ESTIMATING THE RATE OF GROWTH OR SHRINKAGE OF THE AMUNDSEN CRATER PSR AREA.

C. J. Ahrens[1], N.E. Petro[1], [1]NASA Goddard Space Flight Center, Solar System Exploration Division, Greenbelt, MD (Caitlin.ahrens@nasa.gov).

Introduction: Permanently shadowed regions (PSRs) are areas, particularly within craters, where frozen volatiles can be observed at the lunar poles, and have been measured by the Lunar Reconnaissance Orbiter's Lunar Orbiter Laser Altimeter (LRO-LOLA), Diviner Lunar Radiometer Experiment (Diviner), and Moon Mineralogy Mapper (M^3). Many PSRs near the lunar south pole have maximum surface temperatures < 100 K, consistent with the presence of stable water ice found using LRO's Lyman Alpha Mapping Project (LAMP) [1, 2]. Surface temperatures in these shadowed regions are largely controlled by reflected sunlight and irradiated infrared light from adjacent topography [3-6]. These areas are cold traps, capable of accumulating water and other volatile compounds over time [7]. However, surfaces that experience temperatures > 100 K should lack surface water ice due to the temperature-dependent sublimation [8]. Conversely, surfaces with < 100 K temperature conditions may preserve surface volatiles over geological time periods.

There is a lack of understanding regarding the surface thermal changes at these relatively small PSRs, particularly how these pockets of < 100 K temperatures change on a yearly basis and may inhibit growth or shrinkage of volatile accumulation or ablation, respectively. Here, we measure the bolometric temperatures derived from Diviner over several years (2010-2015). From observed changes in surface temperatures, we can calculate the surface area of the PSR and use a snowline model to estimate growth/shrinkage of the PSR area. We used the PSR within Amundsen crater as an example.

Methodology: LROC Wide Angle Camera (WAC) and Diviner data were used, all publicly available on the Planetary Data System (PDS) Geosciences Node, together with the Java Mission-planning and Analysis for Remote Sensing (JMARS) software. Coincident average Diviner temperature data was available at a resolution of 500 m/px [9]. The day and night bolometric temperatures (brightness temperatures of the individual Diviner spectral channels) were measured over a five-year period (2010 – 2015). The temperatures were then used to form part of the PSR "profile" [Figure 1]- which consists of the length of the PSR from a designated central point and the temperature.

The snow line, adapted from Weertman's Glacier Model [10], separates colder areas where water ice will accumulate to form ice and from warmer regions where the melting exceeds the accumulation of ice and thus the PSR will experience a loss of ice [Black line in Figure 1]. For example, in a crater with partial illumination and observed PSR areas (like Amundsen), temperature fluctuations could influence the accumulation dynamics of the PSR coldspot area. Excessive illumination and rise in temperatures (whether seasonally or solar activity) would potentially cause the PSR to decrease in area (and vice versa with colder temperatures).

This "snow line" slopes gently up to the right towards the warmer side of the diagram. The endpoints to make the snowline are derived from: 1) minimum temperature and average length of the PSR at the end of the observed year; and 2) maximum temperature and average positive horizontal distance from the center point of the PSR. The intersection of this snow line to the surface-temperature profile divides the PSR body into its accumulation zone and sublimation zone. The model starts with an initial PSR length compared to a final size (the beginning and ending of a calendar year in this case), and from that we can calculate the profile of the PSR and its cross-sectional area based on Diviner temperatures.

Results: We used Amundsen crater (84.4°S, 86.2°E) as an example, mostly due to its large PSR size and PSR placement to the side of the crater in an otherwise partially-illuminated crater floor environment. Such illumination changes can potentially change the dynamics of the volatiles (e.g., sublimation/accumulation), thus growth or shrinkage dynamics.

Using the glacial model described earlier, we found that the Amundsen PSR had the following pattern:

- 1.37 cm2/s shrinkage (2010)
- 2.56 cm2/s shrinkage (2011)
- 4.21 cm2/s growth (2012)
- 0.64 cm2/s shrinkage (2013)
- 1.4 cm2/s growth (2014)
- 1.36 cm2/s growth (2015)

We observe a relatively major accumulation growth in 2012 [Figure 2], with growth counts decreasing to 2015. Further analysis of Diviner data is needed for

2016 to present. While these are estimated growth/shrinkage values based on resolution-limited temperature data, this method can still provide an interesting outlook on the shorter timescale dynamics of PSRs at the lunar poles. We hope to continue this work to other PSRs at the lunar poles for further comparison, especially if certain areas experience similar growth/shrinkage scales as Amundsen, such as Scott E, Cabeus, and Weichert PSRs.

Conclusions: We find that temperature variations are associated with the accumulation (or ablation) of volatiles within lunar PSRs and can be used to estimate the amount of growth or shrinkage of the PSR area on a yearly basis. These PSR area measurements and changes further our understanding of thermal stability, volatile crystallization processes, and cold trapping. Observing the differences in growth and shrinkage can give us insight to the regolith properties and the dynamics between the PSR and its respective crater (especially with transient seasonal illumination differences). These PSR craters have the potential to address key lunar exploration questions, especially the perspective on volatile distribution and regolith properties outlined in the Planetary Science Decadal Survey, Visions and Voyages [11].

Acknowledgments: This research was supported by an appointment to the NASA Postdoctoral Program at the NASA Goddard Space Flight Center, administered by Universities Space Research Association under contract with NASA.

References: [1] Hayne, P., et al. (2015) *Icarus*, 255, 58-69. [2] Gladstone, G.R., et al. (2010) *Space Sci. Rev*.150(1-4), 161–181. [3] Watson, K., et al. (1961) *J Geophys. Res*., 66, 3033-3045. [4] Ingersoll, A., et al. (1992) *Icarus*, 100, 40-47. [5] Salvail, J., Fanale, F., (1994) *Icarus*, 111, 441-455. [6] Vasavada, A., et al. (1999) *Icarus*, 141, 179-193. [7] Li, S., et al., (2018) *PNAS*, 115 (36), 8907-8912. [8] Andreas, E., (2007) *Icarus*, 186 (1), 24-30. [9] Chin, G., et al. (2007) *Space Sci. Rev*., 129 (4), 391-419. [10] Weertman, J. (1964). *Journal of Glaciology*, *5*(38), 145-158. [11] NRC (2011).

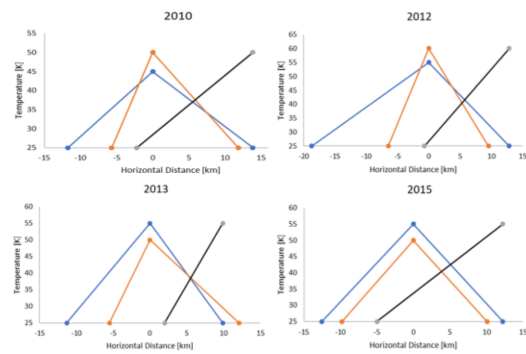

Figure 1: Amundsen PSR snow line profiles for 2010, 2012, 2013, and 2015. Blue lines are the beginning-of-year temperature and area profiles, orange lines are the end-of-year profiles. The black line is the measured snow line, where points higher up on the snow line indicates more ablation. The intersections of the blue and orange lines on the snow line then help us determine the amount of growth or shrinkage.

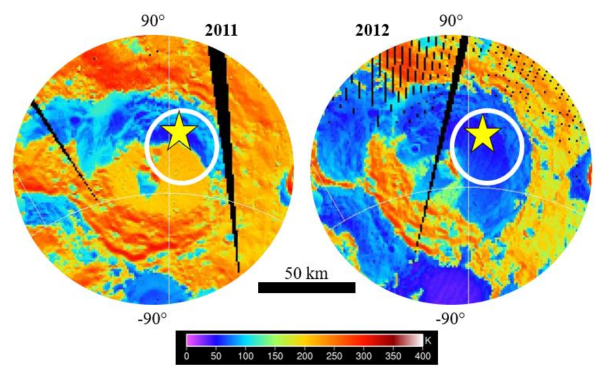

Figure 2: Amundsen crater with Diviner temperature overlay, with the darker blue areas exhibiting colder (< 60 K) temperatures. Shown are the average end-of-year temperatures within 2011 vs 2012, with an increased rate of accumulation in 2012. White circle shows the measured area within Amundsen, with the yellow star indicating the observed PSR location.