MODIS and VIIRS Reflective Solar Bands Calibration, Performance, and Inter-comparison

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Outline

- Background
- MODIS and VIIRS On-orbit Calibration
  - Solar and Lunar Calibration
- On-orbit Performance
  - Sensor Performance
  - Calibration Inter-comparison
- Summary

Background

- **Moderate Resolution Imaging Spectroradiometer (MODIS)**
  - Key instrument for NASA EOS Terra and Aqua missions
  - 20 reflective solar bands (RSB) and 16 thermal emissive bands (TEB)
  - RSB spectral wavelengths: 0.41 - 2.2 μm; TEB: 3.75 - 14.5 μm
  - Spatial resolution: 250 m (2 bands), 500 m (5 bands), and 1 km (29 bands)
- **Visible/Infrared Imager Radiometer Suite (VIIRS)**
  - Key instrument for S-NPP and future JPSS missions
  - 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), and 1 day night band (DNB)
  - RSB spectral wavelengths: 0.41 -2.3 μm ; TEB: 3.75 - 12.2 μm
  - Spatial resolution: 375 m for I bands and DNB; 750 m for M bands

Aqua MODIS is currently used as the reflective solar calibration reference
VIIRS, with strong MODIS heritage, should be considered as a future reference sensor

MODIS and VIIRS Spectral Bands

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

○ Dual gain band

Similar MODIS bands

MODIS and VIIRS On-orbit Calibration

- **Same On-board Calibrators**
  - Solar Diffuser
  - Solar Diffuser Stability Monitor (SDSM)
  - Space View (SV)

- **Solar Calibration**
  - MODIS: Regular SD/SDSM observations (SD door opens only during scheduled SD/SDSM calibration)
  - VIIRS: Continuous SD calibration (no SD door) in each orbit with SDSM currently scheduled on a daily basis
- **Lunar Calibration – same strategy**
  - Regularly scheduled at nearly the same phase angle
  - Observed through SV port
  - SC roll maneuvers

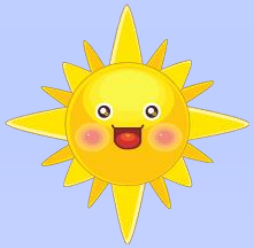
MODIS Solar Calibration

EV Reflectance Factor:

$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$$

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$



Solar Diffuser

SRCA

SDSM

Blackbody

Scan Mirror

Space View

Δ_{SD}: SD degradation factor

Γ_{SD}: SD screen vignetting function

d: Earth-Sun distance

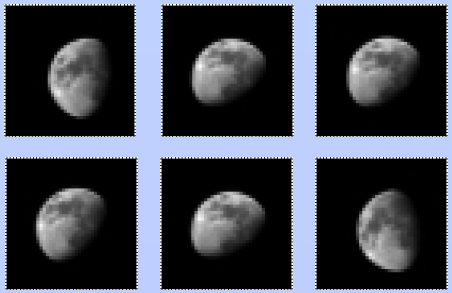
dn*: Corrected digital number

dc: Digital count of SDSM

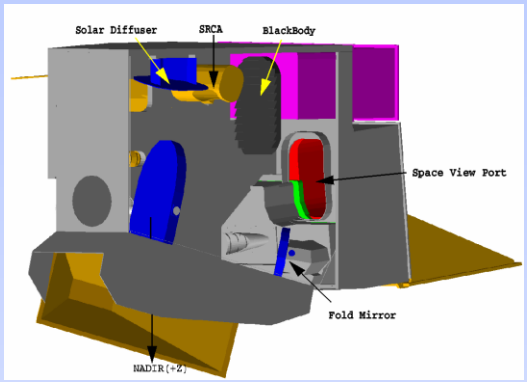
MODIS Lunar Calibration

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

Aqua MODIS B1 Lunar Images



gain ∝ 1/m_1



$$m_1 = \frac{f(view\_geometry)}{< dn^*_{Moon} >}$$

Geometric Factors

MODIS SD and lunar observations are made at different scan angles

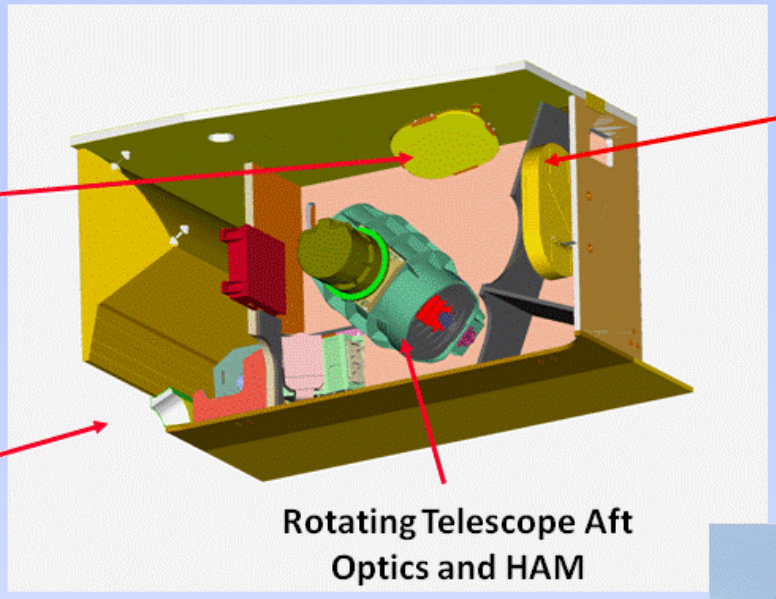
$$f = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{over-sampling}}{d^2_{Sun-Moon} \cdot d^2_{Modis-Moon}}$$

VIIRS On-orbit Calibration

- **Similar to MODIS**
  - **Linear algorithm for MODIS; Quadratic algorithm for VIIRS**
  - **More stringent limit for lunar calibration roll angles**

m_1 => F-factor

Solar Diffuser with Fixed Screen

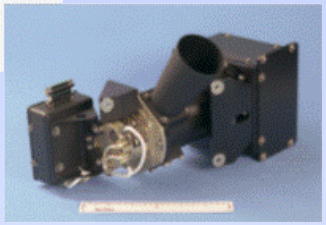


Rotating Telescope Aft Optics and HAM

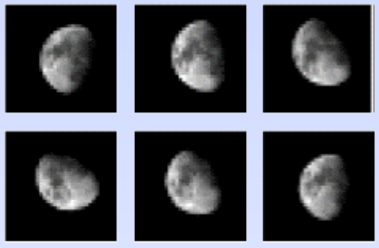
Extended SV Port

Blackbody

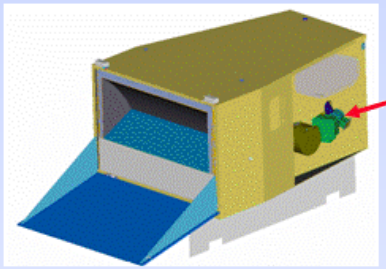
Δ_{SD} => H-factor



Solar Diffuser Stability Monitor



S-NPP VIIRS I1 Lunar Images



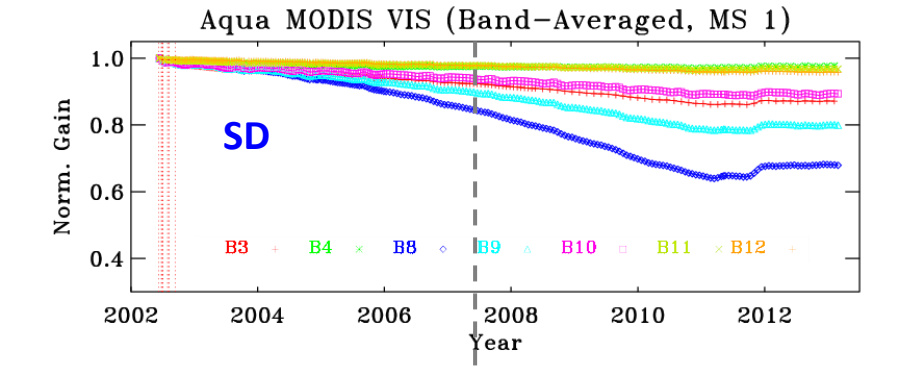
No SRCA for VIIRS

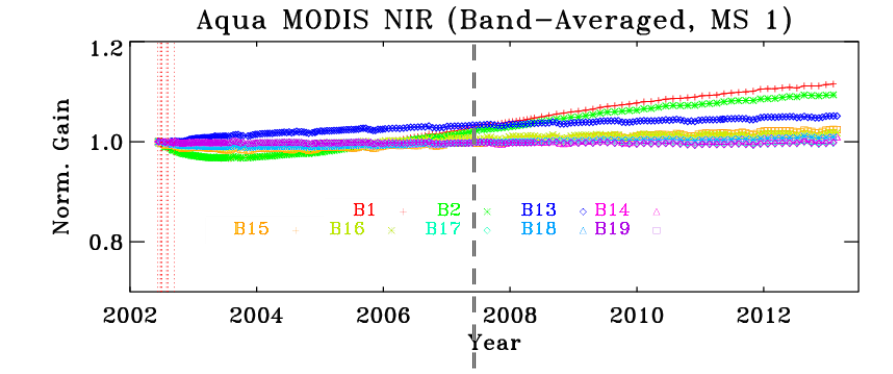
On-orbit Performance

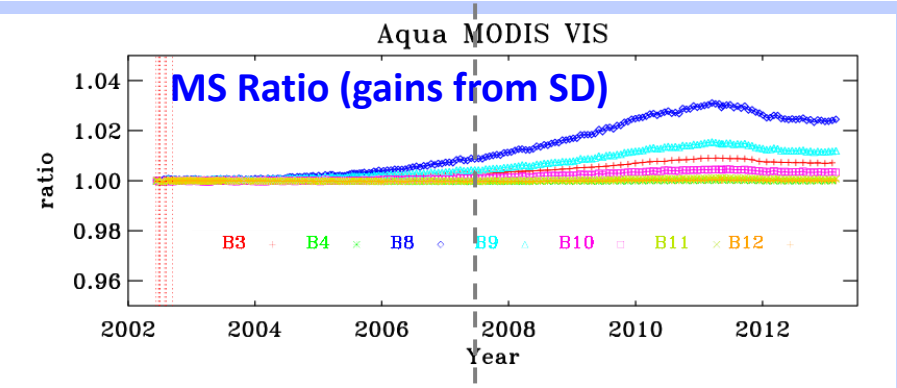
- **Sensor Performance**
  - **Changes in RSB Response**
  - **SD Degradation**
- **Calibration Inter-comparison (preliminary results)**
  - **SNO**
  - **Libya-4 Desert**

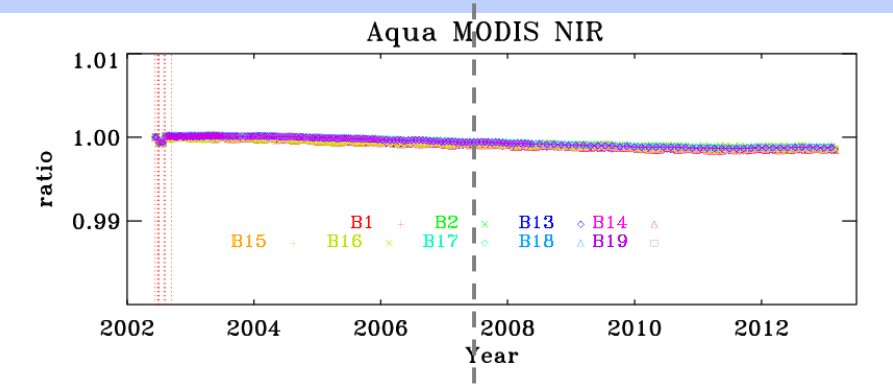
Aqua MODIS and S-NPP VIIRS

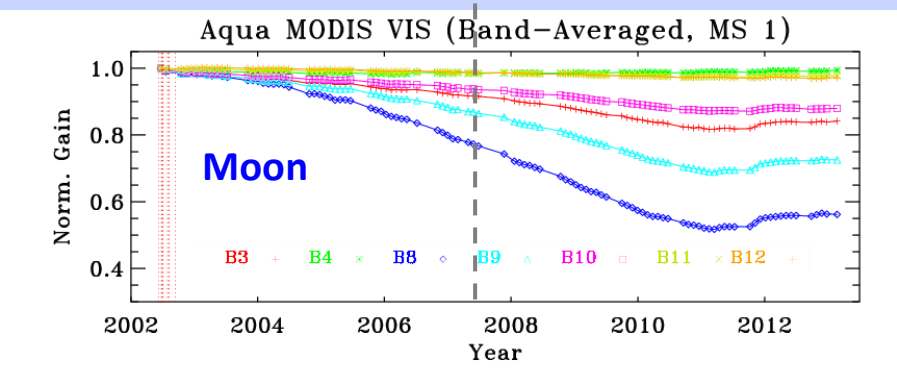
MODIS RSB On-orbit Performance

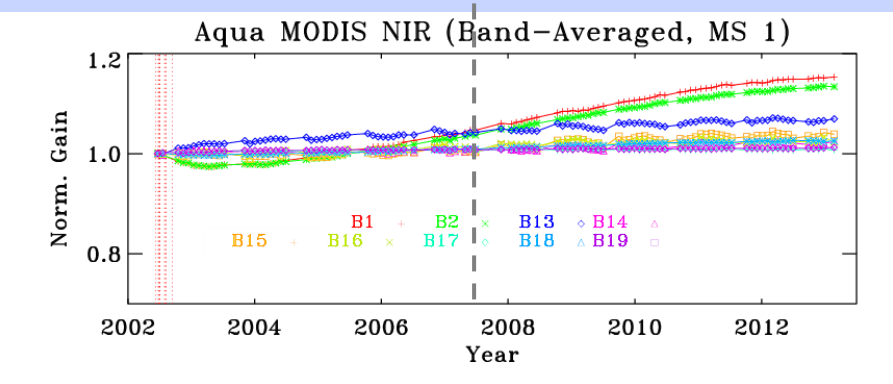






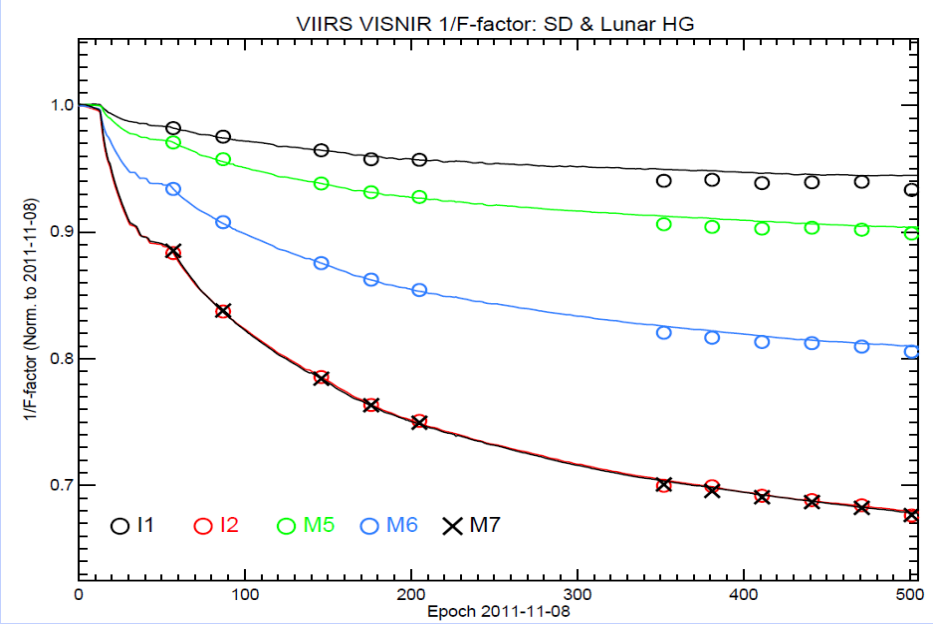


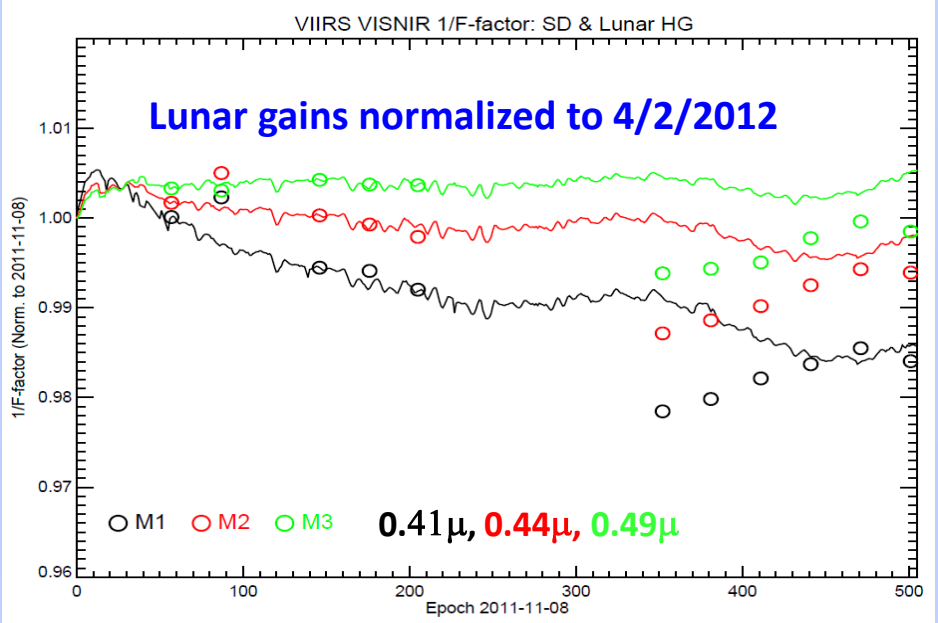


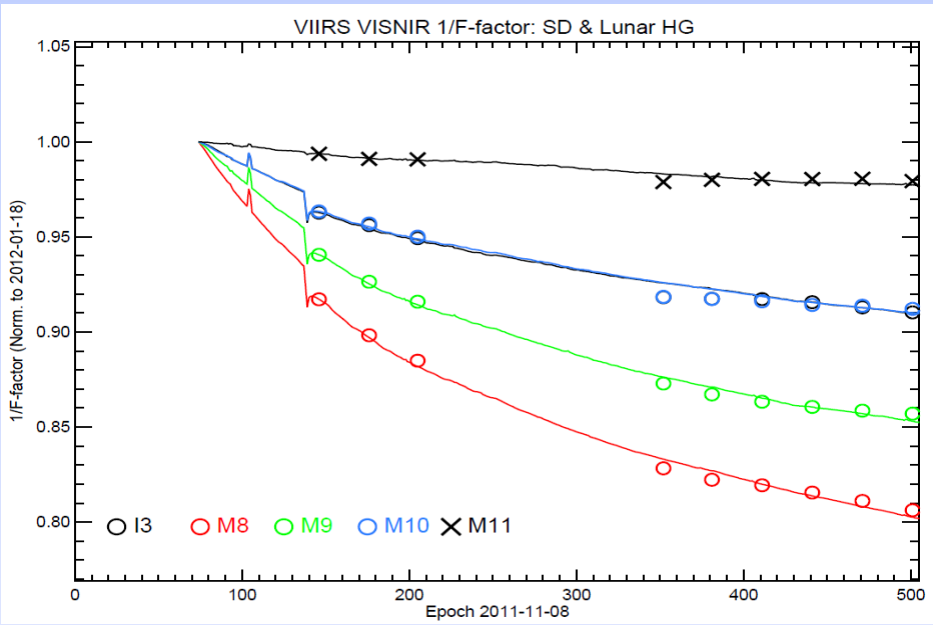


Large Changes in VIS (including mirror side dependence and AOI dependency)

VIIRS RSB On-orbit Performance







Little change for HAM side and AOI dependence

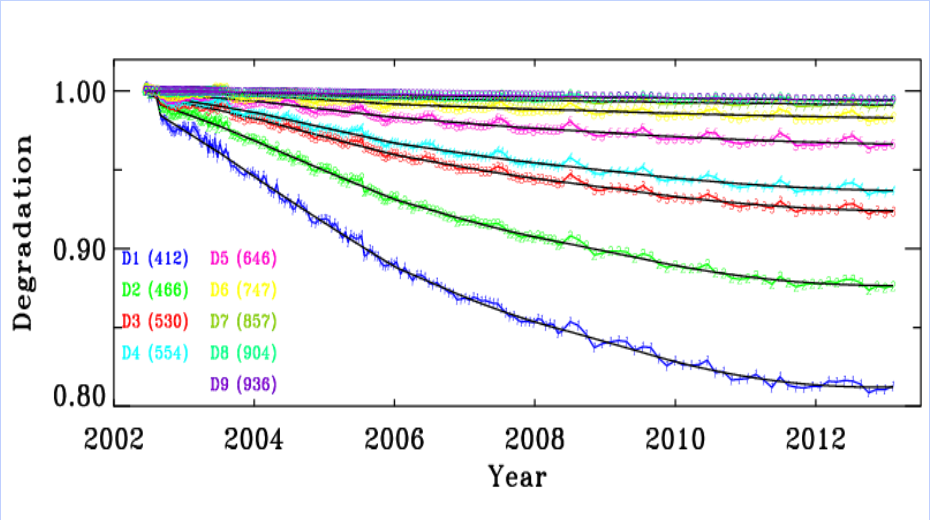
Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration difference in VIS (M1-M3)

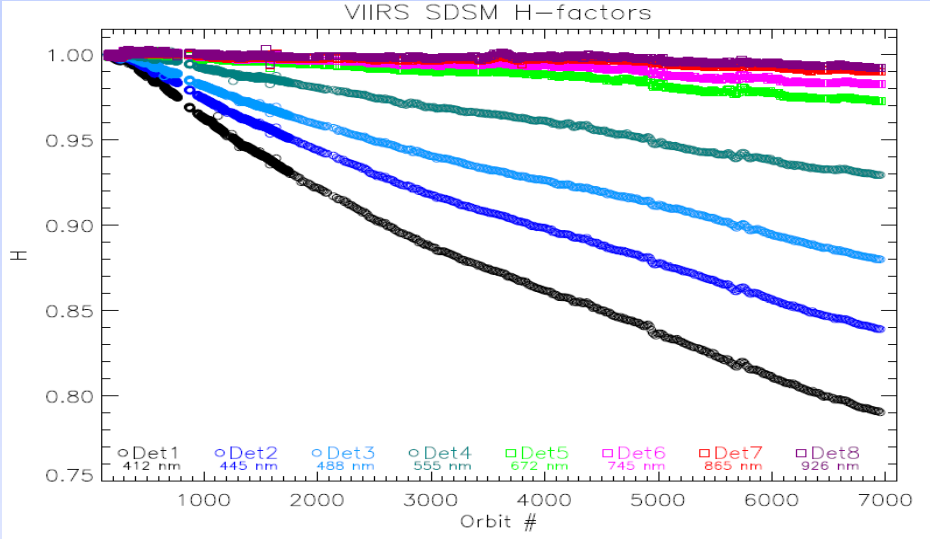
Future Calibration Improvements: Use of modulated RSR

SD On-orbit Degradation

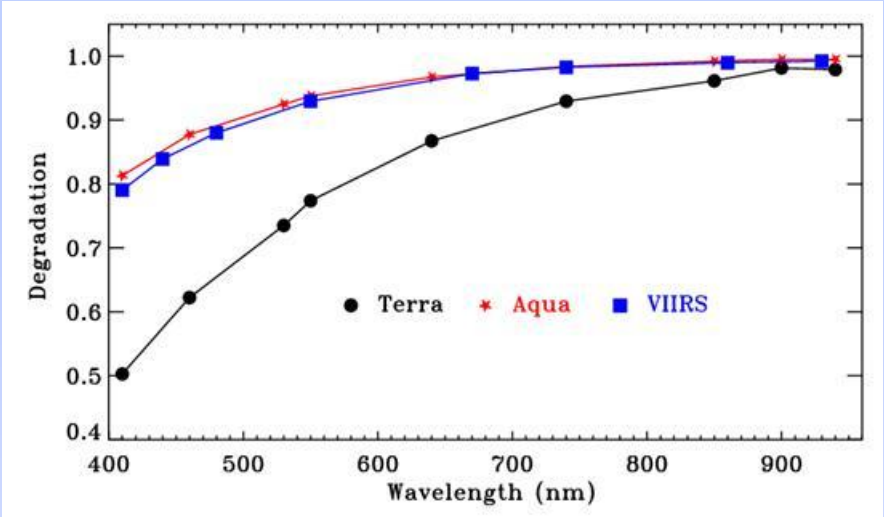
Aqua MODIS (~11 yr)



S-NPP VIIRS (~1.5 yr)



SD On-orbit Degradation Tracked by On-board SDSM



VIIRS has no SD door:

Large degradation in SD BRF

Potential impact on SD calibration

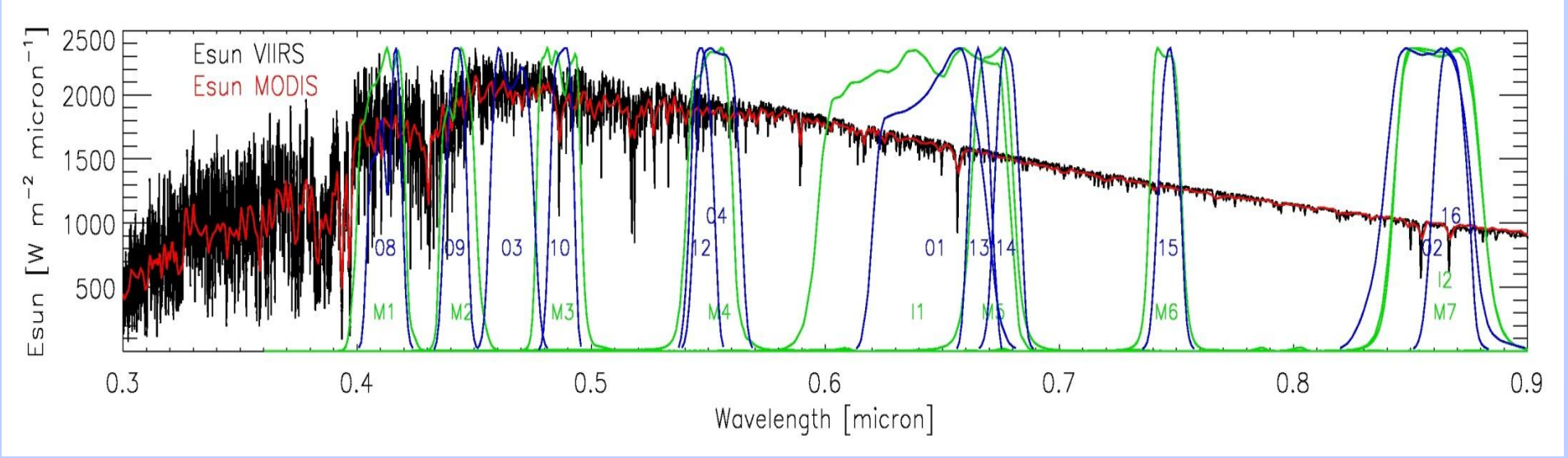
Calibration Inter-comparison

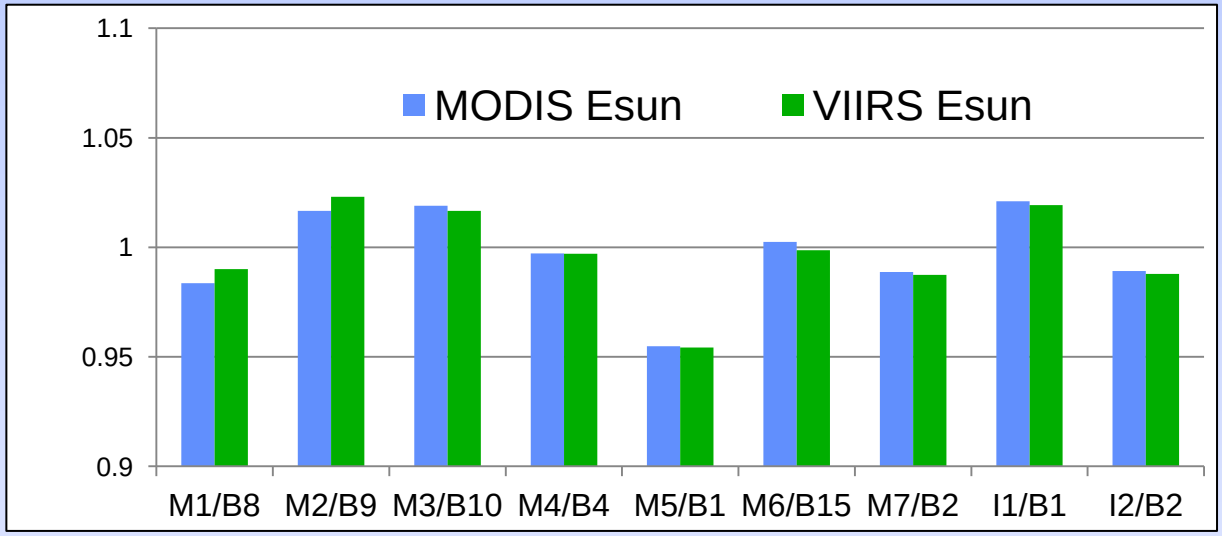
- **Approaches**
  - **SNO**
  - **Libya-4 desert**
- **Methodologies**
  - **Common region of interest (ROI): 20 km by 10 km**
  - **Cloud screening (spatial uniformity checking)**
  - **Correction for sensor RSR difference (MODTRAN simulation)**
  - **Correction for site-dependent BRDF effect (MODIS based BRDF)**

$$\text{BRDF}\ (\theta,\psi,\varphi) = K_0 + K_1 f_1(\theta,\psi,\varphi) + K_2 f_2(\theta,\psi,\varphi)$$

References:
Roujean J.L. et al. 1992, *JGR*; Wu et al., 1995, *JGR*; Schaaf, C.B., 2002, *RSE*

Sensor RSR and Solar Irradiance Model

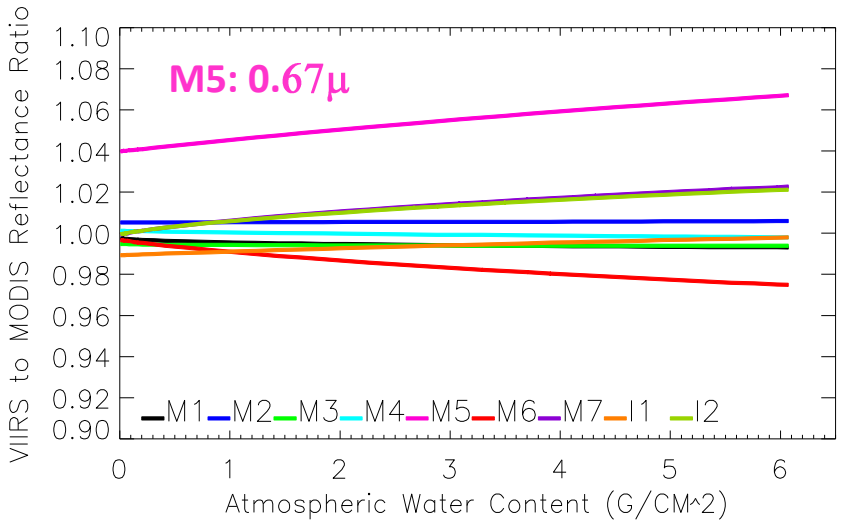


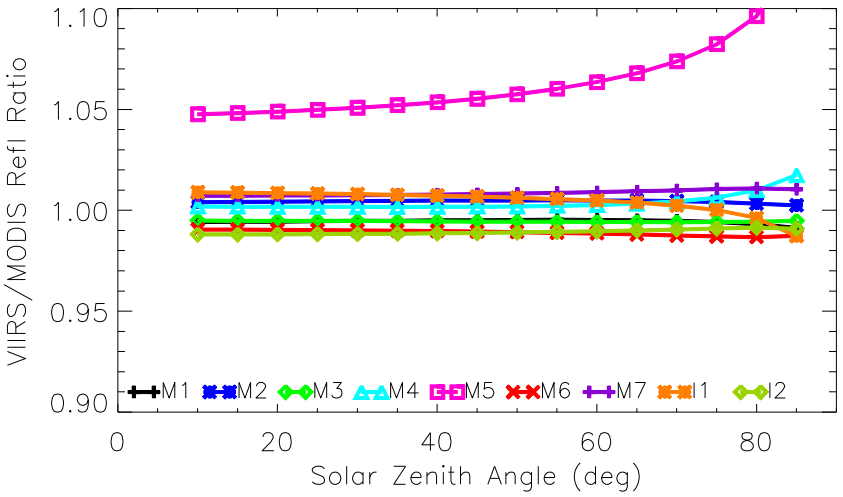


VIIRS to MODIS radiance ratios determined using sensor RSR and Esun models for their spectrally matched bands

MODTRAN5 Simulations

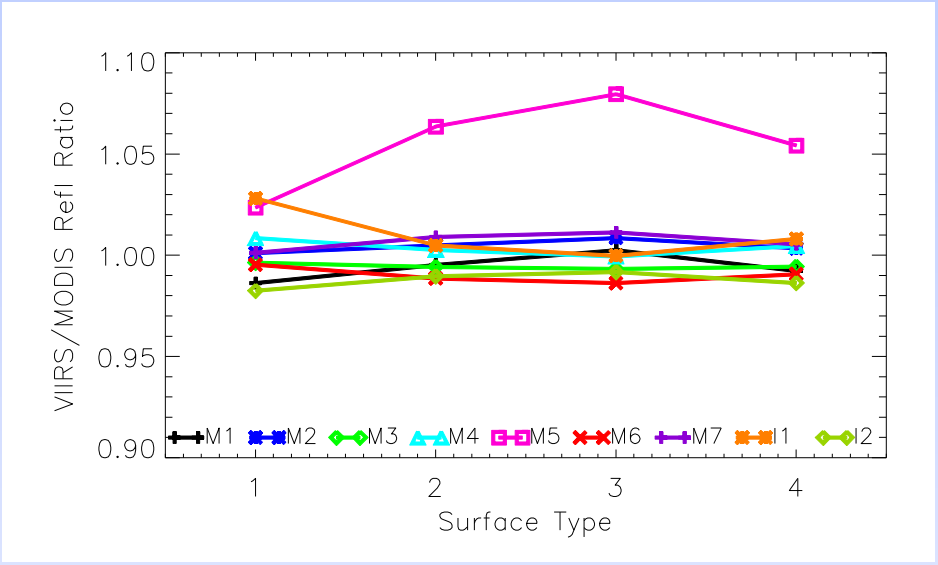
VIIRS/MODIS Reflectance Ratio



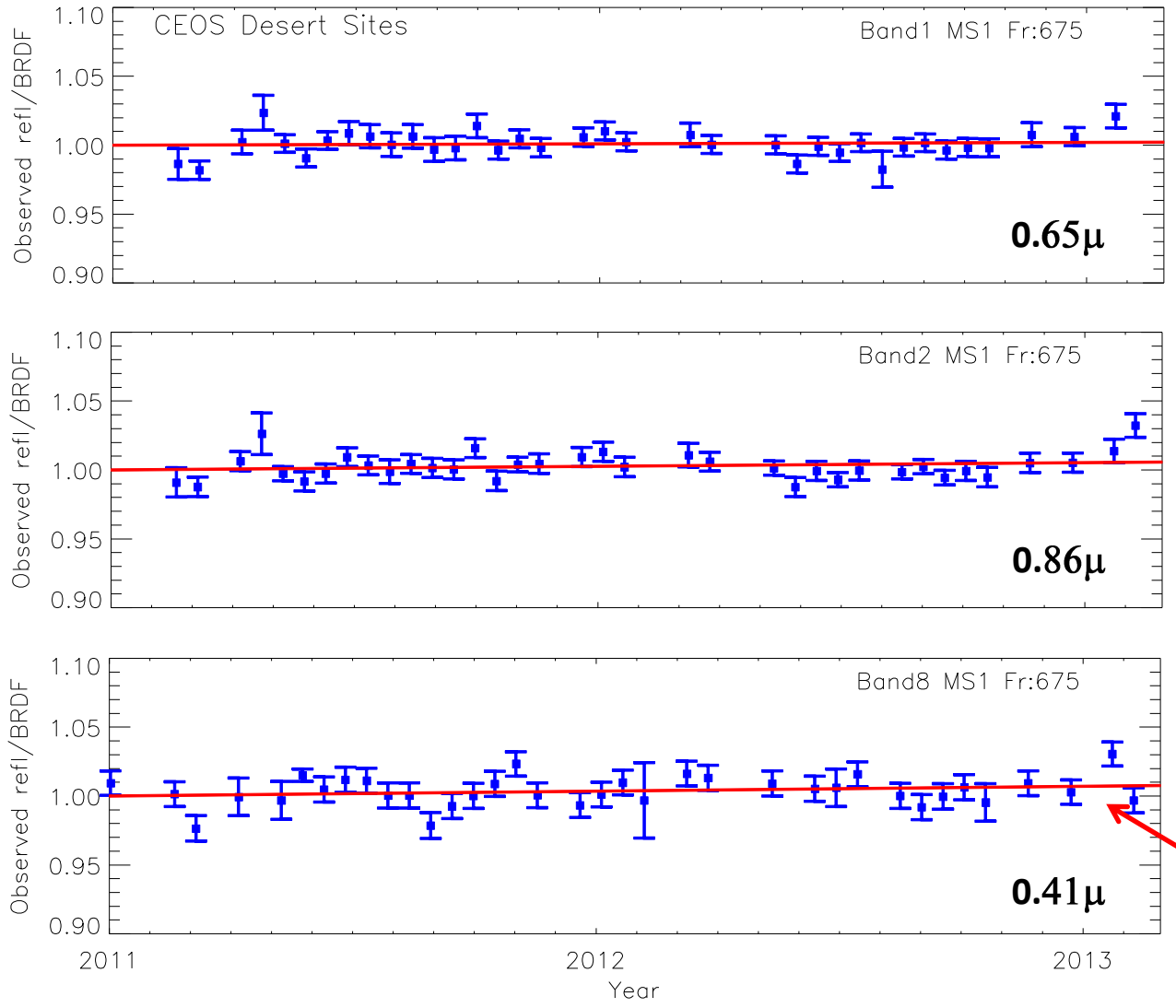


Input options include a standard atmospheric profile (U.S. 1976), a standard aerosol model, a fixed viewing angle, a wide range of solar angle & atmospheric water content, and surface-type dependent spectral reflectances.

Ocean Desert Snow Cloud



Reflectance Trending (Aqua MODIS; Libya 4)



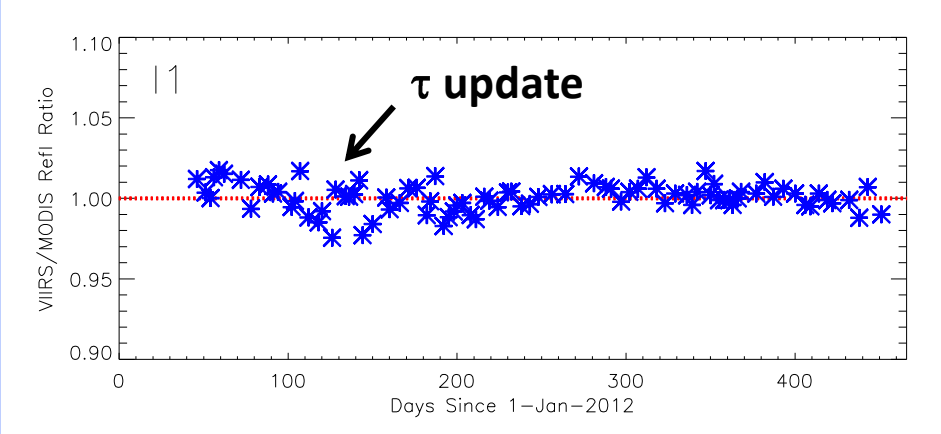
Long-term reflectance trending (MODIS C6) shows that the site is stable to within 1%

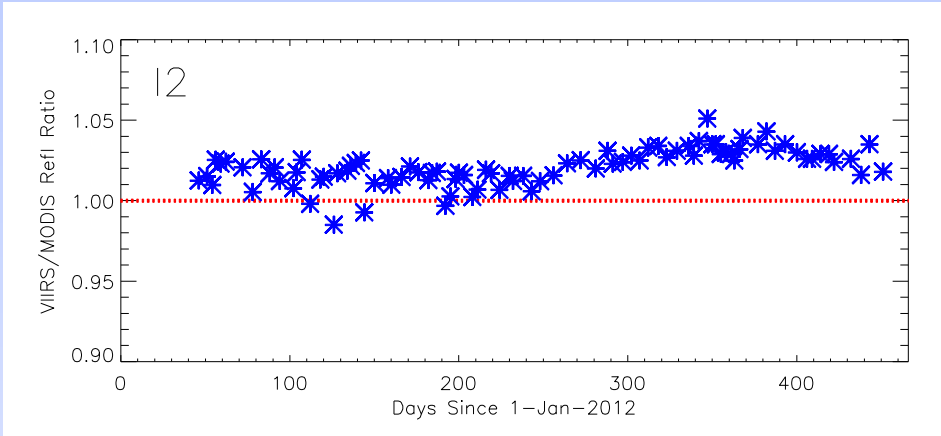
Good reference site to track the sensor on-orbit calibration performance

Linear Regression

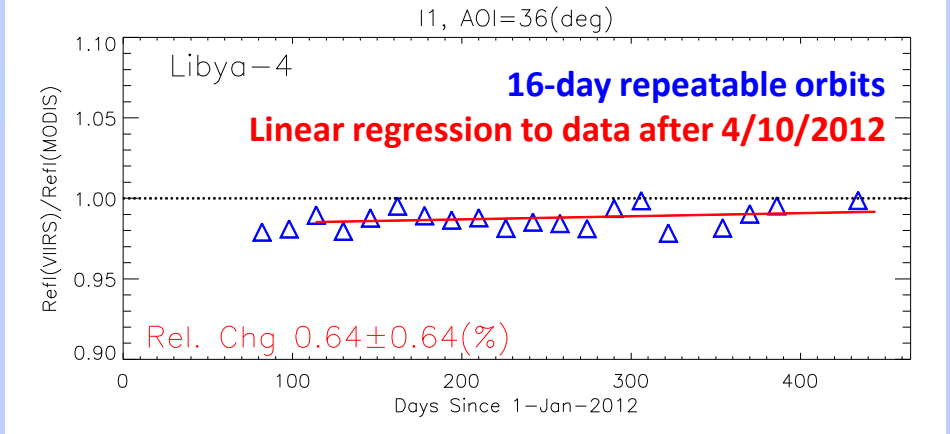
Inter-comparison Results

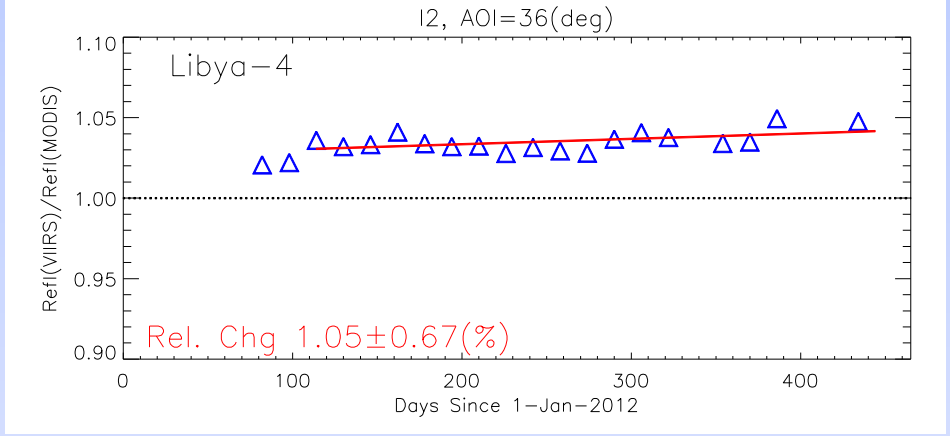
SNO





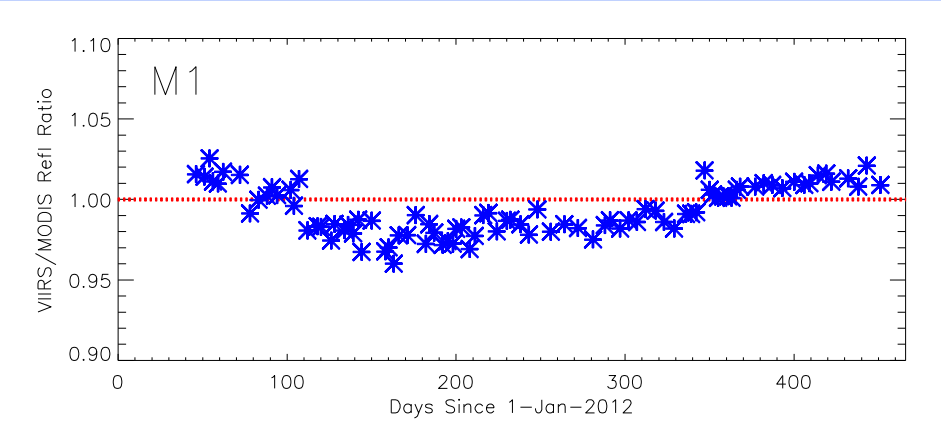
Libya-4

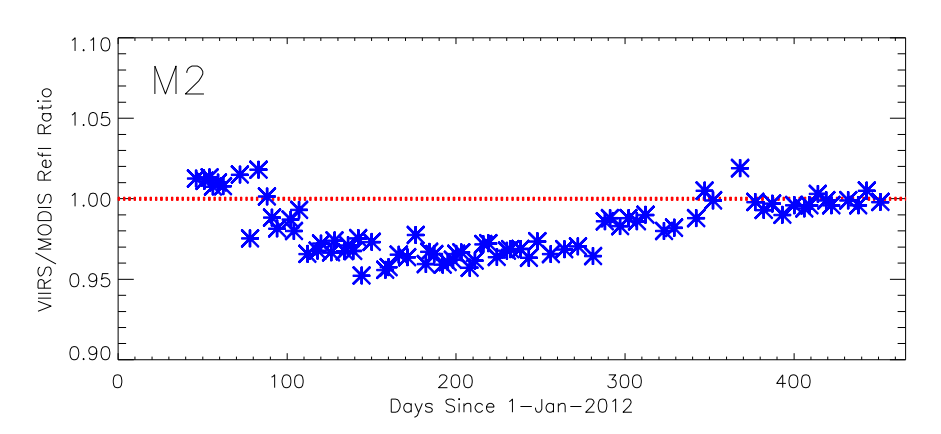




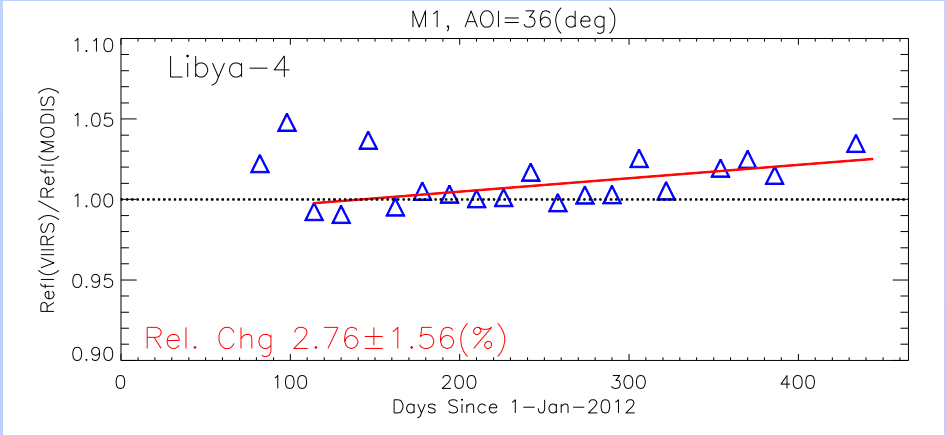
Inter-comparison Results

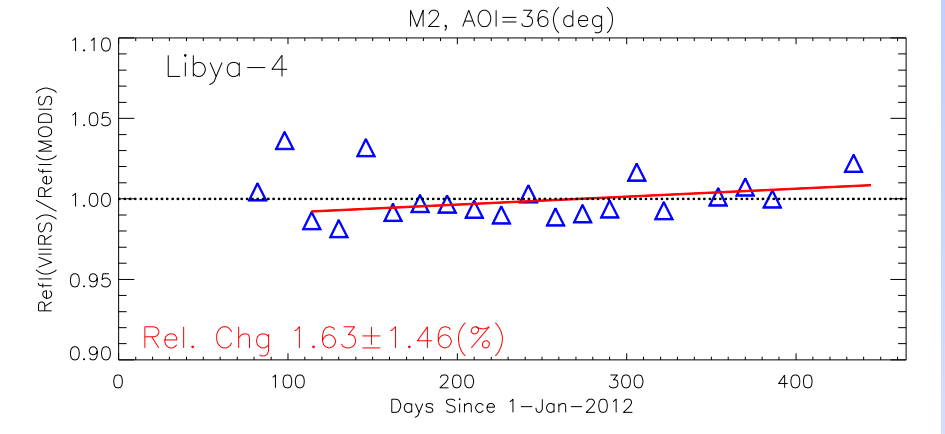
SNO





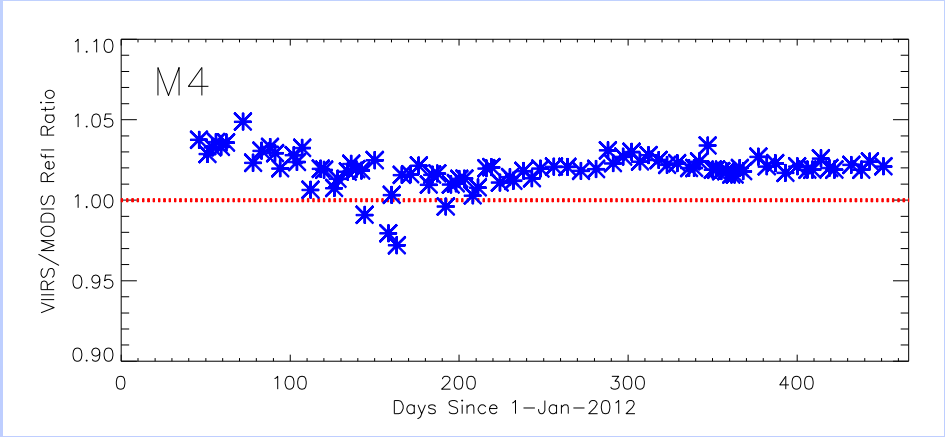
Libya-4

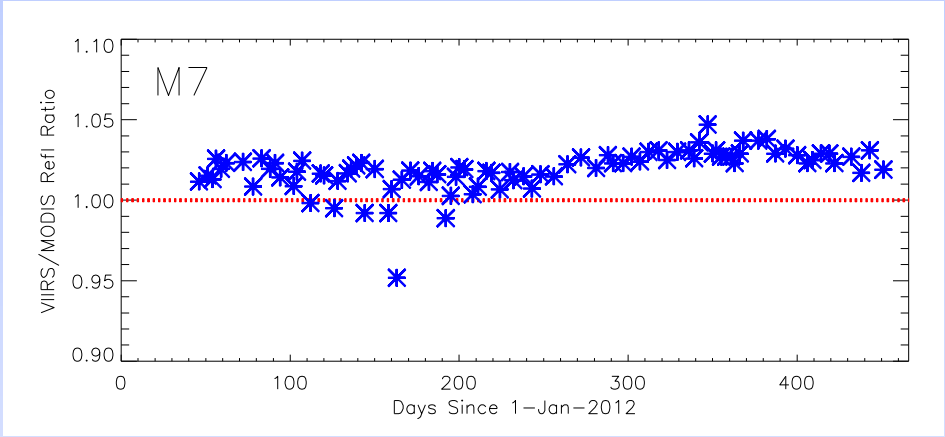




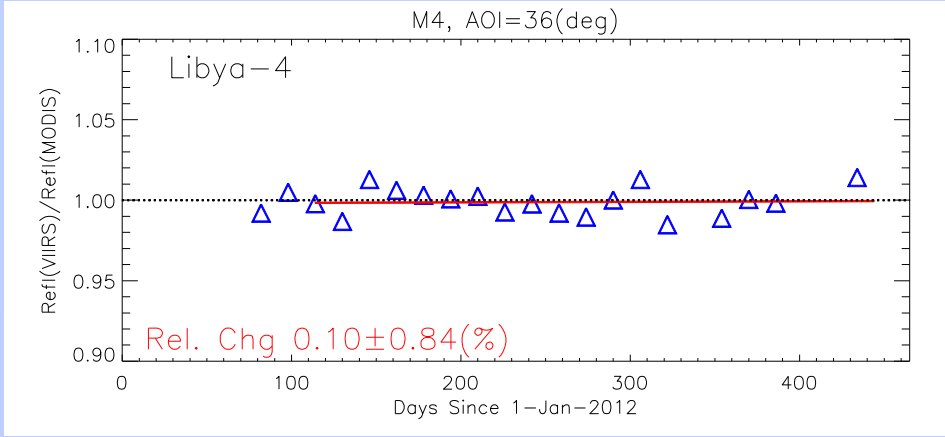
Inter-comparison Results

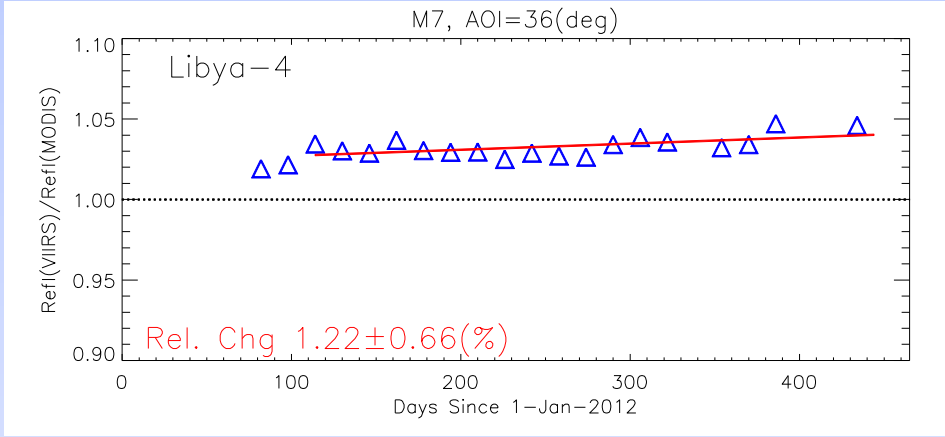
SNO





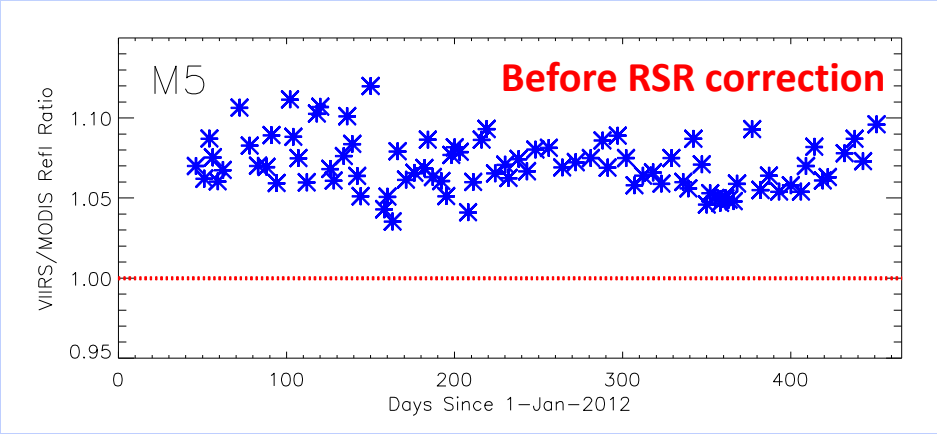
Libya-4

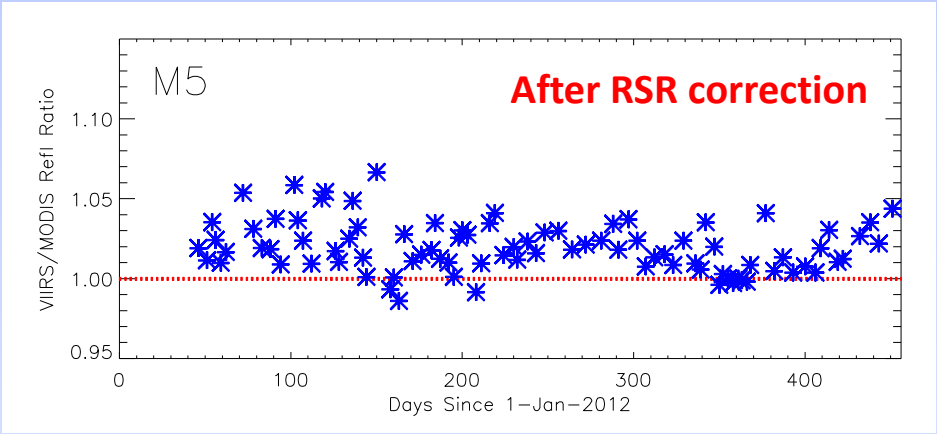




Inter-comparison Results

SNO





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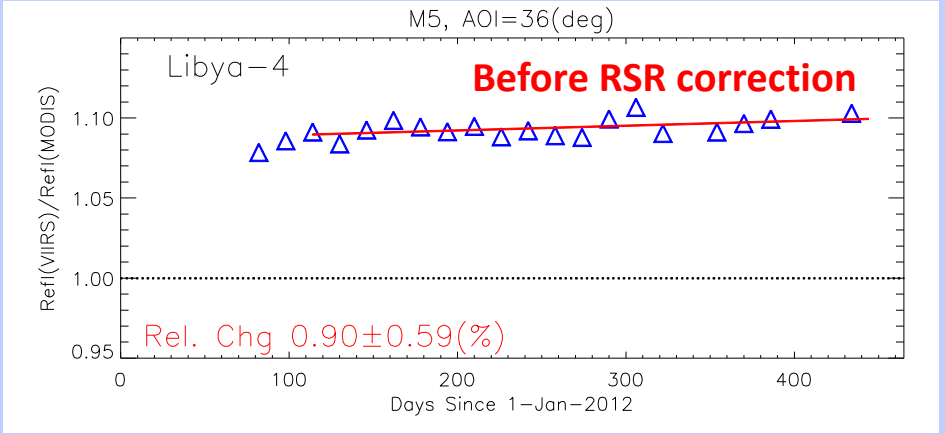
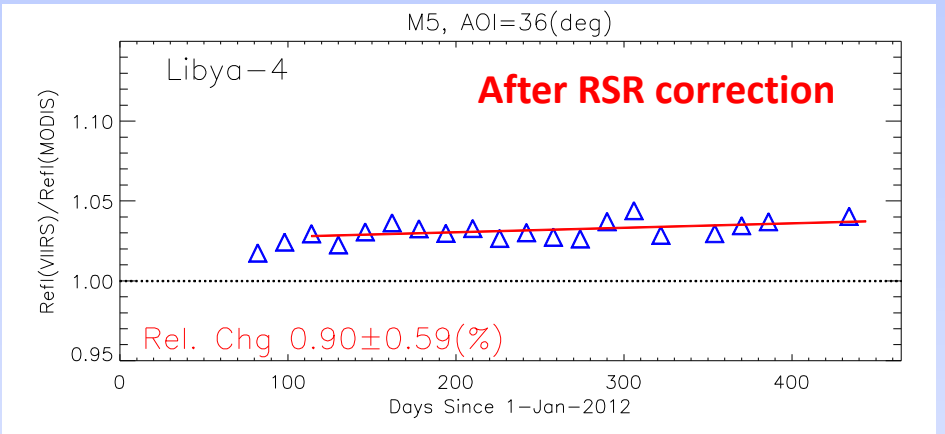




Correction based on MODTRAN5 simulations with averaged atmospheric conditions (std. atmo. profile, 1.0 gcm-2 atmo. water content for SNO, 5.0 gcm-2 for desert)

Inter-comparison Results

	MODIS and VIIRS Reflectance Ratios									
Band	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**I1**	**I2**	**MU**
SNO	0.991	0.987	0.995	1.018	1.069	1.003*	1.019	0.998	1.020	1.6%
Libya-4	1.015	1.000	N/A	0.998	1.099	N/A	1.047	0.995	1.049	1.5%
MODT	0.996	1.006	0.994	1.000	1.046	0.991	1.006	1.009	0.987	1.0%
Diff	**-0.5%**	**-1.9%**	**0.1%**	**1.8%**	**2.2%**	**1.2%**	**1.3%**	**-1.1%**	**3.3%**	**±2.0%**

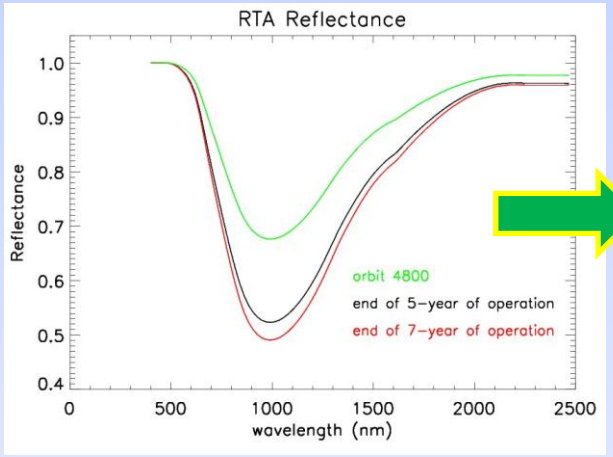
Values are derived using observations after day 100 of 2012

MU – Measurement or model uncertainty (%); MU for M6 ratios is noticeably higher than 2% due to early saturation for the MODIS matching band

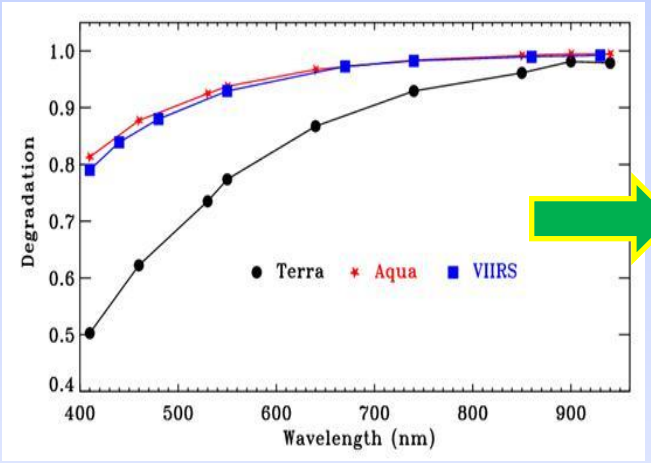
Diff – RSR corrected calibration difference (from SNO) between VIIRS SDR and MODIS L1B (C6)

Future Effort and Improvements

- **Long-term trending with consistent time series (data products)**
  - **MODIS C6**
  - **VIIRS consistently calibrated (reprocessed) radiances and reflectances**
- **Sensor calibration improvements**
  - **Mirror degradation modeling**
  - **Consistency between SD and lunar calibration**
  - **Degradation impact analysis and mitigation strategy**
    - **Use of modulated RSR**
    - **SD degradation impact on sensor and SDSM calibration**



RSR



Solar Irrad.

Summary

- **Both MODIS and VIIRS RSB are well calibrated (joint effort by a gov-led SDR team), meeting specified sensor design requirements**
  - Same on-board calibrators (OBC)
  - Similar calibration methodologies
  - Similar SD degradation (larger at shorter wavelengths)
  - Different trend for sensor/detector response (due to different causes)
- **On-orbit calibration differences between MODIS and VIIRS RSB are generally within 2% (except 3% for I3)**
  - Future improvements with reprocessed SDR
- **Effort for future improvements**
  - VIIRS mirror degradation impact (modulated RSR)
  - Larger SD degradation impact (reflected solar spectra)
  - SDSM detector OOB response (not discussed here)