A Web-Based Lunar Topography Visualization Tool for Surface Mission Planning

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With operations on the surface of the Moon becoming more prevalent, stakeholders will require tools to plan and visualize their activities on the lunar surface. Rendering large models of accurate lunar terrain is computationally costly and unsuitable for the real-time interaction needed to plan lunar activity effectively. We created a set of visualization tools that allow users to explore the lunar terrain at a high level of fidelity while being computationally inexpensive using data provided by the Lunar Reconnaissance Orbiter (LRO) space mission. The tools also allow for generic 3D models to be rendered onto the lunar surface efficiently to enable the planning of human activity. By leveraging a web-based framework, these tools can be used on a personal computer with a web browser and can be integrated into other web-based applications.

I. Nomenclature

$ISRU$	=	In-Situ Resource Utilization
LRO	=	Lunar Reconnaissance Orbiter
$LOLA$	=	Lunar Orbiter Laser Altimeter
API	=	Application Program Interface

II. Introduction

Lunar operations on the Moon are expected to increase substantially in the upcoming years. Within the next four years, at least 22 lunar surface missions are expected to take place [1]. This increase in human activity has the potential to create a new market around cislunar space, estimated by PWC to be valued at $142 billion by 2040 [2]. Understanding how the lunar topology impacts the objectives, requirements, design, and operations of a lunar surface mission is critical to achieving mission success. This understanding relies on our ability to visualize and represent the topographic reality of the Moon at a high level of detail, which requires a complex technical understanding of topographical data and powerful computing capabilities. These are not always available to stakeholders during the ideation phase of lunar surface missions, which makes defining mission goals, requirements, and locations of interest difficult. The influx of stakeholders into the cislunar market who might not have access to these capabilities calls for an improved set of tools to understand how the topology of the lunar surface will affect mission parameters and characteristics. This tool will allow mission planners and stakeholders to effectively plan mission operations on the Moon's surface using an inexpensive and easy-to-use tool, enabling disruptive mission architectures and allowing smaller stakeholders to partake in the growing cislunar space economy.

III. Background

This tool will require significant visualization capabilities to represent the Moon's surface effectively, yet the fragmented nature of this data and the inherent complexity of spatial representation make this visualization difficult. There are two significant challenges when attempting to represent the surface of the Moon with a high level of fidelity:

- **Computational power:** at a resolution of 1 pixel per square meter, the entire lunar surface (comprised of roughly 38 million square kilometers) would require a mesh consisting of 3.8e13 height points to represent, a figure inherently prohibitive for most personal computers.

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- **Polar regions:** the lunar polar regions are difficult to photograph and analyze given their high inclination and low-angle solar lighting. As a result, lunar polar topographical data is highly fragmented and its resolution varies significantly from region to region. This makes unifying these data sources to generate a global map of the lunar surface that includes the lunar poles challenging. Furthermore, most graphical software commercially available utilizes UV-spheres to represent generic spherical shapes, which sacrifice topological accuracy at the poles in favor of faster and more effective representation along the equator.

The issues regarding topographical data around the poles are of special interest in this case, as the lunar polar regions are of special interest to future lunar surface missions. To further illustrate this point, as of the time of writing all 13 regions being considered for the Artemis III mission by NASA are located in the proximity of the South Pole [3]. This interest is driven by these regions hosting a variety of volatile compounds and permanently shadowed regions of special scientific and commercial interests, especially in the field of In-Situ Resource Utilization (ISRU) [4]. Correct representation of the lunar polar regions is thus paramount to enable mission planning for future lunar surface missions.

To summarize, the specific needs of this kind of visualization call for a tool that addresses these challenges while also providing a range of users with diverging mission requirements and needs an effective visualization environment to understand the impact of lunar topology on their respective operational interests.

A. Tool technical requirements

In order to address these challenges and achieve the goals of this tool, a set of technical requirements were defined to guide the high-level technology choices for the tool:

- **Portability:** the tool should be platform-independent for ease of use across multiple operating systems.

- **Integration:** the tool should be easy to integrate with other mission-planning tools to fulfill the terrain visualization requirements that they might have.

- **Efficiency:**the tool should be able to run on a personal computer, with limited computational power available.

- **Framework:** the tool should provide a framework for 3D visualization of the lunar surface as well as man-made objects or structures to serve a wide range of stakeholders with different mission objectives.

- **Usability:** the tool must be easy to use while providing accurate information; it must allow users to gain critical insights into how topology will affect their mission requirements and operations while requiring little technical knowledge to operate.

B. Data source selection

The selection of a data source for topological visualization is critical to ensure the tool can accurately and efficiently represent terrain. There are multiple data sources of lunar topology data available to the public, out of which data from the Lunar Reconnaissance Orbiter (LRO)'s Lunar Orbiter Laser Altimeter (LOLA) was selected [5–9]. LOLA's high resolution of 0.5 meters per pixel, combined with the significant data cleaning and conditioning performed by the LRO mission team made this the ideal data source for this tool. For functionality where the visual appearance of the represented model and the interactivity of the tool are more relevant than its accuracy, data from the NASA Moon CGI kit was also used [10]. This data is also derived from the LRO's LOLA instrument.

IV. Tool overview

The tool is built on Dash, a Python web framework. The use of a web framework makes the tool highly portable, as it can be run on any device with a web browser. Web browser applications also benefit from a range of built-in optimizations that ensure the tool will not require a high-end device to be used. Furthermore, Dash was built with data science in mind, meaning it is designed to handle large datasets like the ones involved in topographical visualization. Plotly, a Python graphing library, was used as the graphing engine as it was found to have sufficient capabilities to render 3D views and models effectively while also providing the user with interactive graphing. This means the user will be able to rotate, pan, and zoom any of the views created, cutting down on development time while increasing functionality. Using an already established graphing engine also allows for the tool to be quick and easy to integrate into other mission planning solutions.

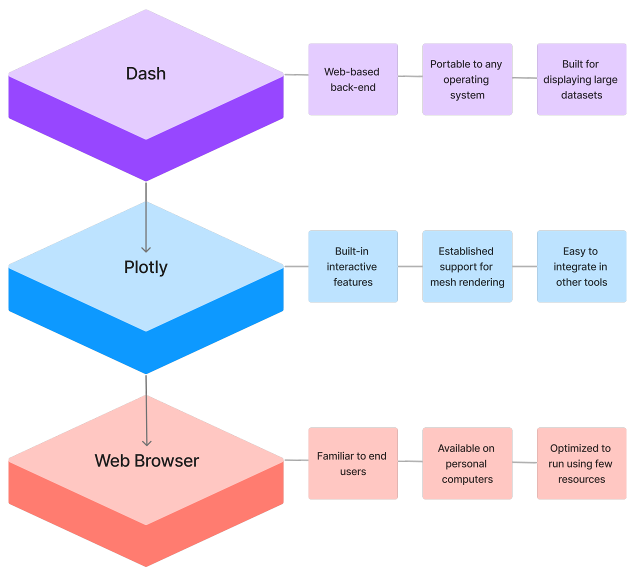

Fig. 1 The tool's technology stack.

In order to fulfill its goals more effectively, the tool was broken down into two separate views: a global low-resolution visualization of the Lunar surface and a second high-resolution region-specific view. This breakdown allows the user to first situate their mission in the broader lunar topology, where they will be able to explore any region of particular interest and determine in which region their planned activity would occur. The second view then allows the user to explore the local topology of the selected region at a high level of detail to determine the feasibility of the selected region for their mission as well as enable insights into how the local topology might play a role in the operations of said mission. These two views work together to achieve what one more computationally expensive view would achieve, with the added benefit of providing a clear workflow for the use of the tool as a whole.

A. Global view

The global view's purpose is to provide users with an overview of the lunar topology as well as give context to the selection of a specific region for a given mission. As a result, the main goal of this view is not complete topographical accuracy but interactivity, as it is meant to allow the user to explore the full range of possible landing regions. Users are able to interact with the lunar topology at a global scale and to understand the context of any given region of interest. This will guide region selection for their mission as well as provide users with alternatives should their initial region of interest prove inadequate for their mission parameters.

Using NASA's Moon CGI kit, a total of 8 points per degree of inclination were extracted for the entire lunar surface. This point cloud was then projected onto a UV sphere to yield a low-resolution model of the lunar surface, where each point was displaced along its corresponding radius based on its color value on the elevation map. Points were then patched into a mesh and passed as the mesh object of a Plotly graph. A color map for the points was also derived from the elevation map provided by NASA's Moon CGI kit and was applied to the mesh after rendering. This yields an interactive plot of the moon that is inexpensive to render, as the projection and mesh generation steps are done in advance by the tool. While it does not include the totality of the topological data available, this view fulfills its objective of providing context for specific regions of the Moon while also being interactive and computationally inexpensive. This method can also be used to show other values of interest apart from terrain elevation, such as the concentration of volatiles or permanently shadowed regions, provided a color map for this data is provided.

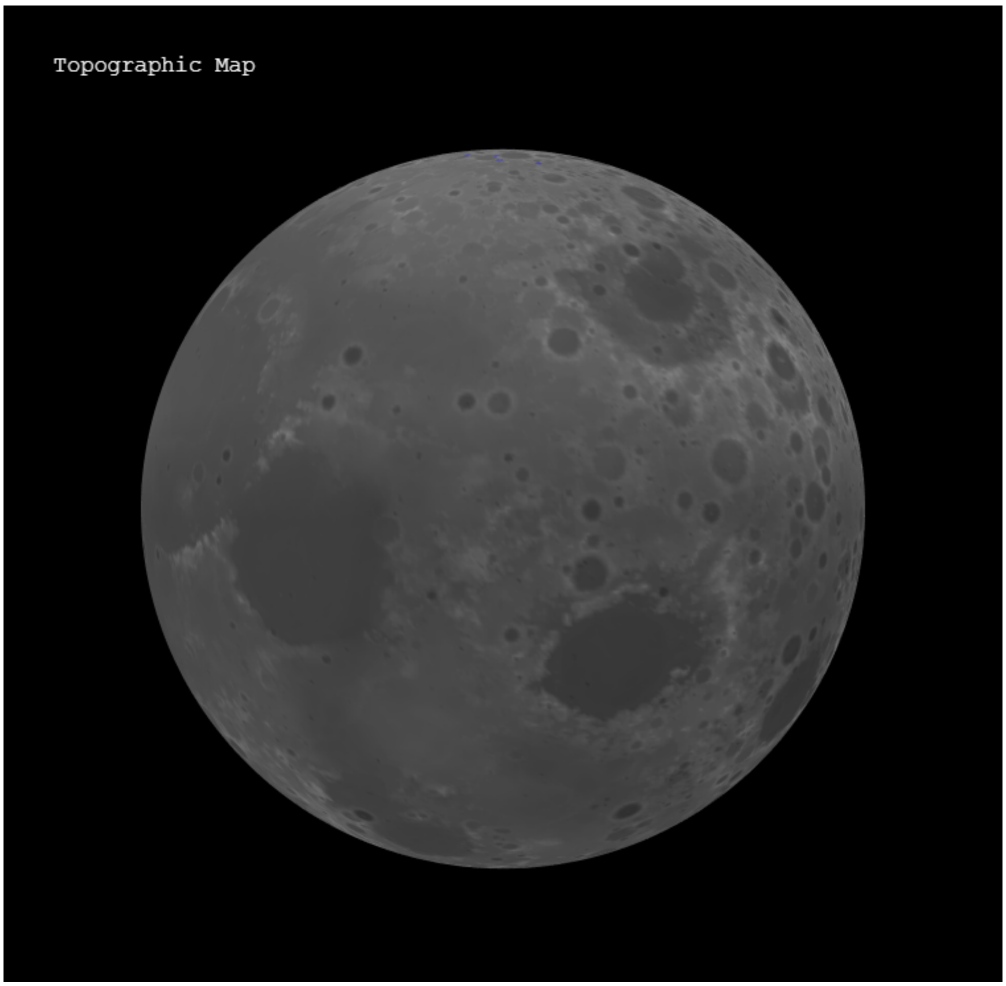

Fig. 2 The global view, showing a planetary overview of the Moon's topography.

Using the same procedure, specific regions of interest can be mapped onto the lunar surface. Any arbitrary region could be mapped, provided that they are small enough to be easily approximated by a plane tangential to the lunar surface. For demonstration purposes, the proposed landing locations for Artemis III were selected to be represented. A list of coordinates for each region, provided by the LRO mission, forms the definition of each region, which is then projected onto a UV sphere and turned into a mesh as described before. The resulting object is added to the rendered graph, which displays the region of interest overlayed on the lunar surface.

Finally, small additions were made to the functionality already provided by Plotly to aid in the use of the tool. A tool tip was implemented that displays the coordinates of any point of the lunar surface as it is selected with the mouse cursor. This tooltip also displays a region's name if the region is selected, which allows users to situate regions of interest in relation to each other and extract valuable information from this view quickly and interactively.

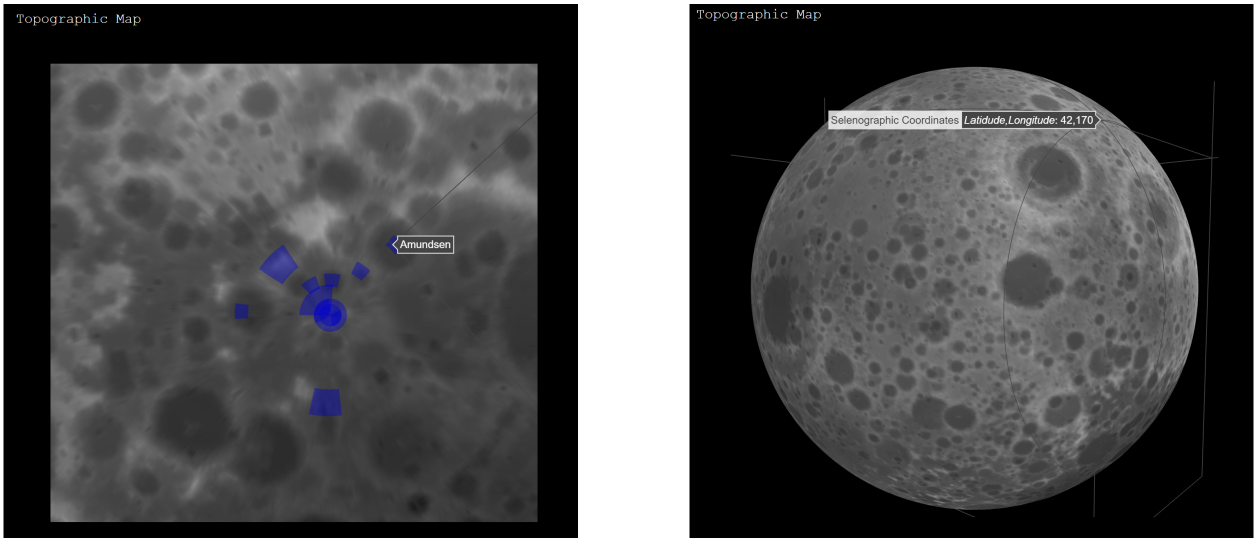

Fig. 3 The global view tooltip, highlighting regions near the South pole and the latitude and longitude of a point.

B. Local view

The local view's purpose is to provide users with a more in-depth understanding of the lunar topology in a specific region or area where their planned surface activity will take place. Representing the local topology accurately is thus paramount to ensure that the conclusions or decisions made based on the tool are valid and useful to the development of their mission. In conjunction with the previous view, the user is able to understand both the context and high-level context of the region selected for a specific mission while also becoming familiar with the local topology of said region. Furthermore, this view supports a more in-depth understanding of the effect this local topology will have on the surface operations of the mission.

In order to achieve the high-fidelity representation needed for this purpose, data for a given region was pulled from the LRO data library, which was provided as height values for a plane of points in 2D Cartesian coordinates. This point cloud was then processed into a mesh associated with each region, which was then displayed on a Plotly graph. This method was chosen for a number of reasons: it relies on the same mesh generation step as the one used for the global view, simplifying development and making the application lighter. It is also agnostic to the shape and size of the selected region to represent, providing the user with flexibility when defining their operational area. Due to a lack of an API to request generic regions programmatically, the tool is currently limited to predefined regions for which local topographical data is readily available. For demonstration purposes, the proposed Artemis III landing sites were again selected to be represented, as the LRO data bank already provides sectioned topographical data for these regions. These regions are:

- Cabeus
- Faustini
- Haworth-Shoemaker
- Intercrater Polar Highlands
- Lenard
- Malapert
- Mount Kocher
- Peary
- Rozhdestbenskiy
- Shackelton (South East)
- Shackelton (West)
- Shoemaker

The regional data provided range in approximate size from 3400 up to 640 thousand square meters. The upper range of these sizes is on the limit of what the tool can represent in real-time on a personal computer with little to no impact on performance. This means the local view can display an area of 800 by 800 meters with a resolution of 0.5 meters per measurement. This corresponds to roughly 2.5 million individual points. Furthermore, this visualization approach does not suffer from the limitations a spherical projection might have for regions near the lunar poles. By restricting the view to small regions where a planar assumption can be made, polar regions can be represented with the same level of fidelity as equatorial regions.

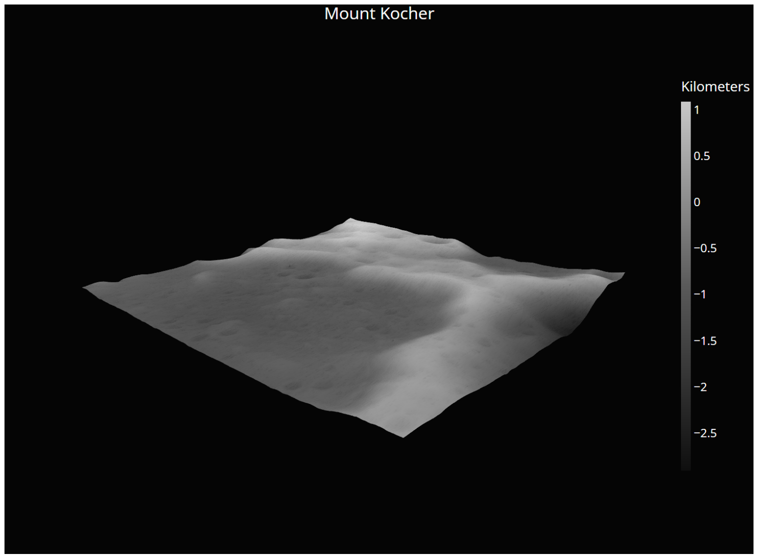

Fig. 4 The local view, showing the local topology of the Mount Kocher region.

In order to enable a more in-depth exploration of how the surface activity will be impacted by topography, a generic 3d model renderer was also implemented. This allows the user to programmatically place an arbitrary 3D model onto the local surface. This feature enables the representation of critical assets on the lunar surface, which is conducive to understanding the impact of local topology on surface operations for a given mission. For demonstration purposes, the model of a proposed lunar habitat was rendered on all selected regions at a random point on the surface.

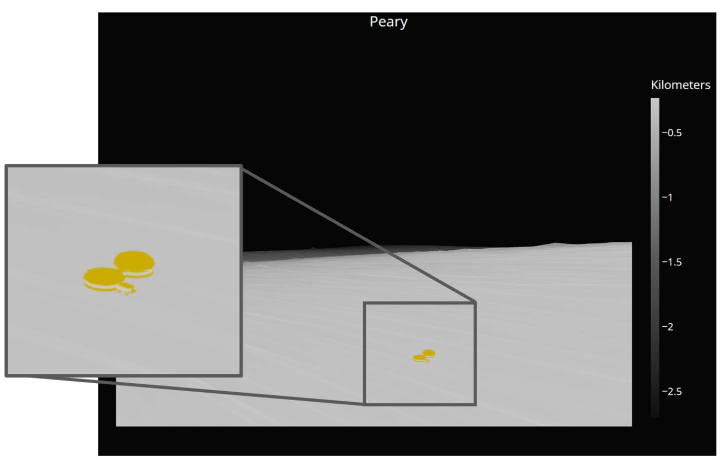

Fig. 5 The local view, rendering a lunar base model on the surface of Peary Crater.

Finally, the ability to show height contour plots directly on the lunar surface was added. This feature allows the user to quickly gauge the slope of a given point on the selected region, as this is an important mission parameter when planning surface operations. The user can freely move the cursor over any point on the terrain and all other points on the mesh with the same height value will be highlighted.

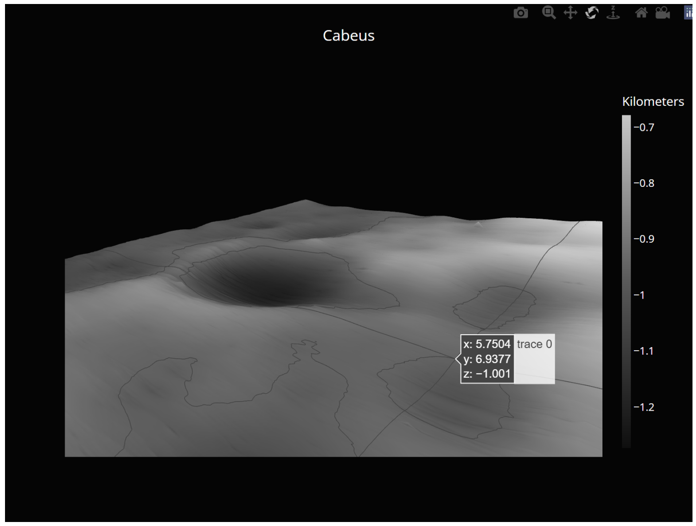

Fig. 6 The local view, displaying a contour plot directly onto the surface of Cabeus Crater.

V. Example Use Case

To demonstrate the workflow associated with this tool, this example use case shows how a user might utilize the capabilities this tool provides to understand how the lunar topology might impact a lunar surface mission. In this situation, the user is planning a mission to test a new ISRU technology and is planning on landing a spacecraft on the surface of the Moon. This technology requires flat terrain and easy access to regions of permanent shadow where resources might accumulate. The user has identified the Cabeus crater region as a possible location for this mission through external research or other topography tools but is unaware of the general location of the region or where it is in relation to other regions of interest. The user can use the global view to identify where the region is in the broader lunar landscape, and then switch to the local view to explore where in the Cabeus region he might perform the planned mission operations.

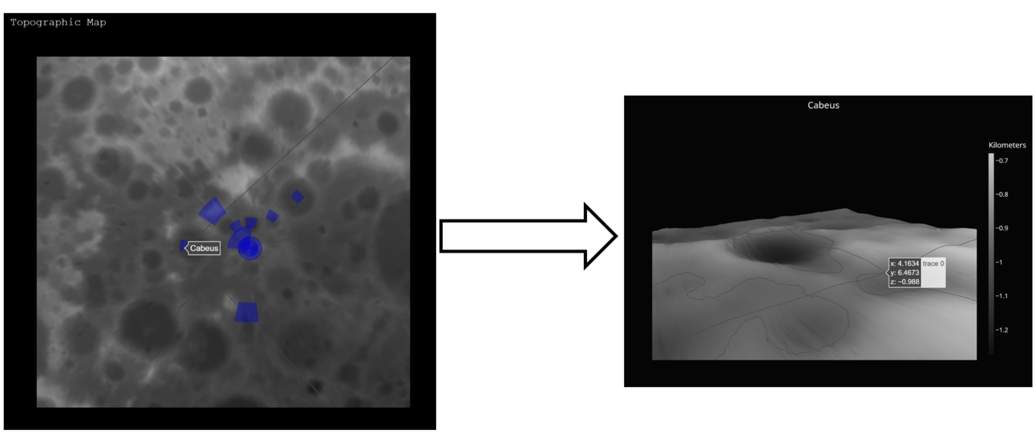

Fig. 7 Using the global and local views to explore a mission's feasibility at Cabeus crater.

Using the contour plot tool, the user decides that Cabeus does not provide the mission with a suitable landing site for the mission. The user then switches back to the global view and starts searching for a new area of interest to perform this mission. Close to the Cabeus crater, they find the Haworth-Soemaker craters region, which provides them with similar region characteristics as the Cabeus region. After further exploration with the local view tool, the region turns out to be an ideal location for this mission. The user can then proceed to map out the location of assets in this region during the mission using the 3D rendering feature.

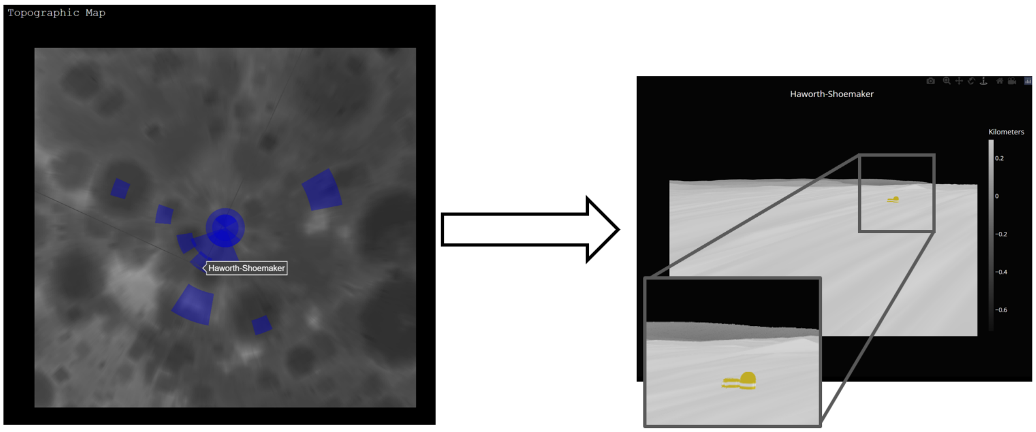

Fig. 8 Using the global and local views to plan surface operations around the Haworth-Soemaker craters.

VI. Conclusion

Future surface missions, lunar or otherwise, will need robust topography visualization tools to enable mission operational success in challenging service environments. Traditionally, lunar topographical data has been difficult to incorporate in early mission planning due to its disaggregated nature and the financially and computationally expensive tools needed to extract insights from it. This is especially true for polar regions, which are poised to play a central role in future lunar exploration and commercialization. This tool provides a robust framework to understand the impact of topographical data on a mission's characteristics and goals. It also enables users to represent their own mission assets on the lunar surface, allowing users to plan out surface operations directly on the location their mission will be carried out. By leveraging web browser technology, this tool can be used by users quickly and with little to no financial or computational cost, which lowers the barrier of entry to lunar surface mission planning and enables quick mission ideation while not sacrificing accuracy and veracity.

Moving forward, new features are being developed to expand the capabilities of this tool. Allowing users to track values other than relative elevation along the lunar surface, for instance, will expand the tool's capabilities beyond a simple topographical visualization tool, providing insights into the concentration of resources like volatiles, radiation exposure, or lunar ice along the lunar surface. Adding 3D assets to the local view is also being streamlined, so models can be included graphically without the user having to manually import the models into the scene. This will allow mission planners to fully leverage the local lunar environment toward achieving their mission goals, enabling new mission concepts and uncovering hidden mission opportunities. The tool presented here provides a robust approach to understanding the reality of the lunar topography, a critical factor in ensuring success in future missions. This understanding will be critical to define the future of human activity on the surface on the Moon as we move towards a sustained presence on the lunar surface, and beyond.

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