NPP and NOAA-20 VIIRS RSB radiometric scaling utilizing multiple approaches

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May 1, 2023

MODIS/VIIRS Calibration Workshop

Outline

- Background
  - CERES EBAF flux product requirements
  - CERES Imager and Geostationary Calibration Group
- Radiometric scaling of VIIRS instruments
  - Methods:
    - All-sky tropical ocean ray-matching (ATO-RM) Aqua-MODIS/VIIRS
    - Polar SNO with Aqua-MODIS/VIIRS
    - PICS approach (Libya-4)
    - Deep-convective clouds invariant target approach
  - Spectral differences and SBAF
- Results
- Conclusions

CERES EBAF product

- The CERES EBAF monthly product provides observed broadband fluxes needed to monitor the Earth's energy balance and validate climate models
- The stability of the EBAF fluxes relies on the
  - The CERES onboard calibration systems
  - The well-maintained sun-synchronous orbits
  - The cloud retrieval continuity between MODIS and VIIRS imagers designed to identify the angular directional model (ADMs) scene types to convert CERES observed radiances into fluxes
  - The diurnal models to estimate the regional flux variability between CERES measurements, which are a combination of geostationary derived broadband fluxes and constant meteorology models
- The CERES EBAF product has transitioned from Terra and Aqua inputs to a N20 only input beginning with the data month of April 2022
  - The Terra and Aqua orbits have drifted outside of their mean local time window
  - The Aqua spacecraft anomaly accelerated the transition
  - The seamless transition was accomplished using regional climatology adjustment factors based on the 5-year Terra and Aqua overlap period that adjusts for the Terra morning observations and the MODIS and VIIRS cloud property induced flux differences

CERES EBAF product

- CERES utilizes their own cloud retrieval algorithm designed to minimize the number pixels with unretrieved cloud properties identified by the cloud mask
- MODIS and VIIRS cloud retrieval continuity requires
  - MODIS and VIIRS on orbit calibration stability
  - Consistent MODIS and VIIRS analogous channel calibration
  - Accounting for spectral band differences
  - Using MODIS and VIIRS channels common to both
  - Accounting for MODIS and VIIRS pixel size differences
- CERES incorporates 22 geostationary imager derived clouds and fluxes
  - The GEO channel radiances are scaled to the Aqua-MODIS C6.1 calibration reference to retrieve GEO clouds consistent the MODIS
  - The GEO derived fluxes are carefully normalized to the CERES observed fluxes to estimate the regional diurnal flux using the same ADMs

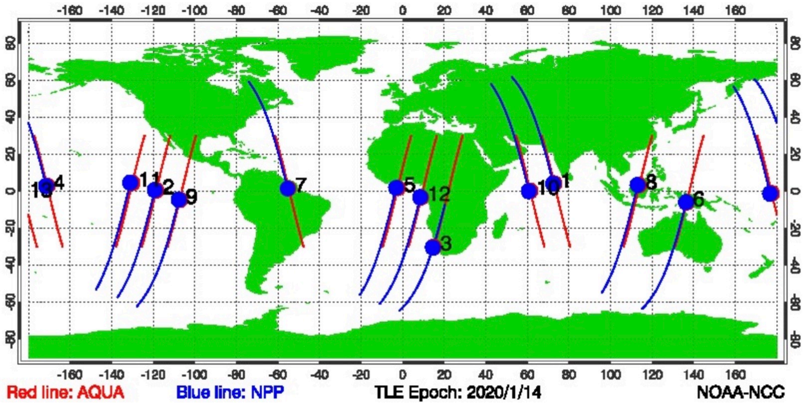
CERES imager and geostationary calibration group (IGCG)

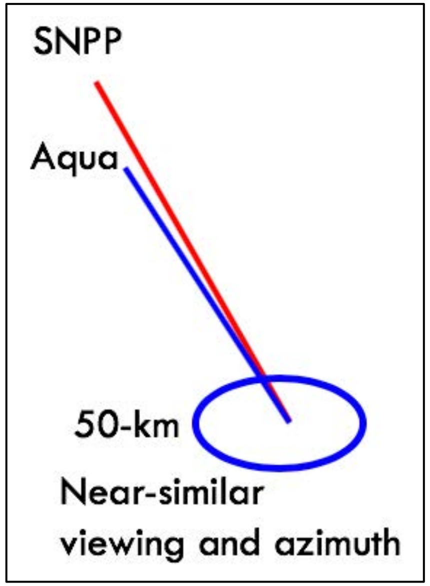
- The group performs calibration assessment of MODIS, VIIRS, and GEO imagers in real-time using multiple approaches
- The calibration group provides the GEO visible radiometric scaling factors referenced to the MODIS C6.1 calibration metric for CERES Edition 4 products (MODIS C7 for Edition 5)
- Three independent reflective solar bands (RSB) cross-calibration approaches are used to estimate radiometric SNPP and NOAA-20 VIIRS biases
  - All-sky tropical ocean ray-matching (ATO-RM) between Aqua-MODIS and VIIRS
  - DCC invariant target
  - Pseudo-invariant ground site (Libya-4 PICS)
- Datasets used are
  - Aqua-MODIS Collection 6.1 level 1B product
  - SNPP VIIRS V2 and NOAA-20 VIIRS V2.1 datasets generated by the NASA VIIRS Land Science Investigator-led Processing System (Land SIPS).

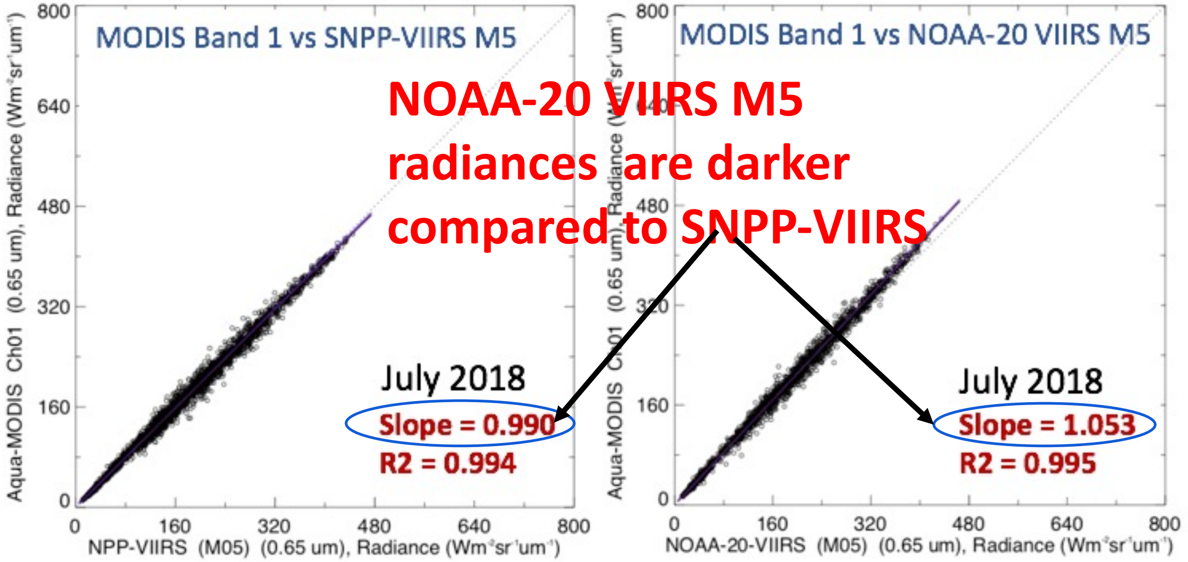
Ray-matching with Aqua-MODIS

- 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 all-sky tropical ocean (ATO-RM) scenes
  - 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.

Tropical SNO, Jan 14, 2020

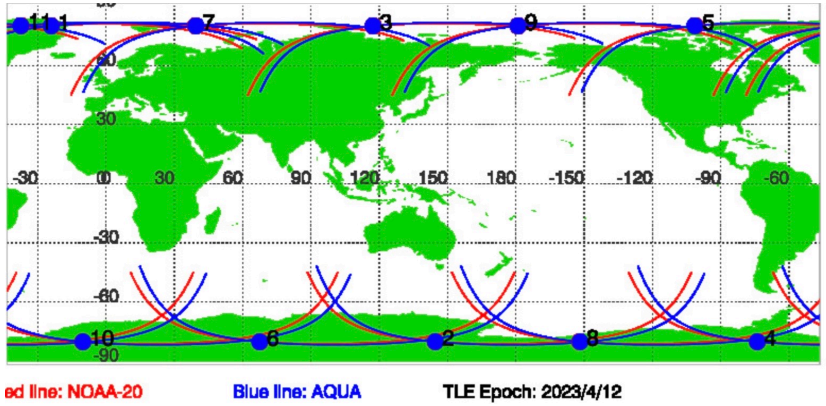






Ray-matching with Aqua-MODIS

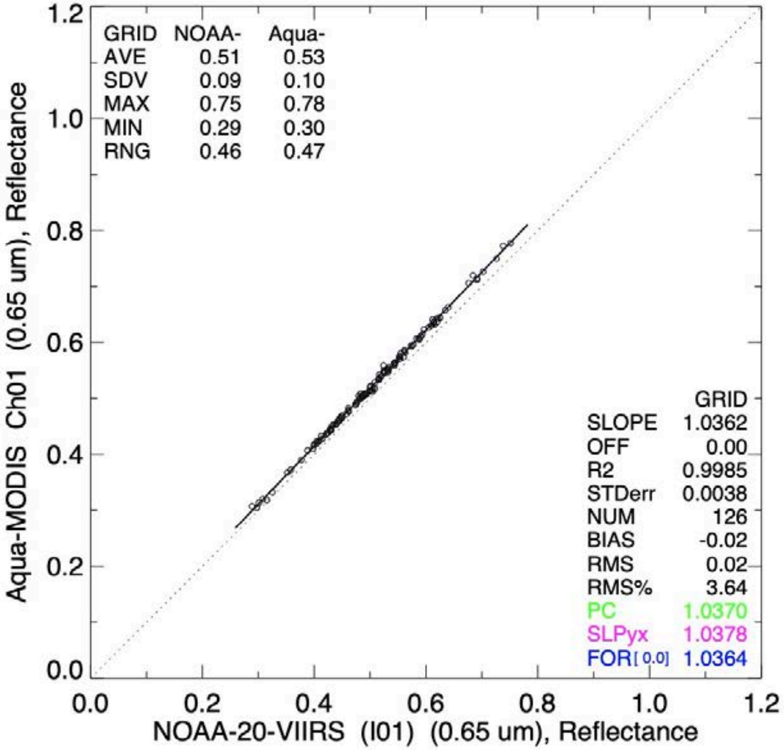
Polar SNO, Apr 12, 2023



- Coincident, co-located, and co-angled radiance pairs for all comparable channels of Aqua-MODIS and SNPP/NOAA-20 VIIRS are acquired poleward of 60° across all surface types.
- Other wise same as ATO-RM approach

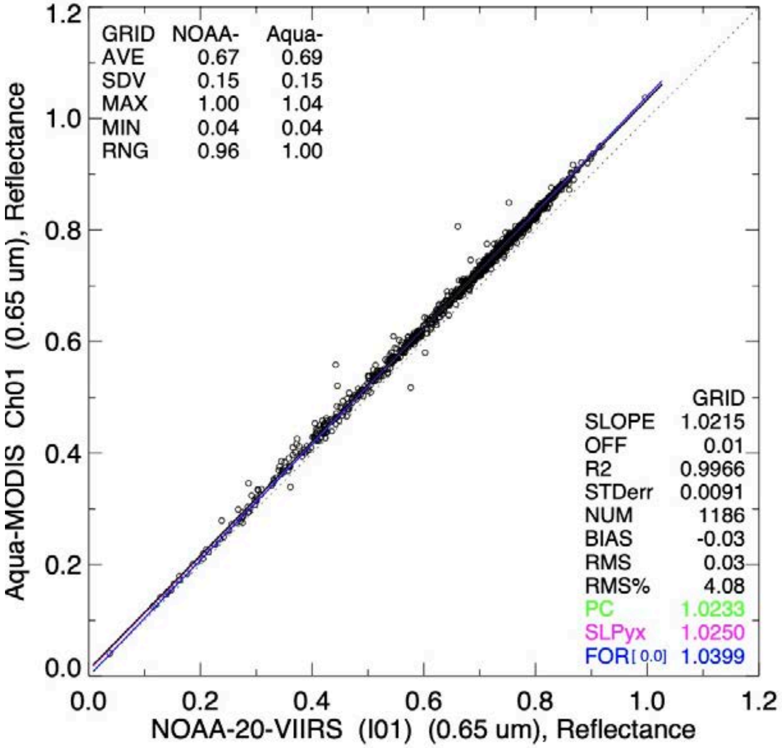
North Pole, 2021_07

Aqua/N20 ratio = 1.036

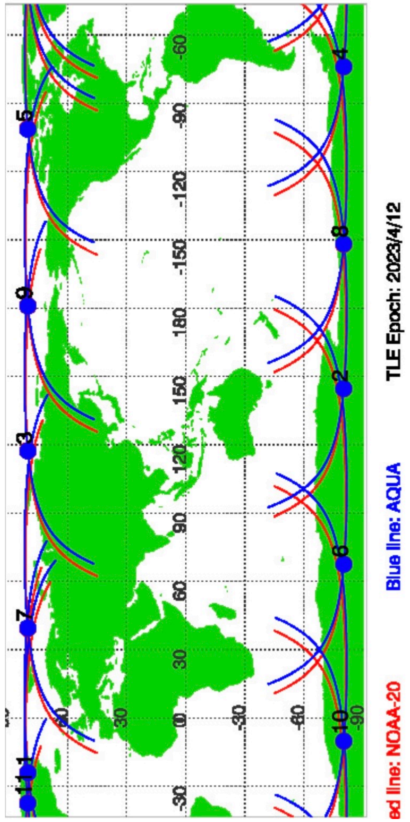


South Pole, 2021_12

Aqua/N20 ratio = 1.040

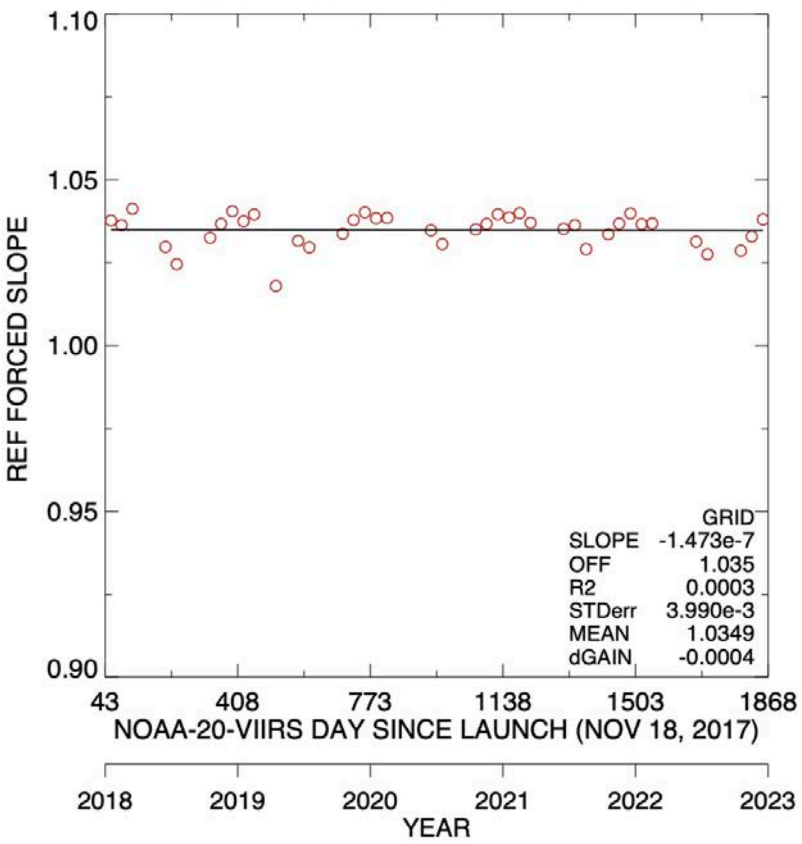


Ray-matching with Aqua-MODIS



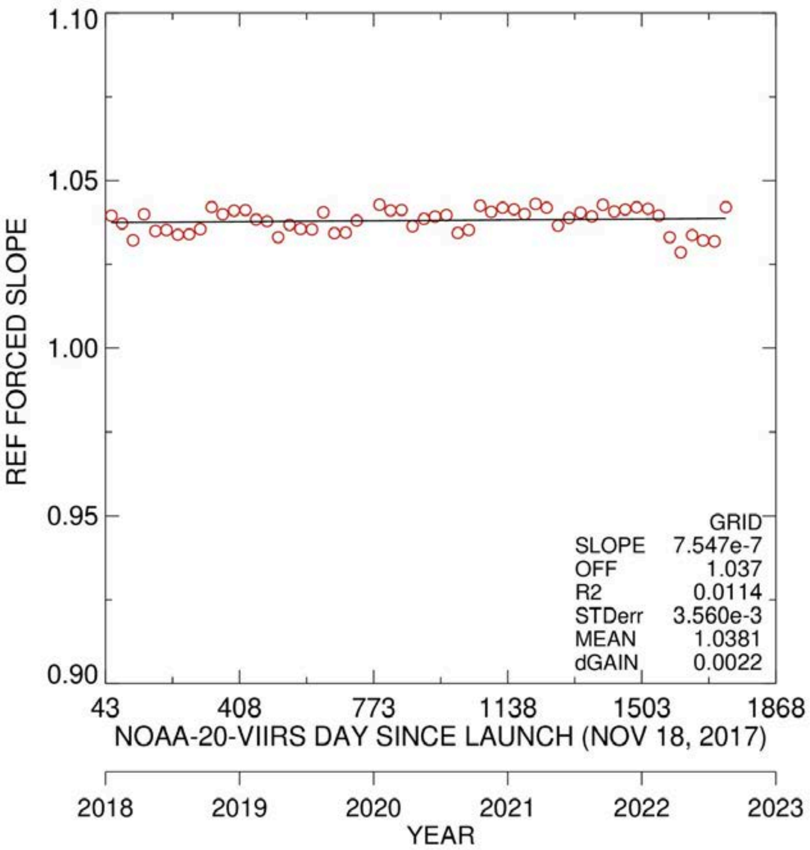
Poles, 2018-2022

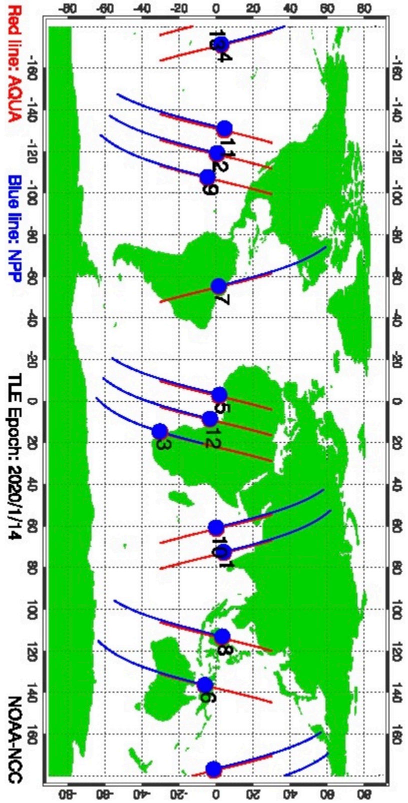
Aqua/N20 mean ratio = 1.035



All-sky Tropical Ocean, 2018-2022

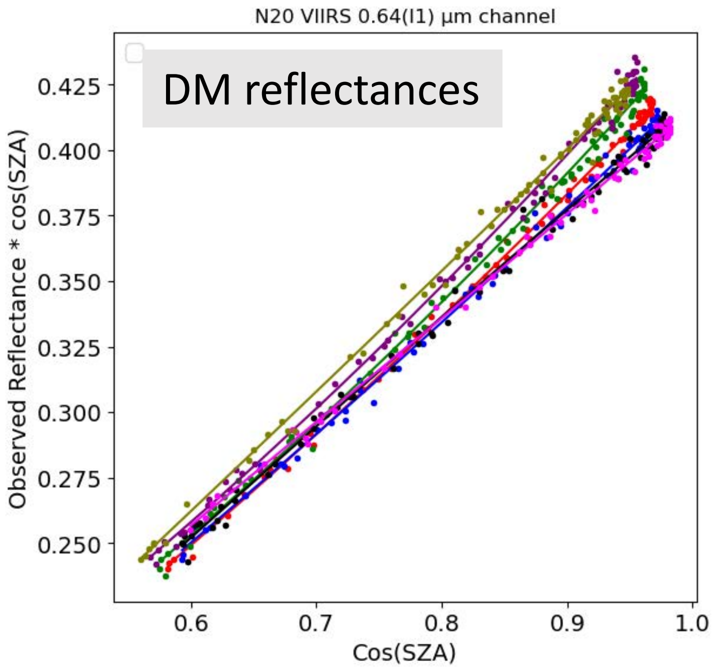
Aqua/N20 mean ratio = 1.038

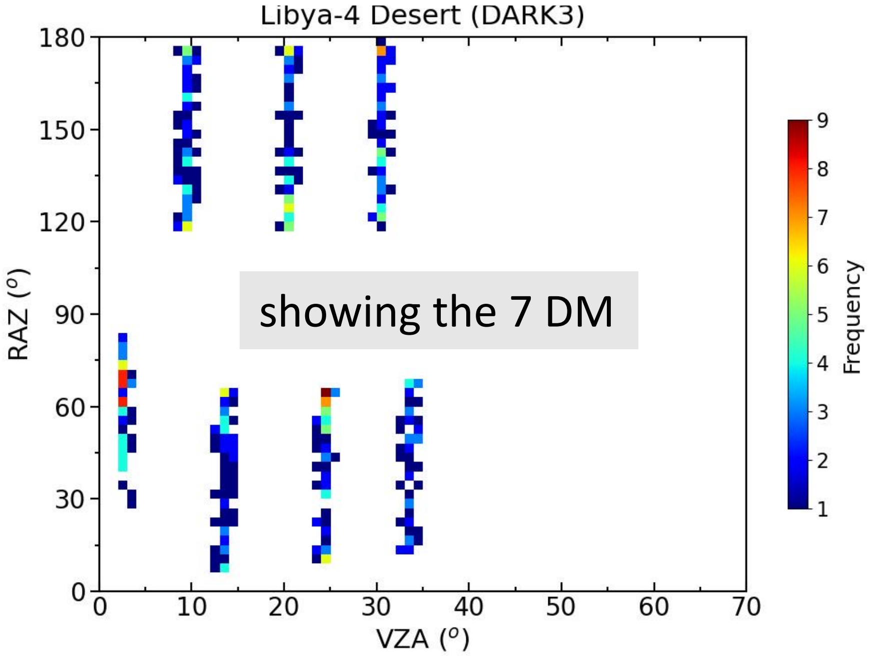




Libya4 Directional Models

- Libya-4 PICS (28.6°N, 23.4°E, 0.5°x0.5°) VZA observations < 35°are considered
- Libya TOA reflectance is modeled as a function of SZA (2nd order regression) and with atmospheric parameters
  - Libya-4 SZA directional models (DM) stratified by back and forward scattering and by VZA
  - Ozone, PW, Wind Speed, Surface pressure
- DM predict the TOA reflectance to monitor the sensor stability
- Sensor pair reflectance ratios are computed from the DMs using the mean conditions of Libya-4
  - SZA= 28.0°, Ozone=292 DOB, PW=1.74 cm, WS=3.9 m/s, Psurf 1003.2 hpa



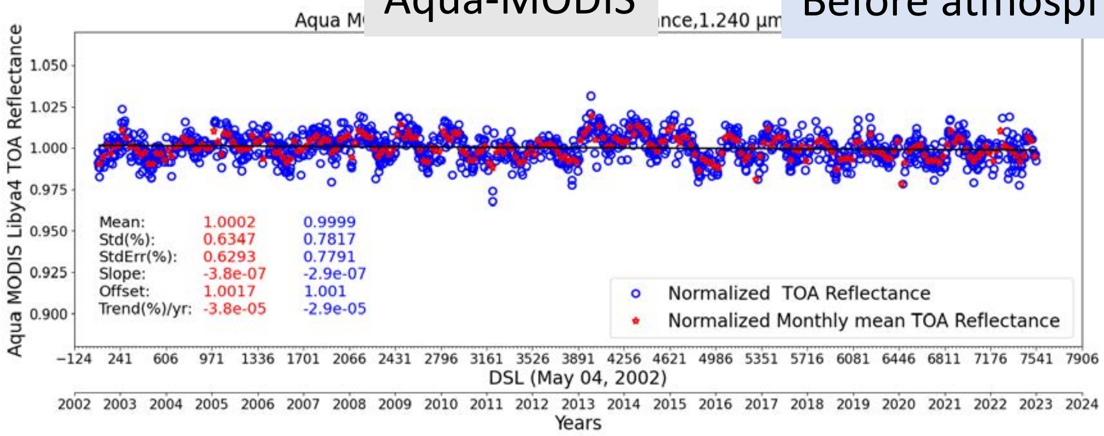


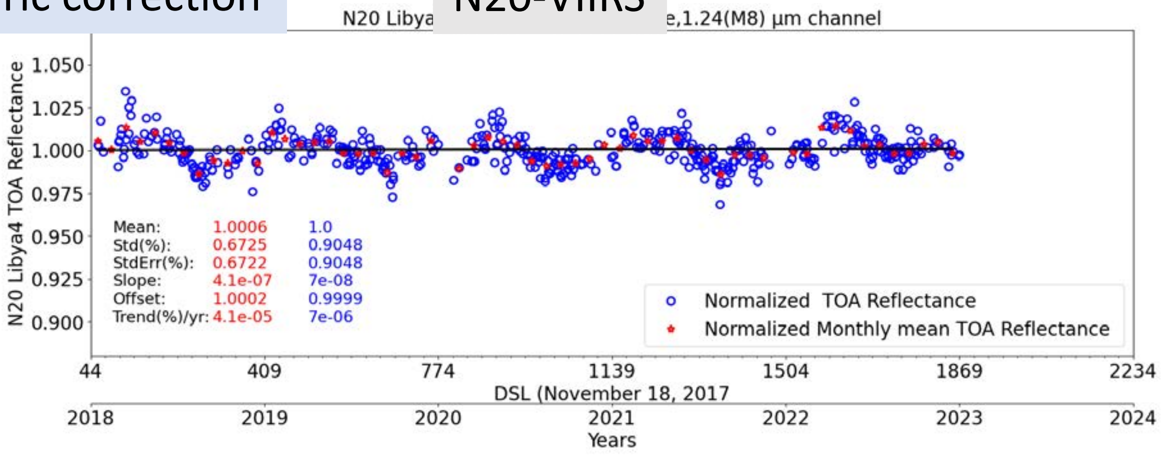
Comparison of Libya-4 1.24µm stability with and without atmospheric parameters

Aqua-MODIS

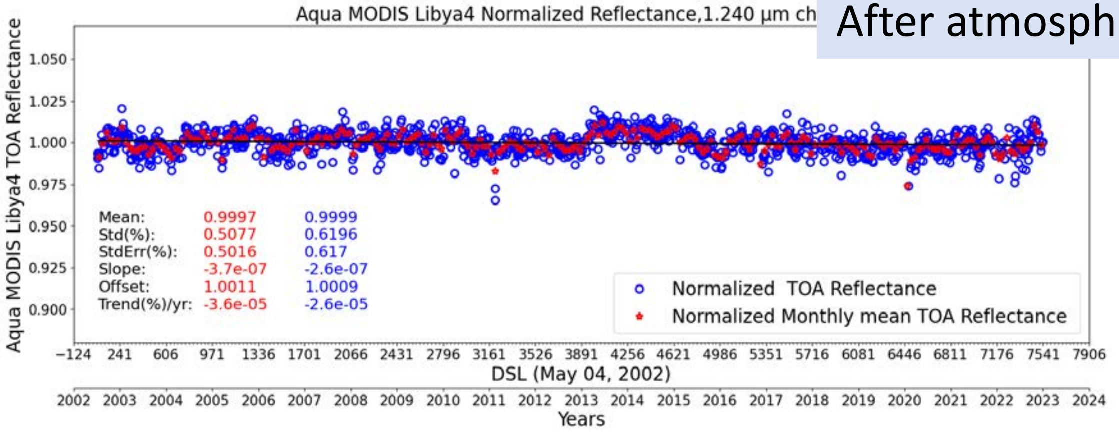
Before atmospheric correction

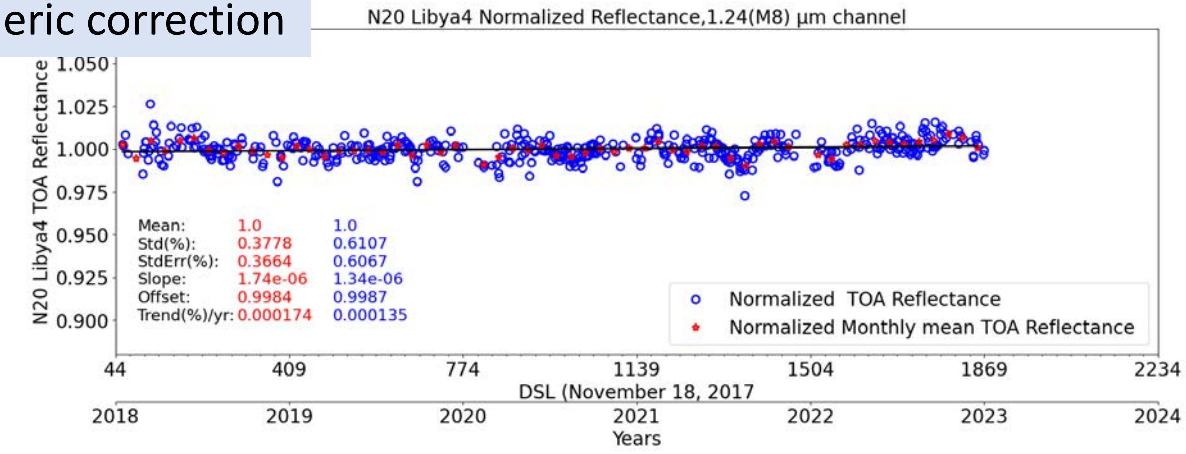
N20-VIIRS





After atmospheric correction





21% sigma reduction for Aqua utilizing atmospheric correction

33% sigma reduction for N20 utilizing atmospheric correction

Libya-4 temporal stability table

monthly Libya-4 reflectance linear regression standard errors in (%)

SAT/BANDS		0.64 (%)	0.87 (%)	0.46 (%)	0.55 (%)	1.24 (%)	1.629 (%)	2.10 (%)	(%)	(%)
Aqua	SZA+SZA^2	0.8328	0.873	0.9791	0.8999	0.7791	0.657	1.793		
	SZA+SZA^2+atm par	0.7031	0.6578	0.9542	0.8346	0.617	0.6323	0.9144		
		15.6	24.7	2.5	7.3	20.9	3.8	49		
Terra	SZA+SZA^2	0.8997	0.9887	1.193	0.9728	0.979	0.6538	2.0208		
	SZA+SZA^2+atm par	0.7832	0.7384	1.1724	0.928	0.8656	0.6198	1.1937		
		13.01	25.43	2.03	4.75	12.40	5.43	40.90		
SAT/BANDS		**0.67 (M5)**	**0.87 (M7)**	**0.49 (M3)**	**0.55 (M4)**	**1.24 (M8)**	**1.629 (M10)**	**2.10 (M11)**	**0.64 (I1)**	**1.61 (I3)**
N20	SZA+SZA^2	0.6741	0.6487	0.9682	0.8688	0.9048	0.5673	1.5368	0.8442	0.6506
	SZA+SZA^2+atm par	0.612	0.5688	0.8791	0.7849	0.6067	0.5084	0.8286	0.7466	0.5876
		9.21	12.32	9.20	9.66	32.95	10.38	46.08	11.56	9.68
NPP	SZA+SZA^2	0.6072	0.6733	0.8817	0.8146	0.8809	0.5381	1.5139	0.7203	0.5412
	SZA+SZA^2+atm par	0.5448	0.5403	0.7912	0.7079	0.5736	0.4859	0.8083	0.6001	0.4906
		10.27	19.75	10.26	13.09	34.88	9.70	46.60	16.69	9.34

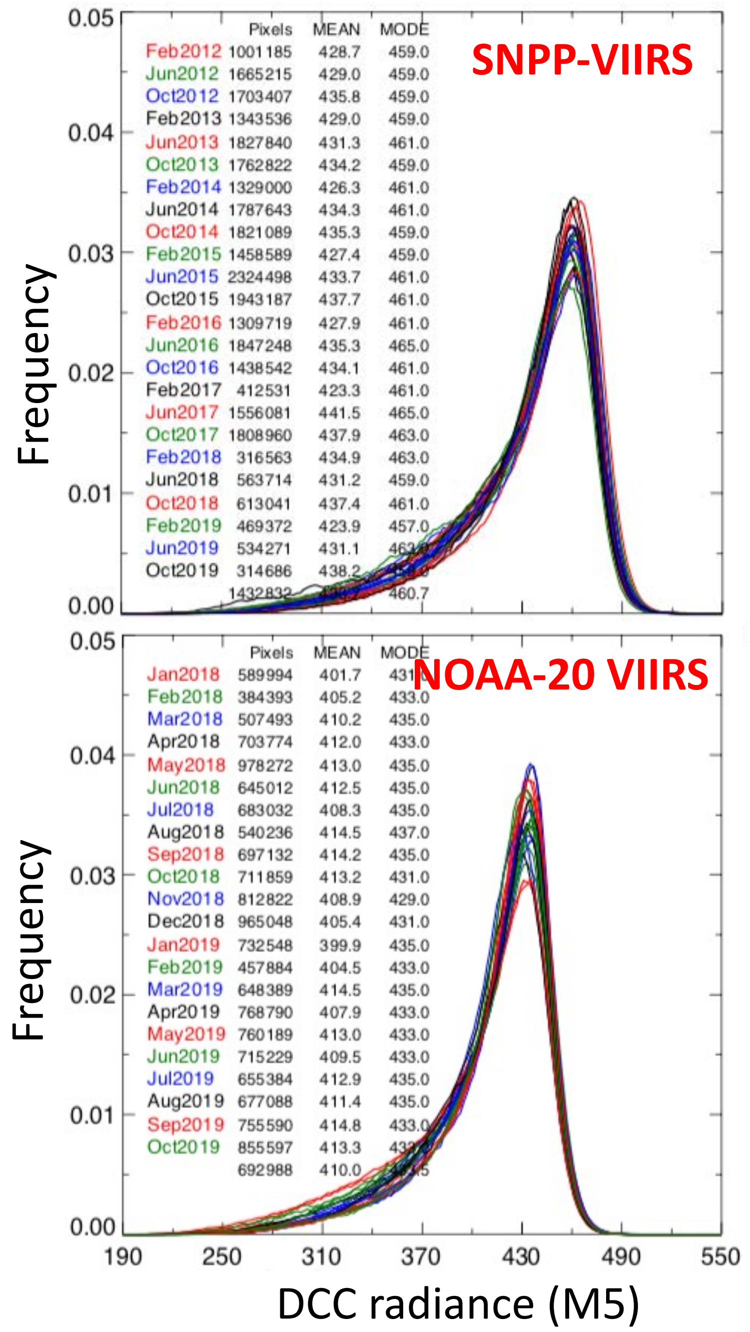
The Libya-4 reflectance is correlated with SZA + SZA^2 + Ozone, PW, Wind Speed, Surface pressure

The red values represent the reduction of the standard error by using atmospheric parameters

PW was the dominant atmospheric parameter

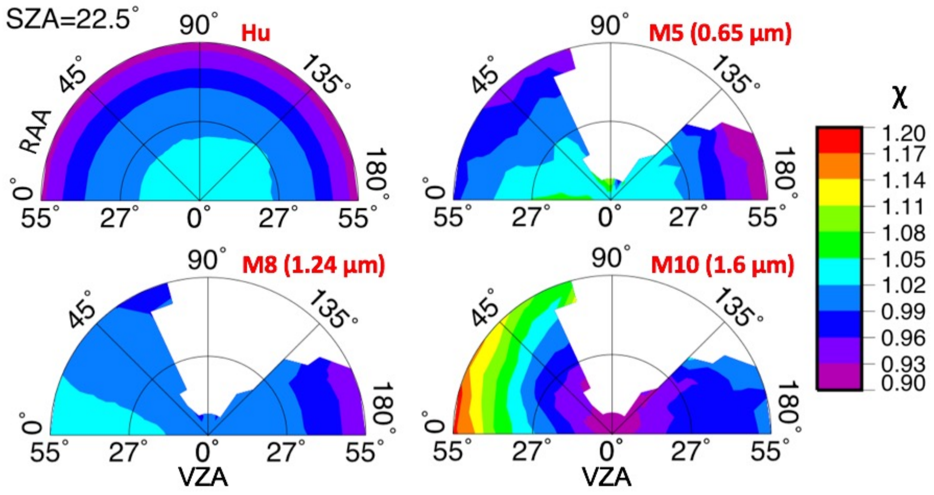
Baseline DCC method

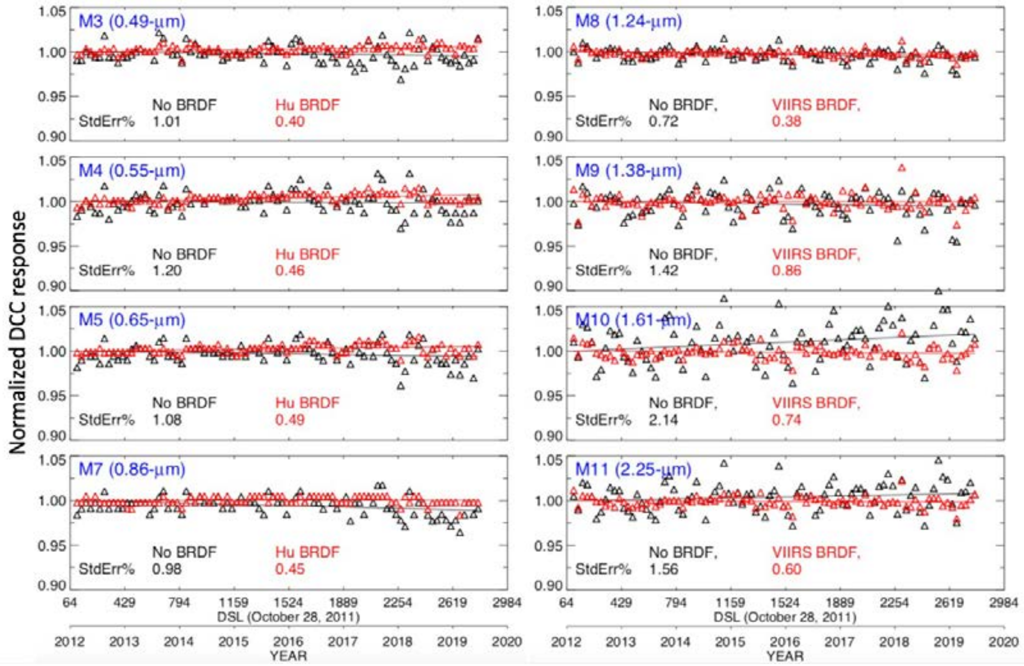
- DCC pixel selection criteria:
  - BT11µm < 205.0°K, SZA < 40°, VZA < 40°, 10° < RAA < 170°, σ(BT11µm) < 1.0° K, and σ(VIS) <3%
- DCC pixels are compiled into monthly probability distribution functions (PDFs) and their modes are tracked over time.
- Anisotropic correction using the angular distribution model by Hu et al [3].
- Suitable for wavelengths <1 µm
- At SWIR wavelengths,
  - DCC reflectivity is affected by ice particle size
  - larger ice particles are more absorbing
  - results in large seasonal cycles
  - DCC response is highly dependent on the IR BT threshold



Improved DCCT for SWIR bands

- Proper seasonal characterization of DCC allows the extension of DCC method to calibrate SWIR channels.
- Channel-specific BRDFs are constructed using the SNPP-VIIRS DCC samples from 2012-2016
- Pixel-level DCC reflectance values are partitioned into angular bins
  - Angular discretization:
    - VZA and SZA range from 0-55° with a 5° step size
    - RAA varies from 0-180° at 10° intervals
- 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 in the case of 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.





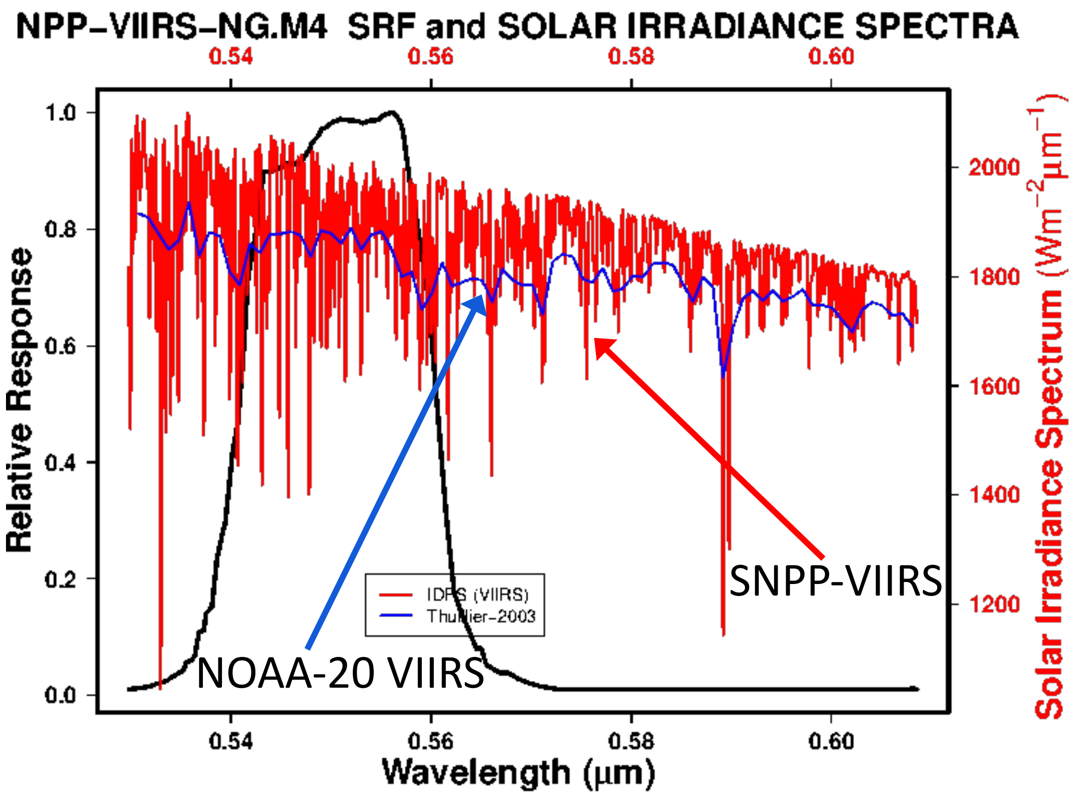
Radiance and Reflectance biases

Reference Solar Spectrum	Impact on M4 band calibration

Reference Solar Spectrum

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

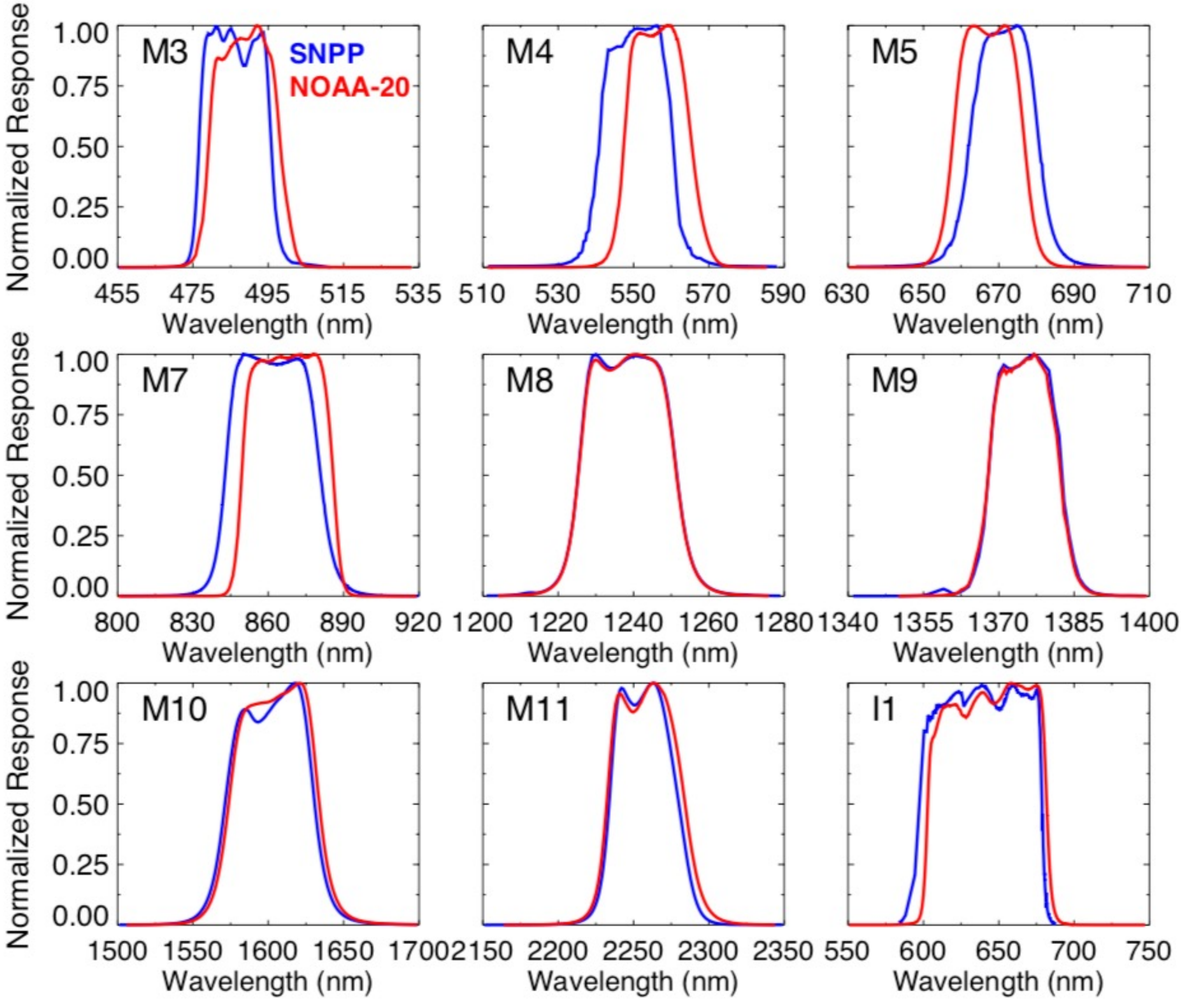
Impact on M4 band calibration

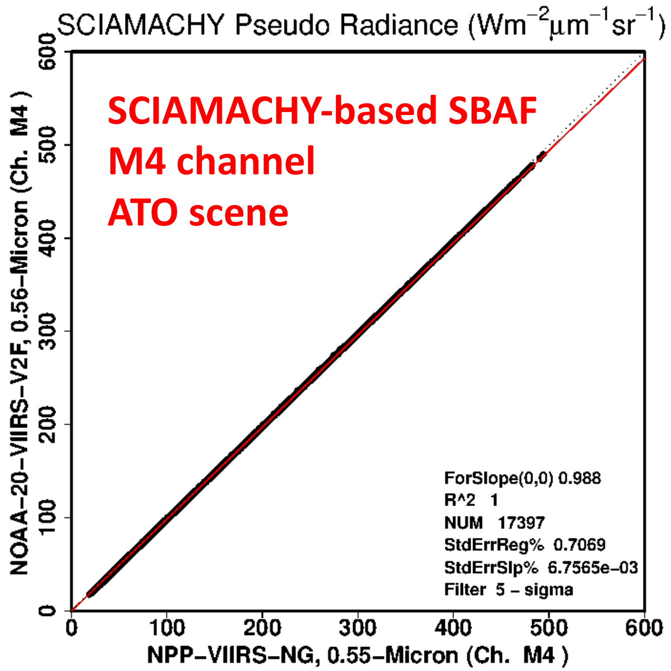


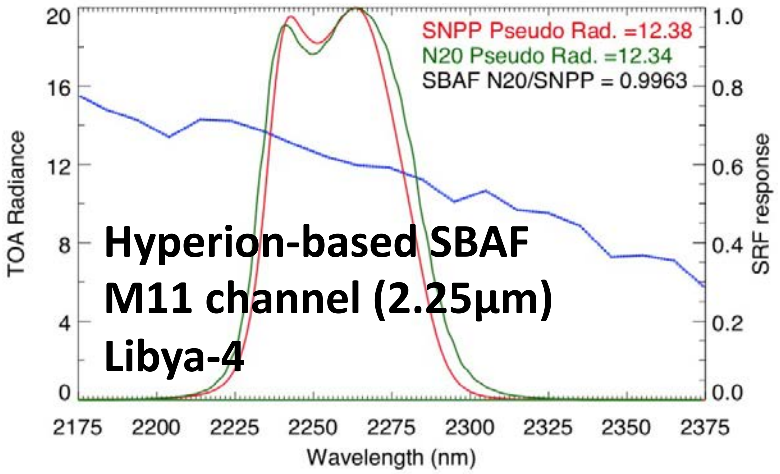
~2% difference in E_{sun} for M4 (0.55 µm) band

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

SRF differences and SBAF

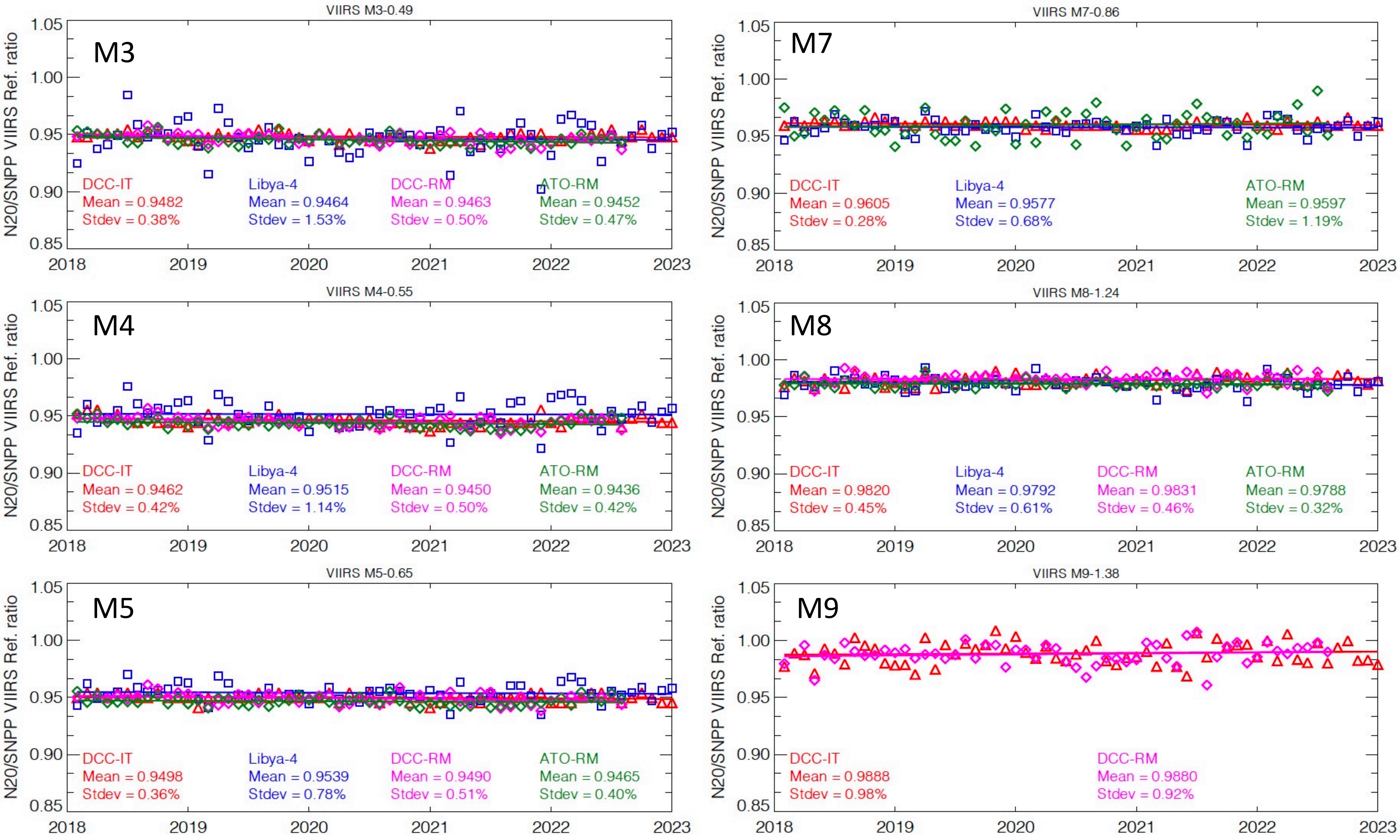




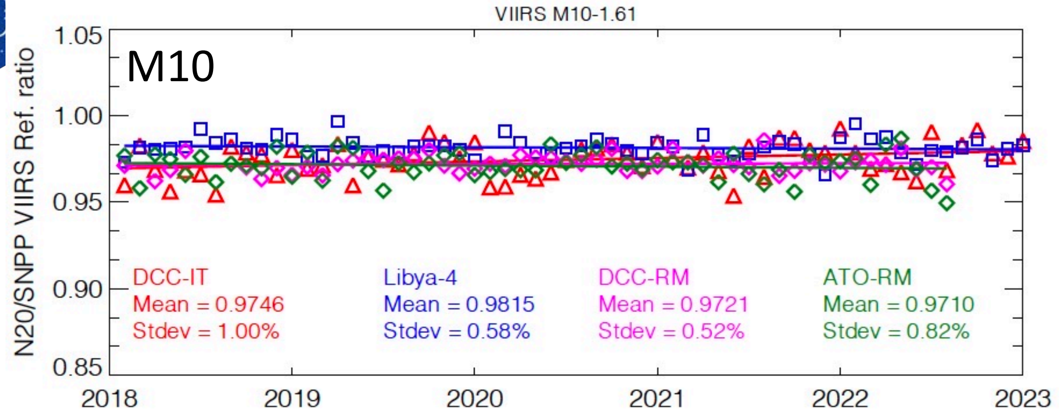


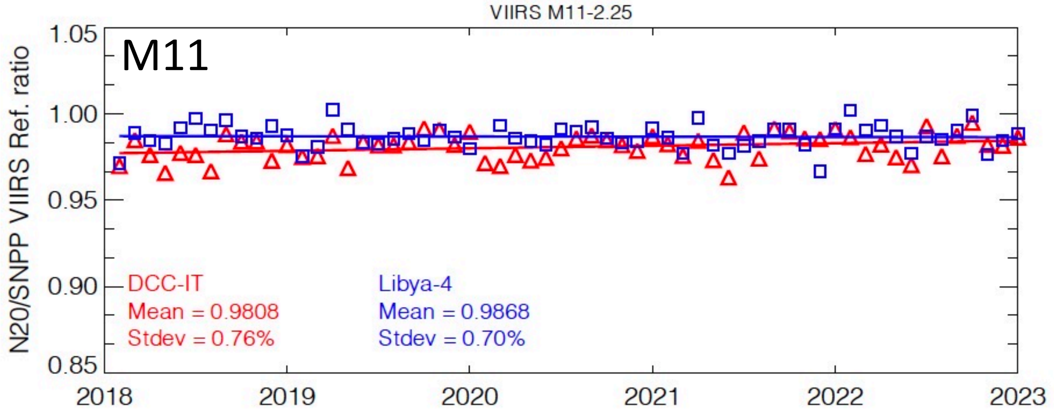
- SRFs are similar for most of the bands
- SBAF correction are within 2% for all scene types

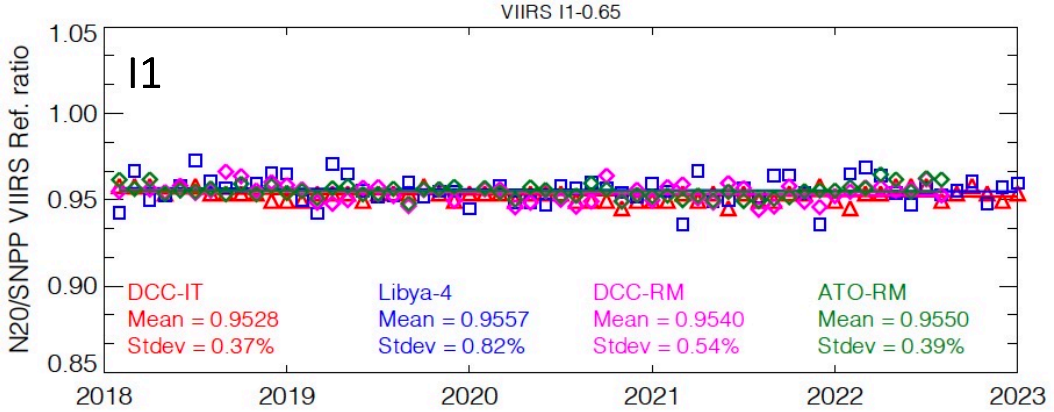
N20/SNPP reflectance ratios

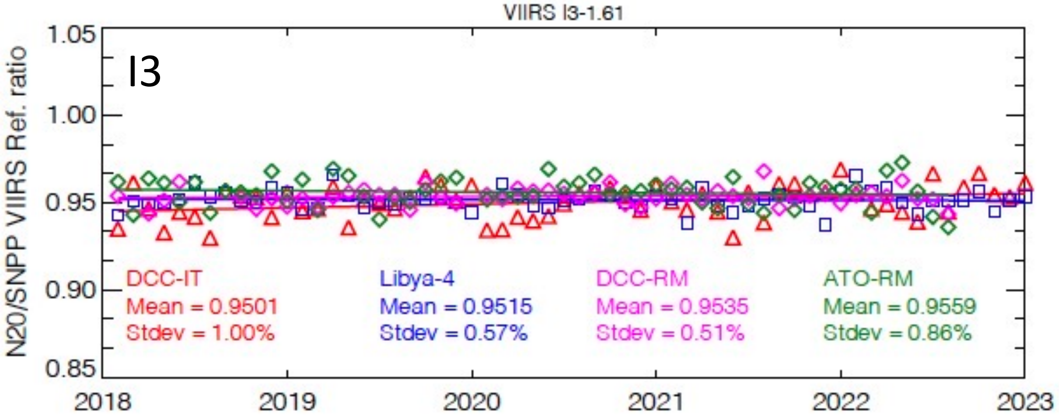


N20/SNPP reflectance ratios









NPP-N20 Bias Table

Band	Radiometric bias 100% x (1-NOAA-20/SNPP)				
	Aqua-MODIS ATO-RM	Aqua-MODIS DCC-RM	Libya-4 PICS	DCC IT	Approach consistency
M3 (0.48µm)	5.5	5.4	5.4	5.2	0.3
M4 (0.55µm)	5.6	5.5	4.9	5.4	0.7
M5 (0.65µm)	5.3	5.1	4.6	5.0	0.7
I1 (0.65µm)	4.5	4.6	4.4	4.7	0.3
M7 (0.86µm)	4.0		4.2	3.9	0.3
M8 (1.24µm)	2.1	1.7	2.1	1.8	0.4
M9 (1.38µm)		1.2		1.1	0.1
M10 (1.6µm)	2.9	2.8	1.9	2.5	1.0
I3 (1.6µm)	4.4	4.7	4.9	5.0	0.6
M11 (2.25µm)			1.3	1.9	0.7

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

I1 bias from multiple approaches are more consistent than M5, since I1 and B1 SRFs are more similar

NPP-N20 Bias Table (%)

Band	CERES-Libya	MAIAC	CERES combined	VCST
M3	5.4	4.8	5.6	4.8
M4	4.9	5.5	5.8	4.5
M5	4.6	4.4	5.4	4.4
M7	4.2	3.8	4.2	3.3
M8	2.1	2.6	2.0	2.4
M10	2.5	2.2	2.5	0.9
M11	1.3	2.0	1.6	1.7
I1	4.4	4.0	4.8	3.9
I3	4.9	5.4	5.0	3.5

CERES Libya-4 and MAIAC within 0.8%
CERES combined and MAIAC agree within 0.8%
CERES combined and VCST agree within 1.7%

Calibration of the SNPP and NOAA 20 VIIRS Sensors for Continuity of the MODIS Climate Data Records, Lyapustin et al. 2023, submitted RSE

Conclusions

- The CERES EBAF product relies on Terra/Aqua MODIS and SNPP/N20 VIIRS cloud retrieval continuity
- The CERES imager and geostationary calibration group (IGCG) utilized ATO-RM, DCC-RM using Aqua-MODIS as a transfer radiometer, Libya-4 and DCC-IT to determine the NPP and N20 radiometric scaling factors
  - All approaches were within 0.8% across all VIIRS channels
  - The combined CERES approaches were within 0.8% and 1.7% of the MAIAC and VCST
- Aqua-MODIS can no longer be used as transfer radiometer to determine the SNPP and N20 VIIRS RSB radiometric scaling
  - The Terra and Aqua orbits are drifting outside of their mean local time windows
- The CERES project will use the Libya-4 and DCC-IT as well Aqua-MODIS/VIIRS polar-RM approaches to determine the SNPP and N20 VIIRS RSB radiometric scaling