Status of MODIS (Terra/Aqua) and VIIRS (S-NPP) On-orbit Calibration

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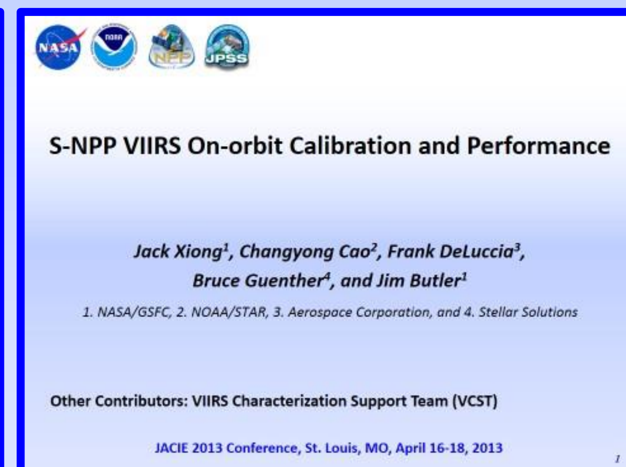
- NASA VIIRS Characterization Support Team (VCST)
- NOAA SNPP/JPSS VIIRS SDR Team (led by C. Cao)
- Presentations from MODIS STM and JACIE Conference



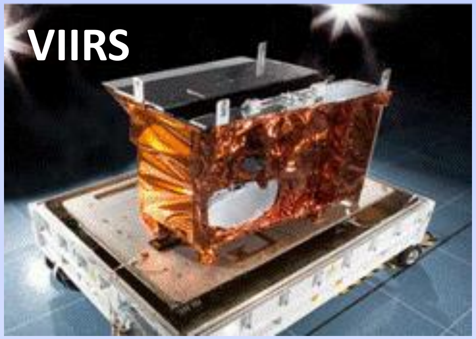
Outline

- **Background**
- **MODIS and VIIRS On-orbit Calibration**
  - **On-board Calibrators (OBCs)**
    - SD, SDSM, BB, SV, SRCA (MODIS only)
  - **Lunar Observations**
- **On-orbit Performance**
  - **Sensor and OBCs**
  - **Calibration Inter-comparison (RSB only)**
- **Summary**

Background

- **MODIS on Both Terra and Aqua**
  - Terra: Dec. 18, 1999 – Present (13+ years)
  - Aqua: May 04, 2002 – Present (11+ years)
- **VIIRS on S-NPP and JPSS**
  - S-NPP: Oct. 28, 2011 – Present (1.5+ year)
  - JPSS-1: Launch in 2017

JPSS



Many applications: 40+ data products from MODIS and 20 EDRs from VIIRS

MODIS and VIIRS

- **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 and night band (DNB)
  - RSB spectral wavelengths: 0.41 -2.3 μm ; TEB: 3.75 - 12.2 μm
  - Spatial resolution: 375 m for I bands; 750 m for M bands and DNB

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

MODIS and VIIRS Spectral Bands

H/L Gain

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

Dual gain band

Similar MODIS bands

MODIS Instrument Operations

Terra MODIS

- Launch: Dec 18, 1999
- First light: Feb 24, 2000
- A-side: launch - Oct 30, 2000
- B-side: Oct 30, 2000 - June 15, 2001
- A-side: July 02, 2001 - Sept 17, 2002
- A-side electronics and B-side formatter: Sept 17, 2002 - present

- BB nominally set at 290 K
- SD door fixed at "open" since July 02, 2003
  - Large SD degradation
- SRCA operated with 2 10-W lamps since 2006
- CFPA controlled at 83 K (was set 85 K briefly: 3-5 Aug 2000)

Aqua MODIS

- Launch: May 04, 2002
- First light: June 24, 2002
- B-side: launch - present

- BB nominally operated at 285 K
- SD calibration: gradually reduced frequency
- SRCA operated with 2 10-W lamps since 2005
- CFPA controlled at 83 K (was set 85 K briefly: 3-5 Aug 2000)
  - Small increase of cold FPA temperatures since 2007

Details on MODIS Operation and Calibration: http://mcst.gsfc.nasa.gov/

MODIS Calibration and Characterization Activities

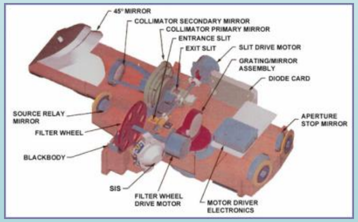
Solar diffuser (SD) and solar diffuser stability monitor (SDSM) for reflective solar bands (RSB) calibration

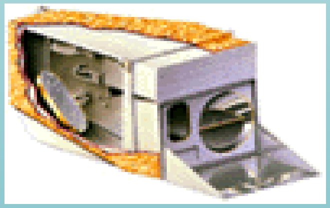
Spectroradiometric Calibration Assembly (SRCA) for instrument spectral and spatial characterization

Solar Diffuser

SDSM

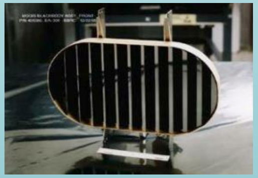
SRCA



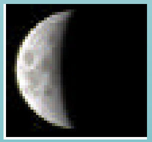


Scan Mirror

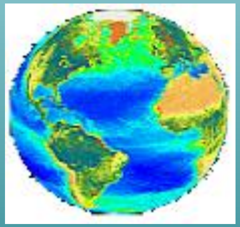
Blackbody



Space View



Blackbody (BB) for thermal emissive bands (TEB) calibration



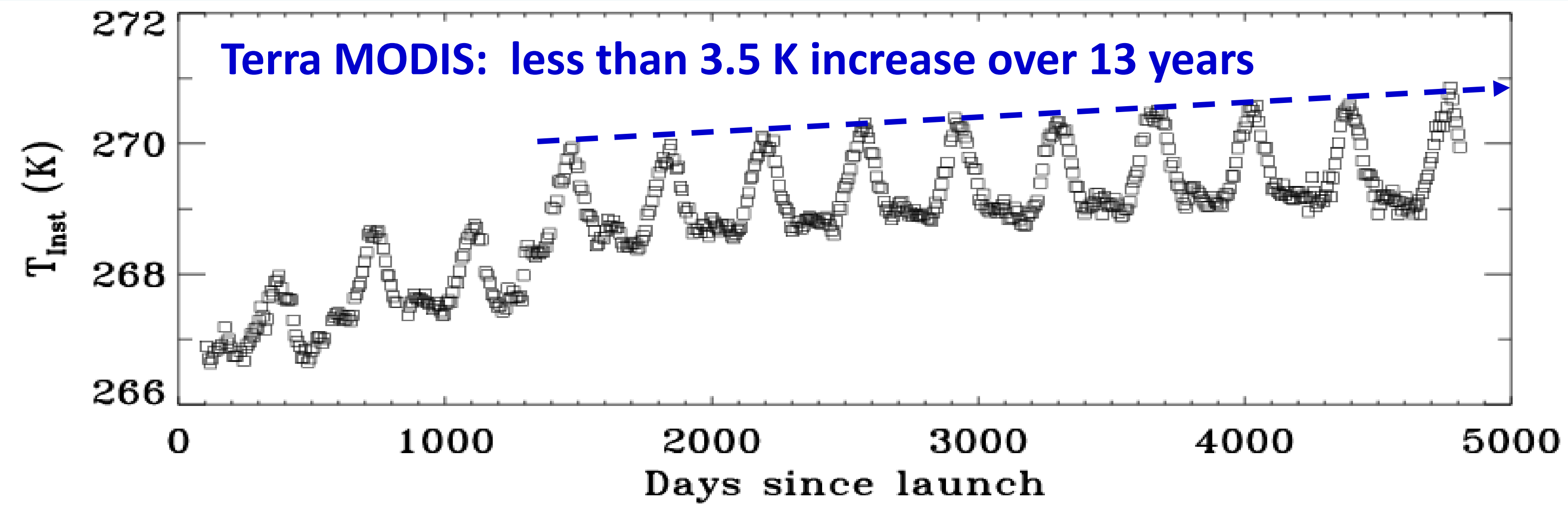
Calibration Maneuvers

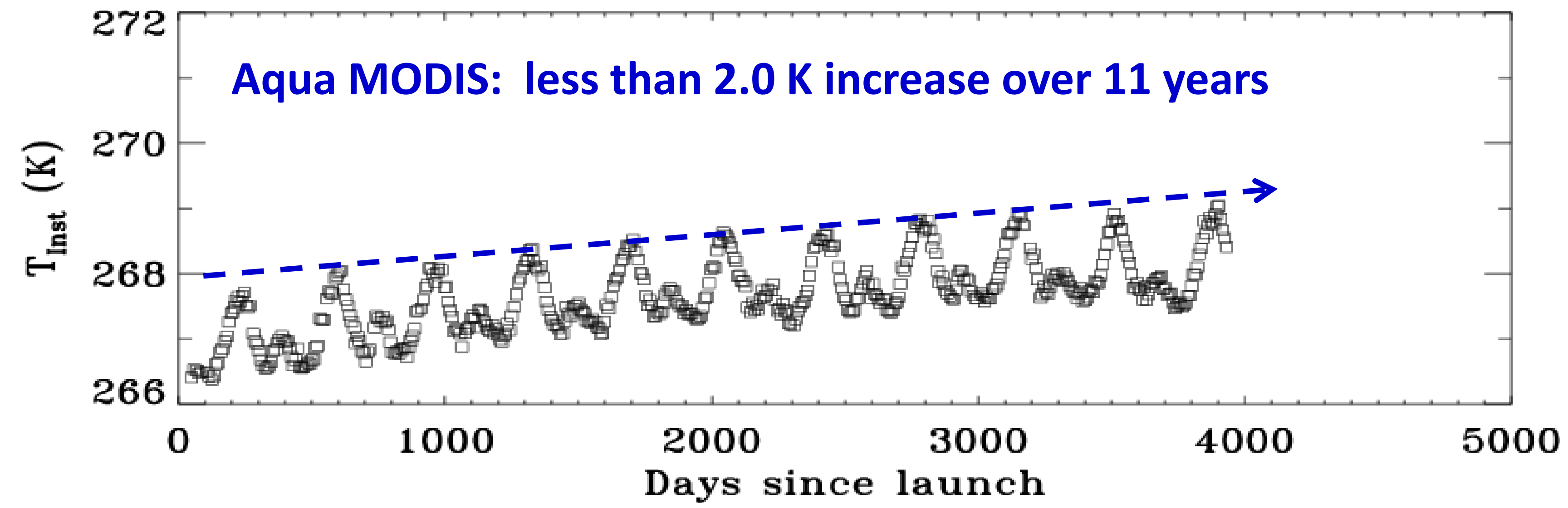
Lunar views through SV port

On-orbit Performance (MODIS)

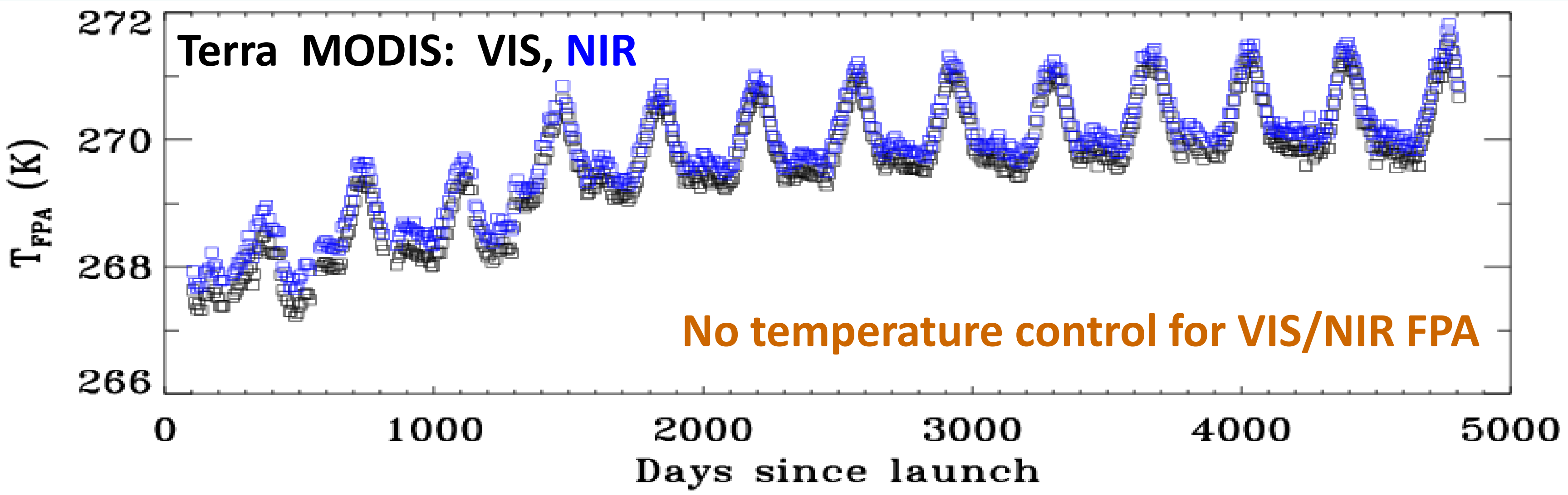
- **Instrument and On-board Calibrators (OBC)**
- **Radiometric**
  - **Spectral band responses**
- **Spectral (backup slides)**
  - Center wavelengths and bandwidths
- **Spatial (backup slides)**
  - Band-to-band registration (BBR)

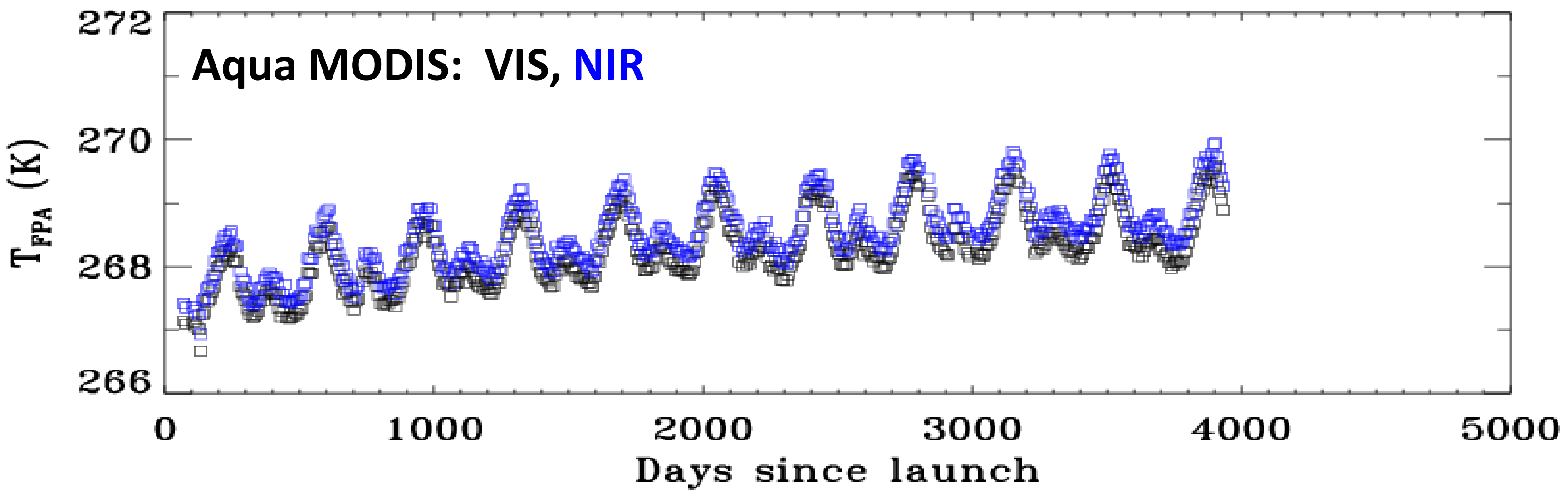
Instrument Temperatures





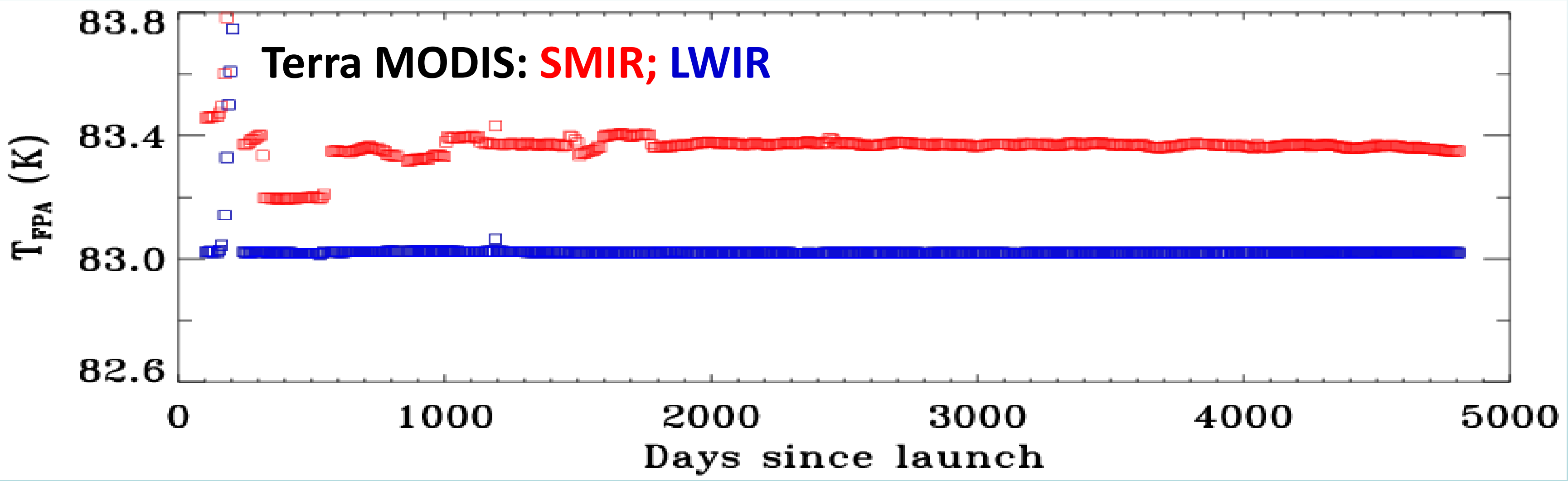
VIS and NIR FPA Temperatures

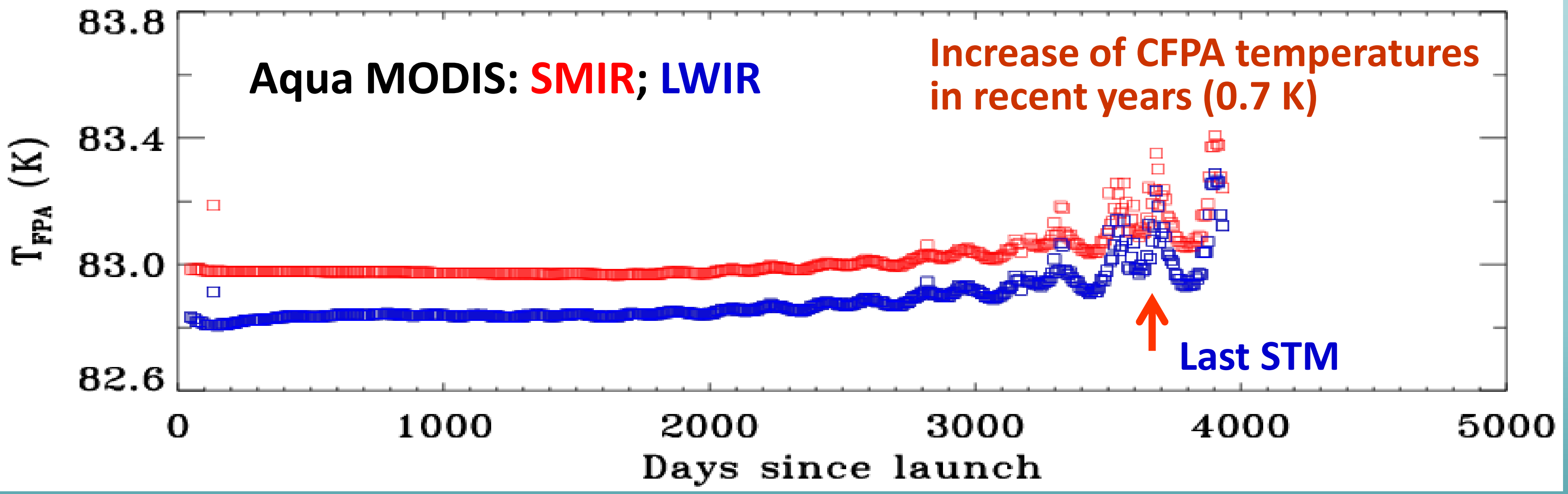




VIS & NIR FPA temperatures: similar to instrument temperatures

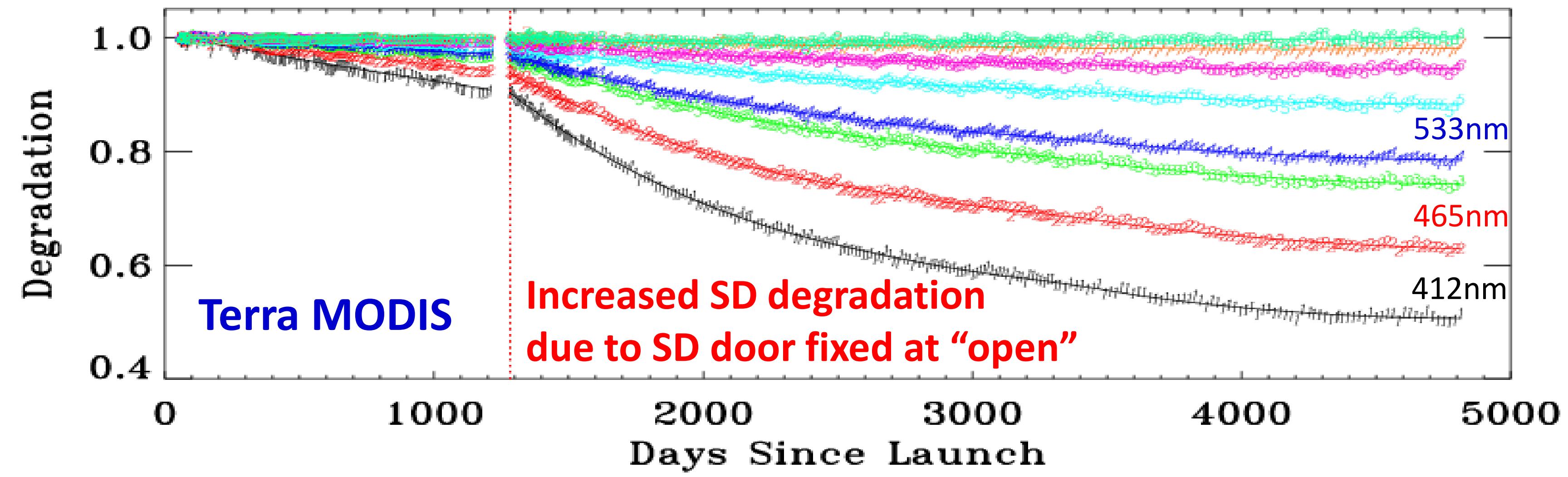
SMIR and LWIR FPA Temperatures

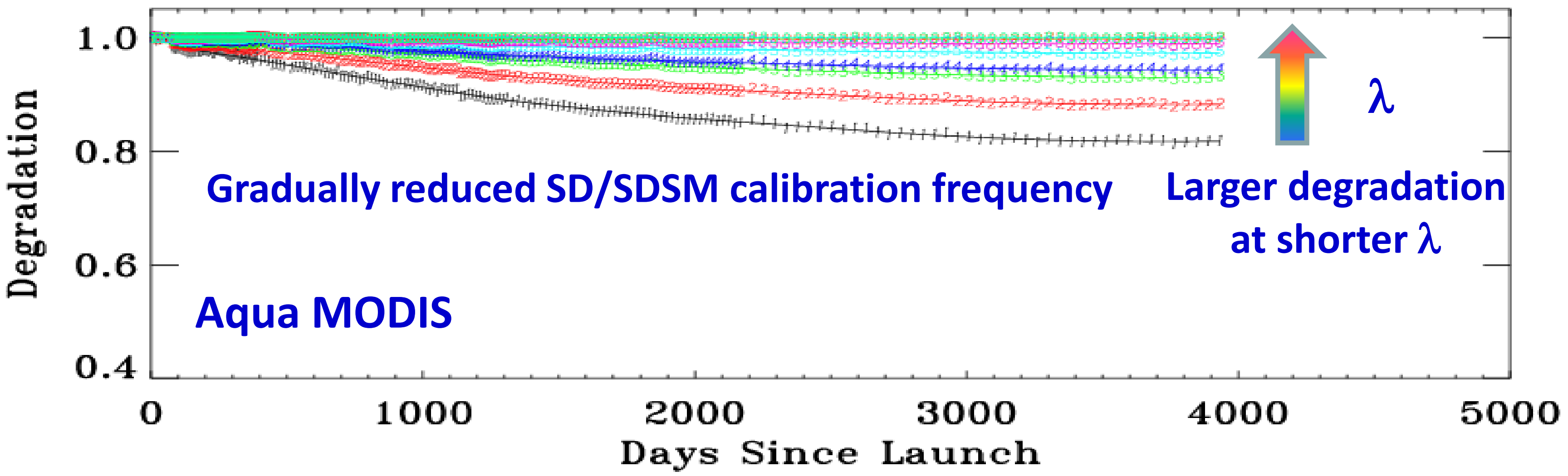




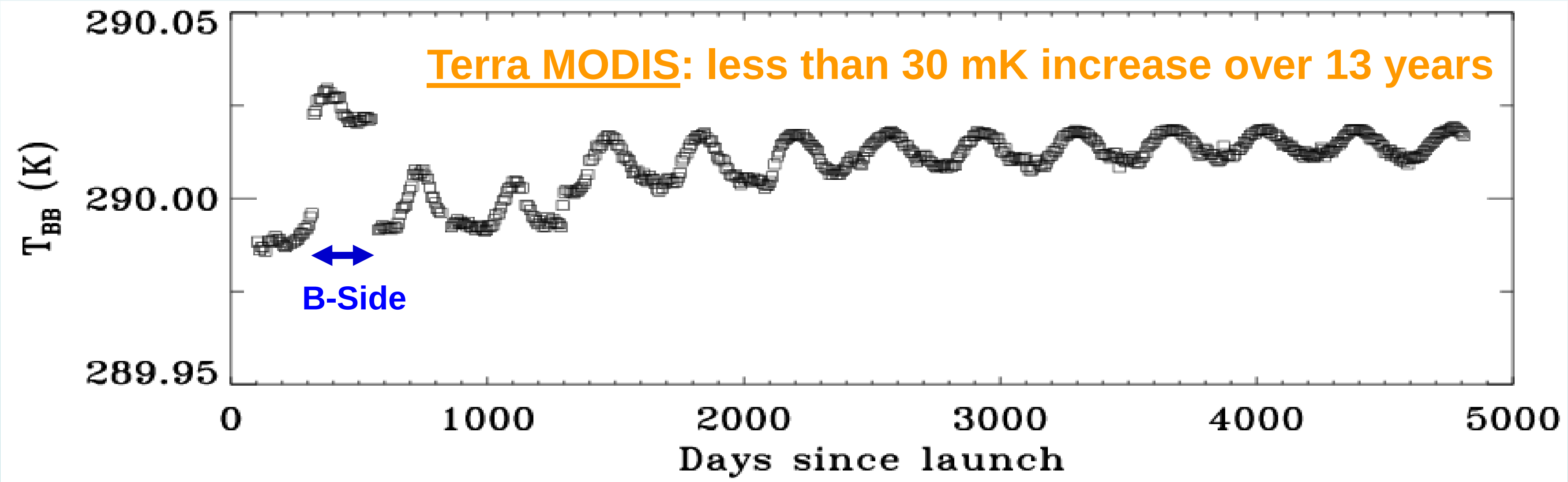
Aqua CFPA Performance and Operation Reviews (5/7/2010, 4/25/2012, 3/27/2013)

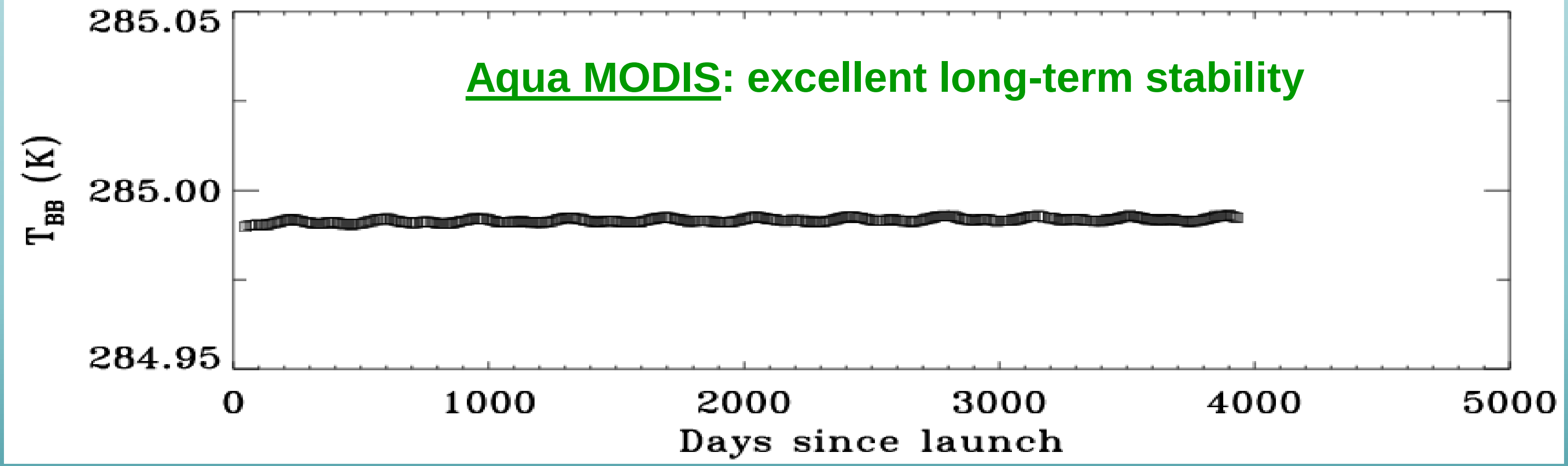
Solar Diffuser (SD) Degradation





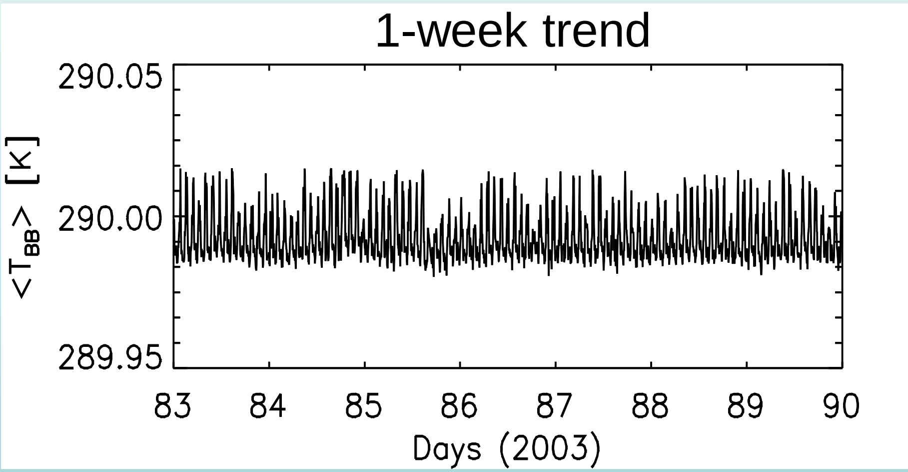
Blackbody Temperatures (nominal operation)

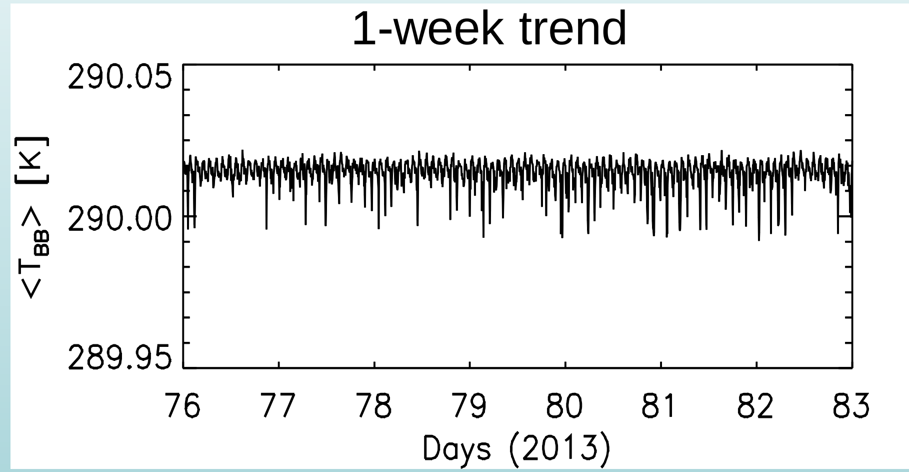




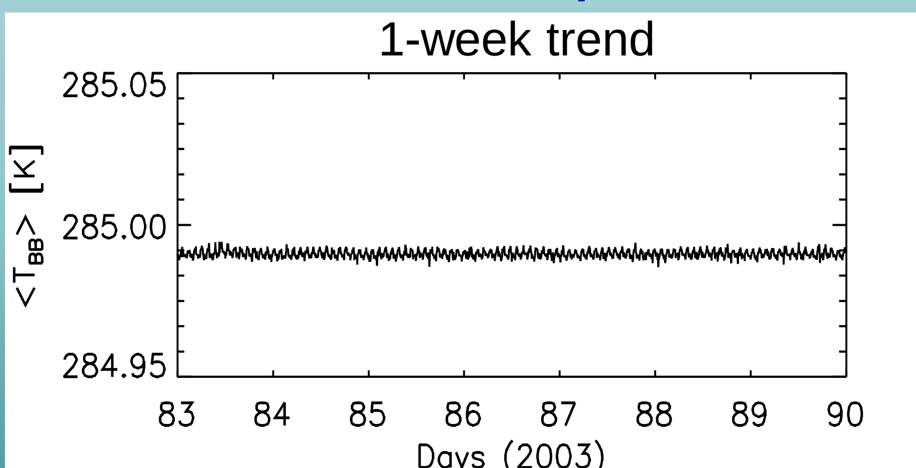
Blackbody Temperatures (nominal operation)

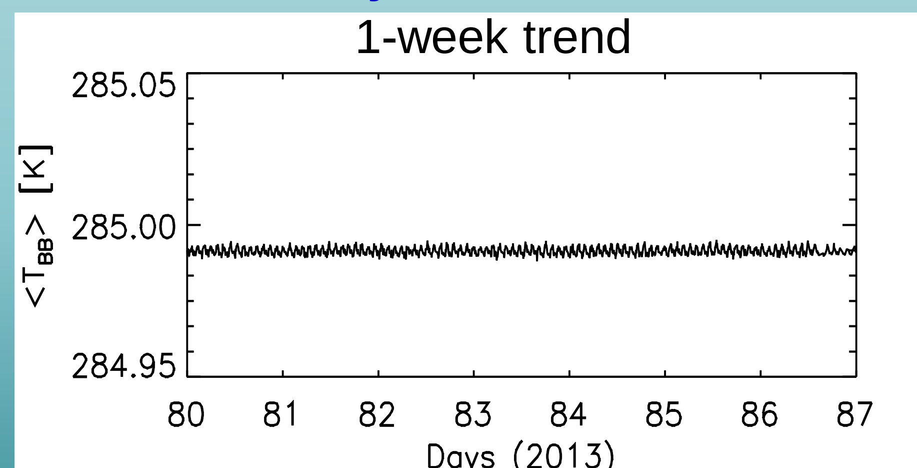
Terra MODIS BB short term stability





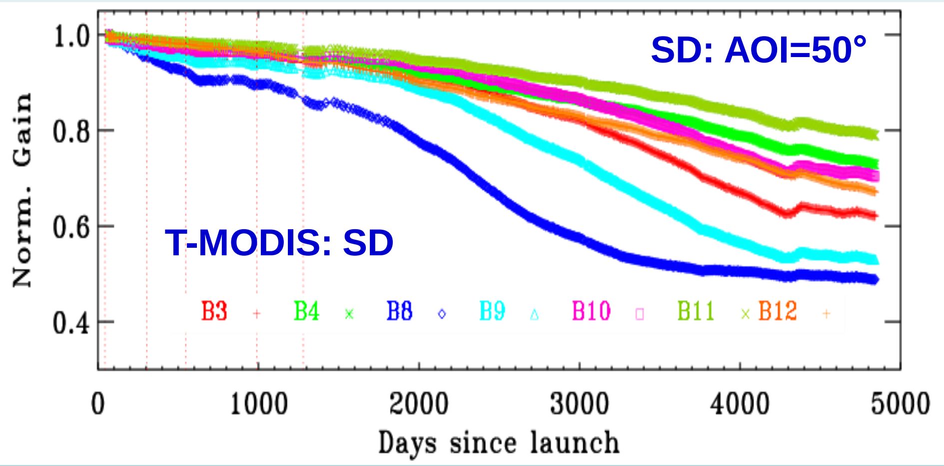
Aqua MODIS BB short term stability

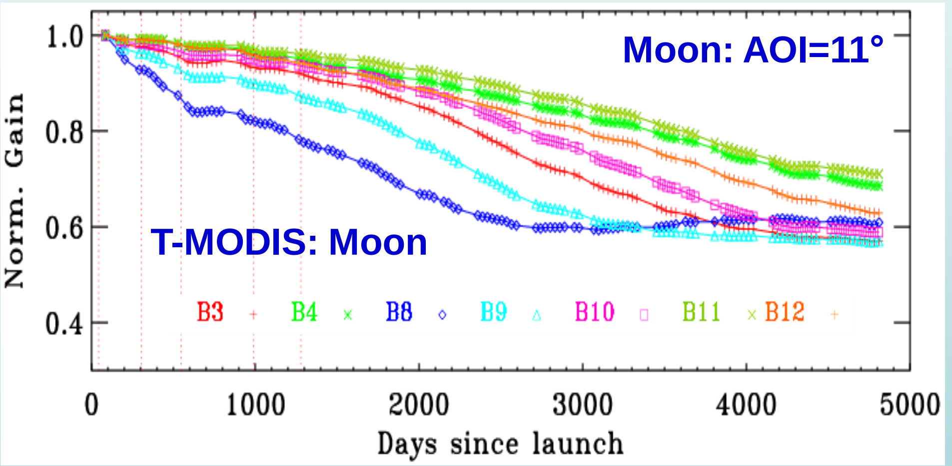


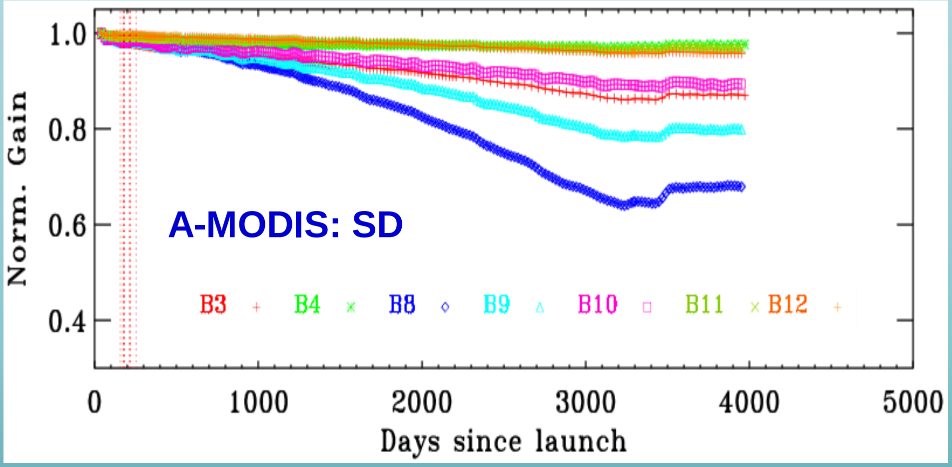


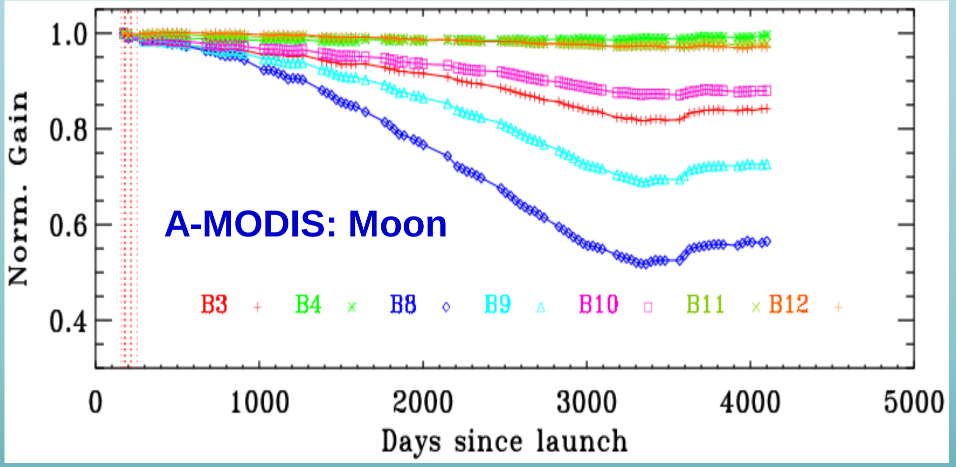
Spectral Band Responses (VIS)

Band Averaged, Mirror Side 1









Larger changes at shorter wavelengths

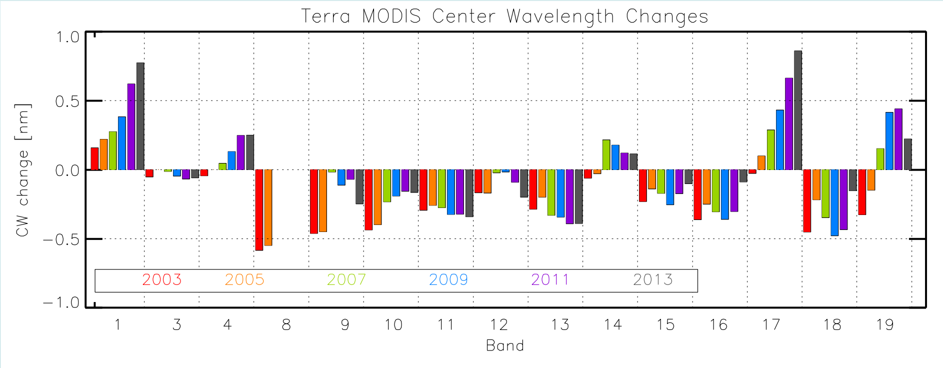
Wavelength, AOI, and mirror side dependent (small MS diff. in A-MODIS)

Radiometric Performance Summary

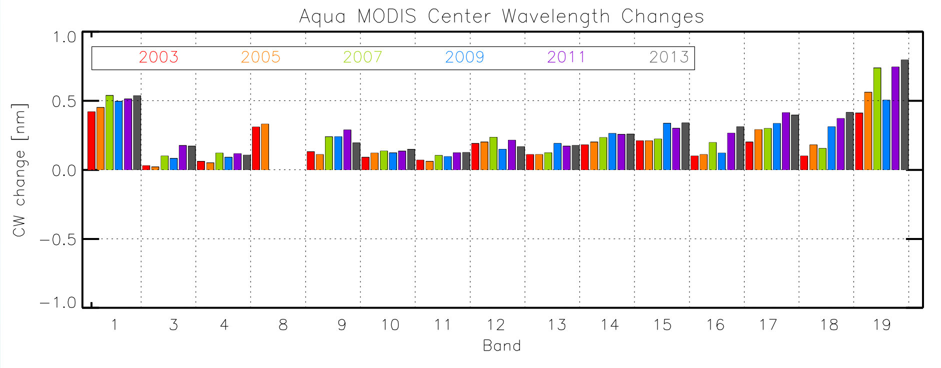
- **Shorter wavelength VIS bands show larger degradation**
  - Strong wavelength, mirror side, and scan angle dependence
  - MS difference in Aqua MODIS is much smaller than Terra MODIS
- **A few NIR bands show gain increases over time**
- **Changes in SWIR responses are very small**
  - SWIR bands are located on CFPA with MWIR bands
- **TEB (MWIR and LWIR) responses have been very stable**
  - Less than 2% changes over entire mission, except up to 10% for Terra LWIR PV bands 27-30
- **Overall SNR and NEdT performance remains satisfactory**

Spectral Characterization Performance

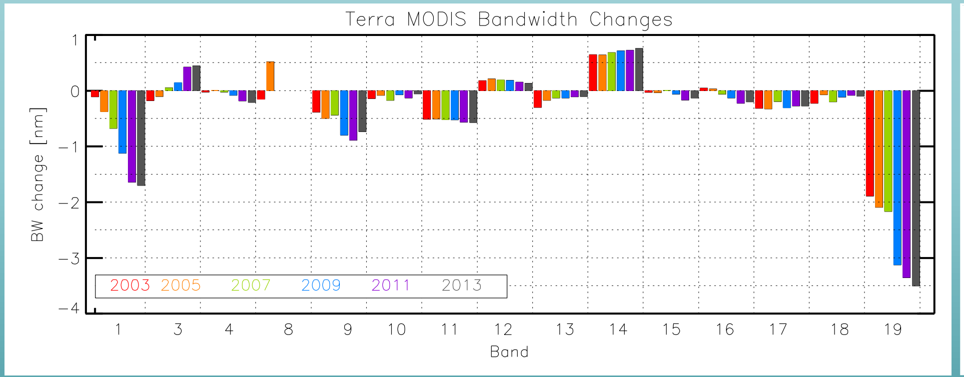
Terra MODIS CW Change



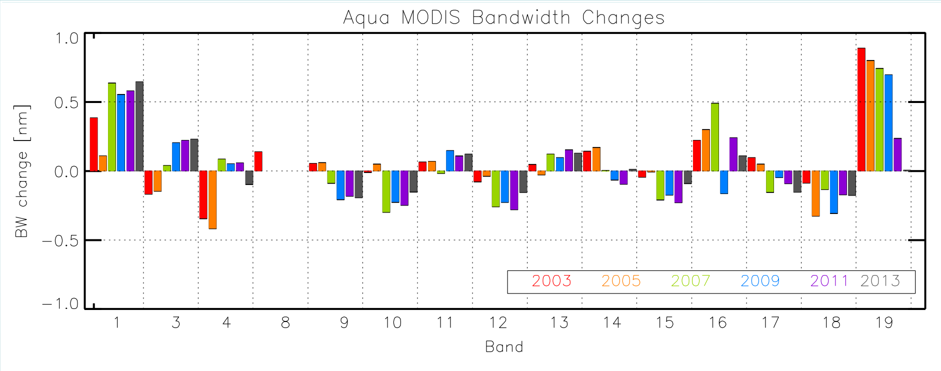
Aqua MODIS CW Change



Terra MODIS BW Change

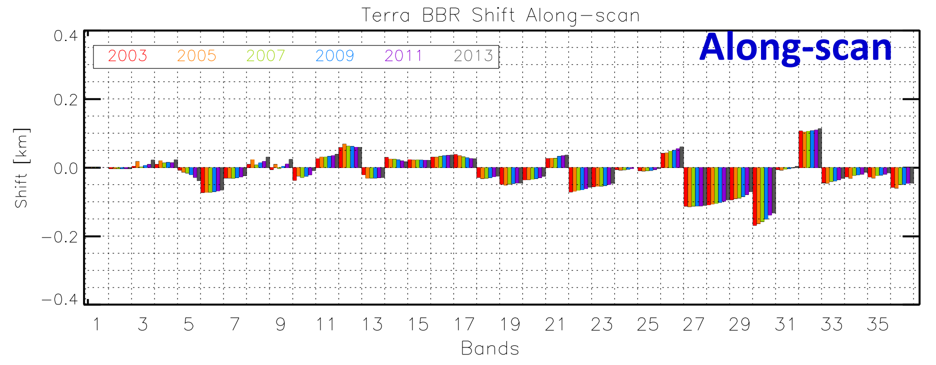


Aqua MODIS BW Change

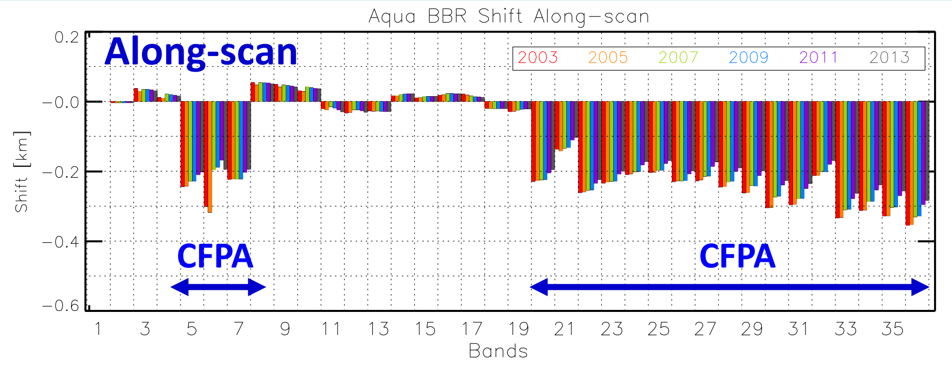


Spatial Characterization Performance

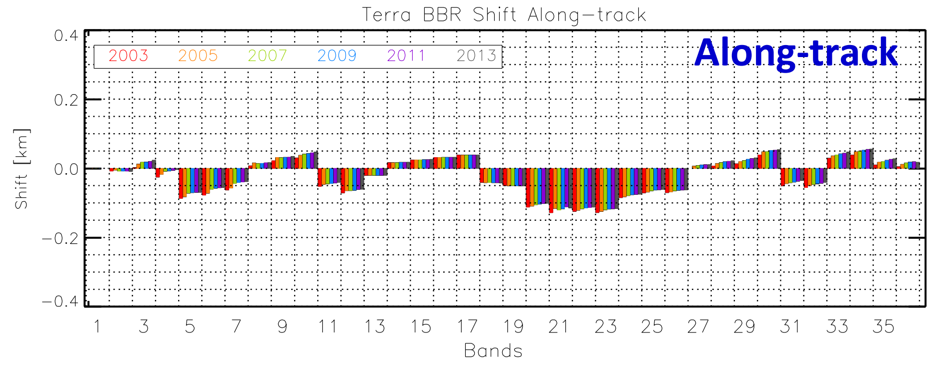
Terra MODIS along-scan BBR



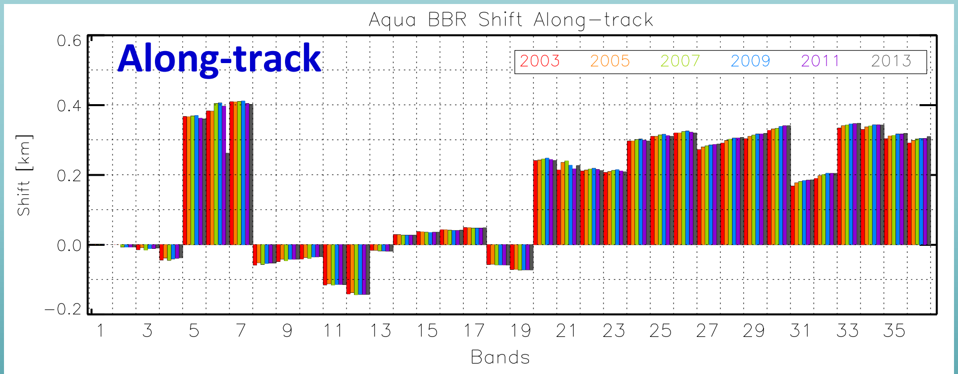
Aqua MODIS along-scan BBR



Terra MODIS along-track BBR



Aqua MODIS along-track BBR



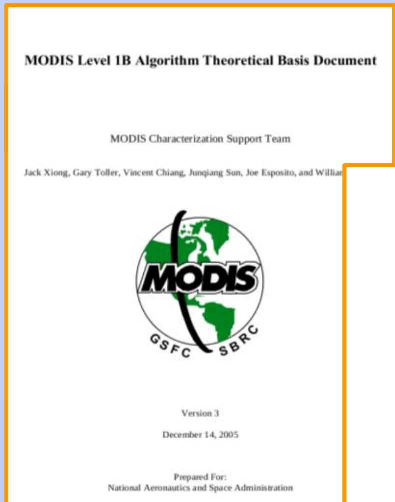
Aqua BBR: a known issue since pre-launch

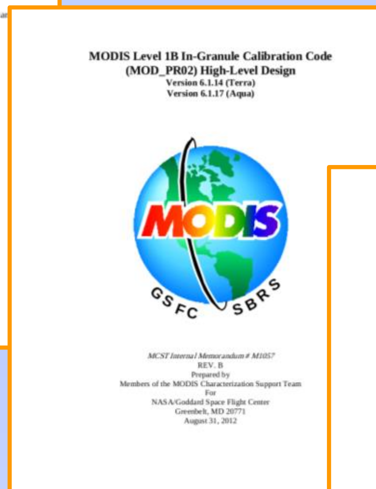
MODIS L1B and Data Collection 6 (C6) Status

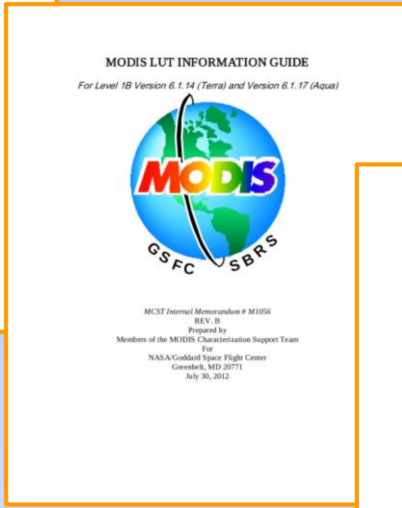
- **MODIS L1B Algorithm (Code and LUTs)**
  - **Developed, maintained, and updated by MCST**
    - Input also provided by MODIS science team representatives and users
    - Algorithm changes and major LUT updates reviewed and approved by the MsWG (MODIS sensor Working Group)
  - **Two separate sets of code and LUTs**
    - One for Terra MODIS and one for Aqua MODIS
  - **L1B collections and versions**
    - Terra MODIS mission: C2 to C6 (18 code versions used in production)
    - Aqua MODIS mission: C3 to C6 (11 code versions used in production)
- **C6 L1B reprocessing completed**
  - **http://ladsweb.nascom.nasa.gov/**
- **C6 Atmosphere reprocessing starting date: early May 2013**
- **C6 Land reprocessing starting date: early July 2013**

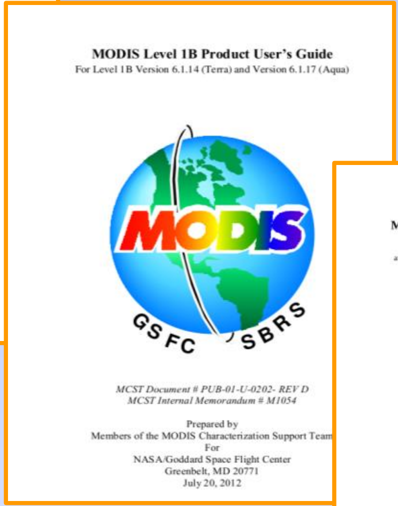
Key L1B Documents

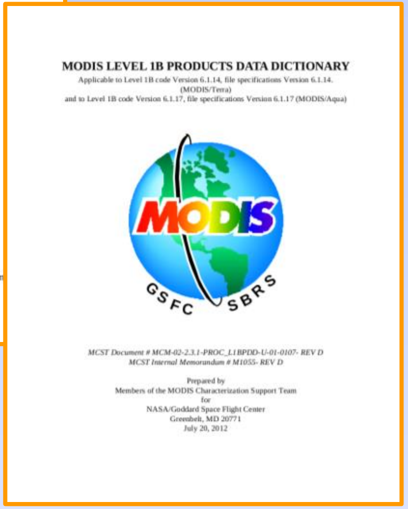
http://mcst.gsfc.nasa.gov/content/l1b-documents











ATBD

High-Level Code Design

LUTs Information Guide

Product User Guide

Data Dictionary

References

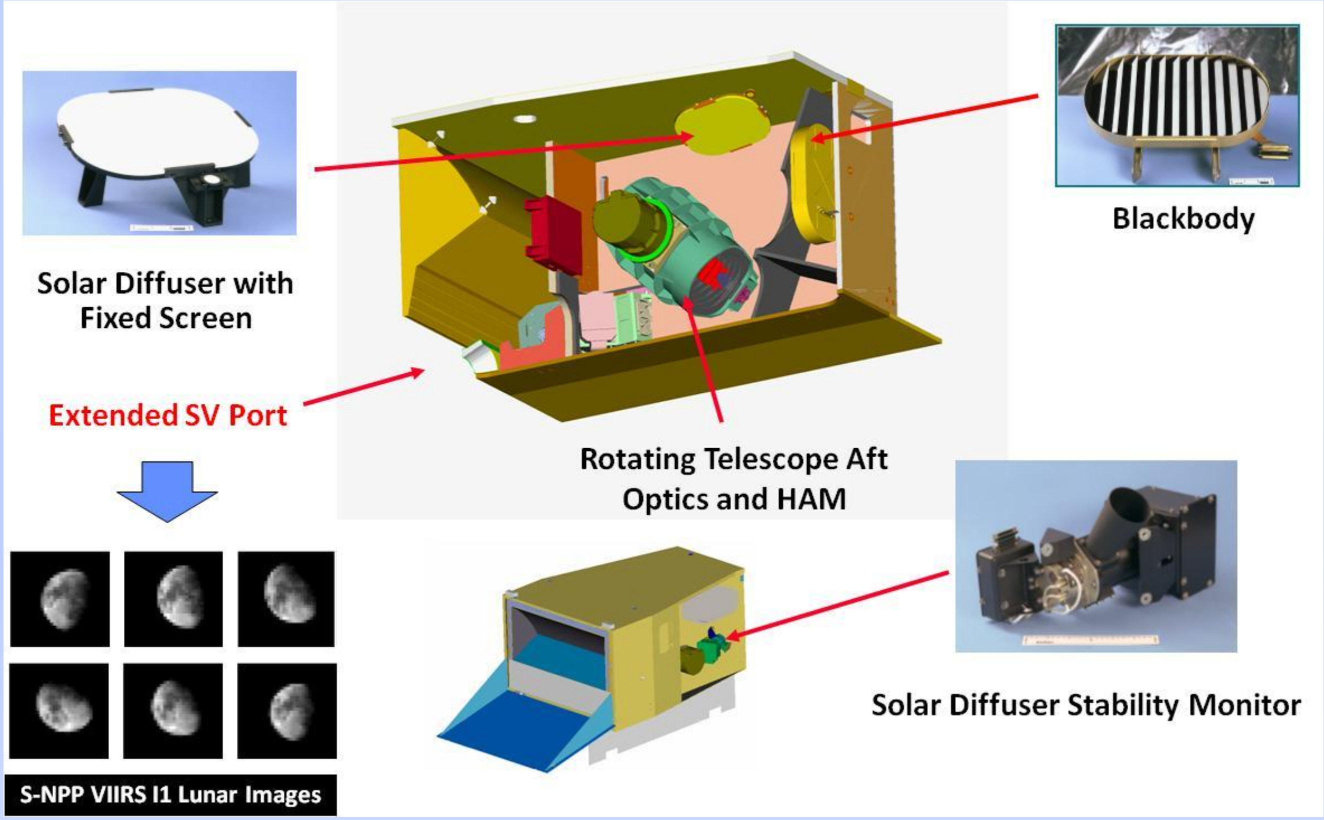
- **Key Journal Papers**

  - Xiong et. al, “Multi-year On-orbit Calibration and Performance of Terra MODIS Reflective Solar Bands,” *IEEE TGRS*, Vol. 45, No. 4, 879-889, 2007
  - Xiong et. al, “Multiyear On-orbit Calibration and Performance of Terra MODIS Thermal Emissive Bands,” *IEEE TGRS*, 46 (6), 1790-1803, 2008
  - Xiong et. al “Aqua MODIS Thermal Emissive Bands On-orbit Calibration, Characterization, and Performance,” *IEEE TGRS*, 47(3), 803-814, 2009
  - Xiong et. al, “On-Orbit Calibration and Performance of Aqua MODIS Reflective Solar Bands,” *IEEE TGRS* 48(1), 535-546, 2010
  - Toller et. al, “Terra and Aqua Moderate-resolution Imaging Spectroradiometer Collection 6 Level 1B Algorithm,” to be published, *J. Appl. Remote Sensing,* 2013

- **Key SPIE Papers**

  - Xiong et. al, “Terra and Aqua MODIS calibration algorithms and uncertainty analysis,” Proc. SPIE 5978, no. 59780V (2005)
  - Sun et. al “MODIS RSB calibration improvements in Collection 6” Proc. SPIE 8528, no. 85280N (2012)
  - Wenny et. al “MODIS TEB calibration approach in collection 6” Proc. SPIE 8533, no. 85331M (2012)

VIIRS On-orbit Calibration (MODIS Heritage OBC)



RSB:

$$F = \frac{L_{SD\_Comp}}{L_{SD\_Meas}}$$

TEB:

$$F = \frac{L_{BB\_Comp}}{L_{BB\_Meas}}$$

Quadratic calibration algorithm for both TEB and RSB

Linear calibration coefficients derived from BB and SD

SD degradation tracked by SDSM

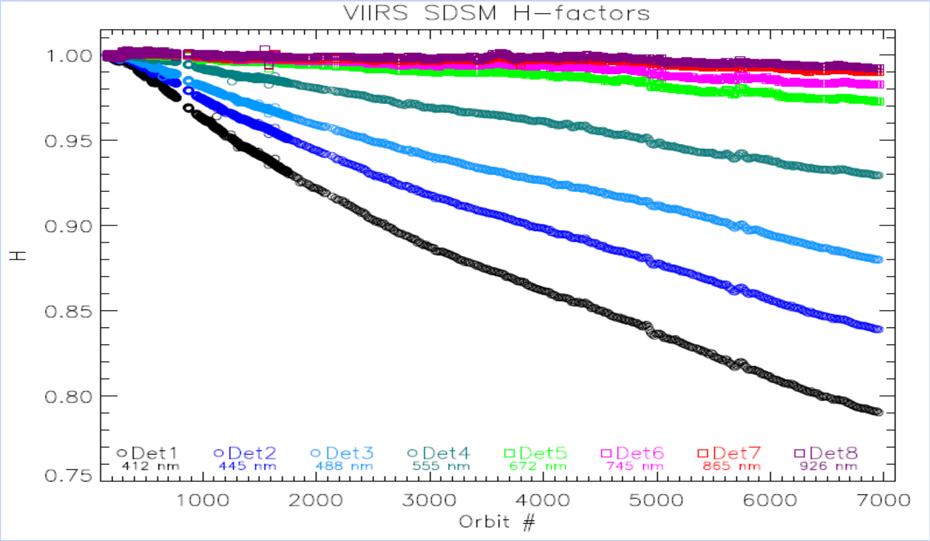
Lunar observations

VIIRS On-orbit Performance

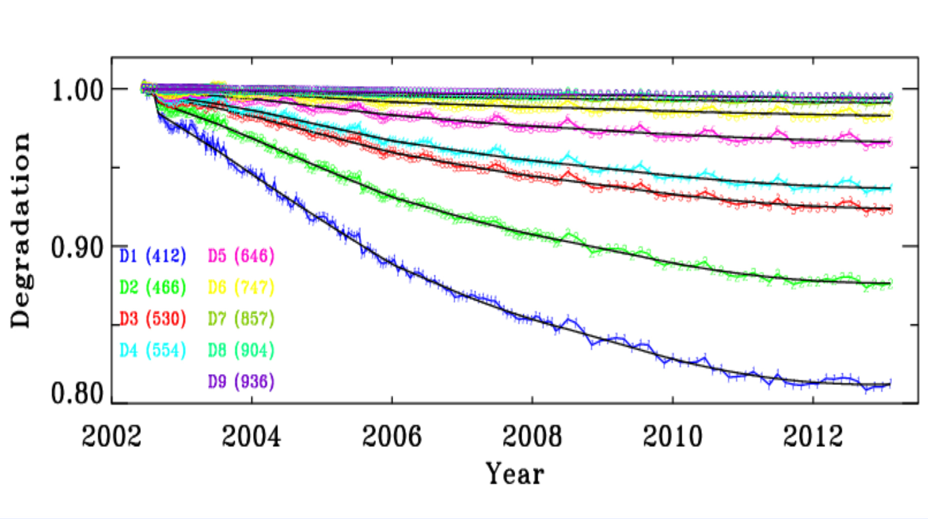
- **On-board Calibrators**
  - SD, SDSM, and BB
- **Changes in Spectral Band Response**
  - Reflective Solar Bands (RSB) and Thermal Emissive Bands (TEB)
- **Detector SNR and NedT**
- **Calibration Inter-comparison with Aqua MODIS**
  - Reflective Solar Bands (RSB) – Backup slides

SD Degradation

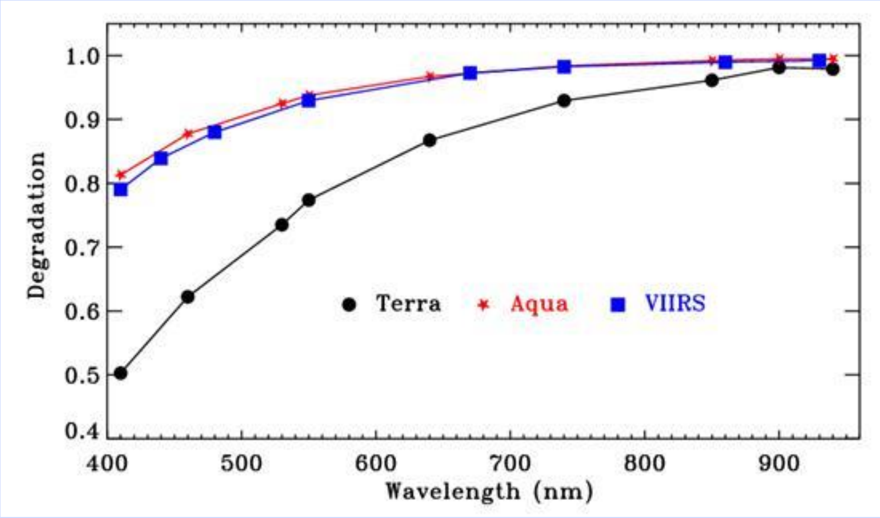
S-NPP VIIRS



Aqua MODIS



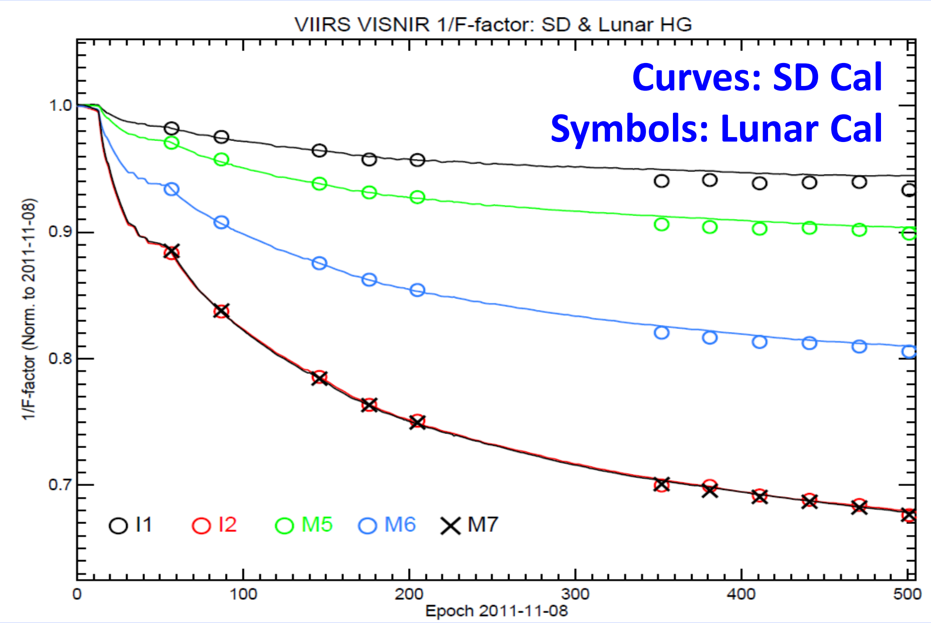
Similar to MODIS with strong wavelength dependence

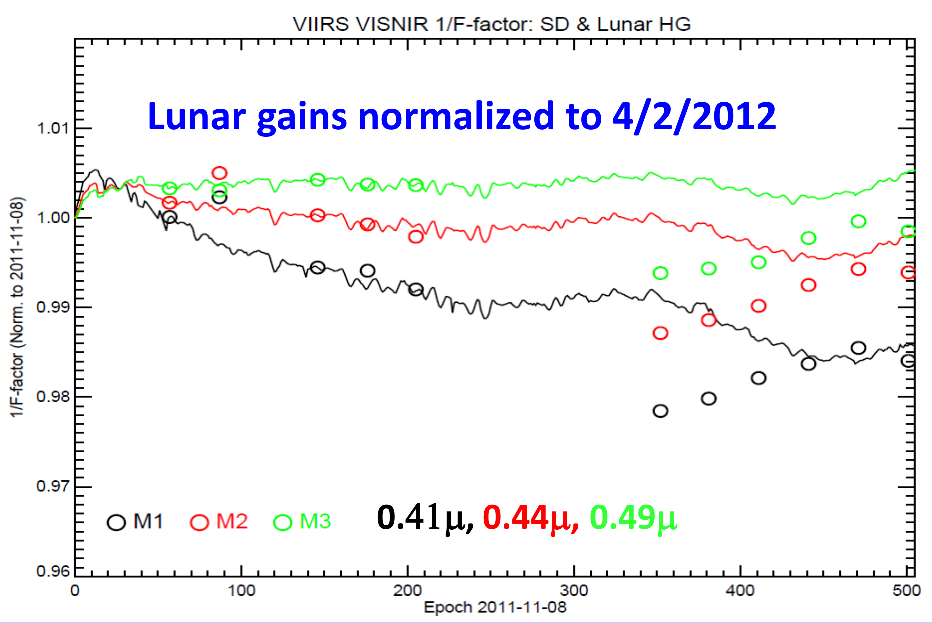


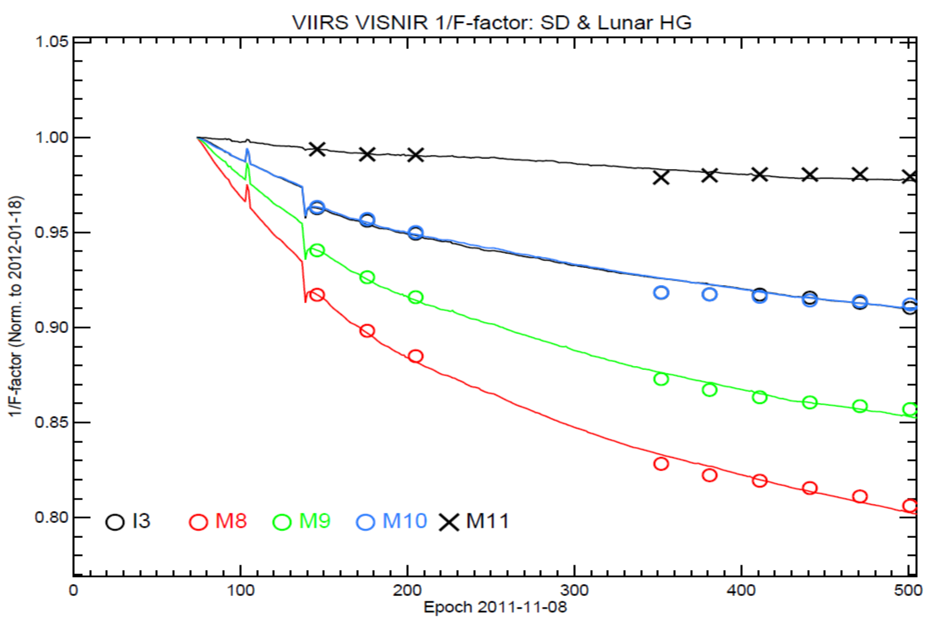
VIIRS has no SD door:

Large degradation in SD BRF at short wavelengths

Changes in Spectral Band Response (VIIRS RSB)







Little change for HAM side and AOI dependence

Large changes in NIR/SWIR response

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

VIIRS BB and TEB Stability

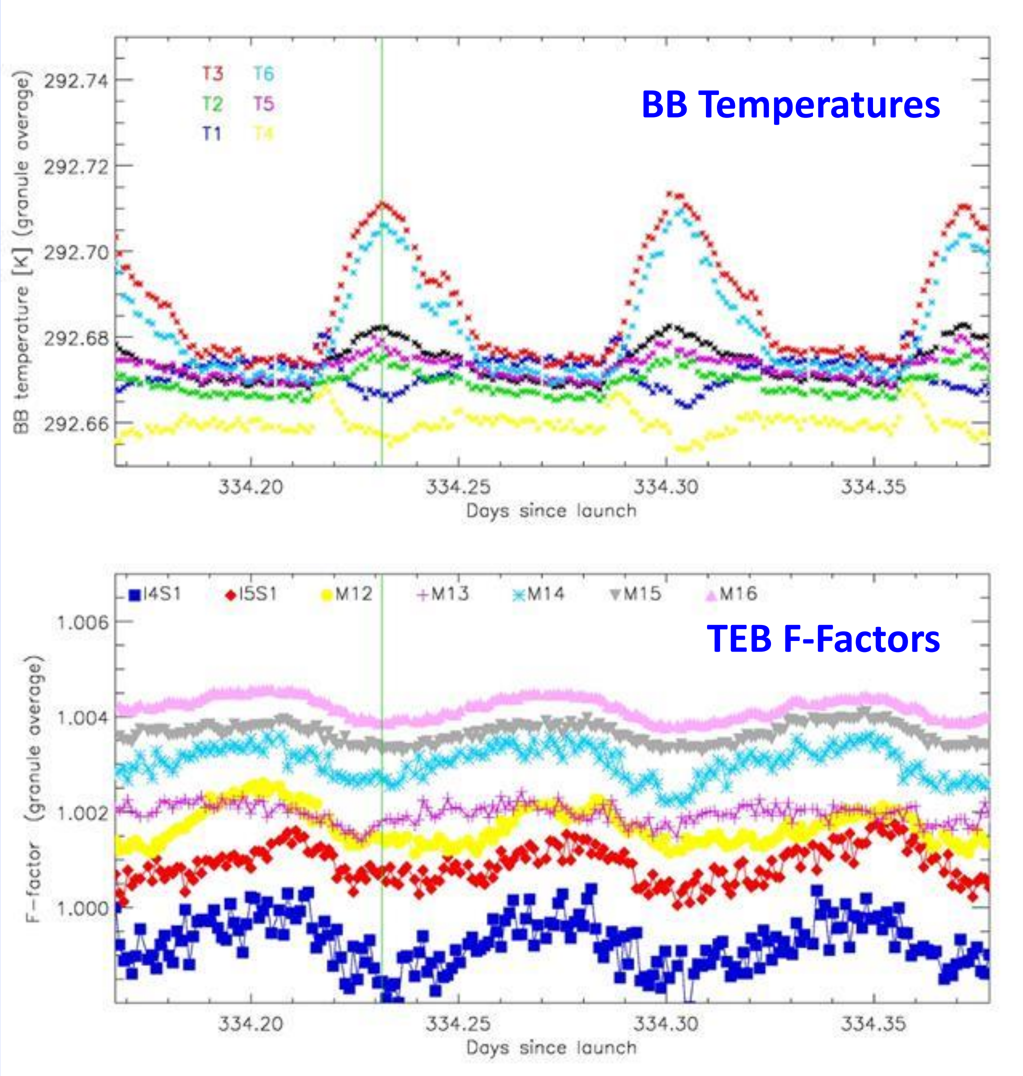
Small orbital variations with similar amplitude for thermistor pairs located at the same scan angle. Thermistors 3 and 6, located at the top of the BB (furthest from the EV), have the largest variation.

$$\Delta\bar{T}_{(T_3,T_6)} = 0.037\,\mathrm{K}$$
$$\Delta\bar{T}_{(T_2,T_5)} = 0.011\,\mathrm{K}$$
$$\Delta\bar{T}_{(T_1,T_4)} = 0.014\,\mathrm{K}$$
$$\Delta\bar{T}_{(T_1,T_2,T_3,T_4,T_5,T_6)} = 0.014\,\mathrm{K}$$

F-factors at nominal temperature show periodic variations of 0.2%, which are correlated with the BB temperature variations.

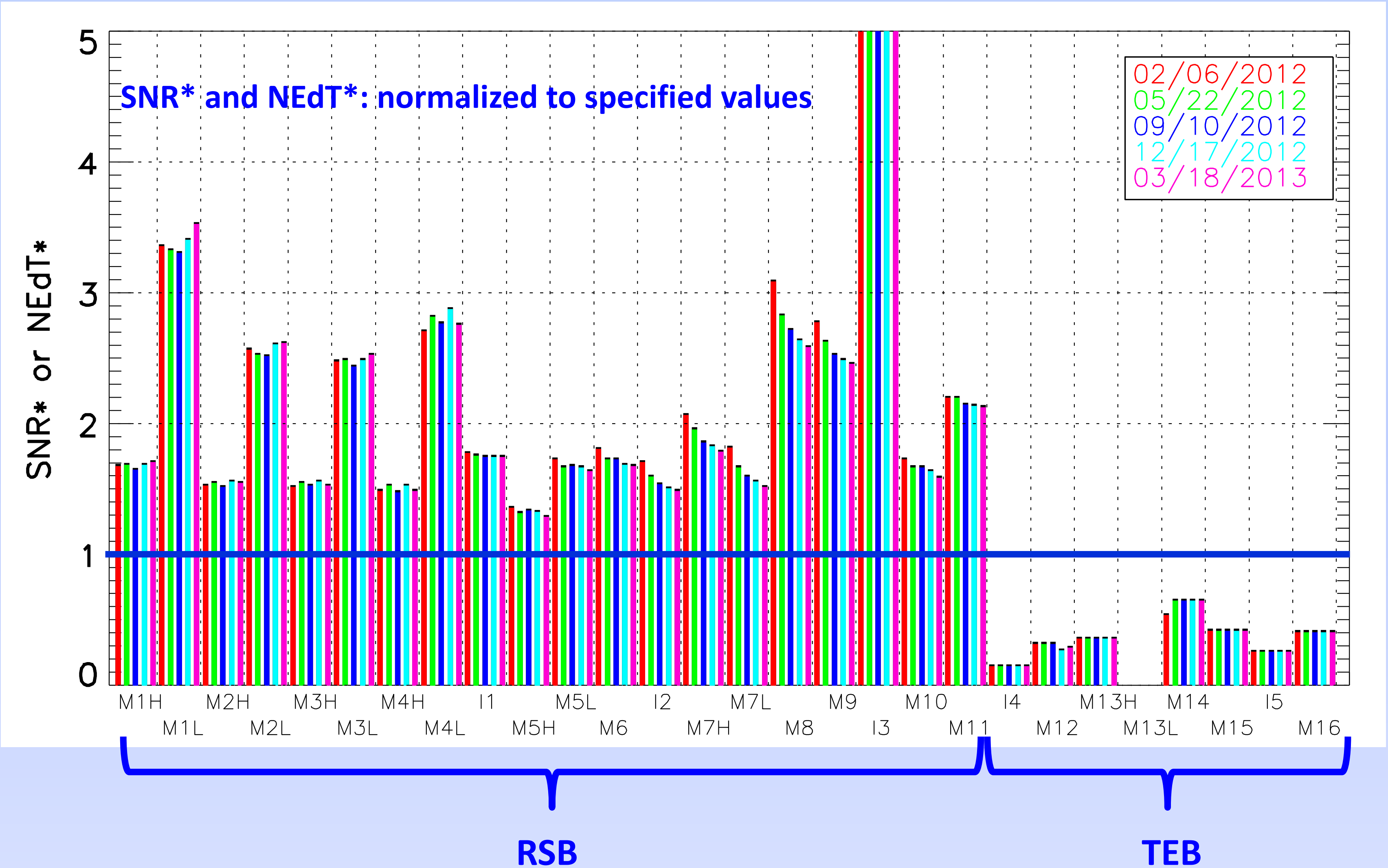
Long-term drift is small (< 0.5%)

Orbits: 4743, 4744, 4745



*** For clarity the F-factors are shifted.**

Detector SNR (RSB) and NEdT (TEB)



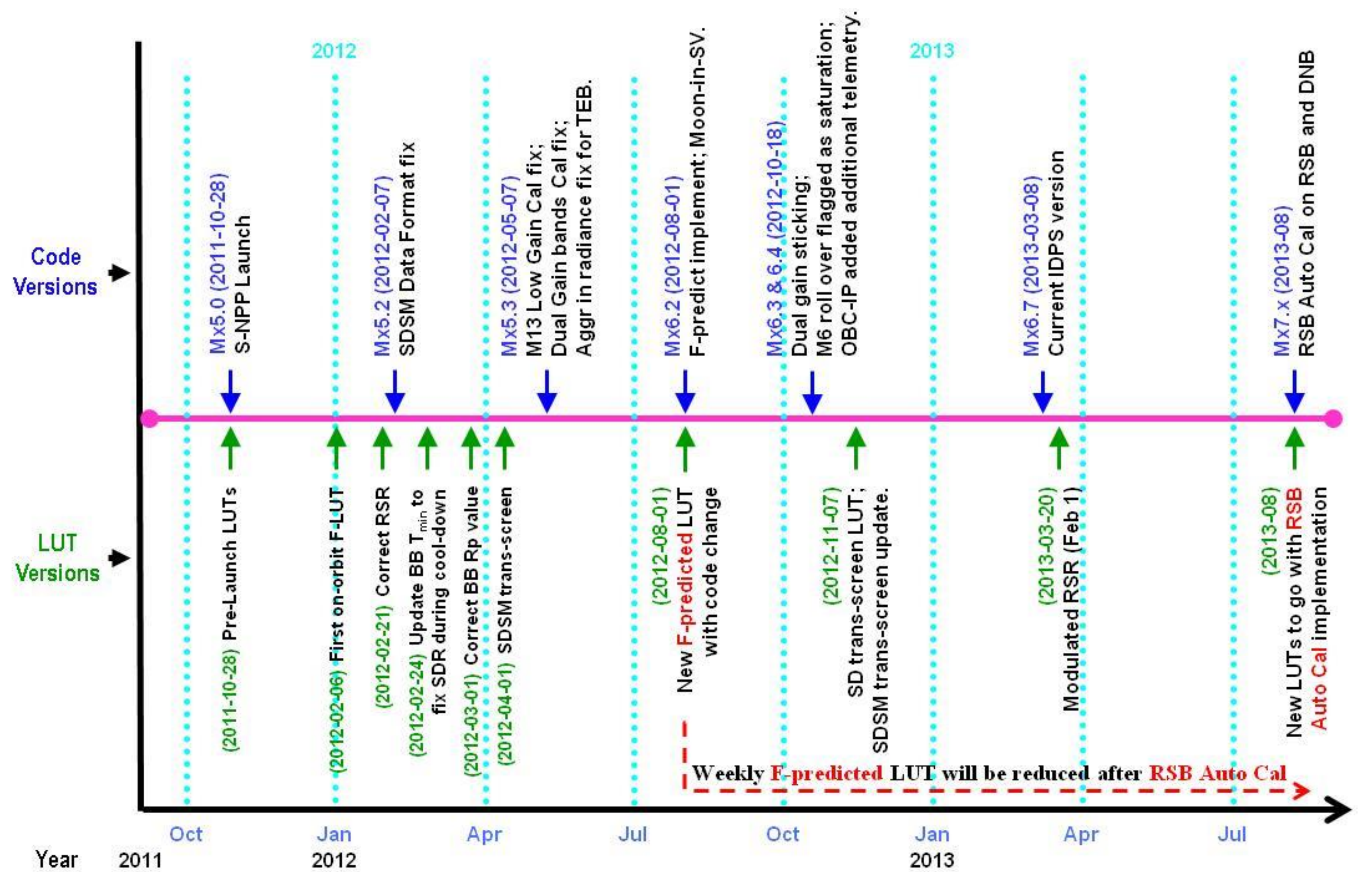
For RSB: SNR* > 1 means performance better than specified requirements

For TEB: NEdT* < 1 means performance better than specified requirements

Status of VIIRS SDR Code/LUTs

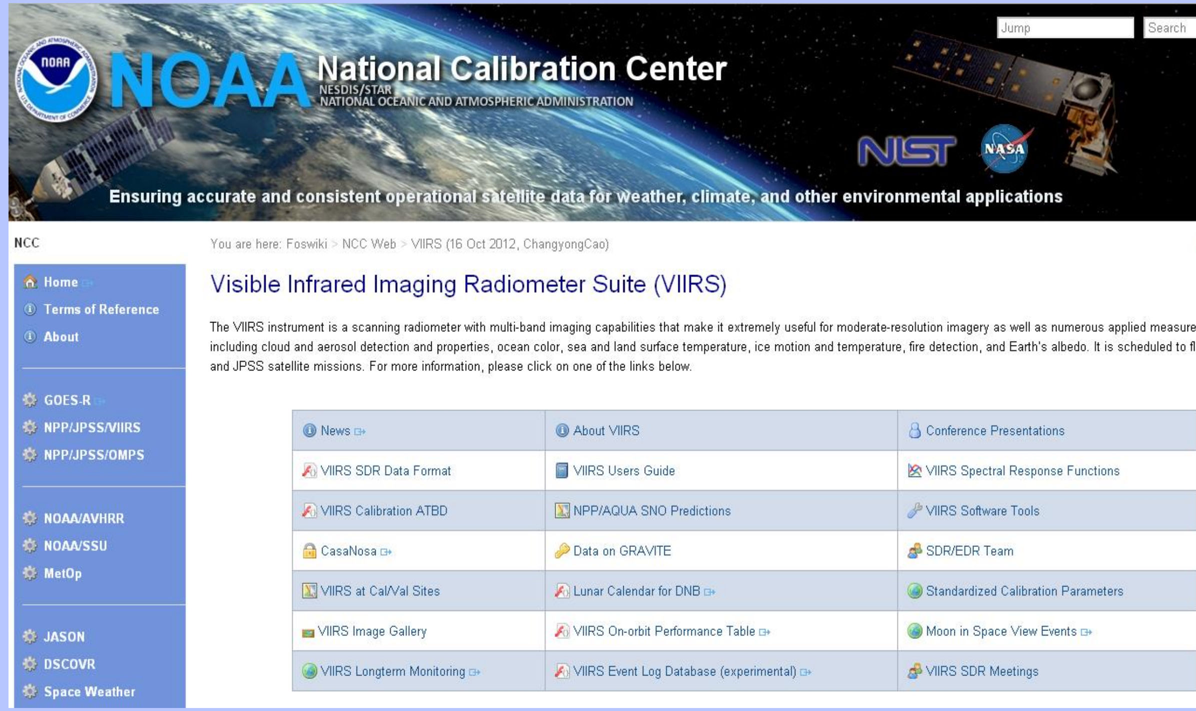
- **IDPS VIIRS SDR Code/LUTs (radiometric)**
  - 6 code versions
  - 9 major LUT updates (weekly updates not included)
  - Improved LUT update strategy (on demand -> weekly -> auto cal)
- **VCST Effort**
  - Independent validation and improvements for SDR code/LUTs
  - Two sets of F-LUTs for VISNIR/SWIR and DNB delivered to Land PEATE for SDR/EDR assessment and reprocess.
    - Jan 31, 2013: LUTs from Jan 2012 to Jan 2013 generated using existing IDPS algorithm but with smoothed functions to remove outliers.
    - Apr 19, 2013: LUTs from Jan 2012 to Mar 2013 generated with "best" sensor characterization improvements, including SD/SDSM screen transmission, SD BRDF, RTA mirrors degradation model, modulated RSRs, and smoothed fitting functions.

Major IDPS SDR Code/LUTs Update Timeline (Radiometric)



VIIRS SDR Data Access and Calibration Knowledge Base

- The VIIRS SDR team developed the Calibration Knowledge base at https://cs.star.nesdis.noaa.gov/NCC/VIIRS with a wealth of information including user's guide, relative spectral response, SNO predictions, image gallery, VIIRS Events, publication database, conference presentations, etc.

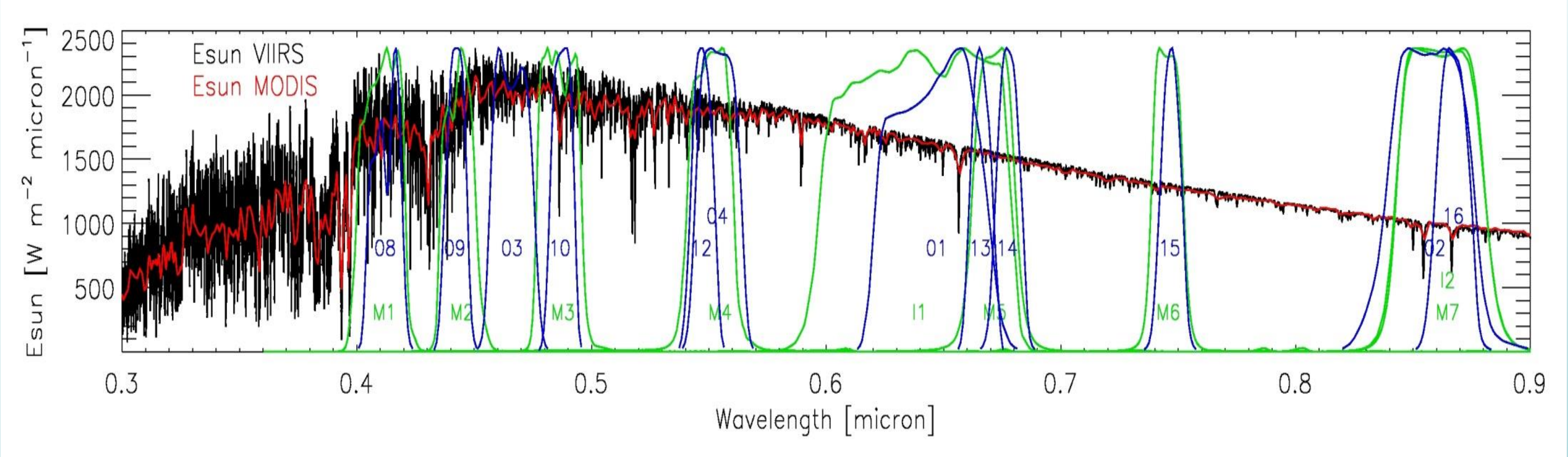


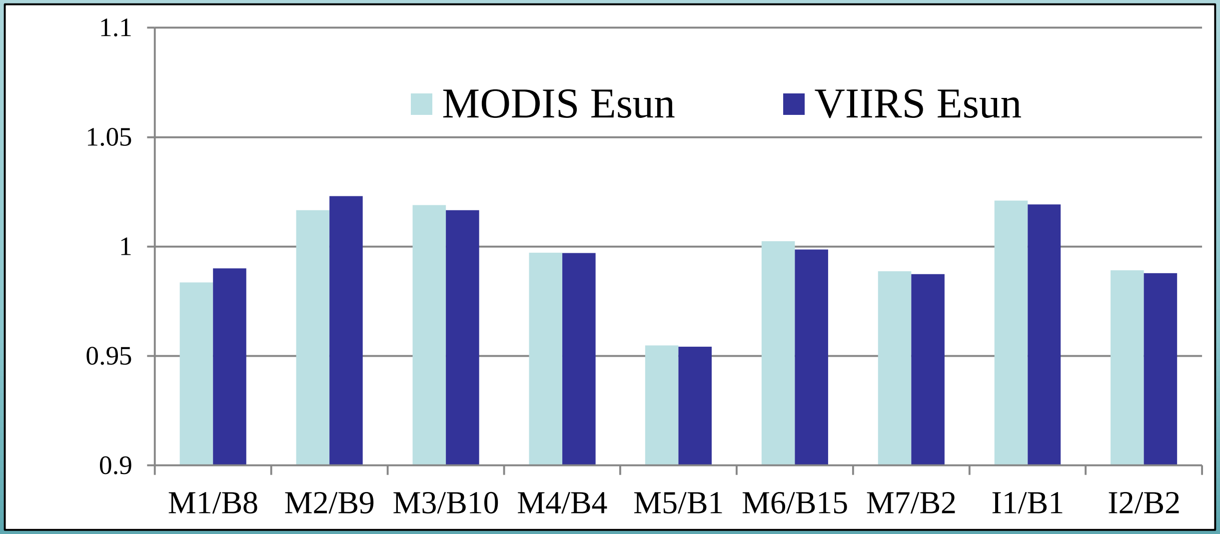
- VIIRS SDR data is available to the public on the NOAA CLASS archive at http://www.class.noaa.gov, and the ftp site: ftp://ftp-npp.class.ngdc.noaa.gov/

Reference:

Cao, C., F. Deluccia, X. Xiong, R. Wolfe, and F. Weng, 2013, Early On-orbit Performance of the VIIRS onboard the S-NPP Satellite, IEEE Transactions on Geoscience and Remote Sensing, in press. DOI: 10.1109/TGRS.2013.2247768

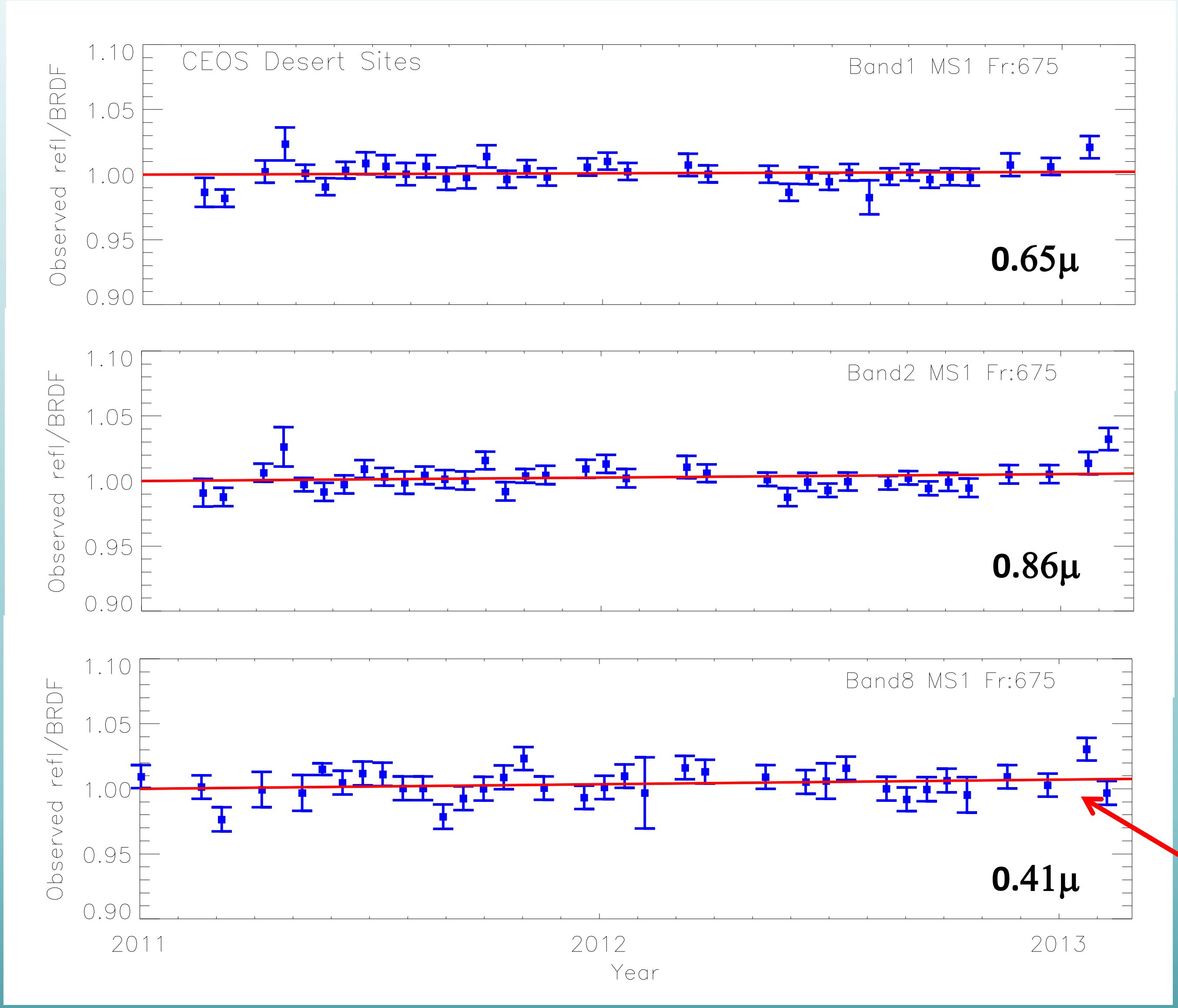
Sensor RSR and Solar Irradiance Model





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

Reflectance Trending (Aqua MODIS; Libya 4)



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

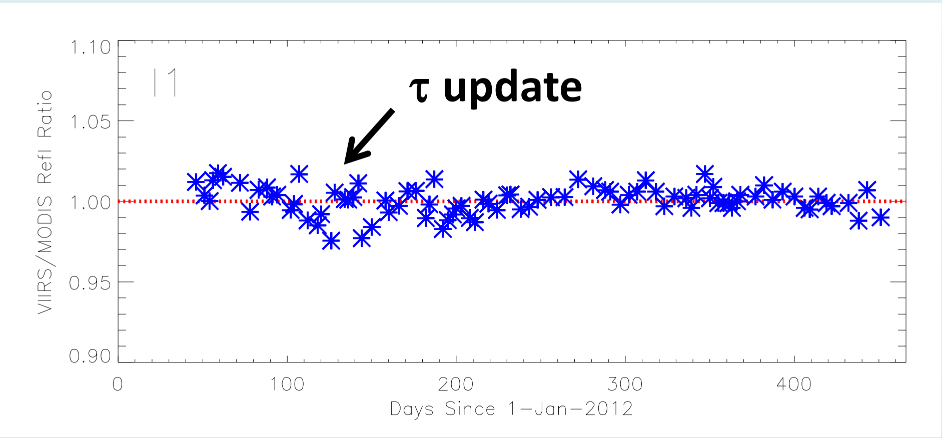
Good reference site to track the sensor on-orbit calibration performance

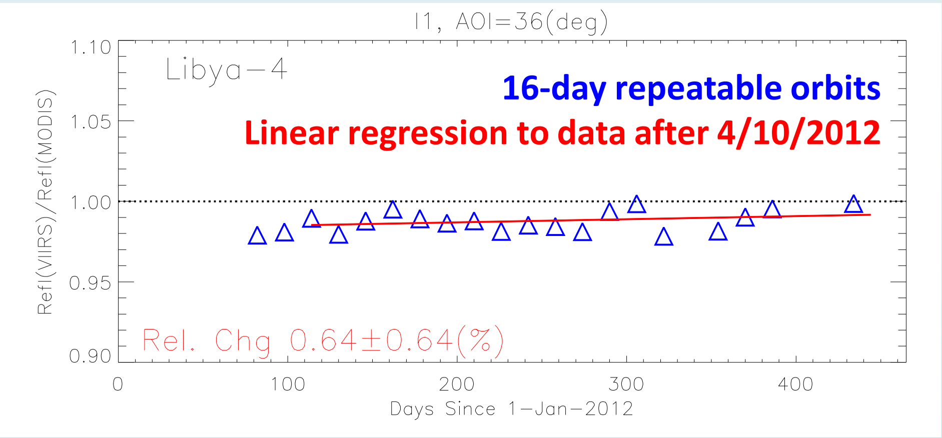
Linear Regression

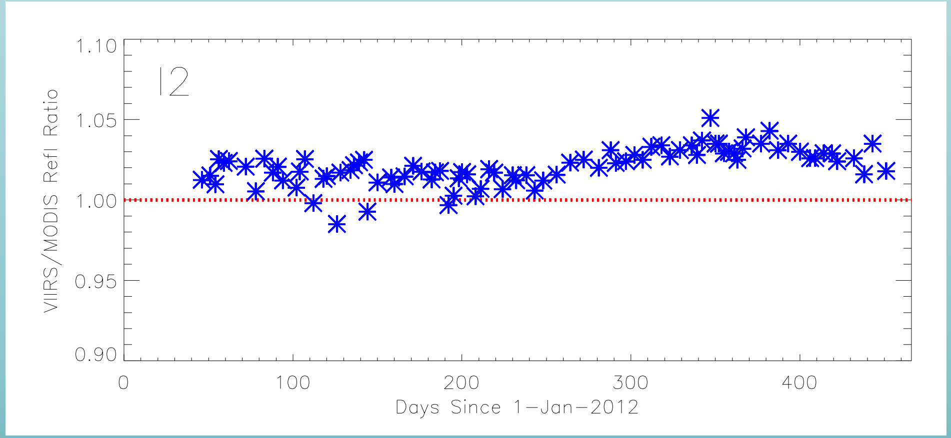
Inter-comparison Results (Examples)

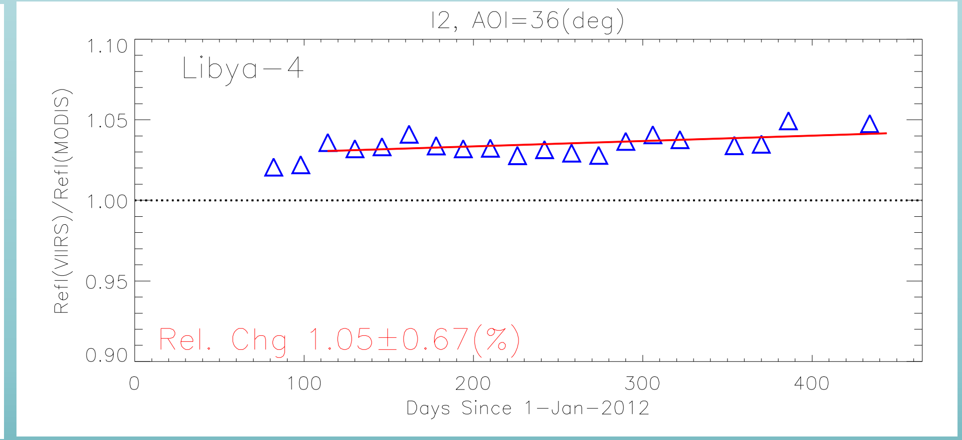
SNO

Libya-4









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 are significantly higher than 2% due to early saturation for MODIS matching band

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

Summary

- Both Terra and Aqua MODIS continue to operate normally
- Instrument on-board calibrators remain capable of all design functions
- Overall sensor performance has been satisfactory (very few noisy detectors in recent years)
- Decade long high quality MODIS data products have significantly contributed to a broad range of scientific studies and applications
- VIIRS has been operated and calibrated as planned and expected
- Overall on-orbit performance meets the design requirements (such as SNR/NEdT)
- Continuous and dedicated efforts are critical for maintaining MODIS and VIIRS calibration and data quality and achieving calibration consistency between the two sensors (significant contributions to remote sensing community)