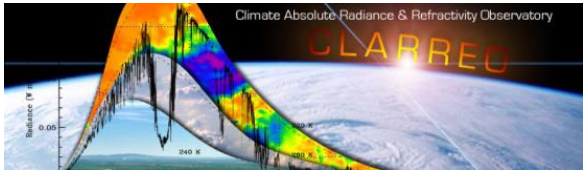

S-NPP VIIRS Instrument Performance and Inter-Calibrations

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NASA Goddard Space Flight Center, Greenbelt, MD 20771

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Science Systems and Applications Inc., Lanham, MD 20760

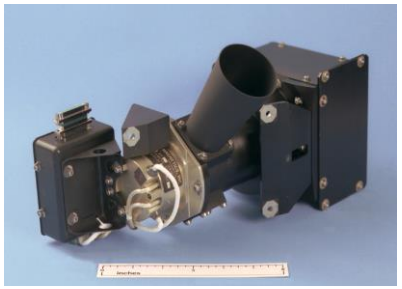
Outline

- **S-NPP VIIRS Reflective Solar Calibration**
- **On-orbit Performance**
  - SD Degradation
  - Spectral Bands Responses and Noise Characterization
  - Recent Changes and Improvements
- **Inter-calibrations**
  - Aqua MODIS and S-NPP VIIRS
  - Inter-calibrations with CLARREO Pathfinder Instrument
- **Summary**

VIIRS Reflective Solar Calibration Strategies and Activities

15 RSB: M1-M11, I1-I3, DNB
H/L gains: M1-5 and M7
λ: 0.4-2.3 μm

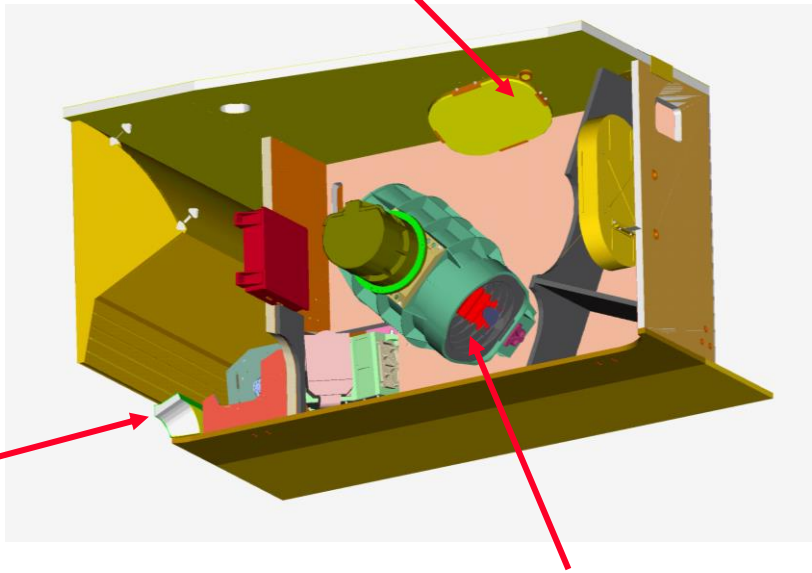
Solar Diffuser Stability Monitor



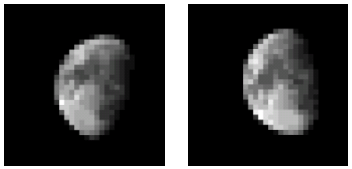
Solar Diffuser

SD calibration each orbit with a fixed screen

Daily operation => 3 per week (8 min => 5 min)



Extended SV Port



Roll maneuvers: 8-9 yearly

Rotating Telescope Assembly (RTA)

Reflectance-based Calibration Approach

VIIRS Radiance (L) Retrieval: $L = F \cdot L_{PL} = F \cdot \underbrace{\left(c_0 + c_1 \cdot dn + c_2 \cdot dn^2\right)}_{L_{PL}} / RVS$

F: Calibration scaling factor from on-orbit calibration

c_i: Pre-launch calibration coefficients (quadratic algorithm)

RVS: Sensor response versus scan-angle (RVS)

Solar Calibration: $F_{SD} = \dfrac{L_{SUN}}{L_{SD,PL}}$ $\quad L_{SUN} \propto \cdot E_{SUN} \cdot BRDF(t) \cdot \tau_{SDS} \cdot \cos(\theta_{inc})$

L_{SUN}: Expected solar radiance reflected from SD panel

$L_{SD,PL}$: Retrieved solar radiance using pre-launch calibration coefficients

Lunar Calibration: Similar to SD CAL with reference to the ROLO model

SD Degradation (H): $BRDF(t) = H_{Norm}(t) \cdot BRDF(t_0)$

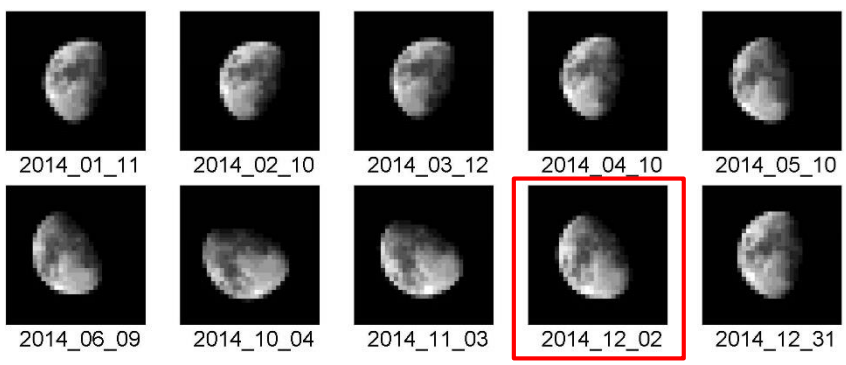
Lunar Calibration Methodologies

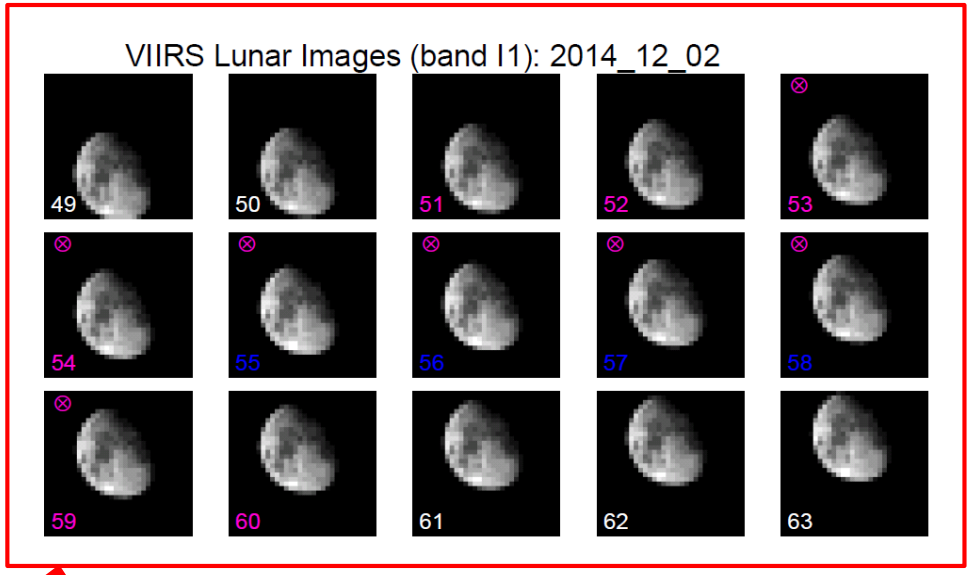
VIIRS Lunar Calibration:

$$F_{MOON} = \frac{I_{ROLO}}{I_{MOON,PL}} = \frac{I_{ROLO}}{\sum_{\det,sam,scan} L_{MOON,PL} \cdot \Omega_B \cdot g / N_{SCAN}}$$

I_{ROLO}: Lunar irradiance (integrated) provided by ROLO model
$I_{MOON,PL}$: Lunar irradiance retrieved using pre-launch calibration coefficients
N_{SCAN}, Ω_B, g: number of scans, pixel solid angle, aggregation factor

Lunar images (I1) from lunar calibration events in 2014

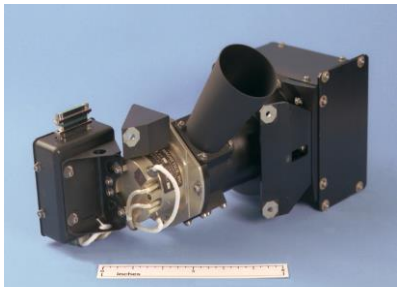




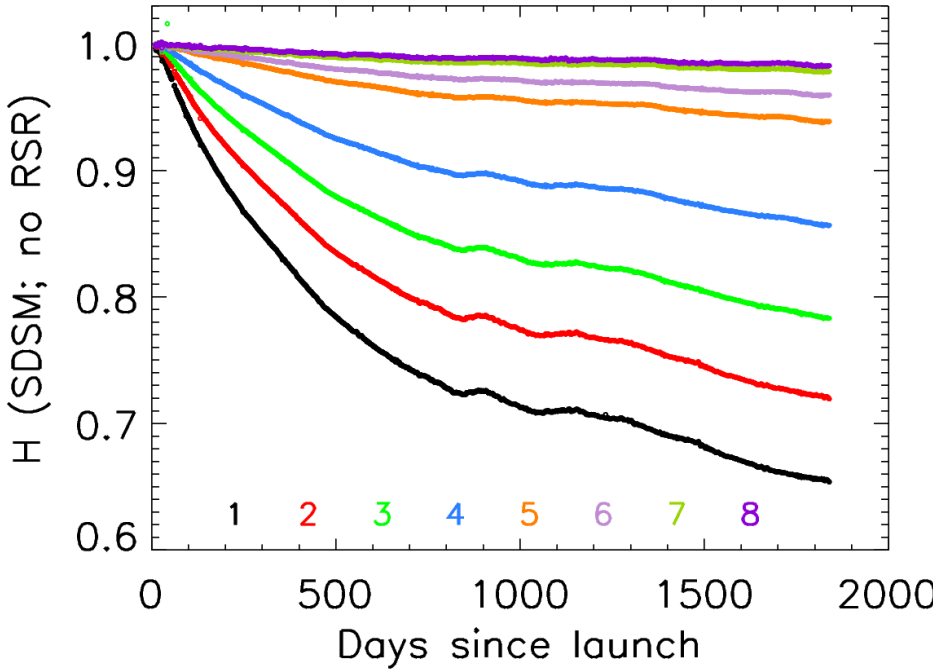
On-orbit Performance

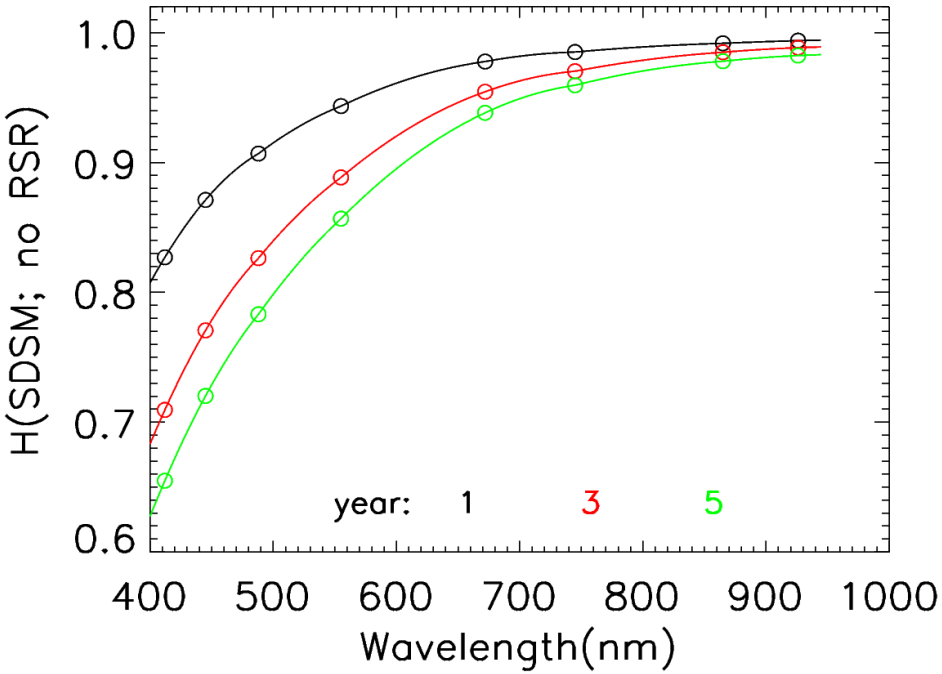
- **SD Degradation**
  - Large degradation at short wavelengths
  - Small but not negligible degradation at SWIR wavelengths
  - Different approach for SD degradation at SWIR as SDSM only covers wavelengths from 0.41 to 0.93 μm
- **Spectral Bands Responses**
  - Large at NIR and SWIR region
  - Strong wavelength-dependent optics degradation => modulated RSR
- **Noise Characterization**
  - Correlated with changes in spectral band responses
  - Sufficient margin remains to meet specified requirements
- **Recent Changes and Improvements**

Solar Diffuser On-orbit Degradation



SDSM
8 detectors: 0.41 – 0.93 μm
3 views: SD, Sun, dark

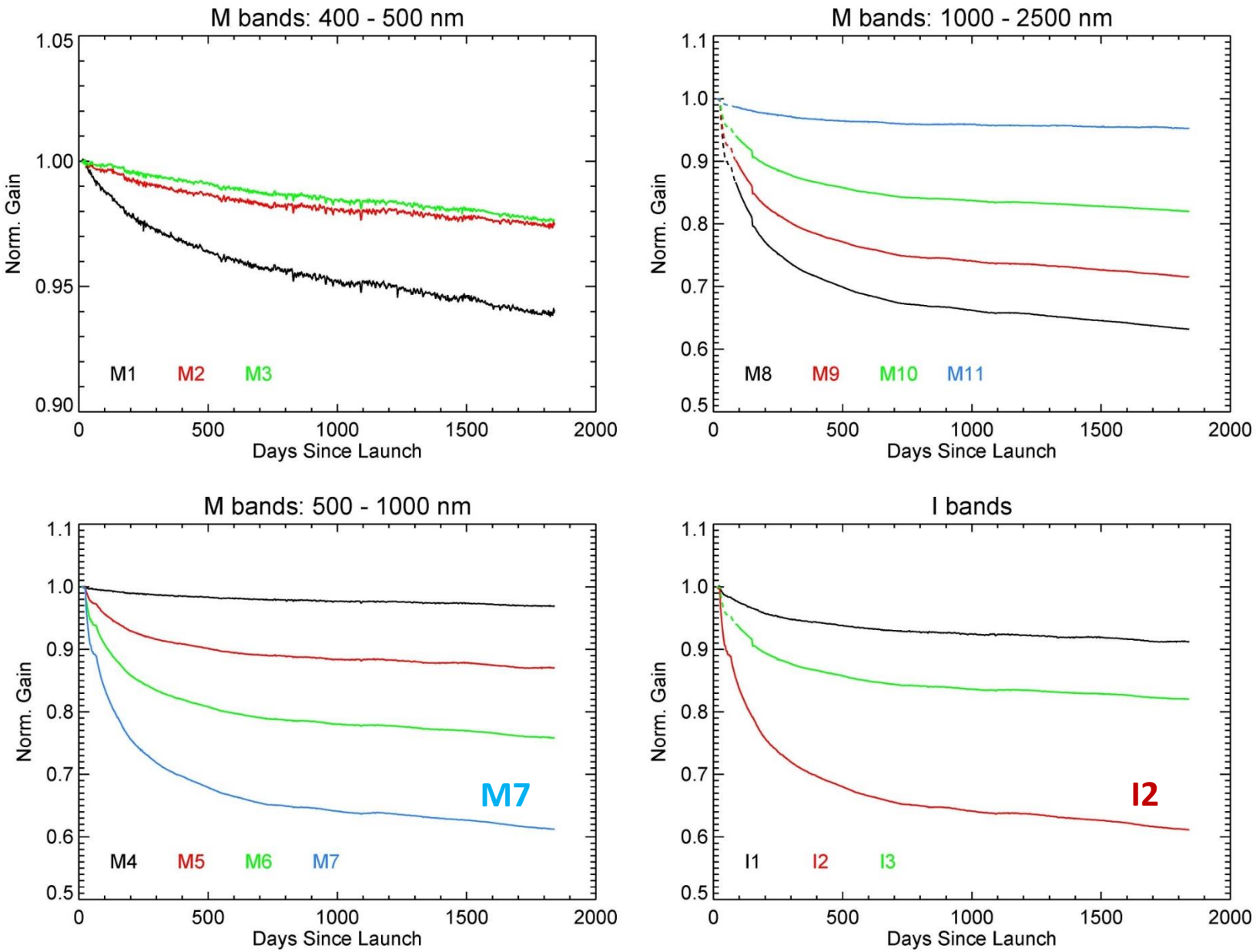




Large at short wavelengths

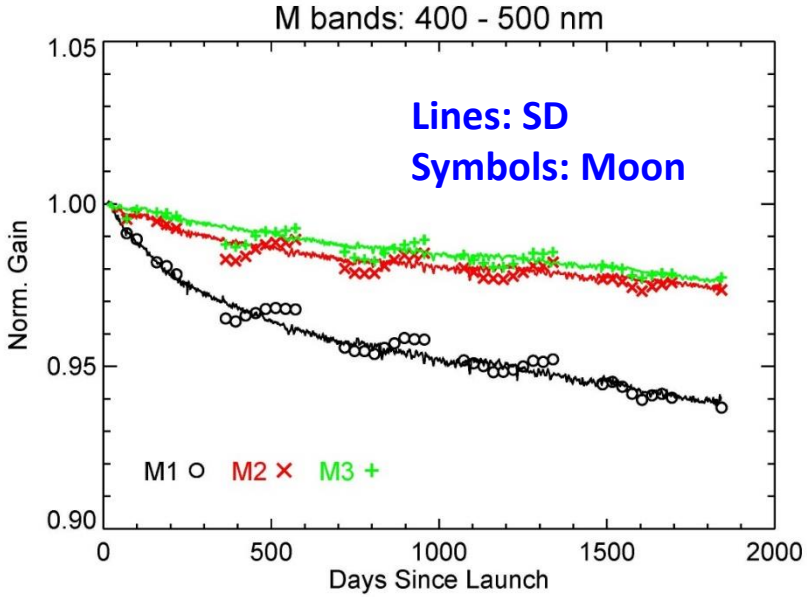
Degradation at SWIR cannot be ignored as mission continues

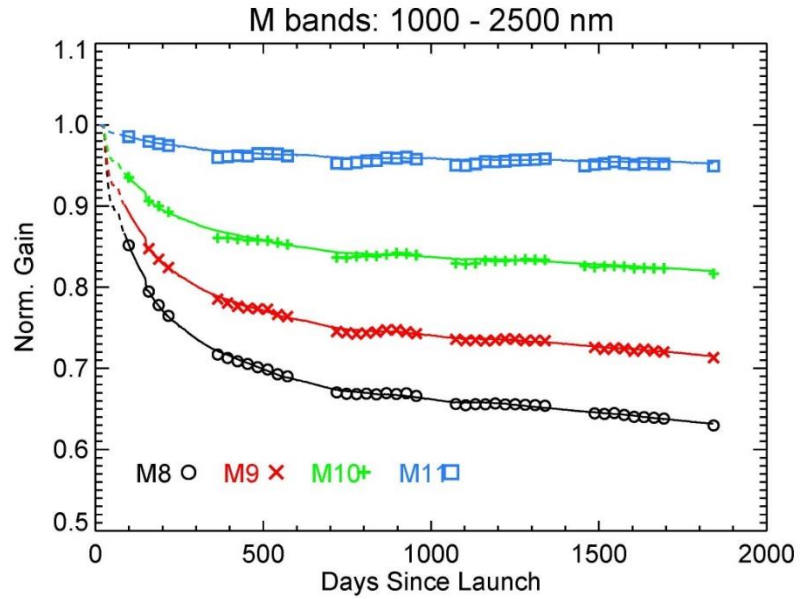
Spectral Bands Responses (SD)

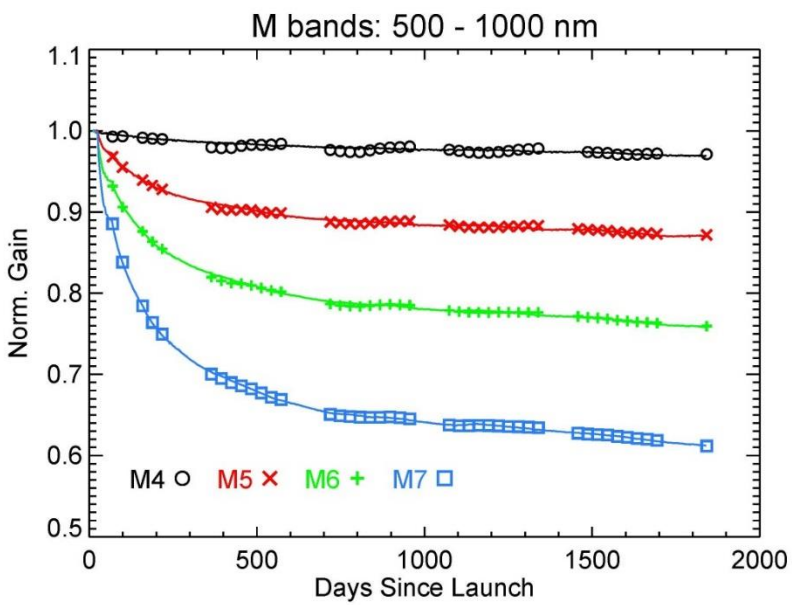


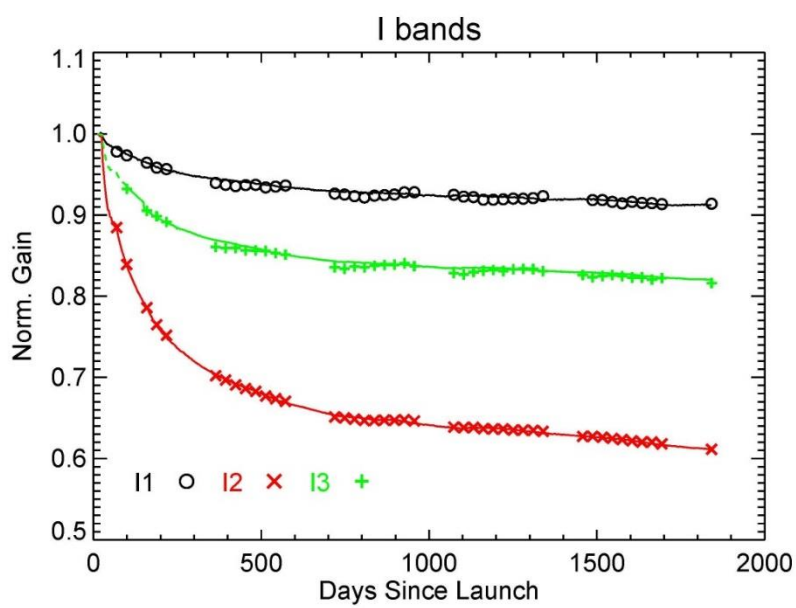
M1	0.41
M2	0.45
M3	0.49
M4	0.56
I1	0.64
M5	0.67
M6	0.75
I2	0.87
M7	0.87
M8	1.24
M9	1.38
I3	1.61
M10	1.61
M11	2.25

Spectral Bands Responses (SD and Lunar CAL)









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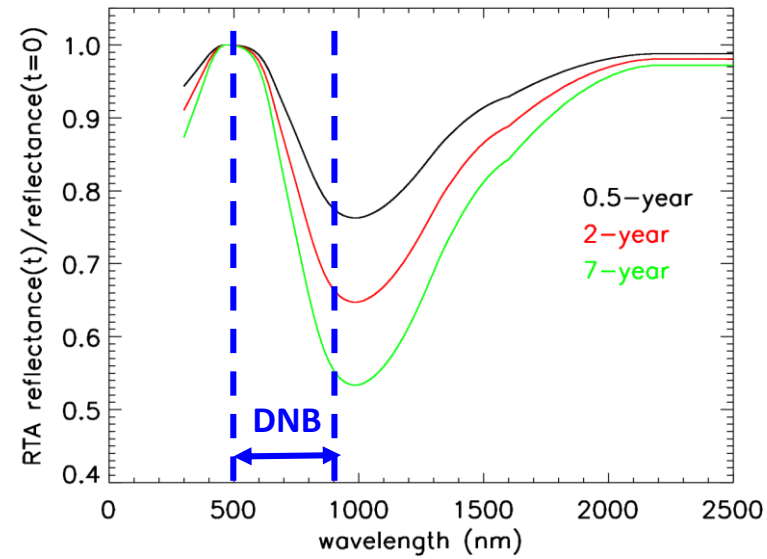
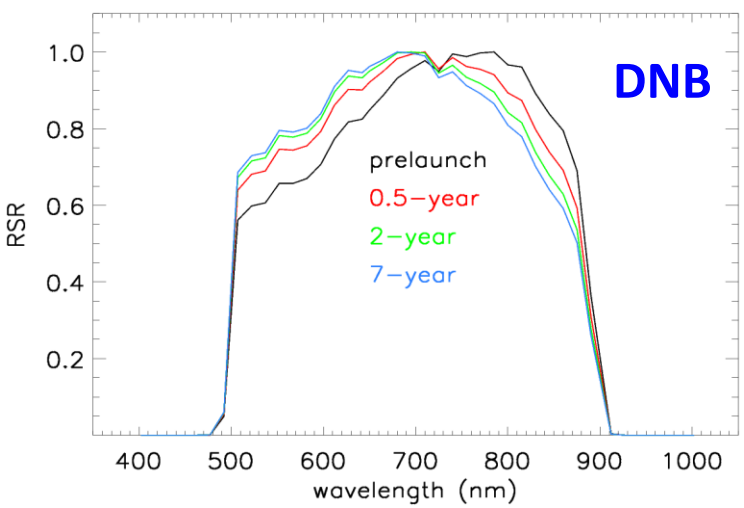
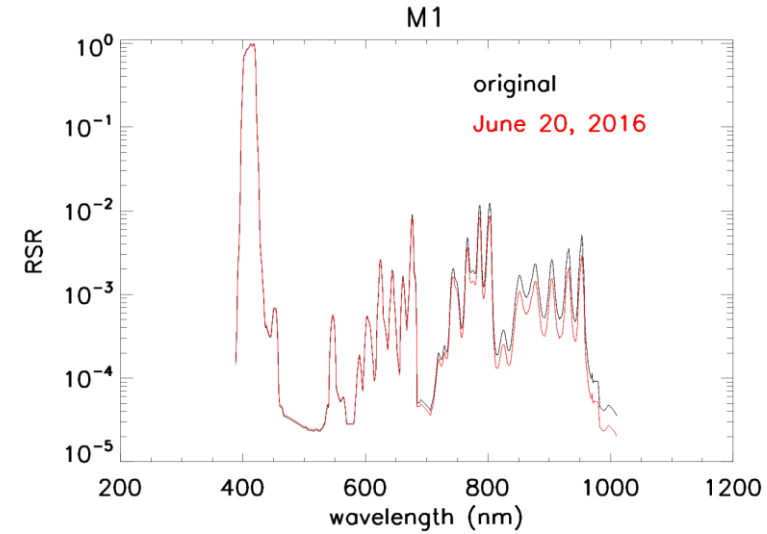
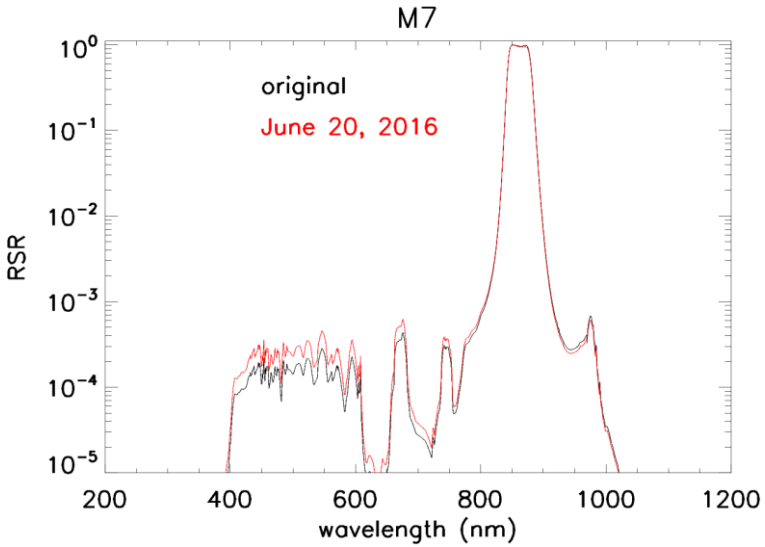
Update and Use of On-orbit Modulated RSR

λ dependent optics degradation





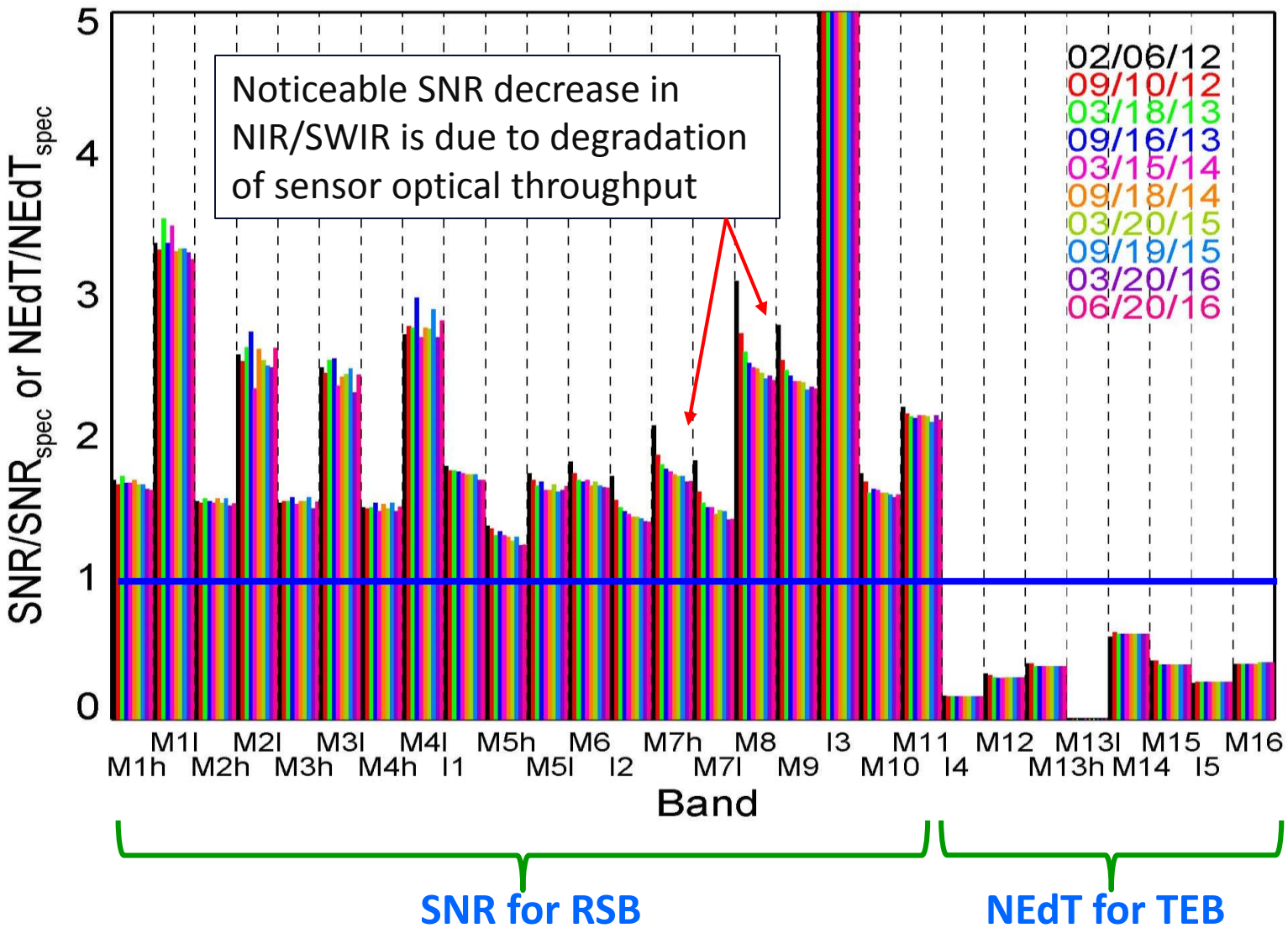




Impact of modulated RSR depends on spectral band location, bandwidth, and OOB response

Detector Noise Characterization

($SNR/SNR_{SPEC} > 1$) or ($NEdT/NEdT_{SPEC} < 1$): better performance



Recent Changes and Improvements

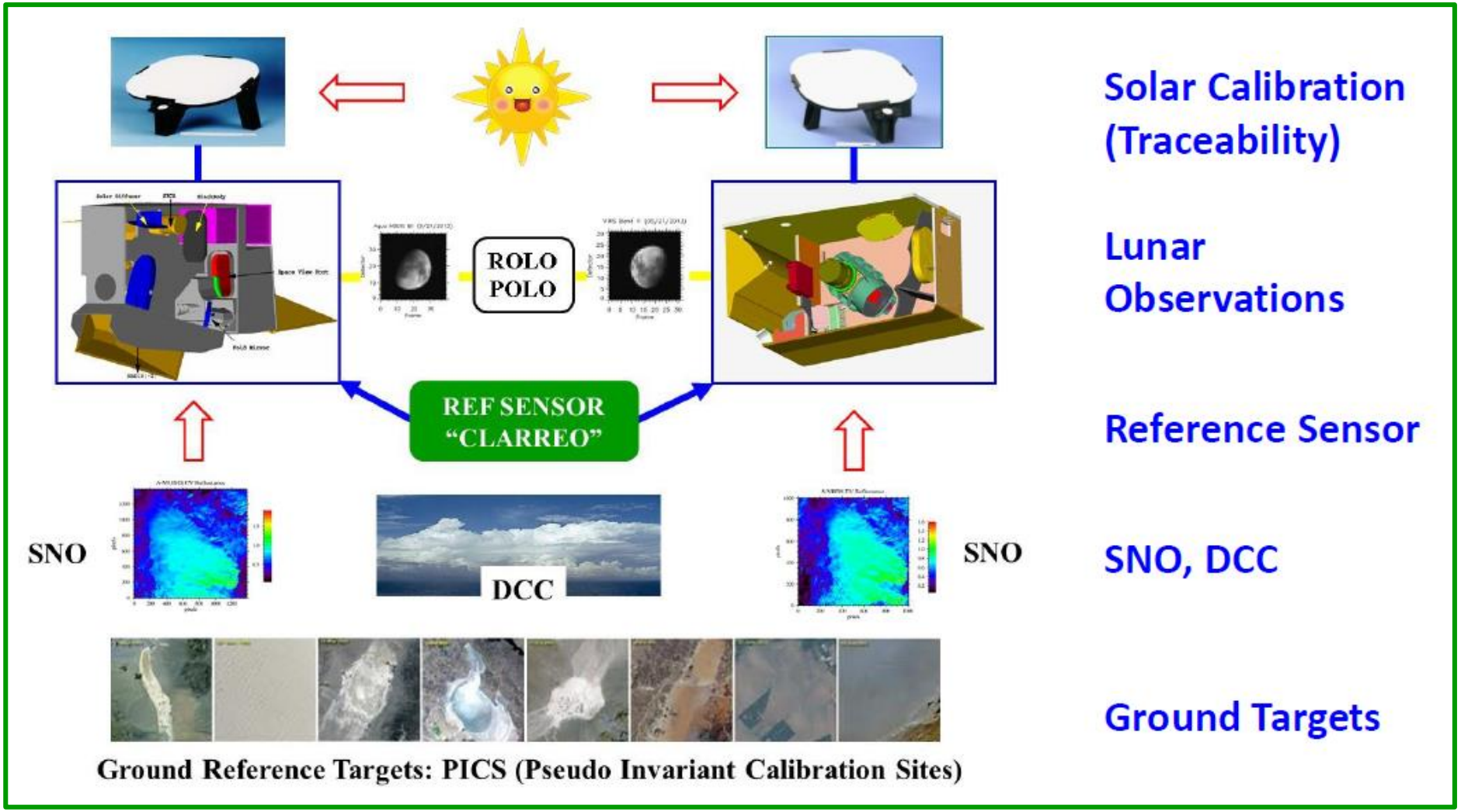
- **Improved SDSM and SD screen vignetting function**
  - Used data from yaw maneuvers and selected regular SD/SDSM calibration events
- **Improved normalization of SD degradation**
  - Revised extrapolation from first SDSM calibration to the mission beginning
- **Use of lunar observations to track SD degradation**
  - Eliminated SD degradation difference between SDSM view and RTA view
  - Derived SD degradation at SWIR wavelengths
- **Added features in NASA SIPS VIIRS L1B**
- **Consistently reprocessed calibration LUTs**

} ***backup slides***

Xiong et al, "Evaluation and Improvements of SNPP VIIRS SDR," NOAA Workshop on Life-Cycle Data Reprocessing to Advance Weather and Climate Applications, May 17-18, 2016

Inter-Calibrations

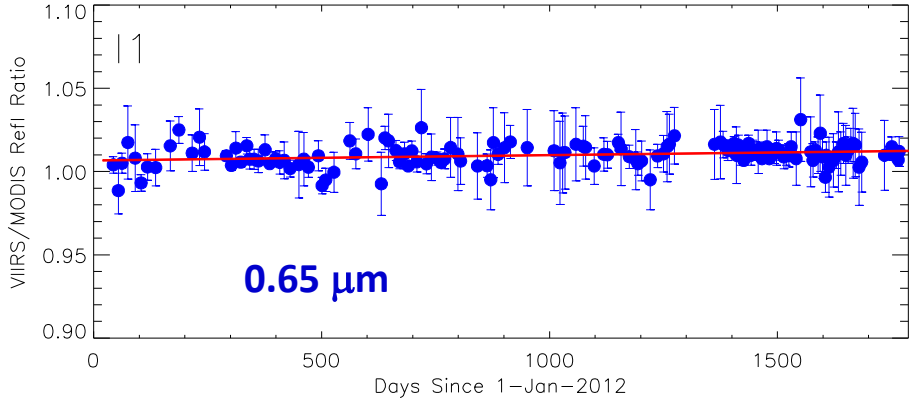
Methodologies for Calibration Inter-comparisons and Reference Transfer

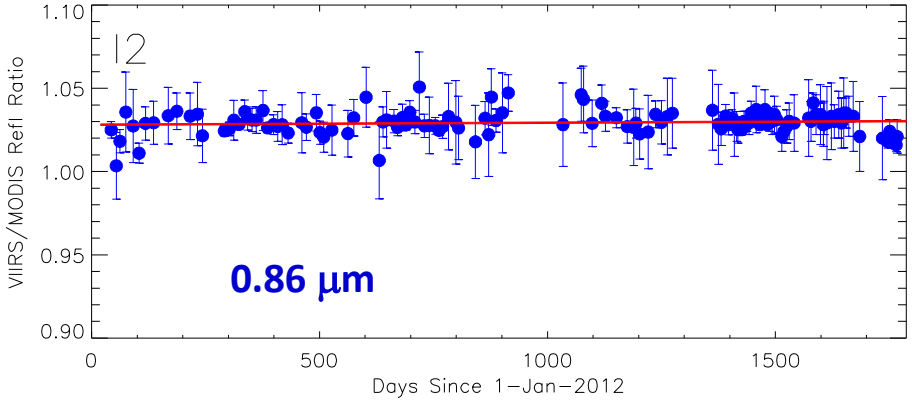


Xiong et al, SPIE 2016

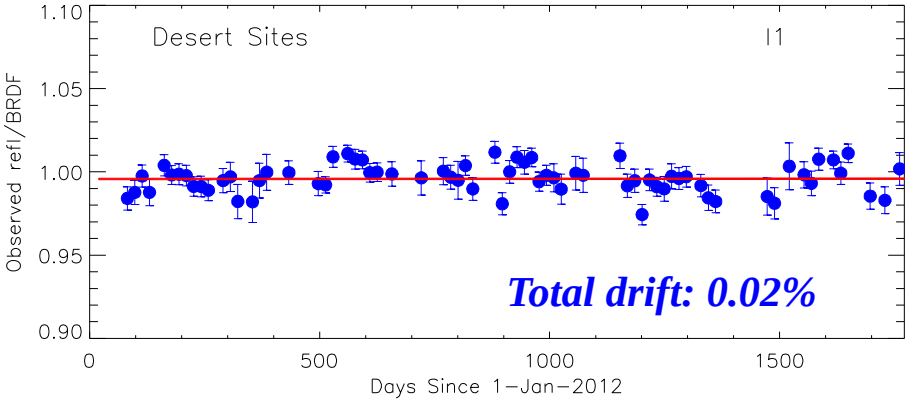
Inter-Calibrations

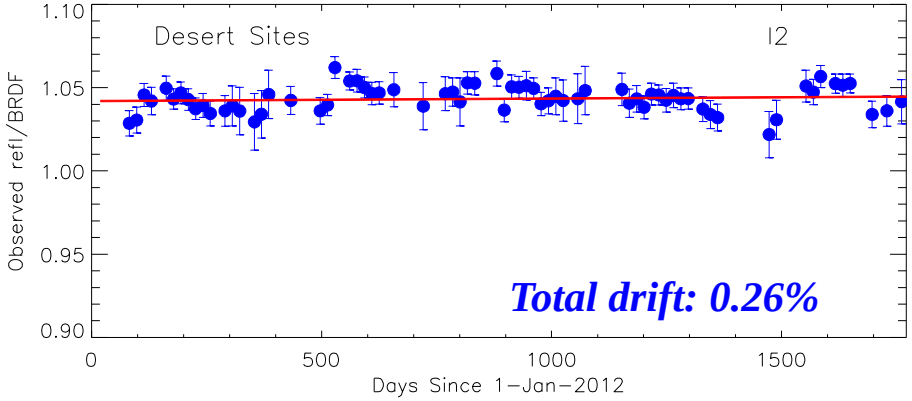
Calibration Inter-comparison of Aqua MODIS and S-NPP VIIRS Using SNO





Calibration Inter-comparison of Aqua MODIS and S-NPP VIIRS Using PICS





MODIS L1B Collection 6; ***VIRIS L1B from NASA Land SIPS***

Published NPP VIIRS (earlier versions) and Aqua MODIS Reflectance Differences (%)

V/M Band	SNO [1]	SNO [2]	Dome C [1]	Dome C [3,4]	Desert [1]	Desert [3-5]	Desert [6]	DCC [7]	Ocean [8]	Ocean [2]
M1/B8	-0.2±1.2	0.8±0.8	-1.3±1.0	-0.2±0.7	0.1±0.9	1.6±0.3	-1.0±0.8	-0.5±1.0	-2.0±1.5	1.2±0.5
M2/B9	-0.7±1.0	-1.7±0.6		-0.5±0.7	-0.3±0.8	0.4±0.3	-1.2±0.8	-0.5±0.8	-4.0±2.0	-1.8±0.5
M3/B10	-1.0±0.7	-1.3±0.4	0.2±0.9	-0.2±0.8		1.3±0.4		-1.0±0.8	-3.5±2.0	-0.1±0.6
M4/B4	1.5±0.7	-1.5±0.3	1.8±1.5	1.6±1.0	-0.9±1.0	-0.2±0.4	-1.5±0.5	2.0±1.0	-1.5±1.5	-0.2±0.9
M5/B1	6.5±1.9	10.0±0.6	5.7±1.8	4.8±0.9	9.2±0.8	9.5±0.5	9.0±0.5	9.0±0.7	1.5±0.5	
M7/B2	2.5±0.6	4.0±0.5	2.2±1.7	2.8±1.4	3.9±0.7	4.0±0.5	3.5±0.5	2.5±0.5	4.0±2.0	
I1/B1	-0.3±0.7		-0.4±1.5		-1.7±0.9		-2.0±0.5			
I2/B2	2.6±0.6		2.3±1.8		4.0±0.7		3.5±0.5			

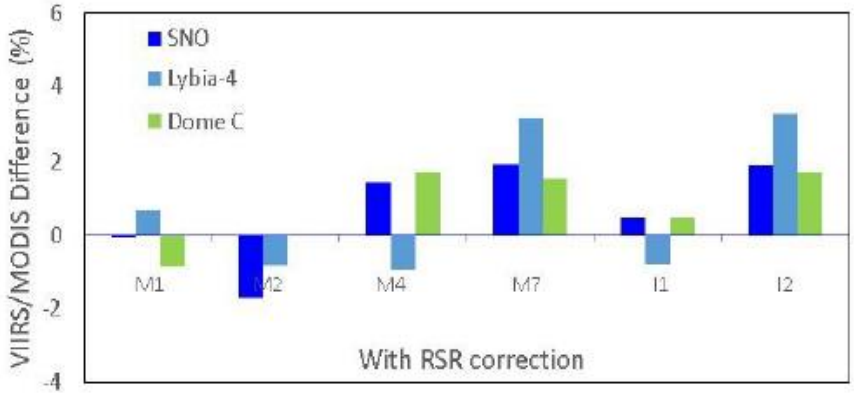
Difference (%) = (VIIRS – MODIS)*100/MODIS (**no RSR correction**)
Differences remain after RSR correction (some getting smaller and some larger; scene dependent)

References

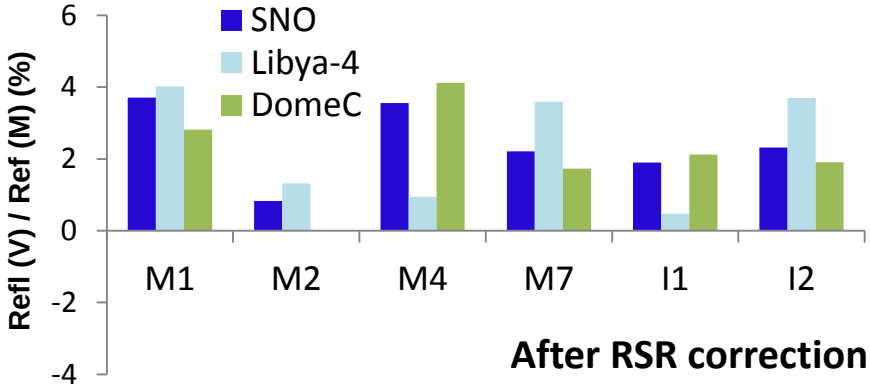
1. Wu, A., X. Xiong, C. Cao, and K. Chiang, “Assessment of SNPP VIIRS VIS/NIR radiometric calibration stability using Aqua MODIS and invariant surface targets”, IEEE Transactions on Geoscience and Remote Sensing, Vol. 54, No. 5, pp. 2918-2924, 2016.
2. Uprety, S., C. Cao, X. Xiong, S. Blonski, A. Wu, and X. Shao, “Radiometric Intercomparison between Suomi-NPP VIIRS and Aqua MODIS Reflective Solar Bands Using Simultaneous Nadir Overpass in the Low Latitudes”, J. Atmos. Oceanic Technol., 30, 2720–2736. 2013.
3. Uprety, S., C. Cao, S, Blonski, W. Wang, Assessment of VIIRS radiometric performance using vicarious calibration sites, Proc. SPIE 9218, Earth Observing Systems XIX, 92180I, doi:10.1117/12.2061855, 2014
4. Uprety, S., C. Cao, Suomi NPP VIIRS reflective solar band on-orbit radiometric stability and accuracy assessment using desert and Antarctica Dome C sites, Remote Sensing of Environment, Vol. 166, pp. 106–115, 2015, doi:10.1016/j.rse.2015.05.021.
5. Uprety, S., C. Cao, S, Blonski,, Retrospective analysis of Suomi NPP VIIRS radiometric bias for reflective solar bands due to operational calibration changes, International J. Remote Sens., 37 (22), pp.5472-5489, 2016.
6. Chang, T., X. Xiong, A. Angal, A. Wu, BRDF characterization and calibration inter-comparison between Terra MODIS, Aqua MODIS, and S-NPP VIIRS, Proc. SPIE 10000, Sensors, Systems, and Next-Generation Satellites XX, 100000Z, doi:10.1117/12.2239888, 2016.
7. Wang, W., and C. Cao, “Assessing the VIIRS RSB calibration stability using deep convective clouds”, Proc. SPIE, 9264, Earth Observing Missions and Sensors: Development, Implementation, and Characterization III, doi:10.1117/12.2068434, 2014.
8. Pahlevan, N., Z. Lee, R. Arnone, and A. Lawson, Investigating the Consistency between VIIRS and MODIS over the Oceans: The Sensor/Environmental Data Records (SDR/EDR), 2013.

Averaged S-NPP VIIRS and Aqua MODIS Reflectance Differences (%)

with RSR correction



NASA VIIRS L1B (before latest reprocessing)



NASA VIIRS L1B (current version)

Inter-calibrations with CLARREO Pathfinder Instrument

- **Calibration accuracy and stability of reference instrument**
- **Accurate characterization of sensor relative spectral response (RSR)**
  - Both in-band (IB) and out-of-band (OOB); OOB impact and correction
- **Accurate characterization of sensor polarization sensitivity**
  - CPF instrument and sensors to be inter-calibrated
  - Experience from MODIS (Terra and Aqua) and VIIRS (S-NPP, J1, J2)
- **Accurate characterization of sensor response versus scan-angle (RVS)**
  - Sensor viewing geometry
  - On-orbit changes

Inter-calibrations with CLARREO Pathfinder Instrument

- **Solar spectral irradiance used by individual sensors**
- **Reflectance versus radiance-based calibration/inter-calibrations**
- **Sensor spatial resolutions**
- **Ground target BRDF and atmospheric effect**
- **Improved (use of) lunar model** (see presentation by T. Stone)
  - ROLO data Reanalysis Effort
  - NIST measurements with high accuracy and traceability
  - Use of CNES POLO data
  - GSICS activities

Summary

- **S-NPP VIIRS continues to operate normally with overall performance meeting the need for operational users (SDRs/EDRs from IDPS) and science community (reprocessed SDRs/EDRs)**
  - Parallel effort by NASA VCST and NOAA SDR team
  - Consistent data reprocessing
- **Approaches derived from sensor calibration inter-comparisons can be adopted for CPF inter-calibration**
- **Considerations and effort need to be made to reduce or minimize the uncertainties of CPF inter-calibration**
  - Reference instrument stability, traceability, and accuracy
  - Sensor performance characteristics (RSR, RVS, POL, …)
  - Spatial sampling, atmospheric effect and BRDF correction

Aqua MODIS	S-NPP VIIRS	JPSS-1 VIIRS	JPSS-2 VIIRS
2002 →	2011 →	2017 →	2021 →

VIIRS and MODIS 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

14 RSB
(0.4-2.3 μm)

Dual Gain Bands:
M1-M5, M7, M13

7 TEB

Status of NASA SIPS L1B

- **NASA SIPS L1B Software**
  - V2.0.0 officially released to SIPS on Oct 18, 2016 (testing and evaluation in July-Oct).
  - VIIRS L1A and L1B software developed under NASA EDOS/SIPS.
  - The L1A, L1B, and LUTs data in NetCDF4 format.
  - The first L1B software V1.1.0 released in Jan 2016 (based on IDPS SDR code version Mx8.10). The contents of NASA L1B V1.1.0 match with NOAA IDPS SDR Mx8.10 or Mx8.11 (current) if the same calibration coefficients and parameters are applied.
  - 6-min L1A granule and L1B calibration Look-Up-Tables (LUTs) are required as input to generate 6-min L1B geolocation and radiometric products, including On-Board Calibrator (OBC) files for calibration and trending purpose.
  - Monthly L1B LUTs updates are provided by VCST.

Collection	Code Base	# of LUTs	Delivery Time	Note
V1.1.0	L1B V1.1.0	9	2016.02 - 2016.10	Redesigned L1B software, LUTs, and data format using L1A data input.
V2.0.0	L1B V2.0.0	3	2016.08 - 2016.10	Improved L1B software functions and algorithms.

Updated by K. Chiang (VCST)

Changes in VIIRS L1B V2.0.0

- **Changes in V2.0.0 compared to V1.1.0**

A. Functional changes

- Add fill values for specific data states requested by Land team.
- Partial scan line processing capability to support along-scan extracts.
- Dual gain bands un-aggregated L1B becomes official product.
- Add RSR tables in RSB LUT. Remove radiance tables from TEB LUT.
- Single resolution processing and output in geolocation.
- Add moon phase angle and moon illumination fraction in DNB geolocation.
- Add limit checks on attitude angles in geolocation.

B. Algorithm changes

- Use solar irradiance at 1 AU distance to avoid computation of large number in meters.
- Temperature dependent coefficients for RSB Cal.
- Apply time-dependent modulated RSR in RSB Cal.
- Add running average option for TEB F-factor in TEB Cal.
- BB thermistors weighting (selection) to decrease orbital variation in F-factor for TEB Cal.
- Alternative calibration when moon is in SV.
- Apply out of range limits based on dn.

Updated by K. Chiang (VCST)