An Overview of NPP VIIRS Pre-launch and On-orbit Calibration and Characterization

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and

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VIIRS Instrument

Pre-launch Calibration and Test Data Analysis

Post-launch Activities

Summary

NPP VIIRS pre-launch calibration and characterization effort included contributions from NASA calibration team, Aerospace, MIT/LL, UW, Raytheon, and NGC; VIIRS post-launch calibration and characterization will be performed by the SDR team managed by NOAA STAR with contributions from different groups.

This presentation focuses on activities supported by the NASA's team
Visible Infrared Imaging Radiometer Suite

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 µm), 12-bit quantization
• **Swath Width:** 3000 km

Status

• Successfully completed comprehensive TV performance testing at instrument and s/c levels
• Performance is nominal
• NPP PSR completed (Aug 17-18)
• Ready for October 25, 2011 launch
### VIIRS Bands and Products

**VIIRS 22 Bands:**
16 M-Band, 5 I-Band and 1 DNB

<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 or 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 or 12</td>
<td>0.545 - 0.565</td>
<td>500</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>
</tr>
<tr>
<td>M5</td>
<td>0.662 - 0.682</td>
<td>750</td>
<td>13 or 14</td>
<td>0.662 - 0.672</td>
<td>1000</td>
</tr>
<tr>
<td>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>I2</td>
<td>0.846 - 0.885</td>
<td>375</td>
<td>2</td>
<td>0.841 - 0.876</td>
<td>250</td>
</tr>
<tr>
<td>M7</td>
<td>0.846 - 0.885</td>
<td>750</td>
<td>16 or 2</td>
<td>0.862 - 0.877</td>
<td>1000</td>
</tr>
<tr>
<td>M8</td>
<td>1.230 - 1.250</td>
<td>750</td>
<td>5</td>
<td>SAME</td>
<td>500</td>
</tr>
<tr>
<td>M9</td>
<td>1.371 - 1.386</td>
<td>750</td>
<td>26</td>
<td>1.360 - 1.390</td>
<td>1000</td>
</tr>
<tr>
<td>I3</td>
<td>1.580 - 1.640</td>
<td>375</td>
<td>6</td>
<td>1.628 - 1.652</td>
<td>500</td>
</tr>
<tr>
<td>M10</td>
<td>1.580 - 1.640</td>
<td>750</td>
<td>6</td>
<td>1.628 - 1.652</td>
<td>500</td>
</tr>
<tr>
<td>M11</td>
<td>2.225 - 2.275</td>
<td>750</td>
<td>7</td>
<td>2.105 - 2.155</td>
<td>500</td>
</tr>
<tr>
<td>I4</td>
<td>3.550 - 3.930</td>
<td>375</td>
<td>20</td>
<td>3.660 - 3.840</td>
<td>1000</td>
</tr>
<tr>
<td>M12</td>
<td>3.660 - 3.840</td>
<td>750</td>
<td>20</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M13</td>
<td>3.973 - 4.128</td>
<td>750</td>
<td>21 or 22</td>
<td>3.929 - 3.989</td>
<td>1000</td>
</tr>
<tr>
<td>M14</td>
<td>8.400 - 8.700</td>
<td>750</td>
<td>29</td>
<td>SAME</td>
<td>1000</td>
</tr>
<tr>
<td>M15</td>
<td>10.263 - 11.263</td>
<td>750</td>
<td>31</td>
<td>10.780 - 11.280</td>
<td>1000</td>
</tr>
<tr>
<td>I5</td>
<td>10.500 - 12.400</td>
<td>375</td>
<td>31 or 32</td>
<td>10.780 - 11.280</td>
<td>1000</td>
</tr>
<tr>
<td>M16</td>
<td>11.538 - 12.488</td>
<td>750</td>
<td>32</td>
<td>11.770 - 12.270</td>
<td>1000</td>
</tr>
</tbody>
</table>

| Dual gain band | Similar MODIS bands |

### VIIRS 24 EDRs
Land, Ocean, Cloud, Snow

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

* Product is a Key Performance Parameter (KPP)
Pre-launch Calibration and Characterization

• NPP VIIRS (F1) testing program has completed all planned testing phases
  – Ambient Testing: 06/20/07 – 11/30/07
  – Sensor TVAC Testing: 05/03/09 – 08/23/09
  – Spacecraft TVAC Testing: 03/10/11 – 04/25/11

• NPP VIIRS pre-launch testing has provided necessary test data to calibrate and characterize sensor performance, and to establish a baseline for sensor on-orbit operations
  – Radiometric: gains, dynamic range, gain transition, linearity, SNR/NEdT, uniformity, uncertainty, polarization sensitivity, RVS, …
  – Spectral: RSR or SRF (in-band and out-of-band), spectral band-to-band crosstalk, …
  – Spatial: LSF/MTF, FOV, BBR, …
Pre-launch Calibration and Characterization

- NASA team has performed extensive test data analyses for VIIRS F1 performance evaluation and requirement verification
  - Participated key technical meetings, reviews, working group activities
  - Supported on-site test data analysis during sensor and spacecraft TVAC calibration and characterization
  - Produced 296 data analysis reports and 191 technical memos:
    - EDU Test: 42 reports and 88 memos
    - F1 Sensor-level Test: 217 reports and 96 memos
    - F1 Spacecraft-level Test: 37 reports and 7 memos
- All performance waivers have been evaluated by NGST and reviewed by NASA team
  - Most waivers have small to negligible EDR performance impacts
  - Algorithm revisions and/or changes to Cal/Val tasks were added to support waivers
VIIRS F1 Performance Summary

- **Radiometric**
  - VIIRS meets all Requirements for Signal to Noise Ratio, Dynamic Range, Gain Transitions, Linearity, Uncertainty, Stability and Polarization
  - Minor Variances for: M1, I2 and M8 not reaching specified maximum radiance, but no impact is expected from these non-compliances; detector uniformity with potential for striping (plan for post-launch fix, if needed)

- **Spectral**
  - Spectral Band Center, Spectral Bandwidth, Extended Bandwidth: Minor non-compliances are well characterized, no impact is expected.
  - Integrated Out-of-Band and Optical Crosstalk between VisNIR bands is extensively analyzed, and a mitigation plan is in place. On-orbit cal/val activities will assess efficiency of this mitigation plan.

- **Spatial**
  - IFOV, DFOV, HSR and BBR: Overall, performance meets Spec, with some detectors marginally out-of-Spec, but no impact is expected.
  - Band-to-Band Registration: Meet requirements, except for few detector pairs. On-orbit jitter might degrade BBR performance, but impact on product quality should be small.
<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
<th>Results and Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spikes</td>
<td>Large sample spikes in the sensor signal observed for few bands during operational mode, only on A-side (Redundant) Electronics</td>
<td>No impact. This issue was never observed on Primary Electronics (B-Side). A plan to correct for this issue is in place.</td>
</tr>
<tr>
<td>Vignetting</td>
<td>Observed at FU1 TV Cold functional plateau, but goes away when sensor temperature warms up closer to TV Cold performance. Vignetting was not noticeable at any Performance plateau (Cold, Nominal, Hot).</td>
<td>No impact. Issue is not expected for on-orbit sensor temperatures. Program has provided STOP model #6 that includes vignetting component. This model can be used on orbit for any anomaly simulation and mitigation/correction approach if needed.</td>
</tr>
<tr>
<td>Gain bit crosstalk effect</td>
<td>Some bands calibration results are showing dependency on other bands gain status (High Gain vs Low Gain).</td>
<td>Small impact. This error will be considered in the final calibration error budget and impact assessments.</td>
</tr>
<tr>
<td>M1 and M11 tail and side lobe artifacts</td>
<td>LSF measurements have revealed side lobe features for M11 and M1. M11 side lobe might be attributed to field stop reflections, and M1 side lobe might be contributed to optical crosstalk.</td>
<td>Small impact. Need further modeling, to determine impact since on orbit illumination will have broad spectrum. It is not known how this side lobe is going to be varying on orbit (Ghosting shift if coming from mechanical part).</td>
</tr>
<tr>
<td>Gain transition noise</td>
<td>Increase of radiance non linearity and noise for dual gain bands at approximately 10% below Lmax.</td>
<td>No impact. Analysis done and have shown low impact on some EDRs. On-orbit scenes will be analyzed for impact assessment.</td>
</tr>
</tbody>
</table>

Valuable lessons for future JPSS and DWSS VIIRS Design and Test
VIIRS Polarization Performance

- The polarization testing was based on the SIS100 and a polarizer sheet.
- A series tests led to high quality polarization measurements with good repeatability.
- The derived polarization factors satisfy design specifications for sensitivity and uncertainty.
- The derived polarization factors vary strongly with detector and the variability depends on the scan angle.
VIIRS Response Vs. Scan (RVS)  
Pre-Launch Performance

- **M9 was impacted by water vapor**
  
  - **RSB Uncertainty:**  
    - Spec = 0.3%
  
  - **TEB Uncertainty:**  
    - Spec = 0.2%

Band averaged RVS  
Red = HAM A  
Blue = HAM B

**Fitting Uncer (%)**
VIIRS F1 TV RSRs (SpMA)
SpMA RSRs vs SIRCUS RSRs (VisNIR bands only)
On-orbit Calibration and Characterization

• VIIRS post-launch calibration and characterization will be performed by the SDR team managed by NOAA STAR with contributions from
  – NOAA, NASA, Aerospace, Raytheon, UW, MIT/LL, and NGC

• Calibration strategies and activities have been developed via an intensive government-contractor team collaboration, heavily based on MODIS lessons and experience; 54 tasks in 6 categories
  – Functional Performance and Format Evaluation (FPF 1-7)
  – Calibration System Evaluation (CSE 1-6)
  – Image Quality Evaluation (IMG 1-4)
  – Radiometric Evaluation (RAD 1-25)
  – Geometric Evaluation (GEO 1-7)
  – Performance and Telemetry Trending (PTT 1-5)

• NASA team will support all phases of NPP VIIRS post-launch calibration and characterization
  – EOC, ICV, and LTM
VIIRS Cal/Val Activities by Phases

- Pre-Launch Phase
  - Sensor Characterization
  - Performance & Telemetry Trending Baseline
  - SDR Cal/Val Plan Development
  - SDR Algorithm Initialization & Update Capability
  - Cal/Val Tool Development

- Early Orbit Checkout (EOC) Phase
  - Functional Checkout
  - Data Inventory
  - RDR/SDR Verification

- Intensive Calibration & Validation (ICV) Phase
  - Radiance Match-Ups
  - Geolocation
  - Performance & Telemetry Trending
  - SDR Algorithm Tuning
  - SDR Parameter & LUT Updates

- Long Term Monitoring (LTM) Phase
  - Radiance Match-Ups
  - Geolocation
  - Performance & Telemetry Trending
  - SDR Parameter & LUT Updates
On-board Calibrators

- SD and SDSM
- BB

**Lunar Observations:** whenever a -55° phase Moon is visible to VIIRS (assuming 10/25/11 launch, first opportunity will be day L+71)

**S/C maneuvers**

- All planned VIIRS maneuvers have been approved by NPP Project
- Lunar rolls for degradation trending and reflective solar bands stability monitoring
- Pitch-up deep space view for thermal emissive bands response vs. scan angle (RVS)
- Yaws for SD and SD stability monitor attenuation screen characterization

Tools have been developed and tested to support NPP VIIRS on-orbit Cal/Val planning, data analysis, and performance monitoring
On-orbit Calibration and Characterization

MODIS Instrument Temperatures

- **T-MODIS**
  - On-orbit Degradation
    - Wavelength dependent SD degradation

Blackbody Warm-up and Cool-down

- **T-MODIS**
- **A-MODIS**

On-orbit Lunar Calibration

- SeaWiFS Lunar Calibrations
  - Normalized Radiance
  - Days Since First Image

- Bands: 1, 2, 3, 4, 5, 6, 7, 8
Summary

• NPP VIIRS test program at the instrument and observatory level is complete and has provided an extensive amount of high quality data to enable the assessment of sensor performance
  – VIIRS performance exceeds requirements with only a few non-compliances
  – Non-compliances have been reviewed and impacts have been assessed.

• On-orbit calibration and characterization plan
  – In Integrated Government Team (IGT) has developed a comprehensive cal/val plan for SDR products to ensure high quality measurements.
  – Task leads and support were identified to develop and verify approx. fifty (50) on-orbit cal/val tools. We expect full readiness to support NPP Launch.

• Launch readiness testing/rehearsal
  – VIIRS cal/val team performed 2 rehearsals to exercise on-orbit cal/val tools and processes (July 18-22, August 22-27, 2011).
  – Both rehearsal phases were successful, and issues identified are being addressed to make sure all components critical to VIIRS cal/val are ready and fully verified.
Backup
VIIRS F1 Performance Status

Based on sensor level TV testing

### Reflective Solar Band (RSB) Performance

<table>
<thead>
<tr>
<th>Performance</th>
<th>Requirement Verification</th>
<th>Expected Risk to EDRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR</td>
<td>All RSB bands meet SNR specifications with margin</td>
<td>Low</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>M1 and I2 slightly not compliant</td>
<td>Low</td>
</tr>
<tr>
<td>Gain Transition</td>
<td>Only M1 is not compliant. Margin is about -10% of Lmax.</td>
<td>Low</td>
</tr>
<tr>
<td>Linearity</td>
<td>All RSB bands meet Linearity specification with margin</td>
<td>Low</td>
</tr>
<tr>
<td>Uniformity</td>
<td>1 NeDL requirement not met for some cases</td>
<td>Medium</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>All bands are meeting specification</td>
<td>Low</td>
</tr>
<tr>
<td>Stability</td>
<td>All RSB bands meet Stability requirements with margin</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Thermal Emissive Band (TEB) Performance

<table>
<thead>
<tr>
<th>Performance</th>
<th>Requirement Verification</th>
<th>Expected Risk to EDRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NeD T</td>
<td>All TEB bands meet NeD T specifications with margin</td>
<td>Low</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>All TEB bands compliant for Lmax.</td>
<td>Low</td>
</tr>
<tr>
<td>Gain Transition</td>
<td>Only M13 is slightly not compliant.</td>
<td>Low</td>
</tr>
<tr>
<td>Linearity</td>
<td>All TEB bands meet Linearity specification with margin</td>
<td>Low</td>
</tr>
<tr>
<td>Uniformity</td>
<td>All TEB bands meeting uniformity requirement (1 NeDL)</td>
<td>Low</td>
</tr>
<tr>
<td>Absolute Calibration</td>
<td>All TEB bands are meeting specification with margins</td>
<td>Low</td>
</tr>
<tr>
<td>Stability</td>
<td>All TEB bands meet Stability requirements with margin</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Spatial Performance

<table>
<thead>
<tr>
<th>Performance</th>
<th>Requirement Verification</th>
<th>Expected Risk to EDRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Spread Function (LSF)</td>
<td>Scan DFOV is compliant for majority of M-bands and I-bands.</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Track IFOV is compliant for all M-Bands and I-bands, Except M12 Det #1.</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Scan MTF is compliant for majority of M-bands</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Track MTF is compliant for all M-Bands.</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Scan HSR is compliant for majority of I-bands</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Track HSR iscompliant for all I-bands</td>
<td>Low</td>
</tr>
<tr>
<td>Band to Band Registration (BBR)</td>
<td>BBR is compliant for all band pairs, except few cases.</td>
<td>Low</td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>Pointing stability is compliant, except daily stability in track direction</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Spectral RSR Performance

<table>
<thead>
<tr>
<th>Performance</th>
<th>Requirement Verification</th>
<th>Expected Risk to EDRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Band Center</td>
<td>Only M4 and M16 are slightly not meeting specification</td>
<td>Low</td>
</tr>
<tr>
<td>Spectral Bandwidth</td>
<td>Only M2, M8 and M14 slightly not compliant. M16A Detectors #5-7 also slightly not compliant</td>
<td>Low</td>
</tr>
<tr>
<td>Extended Bandwidth</td>
<td>Only I5 is slightly not compliant for the upper 1% limit</td>
<td>Low</td>
</tr>
<tr>
<td>Integrated Out-Of-Band</td>
<td>Many bands are slightly not compliant. However, OOB is well characterized</td>
<td>Medium-High</td>
</tr>
<tr>
<td>Band to Band Crosstalk</td>
<td>Many bands are not compliant. However, crosstalk characterization will support on-orbit mitigation.</td>
<td>Medium-High</td>
</tr>
</tbody>
</table>

- VIIRS F1 test program is complete and has provided good test data to assess sensor performance.
- Sensor performance exceeds requirements in most cases, and non compliances were addressed in waiver packages and impact assessments.
- NASA performance assessments are beginning of life (BOL). Modeling of EOL performances are available in Raytheon Performance Verification Reports (PVRs).
- Government team finalized VIIRS F1 Performance assessments to generate on-orbit LUTs for SDR algorithm.