System Characterization Results for the QuickBird Sensor

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Outline

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• Geopositional Characterization
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  – Results
• Spatial Characterization
  – Methodology
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• Radiometric Characterization
  – Methodology
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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 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:
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.
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

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

Example from 27 OCT 2005 QuickBird imagery over SSC using ArcMap

Cursor Location/Value of Point 2I
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**
- $C_{E90}$: 8.17 m
- $C_{E95}$: 8.38 m
- Circular Standard Error: 0.64 m

**23 MAR 2006**
- $C_{E90}$: 15.54 m
- $C_{E95}$: 15.85 m
- Circular Standard Error: 1.03 m
Scatterplot

QuickBird Scatterplot

- Red dots: 27 OCT 2005, Standard "Ortho Ready"
- Yellow dots: 07 FEB 2006, Standard "Coarse DEM"
- Green dots: 23 MAR 2006, Standard "Coarse DEM"

Y error (m)
X error (m)
Geopositional Summary

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

- 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

Blue acquisitions were characterized by South Dakota State University
Red Acquisitions were characterized by NASA Stennis Space Center
**QuickBird panchromatic image acquired on January 10, 2004**

**GSD = 60 cm**

**Edge target tarps oriented for testing in the Easting direction**

Edge target formed from two high-contrast tarps: nominally 3.5% and 52% reflectance, 20 m × ~21 m each.

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System Characterization Results for the QuickBird Sensor

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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
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

QuickBird panchromatic image acquired on March 15, 2006
- GSD = 60 cm
- Cubic convolution resampling kernel

ER(0.5) - ER(-0.5) = 0.49436
For QuickBird panchromatic images processed with the cubic convolution resampling kernel, RER is approximately equal to 0.5.

Error bars show uncertainty estimated from standard deviation of repeated edge response analyses.
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

ASR and Best MODTRAN Transmissions for 248 km Visibility (Haze = 6)

MODTRAN and MFRSR Diffuse to Global (D2G) Ratios

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Ground Truth Collection and Processing (cont)

Laboratory Calibration and Environmental Testing of Field Equipment

Target Reflectance for Stennis Space Center, 3/12/20 QuickBird

Radiance Spectralon Panel Wiggins 3/16/06: 6069

BRDF Corrected Reflectance

Spectralon Panel Radiance

BRDF Corrected Reflectance

Laboratory Apparatus

OL 750 spectroradiometer
Fiber optic cable
Reflex telescope
NIST calibrated Spectranor or tarp sample
Coneimeter
Collimating mirror (off axis paraboloid)
FEL lamp

Atmosphere

Target

Atmosphere
QuickBird Imagery
February 7, 2006
True-Color Pan-Sharpened
## 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>Wiggins East 1/7/06</td>
<td>17:05</td>
<td>67.8 deg</td>
<td>301.9 deg</td>
<td>35.3 deg</td>
<td>163.7 deg</td>
</tr>
<tr>
<td>Wiggins West 1/25/06</td>
<td>17:05</td>
<td>68.8 deg</td>
<td>304.0 deg</td>
<td>38.1 deg</td>
<td>160.7 deg</td>
</tr>
<tr>
<td>Stennis 2/7/06</td>
<td>17:01</td>
<td>83.9 deg</td>
<td>356.4 deg</td>
<td>41.0 deg</td>
<td>157.0 deg</td>
</tr>
<tr>
<td>Wiggins East 3/15/06</td>
<td>17:02</td>
<td>76.9 deg</td>
<td>321.3 deg</td>
<td>54.2 deg</td>
<td>152.7 deg</td>
</tr>
</tbody>
</table>

![Sun and QuickBird diagrams for different dates and times.](image)

Wiggins, MS, 1/7/06

Wiggins, MS, 1/25/06

Stennis, MS, 2/7/06

Wiggins, MS, 3/15/06

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QuickBird Green Band Calibration

Summary

Green Band Calibration Summary

NASA Radiance = DN $\times 0.156 \pm 0.008$

QB Radiance = DN $\times 0.145$
QuickBird Red Band Calibration

Summary

NASA Radiance = DN \times 0.187 \pm 0.011

QB Radiance = DN \times 0.179

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System Characterization Results for the QuickBird Sensor
QuickBird NIR Band Calibration Summary

\[ \text{QB Radiance} = \text{DN} \times 0.135 \]

\[ \text{NASA Radiance} = \text{DN} \times 0.132 \pm 0.006 \]
## Average Spectral Radiance Calibration Coefficients

<table>
<thead>
<tr>
<th>Bandwidth FWHM (μm)</th>
<th>NASA 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>0.255 ± 0.013</td>
<td>0.236</td>
<td>7.5%</td>
</tr>
<tr>
<td>2 0.500 - 0.595</td>
<td>0.156 ± 0.008</td>
<td>0.145</td>
<td>7.1%</td>
</tr>
<tr>
<td>3 0.620 - 0.690</td>
<td>0.187 ± 0.011</td>
<td>0.179</td>
<td>4.3%</td>
</tr>
<tr>
<td>4 0.755 - 0.875</td>
<td>0.132 ± 0.006</td>
<td>0.135</td>
<td>-2.3%</td>
</tr>
</tbody>
</table>

Percent difference is calculated by \((1 – \text{QuickBird/NASA Mean})\)
Radiometric Temporal Results

Blue Band

Green Band

Red Band

NIR Band

Year

Calibration Coefficient (Wm² sr⁻¹ µm⁻¹ DN⁻¹)

QB = 0.236

QB = 0.145

QB = 0.179

QB = 0.135

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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

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