Application of NGA's GLAS Model to Georegistration of KH Imagery

P3DL CoP Conference

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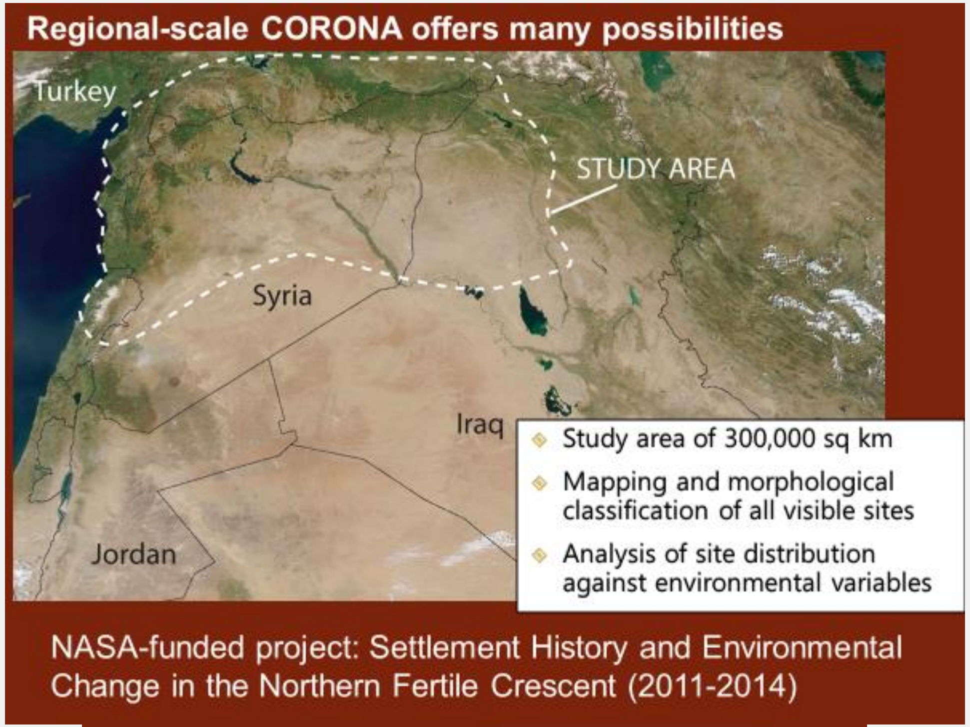
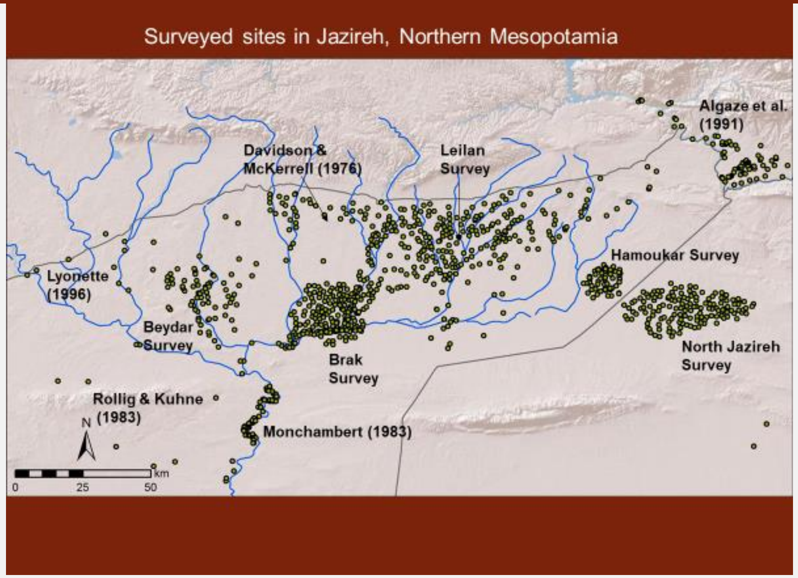
Outline

- Background
- Corona Satellite Imaging
- Previous Model: Sohn
- New Model: Generic Linear Array Scanner (GLAS)
  - Standard Implementation
  - Improved Accuracy
  - Extensible to KH-9
- Bundle Adjustment
- Summary and Future Work

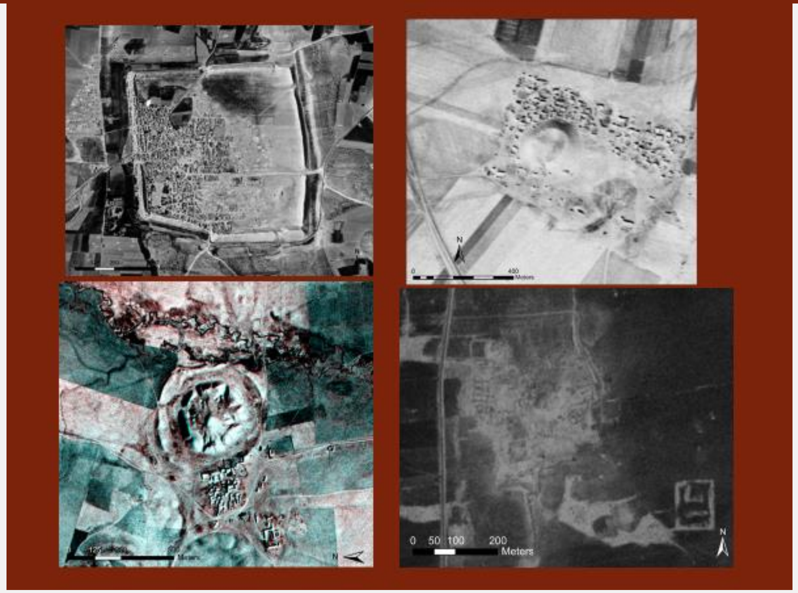
Background



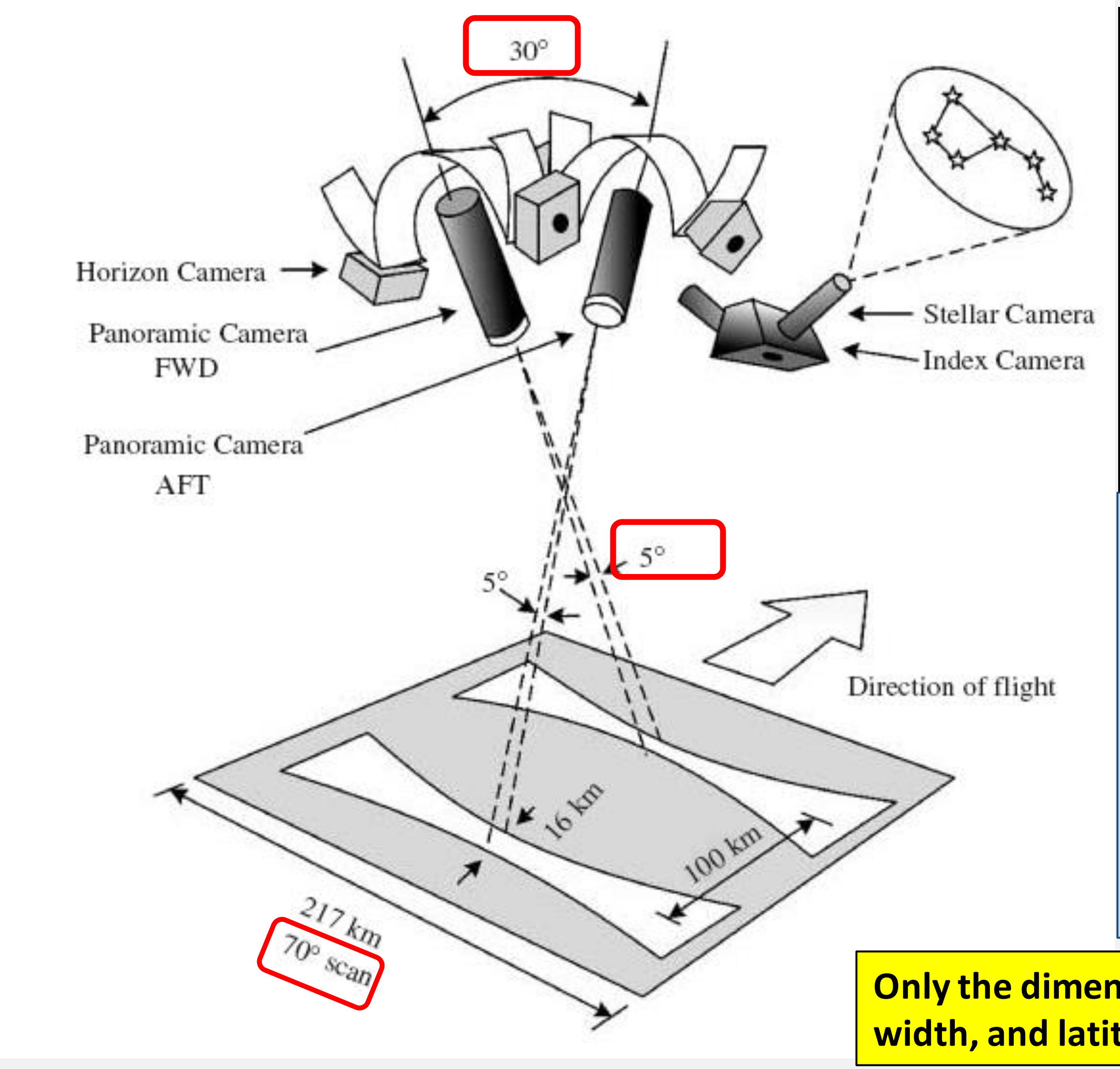


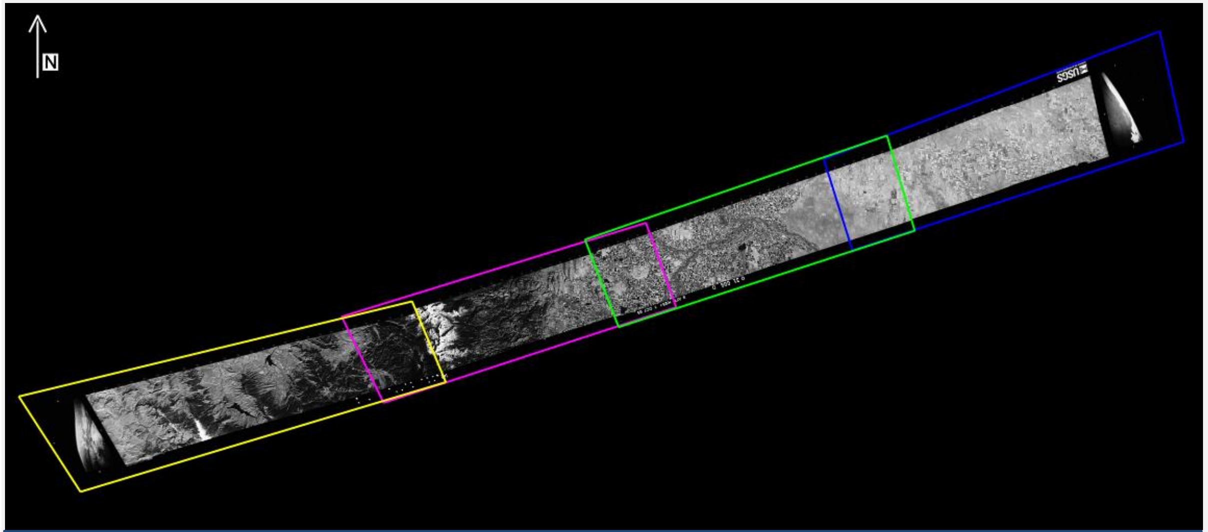
CAST has been involved in exploiting Corona imagery since 2008

- Photogrammetric modeling
- Software applications supporting archaeology



Corona Satellite Imaging





USGS scans the Corona images into 4 (typically) segments

- CAST uses automated image matching techniques to stitch them back together into the original strip
- Corners of the image are manually measured and treated as fiducial marks to define a film coordinate system
- A Fiducial to Line-Sample coordinate transformation is applied to facilitate integration into the GLAS model

Only the dimensions in this figure, nominal flying altitude, focal length, film width, and latitude and longitude of the 4 corners are used to initialize the model

Previous Model: Sohn

- The Panoramic Sensor Model currently used to model KH-4 imagery in CAST tools is based on Sohn, et al. (2003)
  - Originally selected because the geometry can be transformed into that of a traditional frame camera model, thereby facilitating integration into open-source software
  - 7 Adjustable Parameters (red outlines): Exterior Orientation plus platform movement

$$\begin{bmatrix} f\tan\alpha \\ \dfrac{y-y_o}{\cos\alpha}+\dfrac{Vf}{H\delta}(\alpha-\tan\alpha) \\ -f \end{bmatrix} = \lambda \boxed{R_{\omega\varphi\kappa}} \begin{bmatrix} X-\boxed{X_o} \\ Y-\boxed{Y_o} \\ Z-\boxed{Z_o} \end{bmatrix}$$

$\alpha = \dfrac{x-x_o}{f}$, scan angle for any give pixel on the image

$\boxed{\dfrac{V}{H\delta}}$ is treated as a single parameter modeling platform movement

GLAS: Standard Implementation

- Developed by National Geospatial-Intelligence Agency (NGA) to mitigate the re-coding of geometry model functionality by downstream geospatial exploitation tools
  - Standard set of metadata defined here, as part of Common Sensor (CS) Support Data Extensions (SDEs): https://nsgreg.nga.mil/doc/view?i=5044
    - CSEXRB: Exploitation Reference Data
    - CSEPHB: Ephemeris Data
    - CSATTB: Attitude Data
    - CSSFAB: Sensor Field Alignment Data
    - CSWRPB: Warping Data
    - CSCSDB: Covariance Support Data
  - An associated Geometry Model Document: pending release on Geospatial-Intelligence Standards Working group (GWG) website
  - Applies to pushbroom (scan by vehicle motion), whiskbroom, panoramic, and other linear array scanners, both airborne and spaceborne

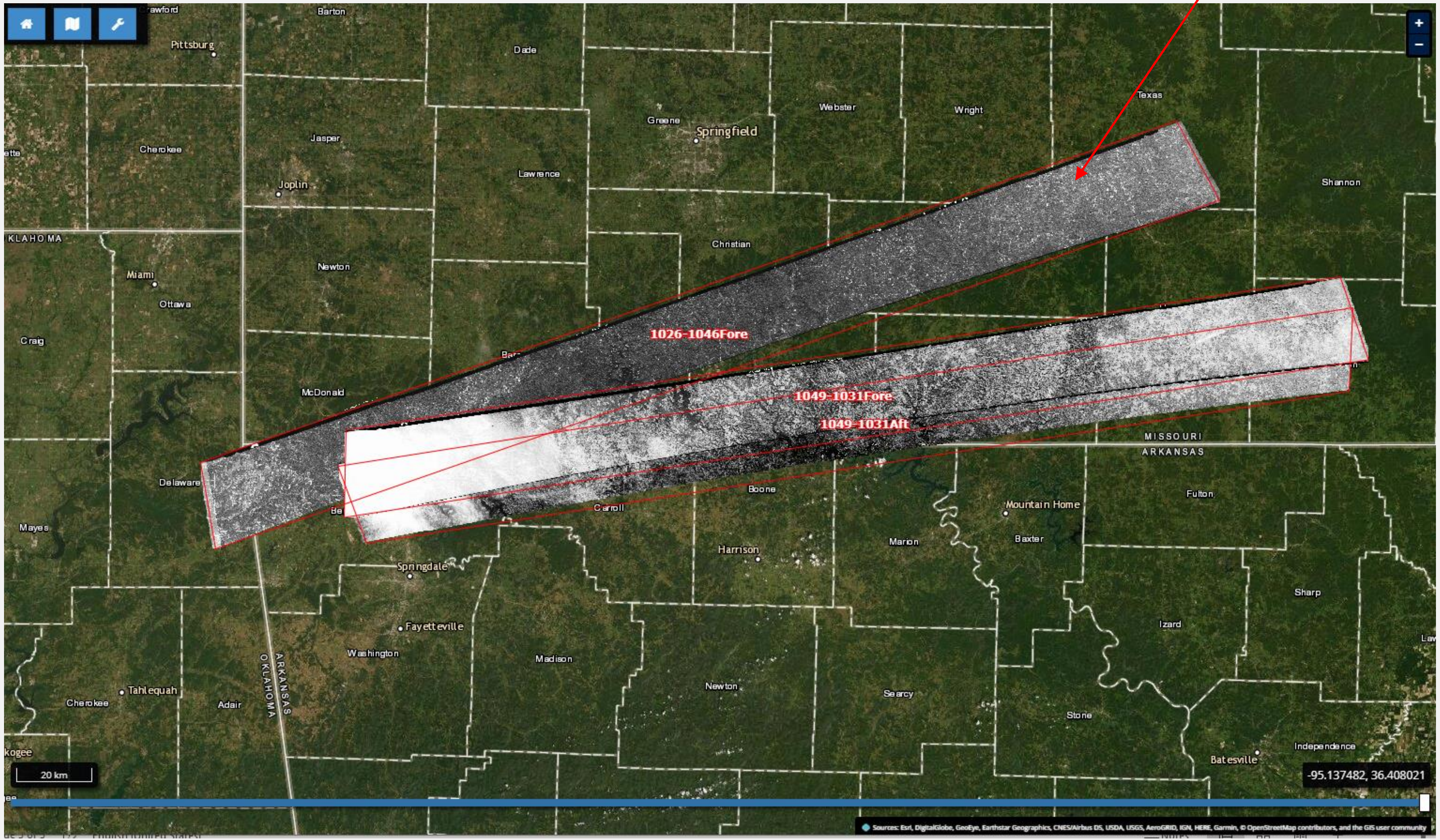
GLAS: Standard Implementation (cont'd)

- While the main impetus for the GLAS concept was to drive data providers to populate GLAS metadata, recent use cases have exercised the power of reverse engineering GLAS metadata and proceeding with the flexible and rigorous model
  - Ex. 1: NGA's Hyperion HSI metadata as an exemplar of the new Spectral NITF Implementation Profile (SNIP), https://doi.org/10.5194/isprs-annals-V-1-2020-49-2020
  - Ex. 2: NGA Research's leveraging of GLAS to implement rigorous error propagation in predicting the low-frequency accuracy of DSMs generated from hundreds of overlapping WorldView images, http://arxiv.org/abs/2104.04843
  - Ex. 3: Panoramic Sensor Modeling of KH-4 and KH-9; i.e., this presentation
    - Technical Paper forthcoming

GLAS: Improved Accuracy

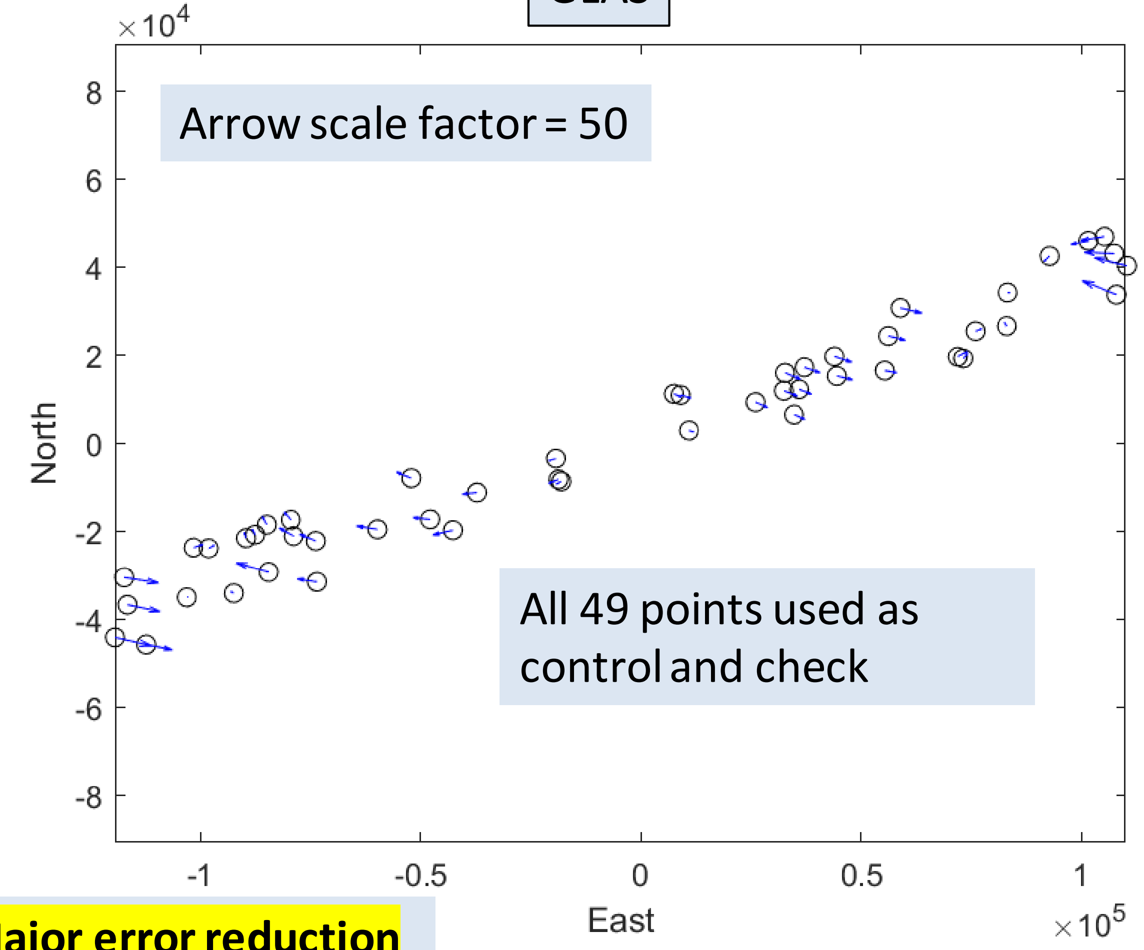
Data Set

This image in NW AR:
DS1026-1046DF021

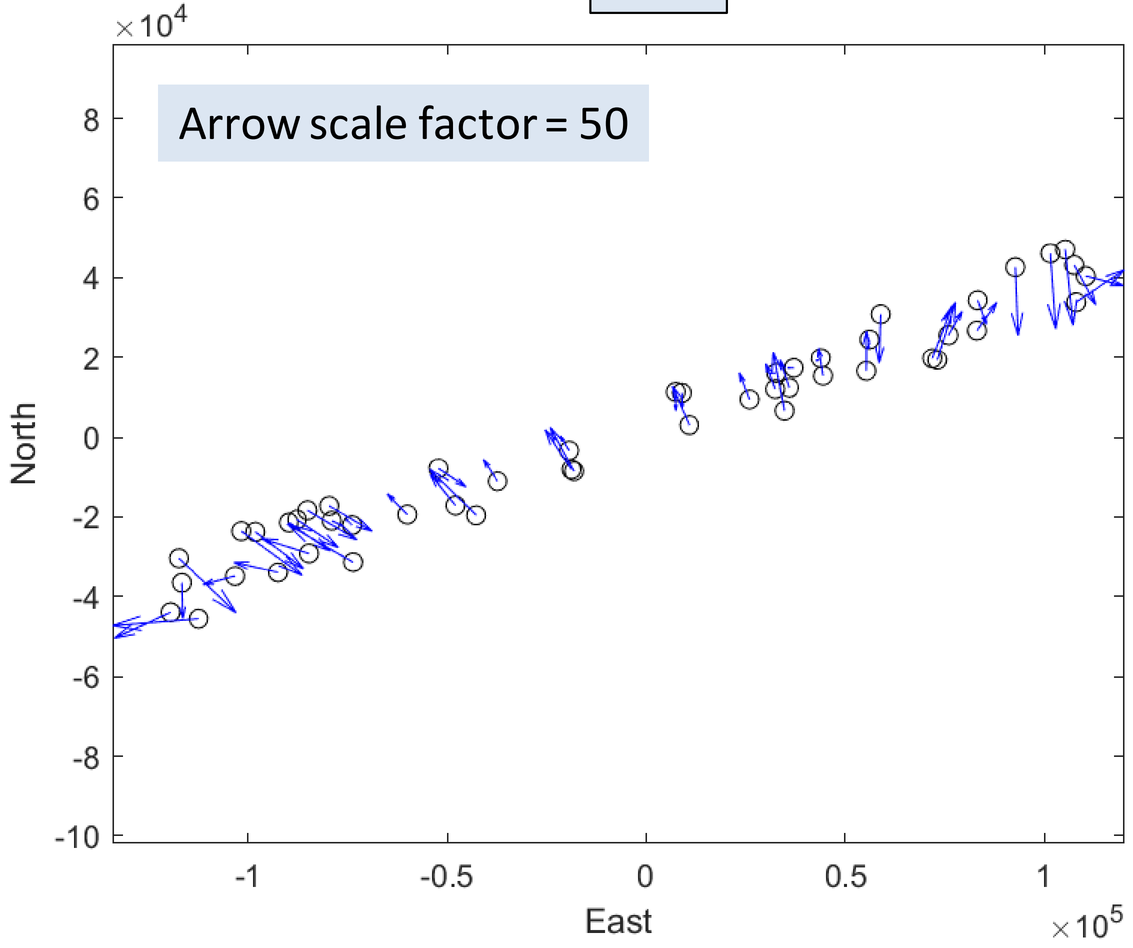


GLAS: Improved Accuracy (cont'd)

GLAS



Sohn



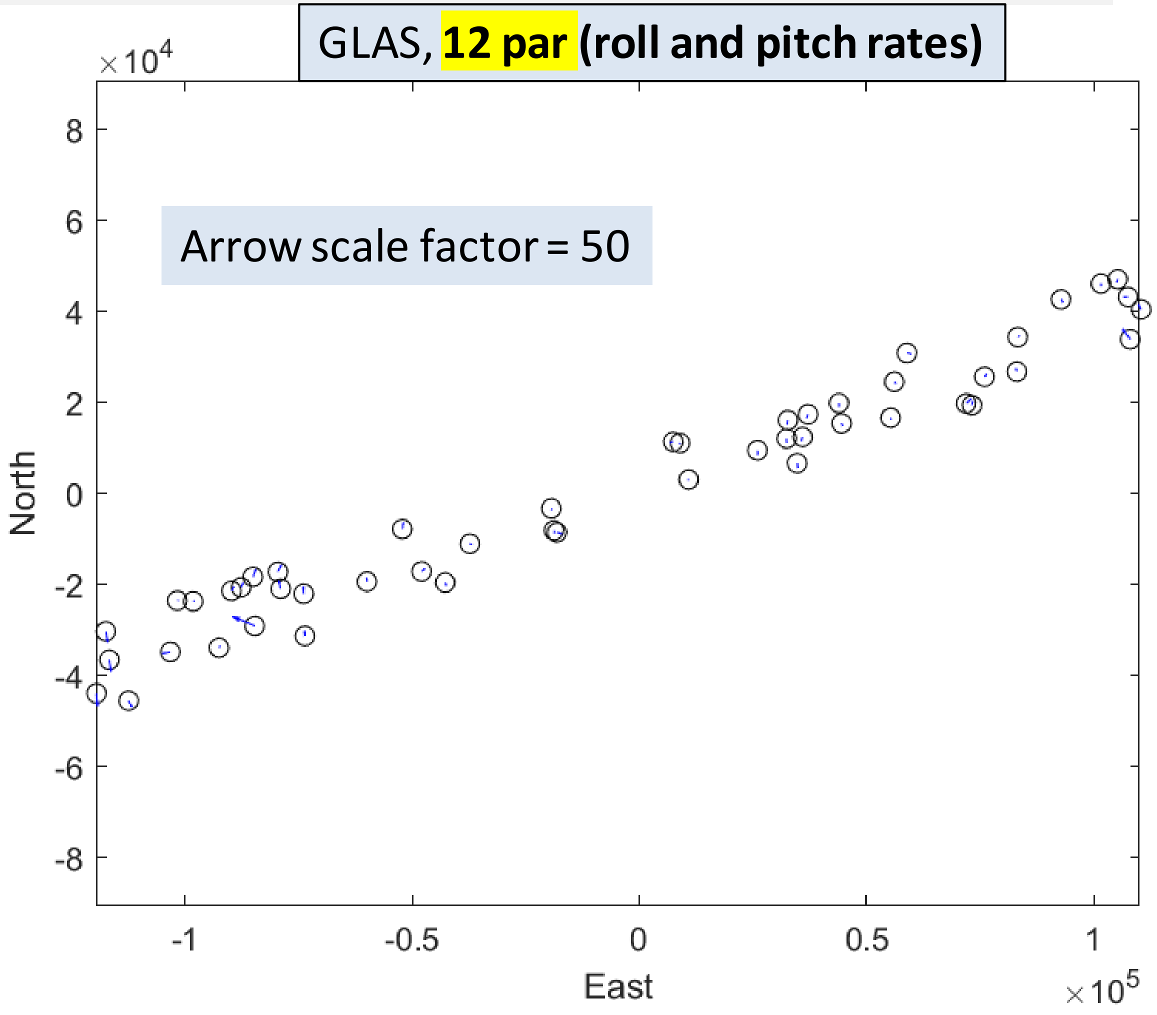
Major error reduction

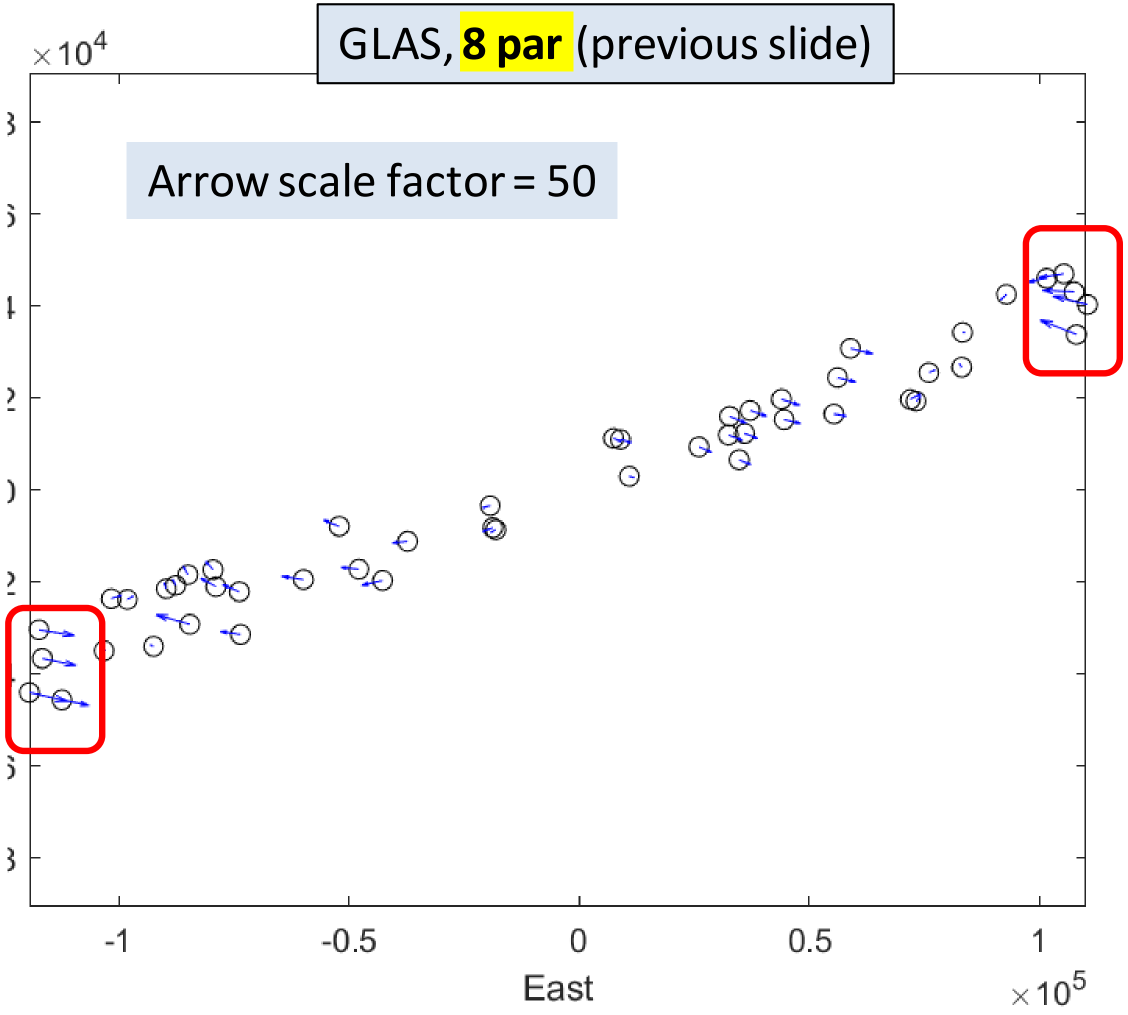
chk_rms =	**80.1**	**24.4**
chk_bias =	-0.29	-0.21

KH-4A: **8-par** (similar for both models) Resection Example

chk_rms =	**159.5**	**176.7**
chk_bias =	0.14	-0.73

GLAS: Improved Accuracy





chk_rms =	**18.5**	**22.9**
chk_bias =	-0.10	-0.13

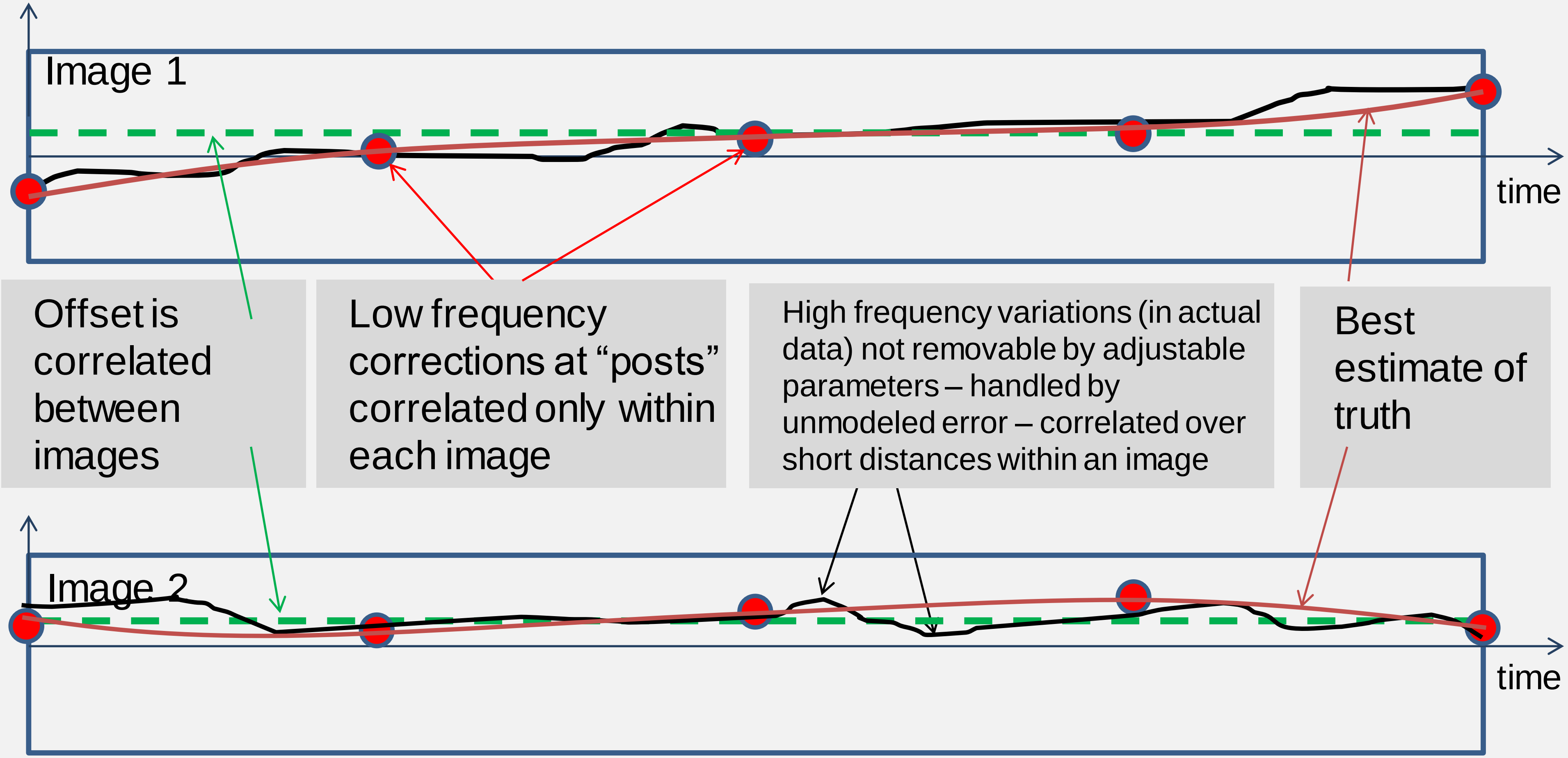
4X reduction!

chk_rms =	**80.1**	**24.4**
chk_bias =	-0.29	-0.21

GLAS: Advanced Adjustable Parameters

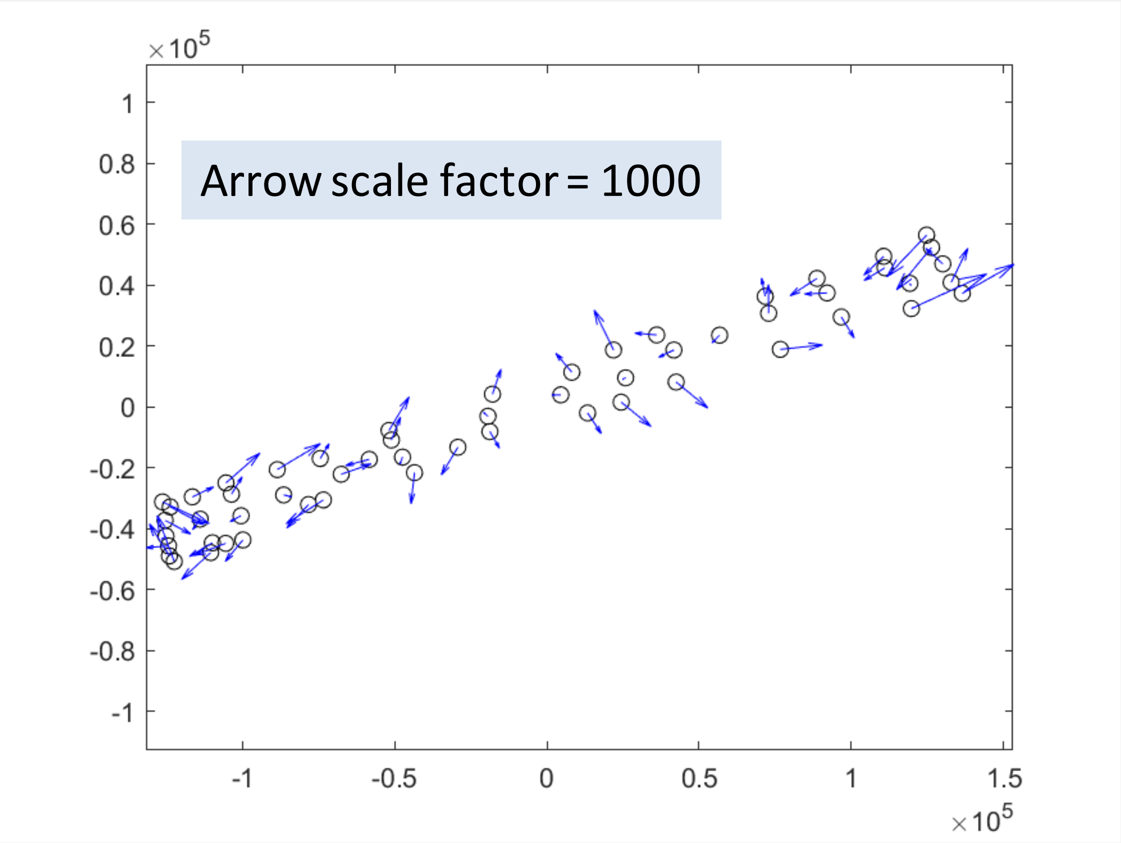
- The Figure shows GLAS's adjustable parameter model
  - One key takeaway is the flexibility offered by introducing "correction posts" (red dots)
    - 2 posts acts like attitude rate error (example on last slide)
    - 3 or more posts acts like a polynomial correction, but without the erratic behavior and unpredictability that occurs during extrapolation or long-interval interpolation

1D example of sensor errors as a function of time (truth (black); best estimate of truth (solid blue) is sum of offset (dotted green) and interpolated correction posts (red dots))



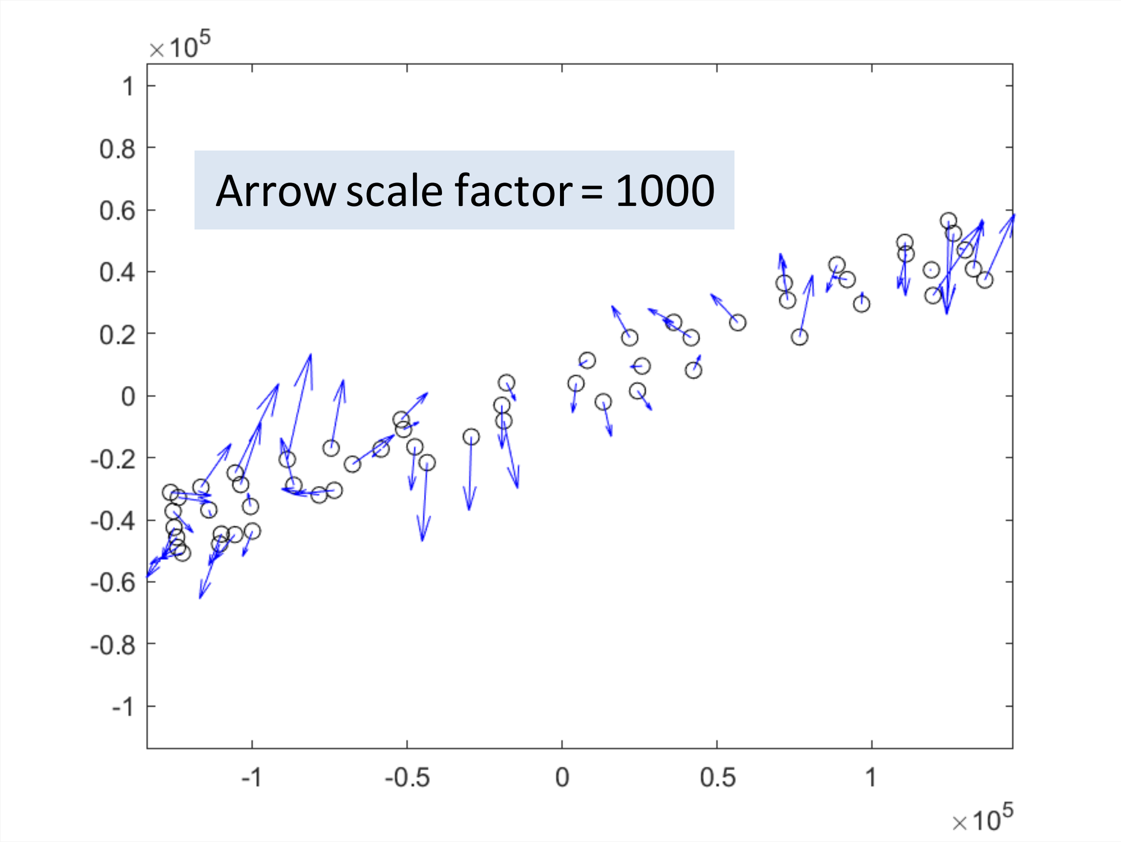
GLAS: Advanced Adjustable Parameters (cont'd)

GLAS, **28 par** (8 roll/pitch attitude posts)



chk_rms = 8.3, 7.2
chk_bias = 0.1, -0.2

GLAS, **12 par (roll and pitch rates)**



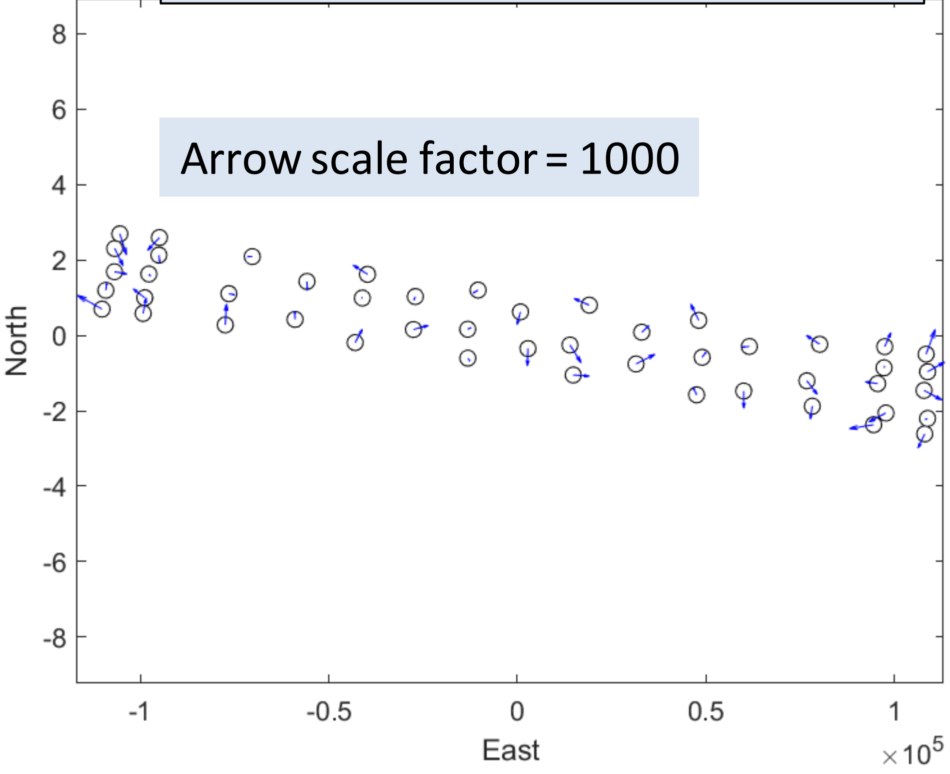
chk_rms = 6.7, 14.1
chk_bias = 0.1 -0.2

Note: while the "12 par" case was shown on a previous slide, these results use a different set of 56 measured points

GLAS: Extensible to KH-9

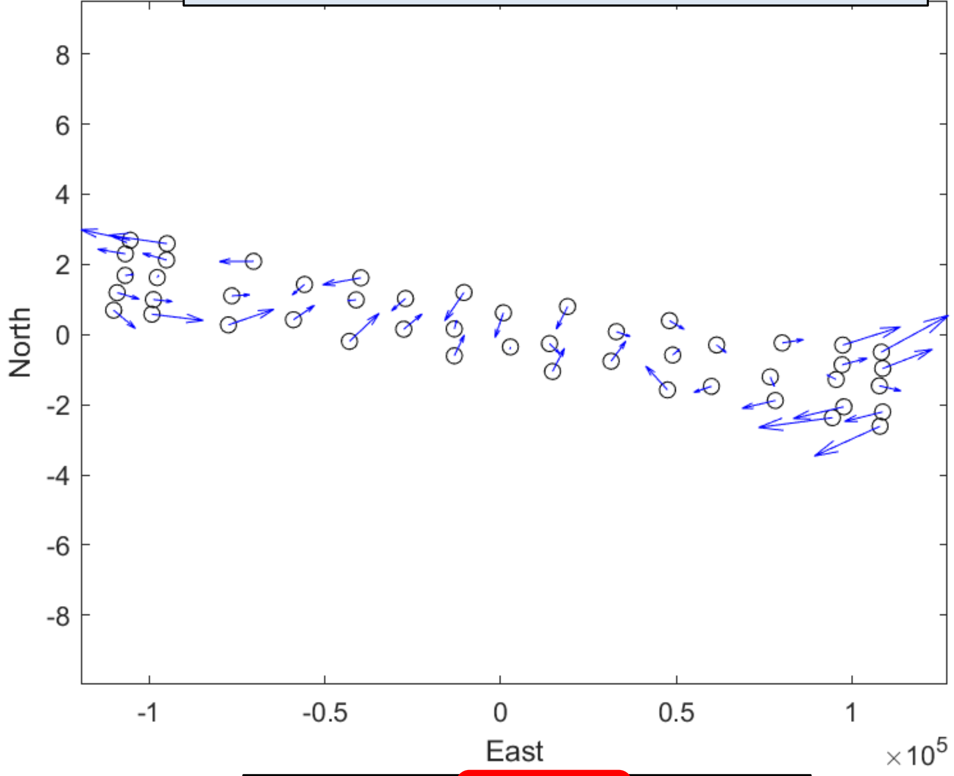
- GLAS was implemented successfully on several KH-4A and -4B images, both fore and aft looking
- Implementation on KH-9 required the addition of post adjustable parameters for yaw (rotation about the line-of-sight)

GLAS, 2 posts for **roll, pitch, and yaw**



chk_rms = 2.72, 2.92

GLAS, 2 posts for **roll and pitch only**



chk_rms = 8.99, 4.17

<u>Other Examples:</u>

8 posts for roll, pitch, and yaw

- <u>Ex 1</u>: All 48 control

chk_rms = 1.86, 1.30

- <u>Ex 2</u>: 32 GCPs and 16 check points around edges

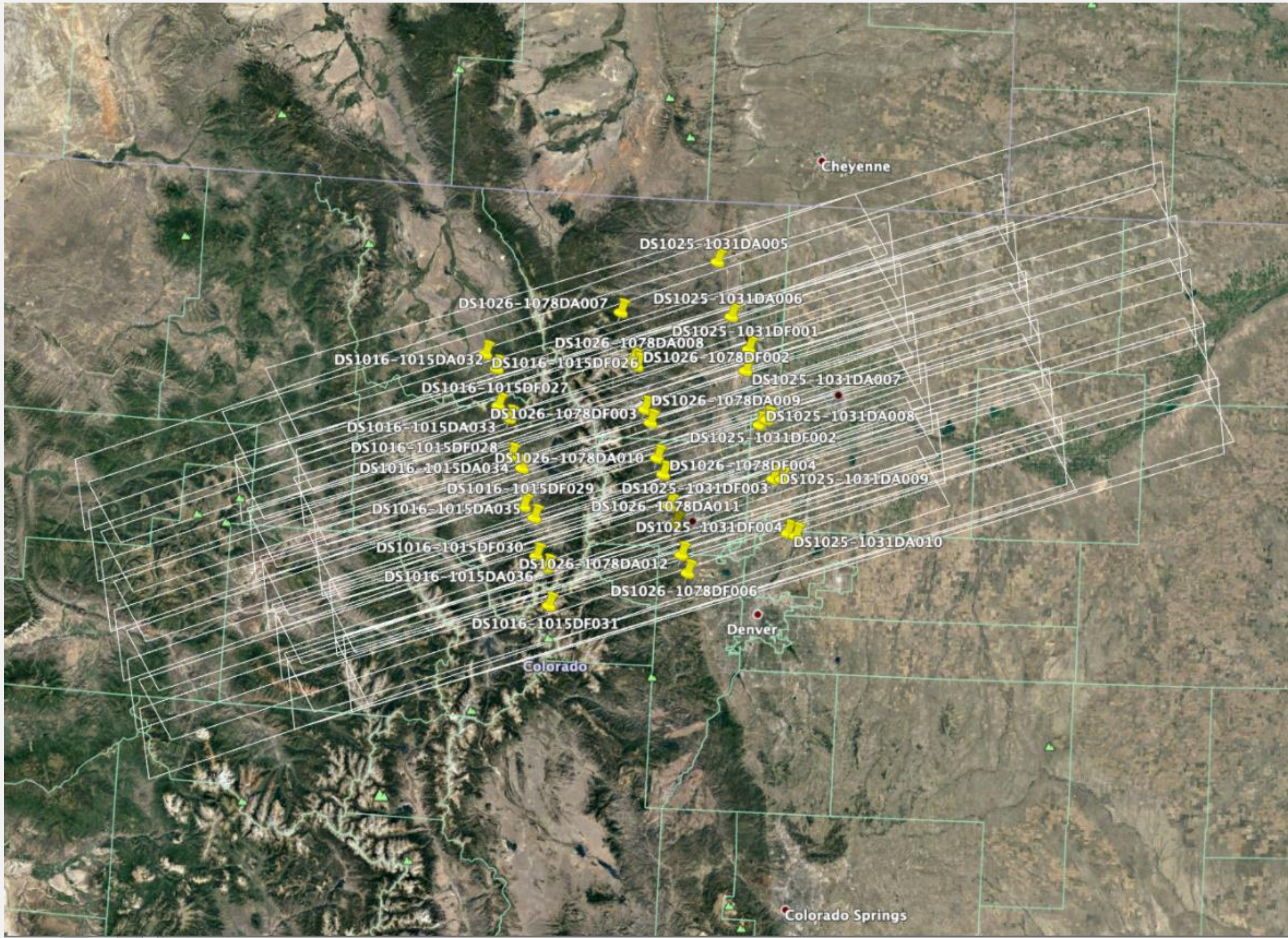
chk_rms = 5.82, 3.15

- <u>Ex 3</u>: Only 14 GCPs and 34 as check

chk_rms = 4.64, 3.56

Applications: Bundle Adjustment

- Obtained a block of 32 KH-4A images, over Colorado, to use in bundle adjustment experiments
- Will use our own custom-written code:
  - Bundle adjustment with:
    - Covariance, residual, and parameter adjustment analysis
    - Outlier detection
    - Possibility to semi- or fully-automate outlier removal
  - GLAS sensor model
- Currently a weak network due to sparse tie point measurements
  - Results with a 4-image block shown on the next slides
    - 2 Fore and 2 Aft images from the same pass

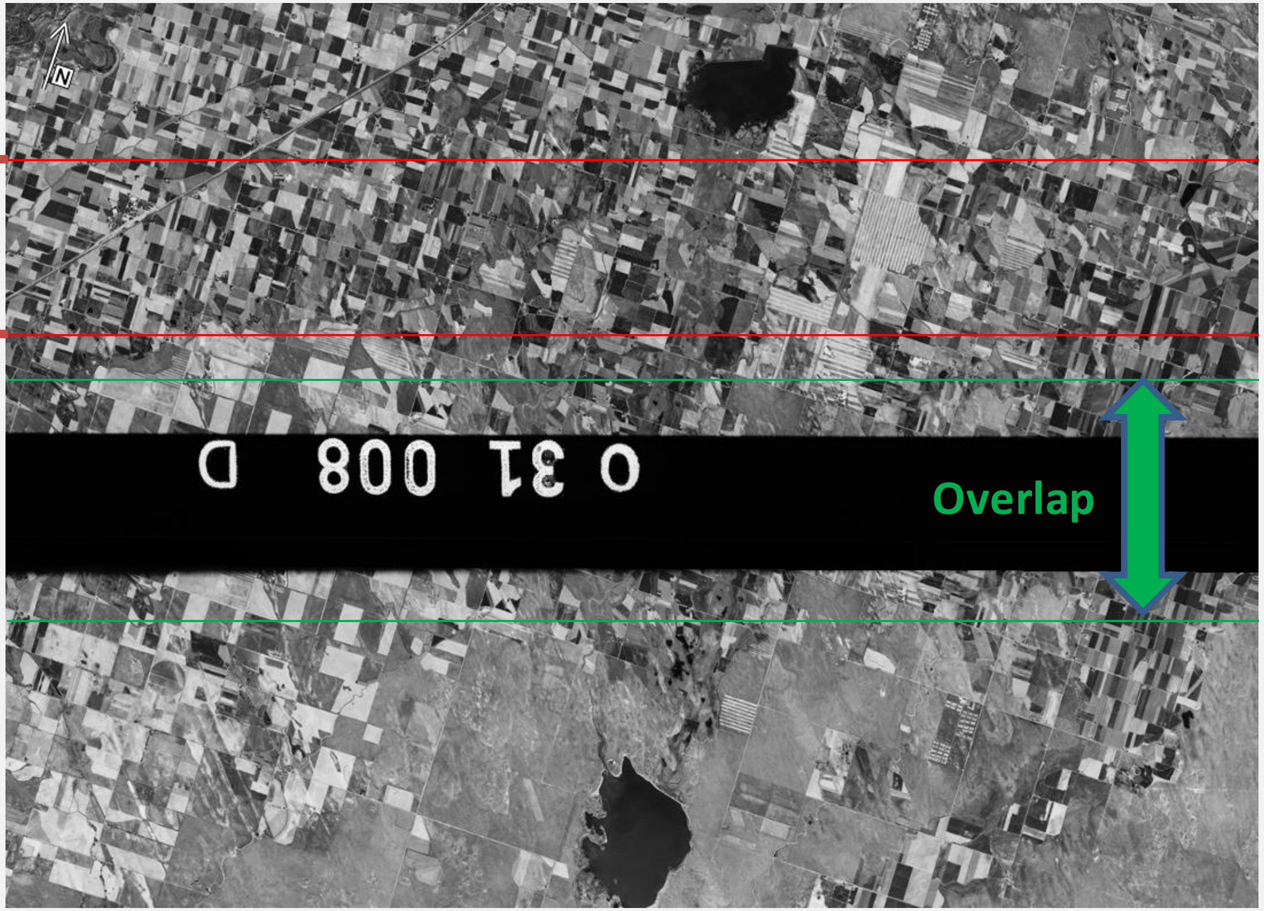


Four Image Block

Fore Looking (looking into the sun)

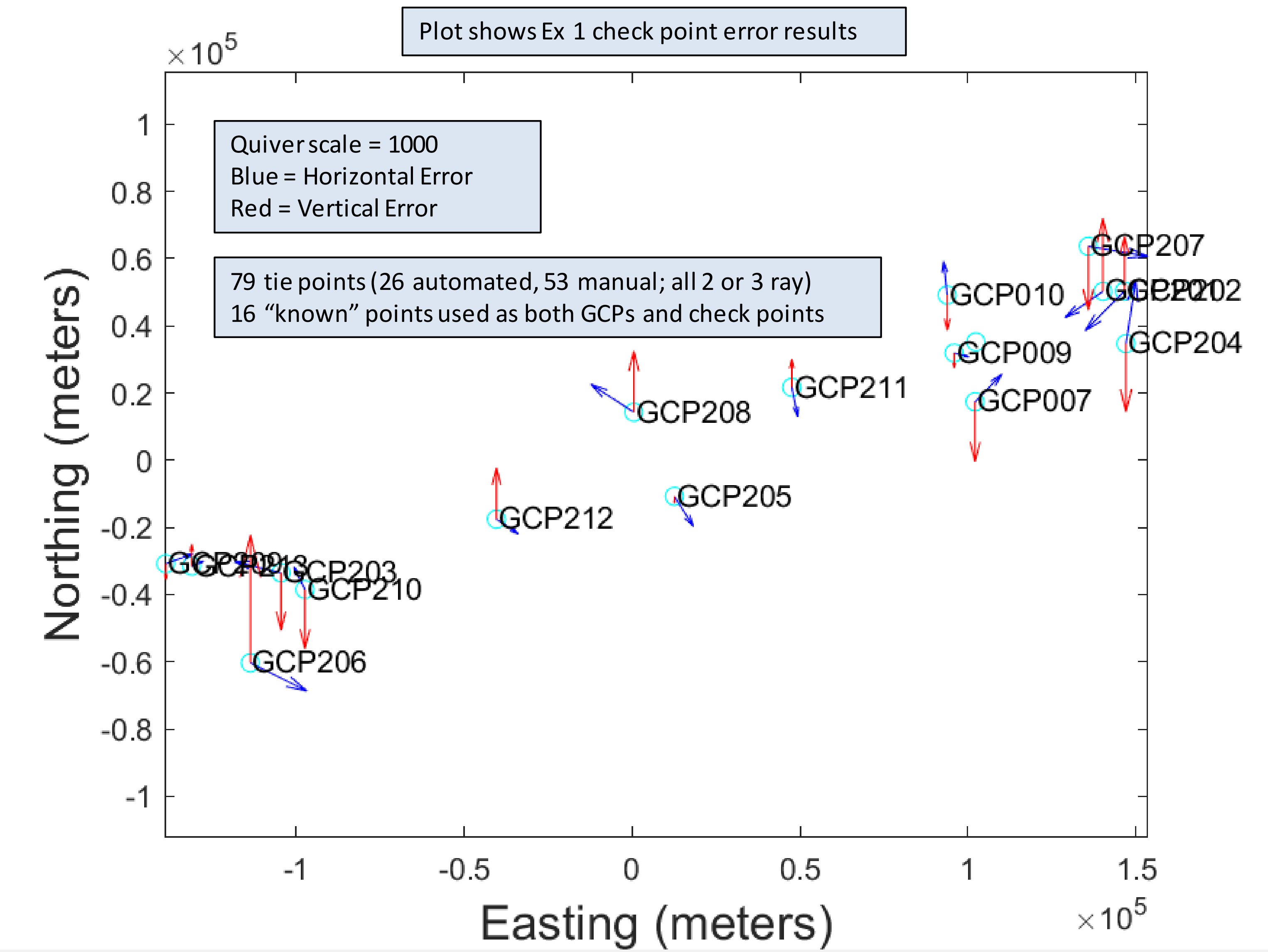
Negative Overlap (a Gap exists) Between Adjacent Images

Aft Looking (sun behind camera)



Small Overlap Between Adjacent Images

Four Image Block (cont'd)



<u>Input sigmas:</u>

- Img coord meas: 2 pixels
- GCP horizontal (per axis): 3 meters
- GCP vertical: 6 meters

<u>RMS error (X, Y, Z) in meters</u>

16 GCPs (also used as check)

- <u>Ex 1</u>: 2 posts

  chk_rms = 9.6, 8.3, 17.1
  sigma_o_hat = 1.68

- <u>Ex 2</u>: 5 posts

  chk_rms = 8.2, 6.7, 14.0
  sigma_o_hat = 1.51

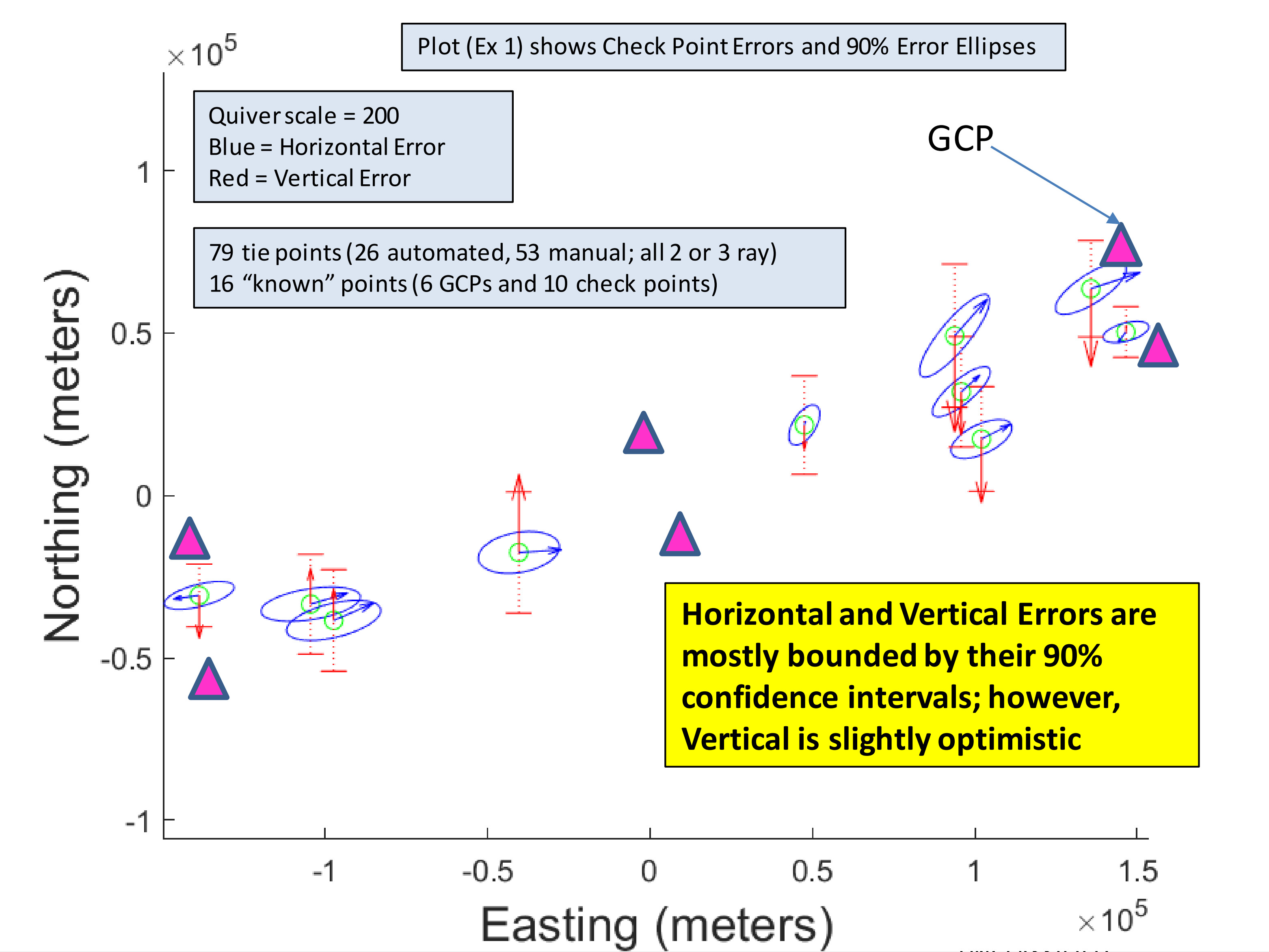
Posts offer small improvement in all 3 axes

Four Image Block (cont'd)

GLAS: Error Propagation

- Uncertainty estimation (aka rigorous error propagation) is a by-product of using the GLAS model
  - e.g., 3D error ellipsoid generation associated with a geolocation
  - 2D error ellipses and vertical confidence interval (both at 90% probability) of check points are illustrated in bundle adjustment results on next slide
  - Divides 16 "known points" from previous slide into:
    - 6 Well-distributed GCPs
    - 10 Check Points evaluated in X, Y, Z

Four Image Block (cont'd)



<u>RMS error (X, Y, Z) in meters</u>

- <u>Ex 1</u>: 2 posts

chk_rms =	49.6, 25.4, 87.3
sigma_o_hat =	1.75

- <u>Ex 2</u>: 5 posts

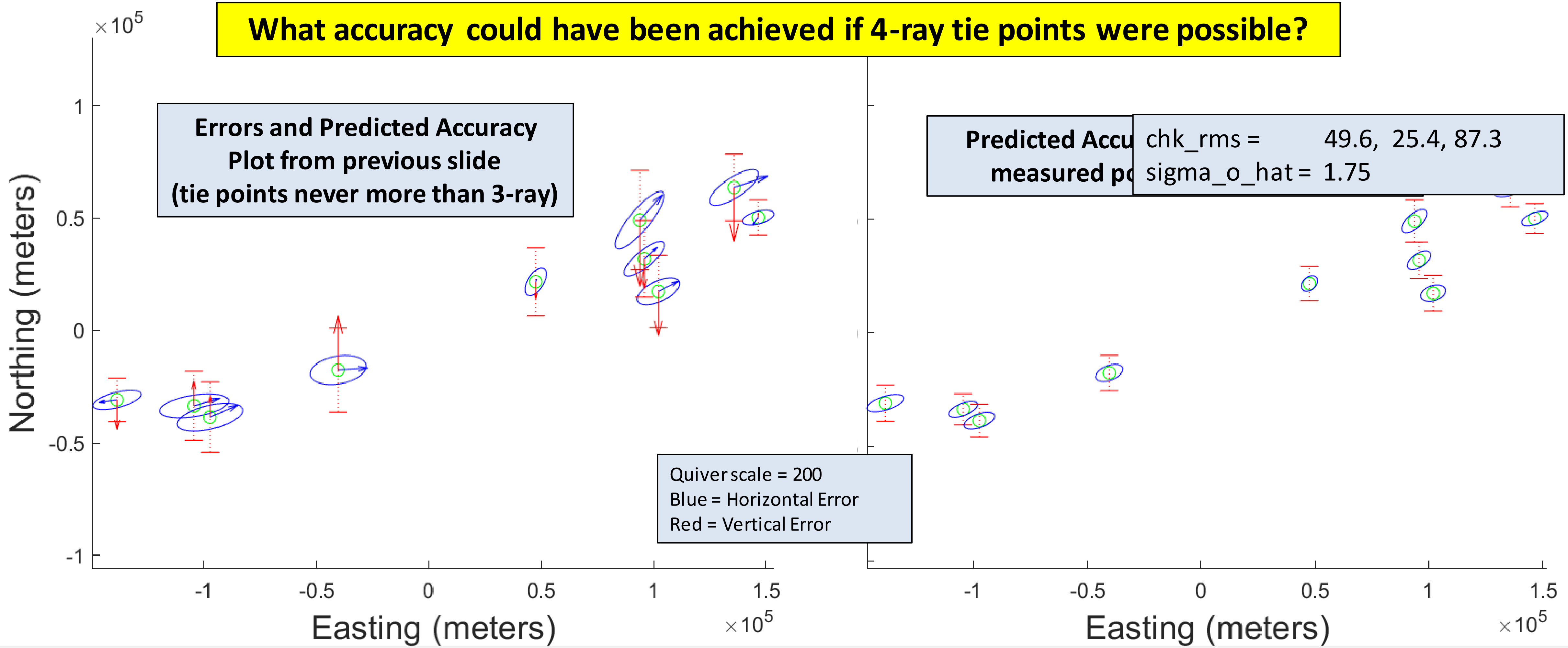
chk_rms =	201.0, 172.3, 507.4
sigma_o_hat =	1.27

2 Posts → 5 Posts causes major degradation:

- **Used only 6 GCPs (practical number compared to single image case)**
- **Inability to measure 4-ray tie points due to negative overlap**
- **Posts compete between removing rate errors (huge) and jitter (small) at the same time for this weak network**
    - **May need a 2-stage adjustment**

Four Image Block (cont'd)

What accuracy could have been achieved if 4-ray tie points were possible?



Predicted Accuracy confidence intervals would be cut almost in half:
~(50, 25, 87) → ~(25, 15, 50)

Summary and Future Work

- **Summary**
  - Demonstrated improved accuracy of GLAS with respect to Sohn model
  - Demonstrated GLAS's Advanced Adjustable Parameters and Error Propagation
    - Single image triangulation
    - 4-image block triangulation
- **Future Work**
  - Perform Bundle Adjustment on Entire Block of KH-4 (and other) Images
  - Automate the Image Matching
    - Feasible for same-pass images
    - Challenging for between-pass images (consider semi-automation)
    - Semi-automation likely required for KH to Reference