Improvements and Challenges of Sensor Reflective Solar Calibration

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Contributions:

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Contents

- **Reflective Solar Calibration Approaches**
- **MODIS and VIIRS Calibration**
- **Calibration Improvements**
- **Challenging Issues**
- **Way Forward**

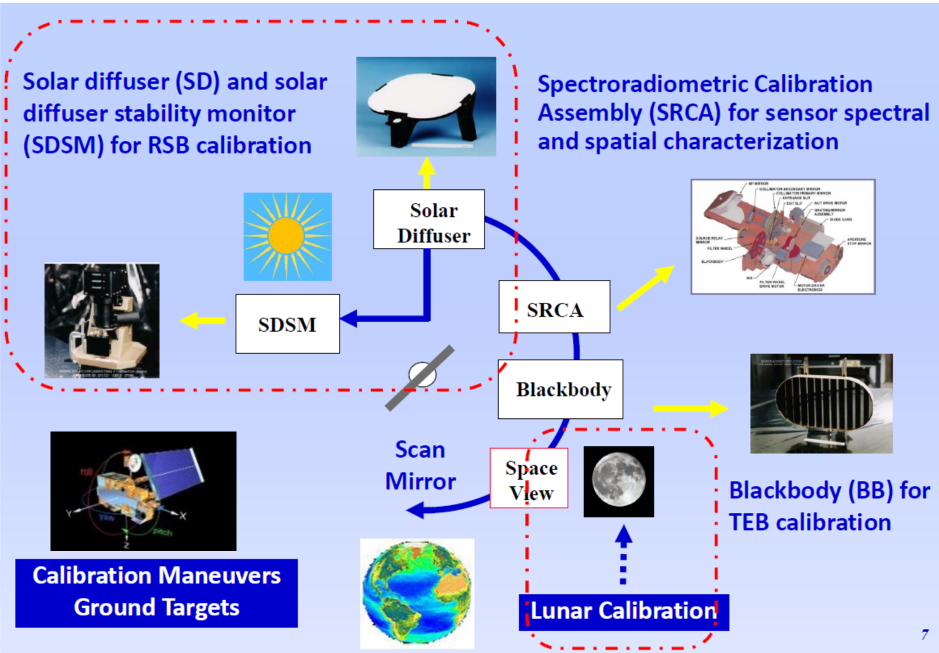
Focusing on MODIS and VIIRS reflective solar on-orbit calibration

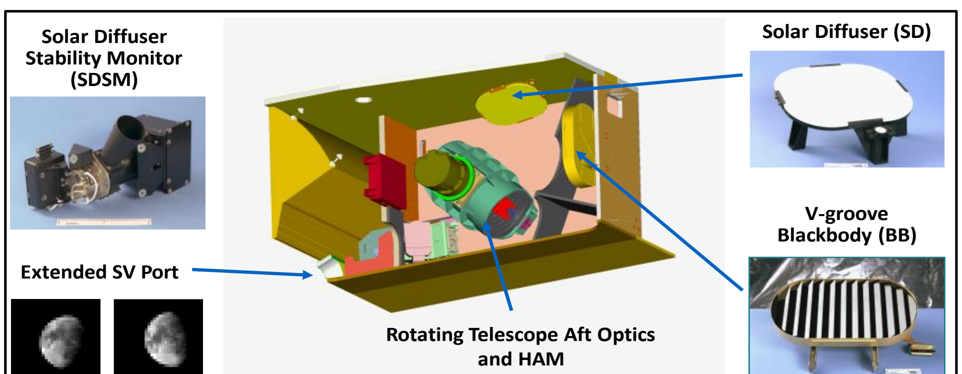
Reflective Solar Calibration Approaches

- **On-board Calibrators**
  - Solar diffusers (Spectralon, Al plates coated with YB71, QVD, …)
  - SD stability monitors (a ratioing device, a second diffuser, lamps, …)
  - Lamps
- **Lunar Observations**
  - Scheduled (same phase angles)
  - Unscheduled (various phase angles)
- **Vicarious Calibration Targets**
  - Pseudo Invariant Calibration Sites (PICS)
  - Deep Convective Clouds (DCC)
- **Cross-sensor Inter-comparisons**
  - SNO (including double difference approach)
  - Ground calibration/reference targets (e.g., RadCalNet)

Different approaches used by various sensors (AVHRR, GOES-14/15/16/17, L7 ETM+, L8 OLI, SeaWiFS, Terra/Aqua MODIS, S-NPP/N-20 VIIRS, S2A/2B MSI, S3A/B OLCI)

MODIS and VIIRS On-orbit Calibration





MODIS (Aqua)

- SD calibration: weekly to tri-weekly
- SDSM operation: weekly to tri-weekly
- Lunar observations: near-monthly
- SRCA (with lamps): regularly scheduled
- Ground targets: PICS and DCC

VIIRS

- SD calibration: each orbit
- SDSM: daily to weekly
- Lunar observations: near-monthly
- Ground targets for validation

- **MODIS SD calibration system includes a SD door and an optional screen**
- **VIIRS uses a fixed attenuation screen (no SD door)**

Calibration Improvements and Challenges

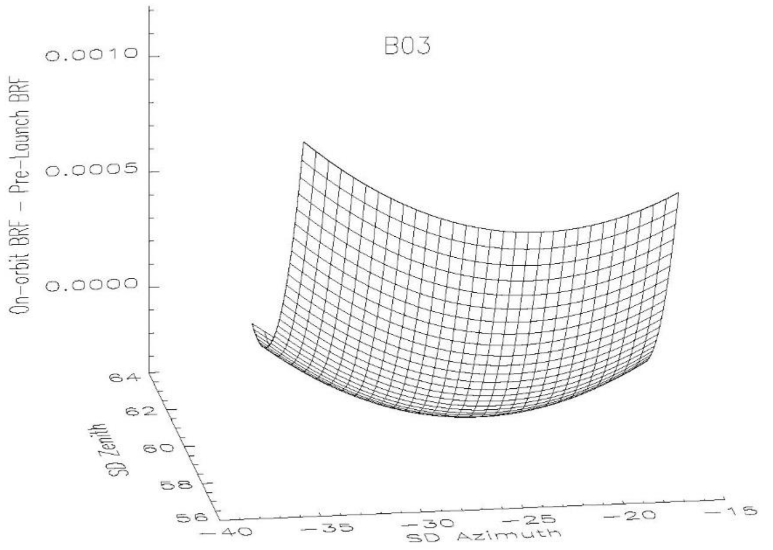
- No pre-launch characterization for MODIS SD and SDSM screen transmission
- Pre-launch BRDF and screen characterization (for VIIRS) were made at limited wavelengths and illumination/viewing geometries
- SD degradation at SWIR wavelengths

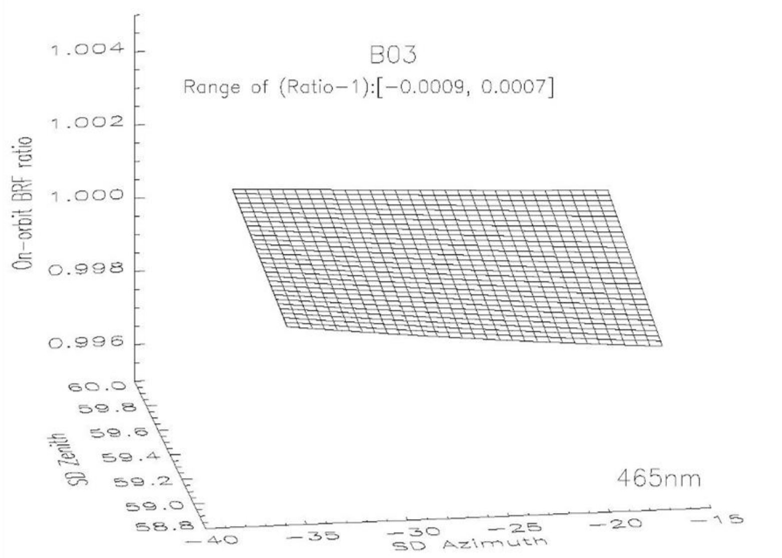
- Yaw maneuvers to characterize SD BRDF and its screen transmission (τ) (only the product of BRDF and τ for VIIRS)
- Yaw maneuvers to characterize SDSM screen transmission
- Roll maneuvers for lunar observations
- Strategies to improve SD degradation characterization

- MODIS - ground targets to characterize changes of sensor response versus scan-angle (RVS) and polarization sensitivity
- MODIS SWIR crosstalk characterization and correction
- S-NPP - modulated relative spectral response (RSR) – caused due to mirror coating contamination

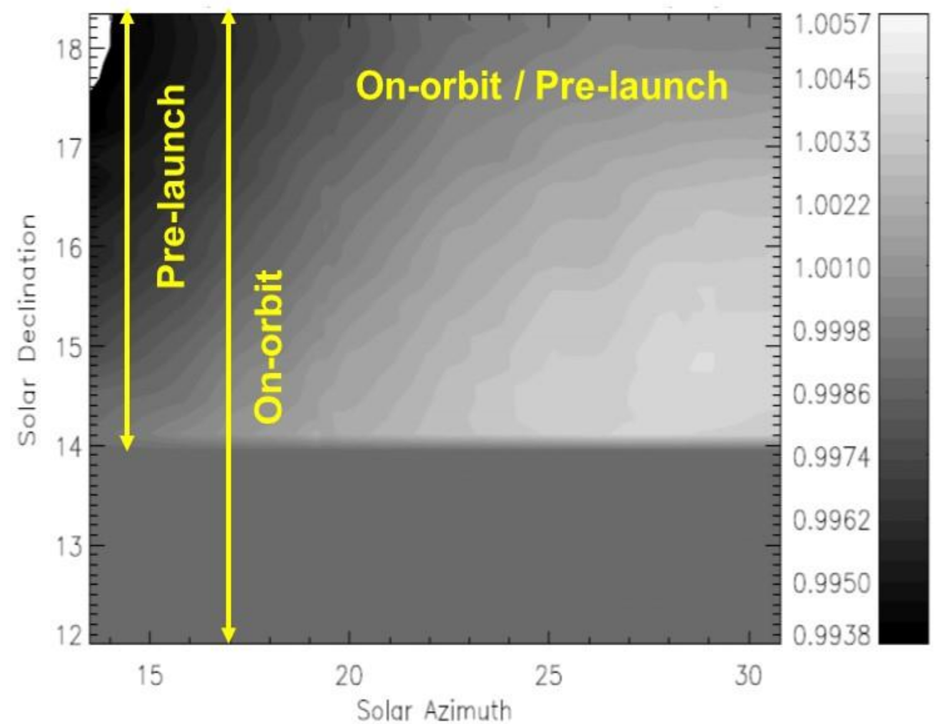
SD BRF and Screen Transmission (τ_{SD})

Terra MODIS BRF (< 0.15%)





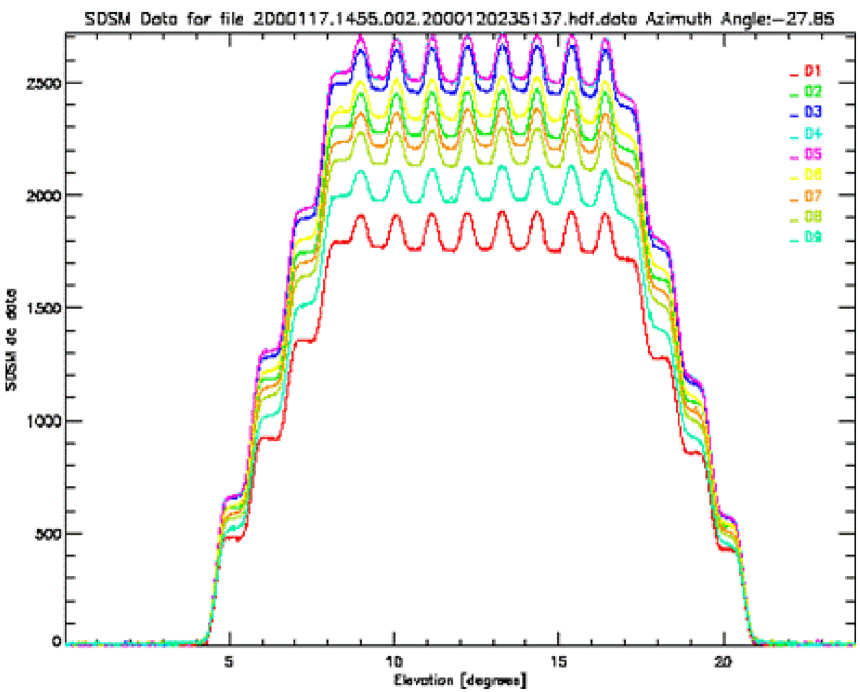
S-NPP BRF*τ_{SD} (< 0.35%)



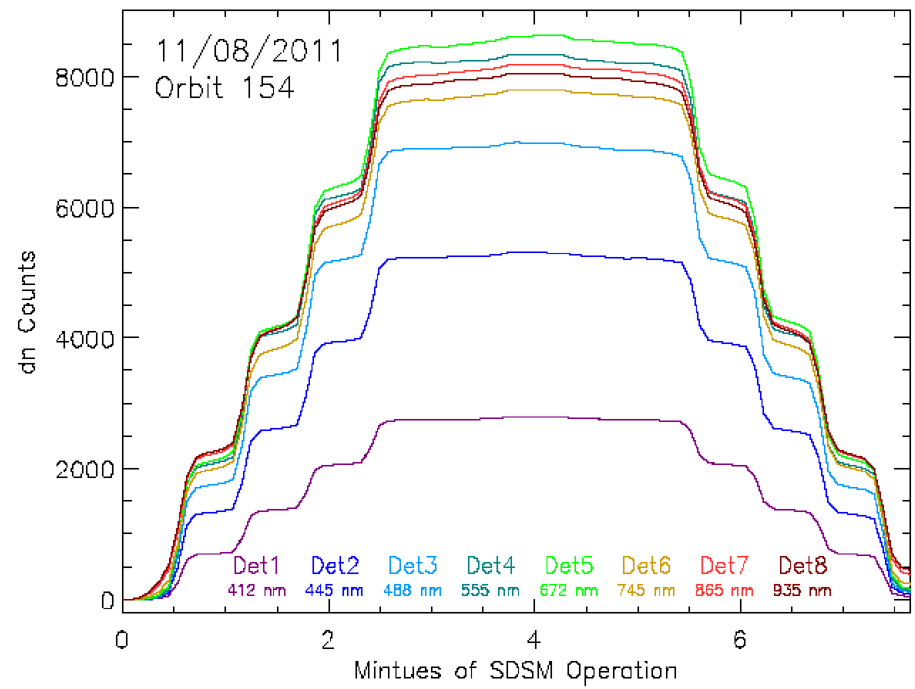
Illumination/viewing geometries and resolutions with sensor detectors (wavelengths)

SDSM Screen Transmission (τ_{SDSM})

Large variations in MODIS SDSM Sun View responses due to design artifact



MODIS SDSM Sun View Responses



VIIRS SDSM Sun View Responses

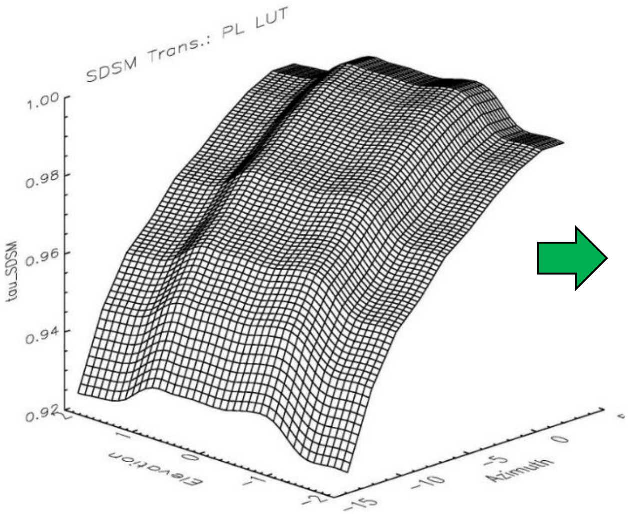
$$\Delta_{SD} \propto \frac{\overline{dc_{SD}}}{dc_{Sun}} \Rightarrow \left\{ \frac{dc^{D1}_{SD\_view} / dc^{D1}_{Sun\_view}}{dc^{D9}_{SD\_view} / dc^{D9}_{Sun\_view}} \right\}$$

MODIS/VIIRS SDSM has 9/8 detectors covering wavelengths from 0.41 µm to 0.94 µm

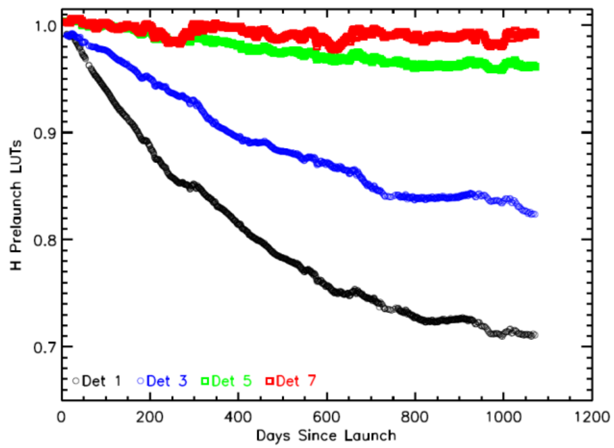
Lessons from MODIS to VIIRS and on-orbit to pre-launch

SDSM Screen Transmission (τ_{SDSM})

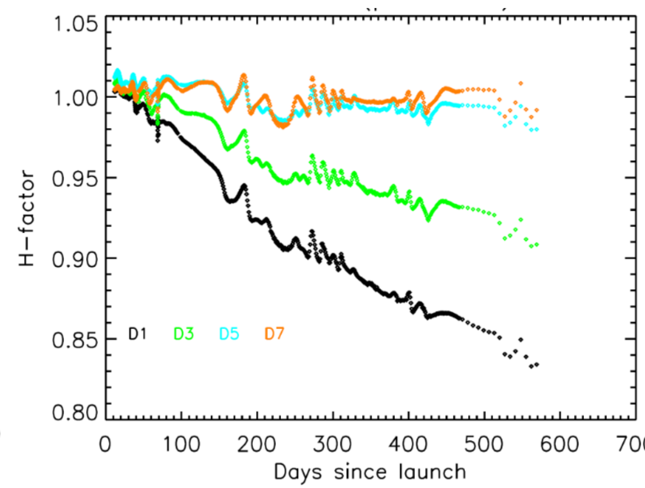
S-NPP pre-launch τ_{SDSM}



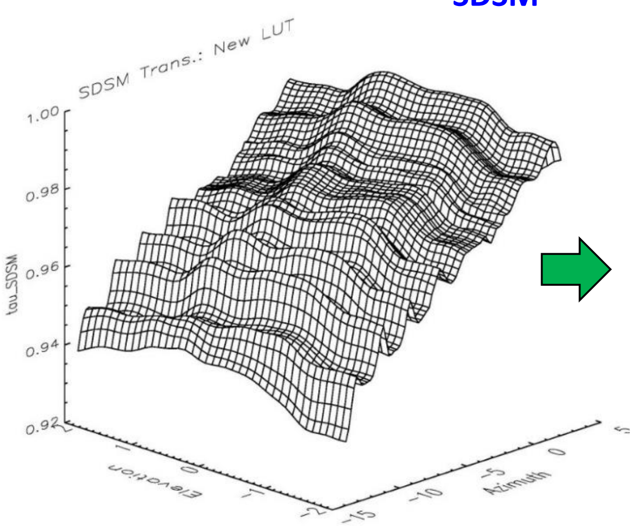
S-NPP SD degradation



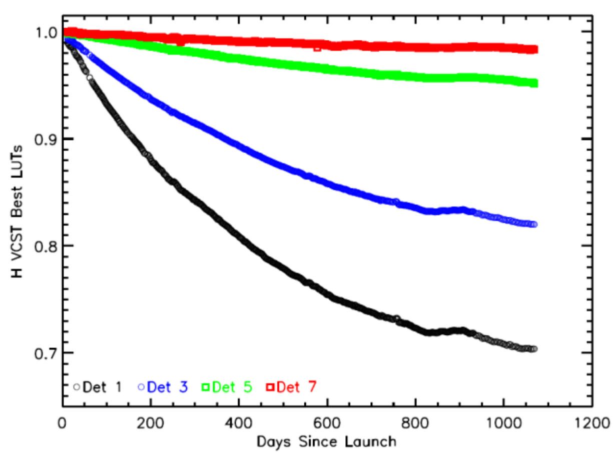
N-20 SD degradation



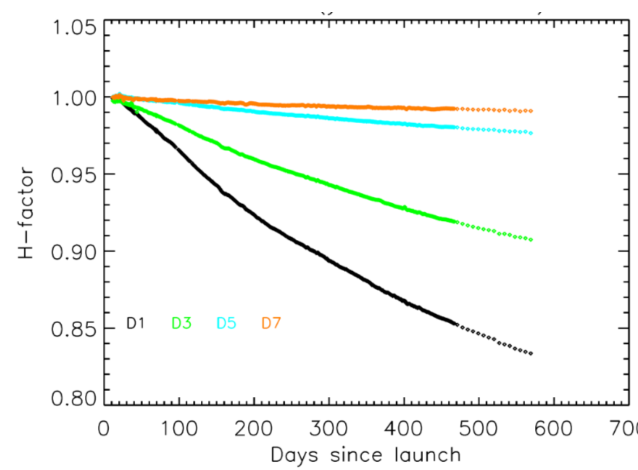
S-NPP on-orbit τ_{SDSM}



S-NPP SD degradation



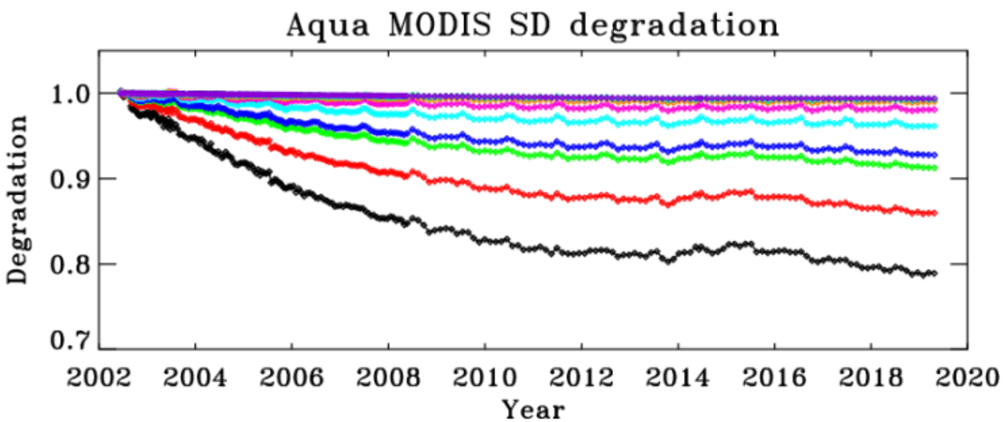
N-20 SD degradation

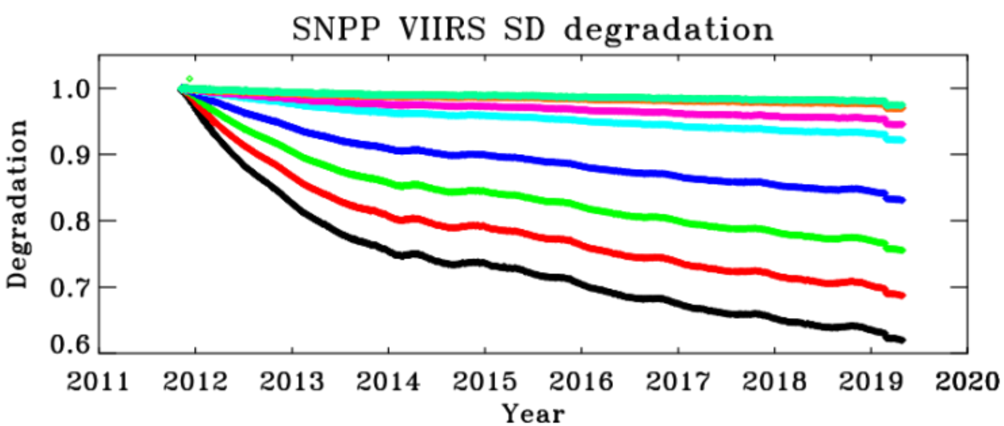


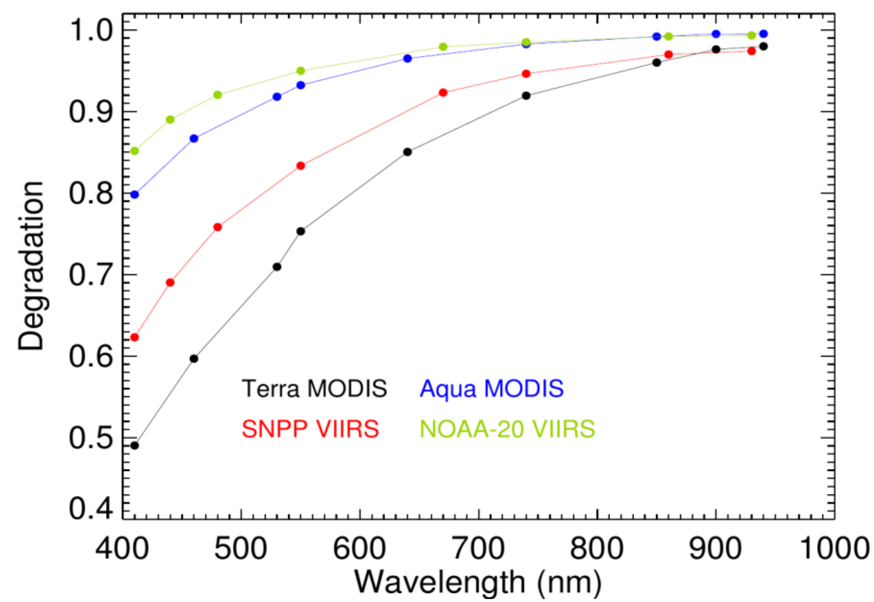
Smooth SD degradation with improved screen transmission

MODIS and VIIRS SD Degradation

- Larger SD degradation at shorter wavelengths
  - VIIRS has no SD door; Terra MODIS SD door fixed at “open” at L+2.5 yr





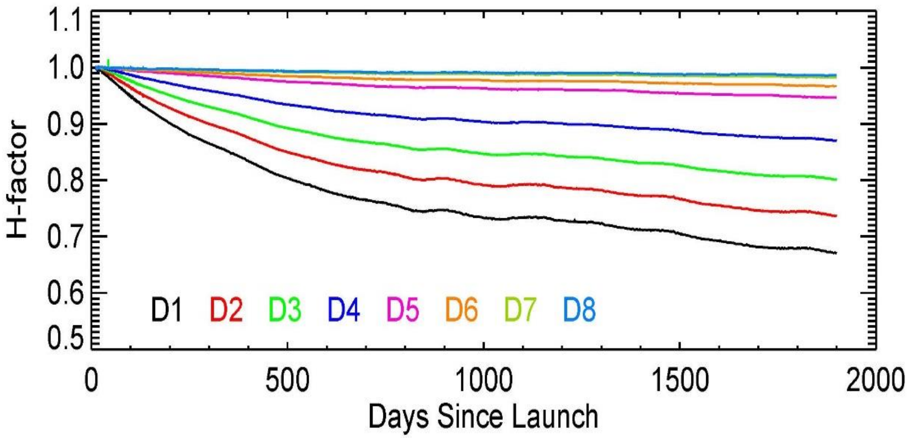


19 years. 17 years, 7 years, 1 year

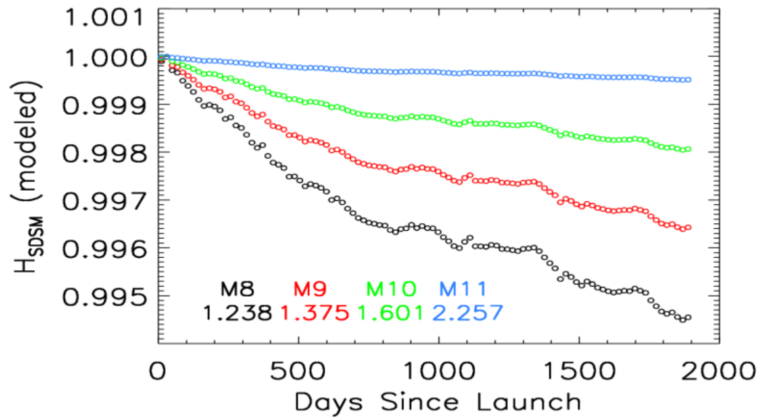
S-NPP SD degradation is more closer to T-MODIS and N-20 is more closer to A-MODIS

VIIRS SD Degradation at SWIR Wavelength

SDSM: from 0.41 to 0.93 μm



SWIR bands: from 1.2 to 2.3 μm



$$1 - H(\lambda, t) = \frac{\alpha(t)}{\lambda^{4.07}}$$

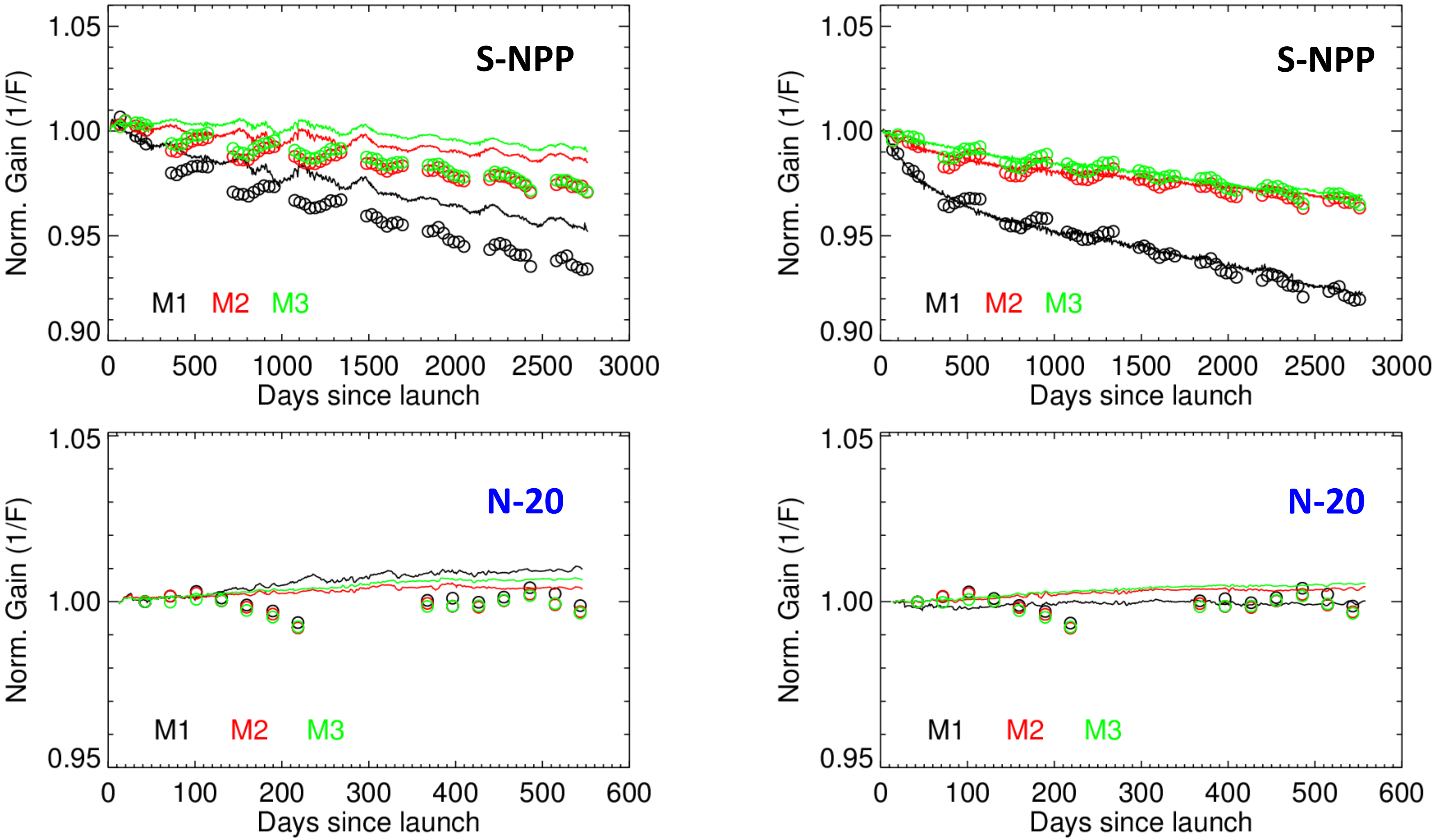
Useful to track small SD degradation (e.g., at mission beginning)

For MODIS:

- A different approach was proposed but not implemented
- Long-term SWIR degradation is tracked using desert and DCC response trends and using band-to-band response ratio

Use of Lunar Observations (VIIRS)

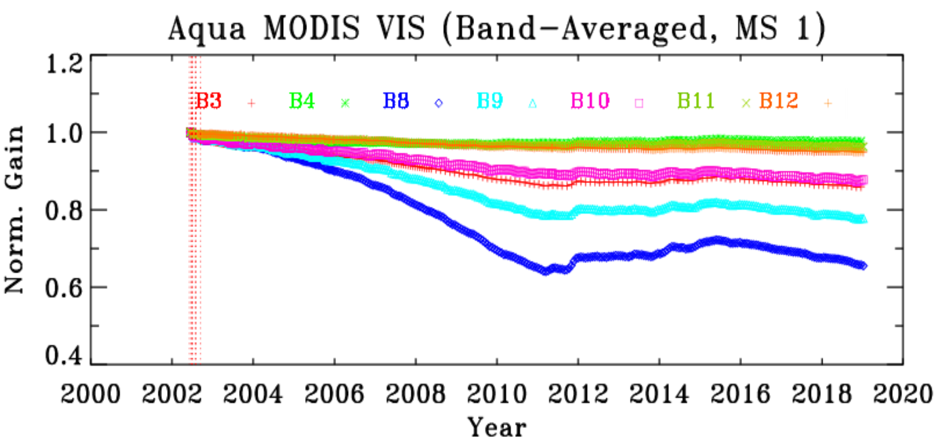
- VIIRS SD and lunar observations are made at the same AOI
  - Lunar data used to track sensor long-term response; SD degradation concerns eliminated



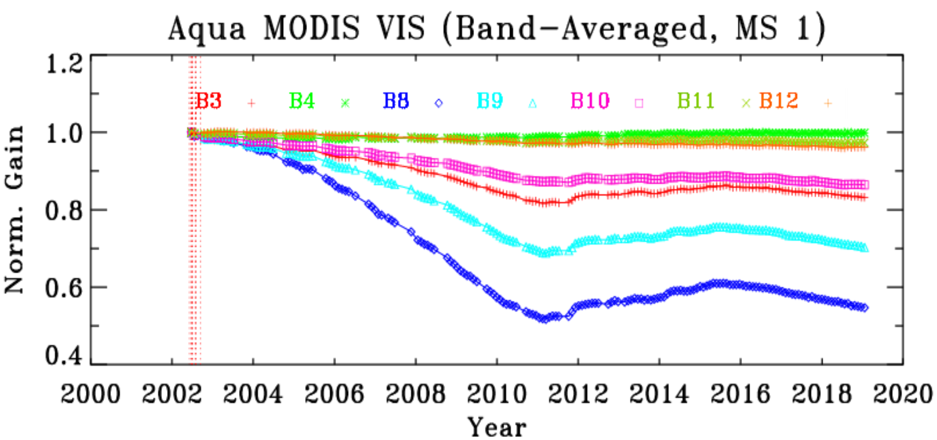
Use of Lunar Observations (MODIS)

- MODIS SD and lunar observations are made at the different AOI
  - Lunar and SD data used to track sensor response versus scan-angle (RVS); long-term SD degradation concerns remained

SD Calibration (AOI: 50^o)



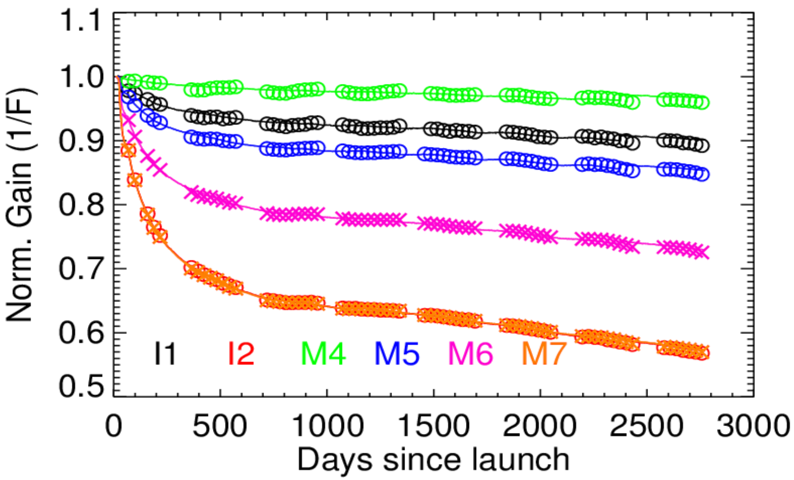
Lunar Calibration (AOI: 11^o)

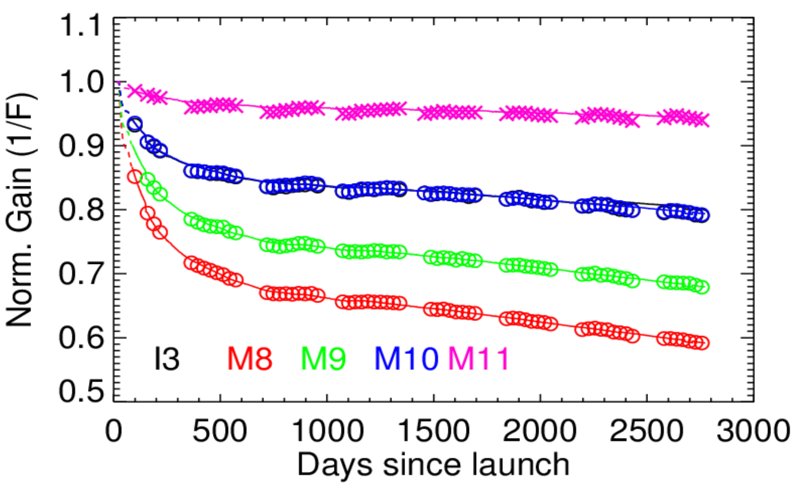


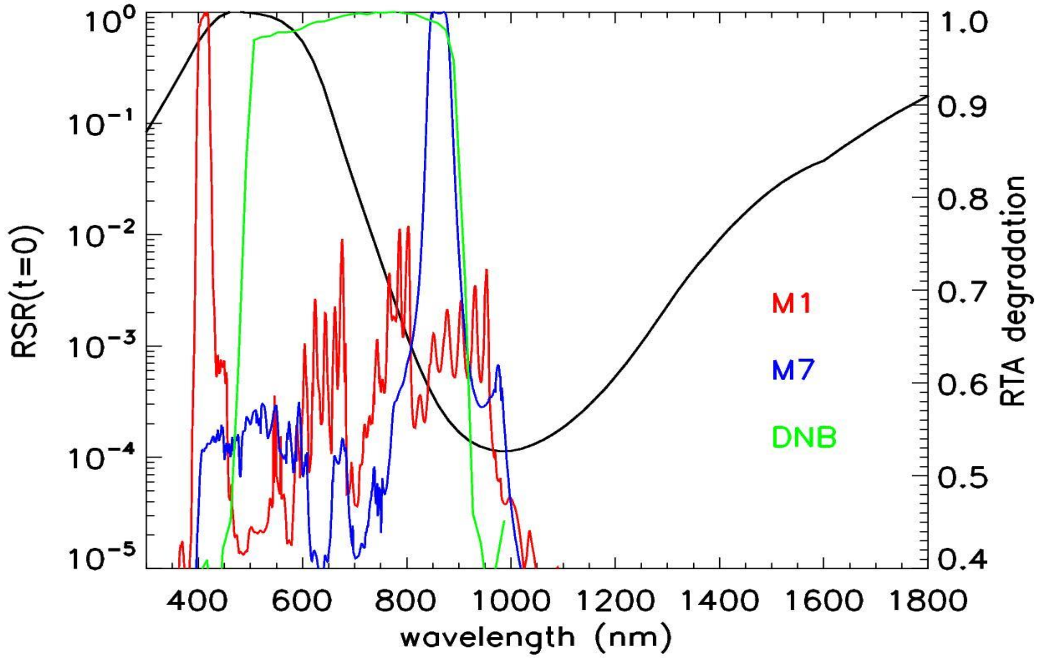
For bands with large changes, earth view response trends at multiple AOIs are also used to support RVS characterization

On-orbit Modulated RSR (S-NPP)

- S-NPP RTA (rotating telescope assembly) mirror coating contamination
  - Large decrease of optical throughput at NIR and SWIR





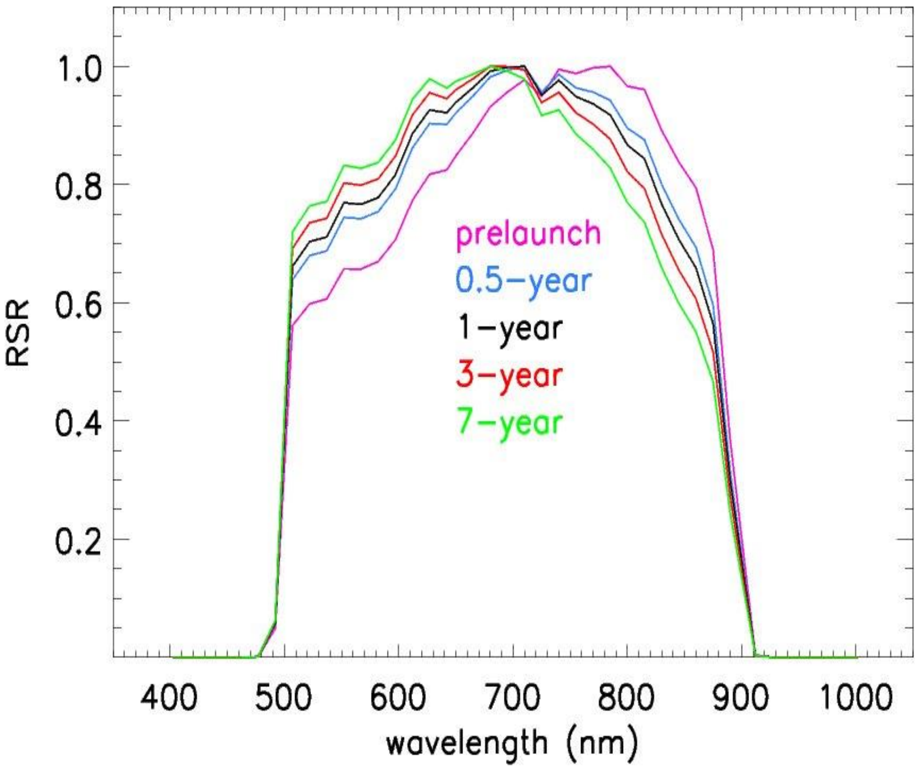


Small impact for bands with narrow bandwidths and small OOB responses

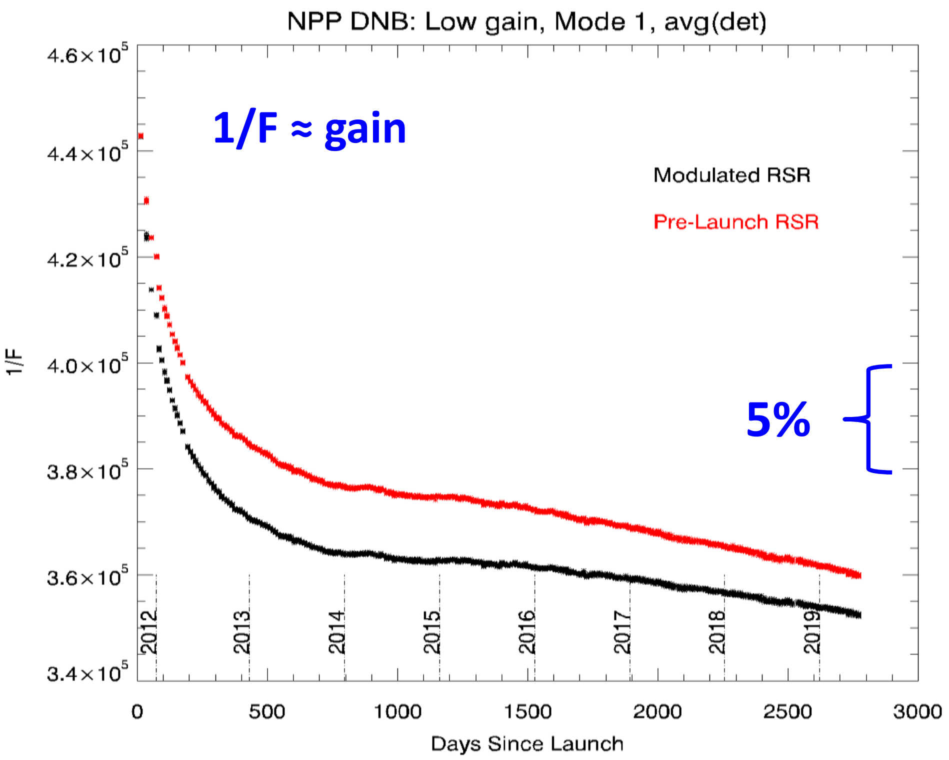
Large impact on DNB with broad bandwidth

On-orbit Modulated RSR Impact for DNB Calibration

DNB LG Modulated RSR



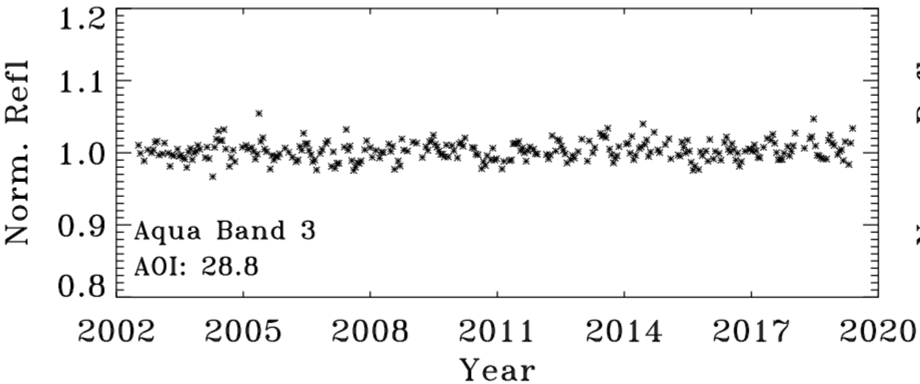
DNB LG SD Calibration

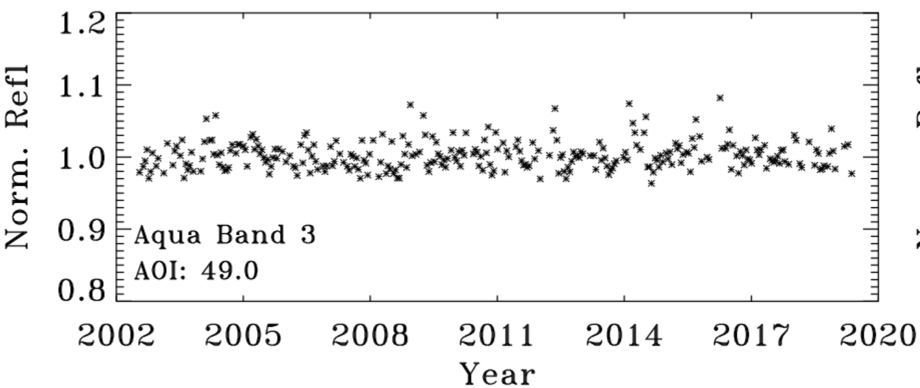


Similar effect in lunar calibration

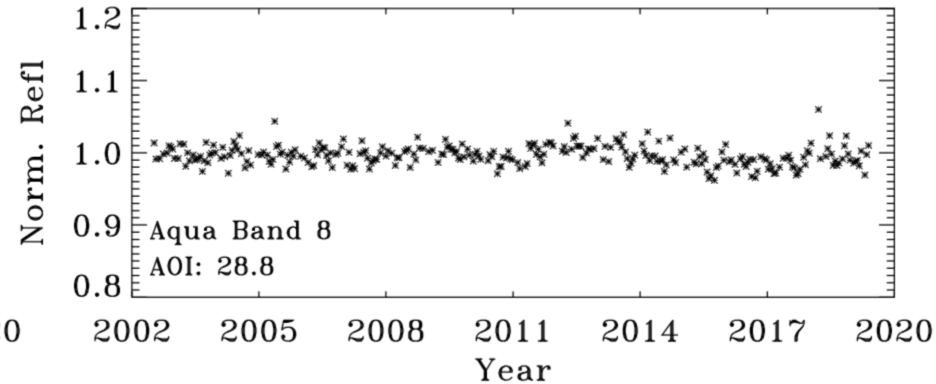
Use of Earth View Trending (Aqua)

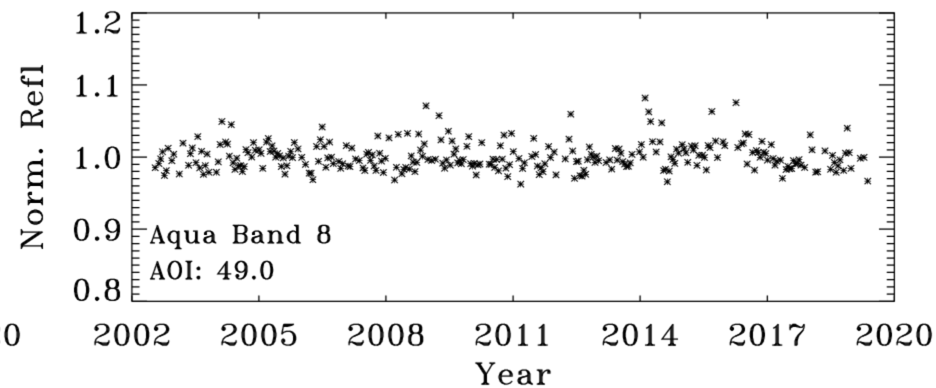
MODIS band 3 (0.48 μm)





MODIS band 8 (0.41 μm)

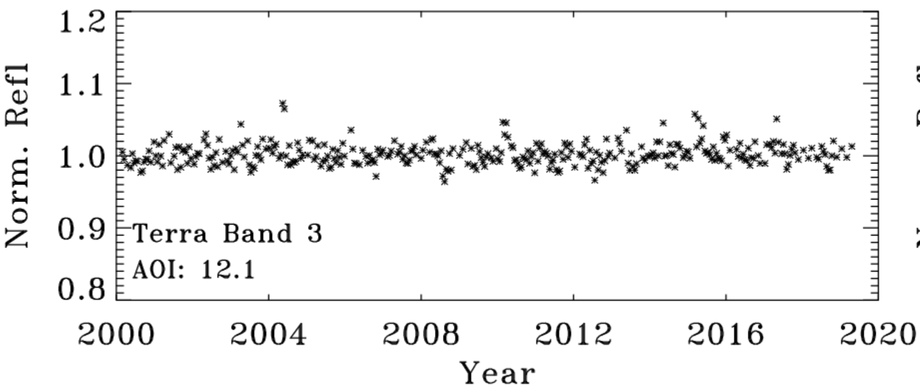


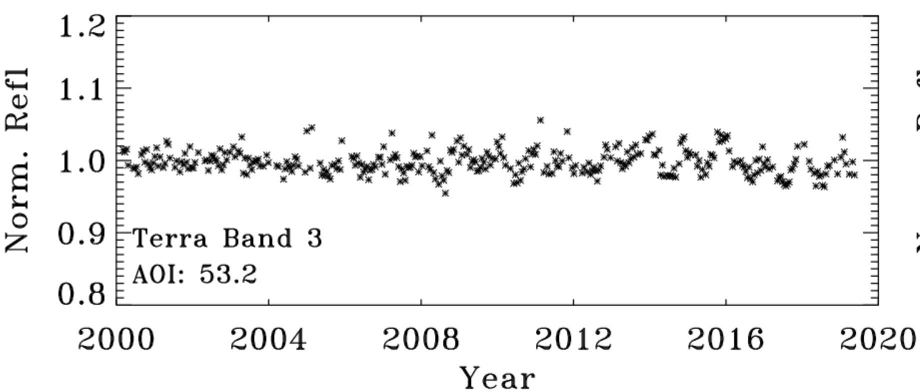


No on-orbit changes in Aqua polarization sensitivity (verified with ocean products)

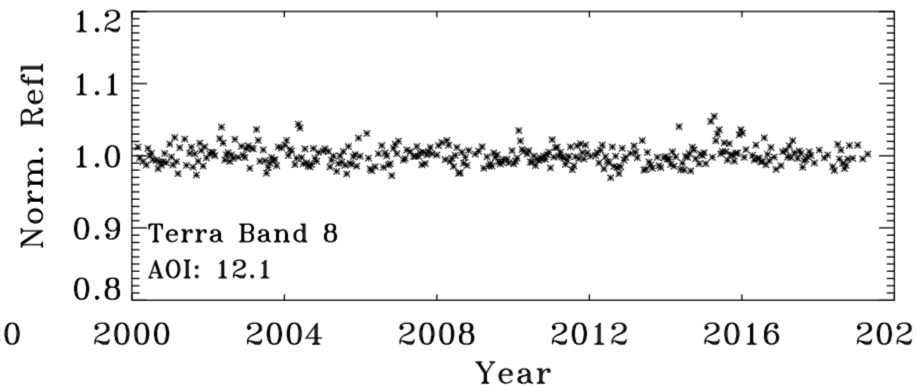
Use of Earth View Trending (Terra)

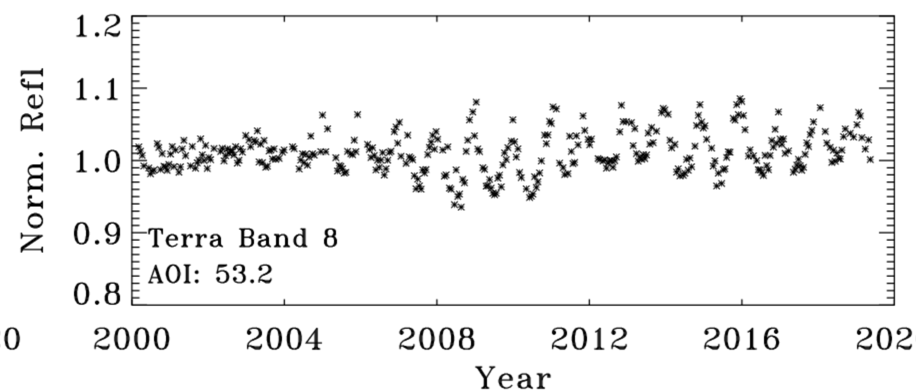
MODIS band 3 (0.48 μm)





MODIS band 8 (0.41 μm)





Future RVS characterization: polarization corrected earth view response trending

Other Issues

- **Pre-launch**
  - RSR characterization
  - Polarization characterization (J1 VIIRS M1-M4)
  - Stray light and cross-talk characterization (MODIS SWIR)
  - Complete end-to-end testing (including on-board calibrators)
- **Pre-launch to on-orbit transfer**
  - Unbroken chain of sensor calibration
- **On-orbit**
  - Long-term calibration stability
  - Multi-sensor calibration consistency

Way Forward

- **Continuing efforts to maintain sensor calibration stability and data quality**
  - Track and correct for changes in sensor and OBC responses, including sensor RVS and polarization sensitivity
  - Generate consistent calibration LUTs to support data reprocessing
- **Coordinated efforts to address multi-sensor calibration consistency**
  - Joint efforts from different agencies and missions or programs
  - Close interaction between calibration team and science teams or data users for better understanding of the observed differences (over difference targets and among different sensors)
  - Use of calibration reference instrument(s) and the Moon

VIIRS Spectral Bands

16 Moderate (radiometric) bands, 5 Imaging bands, 1 DNB

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

1 DNB:
L/M/HG
32 Agg. Modes

14 RSB:
0.41-2.3 μm

7 DGB:
M1-M5, M7, and M13

7 TEB:
3.7-12.1 μm