Analytical Methods to Assess the Geometric Fidelity of a Sensor Model

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Outline

- Purpose
- CSM Overview
- GSET Overview
- GSET Capabilities
- DGA
- PMA
- Conclusions

Purpose

- Identify sensor model issues before they become part of a tool used for geolocation, mensuration, or registration
- Show example analyses from the Generic Sensor Exploitation Tool (GSET), which evaluates a sensor model that has been built to the Community Sensor Model (CSM) Application Programming Interface (API)
- Image geometry model (sensor model) must support:
  - Precise image-to-ground and ground-to-image
  - Covariance propagation
  - Adjustability

CSM Overview

Example Sensor Model Functionality

- Image-to-ground
- Ground-to-image
- Compute sensor partials
- Compute ground partials
- Get/set parameter covariance
- Get parameter cross covariance
- Get un-modeled error
- Get un-modeled cross covariance

CSM API

Example Sensor Exploitation Tool (SET) Functionality

- Resection
- Triangulation
- Registration
- Multi-image Geopositioning
- Ortho-rectification
- Direct Geopositioning
- Relative Mensuration

GSET Overview

- Internal Consistency Testing
  - Are the CSM functions implemented mathematically correctly assuming a correct implementation of i2g?
  - Requires real image support data, but no GCPs and no measurements
- Direct Geopositioning Analysis (DGA) – absolute acc.
  - Is the support data quality commensurate with its associated covariance information?
  - Is the error behavior biased in image space?
  - Requires many real images, and few GCPs and associated image measurements per image
- Precision Modeling Analysis (PMA) – relative acc.
  - Is the i2g function, with its adjustable parameters, a correct/precise implementation of the physical/geometric 2D to 3D relationship?
  - Requires few real images, and many GCPs and associated image measurements per image

GSET Capabilities (1/2)

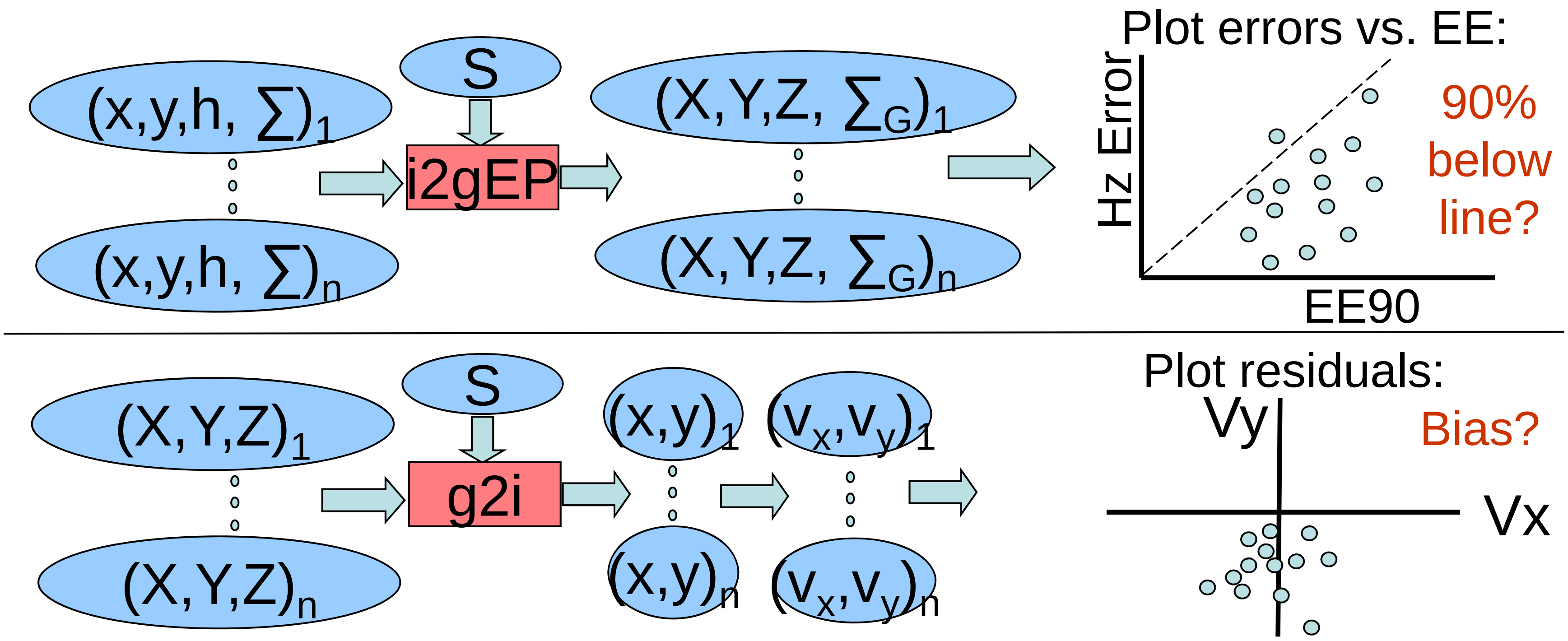
Required inputs: Images Reqd, Points reqd (per img)
Functionality tested: Sensor cov, Sensor cross cov, Adj params, G2I & I2g impl, Unmod error, Unmod cross cov

	Untriang or Triang	Absolute or Relative	Images Reqd	Points reqd (per img)	Sensor cov	Sensor cross cov	Adj params	G2I & I2g impl	Unmod error	Unmod cross cov
DGA Single	U	A		GCP						
DGA Stereo	U	A		GCP						
DGA MIG	U	A		GCP						
PMA Single	T	A		GCP						
		R		GCP						
	U	R		GCP						
PMA Stereo	U	R		GCP						
PMA Multi	T	A		TP						
		R		TP						

GSET Capabilities (2/2)

			Required inputs		Functionality tested					
	Untriang or Triang	Absolute or Relative	Images Reqd	Points reqd (per img)	Sensor cov	Sensor cross cov	Adj params	G2I & I2g impl	Unmod error	Unmod cross cov
DGA Single	U	A		GCP	1 set					
Stereo	U	A		GCP						
MIG	U	A		GCP						
PMA Single	T	A		GCP			2 datasets			
	T	R		GCP						
	U	R		GCP						
Stereo	U	R		GCP						
Multi	T	A		TP						
	T	R		TP						

DGA (1/4)



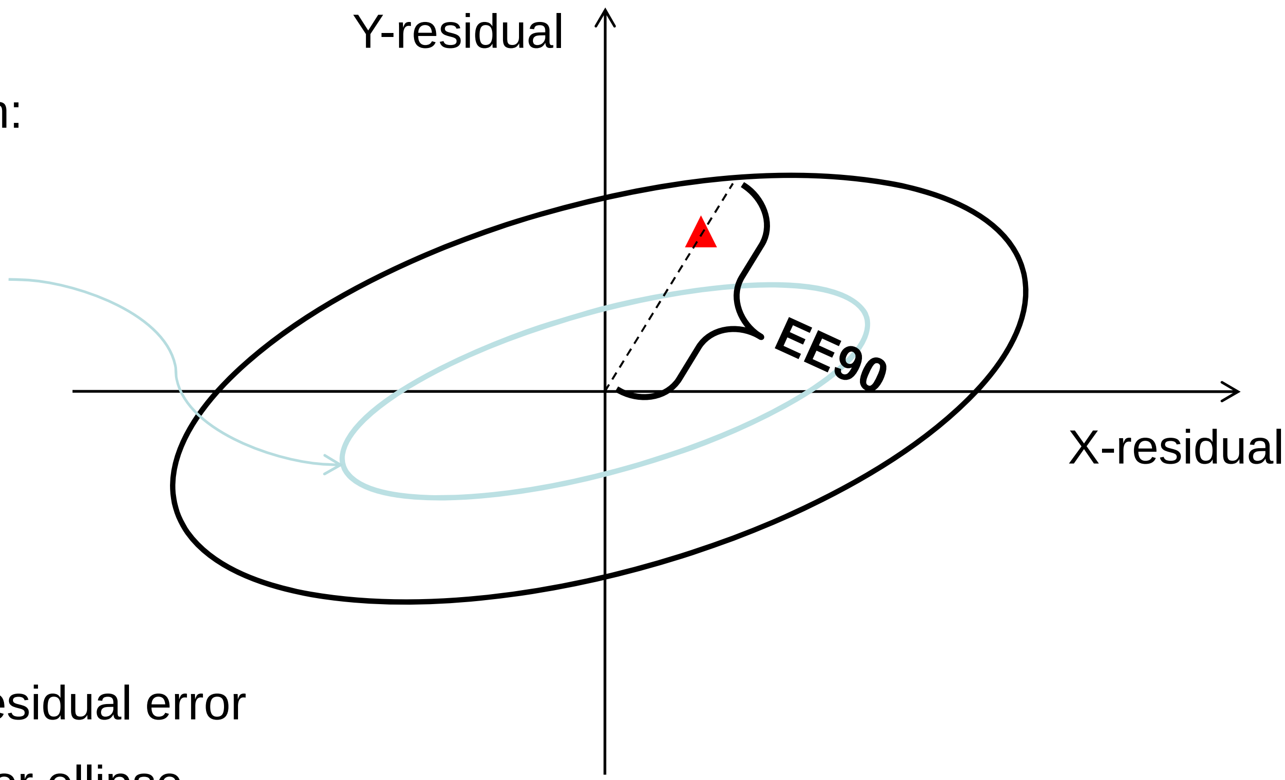
- Requires manually measured x,y,X,Y,Z coordinates for many image data sets

DGA (2/4)

What do we mean by EE90 (error ellipse at 90%)?
How do we know if the measured error is less than it?

From error propagation:

$$\Sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{xy} & \sigma_{yy} \end{bmatrix}$$



▲ Calculated residual error

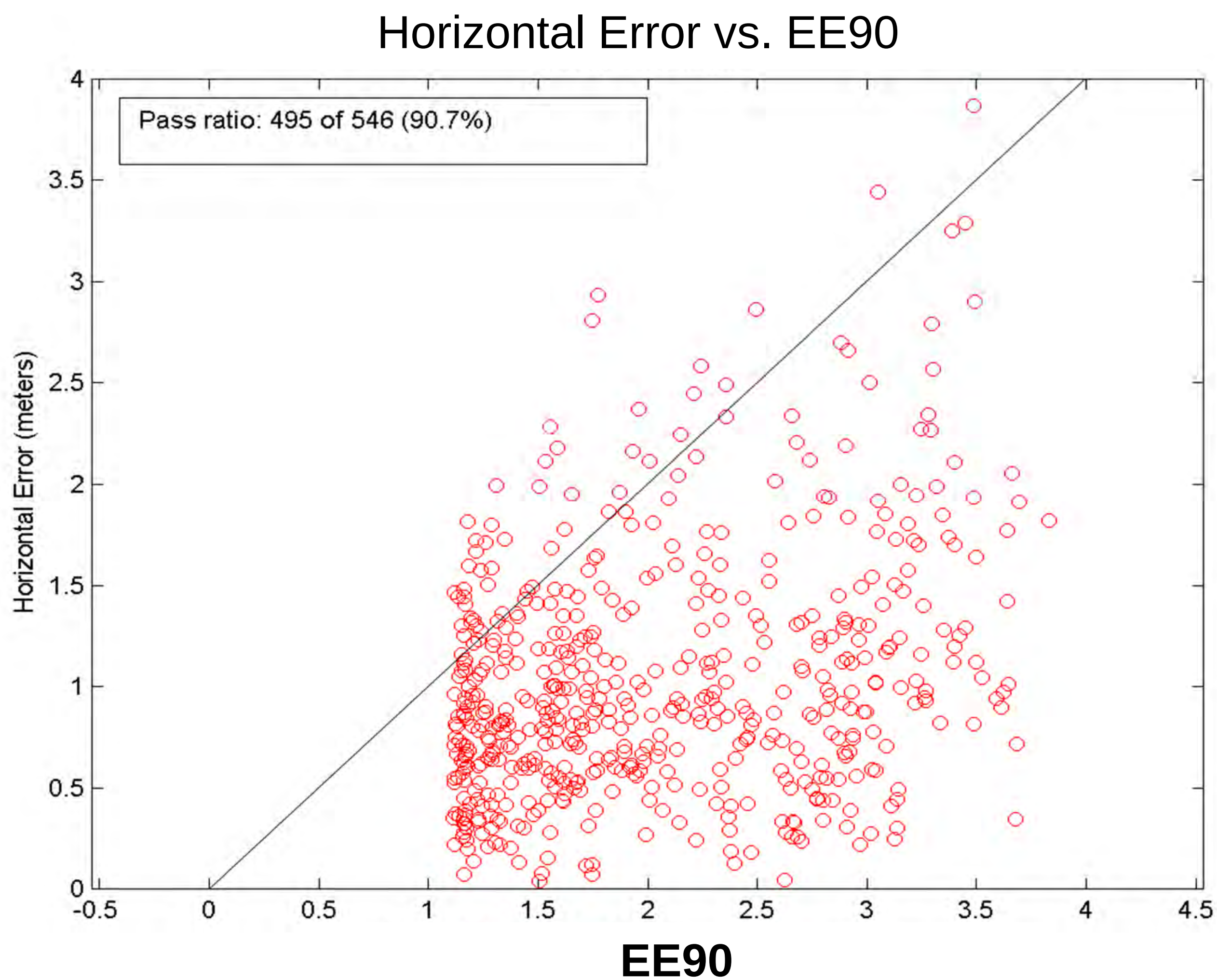
Standard error ellipse

90% error ellipse (x2.146)

DGA (3/4)

- Example with 26 SAR Slant Plane Images
  - Pixel spacing: 0.25 meters
  - Grazing angle: 11.5 deg grazing angle
  - Squint angles: 30 (from broadside)
  - Flying altitude: 12,000 ft AGL
  - Position uncertainty: 0.5m horizontal, 0.5m vertical
  - Velocity uncertainty: 0.01m/s horizontal, 0.01m/s vertical

DGA (4/4)


Horizontal Error vs. EE90
Pass ratio: 495 of 546 (90.7%)
Horizontal Error (meters)
EE90
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

PMA Introduction (1/2)

- The DGA slides showed good consistency between actual errors and predicted errors for single-image geolocation from several images
- The upcoming slides will now take a close look at the internal relative geometry of the images

PMA Introduction (2/2)

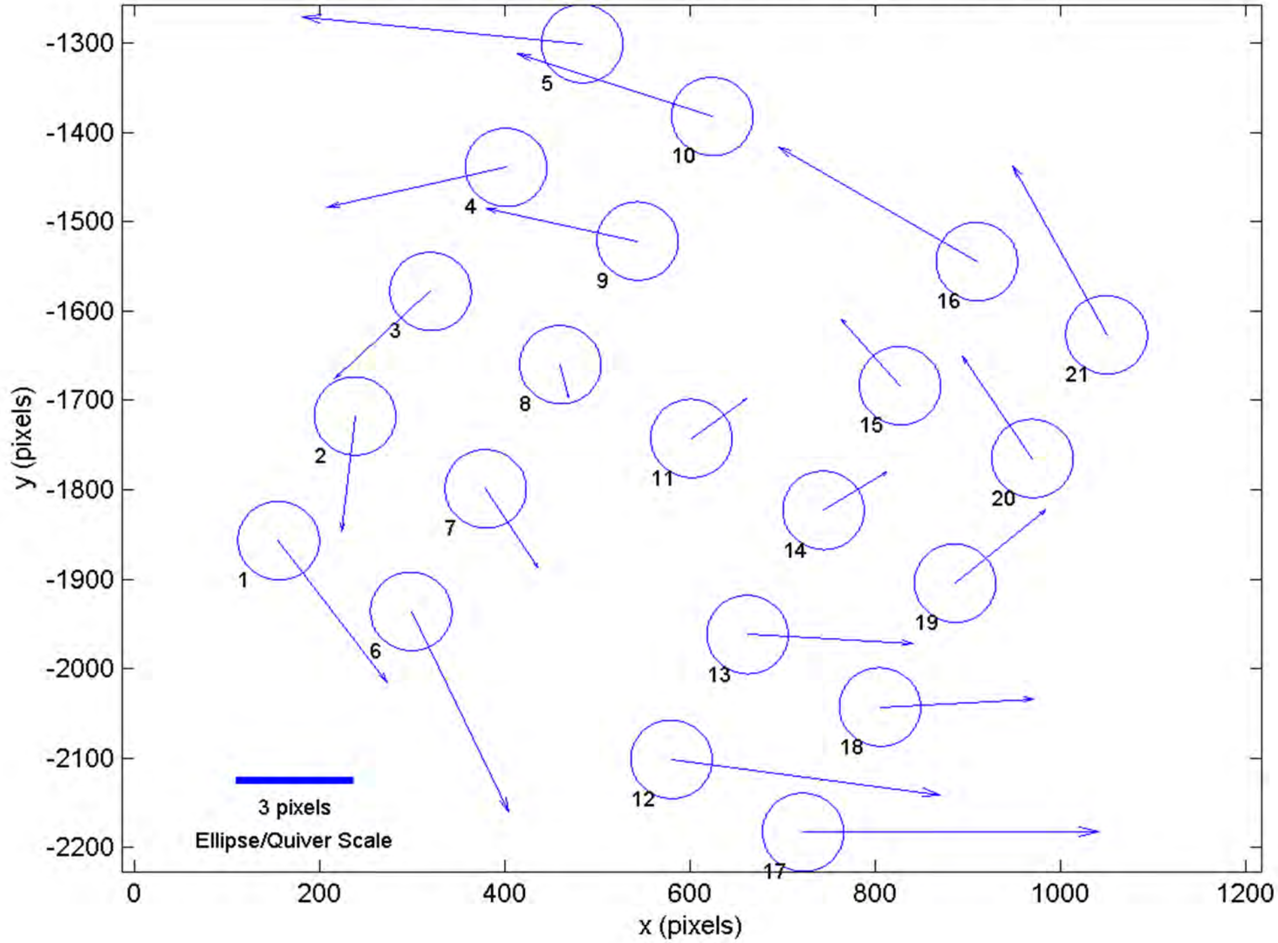
- Inputs:
  - CSM plugin
  - Single image at a time
  - File containing measured points:
    - Identified as Control or Check
    - Image and ground coordinates
    - Full covariance matrices for all measurements
- Calculate Residuals against Check points:
  - Prior to Resection (Optional)
    - for point pairs
  - After Resection
    - for points and point pairs
- Outputs (in image space or ground space):
  - Measured accuracy
  - Reliability (measured versus predicted accuracy)
  - Tables and Figures output to Powerpoint file
  - Examples on next slides

PMA Dataset 1 (1/14)

- 13 SAR images, resected one at a time
  - 21 ground control points (all used as control and check)
  - 6 Adjustable parameters (all components of position and velocity)
  - 5cm sigmas (E, N, U) on ground control (0.2 pixel)
  - 1 pixel sigma on image coordinate measurements

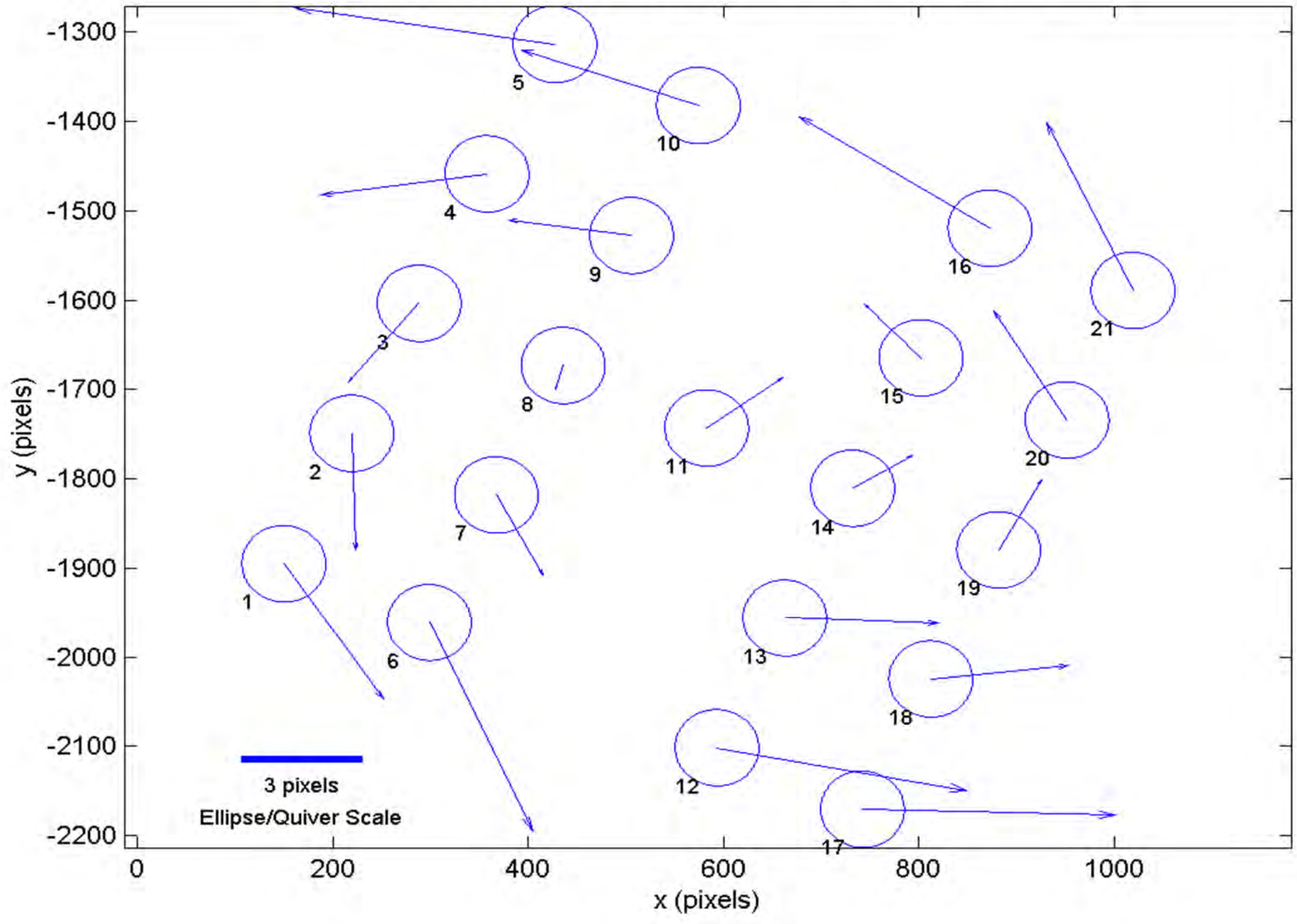
PMA Dataset 1 (2/14)

+30º Squint



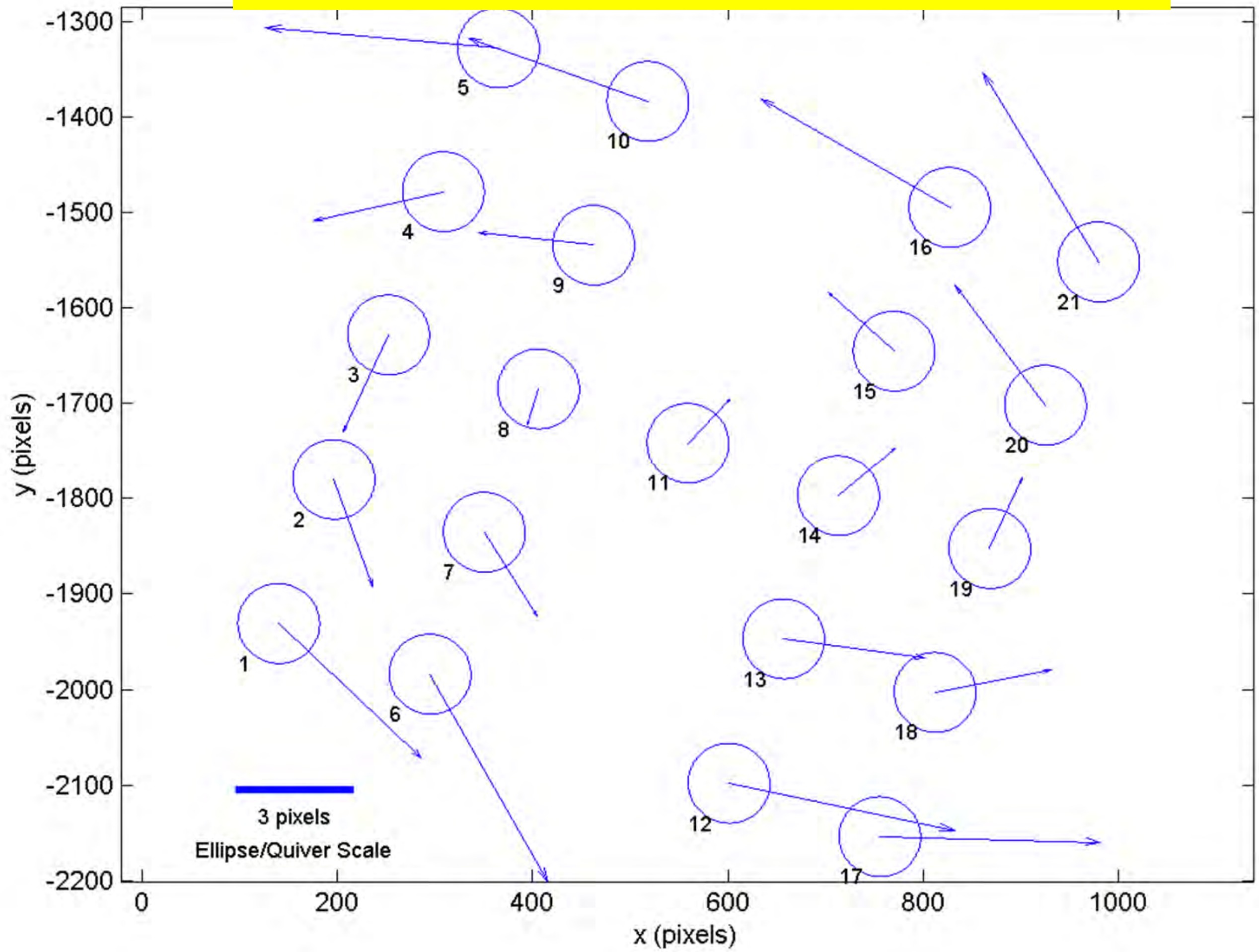
PMA Dataset 1 (3/14)

+25º Squint



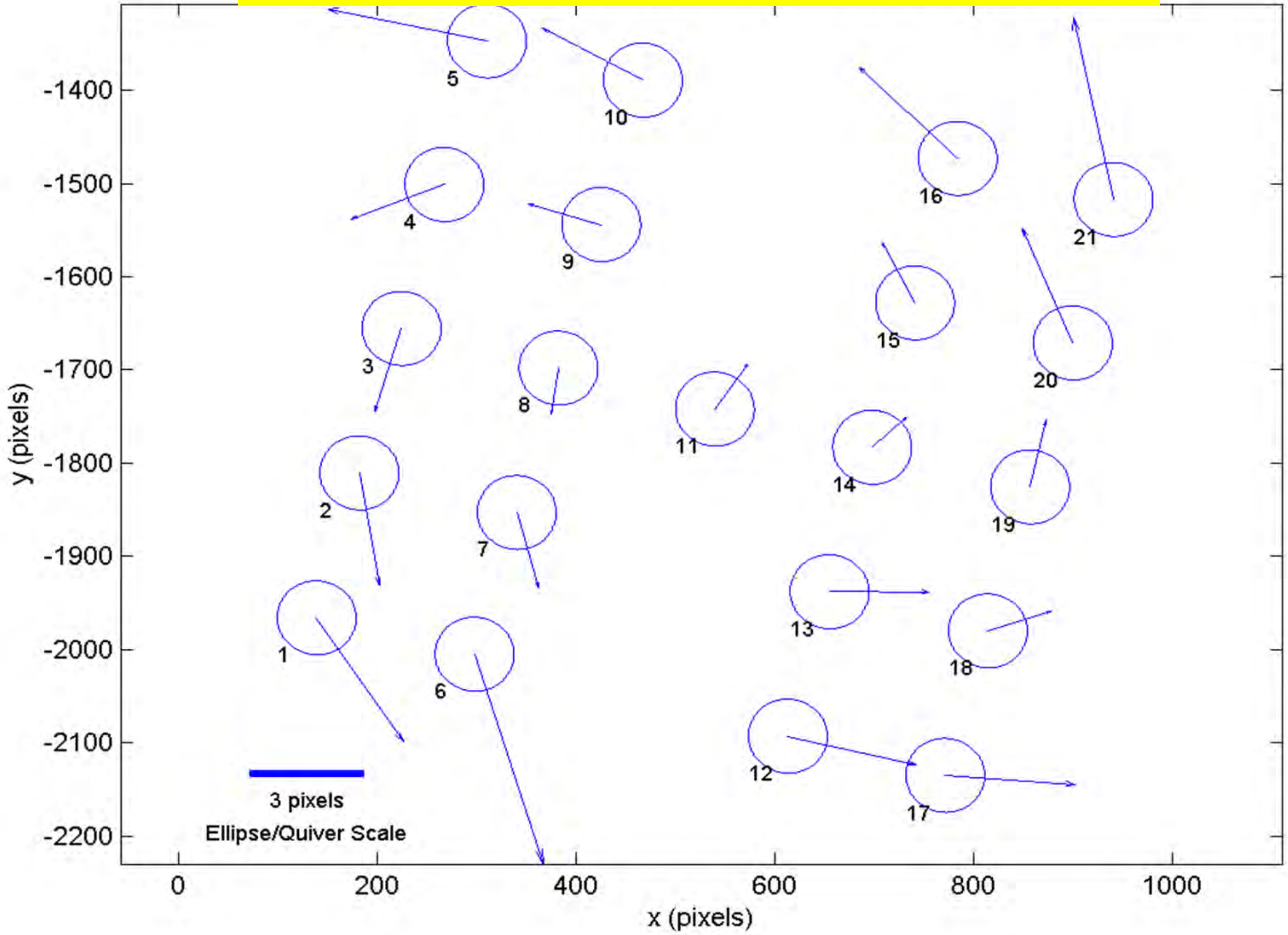
PMA Dataset 1 (4/14)

+20º Squint



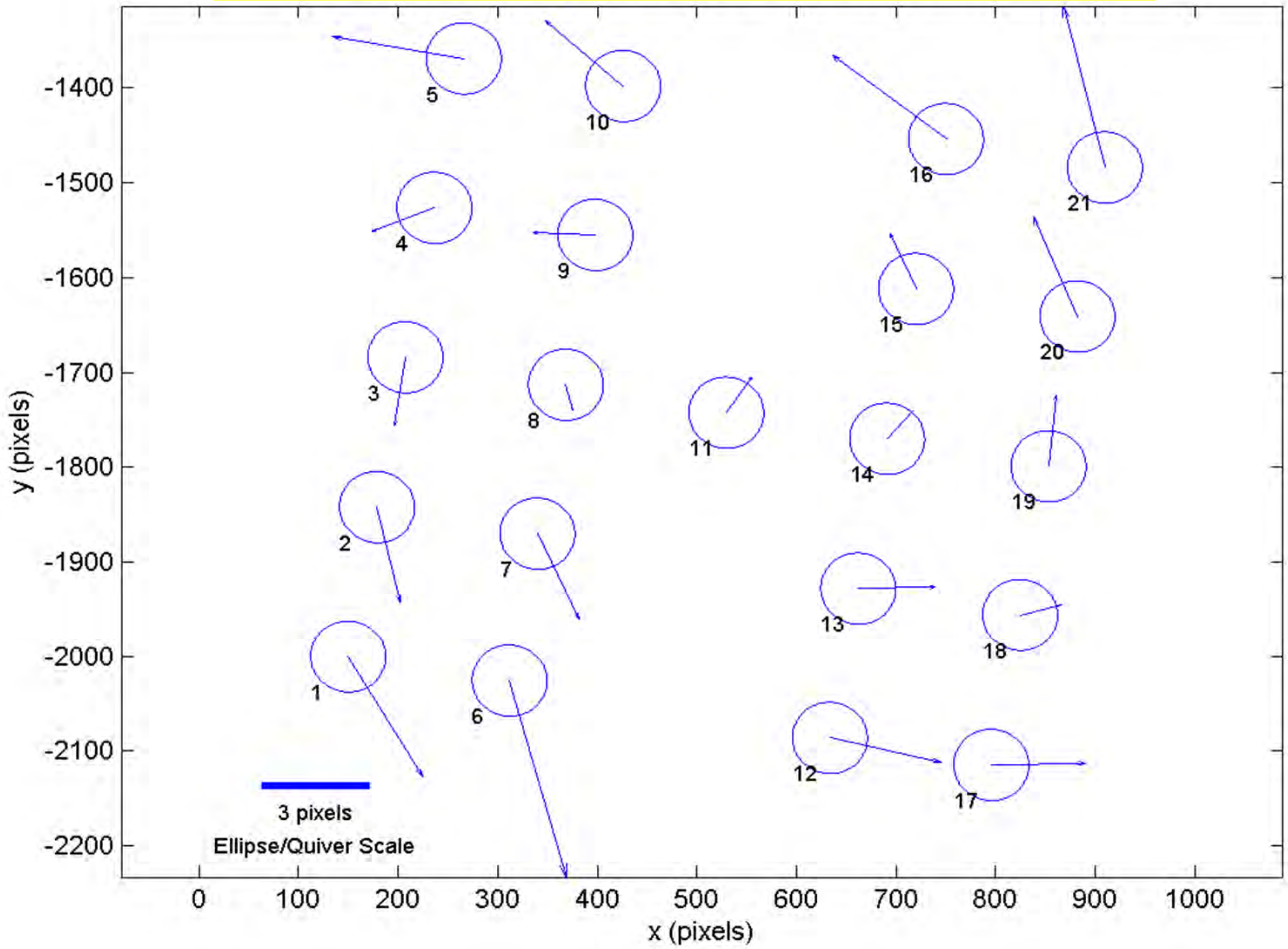
PMA Dataset 1 (5/14)

+15º Squint

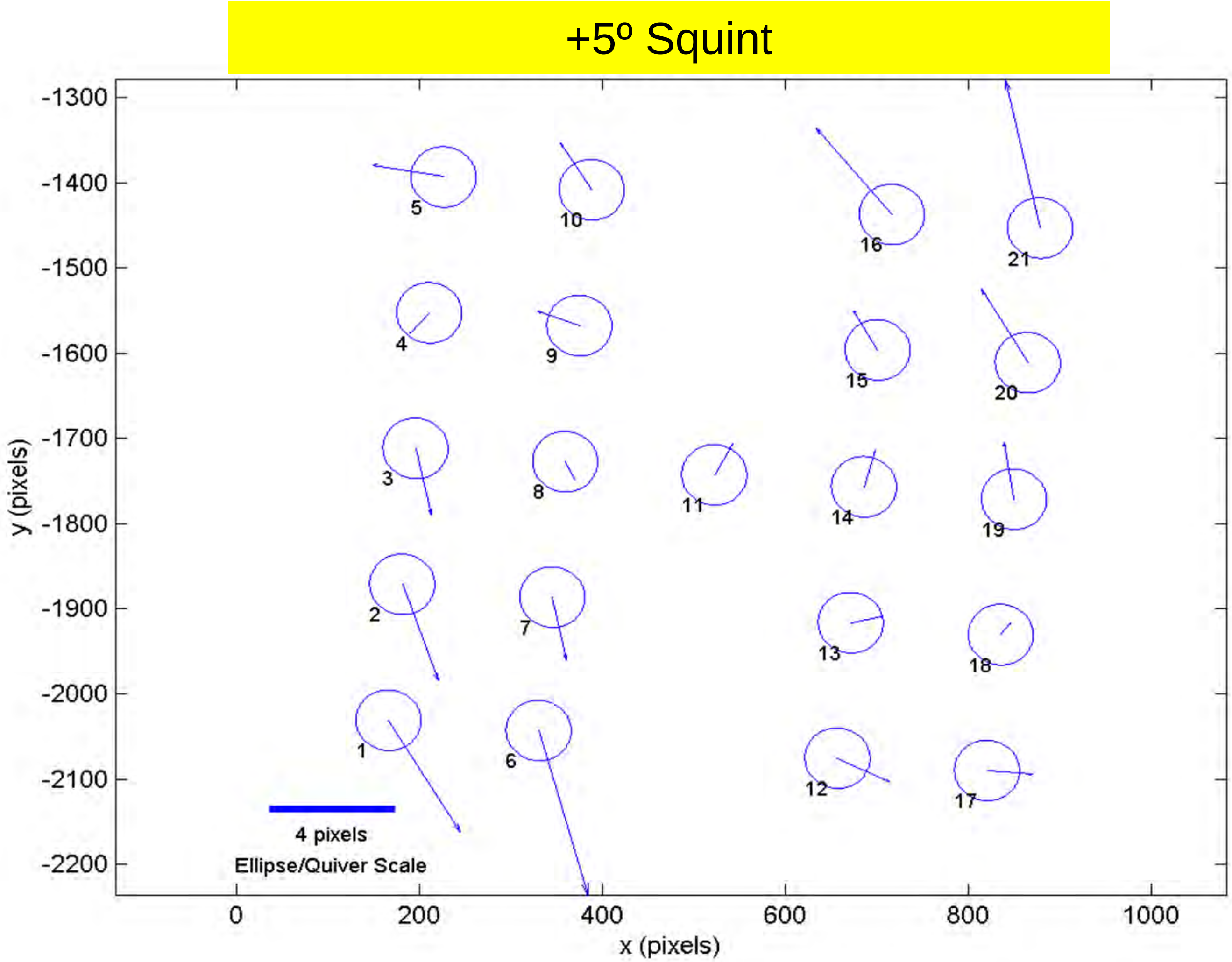


PMA Dataset 1 (6/14)

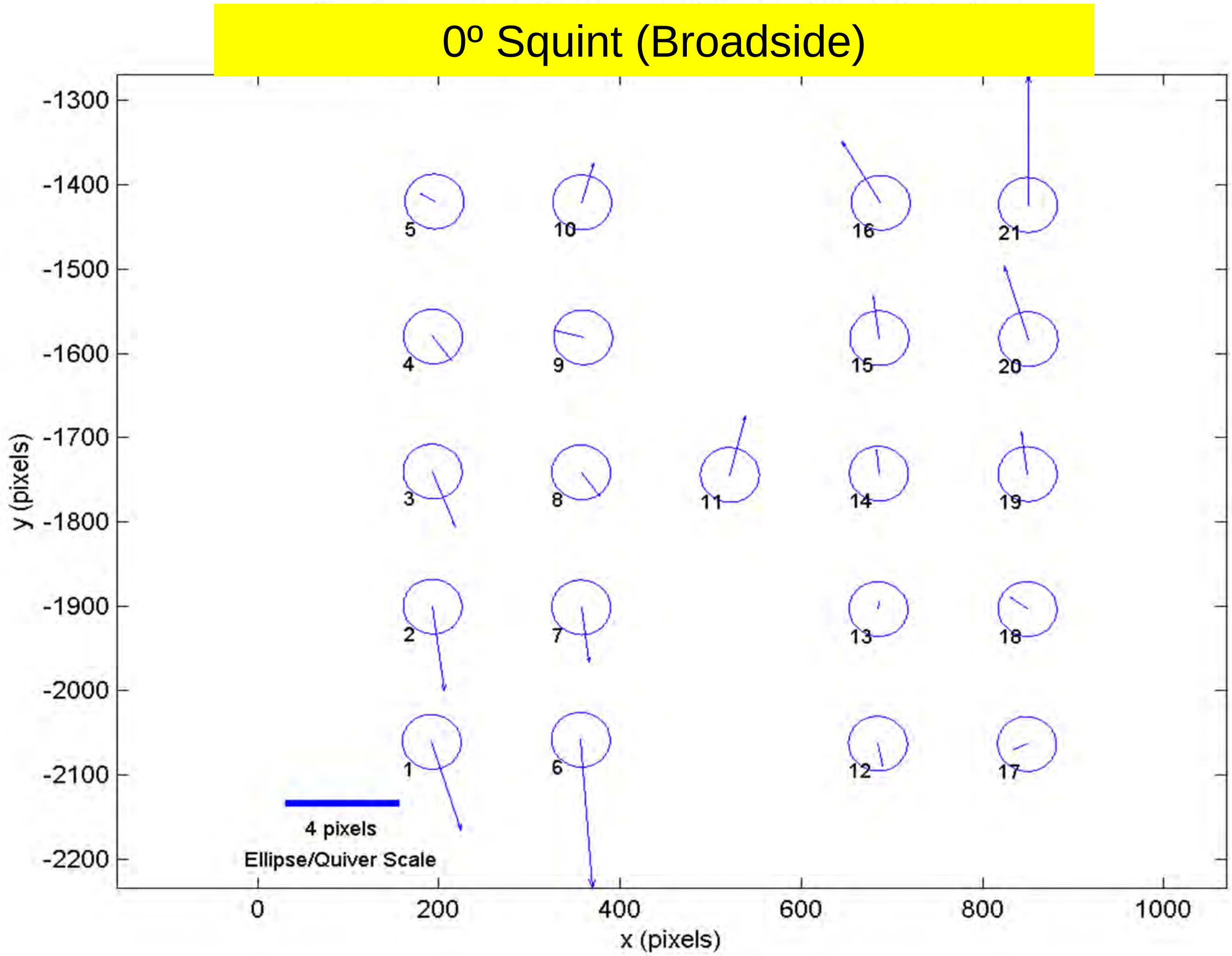
+10º Squint



PMA Dataset 1 (7/14)

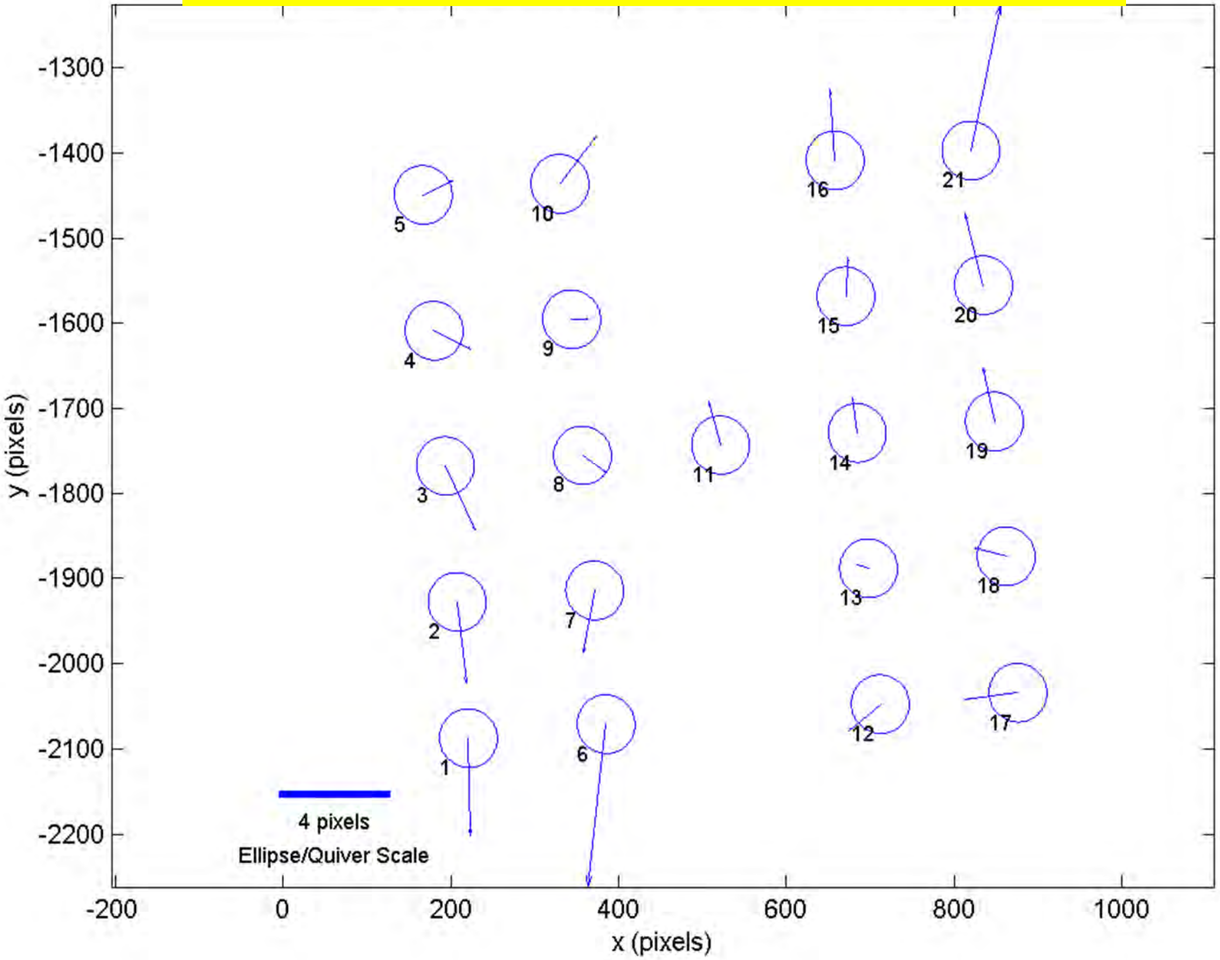


PMA Dataset 1 (8/14)



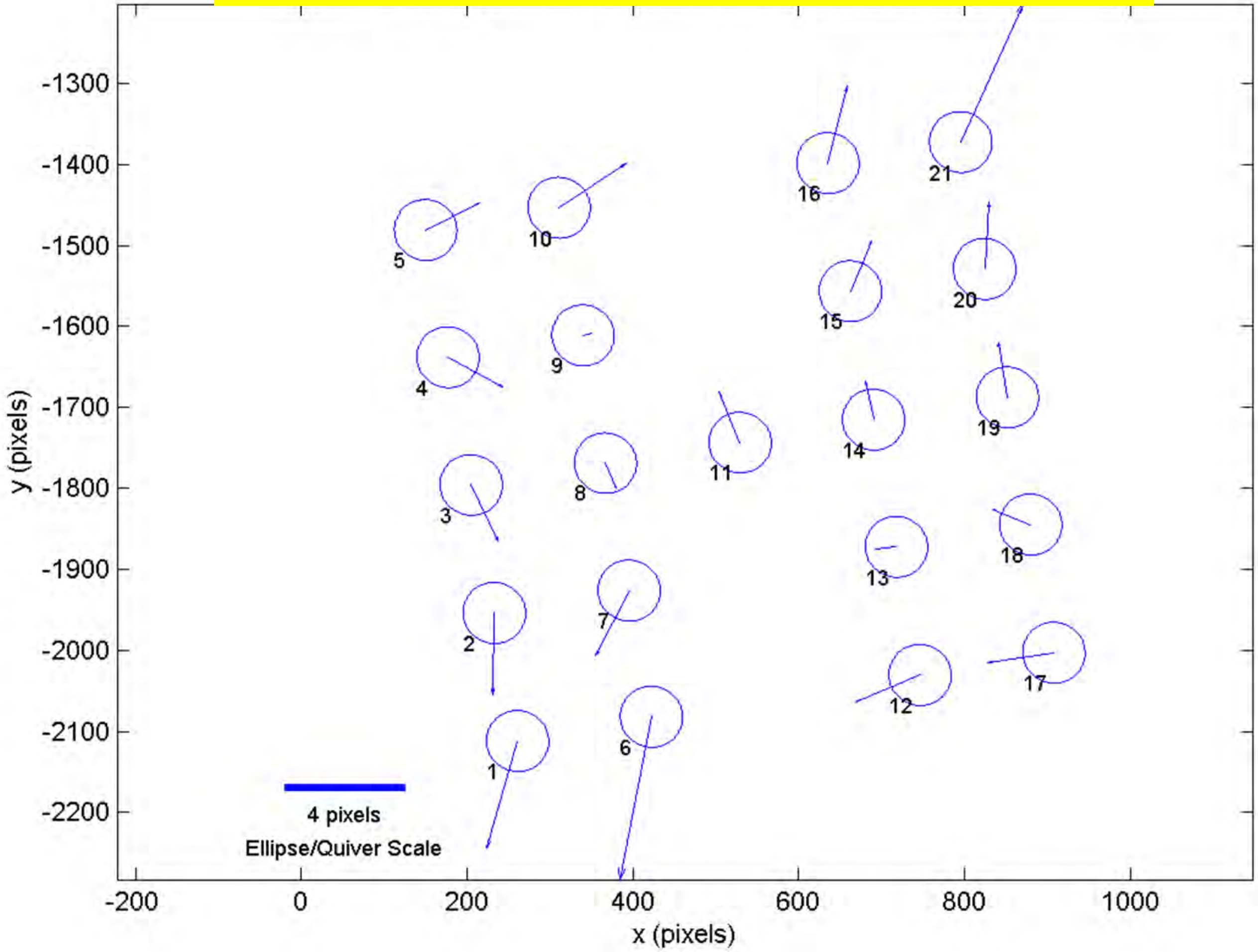
PMA Dataset 1 (9/14)

-5º Squint



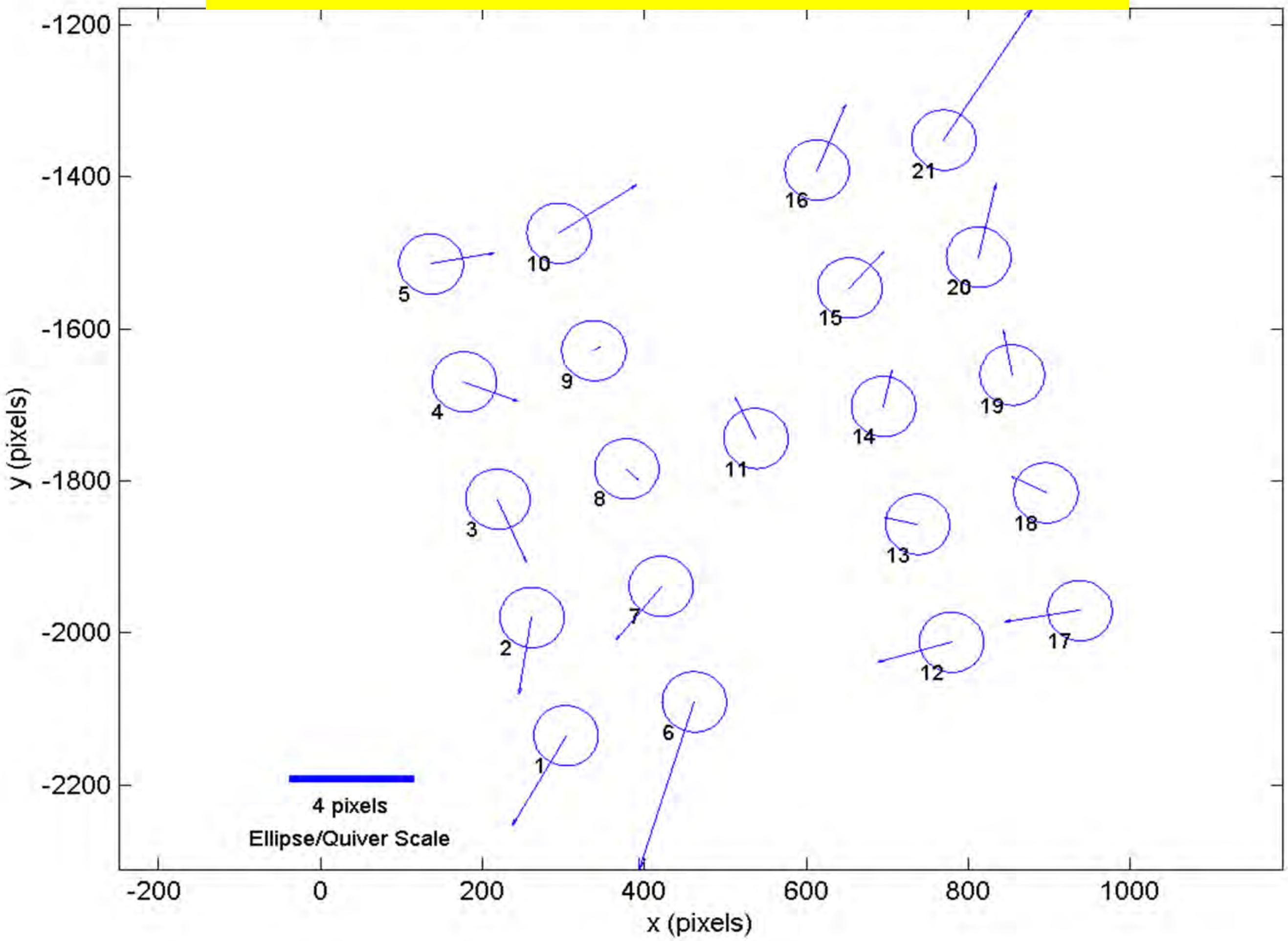
PMA Dataset 1 (10/14)

-10º Squint



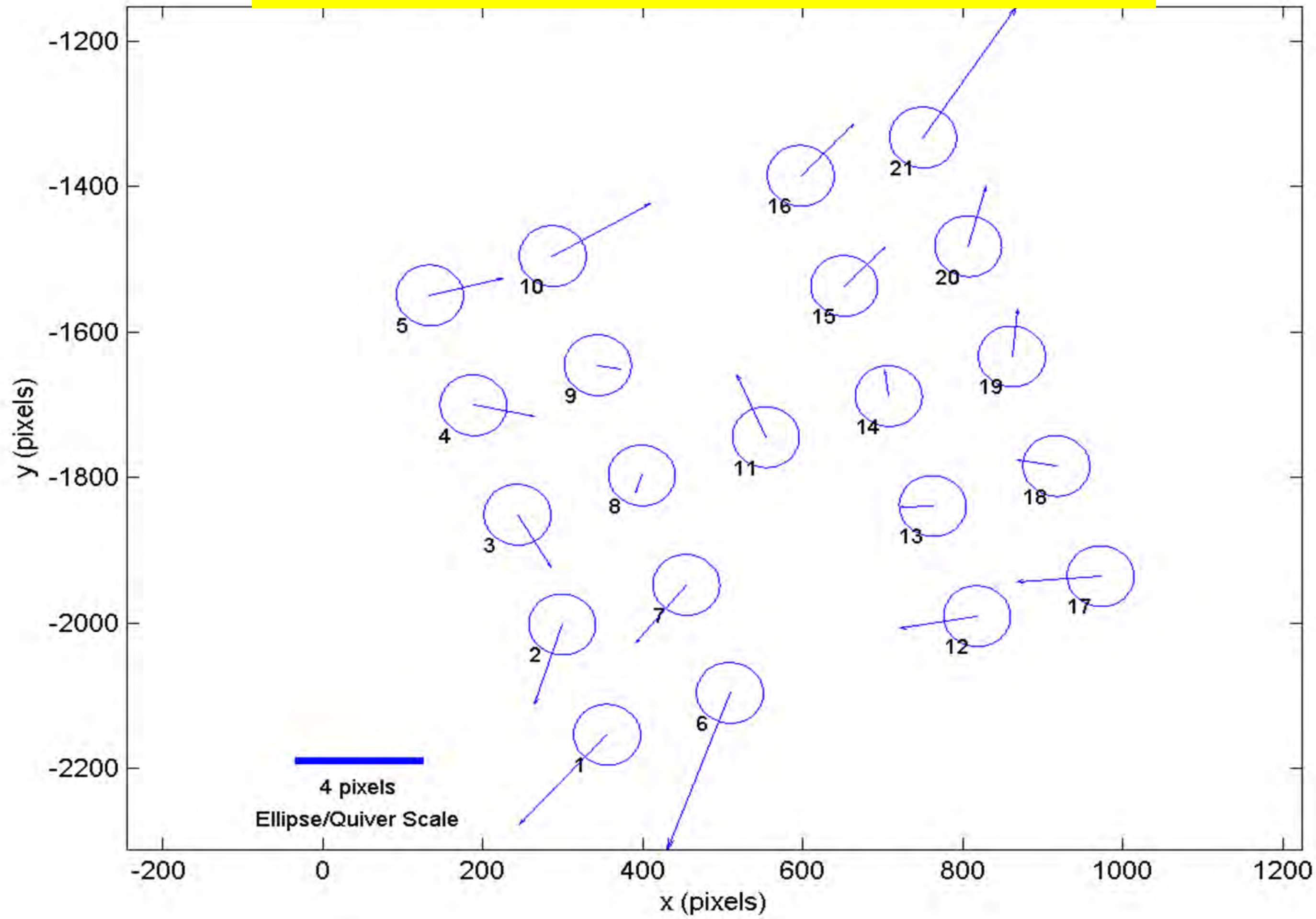
PMA Dataset 1 (11/14)

-15º Squint



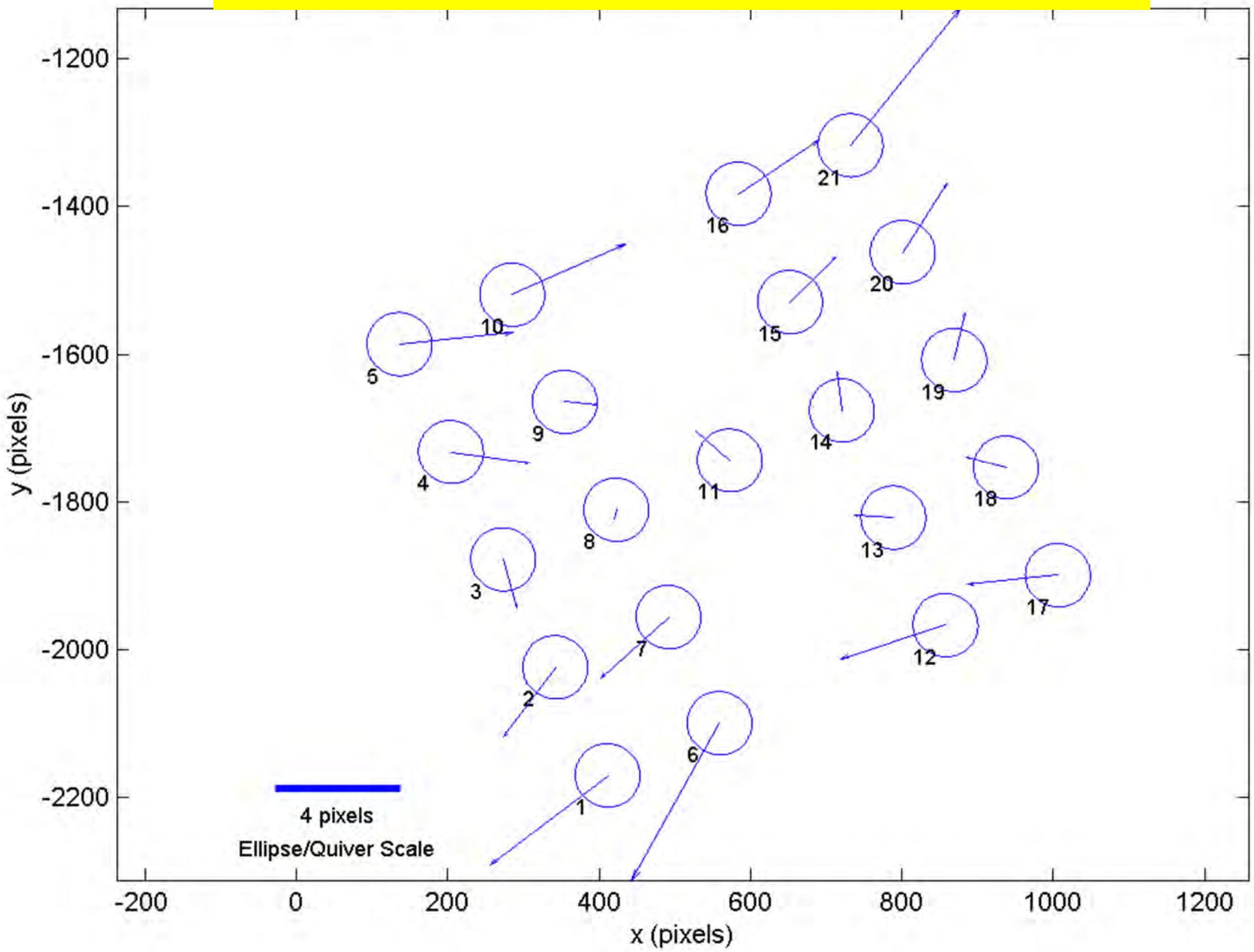
PMA Dataset 1 (12/14)

-20º Squint



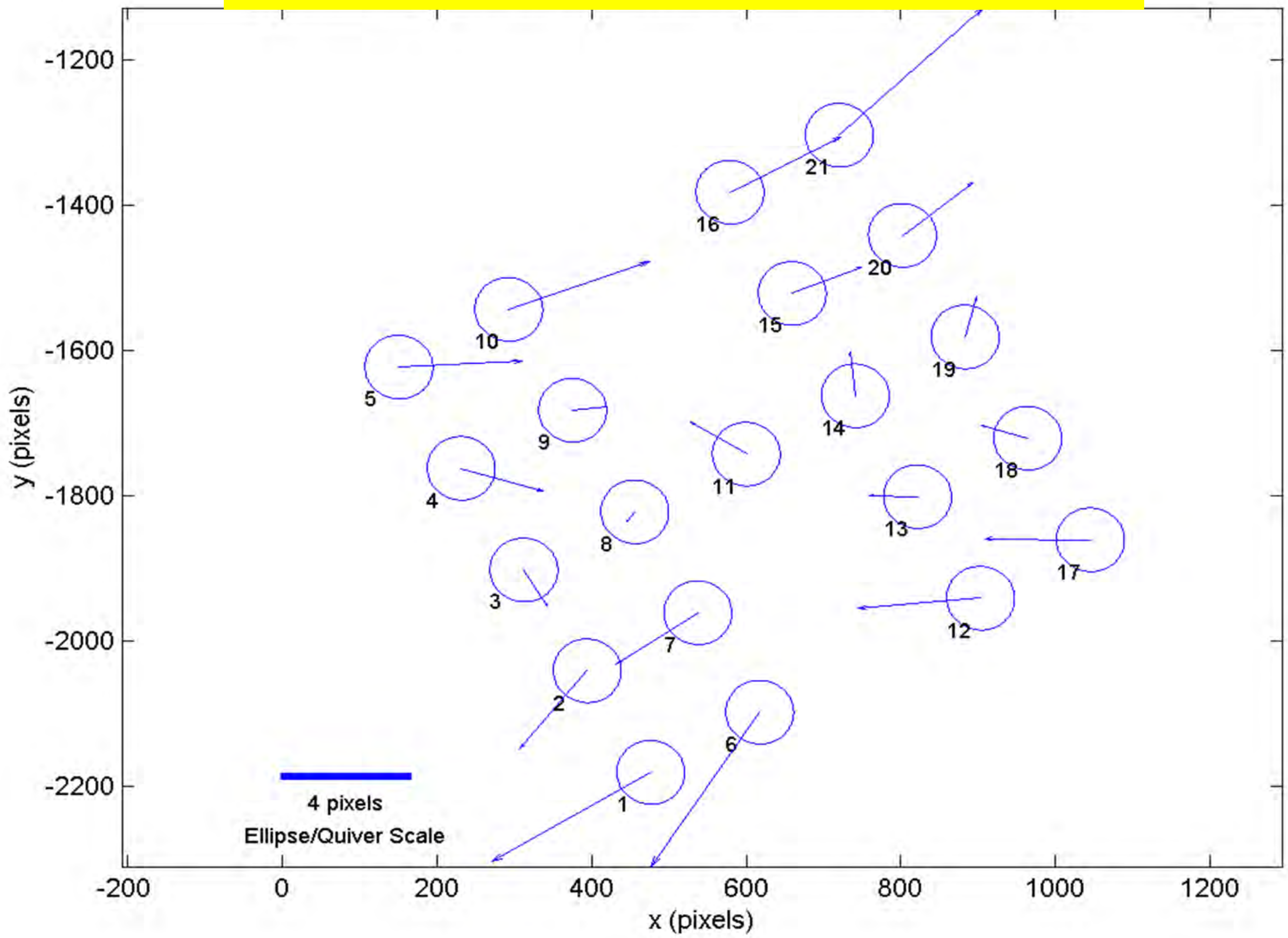
PMA Dataset 1 (13/14)

-25º Squint



PMA Dataset 1 (14/14)

-30º Squint



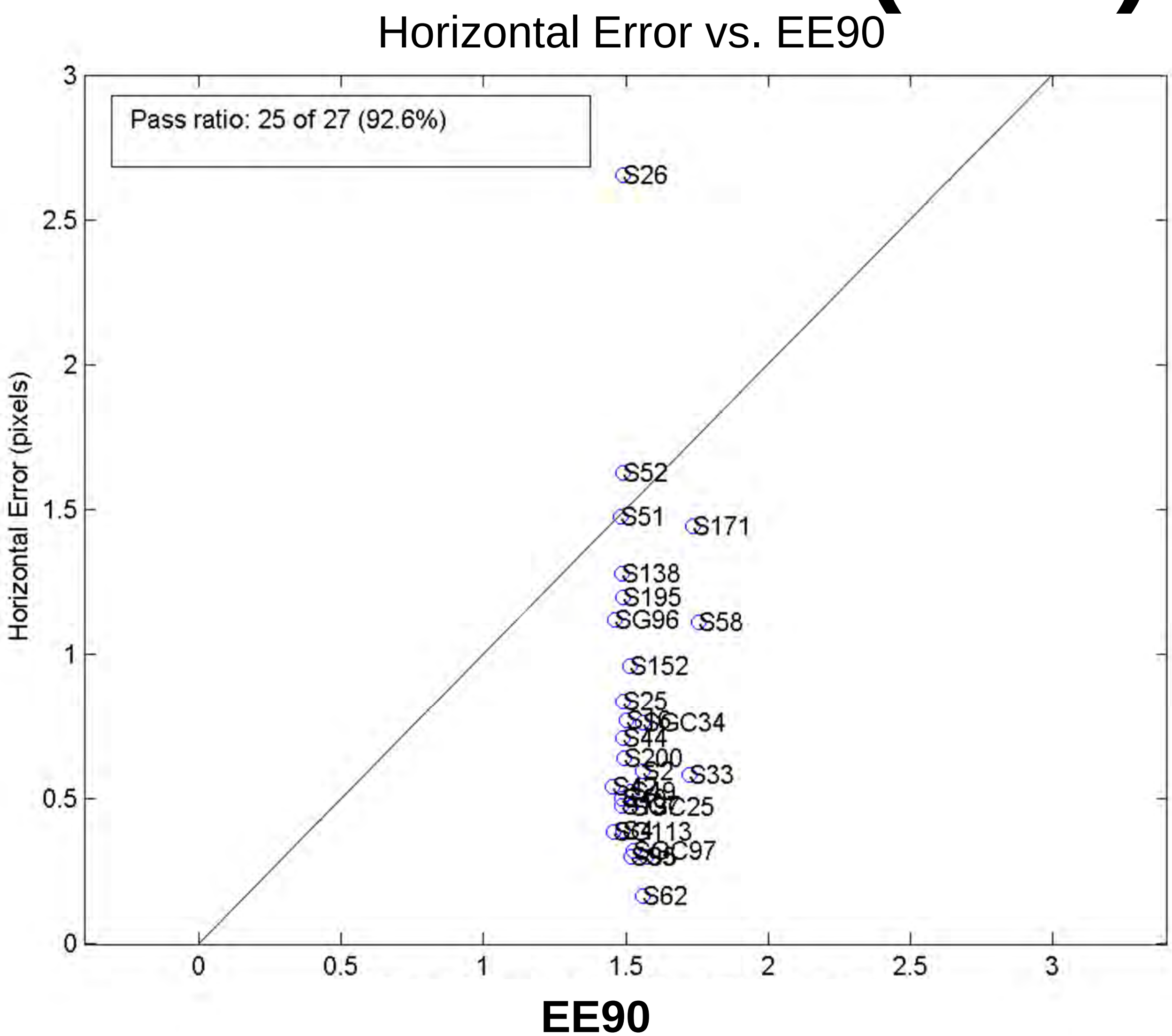
PMA Dataset 2 (1/10)

EO Frame

- A vertical aerial photograph over Purdue campus
- 27 Ground control points
  - 5cm sigma (E, N, U)
- Altitude ~600 meters AGL
- GSD 12 cm
- Pixel size 30 μm
- Dimensions
  - 7712x7776

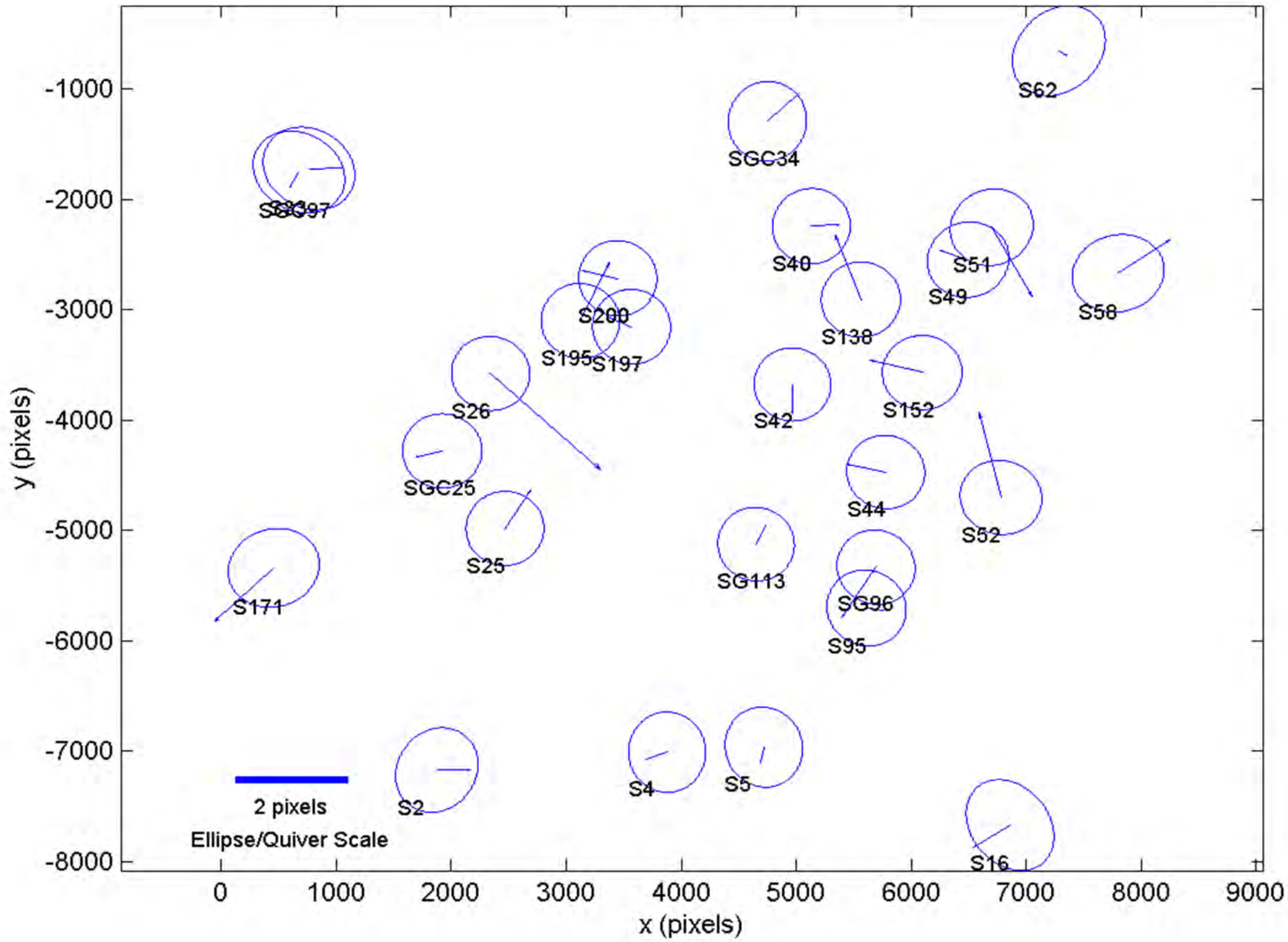
Scanned frame images are courtesy of Purdue University, 1999.

PMA Dataset 2 (2/10)



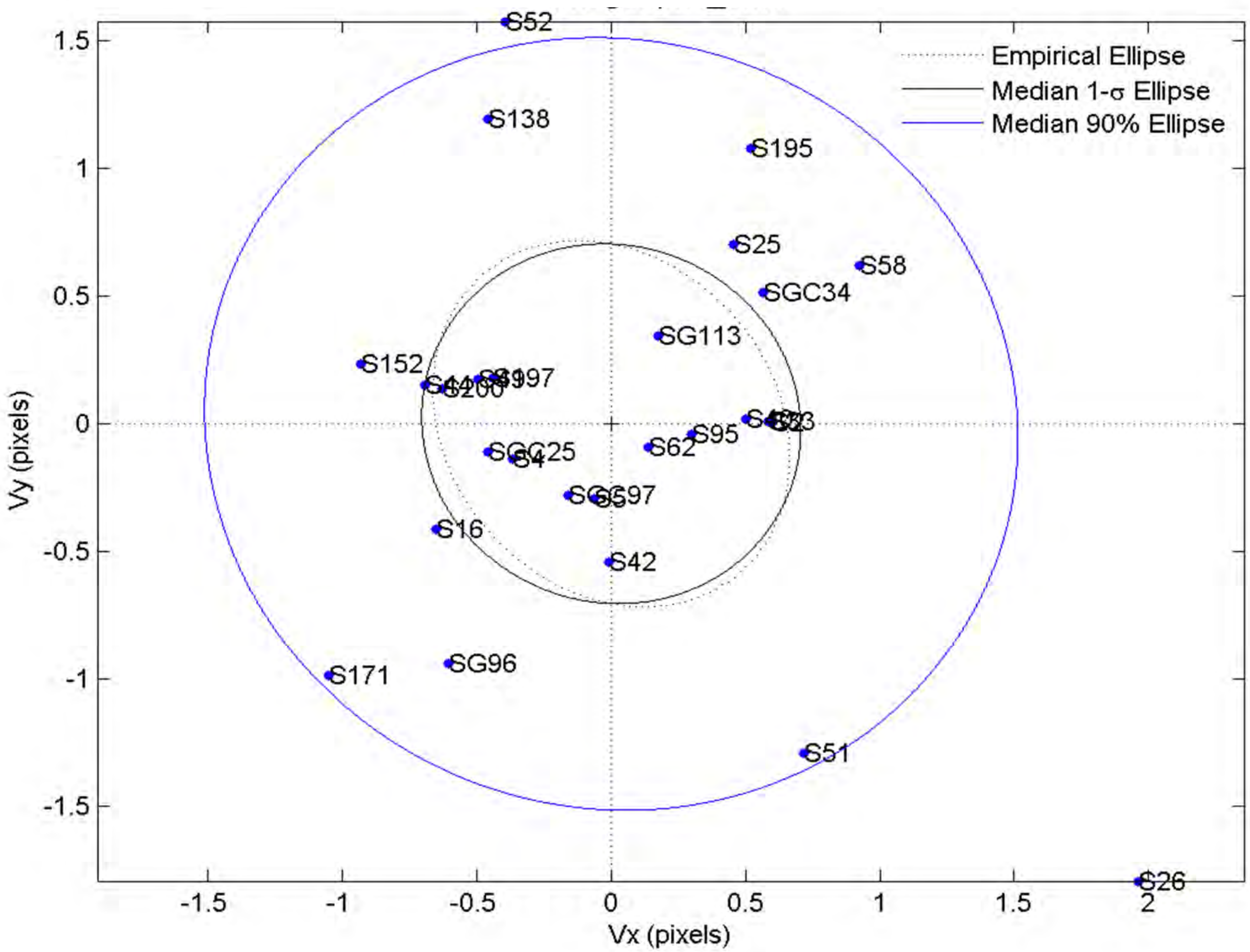
PMA Dataset 2 (3/10)

Check point Residuals and Associated Error Ellipses



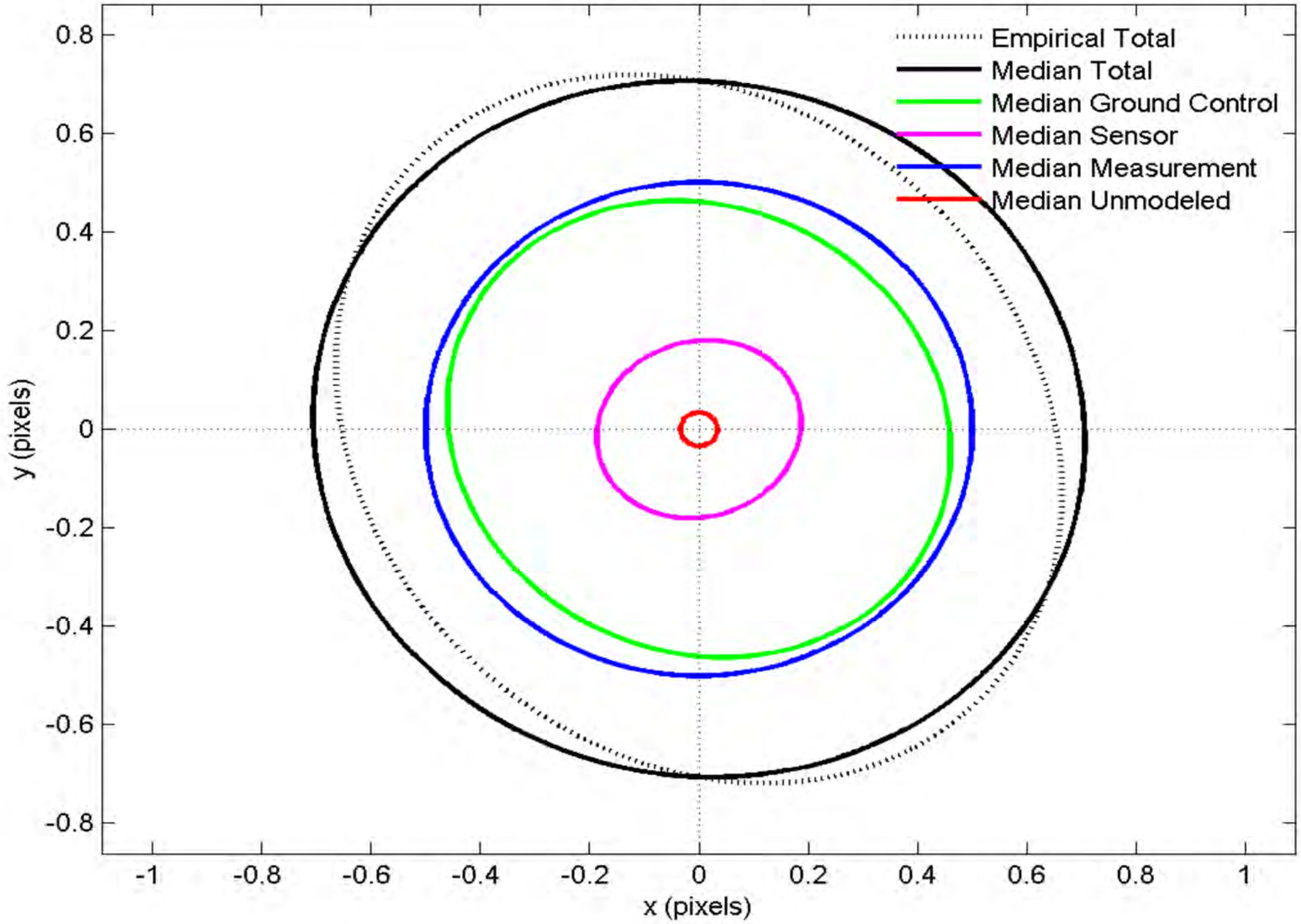
PMA Dataset 2 (4/10)

Check point Residuals



PMA Dataset 2 (5/10)

Check point Residuals and Error Ellipse Components



PMA Dataset 2 (6/10)

Summary Table

Units of pixels

						Mean x	Mean y	Std x	Std y	RMS x	RMS y	Vx max	Vy max	38% pass ratio	% passed	90% pass ratio	% passed
abs.	Image	resected	Biased	Check	radial	0.002	-0.018	0.84	1.05	0.84	1.05	2.06	2.95	12/21	57	19/21	90
relative	image	resected	Biased	Check	radial	0.087	-0.014	1.47	1.28	1.47	1.28	5.86	3.99	107/194	51	194/210	92

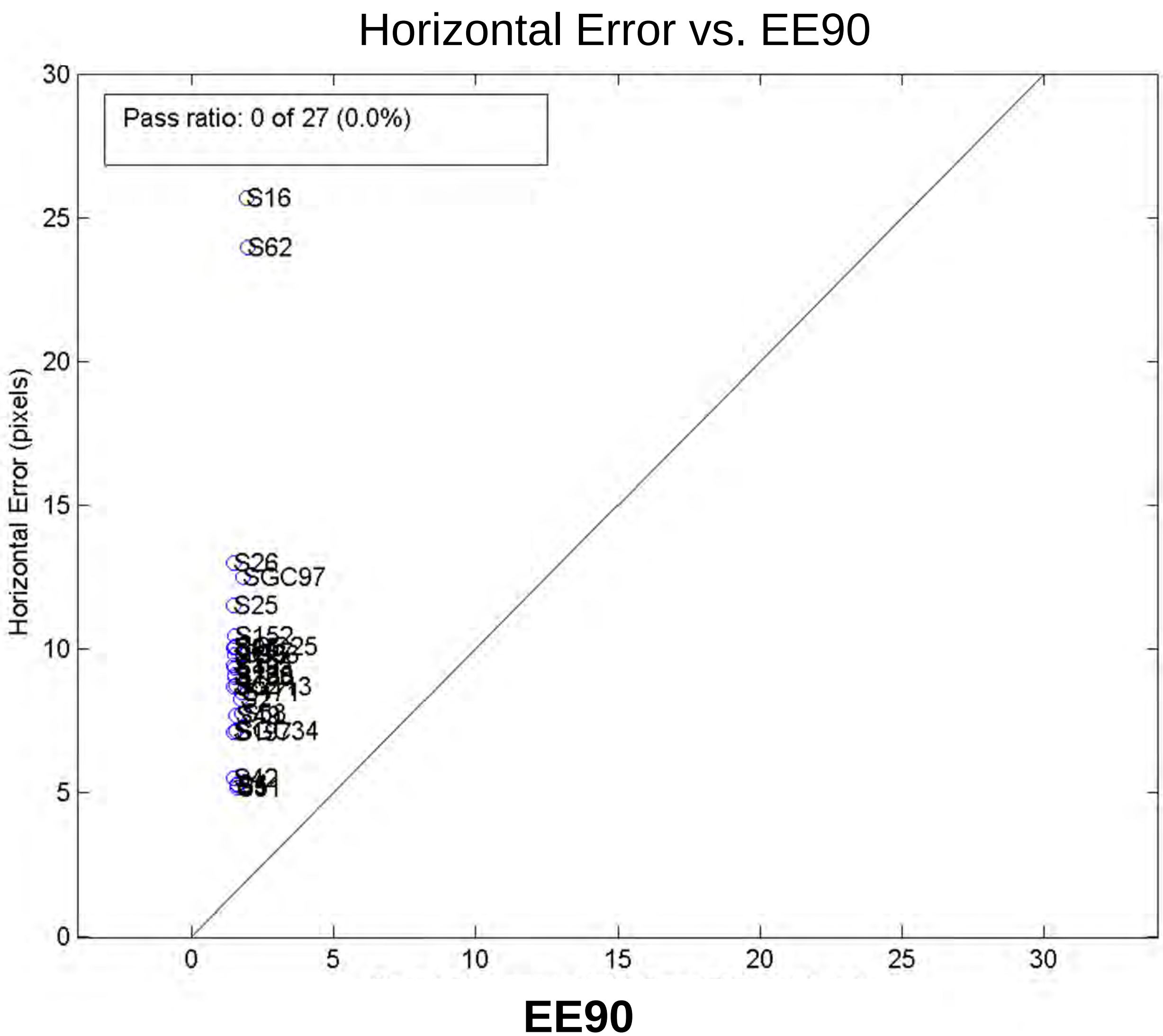
accuracy

reliability

PMA Dataset 2 (7/10)

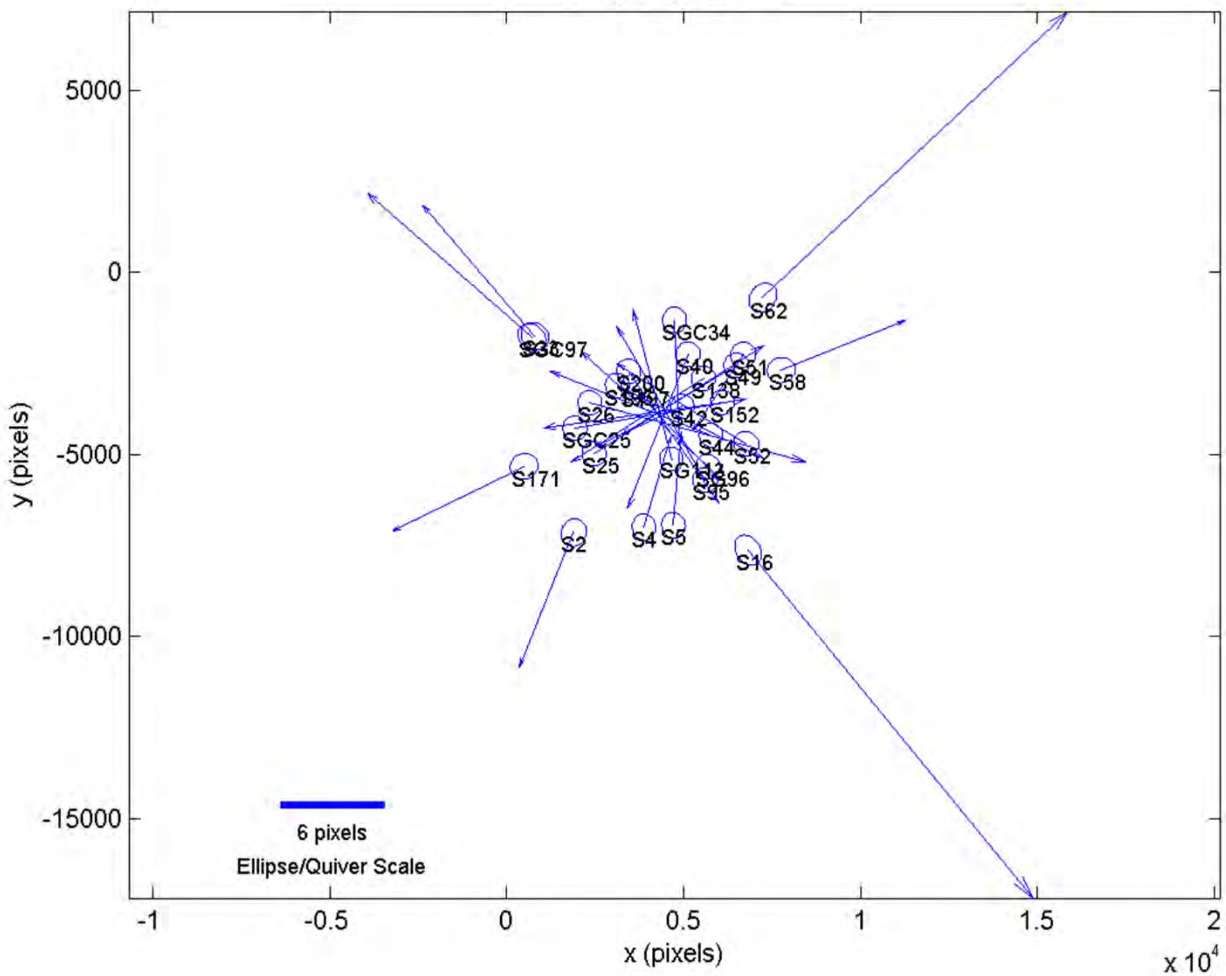
- The last several slides showed the results of a sensor model with a reasonable set of adjustable parameters
- The next slides show the results of the same sensor model with a manually induced radial lens distortion, not included in the sensor model

PMA Dataset 2 (8/10)



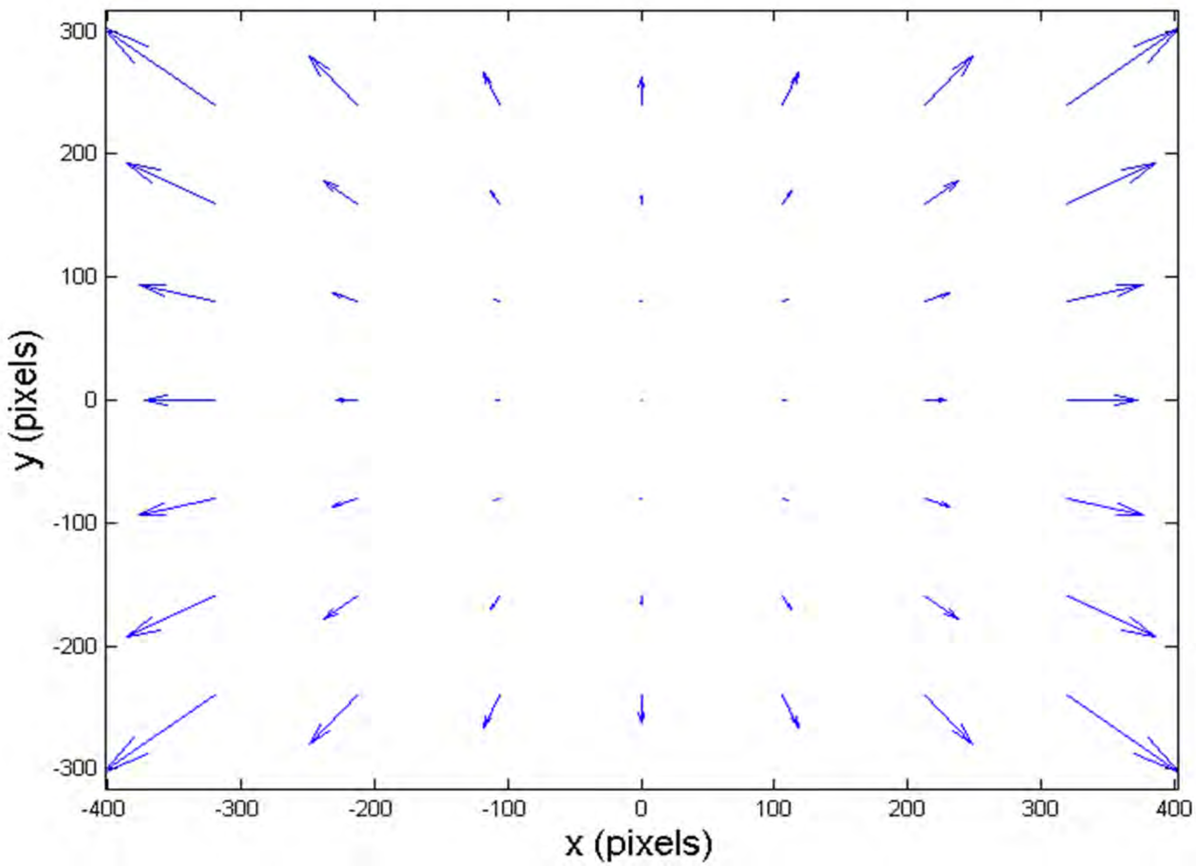
PMA Dataset 2 (9/10)

Check point Residuals and Associated Error Ellipses



PMA Dataset 2 (10/10)

K_1 (Radial Lens Distortion)



Conclusions

- A tool like this is needed for sensor model validation
- If a geometry model has problems, GSET:
  - Raises a “red flag”
  - Provides intuitive visual diagnostics
- Takes advantage of surveyed GCPs when available
- Provides an alternative when no GCPs are available
- Just because a model passes one test, e.g. absolute accuracy, it may fail another test, e.g. relative accuracy

Acknowledgements

- The authors acknowledges, with thanks, the hard work and significant contributions from software members of the SGC team who have implemented these concepts into a user-friendly software including a GUI

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