NASA CERES Strategy for radiometric scaling between SNPP and NOAA-20 VIIRS reflective solar bands

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MODIS/VIIRS Calibration Workshop, Nov 18, 2019

The Hotel at the University of Maryland, College Park, MD

Outline

- Background
  - SNPP and NOAA-20 VIIRS radiometric consistency importance to CERES
  - CERES Imager and Geostationary Calibration Group
- Radiometric scaling of VIIRS instruments
  - Methods:
    - All-sky tropical ocean (ATO) ray-matching with a GEO imager
    - Simultaneous Nadir Overpass (SNO) with Aqua-MODIS
    - PICS invariant target approach (Saharan desert)
    - Deep-convective clouds (DCC) invariant target approach
  - Spectral differences and spectral band adjust factor (SBAF)
- SNPP and NOAA-20 VIIRS radiometric scaling results
  - Consistency among methods
- Conclusions

Background

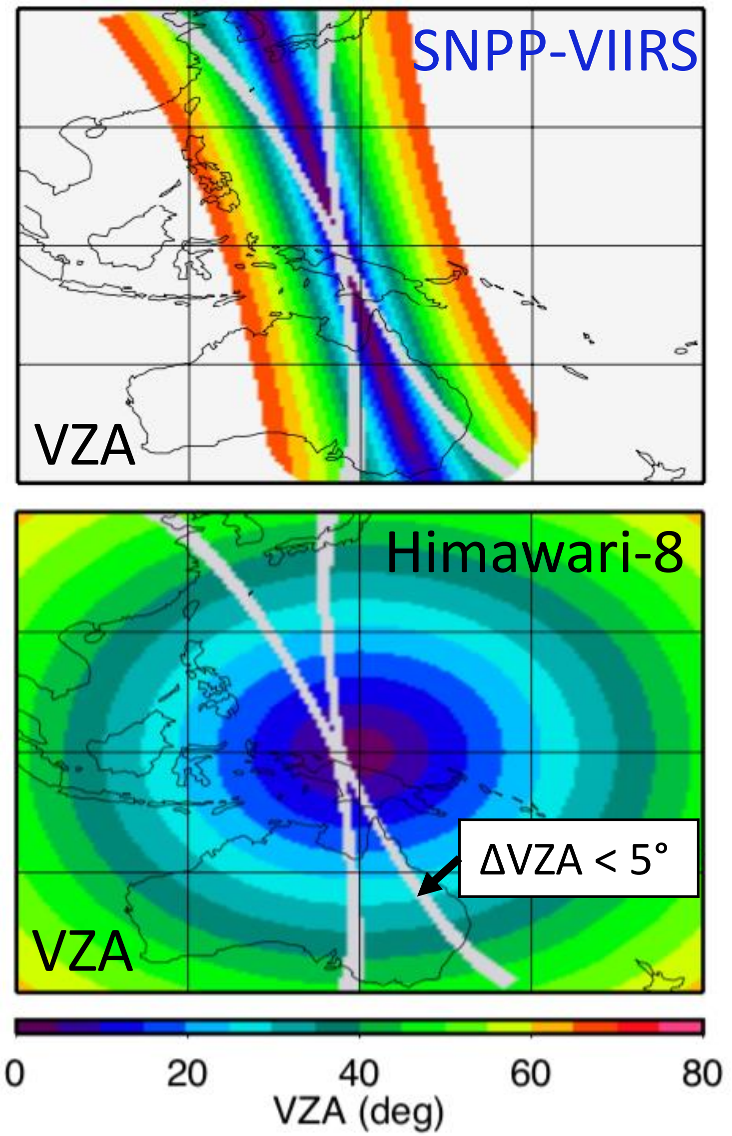
- **Why consistent calibration of two VIIRS instruments matter to CERES?**
  - CERES relies on coincident measurements from onboard imagers (MODIS, VIIRS) for proper scene identification needed to convert CERES radiances into radiative fluxes
  - Consistent retrievals of cloud properties requires
    - **Individual imager records are temporally stable in their calibration**
    - **Both VIIRS imagers are radiometrically consistent**
- CERES also utilizes geostationary (GEO) imager radiances to retrieve clouds and derive broadband fluxes that are used to account for the regional diurnal flux variation between the CERES measurements.
- CERES imager and geostationary calibration group (CIGC) performs calibration assessment of MODIS, VIIRS, and GEO imagers in real-time using multiple approaches

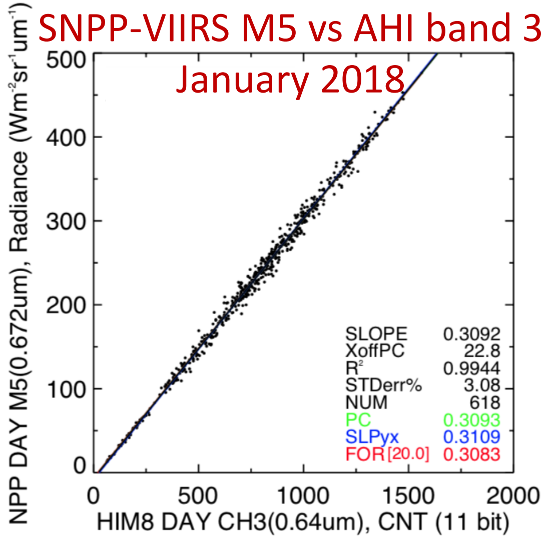
Background (contd.)

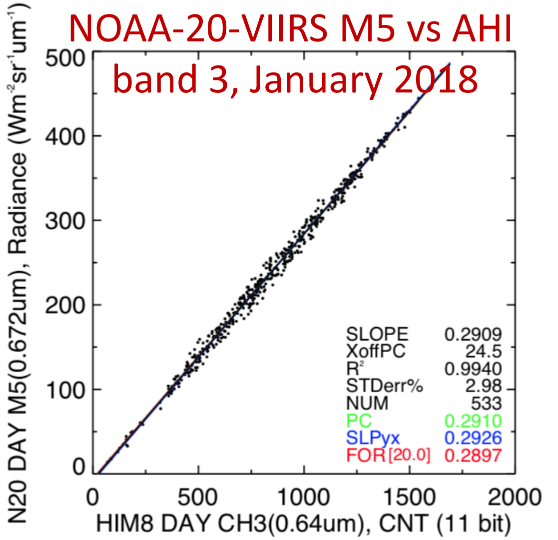
- Three independent cross-calibration approaches are used to estimate radiometric biases between the reflective solar bands (RSB) of SNPP and NOAA-20 VIIRS instruments:
  - Ray-matching with a GEO imager and Aqua-MODIS over ATO
  - DCC invariant target
  - Pseudo-invariant ground site (Libya-4 PICS)
- Datasets used are
  - Aqua-MODIS Collection 6.1 level 1B product
  - SNPP VIIRS V1 and NOAA-20 VIIRS V2 datasets generated by the NASA VIIRS Land Science Investigator-led Processing System (Land SIPS).

ATO-RM with a GEO imager

- Both VIIRS instruments are calibrated against Himawari-8 AHI imager over all-sky tropical ocean targets (0.5° grids)
- Himawari-8 AHI is a transfer radiometer
- Calibrate full dynamic range of sensor
- Matches within 15 minutes
    - VZA, SZA<40°; △VZA=5°-15° 10°<RAA<170°; △RAA=5°-15°
- Linear regression of the matched data on a monthly-basis
- Ratio of the two regression slopes gives radiometric biases between SNPP and NOAA-20 VIIRS

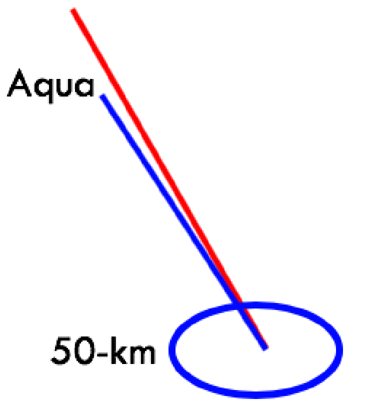


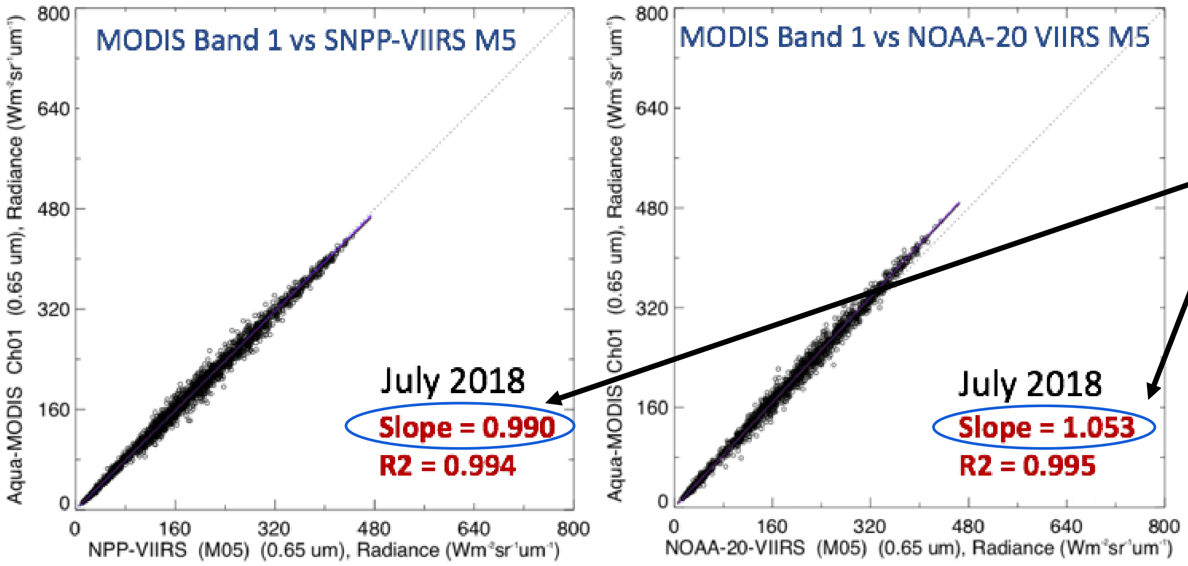




Ray-matching with Aqua-MODIS

- Coincident, co-located, and co-angled radiance pairs for all comparable channels of Aqua-MODIS and SNPP/NOAA-20 VIIRS are acquired between 30 °N and 30 °S.
- Ray-matching is performed over ATO scenes, when the two orbits overlap in time (every 2.5 days)
  - pixels averaged within a shared 50-km diameter constitutes one ray-matched radiance pair
  - VZA/SZA differences < 3°, RAZ difference <10°
- A linear regression forced through zero is fitted to the radiance pairs on a monthly basis and the forced-slope is used as the cross-calibration ratio.

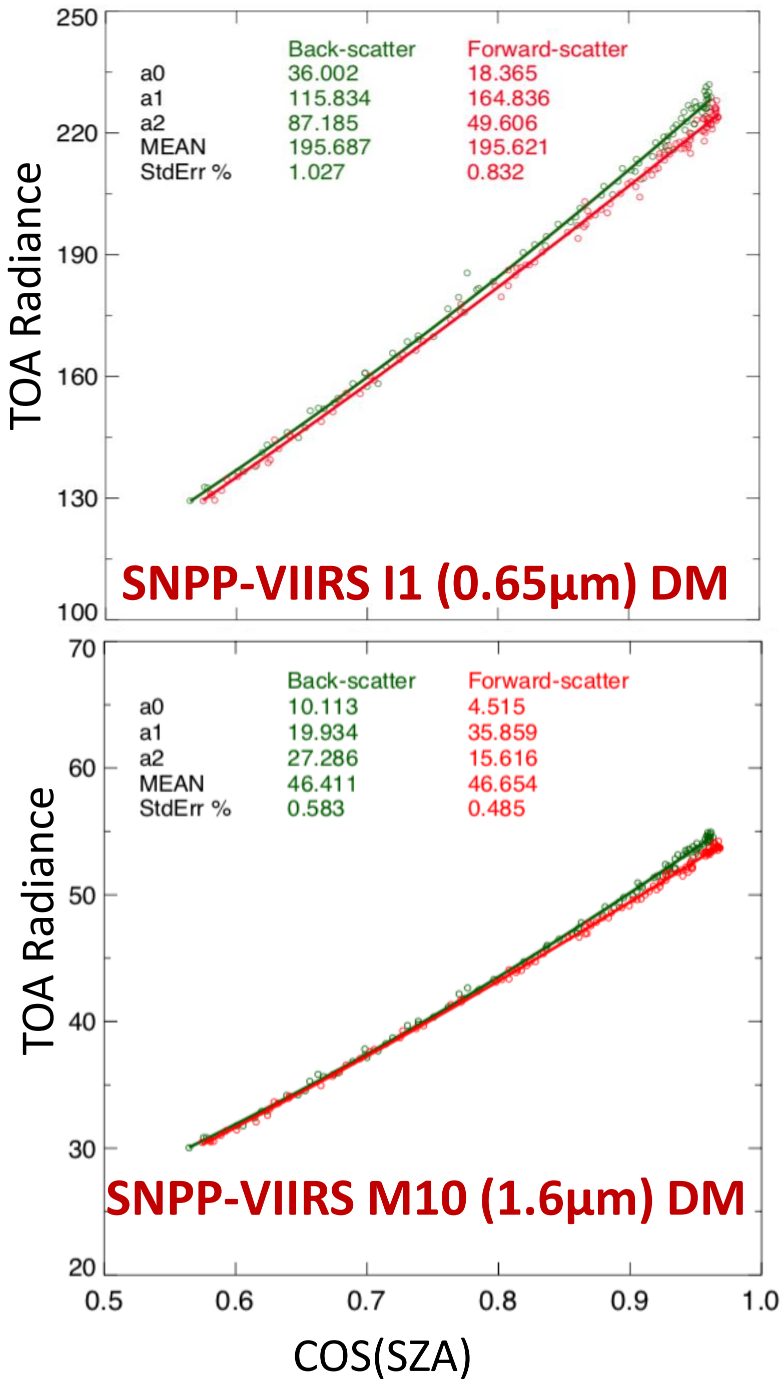




NOAA-20 VIIRS M5 radiances are darker compared to SNPP-VIIRS

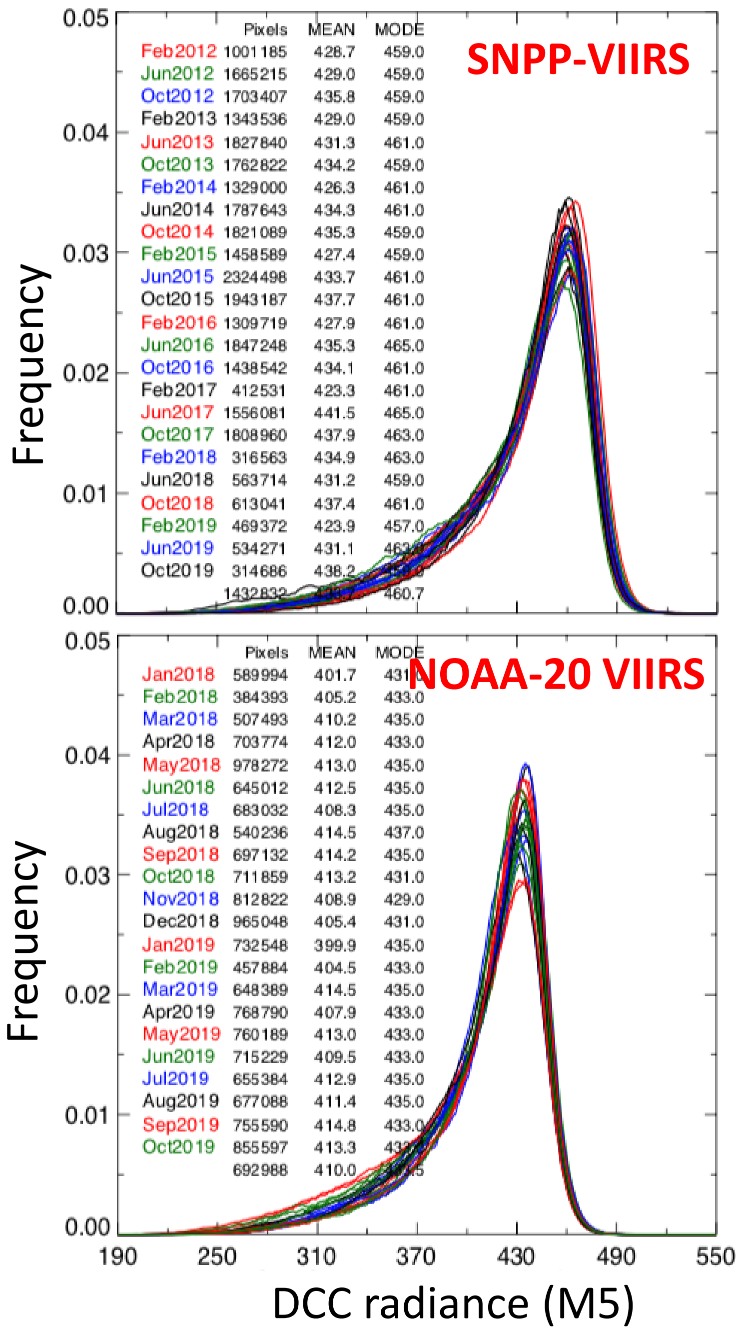
PICS Method

- Libya-4 PICS (28.6°N, 23.4°E, 0.5° x0.5° ROI)
- Only near-nadir observations (VZA < 10°) are considered
- PICS TOA radiance is modeled as a function of SZA (2nd order regression)
  - Libya-4 directional models (DM) stratified by scattering direction (back/forward)
  - 7-year data from SNPP-VIIRS are used to construct DM
- DM can predict TOA radiance for a given SZA of a target LEO (NOAA-20 VIIRS).



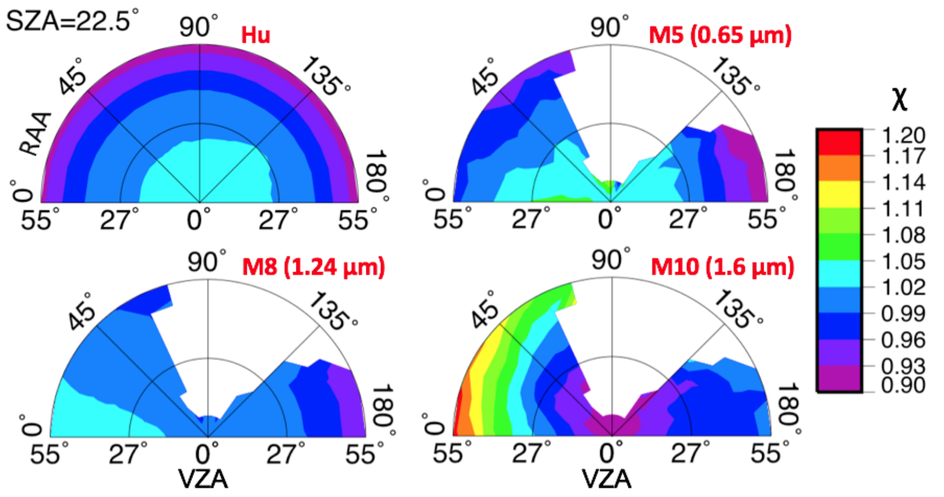
Baseline DCC method

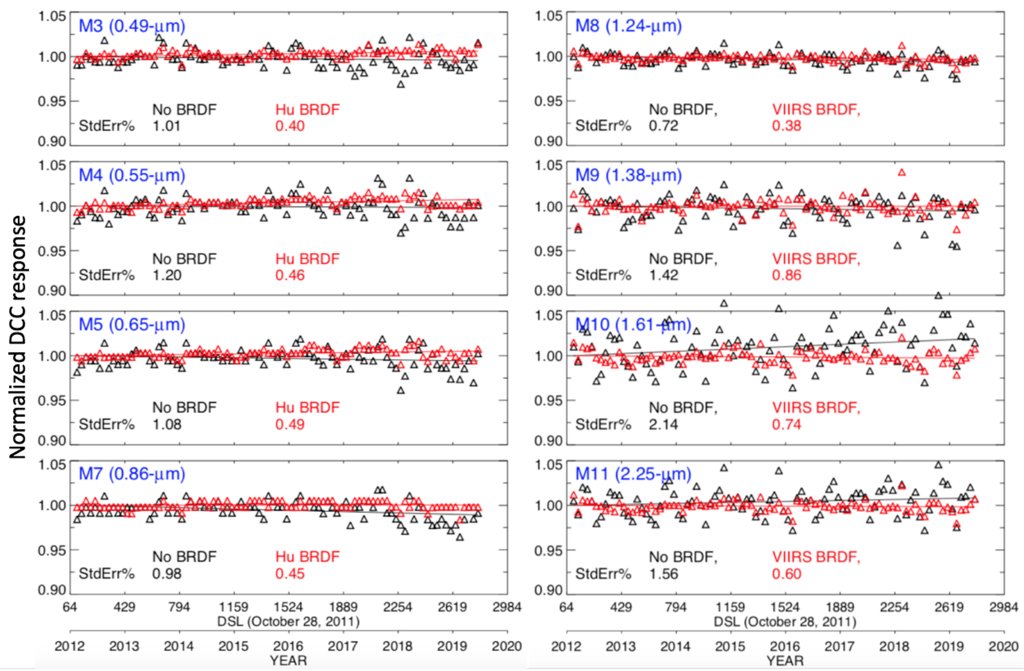
- DCC pixel selection criteria:
  - BT11µm < 205.0°K, SZA < 40°, VZA < 40°, 10° < RAA < 170°, σ(BT11µm) < 1.0° K, and σ(VIS) <3%
- DCC pixels are compiled into monthly probability distribution functions (PDFs) and their modes are tracked over time.
- Anisotropic correction using the angular distribution model by Hu et al 2004.
- Suitable for wavelengths <1 µm



Improved DCCT for SWIR bands

- At SWIR wavelengths,
  - DCC reflectivity is affected by ice particle size
  - results in large seasonal cycles
  - DCC response is highly dependent on the IR BT threshold
- Channel and seasonal specific empirical BRDFs are constructed using the SNPP-VIIRS DCC reflectances from 2012-2016
- VIS-NIR BRDFs are similar to Hu model
- Cirrus Channel (1.38 µm)
  - Ground PICS are inapplicable for vicarious calibration
  - Radiation is mostly absorbed by atmosphere, except for high altitude ice clouds
- SWIR band BRDFs reduces temporal variability of DCC response by up to 65%.
- By implementing similar DCC thresholds and BRDF normalizations, inter-sensor comparison using mean and mode statistics is feasible.



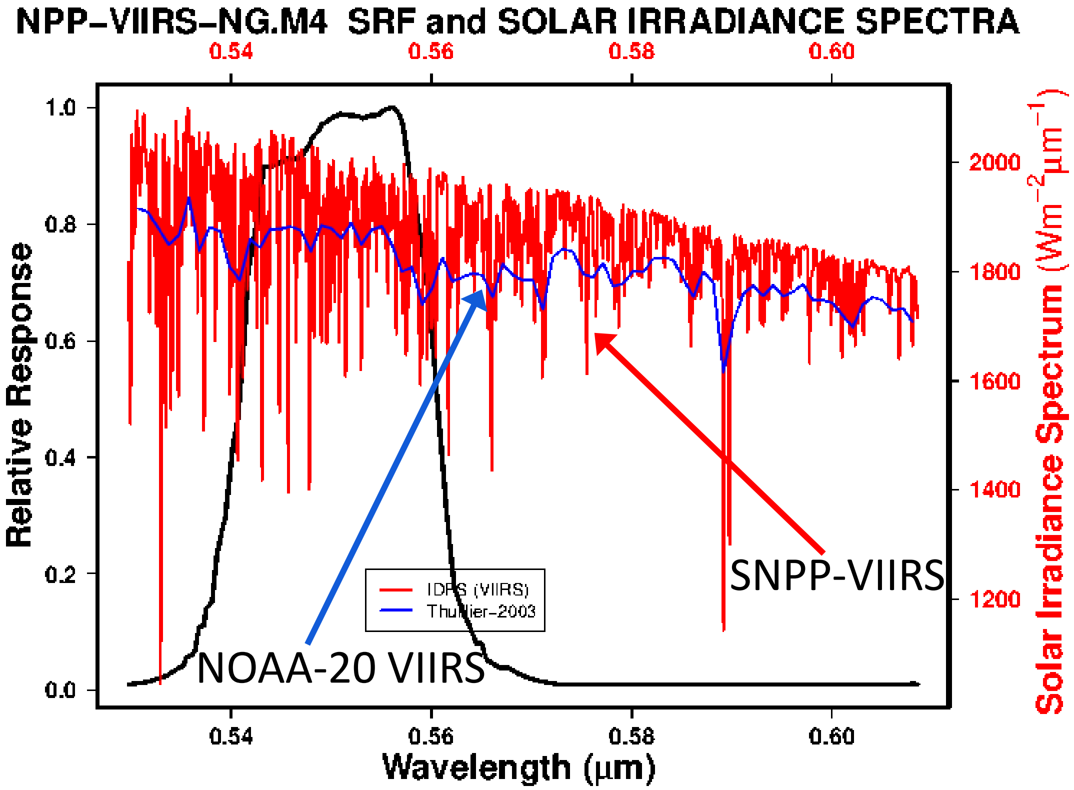


Radiance and Reflectance biases

Reference Solar Spectrum

- VIIRS instruments are calibrated on *Reflectance* scale (solar diffuser reference)
- $Radiance = Reflectance \times E_{SUN} \times \cos(SZA)/d^2$
- SNPP (Modtran) and NOAA-20 (Thuillier) VIIRS use different solar irradiance models
- Biases will differ for radiance and reflectance
- Difference in reference solar spectra can induce additional (+/-) radiance/reflectance bias

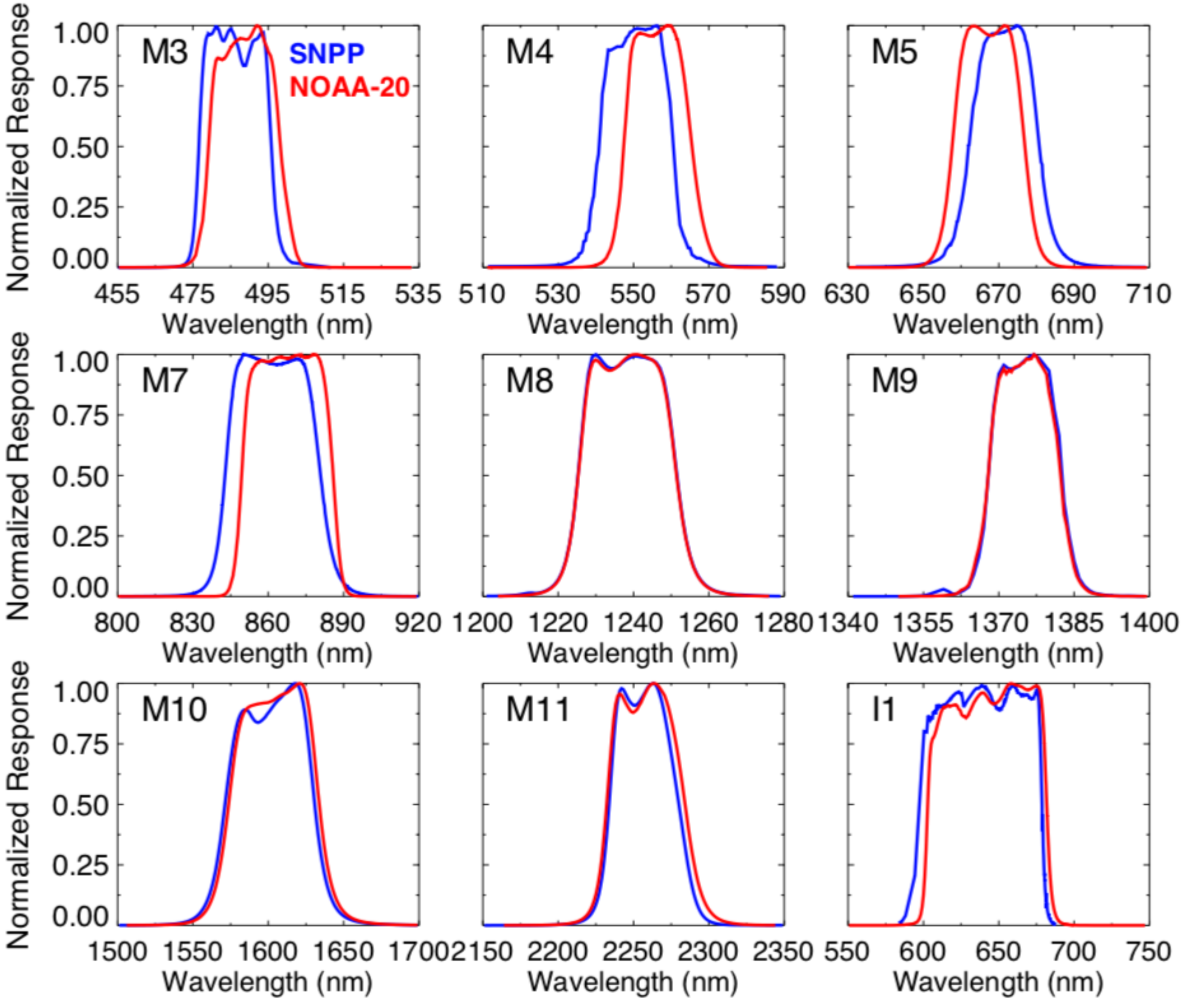
Impact on M4 band calibration

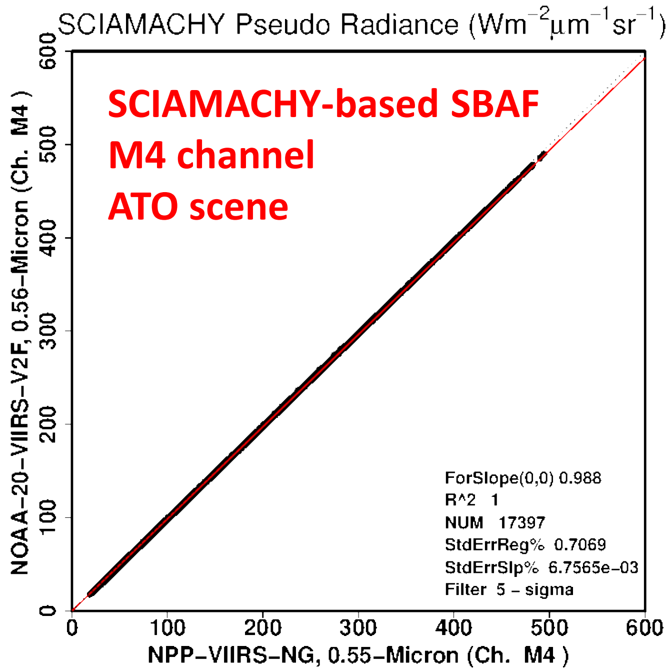


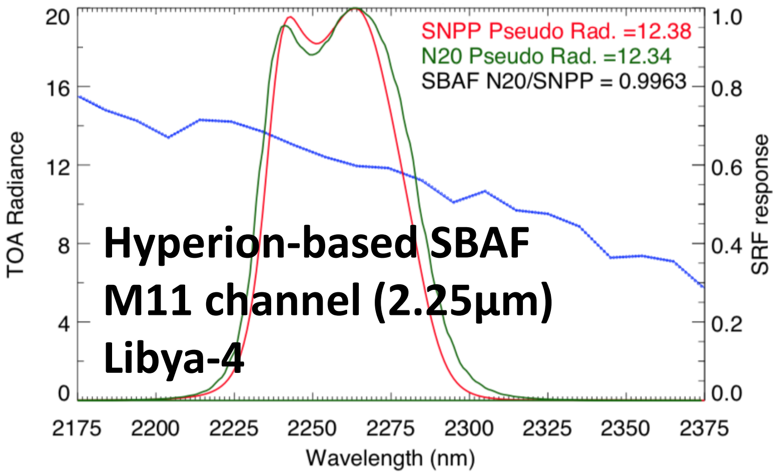
~2% difference in E_{sun} for M4 (0.55 µm) band

Solar constant tool: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS

SRF differences and SBAF



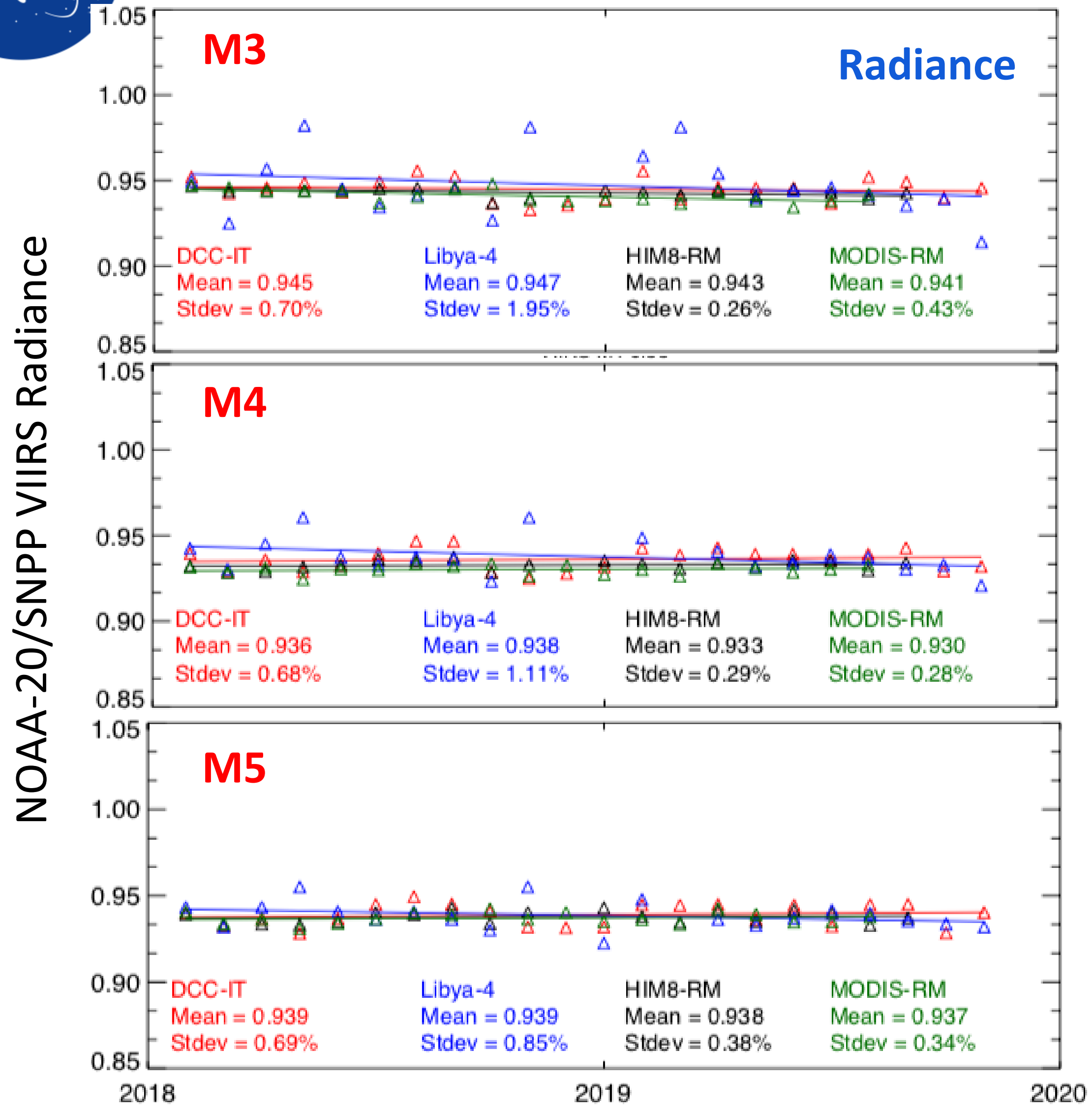


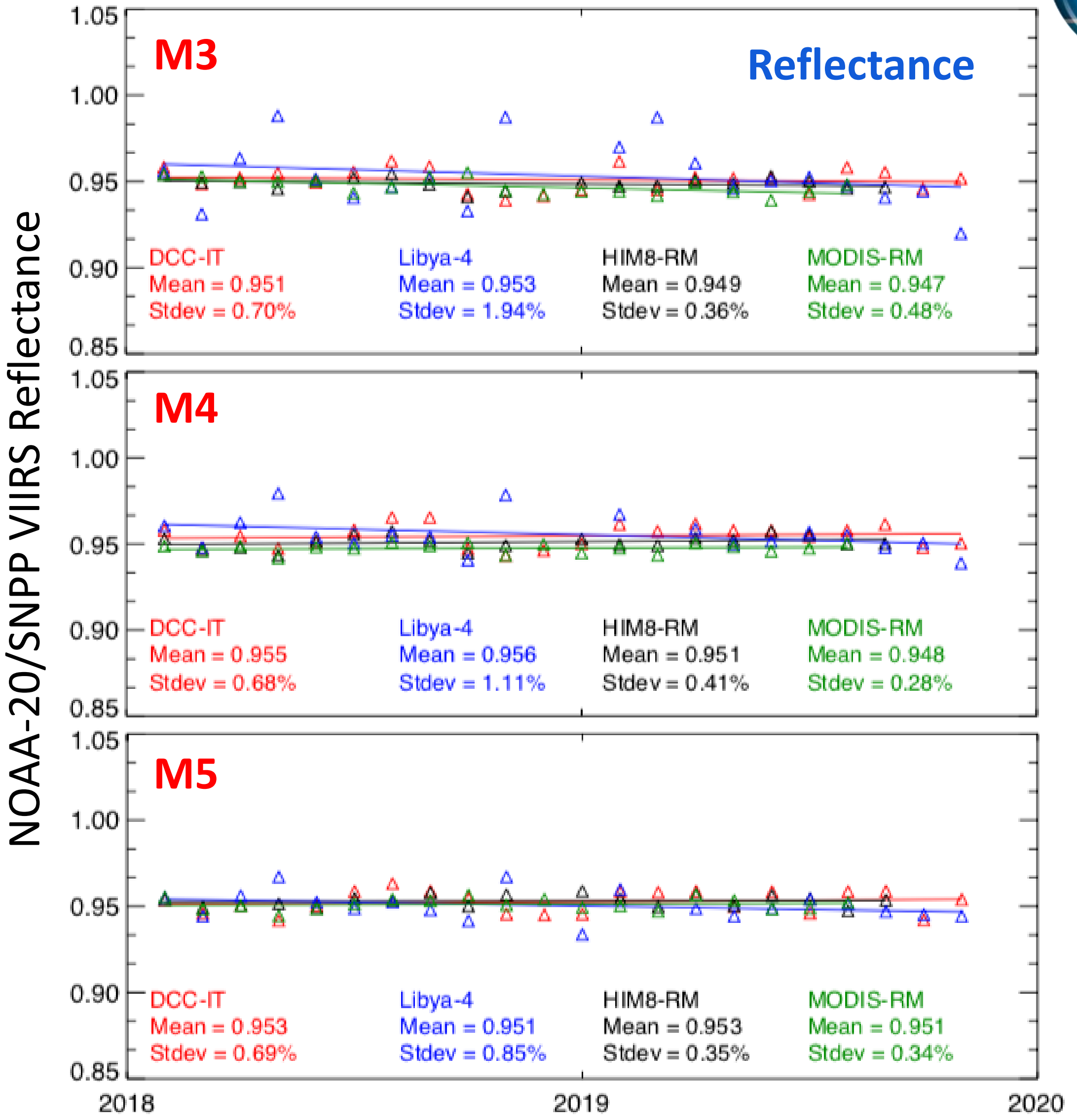


- Mostly similar SRFs and all scene SBAFs are within 2%

Solar constant tool: https://satcorps.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF

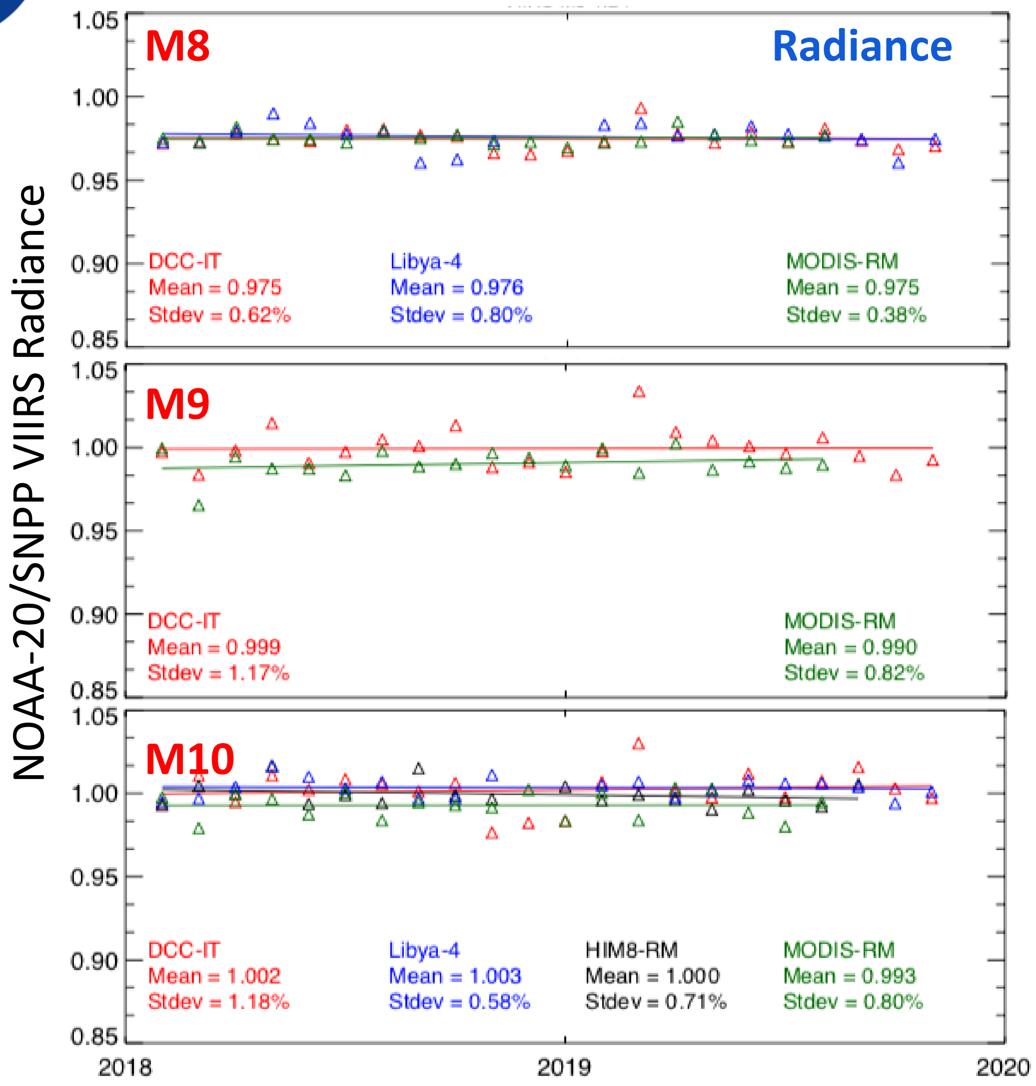
Results

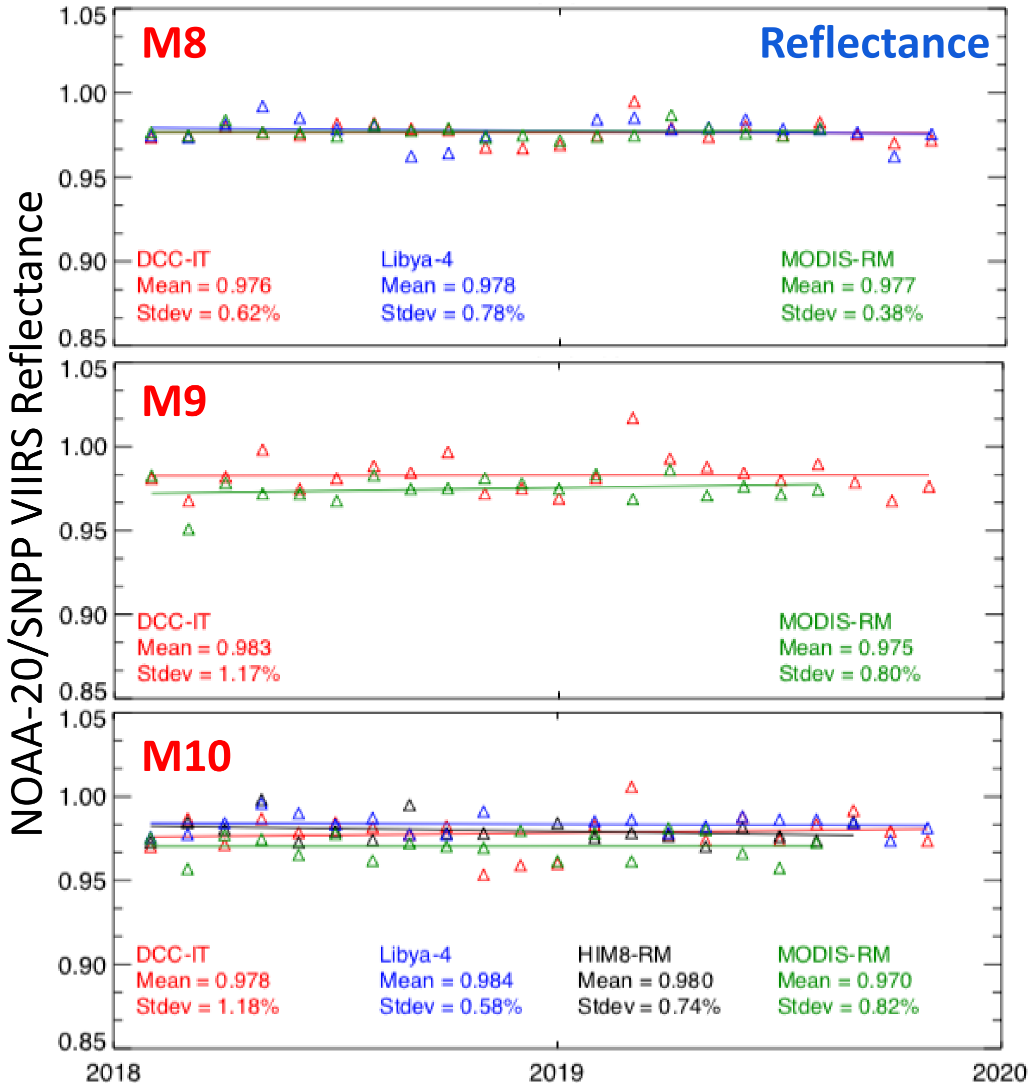




- M4 radiance and reflectance biases differ by 2% (due to solar irradiance model)

Results





All methods agree within ~2%

Bias table

Band	Radiometric bias 100% x (1-NOAA-20/SNPP)				
	HIM8 AHI RM	Aqua-MODIS RM	DCC-IT	Libya-4 PICS	Consistency within
M3 (0.48µm)	+5.7 (+5.1)	+5.9 (+5.3)	+5.4 (+4.9)	+5.3 (+4.7)	0.6 (0.6)
M4 (0.55µm)	+6.7 (+4.9)	+7.0 (+5.2)	+6.4 (+4.5)	+6.2 (+4.4)	0.8 (0.8)
M5 (0.65µm)	+6.2 (+4.7)	+6.3 (+4.9)	+6.1 (+4.7)	+6.1 (+4.9)	0.2 (0.2)
I1 (0.65µm)	+5.6 (+4.5)	+5.6 (+4.5)	+5.2 (+4.3)	+5.8 (+4.7)	0.6 (0.4)
M7 (0.86µm)	+3.5 (+3.8)	+3.5 (+3.7)	+3.8 (+3.9)	+3.9 (+4.1)	0.4 (0.4)
M8 (1.24µm)	NA	+2.5 (+2.3)	+2.5 (+2.4)	+2.4 (+2.2)	0.1 (0.2)
M9 (1.38µm)	NA	+1.0 (+2.5)	+0.1 (+1.7)	NA	0.9 (0.8)
M10 (1.6µm)	0 (+2.0)	+0.7(+3.0)	-0.2(+2.2)	-0.3 (+1.6)	1.0 (1.4)
I3 (1.6µm)	+2.1 (+4.5)	+2.6 (+4.8)	2.0 (+4.6)	+3.3 (+4.6)	1.2(0.3)
M11 (2.25µm)	-1.7(+1.0)	NA	-1.0 (+1.7)	-1.7 (+1.1)	0.7 (0.7)

- Reflectance biases are provided in parenthesis
- '+' indicates SNPP-VIIRS is brighter

- All methods consistent within 0.8%, except for M10
- For bands < 1µm NPP is brighter than NOAA20 VIIRS by 3.5-6%

Conclusions

- NPP and NOAA-20 VIIRS are radiometrically scaled using
  - NPP and NOAA-20 do not have any SNOs, since they are in the same orbit and altitude but are spaced by 45 minutes
  - Transfer radiometers with similar spectral response functions, Himawari-8 and Aqua-MODIS
  - Invariant Earth targets, Libya-4 and deep convective clouds
  - Spectral band adjustment factors are utilized to account for slight spectral response differences
- Both reflectance and radiance scaling factors are computed
  - Reflectance is based on solar diffuser observation. (assumes a EARTH reflected spectra that is flat over the band)
  - Radiance requires a solar spectra. NPP and NOAA-20 use differing solar constants, which are wrapped into the scaling factor.
  - Band spectral difference were taken into account using scene specific SBAFs
- The method specific NPP and NOAA-20 VIIRS radiometric scaling factors are within 0.8%
  - NPP-VIIRS is brighter by 3.5% to 5% for bands < 1µm
- CERES will radiometrically scale the VIIRS to Aqua-MODIS C5 reference to maintain a consistent calibration throughout the 20-year record.