KNaCK

Demonstrating SLAM (Simultaneous Localization and Mapping) LiDAR as a Tool for Exploration and Mapping of Lunar Pits and Caves

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MSFC ENGINEERING

Science & Technology Office

ES Space Systems Dept

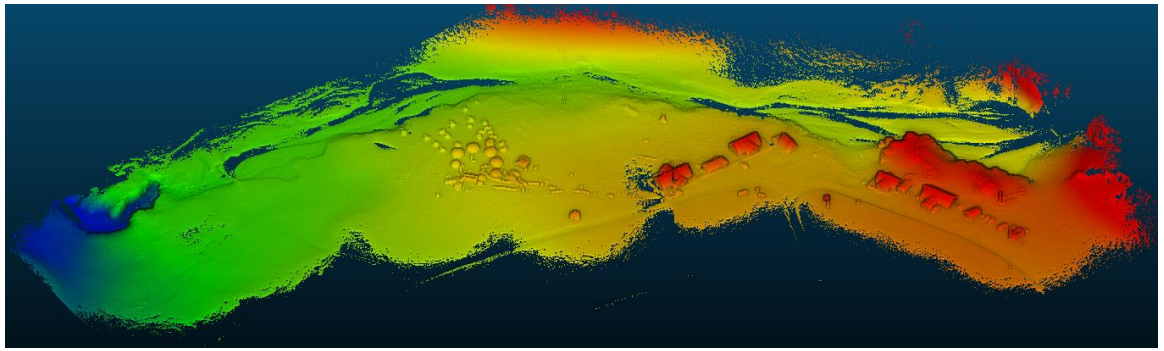
Overview

KNaCK (Kinematic Navigation and Cartography Knapsack) is a backpack-mounted mobile LiDAR (Light Detection and Ranging) system. It can map its surroundings in 3 dimensions and localize itself in space.

The project objective is to explore how LiDAR can advance terrain mapping and navigation at the lunar south pole. KNaCK is lead by Dr. Michael Zanetti of NASA MSFC's Heliophysics and Planetary Science Branch.

KNaCK serves as

- A test article for GPS denied mapping and navigation
- A test bed for SLAM (Simultaneous Localization and Mapping) algorithms
- A test bed for commercial LiDAR units
- A tool for terrestrial science



Advantages of Mobile LiDAR

Advantages:

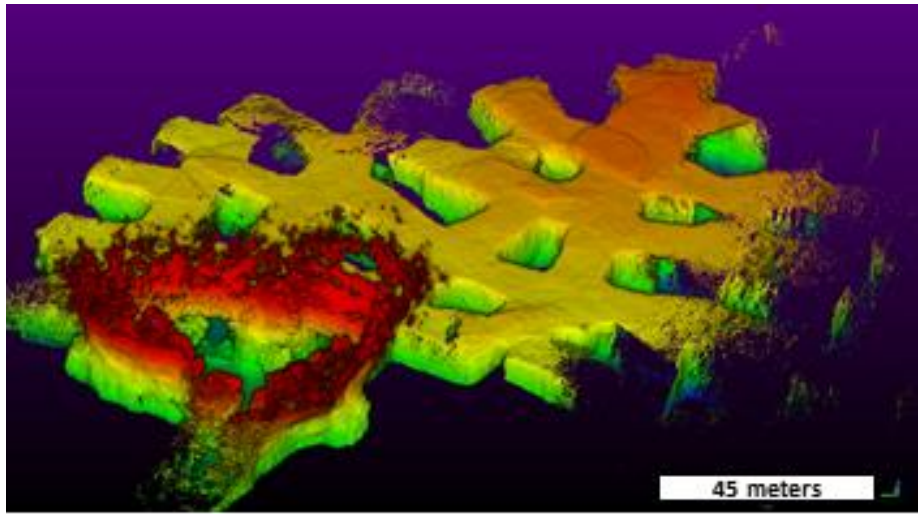
- Not dependent on illumination conditions
- Not dependent on GPS
- Rapid survey potential
- Sufficient detail for geoscientific and architectural use
- Compatibility with EVA suits and exploration vehicles

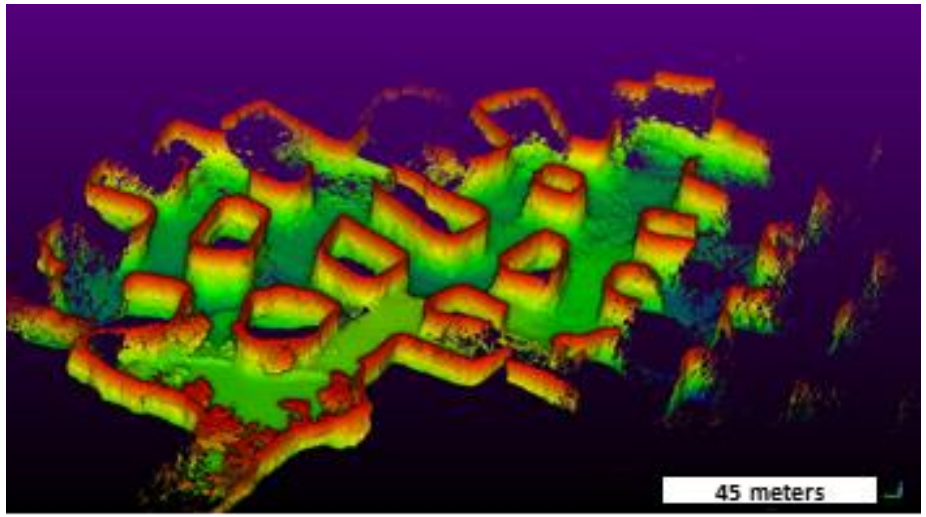
Planetary Cave Applications:

- Assessing significance of features for science, ISRU, or habitation
- Establishing the concepts of operation to enter and explore features on future robotic or manned missions
- Investigate geologic and morphologic history of subterranean spaces

Terrestrial Cave Applications:

- Enhanced studies of geomorphology, speleogenesis, hydrology, air circulation, habitat inventory, and other environmental and geologic studies





3 Caves Quarry, Huntsville, AL, USA

Terrestrial Caves as Planetary Analogs

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Demonstrating GPS Denied Terrain Mapping and Navigation

- Surface Exploration Goals at the Lunar South Pole
- Planetary Void Exploration

Caves Provide:

- GPS Denied Environments
- Challenging Illumination Conditions
- Highly Rugged and Irregular Terrain

- Lava River Cave
  - Location: San Francisco Volcanic Field, Arizona, USA
  - Age: ~700,000 years old
  - Length: 1165 meters surveyed (tape and compass, 1984)
  - Geologic Features: Flow ripples, cooling fractures, splashdowns/rafted blocks, and lavacicles

Lava River Cave

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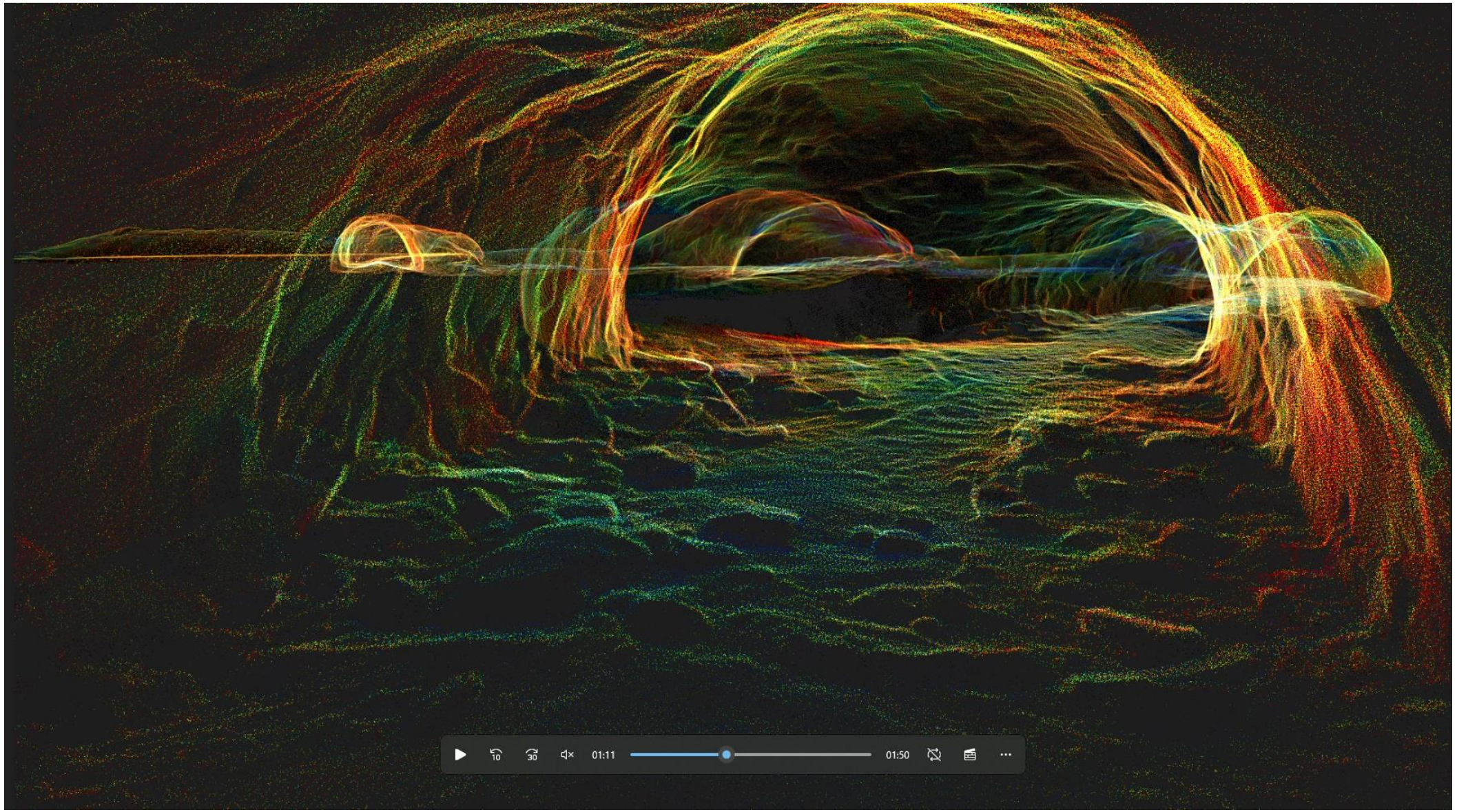

KNaCK SLAM Map

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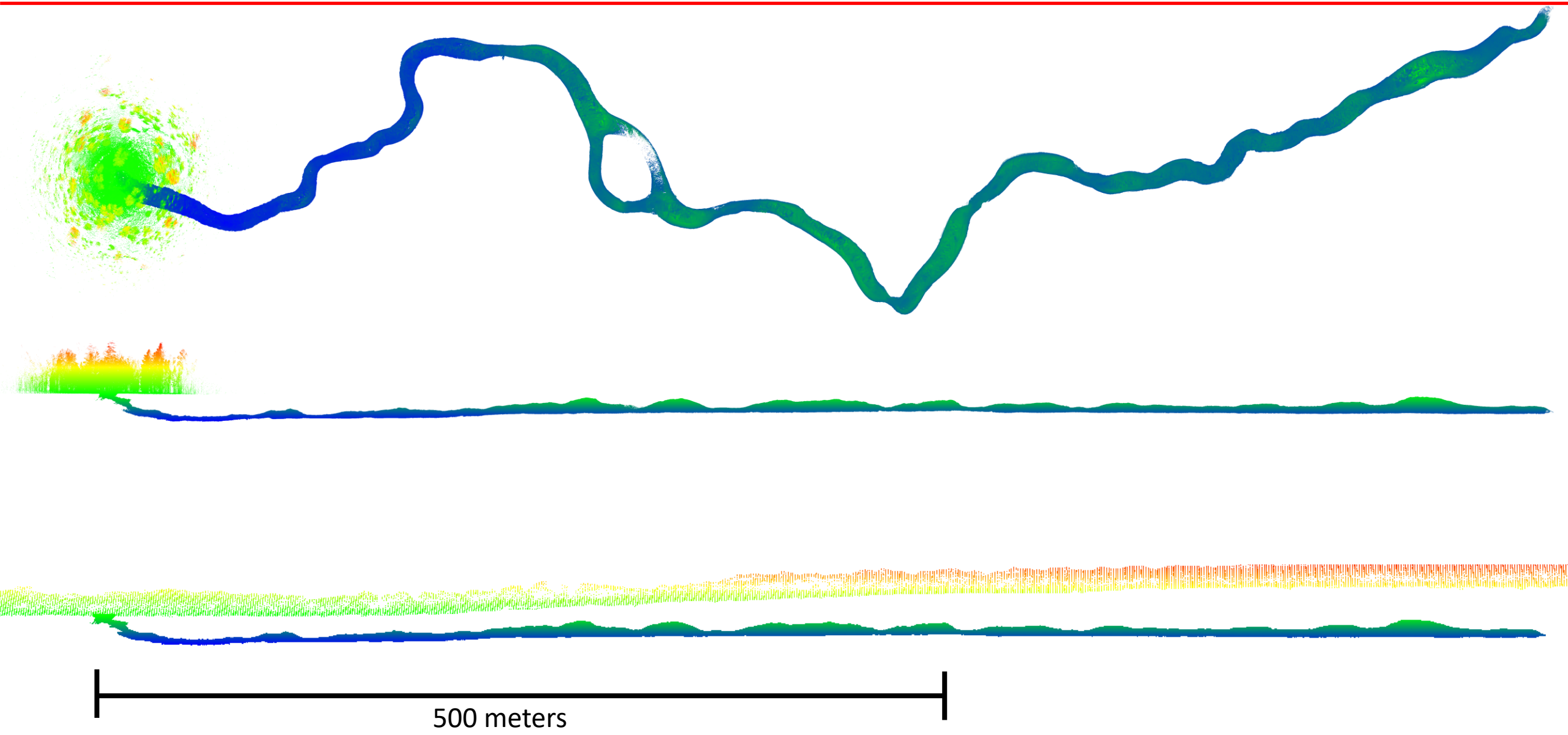
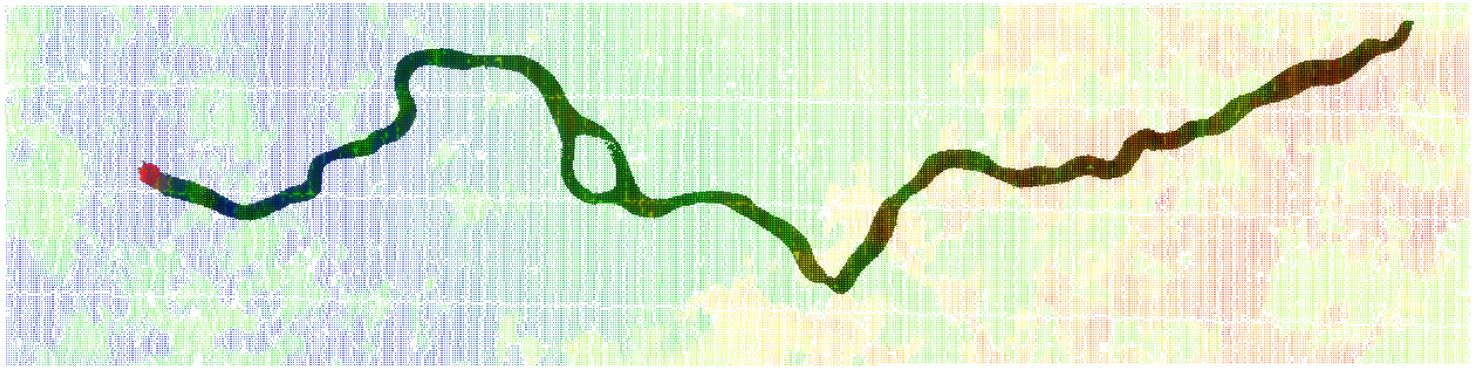
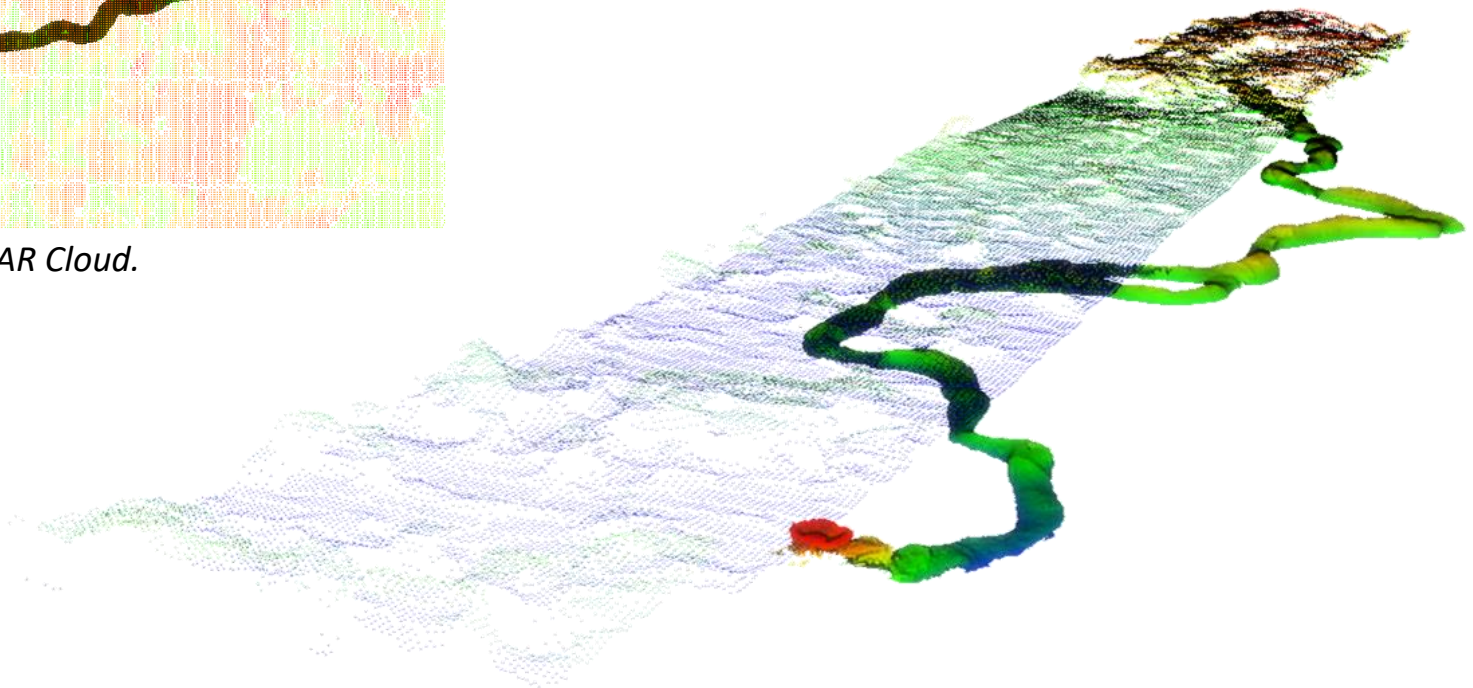


KNaCK SLAM Map

- Lava River Cave scan collected in 44 minutes
- Resulting map contains 44.8M points
- Centimeter scale accuracy
- Integrating existing surface elevation models allows correlation between surface and subsurface features



NAIP Point Cloud (2017) overlaid on Lava River Cave LiDAR Cloud.



Comparing to the 1984 Survey

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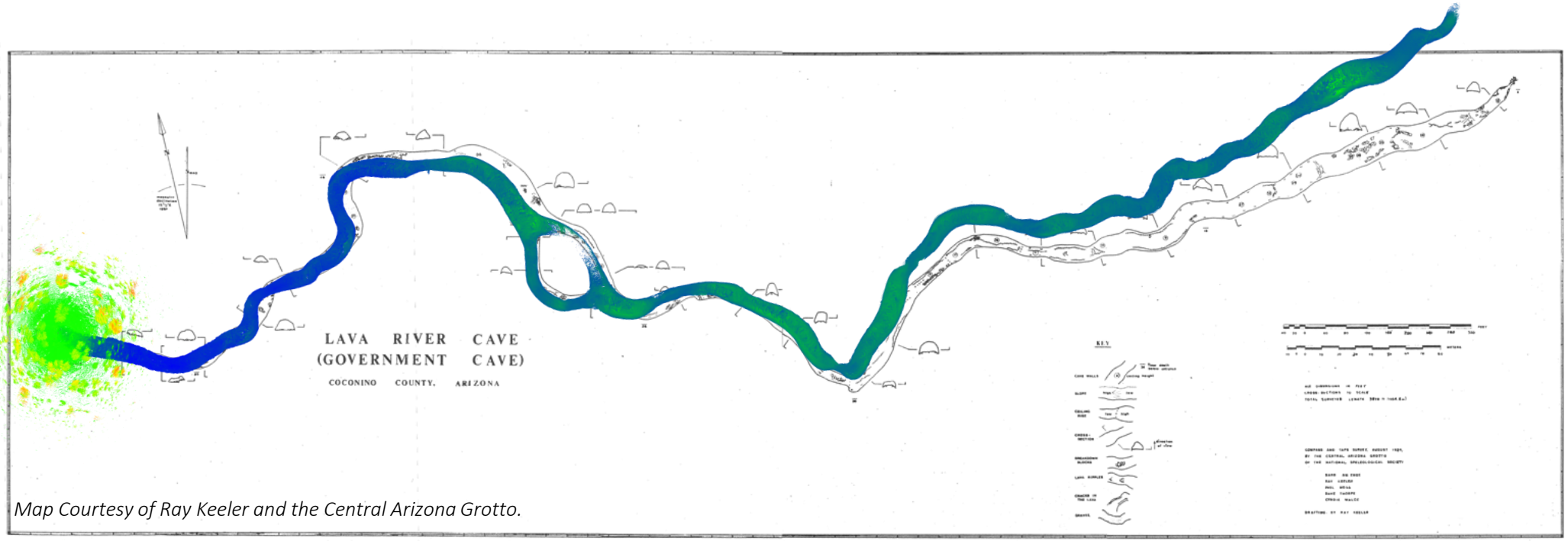
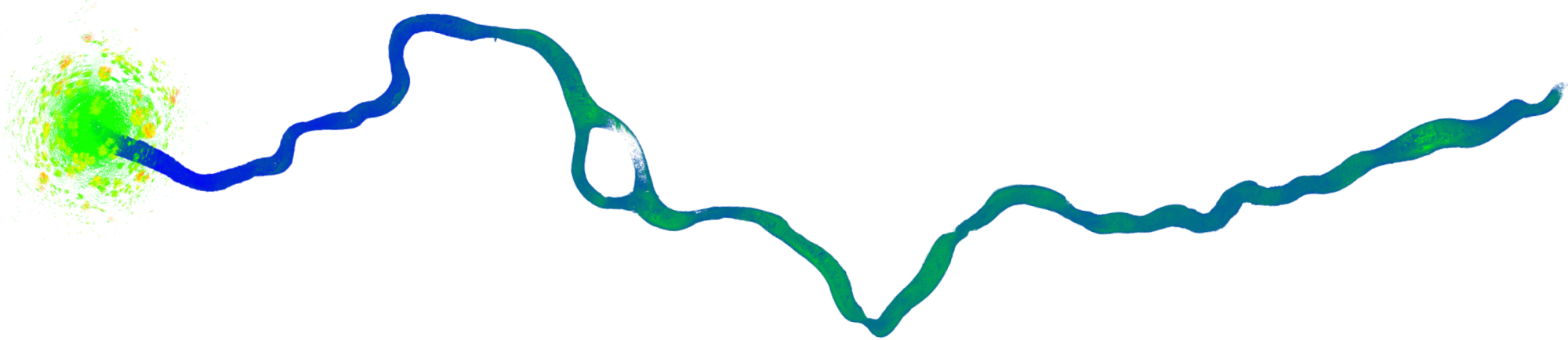


Map Courtesy of Ray Keeler and the Central Arizona Grotto.



500 meters

Comparing to the 1984 Survey

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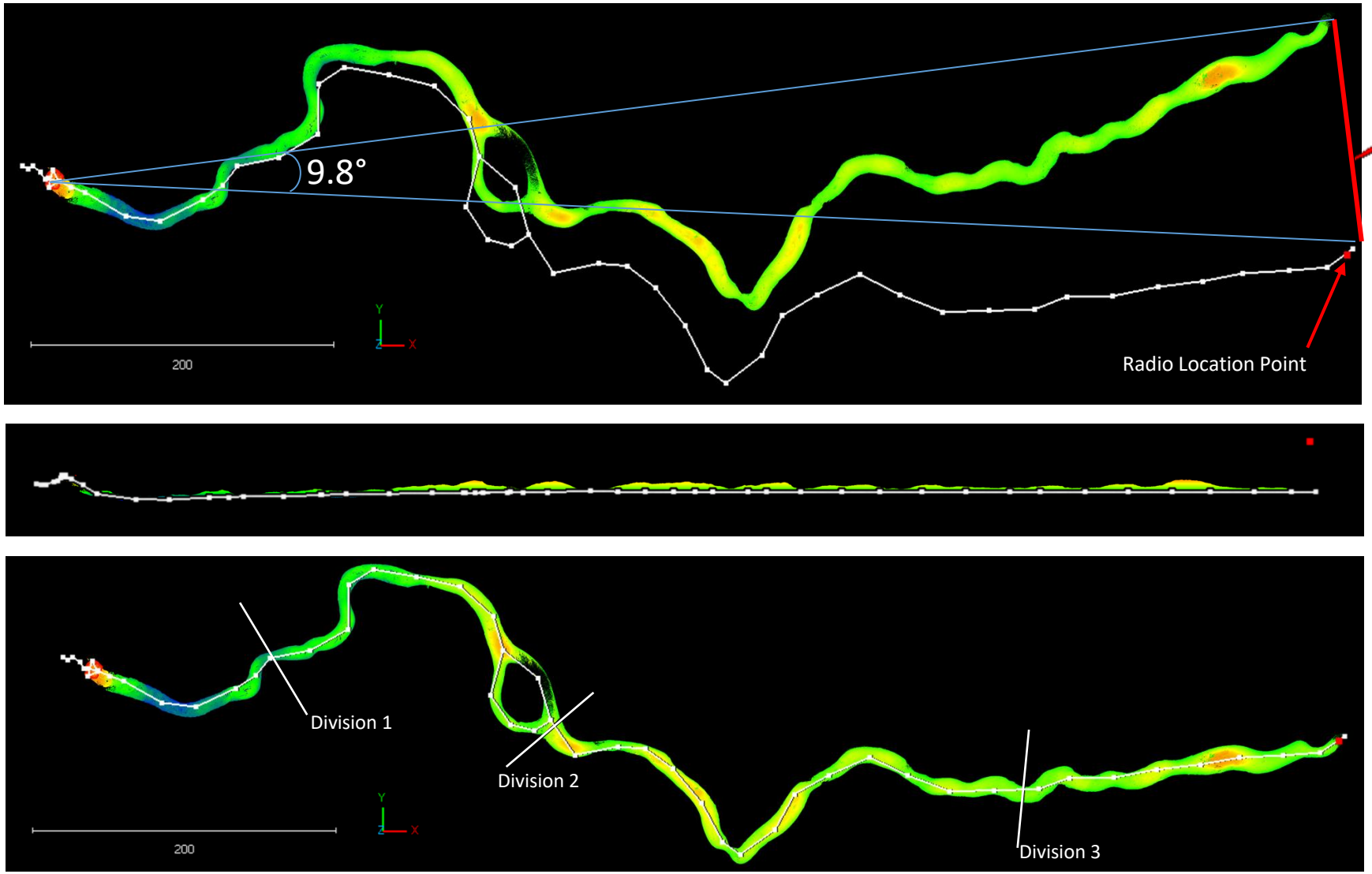
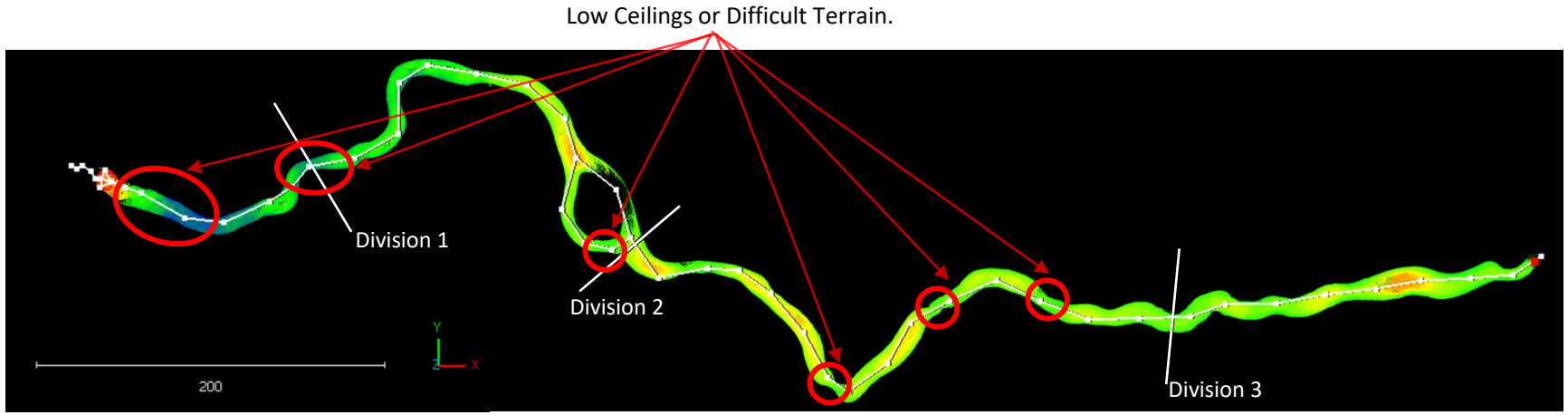


- Alignment based on probable station locations and plausible shots into the cave. Original station placement unknown
- Radio location point indicates accuracy of the 1984 survey
- <10 degrees of total deviation between the point cloud and survey line plot
- Large portions of the point cloud are highly consistent with survey
- Division and manual alignment yields a map with both local and global accuracy

Survey data (line plot) courtesy of Ray Keeler and the Central Arizona Grotto. Radio location data courtesy of Paul Jorgenson.

Comparing to the 1984 Survey

- Small dead reckoning errors accumulate
- Error likely higher in narrow and difficult to traverse sections
- Large number of people moving in the cave may have interfered with scan matching
- Opportunities for enhancement:
  - Processing of complete dataset (out and back)
  - Tuning SLAM parameters
  - Constrain solution with other data (survey data or radio location stations)



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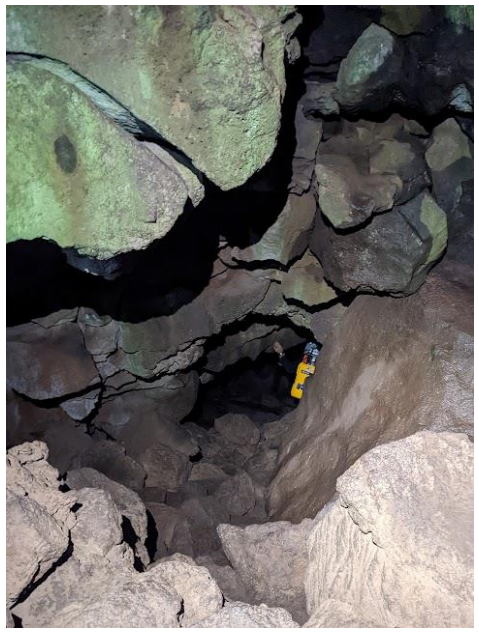

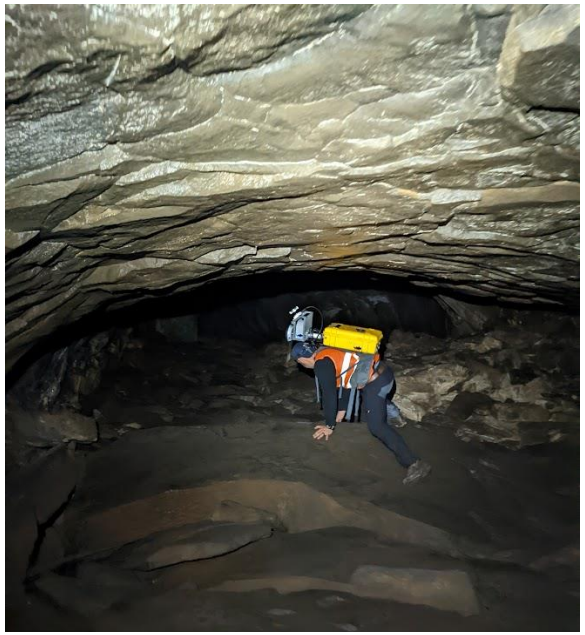

Fine Scale Features

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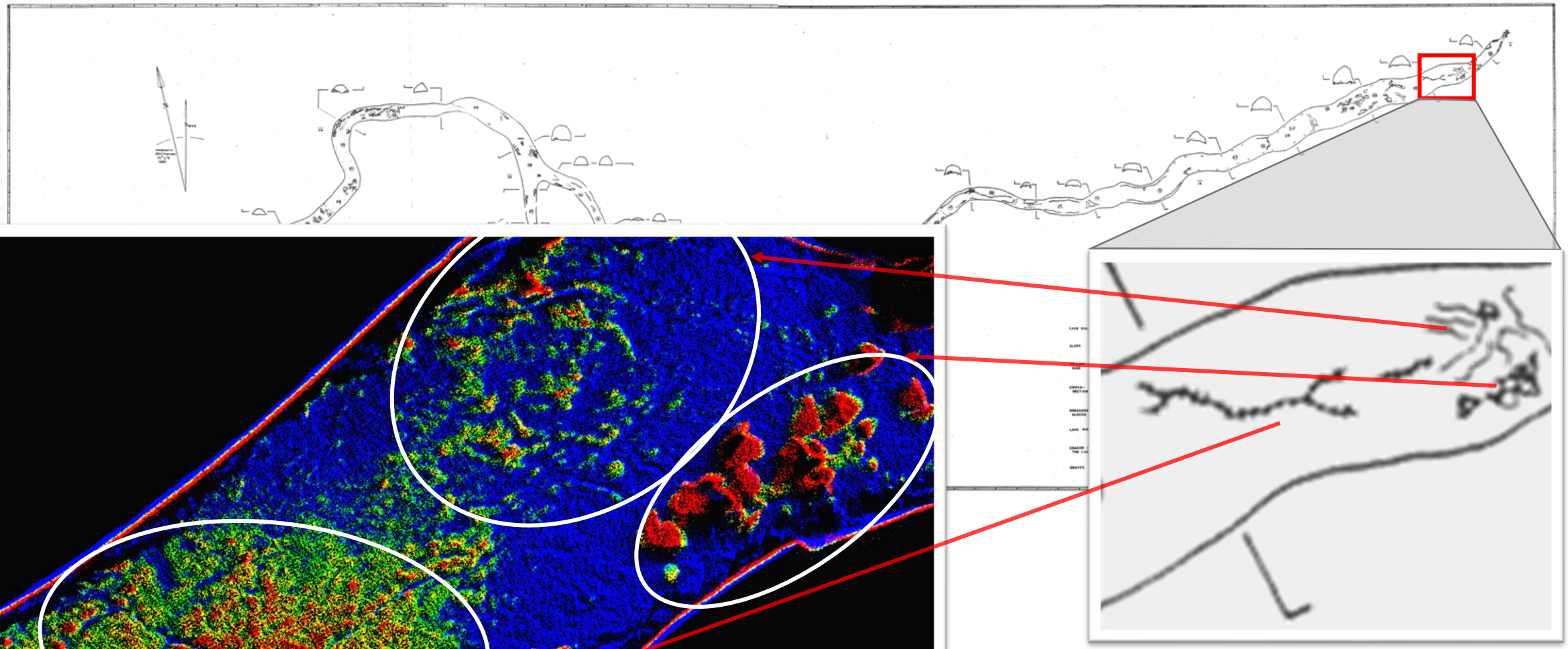

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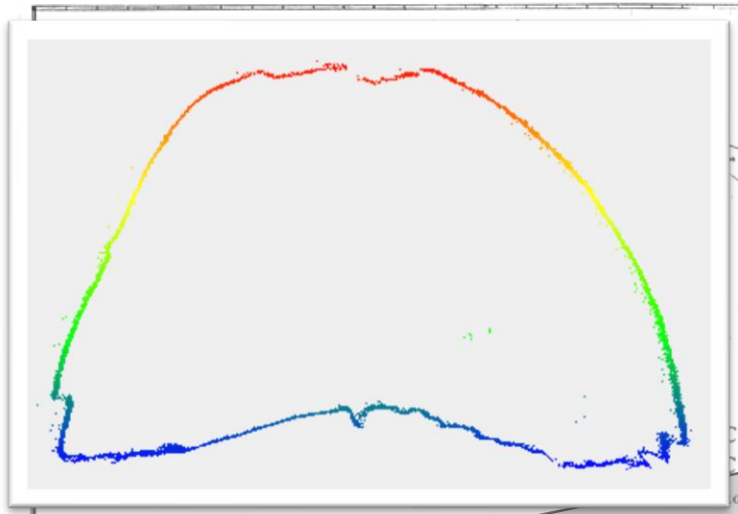

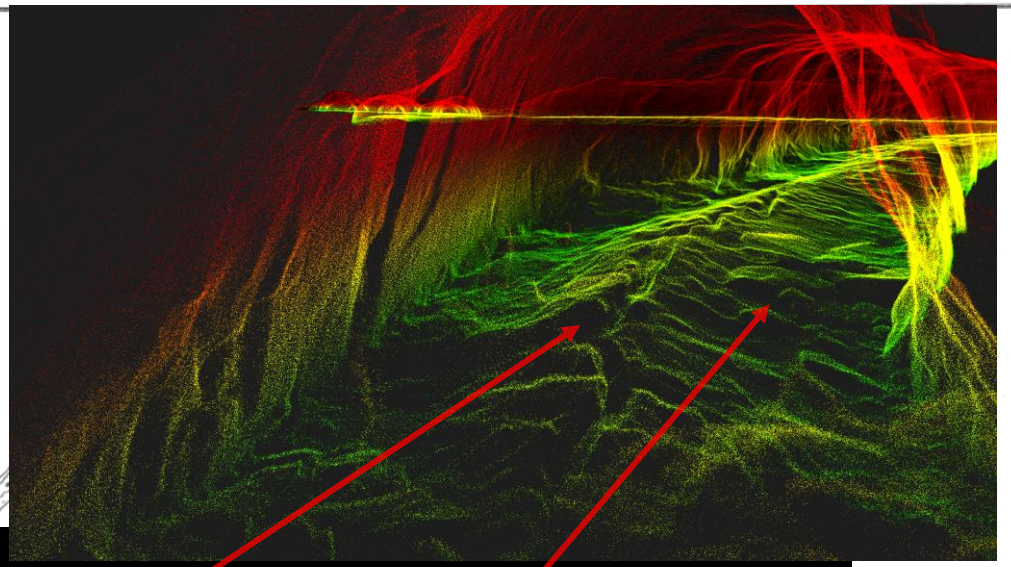

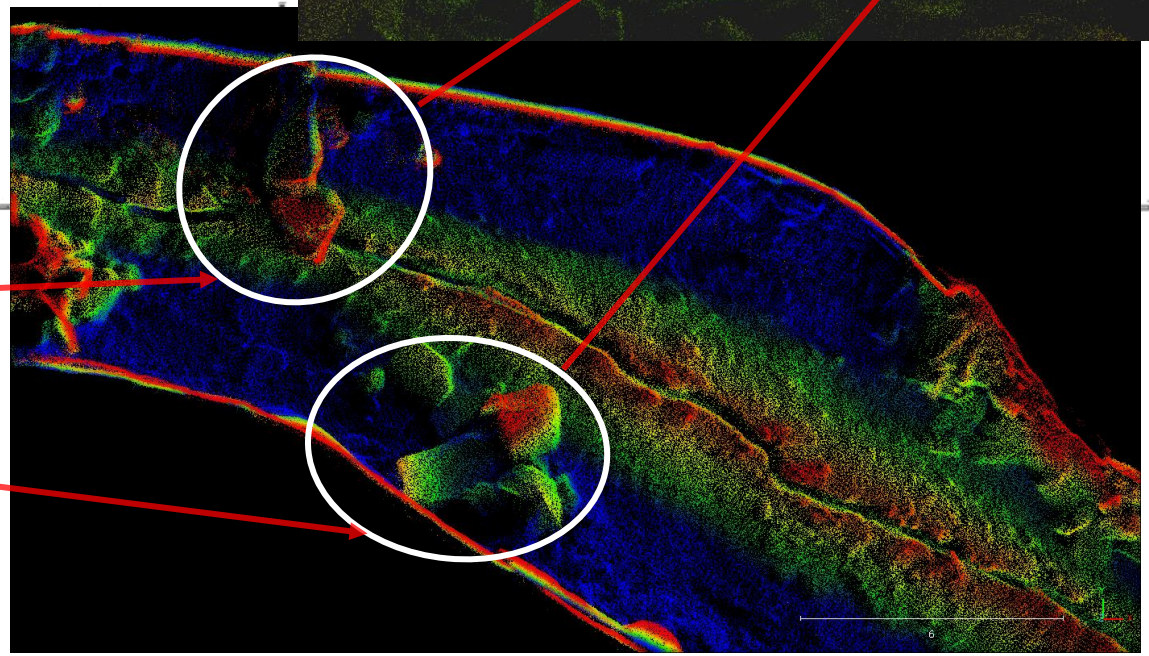

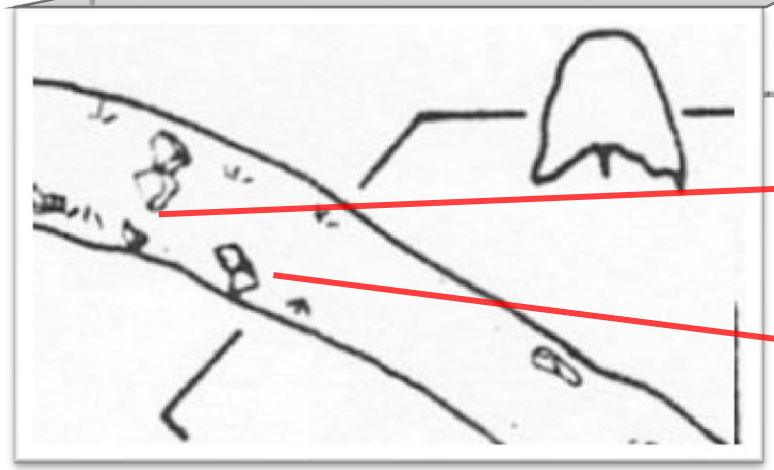

Summary

Kinematic Navigation and Cartography Knapsack.
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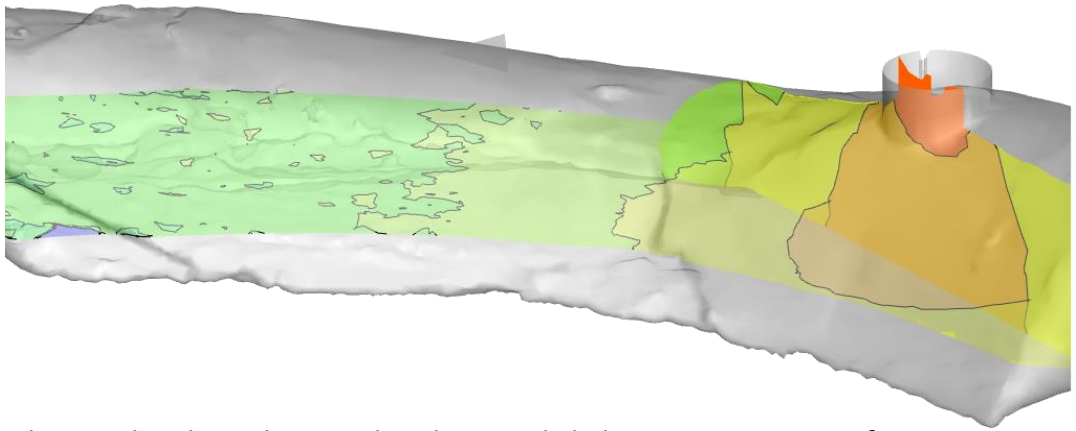
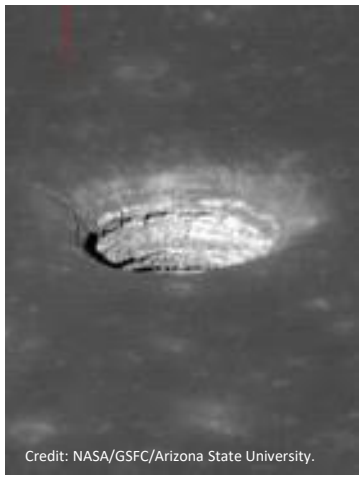
The Kinematic Navigation and Cartography Knapsack(KNaCK) is:

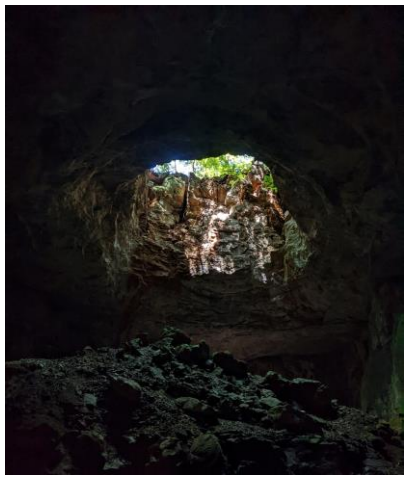
- Refining techniques for mapping and navigation on other worlds while simultaneously advancing State of the Art for terrestrial cave exploration and study. Terrestrial caves are excellent analogs for employing this technology on other worlds
- Easy to operate, sees beyond the cast of visible light, can operate without GPS, and can produce rapid and very detailed surveys
- Could be used to assess scientific significance and geologic history of a feature, its potential for ISRU or habitation, and establish the concepts of operation necessary to enter and explore it on future robotic or manned missions



Notional Radiation Flux through a Simulated Lunar Skylight using LiDAR Data from Lava River Cave. Caffrey J. A. et al. (2023) IPCC IV.



Mare Tranquilitatis Pit, Oceanus Procellarum, the Moon



Skylight in Three Caves quarry, Huntsville, Alabama, USA, Earth

Acknowledgements

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- Thank you to organizers of the 4th International Planetary Caves Conference.
- Open to collaborations!