Diagnosis of Saturation Effects in Infrared Channels of VIIRS Using the NOAA Nightfire Product

Thomas Polivka[1], Edward Hyer[2], Jun Wang[1], David Peterson[3]

[1] University of Nebraska, Lincoln, NE, [2] Naval Research Laboratory, Monterey, CA, [3] National Research Council, Monterey, CA

I. Background

As the first of the next generation of operational Earth-observing instruments, the Visible Infrared Imaging Radiometer Suite (VIIRS) offers many improvements over its predecessors. VIIRS delivers satellite data record (SDR) and environmental data record (EDR) data at higher spatial resolution than legacy instruments, including the MODerate Resolution Imaging Spectroradiometer (MODIS), the Advanced High Resolution Radiometer (AVHRR), and the Operational Line Scanner (OLS). One marked difference between VIIRS and MODIS is that VIIRS employs on-board processing to reduce downlink bandwidth requirements and preserve spatial resolution across the swath. This on-board processing, which involves averaging of multiple detectors to obtain single SDR "pixel" radiances, can have unintended and poorly understood consequences in cases of detector saturation.

The objective of this study was to determine the prevalence of detector-level saturation and the potential effects introduced by it.

About VIIRS Aggregation

- VIIRS aggregates individual detectors based on the scanning angle of the instrument
  - For 0° to 31.589°, 3 detectors = 1 pixel
  - For 31.589 ° to 44.68°, 2 detectors = 1 pixel
  - For 44.68°+, 1 detector = 1 pixel
- No aggregation along-track
- This differs from previous instruments like AVHRR and MODIS, where 1 detector = 1 pixel
- Aggregation reduces pixel growth factor from 6 along-scan to 2 along-scan

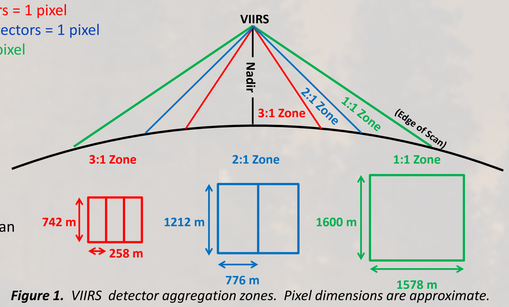

Figure 1. VIIRS detector aggregation zones. Pixel dimensions are approximate.

II. Methods

Dataset Description

- To examine the effects of saturation, this study utilized a NOAA product called "Nightfire"
- Nightfire detects anomalously bright pixels in the short-wave infrared (SWIR) 1.6 µm band (M10), which is the basis for its hot-spot detection (Elvidge et al., 2013)
  - VIIRS is unusual in that it records SWIR data at night unlike its predecessors
  - The lack of solar radiation enables detection of hot sources that would otherwise be masked during daylight
  - In addition to recording the 1.6 µm band, Nightfire also collects simultaneous radiances in other near-infrared (NIR), SWIR, mid-wave infrared (MWIR), and long-wave infrared (LWIR) channels, as well as the Day-Night-Band (DNB)

Band	Wavelength (µm)
M7	0.86
M8	1.24
M10	1.60
M12	3.69
M13	4.06
M14	8.58
M15	10.74
M16	11.87
DNB	0.5-0.9

Table 1. Bands contained in the Nightfire dataset. Bands in red were analyzed. Center wavelengths from Cao et al., 2013.

Analysis

1. Nightfire data from 3/18/13 to 7/14/13 were accrued and filtered such that every pixel had a measurement in each M band and an accurate timestamp, yielding 1,861,865 thermally anomalous pixels (less than 0.01% of the data were rejected)
2. Each infrared band starting with the 1.6 µm (M10) was analyzed for saturation
   - Short wavelength bands are designed to measure reflected solar radiation, so they shouldn't saturate at night
3. Once bands that exhibited saturation were identified, the data were separated by scanning angle to show the impacts of aggregation on retrieved radiances
4. Following the dissection by scanning angle, a simulation was constructed to attempt to highlight the effects of aggregation by drawing from the edge-scan pool (1:1: aggregation) as a baseline for 3.68 µm and 4.06 µm
   - 10 million random samples for edge-scan recreation
   - 20 million pairs for the middle-scan (then averaged)
   - 30 million triplets for the center-scan (then averaged)

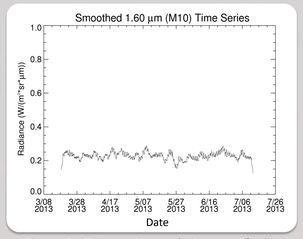

Figure 2. Time series analysis to verify the Nightfire algorithm and satellite calibration was consistent.

Observed Distributions

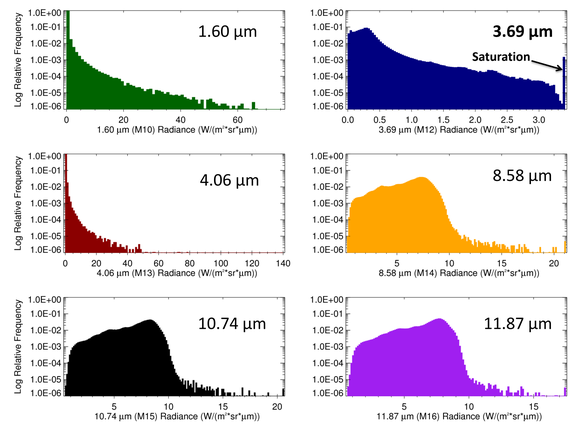

Figure 3. Analysis of the infrared channels. The only channel with obvious saturation is 3.69 µm (M12).

3.69 µm Saturation By Scan Angle

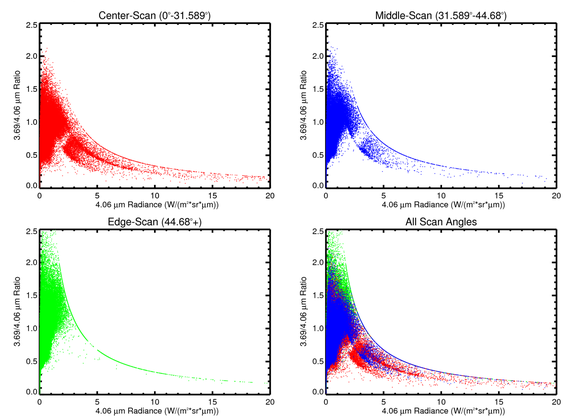

Figure 4. Ratio of the 3.69/4.06 µm data separated by scanning angle to show the effects of on-board aggregation.

III. Results

- As seen in Figure 3, the only channel with apparent saturation issues is 3.69 µm (M12) with a sudden peak of density at 3.39 W/(m²·sr·µm)
  - Possible detector-level saturation was noted near 1.3, 1.8, and 2.3 W/(m²·sr·µm), which can be seen by the small humps at those radiances
- When analyzed by viewing angle, as in Figure 4, the influence of saturation becomes more apparent
  - The asymptotic curve (maximum ratio for a given 4.06 µm radiance value) is a product of the hard saturation limit of 3.39 W/(m²·sr·µm) for the 3.69 µm band (M12)
  - In the edge-scan, there is just one hard limit. However, in the middle-scan, there are two distinct populations showing a similar slope, and in the center scan, there are three populations. These are the product of detector-level saturation being averaged with an unsaturated detector or detectors
- The simulated aggregation effects, while crude, also produced peaks in the appropriate locations for the 3.69 µm band, as shown in Figure 5
  - The discrepancy between the simulated and observed results stems from detector correlation
    - The pairs and triplets generated were random; in reality, neighboring areas are often closely correlated, especially at detector-level resolutions

Simulations

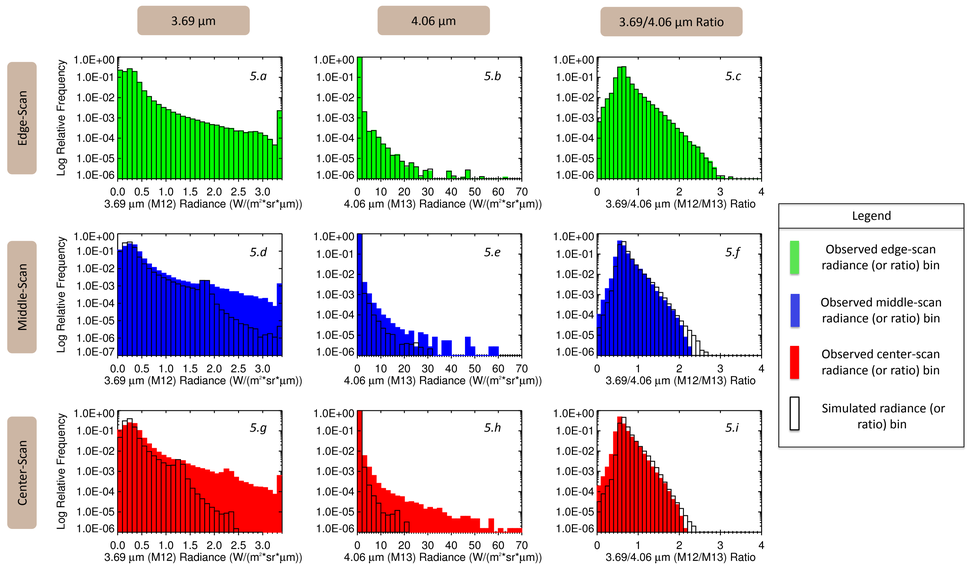

Figure 5. Simulated scan distributions by using the edge-scan data as a baseline to recreate the observed detector-level saturation. General agreement in the locations of the simulated peaks and the observed peaks can be seen in the 3.69 µm data in 5.d) and 5.g). The 4.06 µm band (middle column) is shown to contrast to the saturating 3.69 µm channel.

IV. Conclusions

- The 3.69 µm band (M12) is the only band with obvious saturation problems
  - However, it may still be possible to saturate an individual detector in the TIR bands, which would not be apparent in the case of 3:1 or 2:1 aggregation
- Unfortunately, VIIRS does not reject or flag detector saturation, so there is no way of truly knowing if a detector is saturated (at this time)
- The difference between the simulations and the observed distributions stems from detector correlation, meaning that adjacent detectors often observe similar environments
- The results indicated that the maximum radiance in the 3.69 µm band (M12) before potential detector saturation can occur is approximately 1.3 W/(m²·sr·µm) for center-scans, which equates to a brightness temperature of approximately 330K. Above that, detector saturation is a possibility for nadir cases. In the case of middle-scans, the threshold is 1.7 W/(m²·sr·µm) (337K), and for edge-scans, the threshold is 3.39 W/(m²·sr·µm) (359K)

V. Ongoing/Future Work

- The implications of onboard aggregation must be considered for future instrument designs
- There may be potential detector saturation in the other TIR bands in the case of aggregation, which might be worth investigating
- Impact on fire radiative power (FRP) calculations should also be investigated

Acknowledgements

We would like to thank the Naval Research Enterprise Internship Program for the opportunity to intern at the Naval Research Laboratory in Monterey, California, as well as the staff at NRL-Monterey for their advice and suggestions. Also, we would like to thank the University of Nebraska for funding, and Chris Elvidge's group for their work on Nightfire.

References:

Cao, C.; DeLuccia, F.; Xiong, X.; Wolfe, R.; Weng, F. Early on-orbit performance of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite. *IEEE Trans. Geosci. Remote Sens.* ***2013, doi:10.1109/TGRS.2013.2247768.***

Elvidge, C.D.; Zhizhin, M.; Hsu, F.-C.; Baugh, K.E. VIIRS Nightfire: Satellite Pyrometry at Night. *Remote Sens.* **2013**, *5*, 4423-4449.

Background image: Reuters/Kari Greer/USFS