On-Orbit Geolocation Accuracy and Image Quality Performance of the GeoEye-1 High Resolution Imaging Satellite

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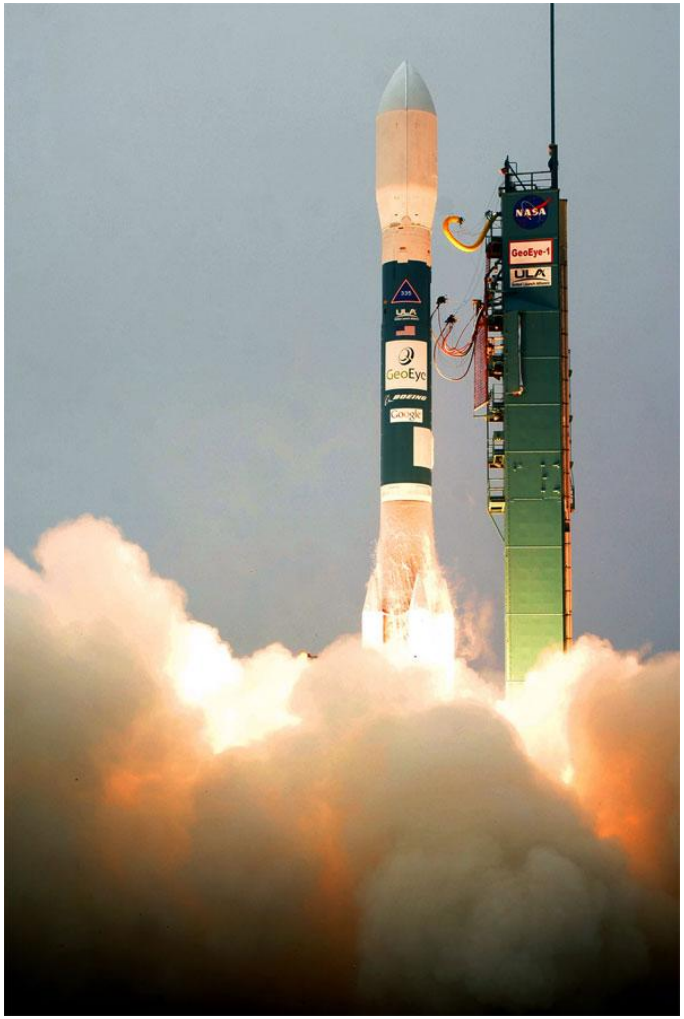
JACIE 2010
Fairfax, VA


High definition image available at
www.GeoEye.com
Fairfax, VA
GeoEye-1 Image Acquired Oct. 21, 2009

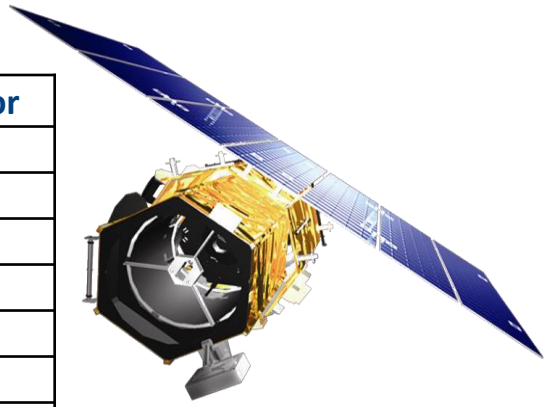
GeoEye-1 Orbit Characteristics



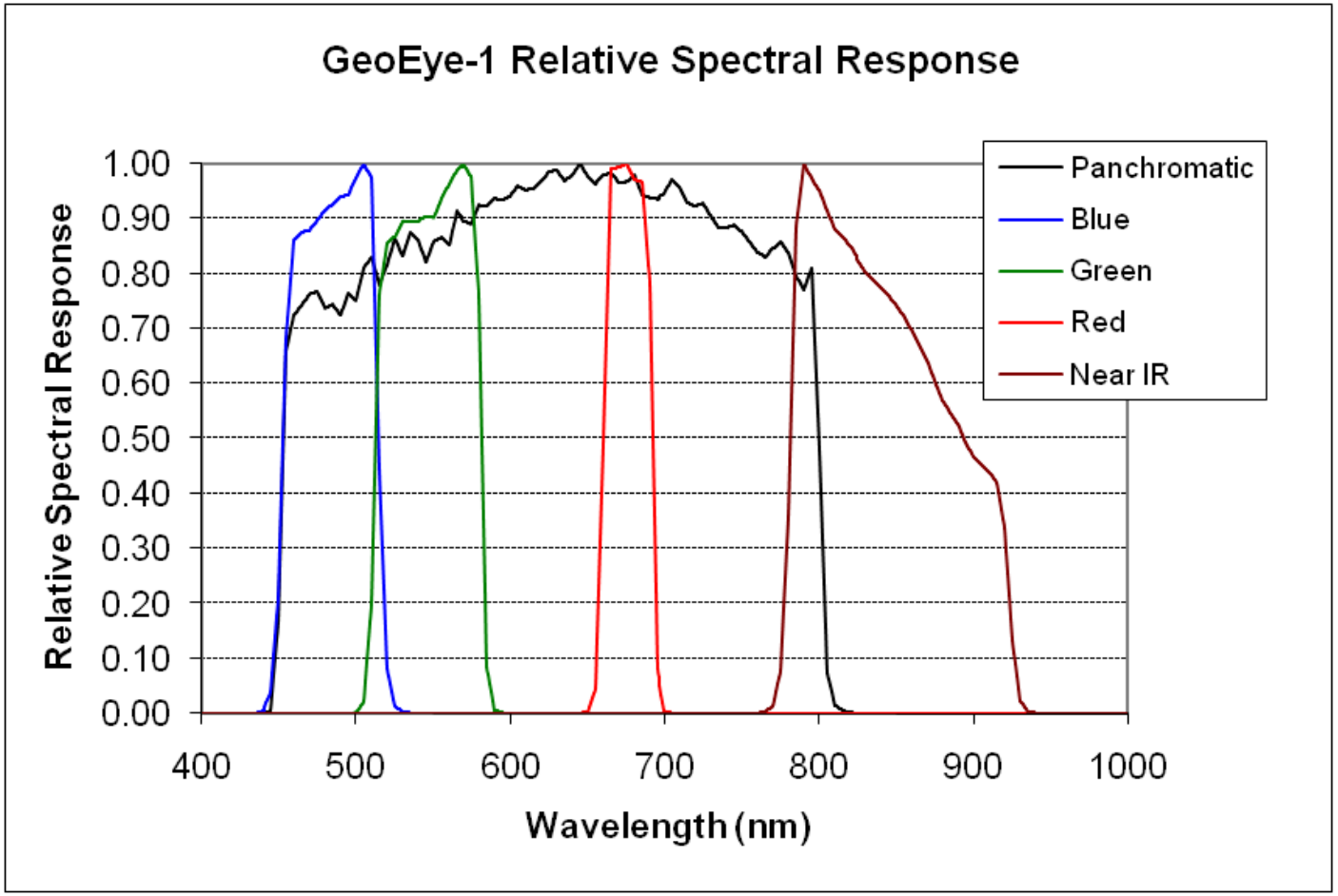
Launch Date	**September 6, 2008**
Orbit Type	**Sun Synchronous**
Altitude	**681 km**
Inclination Angle	**98^{o}**
Descending Node	**10:30am**
Revisit Period	**3 days**

GeoEye-1 Sensor Characteristics

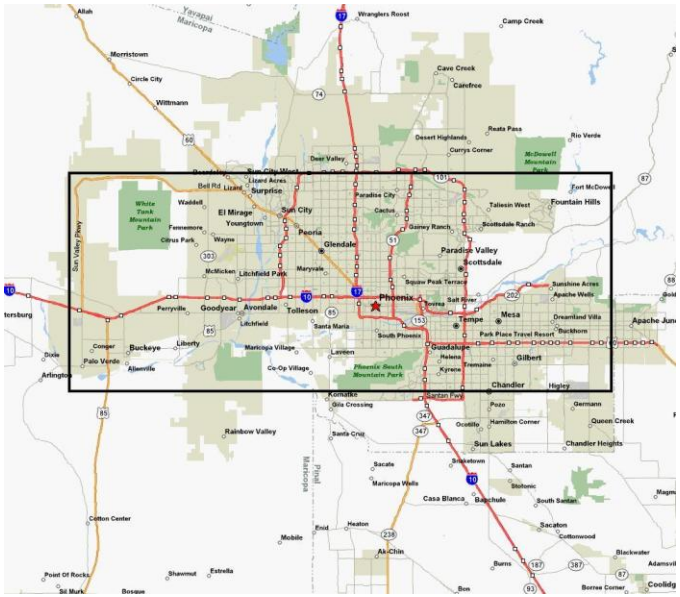
Imaging Feature	Panchromatic Sensor	Multispectral Sensor
Ground Sample Distance (nadir)	0.41m	1.65m
Array Type	Linear 64 stage TDI	Linear 24 stage TDI
Directionality	Bi-directional	Uni-directional
Spectral Range	450 – 800 nm	Blue: 450 – 510 nm
		Green: 510 – 580 nm
		Red: 655 – 690 nm
		Near IR: 780 – 920 nm
Pixel Size	8 μm	32 μm
Stages of TDI	8, 16, 32, 48, 64	3, 6, 10, 14, 18, 21, 24
Pixel Aggregation	1x1, 2x2	1x1, 2x2
Imaging Pixels	37,544	9386
Line Rates	20,000 and 10,000 lines / sec	2,500 lines / sec
Quantization Level	11 bits per pixel	11 bits per pixel per channel
On-board Compression	Visually lossless at 2.5 bpp	Visually lossless at 2.5 bpp per channel

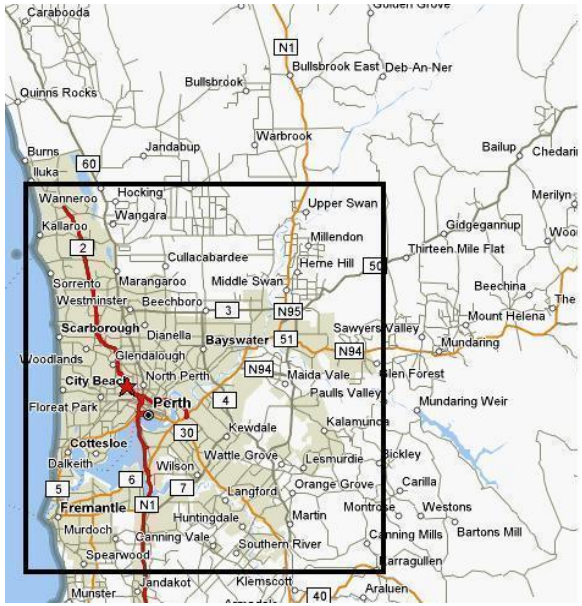


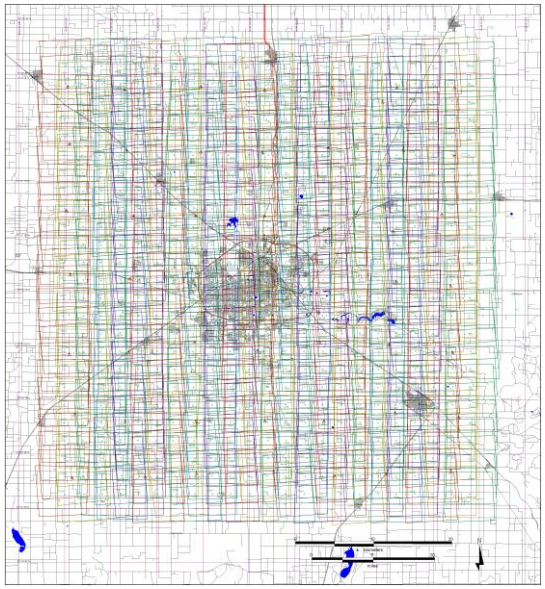
Spectral Response



Geometric Calibration Ranges







Phoenix, AZ

Primary Calibration Range
Primary Characterization Range
115km x 50km extent
1:12,000 aerial photography
98 Geodetic Control Points
0.12m nominal GSD

Perth, Australia

Primary Calibration Range
Secondary Characterization Range
50km x 50km extent
1:15,000 aerial photography
49 Geodetic Control Points
0.25m nominal GSD

Lubbock, TX

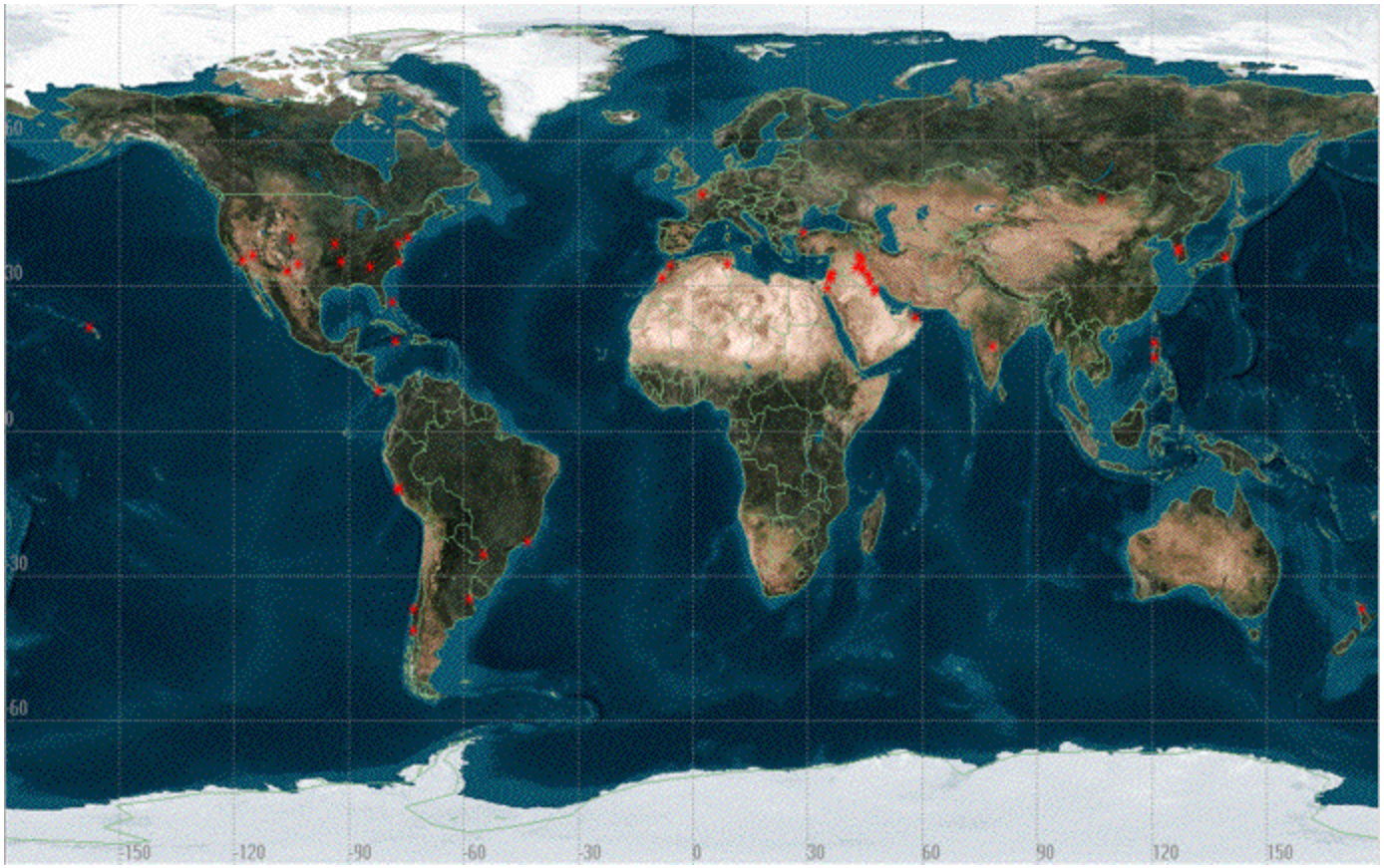
Secondary Calibration Range
50km x 50km extent
1:25,000 aerial photography
48 Geodetic Control Points
0.38m nominal GSD

GeoEye

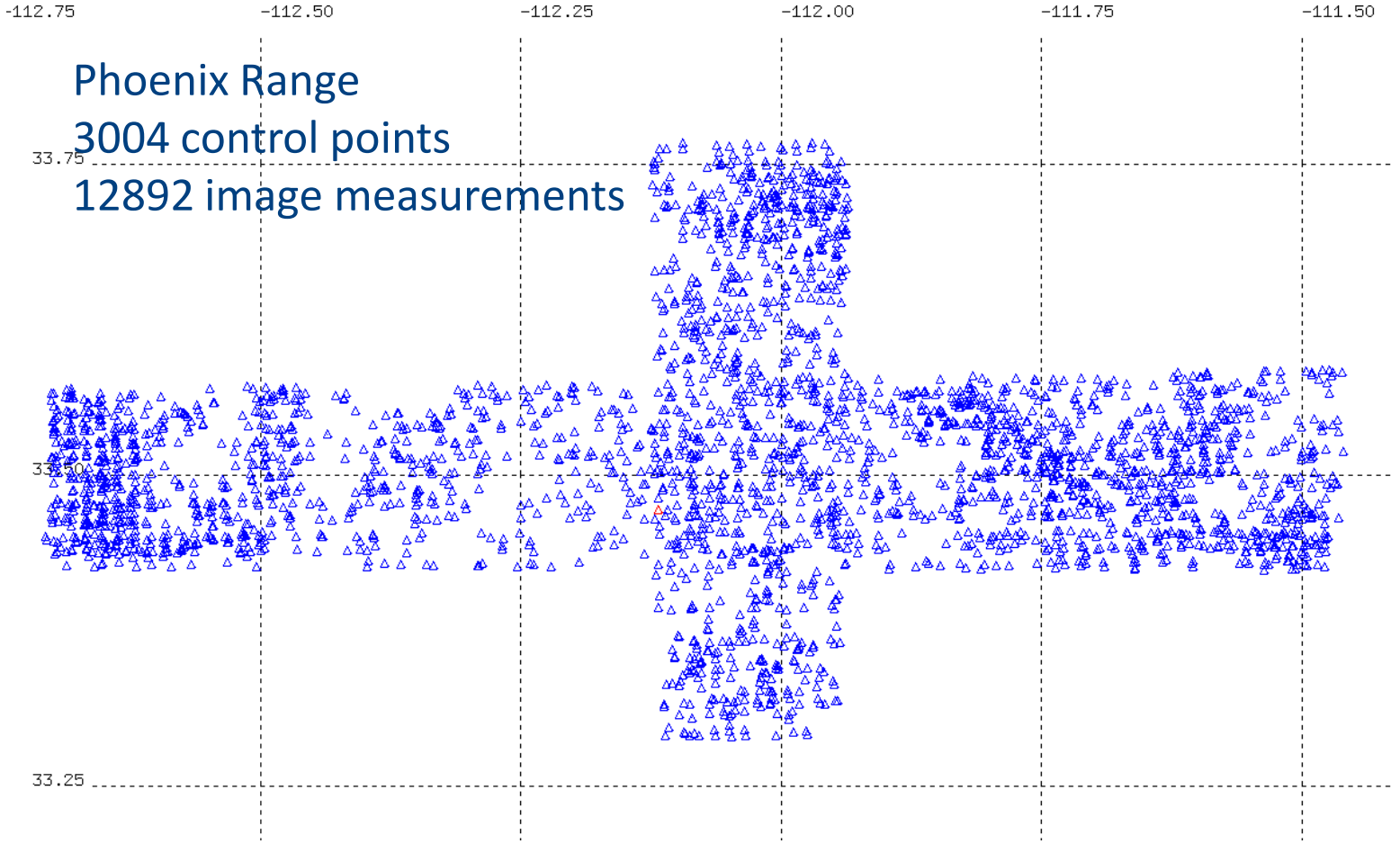
JACIE Conference 2010

Geometric Test & Evaluation Sites

- World wide distribution of T&E sites

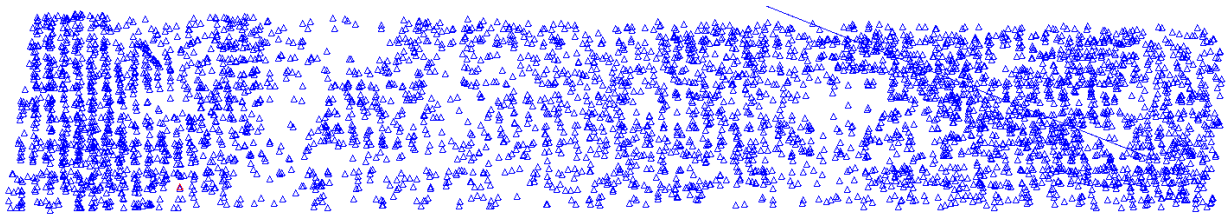


Control Point Generation for Field Angle Map 2009 Jan

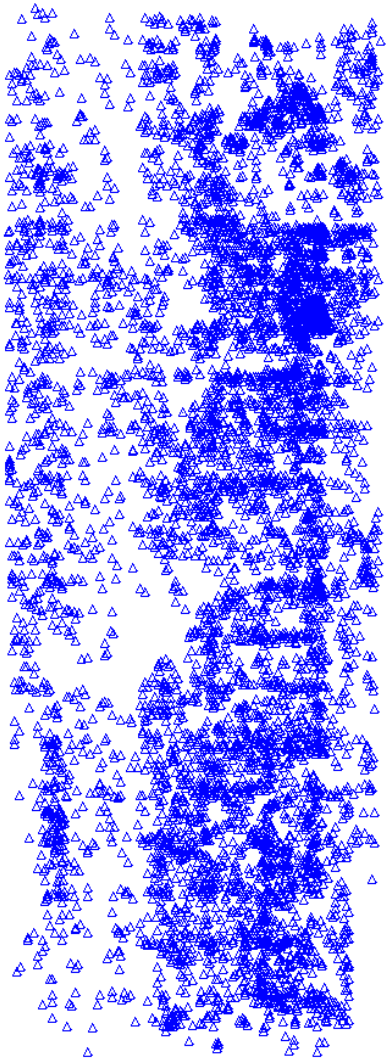


Control Point Generation for Field Angle Map 2009 March

11533 control points
47030 image measurements



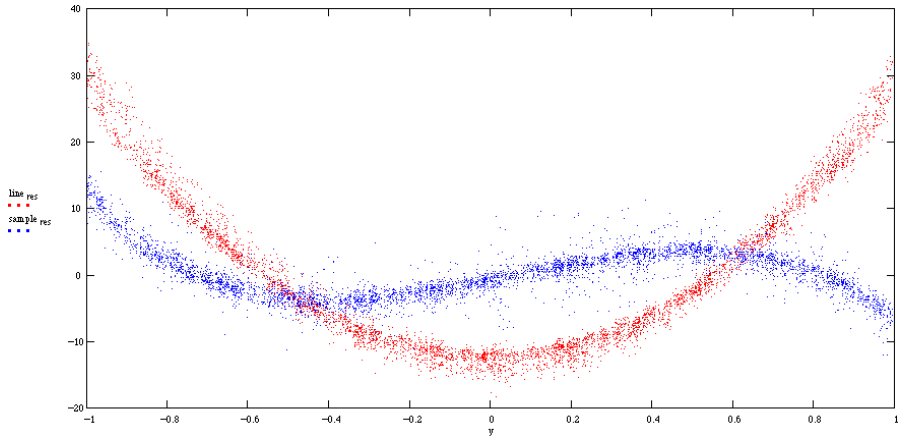
Phoenix Range



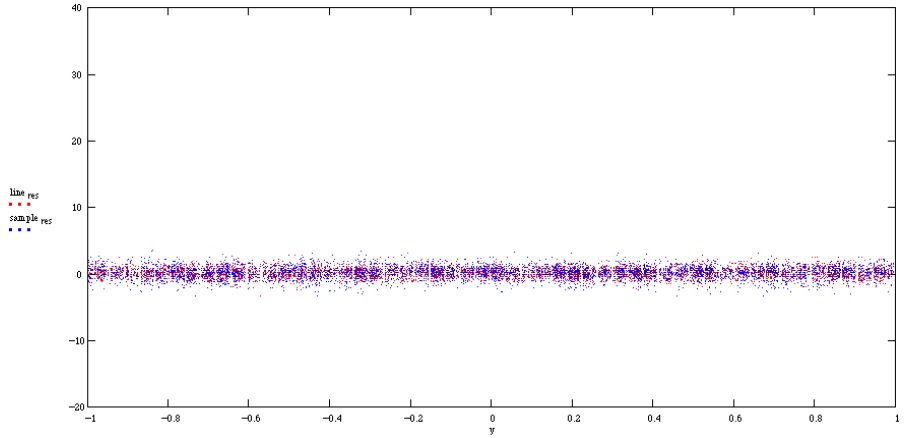
Perth Range

Field Angle Map Calibration

- Image residuals before calibration

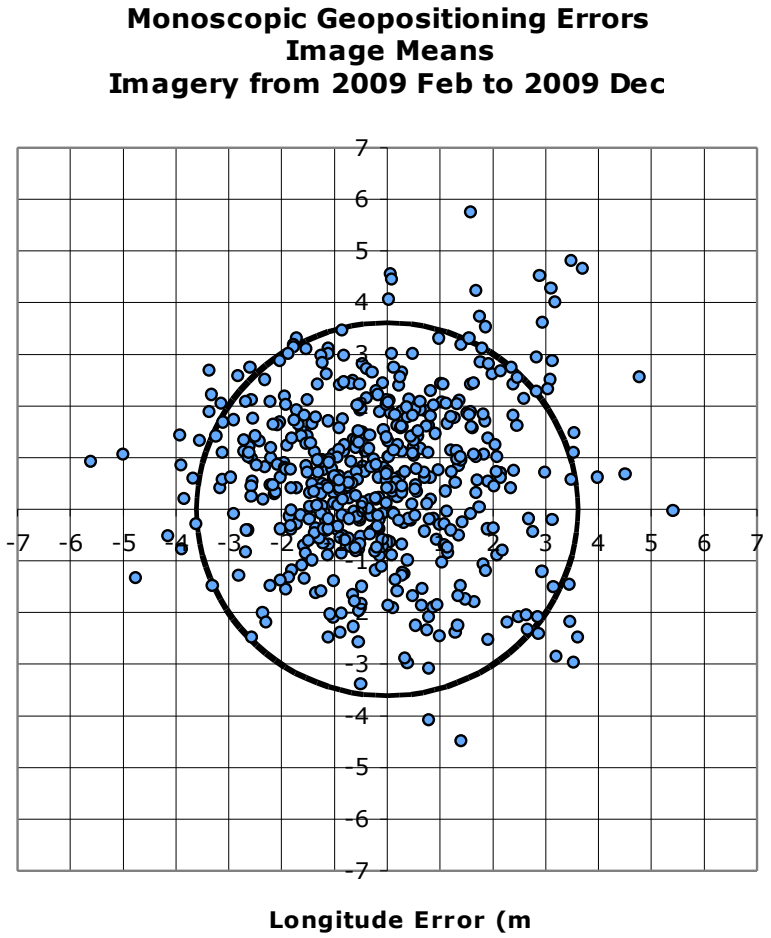


- Image residuals after on-orbit calibration



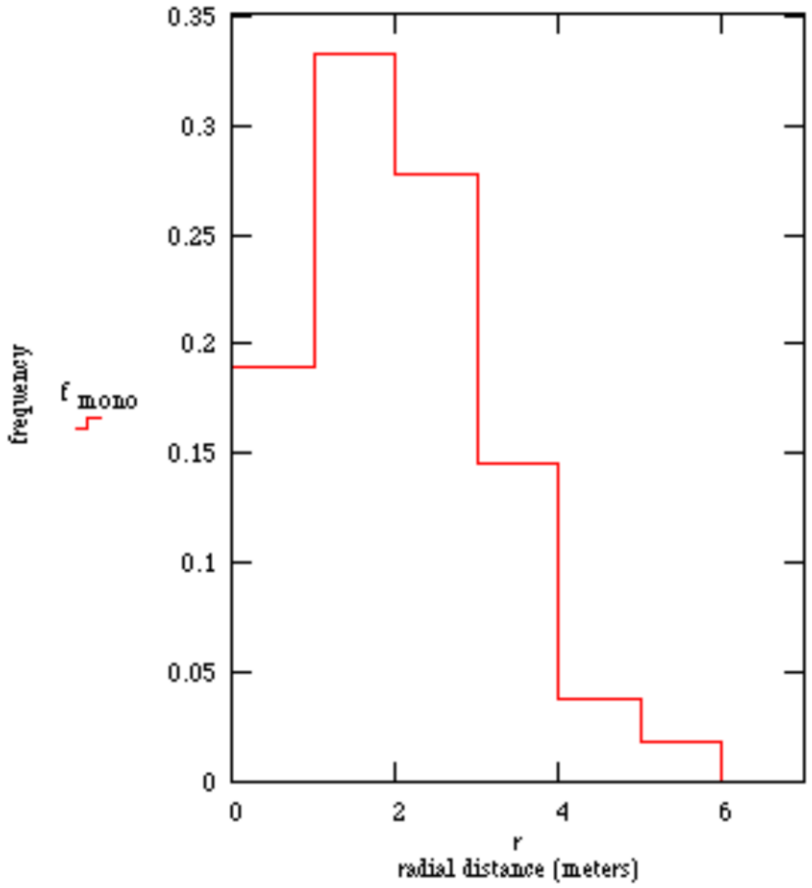
Absolute Monoscopic Geolocation Accuracy

- Based on rigorous (physical) model
- World wide distribution of T&E sites
- Sample of 530 images
- 90th percentile (CE90) = 3.6 m
- Mean errors
  - lat error = 0.6 m
  - long error = -0.2 m



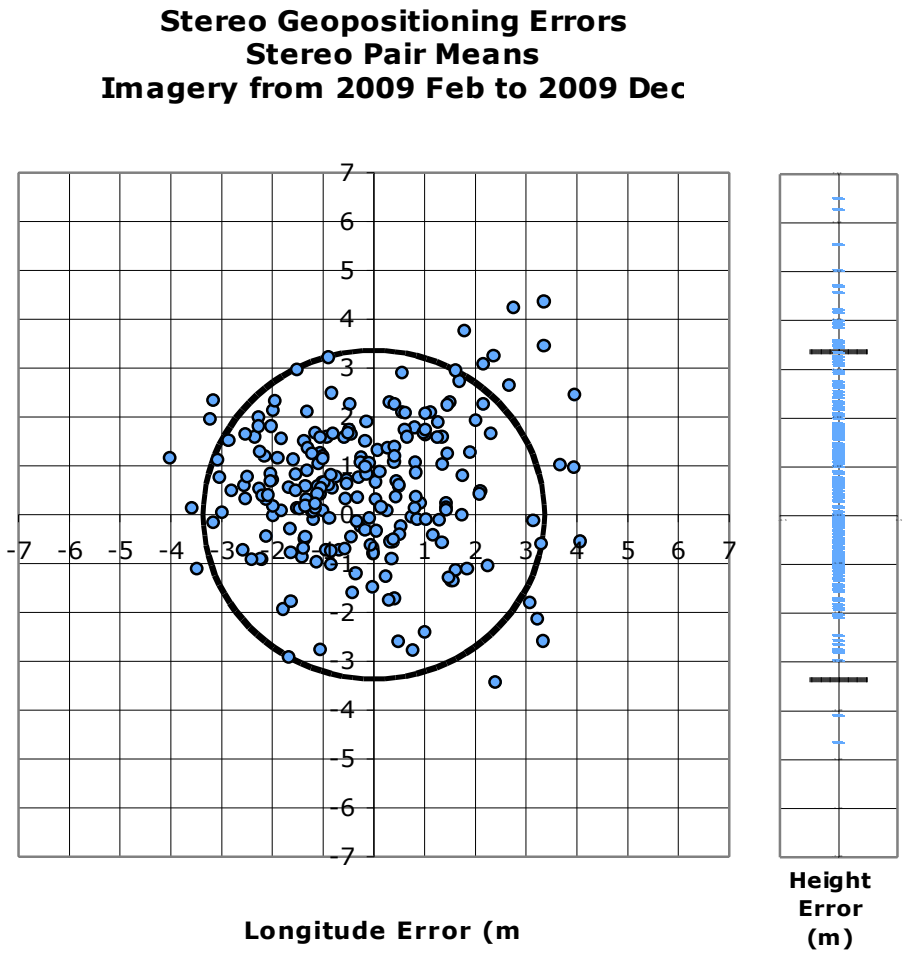
Absolute Monoscopic Geolocation Accuracy

- Histogram of radial error
- 90th percentile (CE90) = 3.6 m
- 2 meters is at 52%
- 5 meters is at 98%
- 6 meters is at 100%



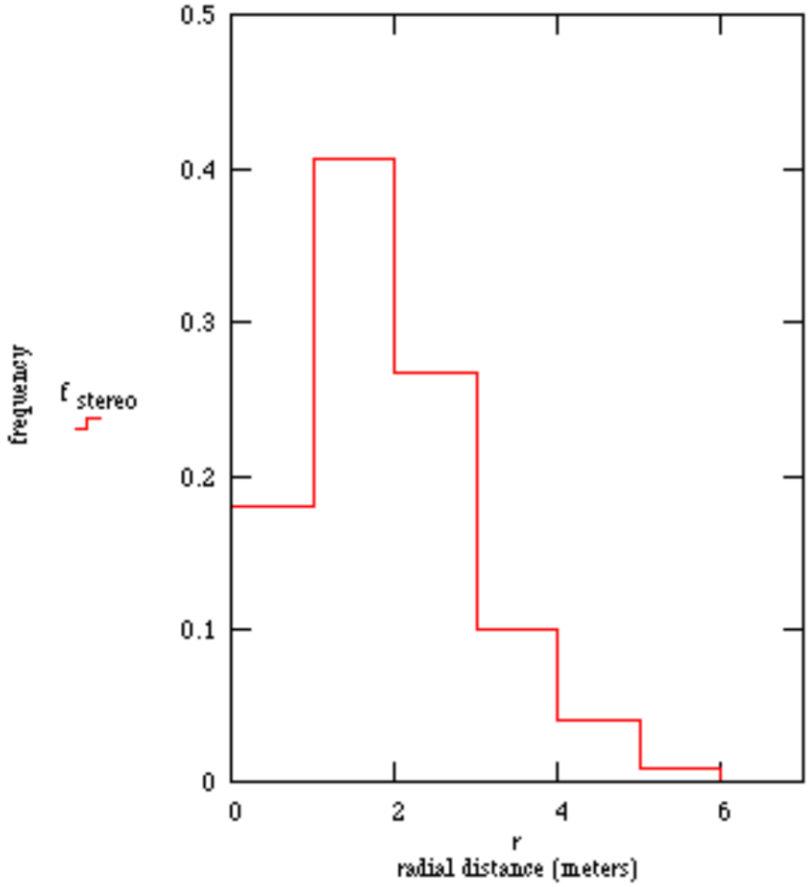
Absolute Stereocopic Geolocation Accuracy

- Based on rigorous (physical) model
- Direct positioning
  - no adjustment of imagery
- Sample of 222 stereo pairs
- 90th percentile
  - horizontal error (CE90) = 3.4 meters
  - vertical error (LE90) = 3.2 meters
- Mean errors
  - lat error = 0.5 m
  - long error = -0.2 m
  - height error = 0.6 m



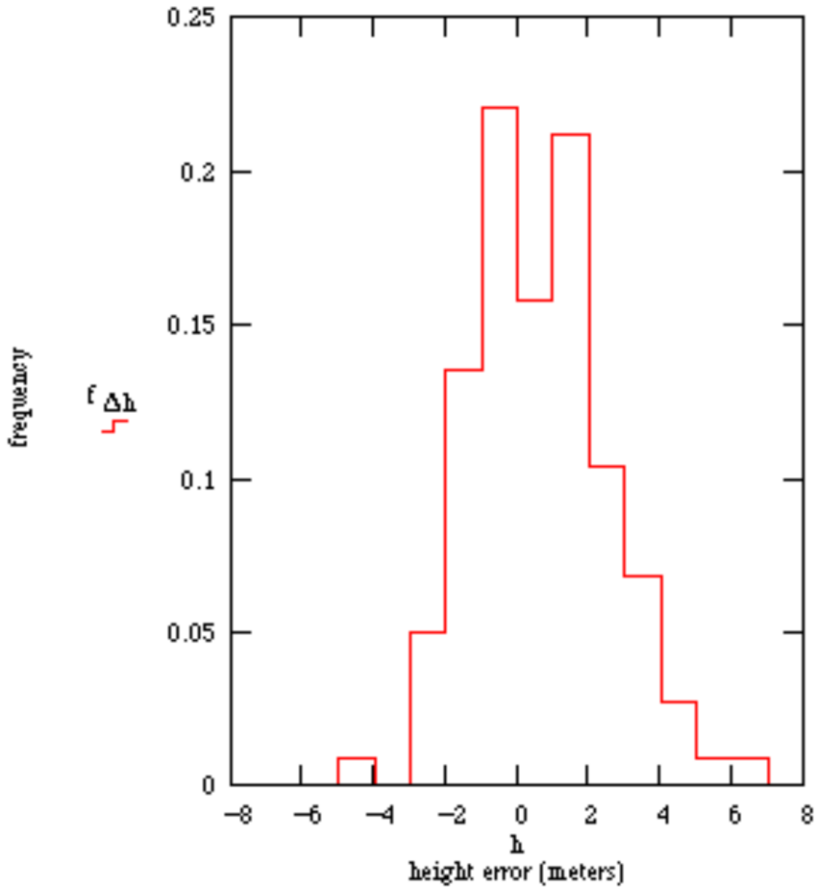
Absolute Stereocopic Geolocation Accuracy

- Histogram of radial error
- 90th percentile (CE90) = 3.4 m
- 2 meters is at 58%
- 5 meters is at 99%
- 6 meters is at 100%



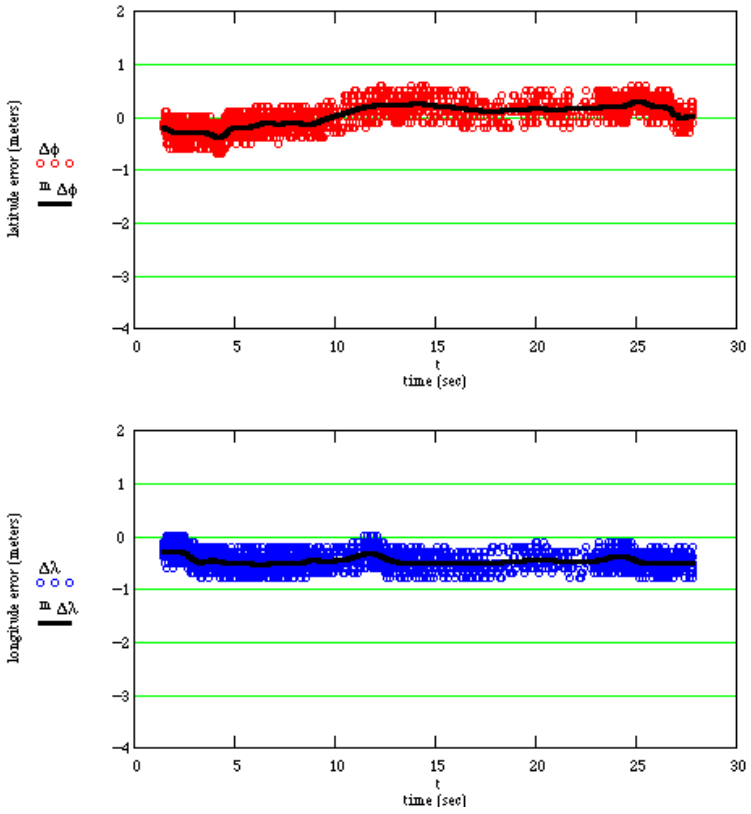
Absolute Stereocopic Geolocation Accuracy

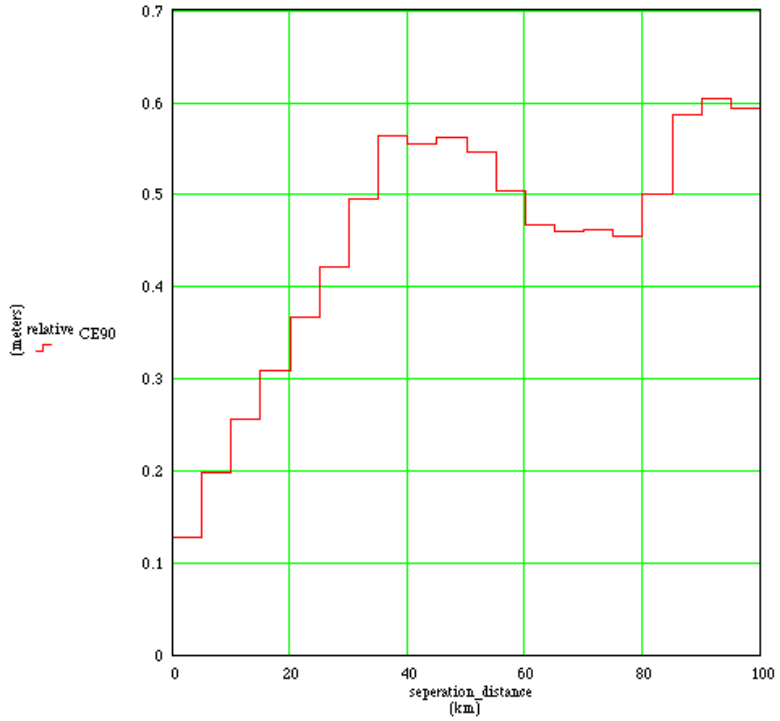
- Histogram of vertical error
- 90th percentile (CE90) = 3.2 m
- +/- 2 meters is at 73%
- +/- 5 meters is at 98%
- +/- 6 meters is at 99%



Relative Monoscopic Geolocation Accuracy

- Phoenix Range 2009-07-07 1st image
  - 3326 points





Relative Monoscopic Geolocation Accuracy

Relative CE90 given in distance bins: 0-5km, 5-10km, 10-15km, …, 95-100km, …

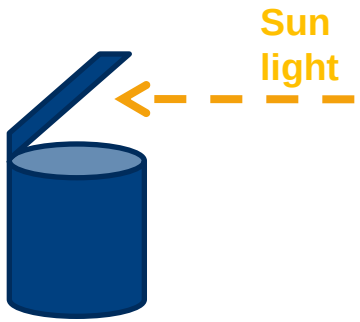
090707_phoenix_1st	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	
090707_phoenix_2nd	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.1	1.0	
090710_perth_1st	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6													
090710_perth_2nd	0.3	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6													
090713_perth_1st	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.1	1.1	1.0												
090713_perth_2nd	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4													
090715_phoenix_1st	0.2	0.2	0.3	0.4	0.6	0.7	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.3	1.3	1.3	1.2	1.1	
090718_phoenix_1st	0.2	0.3	0.4	0.5	0.6	0.8	0.7	0.7	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.6	
090718_phoenix_2nd	0.2	0.3	0.5	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.5	0.5	0.5	0.6	0.7	0.8	1.0	1.0	
090724_perth_1st	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.3													
090724_perth_2nd	0.1	0.2	0.3	0.4	0.6	0.7	0.7	0.8	0.8													
090729_perth_1st	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.7													
090729_perth_2nd	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.5	0.3													
090804_perth_1st	0.2	0.3	0.3																			
090804_perth_2nd	0.1	0.1	0.1																			
090804_perth_3rd	0.2	0.3	0.2																			
090804_perth_4th	0.2	0.2	0.2	0.2																		
090817_phoenix_1st	0.2	0.4	0.5	0.7	0.6	0.7	0.7	0.6	0.7	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.7	0.7	0.9	1.0	1.0	
090817_phoenix_2nd	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	1.0	1.1	1.1	1.2	1.2	1.1	
090820_phoenix_1st	0.2	0.3	0.5	0.6	0.8	0.9	1.0	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.8	0.8	1.0	1.1	1.1	
090820_phoenix_2nd	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3	
090826_perth_1st	0.3	0.3	0.4	0.4	0.4																	
090826_perth_2nd	0.2	0.3	0.4	0.5	0.7																	
090831_perth_1st	0.2	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0												
090831_perth_2nd	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8	1.1												
090922_perth_1st	0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.7	0.7													
090922_perth_2nd	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2													
090925_perth_2nd	0.3	0.3	0.5	0.5	0.6	0.6	0.5	0.6	0.6													
091003_perth_1st	0.3	0.3	0.4	0.5	0.6	0.8	0.8	0.7	0.8													
091003_perth_2nd	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.6													
091014_perth_1st	0.2	0.2	0.3	0.4	0.4	0.4	0.3	0.3	0.2													
091014_perth_2nd	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3													
091017_perth_1st	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3													
091017_perth_2nd	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2													
091025_perth_1st	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7													
091025_perth_2nd	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9													
091105_phoenix_1st	0.2	0.5	0.6	0.6	0.8	0.9	1.2	1.3	1.4	1.4	1.3	1.3	1.5	1.5	1.7							
091105_phoenix_2nd	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.8	0.7							
091116_perth_1st	0.2	0.3	0.4	0.5	0.7																	
091116_perth_2nd	0.3	0.4	0.4	0.5	0.6																	
091127_perth_1st	0.3	0.3	0.5	0.6	0.6																	
091127_perth_2nd	0.3	0.3	0.3	0.4	0.4																	
091202_phoenix_1st	0.2	0.2	0.4	0.4	0.6	0.6	0.7	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.4	1.3	1.4	1.5
091224_phoenix_1st	0.2	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	
091227_perth_1st	0.2	0.4	0.5	0.6	0.7																	
091227_perth_2nd	0.3	0.3	0.4	0.4	0.5																	
mean	**0.2**	**0.3**	**0.4**	**0.4**	**0.5**	**0.6**	**0.6**	**0.6**	**0.7**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**1.1**	**1.1**	
seperation distance	**0 km**					**25 km**					**50 km**					**75 km**					**100 km**	

Absolute Radiometry Calibration

- Current coefficients are based on NIST- traceable pre-launch measurements.
  - Convert DN to mW/(cm2-str-mm)
  - Scale factors vary by camera setting (line rate and TDI)
  - Scale factors are contained in metadata delivered with the image products

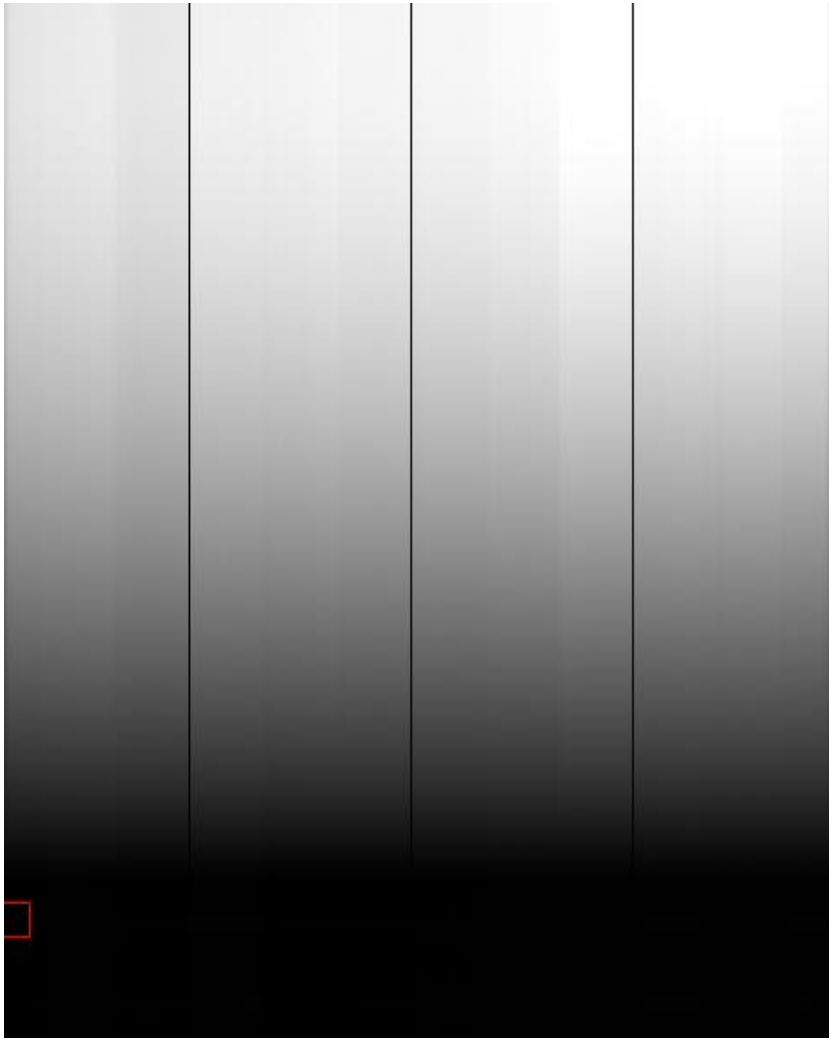
Relative Radiometric Calibration

- Purpose: Detector equalization to reduce pixel-to- pixel and chip-to chip-variations
  - Dark current subtraction
  - Gain correction
- Calibration data acquired from imaging the door to the sensor.
  - Door opens or closes to allow illumination through the dynamic range of sensor.
  - Camera door has been painted to produce a diffuse surface over the spectral range
  - Calibration data is collected in numerous imaging modes.



Relative Radiometric Calibration Data

Example of calibration data - door closing



Example of calibration before and after the data is corrected.

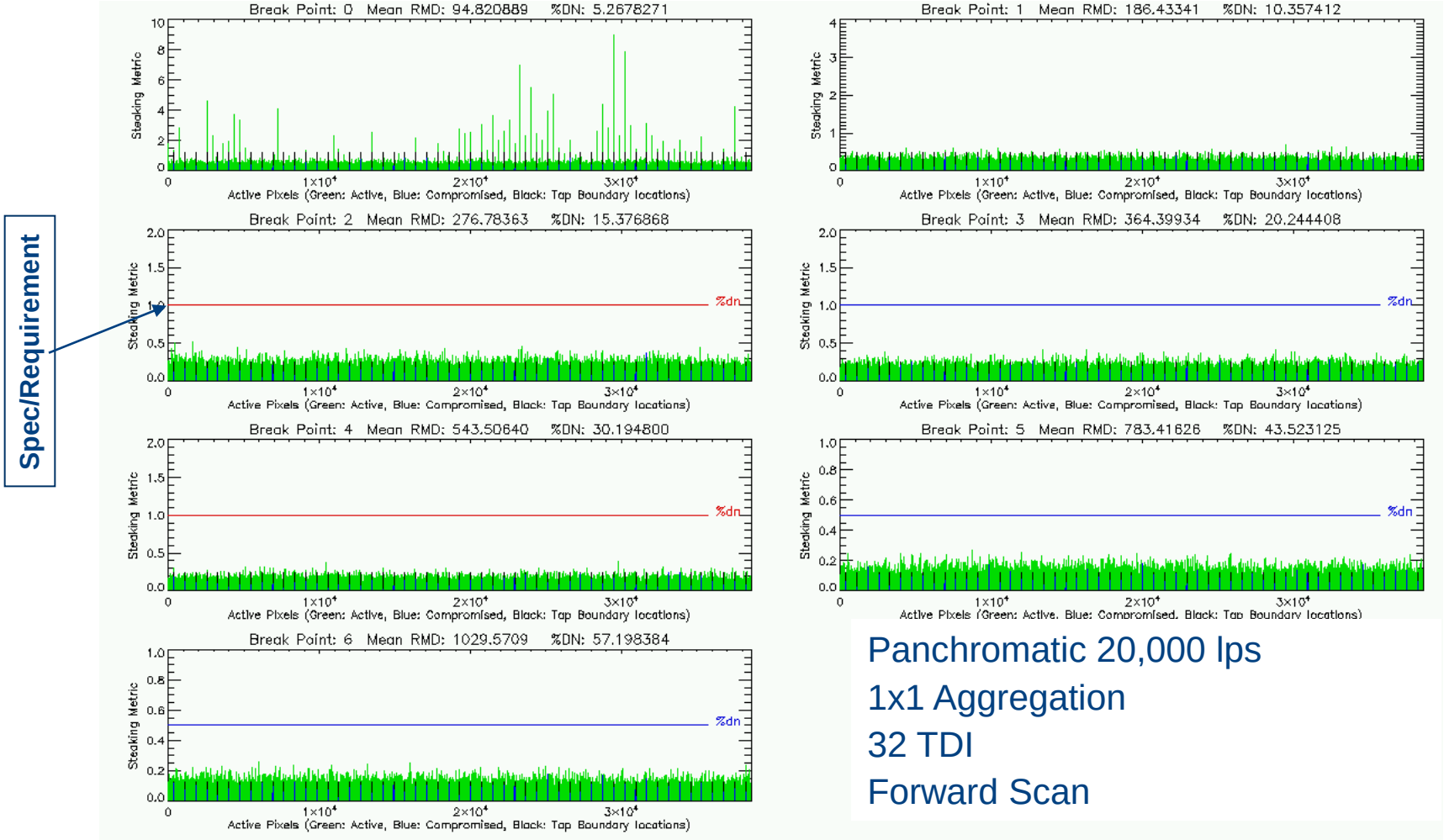
GeoEye-1 Flat-Field Imagery Pre-Correction

GeoEye-1 Flat-Field Imagery Post-Correction

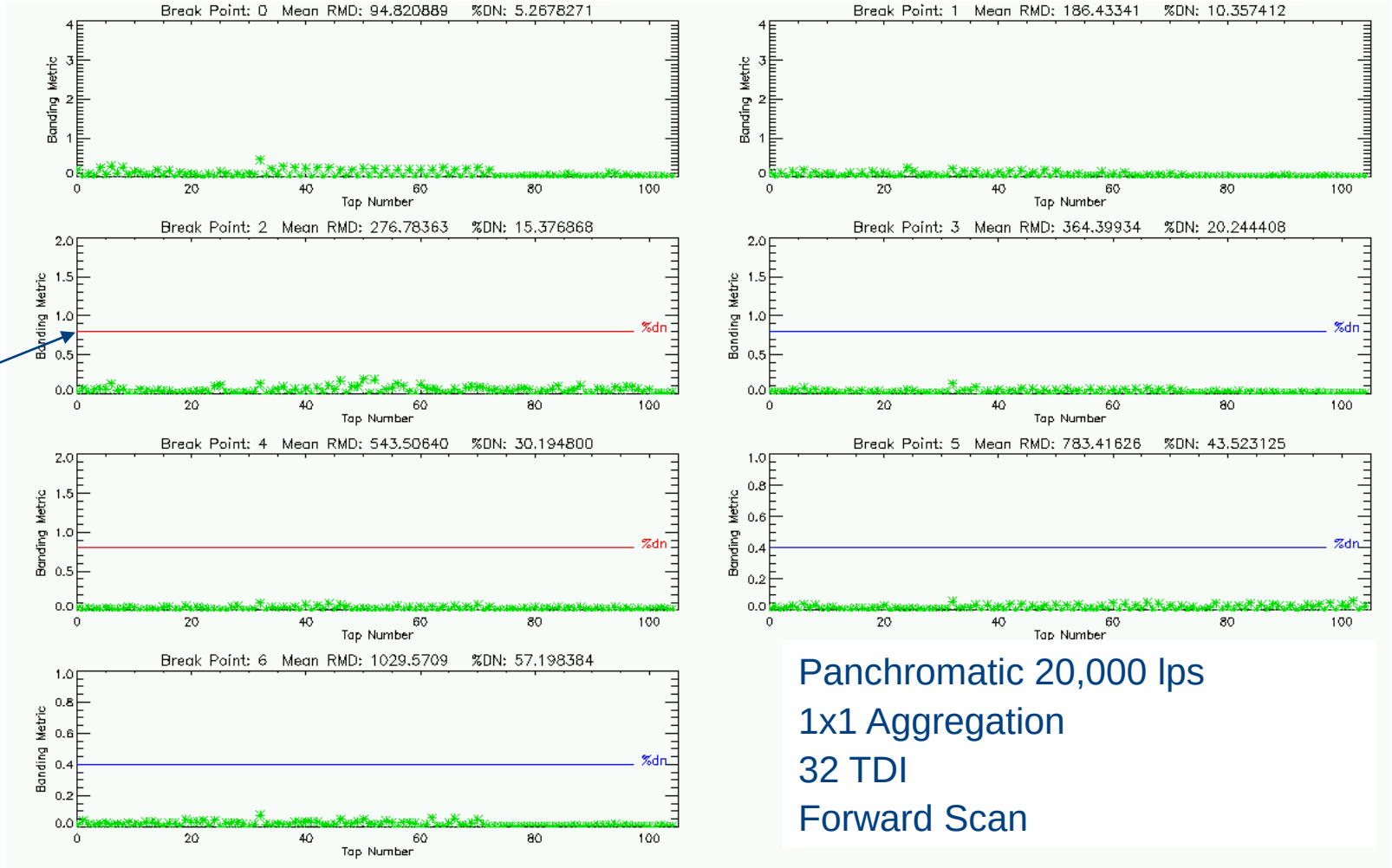
Relative Radiometric Calibration

- Calibration data are calculated and analyzed routinely every 4-6 months.
- Metrics are run on calibrated data to assess success of calibration.
  - Streaking metrics measure pixel to pixel variation
  - Banding metrics measure chip to chip variation
  - Streaking and banding metrics are collected across the focal plane and through the dynamic range.
- Calibrations have shown consistent results through time.

Representative Streaking Metrics



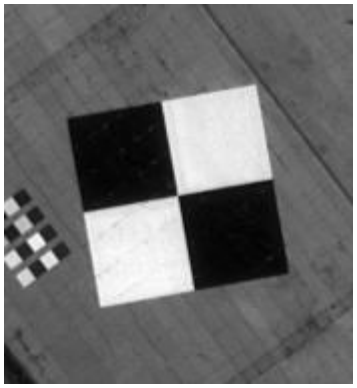
Representative Banding Metrics



Panchromatic 20,000 lps
1x1 Aggregation
32 TDI
Forward Scan

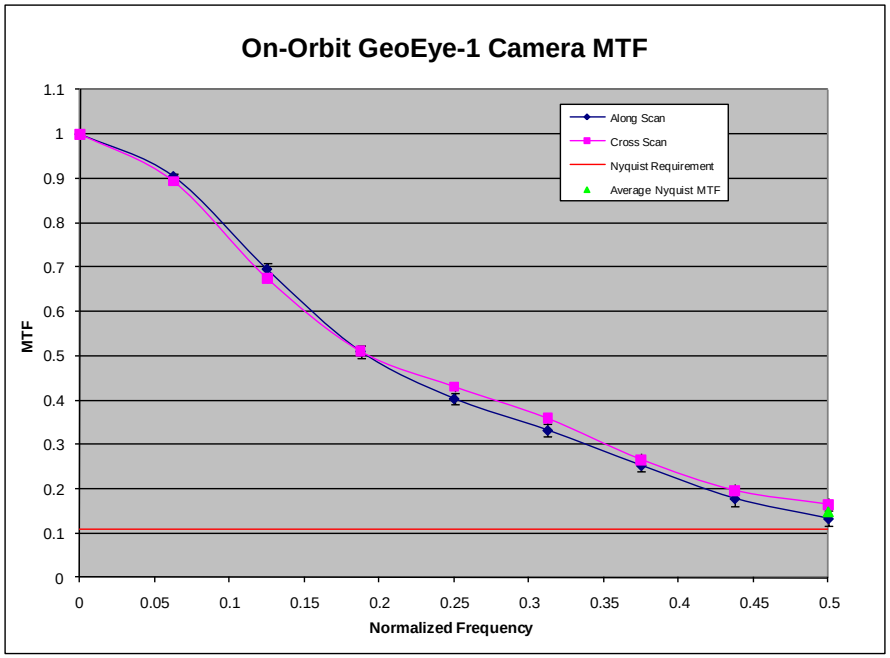
Modulation Transfer Function (MTF)

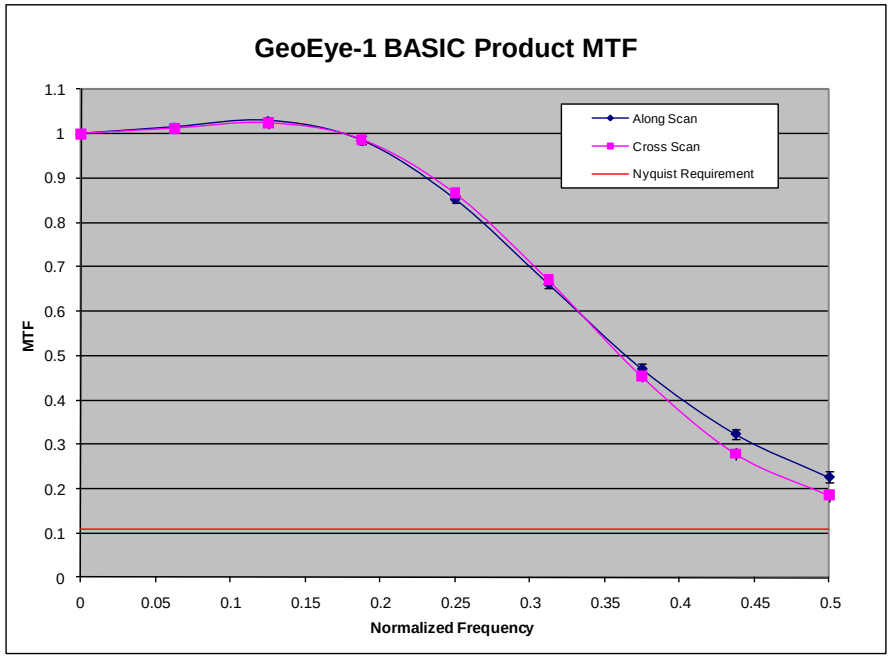
- MTF is a measure of system sharpness
- Measured on-orbit by analyzing high-contrast edges
- Calculated for along-scan and cross-scan orientations
- Measured at the camera level and after ground processing



GeoEye-1 Image of Big Spring MTF target

On-Orbit MTF Measurements

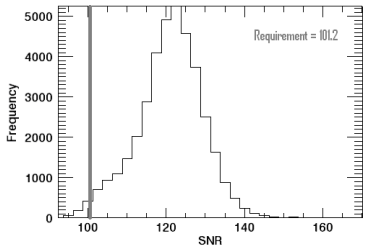




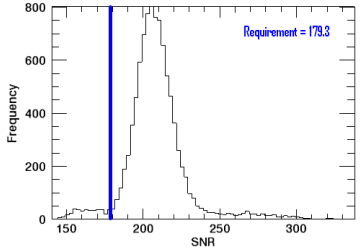
Parameter		Measurement
Camera Level 1x1 aggregation	Along Scan	0.13 +/- 0.01
	Cross Scan	0.16 +/- 0.01
Product Level 1x1 aggregation	Along Scan	0.23 +/- 0.01
	Cross Scan	0.19 +/- 0.01

On-Orbit SNR Measurement

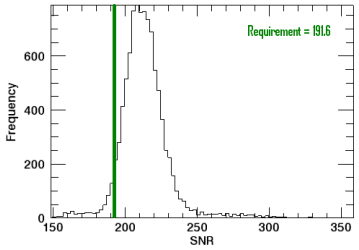
- SNR is a measure of camera noise
- Measured by analyzing flat-field imagery
- SNR is specified at lowest TDI and 15% well fill



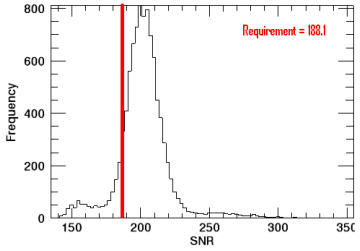
Pan Band: 1x1 agg, 8 TDI, Reverse Array



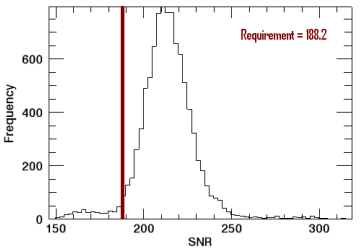
Blue Band: 1x1 agg, 3 TDI, Reverse Array



Green Band: 1x1 agg, 3 TDI, Reverse Array



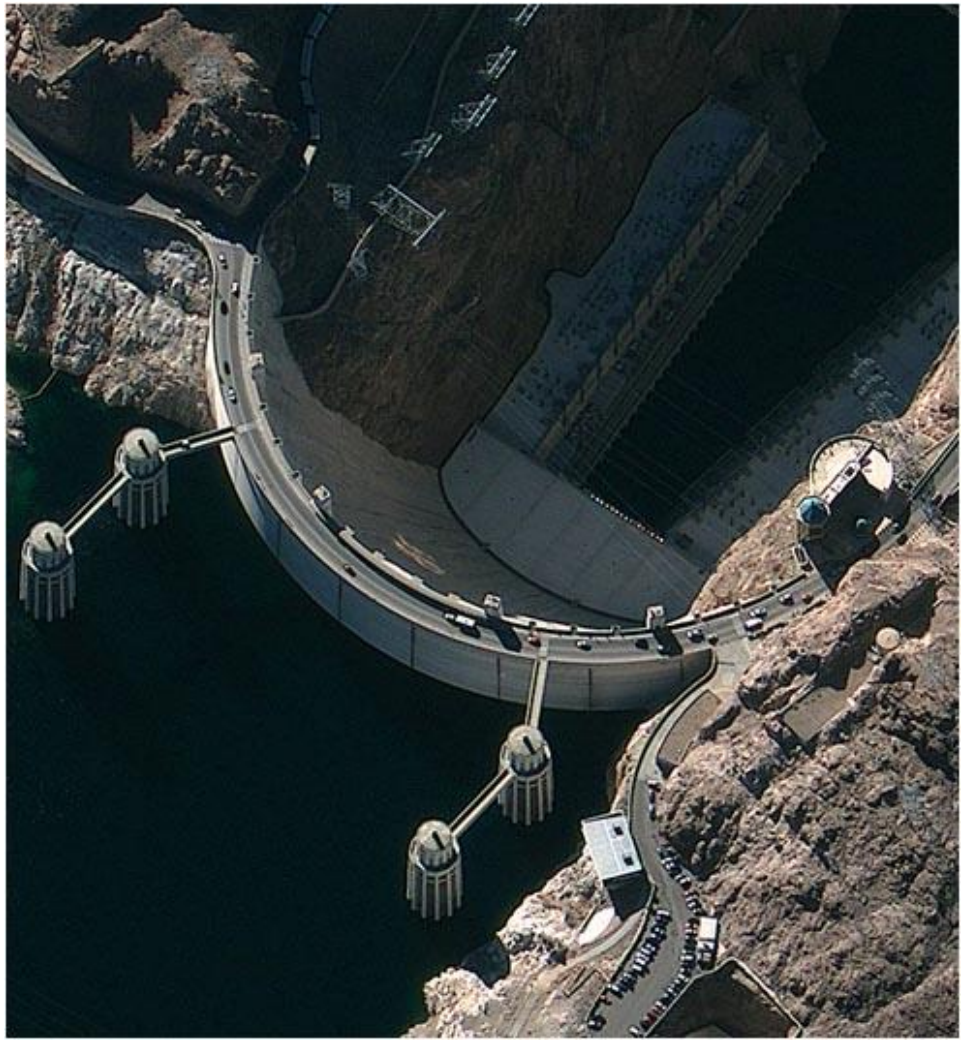
Red Band: 1x1 agg, 3 TDI, Reverse Array



Near IR Band: 1x1 agg, 3 TDI, Reverse Array

Band	Mean Well Fill (%)	SNR Requirement (Scaled to well fill)	SNR Mean
Pan	15.02	101.2	122.5
Blue	14.88	179.3	204.8
Green	15.39	191.6	206.4
Red	14.44	188.1	195.4
NIR	15.31	188.2	210.2

Summary



- GeoEye-1 has been operational for one year
- System produces high quality, accurate imagery
- Calibration and characterization are done throughout the mission

Acknowledgements

- The following GeoEye employees contributed to the technical analysis presented
  - Aaron Cole
  - Robert Arnold
  - Kevin Harrison