Suomi NPP VIIRS Reflective Solar Band (RSB) Calibration Stability Assessments

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Outline

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  – About S-NPP VIIRS

• RSB calibration
  – RSB F/H factors
  – Lunar F-factor

• Results
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    • NOAA VIIRS SDR team RSBAutoCal vs. NASA VCST LUTs
  – Lunar F-factors
  – Solar Diffuser F-factor correction using lunar F-factors
  – Validation Example

• Summary
The Suomi National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS)

- Descriptions of S-NPP VIIRS
  - A whiskbroom scanning radiometer
  - Sun synchronous orbit
  - Field of view of 112.56°
  - Nominal altitude of 829 km
  - A large scan coverage of 3060 km
  - Equator crossing local time of approximately 1:30 pm
  - 22 spectral bands covering a spectral range of 412nm to 12 μm.

From ICVS webpage
http://www.star.nesdis.noaa.gov/icvs/index.php
From VIIRS Radiometric ATBD.
Introduction

• Spectral Responses of the VIIRS RSB
  – RSB cover a spectral range from 412nm to 2.25 µm.
  – There are 14 RSB with 3 image bands (I1-I3) and 11 moderate bands (M1-M11).
  – RSB band calibration is dependent on Solar Diffuser (SD) and Solar Diffuser Stability Monitor (SDSM) observations.
  – The required RSB calibration uncertainty is 2 percent.
    • Ocean Color group wants 0.2 percent level.
RSB Calibration: SD F-factor

- The RSB F-factor is just a ratio of computed sun radiance from SD over observed SD radiance from the VIIRS detectors.

\[
F = \frac{L_{\text{Sun Model}}}{L_{\text{Sun Observation}}} = \frac{\text{Computed } L_{\text{Sun}}}{\text{Observed } L_{\text{Sun}}}
\]

\[
F = \frac{\cos(\theta_{\text{inc}}) \cdot \left[ E_{\text{sun}} \cdot \tau_{\text{SDs}} \cdot BRDF(t) \right] \cdot RV_{SD}}{c_0 + c_1 \cdot d_{SD} + c_2 \cdot d_{SD}^2}
\]

- \(d_{SD}\): offset corrected SD DN, \(RV_{SD}\): response versus scan function at the angle of SD, \(C_{0,1,2}\): detectors and electronics temperature dependent calibration coefficients, \(\theta_{\text{inc}}\): solar incident angle to the SD screen, \(E_{\text{sun}}\): solar irradiance, \(\tau_{\text{SDs}}\): screen transmittance function, \(BRDF\): the BRDF function out of on-orbit yaw maneuvers, \(H(t)\): SD degradation over time

\[
BRDF(t) = H_{\text{Norm}}(t) \cdot BRDF(t_0)
\]

\[
H_{\text{Norm}}(t) \propto \frac{SD_{\text{Response}}(t)}{SUN_{\text{Response}}(t)}
\]
Lunar F-factor: as a Secondary calibration coefficient

The lunar F-factor is calculated as a ratio between the theoretical lunar irradiance and observed lunar irradiance [2]

\[
F(B, D) = \frac{I_{\text{GIRO}}(B)}{I_{\text{RDBL}}(B, D)} = \frac{I_{\text{GIRO}}(B)}{L_{\text{Avg}}(B, D) \cdot \pi \cdot R_{\text{moon}}^2 \cdot \frac{1 + \cos(\phi)}{2 \cdot \text{Dist}_{\text{Sat, Moon}}^2}}
\]

\[
L_{\text{Avg}} = \sum_{\text{Pixel}} L_{\text{pix}} / \text{Number of effective pixels}
\]

\(I_{\text{GIRO}}\): band dependent lunar irradiance value from the Global Space-based Inter-Calibration System (GSICS) Implementation of RObotic lunar observatory (GIRO v1.0.0) model (at [https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea](https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea)), \(\phi\): moon phase angle, \(L_{\text{Avg}}\): averaged radiance of the effective lunar pixels, \(R_{\text{moon}}\): moon radius, \(\text{Dist}_{\text{Sat, Moon}}\): distance between satellite and moon

• Different version of RSB LUTs are available
• SD H & F-factor LUTs
  – Aerospace (Fast track & RSBAutoCal)
  – NASA VCST
  – NOAA Ocean Color group
  – NOAA VIIRS RSBAutoCal & ICVS
• Lunar F-factor LUTs
  – NASA VCST (ROLO, GIRO)
  – NOAA Ocean Color (ROLO)
  – NOAA VIIRS (GIRO, Miller Turner)
• Lunar Band Ratio (LBR)
  – NOAA VIIRS
Results: RSBAutoCal vs. NASA VCST LUTs

• Aerospace RSB LUTs
  – Bi-weekly fast-track LUTs were operational from the start of mission to November 2015.
  – RSBAutoCal LUTs currently operational since November 2015.

• The operational F-factors are monitored by Integrated Calibration/Validation System (ICVS) F-factors

• NOAA VIIRS SDR team produces a new set of VIIRS lifetime RSBAutoCal LUTs for reprocessing.
  – Applying current operational LUTs from IDPS [1].
  – very similar to NOAA ICVS LUTs.

• NOAA Ocean Color group produces their own RSB LUTs.
  – With their own screen transmission, BRF, and sweet spot Defs.

• NASA VIIRS Calibration Support Team (VCST) produces several different version of RSB LUTs.
  – NASA VCST provided latest RSB LUTs to validate.
  – Lunar correction, time dependent RSR corrections, Out-of-band H-factor correction and normalization, Screen transmission table updates, SWIR SD deg.

Results: RSBAutoCal vs. NASA VCST LUTs

• NOAA VIIRS SDR team prepared a set of initial version of reprocessing LUTs.
  – Using RSBAutoCal from the start of S-NPP launch
  – 3236 RSBAutoCal LUTs are generated
  – RSBAutoCal LUTs provide
    • RSB F/H factors

• NASA VCST H/F LUTs
  – VCST provided H(v25) and F(v20) LUTs.
    • 22,864 data points for F-factors (11/8/2011 ~ 5/22/2016)
    • 2,258 data points for H-factors (11/8/2011~5/16/2016)
  – F-factors include middle detectors, HAM side A, HG states for dual-gain bands.
    • The middle detectors are detector 8 for M bands and detector 16 for I bands starting from detector index 1.
  – F-factor comparisons are performed in
    • HAM side A, HG state, Middle detectors.
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST F-factors in VIS and NIR bands
  - M1 (412nm) F-factors show ~3% differences.
  - M5 (672nm): 1%, I2/M7 (867nm): 0.4% → getting smaller.
  - VCST F-factors are larger than RSBAutoCal LUTs.
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST F-factors in SWIR bands
  - I3 and M10 differences are large (>0.5%) with NASA VCST LUTs.
  - VCST LUTs are below RSBAutoCal LUTs.
Results: RSBAutoCal vs. NASA VCST LUTs

- F-factor ratio plot in VIS and NIR bands
  - There are initial offsets and long-term drifts.
  - The differences are larger in short wavelength bands and getting smaller in longer wavelengths.
Results: RSBAutoCal vs. NASA VCST LUTs

- F-factor ratio plot in SWIR bands
  - H-factor (SD degradation) free bands show long-term drifts.
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal (dotted line) vs. VCST H-factor over plot
  - VCST H-factors are larger than RSBAutoCal.
  - The differences seem to be dependent on wavelengths.
  - There are initial state differences.
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST H-factor over plot
  - Thick lines are RSBAutoCal and narrow lines are VCST H-factors.
  - RSBAutoCal H-factors are set to be 1 in M8~M11, I3.
  - VCST has corrected for SD degradation.
Results: RSBAutoCal vs. NASA VCST LUTs

• H-factor ratio plot
  – H-factor differences are very similar to the F-factor differences.
  – F-factor differences are caused by the H-factors.
Results: Lunar F-factor comparisons

- The two F-factors need to be normalized (or scaled) properly because of the different solar irradiance models.
- The SD F-factors (solid lines) are normalized for better comparison and visualization in the figures.
- The best fitting scaling factors are calculated and applied for lunar F-factors (symbols).
- Lunar and SD F-factors are showing similar annual trends in starting from end of 2014 to current time.
- The first two lunar points are below the SD F-factors.
  - Potential errors in SD F-factors.
Results: Lunar F-factor comparisons

- The one-sigma root mean square (RMS) of the differences between SD and lunar F-factors are also shown in Table 1.
  - The SD F-factors are interpolated at the lunar collection time.
  - The short wavelength bands (M1~M4) are well within one percent level.
  - Other bands also show agreements less than 2 percent level.

Table 1. One-sigma RMS of the percentage differences between the SD and lunar F-factors.

<table>
<thead>
<tr>
<th>Band</th>
<th>RMS</th>
<th>Band</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.90</td>
<td>M8</td>
<td>1.70</td>
</tr>
<tr>
<td>M2</td>
<td>0.83</td>
<td>M9</td>
<td>1.59</td>
</tr>
<tr>
<td>M3</td>
<td>0.71</td>
<td>M10</td>
<td>1.46</td>
</tr>
<tr>
<td>M4</td>
<td>0.73</td>
<td>M11</td>
<td>1.33</td>
</tr>
<tr>
<td>M5</td>
<td>0.70</td>
<td>I1</td>
<td>0.75</td>
</tr>
<tr>
<td>M6</td>
<td>1.66</td>
<td>I2</td>
<td>0.90</td>
</tr>
<tr>
<td>M7</td>
<td>0.87</td>
<td>M3</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Results: SD F-factor Correction

- SD F-factor correction to Lunar F-factor
  - Lunar F-factors are fitted.
    \[ Y = a \cdot \log(x-b) + c \cdot x + d \]
  - SD F-factors are fitted to a quadratic polynomial.

1. Develop long-term lunar model

2. Correct the SD F-factor and validate with the Lunar F-factors

3. Normalize the corrected SD F-factor and compare with NASA’s latest RSB LUT.
Corrected F-factors are very similar to the NASA’s LUTs.

Our version of the corrected F-factors have more curvature than NASA LUTs in early lifetime.
Validation Example

- Radiance ratio of VIIRS data generated from IDPS and NASA Land SIPS is obtained for bands M1 through M7 near MOBY site.
- The ratio trends suggest the calibration differences among two products.
- All bands suggest agreement to within ±1% except M1 that shows almost ±2% difference mainly in 2014.
- It is to be noted that SIPS data are reprocessed data whereas IDPS is near real time data.
• RSBAutoCal vs. NASA VCST LUTs
  – Reprocessing LUTs are compared between
    • RSBAutoCal and NASA VCST.
  – There are some initial state differences with long-term drifts up to 3% in band M1 (1% initial and 2% long-term drift).
    • Because of the normalization of H factors.
    • The differences are band wavelength dependent.
  – The F-factor differences are directly caused by the H-factor differences.
  – NASA VCST has corrected for SD degradation in SWIR bands.
    • In the H-factor free bands (M8~M11 and I3).
Summary (2/2)

• The SD and lunar F-factors suggested potential differences.
  – Up to 3 % in band M1 and M2.
  – The SD F-factors can be scaled to match lunar F-factors.
  – The corrected F-factors needs to be validated by other evidences.
    • Deep convection clouds (DCC), pseudo-invariant calibration sites, or sensor cross calibration using simultaneous nadir observations (SNOs).
    • Before applying to operational production and reprocessing.

• The long-term lunar corrections models are developed and applied.
  – Producing very similar results to NASA VCST’s LUTs.

• NOAA VIIRS team will continue to monitor on-orbit calibration coefficients and vicarious observations.
  – Among different agencies (NASA, NOAA, and Aerospace)
  – And different working groups (Ocean Color, and NASA VCST)
Acknowlegdements

• Authors thank to EUMETSAT sharing the GIRO version 1.0.0 with NOAA VIIRS team.
  – Global Space-based Inter-Calibration System (GSICS) Implementation of RObotic lunar observatory (GIRO v1.0.0) model
• Backup slides
• Reflective Solar Band (RSB) F-factor Calculation

  – H: SD degradation factor.

\[
L_{EV} = \frac{F \cdot (c_0 + c_1 \cdot dn_{EV} + c_2 \cdot dn_{EV}^2)}{RVS_{EV}}
\]

\[
F = \frac{L_{Sun\_Model}}{L_{Sun\_Observation}} = \frac{\text{Computed} \_ L_{Sun}}{\text{Observed} \_ L_{Sun}}
\]

\[
F = \frac{\cos(\theta_{inc}) \cdot [E_{sun} \cdot \tau_{sds} \cdot BRDF(t)] \cdot RVS_{SD}}{c_0 + c_1 \cdot dn_{SD} + c_2 \cdot dn_{SD}^2}
\]

\[
BRDF(t) = H_{Norm}(t) \cdot BRDF(t_0)
\]

\[
H_{Norm}(t) = \frac{H(t)}{H(t_0)}
\]

\[
H(t) = \frac{dc_{SD} \cdot \tau_{SDSM}}{dc_{SUN} \cdot BRDF(t_0) \cdot \tau_{SD} \cdot \cos(\theta_{inc}) \cdot \Omega_{SDSM}}
\]

\[dn: \text{VIIRS bias removed response} \]
\[dc: \text{SDSM bias removed response} \]
Lunar F-factor Calculation from the Scheduled Lunar Collections

- Moon observation made through the Space View (SV)
- During the sector rotation, the VIIRS observations are set to be fixed High Gain (HG) mode.
- Spacecraft roll maneuvers are required.
- To avoid the complex oversampling factor calculation,
- Center 5 scans with full moon in the entire scan are used.
• Lunar Band Ratio (LBR)
  – Lunar data processing
    • Lunar area is properly trimmed.
    • Based on all the valid bias corrected lunar pixels.
    • Bias is calculated from the background value.
  – LBR is now calculated using M11 as a reference band

\[
LBR(B) = \frac{\sum dn_{\text{Pixel}}(B)}{\sum dn_{\text{Pixel}}(\text{Band M11})}
\]

• LBR is compared to the SD F-factor ratios
  – Using M11 as a reference band.
1-σ STD values are less than 1% in all bands.
• Zoomed in for M1~M4
  – LBR and F-factor ratios are very consistent except the first two points.

No evidence of long-term differences between SD and LBR

F–factor ratios and best fitting scaled LBR
• SD F-factor correction to Lunar F-factor
  – SD F-factor linear fit to blue solid line.
  – Linear transition between t1 and t2 with Quad fit and linear fit.
  – Linear lunar F-factor is calculated after t1.
  – Constant ratio was found from SD to lunar F-factor after t1.

\[
T_1 = 250 \quad T_2 = 250 + 2 \times 365 = 980
\]
Comparing Reprocessed IDPS Data with Land SIPS

• Previous slide suggests that 2014 exhibits the largest discrepancies between IDPS and NASA Land SIPS data.
• Few IDPS data over desert for 2014 were reprocessed using calibration coefficients generated at STAR.
• Radiance ratio trends between the reprocessed IDPS and Land SIPS data indicates much smaller differences between the two products.
• Blue bands (M1-M3) agrees mostly to within 0.5% and M4 through M8 agree to within 0.3%.