Virtual Session Six: Foundational Data Products
Session Report
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1.0: Introduction and Overview

On November 19, 2020, the sixth Virtual Session of the Lunar Surface Science Workshop was held. This session focused on Foundational Data Products particularly relevant to facilitating new scientific research enabled by human exploration of the lunar south pole. The goal of this session was to both discuss existing relevant data and to identify key gaps in existing data that could be addressed through future precursor missions and/or targeted new observations and analyses. The workshop considered data products relevant to both direct scientific investigation and surface characterization enabling safe, effective, sustained crew activity on the lunar surface.

The session included invited updates and overviews from NASA HQ, HEO, STMD, JAXA, and NASA's Lunar Water ISRU Measurement Study. There was also a real-time demonstration of the online QuickMap tool, which provides an accessible platform for accessing and exploring a number of existing foundational data products.

Contributed talks spanned a range of existing and future instruments and products. The Lunar Reconnaissance Orbiter was well represented, with several talks discussing data from its instrument suite including Diviner, the Lunar Reconnaissance Orbiter Camera, the Lunar Orbiter Laser Altimeter, Mini-RF, and the Lyman Alpha Mapping Project. Several spectral data products from non-LRO instruments were also represented, including the Moon Mineralogy Mapper, the Kaguya Multiband Imager, and the Chandrayaan-1 Hyperspectral Imager. Finally, several instrument concepts were discussed, primarily focused on understanding the compositional and thermal properties of the lunar surface in spatial context.

Following the invited and contributed talks, attendees had the choice of attending two breakout discussions:

1. ***Surface Characterization.*** Major themes to be addressed:
    a. Assessment of local geology and composition, guiding and providing context for scientific investigations at the lunar south pole.
    b. Assessment of local terrain enabling safe, successful exploration.
2. ***Resource Characterization.*** Major themes to be addressed include the distribution and mobility of polar volatiles.

2.0: Breakout Discussion 1: Surface Characterization

Summary of Discussion:

The goal of this breakout discussion was to consider the use and development of foundational data products to guide future surface science investigations of the lunar south pole. Additionally, the breakout group discussed how these and potential future data products can enable safe, successful exploration of the surface. Leading up to this discussion, presentations by various LRO teams as well as other dataset creators provided a good background into the foundational datasets available now as well as areas where advances are being made. One of the main takeaways from the discussion is how recent and ongoing lunar missions have provided key baseline datasets for the polar region. However, continued and new observations are required to improve our characterization of the surface as well as monitor changes to the environment caused by human and robotic exploration of the region.

When discussing current lunar datasets, the group was encouraged by the prior talks to see how the LOLA team has started providing error analysis to offer better context on how the dataset can be used and interpreted. During the breakout session, several suggestions were made on how other datasets could be improved, including the geometric control of LROC NAC observations in the polar regions and refinement of ice stability maps to incorporate image data to help fine-tune locations that have the potential to harbor volatiles. A crucial point of creating and improving upon these foundational data products is not only to guide the planning of future missions, but also provide a baseline to measure how future surface exploration changes the nature of the polar region.

The development of new instruments and potential missions was also discussed during the breakout. While LRO and other recent missions have provided key foundational data products for planning surface exploration, additional datasets are important in better understanding not only the polar environment, but the Moon in general. Several examples mentioned included a high resolution hyperspectral thermal infrared imager, a camera system that could see inside permanently shadowed terrain, and a swath laser ranging system to create dense topographic measurements. While these observations are not required prior to the landing of future missions, their data along with others would improve our understanding of the polar region, identify future sites for surface science investigations/in-situ resource utilization, and aid in terrain relative navigation to improve landing capabilities over shadowed terrain.

Additionally, data collected during and after landed missions was also considered. Future robotic and human landings in the lunar polar region will impose changes to the local environment. For example, building of habitats or any movement of regolith could alter how the sunlight interacts with the surface and create new regions of permanent shadow or alter the thermal environment that can modify volatile stability and transport. Observations from orbit could be used to compare prior datasets to monitor these changes over time. However, it was noted that LRO may not be able to make these key measurements due to the current orbit inclination, which now prohibits nadir observations and requires large slews to get a glancing views of many of the potential Artemis landing sites. Ground measurements were also discussed to monitor changes, including, but not limited to, a mass spectrometer to monitor volatile movement as well as dust, temperature, plasma, and radiation sensors.

Finally, we also discussed how these datasets can be used to identify science sites for future CLPS and Artemis landed mission. A central focus was identifying the best areas in the polar regions where ground truth measurements can be used to test multiple orbital datasets and models. Particularly, in terms of testing the presence of ice/frost as well as the local temperature. In addition, these sites can also be used to gather compositional information, which is typically difficult to do from orbit due to the extreme lighting.

Outstanding Science and Capability Questions:

The discussion identified several outstanding questions relevant to surface characterization before, during, and after surface exploration commences at the lunar south pole.

- Are there ways for multiple data sets to be combined to improve our scientific interpretation of the region (example: integrating Diviner ice stability and location of small PSRs identified in LROC NAC observations)?
- Are there baseline datasets that still need to be collected prior to surface exploration?
- What datasets need to be collected from orbit and on the surface during and after surface exploration to monitor and quantify the effect of surface exploration?

Recommendations:

The discussion resulted in several recommendations for advancing surface characterization:

- Continue to calibrate and improve foundational data products and provide error analysis to improve use and interpretation.
- Maintain/introduce an orbital platform for monitoring the dynamic environment that will be created by surface exploration. New observations during and after surface exploration will enable monitoring of how surface operations impacts the local environment.
- Identify areas on the surface where ground truth of multiple orbital datasets can be gathered to improve our overall interpretation and assess the accuracy of these data products. The CLPS structure could be leveraged to visit several of these sites to improve our understanding of the local geology and thermal environment.

3: Breakout Discussion 2: Resource Characterization

Summary of discussion:
This breakout discussion began by defining a few of the driving questions relevant to lunar surface resource characterization, primarily focused on water. An important was how to define and classify water deposits at different scales. What type of language should be used to describe these deposits (*e.g.*, resource vs. deposit vs. reserve)?

Several attendees expressed interest in better understanding the role of magnetic anomalies and interactions in the creation, distribution, and utilization of volatiles.

A significant amount of the discussion was spent developing a list of relevant existing data products and instruments:

- Lunar Prospector
  - Hydrogen abundance, but at low spatial resolution
- Lunar Exploration Neutron Detector
  - Hydrogen abundance theoretically at better spatial resolution than Lunar Prospector. However, some calibration issues have been noted. A new calibration from the LEND team may address these issues.
- Lunar Crater Observation and Sensing Satellite
  - Point data source rather than distribution map, but provides excellent characterization of cold trap composition, structure, and abundances
- Moon Mineralogy Mapper
  - Surface distribution of water molecules and frosts, with some ability to measure mobility / time-dependence through overlapping observations at different illumination conditions
- Mini-RF
  - Radar measurements are sensitive to thick (10s of cm) layers of relatively pure water ice
- Diviner
  - Provides temperature maps that indicate candidate locations where ice may be stable
- Lunar Orbiter Laser Altimeter
  - Provides topographic data that allow high-resolution illumination models
  - Provides albedo measurements in permanently-shadowed regions, potentially revealing surface frosts
- Lyman Alpha Mapping Project
  - Hydrogen distribution

A number of upcoming instruments and missions were also discussed, including:

- JAXA polar rover
    - Instruments may include a near-infrared spectrometer, a ground-penetrating radar, a neutron spectrometer, a thermal analyzer, a mass spectrometer, and an xray diffraction instrument.
- A thermal infrared spectrometer instrument concept being developed at the University of Hawaii
    - Offers up to 1 m/pixel resolution of candidate polar landing sites.
- The GLEE suite
    - A widely distributed network of landed sensors with thermal, dust, and magnetic field detectors.
- Lunar Trailblazer
    - An orbital near-to-thermal infrared imaging spectrometer with high spatial and spectral resolution (up to 30 m / pixel).
- LWIMS approach
    - A suite of instruments available for an optimized understanding of volatile distribution and mobility.
- Artemis 1 cubesats
    - Include Ice Cube, Lunar HMAP, and Lunar Flashlight, providing hydrogen abundances, lidar, and near infrared spectroscopy.
- ShadowCam
    - Providing 1.7 m/pixel imagery within permanently shadowed regions
- VIPER rover
    - A suite of instruments designed to characterize permanently shadowed cold traps
- Luna 27
    - Stationary resource-prospecting lander
- VNMO
    - Cubesat with a laser instrument to look into permanently shadowed craters (similar to Lunar Flashlight)

Outstanding Science and Capability Questions:

The discussion proceeded to identify a number of outstanding questions relevant to volatile science and capabilities for addressing volatile science questions:

- How can communications needs be met during traverses into permanently-shadowed regions?
- What enabling technologies are required to access the central regions of large permanently-shadowed regions, where resources may be most abundant?
- What is the isotopic composition of lunar hydrogen, and what are the implications for use including astronaut health?

- What are the sources and abundance of contaminants in harvested water?
- What non-water resources are available, and at what abundances?

Recommendations:

The discussion resulted in several recommendations for advancing resource characterization:

- Develop and adopt a classification scheme for different types and scales of resource deposits for clarity in community discussions.
- While drilling is an excellent tool for understanding volatile distribution at depth, trenching is also a valuable approach.
    a. It can often be simpler to implement with a wider variety of tools.
- It is important to understand the porosity of the south polar regolith to understand how liberated subsurface volatiles would be redistributed.