Suomi NPP VIIRS Detector Dependent Relative Spectral Response Variation
Effects using Line-by-Line Radiative Transfer Model Calculations

Zhuo Wanga and Changyong Caob

a University of Maryland, College Park, Maryland, b NOAA/NESDIS/STAR, College Park, Maryland

Abstract

The Visible Infrared Imaging Radiometer Suite (VIIRS) is an advanced focal plane array based radiometer, which has many detectors with slightly different relative spectral response (RSR). Effect of RSR differences on imaginary artifacts, as well as geophysical retrieval uncertainties has not been well studied. Previous studies used the MODTRAN model for detector-level radiative simulations. However, it is limited in reproducing the spectral resolution of the model relative to the narrow spectral bandwidth of the detectors. This study evaluates detector-level RSR using Line-by-Line Radiative Transfer Model (LBLRTM) at higher spectral resolution 0.01 cm⁻¹ for VIIRS bands M15 and M16 under different atmospheric conditions. From the model simulation and case studies of VIIRS SDR brightness temperature data, we found that the stripping in imagery is mostly likely related to the difference between band averaged and detector level RSR, which has some atmospheric dependency. Cumulative histogram method is utilized to quantify the stripping. These findings will help S-NPP and J1 to better understand the impact of the difference in detector-to-detector RSR on VIIRS geophysical retrieval and reduce the uncertainties.

Background

Previous studies have performed the possible causes for SST stripping issue [Padilla and Cao, 2015]. They used MODTRAN model to simulate the spectral radiance at the spectral resolution of 1 cm⁻¹ for five standard atmospheric profiles. Their results indicate that the SST product is likely affected by small differences in detector level SRF, and the detector-to-detector differences have small atmospheric dependence.

A study from SST EDR team [Dash and Ignatov, 2009] evaluated the biases in the top-of-atmosphere (TOA) brightness temperature (BT) model with MODTRAN model. They concluded that MODTRAN model does not reproduce spectral, angular, and water vapor dependencies with accuracies acceptable for SST analyses. Therefore, in this study, we use LBLRTM with higher resolution to investigate the SST stripping issue.

VIIRS Daytime SST Algorithm & Imagiery Analysis

The daytime VIIRS SST is computed from a non-linear split window algorithm using the brightness temperatures from bands M15 and M16:

\[
\text{SST} = a_1 \times T_9 + a_2 \times T_11 + a_3 \times T_13 + a_4 \times T_15 + a_5 \times T_17 + (c_1 - a_5 / a_4) \tag{1}
\]

Where \( T_1 \) and \( T_2 \) are the brightness temperatures at M15 (1.5μm) and M16 (1.2μm), respectively. \( T_3 \) is the first guess SST from either numerical weather prediction or analysis fields. \( a_1, a_2, a_3, a_4, a_5, \) and \( c_1 \) are the coefficients derived from the regression process.

VIIRS SST EDR group found an anomalous stripping pattern in daytime SST product, and they developed an algorithm to improve the quality of the SST product. Therefore, we will need to analyze the stripping at the SDR or L1B level to reduce the propagation of any systematic artifacts to SST product. Figure 1 shows stripping at SDR brightness temperature.

Figure 1. Suomi NPP VIIRS SDR brightness temperature product in M15-M16 over the bay of Bengal on July 3, 2014 (Left): Subset of SDR BT for a uniform ocean surface under clear sky condition.

Line-By-Line Radiative Transfer Model

LBLRTM [Clough et al. 1998] is an efficient and accurate line-by-line radiative transfer model which provides spectral radiance calculations with accuracies consistent with the measurements [Clough et al. 2004]. LBLRTM 12 is used in this study to simulate the TOA spectral radiance under six standard LBLRTM atmospheric profiles.

The output spectral radiance is then convolved with VIIRS relative spectral response (RSR) to get the channel effective temperature (\( T_{\text{eff}} \)) as:

\[
\frac{L_{\text{viirs}}}{L_{\text{rsr}}} = \int \frac{L_{\text{viirs}}(\lambda) \cdot \text{RSR}(\lambda)}{L_{\text{rsr}}(\lambda)} \cdot d\lambda \tag{2}
\]

where \( L \) is the sensor radiance and \( R \) is the RSR of a given band. The simulated effective radiance for each band (\( L_{\text{viirs}} \)) was converted to BT(\( T_{\text{viirs}} \)) using the numerical method by minimizing the difference between BB radiation and channel effective radiance.

In this study, we will check the difference in effective brightness temperature (\( \Delta T_{\text{BT}} \)) between using the detector level RSR and the band averaged RSR:

\[
\Delta T_{\text{BT}} = T_{\text{BT}}(\text{viirs-SNR}) - T_{\text{BT}}(\text{viirs-avg}) \tag{3}
\]

Where \( T_{\text{BT}}(\text{viirs-SNR}) \) is the effective brightness temperature computed using the detector level RSR and \( T_{\text{BT}}(\text{viirs-avg}) \) is the effective temperature computed using the band averaged RSR.

Model Results

Figure 2 shows the effective brightness temperature differences between the detector-level band averaged RSR in VIIRS M15 (Top left), M16 (Top right), and M15-M16 (Bottom) from the LBLRTM radiance output for six atmospheric profiles. Results indicate that there is a small but obvious atmospheric dependency. The odd/even detector pattern is also observed. In M15, the smallest BT difference is at 0.087 K with an average effective RSR and SDR.

Figure 2. Effective BT difference between detector level band averaged RSR and band averaged Relative Spectral Response using LBLRTM in VIIRS band M15 (Top left), M16 (Top right), and M15-M16 (Bottom).

Figure 3. Effective BT difference between detector-level BT and band averaged BT for VIIRS SDR M15-M16 over the bay of Bengal on June 3, 2013 in M15-M16 (Left), as well as M15 and M16 (Right).

The magnitude in effective BT difference among detectors is 0.01 K for tropical atmosphere, and 0.025 K for subarctic atmosphere (top left panel in Figure 3). To see the impact of spectral range, we extend M15 from 800, 1100 cm⁻¹ to the entire spectral range (800, 1330 33) cm⁻¹ and M16 from 769, 950 cm⁻¹ to [769, 1250] cm⁻¹ to include the out-of-band response. The results and BT difference patterns are similar to Figure 2 (figure not shown). In M16 top right panel of Figure 3, there is more obvious atmospheric impact on BT difference than M15, and the tropical atmosphere pattern has the largest variation. Band M16 is more sensitive to water vapor variation due to more water vapor absorption in M16. Detector 6 has the smallest BT difference. Detectors 1 to 6 are more closer to band averaged and then deviate from band average for detectors 8 to 16. For detectors 4 to 16, although Sub-arctic Summer has higher temperature and water vapor, but it has almost same variation as Mid latitude winter. Therefore, besides water vapor and temperature, other instrument factors may also affect the stripping. The term \( (\text{BT}_{\text{viirs}} - \text{BT}_{\text{ref}}) \) is important because it is used in the VIIRS SST retrieval algorithm. The bottom panel shows that M15-M16 has larger magnitude of variation than single band, for example, they are 0.025 K and 0.063 K for tropical atmosphere in (M15-M16) and M15-M16, respectively.

Figure 3. The cumulative histogram for Bay of Bengal over tropical region on June 3, 2013 in M15-M16 (Left), as well as M15 and M16 (Right).

Figure 4. The comparison of effective BT difference between LBLRTM and the VIIRS observation for tropical and polar cases.

Summary

• LBLRTM results show that the stripping pattern in VIIRS SST imagery is mostly likely related to the difference between band averaged RSR and detector level RSR. The effective BT stripping has some atmospheric dependency. The results are consistent with MODTRAN results.

• Ten case studies using VIIRS SDR BT observation over tropical and polar regions also show that the detector level difference in tropical region is more obvious than that in polar region. The BT bias is larger for warm and moist atmosphere, but smaller for cold and dry atmosphere. Band M16 is more sensitive to the atmospheric conditions.

• In general, VIIRS SST observation has larger variability when comparing with the model output. It is not easy to effectively validate. The difference due to atmospheric conditions or water vapor is small and not a dominant factor for stripping.

• Further study will focus on detector stability and fixed pattern noise.

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References