# NOAA-20/S-NPP VIIRS SENSOR DATA RECORD ON-ORBIT PERFORMANCE UPDATES AND RECENT IMPROVEMENTS

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**ABSTRACT**

This paper presents NOAA-20 and S-NPP Visible Infrared Imaging Radiometer Suite (VIIRS) Reflective Solar Bands (RSB) and Thermal Emissive Bands (TEB) Sensor Data Records (SDR) performance and recent improvements to support user communities. Results for NOAA-20 VIIRS and in 2019 are emphasized. NOAA-20 VIIRS geolocation errors are within ±100 m, comparable to S-NPP; RSBs have been stable after achieved validated maturity status, except that small upward trends were observed; TEBs agree with co-located Cross-track Infrared Sounder (CrIS) observations within ~0.1 K at nadir, more stable (relative to CrIS) compared to S-NPP TEBs in 2019. NOAA-20 RSBs continue bias ~2-4.5% lower than S-NPP. Three major improvements to VIIRS SDRs, including the new operational M6 saturation rollover flagging method, the operational TEB warm-up/cool-down bias correction, and the latest results for correcting NOAA-20 TEB scan angle/scene temperature dependent biases, are also presented to address users' concerns.

***Index Terms***— VIIRS, NOAA-20, S-NPP, SDR, TEB, RSB, calibration stability, calibration bias.

## 1. INTRODUCTION

The Visible Infrared Imaging Radiometer Suite (VIIRS), onboard the National Oceanic and Atmospheric Administration - 20 (NOAA-20) satellite, was launched on November 18, 2017, after six years of successful operation by its predecessor on the Suomi National Polar-orbiting Partnership (S-NPP) satellite [1, 2]. S-NPP and NOAA-20 VIIRS are equipped with 5 imaging bands (I-bands, 375 m at nadir), 16 moderate resolution radiometric bands (M-bands, 750 m at nadir), and one Day/Nigh Band (DNB, 750 m). NOAA-20 VIIRS sensor data records (SDR) achieved validated maturity status on April 30, 2018. The operational NOAA-20 SDR products are available to the public since February 1, 2018. NOAA-20 and S-NPP VIIRS SDR products are valuable for monitoring severe weather events and air quality, and deriving a wide variety of environmental data records (EDR), such as cloud and aerosol properties, ocean color, sea surface temperature (SST) and land/ice surface temperature, active fires, and Earth's albedo. Moreover, assimilation of VIIRS clear-sky SST channel radiances to the numerical weather prediction models is ongoing at NOAA. It is important to monitor and improve the operational NOAA-20 and S-NPP VIIRS SDR products to support user communities.

This paper presents NOAA-20 and S-NPP VIIRS RSB/TEB SDR performance and improvements in the NOAA operational processing from the beginning of the NOAA-20 mission to the end of 2019. Results for NOAA-20 VIIRS and in 2019 will be emphasized. Geolocation and RSB/TEB SDR performance will be given in Section 2. Section 3 presents recent major improvements in the VIIRS SDRs. Section 4 summaries this study. DNB SDR performance is not covered here due to space limits.

## 2. NOAA-20/S-NPP VIIRS RSB/TEB ON-ORBIT CALBRATION PERFORMANCE

### 2.1. Performance of Geolocation Products

Accurate geolocation is the prerequisite for quality VIIRS applications. At the NOAA Center for Satellite Application and Research (STAR), VIIRS I-bands and M-bands geometric performance are monitored using the NASA Control Point Matching (CPM) tool [3]. Fig. 1 compares NOAA-20 and S-NPP VIIRS I-bands along-scan and along-track geolocation errors (nadir equivalent) during the past two years. Both NOAA-20 and S-NPP along-scan and along-track errors are better than ±100 m since January 5, 2018. NOAA-20 along-scan errors exhibit larger seasonal variations than S-NPP, while the S-NPP geolocation errors have slightly increased, may due to star tracker reset and/or CERES biaxial scanning. Overall, 95% of the circular geolocation errors are within 200 m, half the size of the I-band pixels. Note that the measurements of the I-band geolocation errors can also be applied to the M-bands.

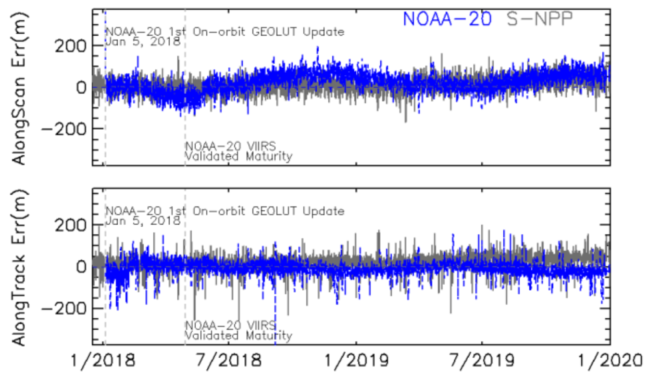


Fig. 1. Time series of NOAA-20 and S-NPP VIIRS I-bands geolocation errors in the along-scan errors (top) and along-track (bottom) directions.

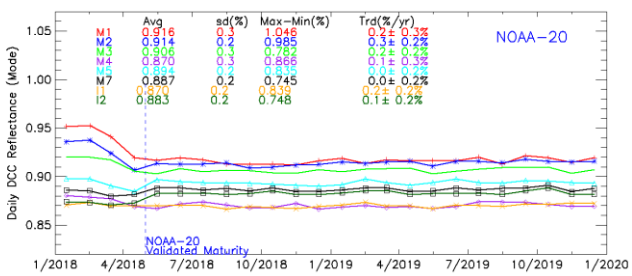


Fig. 2 NOAA-20 VIIRS VIS/NIR bands (I1-I2, M1-M5, M7, and I1-I2) monthly DCC time series. All statistics were calculated using data after achieved validated maturity. M6 is saturated over DCCs and not considered.

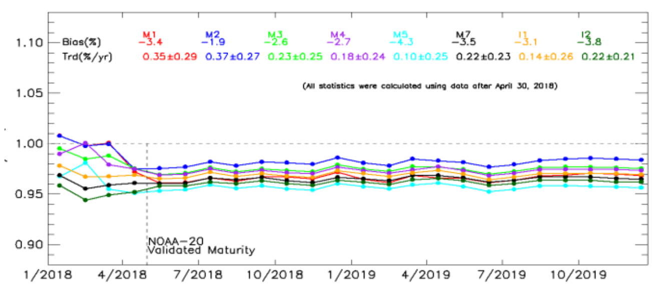


Fig. 3 NOAA-20/S-NPP monthly DCC band ratio time series for VIS/NIR bands.

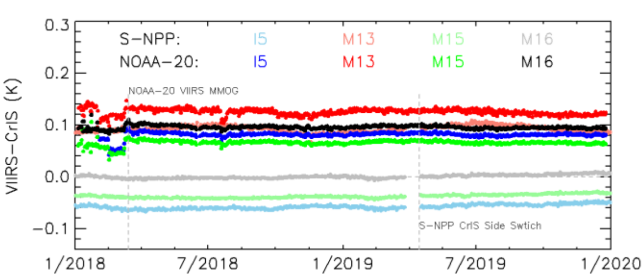


Fig. 4 Time series of NOAA-20 and S-NPP VIIRS – CrIS BT biases at nadir during nominal operations. VIIRS bands M15, M16, M13, and I5 are covered by CrIS spectra.

### 2.2 Performance of RSB SDRs

Long-term calibration stability and biases for NOAA-20 and S-NPP VIIRS RSBs were monitored using monthly/daily Deep Convective Clouds (DCC) [4], lunar calibration [5], Pseudo Invariant Calibration Sites (PICS), and Simultaneous Nadir Overpasses (SNO). We compared results from different methods to support optimal decision making for on-orbit calibration update.

NOAA-20 VIIRS RSBs have been generally stable after achieved validated maturity status on April 30, 2018. NOAA-20 RSBs have been calibrated using constant calibration factors during the past 20 months with the assumption that no significant degradation occurs, different from S-NPP. Fig. 2 shows NOAA-20 visible and near-infrared band (VIS/NIR, I1-I2 and M1-M7) monthly DCC time series. Annual cycles in the DCC time series were corrected using a DCC annual cycle climatology derived using reprocessed S-NPP data. Small upward trends (~0.1-0.3%/year) were observed in some VIS/NIR bands. Meanwhile, S-NPP VIS/NIR DCC time series show no significant trend. The monthly DCC results agree well with that of daily DCC time series and solar/lunar calibration [5]. Relatively larger trends (up to 0.9%/year) were observed in some NOAA-20 and S-NPP VIIRS SWIR bands, which requires further monitoring and study.

NOAA-20 RSBs continue bias lower than S-NPP in 2019, similar to the results for 2018 [6]. Fig. 3 shows NOAA-20/S-NPP monthly DCC band ratio time series for the VIS/NIR bands. NOAA-20 VIS/NIR bands are ~2-4.5% lower than S-NPP, after the correction of spectral response differences between the two VIIRS. Similar results were observed in the daily DCC band ratio, PICS, and VIIRS-MODIS SNO time series. However, small positive trends (0.2-0.4%/year) were observed in the band ratio time series, indicating that the biases may reduce slightly over time.

### 2.3 Performance of TEB SDRs

VIIRS TEB calibration stability and biases were monitored using the co-located Cross-track Infrared Sounder (CrIS) observations [7]. Fig. 4 show NOAA-20 and S-NPP VIIRS – CrIS brightness temperature (BT) difference time series during nominal operations. For I5 and M15-M16, NOAA-20 TEBs are more stable relative to CrIS after the March 12, 2018 mid-mission outgassing (MMOG) [1], with trends ~0.002 K/year. S-NPP VIIRS – CrIS BT different time series show increasing of trends (on the order of 0.01 K/year) after the switch of CrIS electronics side in mid-2019. The issue needs to be further investigated.

NOAA-20 I5, M13, and M15-M16 agree with CrIS within ±0.1 K at nadir, comparable to S-NPP. The relatively larger biases in M13 (~0.14 K for NOAA-20 and ~0.1 K for S-NPP) are due to the use of the normal spectral resolution CrIS data. Our analysis indicates that the M13 biases will be

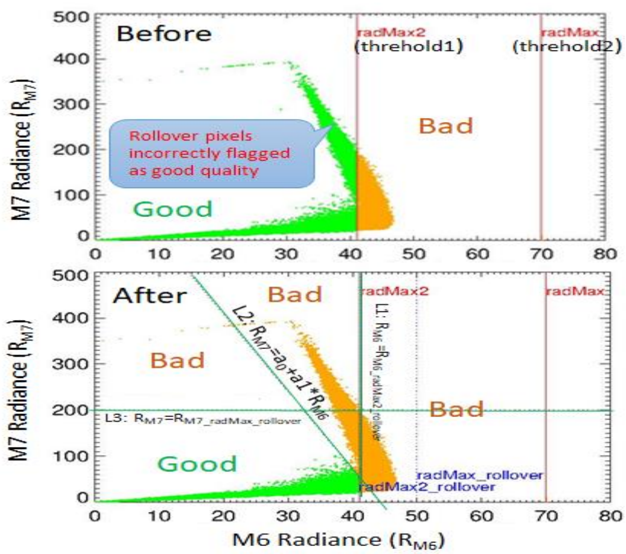


Fig. 5 NOAA-20 M6 saturation rollover flagging (HAM-A, detector 7) for before (top) and after (bottom) the implementation of the new method. One-day (May 2, 2018) of NOAA operational and reprocessed M6 and M7 data were used.

comparable to other bands if full spectral resolution CrIS observations are used.

Two known calibration biases exist in the VIIRS TEB SDRs by the end of 2019. First, warm-up/cool-down (WUCD) biases were observed in the operational NOAA-20 and S-NPP SDRs. Second, NOAA-20 bands I5 and M15-M16 exhibit larger than expected scan angle and scene temperature dependent biases (up to 1.0 K near the beginning of scan) relative to CrIS observations [8]. Our efforts to resolve these biases will be given in Sections 3.2 and 3.3.

## 3. RECENT IMPROVEMENTS IN NOAA-20/S-NPP VIIRS RSB/TEB SDRS

### 3.1 M6 Saturation Rollover Flagging and Platform Dependent Radiance Limit Verification

NOAA-20 and S-NPP VIIRS band M6 (~0.745 µm) is primarily used for atmospheric correction. It has a low saturation radiance (41 W $m^{-2}$ $um^{-1}$ $sr^{-1}$), at the same levels as bright Saharan dust plumes. The original saturation rollover flagging method in the NOAA operational software used two simple platform (NOAA-20 or S-NPP) independent thresholds, maximum radiance (radMax) and maximum good radiance (radMax2) to separate good and rollover pixels. EDR data users have reported that this method cannot flag good and rollover pixels reliably for M6, with large number of NOAA-20 M6 saturation rollover pixels flagged as good quality (see Fig. 5 top) and large number of S-NPP M6 good pixels flagged as bad quality due to its large responsivity degradation in the rotating telescope assembly (>30% in S-NPP M6).

A new method, designed to improve saturation rollover flagging for all VIIRS RSBs, has been developed and implemented in the NOAA operational processing since March 25, 2019 (algorithm version Block2.1 Mx5). It introduces a reference band to assist the detection of rollover pixels in a target band. For example, M7 is used as the reference band for M6. Three platform, half-angle-mirror (HAM) side, and detector dependent lines (L1-L3) were used to better separate good and rollover pixels (see Fig. 5 bottom). Moreover, platform dependent saturation radiances were used. It can be observed in Fig. 5 that the new method is able to flag good and rollover pixels successfully for NOAA-20. Similar improvements were also observed for S-NPP M6.

Besides the new saturation rollover flagging method, platform dependent radiance/BT limits were also implemented to replace the original S-NPP spectral response function based limits. NOAA-20 and S-NPP RSR functions are very close to each other, but not exactly the same. After this improvement, previously incorrect fill values and quality flags in the NOAA-20 VIIRS TEB SDRs at cold scene temperatures were corrected.

### 3.2 Operational TEB WUCD Bias Correction

The S-NPP TEB WUCD biases were studied in-depth in our previous studies [7, 9]. We also analyzed NOAA-20 TEB WUCD biases. NOAA-20 WUCD biases are about 50% smaller than S-NPP. However, WUCD anomaly is still visible in the daytime SST – *in situ* time series (Dr. A. Ignatov, NOAA/STAR SST team, personal communication) and needs to be corrected.

A VIIRS SDR algorithm code change for both NOAA-20 and S-NPP has been implemented in the NOAA operational processing software (version Block2.1 Mx6) in July 2019. Fig. 6 compares VIIRS – CrIS BT difference time series for the NOAA-20 VIIRS March 2019 WUCD, generated using the NOAA operational data (top) and the Block2.1 Mx6 deploy regression test data (bottom, run parallel to the operational processing before the implementation). It can be observed that after the code change, NOAA-20 TEB daily averaged WUCD biases were reduced to ~0.01 K. Similar reductions of WUCD biases were also observed for S-NPP. Some residual biases exist after the correction, especially in M16. Nevertheless, evaluation results using the SST algorithm indicate that the SST WUCD anomaly was successfully removed. The frequency of NOAA-20 and S-NPP WUCD has been reduced from quarterly to annual after the June 2018 WUCD [10]. We also evaluated the code change using operational data during the March 2020 WUCD events. Our analysis indicates that the WUCD bias correction results are as expected for both NOAA-20 and S-NPP.

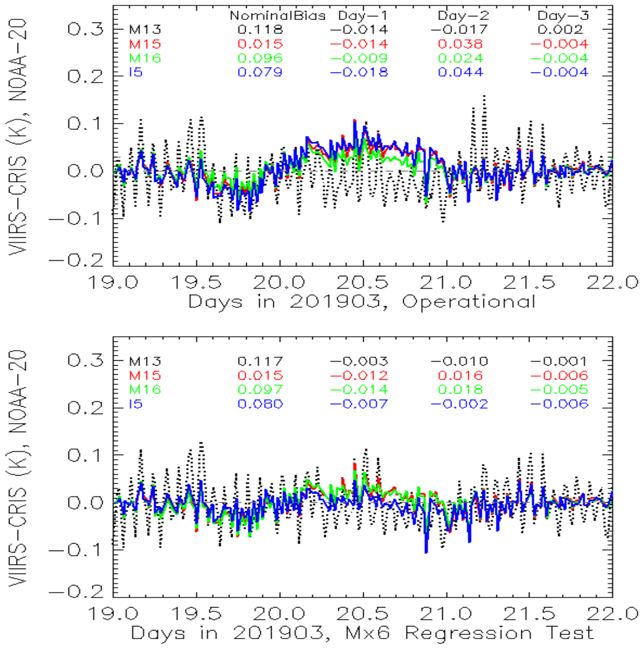


Fig. 6 NOAA-20 VIIRS TEB calibration biases relative to co-located CrIS observations during the March 19-21, 2019 WUCD event: NOAA operational data (top); regression testing data (bottom).

### 3.3 NOAA -20 VIIRS TEB Scan Angle and Scene Temperature Dependent Biases

We also investigated the NOAA-20 bands M15-M16 and I5 scan angle/scene temperature dependent biases relative to CrIS observations. A method to estimate VIIRS TEB on-orbit response versus scan angle (RVS) using pitch maneuver data was developed previously [8]. Evaluation results indicates that the on-orbit RVS can effectively reduce the scan angle and scene temperature dependent biases to 0.15 K. Recently, we further refined the method to better estimate errors in prelaunch RVS and other TEB calibration parameters. Preliminary results indicate that the refined method can effectively reduce the scan angle/scene temperature dependent biases, similar to [8]. Meanwhile, it generates more stable on-orbit calibration factors. The calibration parameters derived using the refined method may be implemented operationally after their impacts on the TEB SDRs are fully evaluated.

## 5. SUMMARY

This paper presents NOAA-20 and S-NPP VIIRS RSB/TEB SDR performances and recent improvements. NOAA-20 VIIRS geolocation errors are within ±100 m, comparable to S-NPP. NOAA-20 RSB SDRs have been stable in 2019, better than S-NPP. NOAA-20 RSBs continue to bias 2-4.5% lower than S-NPP in 2019, which is being investigated. NOAA-20 TEB calibration agrees with co-located CrIS observations within ±0.1 K at nadir. S-NPP VIIRS – CrIS BT difference time series show relatively larger trends in 2019 and need to be investigated.

Several major improvements have been developed and/or implemented in the NOAA operational processing to address concerns from data users. A new saturation rollover flagging method and platform-dependent radiance limits were developed and implemented to improve the image quality of band M6. Operational VIIRS TEB WUCD bias correction was implemented to minimize TEB calibration biases, thence the WUCD anomaly in the daily SST retrievals. Moreover, a refined method was also developed to reduce the observed NOAA-20 TEB scan angle and scene temperature dependent biases.

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