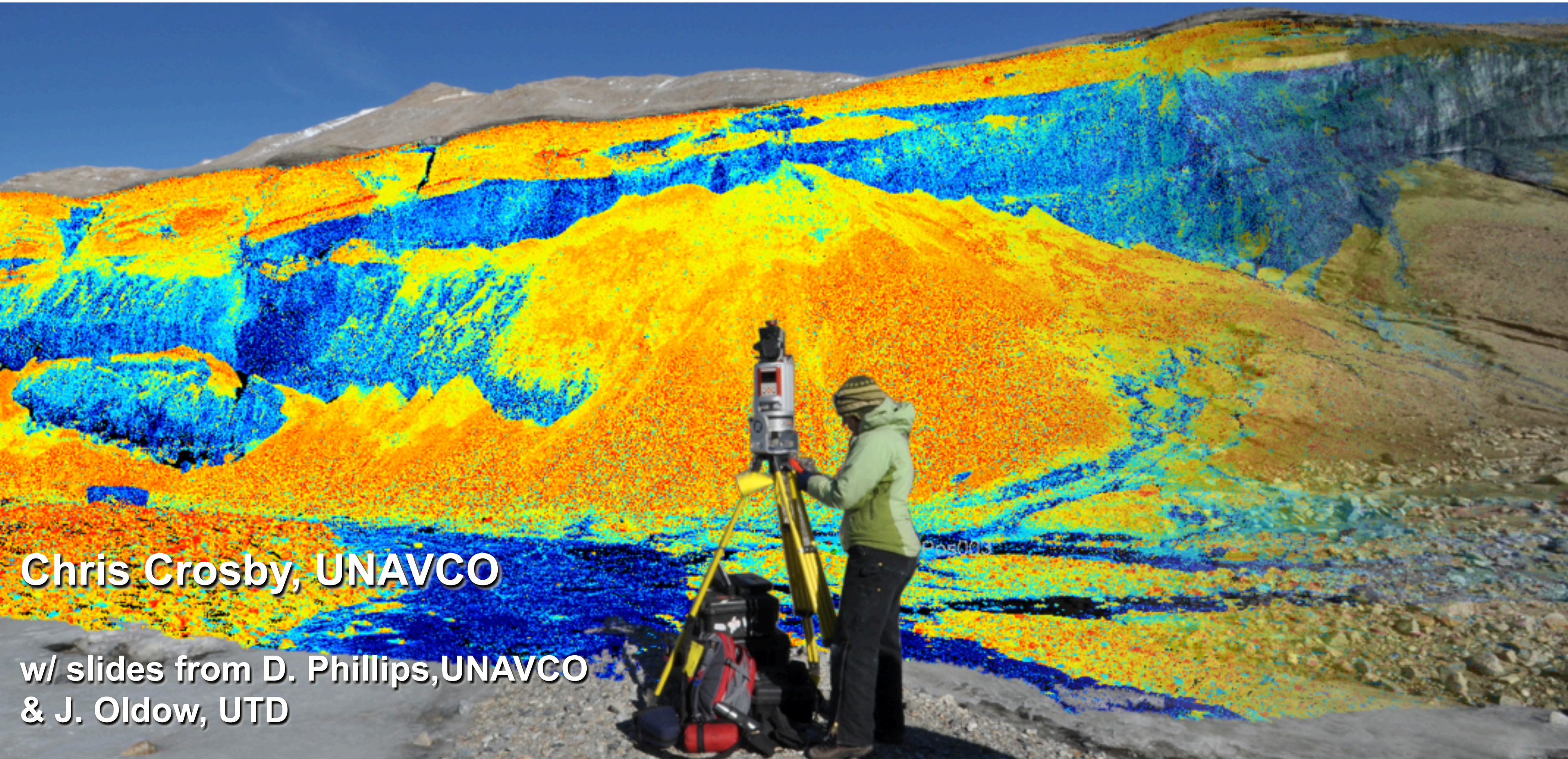
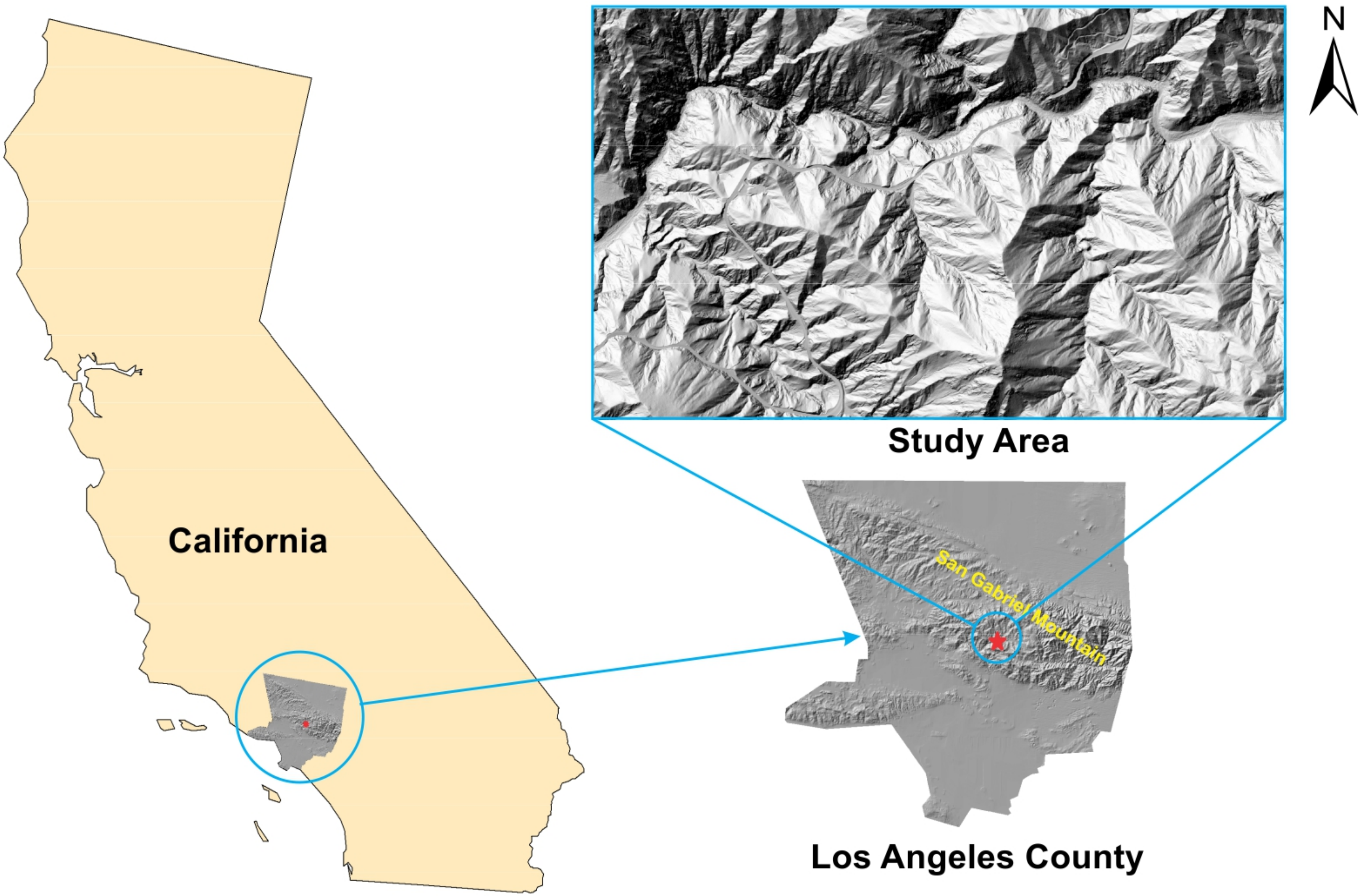
Terrestrial Laser Scanning (Ground-Based Lidar) Methods and Applications in Geologic Research and Education



Chris Crosby, UNAVCO

w/ slides from D. Phillips,UNAVCO
& J. Oldow, UTD

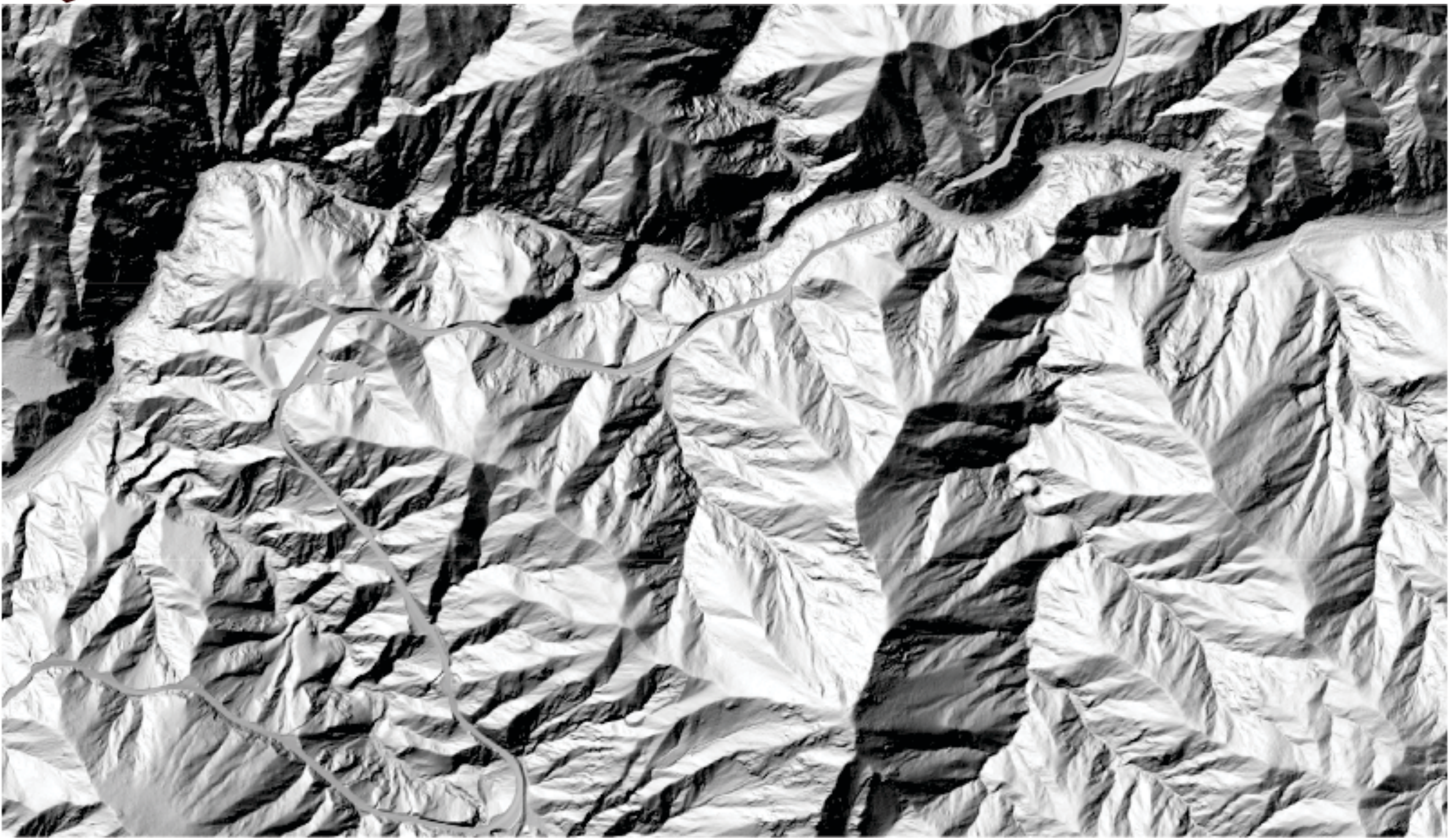
Location of Study Area (San Gabriel, California)



J. Oldow, UTD

Los Angeles County 30m DEM

J. Oldow, UTD



San Gabriel Mountain 1m DEM from airborne lidar

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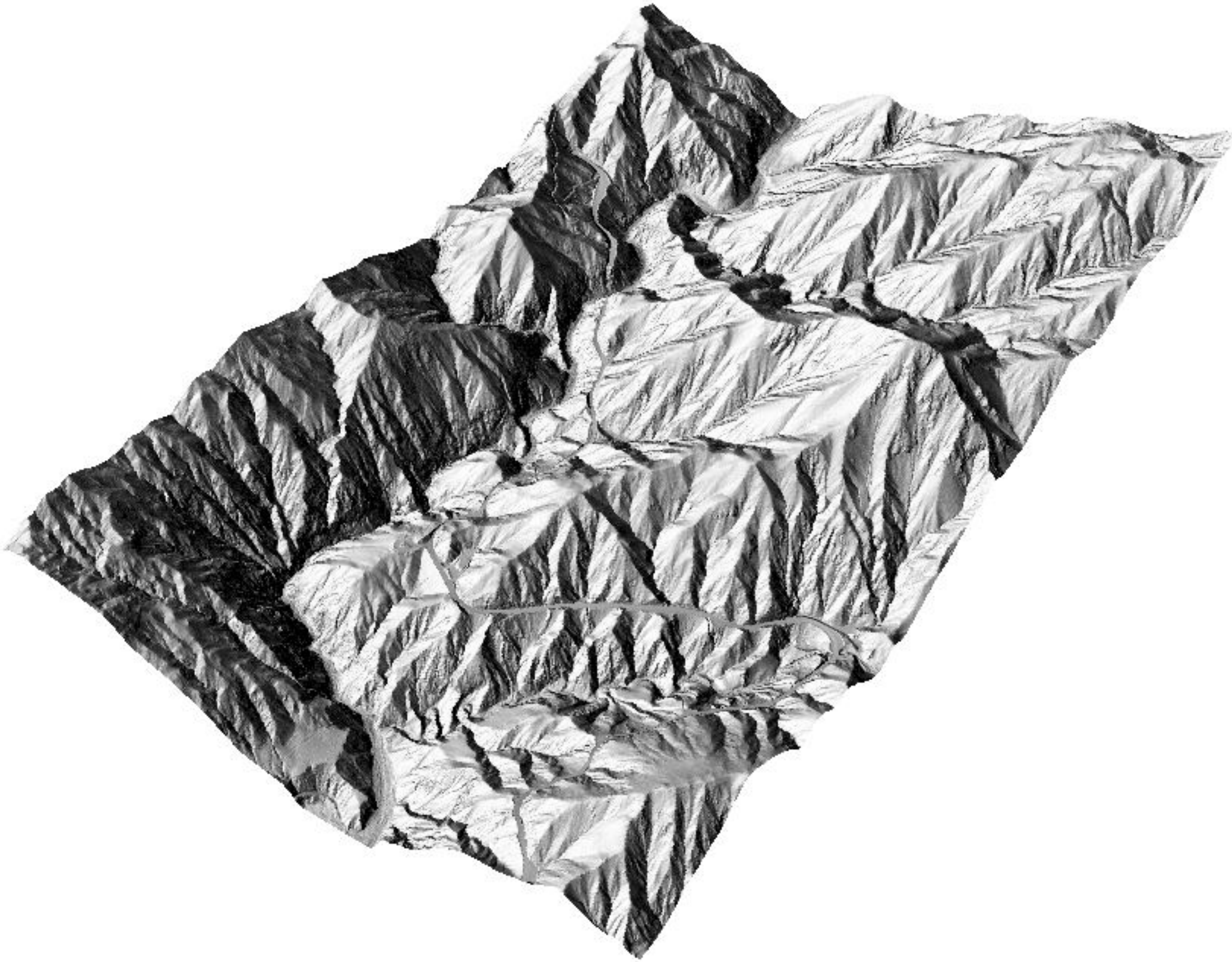

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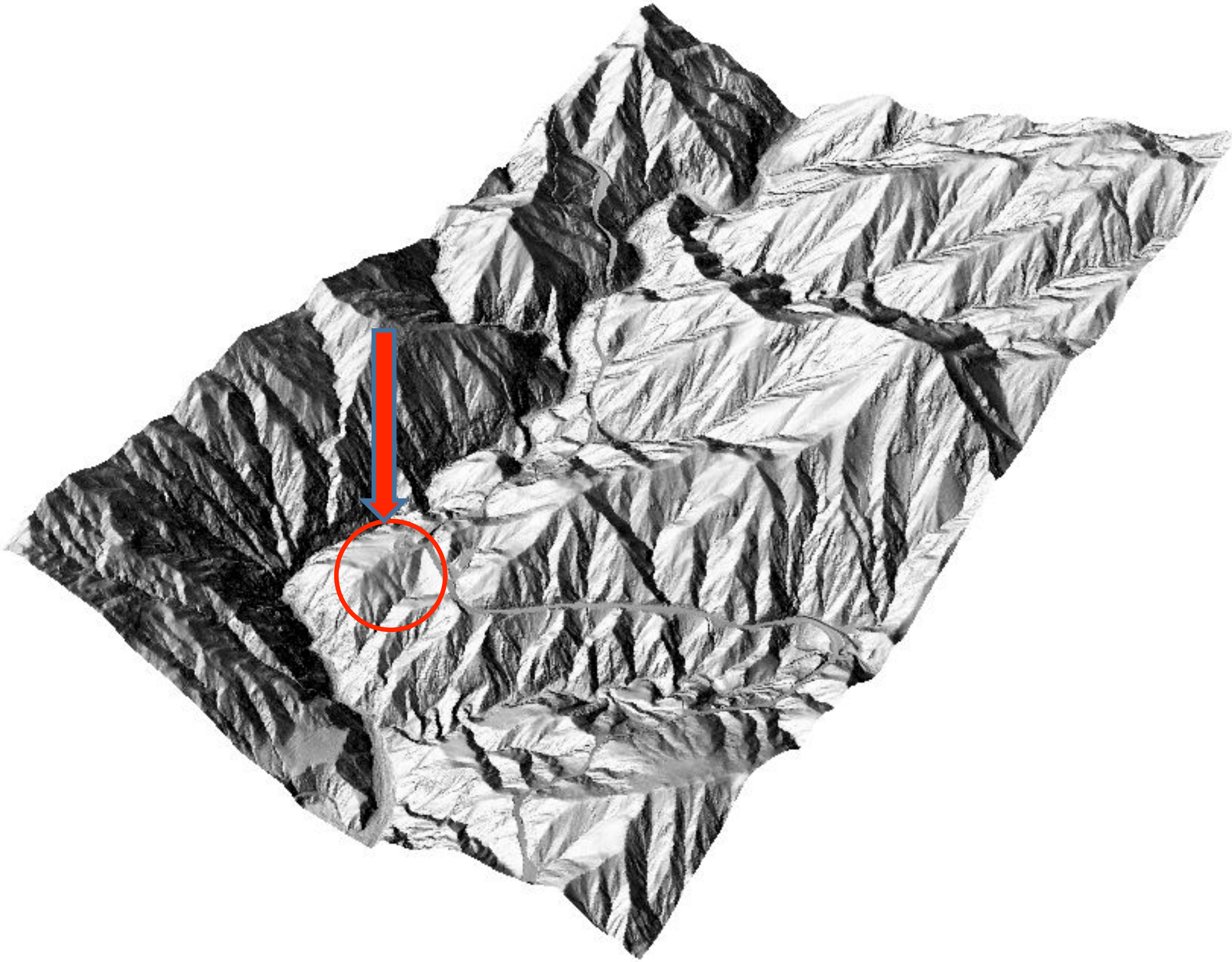
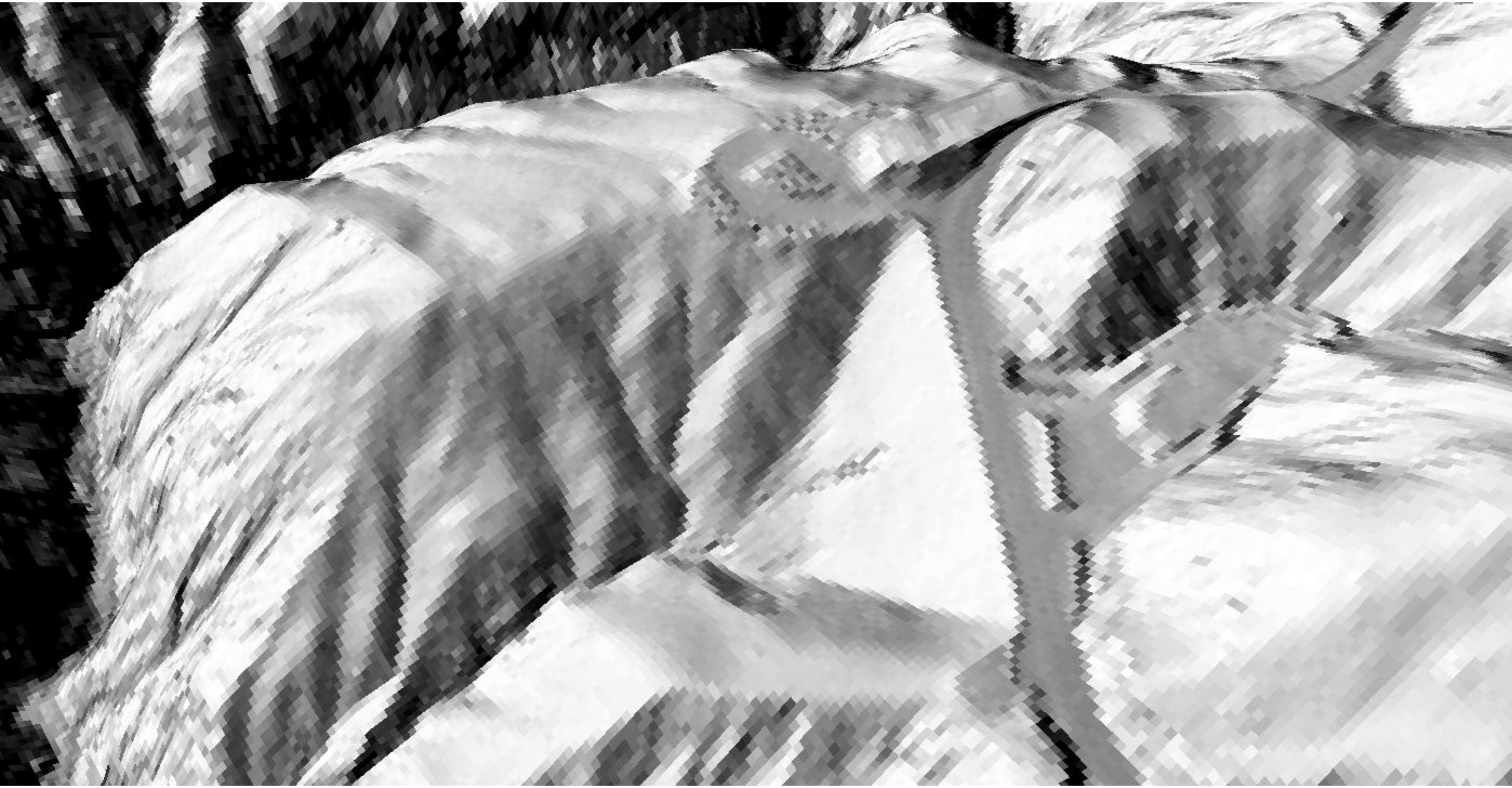
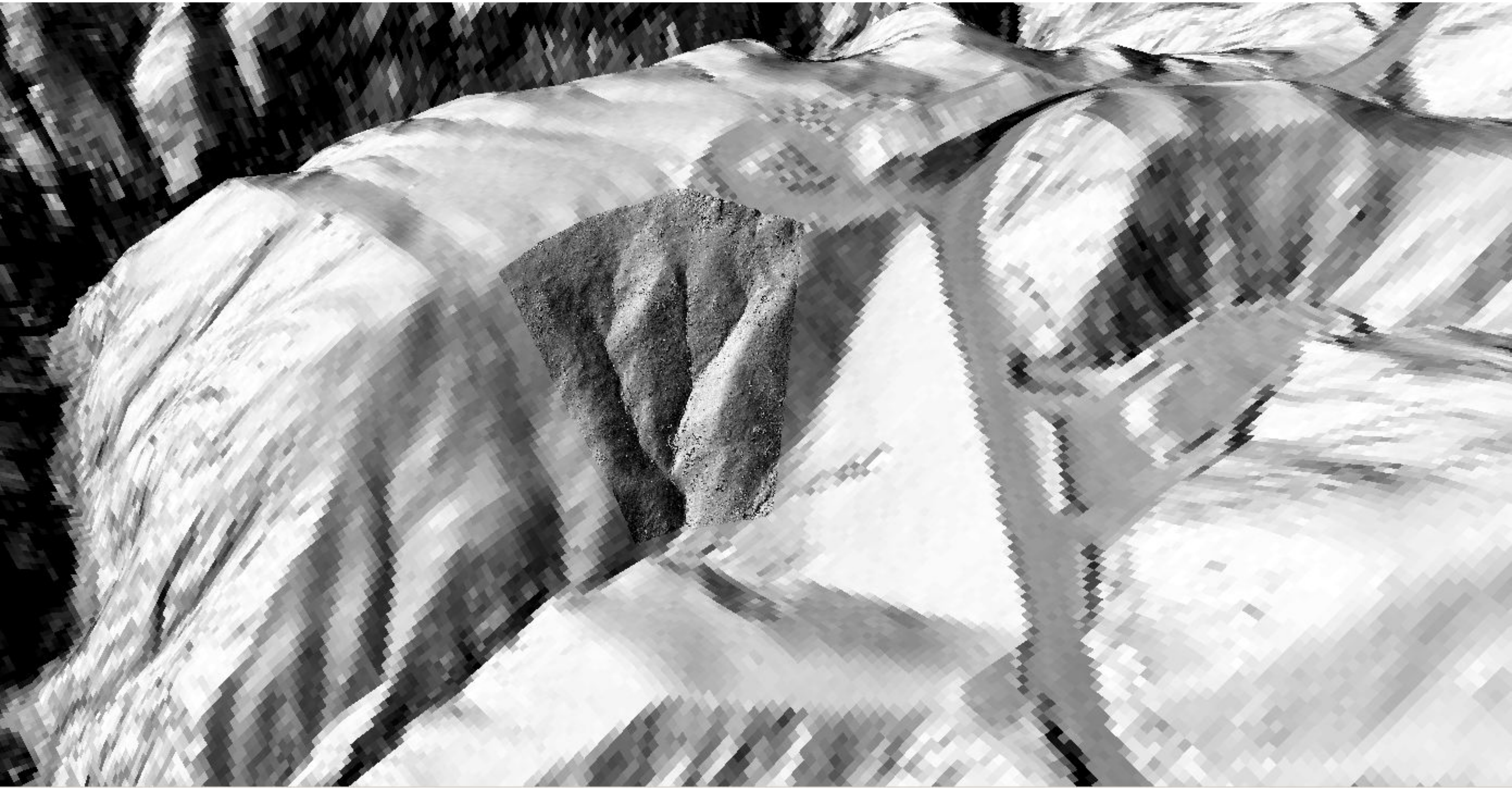


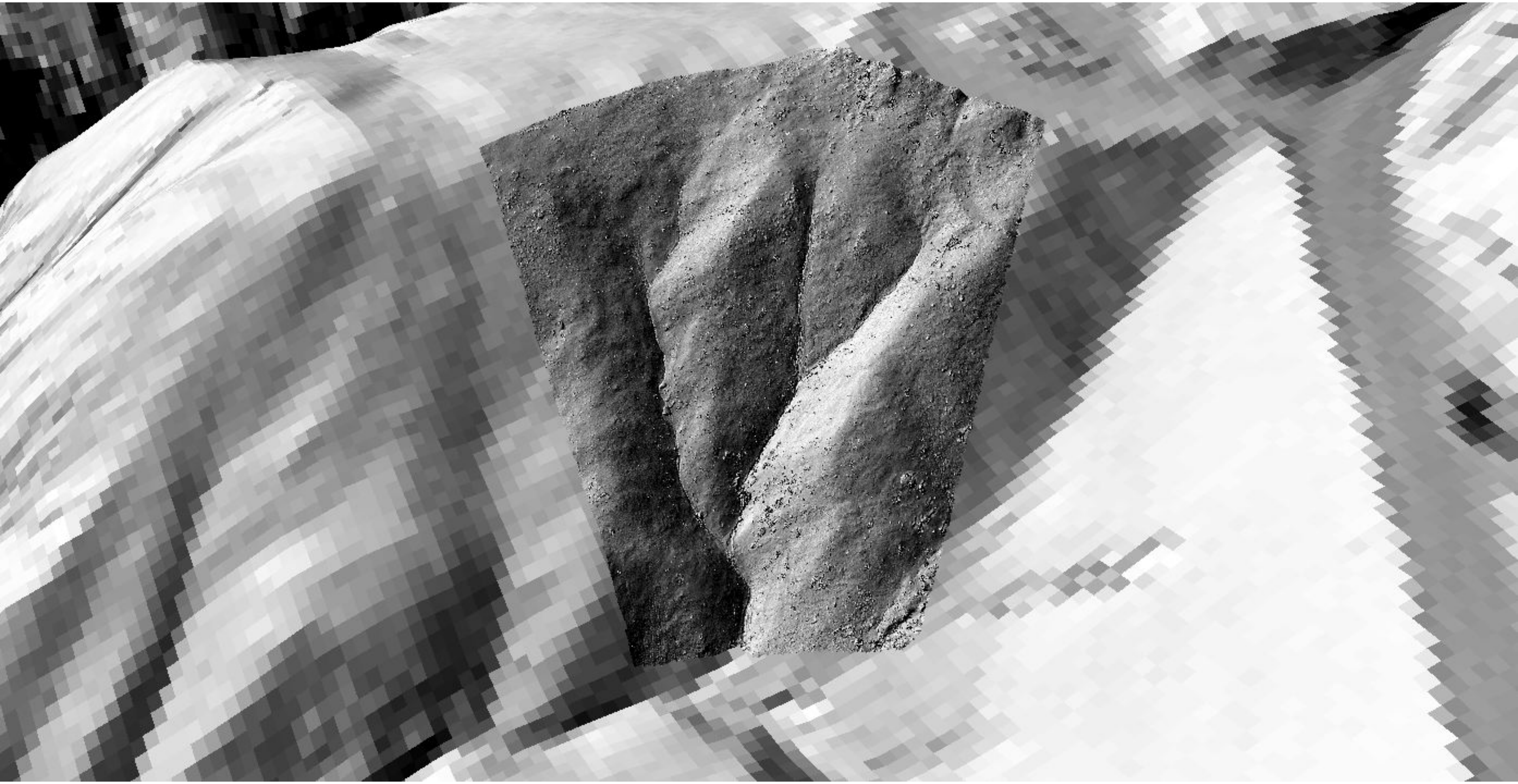
J. Oldow, UTD



J. Oldow, UTD



J. Oldow, UTD



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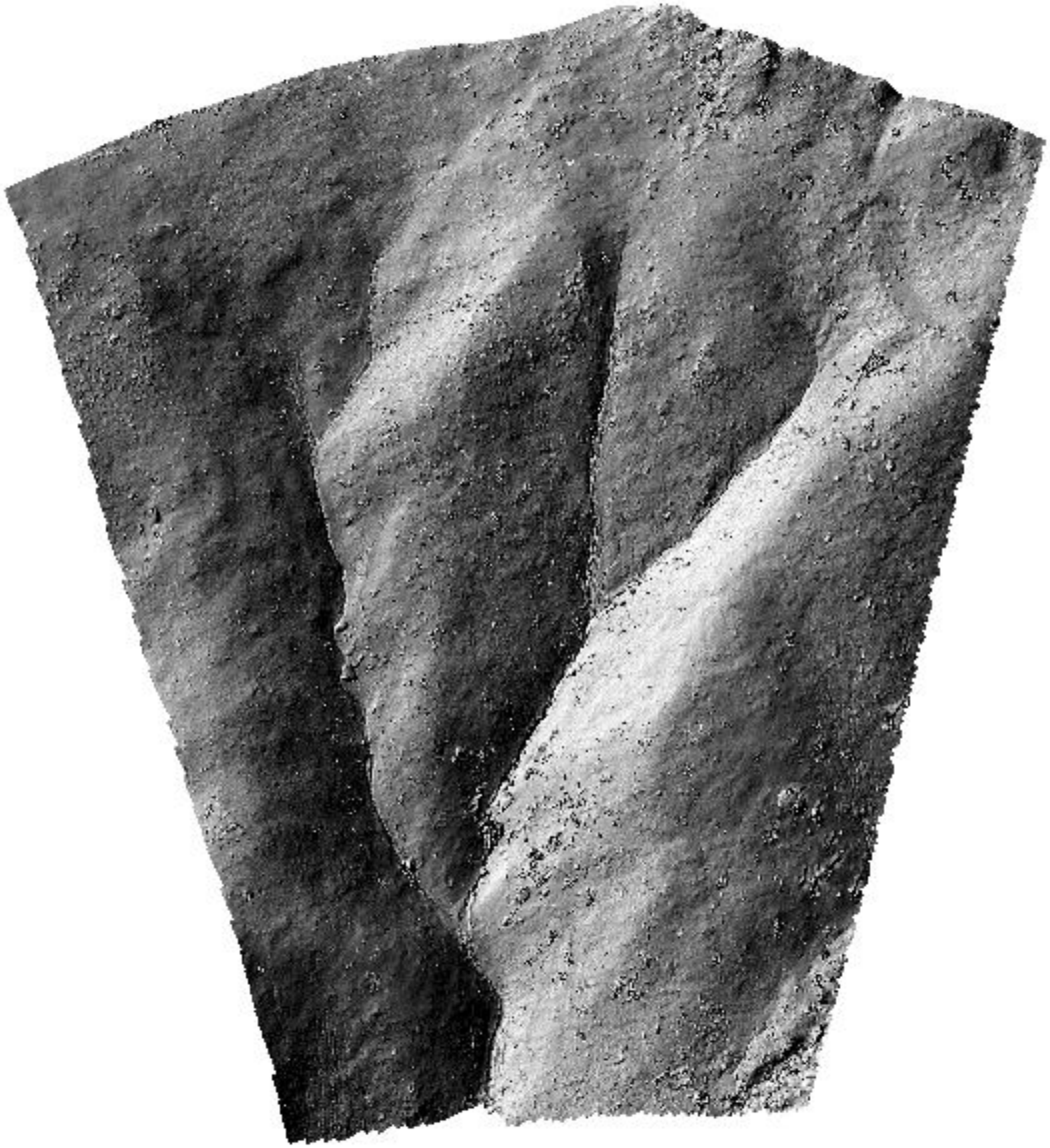
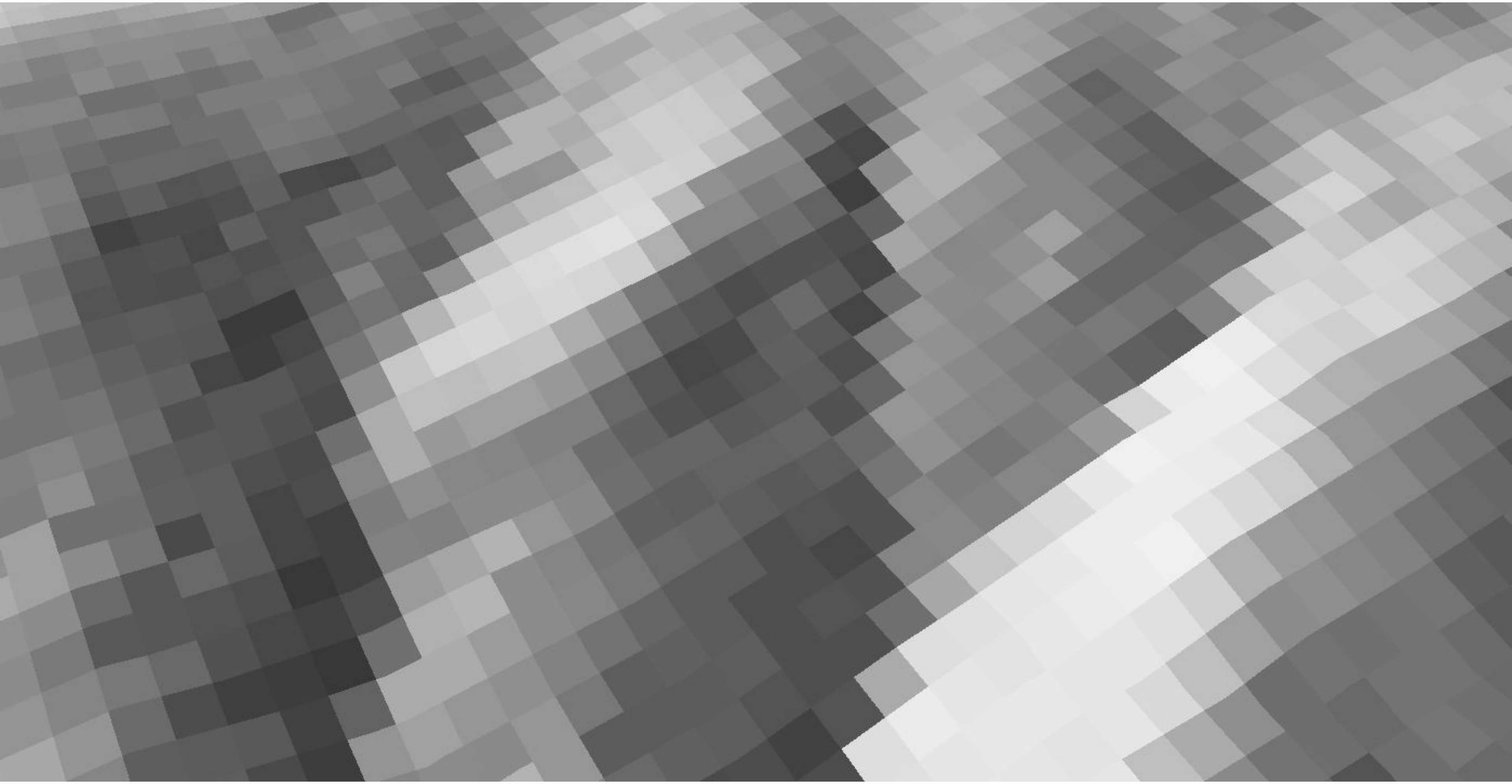


J. Oldow, UTD



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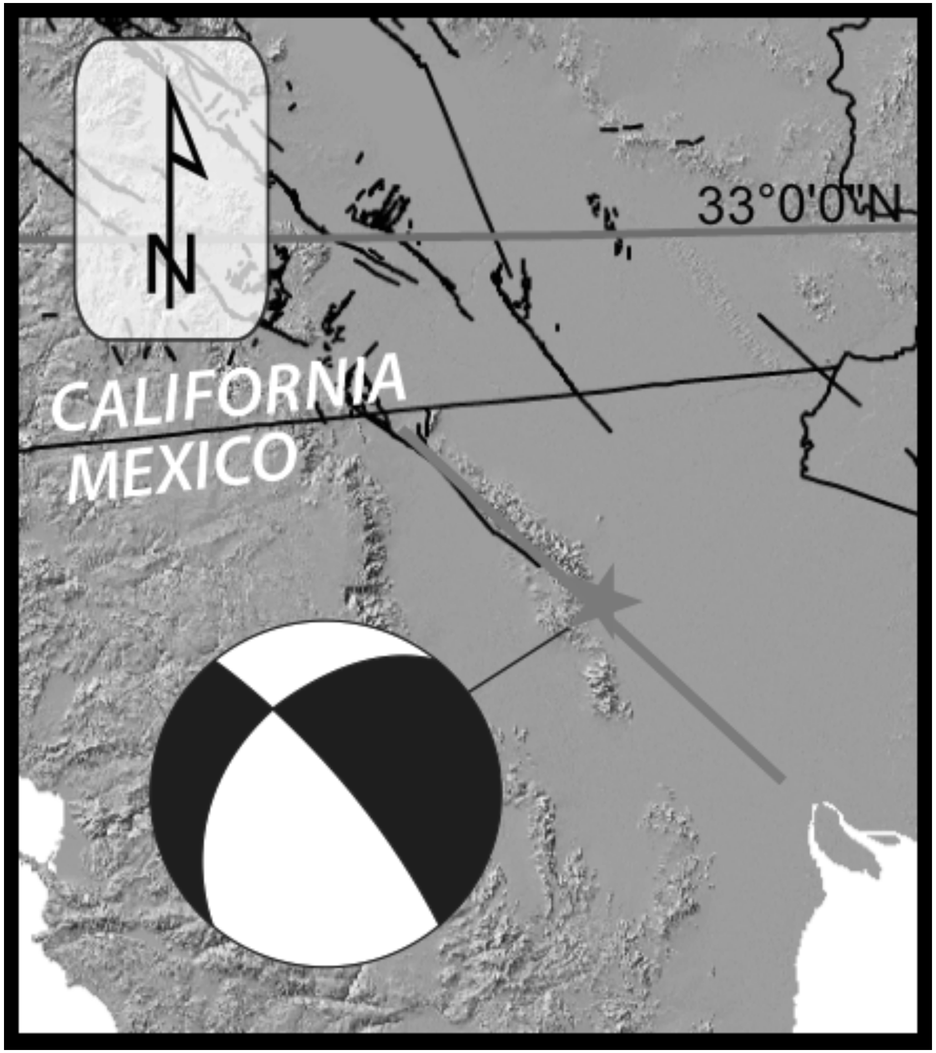
El Mayor-Cucapah Earthquake



- April 4, 2010
- Mw 7.2
- ~100km rupture
- CA-Mexico border to the gulf

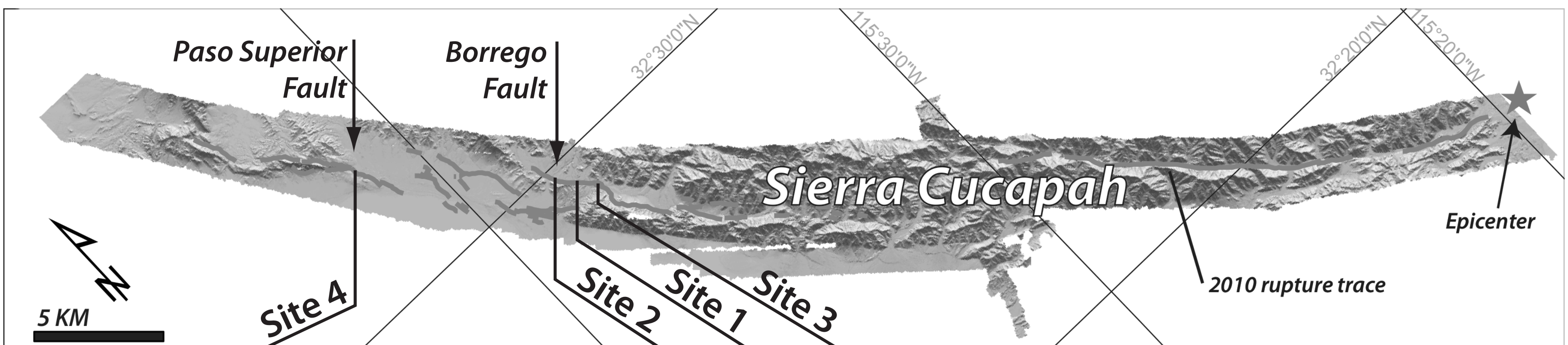
- > 3m right-normal slip north of epicenter
- < 1m right-normal blind faulting south of epicenter

P. Gold, UCD

Motivations: Data Collection

- Preserve primary rupture features for:
  - Remote measurement/analysis
  - Comparison to future scans

- Scan ruptures in a variety of geologic and geomorphic settings



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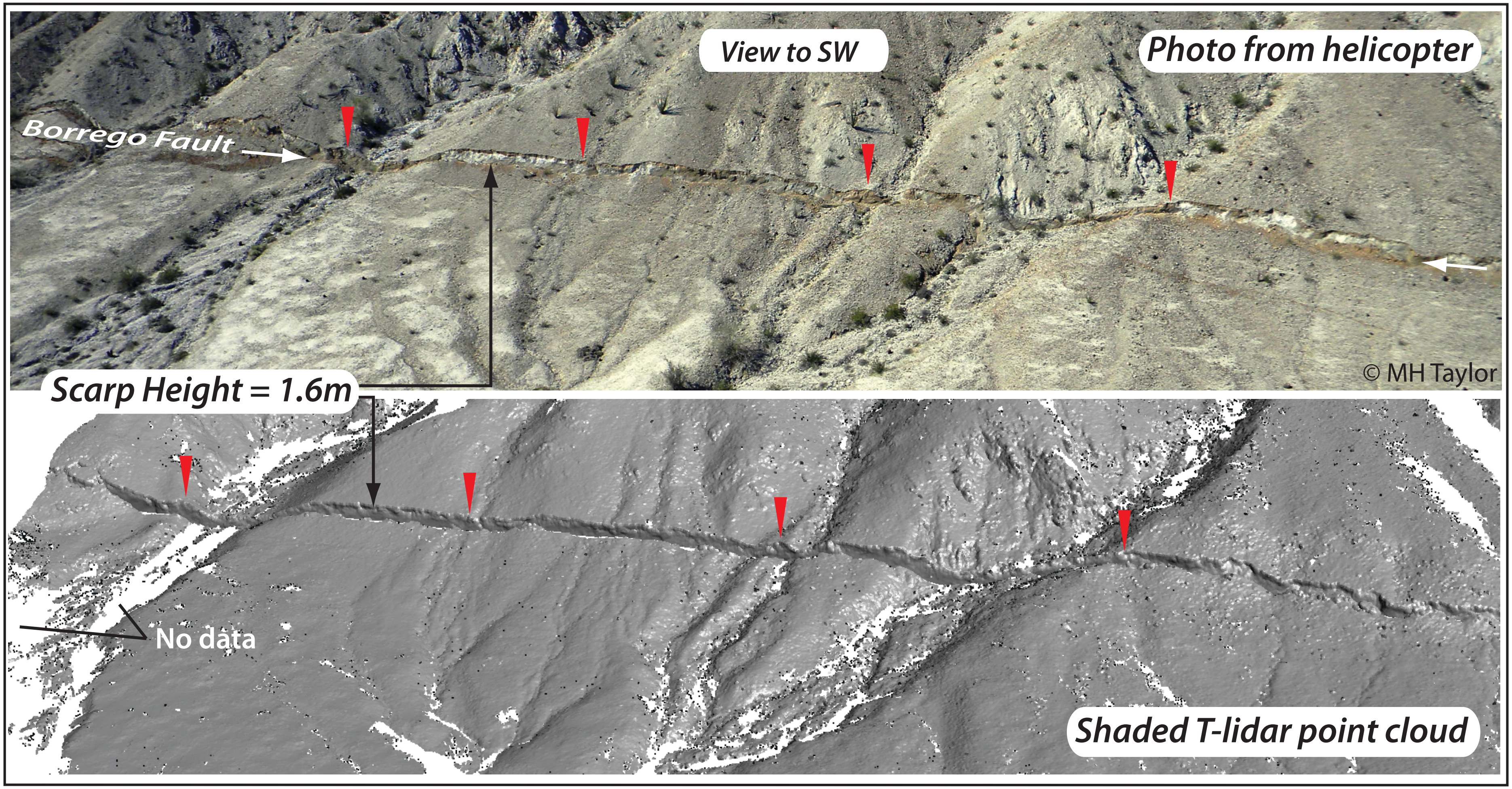
Scale of TLS coverage



- ~200m along-strike distances

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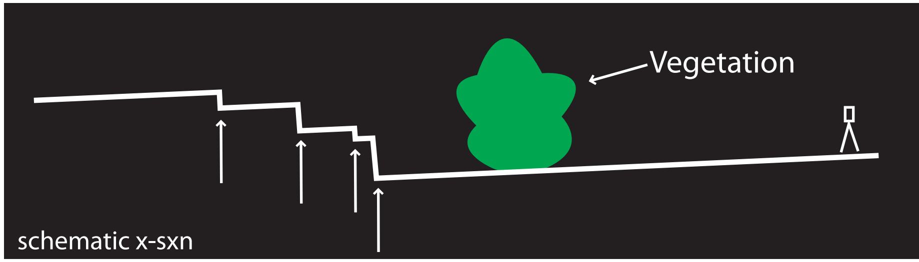
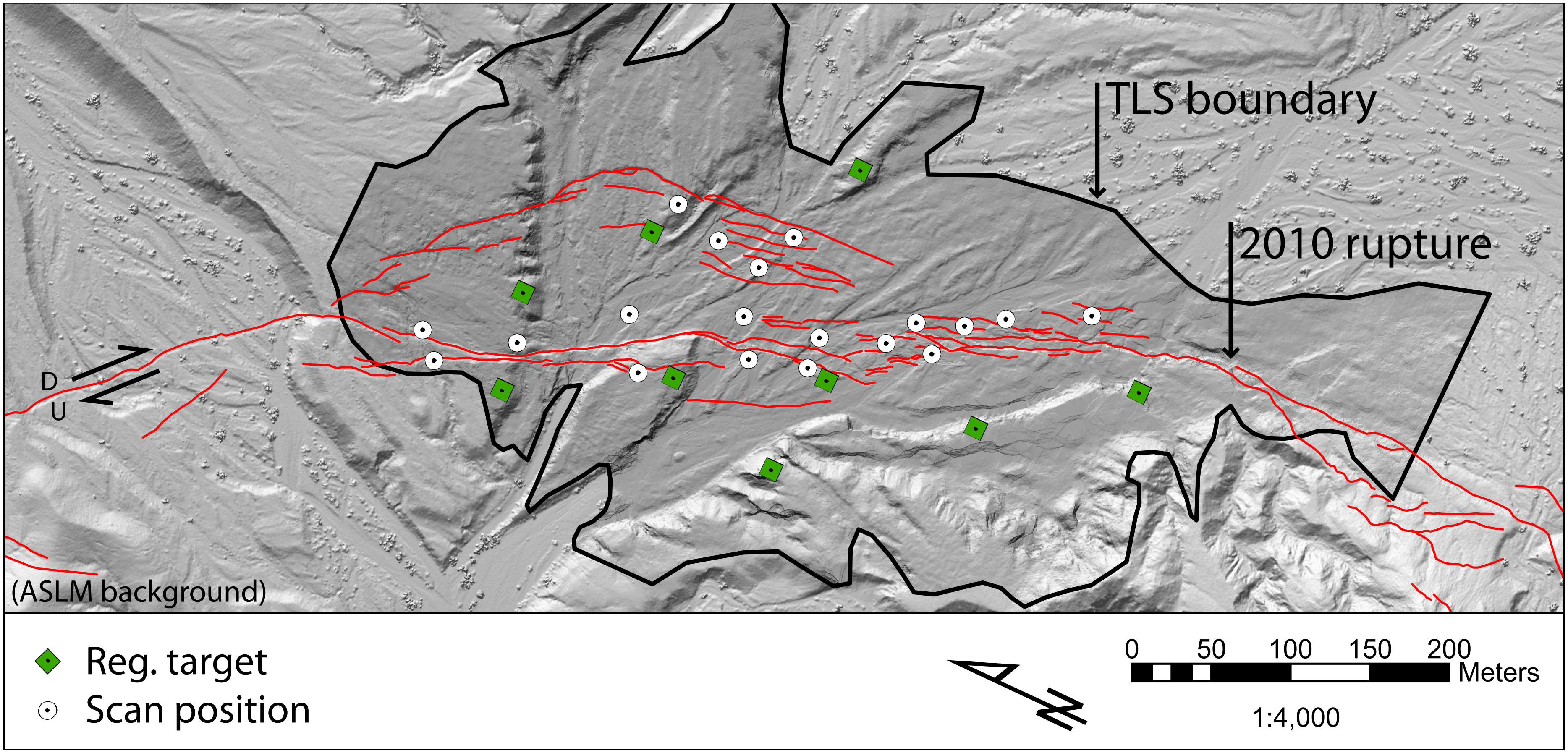
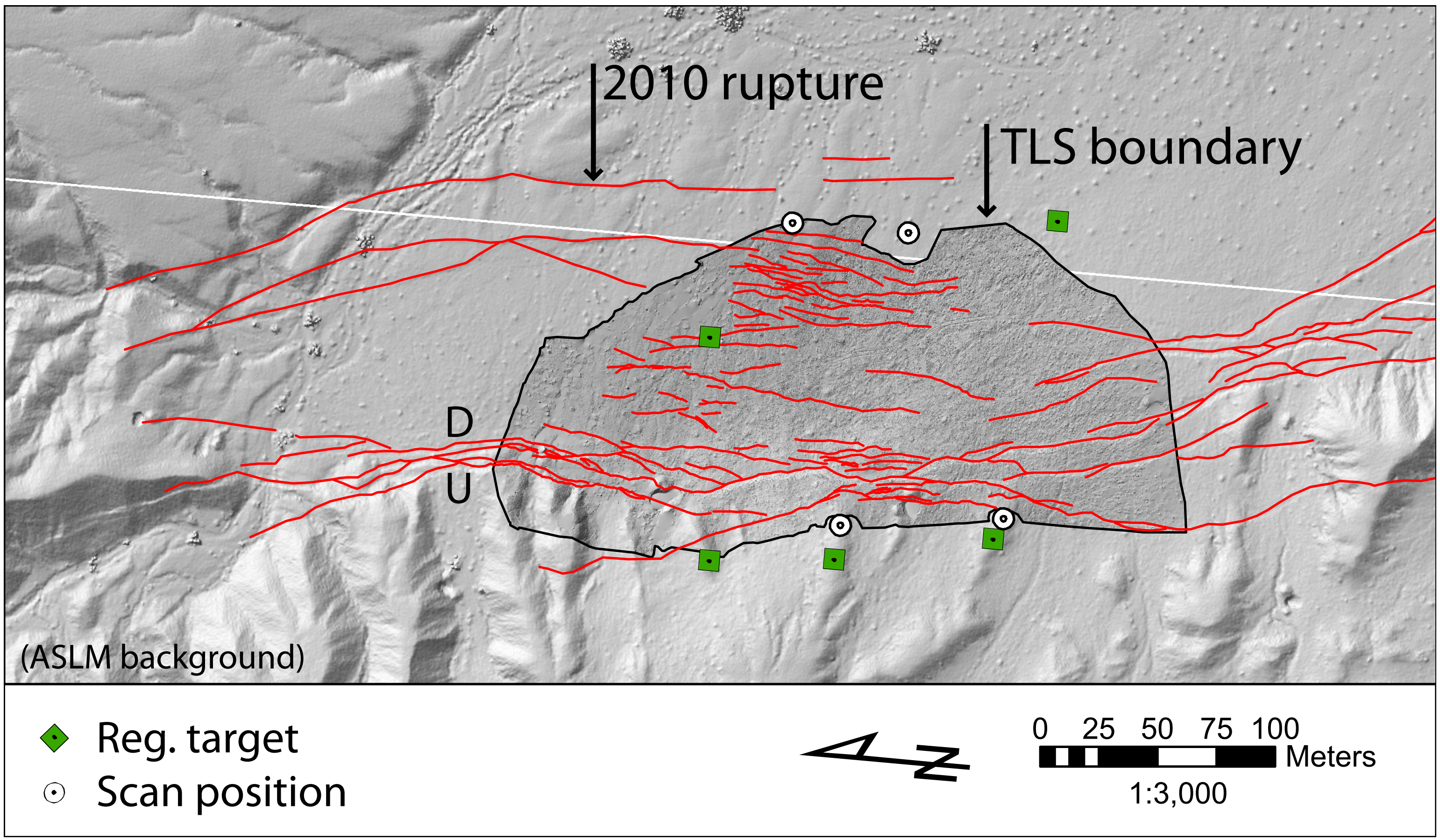
Data Collection

P. Gold, UCD





Data Collection



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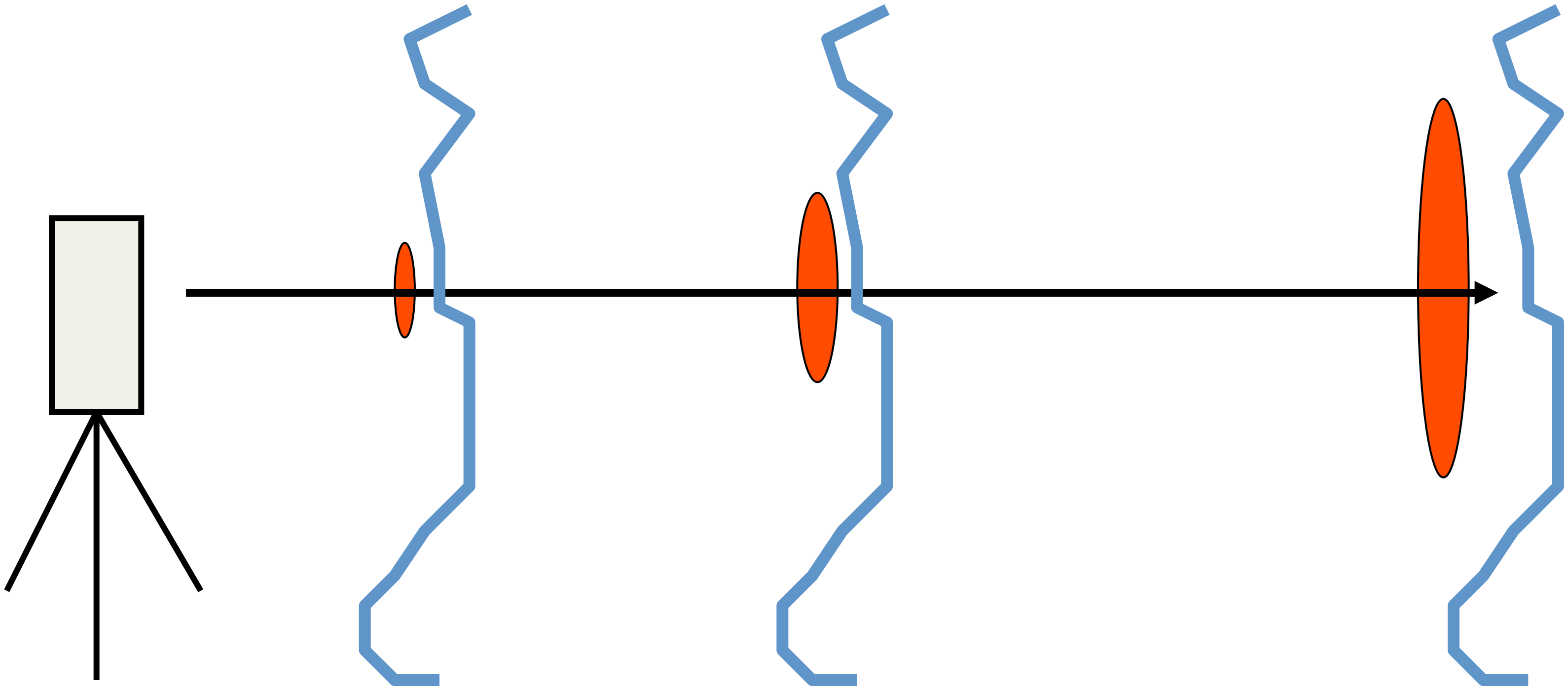
TLS Instrument and Survey Parameters

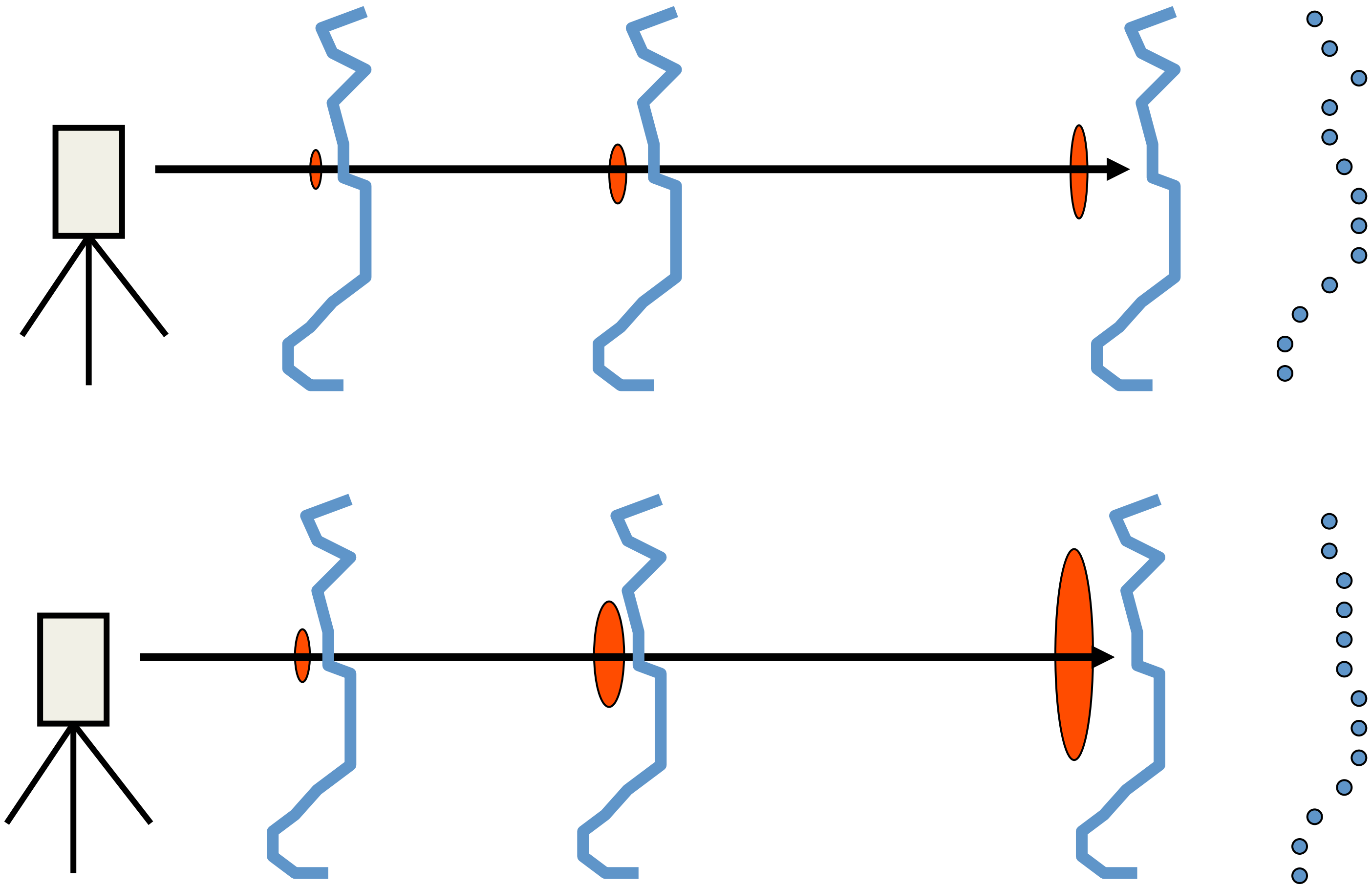
- Spot size (range, divergence)
- Spot spacing (range, angular resolution)
- Spot density (range, angle, number of setups)
- Angle of incidence (spot shape, intensity, range)
- Edge effects
- First return, last return, “other”
- Shadows
- Scan object characteristics (albedo, color, texture)
- Field of View
- Points Per Second

Beam Divergence

Df = (Divergence * d) + Di

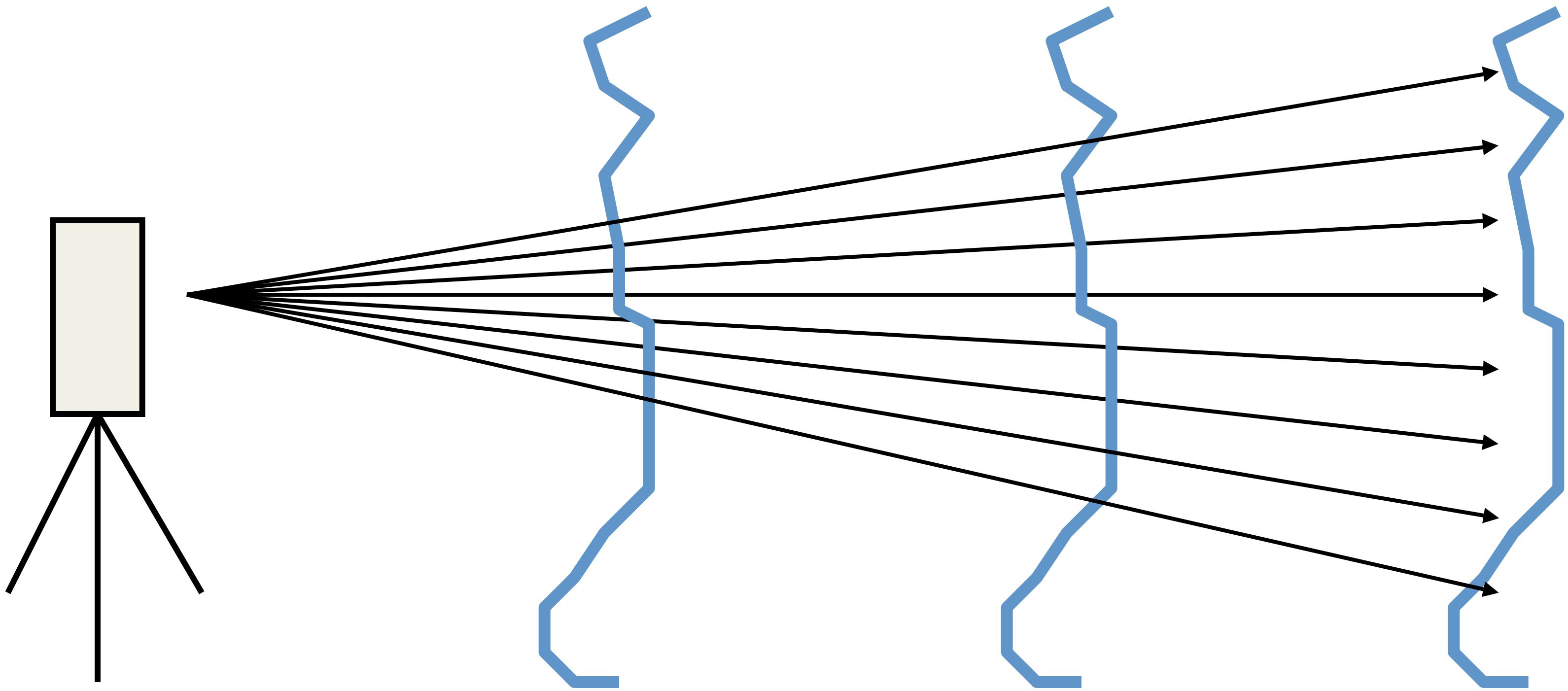


Beam Divergence

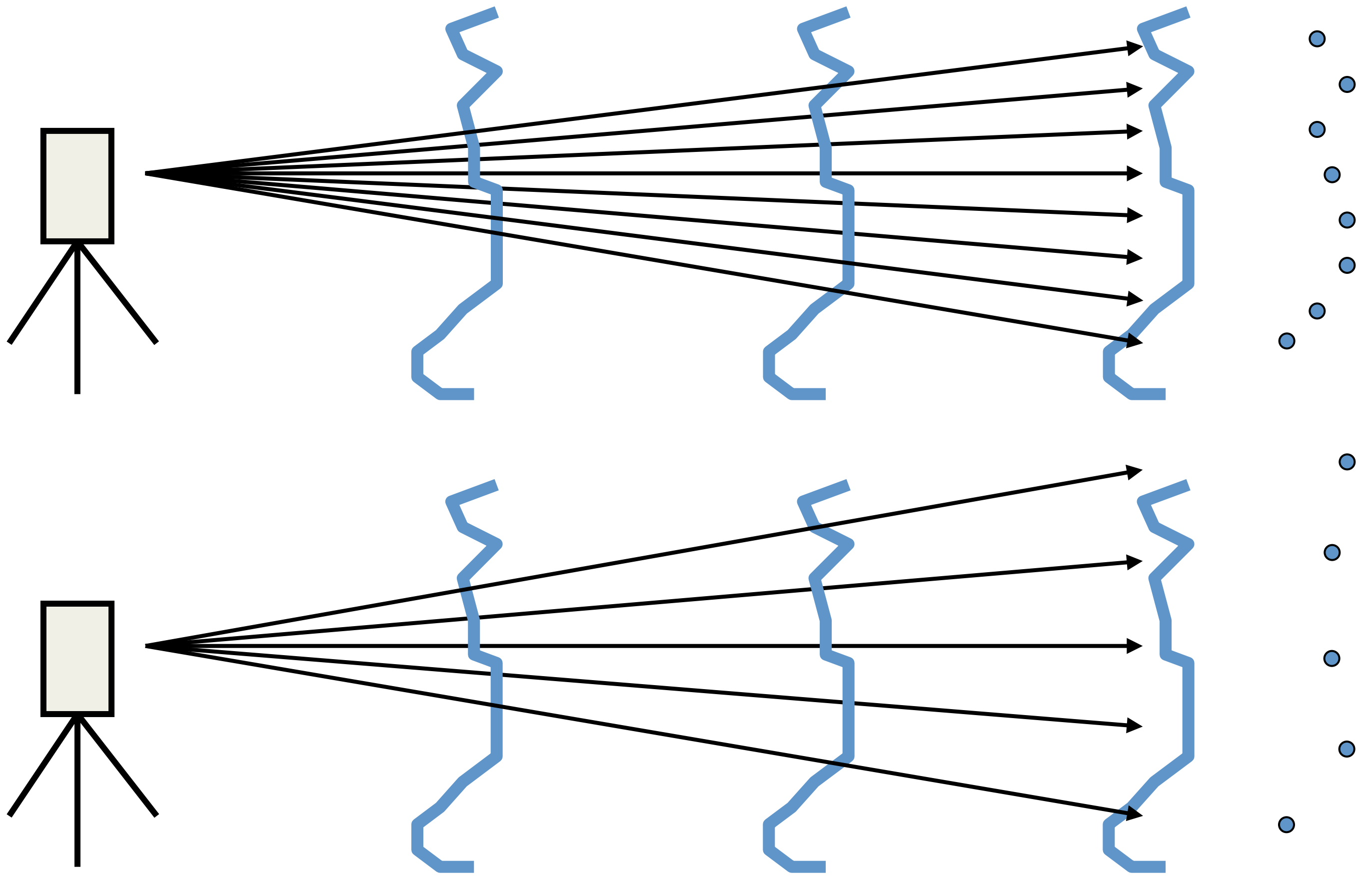


Angular Step

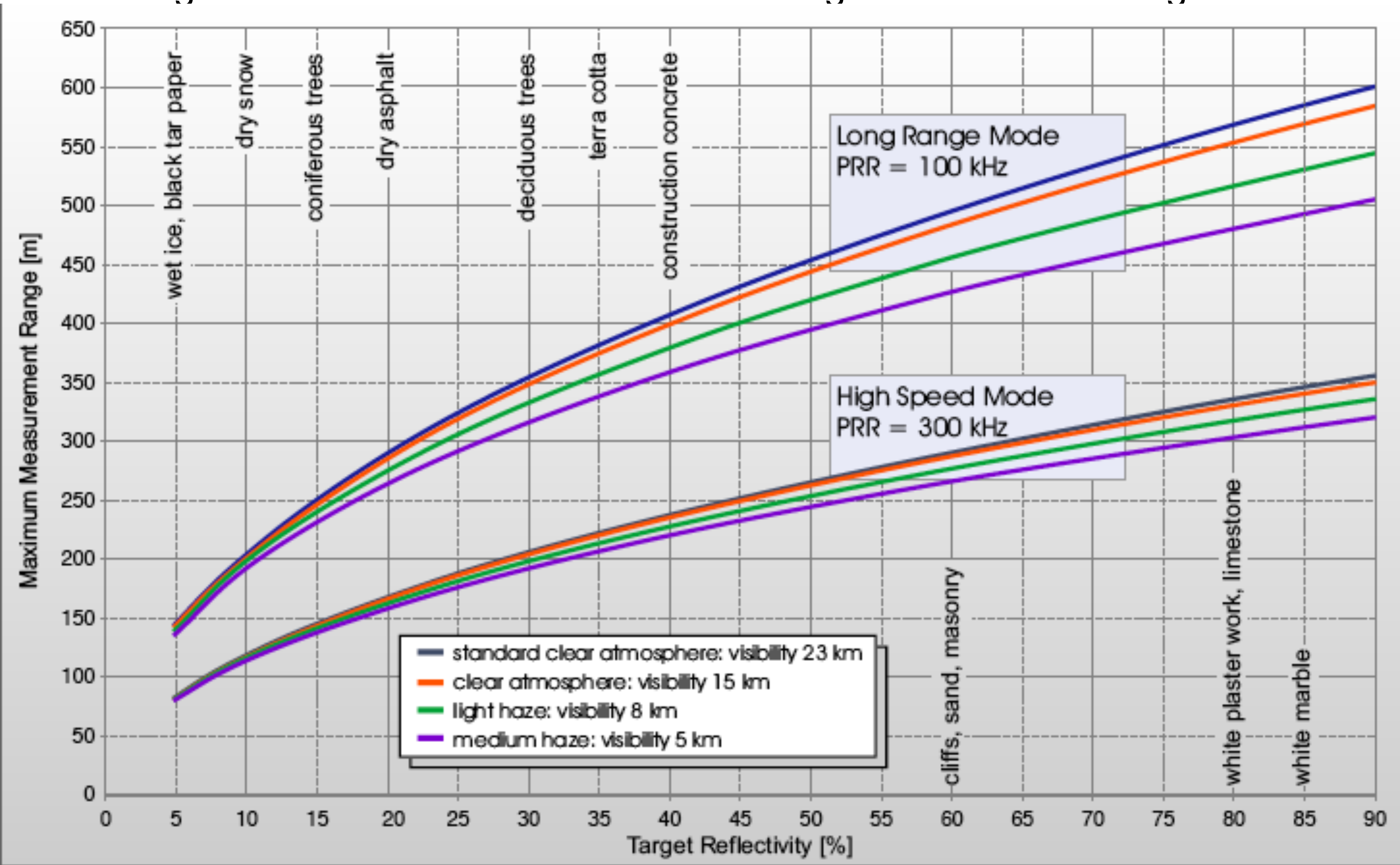
Spacing = d(m)*TAN(step)

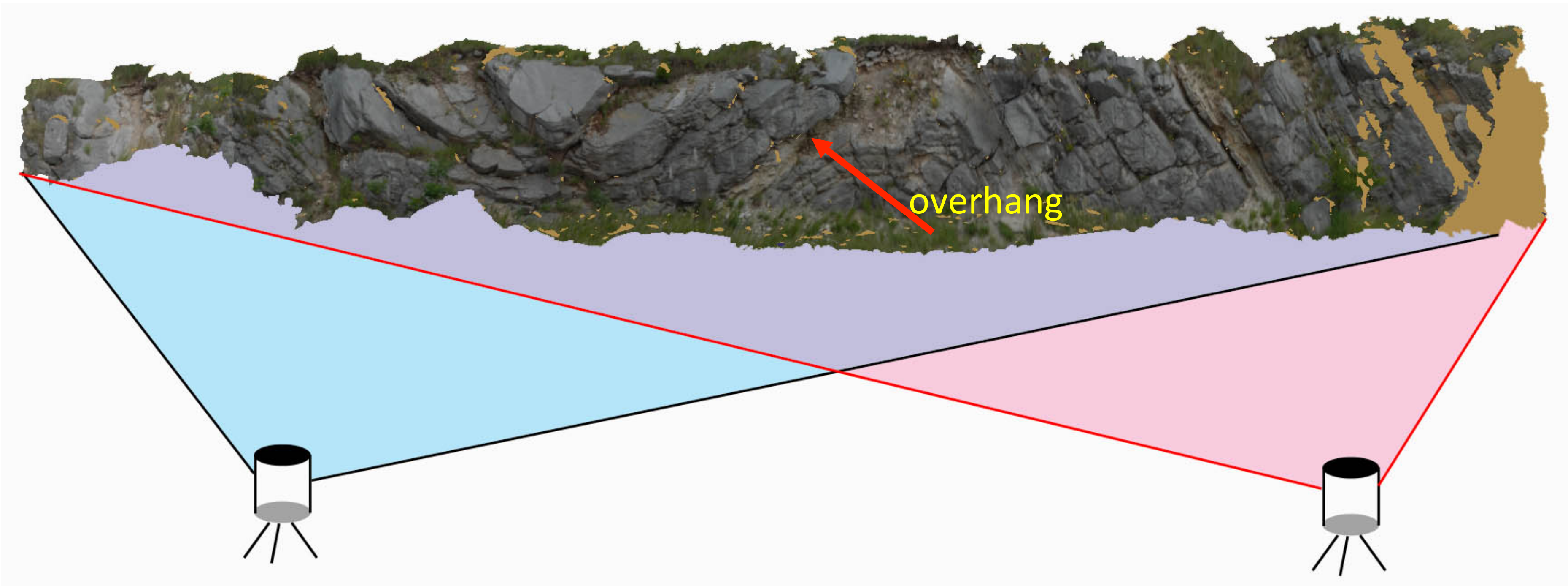


Angular Step



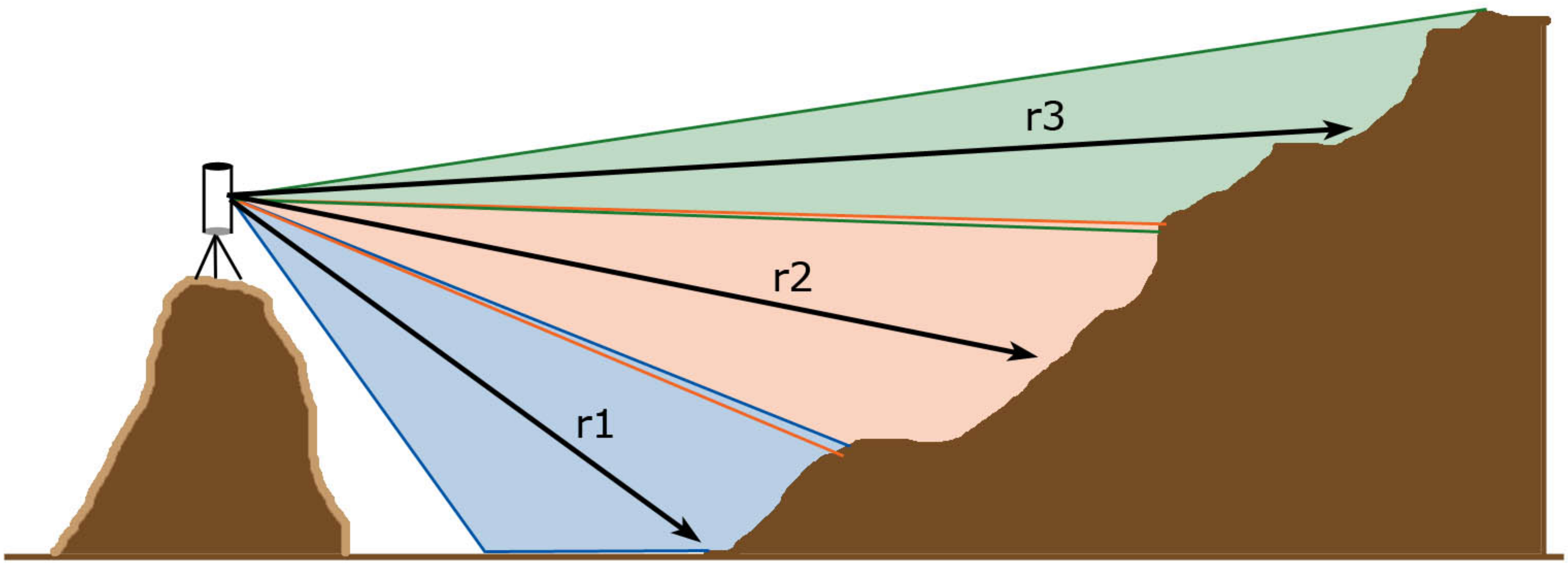
- Riegl VZ400 Maximum measurement range as function of target material





Scan Positions

Choose scan positions to minimize occluded (shadowed or hidden) geometries.



r1 = 280m   r2 = 400m   r3 = 550m

Shot Spacing / Sample Density

- Shot spacing varies as a function of range to target.
- Choose angular scan resolution to optimize sample density.

TARGET BASED WORKFLOW

Standard tie point workflow (e.g., Riegl RiScan Pro)

- Use at least 5 reference targets to register scan positions (the more the better).
- Same targets must be common between scan positions.
- The more targets common to all scan positions, the better

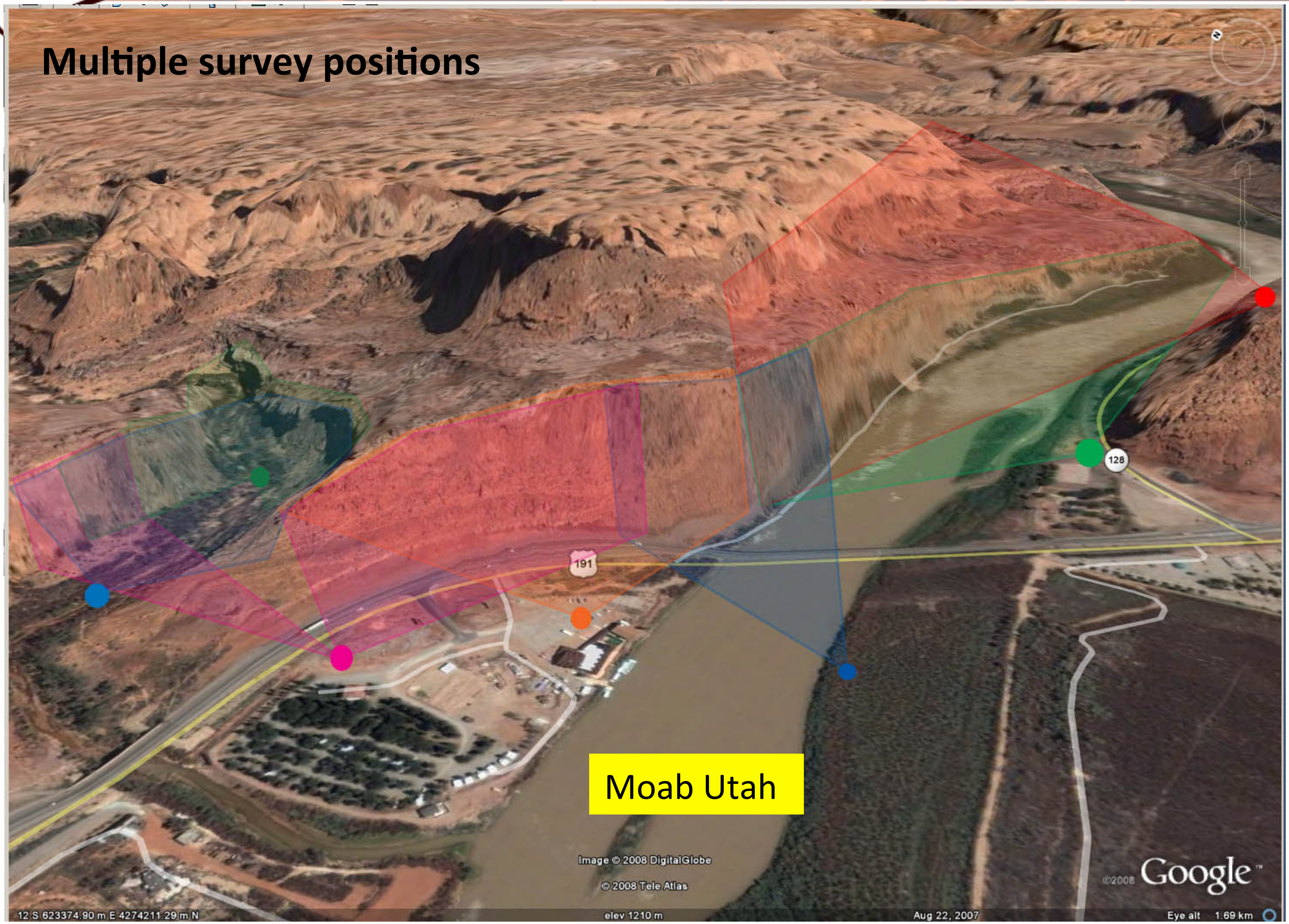
In the field

- Determine scan locations, target locations and GPS locations.
- Set up targets and GPS.
- Scan position 1
  - 360-deg "panorama" scan + Image acquisition if desired.
  - Target fine scan.
  - Area of interest scan + Image acquisition if desired.
- Scan positions 2 +
  - Same as above but then find corresponding points and co-register scan positions.

TLS Instrument and Survey Parameters

Moab, Utah survey site

TLS Instrument and Survey Parameters



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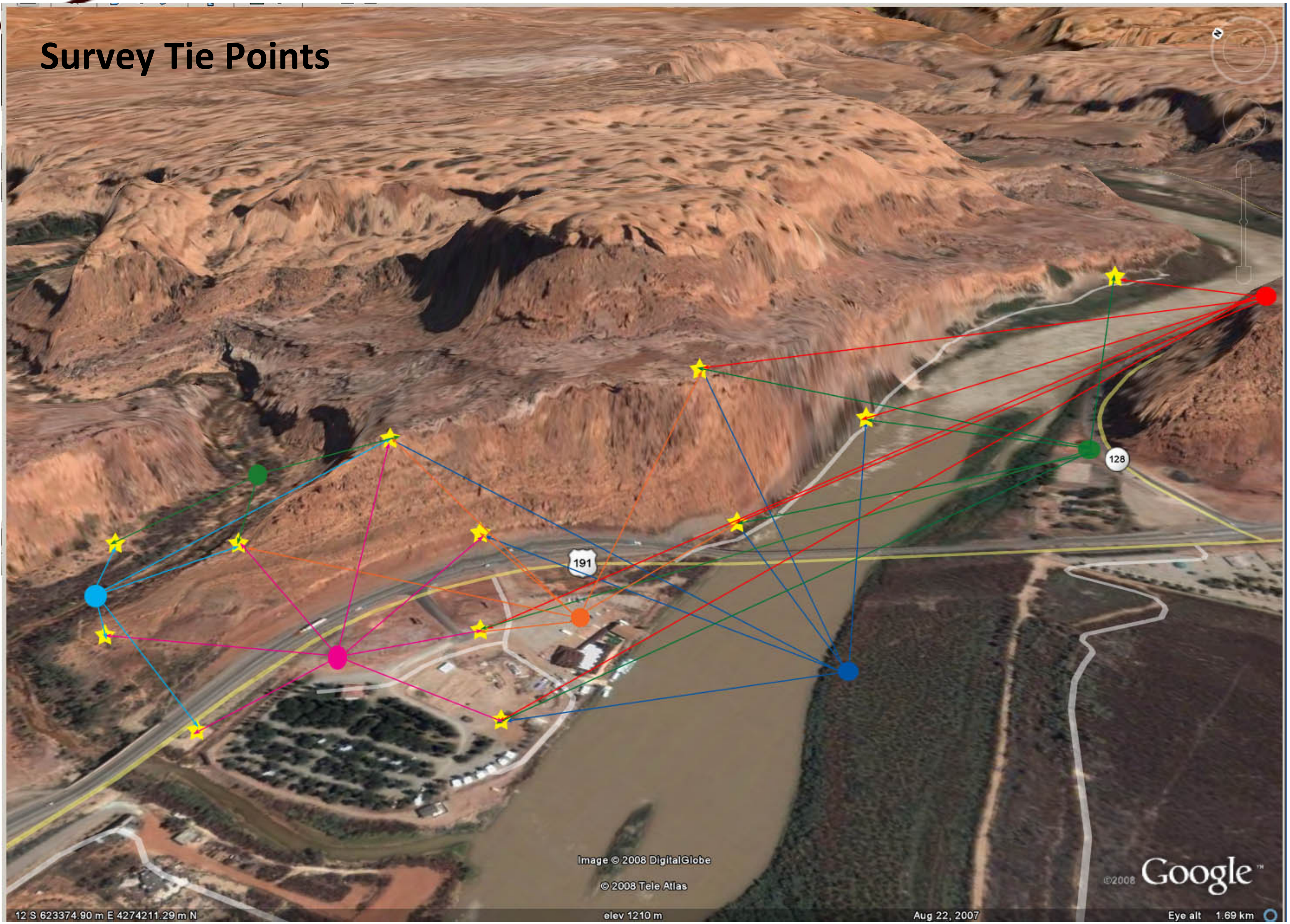
TLS Instrument and Survey Parameters

Survey Tie Points



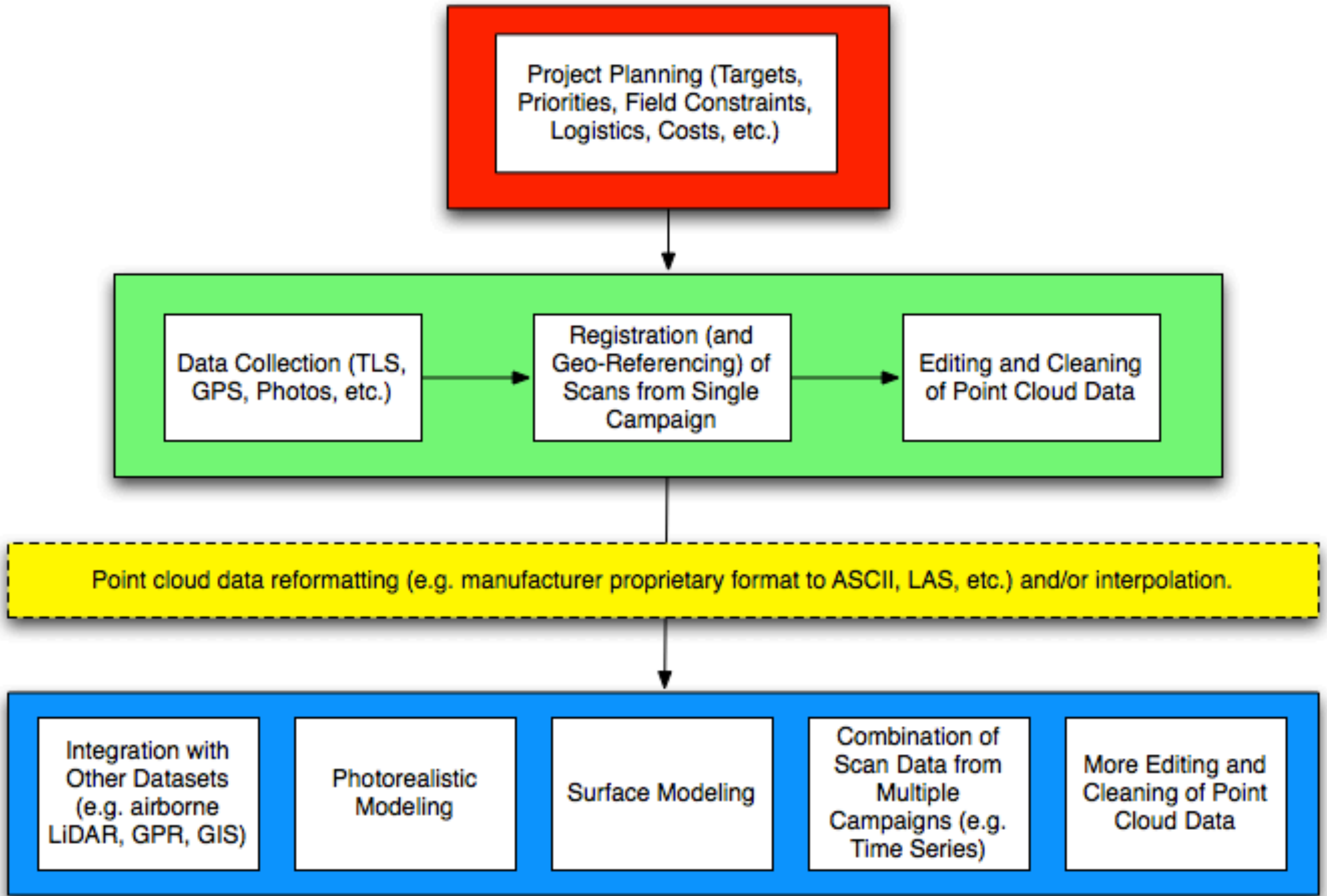
A note on coordinate systems:

- Three types of coordinate systems used in TLS:
  - Scanner coordinates (Riegl = “SCS”)
  - Project coordinates (“PRCS”)
  - Global Coordinates (GLCS)
- Remember the scanner thinks only in **angles and distances**
- Initially, all scans are independent w/ measurements relative to position of the scanner.
- Tie points link scans together = project coordinates (PRCS)
- Independent GPS information allows georeferencing of data (GLCS)

Data volume can be a problem:

- Technology outpaces most software for data processing & management.
- *Just because you can, doesn't mean you should*
- Science application should define data collection.

TLS Workflow Overview



Point Cloud

- 3D “point cloud” of discrete locations derived from range and orientation of scanner for each laser pulse.
- XYZ position in cartesian coordinates plus associated point attributes: intensity, RGB, etc.
- 3D point clouds are the basis for subsequent analysis and used to create CAD or GIS models
- Typically ASCII XYZ + attributes or LAS
  - E57 = New standard under development, minimal adoption
- UNAVCO ***standard deliverable*** = merged, aligned, georeferenced point cloud in ASCII or LAS format.

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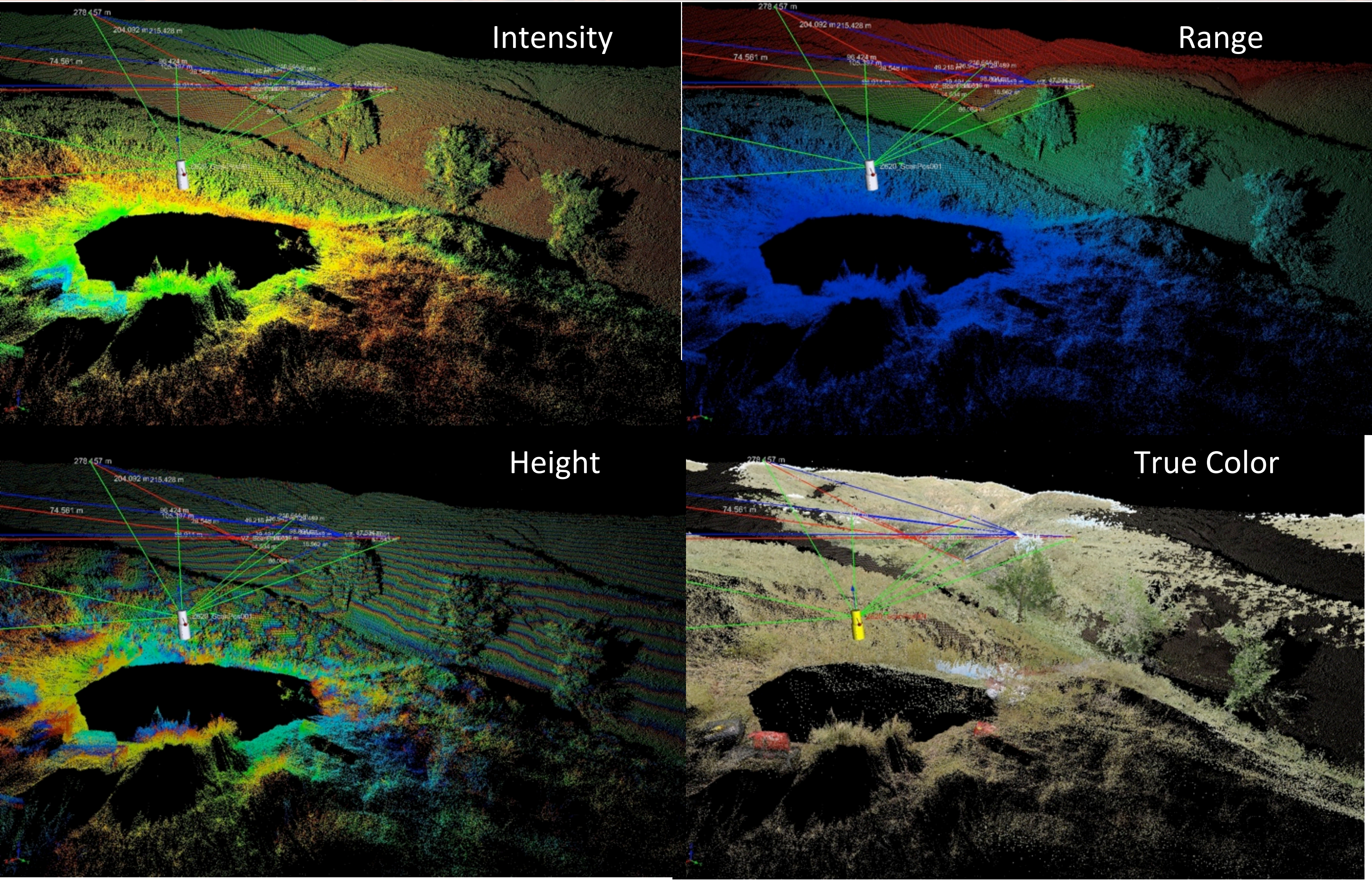
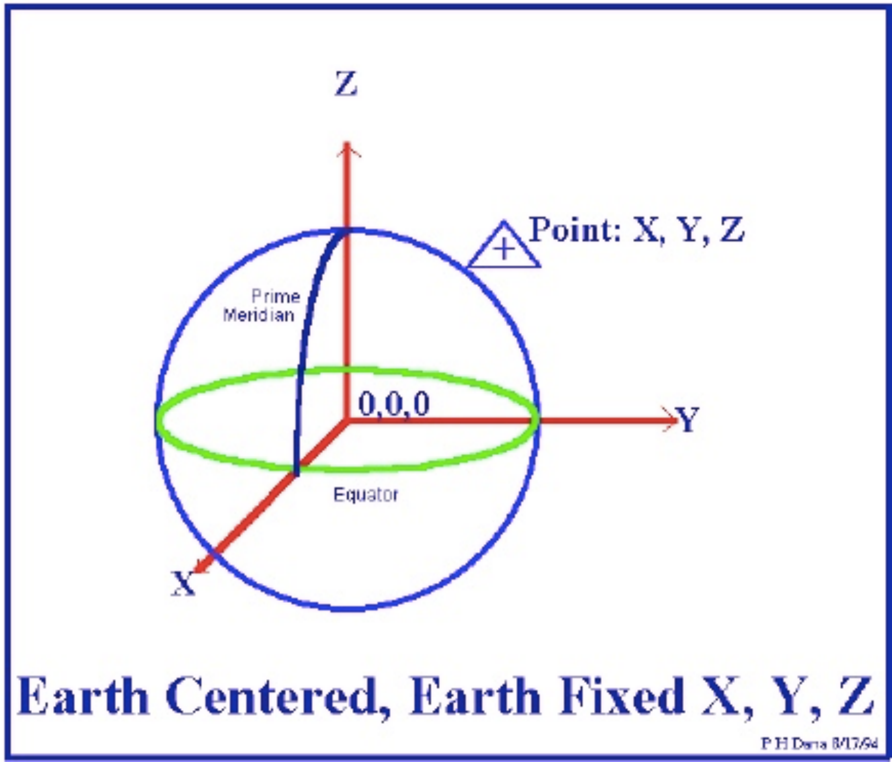
TLS Data



TLS data often delivered in Earth Centered, Earth Fixed coordinates.

- Origin = center of mass of the Earth.
- Three right-handed orthogonal axis X, Y, Z. Units = meters.
- The Z axis coincides with the Earth's rotation axis.
- The (X,Y) plane coincides with the equatorial plane.
- The (X,Z) plane contains the Earth's rotation axis and the prime meridian.

- Preferred by geodesy community
- Not GIS friendly! Requires transformations into 2D cartesian (e.g., UTM).
- Application of data matters
- Beware vertical datums…



TLS Processing Workflow – Software

9. What software do you use to process and/or analyze TLS data? Choose all that apply.

	Response Percent	Response Count
PolyWorks	29.9%	23
Cyclone	19.5%	15
Riscan	35.1%	27
TerraSolid	13.0%	10
Arc/GIS	**61.0%**	**47**
QT Modeler	18.2%	14
Matlab	32.5%	25
Other (specify)	28.6%	22
	Other (please specify)	32

<u>Other</u>:

- 3D Studio
- 3dReshaper
- AutoCad
- BCAL LiDAR Tools
- Blender
- CloudWorx
- Crusta
- ENVI
- FARO Scene
- GDAL
- GeoAnalysis Tools
- Geovisionary
- Global Mapper
- GMT
- GRASS
- IDL
- Kingdom Suite
- LASTools
- libLAS
- MapScenes
- MapTek I-SiTE Studio
- Meshlab
- MicroCad
- MicroStation
- MicroSurveyCAD
- OpenTopography DEM generator
- OpenVC
- Point Cloud Library (PCL)
- Points2Grid
- PointTools
- Python modules and
- custom tools
- RealityLinx
- Split-FX
- Surfer
- TerraModeler
- Trimble RealWorks
- UC Davis tools
- (LidarViewer, Crusta)
- “home grown software”

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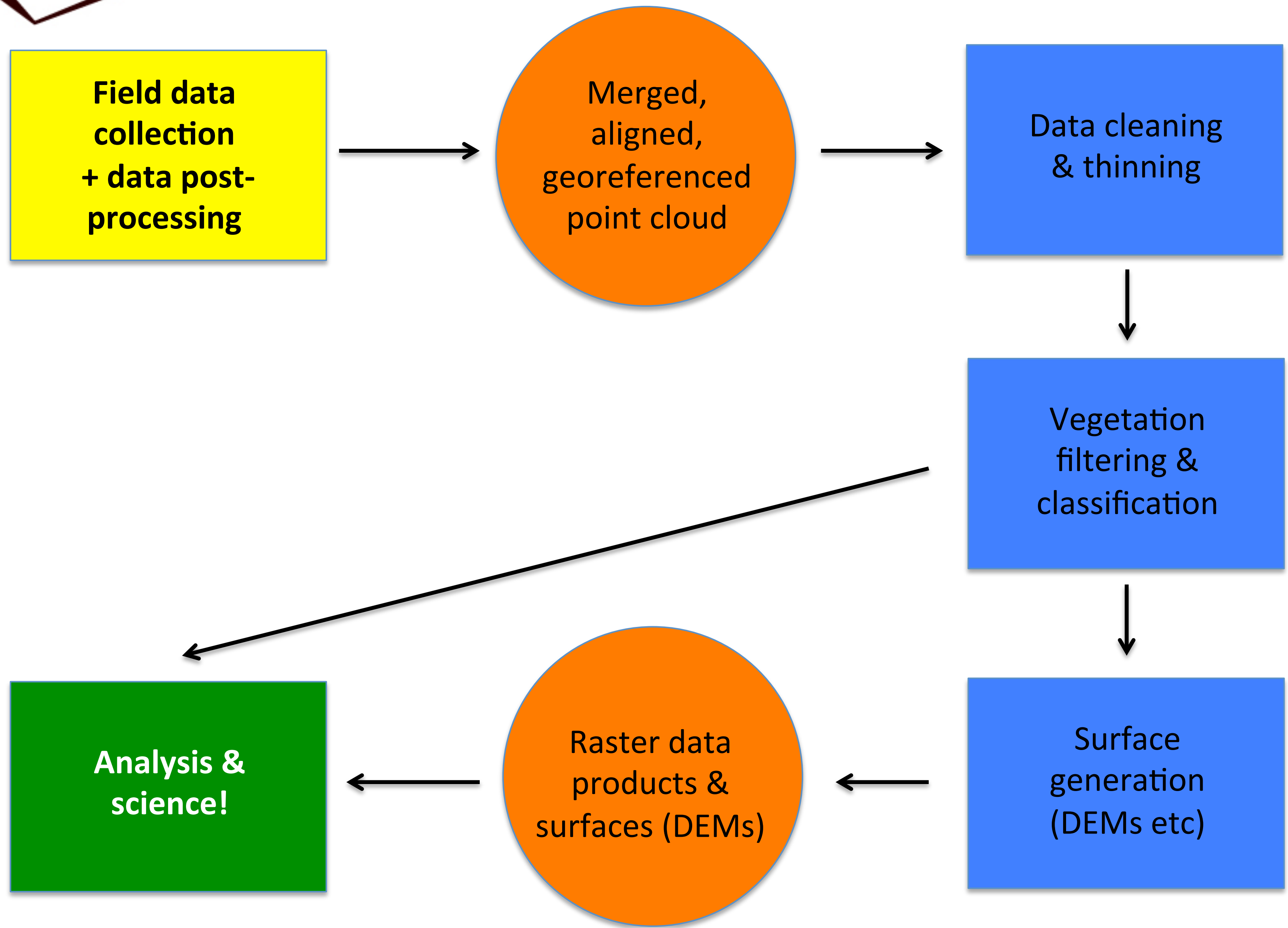
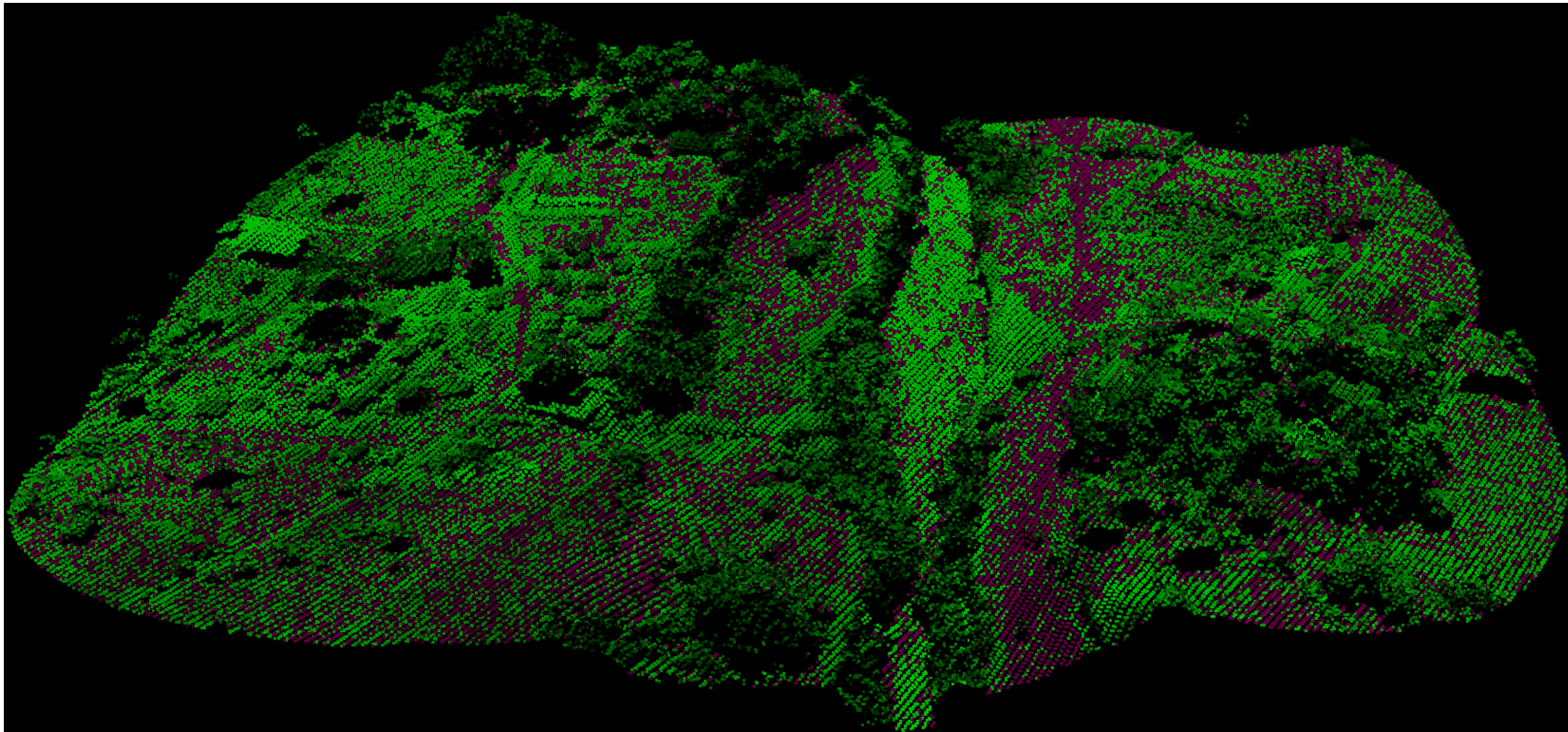
TLS Processing Workflow – Overview



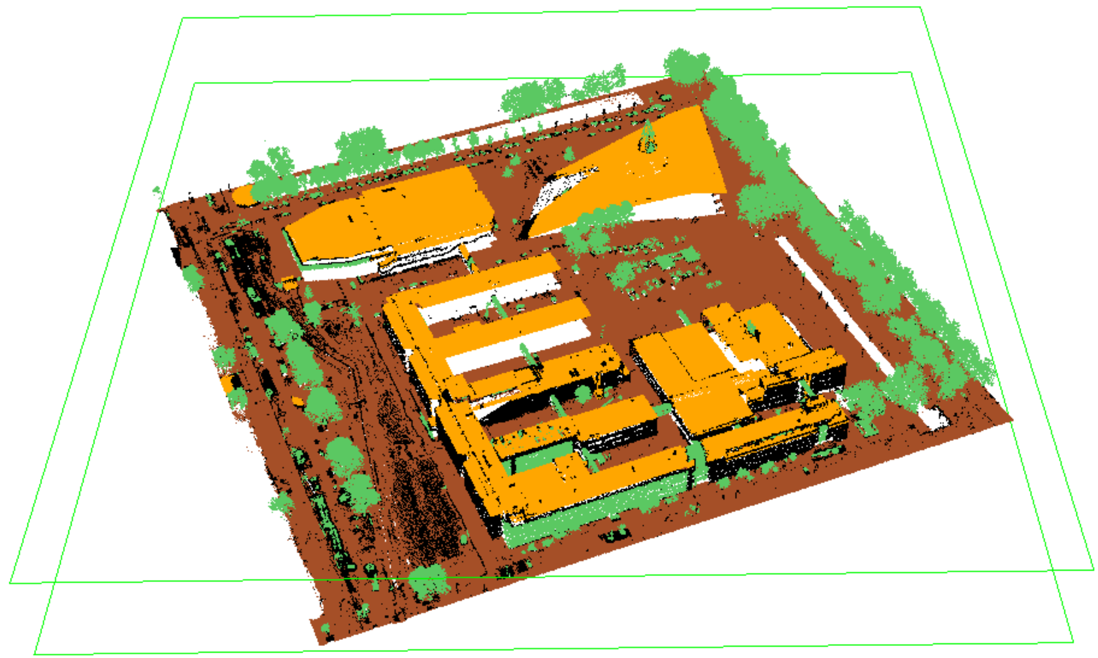
Vegetation is a headache is geoscientists

- *Our noise is someone else's signal*
- How to get good ground model?
- Automated vs manual?



Dumay Slip-Rate Site, Enriquillo Fault, Haiti

P. Gold, UCD



Commercial – Automated:

- RiScan Pro, TeraSolid, etc.

Open Source - Automated:

- LASTools –
  lasground.exe &
  lasclassify.exe
- MCC-lidar
  (Evans & Hudak, 2007)
  http://sourceforge.net/apps/trac/mcclidar/
- BCAL lidar tools (requires ENVI): http://bcal.geology.isu.edu/tools-2/envi-tools

More discussion: http://www.opentopography.org/index.php/blog/detail/tools_for_lidar_point_cloud_filtering_classification#comments

Open Source - Manual:

- LidarViewer (KeckCAVES)

- Digital representation of topography / terrain
  - "Raster" format – a grid of squares or "pixels"
  - Continuous surface where Z (elevation) is estimated on a regular X,Y grid
  - "2.5D"

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0
0	50	100	100	100	100	100	100	100	100	100	100	100	100	100	50	0
0	50	100	150	150	150	150	150	150	150	150	150	150	150	100	50	0
0	50	100	150	200	200	200	200	200	200	200	200	200	150	100	50	0
0	50	100	150	200	250	250	250	250	250	250	250	200	150	100	50	0
0	50	100	150	200	250	300	300	300	300	300	250	200	150	100	50	0
0	50	100	150	200	250	300	350	350	350	300	250	200	150	100	50	0
0	50	100	150	200	250	300	350	400	350	300	250	200	150	100	50	0
0	50	100	150	200	250	300	350	350	350	300	250	200	150	100	50	0
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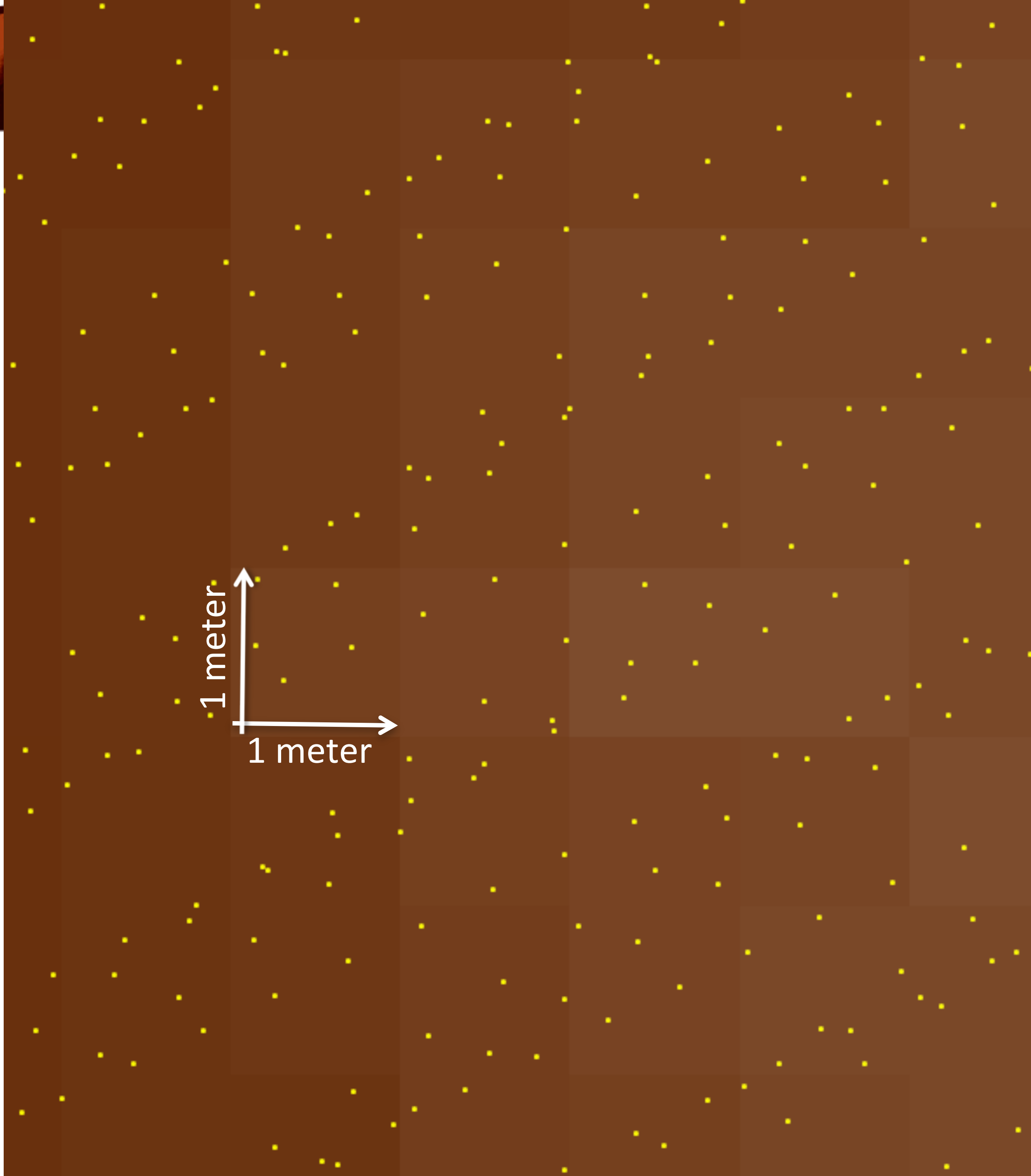
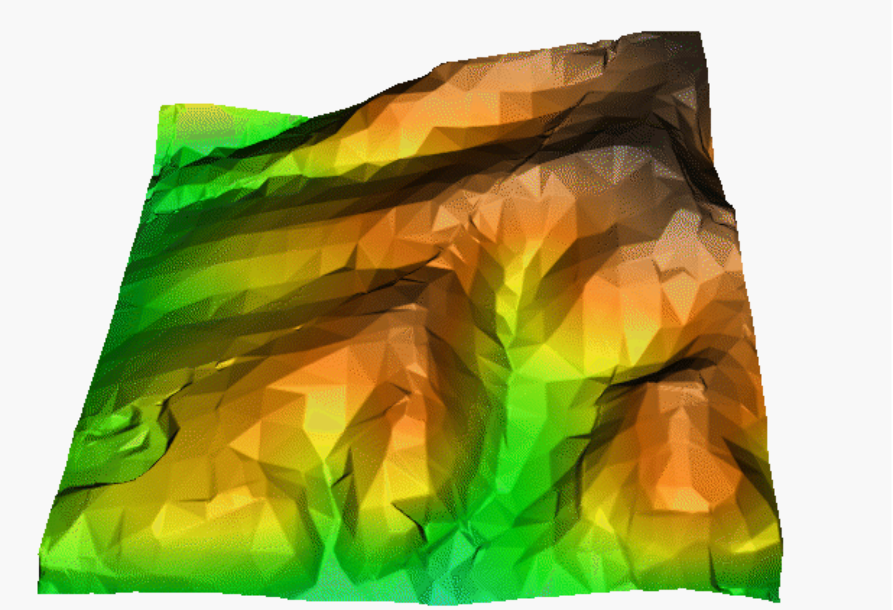
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: http://www.ncgia.ucsb.edu/giscc/extra/e001/e001.html

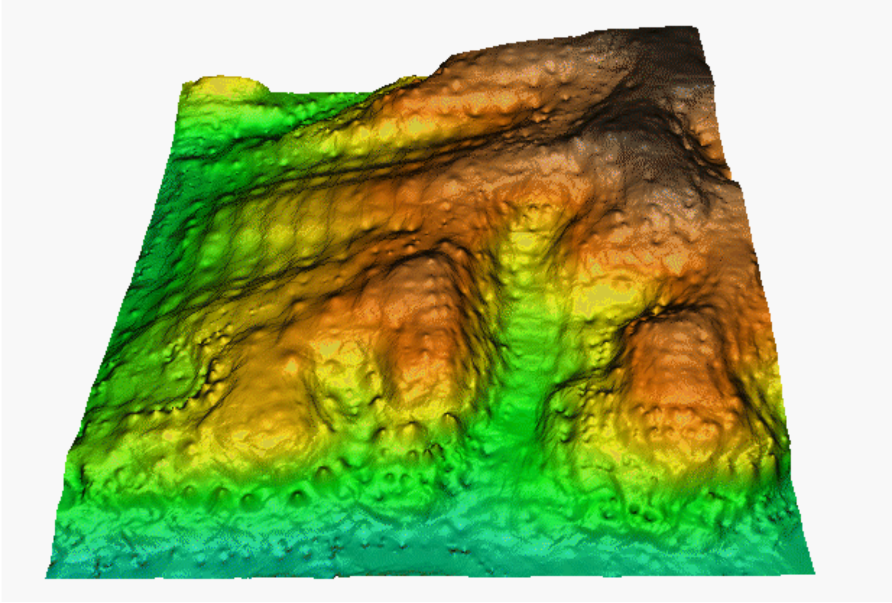
- Grid resolution is defined by the size in the horizontal dimension of the pixel
  - 1 meter DEM has pixels 1 m x 1m assigned a single elevation value.

- LiDAR from EarthScope data
- Example from flat area with little or no vegetation so ground is sampled approx. 5+ times per square meter
- How do we best fit a continuous surface to these points?
- Ultimately wish to represent irregularly sampled data on a regularized grid.

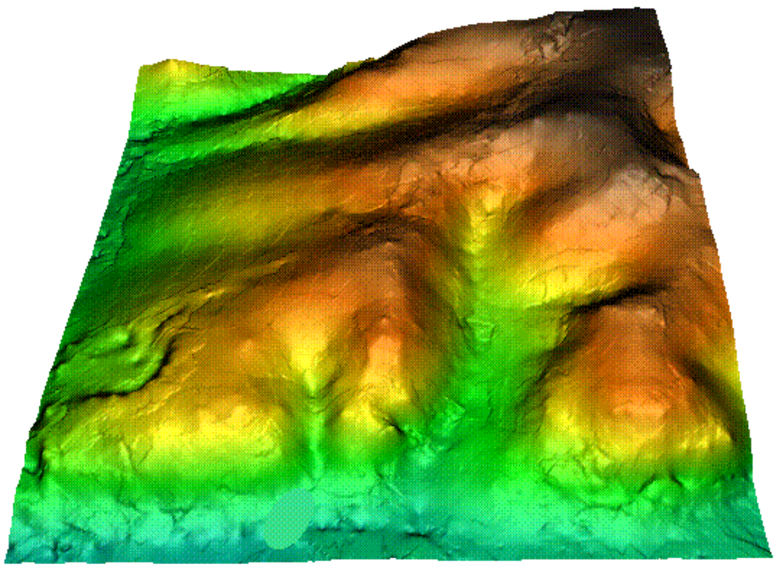




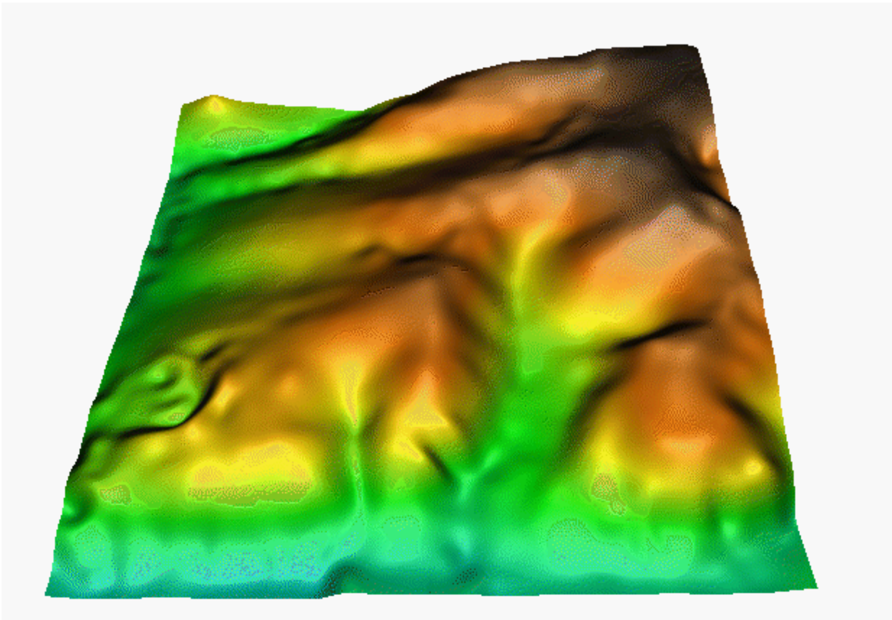
Triangulated Irregular Network (TIN)



Inverse Distance Weighted (IDW)



Kriging



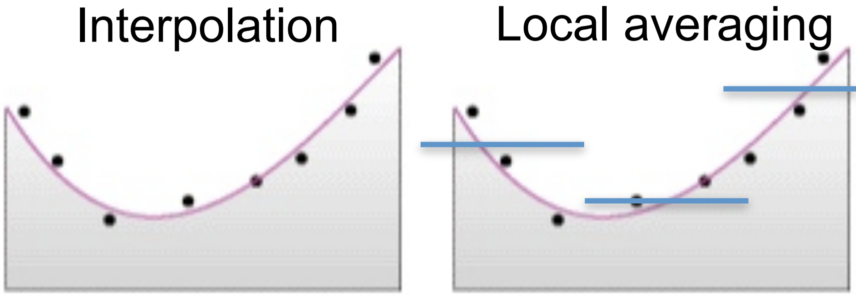
Regularized Spline with Tension and smoothing (RST)

Figure from Helena Mitasova (NCSU): http://skagit.meas.ncsu.edu/~helena/gmslab/index.html

- Massive volume of point cloud data that need to be gridded presents unique challenge to many traditional GIS interpolation approaches.
  – Computation time becomes a serious concern

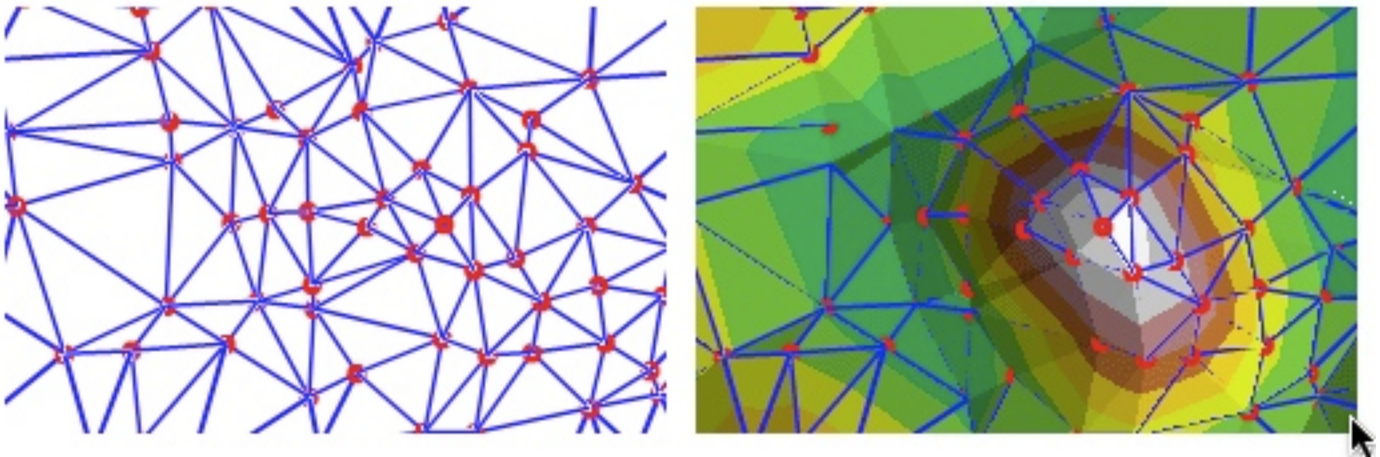
- Global vs Local fit
  – Global fit uses elevations from the region to estimate unknown elevation at the grid node.
    - Ex: Kriging, Trend Surface Analysis, splines
    - Computationally intensive and require segmentation approaches to break input data into pieces which can be processed independently.

    - Often inexact interpolators
      -Surface does not exactly fit all points.
    - Works well in areas where ground is poorly sampled.



http://webhelp.esri.com/

- Triangular Irregular Networks (TIN)
  - Constructed by triangulating a set of points



http://webhelp.esri.com/

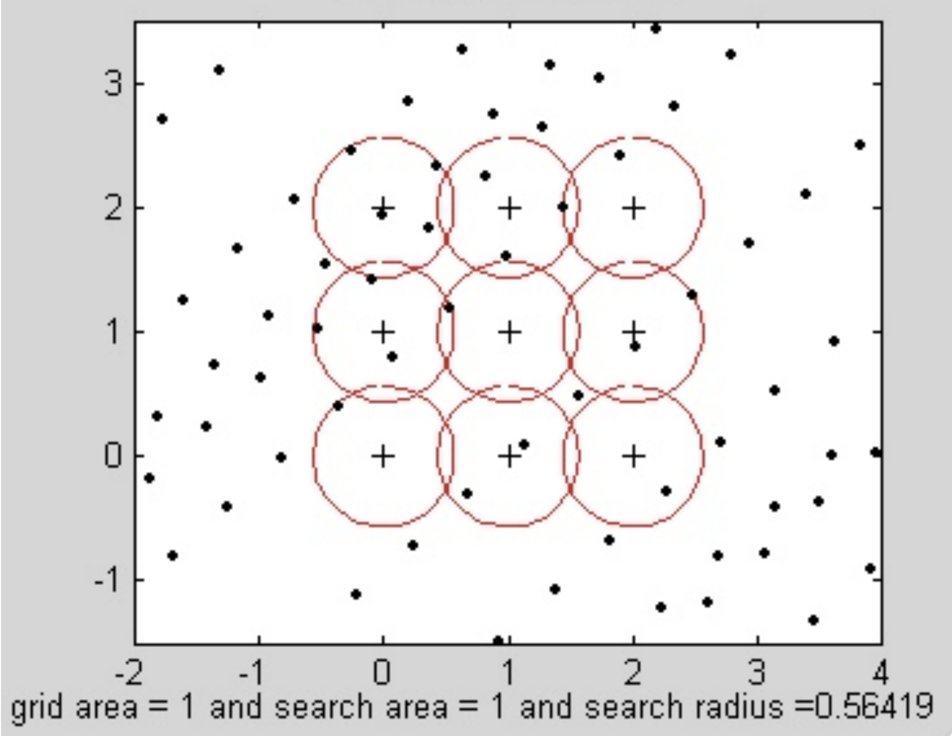
  - Linear interpolation where points are fit exactly
  - Computationally efficient
  - Preserve heterogeneity of detail in sampling
  - Vector-based format so conversion to grid is necessary for many types of analysis.

- Global vs Local fit cont.:
  - Local fit only uses elevations immediately surrounding the grid node to estimate elevation.
    - Nearest neighbor, local binning, moving window
    - For all points that fall within the defined search area, apply mathematical function e.g Z_{mean} Z_{min} Z_{max} Z_{idw}

- Computationally efficient
- Not interpolation!
- Works well when:

Sampling density > grid resolution

Ex: sampling density = 5 shots/m^2
grid resolution = 1 m



Community-wide need to standardize and document TLS data processing workflow & products:

- Metadata content and format
- Generic (vendor neutral/open) exchange formats (e.g., LAS, E57)
- Capture of intermediate data products (e.g., point cloud per scan position)
- Attributes associated with final L2 data product (merged, aligned, georeferenced point cloud)
- Provenance – capture all steps of workflow to ensure repeatable and verifiable science.

Currently industry-wide deficiencies in this area – UNAVCO trying to take a leadership role.

Project Planning

- Choose instrument based on capabilities and science/data goals.
- Schedule based on instrument availability, science requirements, environmental factors.
- Use Google Earth, field site photos, etc. to establish preliminary locations for scan positions, control targets, registration targets, etc.

Instrument calibration & data collection

Post-processing & Analysis

- Make a copy of the data collected in the field. Keep the original project(s) in a safe place. Post process using the copy of the project.

Metadata

- Project summary document.
- GPS data (raw files, rinex files, antenna heights, log sheets, etc.).
- Field photos.
- Google Earth files, etc.