STAR VIIRS SDR CalVal Overview

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April 5, 2012
Cao (management lead) and De Luccia (technical lead) coordinate and execute the 58 VIIRS SDR cal/val tasks defined in the OPSCON.

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RAD-7: SDR Comparison with Model

Objective:
To perform a qualitative evaluation of top-of-atmosphere (TOA) radiances from select scenes.

Methods and Tools:
Use VIIRS SDR, ECMWF inputs and CRTM

Results and Recommendations:
Measurements and CRTM simulations for the VIIRS thermal bands agree well. CRTM is powerful for determining the root cause of M12 striping during daytime.

The VIIRS measurements and the CRTM simulations on M6 and M7 are needed.
The STAR team applied the CRTM to simulate the VIIRS SDR data. It is found that the M12 striping reported by the SST EDR team is caused by the difference in VIIRS azimuth angles among detectors.
Detailed CRTM Calculation for the striping (RAD-7)

<table>
<thead>
<tr>
<th>Detector #</th>
<th>( \tau(\theta_{sat}) )</th>
<th>( \phi_{sat} )</th>
<th>BRDF</th>
<th>A</th>
<th>B</th>
<th>R</th>
<th>Brightness temperature</th>
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<td>80.368</td>
<td>0.04253</td>
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<td>0.10717</td>
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<td>0.12812</td>
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</tbody>
</table>

\[
R = \tau(\theta_{sat})[\varepsilon B(T_s) + (1 - \varepsilon)R_{atm_d}] + R_{atm_u} + F_0 \cos(\theta_{sun}) \tau(\theta_{sun})BRDF(\theta_{sun}, \theta_{sat}, \phi_{sun} - \phi_{sat}) \tau(\theta_{sat})
\]
RAD-8: SDR Comparison with AVHRR

Objective:
To compare VIIRS retrieved TOA radiance with AVHRR retrieved TOA radiance.

Methods and Tools:
Use SNO orbit prediction, VIIRS SDR, and AVHRR 1b readers and data, statistical tools.

Results and Recommendations:
VIIRS and AVHRR TEBs agree (~ 0.3 K). VIIRS and AVHRR RSB agree with the slope. Large bias in RSB needs to be further investigated.
VIIRS and AVHRR SNO Comparison (RAD-8)

- **Bias**=(VIIRS-AVHRR)*100%/VIIRS
- **Spectrally Induced Bias at Libya**
  - Ch1: 9.69% +/- 0.306%
  - Ch2: 15.14% +/- 2.37%
  - The actual bias for AVHRR Ch1 is 8.9% and for Ch2 is 13.7%.
  - Large bias for channel 1 could be due to calibration issue whereas for channel 2, it could be due to water vapor absorption.

Note: the spectrally induced bias for channel 2 (given above) was calculated at NOAA-Libya site whereas this SNOx comparison is performed at different location in Africa. Thus water vapor variability might be much different.
RAD-9: SDR Comparison with MODIS

Objective:
To compare VIIRS retrieved TOA radiance with MODIS retrieved TOA radiance.

Methods and Tools:
Use SNO orbit prediction, VIIRS SDR, and MODIS readers, and analysis tools.

Results and Recommendations:
VIIRS and MODIS TEBs agree well by considering the difference in spectral response between VIIRS and MODIS. VIIRS and MODIS RSB agree, too.

Further comparisons are necessary for monitoring the VIIRS RSB degradation.
SNO Prediction and Analysis

Based on information from the NOAA/STAR/NCC SNO (simultaneous nadir overpass) prediction website, https://cs.star.nesdis.noaa.gov/NCC/SNOPredictions, included all SNO datasets acquired by NPP VIIRS and by MODIS from both Aqua and Terra between February 14 and March 20, 2012.

For each SNO, averaged valid VIIRS and MODIS pixels from a 12-km by 12-km area selected at the intersection of the satellite ground tracks (16×16 750-m pixels for VIIRS and 12×12 1-km pixels for MODIS): typically provides closer spatial coincidence than temporal one (still within ~1-2 min.)

The NPP – Aqua SNOs occurred over snow-covered Antarctica (some at the Dome C site), providing bright surfaces in the VisNIR bands, while the NPP – Terra SNOs occurred over northern Siberia, Scandinavia, and ocean (both dark and bright scenes).

### Table of predicted SNOs for the next 14.0 days since TLE Epoch: 2/11/2012

<table>
<thead>
<tr>
<th>Index</th>
<th>Date (AQUA)</th>
<th>Time (AQUA)</th>
<th>AQUA Lat,Lon</th>
<th>Date (NPP)</th>
<th>Time (NPP)</th>
<th>NPP Lat,Lon</th>
<th>Distance(km)</th>
<th>Time Diff (sec)</th>
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<tbody>
<tr>
<td>1</td>
<td>02/12/2012</td>
<td>14:07:39</td>
<td>68.18,-167.05</td>
<td>02/12/2012</td>
<td>14:06:26</td>
<td>68.31,-168.01</td>
<td>42.15</td>
<td>73</td>
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<td>2</td>
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<td>02/12/2012</td>
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<tr>
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<tr>
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<td>6</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
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<td>73</td>
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<tr>
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<td>02/23/2012</td>
<td>06:21:41</td>
<td>-76.37,144.76</td>
<td>02/23/2012</td>
<td>06:20:44</td>
<td>-76.37,144.78</td>
<td>0.54</td>
<td>57</td>
</tr>
</tbody>
</table>
VIIRS vs. MODIS SNO Comparisons (RAD 9)

- Compared TOA (top-of-atmosphere) reflectance measured by VIIRS and MODIS at the SNO sites (accounts for solar zenith angle differences)
- Because of differences between spectral responses of VIIRS and MODIS bands, reflectance data do not match exactly (1:1 line)
- The effect of the spectral response difference on the measured reflectance (spectral bias) was recently estimated using satellite hyperspectral data collected over the Antarctic Dome C site (Cao et al., submitted for publication)
- Ratios of the VIIRS band M7 and MODIS band 2 data agree very well with the prediction from that study (Spectral Bias line)
- This comparison confirms accuracy of the current radiometric calibration for VIIRS band M7, which is the band the most affected by the mirror degradation anomaly
- Other VIIRS bands also display high correlation with MODIS counterparts (next slide): estimates of spectral biases for these bands are ongoing
- While Terra provides so far most of the low reflectance data, a small bias between Aqua and Terra data can be seen (will investigate)
Antarctic Dome C Observations (RAD 10)

• The Antarctic Dome C site is located in the High Polar Plateau Region at 75°06'S, 123°21'E with mean elevation of 3.2 km above sea level.

• The site has the following characteristics that make it very suitable for radiometric calibration and validation of satellite sensors:
  o Surface is flat and covered with uniformly distributed, permanent snow.
  o Temperatures are extremely cold and stable, except for seasonal variability.
  o Skies are clear most of the time, with more than 75% of days being cloud free.
  o Atmosphere above the site has low water vapor and aerosol loading, thus atmospheric effects are small.

• TOA (top-of-atmosphere) reflectance measured by VIIRS at the Dome C site was averaged over a 48×48-pixel area to reduce effects of radiometric response non-uniformity (striping).

• To mitigate BRDF effects, band ratios were calculated between the bands M1, M2, M4 to M7, and the band M3.
Data points with solar zenith angle larger than 75° or satellite zenith angle larger than 15° were excluded from the analysis.
VIIRS vs. MODIS SNO Comparisons (cont.)

M1 vs. B8

$V = 1.0551 M$

$R^2 = 0.9987$

M2 vs. B9

$V = 1.0591 M$

$R^2 = 0.9891$

M3 vs. B10

$V = 1.0561 M$

$R^2 = 0.9886$

M4 vs. B4

$V = 1.0479 M$

$R^2 = 0.9971$

M5 vs. B1

$V = 1.0998 M$

$R^2 = 0.9907$

M8 vs. B5

$V = 0.9997 M$

$R^2 = 0.9628$
• Procedure:
  – Used both Antarctic and ocean scenes
    • Antarctic scenes are usually bright, but near terminator they may be as dark as ocean scenes
  – Selected the most uniform area from each scene
    • Typically 160×200 pixels
  – Averaged radiance values for each row over all columns in the selected area
  – Points for each detector were plotted with different color
  – Periodicity of image profiles tests scene uniformity
  – Presented results are only for bands M1 and M2
    • More uncertainty in striping analysis for the other VisNIR bands
Uniformity Improvement with LUT Updates (PTT-3)

Striping is greatly reduced since the LUT updates are derived from the on-orbit solar diffuser measurements.
Striping Dependence on Solar Geometry (PTT-3)

Northern Hemisphere

- Dashed lines: ±0.5% of mean value

Southern Hemisphere

- Reversal in detector sensitivity suggests that striping is not caused by imperfect radiometric calibration
- Striping may be due to differences in polarization sensitivity
- If flat-fielding correction is applied, it should be adjusted for each scene
Predictions of Sensitivity Degradation

**Linear Gain / Offset Approach:**
- \( \text{Gain} = \frac{dn}{L_{SD}} \)
- \( dn = D_{NSD} - D_{NSV} \)
- \( L_{SD} = \cos \theta_{inc} \cdot \tau_{sds} \cdot \frac{E_{sun}}{d^2} \cdot BRDF_{SD} \)

**Approximations:**
- \( \theta_{inc} \) smooth function of time
- \( \tau_{sds} = 0.117 \)
- \( d^{-2} = 1 + 0.033 \cdot \cos(2\pi \cdot DOY/365.25) \)
- \( BRDF_{SD} = \pi^{-1} \)

![Graph showing multi-exponential non-linear optimization](image)

**Error estimates with weekly LUT updates**

<table>
<thead>
<tr>
<th>Band</th>
<th>Gain (mW/m²/nm)</th>
</tr>
</thead>
<tbody>
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<td>M1</td>
<td>1705.70 ± 2.67</td>
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<tr>
<td>M2</td>
<td>1906.01 ± 1.43</td>
</tr>
<tr>
<td>M3</td>
<td>1991.44 ± 1.04</td>
</tr>
<tr>
<td>M4</td>
<td>1843.31 ± 0.49</td>
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<tr>
<td>M5</td>
<td>1507.15 ± 0.51</td>
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<tr>
<td>M6</td>
<td>1278.25 ± 0.26</td>
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<tr>
<td>M7</td>
<td>960.90 ± 0.11</td>
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<tr>
<td>I1</td>
<td>1606.40 ± 0.64</td>
</tr>
<tr>
<td>I2</td>
<td>961.39 ± 0.21</td>
</tr>
</tbody>
</table>

- Band M7
- Detector 8
- High gain
- HAM A
Monitoring VIIRS Sensitivity Degradation

• Antarctic Dome C data have shown that VIIRS Earth View (EV) measurements changed with time similarly to the onboard solar diffuser observations.

• Changes of radiometric response are similar both in spectral dependence and in magnitude:
  - The “blue” band M2 is almost stable.
  - The “red” band M5 is moderately affected (~10% change over 3-4 months).
  - The largest decline occurs for the NIR band M7 (~20%).

• Scaling of earlier measurements according to calibration coefficient lookup table (LUT) changes shows continuity of radiometric responses.

• Weekly LUT updates have stabilized radiometric responses starting with LUT 4 (unfortunately the ending of austral summer increased uncertainty of recent Dome C measurements).
Objective:
To verify detector operability, noise, and SNR of all detectors in all bands and gain states; to verify the absence of artifacts in calibration view data. Task repeated through the life of the sensor to monitor performance.

Methods and Tools:
Use OBC-IP data, analysis tools for verifying detector operability and calculating gain, SNR, and noise.

Results and Recommendations:
VIIRS TEBs are stable and preliminary results indicate the performance better than specification.
There still have margins for RSB.

Monitoring the VIIRS RSB degradation continues.
STAR PRT Temperature Monitoring
(PTT-1, PTT-7)

The periodically variation of PRT #3 and #6 highly correlates with solar zenith angle at the Earth’s surface.

http://www.star.nesdis.noaa.gov/smcd/jcsda/nsun/NPP/ipm_telemetry_npp_spacecraft.php
PTT-2: RDR Histogram Analysis

**Objective:**
To verify normal digitization performance.

**Methods and Tools:**
- RDR, SDR extractor, RDR EV Visualization and Analysis,
- Accumulate data over multiple orbits to generate histograms in raw count (digital number; DN) space and then look for under filled and overfilled DN bins.

**Results and Recommendations:**
- Sync scan data loss are identified.
- Works on RDR EV visualization are needed.
PTT-3: Noise and SNR for Uniform EV Scene

Objective:
To calculate signal standard deviation from uniform Earth view (EV) scenes; to evaluate the signal-to-noise ratio (SNR); and to calculate noise/SNR for calibrator views and at various radiance levels.

Methods and Tools:
Use VIIRS, CrIS SDRs, MODIS data, SNO orbit prediction, analysis tools

Results and Recommendations:
Results from Dome-C and uniform ocean scenes show that VIIRS TEBs have good performance within 0.3 K. The correlation between VIIRS and MODIS RSB is larger than 0.9.

Double difference (using CRTM) may be useful to remove natural variation for determining noise and SNR over uniform EV scenes.
Radiometric and Geospatial Differences between VIIRS and MODIS (PTT-3)

After pixel by pixel remapping using fast GSM, the difference image can be analyzed for both radiometric and geospatial differences between VIIRS and MODIS.

Differencing image not only shows cloud movement (within ~10mins), but also geolocation discrepancies for land features.
VIIRS and MODIS Comparison After Geolocation Error Fixed

cloud movement (within ~10mins), new possibility to derive wind vectors.
18:00, February 25 2012
VIIRS and MODIS Comparison (Feb. 25) (PTT-3)

Bias = MODIS - VIIRS
PTT-4: DNB Offset Verification

**Objective:**
Verify that DNB offset Algorithm Support Function (ASF) performs properly.

**Methods and Tools:**
DNB image and analysis tools

**Results and Recommendations:**
DNB image quality was investigated and a high quality DNB image was sent to JPSS program office per request.
Objective:
   To determine the sensitivity of the electronic gain to variations in sensor electronic and thermal state.

Methods and Tools:
   RDR extractor, Calibrator View Visualization and Analysis

Results and Recommendations:
   VIIRS 3D visualization model is generated.
PTT-6: Radiometric Performance Monitoring

Objective:
To calculate and monitor NedT, S/N, and Gains.

Methods and Tools:
- OBC-IP reader, VIIRS LUTs, NOAA calibration tools,
- long-term monitoring system

Results and Recommendations:
NEdT, NEdN, and Gain for VIIRS TEBs are stable. Our RSB gain parameter also predicted the RSB degradations.
STAR monitoring system provided visualized figures for VIIRS calibration teams.
PTT-7: Telemetry Trending and Monitoring

Objective:
To monitor telemetry parameters.

Methods and Tools:
OBC-IP reader, VIIRS LUTs, long-term monitoring system

Results and Recommendations:
STAR monitoring system provided visualized figures for VIIRS telemetry parameters.

Black solid and dashed lines are for measured values at HAM A and B sides. Lines in red are predicted based on single operational BB temperature (see green triangle).
Interactions with Users, SDR and EDR Teams

• Worked closely with EDR teams (e.g. SST, Ocean Color, fire and vegetation, etc EDR teams), NCEP, and JCSDA.

• Established and maintained the SDR/EDR web blog on CasaNosa.

• Got help from EDR teams and users, e.g., JCSDA (CRTM model), SST EDR team (VIIRS BT anomaly during BB WUCD), which led to the finding of errors in the VIIRS parameter file.

• Supported the EDR teams and our users, for example, we helped JCSDA correct the error in using VIIRS RSR.
VIIRS and CrIS Brightness Temperature Comparison
CrIS convolved with VIIRS M15 RSR

Golden day Feb. 25, 2012
VIIRS and CrIS Comparison

2/25/12

3/18/12
New Progress in SNO Prediction and Routine Use for NPP

- The Simultaneous Nadir Overpass (SNO) prediction software has been upgraded with the latest version of the orbital perturbation algorithm and a graphic interface.

- New capabilities developed to predict both traditional SNOs and SNOx extended to the low latitudes.

- The new system has been predicting routinely since NPP launch, and predicted SNOs with Aqua/MODIS are being used for VIIRS channel responsivity diagnosis.

- The SNOs as well as daily NPP orbital ground track predictions are readily available on the NCC website at: https://cs.star.nesdis.noaa.gov/NCC/SNOPredictions
Summary

- VIIRS Thermal Emissive Bands are stable and preliminary results showed TEB performance exceed the specification.
- VIIRS M12 striping at daytime is mainly caused by the difference in VIIRS azimuth angles among detectors. CRTM can simulate the striping effect.
- VIIRS, MODIS and AVHRR agree well over the SNO scenes.
- VIIRS and CrIS cross check can be performed at any time and any location. Both sensors for TEB agree well.
- Updates of the radiometric lookup tables for VIIRS Reflective Solar Bands have improved calibration and uniformity of radiometric response.
- With the LUT updates, radiometric calibration is stable and agrees well with MODIS measurements (barring small spectral biases).
- LUT updates should be applied more frequently than on the weekly basis: the planned scan-by-scan update should be implemented as soon as possible.
Backup Slides
### VIIRS Spectral, Spatial, and Radiometric Characteristics

The table is adapted from VIIRS user guide and the measured values (last two columns) are revised with RSB data calculated from the updated Murphy results by Aerospace and STAR TEB values (March 8, 2012) which agree with NASA’s results.

<table>
<thead>
<tr>
<th>Band No.</th>
<th>Driving EDR(s)</th>
<th>Spectral Range (nm)</th>
<th>Horiz Sample Interval (km) (track x Scan)</th>
<th>Band Gain</th>
<th>Ltyp or Ttyp (Spec)</th>
<th>Lmax or Tmax</th>
<th>Spec SNR or NEdT (K)</th>
<th>SNR Margin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nadir End of Scan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>Ocean Color Aerosol</td>
<td>0.402 - 0.422</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>High</td>
<td>44.9</td>
<td>135</td>
<td>352</td>
<td>578</td>
</tr>
<tr>
<td>M2</td>
<td>Ocean Color Aerosol</td>
<td>0.436 - 0.454</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>High</td>
<td>40</td>
<td>127</td>
<td>380</td>
<td>964</td>
</tr>
<tr>
<td>M3</td>
<td>Ocean Color Aerosol</td>
<td>0.478 - 0.498</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>High</td>
<td>32</td>
<td>107</td>
<td>416</td>
<td>611</td>
</tr>
<tr>
<td>M4</td>
<td>Ocean Color Aerosol</td>
<td>0.545 - 0.565</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>High</td>
<td>21</td>
<td>78</td>
<td>352</td>
<td>522</td>
</tr>
<tr>
<td>I1</td>
<td>Imagery EDR</td>
<td>0.600 - 0.680</td>
<td>0.371 x 0.387 0.80 x 0.789</td>
<td>Single</td>
<td>22</td>
<td>718</td>
<td>119</td>
<td>215</td>
</tr>
<tr>
<td>I2</td>
<td>NDVI</td>
<td>0.846 - 0.885</td>
<td>0.371 x 0.387 0.80 x 0.789</td>
<td>Single</td>
<td>25</td>
<td>349</td>
<td>150</td>
<td>251</td>
</tr>
<tr>
<td>M5</td>
<td>Ocean Color Aerosol</td>
<td>0.662 - 0.682</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>Low</td>
<td>10</td>
<td>59</td>
<td>242</td>
<td>321</td>
</tr>
<tr>
<td>M6</td>
<td>Atmosph. Correct</td>
<td>0.739 - 0.754</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>High</td>
<td>9.6</td>
<td>41</td>
<td>199</td>
<td>355</td>
</tr>
<tr>
<td>M7</td>
<td>Ocean Color Aerosol</td>
<td>0.846 - 0.885</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>Low</td>
<td>33.4</td>
<td>29</td>
<td>215</td>
<td>435</td>
</tr>
<tr>
<td>M8</td>
<td>Cloud Particle Size</td>
<td>1.230 - 1.250</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>Single</td>
<td>5.4</td>
<td>165</td>
<td>74</td>
<td>233</td>
</tr>
<tr>
<td>M9</td>
<td>Cirrus/Cloud Cover</td>
<td>1.371 - 1.385</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>Single</td>
<td>6</td>
<td>77.1</td>
<td>83</td>
<td>231</td>
</tr>
<tr>
<td>I3</td>
<td>Binary Snow Map</td>
<td>1.580 - 1.640</td>
<td>0.371 x 0.387 0.80 x 0.789</td>
<td>Single</td>
<td>7.3</td>
<td>72.5</td>
<td>6</td>
<td>149</td>
</tr>
<tr>
<td>M10</td>
<td>Snow Fraction</td>
<td>1.580 - 1.640</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>Single</td>
<td>7.3</td>
<td>71.2</td>
<td>342</td>
<td>550</td>
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<tr>
<td>M11</td>
<td>Clouds</td>
<td>2.225 - 2.275</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>Single</td>
<td>0.12</td>
<td>31.8</td>
<td>10</td>
<td>21.8</td>
</tr>
<tr>
<td>I4</td>
<td>Imagery Clouds</td>
<td>3.550 - 3.930</td>
<td>0.371 x 0.387 0.80 x 0.789</td>
<td>Single</td>
<td>270</td>
<td>353</td>
<td>2.5</td>
<td>0.4</td>
</tr>
<tr>
<td>M12</td>
<td>SST</td>
<td>3.660 - 3.840</td>
<td>0.742 x 0.776 1.60 x 1.58</td>
<td>Single</td>
<td>270</td>
<td>353</td>
<td>0.396</td>
<td>0.13</td>
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<tr>
<td>M13</td>
<td>Fires</td>
<td>3.973 - 4.128</td>
<td>0.742 x 0.259 1.60 x 1.58</td>
<td>High</td>
<td>300</td>
<td>343</td>
<td>0.107</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>380</td>
<td>634</td>
<td>0.423</td>
<td>--</td>
</tr>
</tbody>
</table>

**Onboard performance**

HSI uses 3 in-scan pixels aggregation at Nadir
Histogram for VIIRS and CrIS Comparison
Monitoring Sensitivity Degradation (cont.)

- **M1 / M3**: LUT 0/1/2 calibration scaled to match LUT 4

- **M4 / M3**: LUT 0/1/2 vs LUT 4/5/6/7/8/9

- **M6 / M3**: Band Ratio vs Date (2011-11-13 to 2012-03-12)
VIIRS vs. MODIS SNO Comparisons (cont.)

M6 vs. B15

M9 vs. B26

M10 vs. B6