Photogrammetric considerations for SfM-based topographic modelling

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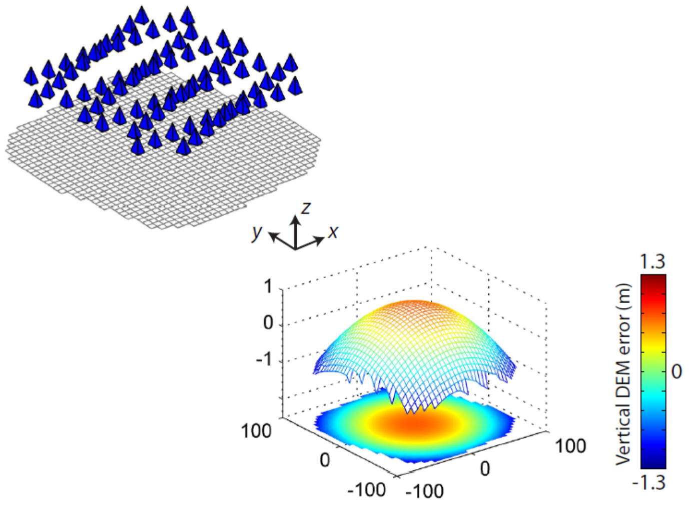
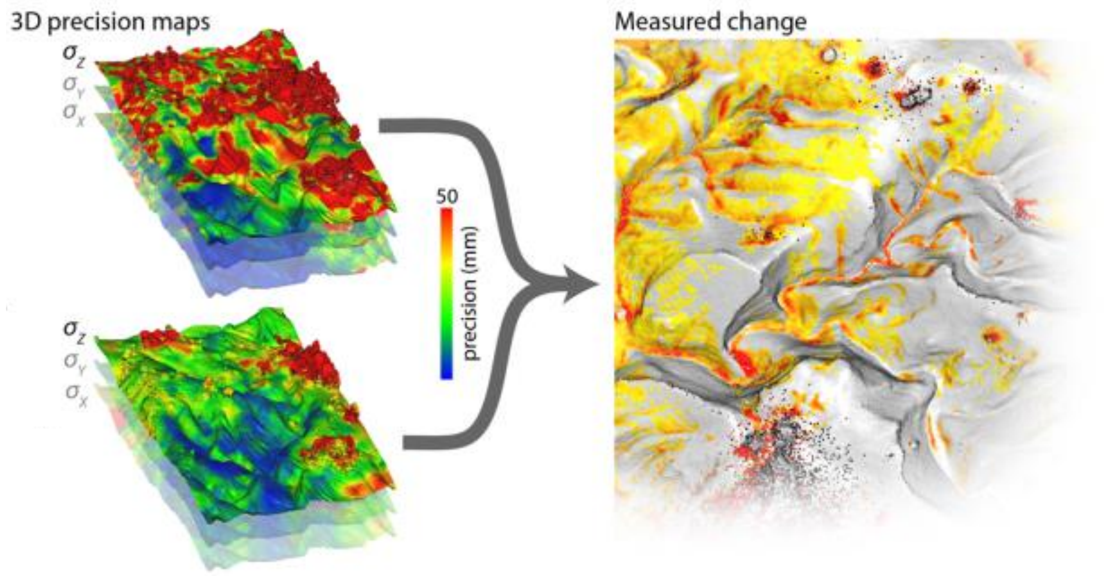
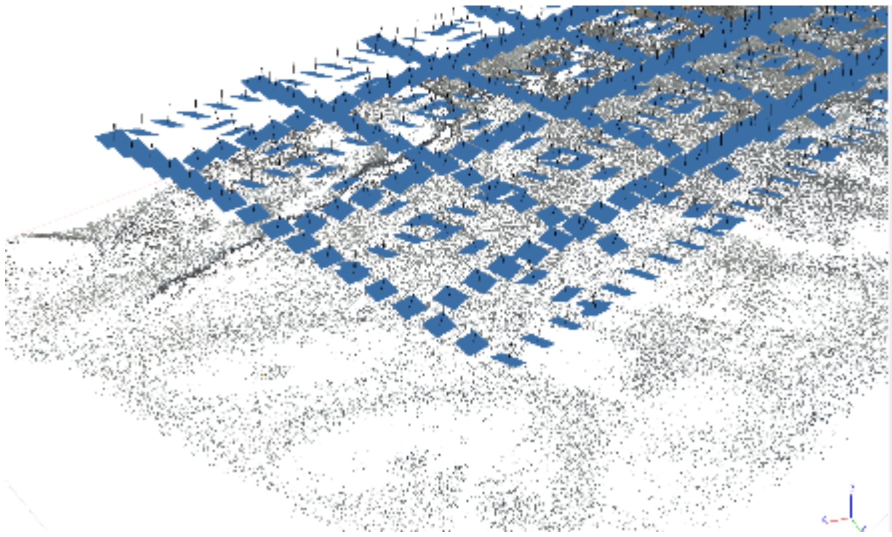


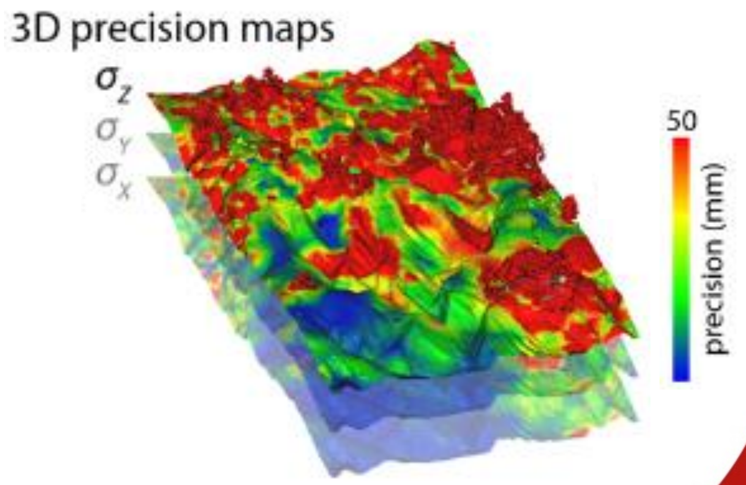


Stuart Robson, Gilles Antoniazza, Stuart Lane

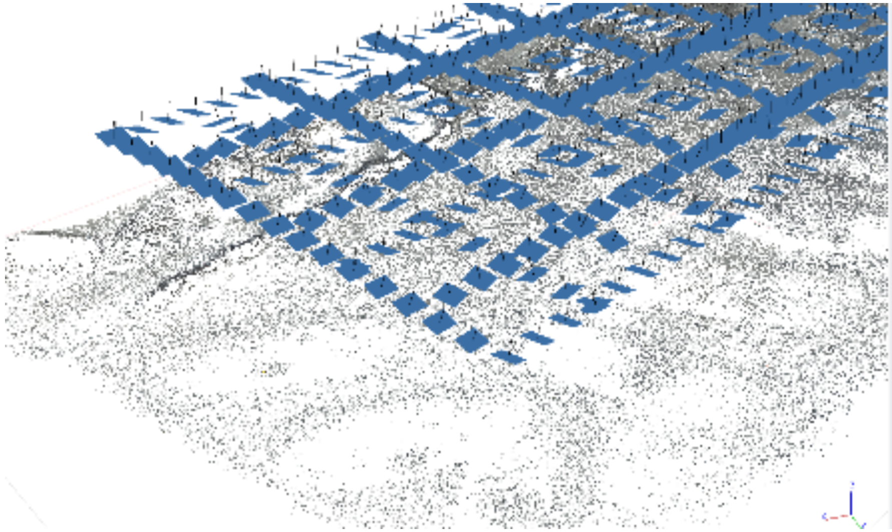
Outline

- Photogrammetry as model-fitting
  - a minimisation problem
- Accuracy
  - systematic model error
  - simulations and surveys from Arolla, Switzerland
- Precision
  - random model error
  - surveys of badlands, Spain





Topographic photogrammetry: *Modelling image observations*



A photogrammetric model estimates image observations using parameters to describe:

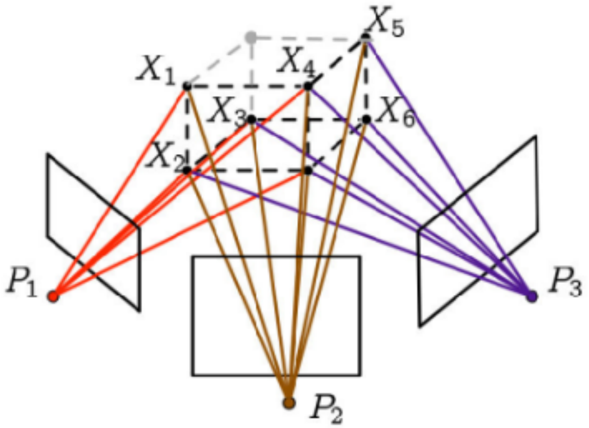
- 3D tie point positions (the 'sparse' point cloud)
- other 3D point positions (control/check points)
- positions and orientations of acquired photographs
- the camera itself (the 'camera model')

Parameter values are optimised ('bundle adjustment') to minimise overall model mistfit to:

- image observations of tie (and any other) points
- control observations (e.g. GCP coordinates)

infrequently reported, but important nevertheless!

usually reported, but *not* independent validation



$$\Pi(x,y,z) = \left(\frac{x}{z}, \frac{y}{z}\right) \qquad \min_{R_i, t_i, X_j} \sum_{ij} \|u_{ij} - \Pi(R_i X_j + t_i)\|^2$$

ceres-solver.org

As a generic modelling process…

Precision estimates can be made for all estimated parameters

- describe how well each parameter has been estimated, given the model structure and the precision of the observations (i.e. random errors):

  3D point positions, positions and orientations of acquired photographs, camera model parameters

Accuracy can only be assessed through comparison of estimated values with external independent measurements

- reflects systematic error resulting from errors in the model structure (e.g. in the camera model) or correlated parameters (inseparable effects within the optimisation)

Accurate camera calibration

For a strong camera calibration:

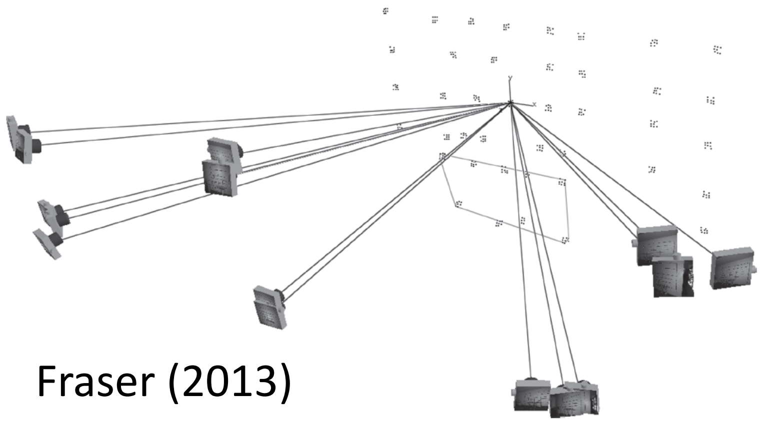
- invariant camera geometry
- convergent imagery, camera rolls
- large variations in observation distance both within and between images

'Standard' aerial survey designs typically involve:

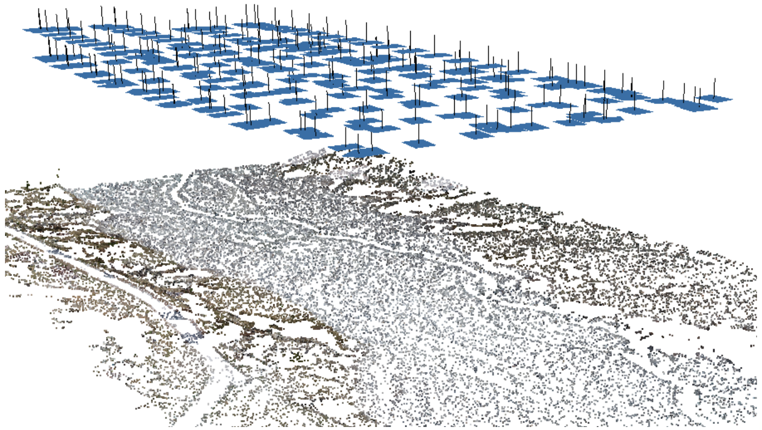
- parallel-axis imagery
- relatively similar observation distances

➔ Some camera parameter values can be poorly resolved, and correlate with surface shape

➔ More ground control effort is required to mitigate the resulting systematic error



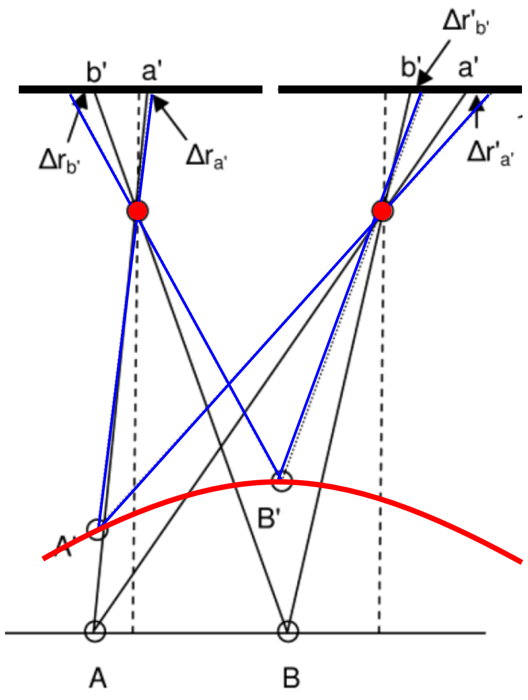
Fraser (2013)



Topographic doming in stereo pairs

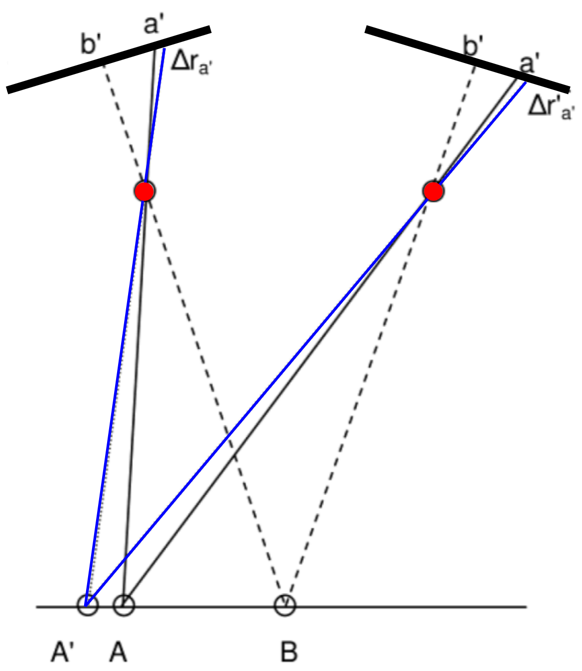
Parallel optic axes:

– radial lens distortion error inseparable from systematic topographic error



Convergent optic axes:

– reduces parameter correlations, so increases the accuracy of estimates

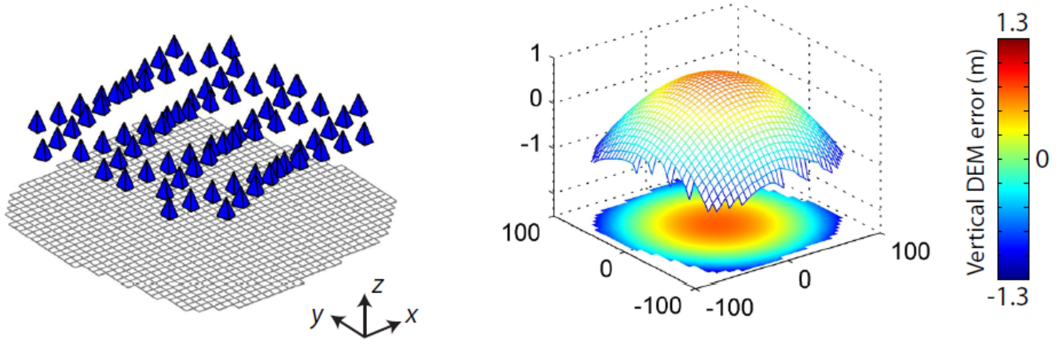


Wackrow & Chandler (2011)

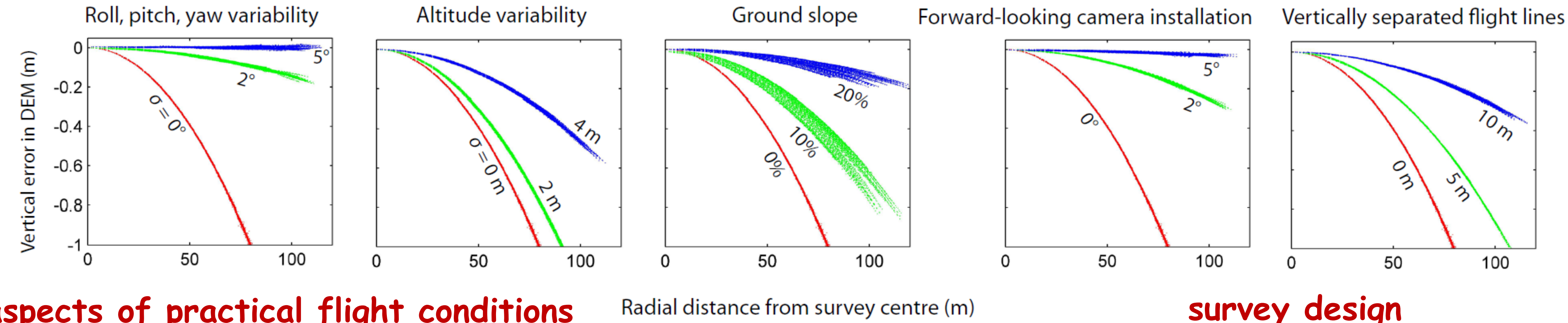
Topographic doming in image blocks

Inseparability of radial image distortion error and topographic error persists…

…but can be mitigated by convergent imaging (and other factors).



topographic target



aspects of practical flight conditions

survey design

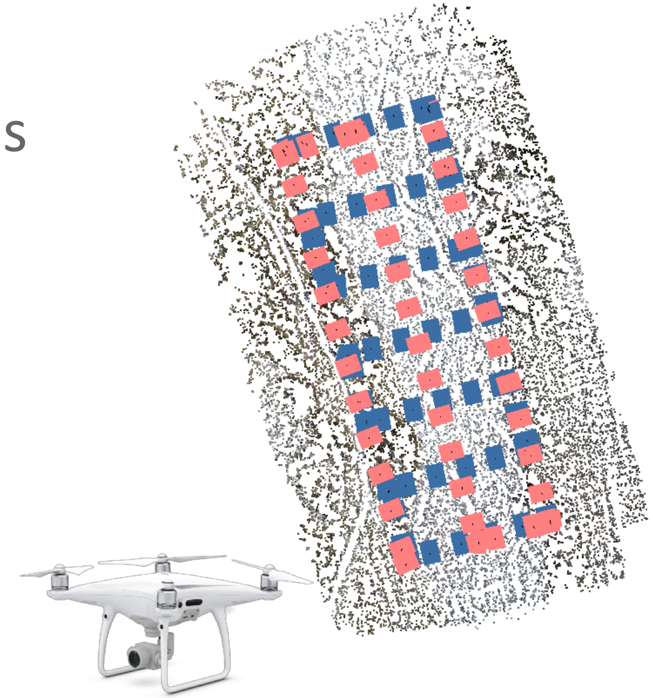
James & Robson (2014)

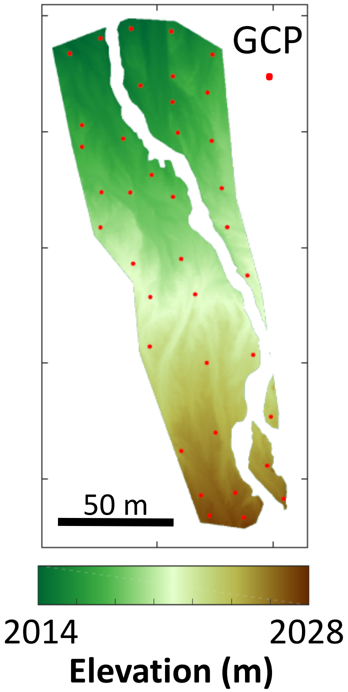
Testing the effect of camera inclination

Lancaster University

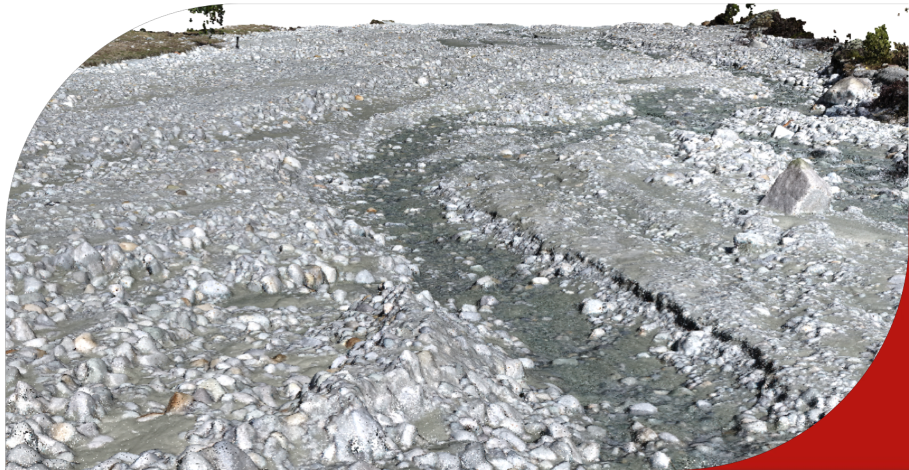
- DJI Phantom 4 Pro quadcopter (P4P)
- ~200 × 50 m, 'double-grid' of orthogonal flight lines
- 80% overlap (along and cross strip)

- 0, 10° & 15° camera pitch
- 30, 60, 90 m flight heights (8 – 25 mm GSD)
- ~110 – 600 images used per survey



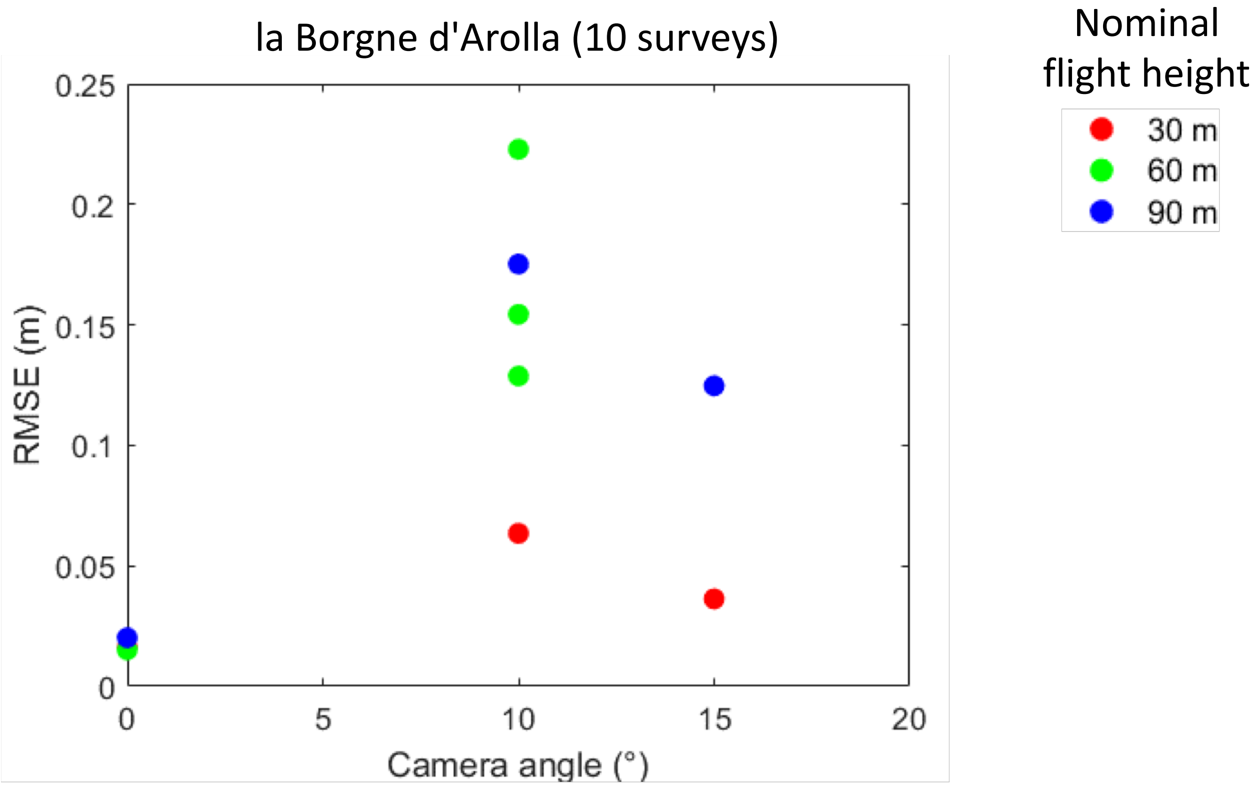


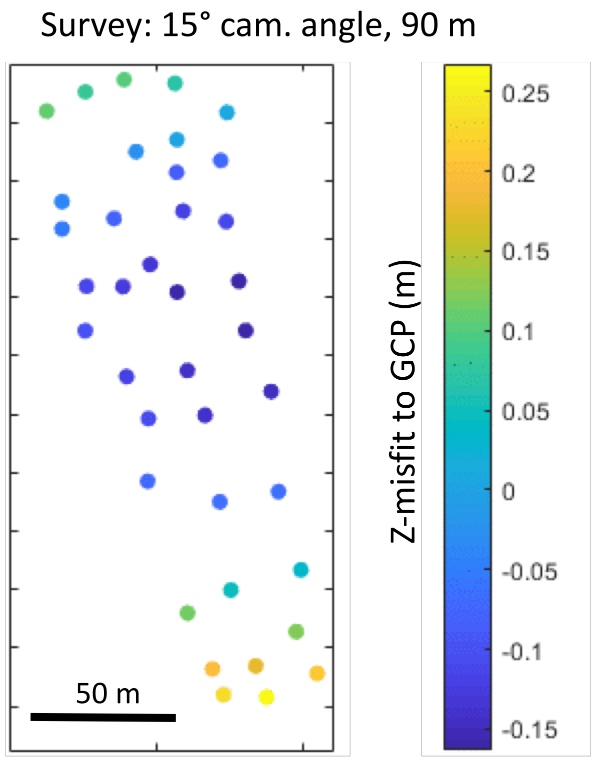
- ~40 ground control targets



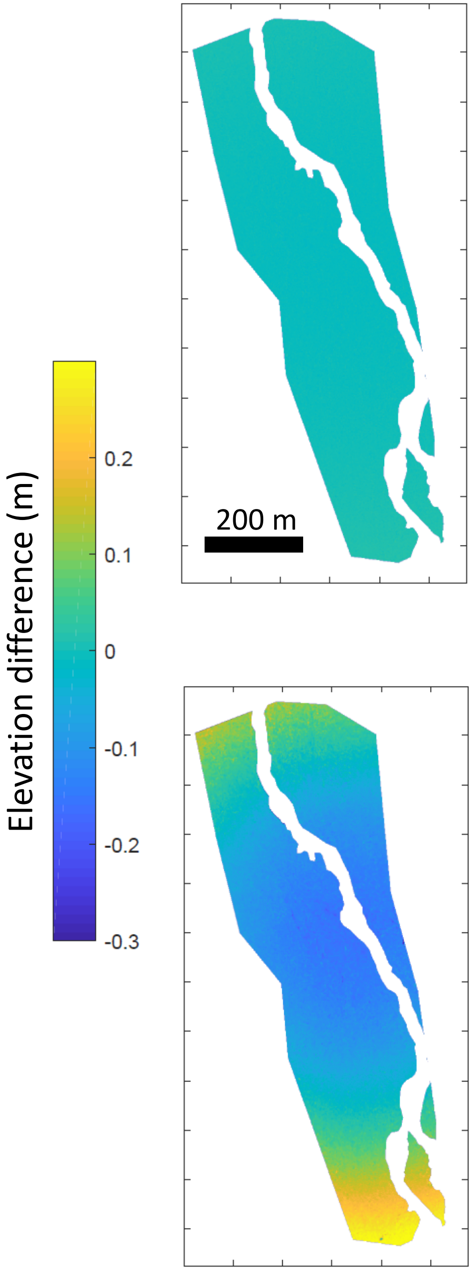
Misfit to GCP coordinates

- Surveys processed with a self-calibrating bundle adjustment
- GCPs *not* used within the adjustment, but only to scale and orient the results





Camera parameter correlations



0° forward pitch (nadir)

Camera parameter correlation coefficients

	Value	Precision	F	CCx	CCy	K1	K2	K3	K4	P1	P2
F	3627	0.910659	1.00	0.24	0.66	0.16	-0.37	0.49	-0.57	-0.19	-0.28
CCx	-15.761	0.024858		1.00	0.18	0.06	-0.10	0.13	-0.15	0.38	0.04
CCy	-2.48439	2.94E-02			1.00	0.11	-0.24	0.33	-0.38	-0.13	0.07
K1	0.002752	4.55E-05				1.00	-0.78	0.72	-0.67	0.02	0.15
K2	-0.06671	0.000181					1.00	-0.98	0.94	0.07	0.10
K3	0.120099	0.000366						1.00	-0.99	-0.09	-0.13
K4	-0.07005	2.47E-04							1.00	0.10	0.15
P1	-0.00087	1.10E-06								1.00	0.08
P2	-0.00115	8.62E-07									1.00

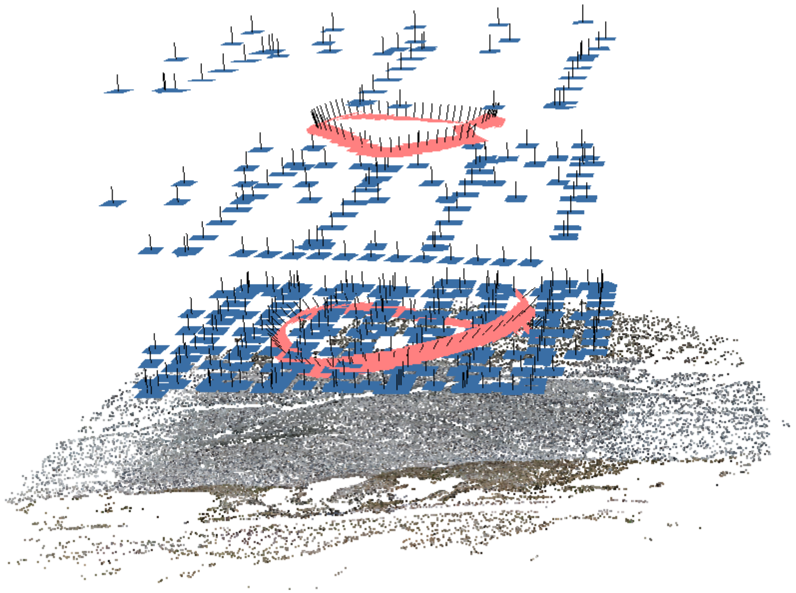
15° forward pitch

Camera parameter correlation coefficients

	Value	Precision	F	CCx	CCy	K1	K2	K3	K4	P1	P2
F	3606.97	0.19605	1.00	0.05	-0.95	0.32	-0.07	0.11	-0.14	-0.02	-0.67
CCx	-19.1492	0.014734		1.00	-0.05	0.01	-0.01	0.02	-0.02	0.65	0.00
CCy	0.832332	0.053243			1.00	-0.39	0.09	-0.12	0.16	0.00	0.79
K1	0.001276	3.53E-05				1.00	-0.89	0.86	-0.82	0.00	-0.48
K2	-0.06599	0.000149					1.00	-0.99	0.96	-0.01	0.09
K3	0.117918	0.000281						1.00	-0.99	0.01	-0.11
K4	-0.06833	0.00018							1.00	-0.01	0.13
P1	-0.00091	9.89E-07								1.00	0.01
P2	-0.001	2.69E-06									1.00

Stronger camera calibration

Combine images captured at different elevations and from convergent 'point of interest' surveys



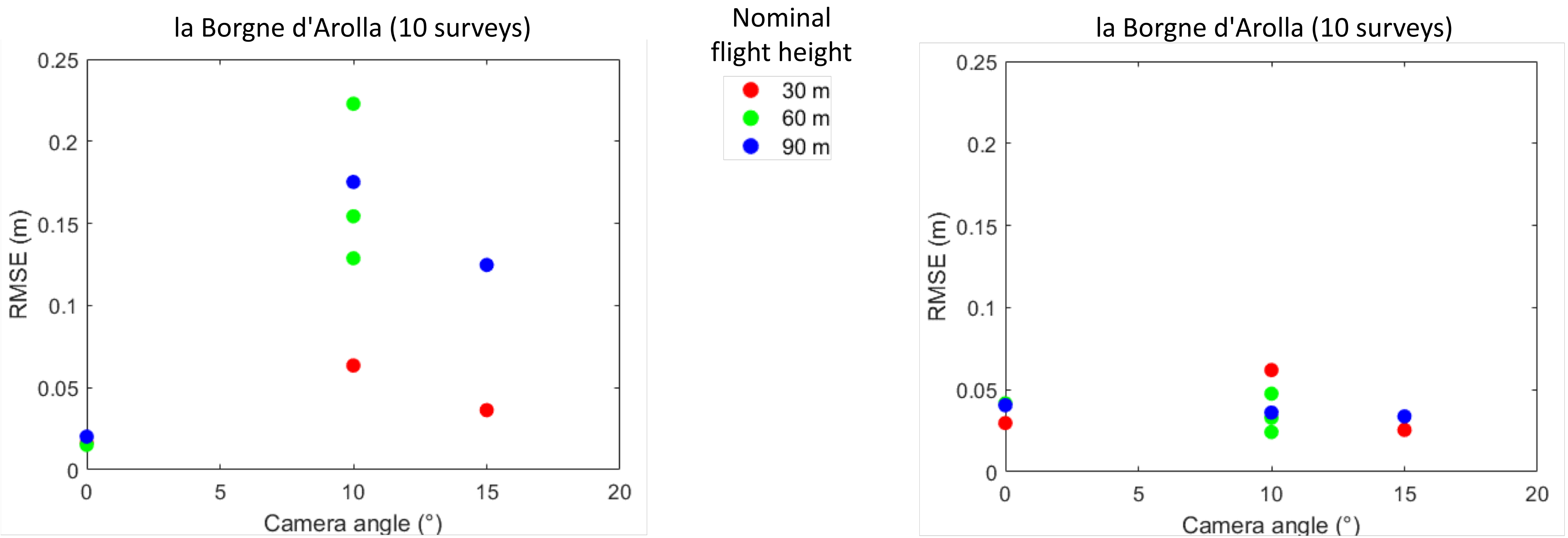
Camera parameter correlation coefficients

	Value	Precision	F	CCx	CCy	K1	K2	K3	K4	P1	P2
F	3621.11	0.0298674	1.00	-0.01	-0.64	-0.19	0.17	-0.15	0.13	0.01	-0.07
CCx	-17.4855	0.0119255		1.00	0.01	0.00	-0.00	0.01	-0.01	0.72	0.02
CCy	-3.40902	0.0163457			1.00	-0.02	0.01	-0.01	0.02	-0.01	0.40
K1	0.00152551	2.86006e-05				1.00	-0.97	0.93	-0.88	-0.00	-0.03
K2	-0.062831	0.000137838					1.00	-0.99	0.96	0.00	0.01
K3	0.113253	0.000261105						1.00	-0.99	0.00	-0.01
K4	-0.0659441	0.000167682							1.00	-0.00	0.01
P1	-0.000863482	8.83663e-07								1.00	0.02
P2	-0.00116292	6.97089e-07									1.00

Improved misfit to GCP coordinates

self-calibrating bundle adjustment

fixed camera calibration



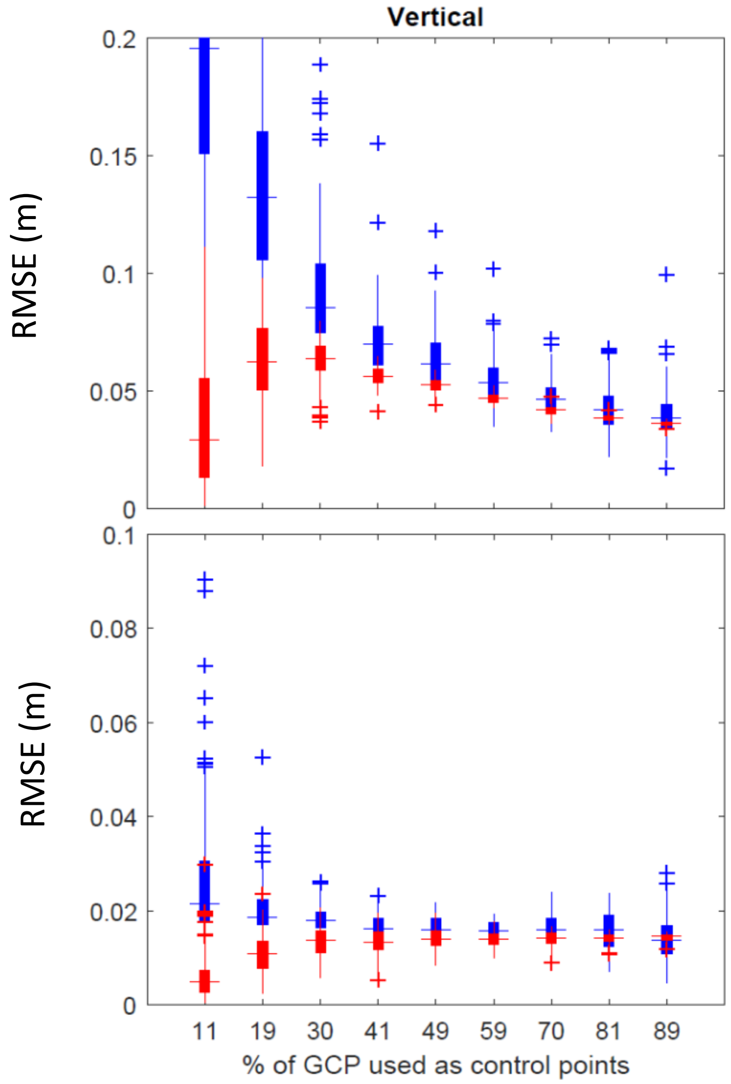
Improving accuracy with ground control

Lancaster University

The influence of ground control points on:

A survey vulnerable to systematic error (10° camera pitch)

A survey resilient to systematic error (0° camera pitch)



Points:

Blue = check

Red = control

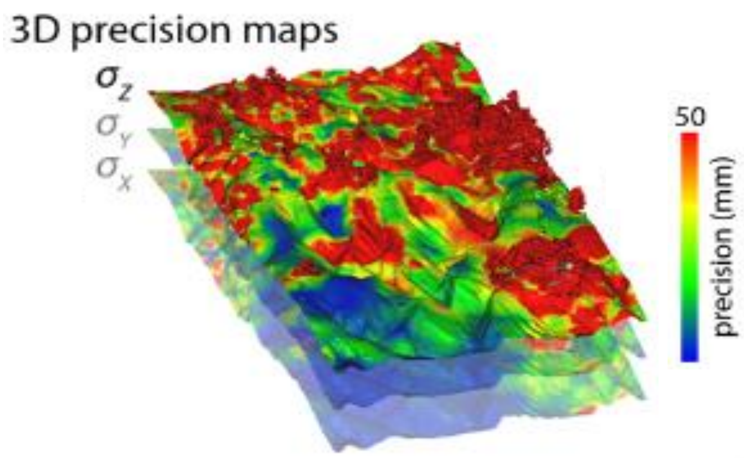
3D point coordinate precision

Lancaster University

Point precision information is (slowly) becoming available in SfM-based photogrammetry software, but can also be derived using a Monte Carlo approach (James *et al*. 2017b).

Estimates of 3D point coordinate precision to be separated into components of:

- **Photogrammetric precision**
  - Describes the reproducibility of the *surface shape*
- **Georeferencing precision**
  - Describes the reproducibility of the *scale, translation and rotation* of the survey within a geographic coordinate system

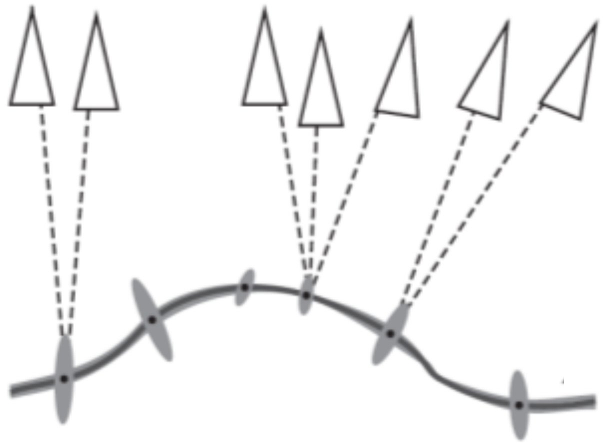


Components of survey precision: *Photogrammetric*

Describes the reproducibility of the *surface shape*

A function of:

- image measurement precision
- number of images each point is observed in
- geometry of the image network



James *et al.* (2017b)

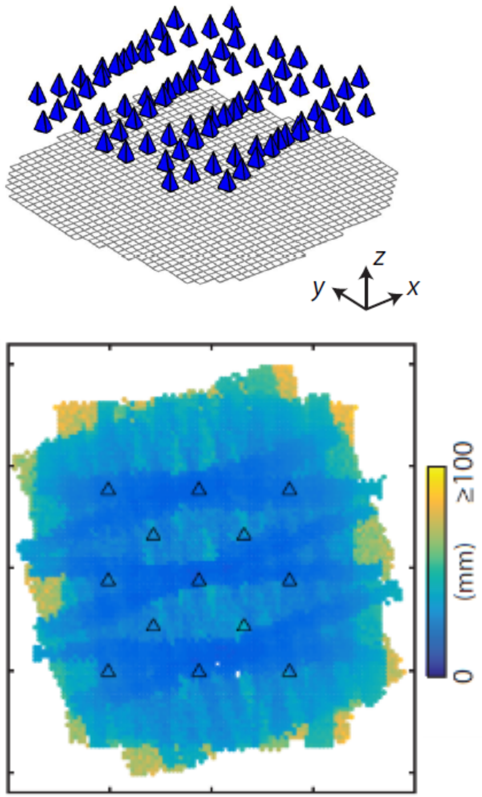
Components of survey precision: *Photogrammetric*

If a survey's overall precision is limited by photogrammetric considerations then

- Precision varies irregularly, reflecting changes in image content, imaging geometry etc…

Precision deteriorates with:

- Less precise image matching.
- Fewer observations of individual points,
- from increasingly parallel directions



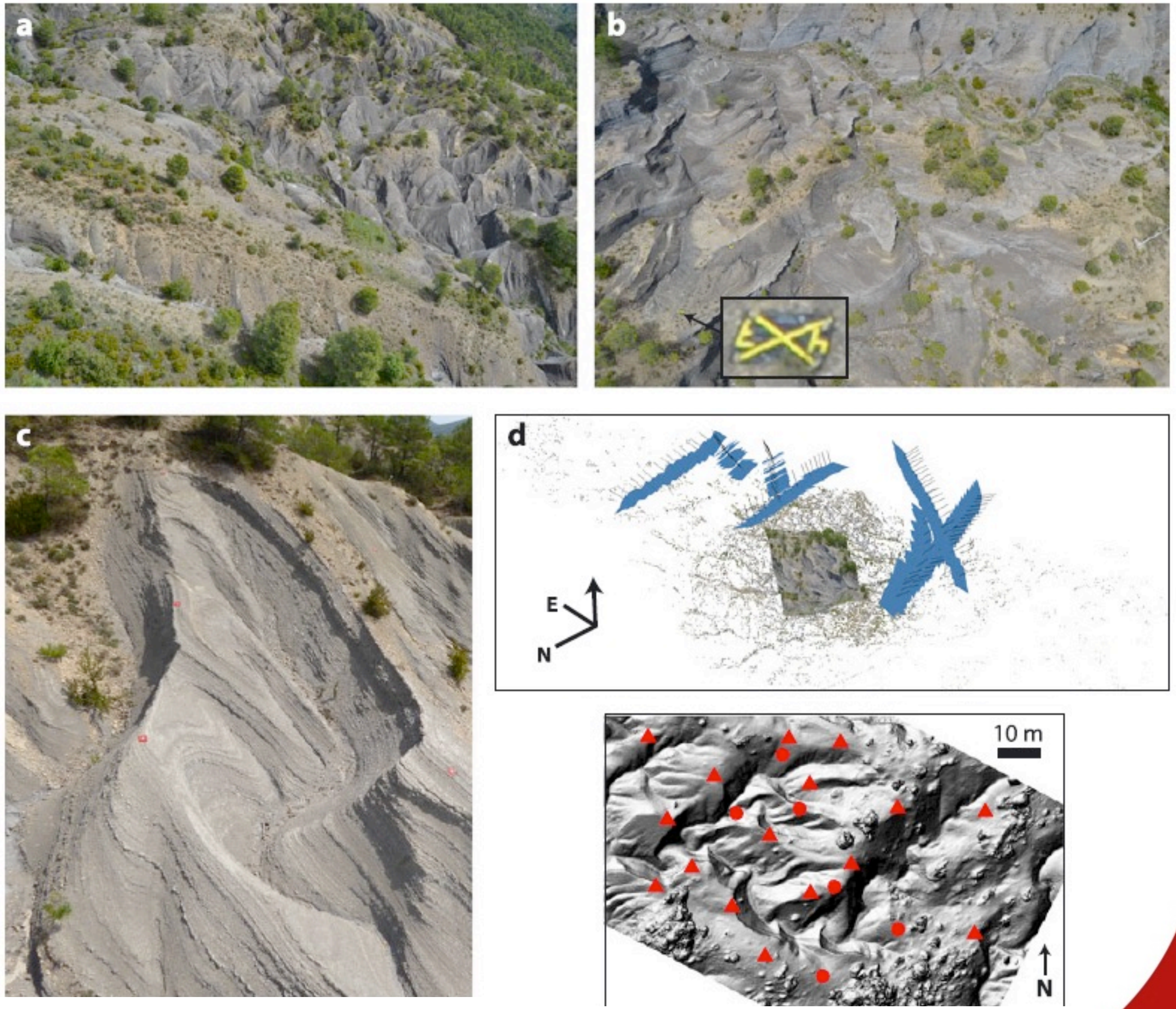
James *et al.* (2017b)

Precision estimates for complex topography

River Cinca, Central Pyrenees, Spain

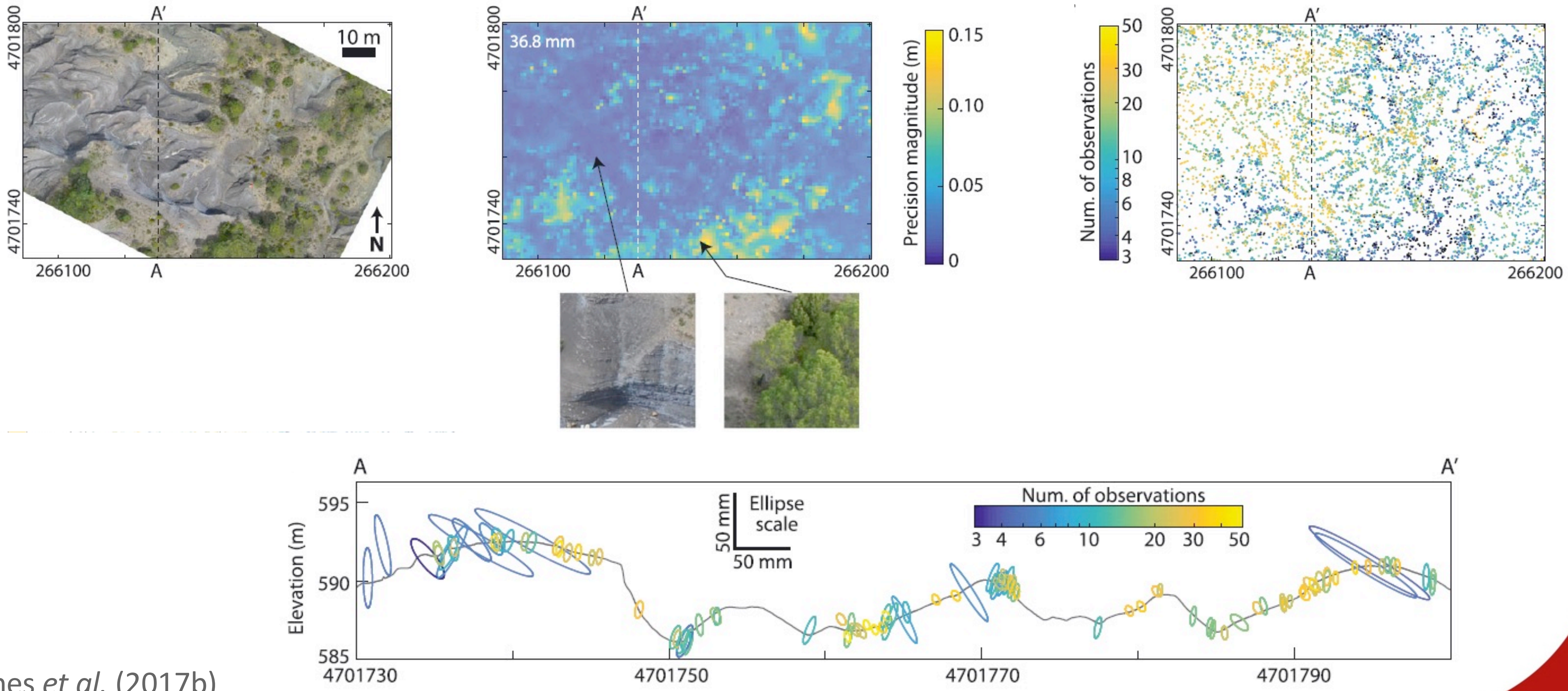
- Gyrocopter-based surveys in 2014, 2015
- Nikon D3100 & D75, 28 mm lens
- Oblique overpasses at a nominal altitude of ~50 m

- 19-20 GCPs, 7 check points
- RMS discrepancies:
  - 2014: ~50 mm
  - 2015: ~15 mm



James *et al.* (2017b)

Precision estimates for complex topography



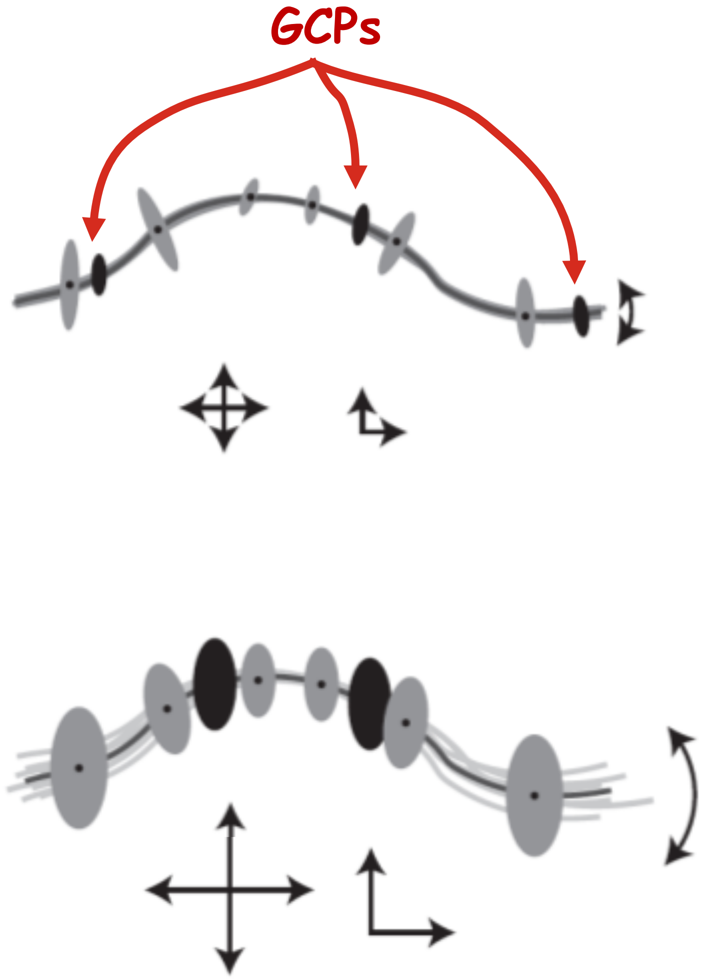
James *et al.* (2017b)

Components of survey precision: *Georeferencing*

Describes the reproducibility of the overall *scale, translation and rotation* of the survey within a geographic coordinate system

A function of the control measurements:

- number of control measurements
- distribution of control
- precision of control measurements



James *et al.* (2017b)

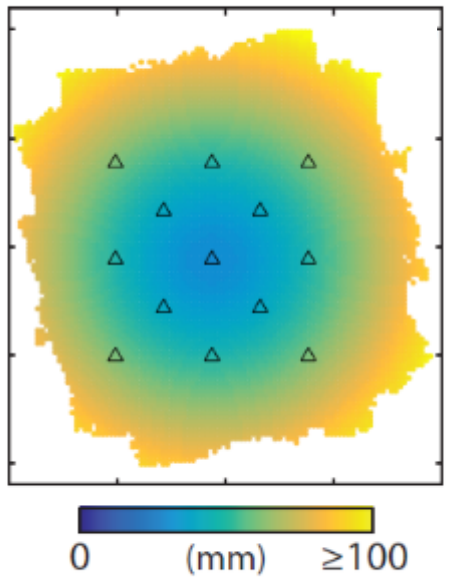
Components of survey precision: *Georeferencing*

If a survey's overall precision is limited by georeferencing then

- point precision varies gradually and systematically

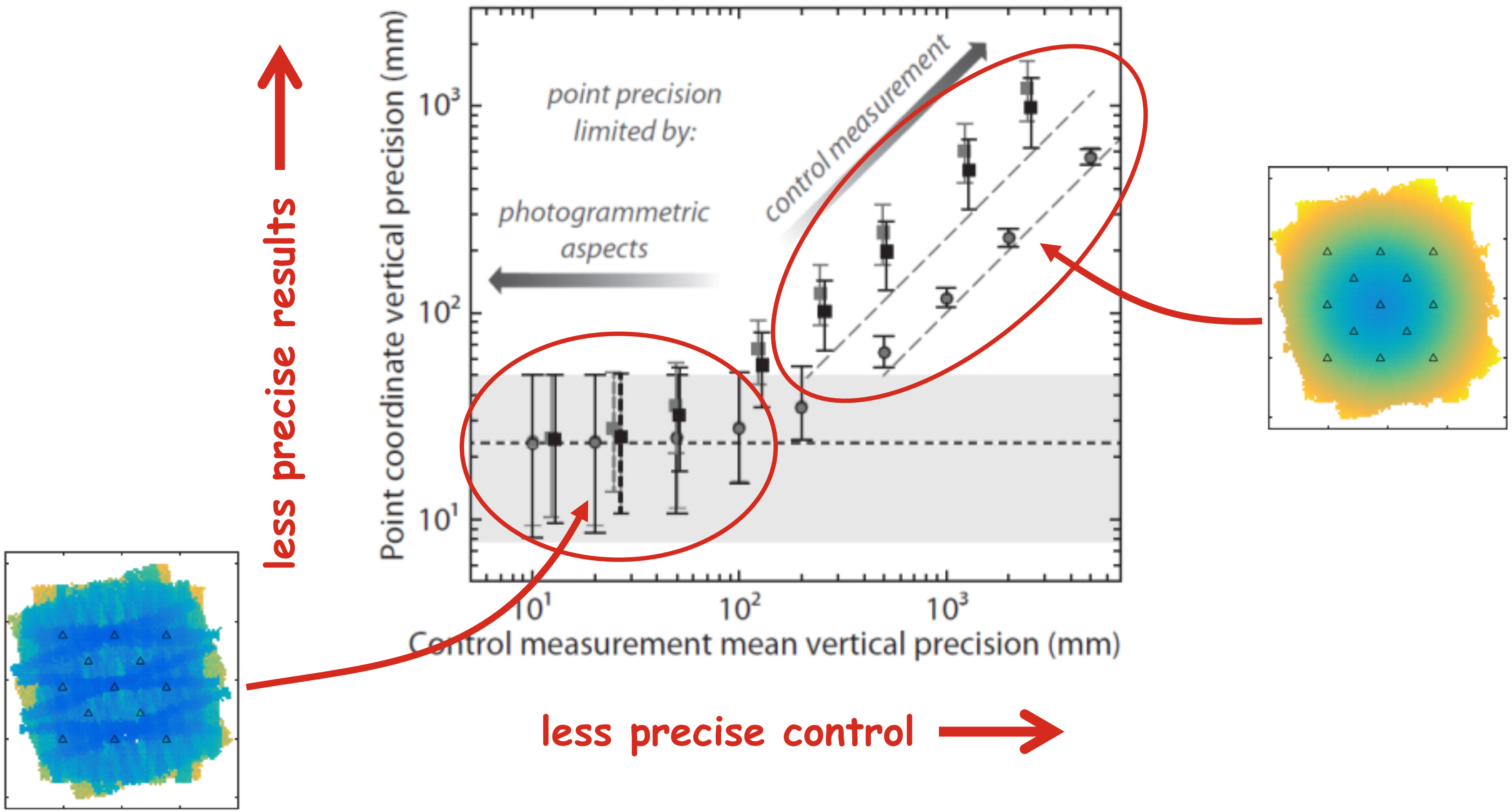
Point precision deteriorates with:

- increasing distance from the centroid of the control measurements
- fewer (or less well distributed) control measurements
- less precise control measurements



James *et al.* (2017b)

Survey precision: A combination of photogrammetric and georeferencing effects



James *et al.* (2017b)

Conclusions

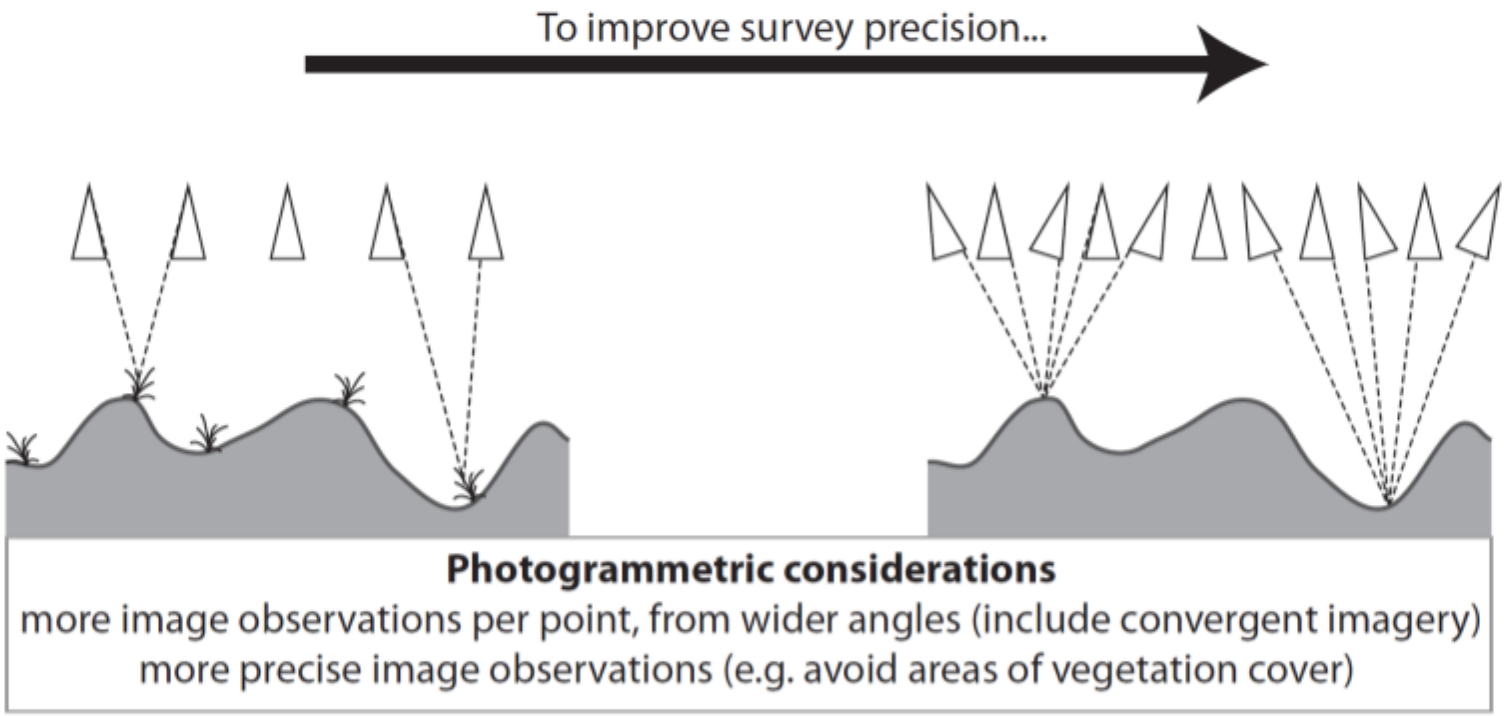
To assess the quality of topographic models:

- consider image residual magnitudes
- check for unexpectedly large correlations between camera parameters that can highlight problems
- visualise the spatial distribution of misfit to independent check data

When comparing topographic models:

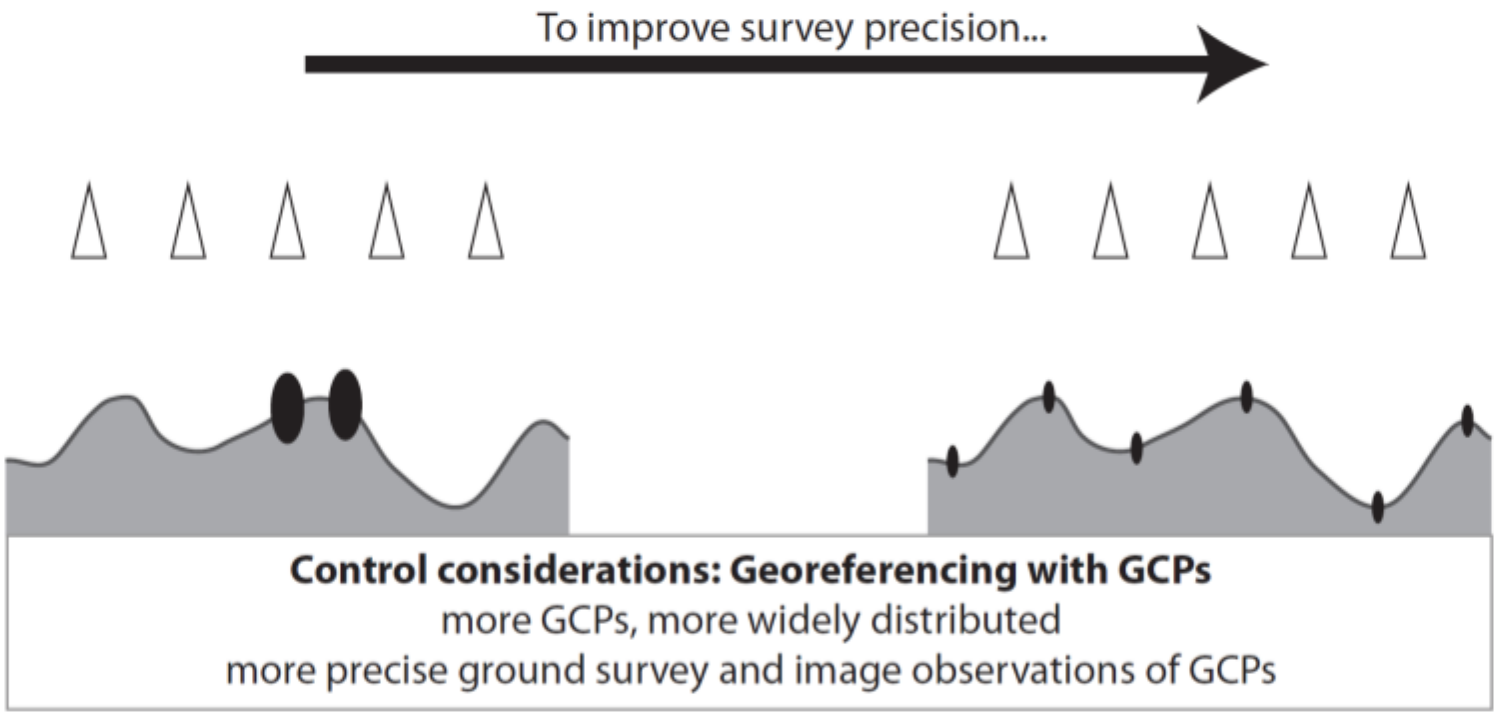
- check for systematic error (accuracy problems)
- consider differences in light of the the expected (or modelled) measurement precision

Recommendations for improving precision: Photogrammetric considerations



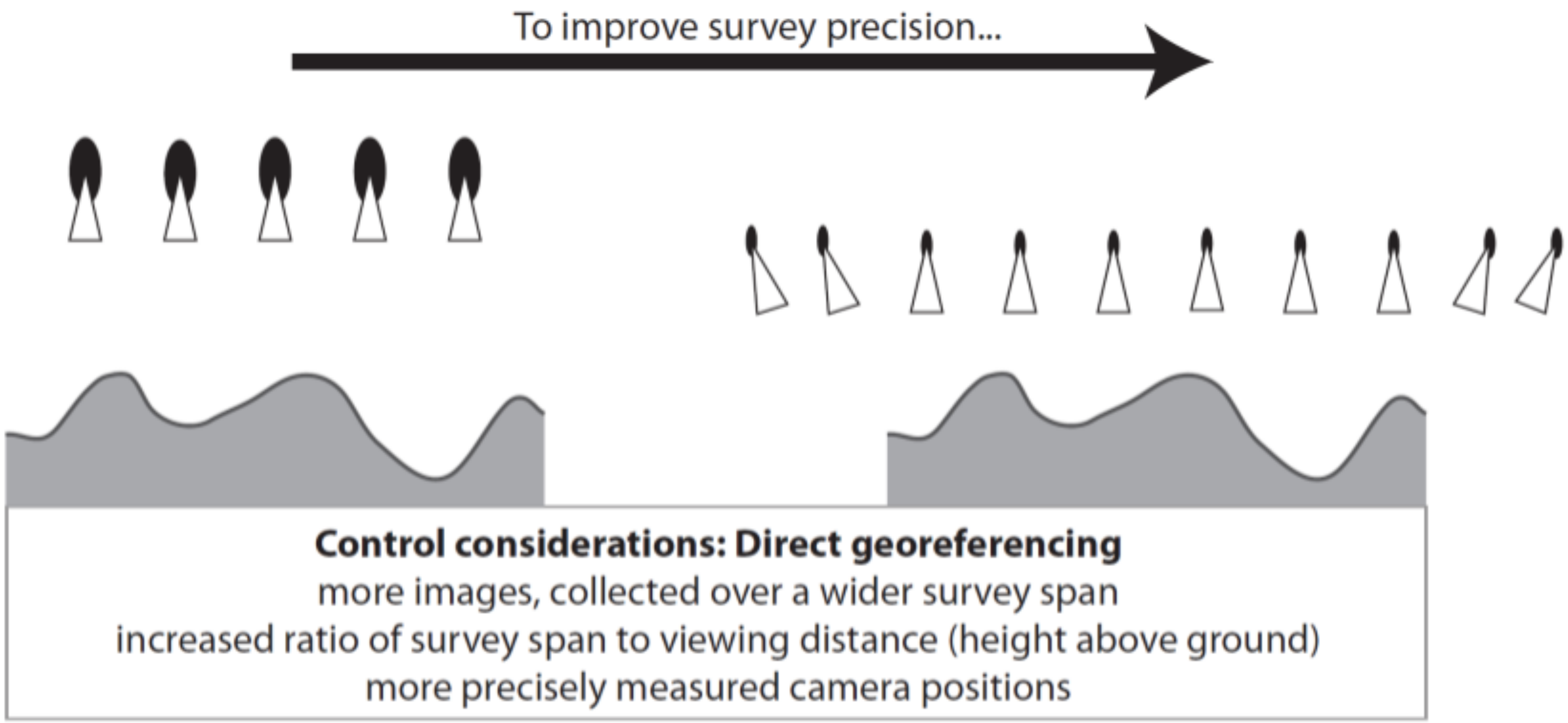
James *et al.* (2017b)

Recommendations for improving precision: Geo-referencing considerations with GCPs



James *et al.* (2017b)

Recommendations for improving precision: Considerations for direct geo-referencing



James *et al.* (2017b)