ILLUMINATION CONDITONS AT THE LUNAR SOUTH POLE FROM HIGH-RESOLUTION LOLA TOPOGRAPHY INCLUDING TOPOGRAPHIC ERRORS.

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Introduction: The altimetric range measurements made by the Lunar Orbiter Laser Altimeter (LOLA) instrument over the past decade have yielded a key dataset for lunar science [1], and helped bring other foundational observations to the same accurate geodetic frame. The LOLA topographic maps of the poles were the first to provide the spatial coverage that allowed accurate studies of the illumination conditions of the poles at fine resolution (<250m) [2,3]. The most advantageous sites from the point of view of solar insolation and Earth line-of-sight visibility were identified [2], and some are now under consideration for the crewed return to the Moon in 2024 [4]. Finer-scale simulations over limited areas were conducted (e.g, [5,6]), but the highest resolutions typically relied on LROC NAC digital elevation models (DEMs) due to coverage and/or sub-10m geolocation errors.

Improved and Updated LOLA maps: Over small areas, the artifacts induced by track position errors can be mitigated with *ad hoc* adjustment methods, such as the iterative discrepancy minimization applied for the Shackleton area in [7]. While simple track position corrections may not apply to long topographic profiles because of the specifics of spacecraft dynamics or instrument pointing, they can be very effective for small regions. Over the four small (20x20km) south pole landing site regions, elevation models as fine as 5 meters/pixel can be derived with effectively no artifact [8]. Moreover, a careful assessment of the error budget for these DEMs was conducted, due to both position knowledge error and to sampling (gaps).

Illumination Conditions: Although the list of most notable sites for high solar input identified in [2] remains valid in simulations performed at higher resolutions, the 'average illumination' metric tends to show reduced values [5]. This is due to the shorter-scale (<250m) roughness of the lunar terrain. Using the improved LOLA maps and our illumination software IllumNG [9], we run simulations for the various sites. Figure 1 shows an example for the Shackleton rim, for both surface level (z=0m) and 10 meters altitude. The rim of extended illumination is very narrow (30-70m for slopes <10°). Over years 2024-2025, the average illumination values reach ~80% at the surface. The longest continuous sunlit periods extend to 125-150 Earth days, and the longest total darkness periods are 4-6 days. At z=10m, the average illumination reaches ~87%, continuous sunlight lasts up to 175 days, and the longest darkness periods are less than 3 days.

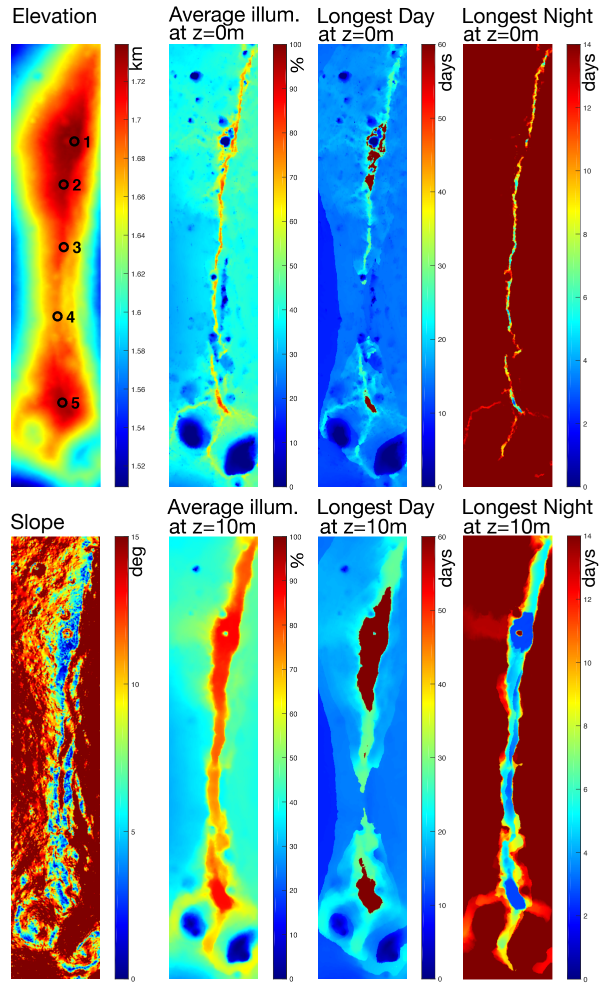

Figure 1 – Maps of a 1x5 km area on the Shackleton rim, in polar stereographic projection at 5 m/px.

Impact of Topographic Uncertainty: We also evaluate the impact of topographic error on illumination conditions. At low resolution (>50 m/px), geolocation and sampling (interpolation) errors are smaller than terrain roughness variation. The LRO position knowledge (<10m horizontally and <1m radially) becomes important at finer resolution (≤20 m/px). The statistical work of [8] to assess the errors on the 5 m/px topographic maps can be directly used here to evaluate their impact on the simulated illumination conditions. In each area, we select the 'best' points, from the point of view of longest day and shortest night, and compute their horizon mask from the nominal topographic map as well as from 30 other 'clones' (where the geolocation of the tracks was perturbed; see [8]). We then evaluate the impact of the topography uncertainty on these illumination metrics. This can be particularly useful for landing site studies, and and inform the need for refining the topographic models from other data (*e.g.*, shape-from-shading from LROC NAC images).

Figure 2 shows preliminary results for high-interest points on the Shackleton rim (indicated on Fig. 1). The angular elevation of the horizon over all azimuths (0-360°) from the 5m/px DEM (1x5 km region padded by 5 km on all sides) are shown as black (nominal DEM) and gray (30 clones that describe the uncertainty range) lines. The blue line shows the horizon due to topography beyond that high-resolution DEM ('far-field'). The actual horizon follows the highest values of the black-blue or grey-blue combinations at each azimuth. The positions of the Sun (between ±2°) are shown as orange dots for a full lunar cycle (~18.6 years). Variations between the DEM models can yield large changes in the computed horizons, particularly in the high-Sun locations which have generally unobscured horizons: a small height change of a nearby track height can more easily become the obstacle in that azimuthal direction. Figure 3 shows the ensembles of average illumination values for the five high-interest points. They can be significantly depressed for several points (sites 1, 3, 5) with some of the clones; other locations (sites 2, 4) are less sensitive to topographic errors, and thus may be attractive to future exploration risk assessment studies.

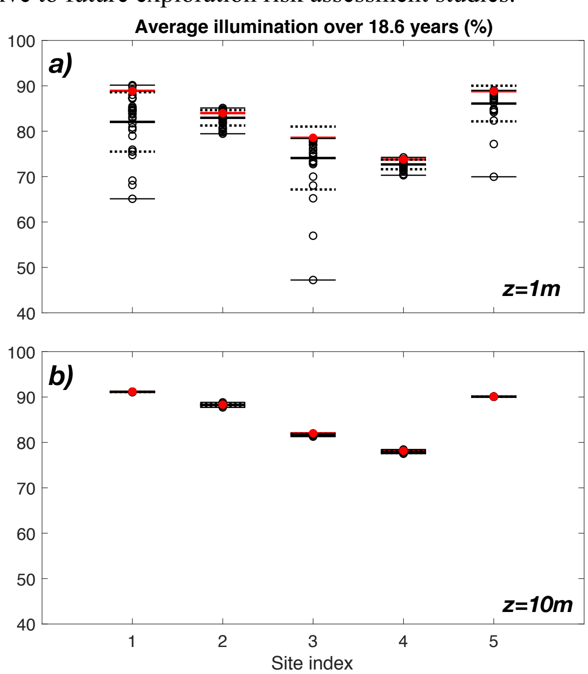

Figure 3 – Statistics of the average illuminaton computed for the five sites indicated on Fig. 1: nominal DEM (red), clones (open black), mean (solid black line). The dotted lines indicate one standard deviation above/below the means.

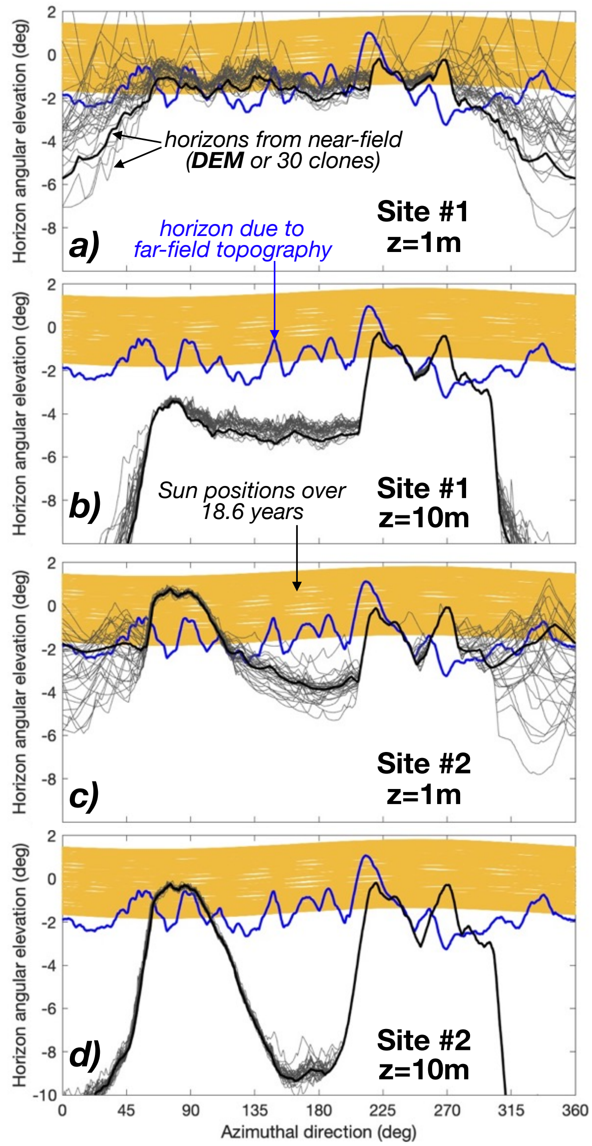

Figure 2 – Sun position over a full lunar cycle (orange dots) and horizons computed from the nominal high-resolution 5 m/px DEM (black), its 30 'clones' (gray), and the far-field topography (blue). These examples are for points #1 (a-b) and #2 (c-d) at z=1m and z=10m.

References: [1] Smith, D. E. et al. (2017) *Icarus*, 283, 70. [2] Mazarico, E. et al. (2011) *Icarus*, 211, 1066. [3] McGovern, J.A. et al. (2013) *Icarus*, 223, 566. [4] Connolly, J. (2019) *LEAG*. [5] Mazarico, E. et al. (2013) *LEAG*, 7041. [6] Glaeser (2018) *P&SS*, 162, 170. [7] Zuber, M.T. et al. (2012), *Nature*, 486, 378. [8] Barker, M.K. et al. (2020), this meeting. [9] Mazarico, E. et al. (2018) *P&SS*, 162, 2.