# First Impressions of CARTOSAT-1

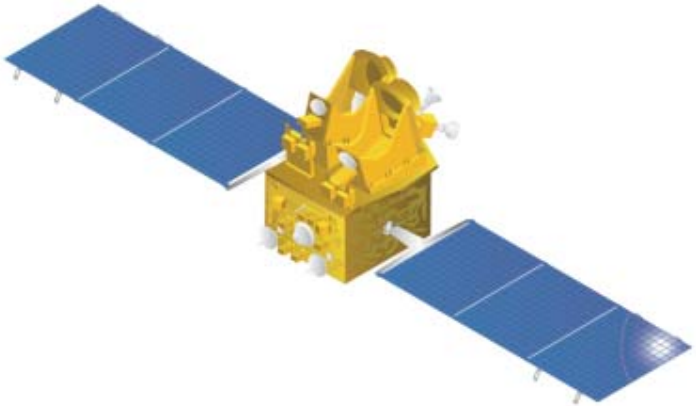
James Lutes

GeoEye

# Presentation Overview

- CARTOSAT-1 Platform Description
- Available Data Products
- Evaluation Procedure Overview
- Evaluation Results

# CARTOSAT-1 Payload Overview



*Launch Date:*

*May 05, 2005*

| | Camera | |
|---|---|---|
| | Fore (+26 deg) | Aft (-5 deg) |
| Spatial Resolution | 2.5 m CT<br>2.8 m AT | 2.2 m CT<br>2.2 m AT |
| Spectral Sensitivity | 500 – 850 nm | 500 – 850 nm |
| Quantization | 10 bits | 10 bits |
| Swath Width | 29 km | 26 km |
| Num detectors | 12000 | 12000 |
| Detector size | 7×7 µm | 7×7 µm |
| Focal length | 1945 mm | 1945 mm |
| Camera FOV | 2.4 deg | 2.4 deg |
| Integration time | 0.336 ms | 0.336 ms |

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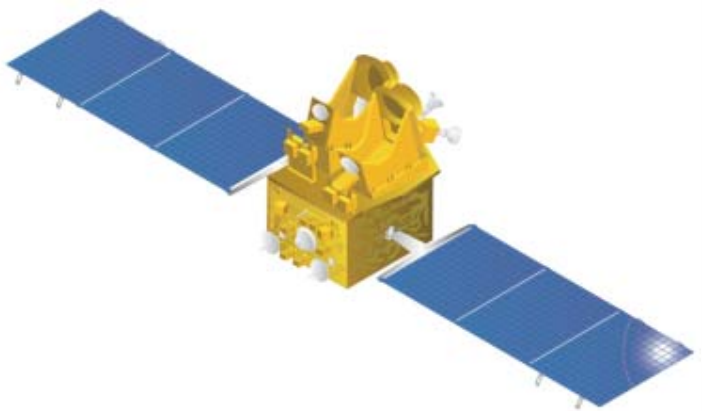
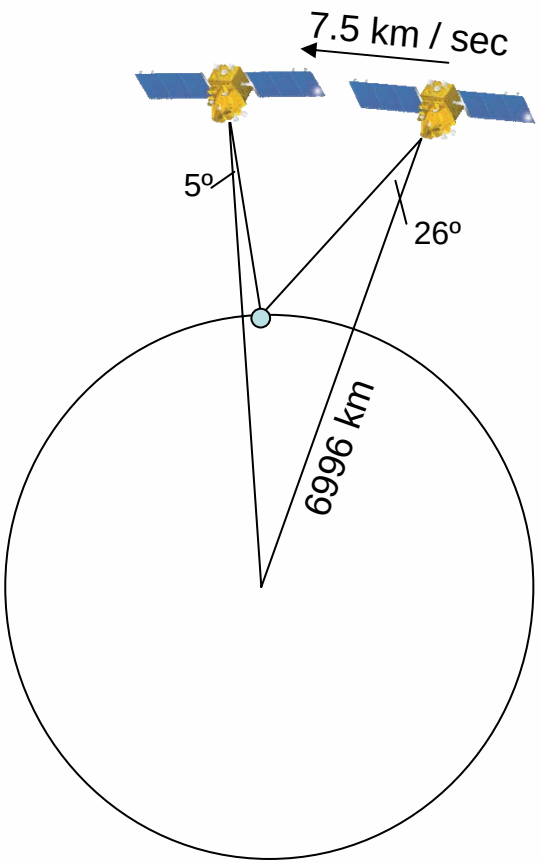
# CARTOSAT-1 Orbit Characteristics



| | |
|---|---|
| Nominal Altitude | 618 km |
| Orbits / day | 14 |
| Orbit Repetition | 126 days |
| Revisit Time | 5 days |
| Equatorial Crossing | 10:30 AM local time |
| Orbital Eccentricity | 0.001 |
| Orbital Inclination | 97.87º |

# CARTOSAT-1 Misc. Notes

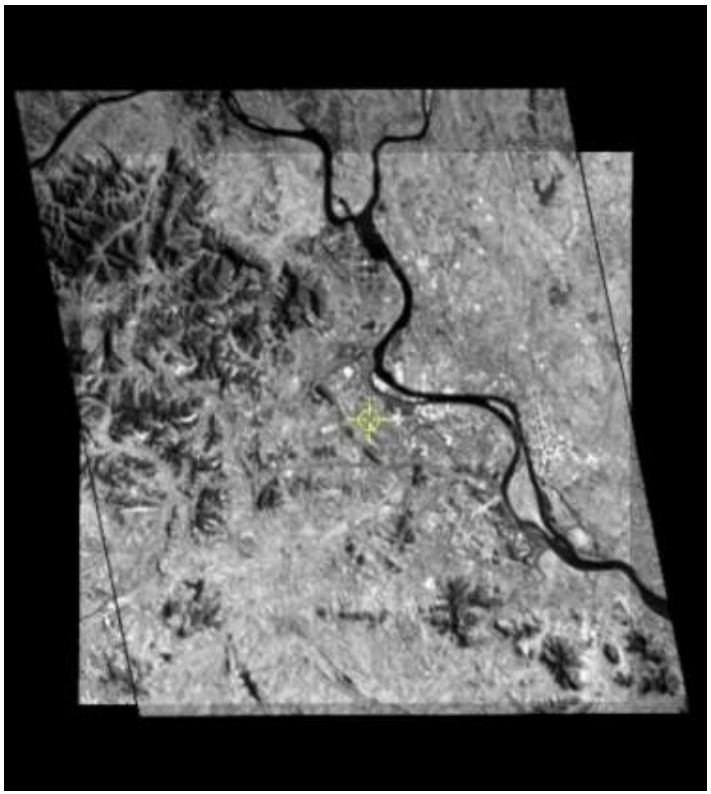



- Stereo B/H ratio: ~0.6
- Time between forward & aft collection: ~53 seconds
- Yaw steering needed to achieve stereo coverage
- Can also collect in ‘mono’ mode with 55 km swath using yaw steering
- 5 day revisit times achieved using cross-track tilt

# CARTOSAT-1 Data Products

- Radiometrically corrected (mono or stereo)
  - LGSOWG format with radiometric corrections only
- Orthokit products (mono or stereo)
  - GeoTIFF + RPC
- Georeferenced (map-projected) products
  - LGSOWG, GeoTIFF, Fast Format

# Source Data for Evaluation



*Typical stereo coverage*

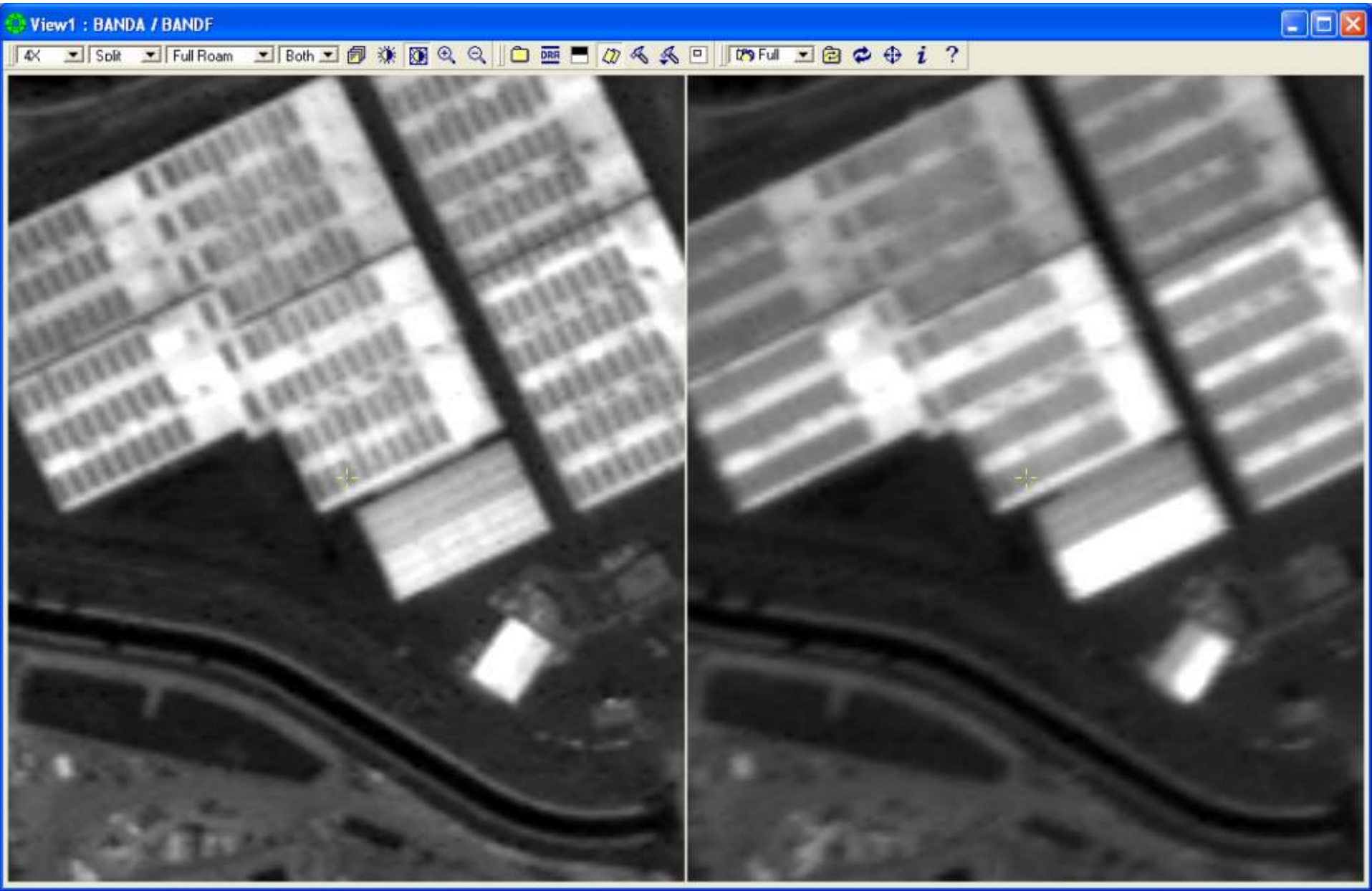
- Six Orthokit (GeoTIFF + RPC) stereo pairs used
- All mostly flat, with some rolling hills
- Collected from June through November 2005

# Image Quality

- Generally:  good for DEM extraction
- BANDF noticeably softer than BANDA (not just because of resolution difference)
- No streaking/banding, no problems with saturation

# Image Quality: Typical Suburban

# BANDA / BANDF Differences



# RPC Quality Checks

- RPC files are encrypted!
  - Software vendors are making arrangements with Antrix to license decryption algorithm
- RPC files appear to be based on product datum (not always WGS84)
  - Solution: re-fit RPCs to WGS84 lon,lat,height grid
- LONG_OFF values not normalized to [-180,180]
  - Problem for SOCET SET 5.1
  - Can be fixed by editing RPC.txt file

# RPC Quality Checks cont'd

- RPCs may have large quadratic + cubic terms
  - Numerically OK, but doesn't reflect imaging geometry
- Some RPCs contain zero crossings in denominator

$$Line = \frac{N_L(\lambda,\phi,h)}{D_L(\lambda,\phi,h)} \cdot S_L + O_L \qquad Sample = \frac{N_S(\lambda,\phi,h)}{D_S(\lambda,\phi,h)} \cdot S_S + O_S$$

  - Causes numerical instability (divide by zero error) in region of the zero crossing
  - Solution: re-fit RPCs to avoid zero crossings
  - Re-fitting required anyway for conversion to WGS84

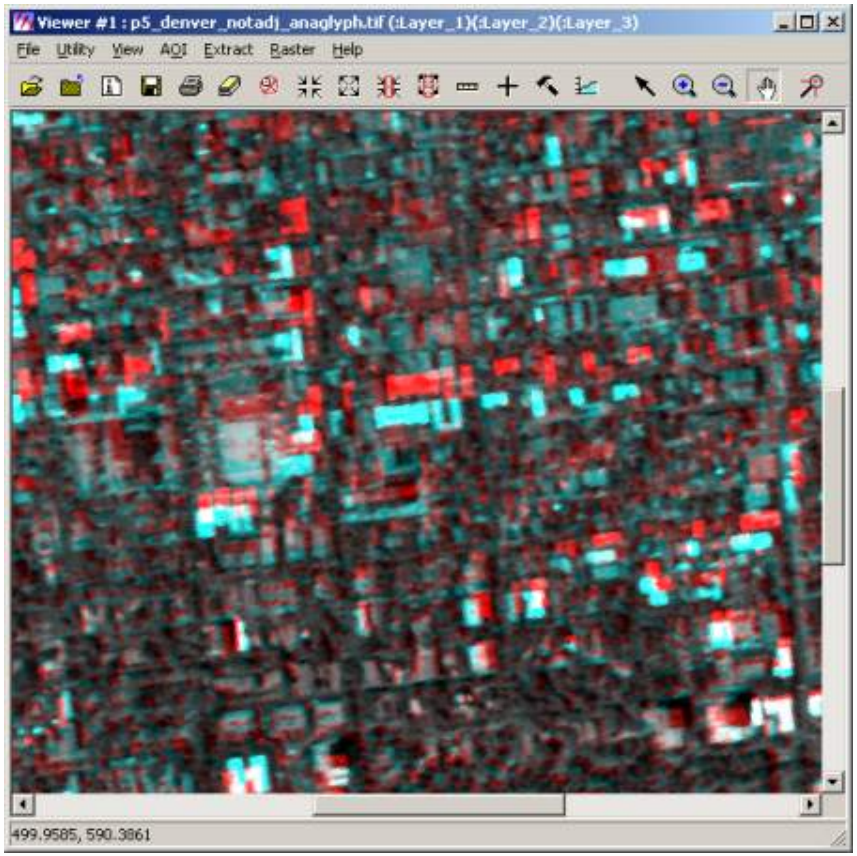
# Accuracy Evaluation Strategy

- Convert RPCs to usable format
- Check relative accuracy of stereo pair
- Build reference block of IKONOS stereo or overlapping mono with good convergence
- Measure dense grid of tiepoints
- Block adjust CARTOSAT to IKONOS
  - IKONOS scenes held fixed in adjustment
  - Different adjustment strategies used for CARTOSAT

# Accuracy Evaluation Strategy cont'd

- Determine tiepoint ground space locations using IKONOS only
- For each CARTOSAT adjustment strategy:
  - Determine tiepoint ground space locations using CARTOSAT-1 only
  - Compute statistics & examine trends in positional differences

# Relative Accuracy Assessment




- Significant Y-parallax encountered
  - 5 to 58 pixels
- Scenes not tied together prior to product generation

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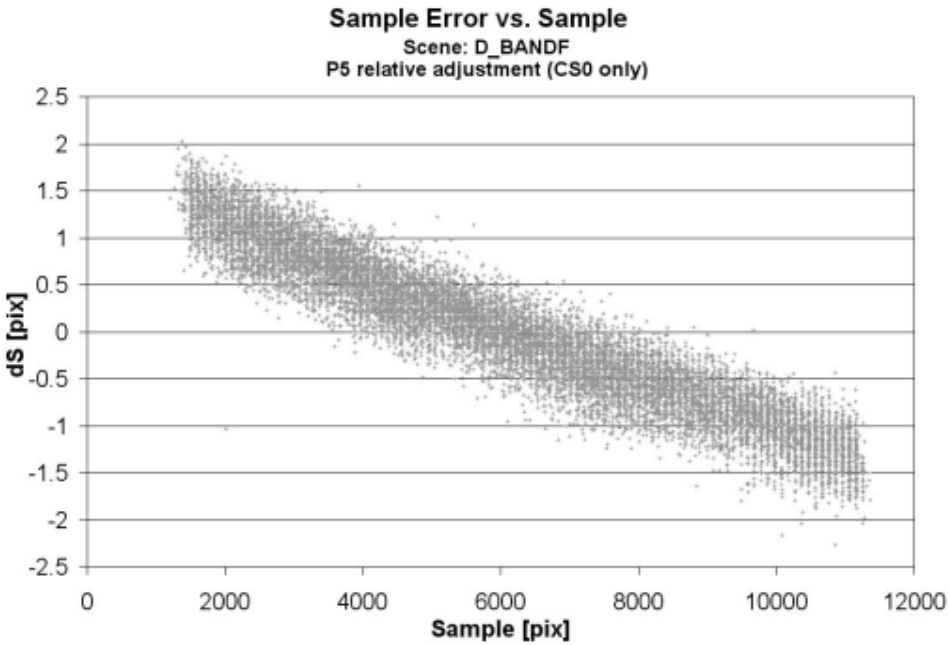
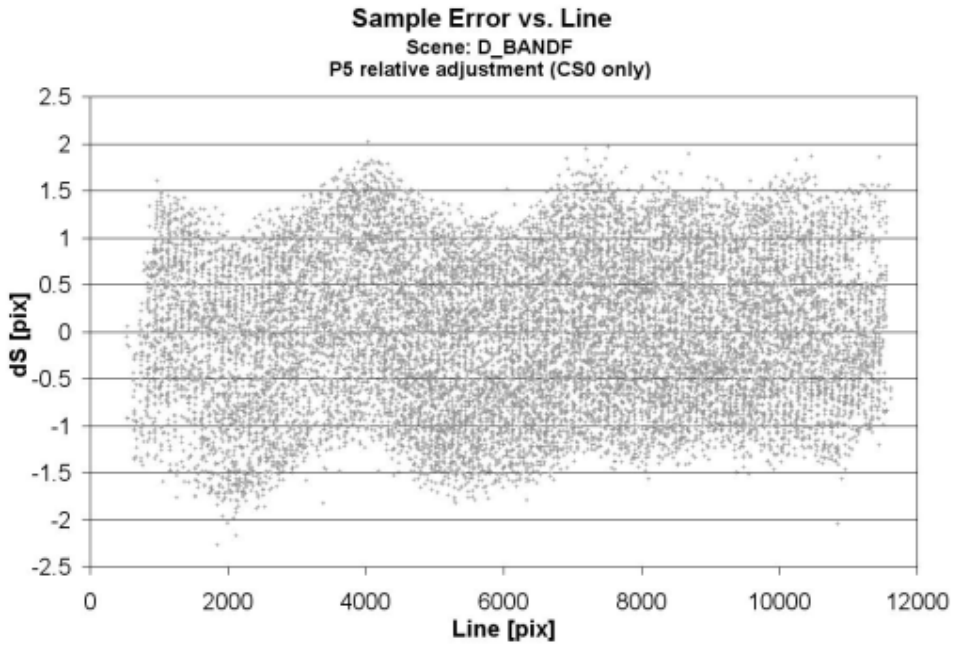
# Relative Correction (Offset Only)




- Noticeable scale difference between BANDA + BANDF (+/- 1.5 pixel)
- Small attitude wobble visible in sample error vs. line

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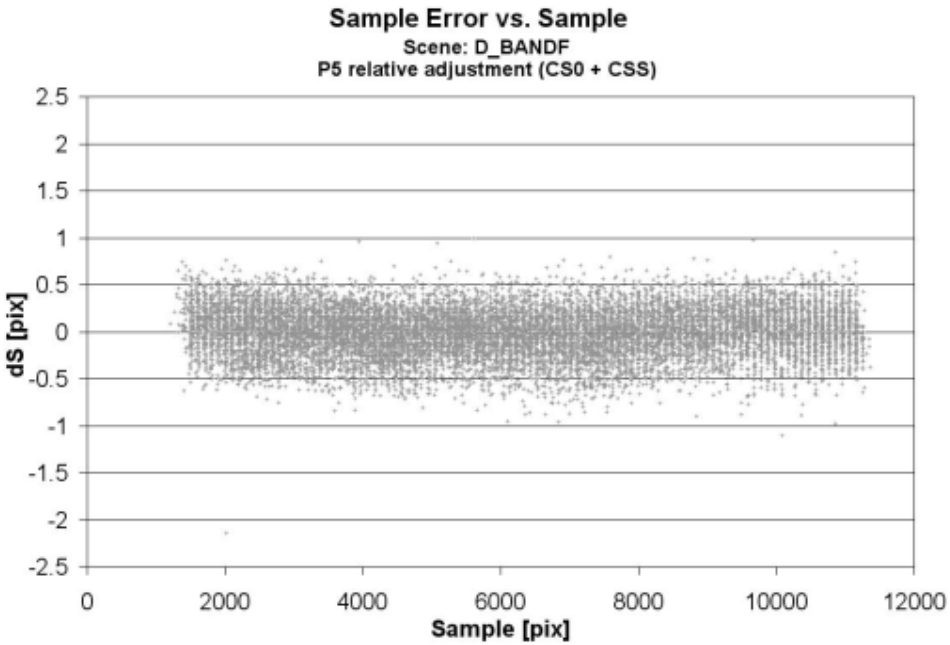
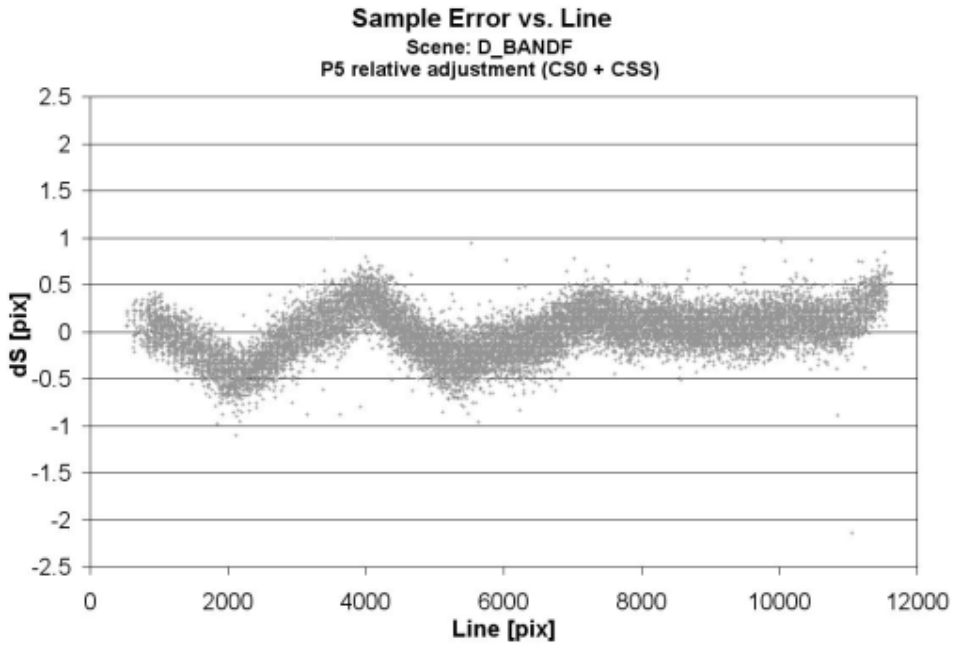
# Relative Correction (Offset + Scale)




- ***Relative*** scale difference between BANDA + BANDF has been removed
- Corrected scenes can be viewed in stereo with no y-parallax

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# Absolute Accuracy Assessment

- Three scenarios presented:
  - Relative adjustment but otherwise uncontrolled
  - Relative adjustment followed by offset-only adjustment to IKONOS block
  - Full 6-parameter adjustment to IKONOS block

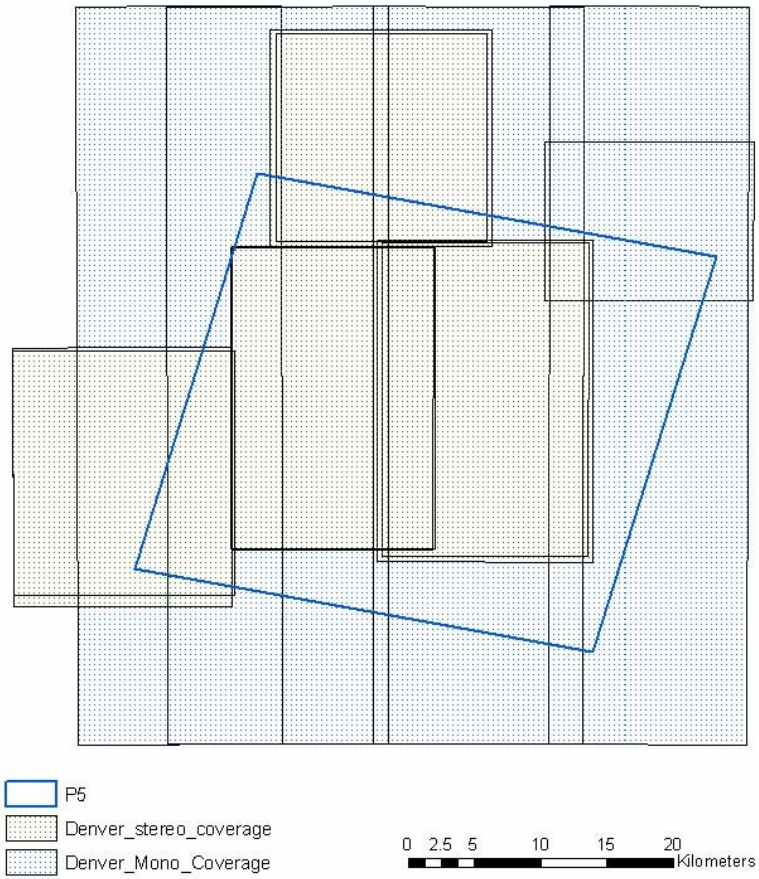
# Uncontrolled Accuracy Checks

- CARTOSAT-IKONOS, IKONOS-IKONOS and CARTOSAT-CARTOSAT tiepoints measured
  - Number of tiepoints obtained varied from 4500 to 31500 depending on scene content
- IKONOS-only block created
  - Scenes held fixed, ground coords of tiepoints computed
  - CARTOSAT data not included at this step

# Uncontrolled Accuracy Checks cont'd

- CARTOSAT-only block created
  - Adjustment terms from relative adjustment applied
  - Scenes held fixed with these adjustment terms, ground coords of tiepoints computed
- Ground coordinates compared between blocks
  - Only tiepoints observed in at least 4 images are common to the 2 blocks!
  - Only points with good IKONOS stereo geometry were utilized (check std. dev. of estimated height)

# Typical Block Layout




- As much IKONOS stereo as possible
- Rest of block: IKONOS mono with good convergence angles
- ~10 IKONOS scenes per block

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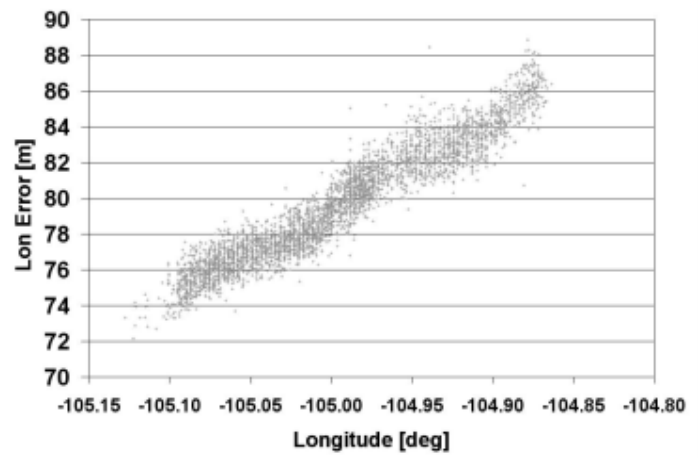
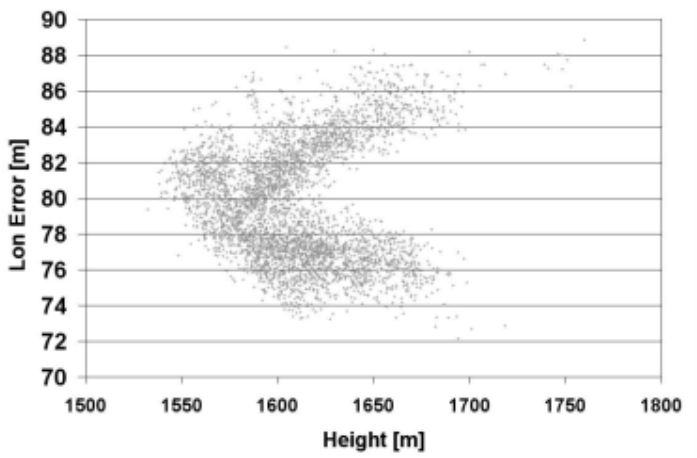
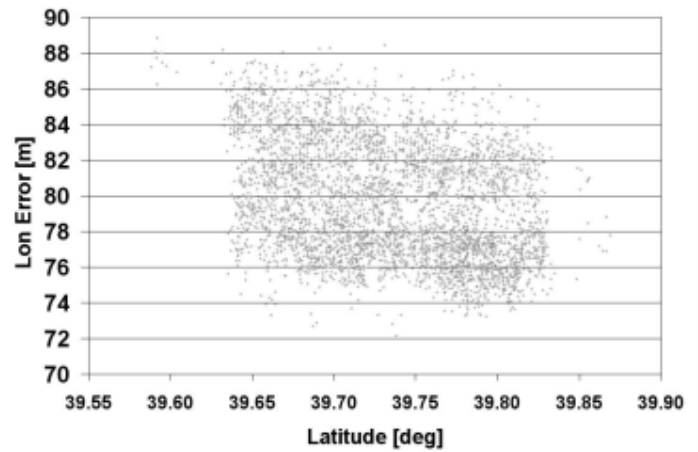
# Uncontrolled Scenes

## Longitude Errors




- Bias and cross-track scale error present
- Slight drift with latitude (i.e., time)

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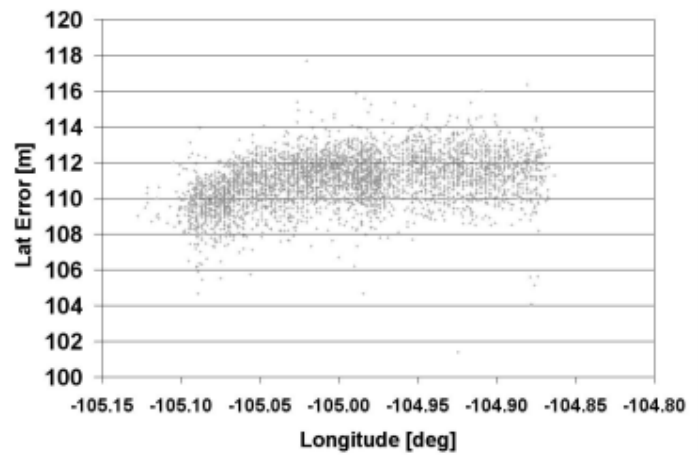
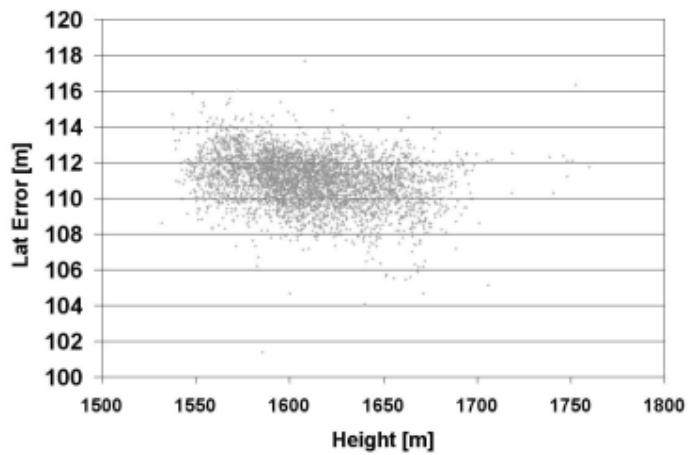
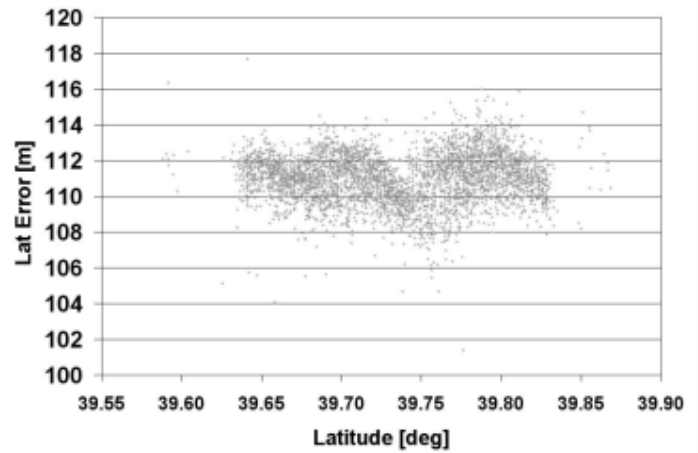
# Uncontrolled Scenes

## Latitude Errors




- Slight trend in latitude vs. height caused by overall height bias

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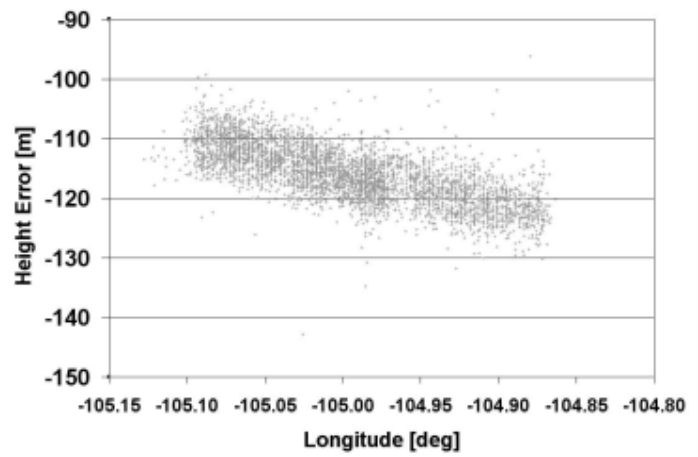
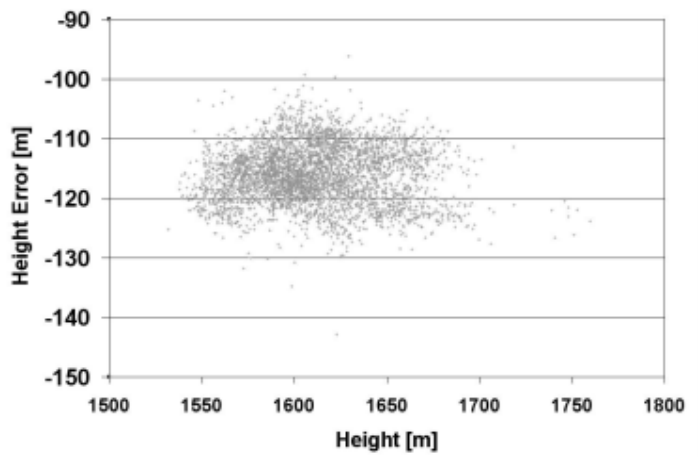
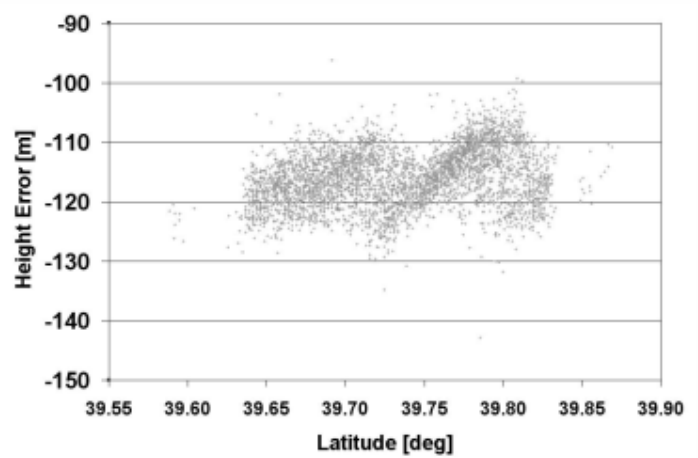
# Uncontrolled Scenes

## Height Errors




- Large vertical biases observed
- Cross-track tilt in height

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# Uncontrolled Accuracy - Summary

| Scene | Avg. dLon [m] | Avg. dLat [m] | Avg. dHt [m] | Std. dLon [m] | Std. dLat [m] | Std. dHt [m] | CE90 Hz [m] | LE90 V [m] |
|---|---|---|---|---|---|---|---|---|
| **J** | 156.7 | 360.7 | 15.7 | 3.7 | 1.8 | 8.2 | **393.3** | **20.7** |
| **D** | 79.7 | 111.0 | -116.0 | 3.2 | 1.3 | 4.7 | **136.8** | **116.2** |
| **R** | 10.2 | 114.6 | -50.6 | 3.7 | 1.4 | 5.4 | **115.2** | **51.4** |
| **A** | -66.6 | 61.3 | -139.7 | 3.2 | 1.8 | 4.5 | **90.7** | **139.9** |
| **P** | -206.1 | 268.9 | -168.8 | 3.2 | 2.4 | 4.3 | **338.8** | **168.9** |
| **C** | -66.9 | 353.9 | -98.9 | 1.6 | 1.5 | 6.4 | **360.2** | **99.5** |

- Large positional biases
- Cross-track scale bias
- Possible yaw errors + drift error
- High-frequency errors relatively small

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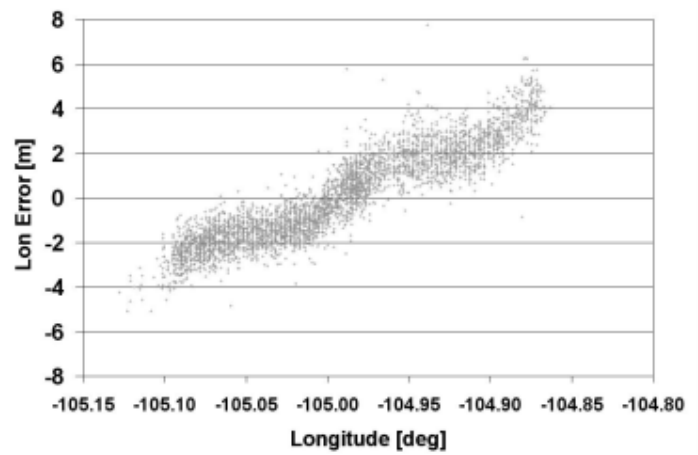
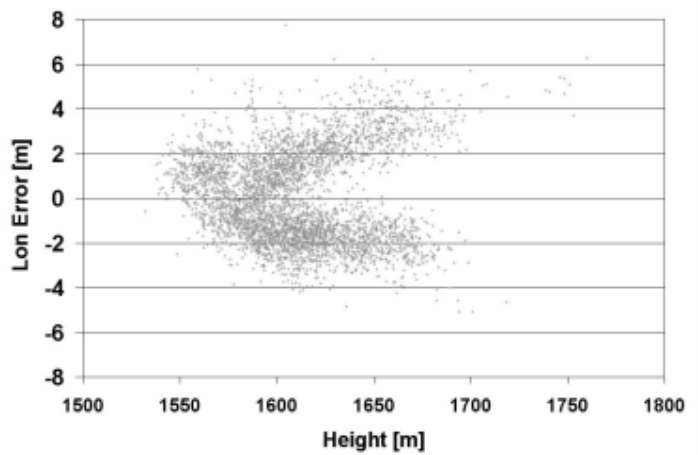
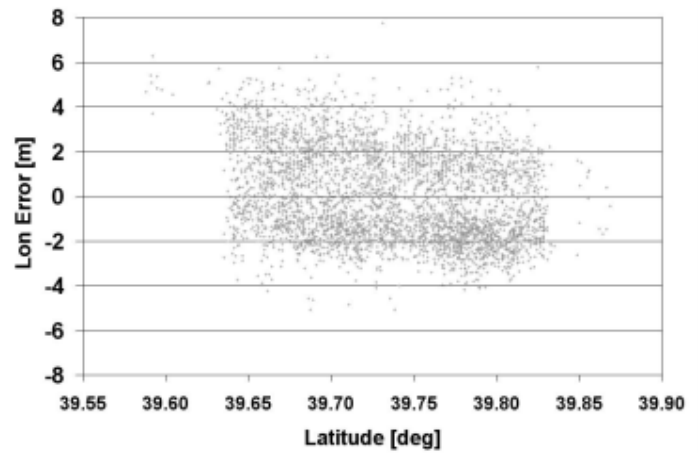
# Relative adjustment + offset correction

## Longitude Errors




- Biases brought to zero mean
- Same general trends

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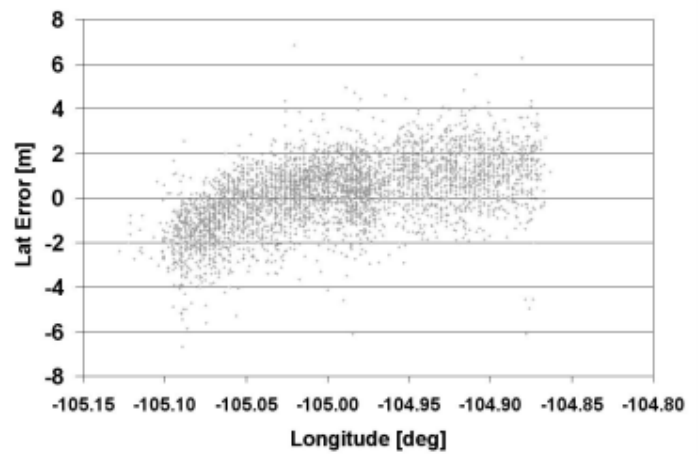
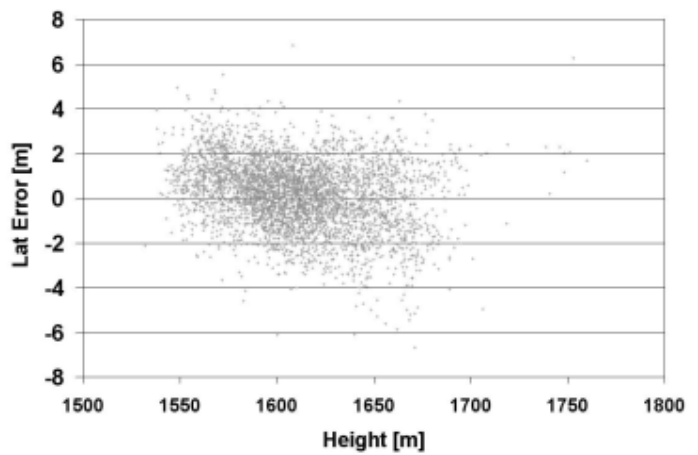
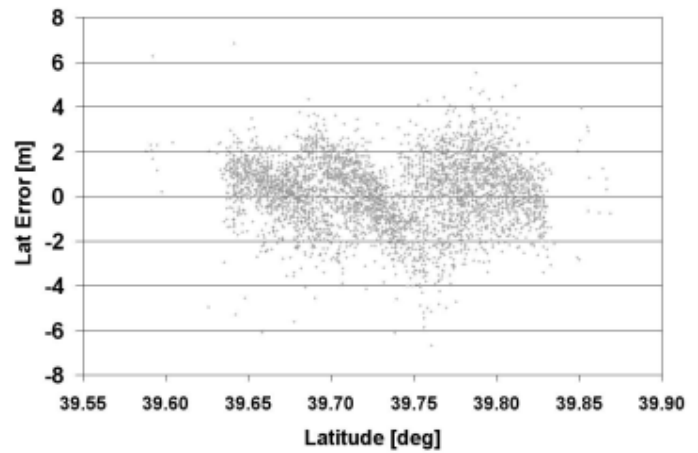
# Relative adjustment + offset correction

## Latitude Errors

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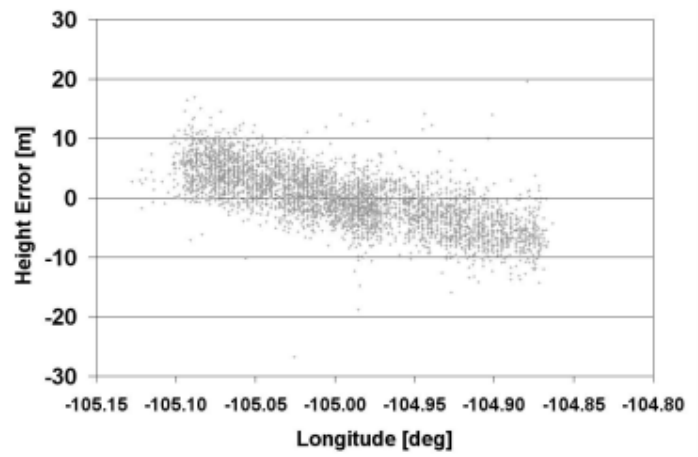
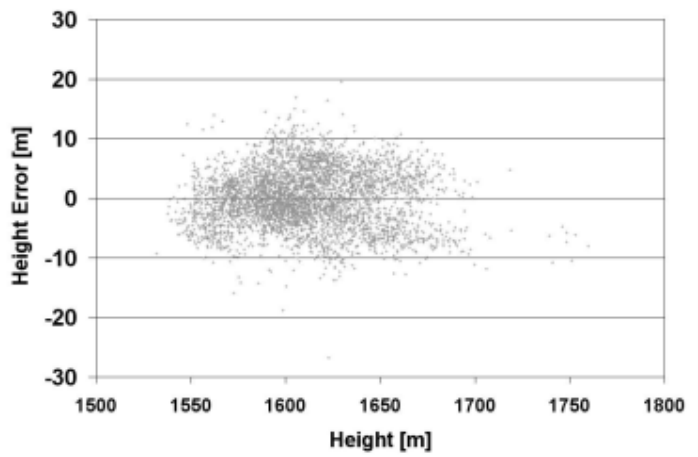
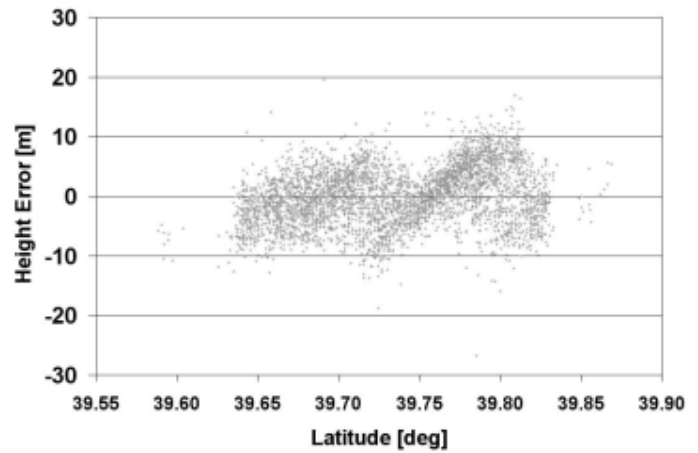
# Relative adjustment + offset correction

## Height Errors

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# Offset Correction - Summary

| Scene | Avg. dLon [m] | Avg. dLat [m] | Avg. dHt [m] | Std. dLon [m] | Std. dLat [m] | Std. dHt [m] | CE90 Hz [m] | LE90 V [m] |
|---|---|---|---|---|---|---|---|---|
| **J** | 0.49 | 0.18 | -0.88 | 3.95 | 1.74 | 8.26 | **6.57** | **13.62** |
| **D** | 0.04 | 0.19 | 0.03 | 2.00 | 1.49 | 4.75 | **3.79** | **7.82** |
| **R** | 0.84 | 0.47 | 0.50 | 3.39 | 1.40 | 5.42 | **5.65** | **8.93** |
| **A** | -0.01 | 0.47 | 2.58 | 2.34 | 1.81 | 4.55 | **4.51** | **7.91** |
| **P** | 0.45 | 0.05 | 0.31 | 2.00 | 2.45 | 3.80 | **4.83** | **6.26** |
| **C** | 0.60 | -0.41 | 1.49 | 1.37 | 1.66 | 6.32 | **3.35** | **10.50** |

- Biases brought to zero by offset parameters
- Trends still remain
- Representative of areas with little ground control

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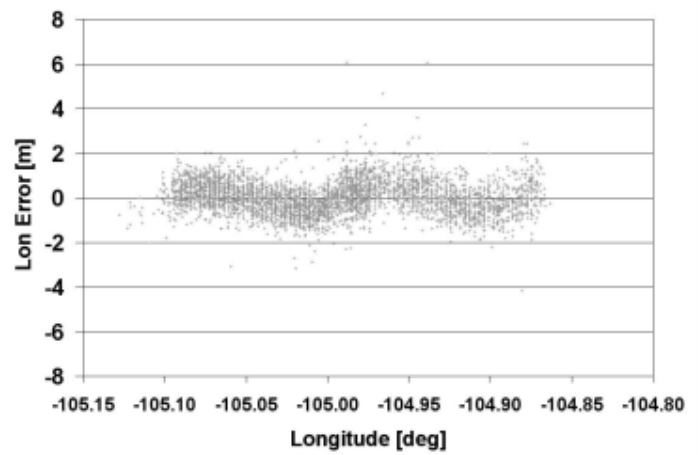
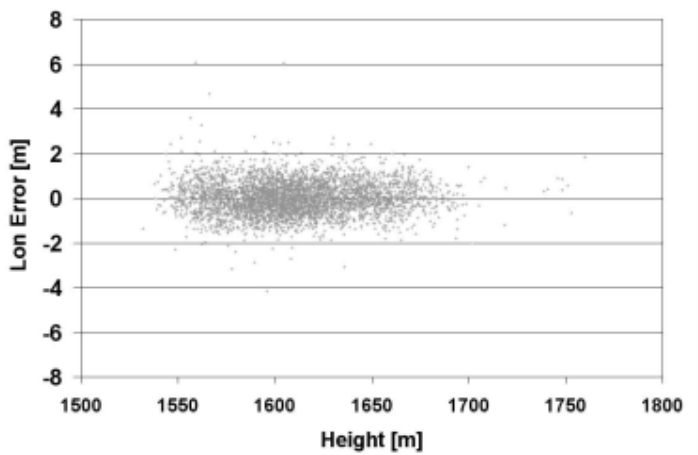
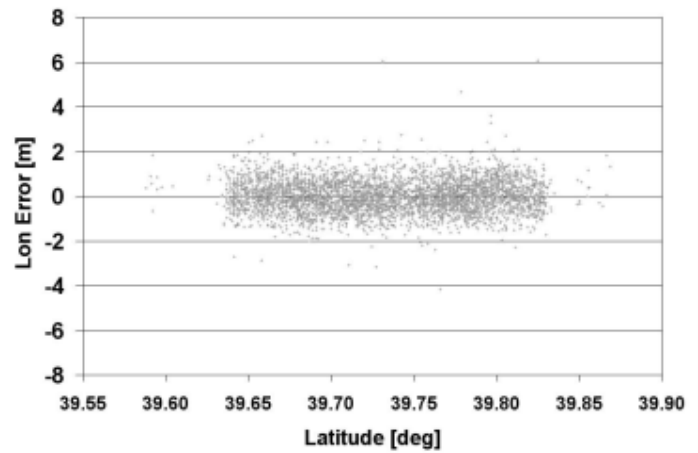
# Affine correction

## Longitude Errors




- All linear trends removed
- High accuracy (w.r.t. ground control) after correction

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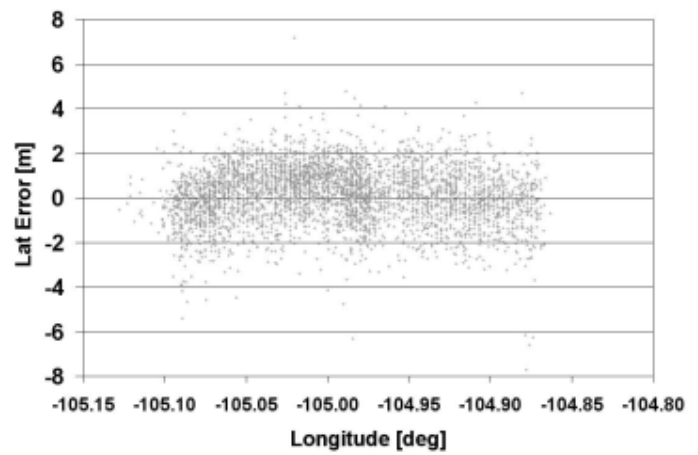
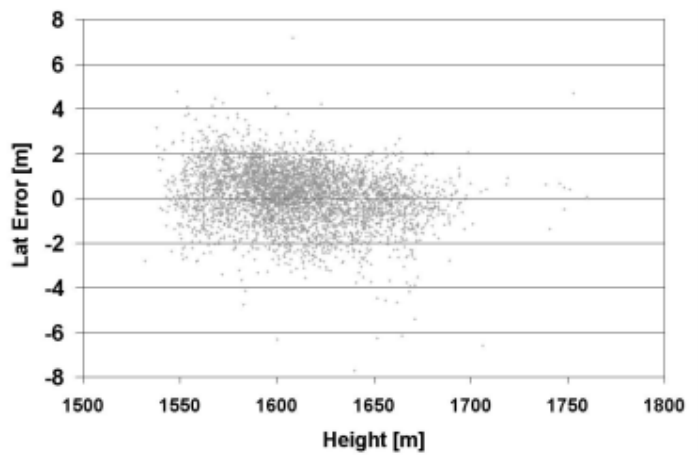
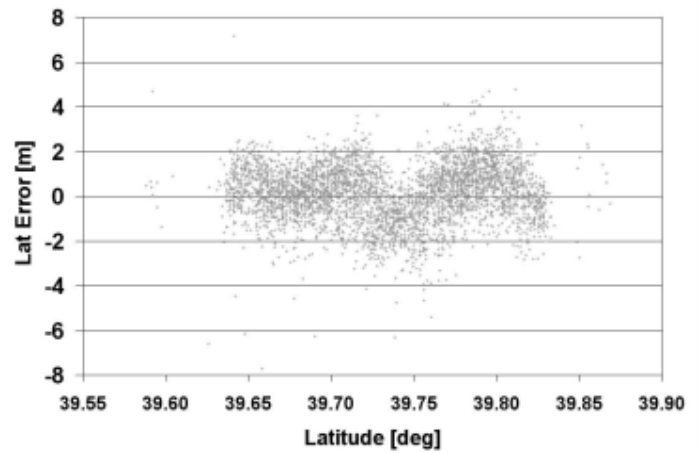
# Affine correction

## Latitude Errors

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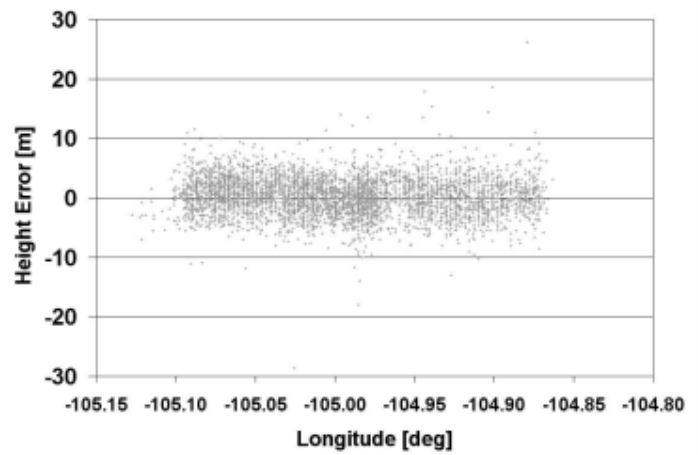
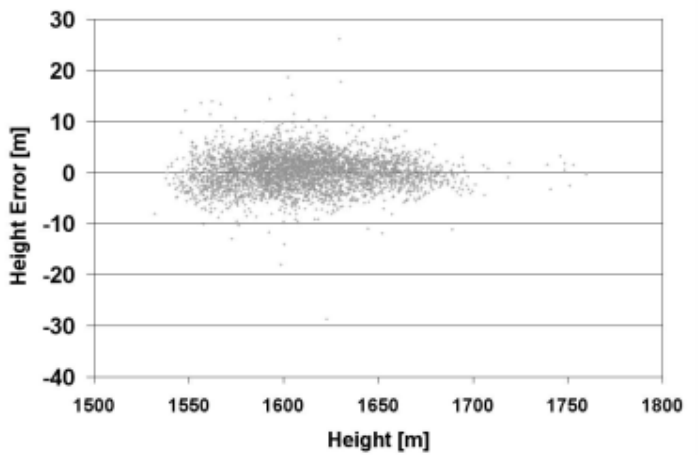
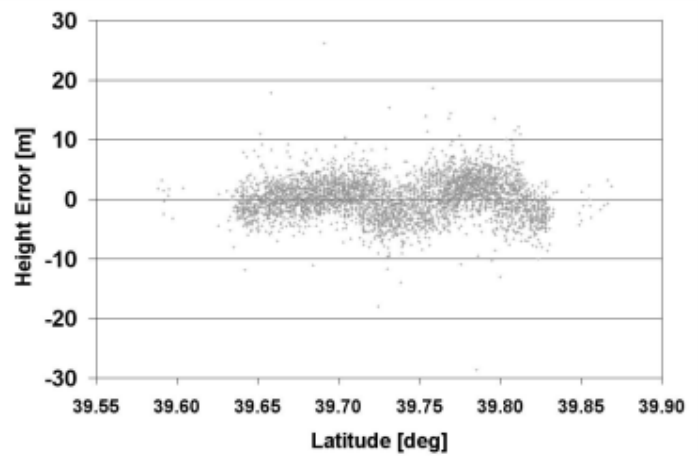
# Affine correction

## Height Errors




- Note: ‘reference’ heights come from tiepoints measured in IKONOS scenes
- Results would be better with surveyed ground control

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# Affine Correction - Summary

| Scene | Avg. dLon [m] | Avg. dLat [m] | Avg. dHt [m] | Std. dLon [m] | Std. dLat [m] | Std. dHt [m] | CE90 Hz [m] | LE90 V [m] |
|---|---|---|---|---|---|---|---|---|
| **J** | 0.04 | -0.01 | -0.25 | -0.85 | 1.14 | 4.92 | **2.16** | **8.10** |
| **D** | 0.01 | 0.14 | 0.27 | 0.73 | 1.24 | 3.18 | **2.19** | **5.24** |
| **R** | 0.30 | 0.01 | -0.45 | 1.59 | 1.21 | 4.27 | **3.05** | **7.03** |
| **A** | 0.07 | 0.27 | 0.78 | 1.10 | 1.58 | 3.97 | **2.93** | **6.57** |
| **P** | -0.14 | -0.02 | 0.01 | 1.94 | 1.76 | 3.19 | **3.97** | **5.26** |
| **C** | 0.23 | -0.06 | 1.27 | 1.34 | 1.36 | 6.20 | **2.91** | **10.28** |

- All biases and linear trends removed
- Good horizontal accuracy (~1.5 pixel CE90)
- Vertical accuracy estimate worsened by IKONOS viewing geometry
- Representative of areas with good ground control

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# Overall accuracy summary

| Scene | Uncontrolled | | Relative corr + offset terms | | Affine correction | |
|---|---|---|---|---|---|---|
| | CE90 Hz [m] | LE90 V [m] | CE90 Hz [m] | LE90 V [m] | CE90 Hz [m] | LE90 V [m] |
| J | 393.3 | 20.7 | 6.57 | 13.62 | 2.16 | 8.10 |
| D | 136.8 | 116.2 | 3.79 | 7.82 | 2.19 | 5.24 |
| R | 115.2 | 51.4 | 5.65 | 8.93 | 3.05 | 7.03 |
| A | 90.7 | 139.9 | 4.51 | 7.91 | 2.93 | 6.57 |
| P | 338.8 | 168.9 | 4.83 | 6.26 | 3.97 | 5.26 |
| C | 360.2 | 99.5 | 3.35 | 10.50 | 2.91 | 10.28 |
| Total | 100-400 m CE90 | | 3-7 m CE90 | | 2-4 m CE90 | |
| | 20-170 m LE90 | | 6-13 m LE90 | | 5-10 m LE90 | |

GeoEye

# Conclusions

- CARTOSAT-1 RPCs need special handling
- Absolute accuracy of uncontrolled scenes is poor (biases > 300 m)
- Noticeable cross-track scale error
  - +/- 3-4 m across stereo pair
- Most errors are either biases or linear in line/sample
  - These are easy to correct with ground control

# Conclusions cont'd

- For low ground control availability, use relative adjustment and offset-only correction:
  - 3-7 m CE90 Horizontal
  - 6-13 m LE90 Vertical
- For better ground control availability (e.g., 6 GCPs), use affine transformation:
  - 2-4 m CE90 Horizontal
  - 5-10 m LE90 Vertical


Denver, CO
2005-Jun-18


Riyadh suburb
2005-Jun-16


Abu Dhabi
2005-Nov-09