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Real-time science operations to support a lunar polar volatiles rover mission

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Abstract

Future human exploration of the Moon will likely rely on in situ resource utilization (ISRU) to enable long duration lunar missions. Prior to utilizing ISRU on the Moon, the natural resources (in this case lunar volatiles) must be identified and characterized, and ISRU demonstrated on the lunar surface. To enable future uses of ISRU, NASA and the CSA are developing a lunar rover payload that can (1) locate near subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials. Such investigations are important both for ISRU purposes and for understanding the scientific nature of these intriguing lunar volatile deposits.

Temperature models and orbital data suggest near surface volatile concentrations may exist at briefly lit lunar polar locations outside persistently shadowed regions. A lunar rover could be remotely operated at some of these locations for the ~2–14 days of expected sunlight at relatively low cost. Due to the limited operational time available, both science and rover operations decisions must be made in real time, requiring immediate situational awareness, data analysis, and decision support tools. Given these constraints, such a mission requires a new concept of operations.

In this paper we outline the results and lessons learned from an analog field campaign in July 2012 which tested operations for a lunar polar rover concept. A rover was operated in the analog environment of Hawaii by an off-site Flight Control Center, a rover navigation center in Canada, a Science Backroom at NASA Ames Research Center in California, and support teams at NASA Johnson Space Center in Texas and NASA Kennedy Space Center in Florida. We find that this type of mission requires highly efficient, real time, remotely operated rover operations to enable low cost, scientifically relevant exploration of the distribution and nature of lunar polar volatiles. The field demonstration illustrated the need for science operations personnel in constant communications with the flight mission operators and the Science Backroom to provide immediate and continual science support and validation throughout the mission. Specific data analysis tools are also required to enable immediate data monitoring, visualization, and decision making. The field campaign demonstrated that this novel methodology of real-time science operations is possible and applicable to providing important new insights regarding lunar polar volatiles for both science and exploration.

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1. Introduction

1.1. Lunar polar rover mission concept

Understanding the form, distribution, and content of water/ice and other volatiles at the lunar poles can have a significant impact on our scientific understanding of the Moon and on plans for utilizing the resources on the Moon for sustained human exploration. Recent orbital remote sensing and surface impact data from lunar spacecraft have provided information on the potential presence and distribution of water/ice on the Moon (Pieters et al., 2009; Sunshine et al., 2009; Colaprete et al., 2010). However, these datasets provide only an initial understanding of the form and distribution of lunar volatiles. Ground-truthing at higher resolution on the lunar surface is now required to further our understanding of volatile form and distribution on the Moon (Sanders et al., 2012).

To further characterize lunar polar volatile deposits at smaller scales than has been possible to date and to assess ISRU potential of such deposits, the National Aeronautics and Space Administration (NASA) and the Canadian Space Agency (CSA) are developing a lunar polar rover mission concept to prospect for lunar volatiles and demonstrate in situ resource utilization (ISRU) on the lunar surface (Sanders and Larson, in this issue). This mission has the goals of (1) locating near subsurface volatiles, (2) excavating and analyzing samples of the volatile-bearing regolith, and (3) demonstrating the form, extractability and usefulness of the materials. The mission is a rover-based platform that includes neutron and near infrared spectrometers to prospect for hydrogen sources and volatiles, a drilling system to collect samples down to one meter below the surface, and a sample analysis oven with a gas chromatograph/mass spectrometer to heat and analyze water and other volatiles released from subsurface samples.

This mission is unique in that mission operations will be conducted in real time, thereby necessitating a new concepts of operations. Since the rover will be operated during a time period of ~2–14 days of sunlight near a lunar pole and the results of the two prospecting instruments (neutron and near infrared spectrometers) will not be known a priori, the Science Team will need to make real-time decisions based on this data. For example, the science team will need to identify the locations of hydrogen (and volatile) hotspots as well as decide when and where to auger and/or drill to collect samples for the sample analysis oven and ISRU measurements. The real time cadence of this mission thereby necessitates that the mission employ real time science operations to achieve the stated mission goals.

1.2. Site selection

Site selection is a key driver of the lunar polar rover mission duration and hence of the mission concept of operations. Site selection is predicated on identifying a region(s) with (1) high hydrogen concentrations, (2) ice stability, (3) visibility from Earth (so a relay satellite is not required to perform the mission), and (4) brief periods of sunlight to allow solar power to be utilized. The need for high hydrogen concentrations drives the mission to the lunar north or south polar regions. Preliminary analysis has also shown that these regions typically experience continual visibility from Earth which enables DTE (direct to Earth) communications without a relay satellite (Heldmann et al., 2012). We now examine the final two criterion (ice stability and brief periods of sunlight) to further refine the site characteristics that are key to defining the science operations constraints.

Recent work has shown that stable ice may exist outside of permanent shadow near the lunar poles. Thermal modeling coupled with Diviner lunar radiometer measurements from the Lunar Reconnaissance Orbiter (LRO) has shown that cryogenic temperatures exist outside of permanent shadow in near-surface regions (Paige et al., 2010). Fig. 1 shows a map of depth to stable ice for the lunar south polar region. Areas where the depth to stable ice is zero meter (white regions in Fig. 1) are primarily regions of permanent shadow. All other regions with a range of depths greater than zero and up to one meter are areas that receive on the order of several days of sunlight per month. The low sun angle coupled with the relative short duration of solar illumination results in the cryogenic subsurface temperatures which enable cold-trapping of water ice and other volatiles, even outside of permanently shadowed regions.

Fig. 2 shows the maximum days of expected sunlight based on Lunar Orbiter Laser Altimeter (LOLA) data from LRO. Areas of permanent shadow (purple areas in Fig. 1 representing zero days of sunlight) correspond to areas where ice is stable on the surface. However, the confluence of Figs. 1 and 2 shows that there are ample regions where ice is stable within the upper meter of the lunar surface

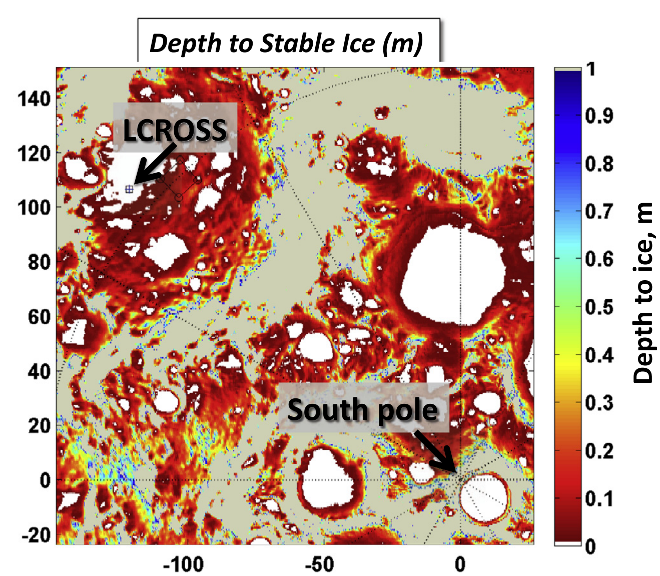

Fig. 1. Polar stereographic map projection of the south pole region of the Moon indicating depth to stable ice. Axes are labeled in kilometers with the map origin at the south pole. The location of the lunar south pole and LCROSS impact site are indicated by black arrows.