GEOSPATIAL INFORMATION STRATEGIES AND REQUIREMENTS FOR ENABLING REAL-TIME CREWED SCIENCE ON THE MOON. J. A. Richardson (jacob.a.richardson@nasa.gov)[1], M. J. Miller[2,3], C. N. Achilles[1], E. R. Bell[4,1], A. W. Britton[2,3], B. A. Cohen[1], L. A. Edgar[5], A. L. Fagan[6], A. H. Garcia[2,3], W. B. Garry[1], J. M. Hurtado[7], S. Jacob[8], S. K. Nawotniak[9], J. Skinner[5], C. M. Trainor[2,3], A. R. Yingst[10], and K. E. Young[1]. [1]NASA GSFC, Greenbelt, MD; [2]NASA JSC, Houston, TX; [3]Jacobs, Houston, TX; [4]UMCP, College Park, MD; [5]USGS Astrogeology, Flagstaff, AZ; [6]WCU, Cullowhee, NC; [7]UTEP, El Paso, TX; [8]ASU, Tempe AZ; [9]ISU, Pocatello, ID; [10]PSI, Tucson, AZ.

Introduction: Like data collected during traditional terrestrial field geology, data gathered during lunar Extravehicular Activity (EVA) are intrinsically geospatial. Linking observations and samples to location expands scientists' ability to interpret the lunar surface and subsurface. In 2022, the Joint EVA & Human Surface Mobility Test Team (JETT) conducted a simulated lunar mission on Earth, *JETT3*, involving two crew members in the field, who performed EVA activities, and a remote Flight Control Team (FCT) [1]. During the test, crew members and members within the FCT—EVA Task and Science consoles in the Multi-Purpose Support Room (MPSR) and a Science Evaluation Room (SER) [2,3]—were required to maintain real-time estimates of crew location without Position, Navigation, and Timing (PNT) information (e.g., GPS location). This abstract summarizes the SER team's experience attempting to support scientific exploration in the absence of a PNT solution for the JETT3 field test.

Past and Current Geolocation Strategies:

Apollo. The first six crewed missions to the Moon located EVA activities using a combination of dead reckoning, studied knowledge of the landing site, electronic cord lengths, and site-specific grid reference systems with 50x50 m dimension alphanumeric grid cells [4]. With the introduction of the Lunar Roving Vehicle in Apollo 15, Apollo J-missions also had access to an on-board range and bearing estimate, with respect to the Lunar Module (LM). Subsequently, NASA Lunar Reconnaissance Orbiter (LRO) data have enabled refined location measurements of assets and EVA activities leading to the reanalysis of science observations during Apollo missions [e.g., 5-8].

Mars Surface Missions. Mars rover and lander teams generate large scale (1:5,000) maps of terrains with dozens of team members [9]. During missions, rovers and instruments can be geolocated to mm-precision by science teams using orbital images and rover images and data along with digital mapping tools, though this process takes hours to months [10].

JETT3 Geospatial Strategies: Prior to the JETT3 test, the SER produced a geologic map of the 2 km-radius EVA area at a 1:24k scale using 0.5 m/px orthoimages and 1.5 m/px elevation maps of the area [11]. JETT tests employed 50x50 m alphanumeric reference grids (Fig. 1). By requiring crew to report grid locations including one decimal point to mission control during EVA traverses, nominal precision was 5 m. This method was performed given an absence of any PNT information, mirroring early Apollo mission design. This strategy depended on the u se of traditional orienteering methods including (sans-compass) triangulation with prominent features and step counting, each of which has inherent accuracy limitations. During the JETT3 test, independently tracked crew locations were shared digitally using prototype mapping software, as provided by the EVA Mission System Software team [12].

Actual crew GPS location data were recorded for post-test analysis; these data were not shared with members of the FCT or crew throughout the duration of the test. Post-test, GPS data were compared with co-temporal Crew, MPSR, and SER location estimates.

JETT3 Simulation Results: Calculated mean(std. dev.) location estimate errors aggregated across all four EVAs were: Crew, 160(190) m (N=34 estimates); MPSR, 120(130) m (N=105); and SER, 130(100) m (N=92).

Factors impacting geolocation. Generating estimates proved to be a time intensive endeavor for Crew, MPSR and SER, requiring the integration of disparate data sets (e.g. video, audio, and maps). SER science discussions frequently stalled or were left unresolved due to unknown crew whereabouts. The cadence of the EVA was higher than rover operations (crew traversed at speeds >1 km/hr on foot), which also imposed a greater time pressure to generate location

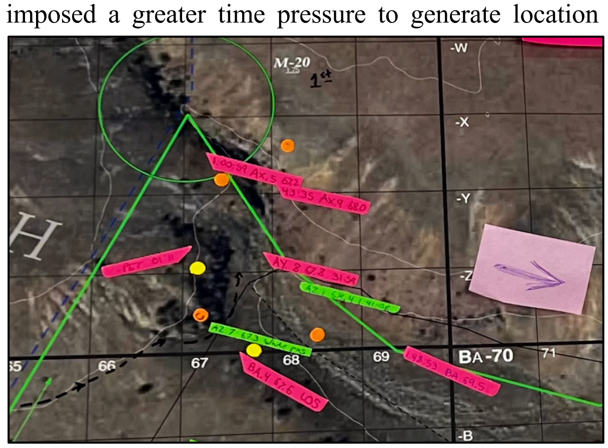

Figure 1. 1:1,300 scale annotated printed map of JETT3 EVA traverse. Long tags estimate crew position over time; circle stickers estimate sample locations.

estimates. This cadence limited SER Map Leads' abilities to contribute more than crew location to mapping software. Geospatial science interpretations and information-dense notes were made on paper maps (Fig. 1) and offline spreadsheets, often without aid from SER Map Leads. In some cases, simulated science was lost due to lack of confidence or errors in location estimation, including attempting to visit the only area designated as a 'PSR'.

Several additional barriers were identified to accurately estimate real-time locations. Repeated morphologically similar features—drainages in the field site, small craters in future Artemis landing sites—led to misinterpreted locations by Crew, MPSR, and SER. Pace calibration exercises performed at EVA start by crew helped this, but uncertainty in traverse distance as well as azimuth of travel increased along traverses to the point where error was similar to or greater than the distance between similar features. Waypoints (e.g., backstops) communicated to crew by the FCT prior to EVAs helped in navigation (like 'turning point rock' en route to Station 6, Apollo 17). Features that were interpreted as 'small' on ground maps were observed as much larger to crew in real life and a lack of a common language to describe geographic features interfered with teamwide understanding. During the test, local low-angle illumination at night rendered distant terrain foreshortened at times, or too dark to use as a navigation aid by crew. Additionally, terrain beyond ~6 m of either crew member was unobservable by FCT members due the groundward orientation of live cameras.

We find that these barriers can be mitigated with training [13] and crew-science team integration [14] in future tests and during crewed missions to the Moon, but it is unclear if these interventions can meet Artemis mission requirements [15]. An automated PNT solution that meets requirements in Tab. 1 and [15] remains a more desirable capability to 1) decrease risk that primary science targets are not visited, 2) decrease risk that visited locations and derived data are not misinterpreted, and 3) decrease time spent by crew and FCT members generating geolocation data at the loss of science activity time.

Acknowledgments: This work is supported by the NASA Analog Activities to Support Artemis Lunar Operations (DRATS) program. JAR contribution also supported by the SSERVI GEODES project (Award #80NSSC19M0216).

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Table 1. EVA PNT Knowledge Impacts Science.

EVA Surface Science Activity	Minimum localization requirement to enable science **Accuracy**	**Cadence**	**JETT and/or literature observations**
Navigating to science station	50-100 m	Continuous during traverse	Stations in JETT3 were designed to be 100 m diameter; smallest currently resolved PSRs are 60 m in diameter [16]; Apollo 14 missed primary target of interest by <100 m.
Sampling/Instrument observations at stations	3-5 m	Per sample	Artemis EVA Reqs. [15]; JETT3 objectives included sampling along geologic contacts/gradients or along trenches; [5, Sec. 7].
stationary geophysical array deployment (e.g. ALSEP)	0.5 m	Once Post-deployment	Artemis EVA Reqs. [15]; "coordinate updates… yield significantly different structural models" [6].
Traverse Instrument Surveys	5 m (0.5 relative precision)	Per measurement	Artemis EVA Reqs. [15]; Apollo seismic sources were separated by 4.6 m [17]; gravity measurements located to 5 m greatly reduced uncertainty [7].
Distinguishing between local features of interest (small craters, boulders)	3-10 m	Immediately as needed	Artemis EVA Reqs. [15]; [5, Sec. 7]; Adjacent PSRs to ~10 m or boulders to ~2 m might be a priori science targets using available orbital data [18].