Spatial Context is for Astronauts: Spatial Products, Tools, and Staff for Human Surface Operations based on Mars In Situ Missions Experience.

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Introduction: Since January 4th, 2004, we have had a continuous robotic presence on Mars' surface. These missions involve integrated science teams supporting operations year after year, developing science goals and objectives for exploration, much as the "backroom" scientists did on the Apollo and Shuttle missions [1]. As rover missions evolved from driving tens of meters to kilometers and mission duration increased from a few months to several years, there became an increased necessity for extending spatial data products and tools for tactical and strategic spatial decisions, from both a science and engineering perspective. Here we discuss the key advances made in providing spatial products, tools, and mapping support for science and engineering operations as well as their integration for decision support relevant for Artemis surface missions.

Mapping from EDL to operations: Entry, descent, and landing (EDL) analysis for Mars has always relied on mapping to pick a statistically safe and scientifically compelling location. With the Mars Exploration Rovers Spirit and Opportunity, the science and safety evaluation was conducted at kilometer to 100 m resolution except in a couple limited strips within the three-sigma landing ellipse at a few meters/pixel, leading to a 'reveal' of the surface at landing. For MER Opportunity, the exploration distance grew from tens of meters to multiple kilometers. Such long drive goals required using higher resolution imagery, in their case HiRISE (High Resolution Science Experiment), to see beyond the rover view and navigate at the rover scale out to Endeavor crater tens of kilometers away. Maps played a key role in governing the rover position as well as for in situ geologic mapping [2], though there was no unified mapping base shared uniformly between and across engineering and science. There was a non-shared, mapping version of a science activity planner [3] used for rover localization, but its capabilities focused on the rover drive positions and traverse.

With the Mars Science Laboratory (MSL, Curiosity) and Mars2020 (Perseverance) rover missions, the engineering and science mapping occurs down to sub-meter scale, orthophoto mosaics where we can see all hazardous landing rocks and the expected terrain view is relatively well understood. New with MSL, the EDL maps were fed directly into science operations both for geologic mapping to identify major features at the rover scale pre/post-landing as well as fed forward to the rover planners to allow strategic route planning in custom software [4] and context for tactical (daily) drives and views beyond viewshed limits. The MSL basemap [5] serves as the basis of communication within the science team for strategic science planning to designated science campaign areas [e.g. 6], but also for engineering aspects like traverse analysis, future communication planning (i.e. horizon mask generation for future drive positions), determining rover position, and science product localization. Initially, all these MSL mapping capabilities used commercial-off-the-shelf (COTS) or in-house JPL mapping enabled applications (e.g. [7]). Maps were generated to track daily in situ science targets, rover position, and for publications. Mars2020 expanded to utilizing an open source, web based, geographic information system (GIS) with a planetary focus [8] (Figure 1) to conduct pre-landing, high resolution, geologic mapping [9] as well as strategic science planning by delineating geologically rich campaign areas that meet the missions major science requirements, including sample collection locations for eventual return to Earth (i.e. Mars Sample Return). The Campaign Analysis Mapping and Planning (CAMP) tool [9], adapted from [8], allows tens to hundreds of gigabytes of mapping layers [e.g. 10] to be shared by all science and engineering team members regardless of their physical location. Being a web-based application, access requires a minimal download of data all within a web browser. Team members can generate their own vector spatial layers for communicating science desires, intent, and direction. [8] was also adapted for use by the InSight lander to quantitatively evaluate the surface using in situ spatial data products of surface roughness, slope, and rock distribution [11] to place the seismometer (SEIS) and heat probe (HP3) instruments. This software is also being used by the European Space Agency (ESA) Rosalind Franklin rover mission to begin its high resolution geologic mapping ahead of its landing in Oxia Planum, Mars with a distributed team [12]. Such software allows the science 'backroom' to be literally anywhere on Earth allowing direct communication between science experts and engineers within one mapping system, without requiring the expertise in cartographic details (i.e. "what projection are we using, what coordinate units, what software do I use, where can I find the basemap?")

Mapping Personnel: While mapping has always played a part in field geologic studies, staffed positions dedicated to mapping support for the science team are relatively new. Localizing the rover (i.e. "Where is the rover now?"), was one of the earliest science team dedicated mapping positions when the MER rovers started their traverses towards distant destinations using various methods [13,14], though was staffed out of necessity. While the MER science team had individual science team members who provided in situ geologic maps [2], this was done on an informal basis, not as part of the original organized staff. For MSL, a dedicated Localization Scientist and "Keeper of the Maps" were staffed to localize the rover after every drive, provide a team integrated mapping base, and generate mapping products as requested using COTS and in-house tools. As the mapping demand increased, an additional mapper was brought on to provide daily target maps (figure 1) based on the daily science planning uplink. InSight also had a "Keeper of the Map" who updated the webgis system [11] after every downlink during the first critical 30 days for instrument deployment on a tactical basis. In addition, two mapping interns supported the instrument teams in using the webgis during the surface analysis phase, though it was also used by many science and engineering team members for their own evaluation. Mars2020 builds on that heritage with three dedicated Mapping Specialists providing tactical and strategic mapping support. All mapping products have been pushed into the CAMP web mapping tool [8,9] and it serves as the basis for enabling mapping and science communication throughout the science and engineering team. After landing, it will be used to evaluate future strategic routes, geologic campaign areas, and provide analysis via overlays, measurements, and viewshed analysis. The Mapping Specialists are cross trained in localizing the rover (which starts pipelines feeding orbital products to rover planners and science product localization outputs after downlink), updating tactical dashboard maps, keeping CAMP up-to-date with new mapping layers, and offer dedicated mapping support to the science and engineering team. In addition, links to 'quicklooks' and initial science results can be linked to and displayed from targets and rover locations within the application, allowing scientists to connect instrument data with location.

Suggestions for Artemis: It is critically important to provide a shared spatial context for scientists and flight engineers as well as the astronauts themselves. As mission duration and locations evolve or repeat, it will necessitate tracking spacecraft and astronaut positions, keeping a detailed daily science target location record, samples retrieved, and where (and when) science observations occurred. Dedicated spatial awareness reduces engineering ("can I get there from here? Did we sample that rock already?") and increases science ("How tall is that hill? Is that science result the same here as at the last outcrop?") by providing accessible answers to common spatial questions. The Moon has similar orbital spatial data coverage and pixel size acquired by the Lunar Reconnaissance Orbiter that nearly matches (or exceeds) products taken by the Mars Reconnaissance Orbiter (MRO). This data should be shared in a web-based GIS system to allow maximum communication between scientists, instrument engineers, robotic platforms, and flight support areas across planetary bodies. A dedicated mapping team can provide the technical support in mapping layers, projections, coordinate systems, localization, and spatial analysis in support of science and engineering. This unified mapping system and mapping team provides critical input to tactical (daily) and strategic planning. Mars rover missions operate with a time delay and plan for next day activities. However, if Artemis extravehicular activity (EVA) mirrors Apollo, which ranged from ~2.5 to 7.5 hours [15], this is a similar duration as Mars rover planning time, which means scientists and engineers can plan the next EVA while astronauts 'sleep' and vice versa. During EVA, live updates of surface activity, including astronaut positions and instrument results (or images and video) should be incorporated real-time into the webgis to feed forward to flight support areas for maximum situational awareness and to the science team for any decisions/changes fed back based on EVA activity. Post EVA, the next planning cycle can have the context to eliminate duplicate sampling or keep the mission on track with long term strategic goals. At a minimum, a dedicated, shared, and supported mapping system and personnel will reduce mission uncertainty and provide a unified base for all surface activities.

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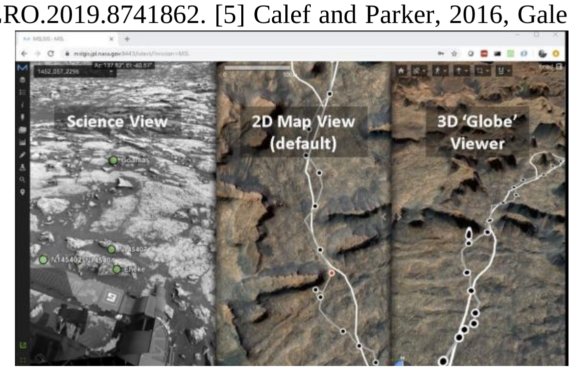

Figure 1: WebGIS [8] used for Mars surface operations.