Geometric and Spatial Performance of Landsat 8

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Overview

- Geometric Calibration
  - Geometric calibration approach
  - Instrument field of view alignment verification
  - OLI geometric calibration
  - TIRS geometric calibration

- OLI and TIRS Geometric Performance
  - Band registration accuracy - OLI, TIRS, TIRS-to-OLI
  - Internal geometric accuracy
  - Geolocation accuracy

- OLI Spatial Performance

- Geometric Performance Summary
Geometric Calibration Approach

- Prelaunch geometric models and calibration parameters were derived using instrument and spacecraft design information
  - The design-based parameters were refined using measurements from instrument-level thermal vacuum testing and observatory integration and test
- The initial on-orbit geometric calibration was performed during the commissioning period in the following sequence:
  - Measured OLI to spacecraft alignment using ground control points
  - Measured OLI focal plane module (FPM) alignment using reference imagery
  - Measured OLI band-to-band alignment
  - Measured TIRS-to-OLI alignment
  - Measured TIRS FPM-to-FPM alignment using OLI as a reference
  - Measured TIRS band-to-band alignment
- The geometric calibration is monitored and updated as necessary during routine operations
OLI / TIRS Field of View Alignment

- Red = Band 10 (TIRS) : Green = Band 7 (OLI) : Blue = Band 1 (OLI)

West Edge of Scene

Edge of TIRS Coverage

East Edge of Scene

Edge of TIRS Coverage
OLI On-Orbit Calibration

- Used ground control points to adjust OLI-to-spacecraft alignment
  - Changes from prelaunch: 1.734 mrad roll, -1.770 mrad pitch, -0.106 mrad yaw

- DOQ reference images and the OLI pan band were used to adjust the alignment of the 14 OLI focal plane modules (FPMs)
  - Outboard FPMs required larger (up to 175 mrad) adjustment than nadir FPMs

- Multispectral bands were then aligned to the pan band
  - Based upon band-to-band tie point measurements

Note: Along-track scale is exaggerated ~8X relative to across-track
TIRS On-Orbit Calibration

- TIRS-to-OLI alignment was measured by comparing TIRS 10.8 µm band to OLI SWIR1 band
  - The TIRS alignment appeared to change slightly as Landsat 8 maneuvered into its final WRS-2 orbit
  - A spacecraft anomaly in late-September caused a step change which has partially recovered
- The alignment of the 3 TIRS focal plane modules (FPMs) was measured using OLI SWIR1 as a reference
- The TIRS 12.0 µm band was aligned to the 10.8 µm band
  - Based upon band-to-band tie point measurements
On-Orbit Calibration Updates

- Several additional on-orbit calibration updates have been issued since the end of commissioning
  - All are minor and none involve internal image geometry

<table>
<thead>
<tr>
<th>Calibration Parameter</th>
<th>Date of Update</th>
<th>Effective Date</th>
<th>Reason for Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLI-to-S/C Alignment</td>
<td>07/01/2013</td>
<td>Launch</td>
<td>Analysis of additional data from WRS-2 orbit</td>
</tr>
<tr>
<td>Ground Control Thresholds</td>
<td>08/21/2013</td>
<td>Launch</td>
<td>Allow scenes with GLS control errors &gt; 100m to process to L1T</td>
</tr>
<tr>
<td>TIRS-to-OLI Alignment</td>
<td>09/27/2013</td>
<td>09/21/2013 – 09/30/2013</td>
<td>Step change following late-September spacecraft anomaly</td>
</tr>
<tr>
<td>TIRS-to-OLI Alignment</td>
<td>11/27/2013</td>
<td>10/01/2013 -</td>
<td>Account for recovery of TIRS alignment following anomaly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>04/01/2013 - 09/20/2013</td>
<td>Improve accuracy for period from arrival in WRS-2 orbit to spacecraft anomaly</td>
</tr>
<tr>
<td>OLI-to-S/C Alignment</td>
<td>02/03/2013</td>
<td>10/01/2013 -</td>
<td>Account for seasonal drift in alignment of both instruments to the spacecraft</td>
</tr>
</tbody>
</table>
OLI Band Registration Accuracy

- Band-to-band registration is evaluated using cloud-free test site scenes
  - These are mainly desert sites to ensure good inter-band correlation

- Using 482 OLI test scenes:
  - 29 high-altitude scenes used for cirrus band assessment
  - OLI band registration accuracy (worst band pair)
    - Line/Sample/Spec: 4.15 / 4.01 / 4.50 meters LE90 (with cirrus)
    - Line/Sample/Incentive: 3.36 / 3.40 / 3.80 meters LE90 (no cirrus)
TIRS Band Registration Accuracy

- **TIRS 10.8 \( \mu \text{m} \) to 12.0 \( \mu \text{m} \) band registration**
  - Results from 215 TIRS band registration test scenes
    - Line/Sample/Specification: 10.4 / 8.8 / 18.0 meters LE90

- **TIRS-to-OLI band registration**
  - Results from 171 cloud-free TIRS-to-OLI registration test scenes over 39 selected test sites
  - TIRS-to-OLI band registration accuracy (worst band pair)
    - Line/Sample/Specification: 20.6 / 19.3 / 30.0 meters LE90

Note: 12.0 \( \mu \text{m} \) band #11 does slightly better than 10.8 \( \mu \text{m} \) band #10. Band #11 is closer to nadir/OLI.
Internal Geometric Accuracy

- Internal geometric accuracy is assessed in two ways
  - Using validation points to assess the accuracy of L1T products
    - Landsat 8 space/ground system accuracy is evaluated at calibration sites with very accurate control and test points
    - Level 1T product consistency, including control effects, is evaluated in every scene containing GLS validation points
  - By comparing L1T products of the same area

- Geometric accuracy
  - Using independent validation points after control is applied
  - For 640 calibration site scenes with GPS-quality control:
    - Accuracy/Spec: 7.8/12.0 meters CE90
  - For 78962 scenes with GLS control:
    - Accuracy: 12.6 meters CE90 (relative to the GLS control)

- Multi-temporal image registration accuracy (128 scenes)
  - Line/Sample/Spec: 6.6/5.1/12.0 meters LE90
Geolocilation Accuracy

- Assessed during L1T product generation using the GLS control
  - Absolute accuracy – difference between predicted ground positions and known GCP positions
  - Relative accuracy – residual difference after mean offset is corrected
- ~38m CE90 GLS control accuracy poses a problem
  - Separate out GLS “anchor” sites that were used to control the original GLS global data set as these should be more accurate
  - Also assess accuracy using high quality control at calibration sites

![Absolute Geodetic Accuracy (CE90) by Quarter](chart1)

![Relative Geodetic Accuracy (CE90) by Quarter](chart2)
Ground Control Accuracy Improvement

- The global control point library used in Landsat L1T processing was derived from the GLS data set
  - Ensures that new products are consistent with the existing archive
- The GLS was established by triangulating blocks of ETM+ imagery containing control provided by NGA
  - Some areas (notably islands) had little or no NGA control
    - Landsat 7 L1GT products were used to control these areas
- L8 geolocation accuracy has allowed us to identify some areas where the GLS control base is deficient
  - This is manifested as repeatable large (tens of meters) offsets for particular WRS path/row locations
- The control library image chips are all L7 ETM+ (8-bit) circa 2000
  - We want to extract new OLI chips for the GCPs in any case
- A GLS control improvement activity is now underway to upgrade the problem areas
GLS Ground Control Rework

- Weak areas are being re-triangulated using L8 data
  - Worked in three phases:
    1. Fifteen high priority areas
    2. Remaining low latitude areas
    3. High latitude (arctic) areas
  - Adjacent areas held fixed to ensure consistency
Spatial Performance - Edge Slope

- OLI spatial performance was specified as the slope of the response to a unit step function
  - Minimum edge slope between the 40% and 60% response points
  - Maximum response slope is also specified to control aliasing
- Prelaunch performance measured during OLI T/V testing
- Estimate on-orbit performance using bridge targets
- Don’t measure TIRS on-orbit performance

Band 8 values are divided by 2 to put them on the same scale
Bahrain and China Bridge Targets

- King Fahd Causeway
  - West Section
  - Center Section
  - East Section

- Qingdao Bridge

Panchromatic Band Images
Single Span Bridges

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### L8 Geometric Summary

- Landsat 8 on-orbit geometric performance is excellent and meets all requirements.
- The Cal/Val team continues to monitor on-orbit performance, adjusting the calibration when necessary.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Measured Value</th>
<th>Required Value</th>
<th>Units</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLI Swath</td>
<td>190.2</td>
<td>&gt;185</td>
<td>kilometers</td>
<td>2.8%</td>
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<tr>
<td>OLI MS Ground Sample Distance</td>
<td>29.934</td>
<td>&lt;30</td>
<td>meters</td>
<td>0.2%</td>
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<tr>
<td>OLI Pan Ground Sample Distance</td>
<td>14.932</td>
<td>&lt;15</td>
<td>meters</td>
<td>0.5%</td>
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<tr>
<td>OLI Band Registration Accuracy (all bands)</td>
<td>4.29</td>
<td>&lt;4.5</td>
<td>meters (LE90)</td>
<td>4.7%</td>
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<tr>
<td>OLI Band Registration Accuracy (no cirrus)</td>
<td>3.35</td>
<td>&lt;4.5</td>
<td>meters (LE90)</td>
<td>25.6%</td>
</tr>
<tr>
<td>Absolute Geodetic (Pre-Control) Accuracy</td>
<td>36.9</td>
<td>&lt;65</td>
<td>meters (CE90)</td>
<td>43.2%</td>
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<tr>
<td>Relative Geodetic Accuracy</td>
<td>20.5</td>
<td>&lt;25</td>
<td>meters (CE90)</td>
<td>18.0%</td>
</tr>
<tr>
<td>Geometric (Post-Control) Accuracy</td>
<td>7.8</td>
<td>&lt;12</td>
<td>meters (CE90)</td>
<td>35.0%</td>
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<tr>
<td>OLI Edge Slope</td>
<td>0.02965</td>
<td>&gt;0.027</td>
<td>1/meters</td>
<td>9.8%</td>
</tr>
<tr>
<td>TIRS Swath</td>
<td>186.2</td>
<td>&gt;185</td>
<td>kilometers</td>
<td>0.6%</td>
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<tr>
<td>TIRS Ground Sample Distance</td>
<td>103.424</td>
<td>&lt;120</td>
<td>meters</td>
<td>13.8%</td>
</tr>
<tr>
<td>TIRS Band Registration Accuracy</td>
<td>10.4</td>
<td>&lt;18</td>
<td>meters (LE90)</td>
<td>42.2%</td>
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<tr>
<td>TIRS-to-OLI Registration Accuracy</td>
<td>20.6</td>
<td>&lt;30</td>
<td>meters (LE90)</td>
<td>31.3%</td>
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</tbody>
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