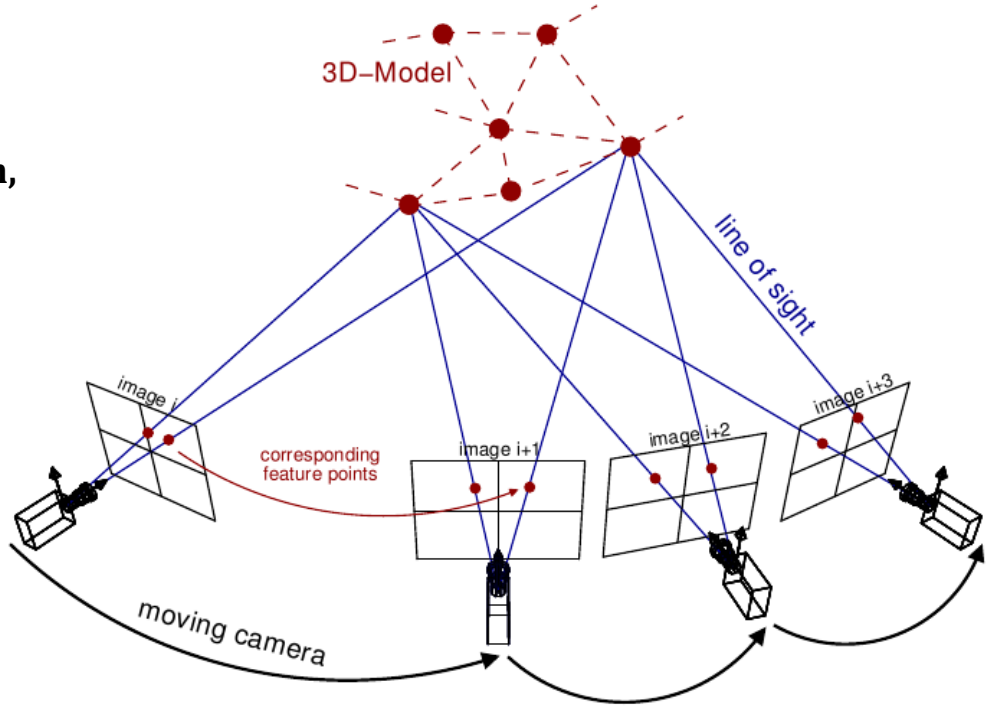
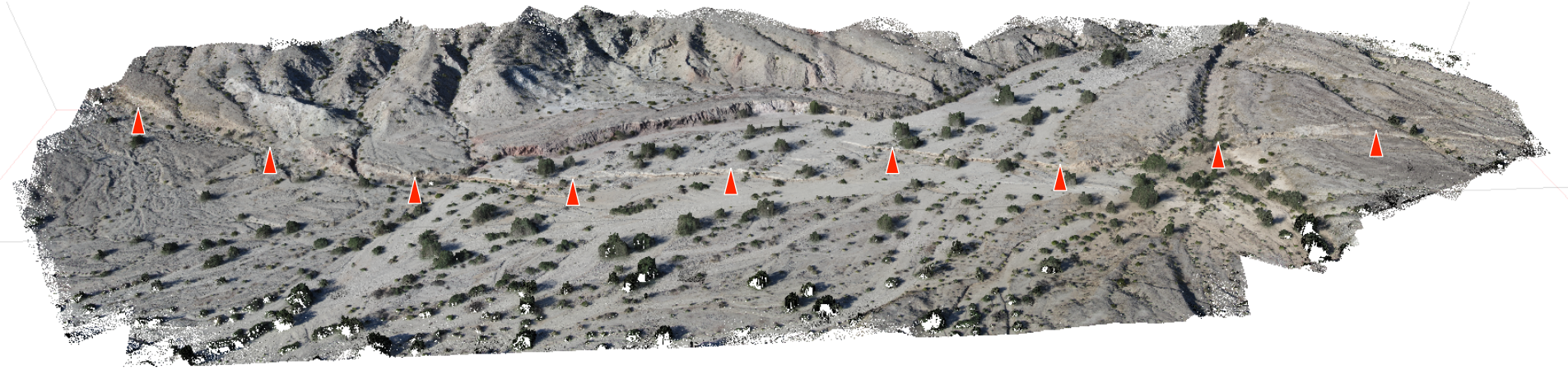
Structure-from-Motion

Chris Crosby (UNAVCO)

with content from Ed Nissen, Ramon Arrowsmith, Kate Shervais, Chelsea Scott



- **Choice of survey platform**
- **Acquisition concepts**
- **Exercise**



~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

PARAMETERS

Photo characteristics

- Camera focal length
- Camera sensor size
- Aspect ratio of photograph
- Effective megapixels of camera
- Distance between camera and feature
- Scale of feature

Survey considerations

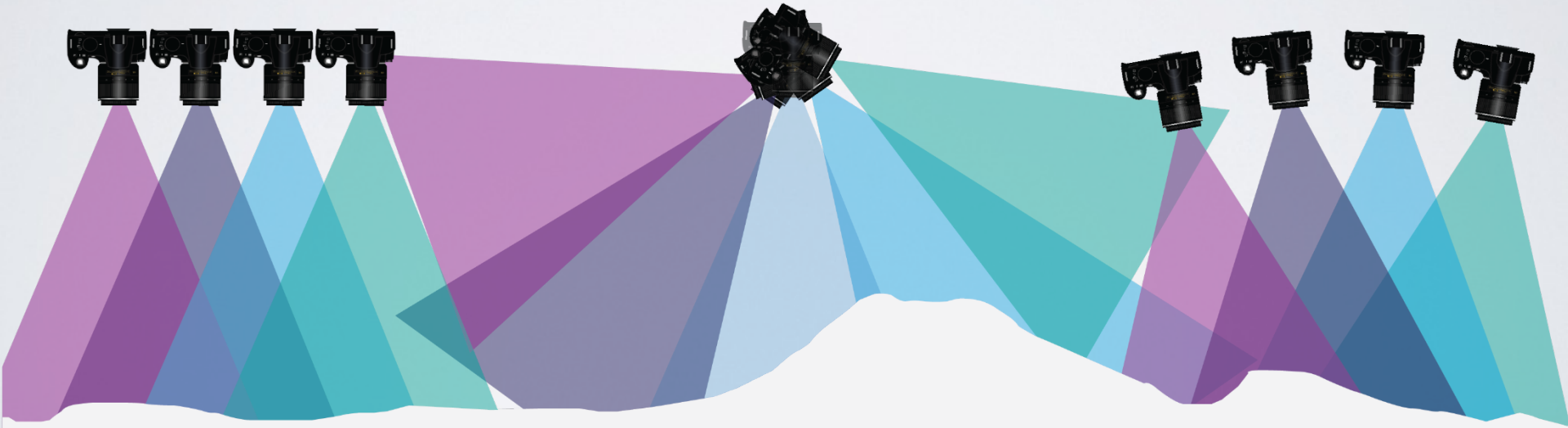
- Angle of photographs
- Overlap between photographs
- Platform
- Targets/GPS
- Surface texture
- Lighting

ANGLE OF PHOTOGRAPHS

Nadir

Divergent

Convergent



X

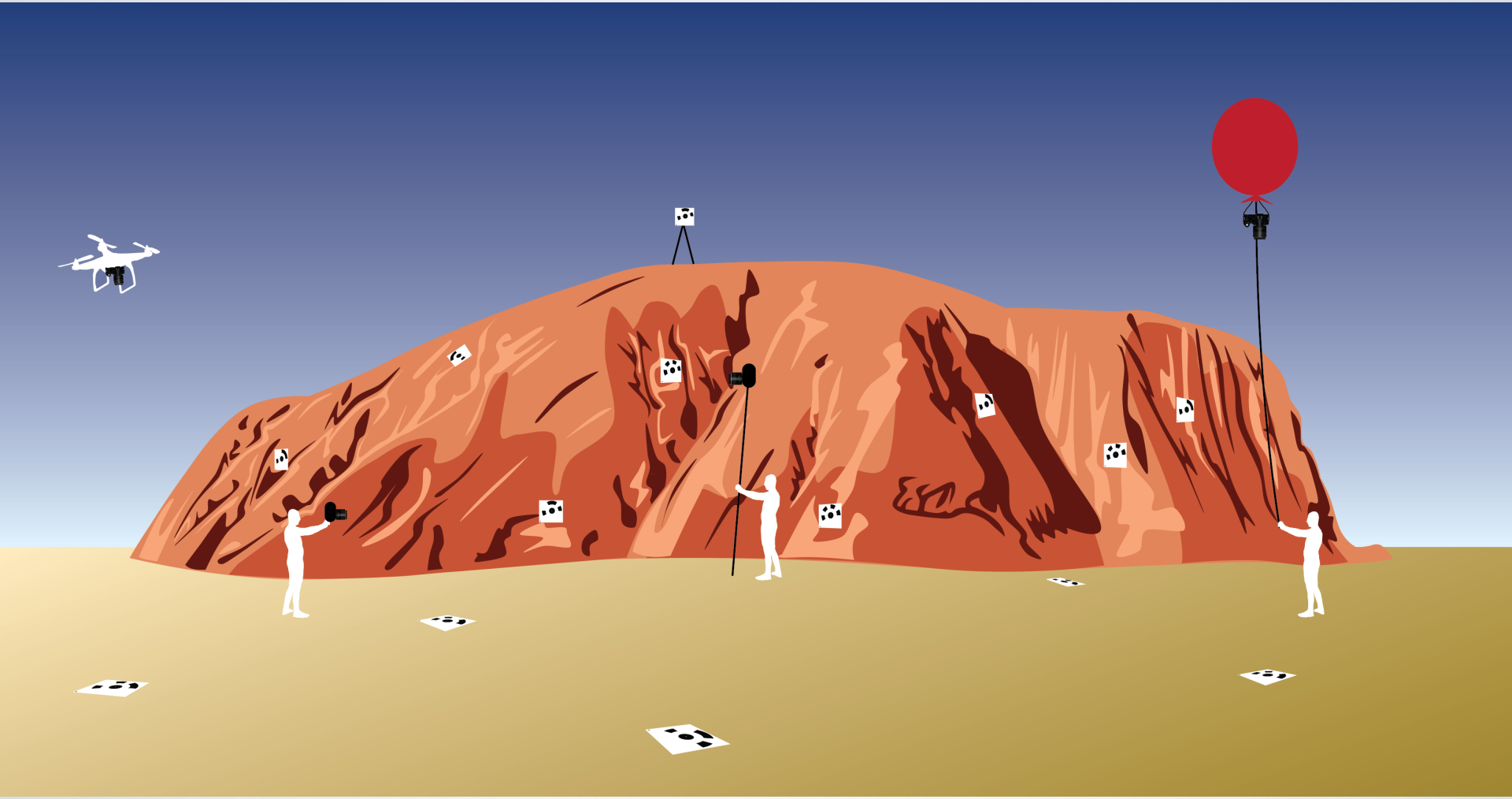
X

UNAVCO

OVERLAP, DISTANCE FROM FEATURE

UNAVCO

PLATFORMS



TARGETS

SfM from Unmanned Aerial Vehicles (UAV)

DJI Phantom 4 Pro quadcopter (~$1500)

Pulse Aerospace Vapor (>$50k)

DJI Mavic Pro (~$1k)

senseFly eBee (~$10k)

SfM from Unmanned Aerial Systems (UAS)

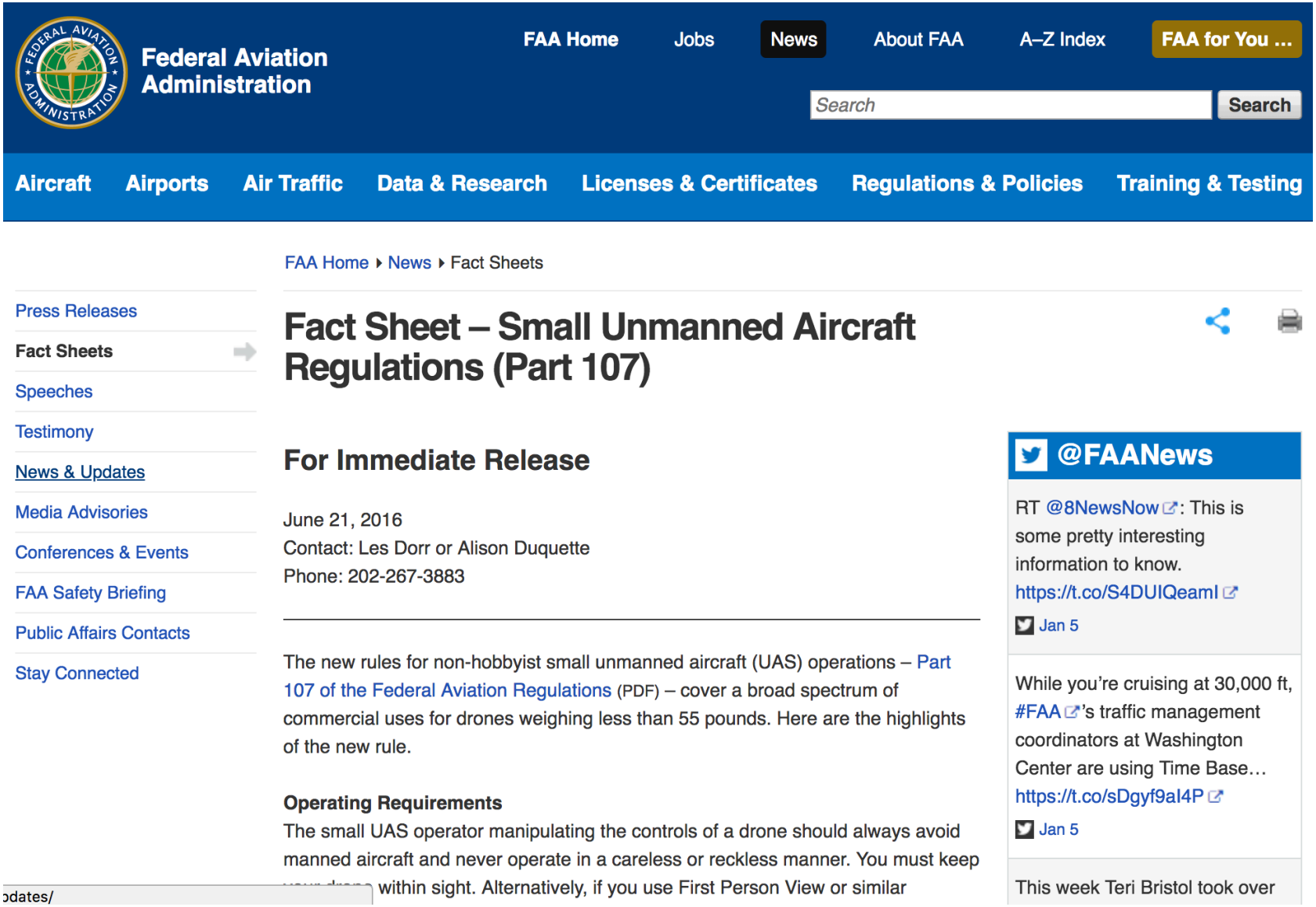
Pros

- App-based survey design effectively automates data collection.
- Reasonably affordable, easy to fly.
- Camera quality ok.

Cons

- Subject to FAA regulations (Part 107) + state and local constraints.
- Short flight durations.
- Crashes are not uncommon.
- Limited payload capacity. Larger cameras require a larger, more expensive UAS.

FAA sUAS Regulations



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Fact Sheet – Small Unmanned Aircraft Regulations (Part 107)

For Immediate Release

June 21, 2016
Contact: Les Dorr or Alison Duquette
Phone: 202-267-3883

The new rules for non-hobbyist small unmanned aircraft (UAS) operations – Part 107 of the Federal Aviation Regulations (PDF) – cover a broad spectrum of commercial uses for drones weighing less than 55 pounds. Here are the highlights of the new rule.

Operating Requirements
The small UAS operator manipulating the controls of a drone should always avoid manned aircraft and never operate in a careless or reckless manner. You must keep your drone within sight. Alternatively, if you use First Person View or similar

odates/

@FAANews

RT @8NewsNow: This is some pretty interesting information to know. https://t.co/S4DUIQeamI

Jan 5

While you're cruising at 30,000 ft, #FAA's traffic management coordinators at Washington Center are using Time Base… https://t.co/sDgyf9aI4P

Jan 5

This week Teri Bristol took over

SfM from tethered balloons

SfM from tethered balloons

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)

The camera should have one essential feature and one preferable one:

Essential Time lapse setting – remotely takes photo every *x* seconds

Preferable Internal or external GPS tagging

Cheap, lightweight cameras can be used but lower-quality lenses can lead to large radial distortions in the photographs.

These can lead to warping of the topography unless they are dealt with.

Camera lens distortions

f = focal length

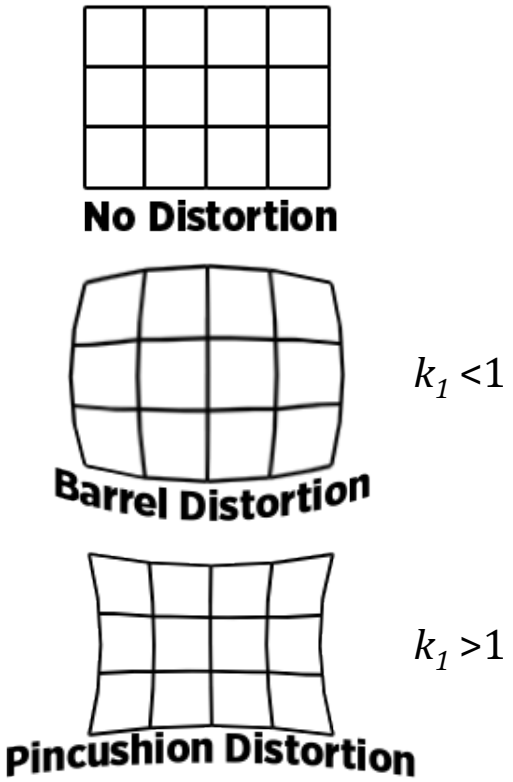
c_x = principal point x coordinate

c_y = principal point y coordinate

k_n = n^{th} radial distortion coefficient

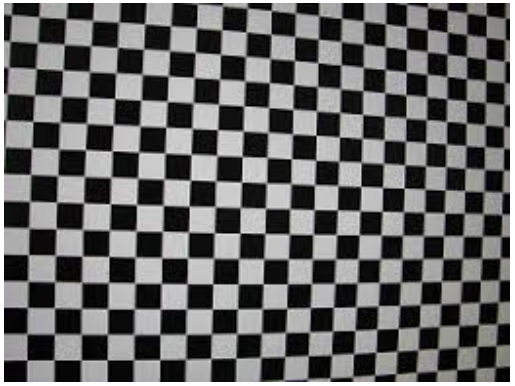
p_n = n^{th} tangential distortion coefficient

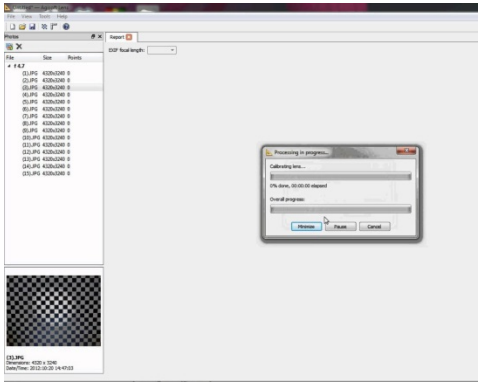
skew coefficient between the x and the y axis.



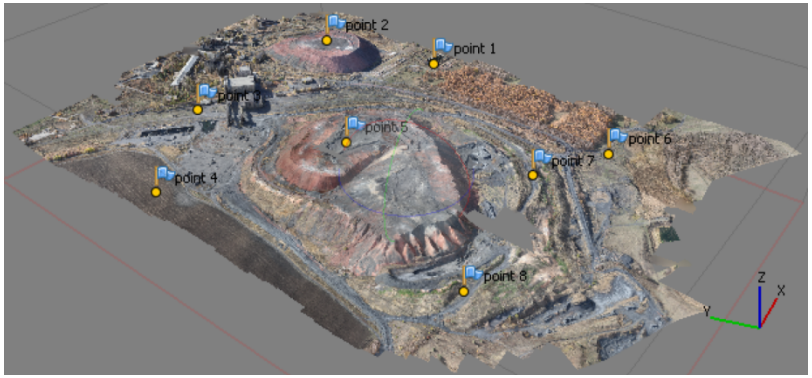
Camera lens distortions

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

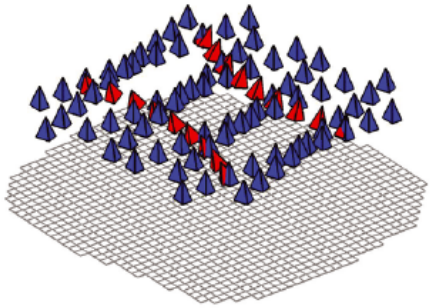


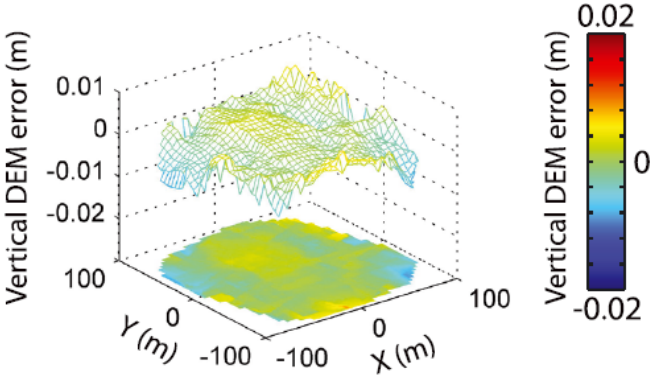


- Doming can be mitigated by georeferencing using ground control points



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





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

SfM & MVS software

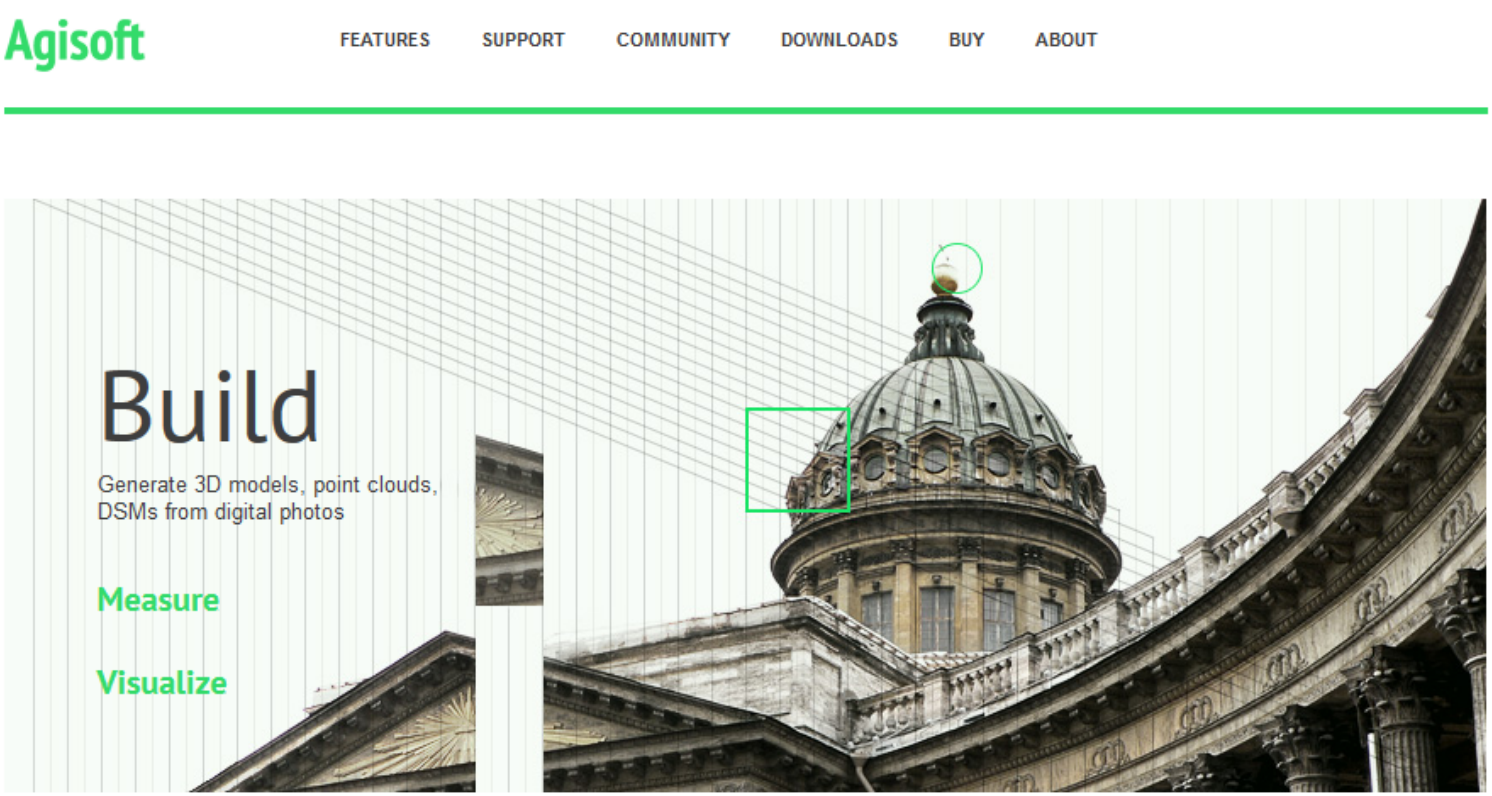
Table 1
Examples of open source and commercial software for photo-based 3d reconstruction.

Software	Url (valid on 17 May, 2014)	Notes
Freely available		
Bundler Photogrammetry Package[a,b]	http://blog.neonascent.net/archives/bundler-photogrammetry-package/	Used in James and Robson (2012). Script-based, no graphical user interface (GUI). Windows OS only.
SFMToolkit[a,b]	http://www.visual-experiments.com/demos/sfmtoolkit/	Similar software to above.
Python Photogrammetry Toolbox (PPT)[a,b]	http://code.google.com/p/osm-bundler/	Formerly OSM-bundler. Python-driven GUI and scripts, with a Linux distribution.
VisualSFM[b]	http://www.cs.washington.edu/homes/ccwu/vsfm/	Advanced GUI with Windows, Linux and Mac. OSX versions. Georeferencing options, but camera model is more restricted than that used in Bundler.
3DF Samantha	http://www.3dflow.net/technology/samantha-structure-from-motion/	SfM only, but with more advanced camera models than all above (Farenzena et al., 2009). Provides output compatible with several dense matching algorithms.
Web sites and services		
Photosynth	http://photosynth.net/	Evolved from Bundler. SfM only, no dense reconstruction. Can incorporate a very wide variety of images, but does so at the cost of reconstruction accuracy.
Arc3D	http://www.arc3d.be/	Vergauwen and Van Gool [2006]
CMP SfM Web service[a]	http://ptak.felk.cvut.cz/sfmservice/	
Autodesk 123D Catch	http://www.123dapp.com/catch/	
Pix4D	http://pix4d.com/	Also available as standalone software.
My3DScanner	http://www.my3dscanner.com/	
Commercial		
PhotoScan	http://www.agisoft.ru/products/photoscan/	Full SfM-MVS-based commercial package.
Acute3D	http://www.acute3d.com/	
PhotoModeler	http://www.photomodeler.com/	Software, originally based on close-range photogrammetry, now also implements SfM.
3DF Zephyr Pro	http://www.3dflow.net/	Underlying SfM engine is 3DF Samantha

Note: Table modified from http://www.lancaster.ac.uk/staff/jamesm/research/sfm.htm.
SfM = Structure from Motion; MVS = Multi-View Stereo.
[a] Uses Bundler (http://phototour.cs.washington.edu/bundler/) to compute structure from motion.
[b] Uses PMVS2 (http://grail.cs.washington.edu/software/pmvs/) as a dense multi-view matcher.

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*

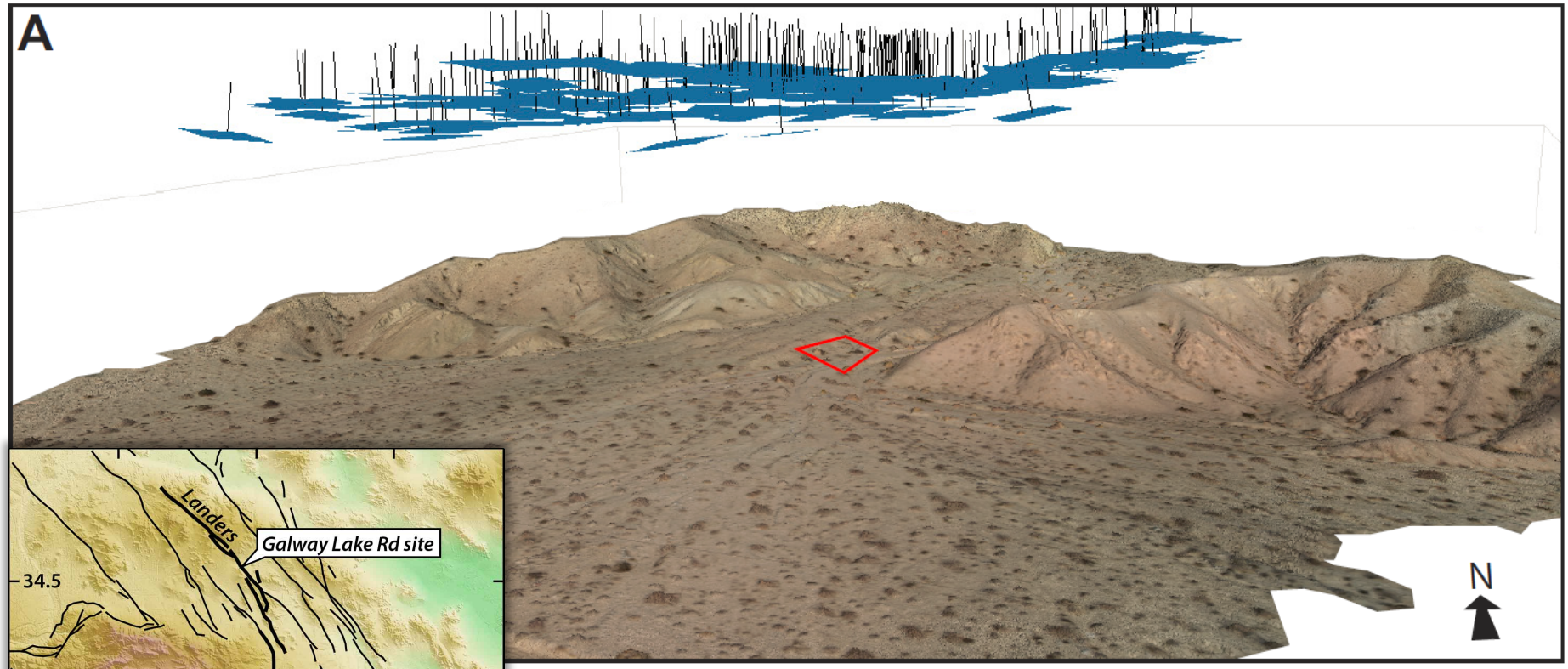
SfM & MVS software

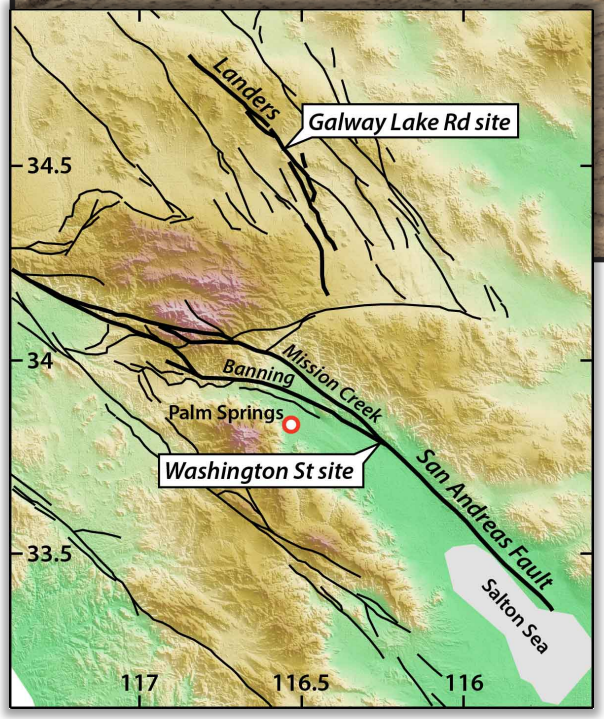


Agisoft Photoscan Pro: $549 for an academic licence.

- Workflow includes *both* SfM *and* MVS, and builds DSM and orthophoto
- Intuitive graphical user interface (GUI)
- Data are georeferenced automatically if camera GPS stamps are available
- Camera calibration with Agisoft Lens
- Vertically-oriented orthophoto possible for trenching (see Reitman *et al.,* 2015, *BSSA*)

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

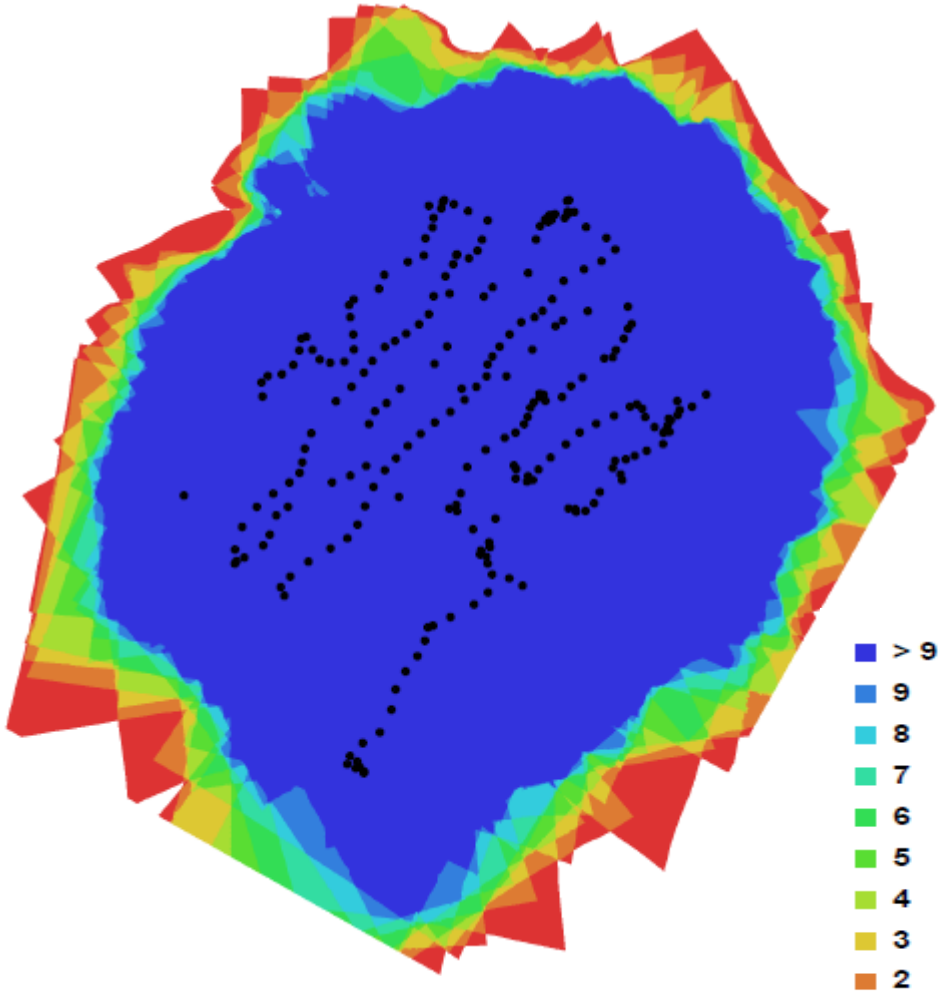
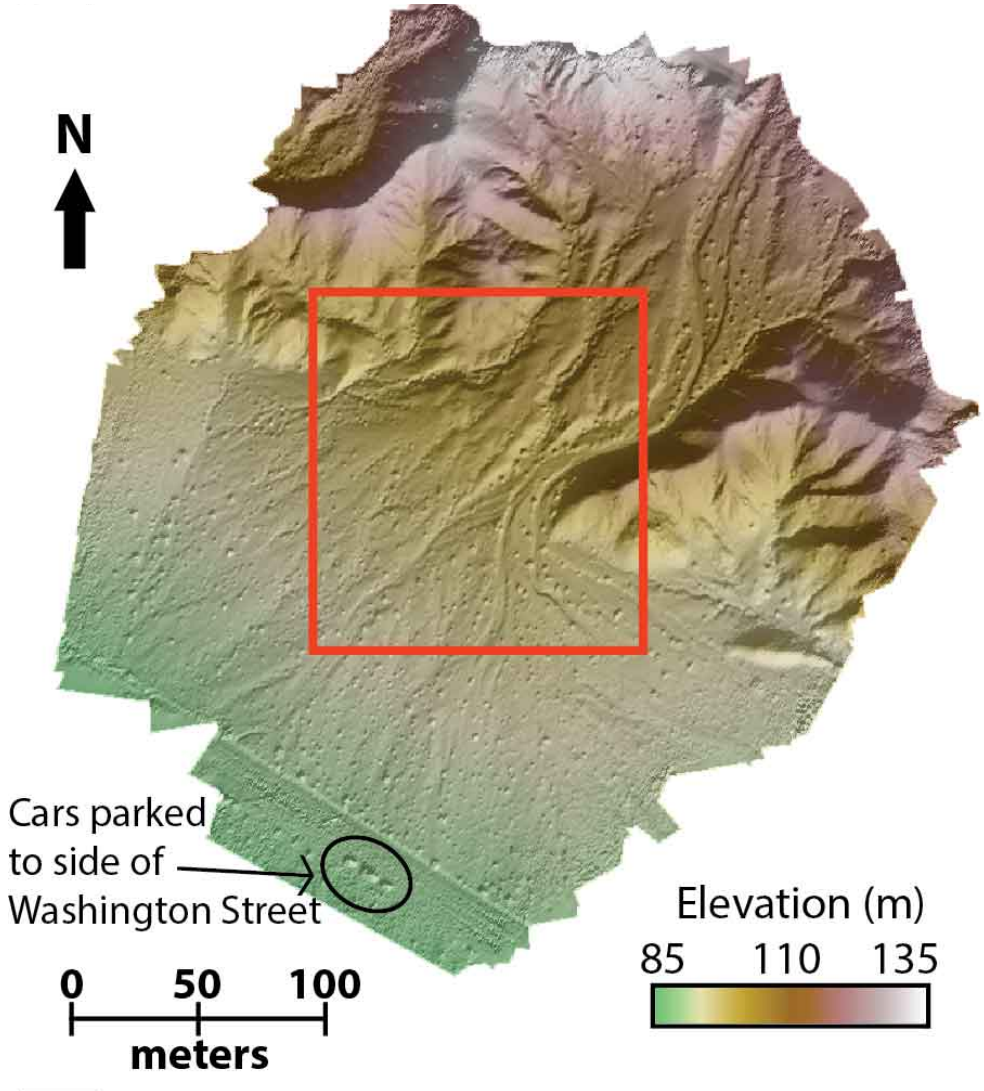
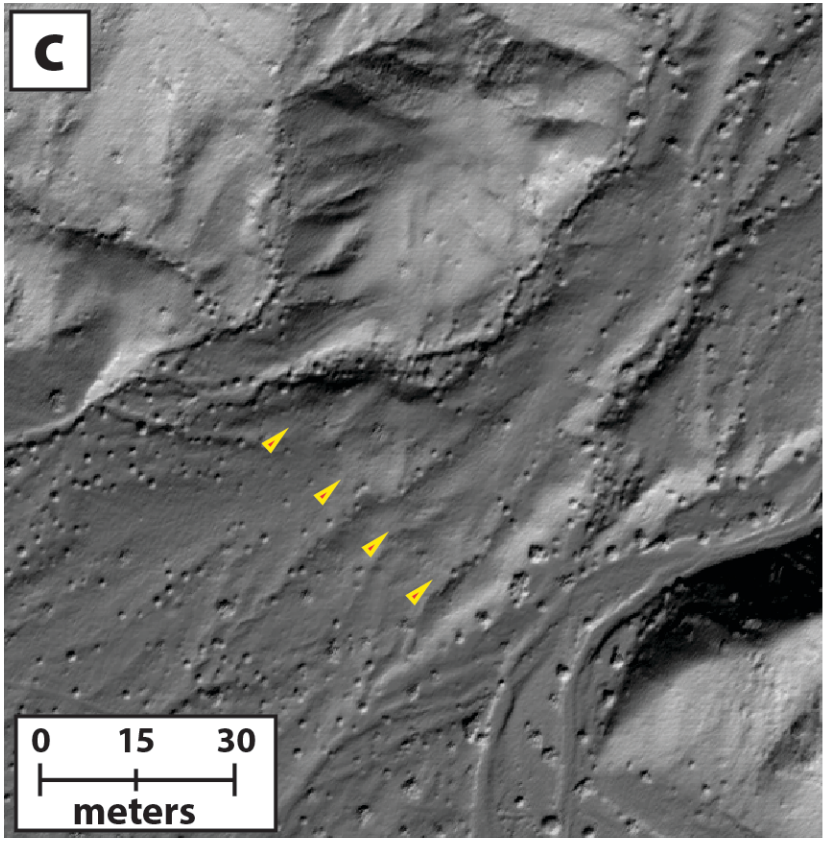


Fig. 1. Camera locations and image overlap.

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

Resolution and precision of SfM topography



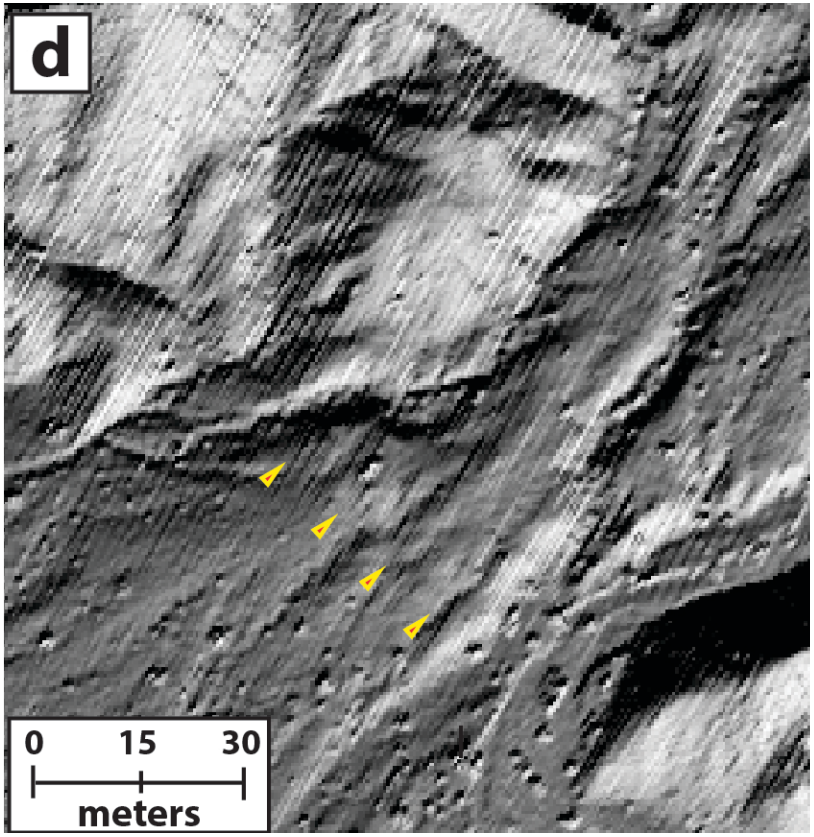


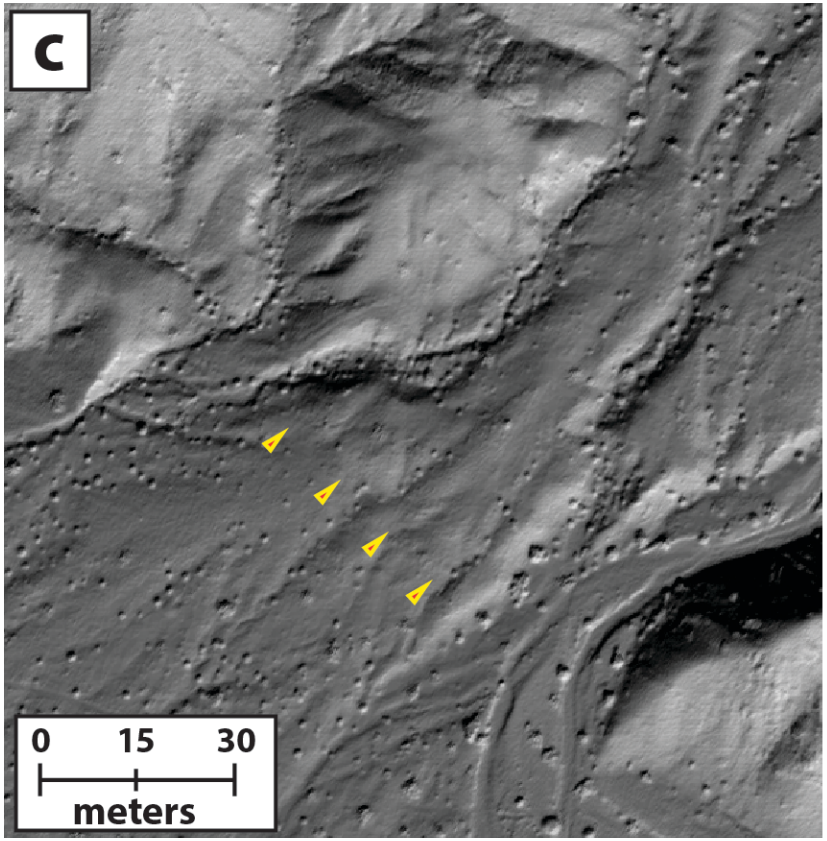
SfM ~700 pts/m^2

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

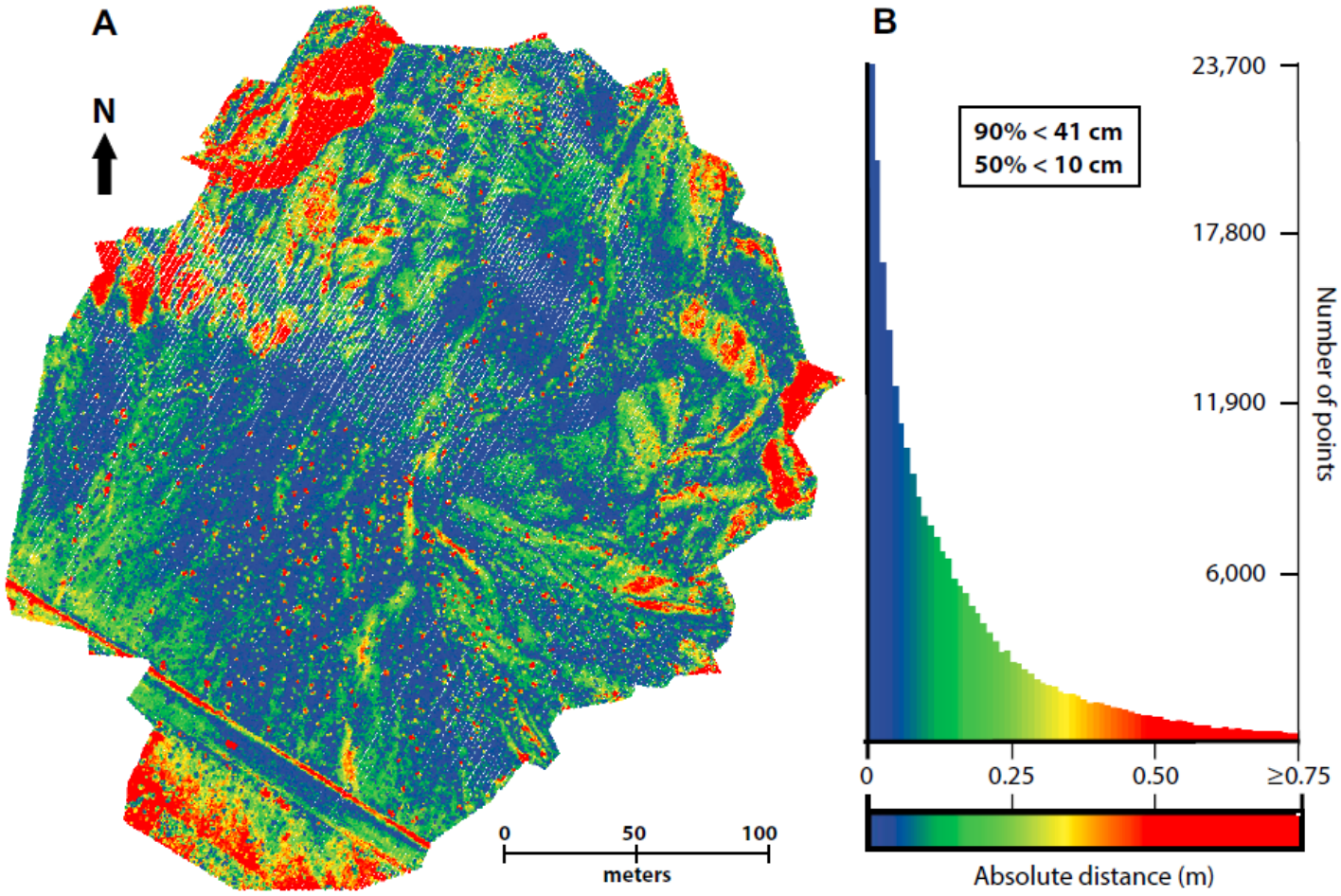
0.5 - 1 m resolution DEM

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*

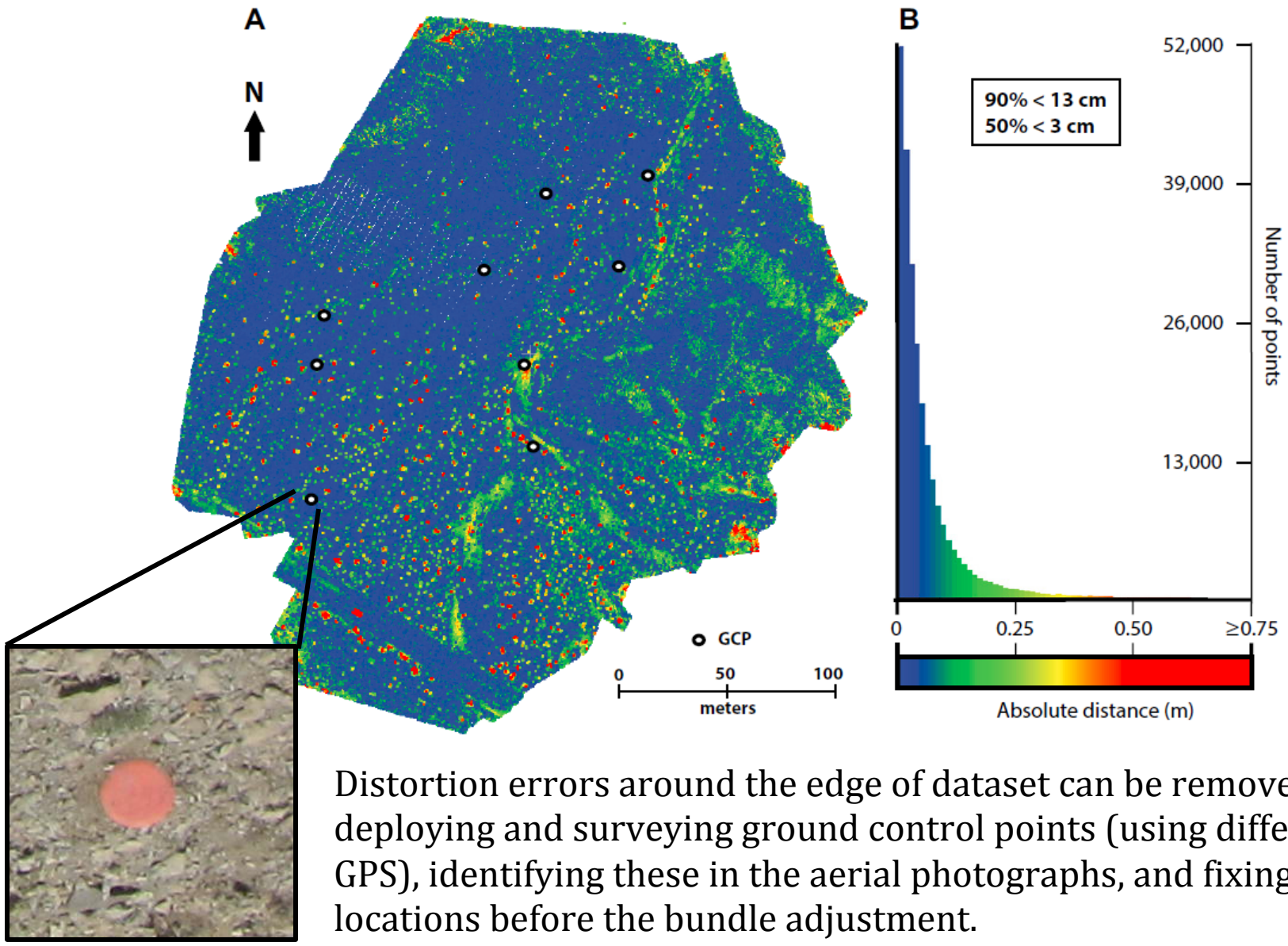
Resolution and precision of SfM topography



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*

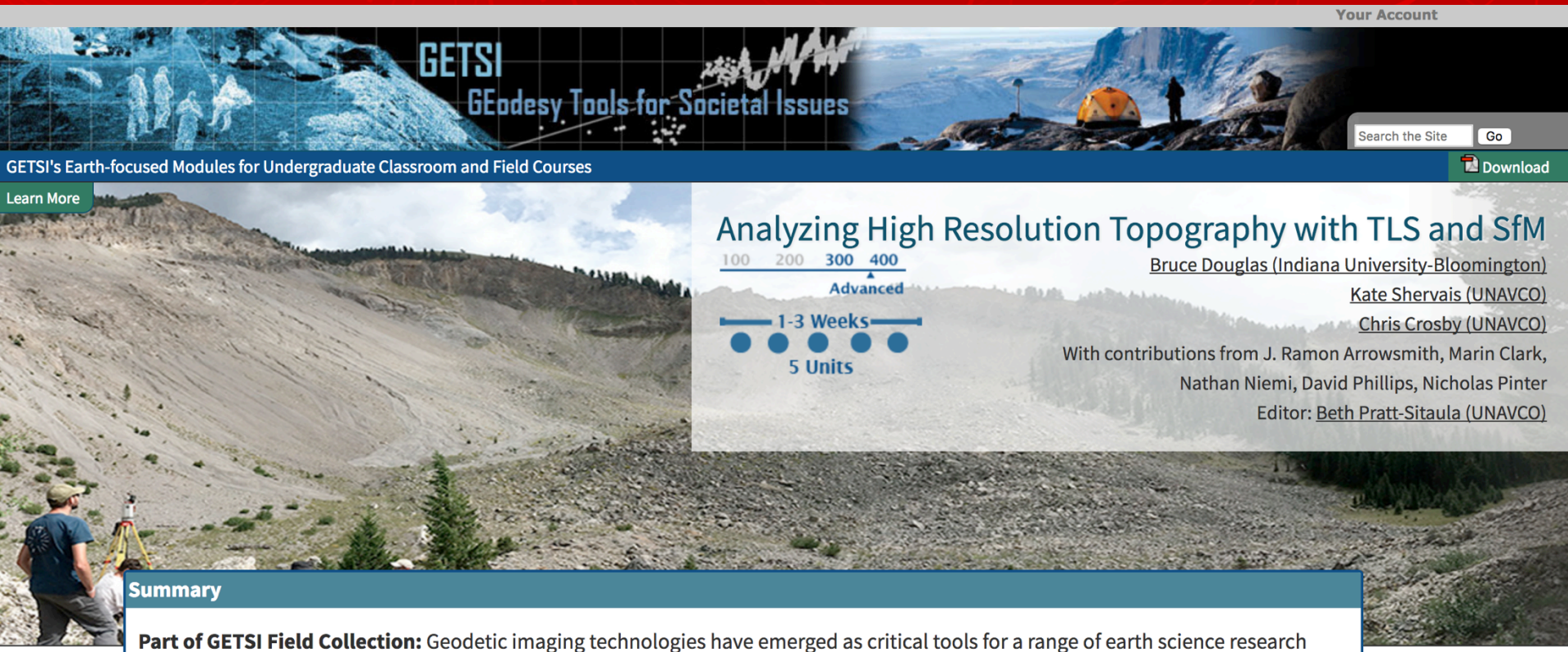
Resolution and precision of SfM topography



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*

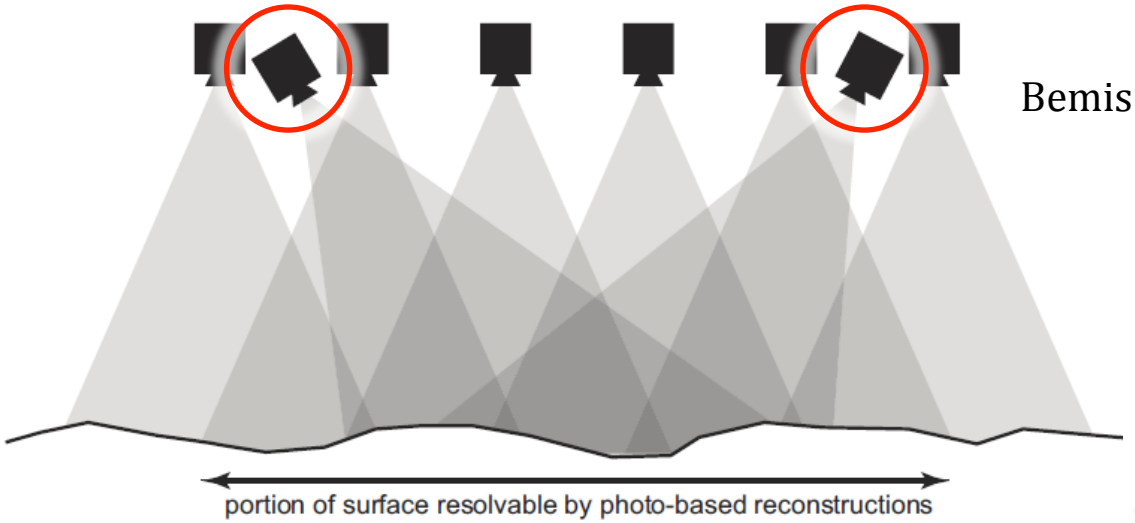
Available Resources



- SfM slides, theory and applications; practical considerations.
- How-to manuals for both field data collection and Agisoft PhotoScan processing

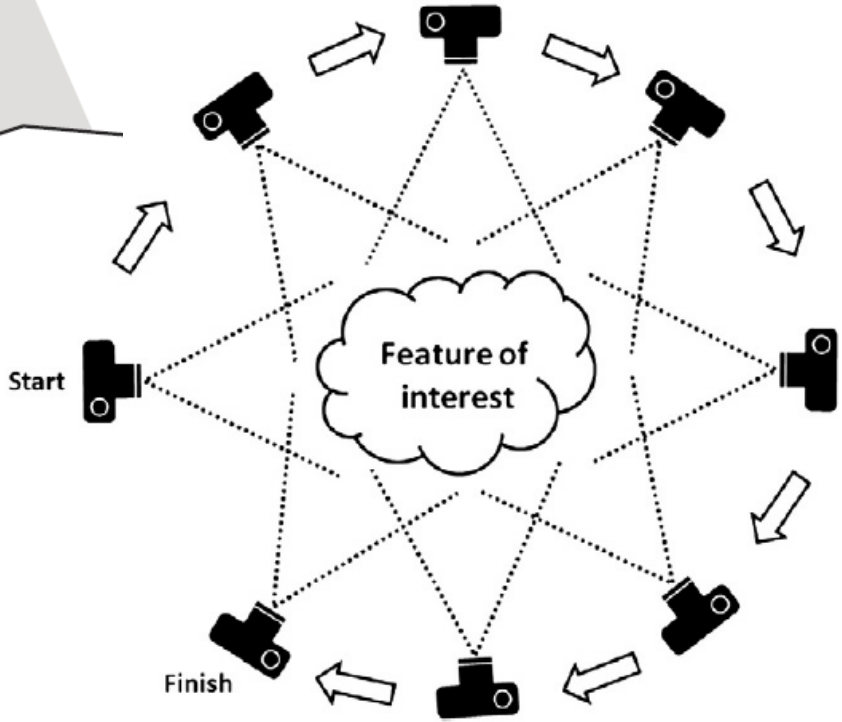
SfM exercise

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

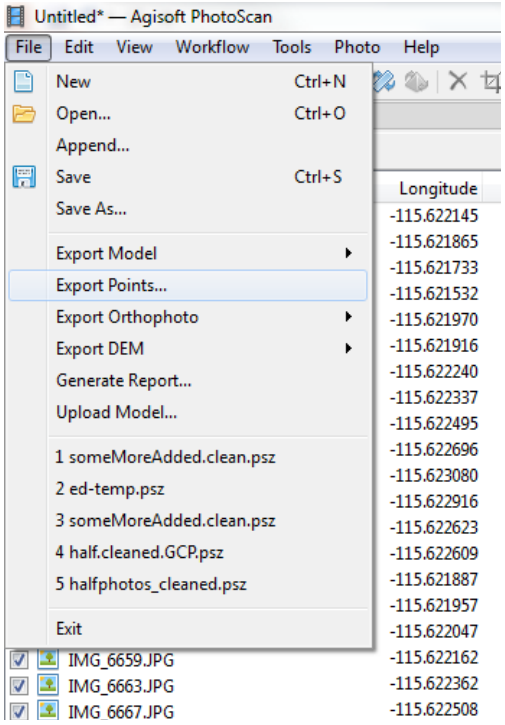
- Choose a target with some texture
- Ensure plenty of overlap between photos
- Capture the target from a variety of angles
- Try to capture the object in ~20 – 30 photos

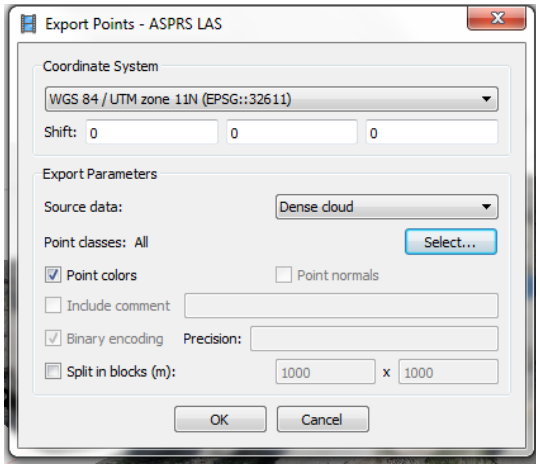
SfM exercise

SfM Pro? Show us how you are using it in your research or teaching.

Email results to:

ramon.arrowsmith@asu.edu





SfM exercise

In the free trial version of Agisoft Photoscan, you are unable to save point clouds or gridded DEMs that you create.

However, if you *had* bought the license, you could then do the following:

File > Export Points

- save point cloud with attributes in a number of formats including .LAS and ASCII, and in a number of coordinate systems including UTM

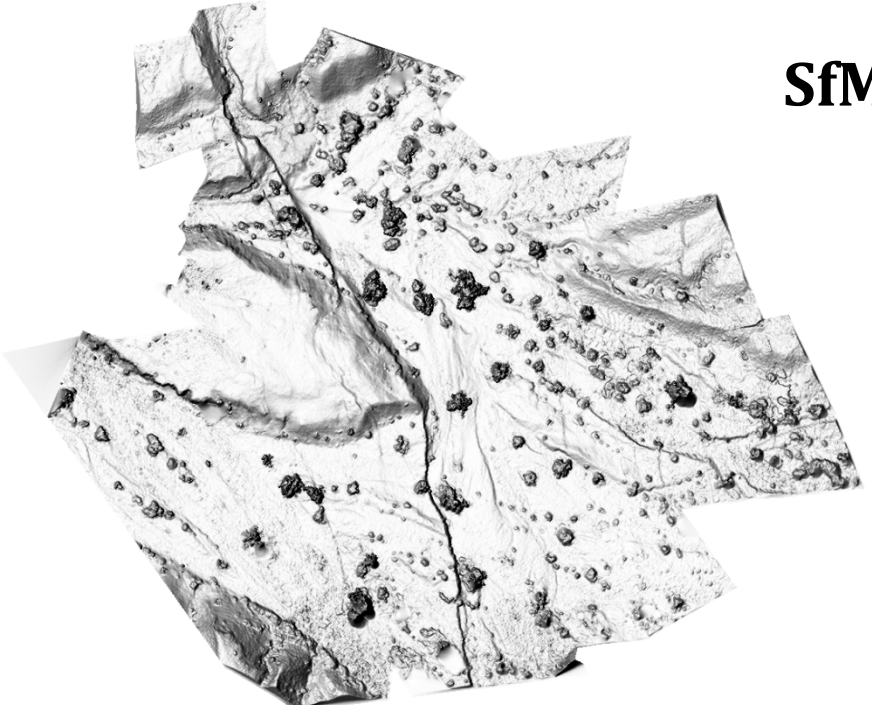
File > Export DEM

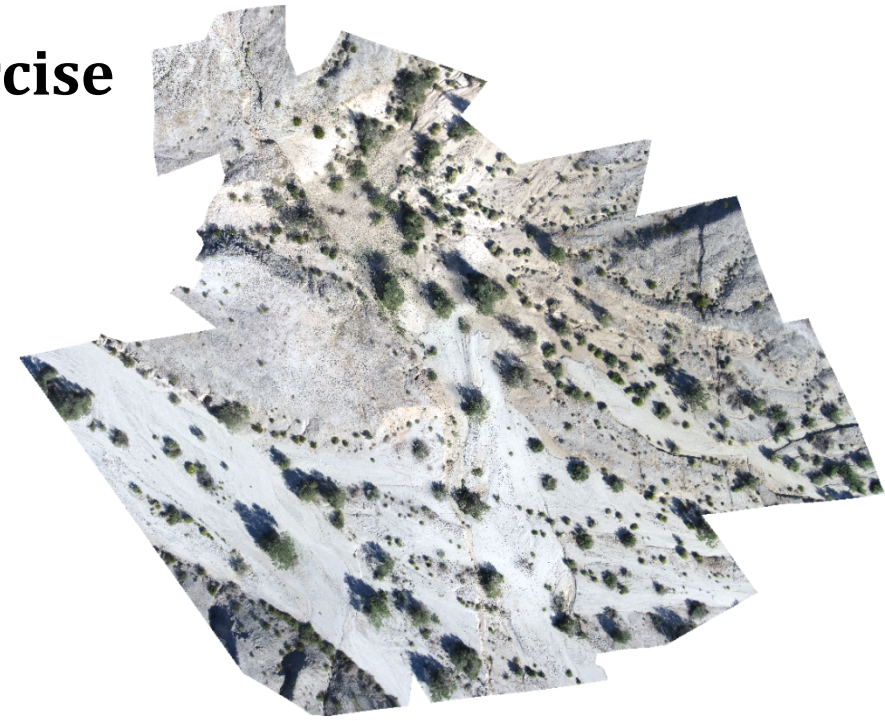
File > Export Orthophoto

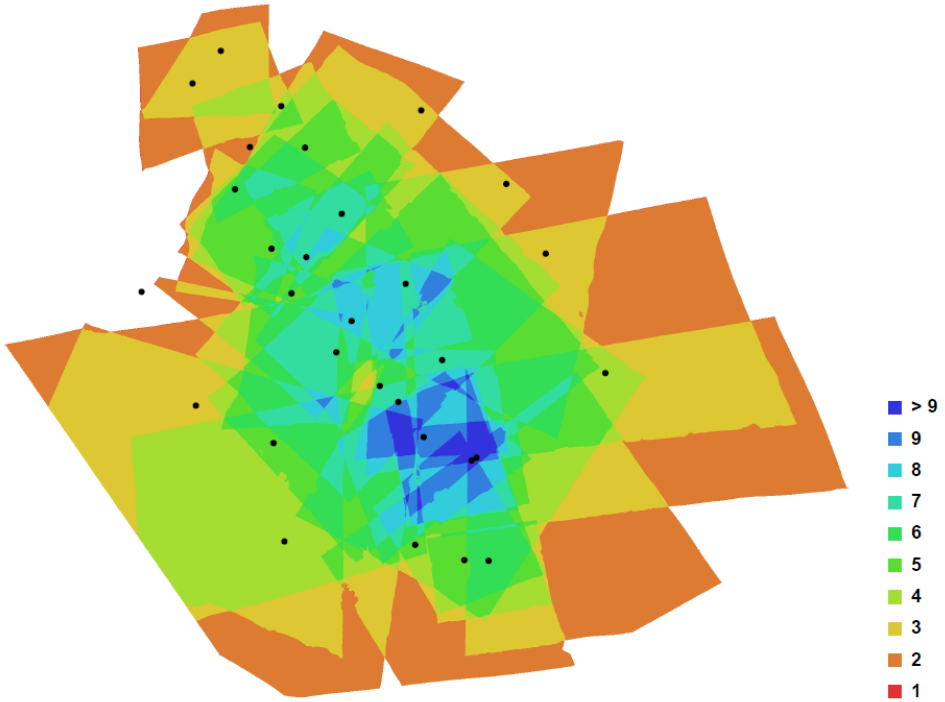
Generate Report

- the report contains a summary of the 3D model and data collection metrics

SfM exercise







Example products

Top left: artificially shaded DEM

Top right: orthophoto

Bottom left: camera locations (black dots) and image overlap (colours show #photos)