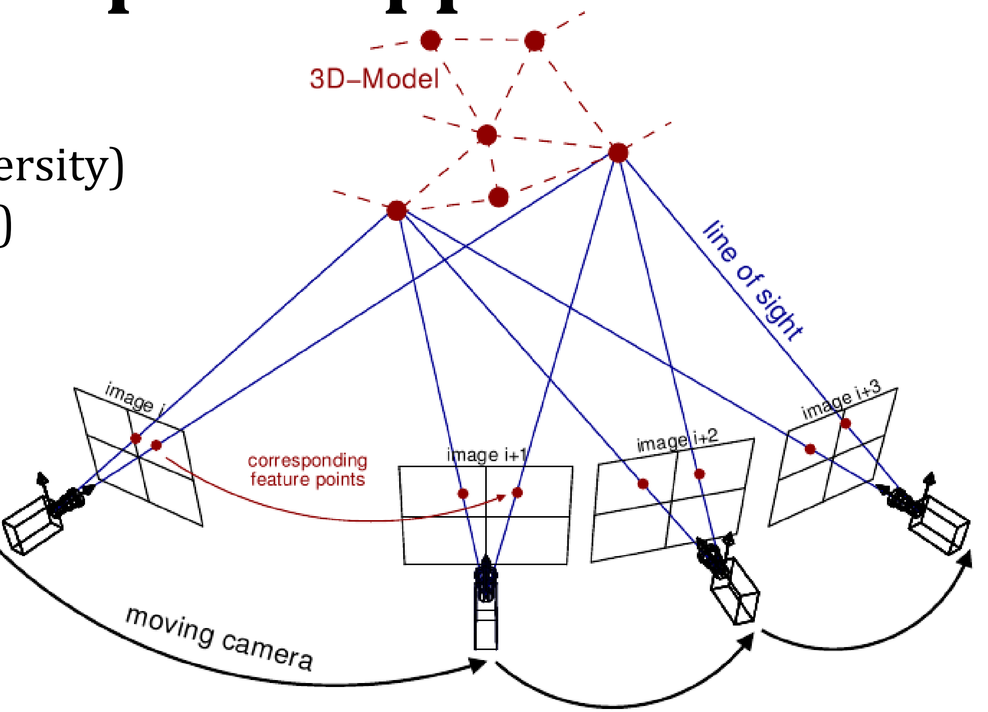
SfM Acquisition Concepts & Applications

Edwin Nissen (Colorado School of Mines)
J Ramon Arrowsmith (Arizona State University)
Chris Crosby (UNAVCO/OpenTopography)



- **Choice of platform**
- **Survey acquisition strategies**
- **Examples of applications**

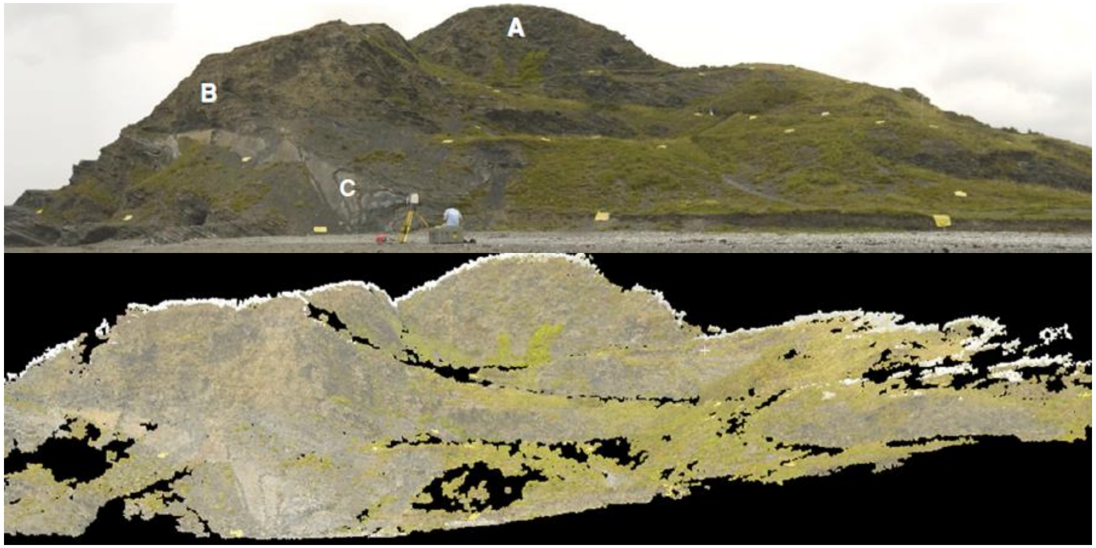
~500 points/m^2 coloured point cloud along a ~1 km section of the 2010 El Mayor-Cucapah earthquake rupture generated from ~500 photographs captured in 2 hours from a helium blimp

SfM from ground-based photographs…
Where it all started

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

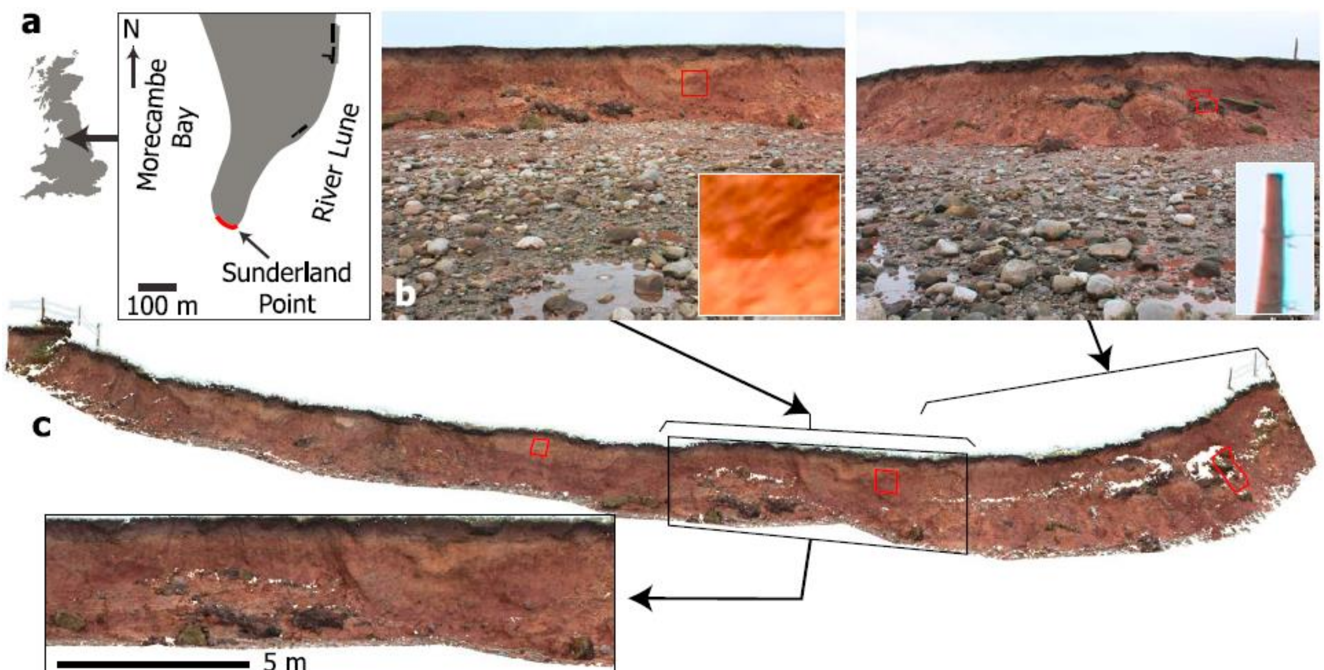
Snavely *et al.* (2007). Modeling the World from Internet Photo Collections, *International Journal of Computer Vision*

SfM from ground-based photographs
First geoscience applications

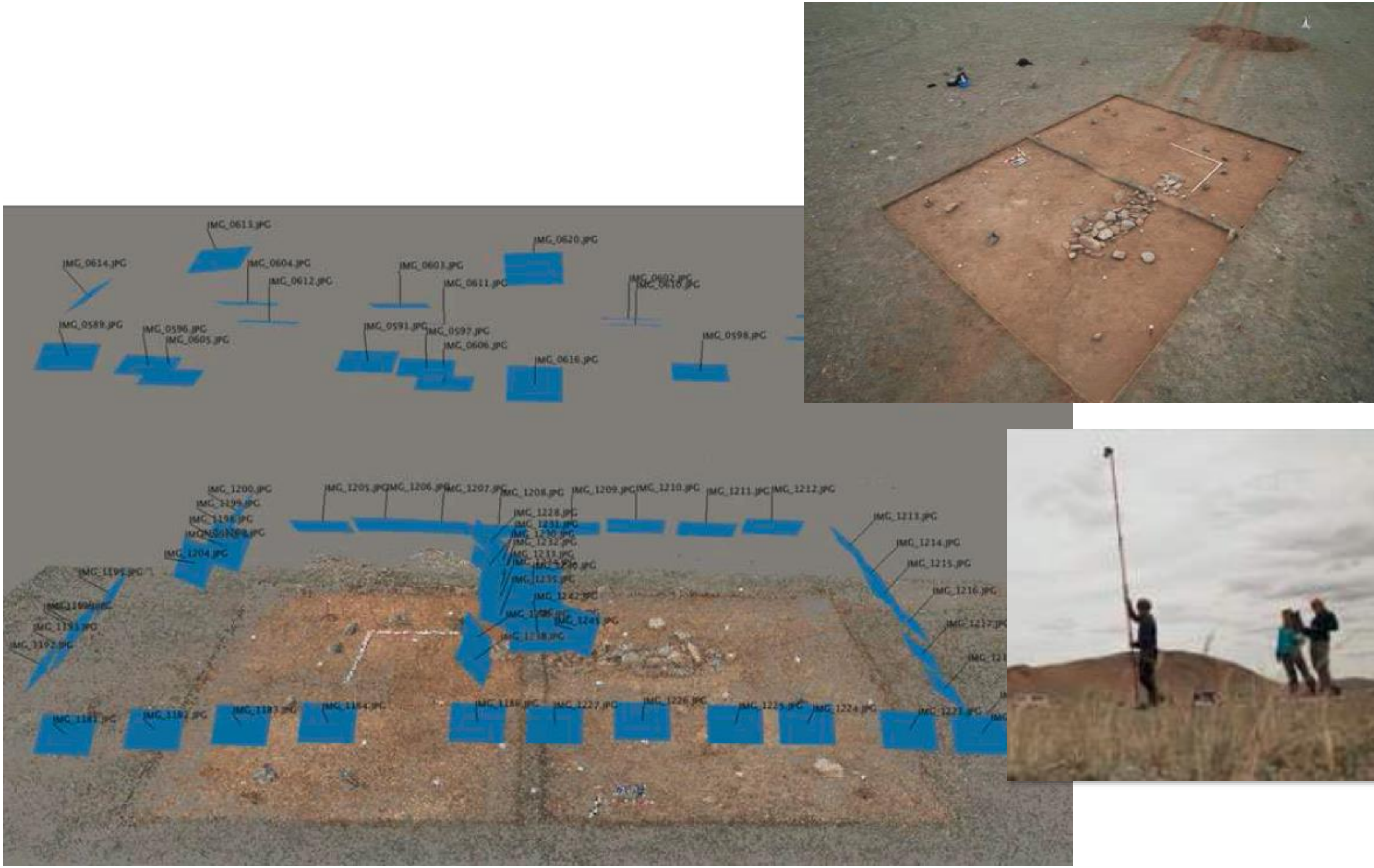


Left. Westoby *et al.* (2012). Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*

Right. James & Robson (2012). Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application. *Journal of Geophysical Research*



SfM from ground-based photographs



Plets *et al.* (2012). Three-dimensional recording of archaeological remains in the Altai mountains, *Cambridge Univ. Press*

SfM from Unmanned Aerial Vehicles (UAV)


DJI Phantom 2 quadcopter (~$1k)


Custom built helicopter (~$15k)


Autokite (~$1k, discontinued)

Falcon Unmanned fixed wing (~$12k)

SfM from helicopters and multi-rotor UAVs

DJI Phantom 2 quadcopter (~$1k)

Custom built helicopter (~$15k)

Pros Robust in high wind and can take off and land anywhere. Larger helicopters can carry large SLR camera. Smaller multi-rotors cannot, but are easier to fly.

Cons Helicopter needs trained pilot to take-off and land and regular refuelling. Initial costs are high and requires careful maintenance.

Regulations may need to be followed (FAA in the U.S.)

SfM from fixed wing UAVs

Pros Relatively easy to pilot. Can cope in moderate winds. Flight durations are normally longer than copters.

Cons Susceptible to damage during landing.

Regulations may need to be followed (FAA in the U.S.)

Autokite (~$1k, discontinued)

Falcon Unmanned fixed wing (~$12k)

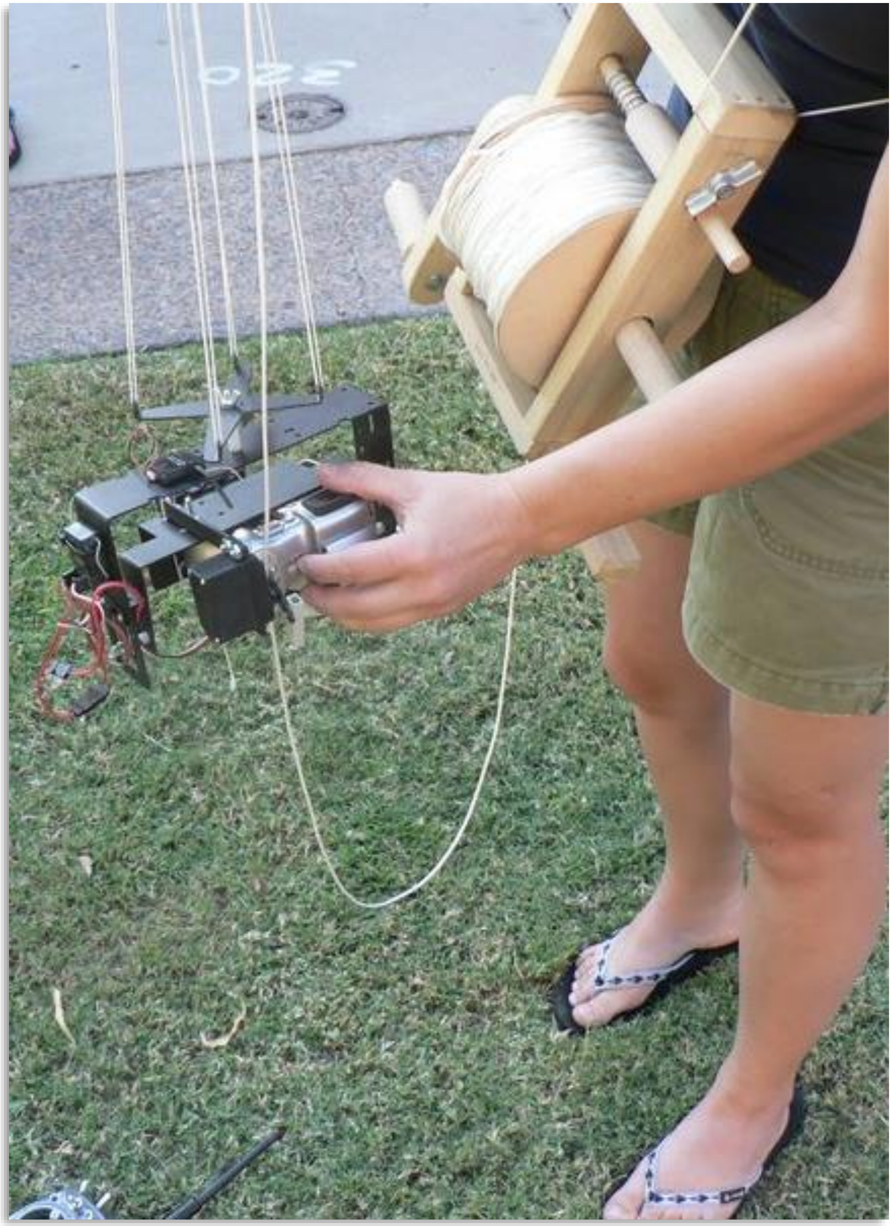
SfM from Unmanned Aerial Systems (UAS)

Allsopp helikite (~$2k)

Brooxes picavet (<$100)

Ramon's balloon (~$100s)

SfM from Unmanned Aerial Systems (UAS)



Pros Easy to drag across target area. Once in the air can remain there. Can carry large SLR cameras. No FAA regulations!

Cons Requires helium, which can be expensive (>$100 per canister), and fiddly picavet. Cannot be automated. Difficult to deploy in windy conditions.

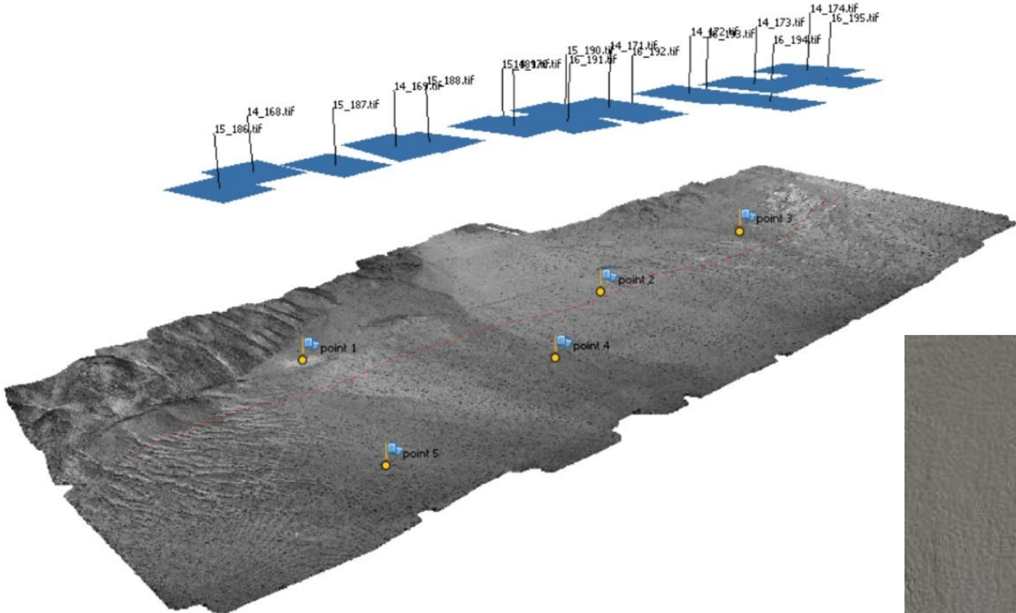
SfM from Unmanned Aerial Systems (UAS)

Pros Easy to drag across target area. Once in the air can remain there. Robust in high wind. No FAA regulations!

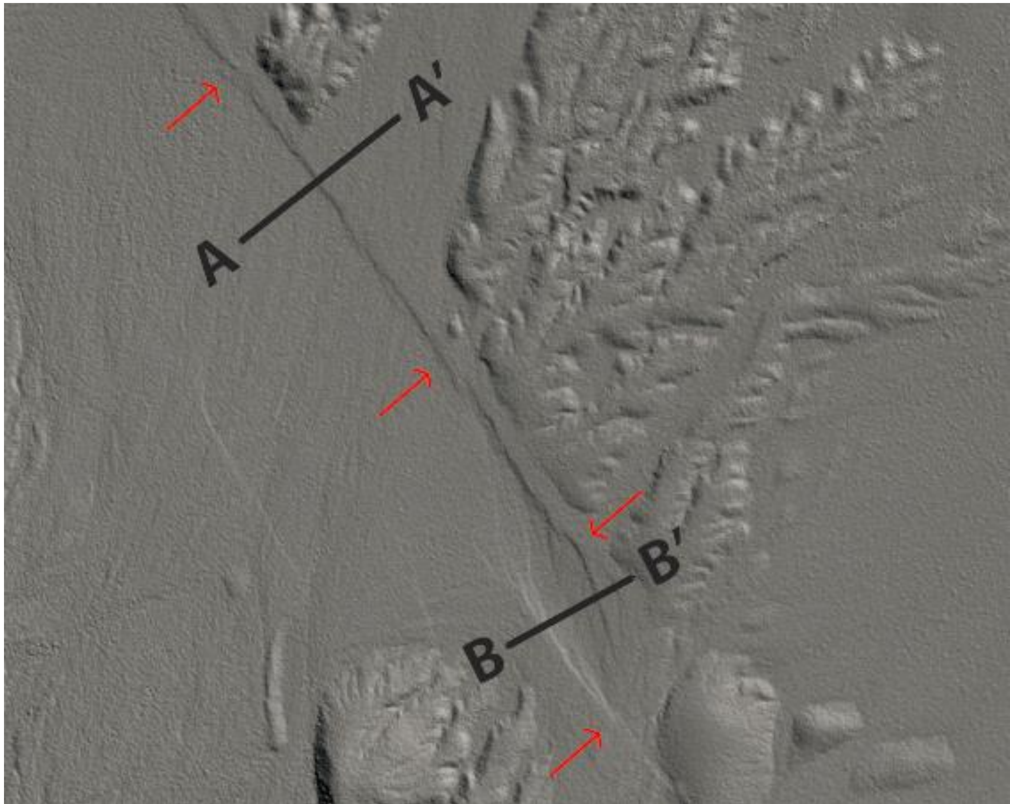
Cons Requires helium, which can be expensive (>$100 per canister). Cannot be automated. Carries small cameras.

SfM from airplane photos

• "Historical topography" and "diachronic geomorphology" possible using legacy air-photos. Requires sufficient photo overlap and georeferencing is a challenge.



(Left) A short section of the ~85 km-long USGS aerial survey of the 1992 Landers rupture, California.



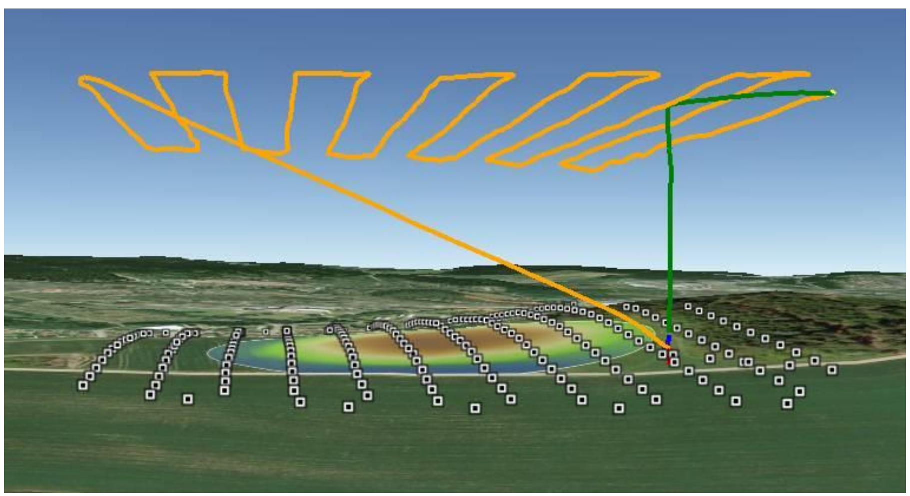
(Right) Resulting 30 cm-resolution DEM, hillshaded to highlight fine geomorphic features.

Georeferencing was undertaken using modern satellite imagery

DroneDeploy

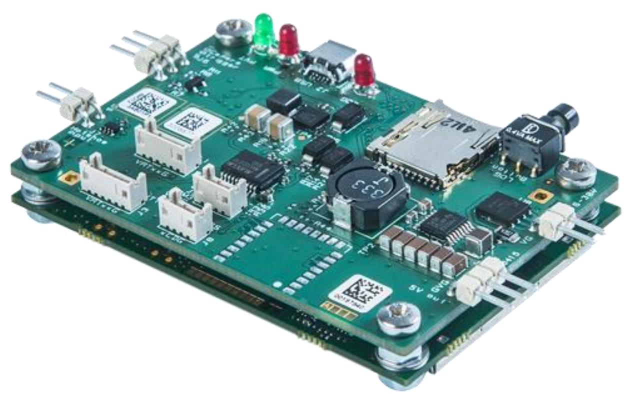
PIX4D

MAPS MADE EASY



Apps for UAS-based mapping

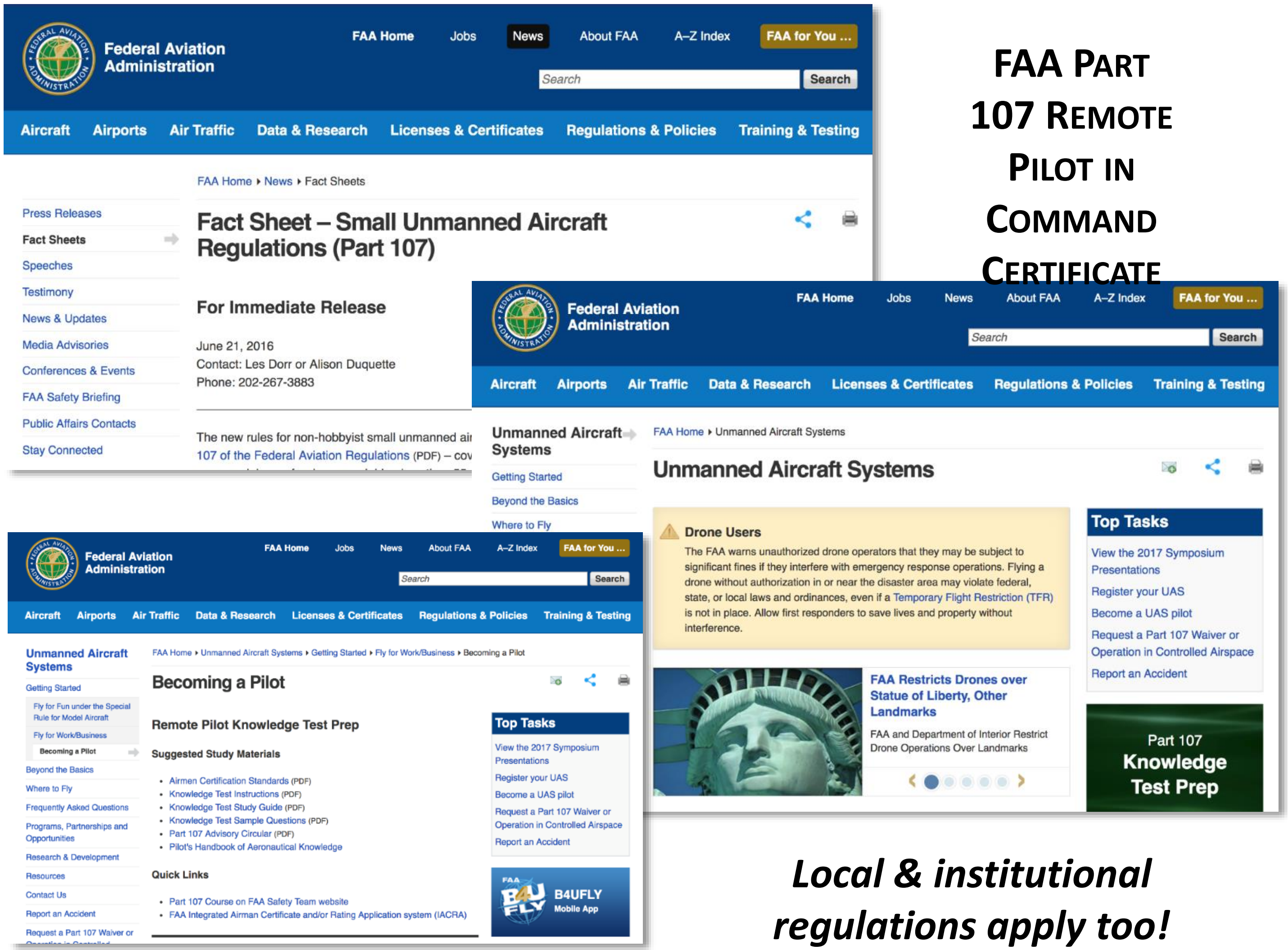
DJI Matrice series



Septentrio AsteRx-m UAS

- RTK GPS board for cm-accuracy camera positions

FAA Part 107 Remote Pilot in Command Certificate



Local & institutional regulations apply too!

Small UAS Certificate of Registration

Name: Arizona State University

Manufacturer: DJI

Model: WM331A

Serial Number: 0AXCE7V0B30381

Certificate Number: FA3KEH44N4

Issued: 12/11/2017 Expires: 12/11/2020

For U.S. citizens, permanent residents, and certain non-citizen U.S. corporations, this document constitutes a Certificate of Registration. For all others, this document represents a recognition of ownership.

For all holders, for all operations other than as a model aircraft under sec. 336 of Pub. L. 112-95, additional safety authority from FAA and economic authority from DOT may be required.

This Small UAS Certificate of Registration is not an authorization to conduct flight operations with an unmanned aircraft. Operations must be conducted in accordance with the applicable FAA requirements. The operator of the aircraft is responsible for knowing and understanding what those requirements are. For more information on flying for non-model purposes, please visit the FAA website at www.faa.gov/uas

Federal Aviation Administration


I UNITED STATES OF AMERICA XI

DEPARTMENT OF TRANSPORTATION • FEDERAL AVIATION ADMINISTRATION

IV NAME

RAMON ARROWSMITH

V ADDRESS 140 E DEL RIO DR

TEMPE AZ 85282-3611

VI NATIONALITY USA

IVa D.O.B. 30 JAN 1967

SEX	HEIGHT	WEIGHT	HAIR	EYES
M	71	180	GRAY	HAZEL

IX HAS BEEN FOUND TO BE PROPERLY QUALIFIED TO EXERCISE THE PRIVILEGES OF

II REMOTE PILOT

III CERTIFICATE NUMBER 4130709

X DATE OF ISSUE 13 MAY 2018

XIV

VIII ACTING ADMINISTRATOR

UAS use with students

- A person may operate an unmanned aircraft for hobby or recreation in accordance with section 336 of the FAA Modernization and Reform Act of 2012 (FMRA)[1] at educational institutions and community-sponsored events[2] provided that person is (1) not compensated, or (2) any compensation received is neither directly nor incidentally related to that person's operation of the aircraft at such events;
- A student may conduct model aircraft operations in accordance with section 336 of the FMRA in furtherance of his or her aviation-related education at an accredited educational institution.
- Faculty teaching aviation-related courses at accredited educational institutions may assist students who are operating a model aircraft under section 336 and in connection with a course that requires such operations, provided the student maintains operational control of the model aircraft such that the faculty member's manipulation of the model aircraft's controls is incidental and secondary to the student's (e.g., the faculty member steps-in to regain control in the event the student begins to lose control, to terminate the flight, etc.).

Federal Aviation Administration

Memorandum

Date: May 4, 2016

To: Earl Lawrenc
AUS-1

John Duncan

From: Reginald C. (

Prepared by: Dean E. Grif

Subject: Educational U

This interpretation addresses: educational institutions and co aircraft in furtherance of recei

There is uncertainty in the mo model aircraft operated for ho The FAA has received many i coursework in the design, con the types of activities in which legal framework.

In light of these questions, we

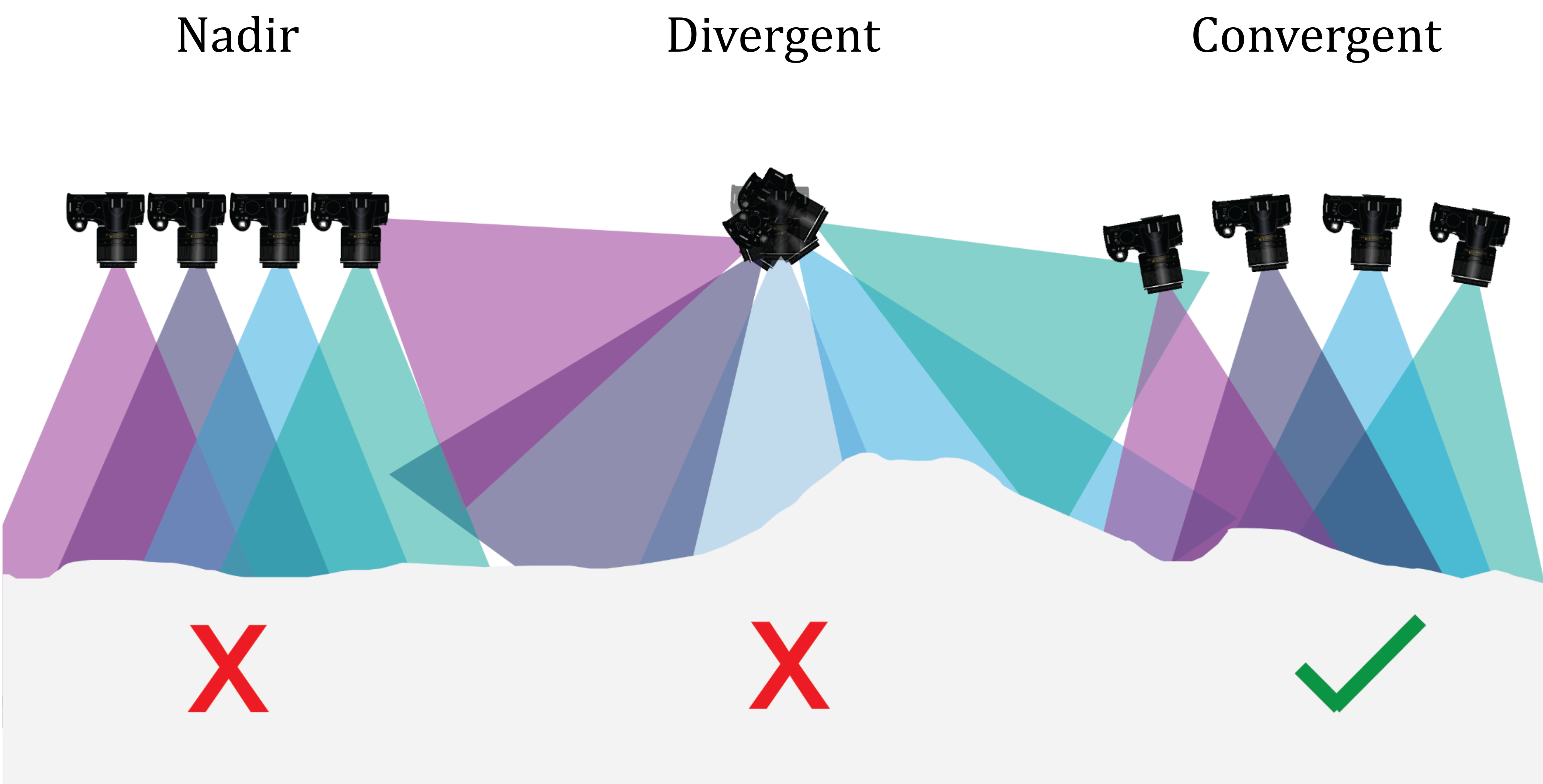
- A person may operate an unmanned aircraft for hobby or recreation in accordance with section 336 of the FAA Modernization and Reform Act of 2012 (FMRA)[1] at educational institutions and community-sponsored events[2] provided that person is (1) not compensated, or (2) any compensation received is neither directly nor incidentally related to that person's operation of the aircraft at such events;
- A student may conduct model aircraft operations in accordance with section 336 of the FMRA in furtherance of his or her aviation-related education at an accredited educational institution.

[1] Pub. L. 112-95, § 336(a)(1)-(5)
[2] Community-sponsored events wou etc.

- Faculty teaching aviatio students who are operating a model aircraft under section 336 and in connection with a course that requires such operations, provided the student maintains operational control of the model aircraft such that the faculty member's manipulation of the model aircraft's controls is incidental and secondary to the student's (e.g., the faculty member steps-in to regain control in the event the student begins to lose control, to terminate the flight, etc.).

On June 25, 2014, the FAA published in the Federal Register its interpretation of the Special Rule for Model Aircraft, section 336 of the FMRA. 79 Fed. Reg. 36172 (June 25, 2014).[3] Currently, the FAA is reviewing the more than 33,500 comments to that Special Rule. In

Acquisition geometry



Acquisition geometry

Convergent with a range of distances

Choice of camera

- Most cameras work
- DEM/orthophoto resolution is governed by the ground pixel resolution of the raw photos, so high megapixel cameras are preferable
- Better lenses of SLR cameras mean fewer radial distortions…
- but radial artefacts arising from cheap camera lenses can be mitigated by deploying ground control points
- fish-eye lenses (e.g. GoPro) give rise to largest distortions, but latest software seems to cope
- **time lapse setting** is essential if camera is deployed from drone
- internal or external **GPS tagging** is another useful function, as it enables rough geo-referencing without ground control points

Camera lens distortions

f = focal length

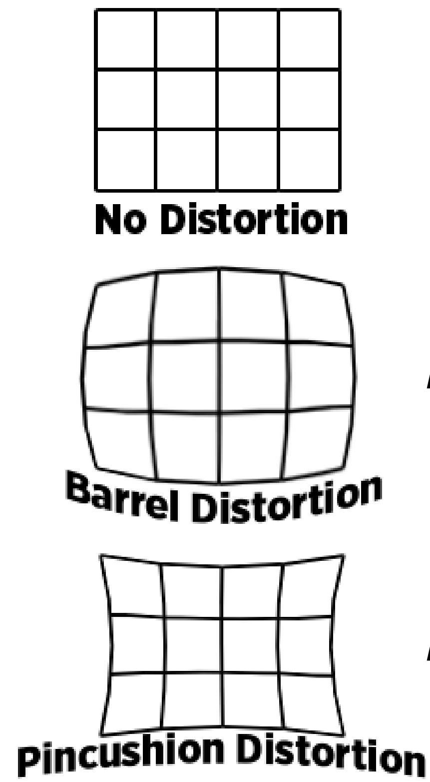
c_x = principal point x coordinate

c_y = principal point y coordinate

k_n = n^{th} radial distortion coefficient

p_n = n^{th} tangential distortion coefficient

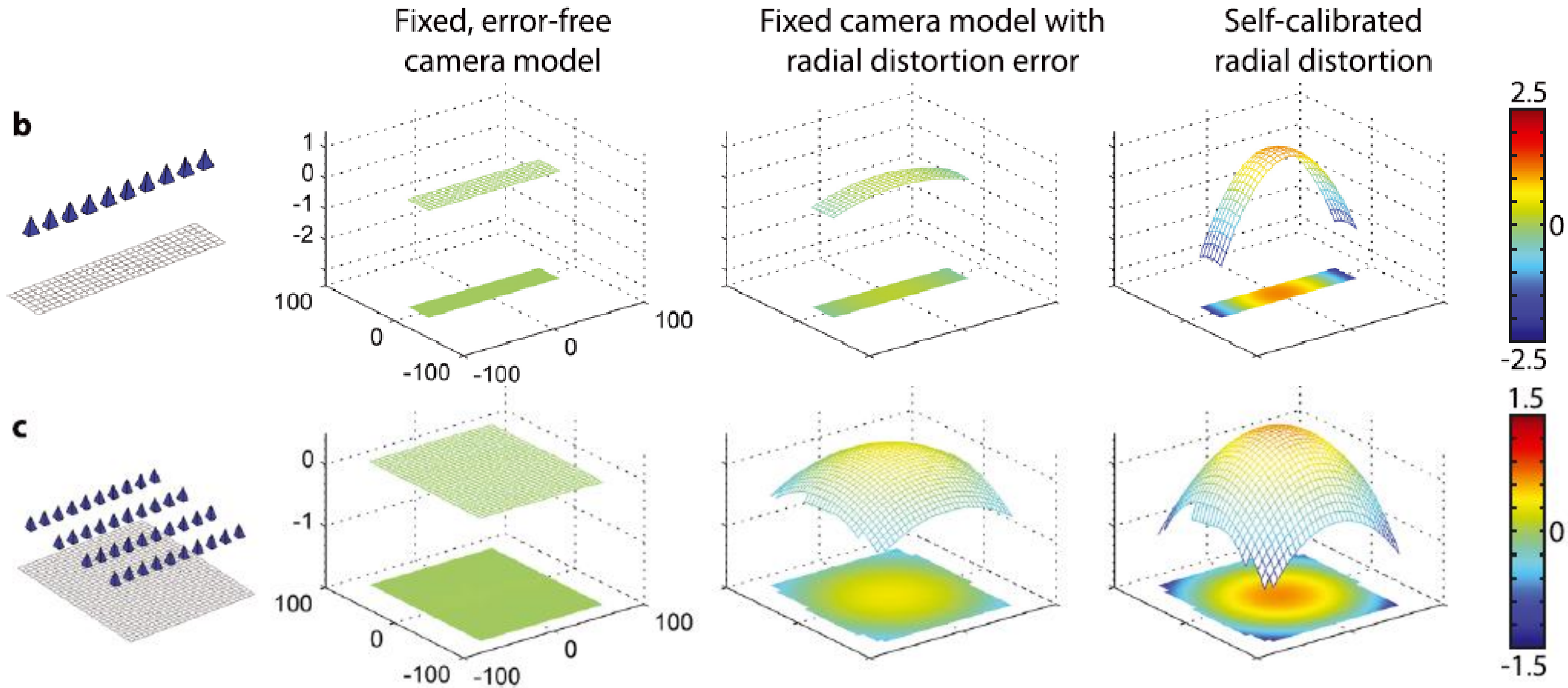
skew coefficient between the x and the y axis.



k_1 <1

k_1 >1

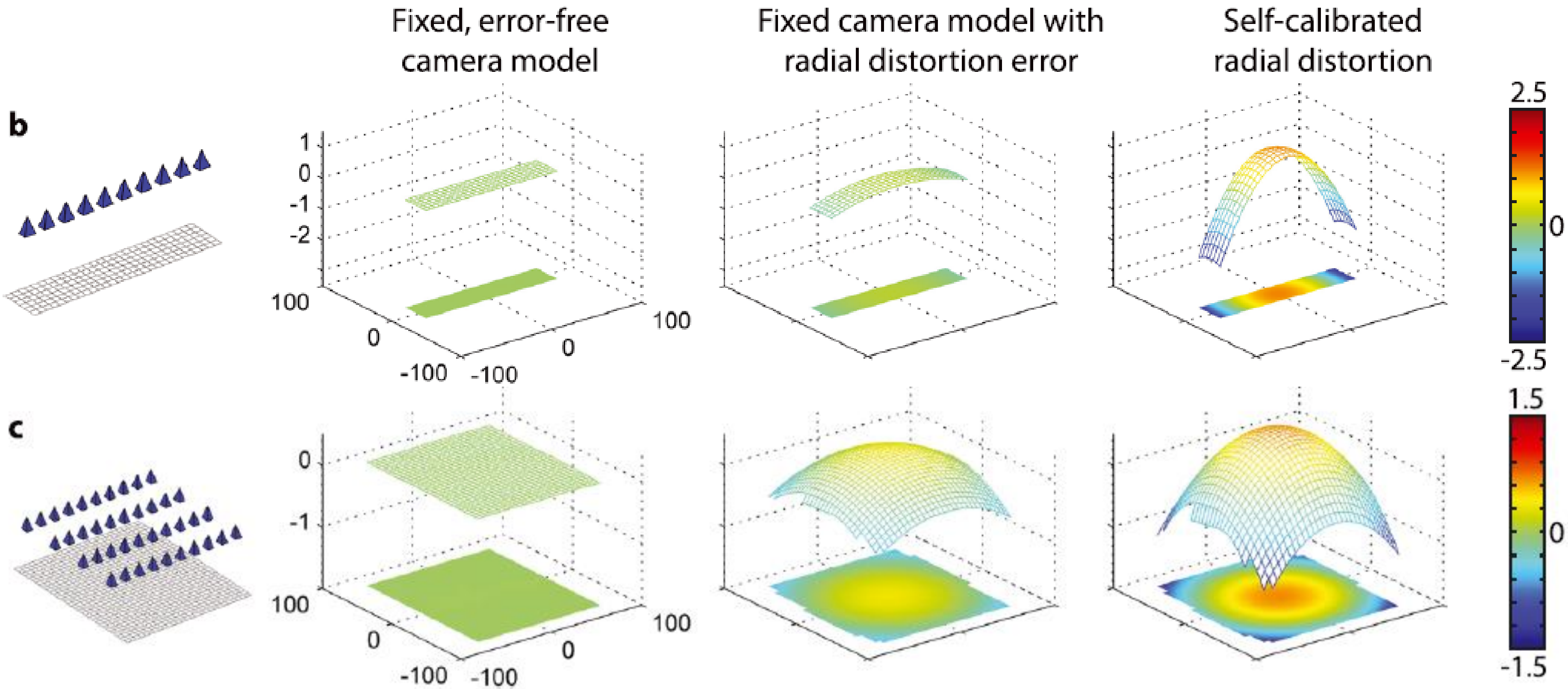
Camera lens distortions



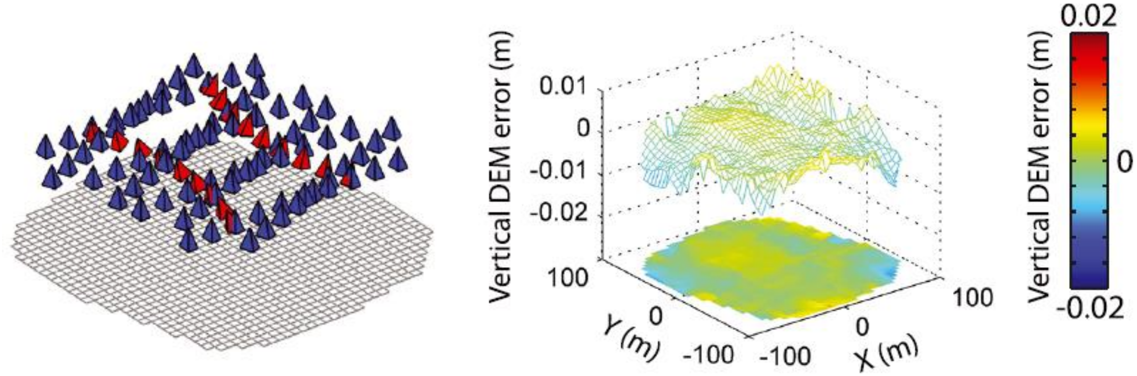
- A trade-off between lens radial distortion term and computed surface form can lead to “doming”

James & Robson (2014), Mitigating systematic error in topographic models derived from UAV and ground-based image networks, *Earth Surface Processes and Landforms*

Camera lens distortions



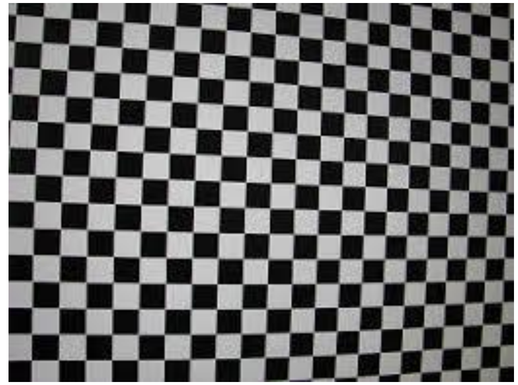
• Doming can be mitigated by incorporating a few oblique camera angles (in red)

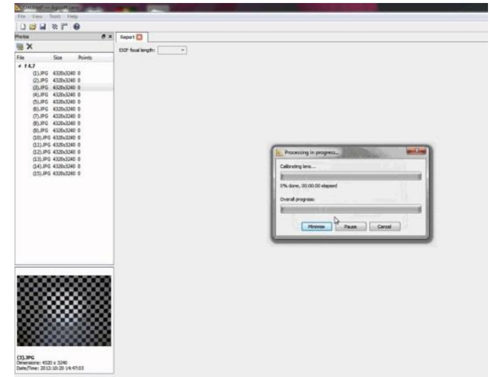


James & Robson (2014), Mitigating systematic error in topographic models derived from UAV and ground-based image networks, *Earth Surface Processes and Landforms*

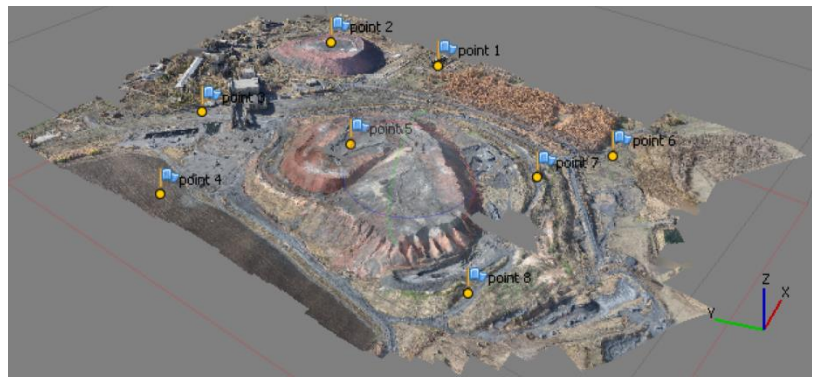
Camera lens distortions

• Doming can be mitigated by calibrating the camera parameters by photographing a calibration target





• Doming can be mitigated by georeferencing using ground control points



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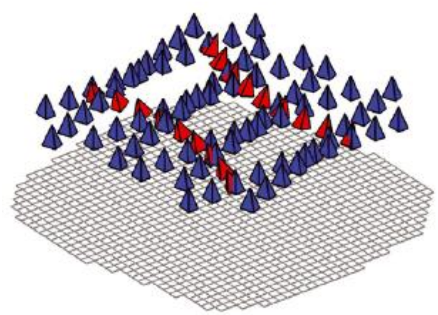
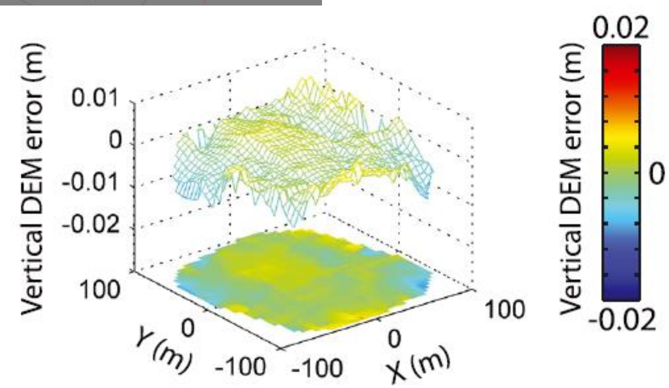
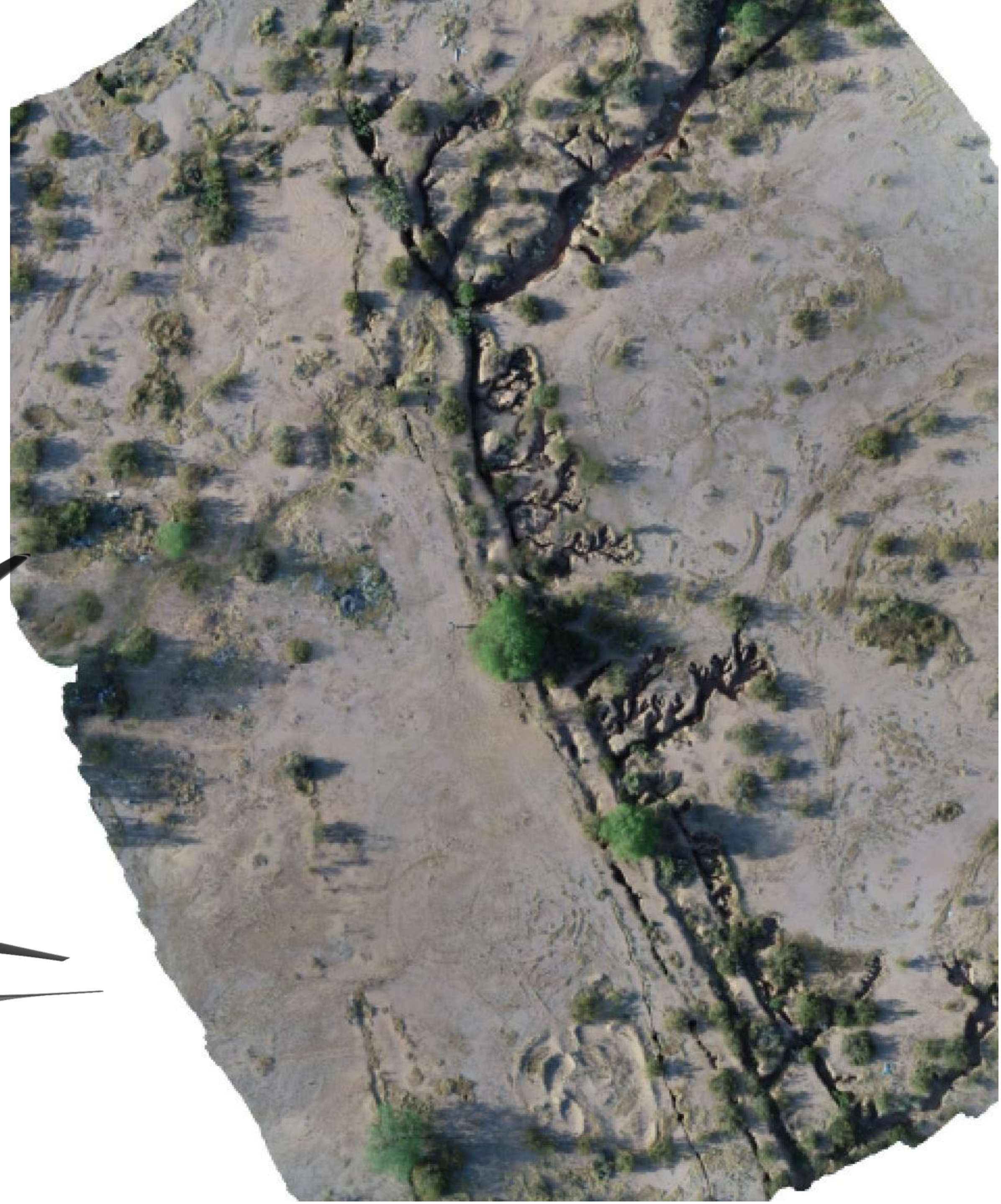




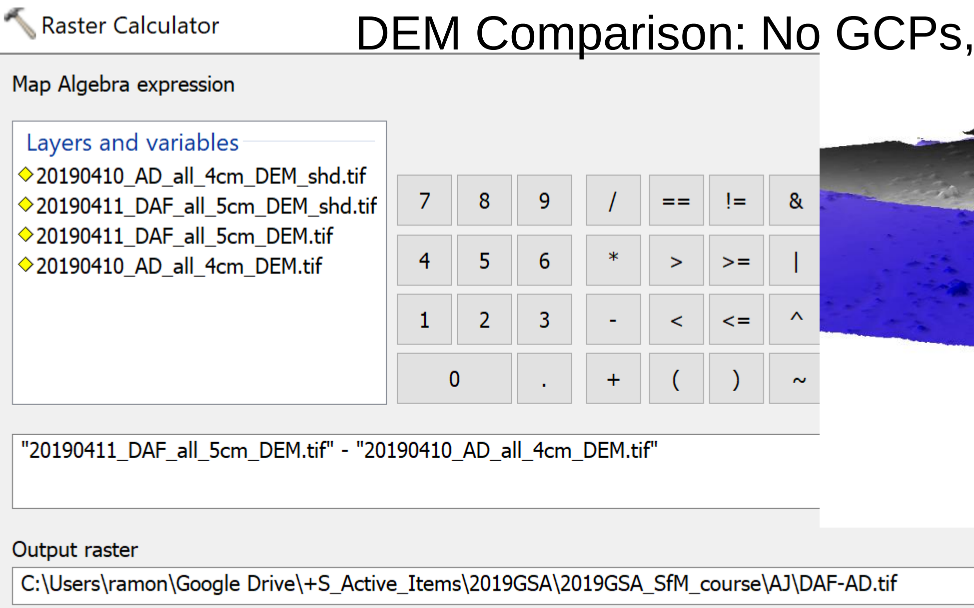
Spring 2019 “fly off”—
Earth Fissures in
Apache Junction, AZ
with Alan Deino and
David Feary (+others)

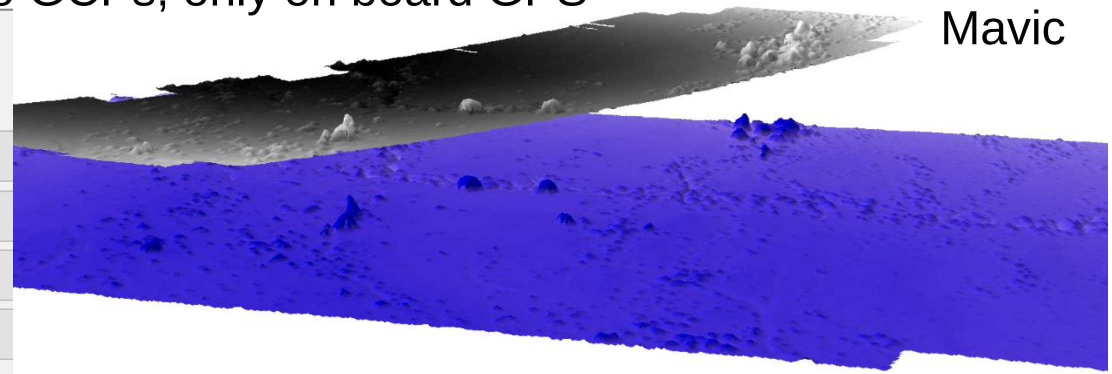
DJI Mavic Pro (Deino)

DJI Inspire 2 + ZenMuse camera (Feary)



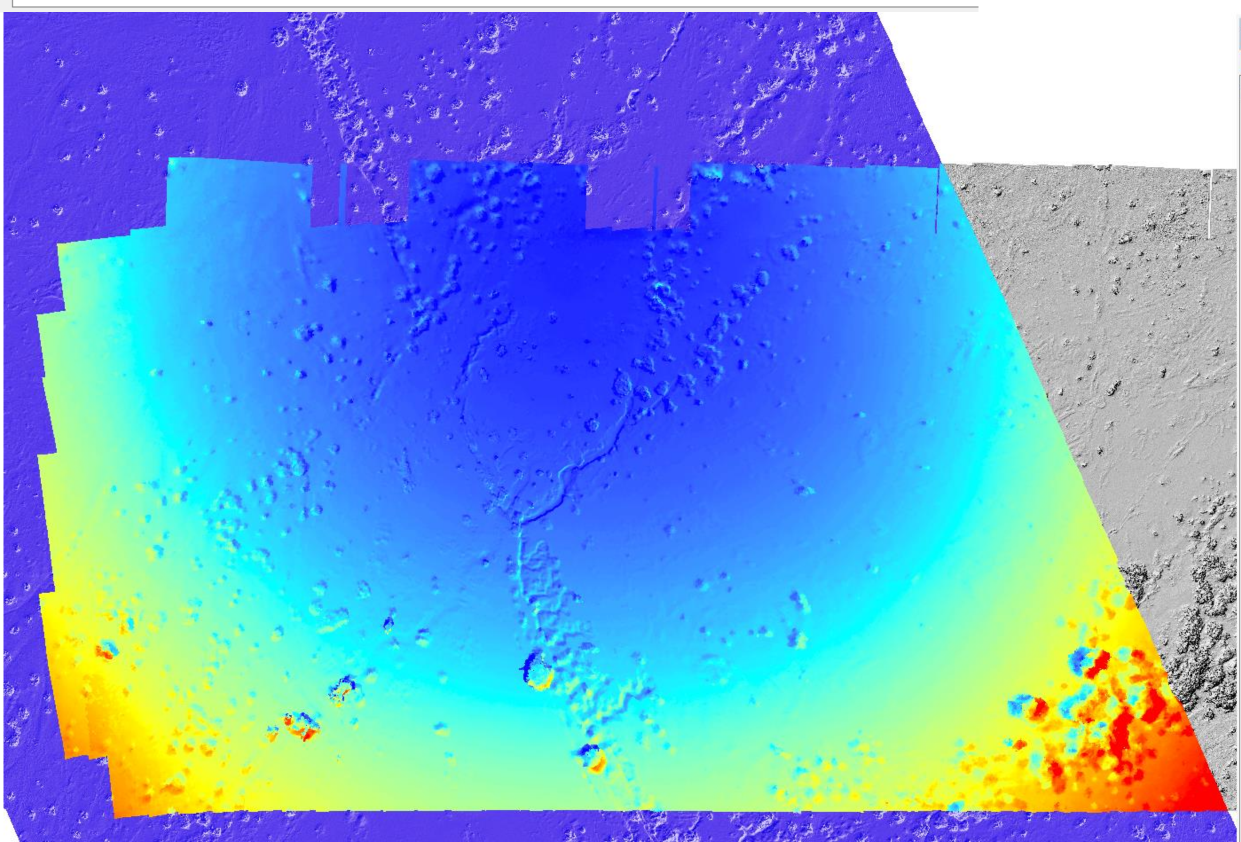
DEM Comparison: No GCPs, only on board GPS

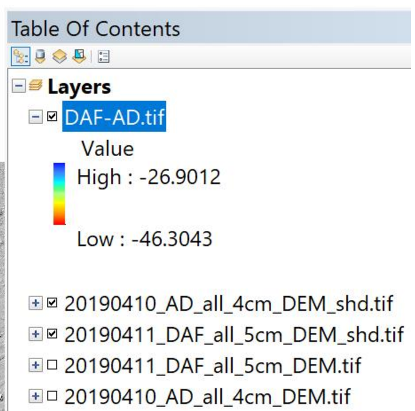




Mavic

Inspire + ZenMuse

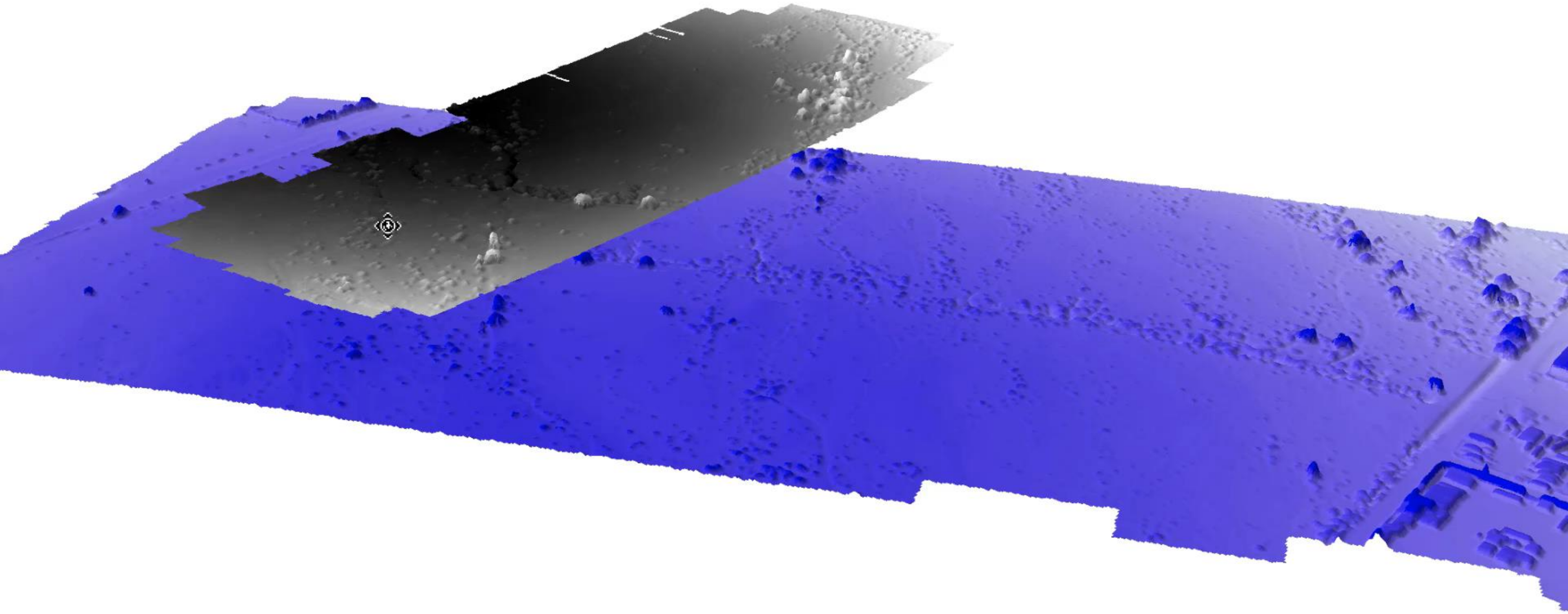




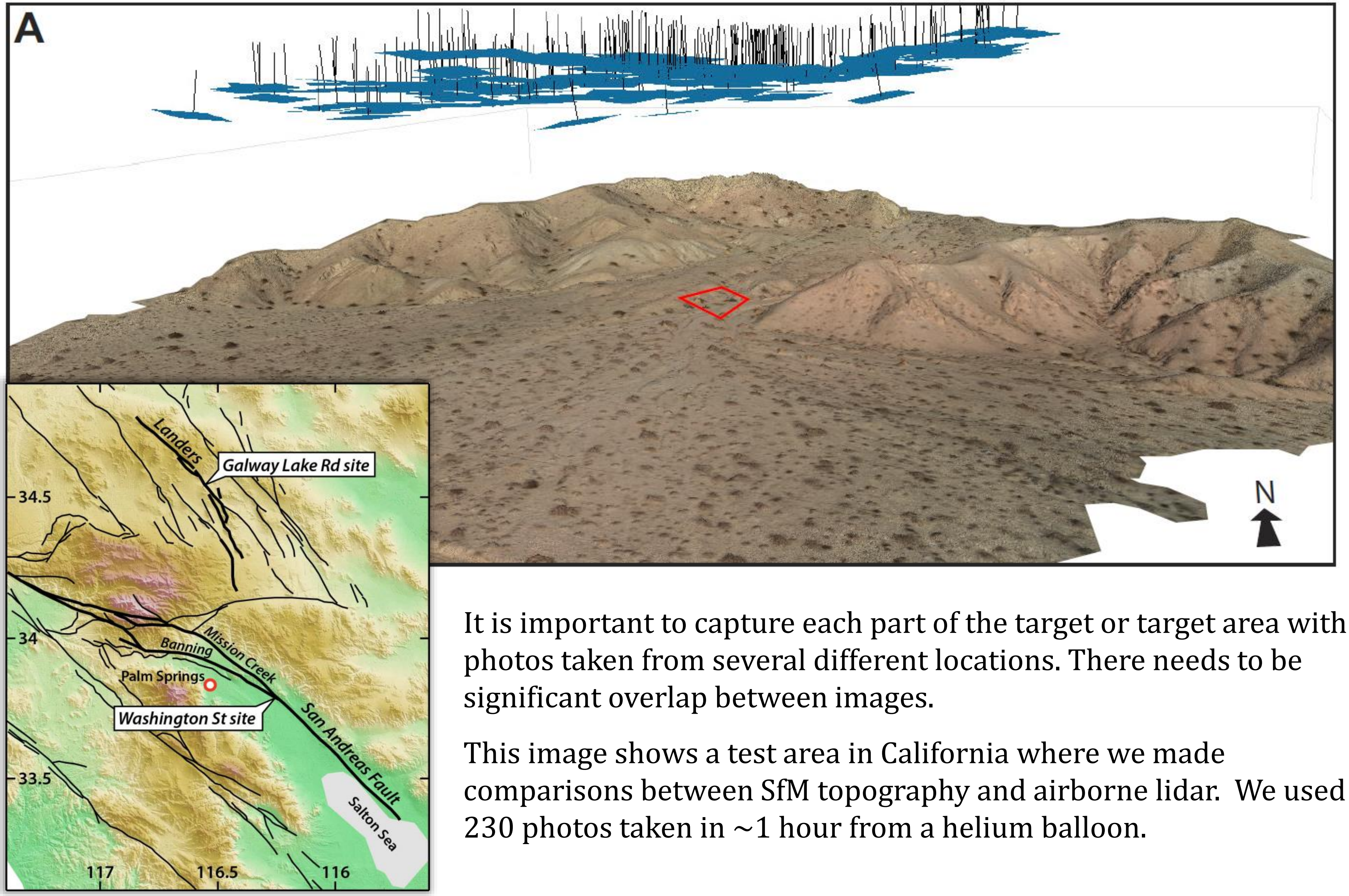
Notice the magnitude and sign of the "doming"

Grey surface is the Mavic

Blue surface is the Inspire + ZenMuse



Resolution and precision of SfM topography



It is important to capture each part of the target or target area with photos taken from several different locations. There needs to be significant overlap between images.

This image shows a test area in California where we made comparisons between SfM topography and airborne lidar. We used 230 photos taken in ~1 hour from a helium balloon.

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

Resolution and precision of SfM topography

Orthophoto

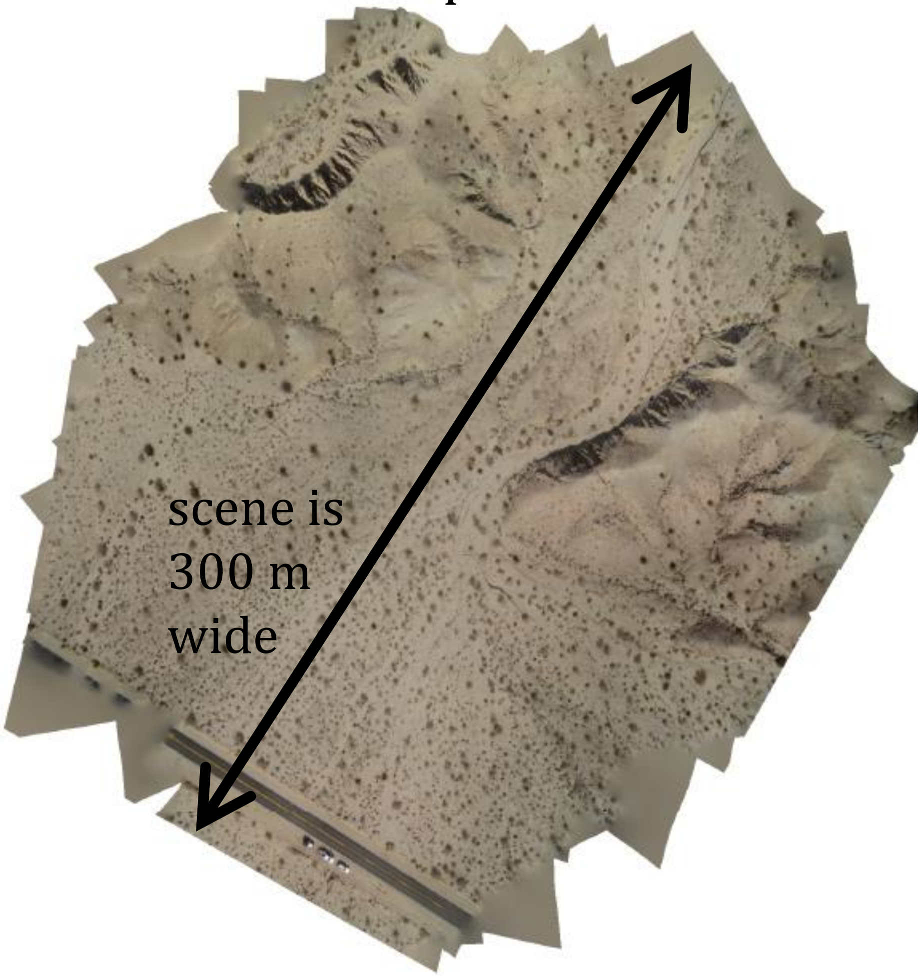


Photo coverage plot

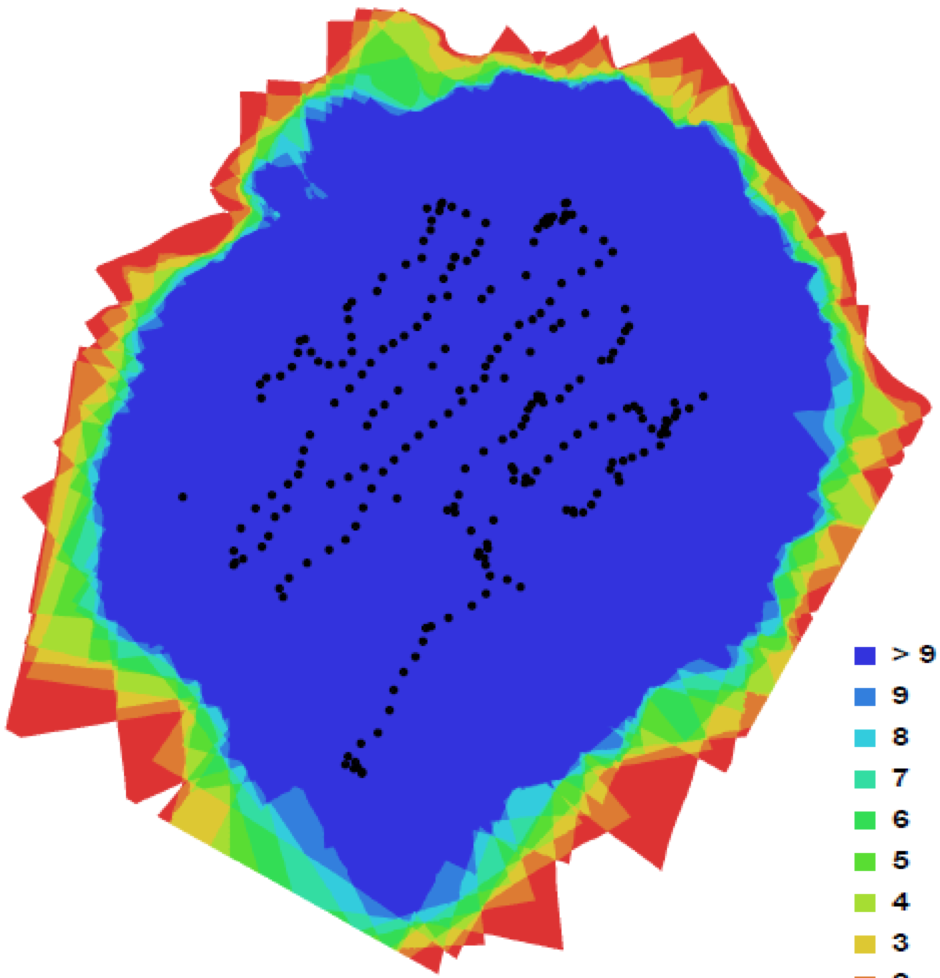
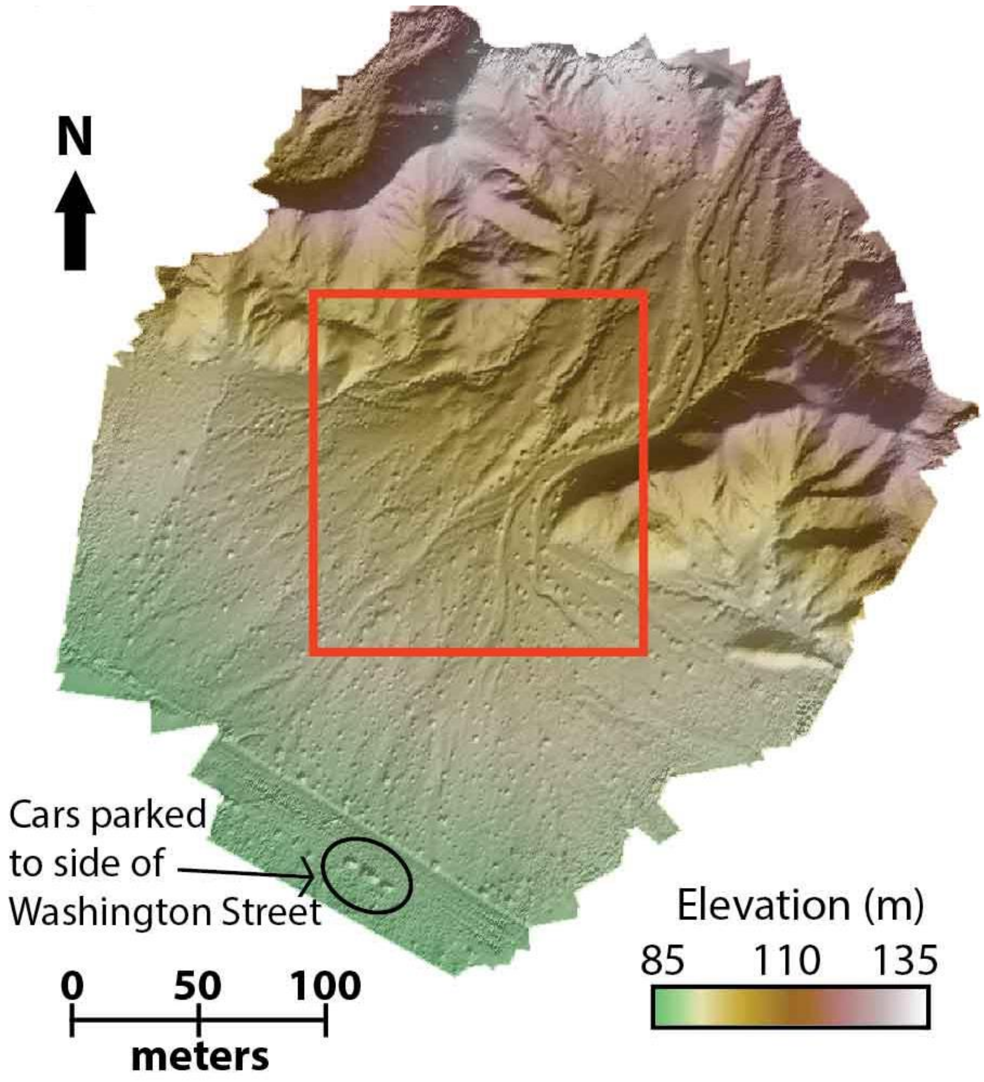
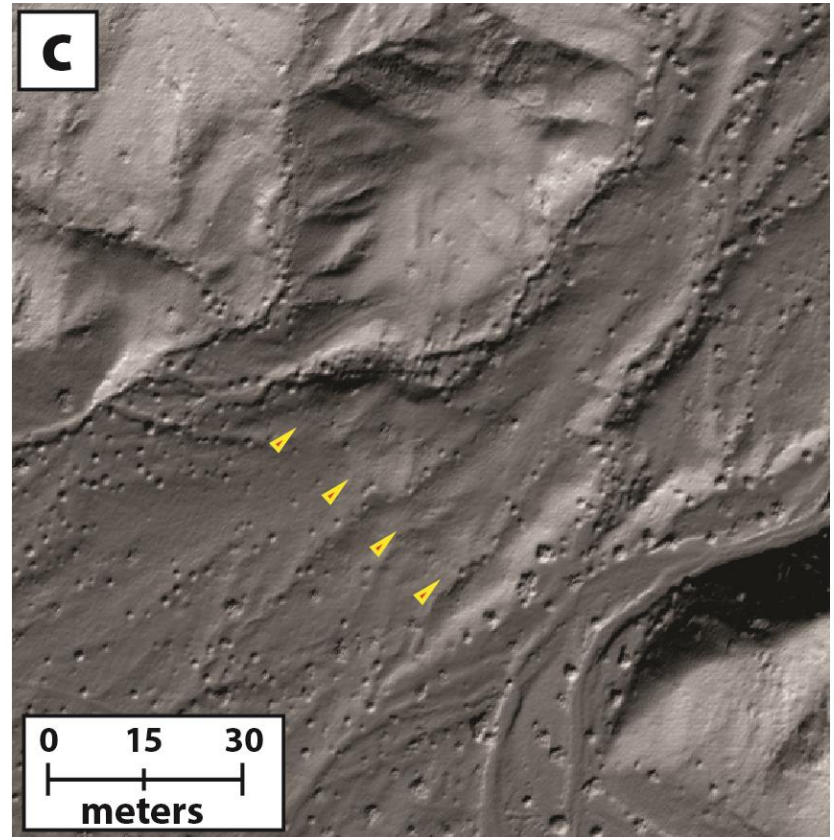


Fig. 1. Camera locations and image overlap.

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

Resolution and precision of SfM topography



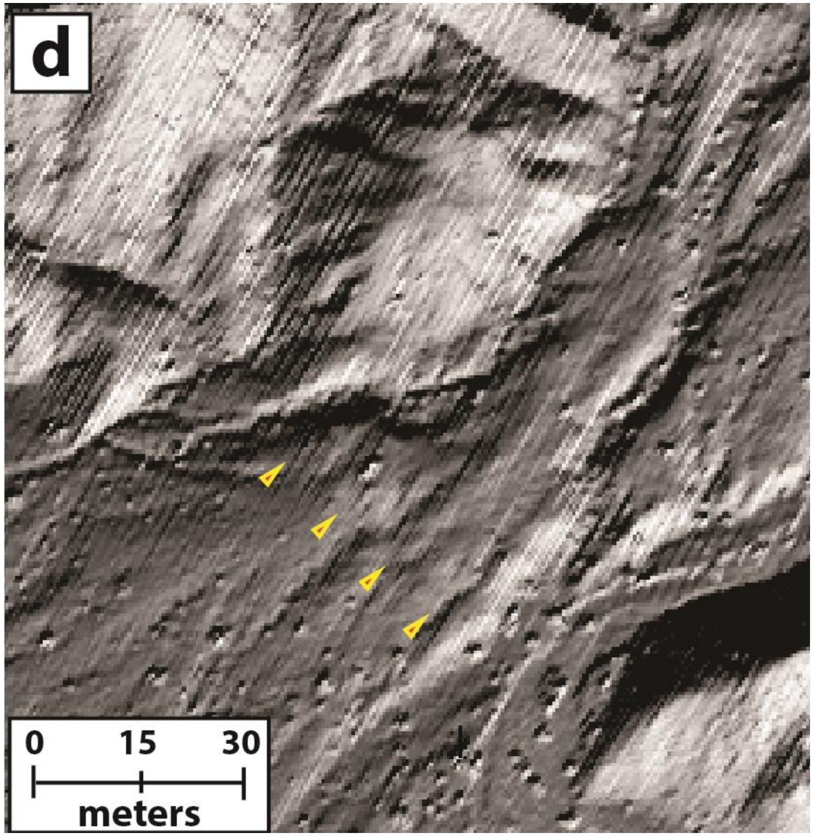


SfM ~700 pts/m^2

5 cm resolution DEM

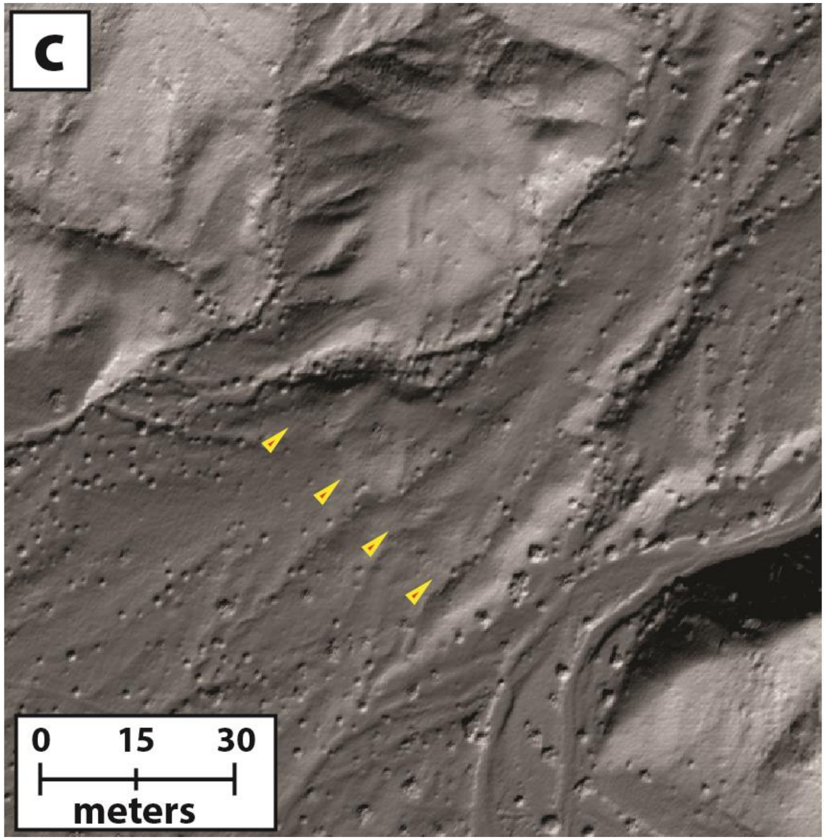
Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

Resolution and precision of SfM topography



B4 LiDAR ~4 pts/m^2

0.5 - 1 m resolution DEM

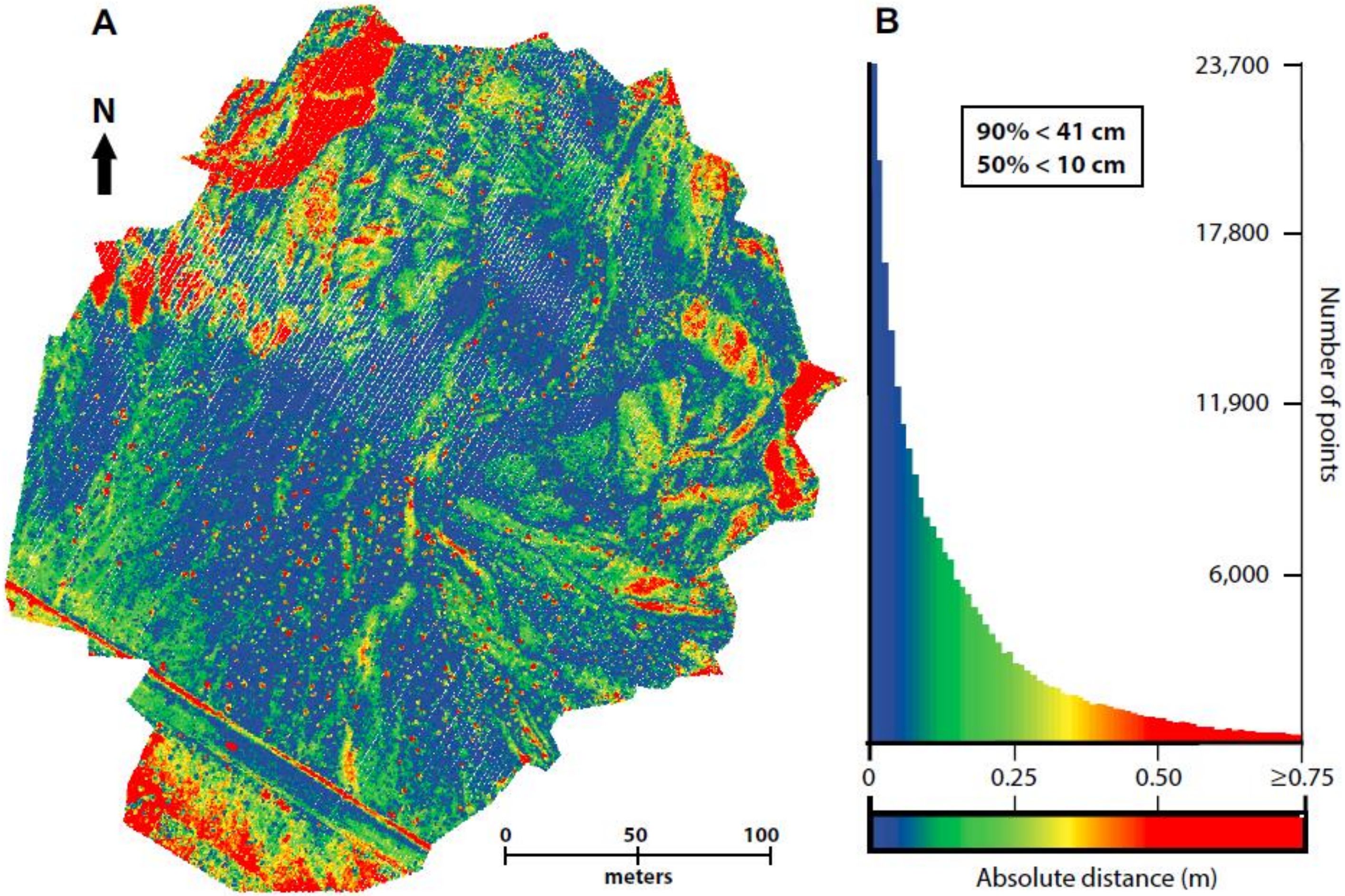


SfM ~700 pts/m^2

5 cm resolution DEM

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

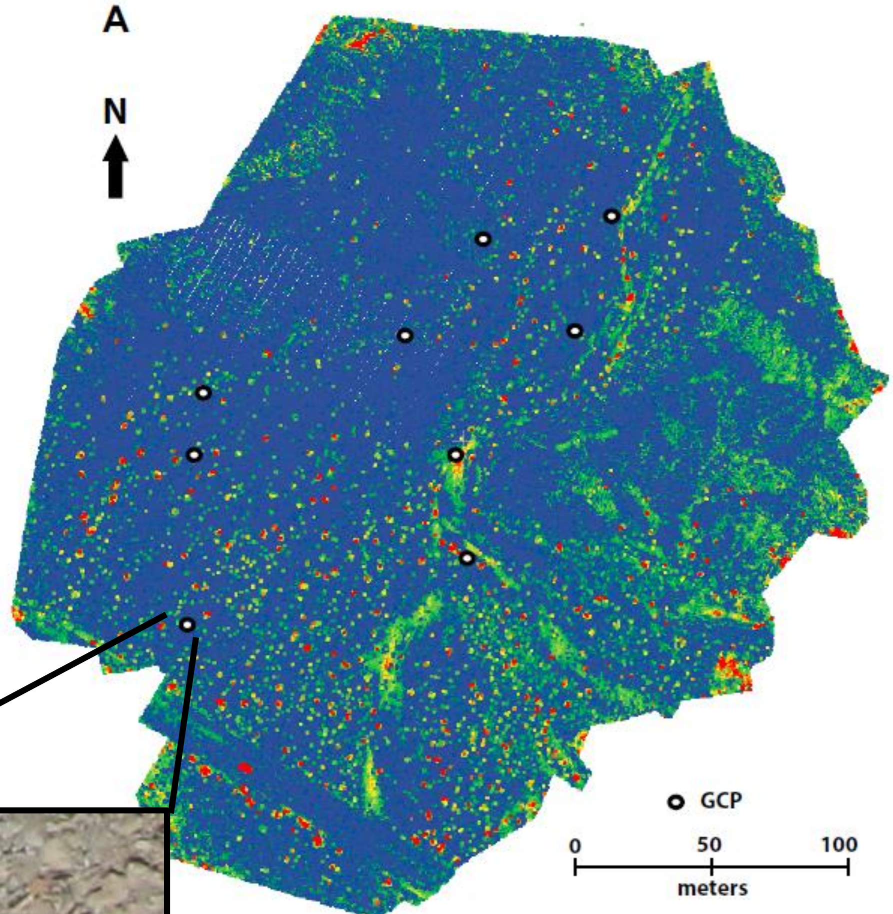
Resolution and precision of SfM topography

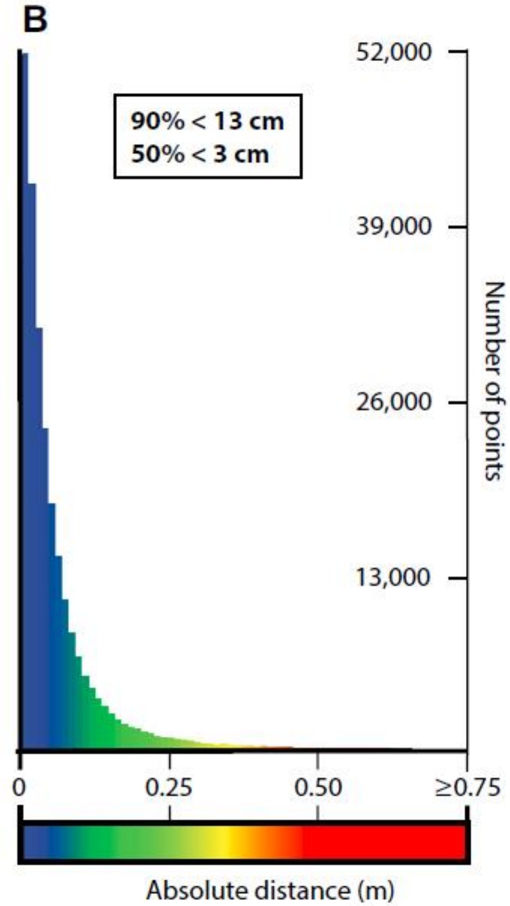


Note errors of >50 cm concentrated around edge of dataset. These probably reflect a trade-off in the bundle adjustment between estimates of the radial distortion of the camera lens and the topography

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

Resolution and precision of SfM topography



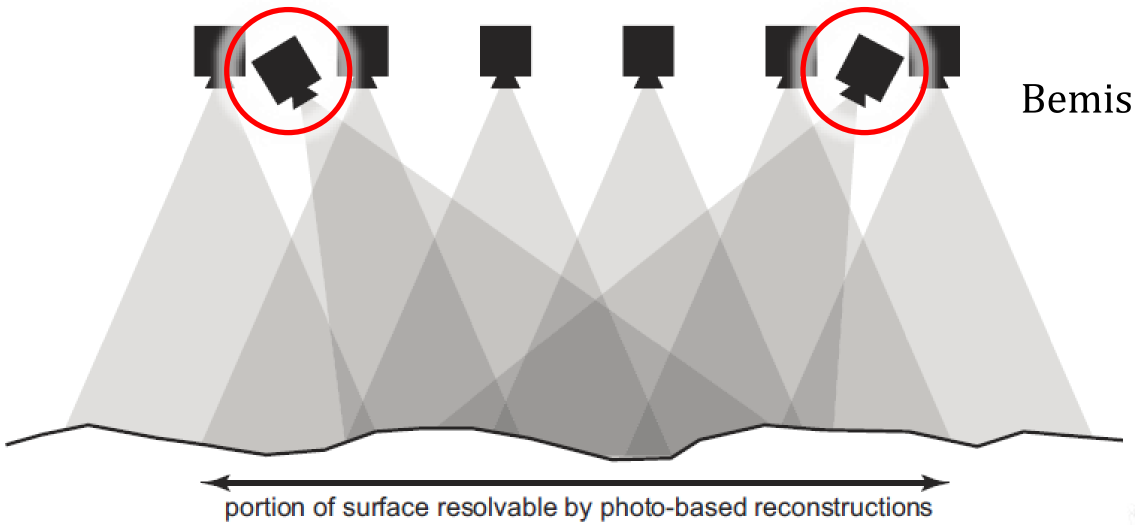


Distortion errors around the edge of dataset can be removed by deploying and surveying ground control points (using differential GPS), identifying these in the aerial photographs, and fixing the locations before the bundle adjustment.

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*

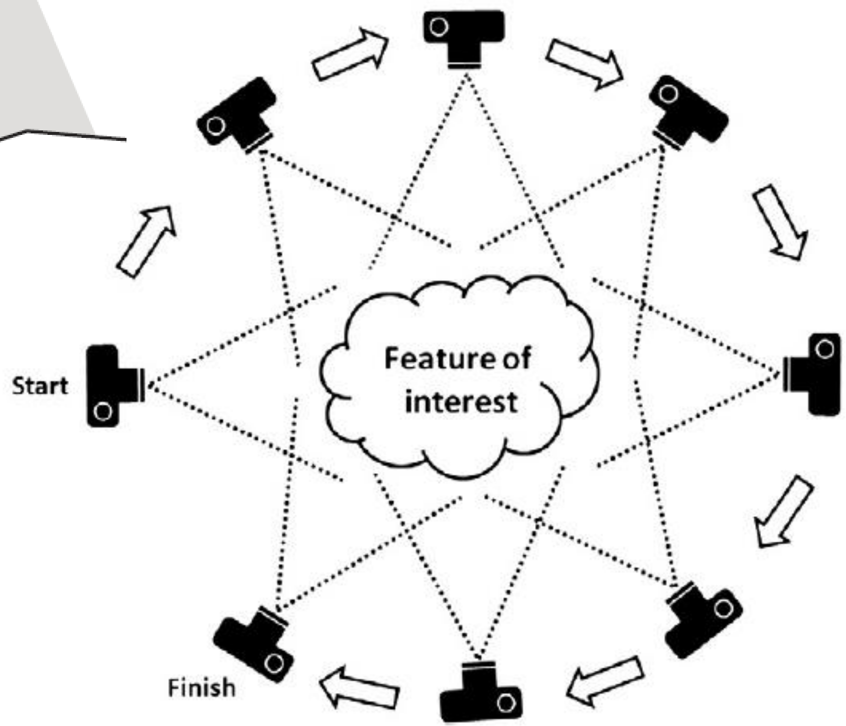
SfM lunch exercise

Build your own model using your own photographs of a target on campus.
Make sure you have a way of transferring your photos onto the computer!



Bemis *et al.* (2014).

Westoby *et al.* (2012).

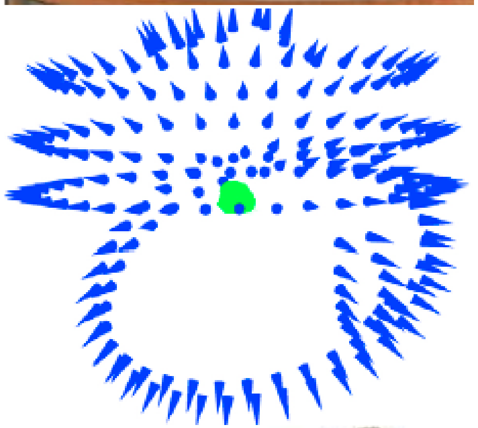


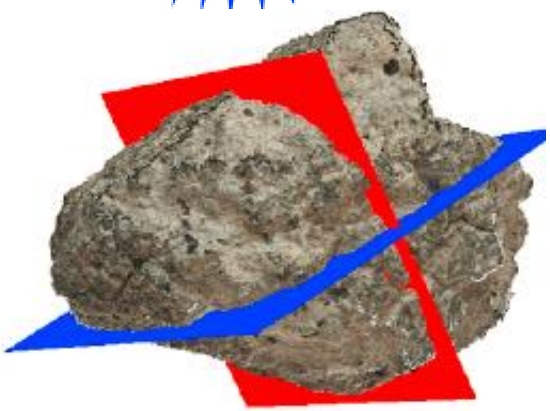
Tips

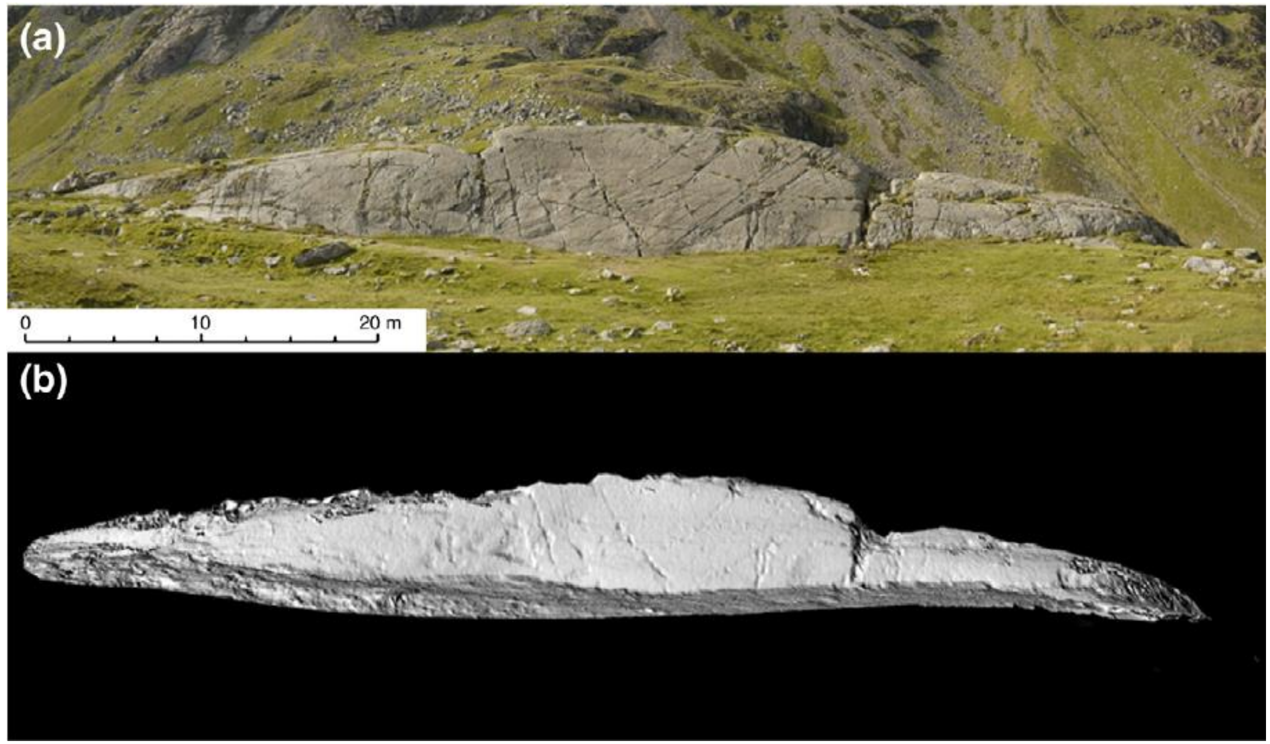
- Choose a target with some texture
- Ensure plenty of overlap between photos
- Capture the target from a variety of angles
- Try to capture the object in ~20 – 30 photos

Applications of SfM

Characterizing hand samples or outcrops



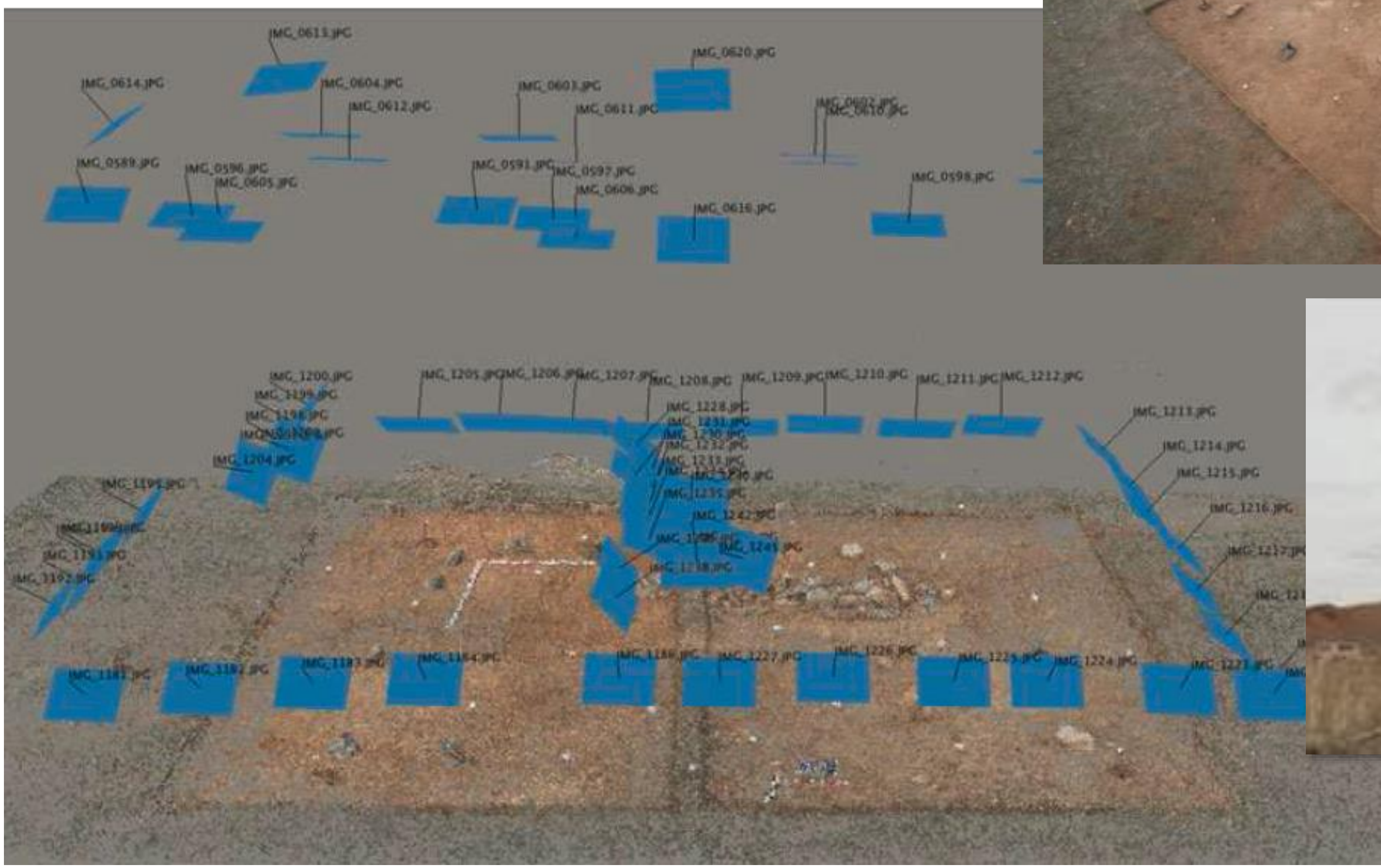




Left. James & Robson (2012). Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application. *Journal of Geophysical Research*

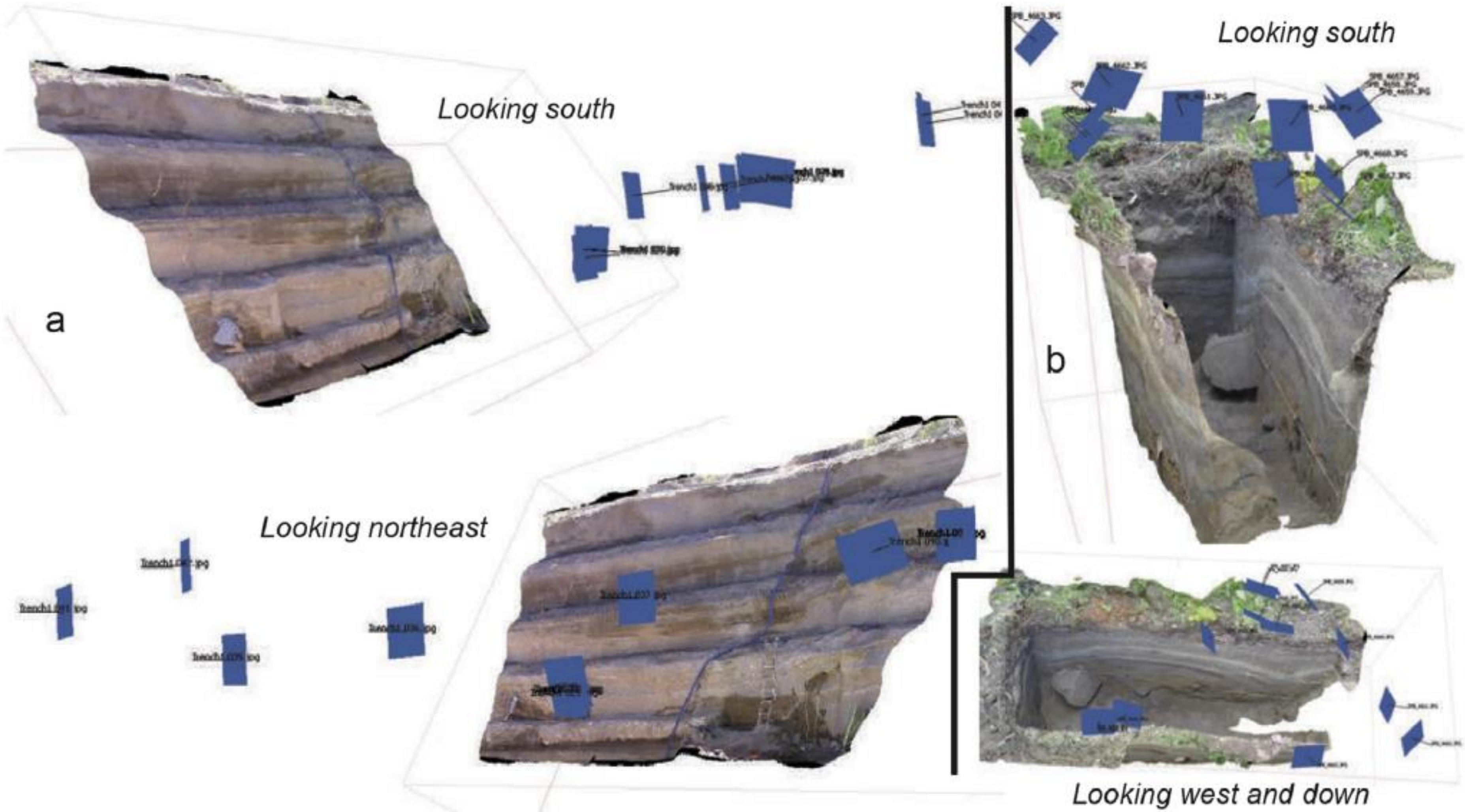
Right. Westoby *et al.* (2012). Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*

Archaeological mapping



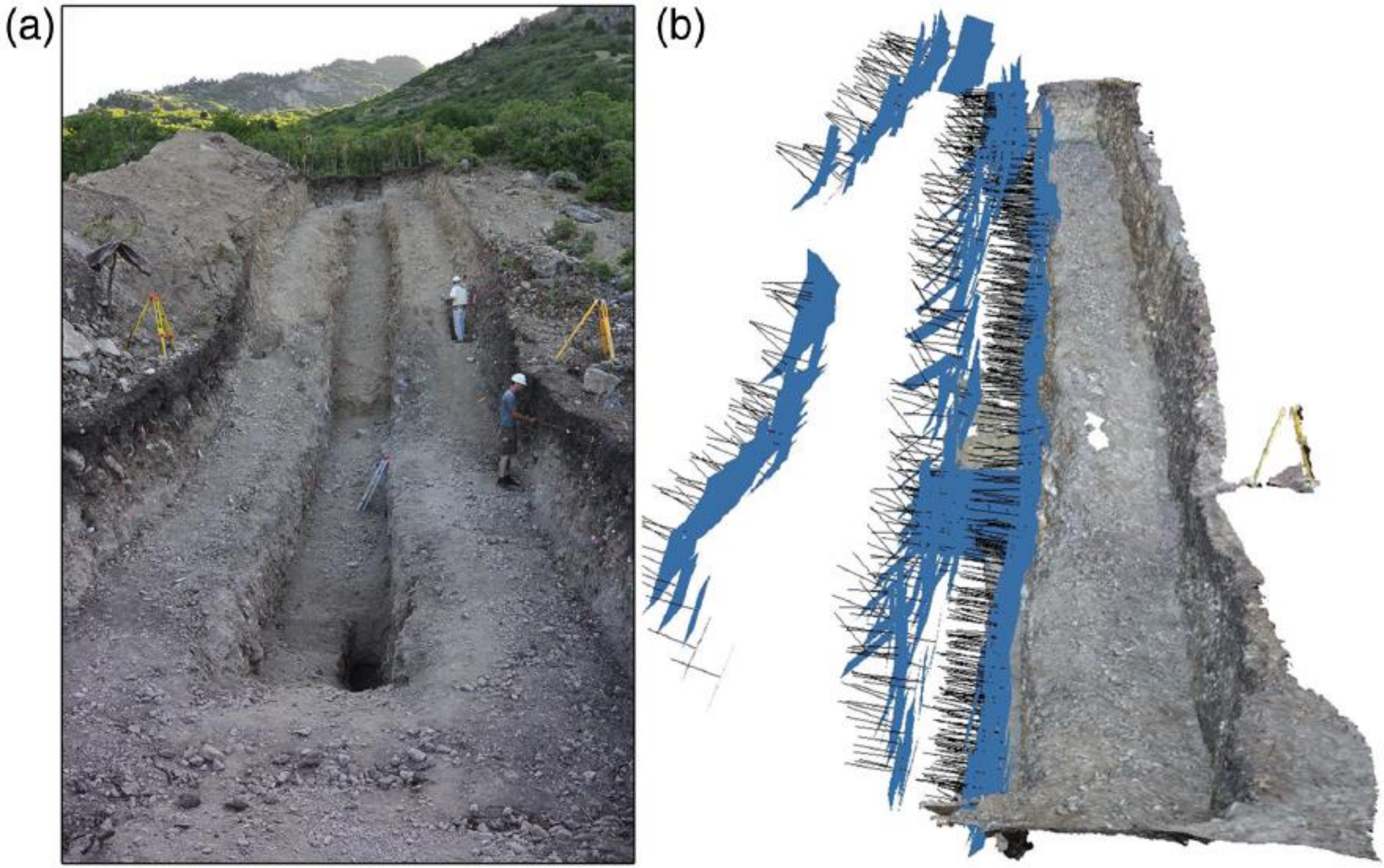
Plets *et al.* (2012). Three-dimensional recording of archaeological remains in the Altai mountains, *Cambridge Univ. Press*

Paleoseismic trenching



Bemis *et al.* (2014). Ground-based and UAV-Based photogrammetry: A multi-scale, high resolution mapping tool for structural geology and paleoseismology. *Journal of Structural Geology*

Paleoseismic trenching



Reitman *et al.* (2015), High-Resolution Trench Photomosaics from Image-Based Modeling: Workflow and Error Analysis, *Bulletin of the Seismological Society of America*

GEOSPHERE

GEOSPHERE, v. 15, no. 1

https://doi.org/10.1130/GES02002.1

9 figures

LIME: Software for 3-D visualization, interpretation, and communication of virtual geoscience models

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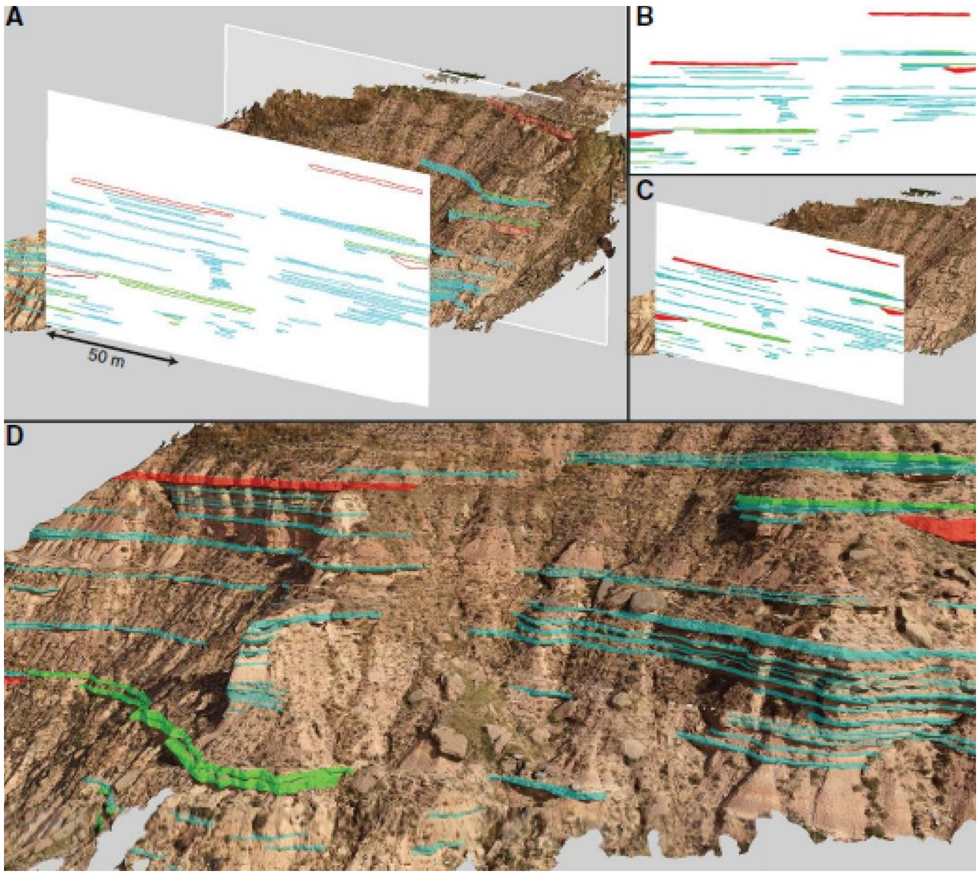
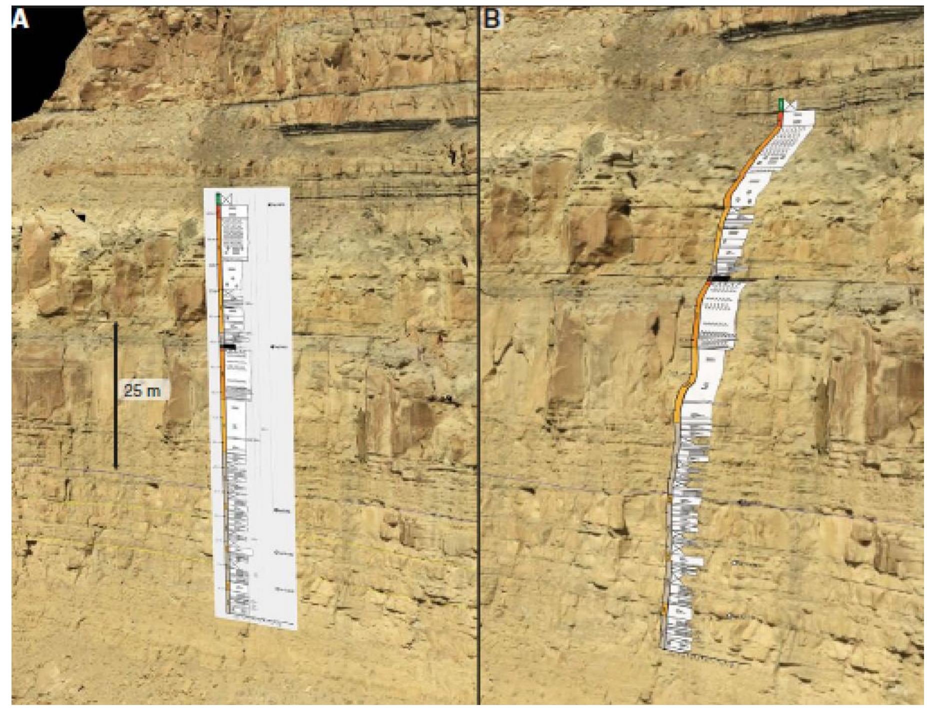
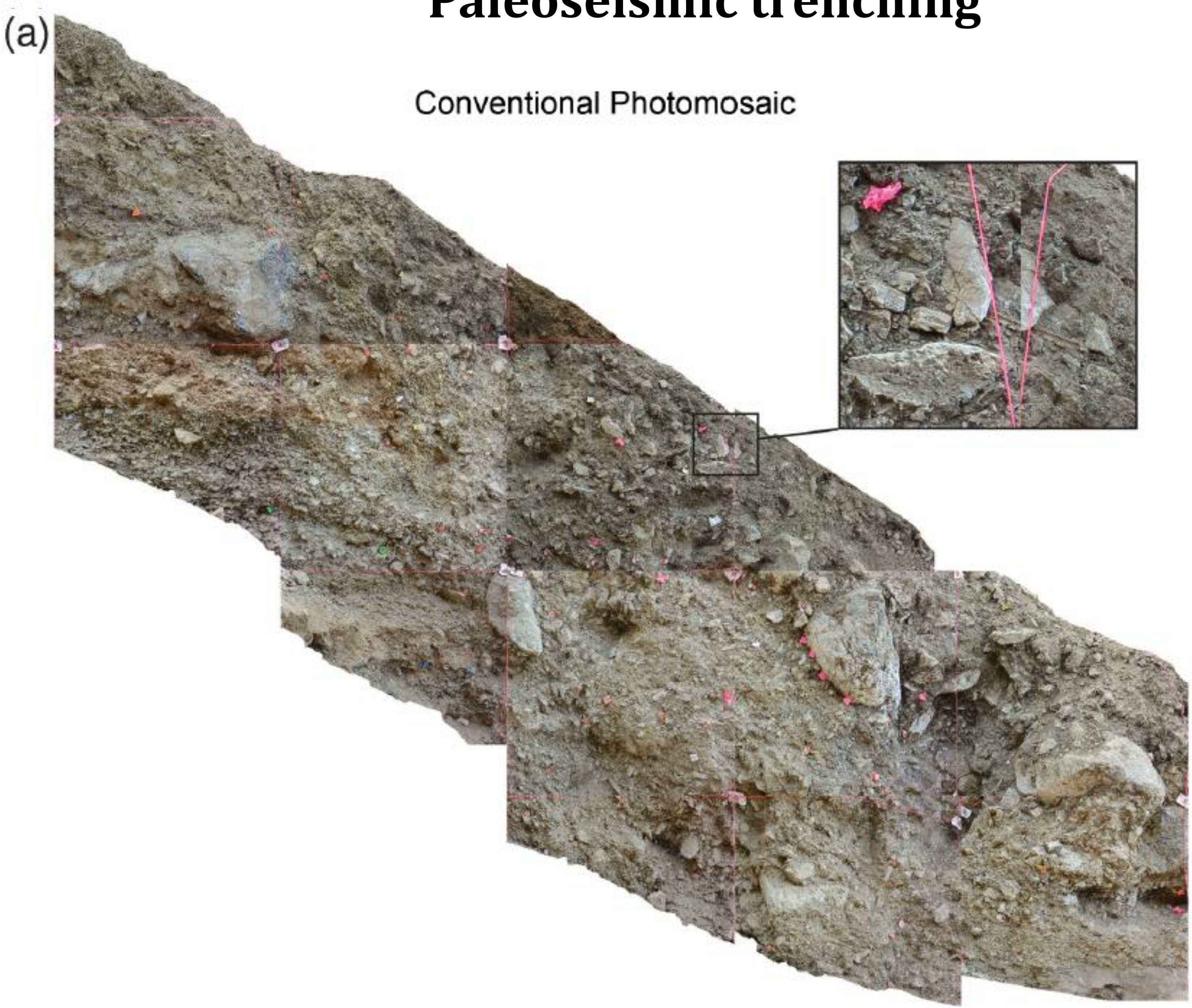


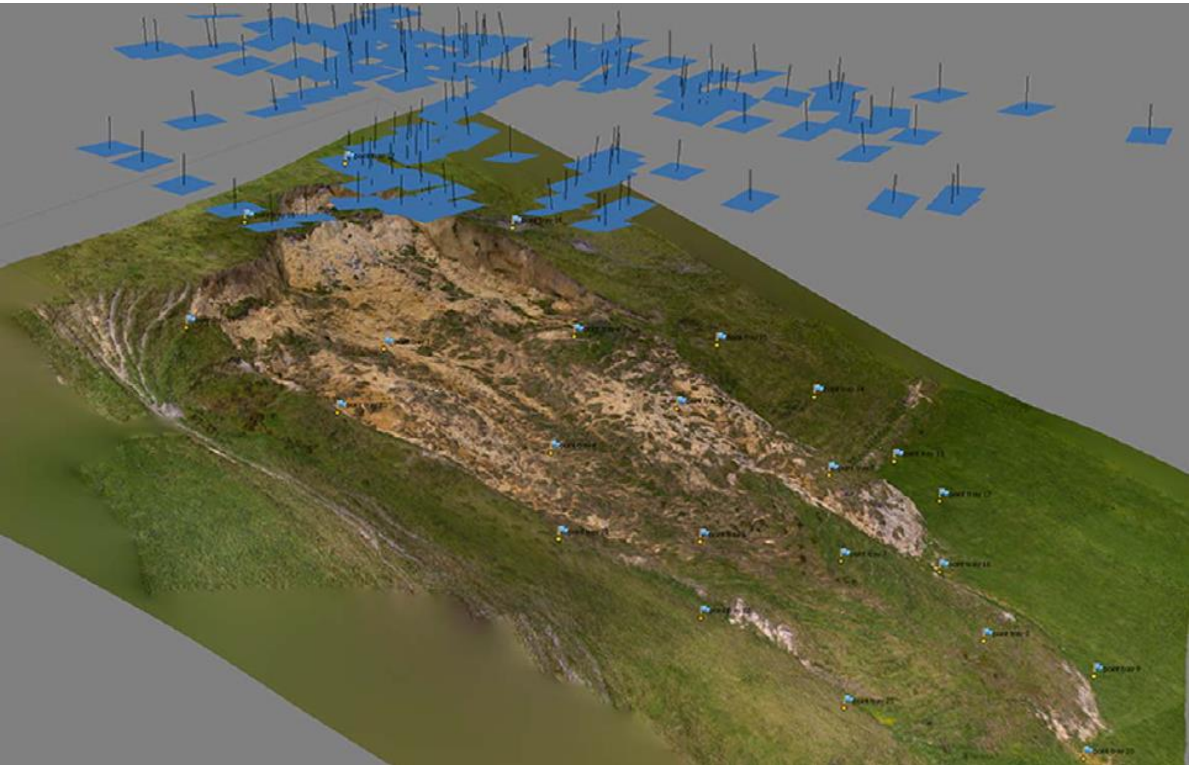


Paleoseismic trenching



Reitman *et al.* (2015), High-Resolution Trench Photomosaics from Image-Based Modeling: Workflow and Error Analysis, *Bulletin of the Seismological Society of America*

Landslide mapping



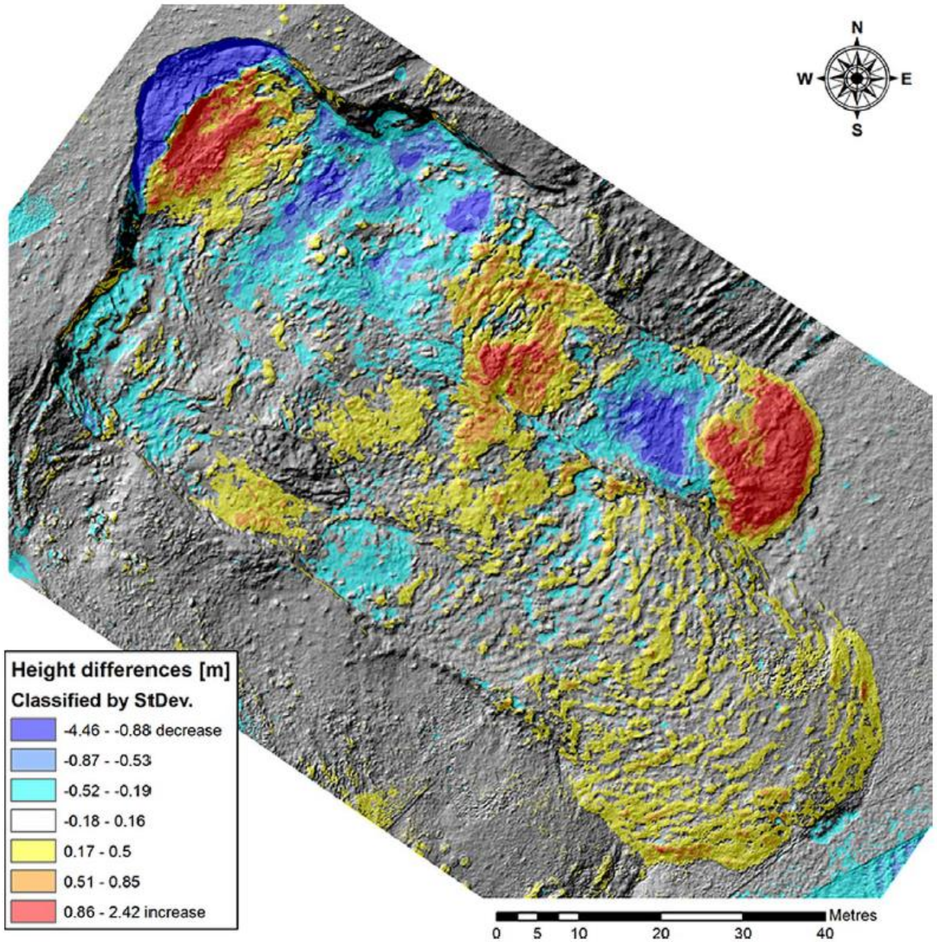
Home Hill landslide, Tasmania, surveyed with oktocopter in July and November 2011.

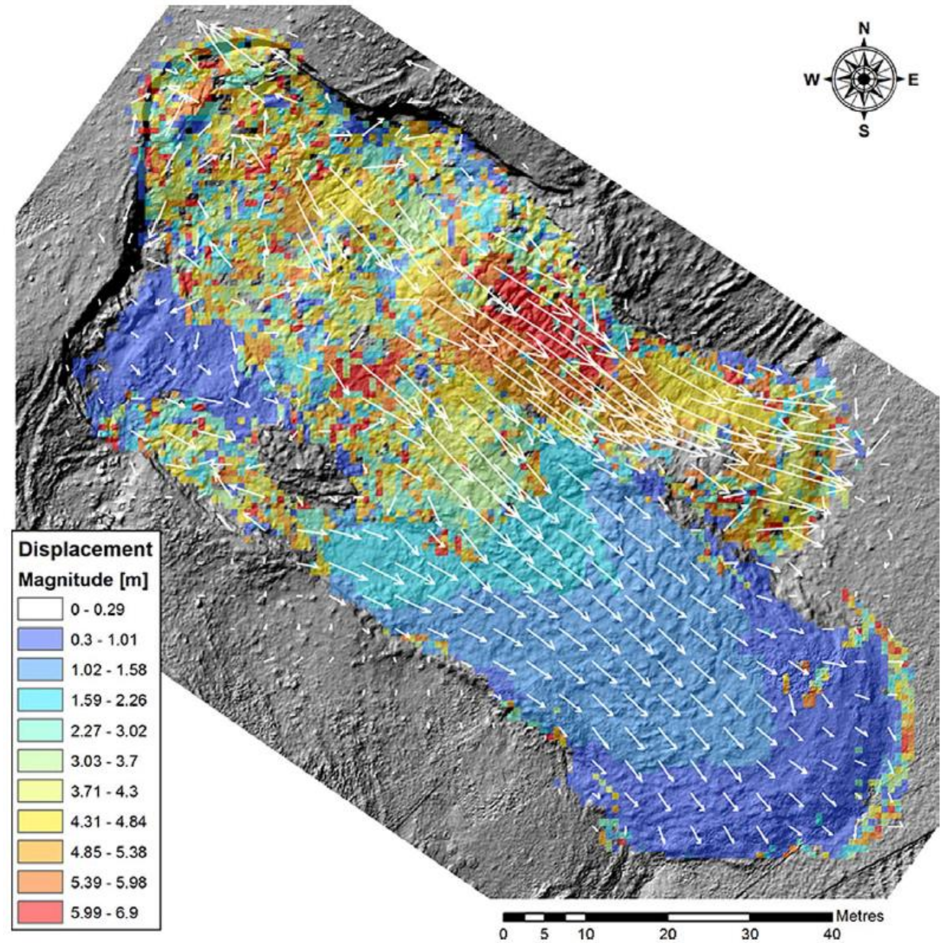
Lucieer *et al.* (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*

Landslide mapping

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

Right. Horizontal displacements from sub-pixel image correlation

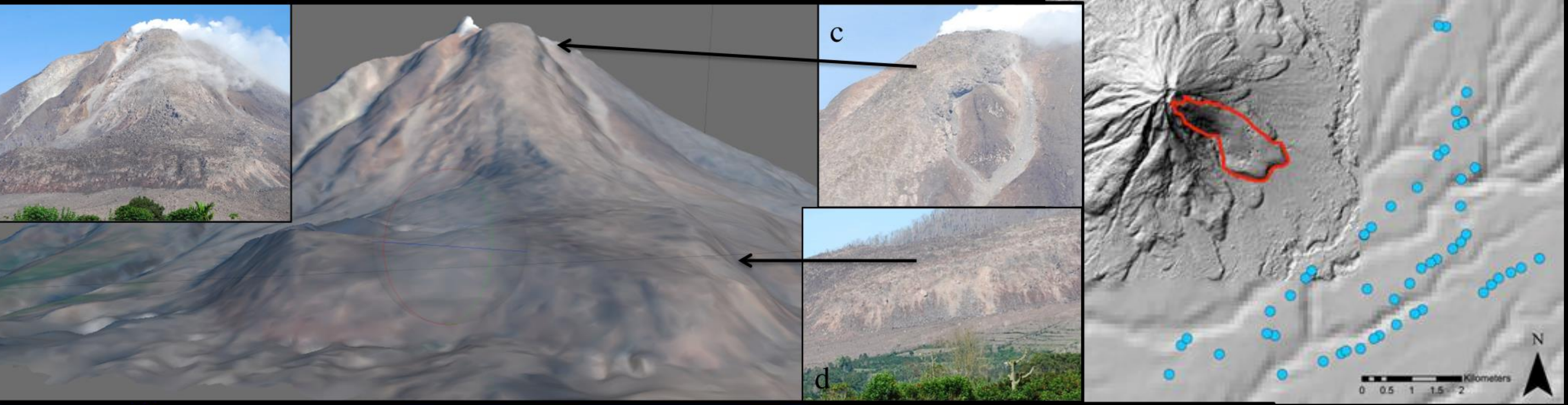


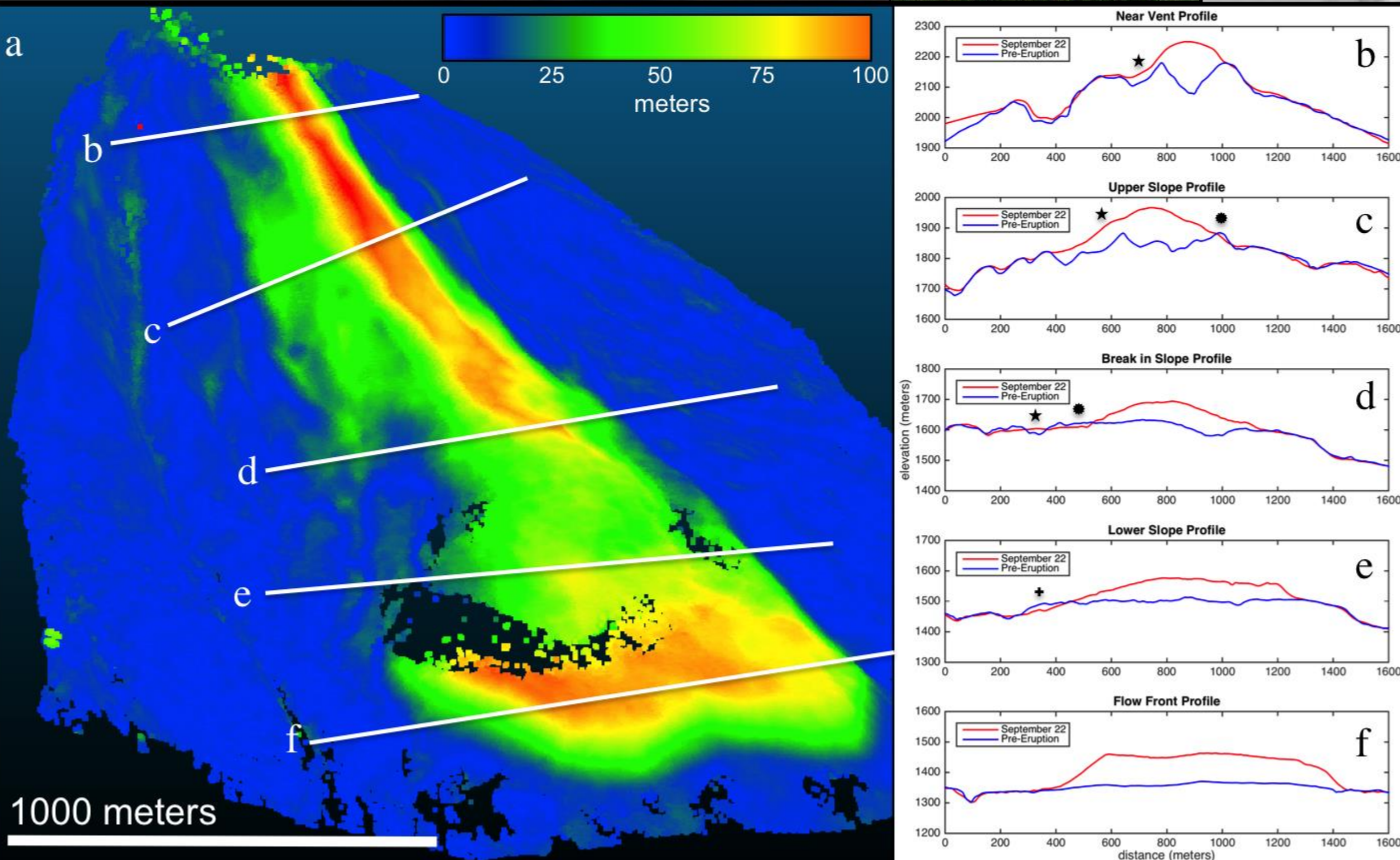


Lucieer *et al.* (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*

Sinabung Indonesia

-simple ground based sfm and differencing for volcano study





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

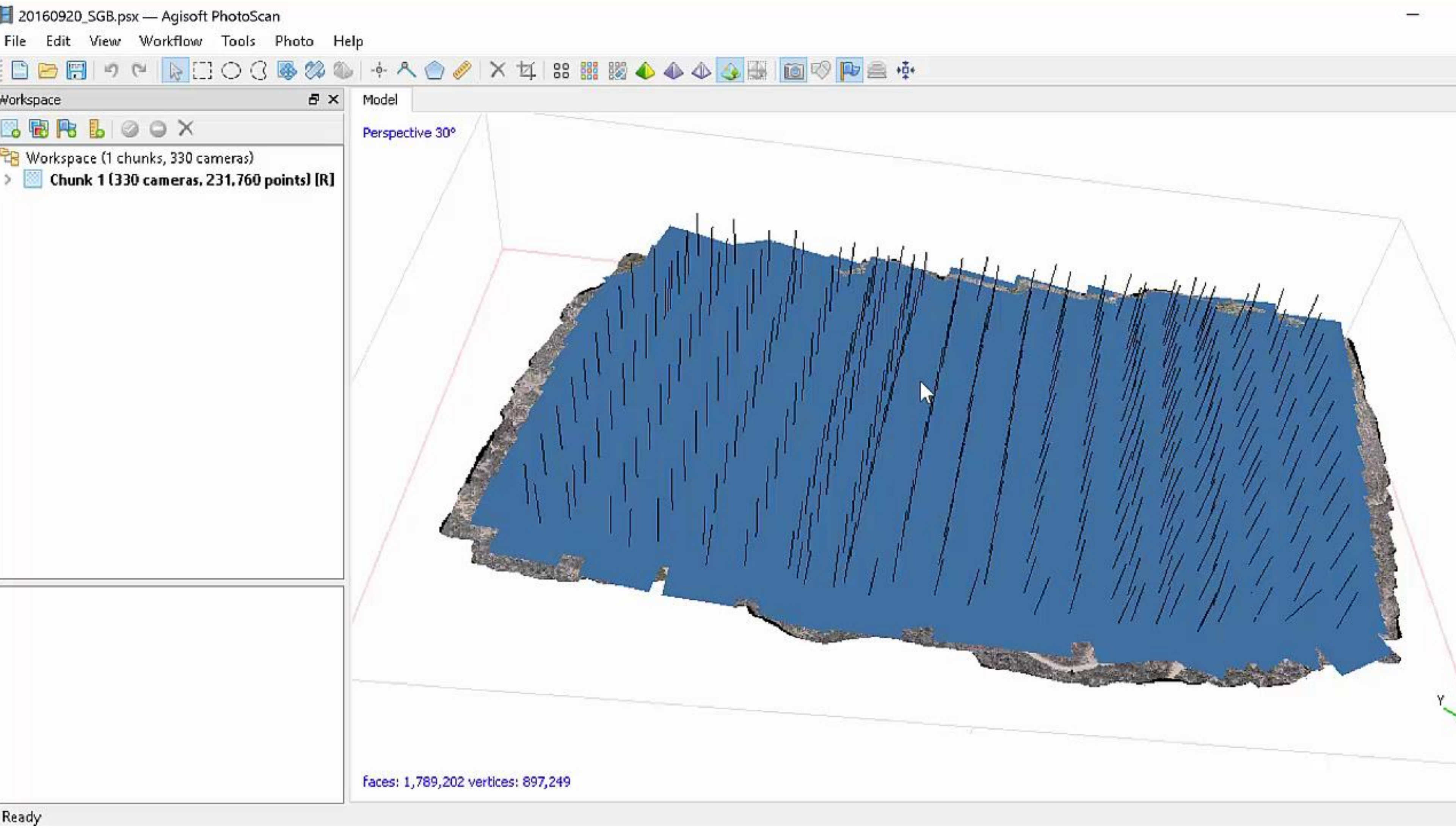
San Jacinto Fault California

-SfM application for site characterization and vegetation filtering

San Jacinto Fault zone, southern California

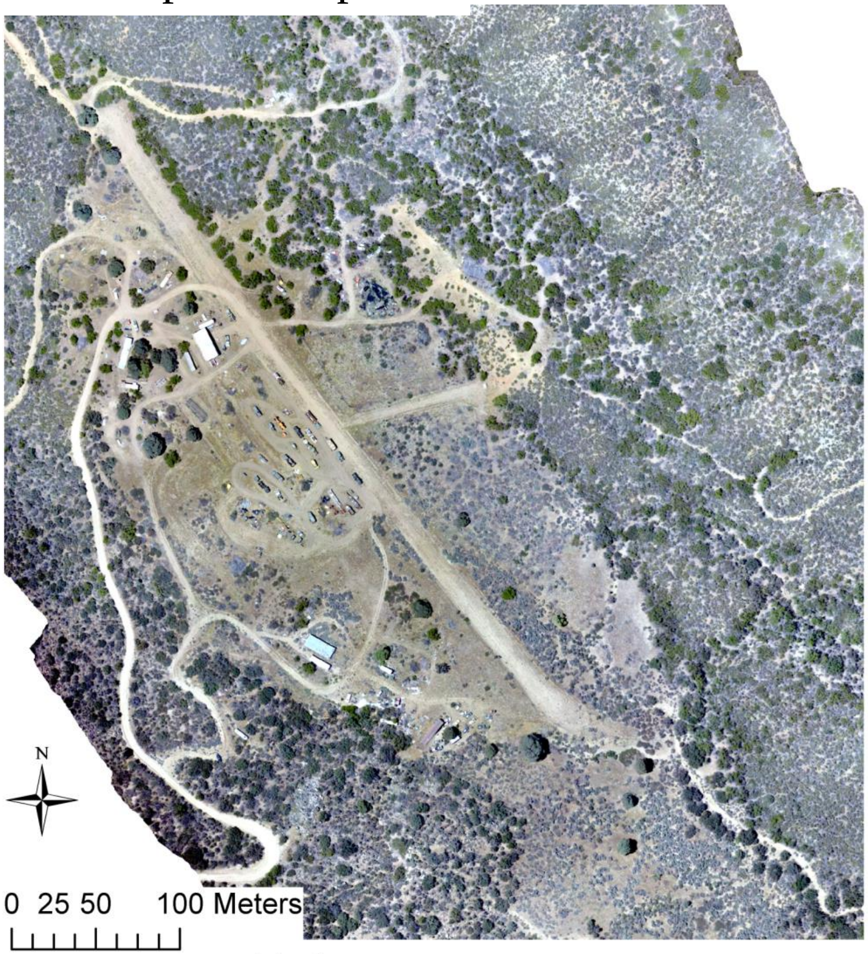
Joe Aletky octocopter (flying with gopro hero4)

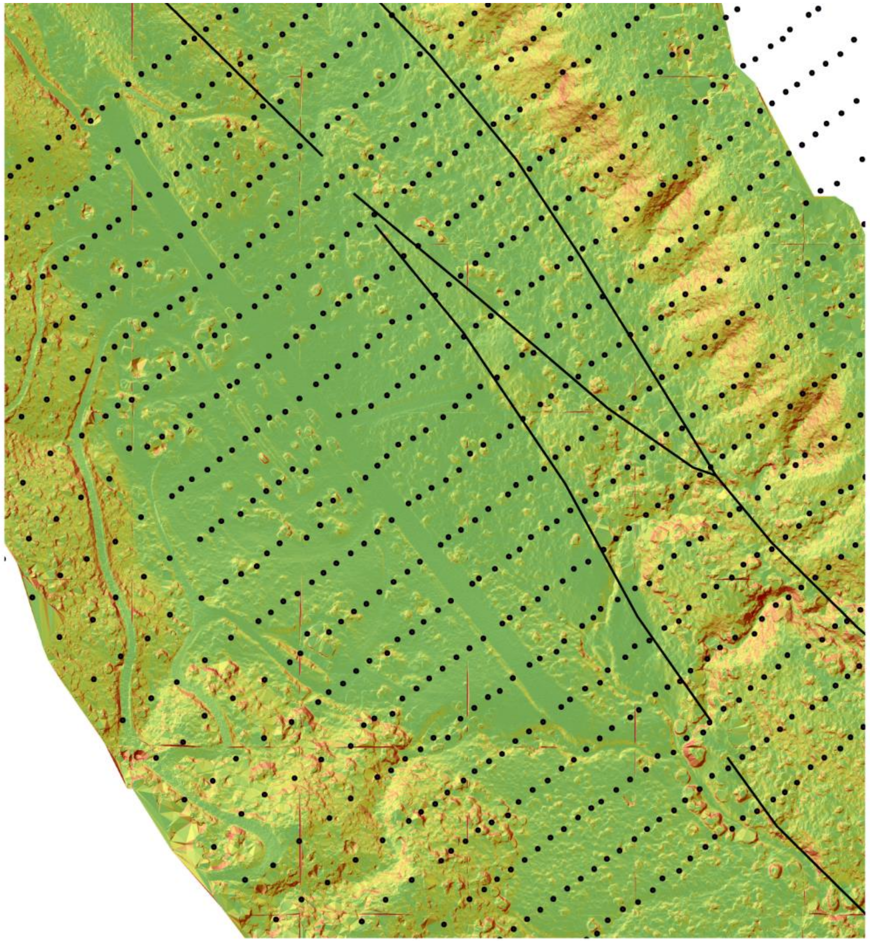
GoPro on OctoCopter

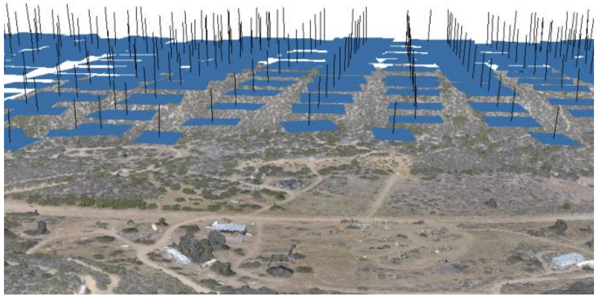


San Jacinto Fault imagery, topography, seismic stations, & faults

0.04 m/pix orthophoto

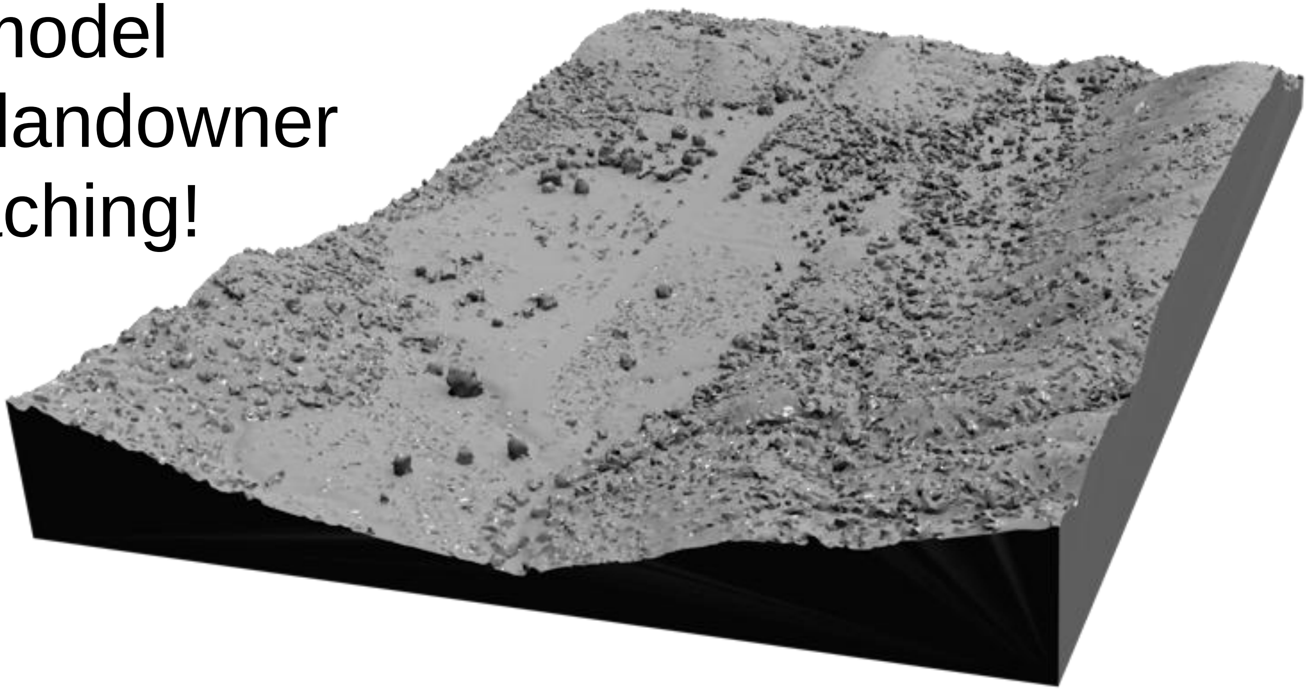


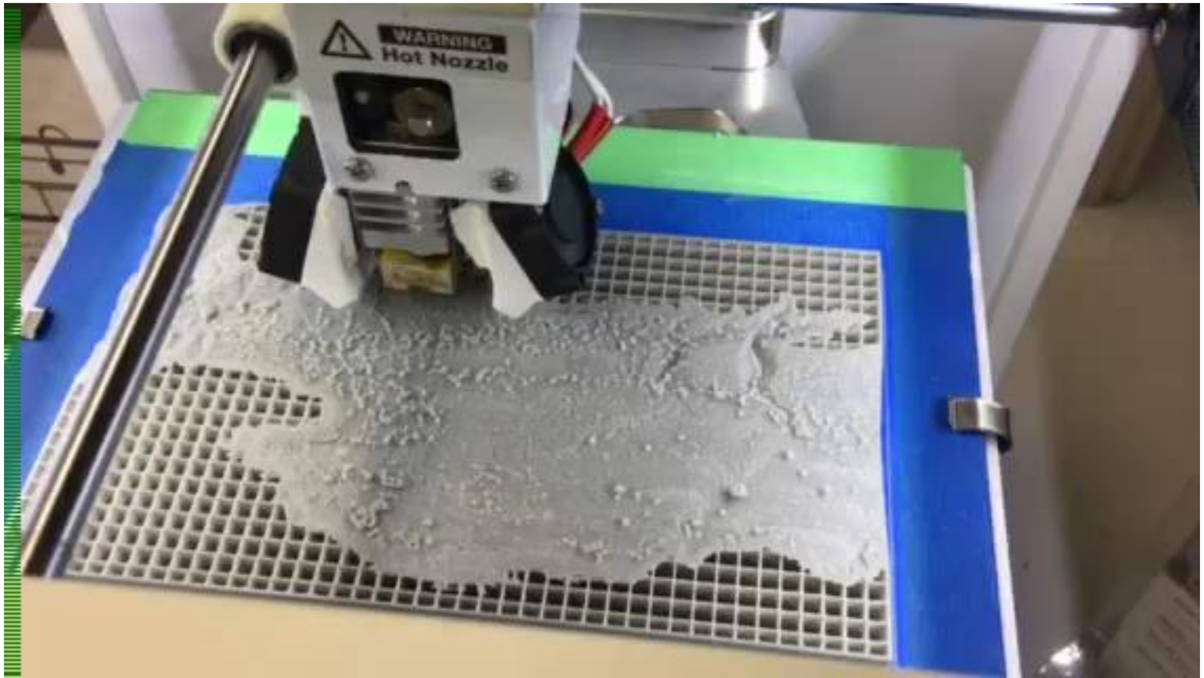




0.15 m/pix digital terrain model (ground classified using lastools; colored by slope over hillshade)

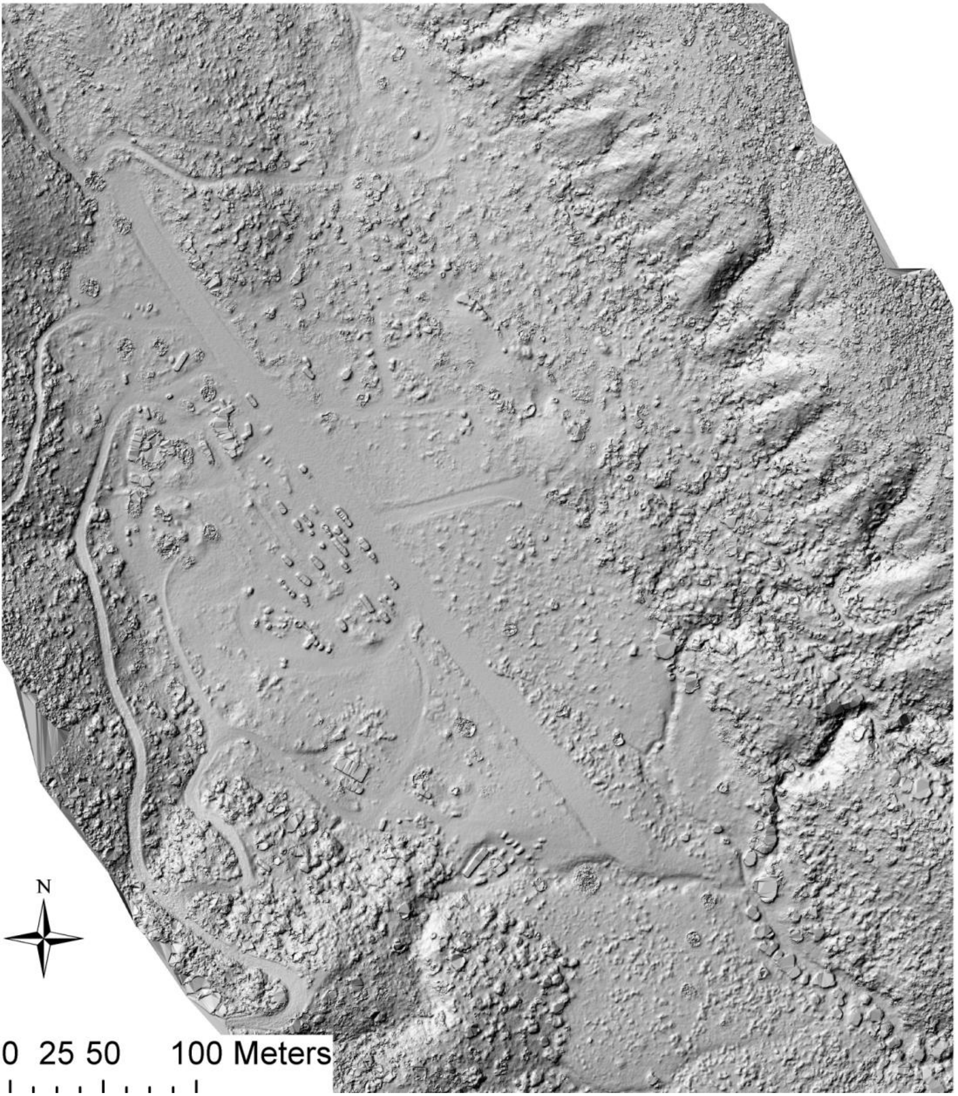
3D printing the model
-nice gift for the landowner
and good for teaching!



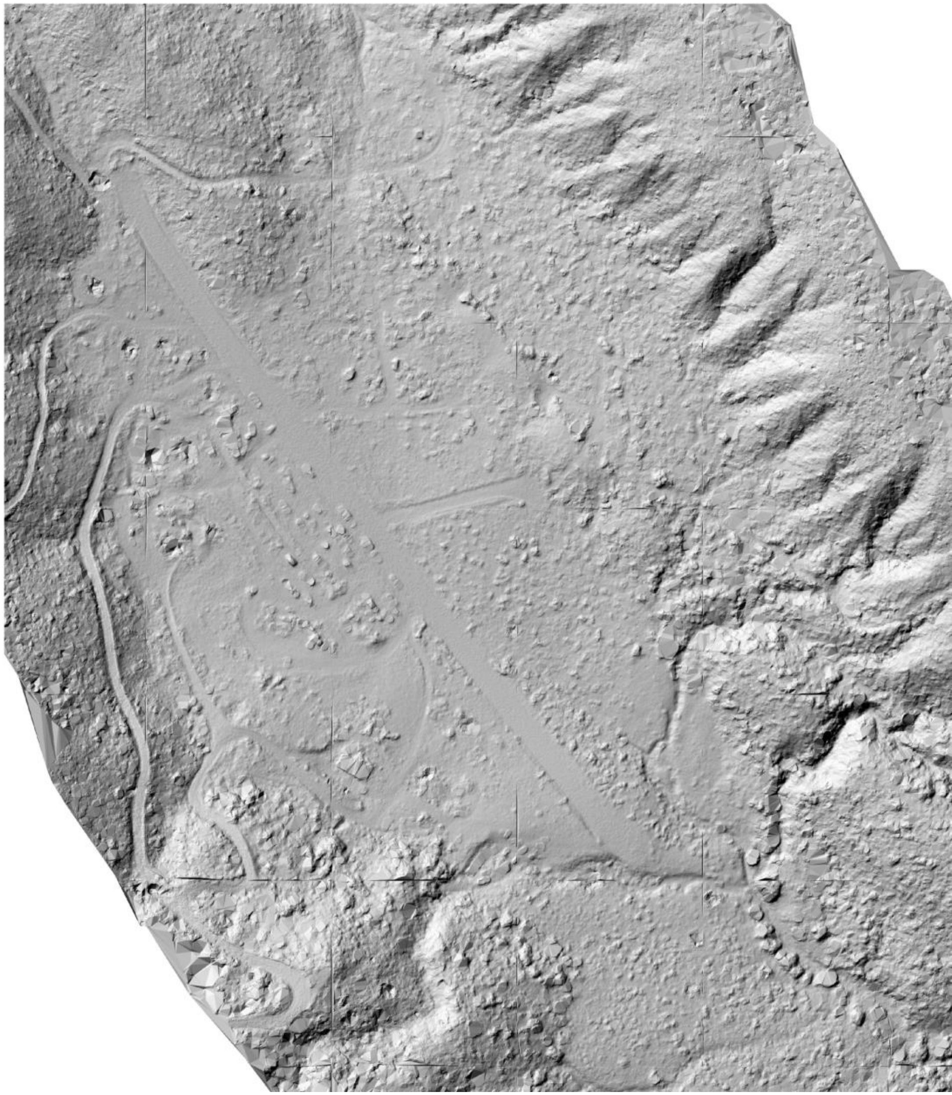


-Andrea
Donnellan
(JPL)

SfM Digital Terrain Models



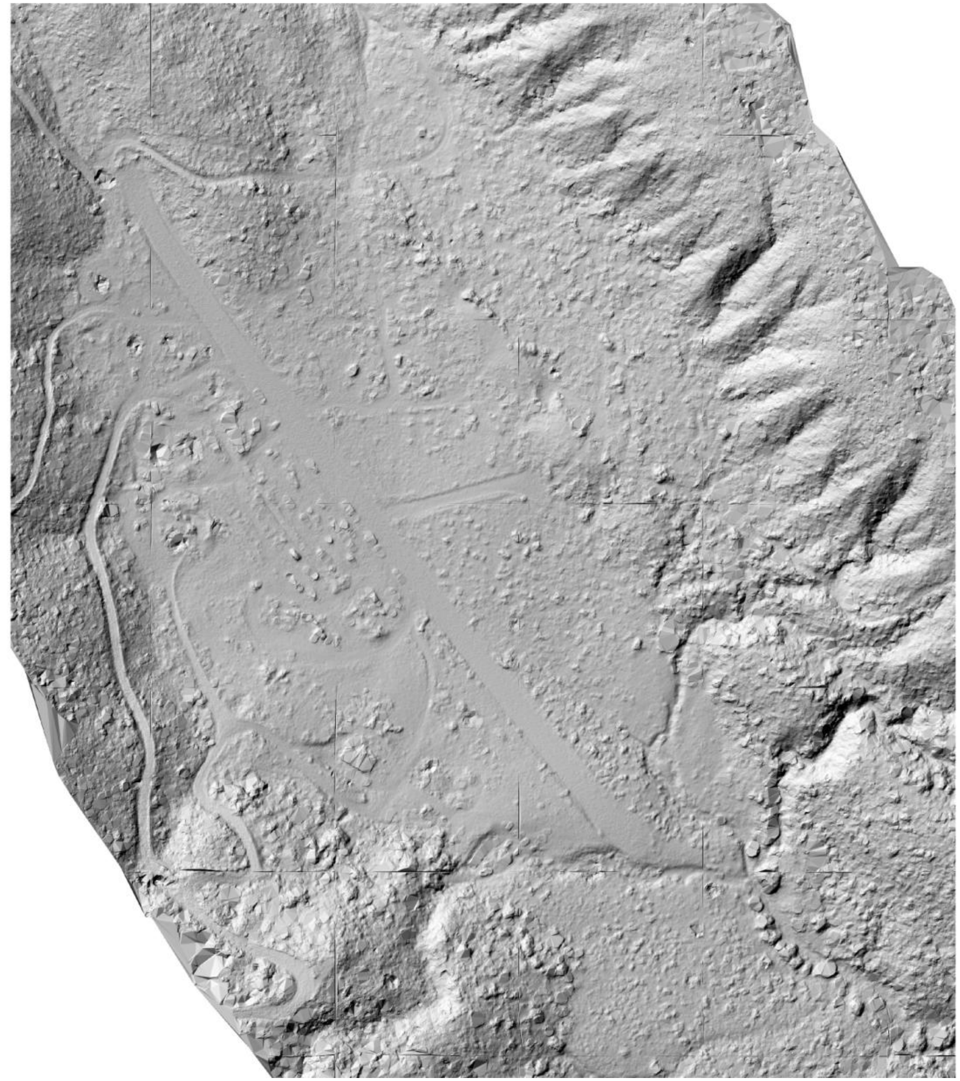
Photoscan “Classify Ground Points”



Lastools lasground_new “town” “fine”

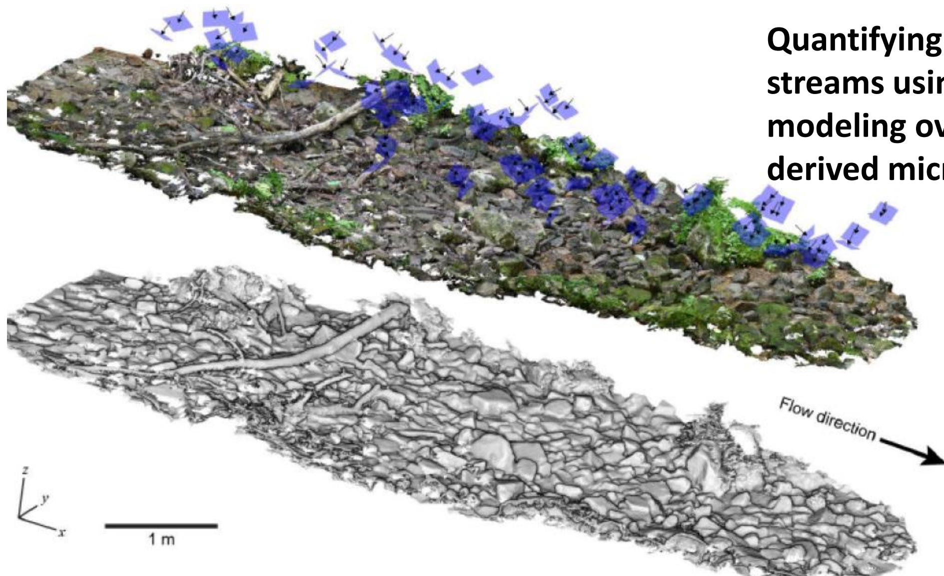
Digital Terrain Models produced from ground classified using lasground_new

B4 B4 airborne lidar 0.5 m/pix



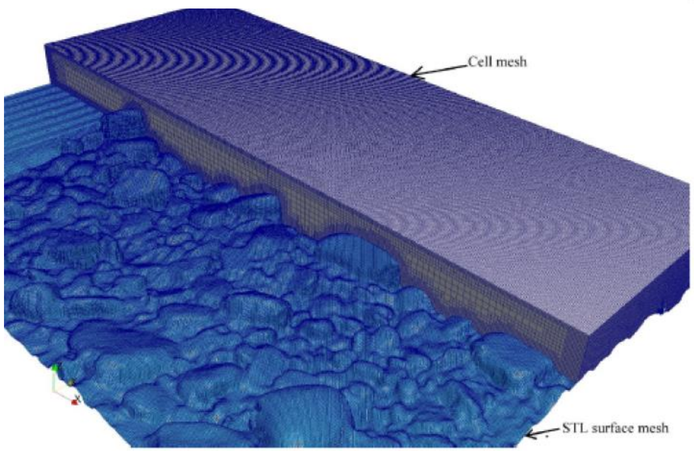
SfM 0.15 m/pix

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

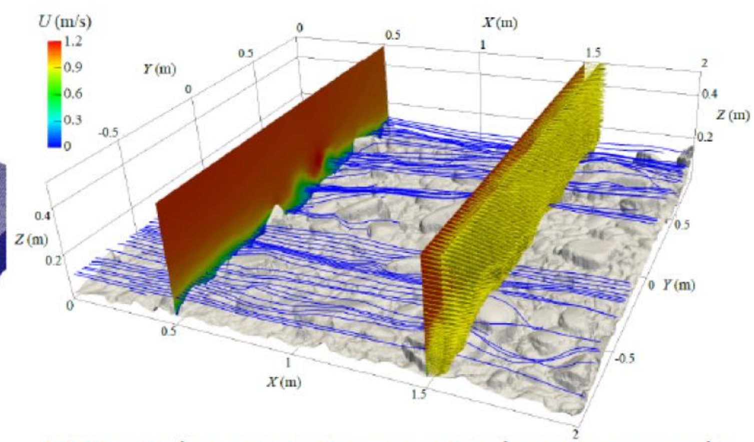


Connect scales of flow resistance with surface roughness and water depth

Chen, DiBiase, McCarroll, Liu, EPSL, 2019



SfM model input to OpenFoam



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