Landsat-8: Lunar Calibrations

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Landsat Calibration and Validation Team

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– Landsat-8 Mission Overview and Status
  • OLI and TIRS on-orbit performance
– Landsat-8 Lunar Calibrations
– Application in OLI Radiometric Stability Performance
– Current Model Improvement Effort
– Other uses for Lunar Observations
  • TIRS Straylight Correction
– Summary
Landsat-8 Overview

Joint project between NASA and USGS

- NASA – Instruments and spacecraft development, on-orbit checkouts, commissioning
- USGS – Ground segment and post-commissioning operations

*Remote Sens.* 2015, 7(3)
All spacecraft subsystems are nominal

- ACS
- FSW
- CDH
- EPS
- TCS
- PROP
- TTC

**OLI**
All systems nominal
Response change in CA band of about -1.2%
Some changes in the primary onboard calibration lamps

**TIRS**
A-side anomaly swap to B-side 2 – March 2015
Reflections from the internal TIRS telescope structure near the third lens caused out-of-field response at about 15° off axis (outside TIRS nominal field of view) – correction routine implemented for products
OLI Overview

- Pushbroom Radiometer, 15° FOV
- Eight 30 m multispectral bands
- One 15 m panchromatic band

<table>
<thead>
<tr>
<th>Band #</th>
<th>Band</th>
<th>Center Wavelength (nm)</th>
<th>Bandwidth (nm)</th>
<th>Lower Band Edge (nm)</th>
<th>Upper Band Edge (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coastal/Aerosol</td>
<td>443.0</td>
<td>16.0</td>
<td>435.0</td>
<td>451.0</td>
</tr>
<tr>
<td>2</td>
<td>Blue</td>
<td>482.0</td>
<td>60.0</td>
<td>452.0</td>
<td>512.1</td>
</tr>
<tr>
<td>3</td>
<td>Green</td>
<td>561.4</td>
<td>57.3</td>
<td>532.7</td>
<td>590.1</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>654.6</td>
<td>37.5</td>
<td>635.9</td>
<td>673.3</td>
</tr>
<tr>
<td>5</td>
<td>NIR</td>
<td>864.7</td>
<td>28.3</td>
<td>850.5</td>
<td>878.8</td>
</tr>
<tr>
<td>6</td>
<td>SWIR 1</td>
<td>1608.9</td>
<td>84.7</td>
<td>1566.5</td>
<td>1651.2</td>
</tr>
<tr>
<td>7</td>
<td>SWIR 2</td>
<td>2200.7</td>
<td>186.7</td>
<td>2107.4</td>
<td>2294.1</td>
</tr>
<tr>
<td>8</td>
<td>Panchromatic</td>
<td>589.5</td>
<td>172.4</td>
<td>503.3</td>
<td>675.7</td>
</tr>
<tr>
<td>9</td>
<td>Cirrus</td>
<td>1373.4</td>
<td>20.4</td>
<td>1363.2</td>
<td>1383.6</td>
</tr>
</tbody>
</table>

Cirrus
Pan

~7000 Detectors per band in 14 Focal Plane Modules (FPM)

Calibration Devices
- On-board lamps
- Solar diffuser
- Lunar
OLI Performance

SNR continues to exceed requirements by 2-3 times; Landsat-7 ETM+ by 8-10 times

OLI Signal-to-Noise Performance at Ltypical
Aug-2015

Precision of Calibrator Data (approximate range)

<table>
<thead>
<tr>
<th>Calibrator</th>
<th>Coastal Aerosol</th>
<th>Red</th>
<th>NIR</th>
<th>SWIR-1</th>
<th>SWIR-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp</td>
<td>±0.15%</td>
<td>±0.02%</td>
<td>±0.01%</td>
<td>±0.01%</td>
<td>±0.01%</td>
</tr>
<tr>
<td>Solar</td>
<td>±0.10%</td>
<td>±0.05%</td>
<td>±0.05%</td>
<td>±0.05%</td>
<td>±0.05%</td>
</tr>
<tr>
<td>Lunar</td>
<td>±0.10%</td>
<td>±0.10%</td>
<td>±0.10%</td>
<td>±0.50%</td>
<td>±0.30%</td>
</tr>
</tbody>
</table>
OLI Calibration Stability

Graphs showing trends in OLI ( Operational Land Imager) CA Band 3, Blue Band 2, Green Band 3, Red Band 4, NIR Band 5, Cirrus Band 9, SWIR1 Band 6, SWIR2 Band 7, and showing data points and trends over time.
• 4 optical element refracting telescope

• Focal plane consists of 3 staggered QWIP arrays

• Two spectral channels:
  10.6 μm - 11.2 μm known as “Landsat 8 band 10”
  11.5 μm - 12.5 μm known as “Landsat 8 band 11”

• Dark band to monitor focal plane drift

• Push-broom configuration: ~1850 detectors across-track per band

• 185 km ground swath (15 degree); 100 meter pixel size on ground;
  
  resampled to 30 meter pixels in final product

• For calibration purposes, a Scene Select Mechanism (SSM) can
  switch instrument view between:
  Nadir – Deep Space Port – Blackbody Calibrator (OBC)
TIRS Noise

- Noise characterization based on collects of OBC

**NEdL @ Source temperature of 295K**

**NEdT @ Source temperature of 295K**

* Actual NEdL & NEdT exceed requirements
Landsat-8 Status Summary

- Landsat-8 has been exceeding expectations in terms of data quantity and quality
  - currently acquires up to 740 images per day — requirements are 400 per day.
- OLI has been extremely stable on-orbit
  - At most 1% change in band average response in Band 1, Coastal Aerosol (CA)
  - variation between the calibration sources is ~0.2%
  - All calibration techniques working and consistent
  - Increase in “brightness” of working diffuser relative to other calibrators
  - Larger scatter in lunar response in SWIR bands, particularly SWIR-1 and Cirrus
  - OLI reflectance absolute calibration generally consistent to 3% with vicarious techniques
  - Small detector to detector variations (generally sub 0.1%) that are well corrected
  - SNR performance 2-3 times requirements
  - 100% detector operability
- TIRS has been extremely stable on-orbit
  - At most 0.5% change in band average response
  - Noise ~8 times better than requirements
  - 100% detector operability
  - Stray light compromises image uniformity and absolute calibration; adequately corrected in band 10 for many applications with simple bias factor
Based on experience on EO-1 (ALI & Hyperion instruments) since 2001*

- Lunar Cals are performed monthly between 5 and 9 deg lunar phase angle
  - The moon is imaged by a spacecraft pitch motion.
  - The pitch rate is constant and well controlled during the imaging interval.
  - Roll and Yaw rates are negligible.
  - Orientation of the scan is such that the bright limbs are at the top and bottom of the image. This provides better estimates of the lunar y-size
- Irradiance values of the lunar image are integrated and compared to the Rolo model.
  - Image is filtered to remove stars and other artifacts
  - No further background correction beyond those in the L1R process.

*Calcon Workshop on Lunar calibrations 2006;
IEEE JSTARS EO-1 Special Issues June 2003 & April 2013
Higher uncertainties in the SWIR Bands

The observed quasi-seasonal variations in SWIR2 does not appear to be correlated to temperature effects.
Development of SLIM Lunar Irradiance Model

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- Spacecraft and Earth-based Lunar Irradiance Model, SLIM
- Support any bands in the 330-2500 nm region
- Based on as many spacecraft as possible
- Follow many of the concepts used by be ROLO
- But, treat ROLO data as just another instrument (current effort uses version 3)
- Use a structure that can readily incorporate additional instruments

There is only one Moon
We need to develop our best estimate of what it is
On-going model improvement effort

Modeling considerations -
1. Spectral coverage of model input data
Model Considerations - continued

Phase angle coverage
Model considerations - continued

Libration coverage
Very preliminary results

Current Rolo model

Using only OLI, Hyperion, MODIS and VIIRS
Does not include non-linear terms, eg the phase angles, residuals for solar longitude, etc.

Difference Ratio

Wavelength [nm]
Very preliminary SLIM results

Using only OLI, Hyperion, MODIS and VIIRS
Does not include non-linear terms, eg the phase angles, residuals for solar longitude, etc.

Continuous wavelength coefficients
Philosophic Issues/Future work

- How to adjust for large differences in the number of data points for an instrument,
  - ROLO: 1239, 32 bands each
  - OLI: 675, 9 bands
  - Hyperion: 20, 196 bands reduced to 26
  - MODIS-Aqua: 53, 12 bands provided
  - VIIRS: 27, 14 bands

- How to account for the different uncertainties among the datasets
  - Use calibration residual level to refine the uncertainty for next iteration.

- How to join the band-by-band results spectrally in a plausible manner.
  - Lab measurements of the Lunar photometric properties are smooth across wavelengths
  - The first attempt yielded promising results

- Incorporate other datasets including those from GOES, Pleiades, and others who would like to contribute to the effort.
Other uses for Lunar Observations

Landsat 8 Thermal Infrared Sensor (TIRS)
Stray Light Correction

- Aaron Gerace
- Matthew Montanaro
Two major artifacts:

1. Non-Uniform Banding

2. Absolute Calibration Error

Day of Year

Apparent Temperature Error (K)

11/14/17 2nd GSICS Lunar Calibration Workshop, Xian, China
Lunar raster scan definitively showed stray light

- Raster-scan the moon around the out-of-field
- Should see “nothing” when moon is outside field-of-view
Lunar locations (blue) in which a stray light signal appeared anywhere on the detectors
Reverse ray trace produces stray light map for each detector

![Stray light map for one detector on array - C](image1)

![Stray light map for one detector on array - B](image2)

- Dots = Optical model
- Circles = Lunar data

* Unique PSF for each detector (i.e. different stray light signal for every detector)
Stray light removal algorithm: Optical model with out-of-field data

\[
\text{StrayLight} = a \cdot (\text{Ext.Sampled}) + b
\]

\[
= a \cdot \left( \sum L_{\text{ext},i} \cdot w_i \right) + b
\]

Calculated signal to remove from TIRS interval
Stray light removal algorithm: Optical model with TIRS data only

\[
StrayLight = a \cdot (\text{Ext.Sampled}) + b \\
= a \cdot \left( \sum L_{\text{ext},i} \cdot w_{i} \right) + b
\]

Calculated signal to remove from TIRS interval
Stray light correction with and without out-of-field knowledge

Original Image  Corrected w/ out-of-field knowledge (GOES)  Corrected w/ only TIRS data

Band10
Heavy black = original
Gray = corrected w/GOES
Black = corrected w/TIRS

Band11

RMS of Residuals

Detector Number

11/14/17  2nd GSICS Lunar Calibration Workshop, Xian, China
During L8/Terra underfly period, TIRS centered on MODIS field-of-view

- Compare TIRS current product and corrected product to Terra/MODIS for all of the following locations:
Example validation data using Path 010, Row 030: Band 10

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>Corrected</td>
<td>Current</td>
</tr>
<tr>
<td>Profile 1</td>
<td>0.258</td>
<td>0.102</td>
<td>1.275</td>
</tr>
<tr>
<td>Profile 2</td>
<td>0.253</td>
<td>0.074</td>
<td>1.145</td>
</tr>
</tbody>
</table>
Example validation data using Path 010, Row 030: Band 11

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>Corrected</td>
<td>Current</td>
</tr>
<tr>
<td>Profile 1</td>
<td>0.573</td>
<td>0.127</td>
<td>2.935</td>
</tr>
<tr>
<td>Profile 2</td>
<td>0.529</td>
<td>0.093</td>
<td>2.281</td>
</tr>
</tbody>
</table>

11/14/17

2nd GSICS Lunar Calibration Workshop, Xian, China
Example validation data using Path 022, Row 030: Band 10

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Corrected</td>
<td>Current</td>
<td>Corrected</td>
</tr>
<tr>
<td>Profile 1</td>
<td>0.201</td>
<td>0.101</td>
<td>1.141</td>
</tr>
<tr>
<td>Profile 2</td>
<td>0.246</td>
<td>0.114</td>
<td>0.856</td>
</tr>
</tbody>
</table>
Example validation data using Path 022, Row 030: Band 11

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile 1</td>
<td>0.451</td>
<td>2.448</td>
<td>-2.406</td>
</tr>
<tr>
<td></td>
<td>0.113</td>
<td>0.124</td>
<td>0.054</td>
</tr>
<tr>
<td>Profile 2</td>
<td>0.494</td>
<td>1.552</td>
<td>-1.472</td>
</tr>
<tr>
<td></td>
<td>0.163</td>
<td>0.227</td>
<td>0.158</td>
</tr>
</tbody>
</table>
RMSE summary ("absolute calibration"):

In terms of Percent Radiance error with Terra/MODIS

Path 198 desert

Path 191 clouds

Large difference between TIRS and MODIS due to the Earth changing between the two overflight times

Band 11

+ Current Product

○ Stray Light Corrected
• Algorithm uses only TIRS interval data (no other sensor data) with optical model
• Able to be run in “real time” (i.e. - no significant processing lag) to produce corrected TIRS scenes
• Significant issues with external sensor (e.g. - GOES) data limit its utility:
  • Band shape
  • View angle
  • cross-cal between sensors required for global coverage
• TIRS-on-TIRS was implemented into USGS ground processing system. Products available through “Landsat 8 Collection 1” data archive.
• Validated correction using Terra/MODIS data during the Terra/Landsat 8 under-flight period following launch.
Publications:


Aaron Gerace (gerace@cis.rit.edu)
Matt Montanaro (matthew.montanaro@nasa.gov)
Summary

• Landsat-8 approaching 5 years of service
• OLI-2 is stable
  – Good agreement among all calibration devices
  – Higher uncertainty for the SWIR bands in the lunar data
• On-going effort to improve the model for both relative and absolute radiometry
  – Developing algorithms to incorporate differences among the instruments/data sources.
• Lunar observations was useful to examine and diagnose image artifacts in both the OLI and, especially for the TIRS
  – Straylight correction routine for successfully incorporated in the Landsat-8 TIRS image products.
Landsat Calibration Validation Team

- USGS Earth Resources Observation and Science (EROS)
  - http://landsat.usgs.gov/
- NASA Goddard Space Flight Center (GSFC)
  - http://landsat.gsfc.nasa.gov/
- NASA Jet Propulsion Laboratory (JPL)
  - http://www.jpl.nasa.gov/
- Rochester Institute of Technology (RIT)
  - http://www.cis.rit.edu/
- South Dakota State University (SDSU) Image Processing (IP) Laboratory
  - http://iplab2out.sdstate.edu/
- University of Arizona (UofA) Optical Sciences Laboratory
  - http://www.optics.arizona.edu/
• Thank you