Status of SNPP VIIRS Instrument Operations

VIIRS Characterization Support Team (VCST)

June 6, 2016
• Status of SNPP/VIIRS Operations:
  – SNPP Burn Maneuvers
  – SNPP/VIIRS Calibration Maneuvers
  – Spacecraft and VIIRS Anomalies
  – VIIRS Flight Software Update
  – Warm-Up/Cool-Down Operations
  – DNB VROP Operations
  – VIIRS Telemetry
Spacecraft Burn Maneuvers

• Drag Make-Up (DMU) Maneuvers
  – Purpose: To keep near orbital period to ~101.5 minutes.
  – 23 DMUs since launch, most recent March 24, 2016.

• Inclination Adjustment Maneuvers (IAM)
  – Purpose: To keep equator crossing time between 1325 and 1330.
  – 5 IAMs since launch, most recent September 23, 2015.

• Risk Mitigation Maneuvers (RMM)
  – Purpose: For collision avoidance.
  – 5 RMMs since launch, most recent November 15, 2015.
Spacecraft Calibration Maneuvers

• VIIRS Lunar Roll Maneuvers (LRM)
  – To observe the Moon through the Space View at near-constant lunar phase. ~9 times/year.
  – 37 LRMs since launch, most recent May 17, 2016.
  – Sector Rotation to put data nadir at center of SV beginning with the April 2, 2012 event (5th event).

• SNPP Yaw Maneuvers

• SNPP Pitch Maneuver
  – Nighttime, for VIIRS, CERES, & ATMS Cal., February 20, 2012.
Spacecraft & VIIRS Anomalies

• Spacecraft Anomalies
  – Sun Pointing: March 24, 2012, effects to some VIIRS band trends.
  – Earth Pointing: June 21, 2012, ~20 hours offline.

• VIIRS “Petulant Mode”
  – Single Board Computer (SBC) lock-up.
  – 8 Events since launch, most recent October 9, 2014.
  – Roughly 2-4 hours to get back online, sometimes longer.
  – None since FSW 0x4016 update in December 2014.

• VIIRS Scan Sync Loss
  – Mirror sync loss between RTA and HAM for short (~2-3 minutes) periods resulting in poor geolocation accuracy.
  – 63 Events since launch, most recent May 16, 2016.
VIIRS Flight Software Update

(Information courtesy of SNPP MOT)

• VIIRS FSW 0x4016
  – Uploaded on December 10, 2014.
  – Implemented software watchdog timer that could assist in understanding and/or preventing SBC lock-up occurrences.

• VIIRS FSW 0x4017
  – Uploaded on April 19, 2016.
  – Trade band M7 for M11 at night per scientist request.
  – Fix segmentation dump and clear fault log in Safe Mode event.
  – M11 at night cannot accomplished until SNPP Block 2.0 is operational.


**VIIRS BB Warm-Up/Cool-Down**

- **WUCD Events for TEB Calibration:**
  - 17 Events since launch, most recent March 14-16, 2016.
  - 8 temperature steps: Min/Max $T_{BB} = 272.5$ to $315.0$ K.
  - Complete in 46 hours.
VIIRS DNB VROP Calibrations

- VROP for DNB Calibration:
  - Monthly events since launch, most recent June 4, 2016.
  - Occurs during New Moon, at night, over the central Pacific.
  - Calibration of DNB Offset, Dark, and Gain Ratios.
VIIRS Telemetry

- Telemetry Monitored Continually:
  - Focal Plane Array Temperatures.
  - On-board blackbody Temperatures.
  - Other temperatures, voltages, etc.
  - No unusual trending seen currently.
• Status of SNPP/VIIRS Operations:
  – SNPP Orbit maintenance continuing.
  – No Petulant SBC lock-up since Oct 9, 2014.
  – RTA/HAM Scan Sync Loss anomalies still occurring.
  – Spacecraft maneuvers for calibration (LRM, etc.) are ongoing.
  – Warm-Up/Cool-Down activities for TEB Cal occur quarterly.
  – DNB VROP operations occur during new moon monthly.
  – VIIRS telemetry being monitored, not showing unusual trends.
  – Swapping M11 for M7 at night after Block 2.0 operation.
NASA VIIRS Level-1 Version-2 Calibration Software

June 6, 2016

Sam Anderson, Chengbo Sun

VCST / NASA GSFC
• Apply running average of TEB F-factor over scans instead of per-scan value
• Apply a time-dependent modulated RSR in the calibration algorithm
• Use solar irradiance at 1 AU to avoid computations of large numbers
• Temperature dependent calibration coefficients for the RSBs
• Alternative blackbody thermistor weighting scheme to decrease orbital variation present in the F-factor
• Improved handling of saturation thresholds and radiance range
• General clean-up and consolidation to improve performance and facilitate maintenance
• Enhancements to time-dependent netCDF4 LUTs
  o Added time-dependent Relative Spectral Response LUT
  o Pre-compute integrated/normalized Solar Irradiance
  o Use Astronomical Units (AU) rather than meters to avoid imprecision arising from use of large numbers

• Apply Finite Impulse Response (FIR) filter to all SV and TEB F-Factor data
  o 201-tap FIR Filter
  o Bandwidth of passband is configurable
  o Requires sequence of three consecutive granules for proper moving averaging

• Revise handling of saturated and out-of-range pixels

• Add optional new diagnostic group to L1B format
Filter TEB F-Factors

Band_I05 Detector 1 H0 : TEB F Factor Filtered

Black Body warm-up/cool-down cycle 12-14-2015 thru 12-17-2015
Filter SV with DC Restore Correction

- 4-day Warm-Up/Cool-Down cycle
- RSB SV exhibits occasional DC Restore fluctuations
- DCR Correction removes discontinuities in SV time series caused by DC Restore offsets (blue)
- Filter is applied (red)
- DC Restore offsets are restored in final time series (black)
• 4-day Warm-Up/Cool-Down cycle

• TEB SV exhibits frequent and substantial DC Restore fluctuations, especially during warm-up/cool-down cycle

• ASP Offset Corrections are applied first

• Filter is then applied

• DC Restore offsets are restored

Black Body warm-up/cool-down cycle 12-14-2015 thru 12-17-2105
Effect of SV Noise on Calibrated Products

- True-Color rendering of the difference between L1B products with and without SV filtering
- Units of radiance scaled to reflectance and then scaled to 16-bit integer
Estimate of Difference Between Filtered and Unfiltered RSB Products

- Analysis based on differences observed in a single granule
  - V2015262003600.L1B-M_SNPP.nc
  - V2015262003600.L1B-I_SNPP.nc
- Statistics based on the difference between L1B products with and without space view filtering
- Units of radiance scaled to reflectance and then to 16-bit integer
- Results show the benefit of SV noise filtering is not extraordinary

<table>
<thead>
<tr>
<th>Band</th>
<th>Standard Deviation of Difference</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>I01</td>
<td>1.28</td>
<td>-8</td>
<td>7</td>
<td>-0.0073</td>
</tr>
<tr>
<td>I02</td>
<td>1.75</td>
<td>-9</td>
<td>8</td>
<td>-0.0024</td>
</tr>
<tr>
<td>I03</td>
<td>3.39</td>
<td>-18</td>
<td>18</td>
<td>0.0335</td>
</tr>
<tr>
<td>M01</td>
<td>0.94</td>
<td>-5</td>
<td>5</td>
<td>-0.0157</td>
</tr>
<tr>
<td>M02</td>
<td>0.97</td>
<td>-4</td>
<td>6</td>
<td>-0.0032</td>
</tr>
<tr>
<td>M03</td>
<td>0.98</td>
<td>-5</td>
<td>5</td>
<td>-0.0063</td>
</tr>
<tr>
<td>M04</td>
<td>1.05</td>
<td>-6</td>
<td>5</td>
<td>0.0109</td>
</tr>
<tr>
<td>M05</td>
<td>1.22</td>
<td>-7</td>
<td>6</td>
<td>0.0090</td>
</tr>
<tr>
<td>M06</td>
<td>0.50</td>
<td>-2</td>
<td>2</td>
<td>-0.0003</td>
</tr>
<tr>
<td>M07</td>
<td>1.36</td>
<td>-8</td>
<td>7</td>
<td>-0.0028</td>
</tr>
<tr>
<td>M08</td>
<td>1.41</td>
<td>-6</td>
<td>6</td>
<td>0.0061</td>
</tr>
<tr>
<td>M09</td>
<td>1.60</td>
<td>-7</td>
<td>6</td>
<td>-0.0026</td>
</tr>
<tr>
<td>M10</td>
<td>1.13</td>
<td>-6</td>
<td>4</td>
<td>-0.0221</td>
</tr>
<tr>
<td>M11</td>
<td>1.75</td>
<td>-7</td>
<td>8</td>
<td>-0.0016</td>
</tr>
</tbody>
</table>
## Estimate of Difference Between Filtered and Unfiltered TEB Products

- Analysis based on differences observed in a single granule
  - V2015262003600.L1B-M_SNPP.nc
  - V2015262003600.L1B-I_SNPP.nc
- Statistics based on the difference between L1B products with and without space view filtering and TEB F-Factor Filtering
- Units of radiance scaled to 16-bit integer
- Results show the benefit of SV and TEB F-Factor noise filtering is more significant for some Long-Wave Infrared (LWIR) Bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Standard Deviation of Difference</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>I04</td>
<td>3.49</td>
<td>-43</td>
<td>44</td>
<td>0.0182</td>
</tr>
<tr>
<td>I05</td>
<td>14.39</td>
<td>-174</td>
<td>163</td>
<td>-0.4033</td>
</tr>
<tr>
<td>M12</td>
<td>2.28</td>
<td>-21</td>
<td>19</td>
<td>-0.0112</td>
</tr>
<tr>
<td>M13</td>
<td>0.098</td>
<td>-1</td>
<td>1</td>
<td>0.0000</td>
</tr>
<tr>
<td>M14</td>
<td>9.23</td>
<td>-44</td>
<td>47</td>
<td>0.0023</td>
</tr>
<tr>
<td>M15</td>
<td>4.08</td>
<td>-25</td>
<td>22</td>
<td>-0.1704</td>
</tr>
<tr>
<td>M16</td>
<td>3.23</td>
<td>-16</td>
<td>20</td>
<td>-0.1519</td>
</tr>
</tbody>
</table>
New Saturation Threshold and Radiance Range Processing

- The maximum radiance supported on a given band may increase substantially with time due to degradation of optical pathway.
- The maximum usable DN on any band, however, is invariant.
- Consequently, we prefer to use DN to establish saturation thresholds and radiance ranges.
- Effective saturation thresholds for some bands are lower than the digital saturation threshold currently used.
- Revised saturation thresholds:
  - Imagery Reflective Solar Bands: 3400 DN
  - Imagery Thermal Emissive Bands: 4095 DN (digital saturation)
  - Moderate Dual-Gain Reflective Solar Bands: 3700 DN
  - Moderate Dual-Gain Thermal Emissive Bands (M13): 4095 DN (digital saturation)
  - Moderate Single-Gain Reflective Solar Bands: 4095 DN (digital saturation)
  - Moderate Single-Gain Thermal Emissive Bands: 4095 DN (digital saturation)
  - Day-Night Band: 7872 DN (digital saturation occurs at 8191 DN)
Revised Saturation Thresholds for Moderate Dual-Gain Bands
Add Optional Diagnostic Array Group

- A set of optional diagnostic arrays has been added to M-band and I-band products
  - Required for testing
  - Useful for analysis
- Imagery (I) Bands
  - SV and TEB_F arrays
    - Dimensions: band x time series x scan x detector x aggregation zone x parity
- Moderate (M) Bands
  - SV_DG, SV_SG, TEB_F_DG, and TEB_F_SG arrays
    - Dimensions: band x time series x scan x detector x gain state*
- Multiple time series show the sequence of filter processing stages
  - Input (after validation and replacement of corrupted SV scans with granule average)
  - DC Restore effects removed to restore continuous time series
  - 201-tap FIR filter applied
  - DC Restore effects restored
- Moon-in-SV Example
- Input to filter has scans contaminated with moonlight removed and replaced with granule-average SV
- DCR Correction removes discontinuities in SV time series caused by DC Restore offsets
- 201-tap FIR filter is applied to the central, current granule
- DC Restore offsets are restored in final time series
• Moon-in-SV Example
• Calculation of F Factor uses SV background reference
• SV scans with lunar contamination are replaced with granule average
• Raw F Factors are computed
• 201-tap FIR filter is applied to the central, current granule
SNPP VIIRS Reflective Solar Bands On-orbit Radiometric Calibration Performance and Improvements

Ning Lei¹, Xuexia Chen¹, Zhipeng Wang¹, and Jack Xiong²

1. VIIRS Characterization and Support Team (VCST), SSAI, Lanham, MD, USA
2. NASA GSFC, Greenbelt, MD, USA

June 6, 2016
TOA spectral hemispherical reflectance is estimated by (Eq. 81, ATBD)

$$\rho(\lambda_B) = \frac{\pi F(B) \times \left(c_0 + c_1 d_{n_{\text{EV}}} + c_2 d_{n_{\text{EV}}}^2\right)}{\text{RVS}(\theta_{\text{EV}}, B) \cos \theta_{\text{sun-earth}} E_{\text{sun}}(\lambda_B, d_{\text{sc}})}$$

(1)

Calibration performance means how accurately the reflectance is measured.

- Error in $d_{n_{\text{EV}}}$: SNR
- Error in $F$
- Error in RVS
- Error in the quadratic polynomial
SNR

![SNR Diagram]

Band

| Band | SNR/\text{SNR}_{\text{spec}}^{\text{spec}}| \text{NEdT/NEdT}_{\text{spec}}^{\text{spec}} |
|------|------------------------------------------|
| M1h  | 02/06/12                                 |
| M2h  | 09/10/12                                 |
| M3h  | 03/18/13                                 |
| M4h  | 09/16/13                                 |
| I1   | 03/15/14                                 |
| M5h  | 09/18/14                                 |
| M6   | 03/20/15                                 |
| M7h  | 09/19/15                                 |
| M8   | 03/20/16                                 |

Note: The diagram illustrates the SNR for various bands over different dates.
SNR projection

Gain (normalized)

640nm(I1) 672nm(M5) 746nm(M6) 865nm(I2)
circles—measured; solid lines—predicted
F Determination

On-orbit Calibration: $F$-factor

\[ F = \frac{\int \text{RSR} (\lambda, B, t) \times L_{SD} (\lambda, t, \phi)}{\left( c_0 + c_1 d n_{SD} + c_2 d n_{SD}^2 \right) \times \int \text{RSR} (\lambda, B, t) d\lambda} \]  

\( L_{SD} \): spectral radiance from the SD; **improved**

\( \text{RSR} (\lambda, B, t) \): slightly **improved**
1/F-factors

- Graphs showing the gain (mid det; day=11) over days since launch for different factors.

- The graphs illustrate the degradation over time for various factors labeled M3, M2, M4, M1, I1, M5, I3, M1G, I2, M7, M6, M9, and M8.
F-factors: new vs old

old

new
$\sigma = 0.072\%$

M1:0.07%, M2:0.07%, M3:0.06%, M4:0.04%, I1:0.06%, …, M11:0.05%
Improved Calculated Sunlit SD Spectral Radiance

\[ L_{SD} = E_{\text{sun}}(\lambda) \cos(\theta_{SD-\text{sun}}) \tau_{SAS} \text{BRDF}_{\text{RTA}}(\lambda, t = 0, \phi) H_{\text{RTA}}(\lambda, t, \phi) \quad (3) \]

\[ H_{\text{RTA}}(\lambda, t, \phi) : \text{SD BRDF degradation factor, biases removed and screen transmittances are more accurate} \]

\[ \tau_{SAS}(\lambda, \phi) \text{BRDF}_{\text{RTA}}(\lambda, t = 0; \phi) : \text{bias removed, 0.05\% along solar azimuth direction} \]
Improvements on $H_{SDSM}$ : part 1

(1) Improved SDSM screen transmittance
use both yaw maneuver and a small portion of regular data (same as last year)

SDSM screen coord.
(2) Improved $\tau(\text{SD}) \ast \text{BRDF}(t=0; \text{SDSM})$

use both yaw maneuver and a small portion of regular data

and remove bias from the angular dependence of $H_{\text{SDSM}}$
Solar angular dependence of SD BRDF degradation factor
(3) Rescale $H_{\text{SDSM}}$

effectively move up $H_{\text{SDSM}}$ at the wavelength of 412 nm (M1) by about 1.0%
(4) Model $H_{SDSM}$ at SWIR band wavelengths
originally $H_{SDSM}(\text{SWIR wavelength})=1$

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

$$\alpha(t) = \langle (1 - H(\lambda, t)) \times \lambda^{4.07} \rangle$$

$$\lambda = (\lambda_{\text{det } 5}, \lambda_{\text{det } 6}, \lambda_{\text{det } 7}, \lambda_{\text{det } 8})$$
Improved $H_{SDSM}$ (SDSM SD view)

$H_{SDSM}$ can be precisely measured with a relative error from high to low 0.0001
Improvements on $H_{\text{RTA}}$ : part 1

(1) $H_{\text{RTA}}$ dependence on solar azimuth angle $\phi_H$

non-observable dependence on $\phi_H$

$F$ calculated with $H_{\text{SDSM}}$
(1) $H_{RTA}$ dependence on solar azimuth angle $\phi_H$

$$F_1 = F / \left[ 1 + \beta(\lambda) \times \left( H_{SDSM, \text{mean RSR}}(t_{mid}) - H_{SDSM, \text{mean RSR}} \right) \times (\phi_H - 48.0^\circ) \right]$$
(2) $H_{\text{RTA}}$ from $H_{\text{SDSM}}$: match scaled lunar results through least square fitting

\[ (2.1) \quad F_2 = F_1 \times \left[ 1 + \gamma(\lambda) \times (1 - H_{\text{SDSM}}) \right] \times H_{\text{SDSM}} \]

\[ H_{\text{RTA}} = H_{\text{SDSM}} \times \frac{[1 + \gamma(\lambda) \times (1 - H_{\text{SDSM}})] \times H_{\text{SDSM}}}{1 + \beta(\lambda) \times (1 - H_{\text{SDSM}}) \times (\phi_H - 48.0^\circ)} \]

Fit $F [1 + \Delta \gamma(\lambda) \times (1 - H_{\text{SDSM}})] \times H_{\text{SDSM}}$ match scaled lunar results again

-> update RSR; iterate until stable
Summary

- SNRs are better than specifications and are projected to be better in the near future
- \textit{F}\text{-factor precisions are better than 0.1\% on a per satellite orbit basis}\n  (M1:0.07\%, M2:0.07\%, M3:0.06\%, M4:0.04\%, I1:0.06\%, \ldots, M11:0.05\%)\n
- New algorithms have been applied to improve the calculation accuracy of the SNPP VIIRS RSB throughput
  (1) removed yearly detector gain undulations (as large as 0.5\% for M1)
  (2) removed biases (originally observed as large as 1.5\% for M1) relative to lunar observations
  (3) removed bias due to incorrect H\textsubscript{SDSM} normalization at t=0 (~1\% for M1)
  (4) removed bias in the original $\tau_{SD \text{ BRDF}_{\text{RTA}}}(t = 0)$ (0.05\%; yaw)
  (5) removed bias for the calculated SWIR band throughput (0.4\% for M8)
  (6) improved accuracies in $\tau_{SD \text{ BRDF}_{\text{SDSM}}}(t = 0)$ and $\tau_{SDSM}^{R}$ (yaw+non-yaw)
    -> $H_{SDSM}$ precision of 0.0003 to 0.0007

- Correct solar vectors, removing a bias as large as 0.5\% for all RSBs
BACKUP
Improvements on $H_{\text{SDSM}}$ : part 4

$$1 - H(\lambda, t) = \frac{\alpha(t)}{\lambda^\eta}$$

$$\langle \eta \rangle = 4.07 \pm 0.06$$

Days since launch

$\eta$
Improvements on $H_{\text{RTA}}$ : part 2

(2) $H_{\text{RTA}}$ from $H_{\text{SDSM}}$: match scaled lunar results through least square fitting

$$H_{\text{RTA}} = H_{\text{SDSM}} \times \frac{[1 + \gamma(\lambda) \times (1 - H_{\text{SDSM}})] \times H_{\text{SDSM}}}{1 + \beta(\lambda) \times (1 - H_{\text{SDSM}}) \times (\phi_H - 48.0^\circ)}$$

![Graph showing the relationship between $\gamma$ and $\lambda$ with a solid line equation $\gamma = 0.334 - 0.352\lambda$]
S-NPP VIIRS DNB On-orbit Performance with Stray-light Estimation and Predication

VIIRS Characterization Support Team
June 6, 2016
Outline

• DNB RSR and Degradation Behavior
• DNB Calibration and Predication Algorithm
• DNB On-orbit Performance and Trending
• Stray-light Estimation and Predication
• Stray-light Features in Northern/Southern Hemisphere
• Examples of Data Fusion for Stray-light LUTs
• Selected Results
• Summary
- RSR shows a gradually shifting from right side to left side, as operation goes forward.

- RTA degradation:

\[
\frac{\int H'(\lambda) \cdot RSR(\lambda) d\lambda}{\int RSR(\lambda) d\lambda}
\]

**NOTE**: \(H'(\lambda)\) is interpolated degradation from SDSM 8 bands.
- RSB have experienced the largest degradation in the first year.
- DNB has about 18.5% degradation entire mission.
- DNB Moon irradiance trending matches well with SD gain trending.
DNB Calibration and L1B Algorithm

LGS Gain Calculation:
- SD radiance: 
  \[ L_{SD} = \cos \theta_{sd} \cdot RVS_{sd} \int BRF(\lambda)T_{sd}H(\lambda,t)RSR(\lambda) \frac{\Phi(\lambda)}{4\pi d^2} d\lambda \]
  SD-SUN angle, HAM relative response at SD AOI, transmittance of pinhole screen, SD degradation index, relative spectral response, solar spectral power distribution.
- Calculate LGS gain coefficient: 
  \[ L_{SD} = c_1 \cdot dn \]

Dark Offset:
- Select dark data as sun declination angles in 40°~140°.
- Use the minimum of fitted values in SV/BB/SD as dark signal

Cross-stage Gain Ratios:
- Compute daily average gain ratio: MGS/LGS, HGS/MGS

MGS and HGS Gain Coefficients:
- MGS gain = LGS gain * MGS/LGS
- HGS gain = MGS gain * (HGA/MGS + HGB/MGS)/2

Gains/Offsets Use Recent 1-year Data with a Linear-fit for L1B
DNB Gain Ratio (HGS/MGS and MGS/LGS)
DNB Gain/Offset Trending and Prediction

VIIRS F1 DNB Mode: 1 HAM A

- LGS C1 ($x10^6$)
- MGS C1 ($x10^4$)
- HGS C1 ($x10^3$)

<table>
<thead>
<tr>
<th>DJ</th>
<th>FMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
</tr>
</thead>
</table>

- LGS DNO (DN)
- MGS DNO (DN)
- HGS DNO (DN)

<table>
<thead>
<tr>
<th>DJ</th>
<th>FMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
<th>JASOND</th>
<th>JFMAM</th>
</tr>
</thead>
</table>

**EOS**

**VCST**

**2016**

**NPP**
• **EV Signals Considered**
  ▶ Use EV data from terminator crossing area during new moon.
  ▶ Separate EV samples into 127 bins of 32 pixels each (4064=127x32).

• **Stray Light Estimation**
  ▶ In twilight regions (SZA < 105°), stray light is assumed the same to the last known value.
  ▶ Produce correction LUT hemisphere, detector, HAM, sample and SZA.
  ▶ Update correction LUT per month (every new moon)

• **Stray Light Predication**
  ▶ Stray-light pattern follows yearly Earth-Sun spacecraft geometry cycle.
  ▶ IDPS uses the same month one-year-ago LUT.
  ▶ VCST uses all previous LUTs via a data fusion mechanism.
NH/SH Stray-light Features

• New moon 03/20/2015
  - Northern, Southern hemisphere: SV, BB, SD view
  - Three detectors, d1/d8/d16
  - Radiance vs solar zenith angle
• NH/SH shows different stray-light features.
• Edge (big slop) makes hard for correction.
• SV data is used to estimate the penumbra angle.

• NH/SH shows different penumbra angle features.
  • SH has large yearly fluctuations, SZA is in the range of 2 degrees.
  • NH is in the range of 0.3 degree.
Multiple-years Data Consideration

• **Stray-light Estimation LUTs**
  - Each year has 12 LUTs (12 new moon events).
  - LUT size: 469x127 (solar zenith 95°-118.5°, 4064 pixels)

• **Multiple-year Stray-light Historic Data**
  - Simply average introduces additional estimation error.
    - DNB degradation impact.
    - Onset SD angle shift (penumbra region).
    - Hard to be normalized by fitting (limited data each year).

• **Data Fusion**
  - Use all possible historic data and truncate them into yearly groups such that each group has 12 points (months).
  - Introduce a similarity metric to find the best degradation adjustment in each group to make all groups as similar as possible (smallest value of the similarity metric)
  - Adjust the best degradation in each group, and then combine the group together.
Example: Straylight Predication using Historic-data

- Relative entropy is used as the similarity metric.
- Similarity versus degradation adjustment.

- Historic data (up-to 08/2015).
- Each group is with different color.
- Line denotes the fusion results.
- Results of two bins with SZA=95 are shown.

- Each month has its own trending.
- Red-square denotes the actually calculated result using the new moon of 09/2015
- Blue-triangle denotes the predicated result using data up-to 08/2015.
Day20160408: gT08:24:21 original/corrected images

Stray-light

IDPS Correction using LUT-20150428

VCST Predication using data upto 03/2016

VCST Estimation using LUT-20160407
• DNB calibration and stray-light estimation/predication have been presented.
  1. Gain and offset use the most recent 1-year data via a linear-fit to generate L1B LUT.
  2. Real-time stray-light correction is possible by using the predicted correction LUT.
  3. L1B forward calibration delivery (gain/stray-light LUTs) can be effectively performed.

• DNB on-orbit performance and trending have been illustrated.
  1. RSB degradation behavior is normal. DNB SD and Moon F-factors are matched well.
  2. LGS gain/offset are stable trending, and gain coefficients gradually increase over time.
  3. HGS gain coefficients have large fluctuations convolving gain ratios of H/M and M/L.

• Stray-light correction results show the effectiveness of estimation/predication.
  1. Fuse historic data (straylight correction LUT) with degradation and/or SZA adjustments.
  3. Example (2016-04): Original/corrected night images show results of using IDPS, VCST and VCST predication LUTs. In the operational point view, VCST predication provides better straylight removal results than IDPS.
S-NPP VIIRS Thermal Emissive Bands On-Orbit Performance and Calibration

Jeff McIntire, Chengbo Sun, Sergey Gusev, and Vincent Chiang

VCST, NASA/GSFC

Acknowledgements: VIIRS SDR Team Members
VCST Members

June 6, 2016
Outline

• TEB Calibration

• On-orbit Performance
  ▪ BB performance
  ▪ Detector short-term stability and long-term response (F-factors)
  ▪ Detector noise characterization (NEdT)
  ▪ Trending during WUCD

• Improvements
  ▪ Improvements already implemented
  ▪ Future improvements

• Conclusions
Calibrated using an on-board blackbody (BB):

- Scaling factor “F-factor” is derived and applied each scan.
- Warm-up and cool-down (WUCD) cycles are performed quarterly to fully characterize TEB detector response, including offset and nonlinear terms.
VIIRS Earth View radiance is retrieved following ATBD Eq. (116)

\[
L_{EV}(B, \theta) = \frac{F(B) \sum_{i=0}^{2} c_i(B)dn^i(B) - \Delta L_{bg}(B, \theta)}{RVS(B, \theta)},
\]

where the \( \Delta L_{bg}(B, \theta) \) is the background difference between the EV and SV path:

\[
\Delta L_{bg}(B, \theta) = (RVS(B, \theta) - RVS_{SV}(B)) \left[ \frac{(1 - \rho_{RTA}(B))}{\rho_{RTA}(B)} L_{RTA} - \frac{1}{\rho_{RTA}(B)} L_{HAM} \right],
\]

The F-factor is derived each scan for each band, detector, and HAM side:

\[
F(B) = \frac{RVS_{BB}(B)L_{ap}(B) + \Delta L_{bg}(B, \theta_{BB})}{\sum_{i=0}^{2} c_i dn_{BB}^i},
\]

and the aperture radiance from the BB is:

\[
L_{ap}(B) = \varepsilon L_{BB} + (1 - \varepsilon)(F_{RTA} L_{RTA} + F_{SH} L_{SH} + F_{CAV} L_{CAV})
\]
BB Performance

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

Short-term stability (scan-by-scan $T_{BB}$):
- Orbital variations of individual thermistors up to 40 mK
- Variations in average temperature ~ 20 mK
- Temperature difference between individual thermistors up to 60 mK
- BB uniformity meets the requirement with standard deviation less than 30mK
Detector responses (F-factors) show small orbital variations:
- ±0.2 % or less on a per scan basis
- ±0.1 % or less on a per granule basis

Would using averaged F-factors improve SDR product?

F-factor orbital variations correlate with $T_{BB}$ variations and instrument temperatures variations.

F-factor shown for orbits 22854 – 22858 for HAM side A.
Detector Long-term Response

Daily average F-factor trend:

- From January 20, 2012 (orbit 1200) to May 1, 2016 (orbit 23361)
- I5 shows the most noticeable trend of ~1.4 %, while the rest of the bands are within 0.47 % (I4).
- Discontinuities in the trend are coincident with anomalies during which the cold FPA and/or instrument temperatures changed.
- Features in LWIR bands F-trend appear to coincide with the passage of the Earth through perihelion.

<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>1.0101</td>
</tr>
<tr>
<td>Average F-factor: 03 26 2016</td>
<td>1.0153</td>
<td>1.0177</td>
<td>1.0077</td>
<td>1.0097</td>
<td>0.9952</td>
<td>1.0070</td>
<td>1.0126</td>
</tr>
<tr>
<td>Trend [%]</td>
<td>0.47%</td>
<td>1.36%</td>
<td>0.42%</td>
<td>0.26%</td>
<td>0.06%</td>
<td>0.14%</td>
<td>0.24%</td>
</tr>
</tbody>
</table>
• Discontinuities in the instrument temperatures trends coincident with discontinuities in the F-factor trends shown on previous slide.

• Features in instrument temperature trends appears to coincide with the passage of the Earth through perihelion. The F-factor for LWIR bands shows features at the same time.

• There is a small increasing trend of SMWIR focal plane temperature, which can explain the trend observed in MWIR bands (I4, M12, M13).
Detector Noise Characterization (NEdT)

\[
NEdT = \frac{NEdL}{\partial L/\partial T} = \frac{L}{SNR \ \partial L/\partial T}
\]

- NEdT routinely trended at 292.5 K: stable since the CFPA temperatures reached ~80 K (orbit 1200). Band averaged values are within 0.2 K for I bands and 0.07 K for M bands
- NEdT at \( T_{\text{TYP}} \) derived periodically from BB WUCD data: stable and meeting the sensor design requirements by a wide margin:
### Detector Noise Characterization (NEdT)

<table>
<thead>
<tr>
<th>Band</th>
<th>T\text{}\textsubscript{Typ} [K]</th>
<th>NEdT at T\text{}\textsubscript{Typ} [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requirement</td>
<td>02/12</td>
</tr>
<tr>
<td>I4</td>
<td>270</td>
<td>2.5</td>
</tr>
<tr>
<td>I5</td>
<td>210</td>
<td>1.5</td>
</tr>
<tr>
<td>M12</td>
<td>270</td>
<td>0.396</td>
</tr>
<tr>
<td>M13</td>
<td>300</td>
<td>0.107</td>
</tr>
<tr>
<td>M14</td>
<td>270</td>
<td>0.091</td>
</tr>
<tr>
<td>M15</td>
<td>300</td>
<td>0.070</td>
</tr>
<tr>
<td>M16</td>
<td>300</td>
<td>0.072</td>
</tr>
</tbody>
</table>

**NEdT at T\text{}\textsubscript{Typ} (derived from BB cool-down data)**

Only February / March cool-down measurements listed

**TEB bands continue to meet the sensor design requirements**
• Band-average \( c_1 \) coefficients, as derived from the thirteen WUCD until March 2016, are shown in red (WU data), and blue (CD data) and compared to pre-launch (green). I5 \( c_1 \) starts to show noticeable trend, consistent with results from F-factor trending.

• Band-average \( c_1 \) coefficients derived during WUCD cycles are within 1.9% on average (at M16 CD) from pre-launch values.

• An offset between WU and CD results is present through the thirteen WUCDs, most prominent for LWIR bands.

\[ \text{Y-range spans } c_{1\text{LUT}} \pm 4\% \text{ } c_{1\text{LUT}} \]
c₀ and c₂ Coefficients

Band average c₀

Band average c₂

Y-range spans: c₀LUT ±0.002  (MWIR),
              c₀LUT ±0.1    (LWIR)

Y-range spans: c₂LUT ±3 x c₂LUT
- F-factor orbital variations are present, on the order of ±0.05 – 0.1%.
- Changing the BB thermistor weighting can reduce the F-factor orbital variations. Using T3 and T6 yield less variation for most bands (except M12 and M13).
- Improving the background model which would also reduce the F-factor orbital variations.

- F-factor shown for orbits 22854 – 22858 for HAM side A.
NASA L1B TEB Improvements

- NASA L1B TEB improvements not in IDPS
  - Moon in SV update
  - Unaggregated M13 output in separate products
  - All radiance now reported as scaled integer
- NASA L1B TEB improvements in progress
  - Update to M13 low gain calibration coefficients
  - Update BB thermistor weighting
  - Uncertainty index added to products
  - Flagging of spurious fires in band I4
Conclusions

- S-NPP VIIRS on-orbit BB long-term (4+ years) performance is very stable. Short-term (orbital) temperature variations are present but within the uniformity requirement of 30 mK.

- Detector response (F-factor) trending is stable, with I5 showing maximum band-average trend of 1.4 % followed by M12 and I4. Small orbital variations are present (±0.0.5 – 0.1 %).

- No change is observed for TEB detector noise characteristics. NEdT at $T_{TYP}$ is in compliance with the requirements.

- Improvements: Moon in SV, scaled integer, and unaggregated M13; uncertainty index, BB thermistor weighting, spurious I4 fire flagging, and M13 low gain calibration.
Back Up
M13 LG Calibration

M13 low gain: No scan by scan F-factor correction

Prelaunch analysis differs between Government team (Aerospace and VCST) and sensor subcontractor – current LUT. Government team results are:

- $c_1 = 0.142$ - 7 % higher than LUT value $c_{1LUT} = 0.132$
- $c_0 = 0$ - inconsistent with $c_{0LUT} = 1.15$

Proposal:
Update M13 low gain coefficients based on Government team pre-launch analysis, which is consistent with results from on-orbit calibration

On-orbit comparison of lunar images in M13 LG and M13 HG - supports Government team pre-launch results:

- $c_1 = 0.142$; 7 % higher than $c_{1LUT}$ - consistent with Gov. team pre-launch
- $c_0 = 0$ consistent with Gov. team pre-launch
Effect of F-factor Noise

Evaluating the effect of using average F-factors

- The VCST VIIRS SDR code was modified to apply average F-factors instead of per-scan F-factors for TEB calibration.
- The F-factors for each band, detector, HAM side are averaged over 24 scans.
- Using average F-factors does not significantly impact the SDR product.
- Striping on the noise level affects SST products based on M15 and M16 brightness temperatures.

![Graph showing M15 - M16 BT vs. Along Track Pixel]

SDR: d20130121_t0736504_e0742307

T(M15)-T(M16)
Short-term Stability - Individual Detectors

Orbits: 17553, 17554, 17555

Granule average (HAM A)

* For clarity the F-factors are shifted.

M16 (not shown) similar to M15; same D16 our of family behavior
Dynamic Range Verification

Dynamic range verified using scheduled Lunar observations

- All detectors of all TEB bands meet the $T_{\text{MIN}}$ (marginal non-compliance at I4) and $T_{\text{MAX}}$ requirements
- For some detectors of some bands the radiance limits in the Radiance-to-Temperature LUT do not extend to the largest possible unsaturated radiance

![Graphs showing dynamic range verification](image-url)
Detector Specific NEdT

- Detector specific NEdT is stable throughout the mission.
Warm-up Cool-down (WUCD) Cycles

WUCD cycles performed: Feb, May, Sep, Dec 2012; Mar, Jun, Sep, Dec 2013, Mar 2014

- Feb. 6 - 10 2012; orb.: 1436 – 1494; ~59 orbits.
- May 22 - 25 2012; orb.: 2939 – 2984; ~46 orbits.
- Sept. 10-12 2012; orb.: 4509 – 4536; ~28 orbits.
- Mar. 18-20 2013; orb.: 7191 – 7219; ~29 orbits.
- June 17-19 2013; orb.: 8482 – 8510; ~28 orbits.
- Sept. 16-18 2012; orb.: 9773 – 9801; ~28 orbits.
- Dec. 16-18 2013; orb.: 11064 – 11092; ~28 orbits.
- Mar. 16-18 2014; orb.: 11064 – 11092; ~28 orbits.
Warm-up Cool-down (WUCD) Cycles

WUCD cycles performed previously: Jun - Dec 2014, Mar - Dec 2015

- Sept 17-19 2014; orb.: 14937 – 14966; ~29 orbits.
- Dec 15-17 2014; orb.: 16228 – 16257; ~30 orbits.
- Mar 16-18 2015; orb.: 17519 – 17548; ~29 orbits.
- June 17-19 2015; orb.: 18838 – 18866; ~28 orbits.
- Sept 14-16 2015; orb.: 20102 – 20129; ~27 orbits.
- Dec 14-16 2015; orb.: 21393 – 21420; ~27 orbits.
Warm-up:
• Orbits: 22684 – 22693; 22708 – 22711
• $T_{BB}$ set to: 297.5K, 302.5K, 307.5K, 312.5K, 315.0K and 272.5K, 282.5K, 292.5K,
• The scans used are highlighted in red.

Cool-down:
• Orbits: 22693 – 22708.
• $T_{BB}$ range: 266.9 K to 315K;
• The scans used are shown in blue.
**C₀ Coefficients**

### Band average c₀

- **M12**
- **M13**
- **M14**
- **M15**

### Detector specific c₀/c₀LUT

- **I4 S0**
- **I4 S1**
- **I5 S0**
- **I5 S1**

Y-range spans: c₀LUT ±0.002 (MWIR),
c₀LUT ±0.1 (LWIR)
C2 Coefficients

Band average $c_2$

Detector specific $c_2/c_{2\text{LUT}}$

Y-range spans $c_{2\text{LUT}} \pm 3 \times c_{2\text{LUT}}$
**Calibration Coefficients – c1/LUT**

Band average: $100 \times \frac{(c_{\text{on-orbit}} - c_{\text{LUT}})}{c_{\text{LUT}}}$:

<table>
<thead>
<tr>
<th></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>WU 02/12 [%]</td>
<td>1.2</td>
<td>-0.8</td>
<td>0.4</td>
<td>1</td>
<td>-1.1</td>
<td>-0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>WU 05/12 [%]</td>
<td>1.2</td>
<td>-0.6</td>
<td>0.4</td>
<td>0.9</td>
<td>-1.7</td>
<td>-0.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>WU 09/12 [%]</td>
<td>1.3</td>
<td>0.2</td>
<td>0.6</td>
<td>1.2</td>
<td>-0.8</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>WU 12/12 [%]</td>
<td>1.3</td>
<td>-0.2</td>
<td>0.6</td>
<td>1.2</td>
<td>-1.2</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>WU 03/13 [%]</td>
<td>1.4</td>
<td>0.4</td>
<td>0.6</td>
<td>1.2</td>
<td>-1.1</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>WU 06/13 [%]</td>
<td>1.4</td>
<td>0.6</td>
<td>0.7</td>
<td>1.2</td>
<td>-0.7</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>WU 09/13 [%]</td>
<td>1.5</td>
<td>0.3</td>
<td>0.7</td>
<td>1.2</td>
<td>-0.8</td>
<td>0.3</td>
<td>0.03</td>
</tr>
<tr>
<td>WU 12/13 [%]</td>
<td>1.4</td>
<td>-0.18</td>
<td>0.7</td>
<td>1.2</td>
<td>-1.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>WU 03/14 [%]</td>
<td>1.4</td>
<td>0.5</td>
<td>0.7</td>
<td>1.2</td>
<td>-1.0</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>WU 06/14 [%]</td>
<td>1.4</td>
<td>1.0</td>
<td>0.7</td>
<td>1.3</td>
<td>-0.5</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>WU 09/14 [%]</td>
<td>1.4</td>
<td>0.2</td>
<td>0.7</td>
<td>1.3</td>
<td>-1.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>WU 12/14 [%]</td>
<td>1.4</td>
<td>0.2</td>
<td>0.7</td>
<td>1.3</td>
<td>-0.8</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>WU 03/15 [%]</td>
<td>1.5</td>
<td>0.8</td>
<td>0.7</td>
<td>1.3</td>
<td>-1.0</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>WU 06/15 [%]</td>
<td>1.6</td>
<td>1.7</td>
<td>0.8</td>
<td>1.3</td>
<td>-0.3</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>WU 09/15 [%]</td>
<td>1.6</td>
<td>1.3</td>
<td>0.8</td>
<td>1.3</td>
<td>-0.5</td>
<td>0.6</td>
<td>1.2</td>
</tr>
<tr>
<td>WU 12/15 [%]</td>
<td>1.6</td>
<td>1.4</td>
<td>0.8</td>
<td>1.3</td>
<td>-0.7</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>WU 03/16 [%]</td>
<td>1.6</td>
<td>1.5</td>
<td>0.8</td>
<td>1.3</td>
<td>-0.6</td>
<td>0.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Calibration Coefficients – c1/LUT

Band average: \(100 \times \frac{(c_{\text{on-orbit}} - c_{\text{LUT}})}{c_{\text{LUT}}}:\)

<table>
<thead>
<tr>
<th></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>CD 02/12 [%]</td>
<td>1.5</td>
<td>0.6</td>
<td>0.6</td>
<td>1.2</td>
<td>0.2</td>
<td>0.4</td>
<td>1.6</td>
</tr>
<tr>
<td>CD 05/12 [%]</td>
<td>1.6</td>
<td>0.5</td>
<td>0.7</td>
<td>1.3</td>
<td>-0.6</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>CD 09/12 [%]</td>
<td>1.6</td>
<td>1.0</td>
<td>0.8</td>
<td>1.7</td>
<td>0.3</td>
<td>0.9</td>
<td>2.2</td>
</tr>
<tr>
<td>CD 12/12 [%]</td>
<td>1.6</td>
<td>0.7</td>
<td>0.8</td>
<td>1.2</td>
<td>-0.2</td>
<td>0.3</td>
<td>1.6</td>
</tr>
<tr>
<td>CD 03/13 [%]</td>
<td>1.7</td>
<td>0.8</td>
<td>0.9</td>
<td>1.3</td>
<td>-0.1</td>
<td>0.6</td>
<td>1.8</td>
</tr>
<tr>
<td>CD 06/13 [%]</td>
<td>1.7</td>
<td>1.1</td>
<td>0.9</td>
<td>1.3</td>
<td>-0.01</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td>CD 09/13 [%]</td>
<td>1.7</td>
<td>1.1</td>
<td>0.9</td>
<td>1.3</td>
<td>0.05</td>
<td>0.6</td>
<td>2.2</td>
</tr>
<tr>
<td>CD 12/13 [%]</td>
<td>1.7</td>
<td>1.7</td>
<td>0.9</td>
<td>1.4</td>
<td>0.4</td>
<td>0.6</td>
<td>2.2</td>
</tr>
<tr>
<td>CD 03/14 [%]</td>
<td>1.7</td>
<td>1.6</td>
<td>0.9</td>
<td>1.3</td>
<td>0.3</td>
<td>0.7</td>
<td>2.4</td>
</tr>
<tr>
<td>CD 06/14 [%]</td>
<td>1.8</td>
<td>2.3</td>
<td>1.0</td>
<td>1.3</td>
<td>0.6</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>CD 09/14 [%]</td>
<td>1.8</td>
<td>1.6</td>
<td>1.0</td>
<td>1.4</td>
<td>0.2</td>
<td>0.7</td>
<td>2.2</td>
</tr>
<tr>
<td>CD 12/14 [%]</td>
<td>1.8</td>
<td>2.3</td>
<td>1.0</td>
<td>1.4</td>
<td>0.3</td>
<td>0.7</td>
<td>2.4</td>
</tr>
<tr>
<td>CD 03/15 [%]</td>
<td>1.9</td>
<td>2.1</td>
<td>1.0</td>
<td>1.4</td>
<td>0.2</td>
<td>0.8</td>
<td>2.4</td>
</tr>
<tr>
<td>CD 06/15 [%]</td>
<td>1.9</td>
<td>2.4</td>
<td>1.0</td>
<td>1.3</td>
<td>0.3</td>
<td>0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>CD 09/15 [%]</td>
<td>2.0</td>
<td>2.2</td>
<td>1.0</td>
<td>1.4</td>
<td>0.3</td>
<td>0.8</td>
<td>2.4</td>
</tr>
<tr>
<td>CD 12/15 [%]</td>
<td>1.9</td>
<td>2.8</td>
<td>1.1</td>
<td>1.4</td>
<td>0.2</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>CD 03/16 [%]</td>
<td>1.9</td>
<td>2.0</td>
<td>1.0</td>
<td>1.4</td>
<td>-0.2</td>
<td>0.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>
• EV retrieved radiance uncertainty propagated using standard NIST formulation (k=1)

• Some uncertainty contributors determined pre-launch by the instrument vendor: RTA reflectance BB emissivity

• Radiometric coefficient and RVS uncertainties determined from NASA pre-launch analysis

• Uncertainties investigated for a range of input signal levels and scan angles
Comparison to Requirement [K]

Uncertainty specifications

Defined in terms of %, at particular uniform scene temperatures, converted to K

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

<table>
<thead>
<tr>
<th>Band</th>
<th>190 K</th>
<th>230 K</th>
<th>270 K</th>
<th>310 K</th>
<th>340 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>M12 spec</td>
<td>---</td>
<td>0.92</td>
<td>0.13</td>
<td>0.17</td>
<td>0.21</td>
</tr>
<tr>
<td>M12 estimate</td>
<td>---</td>
<td>1.11</td>
<td>0.13</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>M13 spec</td>
<td>---</td>
<td>0.85</td>
<td>0.14</td>
<td>0.19</td>
<td>0.23</td>
</tr>
<tr>
<td>M13 estimate</td>
<td>---</td>
<td>1.01</td>
<td>0.14</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>M14 spec</td>
<td>2.60</td>
<td>0.75</td>
<td>0.26</td>
<td>0.23</td>
<td>0.34</td>
</tr>
<tr>
<td>M14 estimate</td>
<td>0.95</td>
<td>0.26</td>
<td>0.12</td>
<td>0.12</td>
<td>0.20</td>
</tr>
<tr>
<td>M15 spec</td>
<td>0.56</td>
<td>0.24</td>
<td>0.22</td>
<td>0.28</td>
<td>0.34</td>
</tr>
<tr>
<td>M15 estimate</td>
<td>0.42</td>
<td>0.18</td>
<td>0.12</td>
<td>0.13</td>
<td>0.19</td>
</tr>
<tr>
<td>M16 spec</td>
<td>0.48</td>
<td>0.26</td>
<td>0.24</td>
<td>0.31</td>
<td>0.37</td>
</tr>
<tr>
<td>M16 estimate</td>
<td>0.35</td>
<td>0.16</td>
<td>0.12</td>
<td>0.14</td>
<td>0.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>267 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>I4 spec</td>
<td>0.91</td>
</tr>
<tr>
<td>I4 estimate</td>
<td>0.468</td>
</tr>
<tr>
<td>I5 spec</td>
<td>1.4</td>
</tr>
<tr>
<td>I5 estimate</td>
<td>0.226</td>
</tr>
</tbody>
</table>
## Uncertainty specifications

**Defined in terms of %, at particular uniform scene temperatures**

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

<table>
<thead>
<tr>
<th>Band</th>
<th>190 K</th>
<th>230 K</th>
<th>270 K</th>
<th>310 K</th>
<th>340 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>M12 spec</td>
<td>---</td>
<td>7.00</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>M12 estimate</td>
<td>---</td>
<td>8.98</td>
<td>0.71</td>
<td>0.27</td>
<td>0.32</td>
</tr>
<tr>
<td>M13 spec</td>
<td>---</td>
<td>5.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>M13 estimate</td>
<td>---</td>
<td>7.50</td>
<td>0.69</td>
<td>0.26</td>
<td>0.31</td>
</tr>
<tr>
<td>M14 spec</td>
<td>12.30</td>
<td>2.40</td>
<td>0.60</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>M14 estimate</td>
<td>4.82</td>
<td>0.84</td>
<td>0.28</td>
<td>0.21</td>
<td>0.29</td>
</tr>
<tr>
<td>M15 spec</td>
<td>2.10</td>
<td>0.60</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>M15 estimate</td>
<td>1.59</td>
<td>0.47</td>
<td>0.22</td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>M16 spec</td>
<td>1.60</td>
<td>0.60</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>M16 estimate</td>
<td>1.24</td>
<td>0.37</td>
<td>0.21</td>
<td>0.18</td>
<td>0.20</td>
</tr>
</tbody>
</table>

### Comparison to Requirement [%]

- **I4 spec**: 5.00
- **I4 estimate**: 2.55
- **I5 spec**: 2.50
- **I5 estimate**: 0.41

Uncertainty specifications are defined in terms of %, at particular uniform scene temperatures. Estimates exceed the specification at lower scene temperatures for bands M12 and M13.
Uncertainty contributors:

- Dominant for MWIR bands are the relative BB radiance uncertainty and the relative EV $dn$ uncertainty (increasing rapidly with decreasing scene temperature).
- The LWIR bands uncertainties are dominated by the $c_0$, RVS, and EV $dn$ relative uncertainties, which increase with decreasing scene temperatures.
Uncertainty contributors:

- Dominant for MWIR bands are the relative BB radiance uncertainty and the relative EV $dn$ uncertainty (increasing rapidly with decreasing scene temperature).
- The LWIR bands uncertainties are dominated by the $c_0$, RVS, and EV $dn$ relative uncertainties, which increase with decreasing scene temperature.
• Currently for TEB, Fill values are assigned in EV SDR when the Moon is in the SV.

• Improved algorithm computes the mean and standard deviation of a 48-frame sample each scan. Then the outlier samples (Moon intrusion) with selected rejection scheme are identified and excluded from the SV average for background subtraction.

Images of calibrated radiance from 4 consecutive Band M12 SDRs, generated with current SDR code (left) and modified (right) calibration algorithms (Data: Jan 22, 2013; Time 22:24:02). [Reference SPIE 2013, 8866-72]
VIIRS Special Calibration Topics: Calibration Stability Monitoring using the Moon and EV Sites

2016-06-06

VIIRS Characterization Support Team
Scheduled Lunar Calibration

- VIIRS lunar calibration has been scheduled on a nearly monthly basis.
- Lunar phases are designated within a range of \([-51.5^\circ, -50.5^\circ]\).
- A satellite roll maneuver is usually necessary for VIIRS detectors to view the Moon through the SV port.

<table>
<thead>
<tr>
<th>Number</th>
<th>M/D/Y</th>
<th>H:M:S</th>
<th>Roll Angle</th>
<th>Phase Angle</th>
<th>SEaVr Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01/04/2012</td>
<td>08:48:53</td>
<td>-9.490</td>
<td>-55.41</td>
<td>35.9</td>
</tr>
<tr>
<td>2</td>
<td>02/03/2012</td>
<td>04:21:32</td>
<td>-5.445</td>
<td>-56.19</td>
<td>41.3</td>
</tr>
<tr>
<td>3</td>
<td>02/03/2012</td>
<td>06:03:34</td>
<td>-5.279</td>
<td>-55.38</td>
<td>39.6</td>
</tr>
<tr>
<td>4</td>
<td>04/02/2012</td>
<td>23:05:11</td>
<td>-3.989</td>
<td>-51.24</td>
<td>23.0</td>
</tr>
<tr>
<td>5</td>
<td>05/02/2012</td>
<td>10:20:06</td>
<td>-3.228</td>
<td>-50.92</td>
<td>340.2</td>
</tr>
<tr>
<td>6</td>
<td>05/31/2012</td>
<td>14:47:14</td>
<td>-0.081*</td>
<td>-52.97</td>
<td>53.5</td>
</tr>
<tr>
<td>7</td>
<td>10/25/2012</td>
<td>06:58:15</td>
<td>-4.048</td>
<td>-51.02</td>
<td>309.0</td>
</tr>
<tr>
<td>9</td>
<td>12/23/2012</td>
<td>15:00:50</td>
<td>-7.767</td>
<td>-50.90</td>
<td>24.0</td>
</tr>
<tr>
<td>11</td>
<td>02/21/2013</td>
<td>09:31:25</td>
<td>-1.712</td>
<td>-50.71</td>
<td>28.8</td>
</tr>
<tr>
<td>12</td>
<td>03/23/2013</td>
<td>03:29:00</td>
<td>-3.320</td>
<td>-51.15</td>
<td>25.2</td>
</tr>
<tr>
<td>13</td>
<td>04/21/2013</td>
<td>19:47:54</td>
<td>-3.882</td>
<td>-50.82</td>
<td>18.6</td>
</tr>
<tr>
<td>14</td>
<td>05/21/2013</td>
<td>08:43:15</td>
<td>-0.809*</td>
<td>-50.67</td>
<td>335.7</td>
</tr>
<tr>
<td>15</td>
<td>10/14/2013</td>
<td>21:39:19</td>
<td>-1.305</td>
<td>-50.95</td>
<td>305.6</td>
</tr>
<tr>
<td>18</td>
<td>01/11/2014</td>
<td>09:59:45</td>
<td>-6.727</td>
<td>-51.30</td>
<td>25.9</td>
</tr>
<tr>
<td>19</td>
<td>02/10/2014</td>
<td>05:34:12</td>
<td>-3.714</td>
<td>-51.03</td>
<td>29.0</td>
</tr>
<tr>
<td>20</td>
<td>03/12/2014</td>
<td>01:11:43</td>
<td>-3.944</td>
<td>-51.05</td>
<td>28.4</td>
</tr>
<tr>
<td>21</td>
<td>04/10/2014</td>
<td>20:53:17</td>
<td>-4.977</td>
<td>-50.60</td>
<td>22.2</td>
</tr>
<tr>
<td>22</td>
<td>05/10/2014</td>
<td>13:13:00</td>
<td>-4.177</td>
<td>-50.91</td>
<td>338.6</td>
</tr>
</tbody>
</table>

*: No satellite roll maneuver when the predicted angle is within ±1 degree
**: Predicted lunar calibration events

- Since 04/02/2012 calibration, the lunar images are read-out from the center of EV data sector by applying electric sector rotation.
Lunar Calibration Parameters

- Instrument parameters at the time of lunar calibration show various seasonal oscillation patterns.
Radiometric Calibration Methodology

• Current lunar calibration methodologies were developed for MODIS and extended to VIIRS with adaptation.
• The Moon and SD are viewed at the same AOI (60.2°) for RTA HAM.
• The lunar F-factor is defined similarly to SD F-factor.

\[
F_{MOON} = \frac{I_{ROLO}}{I_{MOON,PL}} = \sum L_{MOON,PL} \cdot \Omega_B
\]

- \(I_{ROLO}\): the USGS ROLO model predicted lunar irradiance calculated by Tom Stone*. VCST provides input photometric parameters and the VIIRS detector (prelaunch and RTA degradation modulated) RSRs.

- \(I_{MOON,PL}/L_{MOON,PL}\): the lunar irradiance/radiance of individual pixels retrieved with the pre-launch gain coefficient \(c_0, c_1\) and \(c_2\).

\[
L_{MOON,PL} = (c_0 + c_1 \cdot dn_{MOON} + c_2 \cdot dn_{MOON}^2) / RVS_{SV}
\]

• The \(I_{MOON,PL}\) summation is performed over samples and detectors for those center scans (marked in the plot) with “complete” lunar images.

Lunar/SD Calibration Comparison

Land PEATE SD F-factor

L1B SD F-factor

Line - SD  Symbol - Moon
The detector gain changes tracked by SD and Moon overall agree.
SD F-factor calibrated per orbit is used for LUT to produce SDR/L1B.
There are band-dependent drifts between SD and lunar data trends.
The SD F-factor used for L1B v1 is adjusted based on lunar F-factor.
The oscillation of lunar data is tied to lunar irradiance reference.
To accurately determine the drift and apply the adjustment, the oscillation in lunar F-factor trending needs to be mitigated.
Detector Gain Difference

- Lunar F-factors can also be calculated on a detector basis to characterize the detector gain difference within a band.
The detector gain differences derived from Moon and SD overall agree with noticeable temporal drifts for some bands.

SD
Moon
Lunar DNB LGS Calibration

• The DNB LGS can be calibrated similarly to other RSBs.
• The DNB lunar images are composed of pixels at high-gain stage (HGS) and mid-gain stage (MGS), and low-gain stage (LGS).
• Gain ratio LUTs are used to convert $dn$ among different gain stages.
• Dark offset LUTs are used to correct the background.
• The RSR change has more impact to DNB F-factor than other RSBs.
• The impacts to SD and lunar calibrations are different.
- Moon can be viewed without satellite roll maneuver.
- Lunar Images are read-out from SV data sector and are not co-registered in the along-scan direction.
- Till May 2016, 165 lunar observations have been made. 126 of them with 2+ bands capturing unclipped Moon.
- Lunar phases vary significantly between -95° and -35°.
- Lunar irradiance reference introduces mostly phase and libration angles dependent bias.
- Empirical approach can be used to correct lunar data.
• Earth View (EV) targets can be used to track RSB calibration stability.
• Use NASA Land PEATE reflectance time series from 2012 to 2016.
• The widely used pseudo-invariant sites Libya-4 desert.
• A semi-empirical bi-directional reflectance function (BRDF) consisting of two kernel-driven components ($f_1$ and $f_2$):

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

$\theta$, $\psi$, $\varphi$ - solar zenith, view zenith and relative azimuth angle

$K_0$, $K_1$ and $K_2$ – site-dependent coefficients

• Good radiometric stability.
• Repeatable orbits every 16 days maintain constant viewing angles.
• Surface measurement and atmospheric correction are needed to conduct absolute calibration.

20 x 20 km
Libya-4 Reflectance Trending

* VIIRS reflectance normalized by its site-dependent BRDF
Libya-4 Reflectance Trending

The trending is based on Land PEATE C1.1 data.
Libya-4 Reflectance Trending

- Long-term EV reflectance trends can track the calibration stability.
- The drift is expected to significantly decrease in new L1B v1 product, using revised SD F-factor.
- The on-orbit response versus scan-angle (RVS) change is measured.
Improved Lunar BBR Trending

- VIIRS on-orbit spatial characterization can use EV scenes and Moon*.  
- The BBR offset between two bands is characterized as the centroid displacement between their lunar images.
- The impact of the lunar image rotation to BBR trending is eliminated.

Summary

• Remote objects such as the Moon and EV sites have been used to independently track the stability of S-NPP VIIRS RSB radiometric calibration.
• The trends are consistent for all RSB within the design requirement. Long-term drift of up to ±1% have been observed for some bands.
• Adjustment of SD calibrated gain coefficients based on the lunar data trending has been implemented. Adjustment of RVS based on the EV data trending is feasible.
• Spatial parameters such as BBR have been characterized.
• Unscheduled lunar observations are available and the data can be used to derive lunar F-factor and BBR.
• Conduct absolute calibration with the Moon or EV scenes remains a challenging topic.