Status of VIIRS On-orbit Calibration and Performance

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1. NASA/GSFC, 2. NOAA/STAR, 3. Aerospace Corporation, and 4. Stellar Solutions and NOAA/JPSS
Outline

• Background
• VIIRS Operation and Calibration
• On-orbit Performance
• Lessons and Future Work
• Summary
Visible/Infrared Imager Radiometer Suite (VIIRS)

Description
- **Purpose:** Global observations of land, ocean, & atmosphere parameters at high temporal resolution (~ daily)
- **Predecessor Instruments:** AVHRR, OLS, SeaWiFS, MODIS
- **Approach:** Multi-spectral scanning radiometer (22 bands between 0.4 μm and 12.5 μm), 12-bit quantization
- **Swath Width:** 3000 km

Key Features
- MODIS-like on-board calibrators
  - SD, SDSM, and BB
- Moderate, imaging, and day/night bands
- Dual gains
- 3 focal plane assemblies
- ~ constant resolution along-scan
On-orbit Performance

• Spatial/Imaging
  – Well behaved

• Spectral
  – Telescope mirrors created with unqualified processes
  – Sensitive to UV exposure, may degrade to about 65% of at-launch throughput
  – Fully recovered in performance with characterization update

• Radiometric
  – Telescope degradation (above)
    • Will remain within sensor SNR performance specification
  – Day Night Band (DNB),
    • Stray light evident on highest gain scale for new moon ocean observations
On-orbit Performance Spatial/Imaging
VIIRS Geometry/Pointing Summary

- Overall VIIRS Geometry is good
- S/C Attitude control system and on-board GPS ephemeris performance currently meeting VIIRS needs
- SDR/GEO LUT update based on on-orbit control point residual analysis is in IDPS operations (Feb. 23)
- RTA and HAM Encoders are performing well

Wolfe et. al., Apr. 17, 2012
Control Point Matching (CPM) Program

Over 1200 globally distributed Ground Control Point (GCP) chips of Landsat red band (0.64 µm) 30 m nadir resolution

- VIIRS detector point spread function (PSF), including effects of aggregation and bow-tie deletion, is used to simulate VIIRS band I1 (0.64 µm) scenes from Ground Control Point (GCP) chips
- Cross-correlation is performed between the simulated and actual I1 scenes
- Shift the simulated scenes to get location of maximum cross correlation coefficients

Wolfe et. al., Apr. 17, 2012
Residuals for SDR/GEO LUT update

before update

Track Error - Day 347

Unfiltered
Filtered

Matching step size: 0.2 I-band pixels

Scan Error - Day 347

Unfiltered
Filtered

Matching step size: 0.05 I-band pixels

after update

Track Error - Day 347

Unfiltered
Filtered

Scan Error - Day 347

Unfiltered
Filtered

Nadir equivalent units; Cross-correlation > 0.7;
Outliers are filtered (removed) based on three iterations of a 3σ test

Wolfe et. al., Apr. 17, 2012
Geolocation Trending

Error after
LUT update
(2/23/2012, doy 54)

<table>
<thead>
<tr>
<th></th>
<th>Bias (m)</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track</td>
<td>-20</td>
<td>89</td>
</tr>
<tr>
<td>Scan</td>
<td>-9</td>
<td>64</td>
</tr>
</tbody>
</table>

41 days with average of 136 matchups/day (minus 11 outliers/day)

Wolfe et. al., Apr. 17, 2012
Geolocation Within-Scan Residuals

After Feb. 23 LUT update
Nadir equivalent units
Average mirror side offsets: ~1 m
Average north/south hemisphere offsets: ~8 m
41 days with 5555 total matchups (minus 430 outliers)
LUT refinement still needed
On-orbit Performance Spectral & Radiometry
Wavelength dependent degradation – consistent with damaged-surface mirror absorption profile (under UV exposure), confirmed with Aerospace witness sample measurements.
Results of NASA’s 4-parameter Exponential Model
Lunar observations are analyzed and detector responses are trended to track calibration stability; the degradation of the VisNIR bands derived from lunar calibration is consistent with that from SD/SDSM calibration.
ICVS Example: Monitoring VIIRS Blackbody Temperature

Two PRTs are out of the family in blackbody temperature

NPP/VIIRS Instrument Monitoring (Latest 2 Days)
BB_Temperature

NPP/VIIRS Instrument Monitoring (Long Term)
BB_Temperature

BB temperature change control

Cooler open
Imagery Examples
Golden Granule Set #1: Gulf of Alaska
npp_d20120216 thru npp_d20120218

Color composite of 3-NPP granules  Red = M5, Green = M10, Blue = M9

Legend
• Pink = opaque ice clouds
• Blue = thin cirrus clouds
• Yellow = lower-level water clouds
• Gray = higher-level water clouds

Open cell cumulus (red) present in cold air behind front in Gulf of Alaska. Closed cell stratocumulus clouds (turquoise) are indicative of warmer air.

(Keith Hutchison, Barbara Iisager, Robert Mahoney, NGAS)
VIIRS I Bands, Indonesia

D. Hilger, NOAA-STAR
//true_color/viirs
20120331.184858.npp.viirs.True-Color.CONUSNorthEastZoom.x.jpg

(This is the "Closest To" ARCHIVED image. NOTE: click "Latest" for latest image. Click thumb to view full-sized image.)
The Day/Night band (DNB) is a visible-wavelength band, centered at 0.7 µm, is highly sensitive to low levels of light, so that it behaves like a visible channel even at night when the moon is out. As seen in the image, the DNB clearly shows the location of towns and cities at night. Since 8 March 2012 was a full moon, clouds, snow and ice (particularly over Lake Winnipeg) are also visible. The brightest swirl, extending from north of Saskatoon, over Reindeer Lake and into northwestern Manitoba is the aurora borealis. (Courtesy of Steve Miller)
Early SST Image over Panama
VIIRS I-band-1 (375 m) IR image for 24 January 2012 @ ~1102 UTC over the eye of TC Funso. Note the sloping eyewall at this resolution. [Image courtesy of Dan Lindsey, NOAA/STAR]
**VIIRS Imagery Examples:**

Tropical Cyclone Giovanna  east of Madagascar  
13 February 2012 at 0947 UTC

*VIIRS channel I-5 (IR window, 11.45 μm)*  
*VIIRS channel I-1 (visible, 0.64 μm)*

*Courtesy of Dan Lindsey*
Acknowledgement

VIIRS SDR Calibration Team

• NOAA STAR
• Aerospace
• NASA
• University of Wisconsin
• Raytheon
• Northrop Grumman
• MIT Lincoln Laboratory
Back-up Materials
VIIRS On-board Calibrators

- MODIS Heritage SD, SDSM, BB
- Solar Diffuser
- A solar attenuation screen for SD
- Rotating Telescope Aft Optics and HAM
- Blackbody
- Solar Diffuser Stability Monitor
### VIIRS Spectral Bands and Data Products (EDRS)

#### VIIRS 22 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>
</tr>
</thead>
<tbody>
<tr>
<td>DNB</td>
<td>0.500 - 0.900</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>0.402 - 0.422</td>
<td>750</td>
<td>8</td>
<td>0.405 - 0.420</td>
<td>1000</td>
</tr>
<tr>
<td>M2</td>
<td>0.436 - 0.454</td>
<td>750</td>
<td>9</td>
<td>0.438 - 0.448</td>
<td>1000</td>
</tr>
<tr>
<td>M3</td>
<td>0.478 - 0.498</td>
<td>750</td>
<td>3, 10</td>
<td>0.459 - 0.479</td>
<td>500</td>
</tr>
<tr>
<td>M4</td>
<td>0.545 - 0.565</td>
<td>750</td>
<td>4, 12</td>
<td>0.545 - 0.565</td>
<td>500</td>
</tr>
<tr>
<td>M5</td>
<td>0.662 - 0.682</td>
<td>375</td>
<td>1</td>
<td>0.620 - 0.670</td>
<td>250</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>
</tr>
<tr>
<td>M7</td>
<td>0.846 - 0.885</td>
<td>750</td>
<td>16, 2</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>M10</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>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>M12</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>M13</td>
<td>3.973 - 4.128</td>
<td>750</td>
<td>21, 22</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>M17</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>

- **DNB**: Dual gain band
- **Similar MODIS bands**: Similar MODIS bands are available for these VIIRS bands.

#### VIIRS 20 EDRs

<table>
<thead>
<tr>
<th>Name of Product</th>
<th>Group</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagery *</td>
<td>Imagery</td>
<td>EDR</td>
</tr>
<tr>
<td>Precipitable Water</td>
<td>Atmosphere</td>
<td>EDR</td>
</tr>
<tr>
<td>Suspended Matter</td>
<td>Atmosphere</td>
<td>EDR</td>
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<tr>
<td>Aerosol Optical Thickness</td>
<td>Aerosol</td>
<td>EDR</td>
</tr>
<tr>
<td>Aerosol Particle Size</td>
<td>Aerosol</td>
<td>EDR</td>
</tr>
<tr>
<td>Cloud Base Height</td>
<td>Cloud</td>
<td>EDR</td>
</tr>
<tr>
<td>Cloud Cover/Layers</td>
<td>Cloud</td>
<td>EDR</td>
</tr>
<tr>
<td>Cloud Effective Particle Size</td>
<td>Cloud</td>
<td>EDR</td>
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<tr>
<td>Cloud Optical Thickness/Transmittance</td>
<td>Cloud</td>
<td>EDR</td>
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<tr>
<td>Cloud Top Height</td>
<td>Cloud</td>
<td>EDR</td>
</tr>
<tr>
<td>Cloud Top Pressure</td>
<td>Cloud</td>
<td>EDR</td>
</tr>
<tr>
<td>Cloud Top Temperature</td>
<td>Cloud</td>
<td>EDR</td>
</tr>
<tr>
<td>Active Fires</td>
<td>Land</td>
<td>Application</td>
</tr>
<tr>
<td>Albedo (Surface)</td>
<td>Land</td>
<td>EDR</td>
</tr>
<tr>
<td>Land Surface Temperature</td>
<td>Land</td>
<td>EDR</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>Land</td>
<td>EDR</td>
</tr>
<tr>
<td>Surface Type</td>
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<tr>
<td>Vegetation Index</td>
<td>Land</td>
<td>EDR</td>
</tr>
<tr>
<td>Sea Surface Temperature *</td>
<td>Ocean</td>
<td>EDR</td>
</tr>
<tr>
<td>Ocean Color and Chlorophyll</td>
<td>Ocean</td>
<td>EDR</td>
</tr>
<tr>
<td>Net Heat Flux</td>
<td>Ocean</td>
<td>EDR</td>
</tr>
<tr>
<td>Sea Ice Characterization</td>
<td>Snow and Ice</td>
<td>EDR</td>
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<tr>
<td>Ice Surface Temperature</td>
<td>Snow and Ice</td>
<td>EDR</td>
</tr>
<tr>
<td>Snow Cover and Depth</td>
<td>Snow and Ice</td>
<td>EDR</td>
</tr>
</tbody>
</table>

- **Dual gain band**: Dual gain band is available for these VIIRS bands.
- **Similar MODIS bands**: Similar MODIS bands are available for these VIIRS bands.
- *** Product is a Key Performance Parameter (KPP)**

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The VIIRS instrument provides 22 bands with a spectral range from 0.5 to 12.488 microns, covering both visible and infrared regions. The Nadir HSR (m) values range from 250 to 1000 meters, ensuring high spatial resolution for various applications. The EDRs (Enhanced Data Records) available for land, ocean, cloud, and snow provide critical information for environmental monitoring and research.
## On-orbit Detector Noise Characterization

- SNR was averaged over the scans using radiance at the SD view (sweet spot).
- Used corrected gains and measured F factor to take into account radiance degradation.
- RSB SNR is decreasing as expected.
- NEdT is very stable since cryo-cooler door opened.
- Current SNR/NEdT values for all VIIRS bands meet design specifications with margins.

<table>
<thead>
<tr>
<th>Band</th>
<th>Gain</th>
<th>SNR Spec</th>
<th>Pre-Launch (TV)</th>
<th>Post-Launch (SD)</th>
<th>Pre-Launch (TV)</th>
<th>Post-Launch (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SNR @ L_typ</td>
<td>SNR @ L_Typ</td>
<td>Margin to Spec</td>
<td>Margin to Spec</td>
</tr>
<tr>
<td>M1</td>
<td>LOW</td>
<td>316</td>
<td>1092</td>
<td>1045.78</td>
<td>246%</td>
<td>231%</td>
</tr>
<tr>
<td>M1</td>
<td>HIGH</td>
<td>352</td>
<td>616.8</td>
<td>588.90</td>
<td>75%</td>
<td>67%</td>
</tr>
<tr>
<td>M2</td>
<td>LOW</td>
<td>380</td>
<td>1118</td>
<td>1010.76</td>
<td>194%</td>
<td>166%</td>
</tr>
<tr>
<td>M2</td>
<td>HIGH</td>
<td>409</td>
<td>622.4</td>
<td>572.02</td>
<td>52%</td>
<td>40%</td>
</tr>
<tr>
<td>M4</td>
<td>LOW</td>
<td>315</td>
<td>963.2</td>
<td>856.51</td>
<td>206%</td>
<td>172%</td>
</tr>
<tr>
<td>M4</td>
<td>HIGH</td>
<td>362</td>
<td>581.1</td>
<td>534.96</td>
<td>61%</td>
<td>48%</td>
</tr>
<tr>
<td>M3</td>
<td>LOW</td>
<td>416</td>
<td>1111</td>
<td>988.54</td>
<td>167%</td>
<td>138%</td>
</tr>
<tr>
<td>M3</td>
<td>HIGH</td>
<td>414</td>
<td>690</td>
<td>628.46</td>
<td>67%</td>
<td>52%</td>
</tr>
<tr>
<td>I1</td>
<td>HIGH</td>
<td>119</td>
<td>240.7</td>
<td>214.07</td>
<td>102%</td>
<td>80%</td>
</tr>
<tr>
<td>I2</td>
<td>HIGH</td>
<td>150</td>
<td>304.1</td>
<td>264.01</td>
<td>103%</td>
<td>76%</td>
</tr>
<tr>
<td>M7</td>
<td>LOW</td>
<td>340</td>
<td>845.6</td>
<td>631.24</td>
<td>149%</td>
<td>86%</td>
</tr>
<tr>
<td>M7</td>
<td>HIGH</td>
<td>215</td>
<td>519.8</td>
<td>457.54</td>
<td>142%</td>
<td>113%</td>
</tr>
<tr>
<td>M5</td>
<td>LOW</td>
<td>360</td>
<td>827.9</td>
<td>631.26</td>
<td>130%</td>
<td>75%</td>
</tr>
<tr>
<td>M5</td>
<td>HIGH</td>
<td>242</td>
<td>366.6</td>
<td>336.13</td>
<td>51%</td>
<td>39%</td>
</tr>
<tr>
<td>M6</td>
<td>Single</td>
<td>199</td>
<td>415.2</td>
<td>368.40</td>
<td>109%</td>
<td>85%</td>
</tr>
<tr>
<td>M8</td>
<td>Single</td>
<td>74</td>
<td>273</td>
<td>221</td>
<td>269%</td>
<td>198%</td>
</tr>
<tr>
<td>M9</td>
<td>Single</td>
<td>83</td>
<td>253</td>
<td>227</td>
<td>205%</td>
<td>173%</td>
</tr>
<tr>
<td>M10</td>
<td>Single</td>
<td>342</td>
<td>714</td>
<td>586</td>
<td>109%</td>
<td>71%</td>
</tr>
<tr>
<td>M11</td>
<td>Single</td>
<td>10</td>
<td>25</td>
<td>22</td>
<td>150%</td>
<td>118%</td>
</tr>
<tr>
<td>I3</td>
<td>Single</td>
<td>6</td>
<td>172</td>
<td>149</td>
<td>2767%</td>
<td>2391%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>Gain</th>
<th>NEdT Spec</th>
<th>NEdT @ L_typ</th>
<th>NEdT @ L_Typ</th>
<th>Margin to Spec</th>
<th>Margin to Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>M12</td>
<td>Single</td>
<td>0.396</td>
<td>0.13</td>
<td>0.13</td>
<td>67%</td>
<td>67%</td>
</tr>
<tr>
<td>M13</td>
<td>High</td>
<td>0.107</td>
<td>0.04</td>
<td>0.04</td>
<td>63%</td>
<td>63%</td>
</tr>
<tr>
<td>M14</td>
<td>Single</td>
<td>0.091</td>
<td>0.06</td>
<td>0.05</td>
<td>34%</td>
<td>45%</td>
</tr>
<tr>
<td>M15</td>
<td>Single</td>
<td>0.07</td>
<td>0.03</td>
<td>0.03</td>
<td>57%</td>
<td>57%</td>
</tr>
<tr>
<td>M16</td>
<td>Single</td>
<td>0.072</td>
<td>0.04</td>
<td>0.03</td>
<td>44%</td>
<td>58%</td>
</tr>
<tr>
<td>I4</td>
<td>Single</td>
<td>2.5</td>
<td>0.4</td>
<td>0.4</td>
<td>84%</td>
<td>84%</td>
</tr>
<tr>
<td>I5</td>
<td>Single</td>
<td>1.5</td>
<td>0.4</td>
<td>0.4</td>
<td>73%</td>
<td>73%</td>
</tr>
</tbody>
</table>
Radiometry in RSB and TEB

- Both radiometers report radiance values in comparison to on-board radiance standards
- RSB radiance standard is sun reflected off the solar diffuser
- TEB radiance standard is radiance from full aperture blackbody (referenced to SI temperature standard) and cold space
- DNB low radiance signal from “dark ocean” for dark response
  - Terminator crossings allow for reference/overlap of gain levels
Reflective Solar Bands Calibration – SD/SDSM

RSB Calibration: F and H Factors

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

\[
F = \frac{L_{Sun\_Comp}}{L_{Sun\_Meas}} = \frac{\text{Computed } L_{Sun}}{\text{Measured } L_{Sun}}
\]

\[
F = \frac{\Phi_{Sun}}{4\pi \cdot d^2_{Sun}} \cdot \tau_{SDS} \cdot \cos(\theta_{inc}) \cdot BRDF(t) \cdot RVS
\]

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

\[
H_{Nom}(t) = H(t) / H(t_0)
\]

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

The \(dn\) and \(dc\) are VIIRS and SDSM detector responses.
Other parameters are provided by SDR LUTs and the OBC data file.
Thermal Emissive Bands Calibration – BB

**TEB Calibration: F Factor**

\[
F(B, IS, D, H, S) = \frac{\Delta L_{\text{det_computed}}}{\Delta L_{\text{det_retrieved}}}
\]

\[
\Delta L_{\text{det_computed}}(B) = RVS_{BB}(B)\Delta L_{ap}(B) + \Delta L_{\text{bckgr}}(B)
\]

\[
\Delta L_{\text{det_retrieved}}(B) = \sum_{i=0}^{2} c_i \, d_n^i_{BB}
\]

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

\[
\Delta L_{\text{bckgr}}(B) = \frac{(RVS_{BB}(B) - RVS_{SV}(B))}{\rho_{RTA}(B)} \left[ (1 - \rho_{RTA}(B)) L_{RTA} - L_{HAM} \right]
\]

\[
L_i = \int_{\lambda_{\min}}^{\lambda_{\max}} RSR(\lambda, B, IS, D, H) L(\lambda, T_i) d\lambda
\]

\[
L_i \equiv L(T_i, B, IS, D, H) = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} RSR(\lambda, B, IS, D, H) d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} RSR(\lambda, B, IS, D, H) d\lambda}
\]

*\(L_i\) is RSR weighted radiance from Planck function at temperature \(T_i\)*.
VIRIS Lunar Calibration

- Lunar observations are analyzed to track VIIRS VIS/NIR calibration stability
- Corrections for lunar view geometry differences (ROLO model, Stone/USGS)

Examples of band I1 lunar images from 6 consecutive scans (Jan 4, 2012)

- 4 lunar calibration scheduled; 3 successfully implemented
  - Jan 4 (one orbit, limited bands)
  - Feb 3 (2 orbits, nearly all VIR/NIR/SWIR bands)
  - Mar 3 (missed)
  - Apr 2 (1 orbit with sector rotation, all bands)

Lunar Cal agrees with SD Cal
• The F-factors (detector responses) are stable since the cold FPA temperatures reached ~80K at orbit 1200.
  • Slight decrease in I5 observed.
• At BB temperature of 292K F-factor variations are typically within 0.1%.
• During BB warm-up and cool-down (near orbits 1449 and 1494) larger variations in the F-factors up to 0.5% were detected.
BB Warm-up and Cool-down for TEB Calibration

Periodic BB WUCD to verify TEB calibration coefficients (e.g. nonlinearity) and to characterize NEdT at different temperatures

Frequency of WUCD and its impact on operational calibration to be analyzed

Black solid and dashed lines are measured values with HAM side A and B. Red line is generated using predicted values based on a single operational BB temperature at 293K (green triangle).
TEB RVS Verification Using Pitch Maneuver Data

Pitch started at 18:15:34
Pitch ended at 18:59:19

RVS (Pitch) – RVS (LUT) (%) - HAM-A

<table>
<thead>
<tr>
<th>RVS Diff (%)</th>
<th>M12</th>
<th>M13</th>
<th>M14</th>
<th>M15</th>
<th>M16</th>
<th>I4</th>
<th>I5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.0</td>
<td>0.3</td>
<td>-0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.1</td>
<td>0.5</td>
<td>-0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Similar Results for HAM-B
On-orbit Changes in Detector Responses (VIS/NIR/SWIR)

F – factor (1/gain)

M7/I2 (0.85\(\mu\)m), M6 (0.75\(\mu\)m), M5 (0.67\(\mu\)m), I1 (0.64\(\mu\)m), M4 (0.55\(\mu\)m)
M8 (1.24\(\mu\)m), M9 (1.38\(\mu\)m), M10/I3 (1.61\(\mu\)m), M11 (2.24\(\mu\)m)

Larger than expected degradation in NIR/SWIR spectral bands
On-orbit Changes in Detector Responses (VIS/NIR/SWIR)
On-orbit SNR Characterization (VIS/NIR/SWIR)

SNR will continue in spec (enough margin based on actual performance)
Dynamic range and nonlinearity also meet design requirements
On-orbit Changes in SD BRDF

SDSM – tracking SD on-orbit degradation
H - factor

Sun view

SD view

PL LUT

Yaw maneuvers
**SDSM screen transmission updated based on yaw maneuver data**

- H factor variability significantly reduced (especially for high numbered detectors)
- Updated screen transmission better captures fine structure of vignetting function

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**Current LUT**

**Updated \( \tau_{SDSM} \)**

**Yaw maneuver**