System Characterization Results for the QuickBird Sensor

Kara Holekamp, Kenton Ross, and Slawomir Blonski

Science Systems and Applications, Inc.
John C. Stennis Space Center, MS 39529

Civil Commercial Imagery Evaluation Workshop
Fairfax, VA, USA
March 22, 2006

Outline

- Overview
- Geopositional Characterization
  - Methodology
  - Results
- Spatial Characterization
  - Methodology
  - Results
- Radiometric Characterization
  - Methodology
  - Results
- Summary

Overview

- QuickBird is a high-spatial-resolution multispectral sensor owned and operated by DigitalGlobe, Inc.
  - 60-cm resolution panchromatic
  - 2.4-m resolution multispectral
  - 4 multispectral bands: blue, green, red, and near-infrared
- NASA purchased QuickBird data through the Scientific Data Purchase project
- Data acquired over characterization sites every year for the past 5 years
- NASA team performed independent geopositional, spatial, and radiometric characterizations of purchased data
- Characterization results presented for the past 4 years

Geopositional Characterization

Geopositional Overview

Products

Standard (2A) Imagery Products (PAN & Multispectral)

"Standard Imagery products are radiometrically corrected, sensor corrected, geometrically corrected, and mapped to a cartographic projection…Geometric corrections remove spacecraft orbit position and attitude uncertainty, Earth rotation and curvature, and panoramic distortion."

- Coarse DEM Applied (default)

  "Standard Imagery has a coarse DEM applied to it, which is used to normalize for topographic relief with respect to the reference ellipsoid."

- Ortho Ready

  "Ortho Ready Standard Imagery has no topographic corrections, making it suitable for orthorectification. Ortho Ready Standard Imagery is projected to a constant base elevation, which is calculated on the average terrain elevation per order polygon."

Recent Acquisitions

- 27 OCT 2005 (Standard - Ortho Ready)
- 7 FEB 2006 (Standard - Coarse DEM)
- 23 MAR 2006 (Standard - Coarse DEM)

Accuracies

"Standard Imagery products have an average absolute geolocation accuracy of 23-meter CE90%, excluding any topographic displacement and off-nadir viewing angle. Ground location is derived from refined satellite attitude and ephemeris information without requiring the use of Ground Control Points (GCPs)."

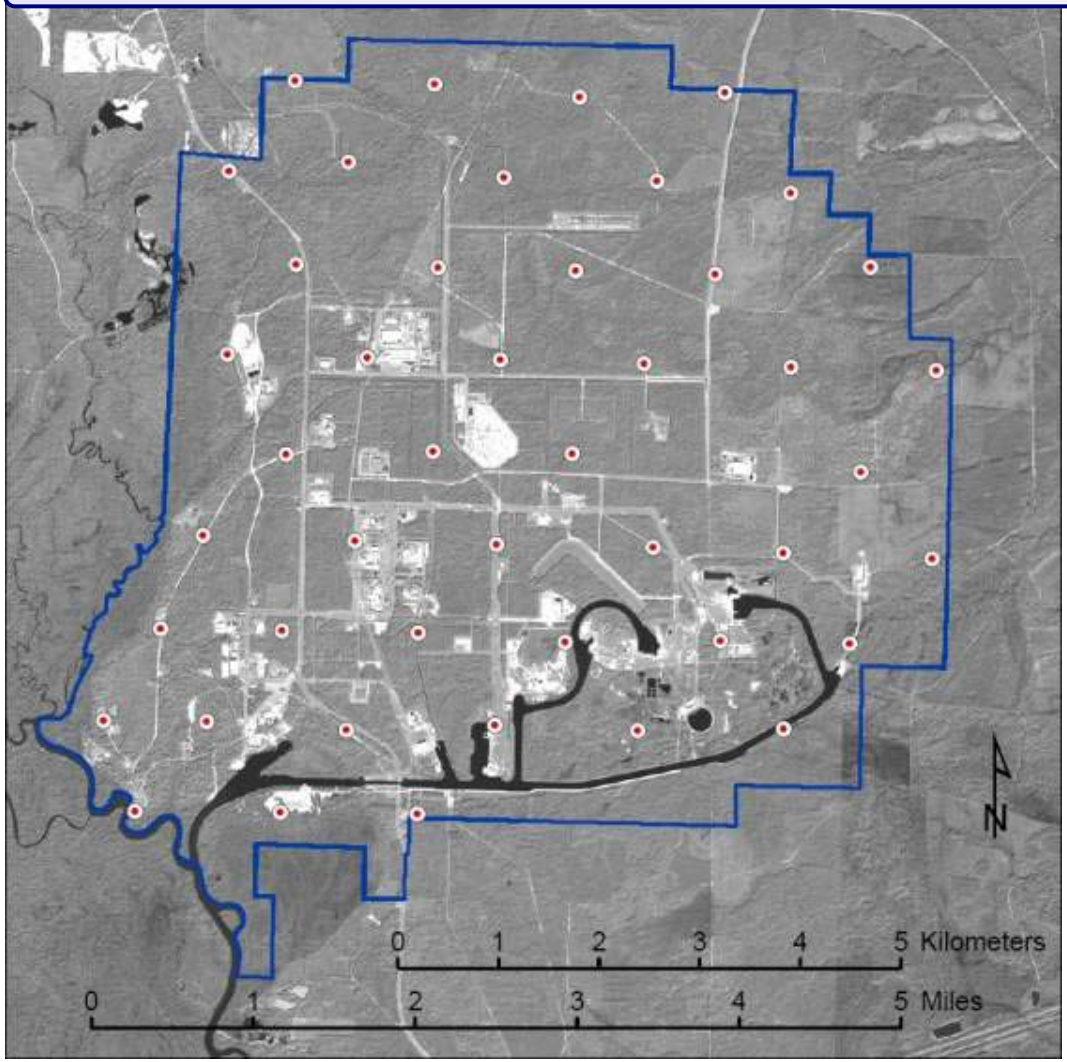
REFERENCE:
DigitalGlobe, 2006. *QuickBird Imagery Products - Product Guide.* Revision 4.7.2, October 18, p. 19
http://www.digitalglobe.com/downloads/QuickBird%20Imagery%20Products%20-%20Product%20Guide.pdf (accessed February 27, 2007).

Note on Coarse DEM vs. Ortho Ready

- In previous JACIE analyses, NASA geopositional analysis of QuickBird imagery has used the Standard Product with coarse DEM terrain corrections applied.
- In the most recent analysis, one available acquisition was the “Ortho Ready” version of the Standard Product, which has no terrain correction.
- Given the relatively flat terrain of the SSC geopositional target range (less than 8 m elevation difference across all targets spread over ~25 square miles) and higher sensor elevation angles, performance of the two products should be comparable.

Geodetic Targets

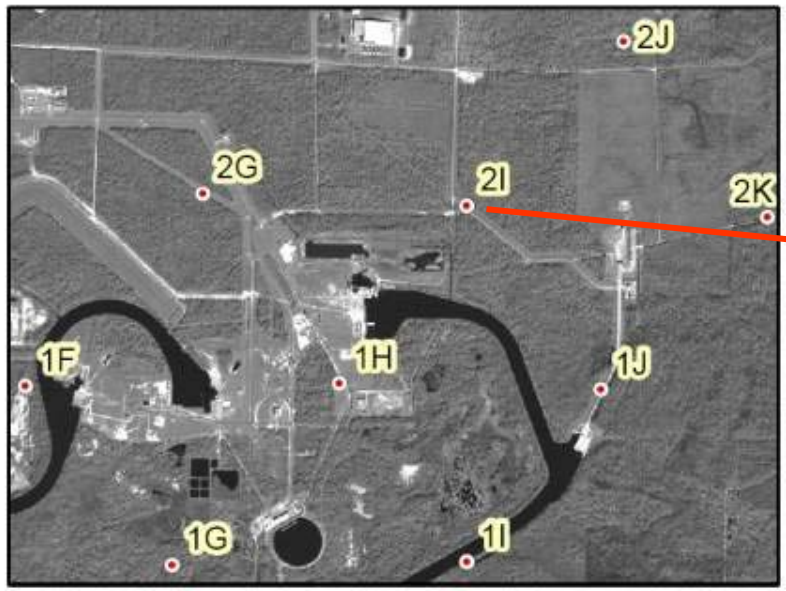
Fall 2005 QuickBird Mosaic with 45 Primary SSC Targets Overlaid



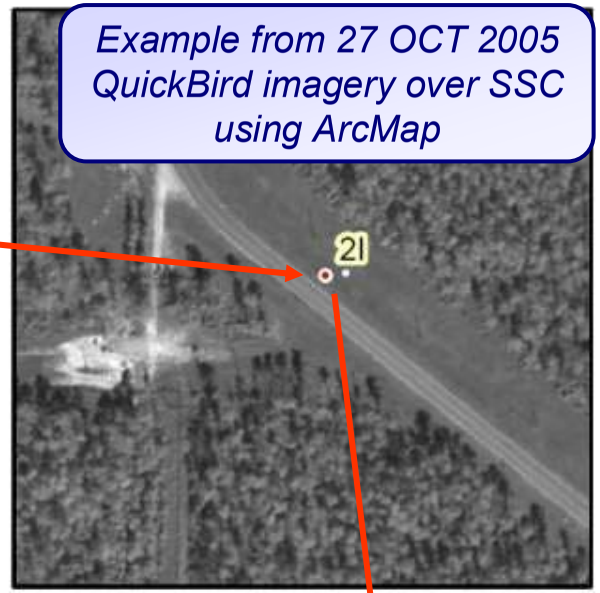
SSC Primary Targets: 2.44 m in diameter, distributed across the Fee Area

- *SSC primary targets are real-time kinematic GPS-located by the SSC survey team to absolute horizontal accuracies in the 3–6 cm range*
- *In addition to the primary targets, SSC maintains well over 100 secondary targets (predominantly painted manhole covers), but these targets were not used in the QuickBird characterizations*

Image Coordinates



Step 1



Step 2

Locating Image Coordinates:
- *Step to next target point*
- *Zoom to point using reference coordinates*
- *Add image coordinates to test point shapefile*

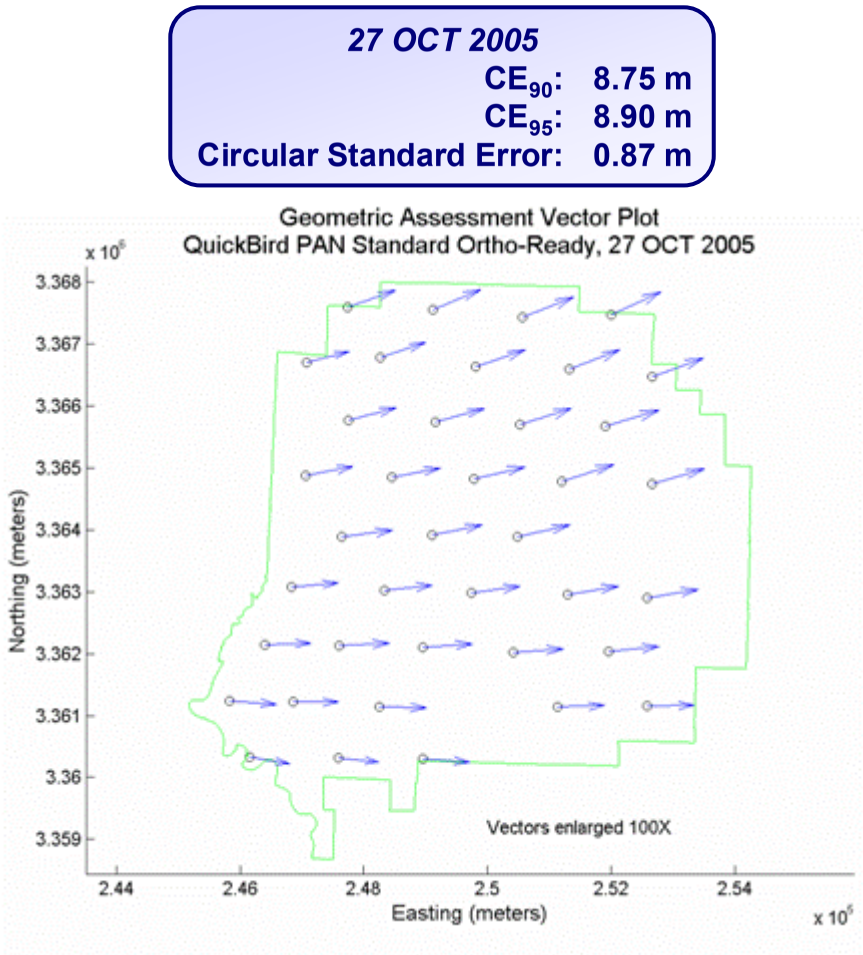
Cursor Location/Value of Point 2I

Step 3

Geopositional Figures of Merit

- **Horizontal Bias** – an estimate of the constant error; it is the magnitude of the vector sum of the average error in the X and the Y
- **Circular Standard Error** – an estimate of the zero-mean circular equivalent error; valid even for elliptical error distributions with minimum to maximum error ratios as low as 0.6
- **RMSE** – Root mean square error (horizontal bias and zero-mean error not decoupled); *relationship to circular error statistics has a non-linear dependency on horizontal bias – not used for this analysis*
- **CE_{90}** – The radial error that 90% of all errors in a circular distribution will not exceed; equivalent to the Circular Map Accuracy Standard
- **CE_{95}** – The radial error that 95% of all errors in a circular distribution will not exceed; equivalent to $Accuracy_r$ (from National Standard for Spatial Data Accuracy)

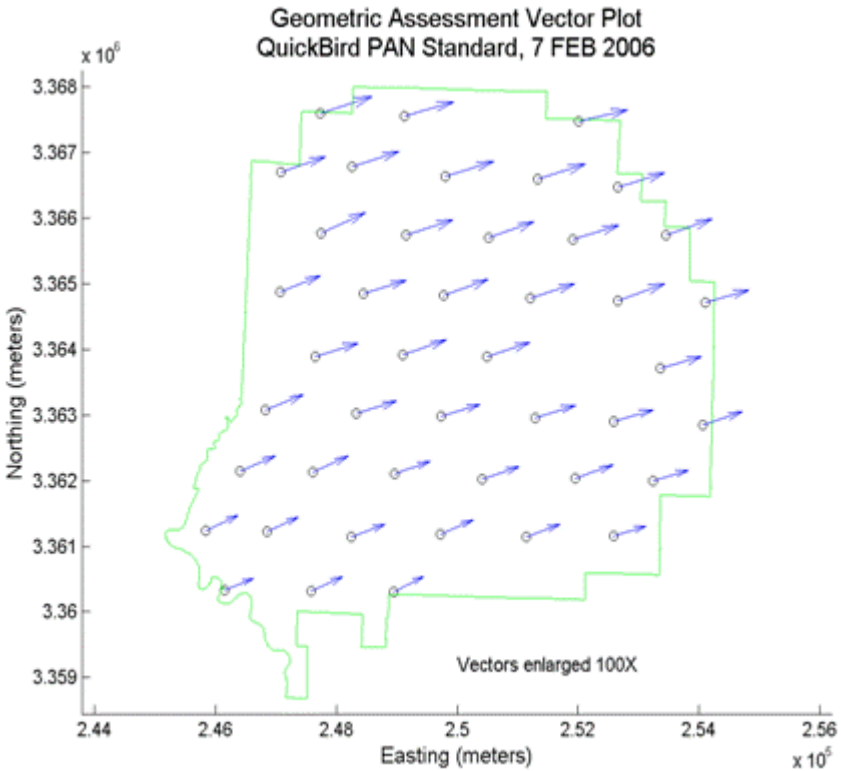
Vector Plots (1)



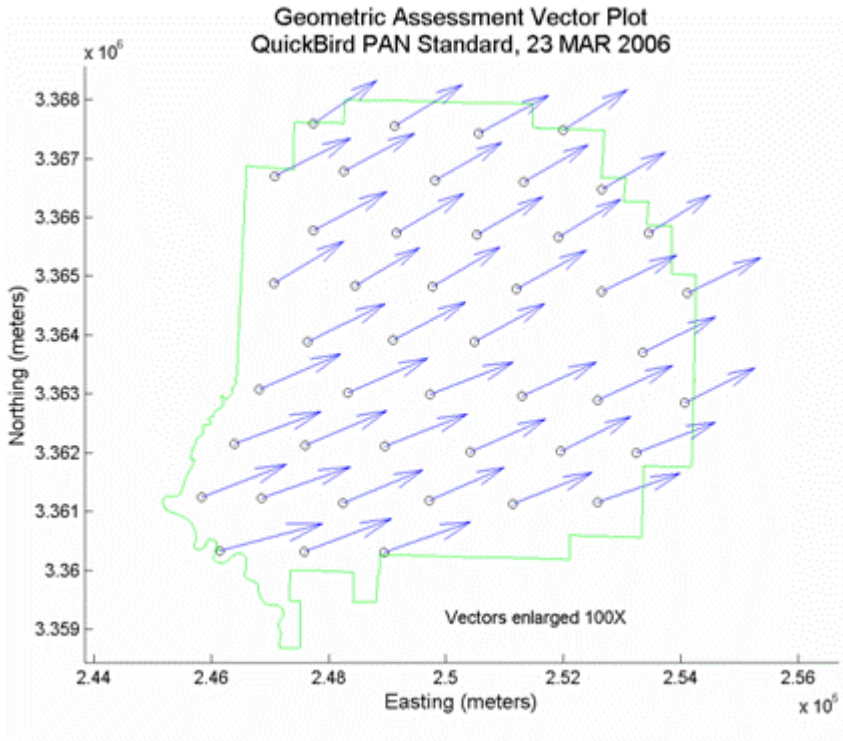
- Similar direction and magnitude of all residuals indicates that the dominant error component is horizontal bias
- Noticeable and somewhat uniform change in direction of residuals from top to bottom indicates higher order systematic error components (a secondary effect)

Vector Plots (2)

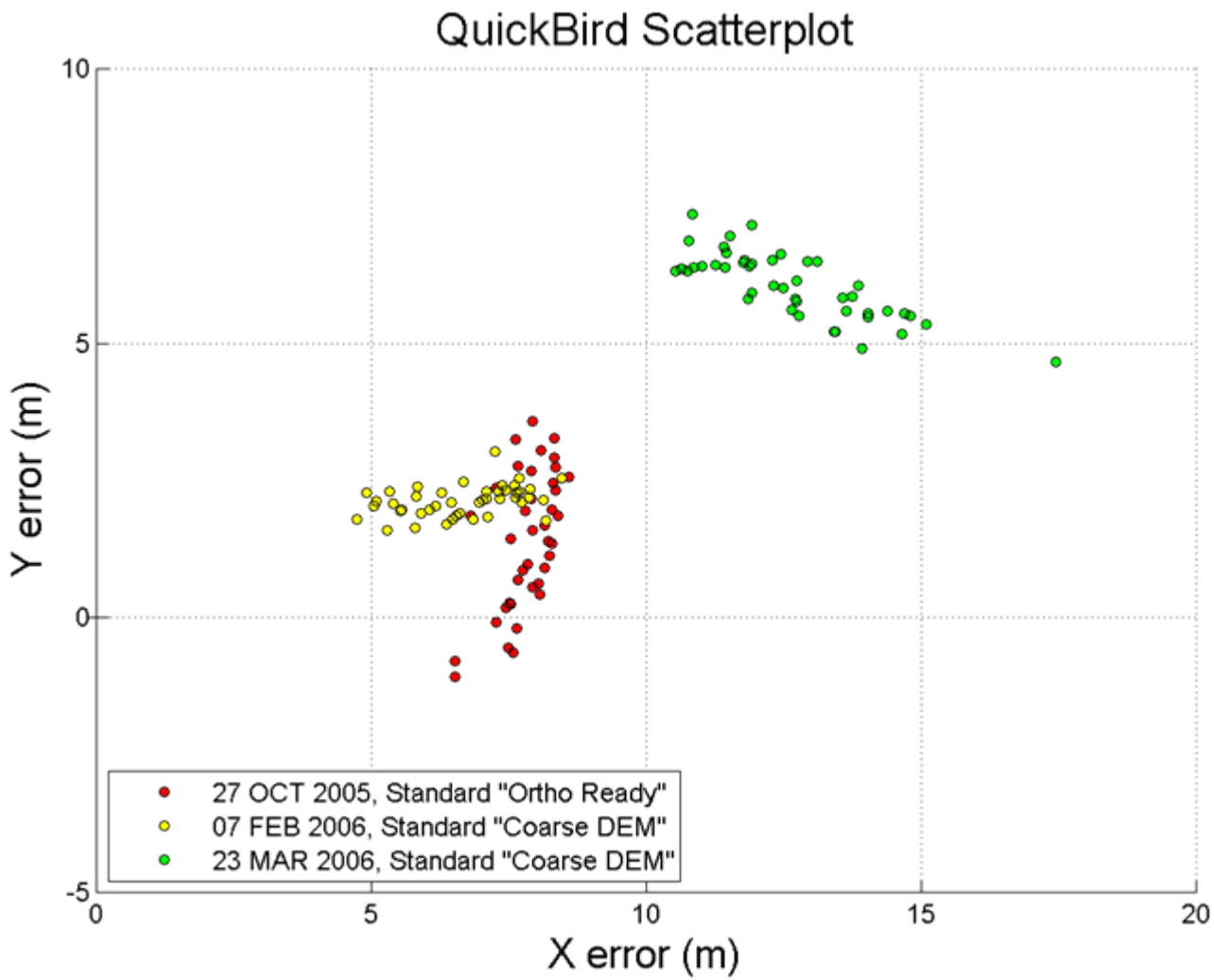
7 FEB 2006
CE_{90}: 8.17 m
CE_{95}: 8.38 m
Circular Standard Error: 0.64 m



23 MAR 2006
CE_{90}: 15.54 m
CE_{95}: 15.85 m
Circular Standard Error: 1.03 m



Scatterplot



Geopositional Summary

Acquisition Date	Elevation Angle (deg.)	Horizontal Bias (m)	Circular Std. Error (m)	Empirical CE_{90} (m)	Empirical CE_{95} (m)
23 AUG 2003	76.8°	11.24	1.33	12.67	12.76
15 SEP 2003	83.3°	16.53	0.71	17.40	17.62
21 OCT 2003	81.3°	12.20	1.09	13.63	13.72
10 JAN 2004	89.2°	15.41	0.54	16.27	16.39
23 JAN 2004	73.0°	11.58	1.11	13.36	13.49
28 JAN 2004	74.6°	18.37	0.53	18.98	19.21
21 JUL 2004	85.9°	18.47	0.31	18.75	18.84
30 AUG 2004	83.2°	25.76	0.66	26.66	26.99
5 OCT 2004	76.1°	24.50	1.01	25.62	25.93
17 JAN 2005	81.1°	34.60	0.36	34.87	34.95
12 MAR 2005	78.0°	14.39	0.34	14.99	15.16
22 JUN 2005	72.5°	15.31	0.97	16.71	17.31
6 SEP 2005	48.6°	23.84	0.61	24.73	24.85
18 OCT 2005	73.2°	12.28	1.12	13.60	13.80
27 OCT 2005	**76.1°**	**7.95**	**0.87**	**8.75**	**8.90**
7 FEB 2006	**84.0°**	**6.99**	**0.64**	**8.17**	**8.38**
23 MAR 2006	**63.3°**	**14.03**	**1.03**	**15.54**	**15.85**

- *Blue acquisitions were characterized by South Dakota State University*
- *Red Acquisitions were characterized by NASA Stennis Space Center*

- In recent acquisitions (**bold**), the mean CE_{90} of QuickBird panchromatic *Standard* images was 10.8 m (95% confidence interval (CI) from 4.9 m to 16.7 m)
- Results are apparently better than previous analysis (mean CE_{90} of 19.2 m with CI from 14.5 m to 23.8 m)
- Given only three recent acquisitions, beneficial product change is not conclusive

Spatial Characterization

Edge Response Measurements

QuickBird panchromatic image acquired on January 10, 2004
GSD = 60 cm
Edge target tarps oriented for testing in the Easting direction

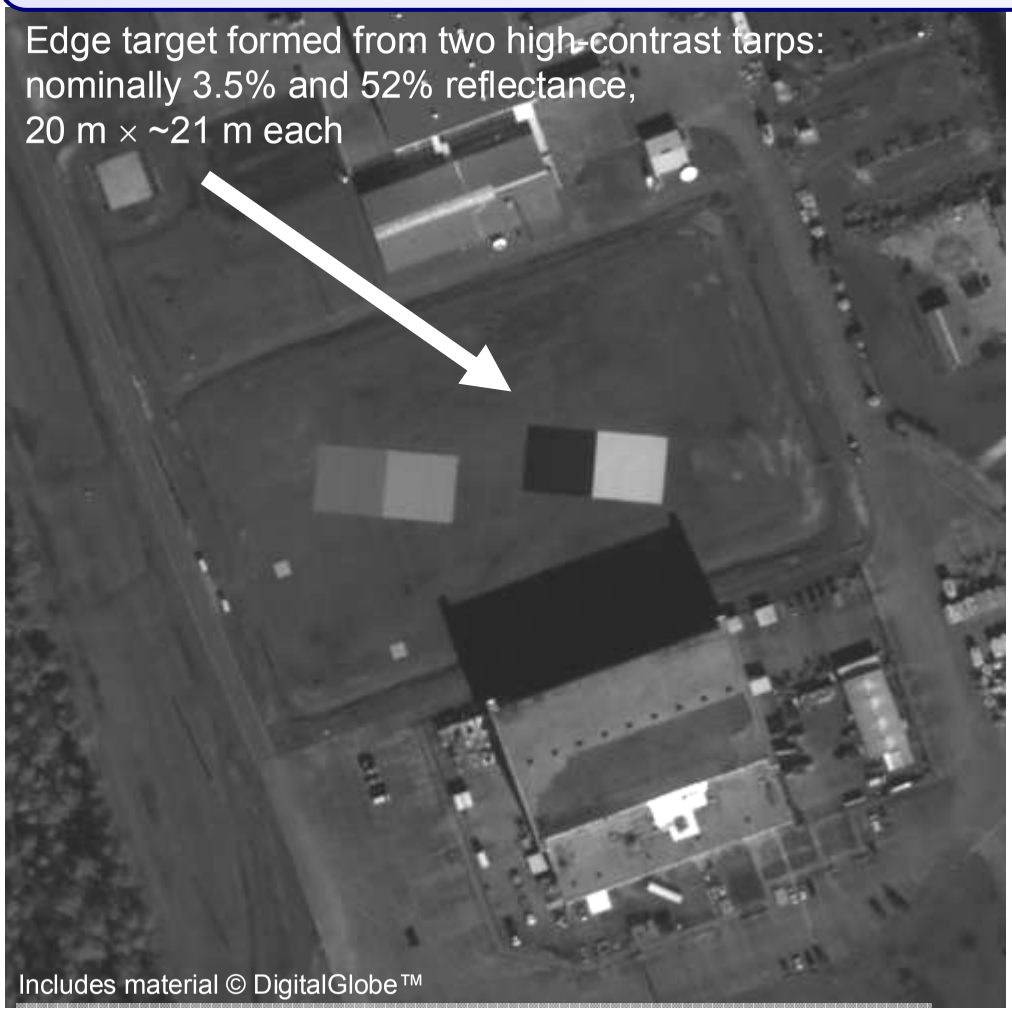
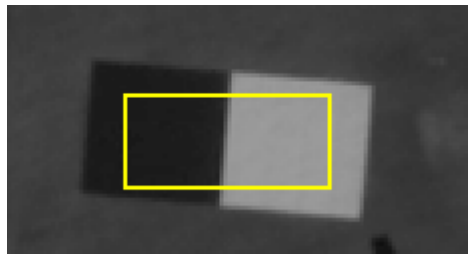
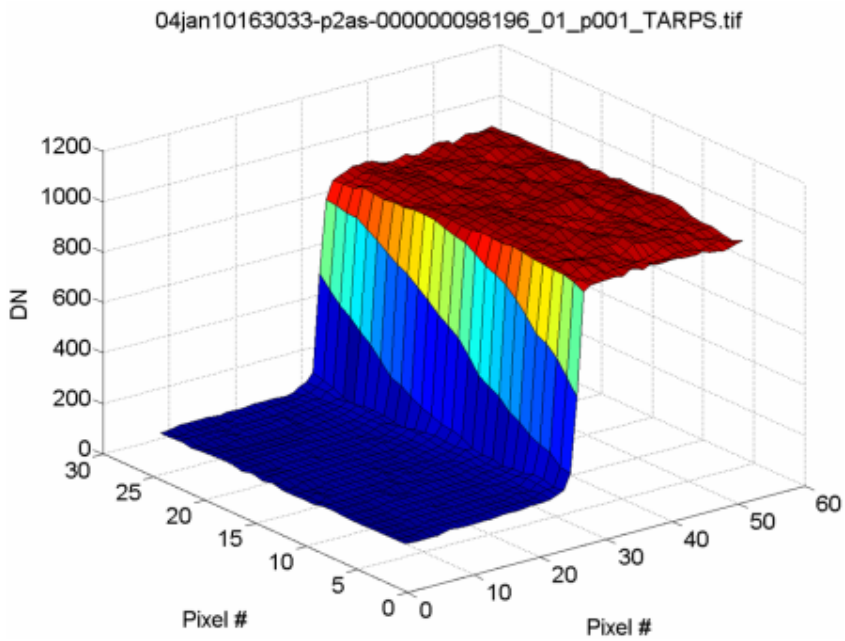


Image area selected for edge response analysis



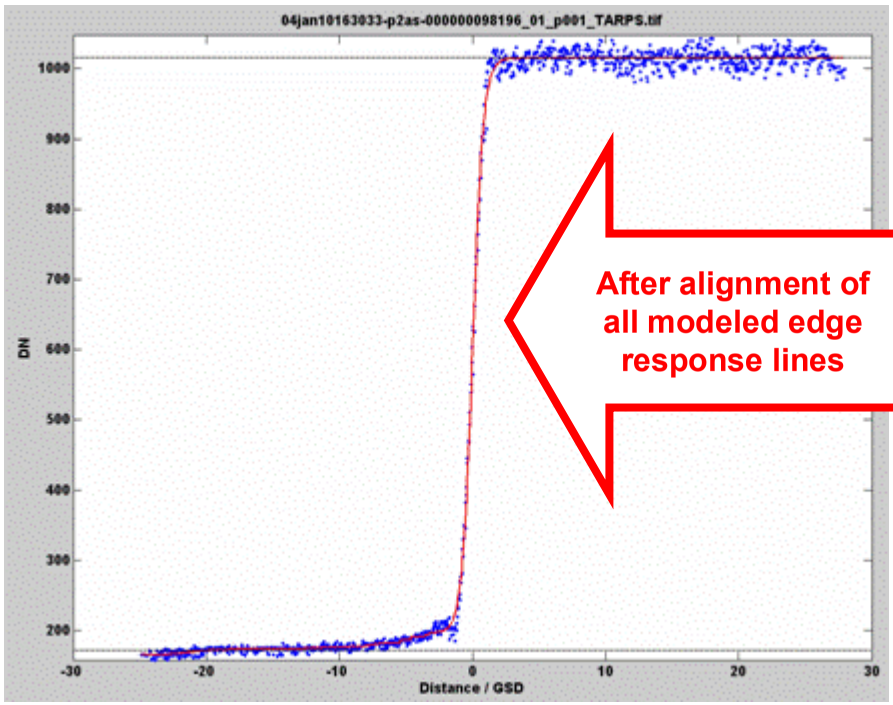
zoom 2×

A set of shifted edge response lines ready for analysis

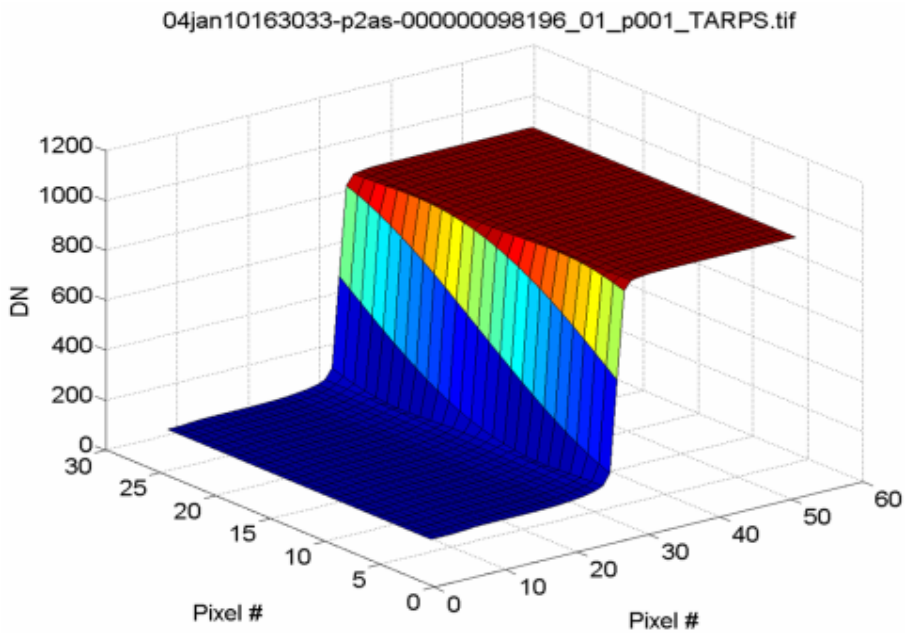


Edge Response Analysis

- The nonlinear least-squares optimization with superposition of *N* sigmoidal functions is conducted seven times for *N* = 3, 5, 7, 9, 11, 13, and 15
- The value of *N* that provides the best fit is selected to generate final results
- Selection of the analyzed area and the optimization are repeated several times to estimate uncertainty of the results based on standard deviation

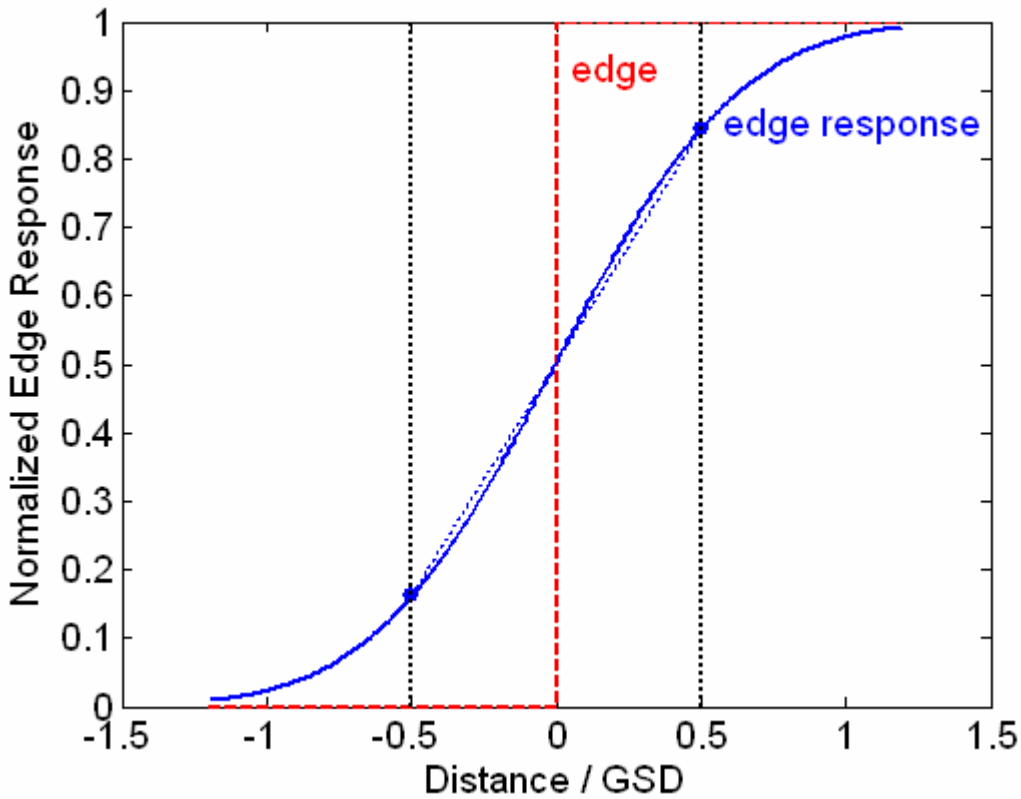


Modeled edge response



Relative Edge Response

Spatial resolution is characterized by a difference of normalized edge response values at points distanced from the edge by -0.5 and 0.5 GSD

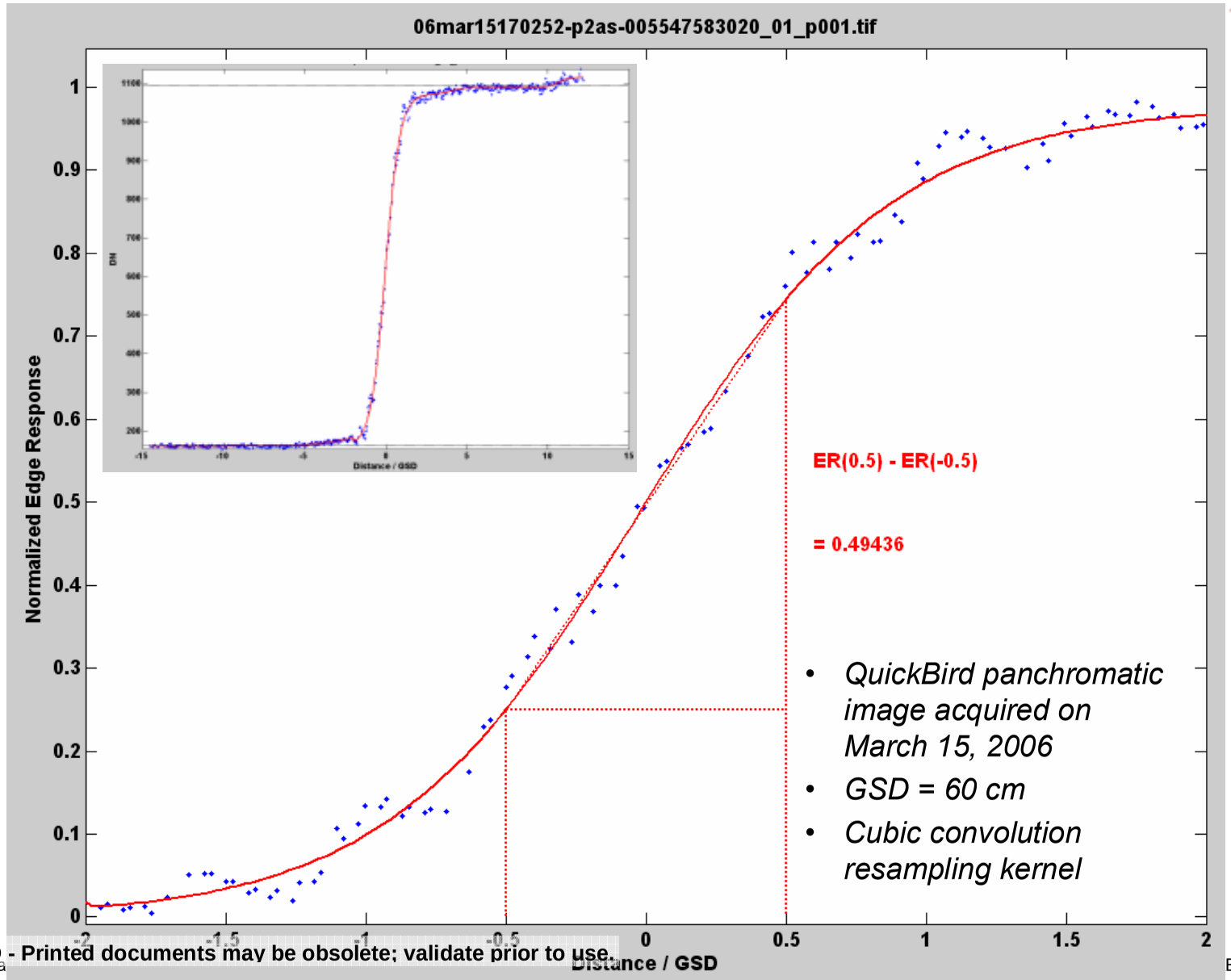


The graph shows a normalized edge response as a function of distance from the edge. The dots indicate edge response points used for calculations of the difference.

RER (Relative Edge Response) is a geometric mean of the normalized edge response differences in two mutually perpendicular directions (e.g., Easting and Northing).

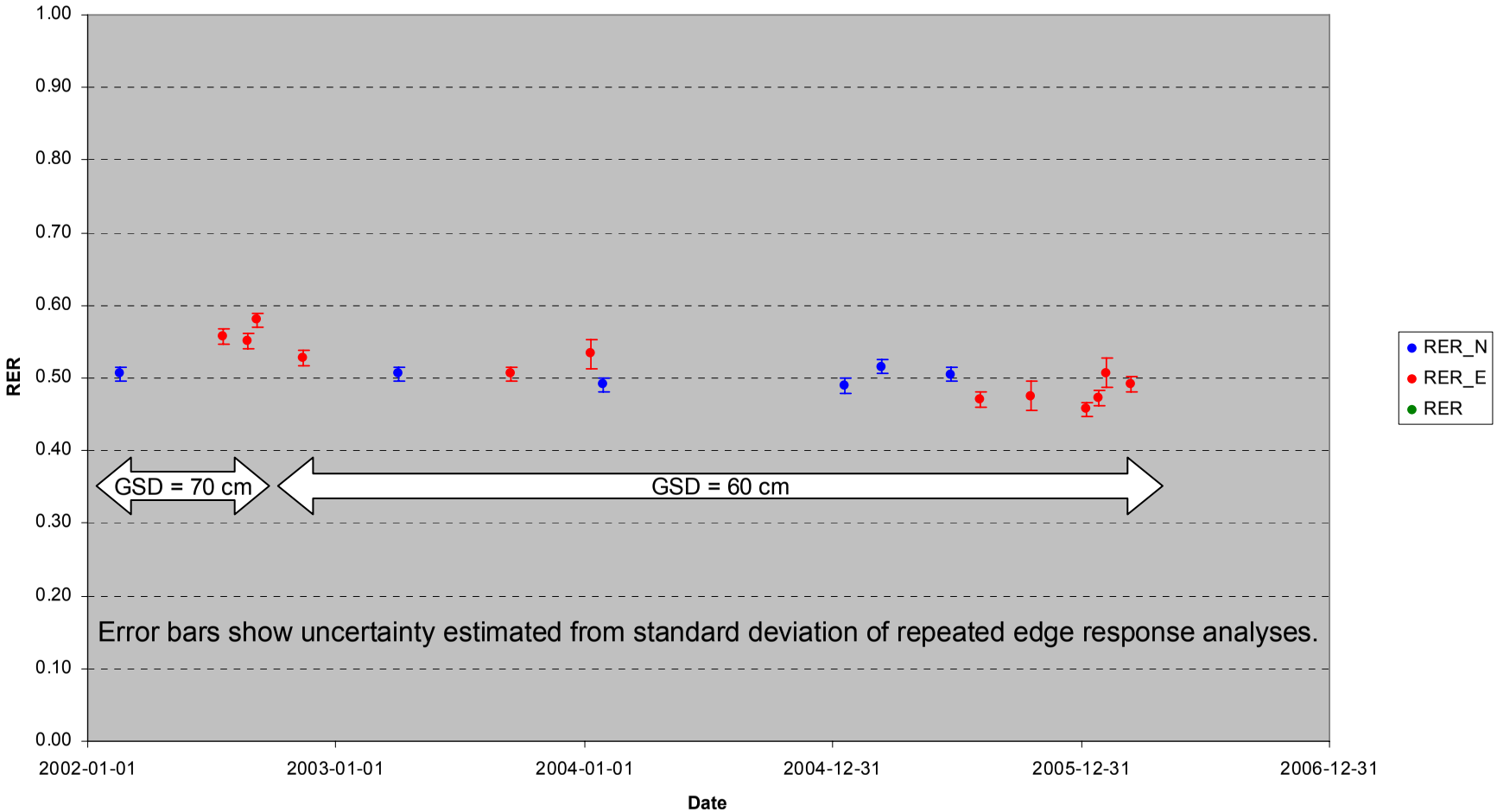
RER values are in the range between 0 (impossibly bad) and 1 (excellent).

Latest Example of QuickBird RER



4-Year Stability of Spatial Resolution

For QuickBird panchromatic images processed with the cubic convolution resampling kernel, RER is approximately equal to 0.5



Radiometric Characterization

Radiometric Vicarious Calibration

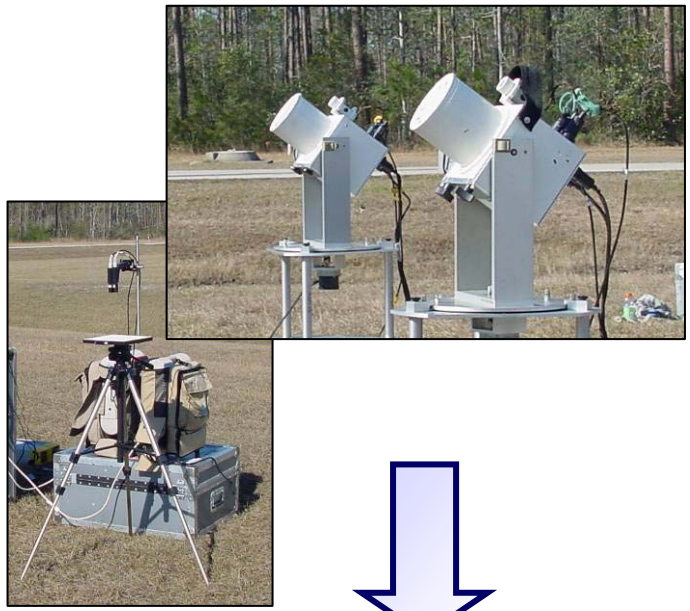
- Reflectance-based approach
- Ground truth collected near-coincident with a satellite overpass
  - Characterize targets: reflectance, BRDF (Bidirectional Reflectance Distribution Function)
  - Characterize atmosphere: transmission, aerosol, water vapor
- Use MODTRAN radiative transport code with ground truth data to predict at-sensor radiance
- Compare predicted at-sensor radiance to actual radiance acquired by sensor

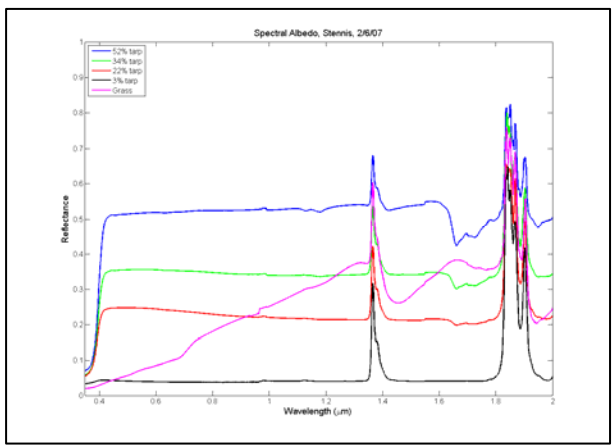
Ground Truth Collection and Processing

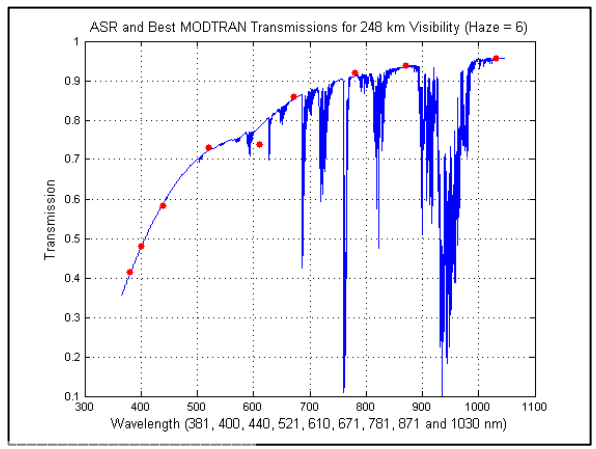
Stennis Space Center

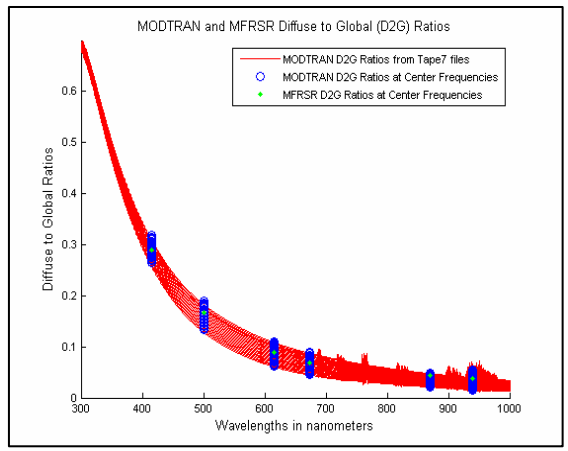
Target

Atmosphere







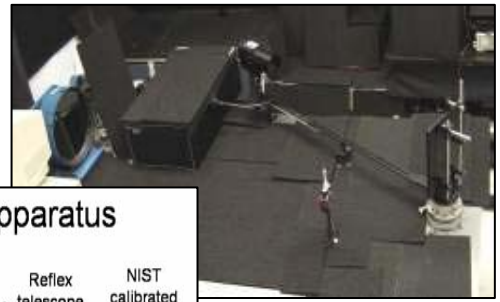


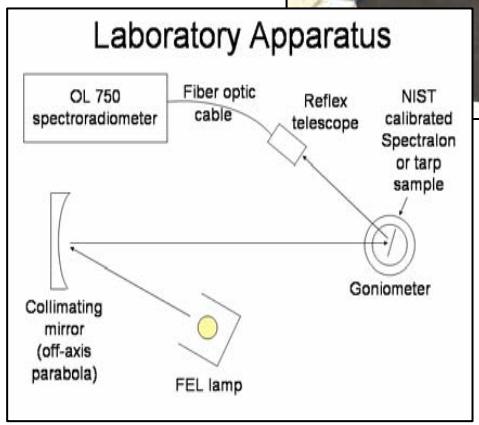
Reflectance | **Transmission** | **Diffuse-to-Global Ratio**

Ground Truth Collection and Processing (cont)

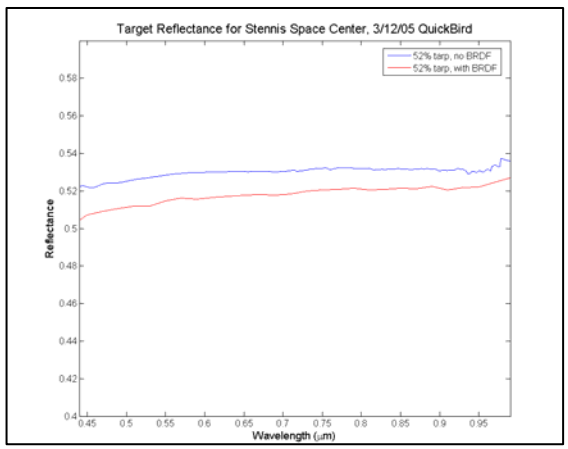
Stennis Space Center

Target



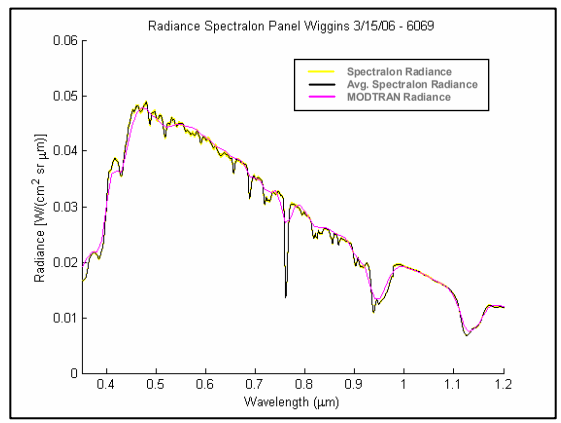


Laboratory Calibration and Environmental Testing of Field Equipment



BRDF Corrected Reflectance

Atmosphere



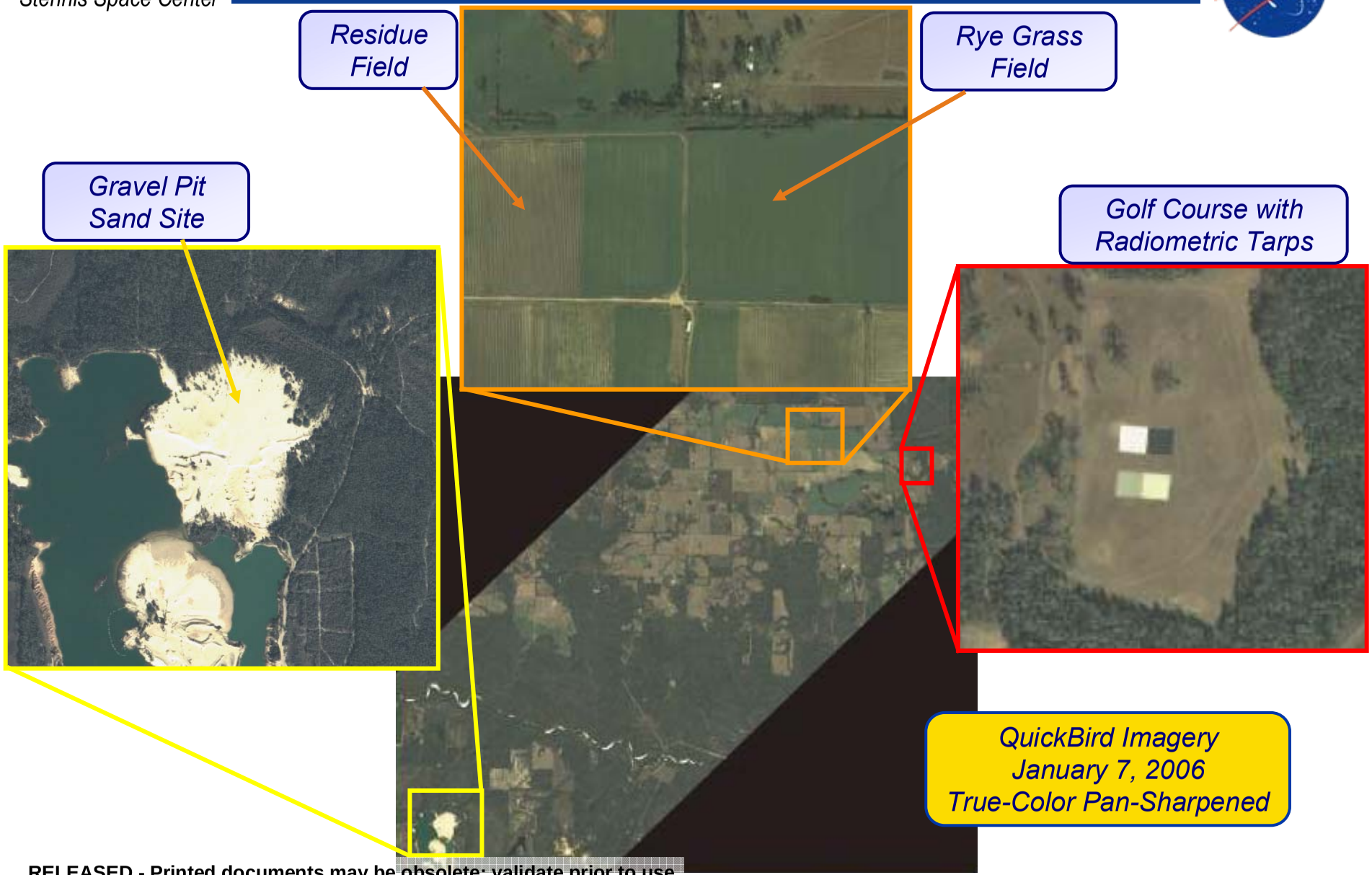
Spectralon Panel Radiance

NASA Stennis Space Center, MS

Stennis Space Center

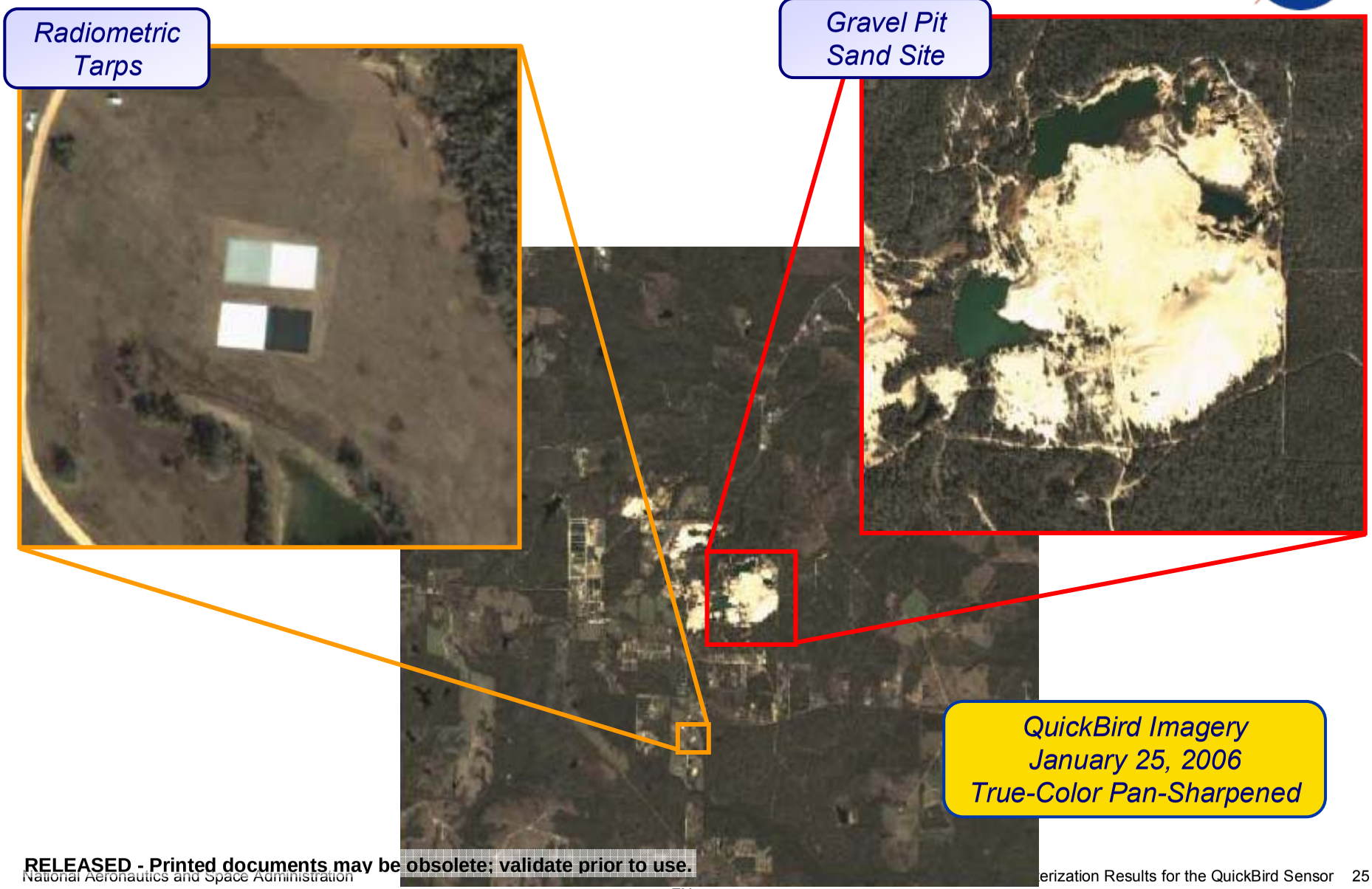
QuickBird Imagery
February 7, 2006
True-Color Pan-Sharpened

Wiggins, MS, East



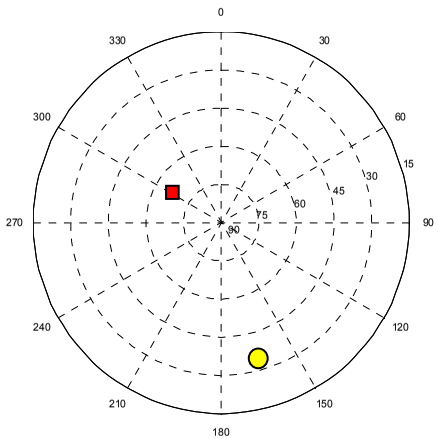
Wiggins, MS, West

Stennis Space Center

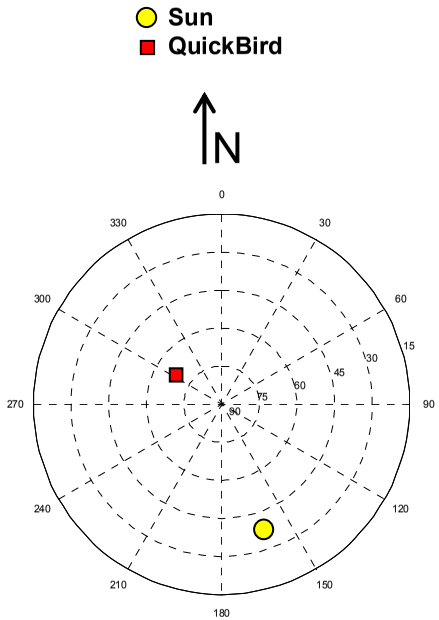


Data Acquisitions

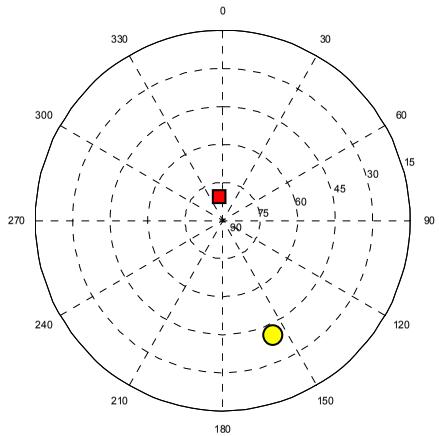
Site/Date	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
Wiggins East 1/7/06	17:05	67.8 deg	301.9 deg	35.3 deg	163.7 deg
Wiggins West 1/25/06	17:05	68.8 deg	304.0 deg	38.1 deg	160.7 deg
Stennis 2/7/06	17:01	83.9 deg	356.4 deg	41.0 deg	157.0 deg
Wiggins East 3/15/06	17:02	76.9 deg	321.3 deg	54.2 deg	152.7 deg



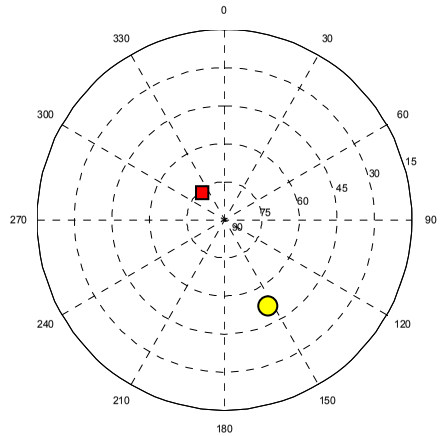
Wiggins, MS, 1/7/06



Wiggins, MS, 1/25/06

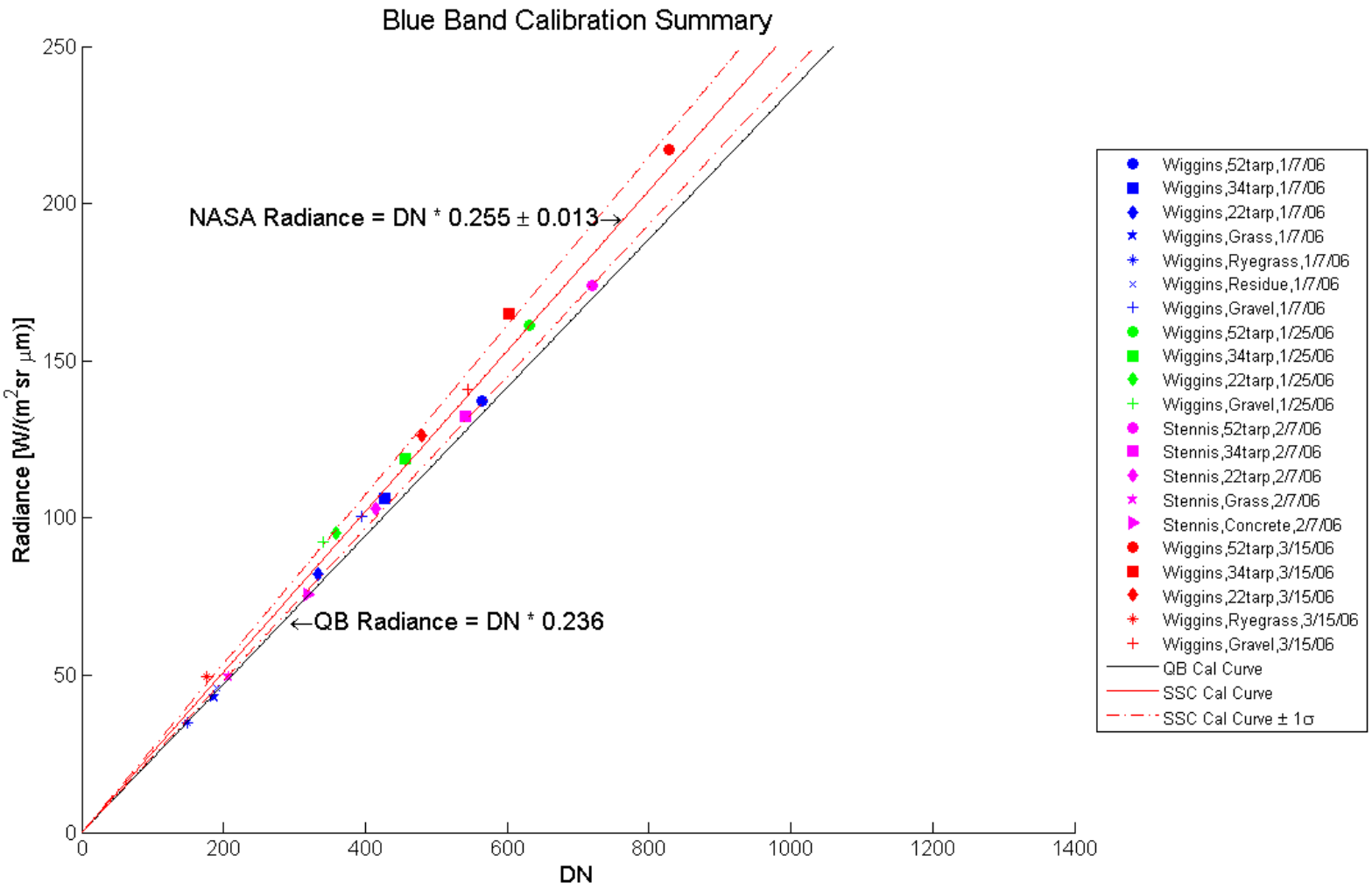


Stennis, MS, 2/7/06

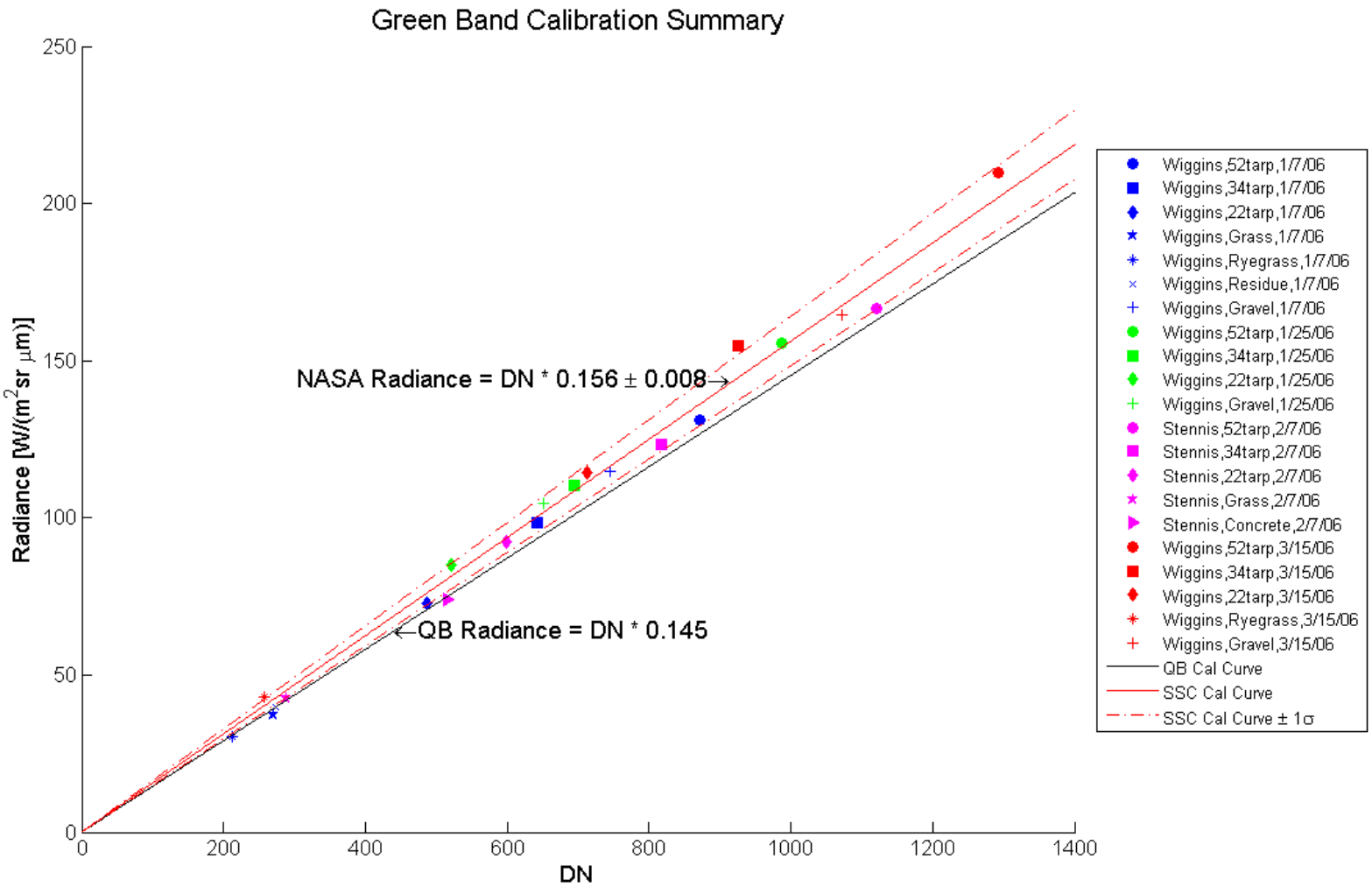


Wiggins, MS, 3/15/06

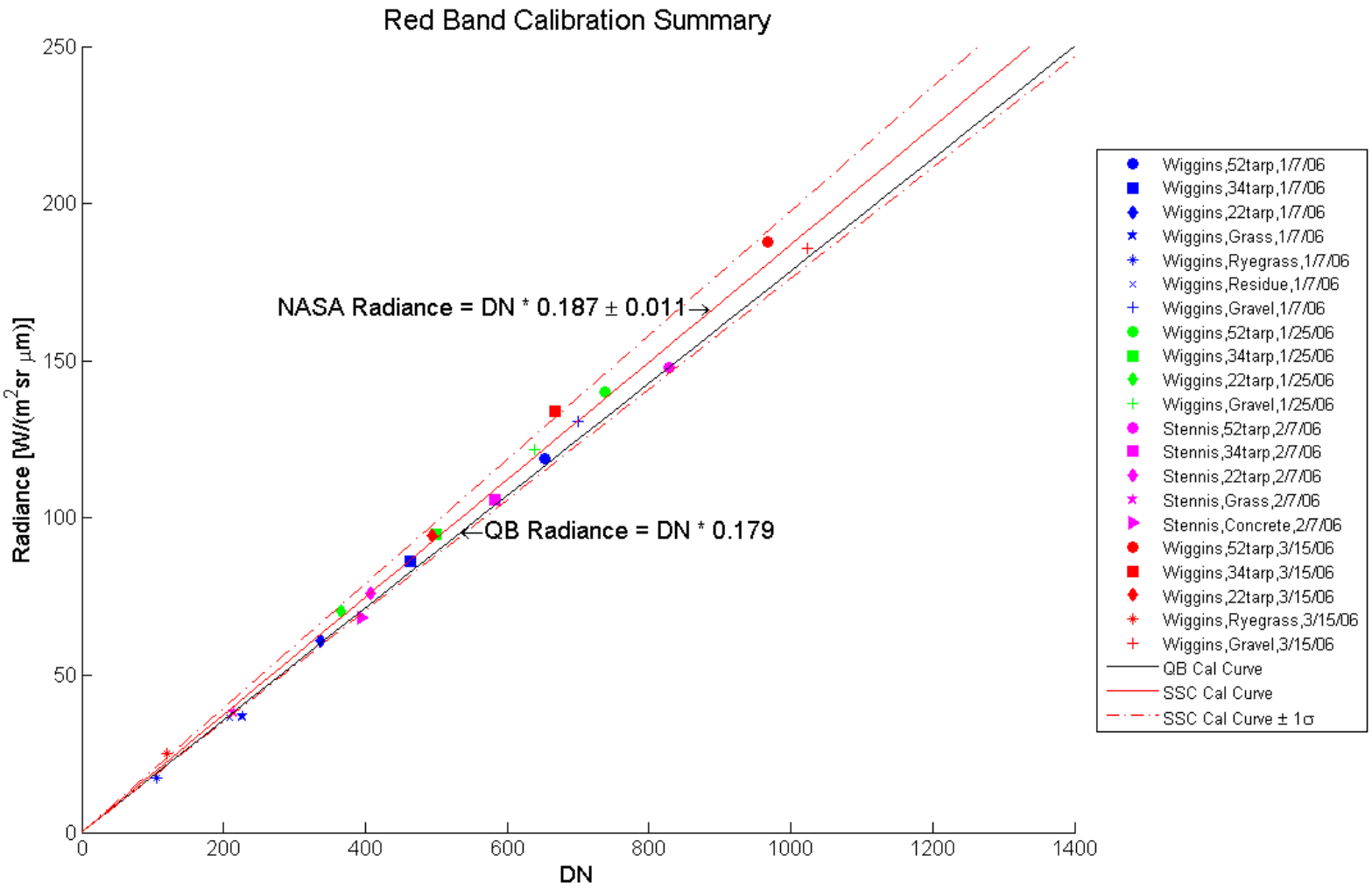
QuickBird Blue Band Calibration Summary



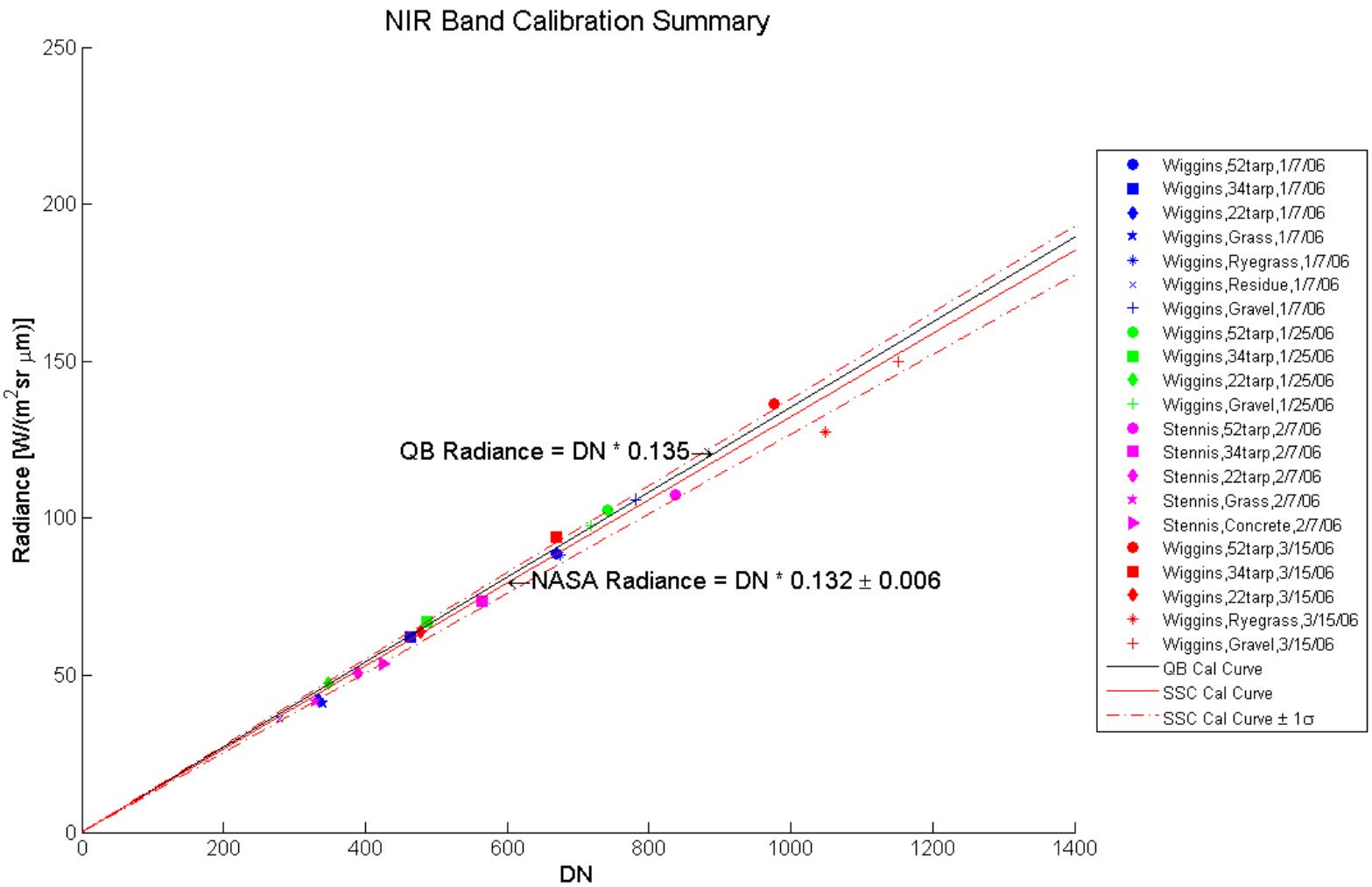
QuickBird Green Band Calibration Summary



QuickBird Red Band Calibration Summary



QuickBird NIR Band Calibration Summary



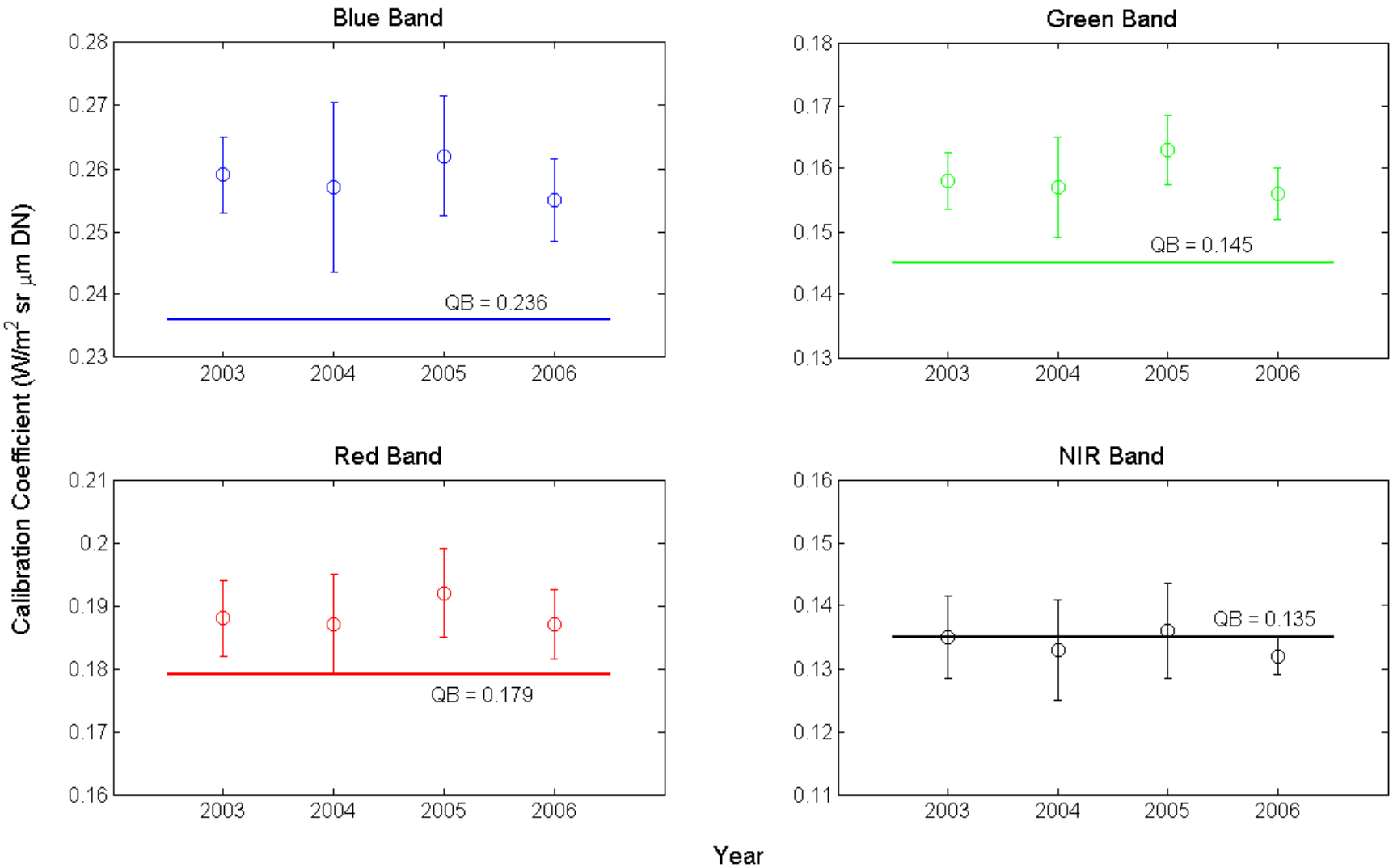
2006 QuickBird Radiometric Assessment

Average Spectral Radiance Calibration Coefficients

Bandwidth FWHM (μm)		NASA Estimate (W/m^2 sr μm DN)	QuickBird Provided (W/m^2sr μm DN)	% Difference
1	0.445 - 0.510	0.255 ± 0.013	0.236	7.5%
2	0.500 - 0.595	0.156 ± 0.008	0.145	7.1%
3	0.620 - 0.690	0.187 ± 0.011	0.179	4.3%
4	0.755 - 0.875	0.132 ± 0.006	0.135	-2.3%

Percent difference is calculated by (1 – QuickBird/NASA Mean)

Radiometric Temporal Results



System Characterization Summary

- Geopositional Characterization
  - The mean CE_{90} of QuickBird panchromatic Standard images was 10.8 m, with the 95% CI from 4.9 m to 16.7 m
  - Results appeared improved over the previous analyses, which had mean CE_{90} of 19.2 m with CI from 14.5 m to 23.8 m
- Spatial Characterization
  - The QuickBird panchromatic cubic convolution resampled imagery RER is approximately 0.5
  - The spatial resolution of QuickBird has been temporally stable
- Radiometric Characterization
  - The QuickBird calibration coefficients continue to agree reasonably well with the NASA estimates (within 8%)
  - The QuickBird temporal radiometric calibration has been extremely stable (differences in estimates from 2.5% to 4.5%)

Contributors

NASA Stennis Space Center

Troy Frisbie
Thomas Stanley

Science Systems and Applications, Inc.

Brennan Grant
Kelly Knowlton
Roxzana Moore
Mary Pagnutti
Robert E. Ryan
Ruby Stubbs
Steve Tate

Computer Sciences Corporation

Ronald Vaughan

Participation in this work by Science Systems and Applications, Inc., was supported by NASA at the John C. Stennis Space Center, Mississippi, under Task Order NNS04AB54T.