POLAR ICE ACCUMULATION ON THE MOON DUE TO VOLCANICALLY INDUCED TRANSIENT ATMOSPHERES. A. X. Wilcoski[1,2], P. O. Hayne[1,2], and M. E. Landis[2], [1]University of Colorado, Boulder, CO, [2]Laboratory for Atmospheric and Space Physics (andrew.wilcoski@colorado.edu).

Introduction: Water ice deposits at the lunar poles have been both directly and indirectly observed, but little is known about their origins [1-4]. Each possible source of lunar volatiles (e.g., impact delivery, solar wind ion implantation, volcanic outgassing) may have affected the distribution, abundance, and composition of polar volatiles in unique ways. Further knowledge of the signatures of these sources are key to understanding the volatile history of the Moon, and to future study and utilization of lunar volatiles.

Recent work has discussed the possibility of ancient, volcanically induced, transient atmospheres, and their potential as sources of H_2O for polar ice deposits. Needham and Kring [5] proposed a volcanically induced, collisional atmosphere at ~3.5 Ga with a lifetime of ~70 Myr. Head et al. [6] suggested that the total volume of magma erupted was lower and was released by smaller eruptions over a period from 4-2 Ga, concluding that even during peak volcanic flux, atmospheric lifetimes were shorter than eruption intervals, so a long-lived atmosphere was unlikely.

Estimates of volatile content of lunar magma suggest that H_2O was a major constituent erupted gases [7], and could have been a significant source of H_2O ice to the polar cold traps. In order to retain the H_2O released by an eruption, the ice accumulation rate onto the surface must exceed the atmospheric escape rate. Earlier studies [5,6] used an atmospheric loss rate of 10 kg s^{-1} derived by Vondrak (1974) [8]. However, this work only considered surface Jeans escape of an O_2 atmosphere with a mean molecular mass much lower than that of a volcanic atmosphere. A more accurate Jeans escape calculation will significantly change the lifetimes of the atmospheres considered by previous studies [5,6].

Here, we model an eruption timeline consistent with earlier studies [6], including atmospheric escape and H_2O ice accumulation on the surface. Our study aims to answer the following questions: (1) How do atmospheric lifetimes compare to H_2O ice accumulation timescales? (2) How much ice would have accumulated during this time period? (3) Where on the surface would ice have accumulated?

Methods: We model 50,000 eruptions over the period of 4-2 Ga [6]. The probability of an eruption occurring in a particular timestep decreases linearly from 4-2 Ga such that 75% of eruptions occur during the first 1 Gyr. The gas mass released in each eruption is derived from a Rayleigh distribution with a mean of 1.2 × 10^{12} kg [6], with volatile content described by [7].

We assume atmospheric escape is dominated by Jeans escape. The escape model uses an exobase altitude that depends on atmospheric mass, and an atmospheric scale height that increases with altitude. We find that exobase temperature (T_{ex}) strongly controls escape rates, and treat it as a free parameter.

Ice accumulation is primarily controlled by atmospheric H_2O vapor pressure and the maximum temperature reached in any potential ice reservoir on the surface. We use maximum temperature maps from the Diviner Lunar Radiometer Experiment onboard the Lunar Reconnaissance Orbiter [9]. The Diviner maps extend from 60-90° latitude in both hemispheres with a spatial resolution of ~250 m, and we consider each pixel to be a potential ice reservoir with cold-trapping efficiency determined by maximum annual temperature. We calculate accumulation rates at each potential reservoir, and couple them to the atmospheric model. Ice accumulation rates are limited by the diffusivity of H_2O through an atmospheric laminar layer directly above the surface. We assume that the atmosphere is well mixed above this layer.

The model updates the mass of H_2O vapor and the mean molecular mass of the atmosphere as ice is accumulated. We also consider the effect of freeze-out of H_2O on the lunar nightside over a diurnal cycle.

Results: Figures 1 and 2 show the total atmospheric and H_2O vapor mass for typical model runs over the 2 Gyr period with T_{ex} = 800 K and T_{ex} = 600 K respectively. With T_{ex} = 800 K, the atmospheric lifetimes (~10^3 yr) are typically too short for an atmosphere to persist between eruptions. With T_{ex} = 600 K, atmospheric lifetimes (~10^5 yr) are longer than the typical periods between eruptions, which causes a fully collisional atmosphere to persist for ~1 Gyr.

In a typical eruption, the resulting atmospheric H_2O vapor is able to completely condense into ice in hundreds of years. This timescale is one order of magnitude shorter than atmospheric lifetimes (i.e., 1 kyr) in the case of a high exobase temperature (Fig. 1). Note this may be an overestimate, since each reservoir is fixed at its maximum Diviner temperature.

Ice accumulates faster in colder regions than warmer regions, so ice deposits will be thicker in colder reservoirs (Fig. 3). Additionally, after the initial post-eruption ice accumulation period, ice will begin to

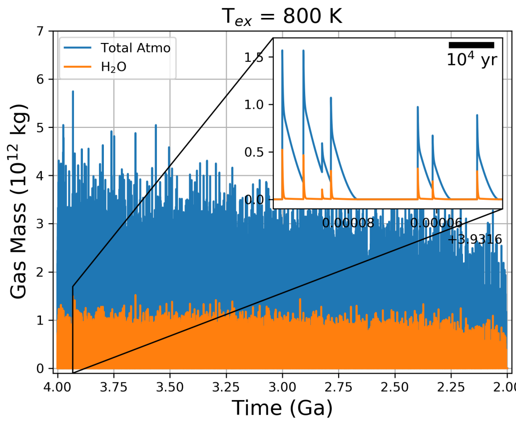

Figure 1 Gas mass for a typical model run with T_{ex} = 800 K. Total atmospheric mass in blue, H_2O vapor mass in orange.

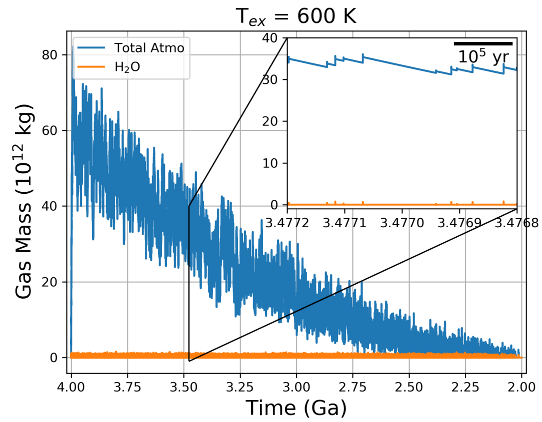

Figure 2 Gas mass for a typical model run with T_{ex} = 600 K. Total atmospheric mass in blue, H_2O vapor mass in orange.

migrate from warmer to colder reservoirs. This secondary process will continue as long as an atmosphere persists to allow communication between reservoirs, and further concentrates ice into the coldest locations. We also find that up to ~15% of H_2O vapor may be sequestered on the nightside as ice while an atmosphere remains collisional.

Conclusions: Our results show the distribution and abundance of H_2O ice likely to occur due to volcanic outgassing, and indicate the possibility of a long-lived atmosphere persisting during the period of peak lunar volcanism. Even in the case of rapid escape (Fig. 1), we find that polar ice accumulation timescales are much shorter than atmospheric lifetimes. This suggests that virtually all of the H_2O released from eruptions should have condensed onto the surface. The secondary effect of ice transport from warmer to colder reservoirs further concentrates ice. Ice should be more concentrated in the coldest reservoirs if atmospheres persisted for longer.

We find that more ice is present at the south pole than the north. This is due to both the greater total cold trap area in the south and the greater area of cold traps with very low temperatures [10], and is consistent with the observations of Rubanenko et al. (2019) [4]. We are currently working on incorporating ice destruction into our model, to more accurately estimate the total mass of volatiles sourced from volcanism and other sources that may exist today.

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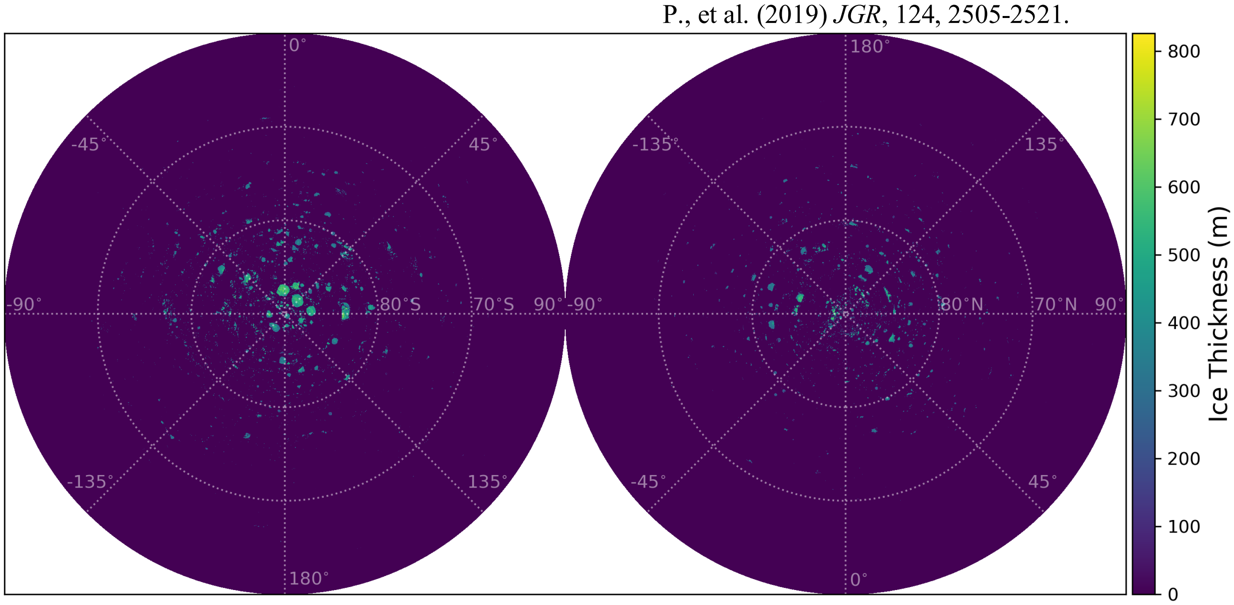

Figure 3 Maps of ice thickness after 2 Gyr eruption period, for T_{ex} = 800 K. The south pole has ~2x the ice mass of the north.