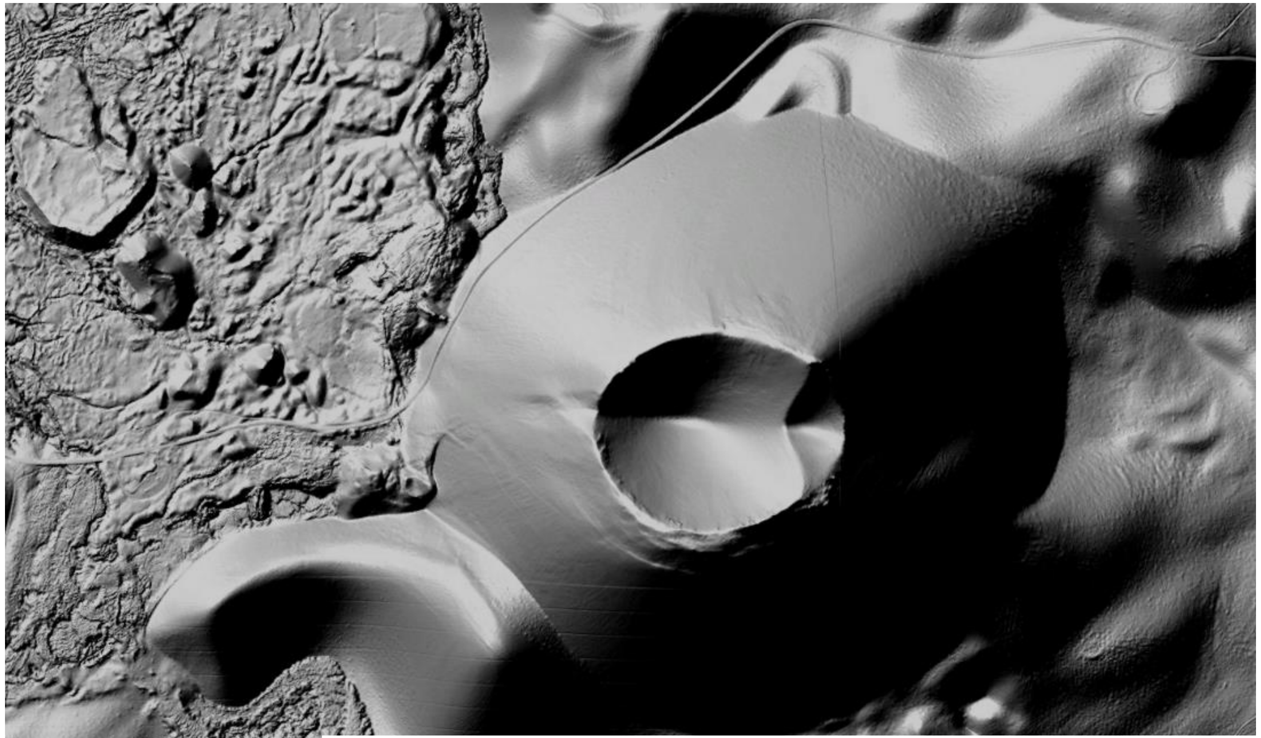
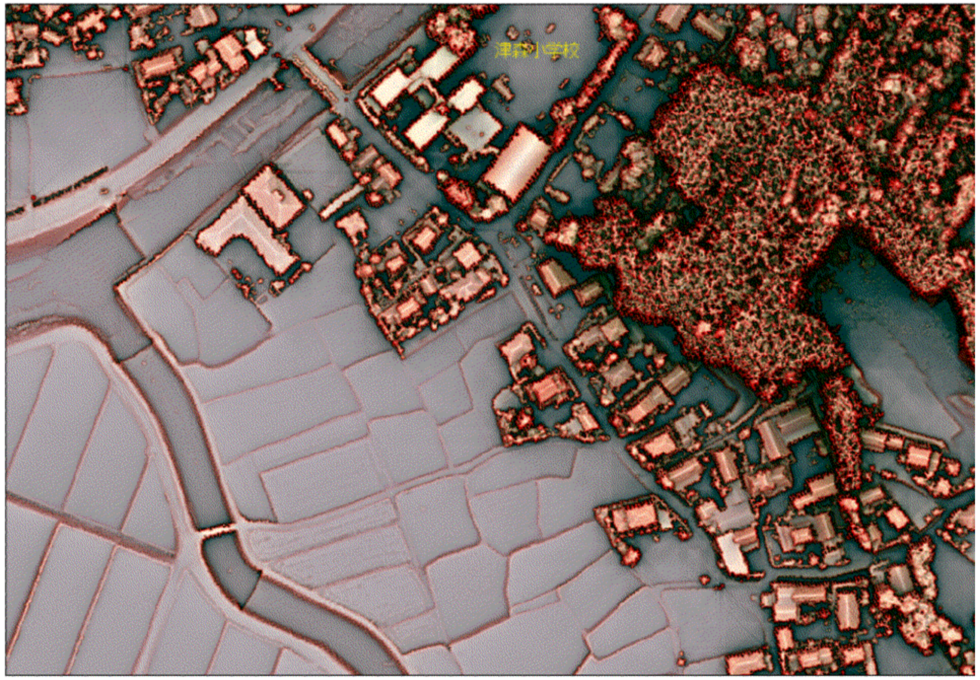
OpenTopography
High-Resolution Topography Data and Tools

Science Applications of High Resolution Topography & Geodetic Imaging

Ramon Arrowsmith (Arizona State University and OpenTopography)



Sunset Crater Arizona bare earth hillshade (US NPS)



4/15計測 DSMデータによる赤色立体地図
益城町 津森小学校周辺

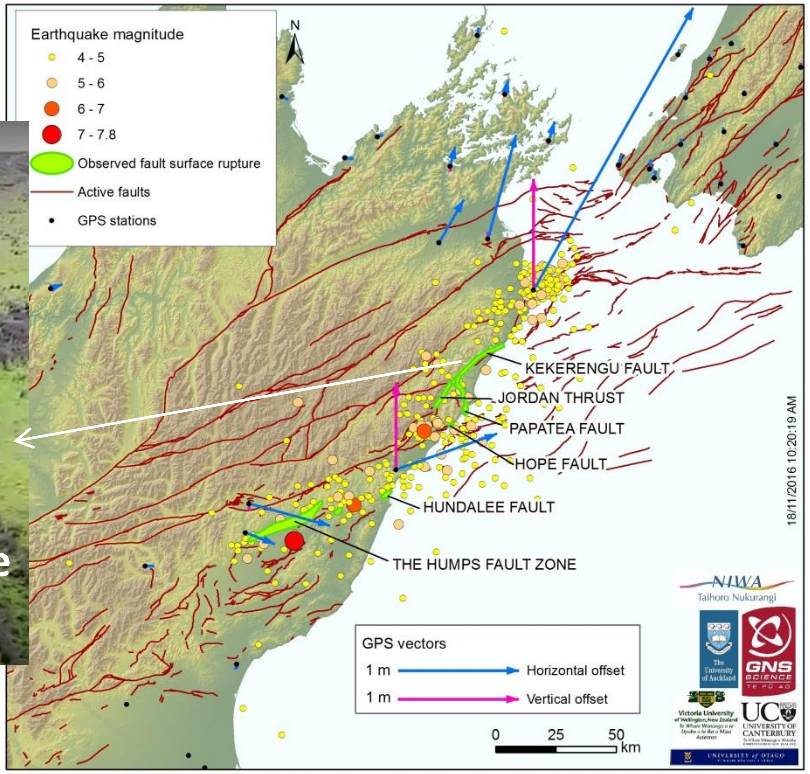
http://www.ajiko.co.jp/saigai/kumamoto_2016_04_2/gif_a.gif

2016 Apr 15 M7
Kumamoto Japan eq

Science requirements

- Need topography data with sufficient spatial extent and resolution to capture phenomena of interest
- Need topography data with sufficient temporal repeat to capture changes of interest

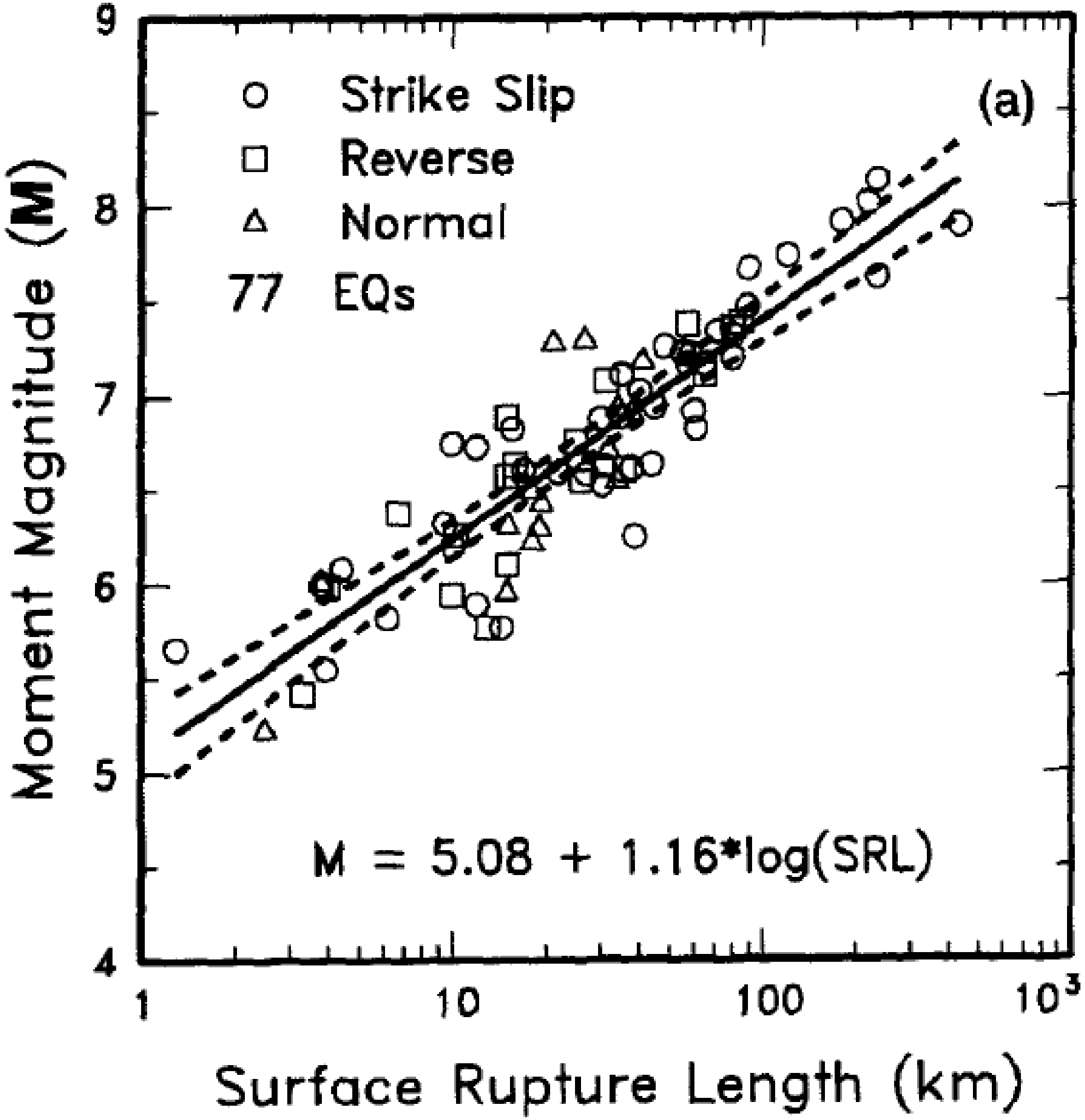
https://www.youtube.com/watch?v=U3H8wlzXGYE&feature=youtu.be

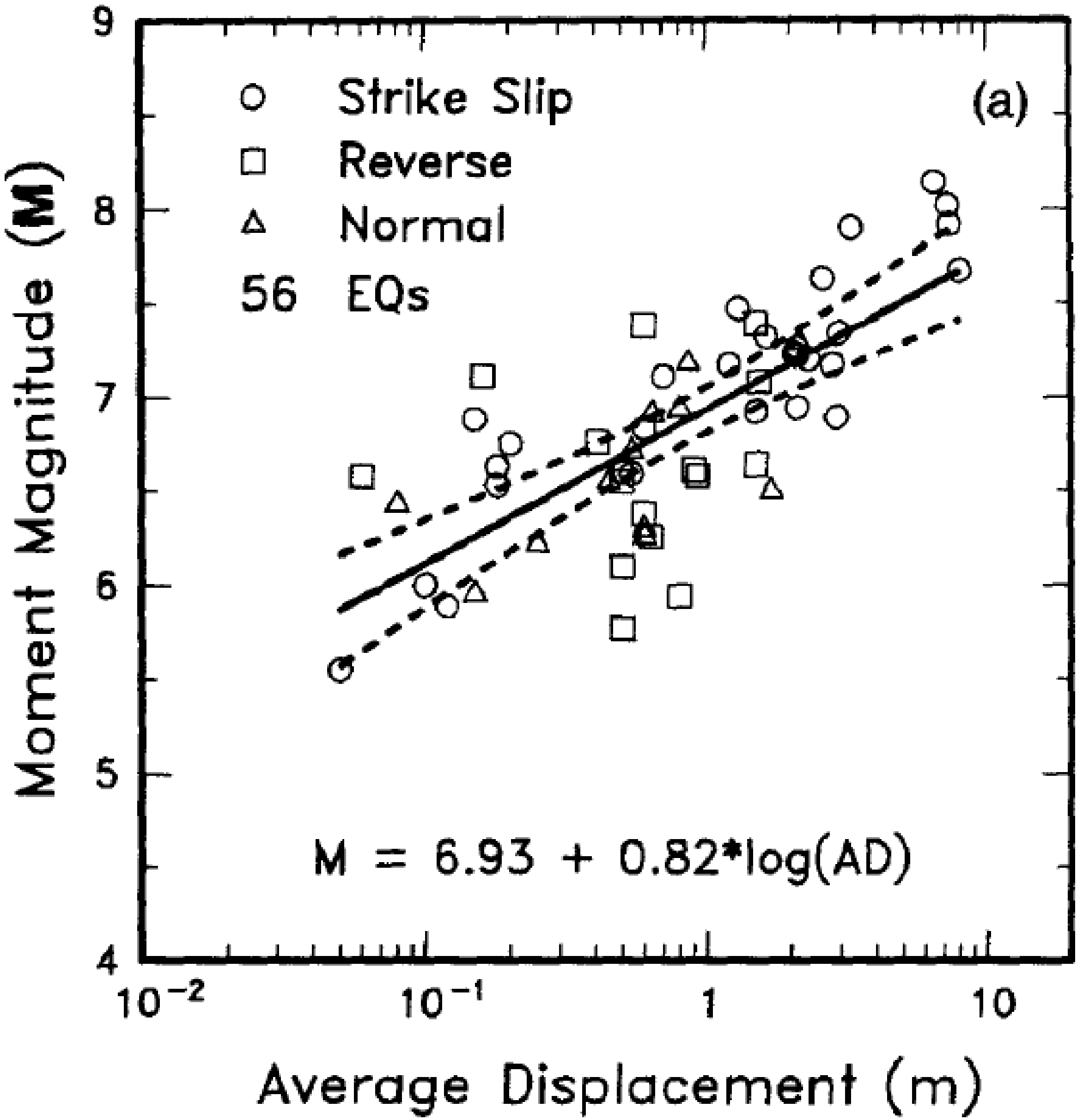


Kekerengu alone is 30+ km of this intricate ground rupture

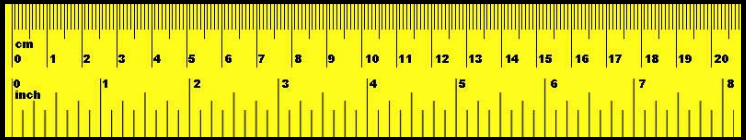
Length scales >10^5m and <1 m

Wells and Coppersmith, 1994





“Seeing” at the appropriate scale means measuring at the right scale



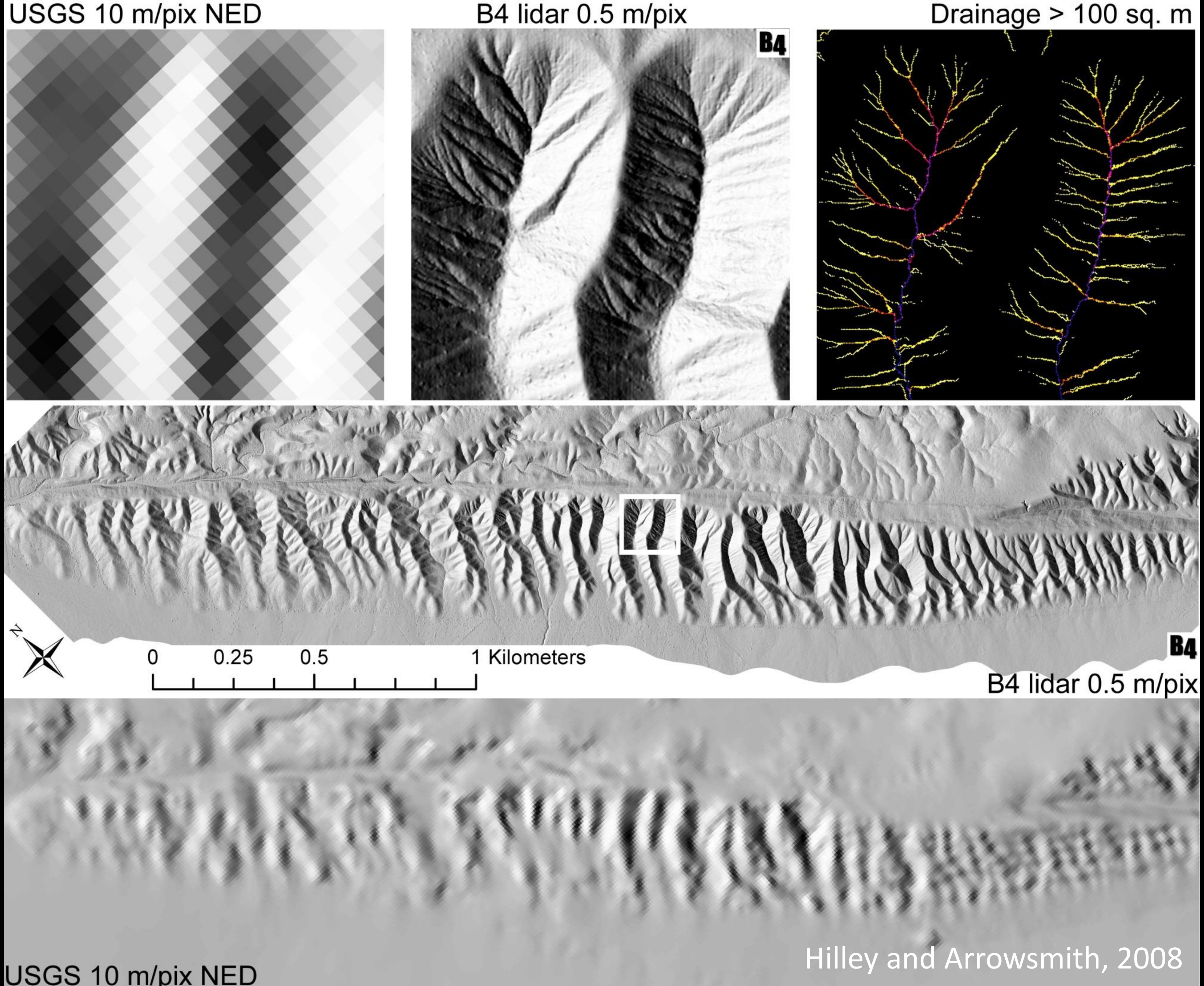
Surface processes act to change elevation through erosion and deposition while tectonic processes depress or elevate the surface directly— their record is best characterized with the right fine scale.

Applies in particular to statistical self similarity

How long is the coast of Britain?
Statistical self-similarity and fractional dimension
Science: 156, 1967, 636-638

B. B. Mandelbrot

http://en.wikipedia.org/wiki/How_Long_Is_the_Coast_of_Britain%3F_Statistical_Self-Similarity_and_Fractional_Dimension



Hilley and Arrowsmith, 2008

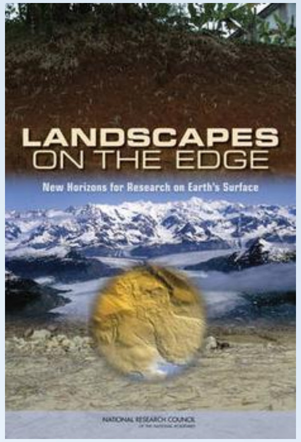
Example scientific targets

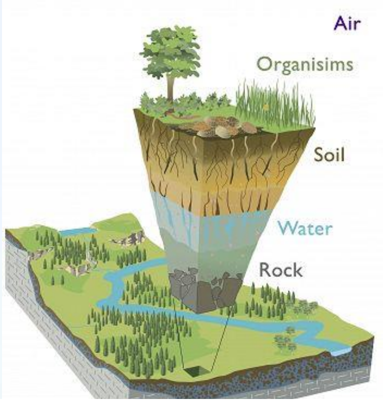
- How do geopatterns on the Earth's surface arise and what do they tell us about processes?
- How do landscapes influence and record climate and tectonics (long and short time scales)?
- What are the transport laws that govern the evolution of the Earth's surface?

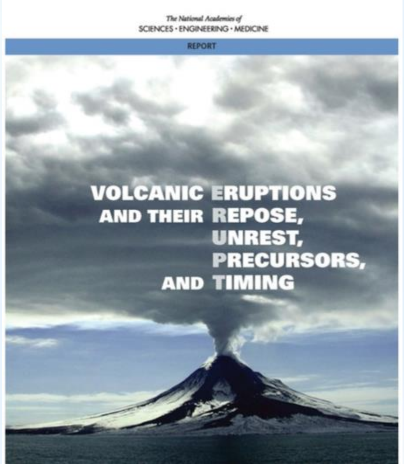
- Coupled hydrogeomorphic-ecosystem response to natural and anthropogenic change
- Landscape and ecosystem dynamics

+Cryosphere!

- Volcano form and process
- Changes in extent of domes, edifice, flows
- Outgassing and plumes
- Stability and hazard







Generic motivations and applications

Surface processes and change: observe the phenomena at the appropriate fine scales at which the processes are operating

Identify scale breaks in phenomena which are crossed at increasingly finer resolution (and accuracy)

Go beyond steady, time independent process rules -> time series

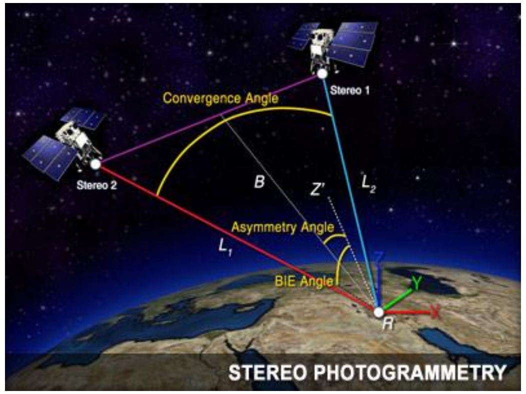
One way to describe applications (mostly faulting examples):

- Mapping and feature identification
- Landscape reconstruction
- Surface process interactions with tectonic, volcanic, cryospheric, ecological processes
- Differencing of repeat surveys—measure changes

Also (geo)science education!

3D IMAGING WITH CAMERAS & LASERS (+RADAR)

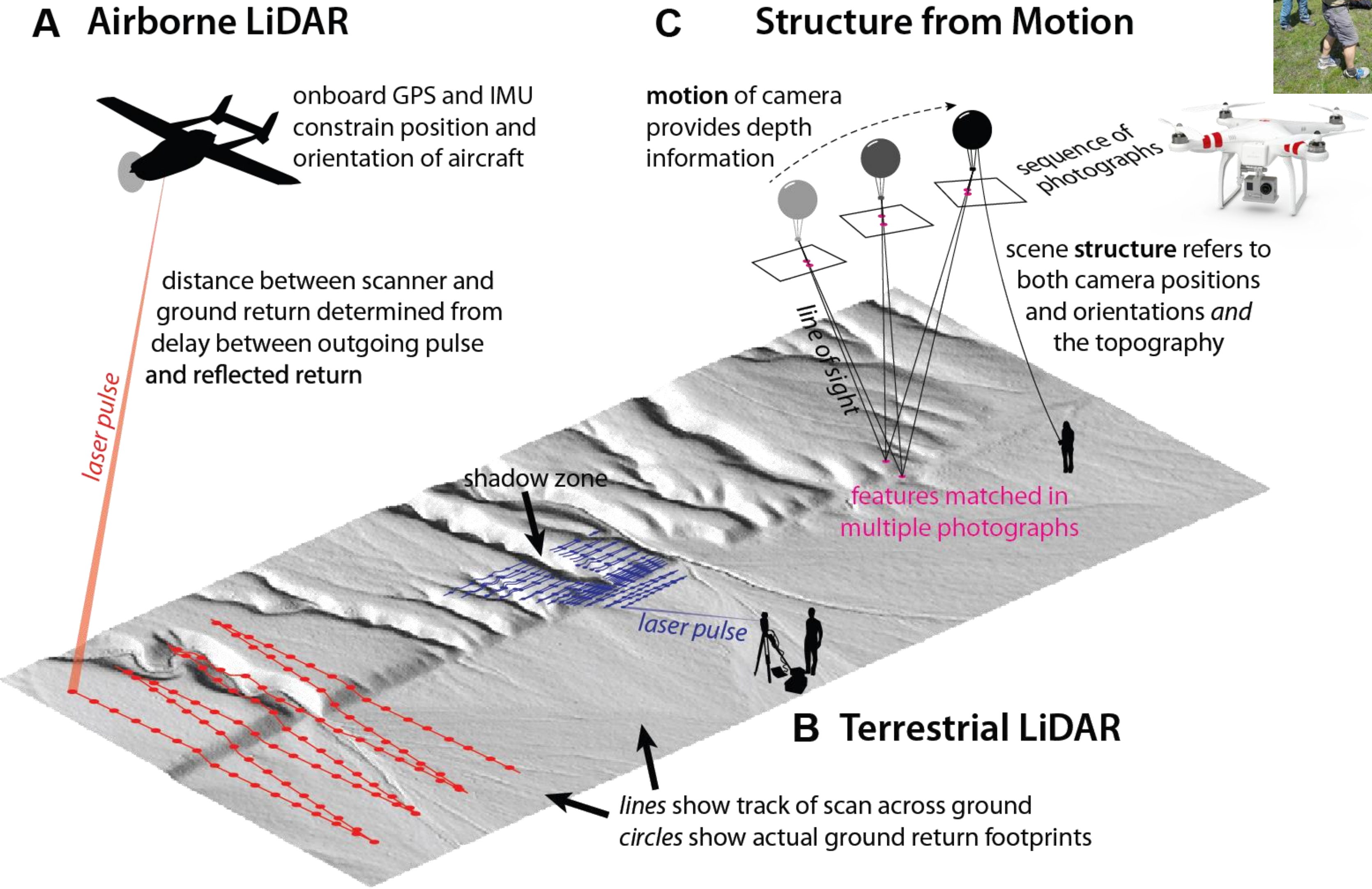
Space-based



DigitalGlobe

planet.

polar geospatial center



Johnson et al., Geosphere, 2014

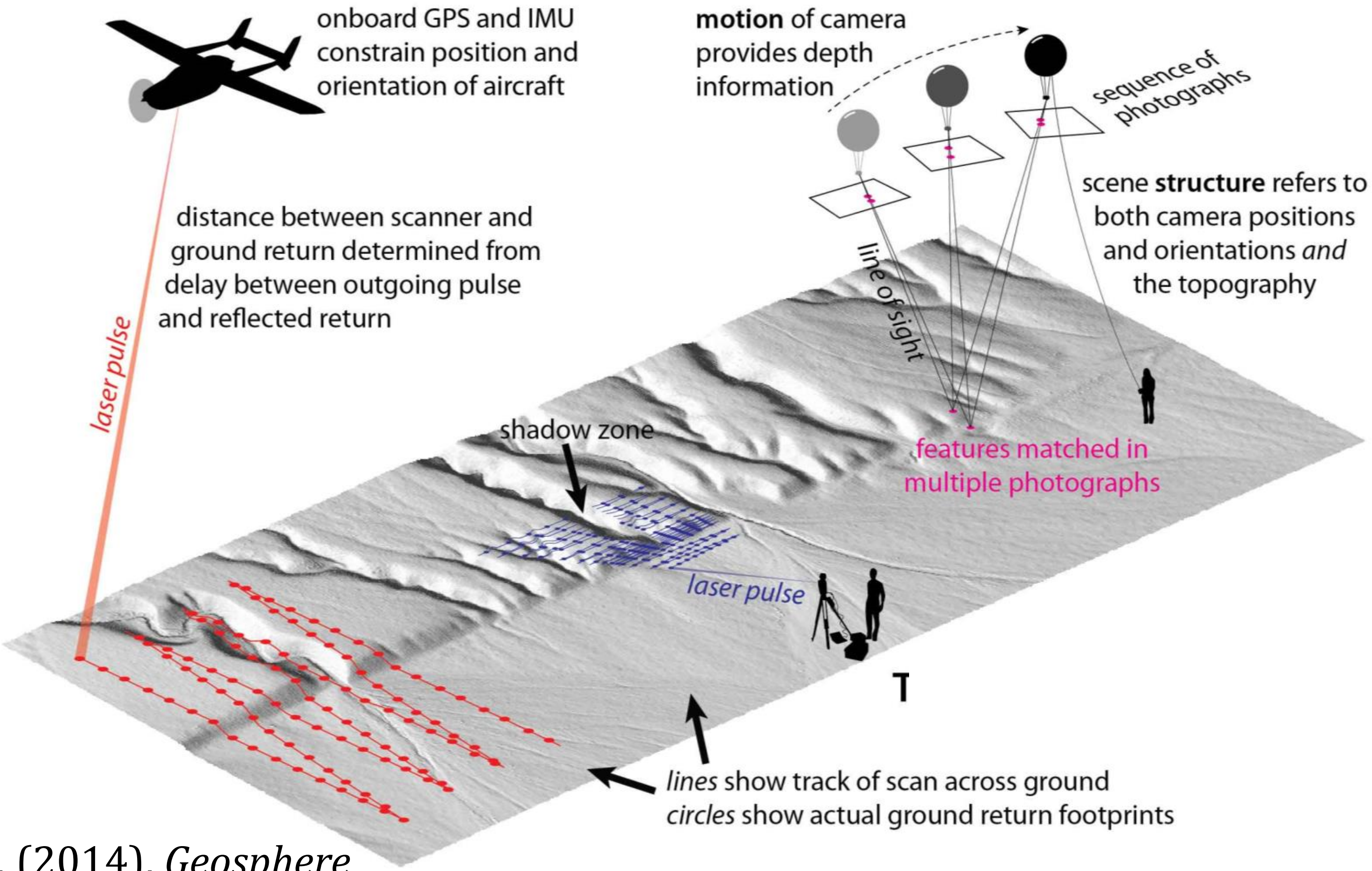
Need ~meter-scale sampling to cover critical scale breaks and temporal repeat to address log(t) response of some phenomena

Lidar (ALS, TLS, MLS)

- Expensive laser equipment required
- Works in densely-vegetated landscapes
- Uses precise time-of-flight measurements but prone to artifacts from GPS and IMU

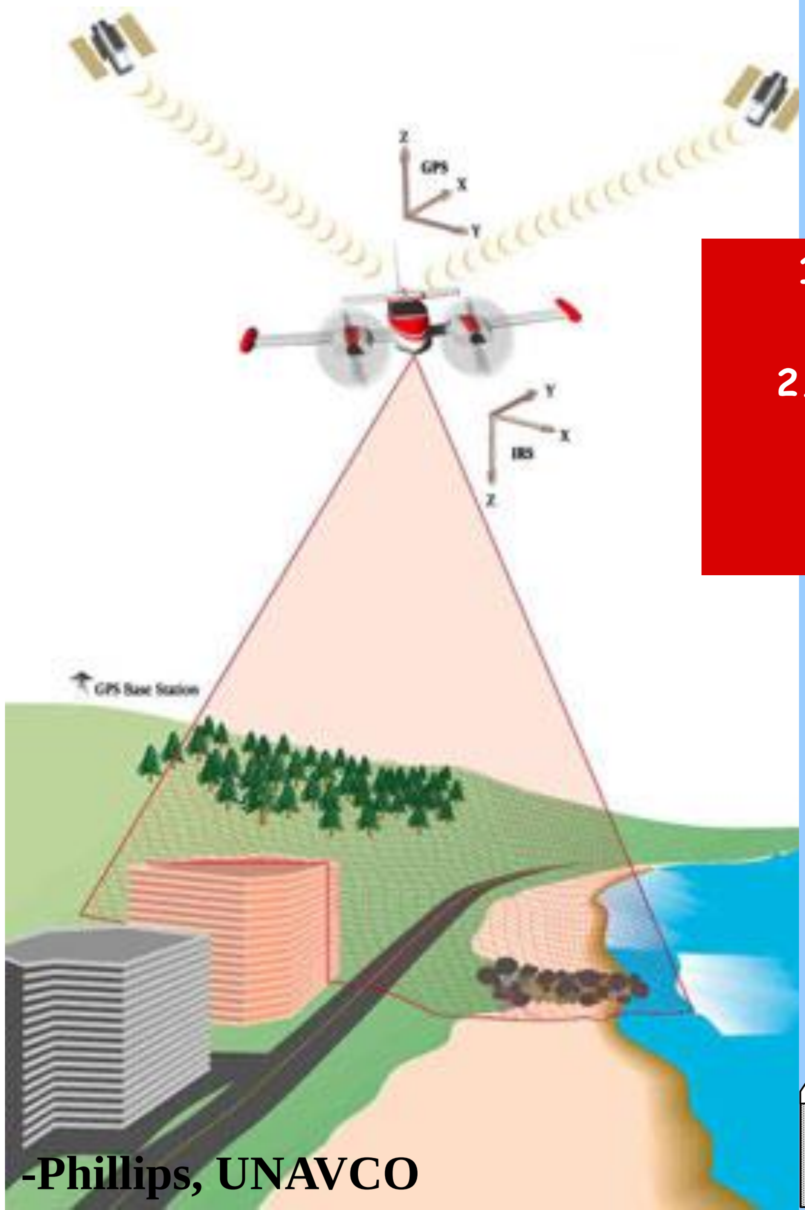
Structure-from-Motion

- Requires only a cheap camera
- Coloured points & orthophoto for texture mapping
- Back-solves for camera parameters; warping artifacts are a common problem but easily mitigated

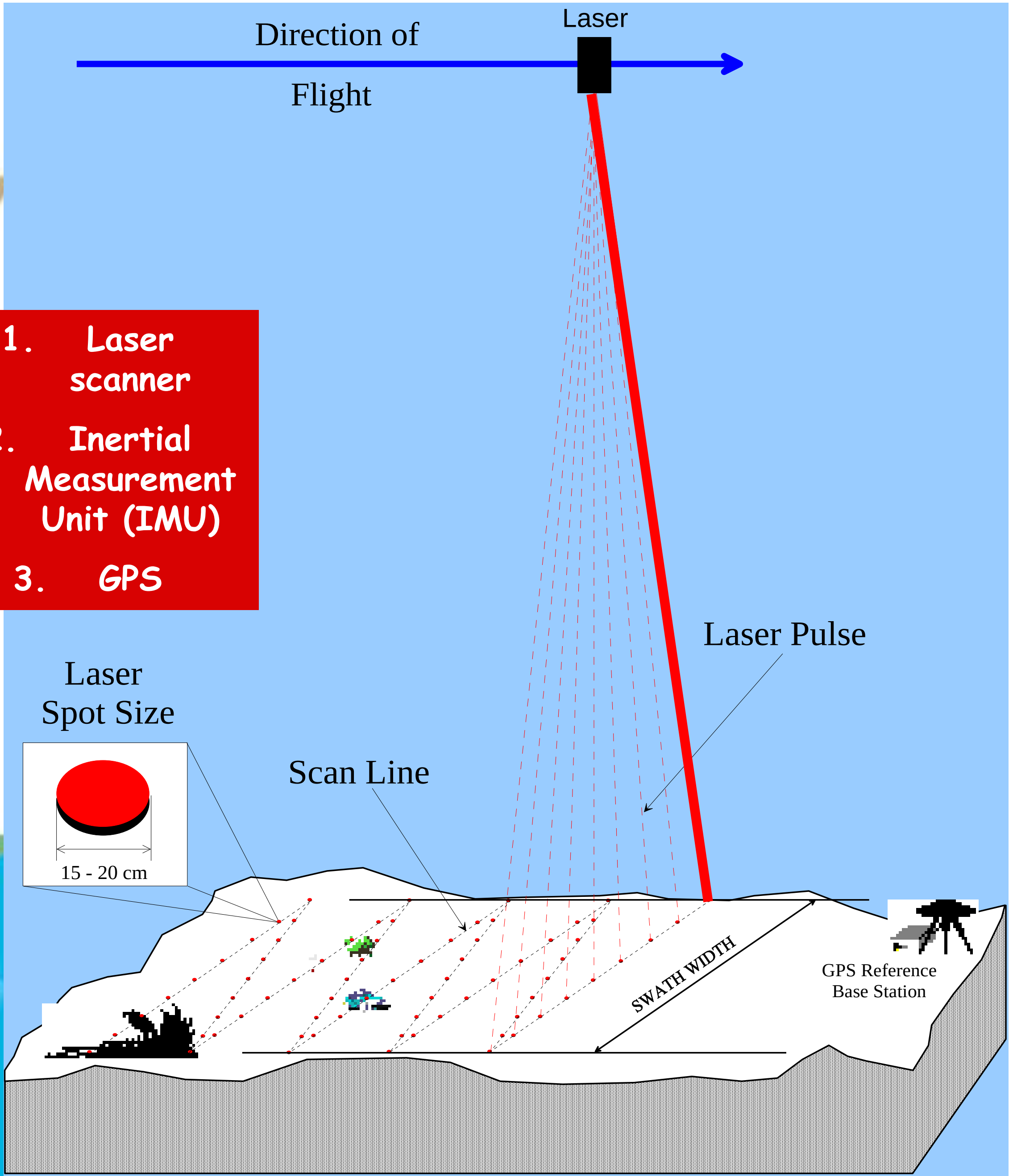


Johnson *et al.* (2014), *Geosphere*

Airborne Laser Swath Mapping (ALSM)



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



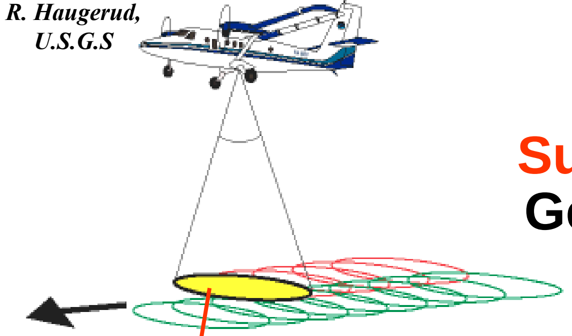
-Phillips, UNAVCO

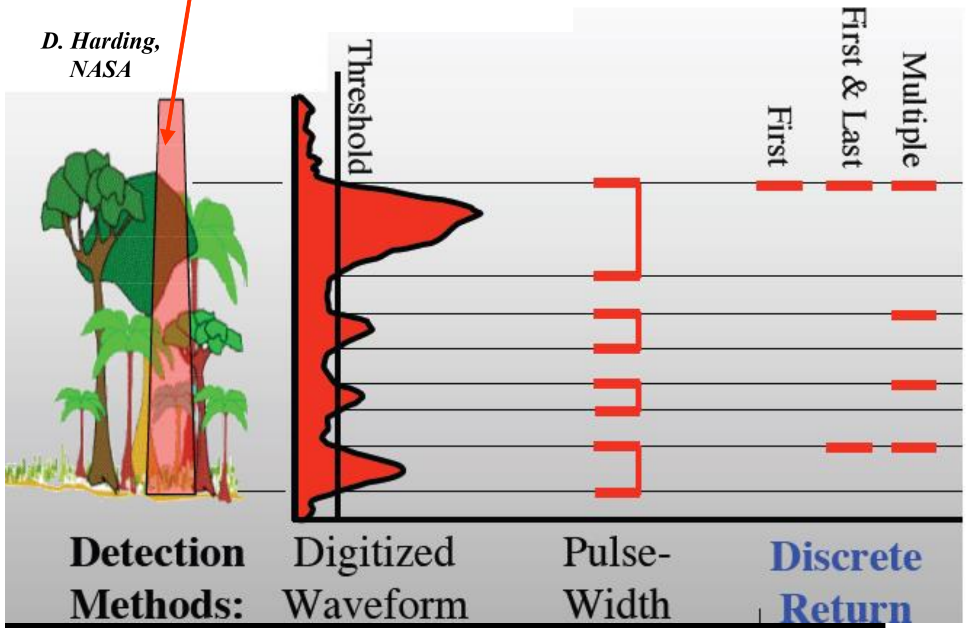
ALSM workflow:

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

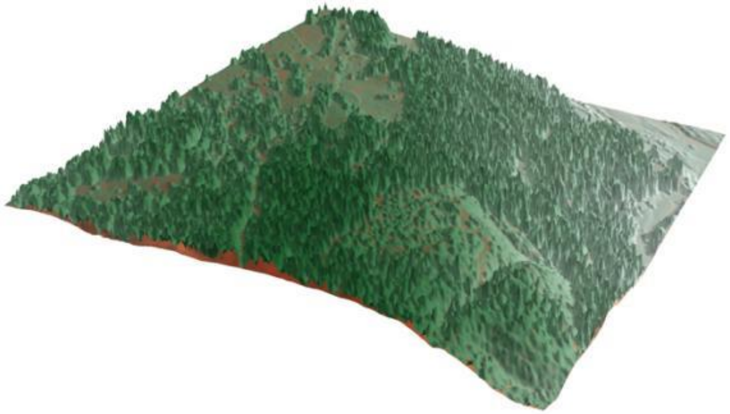
Geodesy and signal processing

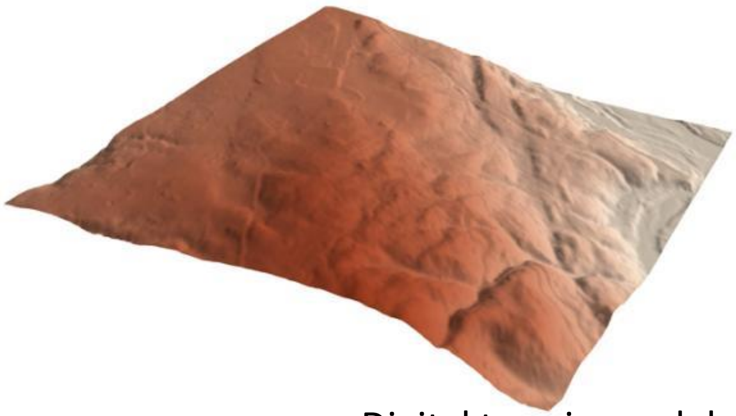
Gridded products



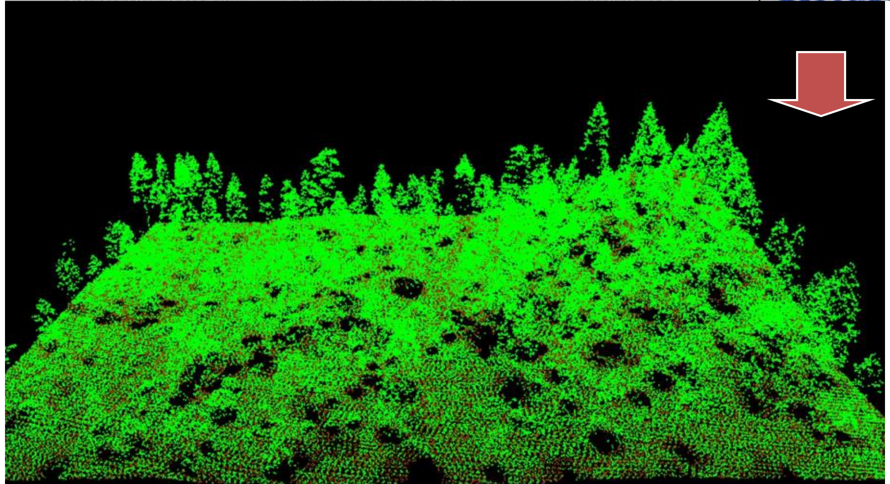


Digital surface model





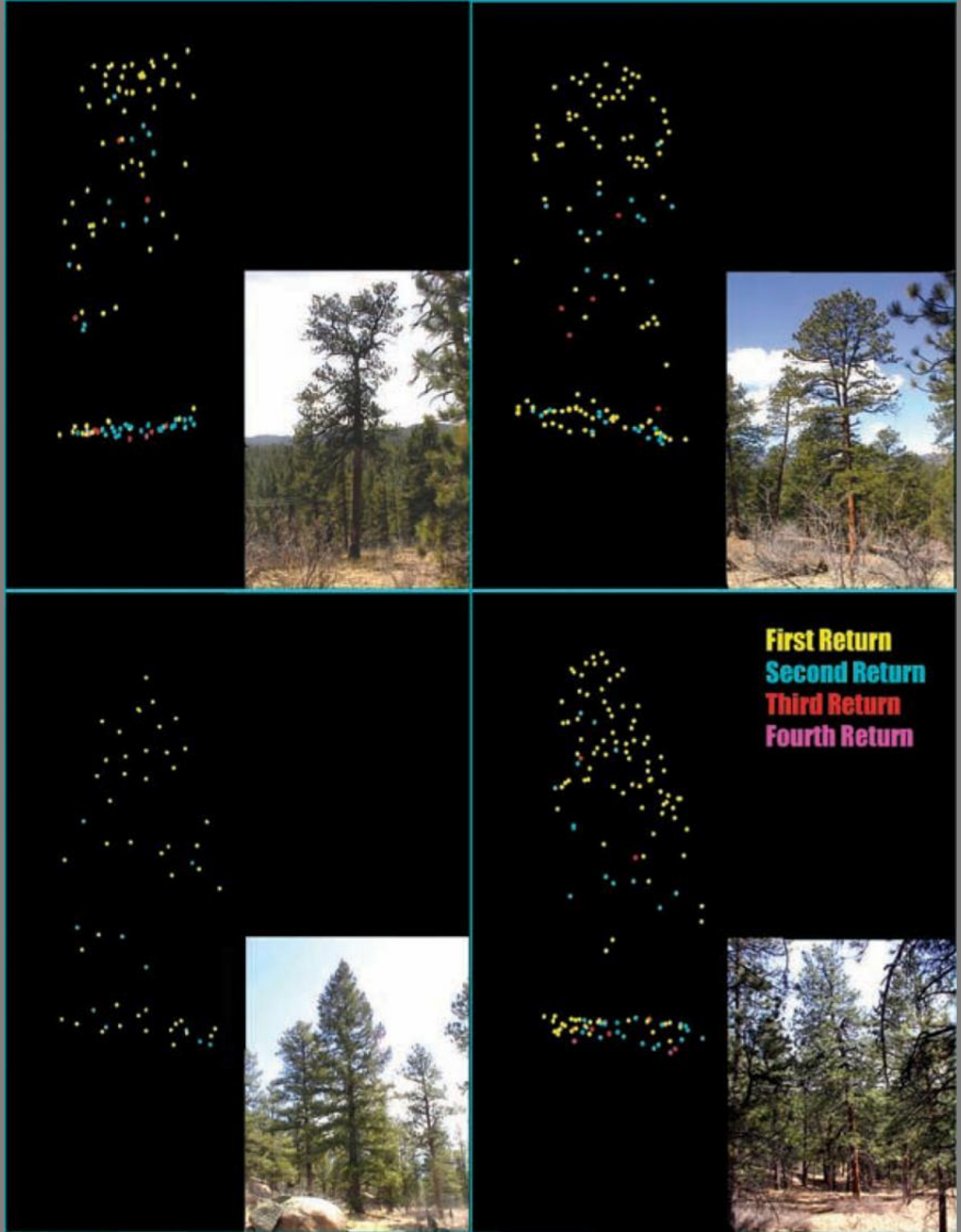
Digital terrain model



Point Cloud

x_n, y_n, z_n, i_n

Answer science question



Ecology Applications:

- 3D vegetation information & interactions between vegetation and topography

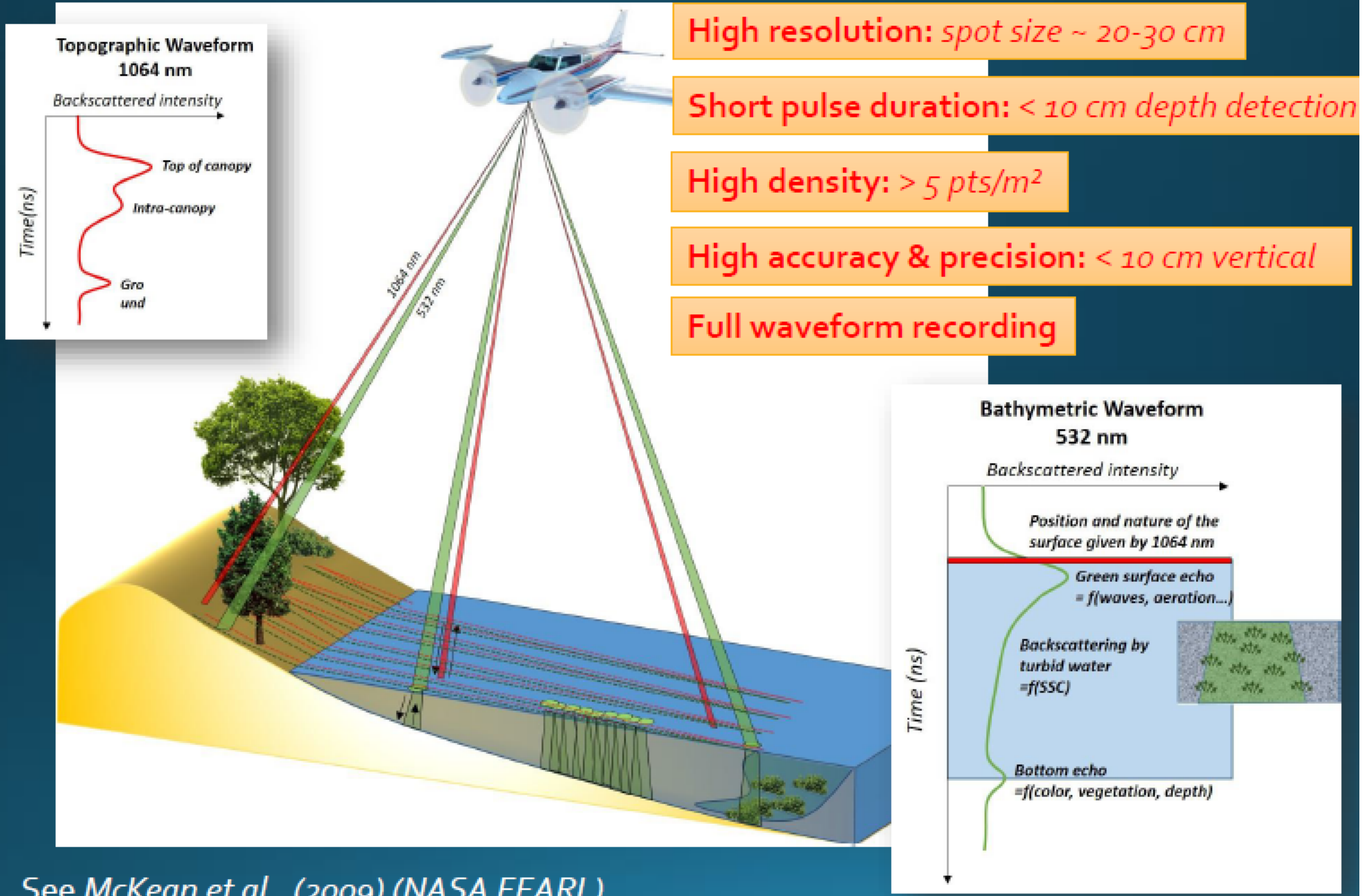
- 3D vegetation structure:
  - estimation of stand height
  - total aboveground biomass
  - foliage biomass
  - basal area
  - tree density,
  - canopy base height
  - canopy bulk density

Stoker et al., 2006

New generation of topo-bathymetric airborne lidar sensors

Plateforme
LIDAR topo-bathymétrique
Nantes-Rennes

- **High resolution:** *spot size ~ 20-30 cm*
- **Short pulse duration:** *< 10 cm depth detection*
- **High density:** *> 5 pts/m²*
- **High accuracy & precision:** *< 10 cm vertical*
- **Full waveform recording**



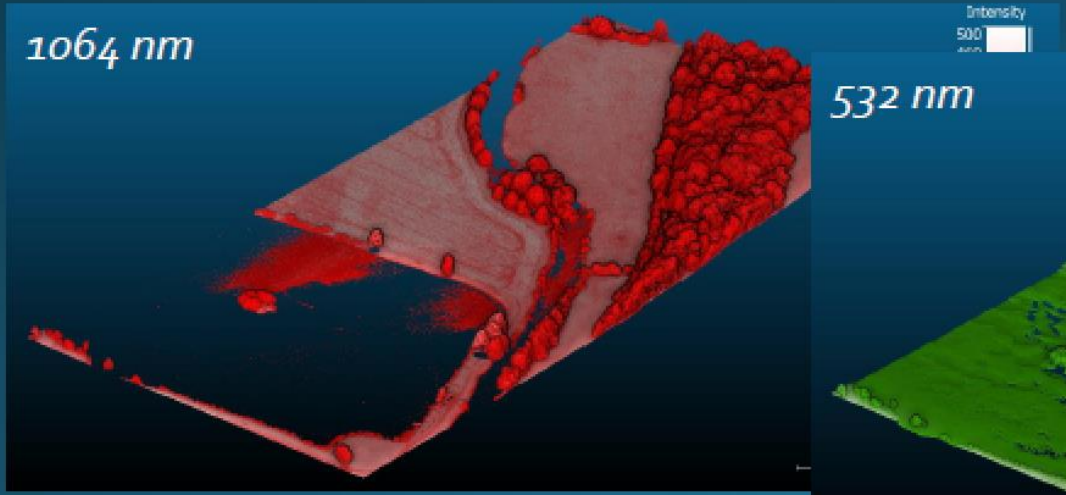
See *McKean et al.*, (2009) (NASA EEARL)
Mandlburger et al., (2015) (RIEGL), *Pan et al.*, (2015) (OPTECH).

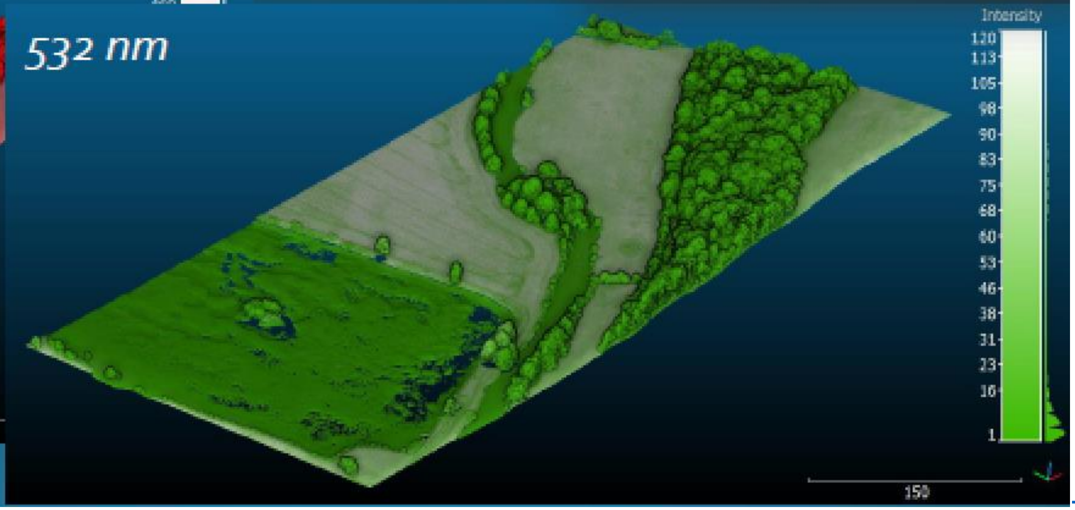
https://www.lidar-nantes-rennes.eu/

Optech Titan Dual Wavelength (2015)

- Co-owned by University of Rennes & Nantes (France)
- Operated with Fit-Conseil (public/private research partnership)
- 1064 nm + 532 nm
- Flight altitude: *350-400 m*
- Z Accuracy: < *5 cm*, Precision: < *10 cm*
- Resulting typical point density :
  - ~ 15-20 pts/m² for bathymetry (single pass)
  - ~ 30-40 pts/m² for topography (532 + 1064 nm)

Plateforme
LIDAR topo-bathymétrique
Nantes-Rennes





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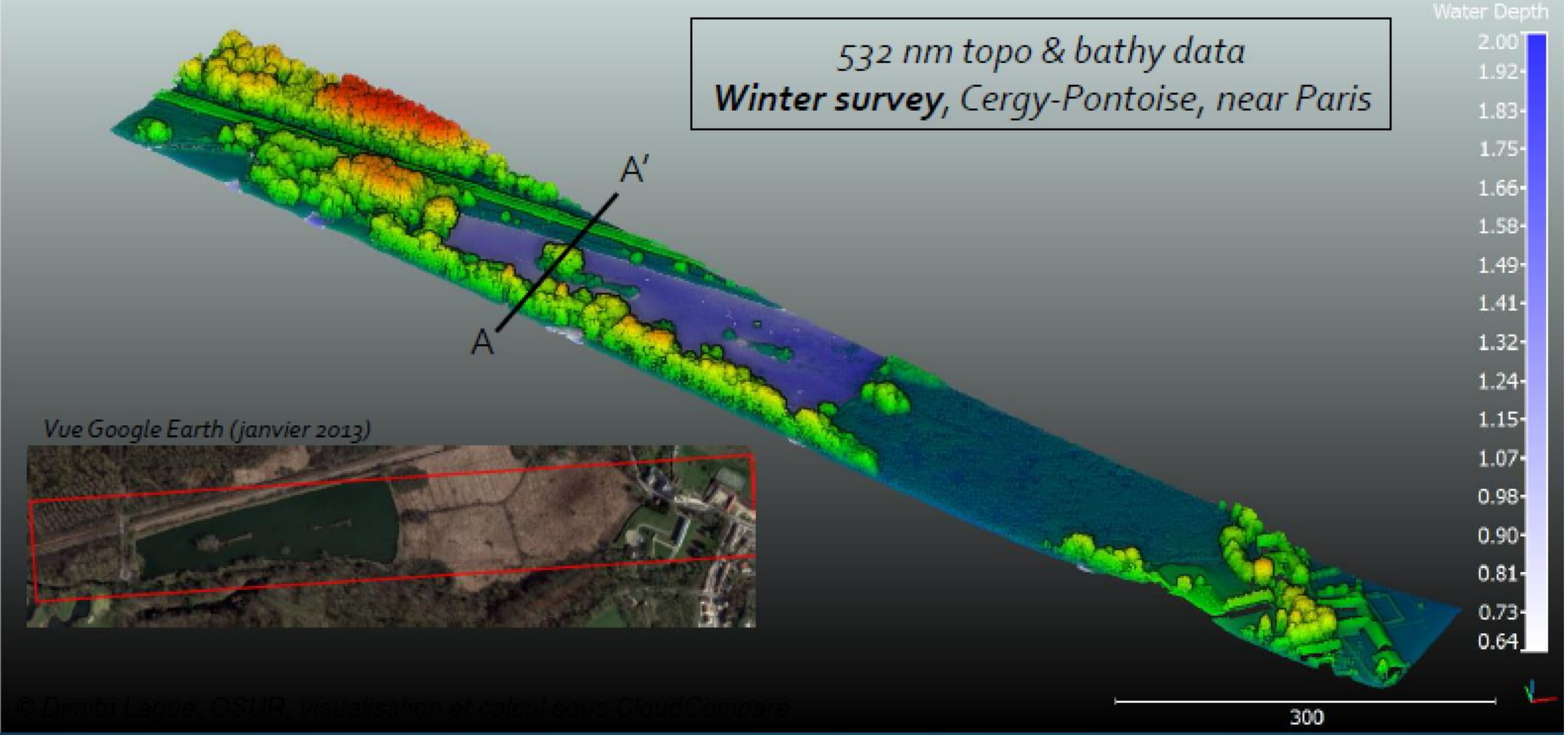

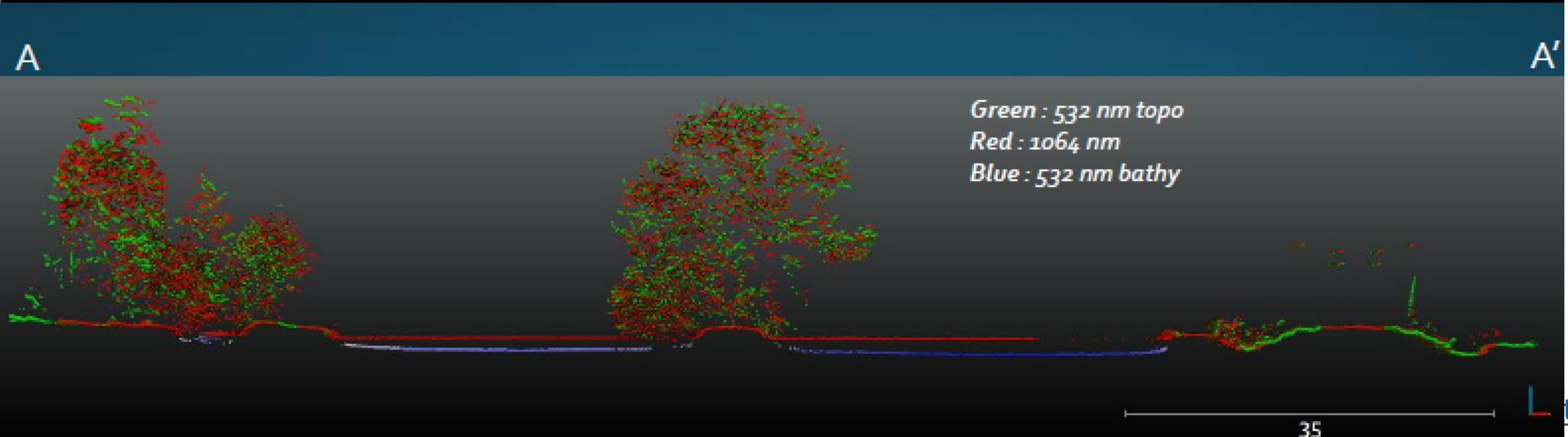

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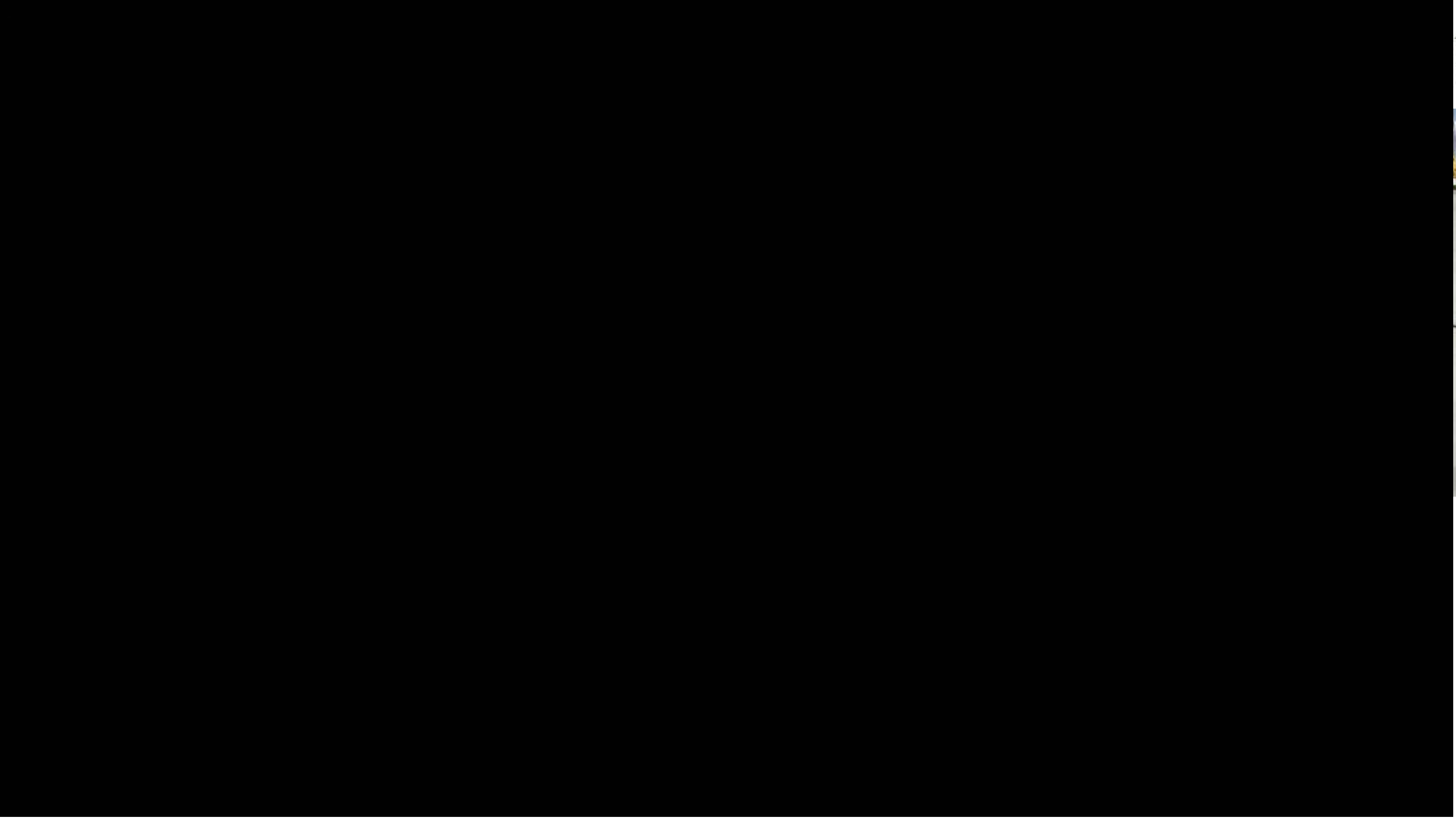
LIDAR topo-bathymétrique
Nantes-Rennes

tps://www.lidar-nantes-rennes.eu/



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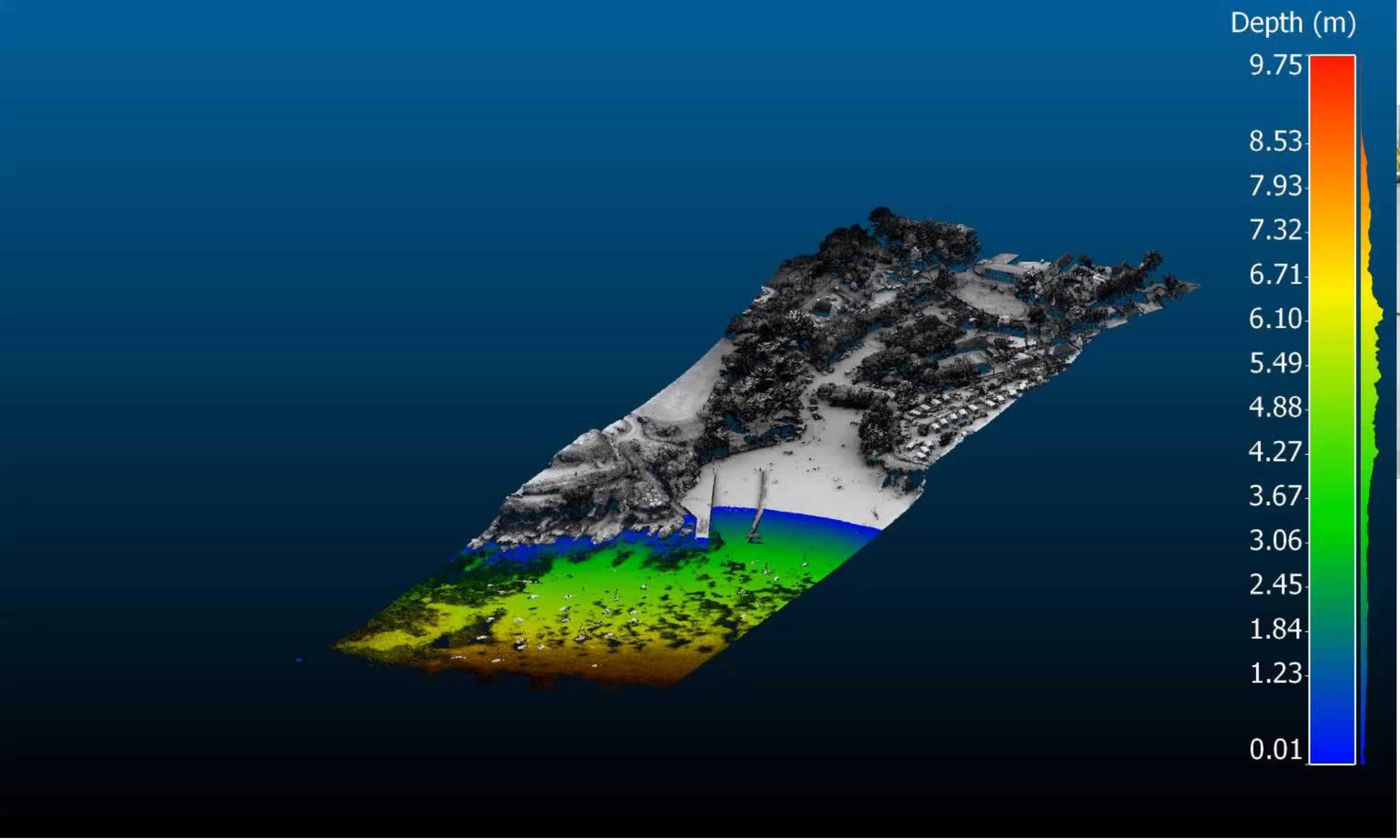

Plateforme
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Advances in and decreasing costs for software (algorithms such as structure from motion), computational hardware (rapid computation of colored point clouds and textured 3D models), and unmanned aerial vehicles (UAVs) as semi-autonomous sensing platforms has absolutely changed the geoscientist's toolkit.

Proc. R. Soc. Lond. B. **203**, 405–426 (1979)
Printed in Great Britain

The interpretation of structure from motion

By S. Ullman
Artificial Intelligence Laboratory, Massachusetts Institute of Technology, 545 Technology Square (Room 808), Cambridge, Massachusetts 02139 U.S.A.

(*Communicated by S. Brenner, F.R.S. – Received 20 April* 1978)

The interpretation of structure from motion is examined from a computational point of view. The question addressed is how the three dimensional structure and motion of objects can be inferred from the two dimensional transformations of their projected images when no three dimensional information is conveyed by the individual projections.

Proc. of the International Conference on Computer Vision, Corfu (Sept. 1999)

Object Recognition from Local Scale-Invariant Features

David G. Lowe
Computer Science Department
University of British Columbia
Vancouver, B.C., V6T 1Z4, Canada
lowe@cs.ubc.ca

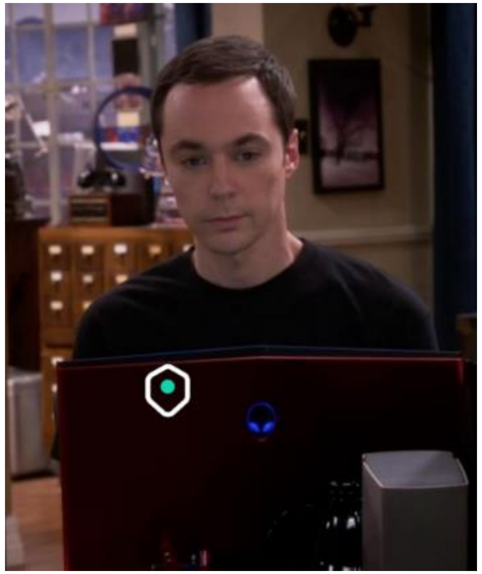
Abstract

An object recognition system has been developed that uses a new class of local image features. The features are invariant to image scaling, translation, and rotation, and partially invariant to illumination changes and affine or 3D projection.

Software
Freely available
Bundler Photogrammetry Package[a,b]
SFMToolkit[a,b]
Python Photogrammetry Toolbox (PPT)[a,b]
VisualSFM[b]
3DF Samantha
Web sites and services
Photosynth
Arc3D
CMP SfM Web service[a]
Autodesk 123D Catch
Pix4D
My3DScanner
Commercial
PhotoScan
Acute3D
PhotoModeler
3DF Zephyr Pro

Bemis, et al., 2014

https://www.dell.com/en-us/gaming/alienware-desktops



Where it all started…

The original idea

Proc. R. Soc. Lond. B. **203**, 405–426 (1979)

Printed in Great Britain

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Where it all started…

The algorithm that powers SfM

Proc. of the International Conference on Computer Vision, Corfu (Sept. 1999)

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Where it all started…

• The **Scale Invariant Feature Transform (SIFT)** (Lowe, 1999) allows corresponding features to be matched even with large variations in scale and viewpoint and under conditions of partial occlusion and changing illumination

Where it all started…

First use of the SIFT algorithm to generate large point clouds

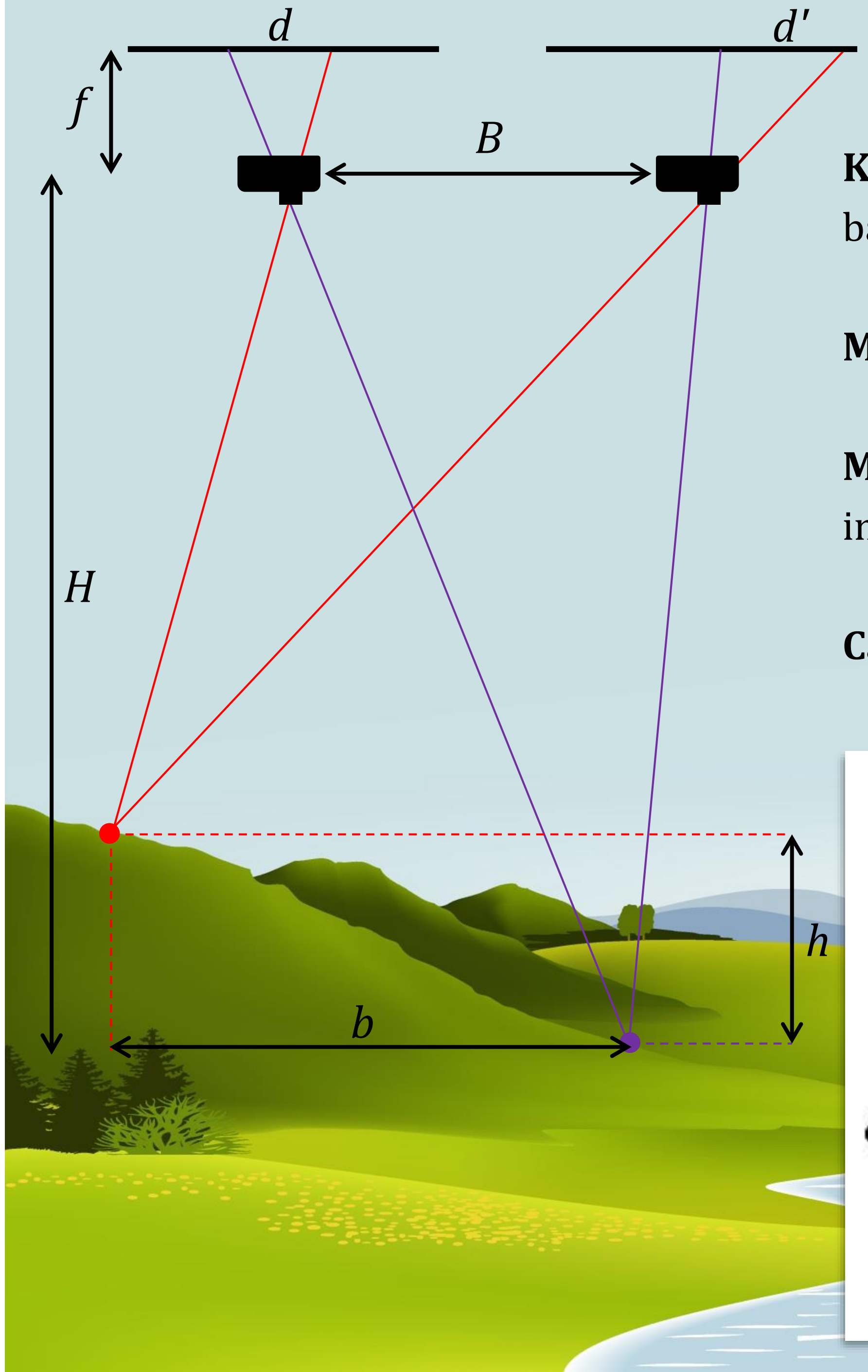
Snavely *et al.* (2006). Photo Tourism: Exploring Photo Collections in 3D, *ACM Transactions on Graphics*

Snavely *et al.* (2007). Modeling the World from Internet Photo Collections, *International Journal of Computer Vision*

Using photographs from a **moving** camera (or cameras)…

… reconstruct the scene **structure** (i.e. the geometry of the target *and* the positions, orientations & lens parameters of the cameras)

Traditional stereo-photogrammetry

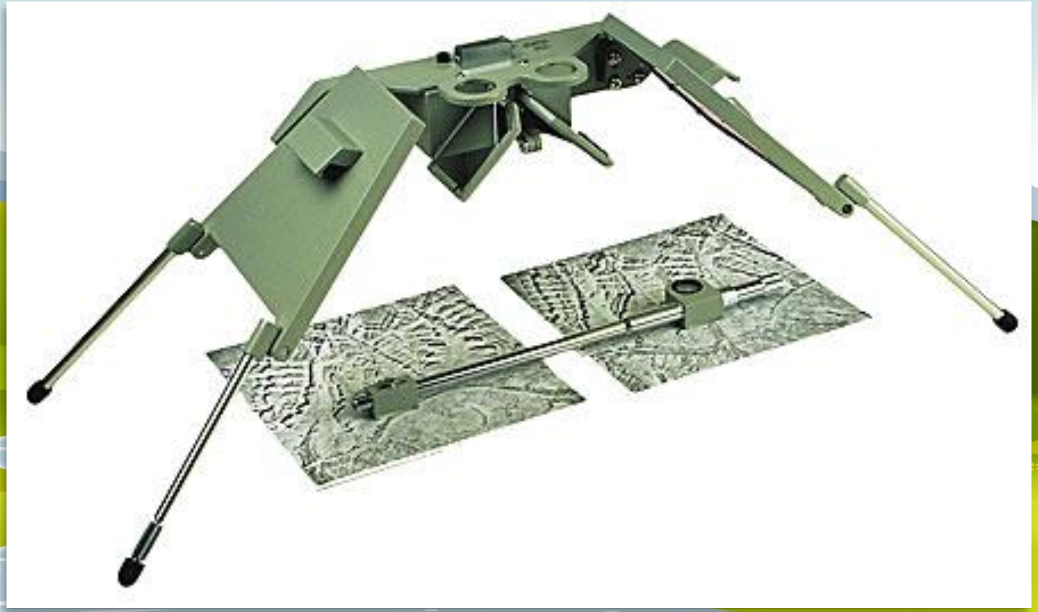


Known camera height *H* and focal length *f*, and the baseline *B* between images

Match corresponding features

Measure distances between features on the camera image plane *d, d'*

Calculate relative positions of features *b, h*

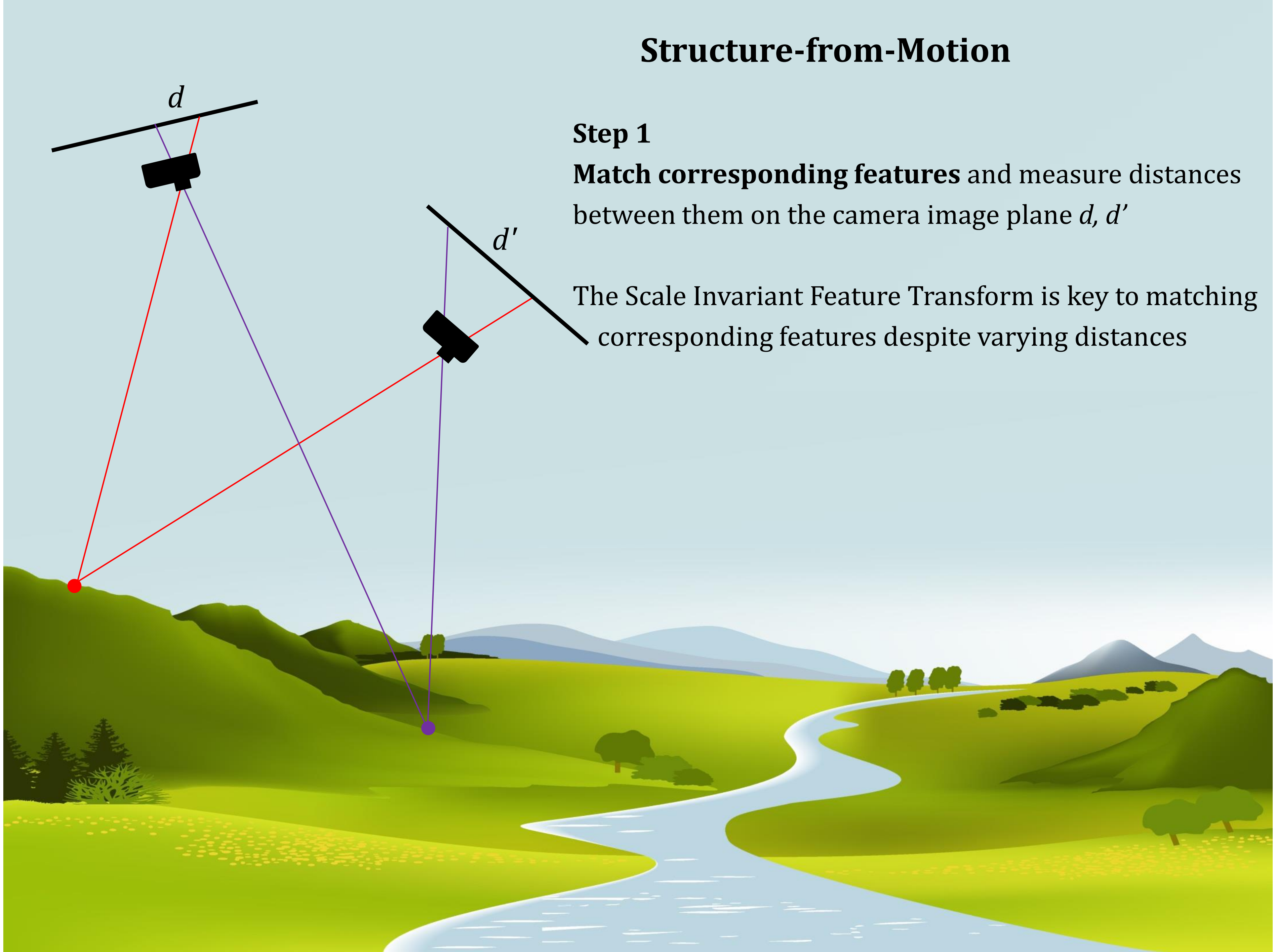


Structure-from-Motion

Step 1

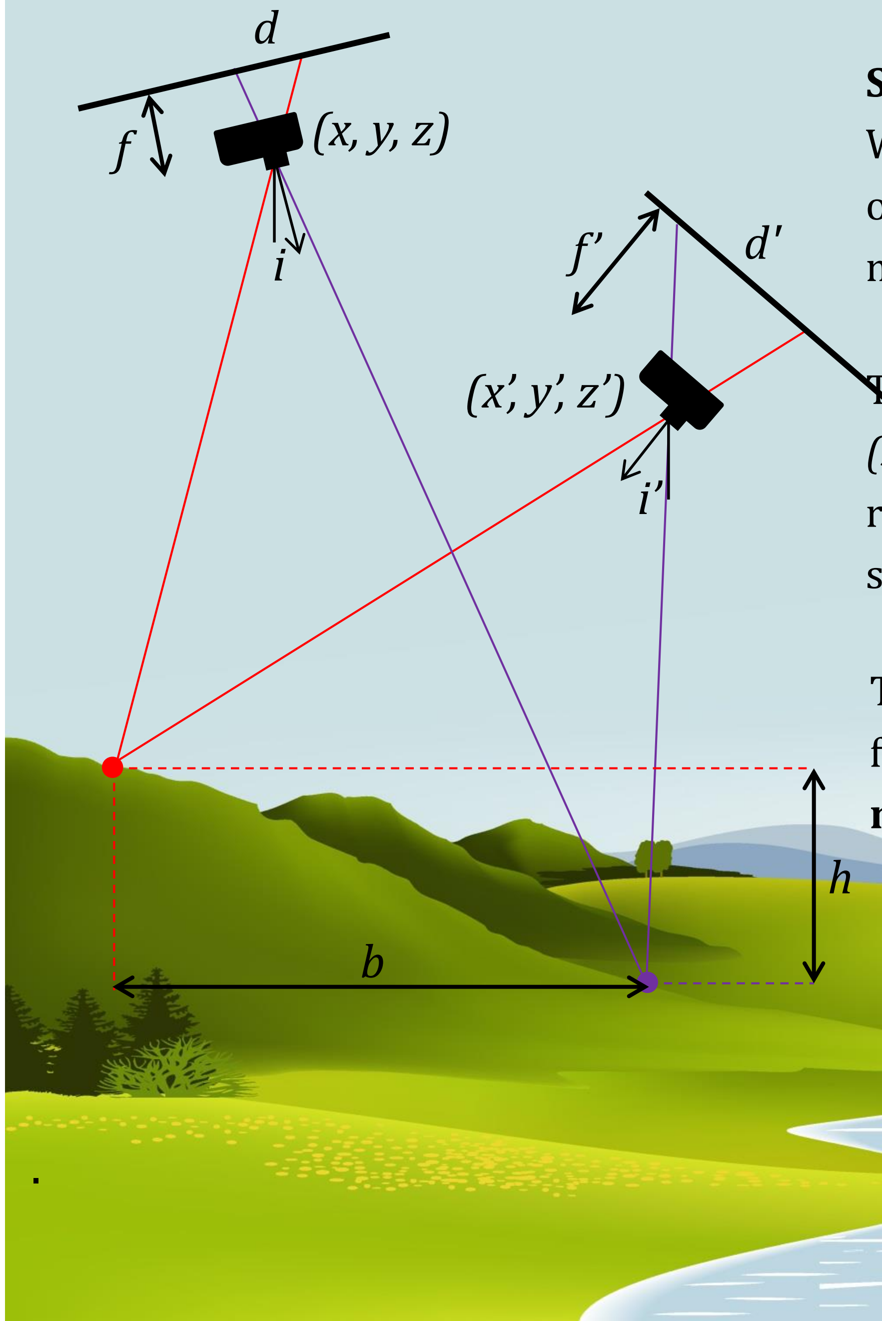
Match corresponding features and measure distances between them on the camera image plane *d, d'*

The Scale Invariant Feature Transform is key to matching corresponding features despite varying distances



• The **Scale Invariant Feature Transform (SIFT)** (Lowe, 1999) allows corresponding features to be matched even with large variations in scale and viewpoint and under conditions of partial occlusion and changing illumination

Structure-from-Motion



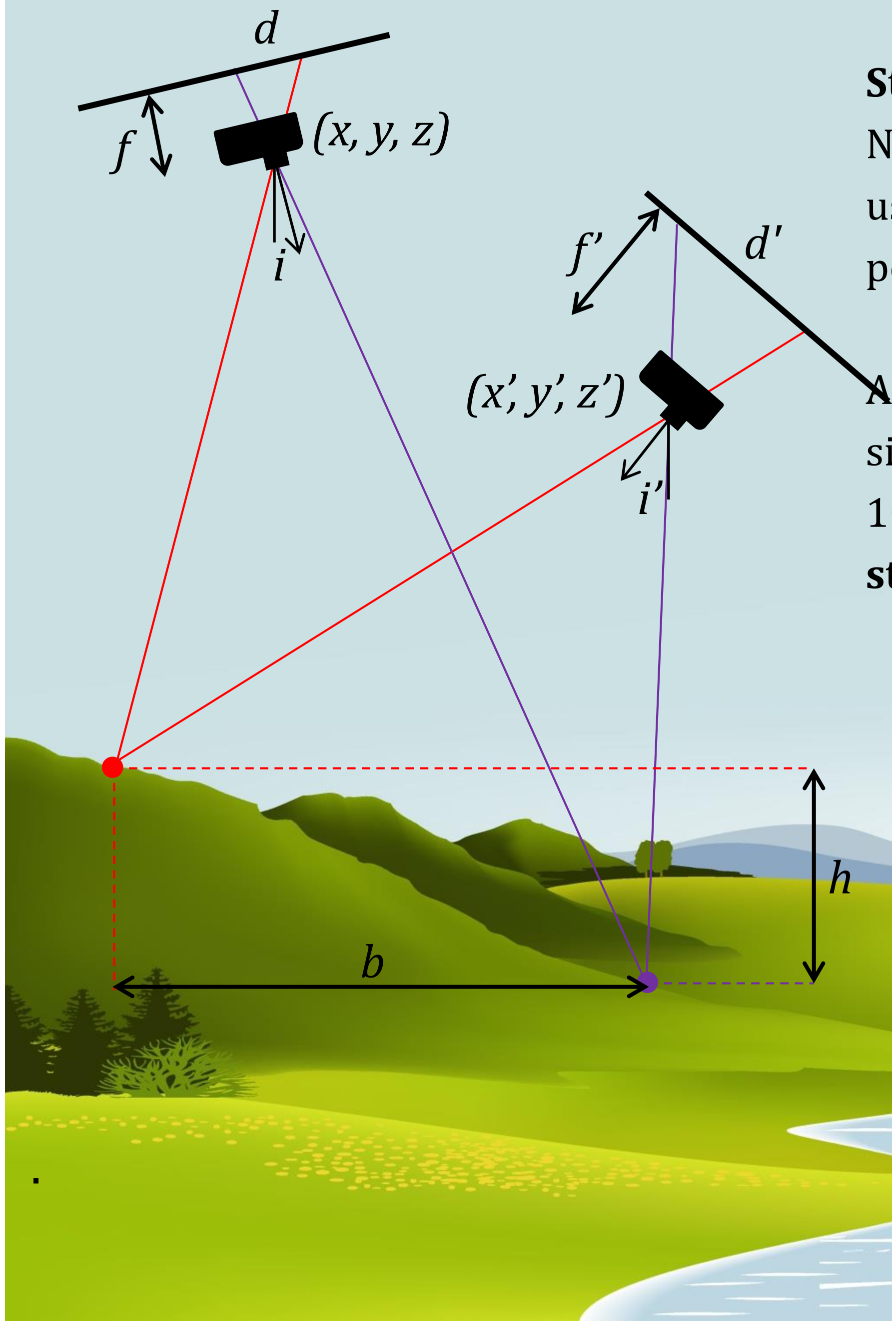
Step 2

When we have the matching locations of multiple points on two or more photos, there is usually just one mathematical solution for where the photos were taken.

Therefore, we can calculate individual camera positions *(x, y, z), (x', y', z')*, orientations *i*, *i'*, focal lengths *f*, *f'*, and relative positions of corresponding features *b*, *h*, in a single step known as **"bundle adjustment".**

This is where the term Structure from Motion comes from. Scene **structure** refers to all these parameters; **motion** refers to movement of the camera

Structure-from-Motion

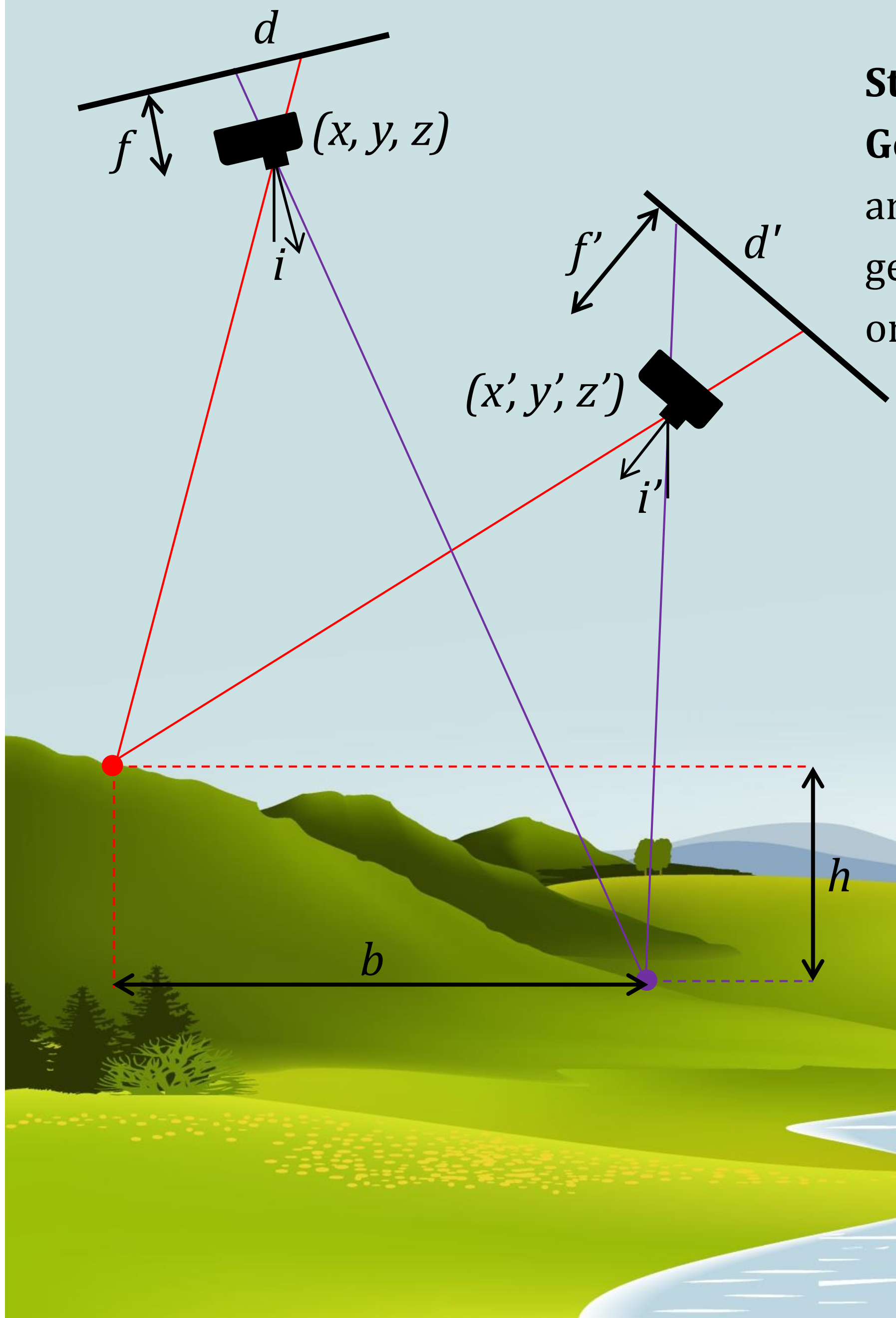


Step 3

Next, a dense point cloud and 3D surface is determined using the known camera parameters and using the SfM points as “ground control”.

All pixels in all images are used so the dense model is similar in resolution to the raw photographs (typically 100s – 1000s point/m^2). This step is called “**multiview stereo matching” (MVS)**

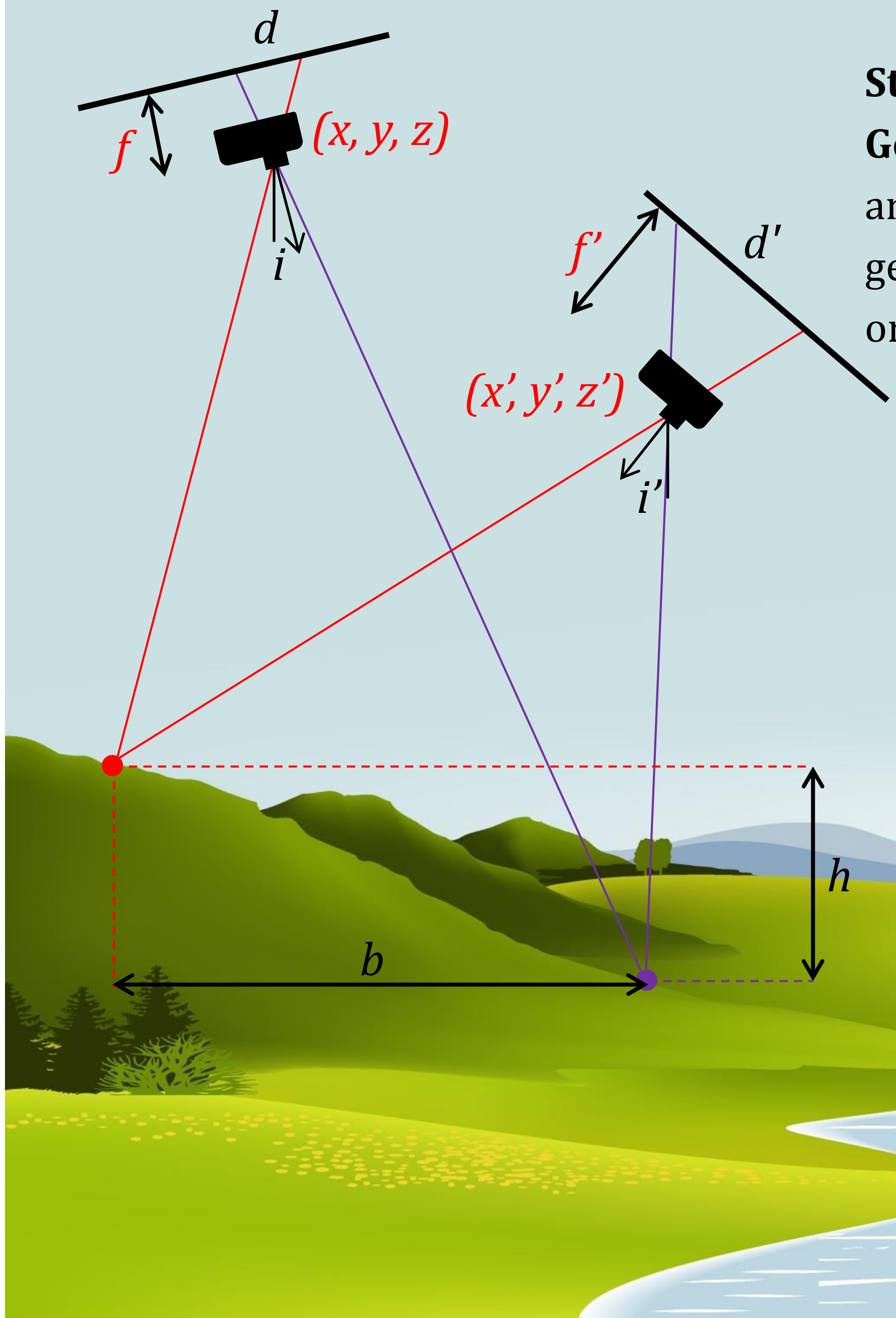
Structure-from-Motion



Step 4

Georectification means converting the point cloud from an internal, arbitrary coordinate system into a geographical coordinate system. This can be achieved in one of two ways:

Structure-from-Motion



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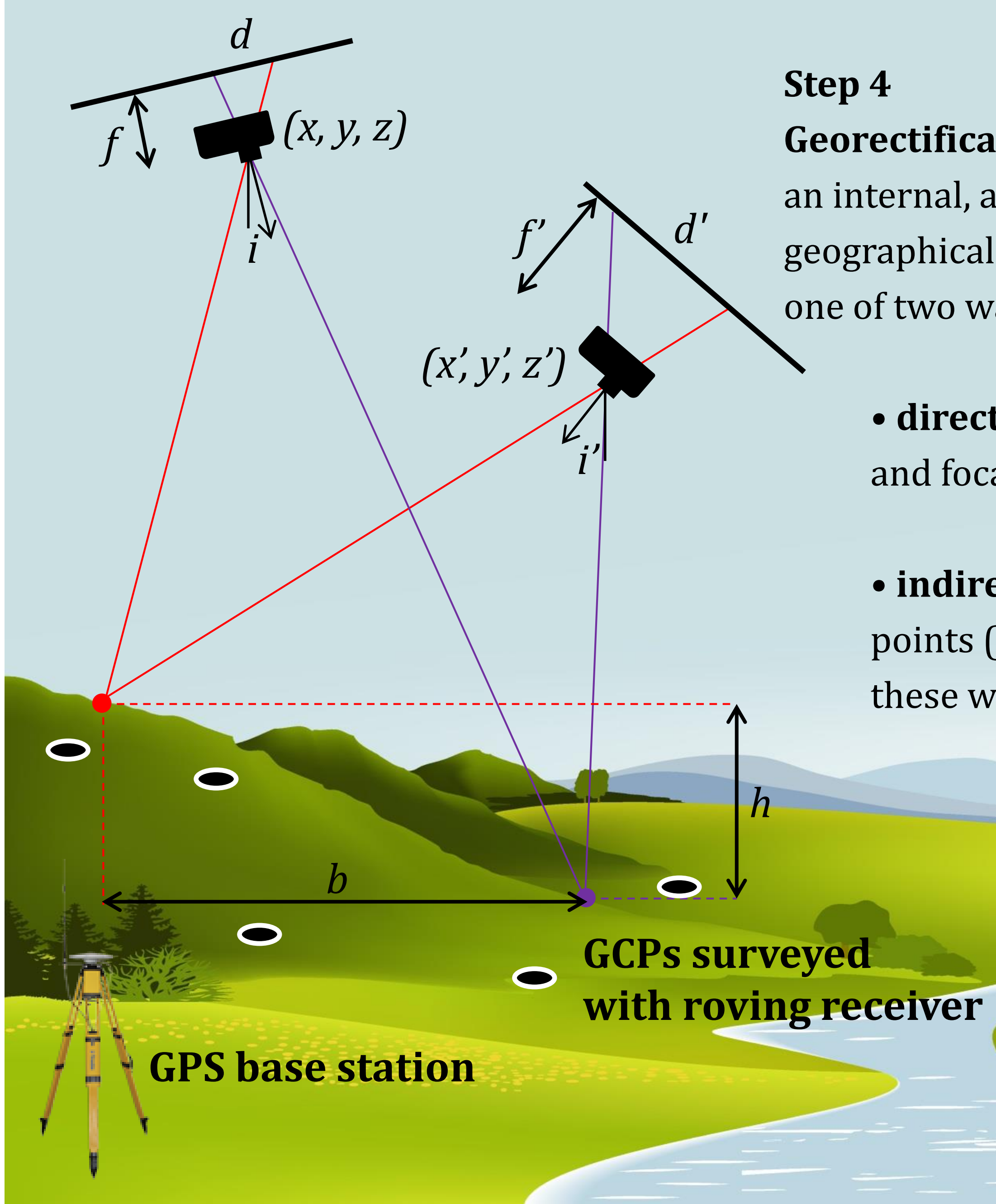
- **directly,** with knowledge of the camera positions and focal lengths

Structure-from-Motion

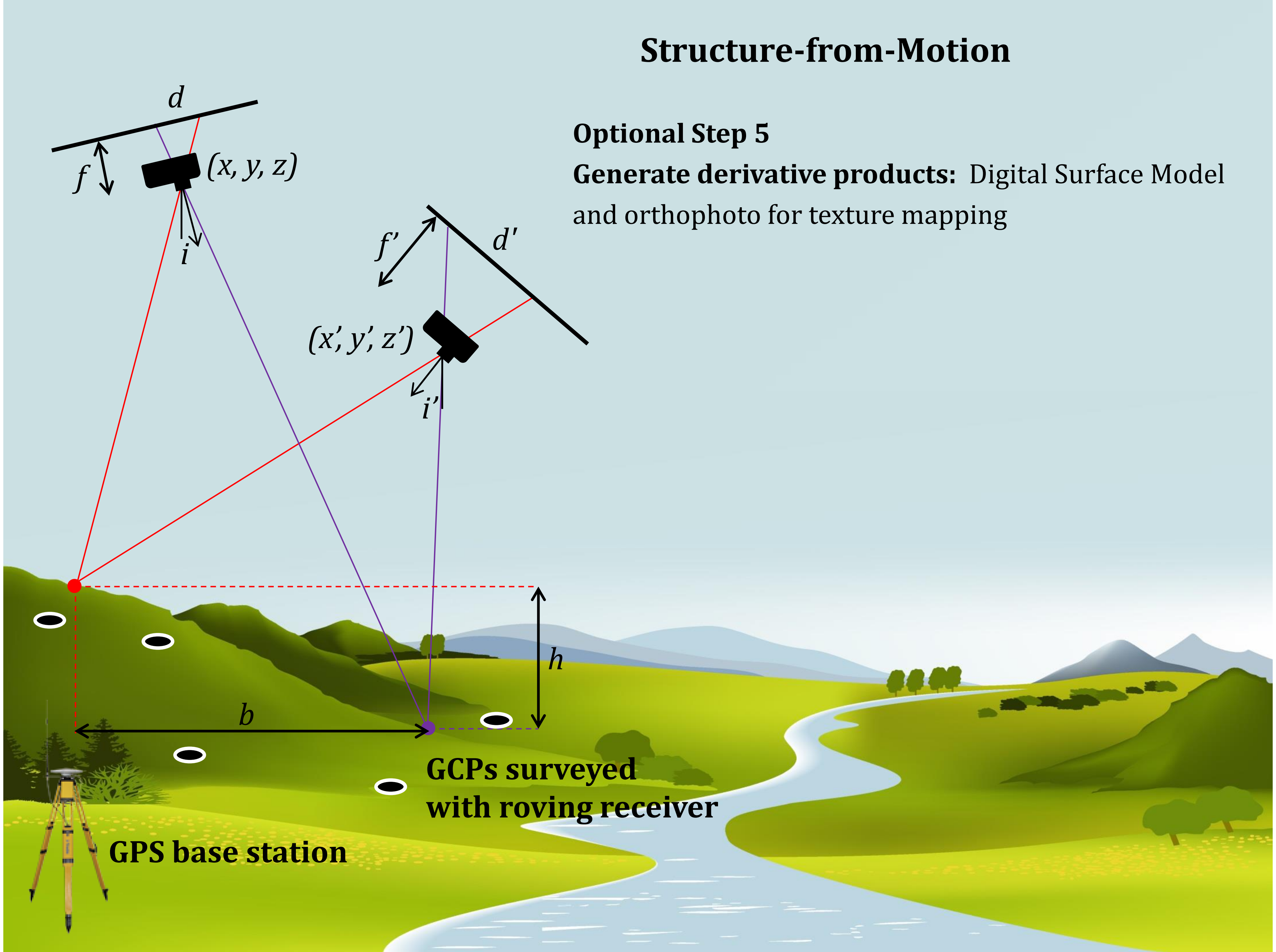


Step 4

Georectification means converting the point cloud from an internal, arbitrary coordinate system into a geographical coordinate system. This can be achieved in one of two ways:

- **directly,** with knowledge of the camera positions and focal lengths

- **indirectly,** by incorporating a few ground control points (GCPs) with known coordinates. Typically these would be surveyed using differential GPS



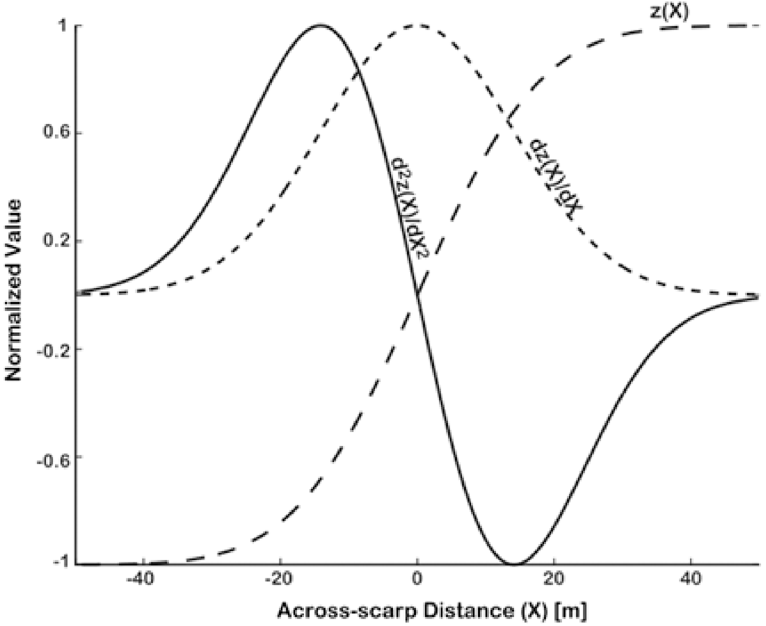
Structure-from-Motion
Optional Step 5
Generate derivative products: Digital Surface Model and orthophoto for texture mapping
d
f
(x, y, z)
i
f'
d'
(x', y', z')
i'
h
b
GCPs surveyed with roving receiver
GPS base station

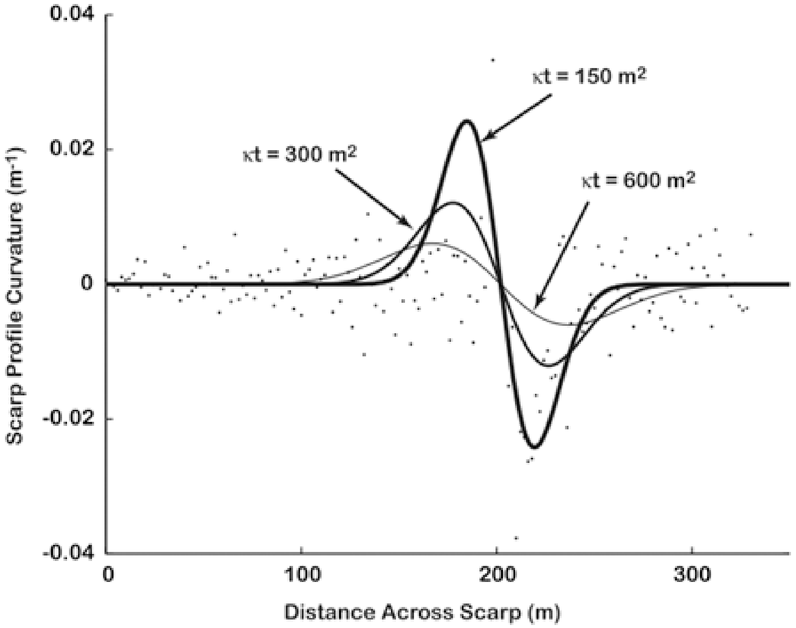
Applications:

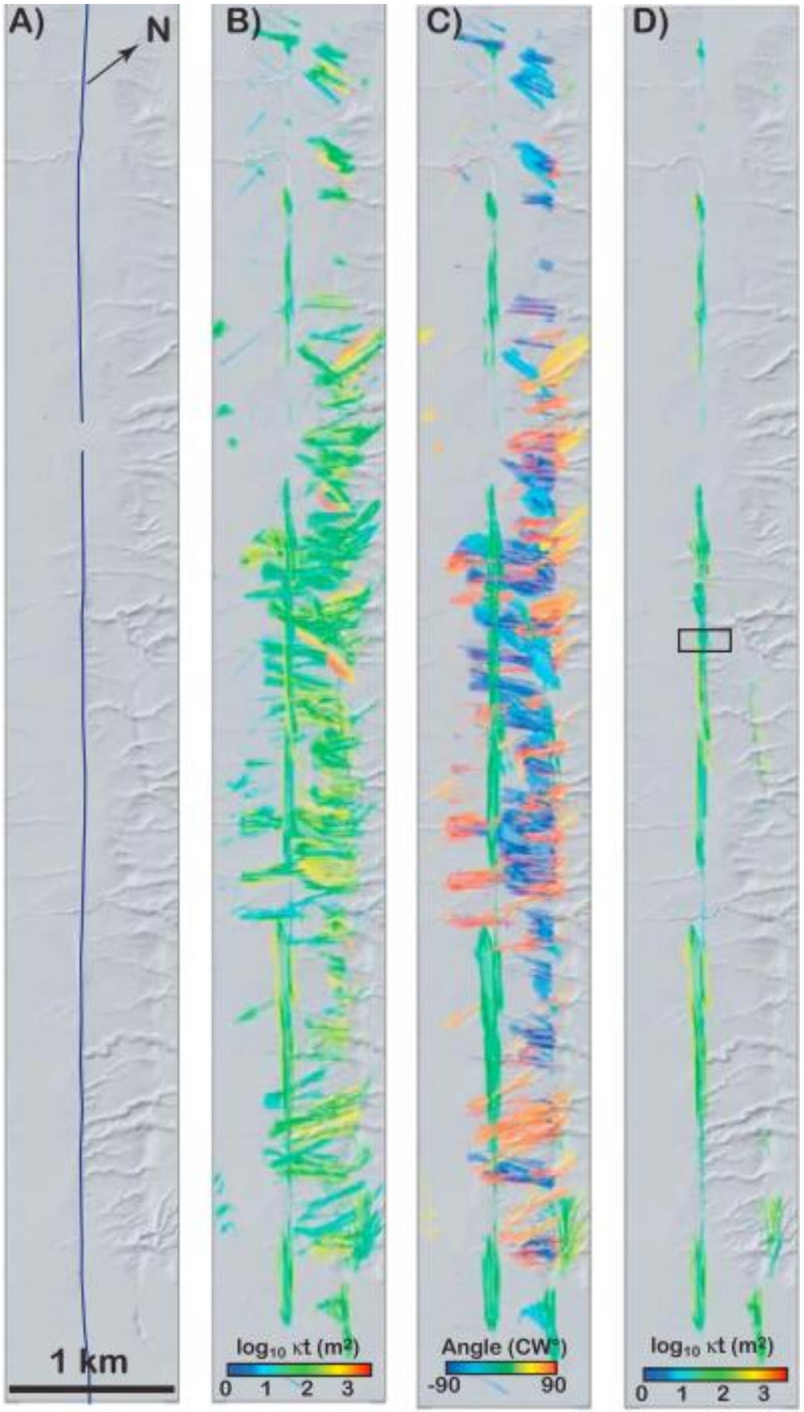
- **Mapping and feature identification**
- Landscape reconstruction
- Surface process interactions with tectonic, volcanic, cryospheric, ecological processes
- Differencing of repeat surveys—measure changes

Northern San Andreas Fault, California (40 km SE of Point Arena)

Northern San Andreas Fault, California (40 km SE of Point Arena)







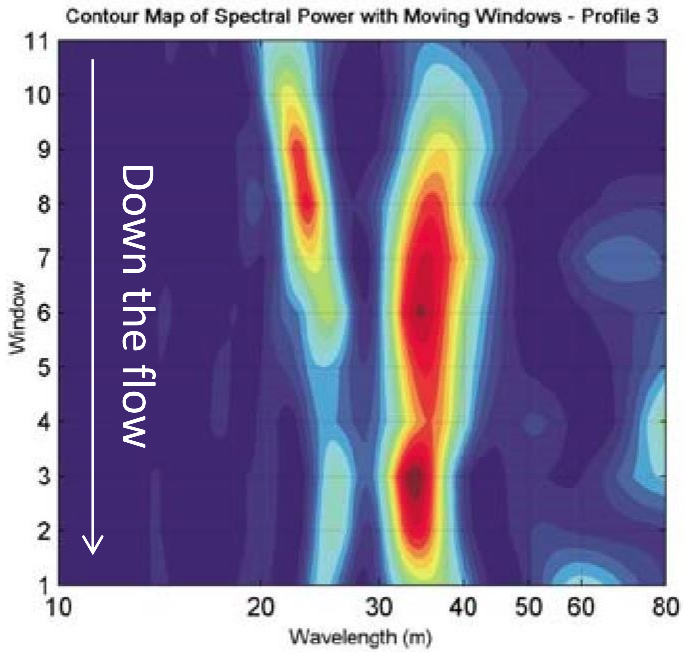
Morphologic dating of fault scarps using airborne laser swath mapping (ALSM) data

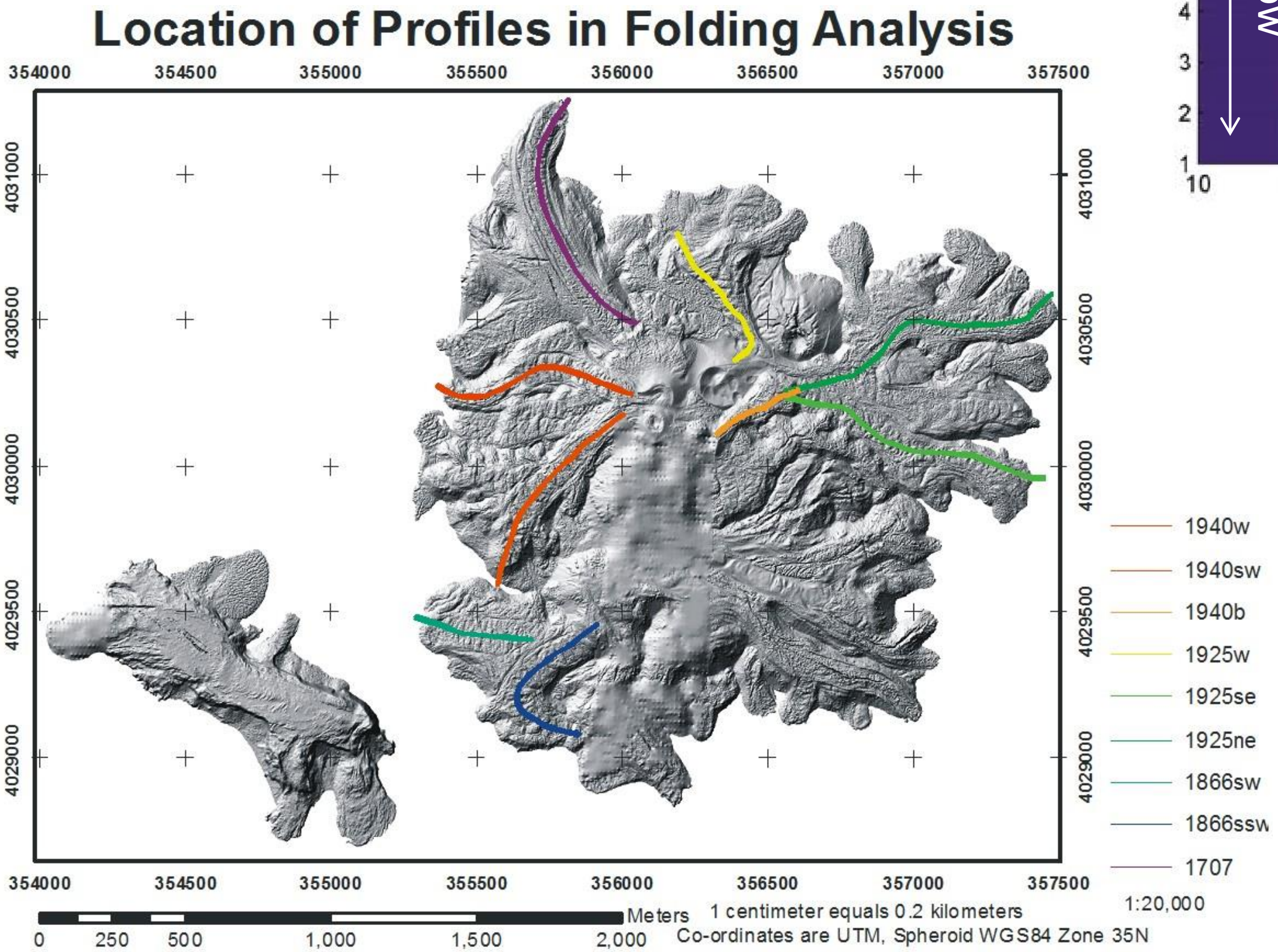
GRL, 2010

G. E. Hilley,[1] S. DeLong,[2] C. Prentice,[2] K. Blisniuk,[3] and JR. Arrowsmith[4]

Quantitative morphology, recent evolution, and future activity of the Kameni Islands volcano, Santorini, Greece

Pyle and Elliott, Geosphere, 2006





"Buckling with an ~20 m wavelength can be observed near the vent; downstream, a 30–40 m wavelength becomes dominant"

5200 page pdf for data supplement…
--cf. OpenTopography

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- **Landscape reconstruction**
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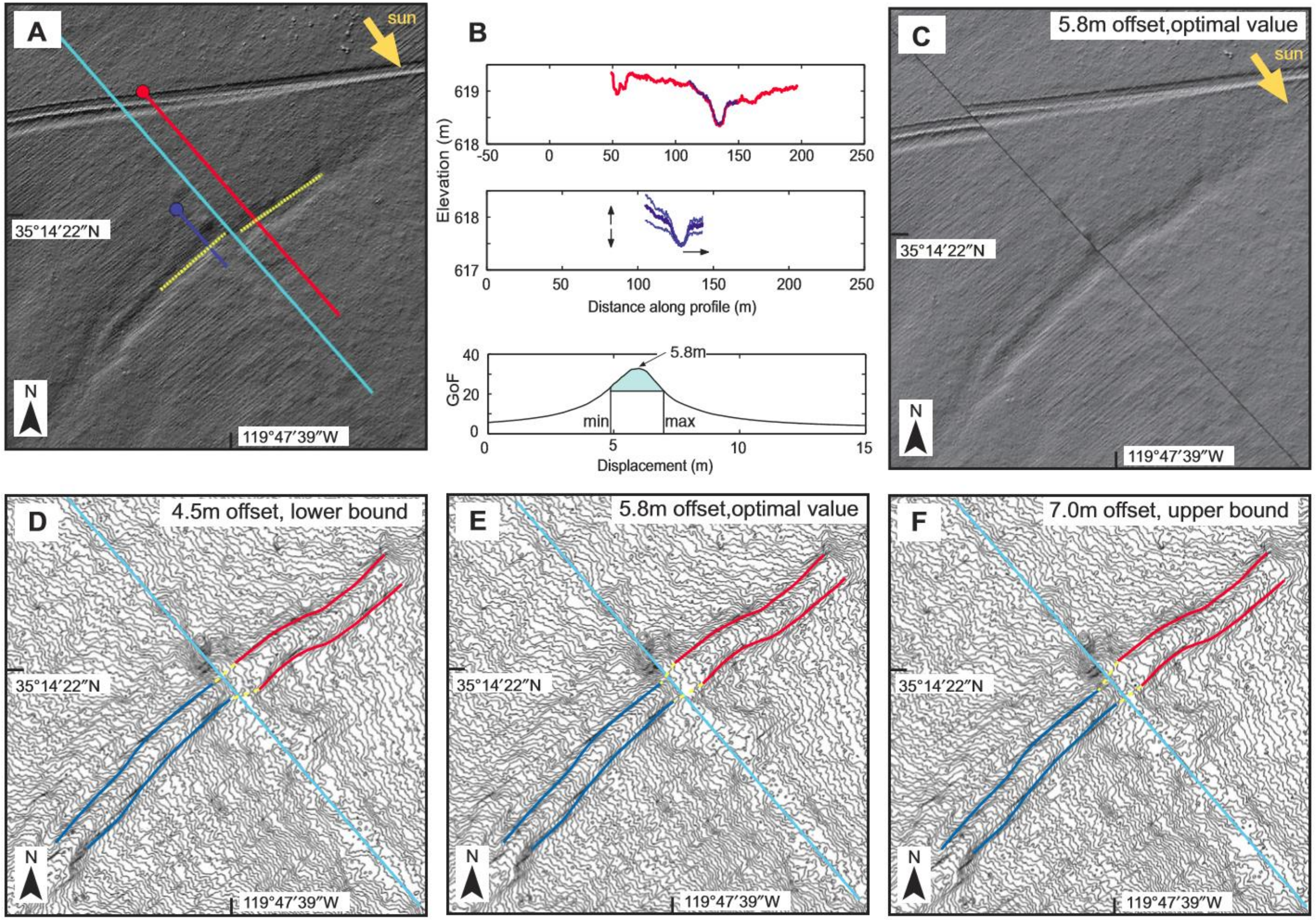
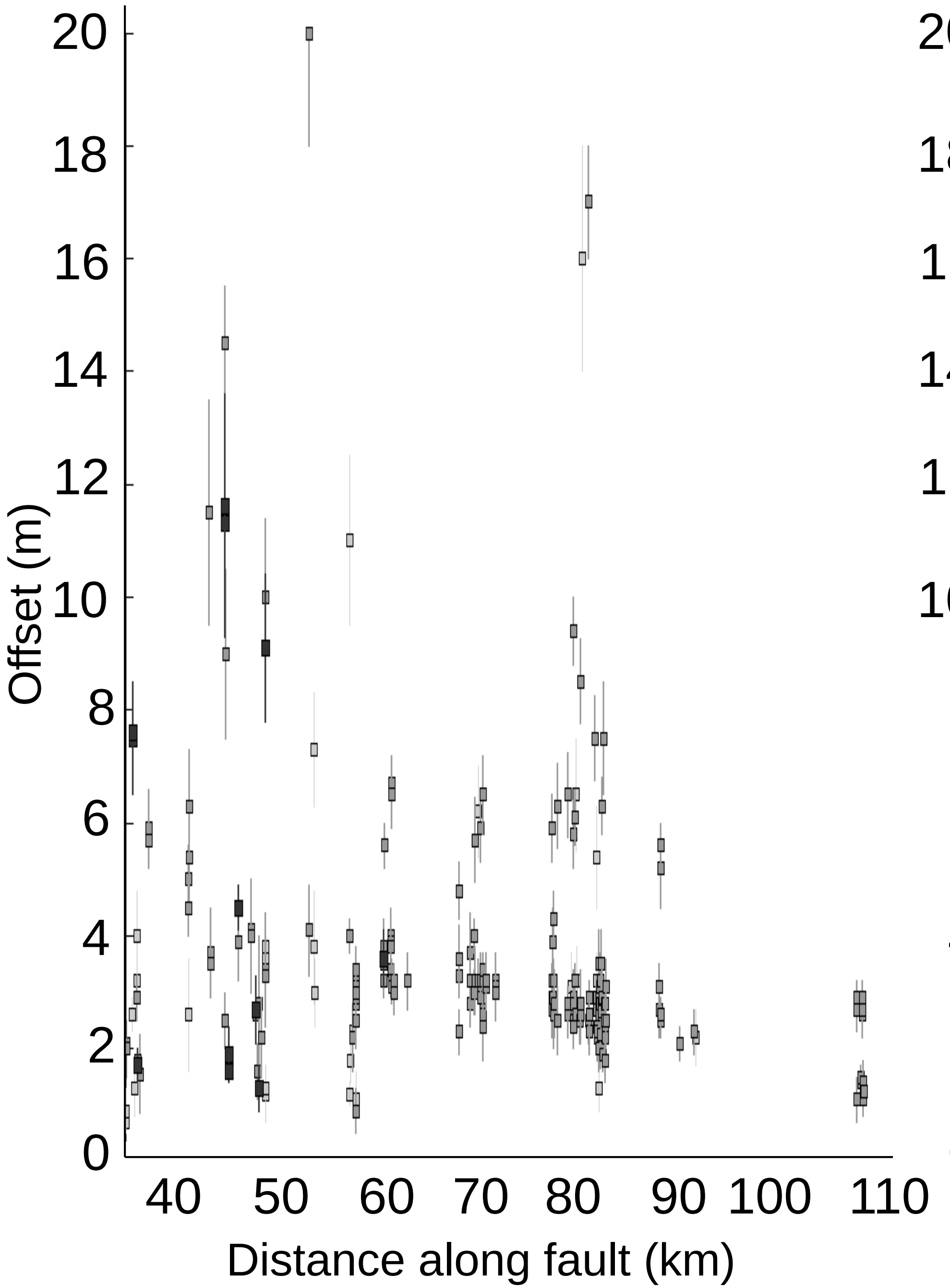


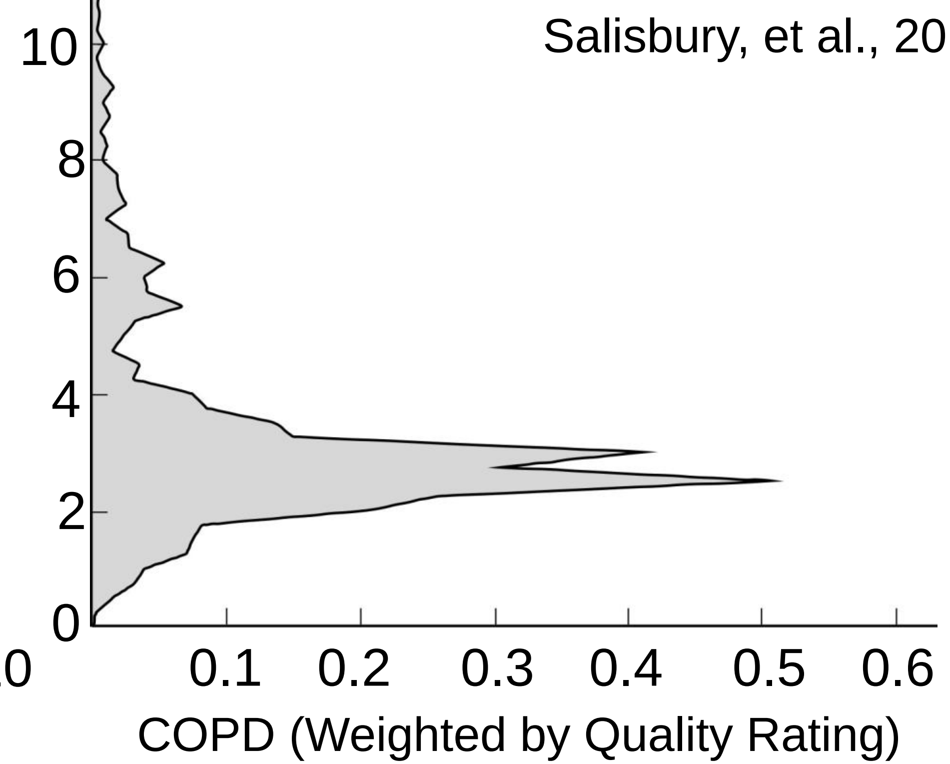
Hudnut, et al., High resolution topography along surface rupture of the 16 October 1999 Hector Mine, California, earthquake (Mw7.1) from airborne laser swath mapping, Bulletin of the Seismological Society of America, 2002.

Zielke, O., Klinger, Y., Arrowsmith, J R., Fault slip and earthquake recurrence along strike-slip faults--contributions of high-resolution geomorphic data [Invited Review], Tectonophysics, 2015.

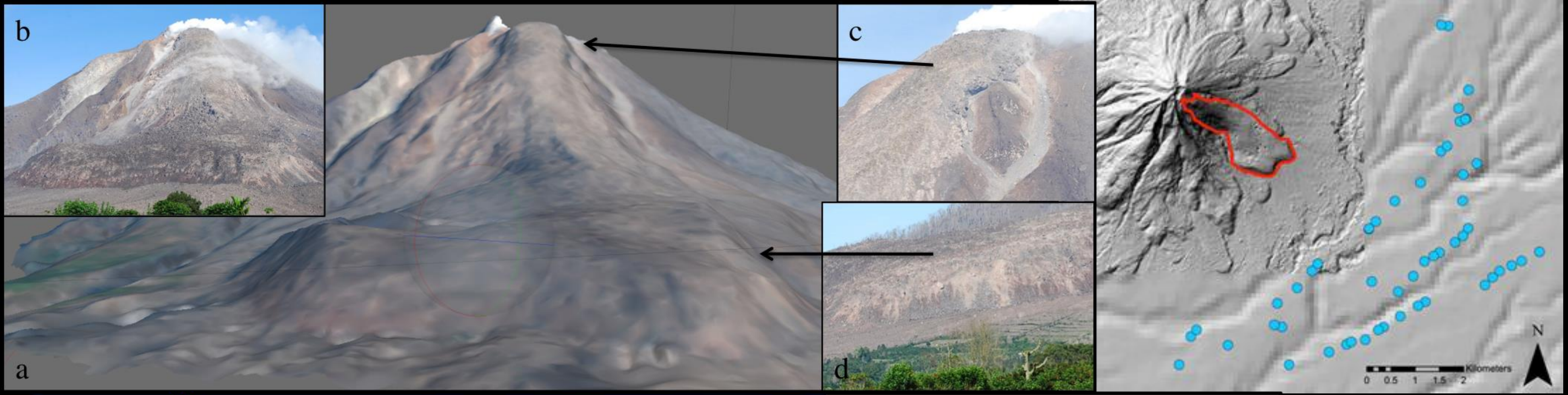
Cumulative Offset Probability Distribution

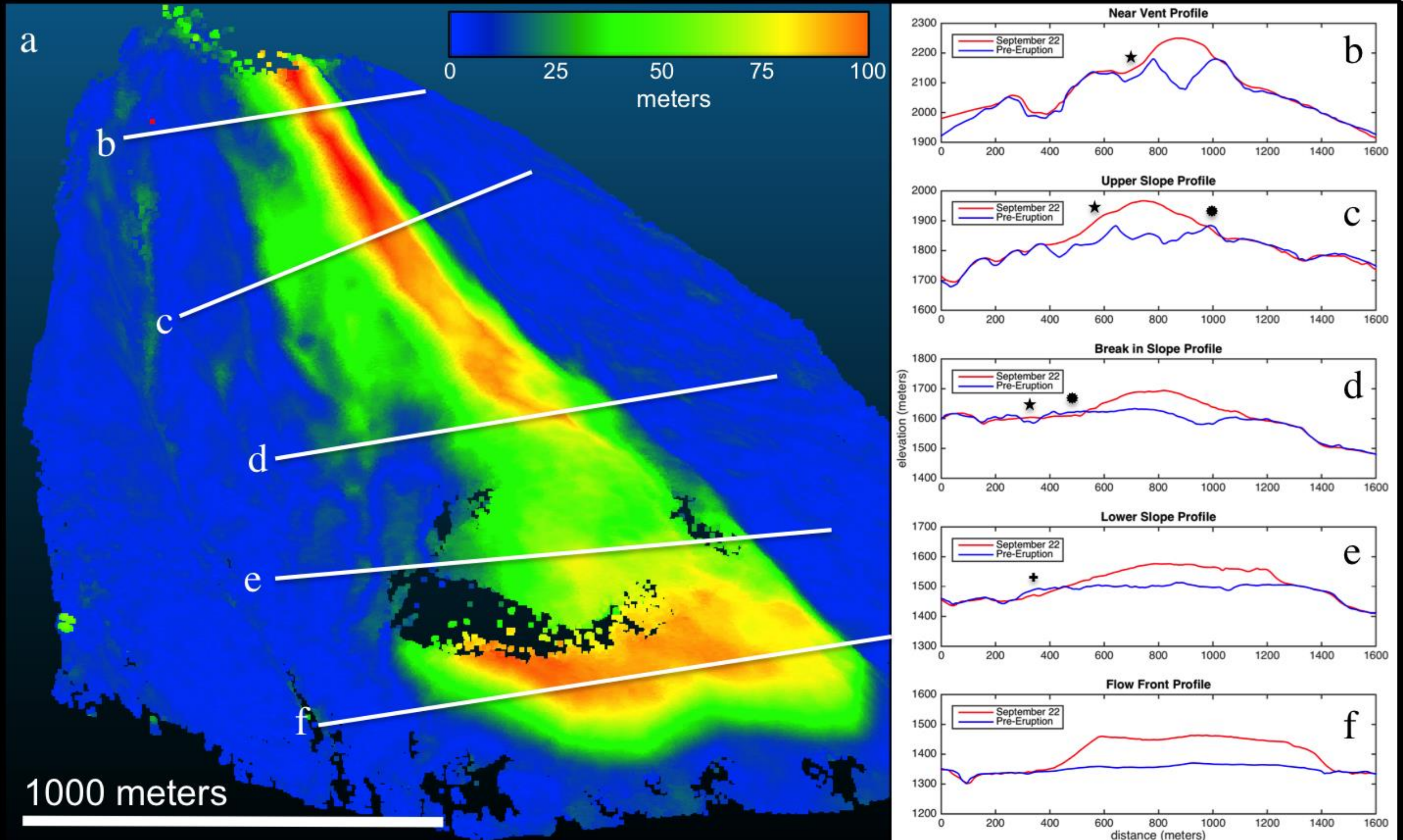
Clark section San Jacinto Fault, CA





Salisbury, et al., 2012





The emplacement of the active lava flow at Sinabung Volcano, Sumatra, Indonesia, documented by structure-from-motion photogrammetry -Carr, et al., in review.

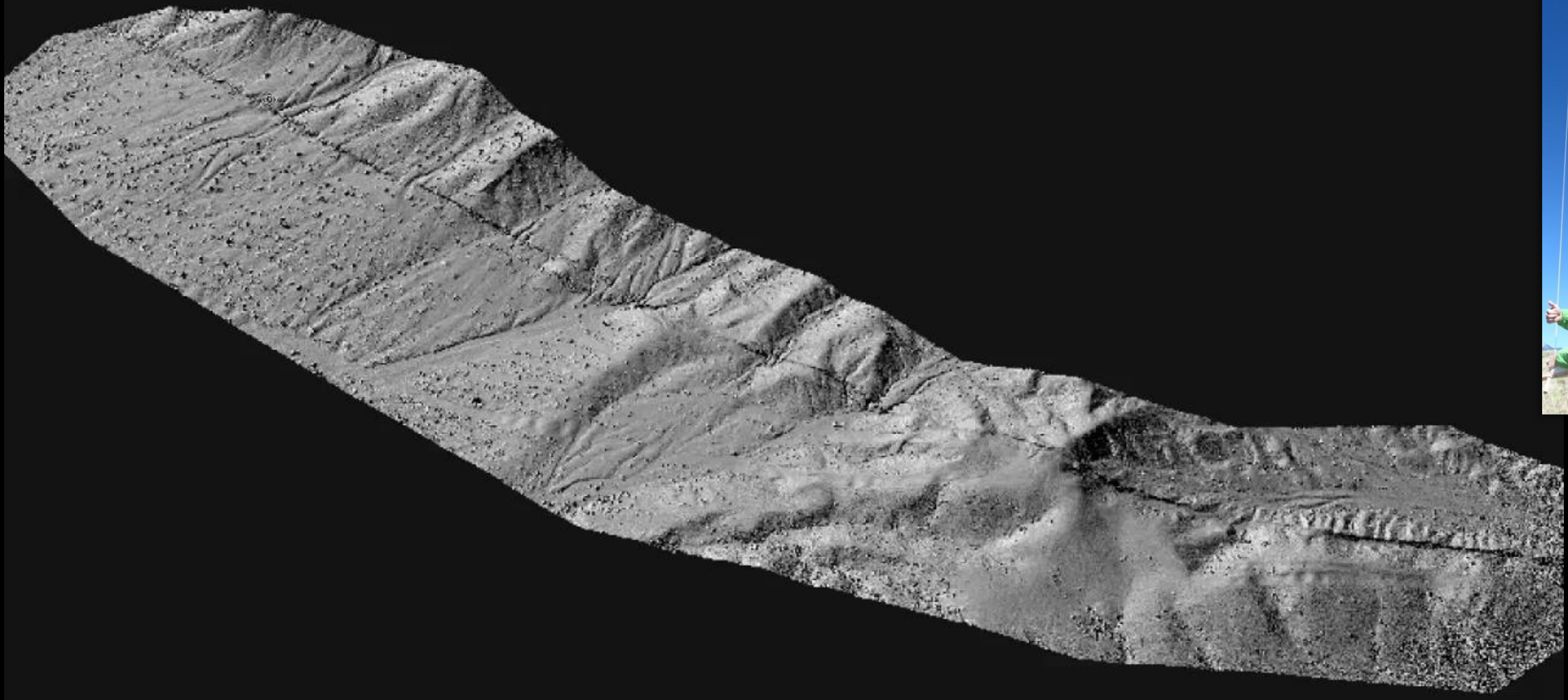
Pre-eruption 5 m DEM and post eruption SfM registered to unchanged areas

Applications:

- Mapping and feature identification
- Landscape reconstruction
- **Surface process interactions with tectonic, volcanic, cryospheric, ecological processes**
- Differencing of repeat surveys—measure changes

Original forms and initial modifications of earthquake surface rupture

Landers, CA 1992 earthquake rupture after 20 years

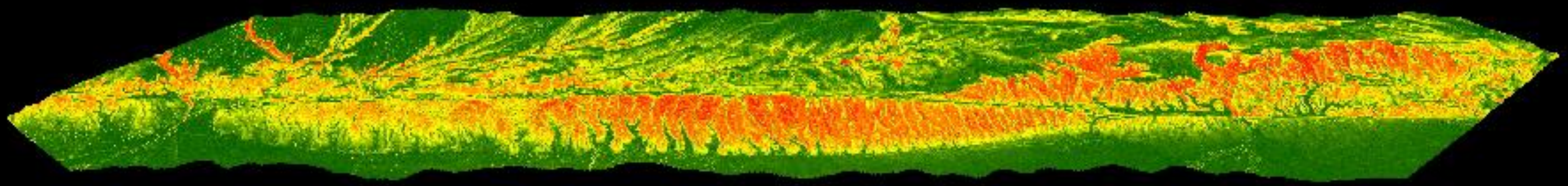


10 cm/pix SfM DEM

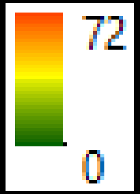
E. Nissen photo

Johnson, K., Nissen, E., Saripalli, S., Arrowsmith, J R., McGarey, P., Scharer, K., Williams, P., Blisniuk, K., Rapid mapping of ultra-fine fault zone topography with Structure from Motion, Geosphere, v. 10; no. 5; p. 1–18; doi:10.1130/GES01017.1, 2014.

10kyr timescale landscape evolution



Dragon’s Back (along the San Andreas Fault) slope distribution (1 m pix)—sensitivity to erosion and rock uplift



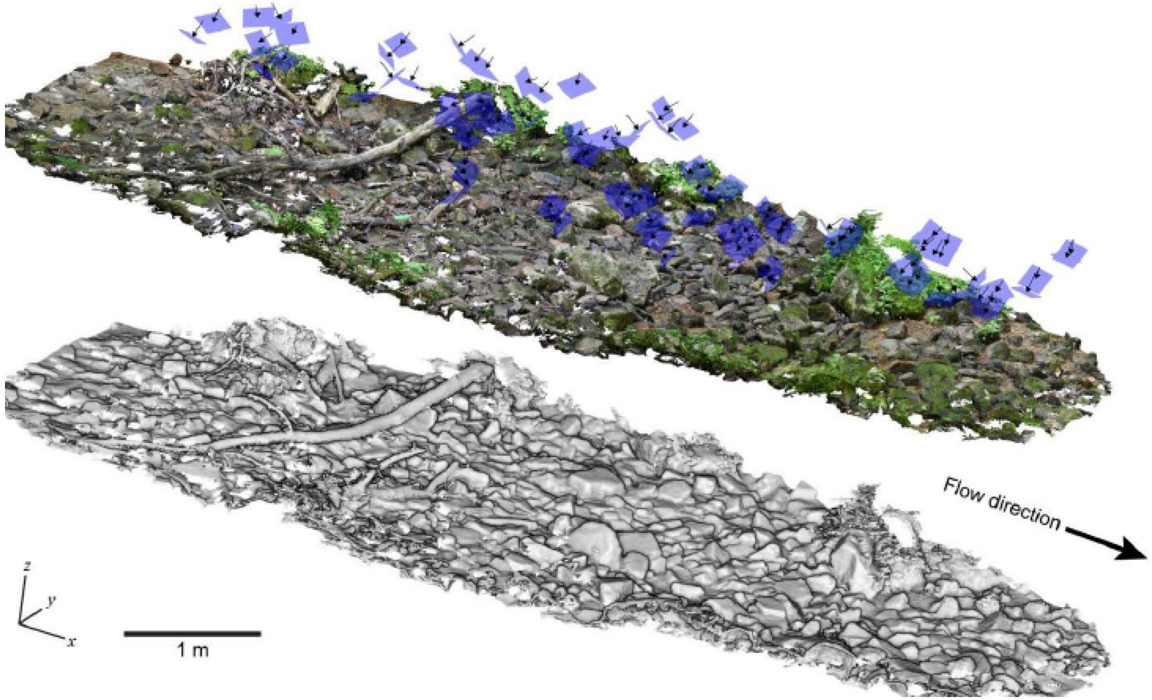
degrees

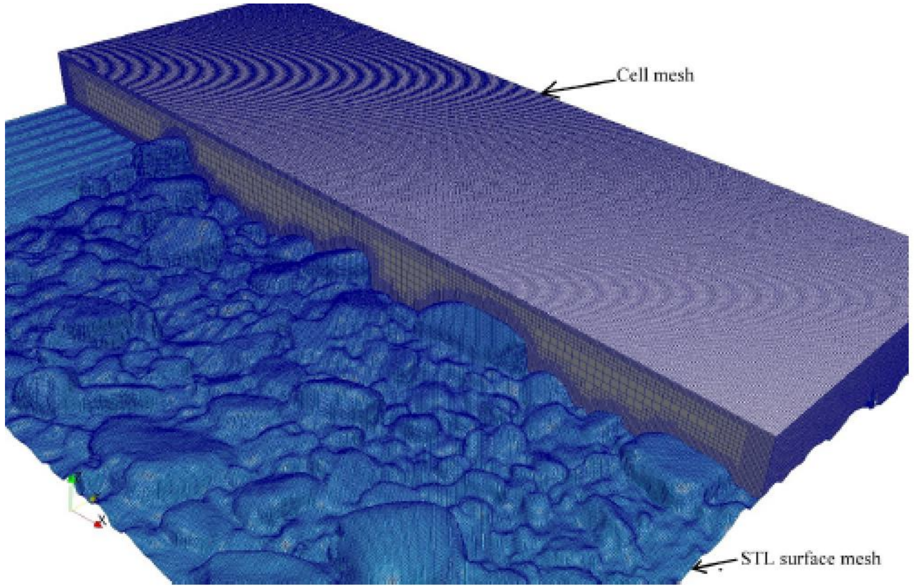
cf. Hurst, M. D., Mudd, S. M., Attal, M., & Hilley, G. E. (2013). Hillslopes Record the Growth and Decay of Landscapes. *Science (New York, N.Y.)*, *341*, 868–871. https://doi.org/10.1126/science.1241791

Quantifying flow resistance in mountain streams using computational fluid dynamics modeling over structure-from-motion derived microtopography

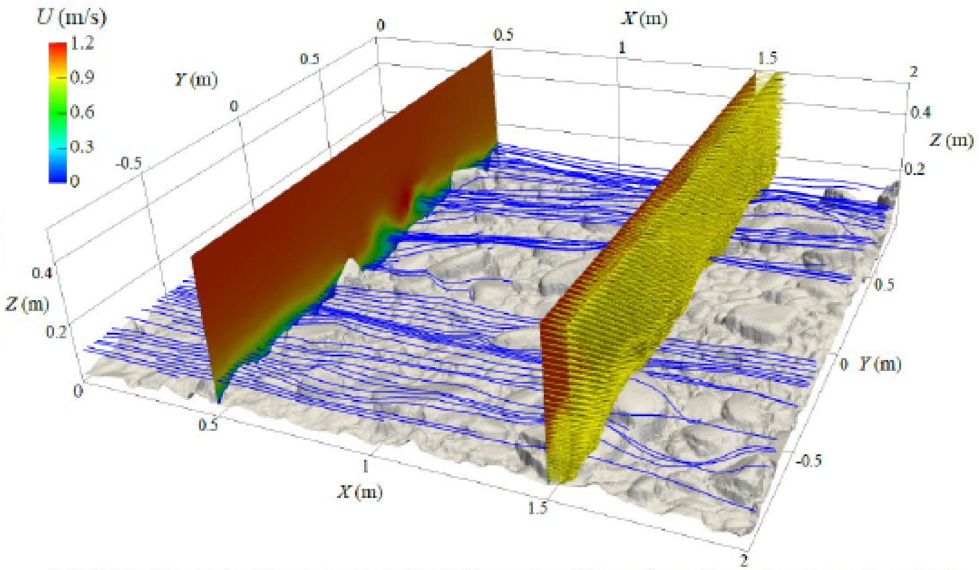
Connect scales of flow resistance with surface roughness and water depth

Chen, DiBiase, McCarroll, Liu, EPSL, 2019





SfM model input to OpenFoam



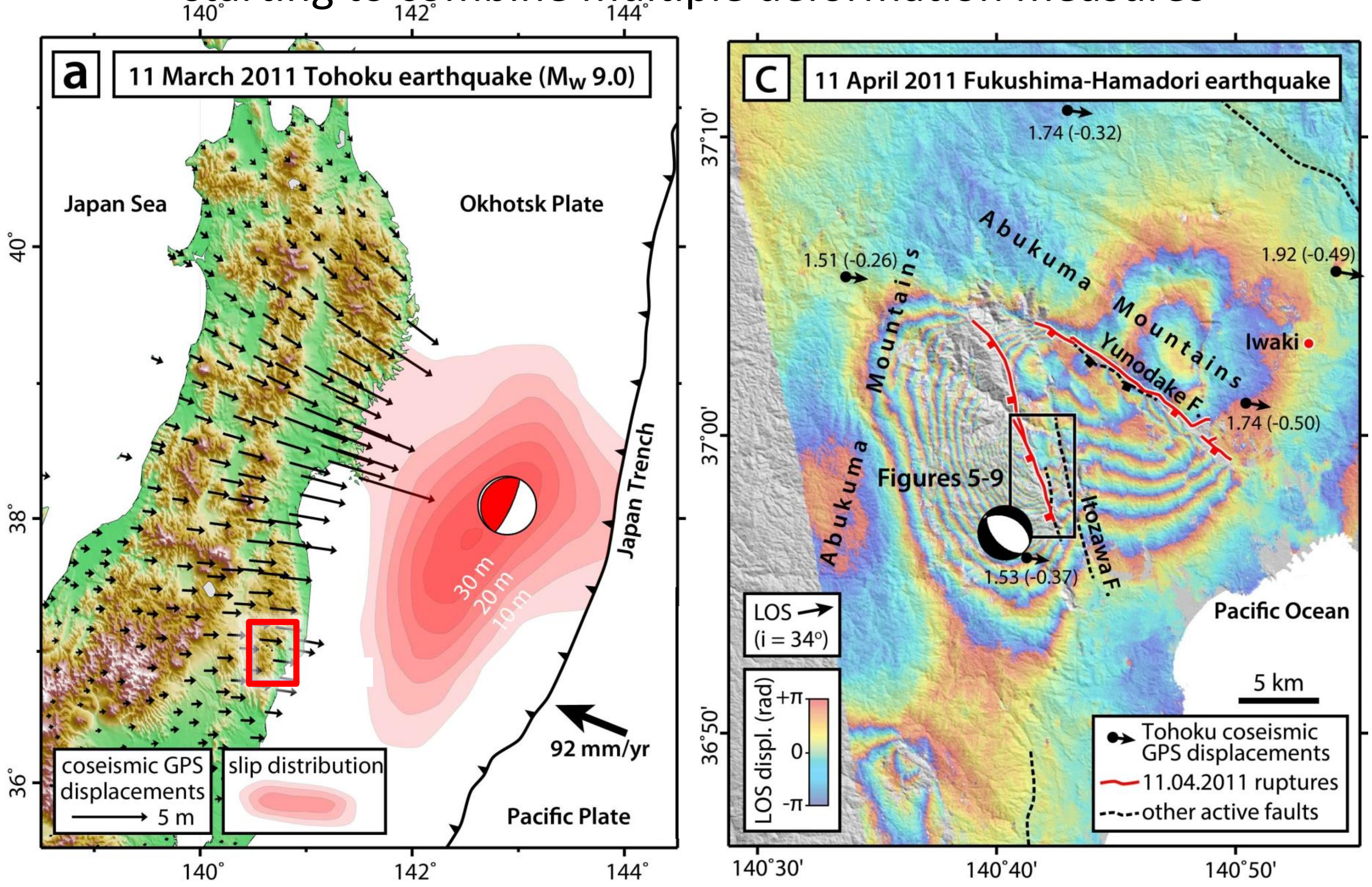
RANS simulation over Bowmans Creek microtopography
(Velocity field for H = 0.5 m)

Applications:

- Mapping and feature identification
- Landscape reconstruction
- Surface process interactions with tectonic, volcanic, cryospheric, ecological processes
- **Differencing of repeat surveys—measure changes**

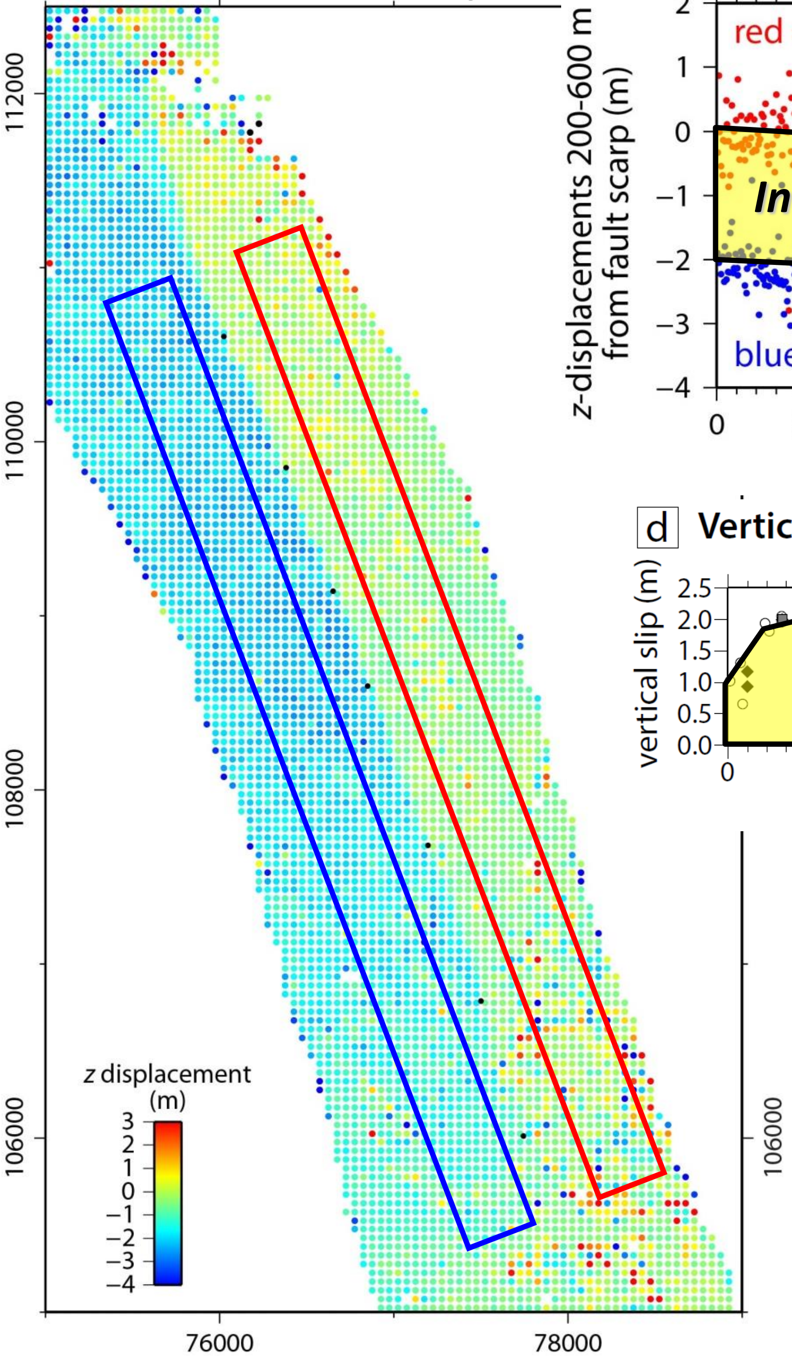
11 April 2011 Fukushima-Hamadori earthquake

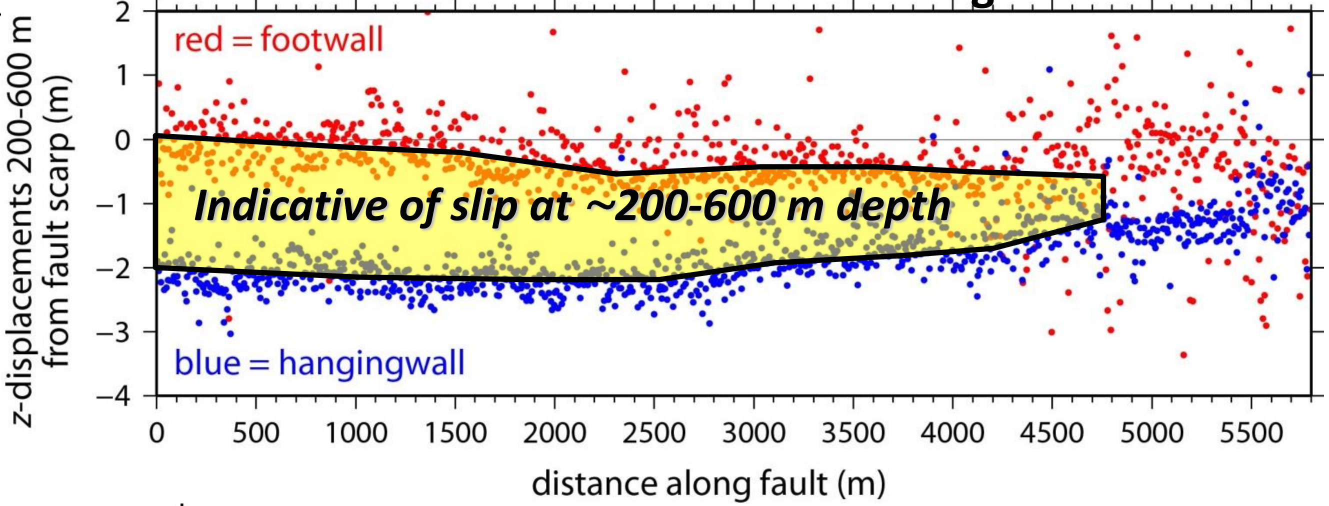
-starting to combine multiple deformation measures

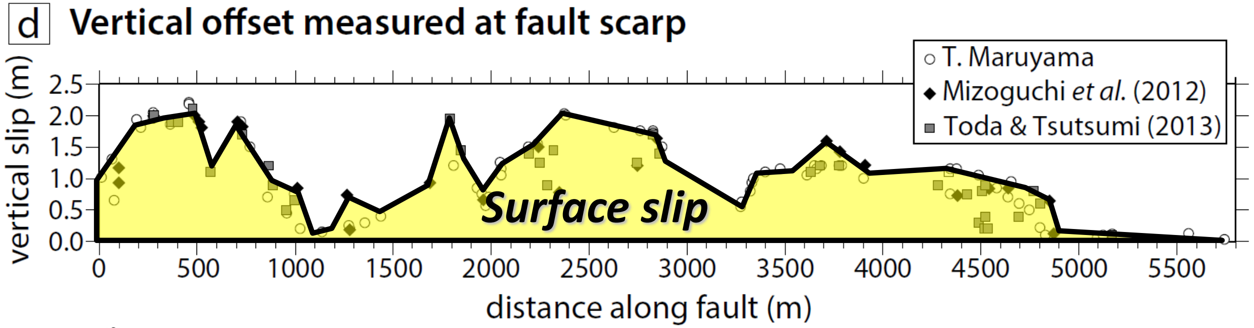


Nissen et al. (2014), *Earth Planet. Sci. Lett.*

2005-2011 vertical displacements from Iterative Closest Point differencing of lidar DTMS



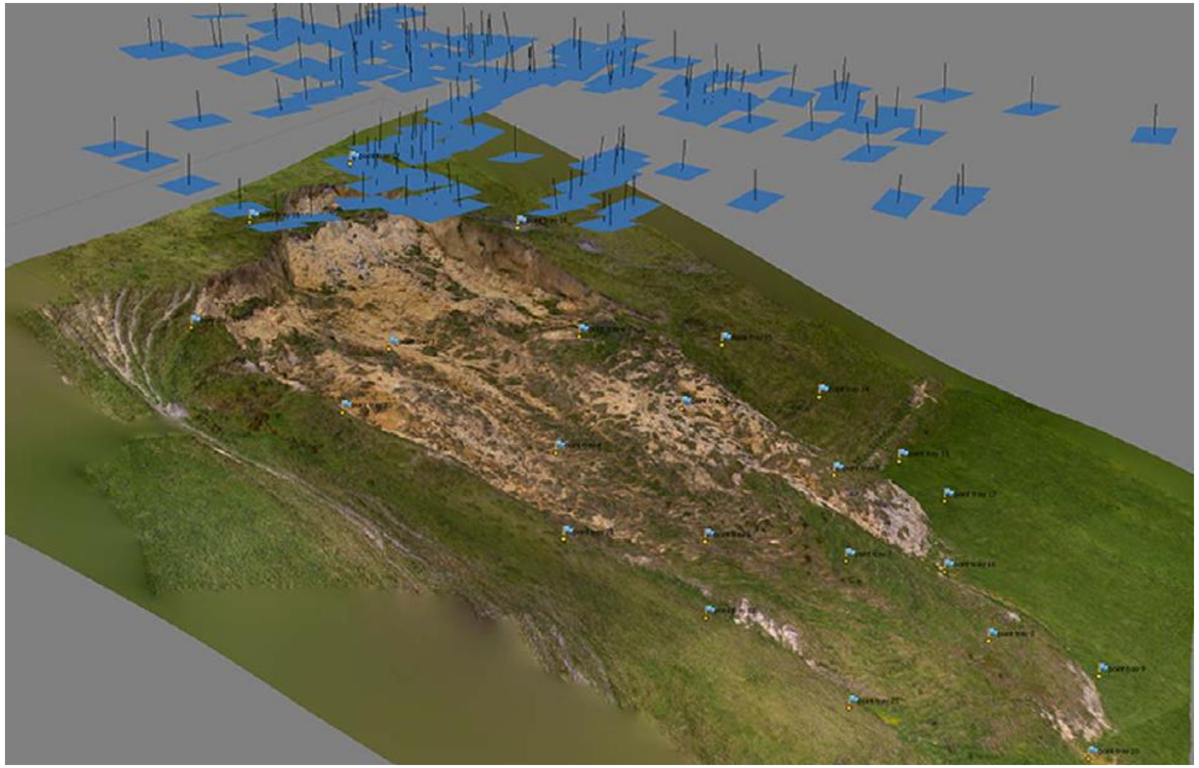




- In many places, only a small proportion of the slip makes it to the surface
- However, slip at depths of a few hundred meters appears to vary smoothly

Nissen et al. (2014), *Earth Planet. Sci. Lett.*

Landslide mapping

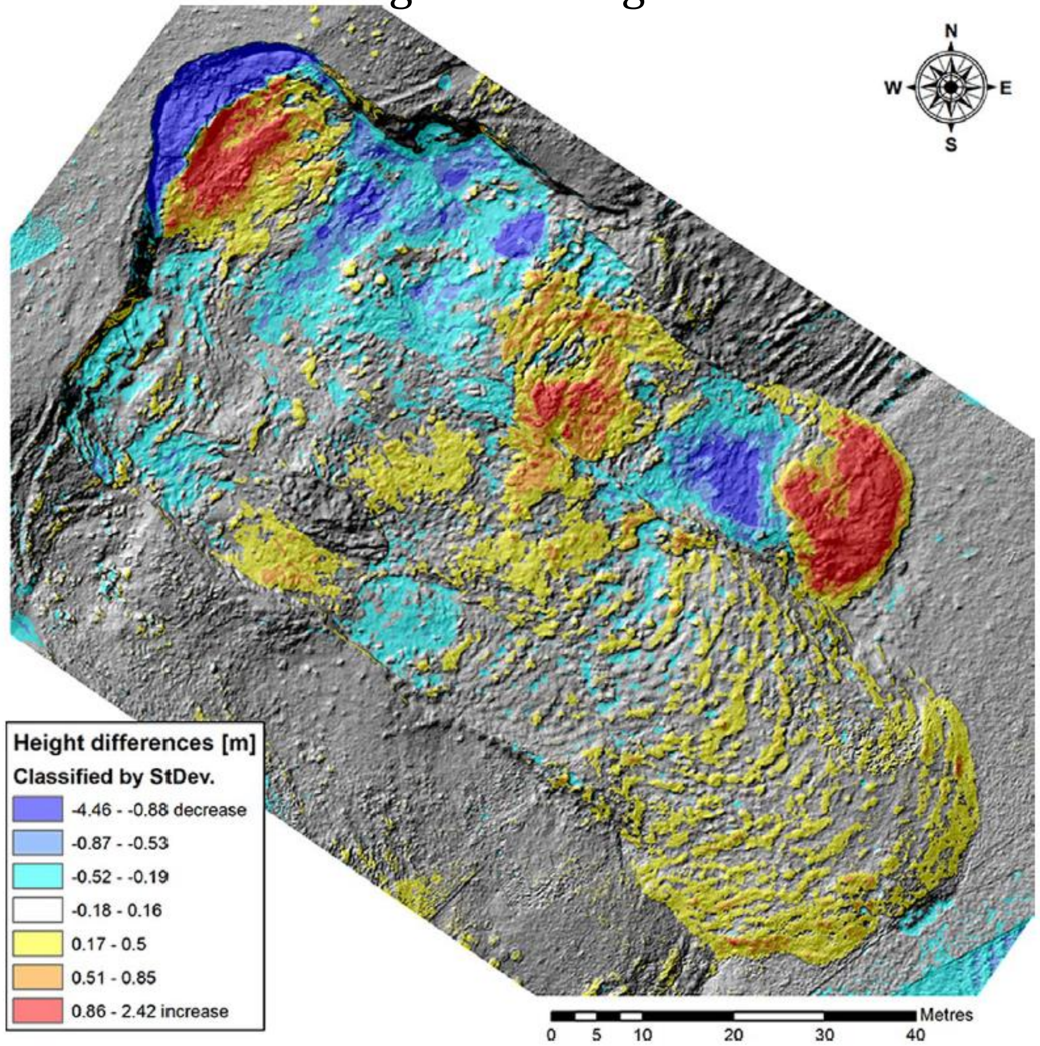


Home Hill landslide, Tasmania, surveyed with oktocopter in July and November 2011.

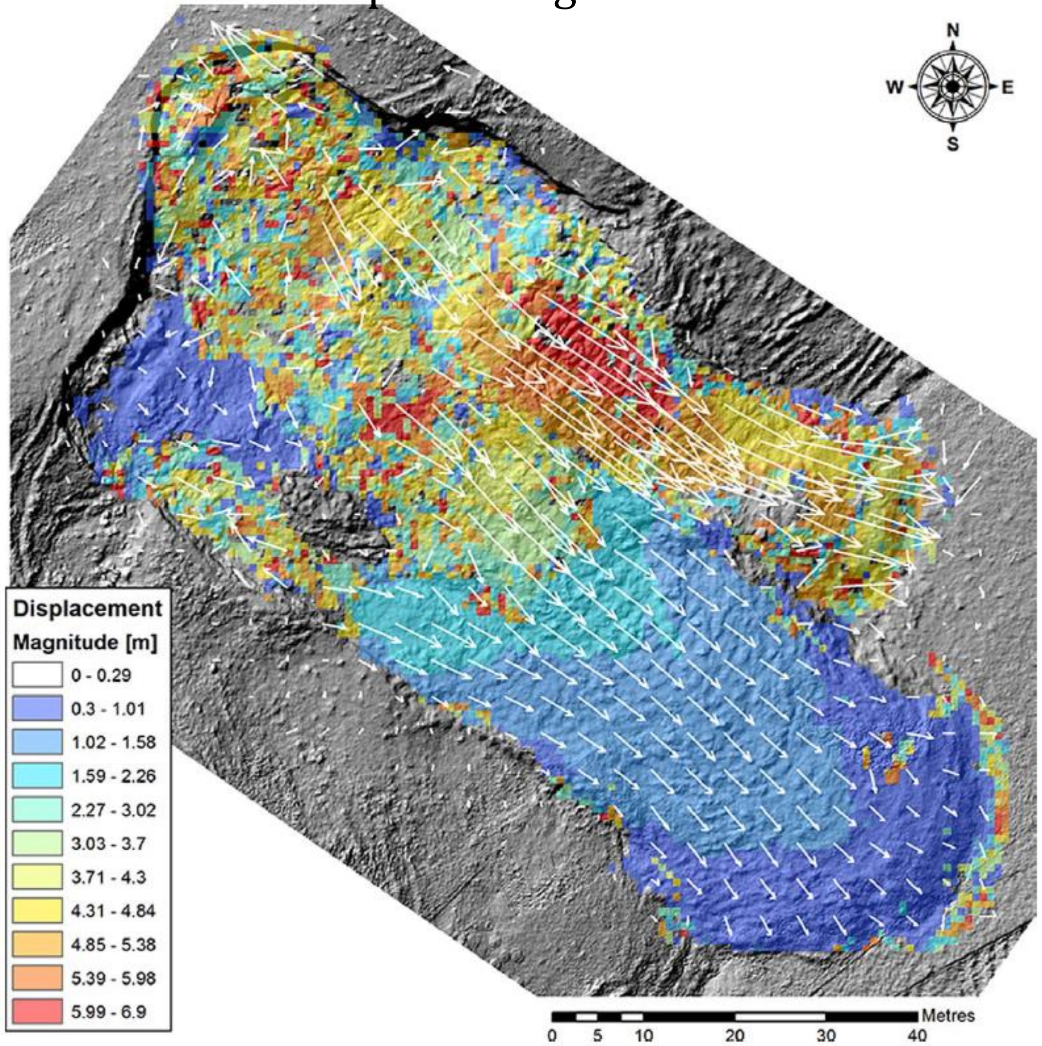
Lucieer *et al.* (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*

Landslide mapping

Left. DEM of Difference (DoD) from subtracting elevation grids



Right. Horizontal displacements from sub-pixel image correlation

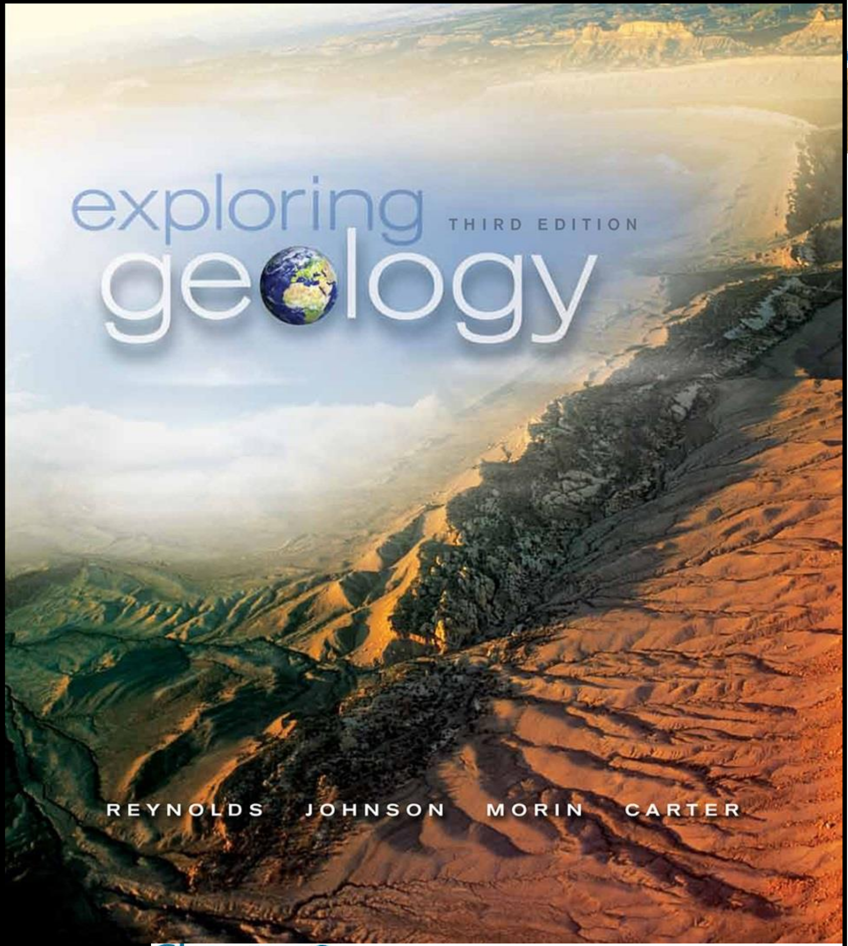


Lucieer *et al.* (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*

Generic science + motivations

Also (geo)science education!

Getting active faults into introductory textbooks!



Chapter 8

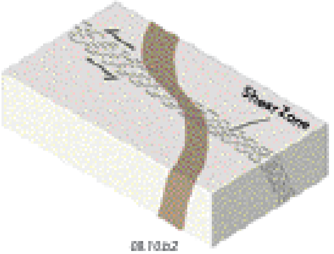
Image Number: 08.00.a3: © Duncan Heron; 08.01.mtb1: Spokane Research Lab/NIOSH/CDC; Courtesy of J.M. Logan and F.M. Chester, Center for Tectonophysics, Texas A&M University; 08.02.mtb1: Spokane Research Lab/NIOSH/CDC; 08.03.c6: © Dean Conger/Corbis; 08.10.c2: Ohio State University, USGS, National Center for Airborne Laser Mapping, OpenTopography, and J Ramon Arrowsmith, Arizona State University; 08.11.a9: © Dr. Marli Miller/Visuals Unlimited;

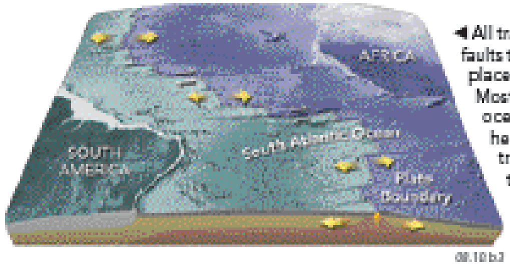
B Where Do Strike-Slip Faults and Shear Zones Form?

During strike-slip movement, one block of rock is sheared sideways past another block of rock. This can occur in various settings, including transform plate boundaries and within the interiors of plates.

Shear stresses can be imposed on rocks horizontally, vertically, or at some intermediate angle. When the shear stresses are horizontal (▲), they act to shear the two sides of a block in opposite horizontal directions. As a result of the stresses, shearing moves rocks horizontally past one another. Shearing in the upper parts of the crust occurs along a fault, as shown here, and is accompanied by fracturing of adjacent rocks. Shearing at depth will occur along a zone of ductile deformation and will be accompanied by metamorphism and the formation of foliation and lineation.

Stresses can form a strike-slip zone that functions as a plate boundary or that is totally within a tectonic plate (▶). A strike-slip zone may offset the rocks hundreds of kilometers or less than a meter. A strike-slip fault with relatively small amounts of displacement is typically a single fault or several adjacent faults, but zones with larger displacements are thick zones of shear (shear zones).





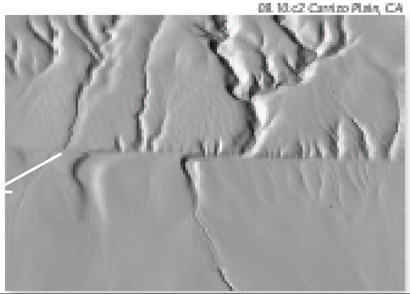
◀ All transform boundaries are strike-slip faults that accommodate the lateral displacement of one plate past another. Most are a boundary between two oceanic plates, as are the ones marked here by small white arrows, but a transform fault can also separate two continental plates or can separate an oceanic plate from a continental one.

C What Features Form Along Strike-Slip Faults?

Strike-slip faults result in a number of distinctive features, including offset streams. They also can have folds formed where one block of rock shears past another or where rocks are forced around a bend in the fault.

Strike-slip faults displace rocks on either side horizontally relative to one another, so in a simple case would not uplift or downdrop either side. However, many strike-slip faults have bends, where the fault changes its trace across the land surface from one orientation to another. Right-lateral motion on the fault shown here causes compression along the bend, forming ridges and troughs that are the surface expression of folds and thrust faults.

Horizontal displacement can offset surface features, including roads, agricultural fields, and streambeds. Over time, offset streams develop a characteristic pattern, where they jog parallel to the fault, before continuing along their prefaulting course. The direction of the jog reflects the direction of relative movement across the fault.



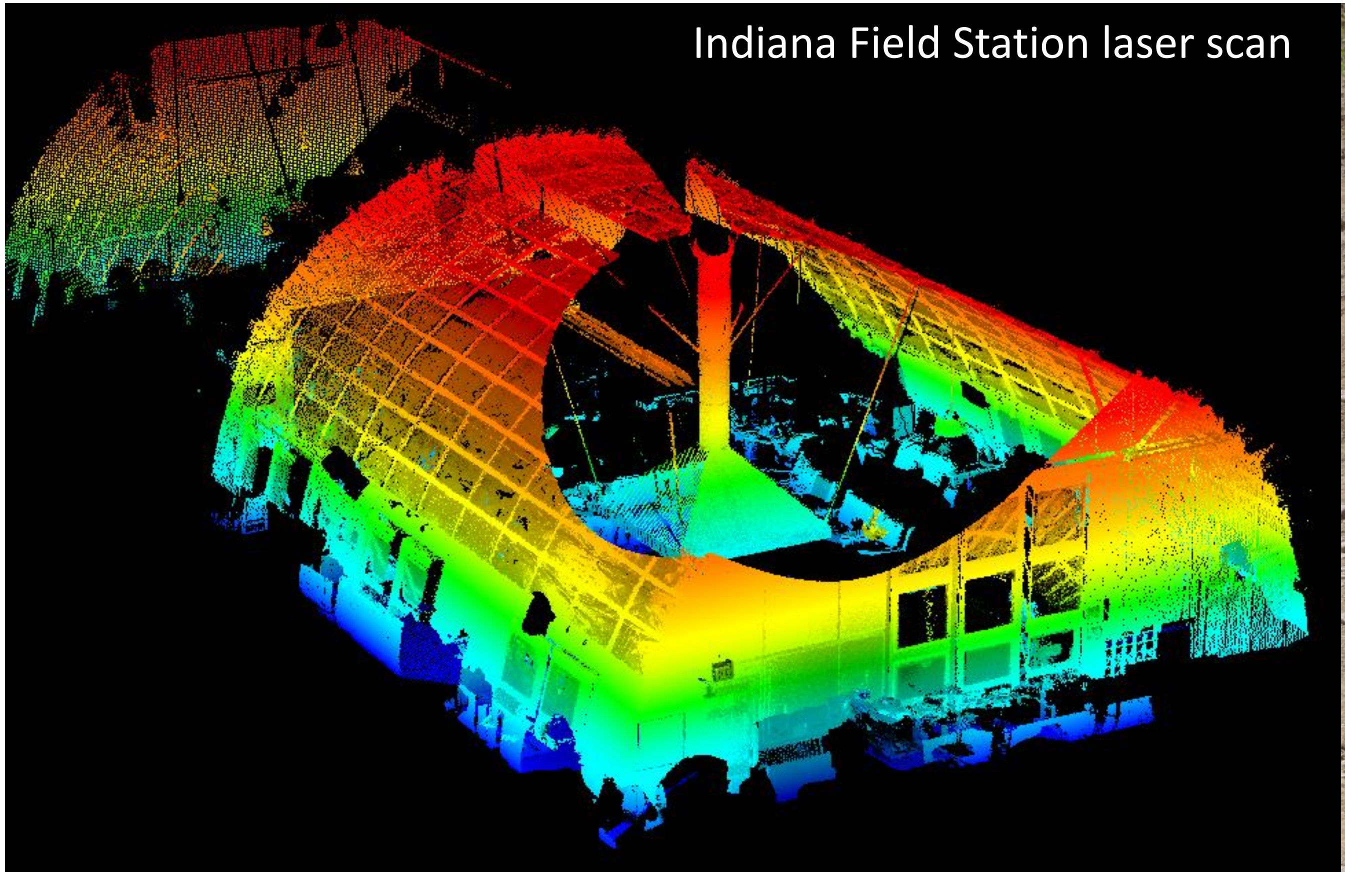
◀ Faults that are currently active can offset streams, ridges, and other topographic features. The San Andreas fault in central California is the linear feature cutting across drainages in the center of this computer-generated view (looking east). The large offset stream takes a jog as it crosses the fault. Is this fault a left-lateral or right-lateral strike-slip fault? Hint: Imagine you are standing in the streambed on the near side of the fault, and then observe which way the streambed on the opposite side has been displaced relative to you.

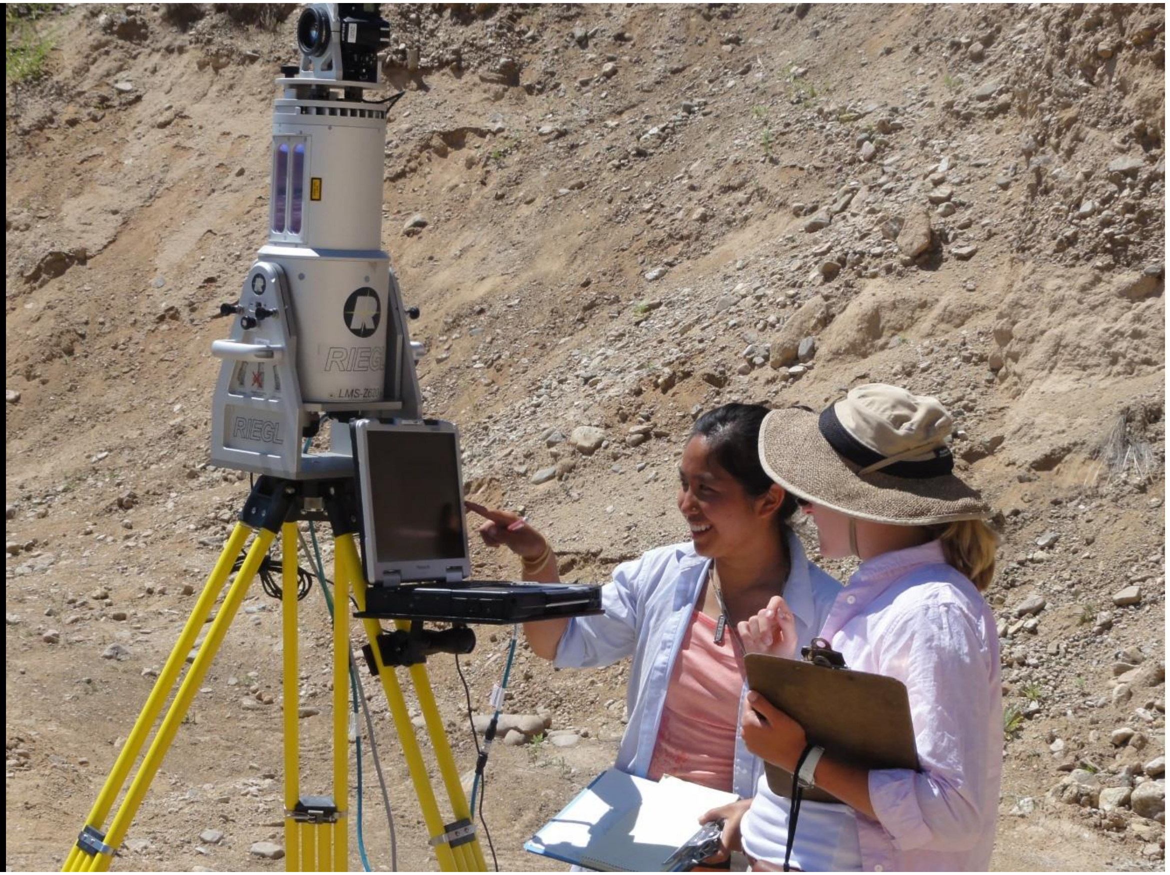
Before You Leave This Page Be Able To

- ✓ Describe or sketch how deformation and metamorphism occur in continental rifts, rifted continental margins, and mid-ocean ridges.
- ✓ Describe strike-slip faults, some settings where they occur, and some features formed on the land surface.

8.10

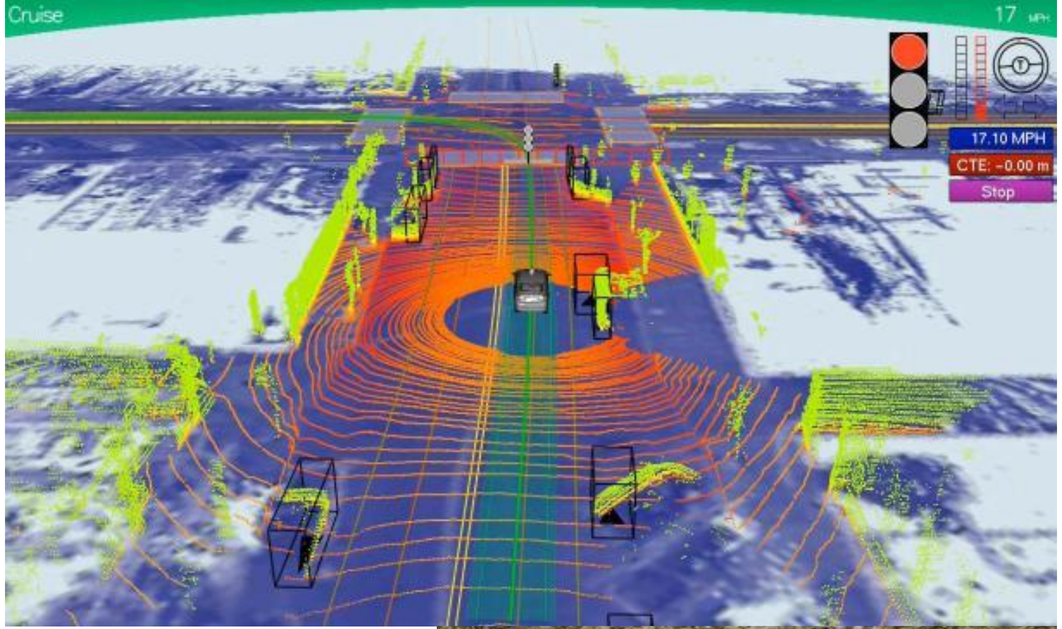
Geodesy in Field Education (supported by UNAVCO)





Collaborative learning; instrumentation in field work; outcrop studies, geomorphic change detection, landform mapping

Bruce Douglas (IU), Nathan Niemi & Marin Clark (U. Michigan),
Beth Pratt-Situala, Chris Crosby, + David Phillips (UNAVCO) + numerous faculty & students



Google car: Gb/sec high accuracy navigation data

Modeling the World from Internet Photo Collections (Snavely, et al., Int J Comput Vis , 2007)

OpenTopography

High-Resolution Topography Data and Tools

Ubiquitous point clouds + 3D models: **coordinated (mapping and monitoring) and haphazard (autonomous navigation, individual photo collections, etc.)**

-Need open access and cyberinfrastructure to support archive, and rapid query, data handling, preprocessing, and differencing

www.opentopography.org

Getting Started | MyOpenTopo | Search OpenTopography...

http://www.opentopography.org

OpenTopography

High-Resolution Topography Data and Tools

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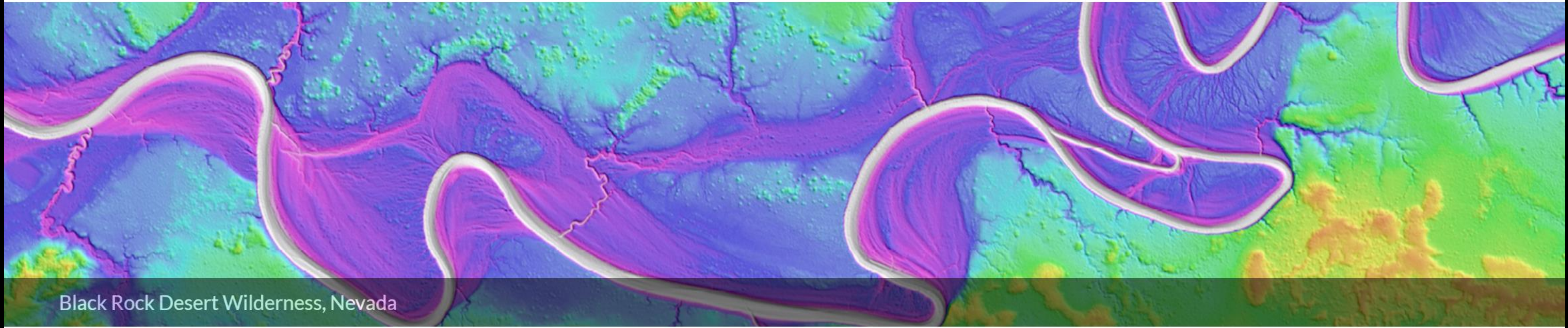

Latest News

OpenTopography at the 2018 International Lidar Mapping Forum (ILMF)

Feb 2, 2018

Come connect with OpenTopography at the 2018 International Lidar Mapping Forum (ILMF) in Denver, February 5-7!

Data and Usage Summary

Point cloud datasets: 260

Point cloud area: 216,978 km²

# of points available: 1.07 Trillion

Raster datasets: 151

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

Trying to get at least a few pictures along the Altyn Tagh Fault, western China (1998)

-16 and 32 sq. ft. Flowform kites

-1280x960 pixels from radio triggered Olympus 340 digital camera

-geometry not appropriate for traditional photogrammetry; we needed structure from motion


Washburn, et al., 2003—1 picture

Trying to build a complete model of SP Crater, Northern Arizona with REU students (2013)

-using balloon and auto kite mounted system
-different surveys, weak ground control, under powered processing machines