Status of MODIS (Terra/Aqua) and VIIRS (S-NPP) On-orbit Calibration

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• NASA MODIS Characterization Support Team (MCST)
• NASA VIIRS Characterization Support Team (VCST)
• NOAA SNPP/JPSS VIIRS SDR Team (led by C. Cao)
• Presentations from MODIS STM and JACIE Conference
• Background

• MODIS and VIIRS On-orbit Calibration
  – On-board Calibrators (OBCs)
    • SD, SDSM, BB, SV, SRCA (MODIS only)
  – Lunar Observations

• On-orbit Performance
  – Sensor and OBCs
  – Calibration Inter-comparison (RSB only)

• Summary
• **MODIS on Both Terra and Aqua**
  - Terra: Dec. 18, 1999 – Present (13+ years)
  - Aqua: May 04, 2002 – Present (11+ years)

• **VIIRS on S-NPP and JPSS**
  - S-NPP: Oct. 28, 2011 – Present (1.5+ year)
  - JPSS-1: Launch in 2017

Many applications: 40+ data products from MODIS and 20 EDRs from VIIRS
• 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 and night band (DNB)
  – RSB spectral wavelengths: 0.41 -2.3 μm ; TEB: 3.75 - 12.2 μm
  – Spatial resolution: 375 m for I bands; 750 m for M bands and DNB

Aqua MODIS is widely used as the reflective solar calibration reference; VIIRS, with a strong MODIS heritage, should be considered as a future reference sensor, and ...
# 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></td>
<td></td>
<td></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>
</tr>
<tr>
<td>M3</td>
<td>0.478 - 0.498</td>
<td>750</td>
<td>3, 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>4 or 12</td>
<td>0.545 - 0.565</td>
<td>500</td>
</tr>
<tr>
<td>M5</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>M6</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>M7</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>M8</td>
<td>0.846 - 0.885</td>
<td>375</td>
<td>2</td>
<td>0.841 - 0.876</td>
<td>250</td>
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<tr>
<td>M9</td>
<td>1.230 - 1.250</td>
<td>750</td>
<td>16 or 2</td>
<td>0.862 - 0.877</td>
<td>1000</td>
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<tr>
<td>M10</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>M11</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>M12</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>M13</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>M14</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>M15</td>
<td>3.660 - 3.840</td>
<td>750</td>
<td>20</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M16</td>
<td>3.973 - 4.128</td>
<td>750</td>
<td>21 or 22</td>
<td>3.929 - 3.989</td>
<td>1000</td>
</tr>
<tr>
<td>M17</td>
<td>8.400 - 8.700</td>
<td>750</td>
<td>29</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M18</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>M19</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>M20</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>

- **H/L Gain**
- **DNB**

**Dual gain band**

**Similar MODIS bands**
<table>
<thead>
<tr>
<th>Terra MODIS</th>
<th>Aqua MODIS</th>
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<tbody>
<tr>
<td>Launch: Dec 18, 1999</td>
<td>Launch: May 04, 2002</td>
</tr>
<tr>
<td>First light: Feb 24, 2000</td>
<td>First light: June 24, 2002</td>
</tr>
<tr>
<td>A-side: July 02, 2001 - Sept 17, 2002</td>
<td>BB nominally operated at 285 K</td>
</tr>
<tr>
<td>A-side electronics and B-side formatter: Sept 17, 2002 - present</td>
<td>SD calibration: gradually reduced frequency</td>
</tr>
<tr>
<td>BB nominally set at 290 K</td>
<td>SRCA operated with 2 10-W lamps since 2005</td>
</tr>
<tr>
<td>SD door fixed at “open” since July 02, 2003</td>
<td>CFPA controlled at 83 K (was set 85 K briefly: 3-5 Aug 2000)</td>
</tr>
<tr>
<td>– Large SD degradation</td>
<td>– Small increase of cold FPA temperatures since 2007</td>
</tr>
<tr>
<td>SRCA operated with 2 10-W lamps since 2006</td>
<td></td>
</tr>
<tr>
<td>CFPA controlled at 83 K (was set 85 K briefly: 3-5 Aug 2000)</td>
<td></td>
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</table>

Details on MODIS Operation and Calibration: http://mcst.gsfc.nasa.gov/
MODIS Calibration and Characterization Activities

Solar diffuser (SD) and solar diffuser stability monitor (SDSM) for reflective solar bands (RSB) calibration

Spectroradiometric Calibration Assembly (SRCA) for instrument spectral and spatial characterization

Blackbody (BB) for thermal emissive bands (TEB) calibration

Calibration Maneuvers

Lunar views through SV port
On-orbit Performance (MODIS)

- Instrument and On-board Calibrators (OBC)
- Radiometric
  - Spectral band responses
- Spectral (backup slides)
  - Center wavelengths and bandwidths
- Spatial (backup slides)
  - Band-to-band registration (BBR)
Instrument Temperatures

Terra MODIS: less than 3.5 K increase over 13 years

Aqua MODIS: less than 2.0 K increase over 11 years
VIS and NIR FPA Temperatures

Terra MODIS: VIS, NIR

No temperature control for VIS/NIR FPA

Aqua MODIS: VIS, NIR

VIS & NIR FPA temperatures: similar to instrument temperatures
SMIR and LWIR FPA Temperatures

Terra MODIS: SMIR; LWIR

Aqua MODIS: SMIR; LWIR

Increase of CFPA temperatures in recent years (0.7 K)

Solar Diffuser (SD) Degradation

- Increased SD degradation due to SD door fixed at "open"

Terra MODIS

- Gradually reduced SD/SDSM calibration frequency

Aqua MODIS

- Larger degradation at shorter $\lambda$
Blackbody Temperatures (nominal operation)

Terra MODIS: less than 30 mK increase over 13 years

Aqua MODIS: excellent long-term stability
Blackbody Temperatures (nominal operation)

Terra MODIS BB short term stability

Aqua MODIS BB short term stability
Spectral Band Responses (VIS)

Band Averaged, Mirror Side 1

Larger changes at shorter wavelengths
Wavelength, AOI, and mirror side dependent (small MS diff. in A-MODIS)
Shorter wavelength VIS bands show larger degradation
- Strong wavelength, mirror side, and scan angle dependence
- MS difference in Aqua MODIS is much smaller than Terra MODIS

A few NIR bands show gain increases over time

Changes in SWIR responses are very small
- SWIR bands are located on CFPA with MWIR bands

TEB (MWIR and LWIR) responses have been very stable
- Less than 2% changes over entire mission, except up to 10% for Terra LWIR PV bands 27-30

Overall SNR and NEdT performance remains satisfactory
Spectral Characterization Performance
Spatial Characterization Performance

Terra MODIS along-scan BBR

Aqua MODIS along-scan BBR

Terra MODIS along-track BBR

Aqua MODIS along-track BBR

Aqua BBR: a known issue since pre-launch
MODIS L1B and Data Collection 6 (C6) Status

- MODIS L1B Algorithm (Code and LUTs)
  - Developed, maintained, and updated by MCST
    - Input also provided by MODIS science team representatives and users
    - Algorithm changes and major LUT updates reviewed and approved by the MsWG (MODIS sensor Working Group)
  - Two separate sets of code and LUTs
    - One for Terra MODIS and one for Aqua MODIS
  - L1B collections and versions
    - Terra MODIS mission: C2 to C6 (18 code versions used in production)
    - Aqua MODIS mission: C3 to C6 (11 code versions used in production)

- C6 L1B reprocessing completed
  - [http://ladsweb.nascom.nasa.gov/](http://ladsweb.nascom.nasa.gov/)

- C6 Atmosphere reprocessing starting date: early May 2013
- C6 Land reprocessing starting date: early July 2013
Key L1B Documents

http://mcst.gsfc.nasa.gov/content/l1b-documents

ATBD
High-Level Code Design
LUTs Information Guide
Product User Guide
Data Dictionary
References

• **Key Journal Papers**

• **Key SPIE Papers**
Quadratic calibration algorithm for both TEB and RSB
Linear calibration coefficients derived from BB and SD
SD degradation tracked by SDSM
Lunar observations

RSB:
\[ F = \frac{L_{SD\_Comp}}{L_{SD\_Meas}} \]

TEB:
\[ F = \frac{L_{BB\_Comp}}{L_{BB\_Meas}} \]
VIIRS On-orbit Performance

• On-board Calibrators
  – SD, SDSM, and BB

• Changes in Spectral Band Response
  – Reflective Solar Bands (RSB) and Thermal Emissive Bands (TEB)

• Detector SNR and NedT

• Calibration Inter-comparison with Aqua MODIS
  – Reflective Solar Bands (RSB) – Backup slides
SD Degradation

S-NPP VIIRS

Similar to MODIS with strong wavelength dependence

Aqua MODIS

VIIRS has no SD door:
Large degradation in SD BRF at short wavelengths
Changes in Spectral Band Response (VIIRS RSB)

Little change for HAM side and AOI dependence

Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration difference in VIS (M1-M3)
Small orbital variations with similar amplitude for thermistor pairs located at the same scan angle. Thermistors 3 and 6, located at the top of the BB (furthest from the EV), have the largest variation.

\[
\Delta T_{(T_3, T_6)} = 0.037 \, \text{K} \\
\Delta T_{(T_2, T_5)} = 0.011 \, \text{K} \\
\Delta T_{(T_1, T_4)} = 0.014 \, \text{K} \\
\Delta T_{(T_1, T_2, T_3, T_4, T_5, T_6)} = 0.014 \, \text{K}
\]

F-factors at nominal temperature show periodic variations of 0.2%, which are correlated with the BB temperature variations.

Long-term drift is small (< 0.5%)

* For clarity the F-factors are shifted.
Detector SNR (RSB) and NEdT (TEB)

For RSB: \( \text{SNR}^* > 1 \) means performance better than specified requirements

For TEB: \( \text{NEdT}^* < 1 \) means performance better than specified requirements
Status of VIIRS SDR Code/LUTs

- **IDPS VIIRS SDR Code/LUTs (radiometric)**
  - 6 code versions
  - 9 major LUT updates (weekly updates not included)
  - Improved LUT update strategy (on demand -> weekly -> auto cal)

- **VCST Effort**
  - Independent validation and improvements for SDR code/LUTs
  - Two sets of F-LUTs for VISNIR/SWIR and DNB delivered to Land PEATE for SDR/EDR assessment and reprocess.
    - Jan 31, 2013: LUTs from Jan 2012 to Jan 2013 generated using existing IDPS algorithm but with smoothed functions to remove outliers.
    - Apr 19, 2013: LUTs from Jan 2012 to Mar 2013 generated with “best” sensor characterization improvements, including SD/SDSM screen transmission, SD BRDF, RTA mirrors degradation model, modulated RSRs, and smoothed fitting functions.
Major IDPS SDR Code/LUTs Update Timeline (Radiometric)

- Mx5.0 (2011-10-28) S-NPP Launch
- Mx5.2 (2012-02-07) SDSM Data Format fix
- Mx5.3 (2012-05-07) Dual Gain bands Cal fix; Aggr in radiance fix for TEB.
- Mx6.2 (2012-08-01) F-predict Implement; Moon-In-SV.
- Mx6.3 & 6.4 (2012-10-18) Dual gain sticking; M6 roll over flagged as saturation; OBC-JP added additional telemetry.
- Mx6.7 (2013-03-09) Current IDPS version
- Mx7.x (2013-08) RSB Auto Cal on RSB and DNB

Weekly F-predicted LUT will be reduced after RSB Auto Cal
VIIRS SDR Data Access and Calibration Knowledge Base

- The VIIRS SDR team developed the Calibration Knowledge base at https://cs.star.nesdis.noaa.gov/NCC/VIIRS with a wealth of information including user’s guide, relative spectral response, SNO predictions, image gallery, VIIRS Events, publication database, conference presentations, etc.


Reference:

Sensor RSR and Solar Irradiance Model

VIIRS to MODIS radiance ratios determined using sensor RSR and Esun models for their spectrally matched bands.
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 (Examples)

SNO

Libya-4

16-day repeatable orbits

Linear regression to data after 4/10/2012

\[ \tau \text{ update} \]
# Inter-comparison Results

<table>
<thead>
<tr>
<th></th>
<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></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></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></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></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 are significantly higher than 2% due to early saturation for MODIS matching band

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

• Both Terra and Aqua MODIS continue to operate normally
• Instrument on-board calibrators remain capable of all design functions
• Overall sensor performance has been satisfactory (very few noisy detectors in recent years)
• Decade long high quality MODIS data products have significantly contributed to a broad range of scientific studies and applications
• VIIRS has been operated and calibrated as planned and expected
• Overall on-orbit performance meets the design requirements (such as SNR/NEdT)
• Continuous and dedicated efforts are critical for maintaining MODIS and VIIRS calibration and data quality and achieving calibration consistency between the two sensors (significant contributions to remote sensing community)