Radiometric Scaling and Stability Assessment of MODIS and SNPP-VIIRS

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CERES Science Team Meeting

Outline

- Background
  - MODIS and VIIRS relevance to CERES
  - CERES Imager and Geostationary Calibration Group
- MODIS and VIIRS Calibration stability assessment
  - Temporal radiometric stability
  - Response versus scan-angle (RVS) dependency
- Radiometric scaling of VIIRS to MODIS
- Radiometric scaling between MODIS collections and VIIRS versions
- Geostationary imager calibration
- Summary

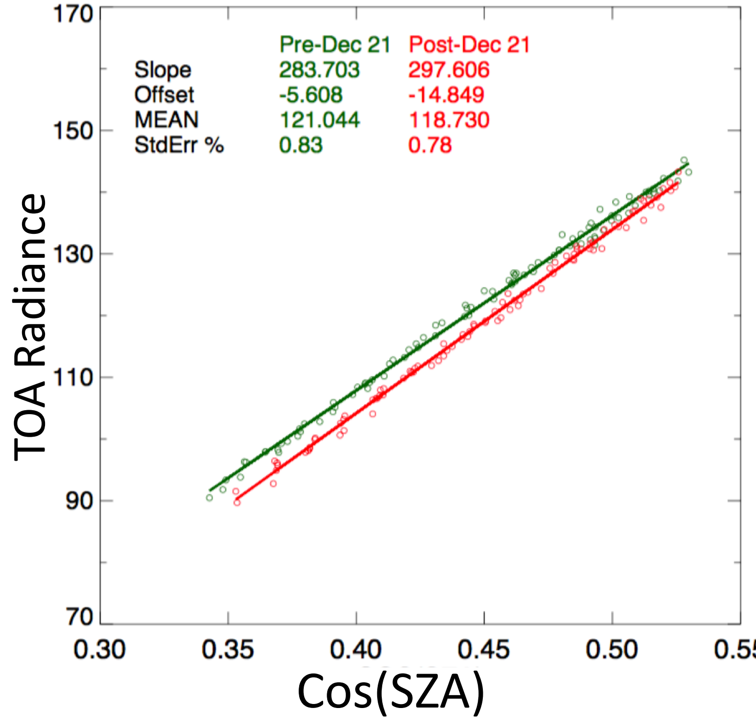
Background

- Why calibration of MODIS and VIIRS 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
  - SYN1deg products utilize GEO derived broadband (BB) fluxes and cloud properties
  - To ensure that the GEO BB fluxes and cloud properties are consistent across GEO sensors, the GEO radiances are radiometrically scaled to MODIS
- Consistent retrievals of cloud properties requires
  - Individual imager records are temporally stable in their calibration
  - MODIS and VIIRS imagers are radiometrically consistent
- Any radiometric drift in MODIS manifests itself in both the MODIS and GEO cloud retrievals
- On-orbit changes in scan-mirror reflectivity and solar diffuser (SD) necessitates independent evaluation of MODIS radiometric quality
- CERES imager and geostationary calibration group (IGCG) performs calibration assessment of MODIS, VIIRS, and GEO imagers in real-time using multiple approaches

MODIS and VIIRS stability assessment based on Earth invariant targets

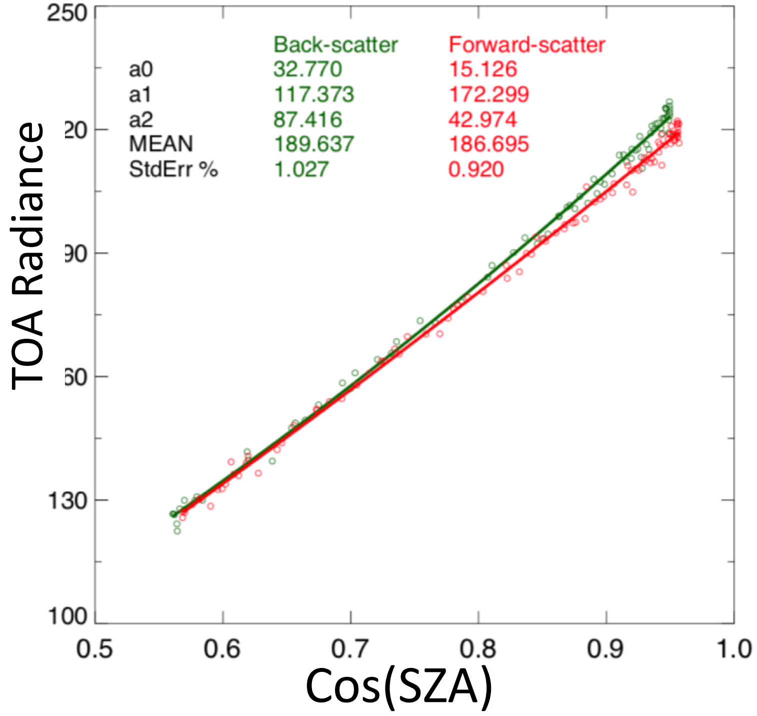
Dome-C

- Near nadir measurements
- Pre and post solstice directional models (DM)
- Construct the DM from stable part of the record



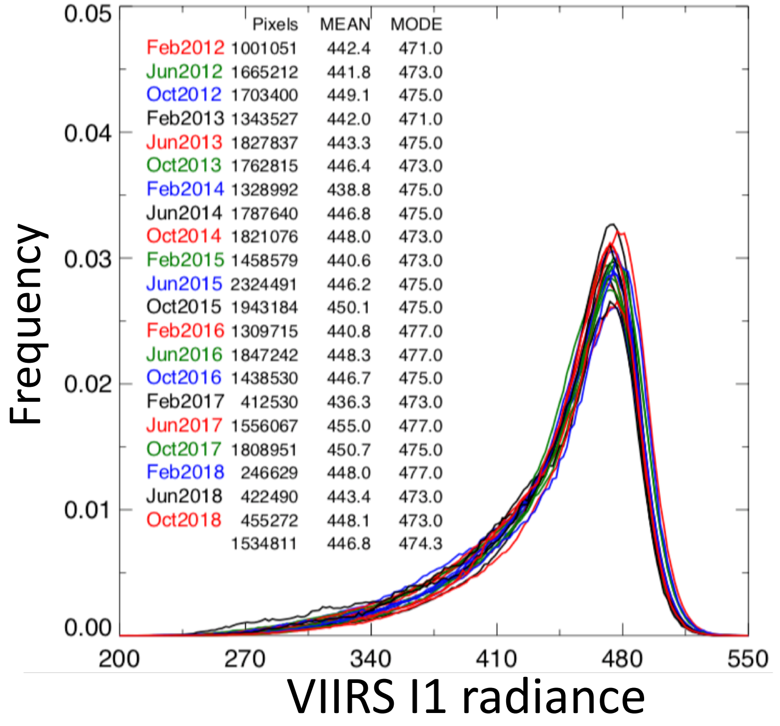
Libya-4

- Near-nadir measurements
- Forward/backward scattering directional models (DM)
- Construct the DM from stable part of the record

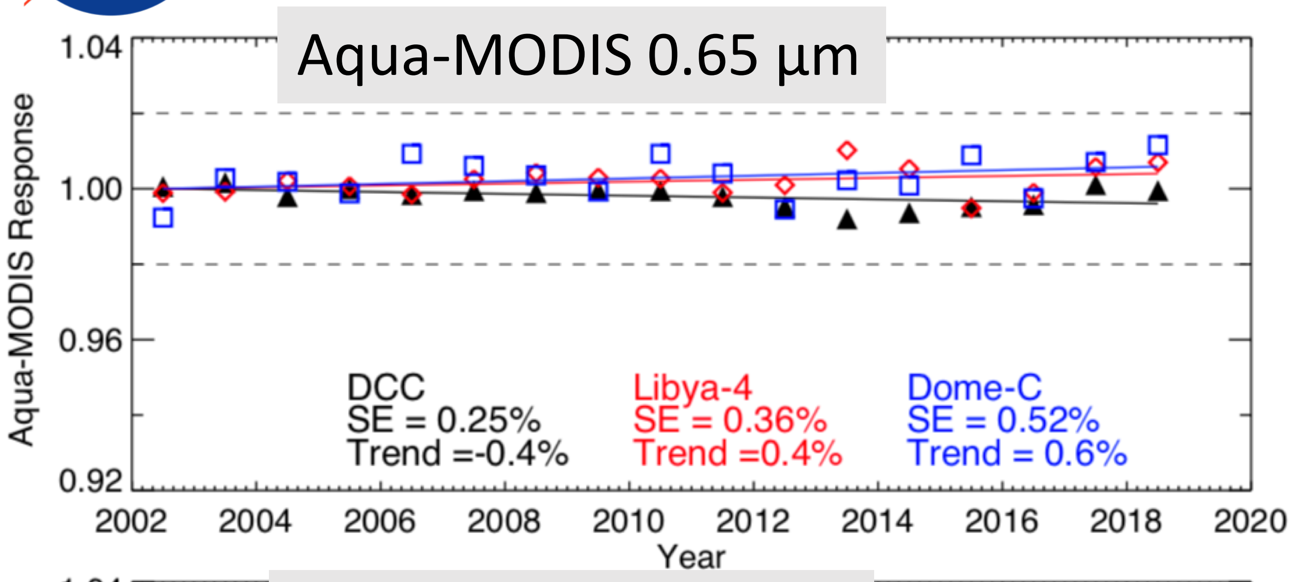


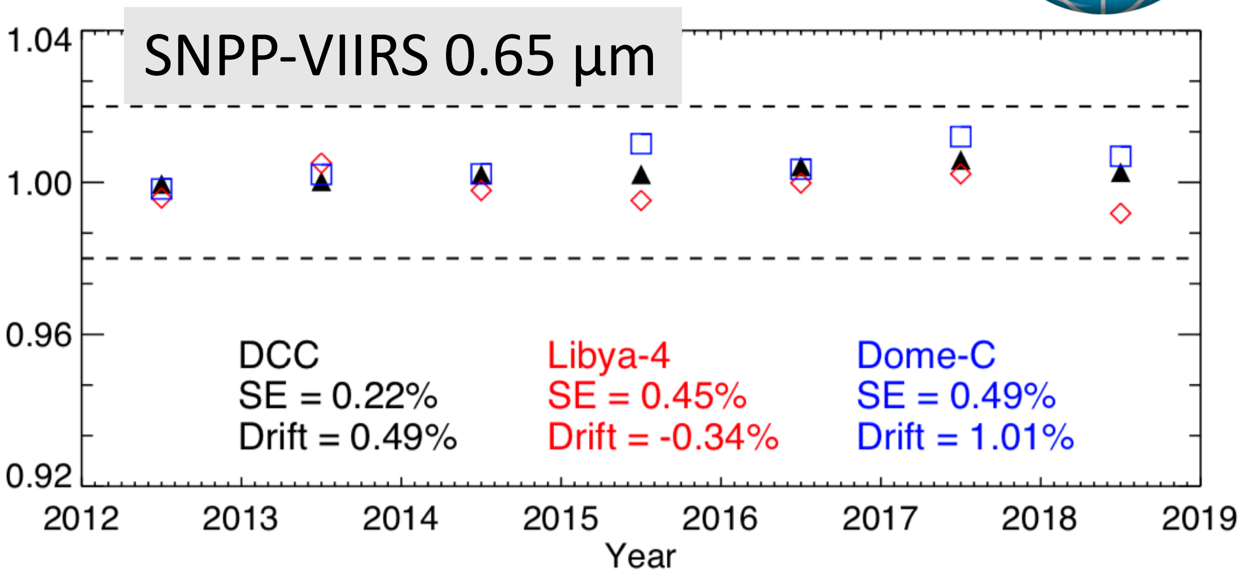
Deep Convective Cloud

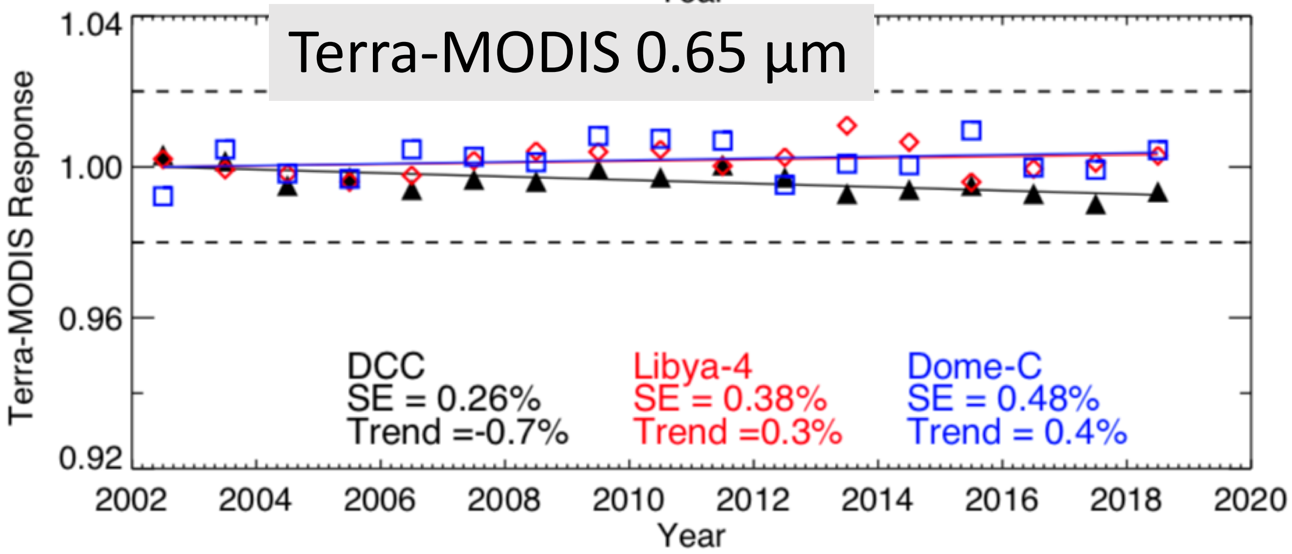
- $\pm 40° \ VZA$, Look-up table BRDFs
- Large ensemble statistical approach
- PDF mode and Mean tracks stability



MODIS C6.1 and VIIRS V1 temporal stability







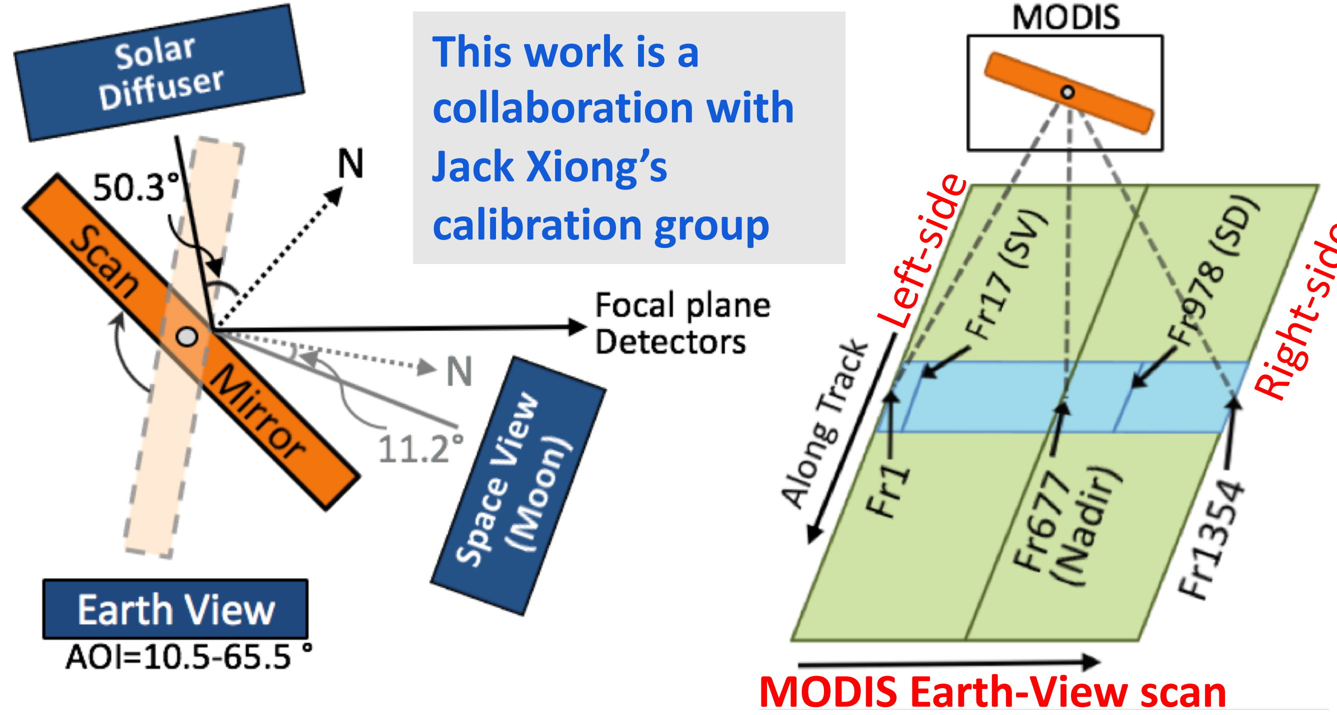
- All reflective solar bands (RSB) of SNPP-VIIRS and Aqua-MODIS are stable within 1%
- Terra-MODIS 0.65-µm band is stable within 1%
- Terra-MODIS SWIR bands exhibit trends and discontinuity in calibration after 2016 when Terra entered into safe mode (will be discussed later)

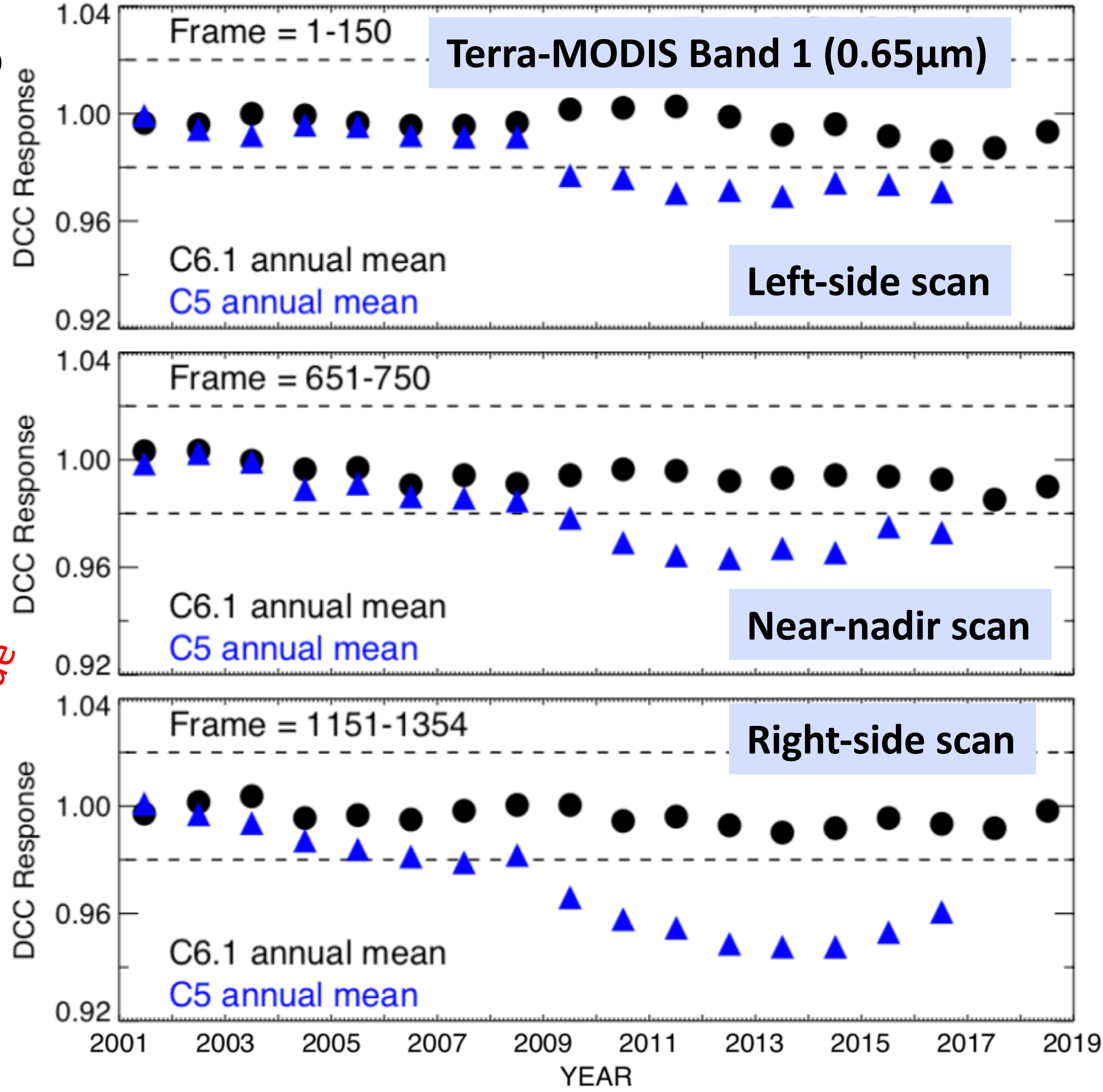
Available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=STABILITY-MODIS
https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=STABILITY-SNPP-VIIRS

RVS improvements in Terra-MODIS C6.1

- Scan-mirror reflectance is a function of AOI
- Solar Diffuser (SD) and lunar view can calibrate at two fixed AOIs
- C5 used linearly-interpolated SD/lunar measurements for RVS characterization
- C6 and C6.1 use SD, lunar, and Saharan Desert sites measurements for RVS characterization
- C5 RVS drifts < 6% for band 1
- C6.1 RVS drifts within ~1.5% for band 1

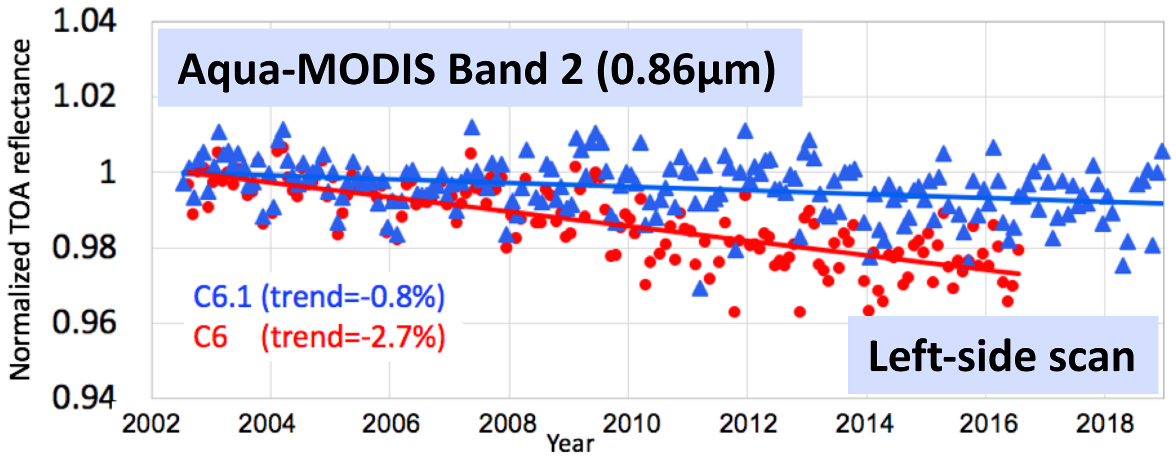
This work is a collaboration with Jack Xiong's calibration group

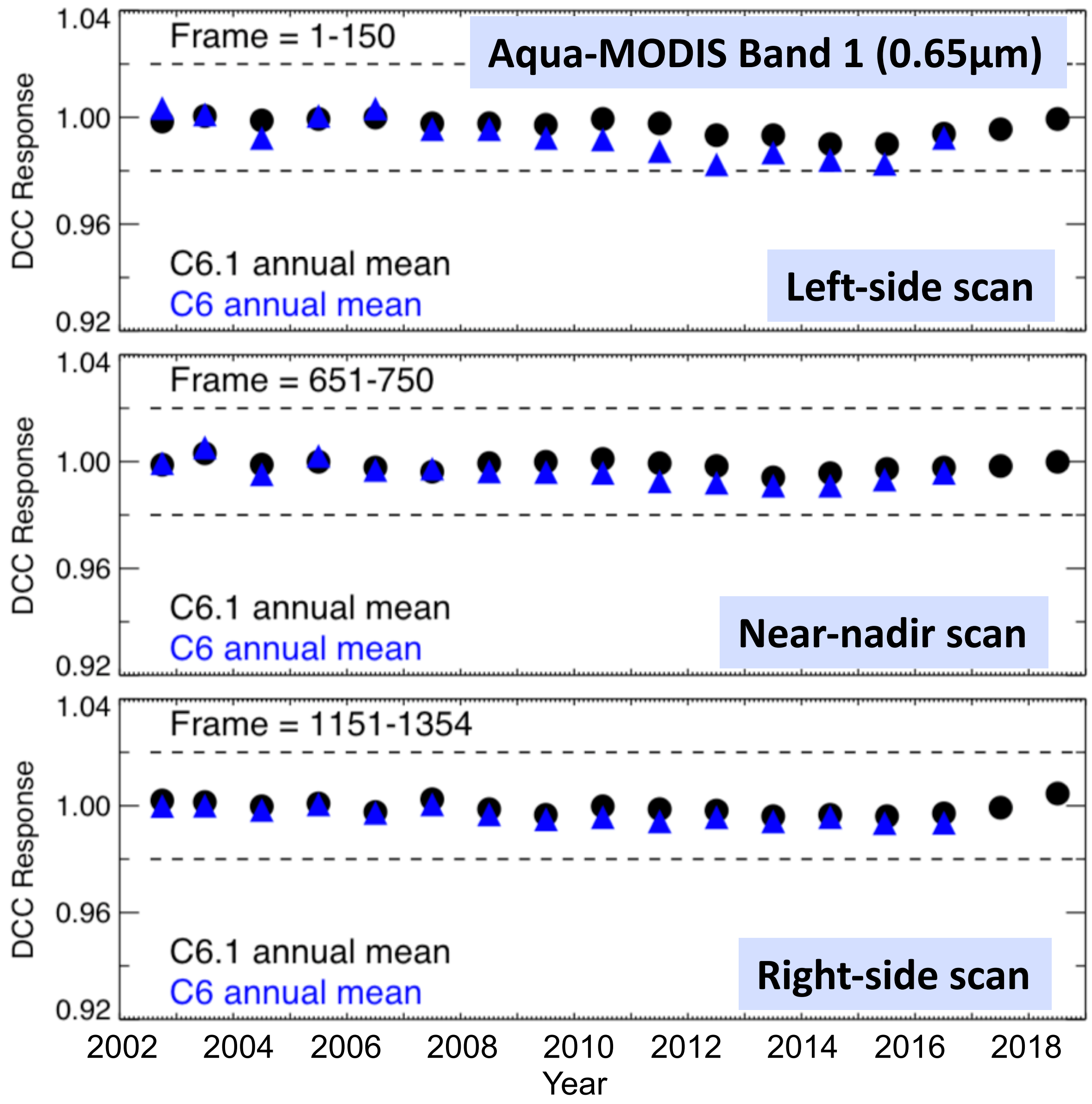




RVS improvements in Aqua-MODIS C6.1

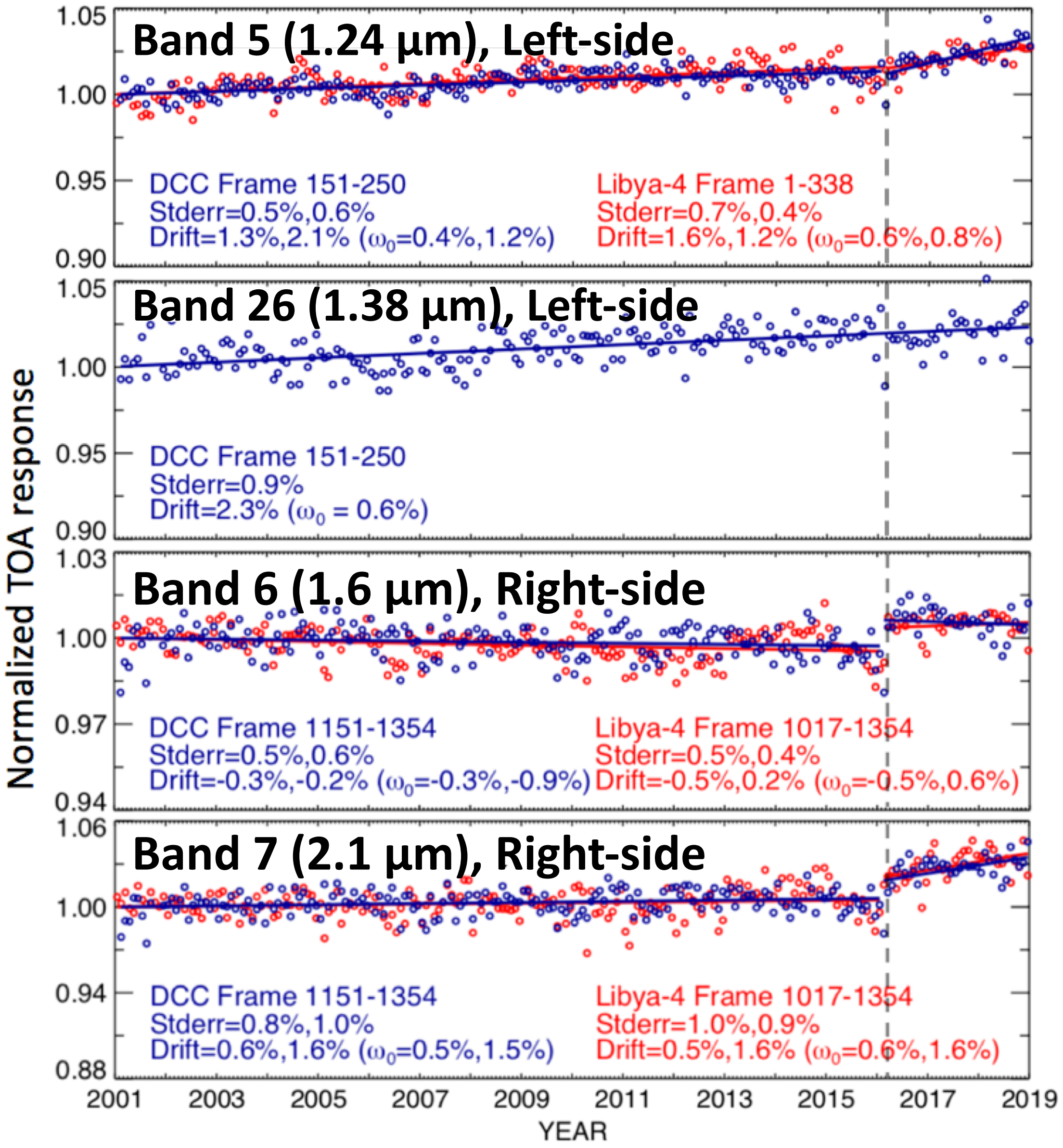
- C5 and C6 (until Jul 2016) used SD and lunar measurements for RVS characterization
- C6 (Jul 2016 onwards) and C6.1 use SD, lunar, and Saharan Desert sites for RVS characterization
- C6 RVS drifts <3% for VIS/NIR
- C6.1 RVS drifts <1% for VIS/NIR





Calibration anomalies in Terra-MODIS C6.1

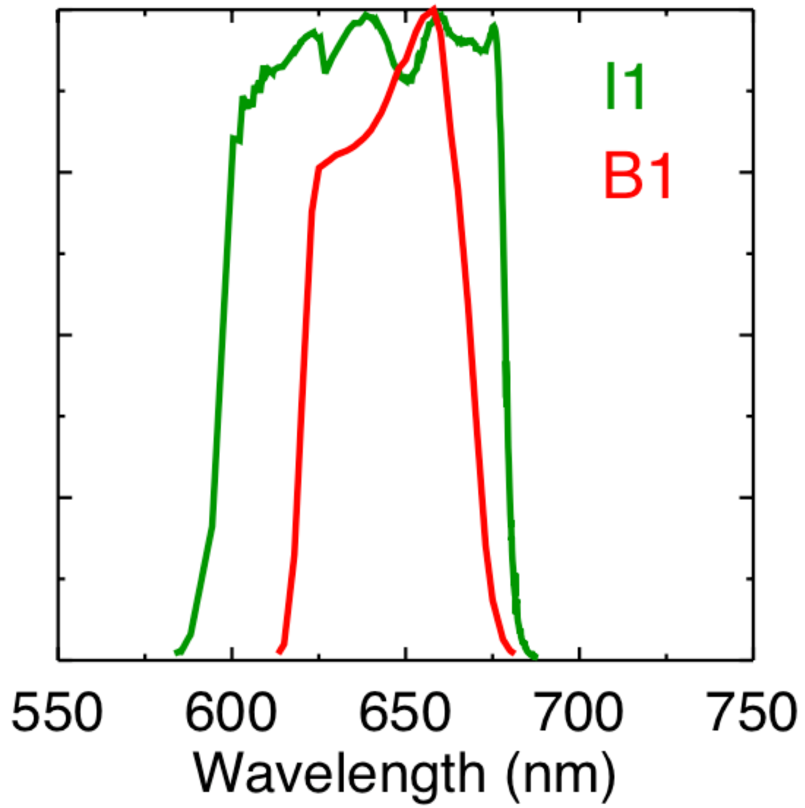
- Terra-MODIS SWIR bands are contaminated by electronic crosstalk from thermal bands
- Crosstalk issue amplified after 2016 safe-mode event, resulting in discontinuities
- 1.24-μm trend rate increased after 2016
- 1.38-μm band reveals positive trend in left-side scans
  - invariant ground sites are inapplicable for RVS characterization
  - DCC approach is still applicable
- 1.6-μm band reveals 1% calibration jump
- 2.1-μm band shows ~3% calibration discontinuity

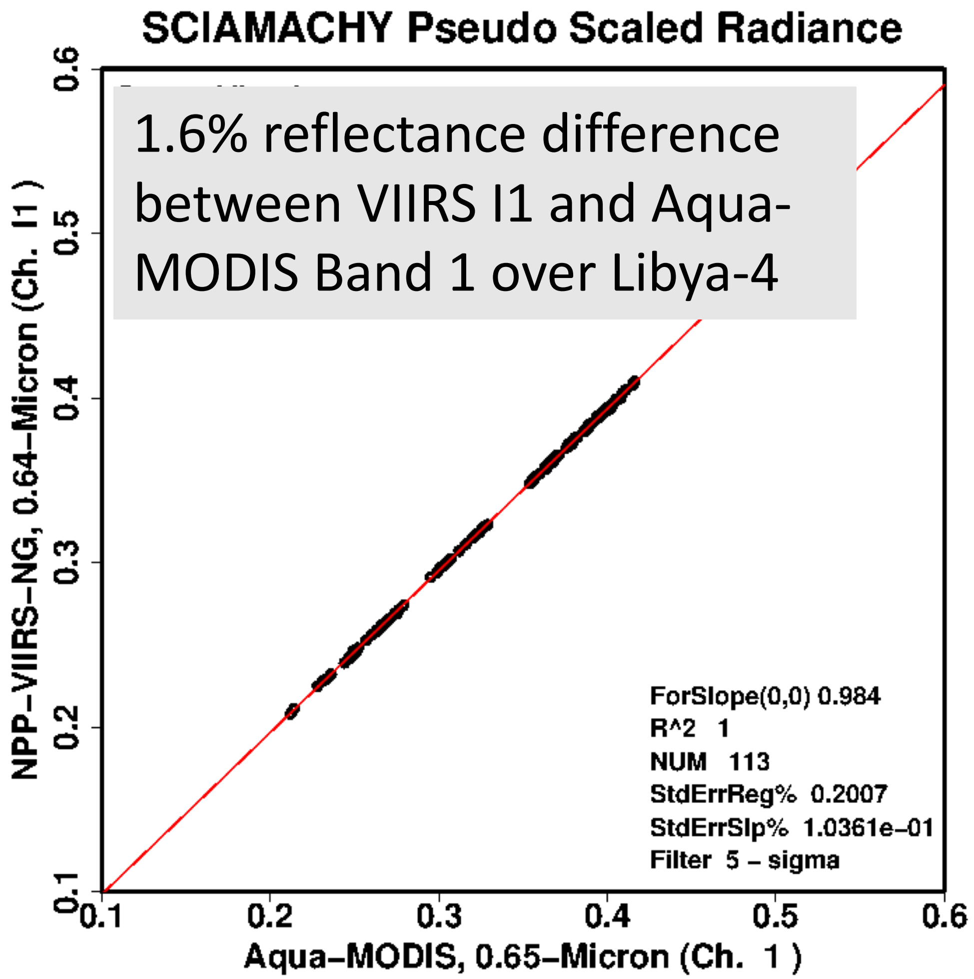


To scale VIIRS to MODIS

Spectral Band differences

- SCIAMACHY spectral band adjustment factor (SBAF)
- Specific to scene type



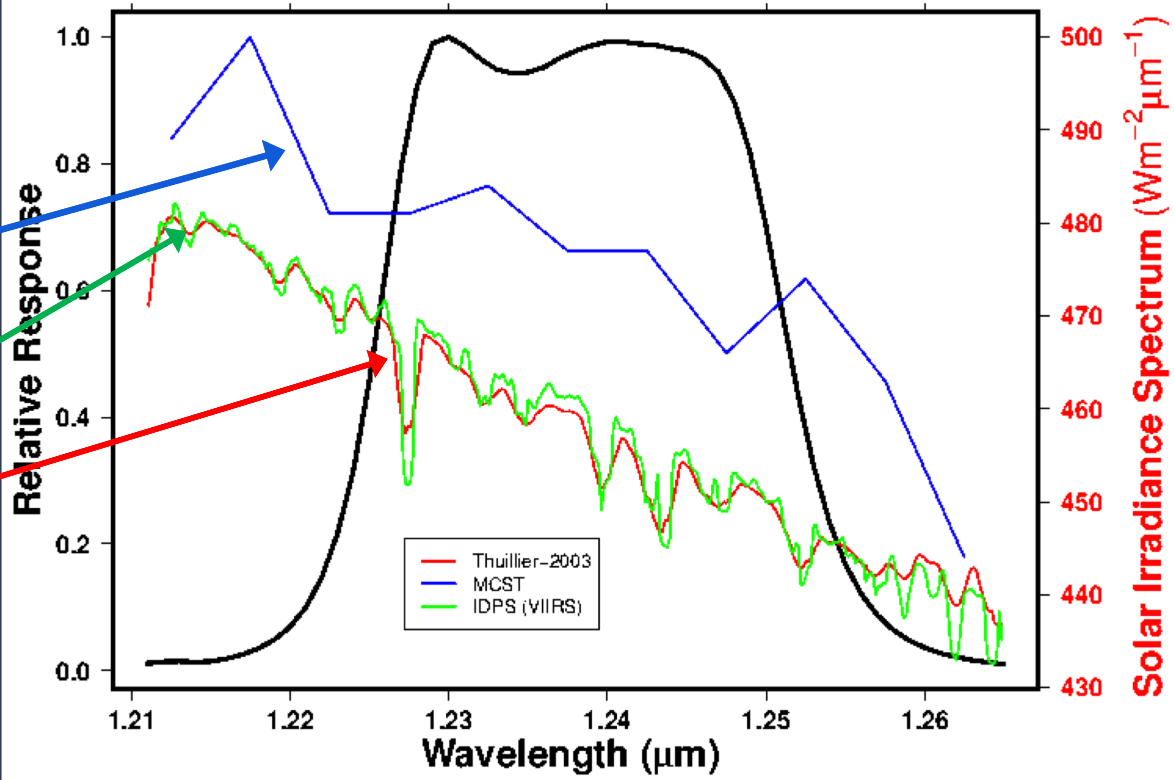


SBAF Tool: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF

To scale VIIRS to MODIS

Reference Solar Spectrum

- MODIS and VIIRS are calibrated on *Reflectance* scale
- $Radiance = Reflectance \times E_{SUN} \times \cos(SZA)/d^2$
- Terra and Aqua MODIS uses mix of **Thuillier**, **Neckel and Labs**, and **Smith and Gottlieb** solar spectra
- SNPP-VIIRS uses **Kurucz solar spectra**
- NOAA-20 VIIRS uses **Thuillier spectra**
- Biases are different for radiance and reflectance
- Difference in reference solar spectra can induce additional radiance bias



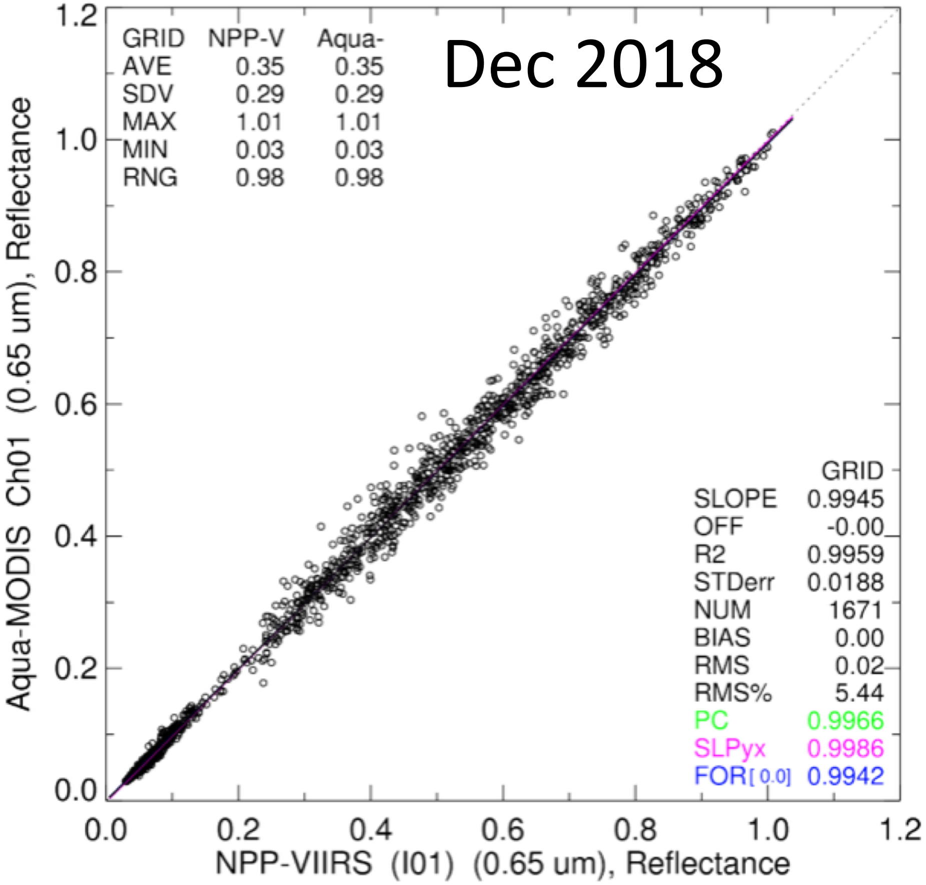
4% difference in E_{sun} for 1.24-µm band

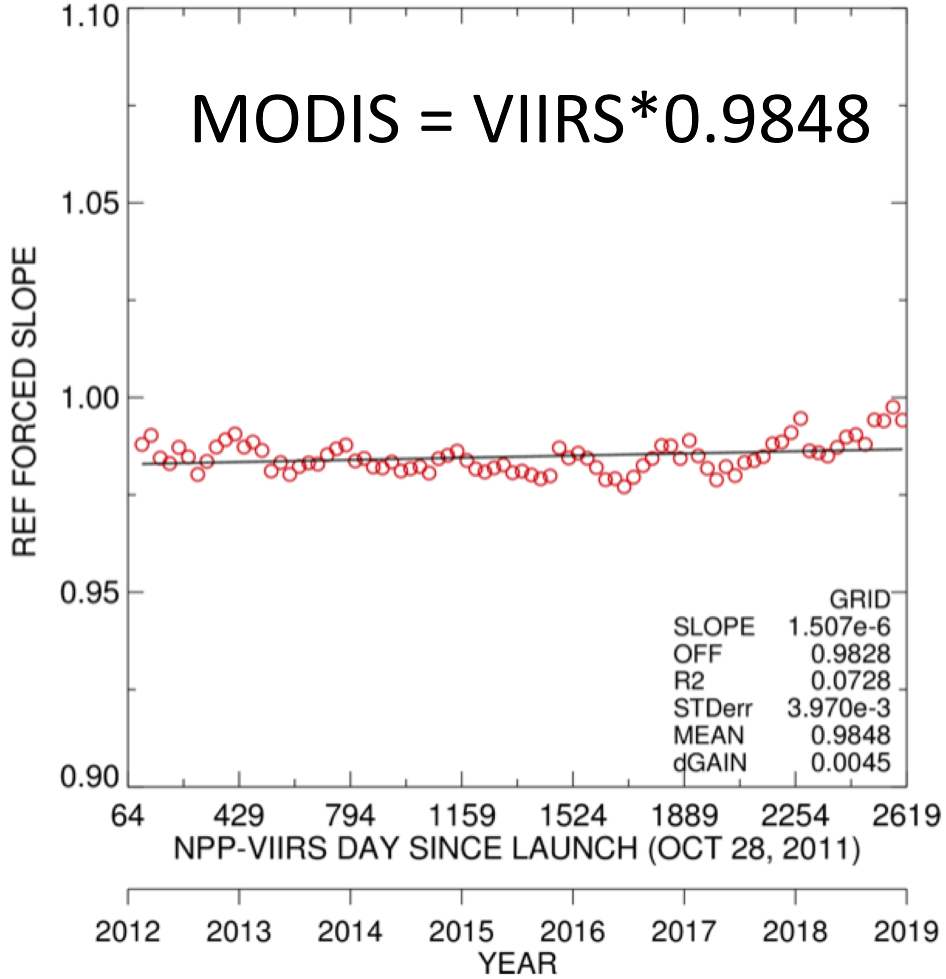
Solar constant tool: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS

Scaling of SNPP-VIIRS V01 to Aqua-MODIS C6.1

Aqua-MODIS Band 1/VIIRS I1

- All-sky tropical ocean ray-matching
- Matches within 15 minutes
- VZA, SZA<40°; ∆VZA, ∆SZA< 3°
- 10°<RAA<170°; ∆RAA=3°-10°



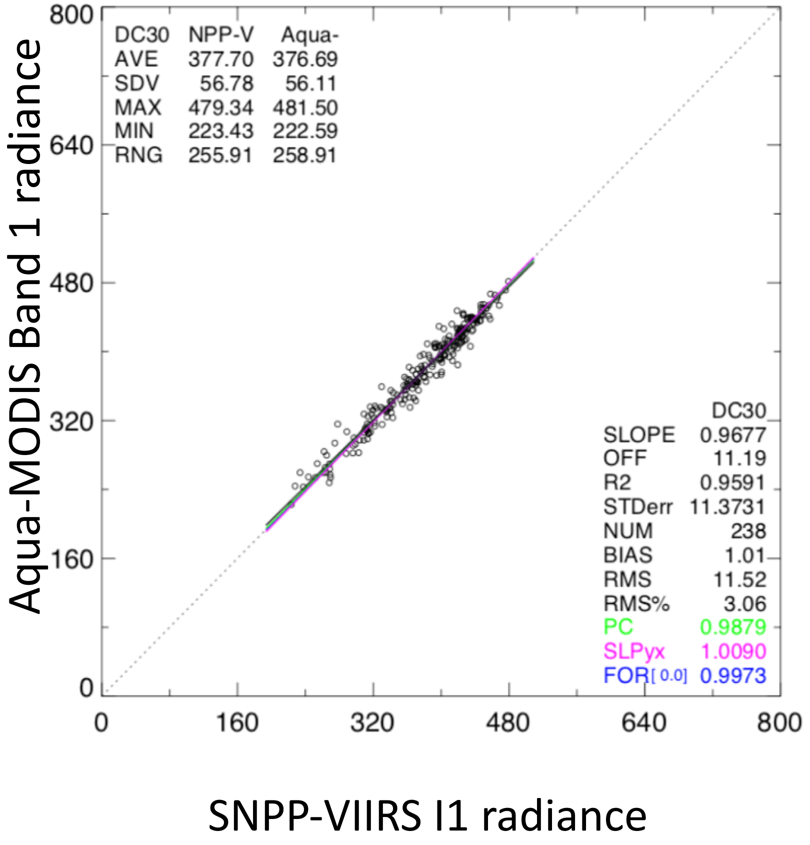


Scaling factors available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=TIMELINE-AQUA6_1-SNPP_1

SNPP-VIIRS to Aqua-MODIS scaling validation

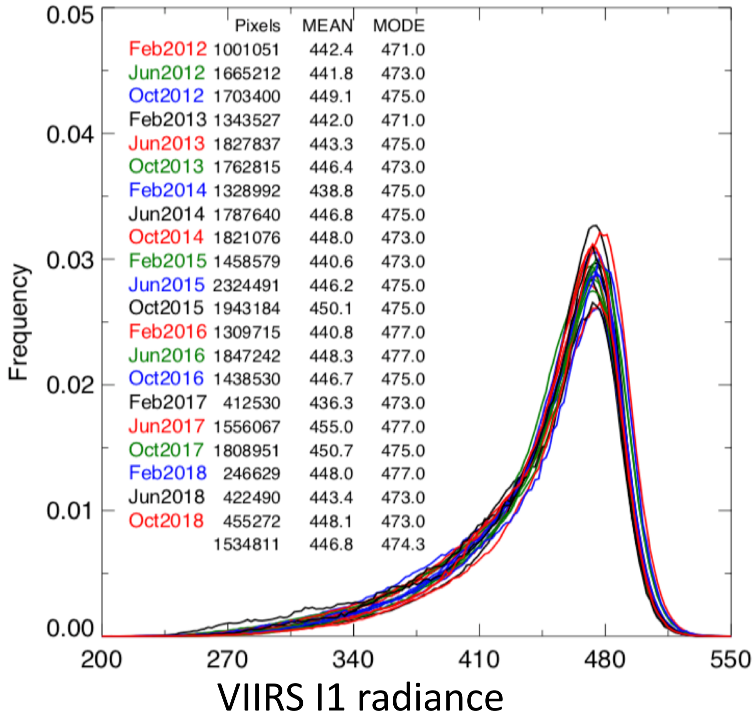
DCC Ray-matching

- Coincident DCC footprints
- Minimal SBAF corrections



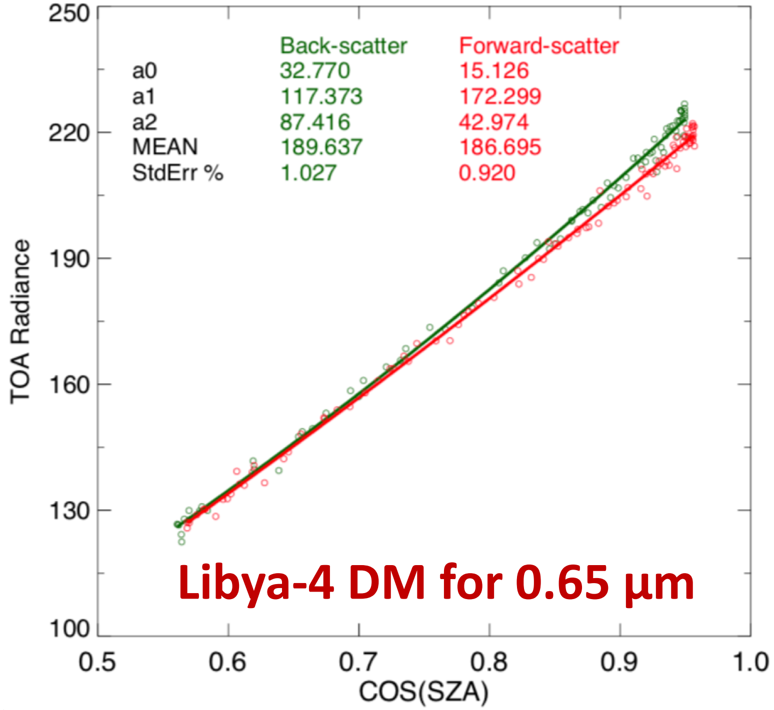
DCC-Invariant Target

- Large ensemble statistical approach
- Comparison of monthly mode and mean
- LUT BRDFs

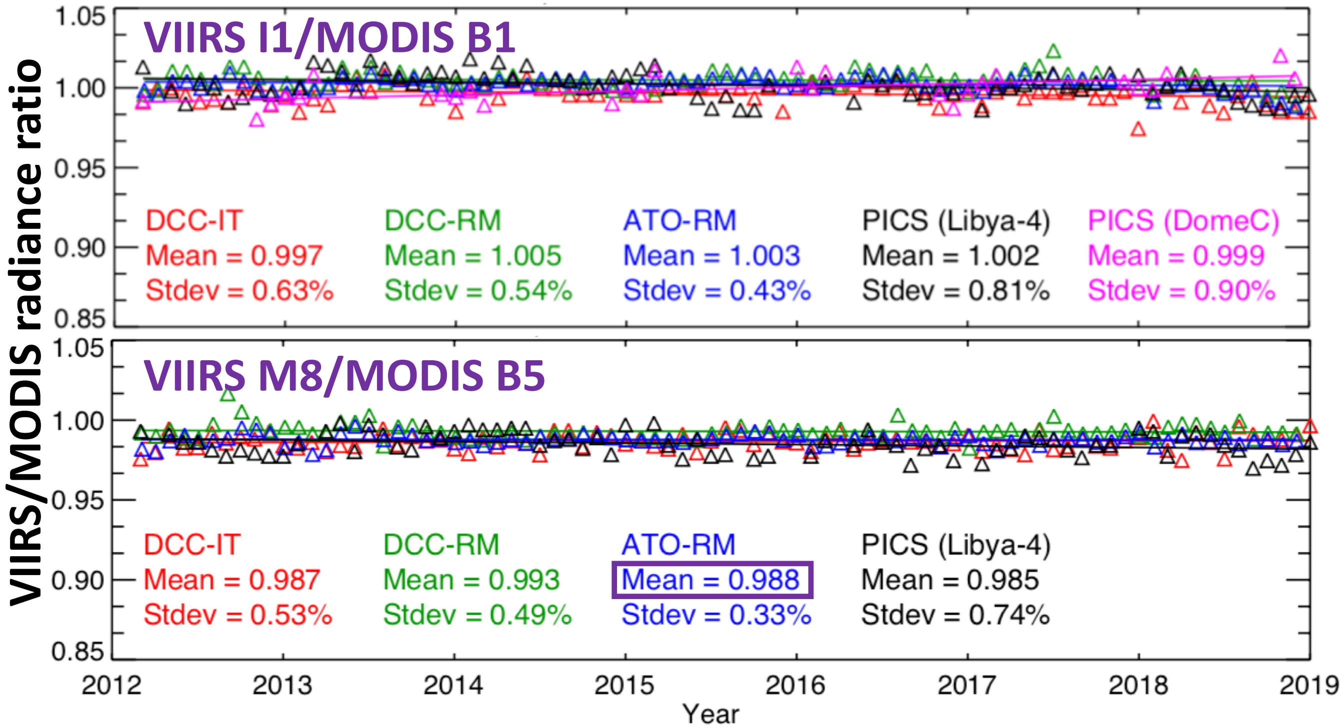


Libya-4 and Dome-C

- Forward/backward scattering directional models (DM)
- VIIRS radiances are compared against MODIS DM



SNPP-VIIRS and Aqua-MODIS biases

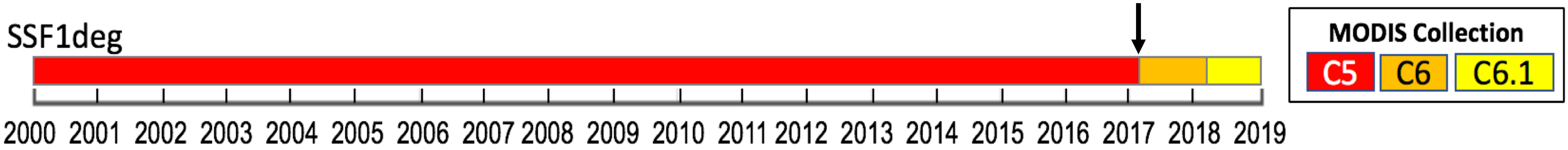


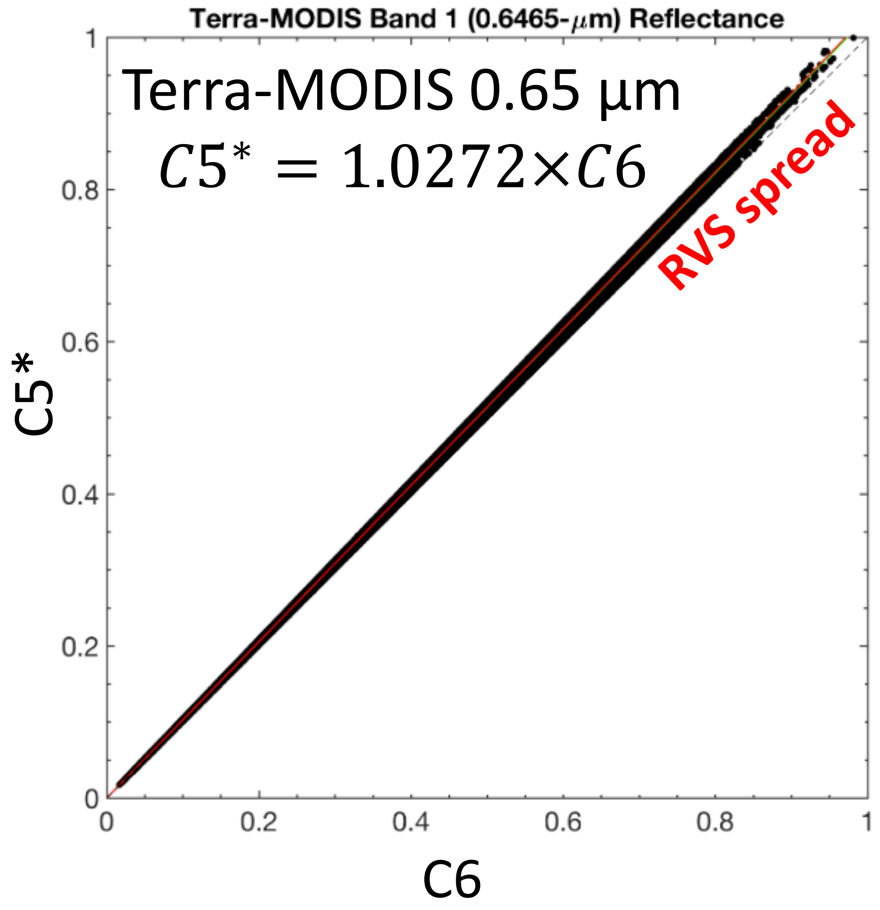
MODIS/VIIRS Band pair	Reflectance Bias (%)				
	ATO-RM	DCC-RM	DCC-IT	Libya-4	Dome-C
B3/M3 (0.48 µm)	+1.2	+2.8	+2.4	+2.9	+2.8
B4/M4 (0.55 µm)	+2.5	+2.7	+1.9	+2.4	+2.5
B1/M5 (0.65 µm)	+2.3	+2.7	+1.9	+2.0	+1.9
B1/I1 (0.65 µm)	+1.1	+1.2	+0.3	+1.0	+1.0
B2/M7 (0.86 µm)	+2.1	N/A	N/A	+2.7	+2.0
B5/M8 (1.24 µm)	+3.3	+3.7	+3.3	+3.2	
B26/M9 (1.38 µm)	+4.7	+5.4	+4.9	N/A	
B6/M10 (1.6 µm)	+2.0	+1.8	+1.1	+4.6	
B6/I3 (1.6 µm)	+3.4	+3.4	+2.6	+6.4	

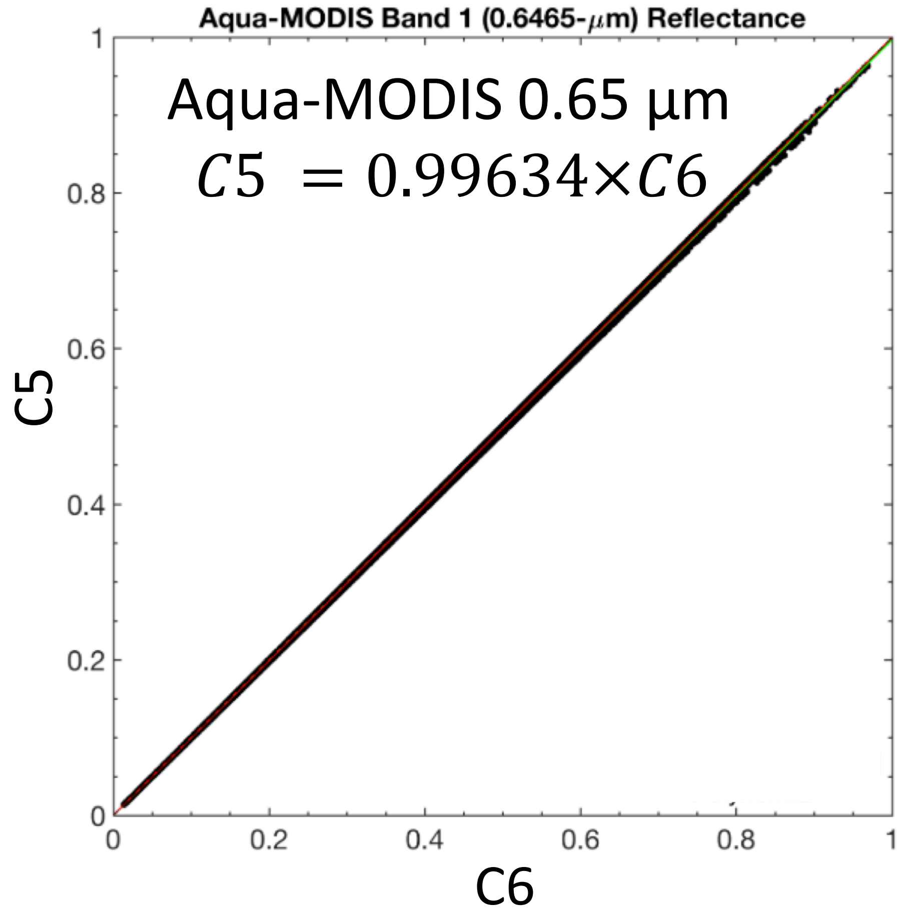
- ATO-RM primary method, other methods are used for validation
- SNPP-VIIRS reflectance values are brighter than those from Aqua-MODIS
- **1.38-µm has largest bias**
- **Larger inconsistency seen in 1.6-µm band using Libya-4 (working with MCST on this)**

Bias = 100% x (VIIRS-MODIS)/VIIRS

Scale MODIS C6 to C5







- CERES Ed4 switched to using MODIS C6 on Feb 2017
- Single granule from TWP domain (Nov 2016)
- Regress C5* and C6 pixel reflectance values
- C5* includes scaling adjustment implemented in Ed4 cloud properties to mitigate the impact of Terra-MODIS degradation in C5

Collaboration with MCST/VCST

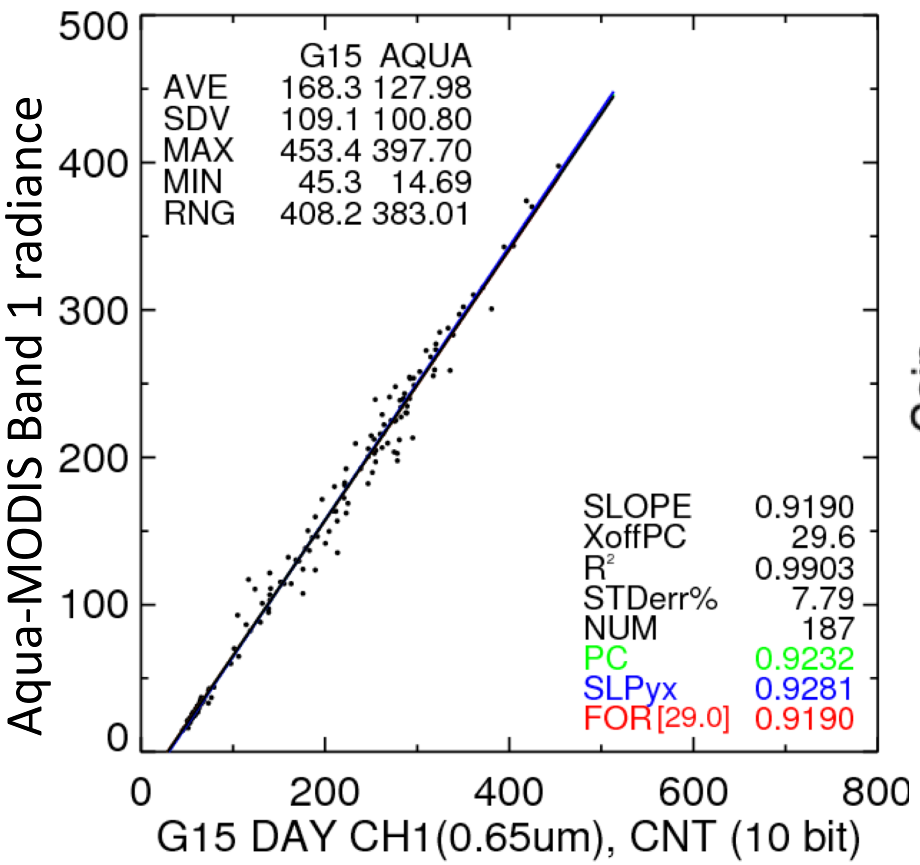
- Methodology sharing, independent validation, improvement suggestions, joint publications (7 journal articles and 2 conference proceedings)

1. R. Bhatt *et al*., “Response Versus Scan-angle assessment of MODIS Reflective Solar Bands in Collection 6.1 Calibration,” *IEEE Transactions on Geoscience and Remote Sensing*, under review, 2019.
2. A. Angal, X. Xiong, Q. Mu, D. R. Doelling, R. Bhatt and A. Wu, "Results From the Deep Convective Clouds-Based Response Versus Scan-Angle Characterization for the MODIS Reflective Solar Bands," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 2, pp. 1115-1128, Feb. 2018.
3. Q. Mu, A. Wu, X. Xiong, D. R. Doelling, A. Angal, T. Chang, R. Bhatt, “Optimization of a Deep Convective Cloud Technique in Evaluating the Long-Term Radiometric Stability of MODIS Reflective Solar Bands,” *Remote Sens*., 9, 535, 2017.
4. R. Bhatt *et al*., “Characterizing response versus scan-angle for MODIS reflective solar bands using deep convective clouds,” *J. Appl. Remote Sens*., vol. 11, no. 1, p. 016014, 2017.
5. D. R. Doelling *et al*., "The Radiometric Stability and Scaling of Collection 6 Terra- and Aqua-MODIS VIS, NIR, and SWIR Spectral Bands," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 8, pp. 4520-4535, Aug. 2015.
6. R. Bhatt, D.R. Doelling, A. Wu, X. Xiong, B.R. Scarino, C. O. Haney, A. Gopalan, “Initial Stability Assessment of S-NPP VIIRS Reflective Solar Band Calibration Using Invariant Desert and Deep Convective Cloud Targets,” *Remote Sens*., 2014, *6*, 2809-2826.
7. A. Wu, X. Xiong, D. R. Doelling, D. Morstad, A. Angal and R. Bhatt, "Characterization of Terra and Aqua MODIS VIS, NIR, and SWIR Spectral Bands' Calibration Stability," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 7, pp. 4330-4338, July 2013.

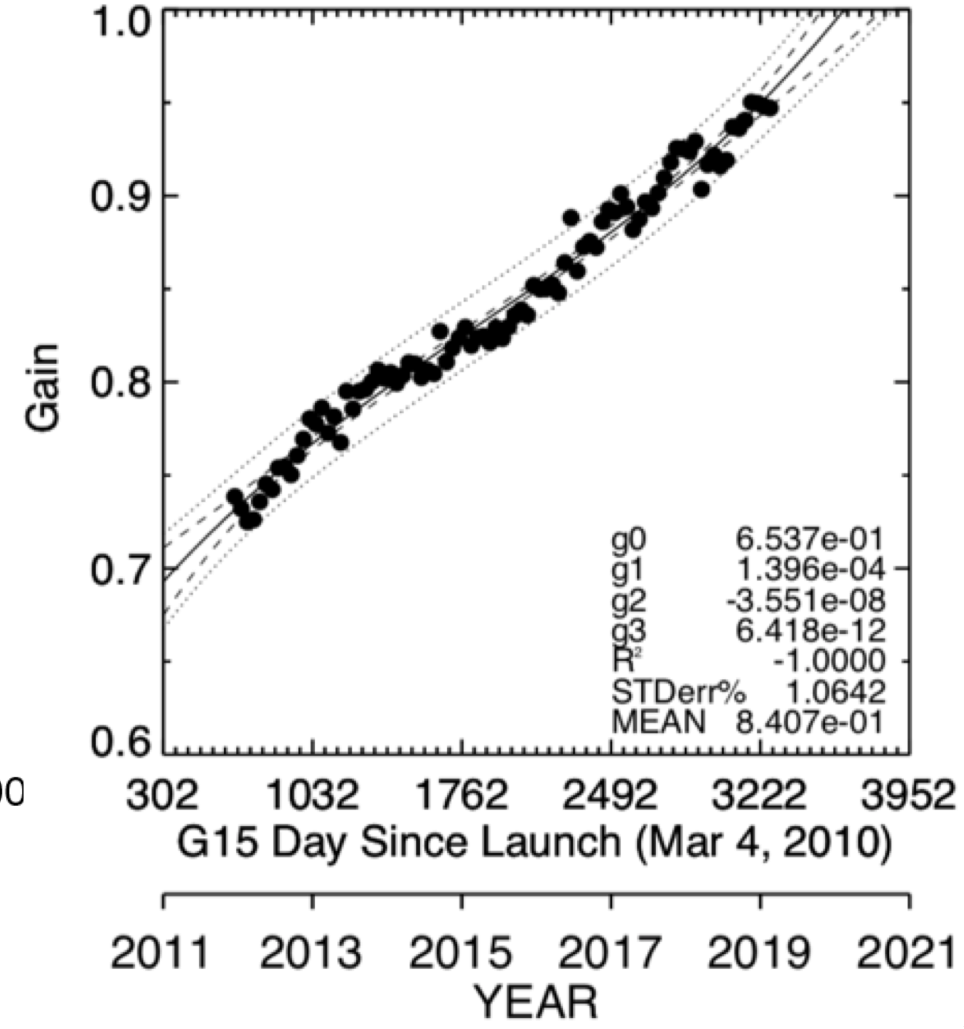
GEO imager calibration

- All-sky tropical ocean ray-matching
- Calibrate full dynamic range of GEO sensor
- Matches within 15 minutes
- VZA, SZA<40°; ∆VZA=5°-15° 10°<RAA<170°; ∆RAA=5°-15°
- Update calibration every 2 months
- MODIS calibration anomalies inherited to GEO

2018 July



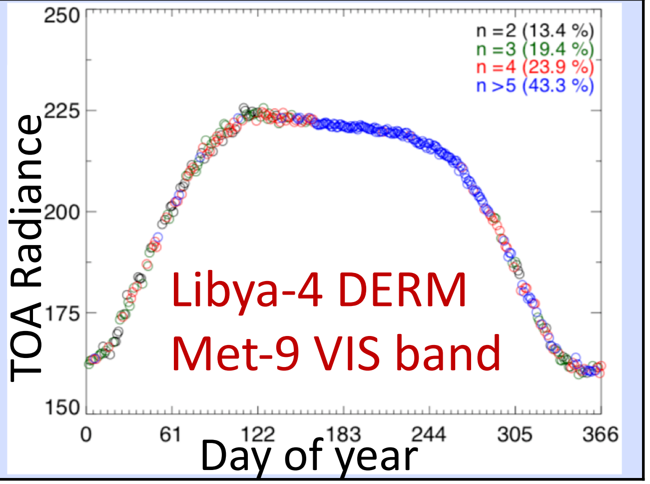
GOES-15/Aqua-MODIS

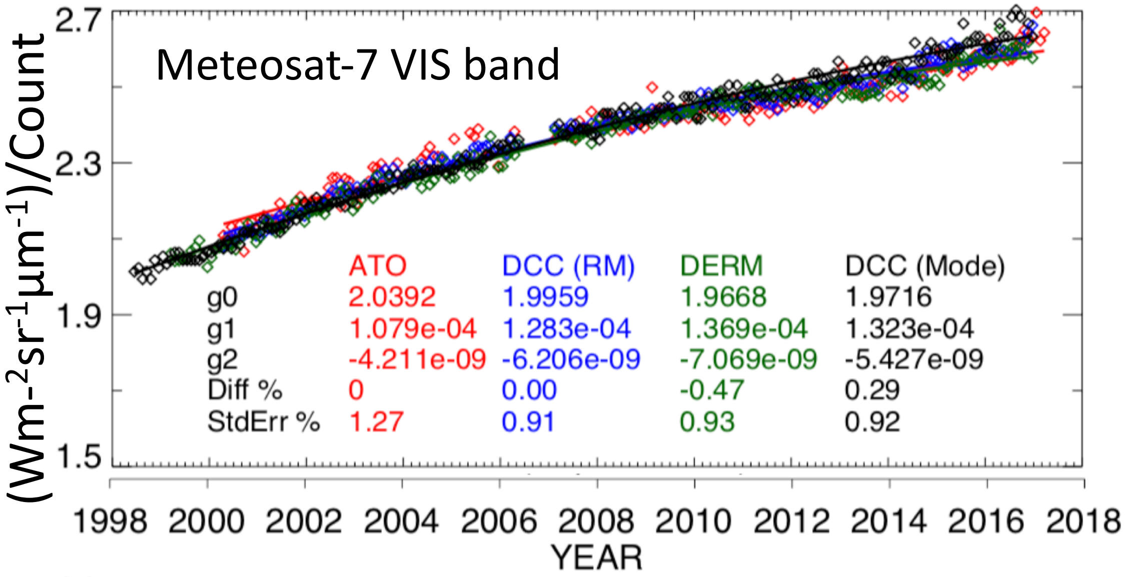


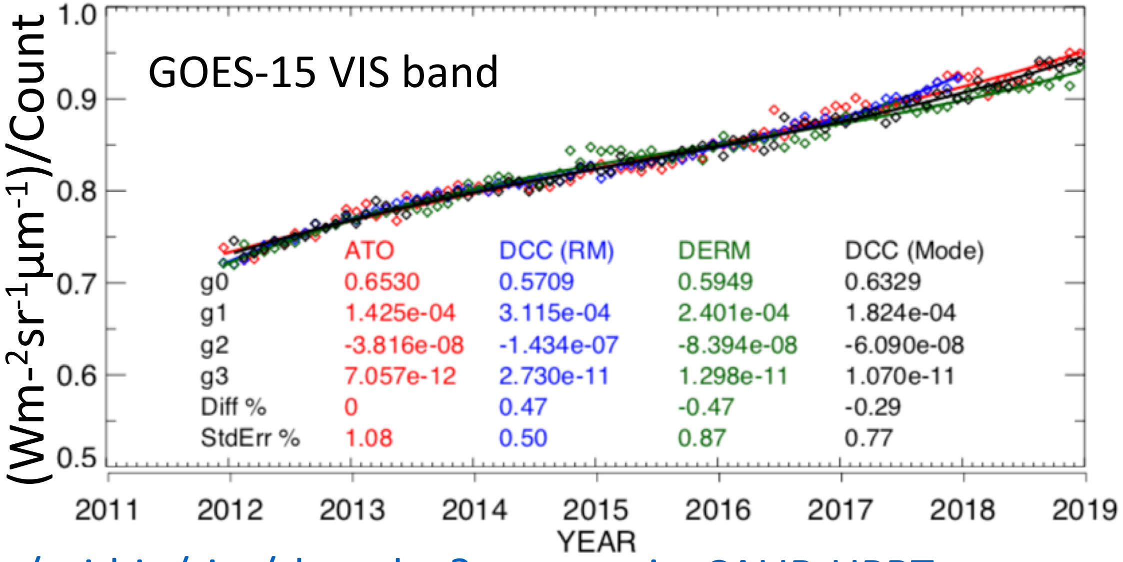
Realtime GEO calibration available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=CALIB-UPRT

GEO imager calibration validation

- Three independent validation approaches
- Referenced to Aqua-MODIS C6.1

DCC Ray Matching	DCC-Invariant Target (DCC-IT)
• Coincident DCC matches with MODIS • Spectral difference effects are minimal • MODIS calibration anomalies inherited to GEO	• Utilizes tropical DCC as invariant targets • Coincident matches not required • Calibrate GEOs in the absence of MODIS
DERM (Desert approach) • Daily exo-atmospheric radiance models over deserts • Benefit from consistent imaging schedules of GEOs • Calibrate GEOs in the absence of MODIS	





Realtime GEO calibration available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=CALIB-UPRT

Summary

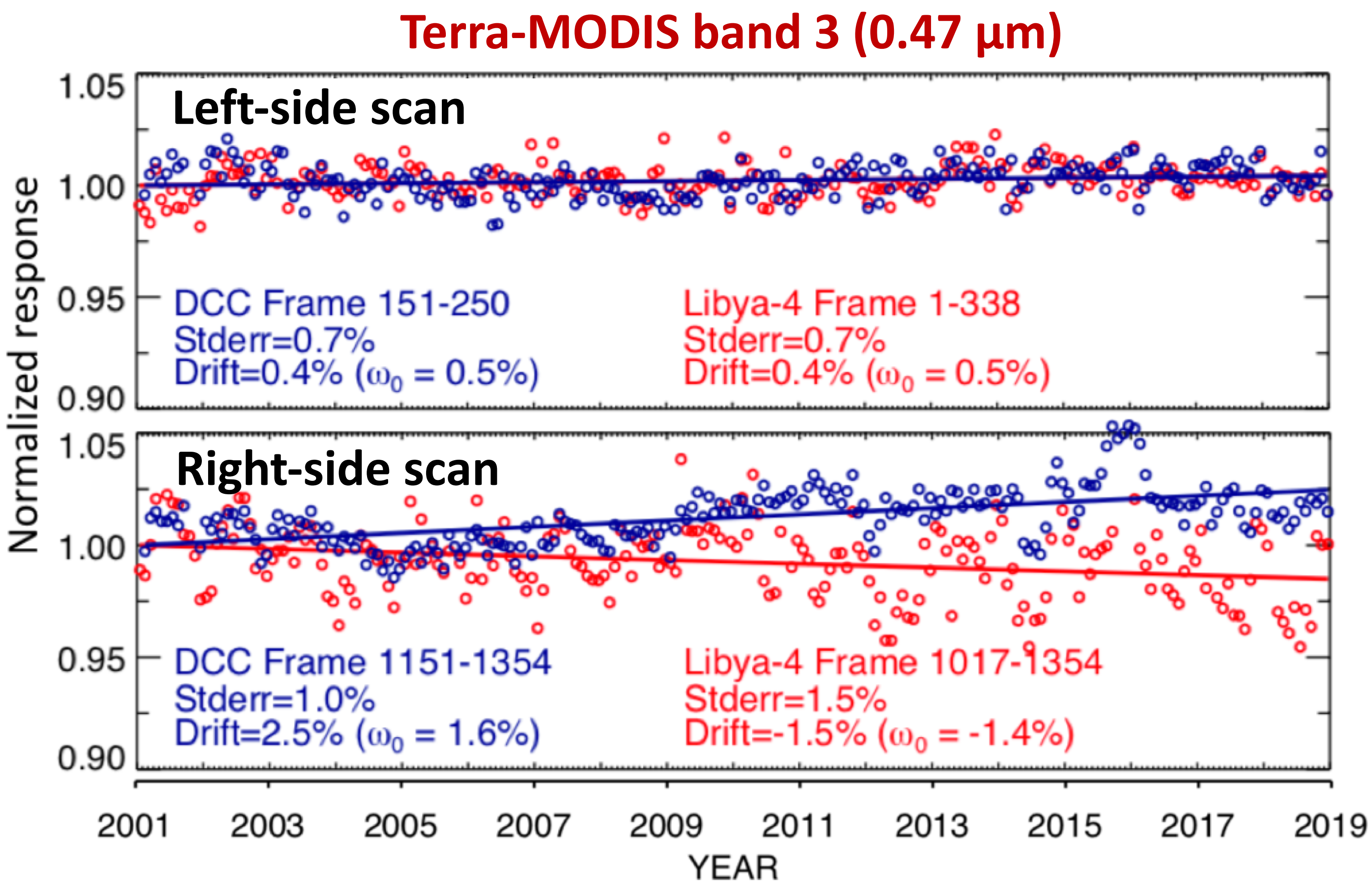
- SD and lunar measurements are inadequate to track on-orbit changes in optical properties of scan mirror in MODIS
- CERES IGCG works closely with MCST/VCST in monitoring the radiometric quality of MODIS and VIIRS L1B products
- CERES IGCG provides
  - independent assessment of MODIS and VIIRS stability (annual update) and RVS performance
  - VIIRS to MODIS scaling factors
  - MODIS Collection and VIIRS version scaling
  - GEO to MODIS scaling (bi-monthly update)
- Observed calibration anomalies in Terra-MODIS C6.1 may potentially influence cloud properties, particularly after 2016
- Plots and coefficients located at web site

https:// cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SAT_CALIB_USER

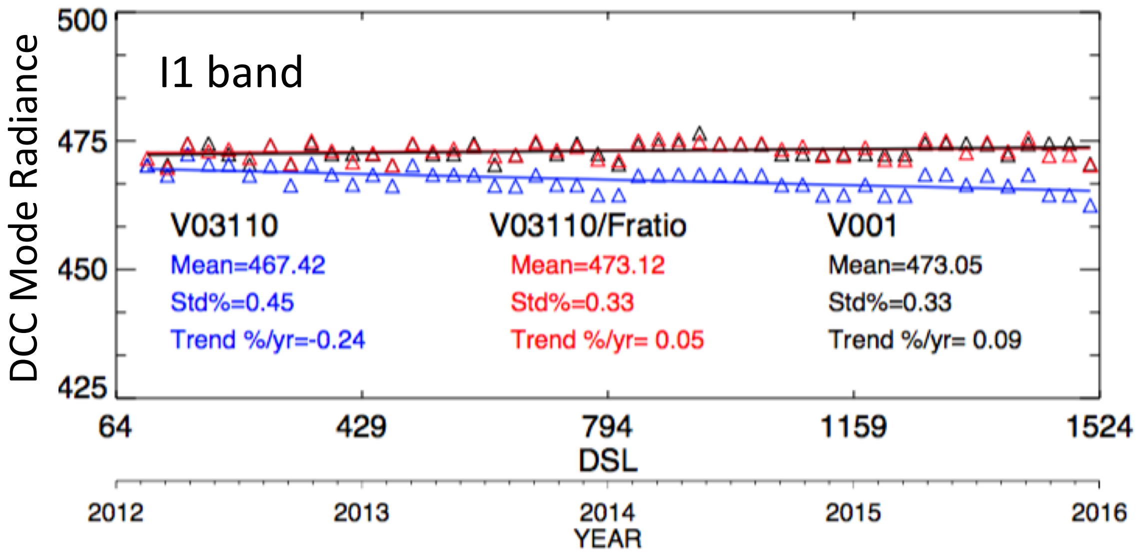
Additional slides

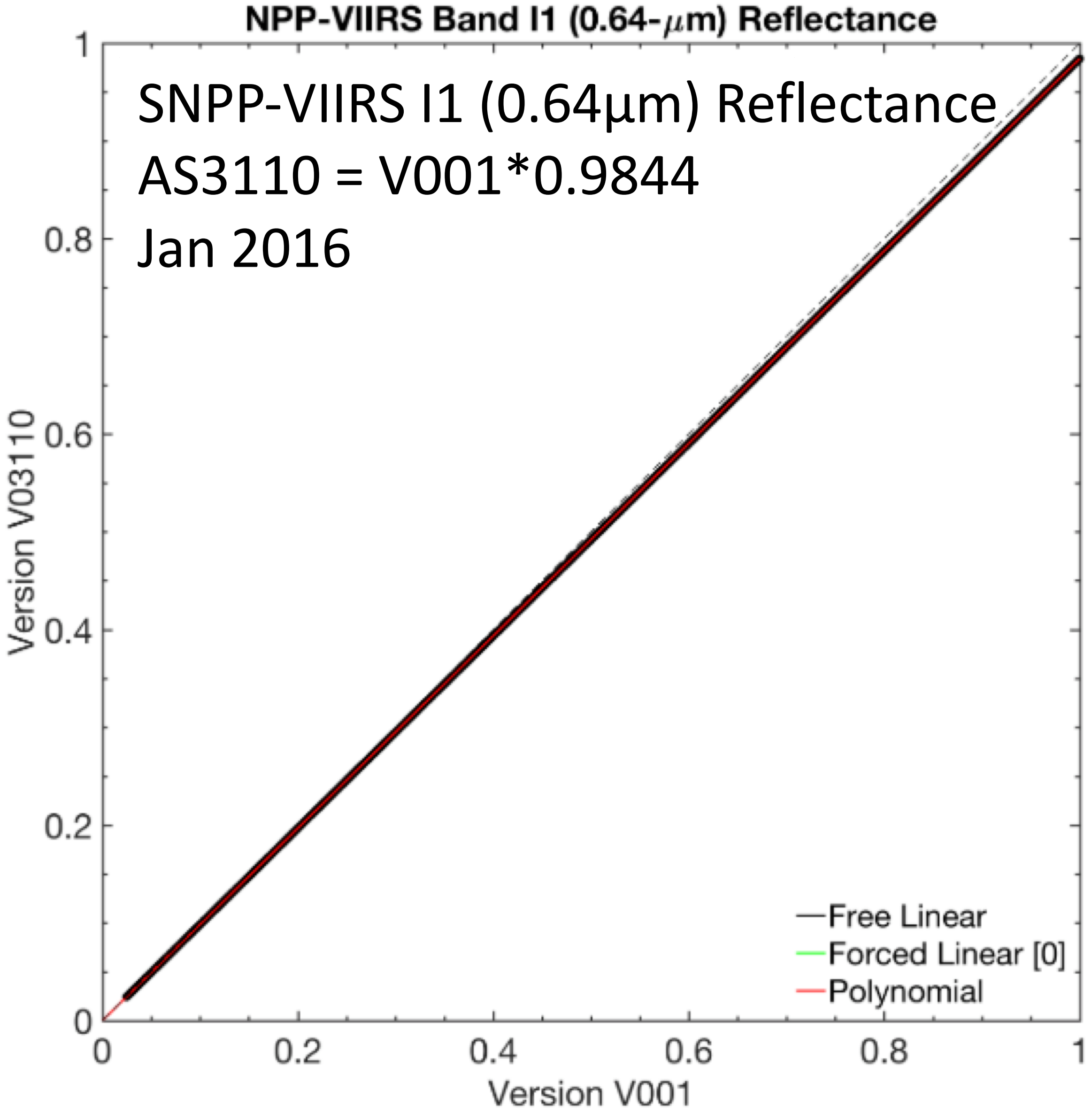
Polarization sensitivity

- Terra-MODIS has significant change in polarization sensitivity at short wavelengths
- Right-side scans are affected
- DCC and desert trends disagree due to difference in the strength of Rayleigh scattering over the scene types



Radiometric scaling between VIIRS versions





- NASA Land SIPS distributes different versions of SNPP VIIRS sub-setted data for CERES.
- New version implements improved calibration algorithm and consistent LUT.
- Scaling between different versions is possible via direct comparison or F-factor ratio (provided by VCST).
- Version 2 will be available soon.

Radiometric stability assessment

- Temporal stability
  - Pseudo-invariant Earth targets (deserts, polar icecap, DCC)
- Response versus scan-angle (RVS) dependency
  - Scan-angle response difference monitored on annual basis
  - Uses DCC and Saharan Deserts
- Kernel-based BRDFs for deserts and polar icecap
- Look-up table BRDFs for DCC
  - Channel-specific for SWIR bands
- Why multiple Earth targets
  - cover sensor dynamic range
  - cover all scan angles
  - channel-specific scenes
  - high confidence in results

DCC LUT BRDF