LANDING SITE ANALYSIS FOR FUTURE LUNAR POLAR EXPLORATION MISSIONS

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Introduction Recently, the lunar polar region has received attention as one of the most attractive exploration targets because remotely sensed observations reveal that valuable resources are likely to exist in the lunar polar region. Due to the long-duration of preferable illumination and volatiles captured in the cold trap, the polar region will be useful for future crewed space exploration missions in the deep space.

However, there still remain many questions about volatiles. In order to investigate these resources, some agencies, such as NASA and ESA currently plan landing missions around the poles of the Moon. JAXA is also considering a Moon polar exploration mission to investigate lunar resources and to study their potential usage. In such a landing mission, we must select a landing site with the possible existence of water ice [1], desirable sunlight, communication with the Earth, slope, and hazards. Landing site selection is critical for mission accomplishment in the polar region, so a great deal of previous work has analyzed various conditions using remote-sensing data on the Moon polar region [2, 3, and 4].

In this paper, we present detailed analysis results for one of the candidates, "de gerlache rim" (*GR1),* by simulating the sunshine, communication with the Earth, and slope conditions. In this analysis, we used Digital Elevation Models (DEMs) created from the observation data of Lunar Orbiter Laser Altimeter (LOLA) of LRO and the Terrain Camera (TC) of SELENE. We also present the landing date for landing on *GR1*. Based on the landing orbit, the landing date should be determined such that the spacecraft can take images of bright regions for localizing and navigating itself. In addition, we search for a start date of the period in which we can expect the long-duration illumination and the preferable communication conditions with the Earth.

Landing Site Analysis In order to select landing sites for the mission, we simulated the conditions mentioned above using the LOLA DEM with a grid resolution of 40 m and the orbit of the Sun relative to the Moon from the SPICE kernels. Figure 1 presents the candidate landing site that we chose as a result of the analyzing sunshine, communication, and slope conditions. The resulting candidates satisfy the following restrictions. 1) The number of sunshine days exceeds 100 in two years. 2) The ratio in which Earth-Moon communication can be conducted exceeds 25%. The sunshine and communication simulations' duration is two years, from April 1, 2022 to May 31, 2024. 3) The slope angle is less than 10 degrees. Here, a sunshine and communication threshold is defined as 50% of the sun disk at 1 m altitude. (For the definition of the sun disk, see [5].)

As an example, we present the simulation result for *GR1* using a DEM with a grid resolution of 2 m. Figure 2 presents the simulations for a 1km square region of *GR1*. Using these analysis results, we decide the way points for the exploration such as the Permanently Shadowed Region (PSR), which is one of the interesting regions.

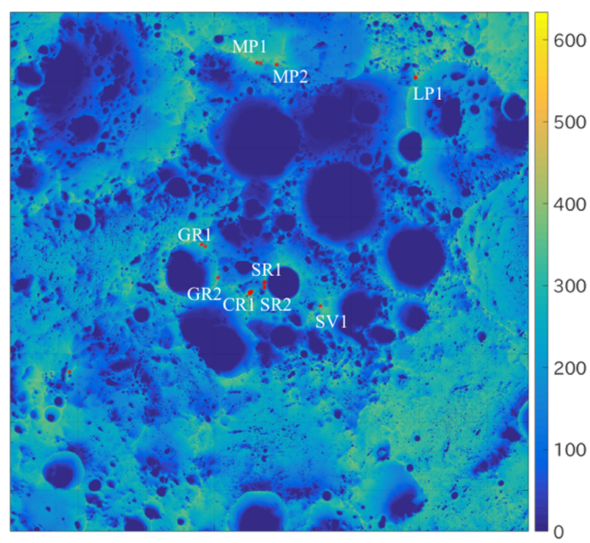

Figure 1. Sunshine analysis result. Red points are candidates of the south region above 85 degrees. The color bar shows the number of sunshine days in two years (Apr. 1, 2022 to Mar. 31, 2024).

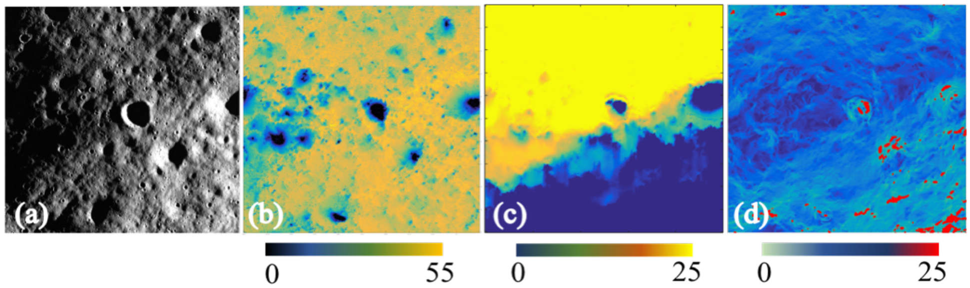

Figure 2 These images represent a 1km square region which is the vicinity of GR1 (88.6952S 68.2846W). (a) Orthorectified LROC Narrow Angle Camera (NAC) image (M143000050). (b) Sunshine ratio [%]. The black region indicates the Permanently Shadowed Region (PSR), which has no sunshine for 20 years in the simulation. (c) Communication ratio with the Earth [%]. (d) Slope condition [deg]. Red indicates the region with more than 25 degrees slope angle.

Landing Date Determination: After choosing landing sites, we determined the appropriate landing date for the selected landing sites from two perspectives. First perspective is associated with the landing sites (i.e., *GR1*). We simulated the illumination and communication conditions on *GR1* and searched for candidate start dates of the period which has favorable illumination and communication as shown in Figure 3. Secondly, we have to consider the sequence of image navigation. During the landing sequence, the spacecraft will take three images of the lunar surface on the navigation points. Therefore, these images have to include a bright region because the spacecraft has to detect features for localization and navigation. We present an example of November 8, 2022 (Figure 4). Note that November 8, 2022 is chosen from the second perspective even though November 7, 2022 is the most preferable starting date from the first perspective.

Conclusions: This paper presents the analysis results as for the landing site selection using previous remote-sensing data. After the landing site is determined, we simulated the illumination, communication, slope, and visibility of the region. In addition, we searched for a landing date by combining two analyses: illumination and communication analysis for *GR1* and simulation of the image navigation. We will simulate these conditions for other candidate landing sites and plan the exploration trajectory.

References: [1] Sanin, A. B., et al. (2017) *Icarus,* 283, 20-30. [2] Heldmann, Jennifer L., et al. (2016) *Acta Astronautica*, 127, 308-320. [3] Ivanov, M. A., et al. (2015) *Planetary and Space Science,* 117, 45-63. [4] De Rosa, Diego, et al. (2012) *Planetary and Space Science,* 74.1, 224-246. [5] Mazarico, E., et al. (2011) *Icarus,* 211.2, 1066-1081.

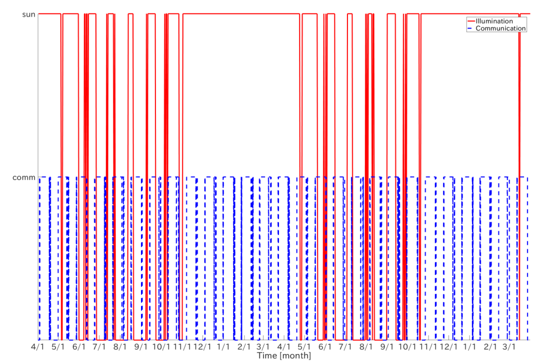

Figure 3 Illumination and communication conditions of *GR1* for Apr. 1, 2022 to Mar. 31, 2023 Red is the illumination condition, and blue is the communication condition. Observe that the longest continuous illumination starts on Nov. 2, 2022, and the start date of communication in the longest illumination term is Nov. 7, 2022.

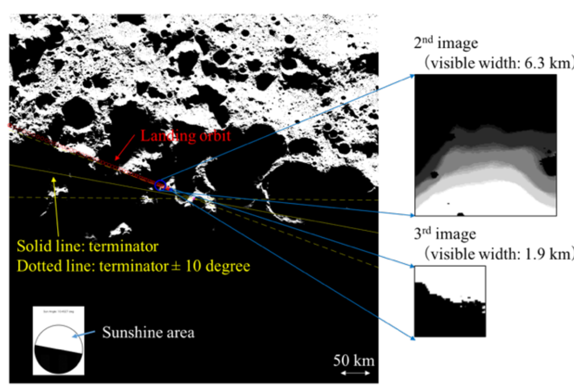

Figure 4 The left image shows sunshine conditions of the lunar south region on Nov. 8, 2022. Black is a shadowed region and white is a sunshine region. The right two images show sunshine conditions on the second and third navigation points, in the landing orbit. The red line indicates the landing orbit; the solid yellow line indicates the terminator.