CHARACTERIZING THE OPTICAL SHADOWING AT THE MOON USING LOLA TOPOGRAPHIC DATA: PREDICTIONS FOR THE LCROSS IMPACT.
T. J. Stubbs [1,2], Y. Wang [1,2], E. Mazarico [2,3], G. A. Neumann [2], D. E. Smith [4], M. T. Zuber [4], and M. H. Torrence [2,5]; [1] Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, MD 21228; [2] NASA Goddard Space Flight Center, Greenbelt, MD 20771; [3] Oak Ridge Associated Universities, NASA Postdoctoral Program; [4] Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139; [5] Stinger Ghaffarian Technologies, Greenbelt, MD 20770. Correspondance to: Timothy.J.Stubbs@nasa.gov

Introduction: Solar illumination is an important factor for determining the conditions at planetary surfaces. This is especially true for airless bodies in the solar system, such as the Moon, which do not have atmospheres as a means of transferring heat between regions on the surface, or for protecting the surface from the full extent of the solar spectrum (including UV and X-rays). The lunar regolith is a good insulator [1], so heat and electric current conduct very slowly between regions in sunlight and shadow, which results in relatively abrupt changes at shadow boundaries. Variations in surface temperature results in the transport and deposition of volatiles [2]. The direct exposure of the regolith to solar UV and X-rays causes surface charging (photoelectric effect), chemical activation, space weathering, the generation of exospheric species (photon-stimulated desorption), and maybe the electrostatic transport of dust [e.g., 1,3].

Solar illumination of the lunar surface is complicated by topography over a wide range of spatial scales – from impact basins and mountain ranges to craters and boulders – which means that a highly accurate digital elevation model (DEM) is required in order to develop a reliable predictive capability. We also need to know the location of the Sun relative to each point-of-interest on the surface.

We have developed an optical shadowing model for the Moon, which we use here with a DEM of the southern lunar polar region produced from Lunar Orbiter Laser Altimeter (LOLA) data [4]. As a test case, we present shadowing predictions for the time at which the Lunar Crater Observation and Sensing Satellite (LCROSS) impacted into Cabeus crater, a permanently shadowed region (PSR) near the south pole [5].

The Orbit and Spin of the Moon: The Moon is in a near-circular orbit about the Earth (eccentricity = 0.055), and, relative to the ecliptic plane, its orbital inclination is 5.15° and its axial tilt is 1.54°. This small axial tilt means that, on average, the lunar poles receive very little sunlight – this can result in some topographic depressions (e.g., craters) becoming PSRs [6,7,8]. Some topographic peaks may also be regions of near-permanent illumination [7,8]. The Moon is in synchronous rotation about the Earth, so it takes an orbital period (≈27.3 days) to complete one spin. Since the Moon's spin rate is so slow (1.5×10^{-4} ° s^{-1}), variations in surface shadowing occur over relatively long timescales (~hours). The Moon's orbit is futher complicated by the fact that its longitude of the ascending node regresses by one revolution every 18.6 years, and its argument of perigee progresses by one revolution every 8.85 years.

LOLA instrument and DEM: LOLA is an instrument aboard the Lunar Reconnaissance Orbiter (LRO), which is in a circular polar orbit at an altitude of 50 km [4]. LOLA is a pulse detection time-of-flight laser altimeter with a 5-spot pattern that both directly measures surface slope and increases the along track resolution. The pulse rate is 28 Hz, and the spots on the surface are spaced 10–12 m apart over a 50–60 m swath. LOLA's objectives are to produce a global DEM, with a nominal accuracy of ~50 m on the surface and 1 m in elevation, and characterize illumination at the poles [4,7].

The LOLA DEM that we use here has a resolution of 1/128° (≈240 m) in latitude and 1/4° (≈660 m at 85° latitude) in longitude. It is in Mean Earth (ME) coordinates (IAU Moon 2000) and heights are given relative to a reference radius of 1737.4 km. We use the SPICE Toolkit for the Sun location and related parameters.

Optical Shadowing Model: For any given time and location on the lunar surface, we are able to calculate the following optical shadowing parameters: (1) the fraction of the solar disk visible from the surface, which accounts for both the angular extent of the solar disk and horizon slope; (2) the solar incidence angle; (3) the normalized incident solar flux; (4) the radial distance to the sunlight/shadow boundary; (5) the closest distance to the sunlight/shadow boundary; and (6) the angular distance to the shadow obstacle. In these calculations, the shadow boundary is defined as the point just below which any part of the solar disk is visible. Example maps are shown in the figure for some these parameters at the time of the LCROSS impact (indicated by the black cross).

Comparisons with an optical shadowing code using the "horizon method" [7], as well as images acquired by the LRO Camera (LROC), indicate that our shadowing code is very accurate. The main limitation is the accuracy and resolution of the DEM.

Predictions for the LCROSS Impact: On 9 October 2009 at 11:31:19 UT, the LCROSS Centaur upper stage impact occurred at latitude 84.675°S and longitude 48.719°W [9]. Using linear interpolation, we estimate this was at a height of −3.83 km. For this location in shadow, our model predicts:

- Radial distance to shadow boundary = 839 m,
- Closest distance to shadow boundary = 833 m,
- Angular distance to source of shadow = 0.371°.

The first two parameters indicate how far ejecta from the Centaur impact had to travel before it was exposed to sunlight. As the impact location is at high latitudes, these two distances to the shadow boundary are very similar; however, for locations at lower latitudes on the nightside, the values can differ significantly.

By adapting this technique, we can also calculate these parameters for "Earthshine shadowing", which indicates how far ejecta must travel before it is visible from the Earth – this is relevant for the many Earth-based observations of the LCROSS impact plume. As viewed from the Earth, the impact site was hidden by the northern edge of Cabeus crater. For an observer at the center of the Earth, our model predicts:

- Radial distance to visibility boundary = 1785 m,
- Closest distance to visibility boundary = 1770 m,
- Distance to visibility obstacle = 43.20 km.

Summary: We have developed a highly versatile and accurate shadowing code that can be adapted to help address many important questions about the lunar environment.

References: [1] Heiken et al. (1991) *Lunar Source Book*. [2] Vondrak and Crider (2003) *Am. Sci.*, 91. [3] Colwell et al. (2007) *Rev. Geophys.* [4] Chin et al. (2007) *Space Sci. Rev.* [5] Ennico et al. (2009) *LPSC 40*, 1878. [6] Bussey et al. (1999) *GRL*. [7] Mazarico et al. (2010), *LPSC 41*. [8] Noda et al. (2008) *GRL*. [9] Marshall, W., *personal comm*.