MODELED EVA TRAVERSES INTO PERMANENTLY SHADOWED REGIONS NEAR SHACKLETON CRATER RIM AND CONNECTING RIDGE. P. Tripathi[1], A. Goodwin[2], E. Peña-Asensio[3,4], J. Sutherland[5,6], K. Mason[7], V. T. Bickel[8], D. A. Kring[9], [1]Indian Institute of Technology Roorkee (ptripathi@ce.iitr.ac.in), [2]The University of Manchester, [3]Autonomous University of Barcelona, [4]Institute of Space Science (IEEC-CSIC), [5]Institut Laue-Langevin, [6]TU Berlin, [7]Texas A&M University, [8]Center for Space and Habitability, [9]Lunar and Planetary Institute,

Introduction: The rim of the ~21 km diameter Shackleton crater and adjoining ridge between Shackleton and Henson craters, near the lunar south pole, are potential sites for Artemis crewed landings [1]. A combination of low solar elevation angle and highly variable topography means sunlight cannot directly illuminate the bottom of many depressions (e.g., craters), forming permanently shadowed regions (PSRs) [2,3,4]. These can behave as local cold traps and may contain frozen volatiles that could be significant for science and in-situ resource utilization.

Here we evaluate the accessibility of PSRs as targets for extravehicular activity (EVA) by first generating a PSR map and then calculating traverse paths to those PSRs that minimize EVA workload.

Study Area. PSRs were mapped over a 300 km^2 area near the lunar south pole at a resolution of ~5 m/pixel. This is a feldspathic highland terrain reworked by impact cratering processes [5]. The $3.43^{+0.04}_{-0.05}$Ga Shackleton crater appears to have excavated anorthositic crust and a layered unit on the structural rim of the South Pole-Aitken basin [5,6]. The most accessible PSRs for Artemis III astronauts on that surface are small, typically ~50 to 100 m diameter, and are thus so young that they will have primarily sequestered volatiles from the solar wind and micrometeorites, rather than volatiles delivered by older basin-forming impact events and volcanism [7].

Mapping PSRs. A map of PSRs was generated using an enhanced 5 m/pixel LDEM product derived from Lunar Reconnaissance Orbiter (LRO) LOLA data [8]. A hillshading tool in ArcMap was applied to the LDEM using ~1.54° maximum solar elevation around 360° azimuth at 0.5° increments and the result-

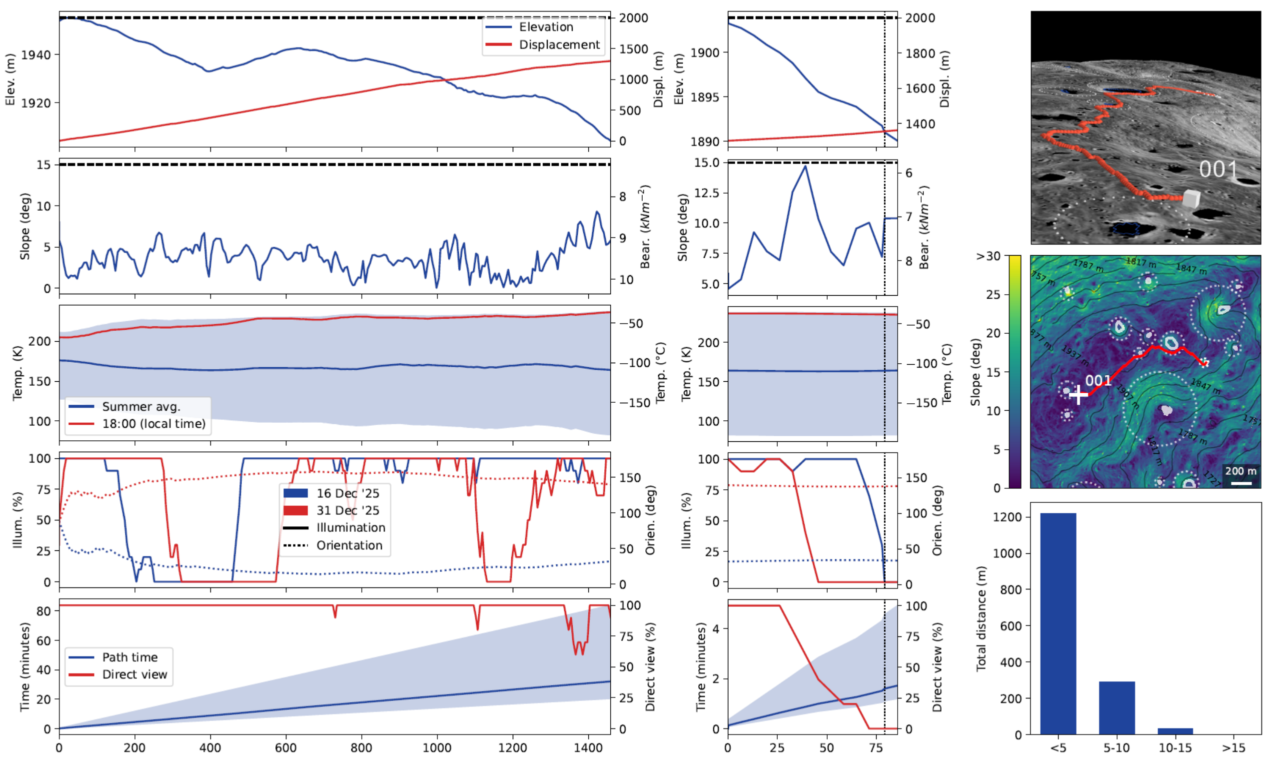

Fig. 1. Summary of one traverse from the potential landing site 001 [12] to a PSR, showing from left to right: (i) column of terrain (elevation, slope), environment (surface temperature, astronaut illumination), time, and visibility variables plotted for each raster pixel of the modeled traverse from location to crater rim; (ii) the same variables plotted from crater rim to PSR center, and; (iii) perspective and plan view maps illustrating the traverses, with histogram of total distance of the EVA spent on different scalar slope inclinations.

ant illumination map was thresholded and filtered, including with manual inspection against a LRO NAC image mosaic [9]. This resulted in 522 PSRs, including those previously identified in the region [10].

Modeling EVA Traverse Paths: Once the PSRs were identified, a version of Dijkstra's algorithm was applied to identify a minimum-cost path from a starting point (either a potential landing site or the edge of a PSR-hosting topographic depression) to the edge and centers of mapped PSRs. The algorithm was applied over the enhanced 5 m/pixel LDEM raster and calibrated to determine minimum cumulative slope. A penalized threshold of 15° maximum slope per pixel was applied. Resultant traverses were used to sample raster datasets, including bearing capacity [10] and temperature [11] to evaluate EVA conditions (**Fig. 1**). At each pixel, ray tracing was used to estimate illumination conditions as a percentage of a modeled 2 m human in direct sunlight, with the astronaut-HLS direct view [12] and the Sun's orientation with respect to the astronaut-HLS line of sight indicated (**Fig. 1**).

Potential Artemis Landing Sites. We examined PSRs around three potential landing sites: 001 (on the Shackleton-Henson Ridge: -89.4532, -137.3385); a location 6 (-89.4666, -137.0456) near site 001 [13], which is a flat (<8°) landing area that meets the slope criteria prescribed by the Human Landing System (HLS) [14]; and 004 (on the rim of Shackleton crater: -89.7796, -155.7805). 18.5×16.2 km^2 regions were examined; 2 km radial exploration zones around each site were further defined, corresponding to the likely limit of a walking EVA by Artemis III astronauts. The nearly 10 km radial limit around sites in the broader region may correspond to future EVAs that utilize an unpressurized rover.

Employing our EVA traverse algorithm, we calculated the traverse path that minimized EVA workload from the crater rim to the center of the PSR for all PSRs and from each landing site to prospective PSRs. Within 2 km of sites 001 and 004, paths were calculated to 22 and 10 PSRs, respectively. We also calculated paths to 20 PSRs from location 6.

Walking EVA Speed. To determine if it was possible for Artemis III crew to complete roundtrip traverses to those PSRs, we re-examined Apollo walking EVA speeds. Apollo 12 EVA 2 and Apollo 14 EVA 2 were digitized alongside transcripts and commentary derived from NASA surface journals [15]. By matching spatial locations with temporal constraints, an average effective astronaut walking speed during an EVA was estimated. Traverses were matched with NAC imagery and a ~2 m/pixel NAC derived DEM. We calculate a mean speed of 0.56±0.39 ms^{-1} for Apollo 12 and 0.81±0.38 ms^{-1} for Apollo 14, in agreement with published biomedical results [16]. Plotting walking speed against inclination results in a weak positive correlation suggesting decreasing speed with steeper uphill gradients. Those results, when applied to traverses (e.g., **Fig. 1**), imply there is sufficient time for roundtrips to the PSR targets within 2 km.

Summary of Model Results: If one is standing on the rim of any of the 522 mapped PSRs and traverses are limited to ≤15° slopes, then 95% of those PSRs are accessible from some location on the rim of their host crater. A total of 67% and 15% of PSRs can be visited from the crater rim with maximum slopes of 10° and 5°, respectively.

Within 2 km of site 001 and nearby location 6, 18 PSRs are accessible. 75 percent of the walking distance from location 6 to each PSR occurs on slopes <5° and can be completed in <2 hours assuming a nonstop walking speed of 0.74 ms^{-1}. That is well within the anticipated EVA duration of 4 hours [17]. PSRs within range of potential landing site 004 generally require less time to access, but the terrain is comparatively steeper.

An atlas was compiled of minimum cost traverses for two traverse types: (i) crater rim to the center of the PSR for all PSRs within the 300 km^2 region of interest, and; (ii) potential landing site to PSRs within 2 km of sites 001 and 004.

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