SUNLIT PATHWAYS BETWEEN SOUTH POLE SITES OF INTEREST FOR LUNAR EXPLORATION.
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Introduction: The lunar polar regions are of key interest to lunar science and exploration. Over the past few decades, observations from multiple missions and instruments have provided evidence for the presence of volatiles in the long-recognized cold traps within polar craters. In particular, the data returned by the Lunar Reconnaissance Orbiter (LRO) have enabled detailed mapping and improved understanding of the polar regions. However, many questions remain. The NASA Artemis III mission is slated to land astronauts in the lunar south pole region (84-90° S) in 2025. The polar regions are valuable from an exploration perspective, given the potential for accessible ice for in-situ resource utilization in the future, but also more immediately given the existence of a small number of sites with extremely favorable illumination conditions [1]. These can support solar-powered exploration and reduce engineering requirements for exploration systems, which may need to survive only a few days of darkness rather than the habitual two weeks [1,2]. As capable exploration support assets are delivered to the Moon, an important question is whether these "light oases" are disconnected islands that need to be explored independently, or whether traveling between them is feasible. Here, we report on "proof of existence" work to find trips between sites where a pre-determined path remains in sunlight for the duration of the traverse.

Data: We use elevation data collected by the Lunar Orbiter Laser Altimeter (LOLA) onboard LRO [3]. The bulk of the dataset was collected early in the mission when LRO was in a near-circular 50-km polar orbit. The decreasing orbit inclination since 2009 has precluded data collection poleward of 89° S after 2013, 88° S after 2014, and 87° S after 2017. The >36 million altimetric measurements in the 88-90° S polar cap support an overall resolution of ~20 m for topographic map, but we use a higher resolution (5 m/px) immediately near the pole and a lower resolution further out. Resolutions down to 240 m/px are used for the most distant topography which needs to be considered for horizon computation (up to ~300 km away). We use updated topographic maps where the LOLA tracks were adjusted to reduce artifacts [4,2,5].

The sites considered in this study are high-illumination locations previously identified [1]. They are located within a subset of the 13 recently announced Artemis III regions [6]. They are near the Shackleton-de Gerlache rim, on the de Gerlache rim, on a peak near Slater crater, and on Malapert massif.

Traverse Planning: We determine traverse paths between the four selected sites (Figure 1). This was done using ArcGIS Pro's Spatial Analyst Cost Path tool. The least-cost path from a source to a destination is computed considering various raster products as weighted constraints. We used an average illumination map [1] as an input to favor more highly-illuminated locations, given our goal is tightly tied to this metric. We also used the LOLA DEM-derived slope map as a proxy for traversability. While more complex models of mechanics and trafficability exist [e.g., 7], their integration for higher fidelity is left to future efforts. The resolution of these maps is 50-60 m/px, which is sufficient for our study. Considering higher-resolution topography would likely increase the path length slightly, to avoid short-scale slopes, craters, or hazards. However, testing with one path below, the 5m-derived path keeps within ~35 m RMS of the 50 m-derived path (about half a pixel), with a maximum of ~100 m. As such, they can still be executed with small changes to the path and traverse speed, with small variations.

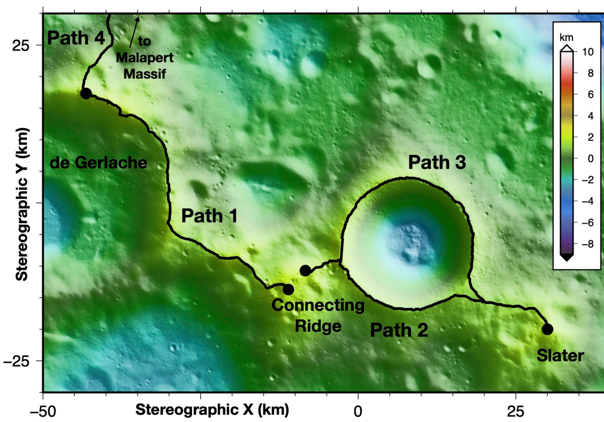

Figure 1. Polar stereographic map of the south pole topography with the least-cost paths shown in black.

Illumination Conditions: We compute the illumination conditions along these pre-determined paths over a study period, which spans ~1.5 years to ensure both winter and summer seasons are complete. We rely on methodology and tools developed for previous work [1,8]. The number of points is significantly smaller than when simulating entire map regions (~10^3, vs. 10^7-10^8), so we record the illumination results in a single "Path Illumination Matrix". Figure 2 shows this PIM for Path 1. The X axis shows time, while the Y axis shows the distance traversed along the path, from the starting point (y=0

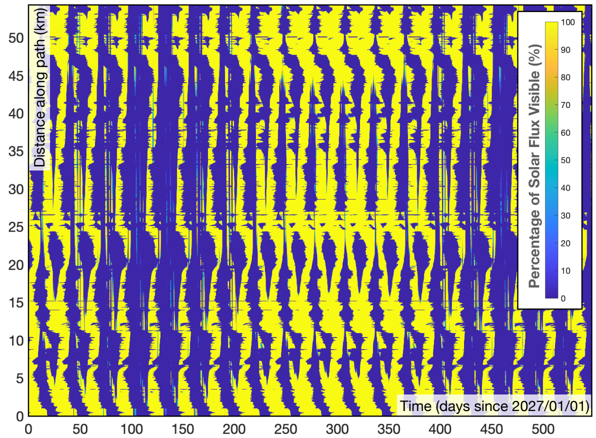

Figure 2. Path Illumination Matrix for Path 1, over the period 2027/01-2028/07.

km) to the end point (y = total path length). From the PIM, one can find a trip that avoids dark sections of the path (blue 'islands') and remains in sunlight (yellow). A trip is defined as a series of discretized points reached at prescribed times; these points need to move forward in time (X monotonically increasing), and the slope between successive nodes on the PIM indicates the speed.

Results: Taking the Path 1 PIM in Figure 2 as an example, we find that the path is never entirely illuminated. The summer season is clearly visible (days ~250-350), with significantly more of the path segments typically sunlit. Figure 3 shows a sample trip along Path 1 from the Connecting Ridge to the de Gerlache rim. The travel speeds are moderate (<7.5 km/day) with frequent stops that may be used to recharge and/or locally explore. The path remains in full sunlight, except for ~1 day when only part of the Sun is visible above the horizon while stationary. However, the trip is noticeably long, spanning ~30 days. So, while this shows fully-sunlit trips are possible, further optimization and other methods may be explored to find faster paths.

We will report on other possible trips between the four sites, which were described recently in a publication [9]. This shows that even with limited assumption on roving capabilities, trips between highly illuminated south pole sites that are conducted entirely or nearly entirely under sunlit conditions are possible.

References: [1] Mazarico E. et al., *Icarus*, 211, 2011. [2] Barker M.K. et al., *Planetary and Space Science*, 203, 2021. [3] Smith D.E. et al., *Icarus*, 283, 2017. [4] Zuber M.T. et al., Nature, 486, 2012. [5] Barker M.K. et al., *LPSC*, 2023. [6] NASA, https://www.nasa.gov/press-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon, Aug. 19, 2022. [7] Speyerer E.J. et al., *Icarus*, 273, 2016. [8] Mazarico E. et al., *Advances in Space Research*, 62, 2018. [9] Mazarico E. et al., "Sunlit pathways between south pole sites of interest for lunar exploration.", *Acta Astronautica*, doi: 10.1016/j.actaastro.2022.12.023, 2022.

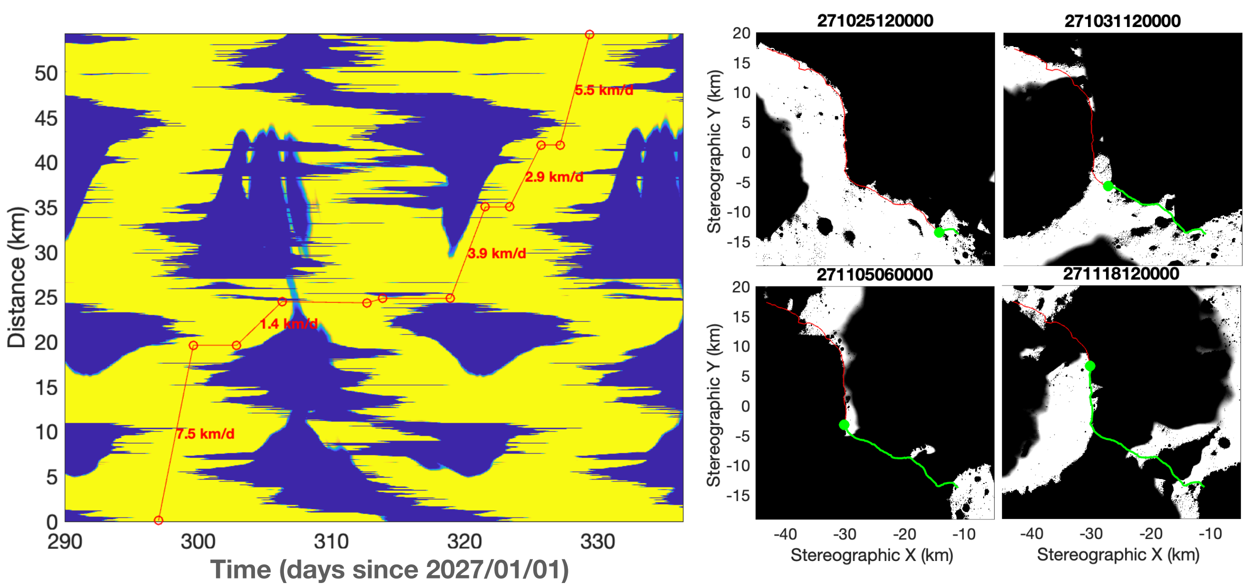

Figure 3. (Left) Section of the PIM (Fig. 2) during the summer season, on which an example trip is shown in red. The average travel speeds are indicated. (Right) Four snapshots of the trip, with the date indicated. The completed part of the trip is shown in green. The illumination conditions of the surrounding area are shown for context, but not used in the determination of the trip.