MODELING OF LUNAR EXOSPHERIC WATER EVENTS DUE TO METEOROID IMPACTS. C. Knez[1], D. M. Hurley[1], and M. Benna[2], [1]Johns Hopkins University - Applied Physics Laboratory (11100 Johns Hopkins Rd., Laurel, MD 20723; Claudia.Knez@jhuapl.edu), [2]NASA Goddard Space Flight Center.

Introduction: Understanding the lunar water cycle has been the subject of much investigation. While enhancements of water and other volatiles are known to exist in permanently shadowed regions (PSR) near the lunar poles (e.g., [1]) and likely ancient deposits, there is evidence of water diurnal variability [2] that is consistent with contributions of water from an ongoing source.

High speed meteoroids impacting the lunar surface are an exogenous source of water on the Moon since the meteoroids are partially composed of hydrated minerals and other volatile species [3]. The Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft used the Neutral Mass Spectrometer (NMS) to measure and correlate the occurrence rate of sporadic water spikes with meteoroid flux in the range of masses likely to produce detectable plumes [4]. Because of LADEE's short duration and the coarse temporal resolution of NMS, the number of water observations were limited to <1000.

A modeling framework was created to aid future missions in characterizing reservoirs of water on the Moon [5]. The framework includes simulations of propagation of water vapor in plumes which result from meteoroid impacts as well as a hypothetical orbiting instrument collecting observations of the events. The results from the simulations compared to LADEE NMS observations showed that the spread of observed densities is much wider than would be expected if the mass of water released by impacts is proportional to the mass of the impactor. There are several potential reasons for this discrepancy. In [4], the authors attribute most of the released water to water stored in the lunar regolith rather than hydration brought with the impactor. In this case, they found that the distribution of observed densities can be reproduced by assuming the impactors did not release water into the exosphere unless they were more massive than 0.15 g. This would be the case if the topmost 7-8 cm of regolith is desiccated and only impactors larger than 0.15 g penetrate deeply enough to release water from a hydrated layer below. However, another potential reason for the discrepancy is that the effects of known aspects of variability in the meteoroid flux to the Moon were not included in the initial, simple model. This works expands on the work done in [5] to explore the effects of the known variability in the meteoroid integrated mass flux to the Moon in order to better understand the distribution of water in the near surface of the Moon, the fate of meteoroid-released water, and the role of meteoroids in the lunar water cycle.

Simulations: There are multiple properties of meteoroid released water that we will examine, including: variability in the number flux of impactors important on short timescales, e.g., meteoroid streams; variability in the average impact velocity; and variability induced by phase effects from the Moon's orbital velocity. Each one of these factors can introduce an increase by a factor of a few in the expected density of water observed.

In order to simulate a varying meteoroid number flux, various functions were used for the number of impacts occurring during the simulation. The previous work used the average sporadic impactor flux to seed the Poisson distribution of number of impacts in a given impactor mass range. In this work, there were 3 functions used for calculating the impacts on the lunar surface producing water plumes: 2 constants values and a linear function. The first constant function consists of the average number of impacts across the entire set of orbits. The second constant function factors in a 5 % period of time in which the meteoroid flux is 12 times higher than the average [6]. The linear function is constructed such that the maximum value corresponds to the peak meteoroid flux during a Geminid stream [4].

Each simulation consisted of 10,000 orbits to produce a statistically significant set of outcomes. The cumulative distribution function of those 10,000 simulated orbits was then normalized to compare to the LADEE observations.

Results: Figure 1 shows the 3 models compared to the data from LADEE. Figure 1 demonstrates that none of the functions can replicate the data. However, the linear function starts to match the initial downturn even if it comes at lower densities.

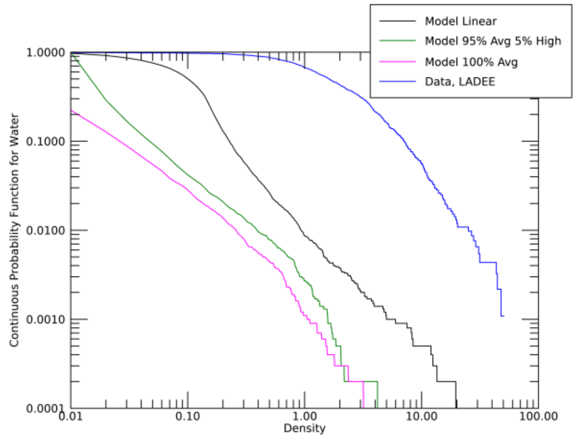

Figure 1: The LADEE water observations (blue) compared to the various models: constant average (magenta), 95% average with 5% with ~10 times the average (green), and a linear model (black).

In order to assess how much more water would need to be produced in order to start to match the observations, the above curves were recalculated using a scalar factor. The factor for which the linear function needs to be multiplied to approximate the 0.5 point in the continuous probability function for water is found to be 12. Including this factor of 12 into the constant functions also moves the green and magenta curves to the right (shown in Figure 2). However, the slope of the curve is steeper than in Figure 1.

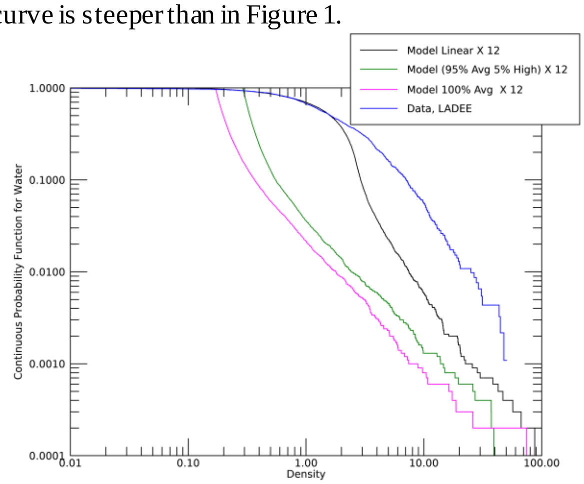

Figure 2: Similar to Figure 1. The modeled number of meteoroid impacts has been multiplied by a factor of 12 for each of the 3 functions: constant average (magenta), 95% average with 5% with ~10 times the average (green), and a linear model (black).

In Figure 1, the LADEE data shows that the 0.5 value for the continuous probability function occurs at a density of 1.6 cm^{-3}. The linear function has the 0.5 value at a density of 0.1 cm^{-3}. When using Figure 2 to compare the linear model with the observations the 0.5 value for the linear model occurs at a density of 1.6 cm^{-3} which matches the data. The constant functions do not exhibit the same shape as either the linear function or the data. At higher densities the linear function diverges from the data and cannot account for the observed water (see Figure 2).

Conclusions: Because the simulated values using a fraction of water released consistent with the expected hydrated content of the incoming meteoroids are so much lower than the observed value, this suggests that most of the water observed did not originate in the meteoroids themselves. The scale factor of >10 suggests that water observed in the Moon's exosphere predominantly originated in the Moon's surface, as concluded by [4]. However, we note that including some of the known variability of the impactor flux does broaden the observed distribution of densities. Further work in implementing realistic properties in meteoroid distributions may be able to reproduce LADEE observations without invoking a desiccated layer.

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