**IN SEARCH OF SHADE IN PERSISTENTLY ILLUMINATED REGIONS NEAR THE LUNAR POLES.**

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**Introduction:** The Moon's slightly tilted spin axis (1.54° at its current state) relative to the ecliptic normal provides a unique lighting environment near the lunar poles [1]. Topographic highs (e.g., crater rims and elevated massifs) remain persistently illuminated for the entire precessional cycle (18.6 years). Meanwhile, some crater floors and topographic depressions remain in shadow throughout the same cycle. These two areas are unique exploration sites for future human and robotic explorers. Areas of persistent illumination that remain illuminated for a majority of the year and are only in shadow for short intervals provide extended periods of insolation enabling long-lived surface operations using solar power. Meanwhile, regions in persistent and permanent shadow may contain volatiles that have collected in natural cryogenic traps [2,3]. Using models of simple craters and Lunar Reconnaissance Obiter (LRO) Narrow Angle Camera (NAC) images, we identify the occurrences of these two environments coexisting in small, localized areas.

**Previous Studies:** Many studies have focused on identifying and delimiting these two environments (persistently illuminated and permanently shadowed) using both topographic and image based datasets. Most recently, from altimeter data from Laser Altimeter (LALT) and Lunar Orbiter Laser Altimeter (LOLA) onboard the Kagyua and LRO spacecraft, researchers have simulated the lighting conditions of the polar region over part or the entire 18.6 year cycle [4-6]. These simulations identified discrete points in the elevation models that receive the most illumination and quantify the surface area near the pole in permanent shadow.

Recent work [7] using images acquired by the LRO Wide Angle Camera (WAC) revealed a highly illuminated region (0.93 km$^2$) on the rim of Shackleton crater that remains persistently illuminated for 94% of the year and recedes into shadow for a maximum period of only 62 hours (Figure 1). Such a location is ideal for future missions and long duration habitats due to its persistent access to solar energy and proximity to large permanently shadowed regions (PSRs), like the floor of Shackleton crater.

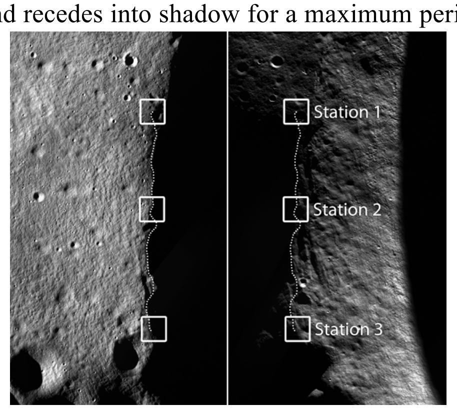


**Figure 1:** These three stations (Station 1: 89.78S 205.22E; Station 2: 89.74S 201.19E; Station 3 89.69S 197.48E), shown in these two NAC mosaics, collectively are illuminated for 94% of the year.

**Impact of Small Scale Topographic Elements:** One type of product common to these previous studies is illumination maps that quantify the percentage of time a single point or pixel on the surface is illuminated over a period of time. The scale of the maps depends on scale of the available dataset (LALT = 474 m/pixel, LOLA = 240 m/pixel, WAC = 100 m/pixel). When comparing simulations based on elevation models to WAC image derived maps (that capture the true illumination conditions), it was noted that the illumination percentage of the most illuminated pixel in the map decreased from 82 to 89% in the simulations to 71% in the higher resolution WAC image derived product [7].

This difference is likely due to small localized topographic variations, which may go undetected in lower resolution elevation models. For example, due to the extreme lighting geometry, a meter tall boulder on the surface can cast a shadow for 37 m. Likewise, small impact craters can shadow a majority of their interior from receiving direct sunlight (with the Moon's current obliquity and inclination) [1] These small features can substantially alter the illumination conditions at a given location and must be identified and accounted for when planning surface operations in these regions. To examine this dramatic lighting environment, we investigate the potential of small permanently shadowed craters using illumination simulations of simple shape craters and NAC illumination mosaics of highly illuminated terrain near the lunar poles.

**Crater Illumination Model:** Lighting simulations of simple bowl shaped craters provide baseline estimates for the illumination conditions of crater floors near the poles [1,3,8]. In our set of simulations, we investigated small craters that ranged from 5 to 400 m in diameter, with depth to diameter ratios that represented both young (1/6) and degraded (1/12) states.

To investigate how the latitude of the crater effects the lighting environment, craters were placed over a range of polar latitudes (±86° to the pole). During each run, the light source was scanned around the crater over a full range of sub-solar longitudes (2° increments), while the sub-solar latitude was fixed at 1.54°, which simulates the peak of polar summer. This strategy enables the simulations to calculate the area inside the crater that is in permanent shadow as well as the size of the largest sunlit wall over an entire lunar rotation. The model, like previous studies [1,3,8], assumes a simple crater with continuously sloping walls and a spherical Moon; specifically external and topographic variation along the crater floor are ignored.

From these simulations, we identified the ratio of the area in permanent shadow along the crater floor and the largest area exposed to sunlight during a full revolution. We found that for the range of crater sizes studied (5-400 m), with a fixed depth to diameter ratio, the percentage of the crater in permanent shadow and the percentage of the largest illuminated wall was invariant to the diameter in this latitude range. The models confirm that for craters closer to the pole the ratio of shadowed and illuminated terrain increases and that ratio decreases as the crater matures (Figure 2).

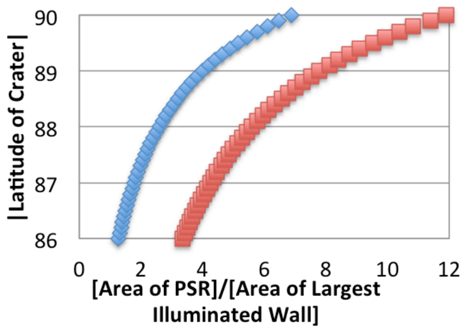


**Figure 2:** Results of illumination simulations near the poles. The red line denotes simulations of young impact craters (depth/diam. = 1/6), while the blue line represents degraded craters (depth/diam. = 1/12).

**NAC Illumination Analysis:** During each orbit (~2 hours), the WAC acquires a 104 km wide image across the pole that is used to create illumination maps of the region [7]. In contrast, the spatial coverage of NAC images acquired during a polar pass are limited due to the narrower field of view (5.7º combined). However, since the start of the mission, the NACs have acquired over 21,000 image pairs within 5º of the north and south pole over a full range of lighting conditions thus providing a dataset for studying the lighting conditions at the meter scale.

In a search for shadowed areas in or adjacent to persistently illuminated regions, we map projected a subset of NAC images covering the rim of Shackleton crater. The mapped images were converted into binary images to represent their illumination state (0=shadowed, 1=illuminated). Binary images were stacked in map space and the percent each mapped pixel was illuminated was calculated. Since the NAC does not image the same surface during every orbit, we cannot provide meaningful estimates for the amount of time a feature is illuminated at this scale, but we can identify potential PSRs that have remained shadowed in all images acquired to date. Figure 3 highlights a collection of craters that have a majority of their interior remaining in shadow, even in these persistently illuminated regions.

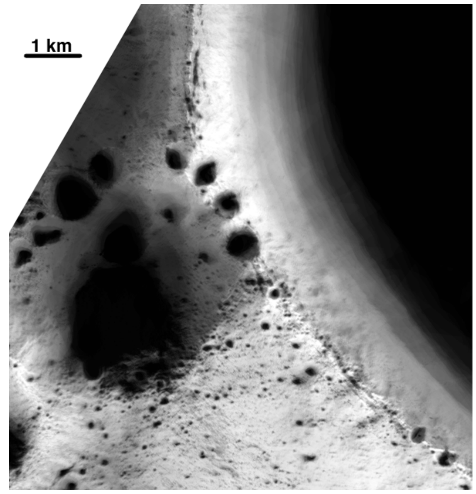


**Figure 3:** NAC illumination mosaic. Dark features identify areas that have remained shadowed from NAC observations.

**Discussion:** The potential presence of permanently shadowed features in the persistently illuminated regions has major implications for future human and robotic exploration of the lunar poles. There have been numerous mission proposals [e.g., 9,10] to explore large PSRs with landers, rovers, and ground-based standoff instruments. These large PSRs generally have long, steep slopes and, by definition, no easy access to direct solar energy making it difficult to traverse and survive for long periods of time. However, small PSRs found in these persistently illuminated regions are more easily accessible and a tall (several meters), but feasible, mast could collect solar energy to support operations [6,11]. Furthermore, a polar rover could explore a series of these small permanently shadowed regions with standoff instrumentation that would require substantially less power than needed to explore the larger and less accessible PSRs like Shackleton crater.

**Future Work:** Having shown with models and NAC images that these features exist in large numbers near the pole, future efforts will include integrating NAC and LOLA derived elevation models. These illumination models, as well as additional thermal models will enable us to identify small craters in persistently illuminated regions that may provide an optimal environment for collecting volatiles.

**References:** [1] Siegler et al. (2011) *JGR*, 116, E03010. [2] Ingersoll et al. (1992) *Icarus*, 100, 40-47. [3] Feldman et al. (2000) *JGR*, 105, 4175-4195. [4] Noda et al. (2008) *GRL*, 35, L24203. [5] Bussey et al. (2010) *Icarus*, 207, 558-564. [6] Mazarico et al. (2010) *Icarus*, 211, 1066-1081. [7] Speyerer et al. (2012) *Icarus*, in review. [8] Bussey et al. (2003) *GRL*, 30. [9] Barlett et al. (2008) Int. Symposium on Artificial Intel. [10] Pedersen et al. (2008) Int. Symposium on Artificial Intel. [11] Bussey et al. (2011) LEAG Annual Meeting.