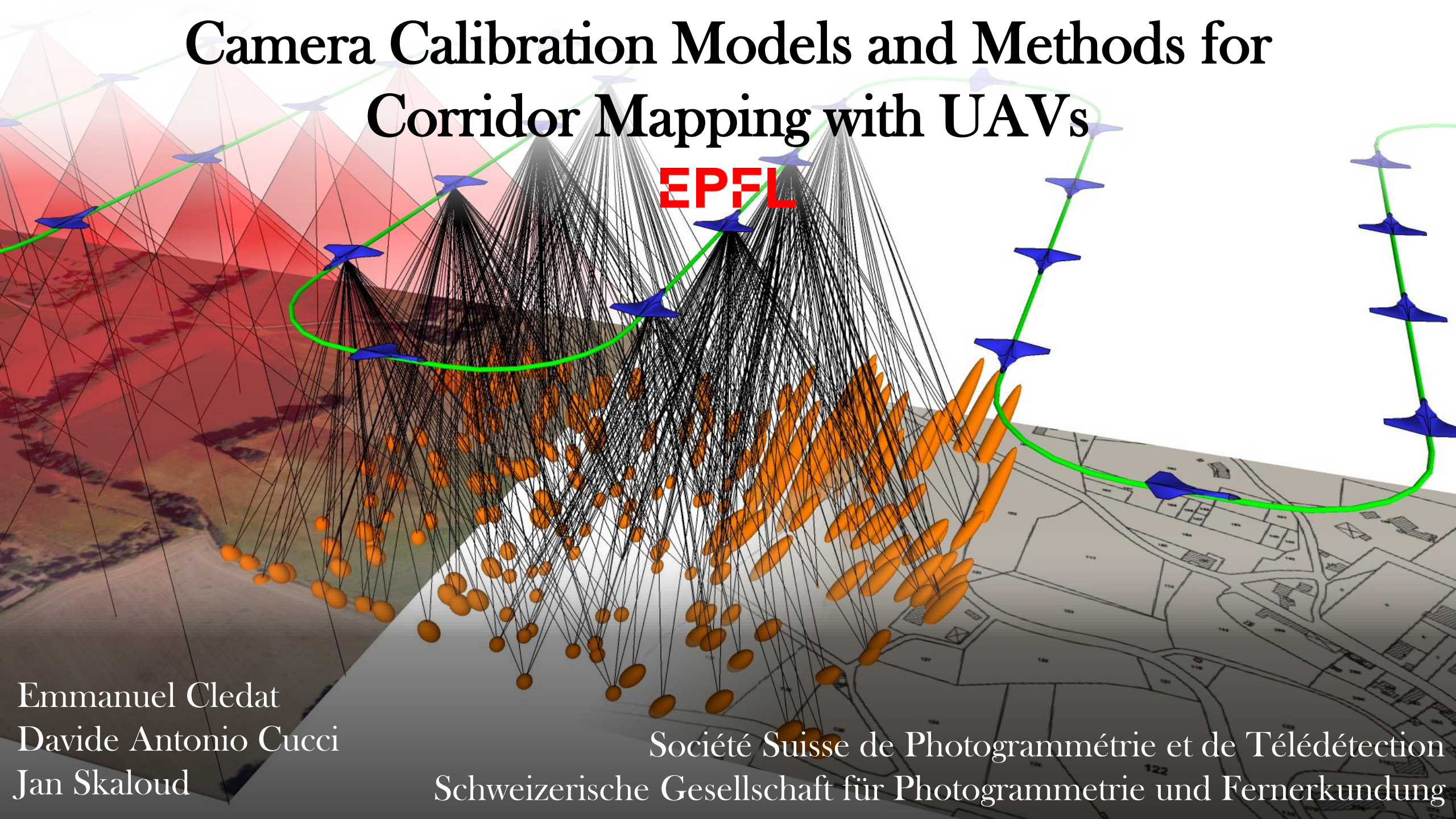
Camera Calibration Models and Methods for Corridor Mapping with UAVs

EPFL



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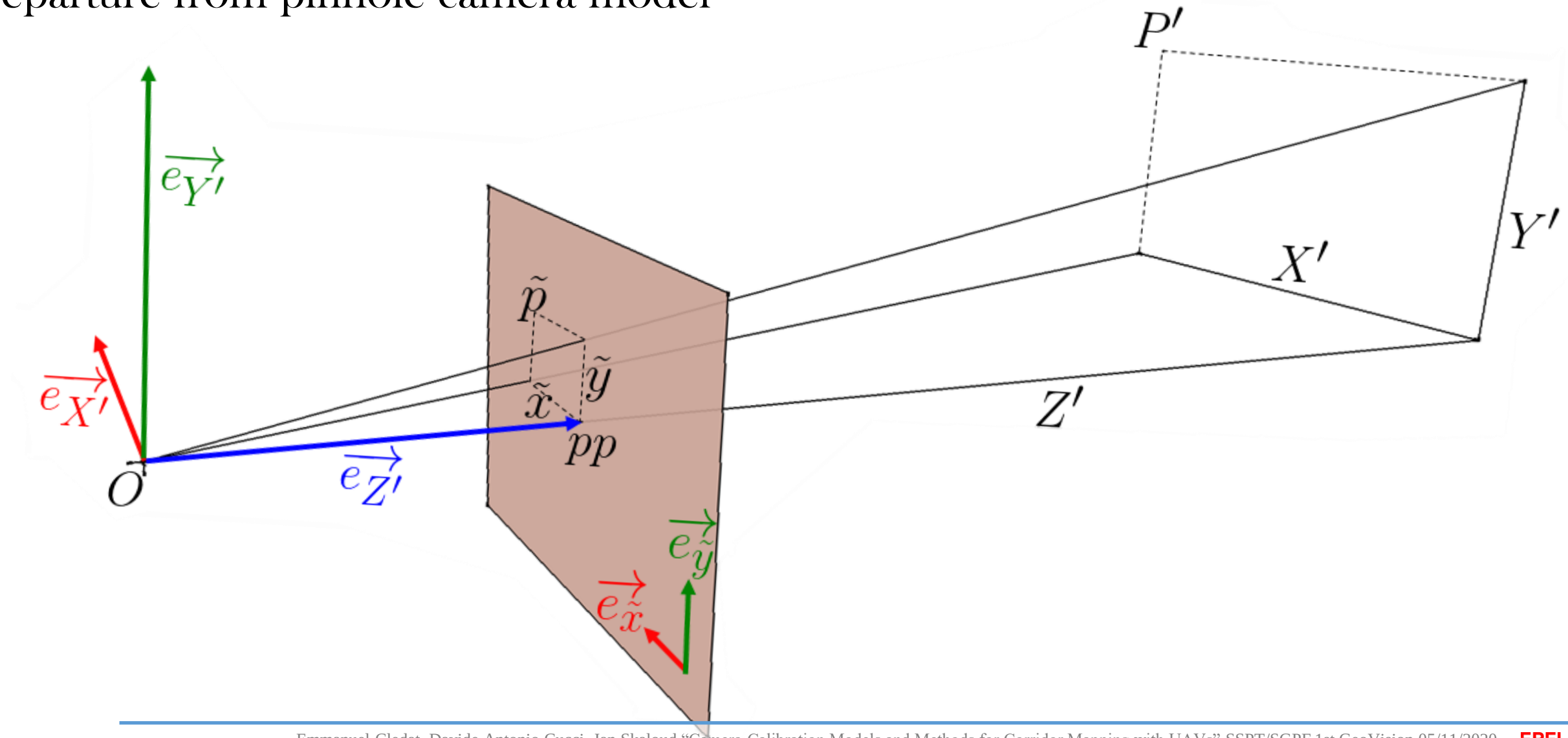
Schweizerische Gesellschaft für Photogrammetrie und Fernerkundung

Camera Calibration Models and Methods... Why?

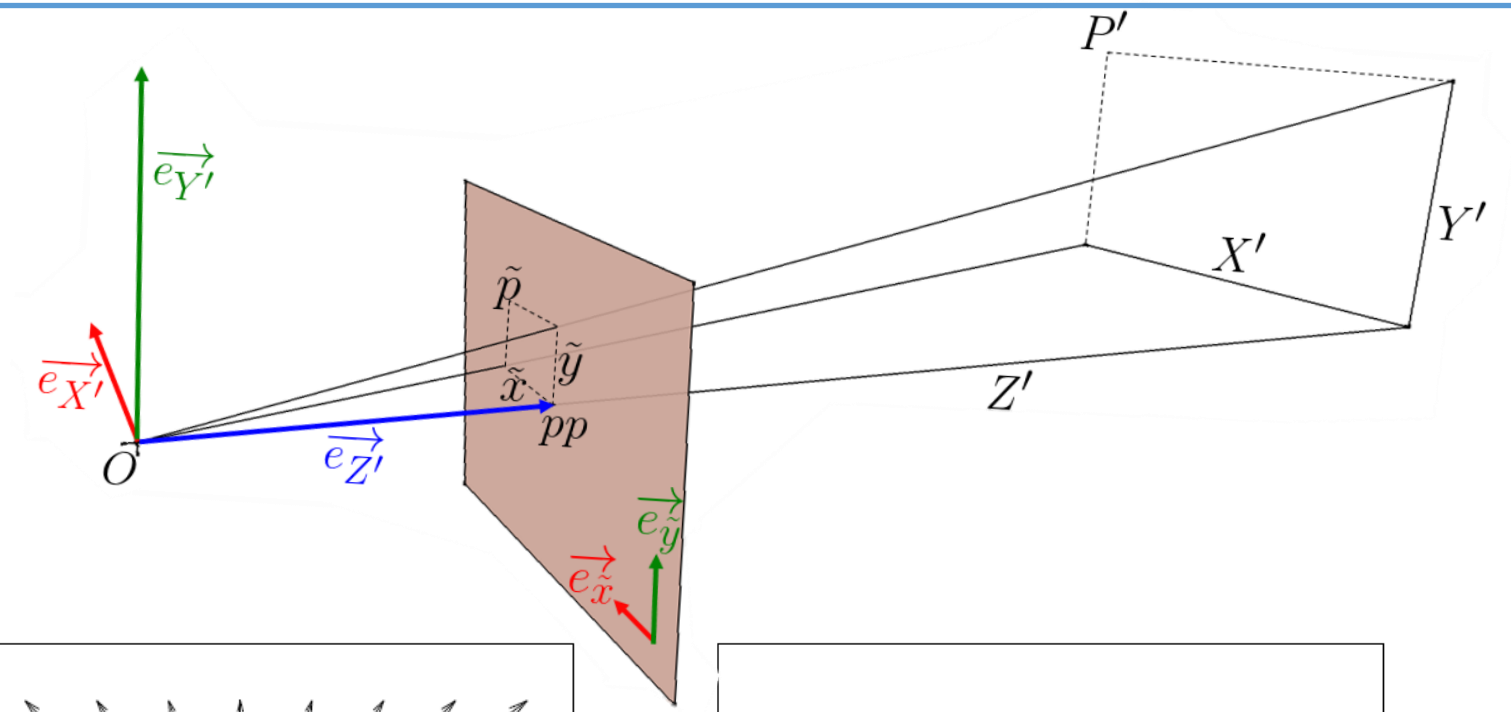
- Camera model
- Calibration method
- Usage mode for mapping

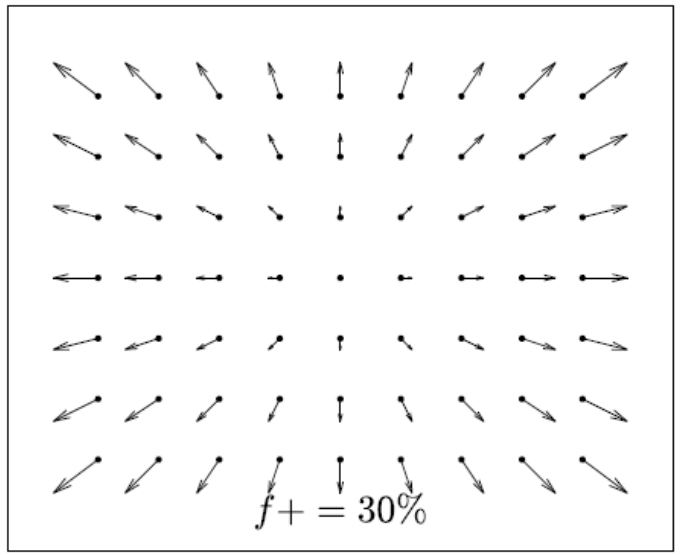
Camera models...

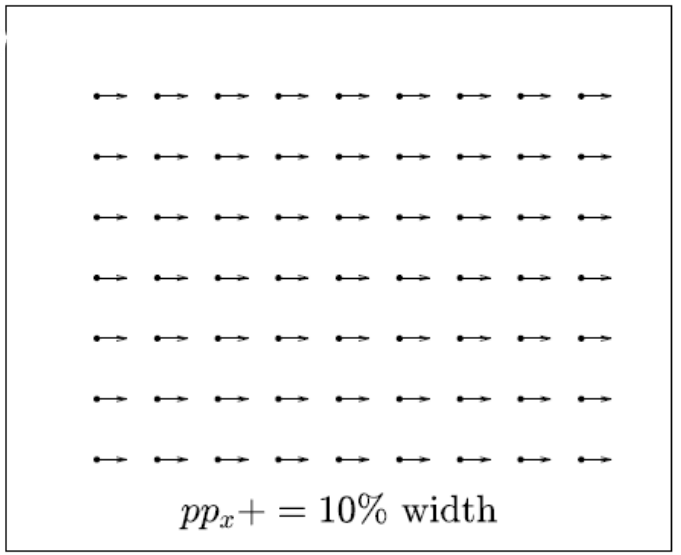
Departure from pinhole camera model

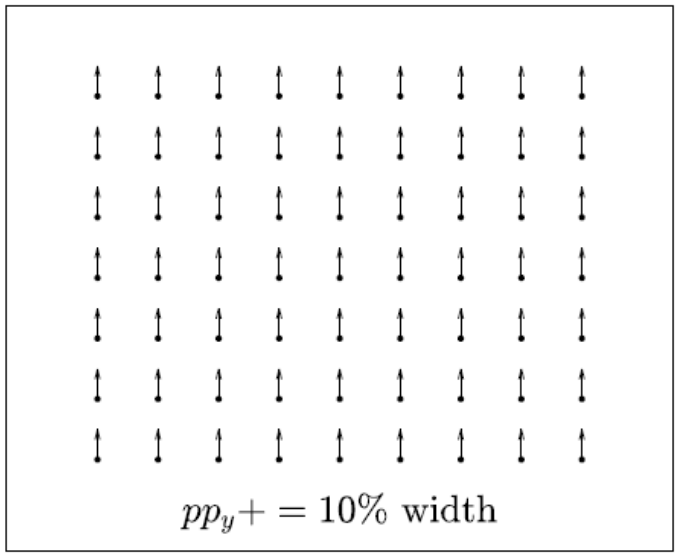


Camera models: Principal point position & Principal distance

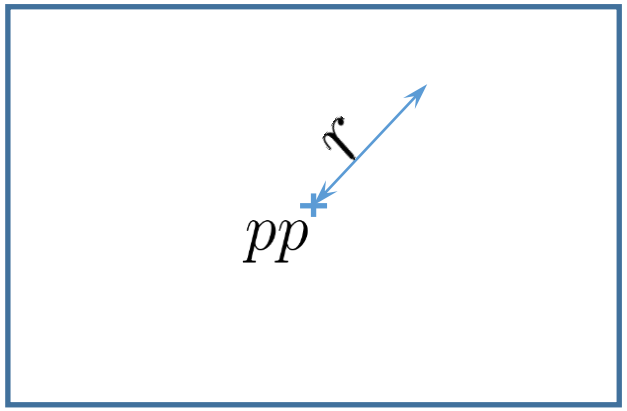


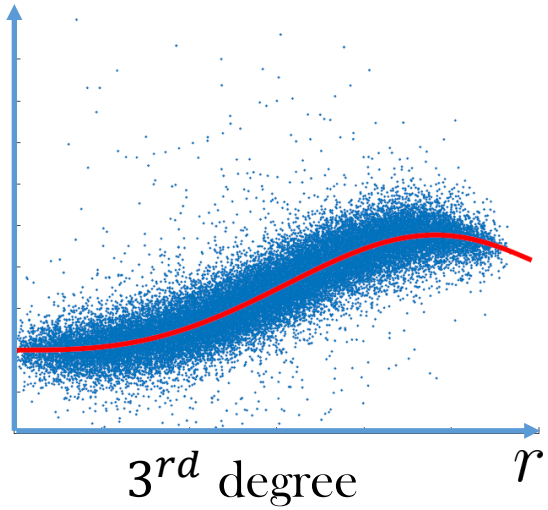




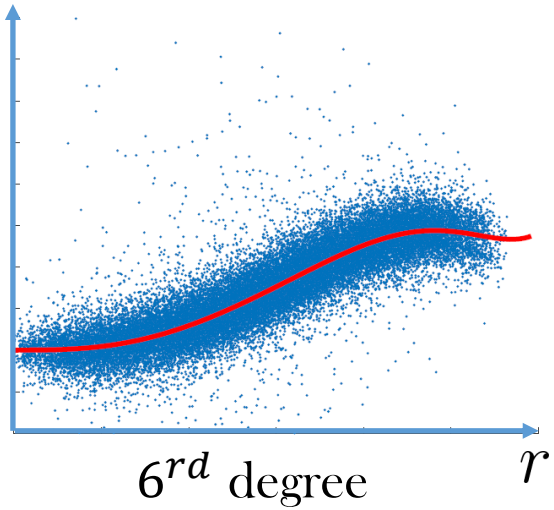


Camera models: Radials distortions

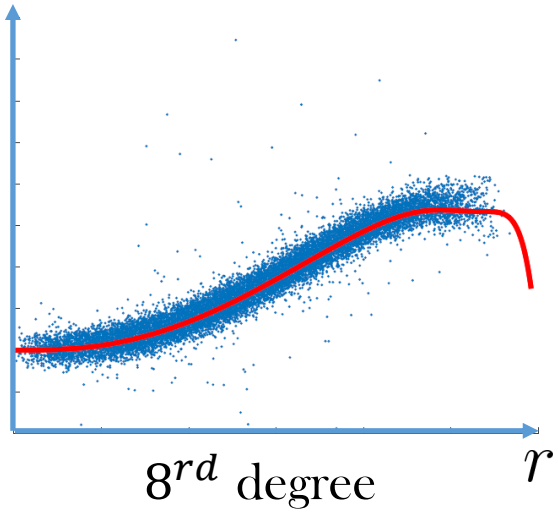




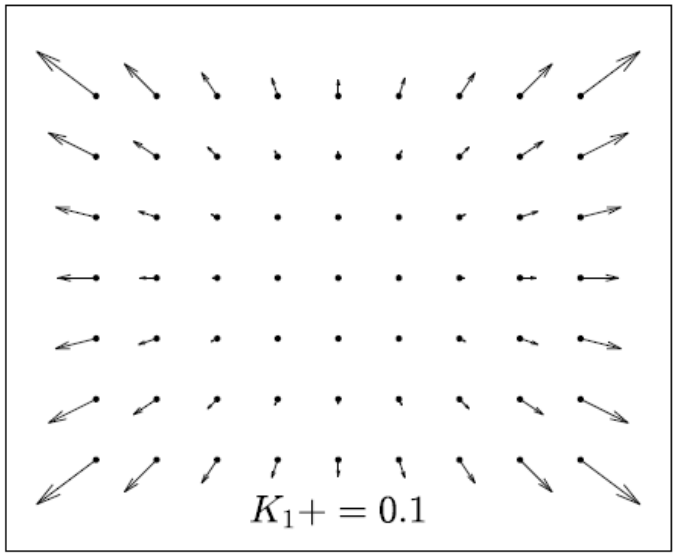
3^{rd} degree

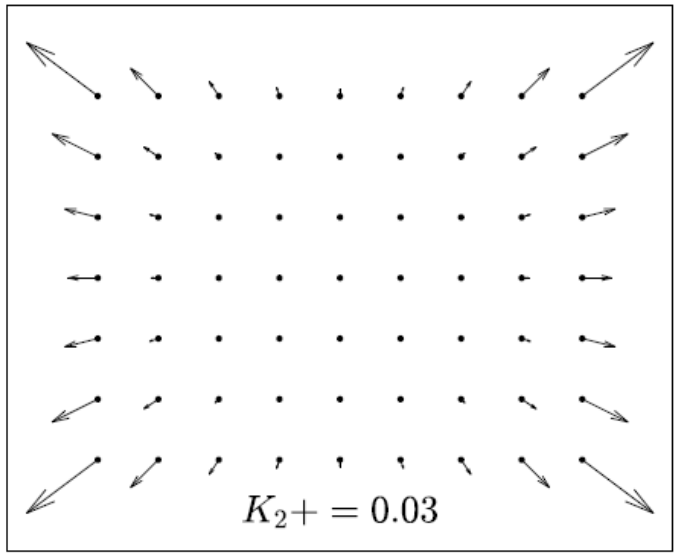


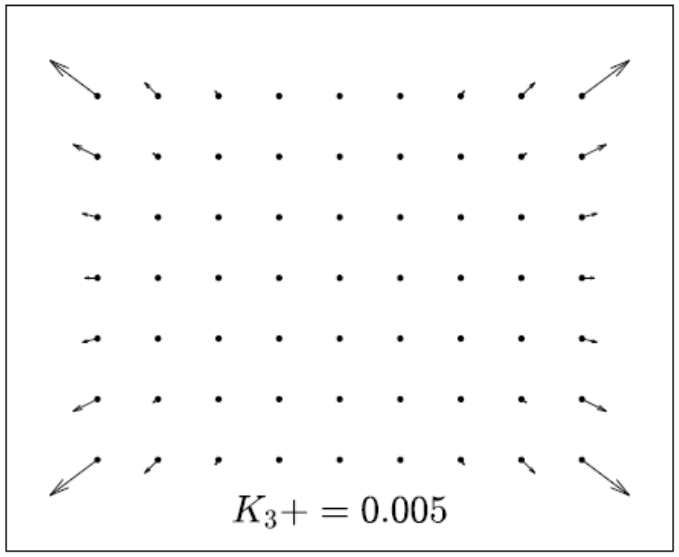
6^{rd} degree



8^{rd} degree

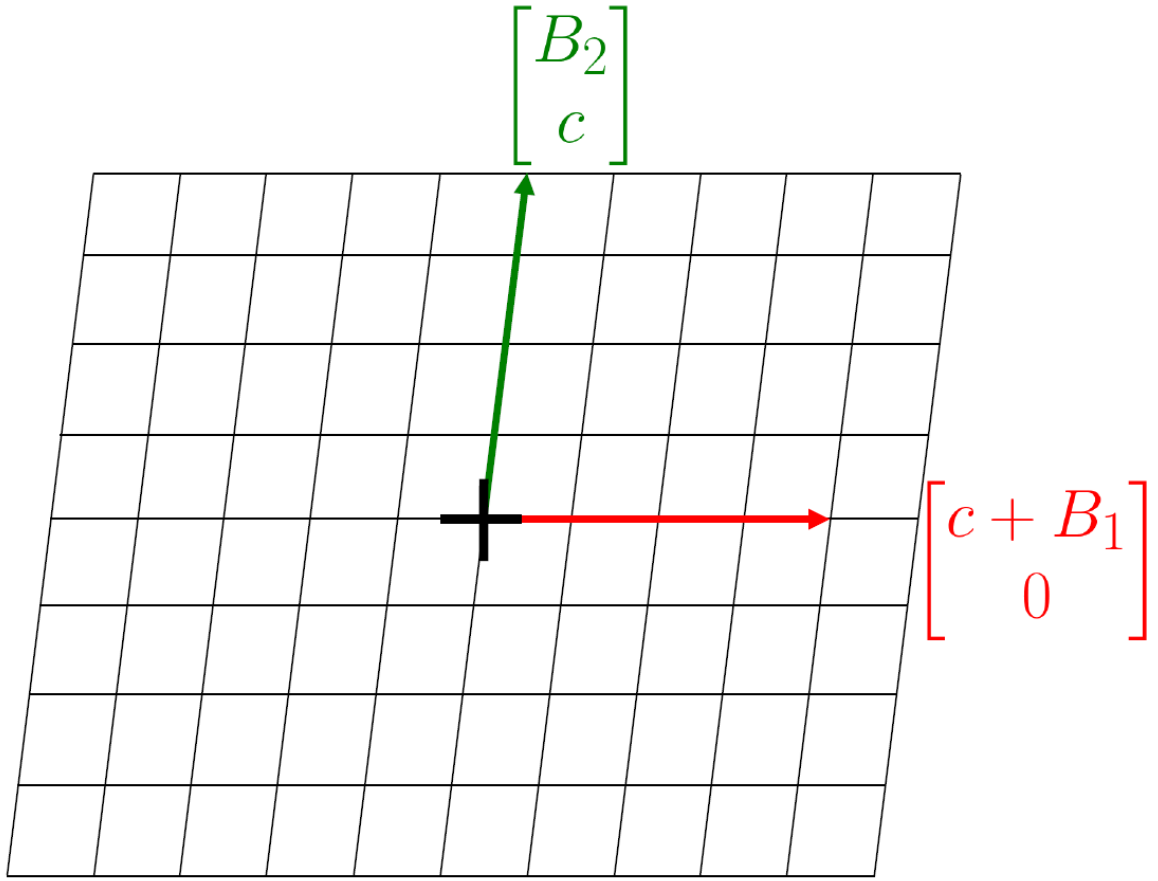


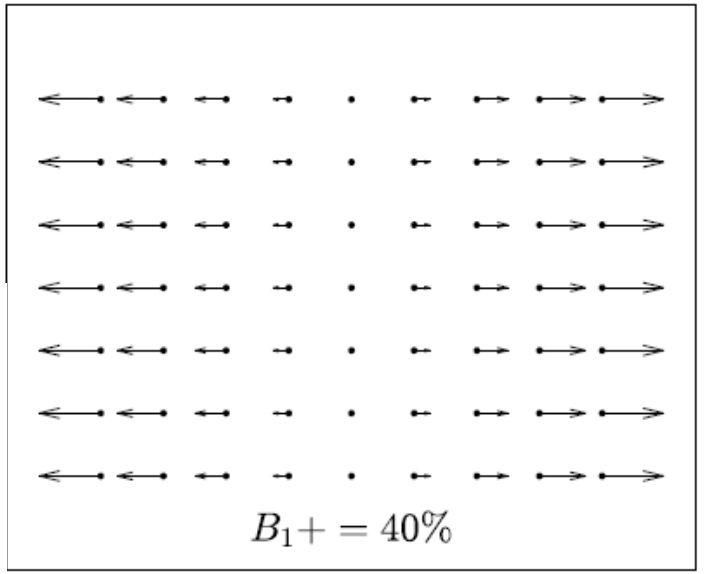


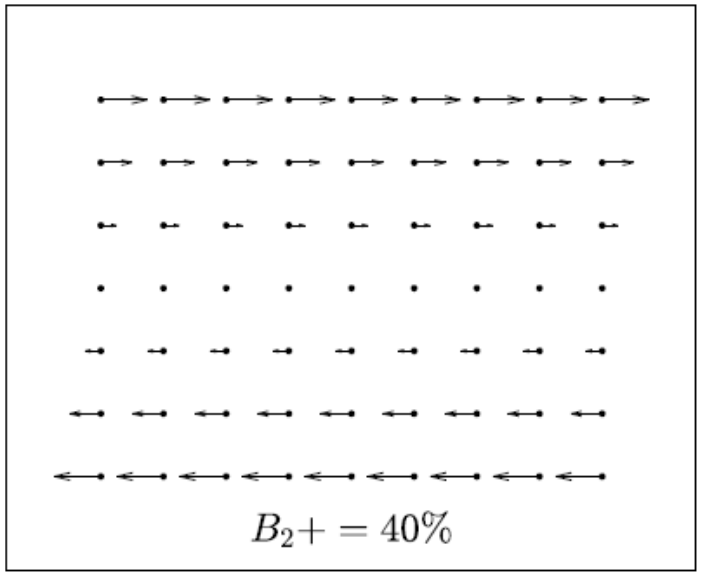


Camera models: Skew parameters

$$\xi_2 : \begin{array}{ccc} \mathbb{R}^2 & \rightarrow & \mathbb{R}^2 \\ \begin{bmatrix} x \\ y \end{bmatrix} & \mapsto & \begin{bmatrix} c+B_1 & B_2 \\ 0 & c \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} pp_x \\ pp_y \end{bmatrix} \end{array}$$

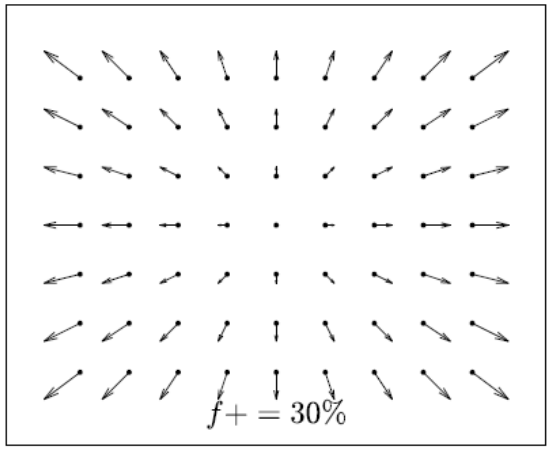


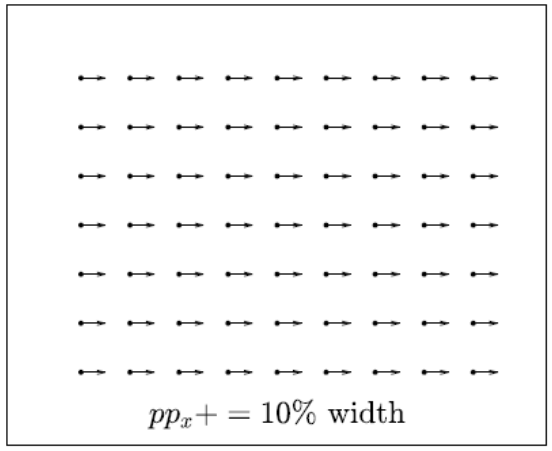


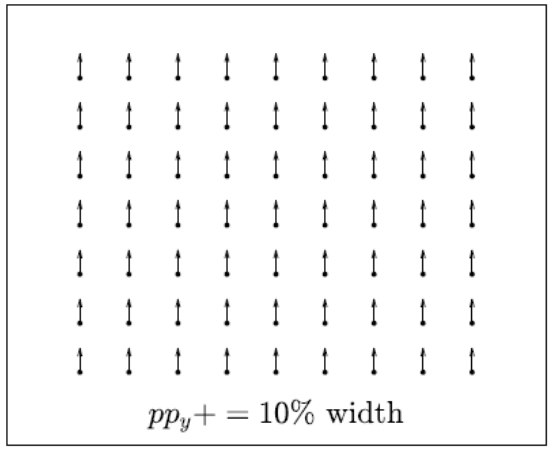


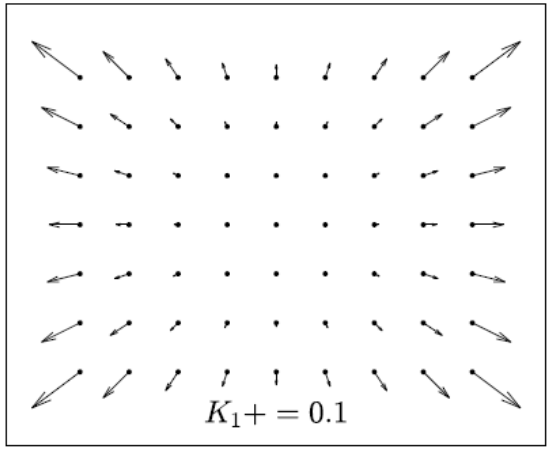
Brown

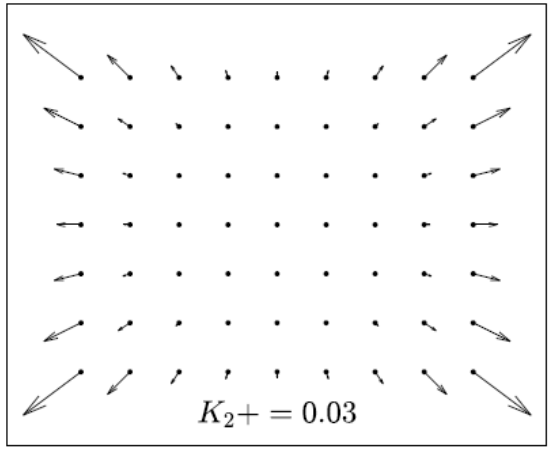
10 parameters version

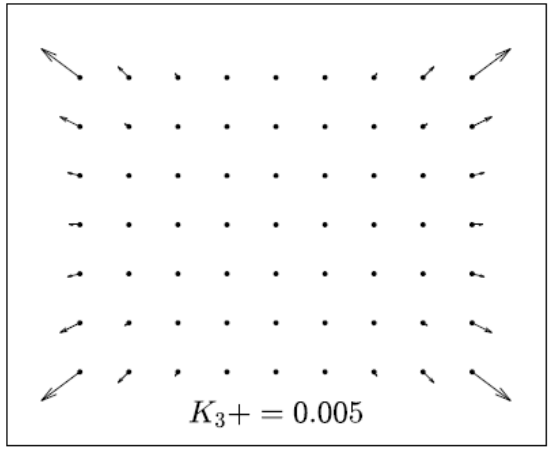


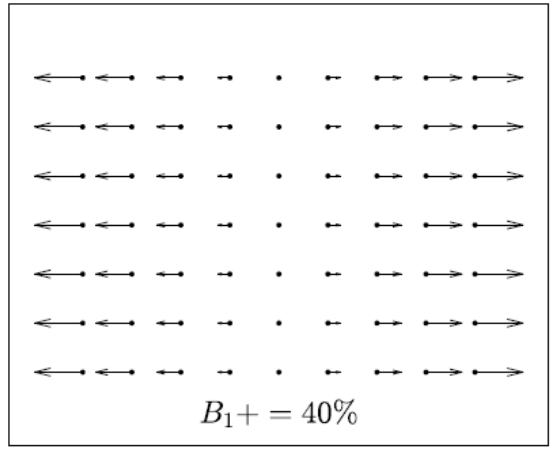


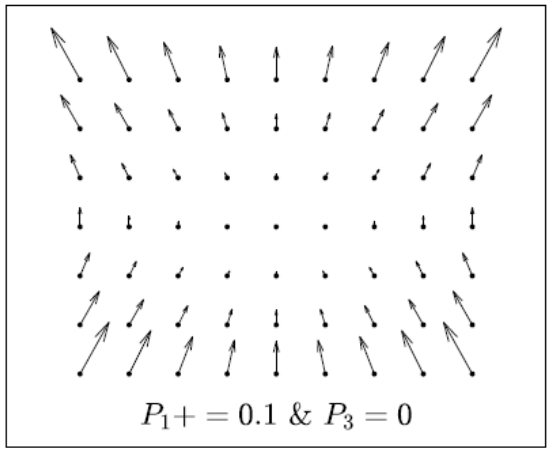


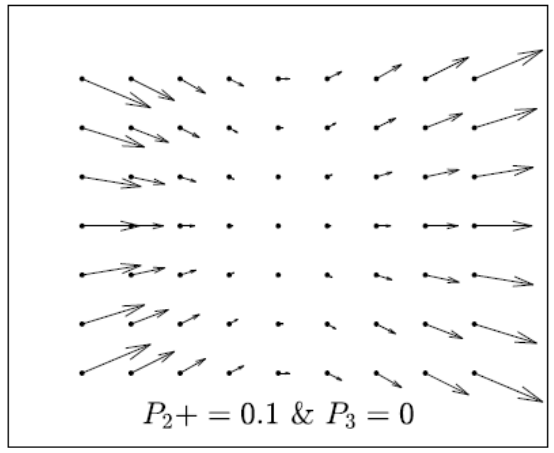


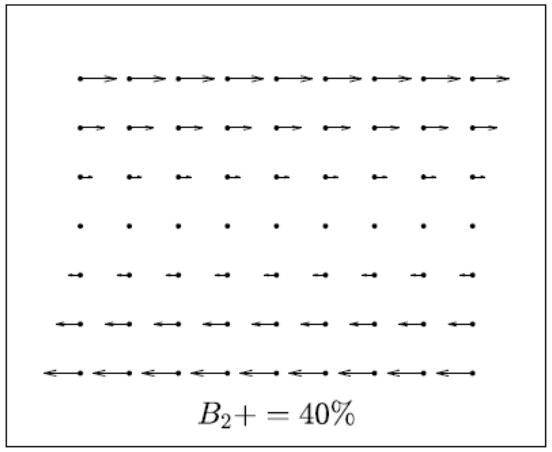




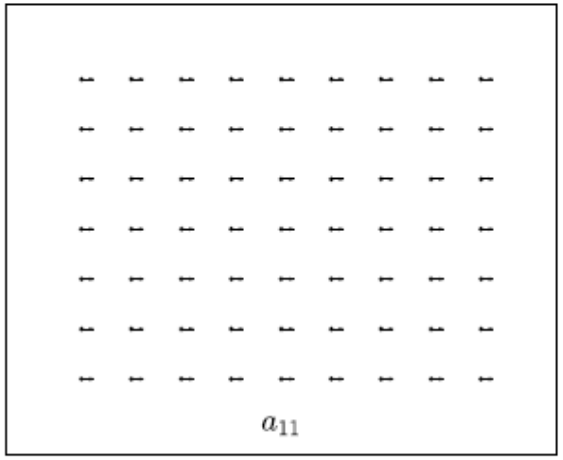


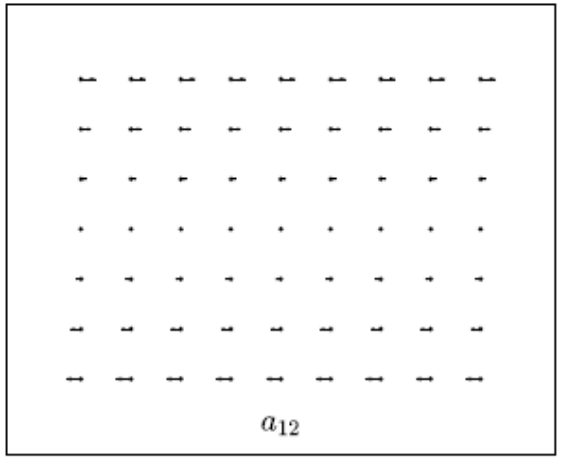


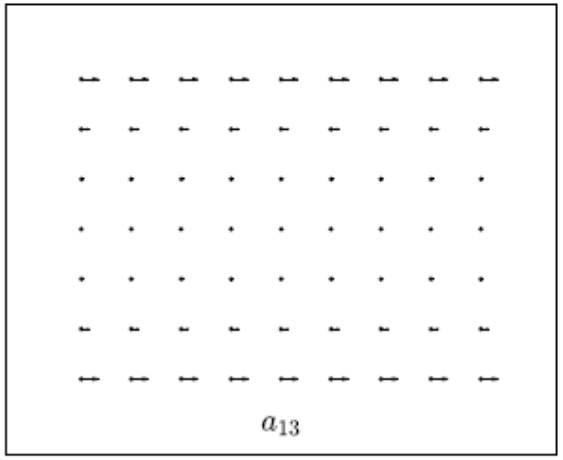


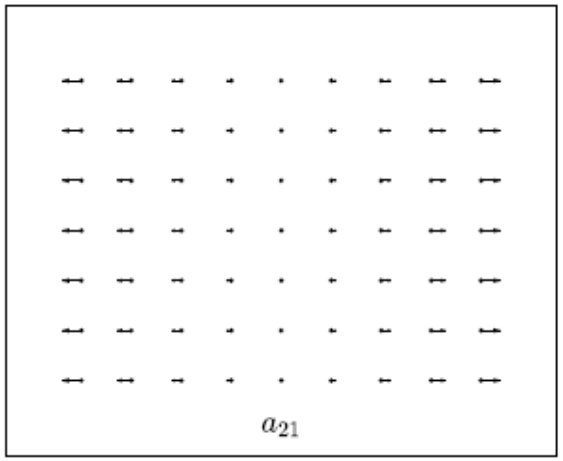


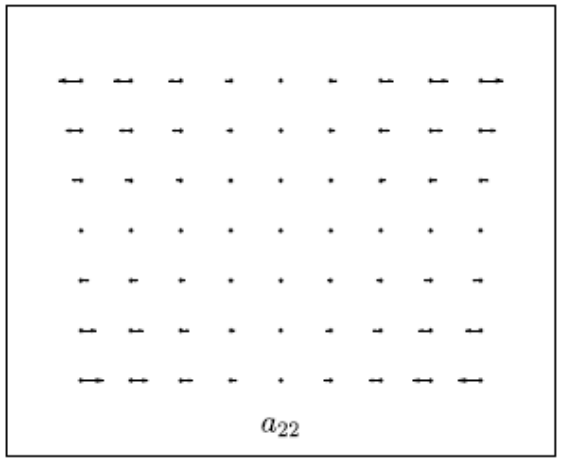
Orthogonal Polynomials

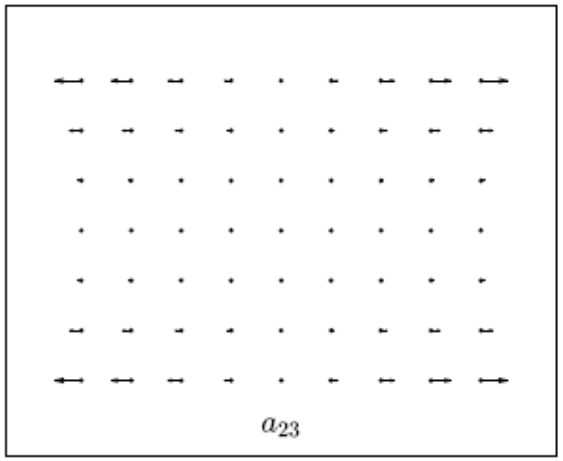


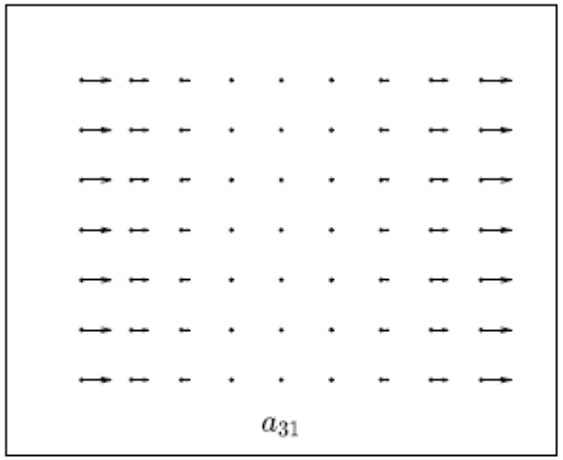


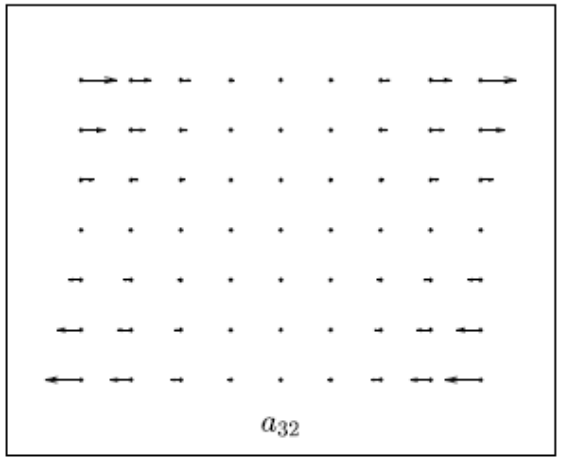


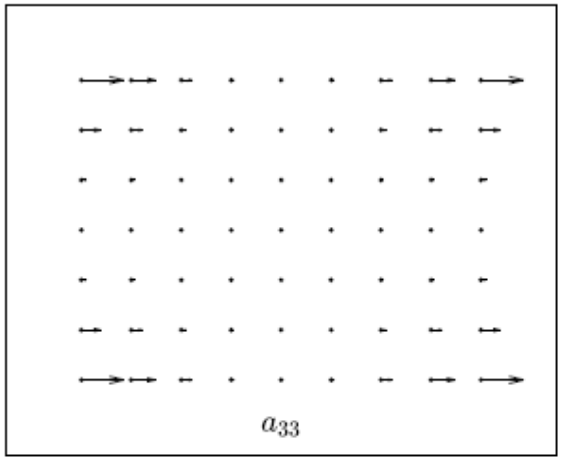










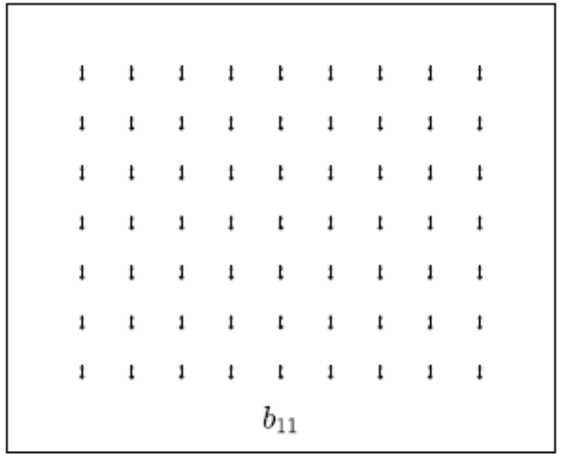


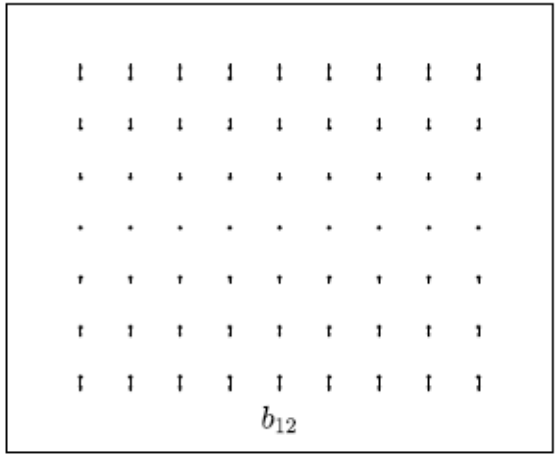
18 parameters

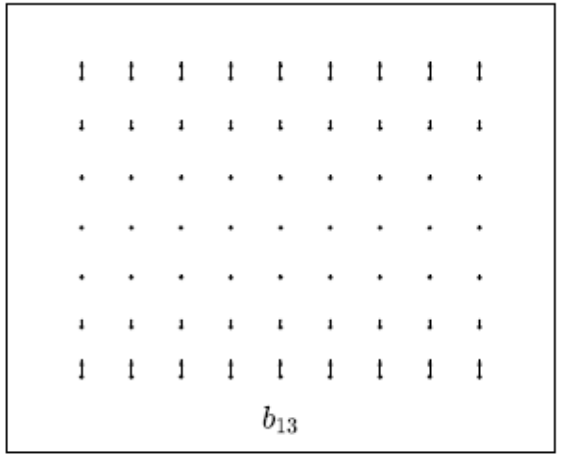
$$\ell_x = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix}$$

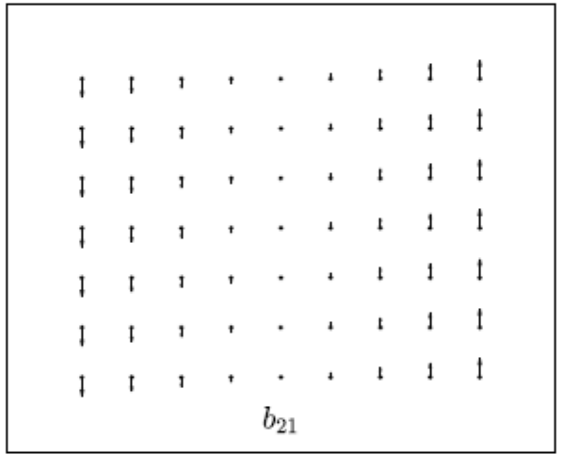
$$\ell_y = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix}$$

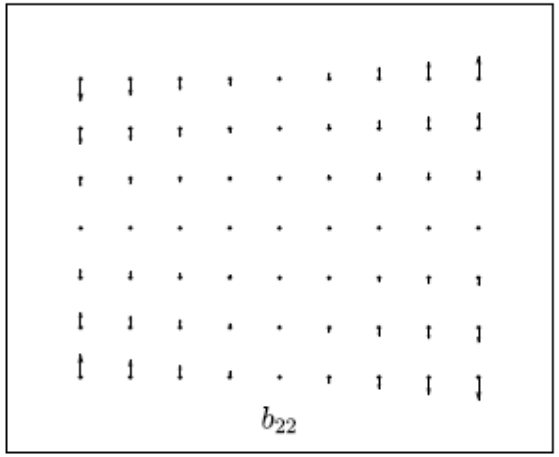
Orthogonal Polynomials

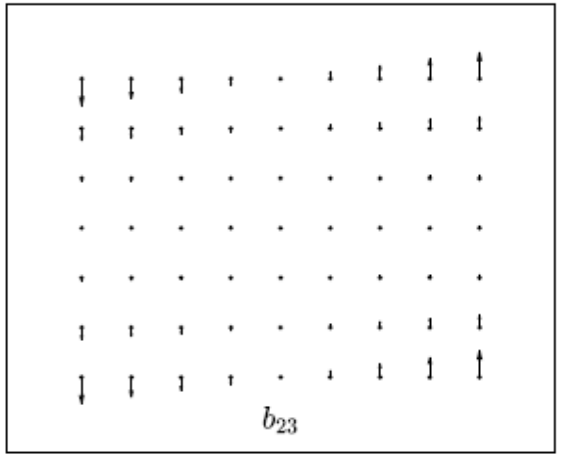


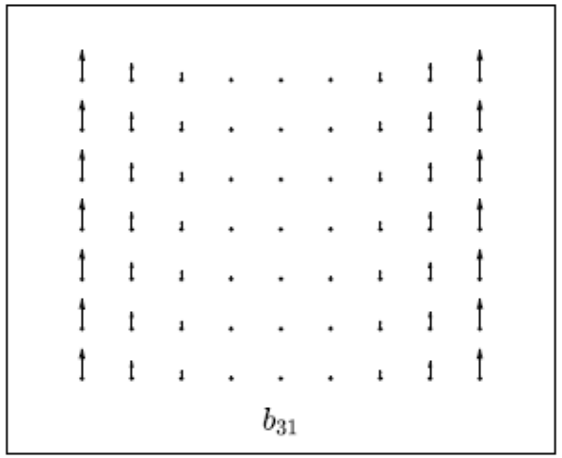


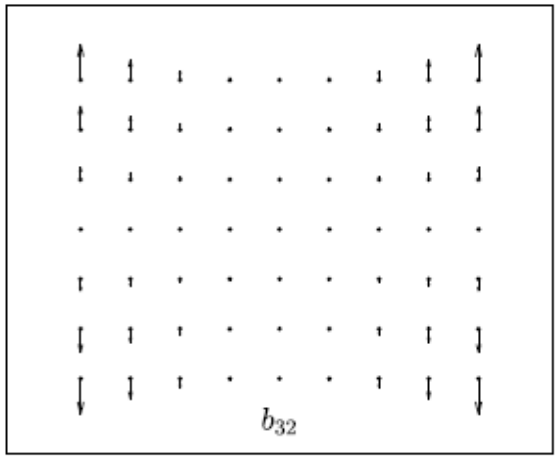


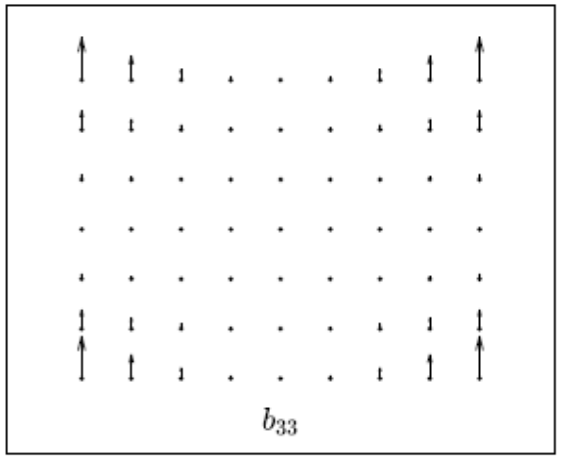












18 parameters

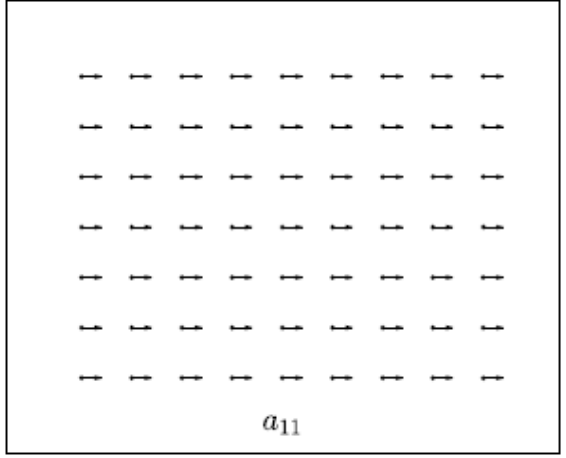
$$\ell_x = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix}$$

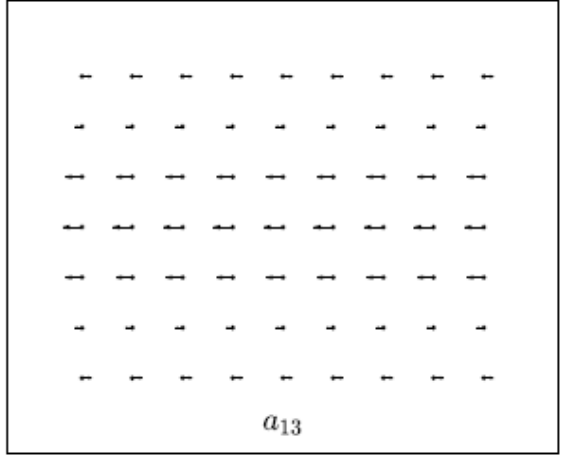
$$\ell_y = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix}$$

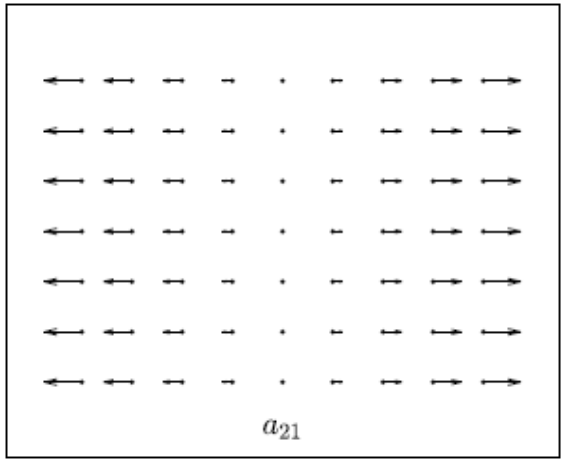
Orthogonal Polynomials

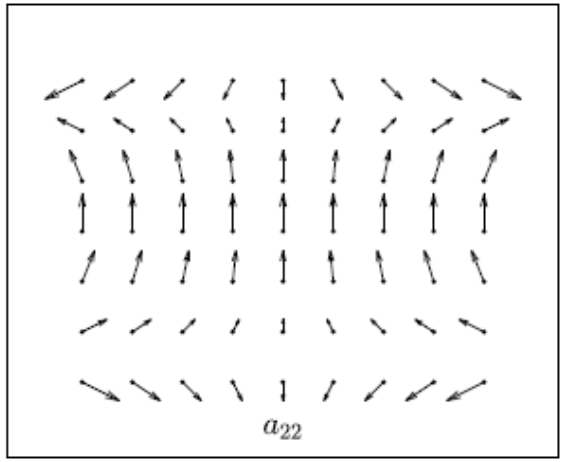
With 3 constraints

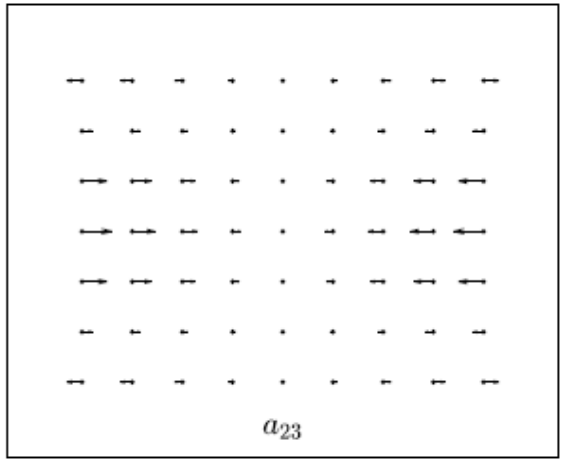
$18 - 3 = 15$



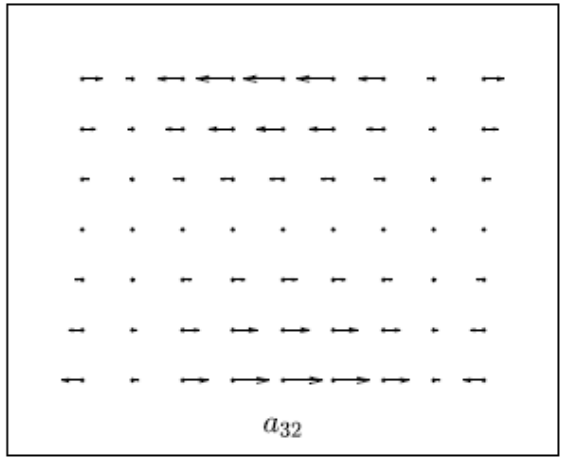


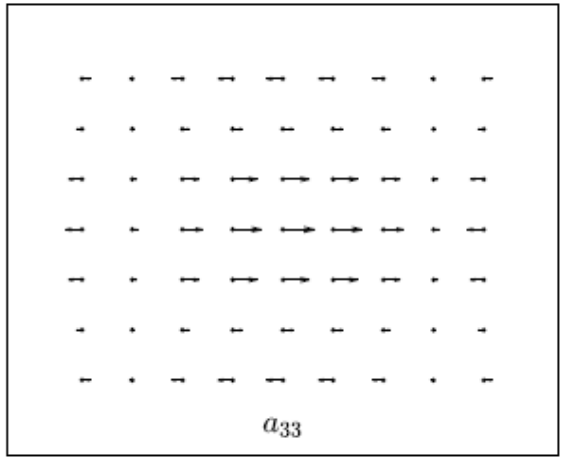






$$\begin{cases} \ell_x = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix} \\ \ell_y = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix} \end{cases}$$



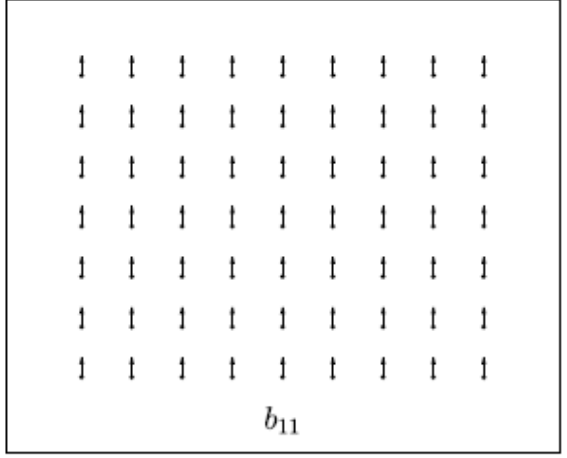


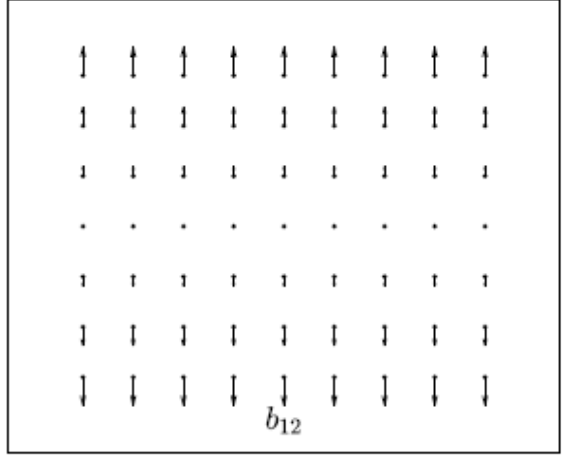
$$\begin{cases} b_{13} + 2 \cdot a_{22} = 0 \\ a_{31} + 2 \cdot b_{22} = 0 \\ a_{12} - b_{21} = 0 \end{cases}$$

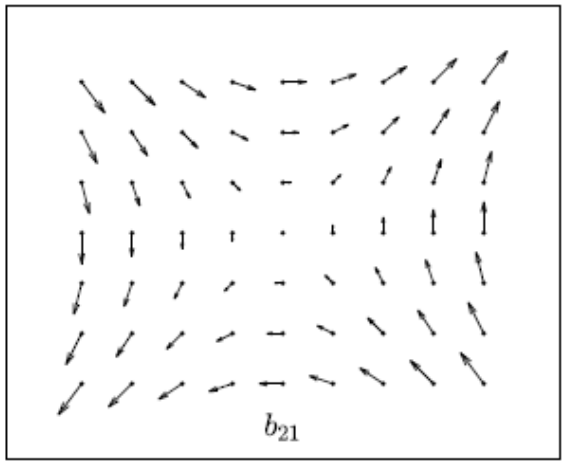
Orthogonal Polynomials

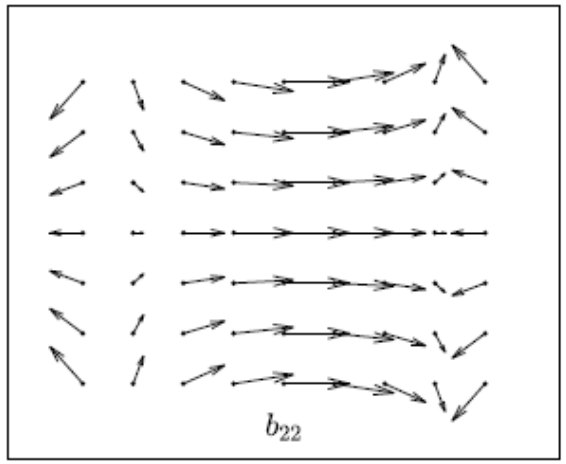
With 3 constraints

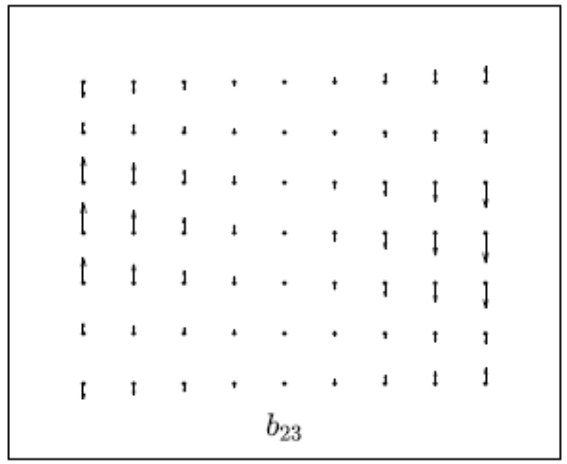
18 – 3 = 15



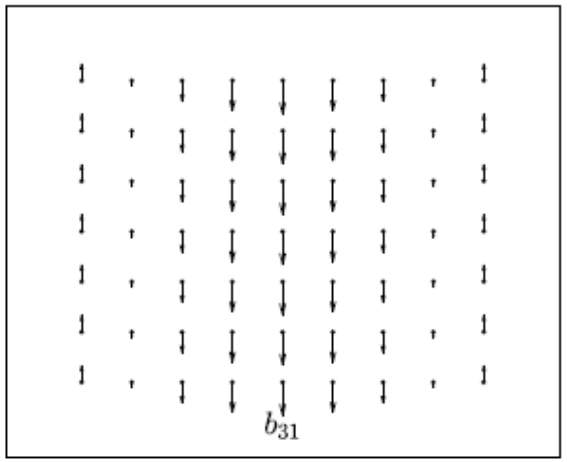


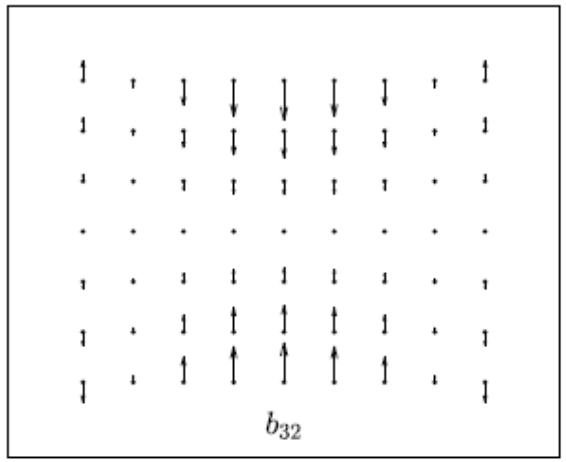


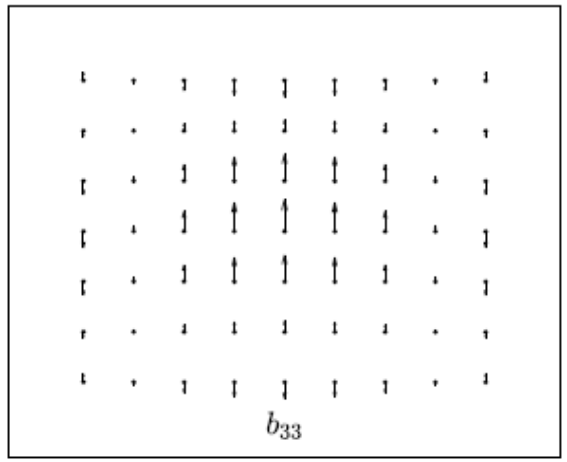




$$\begin{cases} \ell_x = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix} \\ \ell_y = \begin{bmatrix} 1 \\ \tilde{x} \\ \tilde{x}^2 - \frac{2}{3}b_x^2 \end{bmatrix}^T \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \tilde{y} \\ \tilde{y}^2 - \frac{2}{3}b_y^2 \end{bmatrix} \end{cases}$$

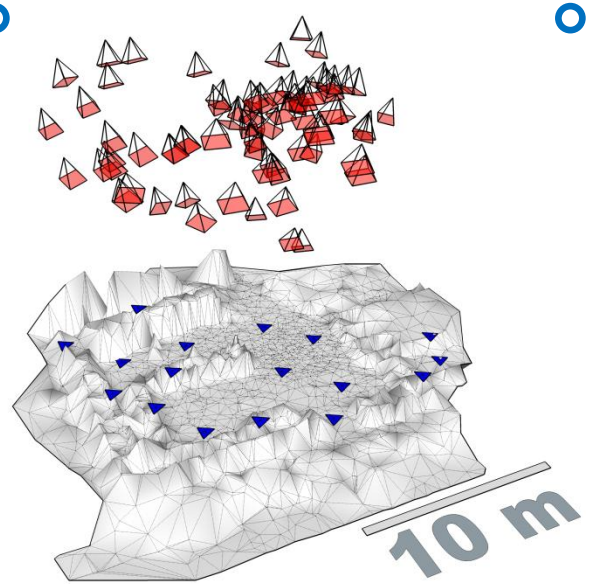


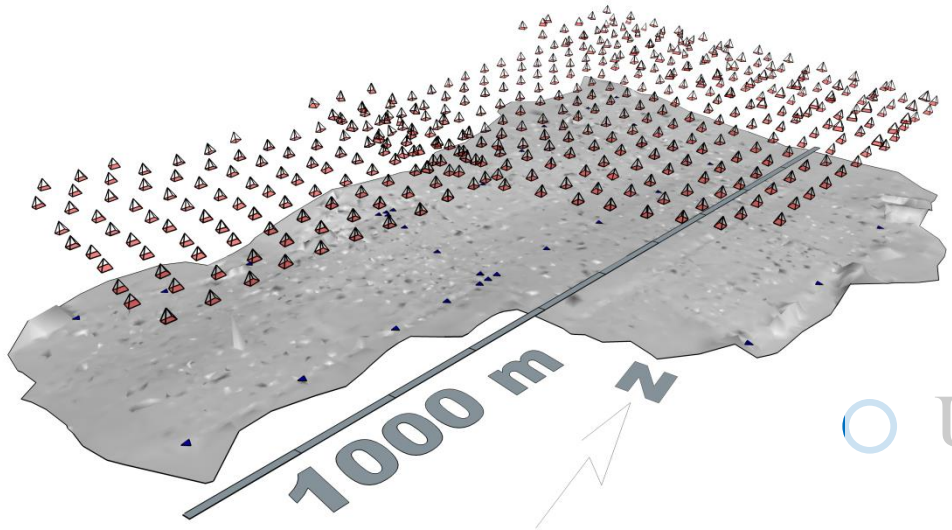




$$\begin{cases} b_{13} + 2 \cdot a_{22} = 0 \\ a_{31} + 2 \cdot b_{22} = 0 \\ a_{12} - b_{21} = 0 \end{cases}$$

Camera calibration model and method: evaluation in application

- Camera model
  - Brown 10
  - Brown 15
  - Brown 18
  - Ortho-Poly 18
  - Ortho-Poly 15
- Calibration method
  - 

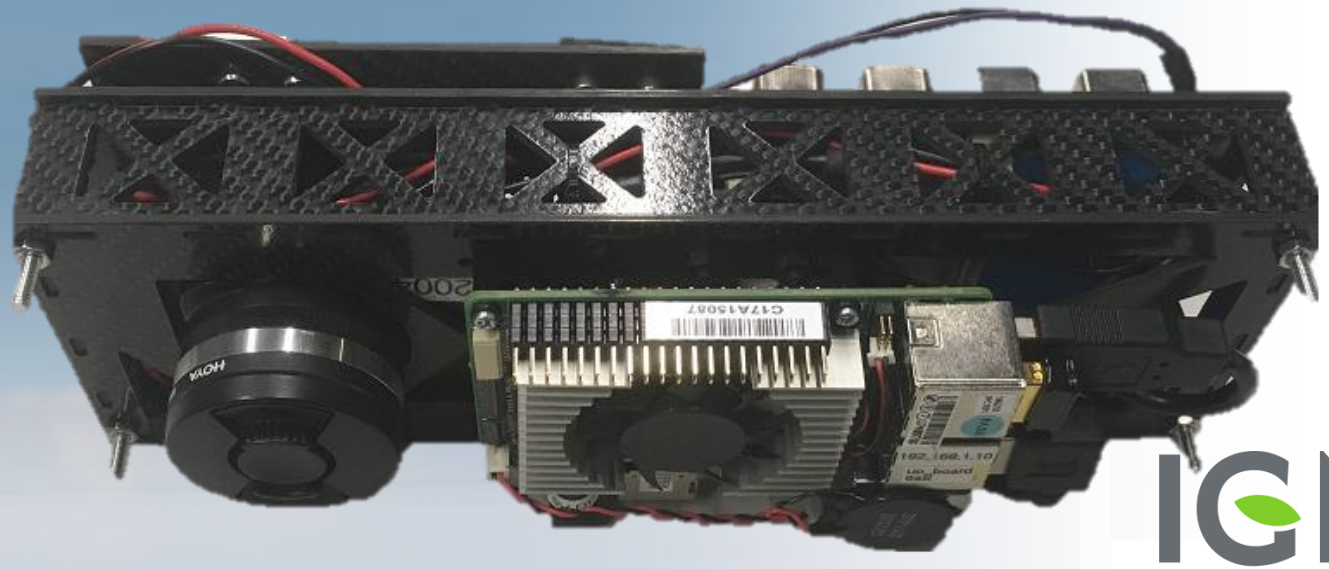
  - 

- Usage mode for mapping
  - FIX
  - APC
  - LEAD
  - APCI

CAM LIGHT from IGN [The French SwissTopo :-]

Fix-Wing Drone
With aerial control

1 m



5 cm

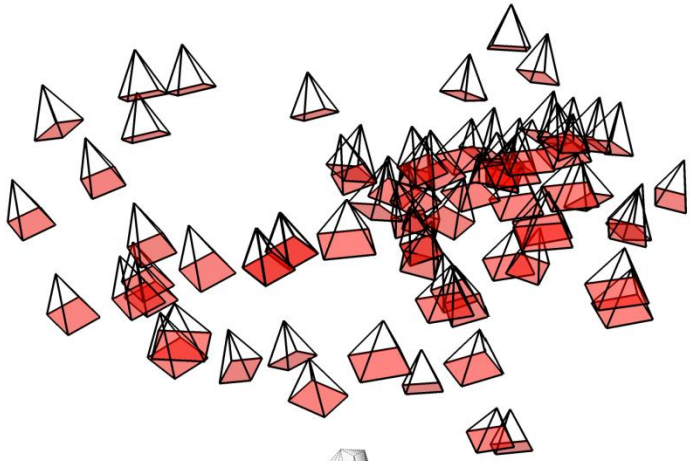
Hexacopter
Without
aerial
control

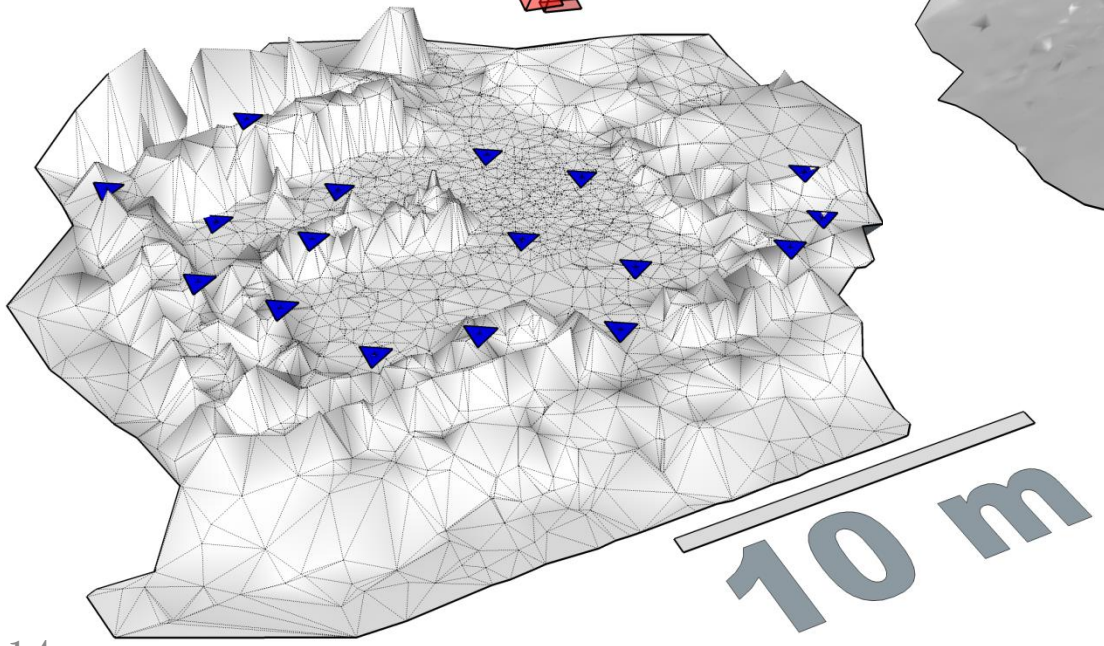
20 cm

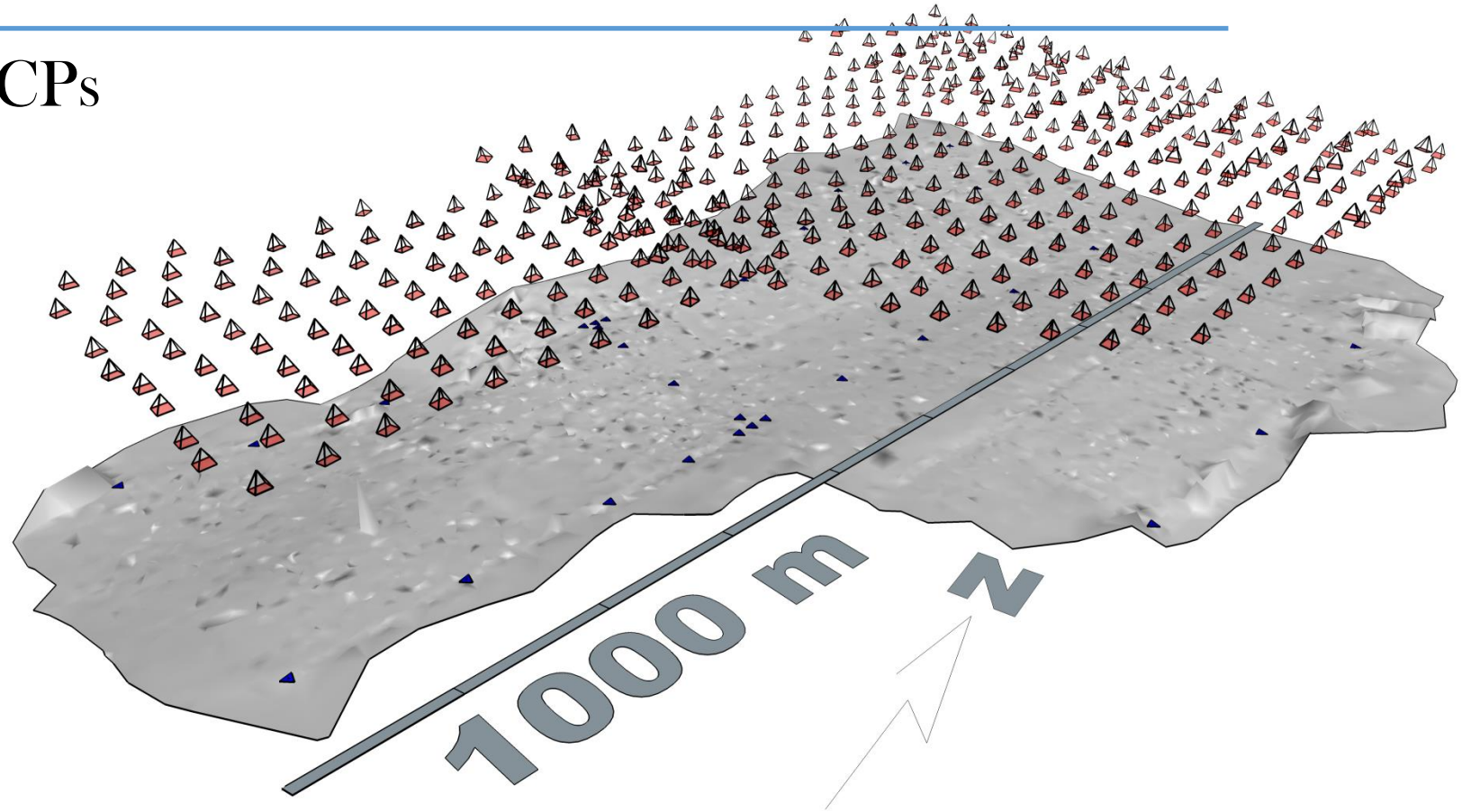
INSTITUT NATIONAL
DE L'INFORMATION
GÉOGRAPHIQUE
ET FORESTIÈRE

Calibration field

Without aerial control, 17 GCPs







With aerial control
21 GCPs

Camera calibration model and method evaluation: SOTA

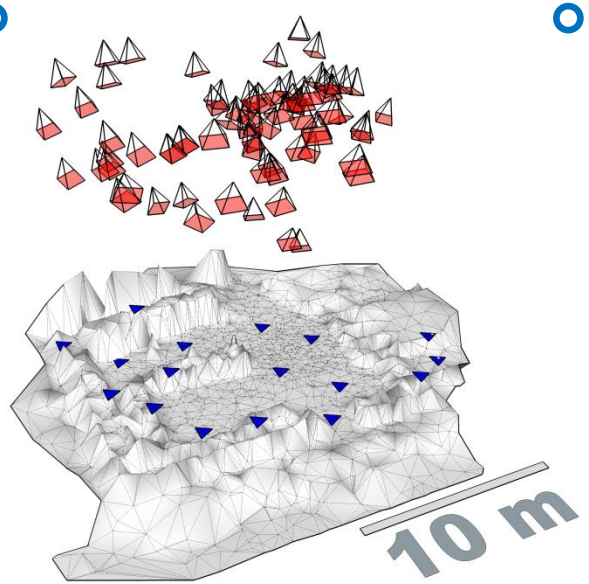
- Images residuals
- GCP residuals
- CP misclosure

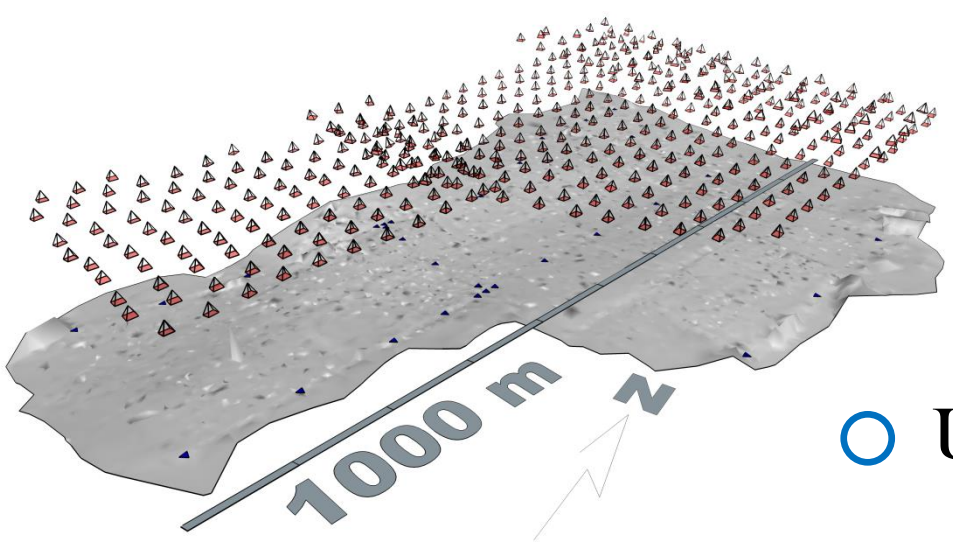
Of the calibration flight

Calibration parameters analysis

	f	ppx	ppy	R1	R2	R3	T1	T2	B1	B2
1.26	1.00	-0.28	-0.97	0.28	-0.02	0.01	-0.65	-0.12	0.73	-0.20
1.46e-01	-0.28	1.00	0.28	-0.11	0.03	-0.03	0.21	0.87	-0.22	0.52
6.56e-01	-0.97	0.28	1.00	-0.29	0.04	-0.03	0.68	0.11	-0.81	0.23
1.88e-04	0.28	-0.11	-0.29	1.00	-0.90	0.85	-0.41	-0.08	0.07	-0.02
1.32e-03	-0.02	0.03	0.04	-0.90	1.00	-0.99	0.07	0.01	-0.02	0.01
3.03e-03	0.01	-0.03	-0.03	0.85	-0.99	1.00	-0.06	-0.01	0.01	-0.01
1.78e-05	-0.65	0.21	0.68	-0.41	0.07	-0.06	1.00	0.15	-0.18	0.05
7.69e-06	-0.12	0.87	0.11	-0.08	0.01	-0.01	0.15	1.00	-0.03	0.22
6.71e-02	0.73	-0.22	-0.81	0.07	-0.02	0.01	-0.18	-0.03	1.00	-0.29
2.26e-02	-0.20	0.52	0.23	-0.02	0.01	-0.01	0.05	0.22	-0.29	1.00

Camera calibration model and method: evaluation in application

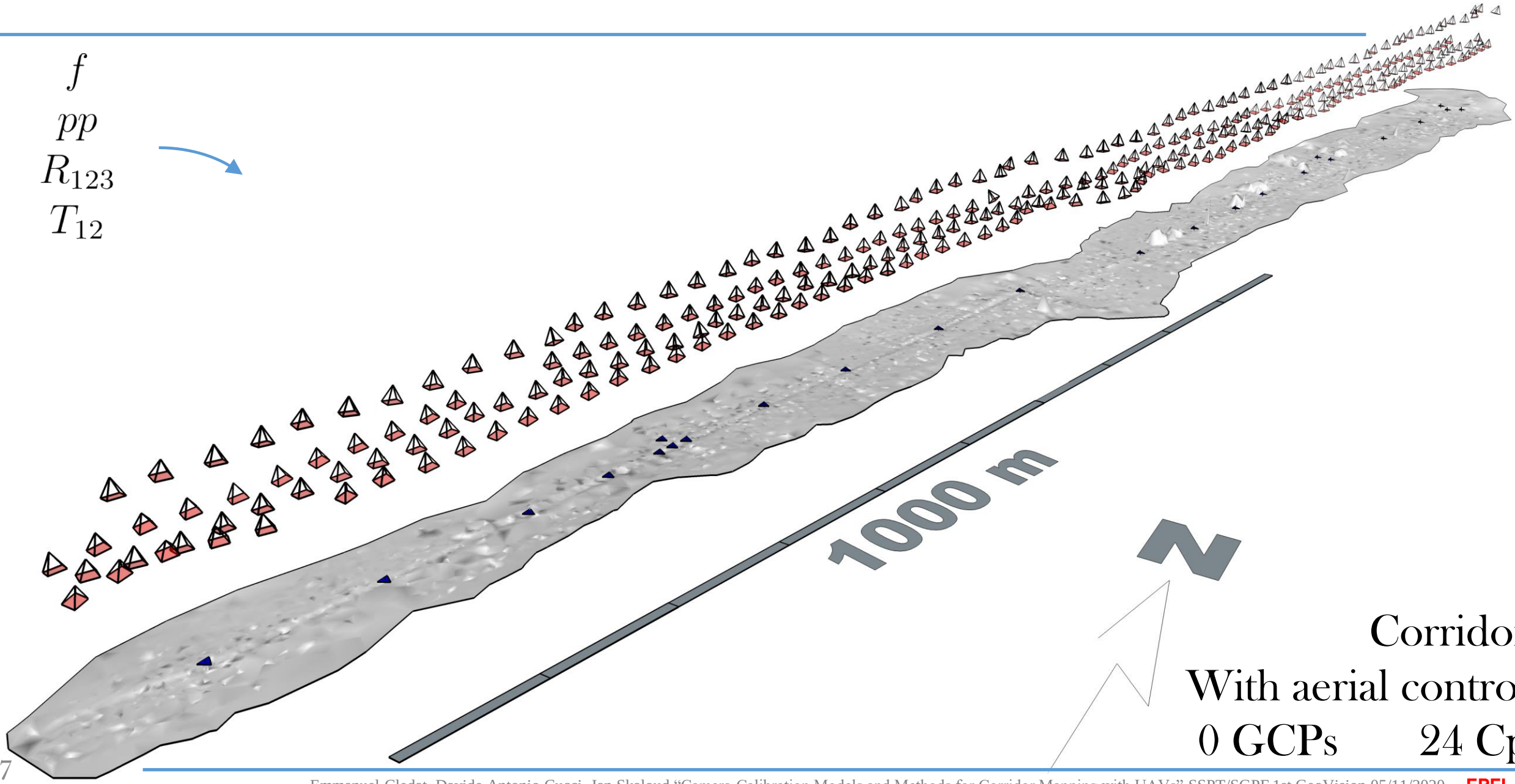
- Camera model
  - Brown 10
  - Brown 15
  - Brown 18
  - Ortho-Poly 18
  - Ortho-Poly 15
- Calibration method
  - 

  - 

- Usage mode for mapping
  - FIX
  - APC
  - LEAD
  - APCI

Application: use of the calibration values

f
pp
R_{123}
T_{12}

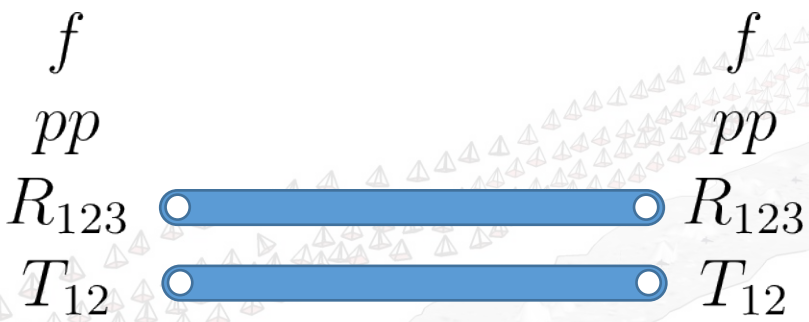


Corridor
With aerial control
0 GCPs 24 Cp

Application: use of the calibration values

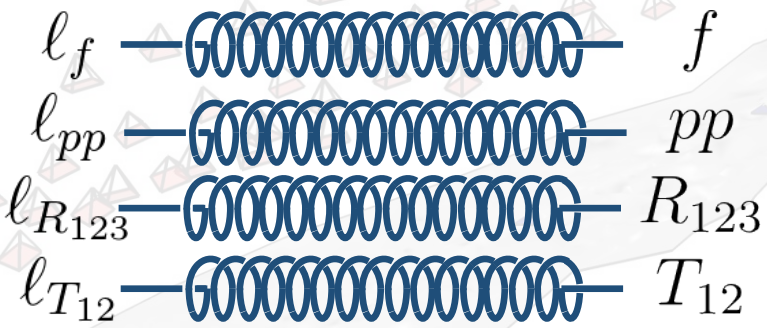
from calib. in use in production flight

FIX



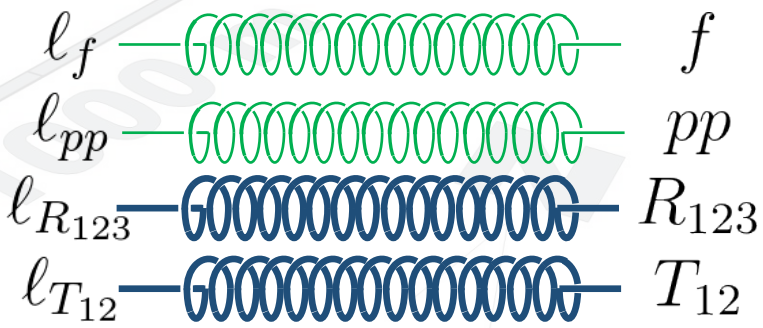
from calib. in use in production flight

Lead



from calib. in use in production flight

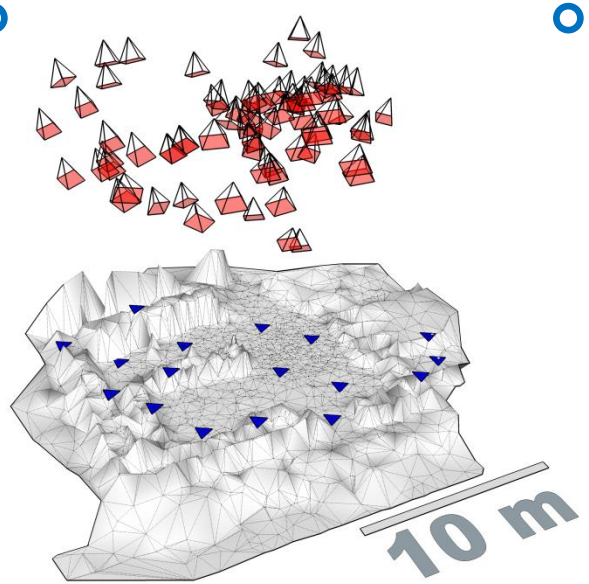
A Posteriori Covariance

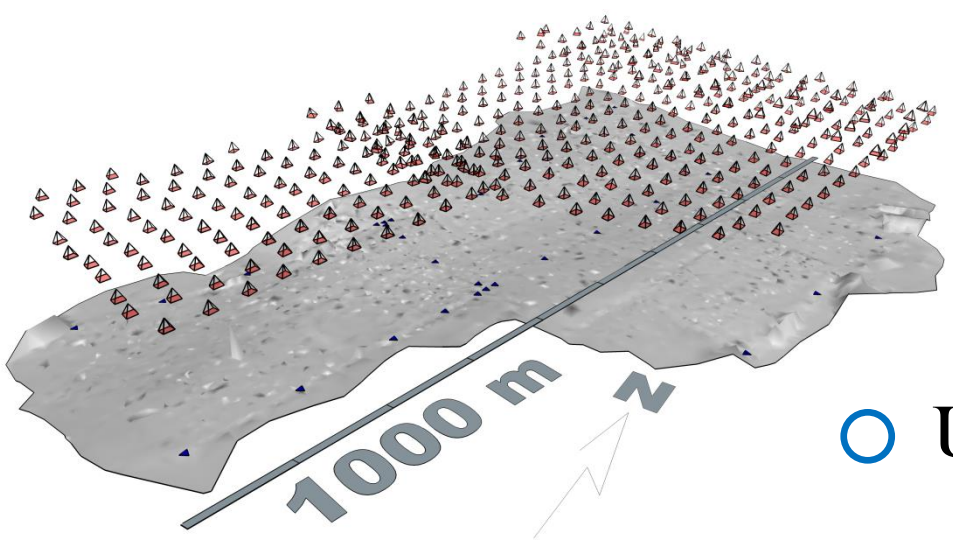


from calib. in use in production flight

A Posteriori Covariance Inflated

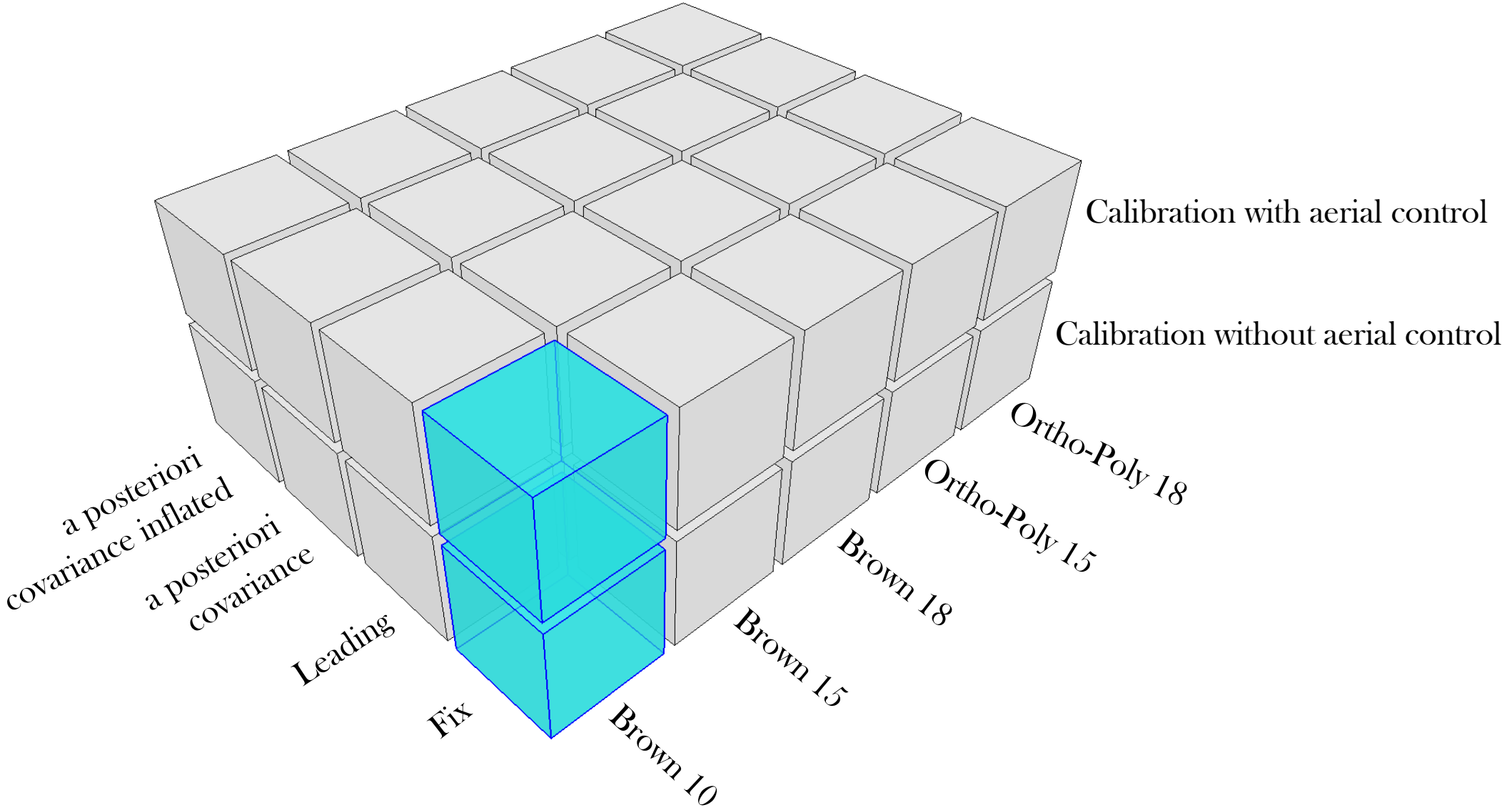
Camera calibration model and method: evaluation in application

- Camera model
  - Brown 10
  - Brown 15
  - Brown 18
  - Ortho-Poly 18
  - Ortho-Poly 15
- Calibration method
  - 

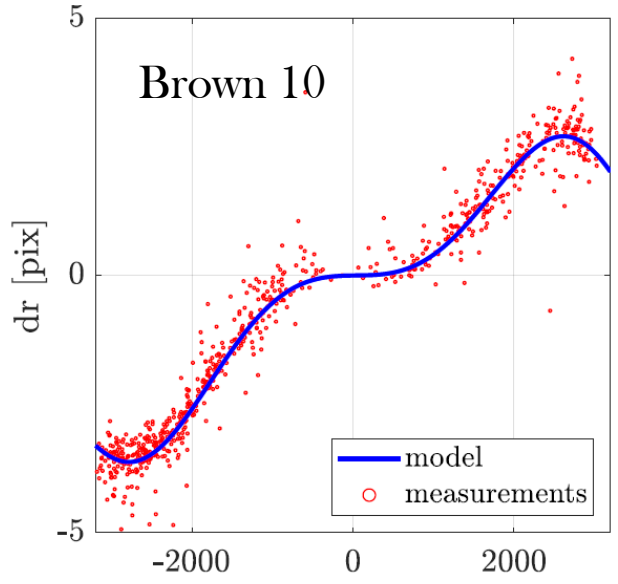
  - 

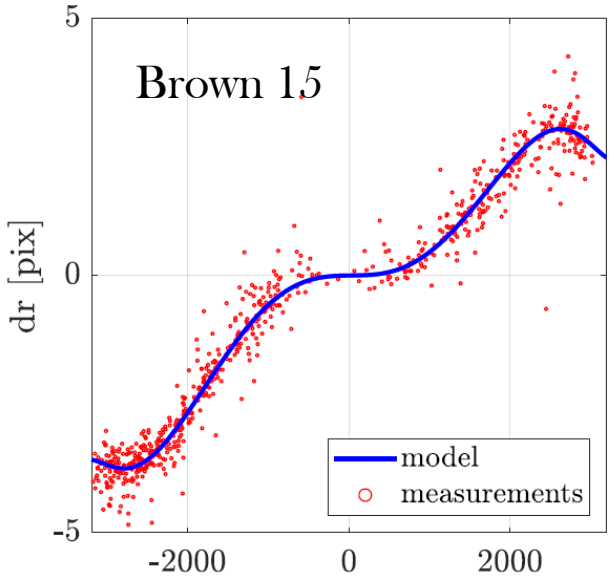
- Usage mode for mapping
  - **FIX**
  - **APC**
  - **LEAD**
  - **APCI**

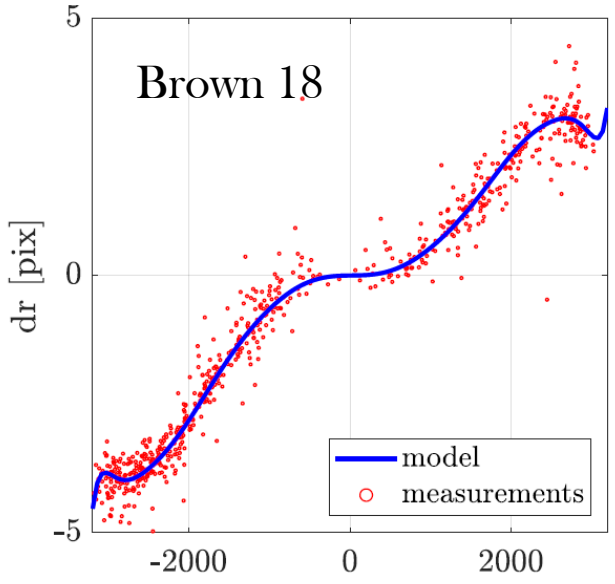
Camera calibration model and method: Results & Conclusions

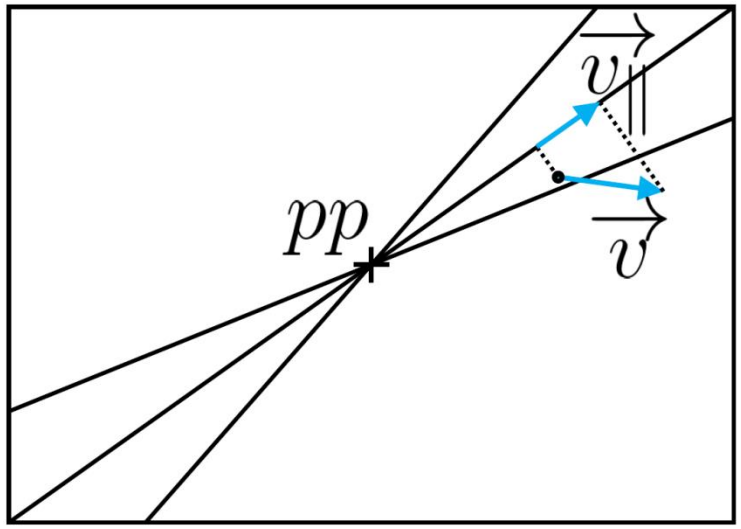


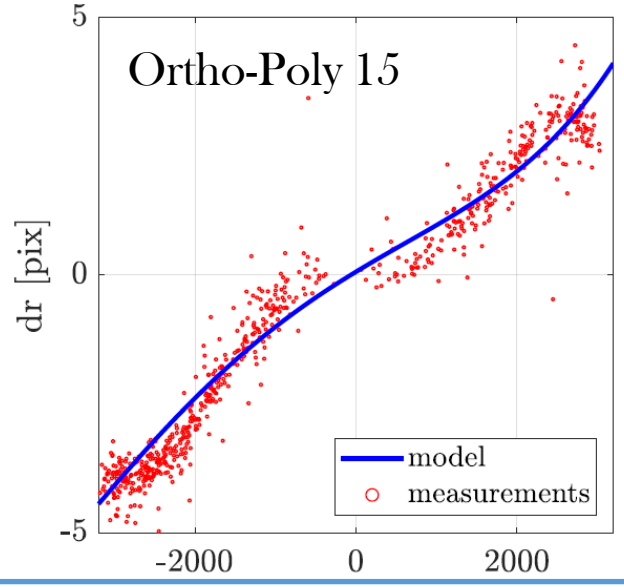
Brown Vs Orthogonal Polynomials

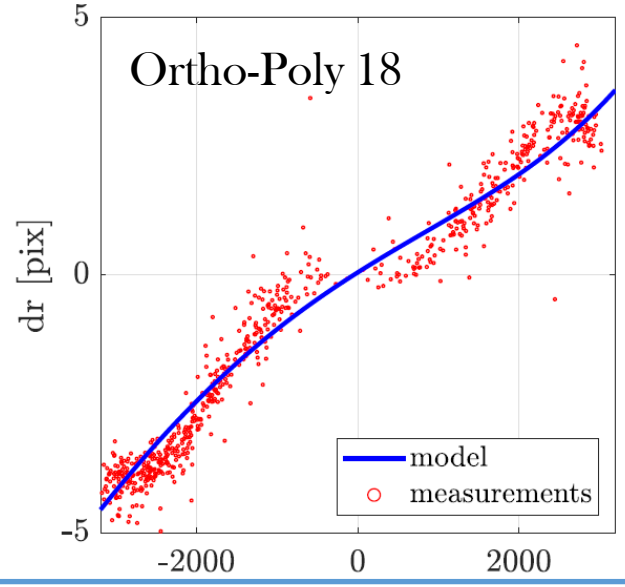












Camera calibration model and method: Results & Conclusions

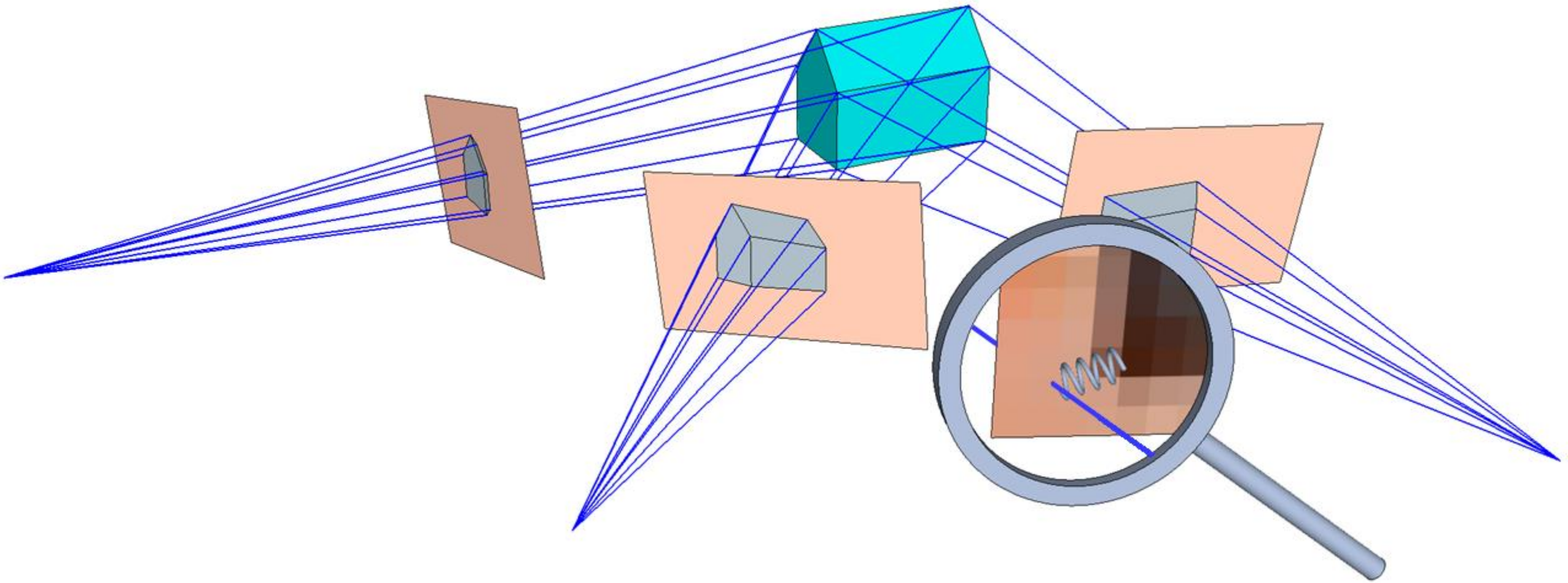
- **`FIX`** Fixing the camera calibration lead to inaccurate result (up to 3x worse than the other methods)
- **`LEAD`** Improves the results with respect to **`FIX`** and sometime yields to the best results
- **`A Posteriori Covariance`** and **`A Posteriori Covariance Inflated`** further improves the results
- Brown model gives results at least 2 times better than Orthogonal polynomials
- Better to perform a calibration flight in similar conditions as the mapping

Questions?

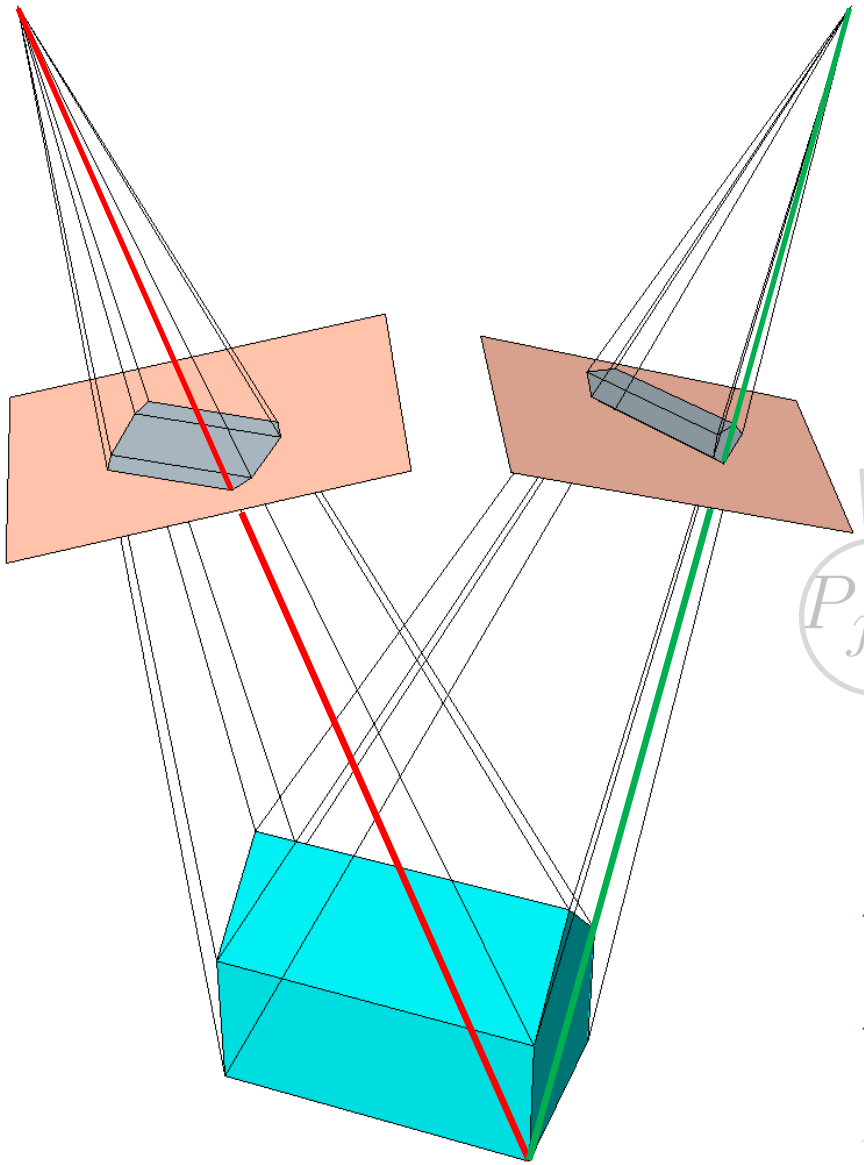
Clédat, E.; Cucci, D. A.; Skaloud, J. “Camera Calibration Models and Methods for Corridor Mapping with UAVs” ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII 2020

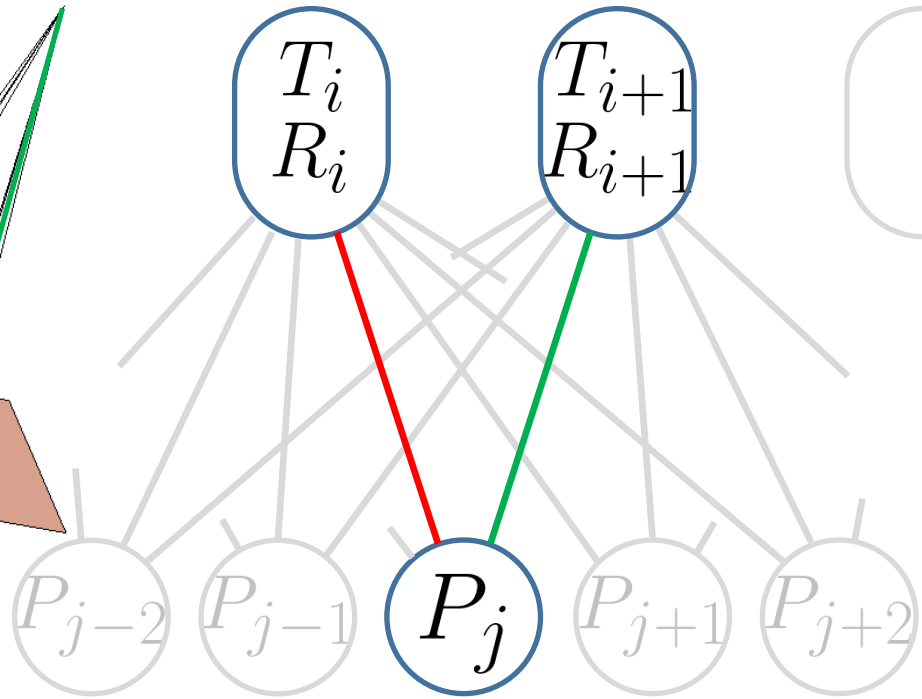
Backup slides

Bundle-Adjustment



Bundle-Adjustment: Graph visualization and Jacobian matrix



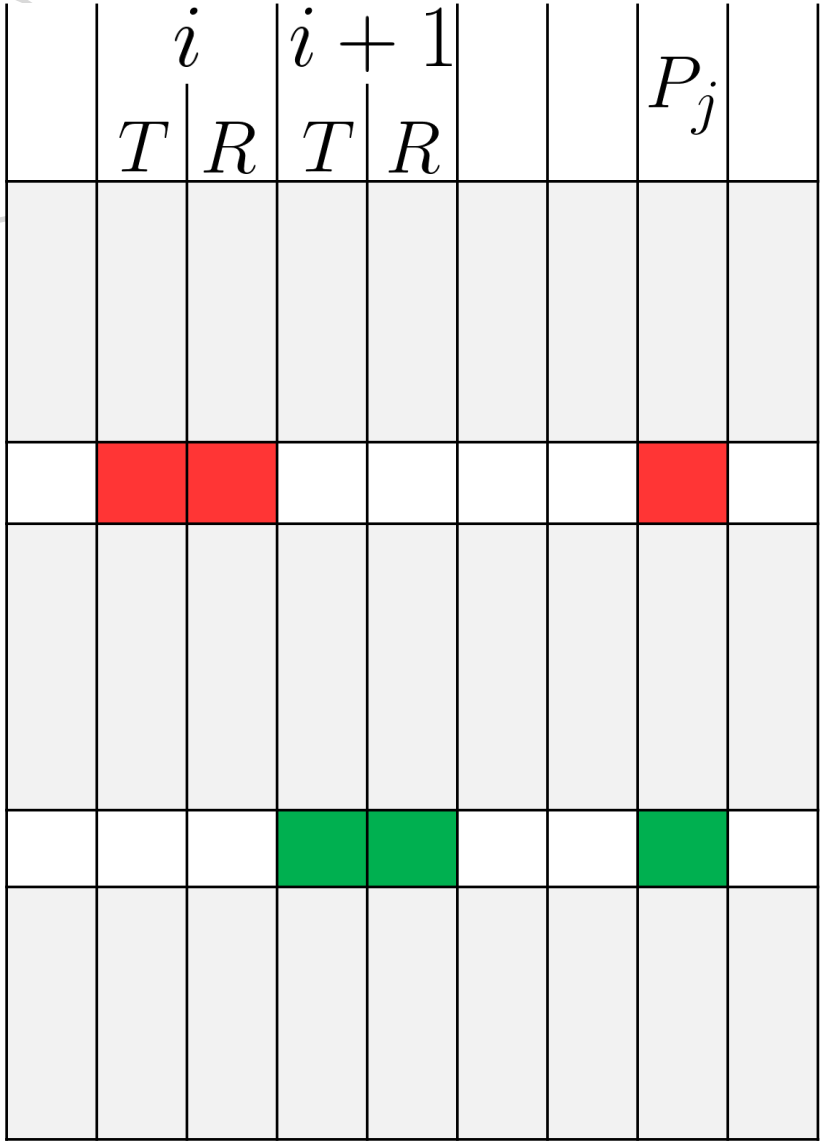


$$\ell_\bullet = f\left(T_\bullet, R_\bullet, P_\bullet\right)$$

$$\ell_\bullet = f\left(T_i, R_i, P_j\right)$$

$$\ell_\bullet = f\left(T_{i+1}, R_{i+1}, P_j\right)$$

$$\ell_\bullet = f\left(T_\bullet, R_\bullet, P_\bullet\right)$$



Brown

$$\xi_1 : \quad \mathbb{R}^2 \quad \rightarrow \quad \mathbb{R}^2$$

$$\tilde{p} = \begin{bmatrix} \tilde{x} \\ \tilde{y} \end{bmatrix} \mapsto \left(1 + K_1\tilde{r}^2 + K_2\tilde{r}^4 + K_3\tilde{r}^6 + \cdots\right)\tilde{p} + \begin{bmatrix} \left(P_1\left(\tilde{r}^2 + 2\tilde{x}^2\right) + 2P_2\tilde{x}\tilde{y}\right) \\ \left(2P_1\tilde{x}\tilde{y} + P_2\left(\tilde{r}^2 + 2\tilde{y}^2\right)\right) \end{bmatrix}\left(1 + P_3\tilde{r}^2 + \cdots\right)$$

$$where \qquad \tilde{r}^2 = \tilde{x}^2 + \tilde{y}^2$$

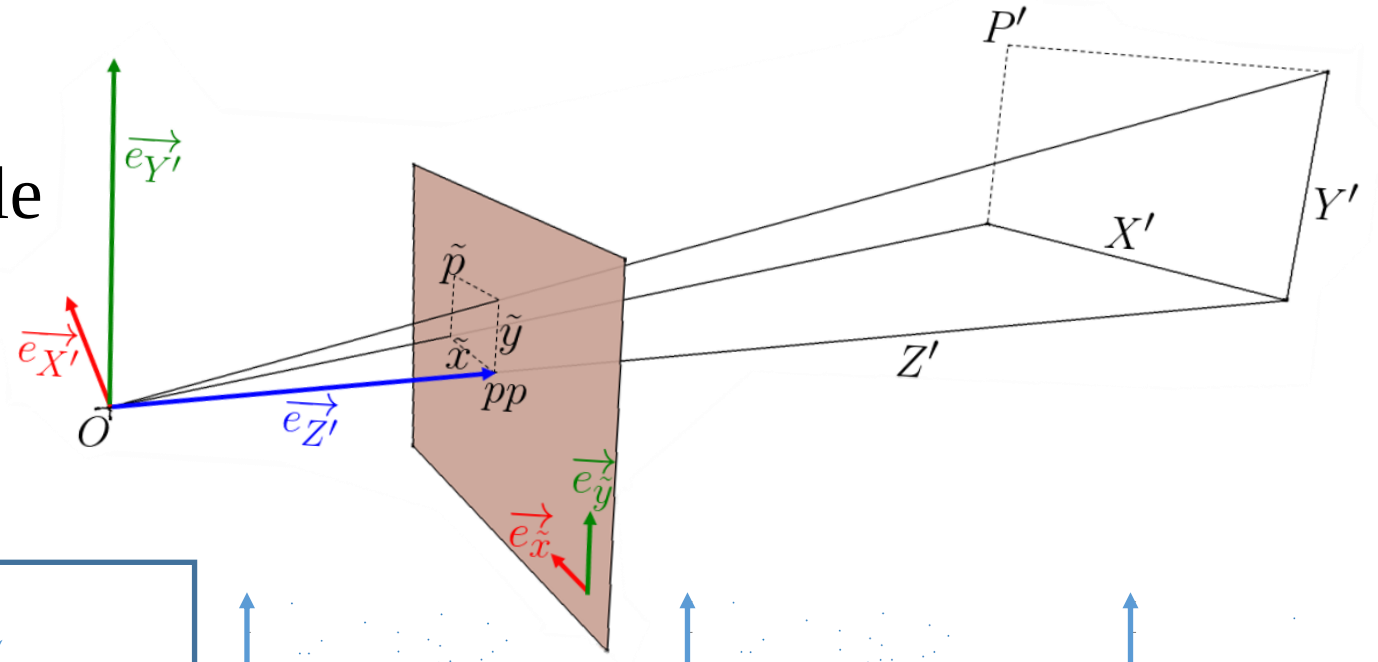
$$\xi_2 : \quad \mathbb{R}^2 \quad \rightarrow \quad \mathbb{R}^2$$

$$\begin{bmatrix} x \\ y \end{bmatrix} \quad \mapsto \quad \begin{bmatrix} c + B_1 & B_2 \\ 0 & c \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} pp_x \\ pp_y \end{bmatrix}$$

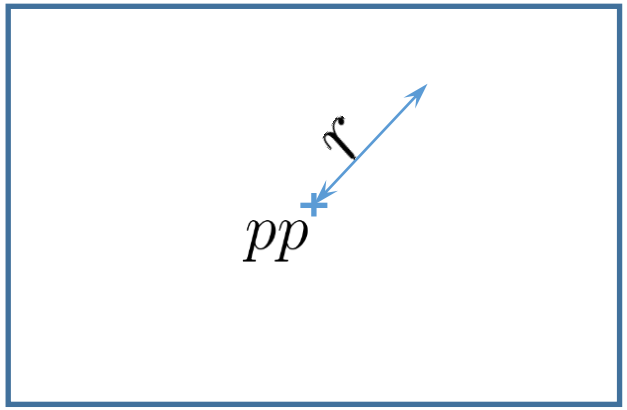
$$\xi = \xi_2 \circ \xi_1$$

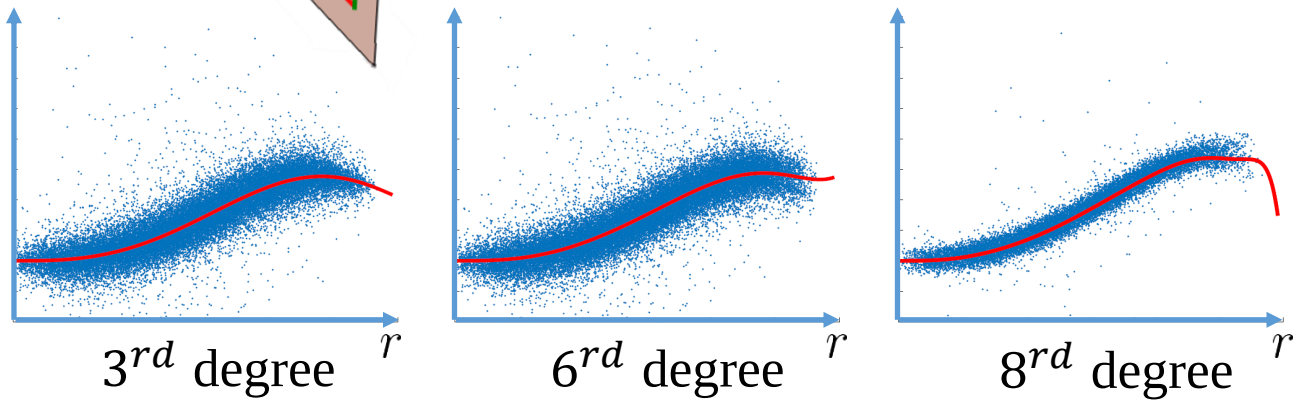
Camera models

- Departure from pinhole camera model

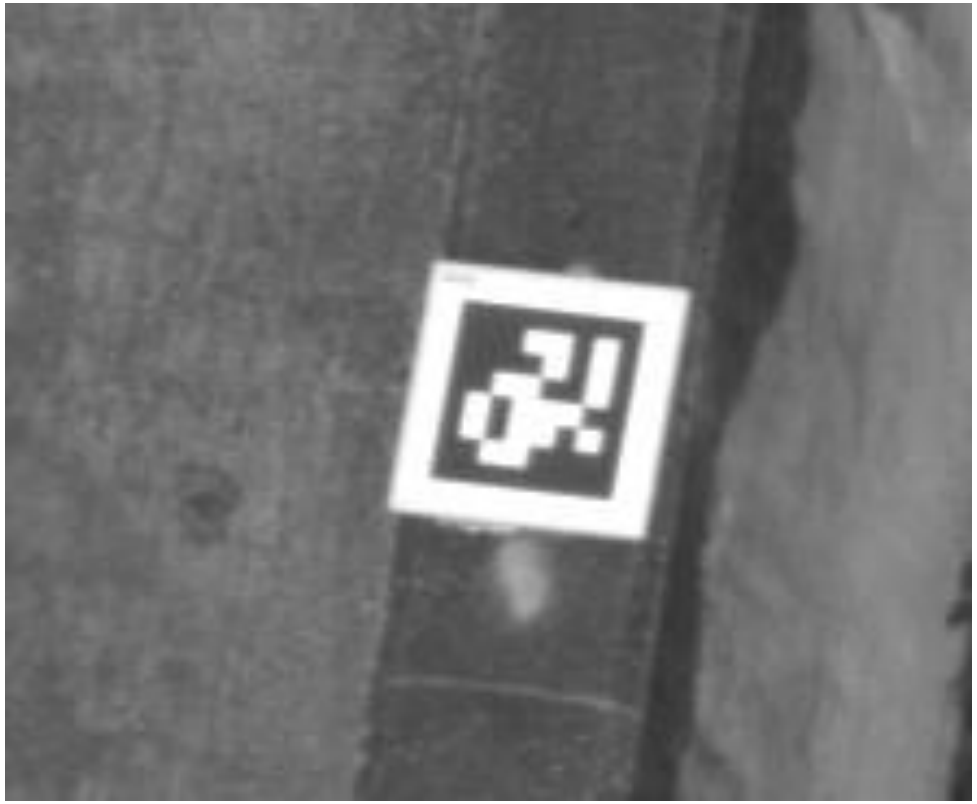


- Radial

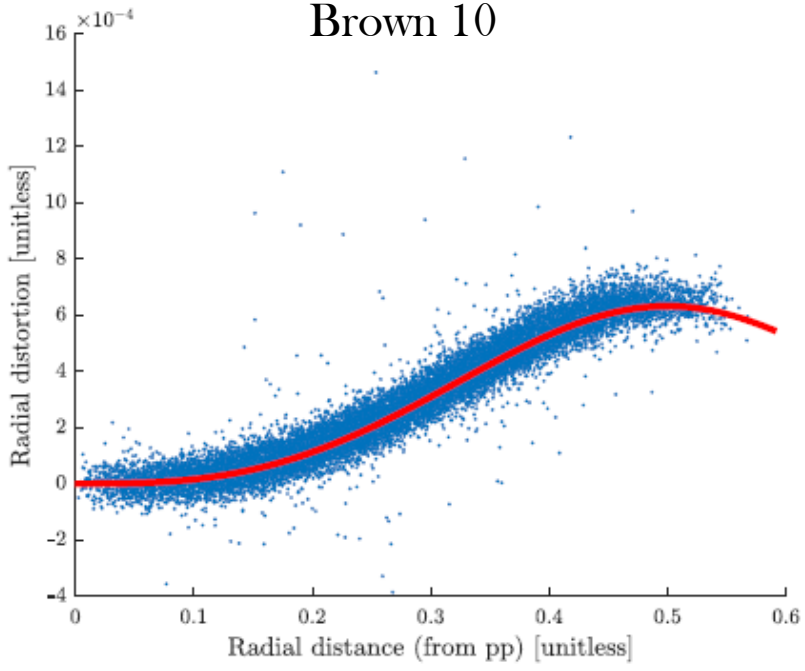




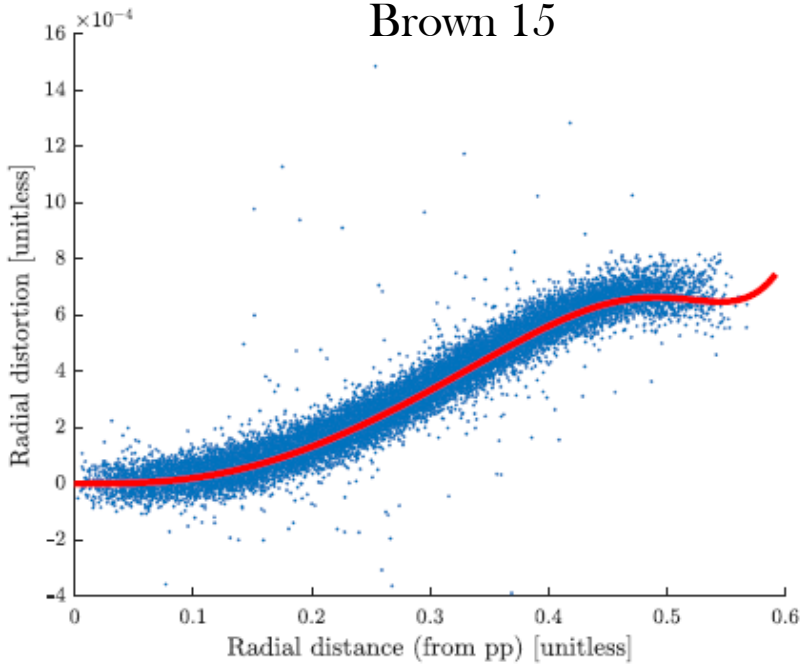
Camera calibration



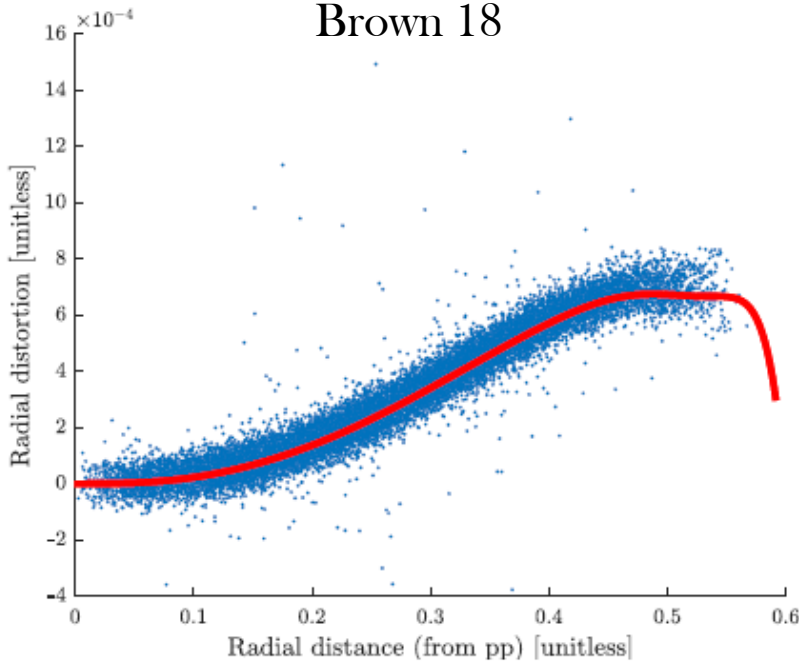
Brown 10

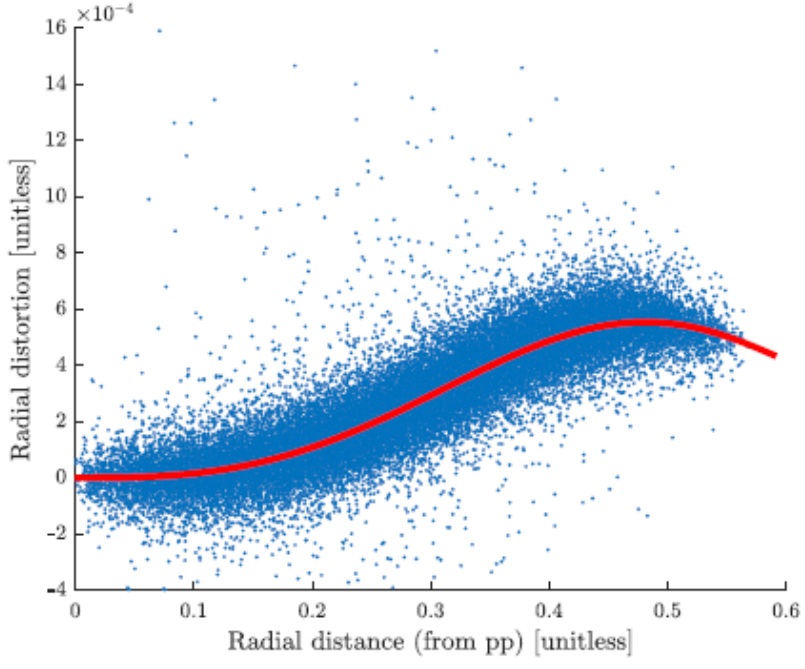


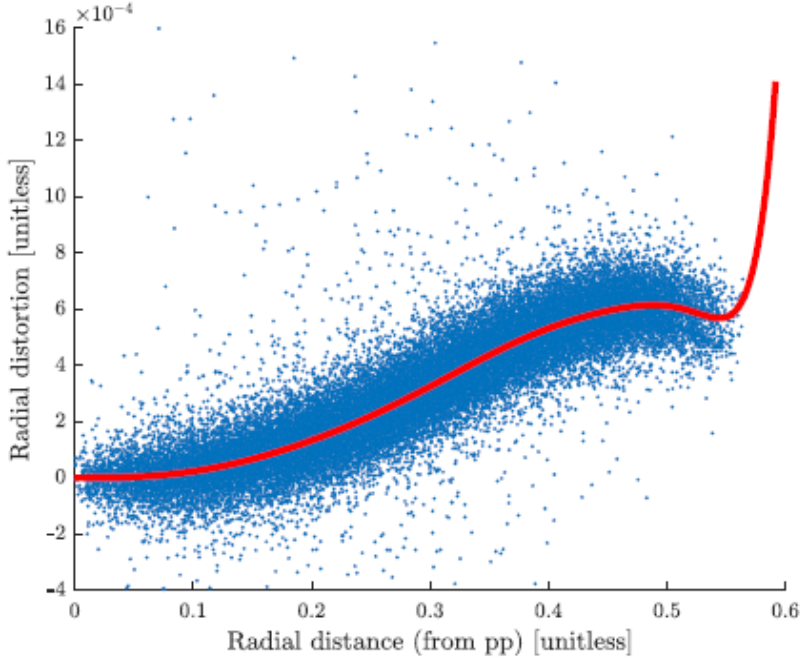
Brown 15

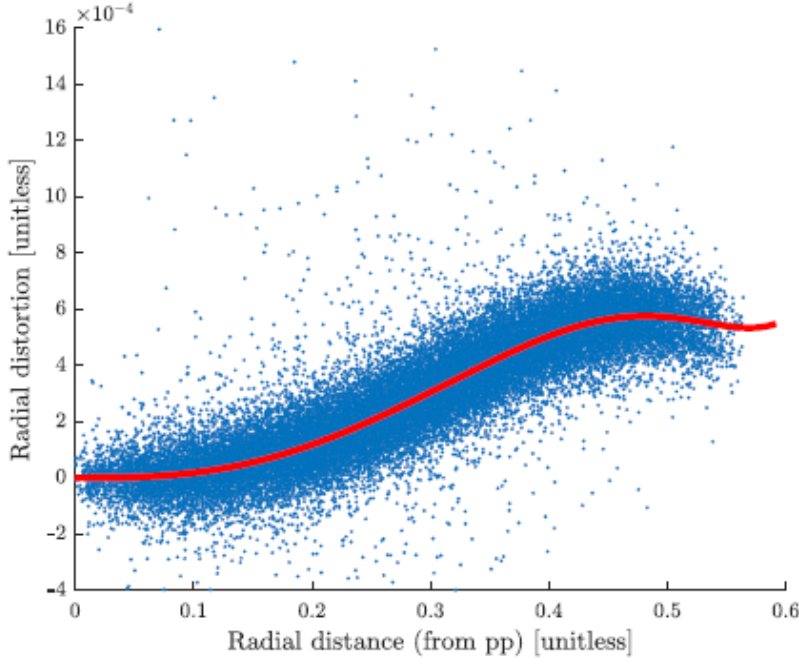


Brown 18



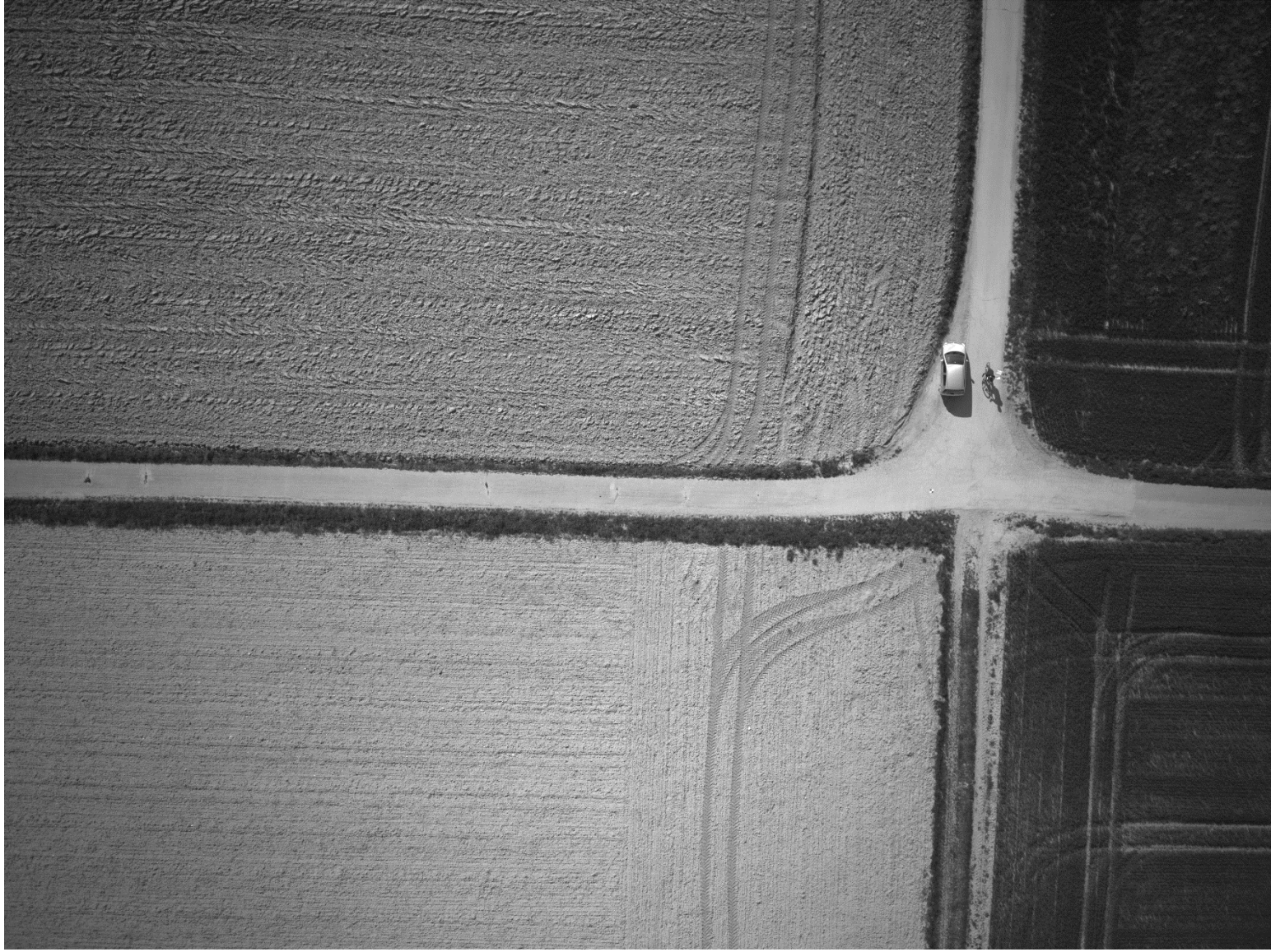


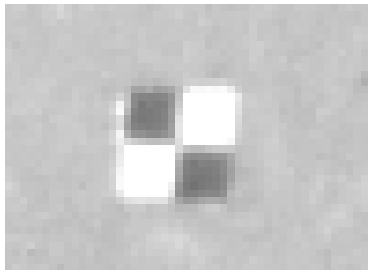




Flight in test-field

200 m





30 cm