Suomi NPP VIIRS On-Orbit Geometric Performance Validation

NASA VIIRS Calibration Support Team (VCST)
Geometric Calibration Group

Robert E. Wolfe, NASA/GSFC Code 619
Mash Nishihama, Sigma Space/GSFC
Guoqing (Gary) Lin, Innovim/GSFC
Krishna P. Tewari, Innovim/GSFC
James C. Tilton, NASA/GSFC Code 606

and

Northrop Grumman Aerospace Systems (NGAS)
Lushalan Liao, Stephanie Weiss

Suomi NPP VIIRS SDR Product Review (Validated Maturity)
19 December 2013
Outline

• Major accomplishments since Provisional
• Geolocation Validation for I-/M-Bands and DNB
• Band-to-band co-registration
• Spatial responses
• Discrepancy Reports (DRs), quality flags, challenges and potential improvements
• Conclusions
• Backup
  o DR list, Trending of orbit parameters, RTA/HAM encoder performance, Land PEATE reprocessing, DNB geospatial performance (by NGAS)
Major Accomplishments since Provisional

- Fine tuned I-/M-bands SDR/GEO LUTs and DNB geo LUT (by NG)
- Updated LUTs in responses to
  - Scan control electronics (SCE) side A (switched from side B in November 2012)
  - Star tracker re-alignment in April 2013
- Worked DNB TC geolocation to be implemented in IDPS expected March 2014 (already in NASA Land PEATE since May 2013)
- Reduced geolocation bias from (up to) 20 km to (up to) 1.5 km when SC diaries were delayed to and TLE used in IDPS
- Added quality flags for sync loss and sector rotation
- Verified (further) on-orbit BBR and LSF
- Trended (2 years) SC ephemeris (mean altitude 838.8 ±0.2 km)
- Published papers and made conference presentations
  - 2 peer reviewed papers (TGRS + JGR)
  - 1 SPIE talk/paper and 1 AGU presentation
3.1 VIIRS POINTING KNOWLEDGE UNCERTAINTY
The geolocation mapping uncertainty for VIIRS EDRs is specified as 400 meters (3 sigma) at the satellite Nadir and 1500 meters (3 sigma) at the VIIRS Edge-of-Scan (EOS) which is 56.0 degrees from Nadir.

Figure 3.1 shows the VIIRS pointing knowledge budget which rolls up requirements and capabilities for the NPOESS 1330 spacecraft and the VIIRS sensor.
On-orbit Geolocation LUT Updates

<table>
<thead>
<tr>
<th>Update</th>
<th>Date</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/19/2011</td>
<td>Cryo-radiator door open</td>
<td>All VIIRS band available, LPEATE re-process start date</td>
</tr>
<tr>
<td>2</td>
<td>2/23/2012</td>
<td>Initial mounting coef. update</td>
<td>Removed bias ~ 1.3 km</td>
</tr>
<tr>
<td>3</td>
<td>3/30/2012</td>
<td>Initial DNB FPA center update</td>
<td>Removed bias ~ 1 km</td>
</tr>
<tr>
<td>4</td>
<td>11/22/2012</td>
<td>Scan control electronics (SCE) was switched from B-side to A-Side</td>
<td>Caused bias ~ 300 m</td>
</tr>
<tr>
<td>5</td>
<td>12/11/2012</td>
<td>Correction after SCE was switched from B-Side to A-side</td>
<td>Removed bias ~ 300 m</td>
</tr>
<tr>
<td>6</td>
<td>2/15/2013</td>
<td>Second, fine DNB FPA center update</td>
<td>Removed DNB bias ~ 300 m</td>
</tr>
<tr>
<td></td>
<td>4/18/2013</td>
<td>Second, scan angle dependent, fine Geo LUT update</td>
<td>Fine tuned and removed scan dependent biases</td>
</tr>
<tr>
<td>5</td>
<td>4/25/2013</td>
<td>Star tracker maintenance/re-alignment</td>
<td>Caused bias ~ 25 m</td>
</tr>
<tr>
<td>6</td>
<td>8/22/2013</td>
<td>Correction to the star tracker re-alignment</td>
<td>Removed bias ~ 25 m</td>
</tr>
</tbody>
</table>

Key: All bands impacted    DNB only    External event
As of Nov 4, 2013, the DNB geolocation accuracy is
Scan: 8 ± 33 μrad  Track: -35 ± 68 μrad
Scan: 7 ± 28 m  Track: -29 ± 57 m
(nadir equivalent with mean altitude of 838.8 km)
VIIRS (I1 Band) Scan Angle Residuals

Starting 8/22/2012

R² = 0.2462

Track residuals (m)
Scan angle (deg)

R² = 0.016

Scan residuals (m)
Scan angle (deg)
## Overall Uncertainty

<table>
<thead>
<tr>
<th>Residuals</th>
<th>Error (Nadir)</th>
<th>Spec (Nadir)</th>
<th>Error (EOS)</th>
<th>Spec (EOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track mean</td>
<td>-9 m</td>
<td></td>
<td>-20 m</td>
<td></td>
</tr>
<tr>
<td>Scan mean</td>
<td>-7 m</td>
<td></td>
<td>-46 m</td>
<td></td>
</tr>
<tr>
<td>Track RMSE</td>
<td>73 m</td>
<td>133 m</td>
<td>161 m</td>
<td>500 m</td>
</tr>
<tr>
<td>Scan RMSE</td>
<td>61 m</td>
<td>133 m</td>
<td>398 m</td>
<td>500 m</td>
</tr>
</tbody>
</table>

- RMSE: Root Mean Square Error (equivalent to unbiased 1 σ)
- Data-days: 632, excluding 18 days right after A/B side switch
- Mean errors are small
- Nadir uncertainties of ~70 m (1 σ) meet spec of 133 m (1 σ) [400 m (3 σ)]
- Edge-of-scan (EOS) uncertainties of ~ 400m (1 σ) meet spec of 500 m (1 σ) [1500 m (3 σ)]
On-Orbit LSF – Bridge

Gaussian functions are used to model pre-aggregated scan LSFs (Line Spread Functions)

Up to 14 scenes for each band each aggregation zone having robust statistics

Stripes are due to Landsat 7 scan line corrector failure. But the center portion is fine.

Bands (3,2,1) = (R,G,B)
21 November 2012

I-Bands (3,2,1) = (R,G,B)
18 November 2012

Images are co-geolocated & histogram equalized

VIIRS pixels (cyan) around the Landsat bridge (red - linear fit)

Wolfe et. al., 19 Dec 2013
On-orbit scan GDFOV (with robust statistics)

GDFOV: Ground Distance Field of View

Scan GDFOV / HSI ratio

Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir | Agg1x1 Start | Agg2x1 Start | Agg3x1 Nadir

Scan GDFOV/HSIRatio

M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | M13 | M14 | M15 | M16

On-Orbit | Ground Test

On-orbit scan GDFOV: (with robust statistics)
Scan Band Offsets from LSF Retrievals

Scan Offset (I - HSI wrt I3)

Scan Offset (M - HSI wrt M10)

On-Orbit
Ground Test

Band/Aggregation_Zone
On-Orbit
Ground Test

Wolfe et. al., 19 Dec 2013
VIIRS Band to Band Registration (BBR)

Band average BBR (wrt. Band I1) compares well to prelaunch performance
(Some M/LWIR bands are saturated by moon)
DRs and Quality Flags

- DR 4924 adds **DNB Terrain Corrected (TC) Geolocation** is being worked: CCR-13-1362 discussed at AERB and planned for Mx8.3 (March 2014)
- DR 4767 added flags and fills in both SDR and GEO when RTA/HAM synchronization loss occurs (35 events so far, 100 seconds or less each). New situation was found and DR 7484 will flag additional scans.
- DR 7023 reduced geolocation bias from (up to) 20 km to (up to) 1.5 km when S/C diary from Svalbard does not arrive at IDPS in time and the backup two line elements (TLE) is used. Scan quality flag was checked and found ~0.2% of products used TLE data. DRs 7145, 7146 and 7147 were filed for changes in IDPS production rules or Svalbard SC diary data delivery rules.
Challenges and Potential Improvements

- Challenging to accurately measure on-orbit BBR for all band pairs, especially for those LWIR bands saturated by the moon.
- Challenging to accurately measure spatial response characterization for all bands, especially LWIR bands – expect no significant change from pre-launch and no significant impacts on EDRs.
- Within orbit thermal correction is likely to be needed – code updated needed.
- Long-term monitoring is needed for accurate geolocation and for responses to possible on-orbit events – we are trending and fine tuning as needed.
- Digital Elevation Model (DEM) and Land/Water (L/W) mask should be updated (such as those in MODIS Collection 6).
- Geolocation accuracy issues during and right after spacecraft maneuvers needs to be better understood and clearly identified.
Conclusions

• VIIRS geometric performance is as expected
• Geolocation mean errors for I-/M-bands are near 0 and uncertainties are ~ 70 m at nadir, meeting specifications at nadir and edge-of-scan
  – Caveat: DNB terrain corrected geolocation product is expected in Mx8.3 in March 2014
• Encoder and scan time/period are nominal
• Orbit and attitude are nominal
• Quality flags are well-understood
• Limited verification of on-orbit spatial responses and BBR agrees with prelaunch measurements
• VIIRS SDR/Geometric performance maturity should be rated as Validated (except for DNB TC geolocation)
Publications


Backup Slides

• DR list
• Trending of orbit parameters
• RTA/HAM encoder performance
• Land PEATE reprocessing
• DNB geospatial performance (by NGAS)
# Major Geometric related DRs & Status

<table>
<thead>
<tr>
<th>DR #</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4423</td>
<td>Fixed</td>
<td>RTA/HAM timestamps reversal</td>
</tr>
<tr>
<td>4428</td>
<td>Resolved</td>
<td>Rotation Matrix in LUT Used by SDSM Code</td>
</tr>
<tr>
<td>4629</td>
<td>Completed</td>
<td>Initial on-orbit update of the VIIRS DNB GEO LUT</td>
</tr>
<tr>
<td>4703</td>
<td>Completed (Mx6.2)</td>
<td>Add mirror side to VIIRS geolocation products</td>
</tr>
<tr>
<td>4737</td>
<td>LUTs ready for SCE switch</td>
<td>Scan Encoder Electronics (SCE) A-side missing in geolocation parameter LUTs</td>
</tr>
<tr>
<td>4759</td>
<td>Being verified (Mx6.3/4)</td>
<td>Determine Scan Encoder Electronics Side in Geolocation products</td>
</tr>
<tr>
<td>4767</td>
<td>Completed (Mx7.0)</td>
<td>SDR/GEO should be fill and flagged when HAM/RTA sync is lost</td>
</tr>
<tr>
<td>4776</td>
<td>Completed (Mx7.0)</td>
<td>Sector Rotation caused erroneous geo results</td>
</tr>
<tr>
<td>4795</td>
<td>Completed (Mx7.0)</td>
<td>VIIRS SDR Cal: Add major HAM/RTA sync loss flag to VIIRS SDR Cal</td>
</tr>
<tr>
<td>4894</td>
<td>In-Progress (for Mx7.1) confirmation needed</td>
<td>Unexpected high values of Satellite zenith angles</td>
</tr>
<tr>
<td>4917</td>
<td>IDPS alerted (June 2013) – closed</td>
<td>IDPS Incorrect Handling of Leap Seconds</td>
</tr>
<tr>
<td>4924</td>
<td>In-Progress (for Mx8.3)</td>
<td>VIIRS DNB Geolocation Terrain Correction is needed</td>
</tr>
<tr>
<td>7145</td>
<td>In-Progress</td>
<td>VIIRS SDR Controller should wait for the Spacecraft Diary</td>
</tr>
<tr>
<td>7146</td>
<td>In-Progress</td>
<td>Replacement VIIRS SDR Granules should be manufactured if the Spacecraft Diary become available post-production</td>
</tr>
<tr>
<td>7147</td>
<td>In-Progress</td>
<td>Maintain an IDPS Production History</td>
</tr>
<tr>
<td>7203</td>
<td>Completed (Mx7.0)</td>
<td>Degraded VIIRS (and possibly other instruments) geolocation from backup TLE</td>
</tr>
<tr>
<td>7443</td>
<td>In-Progress</td>
<td>VIIRS GEO FILL differences noted in Maneuver granules</td>
</tr>
<tr>
<td>7484</td>
<td>In-Progress</td>
<td>Observed toggling in the VIIRS engineering packet sync loss indicator as the instrument is recovering from sync loss</td>
</tr>
</tbody>
</table>
Trends of Orbit Parameters

• **Altitude (km)**
  - Mean: 838.8 ±0.2 Peak-to-Valley
  - Min: 828.5 ±0.6 P-V; Max: 856 ±0.6 P-V; Equator: 829.8 ±1.0 P-V
• Drag make-up (DMU) maneuvers keeps altitude from falling and 16-day ground track repeatable (±20 km P-V)
• Local time of ascending node (LTAN) drifts from 13:25:24 in Nov 2011 westward 66 km to 3:23:02 in Nov 2012 then back eastward 104 km to 13:26:46 in 4 Dec 2013, continues eastward
• Orbital period: 101.5 min ±0.3 sec P-V
• Inclination angle drifts 98.65 → 98.72 deg (0.07 degrees away from the poles) in 2 years, and continues to move away from the poles

Wolfe et. al., 19 Dec 2013
Equator-crossing local time

SNPP Equatorial Crossing Time

- SNPP Orbit ground track at equator drifted ~66 km westward in 350 days
- It then moves back eastward ~104 km as of 4 Dec 2013 (~ 40 km from launch date)
- SNPP continues moving eastward (sun zenith angle up). It will peak @ ?(future data)
• The linear scan rate of telescope was 3.531 rad/sec on Nov 9, 2011.
• The offset variation is consistent with pre-launch tests (more in NG slides)
• Rotating Telescope Assembly (RTA) and Half Angle Mirror (HAM) encoder datasets had been erroneously swapped in the at-launch IDPS code. The error was corrected, as plotted here, and implemented in IDPS drop Mx5.1 on Dec 19, 2011.
Scan to scan start angle

Variations around -56.34° (used in the geolocation algorithm)
- Magnitude ~ 16 arcsec, half of an I-band scan sampling interval
- Data from one 48-scan (85-sec.) granule on data-day June 27, 2012
VIIRS Residual Trend

Scan residuals (m)

Years since Jan. 1, 2000

IDPS

Land PEATE Re-processed

1/19/2012

2/23/2012

3/30/2012

11/22/2012

12/11/2012

4/18/2013

4/25/2013

8/22/2013

1/19/2012

2/23/2012

3/30/2012

11/22/2012

12/11/2012

4/18/2013

4/25/2013

8/22/2013

Wolfe et al., 19 Dec 2013

VCST/GEO 25
VIIRS Scan Angle Residuals

R² = 0.8089

IDPS

R² = 0.2462

Land PEATE Re-processed

Wolfe et. al., 19 Dec 2013

VCST/GEO 26
VIIRS Scan Angle Residuals

Scan residuals (m)

Scan angle (deg)

IDPS

R² = 0.0149

Land PEATE Re-processed

R² = 0.016
# Overall Error

<table>
<thead>
<tr>
<th>Residuals</th>
<th>Error IDPS</th>
<th>Error Land PEATE Re-processed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track mean</td>
<td>-9 m</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Track RMSE</td>
<td>73 m</td>
<td>69 m</td>
</tr>
<tr>
<td>Scan RMSE</td>
<td>61 m</td>
<td>58 m</td>
</tr>
</tbody>
</table>

- Nadir equivalent accuracy (RMSE – Root Mean Square Error)
- Data-days
  - IDPS: 632      Land PEATE: 637
- Average CP residuals per day (after filtering)
  - IDPS: 135     Land PEATE: 138
- Time period:
  - IDPS: Feb. 23, 2012 (VIIRS I/M-band LUT update) to Dec. 5, 2013; excluding 18 days right after A/B side switch
DNB spatial characteristics

DNB HSR is approximately a constant multiple of the horizontal sampling interval (HSI) for aggregation zones 1-24. This results in approximately constant HSR in units of ground distance, with saw tooth pattern that is inherent in the ground HSI. HSR meets the requirement of 800 meters up to scan angle of 52 degrees.

Model based line spread function (LSF) construction using ice edge scenes was utilized to retrieve horizontal sampling resolution (HSR). Correction for edge slant was performed in Fourier space.

L.B. Liao, NGAS

Wolfe et. al., 19 Dec 2013