NOAA-20 VIIRS ON-ORBIT CALIBRATION IMPROVEMENTS

X. Xiong[1], C. Cao[2], A. Angal[3], S. Blonski[4], K. Chiang[3], T. Choi[4], Y. Gu[4], N. Lei[3], Y. Li[3], X. Shao[5], K. Twedt[3], S. Uprety[5], and W. Wang[5]

[1]Sciences and Exploration Directorate, NASA/GSFC, Greenbelt, MD 20771, USA
[2]Center for Satellite Applications and Research, NOAA NESDIS, College Park, MD 20740, USA
[3]Science Systems and Applications, Inc., Lanham, MD 20706, USA
[4]Global Science & Technology, Inc., Greenbelt, MD 20770, USA
[5]Cooperative Inst. for Satellite Earth System Studies, Univ. of Maryland, College Park, MD 20740, USA

ABSTRACT

The NOAA-20 (N-20) VIIRS has successfully operated for more than two years since its launch in November 2017. Shortly after completing its initial function check-outs and post-launch testing (PLT) activities, the N-20 VIIRS sensor data records (SDR) achieved the beta, provisional, and validated maturity status in January, February, and April 2018, respectively. In this paper, we describe briefly the instrument on-orbit operation and calibration activities, provide an overall assessment of its on-orbit performance, and discuss the methodologies developed to maintain and improve the calibration and data quality. As illustrated in this paper, the N-20 VIIRS continues to perform with excellent stability, allowing high-quality environmental data records (EDR) to be generated from its well-calibrated SDR.

Index Terms **-** NOAA-20, VIIRS, on-orbit calibration

1. INTRODUCTION

The VIIRS is a key instrument for the S-NPP and JPSS missions. The first VIIRS, launched onboard the S-NPP spacecraft in 2011, has successfully operated for more than 8 years and continues to perform its design functions and collect useful data to produce high-quality SDR and EDR in support of studies of the Earth's key environmental parameters [1]. The second VIIRS is operated onboard the N-20 (or JPSS-1) satellite launched in November 2017. Three additional VIIRS will be launched in 2022, 2026, and 2031 on the JPPS-2, -3, and -4 satellites, respectively. This paper provides an update to the N-20 VIIRS on-orbit performance [2]. It focuses on the improvements and changes made since completing its initial function check-outs and a full set of PLT activities developed to help assess its calibration and data quality.

The VIIRS collects data in 22 spectral bands: 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB) and 1 day and night band (DNB), covering wavelengths from 0.41 to 12.2 μm. Bands M1-M11 and I1-I3 are the RSB and bands M12-M16 and I4-I5 the TEB (M for moderate resolution and I for imaging). Bands M1-M5, M7, and M13 are the dual-gain bands and the DNB is capable of collecting data at three gain stages. The VIIRS on-orbit calibration is performed via a set of on-board calibrators (OBC). Its SDR are derived from the measurements made by its 22 spectral bands, including calibrated scene radiances, reflectances, and brightness temperatures, and serve as key input for generating the EDR products. Shortly after completing the PLT activities, the N-20 VIIRS SDR achieved the beta, provisional, and the validated maturity status successively in January, February, and April 2018. Since then, continuing efforts have been made by the calibration teams at NASA and NOAA to further improve the N-20 VIIRS calibration and its SDR quality. Recent improvements or changes and their associated impact on sensor calibration are presented in this paper.

2. ON-ORBIT CALIBRATION

The VIIRS OBC include a solar diffuser (SD), a solar diffuser stability monitor (SDSM), a blackbody (BB), and a space view (SV) port, which is part of the extended Earth view port. The RSB are calibrated by the SD and SDSM, together with regularly scheduled lunar observations. Through an attenuation screen, the sunlit SD panel allows the RSB calibration to be performed each orbit. The SDSM operation was initially every orbit, then daily, and now weekly starting March 1, 2019. The TEB are calibrated using the BB, nominally controlled at 292.5 K. Except at the mission beginning, the BB WUCD calibrations are performed annually. Figure 1 shows the VIIRS instrument, including its rotating telescope assembly (RTA) and the OBC. The VIIRS lunar observations are made at phase angles near -51° through its SV port and often with spacecraft roll maneuvers [3]. As of Jan 14, 2020, 18 lunar observations have been scheduled and performed for N-20 VIIRS.

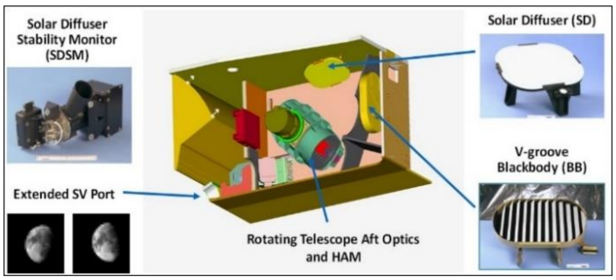

Fig. 1 VIIRS instrument scan cavity, its rotating telescope assembly (RTA) and on-board calibrators (OBC).

In addition to roll maneuvers, spacecraft yaw and pitch maneuvers were performed at the mission beginning to acquire special data sets to help validate and improve key calibration parameters of N-20 VIIRS derived from pre-launch measurements. For example, data from yaw maneuvers has been used to characterize and improve the SD and SDSM screen transmission and that from the pitch maneuver has been applied to validate the TEB response versus scan-angle (RVS) and to update the DNB dark offset tables. On a regular basis, special DNB calibrations are also conducted.

3. CALIBRATION PERFORMANCE AND IMPROVEMENTS

Illustrated in Figure 2 are the F-factors, or the inverse of detector gains, for the visible and near-infrared (VIS/NIR) spectral bands, derived with the improved product of SD bidirectional reflectance distribution function (BRDF) and its screen transmittance function ($BRDF_{SD}*\tau_{SD}$) and improved SD degradation or H-factors. They are averaged over all detectors for the side A of the half-angle mirror (HAM) and high gain (HG) stage in the case of dual-gain bands. Also included in Figure 2 are F-factors derived from lunar observations (normalized to the SD F-factors). The improvement of the $BRDF_{SD}*\tau_{SD}$ is achieved by using data collected during yaw maneuvers as well as that from regular SD calibrations over a strategically selected period of time. The same strategy, previously developed for MODIS and applied to S-NPP, has also been used to improve the SDSM screen transmission (τ_{SDSM}) measured pre-launch [4,5]. This, along with the use of lunar observations or the correction to account for viewing angle dependent SD degradation, has led to more accurate H-factors, including those in the short-wave infrared (SWIR) region that is not covered by the SDSM. The newly improved calibration parameters and look-up tables (LUT) have been delivered to NASA's Land Science Investigator-led Processing System (SIPS) to reprocess the N-20 VIIRS SDR over its entire mission and to help generate consistent science products. Similar improvements have also been applied to the NOAA Interface Data Processing Segment (IDPS) in support of its EDR production and operational users.

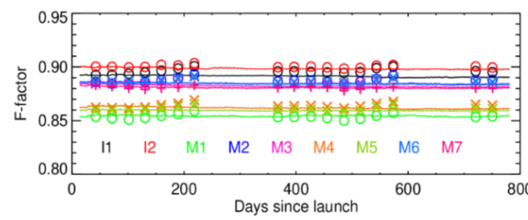

Fig. 2 F-factors deived from SD/SDSM (lines) and lunar observarions (symbols) for the VIS/NIR spectral bands.

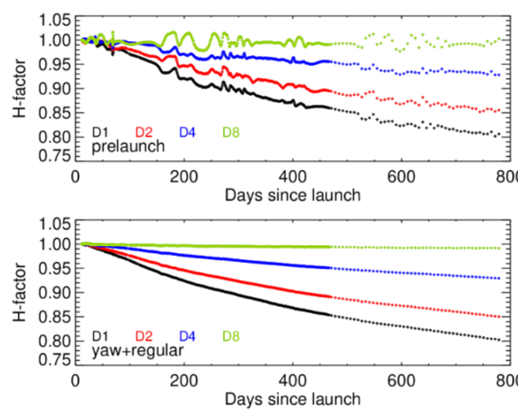

Fig. 3 H-factors derived from pre-launch and on-orbit SDSM screen transmission at its detector 1, 2, 4, and 8 wavelengths (0.41, 0.44, 0.55, and 0.93 μm).

The improvement of the H-factors is demonstrated in Figure 3 by comparing the SD degradation derived from the pre-launch τ_{SDSM} and that from the improved on-orbit τ_{SDSM}. Although the SD has experienced a strong wavelength dependent degradation, larger at shorter wavelengths, on-orbit changes in N-20 VIIRS RSB responses have been very small (less than 0.5%). This is a significant improvement compared to S-NPP VIIRS RSB performance. Regularly scheduled lunar observations have also been used to track on-orbit changes of the RSB band-to-band registration (BBR) [6]. From launch to present, the N-20 BBR performance in both along-scan and along-track has been very stable, as demonstrated in Figure 4.

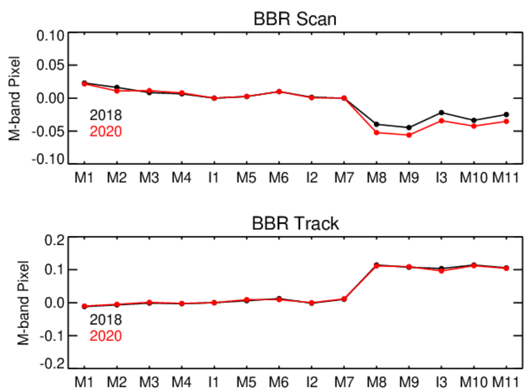

Fig. 4 RSB along-scan (top) and along-track (bottom) BBR dereived from lunar observations.

The RSB signal-to-noise ratios (SNR) are computed using the detector responses to the sunlit SD. The SNR at different signal levels are fitted to a function so that the SNR at the typical radiance levels can be derived. Presented in Table 1 are the SNR design requirements for the VIS/NIR spectral bands and their pre-launch and on-orbit performance, showing excellent stability and large margin compared to specified requirements. The SWIR bands also have similar SNR performance.

Table 1 SNR specification and performance (pre-launch, on-orbit in Jan 2018 and 2020) for the VIS/NIR spectral bands (I1-I2, M1-M7, HG only). Ratio = SNR (measured) / SNR (specified).

Band	I1	I2	M1	M2	M3	M4	M5	M6	M7
SNR spec.	119	150	352	380	416	362	242	199	215
PL ratio	1.91	1.91	1.81	1.51	1.70	1.54	1.57	2.15	2.55
Jan-2018 ratio	1.89	1.88	1.81	1.49	1.67	1.51	1.61	2.10	2.47
Jan-2020 ratio	1.88	1.89	1.84	1.50	1.68	1.53	1.61	2.10	2.49

The TEB are calibrated by the on-board BB, nominally controlled at 292.5 K. Their mission-long F-factors are shown in Figure 5. Noticeable rapid increases of the LWIR (bands M15, M16, and I5) F-factors (or decrease of gains) at the mission beginning were caused by the ice buildup inside the dewar window of the LWIR focal plane assembly (FPA). Following a special mid-mission outgassing operation performed in March 2018, the LWIR bands regained their responses (gains) to the expected level [2,7]. Since then, all N-20 TEB responses have continued to be stable, showing nearly identical behavior to that of S-NPP TEB, including relatively large change in the I5 (0.3%/year).

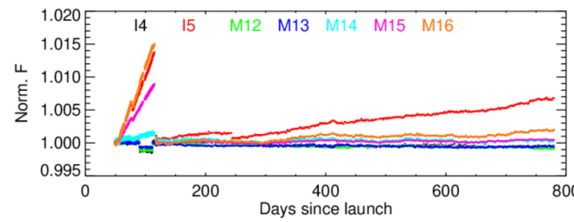

Fig. 5 TEB F-factors (band averaged, HAM side A).

Table 2 TEB NEdT specification and performance (pre-launch, on-orbit in Jan 2018 and 2020). Ratio = NEdT (measured) / NEdT (specified).

Band	I4	I5	M12	M13	M14	M15	M16
NEdT spec.	2.50	1.50	0.40	0.11	0.09	0.07	0.07
PL ratio	0.17	0.27	0.30	0.40	0.55	0.37	0.60
Jan-2018 ratio	0.16	0.27	0.25	0.37	0.52	0.34	0.43
Jan-2020 ratio	0.16	0.28	0.25	0.36	0.51	0.34	0.43

The TEB specified noise equivalent temperature difference (NEdT) and the N-20 on-orbit performance are summarized in Table 2 (high gain only). The on-orbit NEdT are characterized at different temperatures during BB WUCD and constantly monitored using data from its nominal operation. The performance is evaluated using the ratio of the measured to specified NEdT. Thus, ratios with values of less than 1 indicate better performance (or smaller detector noise). Similar to S-NPP, the N-20 VIIRS BB has shown excellent short- and long-term stability with the nighttime orbits being more stable and uniform than the daytime orbits. However, during BB WUCD, the performance becomes less stable and uniform and can impact the quality of TEB calibration. Because of this, a special TEB WUCD correction, developed for S-NPP, has been applied in the NOAA operational processing software (version Block2.1 Mx 6).

Based on lessons from S-NPP, several enhancements have been made for the N-20 DNB calibration and stray light correction (SLC), especially for the extended zone 21, including an improved algorithm for determining the DNB gain ratios to correct the biases due to detector nonlinearity. In order to synchronize the improved DNB calibration algorithm and its updates with the DNB SLC, monthly DNB SLC LUTs are generated for over a full year period and used for the successive years. Figure 6 shows the DNB images (Jan 6, 2019) over the southern hemisphere using the SLC LUT generated with Jan 2018 DNB data and previous algorithm (top) and the SLC LUT generated with Jan 2019 DNB data and the improved algorithm (bottom). The removal of striping in aggregation zone 21 at the left edge of the DNB image after applying the more recent SLC LUT can be clearly seen.

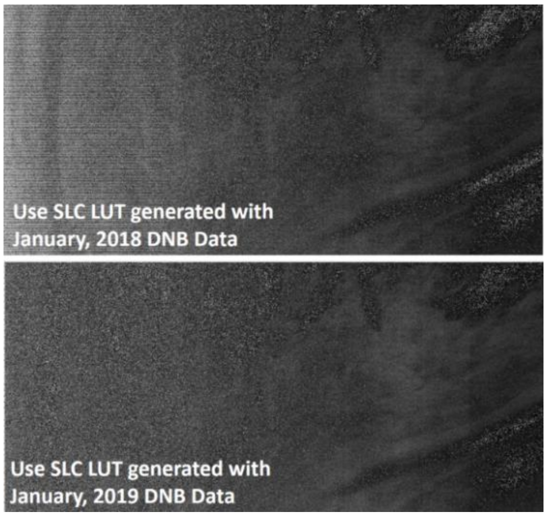

Fig. 6 Examples of striping removal in aggregation zone 21 images of N-20 DNB over southern hemisphere with SLC synchronized with the calibration algorithm update (see text for details)

In addition to routine OBC and lunar calibration activities, extensive efforts have been made to validate and monitor the N-20 SDR calibration stability and consistency with S-NPP using different approaches. These approaches include but are not limited to the use of SNOs of VIIRS with Aqua MODIS and calibration inter-comparisons with the CrIS, long-term response trends over DCC and select ground calibration sites. As expected, the VIIRS on-orbit calibration quality has greatly benefitted from the results derived and issues identified from various vicarious calibration and validation activities.

4. FUTURE WORK

Remaining concerns and issues to be identified as the mission continues, as well as their associated impact on data quality need to be addressed with dedicated efforts. For RSB, the future work will focus on the improved strategy to combine SD and lunar calibration coefficients to minimize the impact due to uncertainty of SD degradation characterization and to better understand and address calibration biases between S-NPP and N-20. For TEB, small but noticeable scan angle and scene temperature dependent biases compared with the CrIS observations will be investigated further. The NOAA SDR team will continue to coordinate with the SST team to further reduce the WUCD related biases. The DNB work will be focused on DNB SLC enhancements by exploring more effective and efficient approaches.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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