ILLUMINATION SIMULATIONS IN SUPPORT OF LUNAR SURFACE OPERATIONS. D. B. J. Bussey (ben.bussey@jhuapl.edu)[1], J. A. McGovern[1], A. M. Stickle, and P. D. Spudis[2] [1]Applied Physics Laboratory, Laurel MD, [2]Lunar and Planetary Institute, Houston TX.

Introduction: The recent armada of international missions to the Moon has acquired high quality of topography data of the entire lunar surface [1,2]. These data are of sufficient fidelity that we can simulate the illumination conditions for any desired Sun location with a high degree of confidence in the result (Figure 1) [3]. This permits the production of very detailed simulations that show the surface illumination conditions during the entire duration of a lander or rover mission. These results are useful in planning mission operations, and are also beneficial in system design, e.g. the mass of required batteries to survive the lunar night.

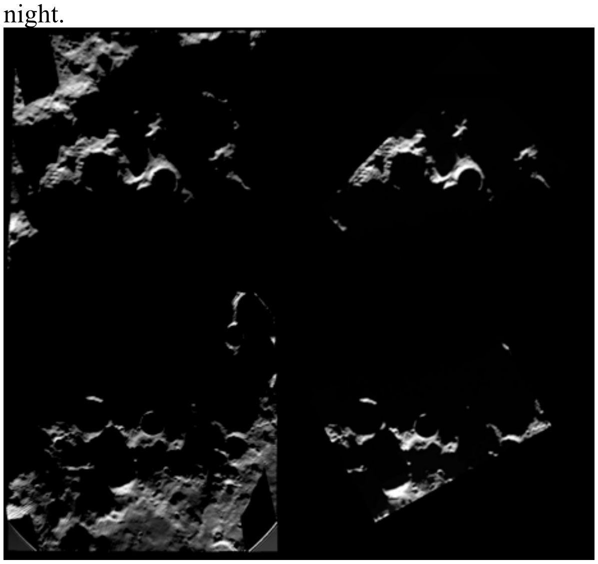

Figure 1. Comparison between two Kaguya-derived simulations (left) and actual Clementine images (right) of the region near Shackleton crater. Earth is towards the top of the images. The Sun direction for the top images is 15°W and for the bottom images is 167°E. The Kaguya DEM can be used to accurately predict the illumination conditions. From [3].

While images provide definitive information on the surface illumination conditions, and may provide details at spatial resolutions higher than possible with simulation capabilities (although this is becoming less of an issue as computing power increases) simulations offer some useful additional information. A key piece of information returned by simulated images is that images can be produced using the exact Sun position that will be experienced during surface operations. Another is that simulations permit the investigation of the benefit of placing solar arrays on a mast.

LunarShader: As part of our polar-focused NLSI team's effort we have developed a software tool, called LunarShader, that can precisely simulate lunar illumination conditions. Each simulation is run with a fixed Sun position and a gridded topographic image file. The output of the simulation is another gridded image file, with the same dimensions as the input file, containing percentage of Sun visible to each pixel. The Sun location can either be defined by sub-solar latitude and longitude, or by choosing a date and time. A set of simulations is run covering a period of time (e.g. the year 2018) with a constant time difference between each simulated time, usually 1 – 6 hours depending on what information is required. Producing data to support rover traverse planning will likely use a shorter time period between simulations compared say to producing data to characterize the illumination conditions of a large region.

Data Analysis: Analysis of the results from LunarShader is used to derive several parameters of interest when planning either a lunar lander or rover mission. Examples of such parameters include:-

1. Longest single period of continuous illumination
2. Longest single period of constant shadow
3. Mean amount of illumination
4. Areas receiving no illumination (permanently shadowed)
5. Earth-visibility maps

Each of these parameters are useful for different types of mission…

1. Regions which have the longest single period of constant illumination, centered on mid-summer, are of interest for lander missions that want as long a duration as possible but are not designed to survive a lunar night. Analyses of the polar regions have revealed that locations exist that are continuously illuminated for several months [3].

2. For extremely long surface missions, i.e. multiple years, a key parameter is the longest single period of constant shadow. This can determine the battery mass that is required to provide enough energy to heat key components. If the lander can survive the longest shadow it should be able to survive the whole year, so long as there is enough time to recharge once the longest shadow period ends before the next period begins.

3. The mean amount of illumination simply shows the percentage of time that a point on the surface is illuminated. We have known for sometime that places exist that are illuminated for over 70% of the time during a winter day and 100% of a summer day [1,2,5,6]. Often this type of study is undertaken to identify which locations to do detailed illumination studioes on, e.g. Figure 2.

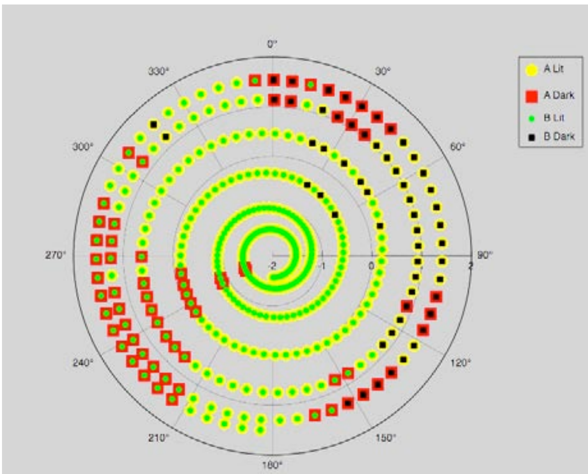

Figure 2. Detailed illumination profiles for two areas near Shackleton crater.

4. Areas that receive no illumination, i.e. are permanently shadowed are known to be extremely cold [7] and can harbor volatile deposits. Analysis of LOLA topography revealed that permanent shadow can exist at latitudes as low as 58° [4].

5. LunarShader can also determine whether a location can see the Earth at a particular time. This is key information for either a lander or rover that will use Direct To Earth (DTE) communications rather than a relay communication satellite (Figure 3).

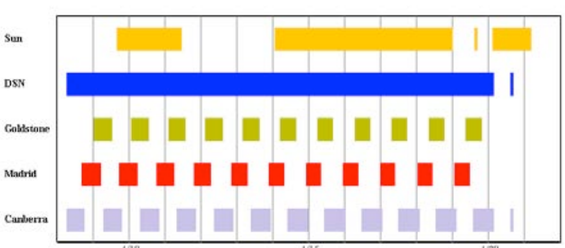

Figure 3. Example of a typical illumination and communication analysis for a two week period for a chosen location. The yellow bar shows when the location is lit. The green, red and purple brs show the visibilities of the three DSN stations.

Summary: We have been using the results of our LunarShader software to derive parameters in support of several mission planning activities. This included ESA's Lunar Lander effort and we are currently part of NASA's Resource Prospector Mission team, looking at the best locations in the lunar poles for the proposed rover mission (Figure 4).

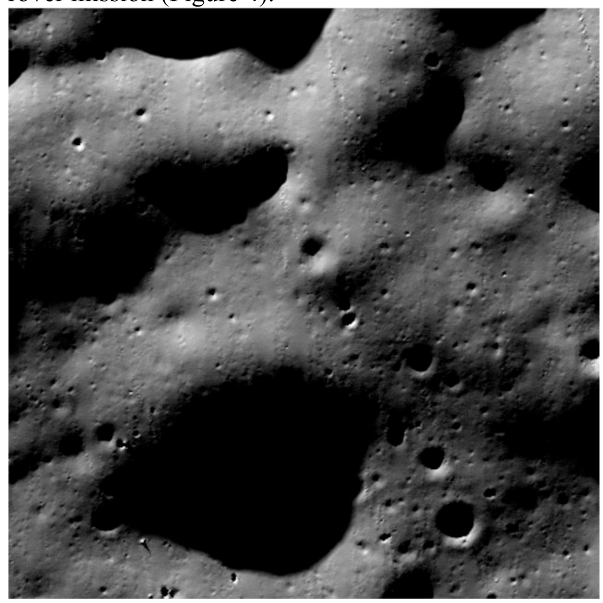

Figure 4. Example of a simulated image made usng a 20 meter scale DEM. The abilty to predict exact shadow locations is useful for rover traverse planning.

References: [1] Noda H. et. al. (2008) *GRL* 35. [2] Mazarico e. et al. (2010) *Icarus 211*, 1066-1081. [3] Bussey D.B.J. et al. (2010) *Icarus 208*, 558-564. [4] McGovern 2013., [5] Bussey D.B.K. et al. (1999) *GRL 26*, 1187-1190. [6] Bussey D.B.J. et al. (2001) *Nature 434*, 842. [7] Paige D. et al. (2010) *Science 330*, 479-482.