FROM TRANSIENT TO SEQUESTERED: VERTICAL TRANSPORT OF WATER ICE IN SEASONALLY SHADOWED REGIONS. K. M. Luchsinger[1] and N. J. Chanover[1], [1]New Mexico State University (kluchsin@nmsu.edu).

Introduction: The study of lunar volatiles, in particular the study of lunar water ice deposits, has focused primarily on the long-term deposits sequestered within permanently shadowed regions at the poles. These deposits remain cold enough to persist over geologic time scales, and therefore offer an opportunity to probe the water ice history of the Earth-Moon system. However, with the recent discovery and characterization of a possible active water cycle due to the chemical interactions between solar wind protons and oxygen within lunar rocks [1,2,3], we can now incorporate transient deposits of lunar water ice and form a picture of a global water system. We know now that these transient deposits can be found even on sunlit surfaces. However, in order to truly understand the lunar water ice history and current behavior, we need to understand both the transient and the sequestered water ice deposits. In order to better understand the water in both states, actively migrating and captured, we are exploring locations on the lunar surface where water regularly transitions between these two states: seasonally shadowed regions.

Methods: Seasonally shadowed regions are locations on the lunar surface that have at least one full lunar day of shadow and at least one lunar day in which the sun rises above the local horizon. The regions that fulfill that description represent a broad range of illumination conditions, from regions that are functionally permanently shadowed to regions with shadowed periods that are not long enough for the lunar regolith to cool, even temporarily, down to temperatures cold enough to trap water ice [4]. In between these extremes lie locations that behave like permanently shadowed regions in the lunar winters, and like their sunlit neighbors in the lunar summers.

During the sunlit lunar summers, transient water is deposited on the surface and should behave in similar ways to transient water deposits at lower latitudes. Then, during periods of seasonal shadow during the lunar winter, this transient water undergoes sequestration processes, similar to the sequestration processes that occur constantly within permanently shadowed regions. The sequestration processes are, however, interrupted at the end of the seasonally shadowed period, and the water at the surface returns to a transient state. However, any water that has been sequestered sufficiently far beneath the surface to be sheltered from increased temperatures from the sunrise may remain in a sequestered state. Because water ice deposits in seasonally shadowed regions participate in both transient and sequestered behaviors, we can study the water ice deposits and compare them to water ice deposits in regions with no extended shadowed periods, which will allow us to study the sequestration processes in shadowed regions. The difference in the transient water deposits, both in the quantity of water ice escaping over time and in the vertical water ice profile, due to sequestration allows us to probe the sequestration processes undergone by the ice during the period of seasonal shadow. If we can leverage the seasonally shadowed regions, which are more accessible and more active, to understand permanently shadowed regions, we will be better able to interpret complex water ice signatures from permanently shadowed regions.

In order to identify and quantify what those differences may be, we are modeling the vertical transport and deposition of H_2O over one lunar year in a grid search across seven craters in the lunar south pole: Cabeus, Amundsen, Faustini, Haworth, Shackleton, Hale Q, and Idelson L craters. These craters represent a diverse selection of lunar polar environments, spanning a range of latitudes, average temperatures, illumination conditions, and crater diameters. I selected points across these craters in grid search, with a mesh of roughly ten kilometers, as shown in Figure 1.

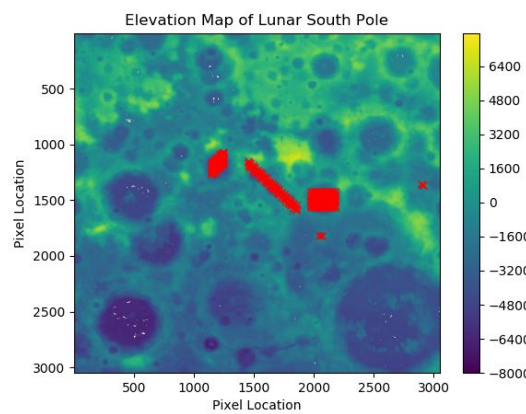

Figure 1: Selected locations for study include the Cabeus, Amundsen, Haworth, Shackleton, Faustini, Hale Q, and Idelson L craters. These locations represent a diverse selection of south polar craters, spanning a range of latitudes, average temperatures, illumination conditions, and crater diameters. I search in a grid with a mesh of roughly ten kilometers between points, with the points indicated by red x marks in above.

Throughout the modeled lunar year, volatiles are deposited on the surface and allowed to migrate and escape, with residence times given by local thermal conditions [5,6]. We explore whether the volatiles have time to migrate far enough below the surface to be insulated; the mass of the possible sequestered water ice deposit; and if there is a detectable impact in the behavior of the transient water ice.

As a first test case, we selected a location in Cabeus crater, chosen due to the low flux received over the course of the year, with only six sunrises and low incident flux angles. As the temperatures do not rise above 120 K, the water ice remains stable even during the brief periods of illumination, as expected [7]. This location therefore represents a boundary case for seasonally shadowed regions: given low enough illumination, a seasonally shadowed region can and does behave like a permanently shadowed region, and transient ice deposited on its surface will become a sequestered ice deposit.

In order to demonstrate the case where illumination conditions deliver an increased amount of heat, the sequestered ice at the surface will return to a transient state, we also tested a case with the same illumination conditions, but increased surface heat as a result of sunlight. The ice was permitted to migrate vertically during the seasonally shadowed portion of the year, and permitted to escape with a residence time determined by local thermal conditions. Therefore, as the surface temperature increased and the thermal gradient propagated downward, the surface ice returned to a transient state and escaped from the crater. However, by about 5 cm below the surface, some ice was sufficiently insulated that it was able to remain sequestered. In Figure 2, we show the ice mass in kg within the uppermost 20 cm in a seasonally shadowed region in Cabeus crater over the course of one year. In this hypothetical test scenario, we see that some ice returns to transient behavior and some ice remains in a sequestered state. Analyzing the behavior of water ice within a seasonally shadowed location could therefore help us understand the transition between transient water ice and sequestered water ice, and help us better understand the processes occurring within permanently shadowed regions.

Expected Results: We will model the transport and loss of water ice over the course of a year in a grid search across seven craters with seasonally shadowed regions. Our primary goal is to identify the regions where sequestered ice may be present at depth. Additionally, we will predict the vertical distribution of water ice and temporal variations in transient water ice in seasonally shadowed regions over the course of a year. These are signatures that, if detected, could be used to quantify the transient to sequestered ice ratio within the seasonally shadowed region, allowing us to probe the transition between transient and sequestered deposits and to study the sequestration processes operating within both the seasonally and the permanently shadowed regions at the lunar poles.

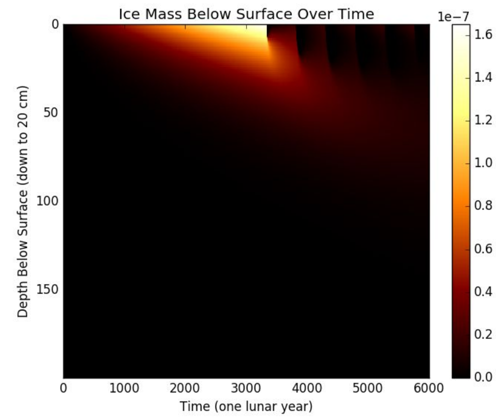

Figure 2: The mass of ice within the uppermost 20 centimeters of lunar sediment in a seasonally shadowed portion of Cabeus crater over the course of one year. This location sees six sunrises over the course of the year, and we see six corresponding signatures of volatile escape. However, some ice is able to persist. We include a constant influx of ice at the surface, and allow the ice at all depths to escape with a residence time dependent on the temperature at that depth.

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