COMMUNICATION AND ILLUMINATION CONDITIONS AT INA D: AN INFORMATION FUSION APPROACH FOR LUNAR EXPLORATION PLANNING.

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Introduction: Knowledge of line-of-sight and local solar illumination conditions (LoSSIC) drive science and exploration mission planning for lunar surface operations. Accurate knowledge of LoSSIC (derived from high resolution digital terrain models, or DTMs) greatly enhances communication and traverse planning. The use of viewsheds and solar illumination maps for selecting potential lunar landing sites can be found in earlier work [**1,2**]. However, lunar LoSSIC map products or tools for generating combined LoSSIC knowledge maps were not widely available since DTMs for LoSSIC evaluation have existed only recently at a scale relevant to surface landers and rovers. New high-resolution (2-m postings) Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) based DTMs [**3**] are now available for key sites on the Moon.

In this work a LoSSIC analysis is presented for the feature known as Ina D (18.634°N, 5.308°E); an enigmatic depression exhibiting both smooth mounds surrounded by a relatively rough floor [**4**], and is likely volcanic in origin is one of the youngest endogenic forms on the Moon [**5,6**]. Since Ina D is a high priority central nearside science target we choose it to demonstrate the utility of LoSSIC analysis for mission planning.

Methods: We first generated three basic (level 1) LoSSIC components from the NAC DTM and positional knowledge of the Earth, the Sun and the Moon in a fixed reference frame. All three components have a pixel sampling of 5 m.

The first component is the viewshed, a location (geographic/cell/pixel) specific visible area from one asset to another (traced out by scanning the LOS). The second LoSSIC component is an Earth visibility map that represents LoS availability between each surface location and Earth at a particular time (indicating the feasibility of direct-to-Earth (DTE) communication). The third LoSSIC component is a time dependent solar illumination map for the site (indicating the availability of solar power). In this study solar illumination maps and Earth visibility maps were generated over an analysis period of ~ 29.53 days sampled at 15 minute intervals. The basic LoSSIC components are stacked and then used to make the level 2 map products which represent information accumulated over time or possibilities (position of observer in case of viewsheds). In the case of viewsheds, the information accumulated over multiple observer positions is obtained by merging all

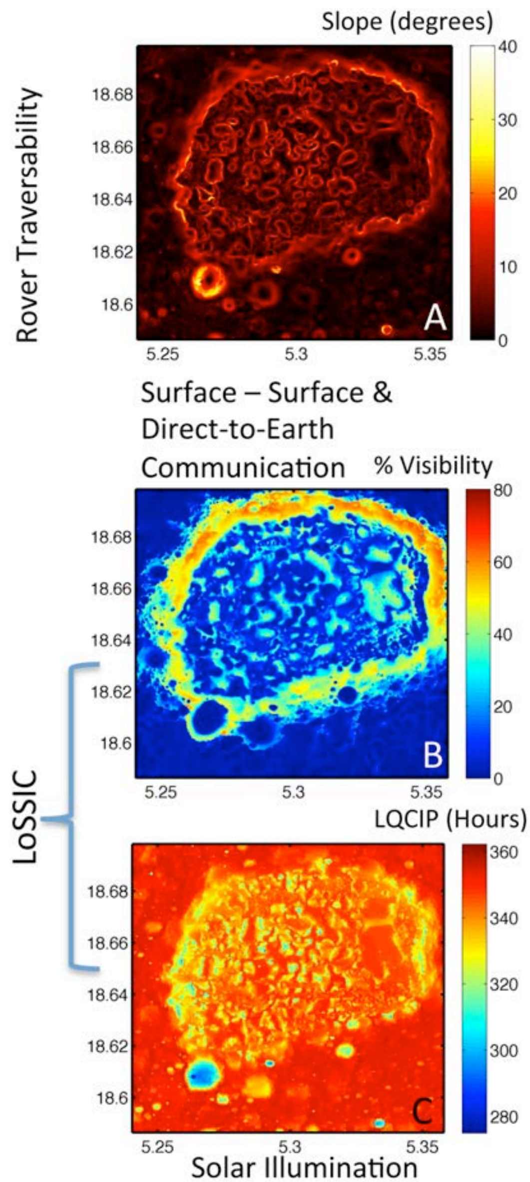

Figure 1: (A) Slope map for estimating rover traversability conditions. (B) Visibility index map for Ina D showing what percentage (area) of the entire site is visible from a location. (C) Continuous solar illumination availability in hours.

possible viewsheds to form a visibility index map (**Fig. 1B**). For Earth visibility, the probability of the Earth being visible for the entire analysis period is evaluated. For the Ina D site every location always visible from Earth (a nearside exploration was assumed to minimize complexity). Information is accumulated from the stack of illumination maps by computing at each location the duration of the longest quasi-continuous illumination period (LQCIP [**1**]) (**Fig. 1C**) and also the probability of a continuous illumination for an hour. In addition to LoSSIC, surface slope (15 m baseline) was generated (**Fig. 1A**) from the DTM for use as a roughness parameter indicating rover traversability conditions. The LoSSIC information aggregates and the rover traversability information were combined in an information fusion framework. Fusion methods can be a simple weighted average (used for this example) or Bayesian networks which would take into account the uncertainty present at each location.

Discussion: The aspect of resolution is vital if viewsheds, illumination maps and other similar products are used for predictive analysis in the planning phase for a lunar mission. At lower resolutions, uncertainty magnitudes related to LoS computations are higher [**7**] making their use inefficient and possibly misleading. Changes in illumination with time (direction and magnitude) can be used to define the required velocity of a rover for a traverse segment and can also affect the traverse path selection (to maintain a particular speed between waypoints under specific illumination conditions). However, effectiveness of such computations improves as the map sample spacing approaches the physical dimensions of a rover (2 m or smaller). Moreover minimum elevation uncertainty is also important (NAC DTM products at 5 m/pixel have an elevation uncertainty less than 0.5 m).

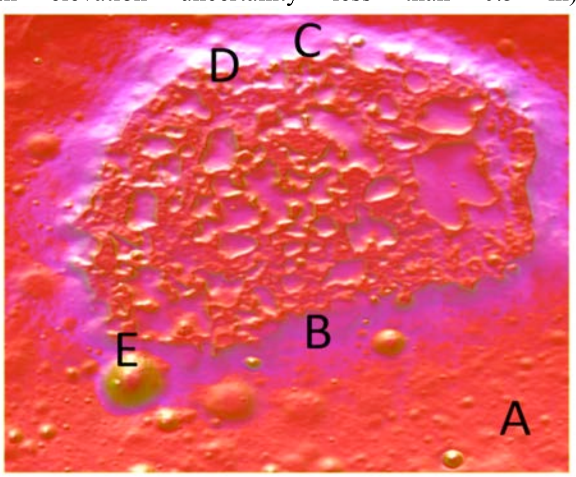

Figure 2: LoSSIC and traversability for Ina D; colors are formed as Solar illumination availability (R,) Slope (G) and Percent visibility (B).

Structured information accumulation improves efficiency during the exploration planning process and this is the focus of this work. While viewsheds are useful by themselves, N^2 viewsheds are possible for a DTM raster of side N cells making individual viewshed assessment inefficient while evaluating the condition for the entire site. Visibility indices enable a hierarchical scheme for statistically assessing the feasibility of a location for surface communication purposes. Higher values indicate better locations for setting up antennas. For Ina D, a region of high visibility in the north (**Fig. 1B**) also indicates an efficient traverse route for scouting. The associated local slopes are less than 25°. The Earth visibility map was not analyzed separately for Ina D because at every location on the visibility index map a DTE link exists.

The spatio-temporally accumulated LoSSIC information can be used directly for making decisions during the planning phase and in defining the mission conops. Visualization based methods are a powerful tool for reducing multiple layers of information to a sensible map. In this work, LoSSIC and slope information are displayed together (**Fig. 2**) by using a pseudo RGB colormap (R-solar illumination availability, G-slope, B-percent visibility index). The resulting colors display the conditions of all the variables aid decision making (**Table 1**) in an easily interpretable form.

Table 1: Color based exploration planning

Region	Color explanation from component state	Remarks
A	High solar illumination, Low slope, low visibility index	Landing/ touchdown location
B	High solar illumination, Low slope, high visibility index	Waypoint to the interior caldera
C	High solar illumination, low slope, high visibility index	Scouting without risk
D	High solar illumination, high slope, high visibility index	Scouting with risk
E	High solar illumination, High slope, low visibility index	Illuminated crater

Conclusion: High quality LoSSIC information integrated over time and spatial extents simplify future lunar exploration planning. An example of Ina-D was chosen in this work to illustrate the proposed method of extracting information for 3 key pertinent variables (LoS between surface assets, LoS between a surface asset and Earth, and solar illumination availability). Regions near the poles have more complicated Earth viewing and solar illumination conditions that are easily delimited and integrated with LoSSIC products for cognizant mission planning.

References: [**1**] Diego De Rosa et al., Planetary & Space Sci.,74(1), 224-246 (2012) [**2**] Mahanti et al. *Proc.* Annual Meeting of the Lunar Exploration Analysis Group *No. 1748* (7014). [**3**] Tran, T., et al. *Proc. ASPRS/CaGIS Fall Specialty Conference*. (2010). [**4**] Strain, P. L. and El-Baz, F. *Proc. Lunar Sci. Conf.* 11, 2437–2446 (1980). [**5**] Braden et al., *Nat. Geo*., in review. [**6**] Schultz et al.. *Nature* 444, 184-186 (2006). [**7**] Mahanti et al. *Proc. Lunar Sci. Conf. 44*, 1739 (2013).