Status of Terra and Aqua MODIS Reflective Solar Bands Calibration and Performance

MODIS Characterization Support Team

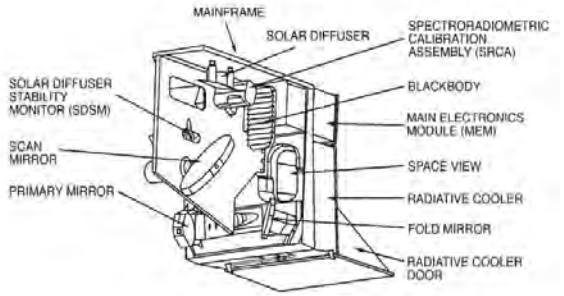
Presented by Amit Angal (SSAI), Xiaoxiong Xiong (NASA GSFC)

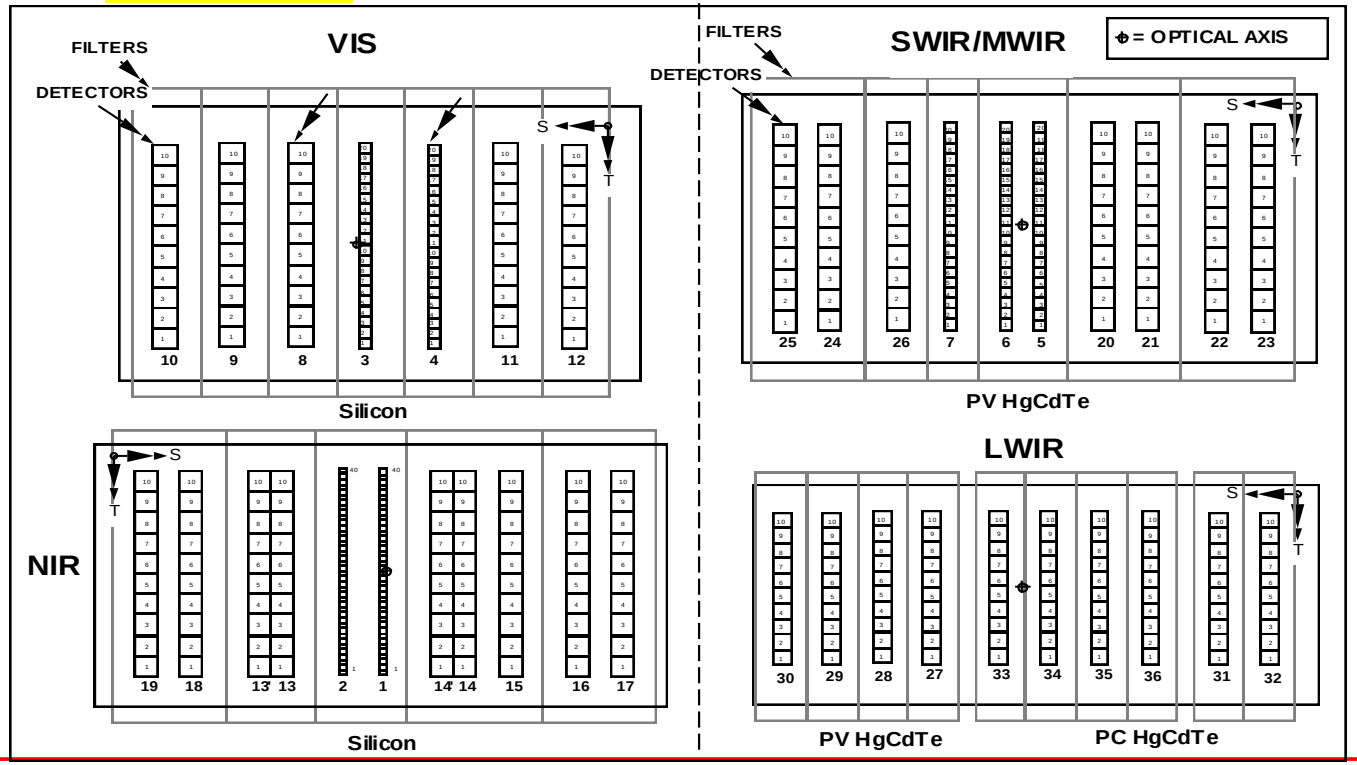
February 4, 2022

Outline

- MODIS Instrument Overview
- Reflective solar bands calibration methodology
- On-orbit Performance
- L1B status and Calibration Improvements
- Future Efforts
- Summary

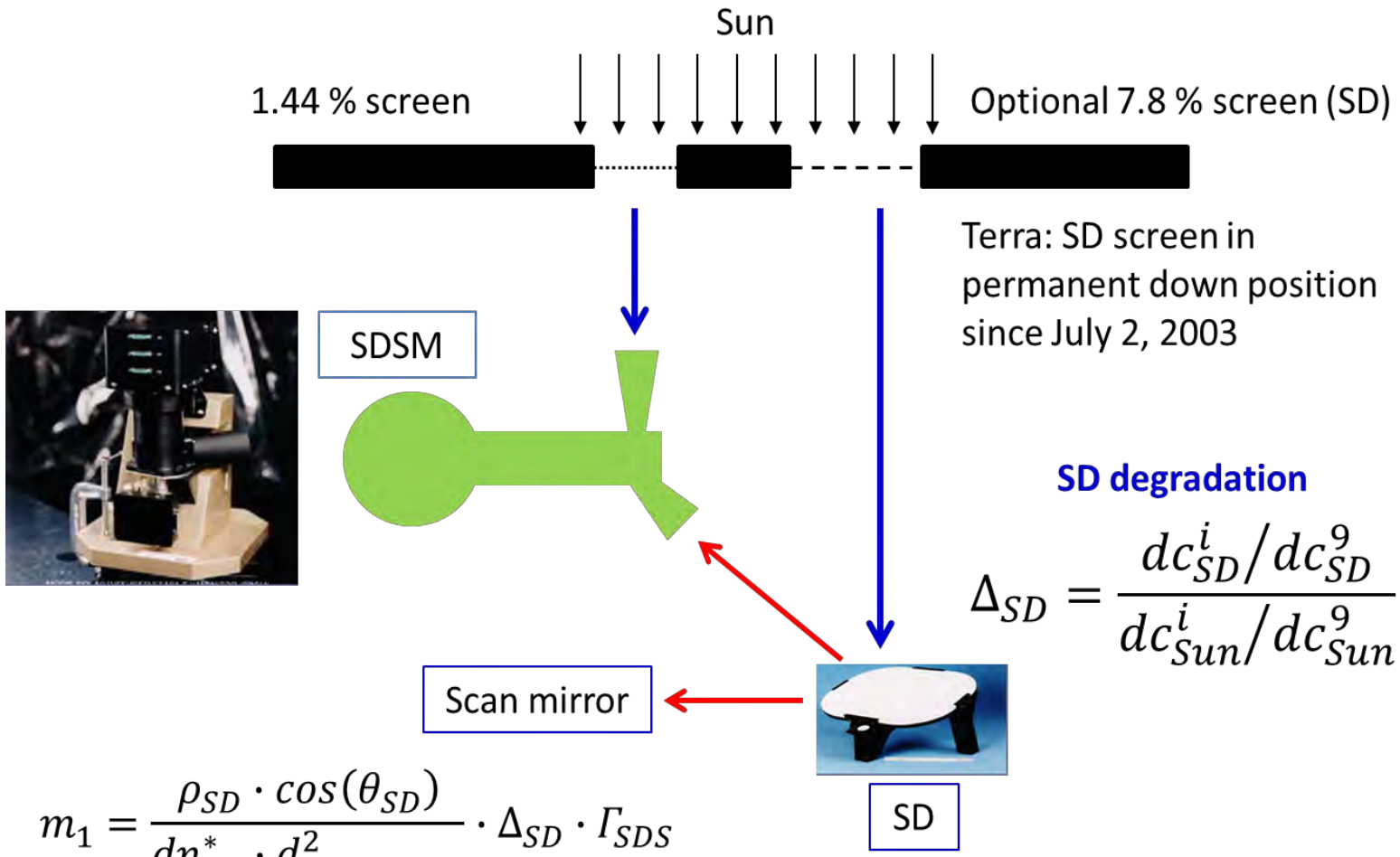
MODIS Instrument Overview





- **On-board Terra (since Dec 1999) and Aqua (since May 2002) spacecraft**
- **36 spectral bands (0.4 - 14.4 μm)**
  - Reflective Solar Bands (RSB): bands 1-19 and 26
  - Thermal Emissive Bands (TEB): bands 20-25 and 27-36
- **Nearly 40 data products (land, oceans, atmosphere)**
- **3 spatial resolutions: 250 m, 500 m, and 1000 m (nadir)**
- **4 focal plane assemblies (FPA): 490 individual detectors**
- More information: https:/modis.gsfc.nasa.gov and https://mcst.gsfc.nasa.gov

MODIS RSB Calibration Methodology: Solar Diffuser



SD degradation

$$\Delta_{SD} = \frac{dc_{SD}^{i}/dc_{SD}^{9}}{dc_{Sun}^{i}/dc_{Sun}^{9}}$$

$$m_1 = \frac{\rho_{SD} \cdot cos(\theta_{SD})}{dn_{SD}^{*} \cdot d_{Earth\_Sun}^{2}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}$$

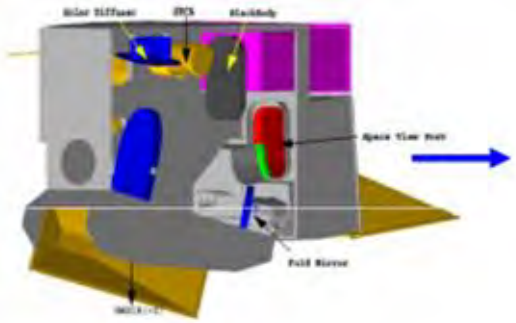
$\rho_{SD} \cdot cos(\theta_{SD})$ = BRF, dn_{SD}^{*} = Signal from SD (temperature and background corrected), Δ_{SD} = SD degradation, Γ_{SDS} = screen attenuation

- Currently, SD/SDSM calibration performed once every three weeks for both the MODIS instruments
- SD degradation of the NIR bands used in the prediction of the SD degradation at SWIR wavelengths
- Additional correction for electronic crosstalk and out-of-band responses for the SWIR bands

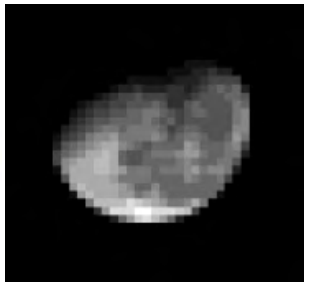
Xiong, X., A. Angal, J. Sun, T. Choi, and E. Johnson, "On-orbit performance of MODIS solar diffuser stability monitor", Journal of Applied Remote Sensing, vol 8, 083514, 2014.

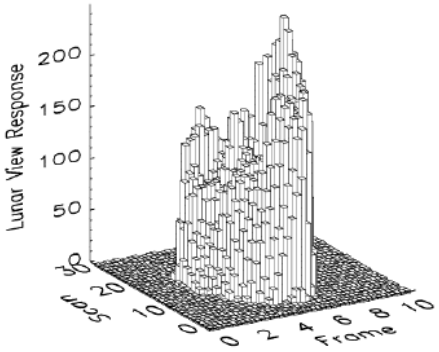
MODIS RSB Calibration Methodology: Lunar Calibration

MODIS



Moon





MODIS Response

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

$$m_1^{moon} = \frac{f_{vg}}{< dn^*_{moon} >}$$

Bands 13-16 (saturated)

$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

View geometry correction

$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

Oversampling effect also needs to be corrected if multiple scans are used

- Near-monthly lunar calibrations performed within a constrainted phase angle range.
- Aqua MODIS views a waxing moon while Terra MODIS observes a waning moon (55°-56°).
- Phase, Libration, and oversampling corrections provided by ROLO model

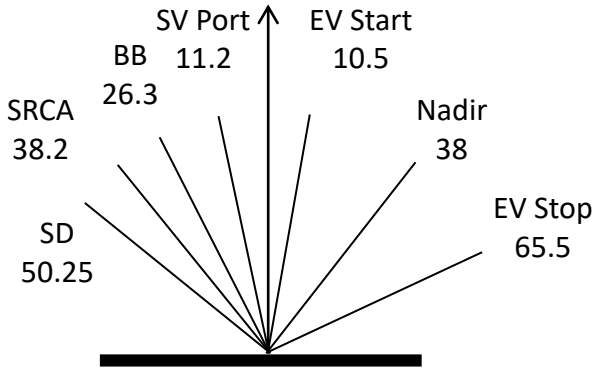
Sun, J.-Q., X. Xiong, W. L. Barnes, and B. Guenther, "MODIS Reflective Solar Bands On-Orbit Lunar Calibration", IEEE Transactions on Geoscience and Remote Sensing, vol. 45(7), 2383-2393, 2007.

MODIS RSB Calibration Methodology: RVS

- EV Reflectance

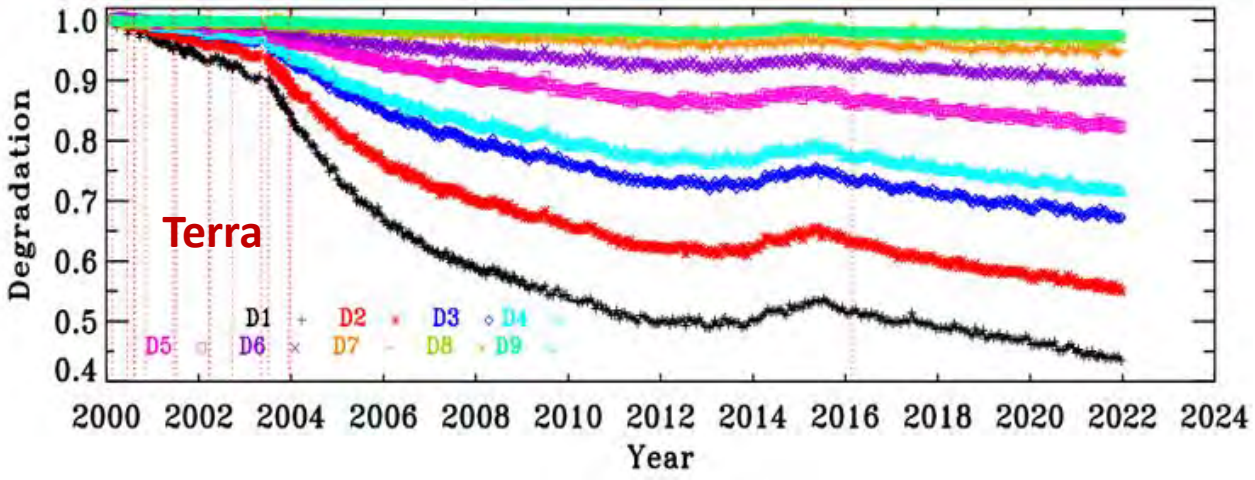
$$\rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS}$$

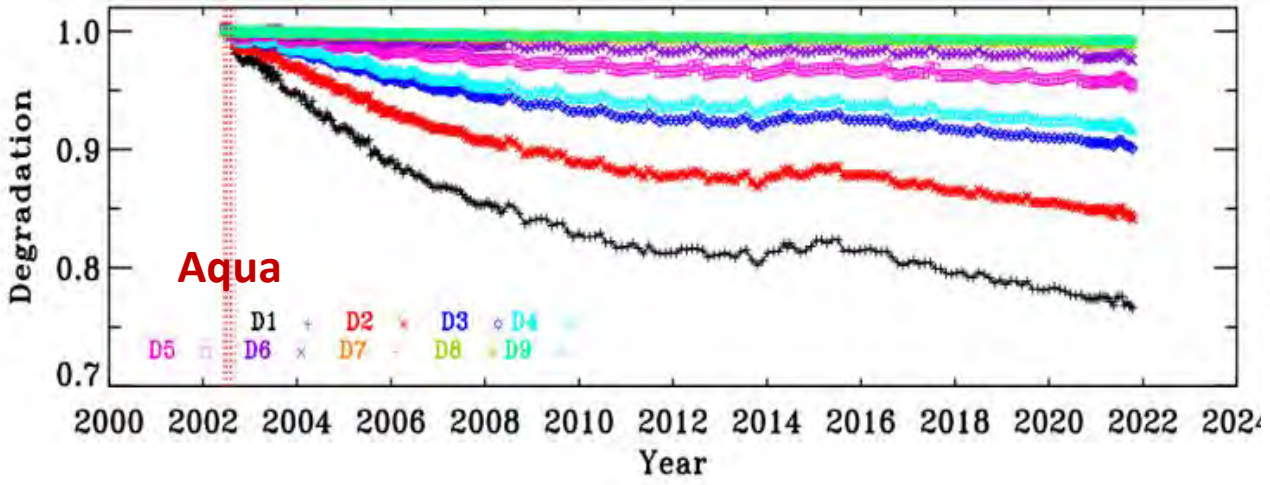
- Look-Up-Tables (LUTs) updated regularly for RSB
  - m_1: Inversely proportion to gain at the AOI of SD
  - RVS : Sensor Response versus Scan angle (normalized to SD AOI)
  - Uncertainty tables
  - SWIR crosstalk correction (Terra)
- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - EV mirror side (MS) ratios
  - Nighttime day mode observations (SWIR)
  - Response trending from Libya desert targets
    - Starting Collection 7, EV data from DCC and ocean targets also used



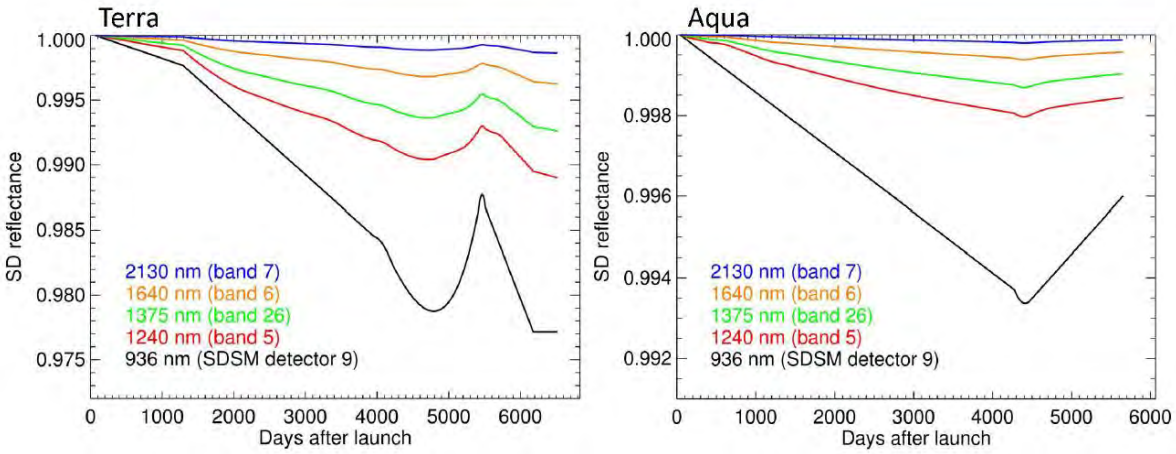
Sun, J., X. Xiong, A. Angal, H. Chen, A. Wu, and X. Geng, "Time-Dependent Response Versus Scan Angle for MODIS Reflective Solar Bands", IEEE Transactions on Geoscience and Remote Sensing, vol 52(6), 3159-3174. 2014.

On-orbit Performance





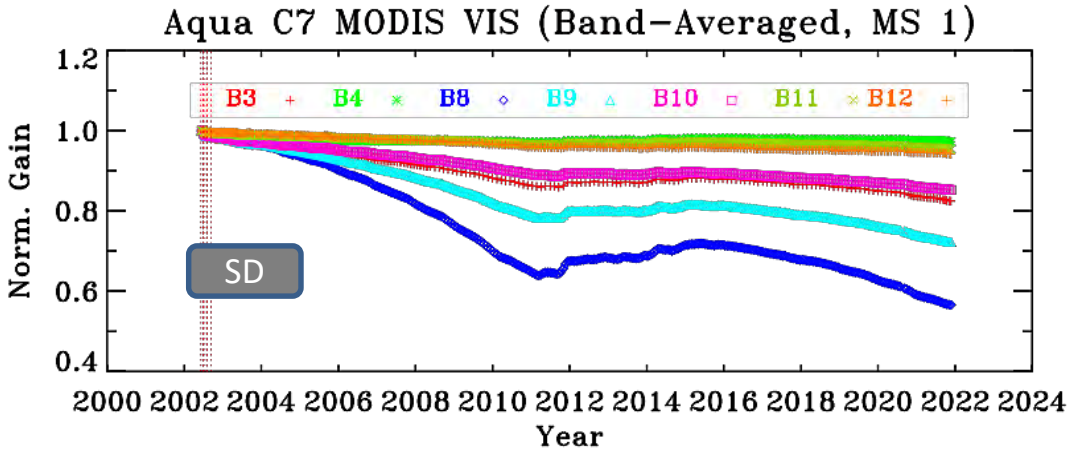
- Increased degradation after Terra SD door anomaly on July 2, 2003.
- Larger SD degradation at shorter wavelengths for both instruments
- SD degradation correction also applied at the SWIR wavelengths

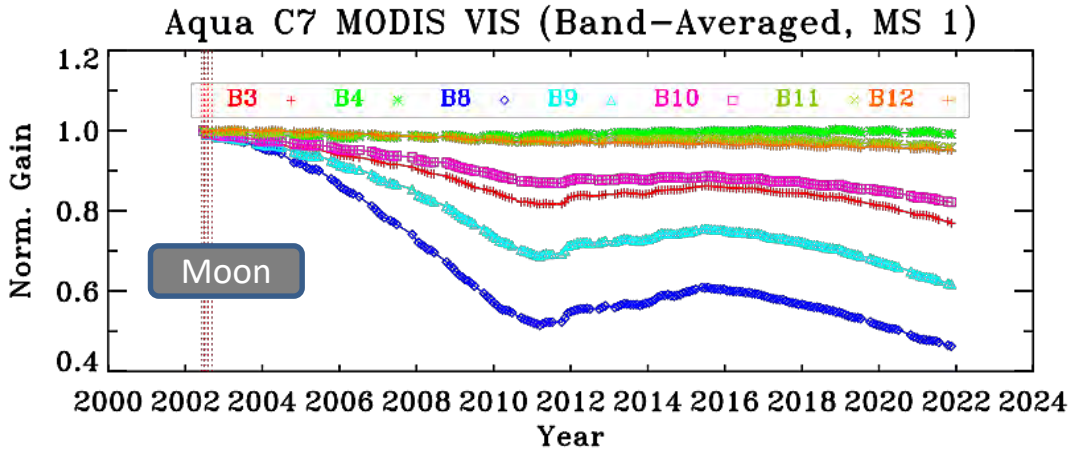


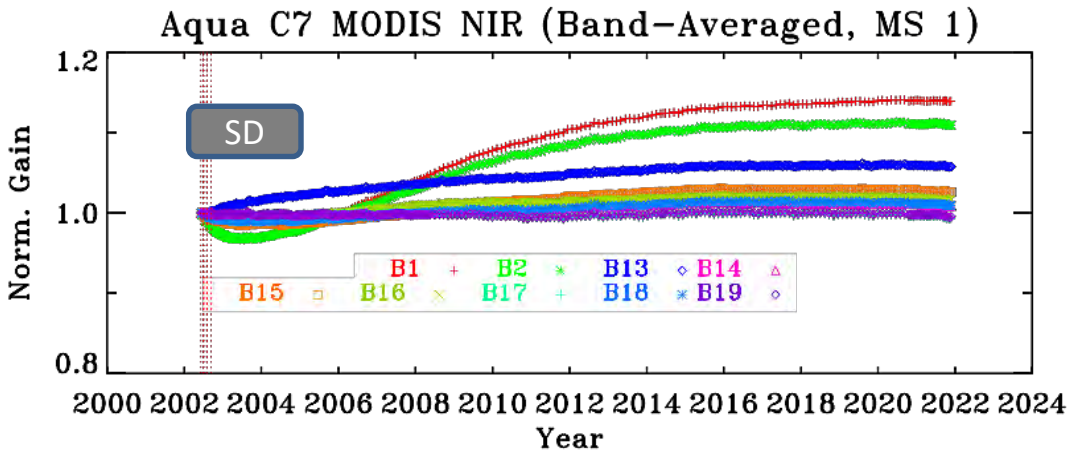
Chen, H., X. Xiong, A. Angal, and K. A. Twedt, "On-orbit Characterization of the MODIS SDSM Screen for Solar Diffuser Degradation Estimation", IEEE Transactions on Geoscience and Remote Sensing, vol. 55(11), pp. 6456-6467, 2017.

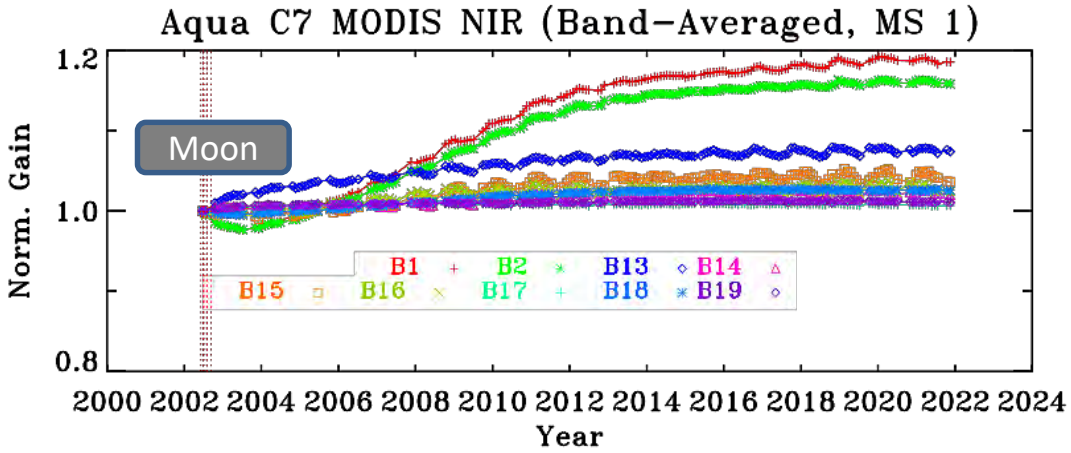
Twedt, K. A., A. Angal, X. Xiong, X. Geng, and H. Chen, "MODIS solar diffuser degradation at short-wave infrared band wavelengths", Proc. SPIE 10402, Earth Observing Systems XXII, 104022K, 2017.

On-orbit Performance



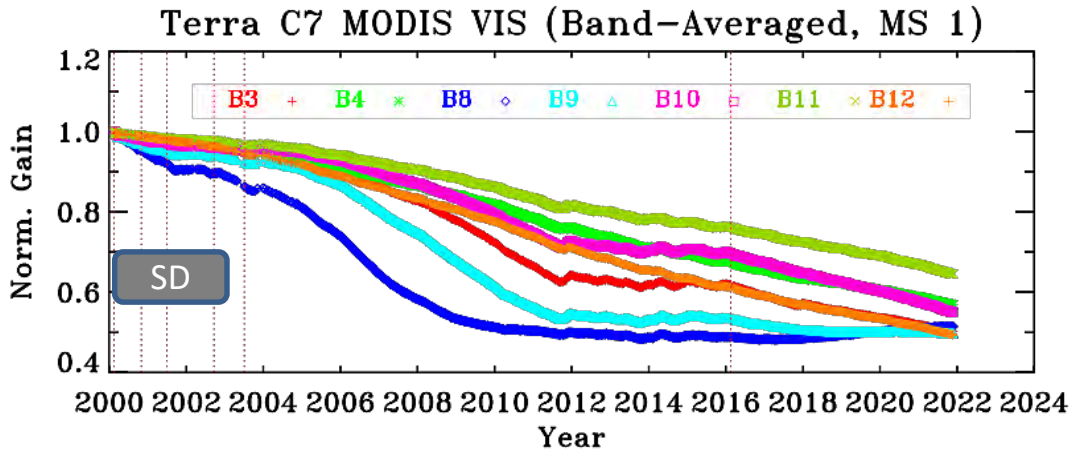


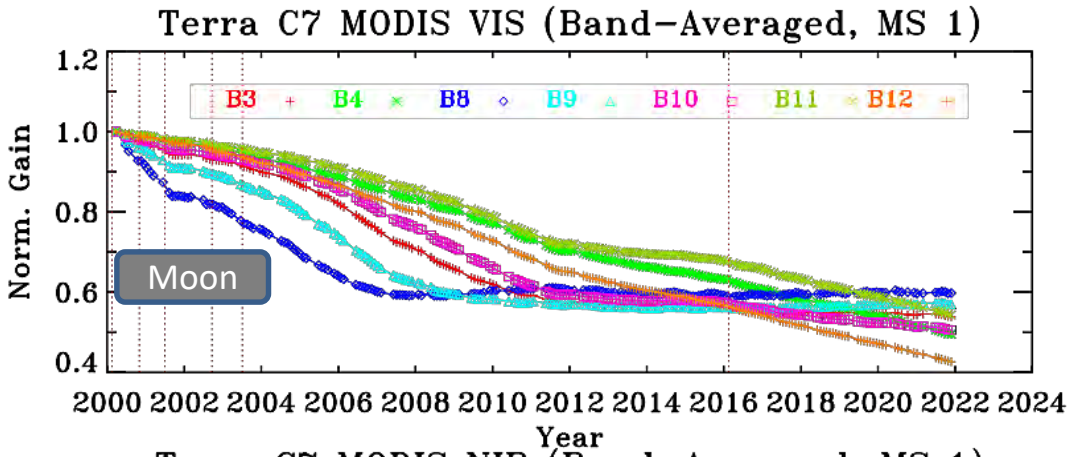


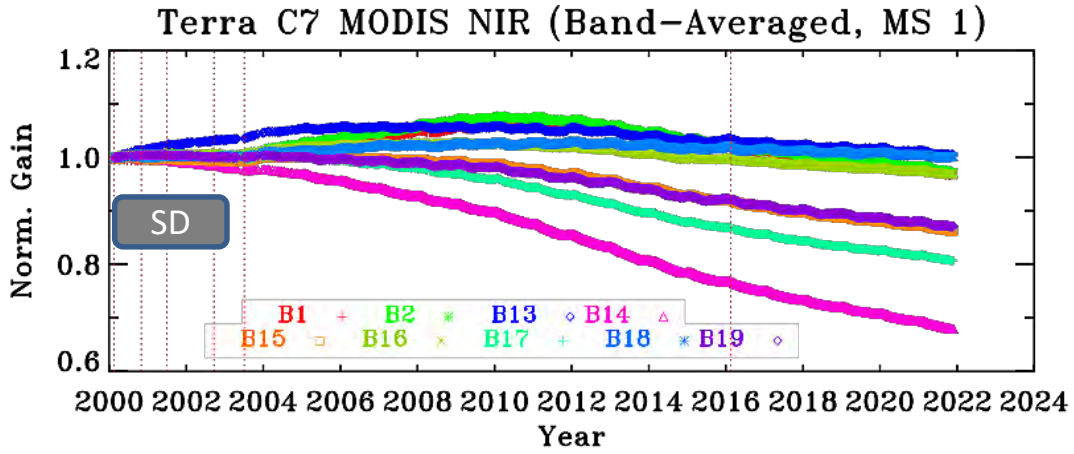


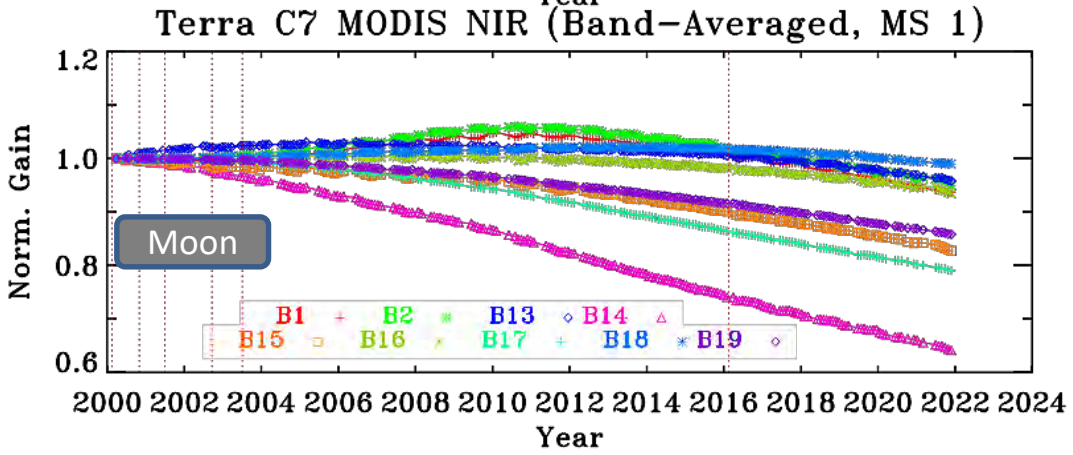
- Most change observed for short-wavelength bands
- Band 8 (.412 µm) maximum change is ~40%
- Aqua VIS bands have a maximum mirror-side difference of about 3.5% at the SD AOI (Band 8)

On-orbit Performance









- Most change observed for short-wavelength bands
- Band 8 (0.412 µm) changes by over 50%
- Terra VIS bands have a maximum mirror-side difference of about 11% at the SD AOI

Xiong, X., A. Angal, K. Twedt, H. Chen, D. Link, X. Geng, E. Aldoretta, Q. Mu, "MODIS Reflective Solar Bands On-Orbit Calibration and Performance", IEEE TGRS, vol 57, issue 9, pp 6355-6371, 2019

L1B Status and Calibration Improvements

- Terra MODIS (22+ years): from C2 (at launch) to C6.1 (current)
- Aqua MODIS (19+ years): from C3 (at launch) to C6.1 (current)
- Continuing support for ocean data reprocessing
- Terra MODIS data collection timeline (approximate)
  - C2: stated L+3 months
  - C3: started L+18 month
  - C4: started L+3 years
  - C5: started L+5 years
  - C6: started L+12.5 years (delayed due to a number of factors)
  - C6.1: started L+17 years
  - C7: Expected to start Spring 2022
- Aqua MODIS started from C3
  - Collections are synchronized with Terra with slightly different starting time

L1B Status and Calibration Improvements

Collection 7 Improvements

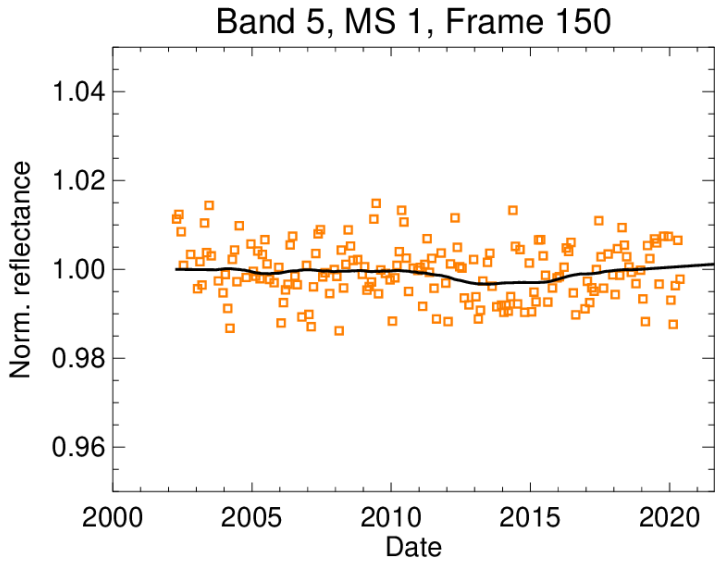
- Terra
  - Polarization correction applied to desert data prior to deriving RVS for Terra bands 3, 4, 8, 9, and 10
  - Improvements to OOB/crosstalk correction algorithm for Terra SWIR bands applied for entire mission
    - Implemented in forward Terra C6/C6.1 LUT starting June 2019.
  - SWIR bands 5 and 26 use time-dependent RVS based on DCC data
  - Use an inter-band approach that relies on relative trends of ocean data to derive RVS for Terra bands 11 and 12
  - Improvements to desert data fitting methods for RVS derivation
  - Extend detector-dependent RVS to Terra band 4
- Aqua
  - Improved SD screen transmission function applied for ocean bands 8-16
  - Improvements to desert data fitting methods for RVS derivation

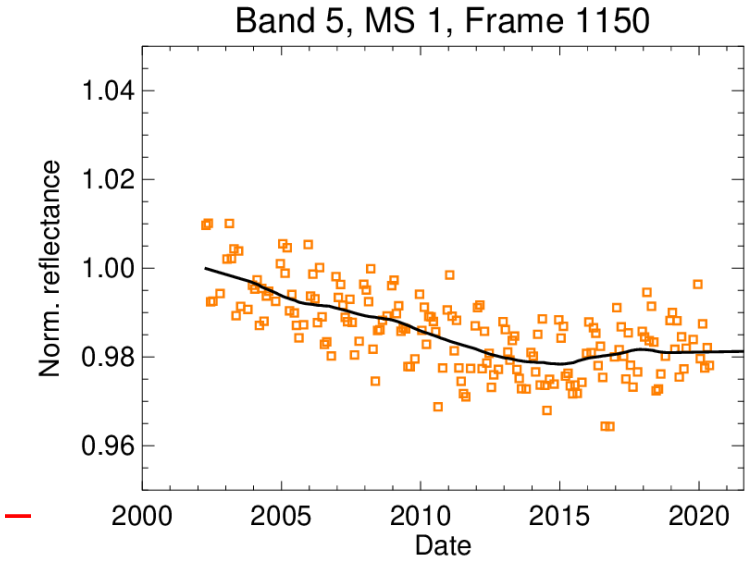
L1B Status and Calibration Improvements

- The polarization sensitivity of scan mirror has impacted performance of Terra MODIS short-wavelength RSB
  - C6/C6.1 L1B does not include any correction for polarization effects
- Current mitigation strategy for L2 products
  - NASA OBPG has derived polarization correction coefficients from a cross-cal with SeaWIFS/Aqua MODIS over ocean targets
  - For land products, use the OBPG polarization coefficients to generate a L1B_PC product followed by de-trending to correct gain based on desert site trends
- Collection 7
  - MCST will apply polarization correction prior to derivation of gain from desert sites for Terra bands 8, 9, 3, 4, and 10.
  - Significant improvement in accuracy of L1B product and forward-predicted gain.
  - Will significantly reduce the magnitude of downstream gain (M11) and de-trending corrections.
  - These changes will improve the instrument gain calibration only; there will still be scene-dependent impacts from polarization in the L1B product.

L1B Status and Calibration Improvements

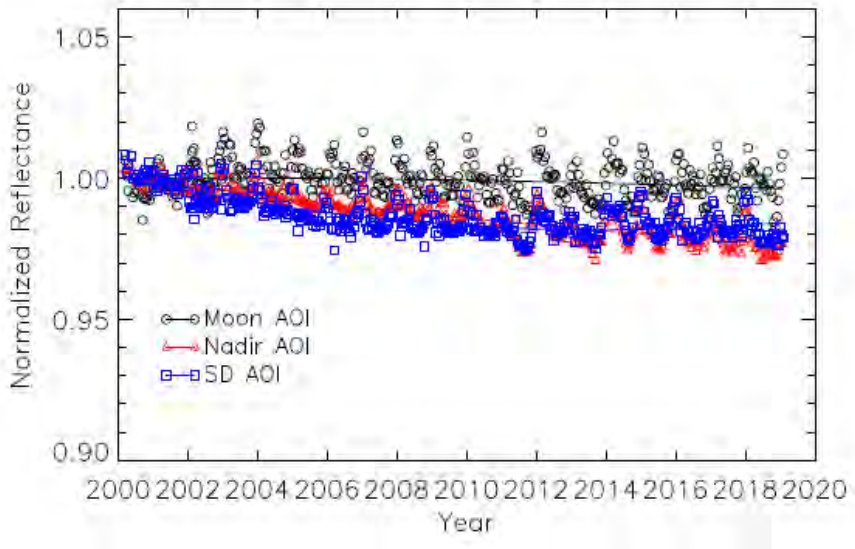
- Trends of C6.1 reflectance from DCC and Libya desert sites indicate need for on-orbit RVS
  - Plots show DCC reflectance calculated with only SD-based m_1 and pre-launch RVS.
  - Fit in time and frame to derive time-dependent RVS and time-dependent m_1 correction.
- EV-based RVS applied to band 5 (up to 2% impact) and band 26 (up to 1% impact). Bands 6 and 7 don't show indication of on-orbit RVS change and will continue to use pre-launch RVS.
- EV-based m_1 correction applied to all SWIR bands.
- Results agree with desert data for bands 5, 6, and 7.

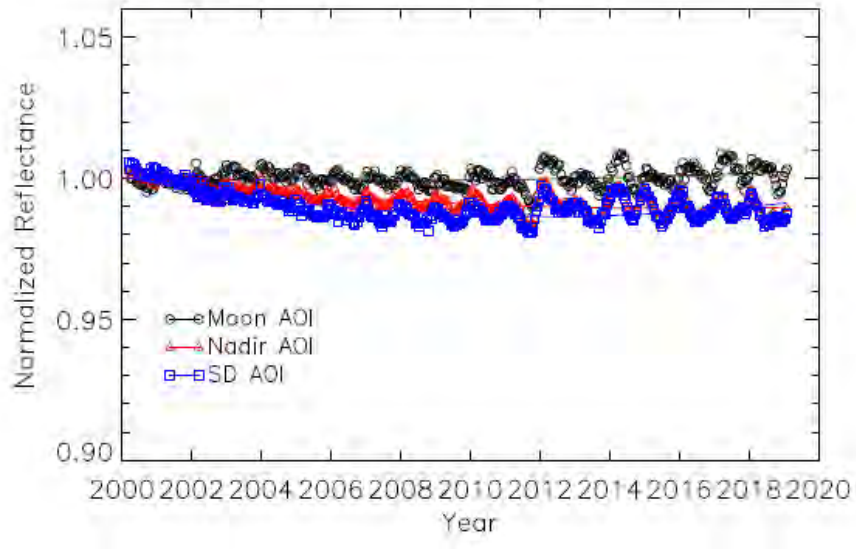




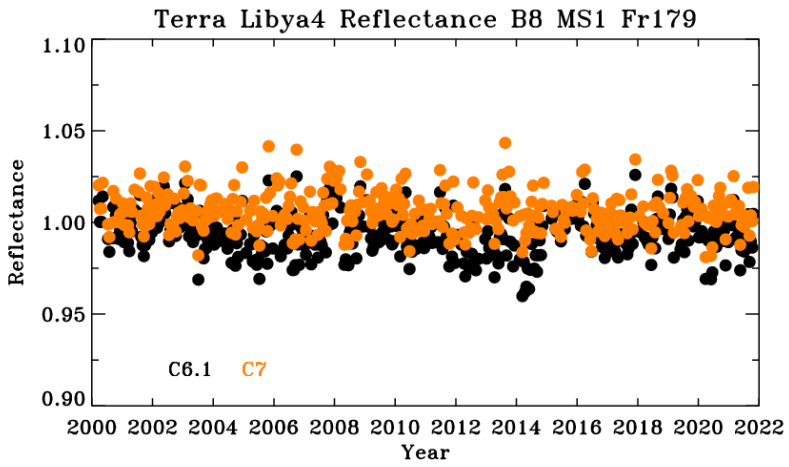
L1B Status and Calibration Improvements

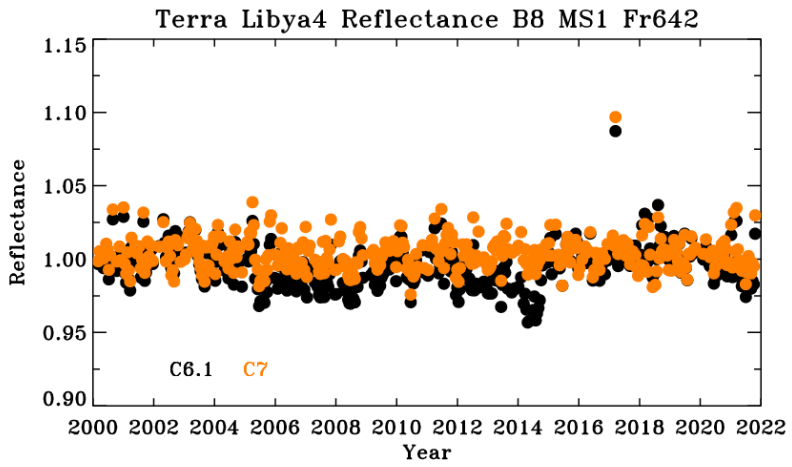
- In C6.1 Terra bands 11 and 12 use only SD and lunar data to characterize m_1 and RVS.
  - Desert trends are used in calibration for other short-wavelength bands 8, 9, 3, 10, and 4.
  - However, the desert-based approach is not viable for bands 11 and 12 (and other high-gain ocean bands) as they saturate while viewing the high-radiance desert.
- An inter-band calibration approach with band 4 (spectrally overlapping) as a reference is used to monitor the long-term reflectance for bands 11 and 12 using ocean scenes.
- Using SD-lunar based calibration, a long-term drift is observed at nadir and SD AOIs for both bands with band 11 showing more than 2% drift, demonstrating the need for EV-based calibration of these bands.
- For C7, these reflectance trends are fit in time and frame to provide adjustment to m_1 and RVS LUTs.

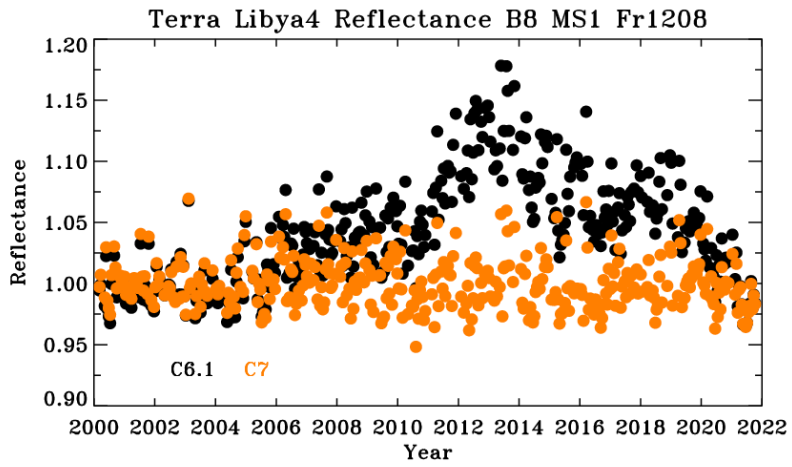


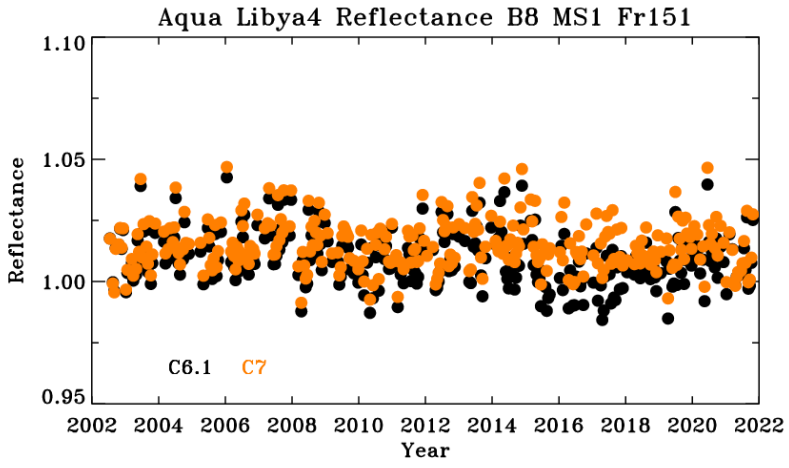


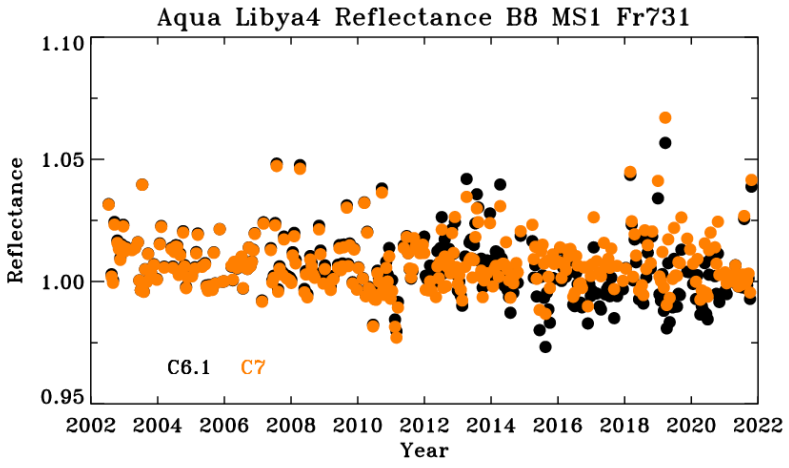
L1B Status and Calibration Improvements

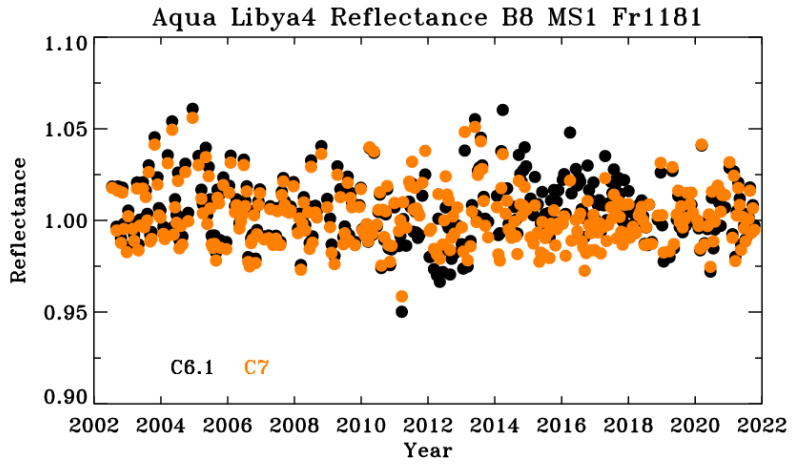












Noticeable improvements in the long-term reflectance trends with C7. Similar improvements also seen for Terra MODIS bands 3 and 9

Future Efforts

- Continue to monitor sensor performance and to derive and update calibration LUTs in support of C6, C6.1, and future C7 data production
  - C6 L1B expected to be discontinued in June, 2022
- Support FOT for Terra and Aqua Constellation Exit Maneuver (CEM) activities
- Develop post-CEM calibration strategies in support of extended Terra and Aqua MODIS missions (use of OBC and lunar observations, vicarious calibration targets, and alternative approaches)
  - Use new fitting approach for RSB RVS (single-site AOI fitting, site-independent approaches, DCC, inter-band calibration, …)
- Assessing the calibration consistency between Terra and Aqua MODIS (& with future VIIRS instruments)

Summary

- Both Terra (launched in 1999) and Aqua (launched in 2002) MODIS and their on-board calibrators continue to operate and function normally
- Dedicated efforts have been made by the MCST
  - Characterize on-orbit sensor performance
  - Evaluate and address issues identified, including cross-sensor calibration differences (critical to consistent and long-term data records)
  - Support science data production and reprocessing (MODIS C6/C6.1/C7)
  - Develop post-CEM (constellation exit maneuver) calibration strategies (Terra and Aqua)