Radiometric Source Traceability for the Ground Calibration of OLI-2

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CALCON 2019
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Outline

Introduction

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OLI-2 Calibration Overview

**Spectrum**
- Operational Land Imager 2 (OLI-2) has 9 spectral bands

<table>
<thead>
<tr>
<th>#</th>
<th>Band Name</th>
<th>Label</th>
<th>Center Wavelength [nm]</th>
<th>Bandwidth [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coastal Aerosol</td>
<td>CA</td>
<td>443</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Blue</td>
<td>B</td>
<td>482</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>Green</td>
<td>G</td>
<td>562</td>
<td>75</td>
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<tr>
<td>4</td>
<td>Red</td>
<td>R</td>
<td>655</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>NIR</td>
<td>NIR</td>
<td>865</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>SWIR 1</td>
<td>1SW</td>
<td>1610</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>SWIR 2</td>
<td>2SW</td>
<td>2200</td>
<td>200</td>
</tr>
<tr>
<td>8</td>
<td>Panchromatic</td>
<td>P</td>
<td>590</td>
<td>180</td>
</tr>
<tr>
<td>9</td>
<td>Cirrus</td>
<td>CRS</td>
<td>1375</td>
<td>30</td>
</tr>
</tbody>
</table>

**Requirements**
- NIST-traceable sources must contribute < ±2.5% (k=1) absolute band-weighted radiance uncertainty
- Radiance is calibrated at 20 levels per band:
  - 10 levels $L_{typ}$ span to $L_{max}$, where $L_{typ} \approx 0.06 \times L_{max}$
  - 10 levels down to $0.1\times L_{typ}$ (looser requirements)
Calibration Process

- **NIST-traceability via FASCAL, FASCAL 2, and ROSI**
  - Ball SSS, 12” integrating sphere (non-Cirrus)
  - Ball FEL lamp & Spectralon panel (Cirrus)

- **Radiometers**
  - Ball CXR radiometer (350-2500nm)
  - GSFC LXR radiometer (440-860nm)
  - UA VNIR radiometer (440-860nm)
  - UA SWIR radiometer (870-2700nm)

- **Source under calibration**
  - Ball DSS, 40” integrating sphere
Ball Radiometric Sources

SSS
- Diffuser: 12” diam. PTFE
- Aperture: 3 in.
- Lamps: 3x 30W QTH
- Cooling: passive
- Power: constant current
- Control: open (monitored)

Lamp & Panel
- Diffuser: 12” sq. Spectralon
- Lamp: 1000W QTH
- Cooling: passive
- Power: constant current
- Control: open (monitored)

DSS
- Diffuser: 40” diam. BaSO$_4$
- Aperture: 14 in.
- Lamps: 18x QTH (150-600W)
- Cooling: water manifolds
- Power: constant current
- Control: lamp attenuators
CXR Radiometer

ASD FS3 WR 350-2500 VNIR-SWIR spectrometer

MIRROR/OPEN

Filters (12x)

"OPEN"

lens & baffle assembly

"MIRROR"

2-color TEC-cooled photodiode

CXR data acquisition

START TEST

Advance
Path = "MIRROR"

Wait
Settling time

Acquire
Si & InGaAs photocurrent

Advance
Filter position + 1

repeat

STOP TEST

Advance
Filter position = 1
Path = "OPEN"

Wait
Settling time

Acquire
Si & InGaAs photocurrents (dark)

Acquire
ASD spectrum (dark-corrected)

SSS spectrum

OLI-2 witness filters

Spectral Radiance [W/(m²·sr·μm)]

Wavelength [nm]
**CXR Out-Of-Field (OOF) Correction**

- **CXR is susceptible to “out-of-field” response**
  - Stray light from *within* source aperture, but *outside* nominal CXR field of regard
  - Photocurrent biased by apparent source extent, i.e. larger for DSS $\Omega_{\text{Large}}$ vs. SSS $\Omega_{\text{Small}}$
  - Bias correction: subtract photocurrent contribution outside small region

- **Signal from outside $\Omega_{\text{Small}}$ is measured by blocking inner region:**

\[
\begin{align*}
\zeta_{\text{OOF},n}(\Omega_{\text{Large}}, \Omega_{\text{Small}}) &= \zeta_{\text{OOF},n}(\Omega_{\text{UB}}, \Omega_B) = \left( 1 - \frac{I_{B,n}}{I_{UB,n}} \right) \\
I_{B,n}(\Omega_B) & \text{ “Blocked”} \\
I_{UB,n}(\Omega_{UB}) & \text{ “Unblocked”}
\end{align*}
\]
CXR Out-Of-Field (OOF) correction

- CXR OOF correction measurement in practice:
- Uncertainty allocation = (correction %) / 2
- Radiometers: CXR (Ball), LXR (GSFC), UA VNIR and UA SWIR (U of A)
- Sources: SSS (30W and 90W), GSFC Grande sphere (4 lamps and 9 lamps)
- All radiometers measured all source levels 2-3x
  - SSS 90W used as standard, non-Cirrus band source stability within $\pm 0.2\%$
  - RSR data for LXR, UA VNIR, UA SWIR provided to Ball
  - RSR-weighted CXR radiances compared to other radiometers’ in-band radiance results
  - Radiometers generally within $\pm 0.5\%$ of CXR radiance
  - Exceptions: SWIR2 within $\pm 0.75\%$, Cirrus within $\pm 1.75\%$
DSS Calibration – Ball Aerospace

- Calibration performed with CXR
- SWIR relative radiance validated by UA SWIR
- Initial baseline/checkout measurements
  - Validated functionality and radiance range
  - Linearized variable light control
  - Planned setpoints for instrument test
- Calibrated DSS from OLI-2 TVAC test location
- In situ cal reduces uncertainty from:
  - TVAC chamber window transmission
  - Chamber stray light effects
- Calibrated 180 levels:
  - In-band monitor 2hr stability: < ±0.05%
  - Relative radiance knowledge: < ± 0.5%
  - Absolute radiance knowledge: < ± 2.0% (non-Cirrus)
    < ± 2.4% (Cirrus)
# DSS Calibration Error Budget

<table>
<thead>
<tr>
<th></th>
<th>Coastal Aerosol</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
<th>NIR</th>
<th>SWIR1</th>
<th>SWIR2</th>
<th>Pan</th>
<th>Cirrus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traceability</td>
<td>443</td>
<td>482</td>
<td>562</td>
<td>655</td>
<td>865</td>
<td>1610</td>
<td>2200</td>
<td>590</td>
<td>1380</td>
</tr>
<tr>
<td><strong>NIST SSS calibration</strong></td>
<td>±0.6%</td>
<td>±0.49%</td>
<td>±0.41%</td>
<td>±0.4%</td>
<td>±0.4%</td>
<td>±0.67%</td>
<td>±0.74%</td>
<td>±0.41%</td>
<td>±0.84%</td>
</tr>
<tr>
<td><strong>SSS to CXR transfer</strong></td>
<td>±0.74%</td>
<td>±0.75%</td>
<td>±0.74%</td>
<td>±0.74%</td>
<td>±0.74%</td>
<td>±0.75%</td>
<td>±0.78%</td>
<td>±0.75%</td>
<td>±1.33%</td>
</tr>
<tr>
<td><strong>CXR to DSS transfer</strong></td>
<td>±0.99%</td>
<td>±0.83%</td>
<td>±0.74%</td>
<td>±0.71%</td>
<td>±0.7%</td>
<td>±0.75%</td>
<td>±0.86%</td>
<td>±0.97%</td>
<td>±1.43%</td>
</tr>
<tr>
<td><strong>DSS to OLI transfer</strong></td>
<td>±0.33%</td>
<td>±0.28%</td>
<td>±0.28%</td>
<td>±0.28%</td>
<td>±0.3%</td>
<td>±0.3%</td>
<td>±0.54%</td>
<td>±0.37%</td>
<td>±1.04%</td>
</tr>
<tr>
<td><strong>Expected error (k=1)</strong></td>
<td>1.76%</td>
<td>1.57%</td>
<td>1.46%</td>
<td>1.43%</td>
<td>1.42%</td>
<td>1.61%</td>
<td>1.82%</td>
<td>1.68%</td>
<td>2.37%</td>
</tr>
</tbody>
</table>
Round Robin – Ball Aerospace

- Radiometers: CXR (Ball), LXR (GSFC), UA VNIR and UA SWIR (U of A)
- Sources: SSS (90W), DSS, FEL Lamp & Panel (L&P)
- SSS – confirmed mutual stability of radiometer responsivity < 0.2%
- Lamp and Panel – CXR and UA SWIR Cirrus results match to < 0.4%
- DSS – Relative radiance knowledge confirmed by LXR, UA VNIR and UA SWIR to < 0.5%
- DSS – Absolute radiance confirmed at $L_{typ}$ by LXR, UA VNIR and UA SWIR to < 0.4%

<table>
<thead>
<tr>
<th>Radiometer</th>
<th>DSS Control Band</th>
<th>CXR Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>LXR</td>
<td>Coastal Aerosol</td>
<td>-0.28%</td>
</tr>
<tr>
<td>UA VNIR</td>
<td>Coastal Aerosol</td>
<td>-0.33%</td>
</tr>
<tr>
<td>LXR</td>
<td>Blue</td>
<td>-0.25%</td>
</tr>
<tr>
<td>LXR</td>
<td>Green</td>
<td>0.09%</td>
</tr>
<tr>
<td>LXR</td>
<td>Red</td>
<td>0.04%</td>
</tr>
<tr>
<td>LXR</td>
<td>NIR</td>
<td>-0.14%</td>
</tr>
<tr>
<td>UA SWIR</td>
<td>SWIR 1</td>
<td>0.13%</td>
</tr>
<tr>
<td>UA SWIR</td>
<td>SWIR 2</td>
<td>0.22%</td>
</tr>
</tbody>
</table>
Conclusion – Keys to Success

- **Efficiency | CXR Radiance Transfer Algorithm**
  - Improved data processing flow
  - Quick-turn and repeatable results

- **Stray Light Mitigation | CXR Out-Of-Field correction**
  - Validated correction method ahead of DSS calibration
  - Applied methodology to *all* radiance transfers

- **Spectral Accuracy | CXR SWIR band OLI-2 witness filters**
  - RSR matching mitigates low SWIR spectrometer resolution
  - Allows accurate radiance transfer between dissimilar spectra

- **Stability | DSS in-band monitoring and control**
  - Mitigates source spectral drift
  - Careful planning of levels for minimal lamp state changes
Acknowledgements

- **Ball calibration specialists** – Hansford Cutlip, Geir Kvaran, Sandra Collins
- **Ball test support** – Ryan Romero, Cameron Stutheit, OLI-2 I&T team
- **University of Arizona** – Remote Sensing Group, Stuart Biggar and Nikolaus Anderson
- **NASA** – Funding and calibration support