TEMPERATURE VARIATIONS WITHIN THE MOON'S PERMANENTLY SHADOWED REGIONS. M. E. Landis[1], B. T. Greenhagen[2], P. O. Hayne[1], D. A. Paige[3], and J.-P. Williams[3]. [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, USA (margaret.landis@lasp.colorado.edu), [2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA, [3]Department of Earth, Planetary, and Space Sciences University of California, Los Angeles, CA, USA

Key Points

- We investigate the diversity of temperatures within permanently shadowed regions (PSRs) and identify the locations best suited for the study of the long-term preservation of a variety of ices. We suggest that timing of sample acquisition even within PSRs is key for detection of diurnally and seasonally mobile volatiles.
- Maximum temperatures and the magnitude of diurnal and seasonal temperature changes also vary within PSRs, which makes some parts of PSRs more potentially accessible to human and robotic explorers than others.

Introduction: Permanently shadowed regions (PSRs) on the Moon provide a unique thermal environment where a variety of volatiles could be resistant to sublimation. The presence of volatiles has been confirmed in some locations from the LRCOSS artificial impact experiment and remote sensing (e.g., [1-6]). However, the extent and source of these lunar volatiles is not well constrained, though they likely originated from some combination of lunar volcanism [e.g., 7], solar wind implantation [e.g., 8], and/or icy small body impacts [e.g., 9].

Direct observations of volatile deposits at the lunar south pole is essential to constrain the source and current flux of volatiles. This will help determine the source of lunar volatiles over time, as well as determine the replenishment rate of any water or other volatiles that could be useful for in situ resource utilization (ISRU). In this white paper, we discuss the variations of temperature within PSRs spatially and temporally, and discuss implications for Artemis-era exploration.

Data Set and Data Processing: In order to quantify temperatures in the current Artemis mission region of interest (within 6 degrees of the south pole), we utilize the Lunar Reconnaissance Orbiter's Diviner radiometer [10]. Diviner has been collecting data for over 11 years, and we processed data according to [11] to obtain bolometric temperatures from individual channel measurements. Diviner data has a footprint of ~ 250 m, therefore smaller temperature variations likely exist on scales smaller than this (e.g., Hayne et al., Artemis white paper) and are essential to measure in situ [e.g., 12]. We look at maximum temperatures as a proxy for surface volatile stability (<1 mm/Gyr of sublimation) based on volatility temperatures from [13]. Seasonally varying temperatures are documented in [14] and methods used to generate the maximum temperatures in [15].

Spatial Variation of Maximum Temperatures in PSRs: While PSRs are areas where no direct sunlight illuminates the surface, differences in the amount of scattered and emitted photos results in substantial variations in maximum temperatures within PSRs. We quantify this effect in terms of maximum surface temperatures attained within 6 degrees of latitude of the south pole in *Fig. 1***.**

The locations of volatile stability identified in these maps are likely more restrictive due to the low sublimation rate chosen (<1 mm/Gyr). However, where water ice (stability temperature: ~107 K) is present, any sulfur (S_2, ~202 K) that may be present from lunar volcanism would also be stable. Additionally, super-volatiles that could be delivered via comets could be present within the water (e.g., hydrogen cyanide, ~81 K or carbon disulfide, ~74 K). Some regions also have low enough temperatures for volatiles that have negative health effects in humans, like hydrogen cyanide or toluene (~88 K), to be stable.

The volatiles that are present in any extant surface deposit depends on supply and destruction rates. Therefore, taking a sample from a location where multiple volatiles could be stable on the surface and identifying the constituent parts should be a key science objective, as well as critical information for evaluating how useful the surface water ice deposits are to ISRU.

Seasonal Variation of Temperatures within PSRs: In addition to spatial variations within PSRs, there are also seasonal variations in surface temperatures within these regions. This analysis has been done in [14] for summer and winter temperatures and the north and south pole of the Moon. This work finds that even within PSRs at the Diviner footprint scale, summer surface temperatures can vary by up to 40-60 K (e.g., *Fig. 2*) and could be higher due to cm-scale roughness elements [16]. The timing of when surface volatile deposits are sampled may or may not result in capturing seasonal deposits of water and other materials. Balancing when Artemis missions sample materials to maximize seasonal volatile presence with when temperatures acceptable for operations is key for future mission planning.

Acknowledgments: This work was supported by the NASA Lunar Reconnaissance Orbiter and Lunar Flashlight projects.

References: [1] Colaprete, A., et al. (2005). *Nature*, 435 [2] Sefton-Nash, E., et al. (2019). *Icarus*, 332 [3] Schultz, P.H., et al. (2010). *Science*, 330 [4] Pieters, C.M., et al. (2009). *Science*, 326 [5] Hayne, P.O., et al. (2010). *Science*, 330 [6] Feldman, W.C., et al. (1998). *Science*, 281 [7] Needham, D.H., et al. (2017). *EPSL*, 478 [8] Morgan, T.H., et al. (1991). *JGR: Space Physics*, 96 [9] Bockelée-Morvan, D. (2011). *Proceedings of the IAU*, 7(S280) [10] Paige, D.A., et al. (2009). *Space Science Reviews*, 150 [11] Paige, D.A., et al. (2010). *Science*, 330 [12] Greenhagen et al., (2020), Lunar Surface Science Workshop abstract #5097 [13] Zhang, J.A., et al. (2009). *GRL*, 36(16) [14] Williams, J.P., et al. (2019). *JGR: Planets*, 124(10) [15] Landis, M.E., et al. (2020), LPSC abstract #1493. [16] Hayne, P.O., et al. (2020). arXiv:2005.05369

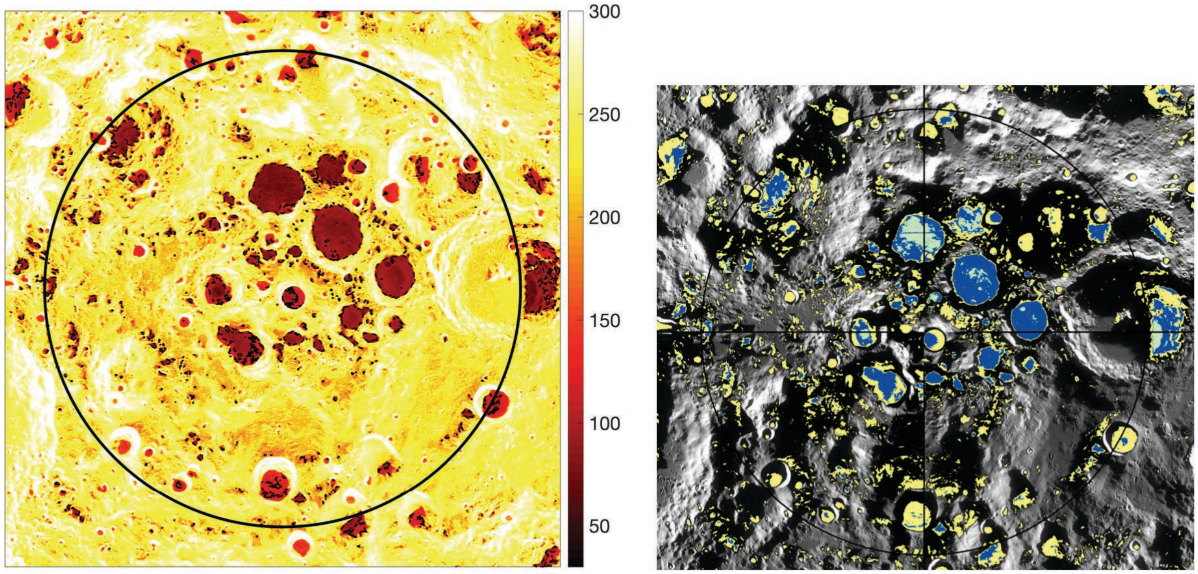

Figure 1. (left) Maximum south polar bolometric temperatures. Solid black line is 84° S (within 6° of the south pole, as per the Artemis mission guideline), dashed black lines enclose areas less then 107 K. (right) Substantial lateral temperature variations in maximum bolometric temperature still exist within these regions, suggesting areas where different volatiles (sulfur, yellow; hydrogen cyanide, green) in addition to water (blue) could be stable. The black circle again indicates 84° S. Background image: LROC WAC mosaic.

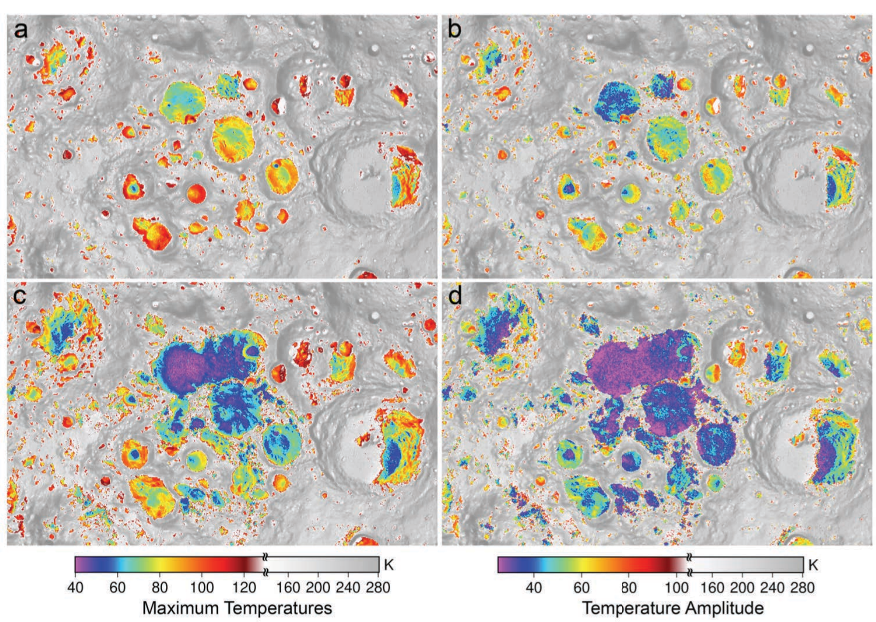

Figure 2. Reproduced from [13] where (a) the maximum summer temperatures within PSRs at the south pole, (b) the amplitude of summer temperature extremes, (c) maximum winter temperatures and (d) amplitude of winter temperature extremes.