Radiometric Characterization of the IKONOS, QuickBird, and OrbView-3 Sensors

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Civil Commercial Imagery Evaluation Workshop
Laurel, Maryland, USA
March 15, 2006
NASA Stennis Space Center, MS

- **Site:** Scattered buildings within a heavily wooded area; manmade reservoirs and canals

- **Elevation:** 5.5 m – 10 m

- **Centerpoint:** 30.356° N, 89.62° W

- **In-situ Instrumentation:** Analytical Spectral Devices FieldSpec® FR spectroradiometers, Yankee multifilter rotating shadowband radiometers (MFRSRs), automated solar radiometers (ASRs), novel hyperspectral sun photometer, Sippican® radiosonde, Yankee total sky imager, 20 m x 20 m radiometric tarps, 99% reflectance Spectralon® panels
NASA SSC Target Field

QuickBird Imagery
March 12, 2005
True-Color Pan-Sharpened
Wiggins, MS

- **Site**: Rural area with a gravel pit sand site, large monoculture fields, and a cut-grass amateur golf course

- **Elevation**: 70 m – 85 m

- **Centerpoint**: 30.79° N, 89.06° W

- **In-situ Instrumentation**: Analytical Spectral Devices FieldSpec® FR spectroradiometers, Yankee MFRSRs, ASRs, Yankee total sky imager, 20 m x 20 m radiometric tarps, 99% reflectance Spectralon® panels

*Includes material © Space Imaging, LLC*
Wiggins Target Fields

IKONOS Imagery
March 24, 2005
True-Color Pan-Sharpenced

Rye Grass Field
Gravel Pit
Sand Site
Golf Course with Radiometric Tarps

Includes material ©
Space Imaging, LLC
**Site**: Heavily wooded rural area with a field containing an Aerosol Robotic Network (AERONET) site

**Elevation**: 475 m

**Centerpoint**: 45.95° N, 90.27° W

**In-situ Instrumentation**: Analytical Spectral Devices FieldSpec® FR spectroradiometers, CIMEL Electronique automatic suntracking photometer, novel hyperspectral sun photometer, 20 m x 20 m radiometric tarps, 99% reflectance Spectralon® panels
Park Falls Target Field

QuickBird Imagery
August 5, 2005
True-Color Pan- Sharpened

Includes material © DigitalGlobe™
Radiometric Tarps

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

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

• Bidirectional Reflectance Distribution Function (BRDF) of radiometric tarp witness samples measured in laboratory
  – Witness samples removed from tarps after ground truth data collection
  – Sun and satellite geometry recreated in the laboratory to determine BRDF correction factors for each radiometric tarp
• Calculated correction factors incorporated into reflectance data files
SSC Calibration and Characterization of Spectroradiometers

• NASA SSC maintains four Analytical Spectral Devices FieldSpec® FR spectroradiometers
  – Laboratory transfer radiometers
  – Ground surface reflectance for verification and validation (V&V) field collection activities
• Radiometric Calibration
  – National Institute of Standards and Technology (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
Novel Hyperspectral Sun Photometer

- Novel hyperspectral sun photometer is capable of acquiring measurements comparable to both ASRs and MFRSRs by making use of the laboratory radiometric calibration of the FieldSpec® FR spectroradiometers
  - Optical Depth/Transmission
  - Diffuse-to-Global Ratio
- Sun photometer developed with fewer limitations than current sun photometers, utilizing equipment already used in the field
  - Radiometrically calibrated FieldSpec® FR spectroradiometers
  - 99% reflectance Spectralon® panels
- Measurements are made only at the time of overpass, thus reducing the impact of a changing atmosphere on the calculation of optical depth
  - Resulted in a change to previously published OrbView-3 radiometric characterization

Sample Results

<table>
<thead>
<tr>
<th>Band</th>
<th>ASR 27</th>
<th>ASD</th>
<th>Difference</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>380 nm</td>
<td>0.588</td>
<td>0.5982</td>
<td>-0.010</td>
<td>-1.74%</td>
</tr>
<tr>
<td>400 nm</td>
<td>0.495</td>
<td>0.4852</td>
<td>0.010</td>
<td>1.99%</td>
</tr>
<tr>
<td>440 nm</td>
<td>0.366</td>
<td>0.3216</td>
<td>0.044</td>
<td>12.14%</td>
</tr>
<tr>
<td>520 nm</td>
<td>0.224</td>
<td>0.1988</td>
<td>0.025</td>
<td>11.25%</td>
</tr>
<tr>
<td>610 nm</td>
<td>0.161</td>
<td>0.1563</td>
<td>0.005</td>
<td>2.91%</td>
</tr>
<tr>
<td>670 nm</td>
<td>0.108</td>
<td>0.1002</td>
<td>0.008</td>
<td>7.26%</td>
</tr>
<tr>
<td>780 nm</td>
<td>0.07</td>
<td>0.0691</td>
<td>0.001</td>
<td>1.33%</td>
</tr>
<tr>
<td>870 nm</td>
<td>0.049</td>
<td>0.0508</td>
<td>-0.002</td>
<td>-3.58%</td>
</tr>
</tbody>
</table>

RMS 1:8 0.019
Comparison to Spectralon Panel

• Verification of parameters used to generate Moderate Resolution Transmittance (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
IKONOS Radiometric Characterization
## 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
IKONOS Sample Calibration Summary

Red Band Calibration Summary

NASA Radiance = DN / 93.00 ± 3.31
IK Radiance = DN / 94.90
Inband Radiance Calibration Coefficients

<table>
<thead>
<tr>
<th>Bandwidth FWHM ((\mu m))</th>
<th>NASA Team Estimate [DN/(W/m(^2) sr)]</th>
<th>IKONOS Provided [DN/(W/m(^2)sr)]</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.450 - 0.520</td>
<td>67.8 ± 2.6</td>
<td>72.8</td>
<td>-7.4%</td>
</tr>
<tr>
<td>2 0.510 - 0.600</td>
<td>71.2 ± 2.9</td>
<td>72.7</td>
<td>-2.1%</td>
</tr>
<tr>
<td>3 0.630 - 0.700</td>
<td>93.0 ± 3.3</td>
<td>94.9</td>
<td>-2.0%</td>
</tr>
<tr>
<td>4 0.760 - 0.850</td>
<td>82.3 ± 2.1</td>
<td>84.3</td>
<td>-2.4%</td>
</tr>
</tbody>
</table>

Percent difference is calculated by \((1 - \text{IKONOS/NASA Mean})\)
2004/2005 IKONOS Results Summary

- The NASA team of University of Arizona, South Dakota State University, and NASA SSC produce consistent results

- The IKONOS calibration coefficients continue to agree well with the NASA team estimate (within 2.5% except for blue band)

- The NASA team will continue to assess IKONOS radiometric accuracy
QuickBird Radiometric Characterization
## QuickBird 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 3/12/05</td>
<td>16:55</td>
<td>78 deg</td>
<td>270 deg</td>
<td>52.4 deg</td>
<td>149.2 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Park Falls 8/5/05</td>
<td>17:20</td>
<td>69.3 deg</td>
<td>261.6 deg</td>
<td>59.4 deg</td>
<td>157.4 deg</td>
</tr>
</tbody>
</table>

Standard imagery
4x4 Cubic Convolution resampling

- Stennis Space Center, MS, 3/12/05
- Park Falls, WI, 8/5/05

![Graphs showing satellite and sun positions](image-url)
QuickBird Sample Calibration Summary

Red Band Calibration Summary

NASA Radiance = DN \times 0.19 \pm 0.01

QB Radiance = DN \times 0.18

Radiance [W/m^2 sr \mu m]

0 50 100 150 200 250

0 200 400 600 800 1000 1200 1400 1600

DN

1/17/2007
### Average Spectral Radiance Calibration Coefficients

<table>
<thead>
<tr>
<th>Bandwidth FWHM (μm)</th>
<th>NASA Team Estimate (W/m² sr μm DN)</th>
<th>QuickBird Provided (W/m²sr μm DN)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.445 - 0.510</td>
<td>0.26 ± 0.02</td>
<td>0.236</td>
<td>9.2%</td>
</tr>
<tr>
<td>2 0.500 - 0.595</td>
<td>0.16 ± 0.01</td>
<td>0.145</td>
<td>9.4%</td>
</tr>
<tr>
<td>3 0.620 - 0.690</td>
<td>0.19 ± 0.01</td>
<td>0.179</td>
<td>5.8%</td>
</tr>
<tr>
<td>4 0.755 - 0.875</td>
<td>0.14 ± 0.01</td>
<td>0.135</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

Percent difference is calculated by (1 – QuickBird/NASA Mean)
• The NASA team of University of Arizona, South Dakota State University, and NASA SSC produce consistent results

• The QuickBird calibration coefficients continue to agree reasonably well with the NASA team estimate (within 10%)

• The NASA team will continue to assess QuickBird radiometric accuracy
OrbView-3 Radiometric Characterization
## OrbView-3 Data Acquisitions

### Stennis Space Center

<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 3/12/05</td>
<td>16:53</td>
<td>76.1 deg</td>
<td>283.8 deg</td>
<td>52.0 deg</td>
<td>148.6 deg</td>
</tr>
</tbody>
</table>

Basic imagery

![Diagram showing Sun and OrbView positions on a coordinate system with elevation and azimuth angles.](image-url)
OrbView-3 Sample Calibration Summary

Red Band Calibration Summary

- NASA Radiance = DN * 0.27 ± 0.01
- OV Radiance = DN * 0.21

1/17/2007
## Average Spectral Radiance Calibration Coefficients

<table>
<thead>
<tr>
<th>Bandwidth FWHM (μm)</th>
<th>NASA Team Estimate (W/m²sr μm DN)</th>
<th>OrbView Provided (W/m²sr μm DN)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.450 - 0.520</td>
<td>0.35 ± 0.02</td>
<td>0.269</td>
<td>23.1%</td>
</tr>
<tr>
<td>2 0.520 - 0.600</td>
<td>0.31 ± 0.01</td>
<td>0.249</td>
<td>19.7%</td>
</tr>
<tr>
<td>3 0.625 - 0.695</td>
<td>0.27 ± 0.01</td>
<td>0.210</td>
<td>22.2%</td>
</tr>
<tr>
<td>4 0.760 - 0.900</td>
<td>0.18 ± 0.00</td>
<td>0.142</td>
<td>21.1%</td>
</tr>
</tbody>
</table>

Percent difference is calculated by \((1 - \text{OrbView/NASA Mean})\)
• The NASA team of University of Arizona, South Dakota State University, and NASA SSC produce consistent results

• The OrbView calibration coefficients do not appear to agree well with the NASA team estimate (~20% difference)

• Discussions with GeoEye™ (formerly ORBIMAGE®) personnel are ongoing to update the calibration coefficients

• The NASA team will continue to assess OrbView radiometric accuracy
Contributors

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Back-up
IKONOS Blue Band Calibration Summary

NASA Radiance = DN / 67.77 ± 2.56

IK Radiance = DN / 72.80
IKONOS Green Band Calibration Summary

Green Band Calibration Summary

NASA Radiance = DN / 71.19 ± 2.86

IK Radiance = DN / 72.70
IKONOS Red Band Calibration Summary

Red Band Calibration Summary

NASA Radiance = DN / 93.00 ± 3.31

IK Radiance = DN / 94.90
IKONOS NIR Band Calibration Summary

NASA Radiance = DN / 82.32 ± 2.07
IK Radiance = DN / 84.30
QuickBird Blue Band Calibration Summary

NASA Radiance = DN \times 0.26 \pm 0.02

QB Radiance = DN \times 0.24
QuickBird Green Band Calibration Summary

Green Band Calibration Summary

NASA Radiance = DN \times 0.16 \pm 0.01

QB Radiance = DN \times 0.15

1/17/2007
QuickBird Red Band Calibration Summary

Red Band Calibration Summary

NASA Radiance = DN * 0.19 ± 0.01
QB Radiance = DN * 0.18

1/17/2007
QuickBird NIR Band Calibration Summary

NIR Band Calibration Summary

NASA Radiance = DN * 0.14 ± 0.01

QB Radiance = DN * 0.14

1/17/2007
OrbView-3 Blue Band Calibration Summary

Blue Band Calibration Summary

NASA Radiance = DN \times 0.35 \pm 0.02

OV Radiance = DN \times 0.27
OrbView-3 Green Band Calibration Summary

Green Band Calibration Summary

NASA Radiance = DN $\times 0.31 \pm 0.01$

OV Radiance = DN $\times 0.25$
OrbView-3 Red Band Calibration Summary

Red Band Calibration Summary

NASA Radiance = DN ^ 0.27 ± 0.01

OV Radiance = DN ^ 0.21
OrbView-3 NIR Band Calibration Summary

NASA Radiance = DN * 0.18 ± 0.00

OV Radiance = DN * 0.14

1/17/2007