Radiometric Performance of Landsat 8

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Overview

- Landsat Cal/Val Team
- Brief summary of Landsat 8 Sensors
- Radiometric Performance
  - Noise
  - Radiometric Stability
  - Artifacts
  - Pixel-to-Pixel Uniformity
  - Radiometric Accuracy
  - Summary
Landsat Calibration Validation Team

- USGS Earth Resources Observation and Science (EROS)
- NASA Goddard Space Flight Center (GSFC)
  - [http://landsat.gsfc.nasa](http://landsat.gsfc.nasa)
- NASA Jet Propulsion Laboratory (JPL)
- Rochester Institute of Technology (RIT)
  - [http://www.cis.rit.edu/](http://www.cis.rit.edu/)
- South Dakota State University (SDSU) Image Processing (IP) Laboratory
  - [http://iplab2out.sdstate.edu/](http://iplab2out.sdstate.edu/)
- University of Arizona (UofA) Optical Sciences Laboratory
  - [http://www.optics.arizona.edu/](http://www.optics.arizona.edu/)
L7 vs. L8 spectral bands
Operational Land Imager (OLI)

- 6916 active detectors per band (13,832 pan)
- Each Focal Plane Module (FPM) is 494 detectors wide (988 pan)
- Each FPM has its own spectral filters
- 14 FPMs make up the Focal Plane Assembly (FPA).
- FPMs also called Sensor Chip Assemblies (SCA)
Two thermal bands
- 1 centered at (10.8\(\mu\)m)
- 1 centered at (12.0\(\mu\)m)
- 185 km swath width; 100 m GSD

1920 Detectors across full FPA
640 detectors on each SCA
35 pixels in overlap
1850 pixels in product
Noise: OLI SNR

OLI SNR consistent with pre-launch at typically 2-3x better than requirements, 8x better than heritage
Noise: TIRS NEΔT

- All TIRS detectors have similar NEΔT
- Band averages:
  - B10: 0.048
  - B11: 0.052

Noise is about 8x better than requirements; about 4x better than heritage
OLI Radiometric Stability

- Around orbit [measured with stim lamps taken at different positions in the orbit]
  - No orbital position sensitivity observed
- Since launch [measured with daily stim lamps]
  - Better than 0.3% (2 sigma) over 60 days; requirement is 1% (2 sigma) over 16 days!
  - Trends less than 0.5% over 60 days, i.e., no significant contamination apparent

<table>
<thead>
<tr>
<th></th>
<th>C/A</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
<th>NIR</th>
<th>SWIR 1</th>
<th>SWIR 2</th>
<th>Pan</th>
<th>Cirrus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.29%</td>
<td>0.25%</td>
<td>0.20%</td>
<td>0.12%</td>
<td>0.02%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.13%</td>
<td>0.01%</td>
</tr>
</tbody>
</table>
TIRS Radiometric Stability

- **Within Interval (between calibrations)**
  - Typically <0.1% (1 sigma) over 40 minutes; requirement is 0.7% (1 sigma)
  - Similar performance over 1 ½ orbits
- **Since Achieving Final Telescope Temperature**
  - Typically range of ± 0.02% over ~ 30 days; slight variation within interval
Artifacts

- No coherent (a.k.a. pattern noise) observed in either instrument
- Spatial artifacts (i.e., ghosting, crosstalk) within requirements on both instruments

TIRS band 10 – weak ghost ~0.1% of lunar signal

OLI Band 9 (Cirrus) very weak ghost/ halo

OLI Band 6 (SWIR 1)
Artifacts
TIRS Out-of-field Stray Light
Pixel-to-Pixel Uniformity - Streaking

- Streaking is uncorrected individual detector-to-detector variation
  - Requirement is <0.5% [1% for band 8]; limited number of failing detectors allowed in out-of-spec bin (99.75% of detectors in a band must be within spec)
- Most bands meet streaking requirements with current calibration parameters w/o excluding any detectors
  - OLI: occasionally some SWIR detectors (all bands in spec after allowed exclusions)
  - TIRS: few detectors fail, mainly in band 11, though not real streaking (in spec after allowed exclusion)
Pixel-to-Pixel Uniformity – Banding (type 2)

- Banding, under this definition, is the standard deviation across a 100-pixel wide moving window
  - Requirement is 0.25% for OLI and 0.5% for TIRS
  - Usually associated with radiometric discontinuities between adjacent Focal Plane Modules or Sensor Chip Assemblies
- Most bands meet this banding requirement
  - OLI: All bands exceed this requirement
  - TIRS: Does not consistently meet requirement at either SCA boundary
Radiometric Accuracy - Radiance

- Across primary range of radiance levels:
  - OLI absolute radiance uncertainty requirement is < 5% (1 sigma)
  - TIRS absolute radiance uncertainty requirement is <2% (1 sigma)
- Requirement is met prior to launch via sources traceable to NIST
- On-orbit confirmation involves ground reflectance or temperature measurements and atmospheric propagation or comparison to other sensors, which typically have higher uncertainty, so process typically takes time to tie down. SWIR bands still have significant solar irradiance uncertainty (~4%)
- Ground “vicarious” teams have been in place and will continue to be in place to provide needed measurements
- Between some very dedicated ground teams, well developed techniques and cooperative weather, we have better information at this point than in any previous mission
Radiometric Accuracy - Reflective

- Our primary reflective band vicarious cal team (U of Arizona) has obtained 10 good calibrations of OLI with excellent reproducibility (circa 1% one sigma)
- Initial analysis shows good agreement to operational OLI calibration (within ~3%, depending which solar spectrum is used)
- Initial analysis of cross calibration with Landsat-7 ETM+ (South Dakota S U) also shows consistent results within 2%
**TIRS Radiometric Accuracy**

- Thermal calibration teams (RIT and JPL) acquired data from Lake Tahoe, Salton Sea, numerous ocean and Great Lakes buoy data
- Offset determined based on initial calibration, likely due to stray light
- Current accuracy after offset correction:
  - B10: 1.2% $1\sigma$
  - B11: 2.2% $1\sigma$
**OLI Radiometric Performance Summary**

- On-orbit characterization of radiometric performance has confirmed that the vast majority of evaluated requirements have been met; some uncertainties remain.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Measured Value (worst case)</th>
<th>Required Value</th>
<th>Units</th>
<th>Margin (worst case)</th>
<th>Requirement Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLI Ghosting</td>
<td>meets</td>
<td>varies</td>
<td>percent</td>
<td>----</td>
<td>OLI-788</td>
</tr>
<tr>
<td>OLI Absolute Radiance Uncertainty</td>
<td>4*</td>
<td>&lt;5</td>
<td>percent</td>
<td>20%*</td>
<td>OLI-792</td>
</tr>
<tr>
<td>OLI Absolute Reflectance Uncertainty</td>
<td>reanalysis</td>
<td>&lt;3</td>
<td>percent</td>
<td>TBD</td>
<td>OLI-792</td>
</tr>
<tr>
<td>OLI Median SNR Ltypical</td>
<td>meets</td>
<td>varies</td>
<td>-</td>
<td>83%</td>
<td>OLI-875</td>
</tr>
<tr>
<td>OLI Median SNR Lhigh</td>
<td>meets</td>
<td>varies</td>
<td>-</td>
<td>87%</td>
<td>OLI-875</td>
</tr>
<tr>
<td>OLI Uniformity Full Field of View</td>
<td>0.35</td>
<td>0.5</td>
<td>percent</td>
<td>30%</td>
<td>OLI-951</td>
</tr>
<tr>
<td>OLI Uniformity Banding RMS</td>
<td>0.8</td>
<td>1</td>
<td>percent</td>
<td>20%</td>
<td>OLI-955</td>
</tr>
<tr>
<td>OLI Uniformity Banding Stdev</td>
<td>0.15</td>
<td>0.25</td>
<td>percent</td>
<td>40%</td>
<td>OLI-962</td>
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<tr>
<td>OLI Uniformity Streaking</td>
<td>0.5***</td>
<td>0.5, 1</td>
<td>percent</td>
<td>---***</td>
<td>OLI-973</td>
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<tr>
<td>OLI Coherent Noise</td>
<td>meets</td>
<td>&lt;equation</td>
<td>---</td>
<td>----</td>
<td>OLI-761</td>
</tr>
<tr>
<td>OLI Saturation Radiances</td>
<td>meets</td>
<td>varies</td>
<td>W/m² sr µm</td>
<td>8%</td>
<td>OLI-996</td>
</tr>
<tr>
<td>OLI 16-day Radiometric Stability</td>
<td>0.23****</td>
<td>1</td>
<td>Percent (2 sigma)</td>
<td>77%+</td>
<td>OLI-1001</td>
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<tr>
<td>OLI 60 second Radiometric Stability</td>
<td>0.1</td>
<td>0.5</td>
<td>Percent (2 sigma)</td>
<td>80%</td>
<td>OLI-1003</td>
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<tr>
<td>OLI Inoperable Detectors</td>
<td>0</td>
<td>&lt;0.1</td>
<td>Percent</td>
<td>100%</td>
<td>OLI-1013</td>
</tr>
<tr>
<td>OLI Out-of-Spec Detectors</td>
<td>0.14</td>
<td>&lt;0.25</td>
<td>Percent</td>
<td>44%</td>
<td>OLI-1020</td>
</tr>
</tbody>
</table>

* Band 7 compliance depends on solar spectrum used
*** Few intermittently streaky detectors above requirement level placed in out-of-spec bin as allowed
**** 60 days
TIRS Radiometric Performance Summary

- TIRS product uniformity is current focus of CVT and TIRS team analyses. Significant improvements to the uniformity are expected with updated parameters and/or algorithms.

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<thead>
<tr>
<th>Requirement</th>
<th>Measured Value (worst case)</th>
<th>Required Value</th>
<th>Units</th>
<th>Margin (worst case)</th>
<th>Requirement Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIRS Ghosting</td>
<td>meets</td>
<td>varies</td>
<td>percent</td>
<td>----</td>
<td>TIRS-403</td>
</tr>
<tr>
<td>TIRS Absolute Radiance Uncertainty</td>
<td>2.2</td>
<td>2</td>
<td>percent</td>
<td>----*</td>
<td>TIRS-427</td>
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<tr>
<td>TIRS NEΔT (@300K)</td>
<td>0.05</td>
<td>0.4</td>
<td>K</td>
<td>80%</td>
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<tr>
<td>TIRS Uniformity Full Field of View</td>
<td>1</td>
<td>0.5</td>
<td>percent</td>
<td>----*</td>
<td>TIRS-503</td>
</tr>
<tr>
<td>TIRS Uniformity Banding RMS</td>
<td>1</td>
<td>0.5</td>
<td>percent</td>
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<tr>
<td>TIRS Uniformity Banding Stdev</td>
<td>1</td>
<td>0.5</td>
<td>percent</td>
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<td>TIRS-514</td>
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<tr>
<td>TIRS Uniformity Streaking</td>
<td>0.4</td>
<td>0.5</td>
<td>percent</td>
<td>20%</td>
<td>TIRS-525</td>
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<tr>
<td>TIRS Coherent Noise</td>
<td>meets</td>
<td>&lt;equation</td>
<td>---</td>
<td>----</td>
<td>TIRS-532</td>
</tr>
<tr>
<td>TIRS Saturation Radiances</td>
<td>28.4, 19.2</td>
<td>20.5, 17.8</td>
<td>W/m² sr μm</td>
<td>8%</td>
<td>TIRS-545</td>
</tr>
<tr>
<td>TIRS 40 minute Radiometric Stability</td>
<td>0.1</td>
<td>0.7</td>
<td>percent (1 sigma)</td>
<td>86%</td>
<td>TIRS-547</td>
</tr>
<tr>
<td>TIRS Inoperable Detectors</td>
<td>0</td>
<td>&lt;0.1</td>
<td>percent</td>
<td>----</td>
<td>TIRS-550</td>
</tr>
<tr>
<td>TIRS Out-of-Spec Detectors</td>
<td>0.21</td>
<td>&lt;0.25</td>
<td>percent</td>
<td>16%</td>
<td>TIRS-555</td>
</tr>
</tbody>
</table>

*Likely due to stray light; Cal/Val team working with TIRS team on potential correction algorithm