PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Radiometric performance characterization of NOAA-20 VIIRS reflective solar bands

Uprety, Sirish, Cao, Changyong, Shao, Xi

Sirish Uprety, Changyong Cao, Xi Shao, "Radiometric performance characterization of NOAA-20 VIIRS reflective solar bands," Proc. SPIE 11501, Earth Observing Systems XXV, 1150115 (9 September 2020); doi: 10.1117/12.2568721

Event: SPIE Optical Engineering + Applications, 2020, Online Only

Radiometric Performance Characterization of NOAA-20 VIIRS Reflective Solar Bands

Sirish Uprety[1], Changyong Cao[2], and Xi Shao[1]

[1]University of Maryland, College Park, MD, USA, [2]NOAA/NESDIS/STAR College Park, MD, USA

ABSTRACT

NOAA-20 VIIRS Reflective Solar Bands (RSBs) have been performing well since launch with good quality sensor data records (SDRs). The radiometric performance of these SDRs have been continuously analyzed and monitored using various independent validation techniques. It is important to maintain radiometric consistency between NOAA-20 VIIRS SDRs and other well calibrated instruments such as S-NPP VIIRS for long term environmental applications. Past studies have shown that there exists a near consistent bias in RSBs between the two VIIRS instruments, with NOAA-20 VIIRS top-of-atmosphere (TOA) reflectance being lower by nearly 2-3%. It is crucial to monitor the radiometric consistency between the two VIIRS instruments and help the user community understand the trending of the relative bias between two VIIRS and its impacts on the higher level EDR products. This study is focused on analyzing NOAA-20 VIIRS radiometric bias relative to S-NPP VIIRS operational SDR using different techniques such as the pseudo-invariant calibration sites (PICS) and inter-comparison with other satellite instruments using Simultaneous Nadir Overpasses (SNOs). The impact on bias due to spectral differences between the two VIIRS instruments is quantified using hyperspectral measurements from Sciamachy. Since S-NPP VIIRS is used as a reference, any residual degradation in its operational calibration since 2018 needs to be accounted. The correction for residual degradation will be performed in future for more accurate NOAA-20 VIIRS bias trending once the S-NPP VIIRS reprocessing is completed to the more recent date. The study suggests that NOAA-20 VIIRS reflective solar bands are consistently lower in reflectance than that from S-NPP VIIRS by about 2-3% for most bands. Larger bias is observed for bands M5 (0.67 µm) and M7 (0.86 µm) bands mainly because S-NPP VIIRS absolute calibration for these bands is biased high by about 2%. NOAA-20 VIIRS bias values estimated in this study are consistent with the past studies. The bias remains nearly constant for all the bands.

Thus, the study also uses the trend-corrected S-NPP VIIRS data to quantify NOAA-20 VIIRS temporal radiometric bias. Due to shorter span of time for NOAA-20 VIIRS, i.e. ~ two years in orbit, analyzing its radiometric stability using calibration sites is more challenging and results in higher uncertainty. This study uses Libya 4 calibration site to further analyze and validate the radiometric

Keywords: VIIRS and ABI consistency, NOAA-20 VIIRS calibration, VIIRS RSB bias, double differencing

1. INTRODUCTION

Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (S-NPP) has been providing well calibrated critical global earth observation data for more than eight years. With major calibration updates over its mission life, the operational data quality is maintained well within the specification. In addition, the launch of NOAA-20 in 2017 has been supplementing the S-NPP VIIRS data by doubling the global observation frequency which is critical to near-real time applications. For long term environmental studies, the radiometric stability and accuracy of the satellite sensor needs to be characterized well such that the Earth observation data continuity is established precisely, independent of the satellite platform. The same applies to the two VIIRs sensors in space. To establish long term data continuity among VIIRS products, the key requirement is to have the VIIRS instruments to be

Earth Observing Systems XXV, edited by James J. Butler, Xiaoxiong (Jack) Xiong,
Xingfa Gu, Proceedings of SPIE Vol. 11501, 1150115 · © 2020 SPIE
CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2568721

radiometrically consistent. However, past studies have shown that there exists near consistent radiometric bias between the two VIIRS sensors for reflective solar bands (RSBs), the results suggested that NOAA-20 observed TOA reflectance is lower than SNPP VIIRS by mostly within 2-3% [1, 2, 3].

Radiometric performance of Satellite sensors can be accessed using different independent techniques. This study uses multiple techniques such as Simultaneous Nadir Overpass (SNO), SNOs extended to low latitude Saharan desert and using pseudo-invariant calibration sites (PICS) to analyze NOAA-20 VIIRS performance. For SNO based comparison between NOAA-20 and S-NPP VIIRS, a double differencing approach is used for due to no direct SNOs. Both N20 and SNPP have SNOs with AQUA MODIS. After double difference, the impact of presence of any MODIS absolute calibration bias is mostly cancelled out and thus the difference indicates the bias relative to NOAA-20 and S-NPP VIIRS. The details on SNO can be found in past study by Cao et al., 2002 [4]. Uprety et al., 2013 shows how the extended SNOs can be used to evaluate the VIIRS sensor performance [5]. In addition to SNOs, PICS based intercalibration is another widely used technique to validate the sensor performance. PICS can also be used to analyze the temporal stability of RSBs. This study uses Libya 4 PICS site since it is a well characterized site and widely used for VNIR sensors calibration and validation. Libya4 is also a CEOS endorsed calibration site. TOA reflectance time series of each VIIRS instrument over Libya 4 desert calibration site is analyzed to quantify the radiometric performance. Libya 4 is chosen since this is a well characterized site widely used for VNIR sensors calibration and validation. Uncertainties is bas could be contributed by calibration uncertainties, BRDF, cloud contamination, spectral differences and atmospheric absorption variabilities. Spectral differences between the two VIIRS instruments is analyzed using spectral band adjustment factors (SBAF) which is derived using Sciamachy.

2. METHODOLOGY

VIIRS instruments are compared to each other using SNOs and through direct comparison over Libya 4 desert. The steps for comparison using SNOs are summarized below:

a. For each SNO comparison event between VIIRS and MODIS, collect the dataset.
b. Collocate the overlapping region between MODIS and VIIRS for each SNO.
c. Compare the average value of TOA reflectance over the overlapping region (30 km × 30 km)
d. Derive the bias time series of each VIIRS relative to MODIS.
e. Analyze the radiometric performance of NOAA-20 VIIRS relative to S-NPP

Similarly, the steps for comparison over PICS are summarized below:

a. For each nadir overpass over the Libya 4 site, collect VIIRS data.
b. Compute the average reflectance over the ROI (30 km × 30 km).
c. Derive the time series for both the VIIRS instruments and characterize the radiometric consistency.
d. In addition, analyze the time series to quantify the radiometric stability.

2.1 Datasets for NOAA-20/S-NPP VIIRS and AQUA MODIS

The datasets used in comparison are TOA reflectance measurements from S-NPP/NOAA-20 VIIRS and AQUA MODIS. VIIRS data are downloaded from NOAA CLASS (www.class.noaa.gov). MODIS data are downloaded from NASA web (https://ladsweb.modaps.eosdis.nasa.gov/).

Table 1 shows the matching VIIRS and MODIS bands. Small spectral differences between the VIIRS and MODIS exists. Since the study focus on double differencing using SNO, SBAF correction for each VIIRS relative to MODIS is not required. However, SBAF has been applied between the matching VIIRS bands onboard S-NPP and NOAA-20. The spectra differences between two VIIRS can be observed in Figure 1.

Table 1. VIIRS and MODIS matching bands (spectra and table)

VIIRS		MODIS	
Band	Wavelength (μm)	Band	Wavelength (μm)
M1	0.402 - 0.422	8	0.405 - 0.420
M2	0.436 - 0.454	9	0.438 - 0.448
M3	0.478 - 0.498	10	0.483 - 0.493
M4	0.545 - 0.565	4	0.545 - 0.565
M5 I1	0.662 - 0.682 0.600 - 0.680	1	0.620 - 0.670
M7 I2	0.846 - 0.885 0.850 – 0.880	2	0.841 - 0.876
M8	1.230 - 1.250	5	1.230 - 1.250
M10	1.580 - 1.640	6	1.628 - 1.652
M11	2.225 - 2.275	7	2.105 - 2.155

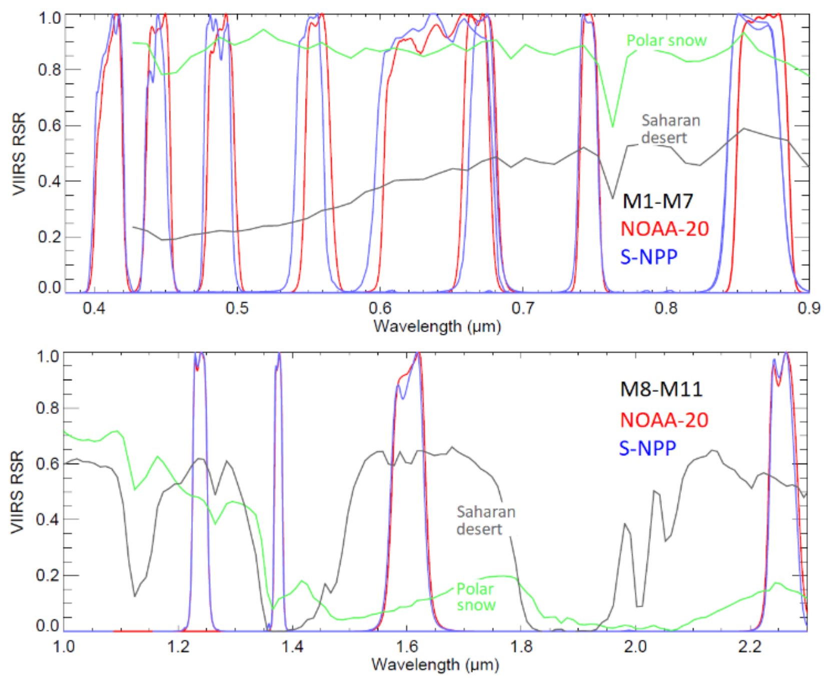

Figure 1. VIIRS RSRs and spectral features over polar snow and Saharan desert

2.2 SNOs

VIIRS and MODIS have direct SNOs over high latitude polar region. Observations over SNOs from two instruments happen at nearly identical solar and sensor geometry, thus greatly reducing the uncertainties. TOA reflectance are compared to calculate VIIRS bias relative to MODIS. The process is repeated for both S-NPP and NOAA-20 VIIRS. This study uses solar zenith angles less than 75° and sensor zenith less than 6°. Figure 2. SNO events over polar region since 01/01/2018, Red: NOAA-20 and AQUA; Blue: S-NPP and AQUA. Similarly, SNOs in the high latitude region are extended to low latitude tropical region (SNOx) to compare over more homogenous and stable Saharan desert. The details on SNOx methodology have been explained in Uprety et al. (2013) [5].

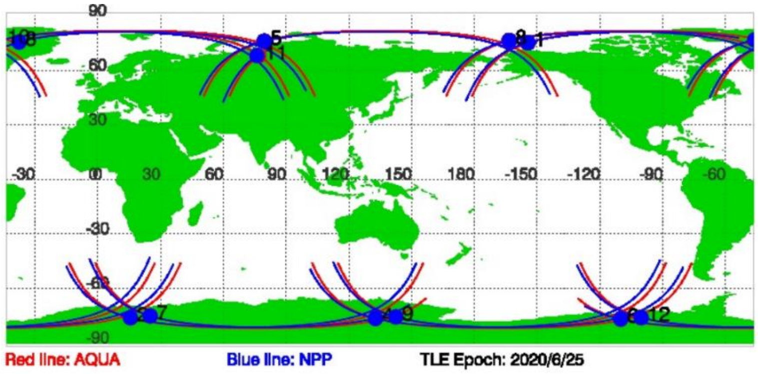

Figure 2. S-NPP VIIRS and MODIS SNOs at polar region (https://ncc.nesdis.noaa.gov/SNOPredictions/)

2.3 PICS

PICS are widely used in validating sensor performance for RSBs (Helder et al., 2008, Markham et al., 2004, 2012). There are many PICS sites that have been used to monitor VIIRS performance (https://ncc.nesdis.noaa.gov/VIIRS/VSTS.php). This study uses Libya 4 site to derive the NOAA-20 VIIRS performance. Nadir observed TOA reflectance over Libya 4 is trended for both the VIIRS instruments. The closest matching observations at nadir are 8-days apart. Thus, the two instruments are compared at similar solar zenith angles to reduce the impact due to BRDF differences. Cloud free data are used in the analysis. Spatial uniformity testing is used to determine the cloud-free observation [5, 9, 10].

2.4 Estimating NOAA-20 VIIRS bias trend

For each SNO event, VIIRS bias relative to MODIS is estimated. After getting bias time series of each VIIRS instrument relative to AQUA MODIS, double differencing is used to estimate NOAA-20 VIIRS bias relative to S-NPP. The difference in bias of two VIIRS instruments relative to MODIS indicates the bias between the two VIIRS instruments. Linear fitting is done over the bias time series to characterize the sensor degradation over time.

2.5 SBAF

To compute the absolute bias, the impact due to RSR differences between the two VIIRS instrument needs to be accounted for. Spectral band adjustment factors (SBAF) is computed for each VIIRS band based on analysis using hyperspectral measurements from Sciamachy (https://www-pm.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF). SBAF values are used to scale NOAA-20 VIIRS remove the bias resulting from spectral differences with S-NPP. Temporal trends of NOAA-20 VIIRS bias since early launch are analyzed to quantify the postlaunch radiometric performance.

3. RESULTS AND DISCUSSION

NOAA-20 VIIRS radiometric performance since early launch has been analyzed. As discussed earlier, double difference of SNOs derived bias trends and direct comparison over Libya 4 are the two techniques used to evaluate the on-orbit radiometric performance. The difference in linear fit trending over the two VIIRS biases relative to MODIS shows the degradation in NOAA-20 VIIRS over time. However, this is under the assumption that S-NPP VIIRS is temporally stable. As discussed in Uprety et al., (2018), S-NPP VIIRS uses Kurucz solar irradiance model from MODTRAN 4.0 whereas NOAA-20 VIIRS uses Thuillier solar model [2]. There is no impact of solar model difference on bias values estimated in this study because the TOA reflectance is independent of solar irradiance. However, if the intercomparison is performed in radiance unit, the impact due to difference in solar models need to be accounted. Otherwise, the impact on bias can be up to 3% for some bands such as M2.

3.1 VIIRS Radiometric performance using SNOs

This study analyze NOAA-20 VIIRS bias for M1-M8 bands except bands M2, M3 and M9. Matching MODIS bands for M2 and M3 are mostly saturated over the high reflectance snow flats and hence are excluded from analysis due to insufficient data with larger uncertainties. Similarly, band M9 is excluded from analysis due to very small signal strength with larger uncertainty. Figure shows the bias time series for VIIRS bands M1 and M4, relative to MODIS. Large spikes near day 950 is due to VIIRS anomaly which is discussed in Zhang et al. (2020) [11]. SNO based intercomaprison over polar snow flats suggests that NOAA-20 VIIRS observed TOA reflectance is consistently lower than that of S-NPP VIIRS. Most recent NOAA-20 VIIRS bias values are computed in two steps. First step is to calculate the mean of each VIIRS bias values over one last one year period and the second step is to take the difference of individual mean bias values. Using data over last one year time, the study suggests that bias values are mostly within 2-3% except for bands M5 and M7. M5 and M7 biases are large mainly due to overestimation in S-NPP VIIRS absolute calibration and has been reported in multiple studies in the past [1, 2, 5, 10]. The estimated bias values reported in the past studies [1, 2 3] agree well with the recent results. This indicates that the NOAA-20 VIIRS bias for moderate resolution bands is nearly stable. Similarly bias for imagery bands I1 and I2 are compared with matching MODIS bands. The results indicate that NOAA-20 VIIRS I1 is lower than S-NPP by nearly 3% whereas I2 is lower by nearly 5%. I2 bias is higher due to same reason as M7 where the S-NPP VIIRS calibration is biased high. It is to be noted that a the impact on bias due to small difference in spectral response function between the matching VIIRS bands has been accounted using SBAF derived using Sciamachy hyperspectral measurements.

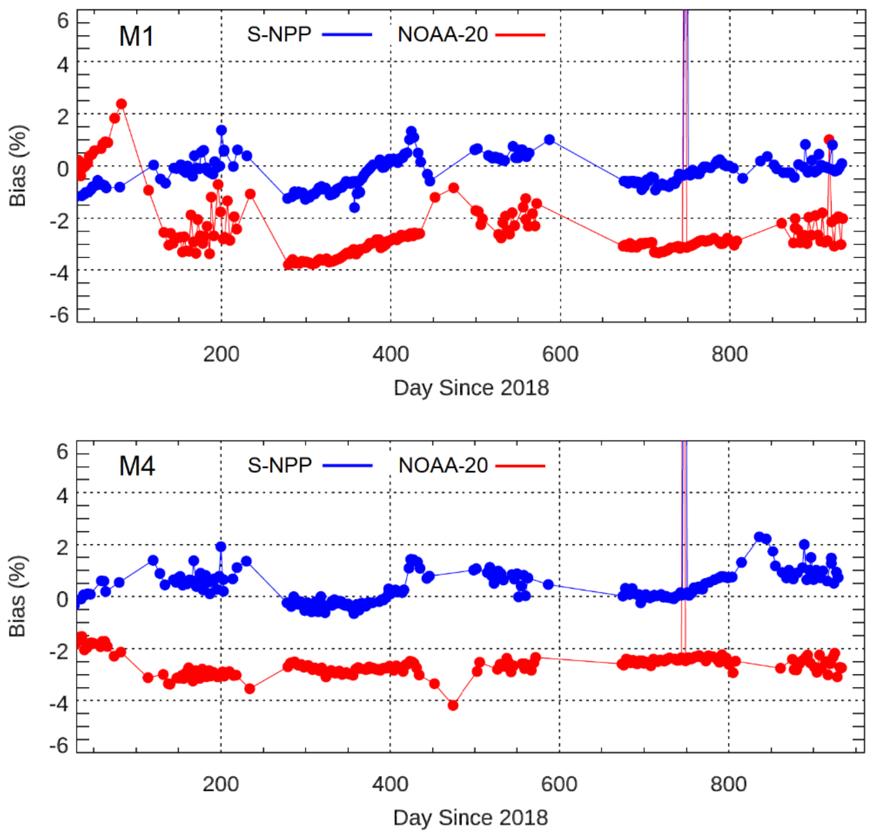

Figure 3. VIIRS bias time series for bands M1 and M4 relative to MODIS using SNOs over polar region

This study also uses SNOs extended to low latitude region over Africa to evaluate NOAA-20 VIIRS bias. This technique is very useful to assess the VIIRS performance over wider dynamic range as discussed and demonstrated in Uprety et al., (2013) [5]. Although the comparison can be performed over both desert and clear sky ocean, this study is limited to desert based comparison only. Figure 4 shows VIIRS M1 band bias time series with NOAA-20 TOA reflectance being consistently lower than S-NPP. The impact due to spectral differences has been accounted. The chart shows that there is short term changes in biase relative to MODIS. However, the changes happen for both the VIIRS instruments and thus has no impacts on double difference. Except M8 band which shows NOAA-20 VIIRS bias to be nearly 3%, rest of the VIIRS bands suggest bias on the order of 2% or less. For all VIIRS bands analyzed, the bias results agree well with SNOs over polar region to mostly within 0.5%. The

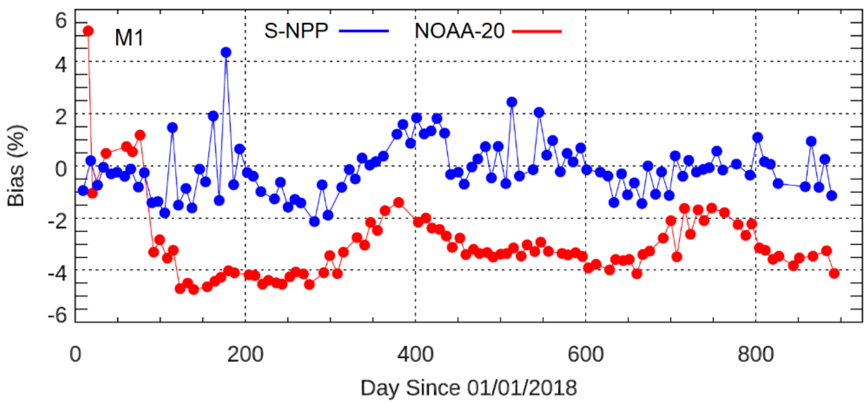

Figure 4. VIIRS M1 bias time series using SNOx over desert. NOAA-20 VIIRS (red) is consistently lower than S-NPP (blue) VIIRS.

3.2 VIIRS Radiometric performance using Libya 4

In addition to SNOs, this study also uses Libya 4 site to analyze VIIRS radiometric consistency for bands M1-7 except M6. The TOA reflectance trend over Libya 4 for VIIRS M1 is shown in Figure 5 for both S-NPP and NOAA-20. Each point represents the average reflectance over a clear sky ROI of 30*30 km. When compared at 20° solar zenith angle, bias for all M bands analyzed in this study (M1-5, M7-8, and M10-11) suggest that NOAA-20 VIIRS TOA reflectance is lower than S-NPP. Bias is on the order 2-3% for most of the bands. M5 and M7 indicate larger bias of about 4%, consistent with results from SNOs as discussed earlier. The NOAA-20 VIIRS bias computed at Libya 4 provides an additional independent validation of VIIRS radiometric consistency.

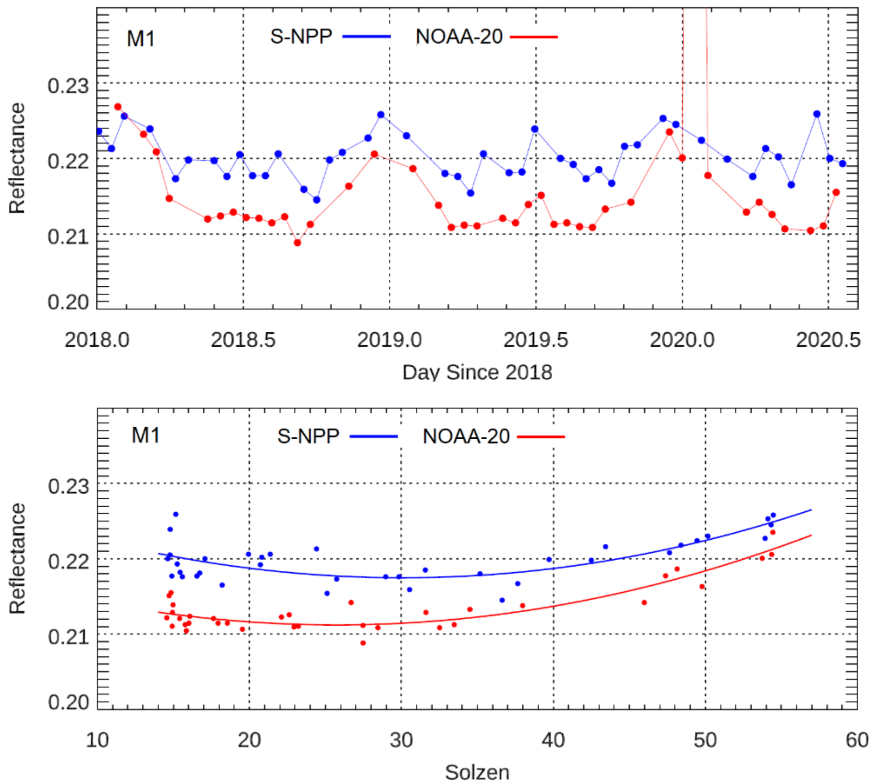

Figure 5. Top: NOAA-20 and SNPP VIIRS TOA reflectance comparison over Libya 4 for matching ABI bands 1-3, 5-6; Bottom: TOA Reflectance as a function of solar zenith angle.

4. CONCLUSION

NOAA-20 VIIRS radiometric performance is independently validated using SNOs over polar snow, using extended SNO over Saharan desert, and using Libya 4 site. Intercomaprison is performed using reflectance and bias is estimated after accounting for RSR differences between the two VIIRS instruments. SBAF derived from Sciamachy were used to account for the spectral differences. The study suggests that NOAA-20 VIIRS observed TOA reflectance is consistently lower than that for S-NPP for all reflective solar bands under study by 2-3%. Larger bias exists for M5 (~5%) and M7 (~4%) because S-NPP VIIRS calibration is overestimated by nearly 2%. Bias results over polar snow and Saharan deserts agree to within 1% for most bands. The presence of bias for NOAA-20 is likely attributed to prelaunch calibration uncertainties. The NOAA-20 VIIRS radiometric performance needs to be regularly monitored to ensure that the data quality meets the user requirements well. In addition, consistent calibration with other instruments such as S-NPP VIIRS is critical to establish data continuity, which is a key requirement for long term environmental studies.

ACKNOWLEDGEMENT

The manuscript contents are solely the opinions of the authors and do not constitute a statement of policy, decision, or position on behalf of NOAA or the U.S. government.

REFERENCES

[1] Uprety, S., Cao, C., & Shao, X. (2020). Radiometric consistency between GOES-16 ABI and VIIRS on Suomi NPP and NOAA-20. *Journal of Applied Remote Sensing*, *14*(3), 032407.

[2] Uprety, S., Cao, C., Blonski, S., & Shao, X. (2018, October). Evaluating NOAA-20 and S-NPP VIIRS radiometric consistency. In *Earth Observing Missions and Sensors: Development, Implementation, and Characterization V* (Vol. 10781, p. 107810V). International Society for Optics and Photonics.

[3] Wang, W.; Cao, C. Evaluation of NOAA-20 VIIRS Reflective Solar Bands Early On-Orbit Performance Using Daily Deep Convective Clouds. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2020, 10.1109/jstars.2020.3007863, 1-1, doi:10.1109/jstars.2020.3007863.

[4] Cao, C., Weinreb, M., & Xu, H. (2004). Predicting simultaneous nadir overpasses among polar-orbiting meteorological satellites for the intersatellite calibration of radiometers. Journal of Atmospheric and Oceanic Technology, 21(4), 537-542.

[5] Uprety, S., C. Cao, X. Xiong, S. Blonski, A. Wu, and X. Shao. 2013. “Radiometric Intercomparison between Suomi-NPP VIIRS and Aqua MODIS Reflective Solar Bands Using Simultaneous Nadir Overpass in the Low Latitudes.” Journal of Atmospheric and Oceanic Technology 30 (12): 2720–2736. doi:10.1175/JTECH-D-13-00071.1.

[6]Helder, D. L., B. L. Markham, K. J. Thome, J. A. Barsi, G. Chander, and R. Malla, "Updated radiometric calibration for the Landsat-5 Thematic Mapper reflective bands." Geoscience and Remote Sensing, IEEE Transactions on 46.10 (2008): 3309-3325.

[7] Markham, B. L., K. J. Thome, J. A. Barsi, E. Kaita, D. L. Helder, J. L. Barker, and P. L. Scaramuzza, "Landsat-7 ETM+ on-orbit reflective-band radiometric stability and absolute calibration." Geoscience and Remote Sensing, IEEE Transactions on 42.12 (2004): 2810-2820.

[8] Markham, B. L., and D. L. Helder. "Forty-year calibrated record of earth-reflected radiance from Landsat: A review." Remote Sensing of Environment122 (2012): 30-40.

[9] Uprety, S., & Cao, C. (2010, August). A comparison of the Antarctic Dome C and Sonoran Desert sites for the cal/val of visible and near infrared radiometers. In *Atmospheric and Environmental Remote Sensing Data Processing and Utilization VI: Readiness for GEOSS IV* (Vol. 7811, p. 781106). International Society for Optics and Photonics.

[10] Uprety, S., and C. Cao. 2015. “Suomi NPP VIIRS Reflective Solar Band On-Orbit Radiometric Stability and Accuracy Assessment Using Desert and Antarctica Dome C Sites.” Remote Sensing of Environment 166: 106–115. doi:10.1016/j.rse.2015.05.021.

[11] Zhang, B., Cao, C., Blonski, S., Wang, W., and Shao, X., 2019, JPSS VIIRS Solar Vector Anomaly Root Cause Analysis and Lessons Learned, 2020 JPSS GOES Proving Ground / Risk Reduction Summit, NOAA NCWCP, College Park, MD.