Introduction to Terrestrial Laser Scanning (Ground Based LiDAR) for Earth Science Research

Instructors

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Hosted By

GSA 2012
Charlotte, NC

4 November 2012

Short Course Agenda

08:00 Morning Session 1 (PHILLIPS)

Course welcome and introductions. Overview of LiDAR and TLS data acquisition concepts and application examples.

09:15 Break

09:30 Morning Session 2 (CROSBY)

TLS data collection, data analysis, data management workflows with application examples.

10:30 Break

10:45 Morning Session 3 (AIKEN)

TLS data integration and visualization, photogrammetry, stratigraphy examples, 3D visualizations.

11:45 Morning Session Q&A

12:00 Lunch (Group Photo and Scan!)

12:30 Afternoon Session 1: Hands on demonstrations

- Split class into 3 groups that will rotate between "demo stations" (~1 hour per station)
- PHILLIPS: TLS data acquisition: Riegl scanner operation and Riscan software.
- CROSBY: TLS data management and analysis workflow.
- AIKEN: TLS data analysis and visualization.

15:30 Break

15:45 Afternoon Session 2: TLS support resources, future trends, open forum.

16:45 Course participant surveys.

17:00 Adjourn

Introductions

1. What is your name?

2. Why are you here?

3. Do have an application that you are wondering if TLS might be useful for?

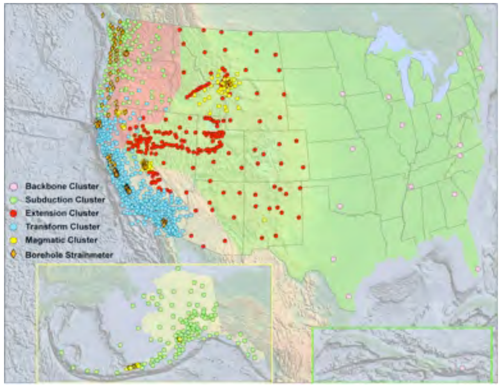
Workshop Summary

- This **1–day workshop** will consist of lectures, hands–on demonstrations of TLS equipment, and LiDAR data visualizations.
- This workshop **will** provide you with an overview of the basic principles of TLS with emphasis on application examples and hands-on learning.
- This workshop will **not** provide you with detailed training in specific software or hardware.
- The **goal** of this workshop is to provide you with a solid introduction to TLS and a good foundation for future learning. We also hope that it will inspire new applications.

UNAVCO

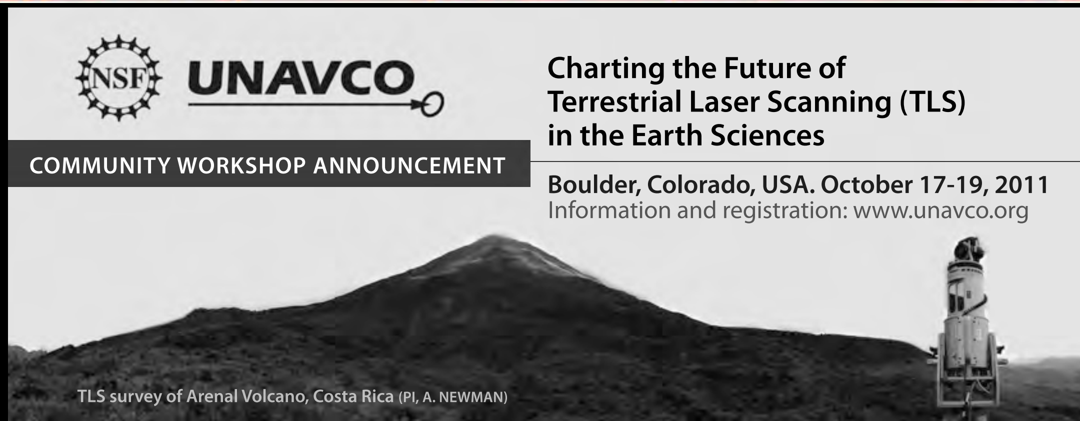
Overview of UNAVCO

- **UNAVCO** is a university-governed consortium that advances and supports **geodesy** community science goals.
- In addition to 100+ US academic **members**, UNAVCO supports 65+ organizations at home and abroad as **associate members** that share UNAVCO's mission and benefit from its programs and services.
- UNAVCO provides **geodetic infrastructure** and **geodetic data services** that support GPS, InSAR, LiDAR and other data by providing instrumentation, engineering, development & testing, data archiving, data products and training.
- UNAVCO operates the **Plate Boundary Observatory** (PBO) instrument network and data products suite.
- UNAVCO works to promote a broader understanding of Earth science through **education and outreach**.
- UNAVCO is based in Boulder, Colorado, USA.



Terrestrial Laser Scanning

- Support Resources
  - Instrumentation (5+ scanners)
  - Field engineering
  - Basic data processing
  - Training
  - Data archiving
- Community Building
  - Community workshops
  - INTERFACE consortium
  - Community partnerships
  - Inter-Agency collaborations
- Education and Outreach
  - Training courses
  - Field camp
  - RESESS



Overview of LiDAR and Terrestrial Laser Scanning (TLS)

Light Detection And Ranging (LiDAR)

- **LiDAR** = Light Detection And Ranging
- Terrestrial Laser Scanning (**TLS**) = Technique that uses LiDAR measurement technology. Also called ground based LiDAR or T-LiDAR. Laser scanning can also be done from moving ground based platforms (Mobile Laser Scanning, MLS).
- Laser scanners used by UNAVCO and EOS utilize pulsed LiDAR Time of Flight (TOF) measurements to generate a 3D "**point cloud**".
- Each measured point has **range** and **intensity** values determined by the laser pulse properties plus an **X, Y, Z** value determined by the scanner's orientation.

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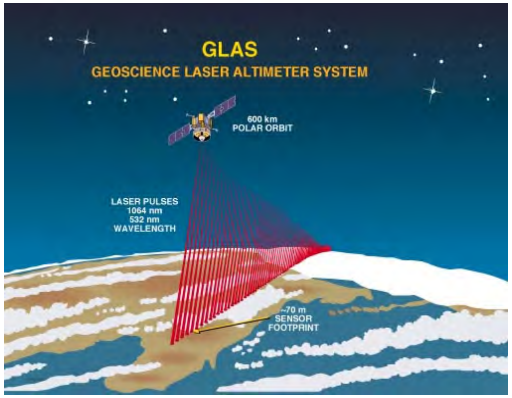
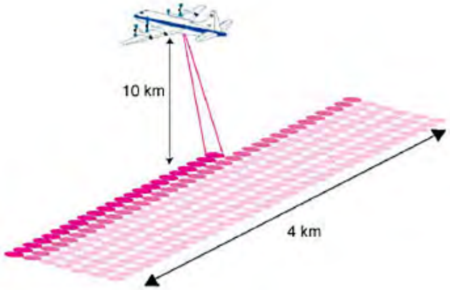
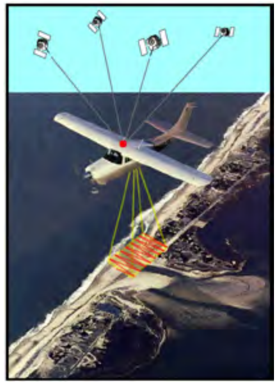
Light Detection And Ranging (LiDAR)







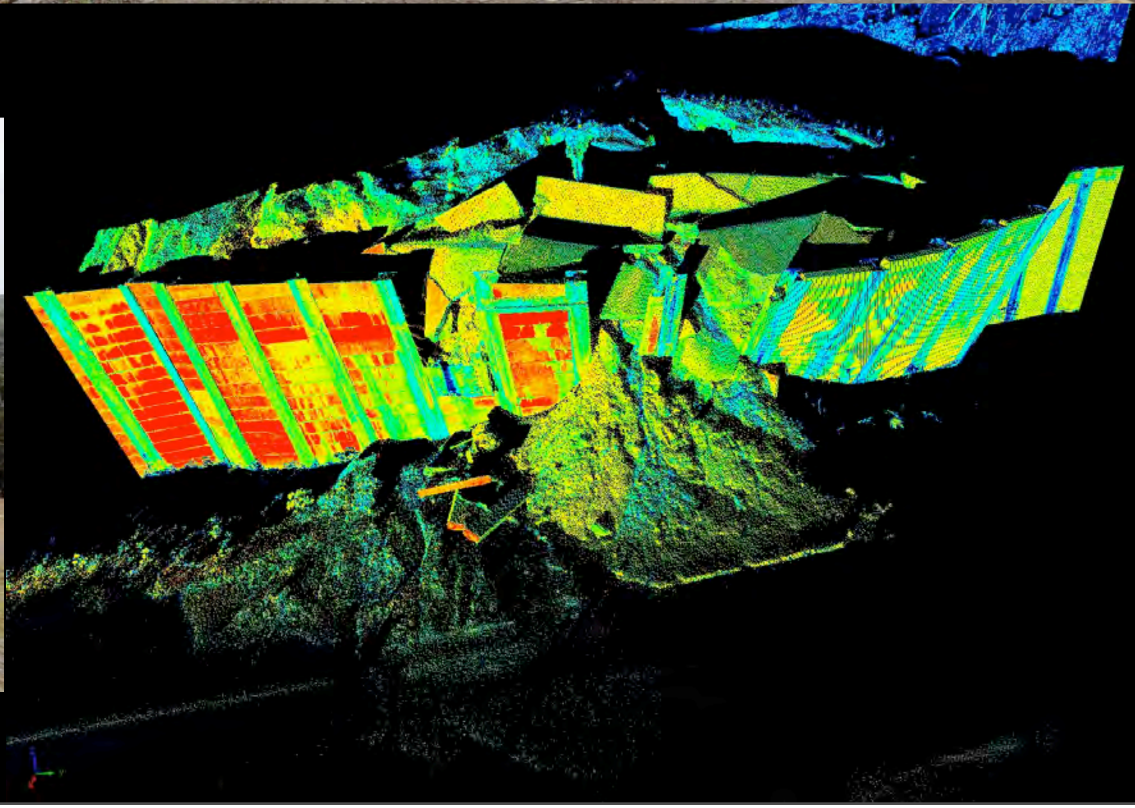
System:	Spaceborne (e.g. GLAS)	High Altitude (e.g. LVIS)	Airborne (ALS)	Terrestrial (TLS)
Altitude:	600 km	10 km	1 km	1 m
Footprint:	60 m	15 m	25 cm	1-10 cm
Vertical Accuracy	15 cm to 10 m depends on slope	50/100 cm bare ground/ vegetation	20 cm	1- 10 cm Depends on range which is few meters to 2 km or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

Examples of Earth science research applications using TLS data

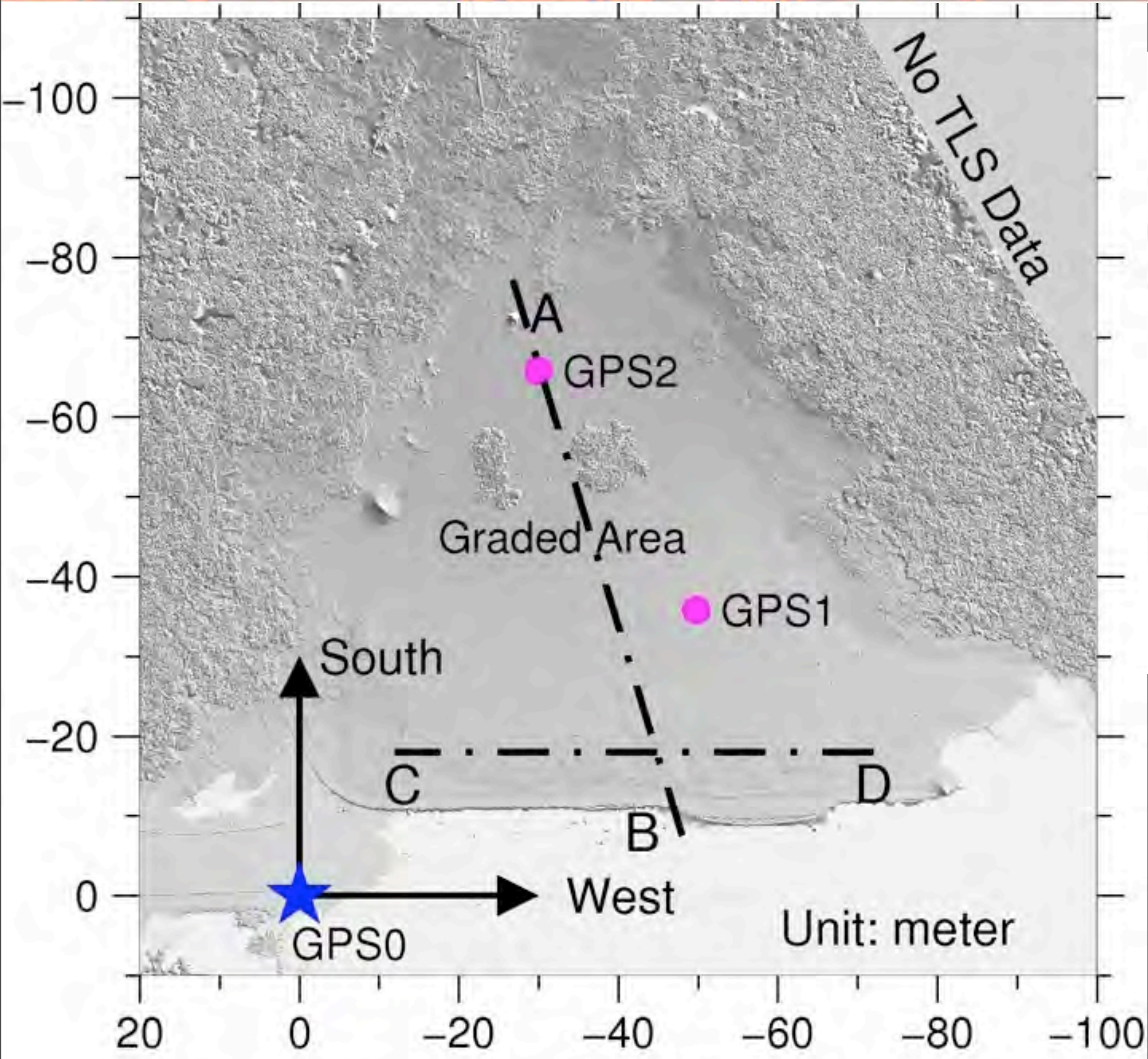
TLS Applications

- Landscape evolution
- Fault mapping
- Paleoseismology
- Paleontology
- Cryosphere
- Ecology
- Landslides
- Volcanoes
- Stratigraphy
- Sediment transport
- Coastal processes
- Non-Earth sciences: forensics, movies, games, architecture, archaeology, civil engineering, manufacturing, etc.

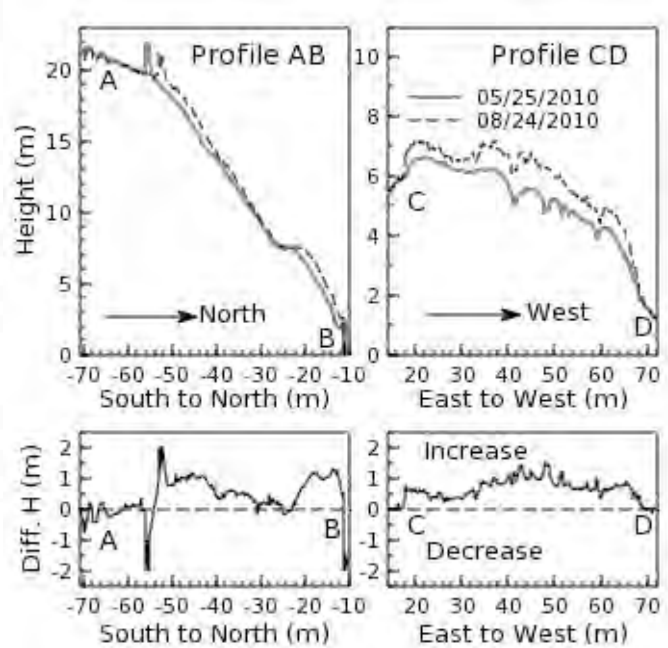
Puerto Rico Landslide (Wang)



Puerto Rico Landslide (Wang)

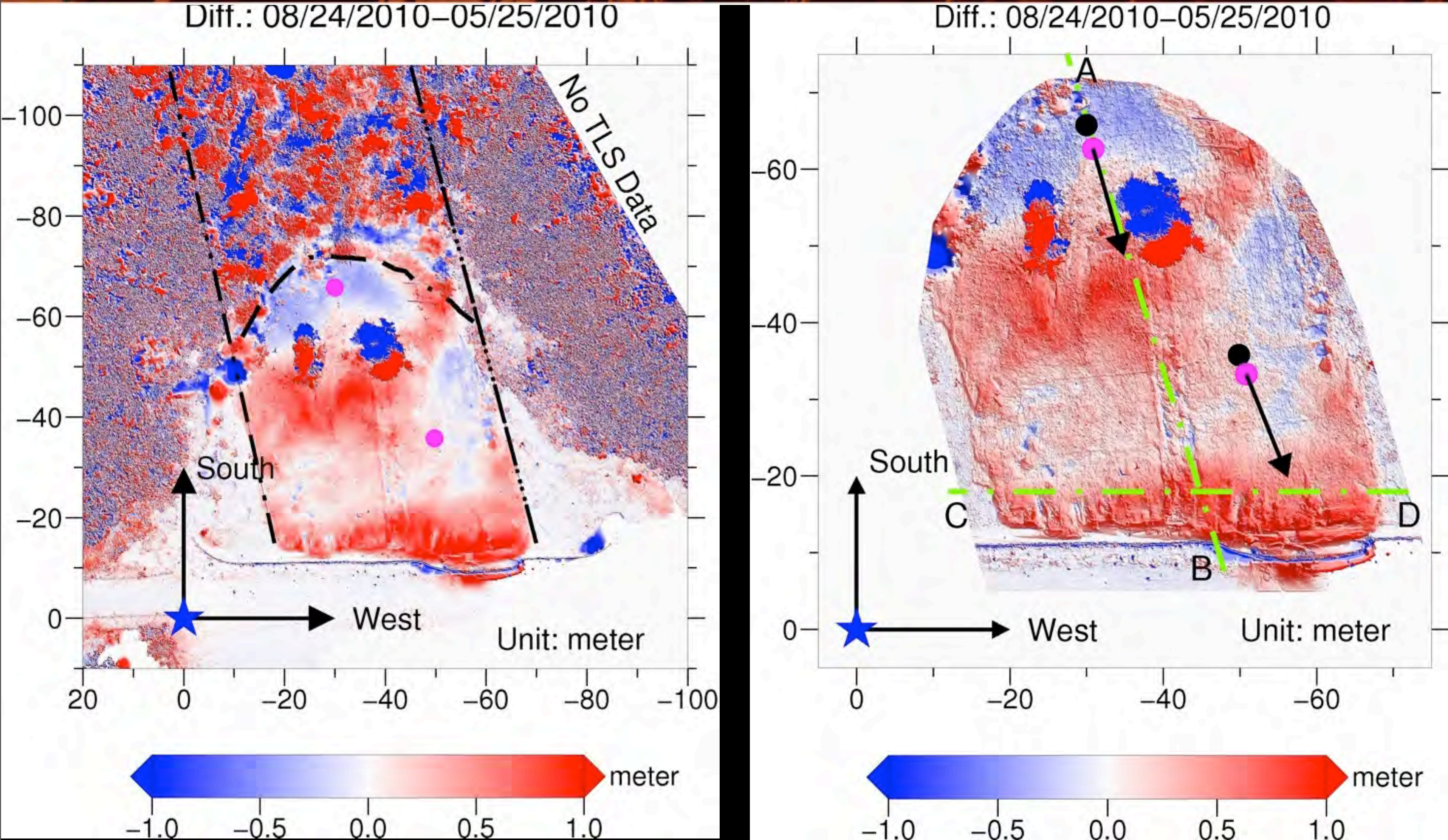


(Grid size: 5 cm by 5cm, 05/25/2010)



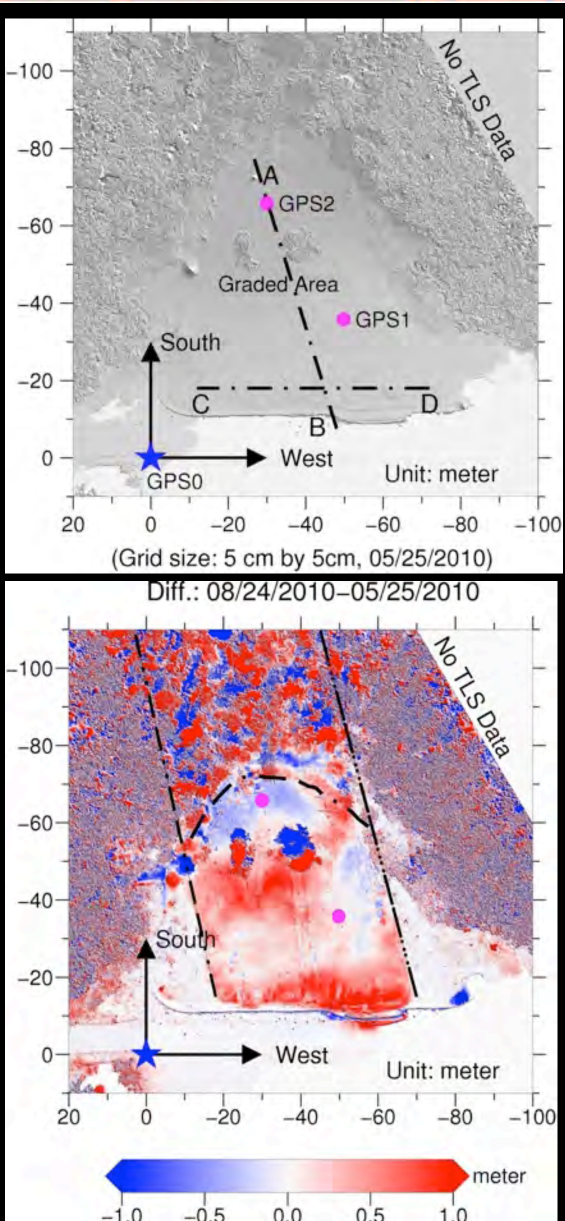
Wang et al., 2011

Puerto Rico Landslide (Wang)



Wang et al., 2011

Puerto Rico Landslide (Wang et al., 2011)



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The Integration of TLS and Continuous GPS to Study Landslide Deformation: A Case Study in Puerto Rico

Research Article

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Abstract:

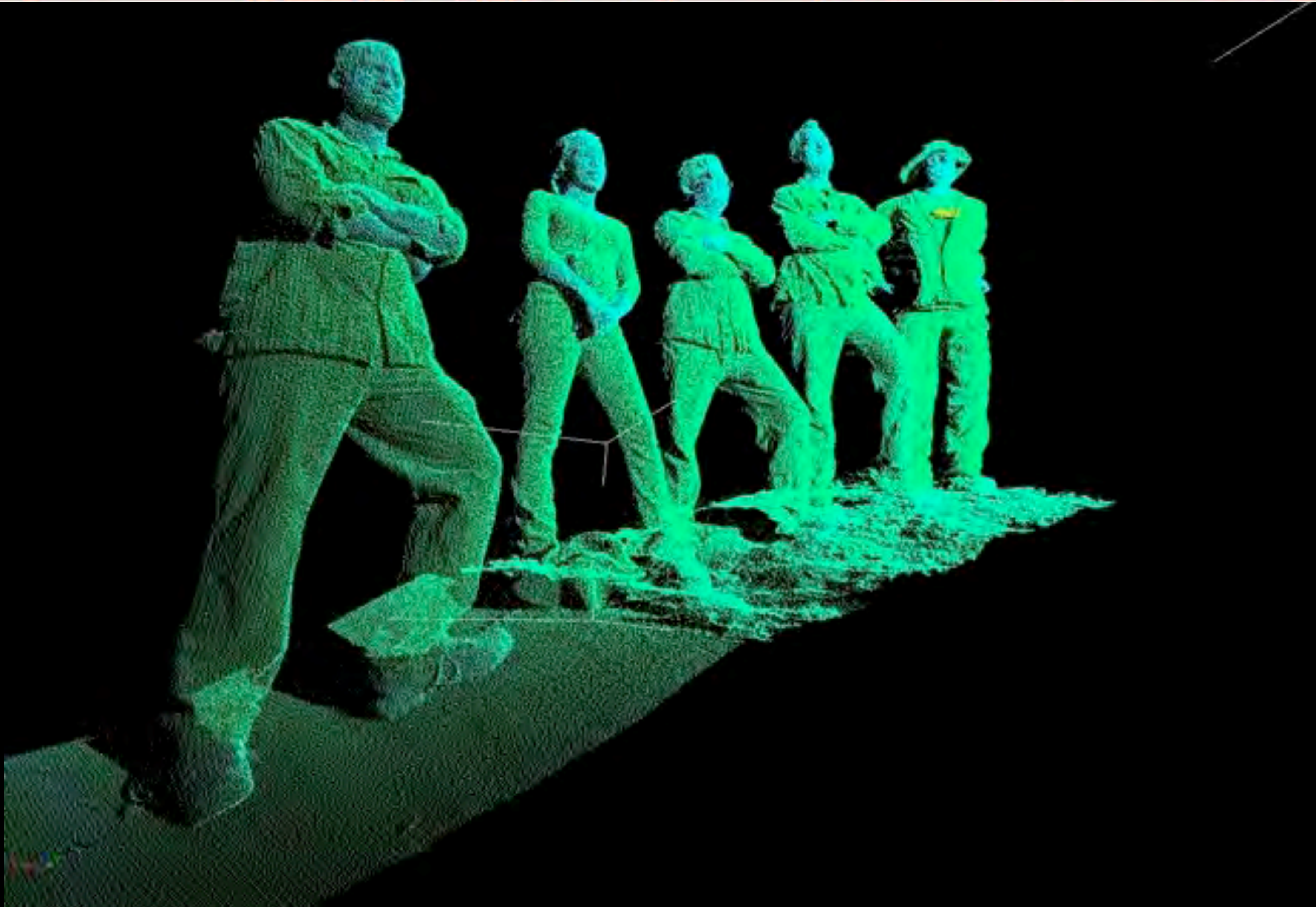
Terrestrial Laser Scanning (TLS) and Global Positioning System (GPS) technologies provide comprehensive information on ground surface deformation in both spatial and temporal domains. These two data sets are critical inputs for geometric and kinematic modeling of landslides. This paper demonstrates an integrated approach in the application of TLS and continuous GPS (CGPS) data sets to the study of an active landslide on a steep mountain slope in the El Yunque National Forest in Puerto Rico. Major displacements of this landslide in 2004 and 2005 caused the closing of one of three remaining access roads to the national forest. A retaining wall was constructed in 2009 to restrain the landslide and allow the road reopen. However, renewed displacements of the landslide in the first half of 2010 resulted in deformation and the eventual rupture of the retaining wall. Continuous GPS monitoring and two TLS campaigns were performed on the lower portion of the landslide over a three-month period from May to August 2010. The TLS data sets identified the limits and total volume of the moving mass, while the GPS data quantified the magnitude and direction of the displacements. A continuous heavy rainfall in late July 2010 triggered a rapid 2-3 meter displacement of the landslide that finally ruptured the retaining wall. The displacement time series of the rapid displacement is modeled using a fling-step pulse from which precise velocity and acceleration time series of the displacement are derived. The data acquired in this study have demonstrated the effectiveness and power of the integrating TLS and continuous GPS techniques for landslide studies.

Keywords:

TLS • Continuous GPS • Landslide • Generic Mapping Tool (GMT) • Puerto Rico • Rainfall • Digital Surface Model

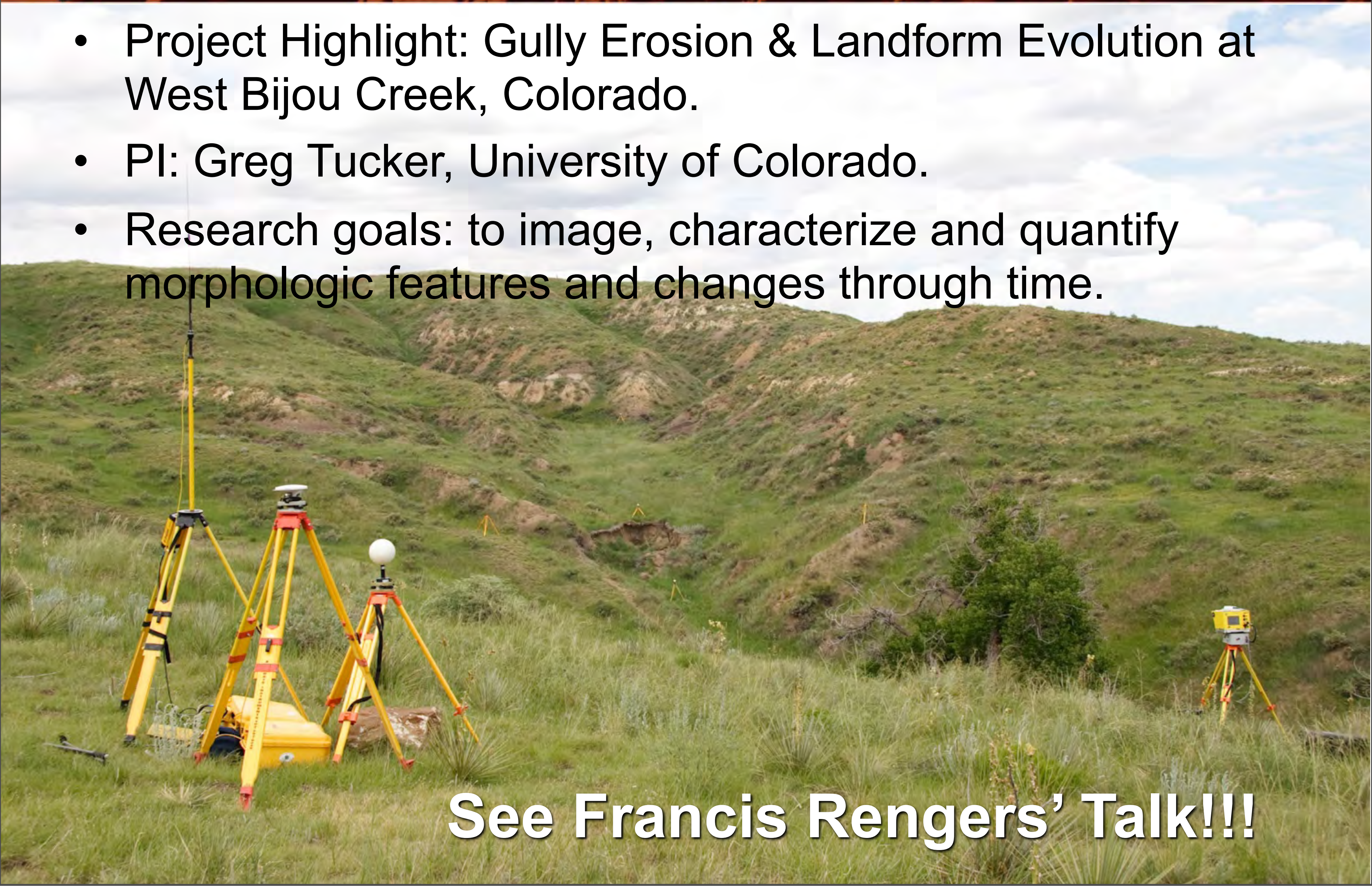
Received 1 October 2010; accepted 26 November 2010

Puerto Rico Landslide (Wang)



Bijou Creek Surface Processes (Tucker)

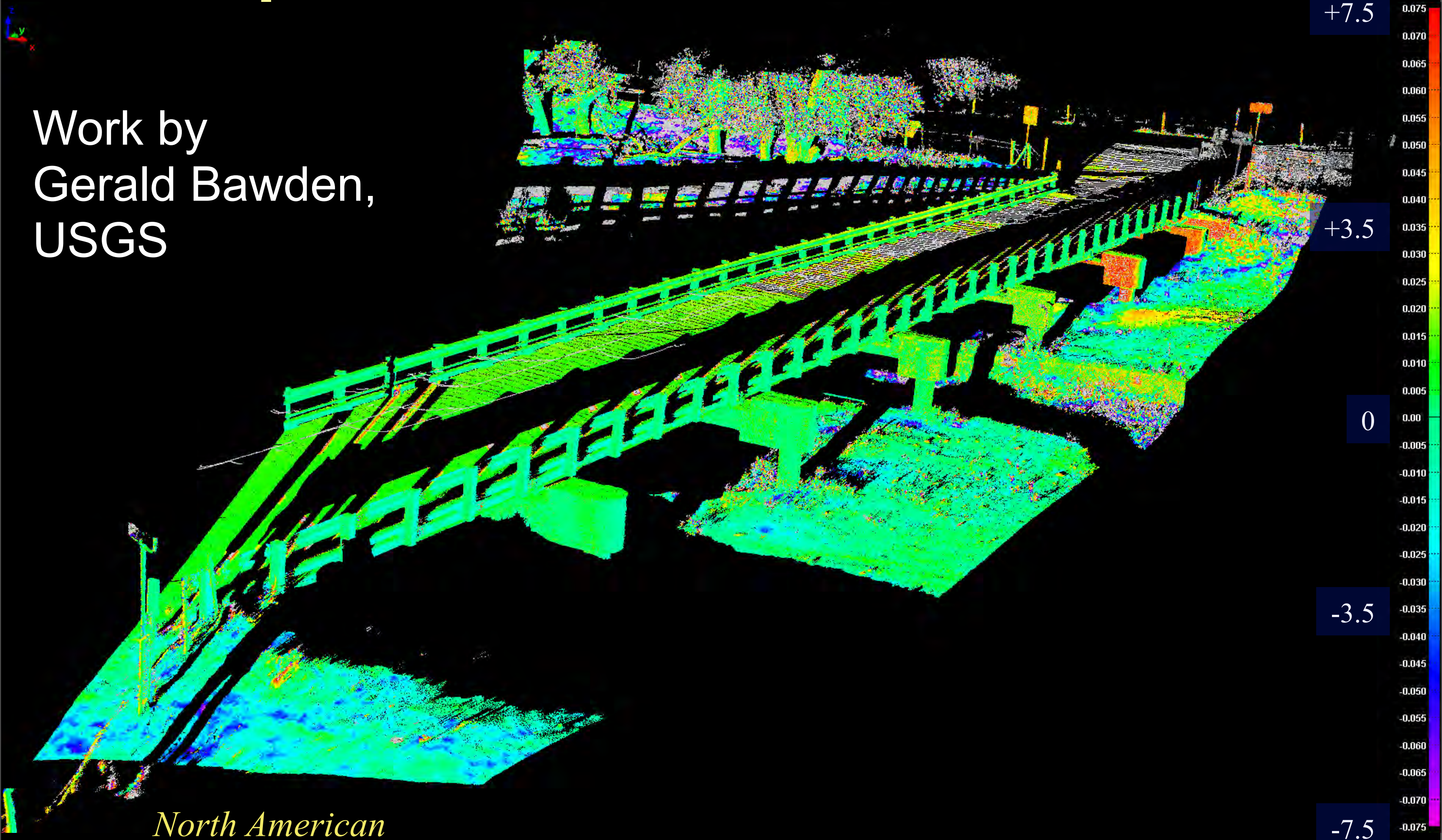
- Project Highlight: Gully Erosion & Landform Evolution at West Bijou Creek, Colorado.
- PI: Greg Tucker, University of Colorado.
- Research goals: to image, characterize and quantify morphologic features and changes through time.



See Francis Rengers' Talk!!!

Parkfield bridge postseismic motion
September to December - 10 weeks

Work by
Gerald Bawden,
USGS



Shortest distance difference in cm

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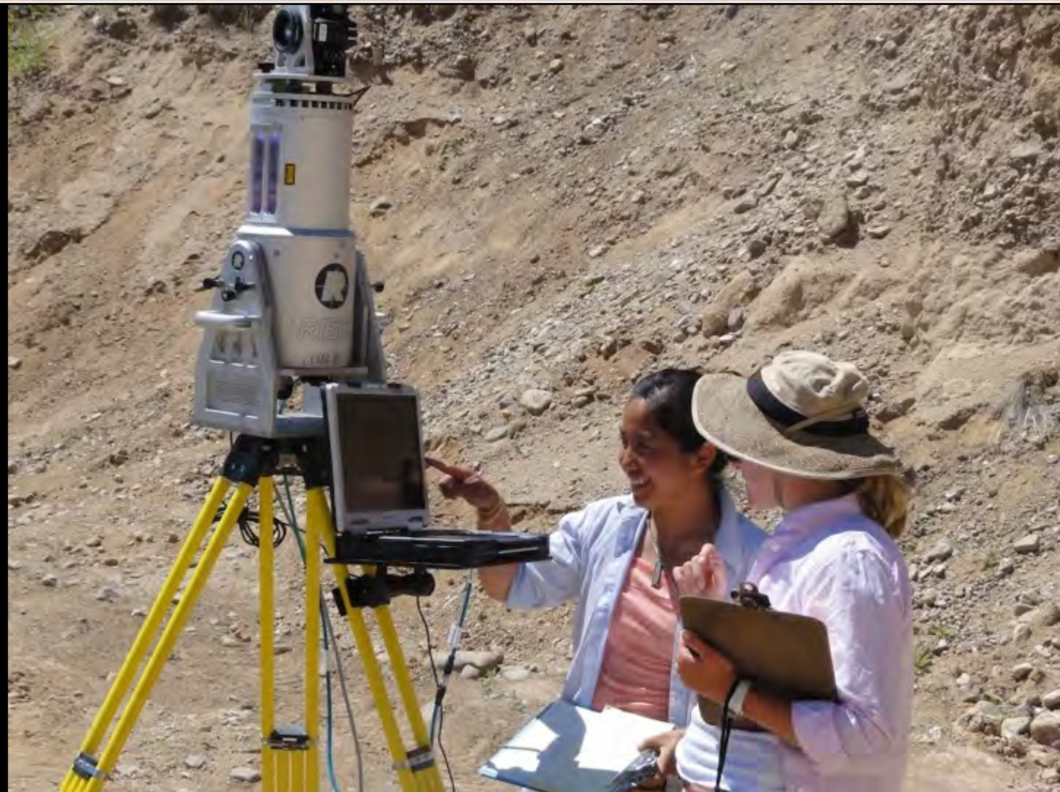
Elsinore Fault Morphology (Rockwell)

UNAVCO

Undergraduate Field Camp (Douglas)



Terrestrial Laser Scanning

"...for the foreseeable future, all geologic studies need to incorporate LiDAR ..."

Dr. Marcia McNutt, Director, USGS

Bloomington, IN February, 2012

Starting in Summer, 2009 the IUGFS G429 field course began to incorporate Terrestrial Laser Scanning within its 7 week schedule as part of G429g.

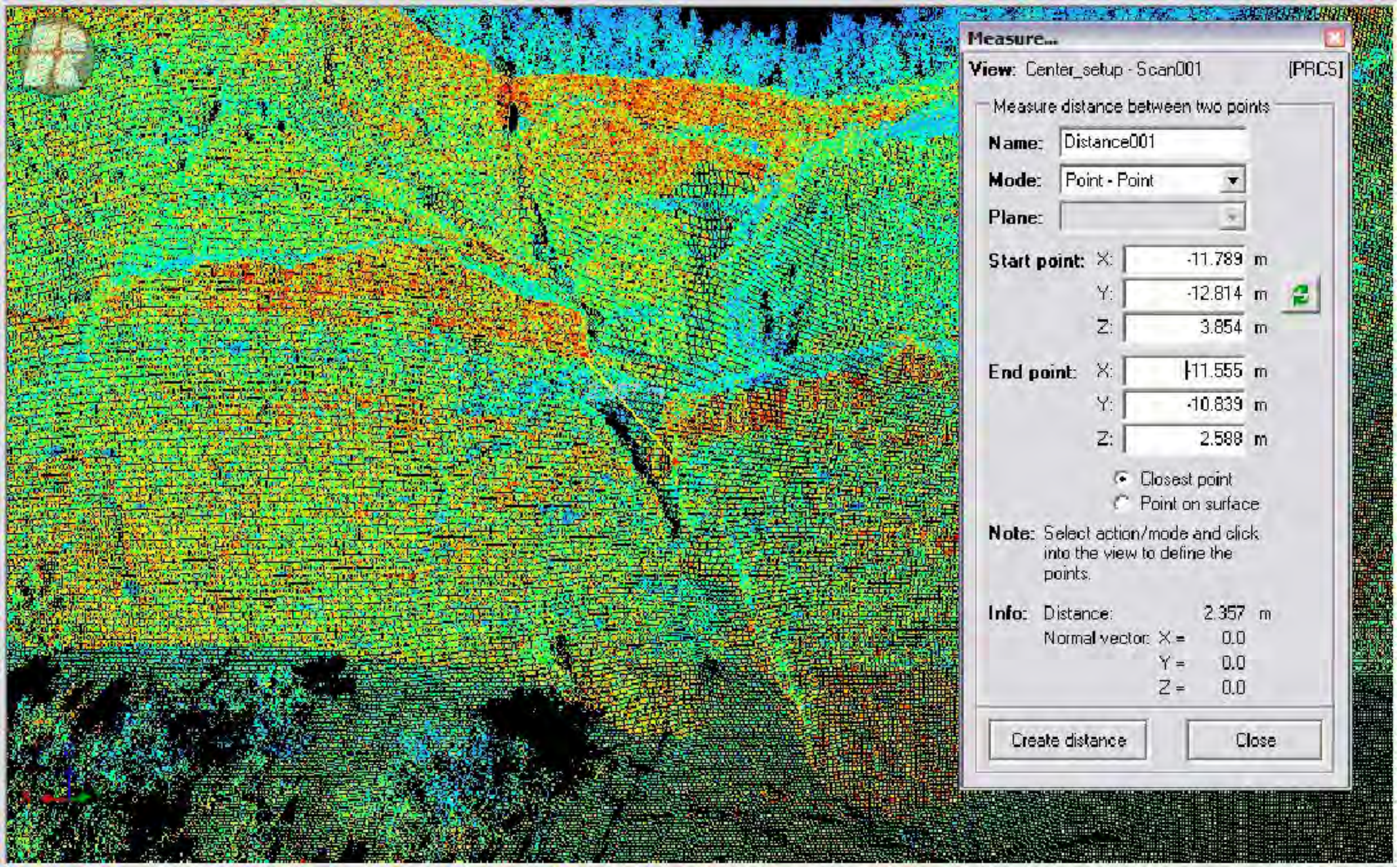
Weeks 1-3 - Traditional field instruction (sedimentology, stratigraphy, structural geology, regional geology)

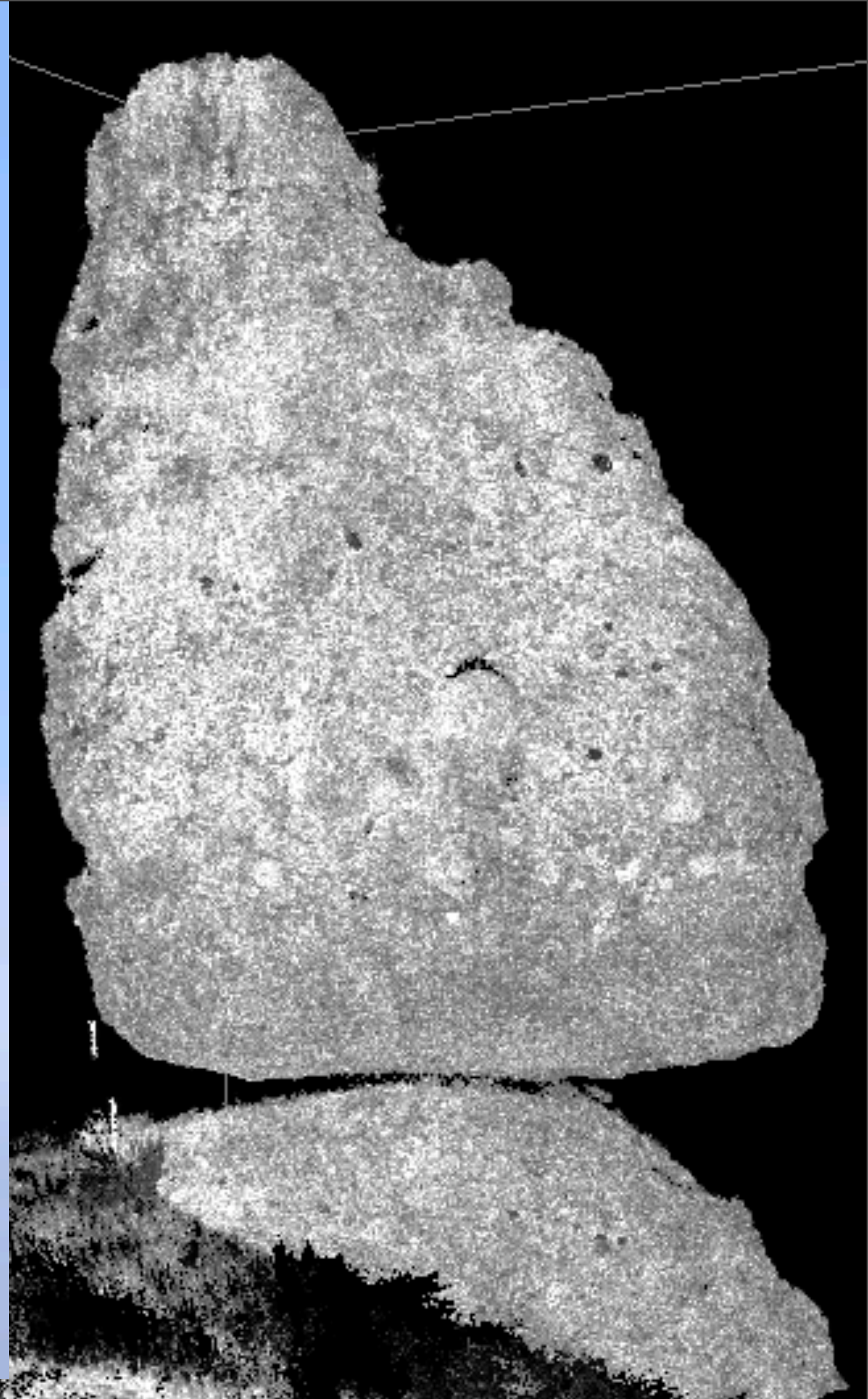
Week 4 - Student elected option for concentration within a specific subfield (hydrology*, geophysics, geochemistry)
*this option began in 1997

Weeks 5-7 - Return to traditional field setting but with the ability to identify areas that could benefit or require incorporation of newly developed skills


• Collaborative Learning
• Determination of optimal instrumentation setup given nature of field problem

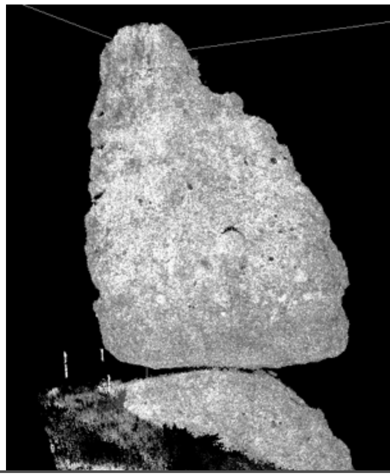
Student Determination of Fault Offset

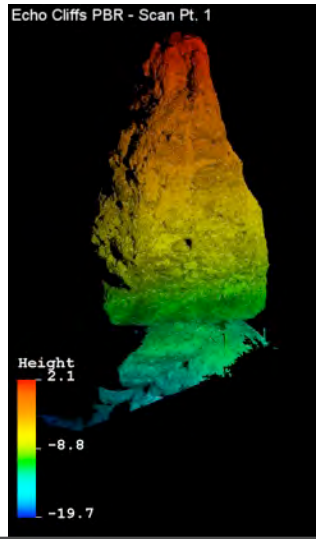




Precariously Balanced Rocks (Hudnut)

- 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.

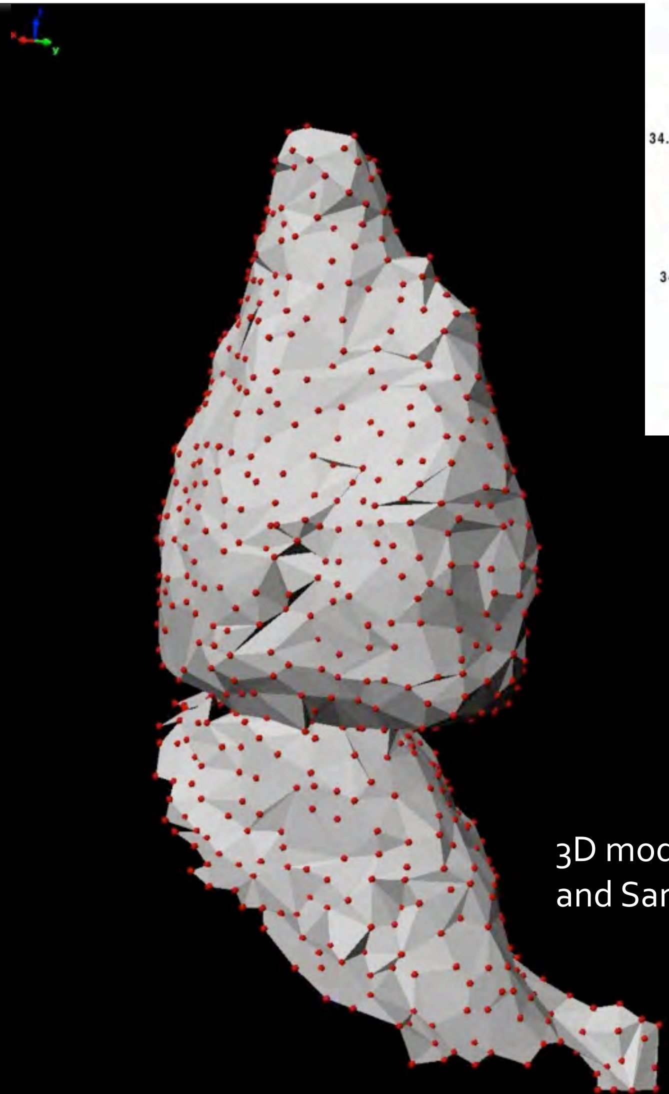




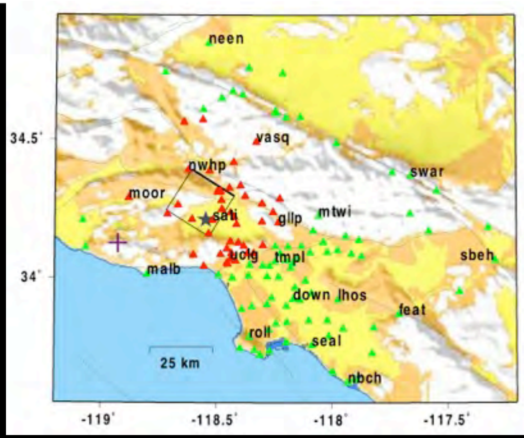
(Hudnut et al., 2009)

Precariously Balanced Rocks (Hudnut)

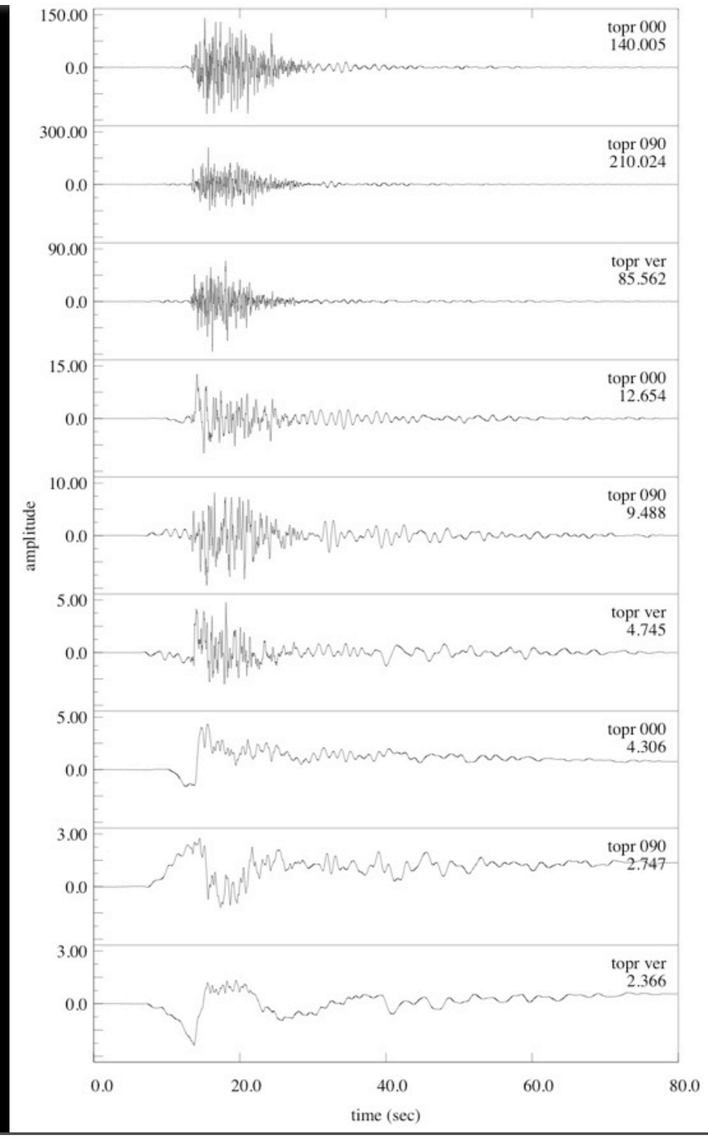
3D surface model (861 nodes) and simulated 1994 Northridge waveforms



3D model by Gerald Bawden and Sandra Bond



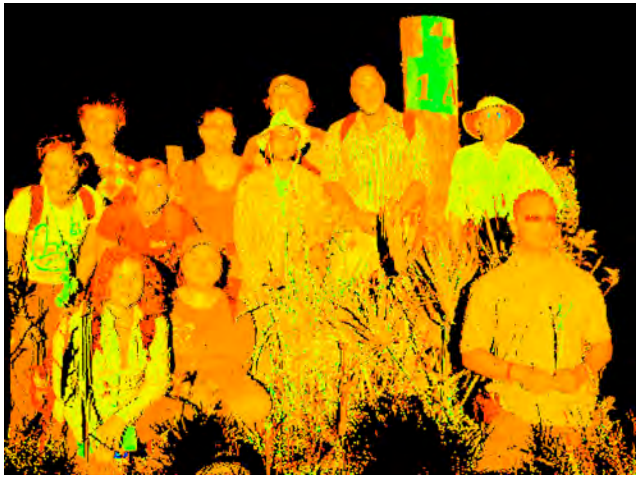
Northridge 1994 simulation by Rob Graves

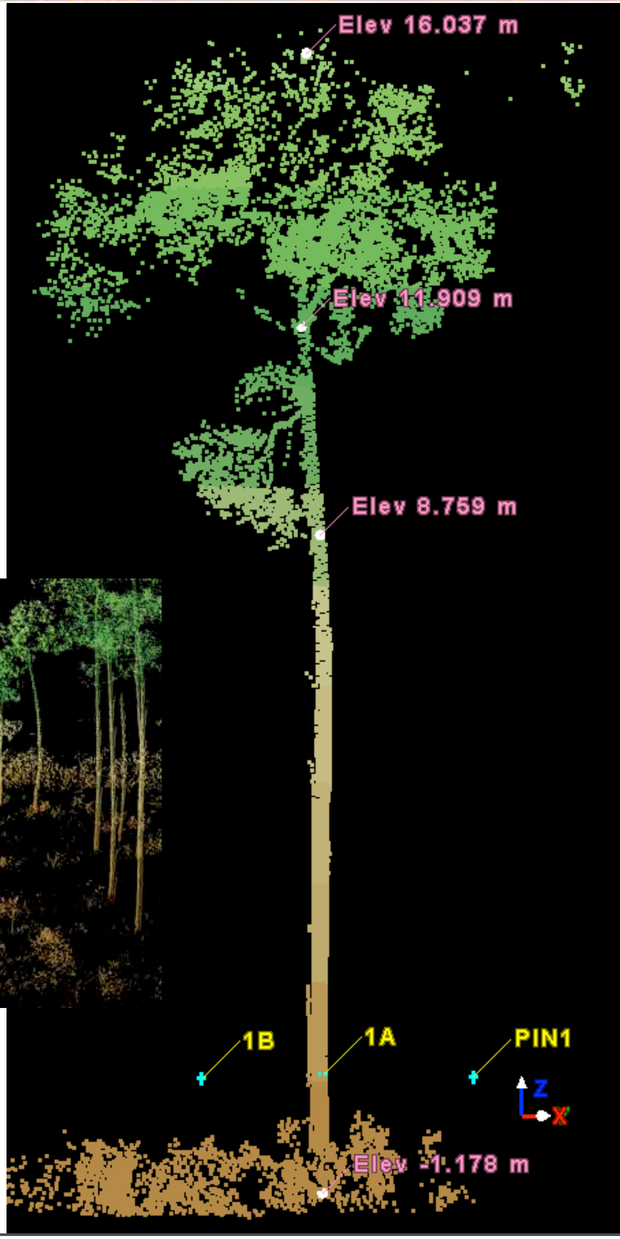


Everglades Biomass (Wdowinski)

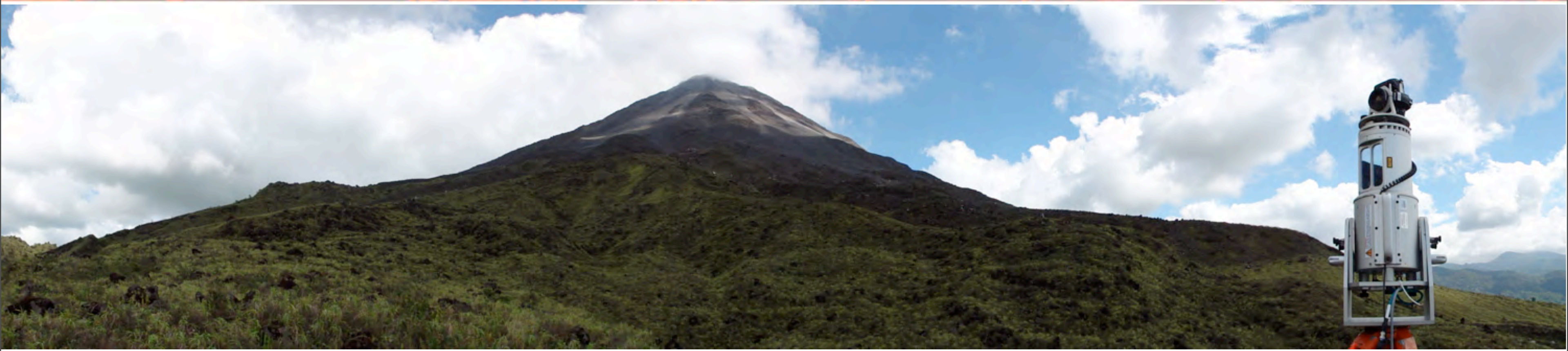
- Scanning to measure biomass in Everglades National Park (PI: Wdowinski).

Everglades Biomass (Wdowinski)

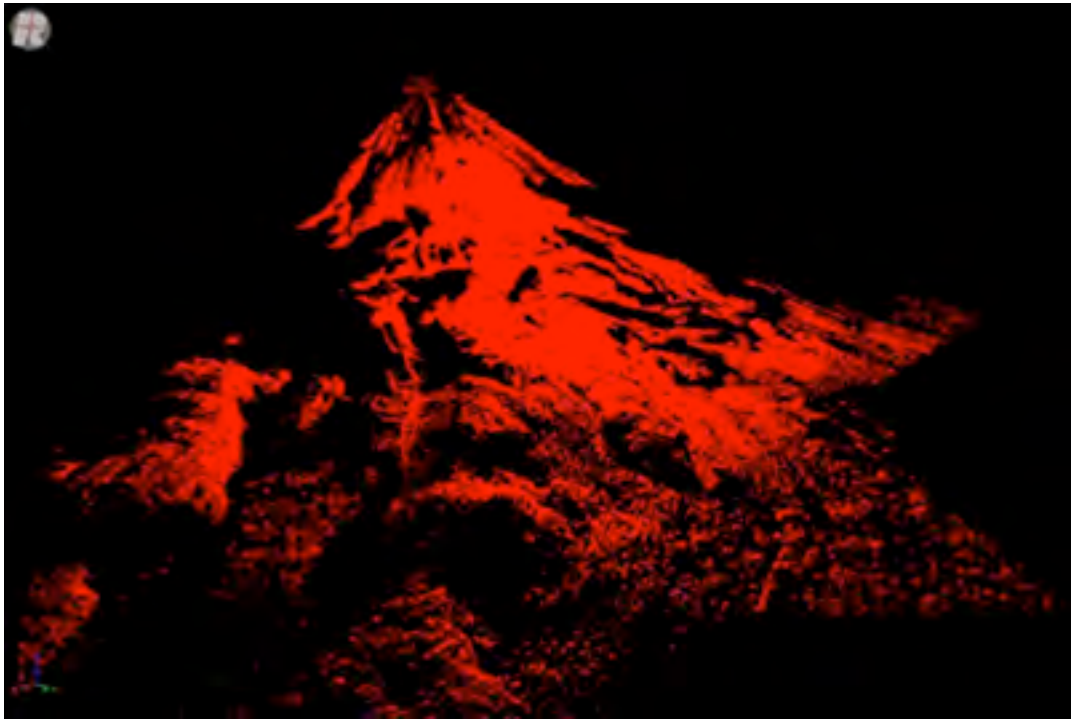




Everglades Biomass (Wdowinski)

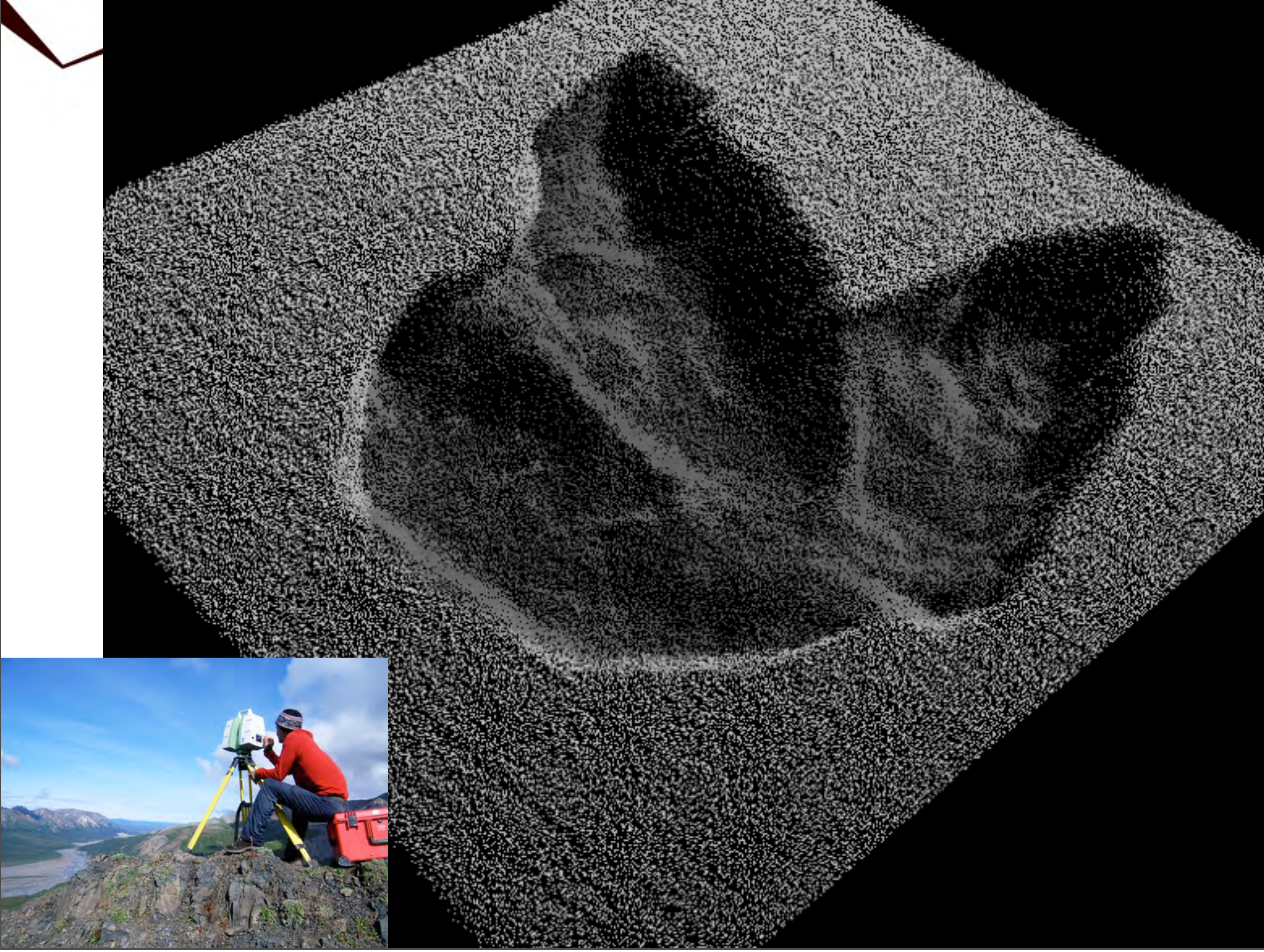


Arenal Volcano, Costa Rica (Andrew Newman)



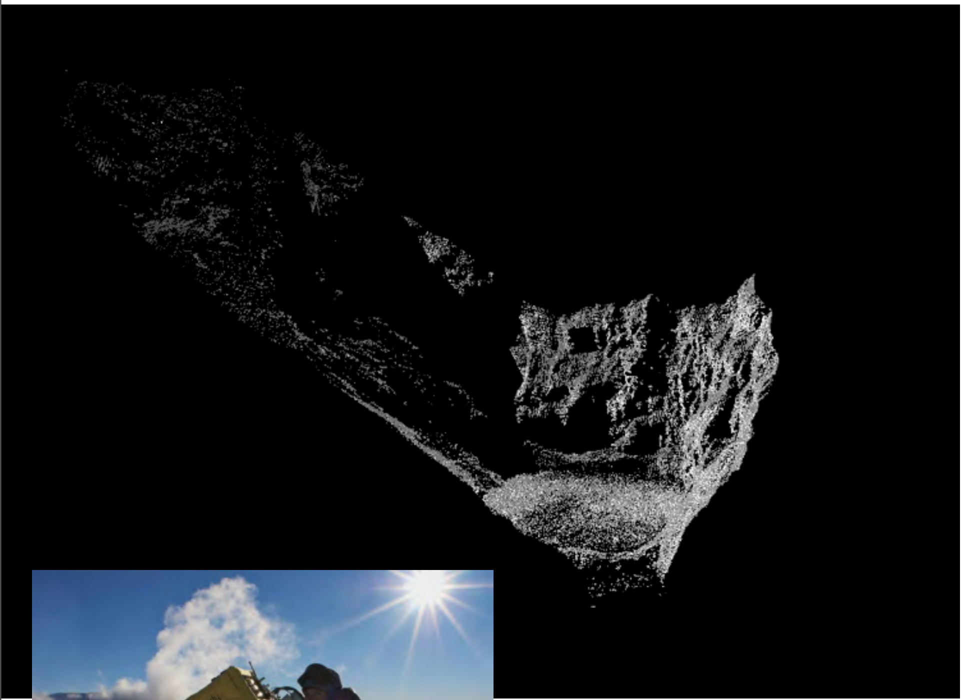
SoCal Paleoseismology (Rockwell)

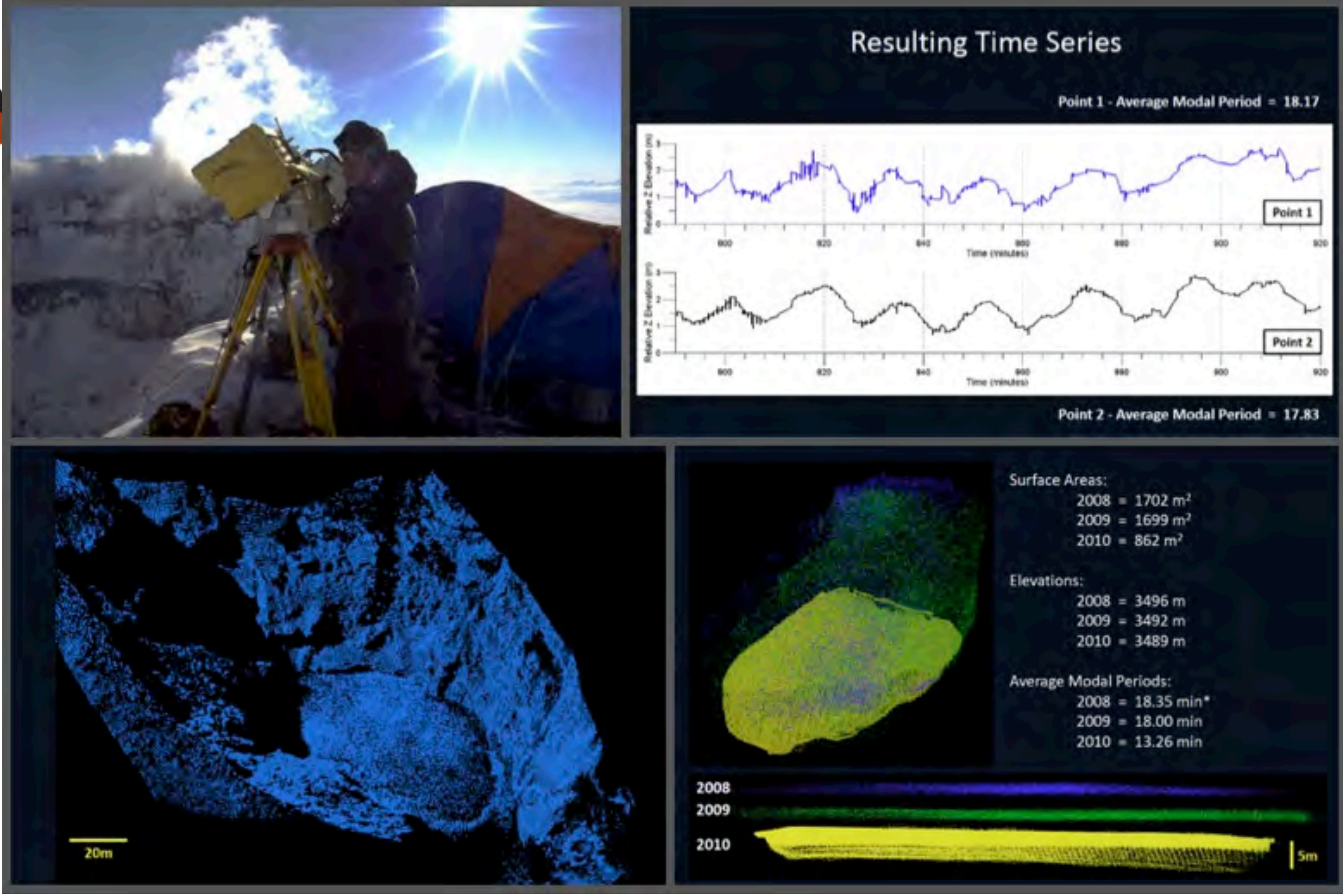
Dinosaur Trackway (Fiorillo)



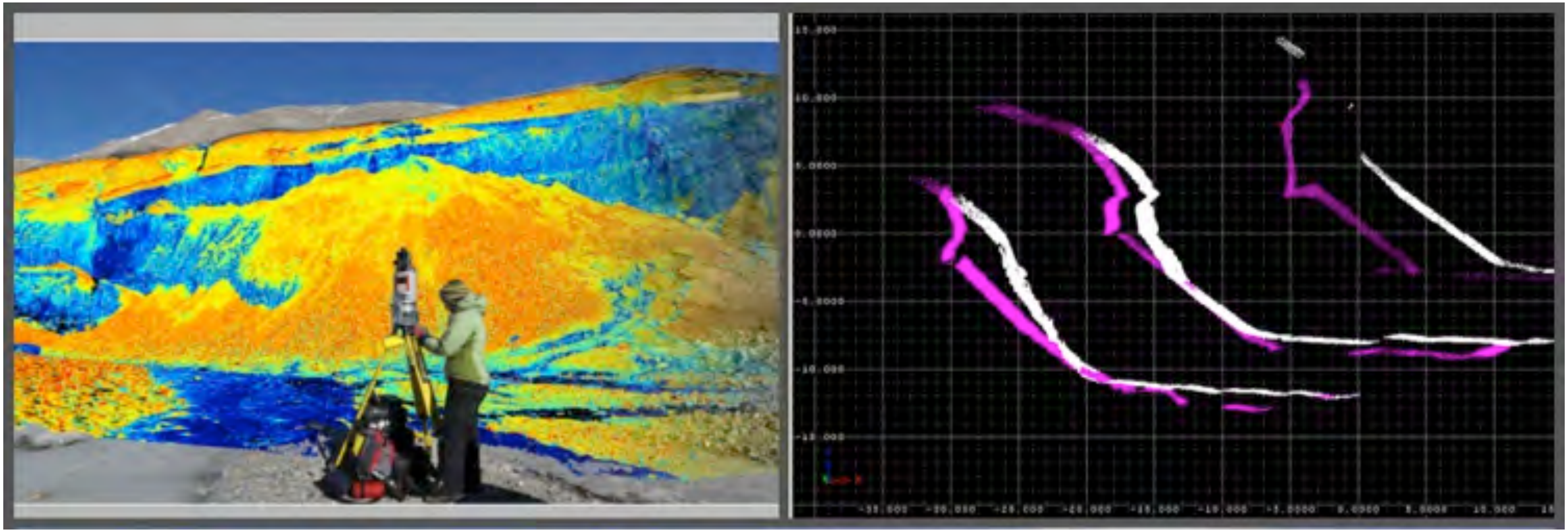
Erebus Lava Lake (Kyle)

- Project Highlight: Mount Erebus Lava Lake, Antarctica.
- PI: Phil Kyle, New Mexico Tech.
- Goal: image lava lake surface, try to measure changes in surface elevation and features through time.



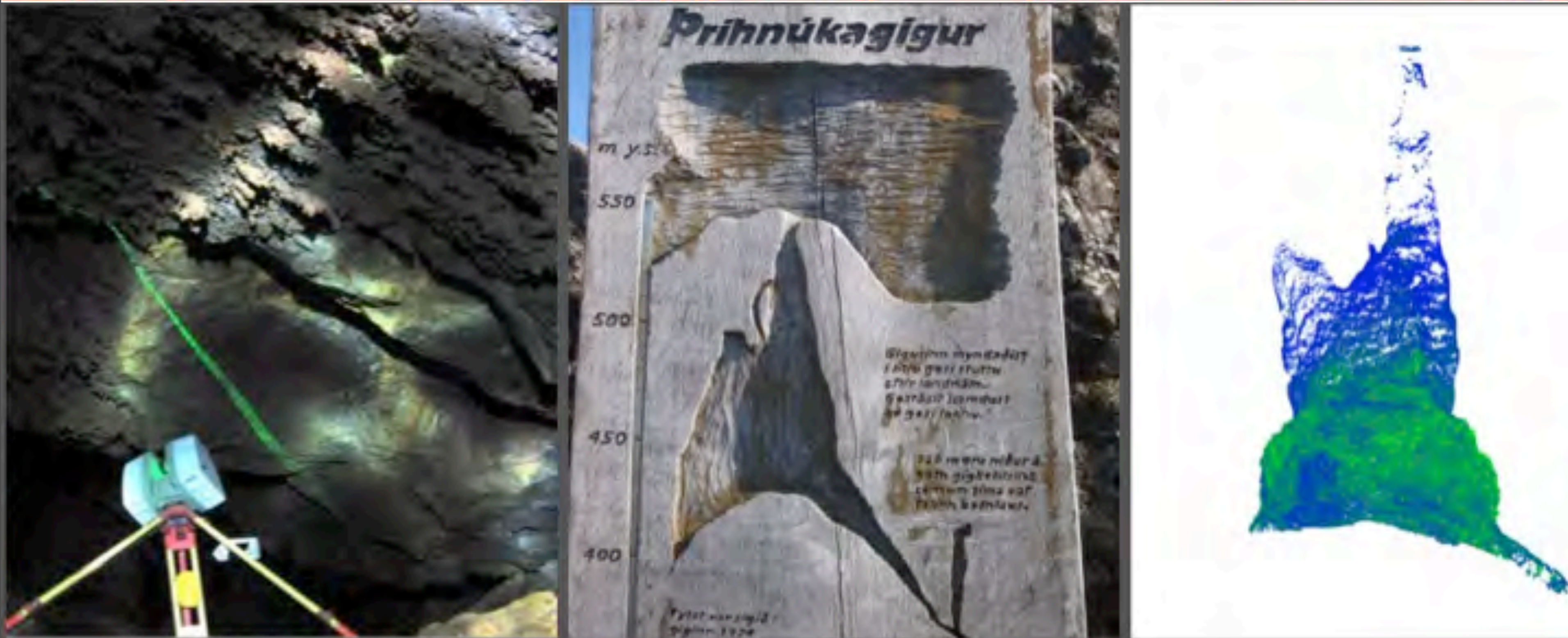


TLS activities monitor the behavior of the Mt. Erebus lava lake. Upper left: The Optech ILRIS-3D sits on Mt. Erebus's crater rim at 3794 m. **Upper right:** TLS data shows the cyclical nature of lava lake levels. **Lower left:** A scan of the inner crater, taken by NMT graduate student Laura Jones, 2009. **Lower right:** TLS data show that lava lake levels are steadily dropping and that the lake diminishes in surface area year after year. From Jones et al., 2010. **PI: Phil Kyle.**



TLS data for PI Joe Levy has been collected twice yearly for 3 years in Garwood Valley. Left: A composite of an intensity-colored point-cloud and a photo taken of the site shows typical scanning operations. Blue data is ice, yellow/orange data represents sandy material. **Right:** A series of TLS data cross-sections of the ice headwall shows significant ice mass loss between Jan. 2011 (white) and Jan. 2012 (fuscia).

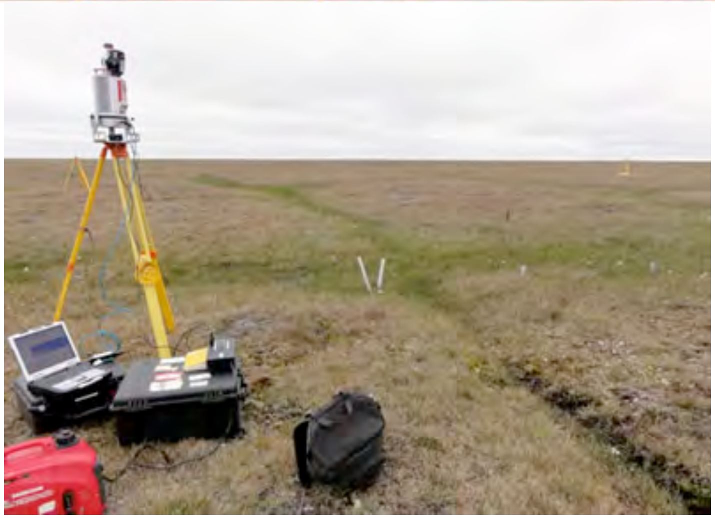
UNAVCO



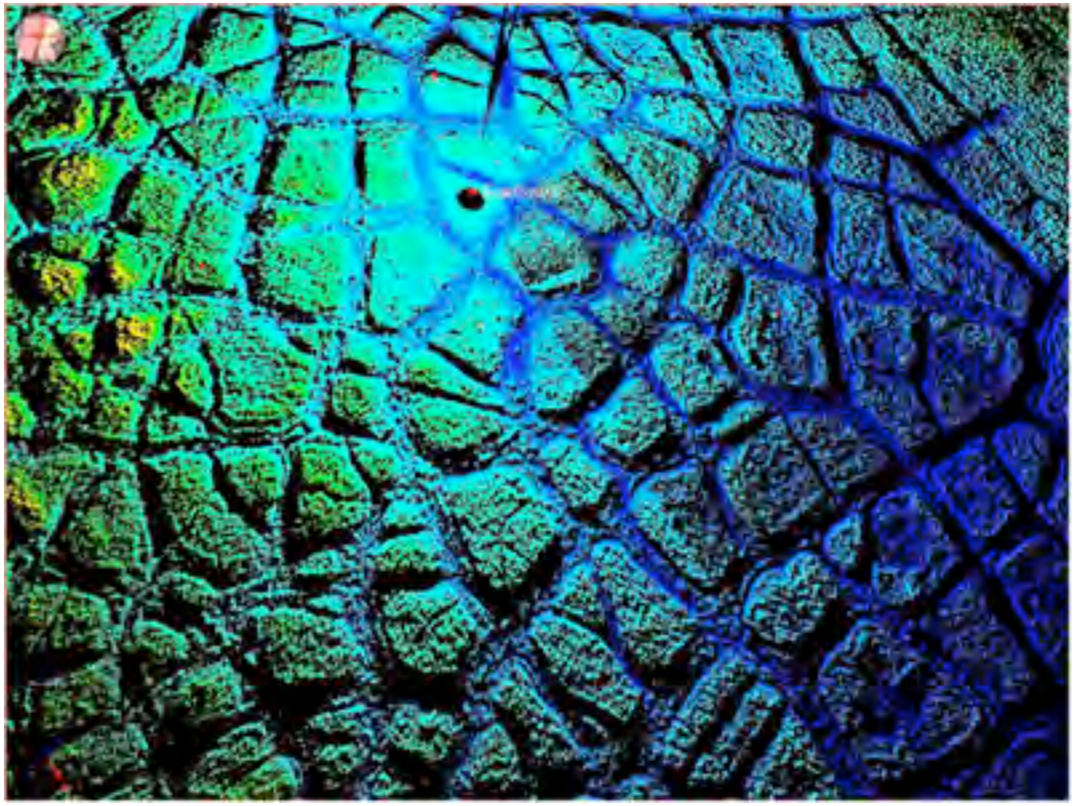
PI Pete LaFemina recently imaged the inside of a volcanic magma chamber in Iceland. Left: The Leica C10 uses its green laser to image the roof of the chamber. **Middle:** A wooden diagram shows visitors the approximate shape of the cavity. **Right:** The resulting scan image gives a highly precise 3D map of the interior of the chamber and matches the general shape of the wooden panel.

Polygons, Barrow, Alaska

Circumpolar Active Layer Monitoring Network – CALM II (Nikolay Shiklomanov)



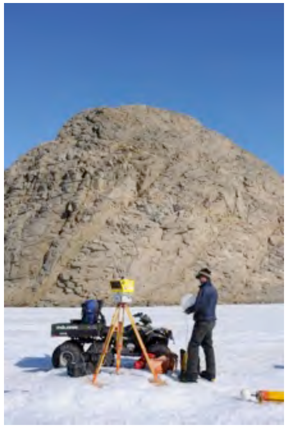
Scanning in the Barrow Ecological Observatory, Alaska, on a typical day in Barrow. The green linear features are water-logged cracks in the earth that will freeze and expand in the winter, creating ice wedges.



A geo-referenced image of the landscape clearly defines the polygonal features that dot the landscape. The color scale represents true elevation and allows us to see larger-scale landscape features.

Antarctic Various

- 2009-10 Antarctic Field Season: numerous projects.




Four Mile Fire Erosion (Moody, Tucker)

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


• Project: 2011 Japan Tsunami measurements
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Terrestrial Laser Scanning

- **Project: 2011 Japan Tsunami measurements**
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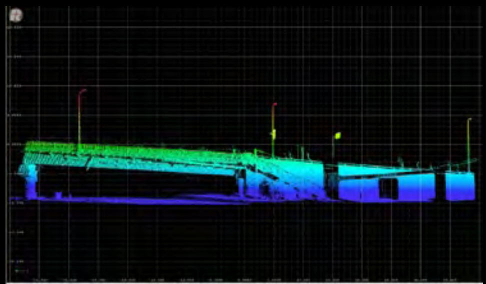
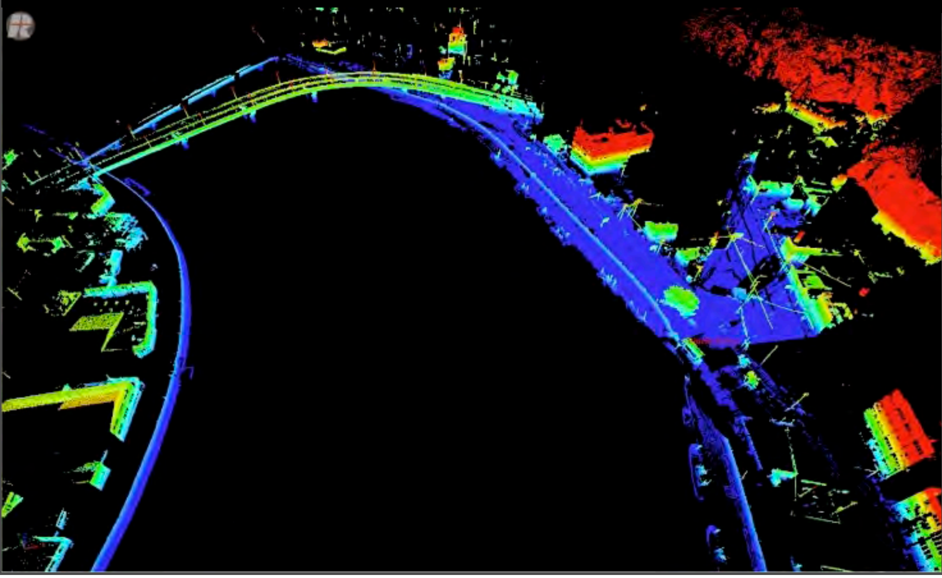
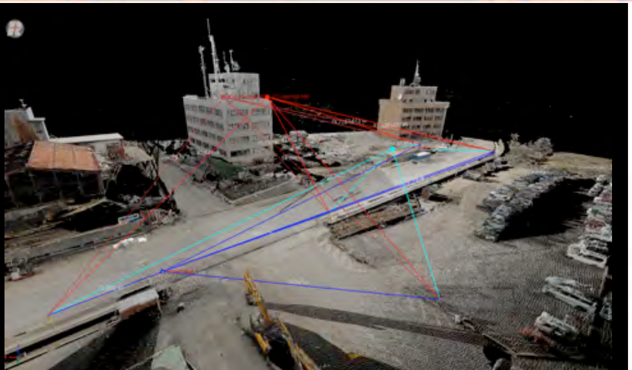
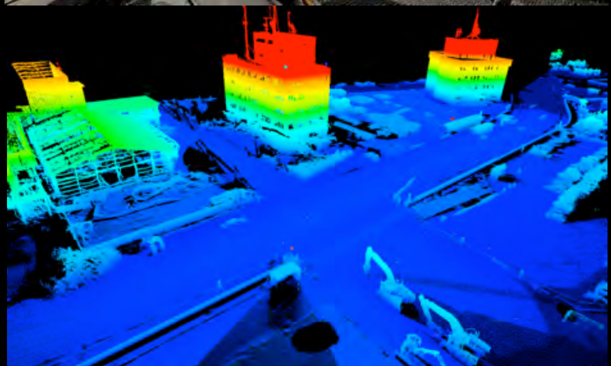




Fritz et al., 2012.





GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L00G23, doi:10.1029/2011GL050686, 2012

The 2011 Japan tsunami current velocity measurements from survivor videos at Kesennuma Bay using LiDAR

Hermann M. Fritz,[1] David A. Phillips,[2] Akio Okayasu,[3] Takenori Shimozono,[3] Haijiang Liu,[4] Fahad Mohammed,[1] Vassilis Skanavis,[5] Costas E. Synolakis,[5,6] and Tomoyuki Takahashi[7]

Received 17 December 2011; accepted 20 December 2011; published 21 January 2012.

[1] On March 11, 2011, a magnitude M_w 9.0 earthquake occurred off the coast of Japan's Tohoku region causing catastrophic damage and loss of life. The tsunami flow velocity analysis focused on two survivor videos recorded from building rooftops at Kesennuma Bay along Japan's Sanriku coast. A terrestrial laser scanner was deployed at the locations of the tsunami eyewitness video recordings. The tsunami current velocities through the Kesennuma Bay are determined in a four step process. The LiDAR point clouds are used to calibrate the camera fields of view in real world coordinates. The motion of the camera during recordings was determined. The video images were rectified with direct linear transformation. Finally a cross-correlation based particle image velocimetry analysis was applied to the rectified video images to determine instantaneous tsunami flow velocity fields. The measured maximum tsunami height of 9 m in the Kesennuma Bay narrows were followed by maximum tsunami outflow currents of 11 m/s less than 10 minutes later. **Citation:** Fritz, H. M., D. A. Phillips, A. Okayasu, T. Shimozono, H. Liu, F. Mohammed, V. Skanavis, C. E. Synolakis, and T. Takahashi (2012), The 2011 Japan tsunami current velocity measurements from survivor videos at Kesennuma Bay using LiDAR, *Geophys. Res. Lett.*, *39*, L00G23, doi:10.1029/2011GL050686.

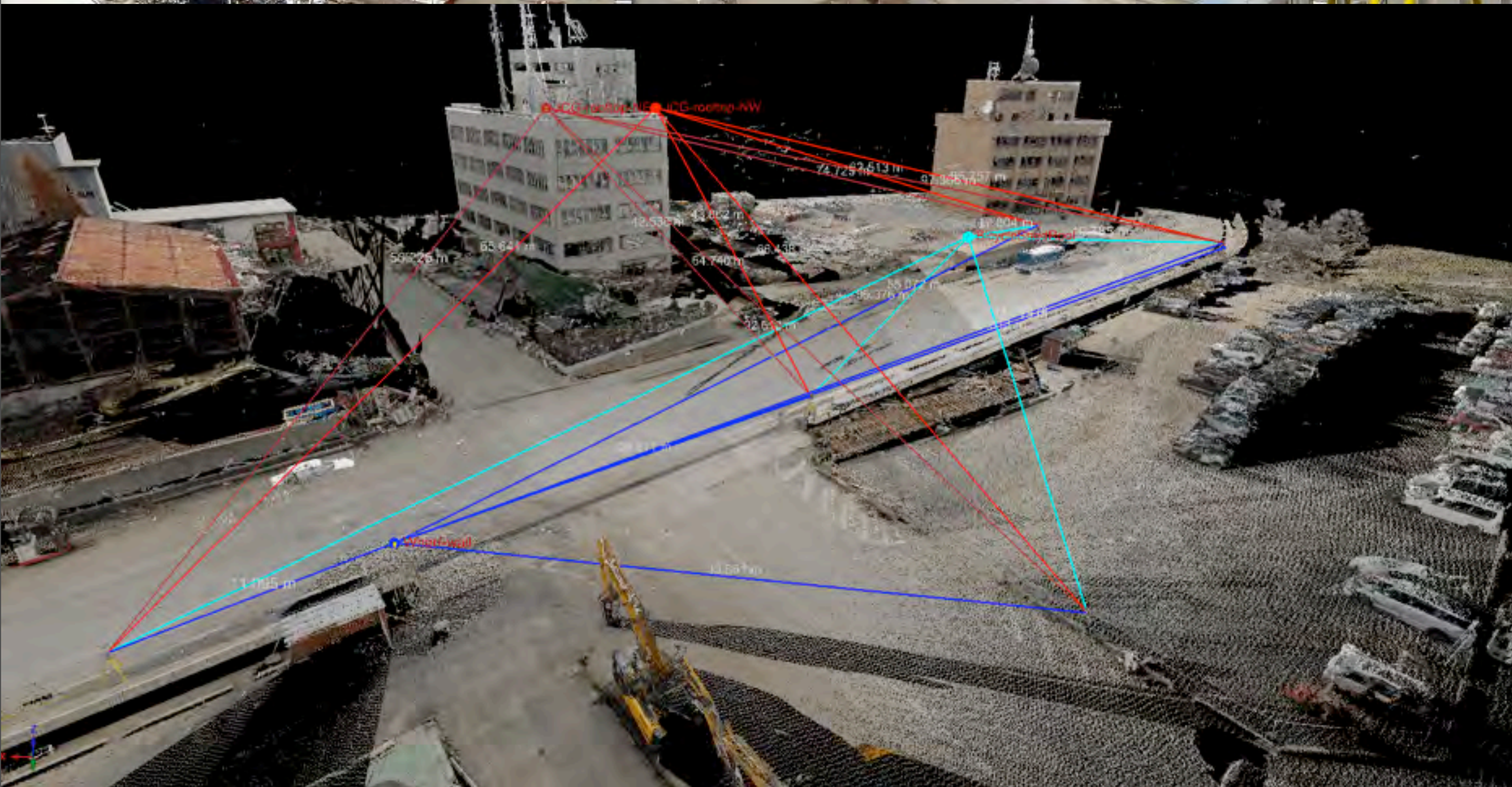
1. Introduction

[2] On March 11, 2011, at 05:46:23 UTC (local time 02:46:23 pm), a magnitude $M_w = 9.0$ earthquake occurred off the coast of Japan's Tohoku region about 130 km east of

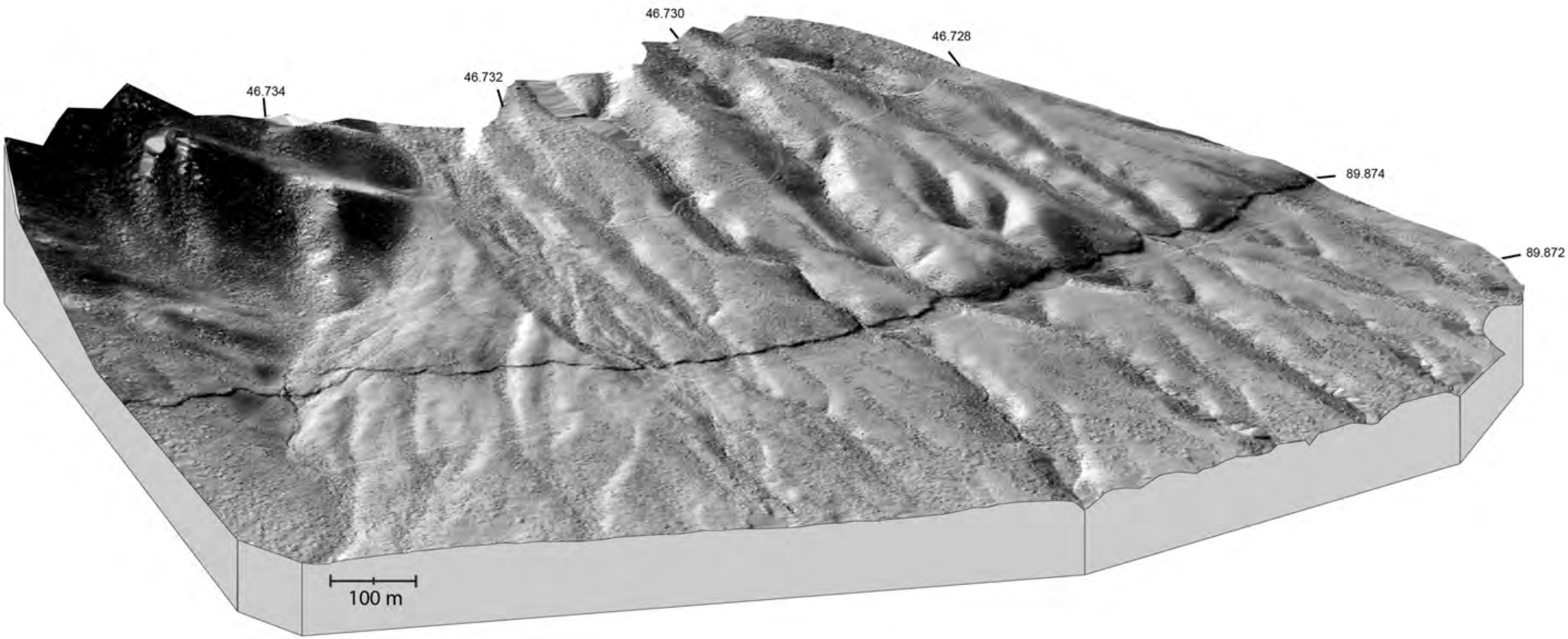
and 3,607 missing presumed dead) were concentrated in the coastal regions of Myagi, Iwate and Fukushima prefectures (http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf; http://www.47news.jp/CN/201104/CN2011041901000540.html). The majority at 92.5% of the fatalities are attributed to the tsunami. The 2011 Tohoku tsunami represents Japan's deadliest tsunami since the 1896 Meiji-Sanriku tsunami earthquake [*Tanioka and Satake*, 1996]. For the 2011 Tohoku tsunami we measured a maximum tsunami runup exceeding 38 m along the Sanriku coast in a narrow valley at Aneyoshi, Iwate Prefecture (http://www.coastal.jp/tsunami2011/) [*Mori et al.*, 2011]. Extreme runup heights were observed along the Sanriku coast in the past with 38 m by the 1896 Meiji tsunami and 29 m by the 1933 Showa tsunami [*Matsuo*, 1933]. These historic Sanriku tsunamis had limited impact further south, while the 869 Jogan earthquake produced large tsunami inundation distances up to a few kilometers preserved in sediment deposits in the Sendai plain [*Minoura et al.*, 2001; *Sawai et al.*, 2008; *Satake et al.*, 2008]. Forecasts by the Earthquake Research Committee (ERC) for the Tohoku region were based on historical earthquakes and limited to estimated earthquake magnitudes up to M~8.2 [*Fujii et al.*, 2011]. Tsunami mitigation and evacuation plans, coastal structures and vertical evacuation sites were designed based on these too conservative forecasts.

2. Post-Tsunami Reconnaissance

[3] Several tsunami reconnaissance trips were conducted in Japan (http://www.coastal.jp/tsunami2011/). This report

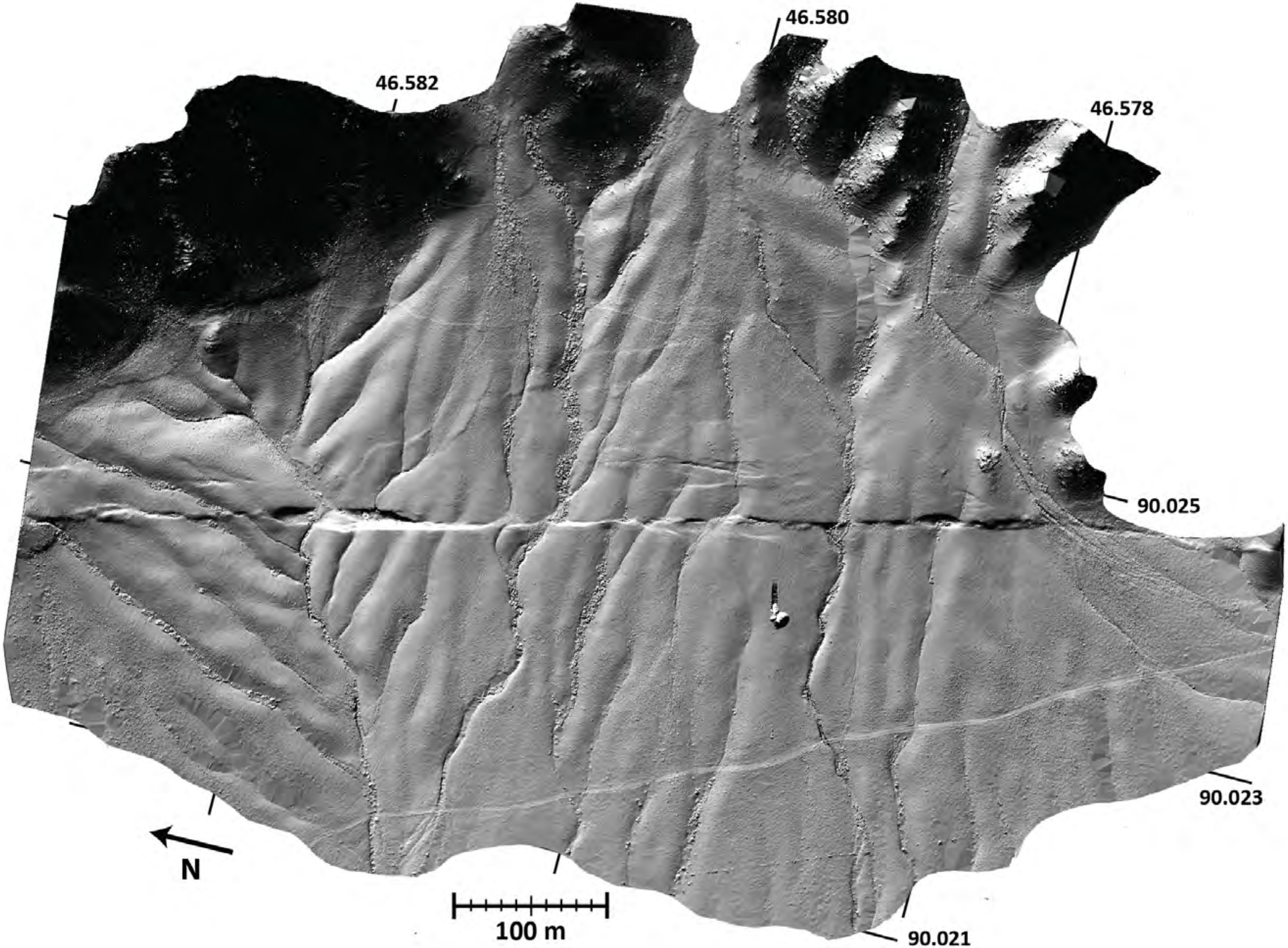


Terrestrial Laser Scanning



Slow Slip Rates and Long Characteristic Earthquake Recurrence Times on the Fuyun Fault, Xinjiang, China.

Marie ETCHEBES, Paul TAPPONNIER, Magali RIZZA, Lok Hang TSANG, Xiwei XU, Yann KLINGER, Jerome VAN DER WOERD, Xin-Zhe SUN



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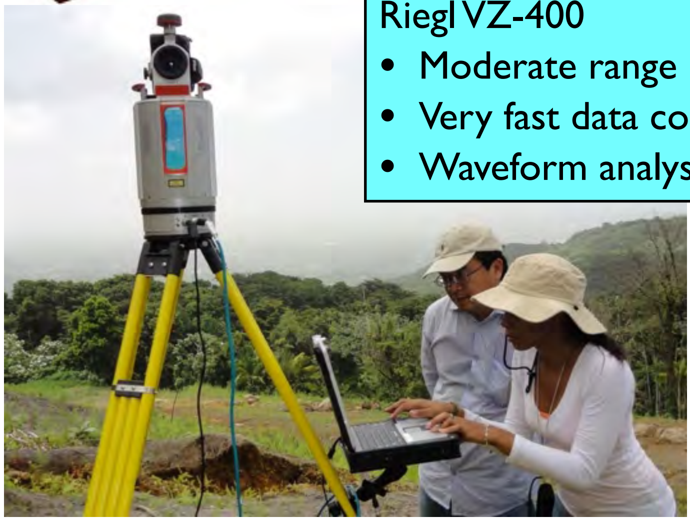
- **Spot size (range, divergence)**
- **Spot spacing (range, angular resolution)**
- **Spot density (range, angle, number of setups)**
- **Angle of incidence (spot shape, intensity, range)**
- **Edge effects**
- **First return, last return, “other” returns, waveforms**
- **LiDAR shadows**
- **Scan object characteristics (albedo, color, texture)**

UNAVCO TLS Instrument Pool: 5+ scanners

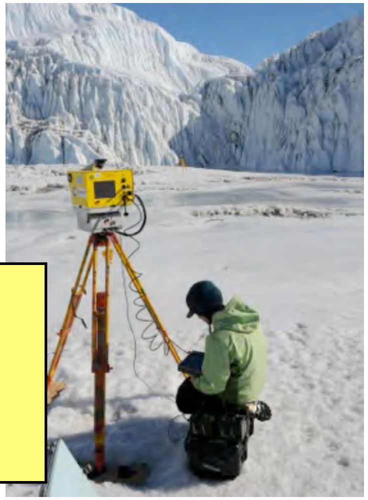


Riegl VZ-400
- Moderate range (up to ~500 m)
- Very fast data collection
- Waveform analysis

Riegl LMS-Z620
- Long range (up to ~2000 m)
- Fast data collection
- Very robust

Leica ScanStation C10
- Short range (up to ~120 m)
- Very fast data collection
- Green laser, small spot size

Optech ILRIS 3D
- Long range (up to ~1500 m)
- UNAVCO unit accessorized for polar deployments



UNAVCO TLS workflows based on INTERFACE best practices. UNAVCO also works closely with manufacturers and community PI's to continuously refine data collection.

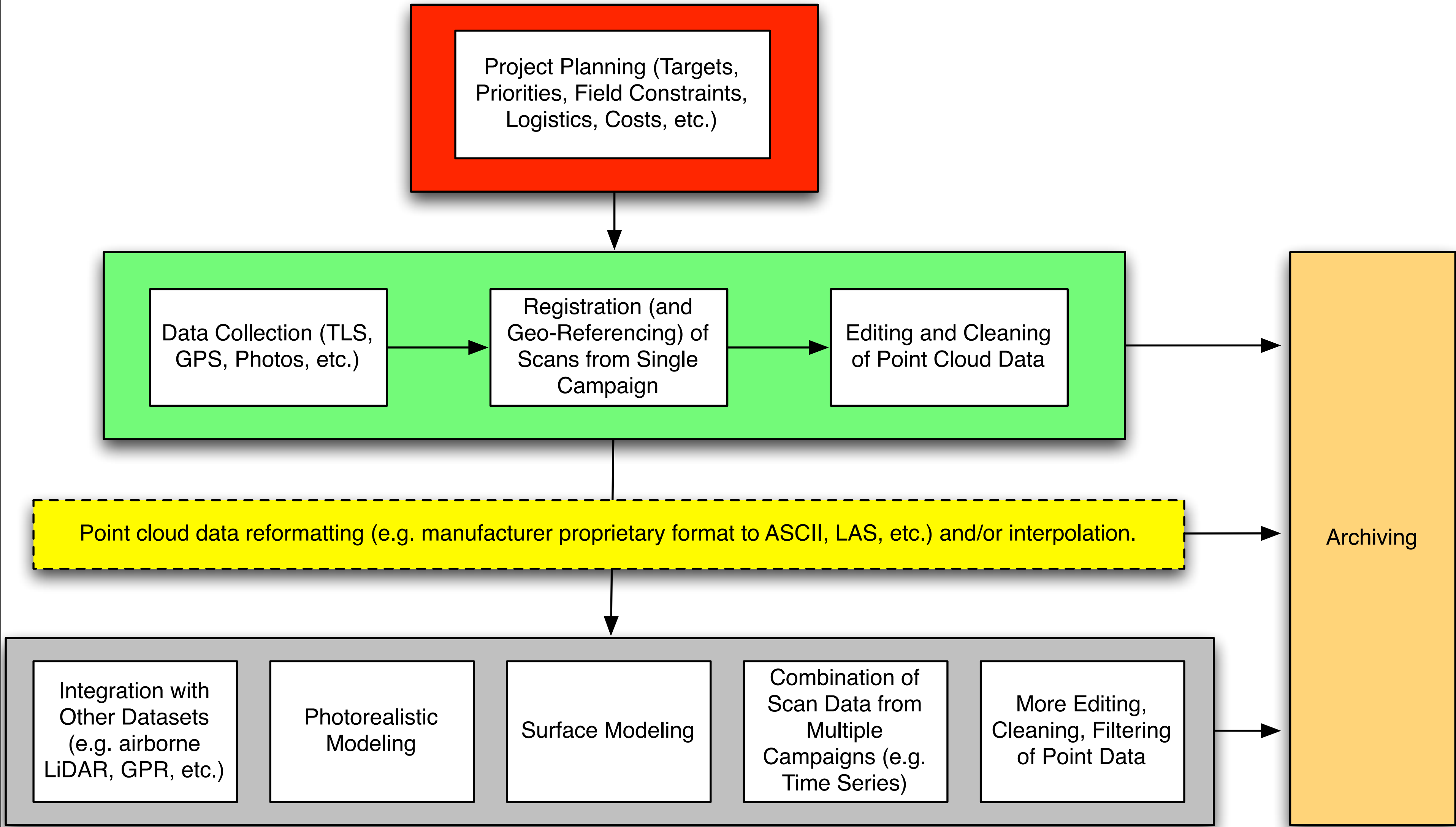
UNAVCO also has formal and informal agreements with other organizations for instrument use on a direct access or referral basis, including NCALM, INTERFACE PI's (UTD, KU), CRREL, USGS, etc.

LiDAR Logistics

- Defining the goal: target identification and prioritization
- Defining collection scheme and data product requirements
  - Resolution vs. coverage
  - End use: stratigraphy, geomorphology, paleoseismology, etc.
  - $$$$$
- Field Logistics
  - Environmental constraints (leaf-off, snow, heat, wind, etc.)
  - Permitting
- Data products
  - Data format and metadata standards
  - Data distribution and analysis challenges

- Resolution vs. Areal Coverage...only so much time available! Let the science be your guide.
- In general, a greater number of short range setups is preferable to a few number of long range setups. This may be limited by access constraints.
- Scan from “strong” angles, minimize LiDAR “shadows”.
- Longer range shots = larger spot size, less angular resolution, less intense return.
- Scan with a spot spacing at least 1/10 the wavelength you want to characterize.
- Atmospheric affects
  - Rain, fog, wet surfaces are major problems.
  - Don’t shoot into the sun.
  - Don’t let machine overheat.
- Treat the equipment gently...it’s finely calibrated and EXPENSIVE!
- The data are only as good as your setup!!!

TLS Workflow Overview Example



Terrestrial Laser Scanning

Yesterday it worked
Today it is not working
Windows is like that

Out of memory.
We wish to hold the whole sky,
But we never will.

Windows has crashed.
I am the Blue Screen of Death.
No one hears your screams.

A crash reduces
your expensive computer
to a simple stone.

A file that big?
It might be very useful.
But now it is gone.

Serious error.
All data have disappeared
Screen. Mind. Both are blank.

ABORTED effort:
Close all that you have.
You ask way too much.

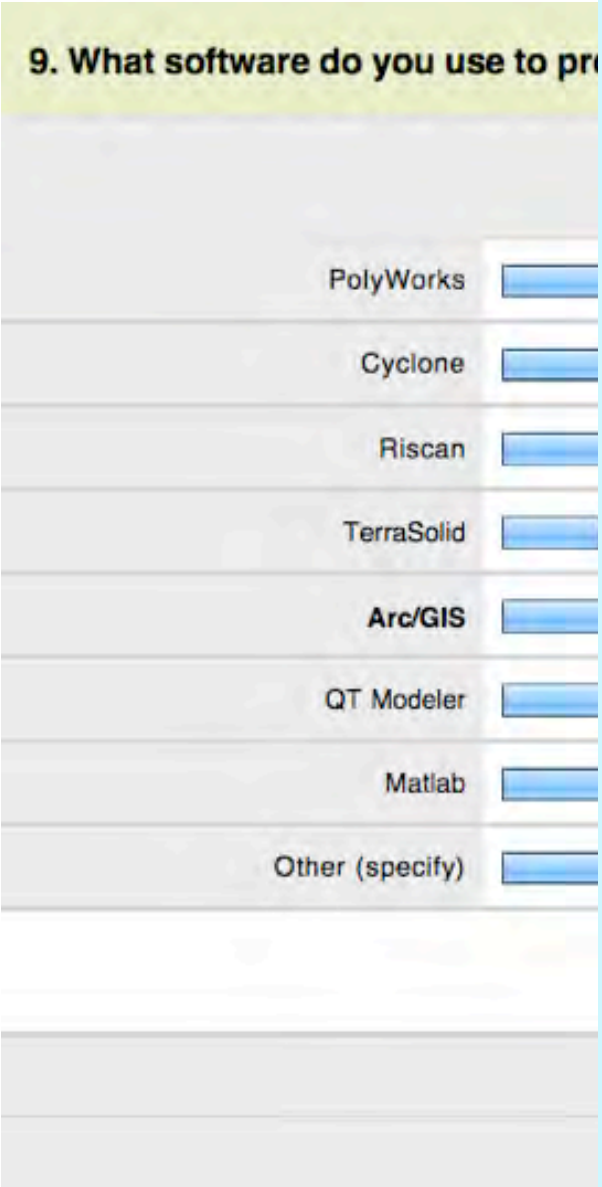
Chaos reigns within.
REFLECT, REPENT, REBOOT.
Order shall return.

To have no errors
Would be life without meaning
No struggle, no joy

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

Community TLS Workshop



Other:

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”