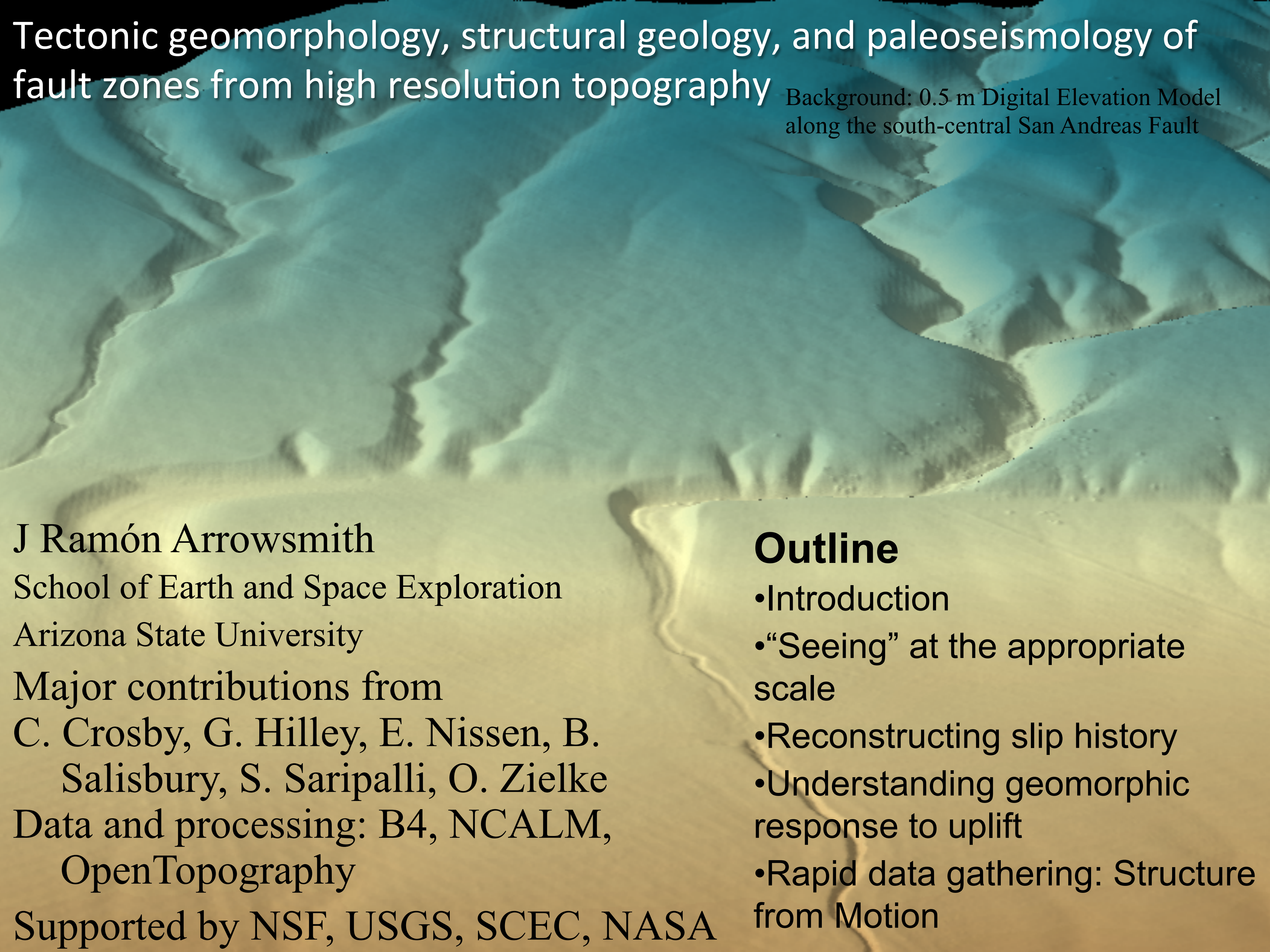
Tectonic geomorphology, structural geology, and paleoseismology of fault zones from high resolution topography



Background: 0.5 m Digital Elevation Model along the south-central San Andreas Fault

J Ramón Arrowsmith

School of Earth and Space Exploration

Arizona State University

Major contributions from

C. Crosby, G. Hilley, E. Nissen, B. Salisbury, S. Saripalli, O. Zielke

Data and processing: B4, NCALM, OpenTopography

Supported by NSF, USGS, SCEC, NASA

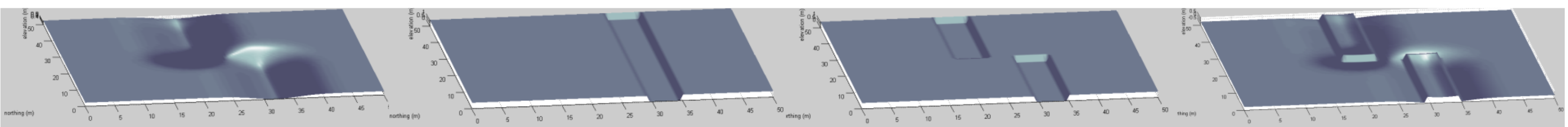
Outline

- Introduction
- “Seeing” at the appropriate scale
- Reconstructing slip history
- Understanding geomorphic response to uplift
- Rapid data gathering: Structure from Motion

Landscape development in areas of active deformation

Surface processes act to change elevation through erosion and deposition while tectonic processes depress or elevate the surface directly.

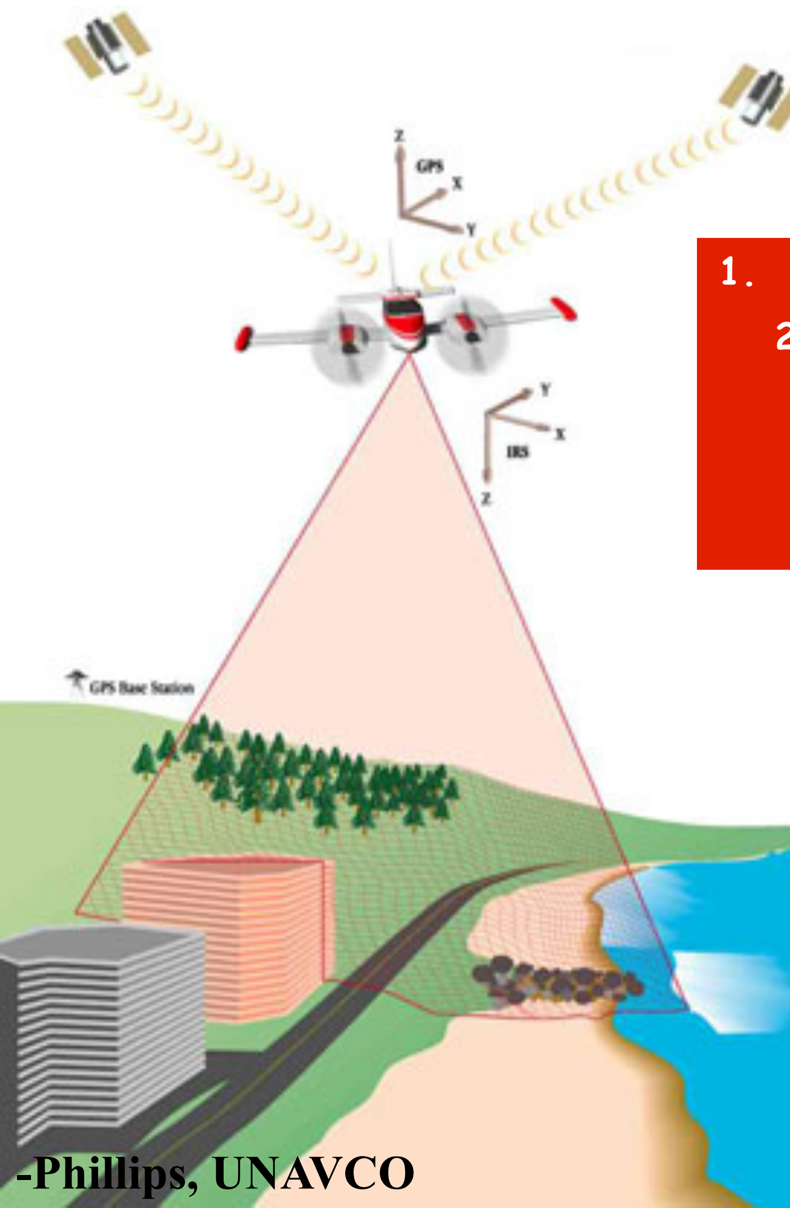
Current elevation = Original elevation + Tectonic displacement + Geomorphic displacement



$$H(x,y,t) = H_0(x,y) + U(x,y,t,H) + V(x,y,t,H)$$

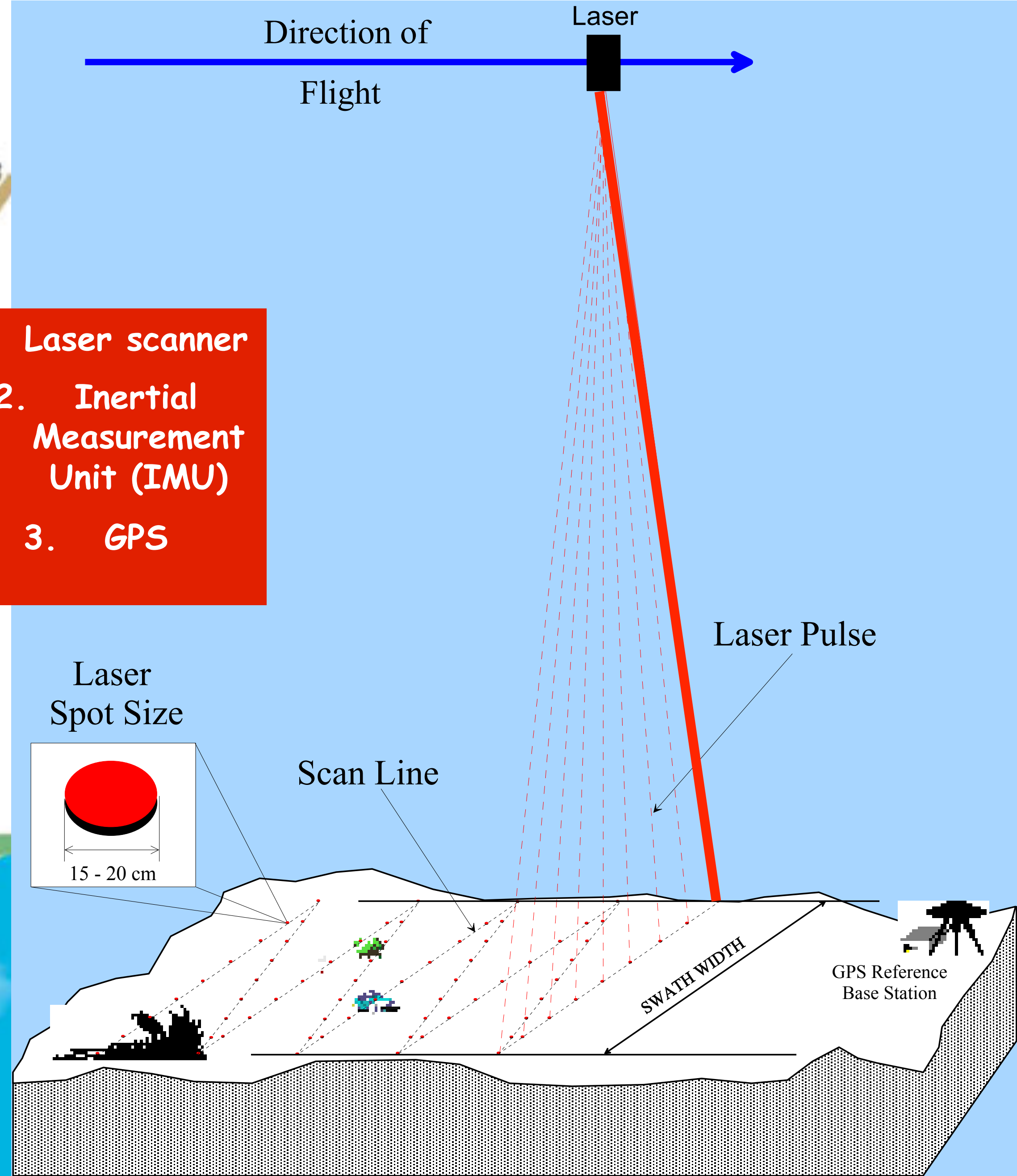
NCALM
The National Center for Airborne Laser Mapping

Airborne Laser Swath Mapping (ALSM)



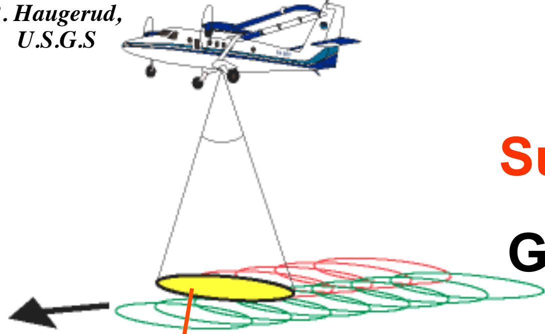
-Phillips, UNAVCO

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

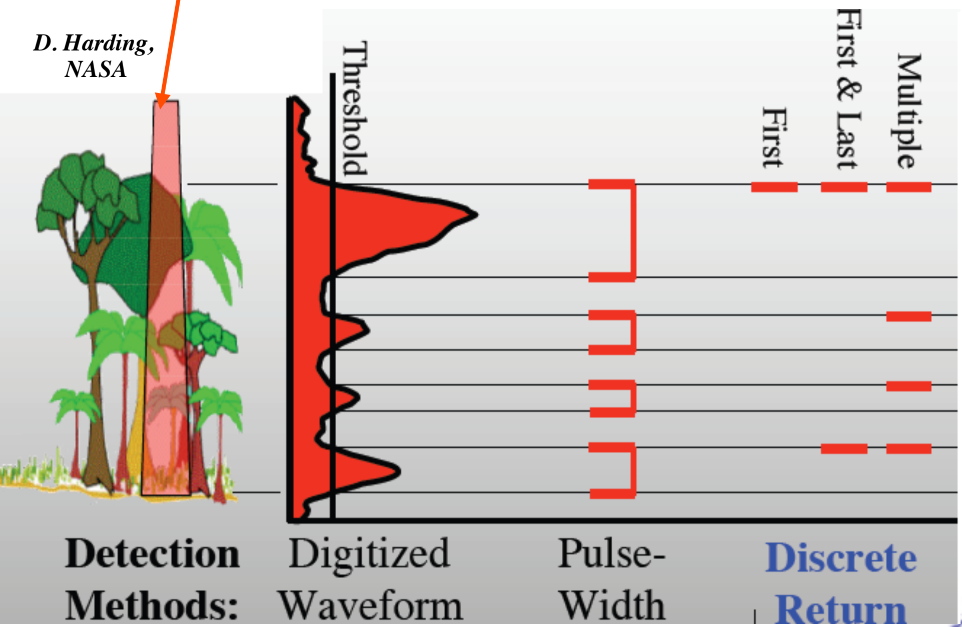


ALSM workflow:

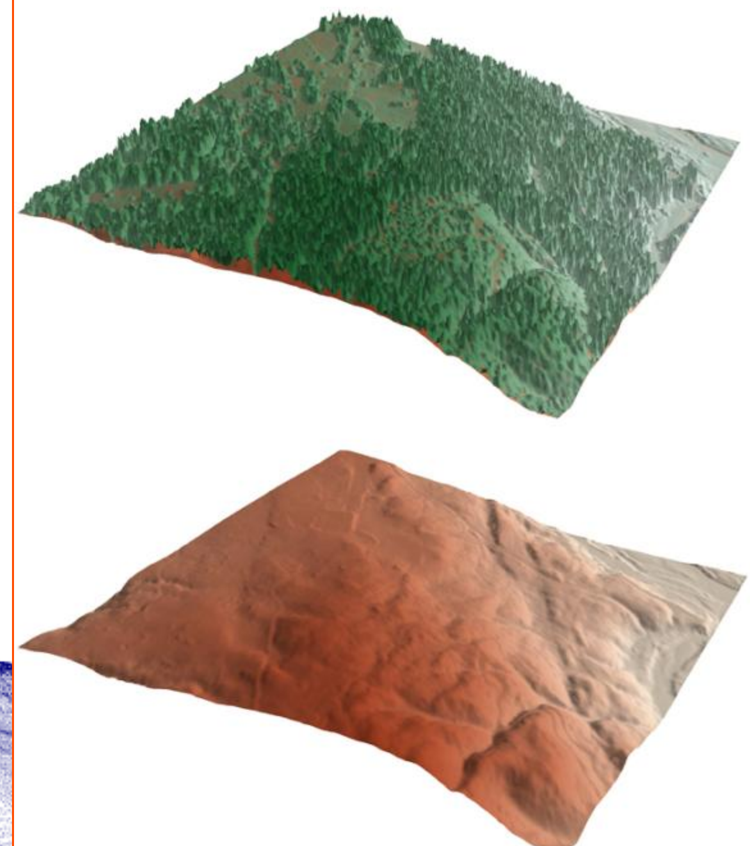
Survey->Process->Classify->Interpolate/Grid->Analyze

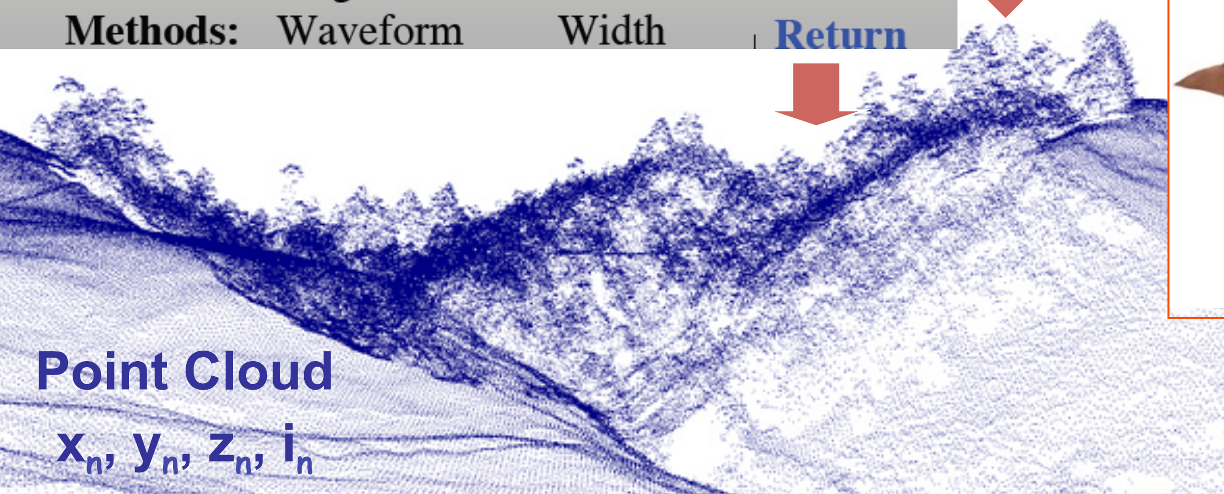


Geodesy and signal processing



Gridded products





Answer science question

Northern San Andreas Fault, California

Northern San Andreas Fault, California

OpenTopography

A Portal to High-Resolution Topography Data and Tools

myOpenTopo

http://www.opentopography.org

Home | About | Data | Resources | Community | Support

LiDAR data for the University of California, Berkeley fused with color aerial photography.

Overview Video | Find Data | Tools | Learn

Spotlight

New Video: *LiDAR - Illuminating Earthquake Hazards*

This educational video, produced by Sarah Robinson (ASU M.S. student) and Andrew Whitesides (USC undergraduate) in a collaboration between the Southern California Earthquake Center (SCEC) and OpenTopography, provides an introduction to both LiDAR technology as well as the earthquake science that is being done with the data.

Latest News

Data Summary

Total Coverage: **13,479 km^2**

Total number of LiDAR returns: **46,234,163,717**

Latest LiDAR Datasets:

El Mayor-Cucapah Earthquake (4 April 2010) Rupture Scan

NOAA ISEMP Bridge Creek, Oregon Survey

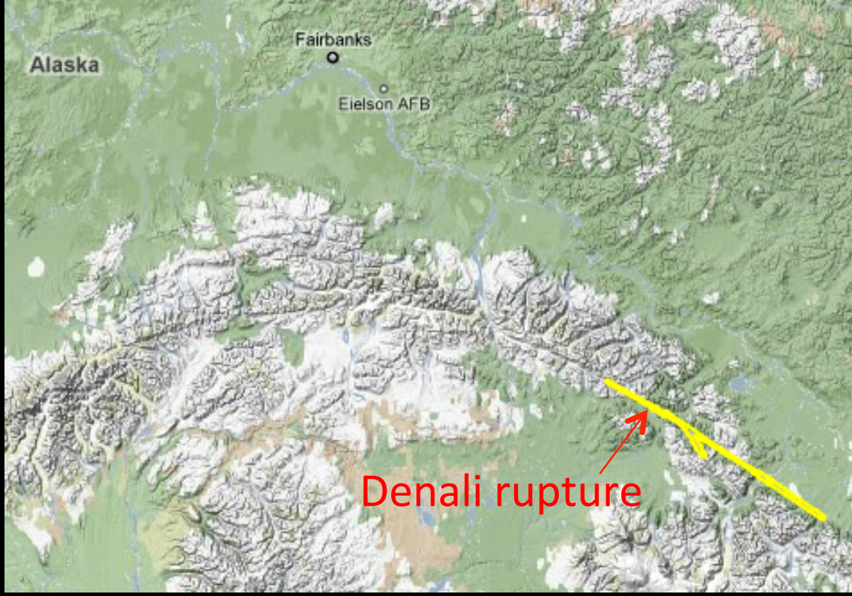
Granite Dells, AZ TLS

LVIS 2008 Sierra Nevada, CA

LVIS 2007 Greenland

More Metrics...

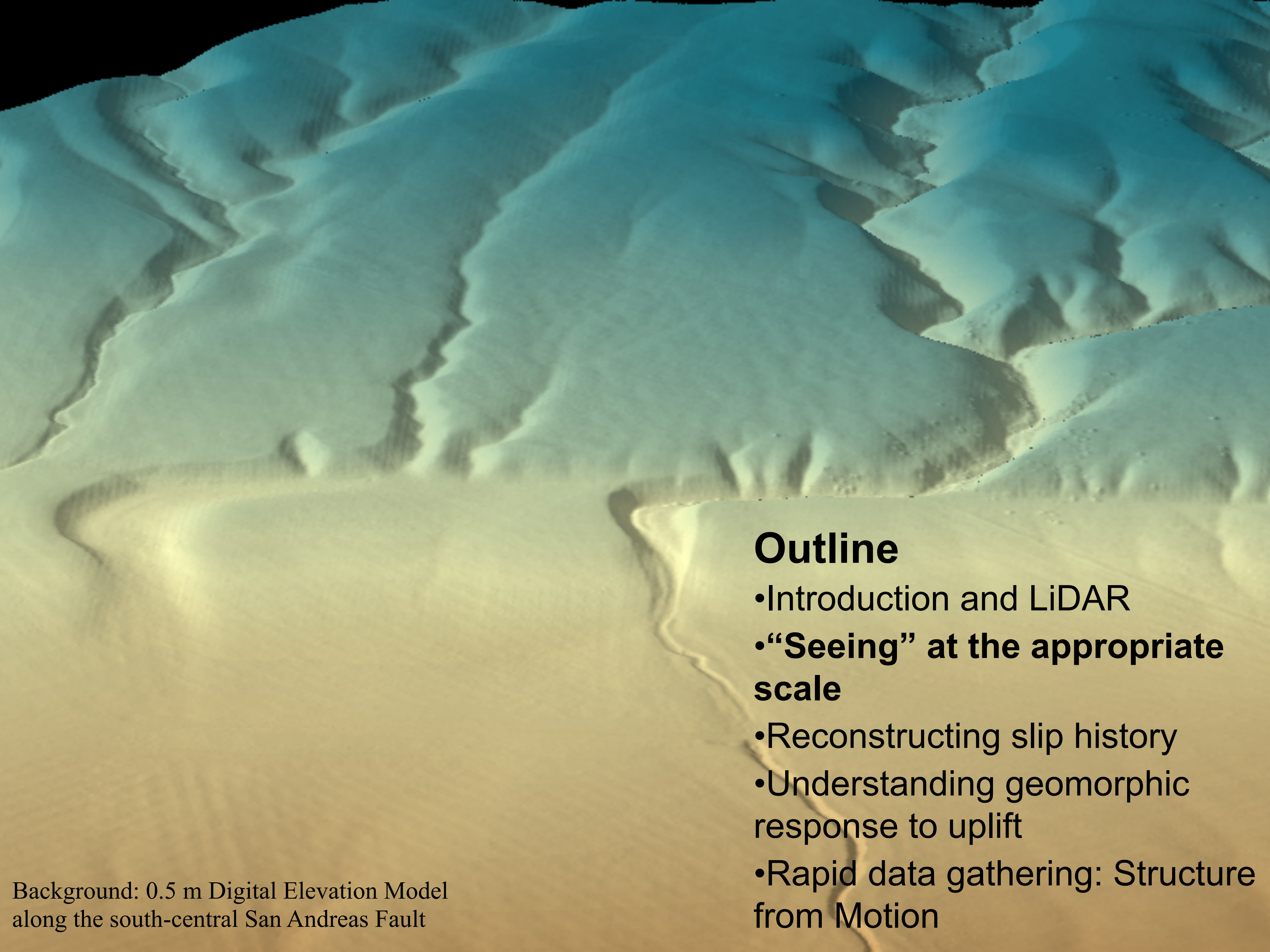
Facilitate community access to high-resolution, Earth science-oriented, topography data, and related tools and resources.



EarthScope (+) LiDAR:

Scan (at dm scale) topography along active faults to measure 10^2-10^5 yr time scale deformation and EXPLORE

See **www.opentopography.org**



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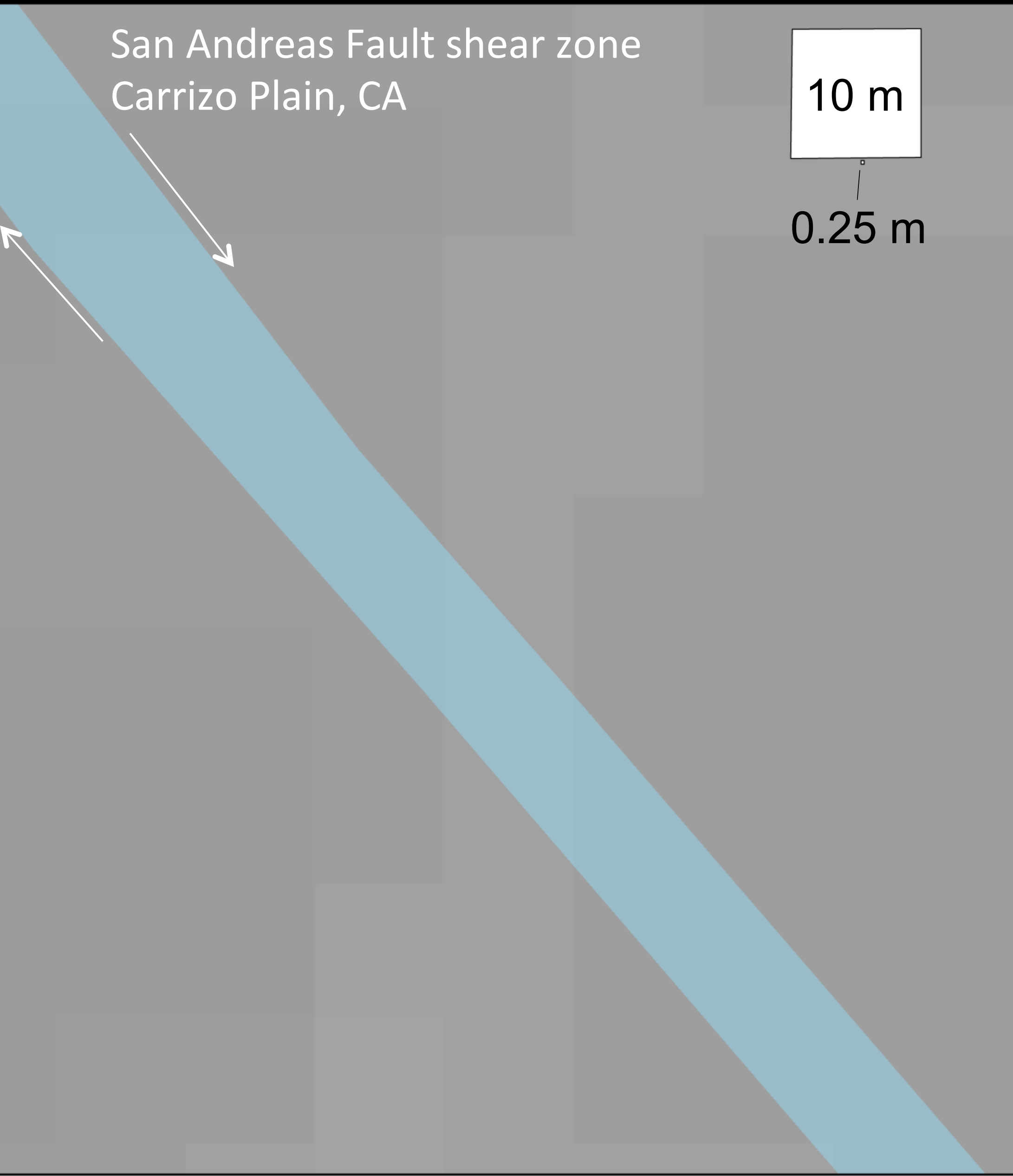
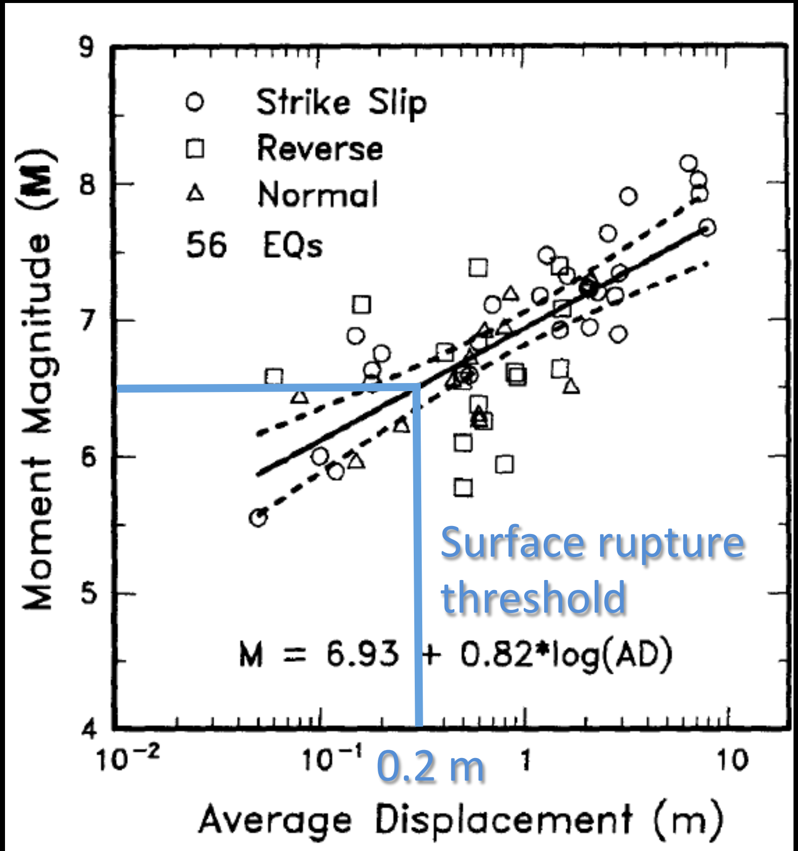
Measure fault slip at the appropriate scale

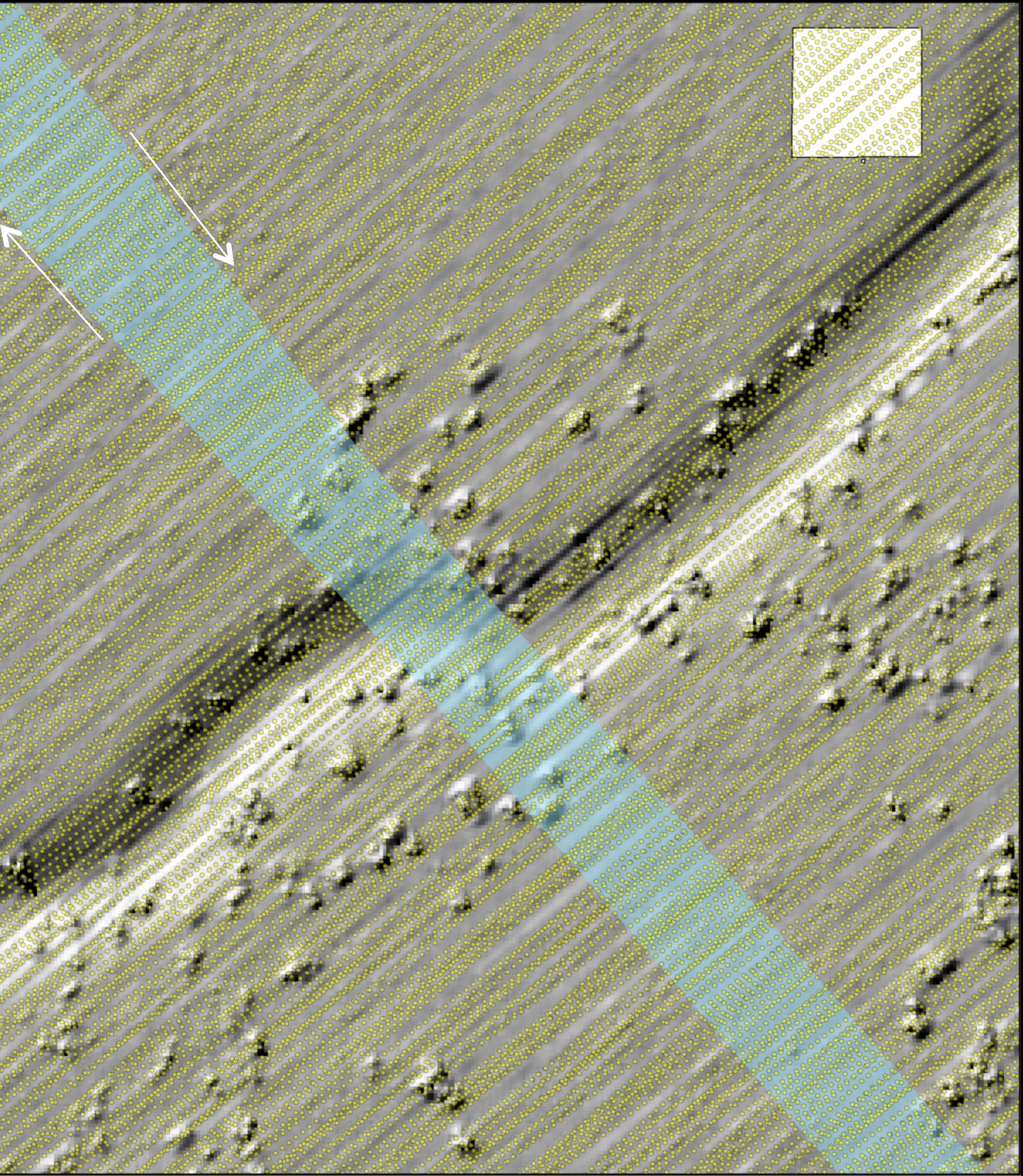
USGS NED 10 m per pixel DEM

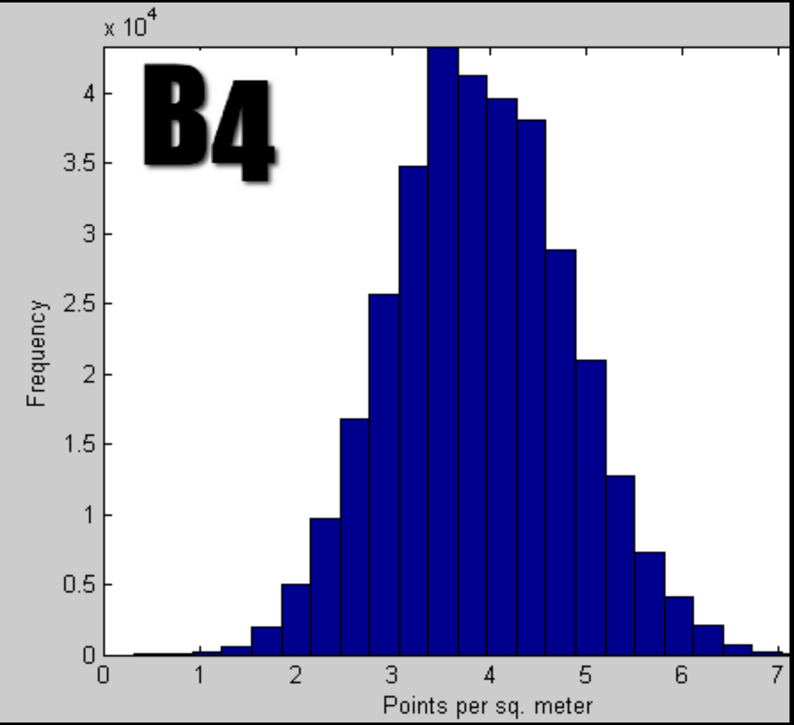




Measure fault slip at the appropriate scale

B4 LiDAR topography 0.25 m DEM

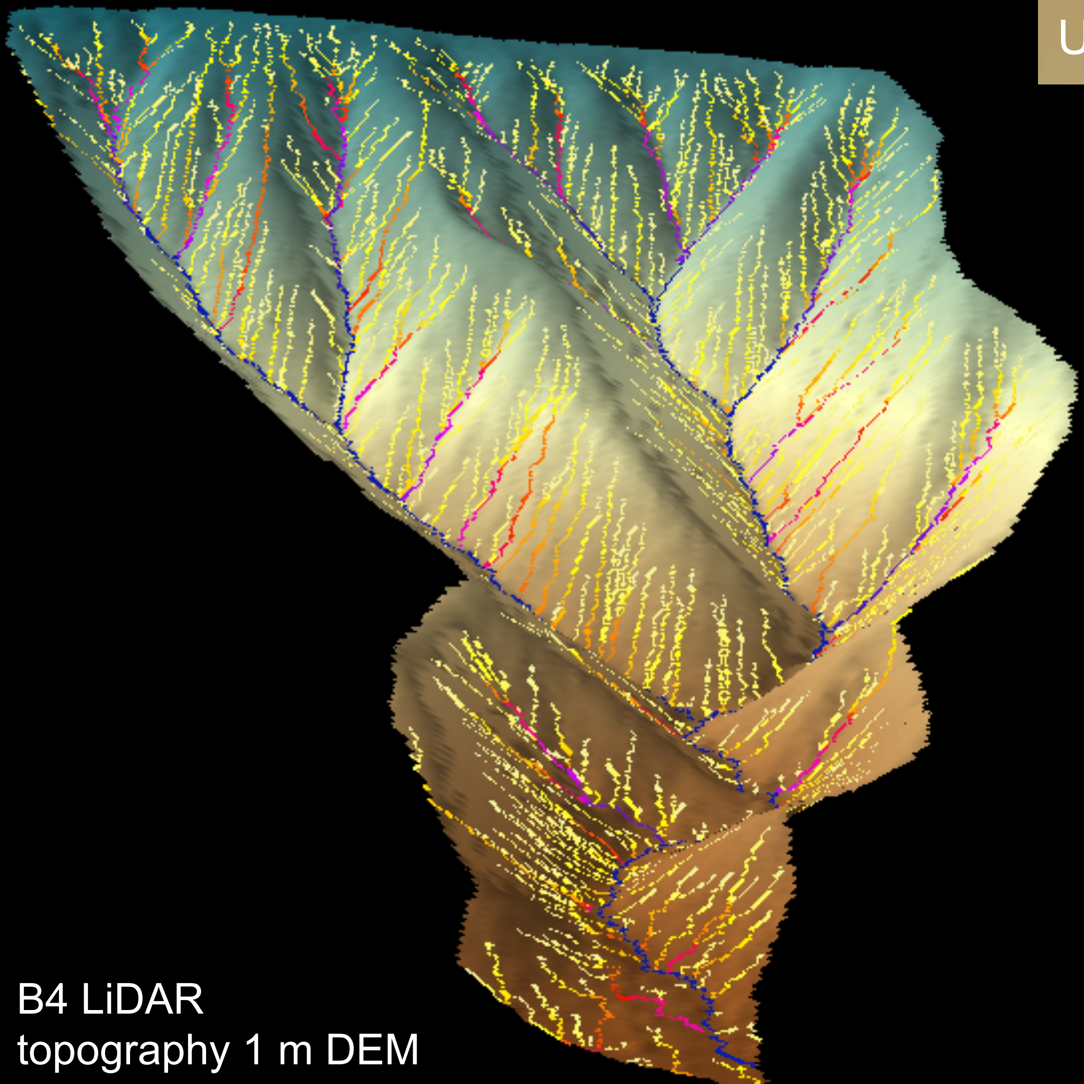




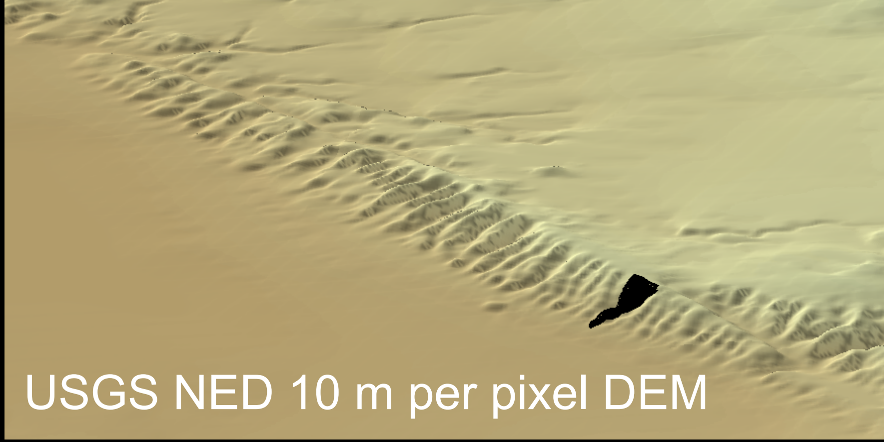
Mean ~4 shots/sq. m

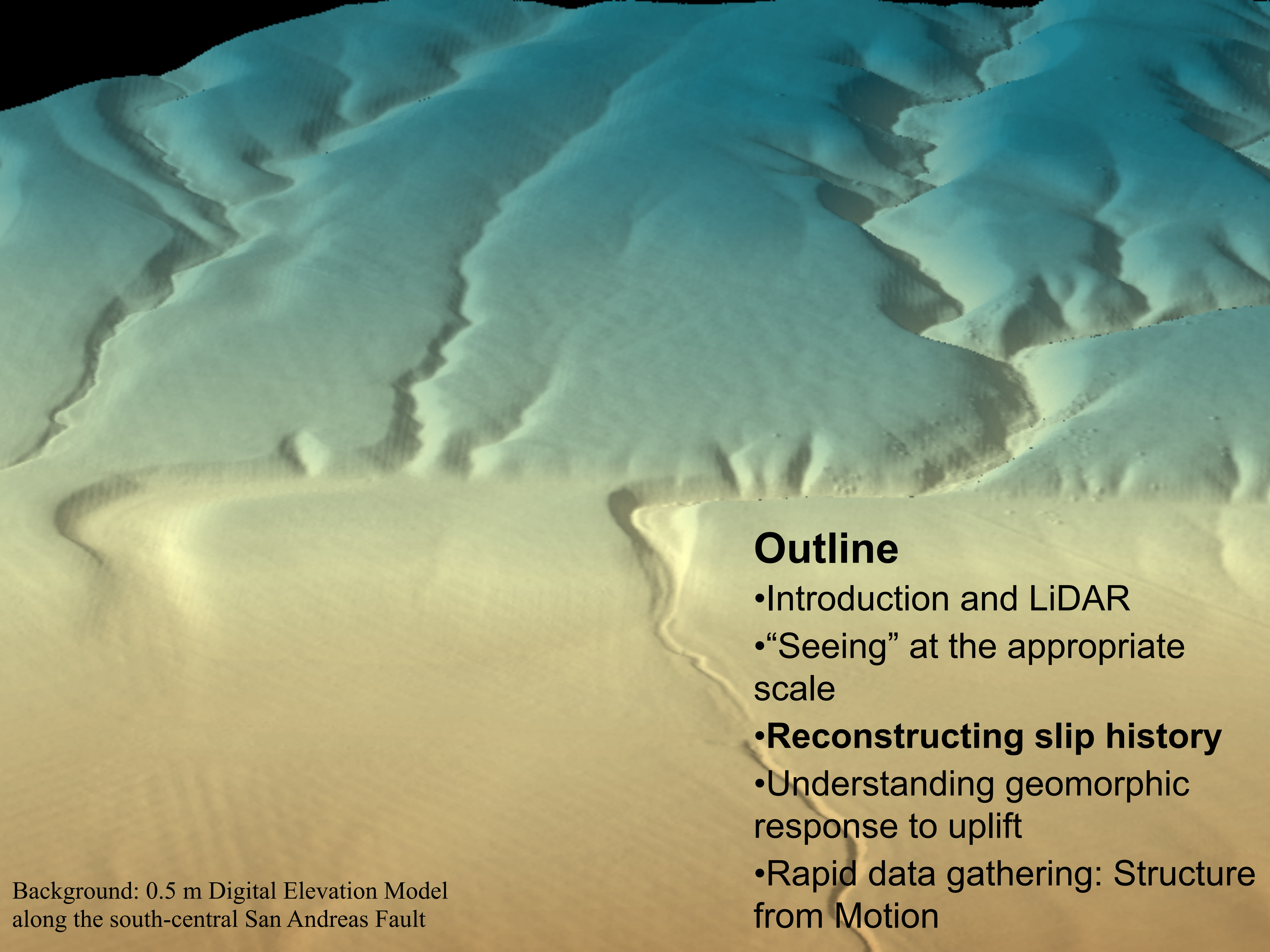
Measure landscape characteristics at the appropriate scale

Drainage network-hillslope transition at 10 m^2 drainage area



B4 LiDAR
topography 1 m DEM





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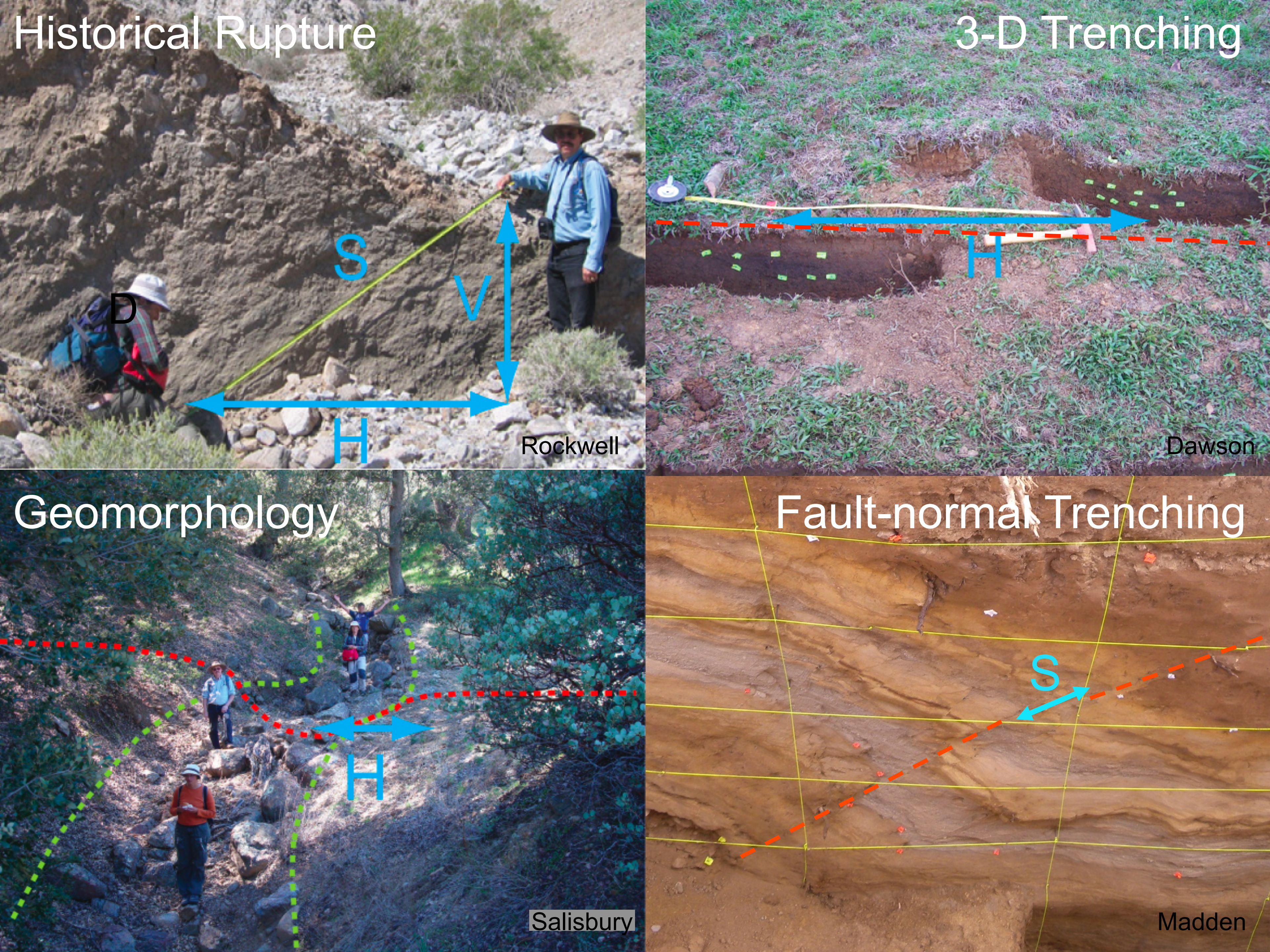
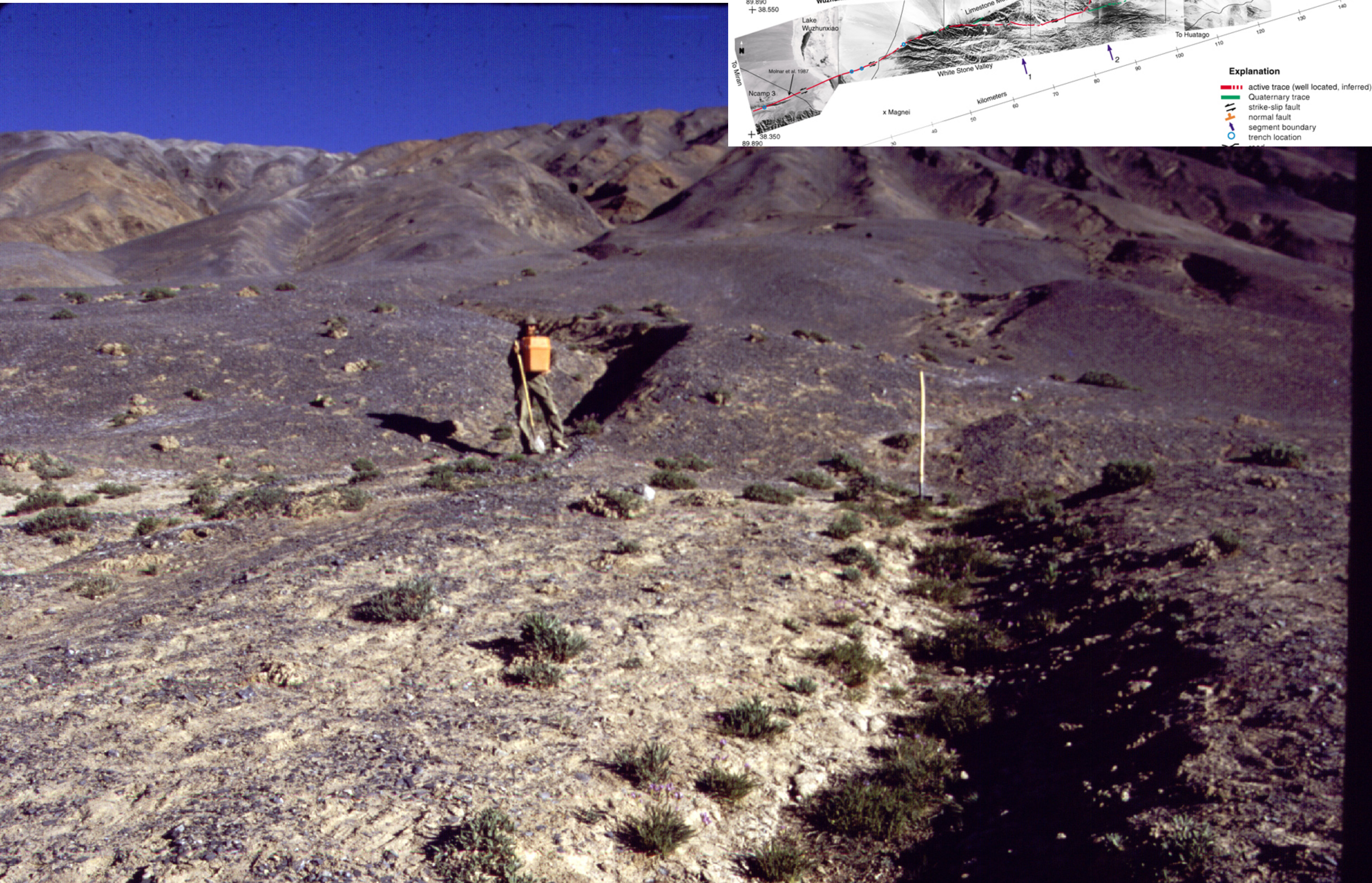
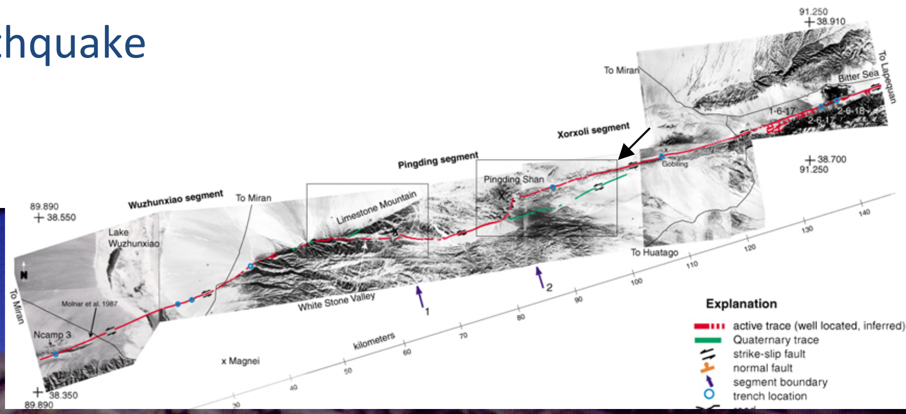
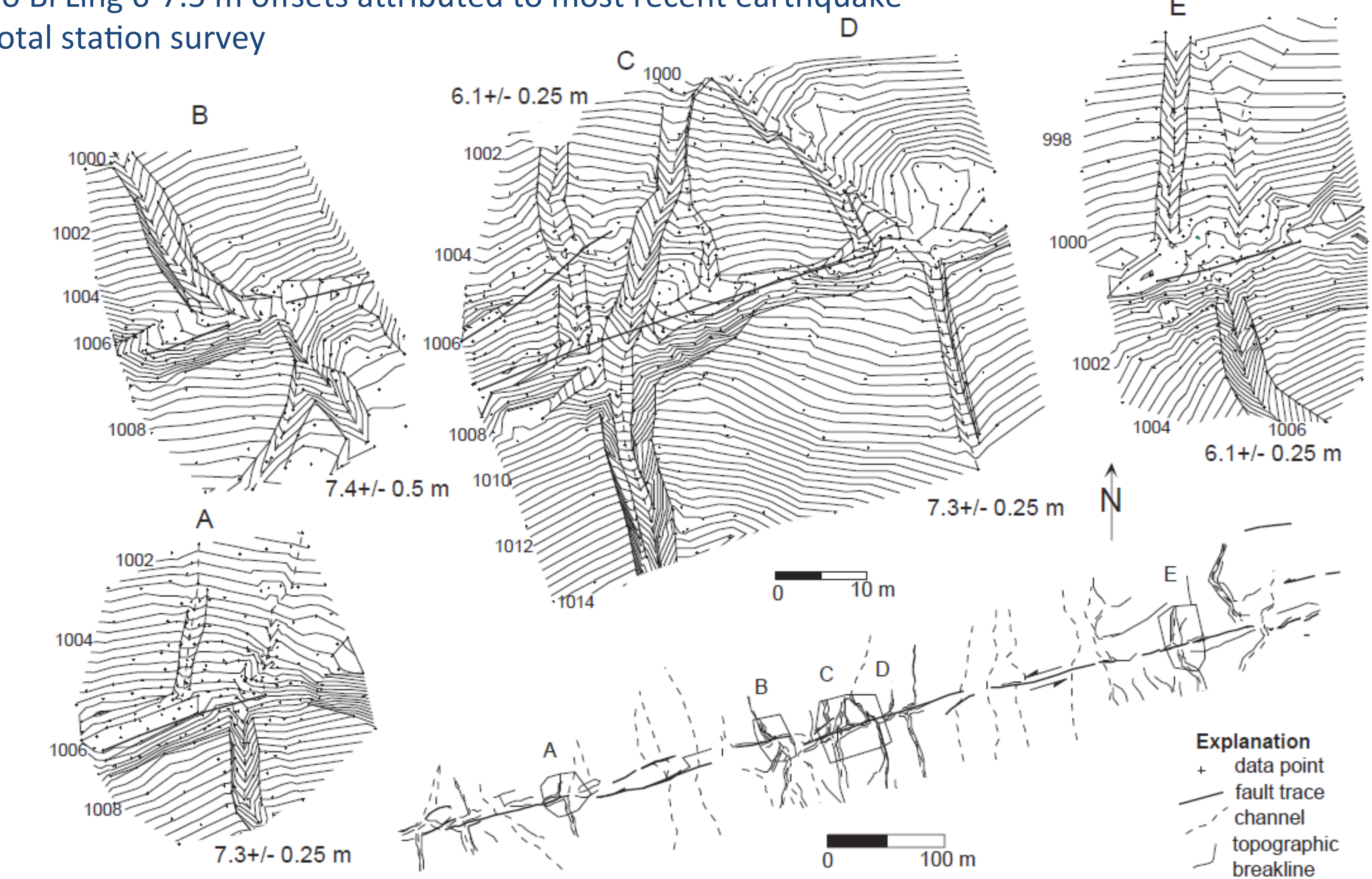

Historical Rupture
S
V
D
H
Rockwell
3-D Trenching
H
Dawson
Geomorphology
H
Salisbury
Fault-normal Trenching
S
Madden

Go Bi Ling 6 m offset attributed to most recent earthquake



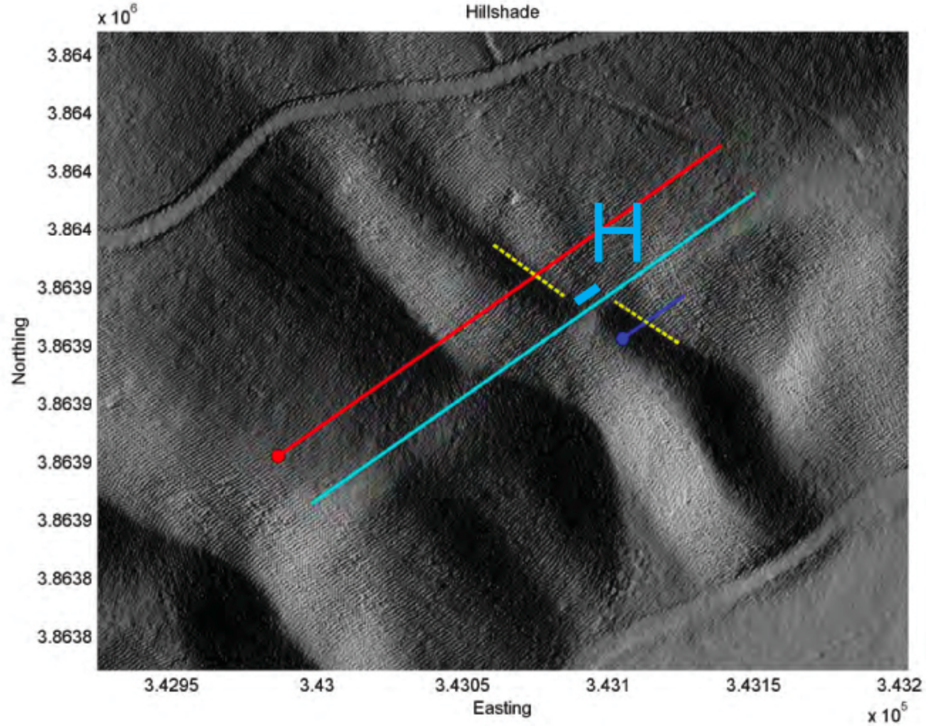


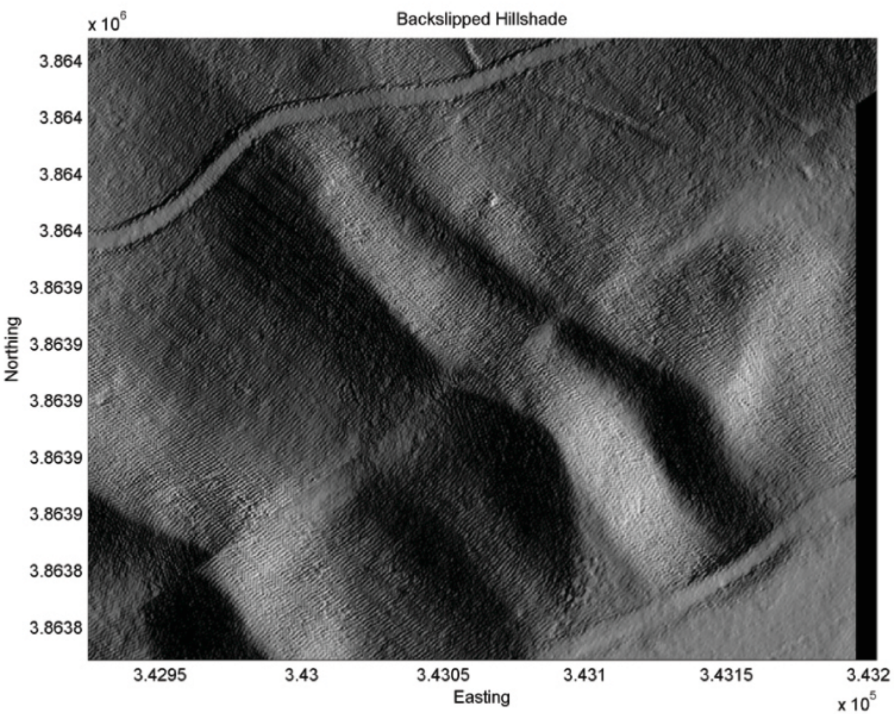
Go Bi Ling 6-7.5 m offsets attributed to most recent earthquake
Total station survey

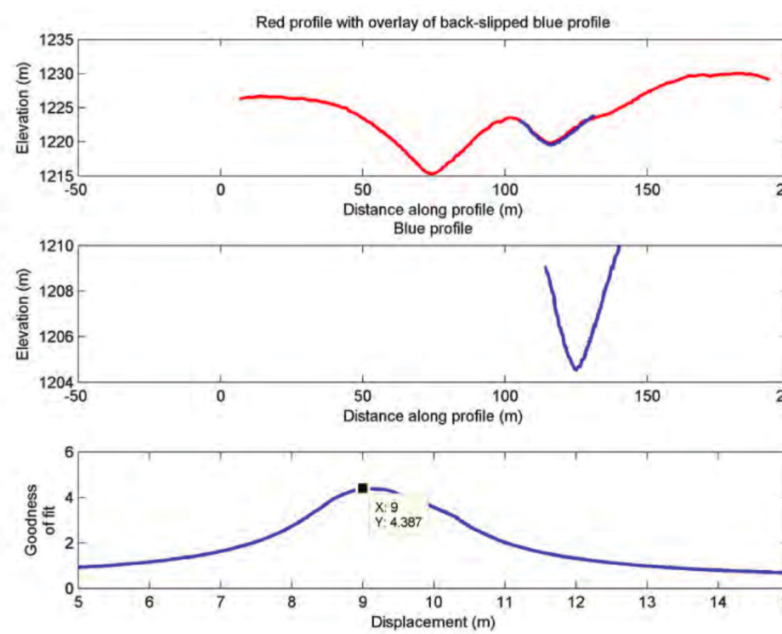


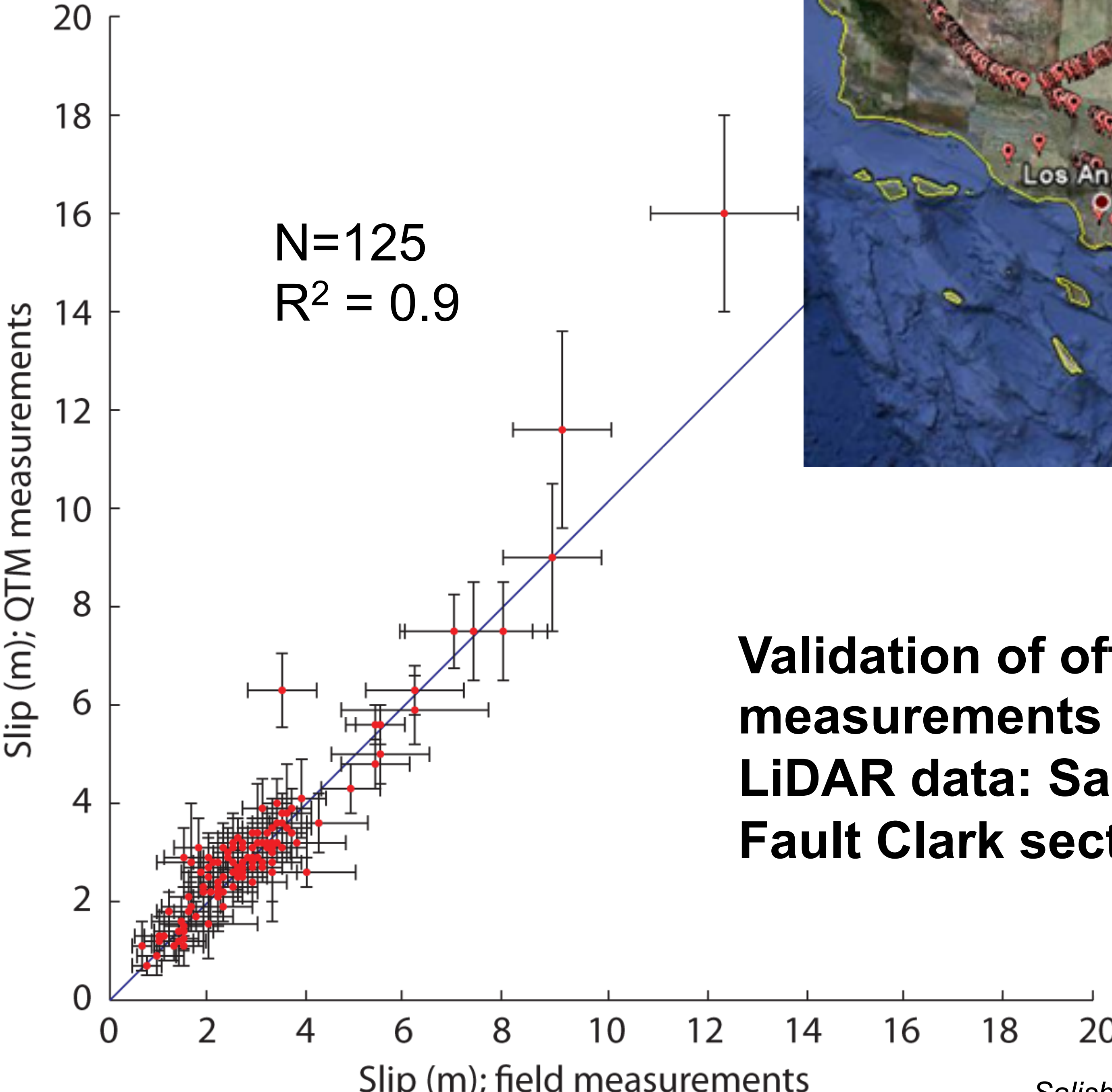
LiDAR is nice but we may lose some meaning?

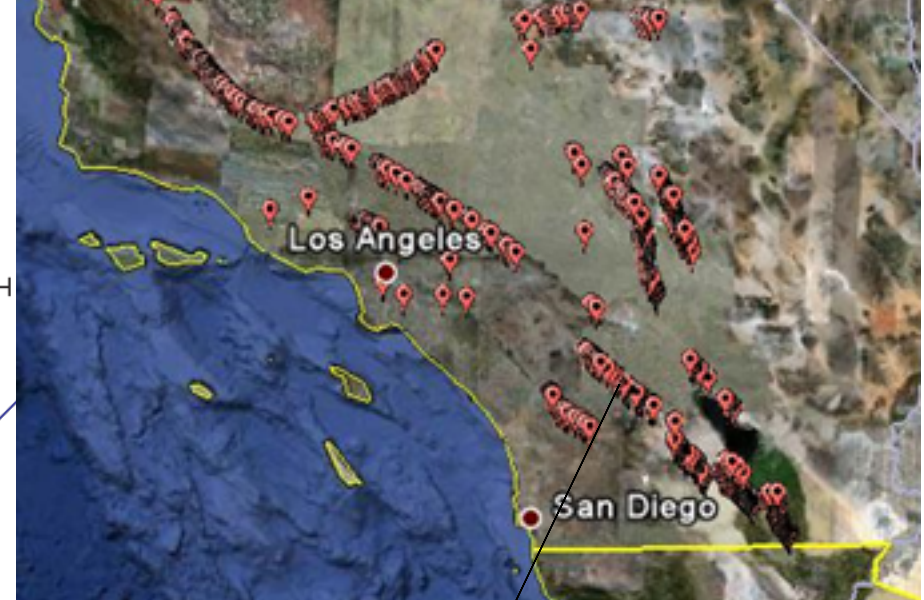
LiDAR Measurements





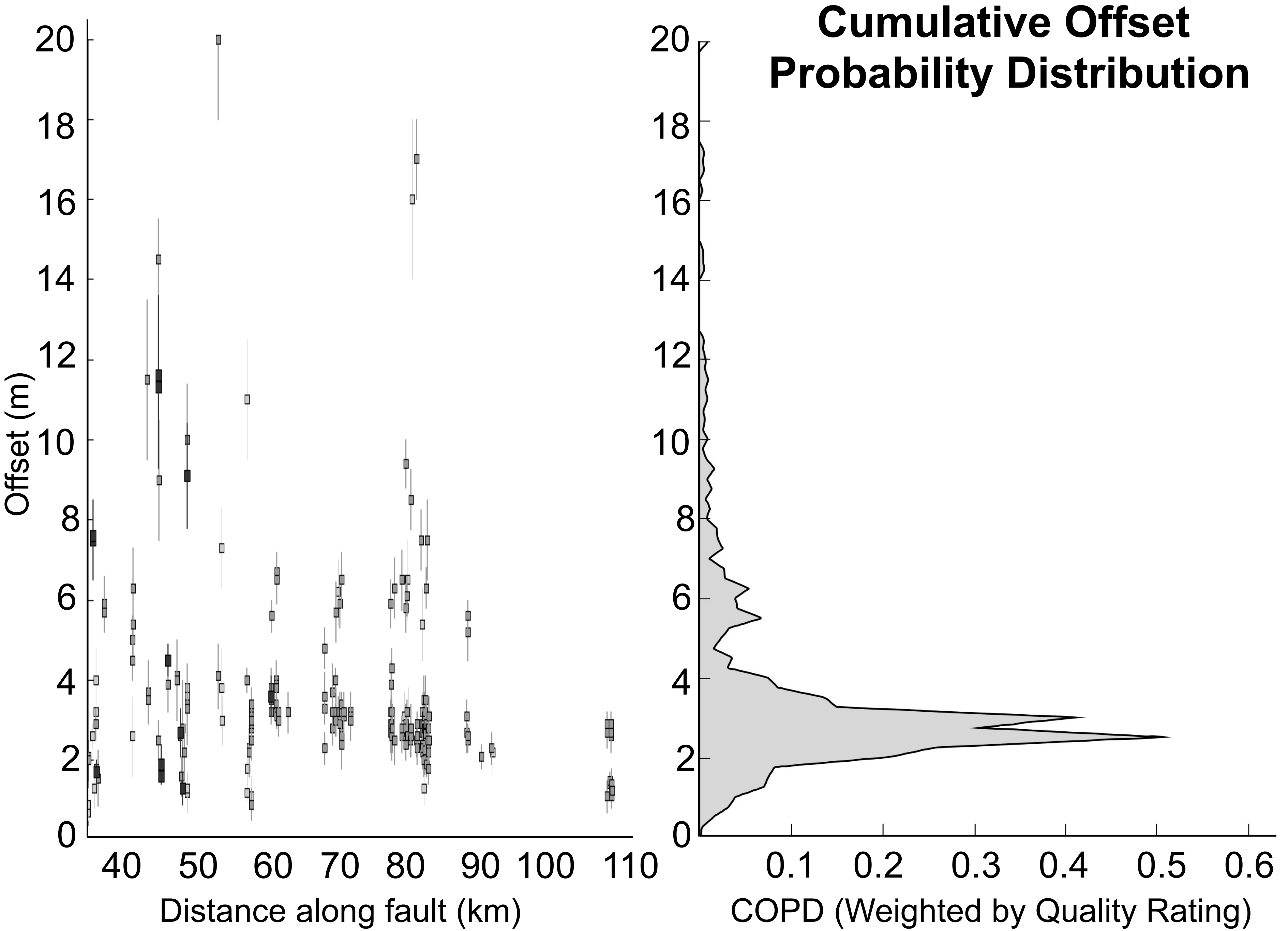




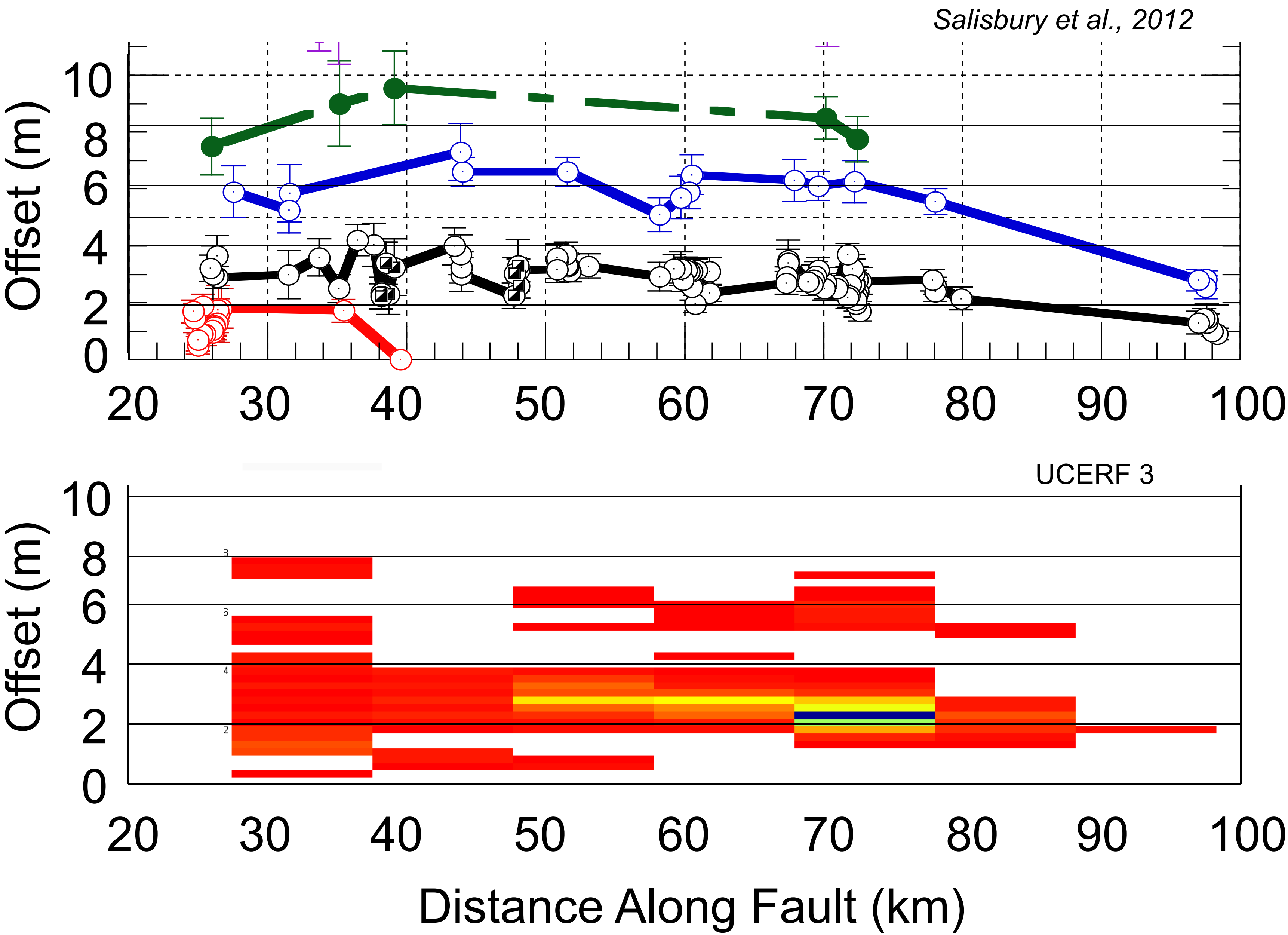


Validation of offset measurements from field and LiDAR data: San Jacinto Fault Clark section

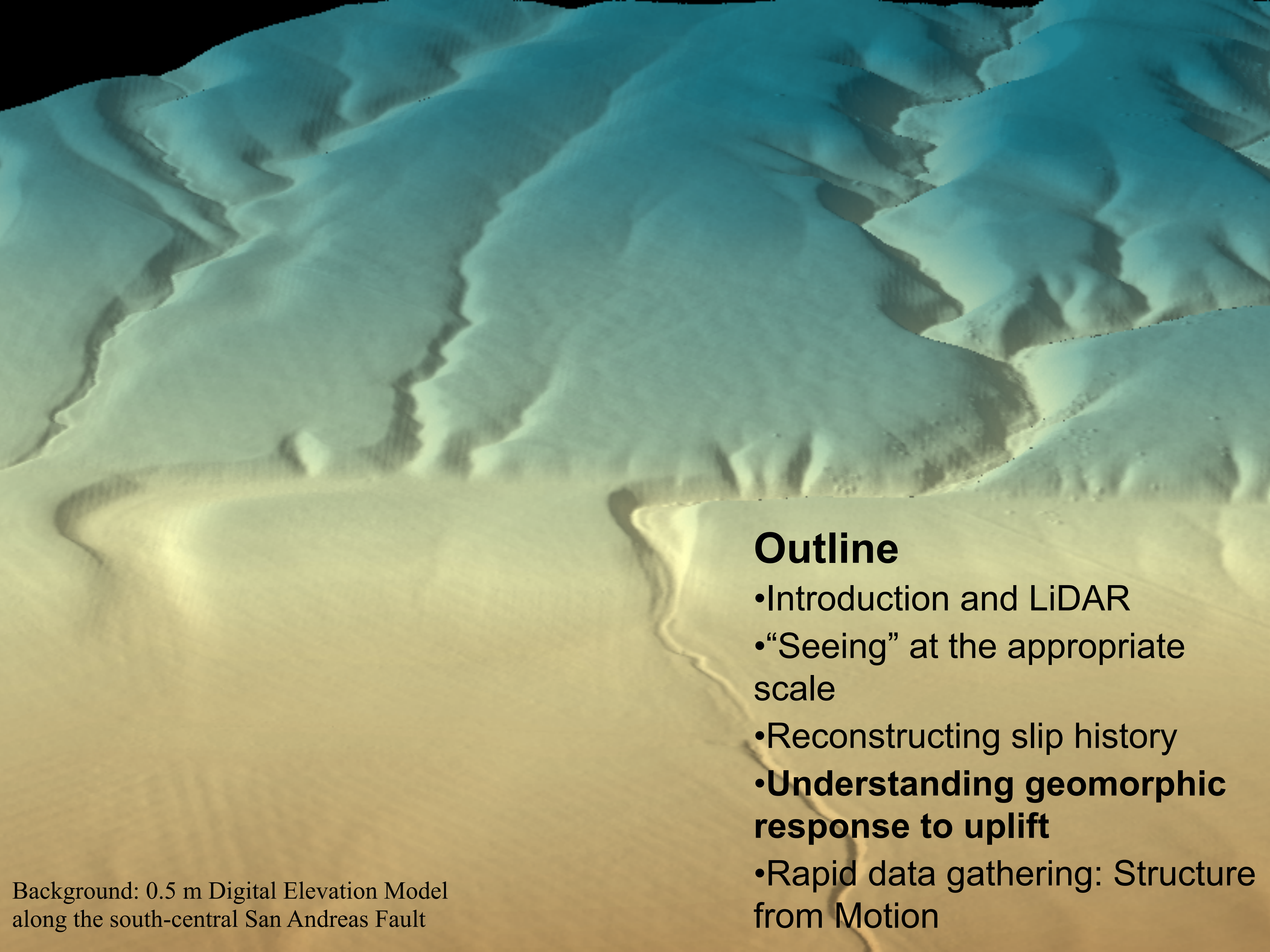
Salisbury et al., 2012



Cumulative Offset
Probability Distribution
Offset (m)
Distance along fault (km)
COPD (Weighted by Quality Rating)
0
2
4
6
8
10
12
14
16
18
20
40
50
60
70
80
90
100
110
0.1
0.2
0.3
0.4
0.5
0.6



Salisbury et al., 2012
Offset (m)
10
8
6
4
2
0
20
30
40
50
60
70
80
90
100
UCERF 3
Offset (m)
10
8
6
4
2
0
20
30
40
50
60
70
80
90
100
Distance Along Fault (km)



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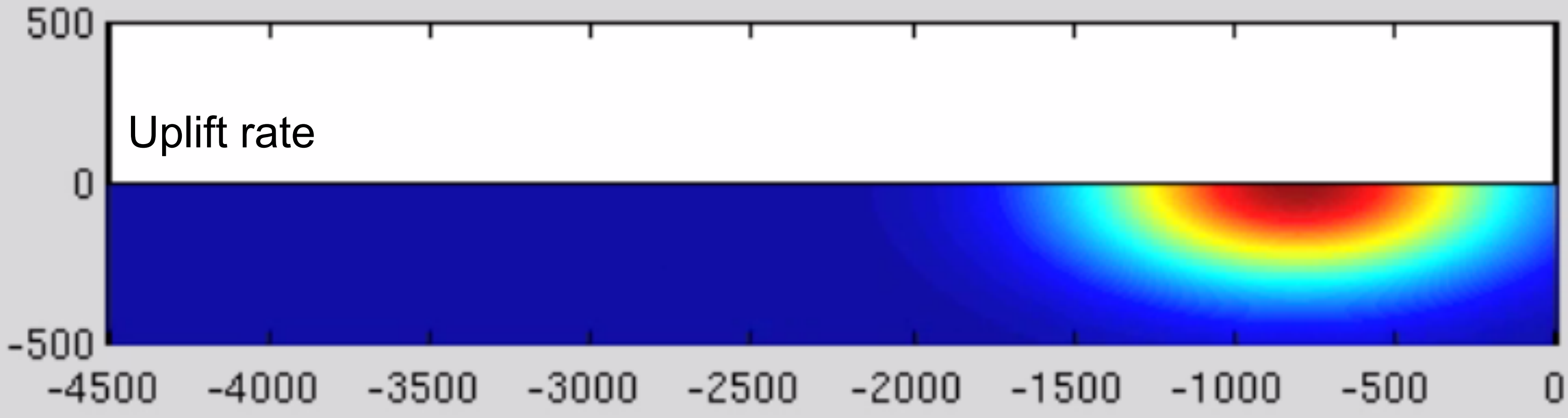
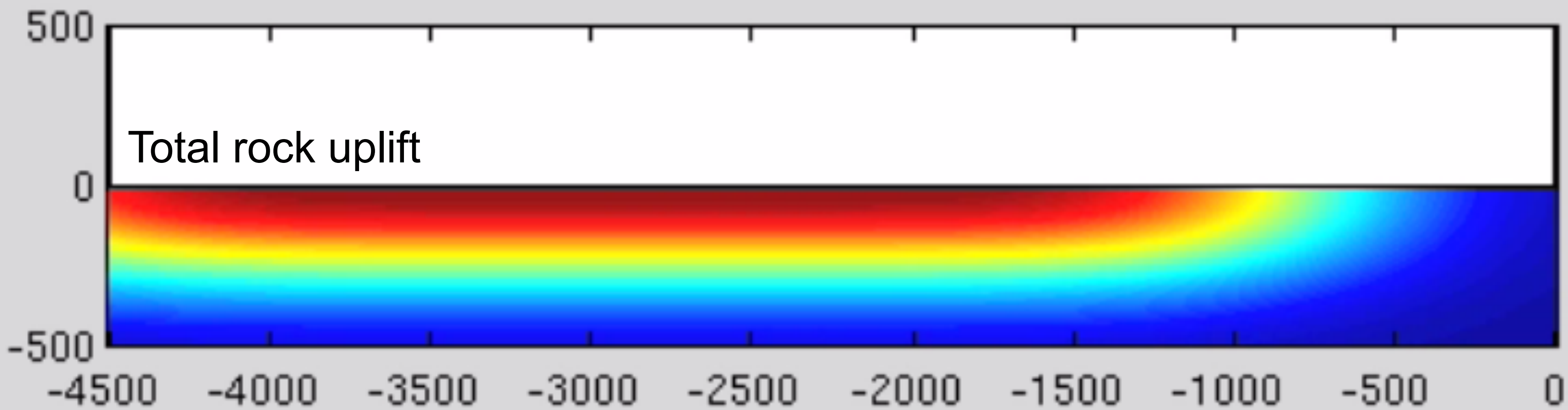
Understanding geomorphic response to uplift



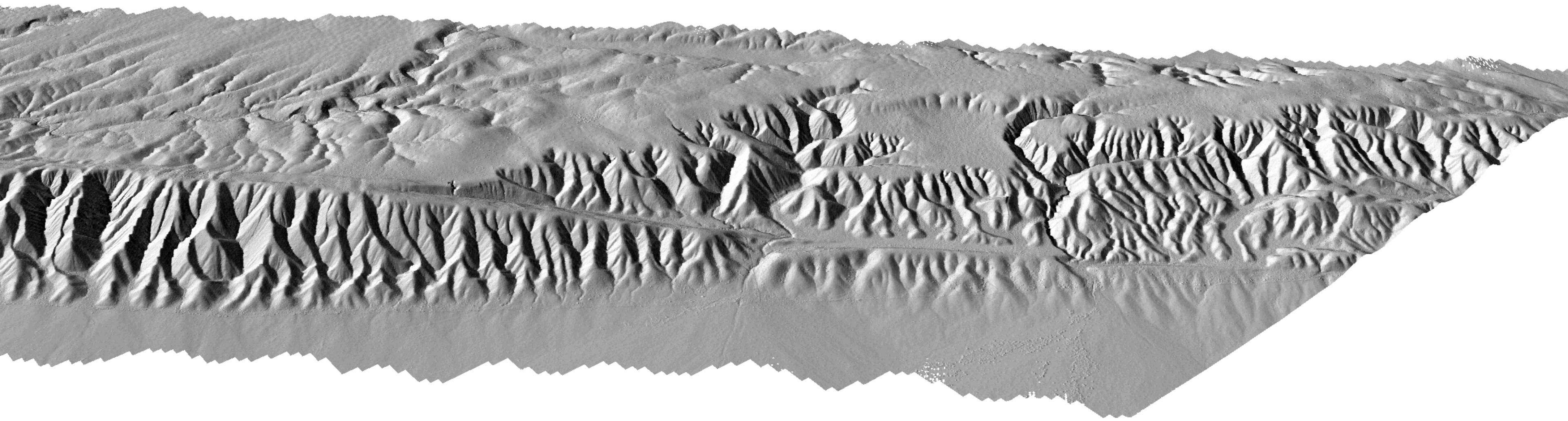
Material moves along fault though relatively stationary uplift zone:

How does landscape respond?

What will the landscape tell us about the geometry of the uplift?

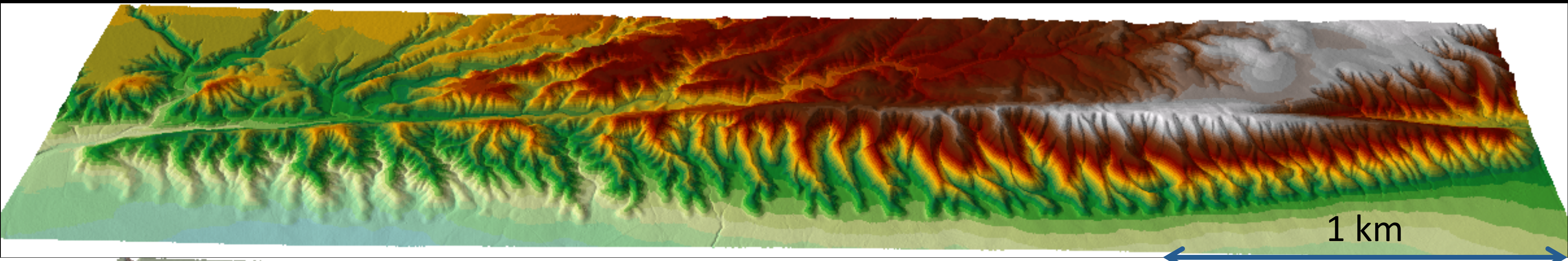


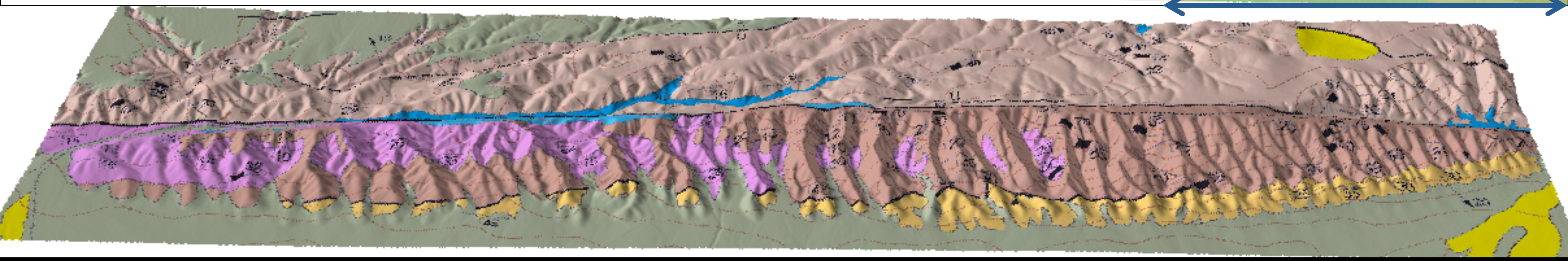
-G. E. Hilley

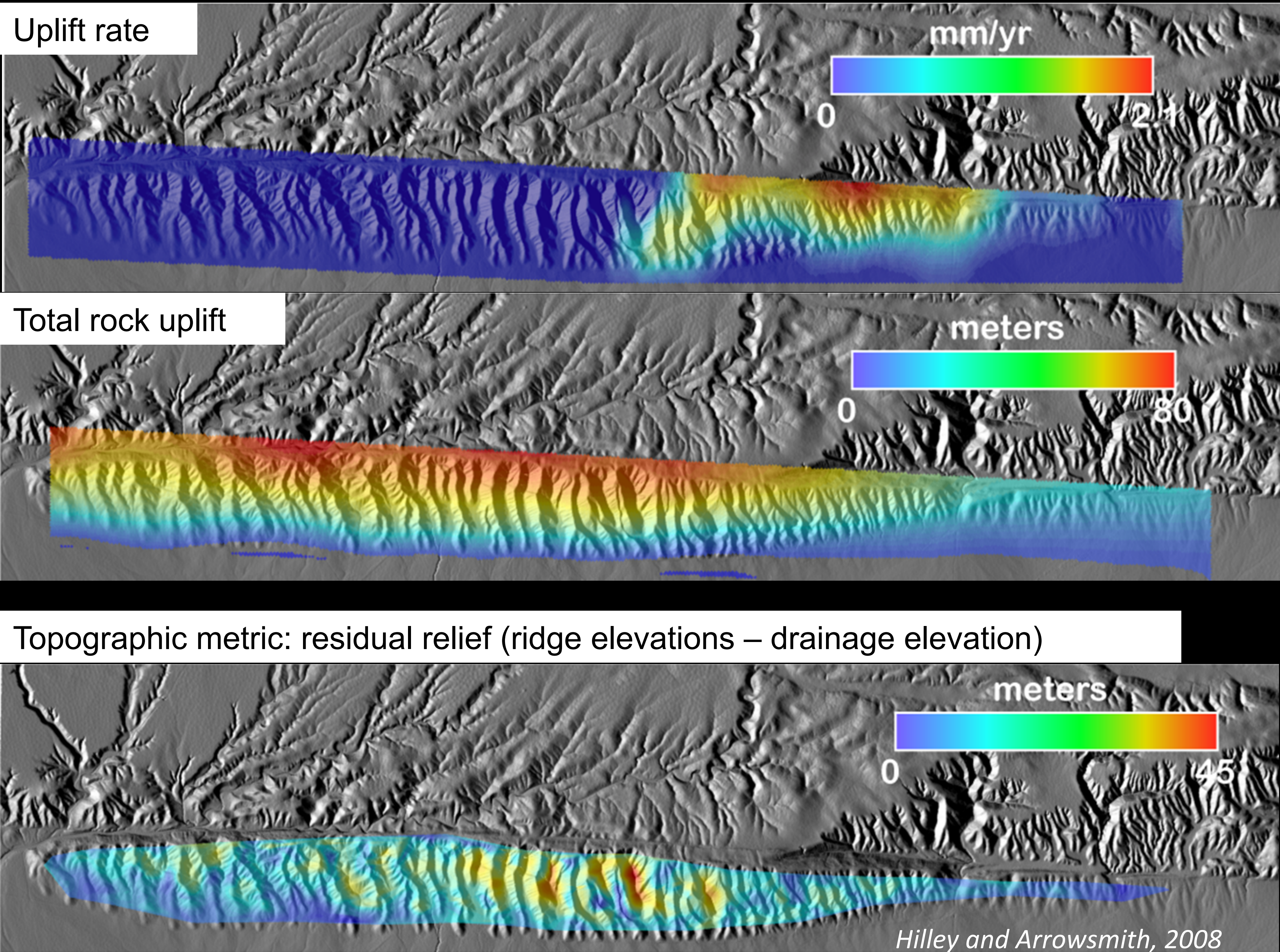


Dragon's Back Pressure Ridge, Carrizo Plain California

Arrowsmith, 1995; Hilley, 2001; Hilley and Arrowsmith, 2008





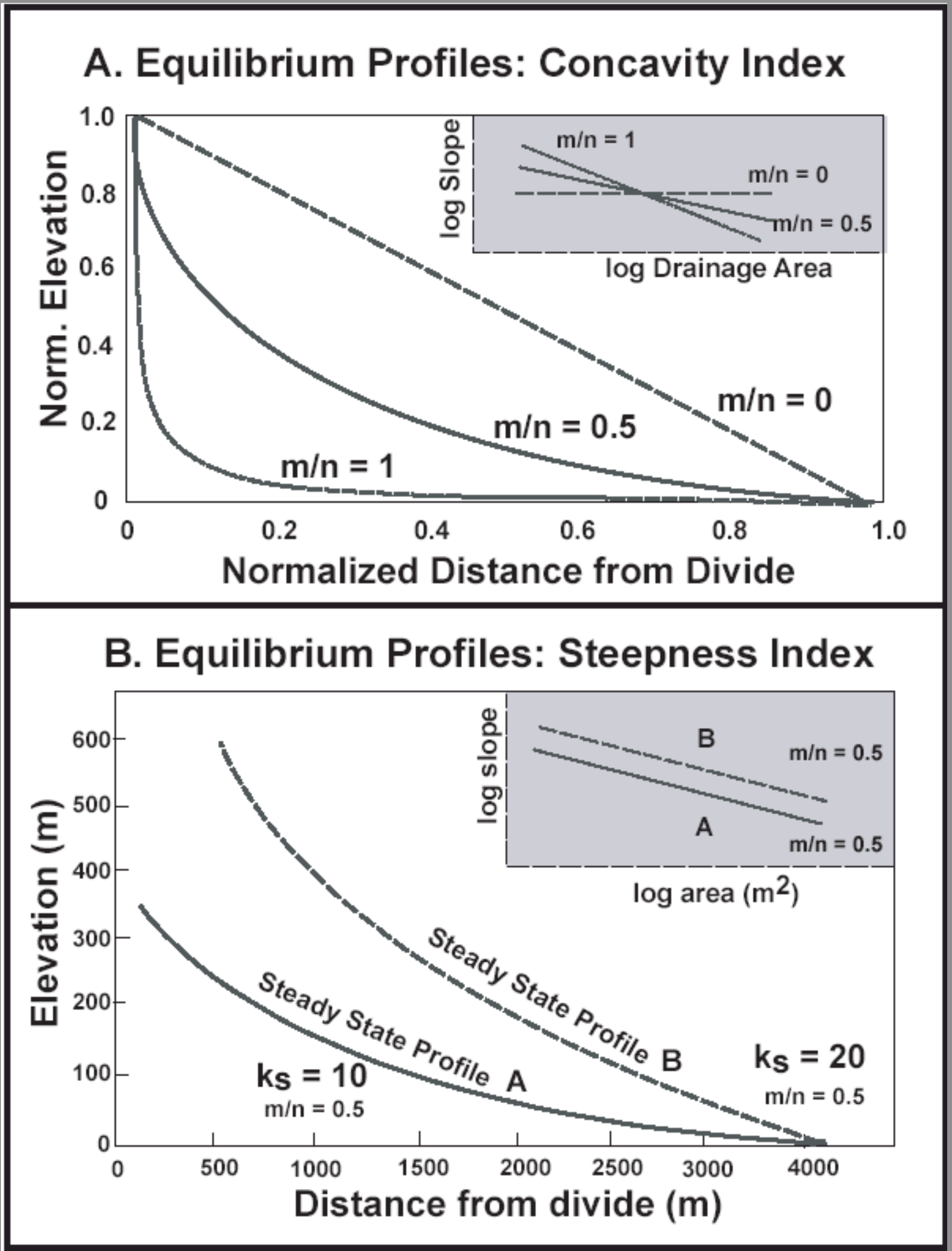

Uplift rate
mm/yr
0
2.1
Total rock uplift
meters
0
80
Topographic metric: residual relief (ridge elevations – drainage elevation)
meters
0
45
Hilley and Arrowsmith, 2008

Duvall, Kirby, and Burbank, 2004, JGR-ES

U = Rock Uplift Rate

Concavity (θ) invariant with U

Steepness (Ks) varies with U

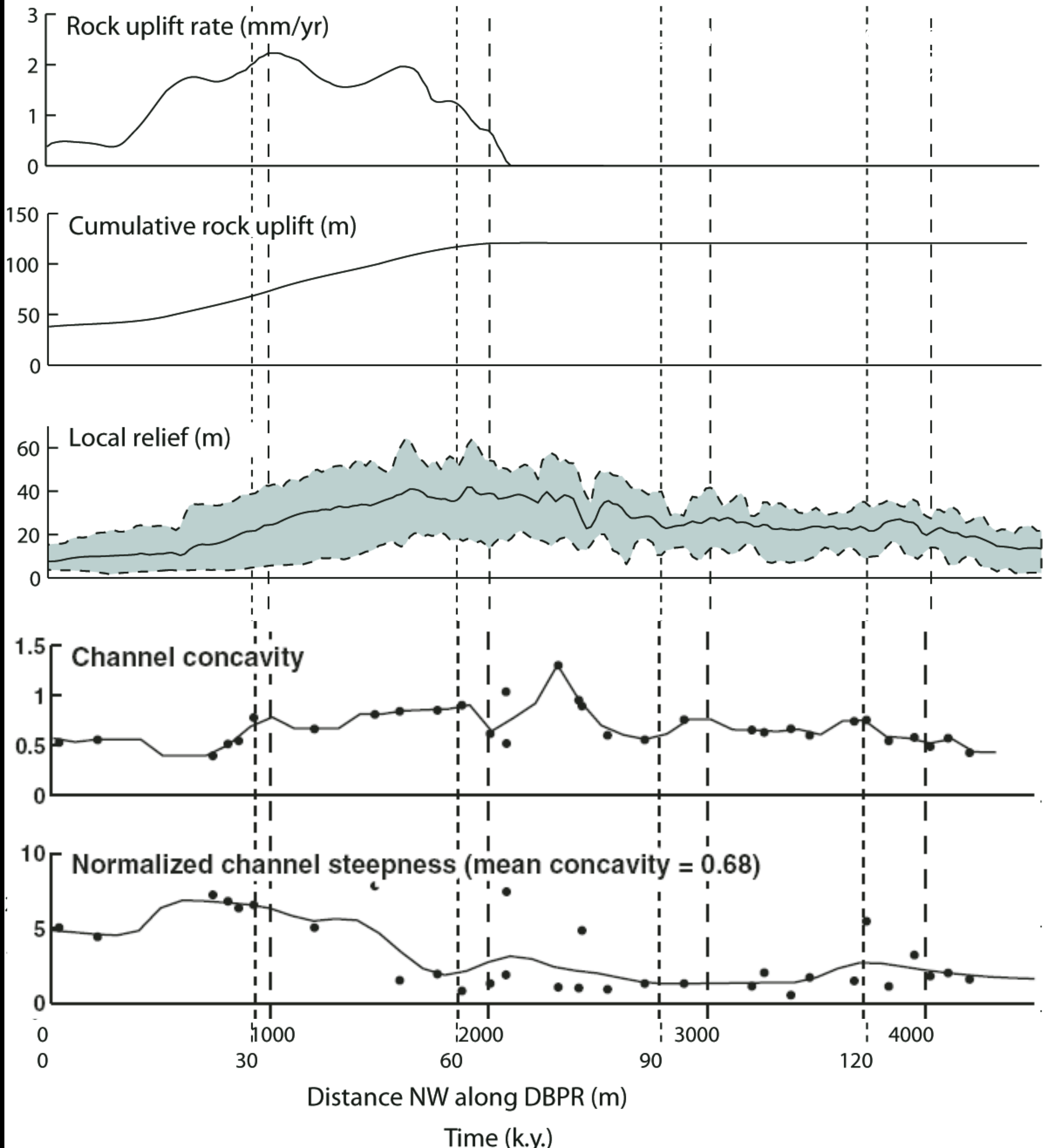


$\theta = m/n$

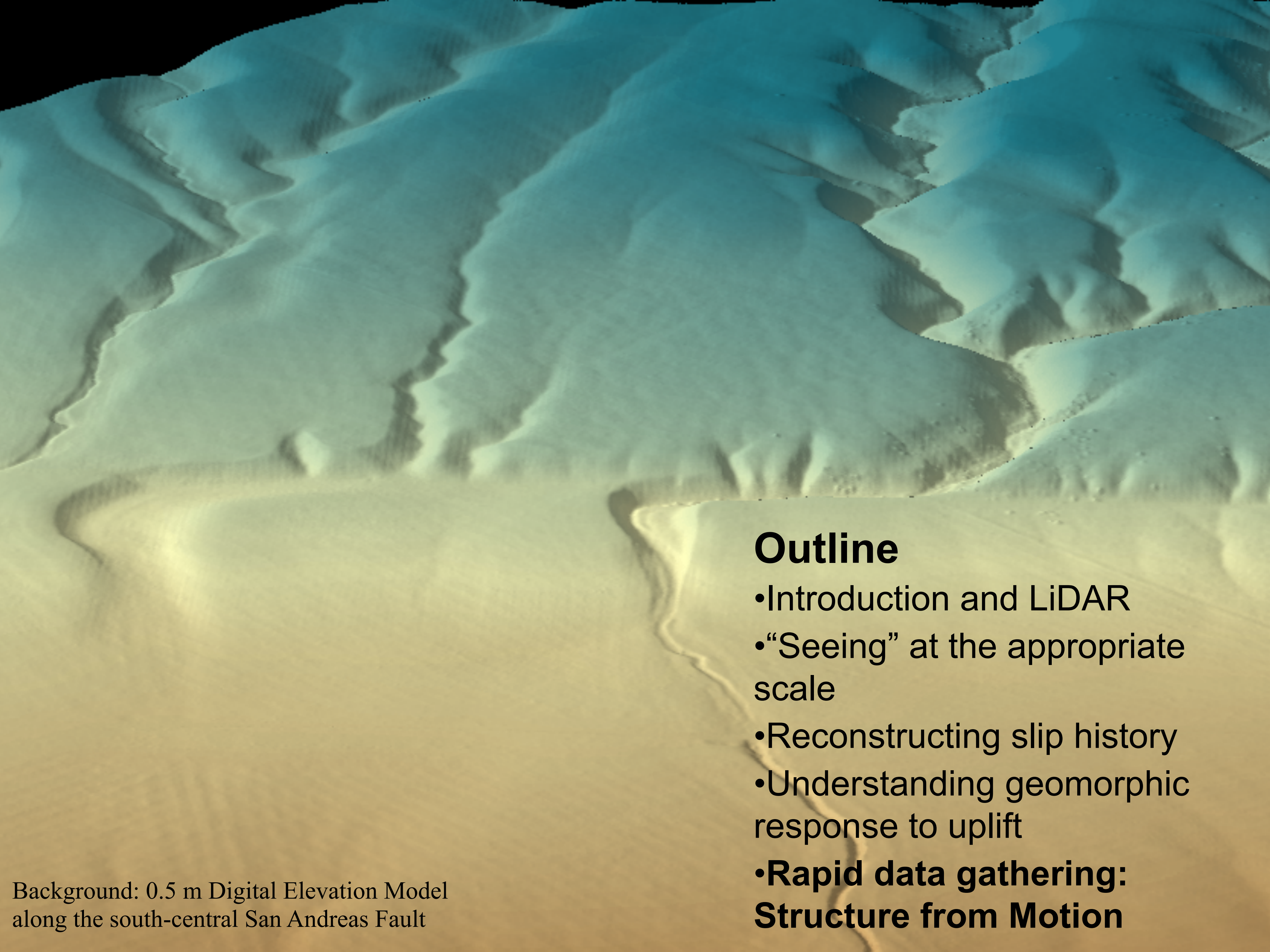
$S = k_s A^{-\theta}$

k_s

--K. X Whipple



Hilley and Arrowsmith, 2008



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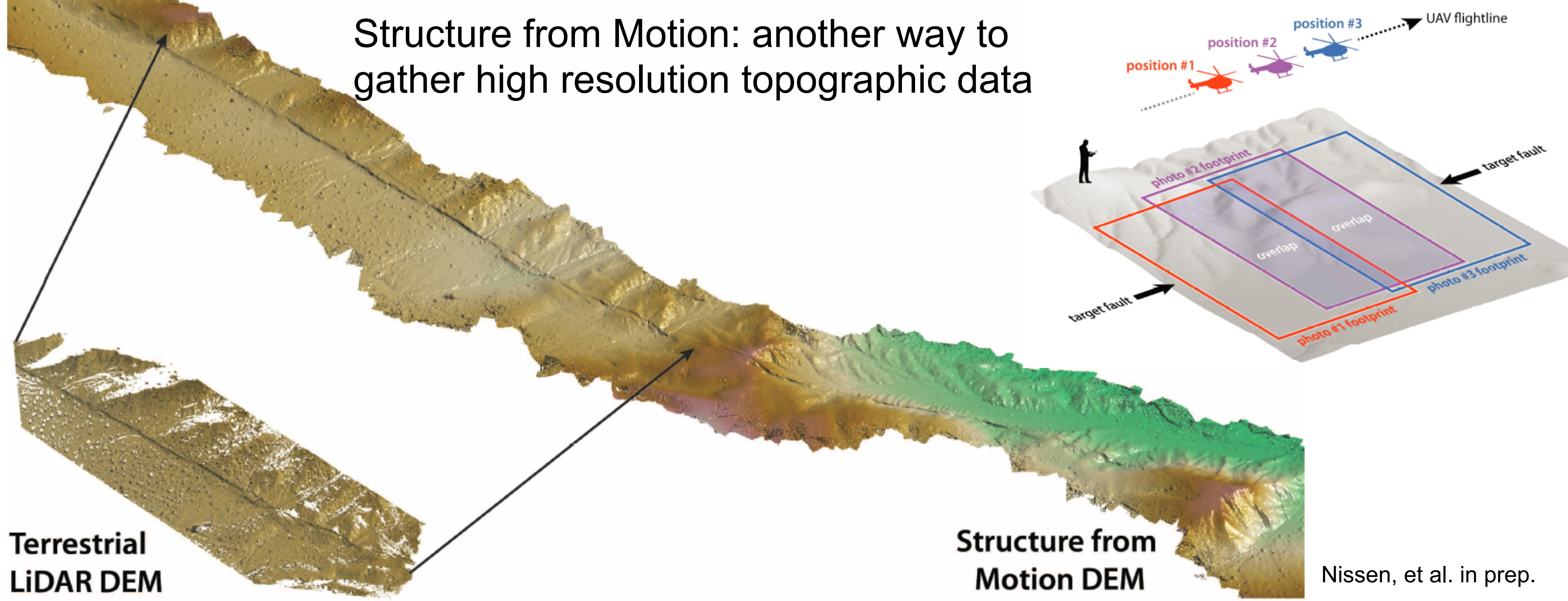
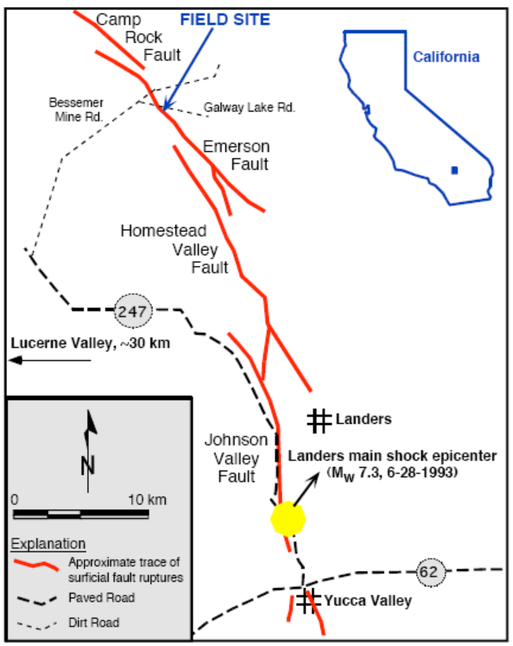
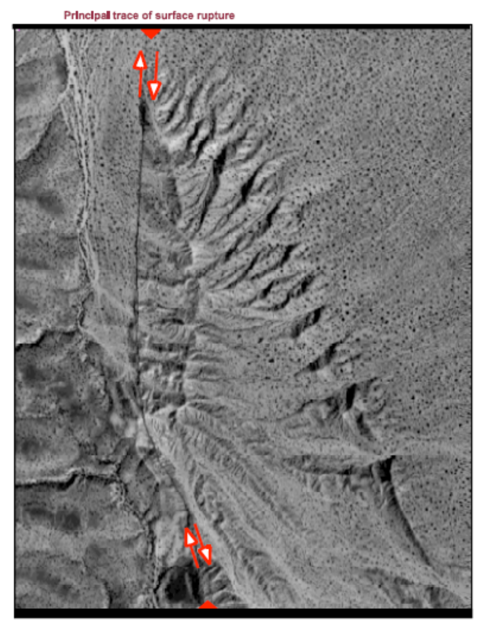
Structure from Motion: another way to gather high resolution topographic data



Nissen, et al. in prep.





6-30-1992: U S Geological Survey

Structure from Motion: another way to gather high resolution topographic data

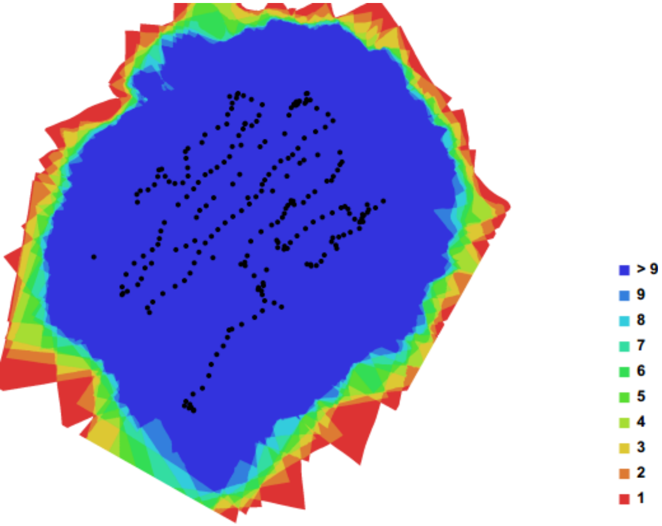
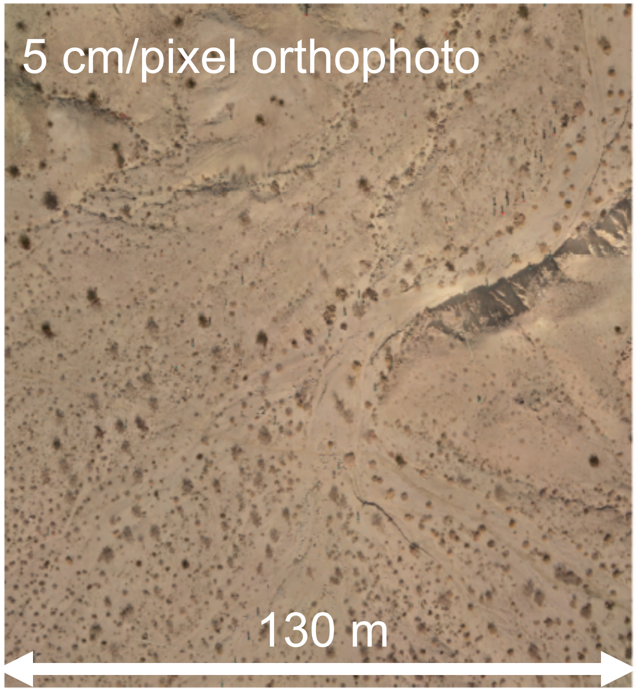
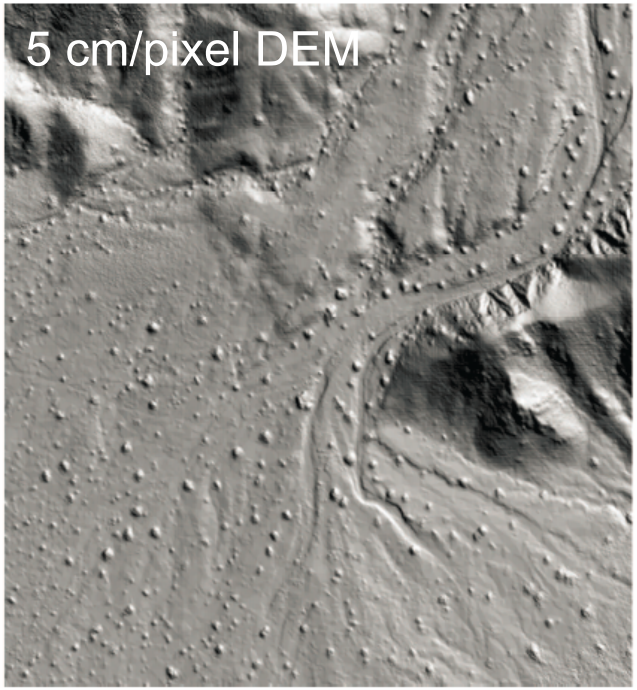
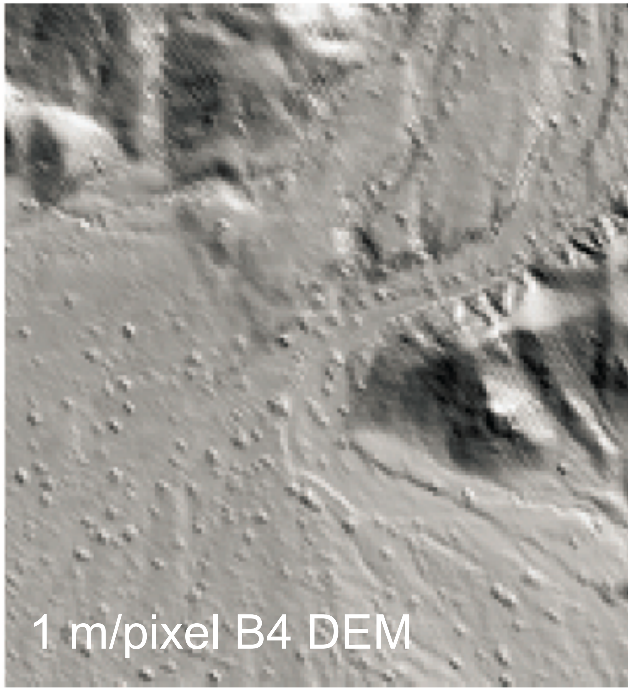


Fig. 1. Camera locations and image overlap.

Nissen, et al. in prep.







Summary

- LiDAR provides dm to cm global accurate measure of the earth's surface
- Meter scale is critical for structural and geomorphic processes
- Main applications in faulting-related investigations can be separated into fault zone mapping, reconstructing offsets, investigating geomorphic responses to active deformation, and differencing of repeat surveys

Looking ahead

- Lots more data and problems out there!
- 4 dimensions: directly measuring the displacements
- Processing and filtering enhancements: looking for the signal in all the data (e.g., Hilley, et al., 2010; Delong, et al., 2010)
- Bring these data and their depiction of the earth's geomorphic and tectonic processes to geoscience education