Update of Terra and Aqua MODIS and S-NPP VIIRS On-orbit Calibration

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<u>Contributions:</u>

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S-NPP and JPSS VIIRS SDR Calibration Team, NOAA

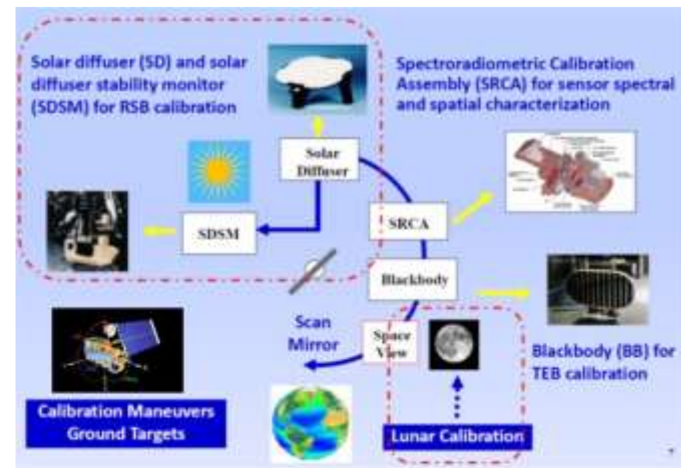
CEOS WGCV-41, Tokyo, Japan (September 5-7, 2016)

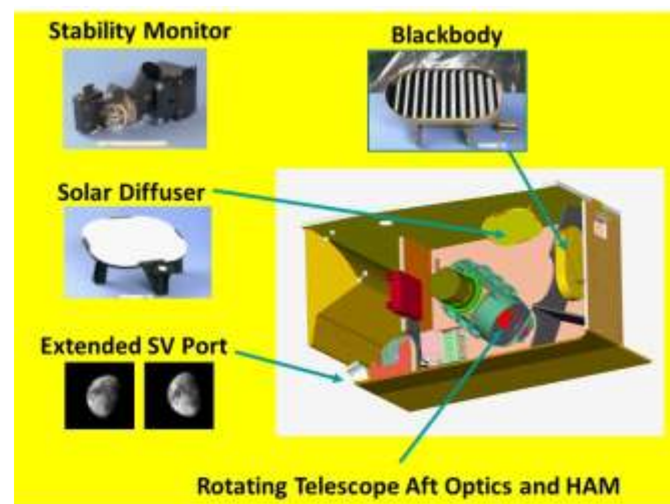
Outline

- MODIS and VIIRS On-orbit Calibration
- Terra and Aqua MODIS Performance
- S-NPP Performance
- Challenging Issues and Future Work

MODIS and VIIRS On-orbit Calibration

- **Terra, Aqua, S-NPP, and JPSS Missions**
  - Terra and Aqua: launched in 1999 and 2002
  - S-NPP: launched in 2011
  - JPSS-1 and -2: launch in 2017 and 2021
- **MODIS**
  - Regular SD/SDSM calibration (SD door opens only during SD/SDSM calibration for Aqua; Terra SD door fixed at open since mid-2003)
  - Regular SRCA operations (3 modes)
  - Quarterly BB warm-up/cool-down
  - Monthly lunar observations at phase angles @ -55^o
- **VIIRS (S-NPP)**
  - SD calibration performed every orbit (no SD door); SDSM operated on a regular basis
  - Quarterly BB warm-up/cool-down
  - Monthly lunar observations at phase angles @ -51^o (originally planned for @ -55^o)





On-orbit Instrument Performance (MODIS)

- **Instrument and On-board Calibrators (OBC)**
  - **Terra MODIS** instrument and VIS/NIR FPA temperature increase: < 3.5 K; CFPA temperatures: very stable; BB temperature increase: < 30 mK; SD degradation: faster at shorter wavelengths
  - **Aqua MODIS** instrument, VIS/NIR FPA temperature increase: < 2.0 K; CFPA temperatures: small variations in 2010-2015 (improved control lately); BB temperatures: extremely stable; SD degradation: same wavelength dependence but slower rate than Terra MODIS
- **Radiometric, Spatial, Spectral, and Geometric**
  - Spectral band responses: large at VIS and NIR; small at SWIR, MWIR, LWIR
  - Band-to-band registration (BBR): very stable
  - Center wavelengths: changes are within 0.5 nm for most VIS/NIR bands; relatively large changes for bands with broad bandwidths (bands 1 and 19)
  - Geolocation accuracy: approximately within ±50 m (C6)

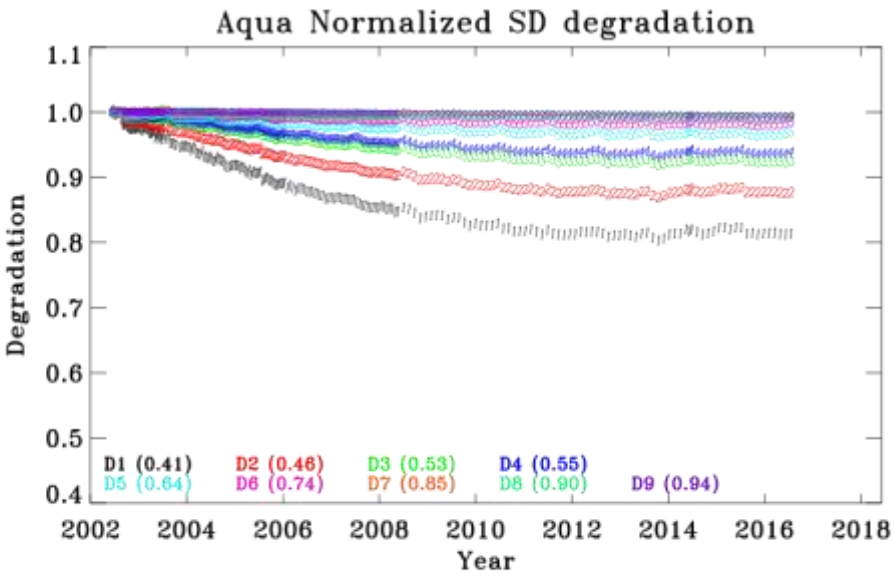
On-orbit Instrument Performance (VIIRS)

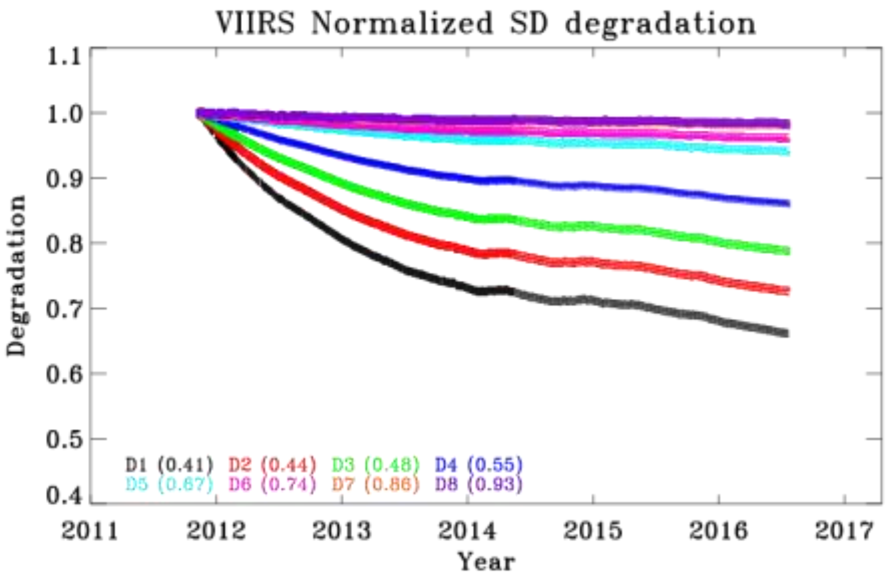
- **Instrument and On-board Calibrators (OBC)**
  - Instrument and FPA temperatures: stable
  - BB stability: extremely stable (similar to Aqua MODIS)

  } **Similar to Aqua MODIS**

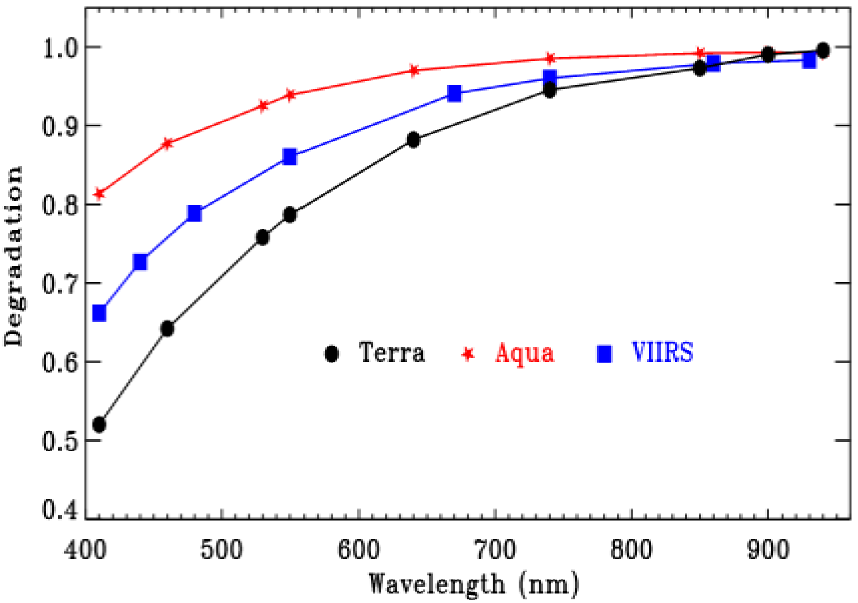
  - SD degradation: larger at shorter wavelengths (similar to Terra MODIS)
- **Radiometric, Spatial, Spectral, and Geometric**
  - Spectral band responses: large at NIR and SWIR; small at VIS, MWIR, LWIR
  - Band-to-band registration (BBR): stable (tracked using lunar observations)
  - Relative spectral response (RSR): modulated on-orbit (due to strong wavelength dependent optics degradation)
    - Noticeable impact for DNB and small effect on M/I bands
  - Geolocation: satisfactory but can be improved further

MODIS and VIIRS SD on-orbit Degradation





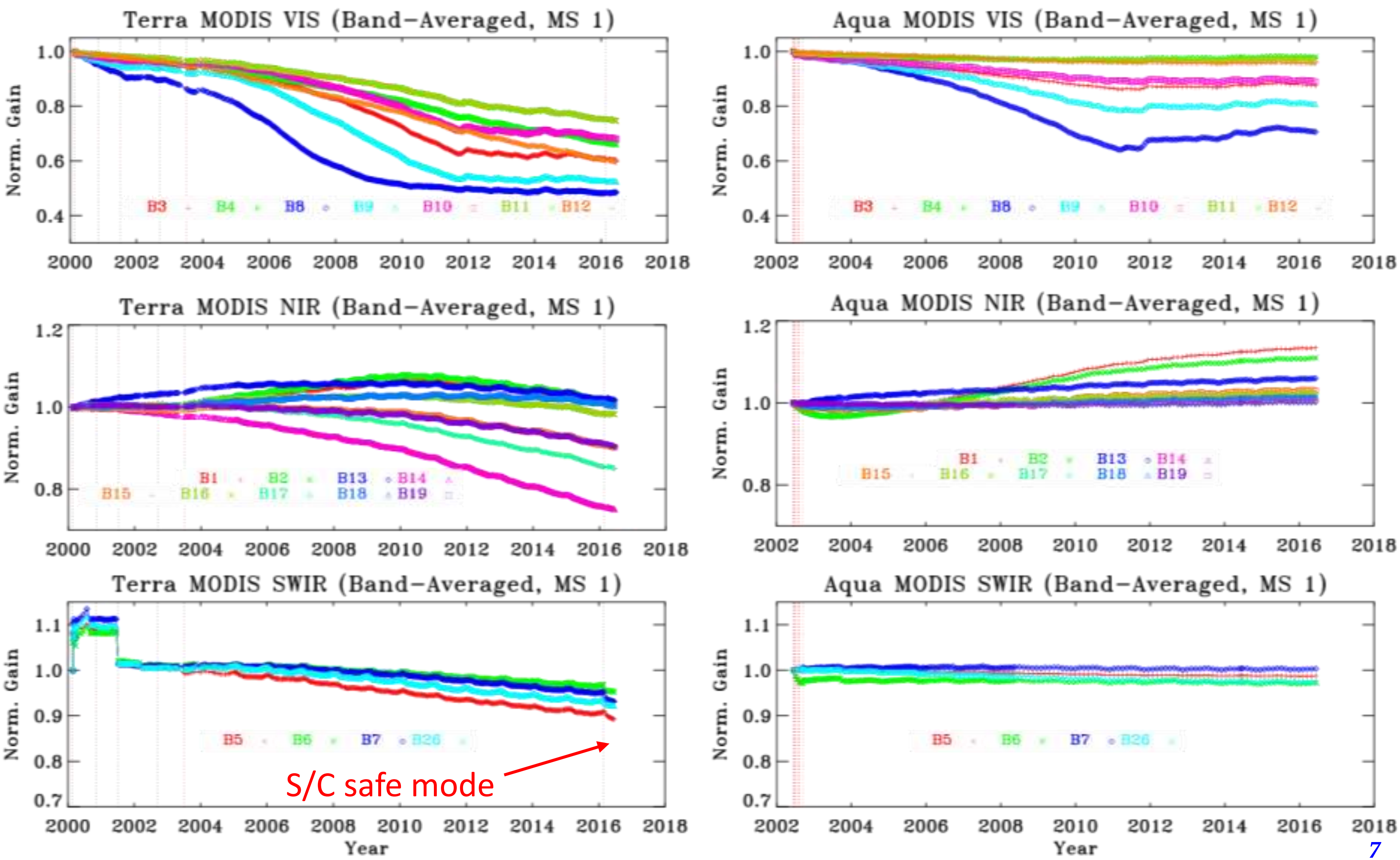
Aqua SD door open/close
Terra SD door fixed at open since 2003
No SD door for S-NPP



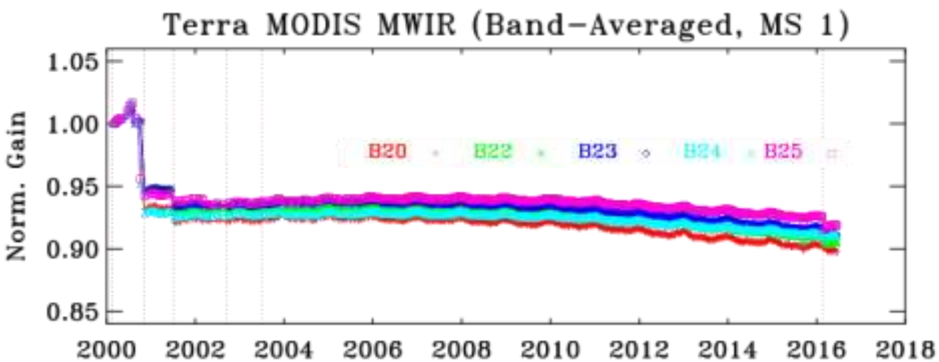
Uncertainties at VIS (large correction) and SWIR (no direct monitoring)

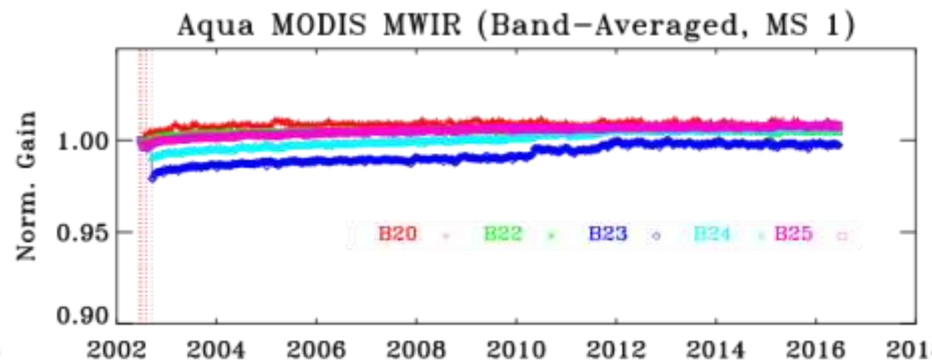
MODIS VIS/NIR/SWIR Spectral Band Responses (Gains)

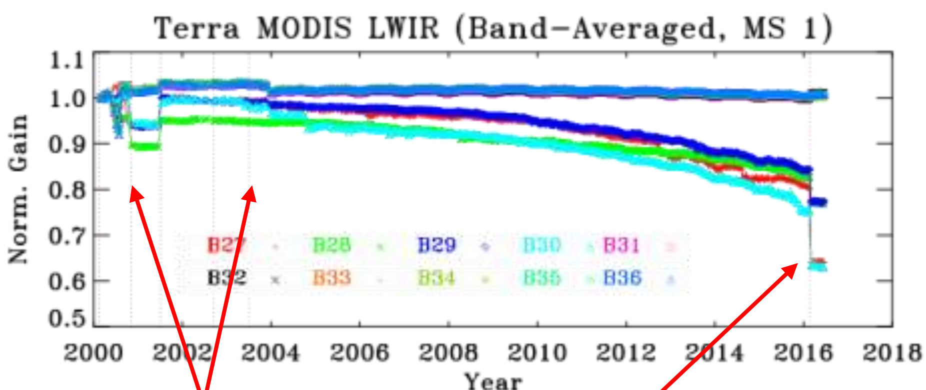
Spectral band responses: large in VIS and NIR; small in SWIR, MWIR, LWIR



MODIS MWIR/LWIR Spectral Band Responses (Gains)

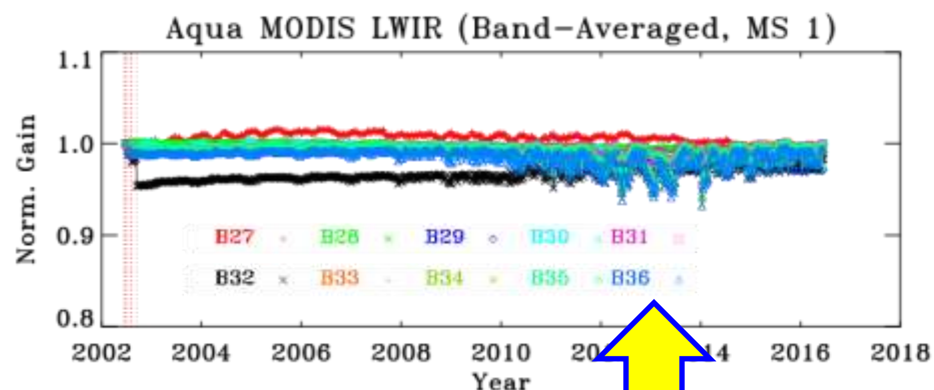




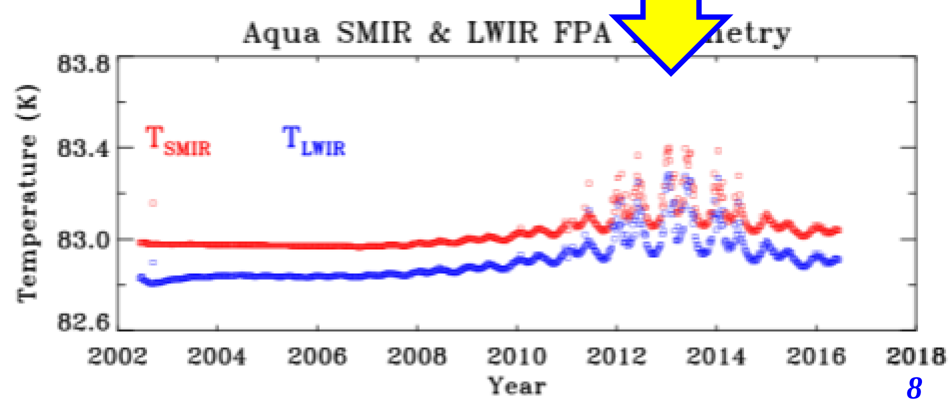


Change of electronic configuration

S/C safe mode

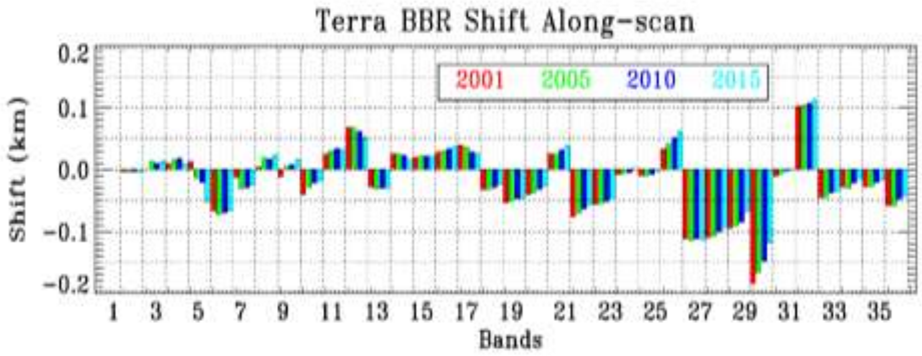


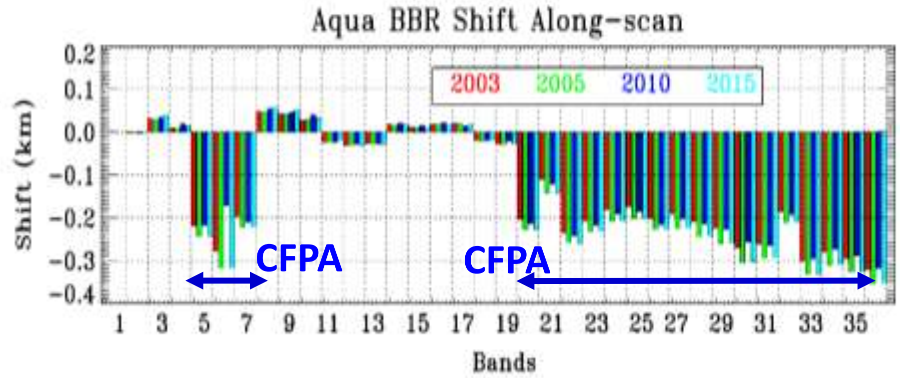
Fluctuations in CFPA temp. led to small variations in LWIR detector responses



MODIS Spatial and Spectral Performance

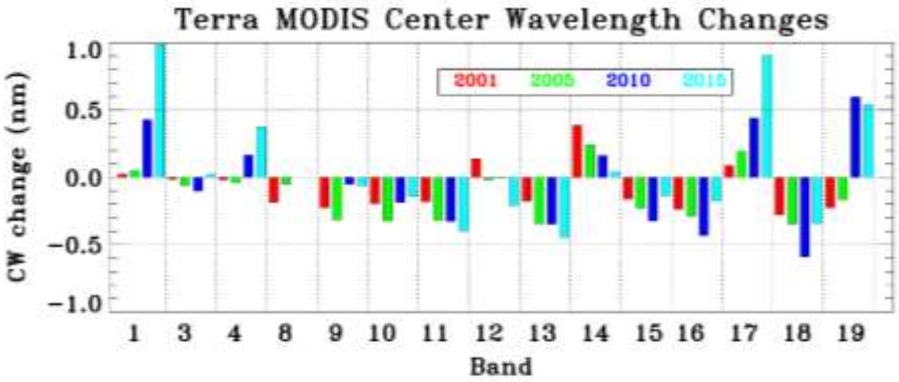
Band-to-Band Registration (BBR) in Along-scan Direction

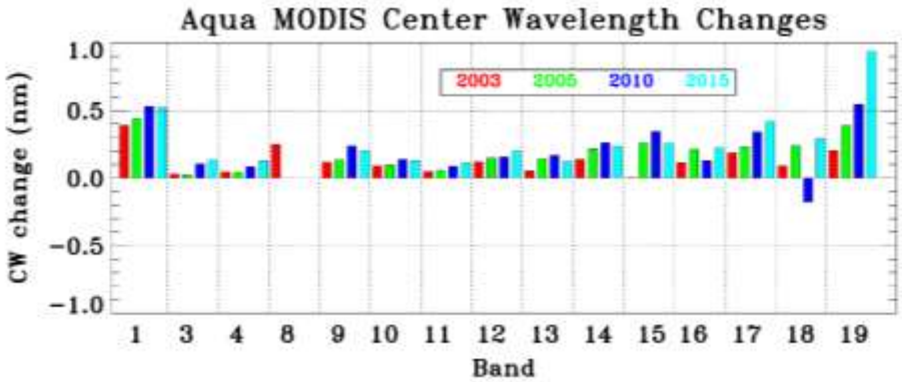




Similar Performance for BBR in Along-track Direction

Changes in Spectral Band Center Wavelengths (CW)



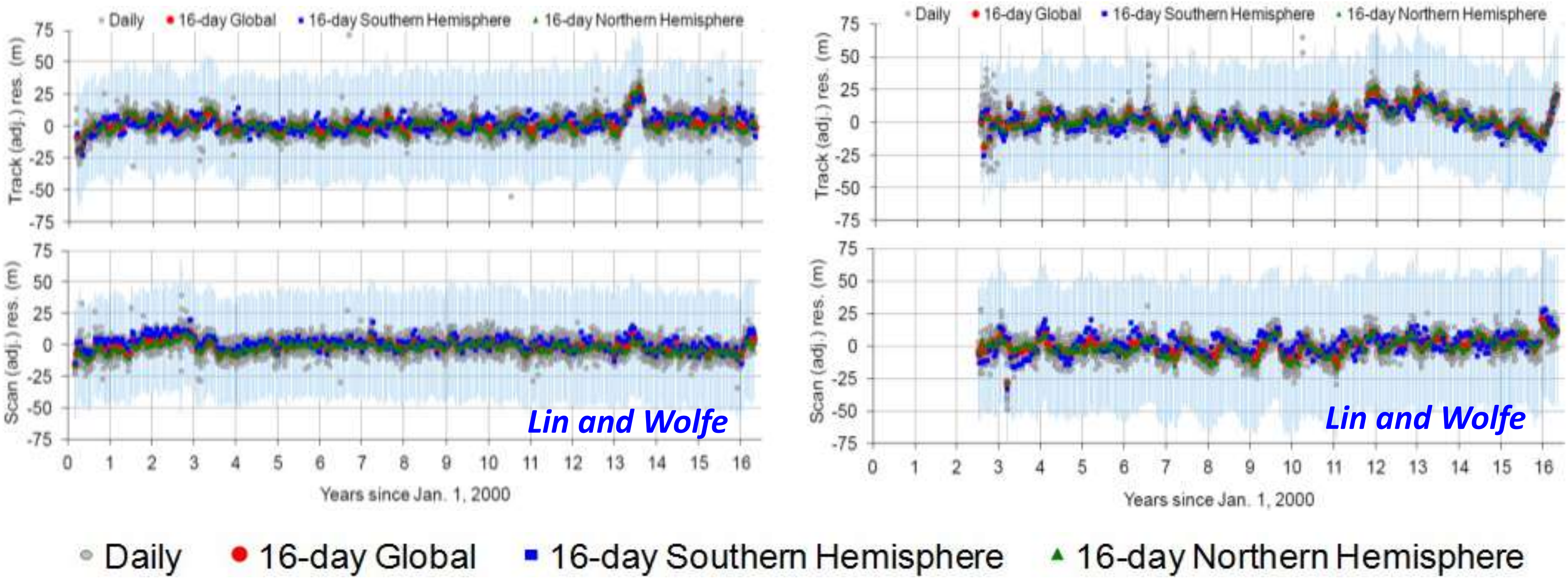


Similar Results for Changes in Bandwidths (BW)

MODIS Geolocation Performance

Terra and Aqua MODIS Geolocation Performance Remains Satisfactory

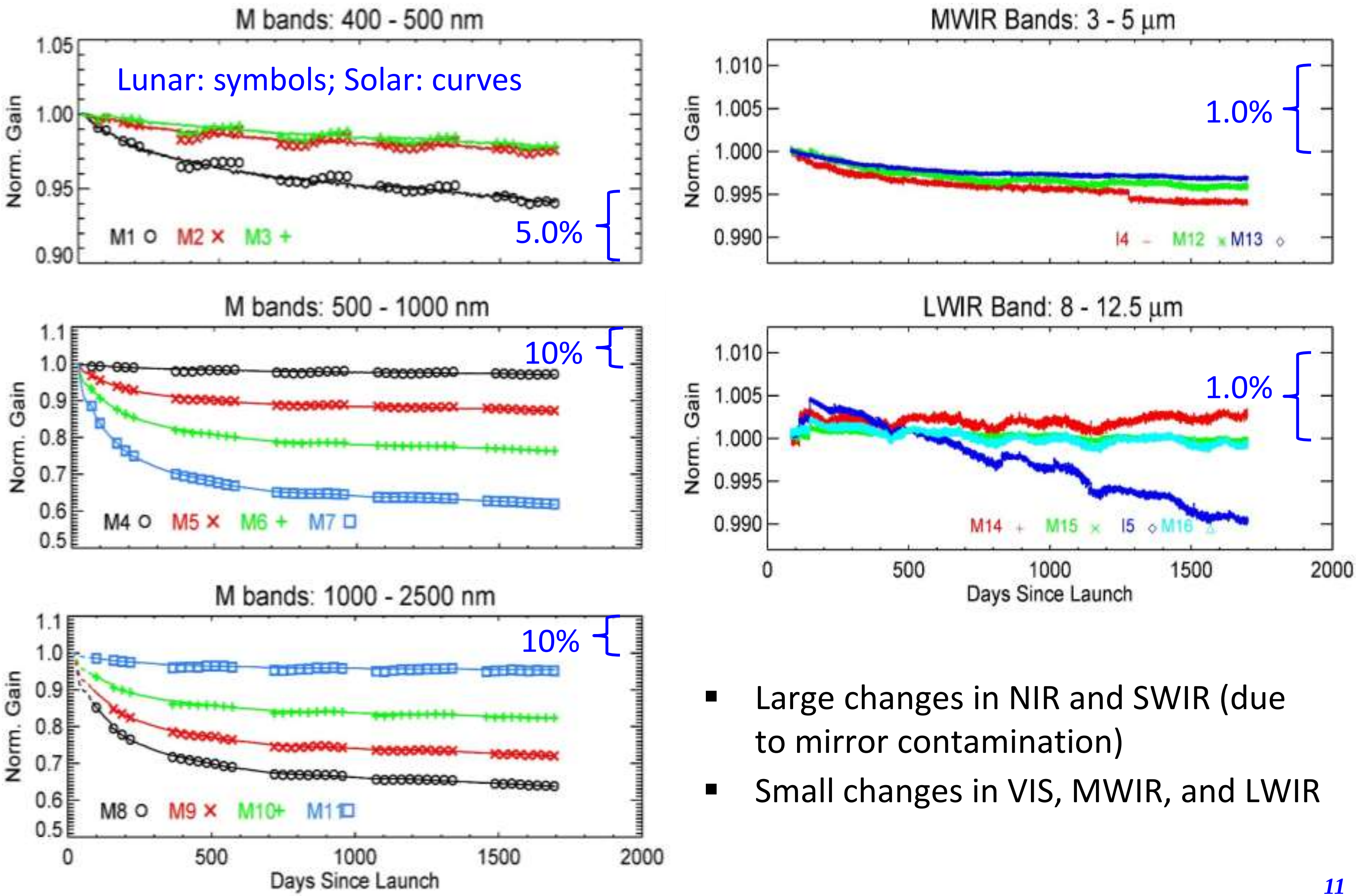
Terra MODIS RMSE (C6)	Aqua MODIS RMSE (C6)
Track: 43 m Scan: 44 m	Track: 46 m Scan: 53 m



Terra track direction jump - due to a delayed implementation/update of Geo LUTs (from 01/01/2013 to 08/10/2013).

Aqua track direction jump at the end of 2011 (now it's back to "normal") - need to model it and update the LUT.

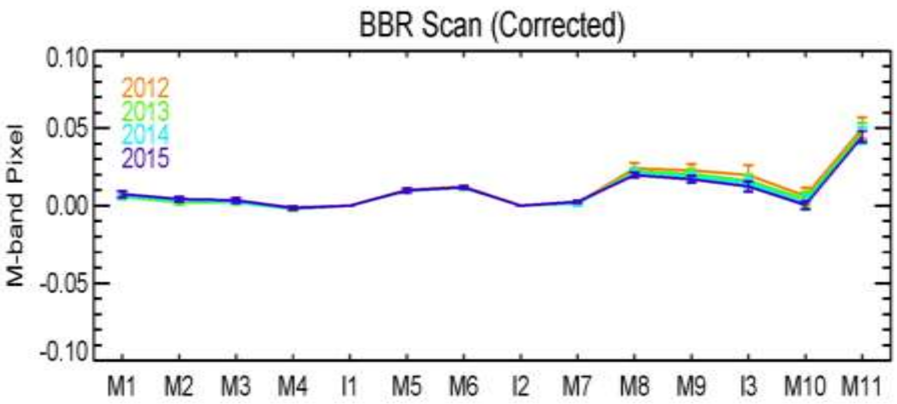
VIIRS Changes in Spectral Band Responses (Gains)

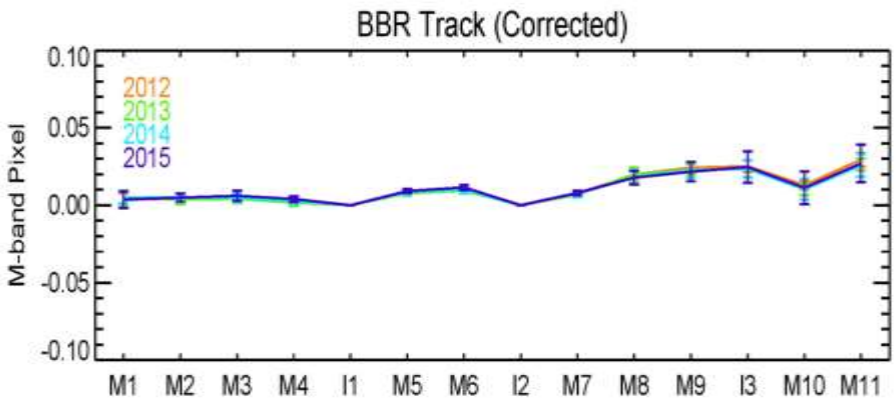


- Large changes in NIR and SWIR (due to mirror contamination)
- Small changes in VIS, MWIR, and LWIR

VIIRS Spatial and Spectral Performance

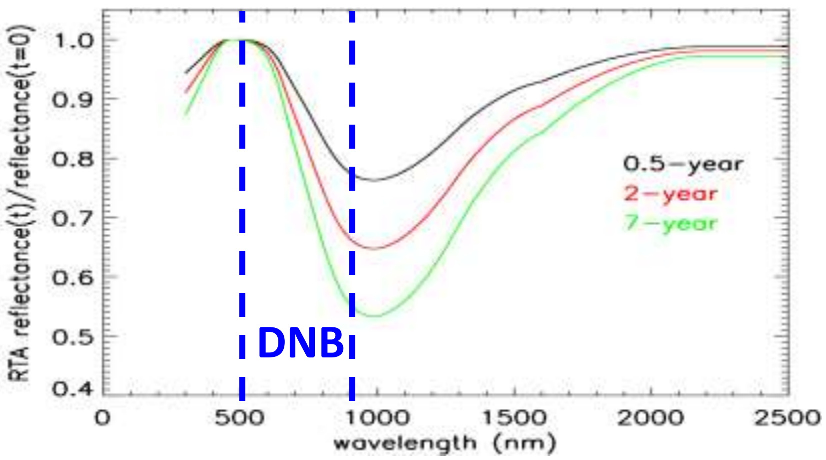
Band-to-band registration (BBR)

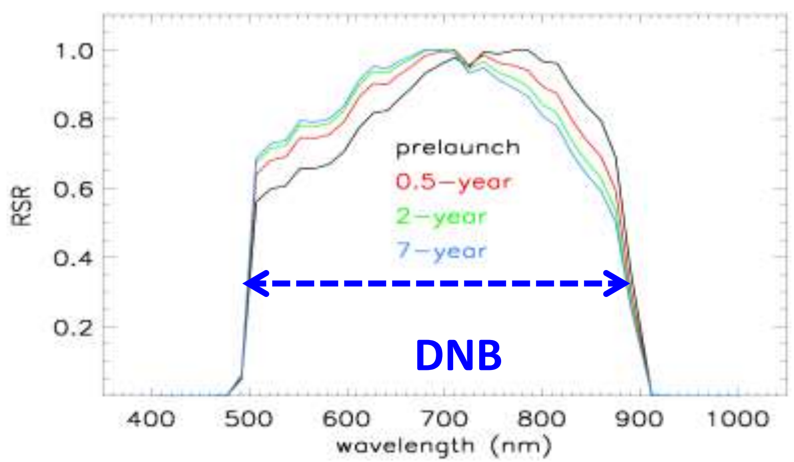




- Improved methodology (originally developed for MODIS BBR using lunar observations and validated using on-board SRCA)
- On-orbit BBR is very stable in both scan and track directions

Modulated RSR

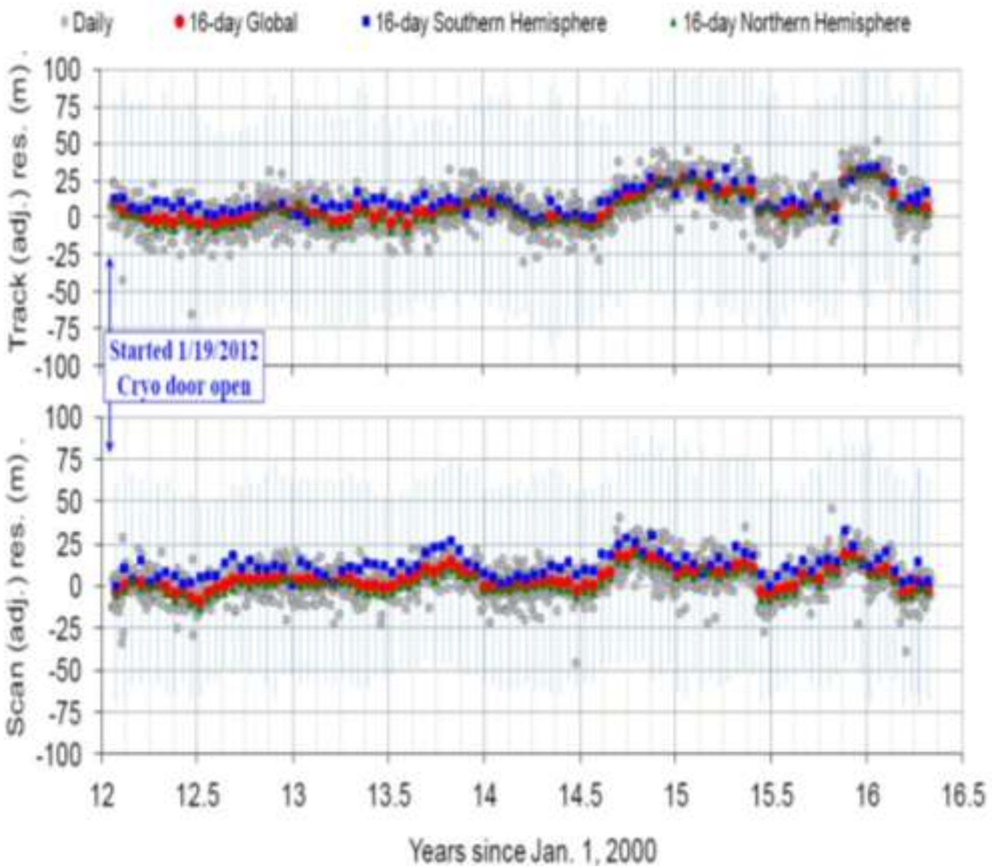




Large impact for DNB (up to 5%); small impact for M/I bands (< 1%)

VIIRS Geometric Performance

Geolocation



S-NPP VIIRS RMSE (C1.1)
Track: 72 m Scan: 61 m

Future improvements (via reprocessing)

Terra MODIS RMSE (C6)
Track: 43 m Scan: 44 m

Aqua MODIS RMSE (C6)
Track: 46 m Scan: 53 m

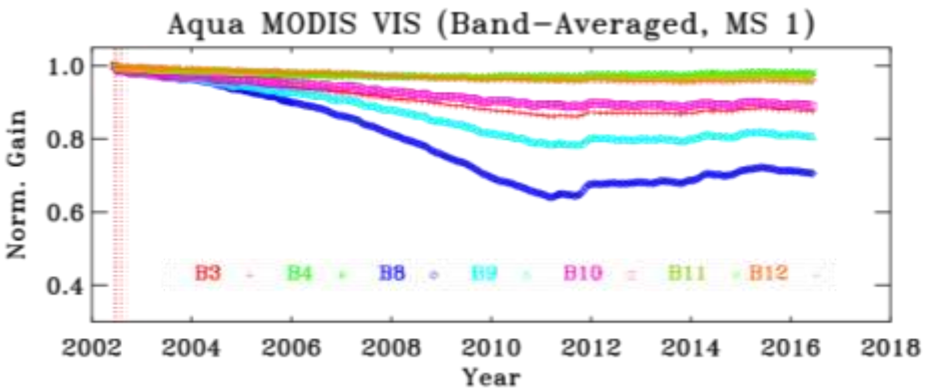
(Geometric Cal: Lin and Wolfe)

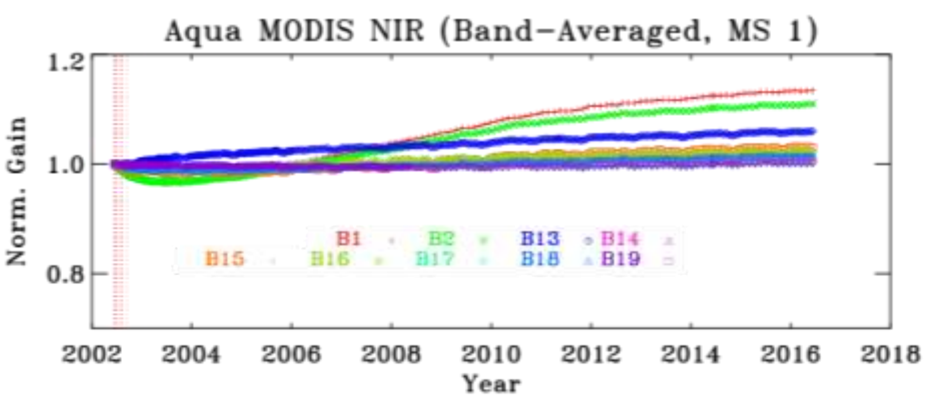
Challenging Issues and Future Work

- **Future work to address existing and new challenging issues and to continue improving sensor on-orbit calibration**
  - Changes in MODIS VIS/NIR response versus scan-angle (RVS) – continuing effort
  - Changes in Terra MODIS polarization sensitivity and impact on sensor's earth view response trending – progress has been made in recent years
  - Uncertainty due to large SD degradation and no SD degradation monitoring for SWIR bands – mitigation strategies developed and applied
  - Terra LWIR PV Xtalk impact – correction algorithm testing and implementation
  - Improved use of VIIRS SD and lunar calibration parameters – impact of RSR
  - Tracking potential changes in VIIRS RVS – lessons from MODIS
  - Special calibration and validation effort in support of VIIRS data reprocessing – effort by both NASA and NOAA
- **MODIS and VIIRS calibration consistency and impact on science products**
  - Extensive calibration and validation effort and science support
  - Community effort and interagency collaboration

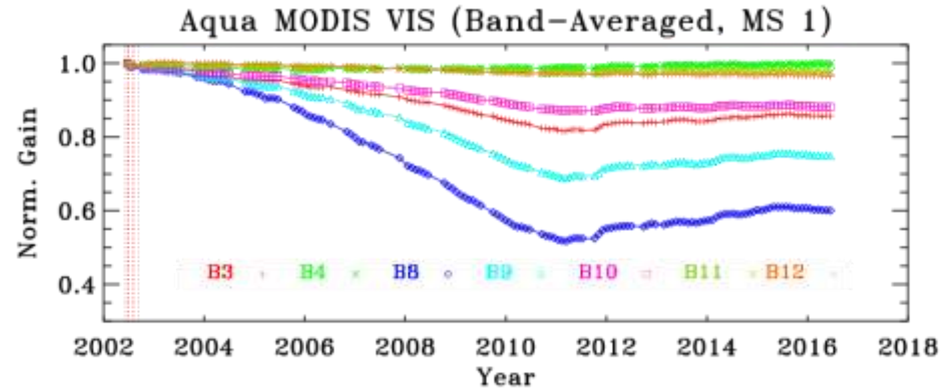
MODIS Changes in Response Versus Scan-angle (RVS)

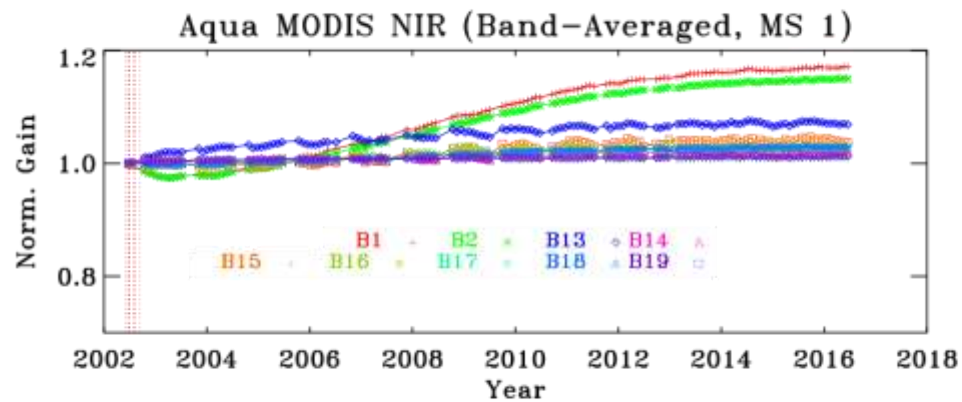
SD Calibration





Lunar Calibration





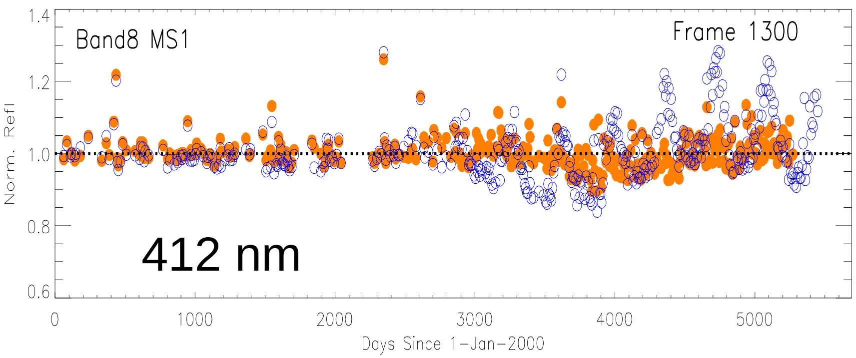
RVS is wavelength, mirror-side, and AOI dependent

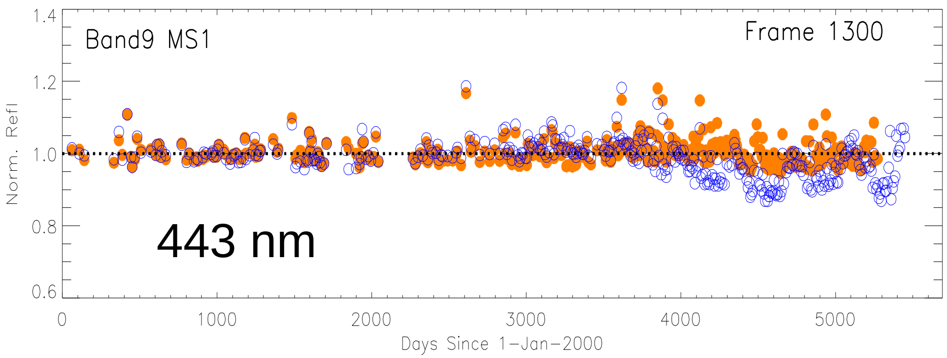
MODIS SD and lunar calibrations performed at 2 different AOIs

VIIRS SD and lunar calibrations performed at the same AOI (closely monitored using PICS)

On-orbit Changes in Terra MODIS Polarization Sensitivity

- Noticeable on-orbit changes in the polarization sensitivity, especially at short wavelengths (412 nm and 443 nm bands most impacted)
- Previous effort by NASA OBPG developed an approach to decouple the impacts of on-orbit changes in the RVS and polarization using L3 ocean products [*Kwiatkowska et.al, in AO 2009*]
- Current MCST effort provides an independent approach to track the on-orbit polarization sensitivity using L1 reflectance over pseudo-invariant desert sites [*Wu et.al, in SPIE 2015*]
  - On-orbit polarization correction based on the Mueller matrix [similar to OBPG approach]. Linear Stokes vector components modeled from 6SV





uncorrected reflectance   polarization corrected reflectance

MODIS and VIIRS Data Processing

- **Continuous effort by NASA MCST to support MODIS data processing**
  - C5 and C6: currently running in parallel (C5 stops at end of 2016)
  - Improvements, when necessary, have been made to C5 and/or C6
- **Continuous effort by NASA VCST to support VIIRS data processing**
  - C1.0 and C1.1: modified IDPS code (Mx#.#) with VCST LUTs
  - V1.1.0: current production version; newly developed L1A and L1B software with VCST LUTs
  - V2.0.0: released in July 2016 for software testing and products evaluation
- **Preparation for NOAA IDPS VIIRS data reprocessing**
  - Extensive effort led by NOAA SDR Team to assess and validate VIIRS SDR quality
  - Ongoing studies conducted in preparation for IDPS VIIRS SDR reprocessing

NASA MODIS and VIIRS Science Team Meeting (June, 2016)
NOAA JPSS Science Team Meeting (August, 2016)

Backup Slides

Status of VIIRS NASA Land SDR Support

- Land SIPS SDR reprocess based on IDPS Mx Code with VCST LUTs (C1.0 and C1.1)
  - Independent validation for SDR code and improvements in LUTs derivation.
  - Running Land's modified IDPS SDR/EDR codes Mx based version with LUTs input from VCST.
  - 41 sets of LUTs for VISNIR/SWIR/DNB have been delivered to Land SIPS for data reprocessing and SDR/EDR assessments in Collections 1.0 and 1.1.

Collection	Code Base	# of LUTs	Delivery Time	Improvements
C1.0	Mx6.3	5	2012.10 - 2013.01	Smoothed functions for SD degradation H-factor and calibration coefficients F-factor.
	Mx6.4	5	2013.04 - 2013.11	Updated SD/SDSM screen transmission, SD BRDF, RTA mirrors degradation model, and modulated RSRs.
C1.1	Mx7.2	25	2013.12 - 2016.02	Improved time-dependent modulated RSR, DNB stray light correction, H & F fitting functions.
	Mx8.11	6	2016.03 - 2016.08	Improved Quality Flags, DNB gain ratio and LGS LUTs introduced, GEO solar/lunar vectors fix, and with RSBAutoCal option.

Status of VIIRS NASA SIPS L1B Support

- NASA SIPS L1B/LUTs for mission reprocess V1.1.0 (current production version)
  - VIIRS L1A and L1B software, LUTs, and data design are developed under NASA EDOS/SIPS.
  - First L1B software V1.1.0 was released in Jan 2016. L1B software generates 6-min granule VIIRS geolocation and radiometric products including OBC from L1A input, all in NetCDF4 format.
  - V1.1.0 is based on IDPS SDR code Mx8.10 algorithms. The contents of L1B V1.1.0 and SDR Mx8.10/8.11 should match if the same calibration coefficients and parameters are used.
  - NASA L1B LUTs are computed by using on-orbit SD/SDSM screen transmission & SD BRDF, modulated RSR, and consistent fitting methods throughout the mission.
- L1B Software V2.0.0 (currently under testing and evaluation)
  - V2.0.0 was released to SIPS in July 2016 for software testing and products evaluation.
  - Two types of data are required for L1B input – L1A file and L1B calibration Look-Up-Table (LUT).
  - Changes in V2.0.0 are described in next slide.

Collection	Code Base	# of LUTs	Delivery Time	Note
V1.1.0	L1B V1.1.0	7	2016.02 - 2016.08	Redesigned L1B software, LUTs, and data format using L1A data input.
V2.0.0	L1B V2.0.0	1	2016.08 -	Improved L1B software functions and algorithms. L1B products are under evaluation.

VIIRS L1B Software V2.0 Changes

- The major changes in V2.0 compared to V1.1:

A. Functional changes

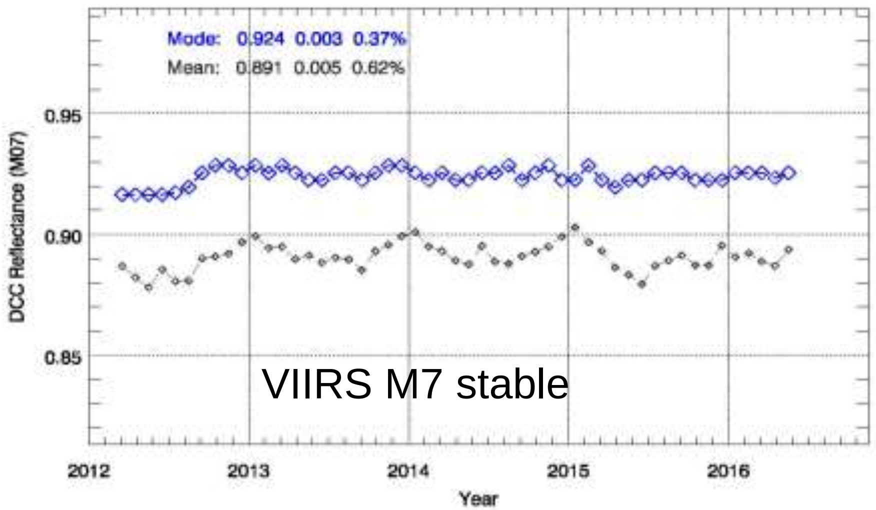
- Add fill values for specific data states requested by Land team.
- Partial line processing to support along-scan extracts.
- Add un-aggregated L1B product for dual gain bands.
- Add RSR tables in RSB LUT. Remove radiance tables from TEB LUT.
- Single resolution processing and output in geolocation.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

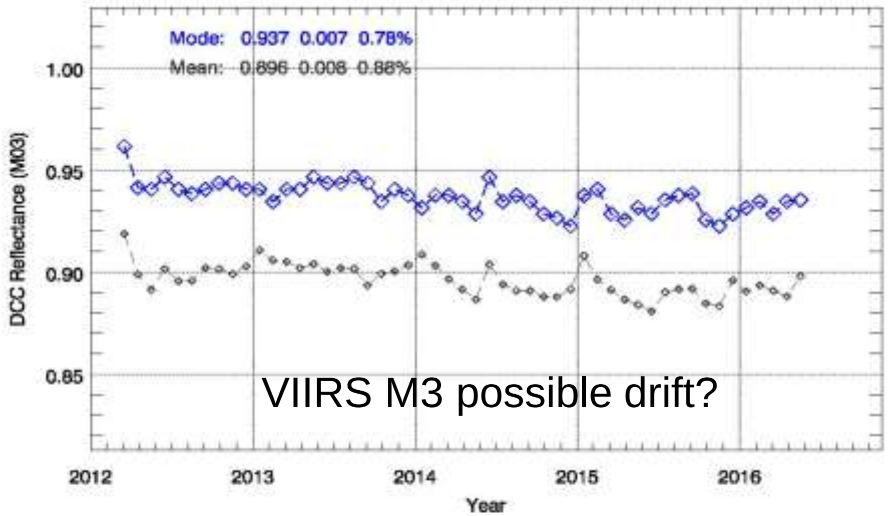
B. Algorithm changes

- Use solar irradiance at 1 AU to avoid computation of large number (in meters).
- Temperature dependent coefficients for RSB Cal.
- Apply time-dependent modulated RSR in RSB Cal.
- Apply running average of 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.

Deep Convective Clouds (DCC) for Stability Assessments

- The reflectance of deep convective clouds (DCC) are known to be statistically stable over time
- Detecting VIIRS calibration drifts < 0.5% in selected bands over several years has been demonstrated
- A large number of data points can help reduce uncertainties
- Additional effort is required to use DCC for calibration inter-comparisons

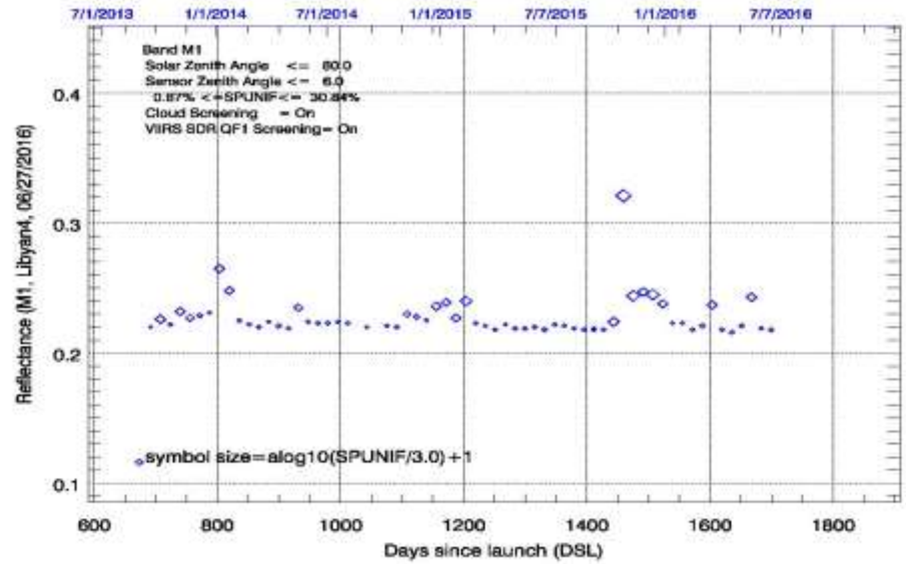


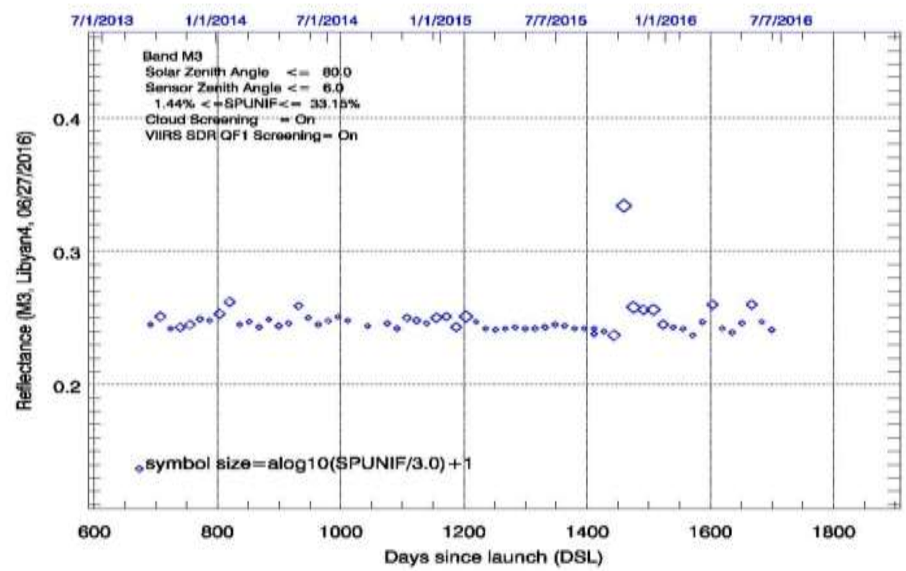


Wang & Cao, Remote Sensing 2016

Desert Sites for Stability Assessments

- CEOS Working Group on Cal/Val (WGCV) has identified and endorsed several pseudo invariant desert sites for calibration stability monitoring, such as Libya4
- Caveats: sky is not always clear in the desert which reduces the number of useful data points; bi-directional reflection introduces uncertainties
- Desert observations have helped MODIS in correcting long-term drift

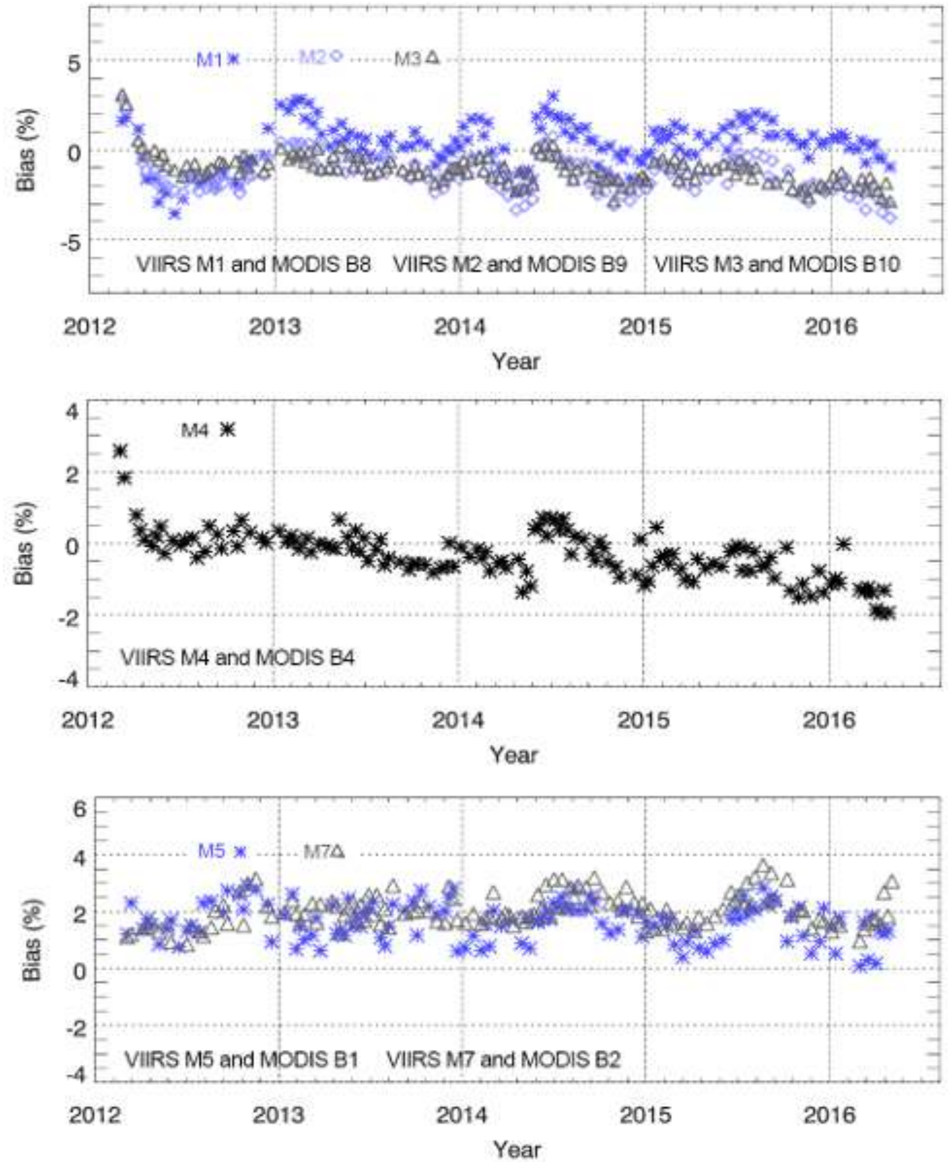




Desert trend doesn't necessarily agree with the DCC trend

SNOs for Sensor Calibration Inter-comparisons

- Comparisons between VIIRS and MODIS have been routinely performed at the Simultaneous Nadir Overpass (SNOs)
- Caveats: this approach only provides relative bias between VIIRS and MODIS, using MODIS as the reference (14 years in orbit)
- Need to extend the inter-comparisons with other satellite instruments at SNOs
- GSICS will help facilitate the comparisons



Uprety & Cao, RSE 2015