Calibration Analysis of the Maxar (Digital Globe) Constellation

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MODIS Calibration Over CEOS Desert Sites

Method:

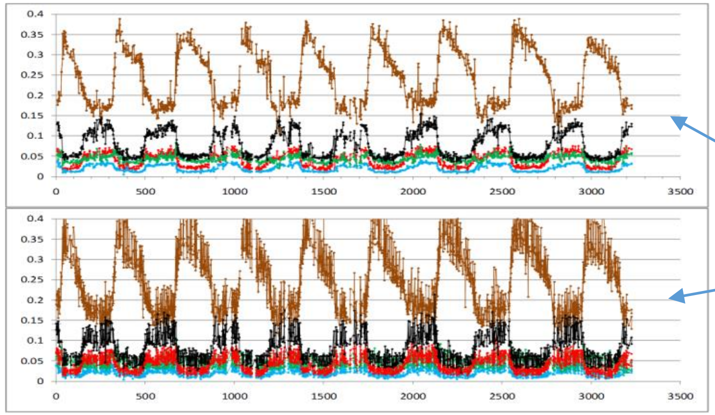
1) Perform MAIAC retrievals (CM, AOT, WV, BRDF etc.);

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

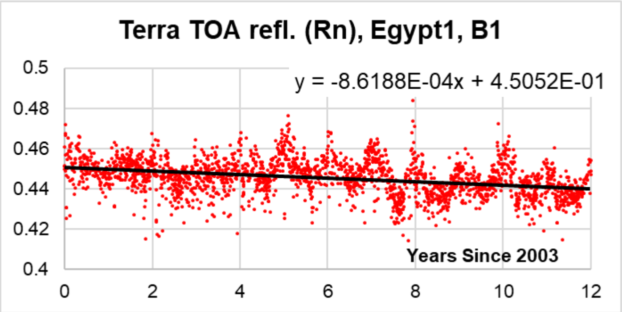
3) Apply de-trending and compute Terra-Aqua X-calibration factor (gain correction for Terra)

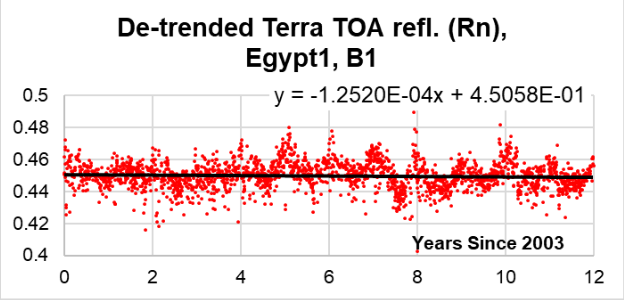
(Lyapustin et al., AMT, 2014)

Lyapustin et al., 2012, RSE



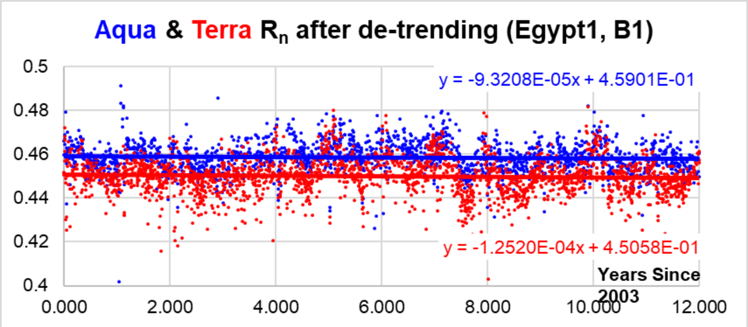
BRDF normalization reduces variability by a factor of ~3-5!

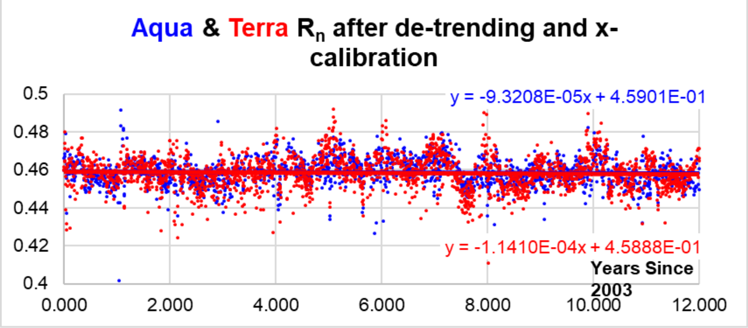




Average trend/year/unit_refl.

	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

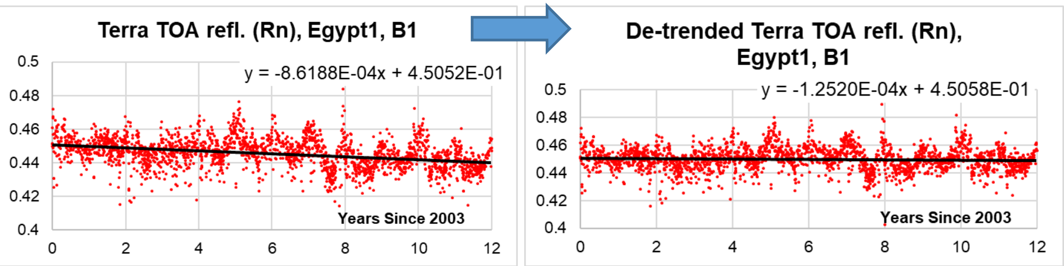
	Average	Stdev
TOA_B01	1.018776	0.000949
TOA_B02	1.000523	0.001054
TOA_B03	0.989436	0.001268
TOA_B04	1.00109	0.001448
TOA_B05	0.98862	0.001855
TOA_B06	0.997128	0.000898
TOA_B07	0.999368	0.000373
TOA_B08	1.003774	0.000948
TOA_B09	1.0014	0.001488
TOA_B10	1.014141	0.002077

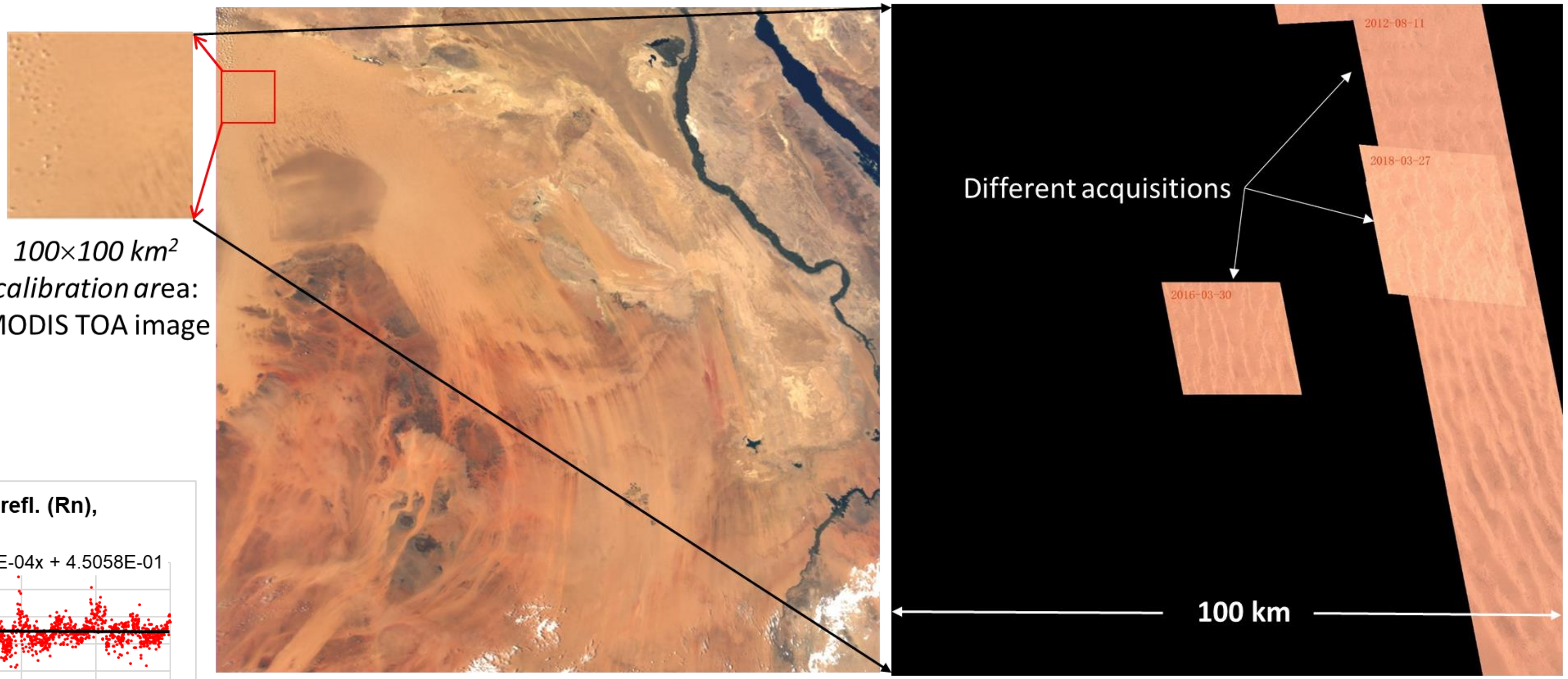
Developed calibration has been a standard part of MODIS Land Discipline Processing in C6 and C6.1.

Maxar Calibration Trend Characterization

- Use Libya4 CEOS cal-val site; follow general methodology developed for MODIS:

Lyapustin, A., Y. Wang, X. Xiong, G. Meister, S. Platnick, R. Levy et al, **Science Impact of MODIS C5 Calibration Degradation and C6+ Improvements**, *AMT*, 7, 7281-7319, 2014





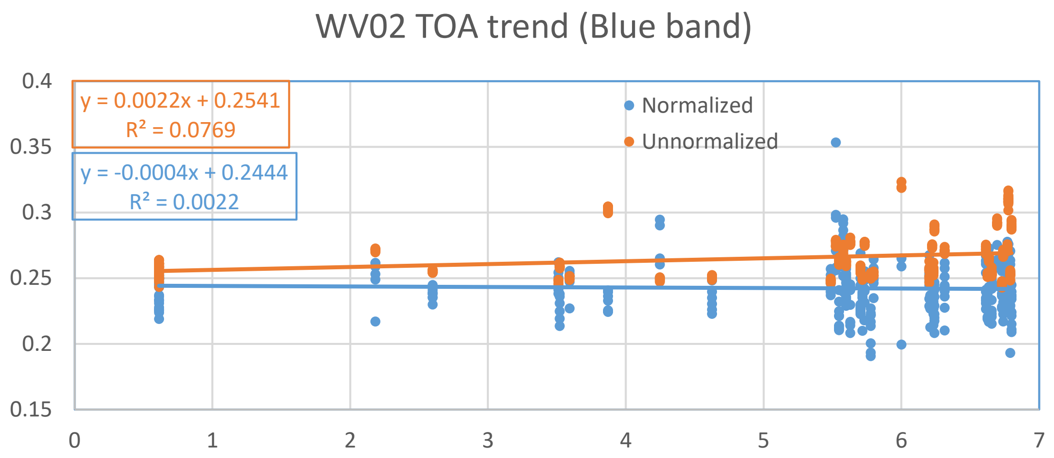
100×100 km² *calibration area*: MODIS TOA image

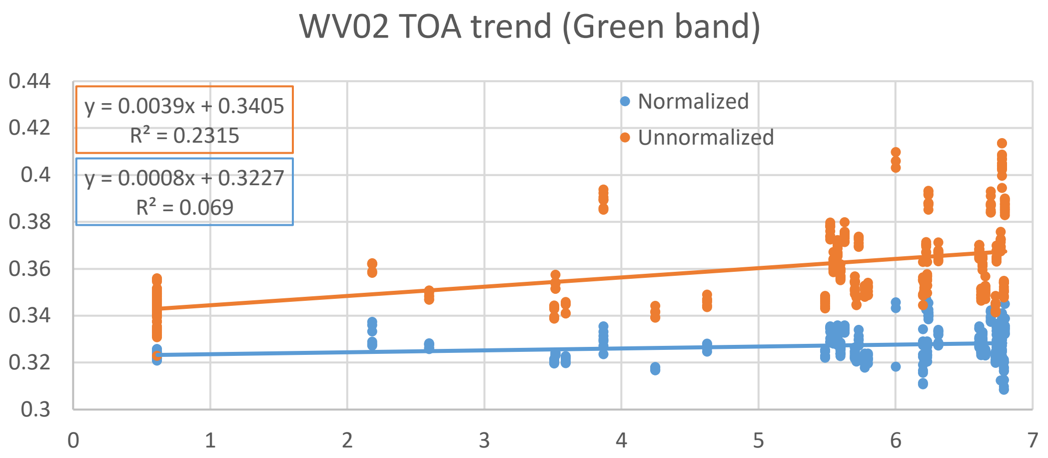
MODIS Tile

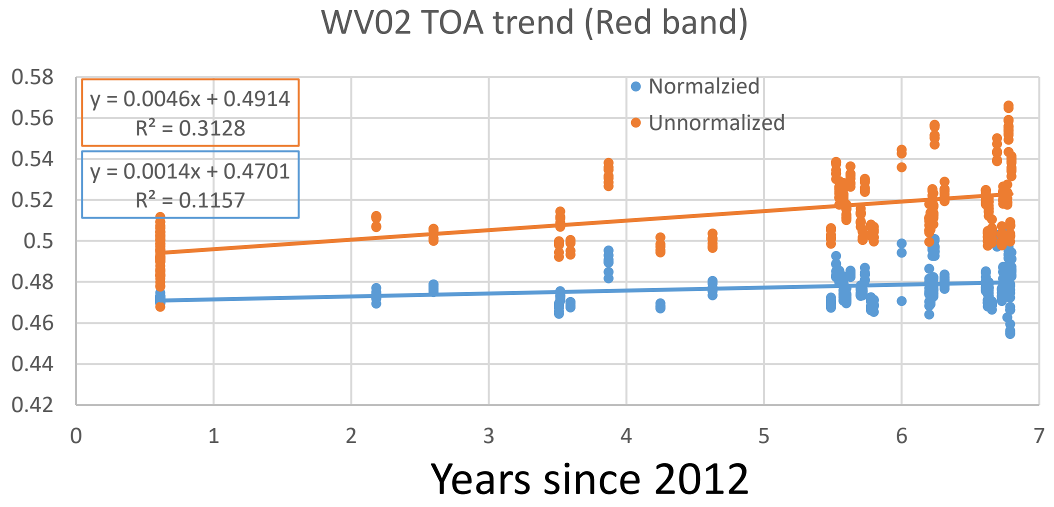
WorldView II data

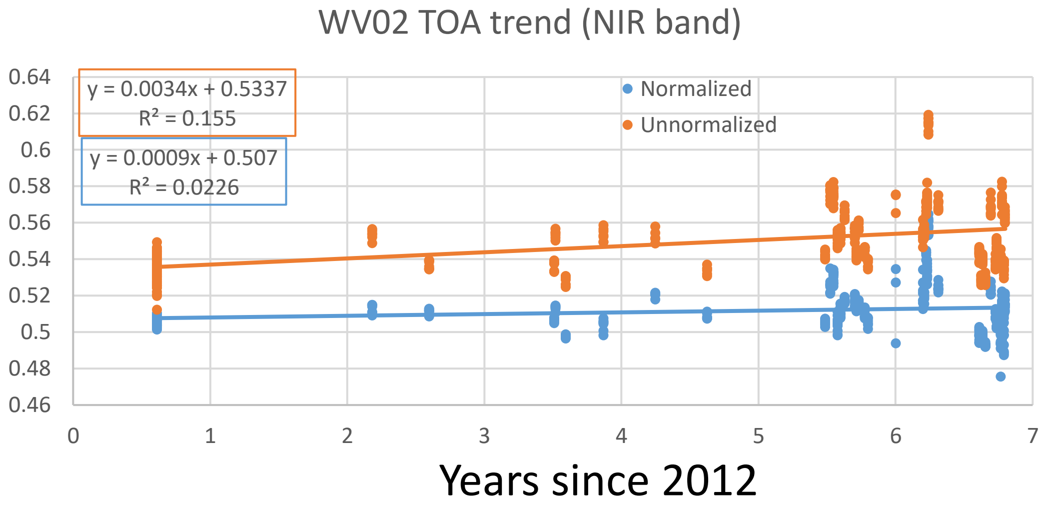
- **Problems**
  - High resolution images are acquired for variable view geometry (SZA~10-54°, VZA~0-37°);
  - Due to small frame size (17km), low spatial overlap among VHR images;
- **Solution** (100×100km² total area, each point is 5×5km² average):
  - Use MAIAC MODIS ancillary data (aerosol, column water vapor, spectral BRDF @ 1km resolution) to perform atmospheric correction of high resolution images;
  - Normalization to the common view geometry (nadir view, SZA=30°);
  - “Spatial transfer” to the common reference calibration point;

WV2 Calibration Trend Analysis





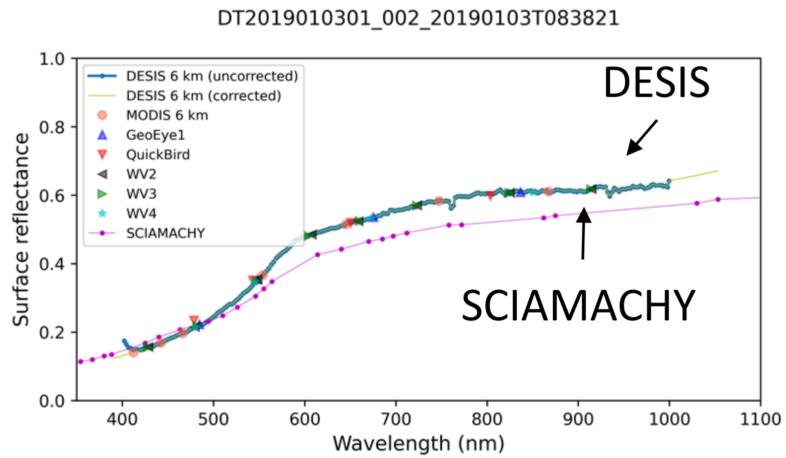


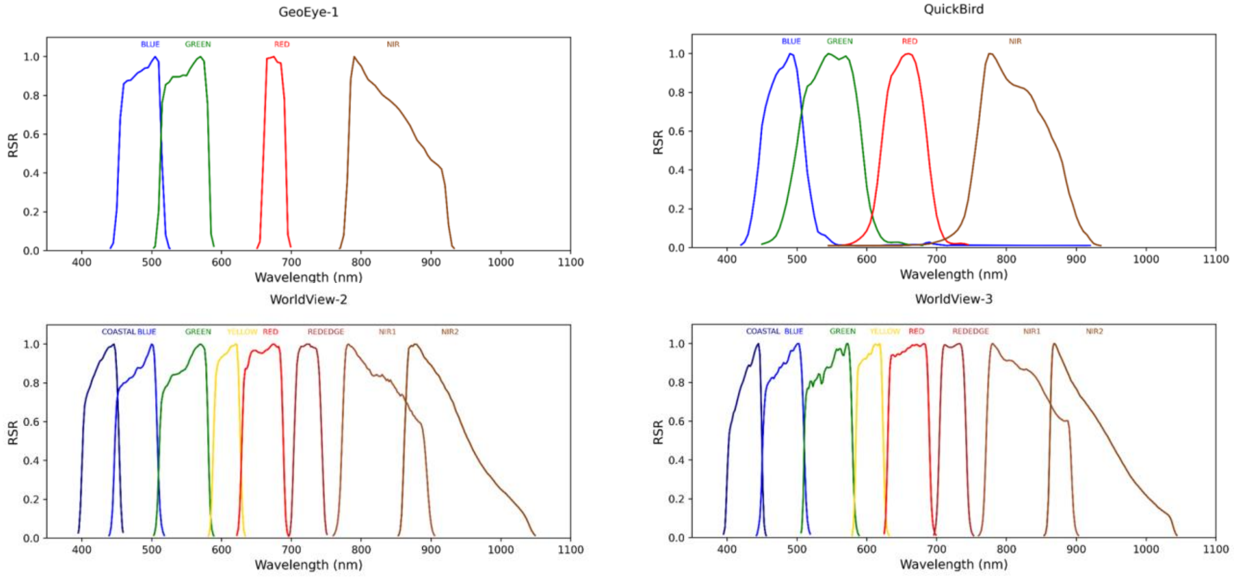


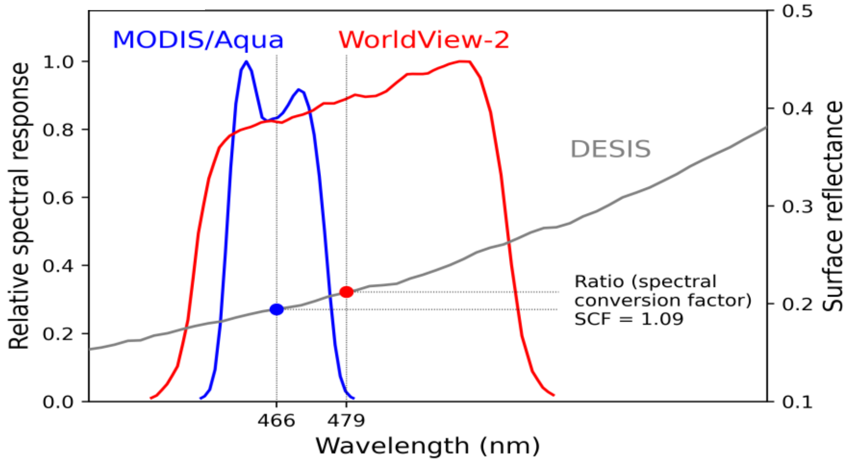
Final Result: Normalized (Blue). A direct (un-normalized) approach produces large errors.

RSR: 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.



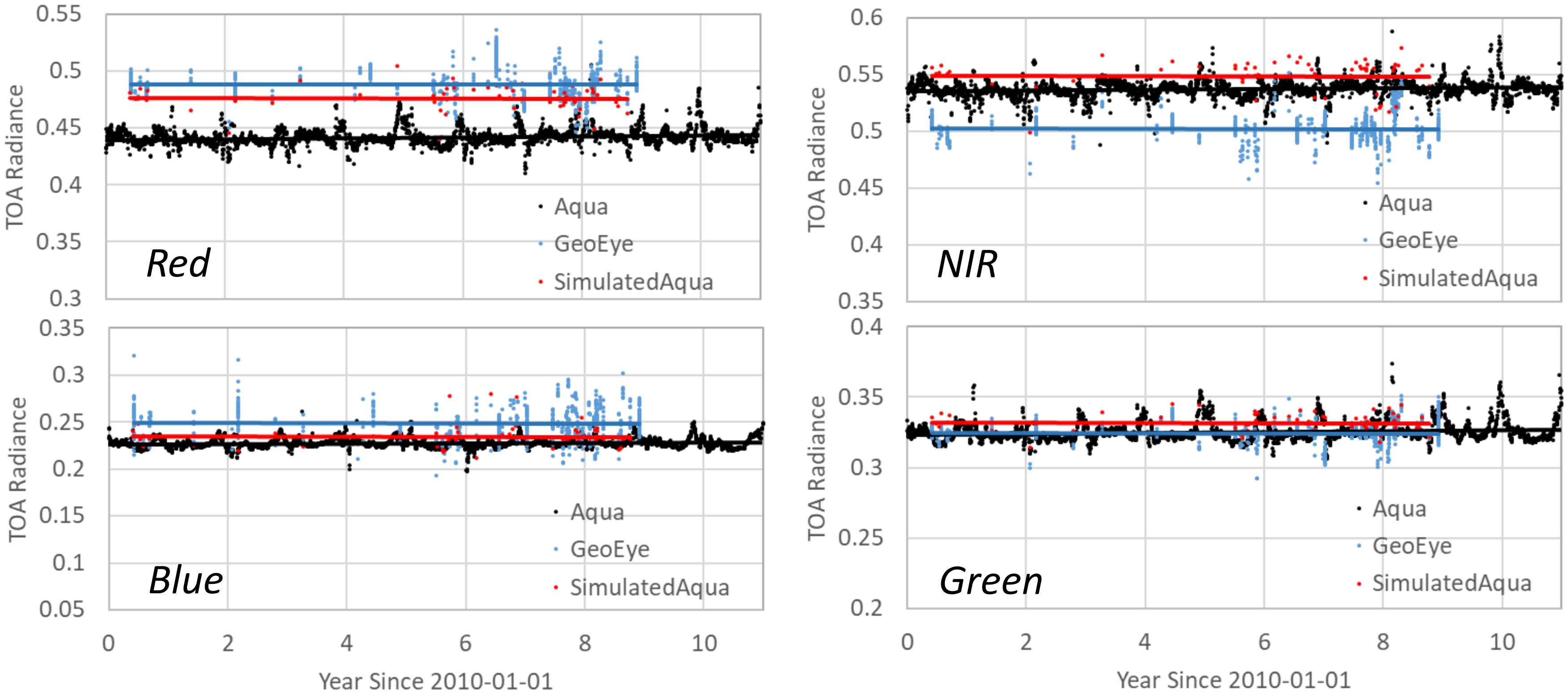




- Spectral convolution of surface reflectance
  - $\rho_{simulated} = \frac{\sum \rho_\lambda E_\lambda RSR_\lambda d\lambda}{\sum E_\lambda RSR_\lambda d\lambda}$
  - ρ_λ: DESIS surface reflectance with high spectral resolution
  - E_λ: solar irradiance
  - RSR_λ: spectral response function
- BRDF normalization 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 = $\frac{\rho^n_{simulated\ (DG\ sensors)}}{\rho^n_{simulated\ (MODIS/Aqua)}}$

Cross-Calibration of De-trended DG to Aqua

- Using MAIAC MODIS ancillary data (CM, aerosol, column water vapor @ 1km) perform AC of de-trended DG;
- Perform normalization to the common view geometry (nadir, SZA=20°) and "spatial transfer" to the common reference calibration ($5x5km^2$) point;
- Apply Spectral Conversion Factor (effectively brings DG reflectance to the reference Aqua band) → ρ^{*DG}. Compute scale to MODIS Aqua BRDF, $\alpha=\rho^{*DG}/BRDF_n$;
- Using scaled BRDF, $RTLS^{*DG}= \alpha RTLS$, compute TOA^{*DG} at normalized geometry (for reference Aqua band). Compute X-cal: TOA^{*DG} / TOA^{Aqua}



Example for GeoEye

TOA_n Aqua
TOA_n GeoEye
TOA_n GeoEye at Aqua band

De-Trending & X-Calibration Coefficients (DG/Aqua)

De-trending

Satellite	Bands	Trend/Year/Unit Refl.	Trend/Year/Unit Refl. (MODIS C5)	Surface Reflectance (reference spot)	Statistically Significant
World View II	Blue	-1.39E-03	-8.90E-04	0.2441	N
	Green	2.38E-03	-5.70E-04	0.3230	Y
	Red	2.89E-03	-1.70E-03	0.4705	Y
	NIR	1.88E-03	7.80E-04	0.5070	Y
World View III	Blue	-9.29E-04	-8.90E-04	0.2381	N
	Green	-2.84E-03	-5.70E-04	0.3253	N
	Red	-1.69E-03	-1.70E-03	0.4739	N
	NIR	-1.24E-03	7.80E-04	0.5128	N
GeoEye I	Blue	-2.48E-03	-8.90E-04	0.2494	Y
	Green	-1.85E-03	-5.70E-04	0.3249	Y
	Red	2.21E-04	-1.70E-03	0.4879	N
	NIR	-2.25E-03	7.80E-04	0.5027	Y
QuickBird II	Blue	3.54E-03	-8.90E-04	0.2548	N
	Green	3.51E-03	-5.70E-04	0.3300	Y
	Red	2.63E-03	-1.70E-03	0.4674	Y
	NIR	9.23E-05	7.80E-04	0.5093	N

Cross-Calibration

Band	GeoEye	QuickBird	WV02	WV03
Blue	1.0350	1.0194	1.0156	0.9956
Green	1.0290	1.1180	1.0343	1.0424
Red	1.0838	1.0959	1.0689	1.0799
NIR	1.0267	1.0670	1.0189	1.0321
N Samp	62	5	35	32

Summary

1. Results for QuickBird are not reliable (low stats)
2. DG sensors are within ~2-3% of each other
3. DG are systematically higher than Aqua:
   - Blue: 0-3.5% (0-1.6%)
   - Green: 2.9-4.2% (3.4-4.2%)
   - Red: 6.9-8.4% (6.9-8%)
   - NIR: 1.9-3.2% (1.9-3.2%)

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This work utilized data made available through the NASA Commercial Smallsat Data Acquisition (CSDA) Program.

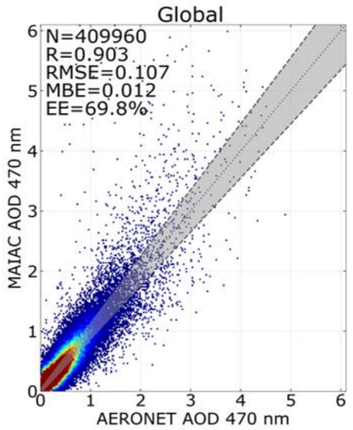
This work was funded through the NASA Commercial Smallsat Data Acquisition (CSDA) Program (manager A. Hall).

Atmospheric Correction of VHR Data

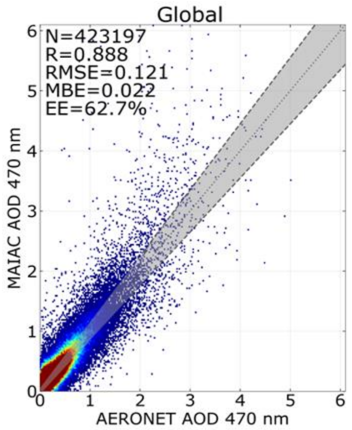
1. **Quality of MAIAC MODIS Ancillary Data:**

CM: MAIAC C6 has 5-25% more high-quality SR data than MOD09 annually (*Lyapustin et al., FRSen, 2021*);
CWV: validated against AERONET within 10% accuracy (Martins et al., 2018; 2019);
AOD: 1km resolution, 10% accuracy (Lyapustin et al., 2018, …) + significant improvement from C6 to C6.1;

21x21 km^2 (50% coverage), 0.47µm



A single 1km pixel



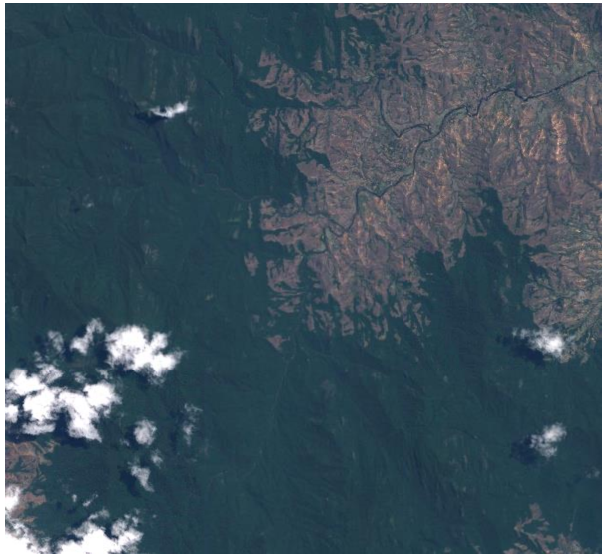
	MAIAC C6	C6.1	C6.1 1km
N	304553	409960	423197
%EE	66%	69.8%	62.7%
R	0.84 →	0.903	0.888
RMSE	0.12 →	0.107	0.121
MBE	0.01	0.012	0.022

2. MAIAC CM and AOD are successfully used to screen "good quality" VHR data with low cloud/cloud shadow fraction and aerosol;
3. Atmospheric Correction with BRDF normalization.

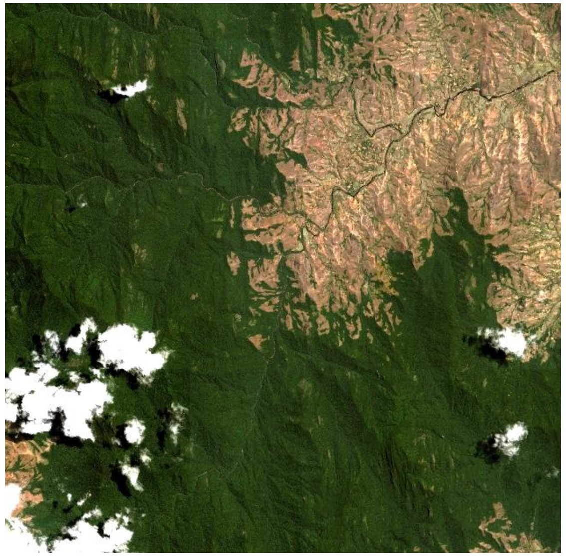
Lyapustin A, Zhao F and Wang Y (2021) A Comparison of Multi-Angle Implementation of Atmospheric Correction and MOD09 Daily Surface Reflectance Products From MODIS. Front. Remote Sens. 2:712093. doi: 10.3389/frsen.2021.712093
Lyapustin, A., Wang, Y., Korkin, S., and Huang, D. (2018) MODIS Collection 6 MAIAC Algorithm, AMT, 11, 5741-5765, https://doi.org/10.5194/amt-11-5741-2018.

Atmospheric Correction of VW2 Data

201410030717, TOA

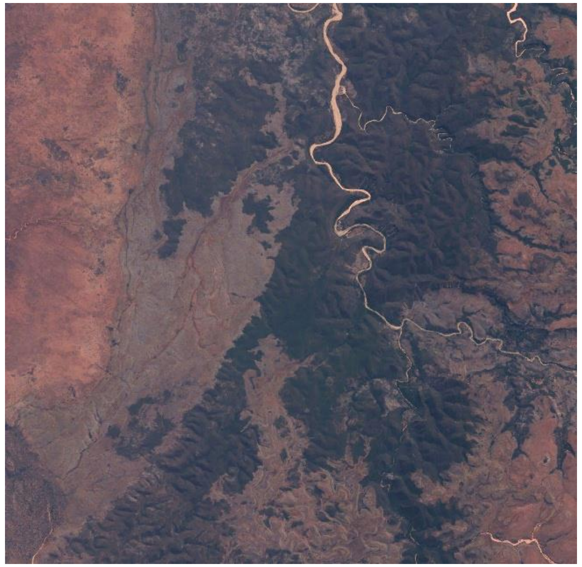


BRF



… somewhere in Madagascar

TOA



201510010718, BRF