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A Global Catalogue of Lunar Permanently Shadowed Regions

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Abstract

The lunar polar regions experience unusual illumination conditions that make them attractive candidate sites for future exploration. The small angle between the Moon's spin axis and the ecliptic plane result in locations that are permanently shadowed as well as some that are nearly continuously illuminated. Using an illumination-simulation tool, together with the latest data sets from the Kaguya and Lunar Reconnaissance Orbiter (LROC), we have mapped all permanently shadowed regions on the Moon larger than 0.04 km^2. We have discovered that permanent shadows exist as far from the pole as +/-58^{o} of latitude. We have begun analysis of these areas to see if they are capable of harboring volatile deposits. The existence of ice deposits at long distances from the poles would represent an exciting resource for future surface missions.

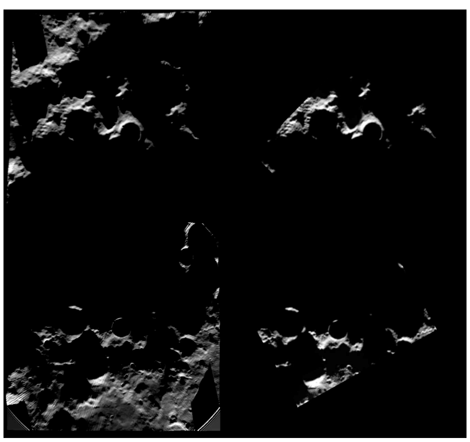

Figure 1. Comparison between two Kaguya-derived simulations and actual Clementine images of the region near Shackleton crater. Earth is towards the top of the images. The Sun direction for the top images is 15°W and for the bottom images is 167°E.

1. Methodology

We have produced 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. We ran multiple simulations using solar positions that correspond to a Clementine UVVIS image. An example using Kaguya topography data is shown in Figure 1. We find that we can predict illumination conditions with a high degree of confidence.

2. Polar Lighting

We have conducted a comprehensive characterization of the illumination conditions in the Moon's polar regions. By considering a full year we are able to determine which locations receive the most sunlight as well as map out permanently shadowed regions that never see the Sun. This includes producing quantitative illumination maps that show the

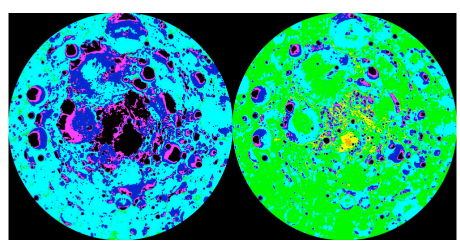

Figure 2. Quantitative north-pole illumination maps for summer (right) and winter (left).

percentage of time that a location receives sunlight during the year (Figure 2).

We discovered that locations exist near both poles that are continuously illuminated for several months based around midsummer [1]. These areas potentially represent ideal landing sites for future robotic and human missions. For these areas we produce detailed illumination profiles that show the number and duration of all shadowed periods. Some areas have a maximum period of shadow that is less than 14 days during lunar winter.

As part of our illumination study we have investigated the use of mast heights. For a given location we consider the effect of placing solar panels on different modest-sized mast heights. We found that even a mast of height of 2 to 3 meters can improve the amount of illumination that is observed. Additionally the location of the "best" pixel (e.g. the one that receives the longest continuously illuminated period) changes with different mast heights.

3. Non-Polar Shadows

The goal of this portion of our study was to map the locations of ALL permanently shadowed regions on the lunar surface using the best available data, with a specific goal of locating those that exist at the furthest distance from the poles. To do this we made use of the excellent extensive new topography data that has become available thanks to both the LOLA and LROC instruments on NASA's Lunar Reconnaissance Orbiter. To find the permanent shadows we simulate the Sun location at 1440 longitudes ($1/4^{o}$ increments) and at the highest sub-solar latitude (closest to the pole we are studying) that the Sun ever reaches.

We found that permanent shadow can exist at latitudes as low as 58°. In fact approximately 50 permanently shadowed regions exist in the 58°-65° latitude range for both lunar hemispheres. Figure 3 shows the locations of shadowed areas between 58°N to 65°N.

Conclusions

Through the combination of a high-fidelity simulation tool and the existence of high-quality topography data we are now able to study the illumination conditions of the Moon in

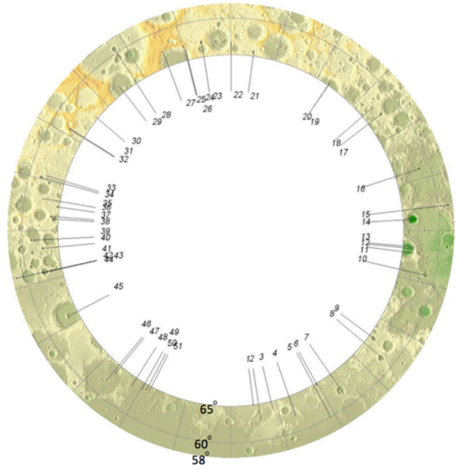

Figure 3. Shaded relief image covering from 58°N to 65°N. Areas of permanent shadow are numbered.

unprecedented detail. This includes discovering which regions near both poles receive illumination that is most favorable for different types of surface operations. It also has permitted the production of a global catalogue of permanently shadowed regions.

References

[1] Bussey D. B. J., Illumination Conditions of the South Pole of the Moon Derived Using Kaguya Topography, Icarus, 2010.