SCATTERED ILLUMINATION MODELING FOR SHADOWCAM. Erwan Mazarico¹, Stefano Bertone², Prasun Mahanti³, Emerson J. Speyerer³, Robert V. Wagner³, Brett W. Denevi⁴, Shuai Li⁵, Mark S. Robinson⁶; ¹NASA Goddard Space Flight Center (erwan.m.mazarico@nasa.gov), ²University of Maryland College Park, ³Arizona State University, ⁴Johns Hopkins University Applied Physics Laboratory, ⁵University of Hawaii (hawaiian)

Introduction: ShadowCam is a NASA instrument onboard the Korea Pathfinder Lunar Orbiter (KPLO, aka Danuri) designed to image the lunar permanently shadowed regions (PSRs) with high spatial resolution (< 2 m) and signal-to-noise ratio (SNR > 100) [1]. Since January 2023, ShadowCam has been collecting more than 25,000 images of the lunar surface, primarily in the lunar polar regions, but also at lower latitudes to image non-polar PSRs [2] and ‘PSR analogs’, equatorial craters imaged near sunrise or sunset to reproduce the grazing solar incidence geometry at the poles [3,4]. The interpretation of these images (e.g., the morphological differences with non-PSR terrain and possible albedo contrasts indicative of surface volatiles) is more challenging than typical sunlit LROC Narrow-Angle Camera (NAC) images, and can benefit from the support of modeling simulations to distinguish the effects of lighting geometry (including surface terrain slopes) from those of intrinsic surface properties. We present part of that team effort; see also [4,5].

Scattered Illumination Conditions: ShadowCam imaging relies on the light scattered off nearby sunlit areas into shadows to illuminate the scene. The much lower received radiance values are compensated by the use of a time-delayed integration (TDI) sensor. However, rather than a single small light source (the Sun) illuminating the scene in daytime LROC NAC images, the scattered light illumination sources consist of extended sunlit areas (e.g., crater walls), which result in more diffuse lighting and shadows. The radiance received when observing a shadowed surface location is the sum of the contributions from all the sunlit elements in its viewshed. Instead of a single set of incidence, emission, and phase angles, the second light bounce at that shadowed point has a broad distribution of these photometric angles [3-6]. (Figure 1). These angles are extremely variable depending on location and time, and intuition for interpretation can easily fail, as the effect of topography can be enhanced and that of surface properties muted.

Illumination Modeling: To support the interpretation and analysis of ShadowCam images, simulated images can be helpful products, particularly to enable the quantitative evaluation of radiance or photometric anomalies. General-purpose illumination models can be used to simulate images, such as IllumNG [7] (Figure 2). However they are not typically optimized for scattered light, and thus computationally expensive (O(N²) where N is the number of surface elements).

Figure 1. Typical distribution of the second-bounce phase angle in selected PSRs, which can be long-tailed. Fast radiosity methods are currently being explored to hierarchically compress the large view factor matrix and enable efficient thermal modeling with a large number of elements [8,9], but are still currently limited in scope.

We developed an alternative methodology for scattered light simulation, specifically adapted for simulating surface images at a given time, rather than for long simulations (large number of time steps, usually benefiting from pre-computing geometry; e.g., [10]). The main concept is to use the full-resolution shape model (large N) for all the photometric computations, but grouping full-resolution elements into coarser and coarser groups as their distance increases. This is done, separately, for both the first surface bounce (photometry evaluated on, e.g., the sunlit crater wall) and for the second surface bounce (the shadowed terrain). This reduces the number of ray interactions to consider from O(N²) to O(2N), with further gains by ignoring shadowed elements entirely from the list of first-bounce elements to consider.

Figure 2. Simulated LROC NAC footprints, with the modeled contributions of direct sunlight (left) and scattered light (right) using IllumNG [6].
Topography Models: For ShadowCam image simulations, we use the recent LOLA shape models of the lunar poles produced at 20 m/pixel from bundle-adjusted and cleaned LOLA profiles [11,12]. These are significantly improved compared to those previously distributed on PDS, with reduced streaky artifacts (Figure 3), which can be particularly problematic for lighting and thermal modeling. The effective resolution of the LOLA polar dataset is lower (i.e., a fraction of 20m pixels does not contain LOLA shots), with median values of ~30m and ~40m at 86°S and 80°S, and ~40m and ~90m at 86°N and 80°N. Given that scattered light simulations are very challenging at 20m/pixel, the resolution of our ShadowCam simulations is typically around 40–60m.

Results: We simulated various LROC NAC and ShadowCam images with our new multi-decimation scattering light simulation model. Figure 4 shows part of the Wiechert E crater floor in the south polar region modeled at two different times. We can also perform multiple simulations of the same region and date, but with different assumed photometric functions; by varying photometric function parameters, in order to evaluate the sensitivity of the observed radiance to those (Figure 5), ultimately allowing for their estimation.

Conclusion: We will present our scattering illumination modeling strategy and its application to ShadowCam images by showing a range of illumination conditions, particularly secondary phase angle.


Figure 3. Comparison of older and updated LOLA DEMs for an area on the Peary Crater floor (88.6° N, 358.6° E) [12].

Figure 4. Simulated scattered light on the Wiechert E crater floor at two different times corresponding to LROC NAC long-exposure images.

Figure 5. Sensitivity (partial derivative) of the simulated scattered radiance with respect to parameter A3 of Boyd et al. (2017) [13].