Advancing Planetary Exploration – Where No LiDAR Has Gone Before

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About Me

- Michael Zanetti
  - Ph.D. Planetary Science from Washington University in St. Louis
  - Research Space Scientist at NASA's Marshall Space Flight Center, Huntsville, AL
  - Formerly a Post-doc at University of Western Ontario

- Interested in the application of LiDAR scanning to scientific research
  - geologic and geomorphologic processes
  - terrain mapping

Presentation Overview

- Comparative Planetology Applications of Ground-based LiDARs (TLS and KLS)
  - Using the Earth as an analog to study other Planets
  - The ‘new’ geomorphologist’s toolbox
  - Getting the message out to academics

- LiDAR for other planets
  - What we have and where we’re (possibly) going
  - Requirements and challenges

- Results from two recent articles for LiDAR Magazine:
  - *Comparative Planetology – LiDAR unveils similarities of Earth and Mars.* Vol. 9, No. 1
    - https://lidarmag.com/2018/04/27/comparative-planetology/
  - *FINESSEing Lunar Exploration – A role for LiDAR in the future of lunar exploration.* Vol. 8, No. 2
    - https://lidarmag.com/2019/01/27/finesseing-lunar-exploration/

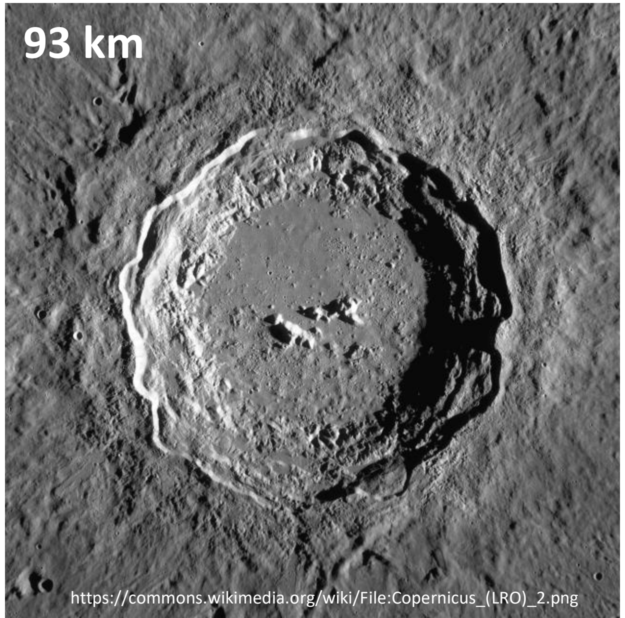
What is Comparative Planetology?

- Study of natural processes and systems on and between multiple planetary bodies
  - geology, geomorphology, hydrology, atmospheric physics, etc.
- Typically remote-sensing based
  - E.g. comparing morphology of impact craters on the Earth vs the Moon vs Mars vs Mercury.
- Need for “Ground-Truthing” observations

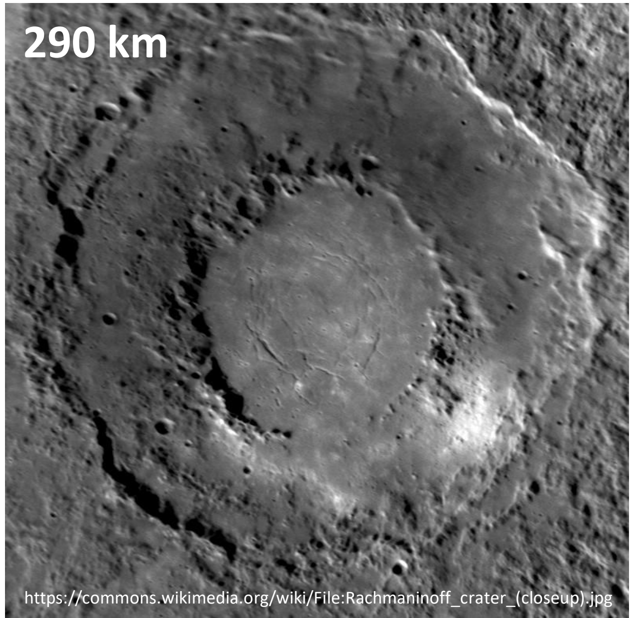
Earth

Mars

Moon



Mercury



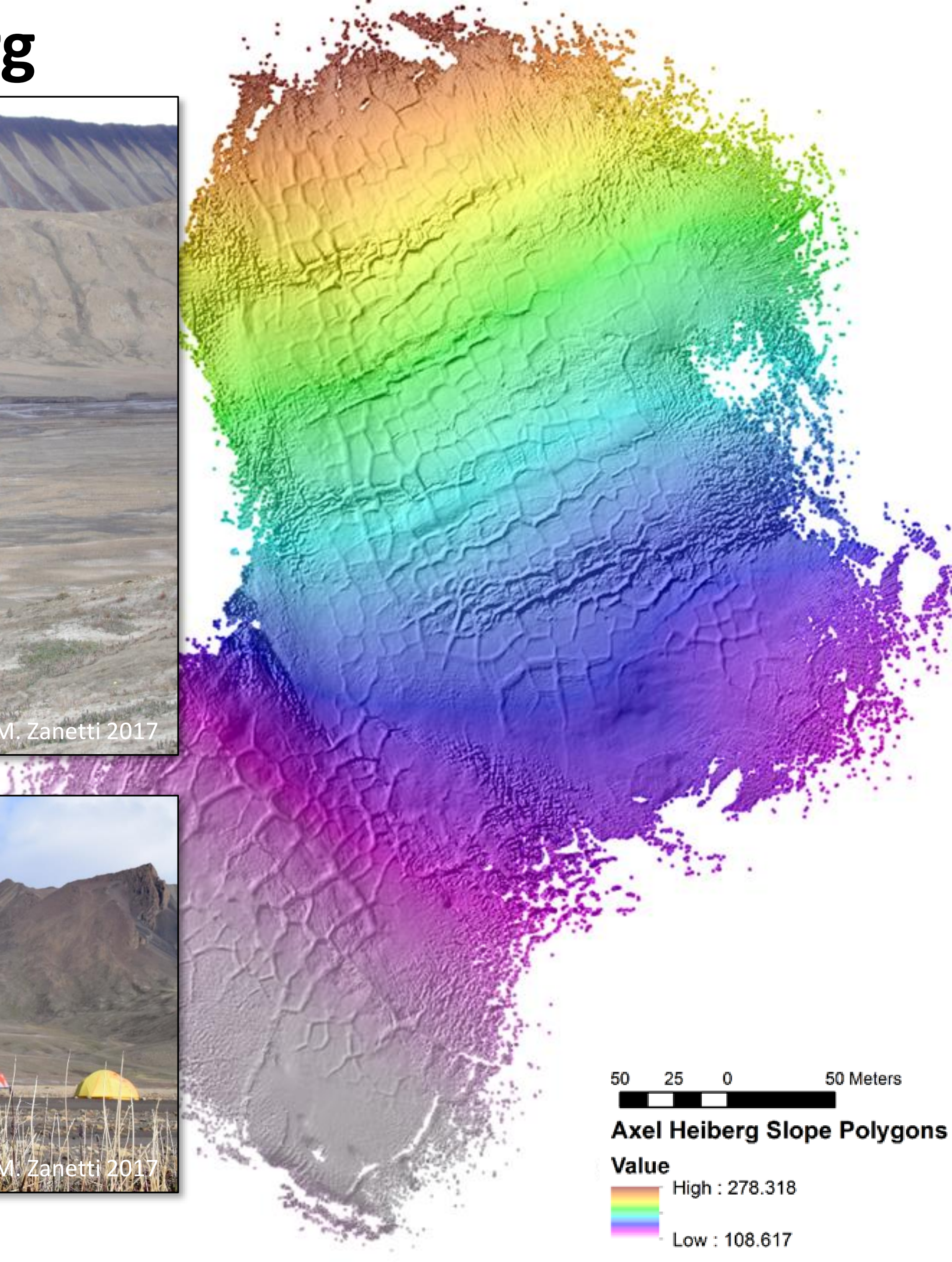
Axel Heiberg Island, Nunavut Canada

Teledyne Optech Maverick at Axel Heiberg

- Evaluating the "New Geomorphologist Toolbox" idea
  - What is the best way to collect site-specific, ultra-high resolution data for remote areas?
- Combining mobile LiDAR and UAV Drone photography

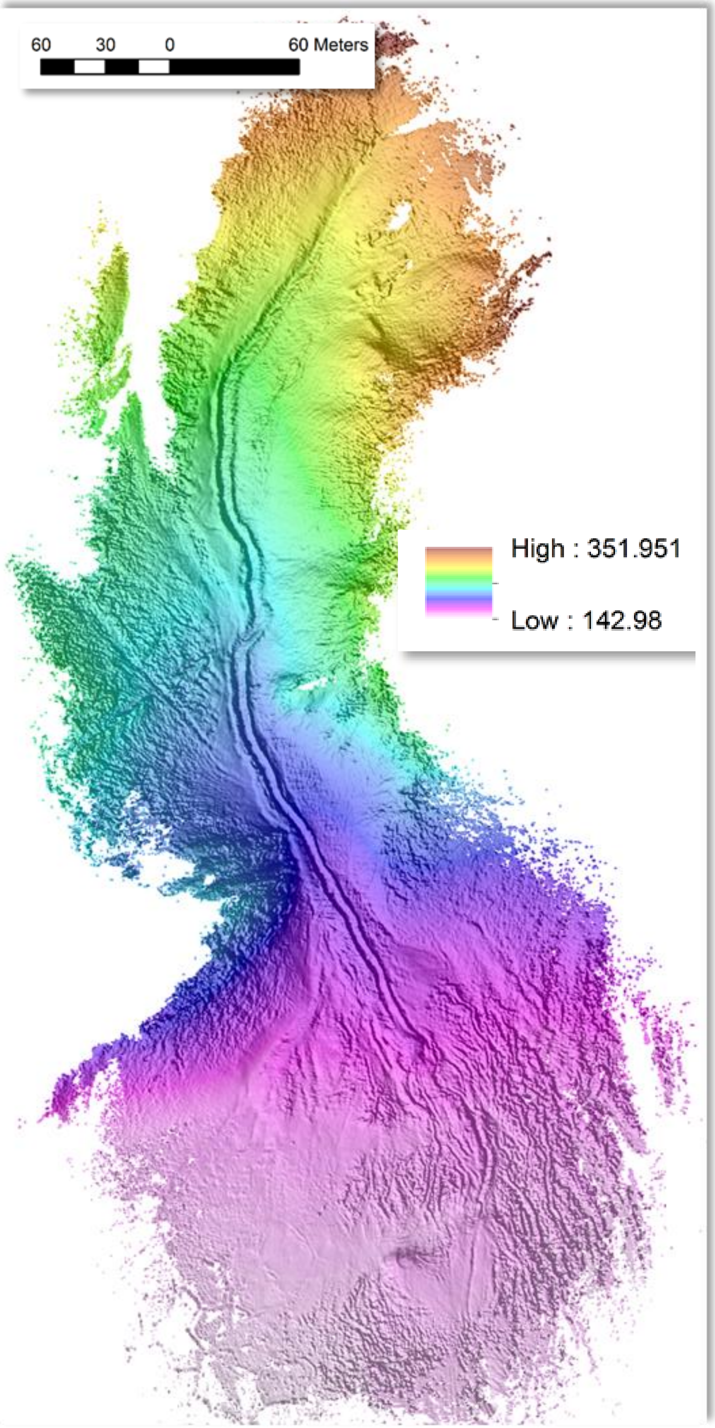
Mapping:

- Polygonal Patterned Ground
- Salt Deposits
- Channels and Gullies



Maverick collection on Salt Diapir Gully

- Mapping to constrain how different substrates change the morphology of gullies

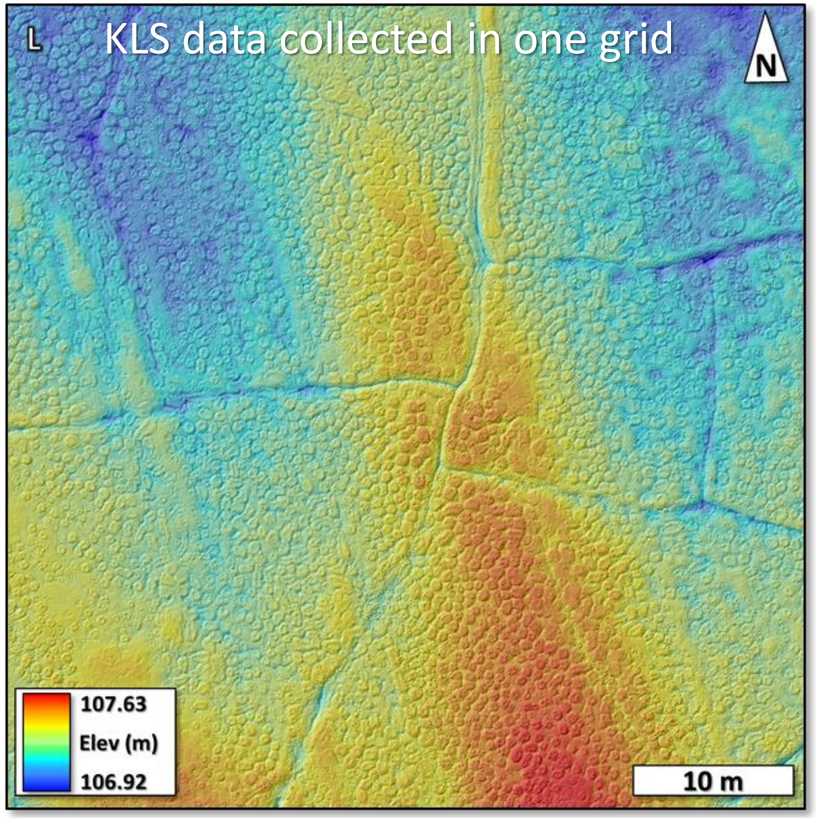


Mapping in Devon Island Canada

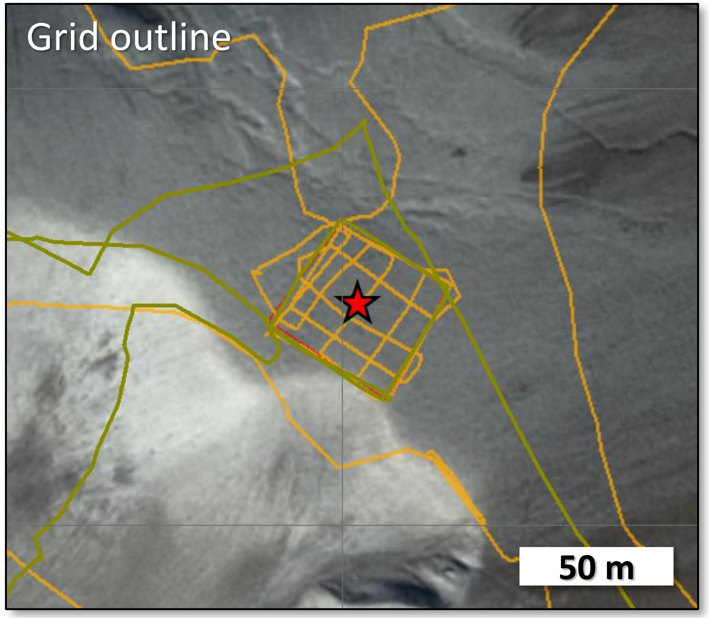
- Used for satellite radar surface-roughness analyses and understanding periglacial features

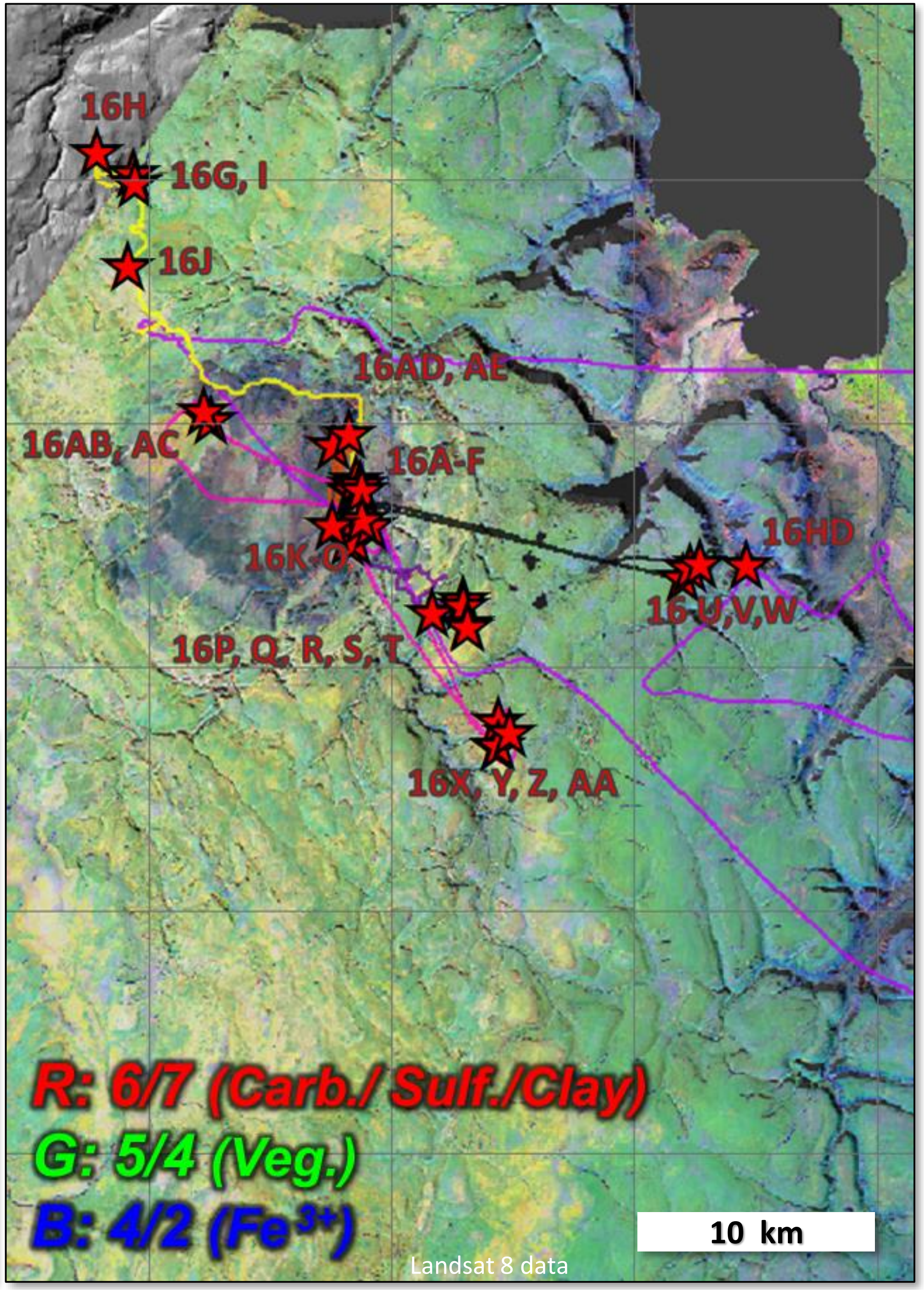
Mapping:

- 35 individual 50 m x 50 m “grids”
- Multiple acre-sized regions
- Gullies, channels, and geologic outcrops



https://en.wikipedia.org/wiki/Devon_Island#/media/File:Devon_Island,_Canada.svg

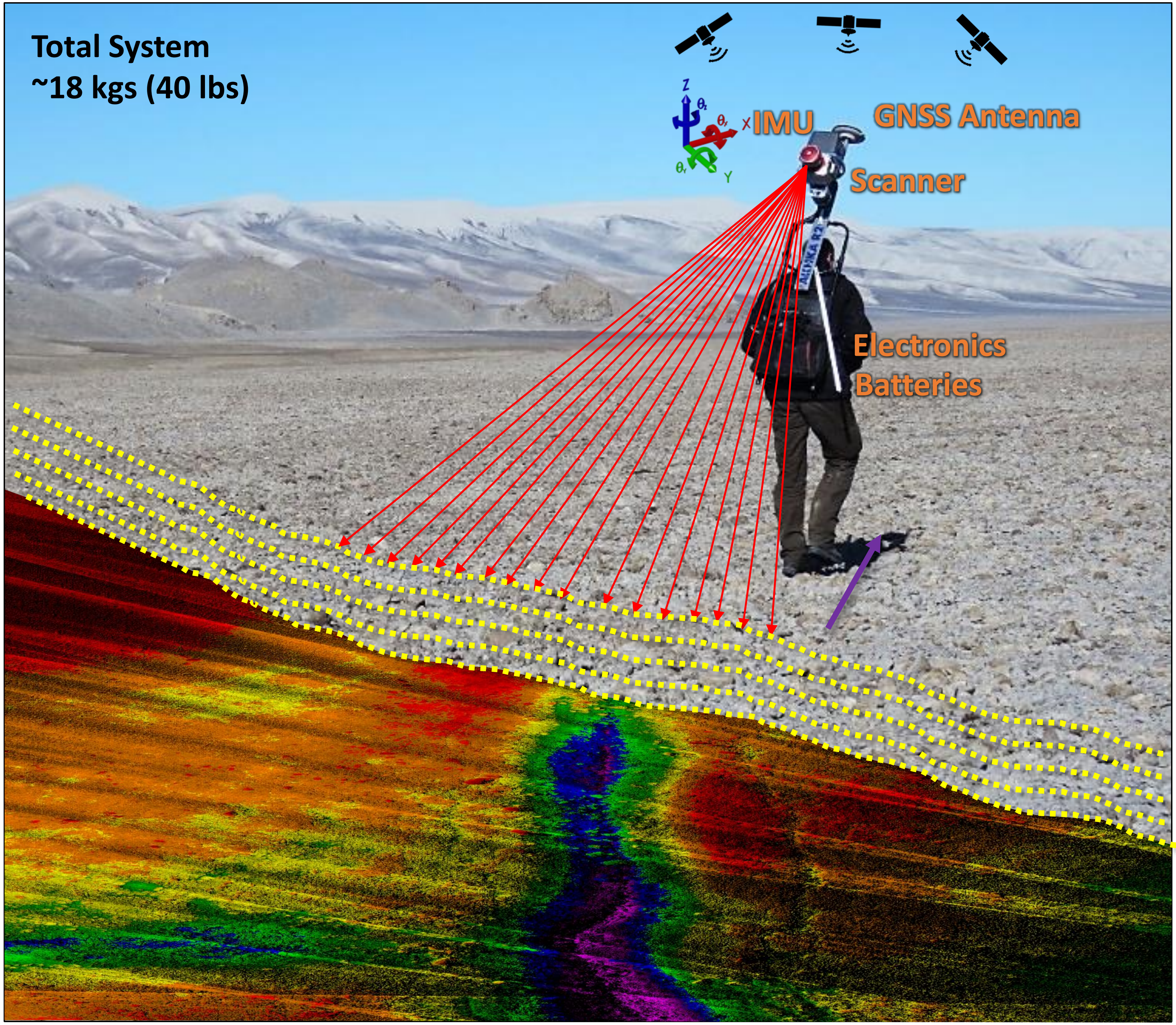




AKHKA-R3 Kinematic LiDAR Scanning (KLS)

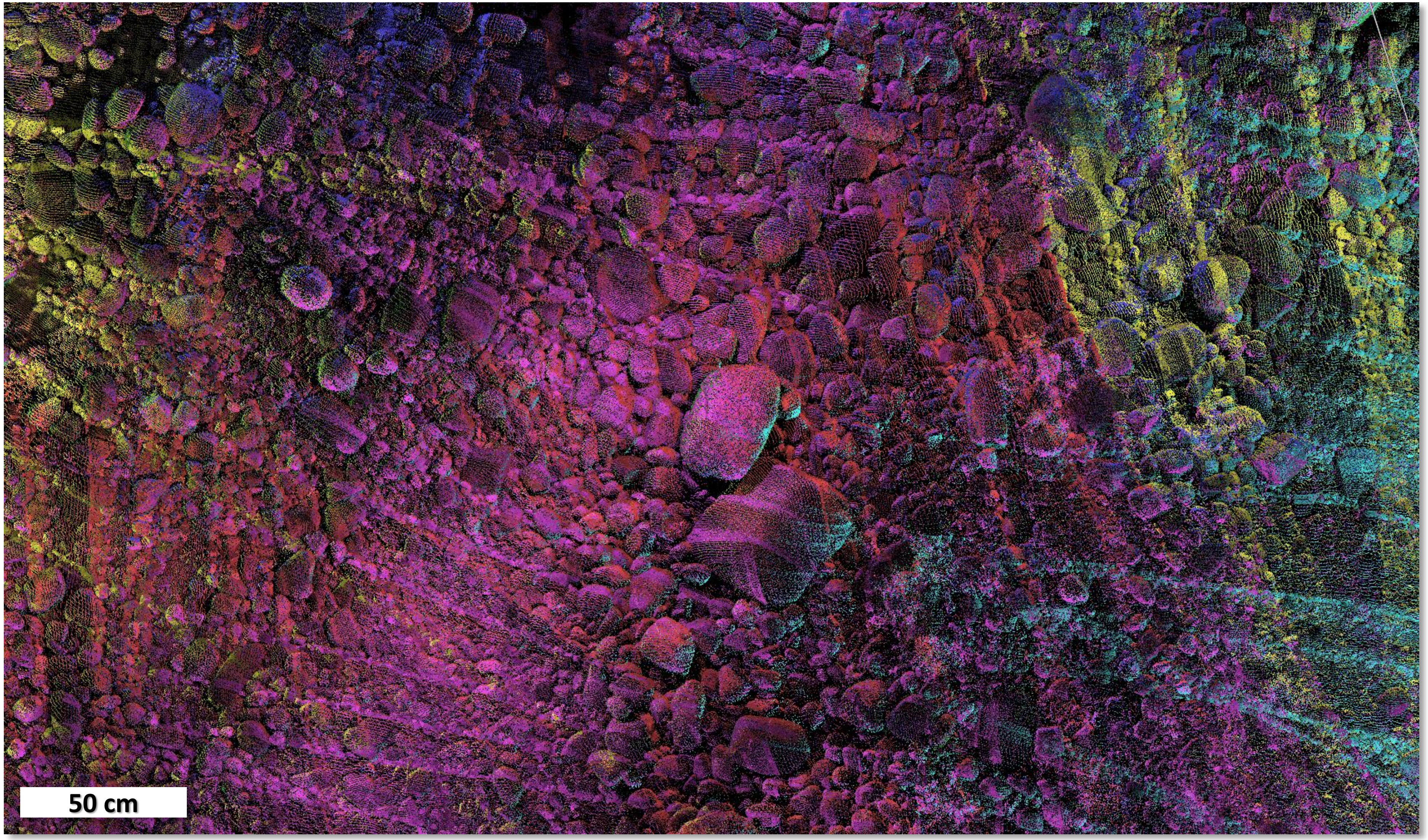
Laser Scanner:

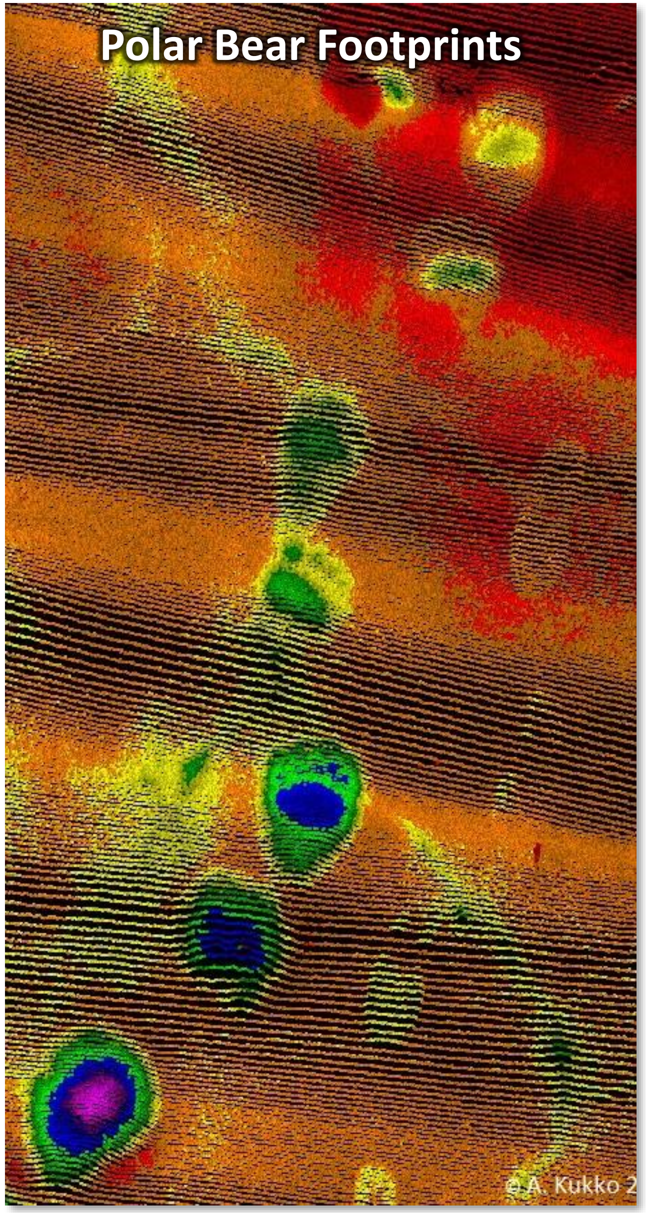
- **Riegl VUX-1HA**
  - 1550 nm
  - *1 Million Points/Second - 250 lines/second*
  - **Range Accuracy: 5 mm**
  - **Range Precision: 3 mm**
  - Range: >250 m
- **GNSS-IMU**
  - UIMU-LCI inertial measurement unit
  - 702GG GNSS antenna
  - Novatel SPAN: Flexpak6
  - 5 Hz range observation frequency
  - Position and attitude: 200 Hz
  - d-GPS accuracy (~1 cm)
- Trajectory is computed in post-processing (Novatel's Waypoint Inertial Explorer) with base station GNSS data for enhanced accuracy
- Features as small as 1 cm are clearly defined

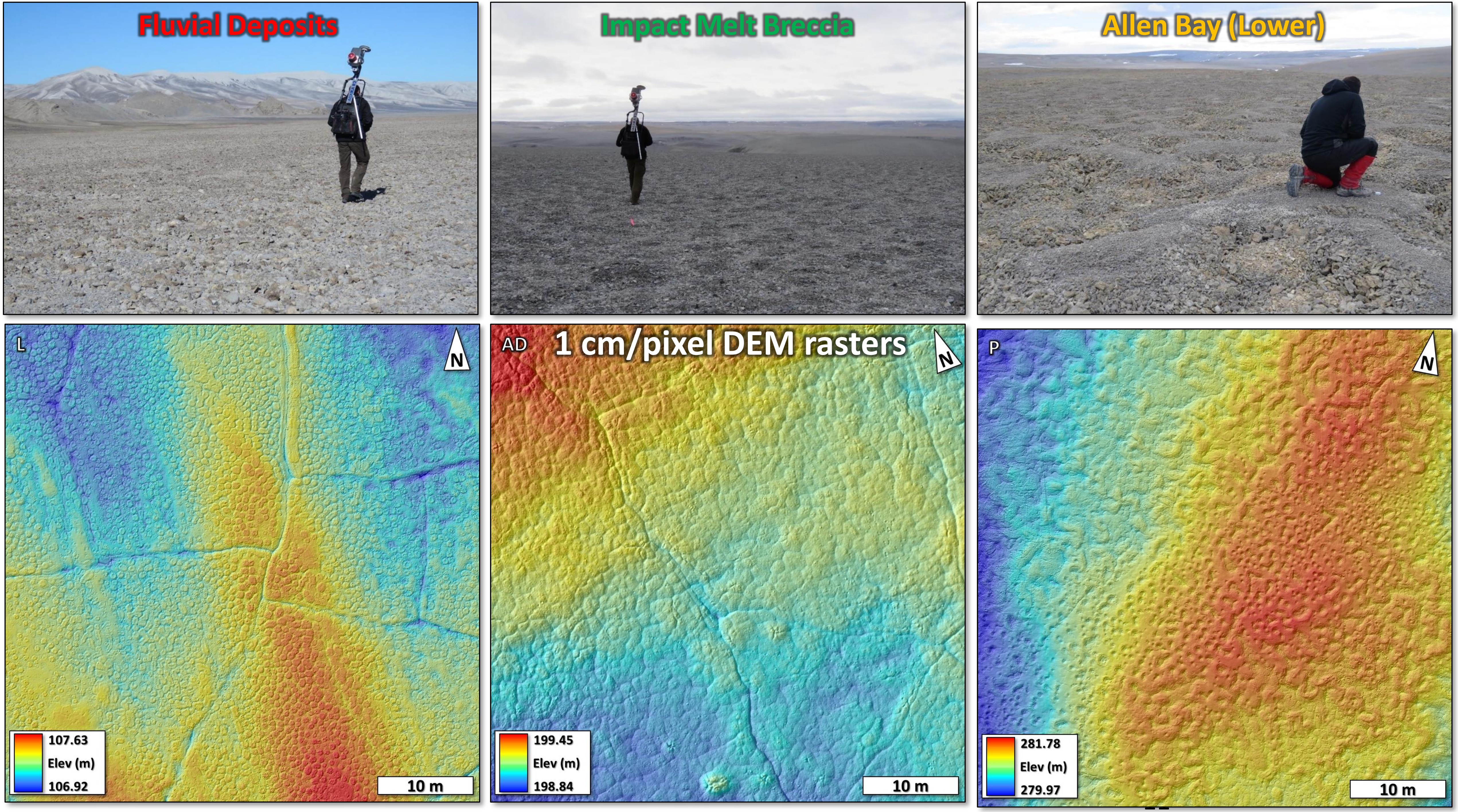


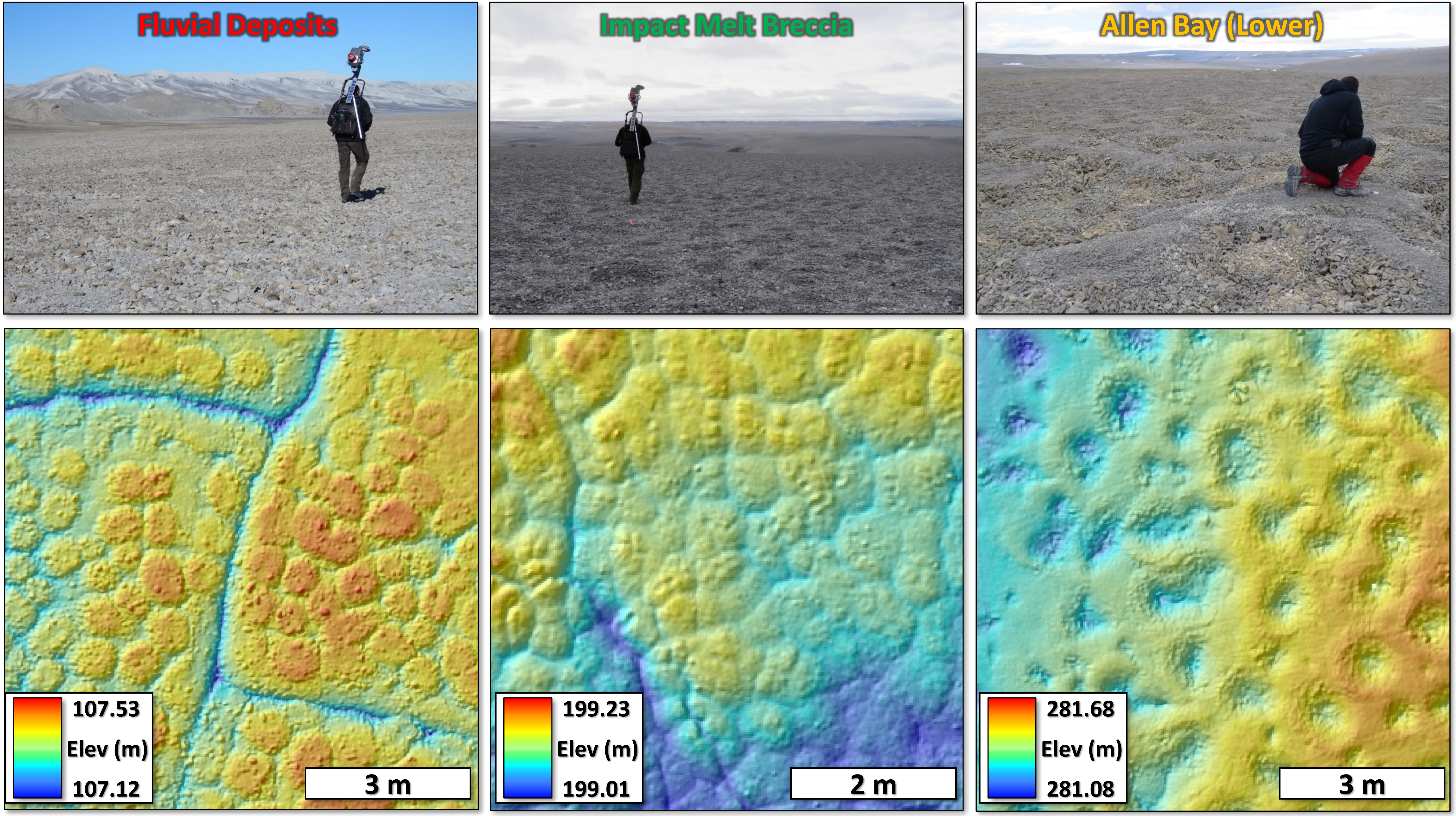
Akhka-R3 - Kinematic LiDAR Scanning Data:

- Typically > 5,000 points/m^2 within ~30 m of scanner
- Vertical accuracy ~5 mm





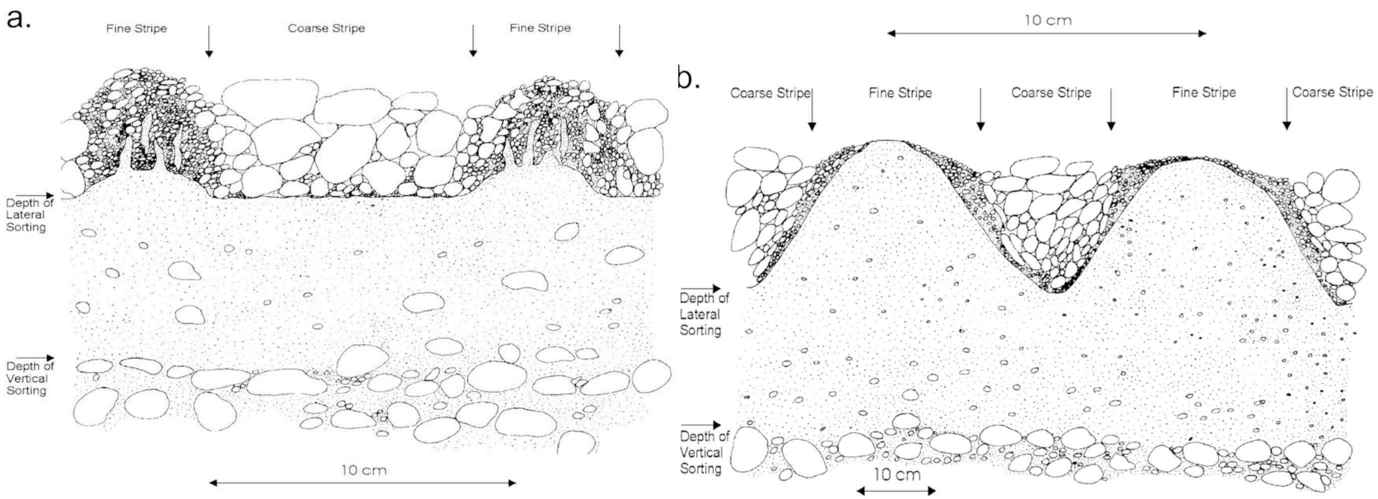

Fluvial Deposits
Impact Melt Breccia
Allen Bay (Lower)
L
N
107.63
Elev (m)
106.92
10 m
AD
1 cm/pixel DEM rasters
N
199.45
Elev (m)
198.84
10 m
P
N
281.78
Elev (m)
279.97
10 m



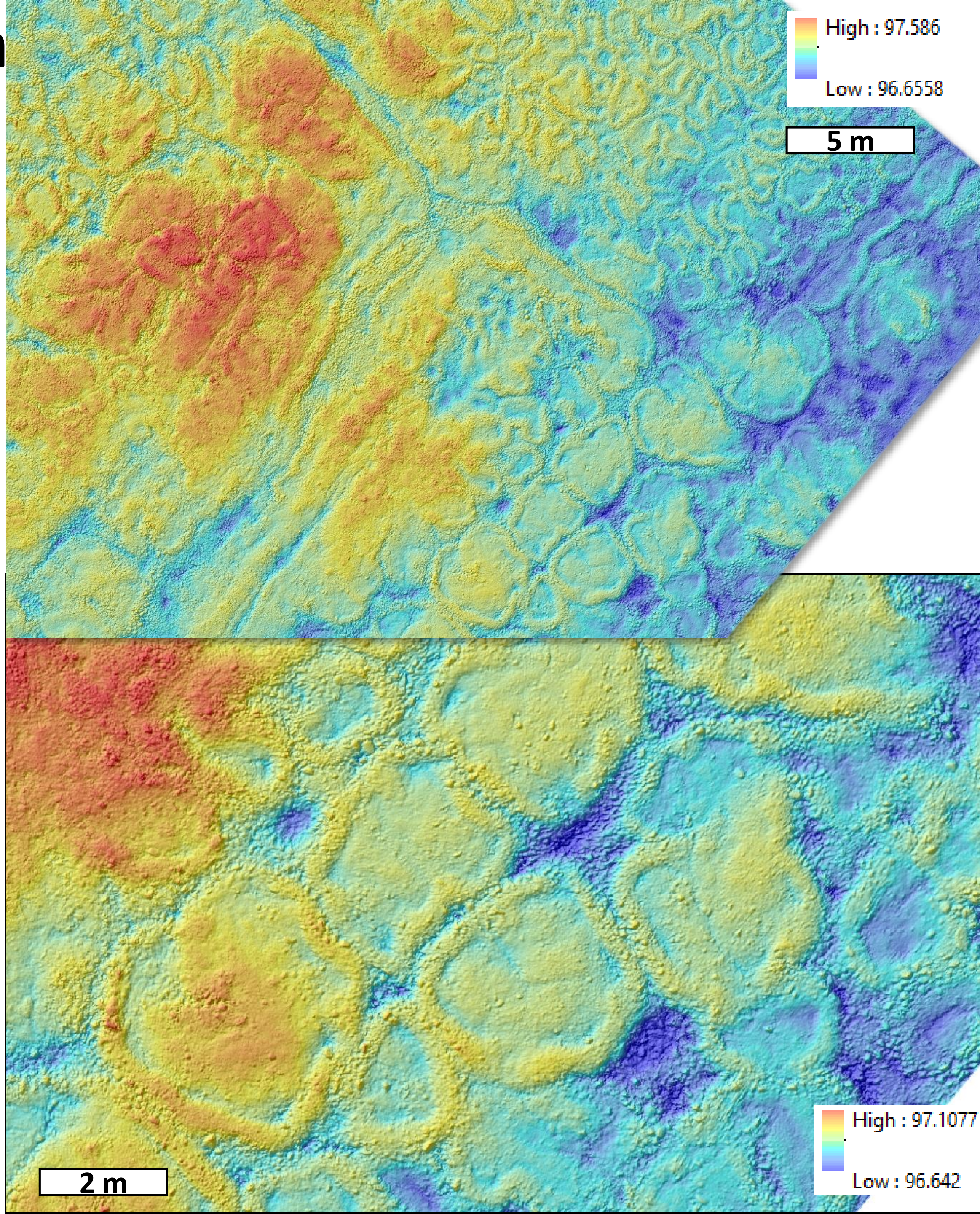
Fluvial Deposits
Impact Melt Breccia
Allen Bay (Lower)
107.53
Elev (m)
107.12
3 m
199.23
Elev (m)
199.01
2 m
281.68
Elev (m)
281.08
3 m

Periglacial Patterned Ground Formation

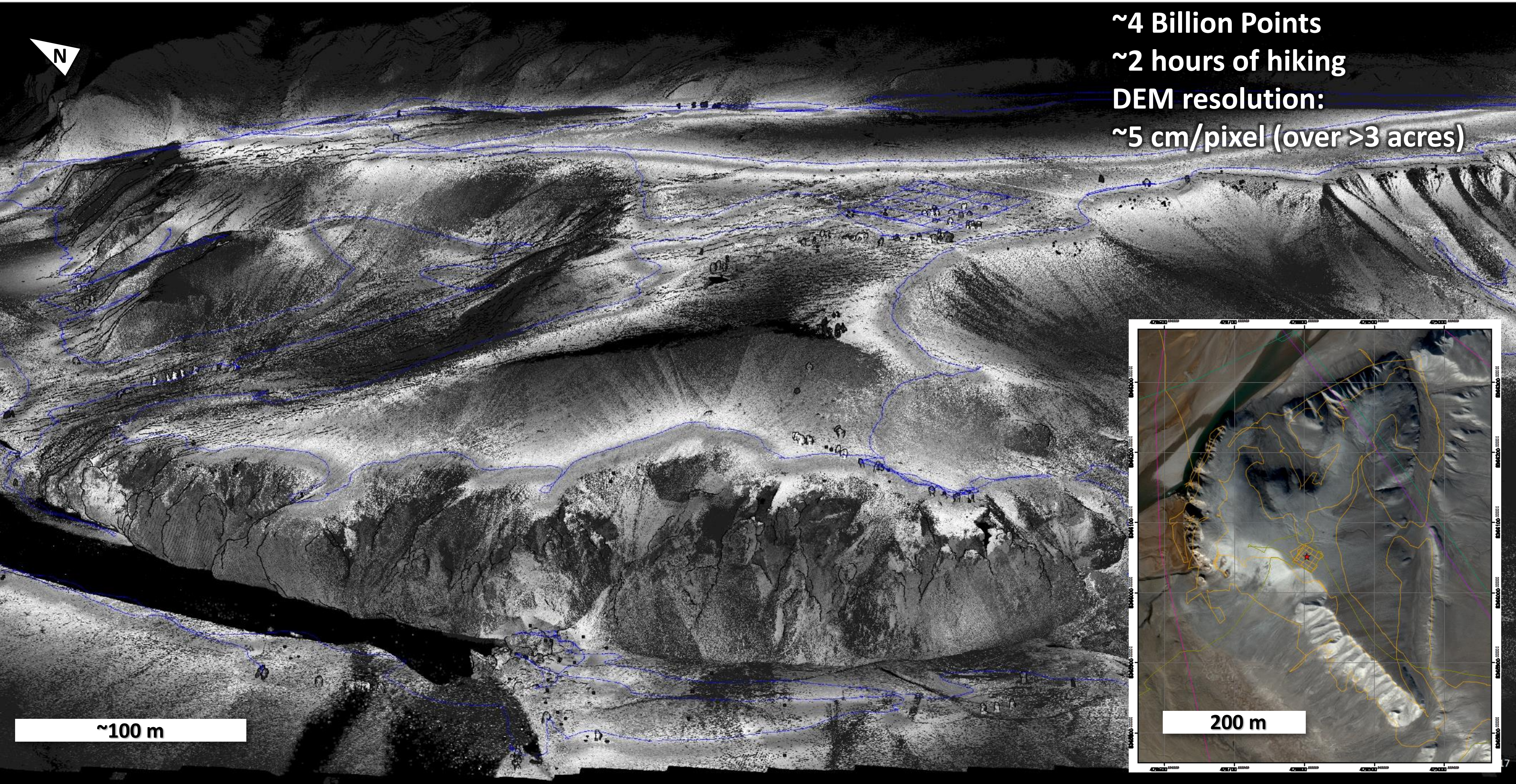
- Circles, polygons, and stripes are formed through freeze-thaw processes that sort fine material and stones through cryoturbation
- KLS data is allowing for never-before-possible measurement over vast scales (acres) and will allow multi-year investigation of formation



Boelhouwers et al., The maritime Subantarctic: a distinct periglacial environment, Geomorphology, Vol 52, Iss 1-2, 2003, p. 39-55

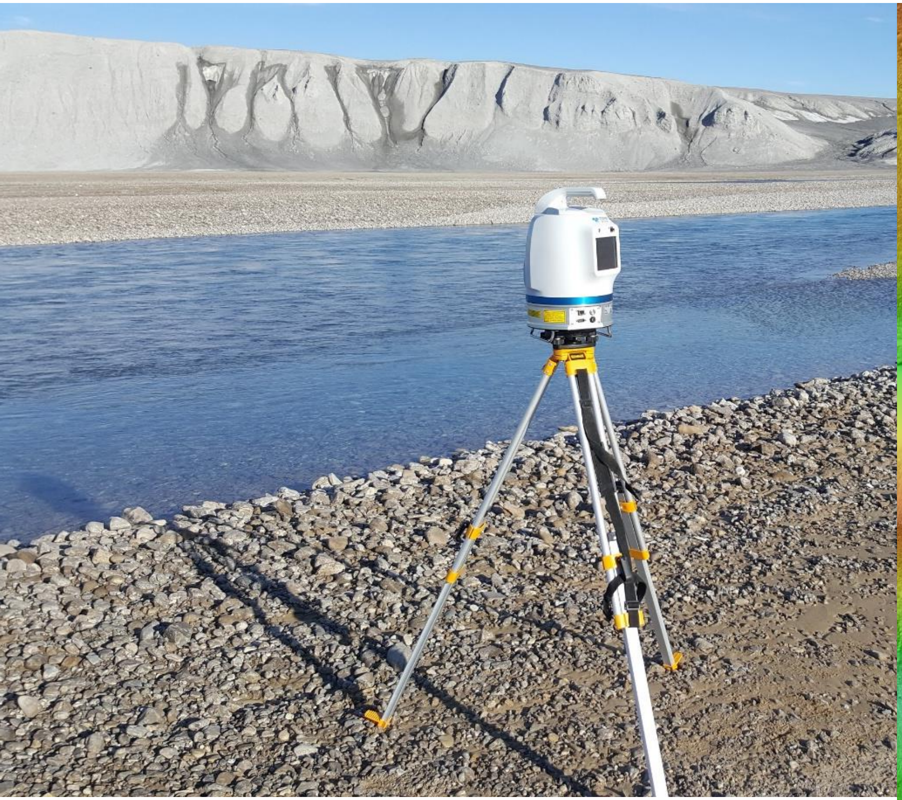


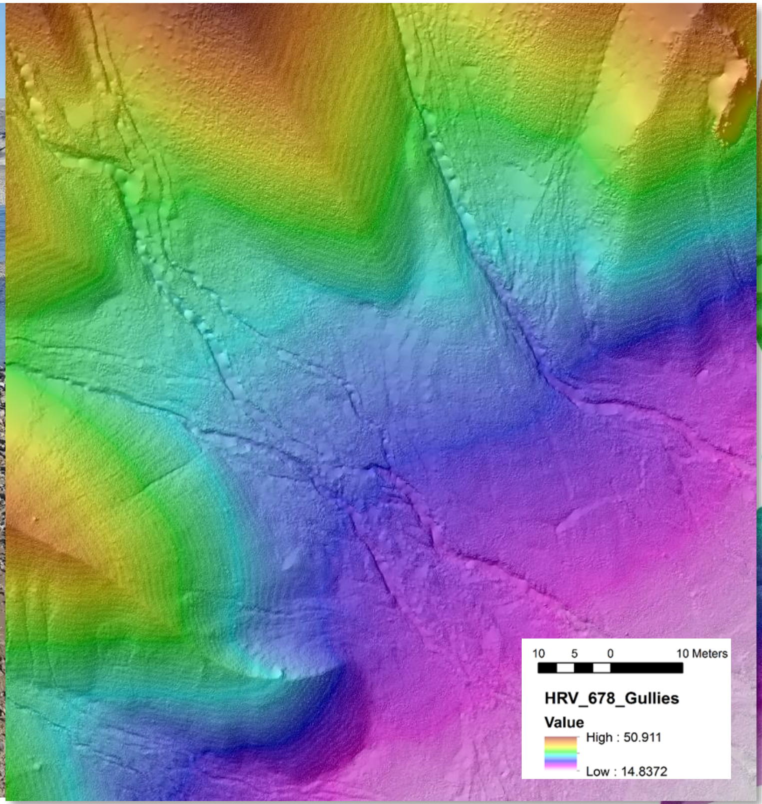
Kinematic LiDAR Scanning: Mapping Mountains

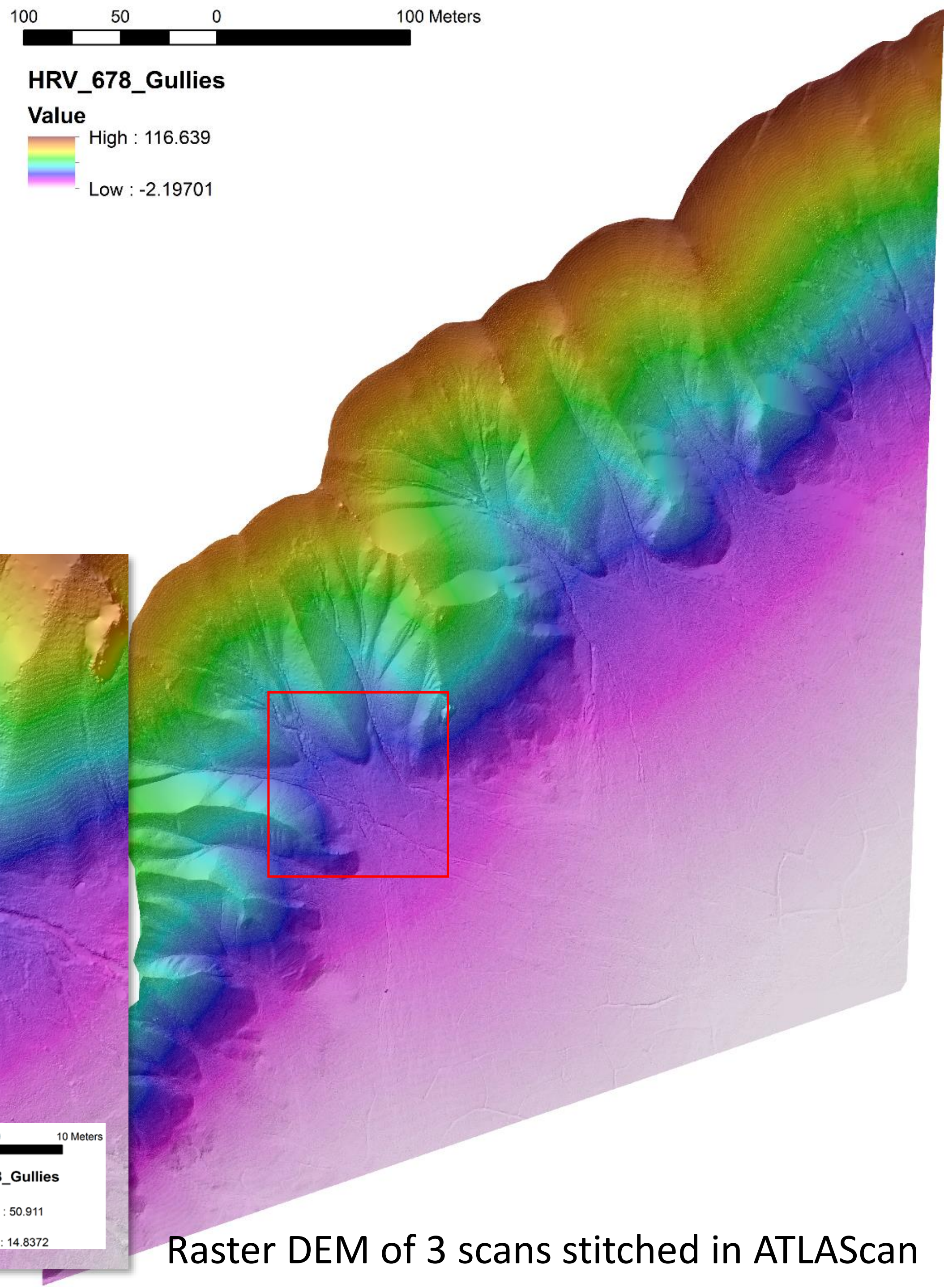


Teledyne Optech Polaris

- TLS scans of gullies to understand hillslope processes
- Multi-year comparison with Optech Illris data for change detection
- Multi-look scans of ground features for comparison with mobile data



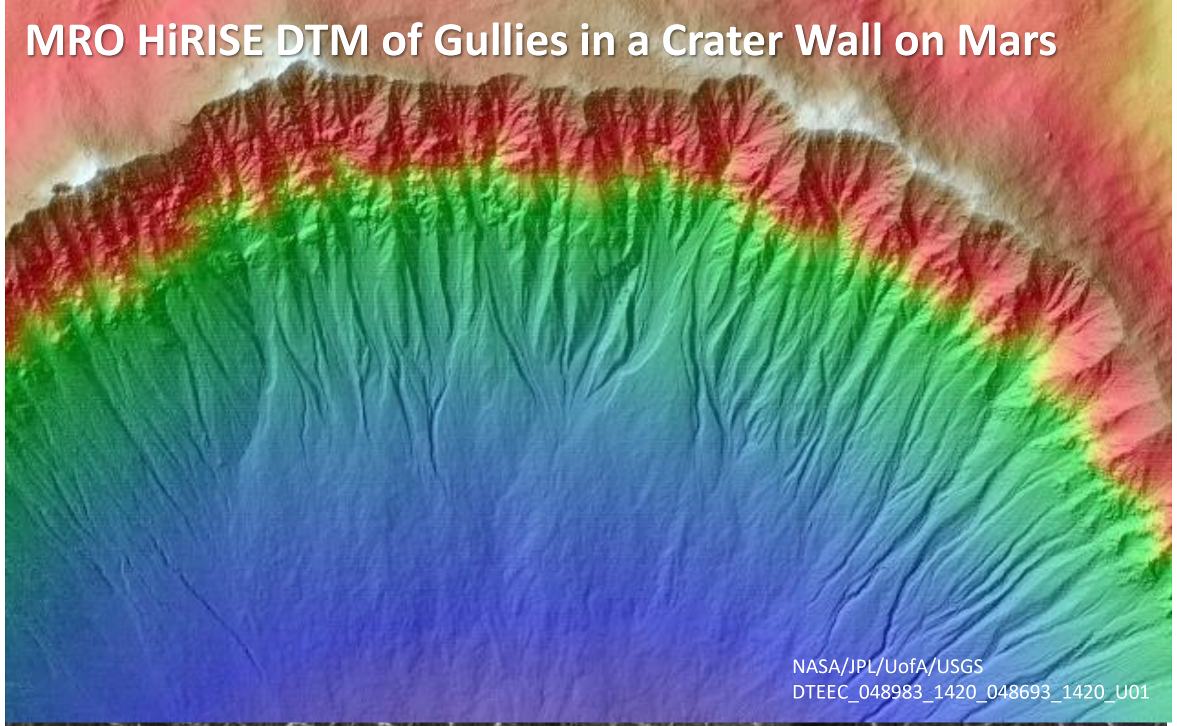


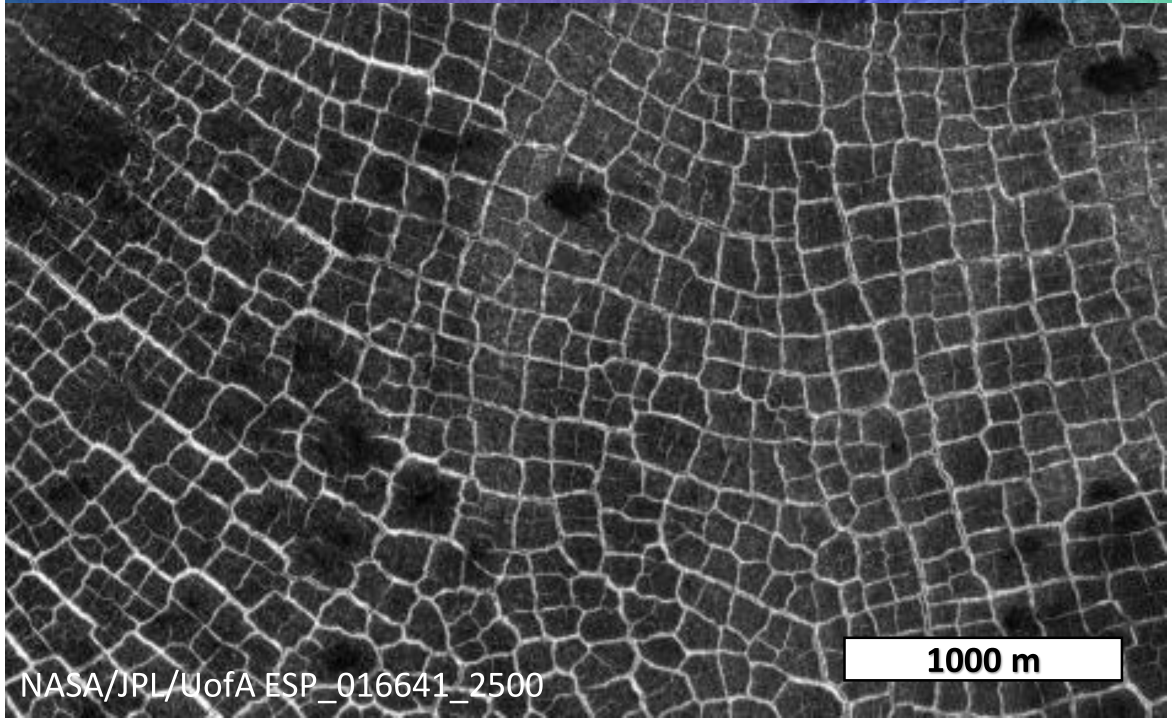


Raster DEM of 3 scans stitched in ATLAScan

Linking to Mars Geomorphology

- Periglacial activity (e.g. gullies and patterned ground) suggest active/recent freeze-thaw cycles
- Water (frozen or liquid) is of paramount importance for resource utilization (drinking and rocket fuel) and potential habitability
- Are the same processes acting on Mars as on Earth?
    - (just because they look similar doesn't mean they formed the same way)



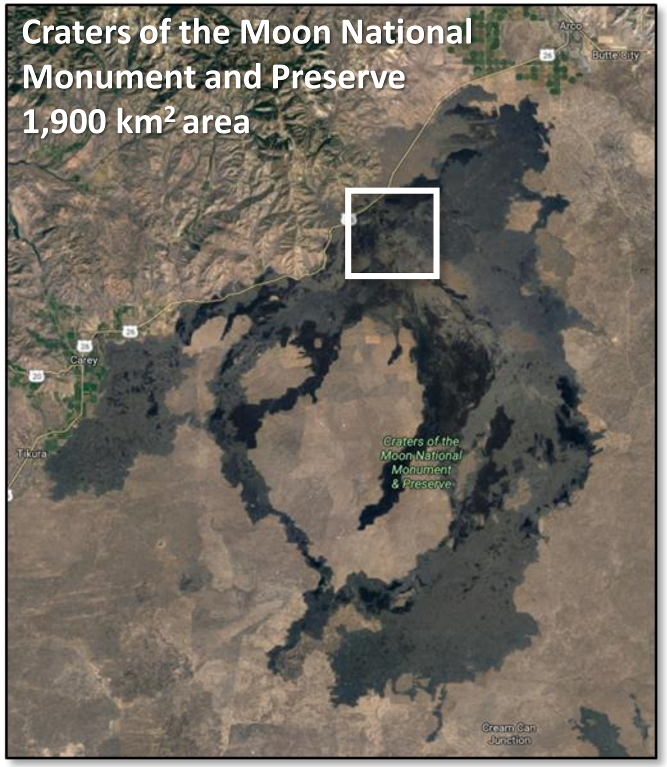


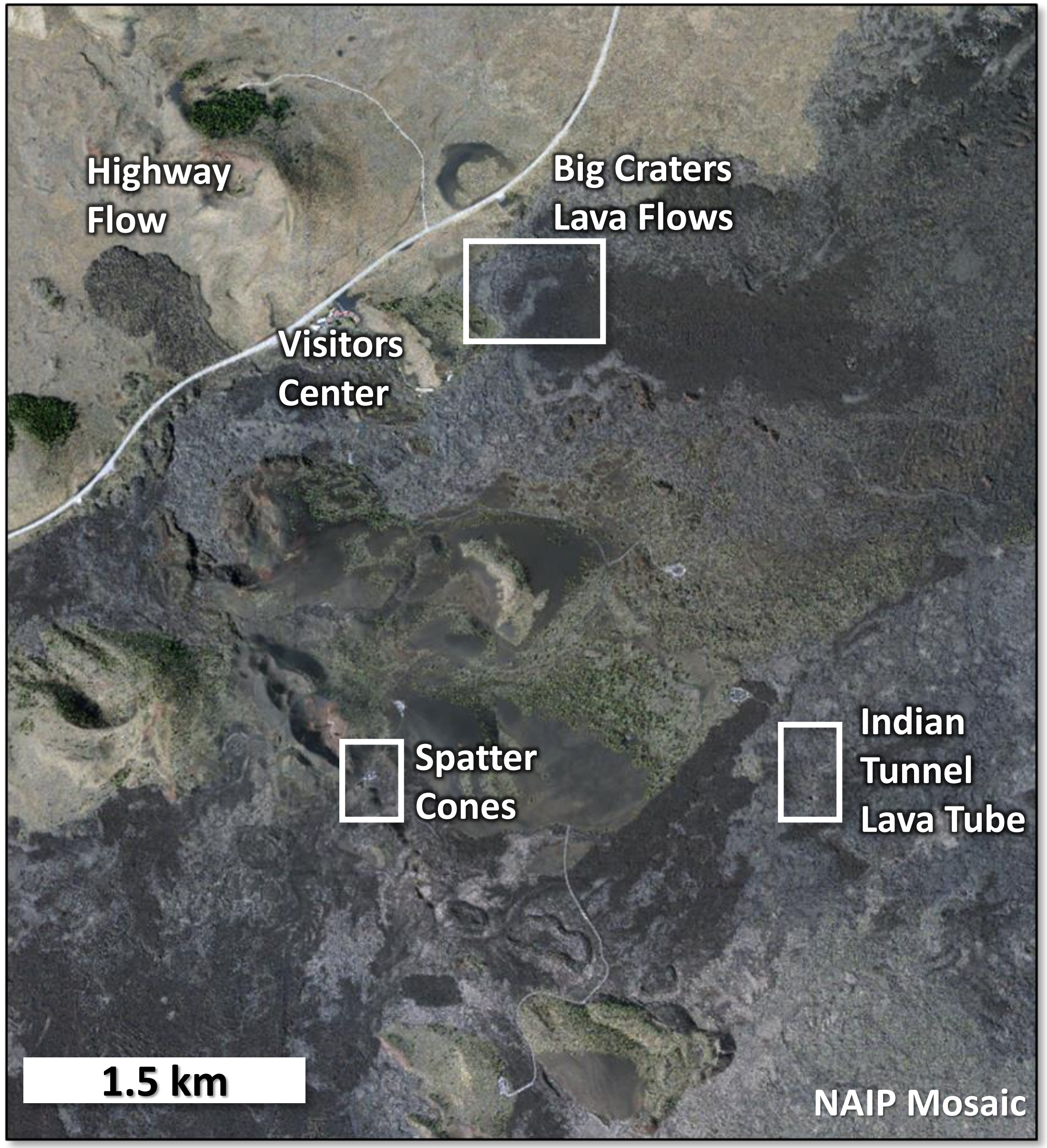
Volcanic Features:
Craters of the Moon National Monument, ID, USA

- NASA SSERVI FINESSE

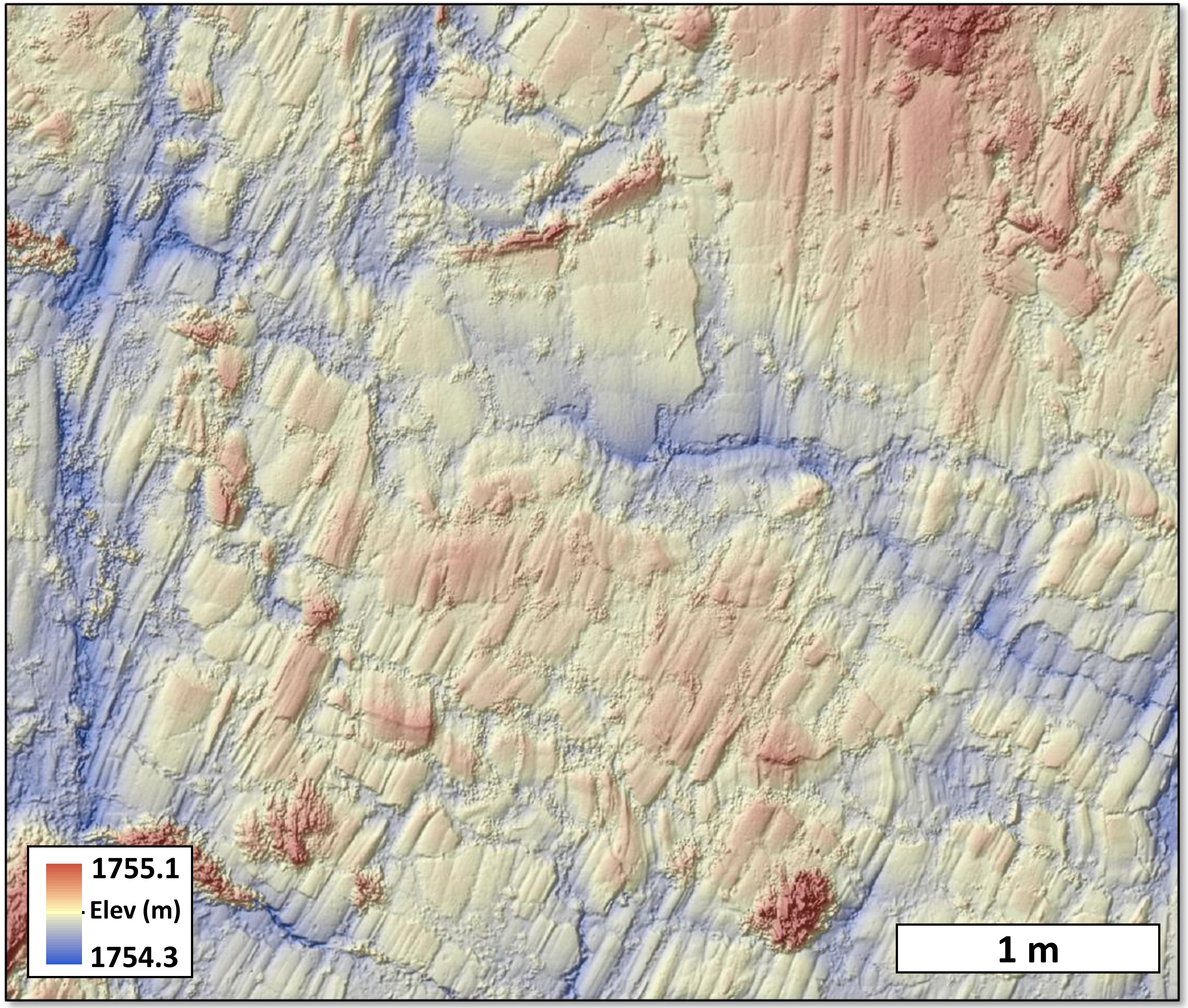
Solar System Exploration Research Virtual Institute - Field Investigations to Enable Solar System Science and Exploration

- Characterize multiple volcanic features
  - Morphometry
  - Surface Roughness
  - Comparison with samples





Lava Flows in Ultra-High Resolution



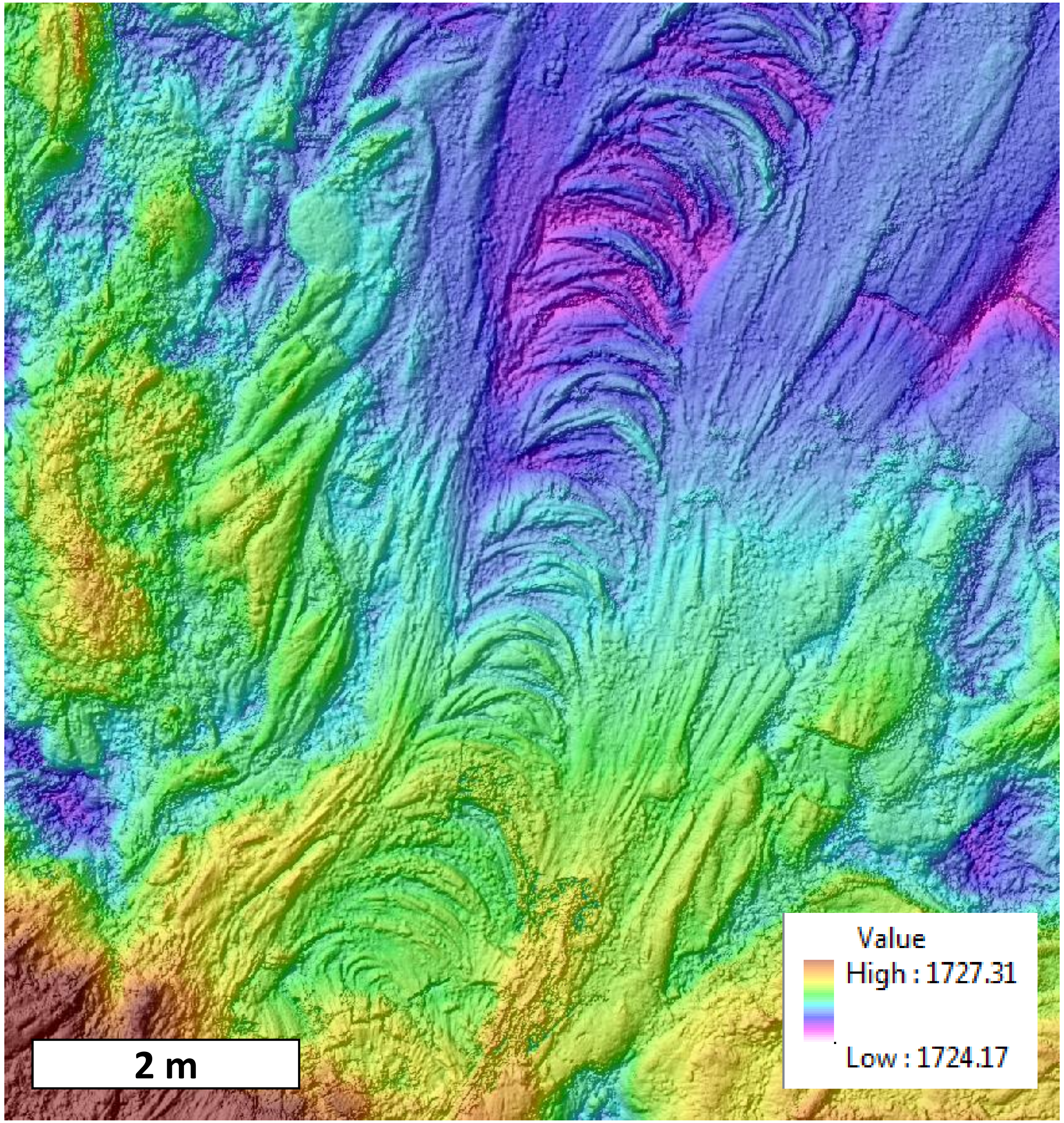
Inflating and flowing lava form striated plates

- Flow Direction
- Flow Dynamics and Evolution

Lava “falls”

- Pressure ridges and flow features frozen when the lava cools
- Allows for mapping and morphology studies
- Enhanced radar returns from oriented surfaces

https://www.usgs.gov/media/images/lava-flow-breakouts-0

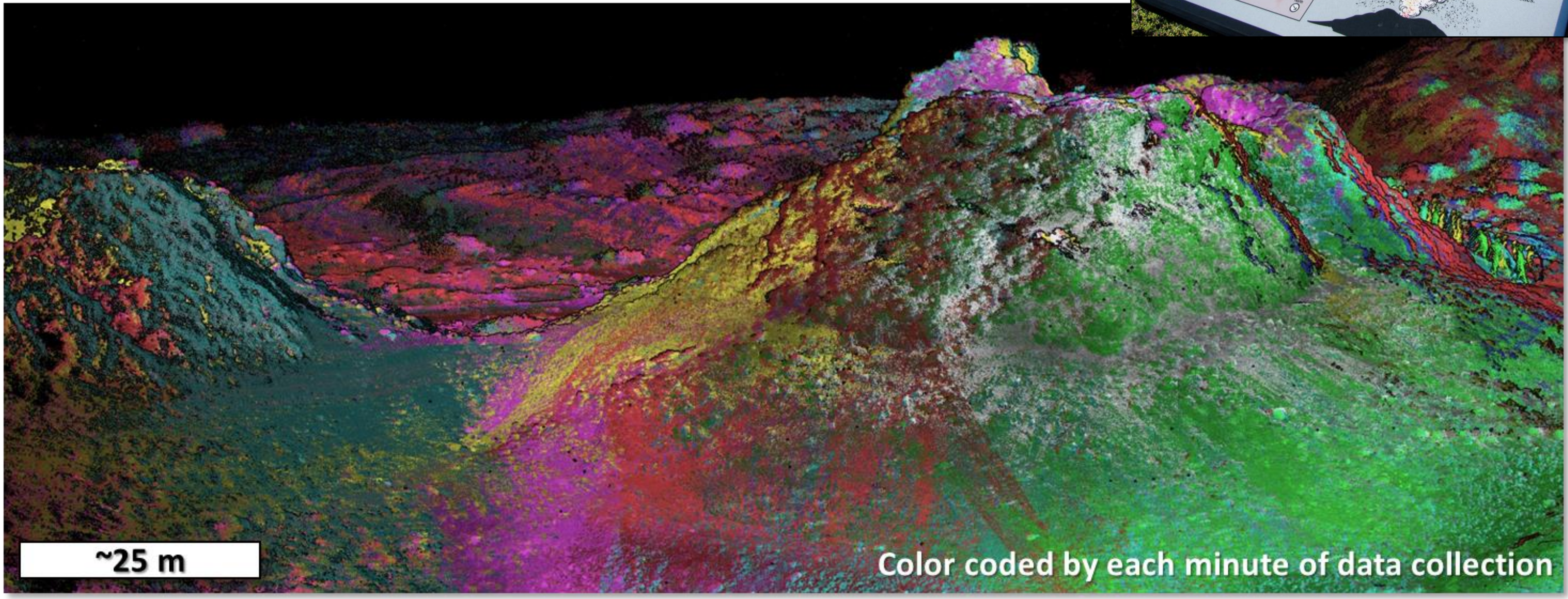


Volcanic Features: Spatter Cones

- Low, steep sided hills emanating from a fissure, consisting of welded individual lava fragments (blobs of spattered lava)

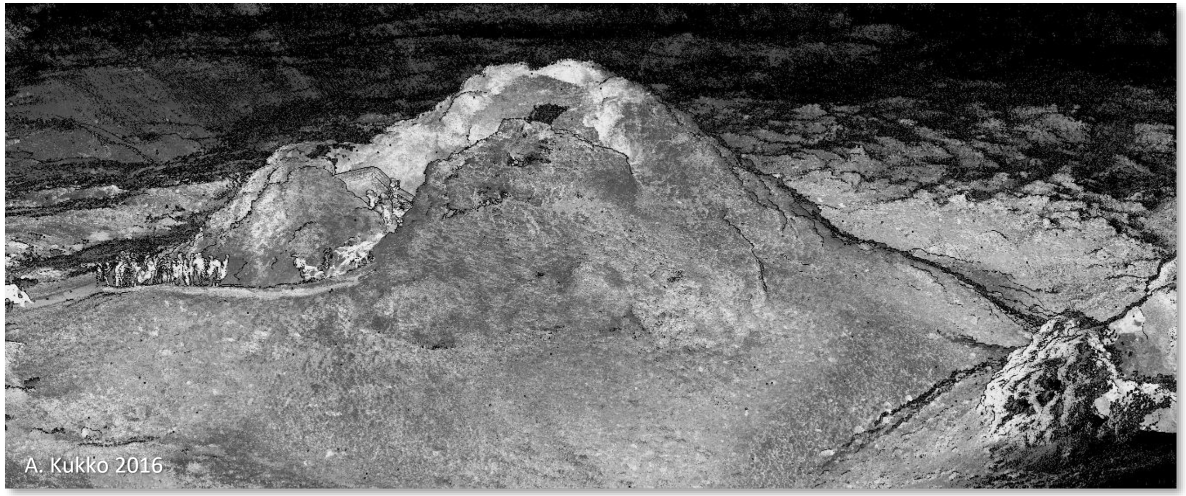
Characterization of:

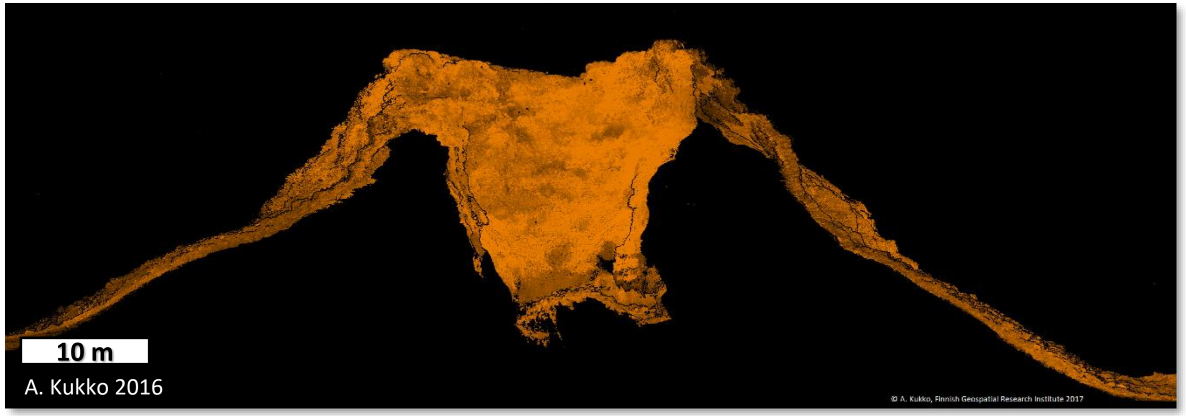
- Morphometry
- Distribution of un-welded spatter
- Rate and volume of volcanic eruptions



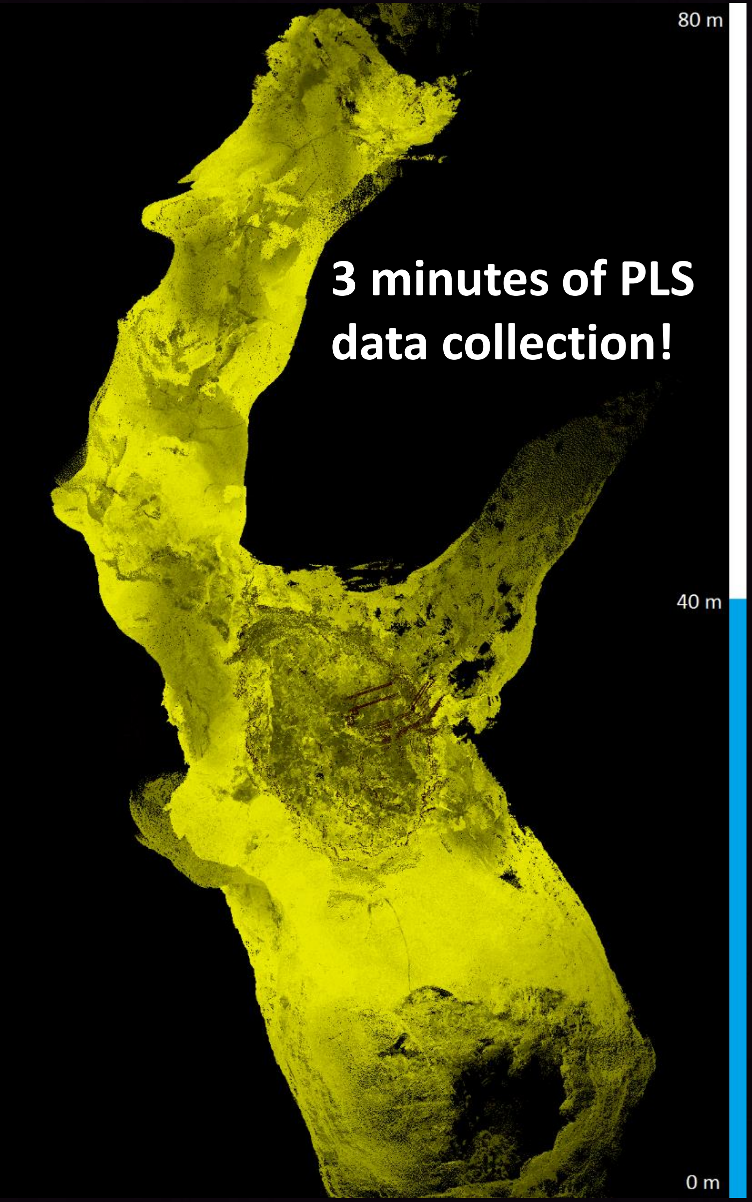
Recreating Volcanic Features

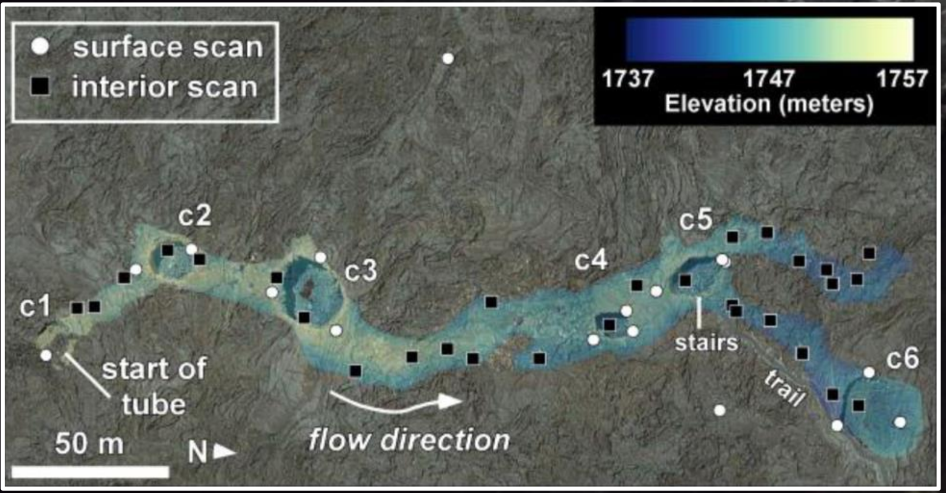
- Large furnace experiments with the University of Syracuse Lava Project
  - http://lavaproject.syr.edu/
- Distribution and nature of "volcanic bombs"
- Flow morphologies across scales
  - related to cooling history and crystallization texture through experiments
  - Volume of erupted material and characterization of eruption style

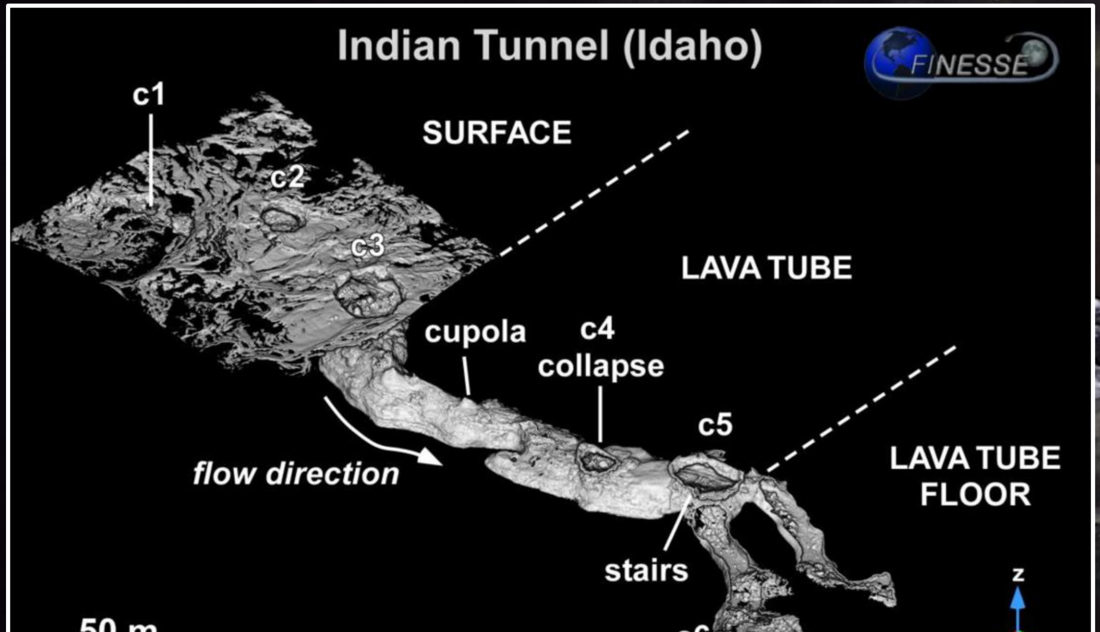




Volcanic Features: Lava Tubes







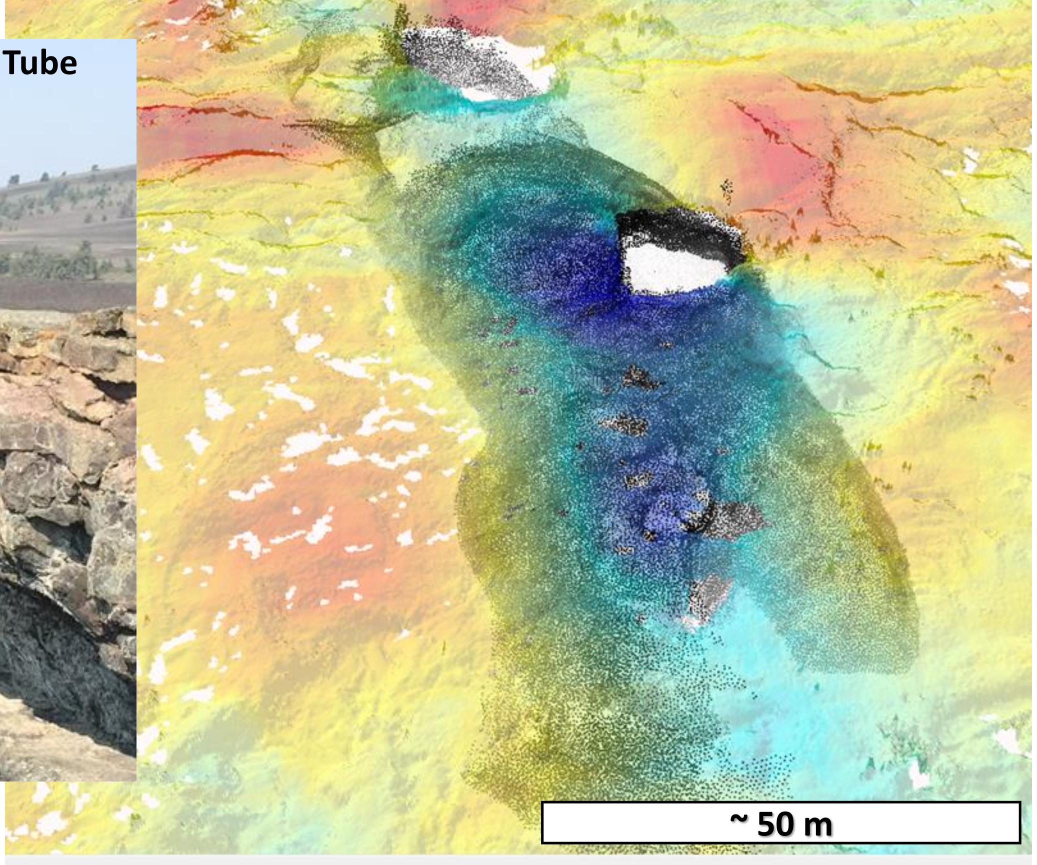
Garry et al. (2017)

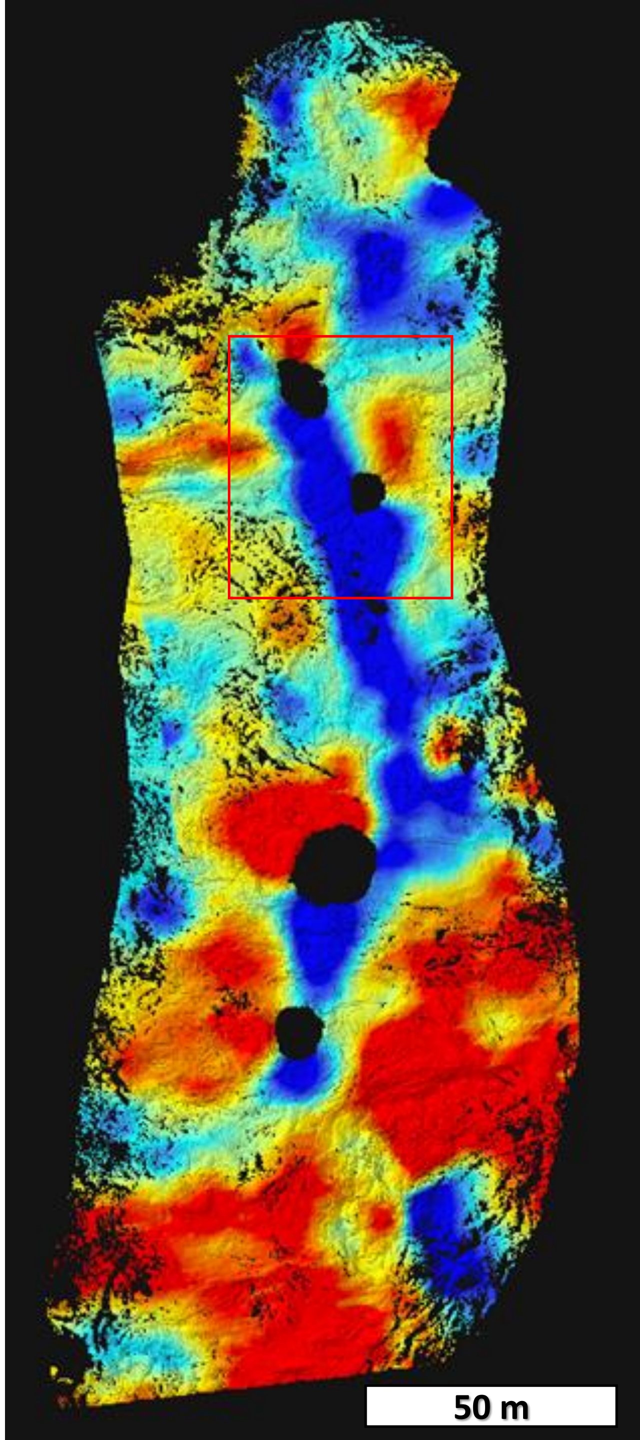
Combining LiDAR and Geophysical Data

- KLS LiDAR provided an ultra-high resolution topographic map of lava tubes used for magnetometry and gravimetry measurements.

Collecting Magnetometry data over Indian Tunnel Lava Tube

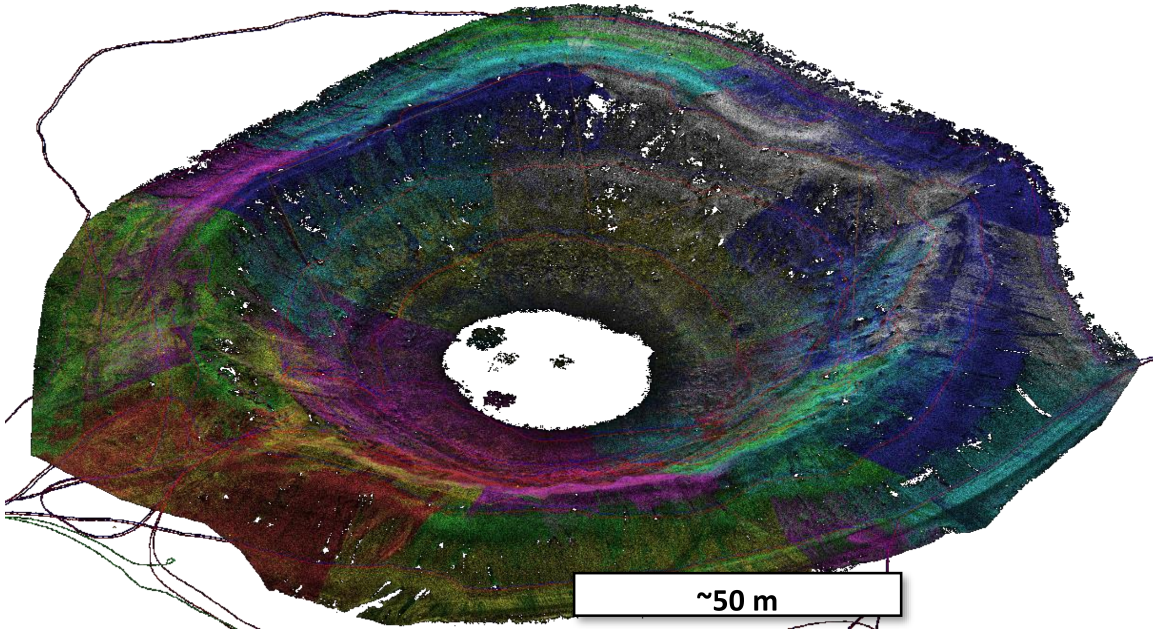
Magnetometry shaded with LiDAR DEM over KLS LiDAR point cloud





Kaali Crater, Saaremaa Island, Estonia

- KLS vs TLS: *30 minutes vs 3 days*
- Crater shape used for hydrocode modeling of impact crater formation



Scientist/User perspective on ultra-high resolution LiDAR data

- Mobile LiDAR mapping and surveying products are pushing the scientists to figure out ways to use the data to its fullest extent
  - How much resolution is needed? Always more! We'll catch up…
- Some measurements can only practically be done with LiDAR
  - e.g. large area surface roughness analyses for radar studies
- New observations/relationships are being discovered because of this level of resolution
  - e.g. Micro-topography differences in patterned ground -> better ways of building construction/management in cold-weather climates

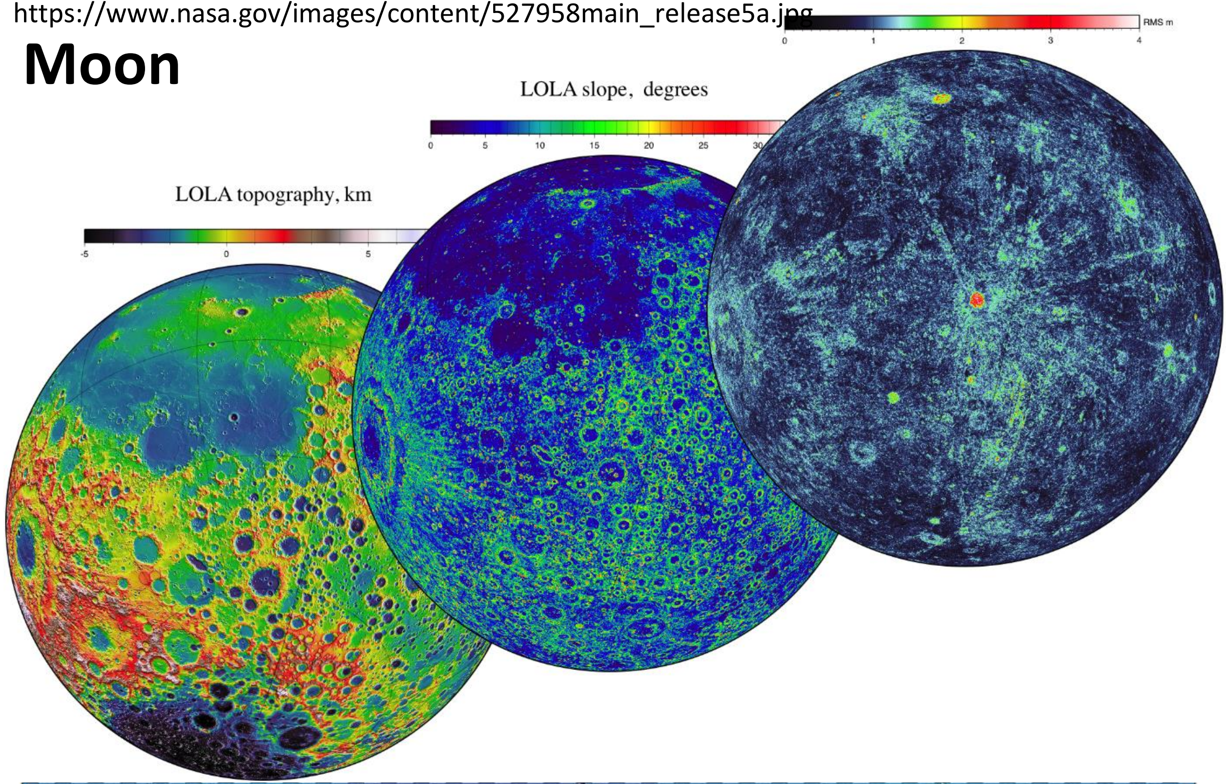
Planetary Exploration LiDARs

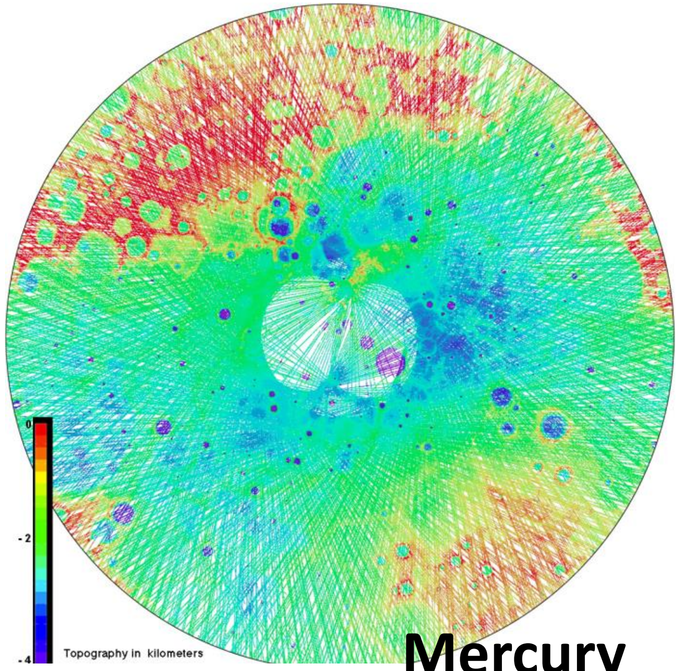
- Laser Altimeters have explored the Moon, Mars, and Mercury
  - Moon: Lunar Orbital Laser Altimeter (LOLA) – LRO mission (2009 – present)
  - Mars: Mars Orbital Laser Altimeter (MOLA) – MGS mission (1996-2006)
  - Mercury: Mercury Laser Altimeter

Review paper: Sun et al. (2013) Space LiDAR Developed at NASA GFSC (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6522192)

https://www.nasa.gov/images/content/527958main_release5a.jpg

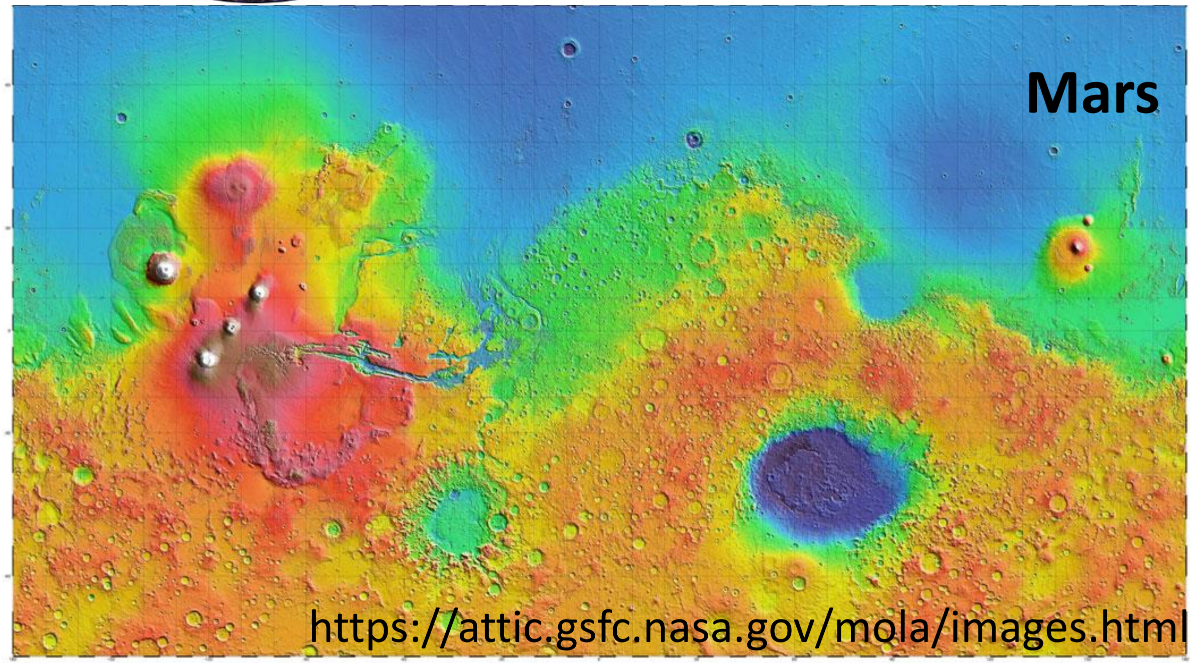
Moon





Mercury

http://messenger.jhuapl.edu/Explore/Science-Images-database/pics/MLA_topography_print_labels.jpg



Mars

https://attic.gsfc.nasa.gov/mola/images.html

Ground-based LiDARs on other planets?

- There has yet to be ground-based (topographic) LiDAR collected from the surface of another planet…
- Currently focused development:
  - entry, decent, and landing (EDL), automated hazard-avoidance, atmospheric LiDARs
  - navigation LiDARs for rovers are being developed (anecdotal)
    - Dual-use navigation/science possibilities
- **Challenges:**
  - Data volumes for science (navigation data can be discarded)
    - Optical communication for the Moon a possibility… OC for other planets is challenging
  - GPS-denied environments
  - Radiation environments
  - Photogrammetry (Does LiDAR provide enough benefit?)

NASA's Interest in LiDAR Technology

- Active optical (Laser/Lidar) measurement techniques are critical for future NASA Earth, Planetary Science, Exploration and Aeronautics measurements.
- The science decadal surveys recommend a number of missions requiring active optical systems to meet the science measurement objectives.

Resources and References:

- NASA Small Business Innovation Research SBIR 2019 Phase I Solicitation
    - S1.01 Lidar Remote Sensing Technologies
- NASA ESTO Lidar Technologies Investment Strategy: 2016 Decadal Update"
    - (https://ntrs.nasa.gov/search.jsp?R=20180002566)
- Conference Proceeding from NASA Technical Interchange Meeting
    - Active Optical Systems for Supporting Science, Exploration, and Aeronautics Measurements Needs (held July 31 - Aug 2, 2018)
    - (https://www.nasa.gov/nesc/tim-active-optical-systems)