Maintaining SNPP VIIRS Reflective Solar Band Sensor Data Record Quality: On-Orbit Update of Screen Transmission and Solar Diffuser BRDF Parameters

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Overview

- Introduction
- Look Up Table Update Methodology
- Studies
- Conclusion

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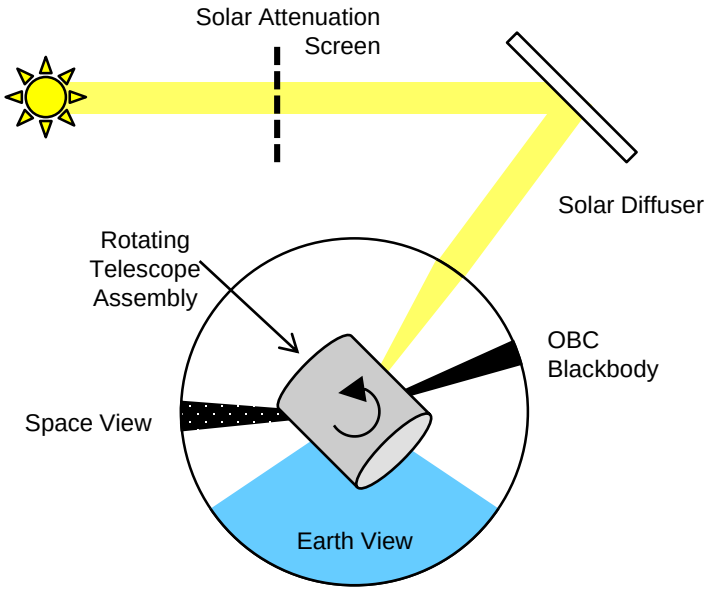
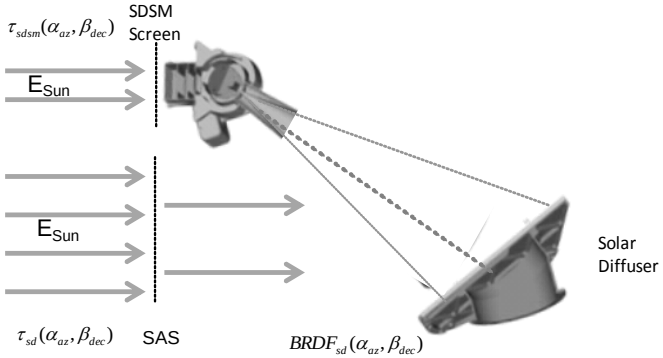
Introduction

- Visible Infrared Imaging Radiometer Suite (VIIRS) was launched October 28, 2011, onboard the Suomi National Polar-orbiting Partnership (SNPP) spacecraft
- 22 bands:
  - *Day Night Band*
  - *7 thermal emissive bands*
  - *14 reflective solar bands (RSBs)*
    - Calibrated using sunlight attenuated by a Solar Diffuser screen and reflected off of the Solar Diffuser (SD)
    - Ratio of calculated and measured SD radiance is called the F factor
    - Radiance when viewing SD is a function of Bidirectional Reflectance Distribution Function (BRDF) of the SD
    - SD BRDF is expected to change throughout the mission and the overall scale of this change is measured and quantified in a parameter called the H factor



Introduction

- On-orbit changes in the SD BRDF are monitored by a separate on-board instrument called the solar diffuser stability monitor (SDSM)
  - *Used at varying frequencies during mission history (3 times per week now) when solar illumination conditions are satisfied*
  - *8 detectors within the range 0.412 to 0.935 μm*
  - *During a VIIRS scan, 5 samples are taken for each SDSM detector in 1 of 3 views: solar, SD, and dark reference*
  - *Attenuation screen reduces incoming solar radiance to levels comparable to those seen by VIIRS when viewing the SD*
  - *From these measurements, the H factor is calculated and trended*



Introduction

- This presentation addresses maintenance of RSB calibration quality through on-orbit updates of the SDSM screen transmission LUT and two LUTs representing the product of SD screen transmission and SD BRDF in two viewing geometries, that of VIIRS and the SDSM (“tau BRDF” LUTs)
  - *These three LUTs are functions of solar geometry, and this geometry varies with the time at which solar calibration data are acquired*

- A combination of data from a yaw maneuver performed in February 2012 and the ever increasing body of solar calibration data acquired over the mission allow for improvements to the LUTs

- Methodology was chosen to be adaptive to aging of the instrument and robust to variations in functional forms used to model SD BRDF degradation

Introduction

- The following equations define the H factor [1]:

$$G_{sd} = \frac{DC_{sd} - DC_{bkg}}{E_{Sun} \cdot \tau_{sd}(\alpha_{az}, \beta_{dec}) \cdot \cos AOI_{sd} \cdot BRDF(\alpha_{az}, \beta_{dec}) \cdot sin^2(FOV_{sdsm})} \quad (1)$$

$$G_{sun} \frac{DC_{sun} - DC_{bkg}}{E_{Sun} \cdot \tau_{ntn} \cdot \tau_{sdsm}(\alpha_{az}, \beta_{dec})} \quad (2)$$

$$G_{sun} = G_{sd} \quad (3)$$

$$\mathrm{H} = \frac{DC_{sd} - DC_{bkg}}{DC_{sun} - DC_{bkg}} \cdot \frac{\tau_{ntn} \cdot \tau_{sdsm}(\alpha_{az}, \beta_{dec})}{\tau_{sd}(\alpha_{az}, \beta_{dec}) \cdot \cos AOI_{sd} \cdot BRDF(\alpha_{az}, \beta_{dec}) \cdot sin^2(FOV_{sdsm})} \quad (4)$$

- G_{sd} is the solar diffuser gain, and G_{sun} is the solar gain
- E_{sun} is the solar irradiance at the satellite
- DC_{sd}, and DC_{bkg} are the SDSM detector voltages from the SD and dark reference paths respectively
- $\tau_{sd}(\alpha_{az}, \beta_{dec})$ corresponds to the SDS transmittance as a function of solar azimuth α_{az} and declination β_{dec}
- AOI_{sd} is the angle of incidence of sunlight on the SD, H is the BRDF degradation factor we seek to trend.
- $BRDF(\alpha_{az}, \beta_{dec})$ is the nominal BRDF as a function of solar angles
- FOV_{sdsm} is the fixed field of view of the SDSM when looking at the SD
- DC_{sun} is the SDSM detector voltages from the Solar path
- τ_{ntn} is the SDSM screen transmittance at normal incidence
- $\tau_{sdsm}(\alpha_{az}, \beta_{dec})$ is the normalized SDSM screen transmittance

[1] Evan Haas, David Moyer, Frank J. De Luccia, et al., "VIIRS solar diffuser bidirectional reflectance distribution function (BRDF) degradation factor operational trending and update," Proceedings of SPIE Vol. 8510, 851016 (2012)

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Introduction

- The following equation defines the F factor [2]:

$$F(t) = \frac{L_{calc}}{L_{meas}} = \frac{P_{sun} \cdot \cos(AOI_{sd}) \cdot H \cdot \tau_{sd} \cdot BRDF(\alpha_{az}, \beta_{dec})}{4 \cdot \pi \cdot d_{se}^2 \cdot (\sum_{i=0}^{2} c_i(T_{det}, T_{elec}) \cdot dn^i)} \quad (5)$$

- L_{calc} is the calculated solar diffuser radiance
- L_{meas} is the measure solar diffuser radiance
- P_{sun} is the spectral solar power of the sun
- τ_{sd} is the transmission of the solar diffuser screen
- AOI_{sd} is the angle of incidence of sunlight on the solar diffuser
- H is the H factor
- $BRDF(\alpha_{az}, \beta_{dec})$ is the nominal BRDF as a function of solar angles
- dse is the earth-sun distance
- dn is the offset corrected solar diffuser measured digital number
- T_{det} is the detector temperature
- T_{elec} is the electronics temperature
- c_i are temperature coefficients measured in pre-launch

[2] Cardema, J., Rausch, K. Lei, N., Moyer, D., De Luccia, F., "Operational Calibration of VIIRS Reflective Solar Band Sensor Data Records," Proceedings of SPIE Vol. 8510, 851019 (2012)

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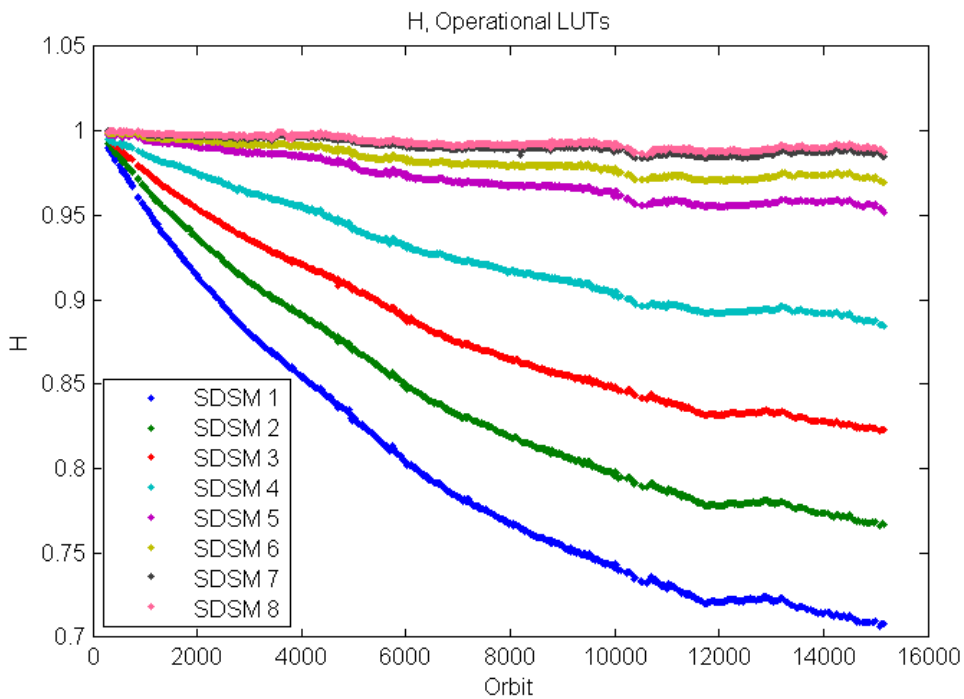
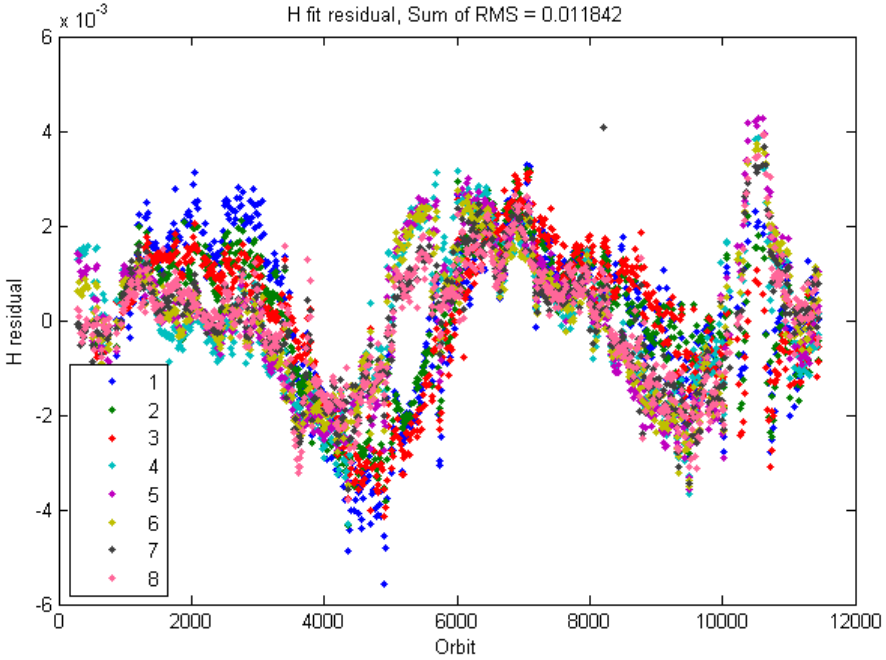
Look Up Table Update Methodology

- H factor behavior represents gradual darkening of the solar diffuser on orbit and therefore is expected to be monotone decreasing
- Waviness seen below is attributed to LUT inaccuracies



Look Up Table Update Methodology

- H Factors are fit with a functional form A*exp(B*orbit)+C
- Residuals of these fits are shown below for data up to orbit 11700
- An objective of the Tau SDSM LUT improvement is to reduce these residuals
- ‘Sum of RMS’, defined as the sum of the RMS residuals for the 8 detectors, is the metric that will be used to assess goodness of fit



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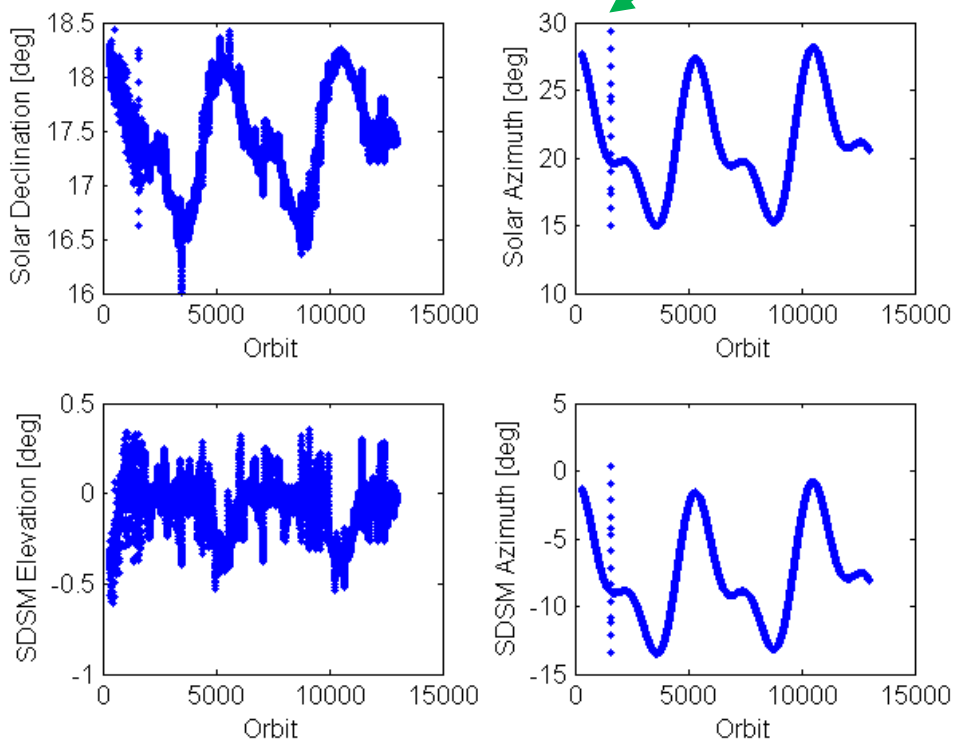
- Solar geometry angles over mission history are shown below
- A fixed rotation matrix transforms between solar angles used for τ_{sd}*BRDF LUTs and SDSM angles used for τ_{sdsm} LUT
- Azimuths sampled during the yaw maneuver can be clearly seen in azimuth plots; finer azimuth sampling obtained over mission is key to LUT improvement

Yaw maneuver azimuths



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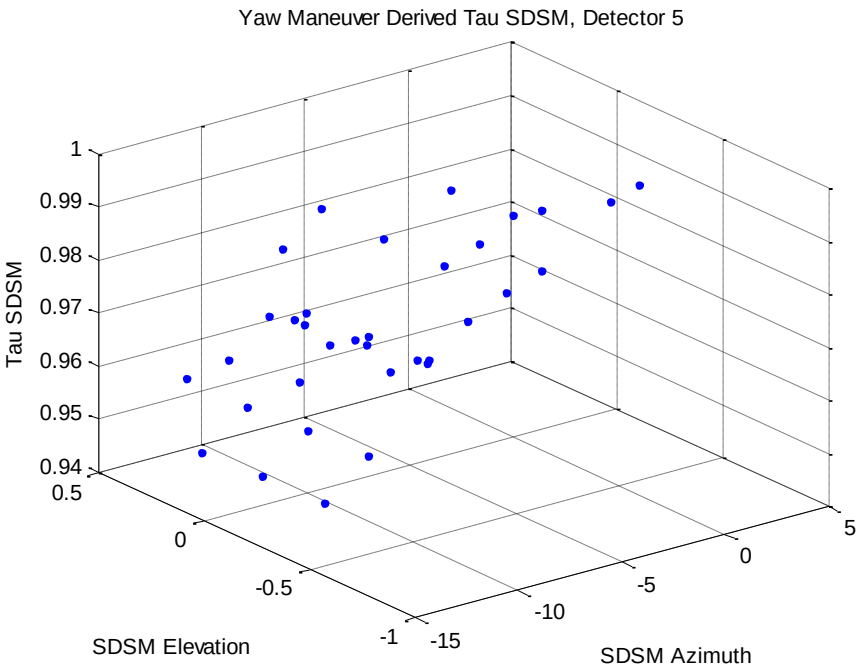
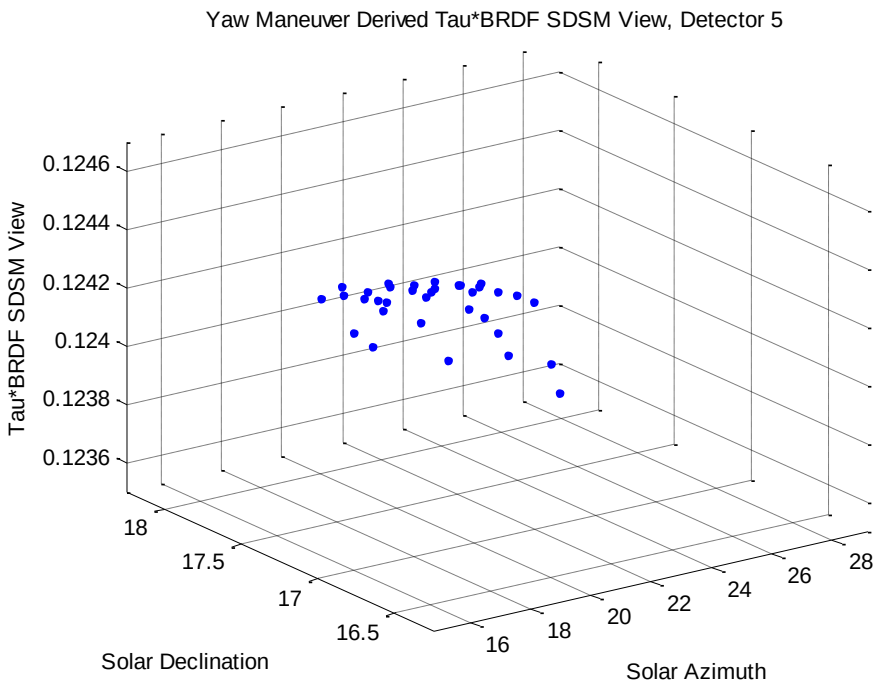
- Yaw maneuver data is utilized to construct preliminary τ_{sd}*BRDF LUT and τ_{sdsm} LUTs
- The first step is to solve equation (2), the Solar Gain equation, for τ_{sdsm}, where the Solar Gain values used are obtained from a linear fit of Solar Gain values derived from operational LUTs over the yaw maneuver orbit range
- The second step is to solve equation (4), the H factor equation, for τ_{sd}*BRDF, using H values from orbit 1570 (the central obit of the yaw maneuver)





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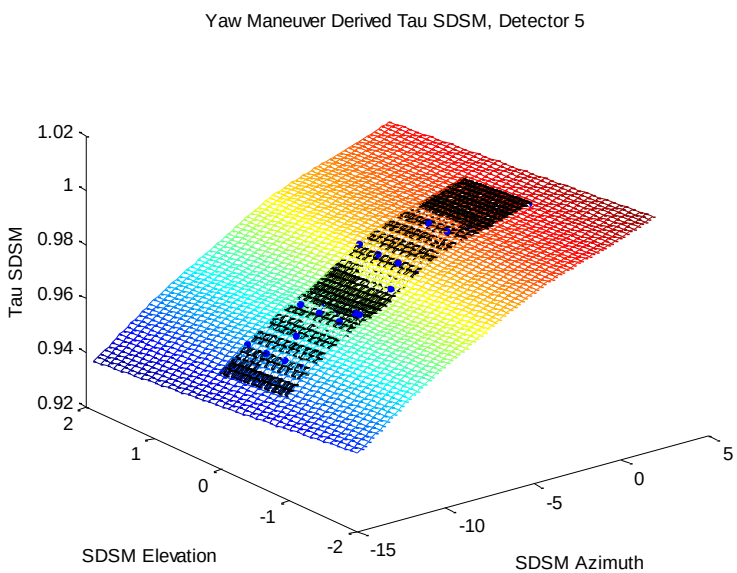
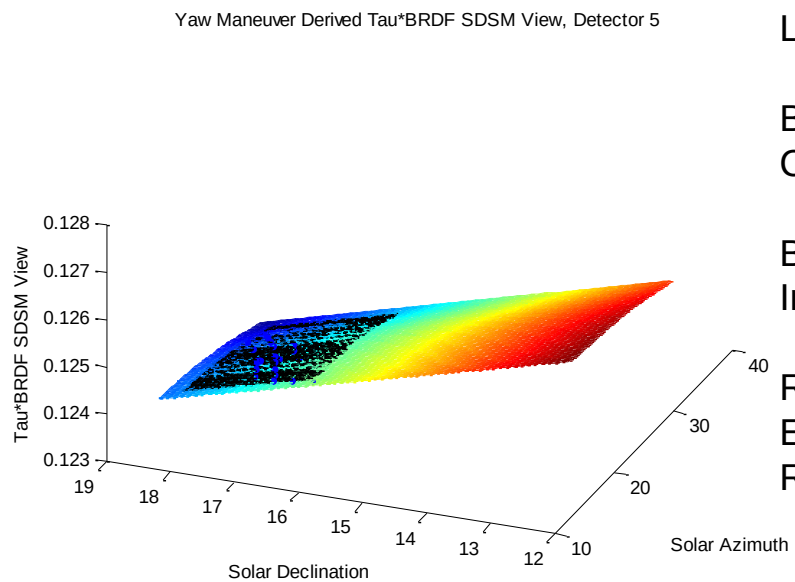
- A Thin Plate Spline is used to interpolate and extrapolate these points to fit the LUT limits
- The τ_{sd}*BRDF table is determined at this point
- The τ_{sdsm} table is further refined, as will be shown





Legend:

Blue Dots = Calculated Points

Black Shading = Interpolated Region

Rainbow Shading = Extrapolated Region

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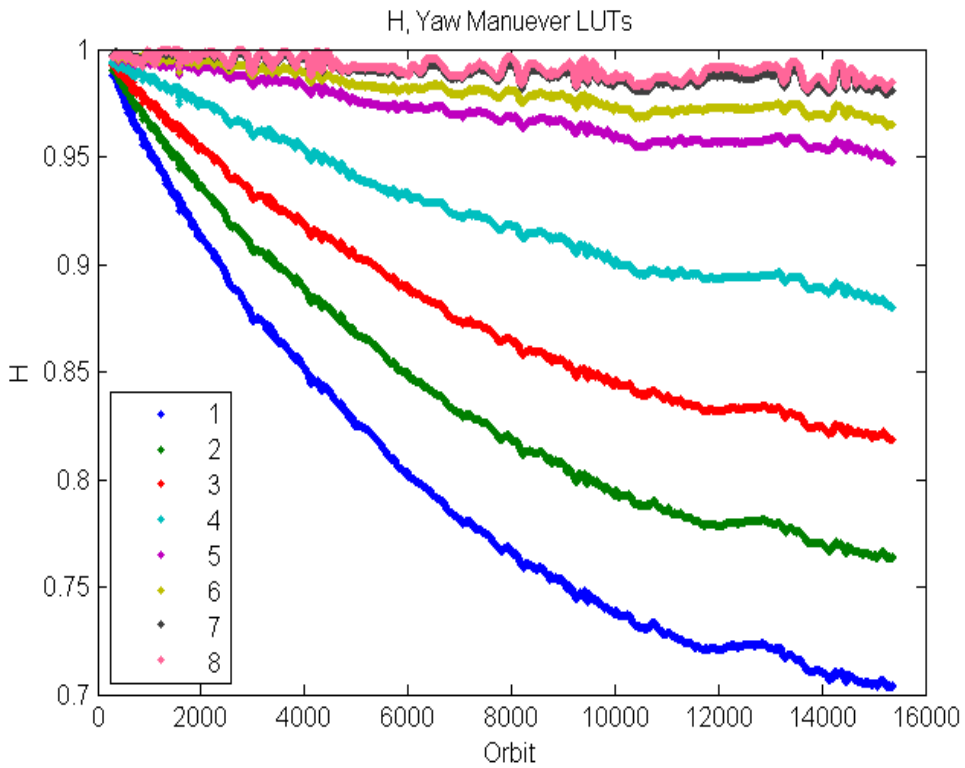
- Next, the H Factor time series is re-processed with the yaw maneuver derived tables
- Many obvious modulations are re-introduced in the data that will be removed



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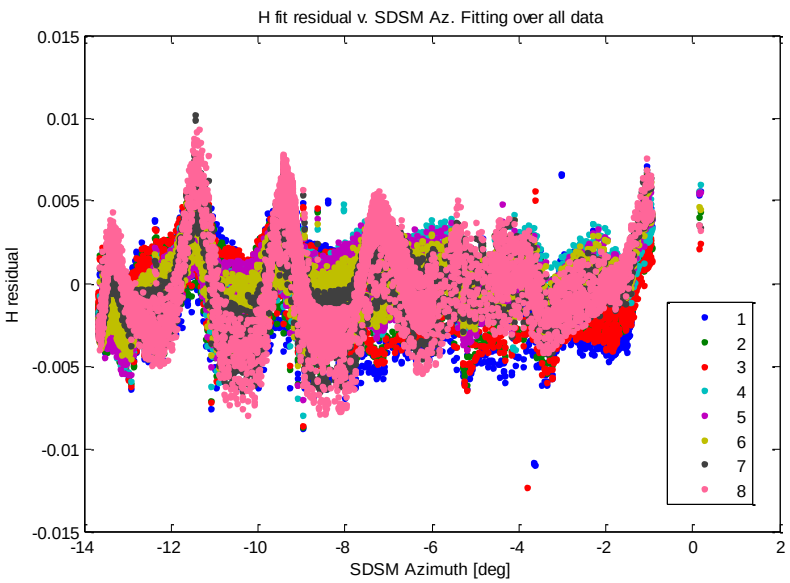
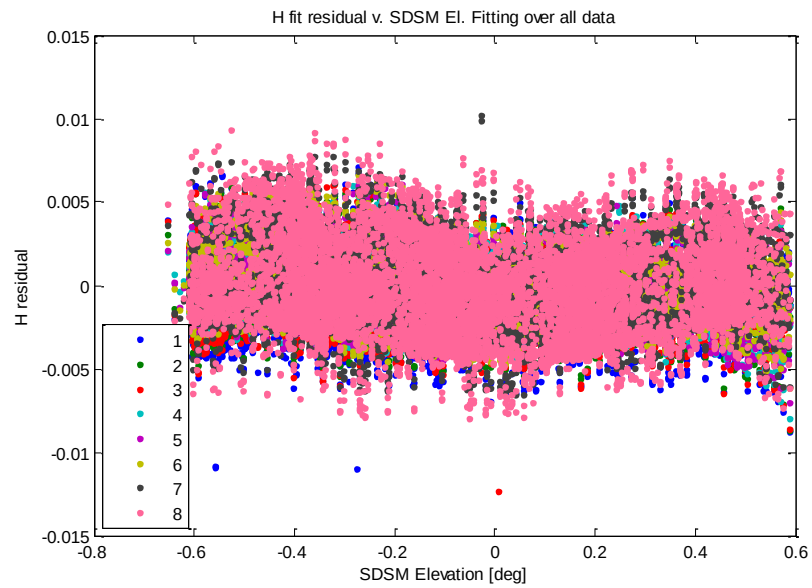
Look Up Table Update Methodology

- A fit of the form A*exp(B*orbit) + C is applied to each H factor
- The residuals of the fit are shown plotted against SDSM azimuth and elevation below
- There is clearly structure to the residual in azimuth, but not much in elevation
- Minimizing the residual in azimuth is key to improving τ_{sdsm}





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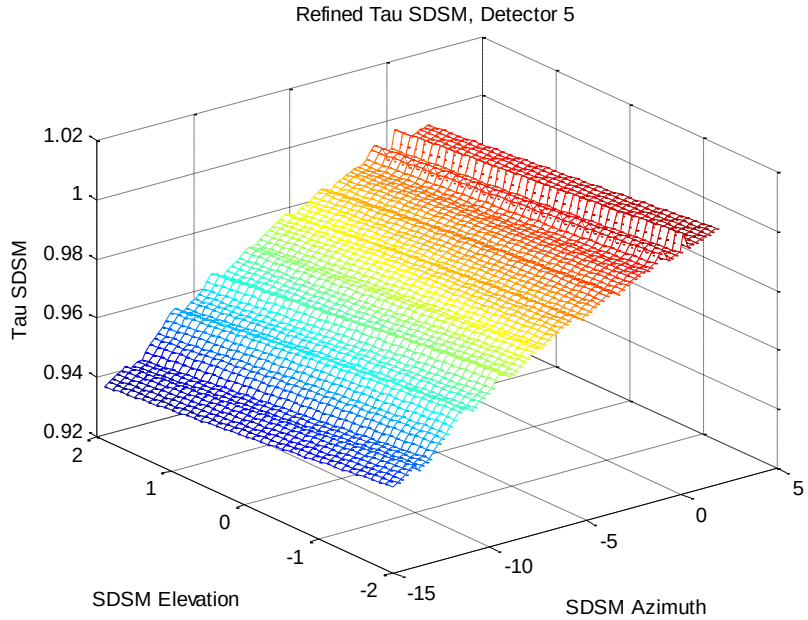
- The residual in azimuth is added to the yaw maneuver defined τ_{sdsm} LUT to create a new refined τ_{sdsm} LUT
- Residuals in elevation are not applied to the table based on a study that showed they had no effect (residuals in elevation average to very close to 0)
- This refinement method is the same as applied in developing the current operational τ_{sdsm} LUT (however it used less than a year's worth of data)



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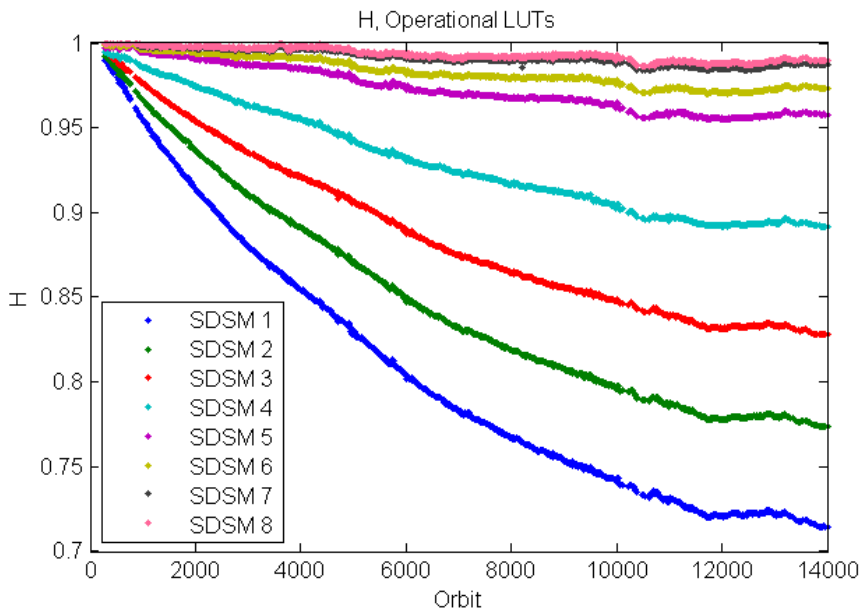
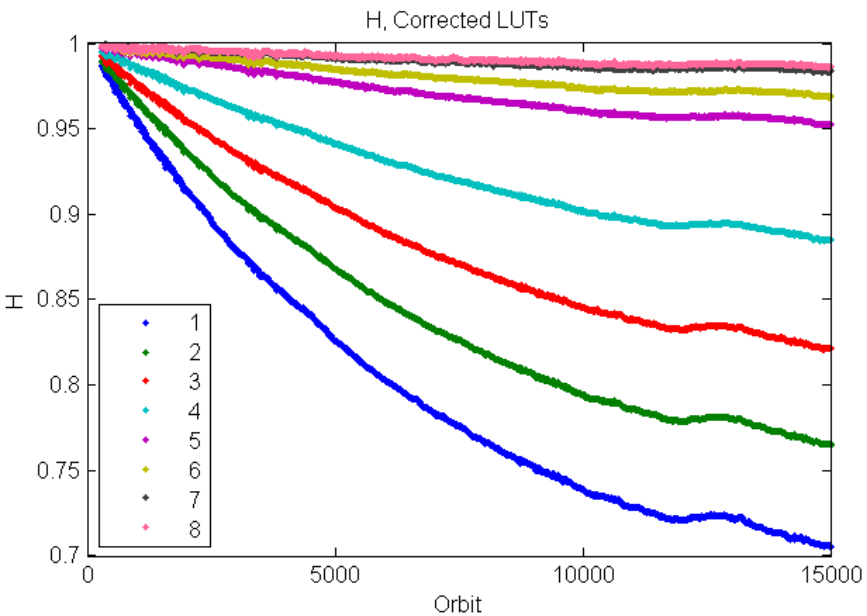
- The H Factor is now re-derived with the new τ_{sdsm} LUT
- There are significant improvements in reducing spurious modulations
- Even modulations after the training period (up to orbit 11700) are improved





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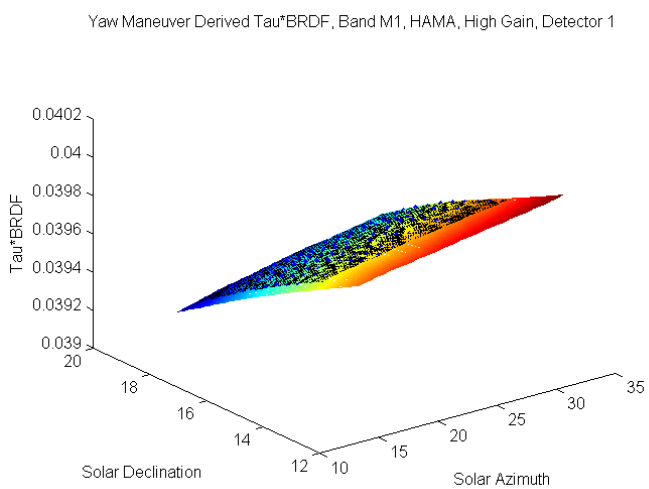
Look Up Table Update Methodology

- Now, the H factor LUTs are complete
- The F factor τ_{sd}*BRDF LUT is now created in the same method as the H factor one, but using the new H factor as an input
- Equation (5) is solved for τ_{sd}*BRDF using the F factor value of the center orbit of the yaw maneuver
- For a given VIIRS band, tables are made for all HAM, gain, and detector combinations, and then averaged



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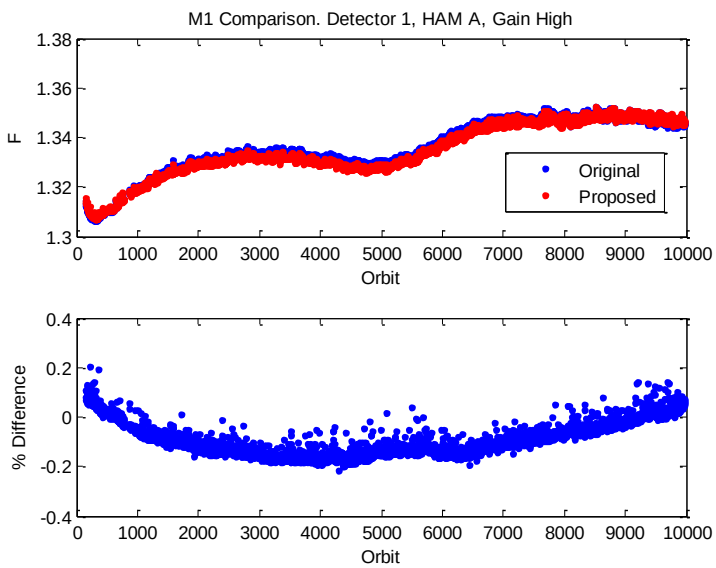
Look Up Table Update Methodology

- F factors are then generated with the new yaw maneuver derived τ_{sd}*BRDF LUT
- New F factors are qualitatively similar to current operational ones, but differ by 0.1% or more, representing improvements in RSB calibration of this magnitude
- Such improvements are significant for the VIIRS derived environmental products most sensitive to the RSB calibration



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Studies

- Many studies were performed to test the robustness of the overall LUT generation method
  - *3 iterations of each set of LUTs were generated with the previous set as the starting point to assess stability of the method*
  - *3 different time periods were compared for applying fit residual corrections in azimuth space: first year, second year, and first two years*
  - *Different forms of exponential fit were applied: A*exp(B*orbit)+C, A*exp(B*orbit^2 + C*orbit), A*exp(B*orbit) + C*exp(D*orbit), and piecewise splines*
- All results were very similar and suggest the method is sound
  - *Extended abstract will present more detail on all methods above*

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Conclusion

- H factor τ_{sd}*BRDF and τ_{sdsm} LUTs and F factor τ_{sd}*BRDF LUT were re-derived from yaw maneuver data using optimized interpolation and extrapolation methods
- The τ_{sdsm} LUT was refined using mission history data, methods and analyses demonstrating:
  - *Stability of the refined LUT to iteration of the derivation*
  - *Insensitivity to choice of training period*
  - *Insensitivity to choice of fitting form for H factor time series*
- New H factor LUTs result in H factor time series that are much smoother and are therefore believed to be more physical
- New F factors with new H factors and new τ_{sd}*BRDF LUT differ from current operational F factors by 0.1% or more in many RSB, representing a significant improvement in RSB calibration accuracy