Status of VIIRS On-orbit Calibration

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1. NASA GSFC; 2. NOAA NESDIS; 3. Sigma Space Corp.

Acknowledgements:
VIIRS Characterization Support Team (VCST), NASA GSFC
S-NPP/JPSS VIIRS SDR Team
Outline

• Background
• On-orbit Calibration and Characterization
• Performance
• Status of VIIRS SDR and LUTs
• Summary
Visible Infrared Imaging Radiometer Suite (VIIRS)

- **Key instrument on S-NPP and future JPSS satellites**
  - S-NPP launched on October 28, 2011
  - JPSS-1 launch in 2017
    - Sensor ambient phase 1&2 completed
    - Sensor TVAC testing in July, 2014

- **Strong MODIS heritage**
  - Spectral band selection
  - On-board calibrators
  - Operation and calibration
    - Strategies for planning/scheduling
    - Data analysis methodologies / tools

S-NPP VIIRS provides linkage btw EOS (MODIS) and future JPSS (VIIRS) and extends long-term data records for studies for the Earth’s land, oceans, and atmosphere
## 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>
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</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>
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<tr>
<td>M3</td>
<td>0.478 - 0.498</td>
<td>750</td>
<td>3, 10</td>
<td>0.459 - 0.479</td>
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<td></td>
<td></td>
<td>0.483 - 0.493</td>
<td>1000</td>
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<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></td>
<td></td>
<td></td>
<td></td>
<td>0.546 - 0.556</td>
<td>1000</td>
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<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></td>
<td></td>
<td></td>
<td></td>
<td>0.673 - 0.683</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>
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<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 1</td>
<td>0.862 - 0.877</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.841 - 0.876</td>
<td>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>
</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 - 4.128</td>
<td>750</td>
<td>21 or 22</td>
<td>3.929 - 3.989</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></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></td>
<td></td>
<td></td>
<td></td>
<td>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>

**VIIRS MODIS Substitute**
- 1 DNB
- 14 RSB (0.4-2.3 μm)
- 7 TEB (3.7-12 μm)
- Dual Gain Bands: M1-M5, M7, M12

16 Moderate (radiometric) bands, 5 Imaging bands, 1 DNB
VIIRS On-board Calibrators (MODIS Heritage)

- Solar Diffuser
- Extended SV Port (Lunar Observations)
- Rotating Telescope Aft Optics and HAM
- Blackbody
- Solar Diffuser Stability Monitor
VIIRS On-orbit Calibration and Characterization

On-orbit Calibration Methodologies:

- **Solar Calibration (RSB)**
  - Quadratic calibration algorithm
  - Linear calibration coefficients derived/updated from SD observations
  - SD degradation tracked by SDSM

- **Lunar Calibration (RSB)**
  - Regularly scheduled at the “same” phase angles
  - Observed through instrument SV port with a data sector rotation
  - Implemented via S/C roll maneuvers (some constraints)
  - Referenced to the ROLO model (USGS)

- **BB Calibration (TEB)**
  - Quadratic calibration algorithm
  - Linear calibration coefficients derived from BB observations
Calibration Activities

- **SD and SDSM**
  - SD calibration every orbit (no scheduling is needed)
  - SDSM currently scheduled for daily operation (**to be reduced to 3 SDSM operations each week**)

- **Lunar Calibration**
  - Regularly scheduled via S/C roll maneuvers (8-9 times/year)

- **BB Calibration**
  - Nominally controlled at 292 K (no scheduling is needed)
  - Periodic warm-up and cool-down (scheduled on a quarterly basis)

- **Calibration Maneuvers**
  - Pitch (during intensive CAL/VAL phase) – characterize TEB RVS
  - Yaw (during intensive CAL/VAL phase) – characterize SD and SDSM screen
  - Roll for lunar calibration
On-orbit Performance

• **Instrument and On-board Calibrators**
  – Key Telemetry (Instrument Temperatures)
  – SD Degradation
  – BB Stability

• **Changes in Spectral Band Response**
  – Reflective Solar Bands (RSB)
    ➢ **Modulated RSR and impact**
  – Thermal Emissive Bands (TEB)

• **Detector SNR and NEdT**
Instrument Temperatures

Vertical lines: SC or sensor anomalies and resets

Telemetry:
- Half Angle Mirror
- Sensor Cavity
- Rotating Telescope
- BB Shield
- Opt. & Mech. Module
- Electronics

Instrument temperatures have been very stable
**SD Degradation**

**VIIRS SD Degradation**
(As of April 2014)

**Shorter wavelength: larger degradation**

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**Comparison of MODIS & VIIRS SD Degradation**

VIIRS has no SD door
A-MODIS SD door is closed when no calibration is scheduled
T-MODIS SD door fixed at open since July 2003
BB Stability

Long-term trend of daily-averaged $T_{BB}$
- Stable to within a few mK.
- ~15mK offsets were due to the use of different $T_{BB}$ settings.

Short-term stability (scan-by-scan $T_{BB}$)
- Orbital variations of individual thermistors up to 40mK
- Variations in average temperature ~ 20mK
- Temperature difference between individual thermistors up to 60mK
- BB uniformity meets the requirement with standard deviation less than 30mK
Changes in Spectral Band Response (RSB)

SD and lunar calibration made at the same angle of incidence (AOI)

Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration seasonal difference in VIS (M1-M3)
Impact of $\lambda$-dependent Changes in Detector Response

Mirror Degradation Impact on Sensor Relative Spectral Response

$\lambda$ dependent optics degradation

Modulate RSR has been applied to VIIRS calibration and data production

Large impact on DNB
Impact of $\lambda$-dependent Changes in Detector Response

Modulated RSR should be applied to both solar and lunar calibration

Remaining issues:
(1) lunar model uncertainty (to be investigated)
(2) solar vector calculation error (in IDPS common geolocation library)
The discontinuities in the F-factor are coincident with SC maneuvers and anomalies during which the cold FPA temperatures changed.

<table>
<thead>
<tr>
<th>Band</th>
<th>I4</th>
<th>I5</th>
<th>M12</th>
<th>M13</th>
<th>M14</th>
<th>M15</th>
<th>M16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average F-factor: 03 26 2012</td>
<td>1.0105</td>
<td>1.0040</td>
<td>1.0035</td>
<td>1.0070</td>
<td>0.9946</td>
<td>1.0056</td>
<td>1.0102</td>
</tr>
<tr>
<td>Average F-factor: 03 16 2014</td>
<td>1.0135</td>
<td>1.0106</td>
<td>1.0068</td>
<td>1.0092</td>
<td>0.9960</td>
<td>1.0065</td>
<td>1.0119</td>
</tr>
<tr>
<td>Trend [%]</td>
<td>0.30</td>
<td>0.65</td>
<td>0.33</td>
<td>0.21</td>
<td>0.14</td>
<td>0.09</td>
<td>0.18</td>
</tr>
</tbody>
</table>
TEB Detector Short-term Stability

Detector responses (F-factors) show small orbital variations: ±0.2% or less for scan-by-scan ±0.1% or less for granule average

F-factor orbital variations correlate with $T_{BB}$ variations

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

RSB SNR* > 1: performance better than specified requirements
TEB NEdT* < 1: performance better than specified requirements

SNR* and NEdT*: normalized to specified values
Status of VIIRS SDR and LUTs

- IDPS VIIRS SDR Code/LUTs (radiometric)
  - 18 code versions post launch; numerous LUT updates.
  - Improved LUT update strategy (on demand -> weekly -> automated).

- VIIRS SDR Cal/Val Maturity
  - Beta review: April 5, 2012
  - Provisional review: October 24, 2012
  - Validated review: December 19, 2013

Improved SD BRF and screen transmission and SDSM screen transmission LUT
Moon in space view algorithm (RSB)
Modulate relative spectral response (RSR)
RSB auto-calibration in SDR
Solar vector error correction to be implemented
Status of VIIRS SDR Code/LUTs

• NASA Land PEATE SDR Code/LUTs and Data Reprocess (C1.0 and C1.1)
  – Enabling independent data quality assessment and validation, and improvements
  – 13 sets of LUTs for VISNIR/SWIR and DNB delivered to Land PEATE for SDR/EDR assessment and data reprocess.
    • Jan 31, 2013: LUTs from Jan 2012 to Jan 2013 generated using IDPS algorithm Mx6.3 but *with smoothed functions to remove outliers*.
    • Nov 13, 2013: LUTs from Jan 2012 to Oct 2013 generated with calibration improvements based on Mx6.4, including *SD/SDSM screen transmission, SD BRDF, RTA mirrors degradation model, modulated RSRs, and smoothed fitting functions*.
    • Mar 12, 2014: LUTs from Jan 2012 to Nov 2013 generated with “best” sensor characterization improvements based on Mx7.2 algorithm for Land PEATE reprocess Collection 1.1, including *DNB Stray Light Correction algorithm and smoothed fitting functions*.
    • Apr 1, 2014: Latest LUTs update for Dec 2013, and Jan/Feb 2014.
Summary

• **VIIRS has continued its nominal operation and calibration**
  – No changes are made in sensor operation configurations
  – SD/SDSM, BB WUCD, and lunar calibration activities are regularly performed
  – Changes in sensor response are accurately tracked by the OBC
  – Calibration LUTs are frequently updated

• **Sensor overall performance meets its design requirements**
  – VIIRS SDR maturity has reached the “Validated” status

• **Dedicated calibration effort remains critically important to assure SDR quality**
  – The modulated RSRs, as a result of mirror degradation, have been developed and applied to sensor SDR calibration and data production
  – SDR impact due to newly identified solar vector error has been assessed and will be addressed in the future updates
  – Small solar and lunar calibration differences to be investigated
Operation and Calibration Activities

• Launch: 10/28/11
• Instrument turn-on: 11/8/11
• Nadir door open: 11/21/11 (first image from VIS/NIR)
• RTA stow (4 times): 12/9/11 – 1/2/12
• Cryo-cooler door open: 1/18/12 (observations from all bands)

• Roll maneuvers: started from 1/4/12 (Lunar calibration)
• Yaw maneuvers; 2/15/12 – 2/16/12 (SD/SDSM screen transmission)
• Pitch maneuvers: 2/20/12 (TEB response versus scan angle)
• OBC calibration activities: SD, SDSM, and BB
Product Maturity Definition

- **Beta (L+150) – April 05, 2012**
  - Early release product, initial calibration applied, minimally validated and may still contain significant errors
  - Available to allow users to gain familiarity with data formats and parameters
  - Product is not appropriate as the basis for quantitative scientific publications studies and applications

- **Provisional (Beta+2mo) – October 24, 2012**
  - Product quality may not be optimal
  - Incremental product improvements are still occurring as calibration parameters are adjusted with sensor on-orbit characterization
  - General research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
  - Users are urged to contact NPP Cal/Val Team representatives prior to use of the data in publications

- **Validated/Calibrated (L+1 yr) – December 19, 2013**
  - On-orbit sensor performance characterized and calibration parameters adjusted accordingly
  - Ready for use by the Centrals, and in scientific publications
  - There may be later improved versions
  - There will be strong versioning with documentation
Major IDPS SDR Code/LUTs Update Timeline (Radiometric)

Weekly F-predicted LUT update until RSB Auto Cal switch to auto mode