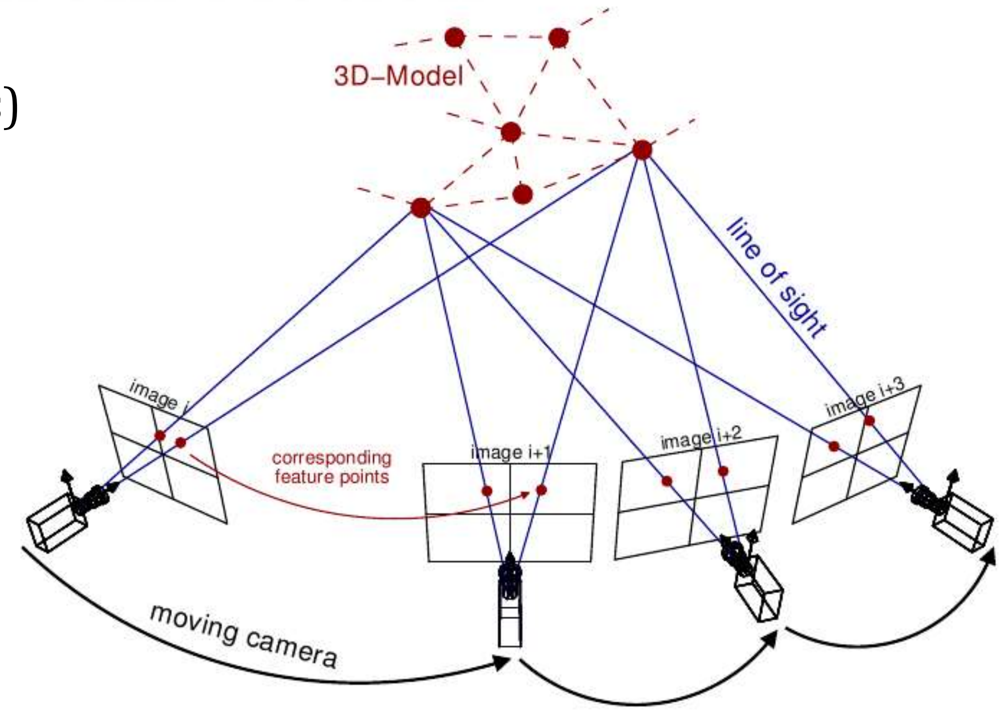
Structure-from-Motion

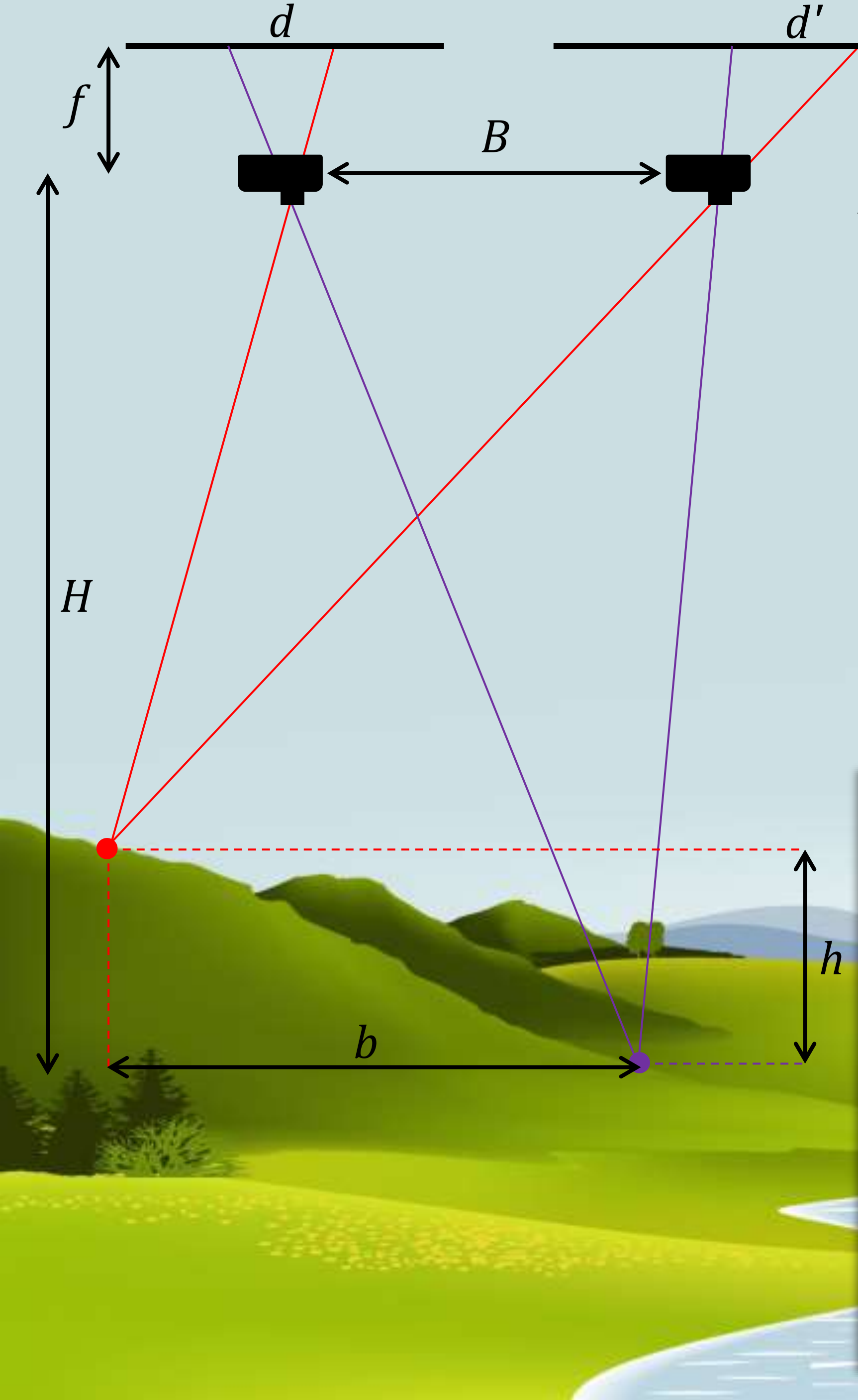
Edwin Nissen (Colorado School of Mines)

with thanks to: Kendra Johnson (CSM),
Sri Saripalli, Ramon Arrowsmith (ASU)



- **What is Structure-from-Motion?**
- **Examples of geoscience applications**
- **Mapping from UAVs and balloons**
- **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



Traditional stereo-photogrammetry

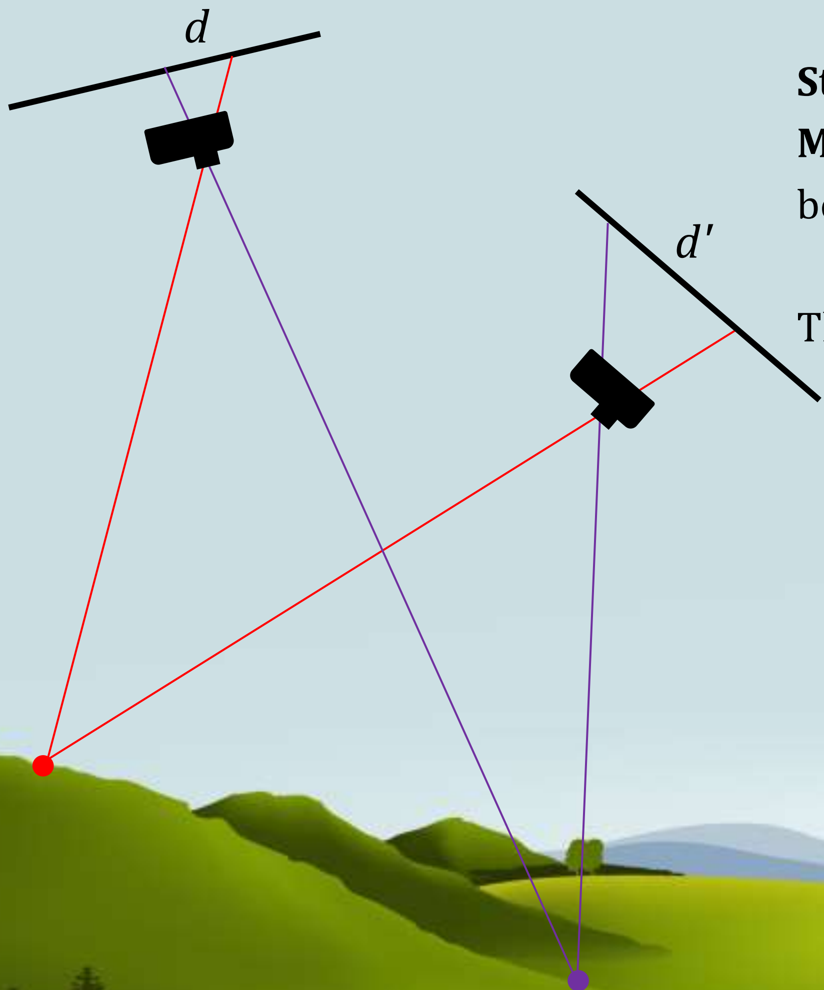
Known camera height *H* and focal length *f*, and the baseline *B* between images

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

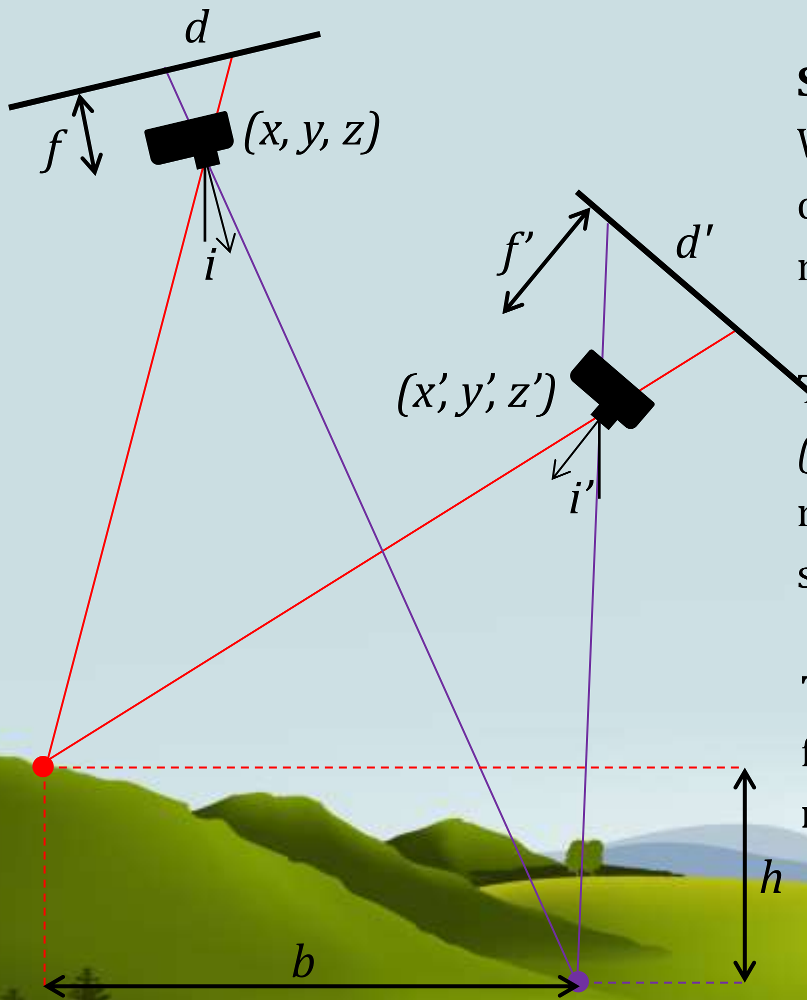
Match corresponding features and measure distances between them on the camera image plane *d, d’*

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

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



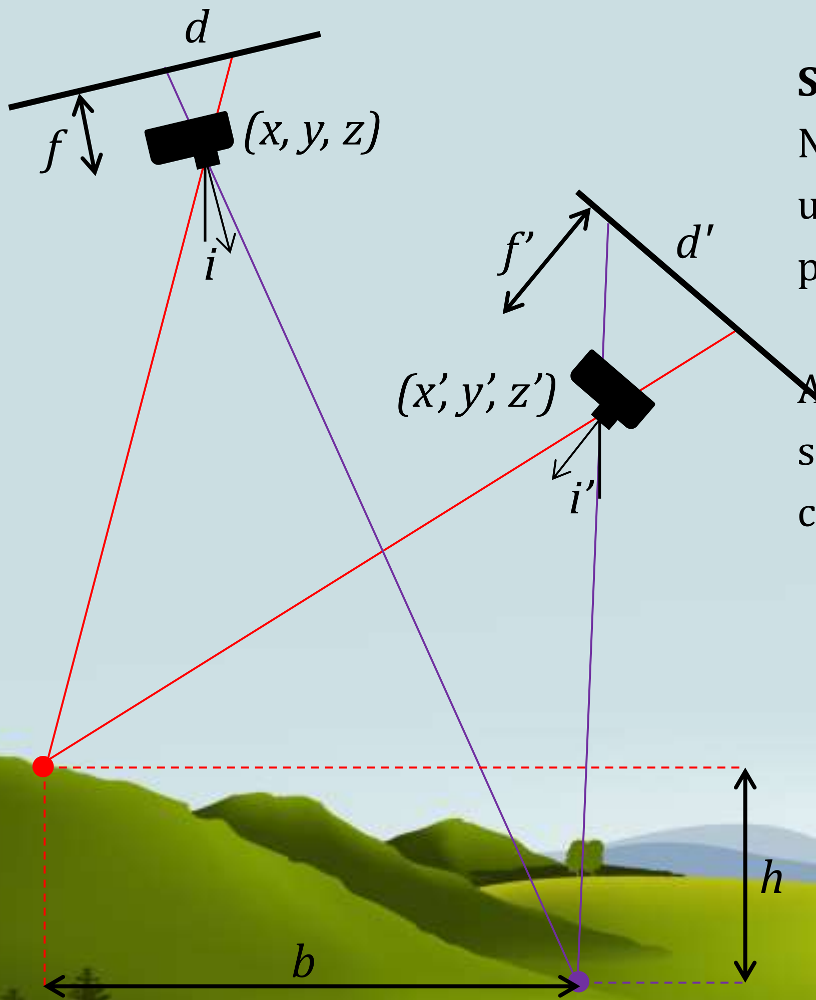
Step 2

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

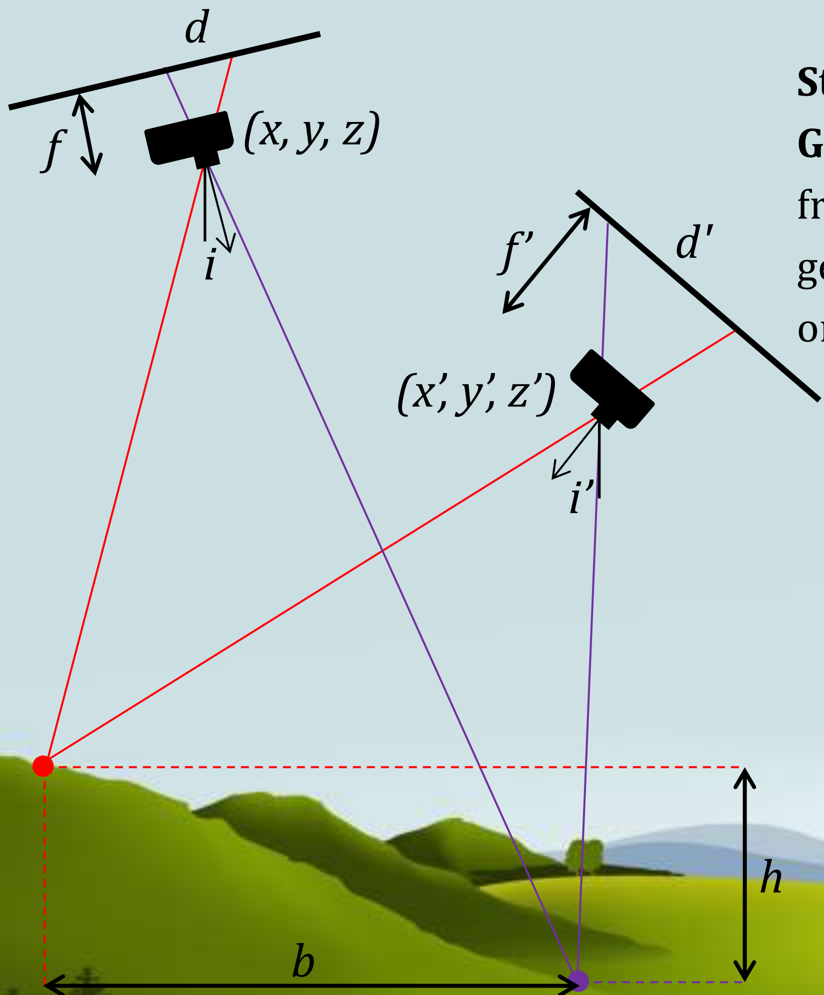


Step 3

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. This step is called "**multiview stereo matching" (MVS)**

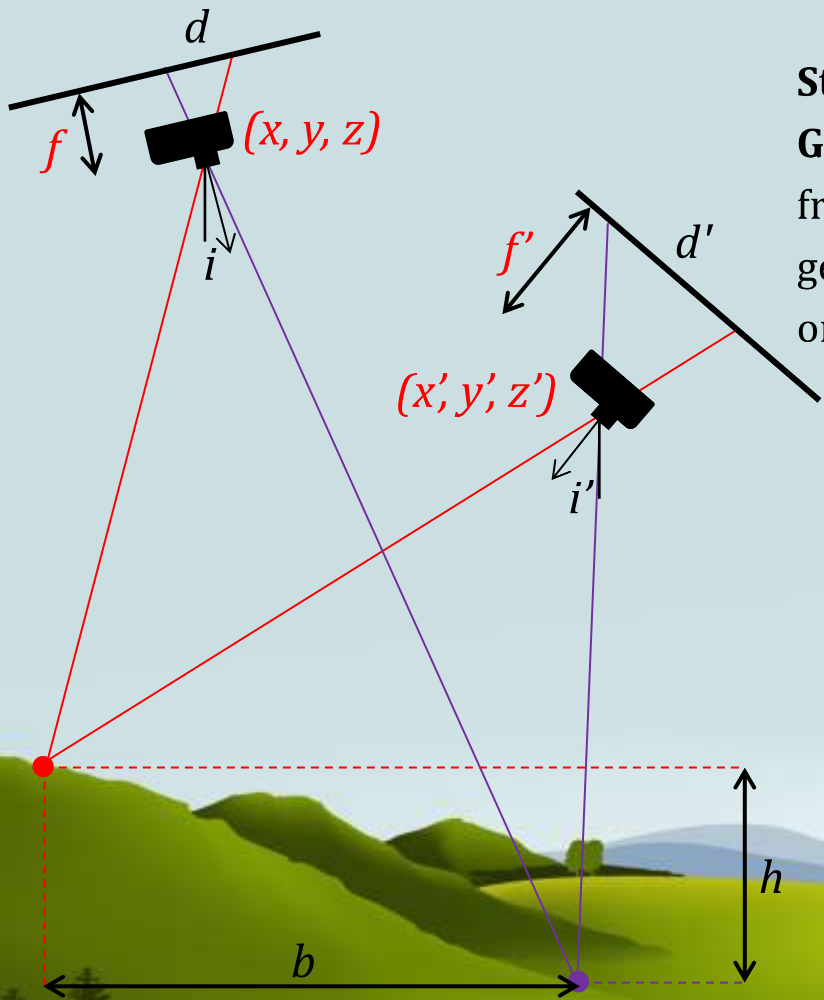
Structure-from-Motion



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

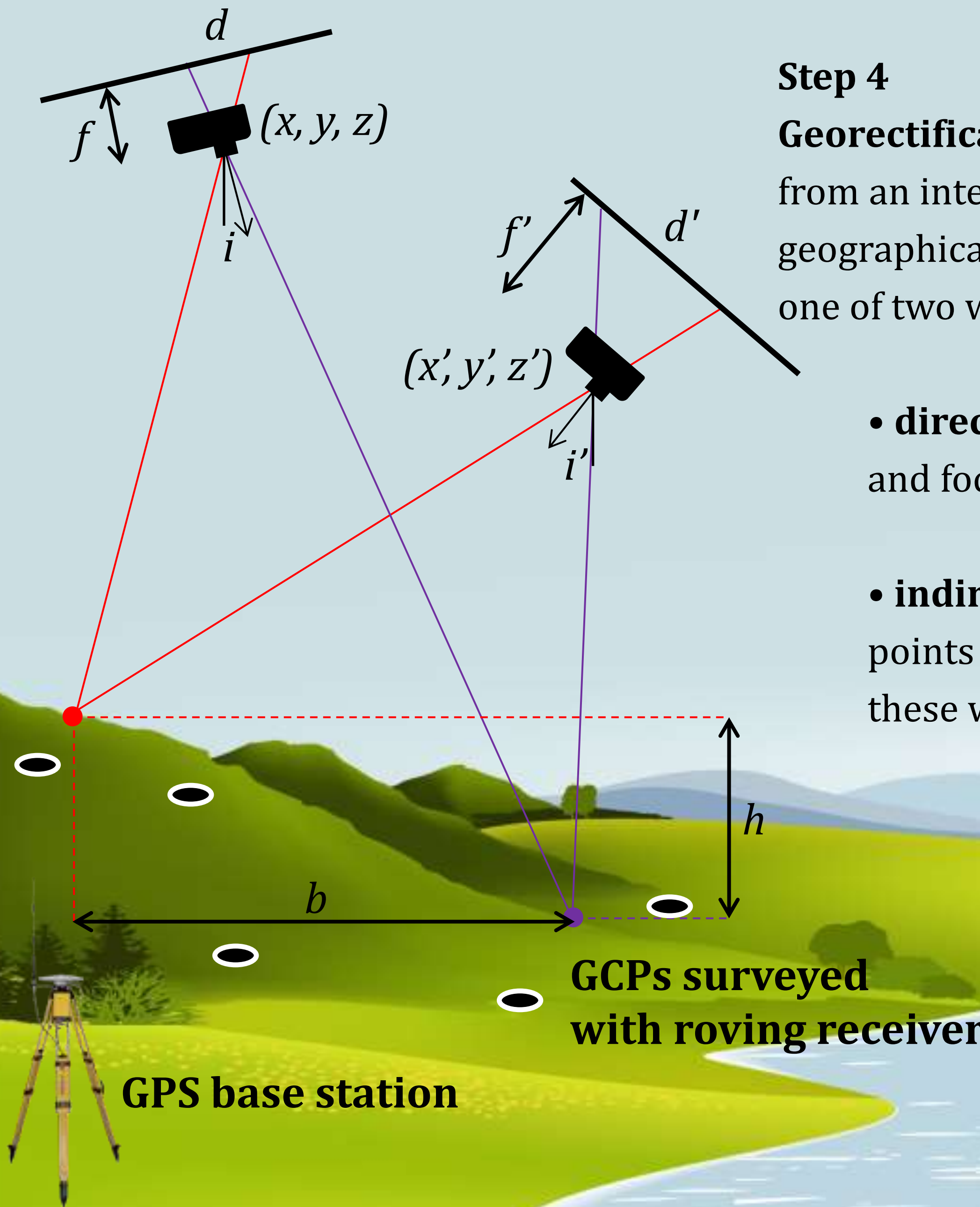


Step 4

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

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

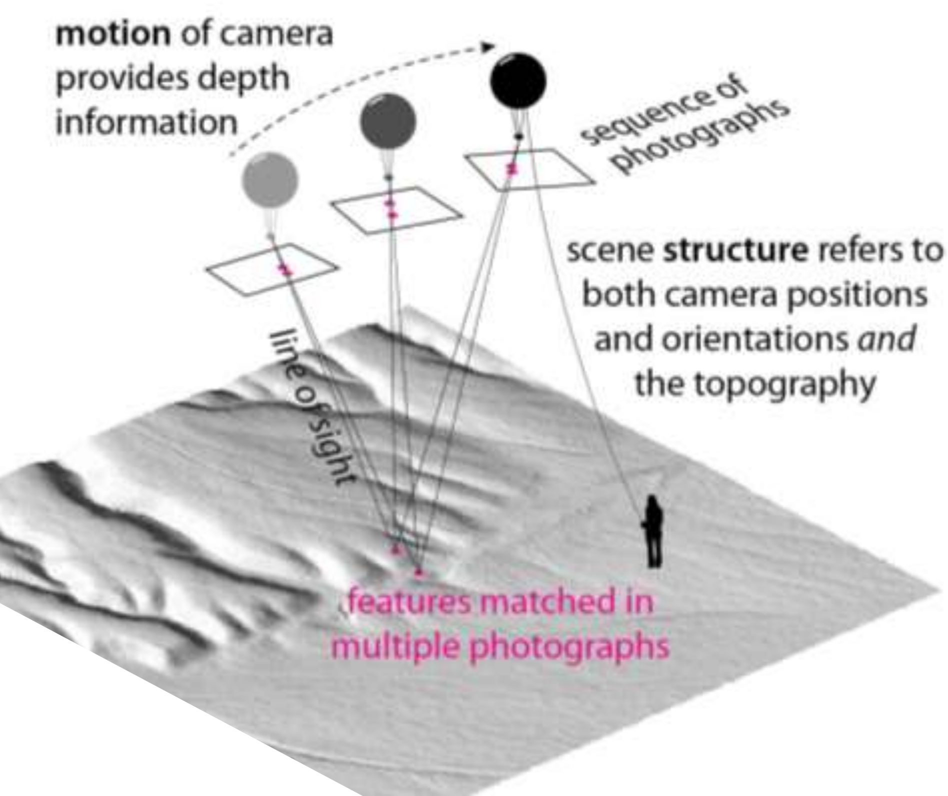
• Photographs from a range of angles and distances can be used, with no *a priori* knowledge of locations or orientations

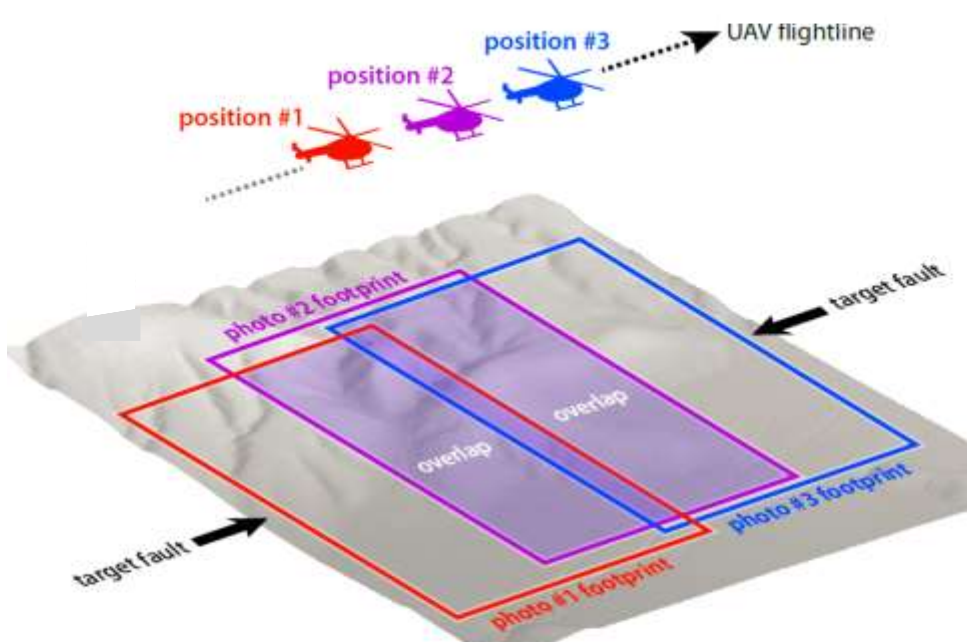
• Enables "unstructured" image acquisition from the ground, from legacy air-photosets, or from cheap, unmanned aerial platforms

Traditional stereo-photogrammetry

• Requires a stable platform such as a satellite or aeroplane at a fixed elevation

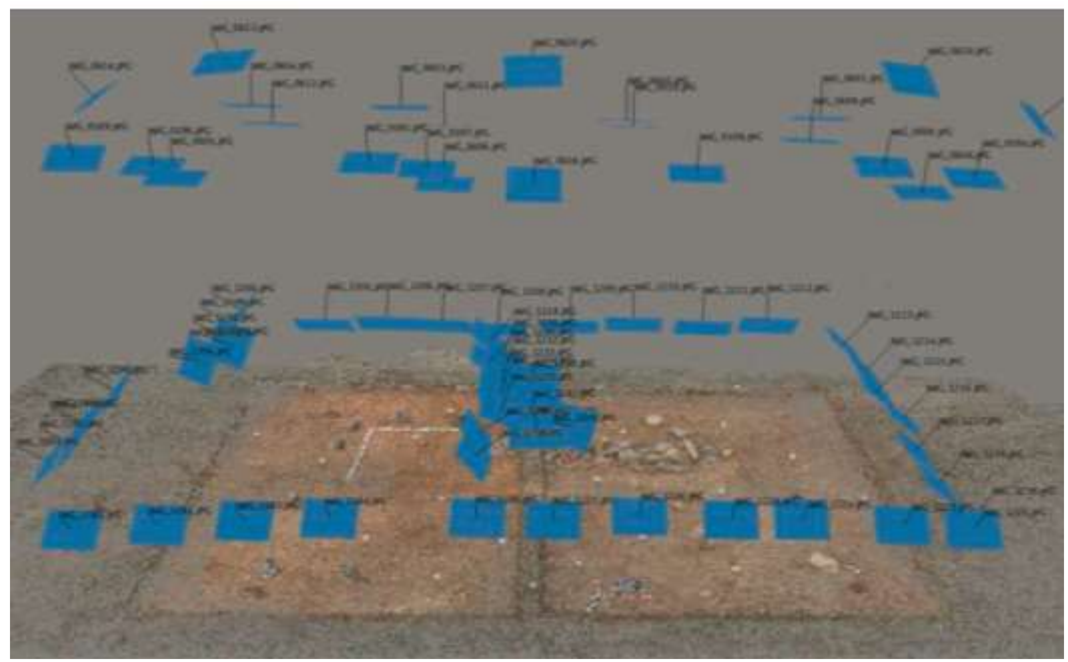
• Photographs collected at known positions and with fixed orientations and incidence angles



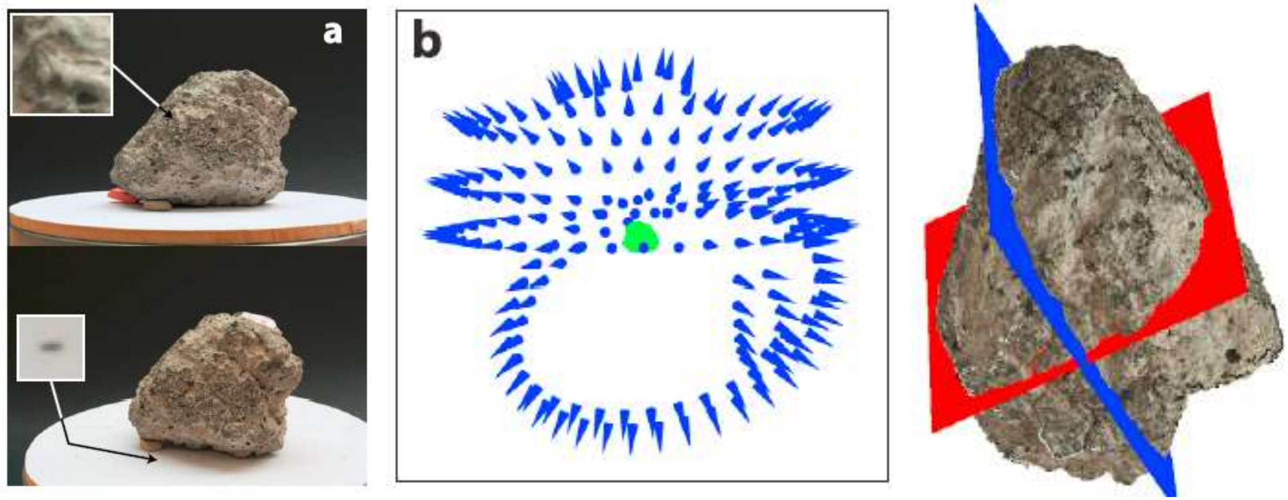


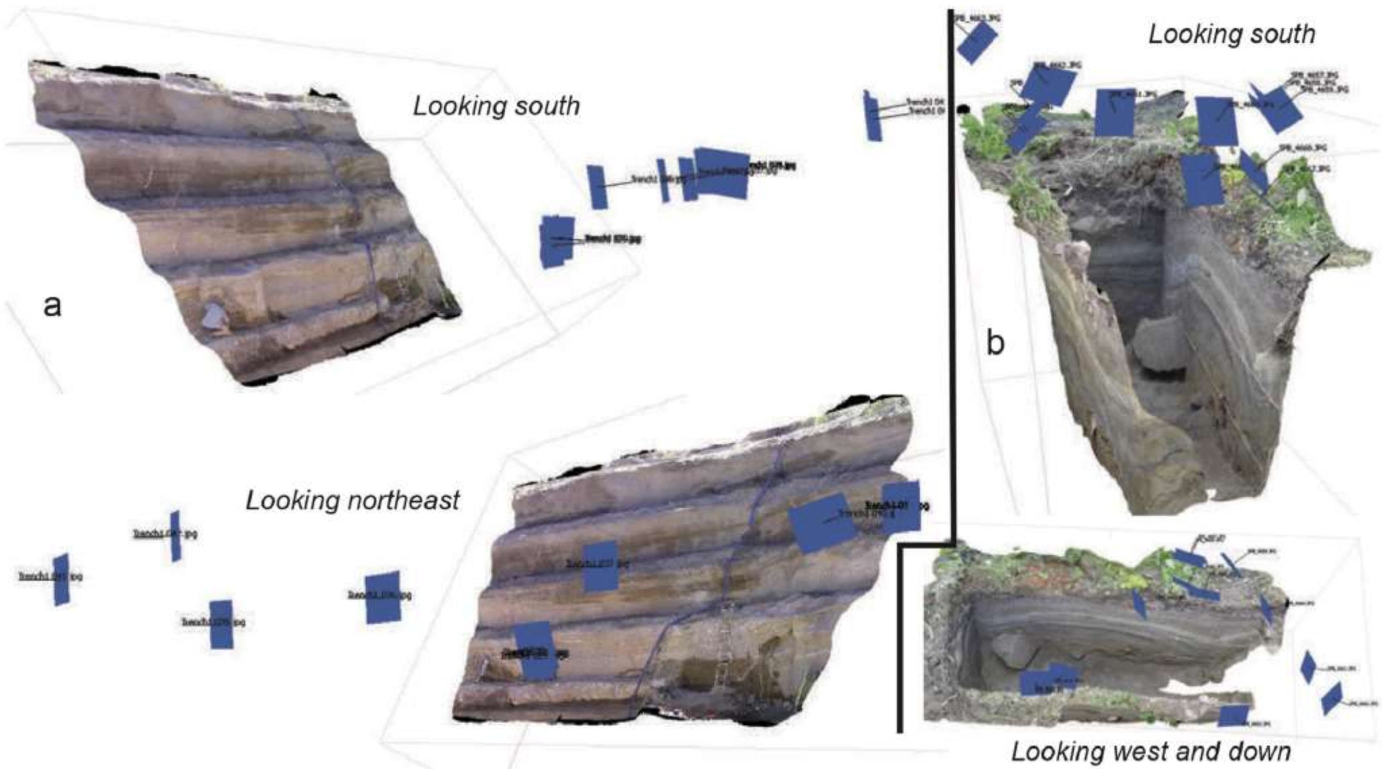
Snavely et al. (2007). Modeling the World from Internet Photo Collections, *International Journal of Computer Vision*

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



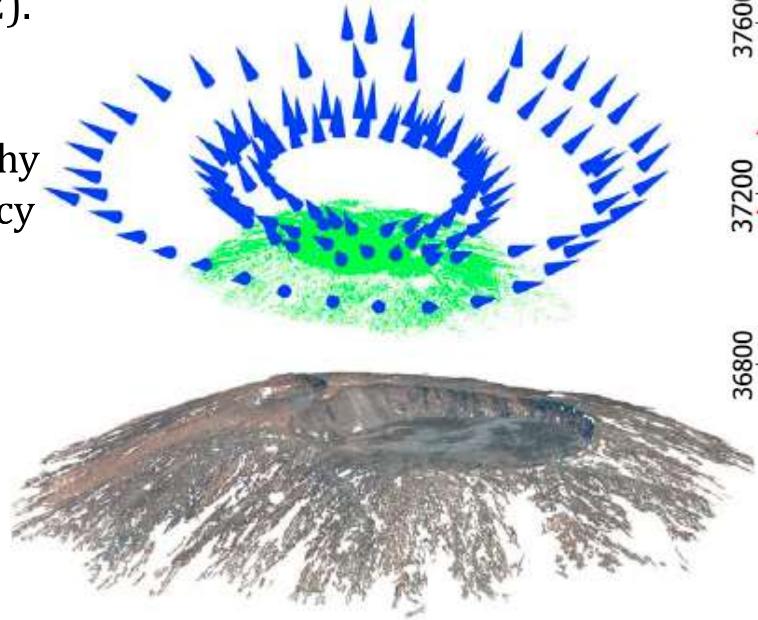
James & Robson (2012). Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application. *Journal of Geophysical Research*

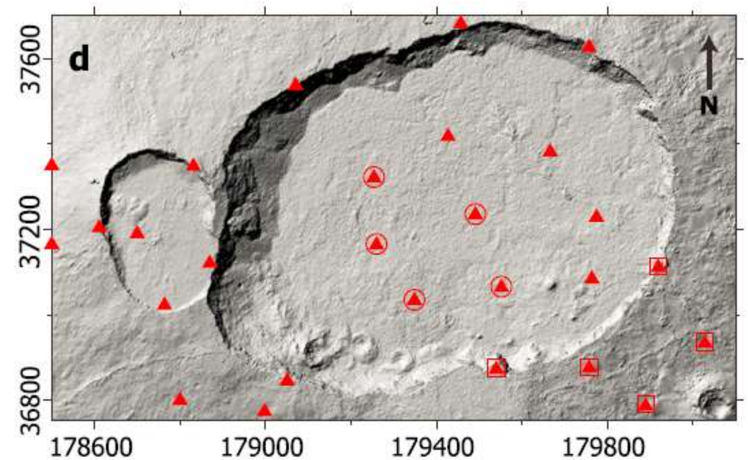




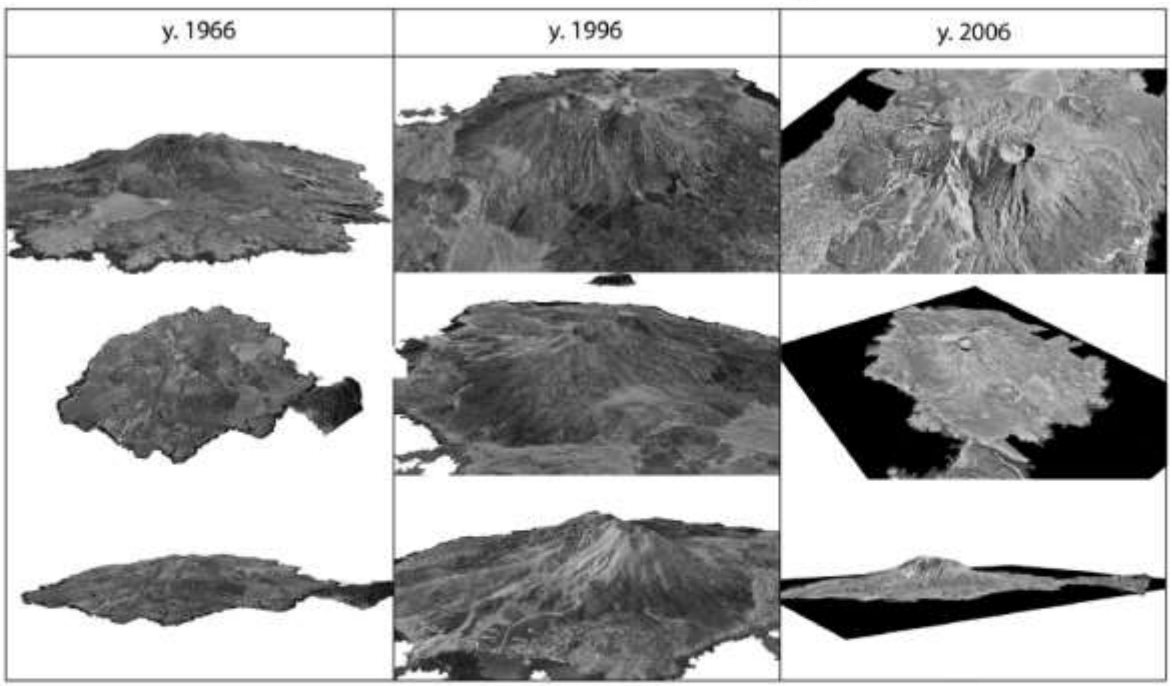
Bemis et al. (2014). Ground-based and UAV-Based photogrammetry: A multi-scale, high resolution mapping tool for structural geology and paleoseismology. *Journal of Structural Geology*

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





Summit crater, Piton de la Fournaise
~100 photos from a micro-light
~2 pts/m^2 point cloud

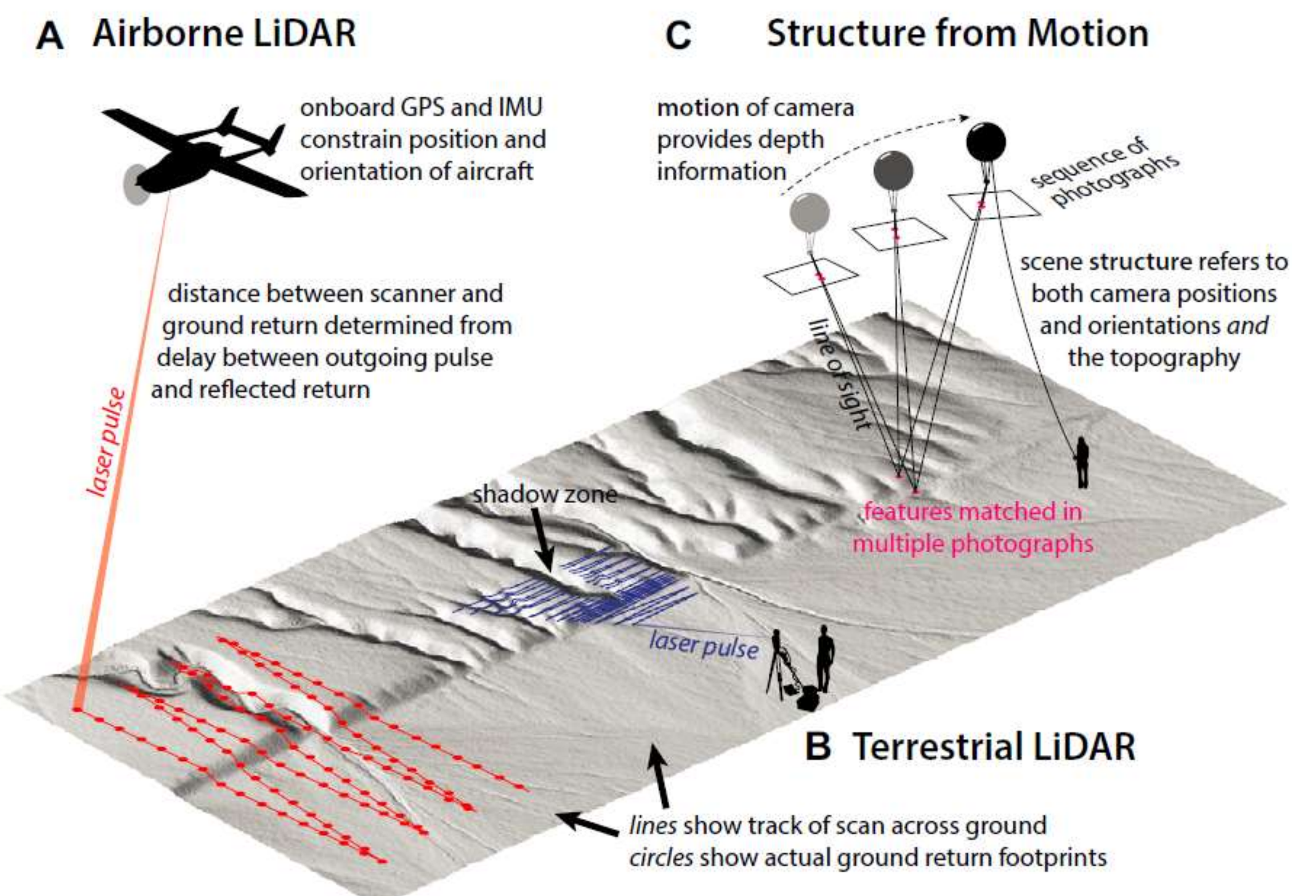


Gomez et al. (2015). A study of Japanese landscapes using structure from motion derived DSMs and DEMs based on historical aerial photographs. *Geomorphology*

Sakurajima volcano, Japan

Structure from Motion using cheap airborne platforms

Pros Much cheaper than Lidar (balloon + camera + software for ~$1000). Easy workflow for collecting and processing data. Data collection is faster than for terrestrial lidar. Produces much denser point clouds than airborne lidar (100s of points/m^2). Produces coloured point clouds adding useful textural information.



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

Cons Cannot easily cover the large areas (>10s of km^2) that airborne lidar can. Cannot "see through" vegetation as lidar can. Centimetric rather than millimetric precision , as can be achieved with terrestrial lidar.

Structure from Motion using cheap airborne platforms

Structure from Motion using cheap airborne platforms

Pros Once in the air, can follow pre-set flight path. Robust in high wind and can take off and land anywhere. Can carry large SLR camera. Expensive.

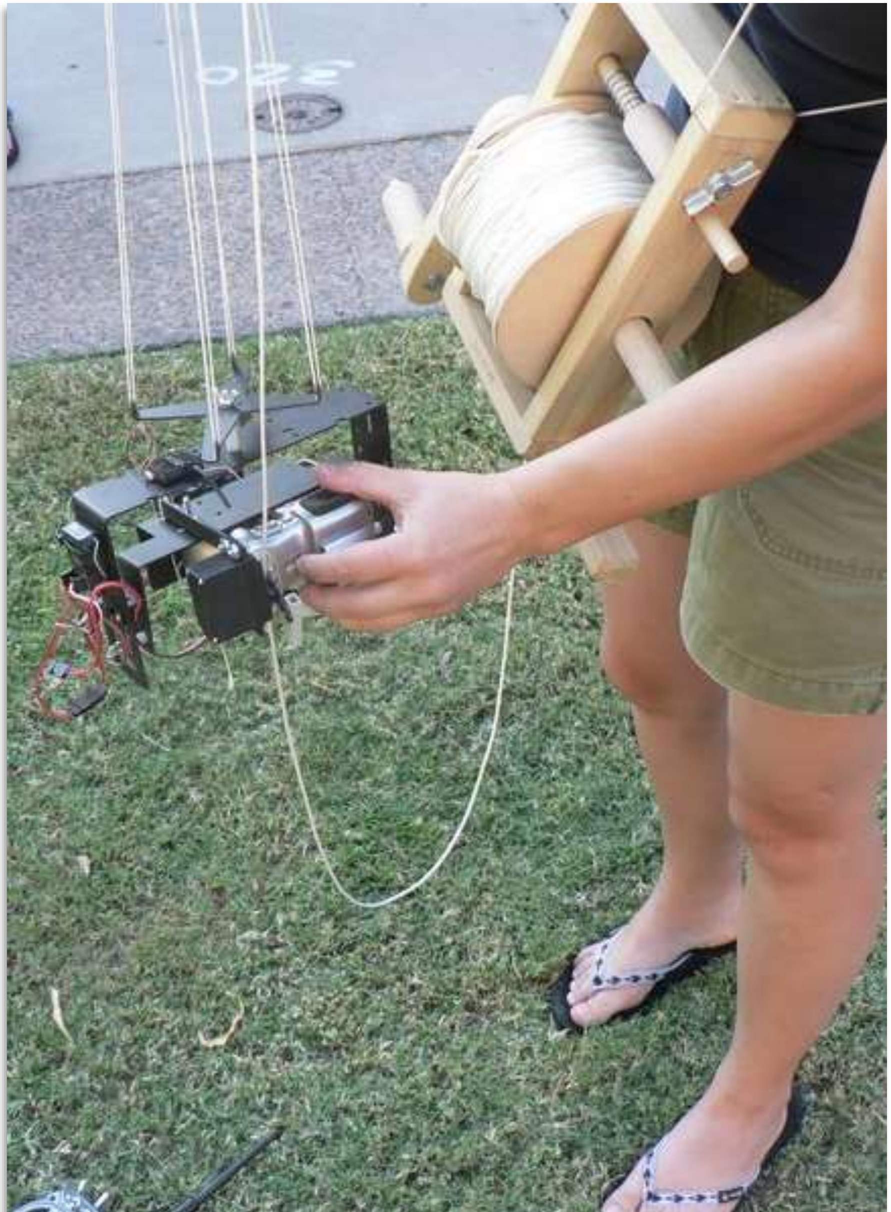
Cons Needs trained pilot to take-off and land and regular refuelling. Initial costs are high and requires careful maintenance. Regulations may need to be followed (FAA in the U.S.)

Structure from Motion using cheap airborne platforms

Pros Easy to self- launch and to pilot. Can cope in moderate winds. Very cheap!

Cons Can only carry small cameras and is susceptible to damage during landing. Batteries need frequent replacing/recharging.

Structure from Motion using cheap airborne platforms



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.

Structure from Motion using cheap airborne platforms

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.

Structure from Motion using cheap airborne platforms

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

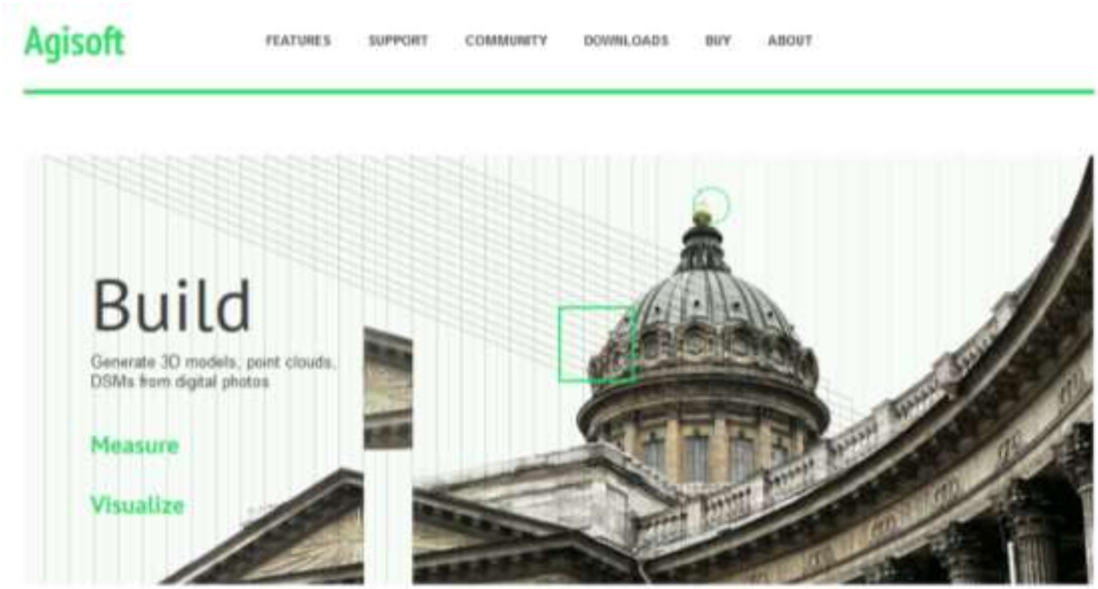
Essential Time lapse setting – remotely takes photo every *x* seconds

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.

Structure-from-Motion software and hardware



Agisoft Photoscan Pro: $549 for an academic licence. Workflow includes *both* Structure from Motion *and* Multiview Stereo and data are georeferenced automatically (using camera GPS stamps and/or GCPs).

Dell Alienware PC: 32GB RAM, Nvidia GeForce GTX 670 ($3,000). Useful for processing large datasets (100s – 1000s of photos)

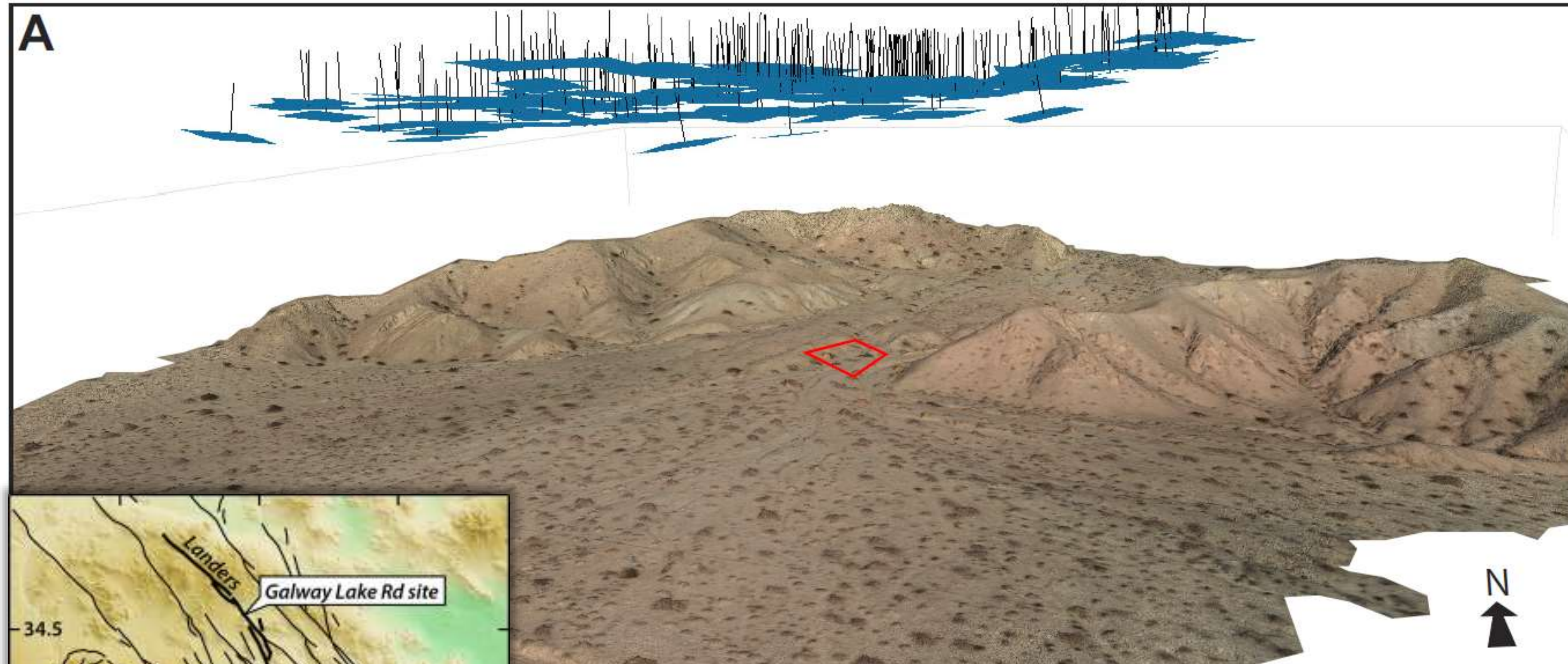
Free options:

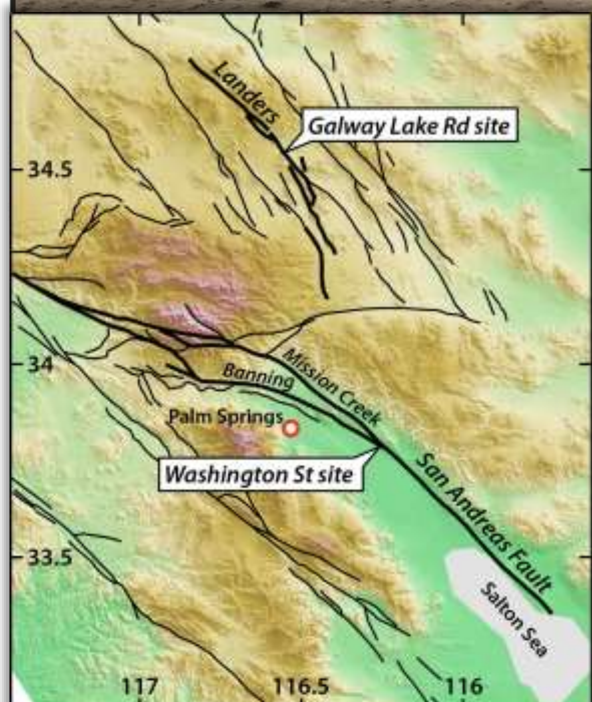
Bundler, **SFMToolkit, VisualSFM** or **Photosynth** to build sparse point cloud

CMVS/PMVS2 or **MicMac** to build dense point cloud

MATLAB scripts can be used to georeference point cloud

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), *Geosphere*

Resolution and precision of SfM topography

Orthophoto

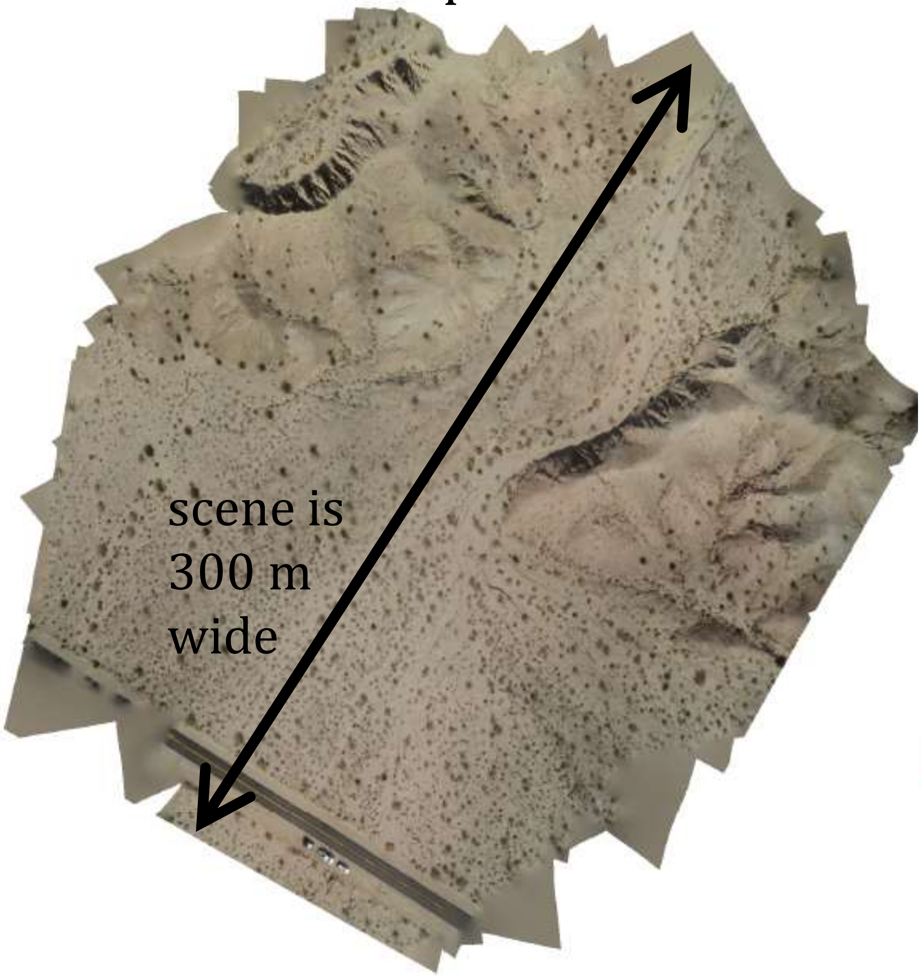


Photo coverage plot

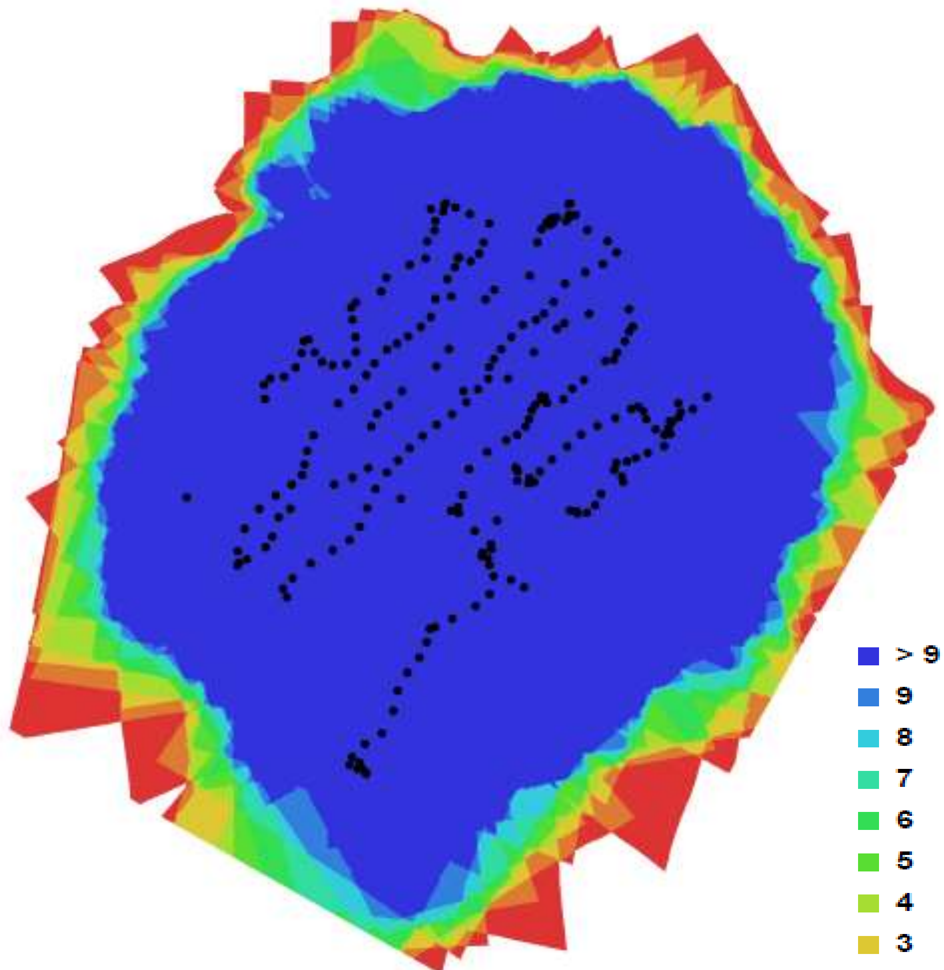
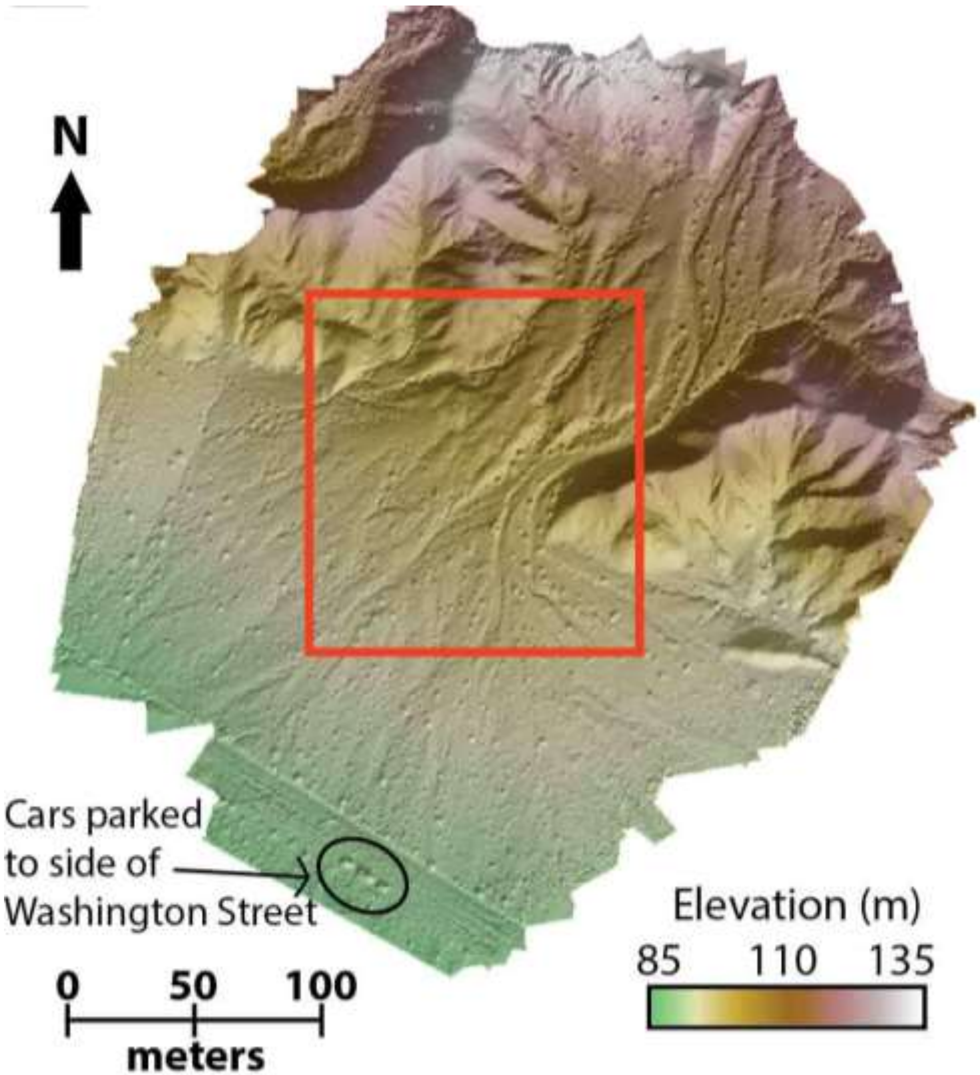
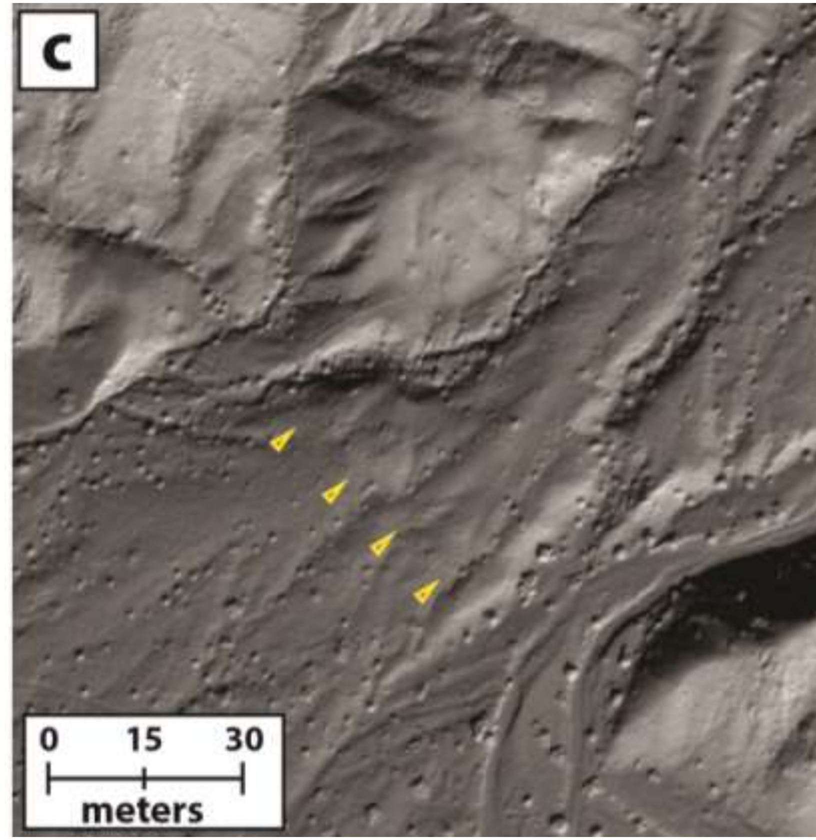


Fig. 1. Camera locations and image overlap.

Johnson et al. (2014), *Geosphere*

Resolution and precision of SfM topography



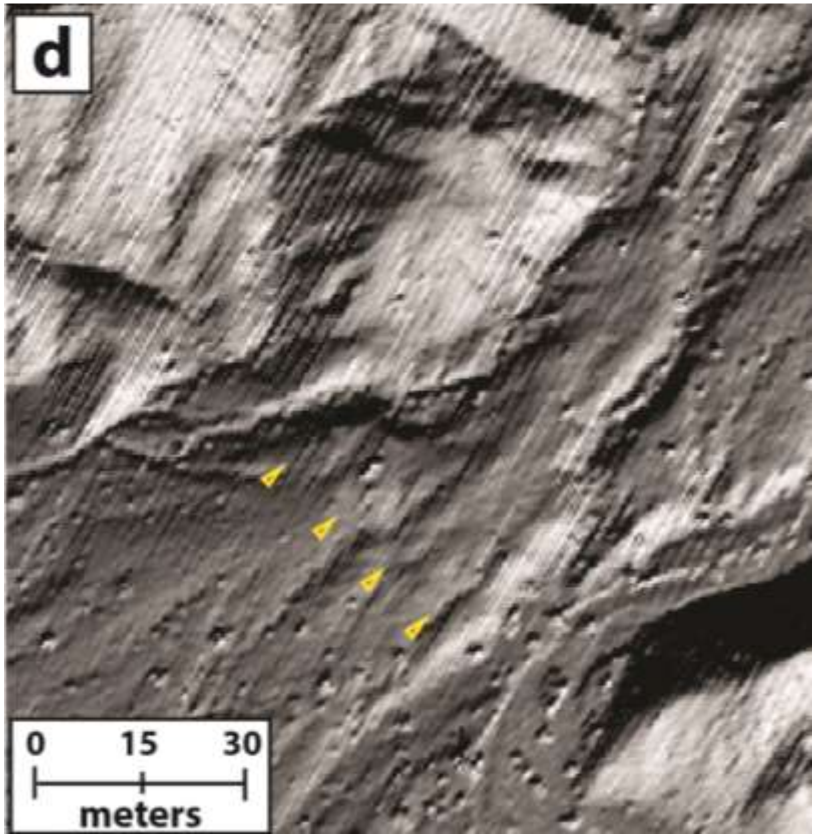


SfM ~700 pts/m^2

5 cm resolution DEM

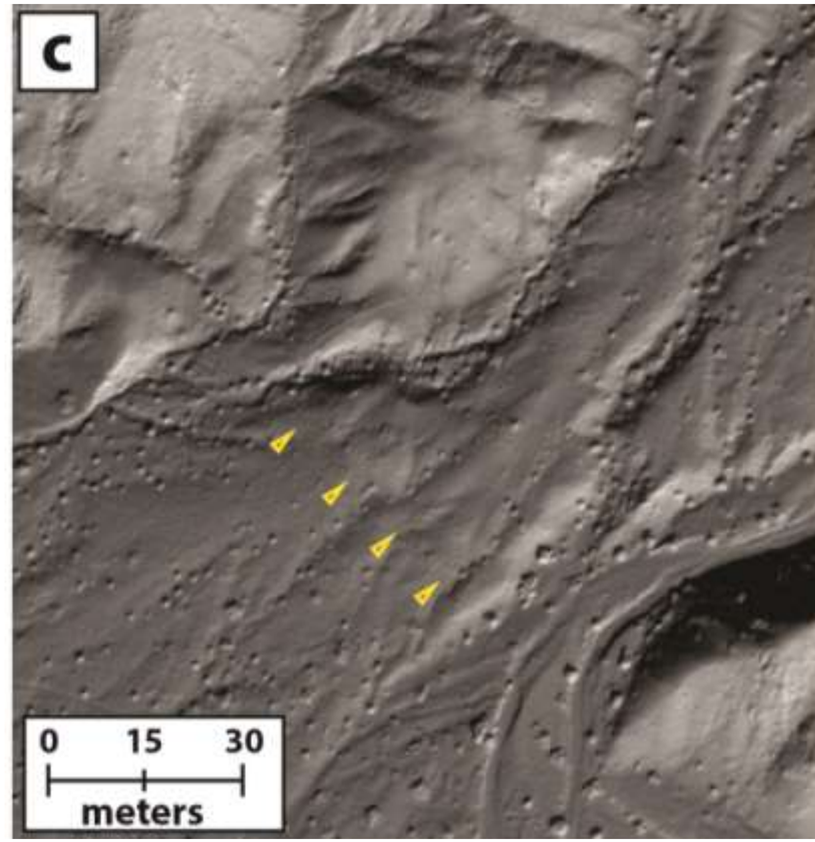
Johnson et al. (2014), *Geosphere*

Resolution and precision of SfM topography



B4 LiDAR ~4 pts/m^2

0.5 - 1 m resolution DEM

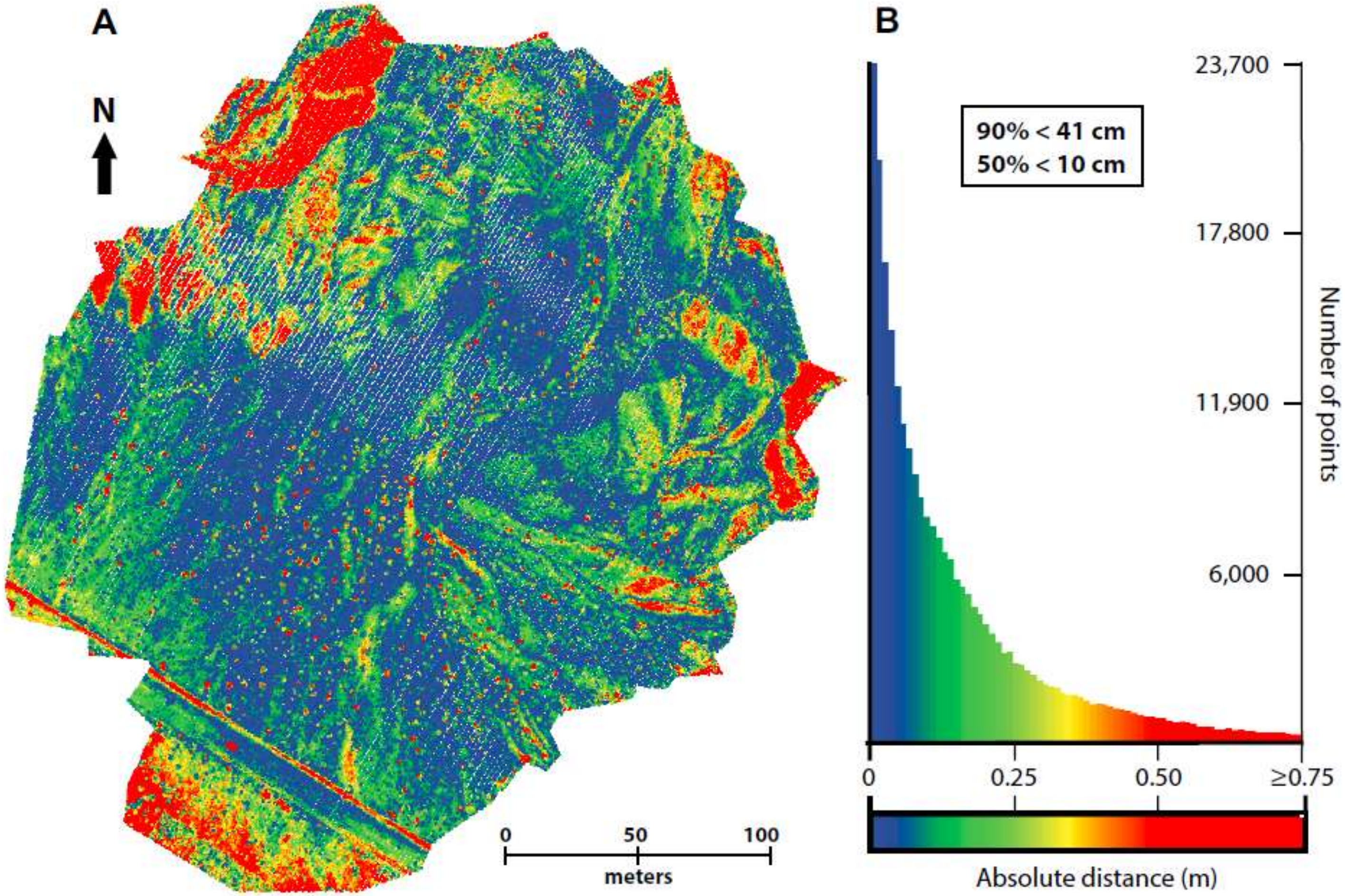


SfM ~700 pts/m^2

5 cm resolution DEM

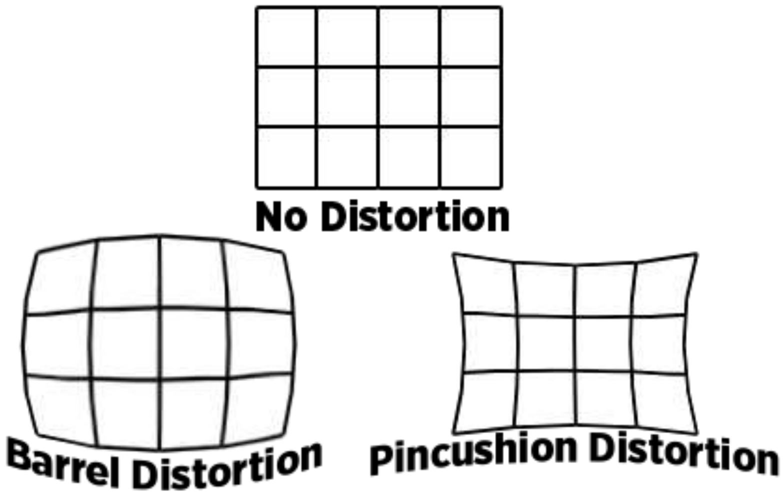
Johnson et al. (2014), *Geosphere*

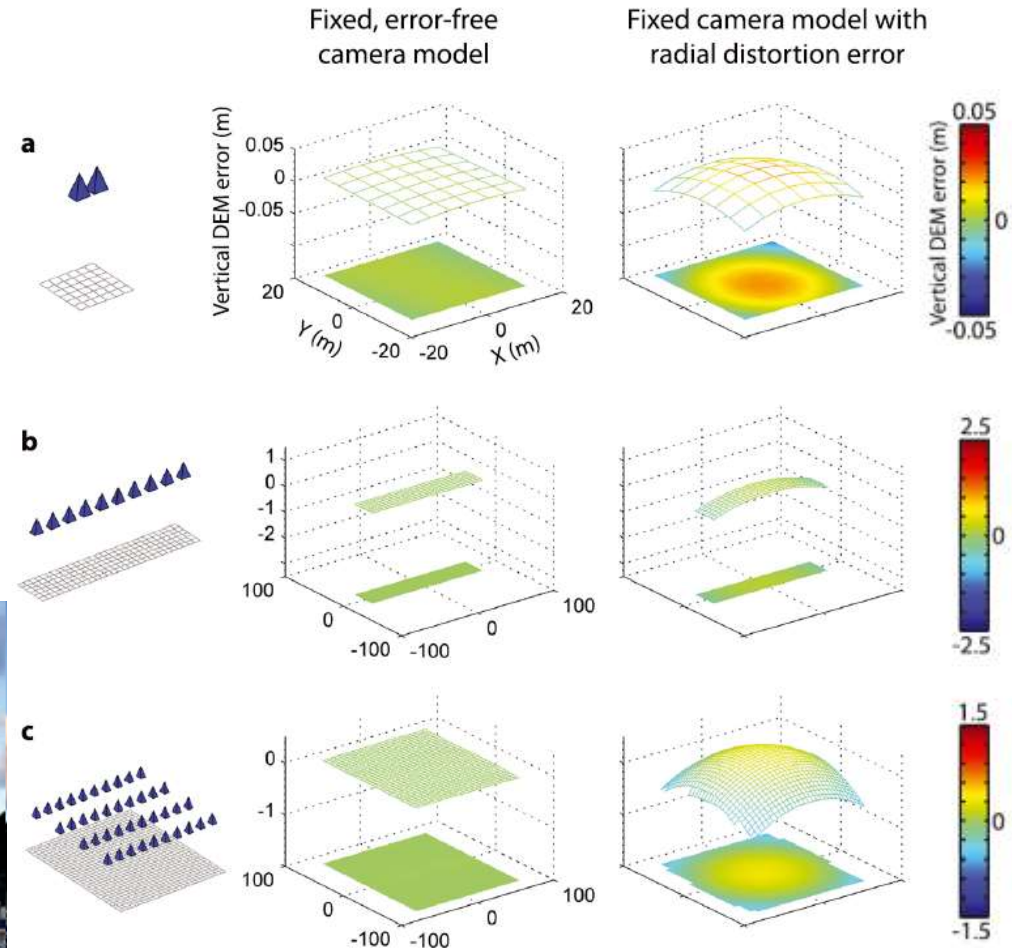
Resolution and precision of SfM topography



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

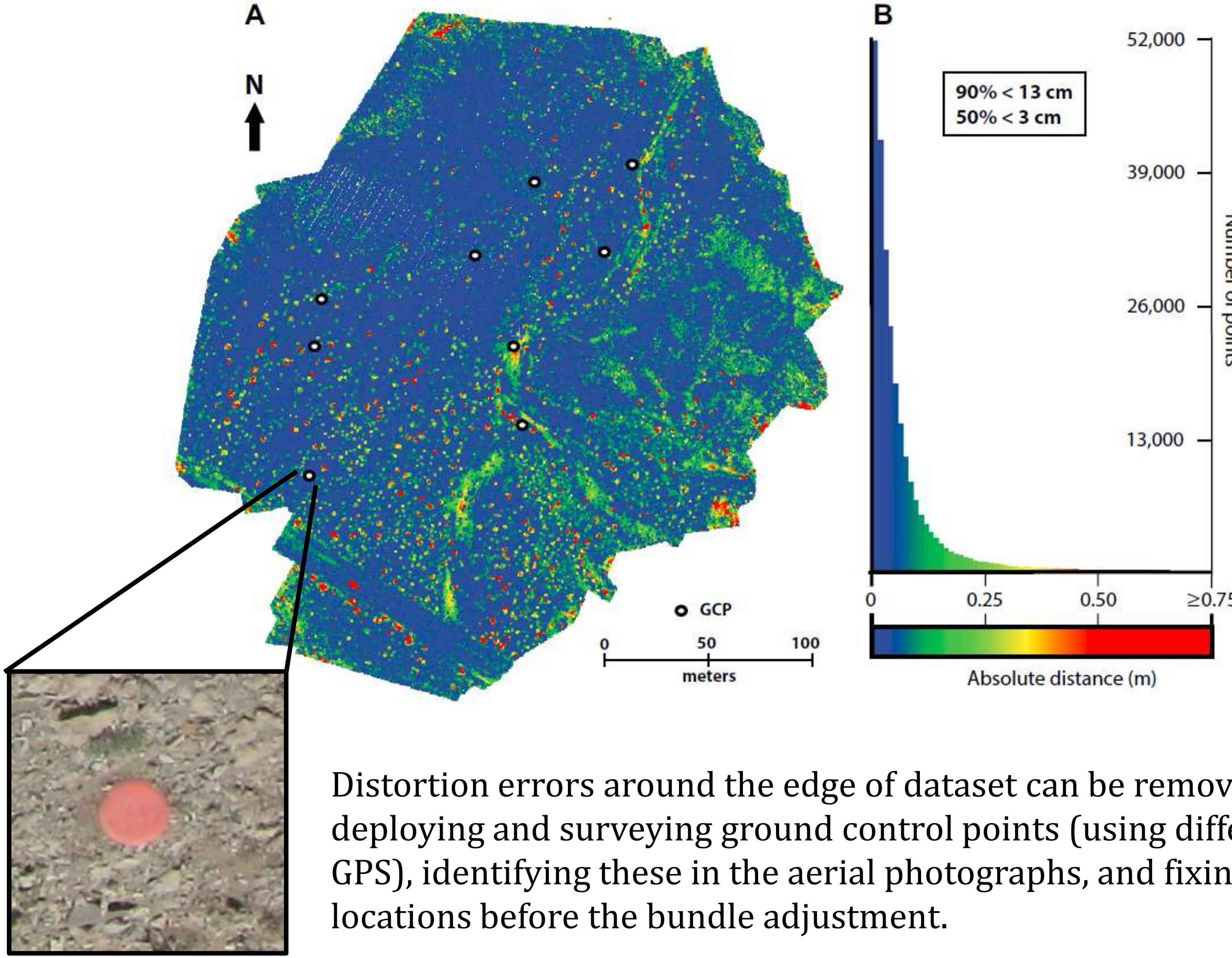
Resolution and precision of SfM topography





James & Robson (2014), *Earth Surface Processes and Landforms*

Resolution and precision of SfM topography

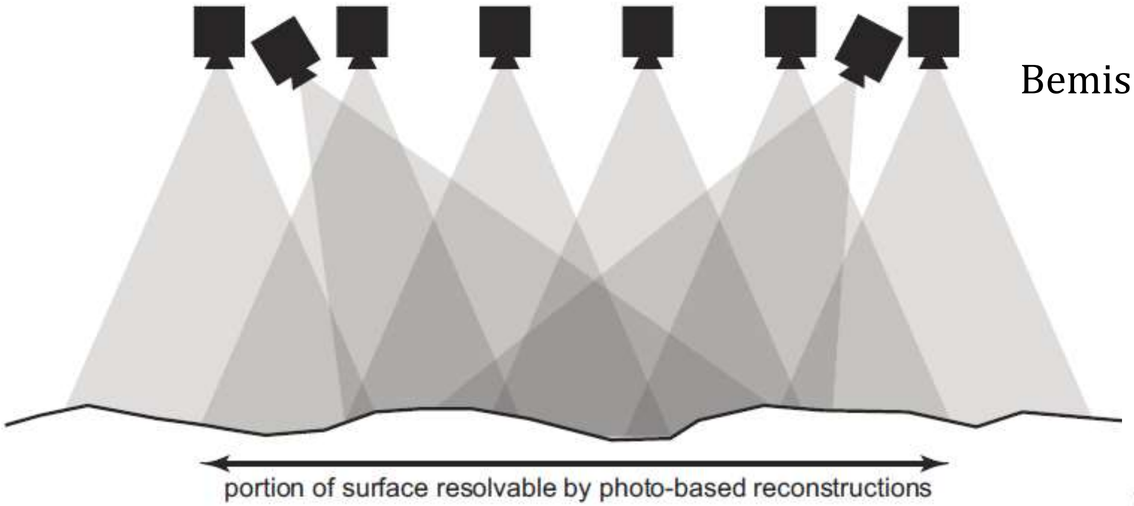


Distortion errors around the edge of dataset can be removed by deploying and surveying ground control points (using differential GPS), identifying these in the aerial photographs, and fixing the locations before the bundle adjustment.

SfM exercise

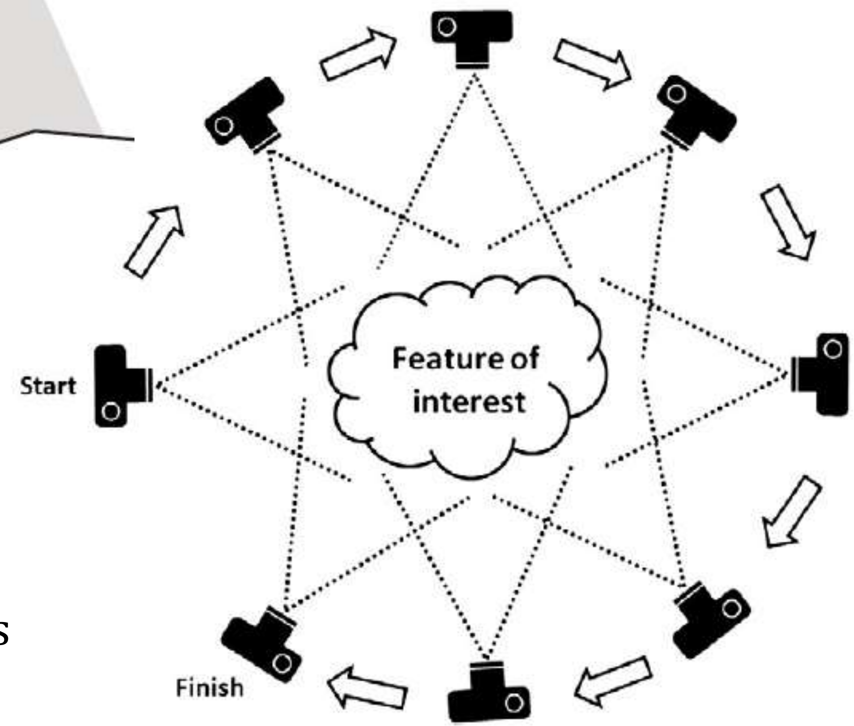
Option 1

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

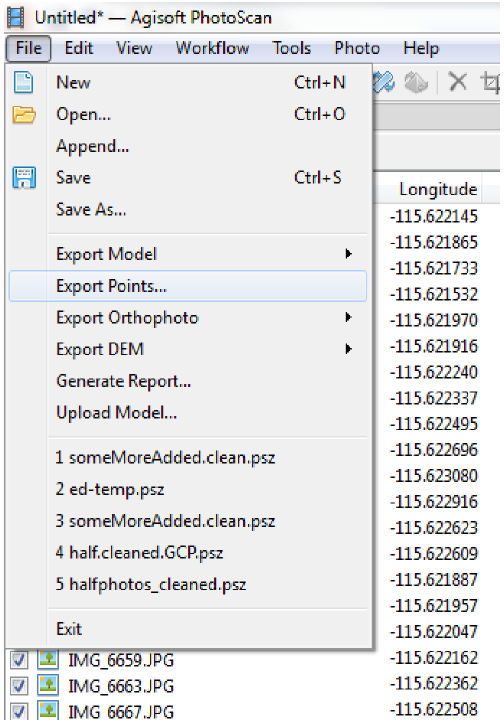
Option 2

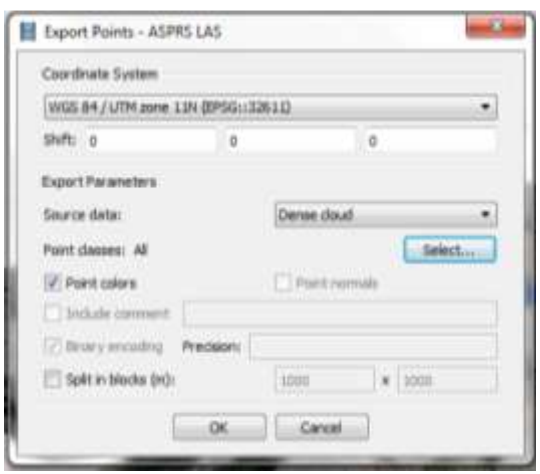
Build a model of the El Mayor-Cucapah rupture using 30 photos collected from a helium balloon

Tuesday, March 24, 2015

Time	Topic
8:30am	OpenTopography and other resources; open source tools and data discussion
9:30am	BCAL Lidar Tools
12:00pm	*Lunch*
1:00pm	**Structure from Motion (SfM)** • SfM Demo: El Mayor-Cucapah Earthquake Photos
3:30pm	**Lesson:**Topographic Change Detection, (e.g. iterative closest point (ICP) using CloudCompare)
5:00pm	Short course wrap up

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

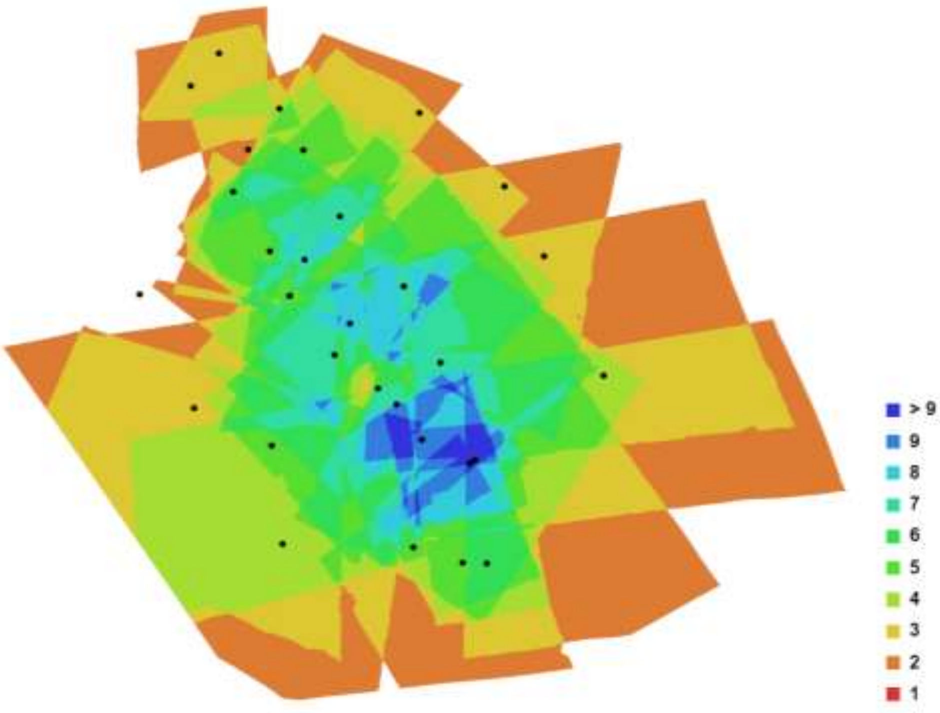
File > Export DEM

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)