S-NPP VIIRS Instrument Performance and Inter-Calibrations

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Outline

• S-NPP VIIRS Reflective Solar Calibration

• On-orbit Performance
  – SD Degradation
  – Spectral Bands Responses and Noise Characterization
  – Recent Changes and Improvements

• Inter-calibrations
  – Aqua MODIS and S-NPP VIIRS
  – Inter-calibrations with CLARREO Pathfinder Instrument

• Summary
VIIRS Reflective Solar Calibration Strategies and Activities

Solar Diffuser Stability Monitor

15 RSB: M1-M11, I1-I3, DNB
H/L gains: M1-5 and M7
\( \lambda: 0.4\text{-}2.3 \ \mu\text{m} \)

SD calibration each orbit with a fixed screen

Extended SV Port

Roll maneuvers: 8-9 yearly

Daily operation => 3 per week
(8 min => 5 min)

Rotating Telescope Assembly (RTA)
Reflectance-based Calibration Approach

**VIIRS Radiance (L) Retrieval:**  
\[ L = F \cdot L_{PL} = F \cdot \left( c_0 + c_1 \cdot dn + c_2 \cdot dn^2 \right) / RVS \]

- **F:** Calibration scaling factor from on-orbit calibration
- **\( c_i \):** Pre-launch calibration coefficients (quadratic algorithm)
- **RVS:** Sensor response versus scan-angle (RVS)

**Solar Calibration:**  
\[ F_{SD} = \frac{L_{SUN}}{L_{SD,PL}} \quad L_{SUN} \propto E_{SUN} \cdot BRDF(t) \cdot \tau_{SD} \cdot \cos(\theta_{inc}) \]

- **\( L_{SUN} \):** Expected solar radiance reflected from SD panel
- **\( L_{SD,PL} \):** Retrieved solar radiance using pre-launch calibration coefficients

**Lunar Calibration:**  
Similar to SD CAL with reference to the ROLO model

**SD Degradation (H):**  
\[ BRDF(t) = H_{Norm}(t) \cdot BRDF(t_0) \]
Lunar Calibration Methodologies

**VIIRS Lunar Calibration:**

\[ F_{MOON} = \frac{I_{ROLO}}{I_{MOON,PL}} = \frac{I_{ROLO}}{\sum_{det,sam,scan} L_{MOON,PL} \cdot \Omega_B \cdot g / N_{SCAN}} \]

- \( I_{ROLO} \): Lunar irradiance (integrated) provided by ROLO model
- \( I_{MOON,PL} \): Lunar irradiance retrieved using pre-launch calibration coefficients
- \( N_{SCAN}, \Omega_B, g \): number of scans, pixel solid angle, aggregation factor

**Lunar images (I1) from lunar calibration events in 2014**
On-orbit Performance

• **SD Degradation**
  – Large degradation at short wavelengths
  – Small but not negligible degradation at SWIR wavelengths
  – Different approach for SD degradation at SWIR as SDSM only covers wavelengths from 0.41 to 0.93 μm

• **Spectral Bands Responses**
  – Large at NIR and SWIR region
  – Strong wavelength-dependent optics degradation => modulated RSR

• **Noise Characterization**
  – Correlated with changes in spectral band responses
  – Sufficient margin remains to meet specified requirements

• **Recent Changes and Improvements**
Solar Diffuser On-orbit Degradation

SDSM
8 detectors: 0.41 – 0.93 μm
3 views: SD, Sun, dark

Large at short wavelengths
Degradation at SWIR cannot be ignored as mission continues
Spectral Bands Responses (SD)

M bands: 400 - 500 nm

M bands: 1000 - 2500 nm

M bands: 500 - 1000 nm

I bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength</th>
</tr>
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<tbody>
<tr>
<td>M1</td>
<td>0.41</td>
</tr>
<tr>
<td>M2</td>
<td>0.45</td>
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<tr>
<td>M3</td>
<td>0.49</td>
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<tr>
<td>M4</td>
<td>0.56</td>
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<tr>
<td>I1</td>
<td>0.64</td>
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<td>M5</td>
<td>0.67</td>
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<td>M6</td>
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<td>I2</td>
<td>0.87</td>
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<tr>
<td>M7</td>
<td>0.87</td>
</tr>
<tr>
<td>M8</td>
<td>1.24</td>
</tr>
<tr>
<td>M9</td>
<td>1.38</td>
</tr>
<tr>
<td>I3</td>
<td>1.61</td>
</tr>
<tr>
<td>M10</td>
<td>1.61</td>
</tr>
<tr>
<td>M11</td>
<td>2.25</td>
</tr>
</tbody>
</table>
Spectral Bands Responses (SD and Lunar CAL)

### Lines: SD
### Symbols: Moon

**M bands: 400 - 500 nm**
- **M1** 0.41
- **M2** 0.45
- **M3** 0.49
- **M4** 0.56
- **M5** 0.67
- **M6** 0.75
- **I1** 0.64
- **I2** 0.87

**M bands: 1000 - 2500 nm**
- **M7** 0.87
- **M8** 1.24
- **M9** 1.38
- **I2** 0.87
- **I3** 1.61

**M bands: 500 - 1000 nm**
- **M4** 0.41
- **M5** 0.45
- **M6** 0.49
- **M7** 0.56

**I bands**
- **I1** 0.64
- **I2** 0.67
- **I3** 0.75

**M bands: 1000 - 2500 nm**
- **M10** 1.61
- **M11** 2.25
Update and Use of On-orbit Modulated RSR

λ dependent optics degradation

Impact of modulated RSR depends on spectral band location, bandwidth, and OOB response
Detector Noise Characterization

(SNR/SNR_{SPEC} > 1) or (NEdT/NEdT_{SPEC} < 1): better performance

Noticeable SNR decrease in NIR/SWIR is due to degradation of sensor optical throughput
Recent Changes and Improvements

- **Improved SDSM and SD screen vignetting function**
  - Used data from yaw maneuvers and selected regular SD/SDSM calibration events

- **Improved normalization of SD degradation**
  - Revised extrapolation from first SDSM calibration to the mission beginning

- **Use of lunar observations to track SD degradation**
  - Eliminated SD degradation difference between SDSM view and RTA view
  - Derived SD degradation at SWIR wavelengths

- **Added features in NASA SIPS VIIRS L1B**
- **Consistently reprocessed calibration LUTs**

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Inter-Calibrations

Methodologies for Calibration Inter-comparisons and Reference Transfer

Solar Calibration (Traceability)
Lunar Observations
Reference Sensor
SNO, DCC
Ground Targets

Ground Reference Targets: PICS (Pseudo Invariant Calibration Sites)

Xiong et al, SPIE 2016
Inter-Calibrations

Calibration Inter-comparison of Aqua MODIS and S-NPP VIIRS Using SNO

Calibration Inter-comparison of Aqua MODIS and S-NPP VIIRS Using PICS

Total drift: 0.02%

Total drift: 0.26%

MODIS L1B Collection 6; VIRIS L1B from NASA Land SIPS
Published NPP VIIRS (earlier versions) and Aqua MODIS Reflectance Differences (%)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>M1/B8</td>
<td>-0.2±1.2</td>
<td>0.8±0.8</td>
<td>-1.3±1.0</td>
<td>-0.2±0.7</td>
<td>0.1±0.9</td>
<td>1.6±0.3</td>
<td>-1.0±0.8</td>
<td>-0.5±1.0</td>
<td>-2.0±1.5</td>
<td>1.2±0.5</td>
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<tr>
<td>M2/B9</td>
<td>-0.7±1.0</td>
<td>-1.7±0.6</td>
<td>-0.5±0.7</td>
<td>-0.3±0.8</td>
<td>0.4±0.3</td>
<td>-1.2±0.8</td>
<td>-0.5±0.8</td>
<td>-4.0±2.0</td>
<td>-1.8±0.5</td>
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</tr>
<tr>
<td>M3/B10</td>
<td>-1.0±0.7</td>
<td>-1.3±0.4</td>
<td>0.2±0.9</td>
<td>-0.2±0.8</td>
<td>1.3±0.4</td>
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<td>-3.5±2.0</td>
<td>-0.1±0.6</td>
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</tr>
<tr>
<td>M4/B4</td>
<td>1.5±0.7</td>
<td>-1.5±0.3</td>
<td>1.8±1.5</td>
<td>1.6±1.0</td>
<td>-0.9±1.0</td>
<td>-0.2±0.4</td>
<td>-1.5±0.5</td>
<td>2.0±1.0</td>
<td>-1.5±1.5</td>
<td>-0.2±0.9</td>
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<tr>
<td>M5/B1</td>
<td>6.5±1.9</td>
<td>10.0±0.6</td>
<td>5.7±1.8</td>
<td>4.8±0.9</td>
<td>9.2±0.8</td>
<td>9.5±0.5</td>
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<td>9.0±0.7</td>
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</tr>
<tr>
<td>M7/B2</td>
<td>2.5±0.6</td>
<td>4.0±0.5</td>
<td>2.2±1.7</td>
<td>2.8±1.4</td>
<td>3.9±0.7</td>
<td>4.0±0.5</td>
<td>3.5±0.5</td>
<td>2.5±0.5</td>
<td>4.0±2.0</td>
<td></td>
</tr>
<tr>
<td>I1/B1</td>
<td>-0.3±0.7</td>
<td>-0.4±1.5</td>
<td>-1.7±0.9</td>
<td>-2.0±0.5</td>
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<tr>
<td>I2/B2</td>
<td>2.6±0.6</td>
<td>2.3±1.8</td>
<td>4.0±0.7</td>
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Difference (%) = (VIIRS – MODIS)*100/MODIS (no RSR correction)
Differences remain after RSR correction (some getting smaller and some larger; scene dependent)
References


Averaged S-NPP VIIRS and Aqua MODIS Reflectance Differences (%) with RSR correction

NASA VIIRS L1B (before latest reprocessing)

NASA VIIRS L1B (current version)
Inter-calibrations with CLARREO Pathfinder Instrument

- **Calibration accuracy and stability of reference instrument**
- **Accurate characterization of sensor relative spectral response (RSR)**
  - Both in-band (IB) and out-of-band (OOB); OOB impact and correction
- **Accurate characterization of sensor polarization sensitivity**
  - CPF instrument and sensors to be inter-calibrated
  - Experience from MODIS (Terra and Aqua) and VIIRS (S-NPP, J1, J2)
- **Accurate characterization of sensor response versus scan-angle (RVS)**
  - Sensor viewing geometry
  - On-orbit changes
Inter-calibrations with CLARREO Pathfinder Instrument

- Solar spectral irradiance used by individual sensors
- Reflectance versus radiance-based calibration/inter-calibrations
- Sensor spatial resolutions
- Ground target BRDF and atmospheric effect
- Improved (use of) lunar model (see presentation by T. Stone)
  - ROLO data Reanalysis Effort
  - NIST measurements with high accuracy and traceability
  - Use of CNES POLO data
  - GSICS activities
Summary

- S-NPP VIIRS continues to operate normally with overall performance meeting the need for operational users (SDRs/EDRs from IDPS) and science community (reprocessed SDRs/EDRs)
  - Parallel effort by NASA VCST and NOAA SDR team
  - Consistent data reprocessing
- Approaches derived from sensor calibration inter-comparisons can be adopted for CPF inter-calibration
- Considerations and effort need to be made to reduce or minimize the uncertainties of CPF inter-calibration
  - Reference instrument stability, traceability, and accuracy
  - Sensor performance characteristics (RSR, RVS, POL, ...)
  - Spatial sampling, atmospheric effect and BRDF correction

<table>
<thead>
<tr>
<th></th>
<th>Aqua MODIS</th>
<th>S-NPP VIIRS</th>
<th>JPSS-1 VIIRS</th>
<th>JPSS-2 VIIRS</th>
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<tbody>
<tr>
<td>2002</td>
<td>2011</td>
<td>2017</td>
<td>2021</td>
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## VIIRS and MODIS 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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<tbody>
<tr>
<td>DNB</td>
<td>0.500 - 0.900</td>
<td></td>
<td></td>
<td></td>
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</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>
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<td></td>
<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>
</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>
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<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>
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<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>
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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>
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<tr>
<td>M7</td>
<td>0.846 - 0.885</td>
<td>750</td>
<td>16 or 2</td>
<td>0.862 - 0.877</td>
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<tr>
<td>M8</td>
<td>1.230 - 1.250</td>
<td>750</td>
<td>5</td>
<td>0.841 - 0.876</td>
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<tr>
<td>M9</td>
<td>1.371 - 1.386</td>
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<td>26</td>
<td>1.360 - 1.390</td>
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<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>
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<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>
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<tr>
<td>M12</td>
<td>3.660 - 3.840</td>
<td>750</td>
<td>20</td>
<td>SAME</td>
<td>1000</td>
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<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>
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<td></td>
<td></td>
<td>3.929 - 3.989</td>
<td>1000</td>
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<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>
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<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>
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<td></td>
<td></td>
<td>11.770 - 12.270</td>
<td>1000</td>
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<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>
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</table>
Status of NASA SIPS L1B

- NASA SIPS L1B Software
  - V2.0.0 officially released to SIPS on Oct 18, 2016 (testing and evaluation in July-Oct).
  - VIIRS L1A and L1B software developed under NASA EDOS/SIPS.
  - The L1A, L1B, and LUTs data in NetCDF4 format.
  - The first L1B software V1.1.0 released in Jan 2016 (based on IDPS SDR code version Mx8.10). The contents of NASA L1B V1.1.0 match with NOAA IDPS SDR Mx8.10 or Mx8.11 (current) if the same calibration coefficients and parameters are applied.
  - 6-min L1A granule and L1B calibration Look-Up-Tables (LUTs) are required as input to generate 6-min L1B geolocation and radiometric products, including On-Board Calibrator (OBC) files for calibration and trending purpose.
  - Monthly L1B LUTs updates are provided by VCST.

<table>
<thead>
<tr>
<th>Collection</th>
<th>Code Base</th>
<th># of LUTs</th>
<th>Delivery Time</th>
<th>Note</th>
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<tbody>
<tr>
<td>V1.1.0</td>
<td>L1B V1.1.0</td>
<td>9</td>
<td>2016.02 - 2016.10</td>
<td>Redesigned L1B software, LUTs, and data format using L1A data input.</td>
</tr>
<tr>
<td>V2.0.0</td>
<td>L1B V2.0.0</td>
<td>3</td>
<td>2016.08 - 2016.10</td>
<td>Improved L1B software functions and algorithms.</td>
</tr>
</tbody>
</table>

Updated by K. Chiang (VCST)
Changes in VIIRS L1B V2.0.0

• Changes in V2.0.0 compared to V1.1.0

A. Functional changes
– Add fill values for specific data states requested by Land team.
– Partial scan line processing capability to support along-scan extracts.
– Dual gain bands un-aggregated L1B becomes official product.
– Add RSR tables in RSB LUT. Remove radiance tables from TEB LUT.
– Single resolution processing and output in geolocation.
– Add moon phase angle and moon illumination fraction in DNB geolocation.
– Add limit checks on attitude angles in geolocation.

B. Algorithm changes
– Use solar irradiance at 1 AU distance to avoid computation of large number in meters.
– Temperature dependent coefficients for RSB Cal.
– Apply time-dependent modulated RSR in RSB Cal.
– Add running average option for TEB F-factor in TEB Cal.
– BB thermistors weighting (selection) to decrease orbital variation in F-factor for TEB Cal.
– Alternative calibration when moon is in SV.
– Apply out of range limits based on dn.

Updated by K. Chiang (VCST)