CHARACTERIZING LANDING SITES AND EXPLORATION ZONES NEAR THE LUNAR SOUTH POLE. A. W. Britton[1], A. M. Jagge[2], and S. R. Deitrick[1], [1]Jacobs Engineering, NASA-JSC 2101 NASA Parkway, Houston, TX, 77058 (andrew.w.britton@nasa.gov, sarah.r.deitrick@nasa.gov), [2]HX5, NASA-JSC, 212 Eglin Pkwy SE, Fort Walton Beach, FL, 32548 (amy.m.jagge@nasa.gov).

Introduction: For more than ten years, a new era of reconnaissance has been carried out in orbit around the Moon, but to date a standard methodology for polar lunar site selection has not been put into place that utilizes this unparalleled dataset. Here we present a top-down science-enabling methodology for characterizing landing sites, solar arrays, and In-Situ Resource Utilization (ISRU) sites at the lunar poles using high-resolution imagery, laser altimetry, numerical radiometer data, and other derived products from NASA's Lunar Reconnaissance Orbiter (LRO). Shackleton Rim is used as an example target area as a proof of concept for our method.

This work can help both phases of NASA's Artemis program as well as precursor missions supported by governmental and commercial organizations alike. To characterize landing sites and exploration zones that meet the requirements for landers and crew mobility, we selected both standard criteria and criteria specific to the lunar poles.

Criteria: Our site characterization methodology defines criteria for illumination, slope, terrain ruggedness index, boulder counts, and finally, proximity to Permanently Shadowed Regions (PSRs).

A minimum solar illumination is crucial for space science, solar power generation, thermal management, and visibility during crewed exploration. Previous work [1,3] has identified illuminated areas with more than 80% of an Earth year. Our procedure chooses this best illumination measure, requiring that polar exploration zones be lit more than 80% for power generation.

To ensure landing modules and habitats do not exceed a tilt of ≥8°, our slope criteria for the respective asset footprints is 5°. Exceeding 8° encumbers launch vectors and pressurized rover to module coupling. The areas between habitats, solar arrays, and ISRU processing sites can have slopes greater than 5°. However, we applied an additional slope benchmark of 20° to ensure traversability between structures.

Terrain Ruggedness Index (TRI) is a measure of elevation variability between a central pixel and its neighboring eight pixels (cells). High values represent rugged terrain whereas low values represent smoother, more level surfaces. The use of TRI can help inform engineering design of structures and vehicles along with site placement and navigation. Numerical values in our TRI map are in meters (as opposed to unitless pixels) and thus enable quick real-world applications. We use a maximum TRI value of 0.2 m for our site selection specification, representing the maximum ruggedness allowed by engineering teams.

Boulders will likely be waypoints during exploration, but large boulders can be hazardous during landing. Thus, it is important to know their abundance and location for safety and accessibility. In order for a site to be considered "safe" for landing, the area must be free of boulders larger than 1 m in diameter.

For the second phase of Artemis, local resources must be utilized to create a sustainable presence on the lunar surface. For maximizing water production and limiting power consumption from excavators and haulers, an ISRU processing site should be less than 10 km from a PSR.

Methodology: Our approach to site characterization begins with points of highest illumination along Shackleton Rim [1,3] (Figure 1.) since lighting will be a critical factor as Artemis plans to go to the lunar south pole. High illumination areas are ideal locations for solar arrays, habitats, and ISRU processing zones, but not necessarily a must for landing/launch sites. Only a small amount of surface area was identified at the lunar south pole with approximately 80% illumination per Earth year [3]. Long duration solar illumination being such a valuable resource, highly illuminated areas need to be reserved for systems that require power or thermal management.

Once areas of highest illumination have been reserved for habitats, solar arrays etc., assessment for landing/launch sites can begin. Due to contaminants from engines and any lunar surface particles agitated by exhaust at ascent/descent sites, habitats on the Moon will be required to be ~1km away. Using Shackleton Rim as an example, we measured a radial distance of ~1km away from the notional habitat site and then identified natural berms to further shield equipment from engine plume ejecta blasts using a site selection analysis workflow in ArcGIS Pro. Following this course of action, we proposed the launch/landing site be located within a saddle on Shackleton Rim.

Calculating slope is a standard exercise for characterizing landing sites, habitat placement, and traverse planning. Using ArcGIS Pro's Slope Raster Function, slope is calculated in degrees with a 2-meter baseline (i.e., changes in slope are calculated at 2-meter intervals) from a Lunar Orbiter Laser Altimeter (LOLA) [5] 5-meter Digital Terrain Model (DTM). The choice of a 2-meter baseline results in a high-resolution slope map. Using coordinates of high illumination, areas around Shackleton Rim are spatially identified and highlighted using a maximum slope of 5°.

After slope is calculated, the next step we implemented was producing a TRI map using GDAL (Geospatial Data Abstraction Library software). Our TRI map is traced from a 4 meter per pixel LRO NAC DTM. During the rendering stage, we applied a simple minimum maximum stretch with endpoints of 0 to 0.2 m combined with a color ramp created with a linear, proportional change in lightness.

The next step in site characterization and assessment is identifying boulder locations and sizes to plan "safe" traverses. NAC imagery has been used to conduct a standard manual boulder count of the western rim of Shackleton Crater.

The presence of PSRs at the poles of the Moon provide both scientific and engineering opportunities. Ices and other materials deposited in these cold traps shielded from solar particles can help tell a story about the early solar system. Volatiles such as water ice can also be utilized for fuel, air, and other consumables. Using PSRs previously mapped [3], we integrated this dataset as a layer for our site assessment and highlighted PSRs proximal to our exploration zone.

Continuing work: Here we demonstrate that this method can be used to assess the feasibility of sites on the Moon for both lunar-bound crewed missions departing Gateway or for future robotic missions. Our method, which includes data collection, boulder counting, and data analysis, will be used for analyzing 3 additional locations at the south pole of the Moon to aid in Artemis mission planning activities. This type of site characterization will be needed for other lunar locations that are accessible by humans and robotic spacecraft. The final products will be published as an online GIS web map interface to allow a more widespread use of the data by various teams for mission planning.

References: [1] Gläser, P., et al. (2018) *PSS* 162: 170-178. [2] Humm, D. C., et al. (2016) *SSR* 200.1-4: 431-473. [3] Mazarico, E., et al. (2011) *Icarus* 211.2: 1066-1081. [4] Robinson, M. S., et al. (2010) *SSR* 150. 1-4: 81-124. [5] Smith, David E., et al. (2010) *SSR* 150.1-4: 209-241. [6] Speyerer, E. J., and M. S. Robinson. (2013) *Icarus* 222.1: 122-136.

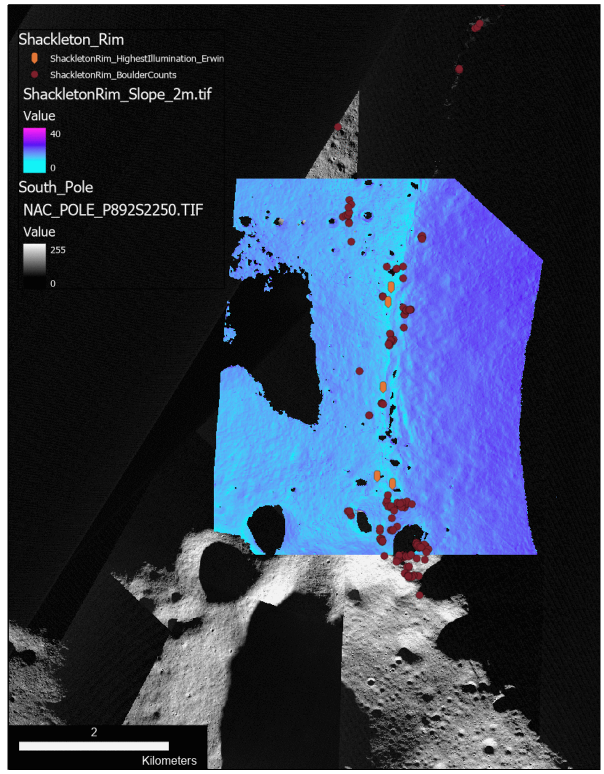

Figure 1: Map with highest illumination points and boulder count points as vectors overlaid on Shackleton Rim slope map. NAC mosaic serves as basemap.