THE AUGMENTED REALITY DATA VISUALIZATION ANALOG RESEARCH CAMPAIGN (ARDVARC) OVERVIEW: FIELD SITE SELECTION AND INITIAL ANALYSIS. Z. R. Morse1,2, S. Scheidt1,2, S. Hudziak4, T. Graff3, J. Richardson2, P. Whelley1,2, J. M. Hurtado6, W. B. Garry2, T. Grubb1, C. Achilles2, M. Battler3, M. Cross7, K. E. Young2, G. R. Osinski8, 1Howard University, Washington DC, 20059, 2NASA Goddard Space Flight Center (GSFC), Greenbelt, MD, 20771, 3University of Maryland (UMD), College Park, MD, 20742, 4University of Iowa, 5NASA Johnson Space Center (JSC), Houston, TX, 77058, 6University of Texas at El Paso (UTEP), El Paso, TX, 79968, 7Mission Control Space Services Inc., Ottawa, Ontario, Canada K1R6N5, Western University, London, Ontario, Canada N6A3K7. (zachary.r.morse@nasa.gov).

**Introduction:** Human-robotic coordination and data visualization in both Virtual Reality (VR) and Augmented Reality (AR) have been identified by the Lunar Exploration Analysis Group (LEAG) as technological opportunities to extend the science return of crewed missions to the lunar surface (Objectives D, F, and J in [1]). The Augmented Reality Data Visualization Analog Research Campaign (ARDVARC) is a three-year NASA PSTAR project simulating both a pre-cursor rover deployment and a post-cursor astronaut deployment to the same lunar analog field site. This scenario is identified as a requirement for sustained crew presence on the lunar surface (i.e., during ‘Artemis Base Camp Missions’) [1]. ARDVARC is working to assess: 1) the Concept of Operations (CONOPS) for a lunar rover deployed as a precursor mission to a low-angle lighting environment, and 2) the use of AR and VR data visualization based on topography and image data collected by the precursor rover to aid astronauts with navigation and scientific investigations in a low-angle lighting environment. Our work in Year 1 of this project, explored in detail below, has set the groundwork for valuable analog deployments in project years 2 and 3.

**Field Site Selection:** The first ARDVARC field deployment took place from August 2-7, 2023. The field team visited a number of planetary analog sites in the San Francisco Volcanic Field around Flagstaff, Arizona [2] to assess their candidacy as locations for the Year 2 and Year 3 ARDVARC analog deployments. The Cinder Lake Crater Fields were selected as the best field site for Year 2 and 3 activities based on field observations and post-field discussions. These sites, created in 1967 to train Apollo crews over lunar-relevant topography [3,4], remain the optimal location in the area, following five criteria: local topography (including slope and obstacles for rover traverses); logistical accessibility; vegetation cover; cellular signal (for communication and teleoperation of the rover); and local geologic diversity.

**Analog Lighting and Nighttime Imaging:** The team conducted a nighttime illumination test at the Cinder Lake Crater Field 2 site. This site features little vegetation and numerous small craters, accurately simulating a realistic lunar landscape (Figs 1 & 2). The team visited the site after dark and illuminated the area using JSC’s “artificial sun” lighting system which simulates the low-angle, near-horizon solar illumination that will be experienced by Artemis crews at the lunar south pole [5]. This approach is taken instead of performing tests at dawn/dusk to enable longer testing periods and to avoid substantial scattered light from the Earth’s atmosphere, which is not analogous to the lighting conditions on the present Moon. The team assessed basic illumination of the crater features from a number of angles and assessed ease of navigation of the field site under the low-angle lighting conditions. A small uncrewed aerial vehicle (UAV) was deployed to collect overhead images and video during the lighting experiment to document and assess overall illumination, test shadow coverage and length, and document multiple perspectives on the field conditions. The aerial images taken during this test illustrate the stark lighting conditions, dark shadowed regions produced, and length of shadows cast by team members (Figs. 1 & 2). Shadows of team members in the scene are cast approximately 100 m down-sun in this lighting configuration. Additionally, even small topographic features such as the tire tracks in the foreground of Fig. 1 cast elongated dark shadows, emphasizing the effect of minor topographic features on visibility and ease of navigation.

**Crater Morphology Analysis:** We produced digital elevation model (DEM) data (4 cm/pixel) and orthographic images of the Cinder Lake Crater field sites (Fig. 3) using stereophotogrammetry from day-time aerial images (1 cm/pixel) collected by a UAV-mounted camera. The data will be used for site analysis leading up to and during the rover and astronaut analog deployments in project years 2 and 3. Derived map products will include parameters that aid real missions, including slope, elevation, hillshade models, and illumination maps based on simulated lighting scenarios. Shadow mapping / modeling for the field site can accurately predict the terrain shadows that will be cast by the set illumination from the artificial lighting system during the upcoming analog deployments, as well as predict temporary versus permanent shadows for lunar conditions [6], making it a useful tool for both pre-planning and navigation during the upcoming field tests.
Figure 1 - Three ARDVARC team members stand in front of a crater at the Cinder Lake Crater Field 2 site. The scene is illuminated by JSC’s “artificial sun” lighting system, simulating near-horizon solar illumination. Dark elongated shadows are cast by topographic features of all scales and by team members.

Figure 2 - Downward looking UAV image of the Cinder Lake Crater Field 2 site during lighting test. This perspective emphasizes the light and shadows cast across multiple degraded craters and illustrates the extent to which the lighting system can illuminate the terrain.

Figure 3 - DEM of Cinder Lake Crater Field 1 generated via UAV photogrammetry. Craters (negative topographic features) and vegetation (positive topographic features) can both clearly be distinguished. The red line shown is ~30m in length.

Future Work: In Fall of 2024 the ARDVARC team will deploy a small 4-wheeled rover platform provided by Mission Control Space Services Inc. to the Cinder Lake Crater Field site. The rover uses onboard camera systems to navigate and will be teleoperated in real-time using their Spacefarer mission operations software platform. The main goal of the rover deployment will be to use onboard cameras and an attached Leica BLK 360 LiDAR system to image and map as much of the designated field area as possible during the operational window. The analog rover deployment will take place over the course of one week, operating during hours after the sun has set, ensuring that the only illumination of the field area will be from the JSC lighting system described above. The rover will be remotely operated from a mission control room at NASA Goddard. The ARDVARC rover deployment will serve as a testbed for con-ops related to real-time rover navigation in a lunar polar lighting environment. The LiDAR and image data collected by the rover will be used to form the basis of a terrain-morphology-based Augmented Reality (AR) data visualization system that will be deployed in project year 3. In Spring of 2025 the final ARDVARC field deployment will take place, involving ARDVARC team members as analog astronauts. The astronauts will use an AR head-mounted display, likely the new Apple Vision Pro system, to assess the viability of AR-based data visualization to assist with human navigation of an analog lunar polar environment. Potential real-time data visualizations include an overlay of the rover traverse path onto the real world terrain, overlay of elevation or slope data, and an overlay of the nominal astronaut traverse path or waypoints to assist with wayfinding during the analog Extra Vehicular Activities (EVA’s).

Conclusion: Cinder Lake Crater Fields continue to serve as excellent lunar analogs for testing, training, and field operations. ARDVARC is set to conduct high-fidelity rover and astronaut operations that will provide valuable scientific and operational insights for several aspects of the Artemis program.

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