Improvements and Challenges of Sensor Reflective Solar Calibration

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Contents

- Reflective Solar Calibration Approaches
- MODIS and VIIRS Calibration
- Calibration Improvements
- Challenging Issues
- Way Forward

Focusing on MODIS and VIIRS reflective solar on-orbit calibration
Reflective Solar Calibration Approaches

• On-board Calibrators
  – Solar diffusers (Spectralon, Al plates coated with YB71, QVD, ...)
  – SD stability monitors (a ratioing device, a second diffuser, lamps, ...)
  – Lamps

• Lunar Observations
  – Scheduled (same phase angles)
  – Unscheduled (various phase angles)

• Vicarious Calibration Targets
  – Pseudo Invariant Calibration Sites (PICS)
  – Deep Convective Clouds (DCC)

• Cross-sensor Inter-comparisons
  – SNO (including double difference approach)
  – Ground calibration/reference targets (e.g., RadCalNet)

Different approaches used by various sensors (AVHRR, GOES-14/15/16/17, L7 ETM+, L8 OLI, SeaWiFS, Terra/Aqua MODIS, S-NPP/N-20 VIIRS, S2A/2B MSI, S3A/B OLCI)
MODIS and VIIRS On-orbit Calibration

MODIS (Aqua)
- SD calibration: weekly to tri-weekly
- SDSM operation: weekly to tri-weekly
- Lunar observations: near-monthly
- SRCA (with lamps): regularly scheduled
- Ground targets: PICS and DCC

VIIRS
- SD calibration: each orbit
- SDSM: daily to weekly
- Lunar observations: near-monthly
- Ground targets for validation

- **MODIS SD calibration system includes a SD door and an optional screen**
- **VIIRS uses a fixed attenuation screen (no SD door)**
Calibration Improvements and Challenges

- No pre-launch characterization for MODIS SD and SDSM screen transmission
- Pre-launch BRDF and screen characterization (for VIIRS) were made at limited wavelengths and illumination/viewing geometries
- SD degradation at SWIR wavelengths

- Yaw maneuvers to characterize SD BRDF and its screen transmission ($\tau$) (only the product of BRDF and $\tau$ for VIIRS)
- Yaw maneuvers to characterize SDSM screen transmission
- Roll maneuvers for lunar observations
- Strategies to improve SD degradation characterization

- MODIS - ground targets to characterize changes of sensor response versus scan-angle (RVS) and polarization sensitivity
- MODIS SWIR crosstalk characterization and correction
- S-NPP - modulated relative spectral response (RSR) – caused due to mirror coating contamination
SD BRF and Screen Transmission ($\tau_{SD}$)

Terra MODIS BRF (< 0.15%)

S-NPP BRF* $\tau_{SD}$ (< 0.35%)

Illumination/viewing geometries and resolutions with sensor detectors (wavelengths)
SDSM Screen Transmission ($\tau_{\text{SDSM}}$)

Large variations in MODIS SDSM Sun View responses due to design artifact

MODIS SDSM Sun View Responses

\[ \Delta_{SD} \propto \frac{dc_{SD}}{dc_{Sun}} \left\{ \frac{dc_{D1\_view}}{dc_{D1\_Sun\_view}} \right\} \left\{ \frac{dc_{D9\_view}}{dc_{D9\_Sun\_view}} \right\} \]

VIIRS SDSM Sun View Responses

MODIS/VIIRS SDSM has 9/8 detectors covering wavelengths from 0.41 $\mu$m to 0.94 $\mu$m

Lessons from MODIS to VIIRS and on-orbit to pre-launch
SDSM Screen Transmission ($\tau_{SDSM}$)

- S-NPP pre-launch $\tau_{SDSM}$
- S-NPP on-orbit $\tau_{SDSM}$
- S-NPP SD degradation
- N-20 SD degradation

Smooth SD degradation with improved screen transmission
MODIS and VIIRS SD Degradation

- Larger SD degradation at shorter wavelengths
  - VIIRS has no SD door; Terra MODIS SD door fixed at “open” at L+2.5 yr

S-NPP SD degradation is more closer to T-MODIS and N-20 is more closer to A-MODIS
For MODIS:

- A different approach was proposed but not implemented
- Long-term SWIR degradation is tracked using desert and DCC response trends and using band-to-band response ratio

**VIIRS SD Degradation at SWIR Wavelength**

SDSM: from 0.41 to 0.93 µm

SWIR bands: from 1.2 to 2.3 µm

\[ 1 - H(\lambda, t) = \frac{\alpha(t)}{\lambda^{4.07}} \]

Useful to track small SD degradation (e.g., at mission beginning)
Use of Lunar Observations (VIIRS)

- VIIRS SD and lunar observations are made at the same AOI
  - Lunar data used to track sensor long-term response; SD degradation concerns eliminated
Use of Lunar Observations (MODIS)

- MODIS SD and lunar observations are made at the different AOI
  - Lunar and SD data used to track sensor response versus scan-angle (RVS); long-term SD degradation concerns remained

For bands with large changes, earth view response trends at multiple AOIs are also used to support RVS characterization
On-orbit Modulated RSR (S-NPP)

- S-NPP RTA (rotating telescope assembly) mirror coating contamination
  - Large decrease of optical throughput at NIR and SWIR

Small impact for bands with narrow bandwidths and small OOB responses
Large impact on DNB with broad bandwidth
On-orbit Modulated RSR Impact for DNB Calibration

**DNB LG Modulated RSR**

**DNB LG SD Calibration**

\[ \frac{1}{F} \approx \text{gain} \]

Similar effect in lunar calibration

NPP DNB: Low gain, Mode 1, avg(det)
Use of Earth View Trending (Aqua)

No on-orbit changes in Aqua polarization sensitivity (verified with ocean products)
Use of Earth View Trending (Terra)

MODIS band 3 (0.48 μm)

MODIS band 8 (0.41 μm)

Future RVS characterization: polarization corrected earth view response trending
Other Issues

• **Pre-launch**
  – RSR characterization
  – Polarization characterization (J1 VIIRS M1-M4)
  – Stray light and cross-talk characterization (MODIS SWIR)
  – Complete end-to-end testing (including on-board calibrators)

• **Pre-launch to on-orbit transfer**
  – Unbroken chain of sensor calibration

• **On-orbit**
  – Long-term calibration stability
  – Multi-sensor calibration consistency
Way Forward

• Continuing efforts to maintain sensor calibration stability and data quality
  – Track and correct for changes in sensor and OBC responses, including sensor RVS and polarization sensitivity
  – Generate consistent calibration LUTs to support data reprocessing

• Coordinated efforts to address multi-sensor calibration consistency
  – Joint efforts from different agencies and missions or programs
  – Close interaction between calibration team and science teams or data users for better understanding of the observed differences (over difference targets and among different sensors)
  – Use of calibration reference instrument(s) and the Moon
### VIIRS Spectral Bands

<table>
<thead>
<tr>
<th>VIIRS Band</th>
<th>Spectral Range (um)</th>
<th>Nadir HSR (m)</th>
<th>MODIS Band(s)</th>
<th>Range</th>
<th>HSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNB</td>
<td>0.500 - 0.900</td>
<td>750</td>
<td>8</td>
<td>0.405 - 0.420</td>
<td>1000</td>
</tr>
<tr>
<td>M1</td>
<td>0.402 - 0.422</td>
<td>750</td>
<td>8</td>
<td>0.405 - 0.420</td>
<td>1000</td>
</tr>
<tr>
<td>M2</td>
<td>0.436 - 0.454</td>
<td>750</td>
<td>9</td>
<td>0.438 - 0.448</td>
<td>1000</td>
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<tr>
<td>M3</td>
<td>0.478 - 0.498</td>
<td>750</td>
<td>3 and 10</td>
<td>0.459 - 0.479, 0.483 - 0.493</td>
<td>500, 1000</td>
</tr>
<tr>
<td>M4</td>
<td>0.545 - 0.565</td>
<td>750</td>
<td>4 or 12</td>
<td>0.545 - 0.565, 0.546 - 0.556</td>
<td>500, 1000</td>
</tr>
<tr>
<td>I1</td>
<td>0.600 - 0.680</td>
<td>375</td>
<td>1</td>
<td>0.620 - 0.670</td>
<td>250</td>
</tr>
<tr>
<td>M5</td>
<td>0.662 - 0.682</td>
<td>750</td>
<td>13 or 14</td>
<td>0.662 - 0.672, 0.673 - 0.683</td>
<td>1000, 1000</td>
</tr>
<tr>
<td>M6</td>
<td>0.739 - 0.754</td>
<td>750</td>
<td>15</td>
<td>0.743 - 0.753</td>
<td>1000</td>
</tr>
<tr>
<td>I2</td>
<td>0.846 - 0.885</td>
<td>375</td>
<td>2</td>
<td>0.841 - 0.876</td>
<td>250</td>
</tr>
<tr>
<td>M7</td>
<td>0.846 - 0.885</td>
<td>750</td>
<td>16 or 2</td>
<td>0.862 - 0.877, 0.841 - 0.876</td>
<td>1000, 250</td>
</tr>
<tr>
<td>M8</td>
<td>1.230 - 1.250</td>
<td>750</td>
<td>5</td>
<td>SAME</td>
<td>500</td>
</tr>
<tr>
<td>M9</td>
<td>1.371 - 1.386</td>
<td>750</td>
<td>26</td>
<td>1.360 - 1.390</td>
<td>1000</td>
</tr>
<tr>
<td>I3</td>
<td>1.580 - 1.640</td>
<td>375</td>
<td>6</td>
<td>1.628 - 1.652</td>
<td>500</td>
</tr>
<tr>
<td>M10</td>
<td>1.580 - 1.640</td>
<td>750</td>
<td>6</td>
<td>1.628 - 1.652</td>
<td>500</td>
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<tr>
<td>M11</td>
<td>2.225 - 2.275</td>
<td>750</td>
<td>7</td>
<td>2.105 - 2.155</td>
<td>500</td>
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<tr>
<td>I4</td>
<td>3.550 - 3.930</td>
<td>375</td>
<td>20</td>
<td>3.660 - 3.840</td>
<td>1000</td>
</tr>
<tr>
<td>M12</td>
<td>3.660 - 3.840</td>
<td>750</td>
<td>20</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M13</td>
<td>3.973 - 4.128</td>
<td>750</td>
<td>21 or 22</td>
<td>3.929 - 3.989, 3.929 - 3.989</td>
<td>1000, 1000</td>
</tr>
<tr>
<td>M14</td>
<td>8.400 - 8.700</td>
<td>750</td>
<td>29</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M15</td>
<td>10.263 - 11.263</td>
<td>750</td>
<td>31</td>
<td>10.780 - 11.280</td>
<td>1000</td>
</tr>
<tr>
<td>I5</td>
<td>10.500 - 12.400</td>
<td>375</td>
<td>31 or 32</td>
<td>10.780 - 11.280, 11.770 - 12.270</td>
<td>1000</td>
</tr>
<tr>
<td>M16</td>
<td>11.538 - 12.488</td>
<td>750</td>
<td>32</td>
<td>11.770 - 12.270</td>
<td>1000</td>
</tr>
</tbody>
</table>

1 DNB: L/M/HG
32 Agg. Modes
14 RSB: 0.41-2.3 μm
7 DGB: M1-M5, M7, and M13
7 TEB: 3.7-12.1 μm