Initial Radiometric Performance and Data Quality of the OLI and TIRS Landsat-8 sensors

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Outline

• OLI Radiometric Performance
  – Noise
  – Stability
  – Uniformity
  – Absolute Calibration
  – Artifacts

• TIRS Radiometric Performance
  – Noise
  – Stability
  – Uniformity
  – Absolute Calibration
  – Artifacts

• Upcoming reprocessing effort
• L-8/L-7 Comparative Images
• Noise
  – Dark
  – SNR
• Stability
  – Dark
  – Responsivity
• Uniformity/Relative Calibration
• Absolute Calibration
• Artifacts
• Summary
OLI Dark Noise - Green

Green Dark Noise

14-bit DN’s
OLI Dark Noise - Cirrus

Cirrus Dark Noise

Last query on 28-SEP-13, plot generated on 18Oct2013_08:07:51

14 bit DN’s
OLI Signal-to-Noise Ratio

• Noise model generated from shutter, lamp and diffuser data
  \[ \sigma_i^2 = a + b \cdot Q_i \]
  – Estimated monthly, once enough collects have been acquired

[Signal to Noise Ratio Model graph]

- SNR model fit
- dark shutter collects
- stim lamp collects
- diffuser panel collects

NIR band, July 2013
Signal-to-Noise Ratio

• The model is interpolated to a defined typical radiance level ($L_{typ}$), per-band

• OLI outperforms ETM+ by $6 – 12 \times$

<table>
<thead>
<tr>
<th>Band</th>
<th>ETM + Band Number</th>
<th>OLI Band Number</th>
<th>“Typical” Radiance Level ($L_{typ}$) [W/m² sr um]</th>
<th>ETM+ SNR (band average, low gain, at $L_{typ}$)</th>
<th>OLI SNR (band median, at $L_{typ}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>-</td>
<td>1</td>
<td>40</td>
<td>-</td>
<td>234</td>
</tr>
<tr>
<td>Blue</td>
<td>1</td>
<td>2</td>
<td>40</td>
<td>39</td>
<td>361</td>
</tr>
<tr>
<td>Green</td>
<td>2</td>
<td>3</td>
<td>30</td>
<td>37</td>
<td>299</td>
</tr>
<tr>
<td>Red</td>
<td>3</td>
<td>4</td>
<td>22</td>
<td>26</td>
<td>223</td>
</tr>
<tr>
<td>NIR</td>
<td>4</td>
<td>5</td>
<td>14</td>
<td>34</td>
<td>199</td>
</tr>
<tr>
<td>SWIR1</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>36</td>
<td>262</td>
</tr>
<tr>
<td>SWIR2</td>
<td>7</td>
<td>7</td>
<td>1.7</td>
<td>27</td>
<td>331</td>
</tr>
<tr>
<td>Pan</td>
<td>8</td>
<td>8</td>
<td>23</td>
<td>16</td>
<td>146</td>
</tr>
<tr>
<td>Cirrus</td>
<td>-</td>
<td>9</td>
<td>6</td>
<td>-</td>
<td>161</td>
</tr>
</tbody>
</table>
Noise Stability

Pan Per-Period Median SNR Model: Spec SNR over Time

SWIR2 Per-Period Median SNR Model: Spec SNR over Time

time since launch (period center) [days]
SNR Variability across FPA

Blue Per-Detector SNR Model: Period 005

SNR

SNR at Ltyp
SNR at Lhigh
Out-Of-Spec Ltyp
Out-of-Spec Lhigh

detector index

NASA
USGS
SNR Variability across FPA

SWIR1 Per-Detector SNR Model: Period 000

- Req: SNR @ Ltyp
- SNR @ Ltyp
- SNR @ Lhigh
- Out-of-Spec Ltyp
- Out-of-Spec Lhigh

SNR [ ]
detector index

0 1000 2000 3000 4000 5000 6000

Reqt: SNR @ Ltyp

NASA

USGS
Stability - Dark Level

CA WORKING Dark Signal

SWIR1 WORKING Dark Signal
Radiometric Stability

- Characterized using response to lamp pairs, solar diffusers and lunar acquisitions +
- Monitor band-average response over time.
Radiometric Stability

• Change to lamp response is generally echoed in the change to solar response, indicating the change is in the instrument, not the calibration device.

<table>
<thead>
<tr>
<th>Band</th>
<th>Lamp Radiance [W/m² sr um]</th>
<th>Change relative to Lamp [%]</th>
<th>Diffuser Radiance [W/m² sr um]</th>
<th>Change Relative to Diffuser [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>5.8</td>
<td>-0.62</td>
<td>500</td>
<td>-0.69</td>
</tr>
<tr>
<td>Blue</td>
<td>9.3</td>
<td>-0.30</td>
<td>517</td>
<td>-0.26</td>
</tr>
<tr>
<td>Green</td>
<td>18.6</td>
<td>0.10</td>
<td>476</td>
<td>0.11</td>
</tr>
<tr>
<td>Red</td>
<td>30.8</td>
<td>0.23</td>
<td>403</td>
<td>0.20</td>
</tr>
<tr>
<td>NIR</td>
<td>47.7</td>
<td>0.13</td>
<td>245</td>
<td>0.18</td>
</tr>
<tr>
<td>SWIR1</td>
<td>33.4</td>
<td>0.01</td>
<td>61.4</td>
<td>0.18</td>
</tr>
<tr>
<td>SWIR2</td>
<td>13.9</td>
<td>-0.05</td>
<td>19.4</td>
<td>0.14</td>
</tr>
<tr>
<td>Pan</td>
<td>22.6</td>
<td>0.03</td>
<td>455</td>
<td>0.17</td>
</tr>
<tr>
<td>Cirrus</td>
<td>42.8</td>
<td>0.03</td>
<td>94.0</td>
<td>0.10</td>
</tr>
</tbody>
</table>

As of mid August 2013
Stability – Ongoing Studies

• Improving precision of Lunar calibration
• Examining repeatability of pointing for solar diffuser measurements
• Examining stability of lamps, photodiodes, temperatures and telemetry
Uniformity

• Challenge due to the large numbers of detectors in each band, high precision of data and low level non-linearity in the system.

• Various metrics attempt to capture individual detector variation (streaking), groups of detectors/FPM’s (banding) and full field of view variability

• Used pre-launch characterization for initial processing
  – Processed scenes generally visually very good
  – On-orbit images have some streaking and banding.
  – Magnitude of non-uniformity generally <0.5%
  – Visible in uniform scenes, particularly CA band, SWIR bands
Uniformity

• Two updates to the calibration parameters have decreased striping and banding.
  • Aug 9, 2013: Linearization function update
    – Based on reanalysis of prelaunch test data
    – Improves SWIR bands
  • Aug 21, 2013: Relative Gain update
    – Based on on-orbit solar diffuser data
• Upcoming: Correcting edge detector relative gains
Egypt: DOY 169, 174/45
CA band, FPM1+
Original calibration parameters
Egypt: DOY 169, 174/45
CA band, FPM1+
Updated calibration parameters
Greenland: DOY 118, 16/4
Green band, FPM3
Original calibration parameters
Greenland: DOY 118, 16/4
Green band, FPM3
Updated calibration parameters
Greenland: DOY 118, 16/4
SWIR1 band, FPM9
Original calibration parameters
Greenland: DOY 118, 16/4
SWIR1 band, FPM9
Updated calibration parameters
Uniformity

• Discontinuities still exist at the boundaries between adjacent FPMs
  – In some cases, as large as 1%

• Result of some combination of
  – Slight view angle differences between odd and even focal plane modules in conjunction with illumination angles and bidirectional reflectance
  – Errors in pre-launch relative calibration
  – Errors in pre-launch linearity characterization
  – Changes in relative calibration since launch

• Studies are ongoing.
Upcoming Changes/Ongoing Studies

• Changing to pure Look-up-table linearization procedure
  – Increased flexibility
  – Should improve low radiance level non-uniformity

• Reexamining linearization assumptions/procedure
  – Parsing detector and electronic linearity to allow updating only electronic linearity on orbit
  – Special solar diffuser collect during solar eclipse

• Reexamining diffuser reflectance “non-uniformity” in diffuser data processing
  – Initially based on heliostat data
  – Testing U of A measurements as alternative

• Side slither, scene statistics, overlap statistics
  – Alternates to solar diffuser
OLI Radiance Calibration Validation

Difference (Field-OLI)/OLI vs Band

- U of AZ - Thullier solar data
- U of AZ - ChKur solar data
- Requirement
- SDSU ETM+ XCal
- ETM+
Absolute Calibration Investigations/Updates

• Upcoming- correcting cirrus band reflectance calibration by ~7%
• Reviewing prelaunch radiance calibration process (for SWIR-2 band in particular) and transfer to orbit test
• Reviewing reflectance calibration
OLI Artifacts

- No coherent (a.k.a. pattern noise) observed
- Spatial artifacts (i.e., ghosting, crosstalk) << requirements

OLI Band 9 (Cirrus) | OLI Band 6 (SWIR 1)
very weak ghost/ halo
OLI Radiometry Summary

• OLI performing well since launch
• Daily acquisitions of the working lamp pair and acquisition of the working solar diffuser every eight days provide useful characterization of OLI
• OLI outperforms ETM+ in SNR by an order of magnitude
• Stability exceeding requirements; no evidence of significant contamination/degradation of instrument or calibrators
• Uniformity has been improved recently, reducing striping by half
  – Discontinuities at FPM boundaries still remain
• Absolute Radiance Calibration generally within ±2% of vicarious measurements – SWIR2 an outlier at 5%
• Absolute Reflectance Calibration generally within ±2% of vicarious measurements – CA and Blue at 4-5%
TIRS

• Noise
• Stability
  – Transfer to Orbit
  – Over Acquisition Interval
  – Over Mission
• Relative Calibration
• Absolute Calibration
• Artifacts
• Summary
Focal Plane Layout

Descending (Day)

SCA3 (SCA-A)
SCA2 (SCA-C)
SCA1 (SCA-B)

Ascending (Night)

SCA3 (SCA-A)
SCA2 (SCA-C)
SCA1 (SCA-B)

(Roughly to Scale)
TIRS On-Orbit Performance: Noise

• Variation of signal to a constant source

• Noise expressed as a variation in radiance: NEΔL

• Noise expressed as a variation in brightness temperature: NEΔT

• View OBC at fixed temperature for one minute (4200 frames)
  ➢ Subtract background from each frame
  ➢ convert each frame to radiance -> take standard deviation of each detector as the NEΔL
  ➢ convert each frame to temperature  -> take standard deviation of each detector as NEΔT
TIRS On-Orbit Performance: Noise (2)

**NE\Delta L @ Source temperature of 295K**

- TIRS meets NE\Delta L and NE\Delta T requirements for source @ 295K by about a factor of 8;
- Factor of ~3 better than ETM+ (similar results for other temperatures)
TIRS Stability: Transfer to Orbit

• Relative ratio of On-orbit to Pre-flight OBC signal illustrates the effect of the contamination in TIRS 2 (band 11)

• Relative ratio of the OBC signal of DOY 165 to DOY 087 illustrates that the contamination has been constant over that time

• Will be continuously monitored throughout operations
• Observed the variation (std.) of the background signal over the same 36 min collect.

• Express the variation in background as a change in radiance @ 300 K and as a change in brightness temperature @ 300 K

• One-sigma variation of ~0.01 radiance units or 0.1 K implies stable background.
TIRS On-Orbit Performance: OBC Response Stability over Interval

- Collected image data of OBC @ 270 K for 36 continuous minutes.
- Observed the variation (standard deviation) of the radiance over that time period.

One-sigma variation is approx. 0.2% of the average radiance
- TIRS requirement states that this variation should be less than 0.7%
- Only slightly higher than within scene noise
TIRS On-Orbit Performance: Stability over mission life

- Calibration collects before and after Earth imaging (typically two collects/orbit; 14.5 orbits/day)
- Means and Standard deviations of each collect stored in Image Assessment System (IAS) database
- No long term degradation/contamination evident
  - Band 10 Gain Trends
    - 0.06%/100 days SCA 1
    - + 0.05%/100 days SCA 2
    - 0.04%/100 days SCA 3
  - Band 11 Gain Trends
    - 0.01%/100 days SCA 1
    - + 0.08%/100 days SCA 2
    - 0.02%/100 days SCA 3
TIRS: On-Orbit Performance: Spatial Uniformity

• Banding/streaking requirements meant to assess the spatial uniformity across the field of view for an Earth scene

• Metrics very dependent on the scene

• As one example, constructed ‘uniform’ scene from statistics from an ocean image
For this particular scene, TIRS meets the banding/streaking uniformity requirements.
TIRS On-Orbit Performance: Spatial Uniformity (3)

• Other scenes exhibit banding artifacts. Example: Salton Sea in California

• Banding between the three focal plane arrays as high as 3% in band 11

• Currently working to understand this behavior
Absolute Calibration: Comparison to Surface Measurements propagated through Atmosphere

TIRS is reporting higher temperatures than expected (by 2 K +)
Significant variability in results, particularly in band 11 (12 micron band)
Understanding TIRS Non-Uniformity and Absolute Calibration Variability

• TIRS non-uniformity varies with scene content
• Significant variability in differences between TIRS calibration and vicarious results
• Working hypothesis is that this is the same phenomena: TIRS out-of-field (OOF) response or ghosting
  – TIRS out-of-field response modeled and partially characterized prior to launch – no significant ghosts predicted or found within telescope FOV
  – On reexamination of pre-launch, some evidence of further out-of-field ghosts
• Two pronged approach
  – Use moon as a source for on-orbit ghost characterization; assess if magnitude of ghosts is sufficient to explain variability (optical modeling)
    • Data acquired while slewing to the moon have shown weak (<0.4%) ghosts in TIRS data beyond the focal plane assembly extent FOV
      – These slews sample a very small range of the TIRS OOF response
    • Special TIRS lunar ghosting collects scanned a larger range of angles around moon—initial examination consistent with an annular ghosting pattern
      – Continue characterizing variability using vicarious methods
TIRS Extended Lunar Scans (Day 289)

Lunar position in FOV
Band positions in FOV

From Allen Lunsford
TIRS Absolute Calibration under study

• Vicarious Calibrations
  – Multiple variables
    • Location in focal plane
    • Temperature
    • Scene content/contrast; day/night
  – Data limitations
    • Fixed cal sites routinely occur at same location in focal plane
      – Point off-nadir for some acquisitions (nighttime) to move location with focal plane
    • Automated access to TIRS data established
    • Increased nighttime acquisitions over coastal US regions

• Implementing Band 10 bias adjustment of -0.32 W/m2 sr μm
  – Reprocessing of already acquired data
Summary

- TIRS is performing well in terms of noise and stability when viewing on-board calibration sources.
  - Large margin on NEΔL and NEΔT and stability requirements

- TIRS meets banding/streaking uniformity metrics on certain Earth scenes yet fails these metrics on others.

- On-going analysis on banding/streaking and absolute calibration issues
  - Special lunar collects to characterize ghosting
  - Reexamination of TIRS stray light model
  - Enhanced vicarious analyses
CPF Update/Reprocessing Summary

• TIRS
  – Change band 10 absolute calibration by -0.32 W/m² sr μm

• OLI
  – Change Cirrus band reflectance calibration by ~7%
  – Increase precision of radiance to reflectance conversion coefficients (<0.3%)
  – Adjust edge detector relative gains

• Timing
  – This week
  – Completion
Landsat-8 Enhancements include:

(1) refined spectral bandpasses to avoid atmospheric absorption features or to provide better contrast,
(2) additional spectral bands at 443 nm for coastal and aerosol studies and 1375 nm for cirrus cloud detection,
(3) splitting the ETM+ thermal band into two spectral bands to allow better surface temperature retrievals,
(4) 12 bit radiometric resolution as opposed to 8-bit,
(5) sufficient radiometric range to cover 100% diffuse reflecting targets at the minimum solar zenith angle observed with the 10 AM equatorial crossing orbit
(6) improved noise performance.
Panchromatic Bandpass Refined

Landsat-7 ETM+  Landsat-8 OLI

Path 38 Row 37 March 29, 2013
New Cirrus Detection Band

OLI natural color (4,3,2)  Cirrus band (9)

Images prepared by P. Scaramuzza, EROS
Increased Saturation Radiance

L7 ETM + Pan Band

Saturated over snow

L8 OLI Pan Band

No Saturation
Improved Thermal Band Noise

Landsat-7 ETM+ Band 6

Landsat-8 (TIRS) Band 10
Landsat-7 ETM+ Natural Color (3,2,1)

From Pat Scaramuzza, EROS
LDCM OLI Natural Color (4,3,2)

From Pat Scaramuzza, EROS
LDCM OLI Natural Color