MODIS and VIIRS Reflective Solar Bands Calibration, Performance, and Inter-comparison

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Outline

• Background

• MODIS and VIIRS On-orbit Calibration
  – Solar and Lunar Calibration

• On-orbit Performance
  – Sensor Performance
  – Calibration Inter-comparison

• Summary
Background

• **Moderate Resolution Imaging Spectroradiometer (MODIS)**
  – Key instrument for NASA EOS Terra and Aqua missions
  – 20 reflective solar bands (RSB) and 16 thermal emissive bands (TEB)
  – RSB spectral wavelengths: 0.41 - 2.2 μm; TEB: 3.75 - 14.5 μm
  – Spatial resolution: 250 m (2 bands), 500 m (5 bands), and 1 km (29 bands)

• **Visible/Infrared Imager Radiometer Suite (VIIRS)**
  – Key instrument for S-NPP and future JPSS missions
  – 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), and 1 day night band (DNB)
  – RSB spectral wavelengths: 0.41 -2.3 μm ; TEB: 3.75 - 12.2 μm
  – Spatial resolution: 375 m for I bands and DNB; 750 m for M bands

Aqua MODIS is currently used as the reflective solar calibration reference VIIRS, with strong MODIS heritage, should be considered as a future reference sensor
### MODIS and VIIRS Spectral Bands

<table>
<thead>
<tr>
<th>VIIRS Band</th>
<th>Spectral Range (μm)</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></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>9</td>
<td>0.438 - 0.448</td>
<td>1000</td>
</tr>
<tr>
<td>M2</td>
<td>0.436 - 0.454</td>
<td>750</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td>0.478 - 0.498</td>
<td>750</td>
<td>3 or 10</td>
<td>0.459 - 0.479</td>
<td>500</td>
</tr>
<tr>
<td>M4</td>
<td>0.545 - 0.565</td>
<td>750</td>
<td></td>
<td>0.545 - 0.565</td>
<td>500</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</td>
<td>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</td>
<td>1000</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>
</tr>
<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>
</tr>
<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 - 4.428</td>
<td>750</td>
<td>21 or 22</td>
<td>3.929 - 3.989</td>
<td>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</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>

- **Dual gain band**

*Similar MODIS bands*
MODIS and VIIRS On-orbit Calibration

- **Same On-board Calibrators**
  - Solar Diffuser
  - Solar Diffuser Stability Monitor (SDSM)
  - Space View (SV)

- **Solar Calibration**
  - MODIS: Regular SD/SDSM observations (SD door opens only during scheduled SD/SDSM calibration)
  - VIIRS: Continuous SD calibration (no SD door) in each orbit with SDSM currently scheduled on a daily basis

- **Lunar Calibration** – same strategy
  - Regularly scheduled at nearly the same phase angle
  - Observed through SV port
  - SC roll maneuvers
MODIS Solar Calibration

EV Reflectance Factor:

\[ \rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot d_{nEV}^* \cdot d_{Earth-Sun}^2 \]

\[ m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{<d_{nSD}^*> \cdot d_{Earth-Sun}^2} \cdot \Gamma_{SD} \cdot \Delta_{SD} \]

\[ \Delta_{SD} = \frac{dc_{SD}}{dc_{Sun}} \]

\( \Delta_{SD} \): SD degradation factor
\( \Gamma_{SD} \): SD screen vignetting function
\( d \): Earth-Sun distance
\( d_{n}^* \): Corrected digital number
\( dc \): Digital count of SDSM
MODIS Lunar Calibration

\[ m_1 = \frac{\text{BRF}_{SD} \cdot \cos(\theta_{SD})}{\langle dn^*_{SD} \rangle \cdot d_{Earth-Sun}^2} \cdot \Gamma_{SD} \cdot \Delta_{SD} \]

\[ m_1 = \frac{f(\text{view}_\text{geometry})}{\langle dn^*_{Moon} \rangle} \]

Gain \( \propto 1/m_1 \)

MODIS SD and lunar observations are made at different scan angles.

Aqua MODIS B1 Lunar Images

Geometric Factors

\[ f = \frac{f_{\text{phase-angle}} \cdot f_{\text{libration}} \cdot f_{\text{over-sampling}}}{d_{Sun-Moon}^2 \cdot d_{Modis-Moon}^2} \]
VIIRS On-orbit Calibration

- Similar to MODIS
  - Linear algorithm for MODIS; Quadratic algorithm for VIIRS
  - More stringent limit for lunar calibration roll angles

\[ m_1 \Rightarrow F\text{-factor} \]

Solar Diffuser with Fixed Screen

Extended SV Port

Rotating Telescope Aft Optics and HAM

\[ \Delta_{SD} \Rightarrow H\text{-factor} \]

No SRCA for VIIRS

S-NPP VIIRS I1 Lunar Images
On-orbit Performance

• Sensor Performance
  – Changes in RSB Response
  – SD Degradation

• Calibration Inter-comparison (preliminary results)
  – SNO
  – Libya-4 Desert

Aqua MODIS and S-NPP VIIRS
MODIS RSB On-orbit Performance

Large Changes in VIS (including mirror side dependence and AOI dependency)
VIIRS RSB On-orbit Performance

Lunar gains normalized to 4/2/2012

Little change for HAM side and AOI dependence

Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration difference in VIS (M1-M3)

Future Calibration Improvements:
Use of modulated RSR
SD On-orbit Degradation

Aqua MODIS (~11 yr)

SD On-orbit Degradation Tracked by On-board SDSM

S-NPP VIIRS (~1.5 yr)

VIIRS has no SD door:
Large degradation in SD BRF
Potential impact on SD calibration
• Approaches
  – SNO
  – Libya-4 desert

• Methodologies
  – Common region of interest (ROI): 20 km by 10 km
  – Cloud screening (spatial uniformity checking)
  – Correction for sensor RSR difference (MODTRAN simulation)
  – Correction for site-dependent BRDF effect (MODIS based BRDF)

\[
\text{BRDF} (\theta, \psi, \varphi) = K_0 + K_1 f_1(\theta, \psi, \varphi) + K_2 f_2(\theta, \psi, \varphi)
\]

References:
Sensor RSR and Solar Irradiance Model

VIIRS to MODIS radiance ratios determined using sensor RSR and Esun models for their spectrally matched bands.
MODTRAN5 Simulations

VIIRS/MODIS Reflectance Ratio

Input options include a standard atmospheric profile (U.S. 1976), a standard aerosol model, a fixed viewing angle, a wide range of solar angle & atmospheric water content, and surfacetype dependent spectral reflectances.

Ocean  Desert  Snow  Cloud
Reflectance Trending (Aqua MODIS; Libya 4)

Long-term reflectance trending (MODIS C6) shows that the site is stable to within 1%

Good reference site to track the sensor on-orbit calibration performance

Linear Regression
Inter-comparison Results

SNO

Libya-4

16-day repeatable orbits
Linear regression to data after 4/10/2012

Rel. Chg. 0.64±0.64(%)
Inter-comparison Results

SNO

Libya-4

Rel. Chg. 2.76±1.56(%)
Inter-comparison Results

SNO

Libya-4

M4, AOI=36\(^\circ\)

Libya-4

M7, AOI=36\(^\circ\)

Libya-4

Rel. Chg 1.22±0.66(%)
Correction based on MODTRAN5 simulations with averaged atmospheric conditions (std. atmo. profile, 1.0 gcm$^{-2}$ atmo. water content for SNO, 5.0 gcm$^{-2}$ for desert)
## Inter-comparison Results

<table>
<thead>
<tr>
<th>Band</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>I1</th>
<th>I2</th>
<th>MU</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNO</td>
<td>0.991</td>
<td>0.987</td>
<td>0.995</td>
<td>1.018</td>
<td>1.069</td>
<td>1.003*</td>
<td>1.019</td>
<td>0.998</td>
<td>1.020</td>
<td>1.6%</td>
</tr>
<tr>
<td>Libya-4</td>
<td>1.015</td>
<td>1.000</td>
<td>N/A</td>
<td>0.998</td>
<td>1.099</td>
<td>N/A</td>
<td>1.047</td>
<td>0.995</td>
<td>1.049</td>
<td>1.5%</td>
</tr>
<tr>
<td>MODT</td>
<td>0.996</td>
<td>1.006</td>
<td>0.994</td>
<td>1.000</td>
<td>1.046</td>
<td>0.991</td>
<td>1.006</td>
<td>1.009</td>
<td>0.987</td>
<td>1.0%</td>
</tr>
<tr>
<td>Diff</td>
<td>-0.5%</td>
<td>-1.9%</td>
<td>0.1%</td>
<td>1.8%</td>
<td>2.2%</td>
<td>1.2%</td>
<td>1.3%</td>
<td>-1.1%</td>
<td>3.3%</td>
<td>±2.0%</td>
</tr>
</tbody>
</table>

Values are derived using observations after day 100 of 2012

MU – Measurement or model uncertainty (%); MU for M6 ratios is noticeably higher than 2% due to early saturation for the MODIS matching band

Diff – RSR corrected calibration difference (from SNO) between VIIRS SDR and MODIS L1B (C6)
Future Effort and Improvements

- Long-term trending with consistent time series (data products)
  - MODIS C6
  - VIIRS consistently calibrated (reprocessed) radiances and reflectances

- Sensor calibration improvements
  - Mirror degradation modeling
  - Consistency between SD and lunar calibration
  - Degradation impact analysis and mitigation strategy
    - Use of modulated RSR
    - SD degradation impact on sensor and SDSM calibration
Summary

- Both MODIS and VIIRS RSB are well calibrated (joint effort by a gov-led SDR team), meeting specified sensor design requirements
  - Same on-board calibrators (OBC)
  - Similar calibration methodologies
  - Similar SD degradation (larger at shorter wavelengths)
  - Different trend for sensor/detector response (due to different causes)

- On-orbit calibration differences between MODIS and VIIRS RSB are generally within 2% (except 3% for I3)
  - Future improvements with reprocessed SDR

- Effort for future improvements
  - VIIRS mirror degradation impact (modulated RSR)
  - Larger SD degradation impact (reflected solar spectra)
  - SDSM detector OOB response (not discussed here)