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

2006 EO/IR Calibration and Characterization Workshop

Mary Pagnutti
Science Systems and Applications, Inc.
John C. Stennis Space Center

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phone: 228-688-2135
e-mail: mary.pagnutti@ssc.nasa.gov
Co-Contributors

Slawek Blonski
Kara Holekamp
Kenton Ross
Robert E. Ryan

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

Thomas Stanley

Applied Research & Technology Project Office
National Aeronautics and Space Administration
John C. Stennis Space Center
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 km², scattered buildings within a heavily wooded area, manmade reservoirs and canals.

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 CE$_{90}$ 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

Geodetic Targets

Manhole Cover Targets

17 A-order Monuments

Includes material © Space Imaging LLC
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\textsubscript{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\textsubscript{95}** – The radial error which 95% of all errors in a circular distribution will not exceed (adapted from Greenwalt and Shultz, 1962)
  - **Equivalent to Accuracy\textsubscript{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.

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

- Empirical approach to CE\textsubscript{90} where CE\textsubscript{90} = 90\textsuperscript{th} percentile of $\Delta R$

• 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 $\text{CE}_{90}$ of 0.39 m, a $\text{CE}_{95}$ of 0.48 m, and a net RMSE of 0.27 m
Example Geometric Characterization – OV-3

**OrbView-3**

<table>
<thead>
<tr>
<th>Acquisition Date</th>
<th>Imagery Band</th>
<th>PAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/17/2003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number Targets Used</th>
<th>Error Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>$\mu_H$ (Bias)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test for Departure from Circular Distribution</th>
<th>Error Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_c$ (Circular Standard Error)</td>
<td>$\mu_H/\sigma_c$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>St. Dev. Min Max Ratio</th>
<th>$\mu_H/\sigma_c$</th>
<th>12.40</th>
</tr>
</thead>
</table>

St. Dev. Min Max Ratio should be at least 0.6 for Circular Error assumptions. If $\mu_H/\sigma_c$ is greater than 0.1, then error calculations should account for bias.

<table>
<thead>
<tr>
<th>Circular Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Empirical CE_{90}</strong></td>
</tr>
<tr>
<td><strong>Empirical CE_{95}</strong></td>
</tr>
</tbody>
</table>

$$CE_{90} \ 8.32 \ m$$

Vector Plot ($\Delta R$)
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)
**Problem:** Digital cameras undersample edge target

**Solution:** Image tilted edge to improve sampling
SSC Painted Concrete Edge Targets

Includes material © DigitalGlobe™
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.

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

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

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

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

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:

$$\frac{L_P}{L_T} \approx RER^2$$

**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).

Example Spatial Characterization – RER

QuickBird panchromatic Imagery acquired January 10, 2004

Cubic Convolution resampling
RER = 0.5

MTF Boost resampling
RER = 0.79
<table>
<thead>
<tr>
<th>Image Tracking ID</th>
<th>Acquisition Site</th>
<th>Acquisition Date</th>
<th>Satellite Angle (°)</th>
<th>Resampled GSD (m)</th>
<th>Resampling Method</th>
<th>Target Direction</th>
<th>MTF Nyquist</th>
<th>RER</th>
</tr>
</thead>
<tbody>
<tr>
<td>88502</td>
<td>Brookings, SD</td>
<td>2003-09-15</td>
<td>6.7 287.2</td>
<td>0.6</td>
<td>CC</td>
<td>Easting</td>
<td>0.14 ± 0.01</td>
<td>0.51 ± 0.01</td>
</tr>
<tr>
<td>98196</td>
<td>SSC, MS</td>
<td>2004-01-10</td>
<td>0.6 244.0</td>
<td>0.6</td>
<td>CC</td>
<td>Easting</td>
<td>0.14 ± 0.02</td>
<td>0.54 ± 0.01</td>
</tr>
<tr>
<td>102569</td>
<td>SSC, MS</td>
<td>2004-01-28</td>
<td>15.4 8.9</td>
<td>0.6</td>
<td>CC</td>
<td>Northing</td>
<td>0.11 ± 0.01</td>
<td>0.49 ± 0.01</td>
</tr>
<tr>
<td>76412</td>
<td>Brookings, SD</td>
<td>2003-09-15</td>
<td>6.7 287.2</td>
<td>0.6</td>
<td>MTF</td>
<td>Easting</td>
<td>0.55 ± 0.07</td>
<td>0.84 ± 0.01</td>
</tr>
<tr>
<td>137430</td>
<td>SSC, MS</td>
<td>2004-01-10</td>
<td>0.6 244.0</td>
<td>0.6</td>
<td>MTF</td>
<td>Easting</td>
<td>0.50 ± 0.01</td>
<td>0.81 ± 0.01</td>
</tr>
<tr>
<td>102569</td>
<td>SSC, MS</td>
<td>2004-01-28</td>
<td>15.4 8.9</td>
<td>0.6</td>
<td>MTF</td>
<td>Northing</td>
<td>0.41 ± 0.04</td>
<td>0.76 ± 0.01</td>
</tr>
</tbody>
</table>

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.

MFRSR/ASR Optical Depth Values for SSC 01-15-2002

<table>
<thead>
<tr>
<th>Center Band Wavelength (nm)</th>
<th>ASR Channels</th>
<th>MFRSR Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>380 nm</td>
<td>ASR #25 SSC Field</td>
<td></td>
</tr>
<tr>
<td>400 nm</td>
<td>MFRSR #451 SSC Roof</td>
<td></td>
</tr>
<tr>
<td>440 nm</td>
<td>MFRSR #477 SSC Field</td>
<td></td>
</tr>
<tr>
<td>520 nm</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>610 nm</td>
<td>615</td>
<td></td>
</tr>
<tr>
<td>670 nm</td>
<td>673</td>
<td></td>
</tr>
<tr>
<td>780 nm</td>
<td>870</td>
<td></td>
</tr>
<tr>
<td>870 nm</td>
<td>870</td>
<td></td>
</tr>
<tr>
<td>1030 nm</td>
<td>1030</td>
<td></td>
</tr>
</tbody>
</table>
MODTRAN At-Sensor Radiance Prediction Process

- Collect ground truth data
- Radiosonde, TOMS, sensor-viewing & solar geometry (P, T, H₂O, O₃, θᵥ, θ₃)
- Sun photometer (aerosol properties)
- Aerosol asymmetry and visibility properties
- Target and background reflectance
- Radiative transfer input parameter setup software

- Check and review input parameters
- MODTRAN verification
  - Ground radiance estimate for reference panel compared to calibrated ASD radiance

  - Radiance estimate agrees with ground measurements?

  - Yes: MODTRAN sensor spectral response
  - No: MODTRAN at-sensor radiance estimation
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

![Photo of Spectralon panel measurement](image)

![Graph of radiance vs. wavelength](image)
### Example IKONOS Data Acquisitions

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

**Standard imagery**

Cubic Convolution resampling, MTFC Off

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Stennis Space Center, MS, 12/15/04

Wiggins, MS, 3/24/05

Stennis Space Center, MS, 4/15/05
IKONOS Spectral Response

IKONOS Relative Spectral Response

- Blue
- Green
- Red
- NIR
2004/2005 IKONOS Calibration Results

Blue Band Calibration Summary

Green Band Calibration Summary

Red Band Calibration Summary

NIR Band Calibration Summary

NASA Radiance = DN / 67.1 ± 1.5

NASA Radiance = DN / 70.0 ± 1.6

NASA Radiance = DN / 91.2 ± 1.7

NASA Radiance = DN / 82.5 ± 1.8
## IKONOS Calibration Coefficients and Associated Uncertainty

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>64.2 ± 4.3</td>
<td>73.9 ± 4.9</td>
<td>73.2 ± 4.7 -0.9%</td>
<td>71.0 ± 4.7 -3.9%</td>
<td>67.1 ± 1.5 -9.2%</td>
</tr>
<tr>
<td>Green</td>
<td>65.4 ± 4.2</td>
<td>73.3 ± 4.7</td>
<td>76.6 ± 3.8 4.5%</td>
<td>73.4 ± 5.0 0.2%</td>
<td>70.0 ± 1.6 -4.5%</td>
</tr>
<tr>
<td>Red</td>
<td>88.1 ± 7.0</td>
<td>99.5 ± 7.9</td>
<td>101.8 ± 5.3 2.3%</td>
<td>97.5 ± 7.7 -2.0%</td>
<td>91.2 ± 1.7 -8.4%</td>
</tr>
<tr>
<td>NIR</td>
<td>73.7 ± 3.8</td>
<td>83.3 ± 4.3</td>
<td>85.9 ± 4.2 3.1%</td>
<td>82.7 ± 5.8 -0.7%</td>
<td>82.5 ± 1.8 -1.0%</td>
</tr>
</tbody>
</table>

Calibration coefficients in units of DN / ( W / m²sr )

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
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
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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