Caribbean LiDAR Initiative Breakout

- ***LiDAR 101***
- *Open data access and capacity building*

Christopher J. Crosby
San Diego Supercomputer Center

COCONet Workshop, Puerto Rico, Feb 3-4, 2011

- Landscape development a combination of many processes:
  - Tectonic
  - Hillslope
  - Fluvial
  - Biologic
  - Anthropogenic

- High-resolution representation of landscape is central to qualitative and quantitative study of process.

- Aerial photography traditional tool for geomorphic studies

- 2D representation

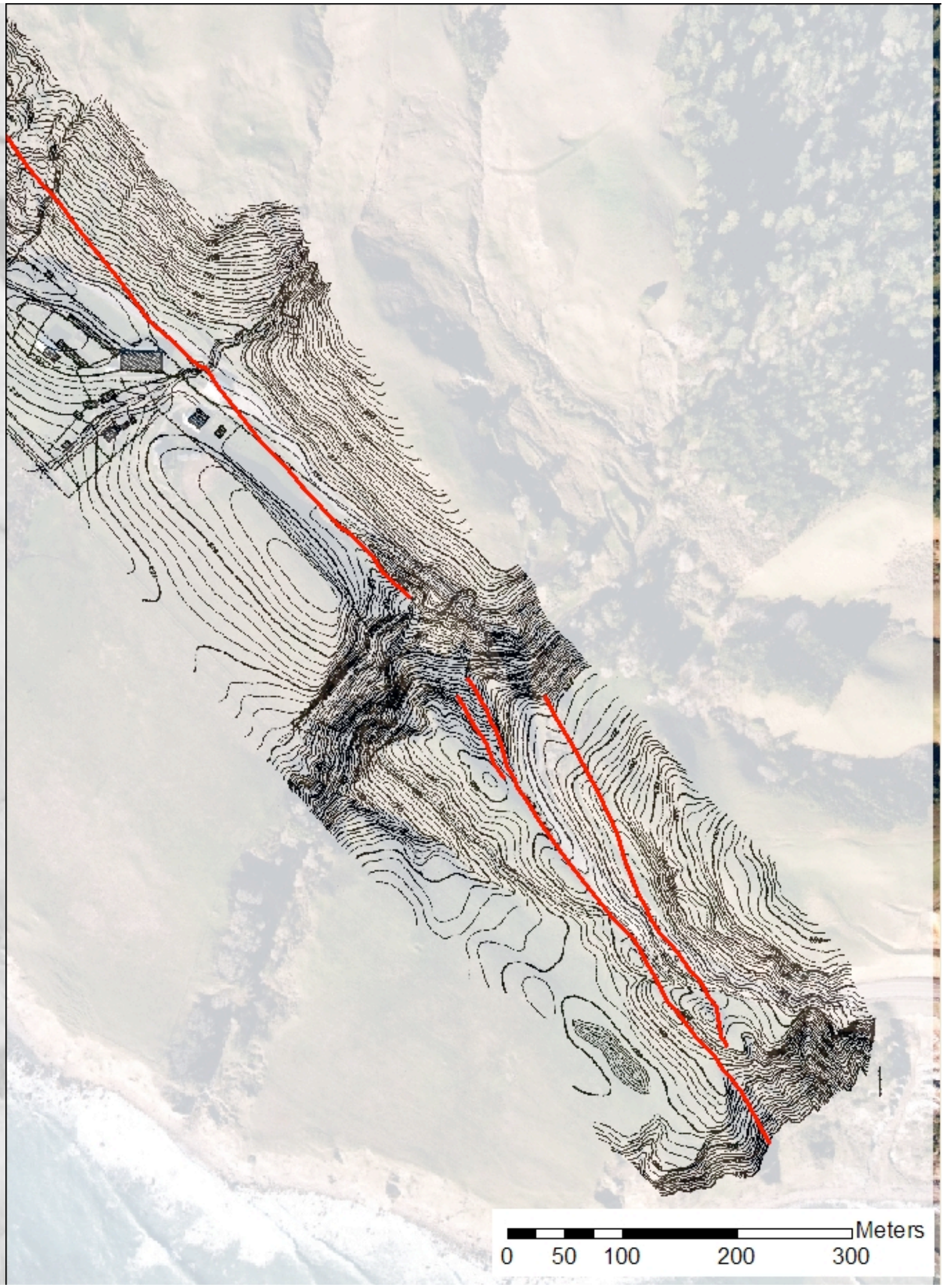
- Qualitative tool

- High-resolution landscape representation has always been important for geomorphic studies

- Post-1906 Earthquake strip map by Francois Matthes

- 5 ft contour interval, weeks of field work to acquire high-resolution topography

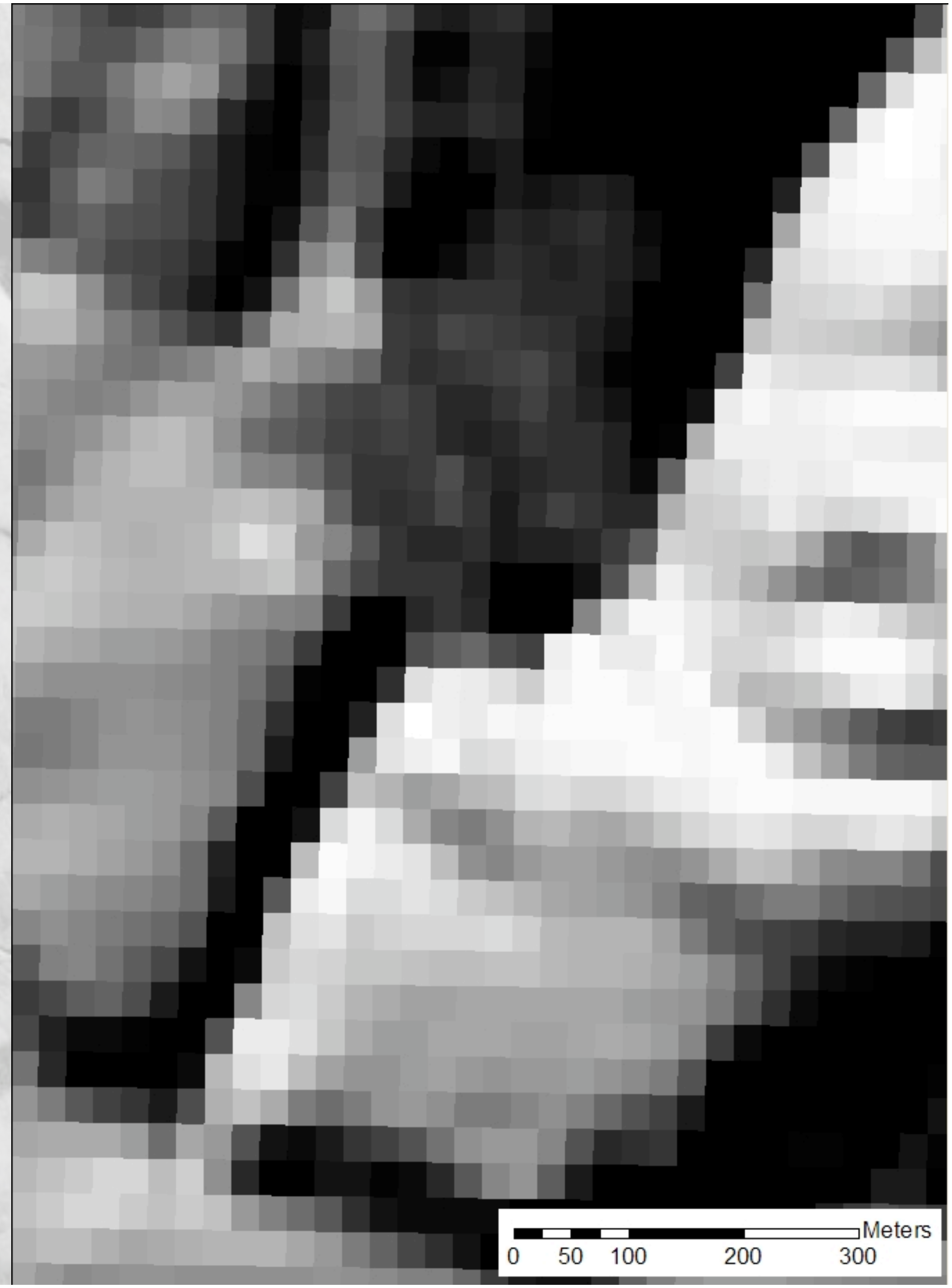
The California Earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission, Andrew C. Lawson, chairman, Carnegie Institution of Washington Publication 87, 2 vols. (1908)



- Digital topography provides 2.5D representation of landscape

- Widely avail. digital topography (digital elevation models - DEMs) are too coarse to provide representation of small geomorphic features / process.

- USGS 30 m DEM = best available US coverage. *Best available in Caribbean = 90m (SRTM)(?)*

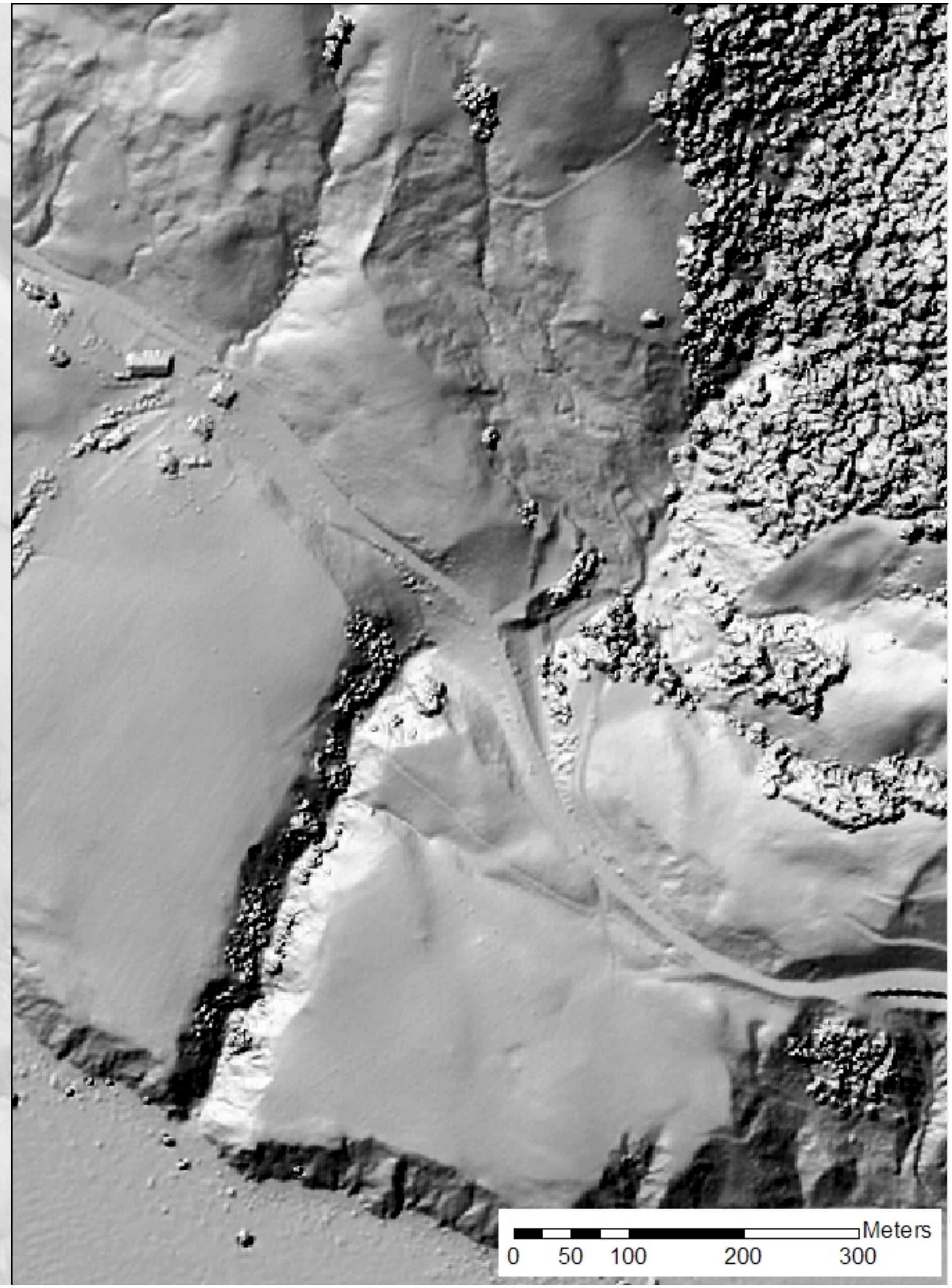


- Digital topography provides 2.5D representation of landscape

- Widely avail. digital topography (digital elevation models - DEMs) are too coarse to provide representation of small geomorphic features / process.

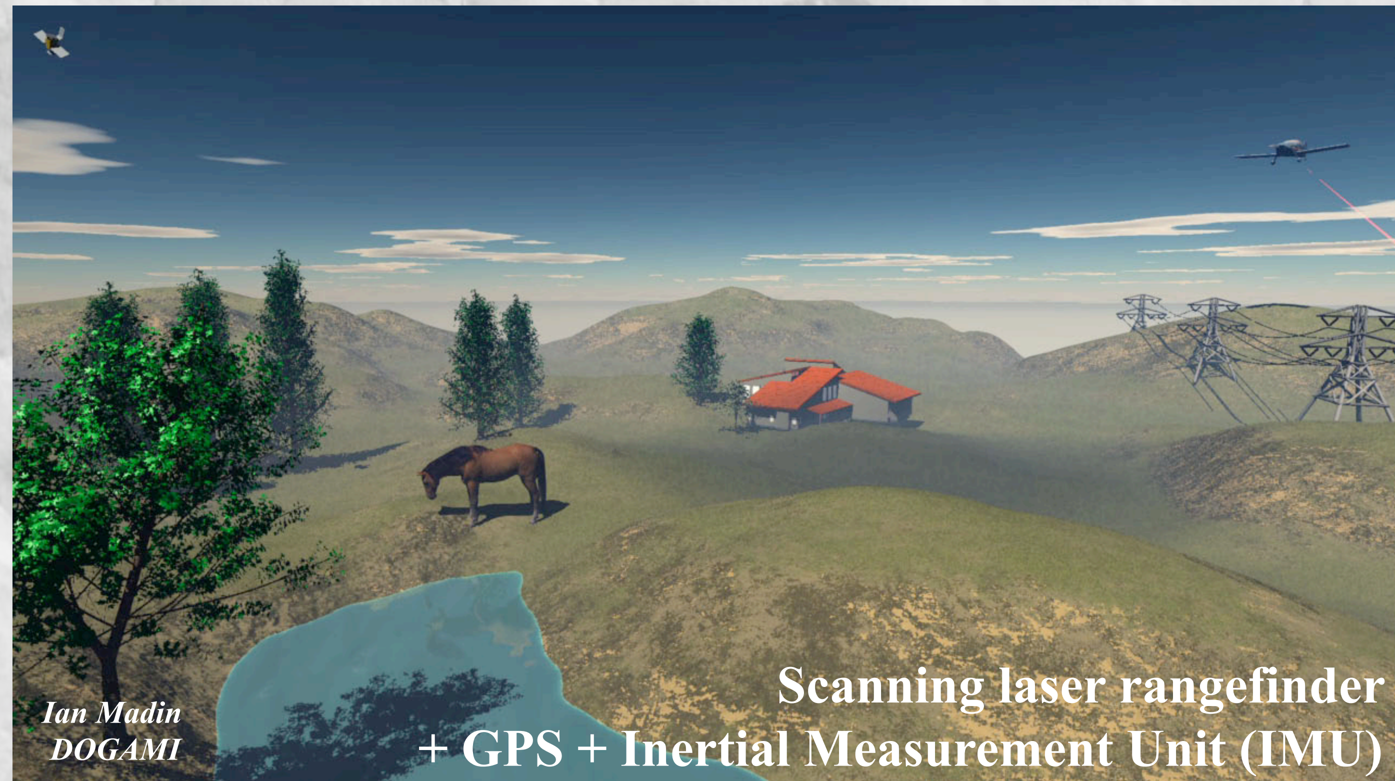
- USGS 10 m DEM

- LiDAR data
- DEMs at resolutions not previously possible but essential to represent process.
  - sub-meter resolution
- Applicable to:
  - Geomorphology
  - Landslide & flood hazards
  - Forestry/Ecology
  - Civil Engineering
  - Urban planning
- Have revolutionized many areas of Geoscience research



Airborne Lidar 101

lidar = light detection and ranging (*aka* airborne laser swath mapping)



- collected at 10s to 100s of kHz
- Vertical accuracy ~15 cm
- Beam diameter 15-20 cm

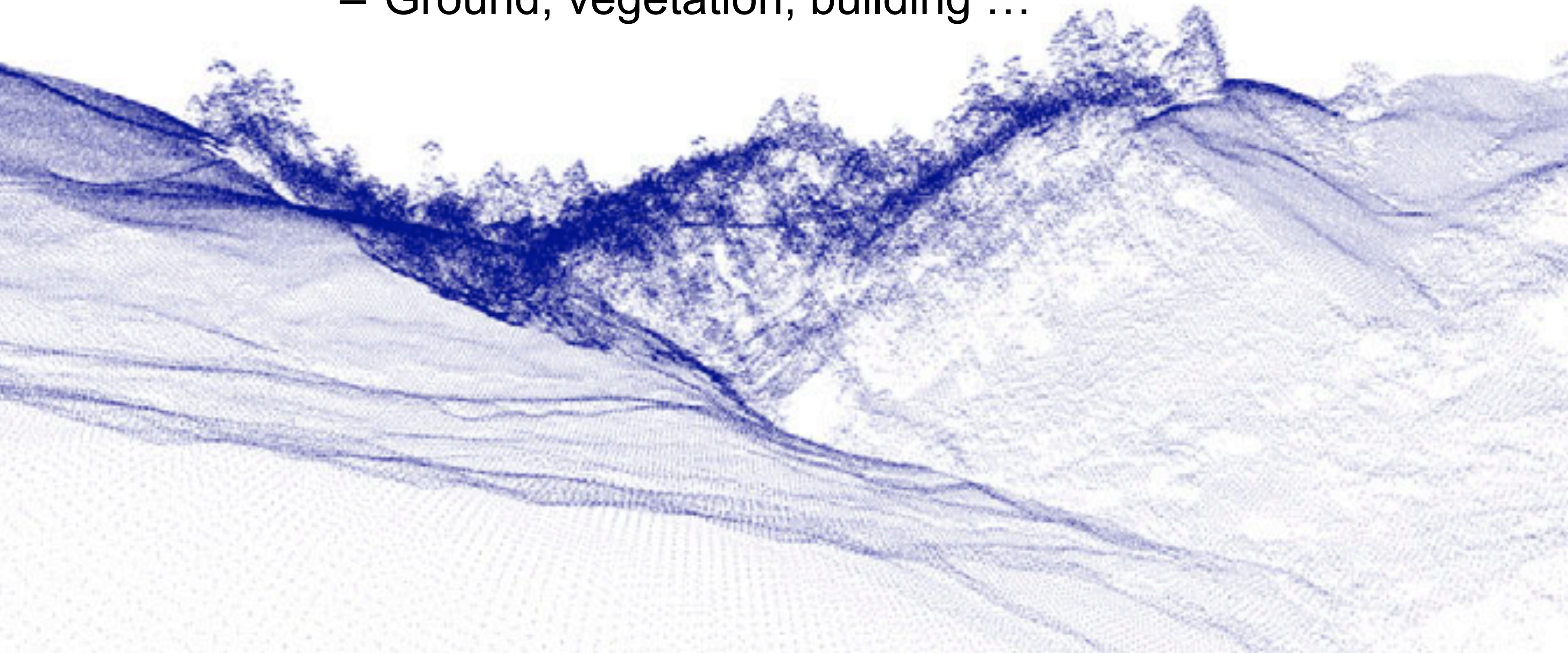
- 10^6 to 10^9 measurements of ground, vegetation, structures
  - *Point cloud (x,y,z* coordinates) = fundamental lidar data product
- Earth's surface sampled 0.25 and > 8 times per meter^2

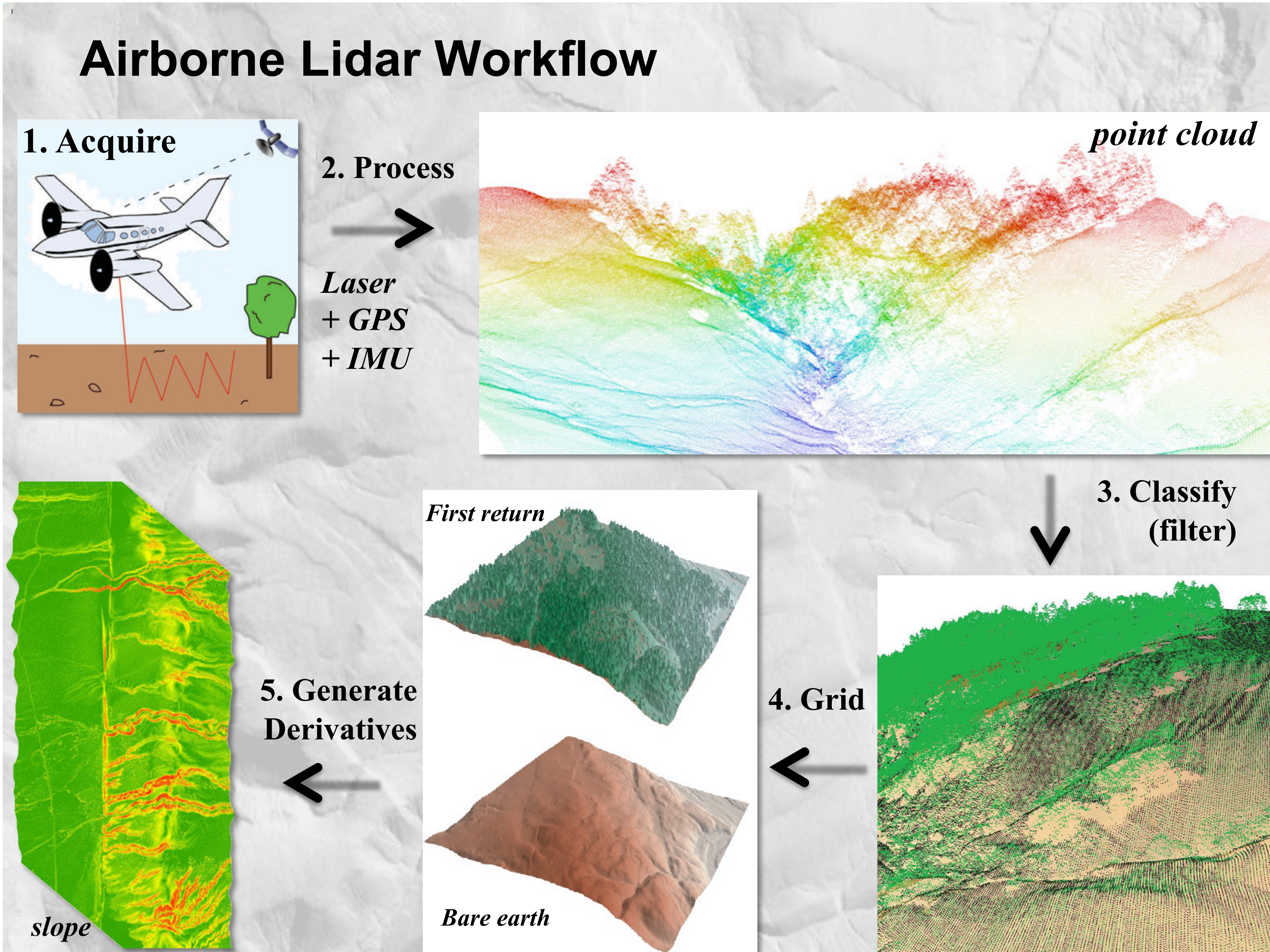
OpenTopography

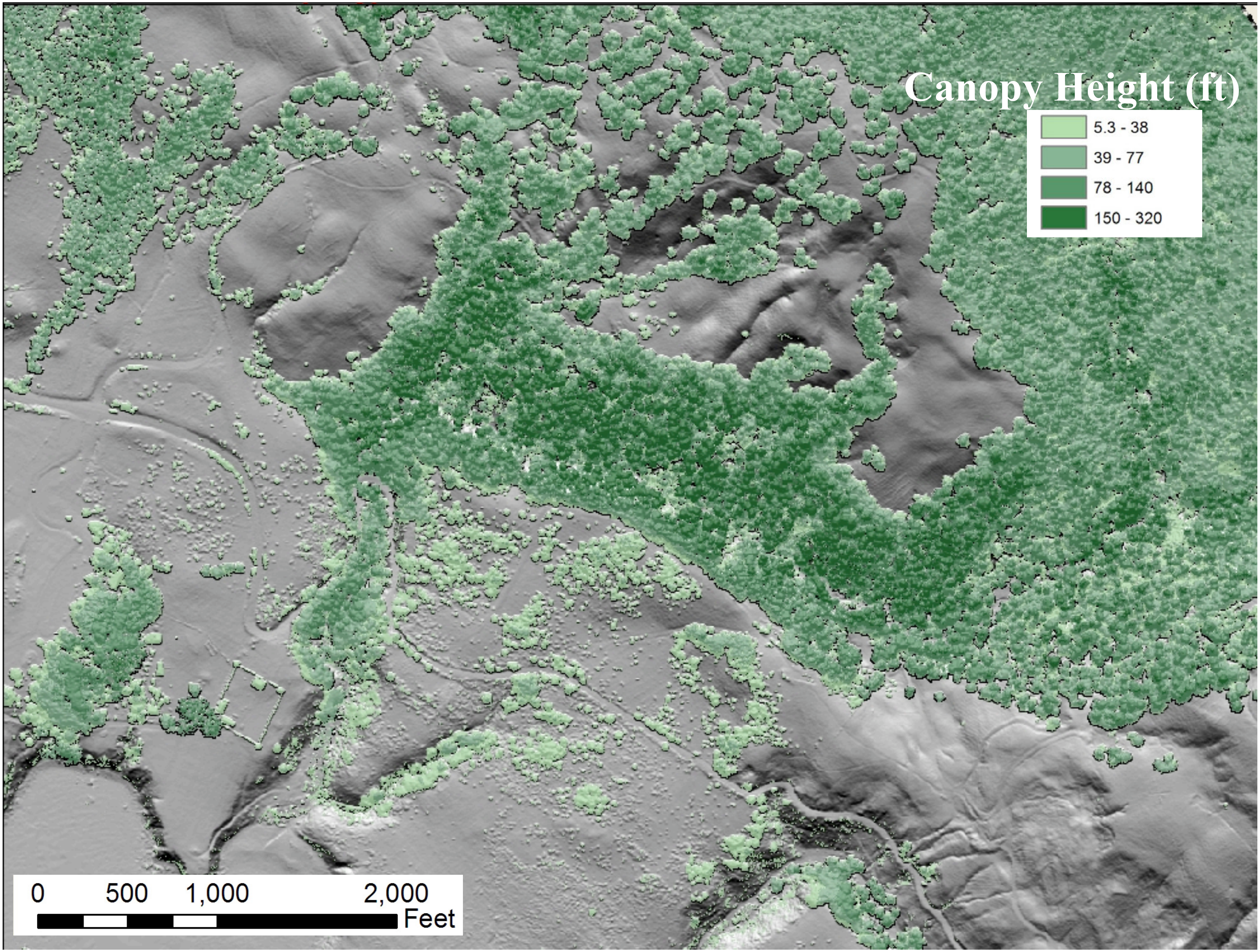
SDSC
SAN DIEGO SUPERCOMPUTER CENTER

LiDAR “point cloud”

- *x,y,z* + attributes
- Filtering algorithms allow classification by return type:
  - Ground, vegetation, building …



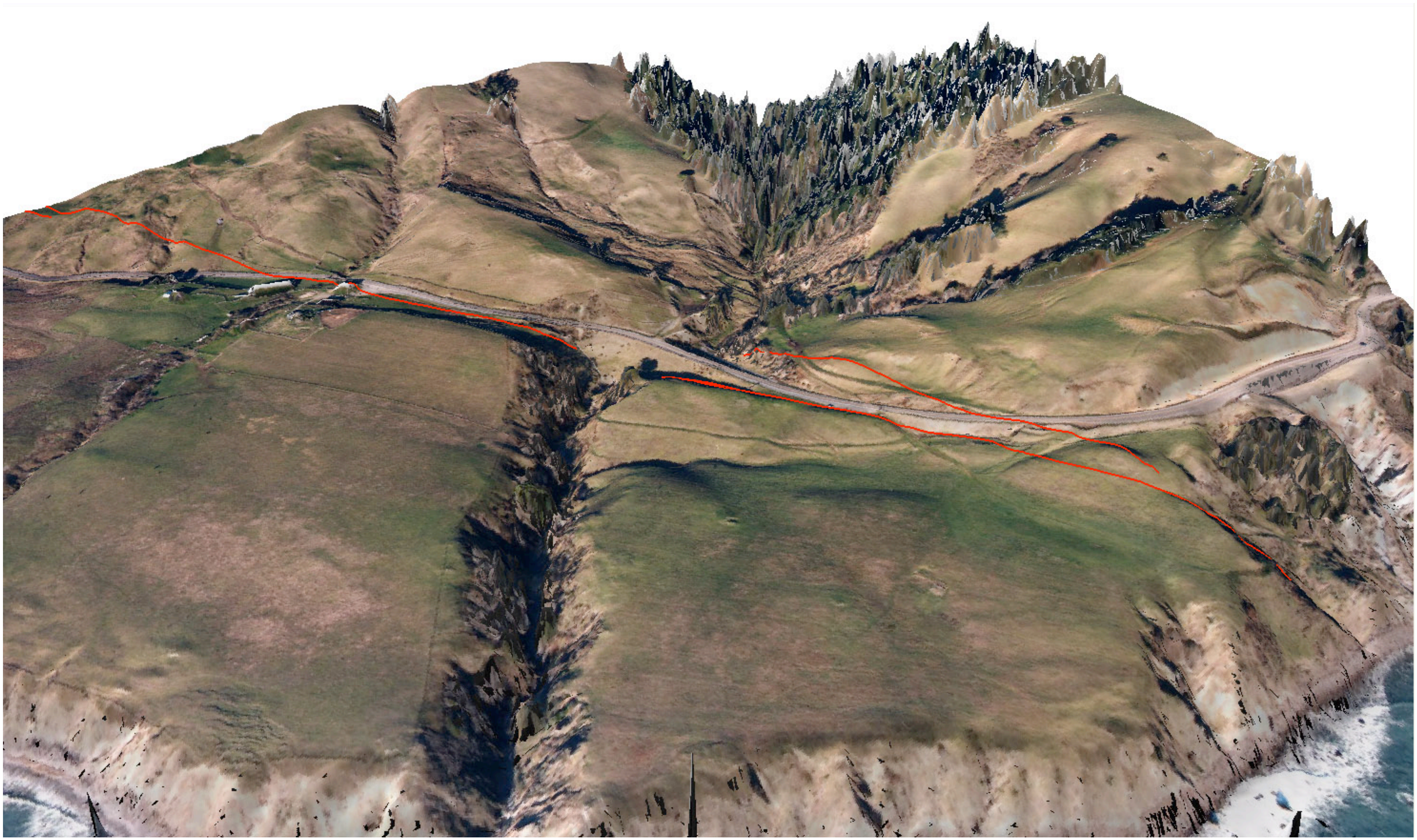

Airborne Lidar Workflow
1. Acquire
2. Process
Laser
+ GPS
+ IMU
point cloud
3. Classify
(filter)
4. Grid
First return
Bare earth
5. Generate
Derivatives
slope



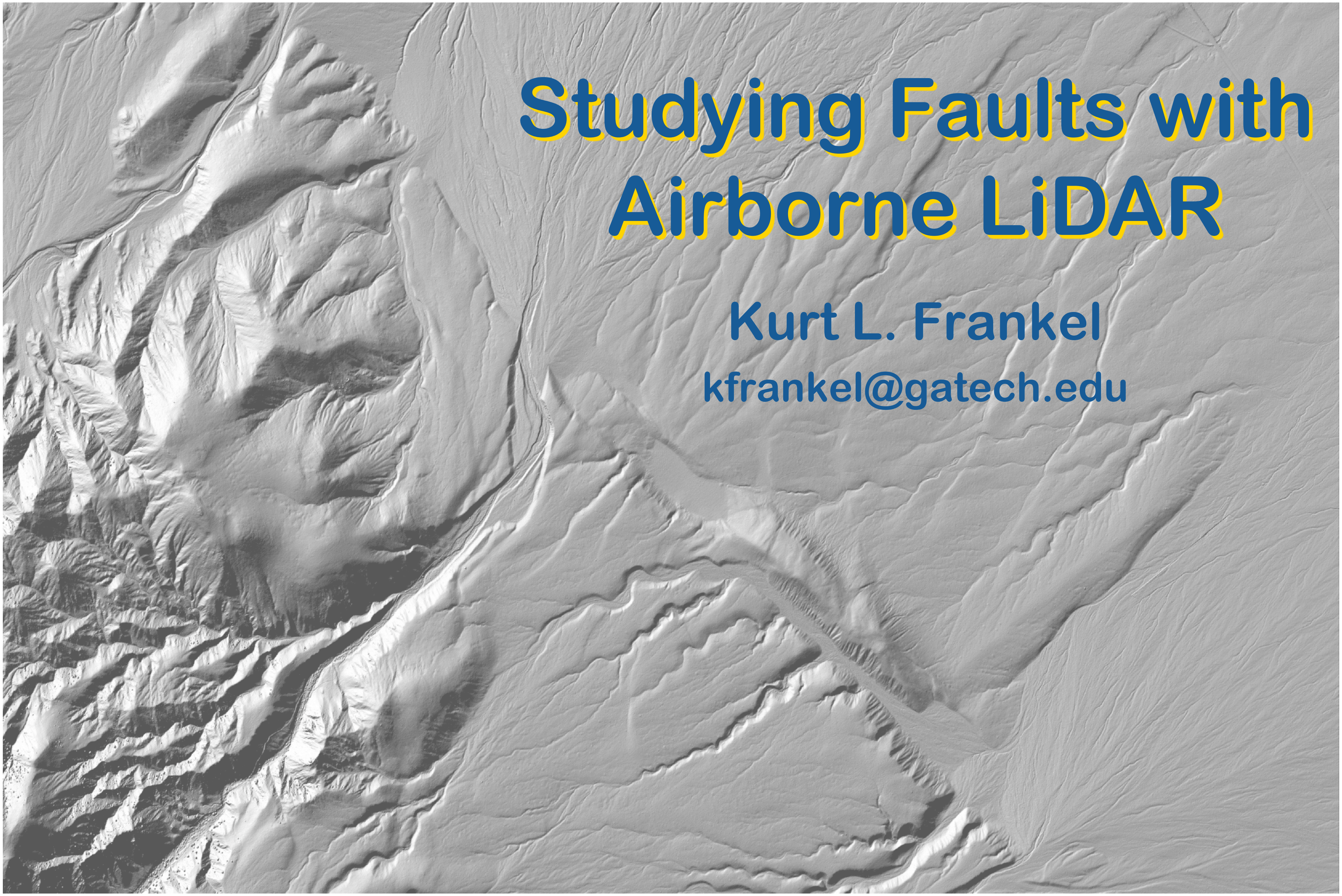
Canopy Height (ft)
5.3 - 38
39 - 77
78 - 140
150 - 320
0
500
1,000
2,000
Feet

3D visualization: DEM + air photo fusion

Collection from same platform



Georgia Institute of Technology
School of Earth and Atmospheric Sciences

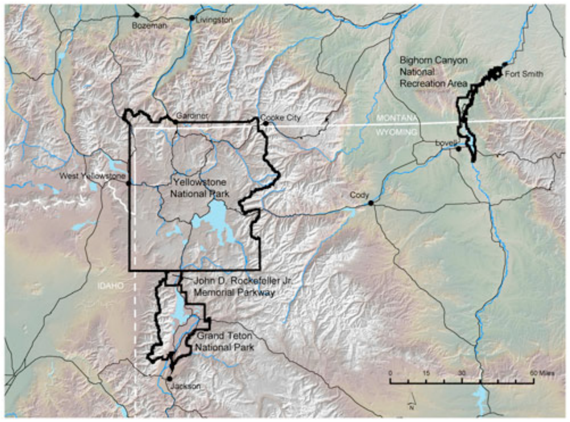


Studying Faults with Airborne LiDAR

Kurt L. Frankel

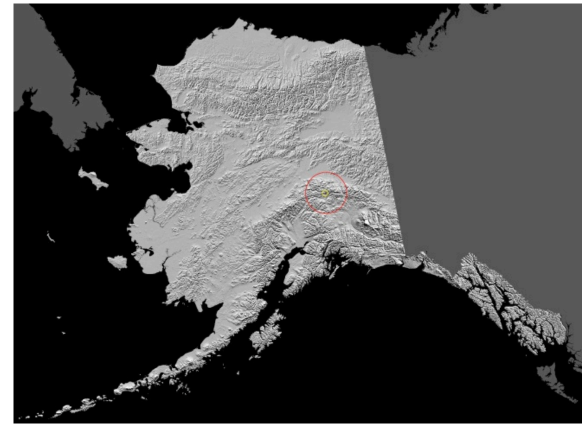
kfrankel@gatech.edu

LiDAR Example Locations



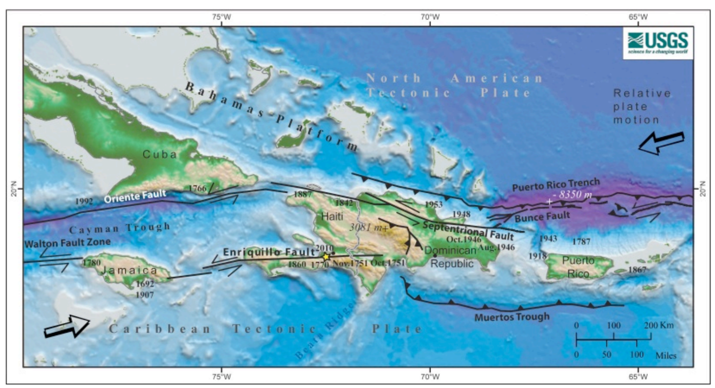
Teton fault, Wyoming

SAF/PAC-NAM Plate Boundary

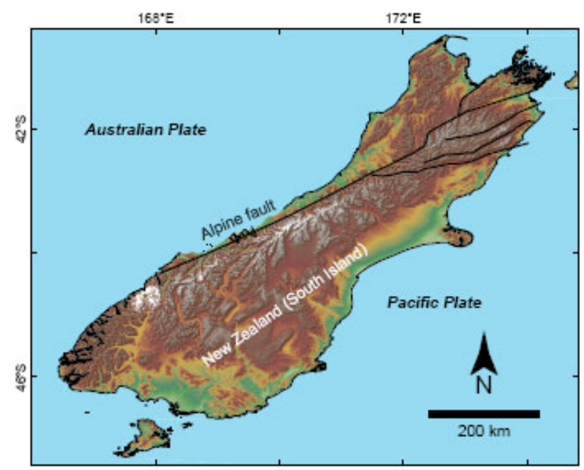


Denali fault, Alaska

Puget Sound, WA

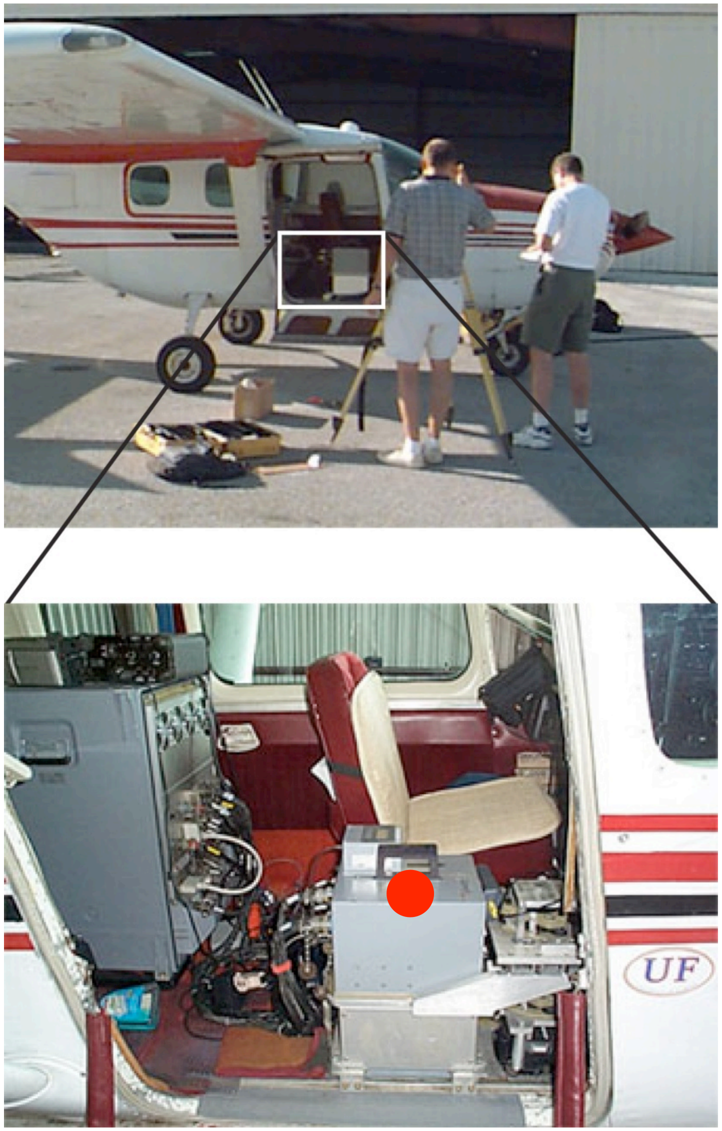


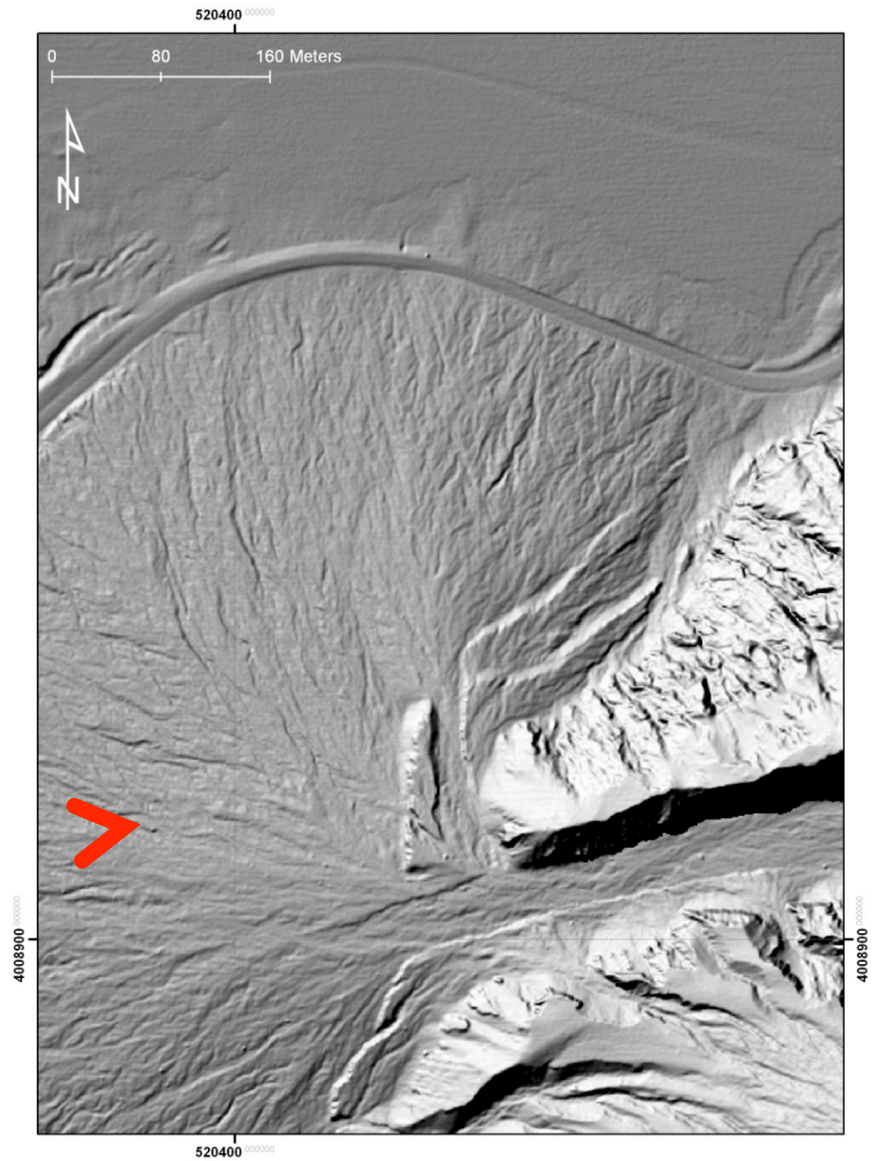
Enriquillo - Plantain Garden fault



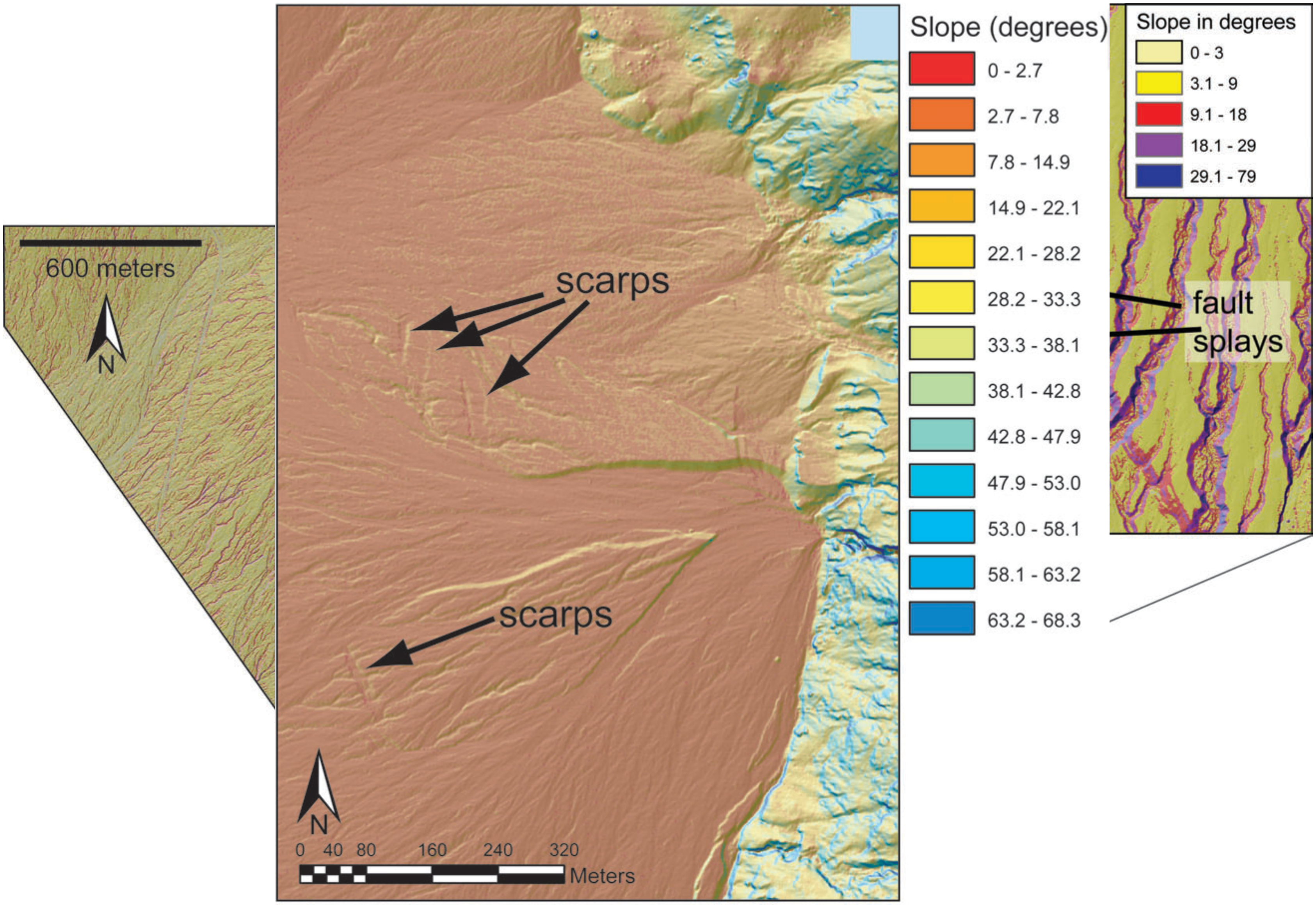
New Zealand

Airborne LiDAR and Faults

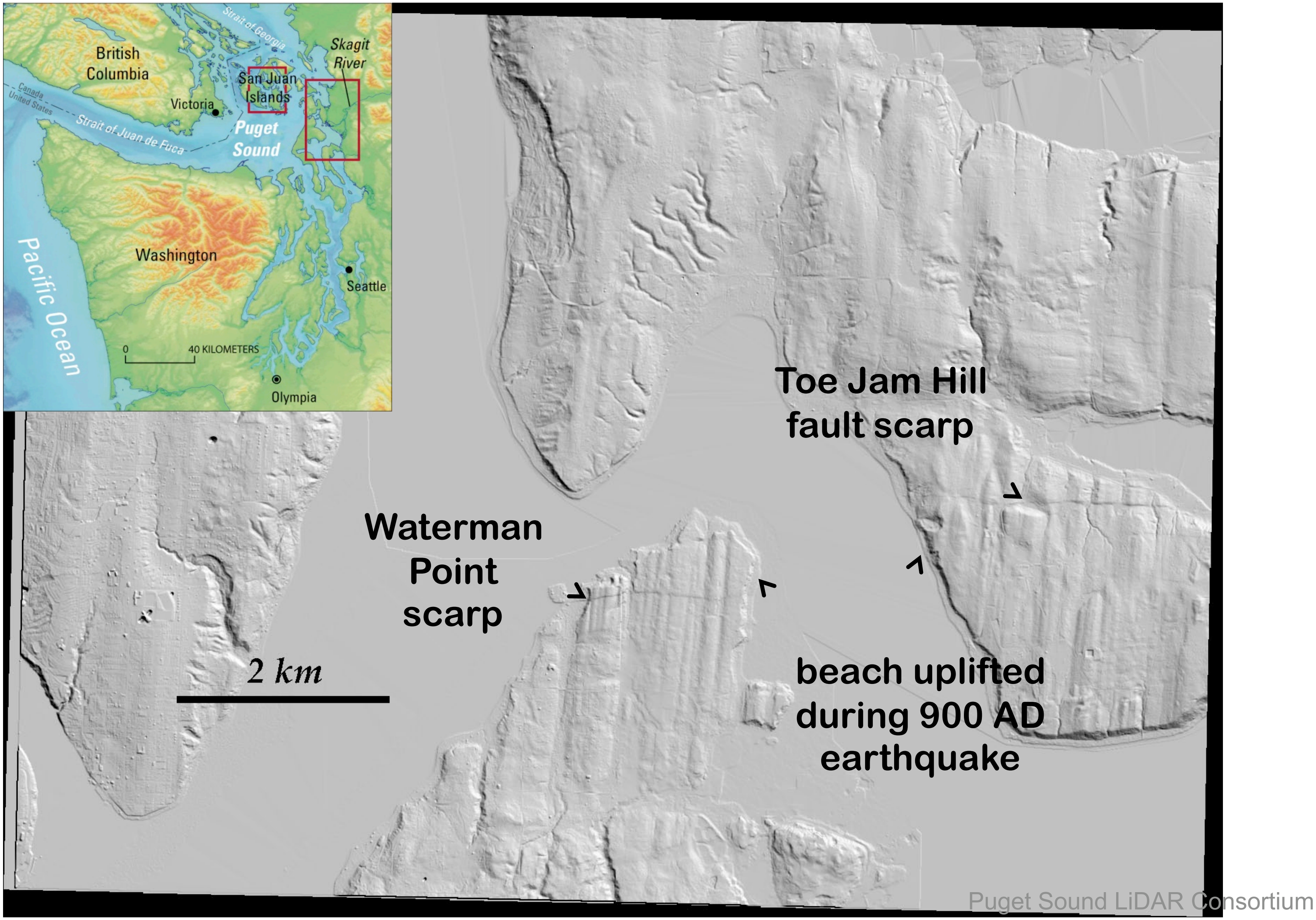




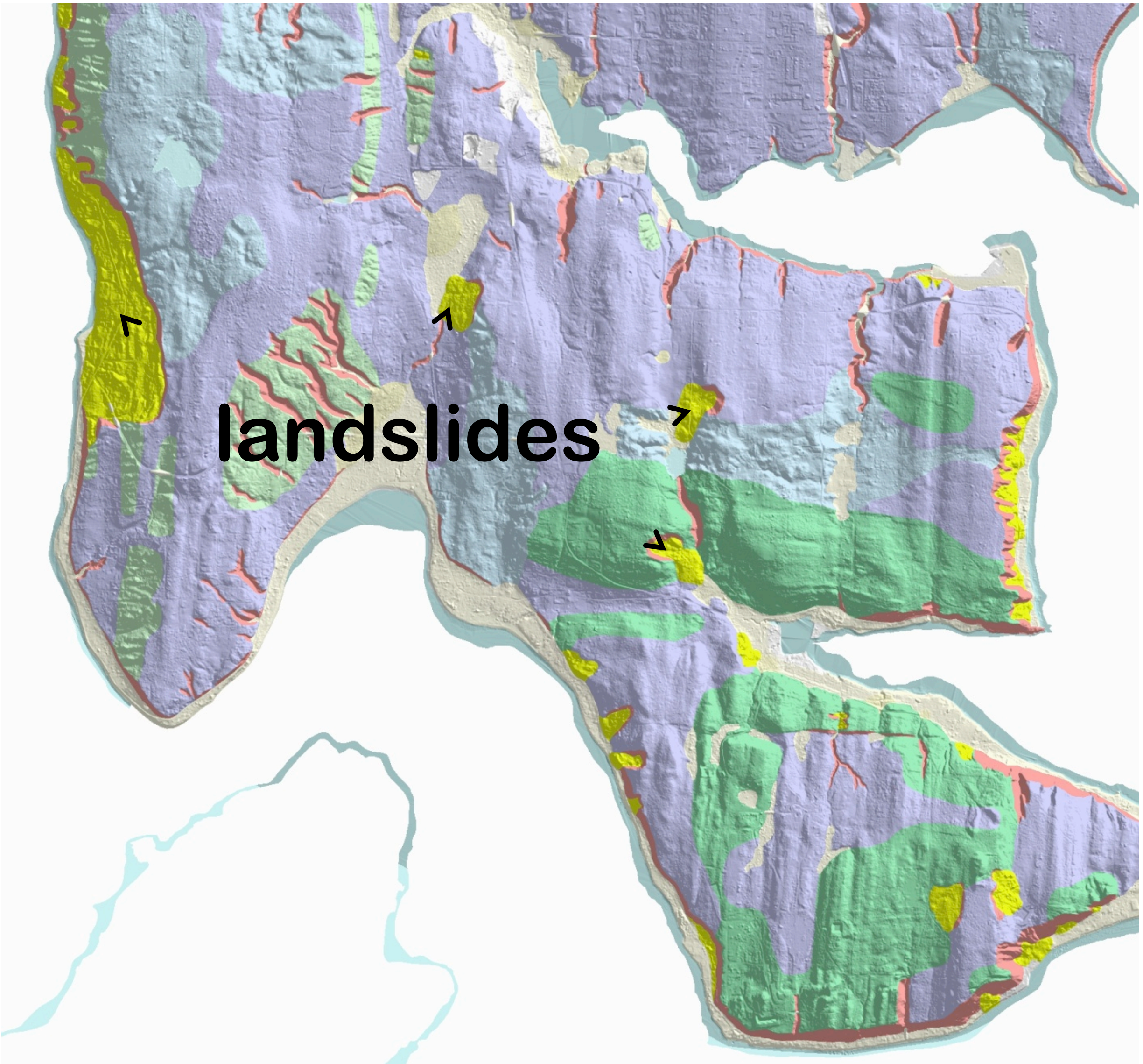
Identifying Faults with LiDAR Data



Puget Sound LiDAR



Puget Sound LiDAR



Puget Sound LiDAR Consortium

Northern San Andreas Fault

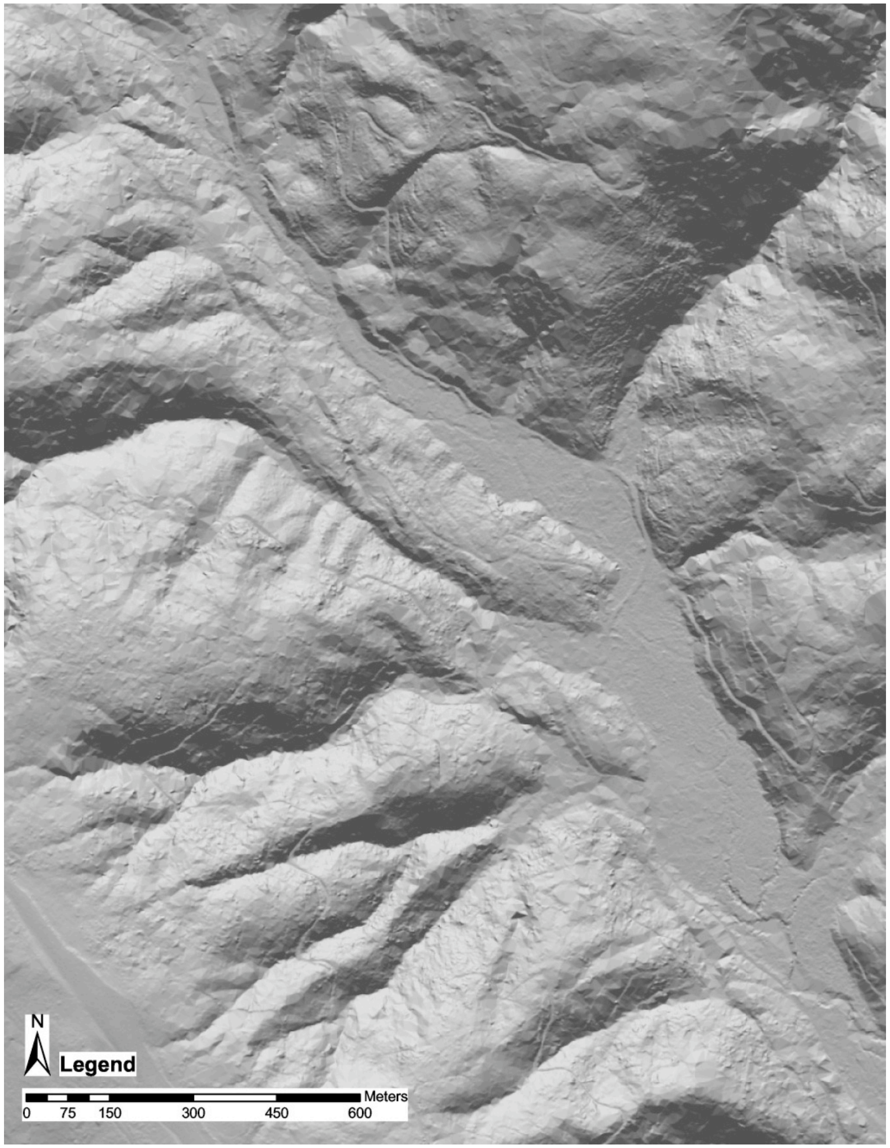
Air Photo

Full Feature LiDAR

Prentice/USGS data

Northern San Andreas Fault

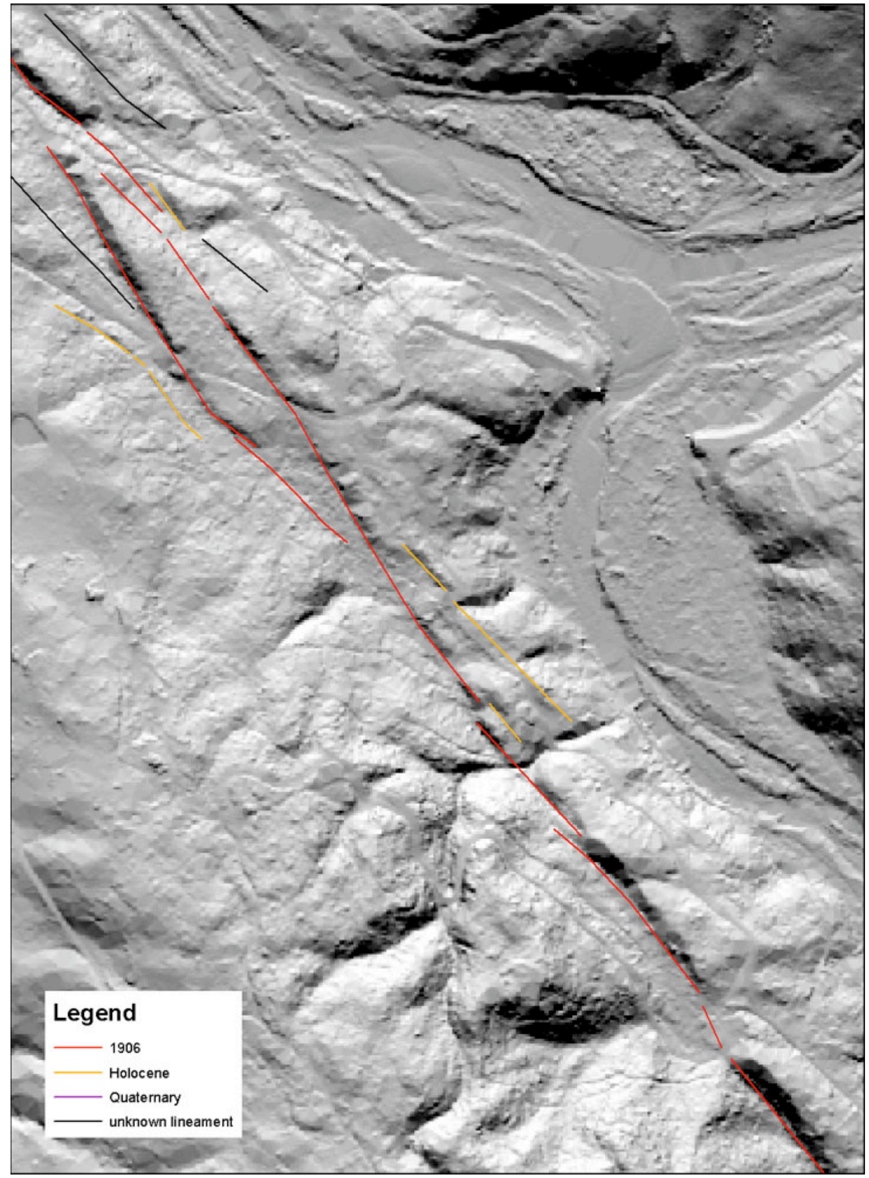
Air Photo



Bare Earth

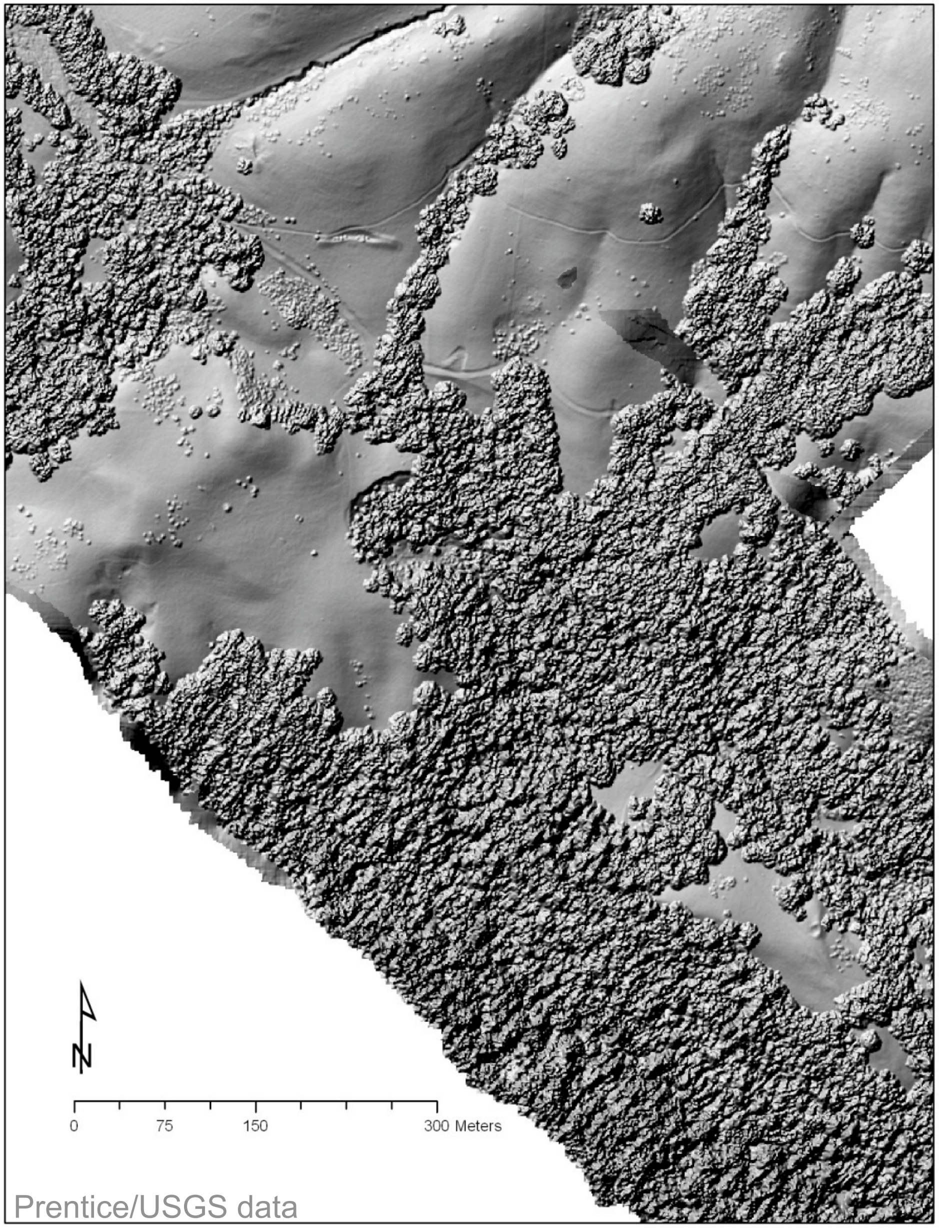
Prentice/USGS data

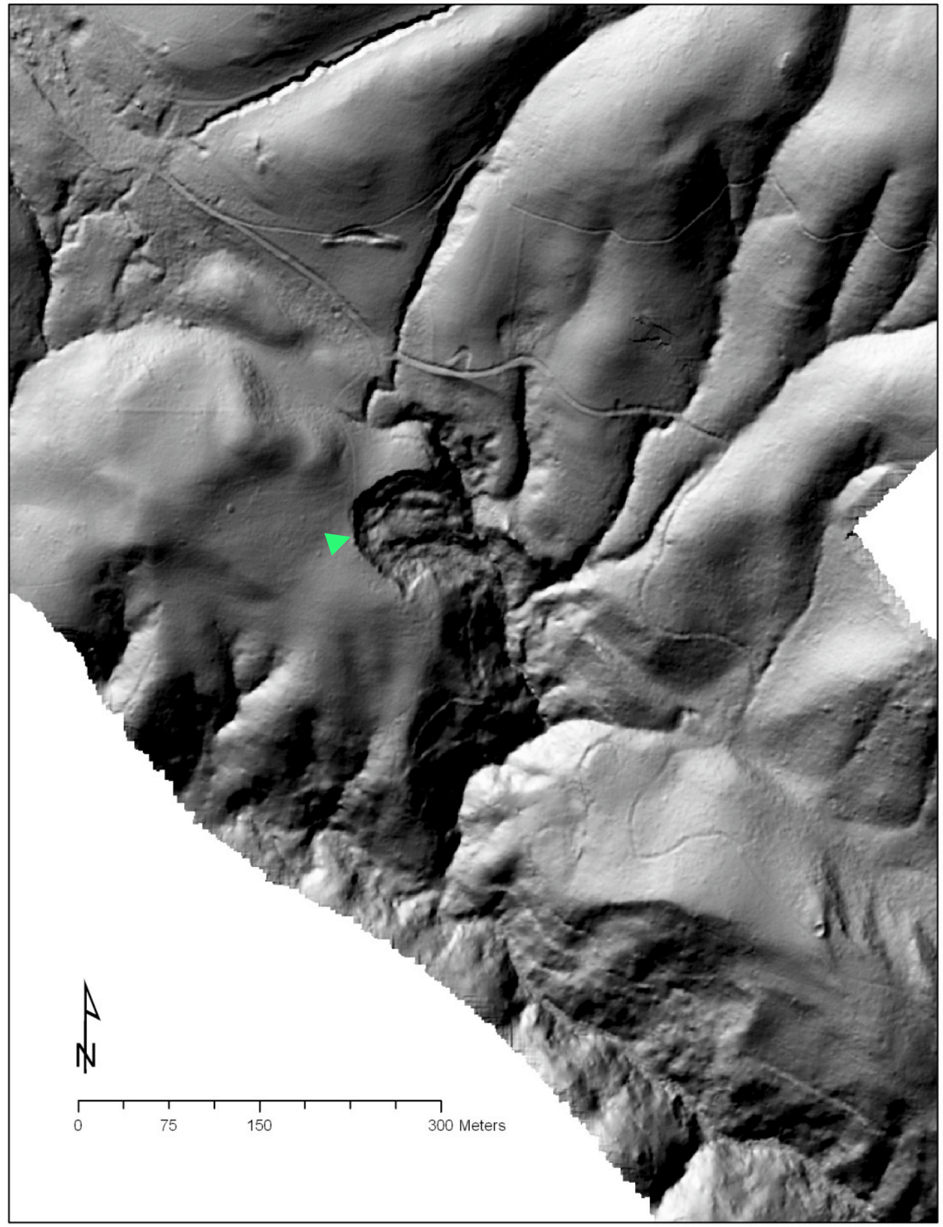
Northern San Andreas Fault



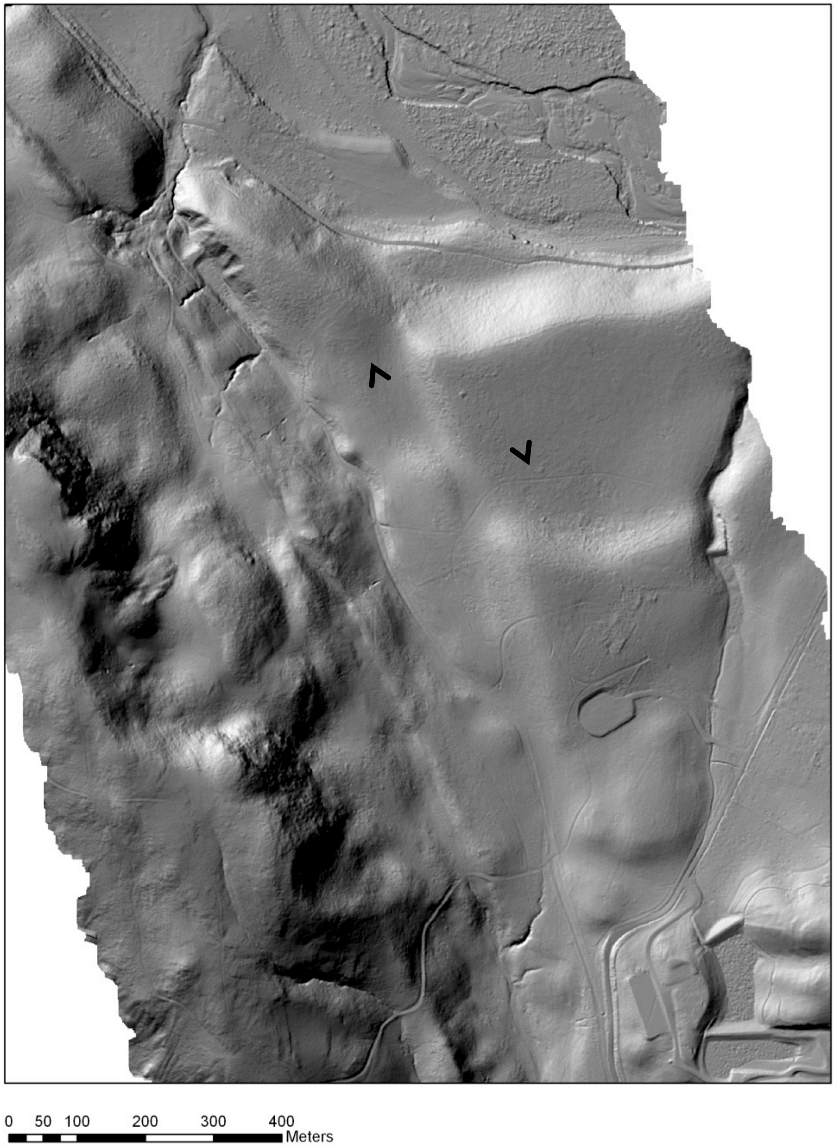
Prentice/USGS data

San Andreas Fault - Stevens Cr.



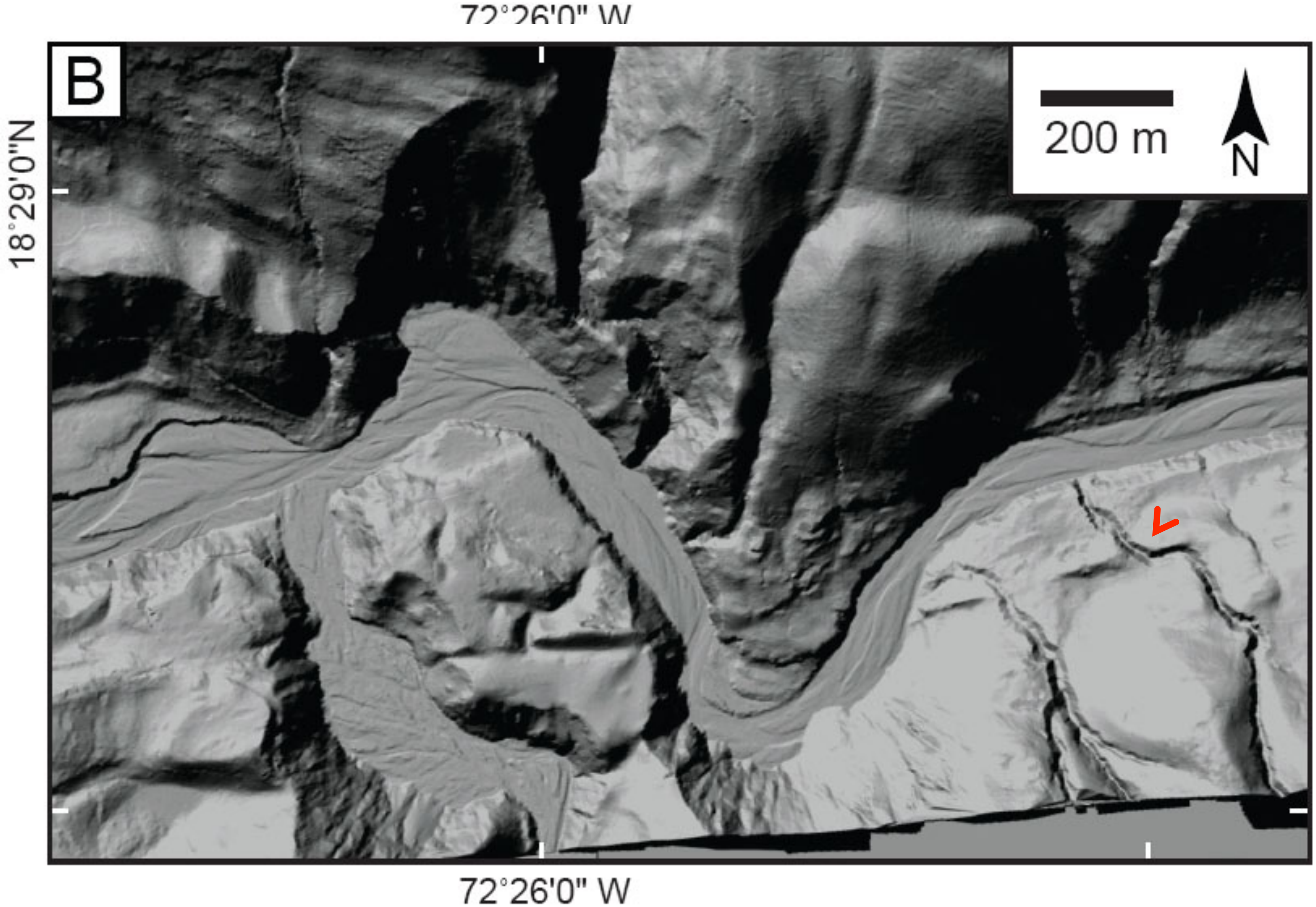


Calaveras Fault - Offset Terraces



Prentice/USGS data

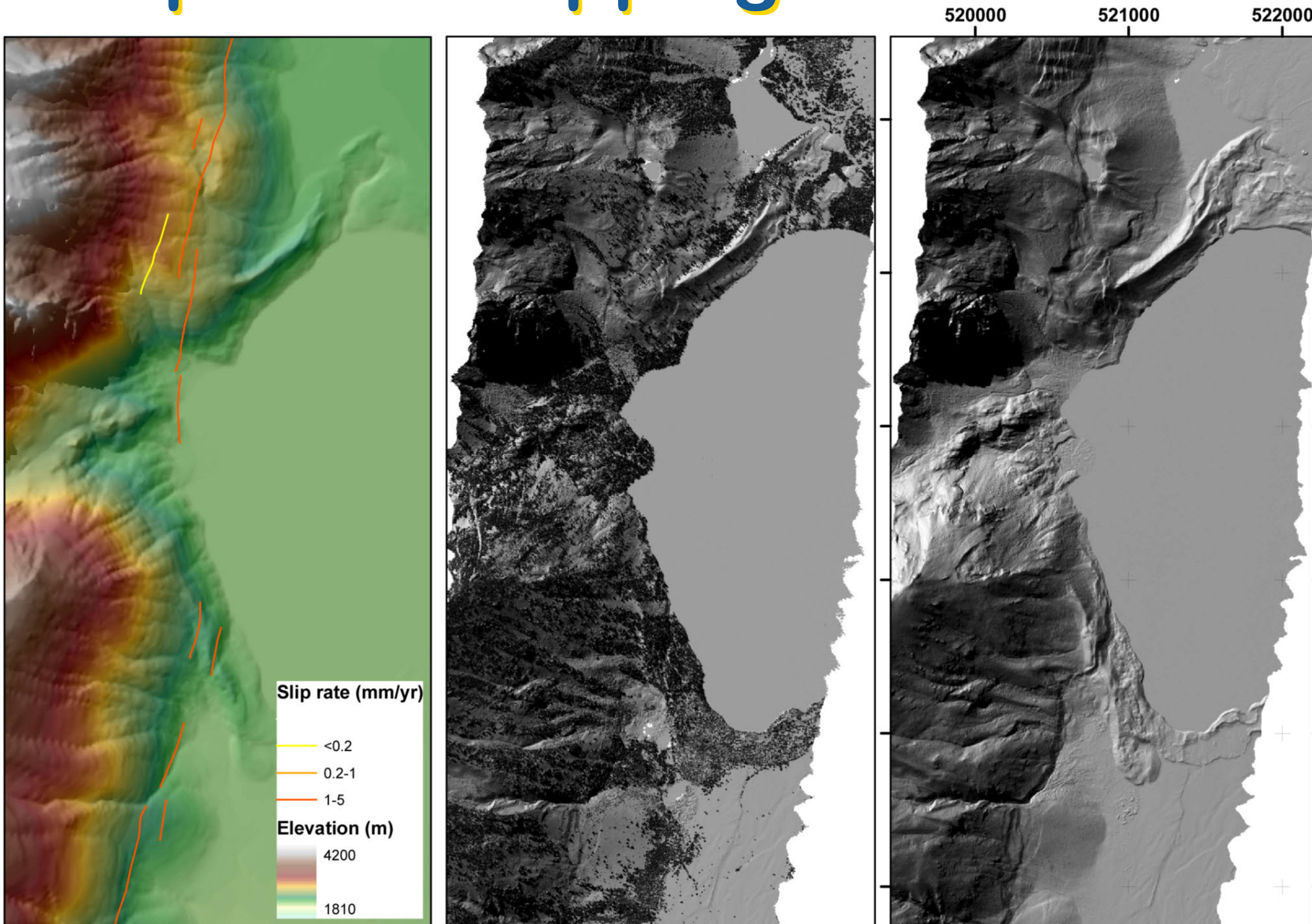
Enriquillo - Plantain Garden Fault



World Bank/Global Facility for Disaster Recovery data

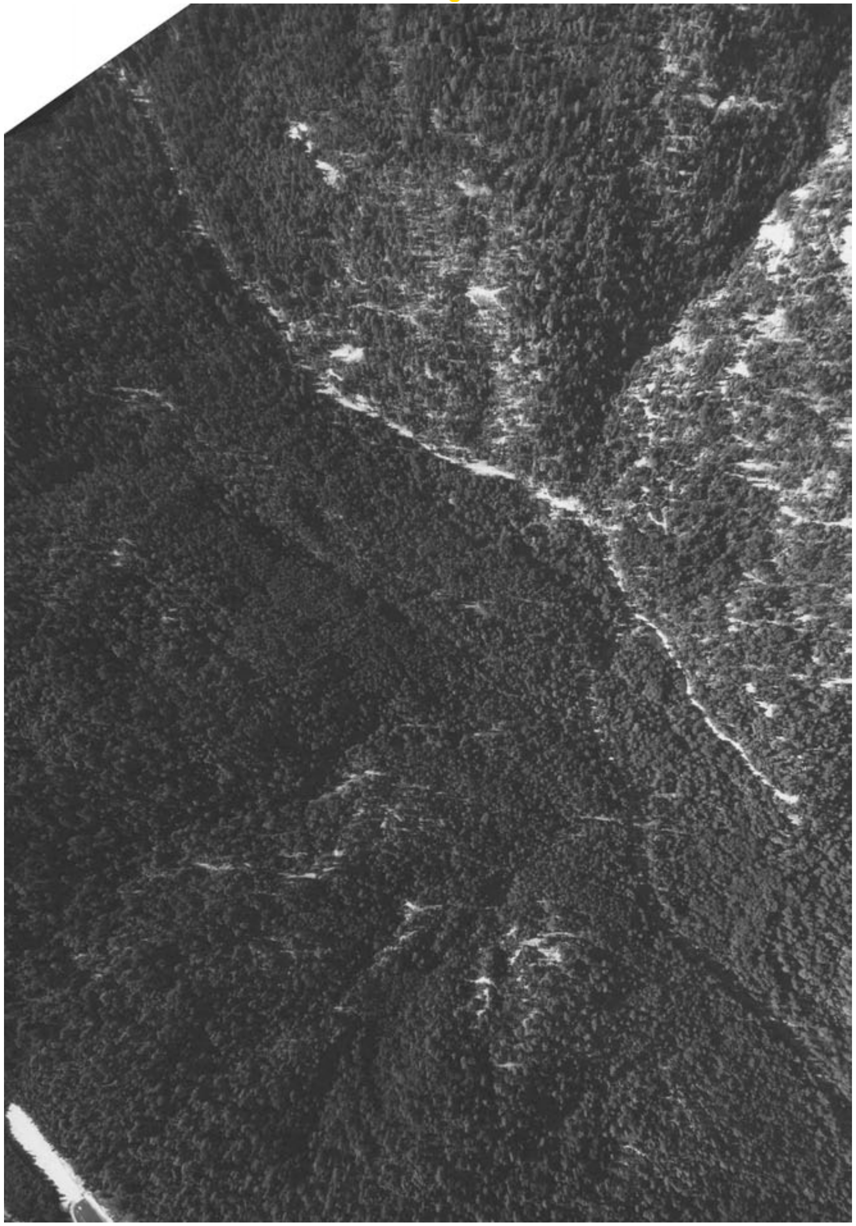
Frankel and Owen , in prep, *Treatise On Geomorph.*

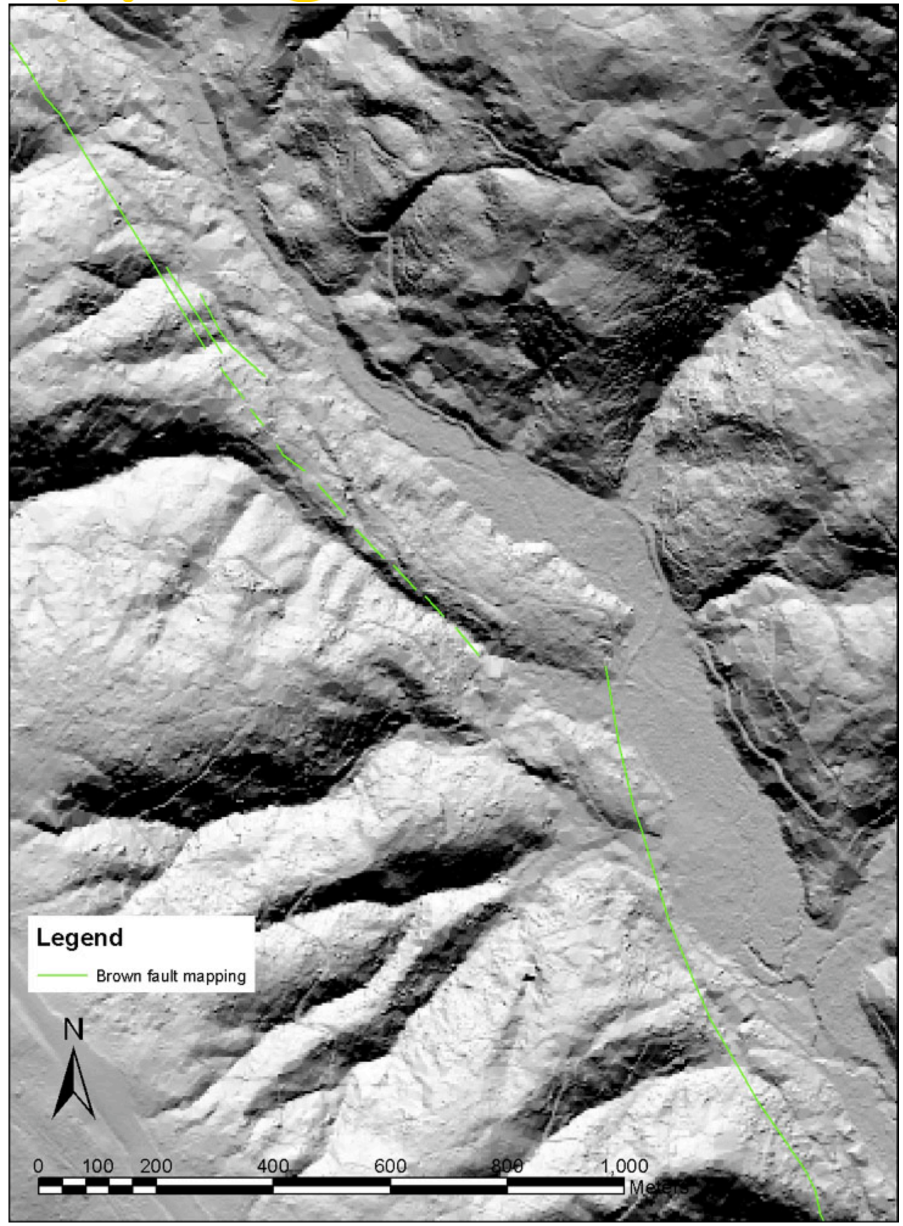
Improved Mapping - Teton Fault



USGS NED and Q Faults | 1 m EarthScope unfiltered DEM | 1 m EarthScope filtered DEM

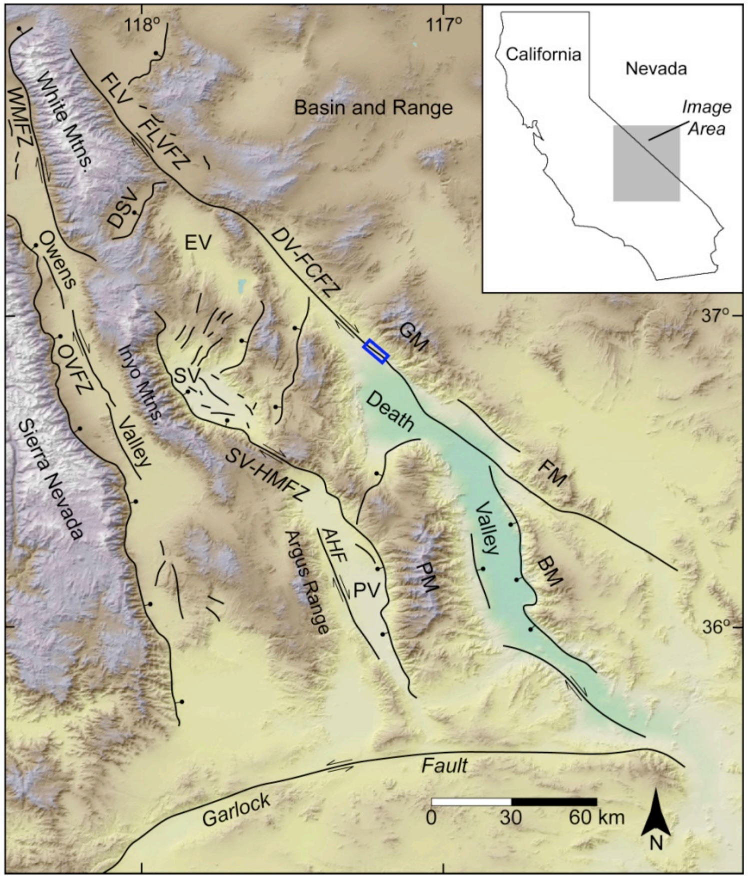
Improved Mapping - SAF

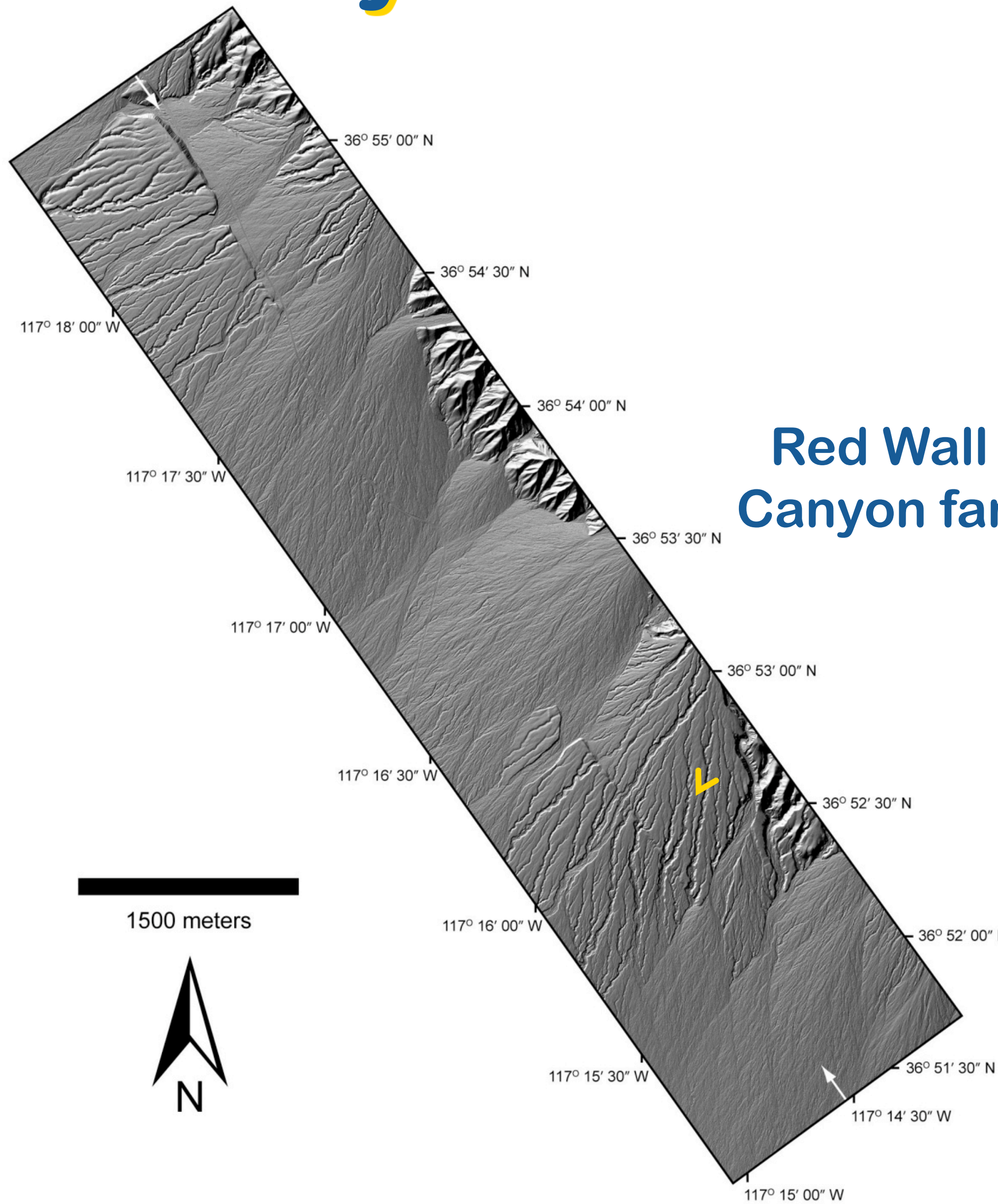




Prentice/USGS data

Northern Death Valley Fault Zone

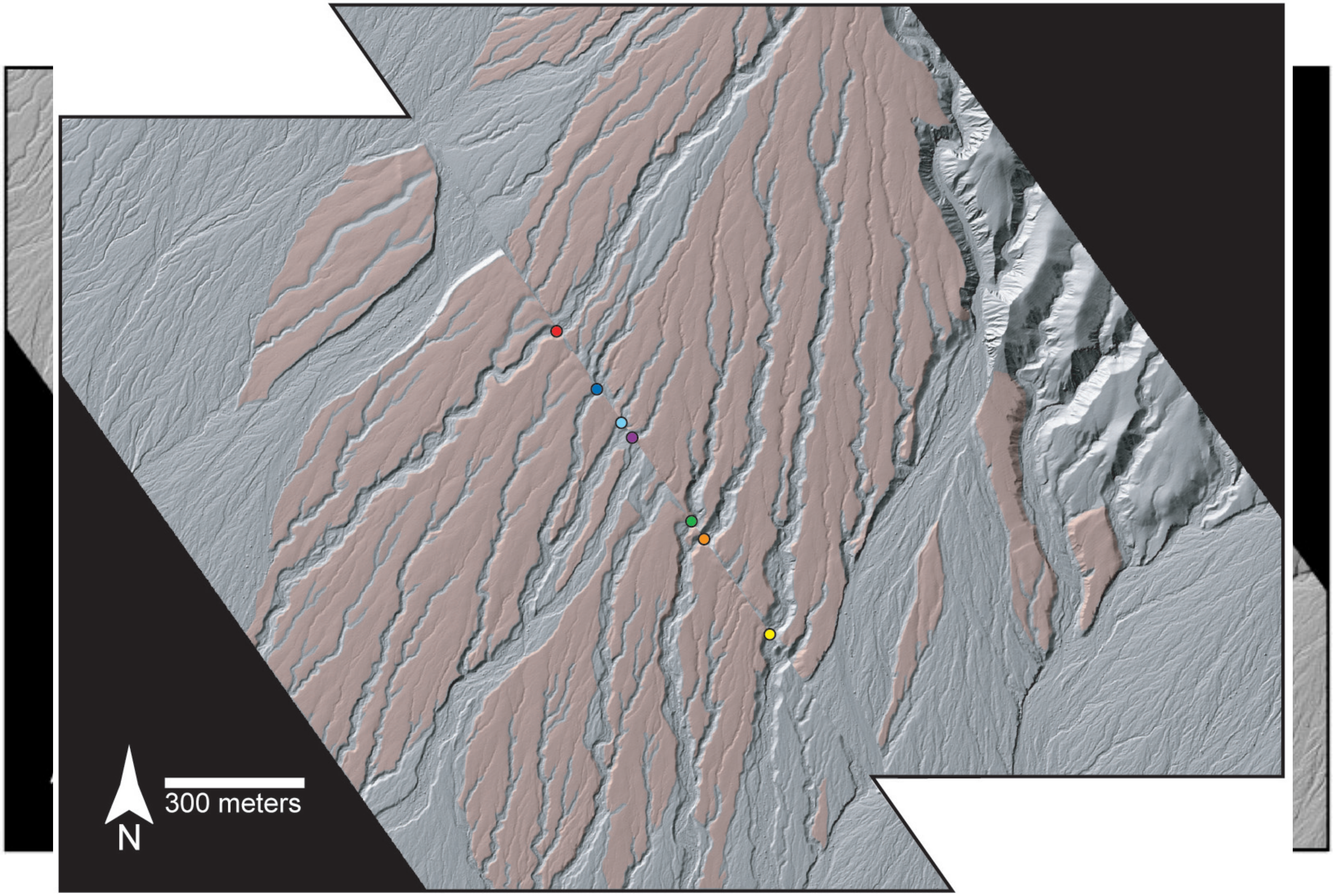




Red Wall Canyon fan

Frankel et al., 2007, *JGR - Solid Earth*

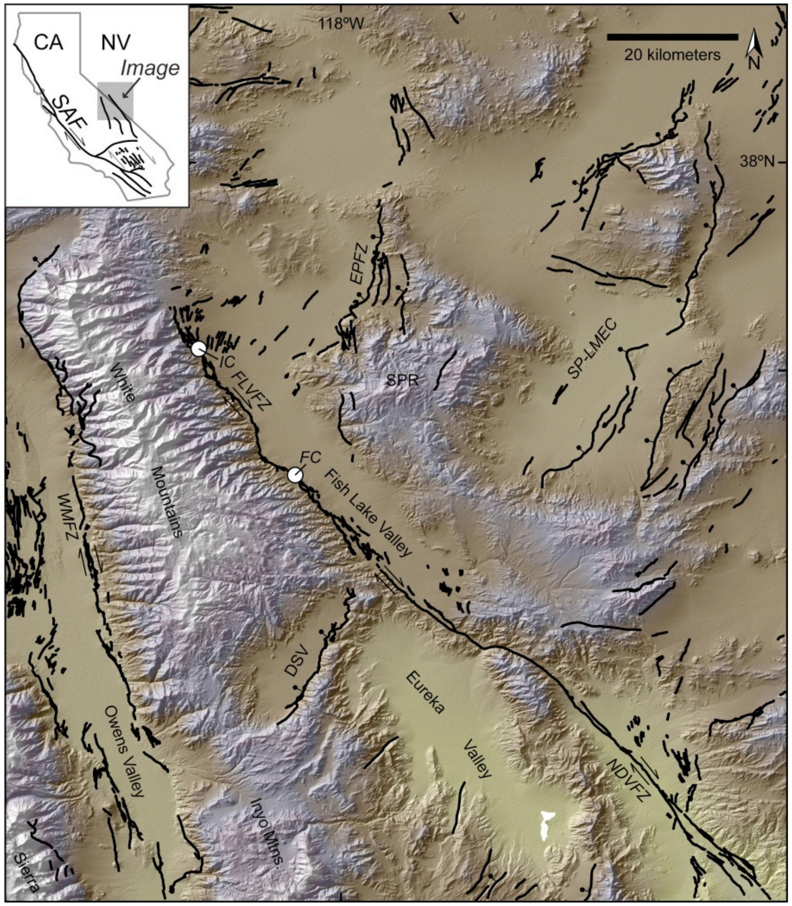
Red Wall Canyon Offset

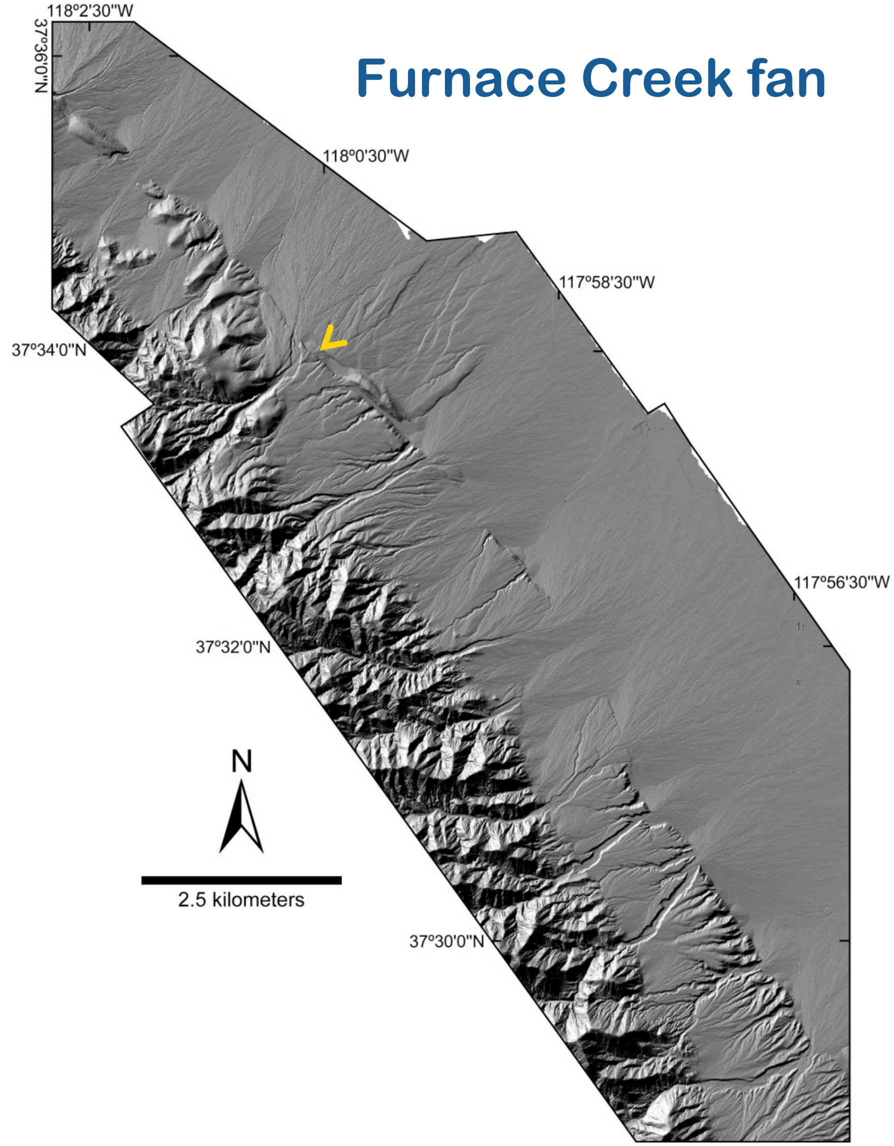


- total displacement = 297 ± 9 meters

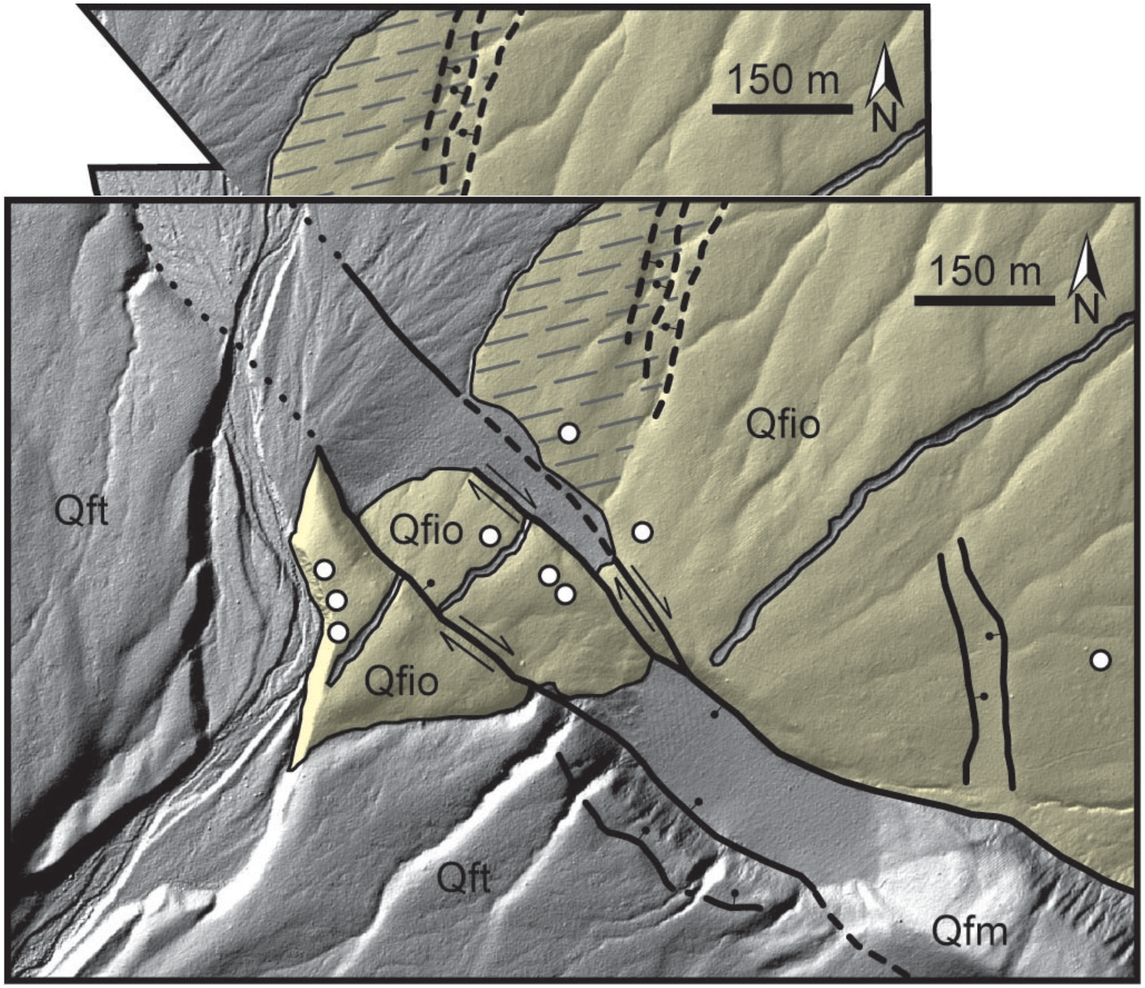
Frankel et al., 2007, *JGR - Solid Earth*

Fish Lake Valley Fault Zone





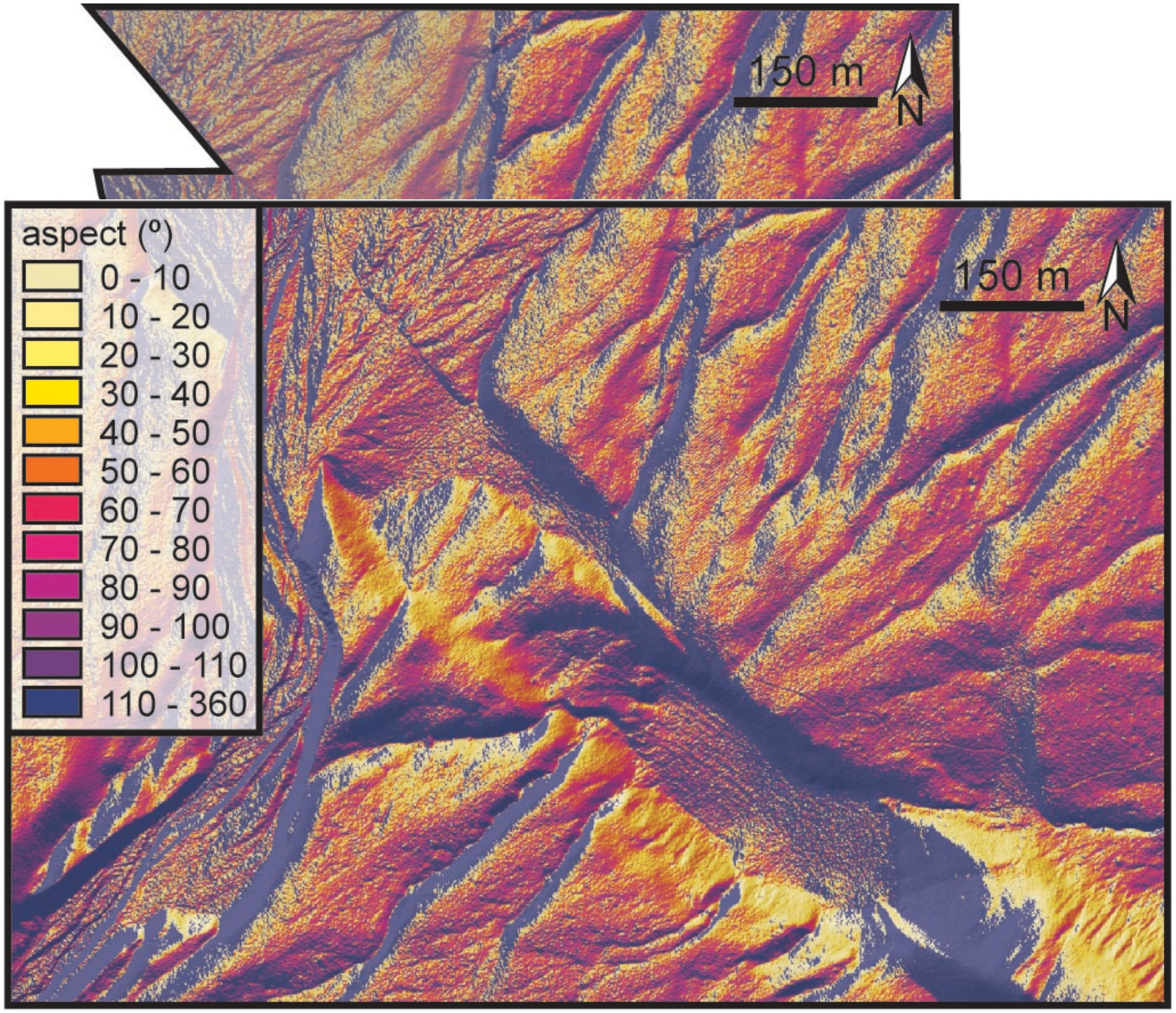
Furnace Creek Offset - Channel



• **total displacement = 290 ± 20 meters**

Frankel et al., 2007, *GRL*

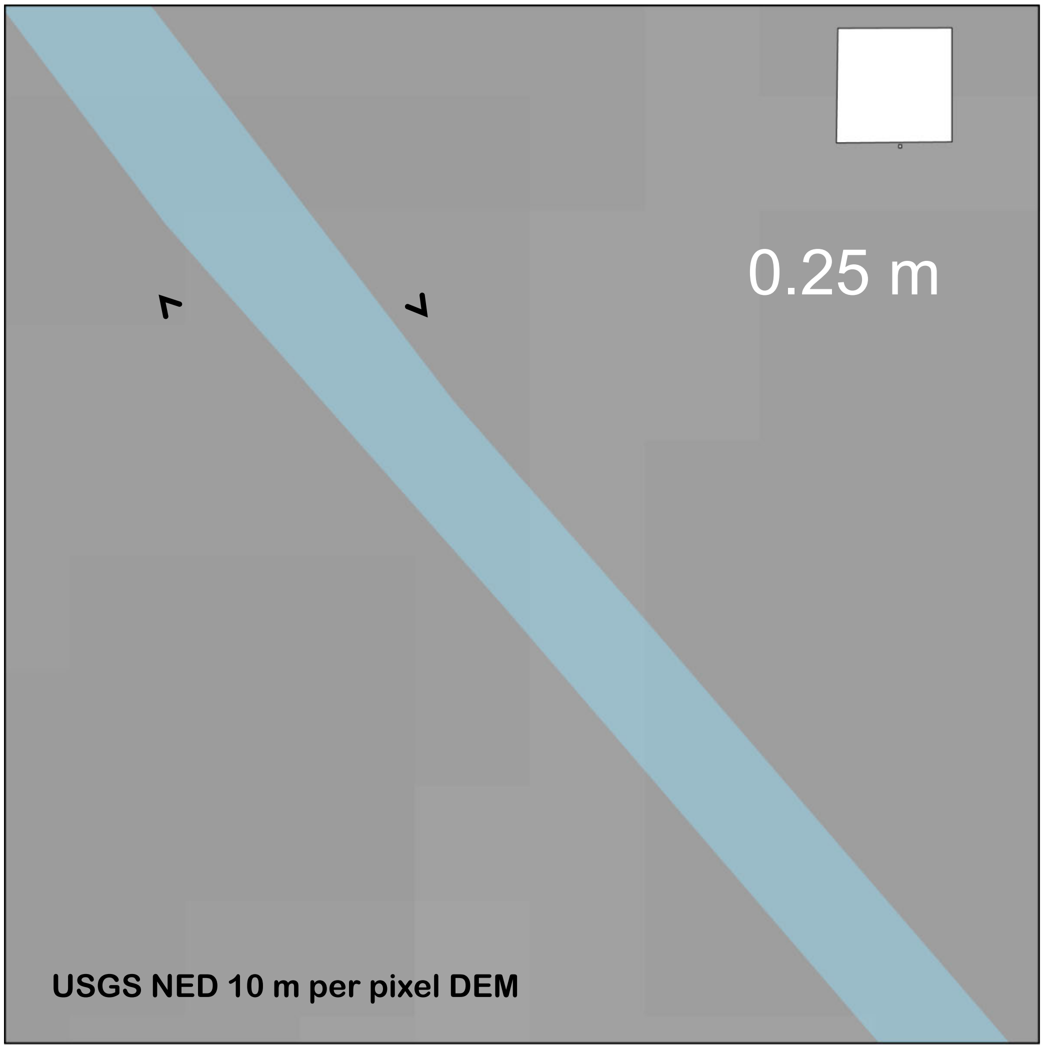
Furnace Creek Offset - Morphology



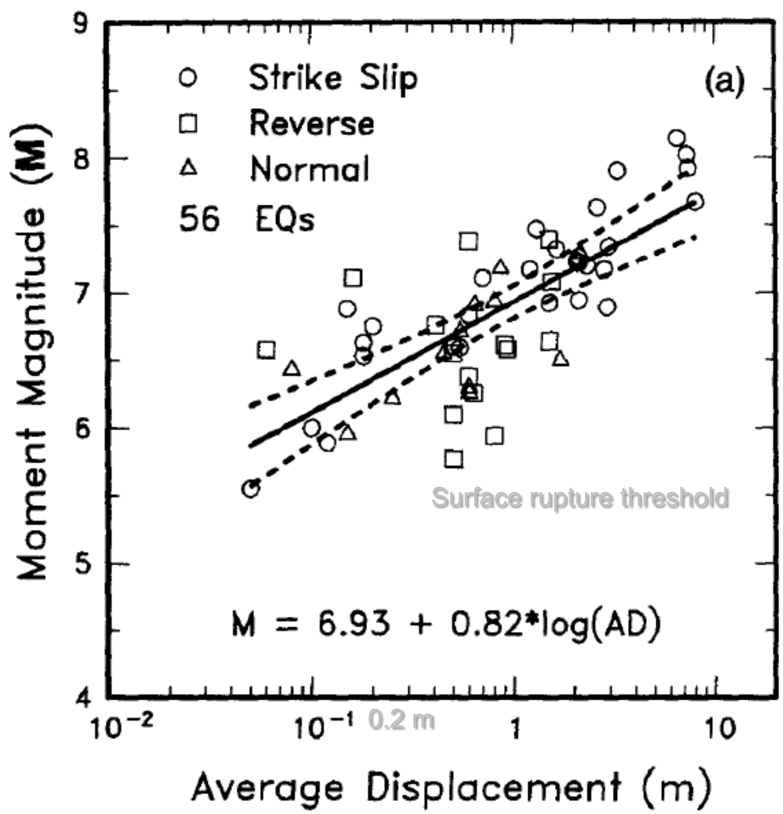
- restored aspect map (offset = 290 m)
- slope aspect map

Frankel et al., 2007, *GRL*

Measuring Slip at the Appropriate Scale

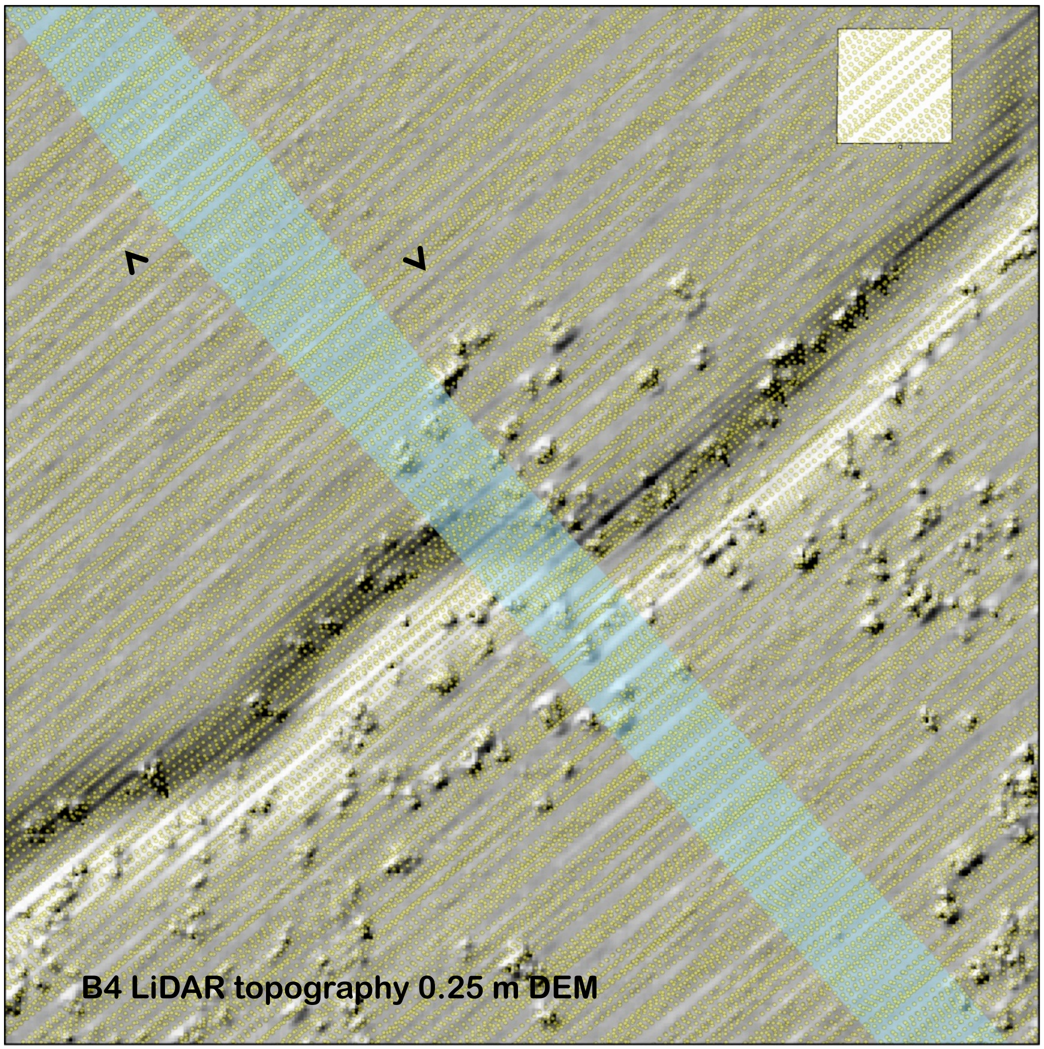


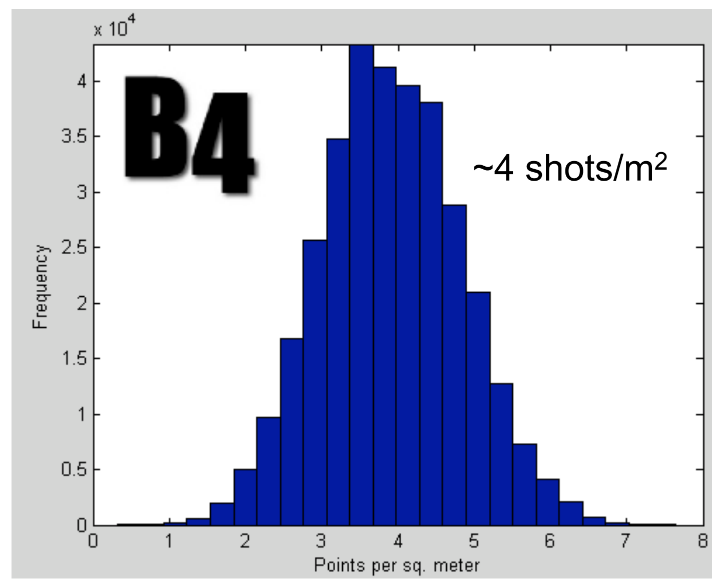
San Andreas Fault
Carrizo Plain, CA



Arrowsmith data

Measuring Slip at the Appropriate Scale

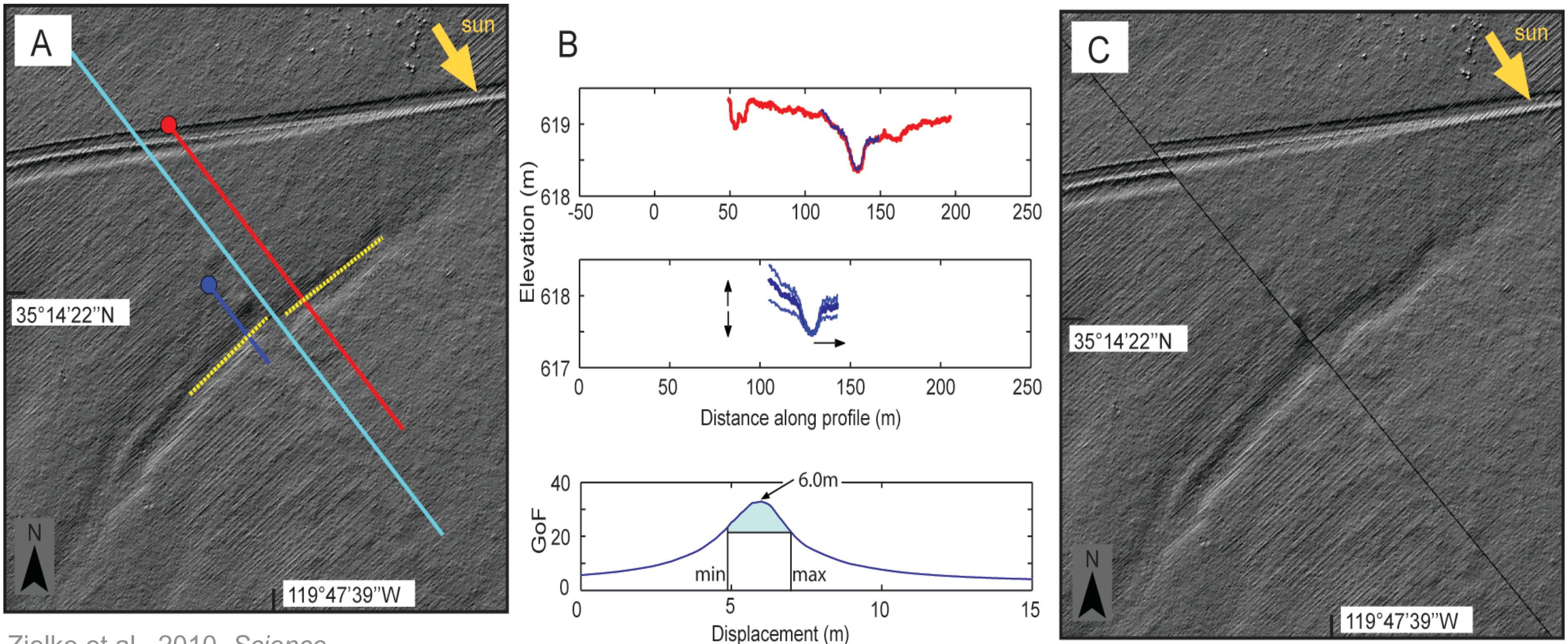




B4/Arrowsmith data

Measuring Slip at the Appropriate Scale

- using 25 cm digital elevation models, delineate fault, feature projection lines, and topographic profile locations.
- backslip projected and rescaled profiles to determine Goodness of Fit, GoF = 1/S[D(elevation)]
- backslip GoF is truncated on plausibility, normalized to produce PDF, and weighted by quality rating of reconstruction

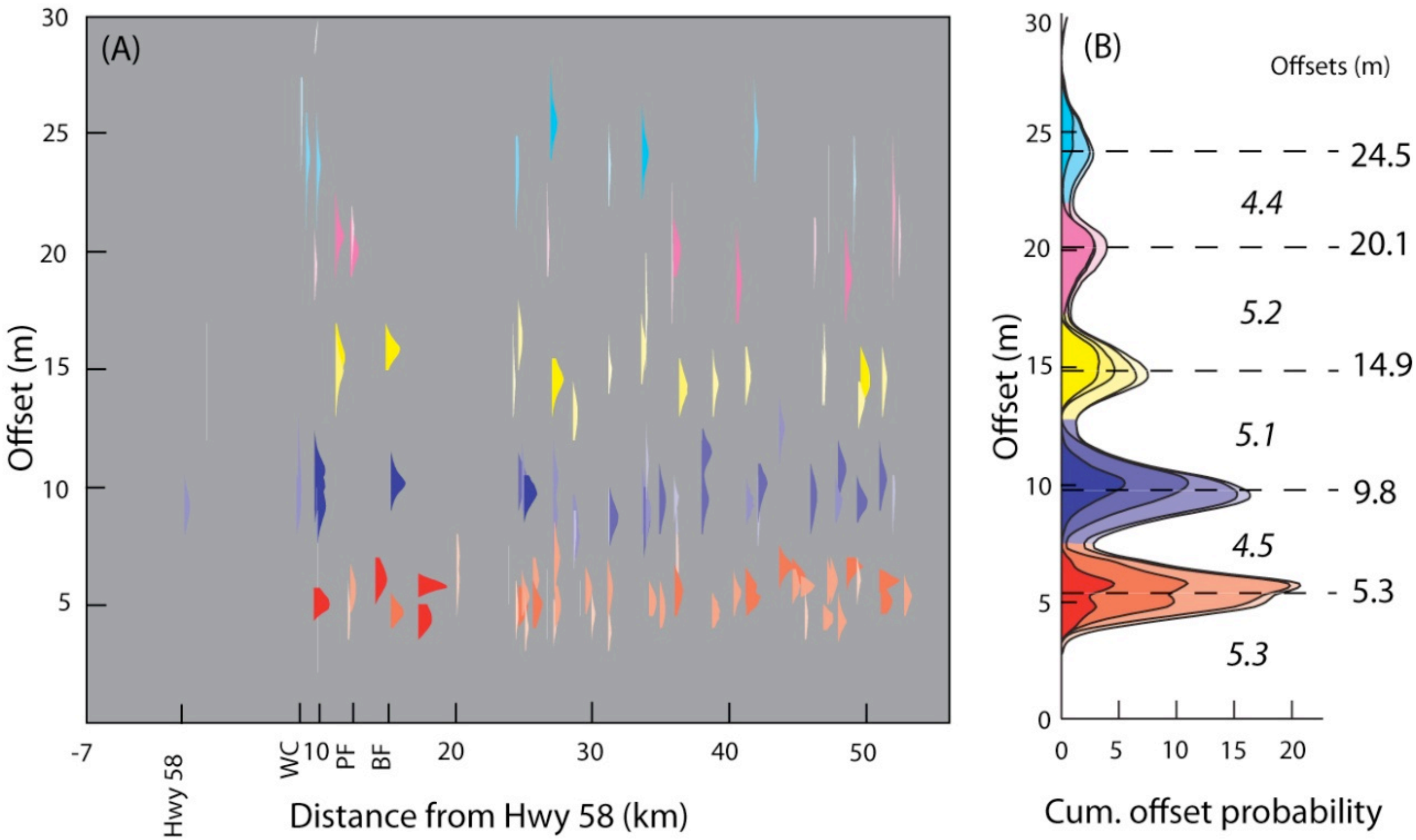


Zielke et al., 2010, *Science*

Slip Per Event - Carrizo Plain, SAF

- offsets fall into well defined groups
- 1857 EQ = 5.3 ± 1.4 m slip
- previously reported value of 8-10 m records cum. slip of multiple (probably 2 large) earthquakes

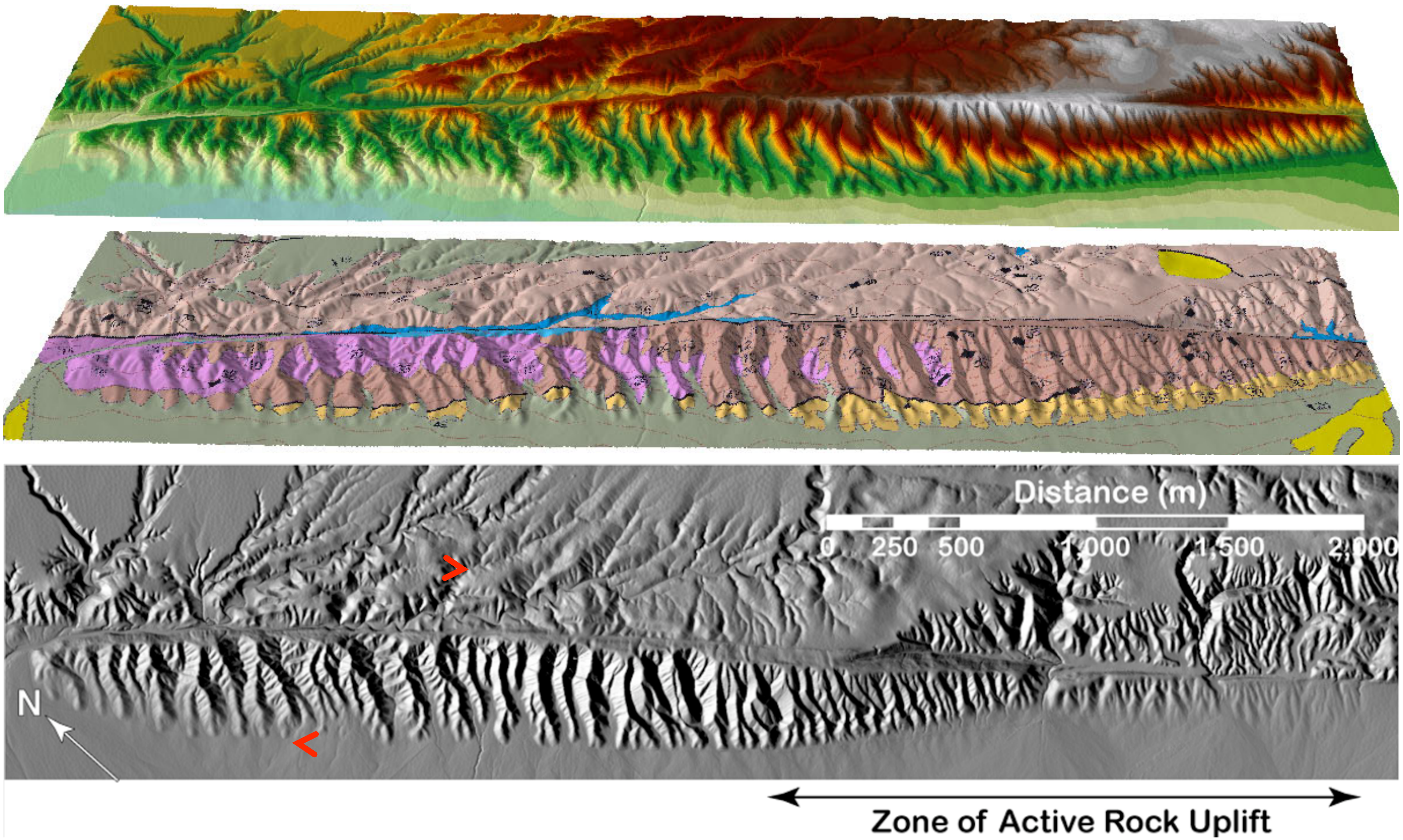
LiDAR-based slip of 1857 earthquake (m): 5.3 ± 1.4
Late Quaternary slip-rate (mm/yr): 34
Strain accumulation rate (mm/yr): 34
Recurrence time of 1857-like Rupture (assuming characteristic EQ model): 140 ± 46 yrs



Assuming each peak corresponds to cumulative offset in successive earthquakes! Will give max. recurrence interval; or recurrence interval for events that dominate slip accumulation

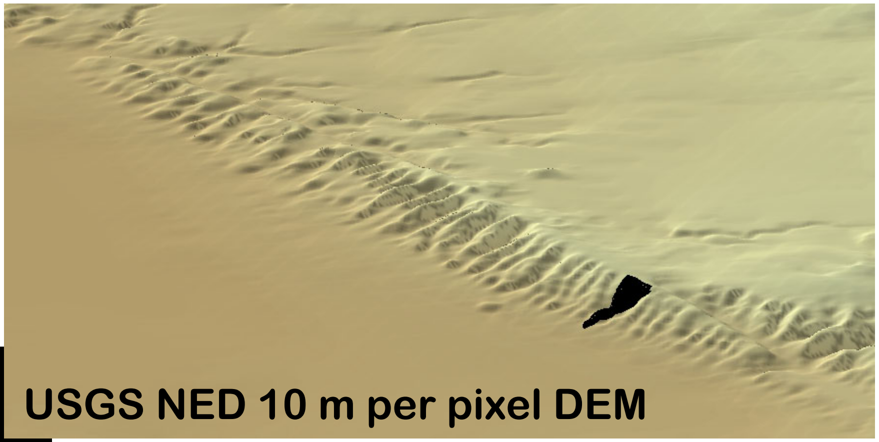
Zielke et al., 2010, *Science*

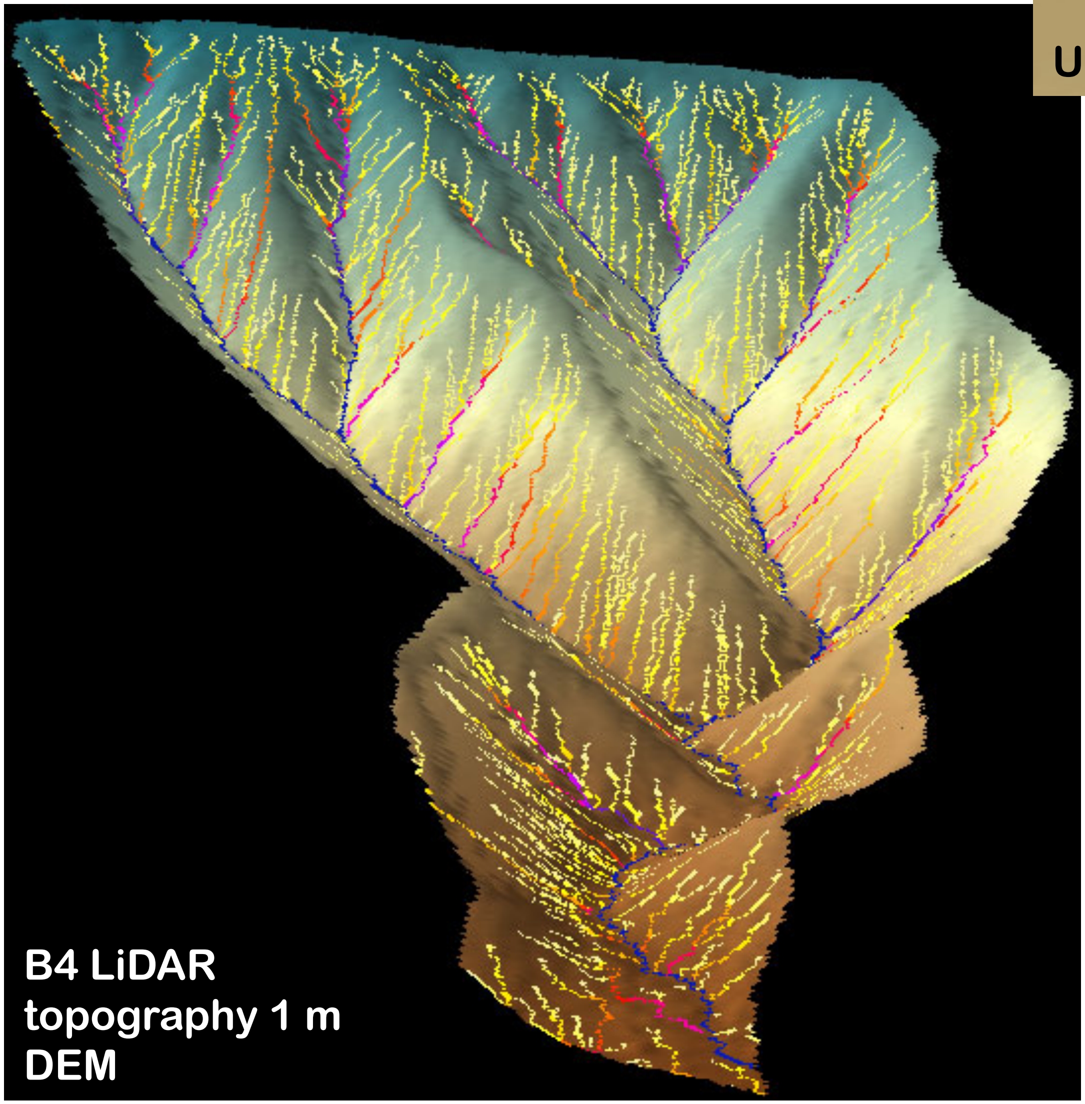
Dragon's Back Pressure Ridge, CA



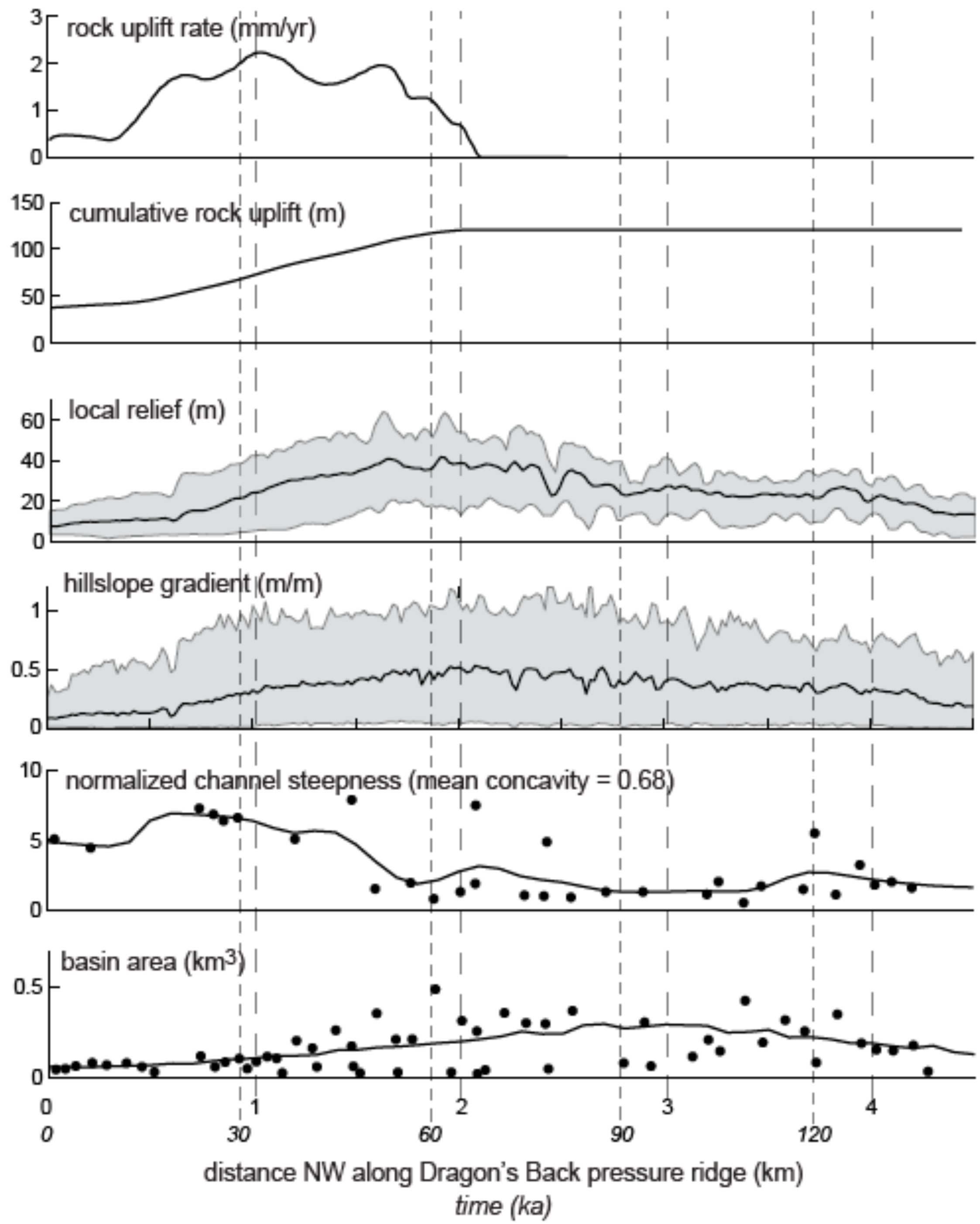
Hilley and Arrowsmith, 2008, *Geology*

Measuring Landscape Characteristics at the Appropriate Scale





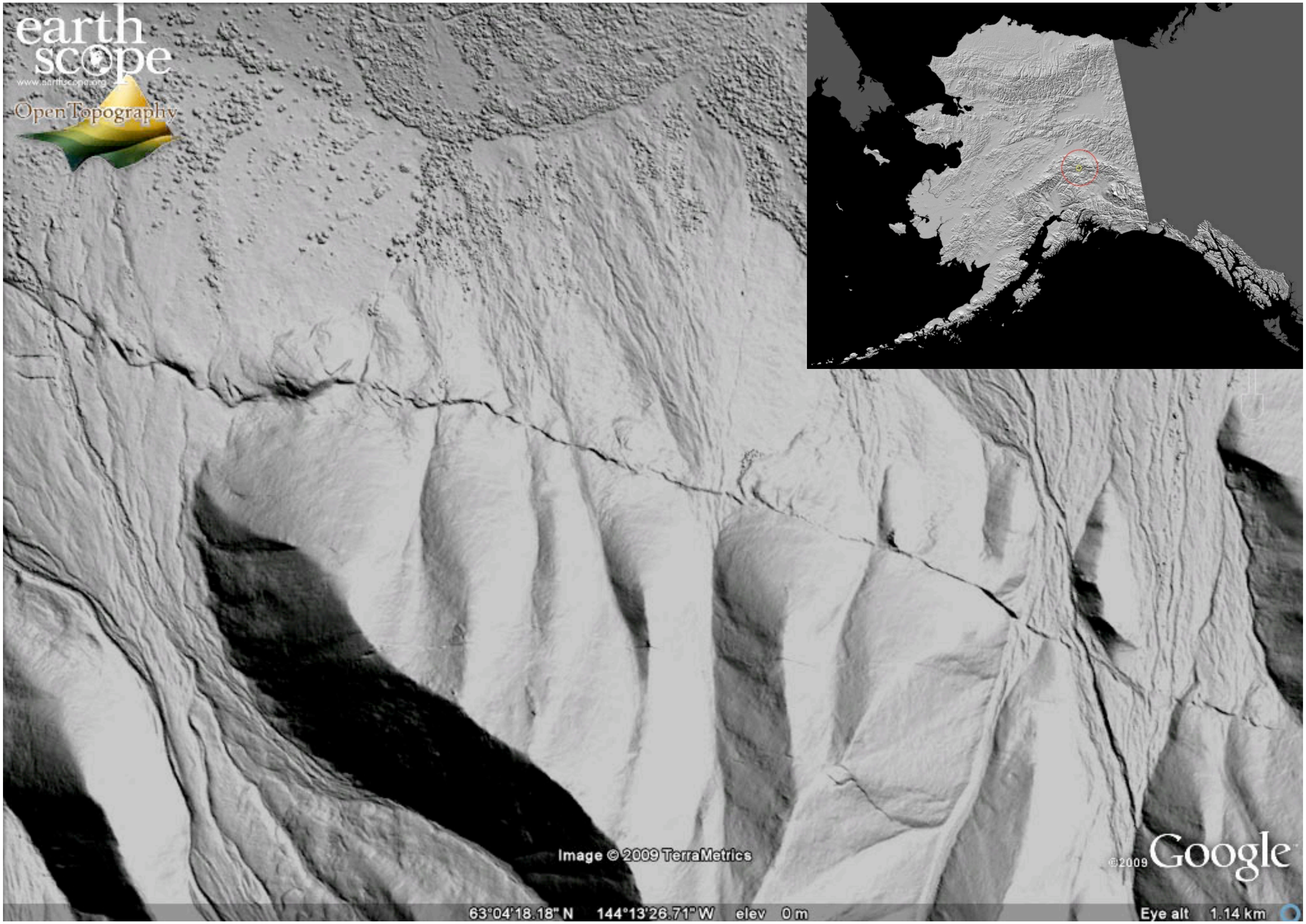
Rock Uplift and Topographic Metrics



- allows a space for time substitution to investigate patterns of rock uplift as a function of fault displacement

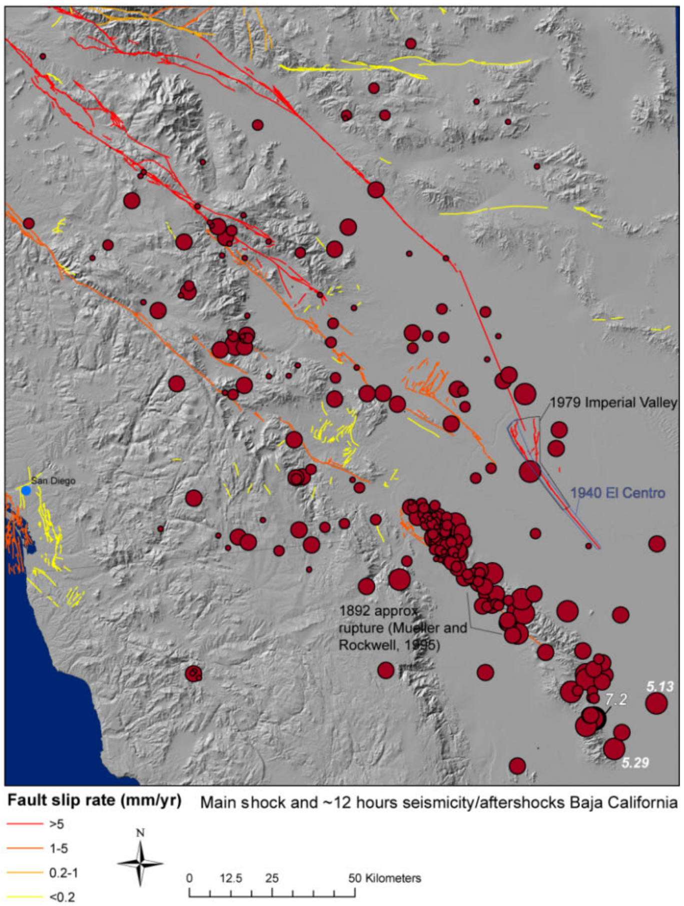
Hilley and Arrowsmith, 2008, *Geology*

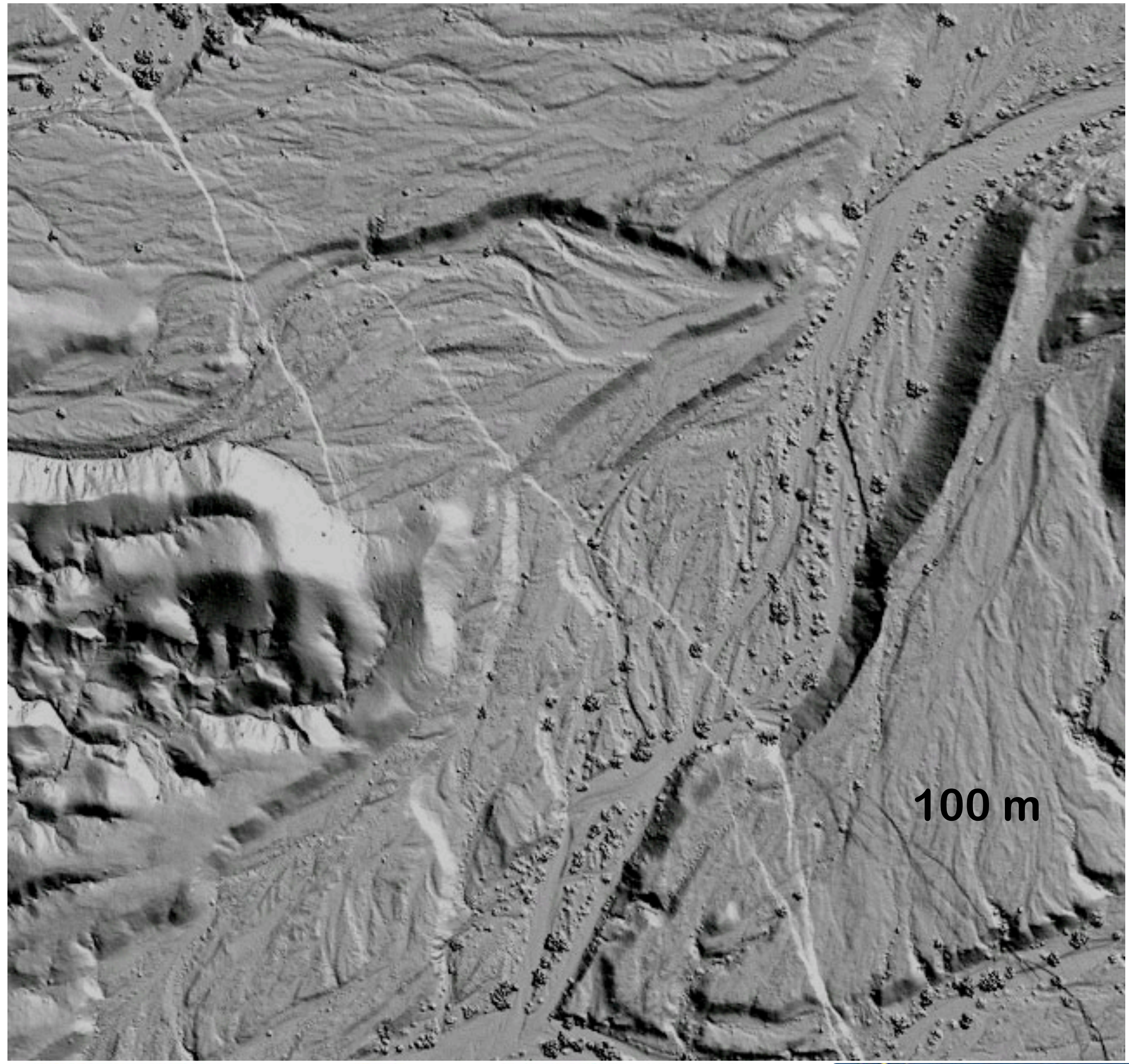
Post Denali, 2002 Earthquake Scan



Post El Mayor-Cucupah EQ Scan

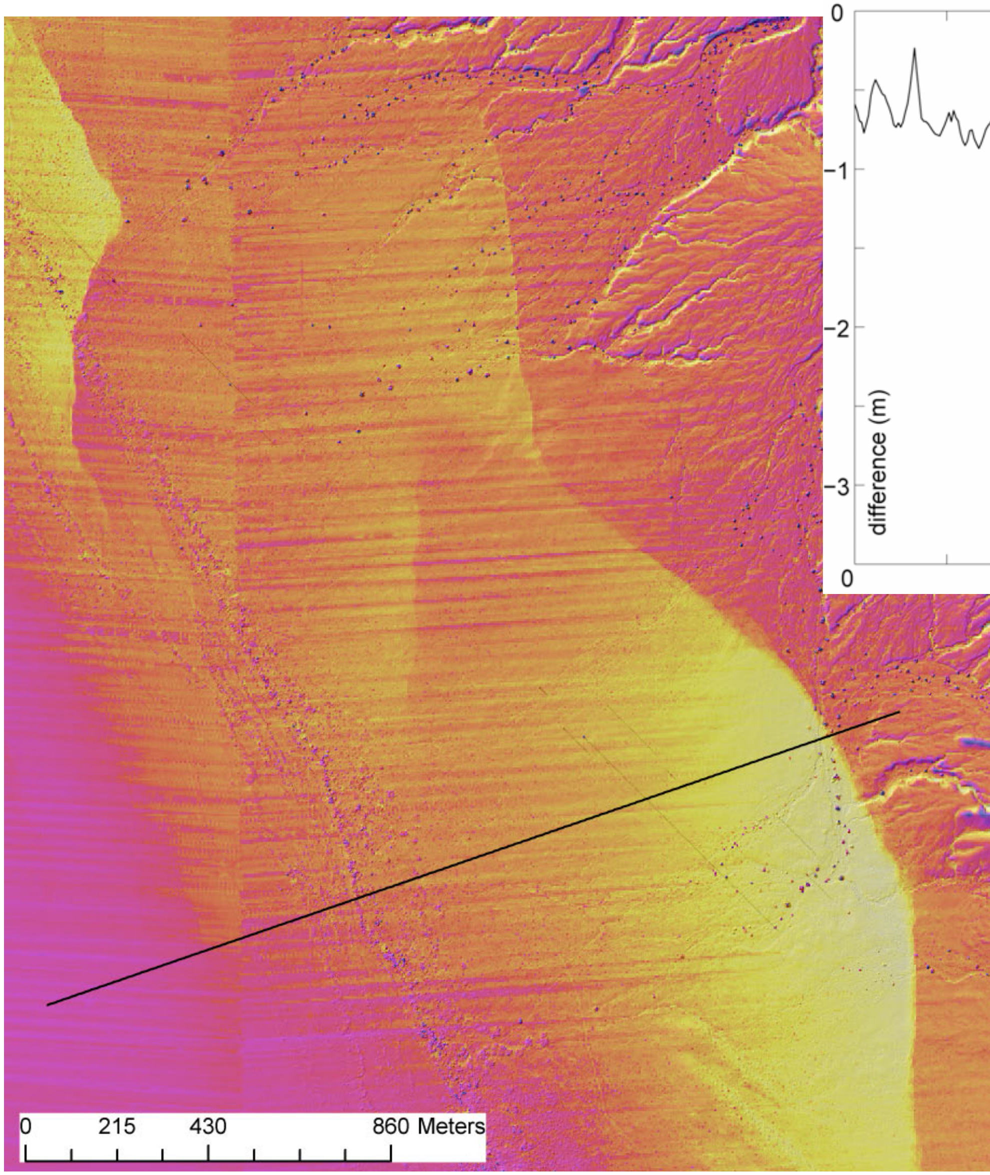
- Oskin, Arrowsmith, Hinojosa, Fletcher (NSF Rapid + SCEC); collected by NCALM

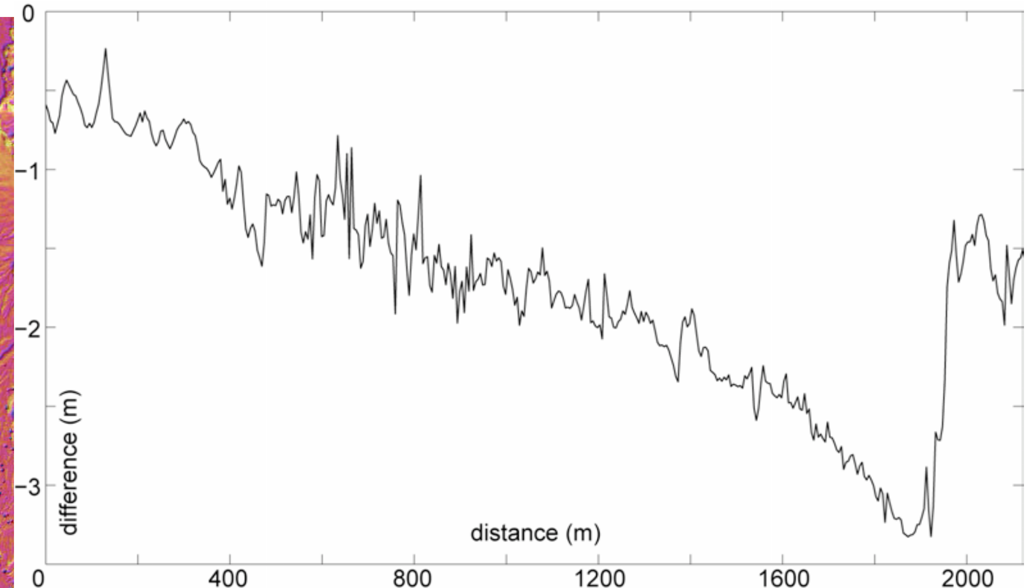




UC DAVIS DEPARTMENT of GEOLOGY
CICESE
ASU School of Earth & Space Exploration Arizona State University
NCALM The National Center for Airborne Laser Mapping

Change Detection with LiDAR Data

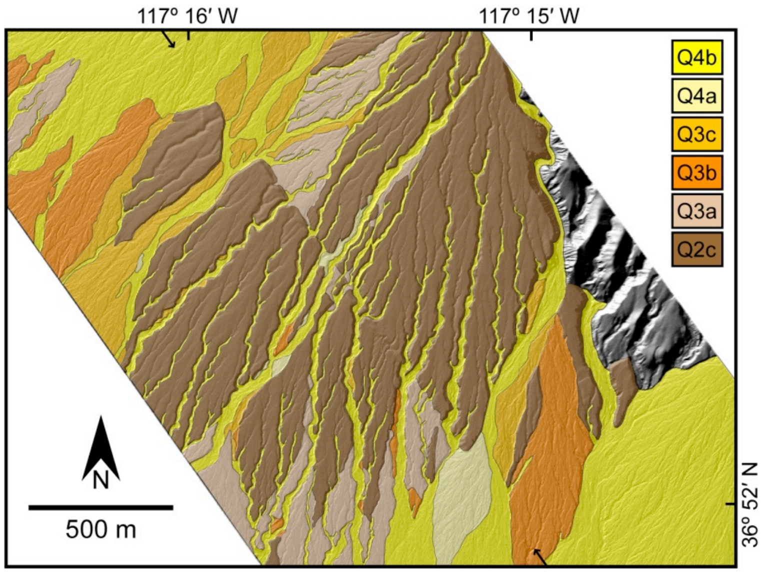




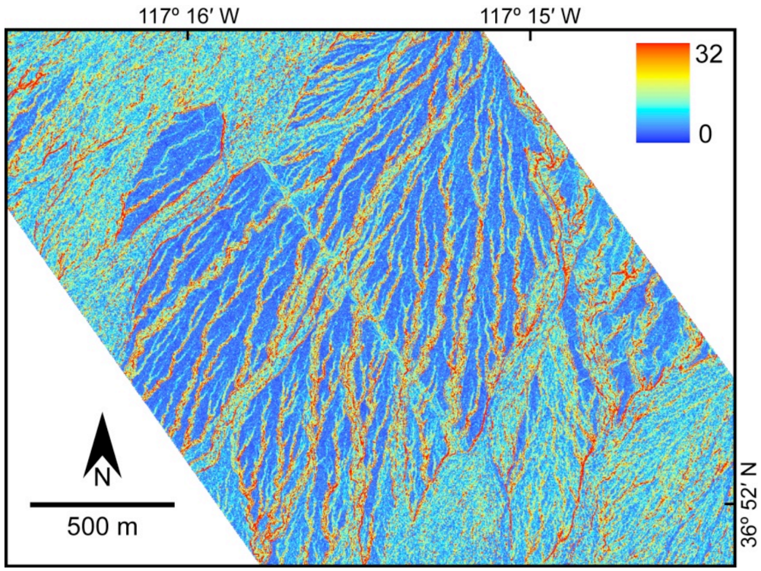
- vertical different pre- and post-El Mayor-Cucupah earthquake
- subtract 5 m pre-earthquake INGEGI DEM from 5 m post-earthquake DEM

Arrowsmith, Oskin, Fletcher, Hudnut, unpub. data

Objective Mapping with Roughness

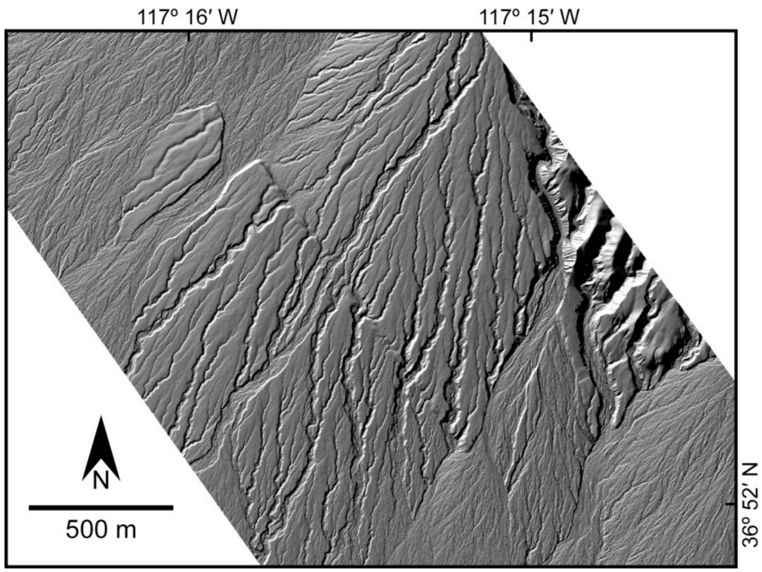


• surficial geologic map



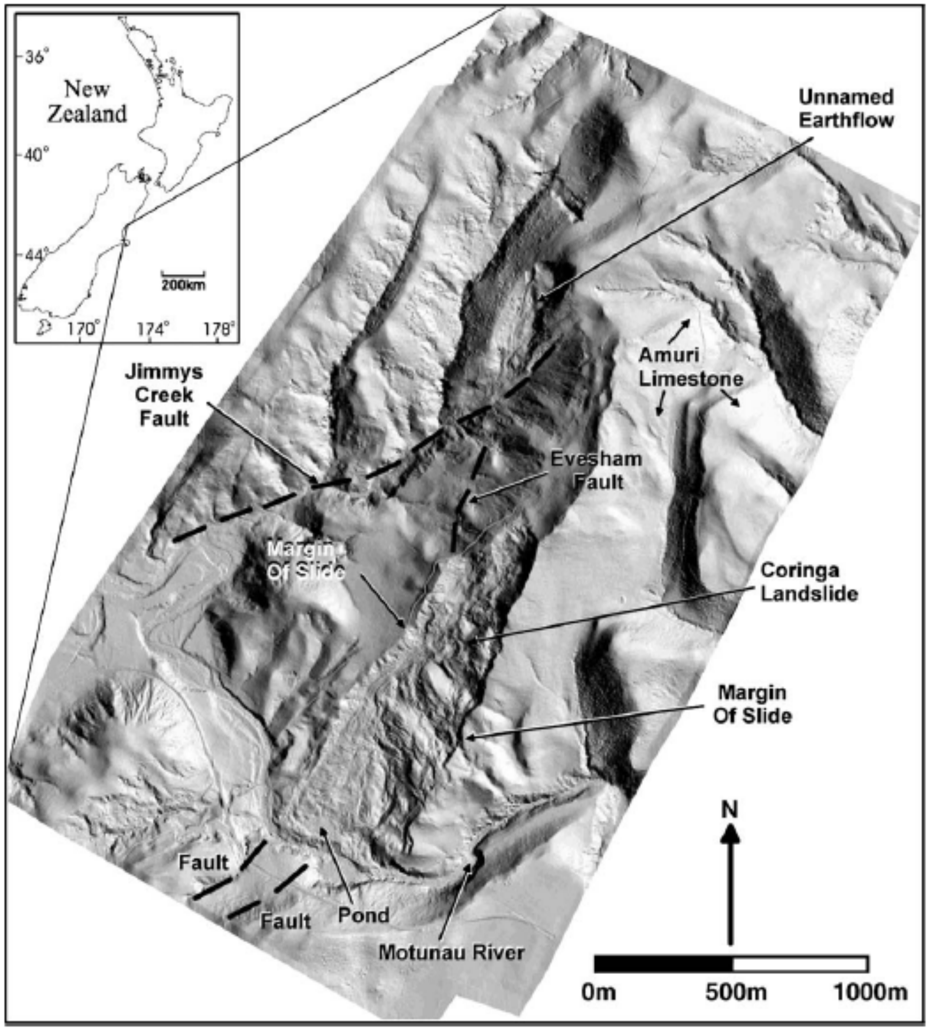
• surface roughness map

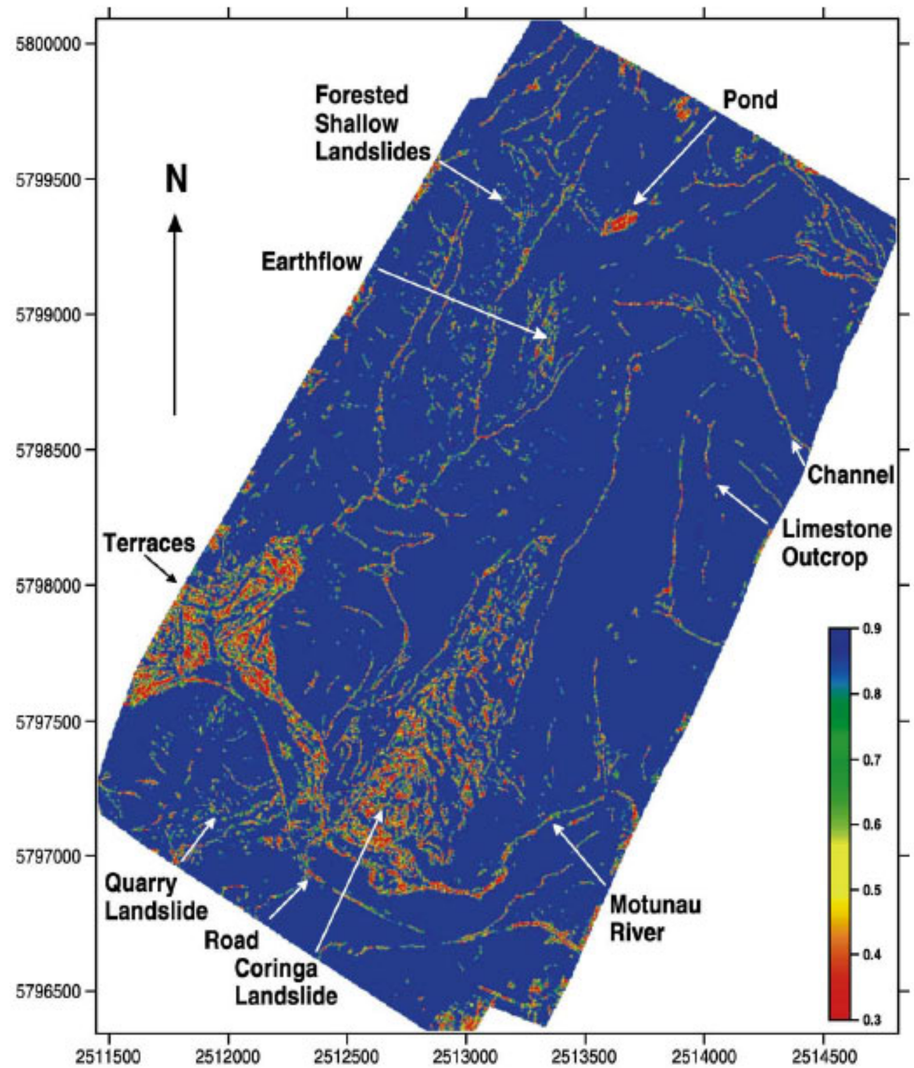
• bare-earth DEM (1 m)



Frankel and Dolan, 2007, *JGR - Earth Surface*

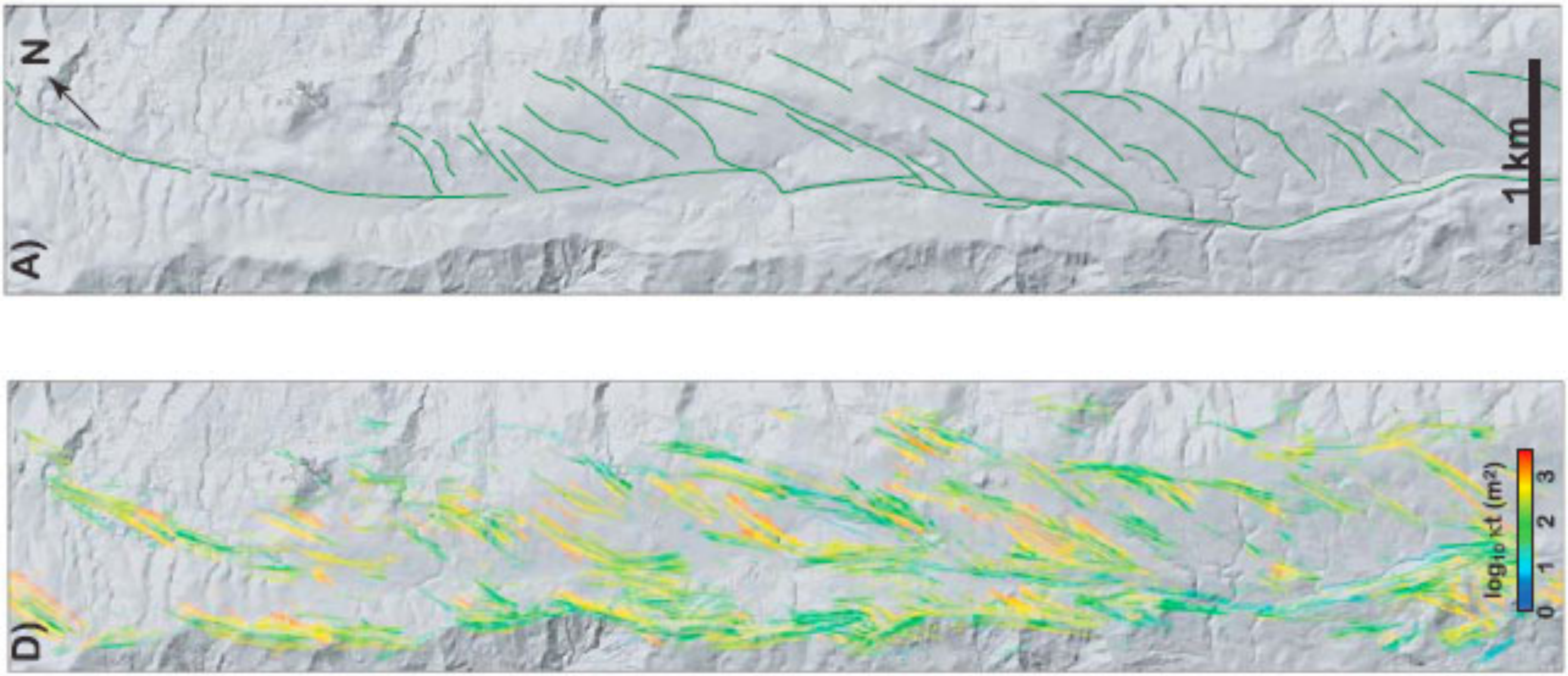
Landslide Identification & Mapping





McKean and Roering, 2004, *Geomorphology*

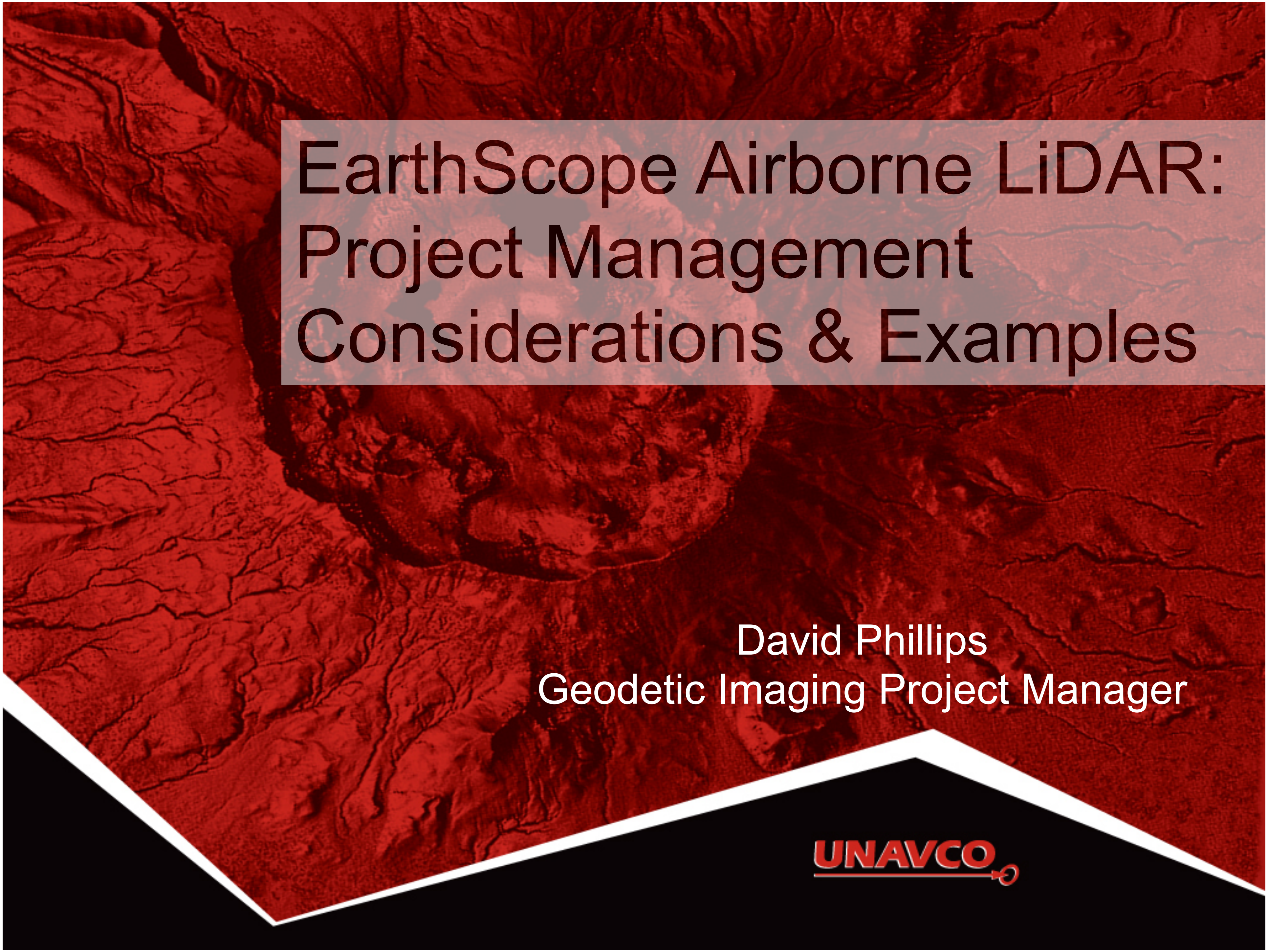
Morphologic Dating of Fault Scarps



Hilley et al., 2010, *GRL*

Conclusions

- LiDAR data are extremely useful for studying active faults, particularly in vegetated regions
- LiDAR can be used to better identify and map structures and quantify displacements
- LiDAR is also useful to investigate landscape response to deformation, objective geologic mapping, and relative (morphologic) dating

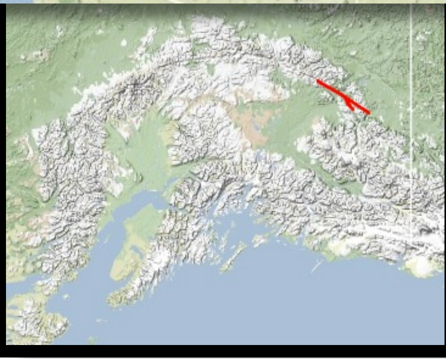


EarthScope Airborne LiDAR: Project Management Considerations & Examples

David Phillips
Geodetic Imaging Project Manager

EarthScope LiDAR

- ~6000 km^2
- High resolution along 1-2 km wide corridors (faults)
- \$300-\$400 / km^2



- Community led planning
  - Identification and development of project objectives, partners and funding (EarthScope: funding from NSF & USGS, extensive participation/support from NPS, military, universities, local agencies; also PSLC examples).
  - Dedicated working group to identify and prioritize basic targets
  - Data coverage vs. resolution vs. cost vs. time, etc.
- Logistics planning and preparation
  - Refinement of targets (flight lines plotting, etc.)
  - Planning for GPS ground control
  - Airfields, fuel, permits, weather (winds, rain, heat, etc.), etc.
- Data collection
- Data processing
- QA/QC
  - Preliminary data products reviewed by science advisors
  - Metadata reports prepared and reviewed
- Data distribution
  - Open access, multiple formats for different user levels (Open Topography)
- Outreach and Education
  - Short Courses (independent and/or part of national meetings)
  - Dedicated training courses (product or group specific)

Caribbean LiDAR Initiative Breakout

- *LiDAR 101*
- ***Open data access and capacity building***

Christopher J. Crosby
San Diego Supercomputer Center

SDSC
SAN DIEGO SUPERCOMPUTER CENTER

COCONet Workshop, Puerto Rico, Feb 3-4, 2011

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Open Data Access:
EarthScope LiDAR data

- LiDAR acquisition over 5600+ km^2 = 35+ billion LiDAR returns!
- Large user community with variable needs and levels of sophistication.

How do we deliver these large community data sets to users?

OpenTopography

SDSC
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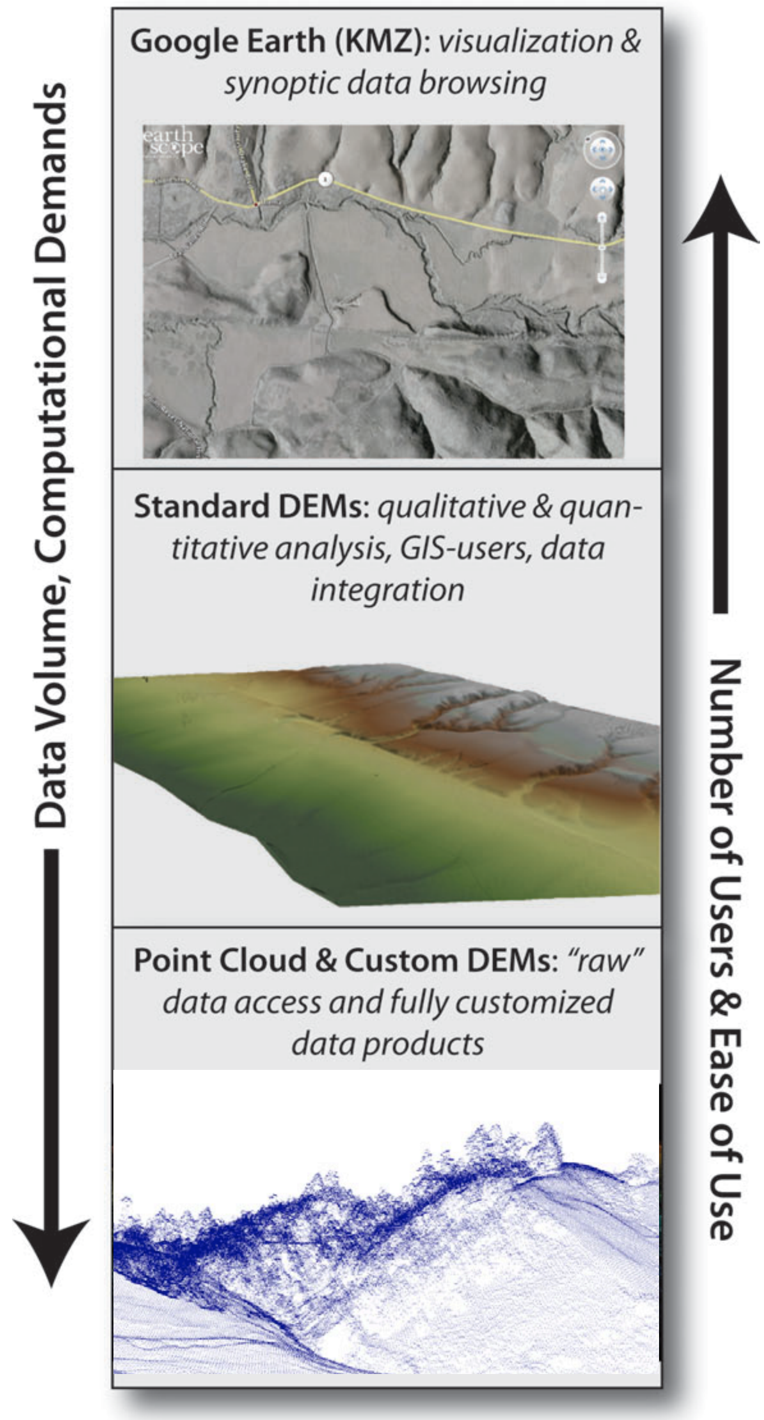
OpenTopography

NSF funding to:

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

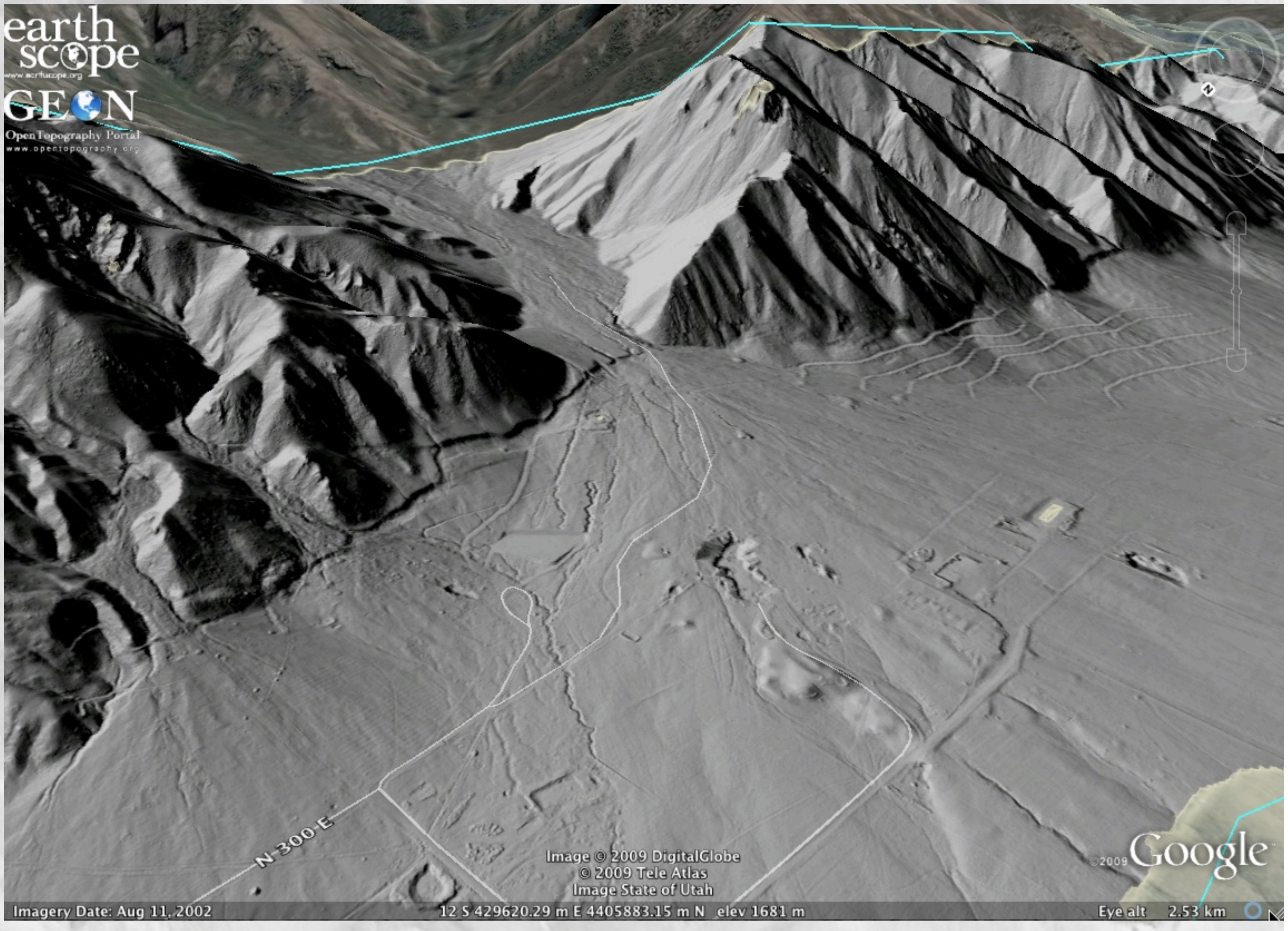
- Large and diverse user community requires range of data products.
  - How do we allow non-experts to access them?
- Training and capacity building to increase the number of data users
- Significant education and outreach potential with these data



LiDAR-derived imagery & Google Earth

Display data in Google Earth for synoptic data browsing, basic mapping and visualization, and education and outreach.

Google Earth:
- Free
- easily to use
- enables integration with imagery, geographic layers, and other data.



OpenTopography

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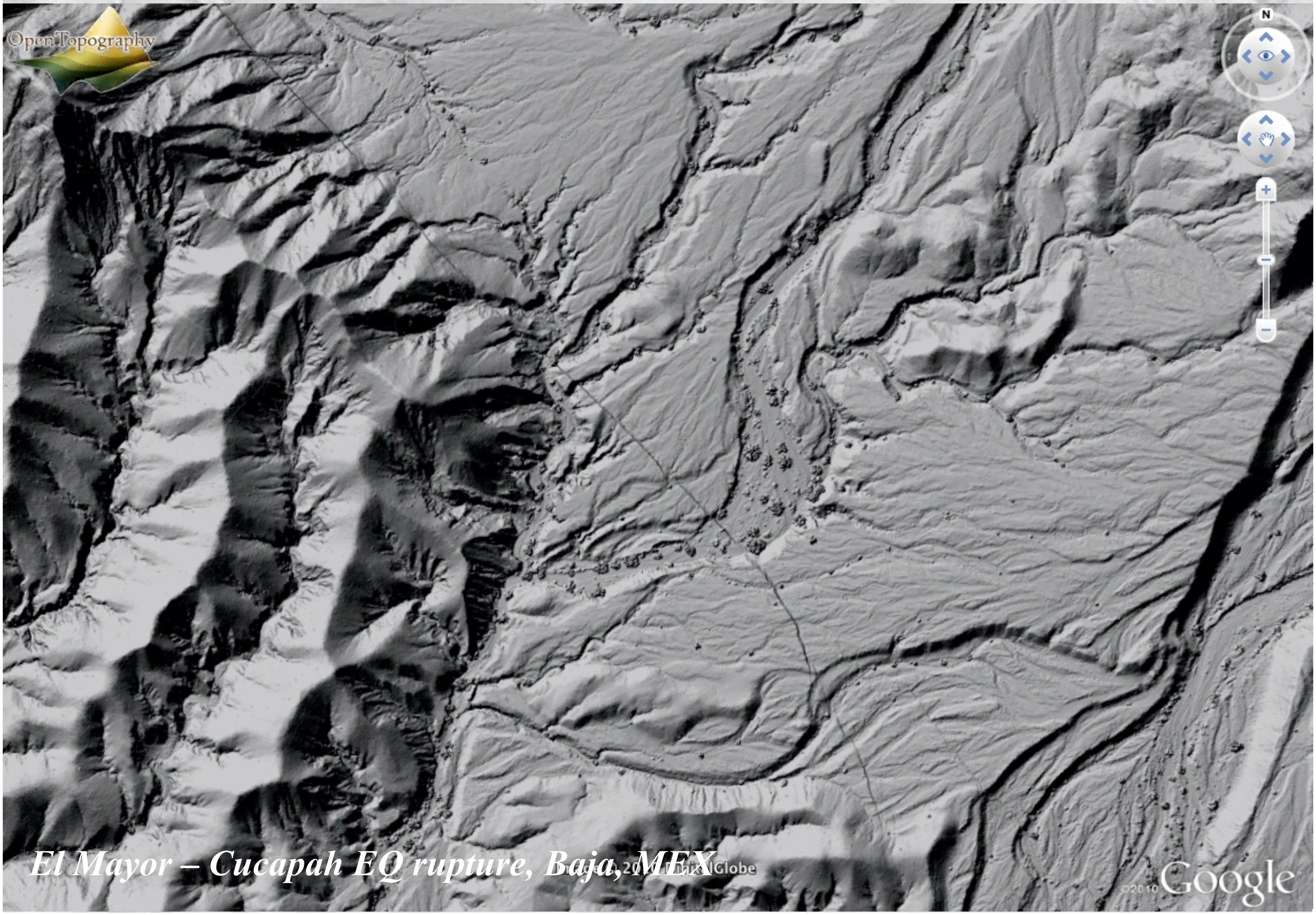
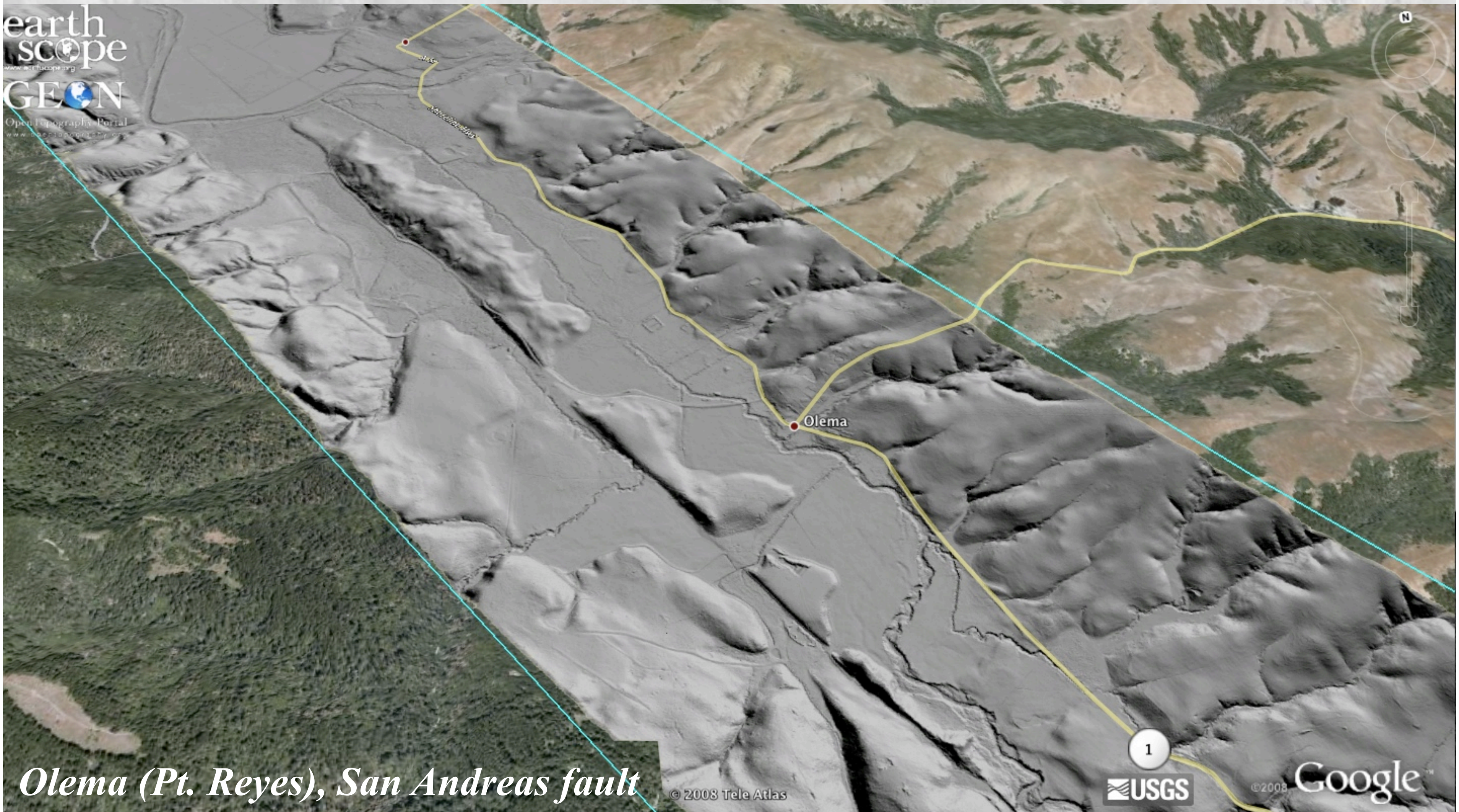
http://www.opentopography.org/kml



El Mayor – Cucapah EQ rupture, Baja, MEX

http://www.opentopography.org/kml



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LiDAR point cloud

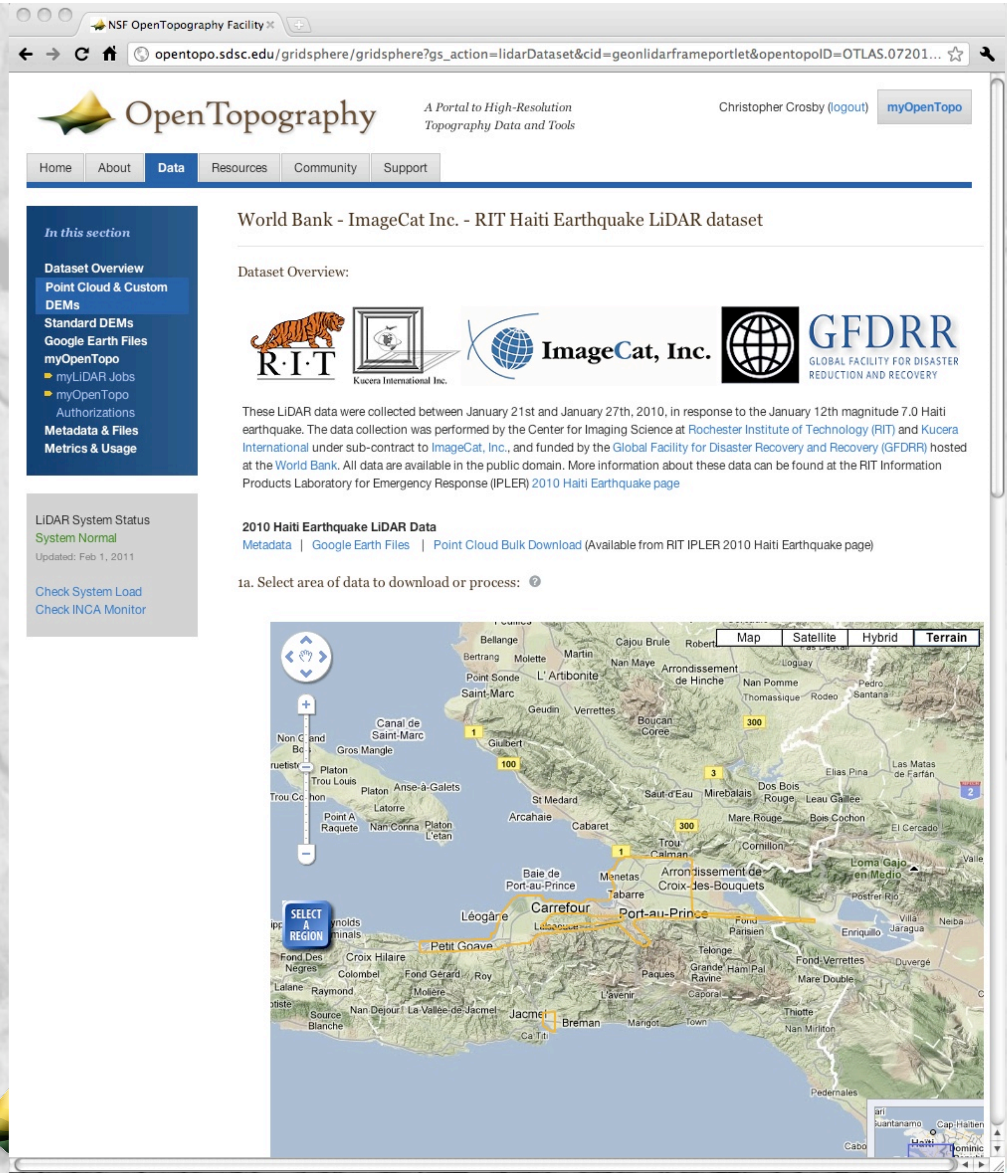
- Full raw datasets freely available

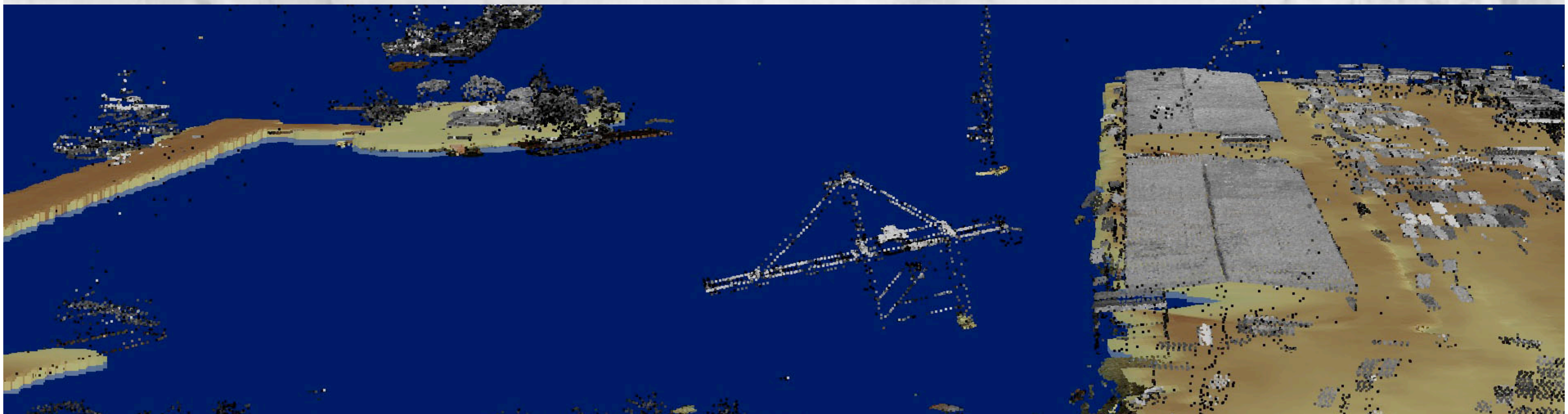
- Web-based tools for basic data processing

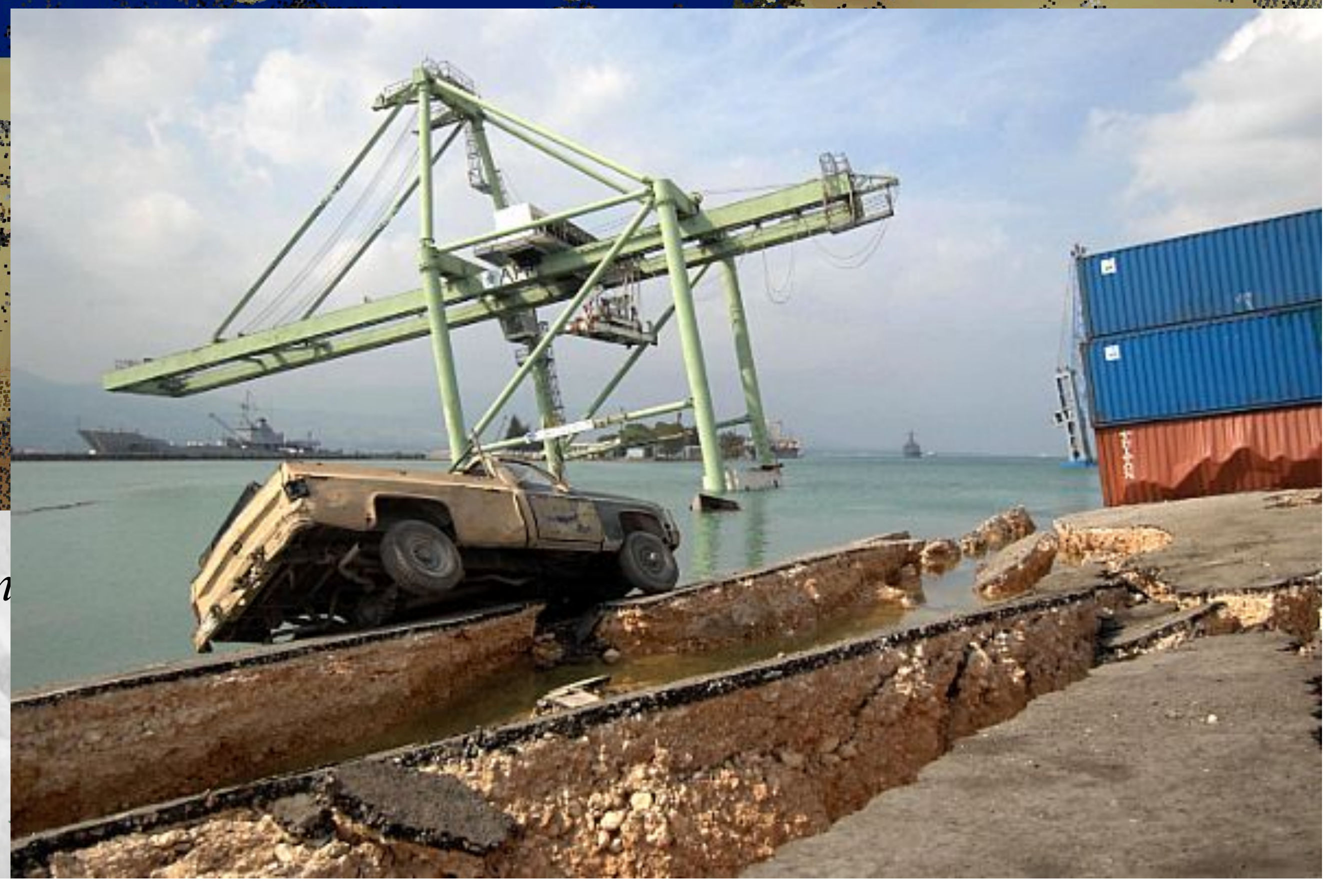
•Example: Haiti:

- 838 km^2

- 2.9 billion lidar pts



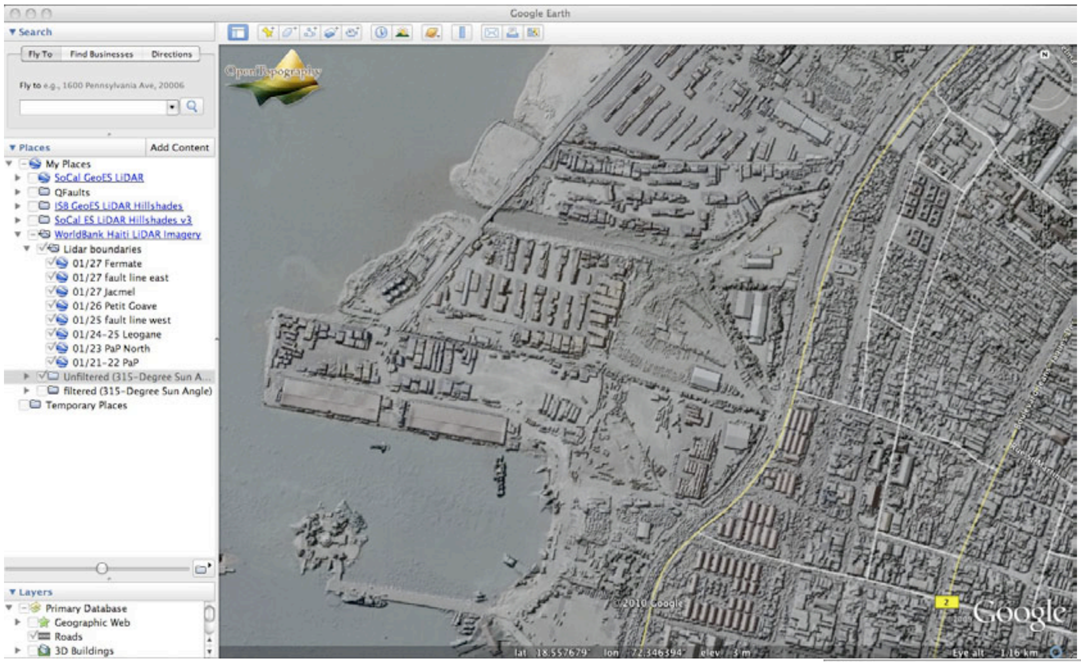




Port-au-Prince waterfron

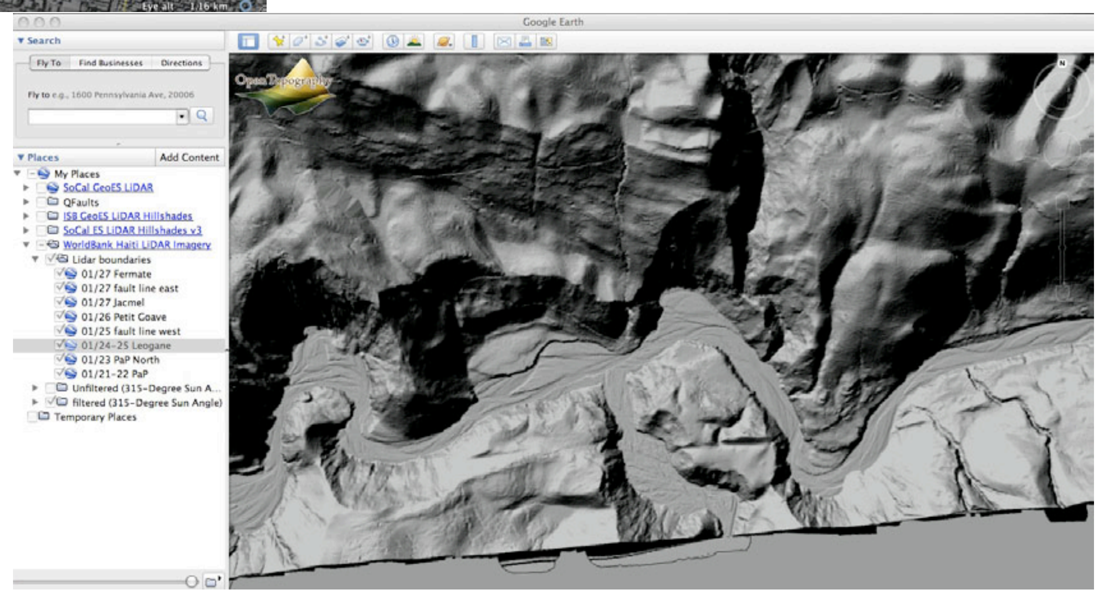
Post-Haiti EQ LiDAR:
LiDAR Imagery in Google Earth

OpenTopography



- Excellent mechanism for delivery of easy to use data products in event response scenario.

- Rapid generation – Files online ~48 hrs after data posted



<u>Data Credit</u>:
Center for Imaging Science at Rochester Institute of Technology (RIT), Kucera International, and ImageCat, Inc. w/ funding from World Bank and the Global Facility for Disaster Recovery and Recovery

When the data are easily accessible, people will use them

EarthScope:

Point Cloud:

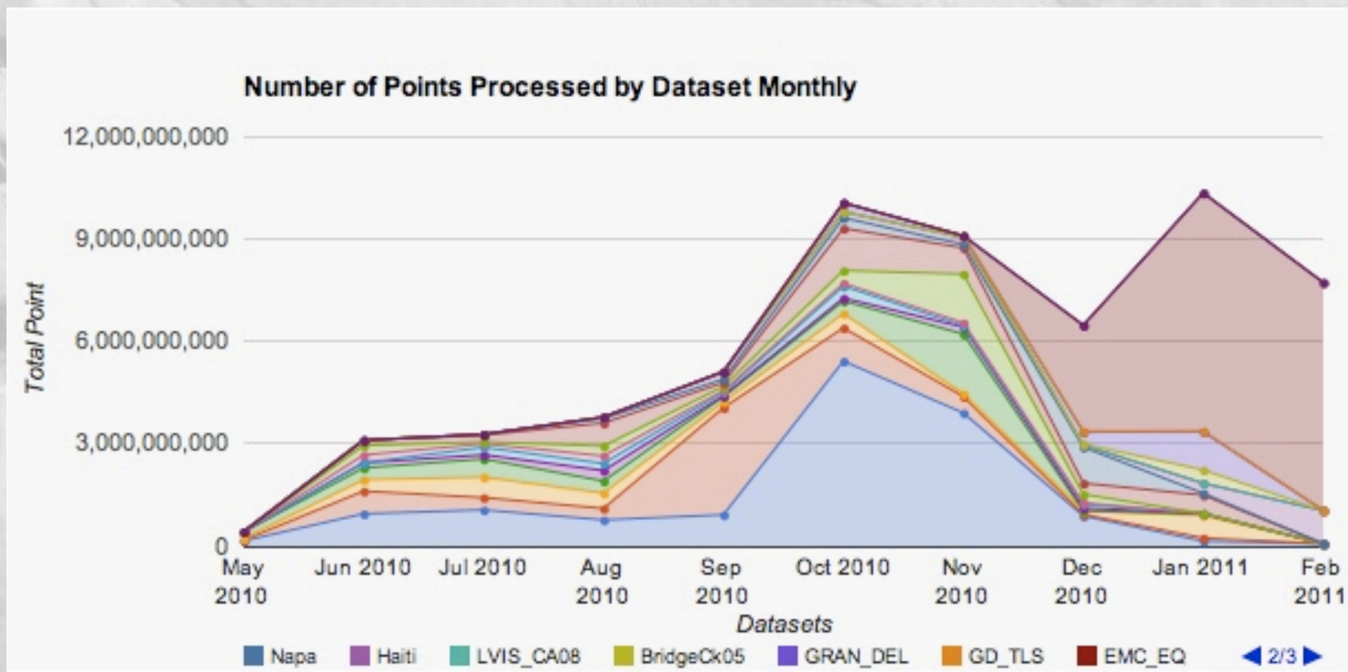
- 1,669 jobs, 40.6 billion points

Google Earth:

- 12,630 downloads

DEMs:

- 88,187 files, 2046 unique IPs



Capacity building

- Hands-on training in processing and analysis of lidar data
  - Held in collaboration w/ regional universities and national agencies
  - Using open source / free software
  - Training materials in Spanish and French

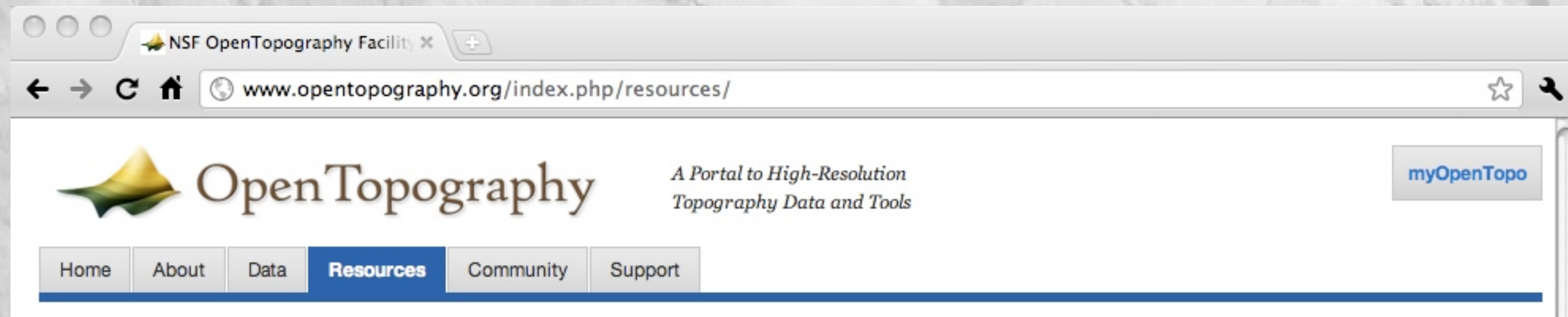
- Modeled after recent workshops held throughout US to build capacity for use of EarthScope and other Earth science oriented lidar.
  - See: http://www.opentopography.org/index.php/resources/short_courses

- Lidar skills = GIS

- Provides fundamentals relevant to working with other geospatial data

2009 SCEC lidar short course

Online Training Resources



- Education & Training resources
  - **Short course materials**: slides, tutorials, sample data
  - Tutorials & videos
  - Classroom resources to encourages use of data in the classroom

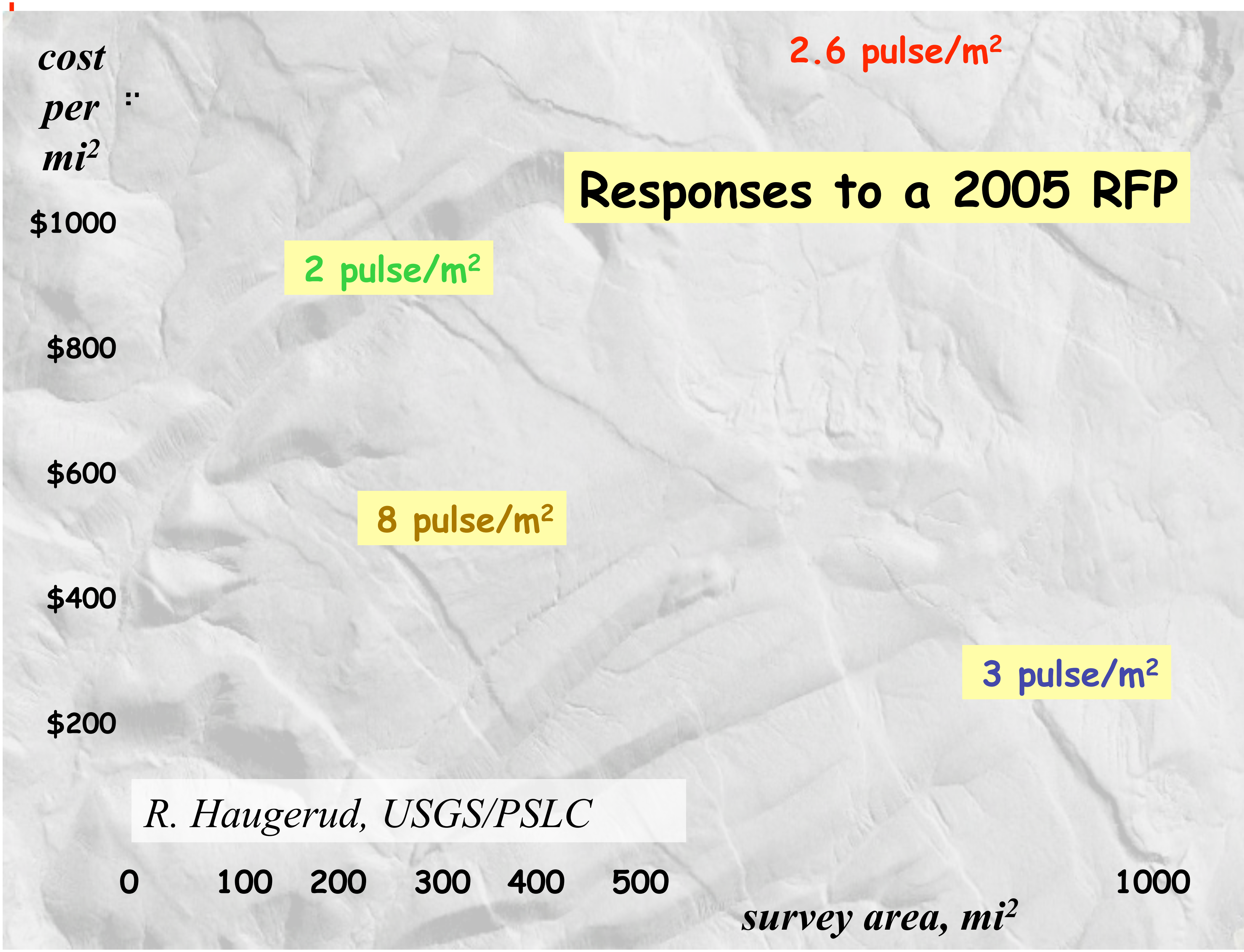
Funding Caribbean Lidar?

Models:

- EarthScope lidar = NSF

- Regional Consortium = partnership with diverse funding sources
  - Leverage economies of scale

  - Puget Sound Lidar Consortium
  - Orgeon Lidar Consortium


Responses to a 2005 RFP
cost per mi²
$1000
$800
$600
$400
$200
2.6 pulse/m²
2 pulse/m²
8 pulse/m²
3 pulse/m²
R. Haugerud, USGS/PSLC
0
100
200
300
400
500
1000
survey area, mi²

Recent PSLC contract:

• 50-100 sq mi^2:	\$943/mi^2	*\$420/km^2*
• 100-150 mi^2:	\$704/mi^2	
• 150-200 mi^2:	\$592/mi^2	
• 200-250 mi^2:	\$521/mi^2	
• > 250 mi^2:	\$472/mi^2	*\$210/km^2*

R. Haugerud, USGS/PSLC

- Mobilization and setup/planning are expensive
- Advantageous to build partnerships, leverage other efforts
- Consistent data specifications & avoids missed areas of interest

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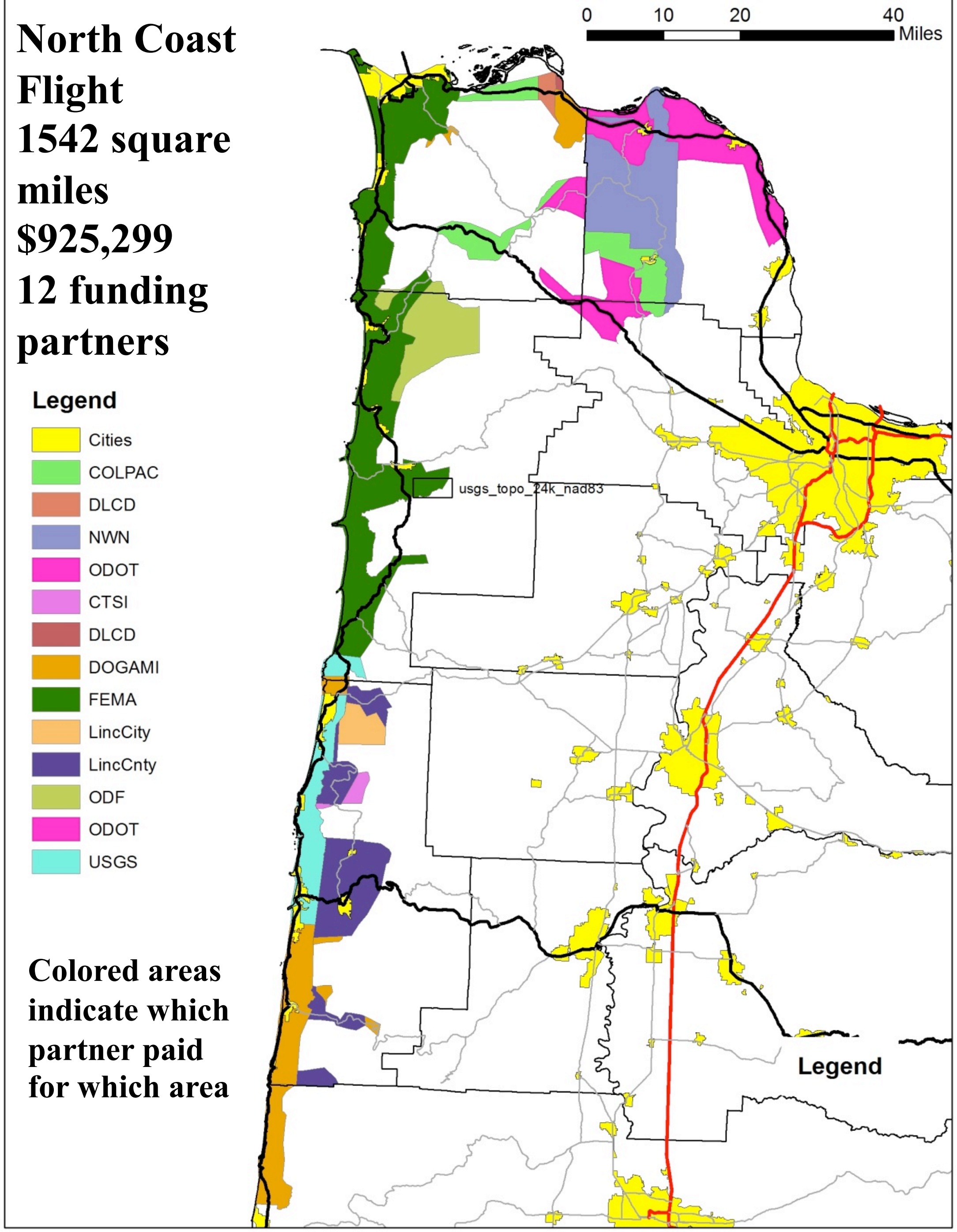
North Coast Flight
1542 square miles
$925,299
12 funding partners



Colored areas indicate which partner paid for which area

<u>OLC business model</u>:

- flight areas anchored by a major funding partner who can commit to a significant initial investment ($50 to $100k).
- With the anchor funding in place, DOGAMI aggressively seeks additional partners in adjacent areas to expand the area.
- Collection areas should be large and contiguous
- All data in the public domain

I. Madin, DOGAMI

Existing Lidar in Caribbean?

- World Bank - ImageCat Inc. - RIT Haiti Earthquake LiDAR dataset
  - Freely available via OpenTopography, and RIT and USGS FTPs

- US Army Corps of Engineers Lidar survey for Puerto Rico
  - Freely available via USGS EROS, but processing is incomplete, resolution low, and geolocation are poor

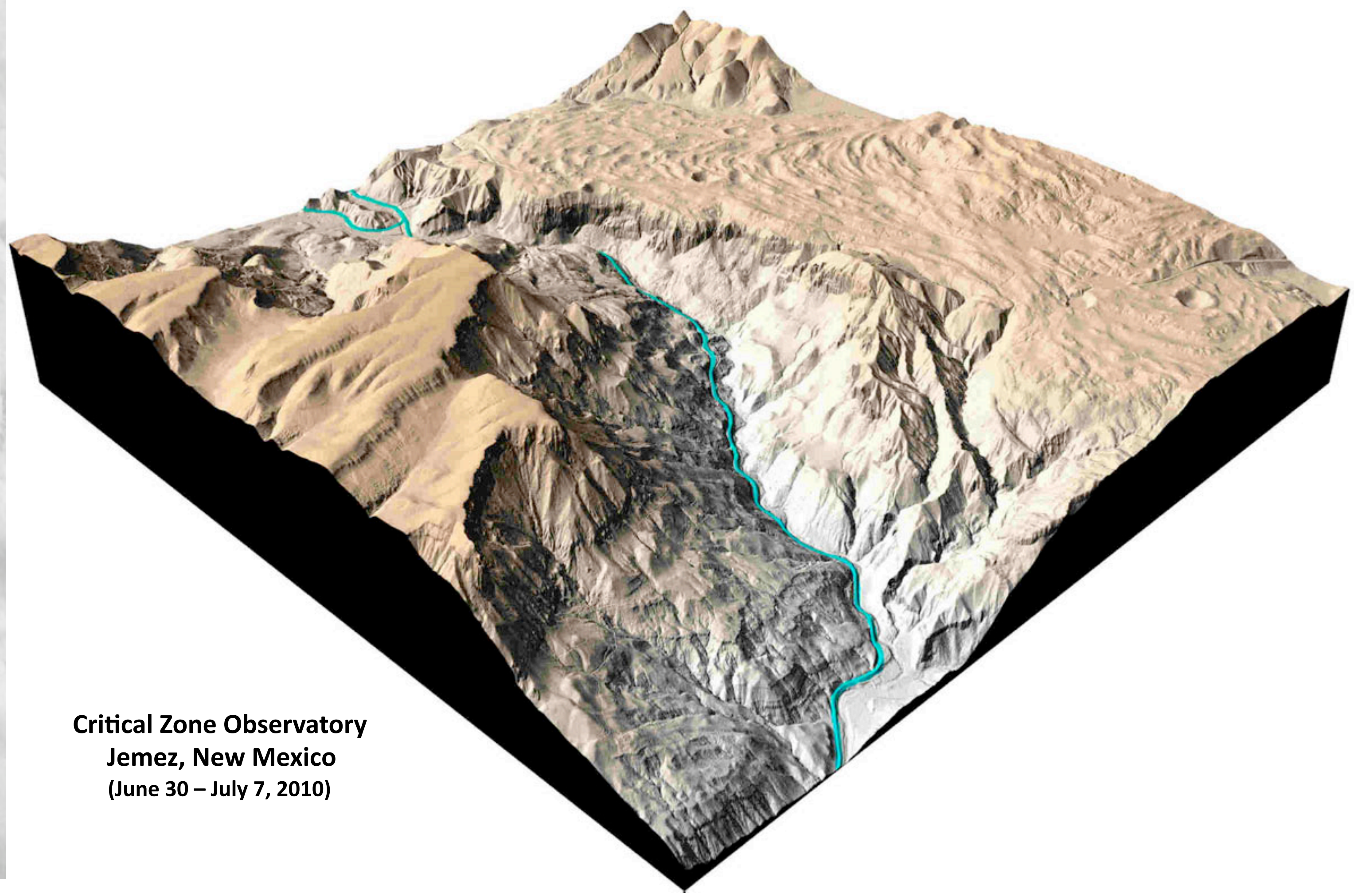
- NSF Luquillo Puerto Rico Critical Zone Observatory (NE Puerto Rico)
  - Collection in process by NCALM. Data to be available (?)

- NCALM Caracol, Belize survey
  - Data to be available (?)
  - more work planned

The National Center for Airborne Laser Mapping

UNIVERSITY of HOUSTON • UNIVERSITY of CALIFORNIA, Berkeley

Topography by GEMINI LiDAR



Critical Zone Observatory
Jemez, New Mexico
(June 30 – July 7, 2010)

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NCALM

The National Center for Airborne Laser Mapping

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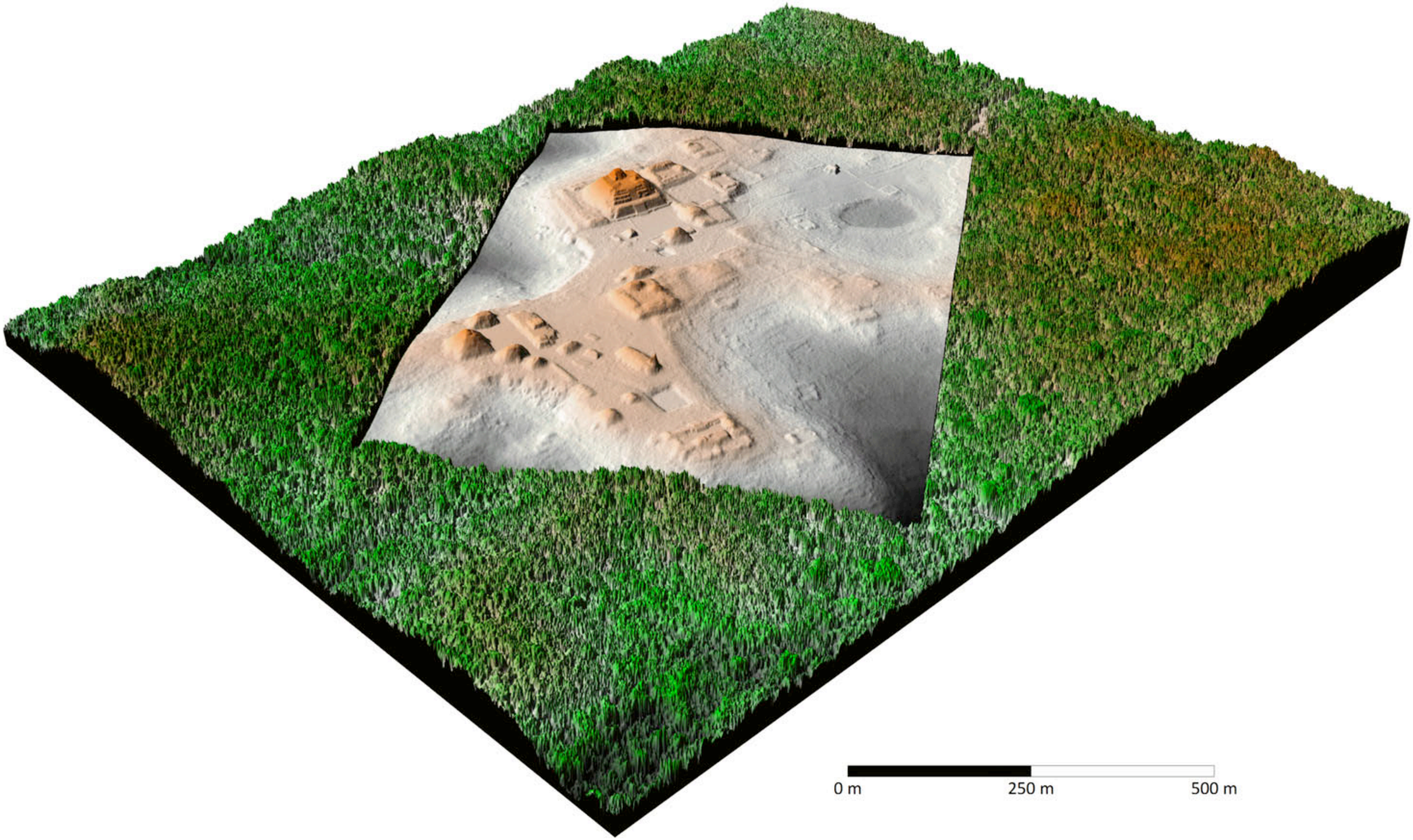

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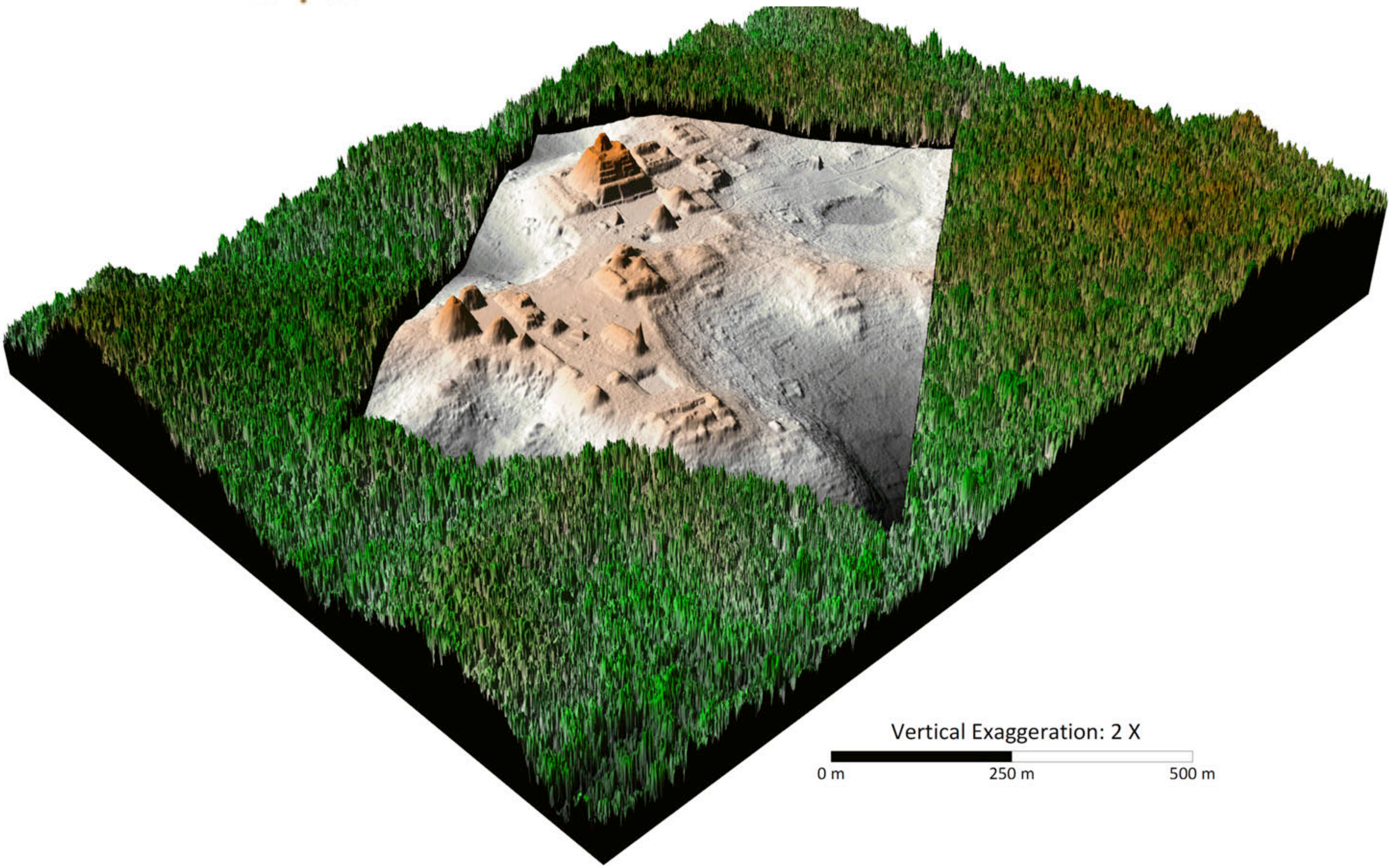

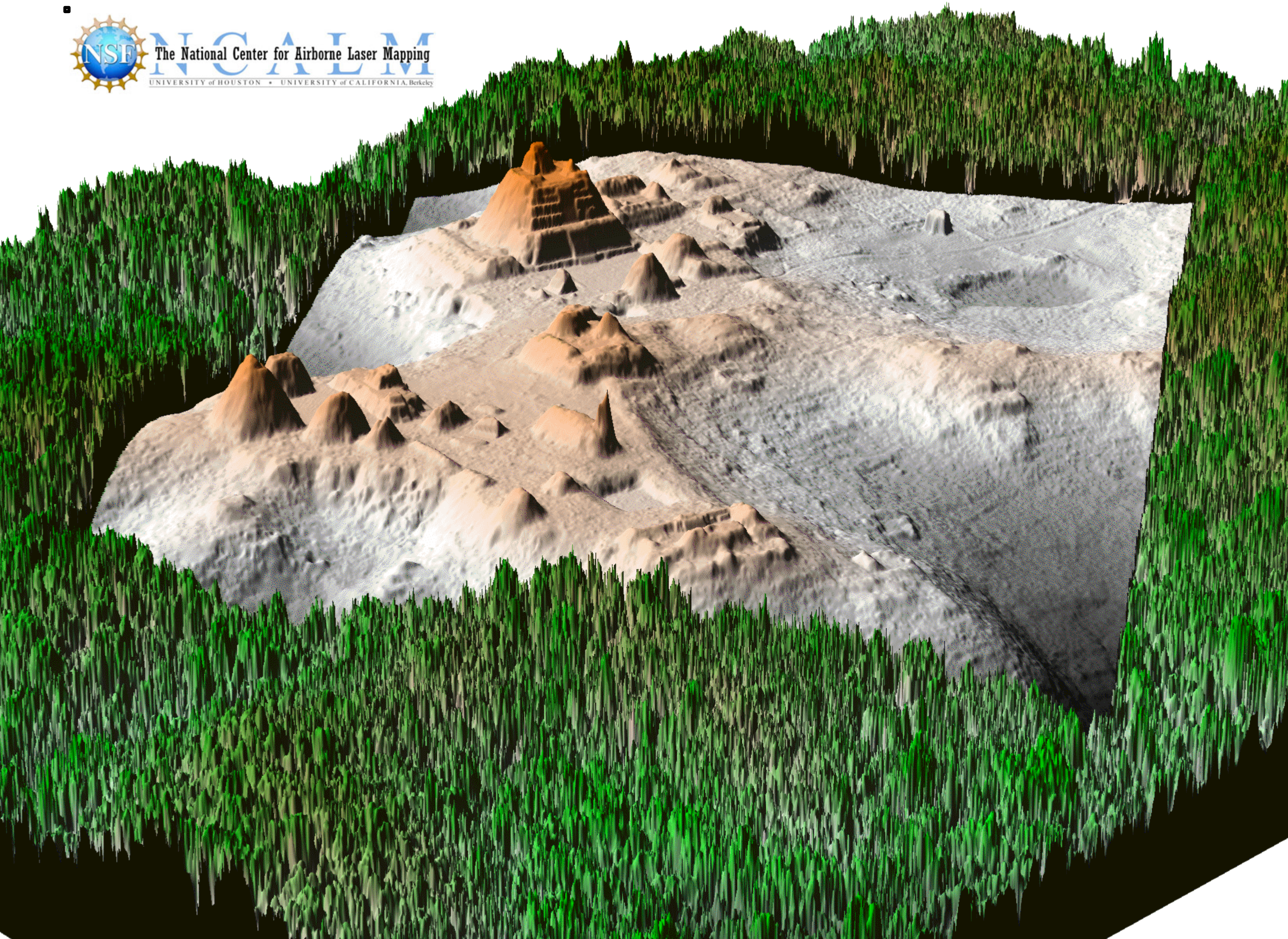
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Discussion topics:

1. **Regional targets and priorities?**

2. **International partners, collaborations?**

3. **Capacity building and training?**

4. **Next steps?**

Volunteer to participate in the white paper writing effort!

contact: **ccrosby@sdsc.edu**

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