

Implementation of Monitoring of VIIRS Ocean Clear-sky Brightness Temperatures against CRTM Simulation in ICVS

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Abstract

Monitoring of VIIRS ocean clear-sky brightness temperatures against CRTM Simulations has been initially implemented in the NOAA Integrated Calibration/Validation System (ICVS) for VIIRS calibration and validation. The initial system builds upon the heritage Monitoring of IR Clear-sky Radiances over Ocean for SST (MICROS). Substantial effort was made to further minimize the observation minus simulation biases. Preliminary results show that both mean biases and standard deviation are significantly improved in ICVS, compared to MICROS. The long term stability has also improved and shows a close cross-sensor consistency between VIIRS and MODIS. The current monitoring system is ready for J1 VIIRS test.

Keywords: ICVS, CRTM, MICROS, O-M, Double Differences, ECMWF, GFS

1. Introduction

The Integrated Calibration/Validation System for long-term monitoring (ICVS, www.star.nesdis.noaa.gov/icvs/) [8] is a near-real time system developed at NOAA to monitor the performance of various sensors onboard environmental satellite. It is used to ensure high-quality satellite imagery and accurate Sensor Data Records (SDR) for weather forecasts and environmental monitoring. The Visible Infrared Imaging Radiometer Suite (VIIRS) [1], flown onboard the Suomi-NPP (S-NPP) and follow-up Joint Polar Satellite System (JPSS) satellites, is the key sensor monitored in the ICVS. With the development of faster and more accurate radiative transfer models (RTM) over the full spectral range from the microwave to the ultraviolet, validating sensor radiometric accuracy against RTM simulation has become an important requirement from both SDR and Environmental Data Record (EDR) user communities. Also, the model data can be used to perform comparisons with sensor measurement in global area without complex collocation in space and time [3-6]. Monitoring sensor Observations (“O”) against radiative transfer Model (“M”) simulations (O-M) has been comprehensively used to evaluate the performance of various sensors. At NOAA, Monitoring of IR Clear-sky Radiances over Ocean for SST (MICROS, www.star.nesdis.noaa.gov/sod/sst/micros/) was developed by the Sea Surface Temperature (SST) Team. It monitors M-O biases in atmosphere window bands to evaluate SSTs and corresponding brightness (BTs) for accuracy, stability and cross-platform consistency [4]. The NOAA fast Community Radiative Transfer Model (CRTM) is used to generate model data. Upon its launch in 2008, MICROS became a reference system for sensor calibration and CRTM validation. This paper documents implementation of the monitoring of VIIRS sensor observation against CRTM simulation system in ICVS for VIIRS sensor calibration, building on the MICROS framework. Substantial effort was made to extend MICROS functionalities and improve the O-M accuracies for VIIRS calibration. The objective of this study is to understand and minimize O-M biases and uncertainty, with a particular focus towards VIIRS SDR calibration and validation, including evaluation of the VIIRS BTs for long term stability and cross-platform consistency.

2. Minimization of O-M Biases and Functionality Extension

2.1. The Heritage MICROS and ICVS Improvements

The initial O-M monitoring in ICVS was built upon the heritage MICROS. The MICROS monitors M-O biases in three SST window bands (3.7, 11, and 12 μm), in global clear-sky ocean domain. The model data are calculated using CRTM in conjunction with $1^\circ \times 12\text{hr}$ National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) upper air fields and 0.1° daily Canadian Meteorology Centre (CMC) SST analysis. The model data are calculated at 1° resolution grid and the result is interpolated to pixel [3], resulting in smaller processing time while keeping all clear-sky pixels in the comparison statistics [5]. The NOAA Advanced Clear-Sky Processor over Ocean (ACSPO) system was employed to identify clear-sky pixels [7]. Overall, the MICROS system proved well suited for SST applications. To focus on the needs of VIIRS SDR calibration and validation, the model simulation and ACSPO clear-sky mask were modified in ICVS as follows. First, higher spatial resolution 0.25° ECMWF forecast data are used in ICVS as CRTM input. Second, the simulations in ICVS are performed in a sub-sample of all clear-sky pixels, defined by a four-by-four moving window, which minimizes the need for spatial interpolation employed in MICROS. Table 1. The different implementation of O-M between MICROS and ICVS

The ACSPO clear-sky mask was modified, to remove model interpolation. Also, analyses have been extended from the initial set of three SST window bands, to include all five TEB/M VIIRS window bands. Table 1 summarizes the differences in the calculation of O-M biases between MICROS and ICVS.

Table 1. The different implementation of O-M between MICROS and ICVS

	Atmosphere Prof.	Model simulation	Cloud mask	Band selection	Sensors	CPU time
MICROS	NCEP GFS 1.0° , 12hr forecast	1.0° model resolution interpolated to pixel	ACSPO clear- sky mask (ACSM)	IR37, IR11, IR12	AVHRR MODIS VIIRS	7 hours
ICVS	ECMWF, 0.25° , 3&9hr forecast	Model calculated in selected pixels in a 4 by 4 moving window	Modified ACSM	M12, M13, M14, M15, M16	VIIRS	15 hours

2.2. Minimization of O-M Mean Biases and Standard Deviations

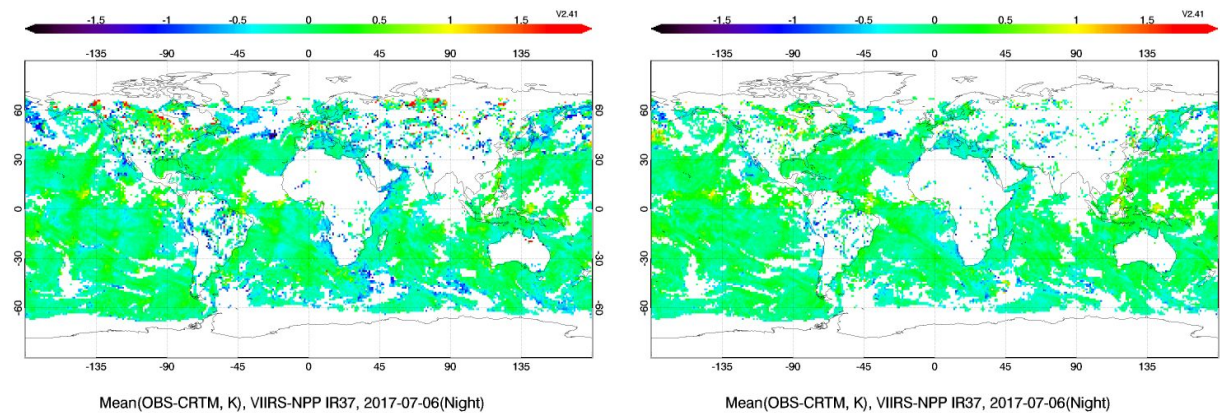


Figure 1. Global Maps of O-M biases in M12 for (Left) MICROS and (right) ICVS.

Figure 1 shows the global maps of O-M biases in VIIRS M12 on 07/06/2017 night for (left panel) MICROS and (right panel) ICVS. Hereafter, only nighttime data are used for evaluation of O-M biases, to minimize the effect of the diurnal cycle and remove the solar reflection contamination [4]. Both maps were gridded to 1° resolution. The global coverage in the ICVS is comparable to that in MICROS. Both O-M mean biases are close to 0K, as expected, but they are more uniform in the ICVS implementation.

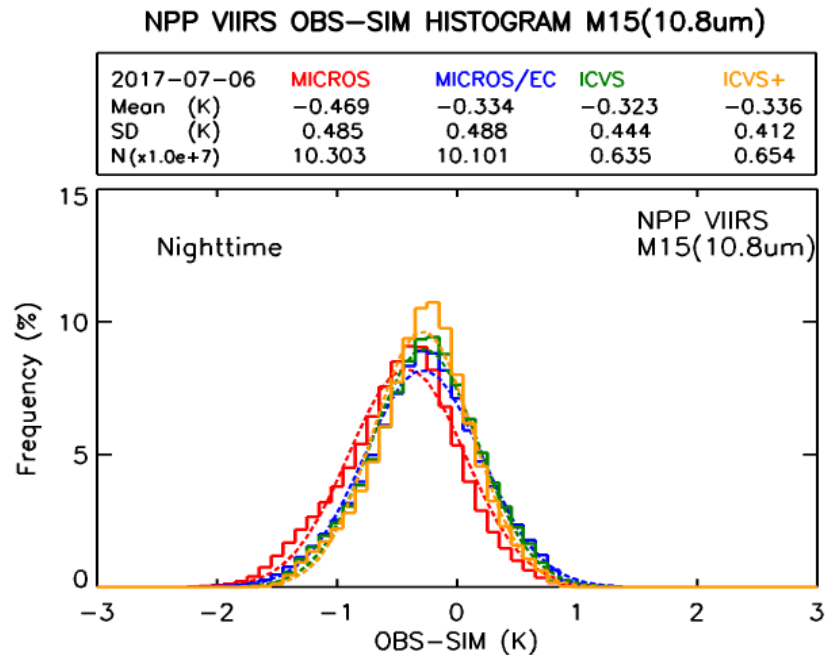


Figure 2. Histograms of O-M biases in M15 for four cases

Figure 2 compares global histograms of the O-M biases between MICROS and ICVS. To facilitate understanding what factors contribute to the ICVS improvement, two additional cases with different model calculations were added. In one, MICROS was used but with the 0.25° ECMWF forecast data instead of GFS (referred to hereafter as MICROS_EC). In another, the ICVS set-up was used, but the ECMWF analysis data is used as CRTM inputs instead of forecast (referred to as ICVS+).

Figure 2 shows the corresponding four histograms of the O-M biases in VIIRS band M15. The global statistics of the mean O-M, standard deviation (SD) and number of clear-sky pixels (N) are also superposed, along with the Gaussian fits (corresponding to these global mean and SD). MICROS has much larger number of clear-sky pixels (~103M/night; hereafter M stand for “million”) than ICVS (~6.35M/night), due to interpolation of the model data in MICROS vs. sub-sampling in ICVS. All cases show cold O-M biases (whose root cause was discussed in [5] and attributed to three factors in model simulations and one factor in observations). However, the mean biases are significantly closer to zero when ECMWF forecast data are used instead of GFS (-0.33 K vs. -0.47 K). This improvement may be in part due to a higher spatial and temporal resolution in the ECMWF data, and in part due to a better quality vertical profiles of the temperature and humidity, compared to the GFS model. Interestingly, the SDs in MICROS and MICROS_EC are comparable (~0.49 K), but they are significantly smaller for the in-pixel ICVS calculations compared to interpolation performed in MICROS. The root-mean-square SD improvement of ~0.2 K in ICVS suggests that the linear interpolation from model data to pixel in MICROS adds noise to the O-M, although it remains efficient for calculation of the global mean O-M biases. In the ICVS, which requires more accurate instantaneous O-M biases, direct model calculation in-pixel was selected. The SDs further reduce (by 0.17 K in RMS sense) when ECMWF analysis data was used in ICVS+, instead of forecast.

Global O-M statistics in all five VIIRS window bands are shown in Table 2. Similarly to the M15, the O-M’s are biased cold in all bands. In the most transparent M12, biases are much closer to 0 and least sensitive to the profiles and calculation scheme, suggesting that at least in part, the O-M biases are due to “dry biases” (underestimated water

vapor in the atmospheric profiles. If that is the case, then these dry biases apparently are larger in the GFS than in the ECMWF data. The SDs are reduced in ICVS implementation, which use direct model calculations with no interpolation, by 0.17 K, 0.30 K, 0.26 K and 0.22 K for M12, M13, M14, and M16, respectively (in RMS sense). (Note that as of this writing, M13 and M14 are still not monitored in the MICROS system operated by the SST Team). The SDs are further smaller in ICVS+, which uses ECMWF analysis instead of forecast.

	μ				σ			
	MICROS	MICROS/EC	ICVS	ICVS+	MICROS	MICROS/EC	ICVS	ICVS+
M12	-0.065	-0.040	-0.027	-0.033	0.341	0.359	0.314	0.307
M13	N/A	-0.616	-0.549	-0.548	N/A	0.387	0.274	0.266
M14	N/A	-0.503	-0.493	-0.511	N/A	0.473	0.398	0.357
M15	-0.469	-0.334	-0.323	-0.336	0.485	0.488	0.444	0.412
M16	-0.590	-0.420	-0.425	-0.447	0.569	0.581	0.536	0.481

Table 2. Global statistics of O-M biases for five VIIRS TEB/M bands.

3. View Zenith Angle Dependencies and M13 Anomaly

Figure 3 shows satellite view zenith angle (SZA) dependencies of O-M mean biases in five window bands. In M12, M14, M15 and M16, the amplitude of SZA dependencies is well within 0.1 K, suggesting a good CRTM performance in the full satellite swath (although part of pixels with large O-M biases may be screened out by ACSPO

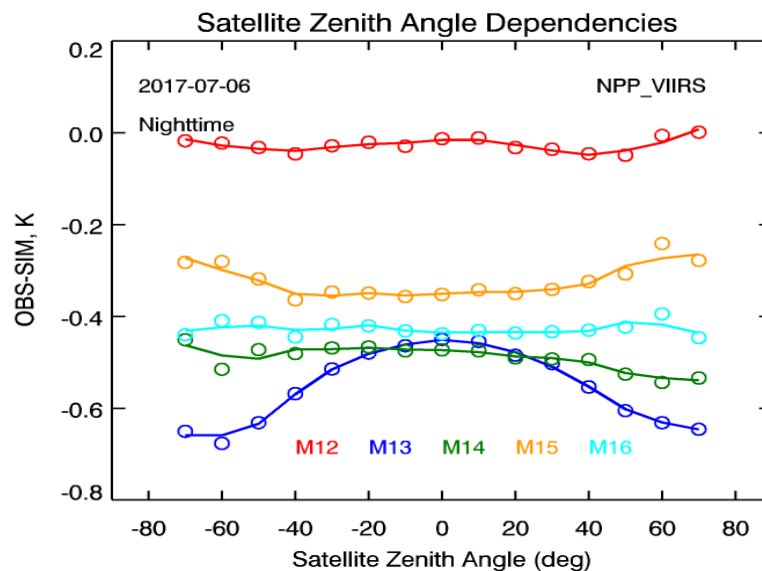


Figure 3. Satellite zenith angle dependencies of O-M biases

clear-sky mask). On the other hand, the SZA dependence in M13 is much larger and reaches ~0.25 K. Hunting root cause of this anomaly in M13 is currently underway, by comparing VIIRS BTs with those obtained by convoluting the CrIS spectra with VIIRS spectral response functions. Results, once available, will be reported elsewhere.

4. Stability and cross-platform consistency of the long term O-M biases

Long-term stability of O-M biases is critically important, to ensure long-term stability of VIIRS SDRs and derived EDRs. Double differences between S-NPP VIIRS and Terra MODIS are employed, to further minimize correlated errors in the O-M biases from both sensors [5].

4.1. Long term stability of the O-M biases

Figure 4 shows time series of O-M (upper panel) mean biases and (bottom panel) corresponding SDs for all five window M bands, for one full year from Sep 2016 – Aug 2017. The temporal mean and variability statistics are also superimposed. The O-M mean biases are generally stable in all bands: the temporal variability is generally within $\sigma(\mu) < 0.035$ K for the means and within $\sigma(\sigma) < 0.01$ K for the SDs. An interesting observation in the time series plots is that BTs show quarterly pop-ups and drop-downs, exactly at the times when the VIIRS SDR team conduct regular Warm-Up-Cool-Down (WUCD) exercises. The effect on BTs and SSTs was first observed in MICROS by SST Team and reported to the VIIRS SDR Team. This effect is seen more clearly in the ICVS O-M monitoring system, due to reduced noise. The O-M biases change significantly during cool-down phase of the WUCD event: BTs in the longwave M14/M15 pop up by +0.1 K in the cold down phase, and drop down in the shortwave M12/M13 by -0.1 K. The M16 is only minimally affected. The SDs are affected negligibly by the WUCD. Overall, the long term O-M biases monitoring system obviously capture BT changes in WUCD events, and it has been used to check WUCD correction conducted by VIIRS SDR Team [2] during WUCD period. The result will be published elsewhere.

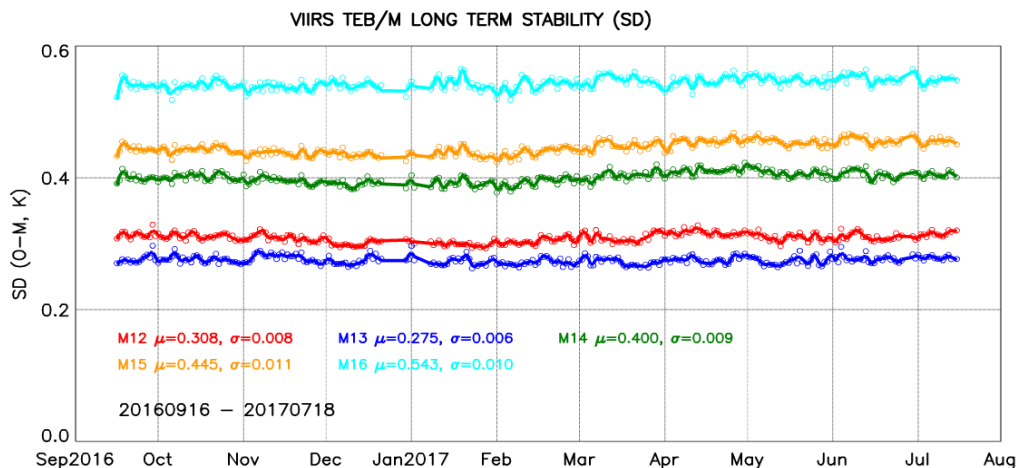


Figure 4. Time series of O-M (upper panel) mean biases and (bottom panel) SDs for five TEB/M bands

4.2. Double Differences

The time series plots of O-M biases show persistent cold O-M biases, of several tenths of a Kelvin for all window bands except M12. The largest cold O-M biases are up to ~0.6 K in M13. The biases largely hint accurately evaluating VIIRS sensor performances. Double differences (DDs) can be used to cancel out or minimize systematical and CRTM model biases, and further minimize their effect on the mean O-M biases [5-6].

DDs use a well-calibrated sensor (similar to VIIRS) as reference, and CRTM as a transfer, and calculate the difference of the O-M for the pair sensors as follows

$$DD = VIIRS(O - M) - REF(O - M) \quad (1)$$

In this study, Terra MODIS was used as a reference. The DDs can check BTs for cross-platform consistency. One month analyses data of Terra MODIS was calculated for DD evaluation. Figure 5 shows corresponding DDs for three SST window bands, M12, M15 and M16.

The mean DDs in M15/M16 are -0.037/-0.013 K, respectively. They are much smaller than the corresponding single-sensor O-M mean biases. For the M12, mean DD is 0.085 K and slightly larger than single mean biases, likely due to different spectral responses between VIIRS M12 and MODIS Band 20. All SDs are smaller compared to single-sensor O-M biases. Overall, DDs cancelled out most model and systematical errors, and show much smaller O-M biases in the longwave IRs. Long term stability is also improved. The DDs will be added in next version of the ICVS.

5. Conclusion and Future Work

Initial monitoring system of VIIRS BTs against CRTM simulation for window bands has been implemented in ICVS, in support of VIIRS calibration. The system was built upon the heritage MICROS system, developed by the NOAA SST Team. The new O-M monitoring system uses 0.25° ECMWF data instead of 1° GFS as CRTM inputs. Also, model simulations are performed in-pixel, using a four-by-four moving window. The ACSPO clear-sky mask was also adjusted for the use in the ICVS. Furthermore, the MICROS functionality was extended, to include analyses in all five window TEB/M bands, in contrast with only three SST window bands analyzed in the current MICROS.

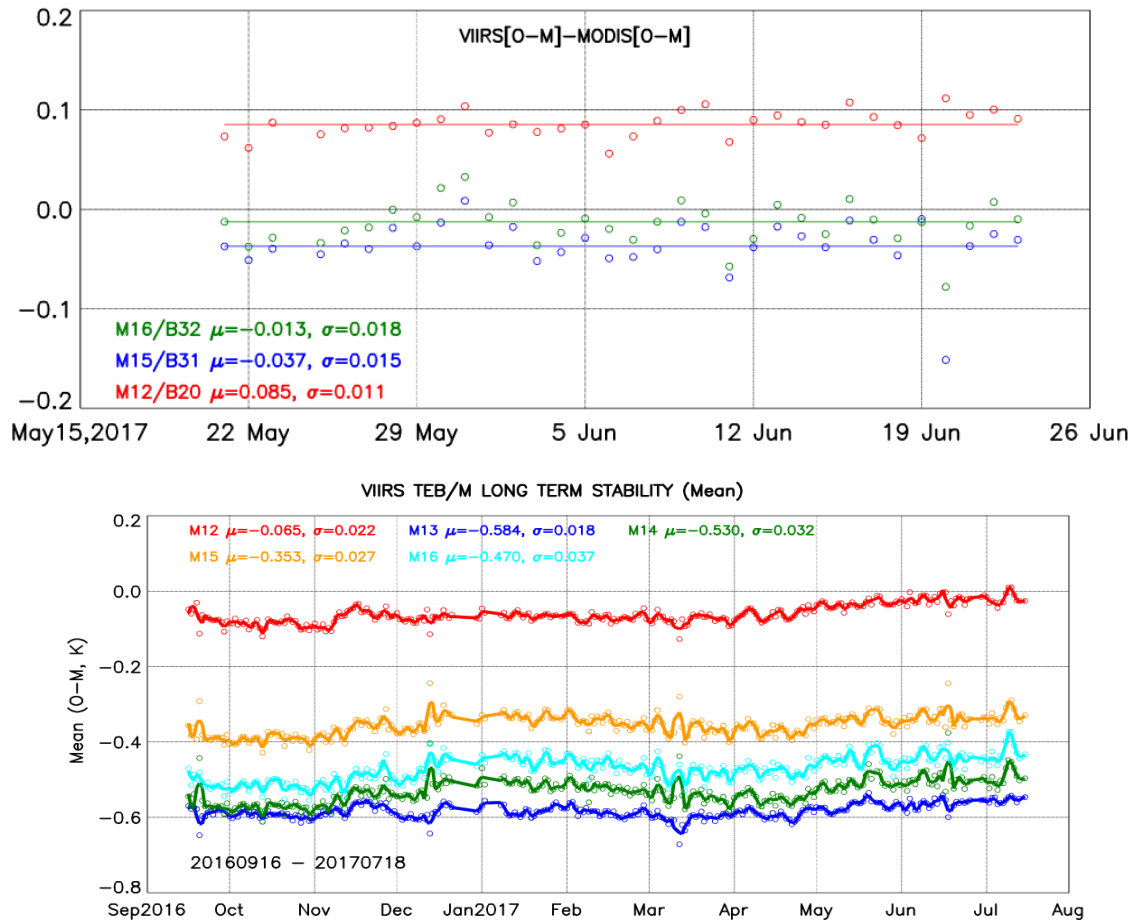


Figure 5. Double differences for M12, M15 and M16 with Terra MODIS as reference.

The sustained efforts in ICVS O-M monitoring system significantly minimized both O-M mean biases and SDs. A case study shows that the mean O-M biases are smaller by ~ 0.16 K in longwave IR, and SDs smaller by ~ 0.15 - 0.30 K, compared to MICROS. There are no obvious VZA dependencies for M12, M14, M15 and M16, suggesting a good CRTM performance for large satellite view zenith angles, up to swath edge. A ~ 0.25 K SZA dependencies in M13 was found, and the root source is being investigated, by comparison of VIIRS BTs with CrIS data.

Time series of the O-M biases in all five TEB bands are stable in time. The temporal variability is within 0.05 K for the mean biases, and ~ 0.01 K for the corresponding SDs. Time series of O-M biases clearly show BT anomalies during the Warm-Up-Cool-Down (WUCD) exercises. The ICVS and MICROS implementations have been used to identify the WUCD anomalies, and check corrections to those developed by the VIIRS SDR Team. A double differences analysis shows much small cross-platform mean biases and SDs, compared to single-sensor O-M biases, in all bands except for the M12/B20 pair, which may be due to different MODIS/VIIRS spectral responses.

The O-M monitoring system has been extended to be ready for J1 VIIRS launch. Future work will be directed towards updating ICVS to ICVS+, using ECMWF analysis as CRTM inputs. The ICVS O-M functionality will be extended to include TEB/I band analysis and the DD analysis.

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