Measurement Sets and Sites Commonly Used for High Spatial Resolution Image Product Characterization

2006 EO/IR Calibration and Characterization Workshop

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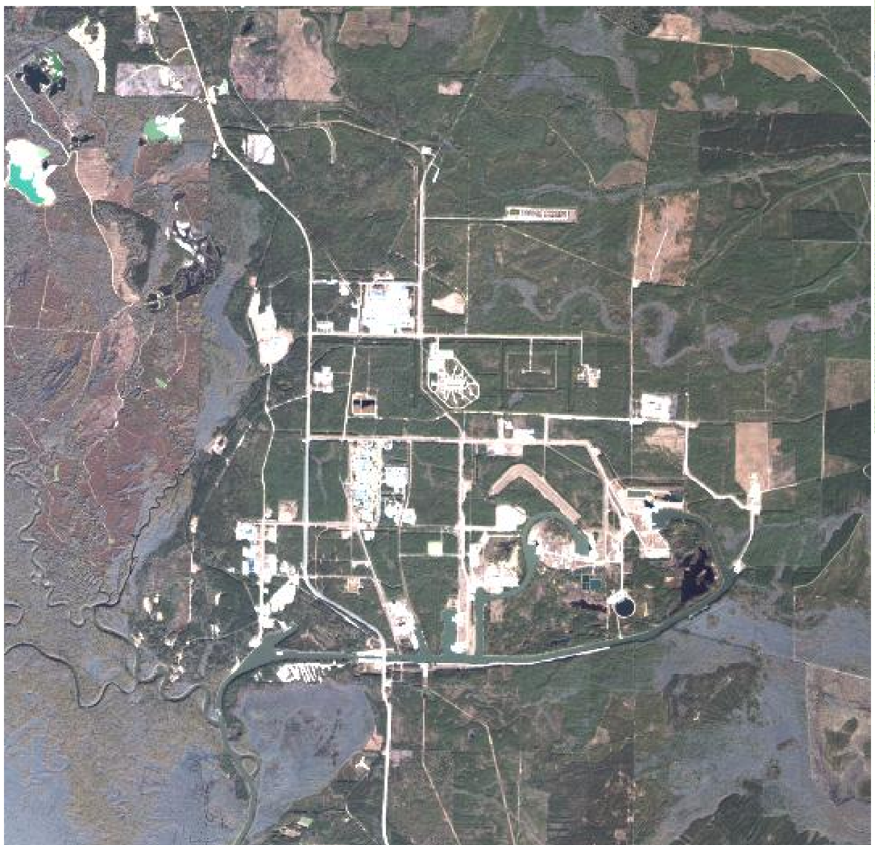
Remote Sensing Data Characterizations

Passive Electro-Optical Systems

- To make sound decisions based on remotely sensed data, scientists and others who use the data need to have a high level of confidence in the data
- Characterizations fall into 3 categories
  - Geometric (absolute and relative)
  - Spatial (GSD, image sharpness-MTF, edge response, …)
  - Radiometric (absolute and relative)
- Characterizations become particularly important when using commercially obtained imagery
  - Designed and operated outside the NASA scientific community
- A single site can be used to characterize high-spatial resolution imagery
  - Increased spatial resolution and decreased swath

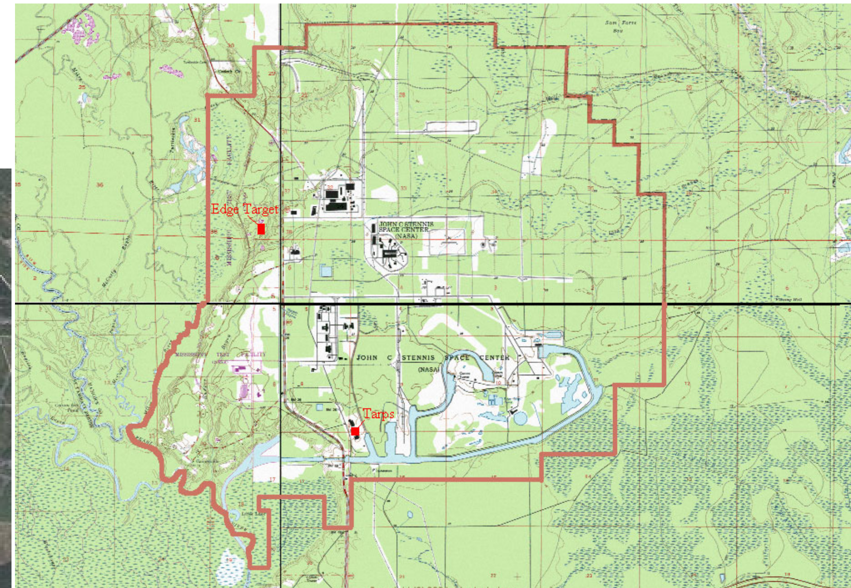
NASA Stennis Space Center, MS

Site: 55 km^2, scattered buildings within a heavily wooded area, manmade reservoirs and canals.



Nicholson Quad

Dead Tiger Creek Quad



Haaswood Quad

Logtown Quad

Elevation: 5.5 m -10 m

Centerpoint: 30.39° N, 89.61° W

Geometric Characterizations

Geometric Characterization

- Site Requirements
  - Array of at least 20 positionally known and identifiable points located evenly throughout the image acquisition area
    - Known to an order of magnitude better than the spatial resolution of the system being characterized
    - National Standard for Spatial Data Accuracy (NSSDA)
- Characterization Technique
  - Compare georeferenced image pixels to surveyed points to determine check point error
  - Calculate measure of merit
    - CE_{90}
    - CE_{95}

SSC Geolocation Targets – Ground Control

SSC Geodetic Targets

- 45 targets currently deployed
- 2.44-m diameter, painted white
- 0.6-m diameter, center painted red
- Target centers geolocated by GPS to within 3 cm horizontal CE_{90} and 9 cm vertical LE_{90}

Painted Manhole Covers

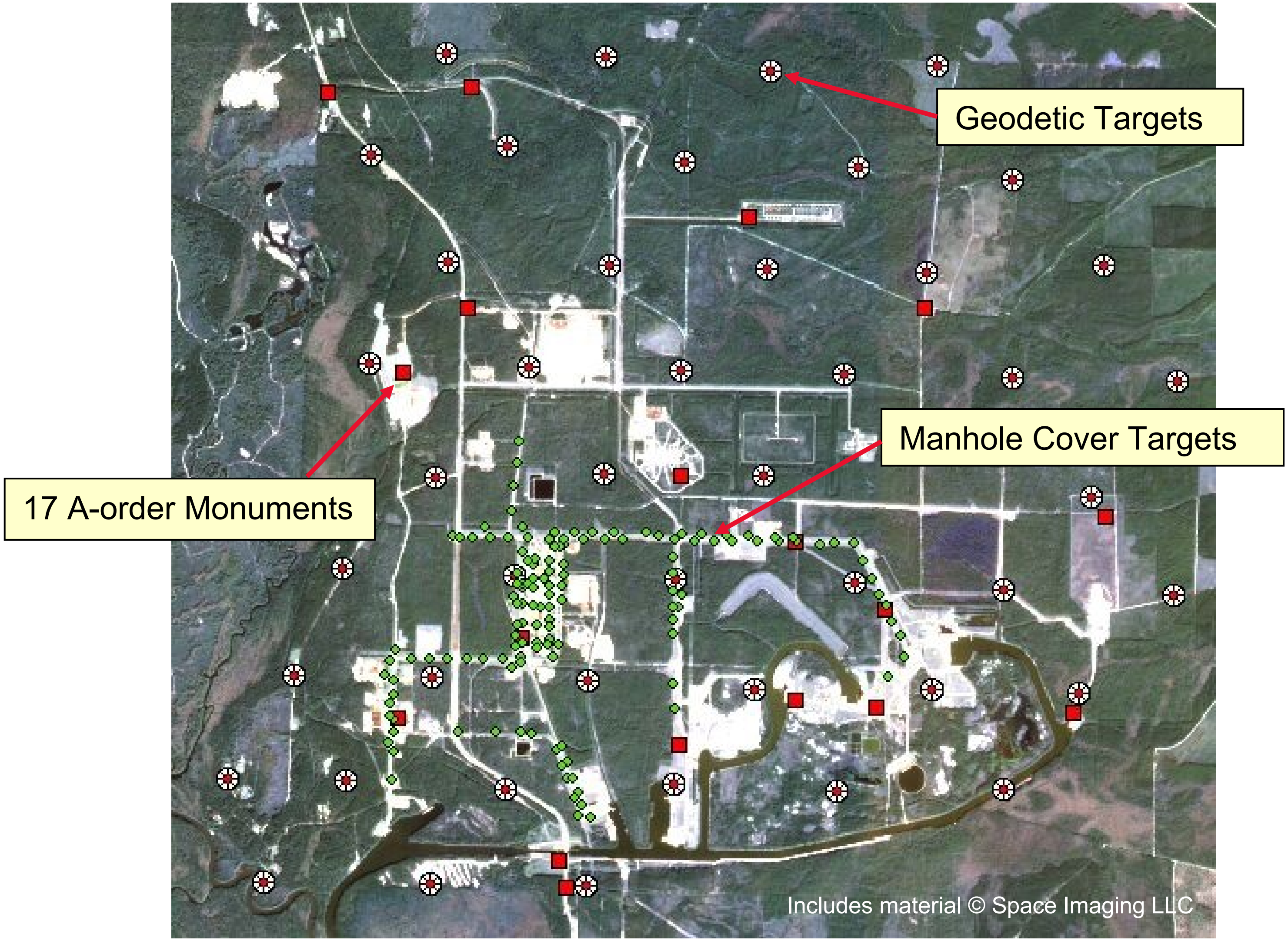
- 136 painted manhole covers
- ~0.65 paint reflectivity
- 0.6- to 2.9-m diameter
- Target centers geolocated by GPS to within 3 cm horizontal CE90 and 9 cm vertical LE_{90}

Ground Control Point Survey

Global Positioning System (GPS) survey of ground control points

Phase differencing receiver operating in real time kinematic (RTK) mode

SSC Target Layout



Check Point Error

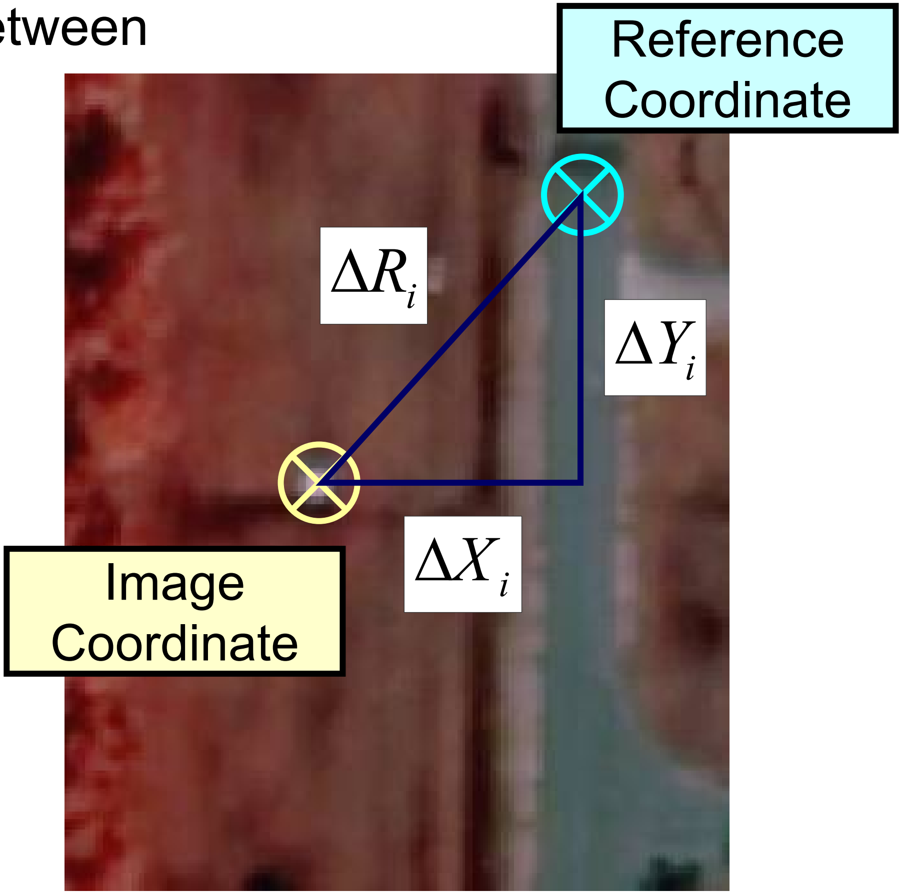
- Check Point Error – differences between image and reference coordinates

$$\Delta X_i = X_{image,i} - X_{reference,i}$$

$$\Delta Y_i = Y_{image,i} - Y_{reference,i}$$

- Check point error radial magnitude calculated by

$$\Delta R_i = \sqrt{\Delta X_i^{\ 2} + \Delta Y_i^{\ 2}}$$



Circular Error Definitions

- CE_{90} – The radial error which 90% of all errors in a circular distribution will not exceed (adapted from Greenwalt and Shultz, 1962)
  - **Equivalent to the Circular Map Accuracy Standard (CMAS)**
- CE_{95} – The radial error which 95% of all errors in a circular distribution will not exceed (adapted from Greenwalt and Shultz, 1962)
  - **Equivalent to $\mathrm{Accuracy}_r$ (from NSSDA)**
- In the normal case, circular error may be generally defined as the circle radius, R, that satisfies the conditions of the equation below (where *C.L.* is the desired confidence level); however, *there is no analytical solution to this equation*.

$$C.L. = \int_{-R}^{R} \int_{\sqrt{R^2 - x^2}}^{\sqrt{R^2 - x^2}} \frac{1}{2\pi\sigma_x\sigma_y\left(1-\rho^2\right)} \exp\left[\frac{-1}{2\left(1-\rho^2\right)}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]\right] dydx$$

- Empirical approach to CE_{90} where $CE_{90} = 90^{th}$ percentile of ΔR

Sources: Ross, K.., 2005. Geopositional statistical methods. In *Proceedings of the 2004 High Spatial Resolution Commercial Imagery Workshop,* NASA/NGA/USGS. U.S. Geological Survey National Center, Reston, VA, November 8–10, 2004. John C. Stennis Space Center, MS: National Aeronautics and Space Administration. CD-ROM.

Greenwalt, C.R., and M.E. Shultz, 1962. *Principles of Error Theory and Cartographic Applications.* ACIC Technical Report No. 96, United States Air Force, Aeronautical Chart and Information Center, St. Louis, Missouri, 98 pp.

Example Geometric Characterization – DMC

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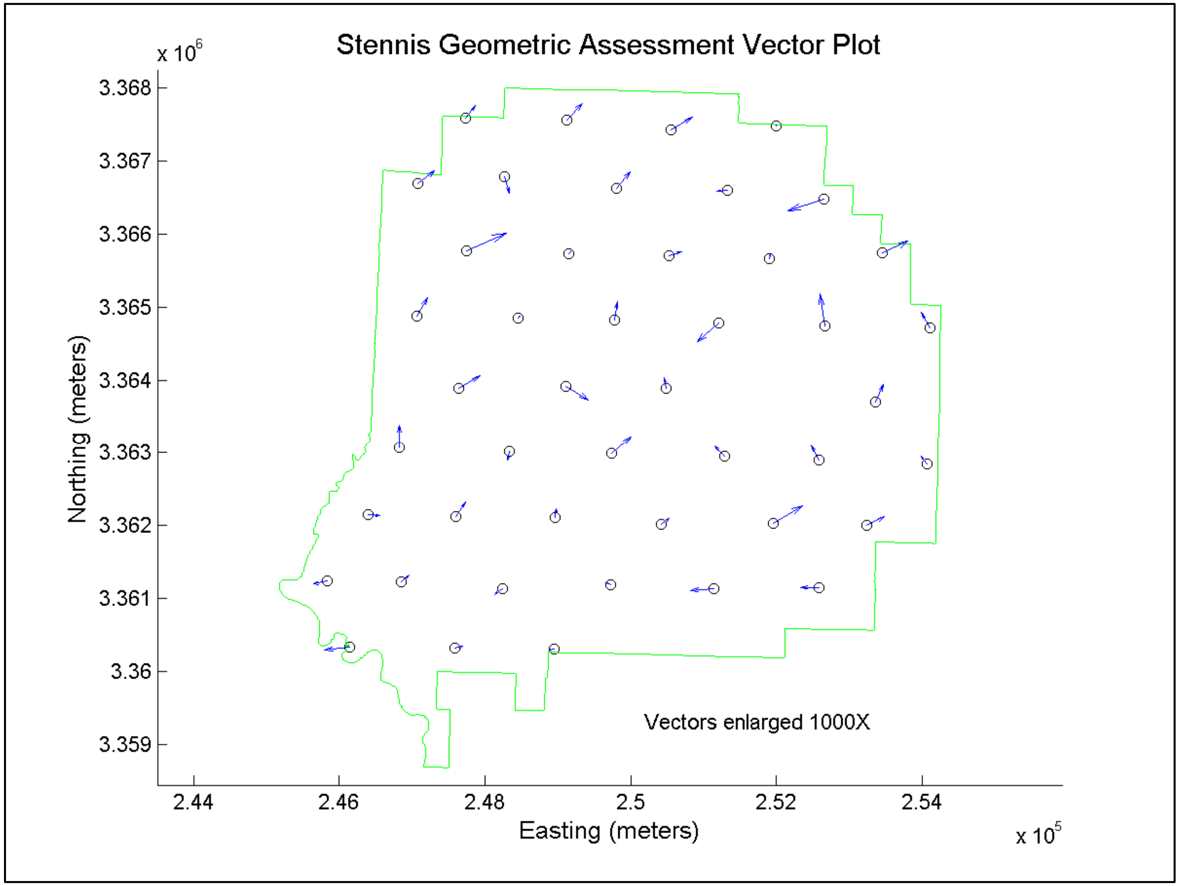
Vector Plot (ΔR)

- Standard mosaicked georeferenced image product
- 3001, Inc., generated using data captured with a Z/I Imaging Digital Mapping Camera (DMC)
- Acquired over SSC November 8, 2004



The calculations for the 0.1524 m (6 in) GSD product indicate a CE_{90} of 0.39 m, a CE_{95} of 0.48 m, and a net RMSE of 0.27 m

Example Geometric Characterization – OV-3

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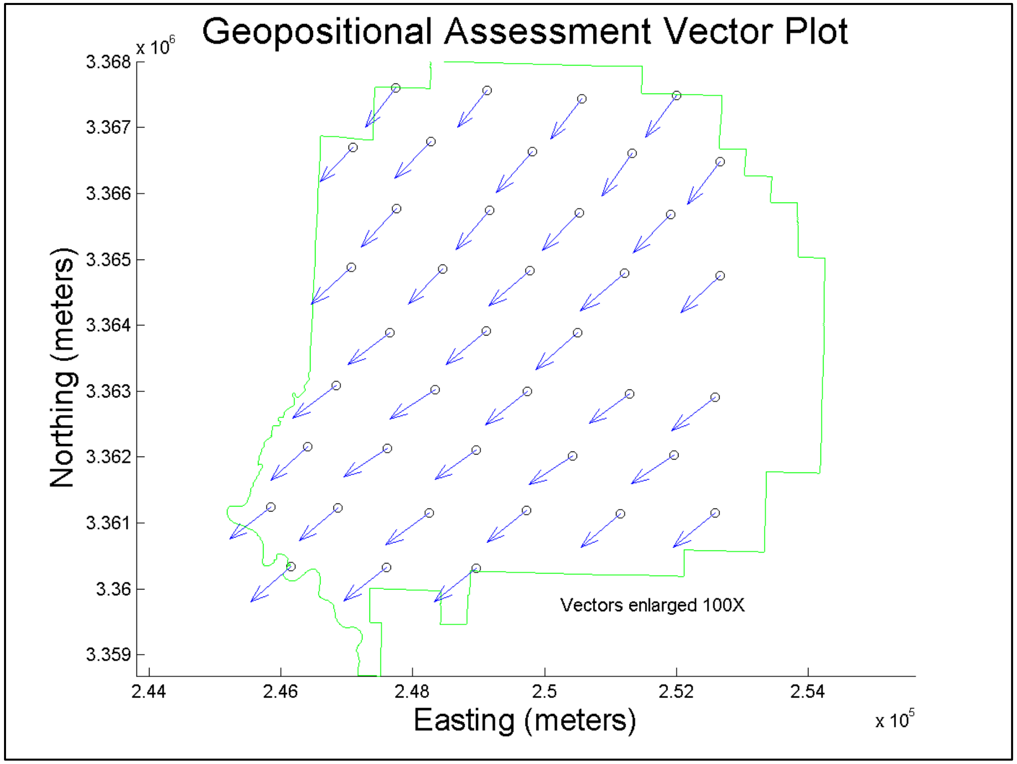
OrbView-3			
Acquisition Date	9/17/2003	***Imagery Band***	PAN
Number Targets Used		**Error Components**	
n	40	***μ_H (Bias)***	7.92 m
Test for Departure from Circular Distribution		***σ_C (Circular Standard Error)***	0.64 m
St. Dev. Min Max Ratio	0.84	***μ_H/σ_C***	12.40
St. Dev. Min Max Ratio should be at least 0.6 for Circular Error assumptions.		If μ_H/σ_C is greater than 0.1, then error calculations should account for bias.	
Circular Error			
Empirical CE $_{90}$	8.32 m	***Empirical CE $_{95}$***	8.44 m

CE_{90} 8.32 m

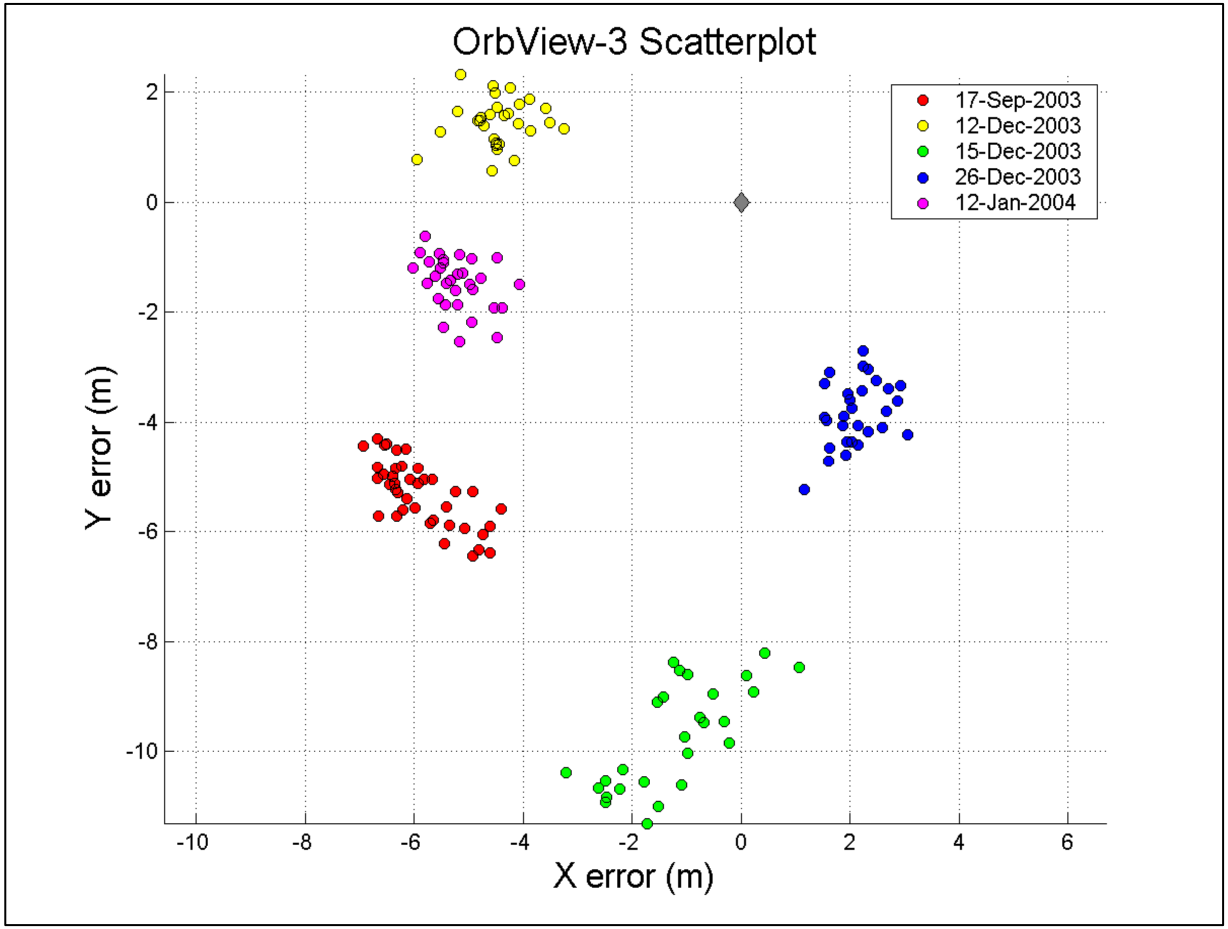
Vector Plot (ΔR)



Example Scatterplot – OV-3

- Position of point clusters away from (0,0) indicate absolute error

- Position of point within a cluster indicate relative error



Spatial Characterizations

Spatial Characterization

- Site Requirements – Edge Analysis
  - High-contrast edge
    - Contrast should strive to maximize the dynamic range of the sensor being evaluated
    - Sized such that at least 30 pixels lie across the edge (10 bright, 10 dark, 10 transition edge)
    - Edges should be formed in two perpendicular planes
- Characterization Technique
  - Edges tilted 4-8 degrees from image frame of reference
  - Edge response plotted
  - Calculate measure of merit – "sharpness" parameter
    - MTF (Modulation Transfer Function) at Nyquist frequency
    - FWHM (Full Width Half Maximum) of line spread function
    - RER (Relative Edge Response)

Tilted Edge Technique

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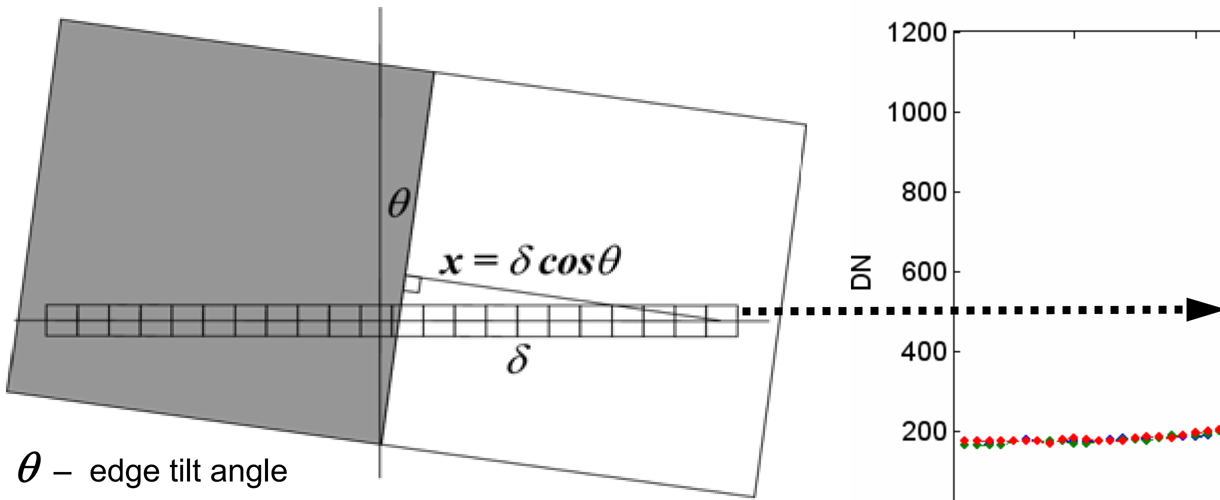
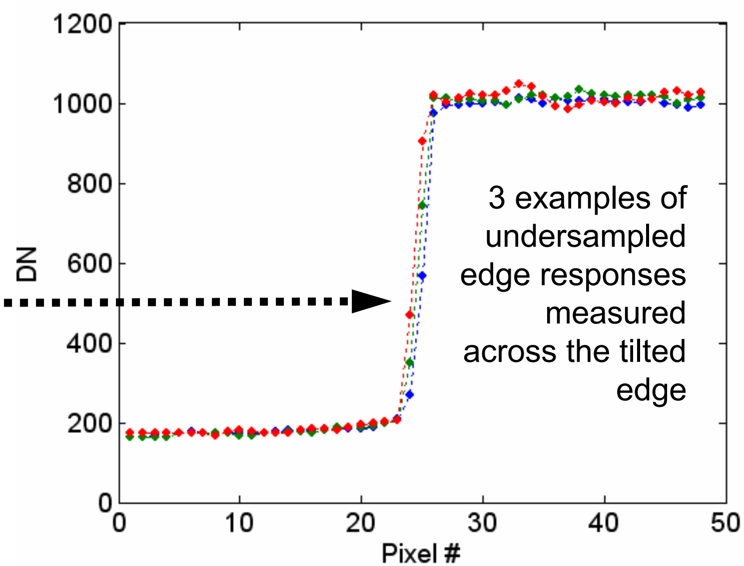
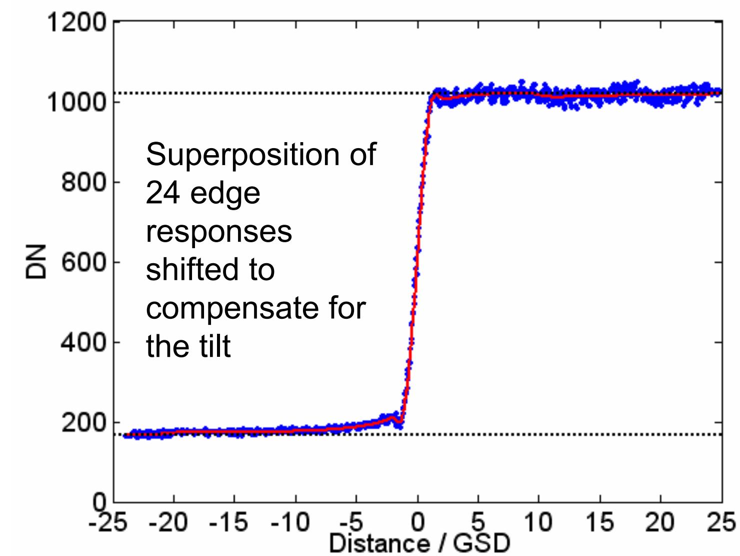


θ – edge tilt angle

δ – pixel index

x – pixel's distance from edge (in GSD)

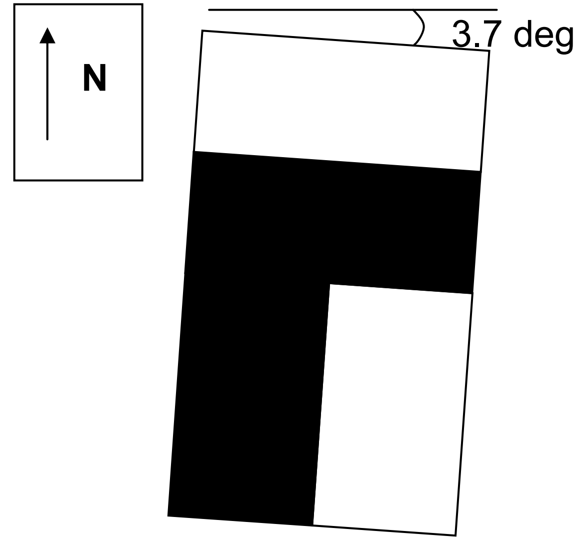


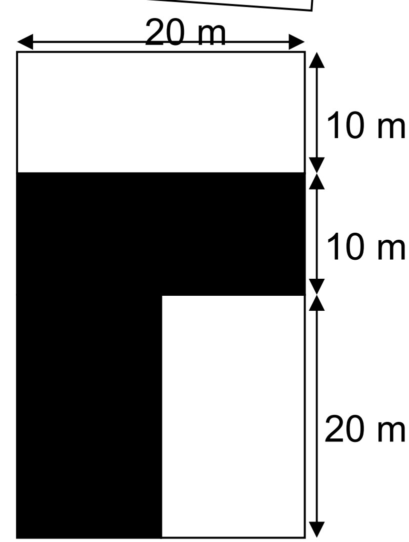


Problem: Digital cameras undersample edge target

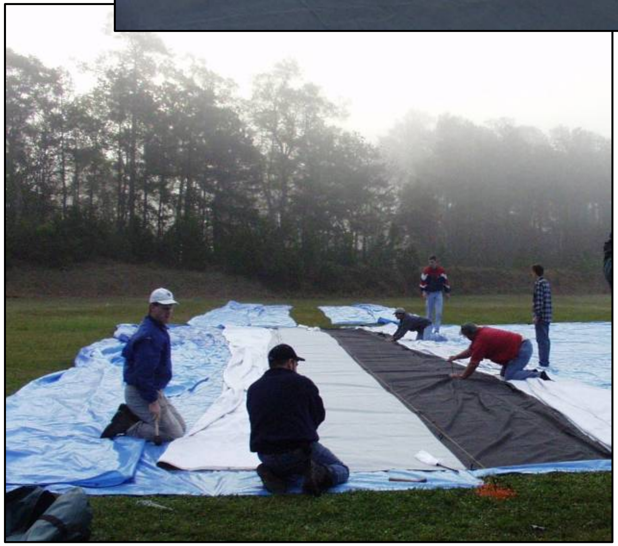
***Solution**: Image tilted edge to improve sampling*

SSC Painted Concrete Edge Targets

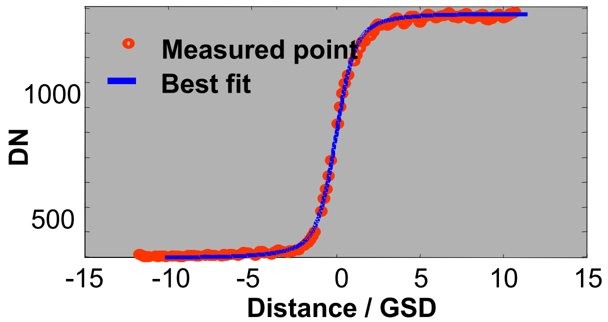




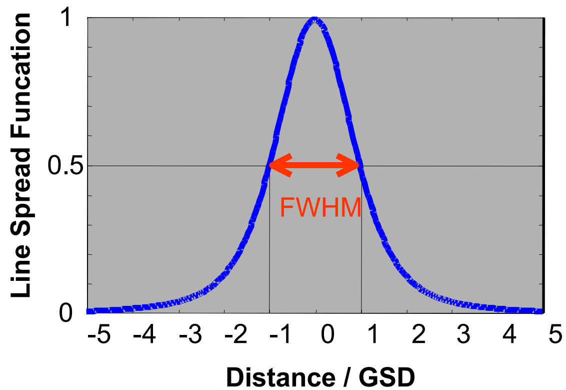
SSC Tarp Edge



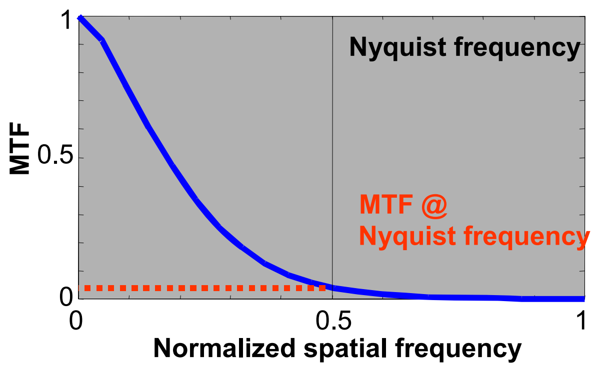
Modulation Transfer Function (MTF)



- Measured edge response along “tilted edge”

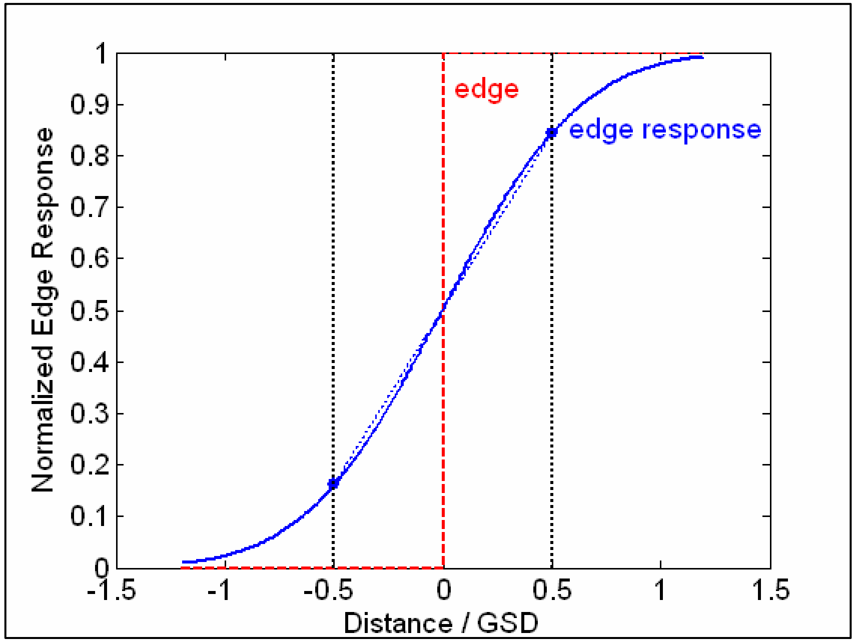


- Derivative of edge response or line spread function



- Fourier transform of line spread function or MTF
- Nyquist frequency is 0.5 * sampling frequency or (1/(2GSD))

Relative Edge Response



- Another measure of spatial resolution is a difference of normalized edge response values at points distanced from the edge by -0.5 and 0.5 GSD
- Relative Edge Response is one of the engineering parameters used in the *General Image Quality Equation* to provide predictions of imaging system performance expressed in terms of the *National Imagery Interpretability Rating Scale*.

$$RER = \sqrt{[ER_X(0.5) - ER_X(-0.5)][ER_Y(0.5) - ER_Y(-0.5)]}$$

Meaning of RER in Remote Sensing

Radiance measured for each pixel is assumed to come from the Earth's surface area represented by that pixel. However, because of many factors, actual measurements integrate radiance L from the entire surface with a weighting function provided by a system's point spread function (PSF):

$$L_T = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} PSF(x,y)L(x,y)dxdy$$

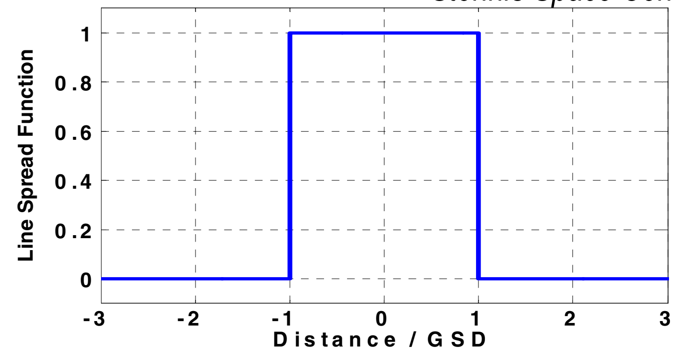
Part of radiance that originates in the pixel area is given by:

$$L_P = \int_{-0.5}^{0.5}\int_{-0.5}^{0.5} PSF(x,y)L(x,y)dxdy$$

Relative Edge Response squared (RER^2) can be used to assess the percentage of the measured pixel radiance that actually originates from the Earth's surface area represented by the pixel:

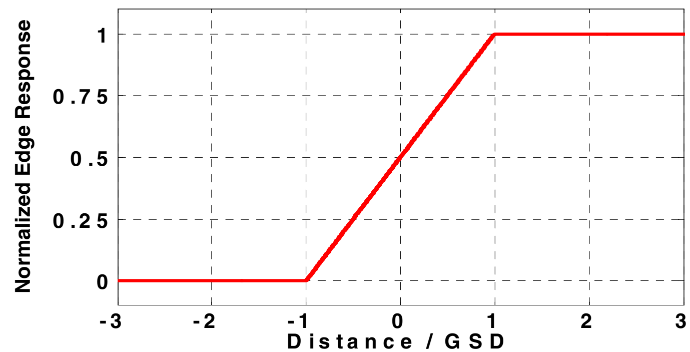
$$L_P / L_T \approx RER^2$$

A simple example:
Box PSF
Width = 2 GSD

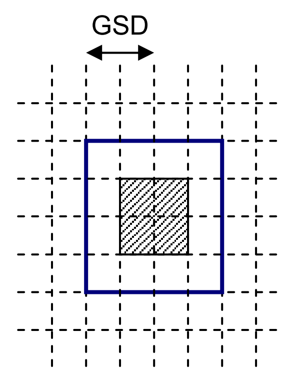


ER(0.5) - ER(-0.5) =
0.75 - 0.25 = 0.50

RER = 0.50



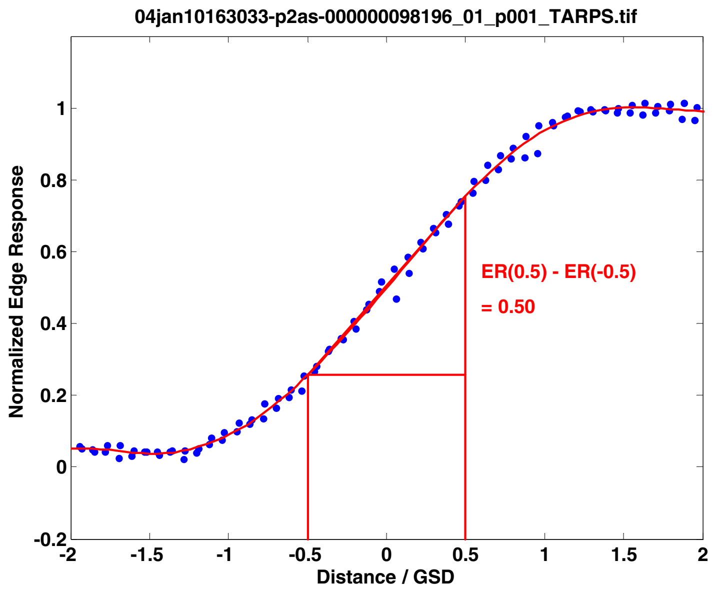
RER^2 = 0.25 means that 25% of information collected with the pixel PSF (blue square) comes from the actual pixel area (shadowed square)



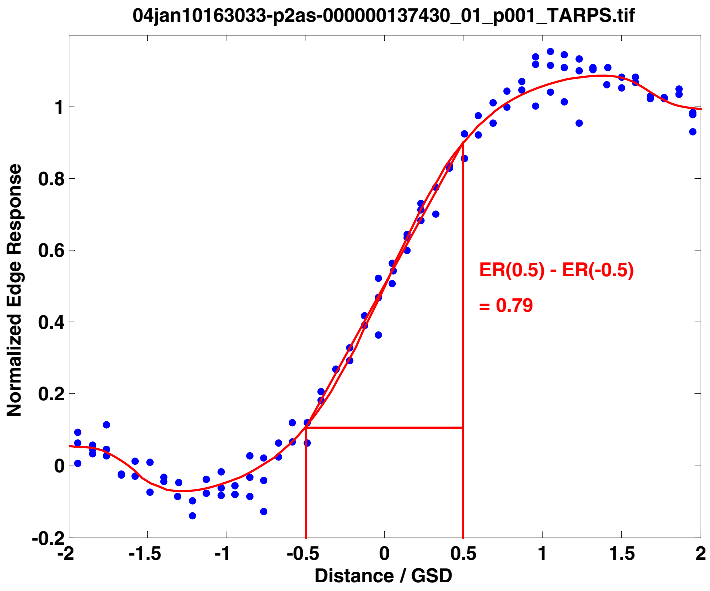
Source: Blonski, S., 2005. Spatial resolution characterization for QuickBird image products: 2003-2004 season. In *Proceedings of the 2004 High Spatial Resolution Commercial Imagery Workshop,* NASA/NGA/USGS. U.S. Geological Survey National Center, Reston, VA, November 8–10, 2004. John C. Stennis Space Center, MS: National Aeronautics and Space Administration. CD-ROM.

Example Spatial Characterization – RER

QuickBird panchromatic Imagery
acquired January 10, 2004



Cubic Convolution resampling
RER = 0.5



MTF Boost resampling
RER = 0.79

Example Spatial Characterization – QB

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Image Tracking ID	Acquisition Site	Acquisition Date	Satellite Angle (°)		Resampled GSD (m)	Resampling Method	Target Direction	$MTF_{Nyquist}$	RER
			Zenith	Azimuth					
88502	Brookings, SD	2003-09-15	6.7	287.2	0.6	CC	Easting	0.14 ± 0.01	0.51 ± 0.01
98196	SSC, MS	2004-01-10	0.6	244.0	0.6	CC	Easting	0.14 ± 0.02	0.54 ± 0.01
102569	SSC, MS	2004-01-28	15.4	8.9	0.6	CC	Northing	0.11 ± 0.01	0.49 ± 0.01
76412	Brookings, SD	2003-09-15	6.7	287.2	0.6	MTF	Easting	0.55 ± 0.07	0.84 ± 0.01
137430	SSC, MS	2004-01-10	0.6	244.0	0.6	MTF	Easting	0.50 ± 0.01	0.81 ± 0.01
102569	SSC, MS	2004-01-28	15.4	8.9	0.6	MTF	Northing	0.41 ± 0.04	0.76 ± 0.01

Spatial characterization summary of QuickBird panchromatic imagery acquired at SSC and at Brookings, SD, in the 2003-2004 time frame (± uncertainty estimated from standard deviation of multiple results).

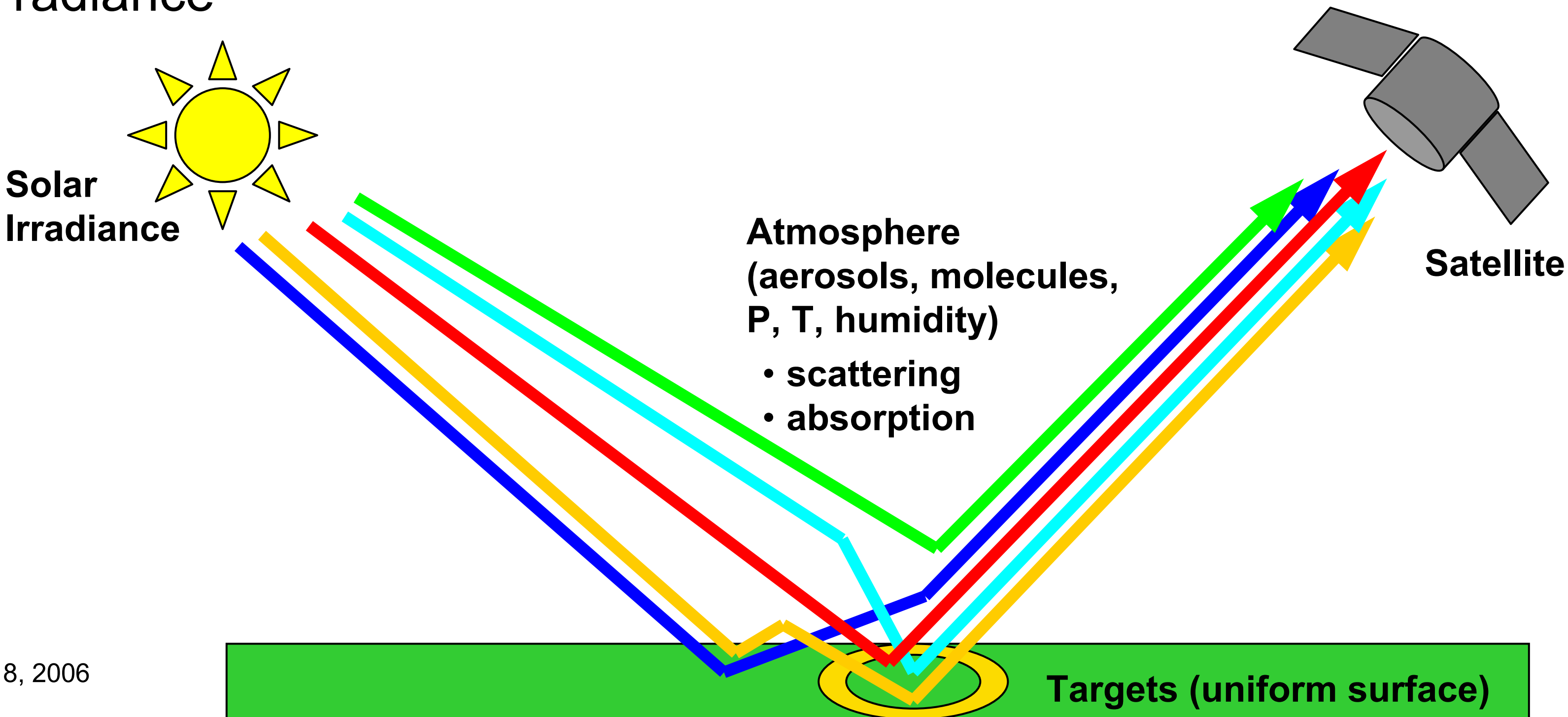
Radiometric Characterizations

Radiometric Characterization Reflective Region

- Site Requirements
  - Uniform Radiometric Targets
    - Manmade or naturally occurring
    - Sufficiently large to reduce/eliminate adjacency effects
  - Target reflectance measurement capability
  - Atmospheric measurement capability
    - Aerosols
    - Water vapor
  - Radiative transport understanding/code capability
    - MODTRAN
- Characterization Technique
  - Reflectance-based vicarious calibration approach

Reflectance-based Vicarious Calibration Approach

- Measure target/ground reflectance coincident with the satellite acquisition
- Measure atmospheric aerosols, and pressure, temperature, and water vapor profiles coincident with the satellite acquisition
- Use these measurements along with acquisition geometry/location parameters as input into a radiative transfer model to predict at-sensor radiance



NASA SSC Target Field

QuickBird image acquired
January 10, 2004
True-Color Pan-Sharpened

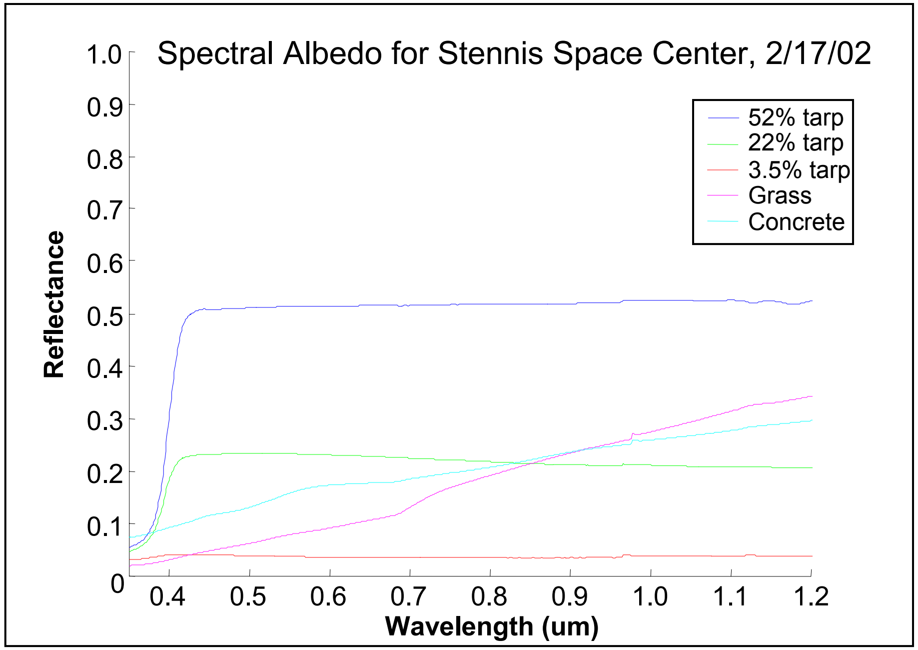
Radiometric Tarps

- Four 20-m x 20-m tarps with reflectance values of approximately 3.5%, 22%, 34%, and 52%
- Spectral measurement range of 400 to 1050 nm
- Standard deviation about average reflectance less than 1% spatially
- Peak-to-peak variation in reflectance less than 10% within any 100-nm spectral band
- Less than 10% variation in reflectance values when measuring tarps from 10° to 60° off axis
- Each side is straight to within ±6.0 cm over the 20-m length
- Each tarp panel has 60 square witness samples measuring 30.5 cm by 30.5 cm

Manufactured by
MTL Systems, Inc. / Group VIII Technology, Inc.

Reflectance Measurements

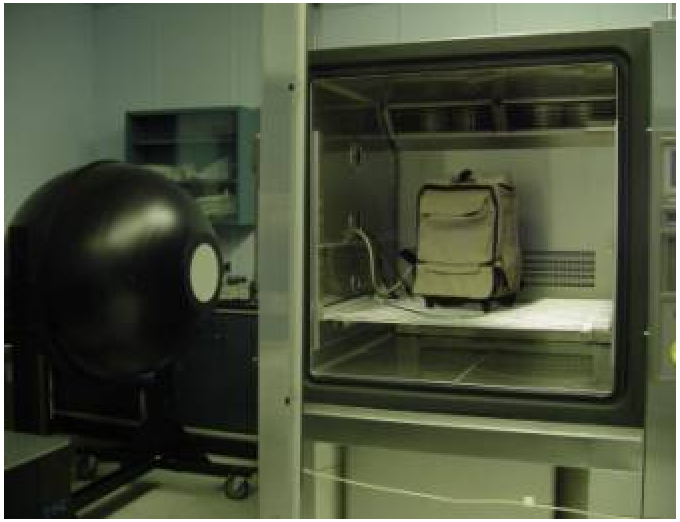
- ASD FieldSpec FR Spectroradiometers measure spectral reflectance and radiance of 99% reflectance Spectralon® panels (modified Jackson BRDF model) and radiometric targets
- ASD FieldSpec FR Spectroradiometers are radiometrically calibrated in the SSC Instrument Validation Lab (IVL) before field use



- All measurements taken within ±20 minutes of satellite overpass
- Most acquisition dates utilized multiple ASDs for cross comparison
- Typically 1000+ spectra are averaged for each target

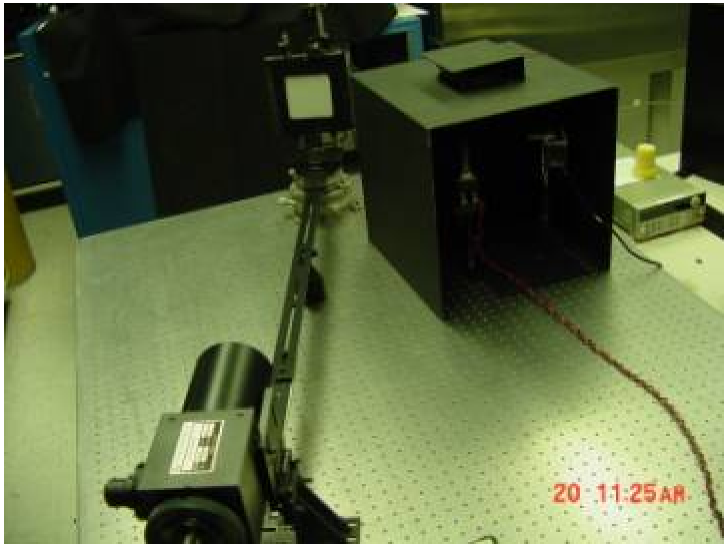
Calibration and Characterization of ASD FieldSpec Spectroradiometers

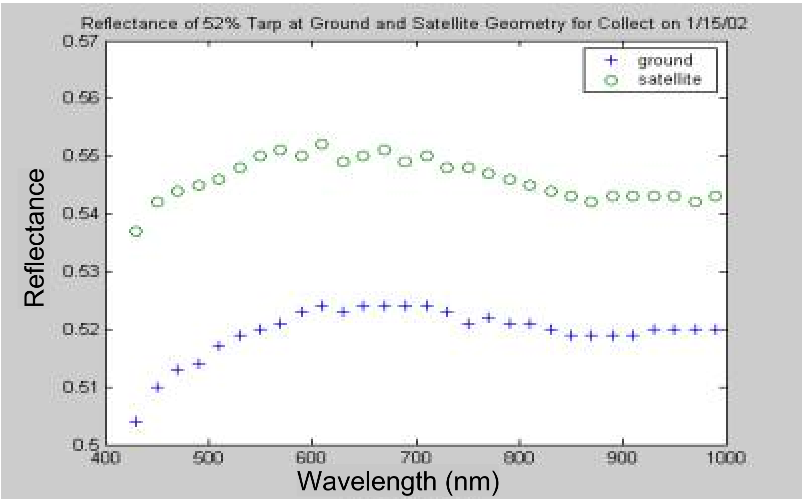
- NASA SSC maintains four ASD FieldSpec FR spectroradiometers
  - Laboratory transfer radiometers
  - Ground surface reflectance for V&V field collection activities
- Radiometric Calibration
  - NIST-calibrated integrating sphere serves as source with known spectral radiance
- Spectral Calibration
  - Laser and pen lamp illumination of integrating sphere
- Environmental Testing
  - Temperature stability tests performed in environmental chamber



Laboratory BRDF Measurements

- Purpose
  - Laboratory BRDF measurements are used to correct ground-based reflectance measurements for satellite viewing and for solar illumination geometry
- Method
  - Collimated FEL lamp source
  - NIST-calibrated Spectralon panel serves as reference
  - Goniometer-mounted sample controls illumination geometry
  - Optronics OL750 hyperspectral instrument measures spectra





Atmospheric Measurements

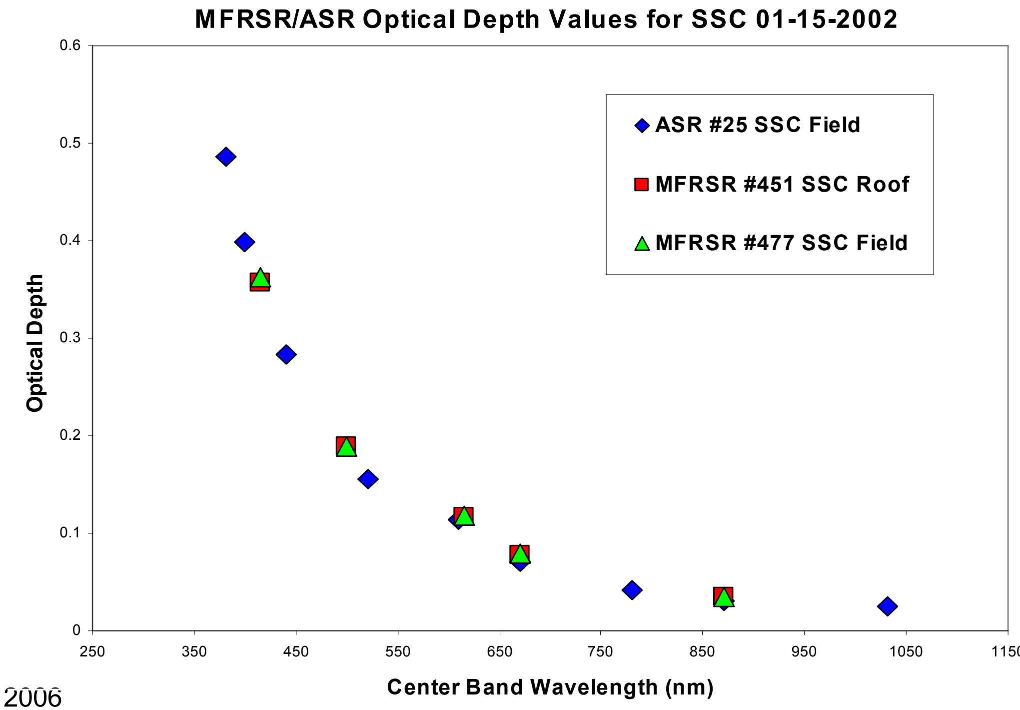
- Cloud cover monitoring – Total Sky Imager
- Direct solar irradiance – Automated Solar Radiometer
- Direct, total, and diffuse irradiance – Multi-filter Rotating Shadow-band Radiometer
- Direct, total, and diffuse radiance – ASD Spectroradiometer/Spectralon white reference
- Vertical profiles of temperature, pressure and relative humidity – Radiosonde Balloon





Cross Comparison of Atmospheric Data

Optical depth comparisons are made between fielded instruments that have different channels and measurement principles.



ASR Channels	MFRSR Channels
380 nm	
400 nm	415
440 nm	
520 nm	500
610 nm	615
670 nm	673
780 nm	
870 nm	870
1030 nm	

MODTRAN At-Sensor Radiance Prediction Process

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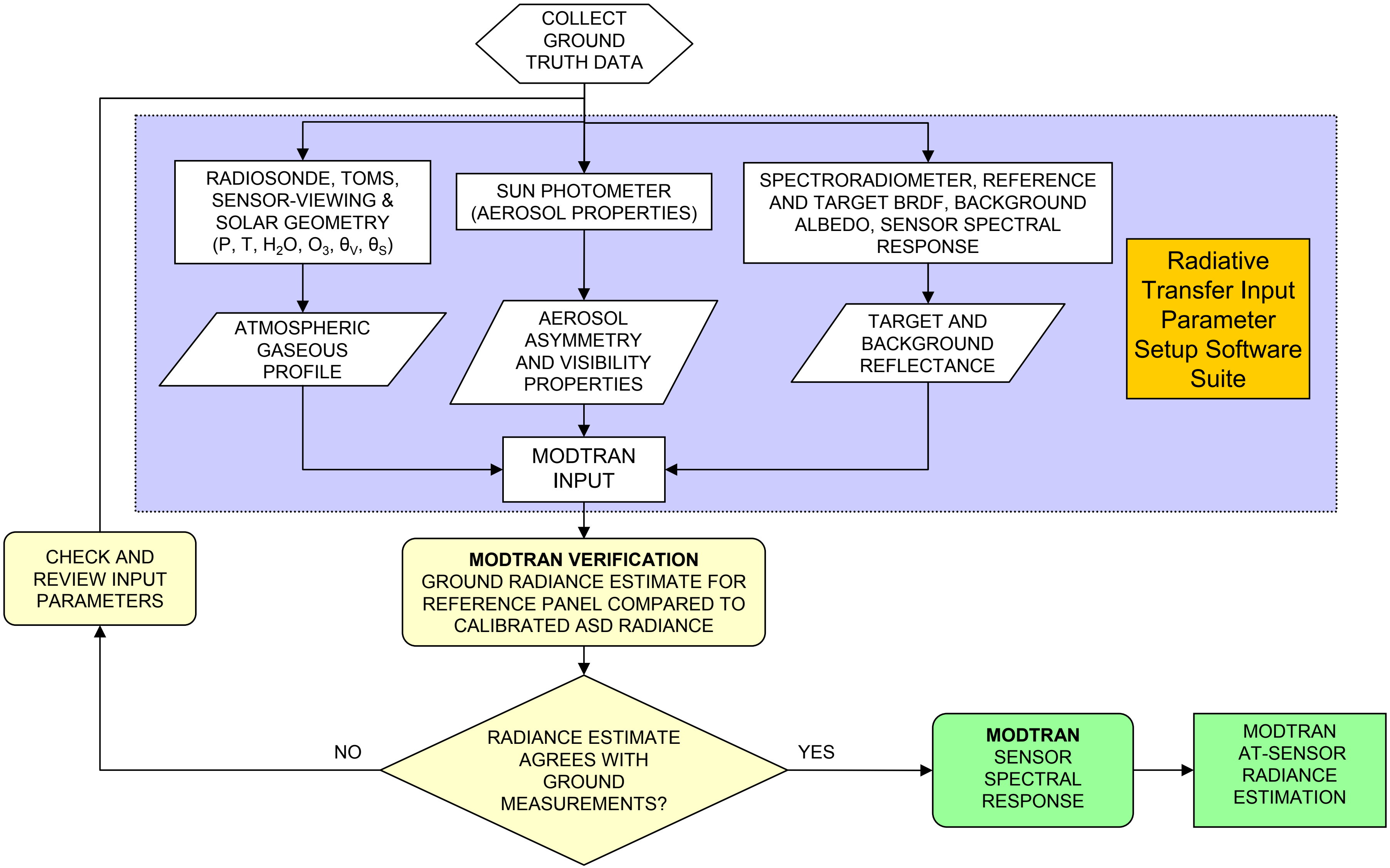

Visibility and Aerosol Asymmetry Estimation

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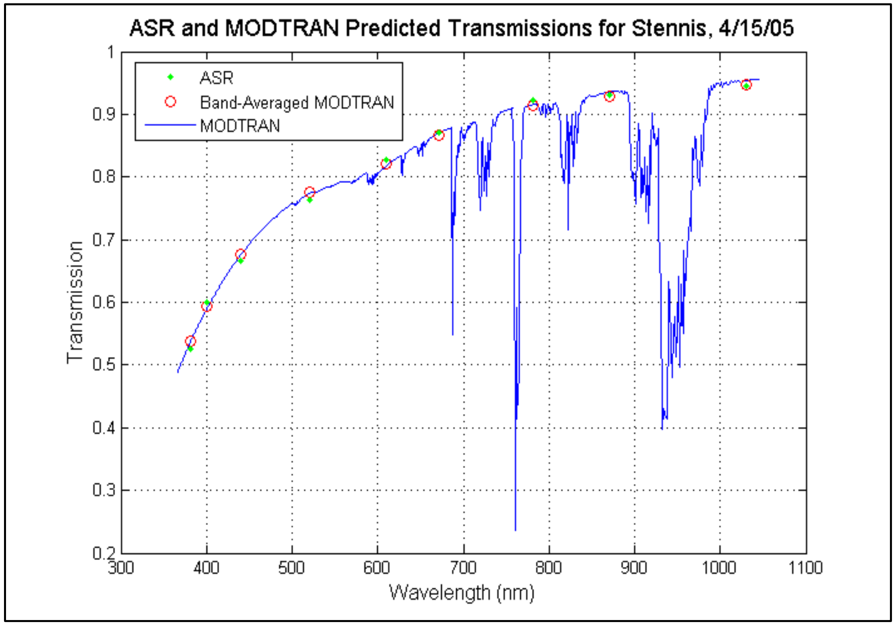
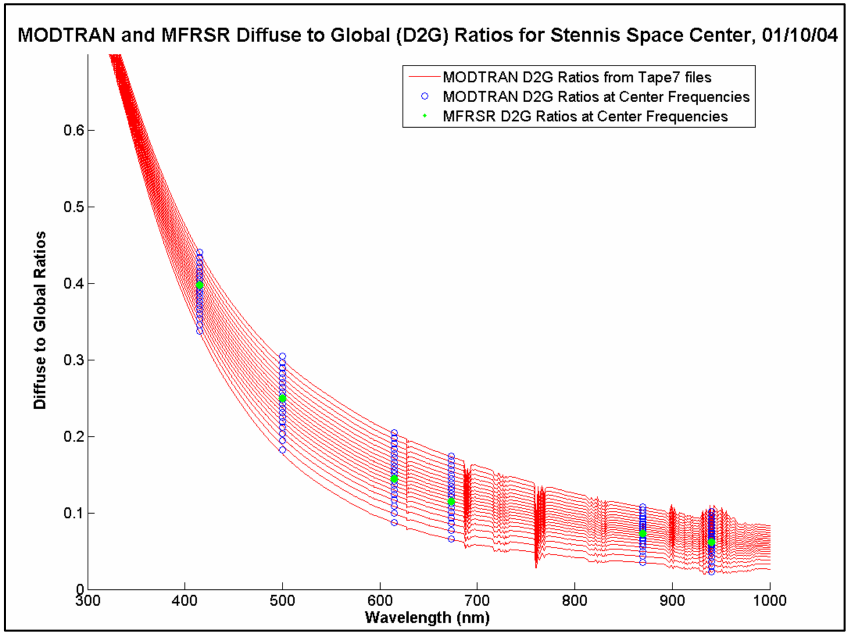


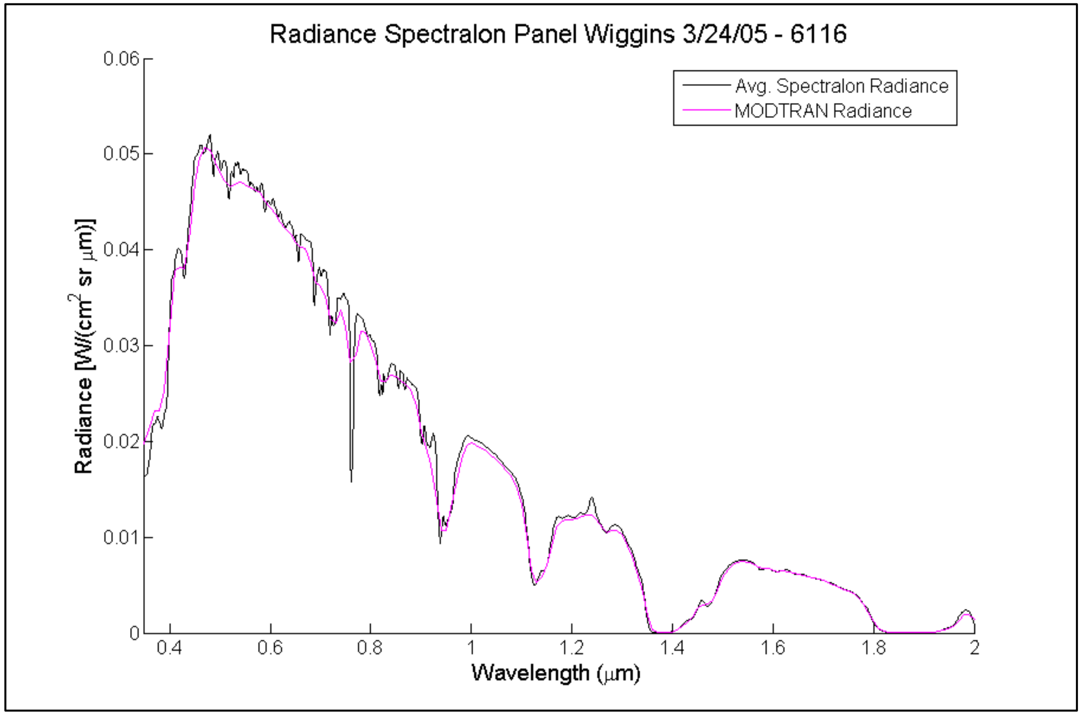


Visibility is estimated by comparing MODTRAN output transmission values to ASR measured values

The asymmetry factor for the aerosol scattering phase function is estimated by comparing MODTRAN output diffuse-to-global ratio values to MFRSR measured diffuse-to-global ratio values

Comparison to Spectralon Panel

- Verification of parameters used to generate MODTRAN at-sensor radiance estimate
  - Measuring the radiance of Spectralon panel with a well-calibrated spectroradiometer is a way of measuring atmospheric global and diffuse irradiance
  - Use ground truth data and geometry modeling an ASD FieldSpec FR spectroradiometer measuring a 99% reflectance Spectralon panel as input to MODTRAN to predict radiance
  - Compare MODTRAN-calculated radiance to actual radiance measured from Spectralon panel to verify the atmospheric model



Example IKONOS Data Acquisitions

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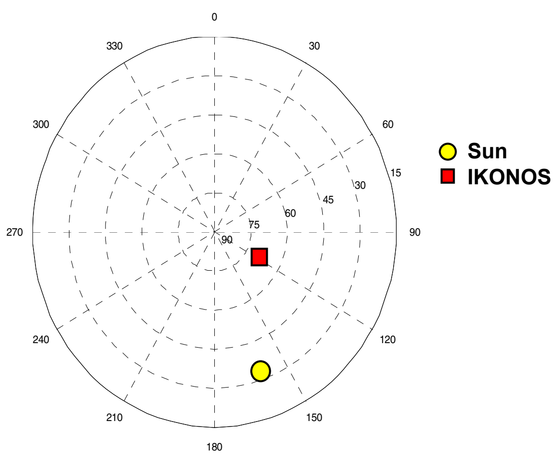
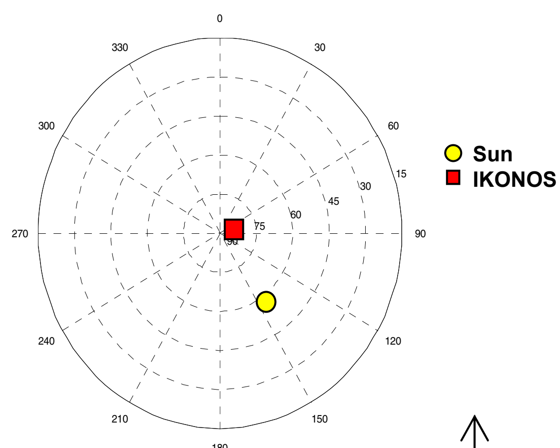
Site/Date	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
Stennis 12/15/04	16:45	68.9 deg	118.6 deg	34.0 deg	160.8 deg
Wiggins 3/24/05	16:50	86.3 deg	71.9 deg	56.3 deg	146.1 deg
Stennis 4/15/05	16:51	72.7 deg	25.4 deg	64.5 deg	138.8 deg

Standard imagery
Cubic Convolution resampling, MTFC Off

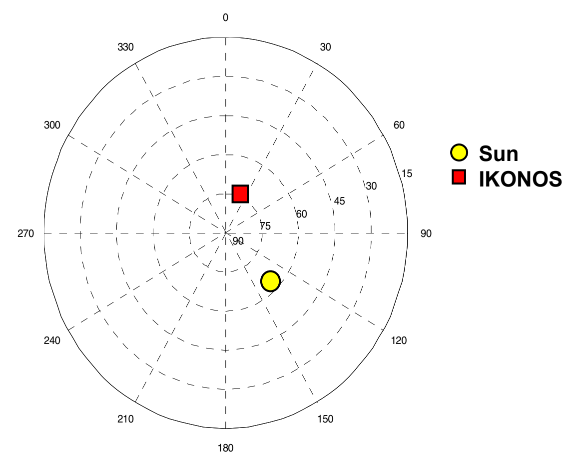


Stennis Space Center, MS, 12/15/04



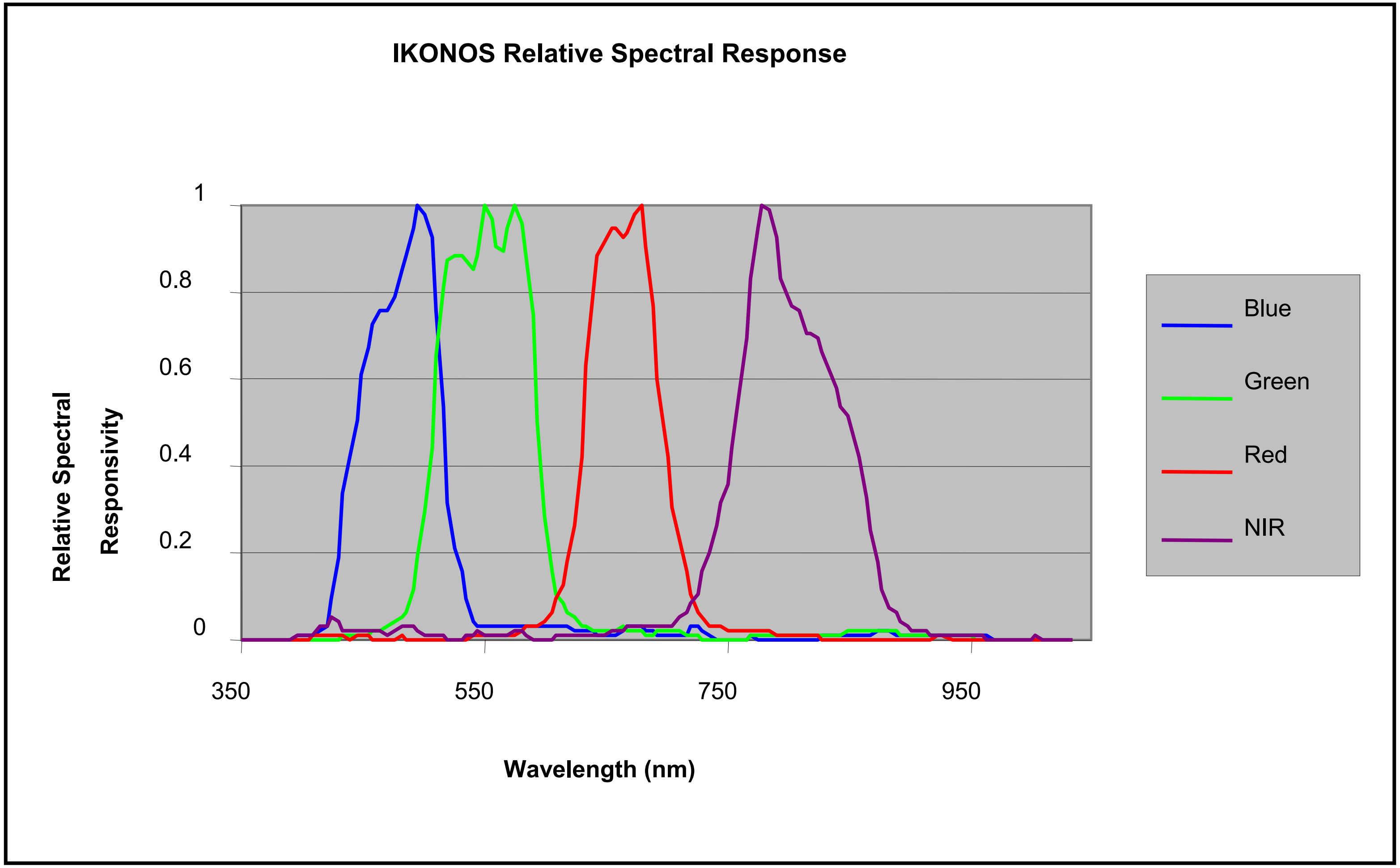
Wiggins, MS, 3/24/05

N



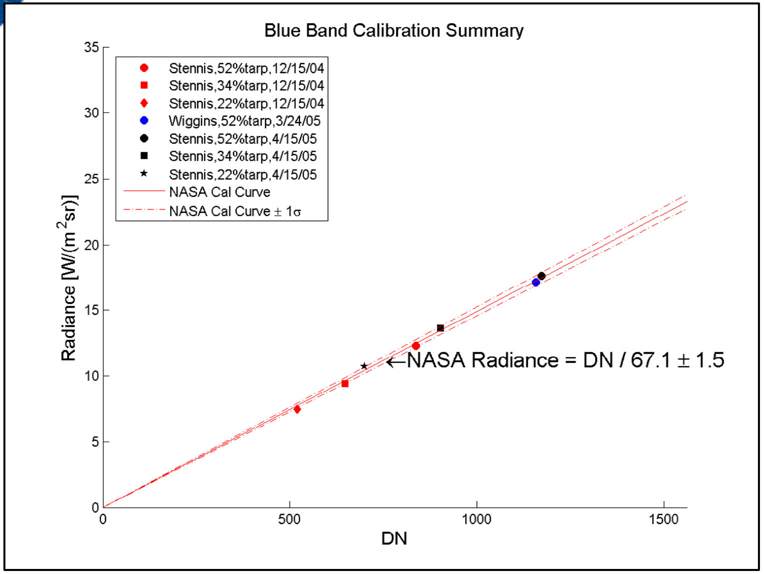
Stennis Space Center, MS, 4/15/05

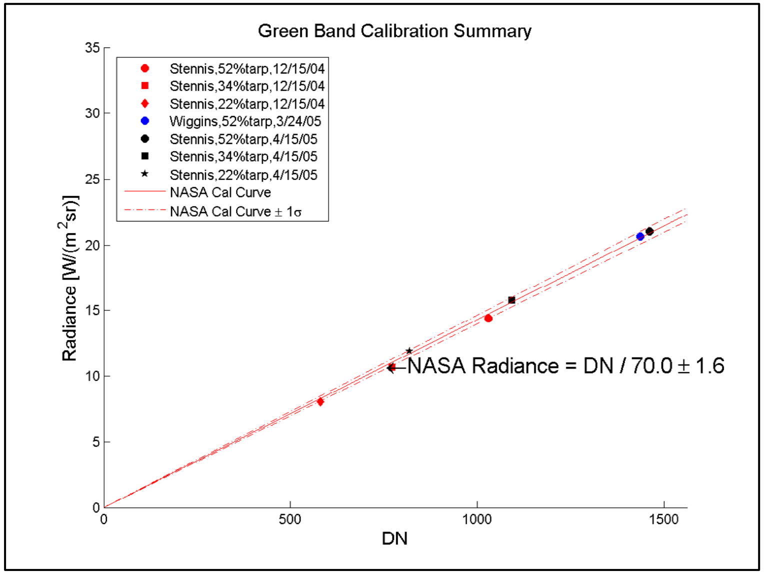
IKONOS Spectral Response

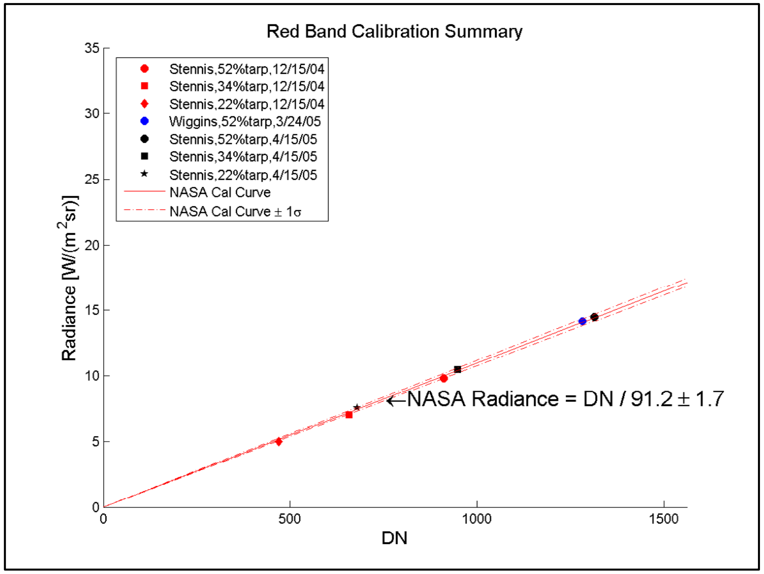


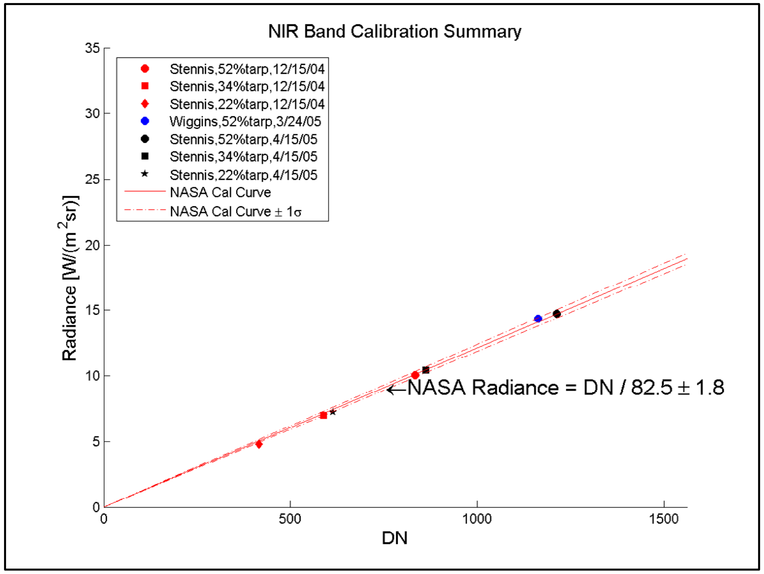
2004/2005 IKONOS Calibration Results

Stennis Space Center









IKONOS Calibration Coefficients and Associated Uncertainty

Band	NASA Estimate 2000*	NASA Estimate 2000 Scaled	NASA Estimate 2001 and % Change	NASA Estimate 2002 and % Change	NASA Estimate 2004/2005 and % Change
Blue	64.2 ± 4.3	73.9 ± 4.9	73.2 ± 4.7 -0.9%	71.0 ± 4.7 -3.9%	67.1 ± 1.5 -9.2%
Green	65.4 ± 4.2	73.3 ± 4.7	76.6 ± 3.8 4.5%	73.4 ± 5.0 0.2%	70.0 ± 1.6 -4.5%
Red	88.1 ± 7.0	99.5 ± 7.9	101.8 ± 5.3 2.3%	97.5 ± 7.7 -2.0%	91.2 ± 1.7 -8.4%
NIR	73.7 ± 3.8	83.3 ± 4.3	85.9 ± 4.2 3.1%	82.7 ± 5.8 -0.7%	82.5 ± 1.8 -1.0%

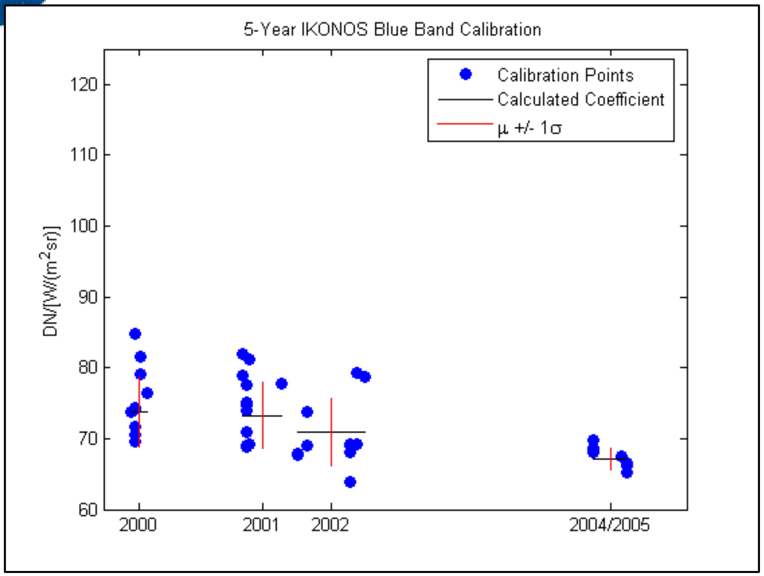
Calibration coefficients in units of DN / (W / m^2sr)

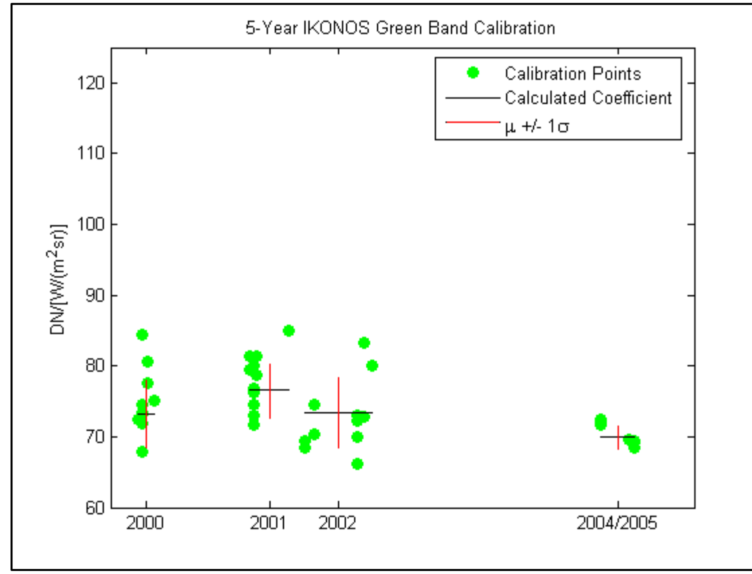
Uncertainty defined as 1-sigma

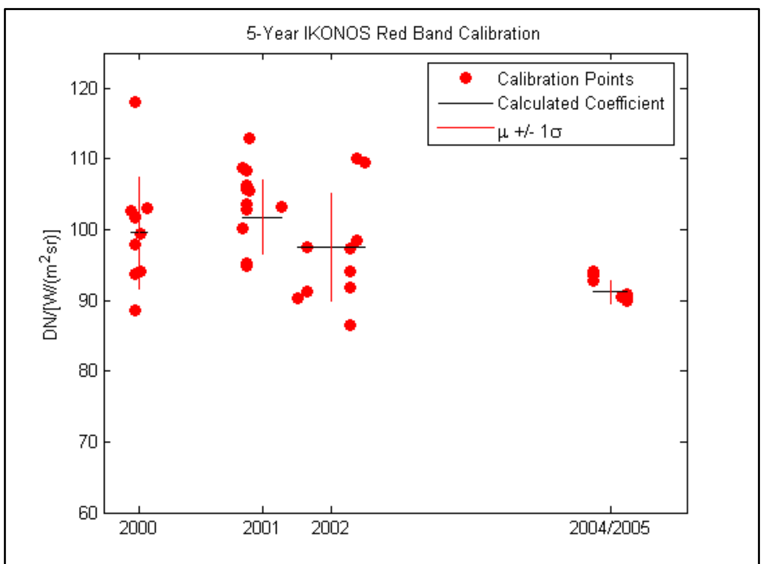
% change relative to NASA estimate year 2000 scaled data

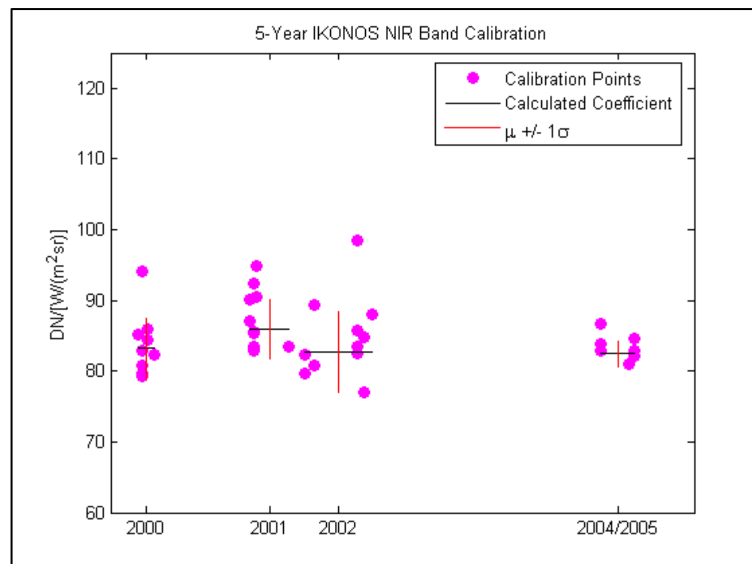
* denotes NASA estimate made before Space Imaging's image processing upgrade

5-Year IKONOS Calibration Summary









NASA Calibration Team Benefits

High Spatial Resolution Commercial Imagery Evaluation

- Three independent groups employed similar approaches but different tools and techniques.
  - Checks and balances between groups
  - Removes/reduces any bias associated with one individual group or set of techniques

- Multiple study sites were used
  - Removes/reduces any bias associated with a single study site
  - Radiance values found within these study site scenes span the dynamic range of the sensor.

Summary

- NASA Stennis Space Center has developed a Verification and Validation site capable of performing geometric, spatial, and radiometric characterizations of high spatial resolution imagery
  - Laboratory calibration facility
  - Field targets and infrastructure
  - Data processing algorithms and techniques

- SSC collaborates with other recognized V&V teams for independent checks/balances

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13. SUPPLEMENTARY NOTES

For presentation at 2006 EO/IR Calibration and Characterization Workshop, Space Dynamics Laboratory, Logan, UT, USA, March 7-9, 2006

14. ABSTRACT

Scientists within NASA's Applied Sciences Directorate have developed a well-characterized remote sensing Verification & Validation (V&V) site at the John C. Stennis Space Center (SSC). This site has enabled the in-flight characterization of satellite high spatial resolution remote sensing system products from Space Imaging IKONOS, DigitalGlobe QuickBird, and ORBIMAGE OrbView, as well as advanced multispectral airborne digital camera products. SSC utilizes engineered geodetic targets, edge targets, radiometric tarps, atmospheric monitoring equipment and their Instrument Validation Laboratory to characterize high spatial resolution remote sensing data products.This presentation describes the SSC characterization capabilities and techniques in the visible through near infrared spectrum and examples of calibration results.

15. SUBJECT TERMS

Verification and Validation, in-flight characterization, high spatial resolution imagery

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