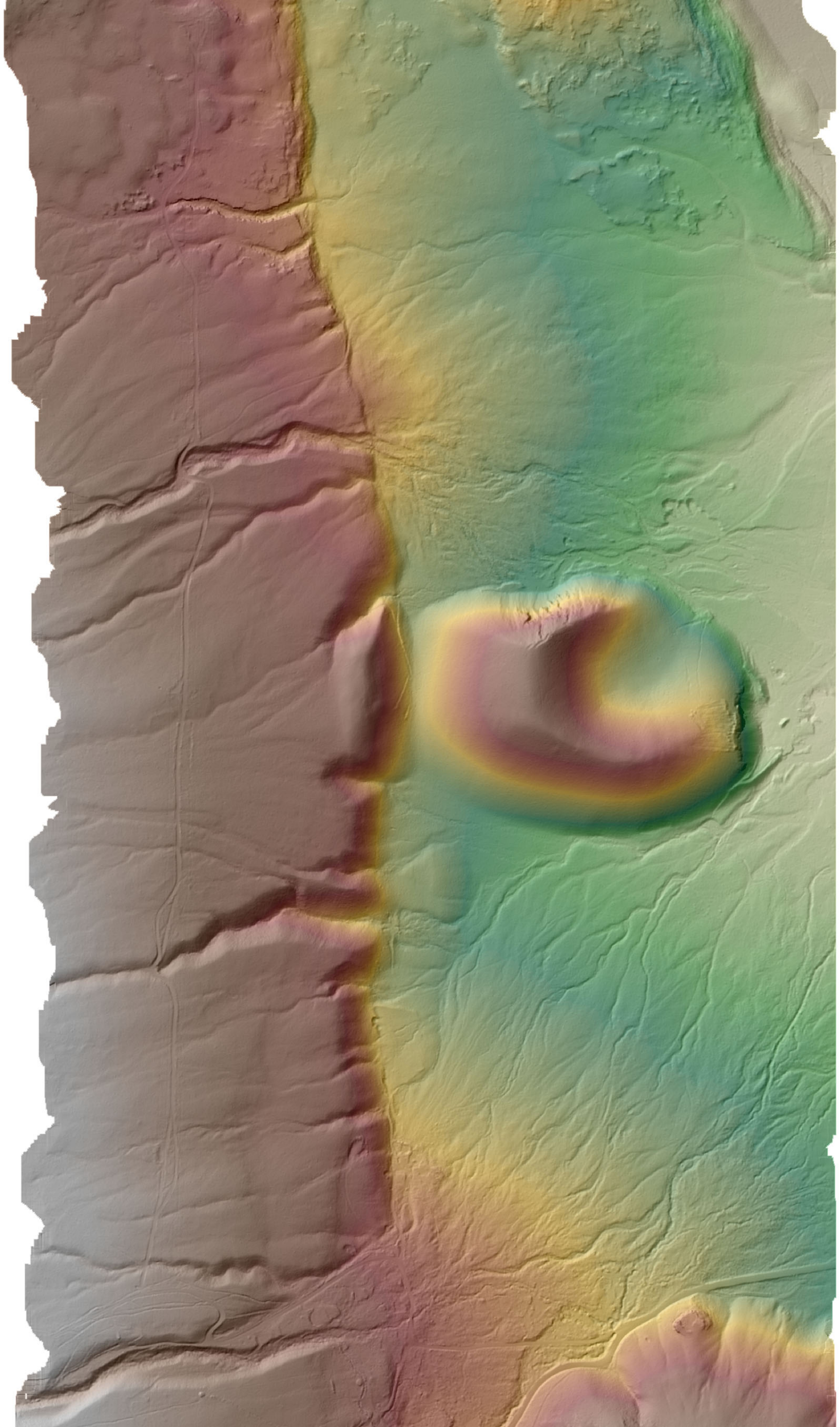


Introduction to Lidar

Christopher Crosby

UNAVCO / OpenTopography

(with content adapted from Ralph Hagerud & Ken Hudnut (USGS); Ian Madin, DOGAMI; Quantum Spatial)

2016 OpenTopography Short Course:

California Geological Survey

May 2-3, 2016

Sacramento, CA

Outline

1. Introduction to lidar technology
2. Lidar and vegetation:
   a. Penetration
   b. Ground classification
3. Pulse density, heterogeneity, resolution
4. Deliverables
5. Errors and things to be aware of.

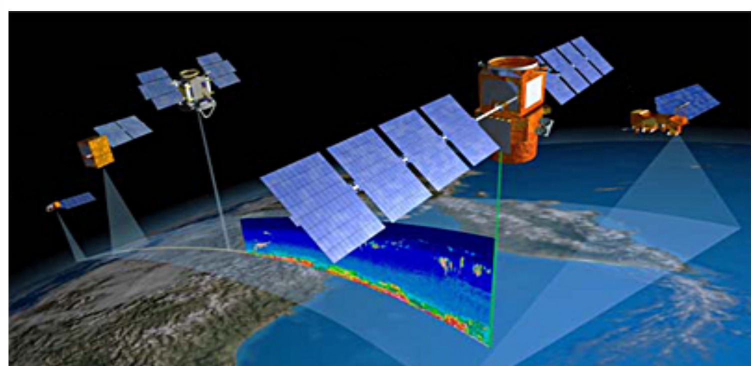
Light Detection and Ranging (lidar)

- Accurate distance measurements with a laser rangefinder
- Distance is calculated by measuring the two-way travel time of a laser pulse.
- Near IR (1550nm) or green (532nm)

Modified from Ian Madin, DOGAMI

Lidar platforms

BUSINESS WIRE COMMERCIAL PHOTO



J. Stoker, USGS

UNAVCO

Light Detection and Ranging (lidar)

Similar technology, different platforms:

Terrestrial Laser Scanning (TLS)

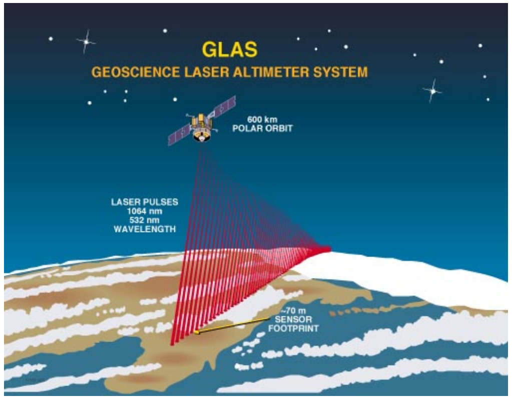
- Also called ground based lidar or T-lidar.

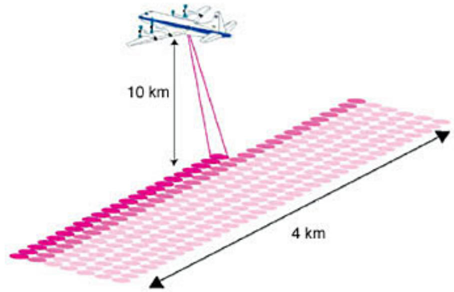
Laser scanning moving ground based platform = Mobile Laser Scanning (MLS).

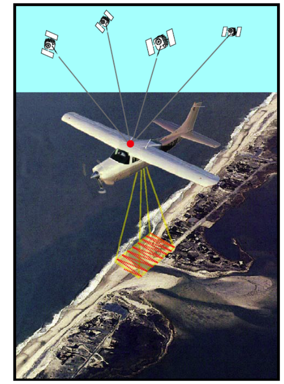
Laser scanning from airborne platform = Airborne Laser Scanning (ALS).

UNAVCO

Light Detection and Ranging (lidar)





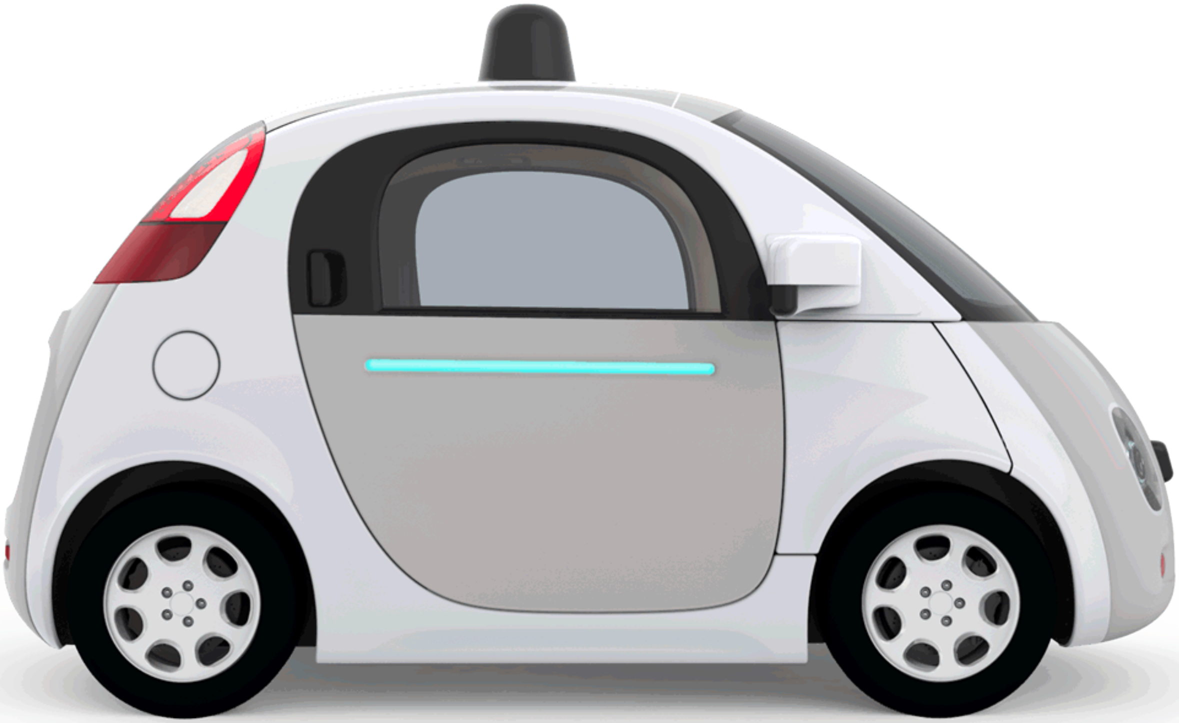


System:	Spaceborne (e.g. GLAS)	High Altitude (e.g. LVIS)	Airborne (ALS)	Terrestrial (TLS)
Altitude:	600 km	10 km	1 km	1 m
Footprint:	60 m	15 m	25 cm	1-10 cm
Vertical Accuracy	15cm to 10m depends on slope	50/100 cm bare ground/ vegetation	20 cm	1- 10 cm Depends on range which is few meters to 2 km or more

Lidar & Autonomous Vehicles

Sight Lines, ScanLAB: https://vimeo.com/145248208

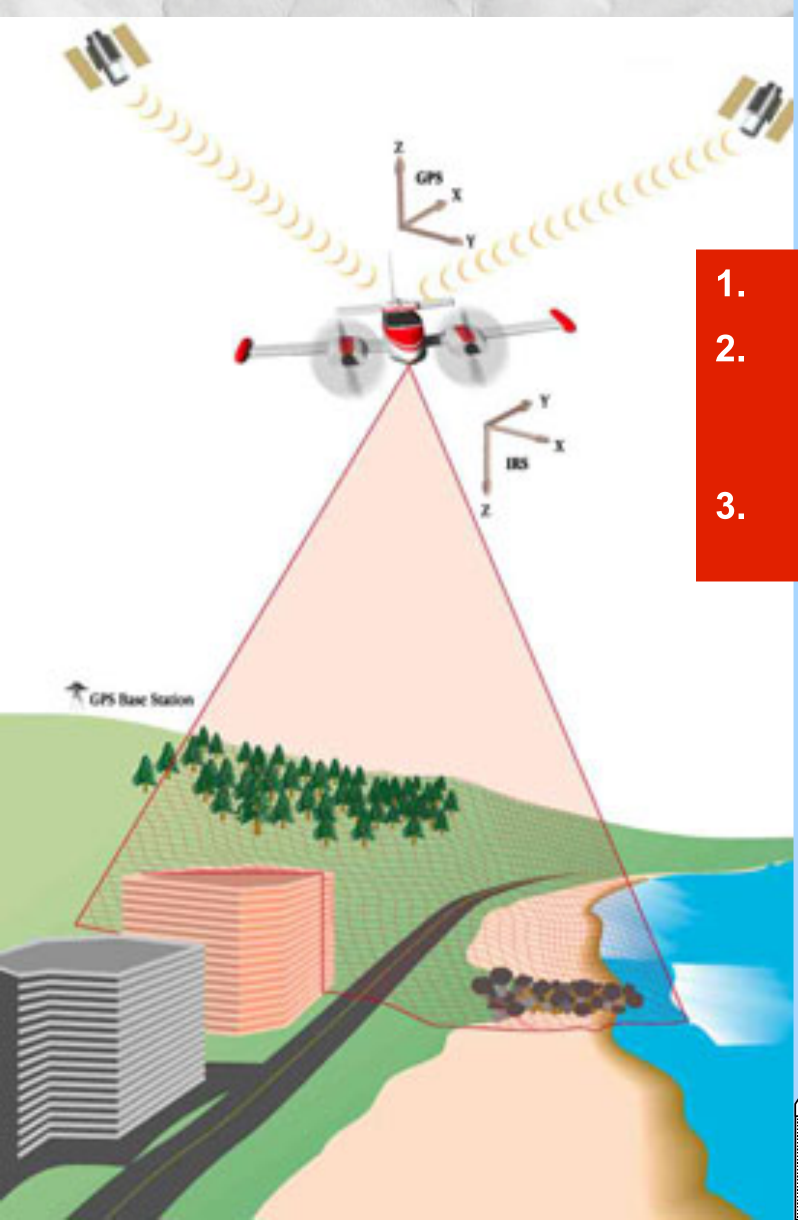
Lidar & Autonomous Vehicles



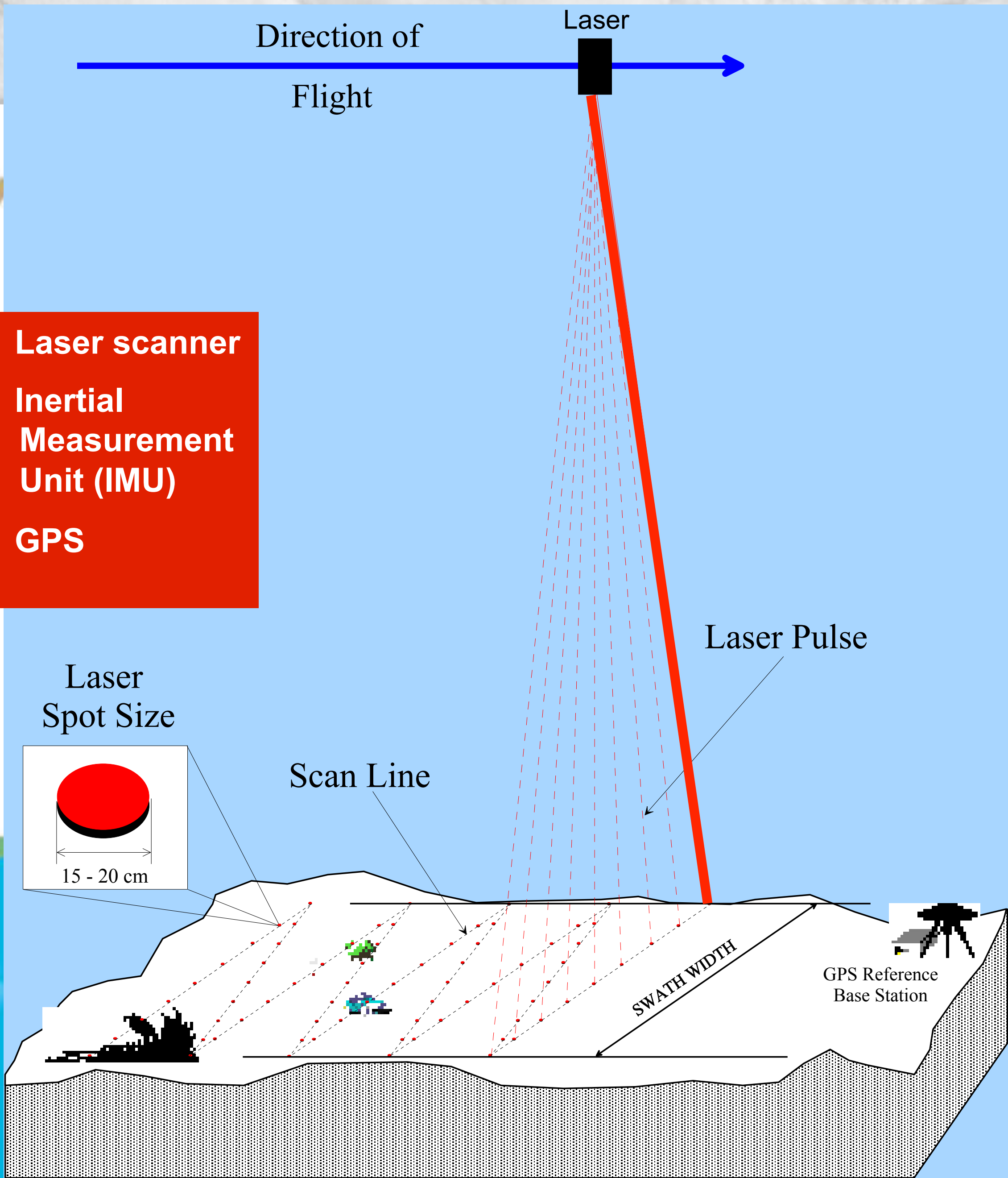
Light Detection and Ranging (lidar)

Ian Madin, DOGAMI

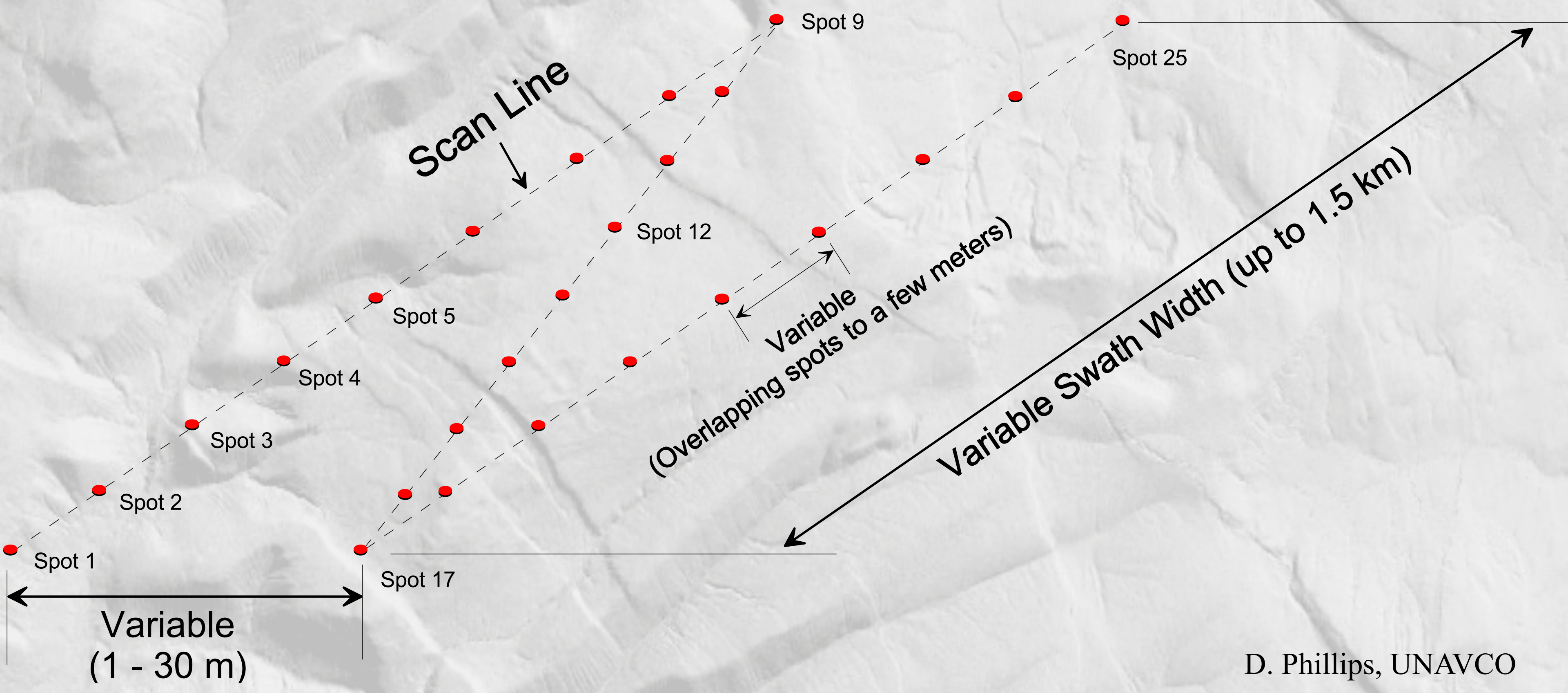
Lidar data collection



1. **Laser scanner**
2. **Inertial Measurement Unit (IMU)**
3. **GPS**



Surface Point Spacing



D. Phillips, UNAVCO

Scan line spacing, swath width, spot size and overlap can all be defined as necessary to achieve target data to specification

Typical Lidar Data Collection Parameters

Aircraft: Cessna 337 Skymaster

Personnel

- One pilot, one operator in plane
- GPS ground crew (2 to 10+ people)

Scanner:	Optech near-IR
PRF:	33-900 KHz
Flying height:	600 – 1,000m AGL
Flying speed:	120 mph
Swath overlap:	50% nominal
Ground truthing:	GPS (campaign & CORS)
Navigation solution:	KARS

Point spacing: sub-meter

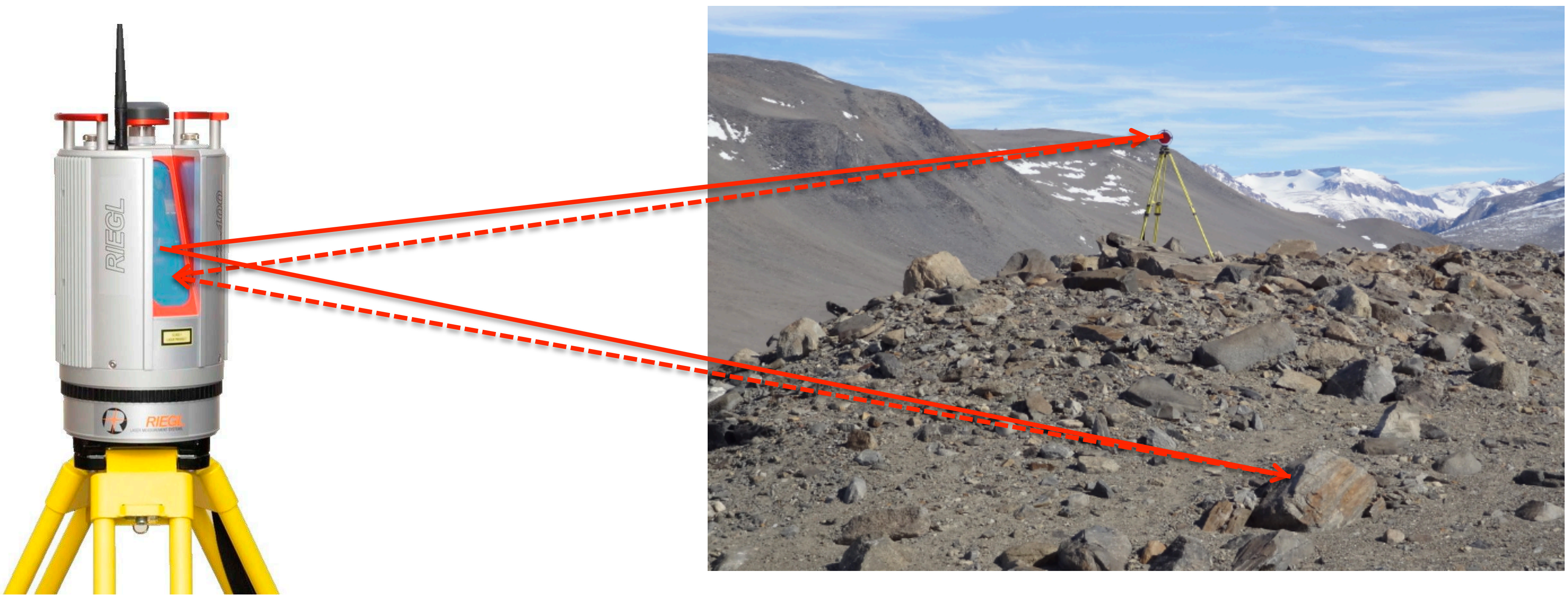
Nominal Accuracy (on open hard and flat surface)

- Vertical: 3 – 6 cm.
- Horizontal: 20 – 30 cm.

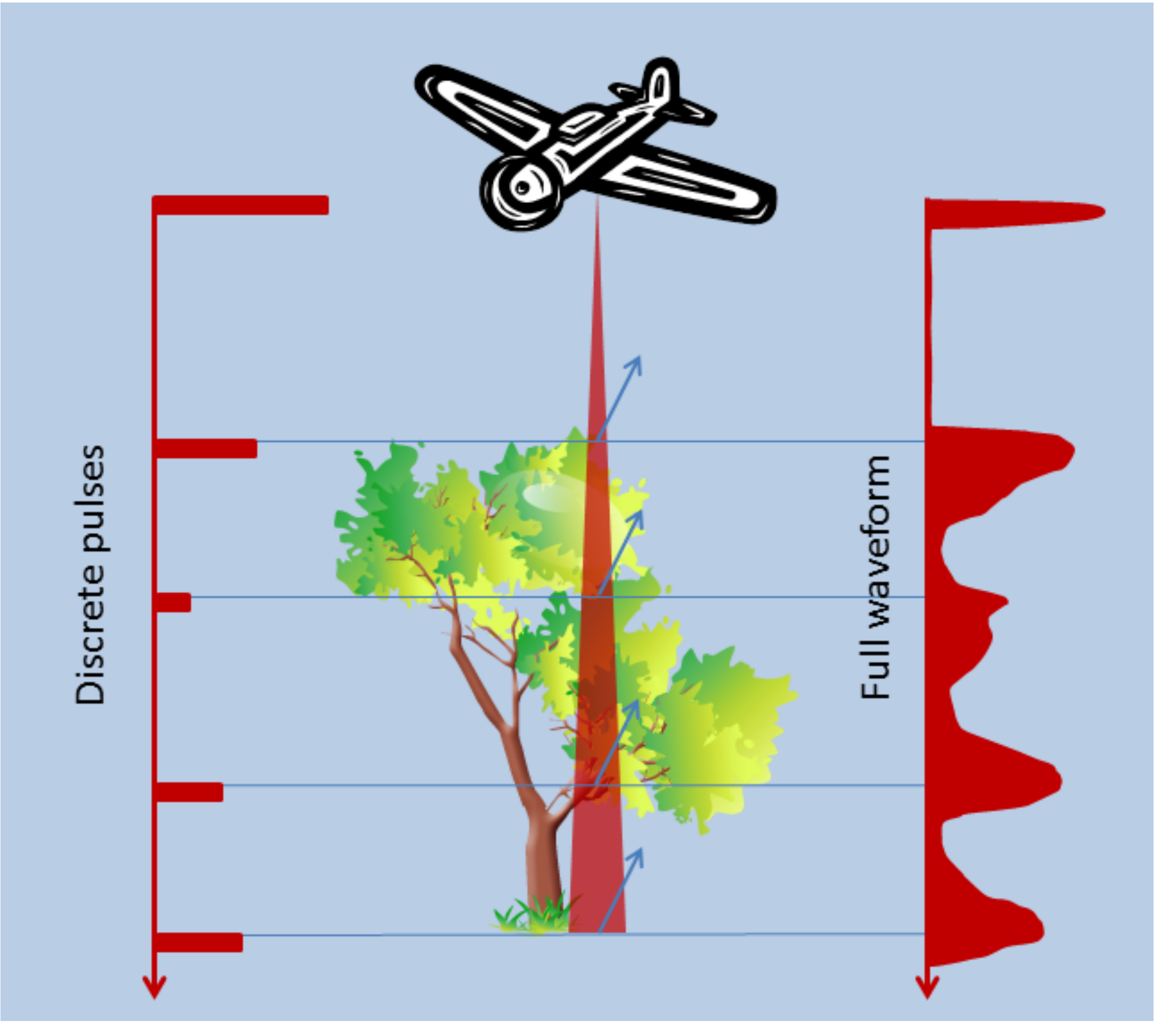
NCALM
The National Center for Airborne Laser Mapping

How a Lidar instrument works

- Transmits laser signals and measures the reflected light to create 3D point clouds.
- Wavelength is usually in the infrared (~1550nm) or green (532nm) spectrum



Discrete pulse and full waveform

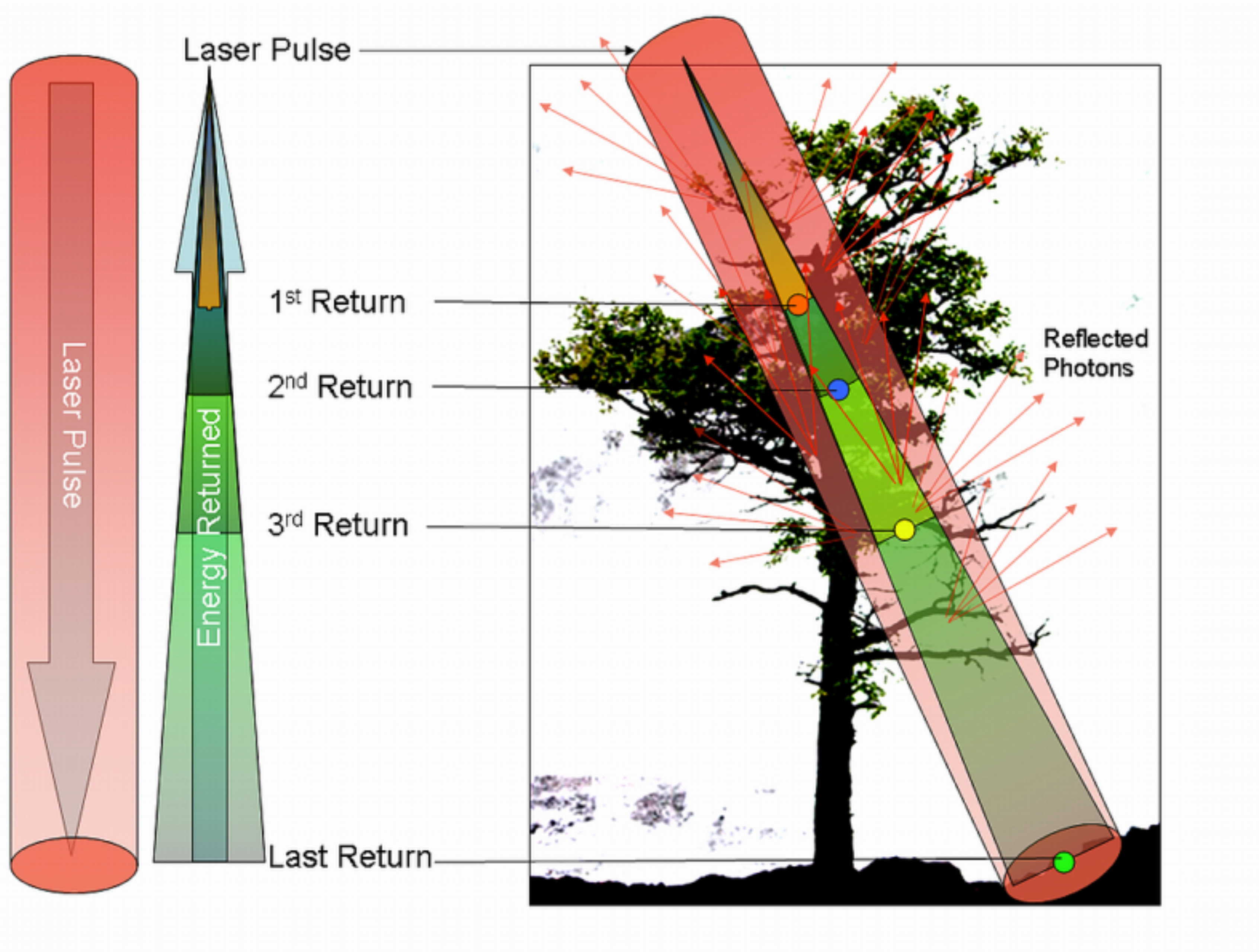


Discrete pulse = binary yes or no return

Full waveform = digitized backscatter waveform

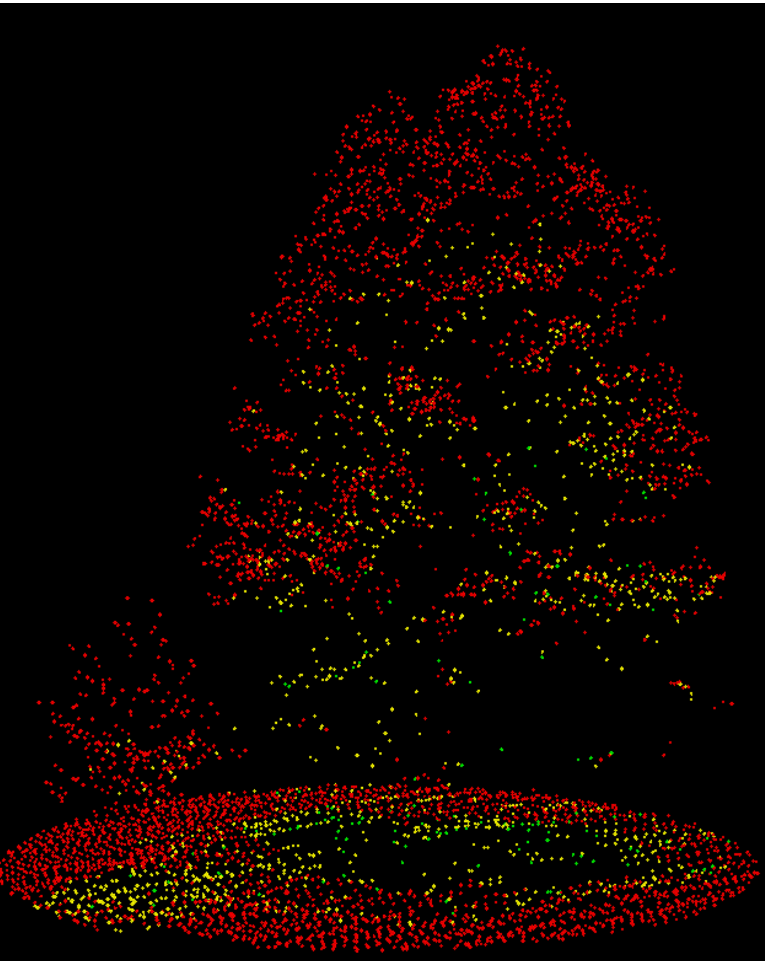
Benefits of full waveform?

- More resolution between pulse width ambiguity
- Spectral property information
- Improved fitting of geometrically defined targets.


Laser Pulse
Laser Pulse
Energy Returned
1st Return
2nd Return
3rd Return
Last Return
Reflected
Photons

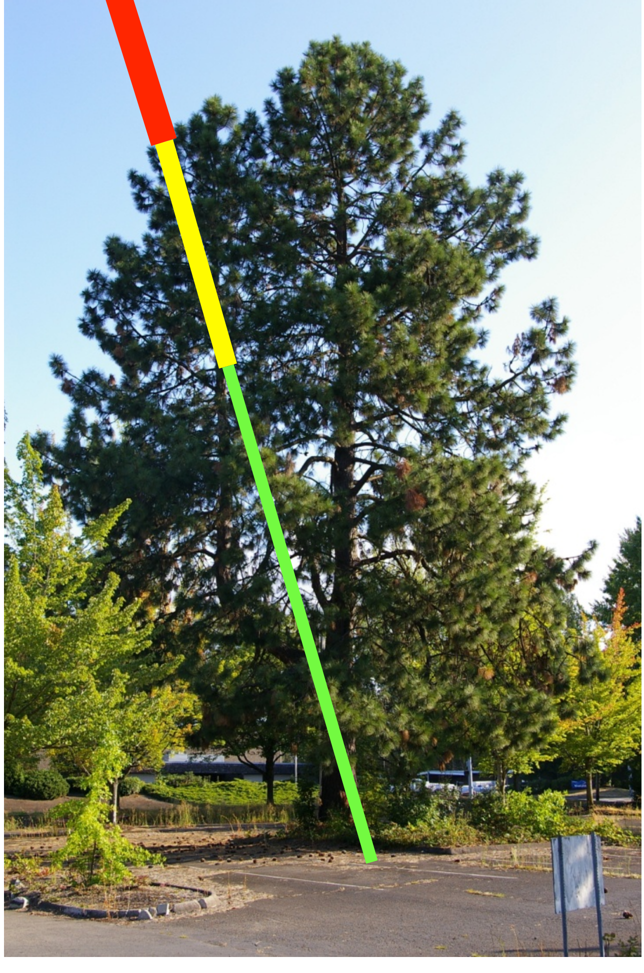
Each laser pulse can produce multiple consecutive measurements from reflections off several surfaces in its path

Ian Madin, DOGAMI

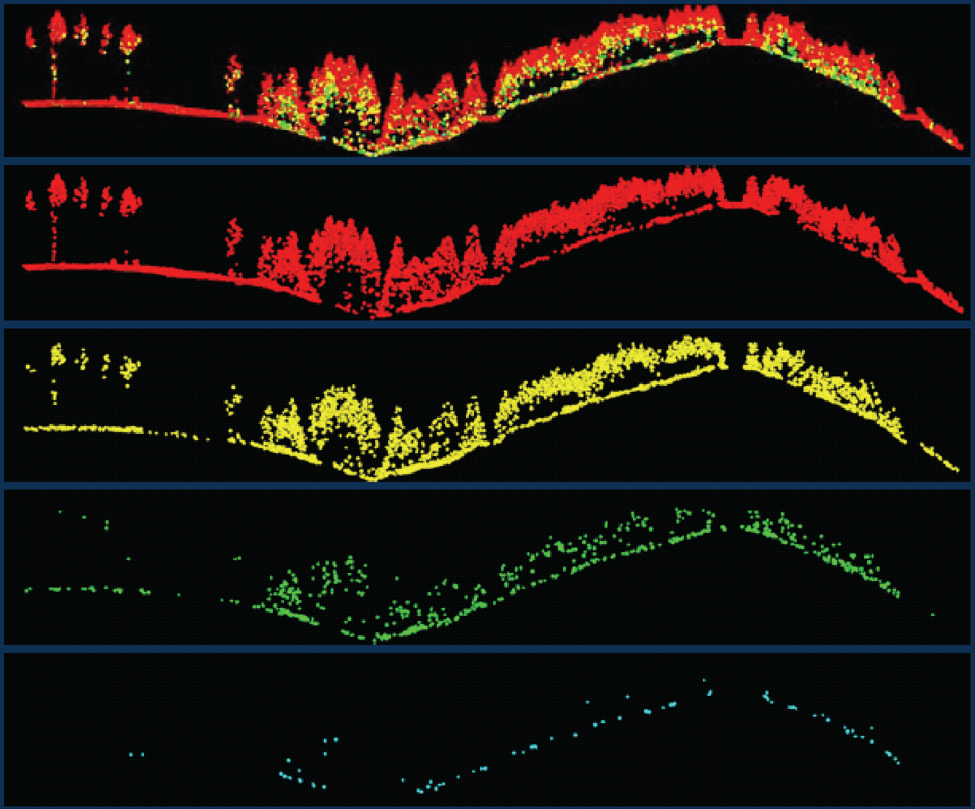


- Left = point cloud view of the tree in the photo on the right. Each point is colored by which return it was from a particular pulse:

- Red= 1st
- Yellow = 2nd
- Green = 3rd



Multiple Return lidar systems



All returns (16,664 pulses)

1st returns

2nd returns (4,385 pulses, 26%)

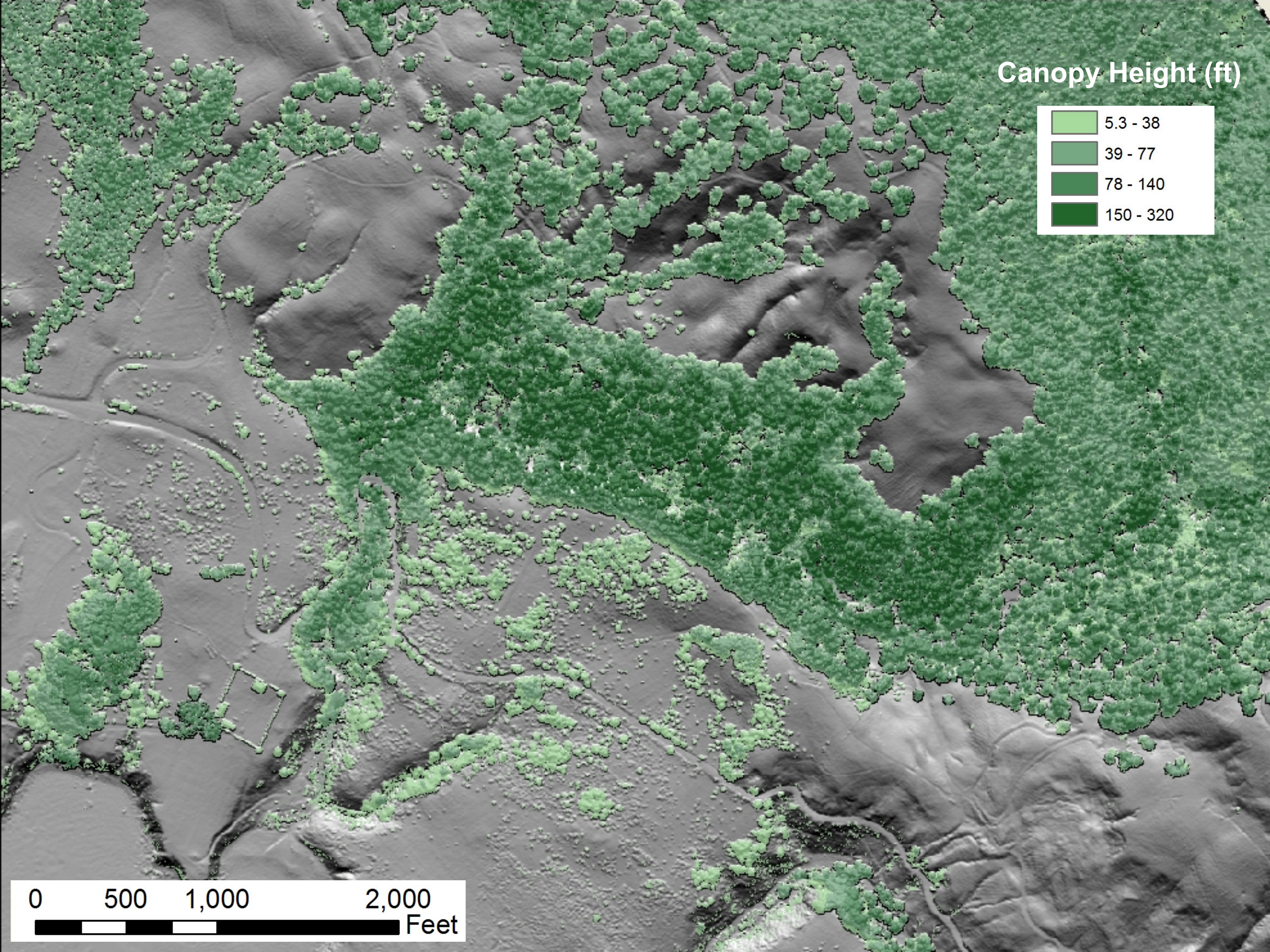
3rd returns (736 pulses, 4%)

4th returns (83 pulses, <1%)

USGS

J. Stoker

Image courtesy Hans-Erik Anderson


Canopy Height (ft)
5.3 - 38
39 - 77
78 - 140
150 - 320
0
500
1,000
2,000
Feet

Lidar ground classification

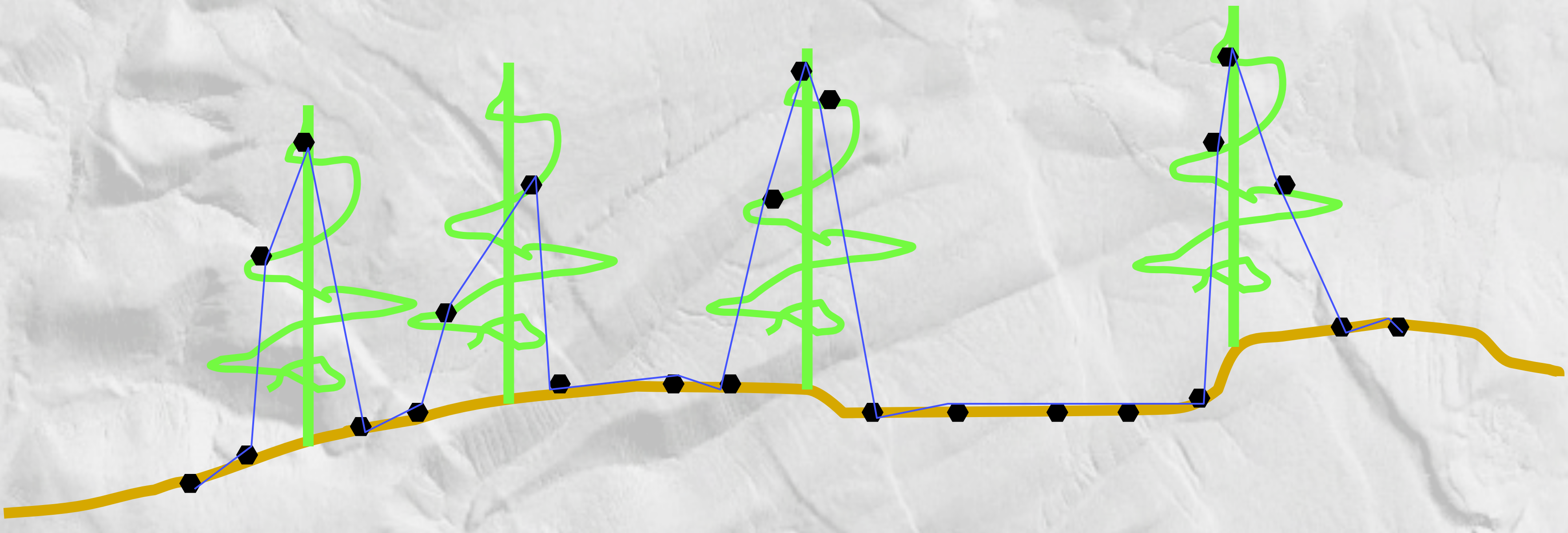
…simplified…

Three assumptions:

1. Ground is smooth
   – Assumption: high curvature is not a point on the ground
2. Ground is continuous (single-valued)
3. Ground is lowest surface in vicinity

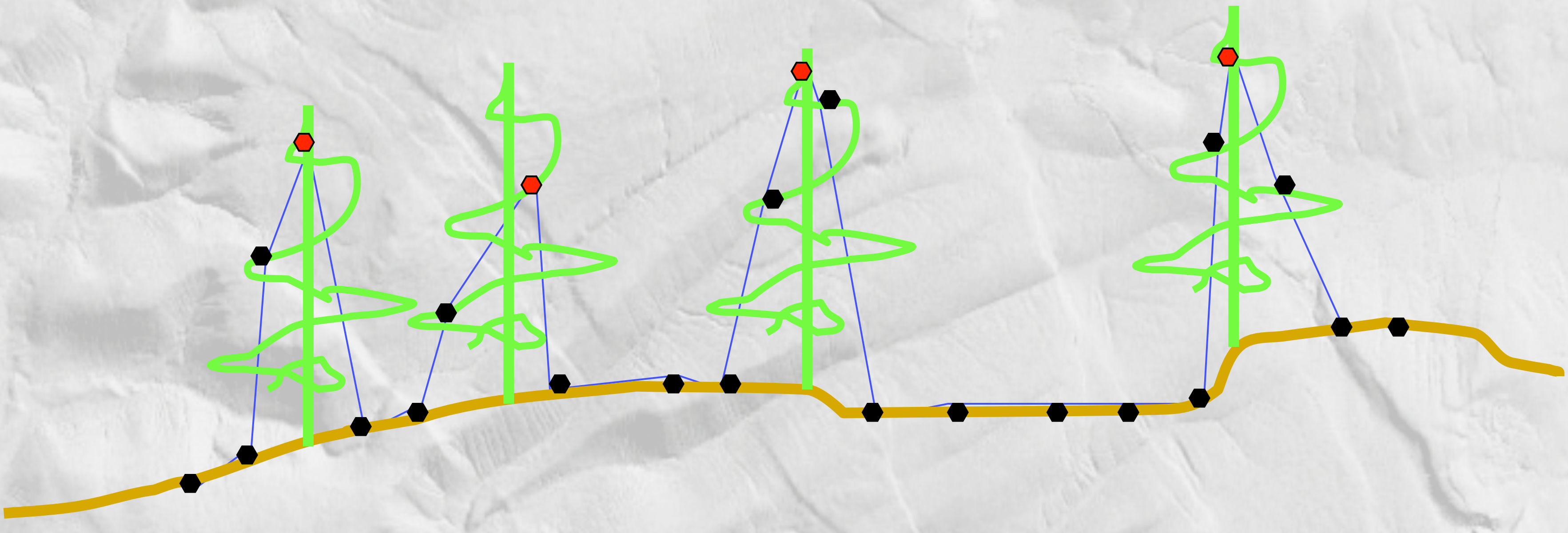
Modified from: R. Hagerud, USGS

Start with mixed ground and canopy returns (e.g. last-return data), build TIN



R. Hagerud, USGS

Flag points that define spikes (strong convexities)

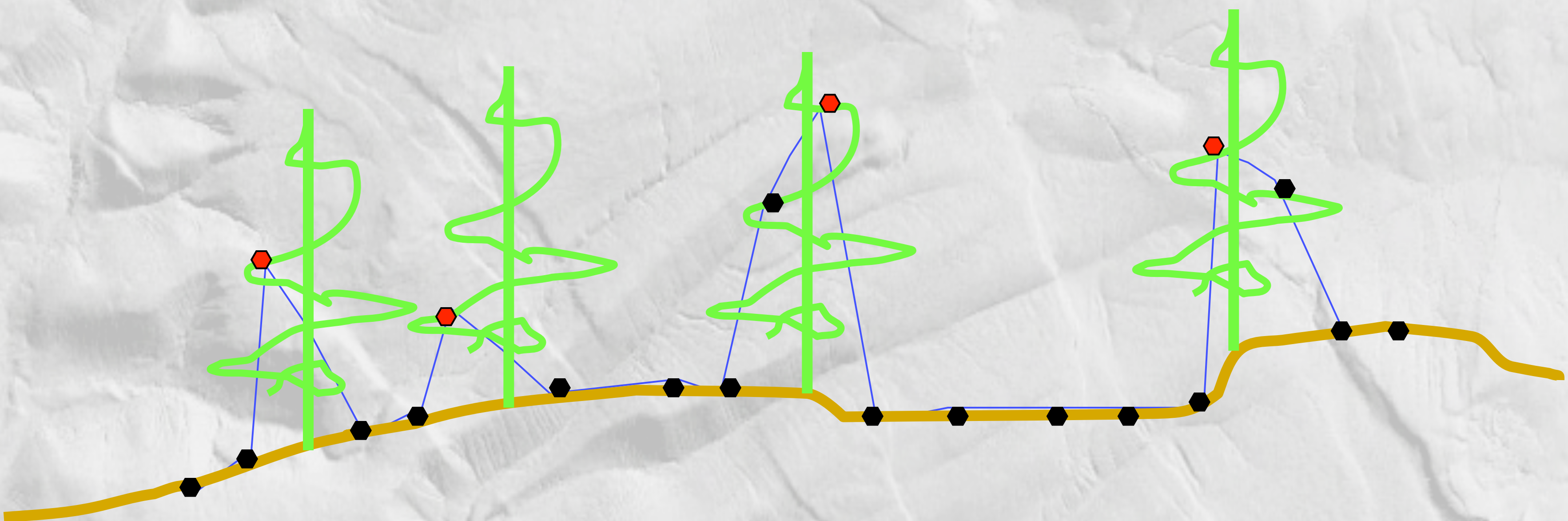


R. Hagerud, USGS

Rebuild TIN

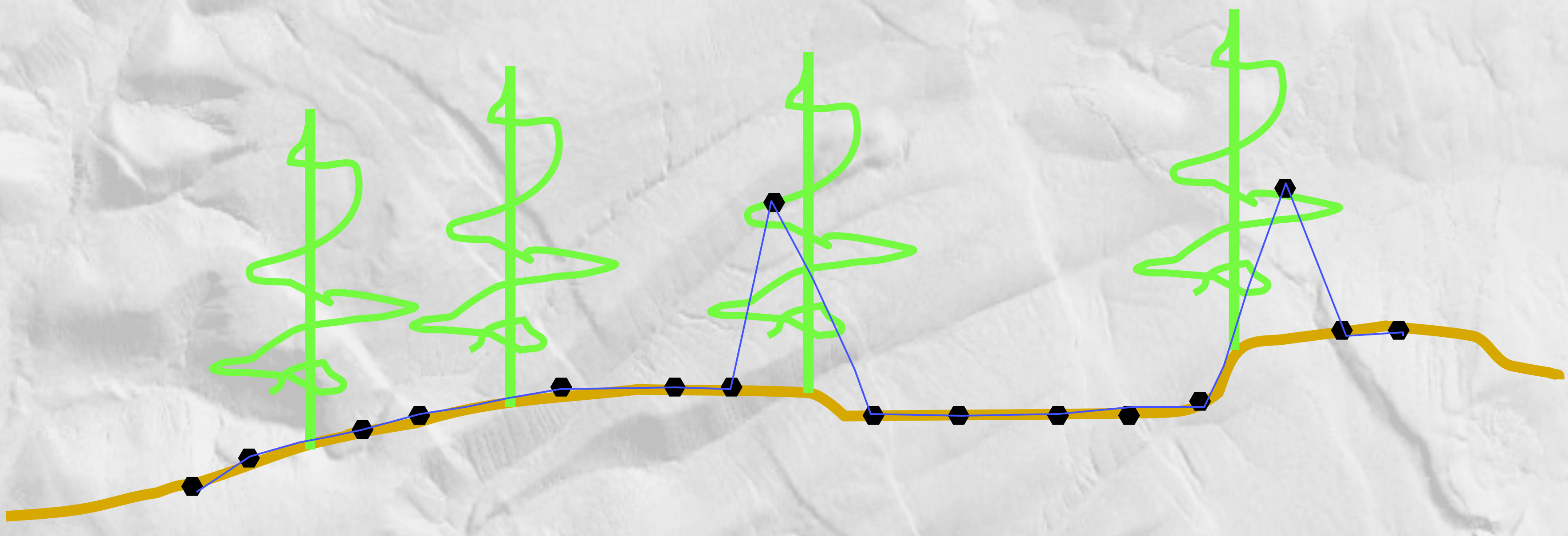
R. Hagerud, USGS

Flag points that define spikes (strong convexities)



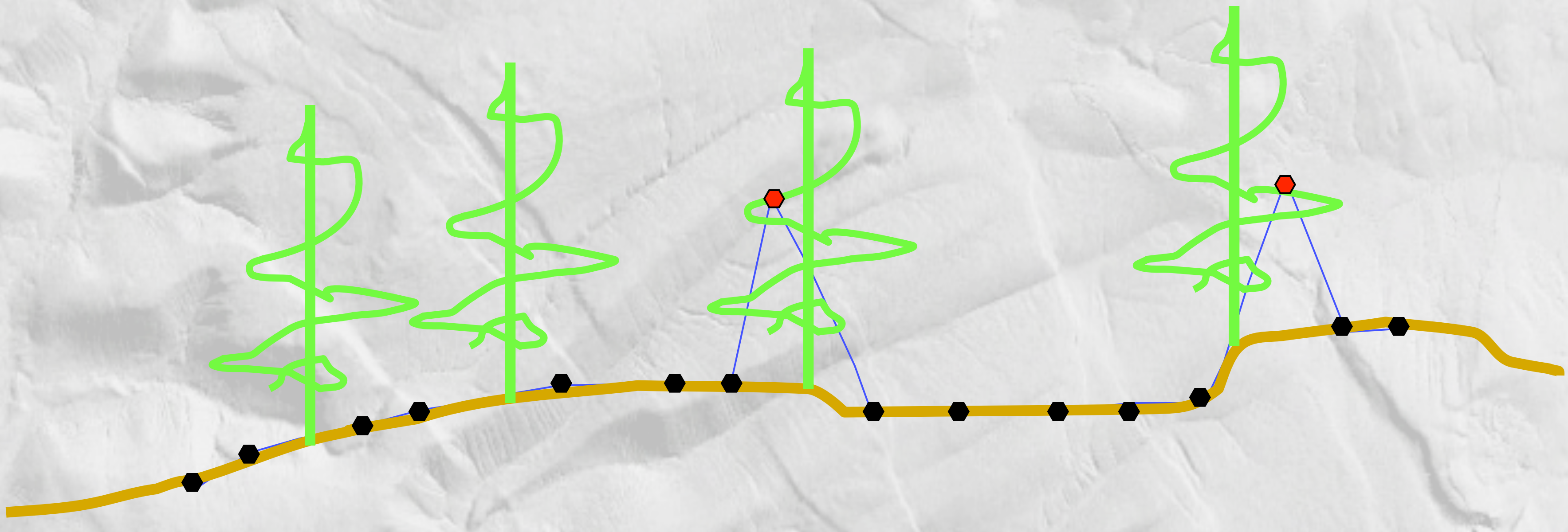
R. Hagerud, USGS

Rebuild TIN



R. Hagerud, USGS

Flag points that define spikes (strong convexities)



R. Hagerud, USGS

Rebuild TIN

R. Hagerud, USGS

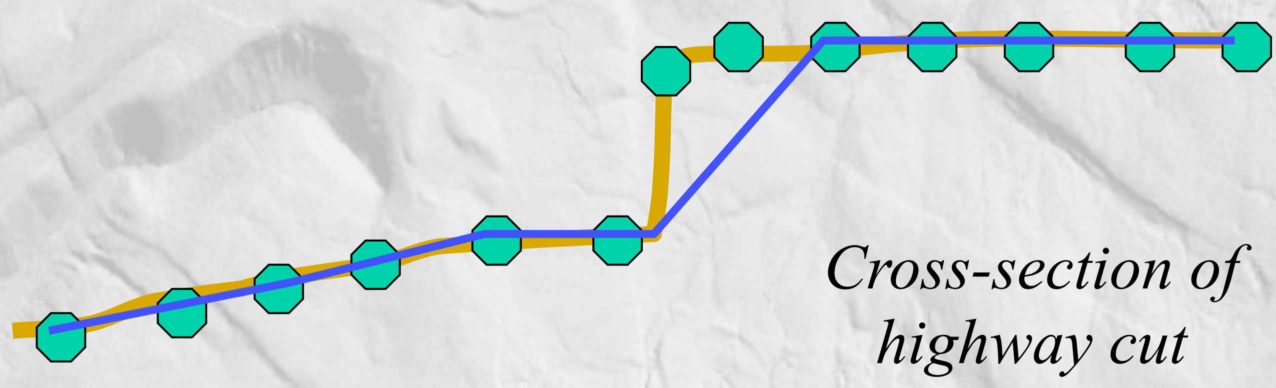
Despike algorithm

<u>Benefits</u>:

- It works
- It's automatic
  - Cheap
  - All assumptions explicit
- It can preserve breaklines
- It appears to retain more ground points than other algorithms

R. Hagerud, USGS

Despike algorithm



Problems:

- Removes some corners
- Sensitive to negative blunders
- Computationally intensive
- Makes rough surfaces
  - Real? Measurement error? Misclassified vegetation?

R. Hagerud, USGS

Lidar Data Quality

Not all lidar is created equal – huge range in quality, resolution, accuracy of data publicly available.

Typical metric is pulse density / shot (“post”) spacing:

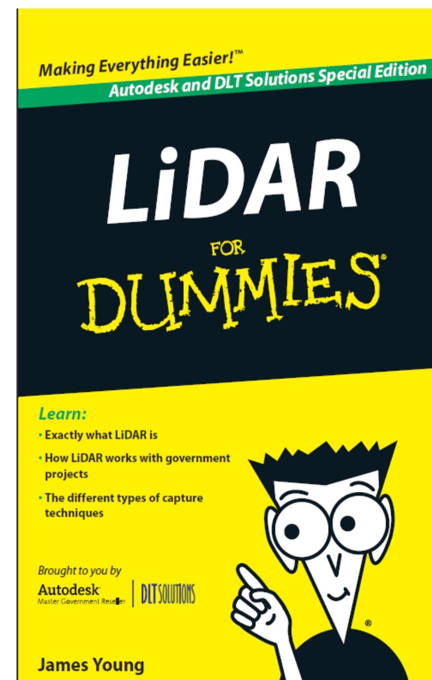
- Describes sampling density of data and potential grid resolution.
- Shot density highly heterogeneous.
- Ground point density typically far lower than total pulse density

Evaluate lidar data quality by:

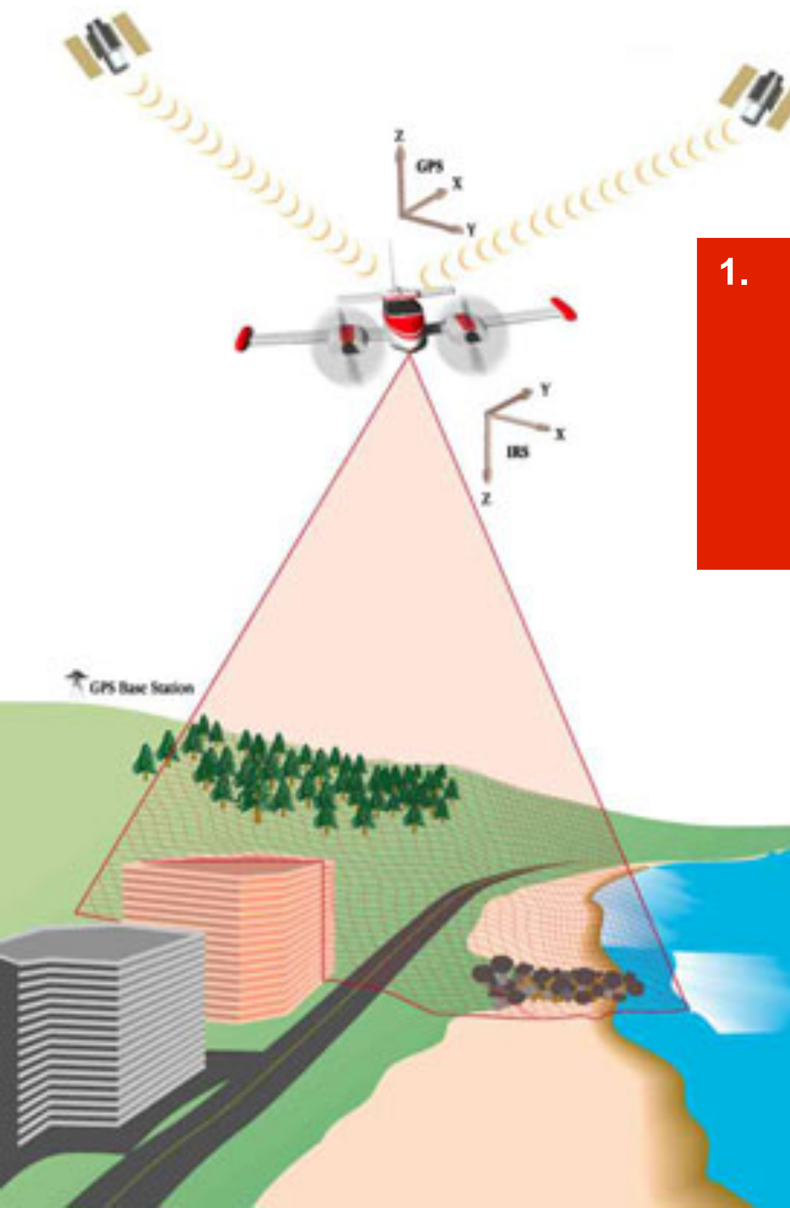
- Testing against ground control
- Looking at big images
- Quantifying swath to swath reproducibility

Read the metadata & survey report

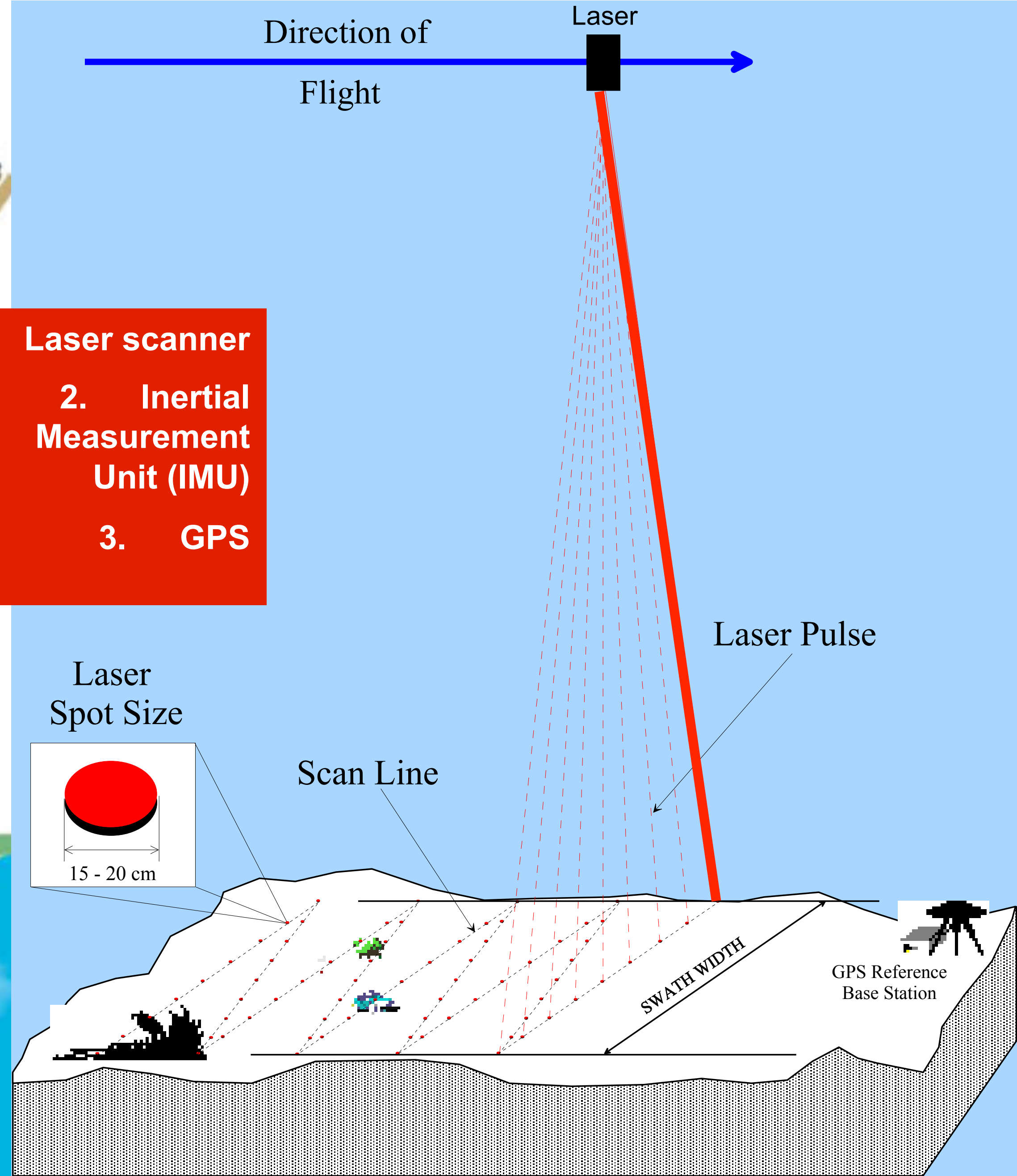
Modified from R. Hagerud, USGS

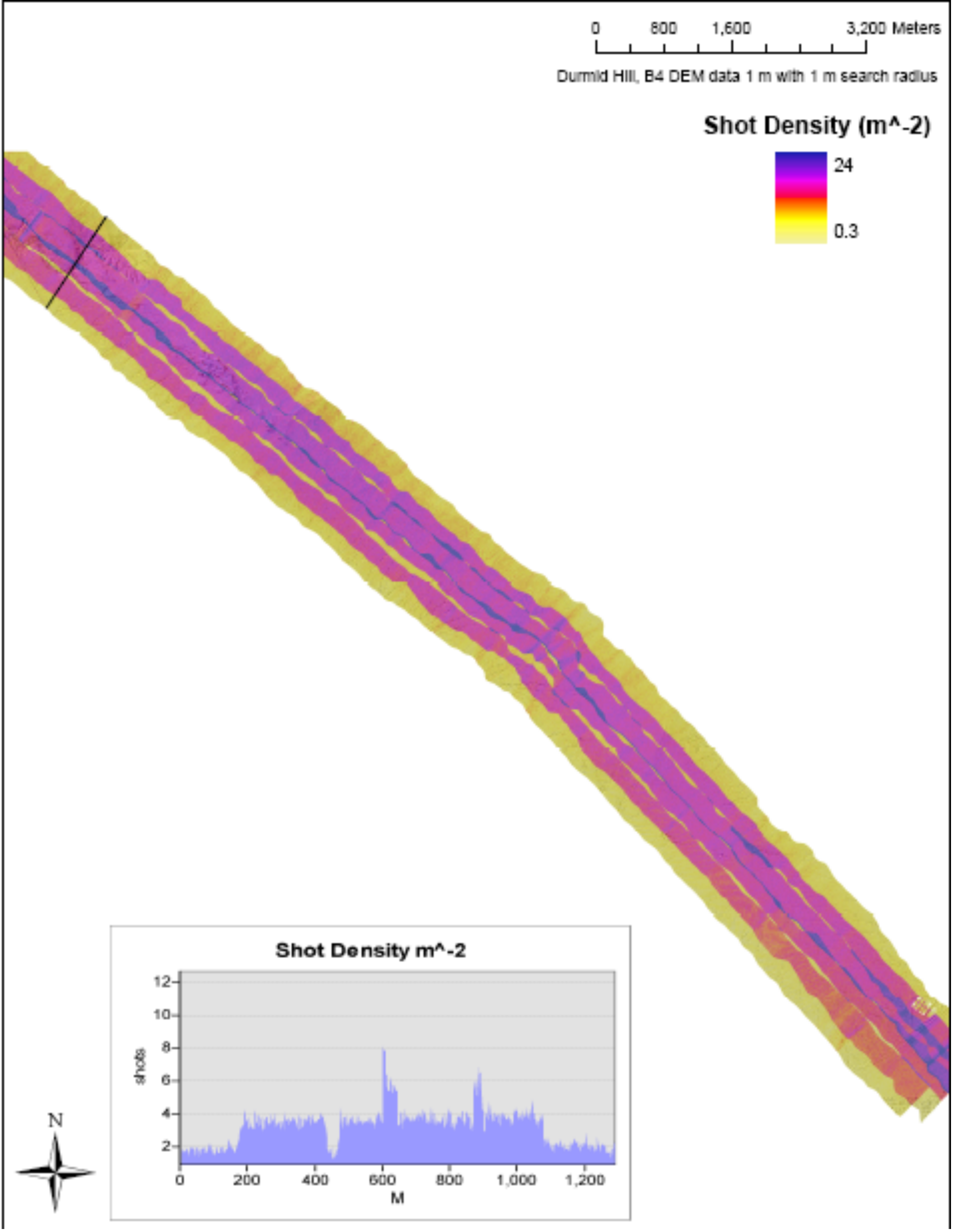


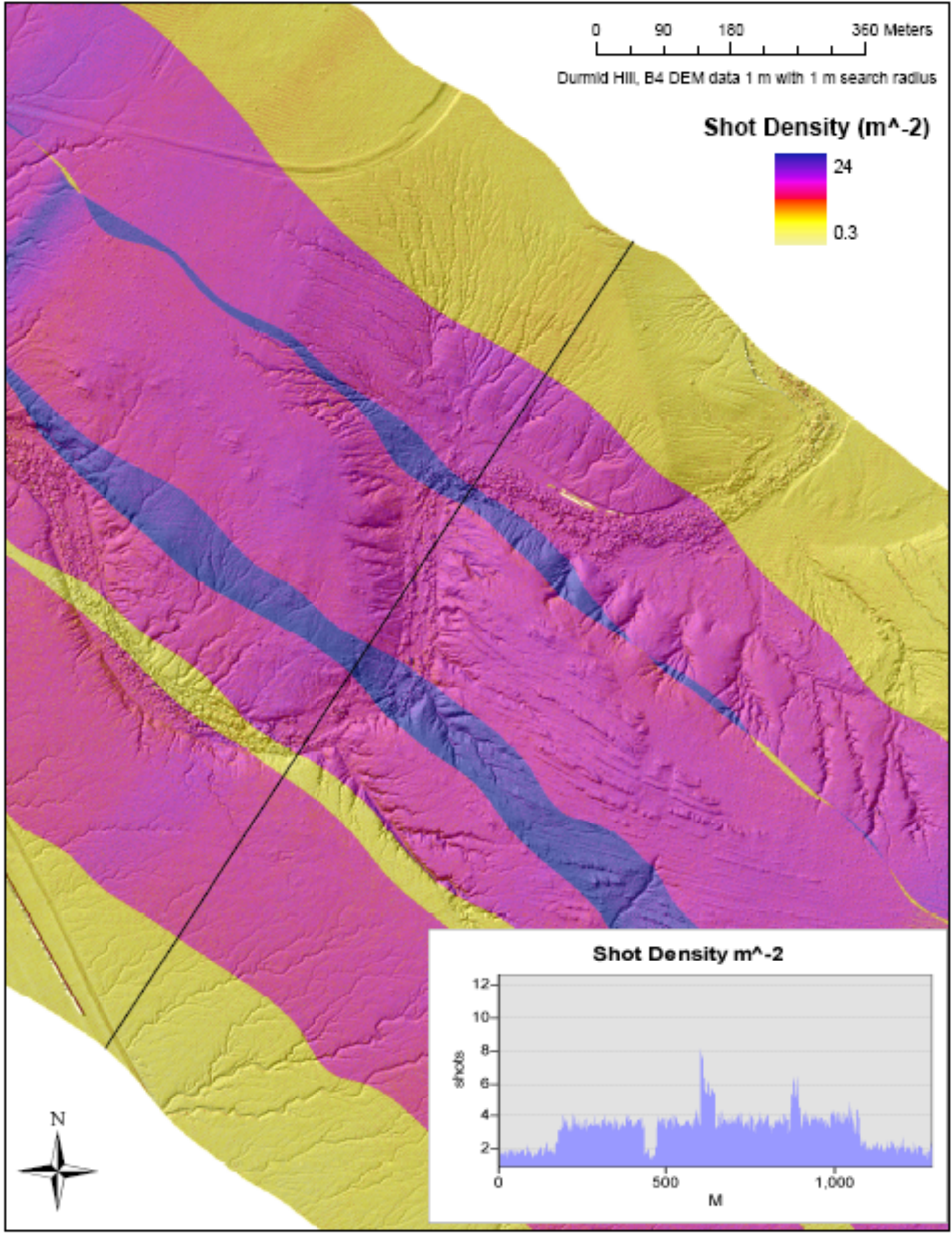
Lidar data collection



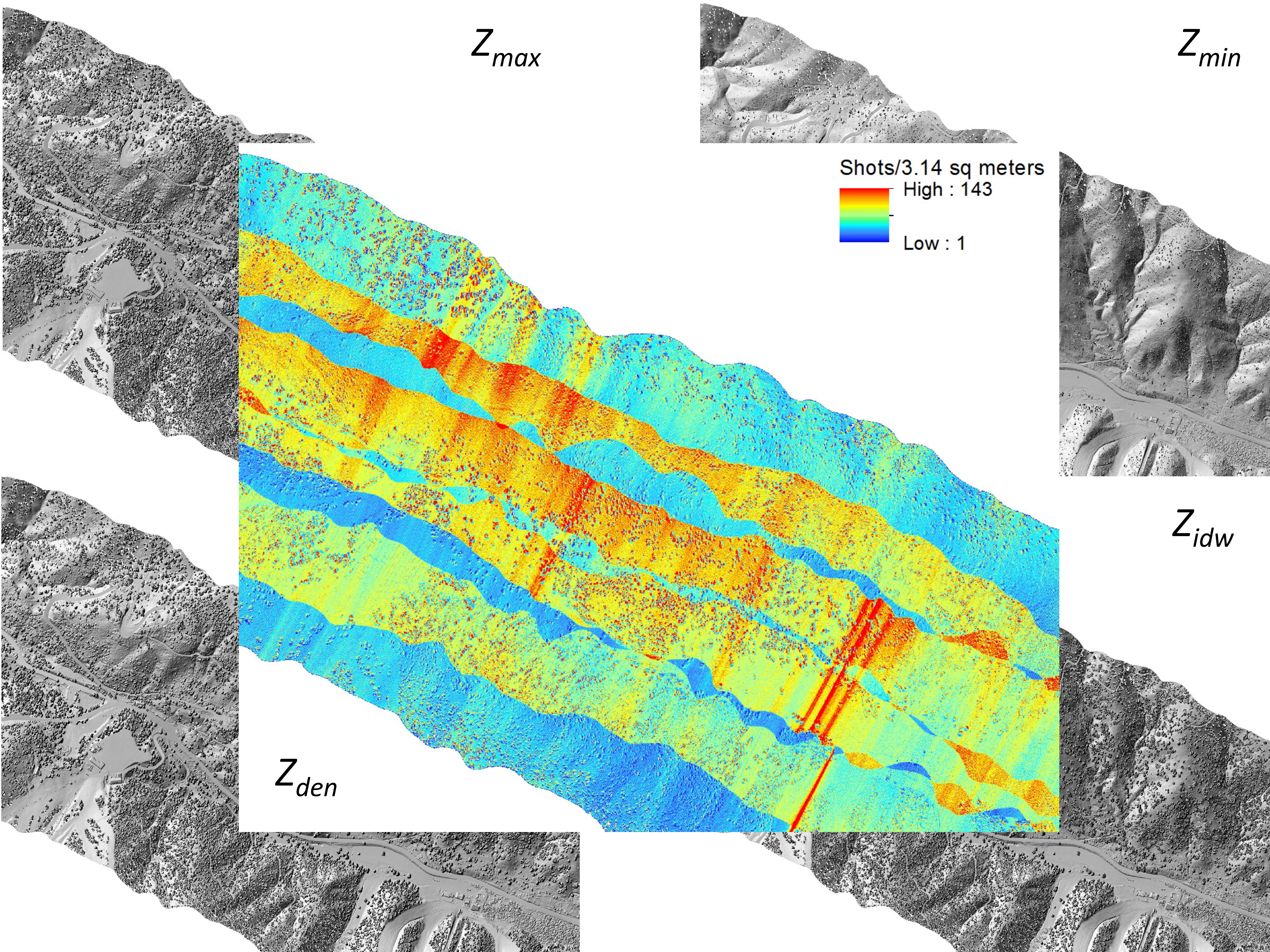
1. Laser scanner
2. Inertial Measurement Unit (IMU)
3. GPS







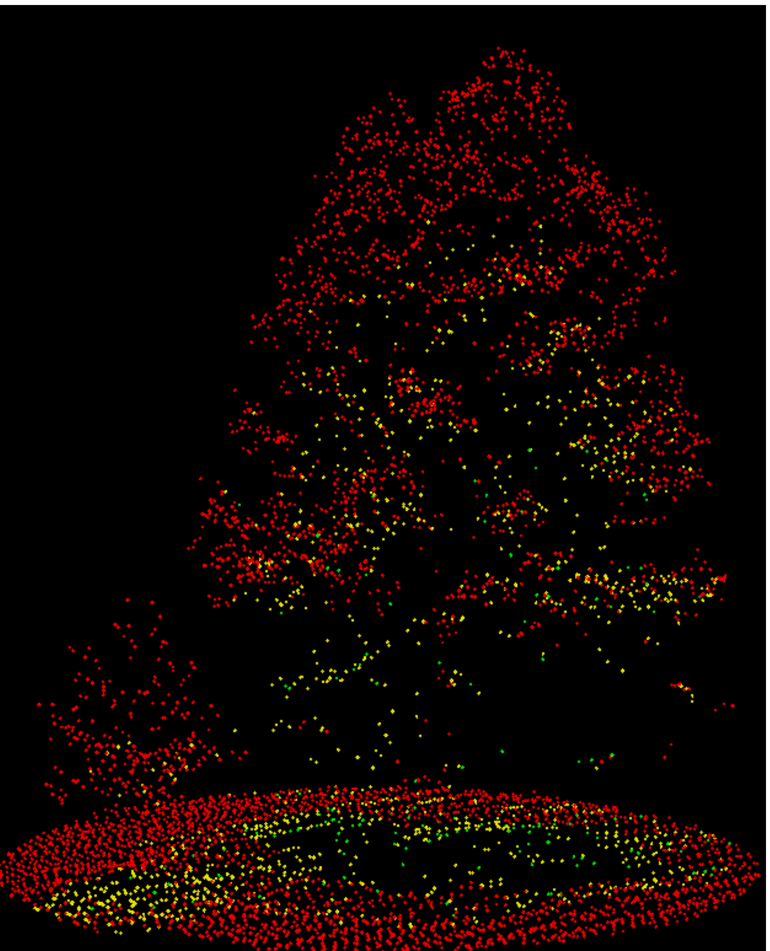
Heterogeneity of surface sampling: B4 shot density maps and profiles



Z max
Z min
Shots/3.14 sq meters
High : 143
Low : 1
Z idw
Z den

Each laser pulse can produce multiple consecutive measurements from reflections off several surfaces in its path

Ian Madin, DOGAMI



Left = point cloud view of the tree in the photo on the right. Each point is colored by which return it was from a particular pulse:

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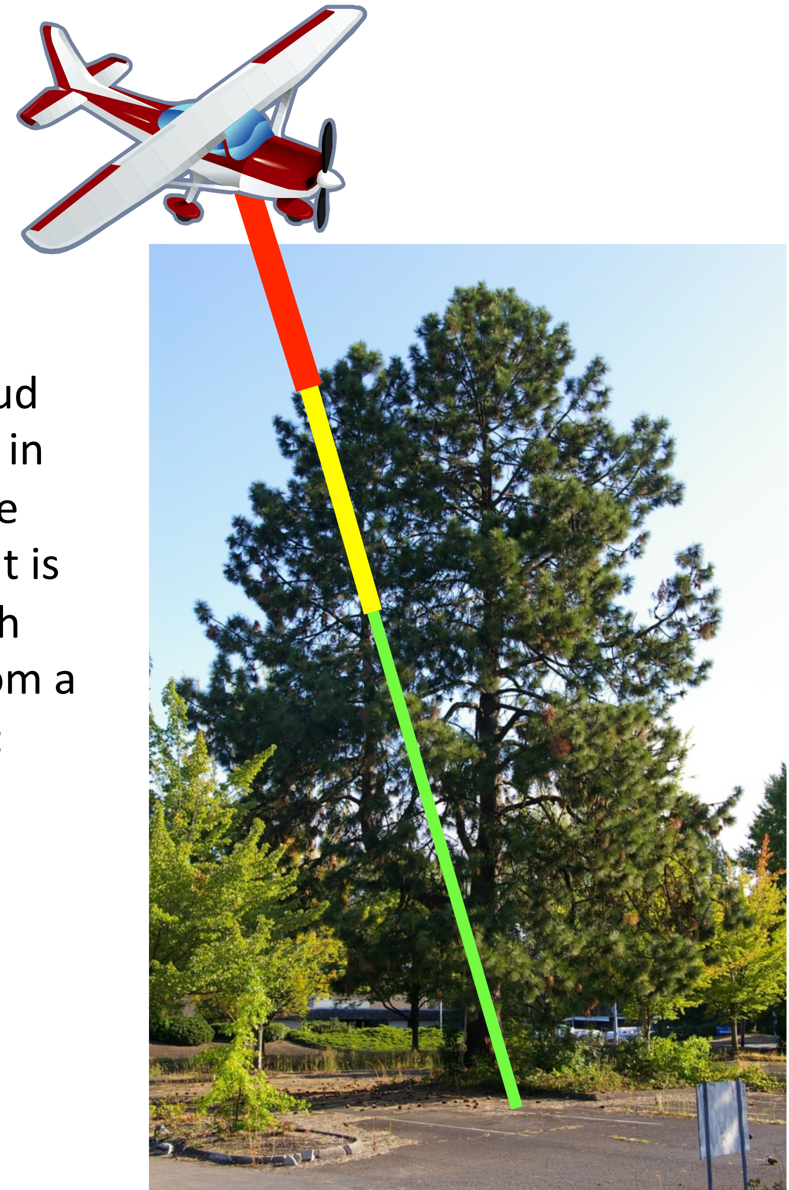
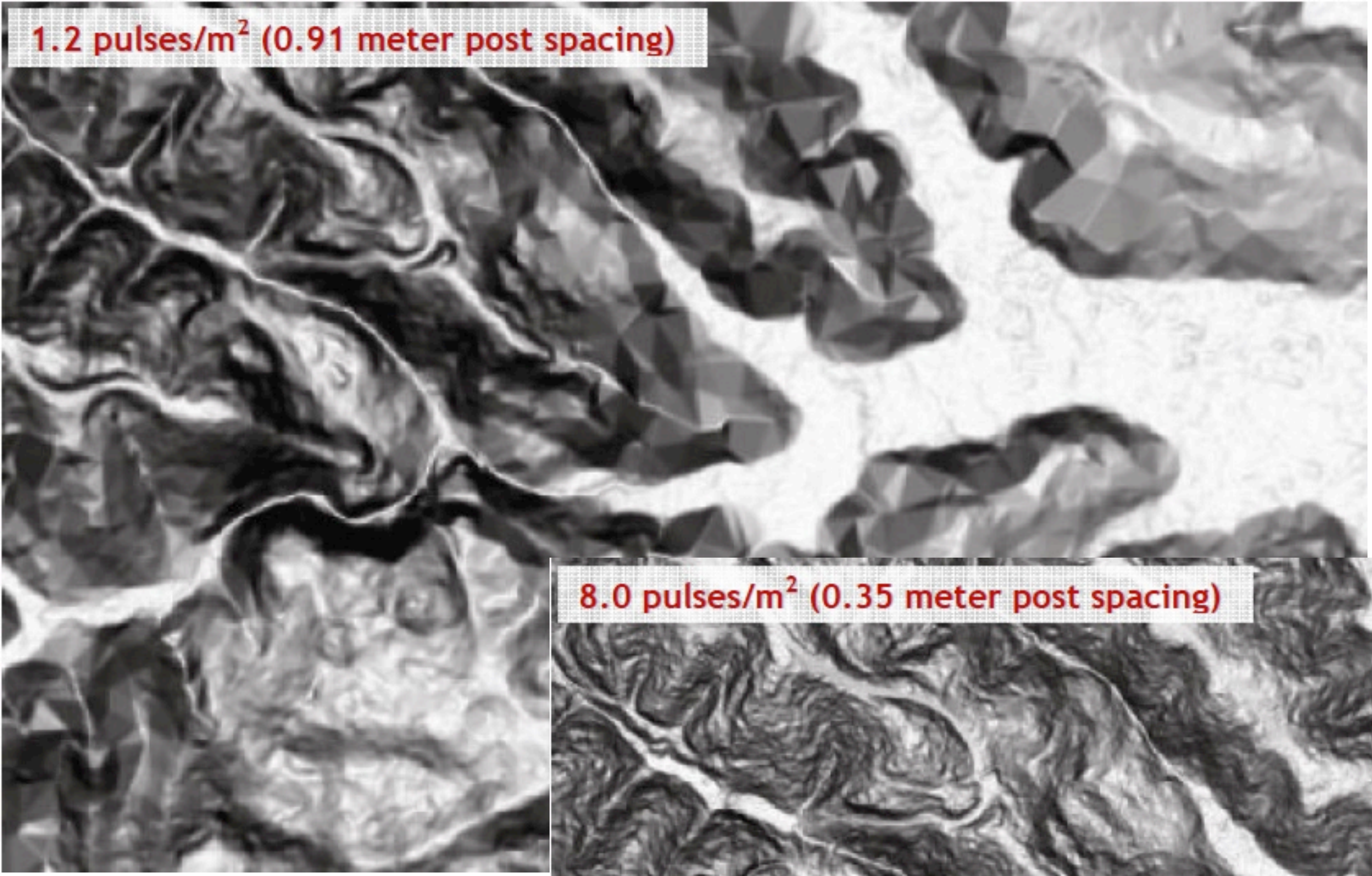
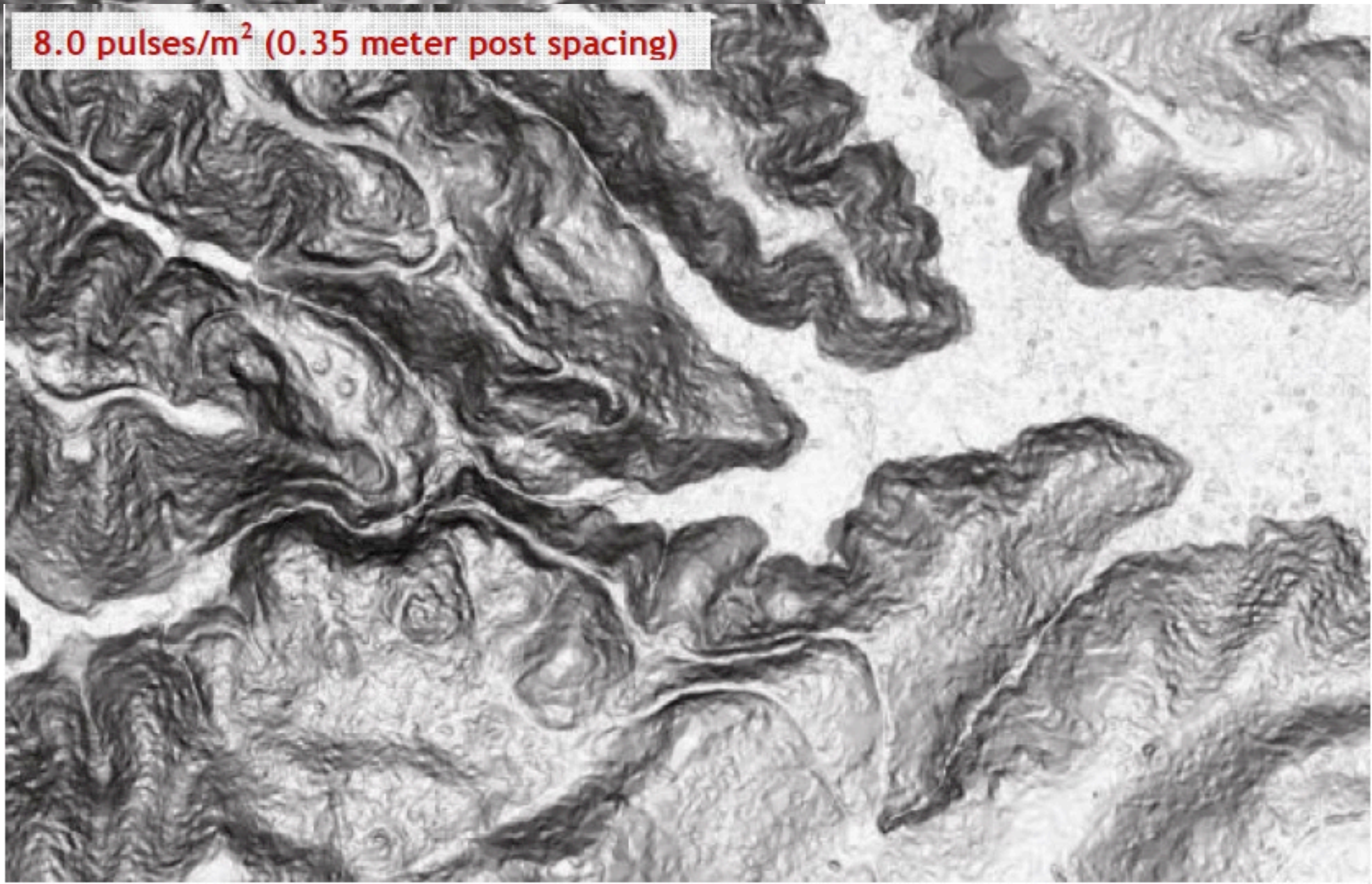
Yellow = 2^{nd}

Green = 3^{rd}



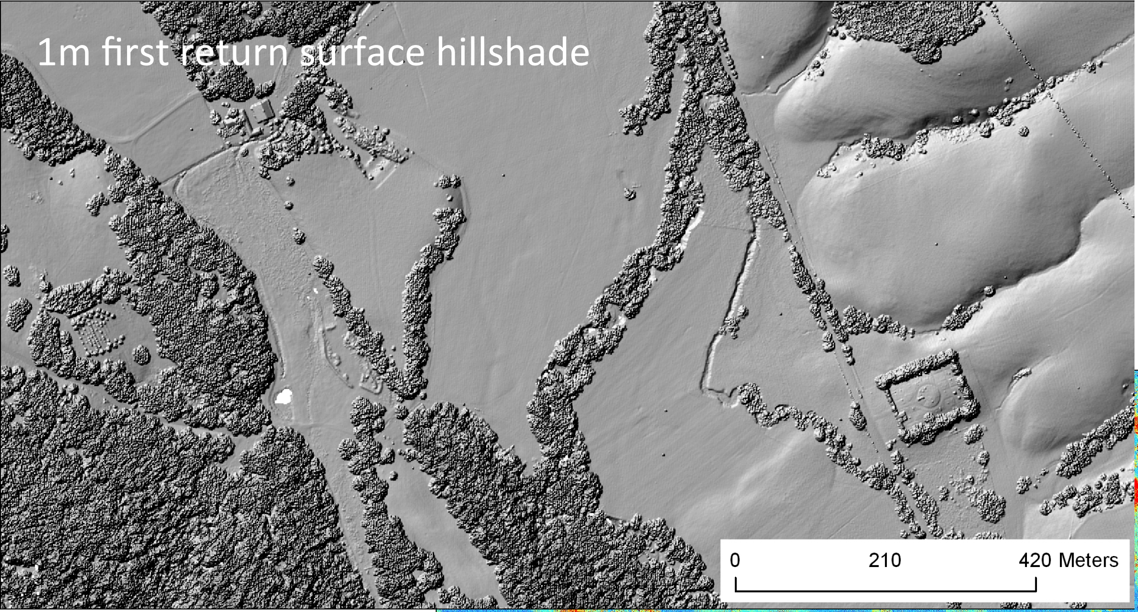


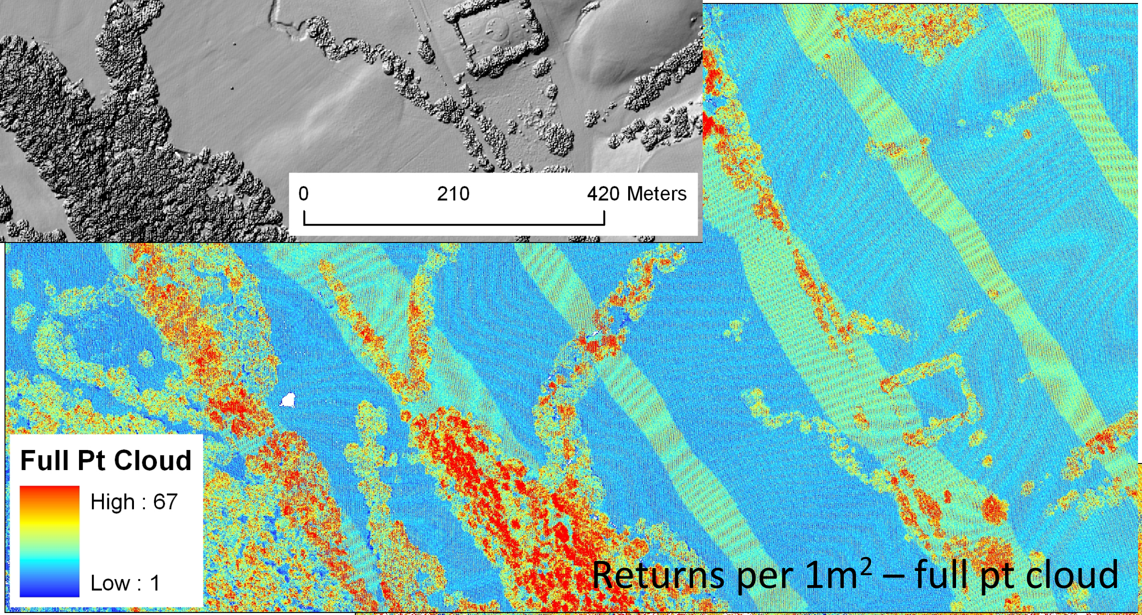


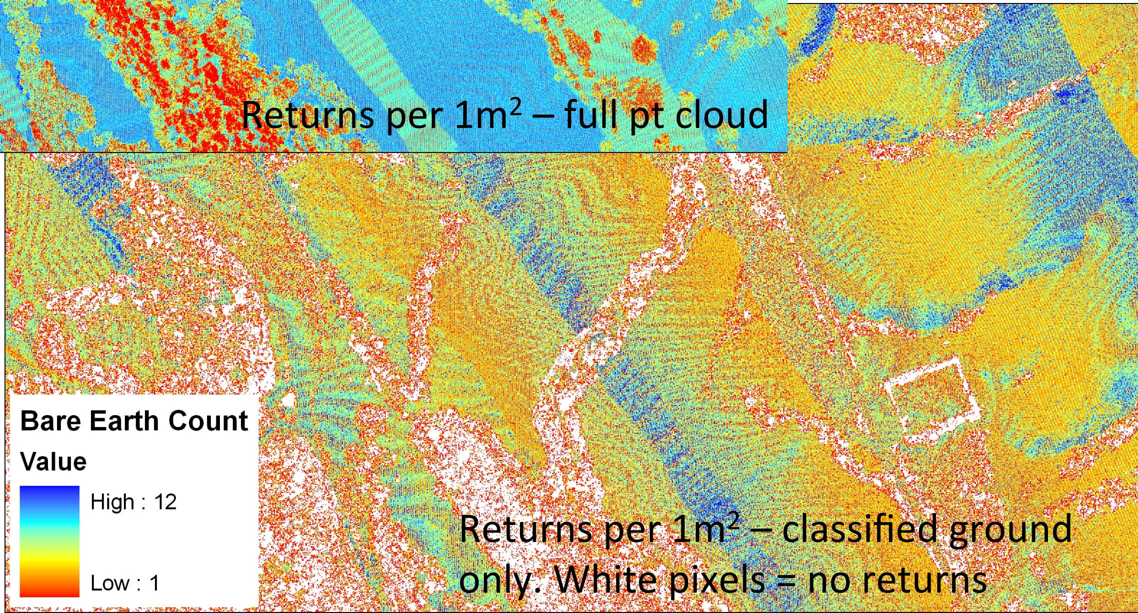
In the PNW:
14% of points classified as ground

Minimum LiDAR Considerations in the Pacific Northwest
Watershed Sciences, Inc.
http://www.oregongeology.org/sub/projects/olc/minimum-lidar-data-density.pdf

Ground return density = DEM resolution







.

TIN or other non-local interpolator necessary in areas of sparse ground returns (right).

Lidar data deliverables

Classified point cloud

- Ground, vegetation, buildings, water, blunders etc.
- Intensity, return number & number of returns, GPS time, RGB…
- Tiled LAS, ASCII

Raster data derivatives

- DTM (“bare earth”), DSM (“highest hit”)
- Hillshades of DTM, DSM; intensity; RGB
- Tiled GeoTIFF, IMG, Arc Binary

Metadata & survey report

asprs
THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

LAS SPECIFICATION

VERSION 1.3 – R10

Approved: JULY 14, 2009

Published by:
The American Society for Photogrammetry & Remote Sensing
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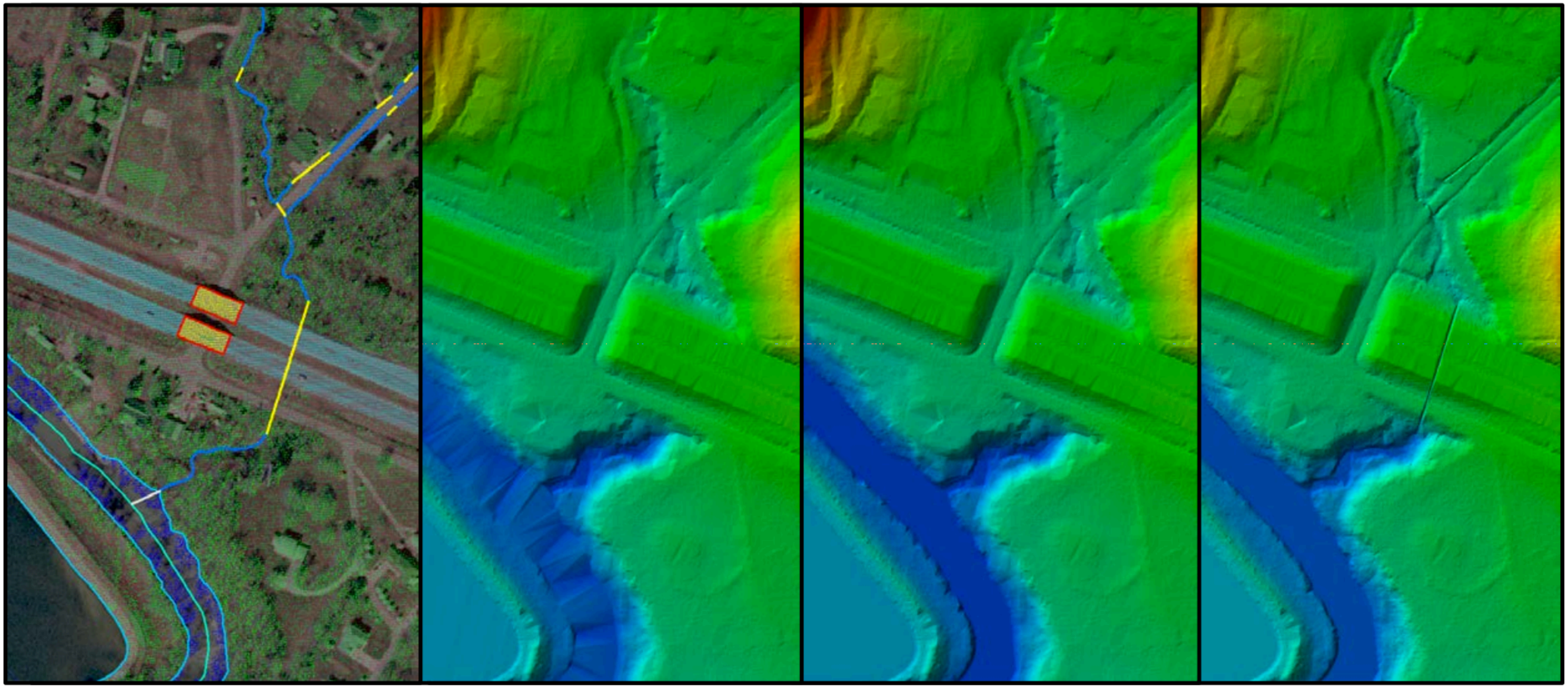
Bethesda, Maryland 20814-2160
Voice: 301-493-0290
Fax: 301-493-0208
Web: www.asprs.org

Lidar data deliverables



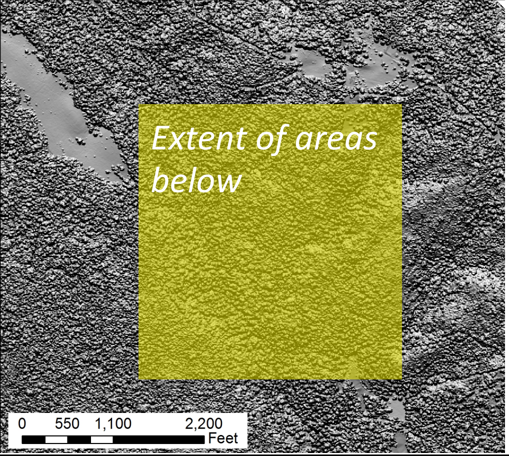
LPC and Breaklines | Pure lidar DEM | Hydro flattened DEM | Hydro enforced DEM

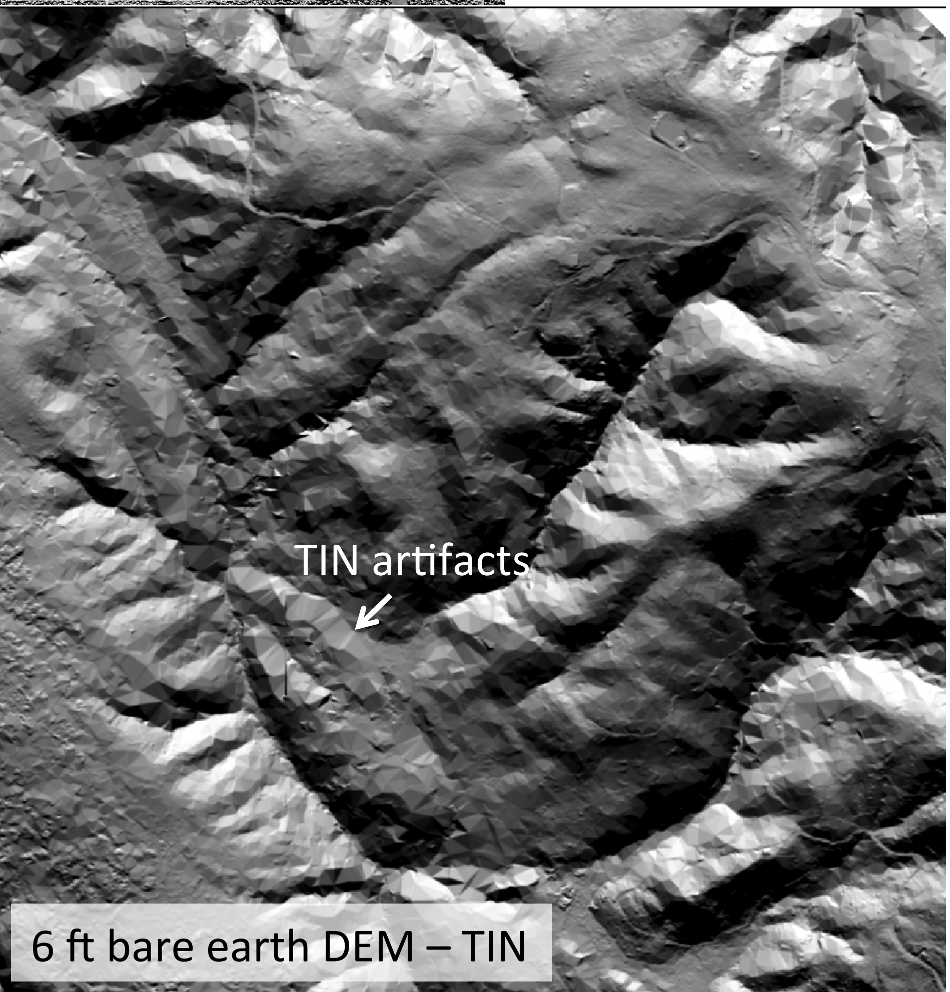
J. Stoker, USGS

Role of gridding method in areas of low return density:

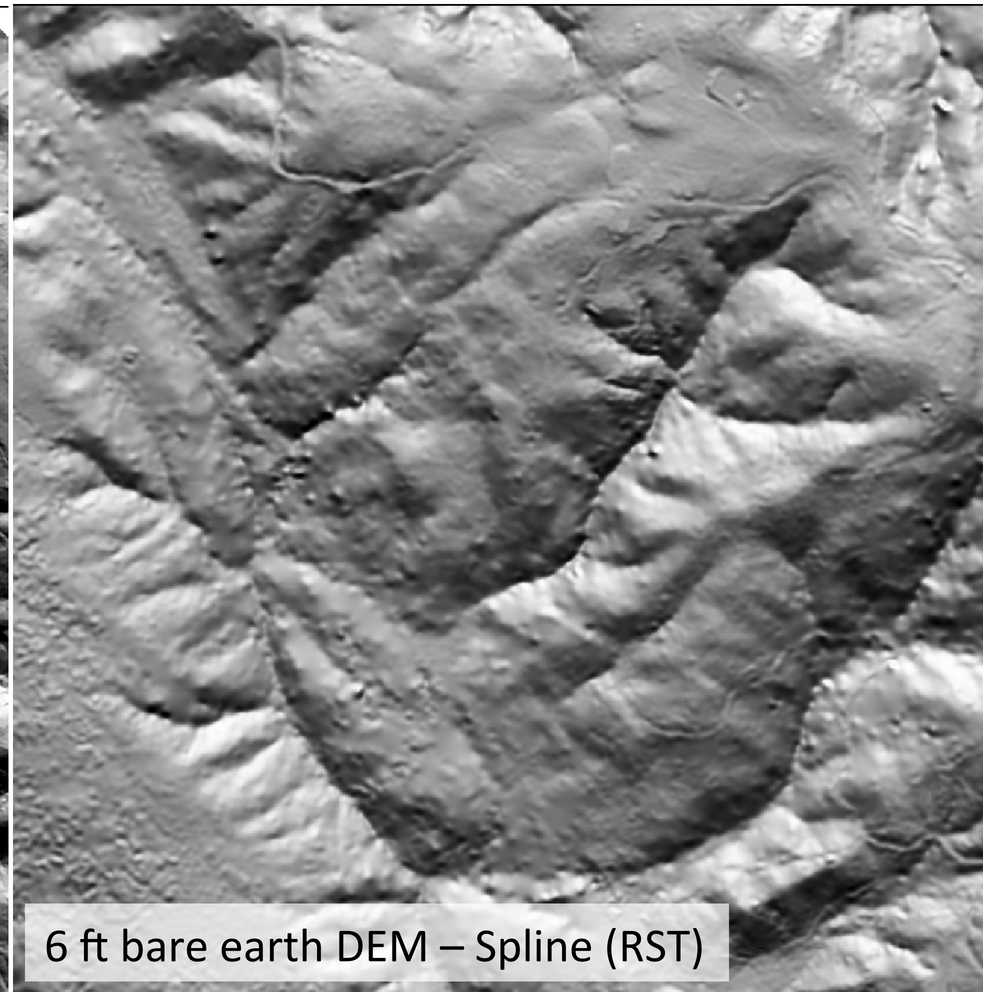
Do you prefer visible artifacts or smoothed regions where surface is less well constrained?

- Local methods can populate pixels without returns to null (swiss cheese surface – very honest representation of data)
- TIN artifacts in low ground return density
- Spline and Kriging = smoother surface…low return density less clear

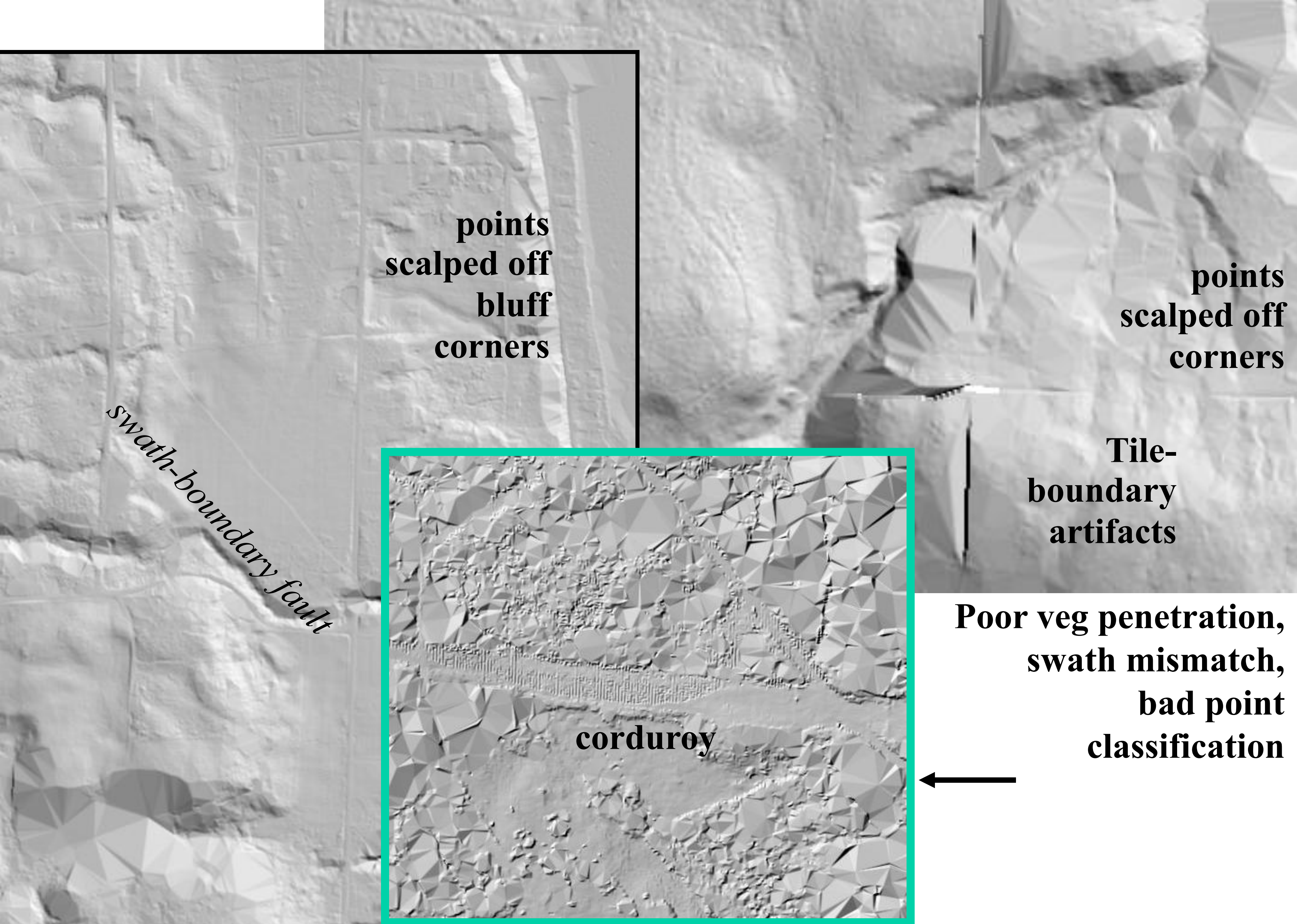




6 ft bare earth DEM – TIN



6 ft bare earth DEM – Spline (RST)



R. Hagerud, USGS

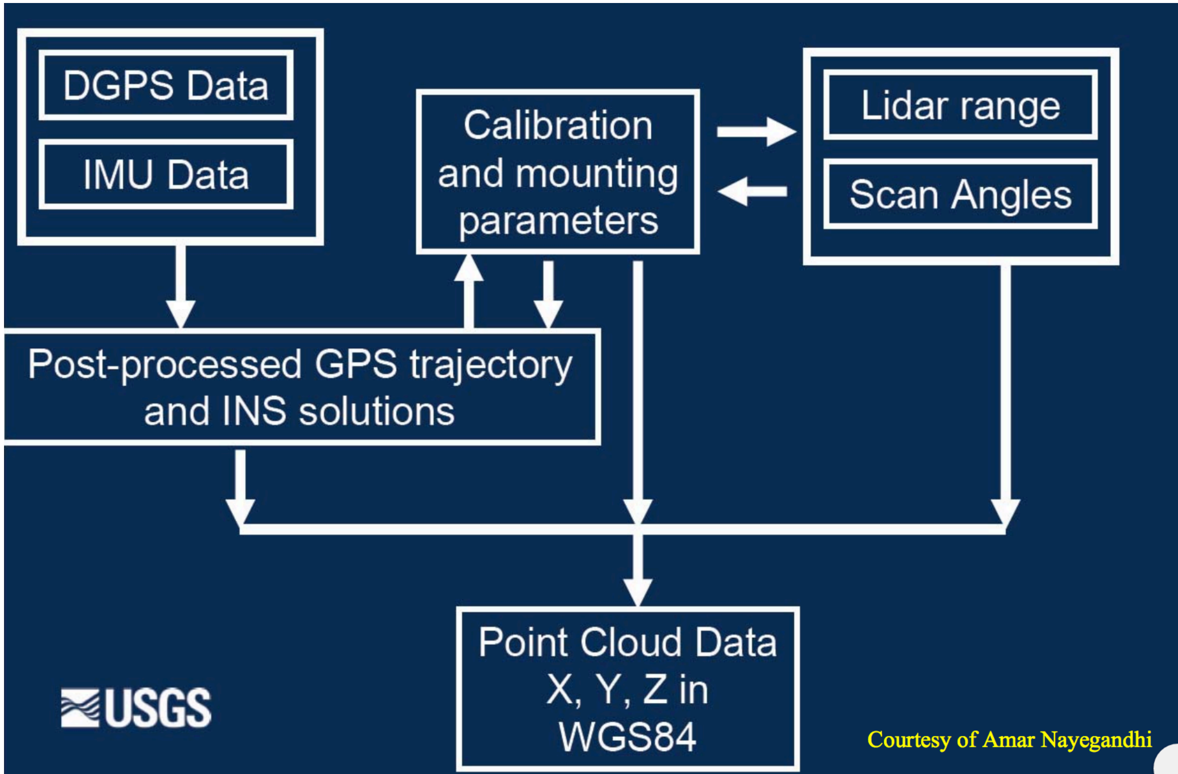

0
60
120
240 Meters

Lidar data error sources

- GPS Precision
- INS Precision
- Lidar System Noise (range error)
- Timing & Mechanical Tolerances (temperature, atmospheric pressure variations)
- Atmospheric Distortions (extreme ground temperature, haze)

Error budget =

+/- 5 to 15 cm
(vertical)



Modified from K. Hudnut, USGS

Corduroy

There are *two* types of 'corduroy' in B4 data

type 1 - 'scan angle artifact' (*INS / bore-sight error &/or scanner error*)

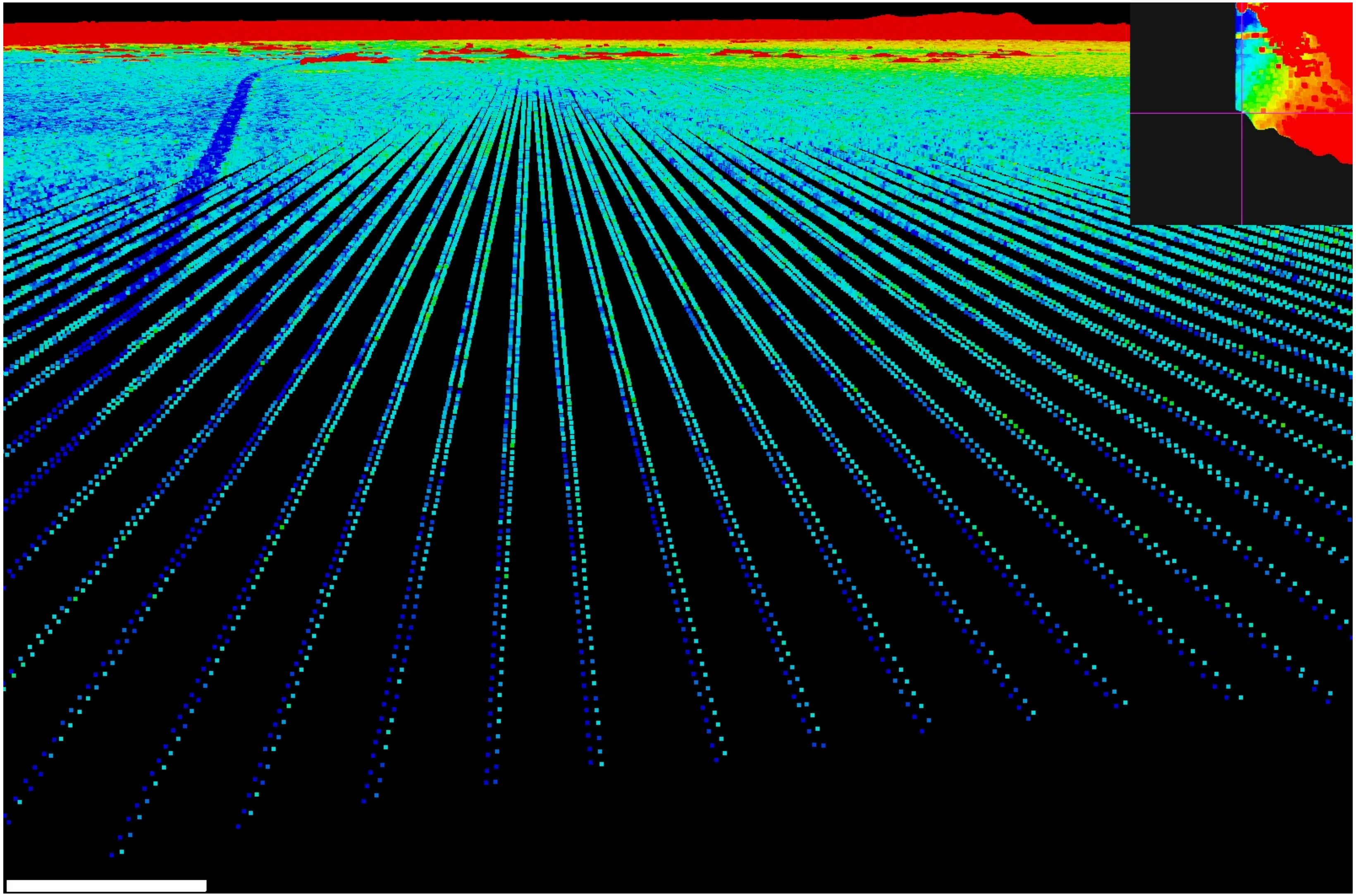
scanner reads higher going one direction than it does in the other

type 2 - 'vertical swath offset'(*GPS error*)

aircraft first pass is vertically mis-aligned with second pass within a given area

Modified from K. Hudnut, USGS

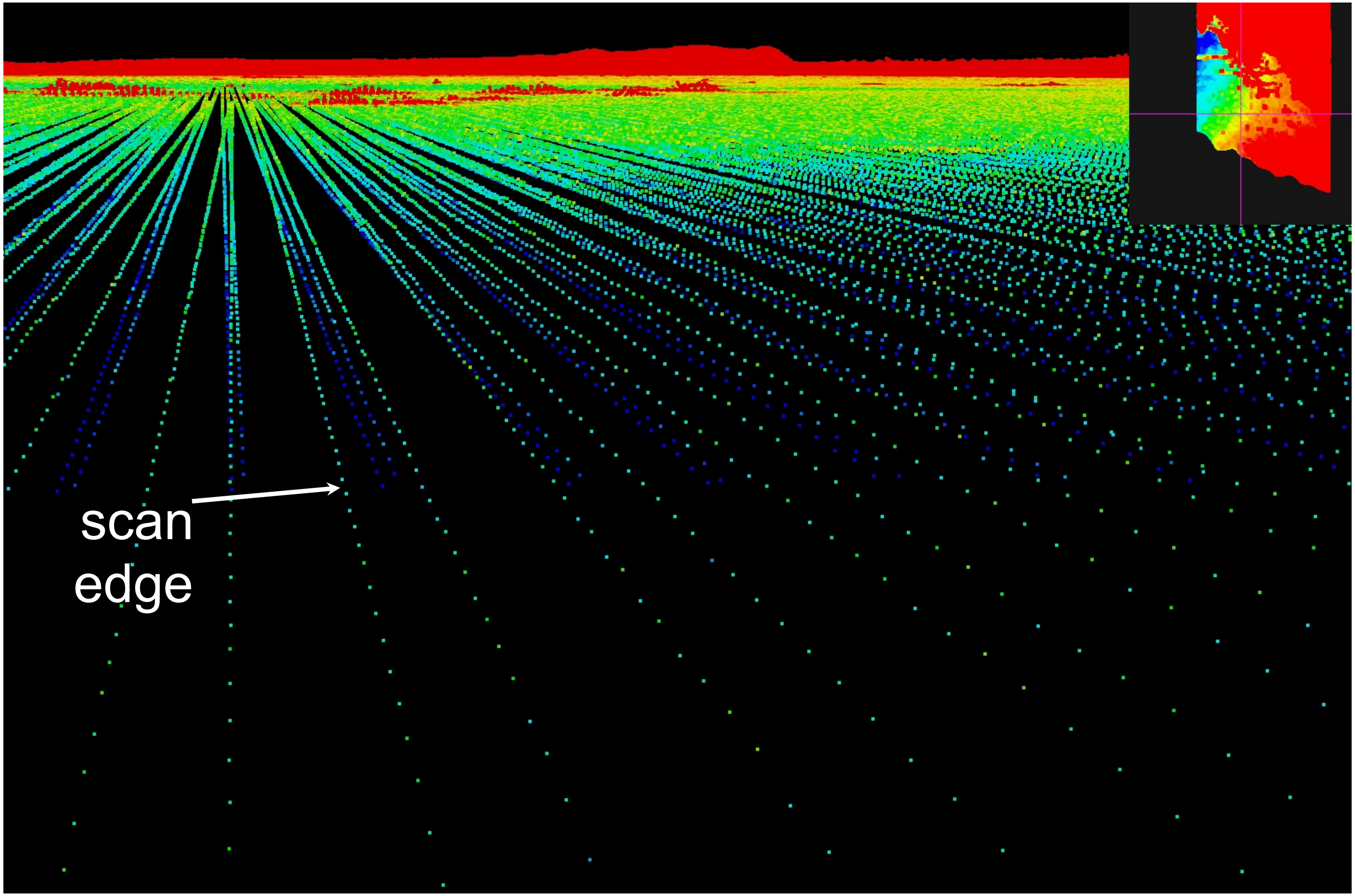
Corduroy & Scan Edge Artifacts – type 1



Scan artifact - at scan edge on dry lake one sees a pattern of up-down consistently; as mirror flips, height reads differently

Modified from K. Hudnut, USGS

Corduroy & Scan Edge Artifacts – type 2

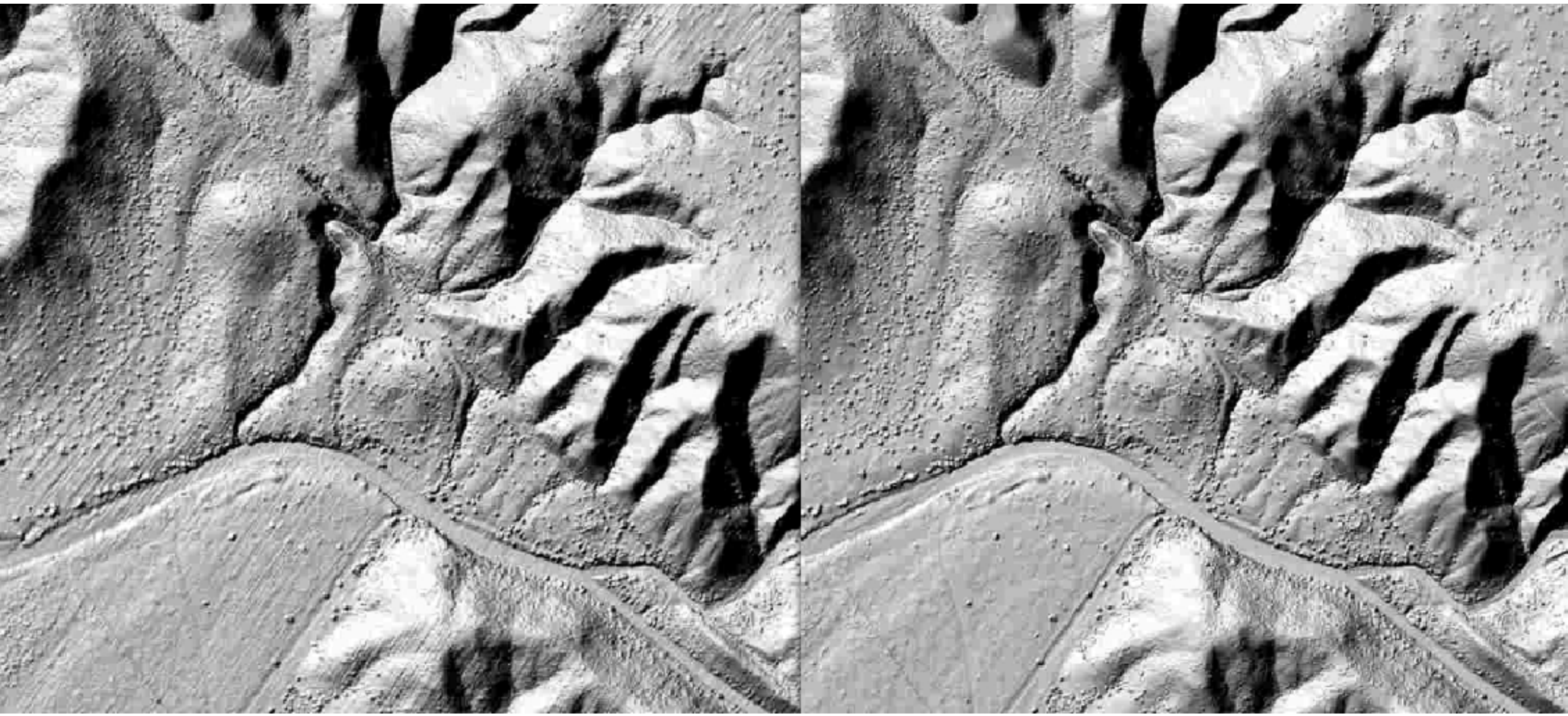


One scan (aircraft pass) is consistently lower than the other scan;
this is a different source of ‘corduroy’, related to aircraft trajectory/positioning.

Modified from K. Hudnut, USGS

Corduroy & Scan Edge Artifacts

The B4 survey was supported by the loan of a 5100 unit from Optech to NCALM.



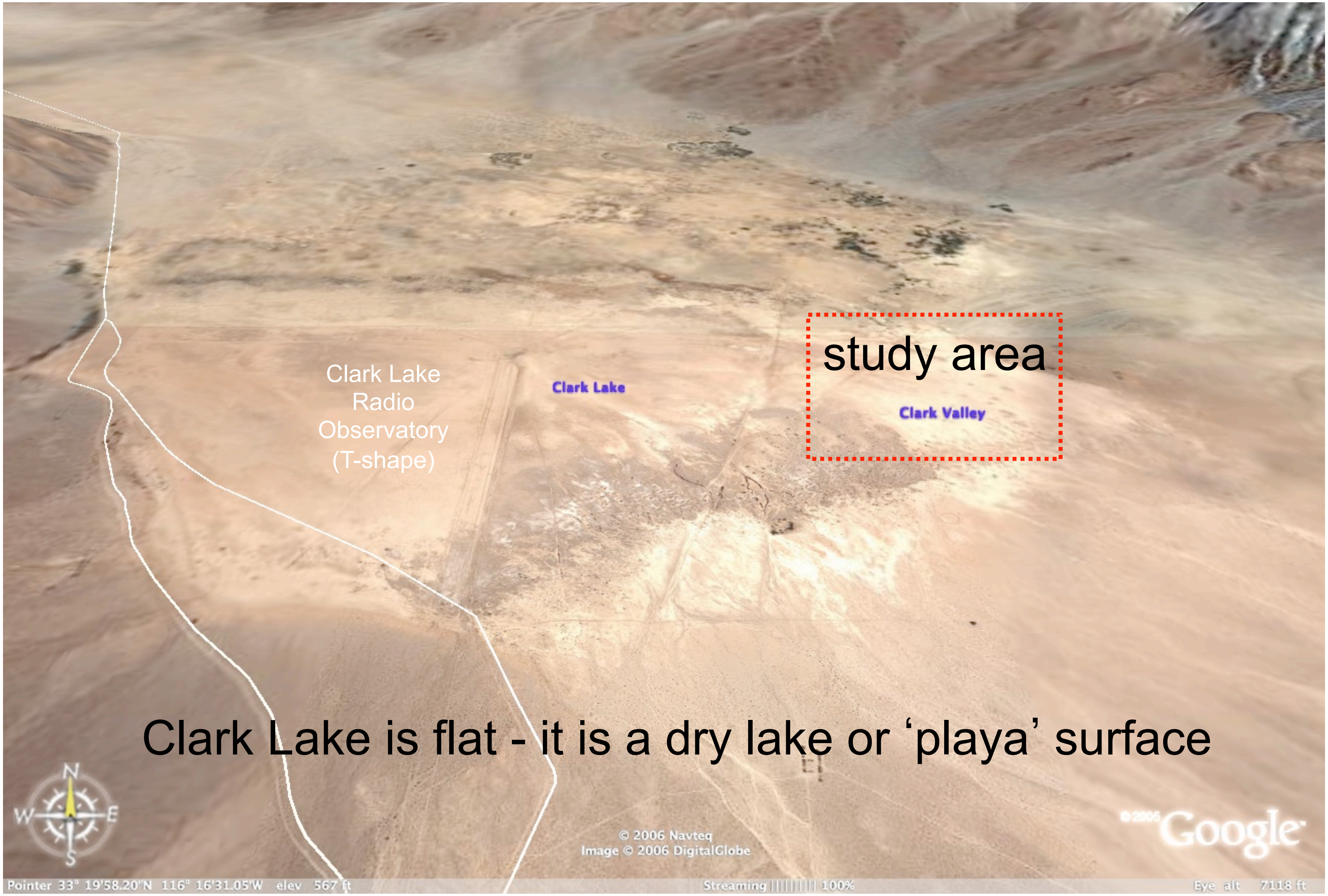
1233 5100

Carizzo Plain

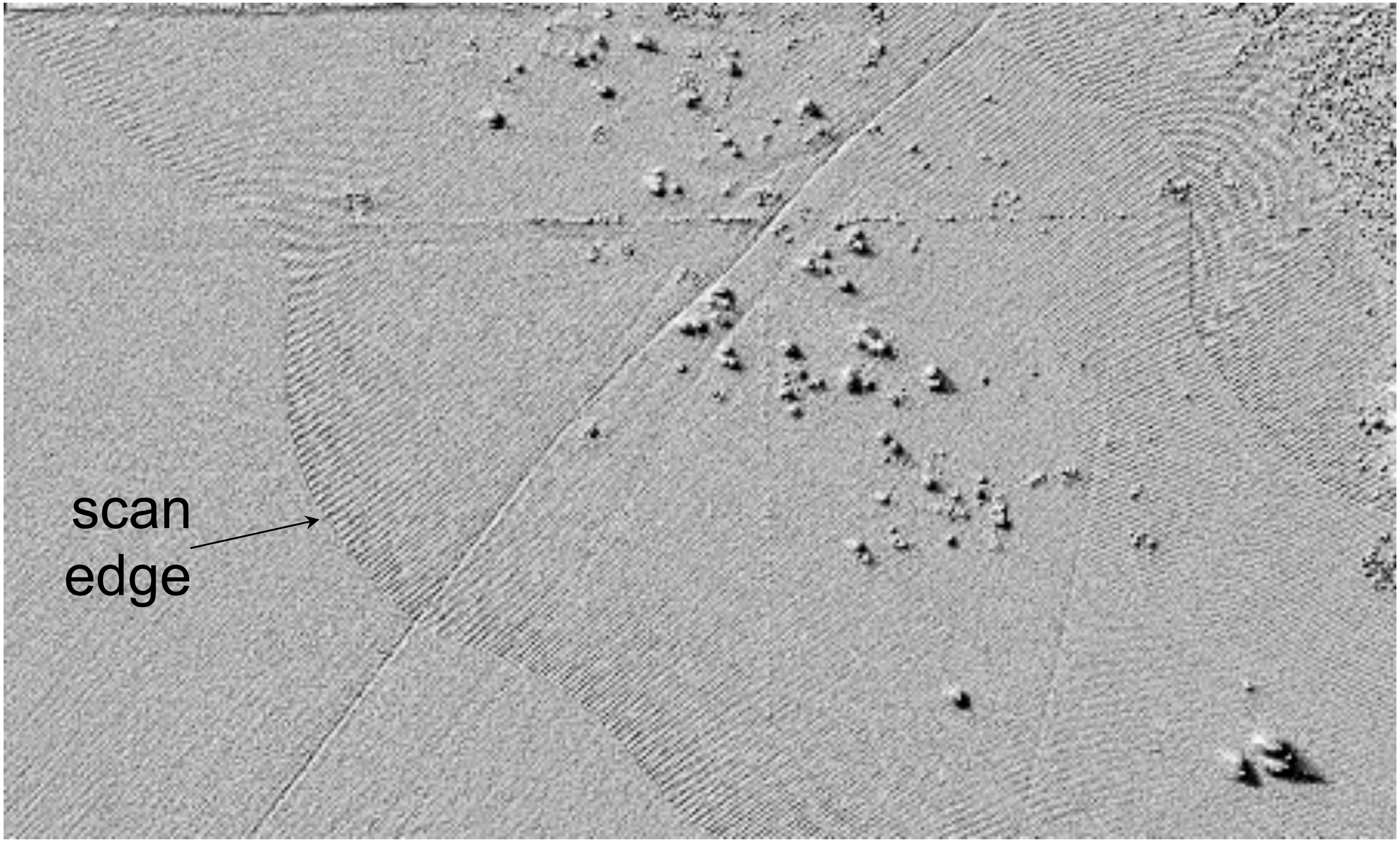
Both models were used over the first few days of the May campaign. In general corduroy, though still present, is more subdued in the 5100 data, as illustrated in these DEM patches.

Modified from K. Hudnut, USGS

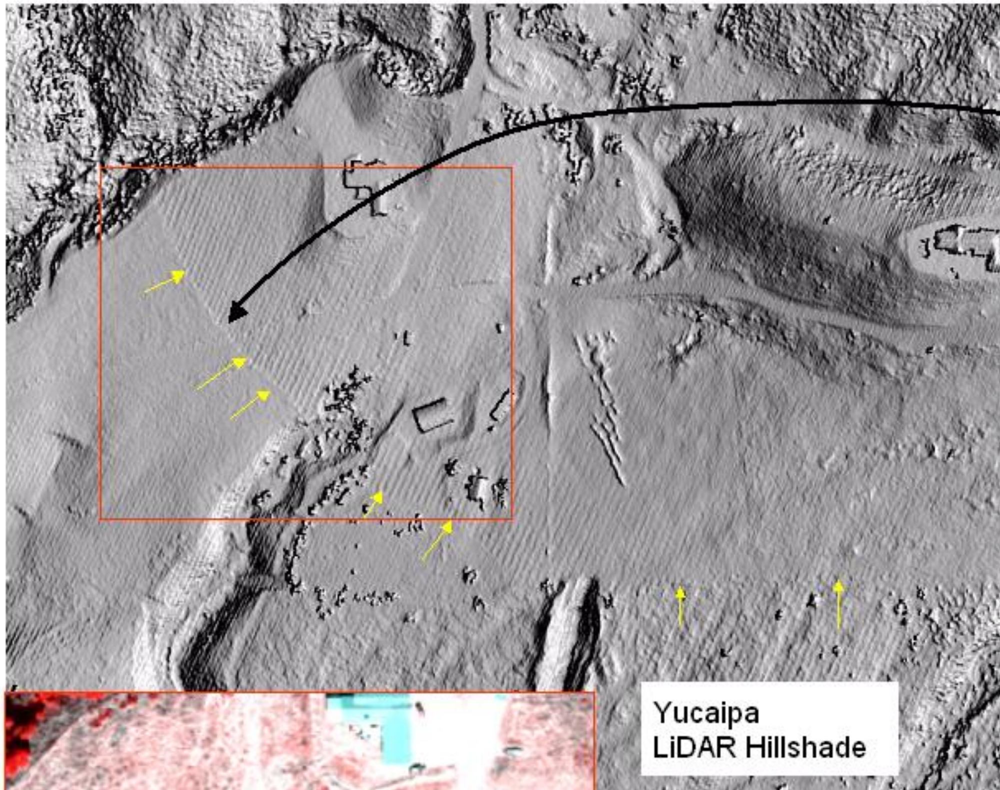
Corduroy & Scan Edge Artifacts

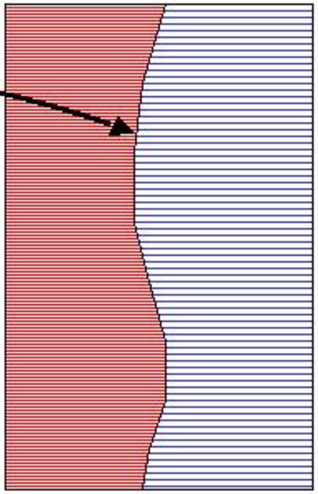


Corduroy & Scan Edge Artifacts

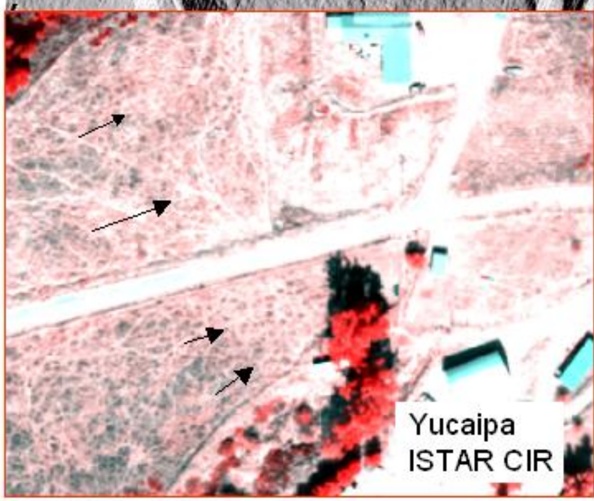


0.5 m DEM from NCALM





"Seam line" between swaths where the corduroy artifacts will not line up due to Vertical Swath Offset.



Red Arrows – features *attributed* to artifacts Green Arrows – "natural" features (aligned drainages, scarplets)

Ante Perez, CGS

Lidar artifacts

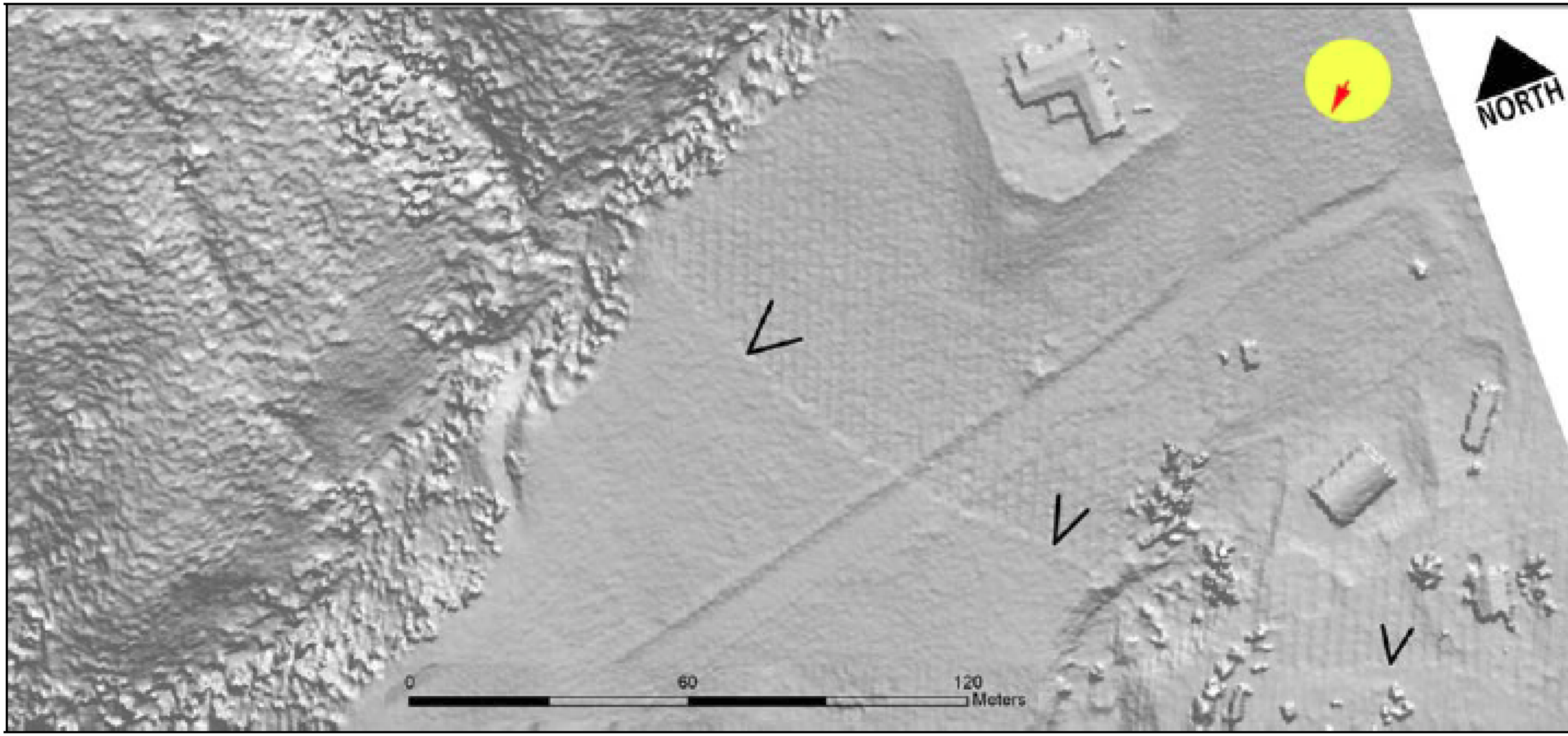
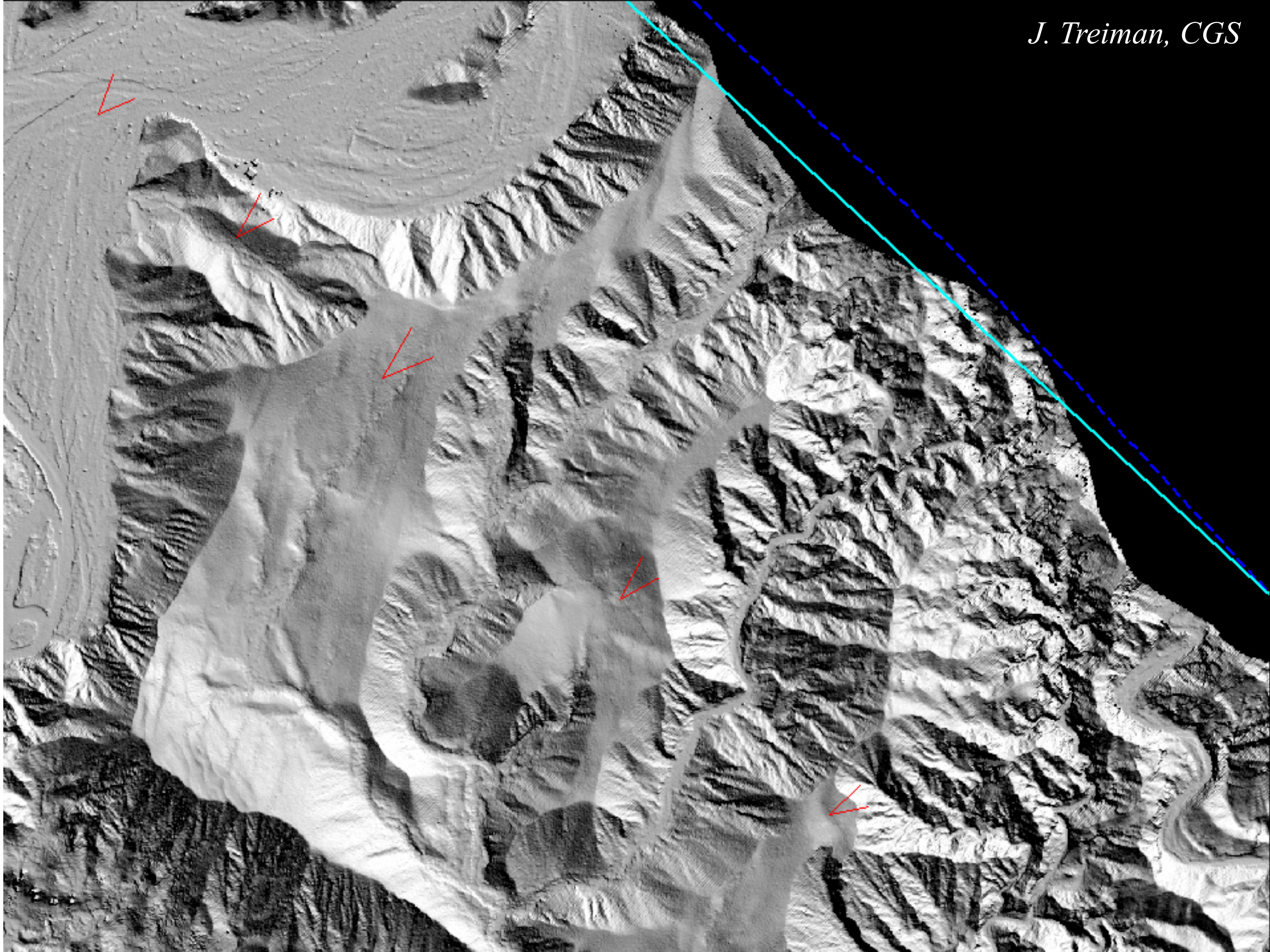


Figure 7a. LiDAR artifact (arrows) in the Yucaipa study area. The artifact appears as a linear highlight suggestive of an east-facing scarp. However, the evident “corduroy” texture on one side versus the other alerts one to the likelihood that this is an artifact. Indeed, it corresponds to the overlap margin between LiDAR swaths.

Treiman, Perez, & Bryant, 2010, USGS Award No. 08HQGR0096
Final Tech. Report


J. Treiman, CGS

Thanks!

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I ♥ LIDAR

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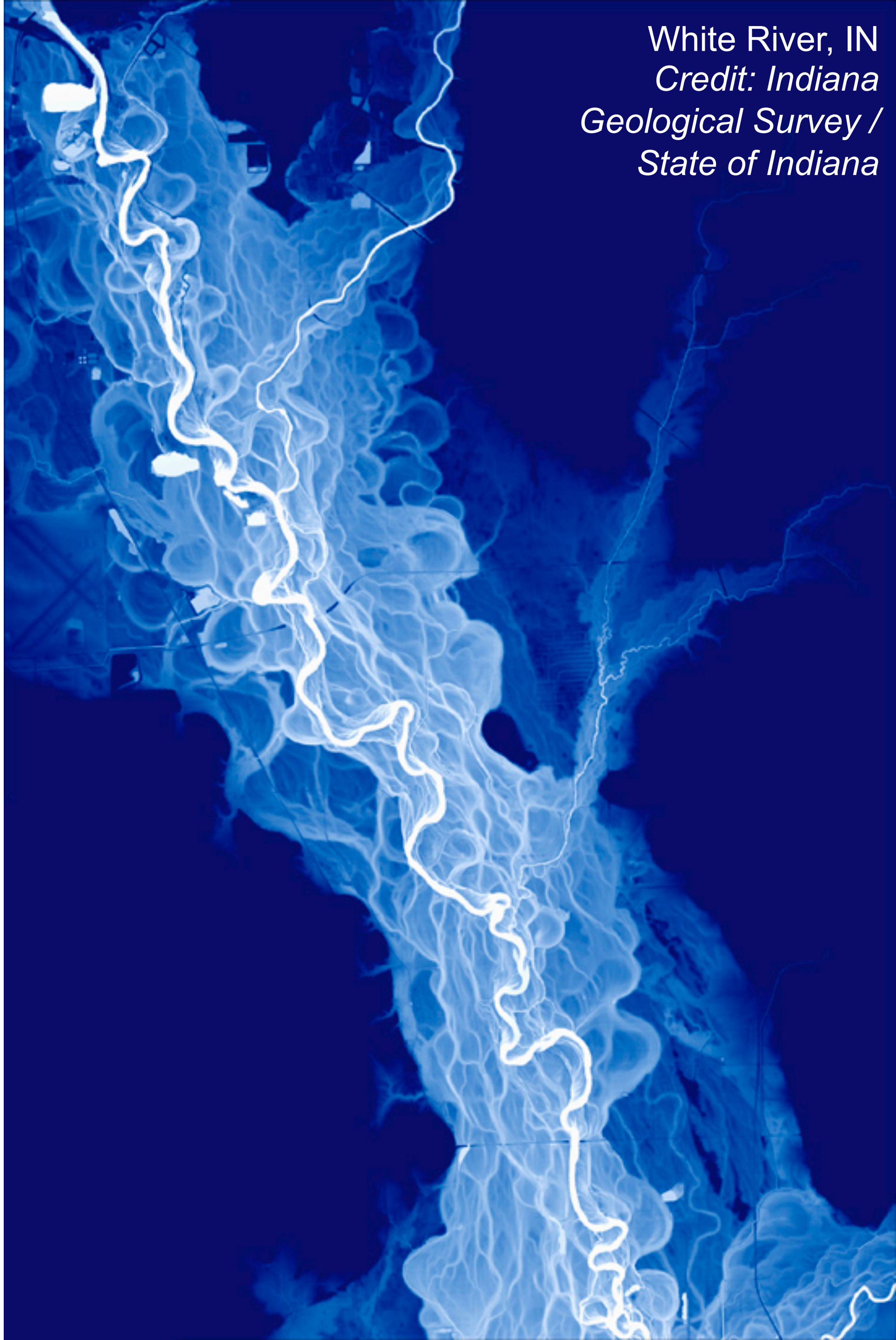


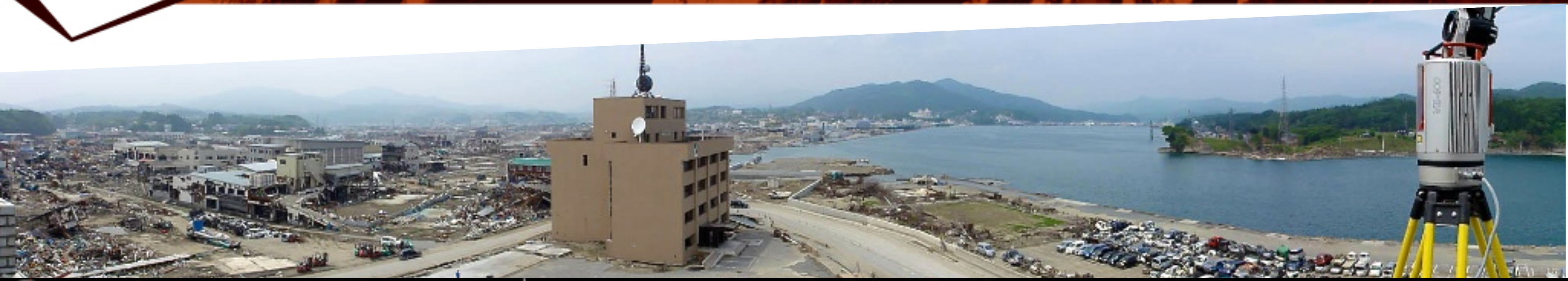
TLS Science Examples

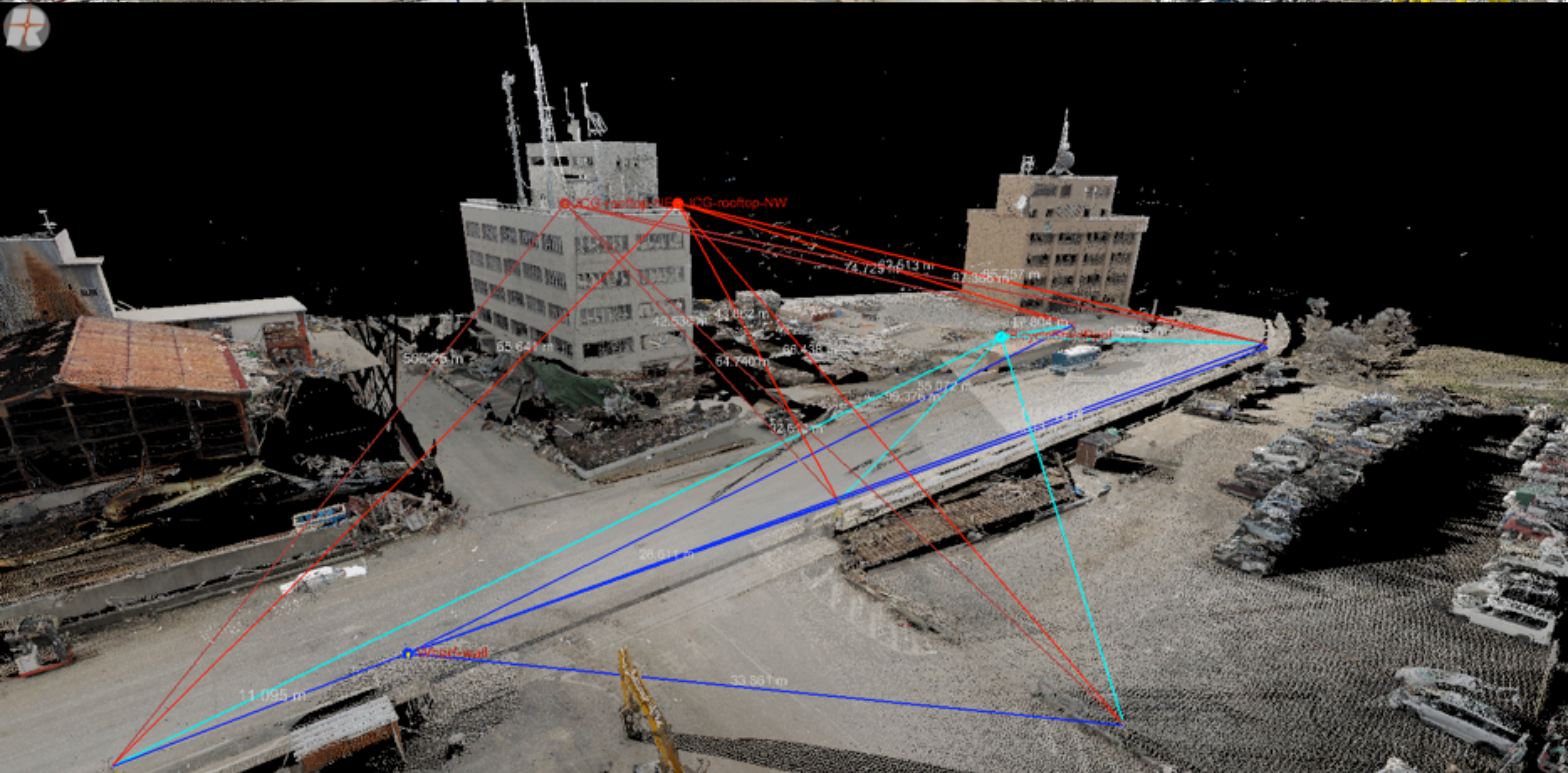
Showcase Video for TLS

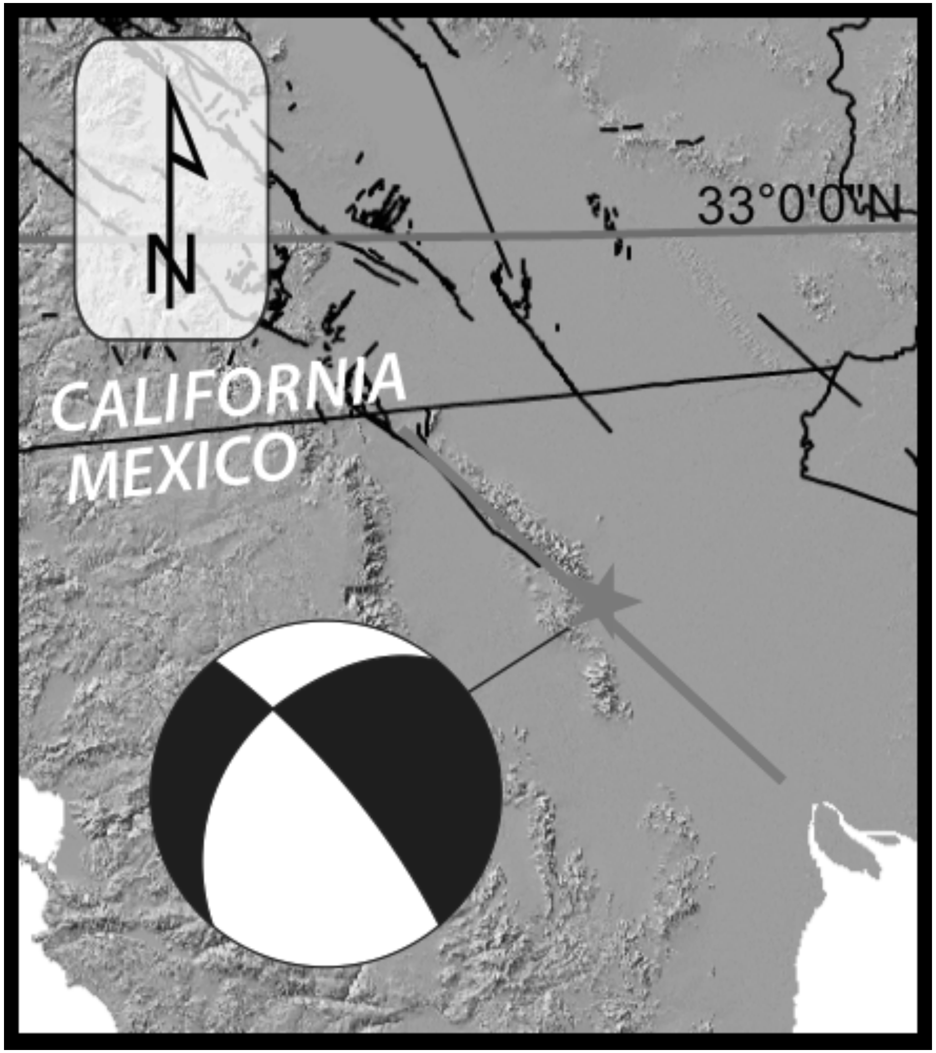
TLS Research Applications

- Project: 2011 Japan Tsunami measurements
- PI: Hermann Fritz (Georgia Tech)
- NSF RAPID project

2011 Japan Tsunami







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

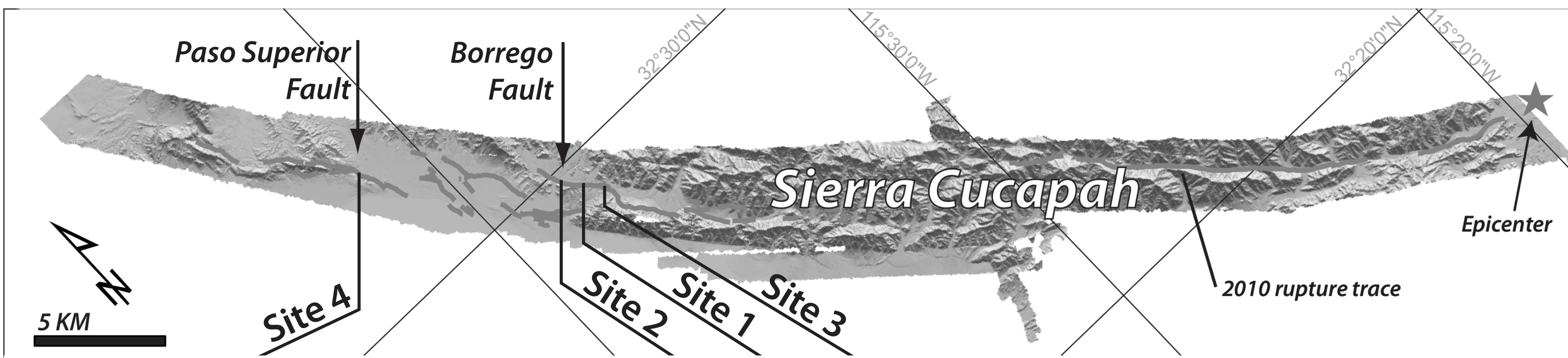
- > 3m right-normal slip north of epicenter
- < 1m right-normal blind faulting south of epicenter

P. Gold, UCD

Motivations: Data Collection

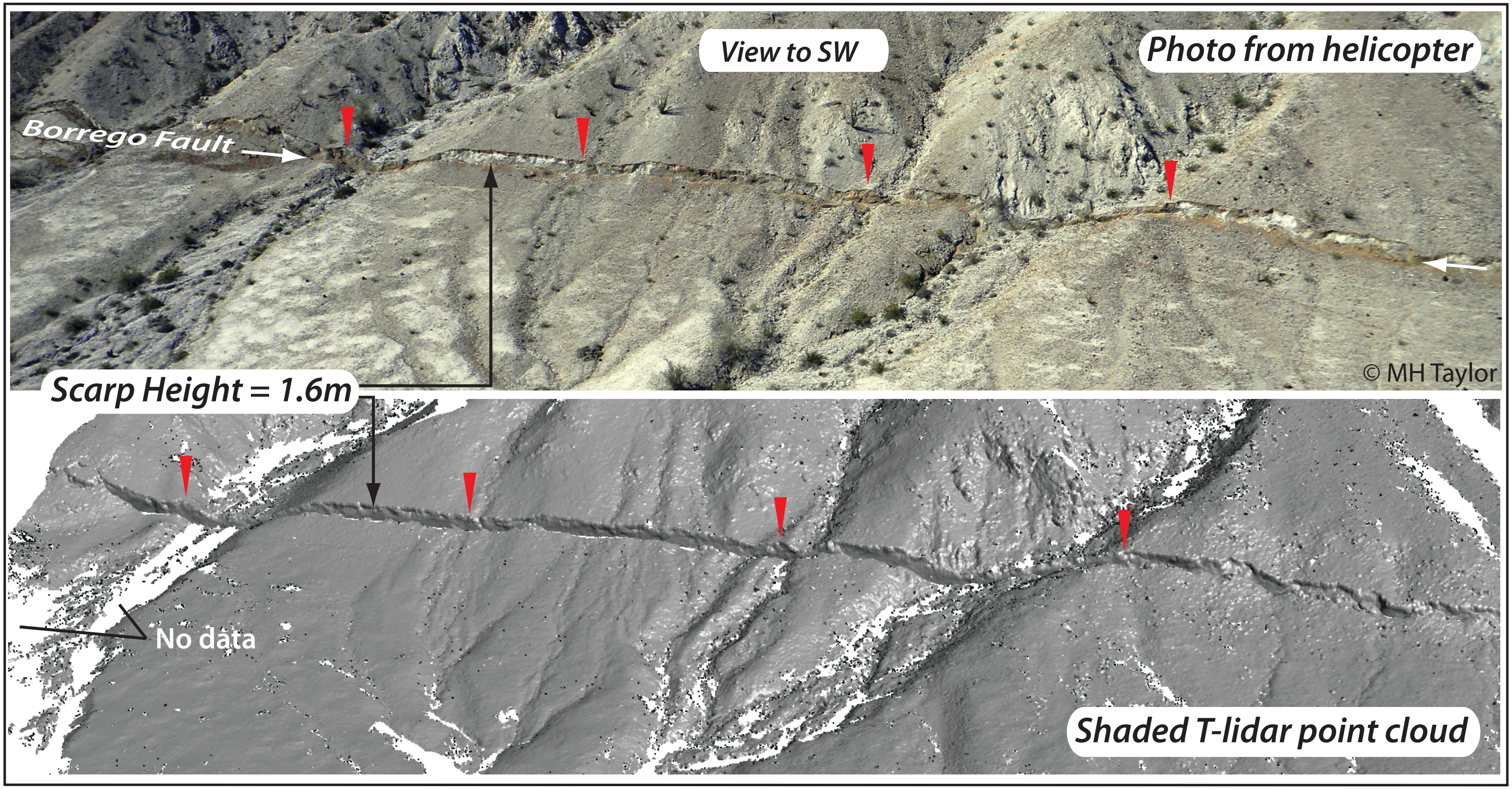
- Preserve primary rupture features for:
  - Remote measurement/analysis
  - Comparison to future scans

- Scan ruptures in a variety of geologic and geomorphic settings



P. Gold, UCD

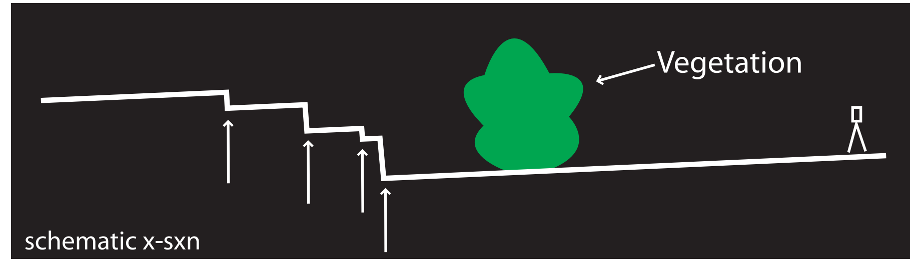
Scale of TLS coverage

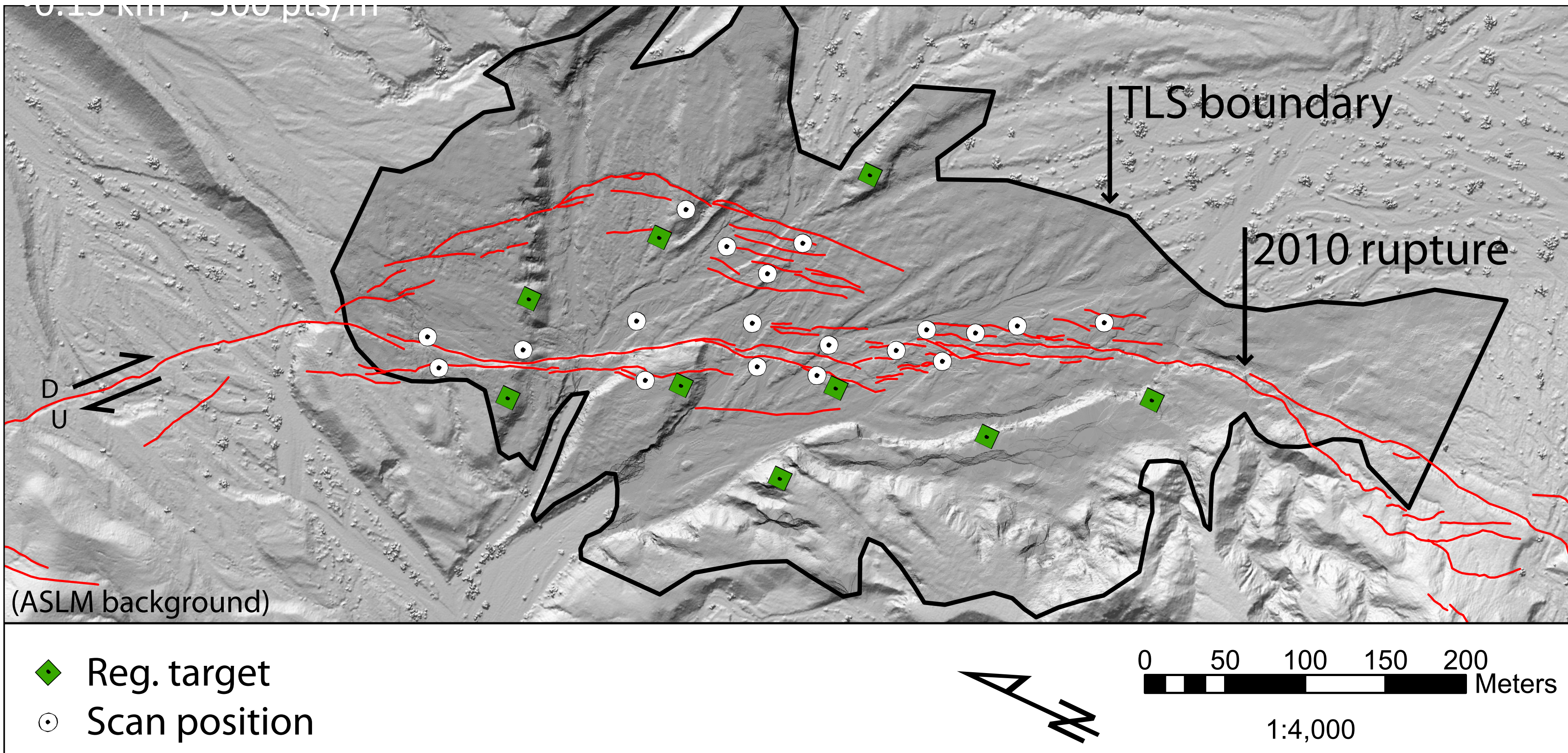


- ~200m along-strike distances

P. Gold, UCD

Data Collection



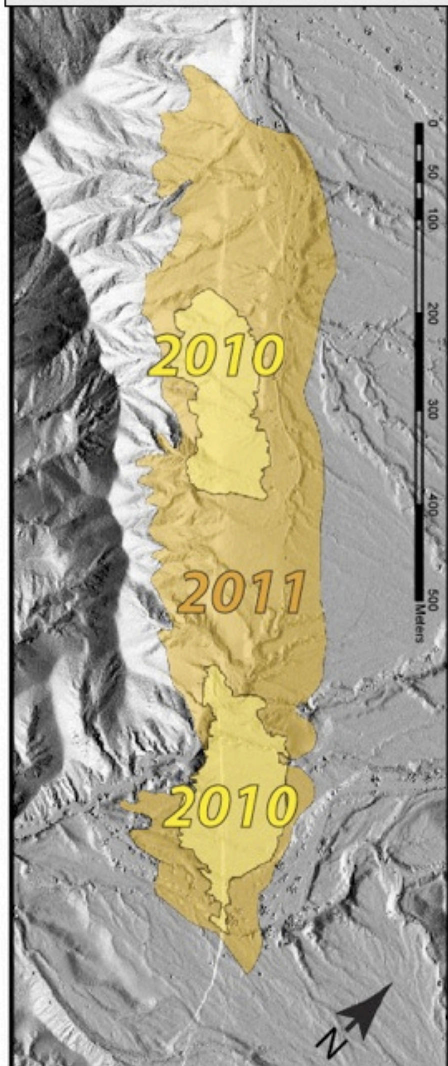


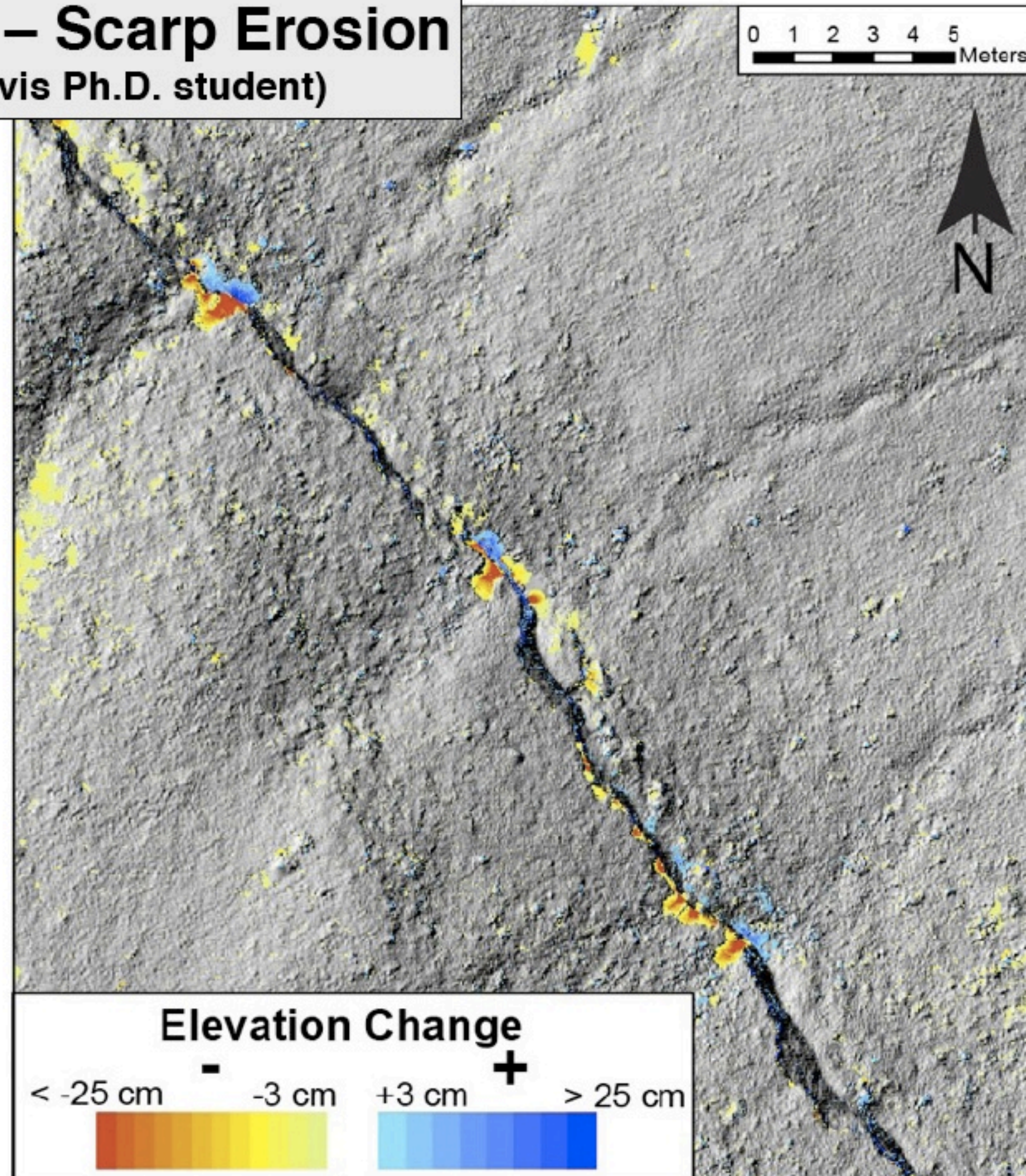
P. Gold, UCD

Scarp Erosion, 2010-2011

Change Detection – Scarp Erosion

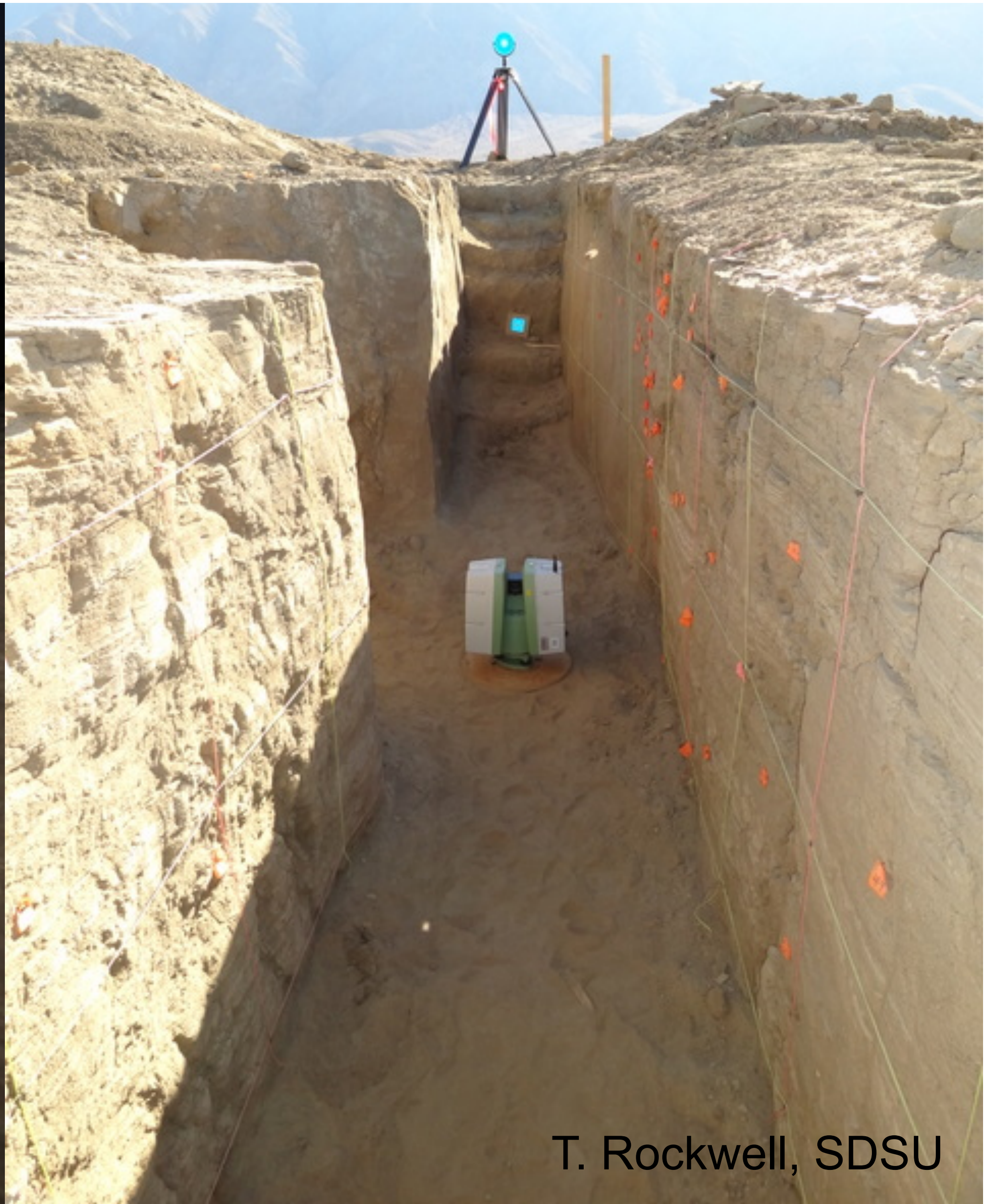
Austin Elliott (UC Davis Ph.D. student)





UNAVCO

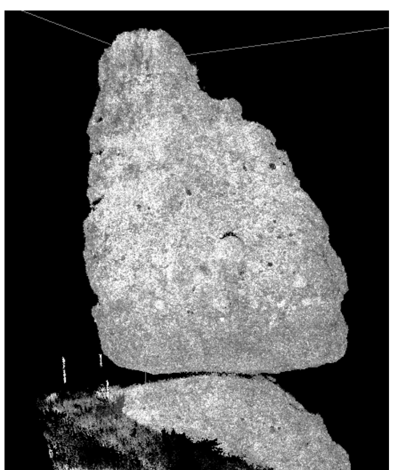
SoCal Paleoseismology

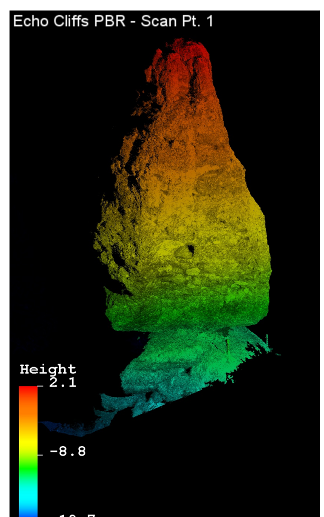


T. Rockwell, SDSU

Precariously Balanced Rocks, PBRs

- Project Highlight: Precariously balanced rock (PBR) near Echo Cliffs, southern California.
- PI: Ken Hudnut, USGS.
- Goal: generate precise 3D image of PBR in order to calculate PBR's center of gravity for ground motion models useful for paleoseismology, urban planning, etc.

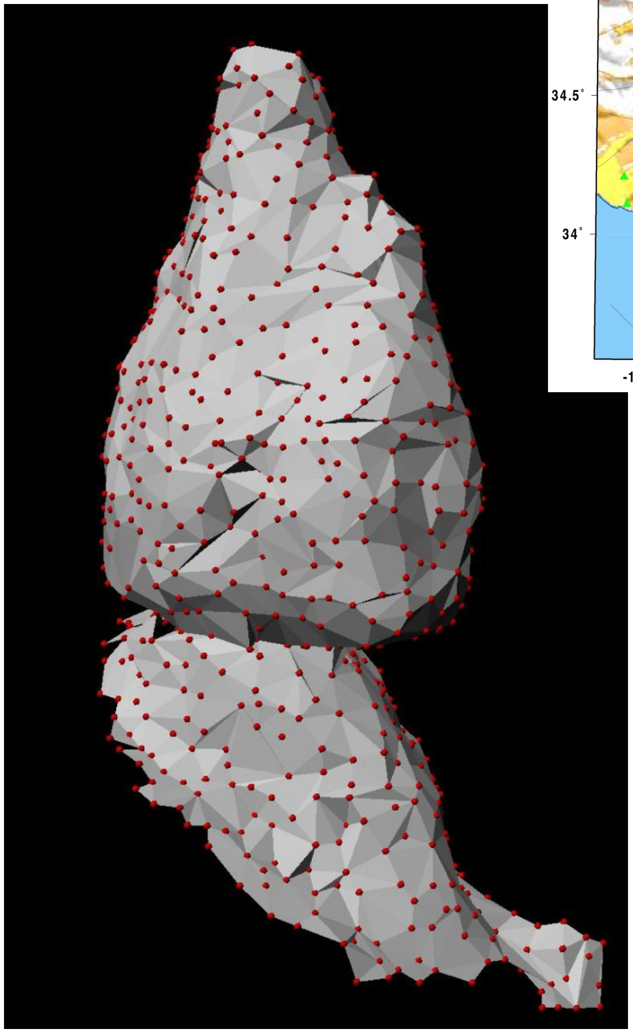


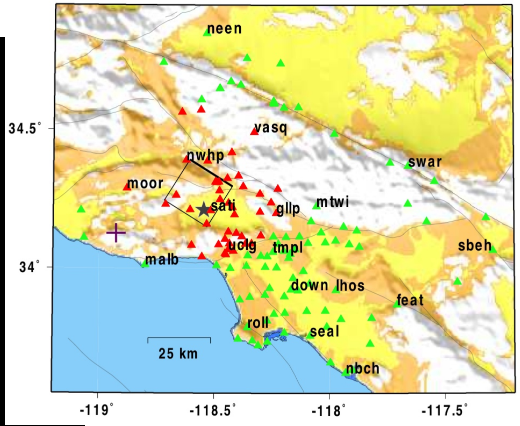


(Hudnut et al., 2009)

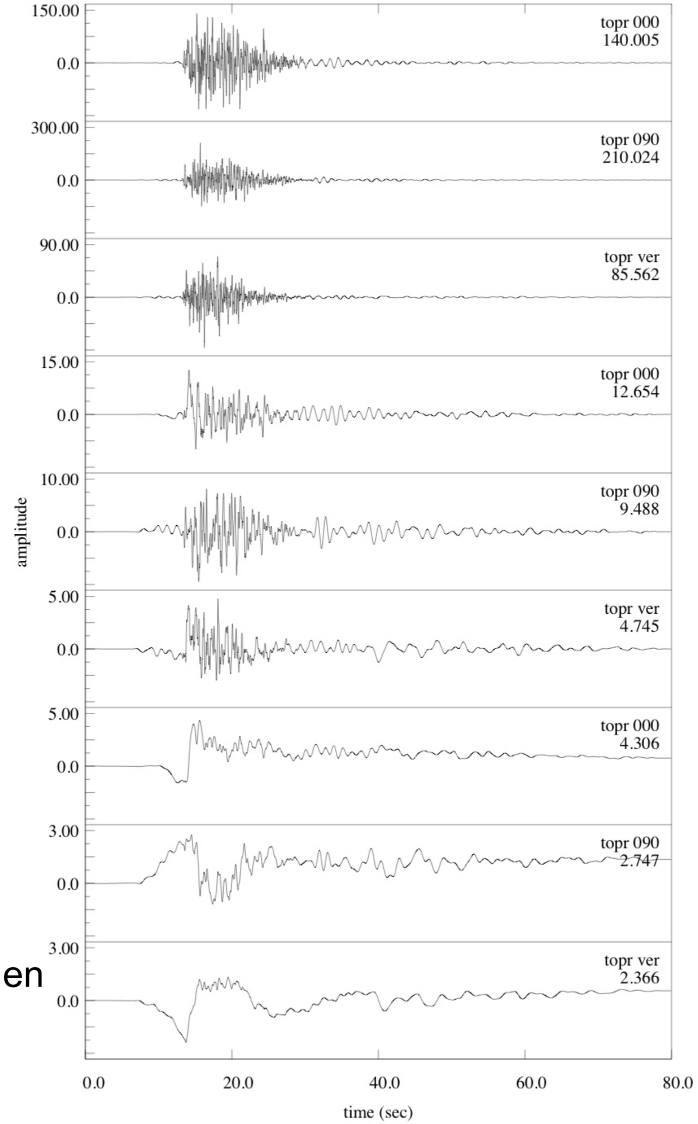
Precariously Balanced Rocks, PBRs

3D surface model and simulated 1994 Northridge waveforms





Northridge 1994 simulation by Rob Graves



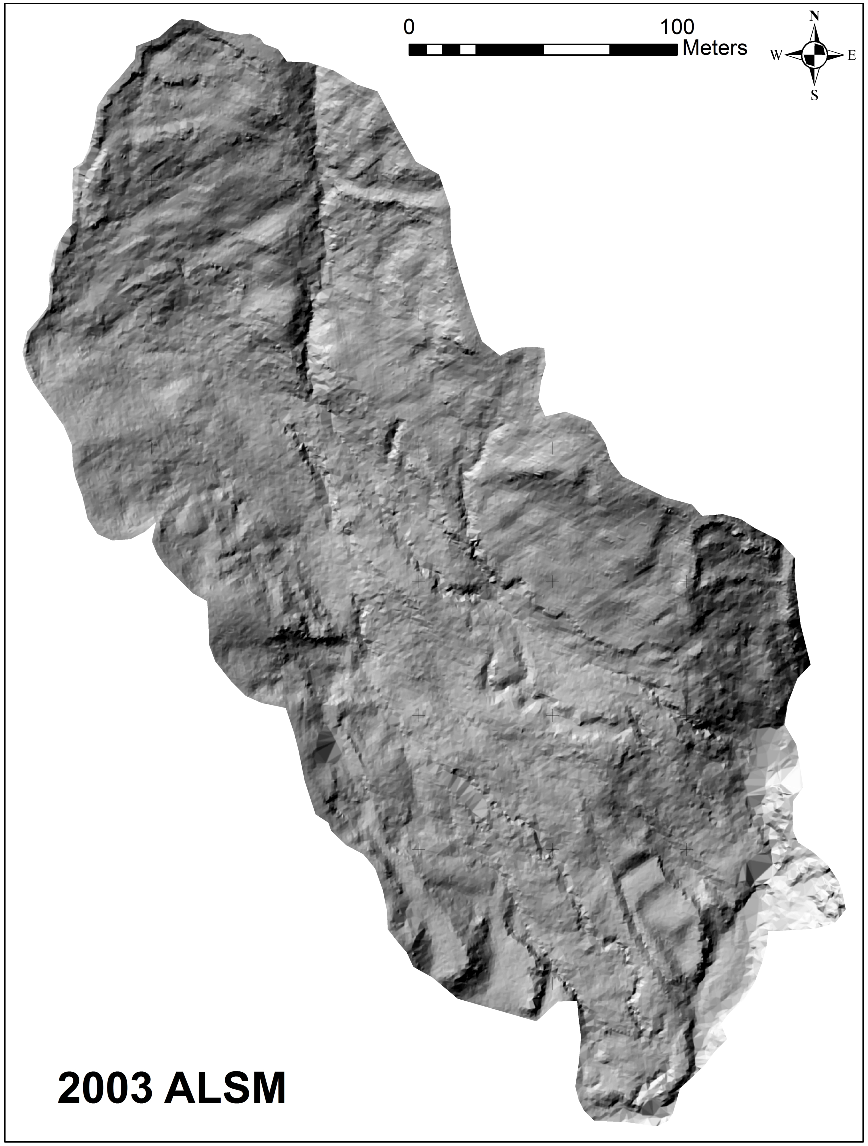
3D model by Gerald Bawden and Sandra Bond

Four Mile Fire, CO, Erosion (PIs: Moody, Tucker)

Mill Gulch earth flow, Sonoma, CA)

Repeat surveys give ability to quantify temporal change.

Integration of TLS and ALS data



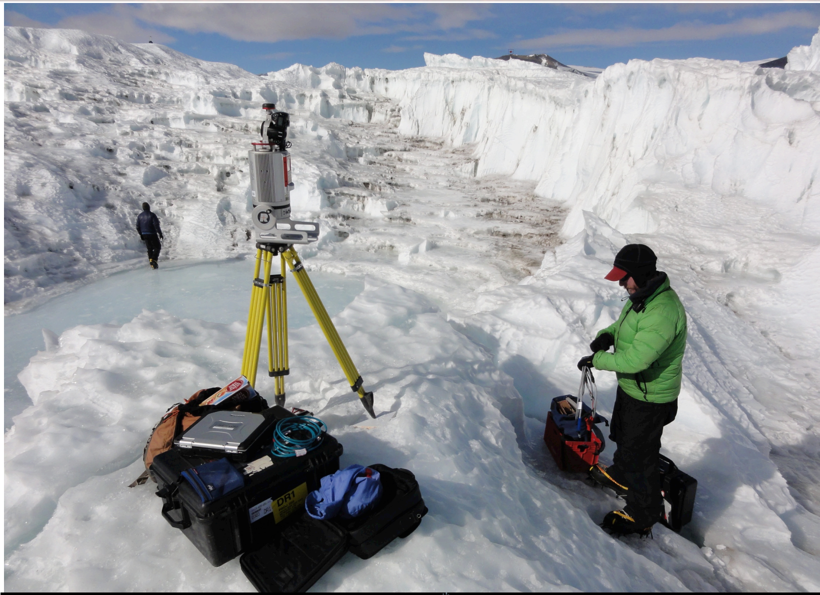
Steve DeLong, USGS

Scanning in Polar Environments

- 10-15 Antarctic and Arctic Projects per yr
- Remote locations, challenging logistics (helicopter, icebreaker, backpack)
- Extreme environmental conditions:
  - -35C to +15C, 20-65 knot winds

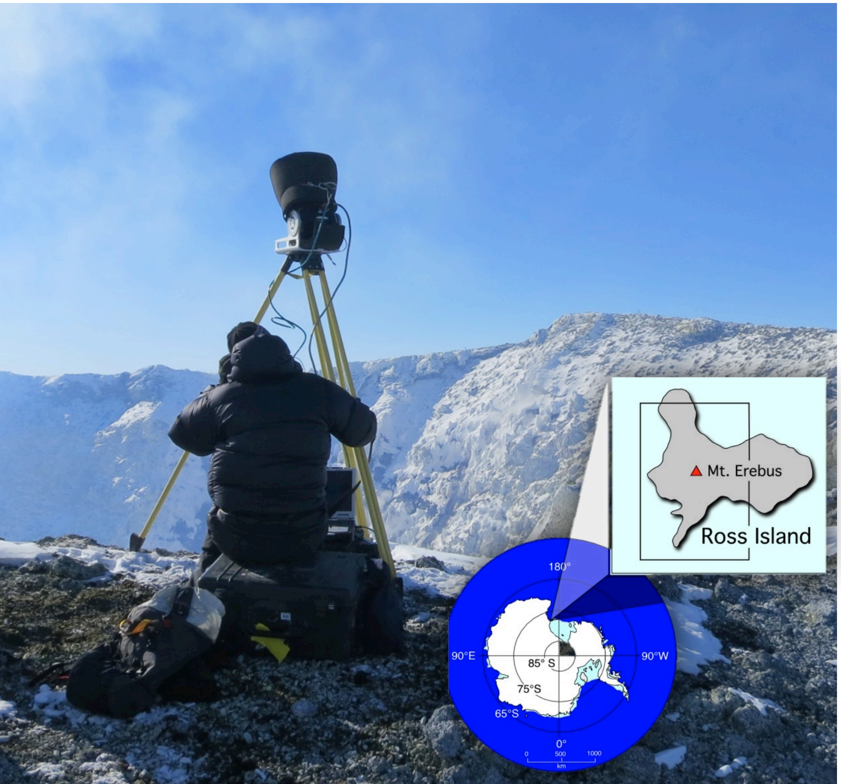
<u>Science:</u>

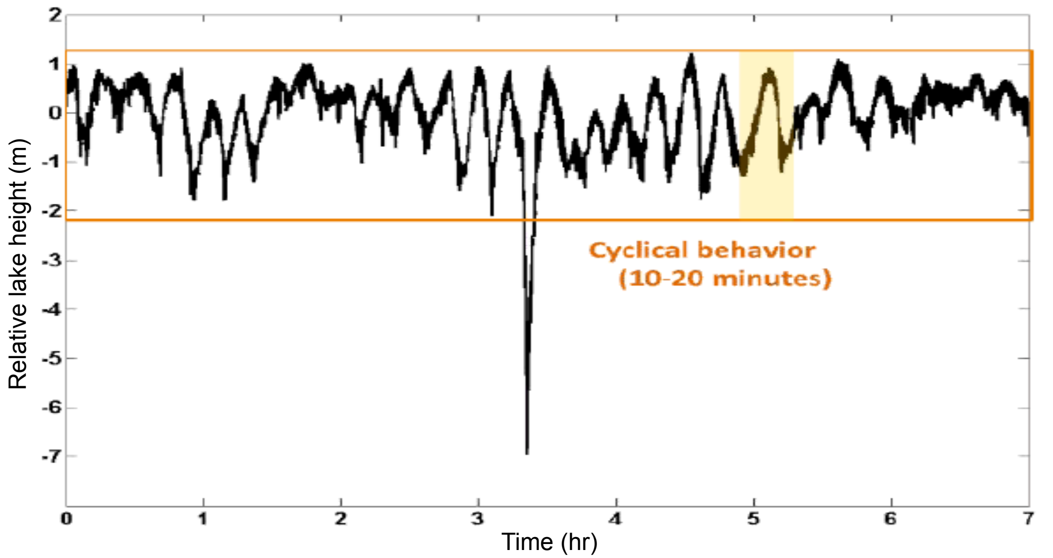
- *Geomorphology:* Frost polygons and ancient lake beds
- *Glaciology:* Glacier melt and ablation
- *Biology/Ecology:* Weddell Seal volume; Microtopology of tundra in Alaska
- *Archeology:* Human impact of climate change



Mount Erebus, Antarctica

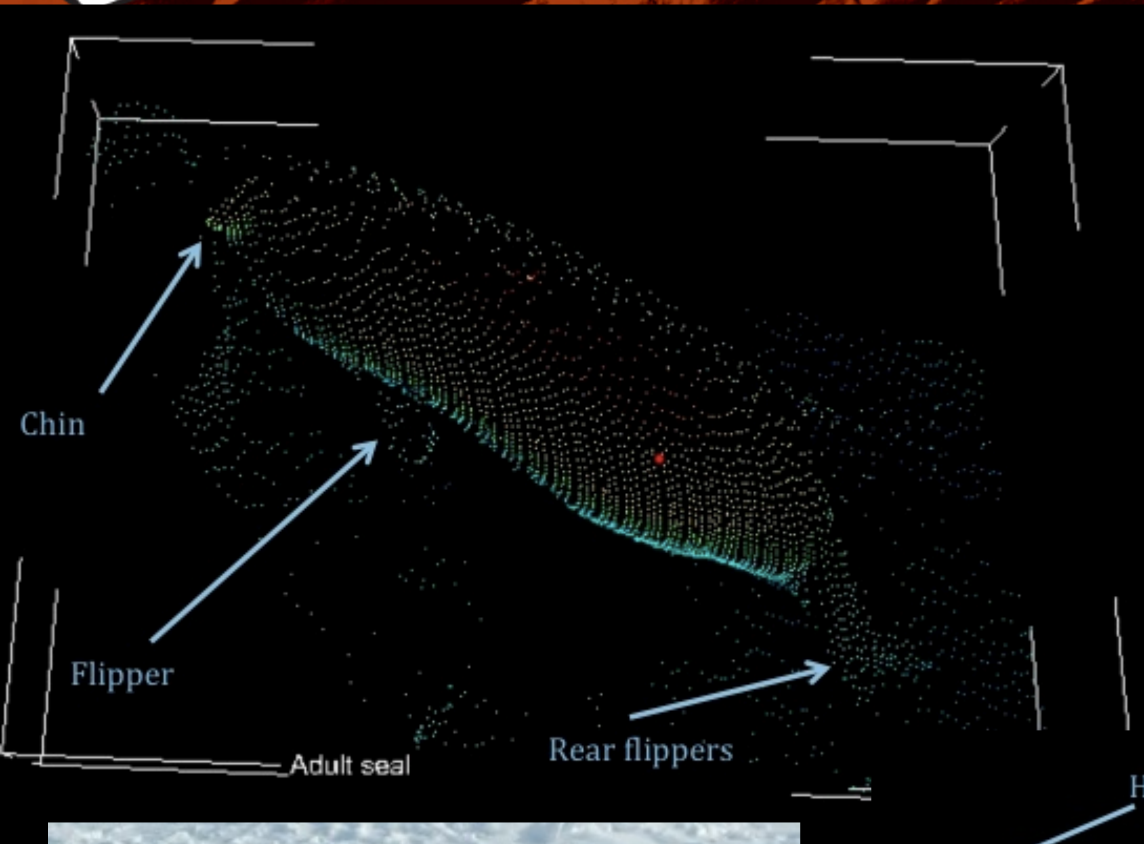
- Lava lake scanned 2008 - 2013, revealing behaviors invisible to naked eye
- Inner crater scan used to augment and truth 2003 aerial scans
- Scans of ice caves and ice towers help determine thermal / energy budget of volcano

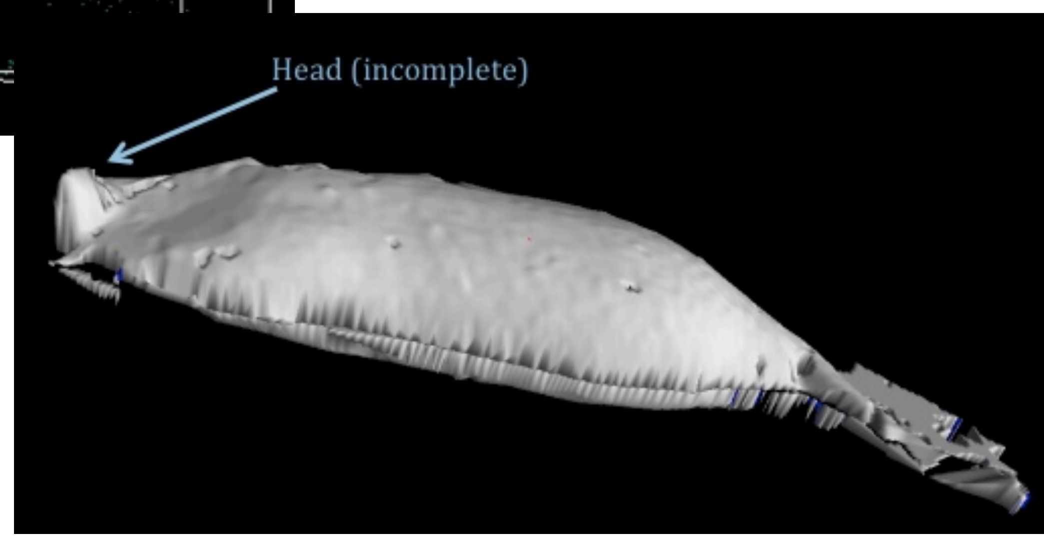




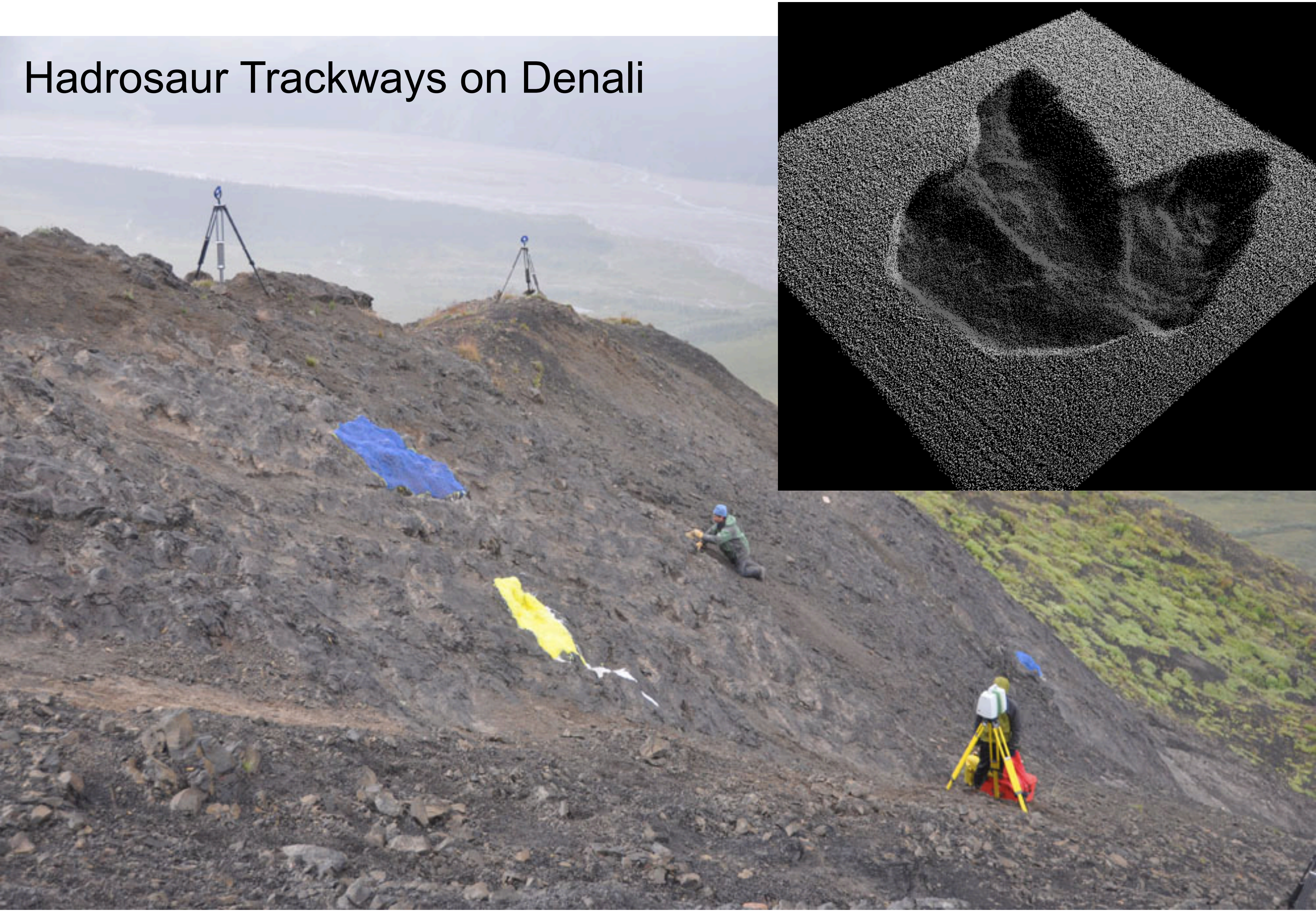
Using TLS to Obtain Volumetric Measurements of Weddell Seals in the McMurdo Sound

Seal body mass = proxy for availability of marine food resources



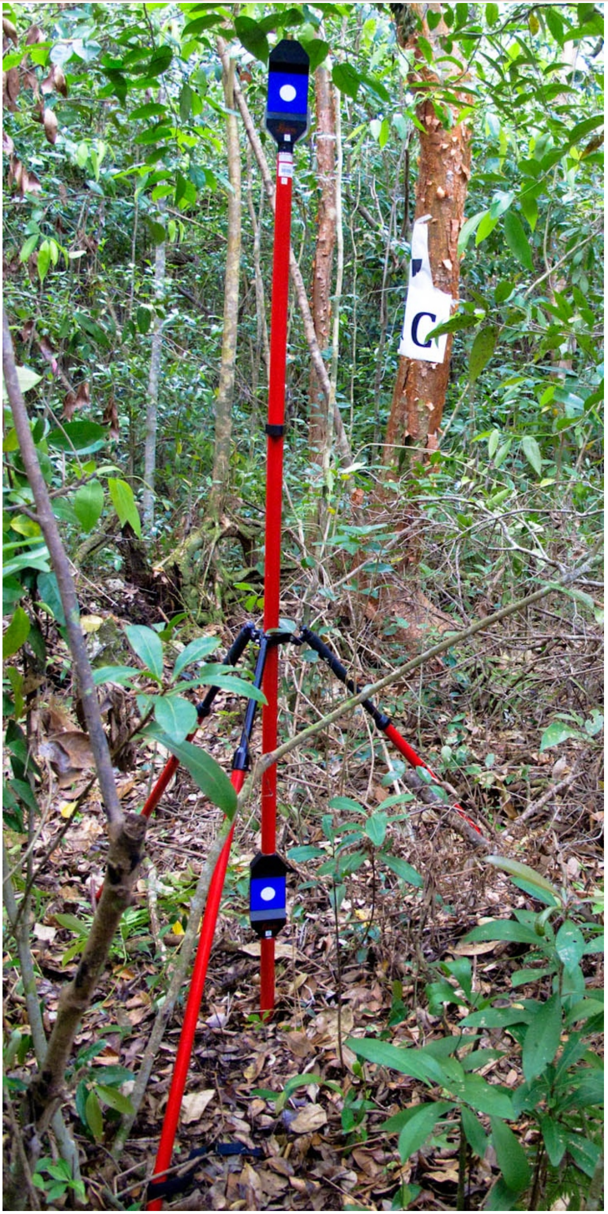


Hadrosaur Trackways on Denali



Fiorillo, et al., 2014, Geology, DOI: 10.1130/G35740.1

Everglades Biomass, Wdowinski



- Scanning to measure biomass in Everglades National Park (PI: Wdowinski).

Everglades Biomass, Wdowinski