Calibration of the SNPP and NOAA 20 VIIRS Sensors for Continuity of the MODIS Climate Data Records

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with contributions from

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MODIS Calibration Over CEOS Desert Sites

Method:

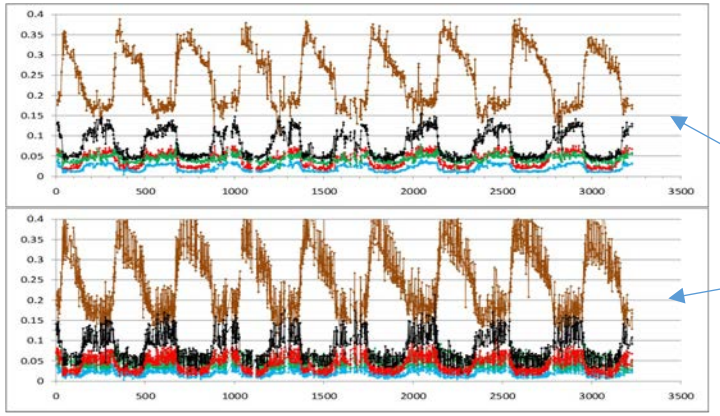
1) Perform MAIAC retrievals (CM, AOT, WV, BRDF etc.);

2) Compute TOA reflectance (R_n) for a fixed view geometry (VZA=0°, SZA=30°) and evaluate trends in both Terra and Aqua;

3) Apply de-trending and compute Terra-Aqua X-calibration factor (gain correction for Terra)

(Lyapustin et al., AMT, 2014)

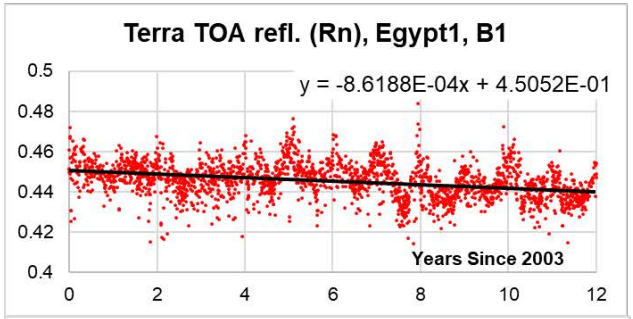
Lyapustin et al., 2012, RSE

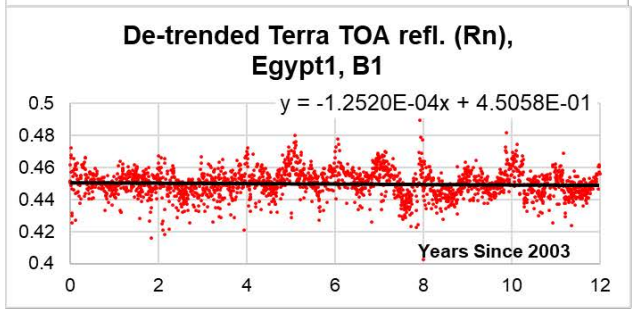


BRDF normalization reduces variability by a factor of ~3-5!

Normalized BRF_n

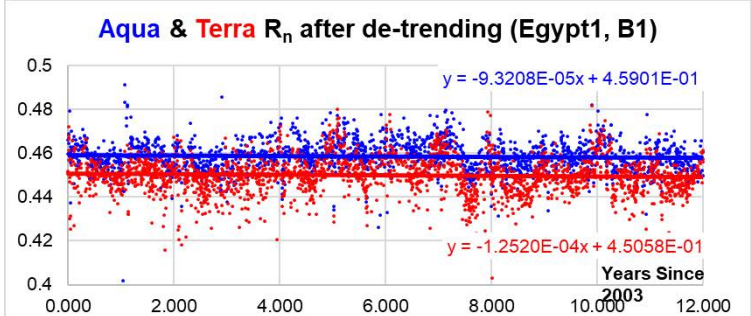
Original BRF (Red, Green, Blue, NIR, SWIR)

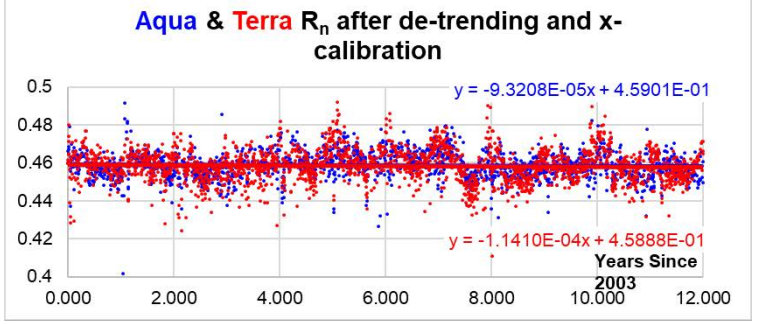




Average trend/year/unit_refl.

	Δ_{Terra}	σ_{Terra}	Δ_{Aqua}	σ_{Aqua}
TOA_B01	-1.6884E-03	2.6114E-04	1.5848E-06	3.9377E-04
TOA_B02	7.7780E-04	2.4303E-04	-6.5120E-05	3.5583E-04
TOA_B03	-8.8922E-04	4.5314E-04	-3.1763E-04	2.8486E-04
TOA_B04	-5.6629E-04	3.2829E-04	-3.9831E-05	5.0202E-04
TOA_B05	1.9477E-04	3.3019E-04	4.5784E-06	3.3528E-04
TOA_B06	-3.9516E-04	3.0211E-04	-3.1194E-04	2.8191E-04
TOA_B07	2.0259E-04	2.4491E-04	-5.8419E-04	3.2705E-04
TOA_B08	-1.2627E-03	1.0018E-03	-5.5178E-04	1.0915E-04
TOA_B09	-3.9874E-04	5.2176E-04	1.3724E-04	2.1120E-04
TOA_B10	-7.2800E-04	8.2601E-04	-3.0632E-04	7.1498E-04





Average X-gain for Terra

	Average	Stdev
TOA_B01	1.018776	0.000949
TOA_B02	1.000523	0.001054
TOA_B03	0.989436	0.001268
TOA_B04	1.00109	0.001448
TOA_B05	0.98862	0.001855
TOA_B06	0.997128	0.000898
TOA_B07	0.999368	0.000373
TOA_B08	1.003774	0.000948
TOA_B09	1.0014	0.001488
TOA_B10	1.014141	0.002077

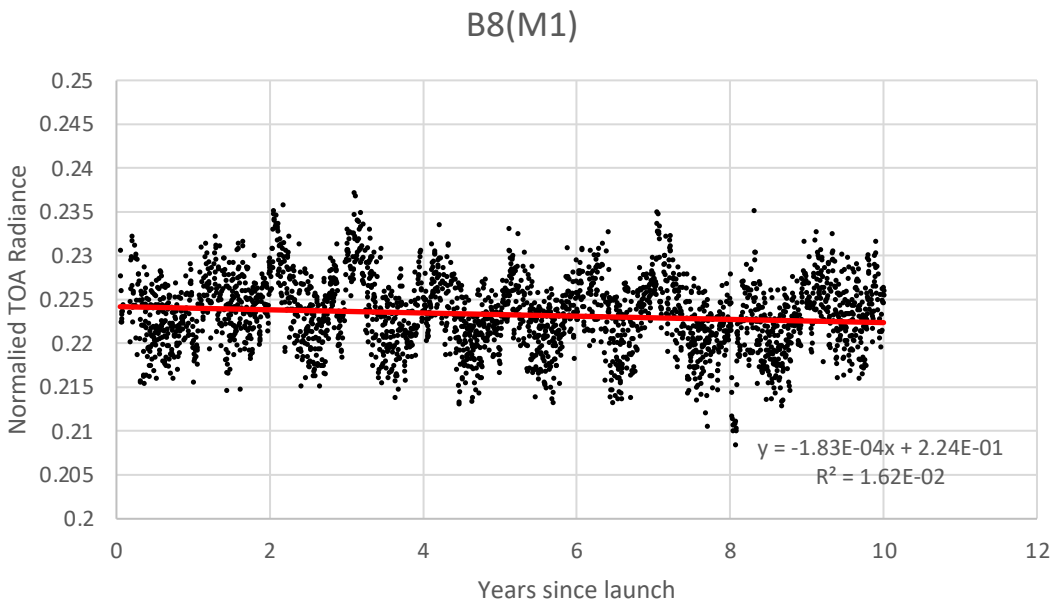
Developed calibration became a standard part of MODIS Land Discipline Processing in Collections C6 and C6.1.

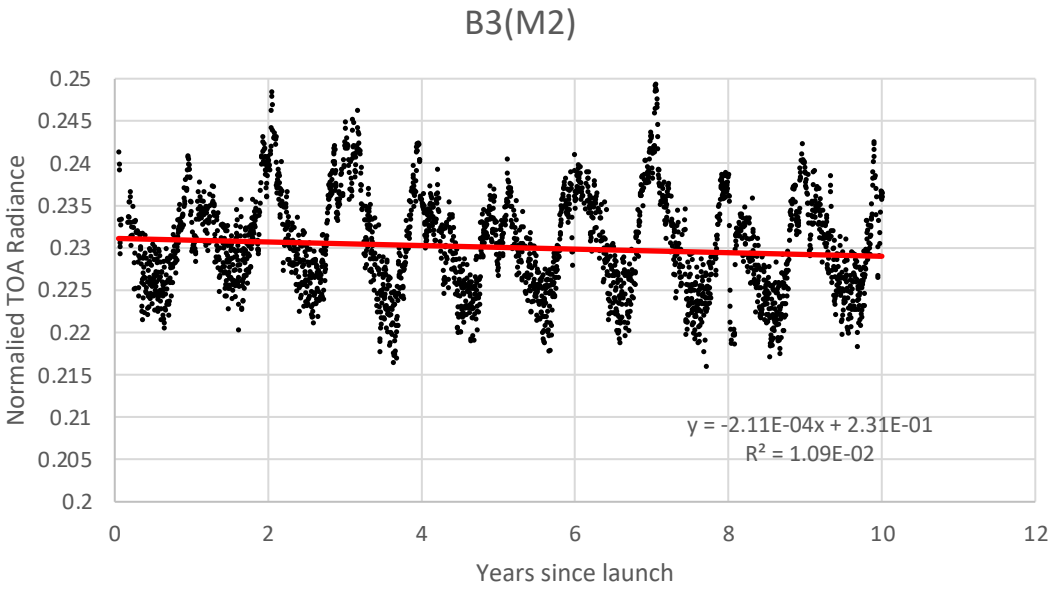
Trend Analysis

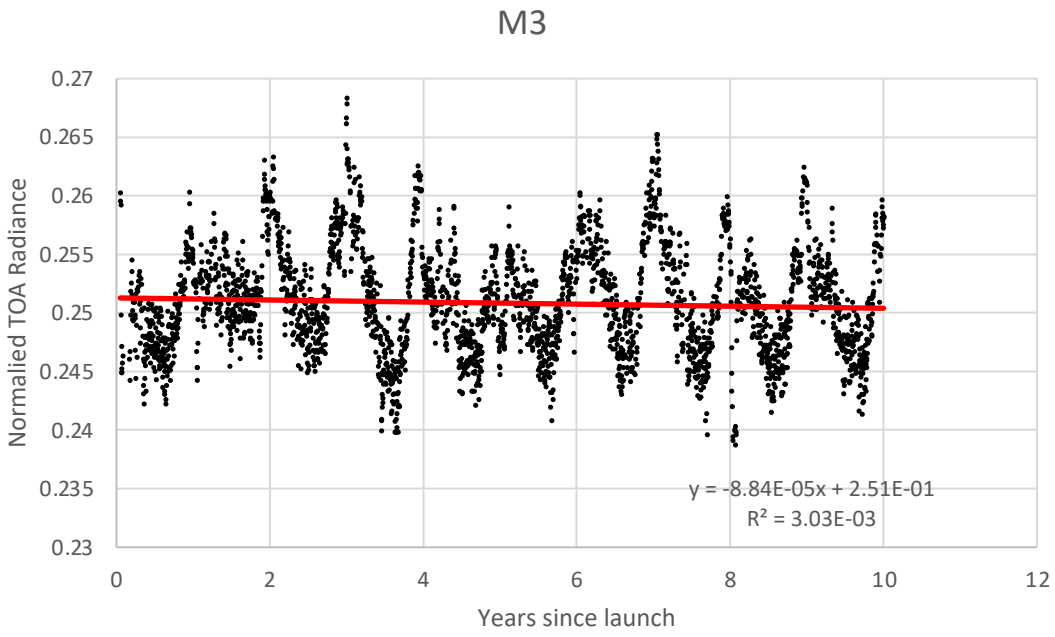
Use the latest versions of L1B data:

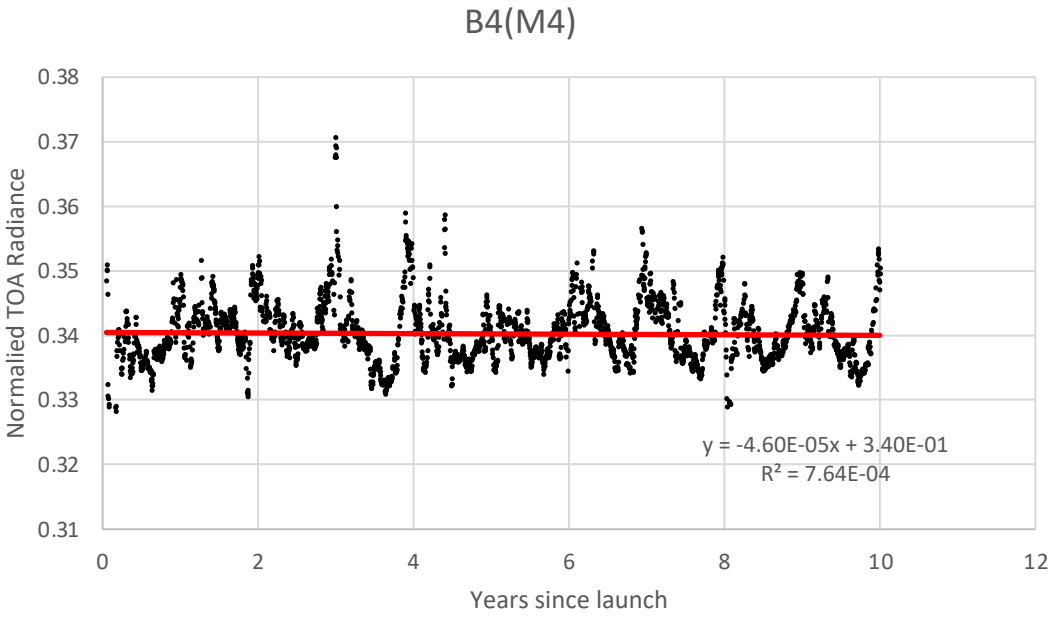
- MODIS C6.1 with polarization correction, de-trending and Terra-to-Aqua cross-calibration;
- VIIRS SNPP C2.0
- VIIRS N20 C2.1

VIIRS SNPP Normalized TOA Radiance Time Series

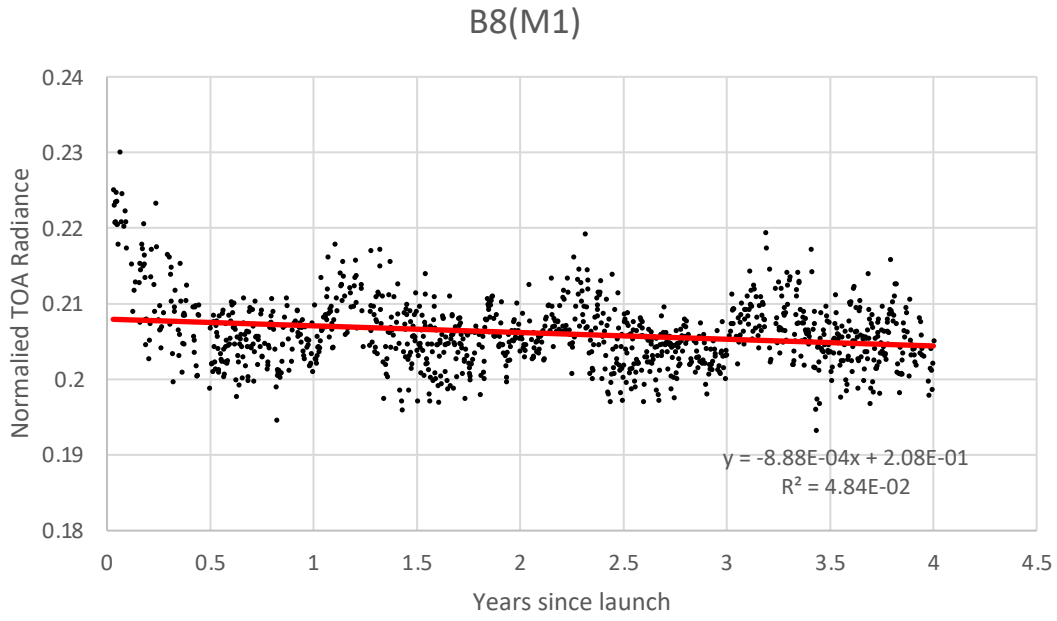


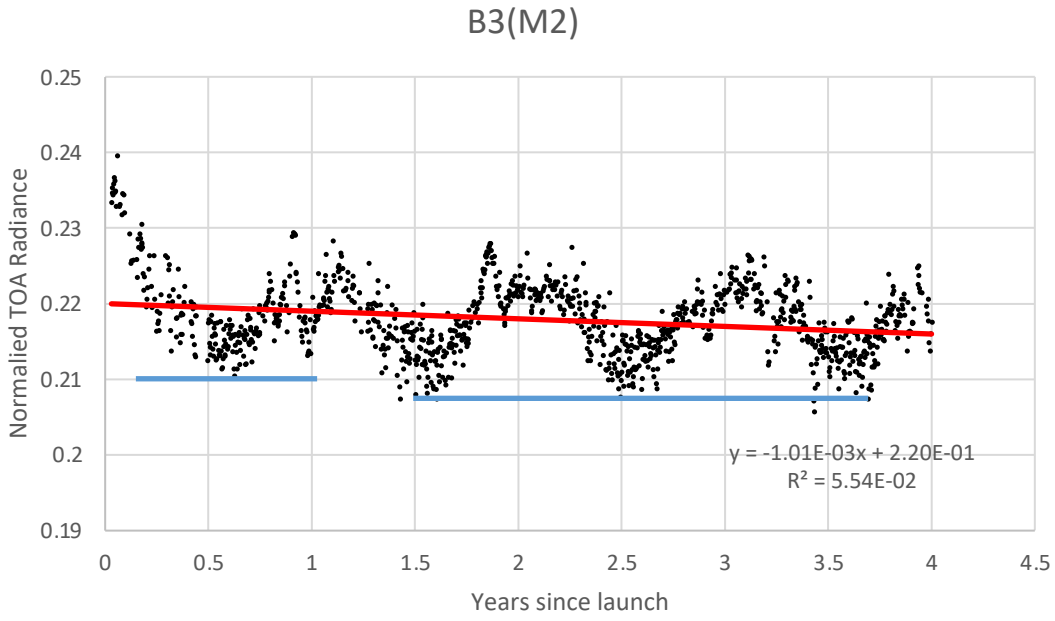


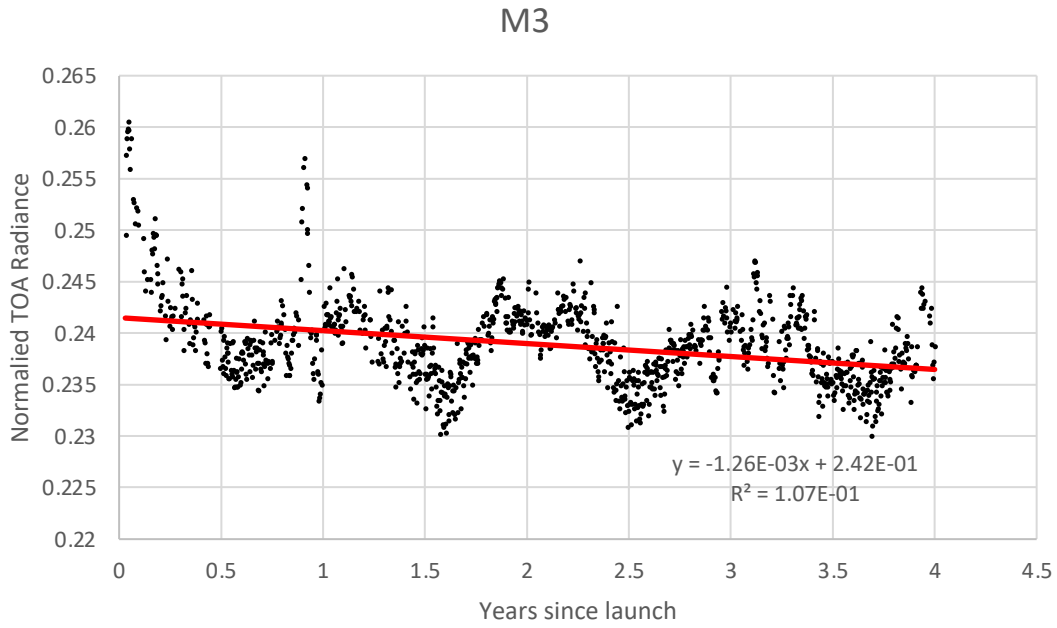


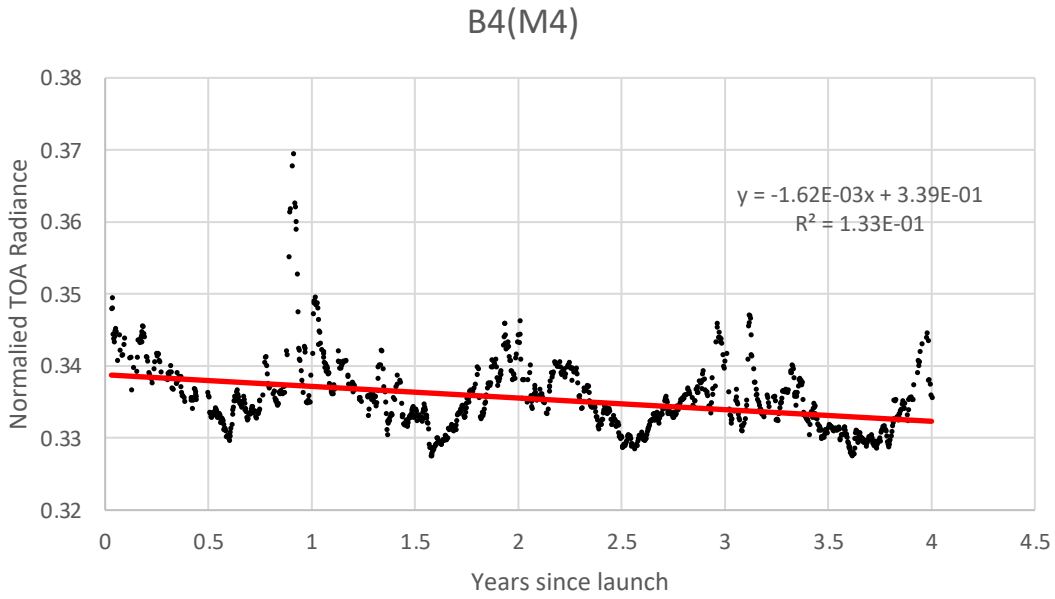


VIIRS J1 Normalized TOA Radiance Time Series









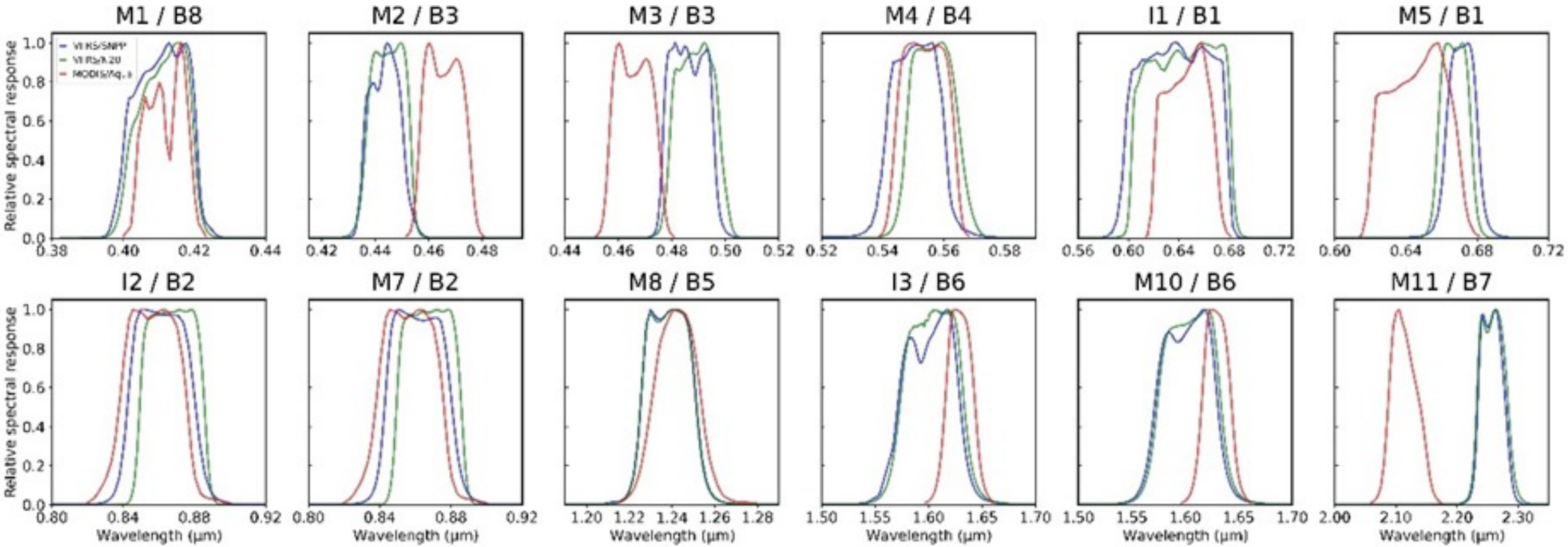
VIIRS Calibration Trends

Band	Intercept		Slope		Slope/Intercept (Trend/year/unit of refl.)	
	SNPP	N20	SNPP ($\times 10^{-3}$)	N20 ($\times 10^{-3}$)	SNPP	N20
M1	0.224	0.209	-0.016 ± 0.027	-1.12 ± 0.16/-0.8	-7.16E-05	-5.35E-03
M2	0.230	0.219	-0.13 ± 0.033	-0.98 ± 0.15/-1.3	-5.55E-04	-4.47E-03
M3	0.251	0.240	-0.055 ± 0.027	-0.98 ± 0.12/-2	-2.20E-04	-4.08E-03
M4	0.340	0.336	-0.063 ± 0.029	-1.24 ± 0.15/-1.4	-1.84E-04	-3.67E-03
M5	0.499	0.476	-0.073 ± 0.034	-0.53 ± 0.17/-0.7	-1.47E-04	-1.11E-03
M7	0.586	0.565	-0.31 ± 0.043	-0.26 ± 0.22/-0.8	-5.31E-04	-4.64E-04
M8	0.662	0.645	-0.44 ± 0.052	-0.11 ± 0.28/0.9	-6.57E-04	-1.74E-04
M10	0.696	0.681	-0.39 ± 0.046	0.81 ± 0.29/0.0	-5.61E-04	1.19E-03
M11	0.587	0.576	-0.59 ± 0.063	-1.49 ± 0.35	-1.00E-03	-2.59E-03
I1	0.463	0.451	-0.31 ± 0.071	-0.82 ± 0.28/-1.5	-6.70E-04	-1.83E-03
I2	0.585	0.563	-0.37 ± 0.070	0.004 ± 0.26/-0.5	-6.28E-04	7.03E-06
I3	0.706	0.670	-0.59 ± 0.085	0.71 ± 0.30/~0.0	-8.43E-04	1.07E-03

Table 1. Results from trend analysis of SNPP and N20 VIIRS including slope and intercept of linear regression, and ratio slope/Intercept in units of reflectance (change)/unit reflectance/year. For N20, a second value separated by '/' gives the VCST trend (Twedt et al., 2022).

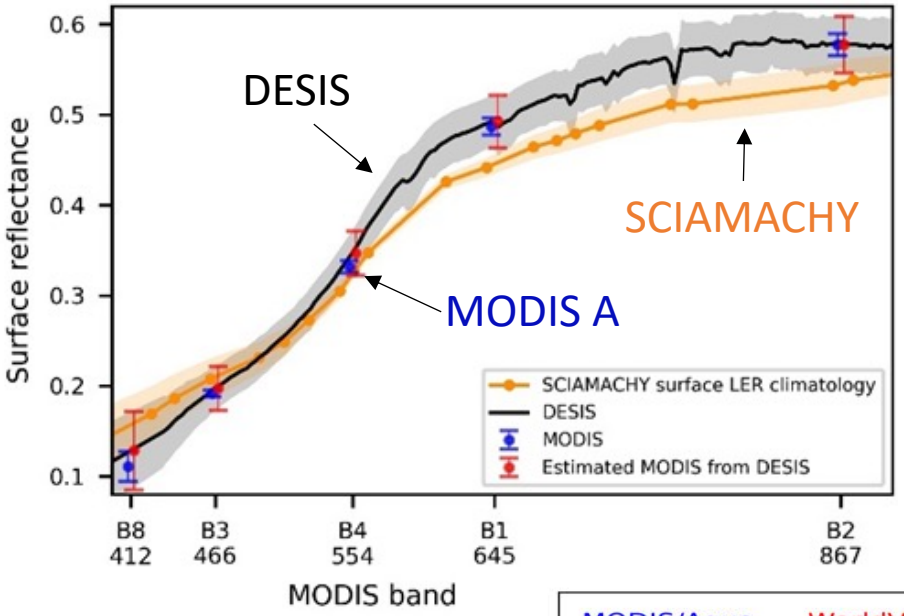
VIIRS X-Cal to MODIS Aqua

Because bands are different, sensors measure different reflectance over the same targets (with spectral dependence), we need to account for the RSR differences

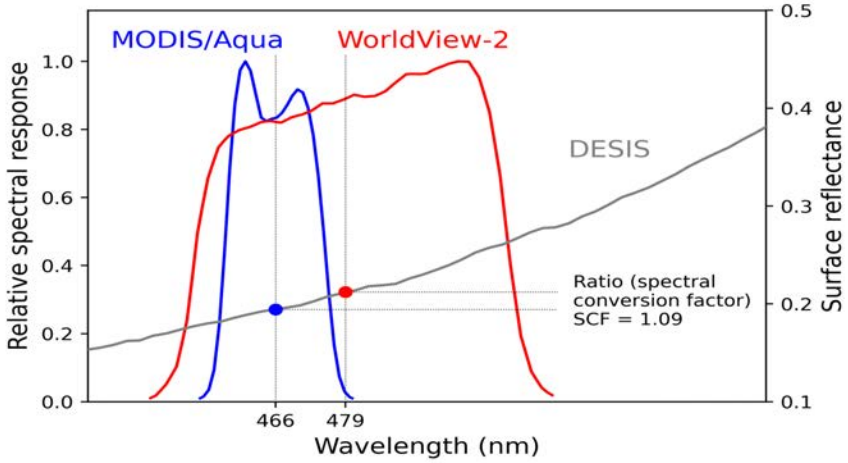


Spectral Conversion Factor

- DESIS - DLR Earth Sensing Imaging Spectrometer, on ISS since 2018 (400-1000nm, spectral sampling at 2.55 nm and res. of 3.5 nm; 30m spatial resolution and ~ 30km swath). By our request, 97 DESIS measurement granules were collected over Libya-4 during 2018–2021. 12 are good.

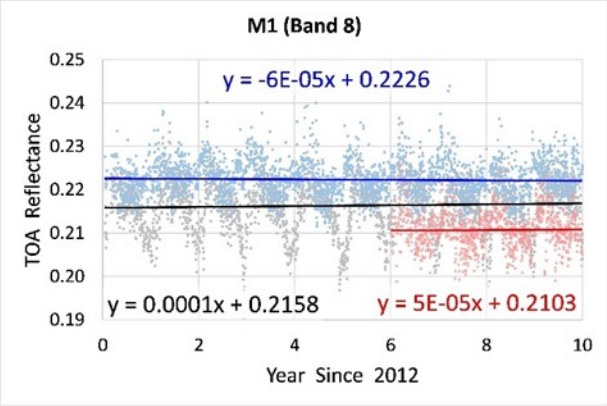


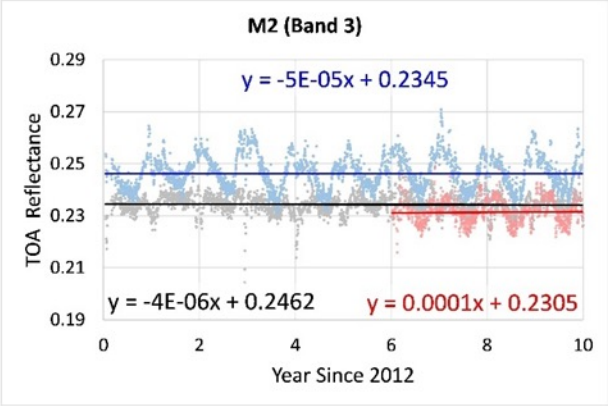
5×5 M-pixels,
10×10 I-pixels
~4×4km^2 area

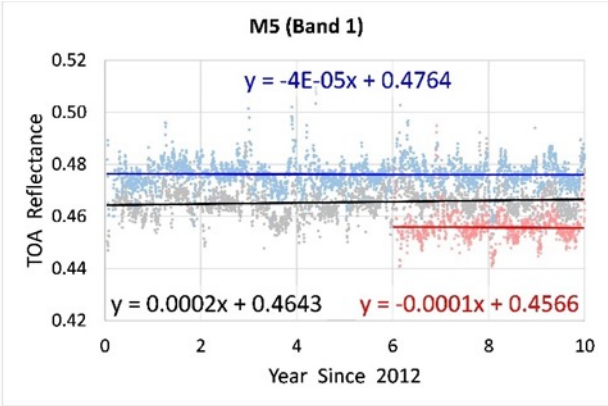


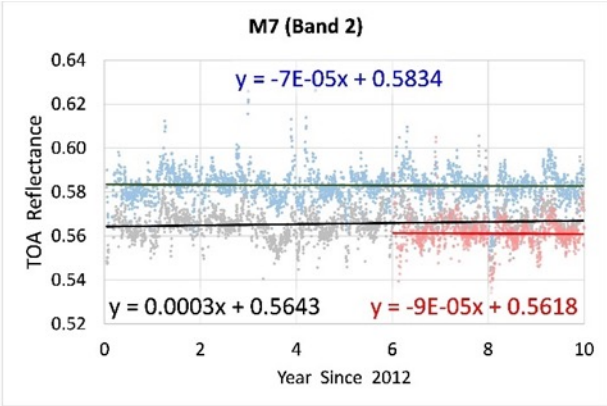
- Spectral convolution of surface reflectance
  - $\rho_{simulated} = \frac{\sum \rho_\lambda E_\lambda RSR_\lambda d\lambda}{\sum E_\lambda RSR_\lambda d\lambda}$
  - ρ_λ: DESIS surface reflectance with high spectral resolution
  - E_λ: solar irradiance
  - RSR_λ: spectral response function
- BRDF normalization factor
  - $c(\lambda) = \frac{BRF\ from\ fixed\ view\ geometry\ (SZA\ 20°, VZA\ 0°, RAA\ 0°)}{BRF\ from\ various\ DESIS\ view\ geometries}$
  - BRDF from MODIS MAIAC
  - $\rho^n_{simulated}(\lambda) = \rho_{simulated}(\lambda) * c(\lambda)$
- Spectral conversion factor (SCF)
  - SCF = $\frac{\rho^n_{simulated\ (DG\ sensors)}}{\rho^n_{simulated\ (MODIS/Aqua)}}$

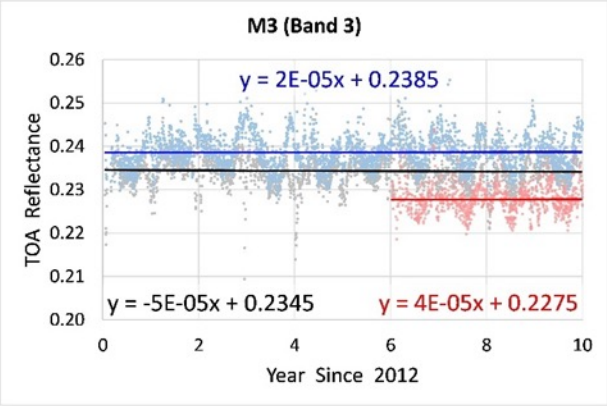
VIIRS X-Calibration to MODIS Aqua

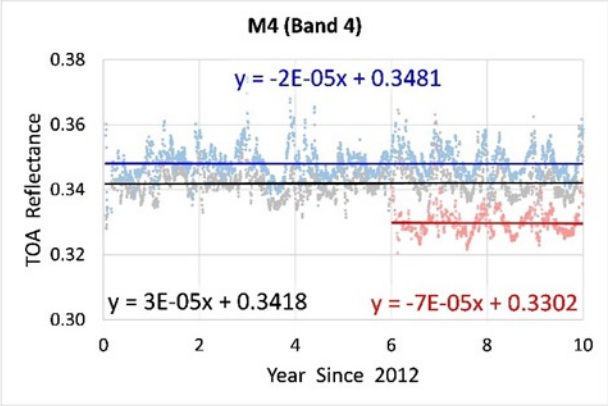


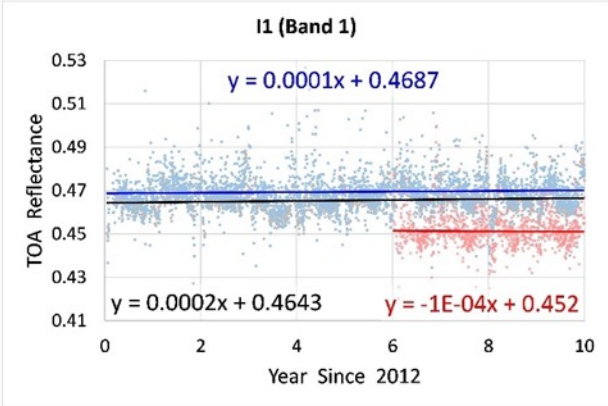


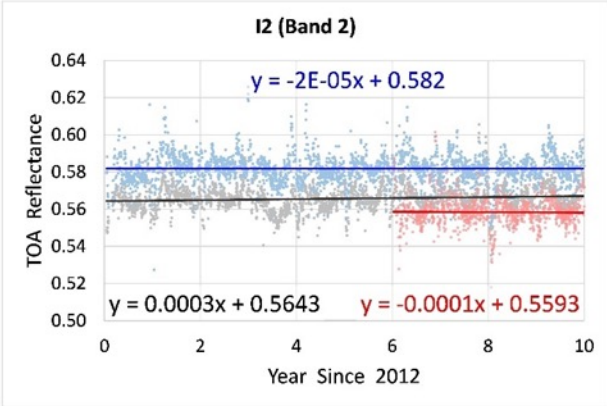












VIIRS BRDF is multiplied by the Spectral Conversion Factor (this effectively “shifts” the VIIRS band to the MODIS reference band), and VIIRS normalized TOA reflectance is computed at the MODIS wavelength. This way, both surface and atmospheric RT computations are done at the same wavelength ensuring 1:1 comparison.

Aqua/VIIRS NPP/VIIRS J1 X-calibration Summary

Band	SBAF		X-calibration Coefficients		
	Aqua/SNPP	Aqua/N20	Aqua/SNPP	Aqua/N20	SNPP/N20
B8/M1	0.960	1.001	0.974 ± 0.033	1.028 ± 0.034	1.055 ± 0.028
B3/M2	1.197	1.191	0.952 ± 0.031	1.014 ± 0.026	1.065 ± 0.034
B3/M3	0.889	0.882	0.982 ± 0.023	1.029 ± 0.021	1.048 ± 0.021
B4/M4	1.026	0.978	0.983 ± 0.018	1.037 ± 0.018	1.055 ± 0.018
B1/M5	0.959	0.962	0.978 ± 0.017	1.021 ± 0.017	1.044 ± 0.016
B2/M7	1.001	0.999	0.971 ± 0.017	1.008 ± 0.017	1.039 ± 0.017
M8	-	-	-	-	1.026 ± 0.017
M10	-	-	-	-	1.022 ± 0.016
M11	-	-	-	-	1.020 ± 0.040
B1/I1	1.016	1.004	0.992 ± 0.023	1.032 ± 0.021	1.040 ± 0.026
B2/I2	1.001	0.998	0.973 ± 0.018	1.013 ± 0.018	1.042 ± 0.019
I3	-	-	-	-	1.054 ± 0.018

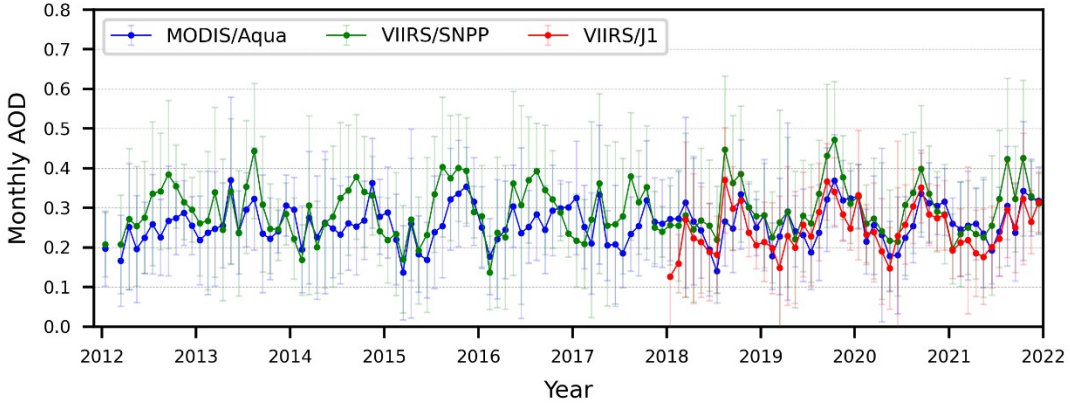
Table 2. Spectral Band Adjustment Factor (SBAF) for SNPP and N20 VIIRS to MODIS Aqua, and pair-wise cross-calibration coefficients among the three sensors.

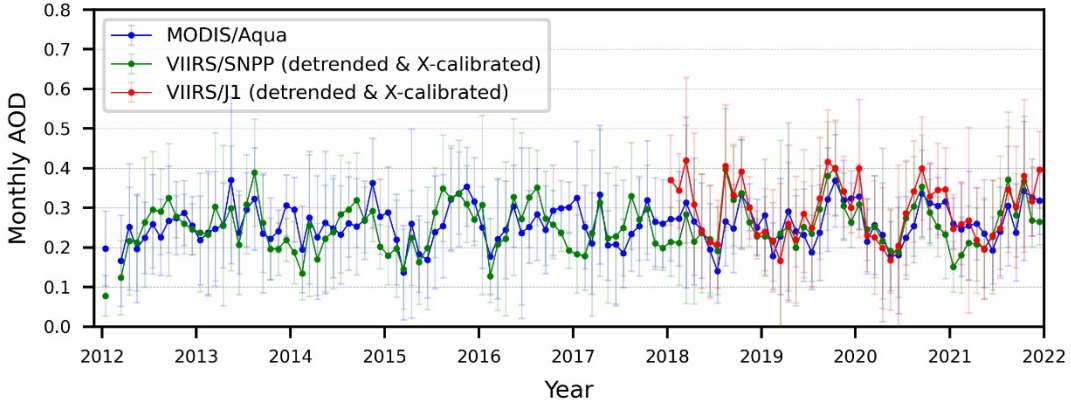
Aqua/VIIRS NPP/VIIRS J1 X-calibration Summary

Band Pair	This work			MCST/VCST (Wu et al., 2022)			CERES-IGCG (LaRC)			Meyer et al (2020)		Sayer et al (2017)
	A/S	A/N	S/N	A/S	A/N	S/N	A/S	A/N	S/N	A/S	A/N	A/S
B8/M1	-2.6	2.8	5.5	-5.0 - -3.8	2.6-4.8	5.9-7.9	-	-	-	-	-	-0.5
B3/M2	-4.8	1.4	6.5	B9: -0.5 - -1.5	5.4-6.2	5.8-6.6	-	-	-	-	-	B9: 0
B3/M3	-1.8	2.9	4.8	B10: -5.5 - -3.2	-1.1-1.7	4.4-5.2	-1.8	3.7	5.6±0.2	-	-	-0.8
B4/M4	-1.7	3.7	5.5	-0.3 - -2.6	1.9-3.6	3.4-5.5	-2.8	2.9	5.8±0.2	-	-	-4.4
B1/M5	-2.2	2.1	4.4	-2.0 - 0.6	2.4-6.0	3.4-5.4	-3.1	2.4	5.4±0.2	-5.0	0	-5.9
B2/M7	-2.9	0.8	3.8	-1.1 - 0.0	0.7-3.1	2.5-4.0	-2.1	2.3	4.2±0.2	-3.0	1.0	-4.0
B5/M8	-	-	2.6	-3.4 - 1.9	-1.4-0.5	1.8-2.9	-3.1	-1.0	2.0±0.2	-1.0	2.0	1.0
B6/M10	-	-	2.2	-3.5 - -1.3	-	1.2-2.9	-1.5	1.4	2.5±0.3	-2.0	2.0	-2.0
B7/M11	-	-	2.0	-	-	1.2-2.1	-	-	1.6±0.5	-3.0	-1.0	-7.0
B1/I1	-0.8	3.2	4.0	-0.6 - 1.3	2.7-4.2	3.0-4.8	-1.0	3.8	4.8±0.2	-	-	-
B2/I2	-2.7	1.3	4.2	-1.0 - -0.1	1.1-3.0	2.6-3.1	-	-	-	-	-	-
B6/I3	-	-	5.4	-3.5 - -1.8	-0.3-2.1	3.1-3.9	-2.2	2.4	5.0±0.3	-	-	-

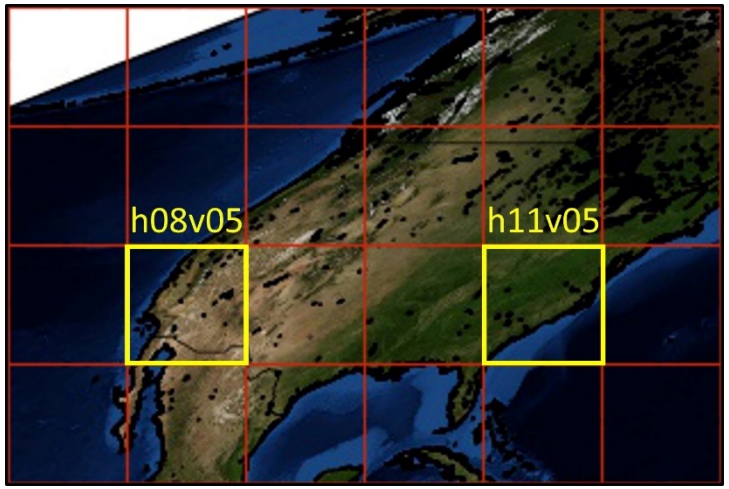
Table 3. Cross-calibration biases (%) among MODIS Aqua (A), VIIRS SNPP (S) and VIIRS N20 (N) from different sources. VCST – Desert, Dome C, SNO, DCC (Wu et al., 2022); LaRC - Desert, Dome C, Ray Matching, DCC.

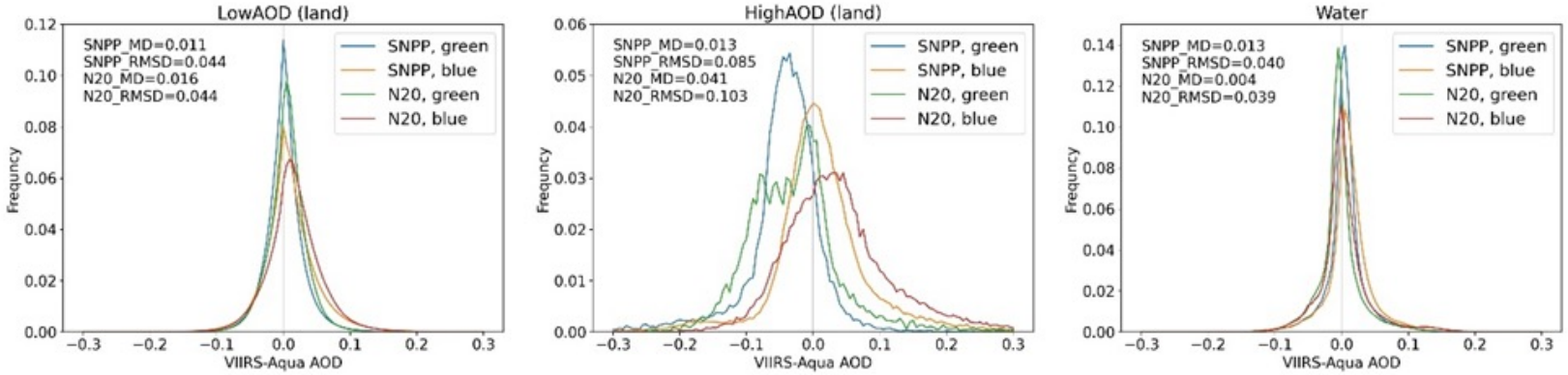
MAIAC MODIS-VIIRS Continuity Analysis





AOD over Libya-4 Before and After X-Calibration

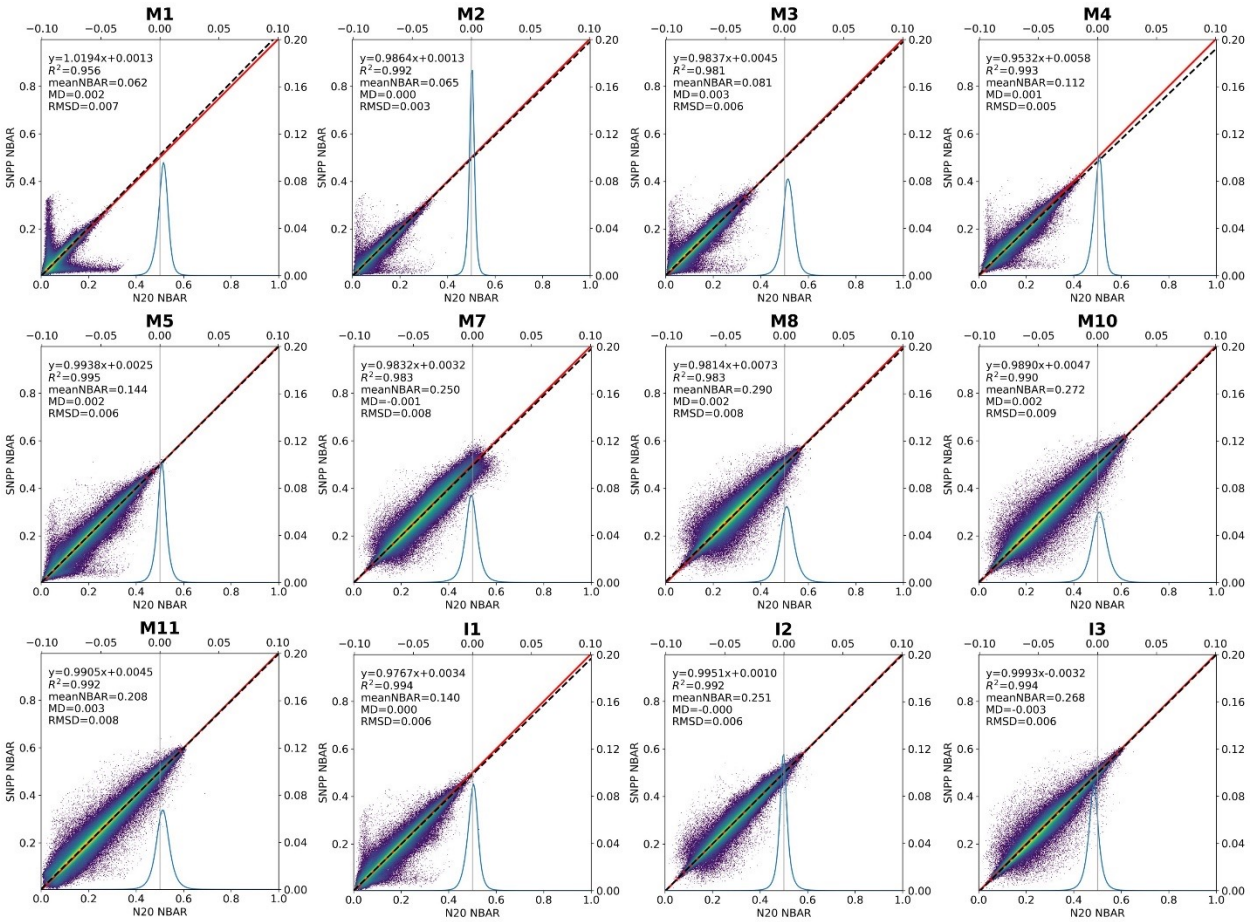


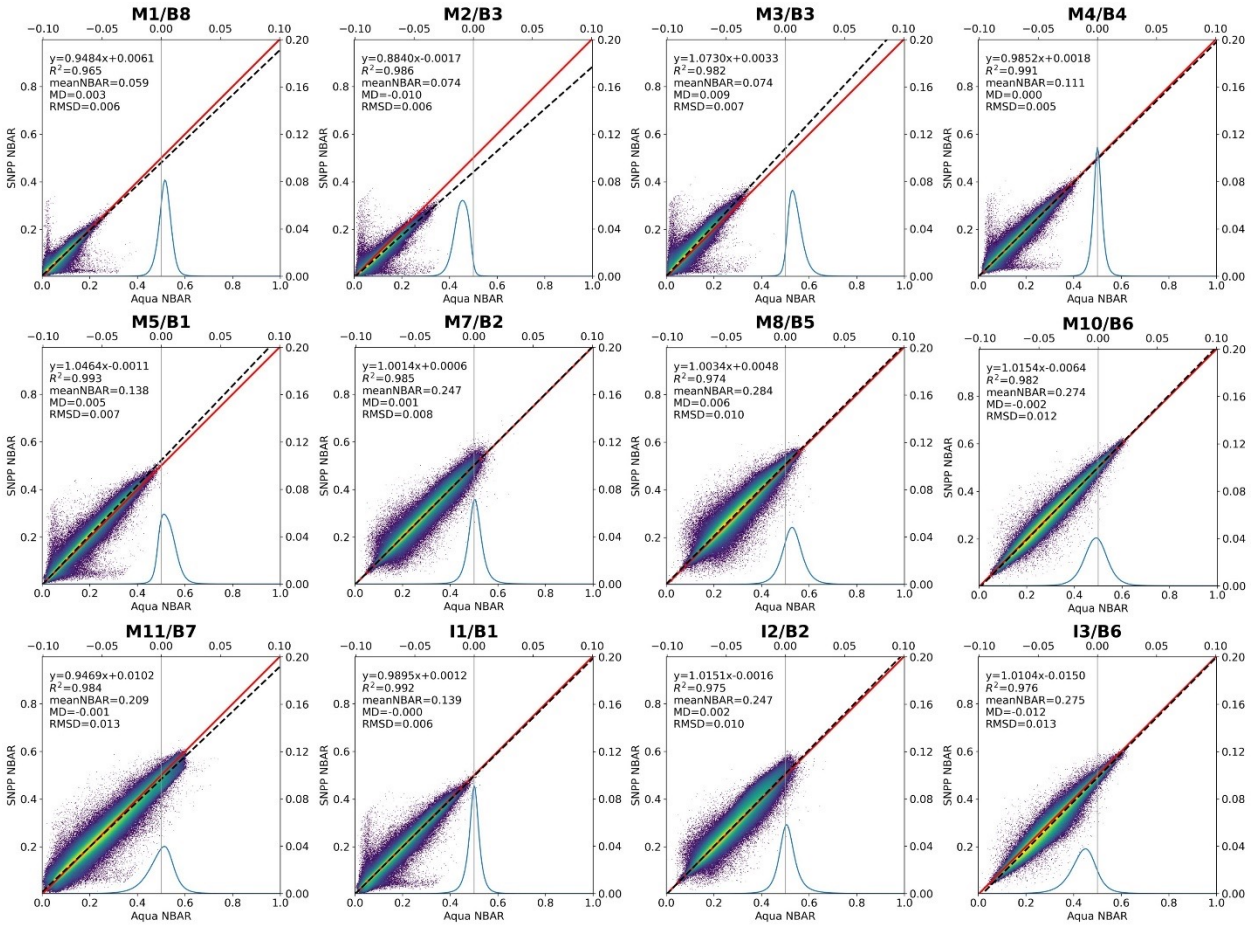


2 tiles, 4 years of data (2018-2021)

Spectral NBAR Comparison

NBAR – nadir BRDF-adjusted reflectance (nadir + local sun at 1:30pm)





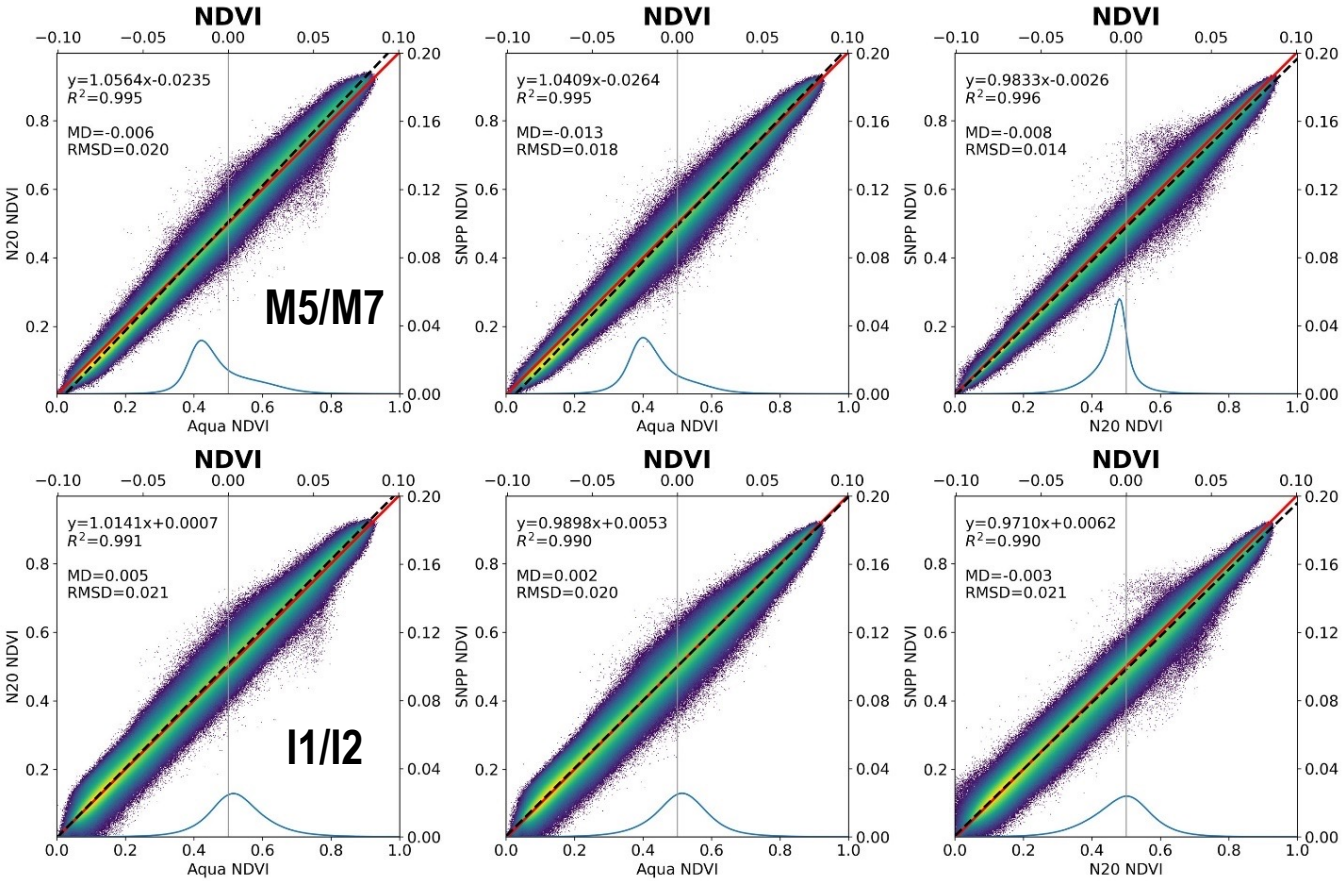
SNPP vs NOAA 20 **SNPP vs Aqua**

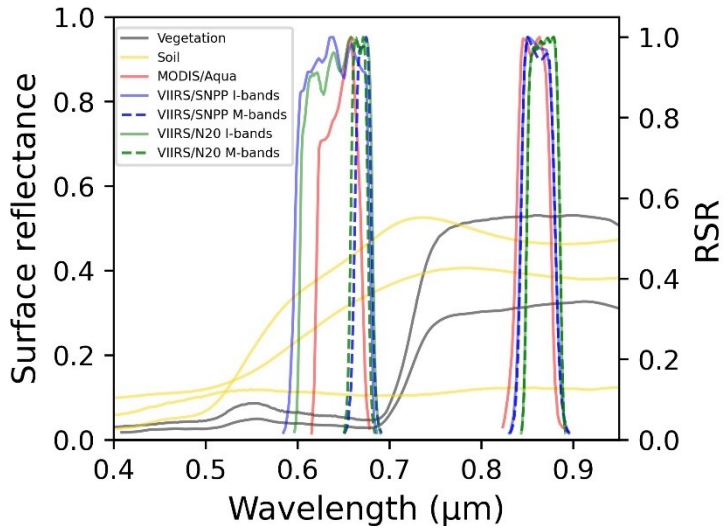
RMSD of 0.005-0.007 in the darker visible and of 0.008-0.013 in brighter NIR-SWIR bands

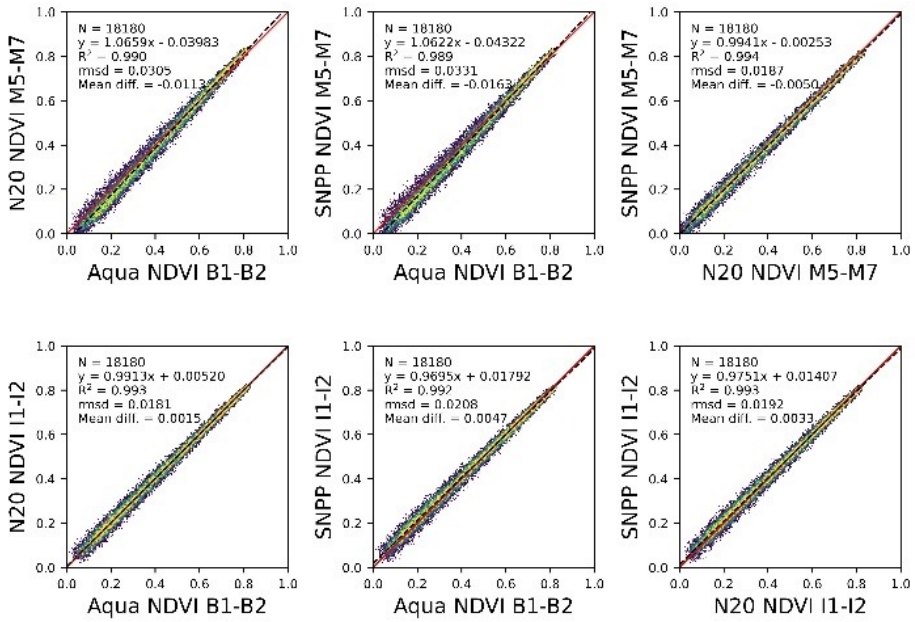
NDVI Analysis

Center Wavelength (nm)

	SNPP (M/I)	N20	A
Red	671/638	668/643	646
NIR	861/861	868/867	856







The MODIS – VIIRS NDVIs agree within *rmsd*~0.02 and an average *MD* -0.01 for $NDVI_M$ and 0.003 for $NDVI_I$.