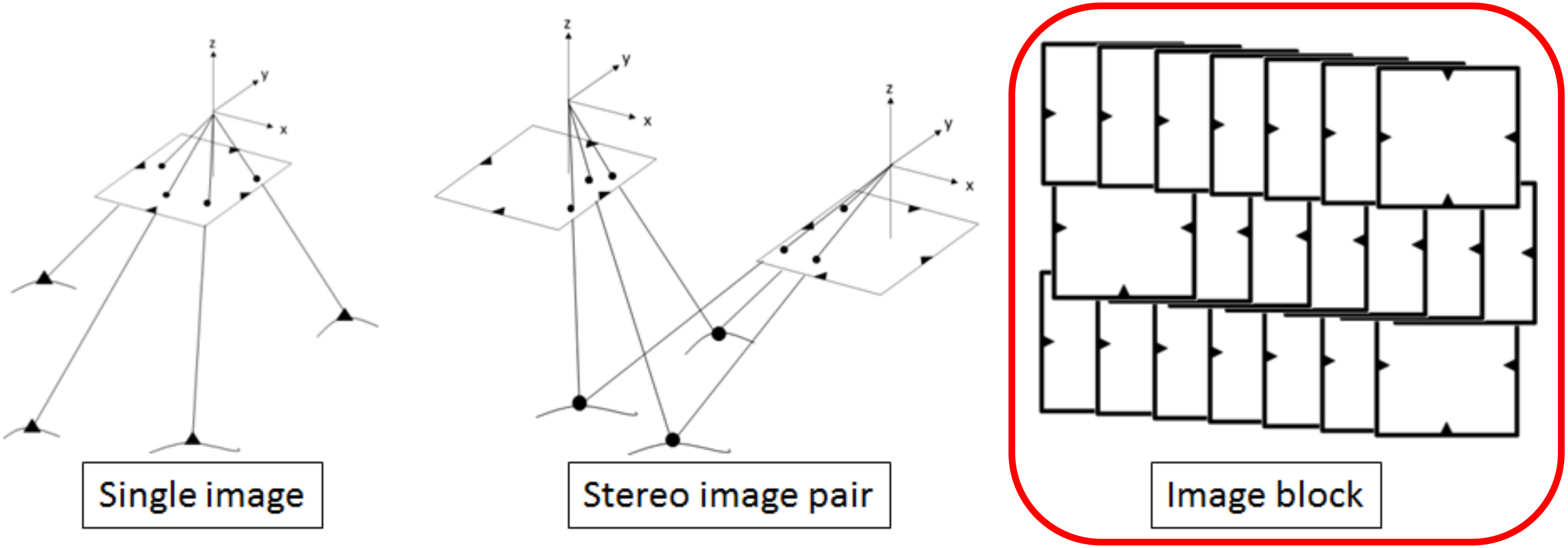
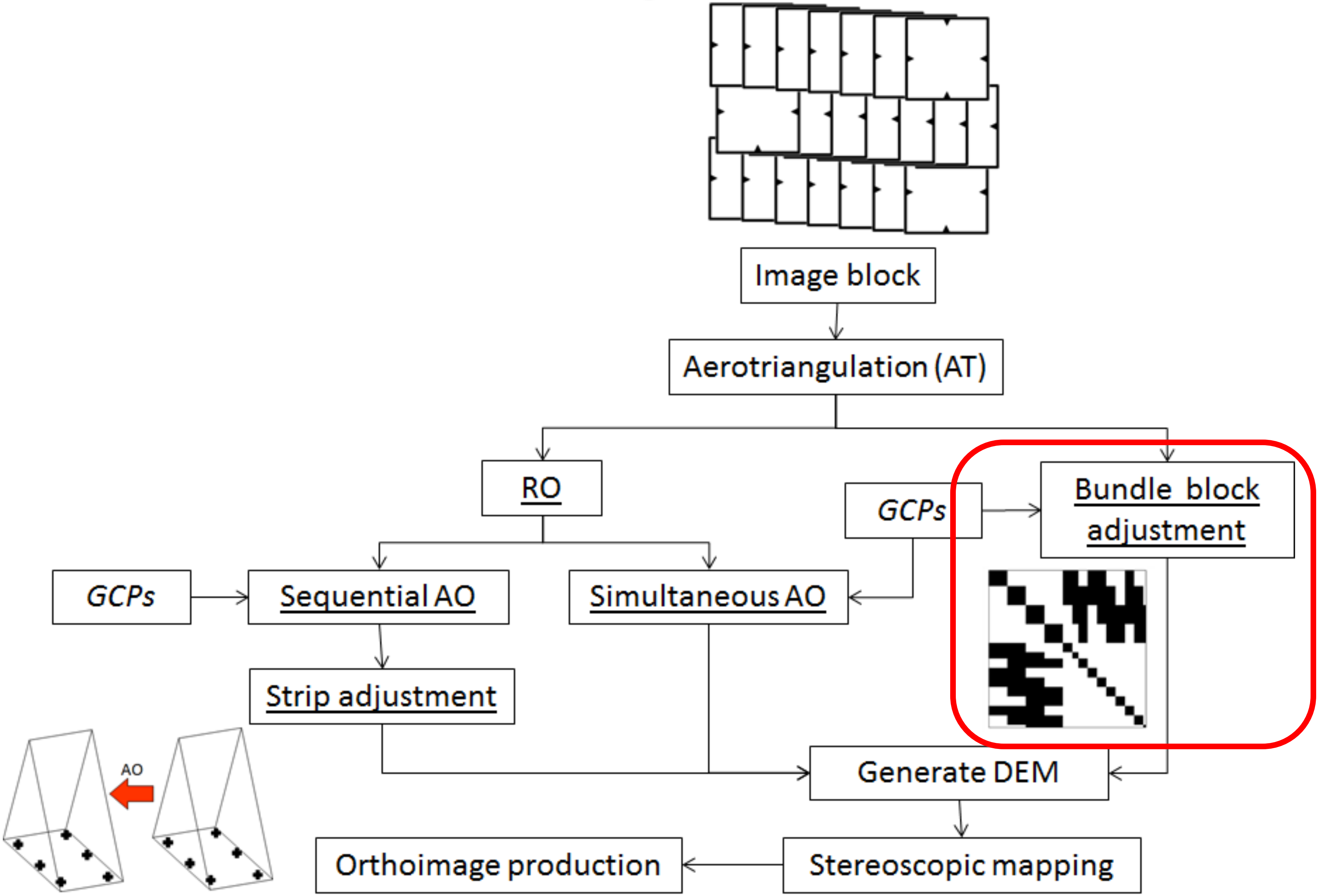
Indirect Image Orientation



All Slides Courtesy of:

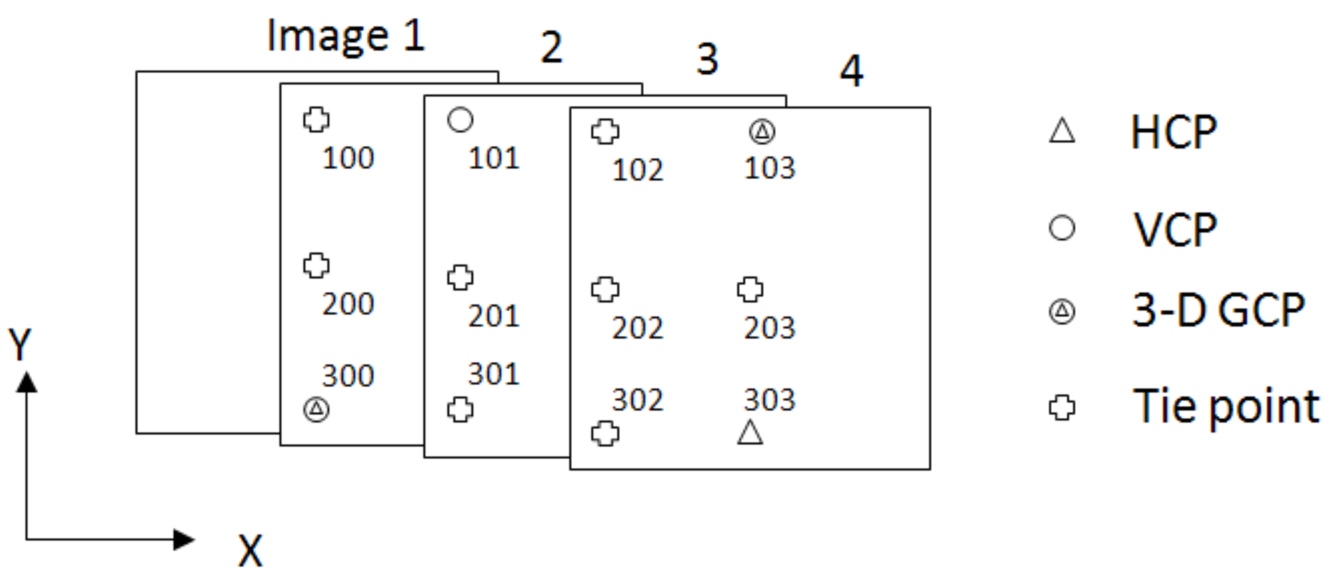
Dr. Derek Lichti
University of Calgary

Indirect image orientation



Matrix Structure Example

- Block layout
  - How many observations, unknowns and degrees-of-freedom are there?



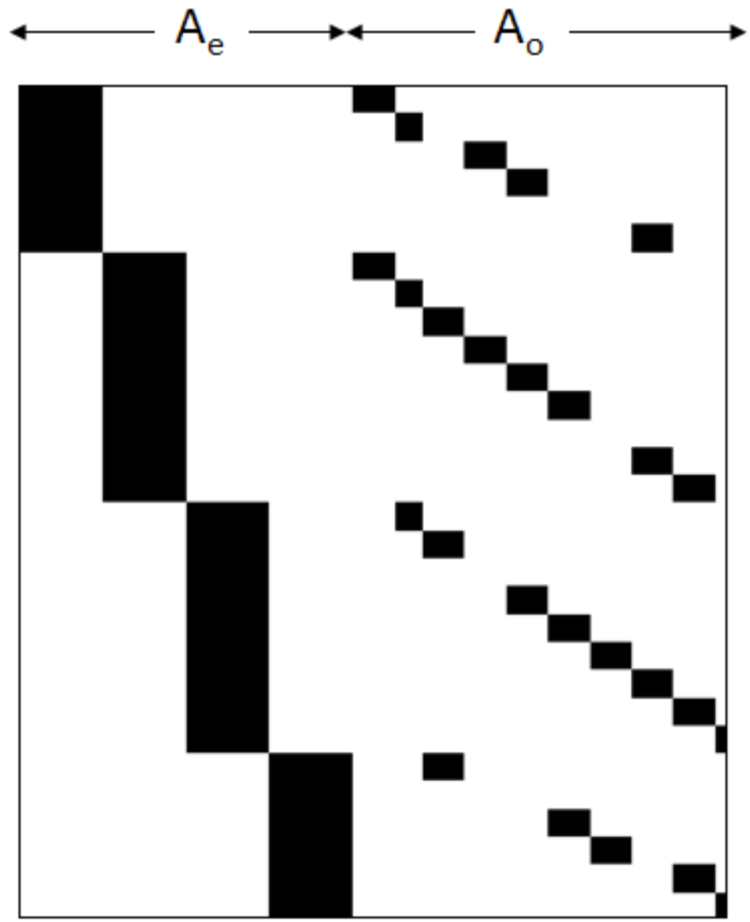
Matrix Structure Example (cont'd)

- General structure of the design matrix

	EO Parameters (A_e)				Object Point Parameters (A_o)									
	Image 1 (6)	Image 2 (6)	Image 3 (6)	Image 4 (6)	100 (3)	101 (2)	102 (3)	200 (3)	201 (3)	202 (3)	203 (3)	301 (3)	302 (3)	303 (1)
Image 1 (12)														
Image 2 (18)														
Image 3 (18)														
Image 4 (12)														

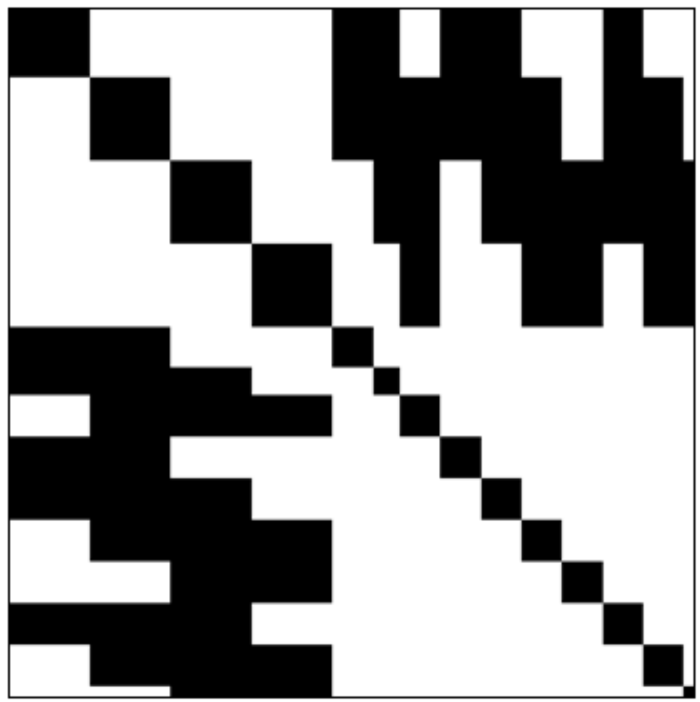
Matrix Structure Example (cont'd)

- Design matrix structure



Matrix Structure Example (cont'd)

- Normal equations matrix structure



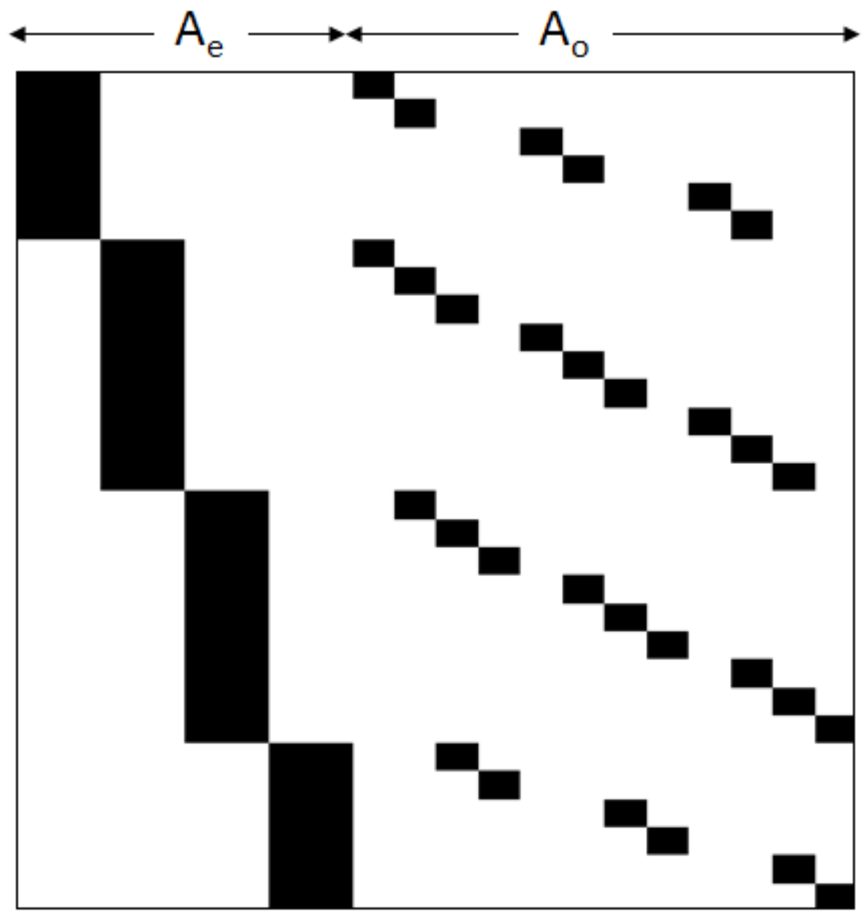
Matrix Structure Example (cont'd)

- **General structure of the design matrix—unified least squares case**

	EO Parameters (A_e)						Object Point Parameters (A_o)									
	Image 1 (6)	Image 2 (6)	Image 3 (6)	Image 4 (6)	100 (3)	101 (3)	102 (3)	103 (3)	200 (3)	201 (3)	202 (3)	203 (3)	300 (3)	301 (3)	302 (3)	303 (3)
Image 1 (12)																
Image 2 (18)																
Image 3 (18)																
Image 4 (12)																

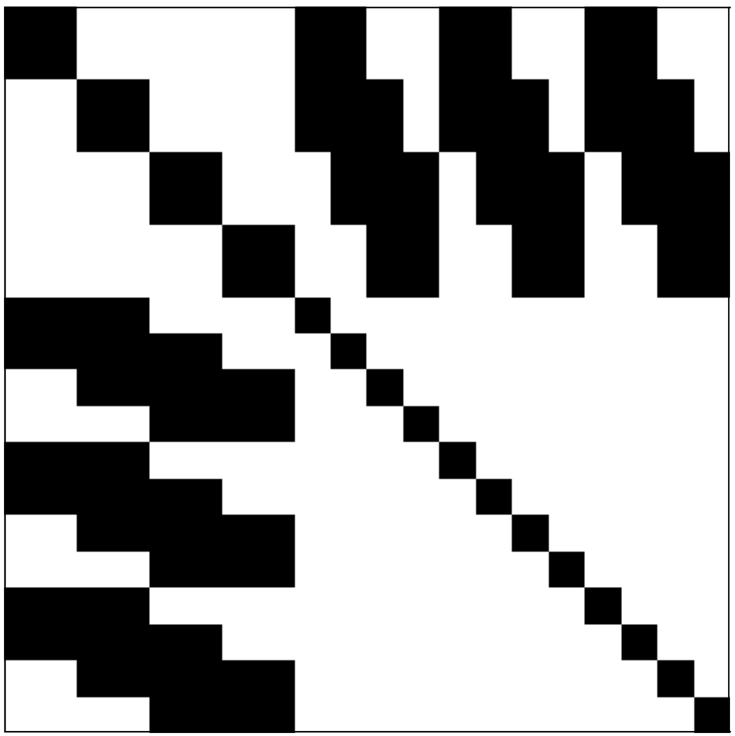
Matrix Structure Example (cont'd)

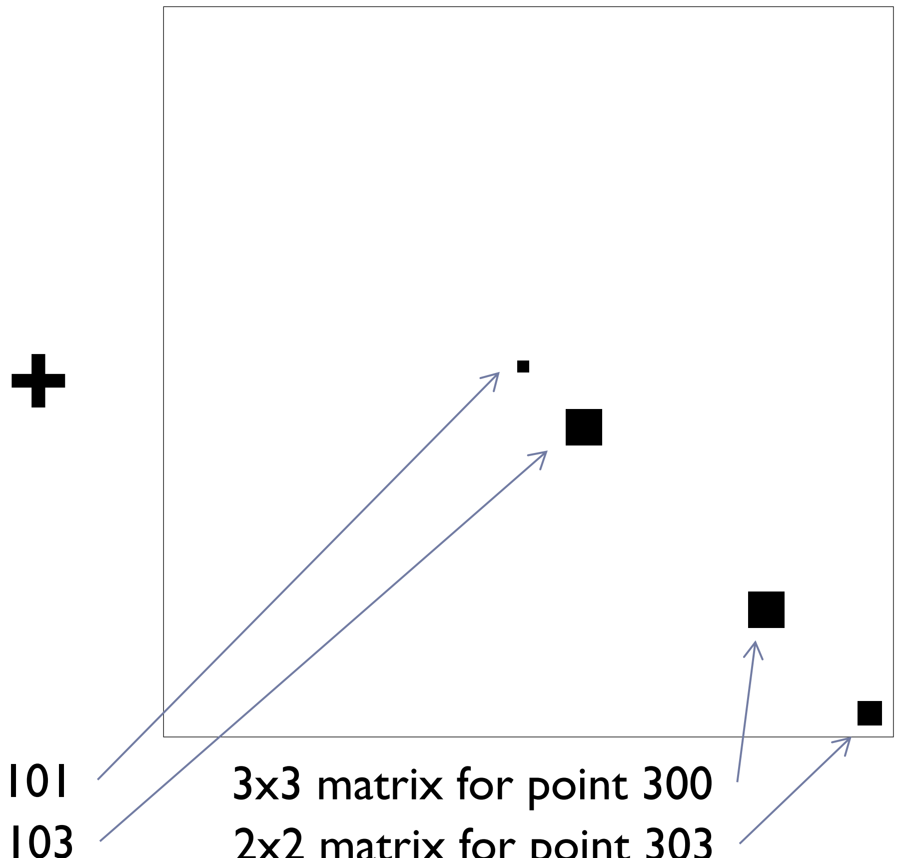
- Design matrix structure—unified least squares case



Matrix Structure Example (cont'd)

- Normal equations matrix structure and parameter weight matrix—unified least squares case





Bundle Adjustment Example 1

- Partial solution
- All the same input data as in the resection and intersection examples
  - 2 images, 2 tie points (72, 127), 4 3D control points
  - Control points treated as constants
  - n=24, u=18, r=6
- Final solution after 4 iterations

Other quantities	
RMS_{vx} (mm)	0.008
RMS_{vy} (mm)	0.009
Redundancy	6
Variance factor	1.283

Bundle Adjustment Example 1 (cont'd)

Residuals (mm)		
	Left	**Right**
x_{30}	-0.010	0.001
y_{30}	0.024	0.000
x_{40}	0.023	-0.002
y_{40}	-0.014	-0.001
x_{50}	-0.012	0.003
y_{50}	0.001	0.000
x_{112}	-0.001	-0.003
y_{112}	-0.011	0.002
x_{72}	0.000	0.000
y_{72}	0.000	0.000
x_{127}	0.000	0.000
y_{127}	0.001	-0.001

Bundle Adjustment Example 1 (cont'd)

Parameters and standard deviations				
	Left		Right	
X^c (m)	6349.495	0.320	7021.896	0.377
Y^c (m)	3965.305	0.412	3775.658	0.408
Z^c (m)	1458.094	0.154	1466.700	0.151
ω (°)	0.98672	0.01501	1.87411	0.01583
ϕ (°)	0.40715	0.01385	1.67510	0.01657
κ (°)	-18.90545	0.00569	-15.74806	0.00494

Parameters and standard deviations		
X_{72} (m)	6869.170	0.111
Y_{72} (m)	3844.538	0.115
Z_{72} (m)	283.205	0.319

Parameters and standard deviations		
X_{170} (m)	6316.138	0.142
Y_{170} (m)	3934.680	0.126
Z_{170} (m)	283.228	0.341

Bundle Adjustment Example 1 (cont'd)

Correlation coefficient matrix of the parameters—left image						
	$\mathbf{X^c}$	$\mathbf{Y^c}$	$\mathbf{Z^c}$	$\boldsymbol{\omega}$	$\boldsymbol{\phi}$	$\boldsymbol{\kappa}$
$\mathbf{X^c}$	1					
Yc	-0.12	1				
Zc	0.71	0.22	1			
$\boldsymbol{\omega}$	0.20	-0.98	0.29	1		
$\boldsymbol{\phi}$	0.97	-0.21	0.80	0.29	1	
$\boldsymbol{\kappa}$	-0.13	-0.66	-0.02	0.59	-0.06	1

Questions for Discussion

- Comment on the RMS of residuals
- Comment on the precision of the tie point co-ordinates relative to the intersection solution
- Comment on the precision of the EO parameters relative to the resection solution

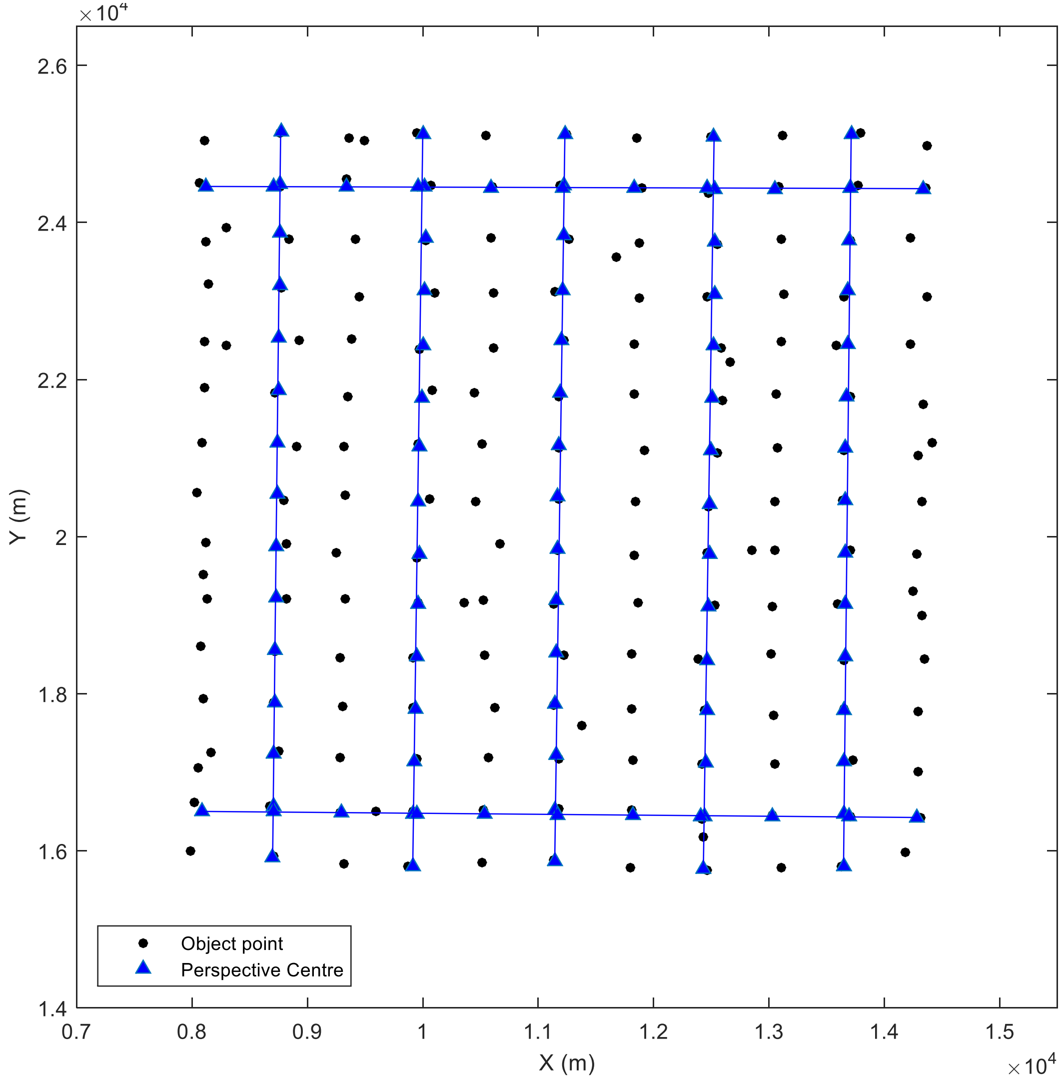
Bundle Adjustment Example 2

- Ellenbrook block
  - 97 images
  - 5 strips and 2 cross-strips
  - 60% end lap and 20% side lap
  - Scale 1:7500
  - 4 weighted control points (co-ordinate parameter observations)
  - 175 pass/tie points
  - 878 image point observations
  - 17 check points (solved as tie points)

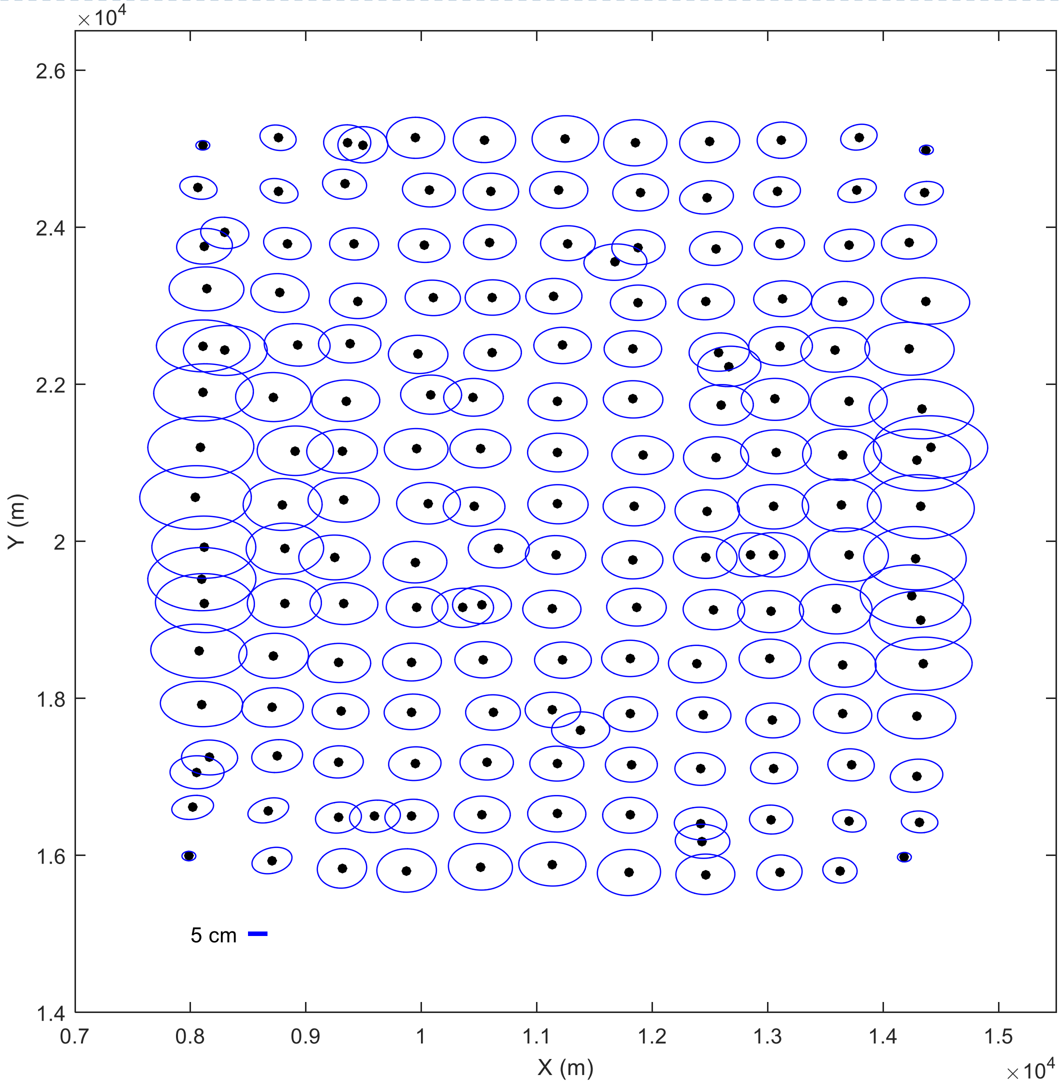
Example 2 Adjustment Cases

1. Minimal ground control: 4 3D GCPs in the corners
2. Full ground control: 21 3D GCPs throughout the block
3. Minimal ground control + airborne GPS observations of each PC

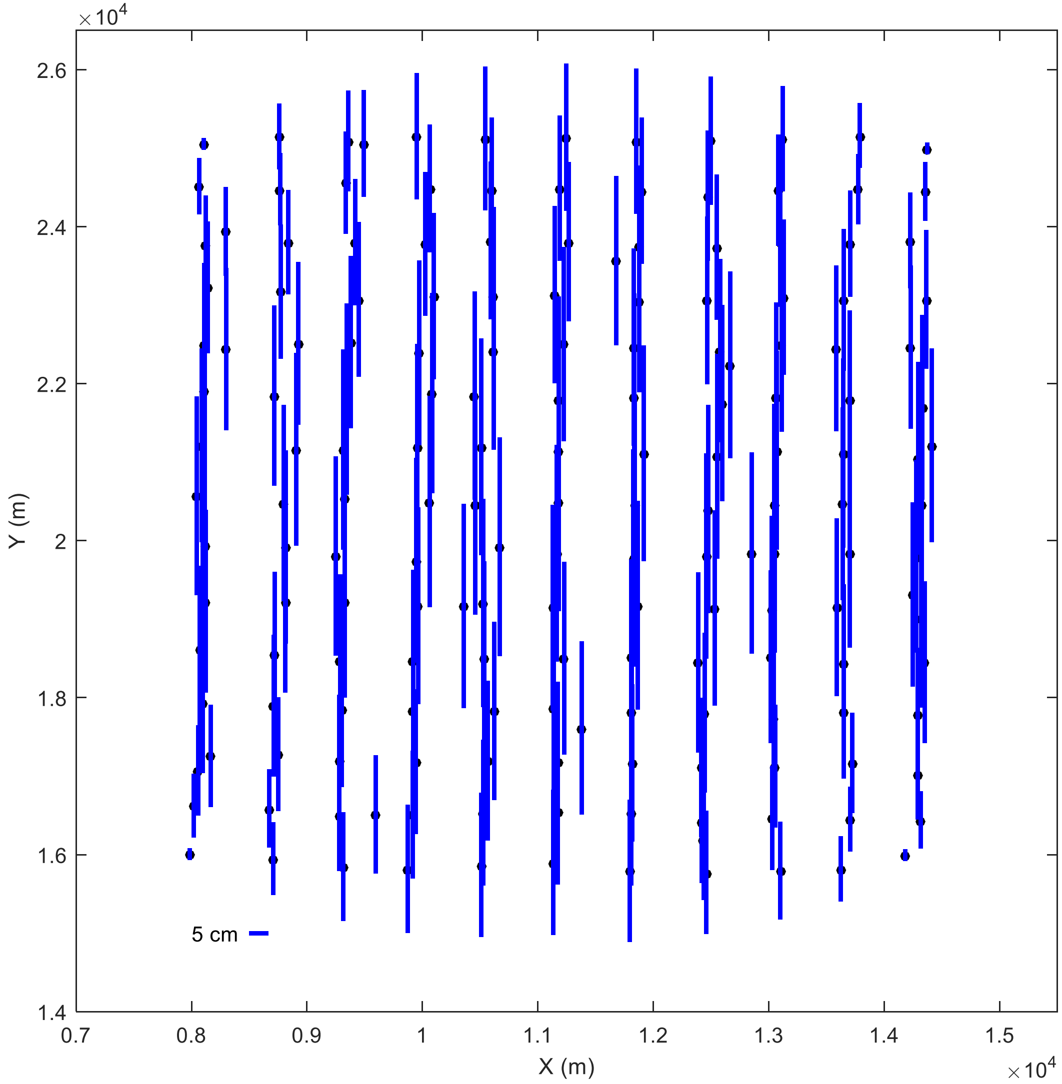
Example 2 Block Configuration



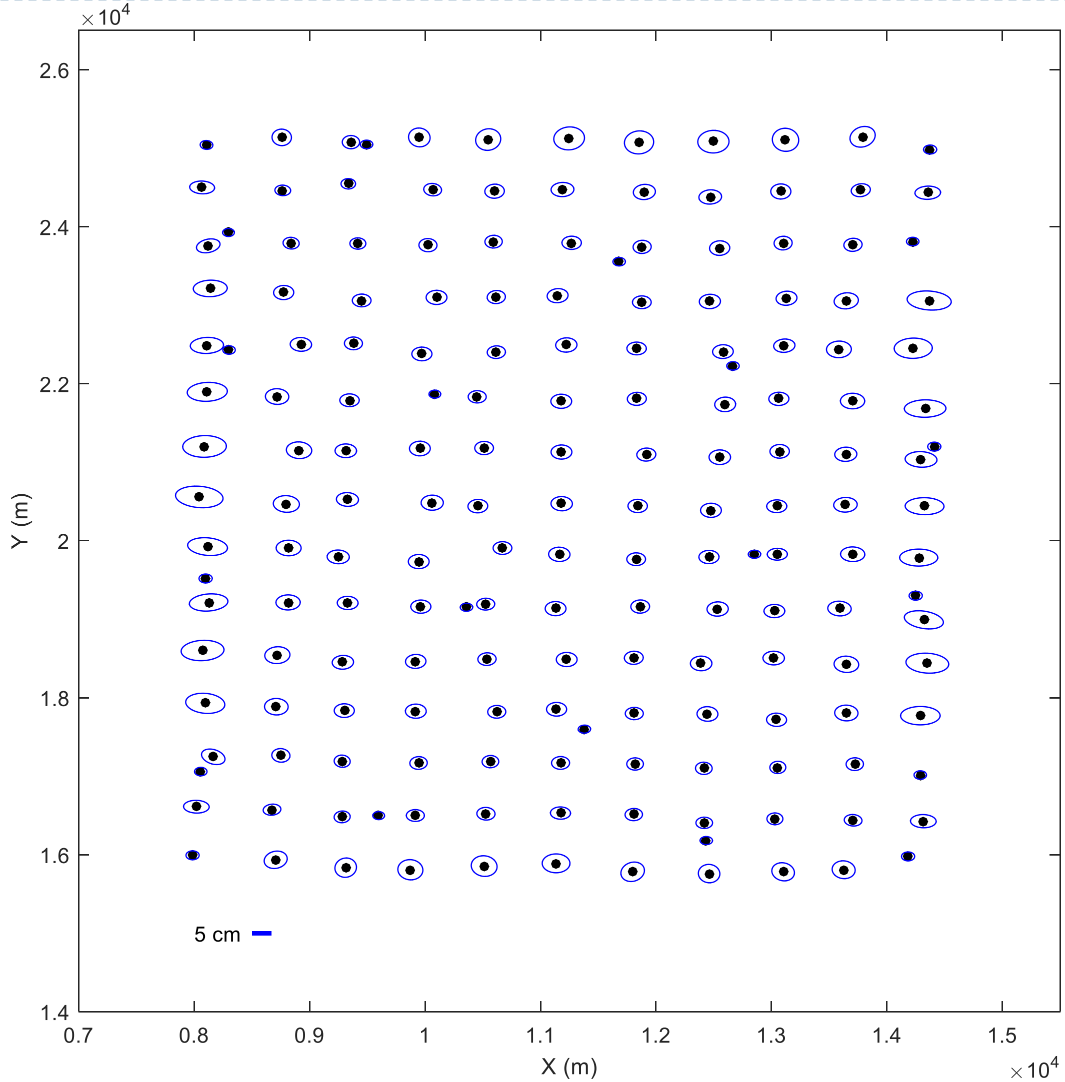
Case 1—Minimum Ground Control Planimetric Precision



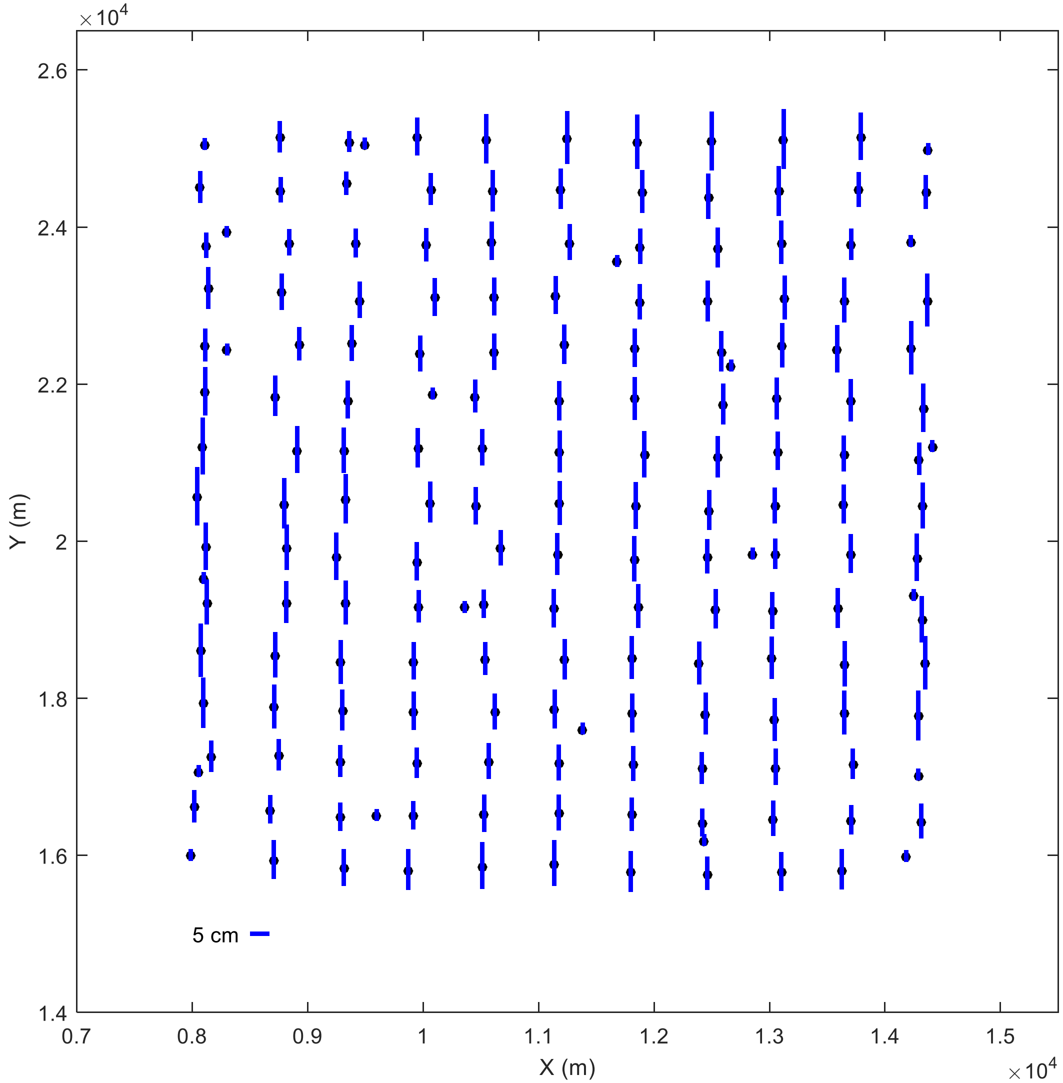
Case 1—Minimum Ground Control Vertical Precision



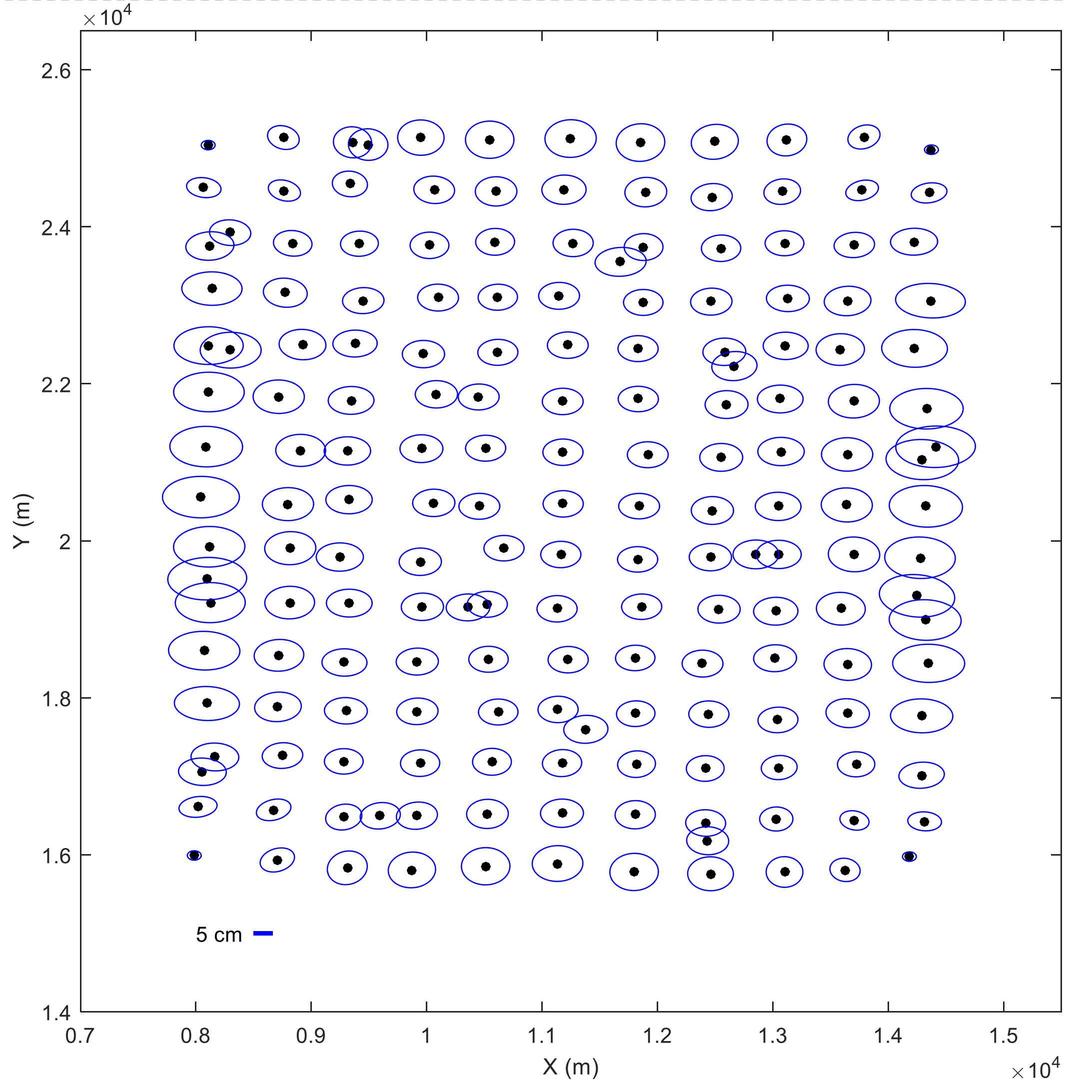
Case 2—Full Ground Control Planimetric Precision



Case 2—Full Ground Control Vertical Precision



Case 3—Min Ground Control+Airborne GPS Planimetric Precision



Case 3—Min Ground Control+Airborne GPS Vertical Precision

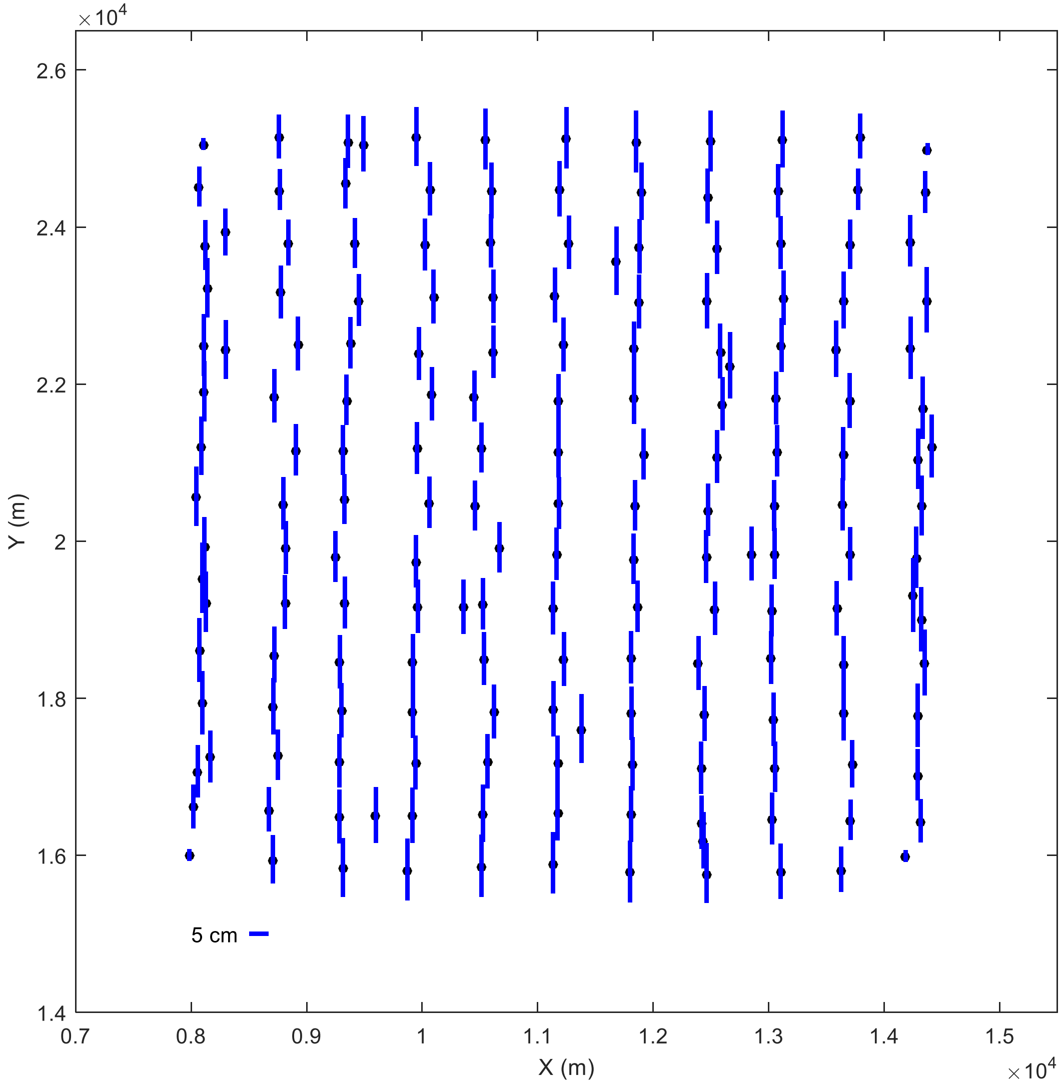


Image Orientation Methods

<u>Indirect Georeferencing</u> 1960s-1970s

- Georeferencing done by ground control points (GCPs)
- Control extended across the block by aerotriangulaiton (AT)

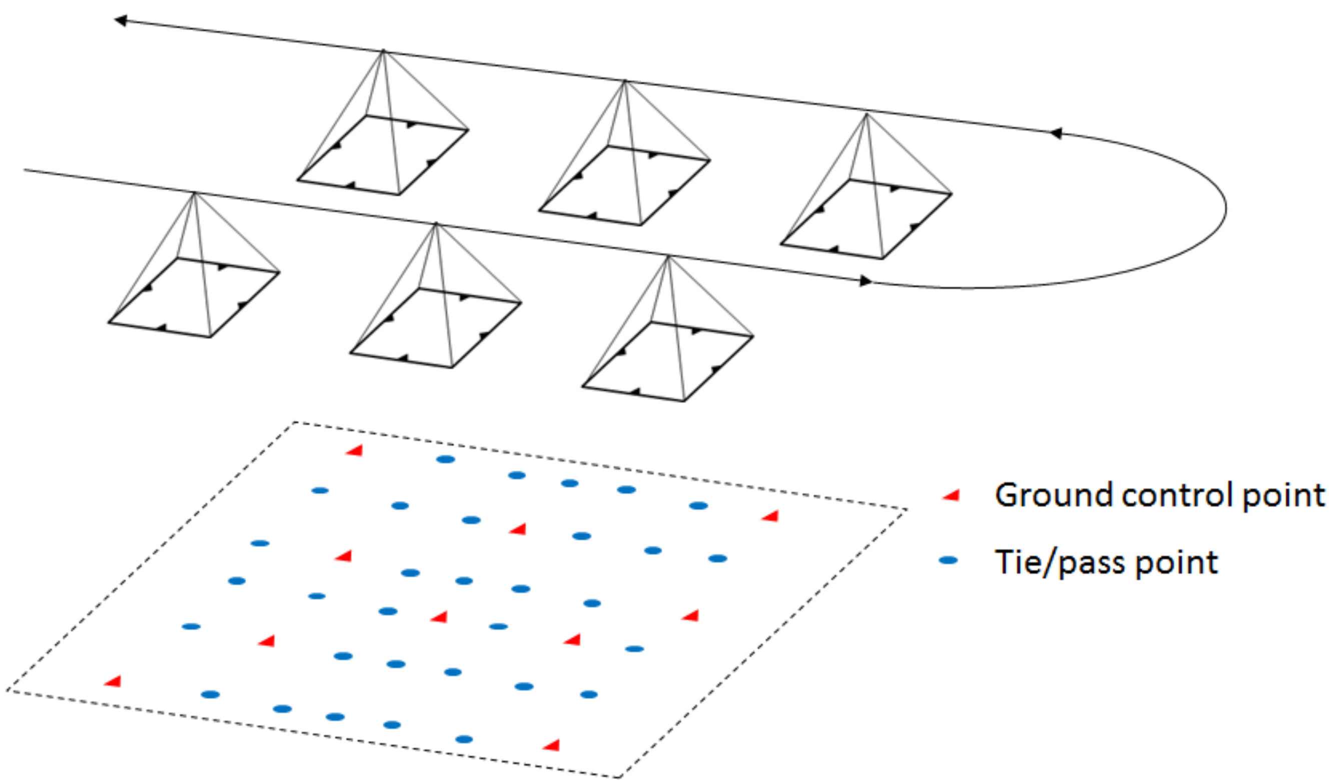
<u>GPS-AT</u> 1980s-1990s

- The beginning of direct measurement of exterior orientation parameters
- GPS antenna used to observe the PC
- GCP requirements reduced to 4 per block

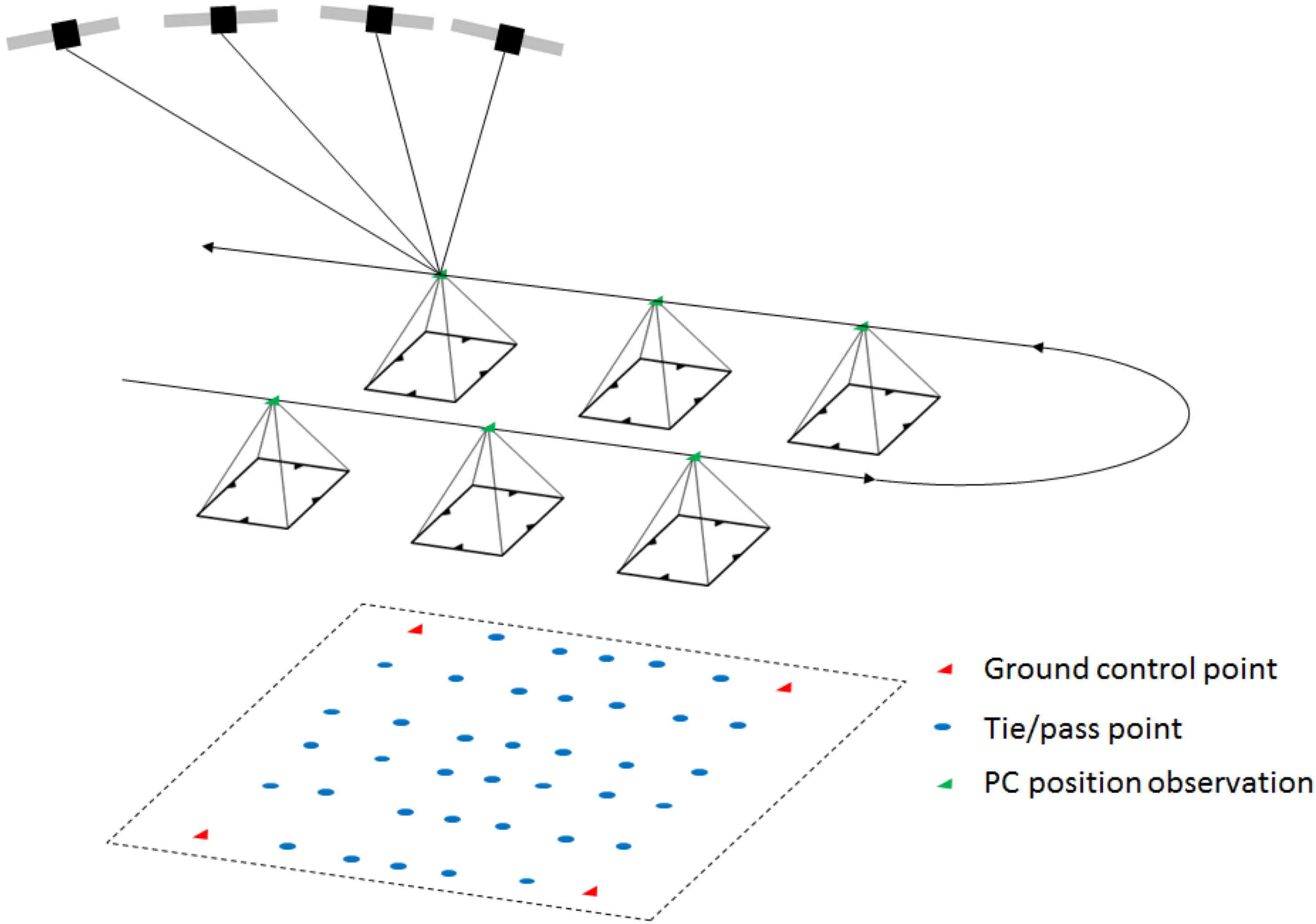
<u>Direct Georeferencing</u> 1990s onward

- Integrated GNSS/IMU systems to determine sensor position and attitude
- At least 2 modes
- Integrated sensor orientation (ISO)
    - Sensor position and attitude observations
    - Image point observations
    - Some ground control
    - Self-diagnostic quality control
    - Self-calibration possible
- Direct sensor orientation (DSO)
    - Sensor position and attitude observations only
    - Accuracy relies on GNSS/IMU alone

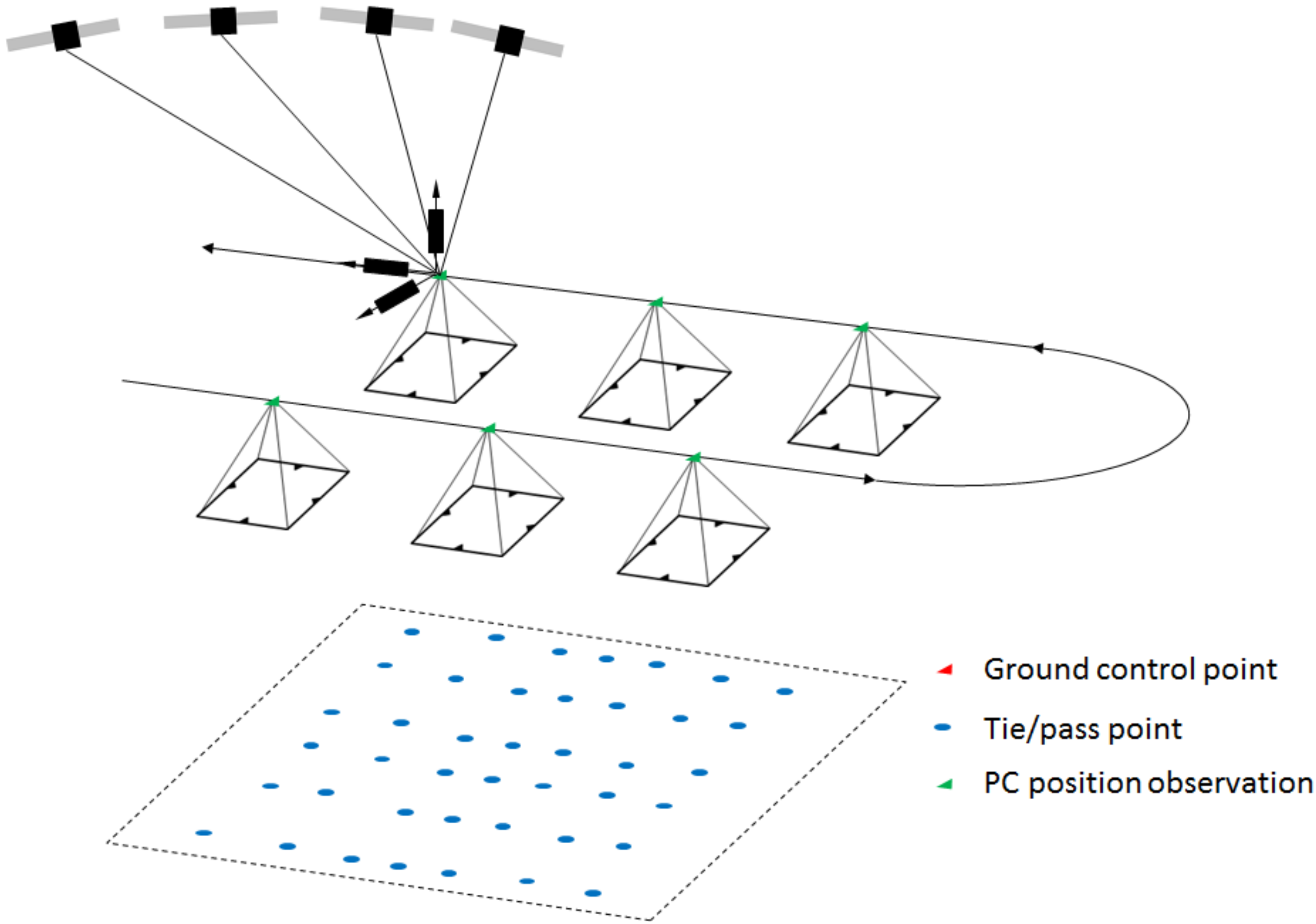
Indirect Georeferencing



GPS-AT


Ground control point
Tie/pass point
PC position observation

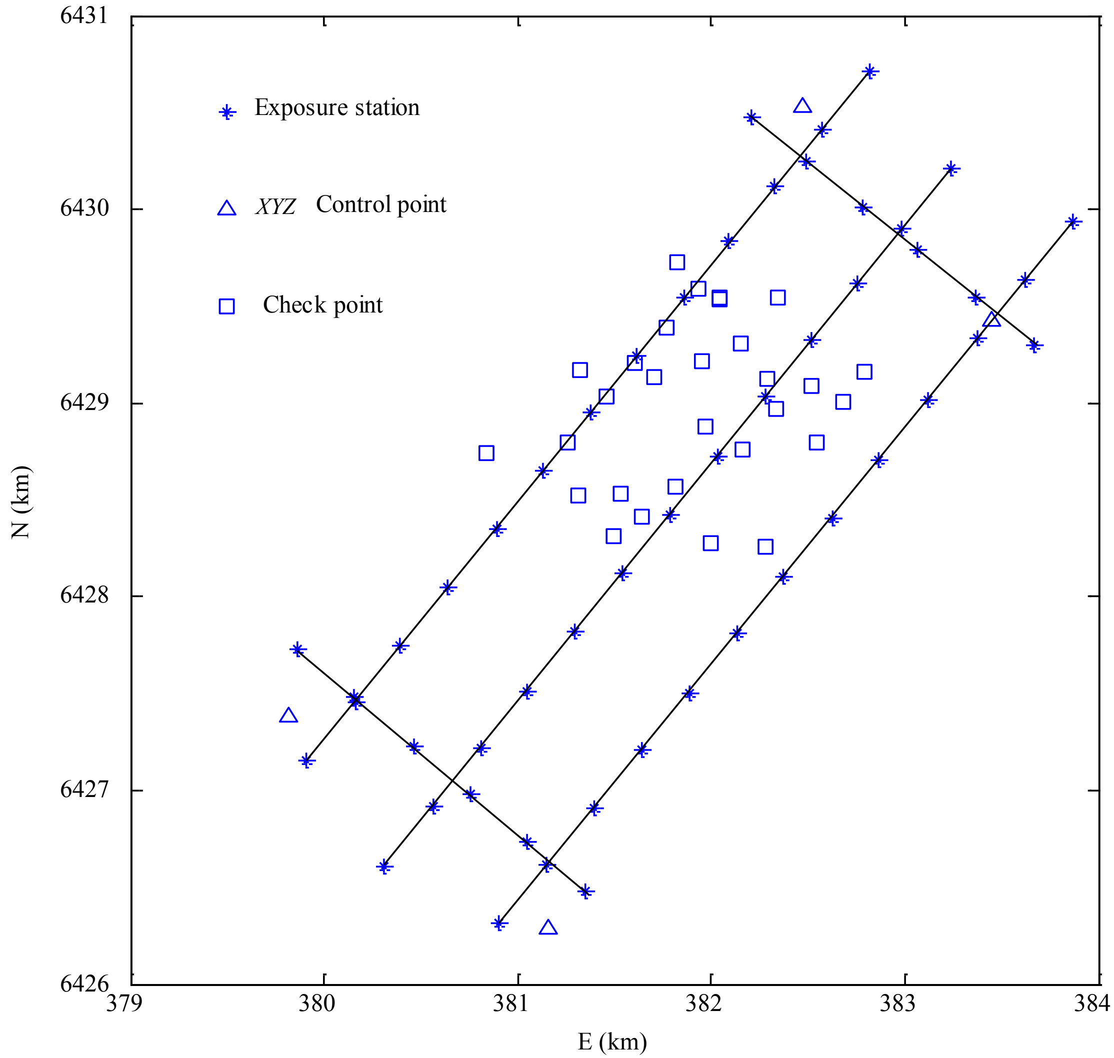
Direct Georeferencing



Bundle Adjustment Example 3

- Rockingham block (GPS-AT example)
  - 51 images observed with GPS (EO parameter observations)
  - 3 strips and 2 cross-strips
  - 60% end lap and 20% side lap
  - Scale 1:5000
  - 4 weighted control points (co-ordinate parameter observations)
  - 238 pass/tie points
  - 934 image point observations
  - 29 check points (solved as tie points)
  - 5 sets of drift parameters to model errors in GPS positions (caused by incorrect integer ambiguities)

Bundle Adjustment Example 3 (cont'd)

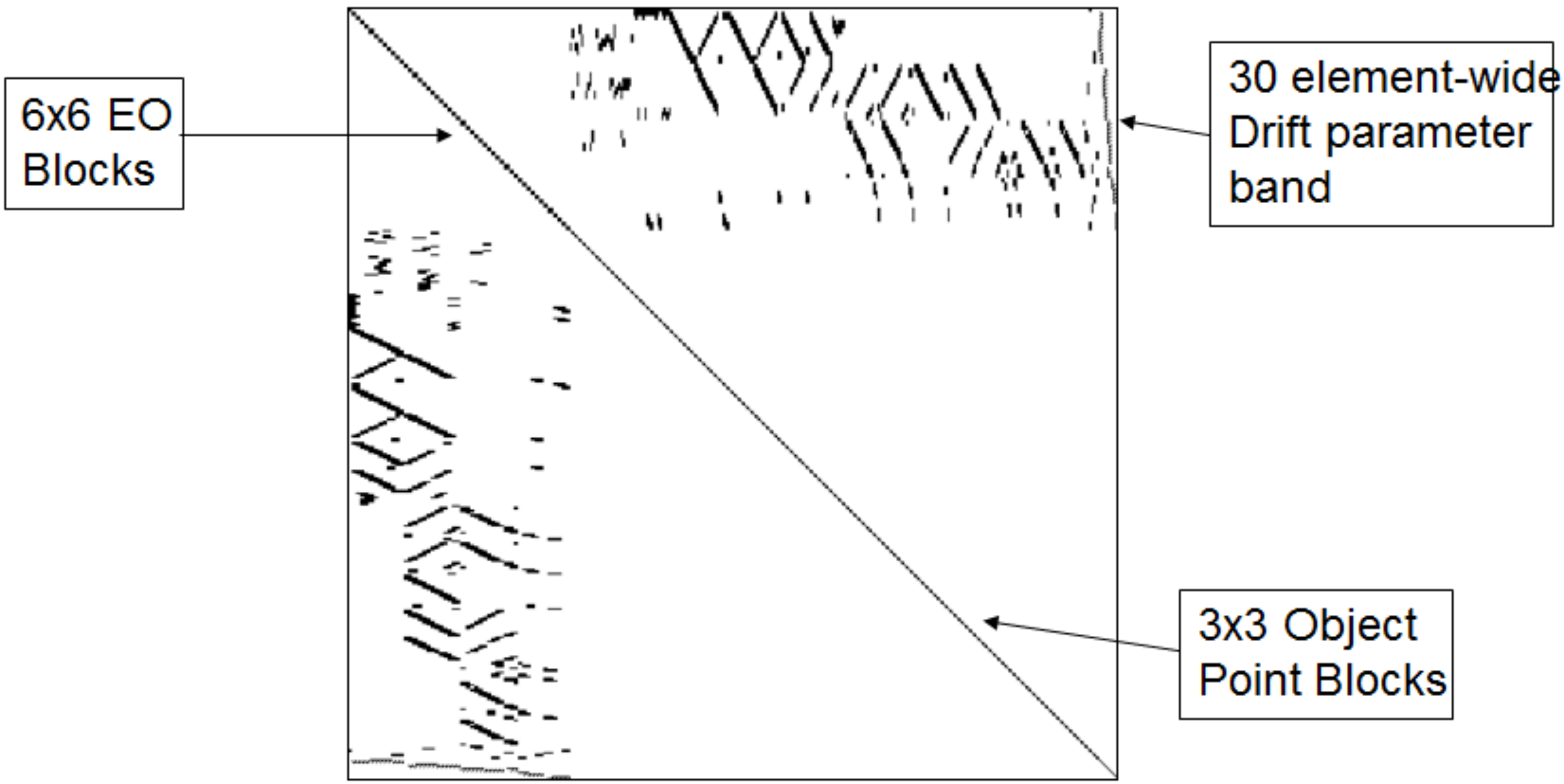


Bundle Adjustment Example 3 (cont'd)

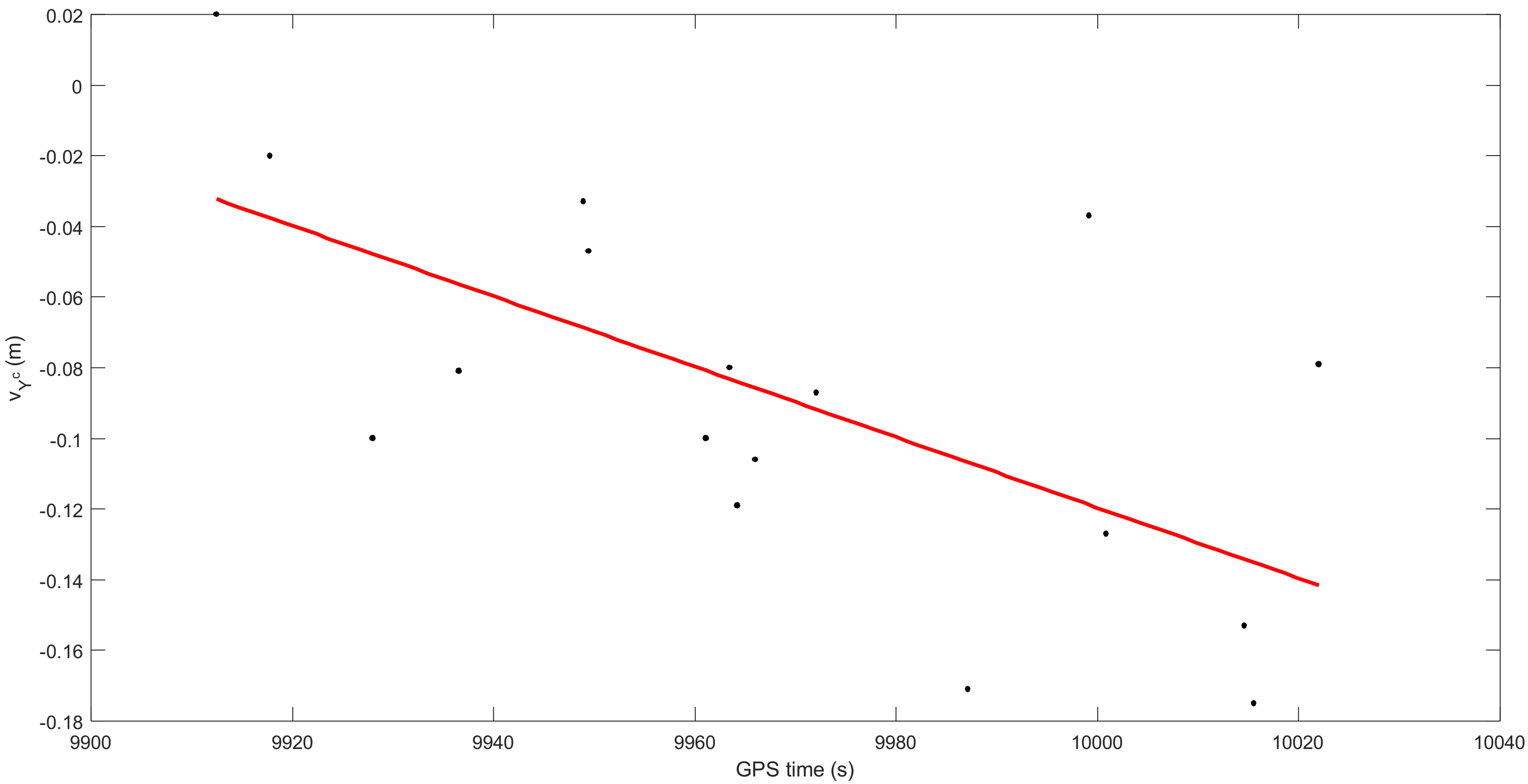
Observations		
GPS PCs $\sigma = \pm 0.05$ m	3 x 51	153
Image points $\sigma = \pm 6\ \mu$m	2 x 934	1868
Control points $\sigma = \pm 0.05$ m	3 x 4	12
Total observations (n)		**2033**
Unknowns		
PCs	6 x 51	306
Tie/pass points	3 x 238	714
Control points	3 x 4	12
Drift parameters	6 x 5	30
Total Unknowns (u)		**1062**
Redundancy (r=n-u)		**971**

Bundle Adjustment Example 3 (cont'd)

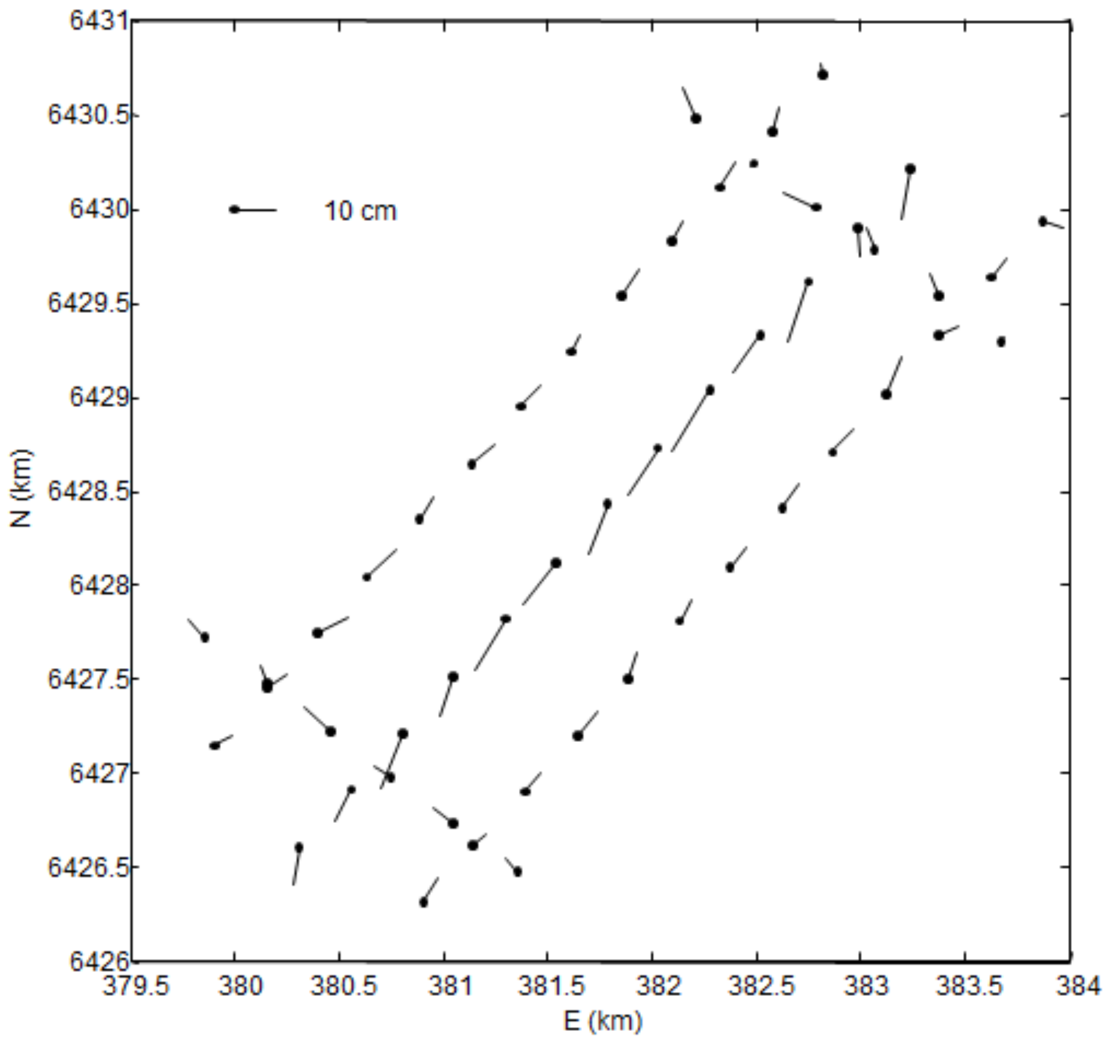
- Normal equations matrix (1062 x 1062)—note sparse structure



Drift vs Time (Single Strip)



Drift Behaviour—Horizontal Component



Bundle Adjustment Example 3 (cont'd)

- Results
  - Mean object point precision

$$\sigma_X = \sigma_Y = \pm 0.05\text{m}$$
$$\sigma_Z = \pm 0.07\text{m}$$

  - Check point difference RMS

$$RMS_X = \pm 0.03\text{m}$$
$$RMS_Y = \pm 0.04\text{m}$$
$$RMS_Z = \pm 0.09\text{m}$$

Summary of Equations

- Observation equations

$$\begin{bmatrix} A_e & A_o \end{bmatrix} \begin{bmatrix} \hat{\delta}_e \\ \hat{\delta}_o \end{bmatrix} + [w] = [\hat{v}]$$

$$\underset{n,u_e}{A_e}\,\underset{u_e,1}{\hat{\delta}_e} + \underset{n,u_o}{A_o}\,\underset{u_o,1}{\hat{\delta}_o} + \underset{n,1}{w} = \underset{n,1}{\hat{v}}$$

$$\underset{n,u_e}{A_e} = \begin{bmatrix} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \cdots & \frac{\partial f_{x_{ij}}}{\partial X_j^c} & \frac{\partial f_{x_{ij}}}{\partial Y_j^c} & \frac{\partial f_{x_{ij}}}{\partial Z_j^c} & \frac{\partial f_{x_{ij}}}{\partial \omega_j} & \frac{\partial f_{x_{ij}}}{\partial \phi_j} & \frac{\partial f_{x_{ij}}}{\partial \kappa_j} & \cdots \\ \cdots & \frac{\partial f_{y_{ij}}}{\partial X_j^c} & \frac{\partial f_{y_{ij}}}{\partial Y_j^c} & \frac{\partial f_{y_{ij}}}{\partial Z_j^c} & \frac{\partial f_{y_{ij}}}{\partial \omega_j} & \frac{\partial f_{y_{ij}}}{\partial \phi_j} & \frac{\partial f_{y_{ij}}}{\partial \kappa_j} & \cdots \\ & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \end{bmatrix} \qquad \underset{n,u_o}{A_o} = \begin{bmatrix} & \vdots & \vdots & \vdots & \\ \cdots & \frac{\partial f_{x_{ij}}}{\partial X_i} & \frac{\partial f_{x_{ij}}}{\partial Y_i} & \frac{\partial f_{x_{ij}}}{\partial Z_i} & \cdots \\ \cdots & \frac{\partial f_{y_{ij}}}{\partial X_i} & \frac{\partial f_{y_{ij}}}{\partial Y_i} & \frac{\partial f_{y_{ij}}}{\partial Z_i} & \cdots \\ & \vdots & \vdots & \vdots & \end{bmatrix}$$

- Normal equations

$$A^T P A \hat{\delta} + A^T P w = 0$$

$$\begin{bmatrix} A_e^T P A_e & A_e^T P A_o \\ \text{sym.} & A_o^T P A_o \end{bmatrix} \begin{bmatrix} \hat{\delta}_e \\ \hat{\delta}_o \end{bmatrix} + \begin{bmatrix} A_e^T P w \\ A_o^T P w \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad \begin{bmatrix} A_e^T P A_e + P_e & A_e^T P A_o \\ \text{sym.} & A_o^T P A_o + P_o \end{bmatrix} \begin{bmatrix} \hat{\delta}_e \\ \hat{\delta}_o \end{bmatrix} + \begin{bmatrix} A_e^T P w + P_e w_e \\ A_o^T P w + P_o w_o \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$