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

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Outline

- Introduction and Motivation
- Line-by-Line Model Methodology
- VIIRS SDR Data Analysis
- Detector stability Analysis
- Summary

Introduction

- Modern satellite radiometers have many detectors with slightly different Relative Spectral Response (RSR).

- Effect of RSR differences on imaginary artifacts, as well as geophysical retrieval uncertainties have not been well studied.

- Previous studies used MODTRAN model for detector-level radiance simulations (Padula & Cao, Applied Optics, 2015). However, it is limited by the spectral resolution of the model relative to the narrow spectral bandwidth of the detectors.

- This study evaluates detector-level RSR differences and potential impacts using LBLRTM at spectral resolution of 0.01 cm^{-1} for VIIRS in bands M15 and M16 under different atmospheric conditions.

Detector-level RSR for S-NPP VIIRS M15

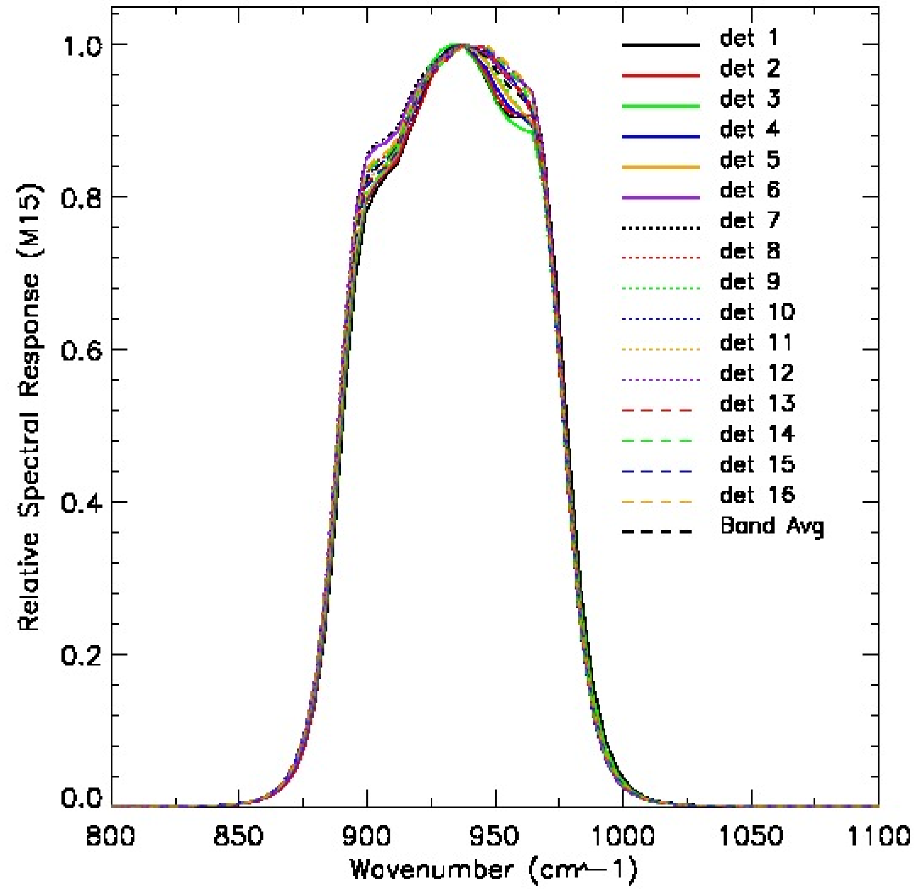
- Relative Spectral Response is slightly different among 16 detectors in band M15.

- This small det-to-det RSR variation will affect the radiance, and therefore brightness temperature.

- The impact of detector level variation on the imagery artifacts will be analyzed.

- Operational processing uses band averaged RSR.

∗ (M16 has similar det-to-det variations, not shown here.)



M15 detector level RSR

Line-By-Line Radiative Transfer Model (LBLRTM)

- LBLRTM is an accurate and flexible radiative transfer model that can be used from the microwave to the ultraviolet, providing the foundation for many radiative transfer applications (Clough et al., 1992, 2005).

- LBLRTM in the thermal infrared bands are recognized as a reference standard for intercomparisons of radiative transfer models.

- LBLRTM v12.2 (released in October 2012) is used in this study to simulate TOA spectral radiance.

- Input: Six standard LBLRTM atmospheric profiles, including Tropical, Mid-Latitude Summer, Mid-Latitude Winter, Sub-Arctic Summer, Sun-Arctic Winter, and U.S. standard 1976.

- LBLRTM run for wavenumber range: [722 – 2650.0] cm^{-1}, Resolution: 0.01 cm^{-1}

- S-NPP RSR wavenumber range: M15: [800 – 1333.333] cm^{-1}
  M16: [769.231 – 1250] cm^{-1}

Methodology

The LBLRTM output spectral radiance is convolved with S-NPP VIIRS RSR to get the band averaged radiance ($mW/m^2\ Sr\ cm^{-1}$)

$$L_{avg} = L(\nu_0, T) = \frac{\int_{\nu 1}^{\nu 2} L(\nu) \cdot RSR(\nu) d\nu}{\int_{\nu 1}^{\nu 2} RSR(\nu) d\nu} \qquad (1)$$

L(ν): the at sensor radiance RSR(ν): the RSR for a given band.

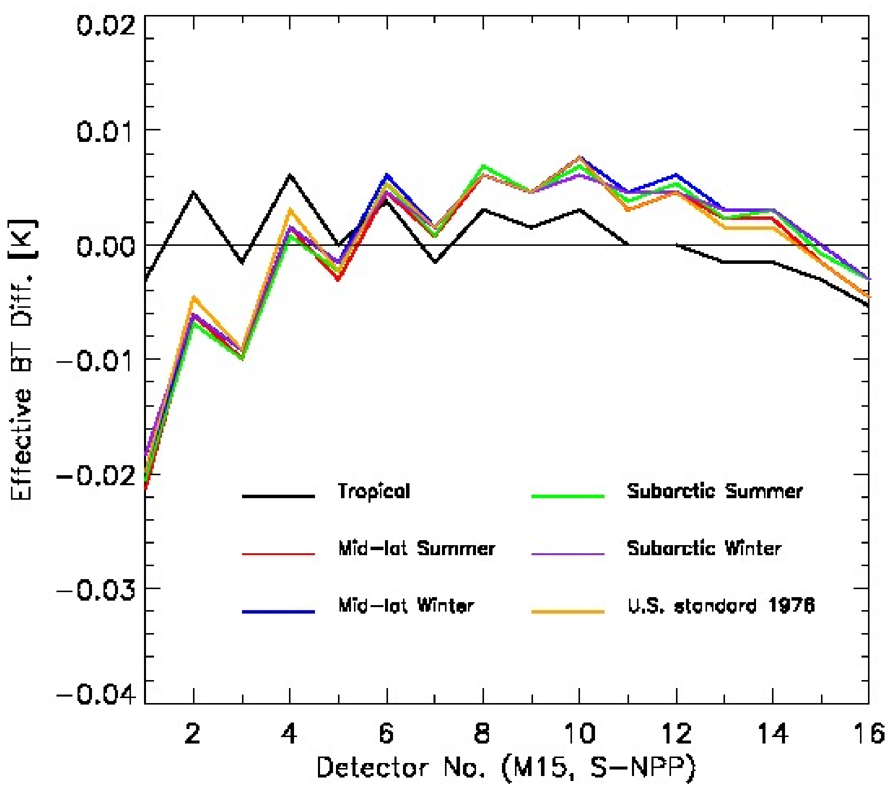
Lavg can be converted to the brightness temperature using a numerical method by minimizing the blackbody and band averaged radiance difference.

The difference in BT (ΔT_{eff}) between using detector-level and band averaged RSR:

$$\Delta T_{eff} = T_{eff\ (\det RSR)} - T_{eff\ (avg\ RSR)} \qquad (2)$$

Effective Temperature Difference (Detector-Level – Band Average) in M15

- The BT difference has a small, but obvious atmospheric dependence.
- The odd/even detector pattern is observed, especially for detectors 1-8.
- The smallest BT difference is at Det 5.
- The magnitude of variation is 0.011K for tropical atmosphere, and 0.025K for subarctic atmosphere.
- After extend to entire spectral range [800, 1333.33] cm^{-1} to include out-of-band response, the pattern does not change too much.



Temperature difference between detector Level and band averaged RSR in M15 for 6 LBLRTM atmospheres.

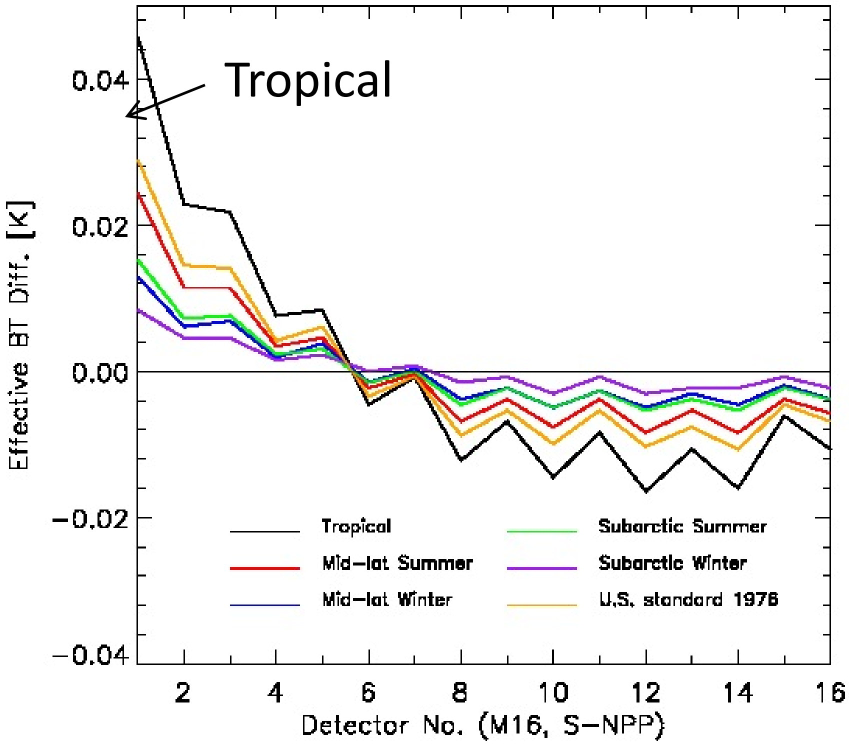
Effective Temperature Difference (Detector-Level – Band Average) in M16

- Obvious atmospheric impact on BT diff. in M16 than in M15, and the tropical atmosphere has the largest variation.

- The magnitude of variation is 0.063K for tropical, and 0.022K for subarctic atmosphere.

- Observed apparent odd/even detector pattern. Det 6 has the smallest BT diff. Det 1 to 6 are closer to band average, and ther deviate from band average for Dets 8 to 16.

- For Dets 4 to 16, although Sub-arctic Summer has higher Temp. and water vapor, it has similar variation as Mid-latitude winter. Therefore, besides water vapor and temperature, other instrument factors may also affect the striping.



Effective temperature difference between detector level and band averaged RSR in M16.

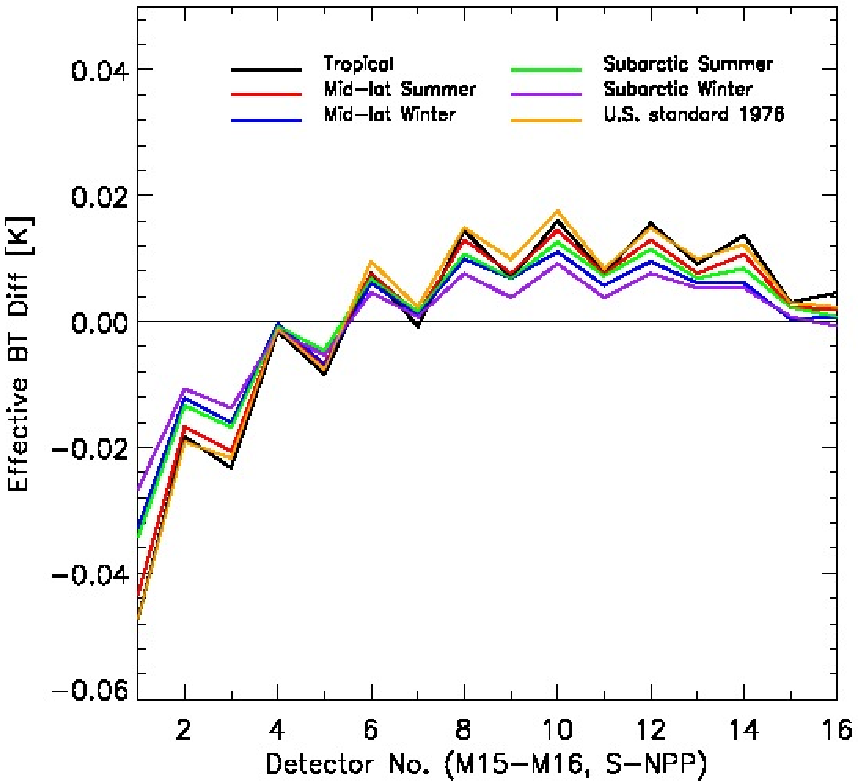
Effective Temperature Diff. (Det-Level – Band Average) in M15–M16

- Since the term (BT_{15} – BT_{16}) is used in the VIIRS SST retrieval algorithm, it should be also analyzed.

- The magnitude of variation in (M15-M16) is larger than that in single band. E.g., for tropical atmosphere, they are 0.072K and 0.063K in M15–M16 and M16, respectively.

- Tropical atmosphere has larger magnitude (0.071K) than subarctic (0.053K).

- Det 1–3 shows the large atmosphere effect, with Det 1 showing the largest difference up to ~ 0.06K for tropical case, which is close to 0.05K in previous study (Padula & Cao, Applied Optics, 2015) using MODTRAN model.



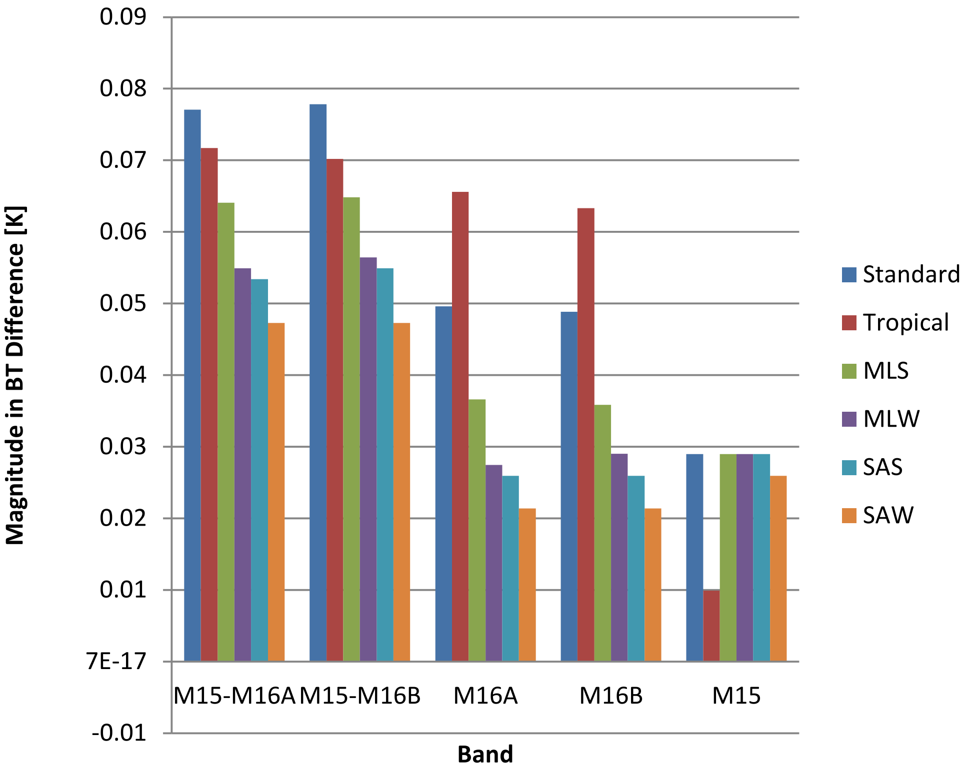
Effective temperature difference between detector level and band averaged RSR in M15–M16.

Magnitude of BT difference for 6 atmospheres

• The magnitude in M15–M16 is larger than that in single band. Band M15 is much less affected by atmosphere.

• Except for M15 and standard atmosphere, the magnitude has obvious atmospheric dependency: the variation for tropical region is much larger than over subarctic region.

• Besides water vapor and temp., instrument effect also plays a role in striping. e.g, SAS has similar magnitude as MLW in M15–M16 and M16 although SAS has higher temperature and more water vapor.



The magnitude of BT difference for six atmospheres.

LBLTRM Results

- The atmospheric impact is more obvious in (M15–M16) than a single band. E.g., for tropical atmosphere, the magnitude of ΔT_{eff} is 0.072K, 0.063K, and 0.010K in M15–M16, M16, and M15, respectively.

- LBLRTM does show small atmospheric dependency. The water vapor has impact on the striping pattern. E.g., the magnitudes in ΔT_{eff} for tropical and subarctic atmosphere are 0.072K and 0.053K in M15–M16, and are 0.063K and 0.030K in M16.

- There is apparent odd/even detector pattern. Compared to the band average, Det1–3 shows the large atmosphere effect, with Det1 showing the largest difference up to ~ 0.06K for tropical case, which is close to 0.05K in previous study (Padula & Cao, 2015).

- VIIRS SDR observation data needs to be analyzed to see whether the water vapor is a dominant factor affecting the striping pattern.

Case Studies Using VIIRS SDR Data

VIIRS SDR brightness temperature observation data in M15 and M16 are analyzed over the tropical and polar region.

- Bay of Bengal (Tropical): 3 cases
  6/19/2013, 6/22/2014, and 7/3/2014

- Gulf of Alaska (Polar): 2 cases
  5/5/2015 and 6/3/2014

- South Pole (Polar): 1 case   4/21/2015

In each image, use VIIRS Cloud Mask product to select a small uniform region under clear sky condition.

Method for Striping Quantification

The cumulative histogram method (Weinreb, etc. 1989; Li 2015) is used to quantify the striping:

$$H_{i,d}(k) = \frac{1}{N_{i,d}} \sum_{l=0}^{k} \left(\sum l \in (l,i,d) \right) \qquad (3)$$

The 1st sum: to count the number of pixels with the value *l* (for det *i* and scan direction *d),* and the 2nd sum is over the pixel value *l*.

$N_{i,d}$: total number of the pixels for det *i* and scan direction *d*.

$H_{i,d}$: the percentage of the pixels with value less than *k*.

If there is striping in an image, the histogram diverges for different detectors and scan. The divergence of the histogram can be characterized as the horizontal distances among the different histograms:

$$g_{i,d,i',d'}(P) = k - k' \qquad (4)$$

Weinreb, M.P., and Coauthors: Destriping GOES Images by matching Empirical Distribution Functions. Remote Sensing of Environment, 29, 185-195.

Zhenping Li: Real Time De-Striping Algorithm for Geostationary Operational Environmental Satellite (GOES) P Sounder Images. (2015)

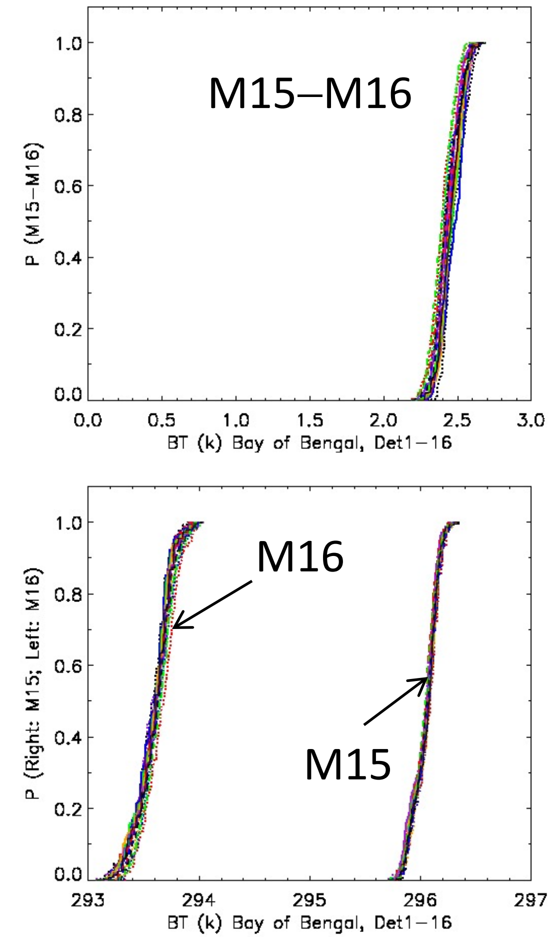
The Cumulative Histogram for Tropical Case1 in M15–M16, M15, and M16

- Bay of Bengal (tropical): June 19, 2013

- P is the percentage of the pixels with the value less than the value in X-axis.
X-axis: BT difference in M15–M16 or BT in single band. Each line is for one detector.

- The horizontal distance is approximately a const.
Ratio= Distance(P=50%) / X-axis range
= 0.187 for (M15–M16)
= 0.107 for M16 and = 0.067 for M15
The ratio in single band is smaller than that in M15–M16.

- The horizontal distance is a little bit larger than LBLRTM magnitude. The largest variation comes from det1. The BT difference is more than 2.0K



The cumulative histogram for the Bay of Bengal over tropical region.

The Cumulative Histogram for Polar Case1 in M15–M16, M15, and M16

- Gulf of Alaska (Polar): May 20, 2014

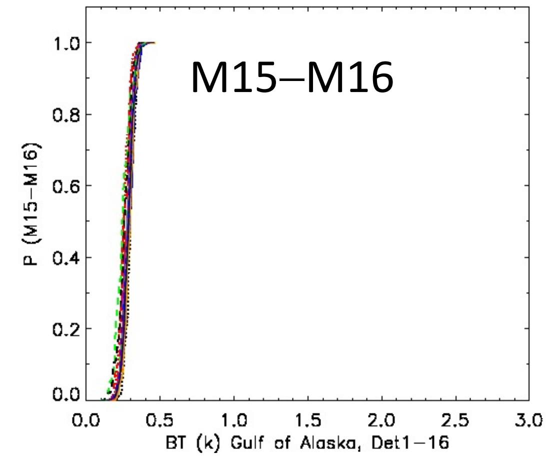
- The horizontal divergence is very small and almost a constant.

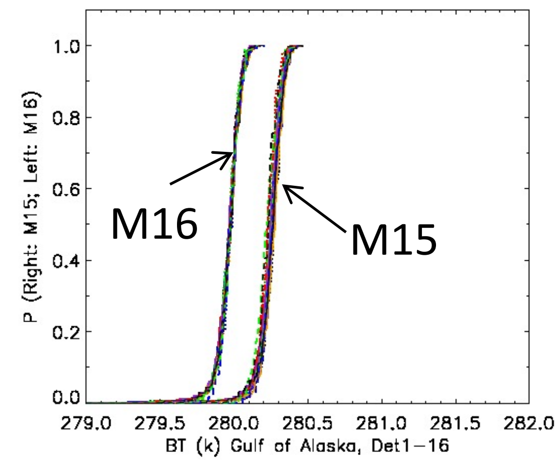
Ratio= Distance(P=50%) / X-axis range
 = 0.149 for (M15–M16)
 = 0.015 for M16 and = 0.044 for M15

- The ratio in single band is smaller than that in M15–M16.

- The histogram divergence is very close to LBLRTM magnitude.

- Polar region has smaller BT difference than tropical region due to water vapor effect.





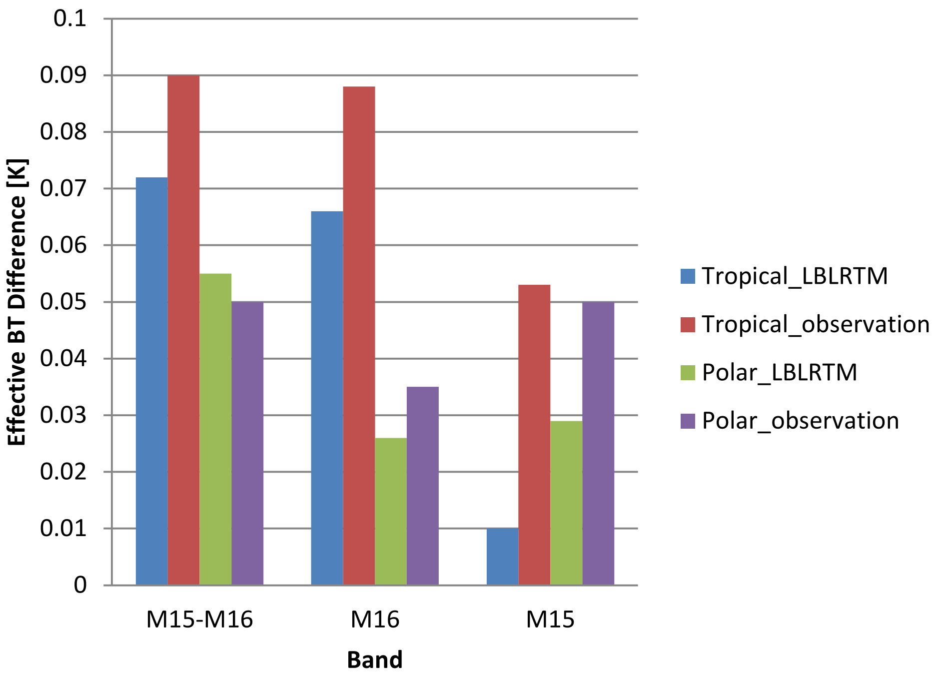
The cumulative histogram for Gulf of Alaska over polar region.

LBLRTM – Observation Comparison of Effective Temperature Difference

- In M15–M16 and M16, both of LBLRTM and VIIRS observation show larger temperature difference over tropical than over polar region.

- In most cases, VIIRS observation has larger magnitude in BT difference among different detectors than LBLRTM except for polar case in M15–M16.

- In general, the magnitude of variation among 16 detectors over tropical region is much more affected by water vapor than that over polar region, i.e., the variation is larger for high BT difference (high water vapor absorption).



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

Note: VIIRS observation use the average to represent the tropical and polar region.

Variations along track vs. along scan for Detector 1 in M15

- Analyzed three OBCIP files on June 30, 2015.

  BB: Blackbody SV: Space View
  SD: Solar Diffuser

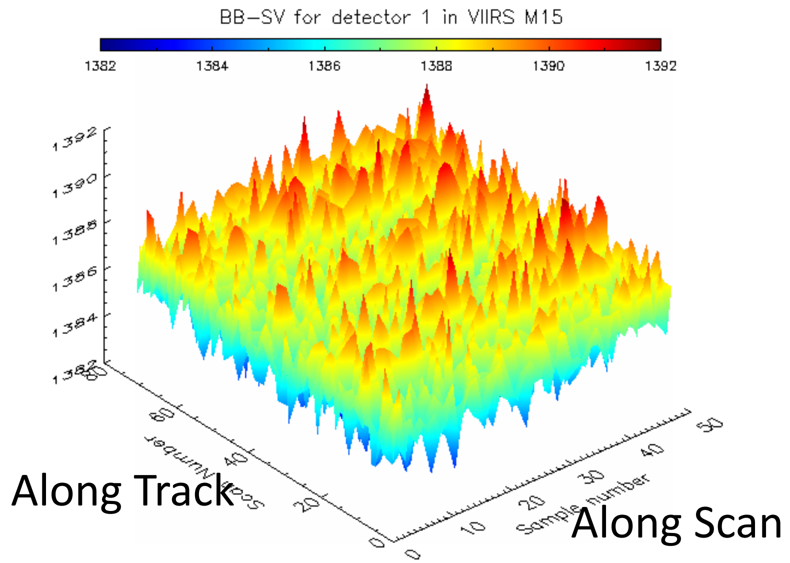
- Upper: 48 Samples × 72 Scans of (BB-SV) for detector 1 in M15

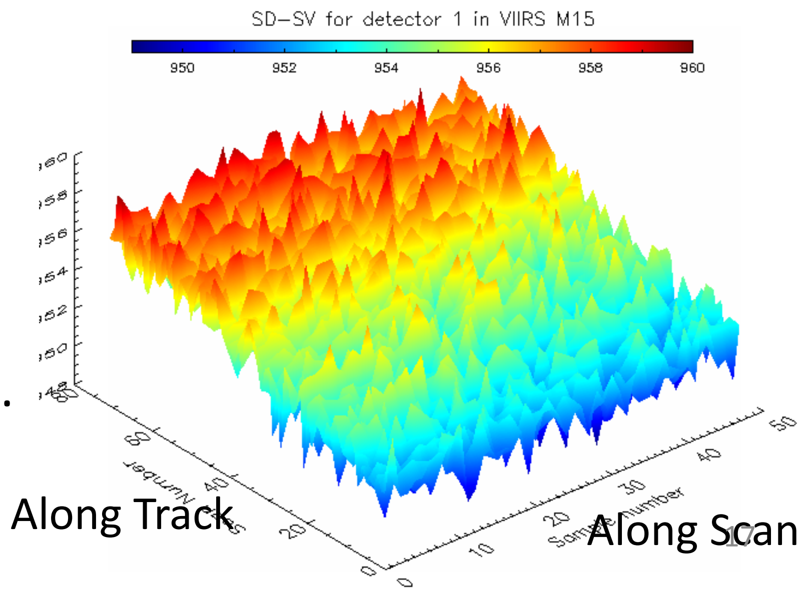
- Lower: 48 Samples × 72 Scans of (SD-SV) for detector 1 in M15

- The patterns are more consistent along scan.

- The variation along track is much larger than that along scan, so the variation along track is an important factor causing the striping pattern.

- Further statistic analysis is done.





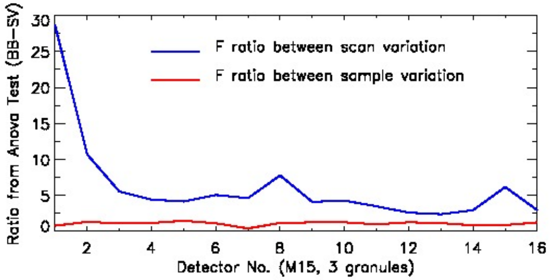
Two Way ANOVA Test for Variance along tracks and along scans

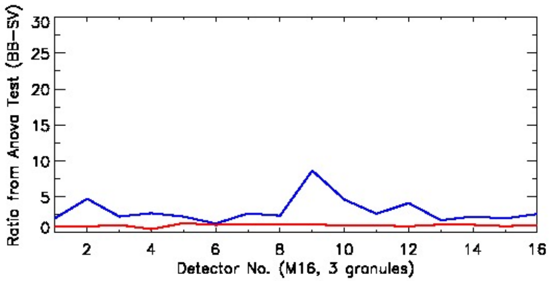
• Analysis of Variance (ANOVA) is used to analyze the differences among and between scans.

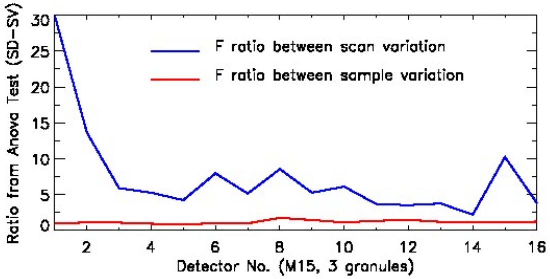
• In M15 and M16, along track variation is larger than along scan variation. The large noise from along track direction is one of major reasons for the striping.

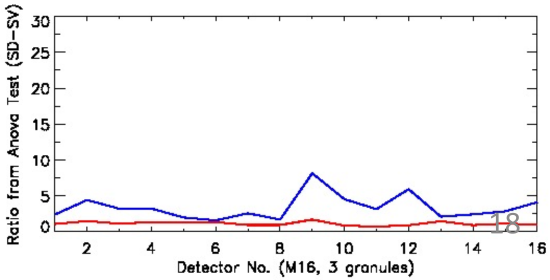
• In M15, compared to other detectors, dets 1 and 2 have much along track variations. i.e, dets 1 and 2 are more noisy than other detectors.

• In M16, the detectors 9 and 12 have larger along track variation than other detectors.
For along scan variation, the detector noises are on similar level.









Summary

- LBLRTM results show the striping pattern in is most likely related to the difference between band-averaged and detector-level RSR. The BT difference has small atmospheric dependency. The results are consistent with MODTRAN results: the difference in tropical region is a little bit larger than cold region.

- Ten case studies using VIIRS SDR BT observation over tropical and polar regions show the detector-level difference in tropical region is more obvious. The BT bias is a little bit larger for warm and moist atmosphere. M16 is more sensitive to atmosphere.

- VIIRS SDR BT observation has larger variability when comparing with the model output. It is not easy to effectively validate. The difference due to water vapor is small and is not a dominant factor for striping.

- Detector noise analysis indicates that the variation along track is an important factor causing the striping. The det1 in M15 is much more noisy than other detectors. In M16, dets 9 and 12 are more noisy than other detectors.

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