

QuickBird Geopositional Status

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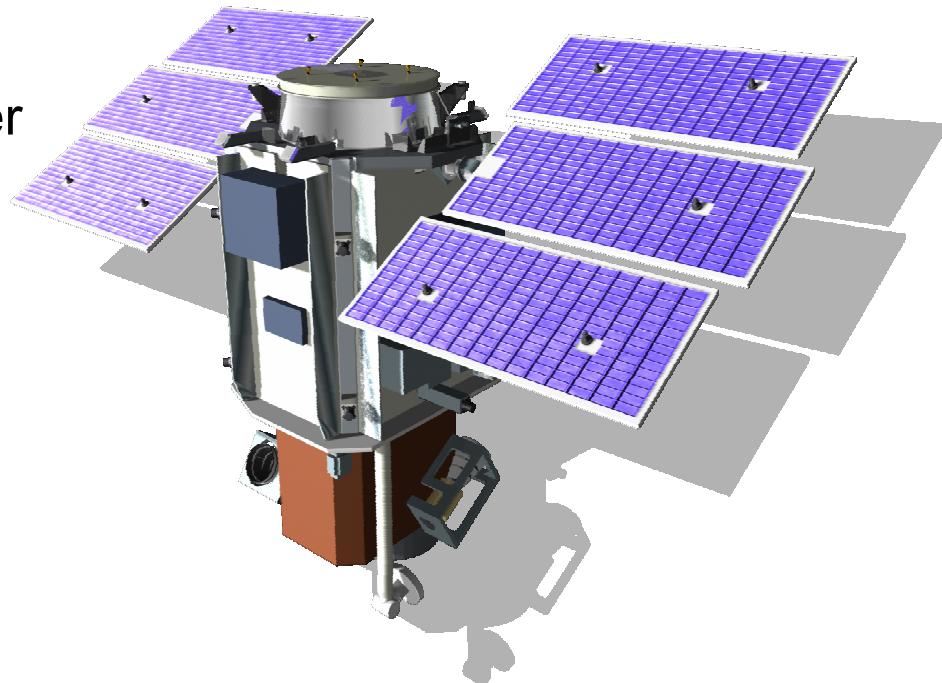
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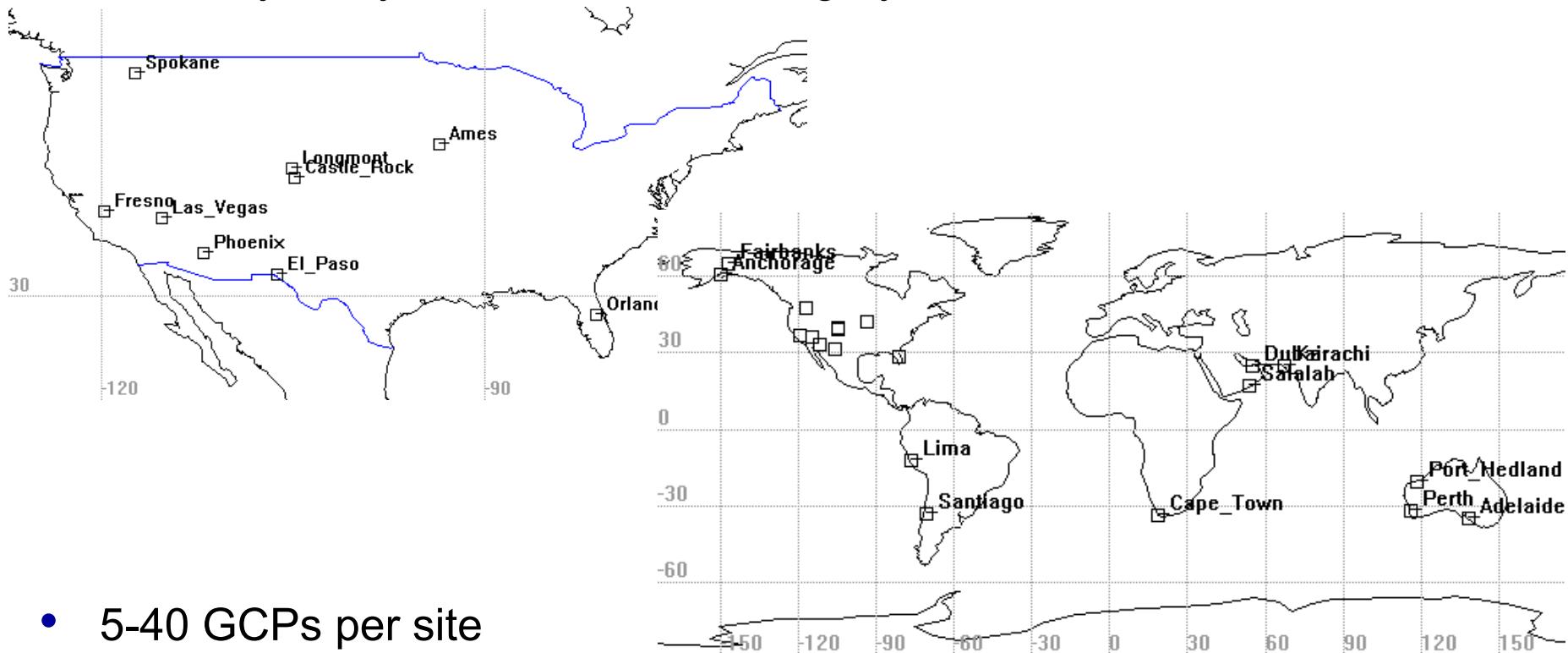
QuickBird Geopositional Performance



- QuickBird Basic Products satisfy 23m CE90 specification
 - at nadir, excluding terrain effects
 - correction with GCPs greatly reduces the errors
- Average Geolocation Accuracies (of images in test set) :
 - Absolute Error: 13.6 m CE90 (uncorrected products)
 - Residual Error: 2 m 1σ
 - Point-to-Point Relative: 5 m CE90
 - Pan-MS Registration: 1 pan-pixel 1σ
- Improvements :
 - Attitude Determination Refinement (latest version is ADP 2.1)
 - Camera Refinement (only slight modifications from pre-launch)
 - Ephemeris Determination Refinement (at ~9m 3σ error)
 - Timing Error Corrections (fixed)

Ground Control

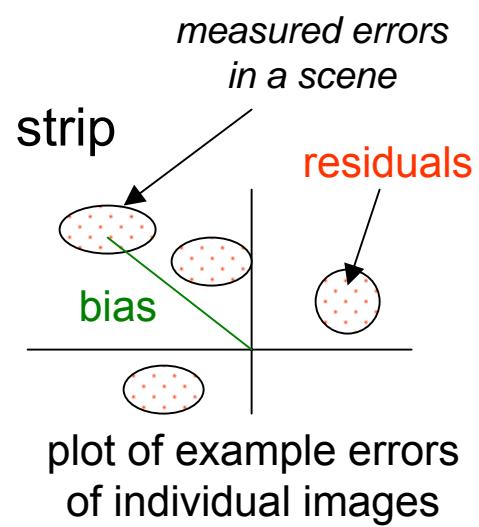
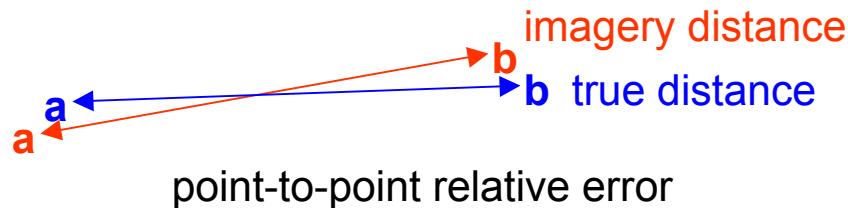
- DigitalGlobe is using >20 sites, >140 scenes for geopositional accuracy analyses of QuickBird imagery



- 5-40 GCPs per site
- GCPs are sub-meter accuracy
- surveyed by CompassCom, Fugro, and DigitalGlobe

Error Measurement

- Geopositional Error Measurement
 - we use rigorous camera model
 - measure vector from Ground “Truth” GCP to Measured Image GCP
 - method eliminates terrain effects
 - verified measurements with RPCs
- Horizontal Error Metrics
 - Errors are calculated on individual image scenes (~17 x 17 km each)
 - Absolute error = average bias of the scene
 - Relative Error = measures distortion errors within the scene
 - Residual = resulting errors once bias is removed
 - Point-to-Point = errors in distance between GCPs
- Analyzed both individual scenes and scenes within a strip
- Reported accuracies are for the test set



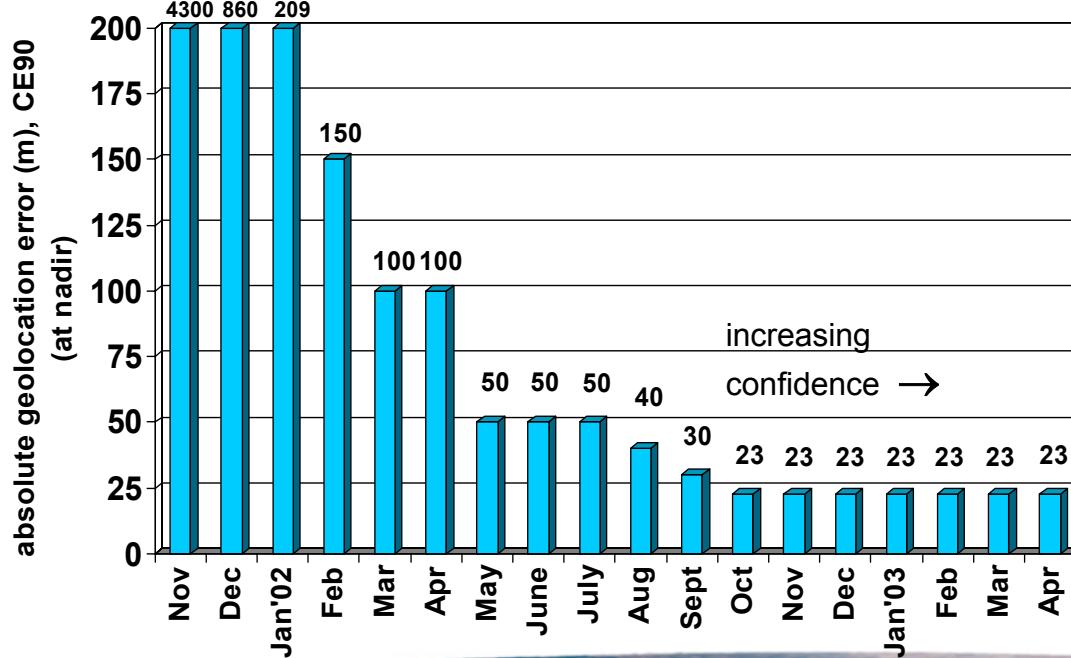
Absolute Geolocation



- Absolute Geolocation = average bias of a scene = mean error
- QuickBird scenes currently meeting 23m CE90 specification
 - specification is at-nadir, excluding terrain effects
 - studies by BAE and EarthSat confirm analysis measurements
 - we have reprocessed imagery attitude for full archive with ADP 2.1
- Calculated in CE90 as specified by NIMA (Tom Ager)
 - “An Analysis of Metric Accuracy Definitions and Methods of Computation”
 - CE90 is calculated for each individual scene (each ~17 x 17 km)
 - can be calculated either with 90% of data points or polynomial combination of means and sigmas
 - previous definition in MIL-STD-600001 “Mapping, Charting and Geodesy Accuracy” did not adequately address horizontal biases in imagery
- Basic Imagery Performance
 - Average Geolocation of test set : 13.6m CE90
 - greater than 95% of images in test set meet 23m CE90

Historical Geopositional Improvement

- Achieving accuracy specification has taken time
 - spacecraft not designed for new lower, sun-synch orbit
 - star tracker placement optimized for all- β sun angle mission
 - telescope on-orbit performance was substantially better than predicted
 - however, focusing took longer than expected
 - new gyros increased reliability, but at increased attitude noise
 - **archive imagery has been reprocessed with ADP 2.1 to meet spec**



Lessons Learned in :

- system timing
- focus adjustment
- star tracker design
- attitude filter design
- production integration
- expectation

*Expect More
Improvements !*

- **Image-level metrics:**

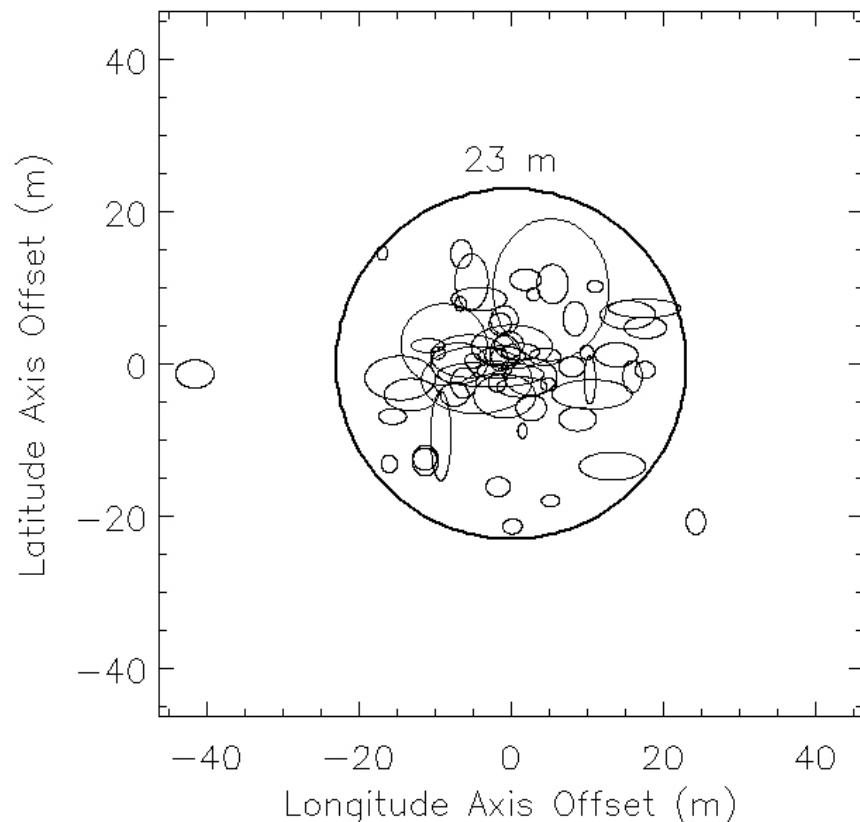
- $\Delta_i = [G_{observed} - G_{truth}]$ = geolocation error at i^{th} GCP
- $\mu_{abs} = \text{mean}(\Delta_i)$ = bias of GCP errors for image
- $\sigma_{abs} = \text{std}(\Delta_i)$ = standard deviation of GCP errors for image
- **CE90_{abs} = *function* (μ_h , σ_h)** [per NIMA paper]

- **System-level metrics:**

- Avg. CE90_{abs} = mean(CE90_{abs} for images in test set)

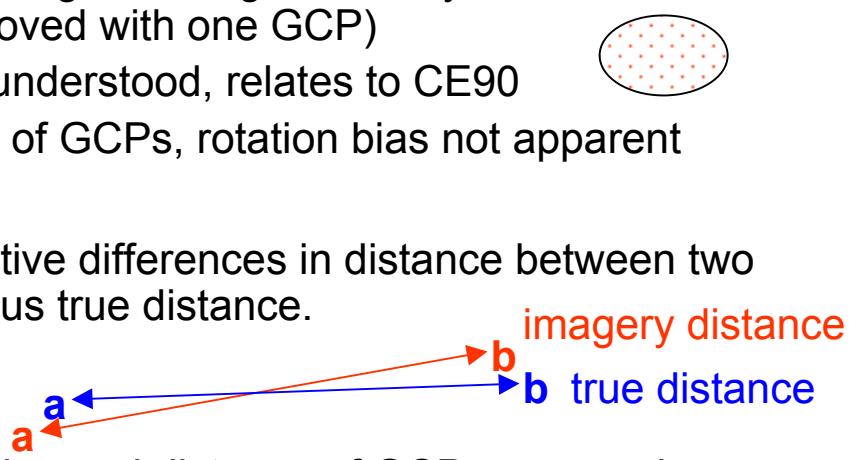
Absolute Geolocation Ellipse Plot

- Example of geolocation data
 - subset from recent period of time
- Each ellipse represents a single basic image product
 - Offset: average of residuals or “bias” for each image
 - Size: 1σ scatter of residuals on each axis
- Circle denotes 23 m
- There are two outliers
 - 2 out of 62 images for this dataset
 - outliers are inherent in statistical systems
 - outliers usually have single star tracker attitude solutions
 - developing ADP improvements to reduce the occurrence of outliers



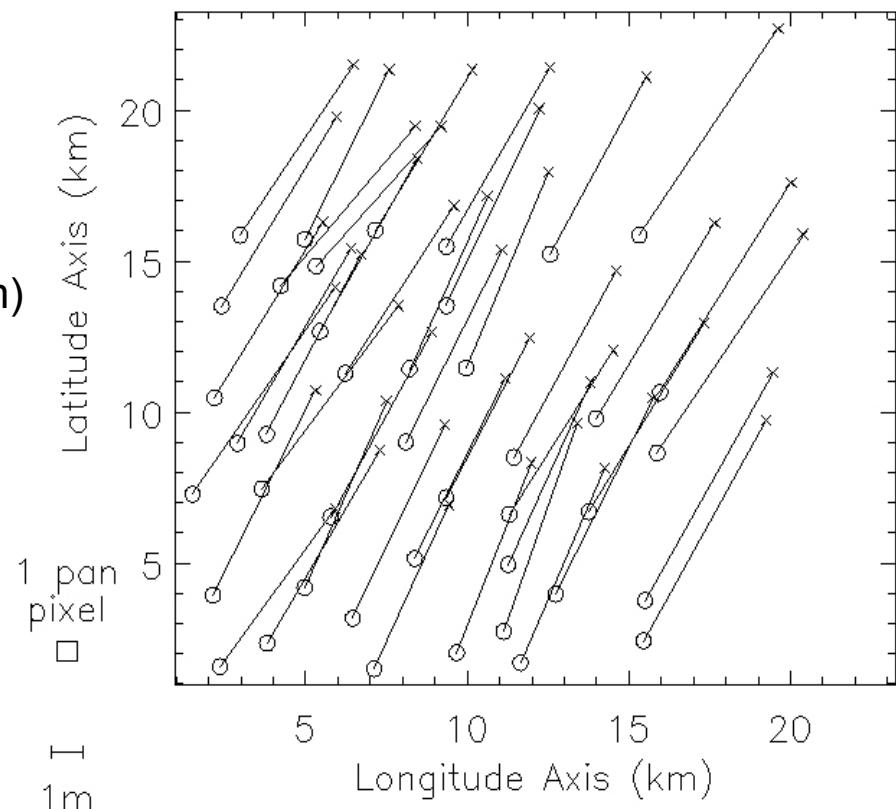
Relative Geopositional Error

- Relative error is in two flavors
 - Residual Error
 - measured as 1σ variation of errors for a given image with only translation bias removed (translation bias can be removed with one GCP)
 - advantage : easy to calculate, easily understood, relates to CE90
 - disadvantage : need good distribution of GCPs, rotation bias not apparent
 - Point-to-Point Relative Error
 - reported as CE90 variation of the relative differences in distance between two GCPs as measured in the image versus true distance.
 - all pairs of GCPs are compared
 - advantage : bias independent
 - disadvantage : dependent on distribution and distance of GCPs, scene size
- Performance
 - Average Residual: 2 m 1σ
 - Average Point-to-Point: 5 m CE90



GCP Absolute Error Plot

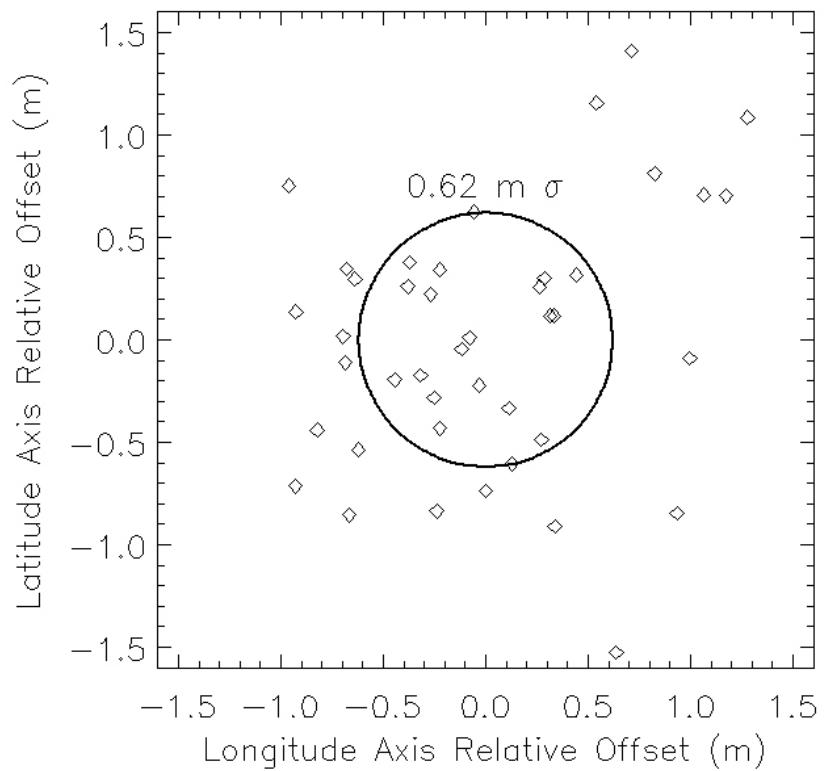
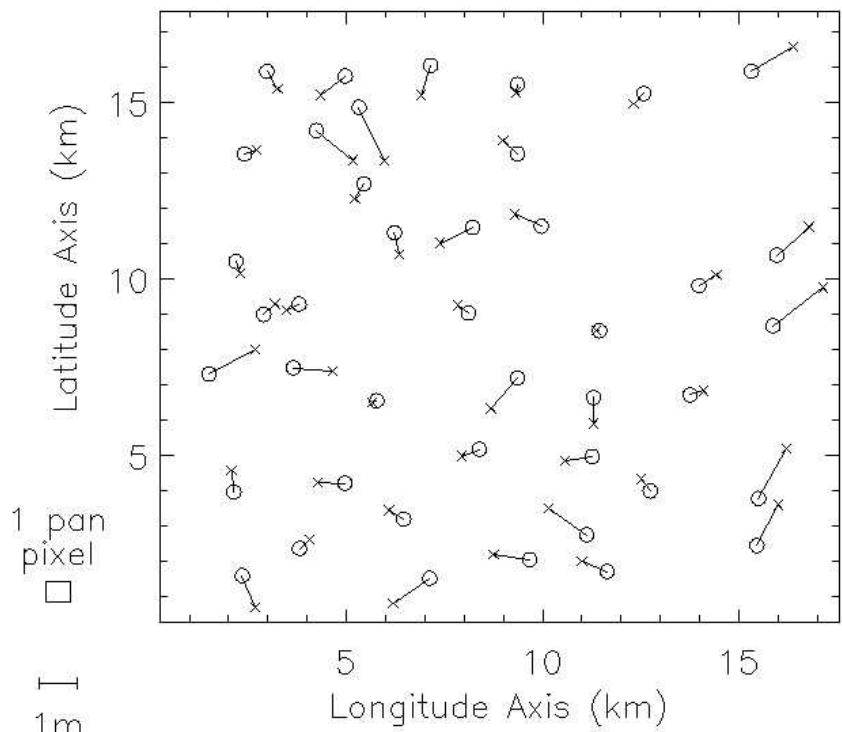
- GCP absolute geopositional error for a single sample image (1010010000CDF101)
- Two scales in this figure
 - GCP locations on the surface (km)
 - circles: ground GCPs
 - GCP residual displacements with
 - ~1000 enlarged scale (m)
 - pluses: displacement to image GCPs
- Systematic bias is evident
 - Average Bias = 9m N, 3m W
- Variation in residual vectors represents scatter



**Average length of error vectors is ~9.5 meters.
Axes in kilometers only to show GCP locations.**

Residual Error Scatter Plot

- Sample residuals for a single image (1010010000CDF101)
 - each point is a GCP residual relative error
 - translation bias removed

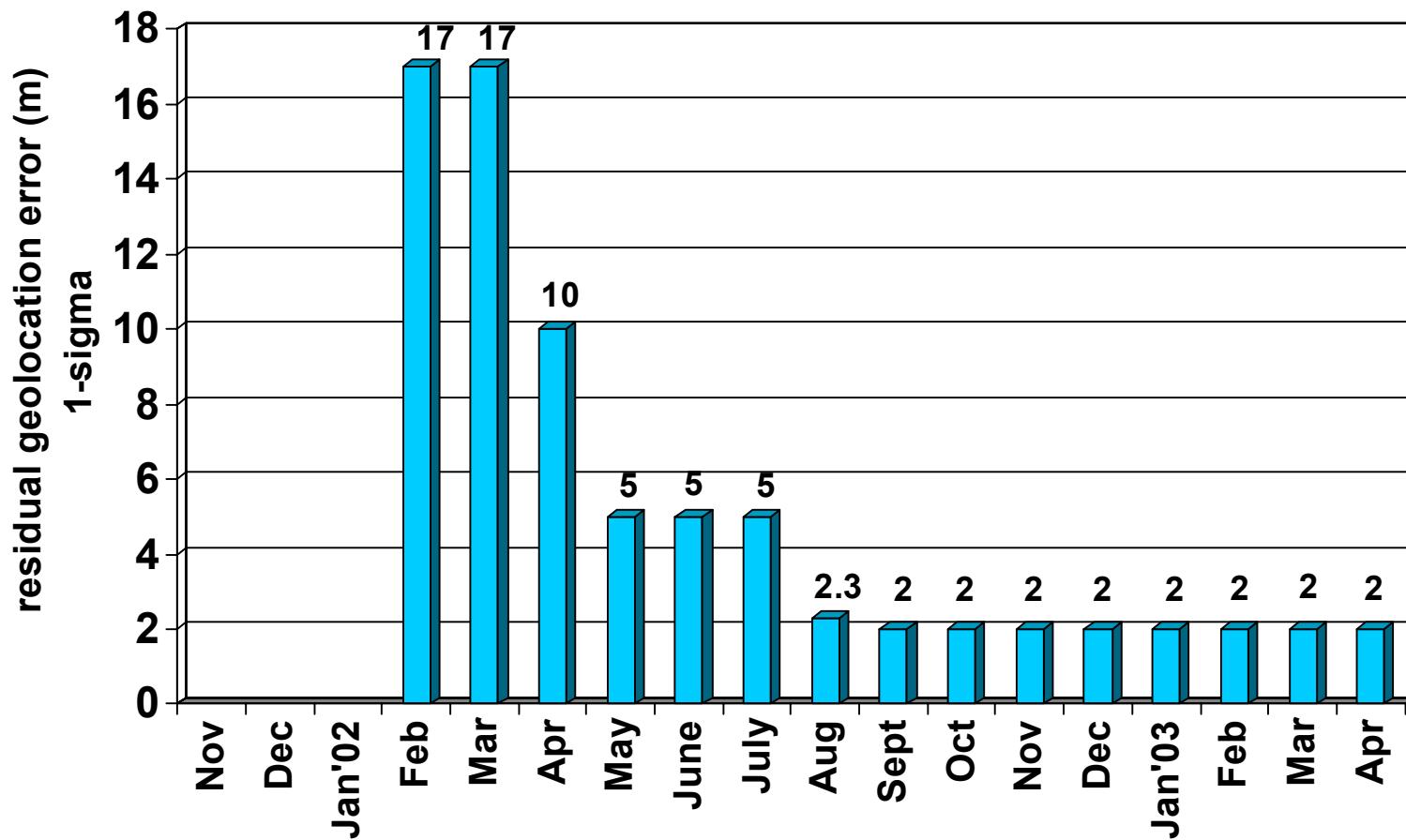


- Large circle represents the standard deviation of the residual error for this image

Historical Relative Geolocation Improvement



- Current average Residual Error is 2 m 1σ for all imagery
 - Earlier imagery has been reprocessed to reduce the relative error



- **Image-level metrics:**

- $\Delta_i = [G_{observed} - G_{truth}]_i$ = geolocation error at i^{th} GCP
- $\eta_{ij} = \Delta_i - \Delta_j$ = point-to-point relative error
- $\mu_{rel} = \text{mean}(\eta_{ij})$ = avg. of pt-to-pt relative errors within image
- $\sigma_{rel} = \text{std}(\eta_{ij})$ = standard deviation of pt-to-pt relative errors within image
- **CE90_{rel} = *function* (μ_h , σ_h)** [per NIMA paper]

- **System-level metrics:**

- Avg. CE90_{rel} = mean(CE90_{rel} for images in test set)

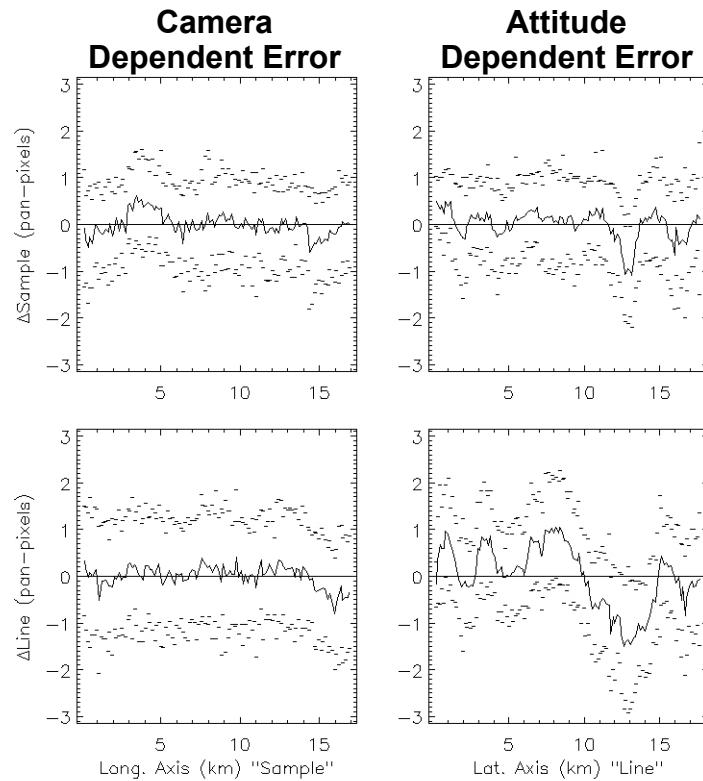
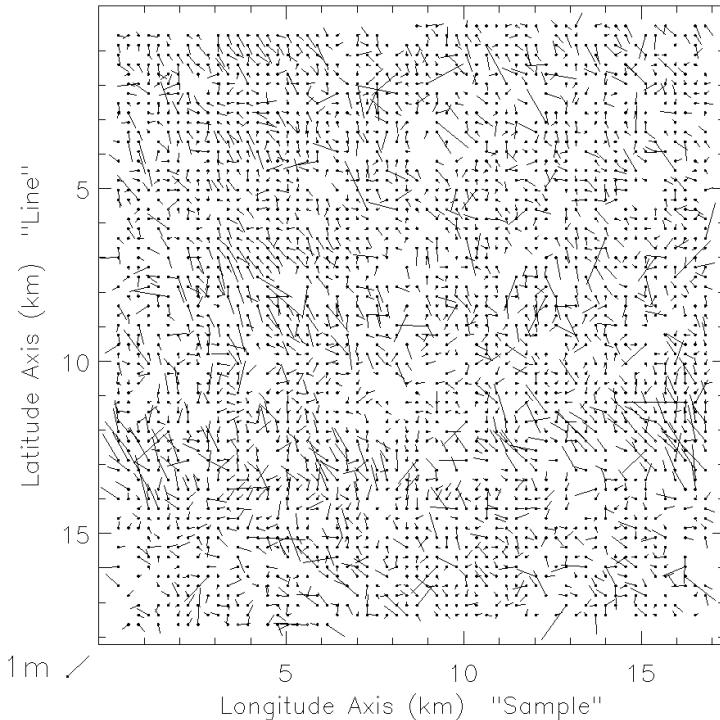
- Pan-MS Band Registration Error Sources
 - Panchromatic detectors are offset from MultiSpectral detectors in scan direction
 - Attitude determination errors during maneuvering for imaging
 - Camera model errors
- Registration offsets determined via auto-correlation of features
 - Red band serves as proxy for MS bands
 - Negligible error between MS bands
- Performance:
 - Average Pan-MS Band Registration: 1 pan-pixel 1σ

Pan-MS Band Registration Quiver Plot



- Separate registration errors into line and sample contributions
 - camera model is primary contributor to sample dependent scatter - average the columns
 - attitude is primary contributor to line (time) dependent scatter - average the rows
 - each scatter contributor is a vector with Δ_{line} and Δ_{sample} components

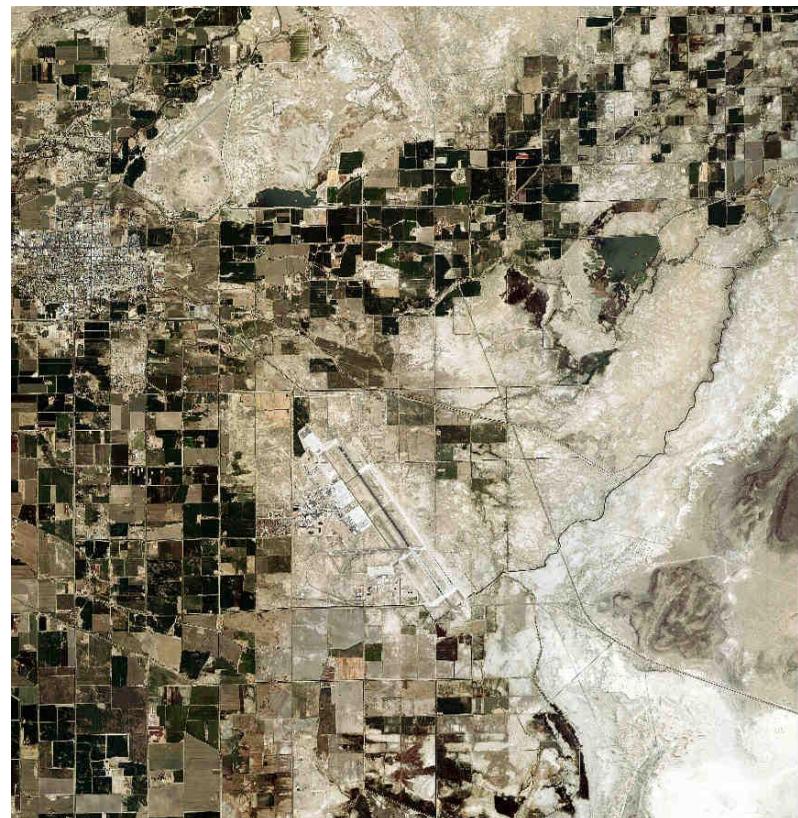
"Quiver Plot" - Band Registration Offsets



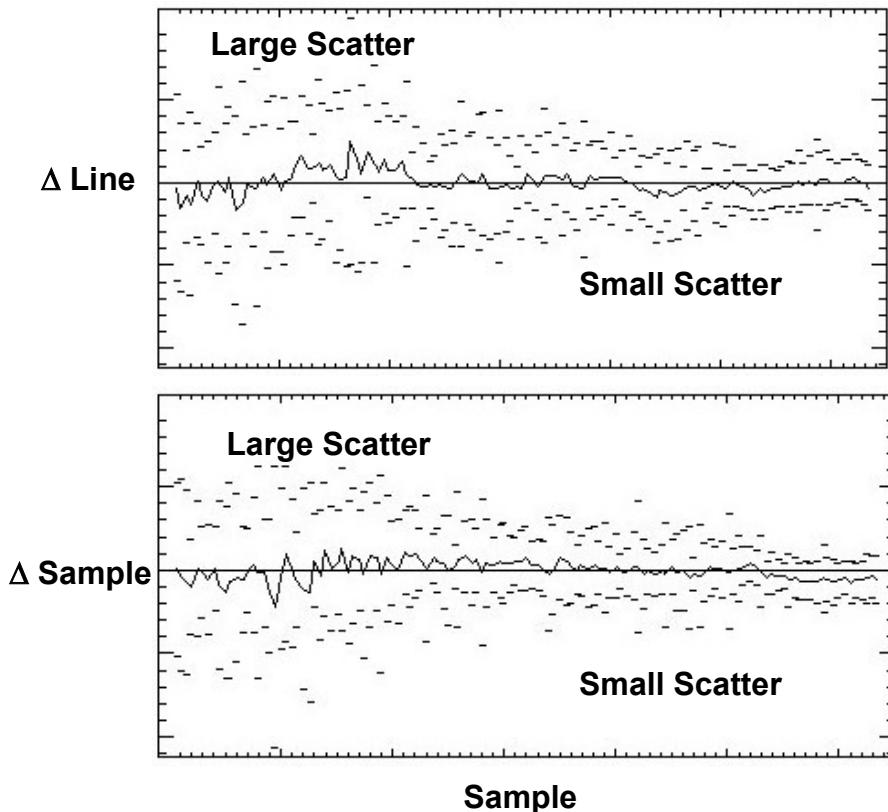
Affect of Scene Content on B2B Scatter



- Scene and sample dependent component of scatter
- Scatter increases from left to right.



Camera Dependent Error - average the columns

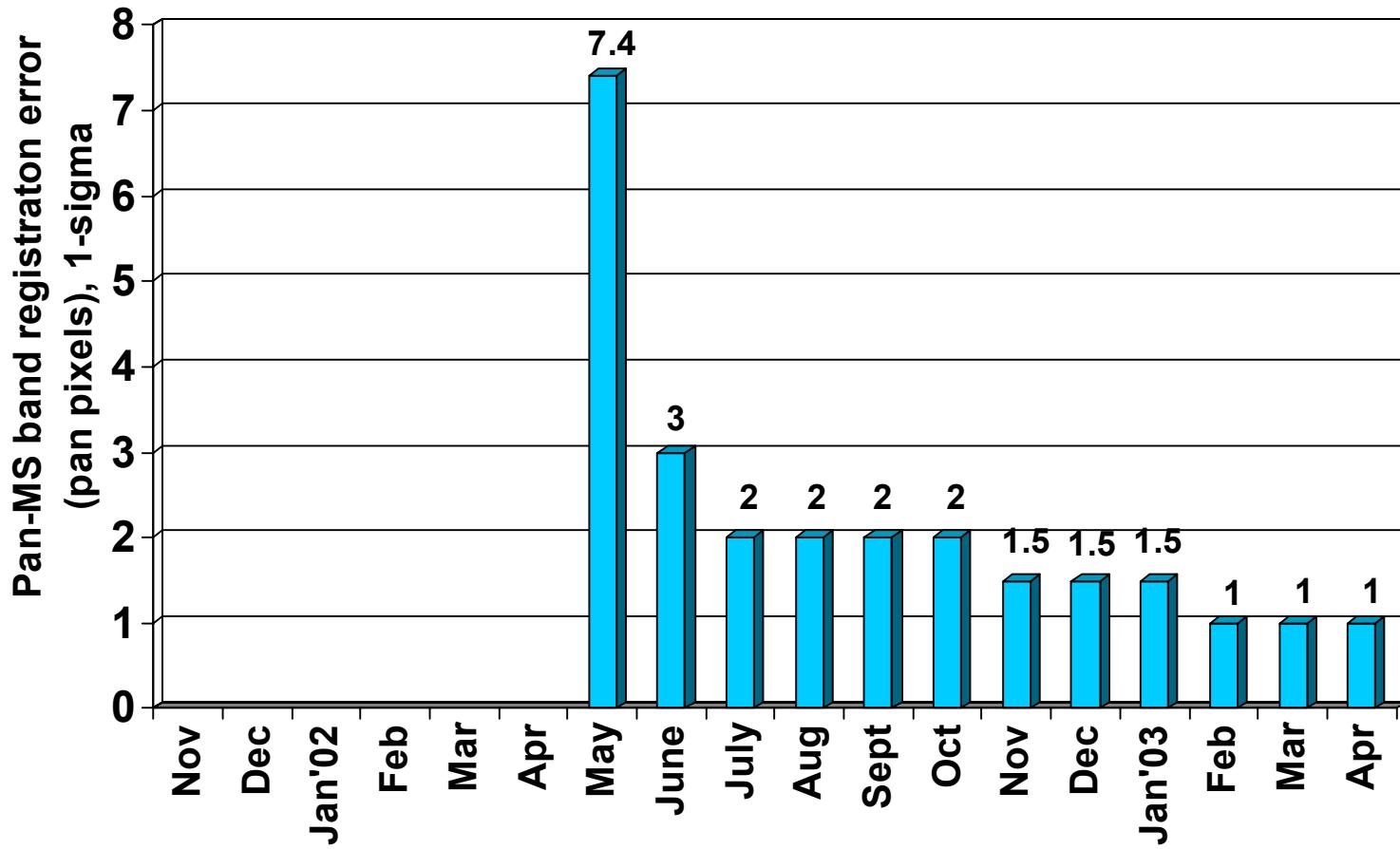


*Small scatter region representative of imaging system.
Large scatter region dominated by content.
Must use multiple images to quantify registration.*

Historical Band Registration Improvement

DIGITALGLOBE™

- Currently Registration is 1 pan-pixel average 1σ – for all imagery.
 - Earlier imagery has been reprocessed to reduce registration error



QuickBird Geopositional Summary



- Absolute Geopositional Accuracy of QuickBird System is currently at specification of 23m CE90, at nadir, excluding terrain
- Third Party Assessments Avg. CE90
 - EarthSat 11.4 m
 - BAE 11.4 m
 - DigitalGlobe 13.6 m
- Primary Efforts : Improve Relative Geolocation
 - Working with NIMA
- Continuing Efforts :
 - Analyzing Attitude Errors (update ADP when significant improvement)
 - Refining Camera Model to reduce relative errors
 - Reduce outliers
- Monitor Performance *Expect More Improvements!*