A Consistent Data Record from the Inherited Solar Bands of VIRR

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Background

- **Visible Infrared Radiometer (VIRR) is the first and the most historic instrument equipped on the Fengyun (FY) polar series satellite.**
- **After the historical data re-processing, VIRR instruments could provide a global data record over 20 years which offers the capacity on studying climate variability.**
- **Because of the lack of onboard calibration system for VIRR solar bands, they must be vicariously calibrated.**

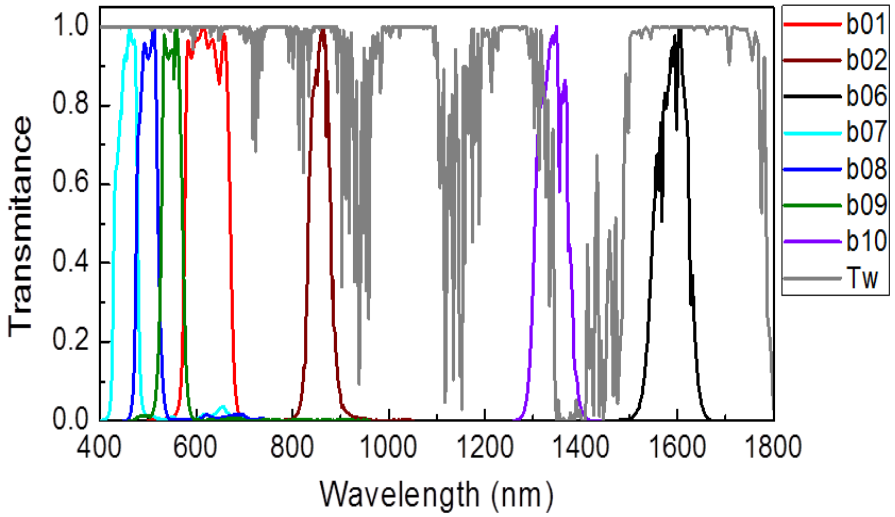
VIRR overview

- **There are 3 versions of VIRRs carried on FY-1 and FY-3 satellites, covering the visible, near-infrared and thermal Infrared spectra.**

VIRR Spectral Specifications

Band	FY-1A/B VIRR-1	FY-1C/D VIRR-2	FY-3A/B/C VIRR-3
1	0.58-0.68	0.58-0.68	0.58-0.68
2	0.725-1.10	0.84-0.89	0.84-0.89
3	0.43-0.53	3.55-3.95	3.55-3.95
4	0.53-0.58	10.3-11.3	10.3-11.3
5	10.5-12.5	11.5-12.5	11.5-12.5
6		1.56-1.64	1.56-1.64
7		0.43-0.48	0.43-0.48
8		0.48-0.53	0.48-0.53
9		0.53-0.58	0.53-0.58
10		0.900-0.960	1.325-1.395

FY-3A/VIRR RSBs



- **Global data could be provided since FY-1C.**

VIRR Global Data Information

Satellite	Launch date	Time range	Coverage	Channels
FY-1A	1988/09/07	1988/09/07–1988/10/15	1-hr	1, 2 and 5
FY-1B	1990/09/03	1990/09/03–1991/02/14	1-hr	1, 2 and 5
FY-1C	1999/05/10	2000/01/21–2004/06/30	Global	1, 2, 4 and 5
FY-1D	2002/05/15	2002/07/11–2012/01/13	Global	1, 2, 4 and 5
FY-3A	2008/05/27	2008/07/01–2015/01/04	Global	1 to 10
FY-3B	2010/11/05	2010/11/14 till now	Global	1 to 10
FY-3C	2013/09/23	2013/10/01 till now	Global	1 to 10

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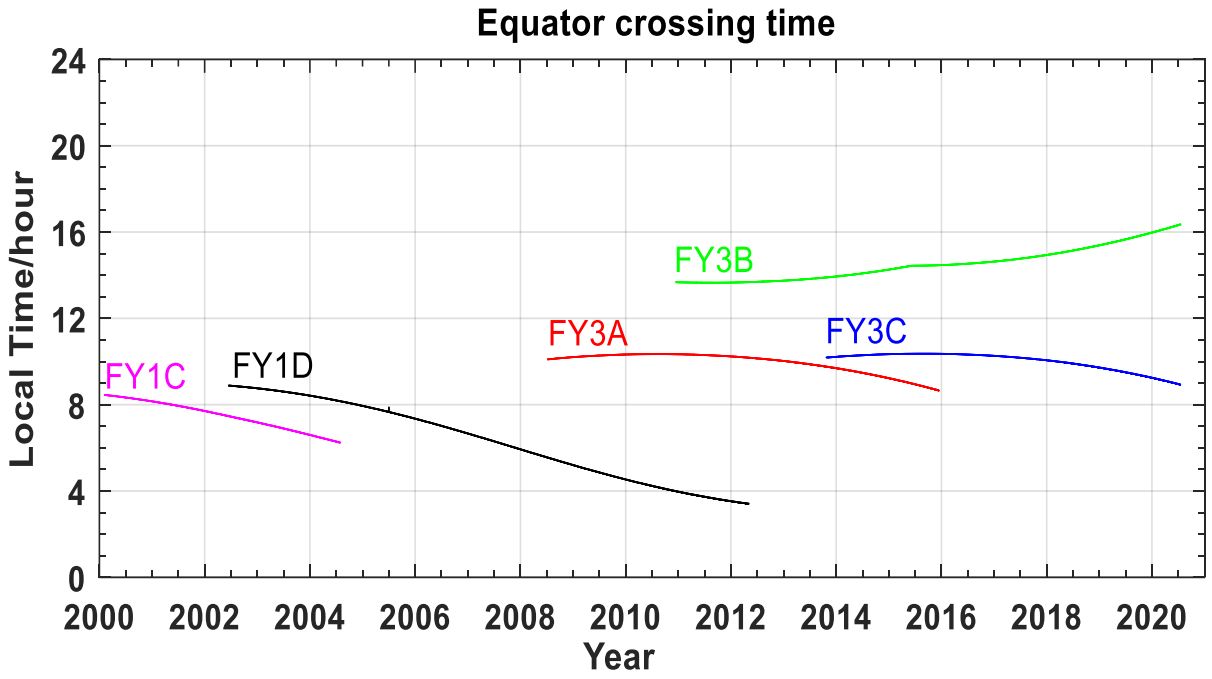
- **FY-1 satellites did not include system to maintain their sun-synchronous orbit. Due to the satellite orbit drift over time, the equator crossing time (ECT) continuously changed.**



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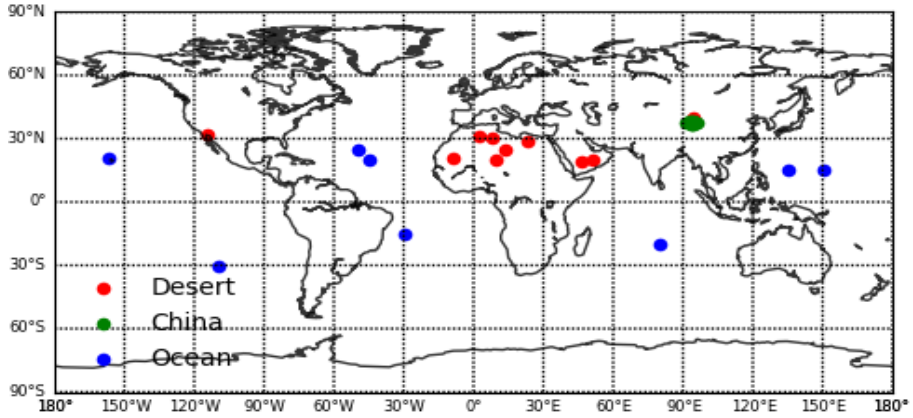
Calibration

- **The multiple site calibration approach is employed for the Ch1 and Ch2 of VIRR sensors on FY-1 and FY-3 platforms, using the RTM predicted reflectance over desert and ocean invariant Earth targets.**

- **The calibration reference of the VIRR solar band record is further traced to Aqua MODIS C6.1 reference calibration by a systematic correction derived from Libya4 desert.**

Long-term calibration scheme for each sensor

- **Three kinds of sites are used, including Chinese PICS located in Qinghai province with altitudes nearly 3 km.**



- **The calibration coefficient is calculated by linear regression, using data during an accumulation period (e.g., 10 days) from all sites.**

$$100\rho_i \cos(\mathrm{SZA}) / d^2 = m_i(\mathrm{EV}_i - \mathrm{SV}_i)$$

- **In linear regression to derive the calibration coefficient , data from different sites are assigned with weighting factor using the inverse of the variance from the radiative simulation evaluation with reference to Aqua MODIS.**

$$w_i = 1/\sigma_i^2$$

- **Piecewise polynomial functions of DSL (number of days since launch) is adopted to describe the calibration coefficient series long-term varying feature.**

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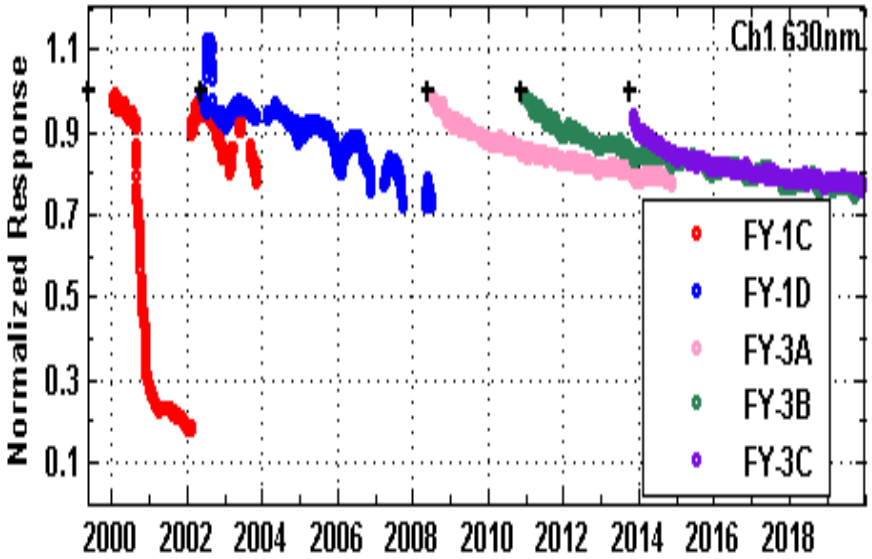
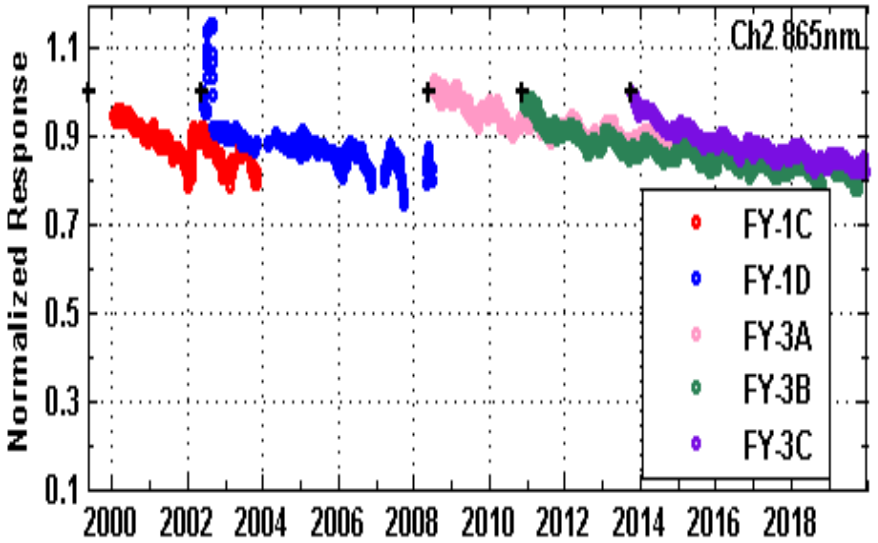
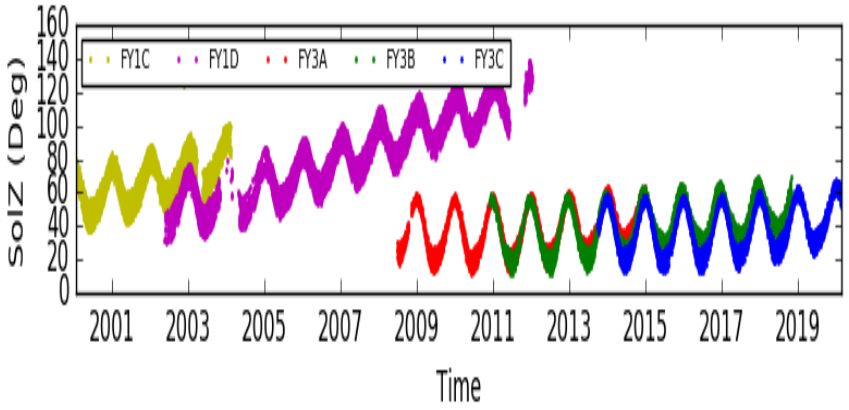




Lifetime normalized response variation of VIRR Ch1 and Ch2.



- **Working unit switch for FY-1C and FY-1D.**
- **Large solar zenith angle due to the orbit drift, especially FY-1, resulting in large oscillation by inadequate description of the anisotropy of calibration targets.**
- **Seasonal variation of Ch2 for FY-3 is obvious, sensor related issues to be analyzed.**

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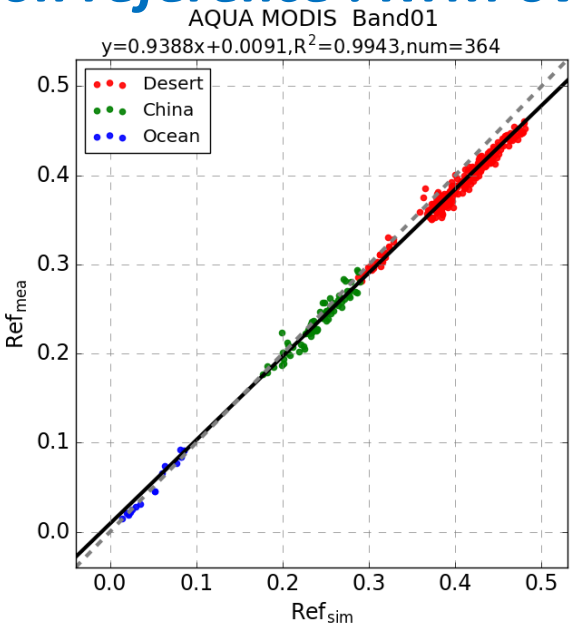
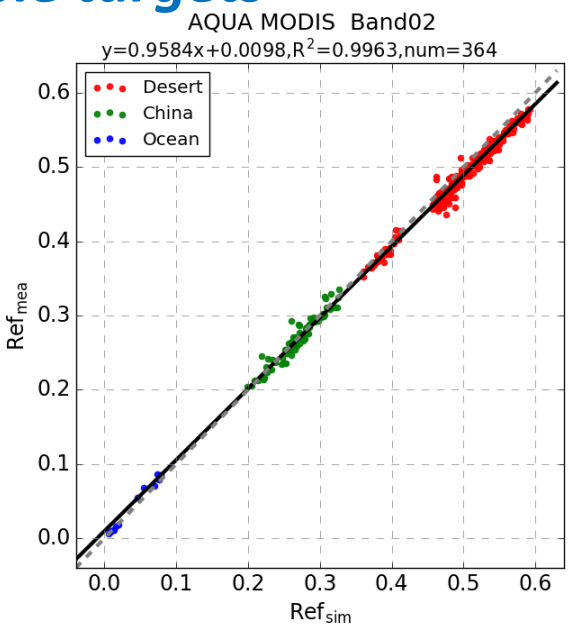
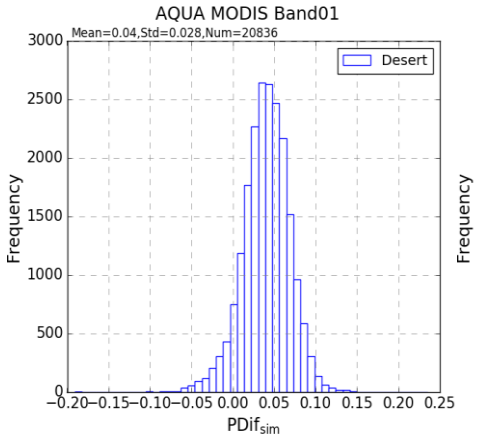
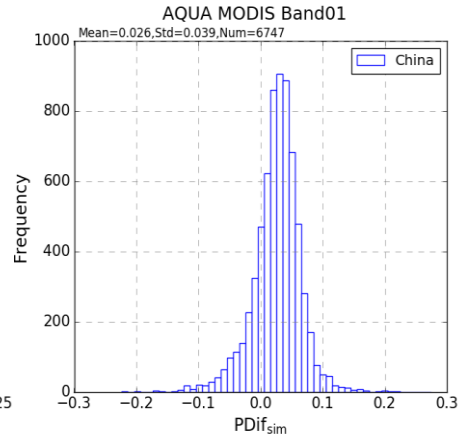
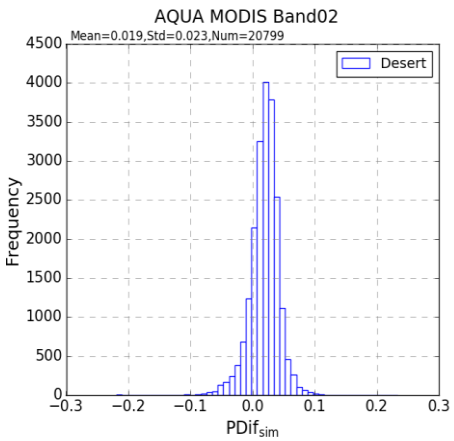
Calibration reference : RTM over stable targets

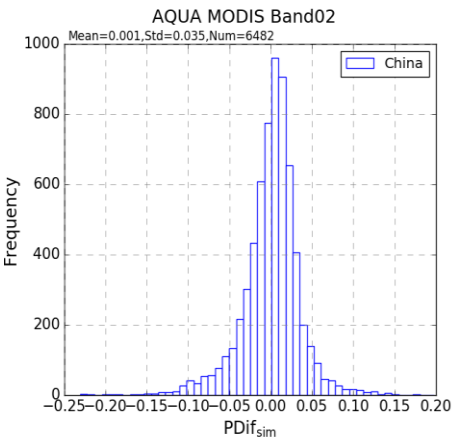












Calibration reference evaluation statistics using Aqua MODIS from 2005 to 2019

Band	Relative Difference(%, Mean ± σ)			
	All Sites	Desert	China	Ocean
1	3.62 ± 4.45	4.01 ± 2.79	2.61 ± 3.90	2.85 ± 13.24
2	1.52 ± 3.98	1.93 ± 2.25	0.07 ± 3.52	2.54 ± 15.08

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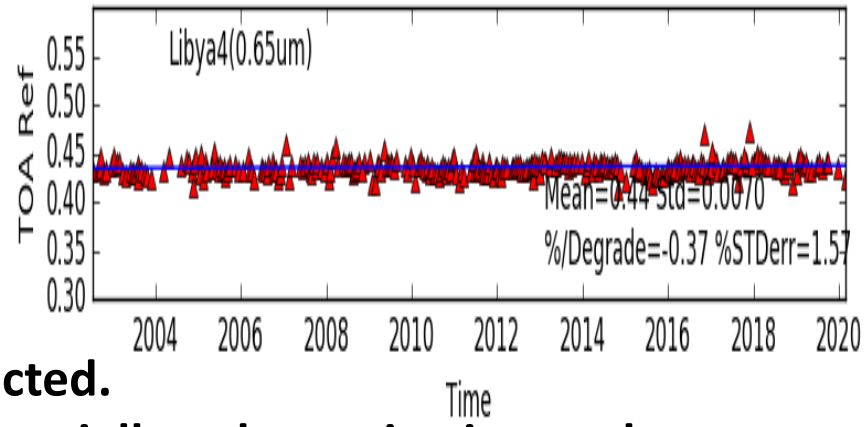
Tracing to Aqua MODIS calibration

- **PICS stability: the average reflectance under clear-sky, and a given set of viewing and solar angular conditions, remains nearly stable over time.**
- **Libya4 is used, temporally stable within 0.5% per decade based on Aqua MODIS band 1.**



- **For TOA reflectance comparison**
  - **Spectral differences should be corrected.**
  - **BRDF effects should be corrected especially at large viewing angles.**

- **The observed sensor reflectance is spectrally adjusted to the FY-3B VIRR SRF and to a common SZA of 30° to provide an observed normalized reflectance.**
- **VIRR record mean value of clear-sky TOA normalized reflectance is compared with that of MODIS, and the ratio is used as the systematic correction factor to trace the VIRR record to Aqua MODIS calibration.**

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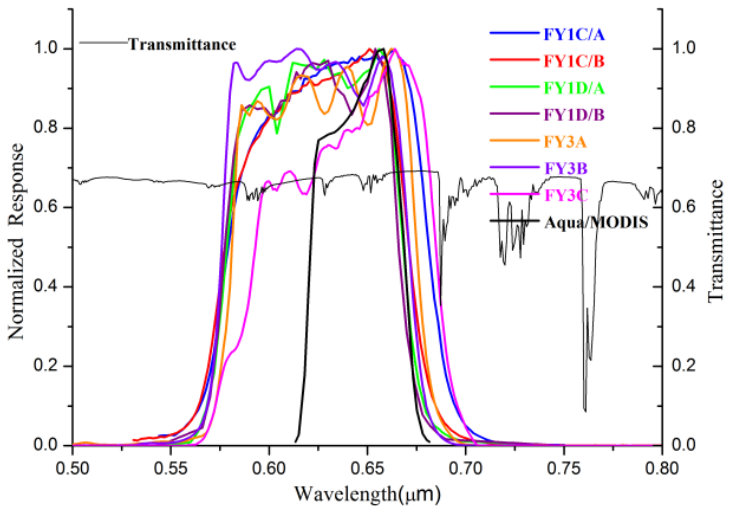
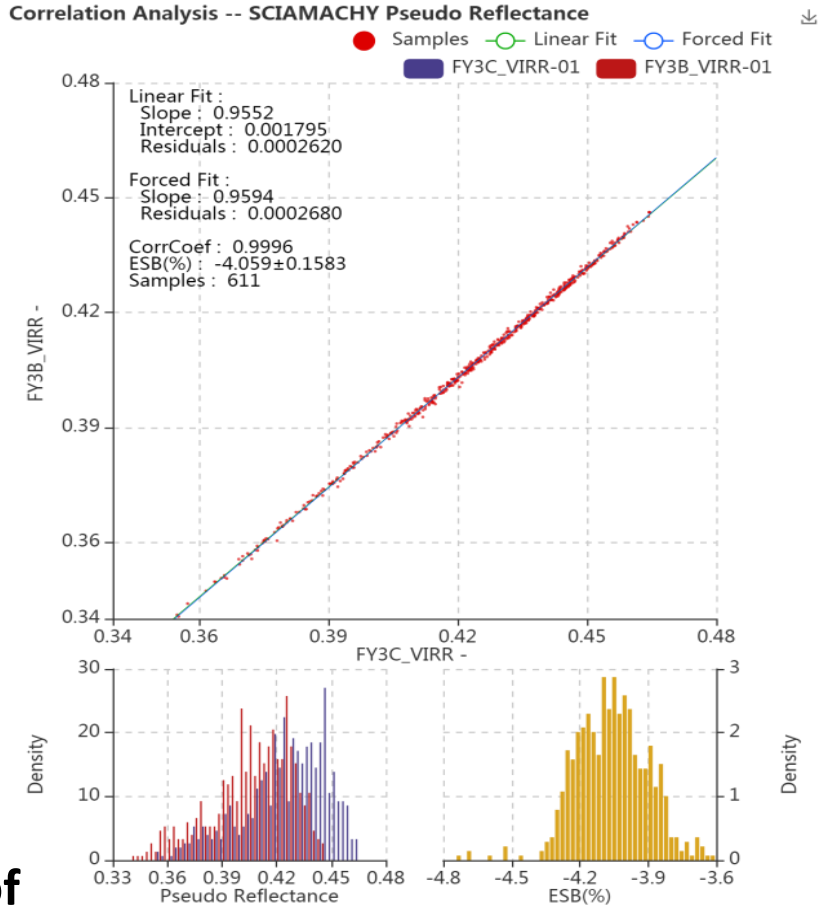
Spectral band adjustments



- **SCIAMACHY data is used to derive the spectral band adjustment factors (SBAFs).**
- **SBAF is derived for certain target by linear regression through the origin (force fit).**

- **Over clear Libya4 desert, the reflectance of FY-3C is nearly 4% higher than that of FY-3B for Ch1, while nearly 4% lower than that of FY-3B for Ch2.**



Libya4
FY-3B vs FY-3C

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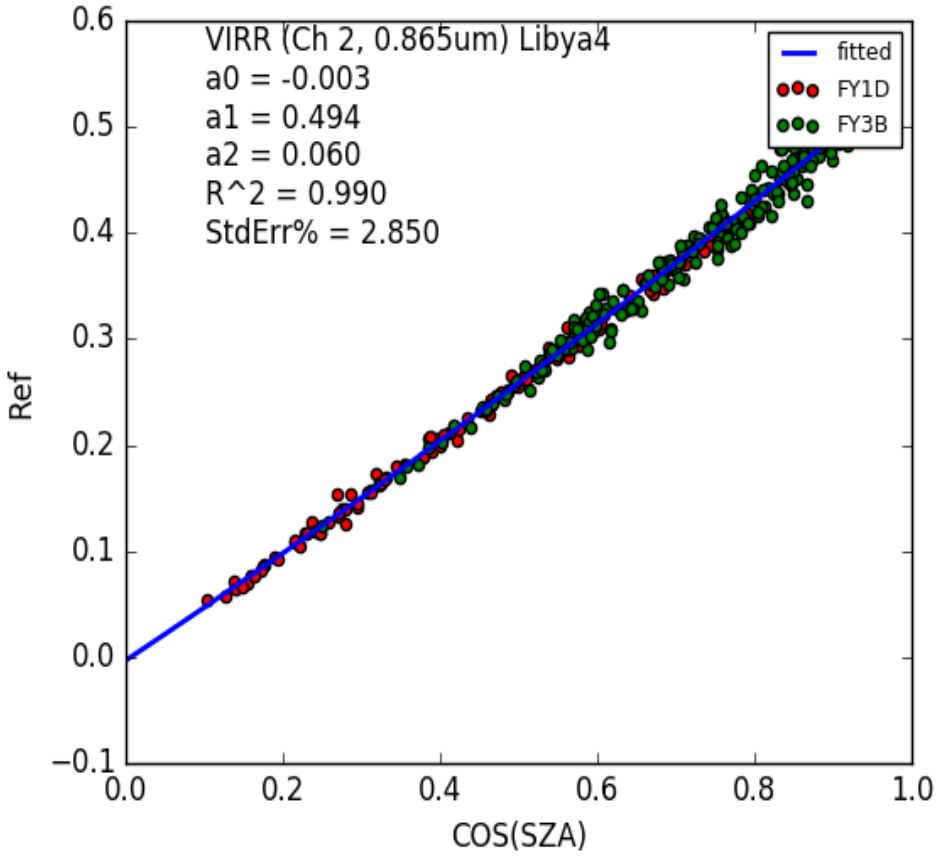
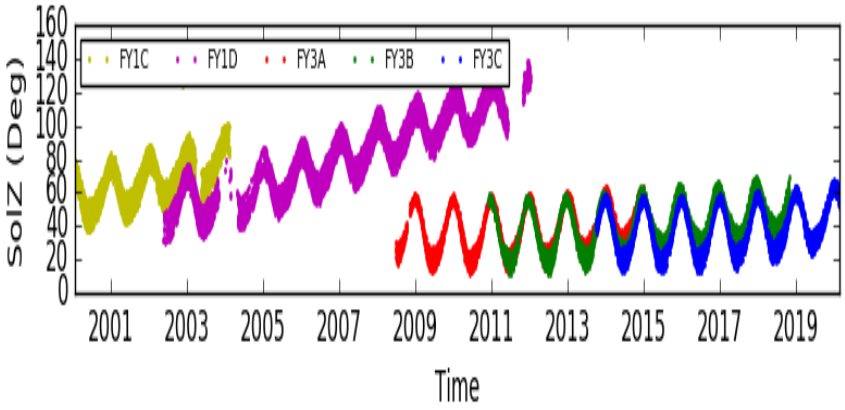
Site-specific directional model (DM)



Libya4 DMs derived from near-nadir reflectance



- **FY-1D and FY-3B have relatively longer records.**
- **To cover the possible solar zenith angles, the recalibrated FY-3B and FY-1D VIRR records are combined to derive the DMs.**

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Evaluation

Vicariously calibrated VIRR record is evaluated using SNO targets with reference to Aqua MODIS, and global stable targets.

- **Comparison with MODIS using SNO over polar regions: for reflectance biases.**
  - **Aqua MODIS C6.1 level 1b data.**
  - **Near-coincident (within 1 min), near-nadir (sensor zenith angle within 10°) matches after angle consistency and spatial uniformity screening.**
  - **SCIAMACHY-based SBAFs are applied.**

- **PICS reflectance time series: for consistency.**
  - **clear-sky TOA reflectance after anisotropic and spectral correction.**

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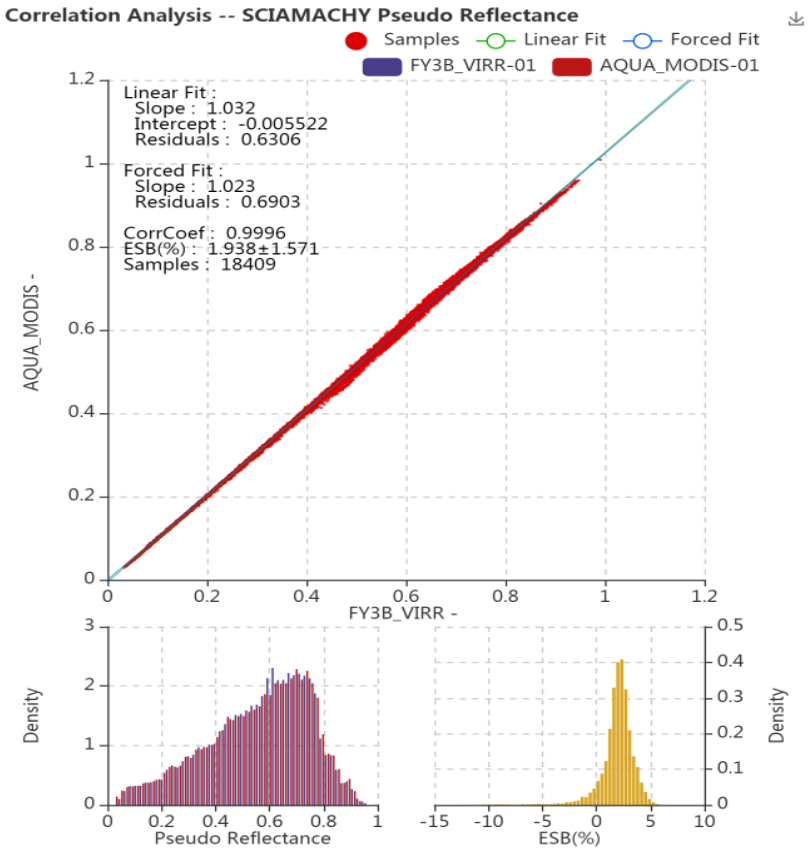
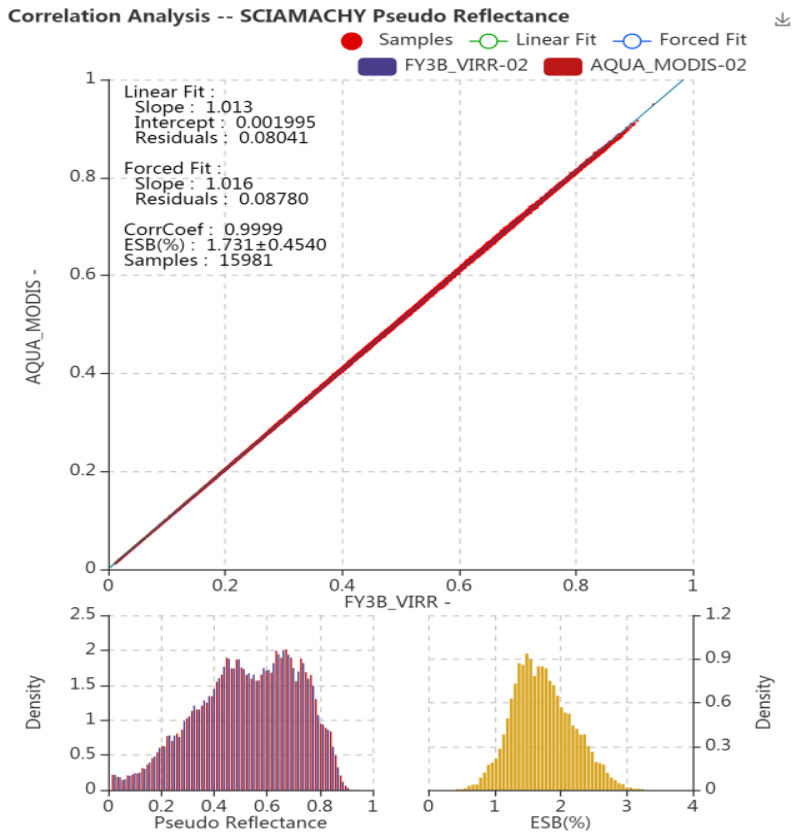
Spectral band adjustments





North Pole region
FY-3B vs. MODIS

- **Over North Pole region, the FY-3B VIRR Ch1 reflectance should be adjusted by 2.3% to achieve spectral consistency with Aqua MODIS, while by 1.6% for Ch2.**

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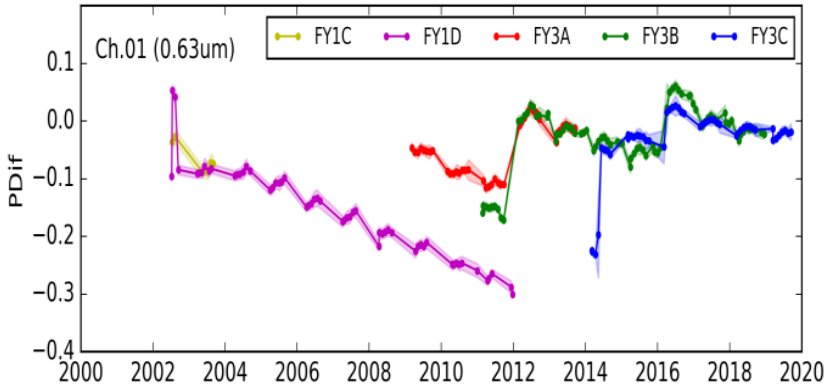
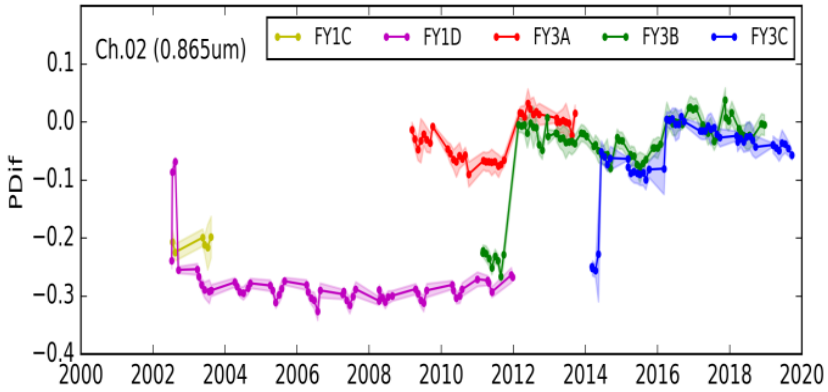
Comparison with MODIS

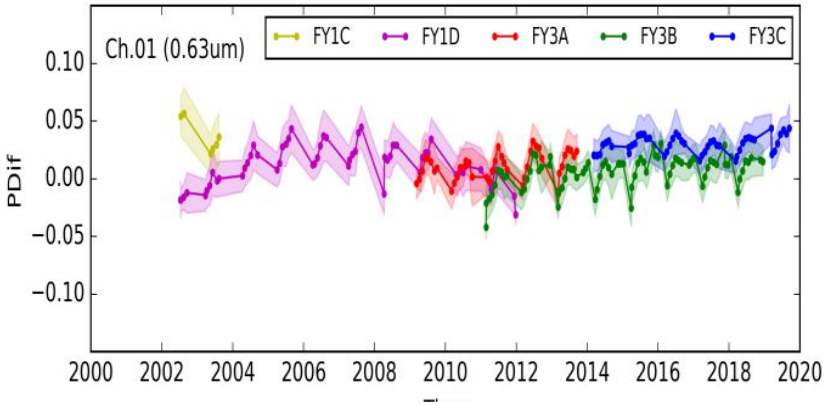
SNO VS. MODIS

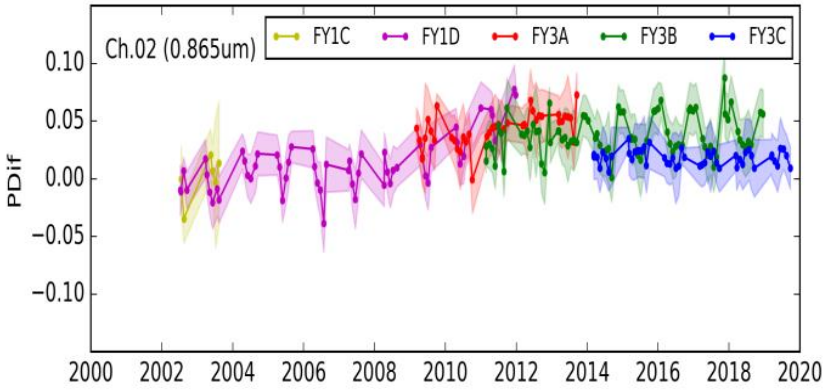
Operational





Re-processed





- **Variation of sensor radiometric response both gradual and sudden degradation is corrected, and the radiometric stability and inter-platform consistency is improved after recalibration.**
- **Lifetime RMS of the relative difference is within 5% for Ch1, 2, 6, 7, 8, while relatively larger for Ch9 at low signal.**

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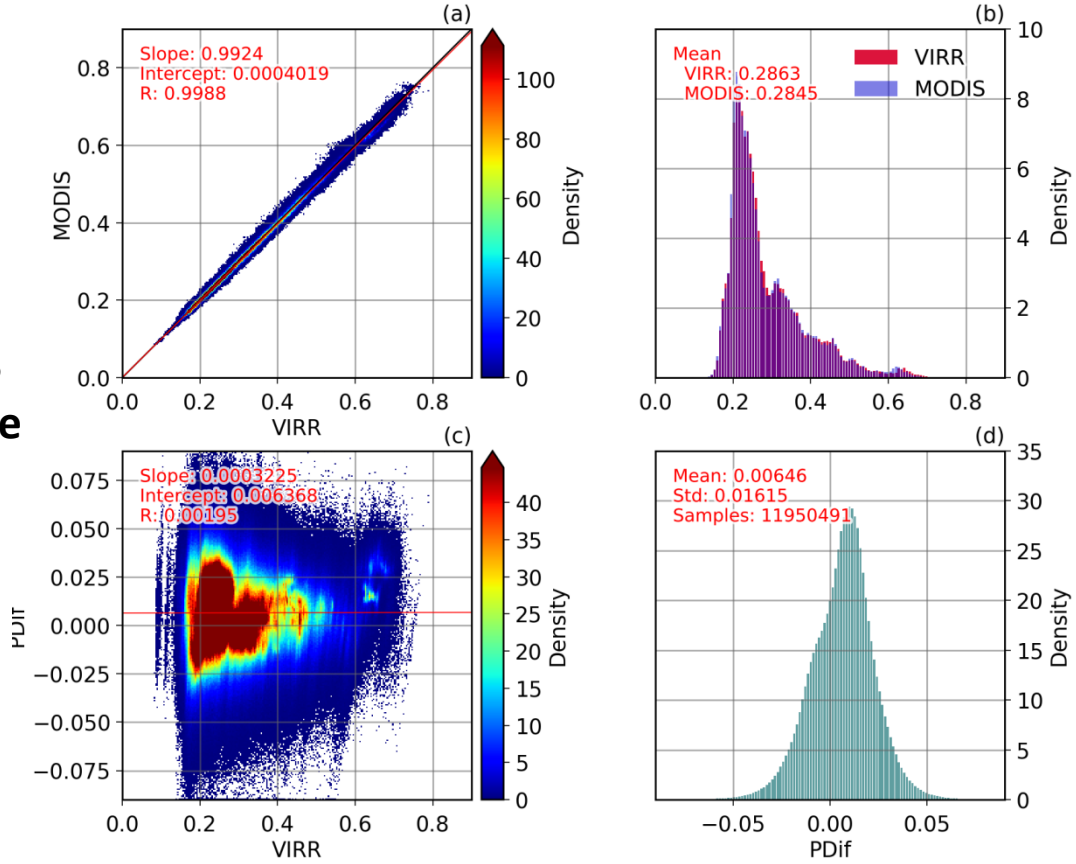
FY-3B lifetime



Comparison statistics of relative difference (%) by SNO against Aqua MODIS

	Ch1			Ch2		
	Lifetime Mean	Mean of monthly RMS	Std of monthly RMS	Lifetime Mean	Mean of monthly RMS	Std of monthly RMS
FY-1C	2.04±2.07	3.24	1.01	0.62±2.84	2.91	1.06
FY-1D	0.87±2.01	2.11	0.66	2.08±2.86	2.70	1.17
FY-3A	0.60±1.60	1.63	0.49	4.31±2.40	4.48	1.44
FY-3B	0.65±1.61	1.57	0.38	4.31±2.47	4.31	1.43
FY-3C	2.62±1.43	3.03	0.60	1.69±2.10	2.46	0.72

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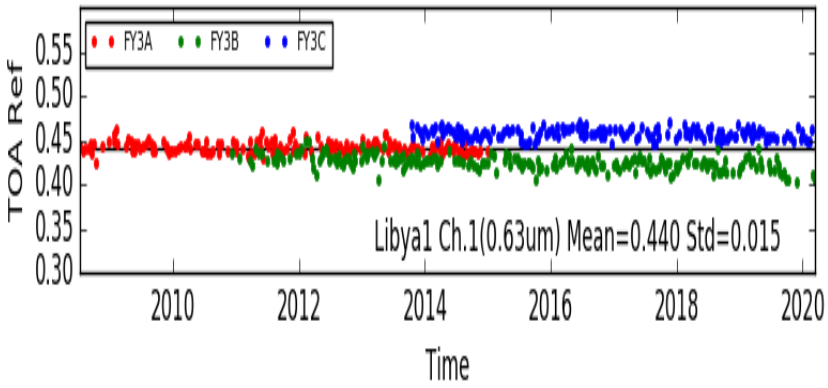
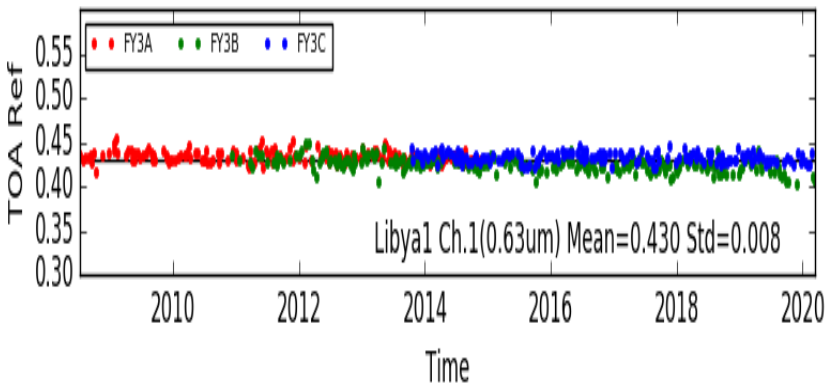
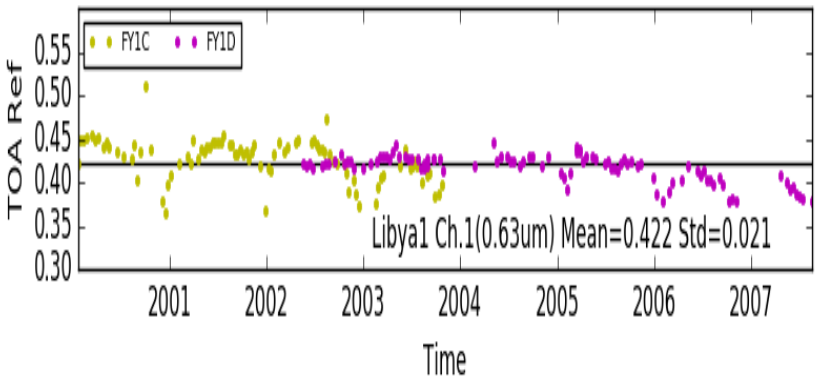
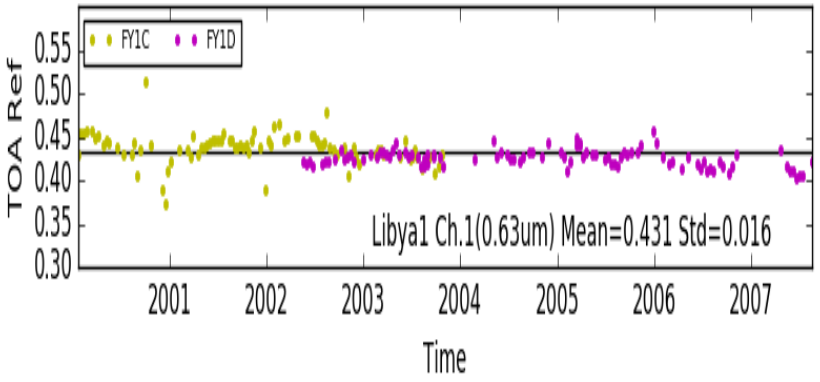
PICS reflectance time series





FY-3 VIRR multi-sensor time series of normalized reflectance (left) without and (right) with the SBAF





FY-1 VIRR multi-sensor time series of normalized reflectance (left) without and (right) with the DM correction

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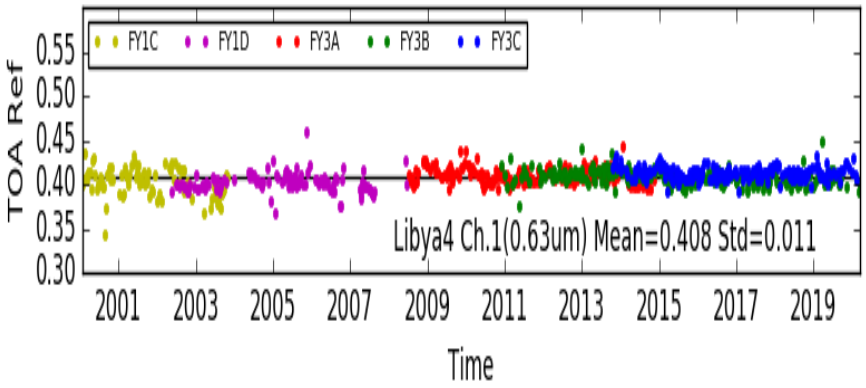
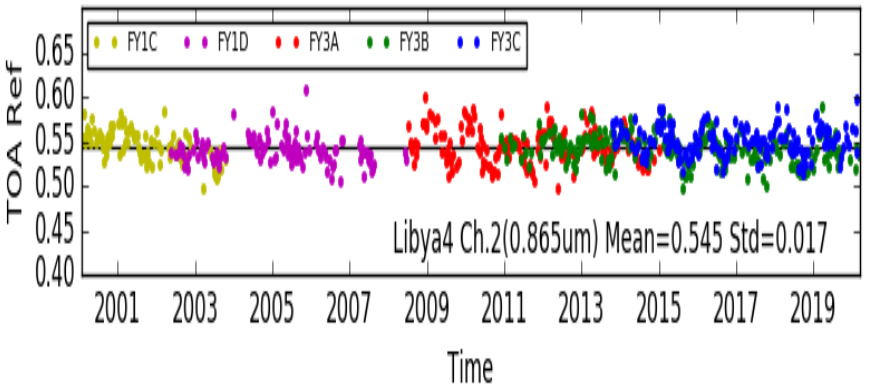
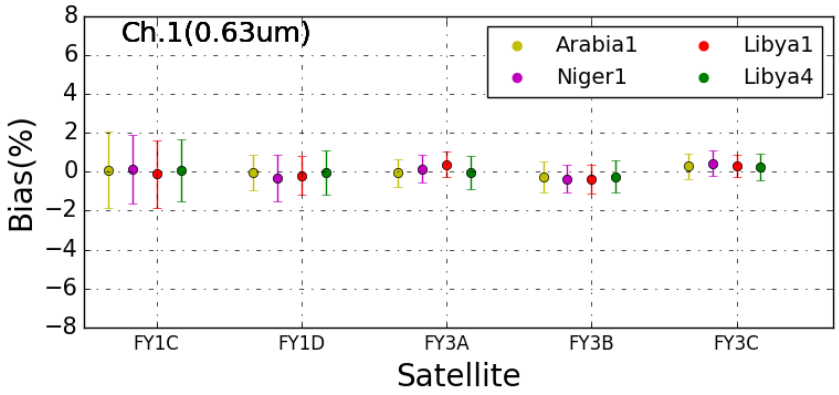
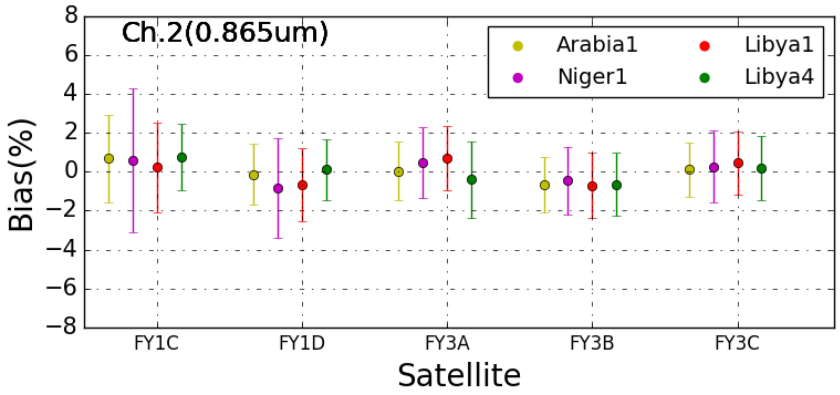
Clear-sky normalized reflectance of invariant deserts









In general, after anisotropic and spectral correction, the TOA reflectance means for each instrument are within 1% of the 20-yr average for channels 1 and 2.

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Summary

- A multisite vicarious approach for consistent calibration of VIRR RSBs is presented and applied, producing calibration coefficients for 5 instruments on FY-1C/D and FY-3A/B/C over two decades (2000-2019), and the record calibration reference is further traced to Aqua MODIS C6.1 by a systematic correction derived from Libya desert.
- The VIRR visible and near-infrared records are systematically larger than Aqua MODIS over the SNO targets. The lifetime relative biases for each sensor is within 2.7% and 4.4% for Ch1 and Ch2, respectively.
- Invariant deserts are adopted to evaluate the VIRR record stability and consistency. In general, the DM and SBAF corrected reflectance means for each instrument are within 1% of the 20-yr average.
- User feedbacks are expected through using the recalibrated dataset.

Sun et al. 10.12185/NSMC.RICHCEOS.FCDR.VIRRRSBsRecalCoef.FY.VIRR.L1.GBAL.POAD.NUL.TXT.2021.1.V1

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Thank you for attention.

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