering an exospheric density of water for a fixed release of water from the surface of the Moon. The model assumes a random encounter timing and orientation relative to the impact.

This is convolved with the mass flux of meteoroids, which has been studied and quantified [15-18]. Fig. 2 presents a simulated set of exospheric measurements from [14] for a putative 1-month of continuous measurements. In order to produce the exopspheric water density, a mass ratio must be assumeds of the mass of water released to the mass of the meteoroids. The water can be derived from the meteoroids themselves or from the target lunar regolith. In this example, we show the values for 1, 2, 4, 8, and 16% ratio of the water mass to impactor mass. We examine the difference in the simulated distribution of water events for

NMS for the three different meteoroid mass flux distributions. We find the best match is obtained using [17].

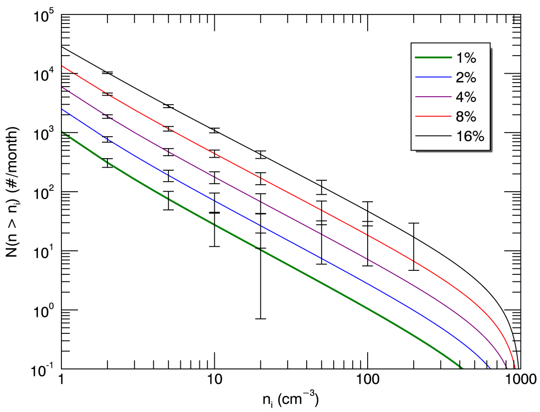

Figure 2. Convolving the plume propogation model with an incident meteoroid flux model, we get the predicted number of events in a 1 month of measurements assuming 1, 2, 4, 8, or 16% ratio of the mass of water released to the mass of the impactor.

Results: The simulations match the NMS data set well, indicating that the NMS water exospheric events are triggered by meteoroid impacts on the Moon. Comparing the mass of water released by impacts to the mass of the impactors reveals that a significant portion of the water detected in the exosphere is derived from the surface of the Moon. Furthermore, given the expected concentration of hydration on the lunar surface [1,2,10,19], the results are consistent with the impact triggering the release of water from the mass of excavated regolith.

Furthermore, no additional background of water in the exosphere is detected. This implies that the simulations of water released by meteoroid impact and surviving only for a single hop accounts for the entire measurement. For water released at 5000 K, 67% escapes lunar gravity. The 33% that returns to the Moon's surface does not continue to migrate immediately. It remains adsorbed to the surface until it is released again later by a subsequent impact.

We examine the recycling of water through multiple releases. We provide estimates of the relative contribution of water initially delivered by the meteoroid and water that is produced by the synthesis of water in the impact process of implanted solar wind hydrogen [20-21].

Conclusion: The LADEE NMS data provide a measurement of water in the lunar exosphere resulting from the impact of meteoroids on the surface of the Moon. Our simulation of the process reveals the meteoroid mass flux distribution that best reproduces the observations, providing a means to calibrate the meteoroid flux in the 1e-2 – 1e3 g impactor mass range. We use the measurements to constrain the delivery of water to lunar cold traps by impact release. Further, we investigate the ultimate source of hydration of the water released by meteoroid impacts.

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