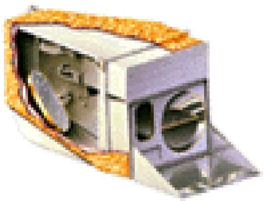
MODIS RSB Calibration and Performance



Outline

- MODIS RSB specs and on-orbit calibration
- Highlights since last STM
  – Impact of ideal BB update
  – Terra OOF detectors
  – Aqua SDSM “fixed” mode results
- SD & lunar gain trending plots
- SNR & uncertainty plots
- Special topics
  – Terra SWIR algorithm improvement
  – Next Collection enhancements
- Summary

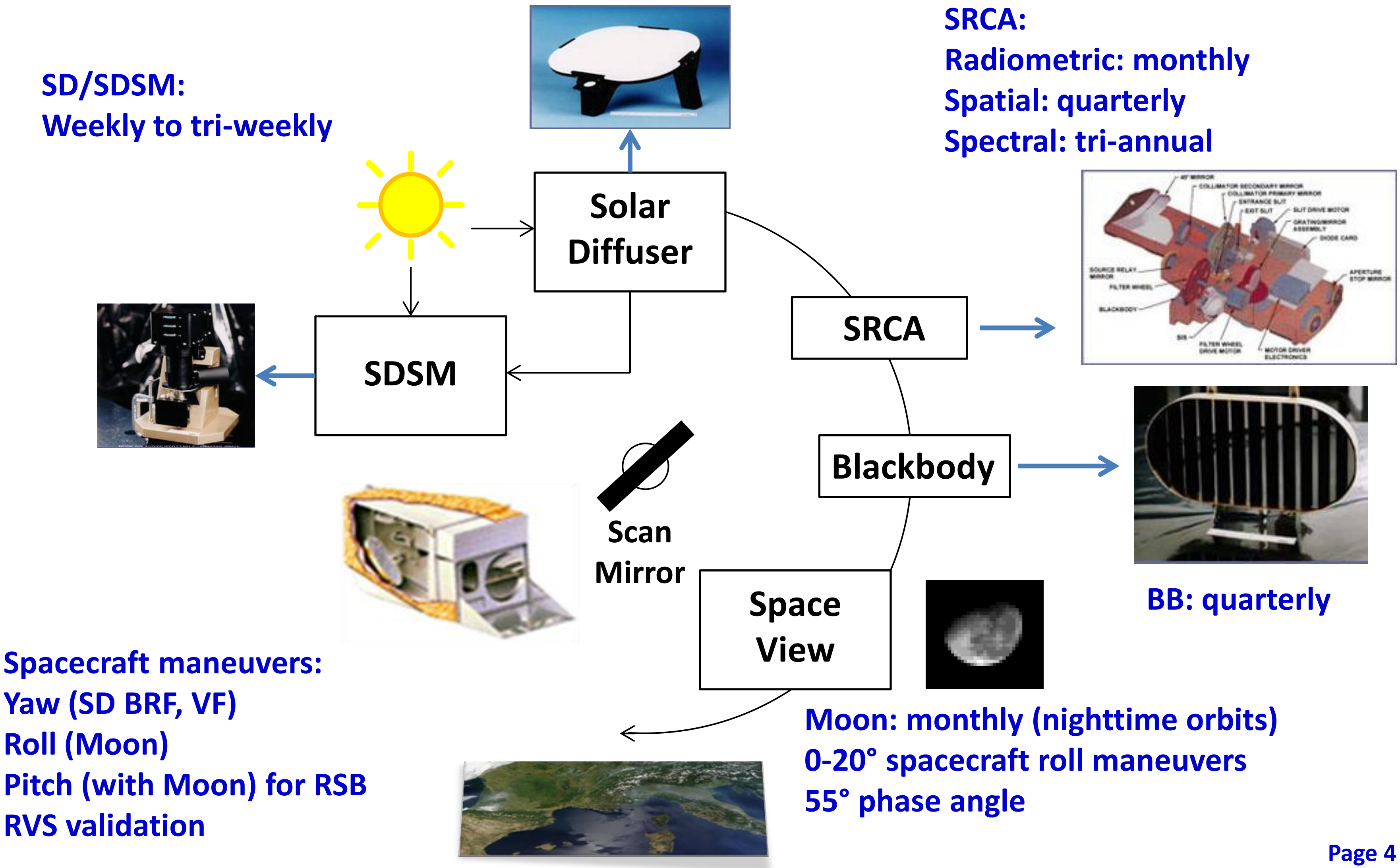
RSB Design Specifications

Band	CW*	Ltyp+	SNR	Primary Use
1	0.645	21.8	128	Land/cloud/aerosol boundaries
2	0.858	24.7	201	
3	0.469	35.3	243	Land/cloud/aerosol properties
4	0.555	29.0	228	
5	1.24	5.4	74	
6	1.64	7.3	275	
7	2.13	1.0	110	
8	0.412	44.9	880	Ocean color, phytoplankton & biogeochemistry
9	0.443	41.9	838	
10	0.488	32.1	802	
11	0.531	27.9	754	
12	0.551	21.0	750	
13	0.667	9.5	910	
14	0.678	8.7	1087	
15	0.748	10.2	586	
16	0.869	6.2	516	
17	0.905	10.0	167	Atmospheric water vapor
18	0.936	3.6	57	
19	0.940	15.0	250	
26	1.37	6.0	150	Cirrus cloud water vapor

*μm

+$W/m^2/sr/\mu m$

On-orbit Calibration Activities



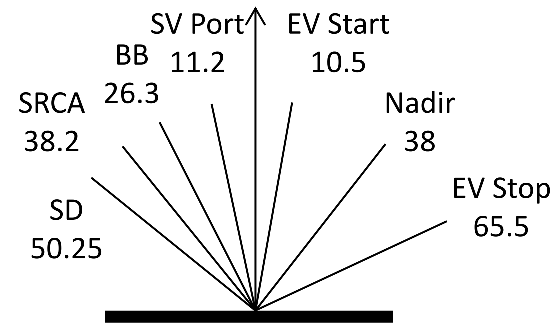
RSB Calibration

- EV Reflectance

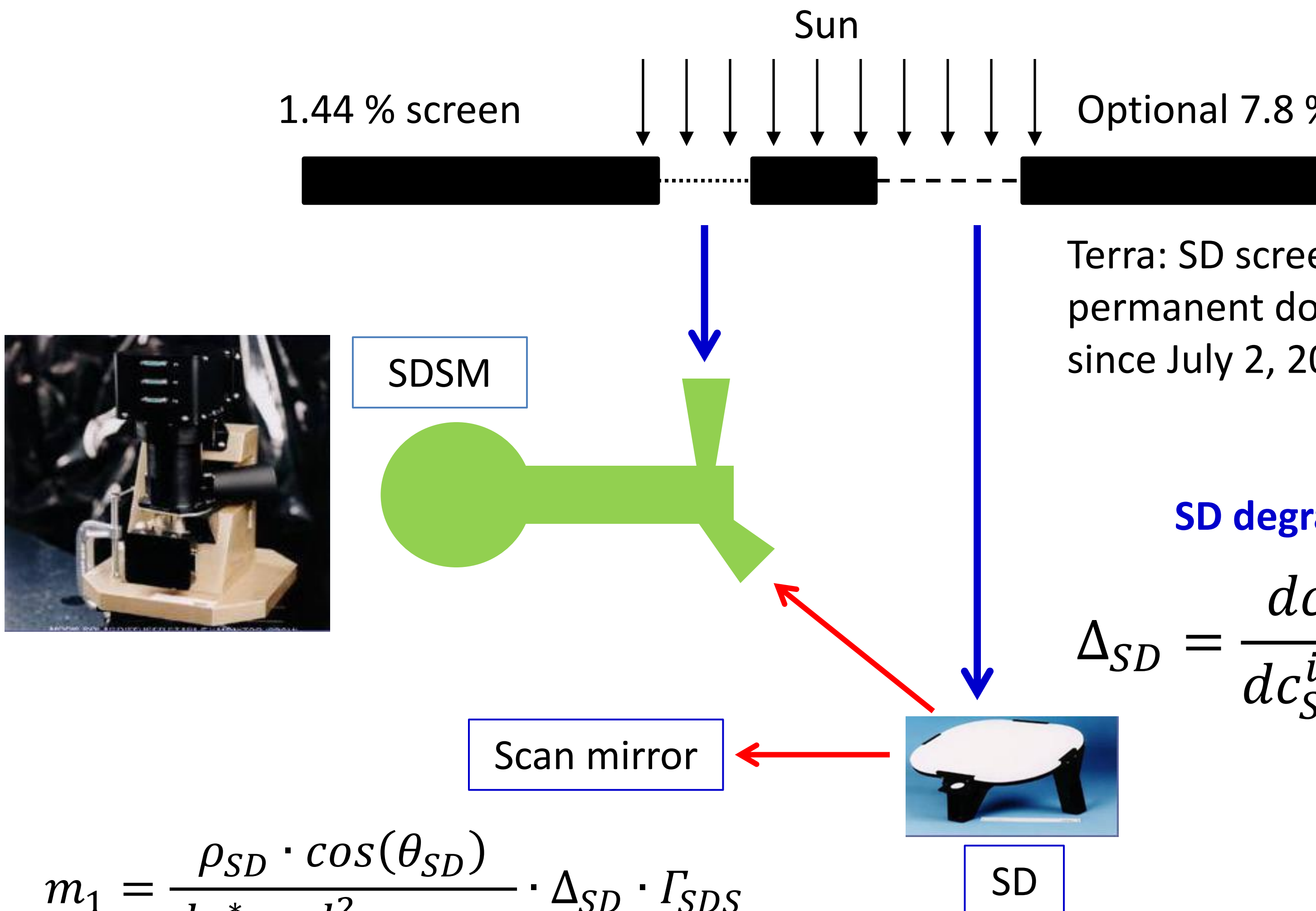
$$\rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS}$$

- Look-Up-Tables (LUTs) updated regularly for RSB
  - m_1: Inversely proportion to gain at the AOI of SD
  - RVS : Sensor Response versus Scan angle (normalized to SD AOI)
  - Uncertainty tables

- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - EV mirror side (MS) ratios
    - SRCA MS ratios (previously used) are not considered due to lamp failures)
  - Response trending from EV targets



RSB SD Calibration



Terra: SD screen in permanent down position since July 2, 2003

SD degradation

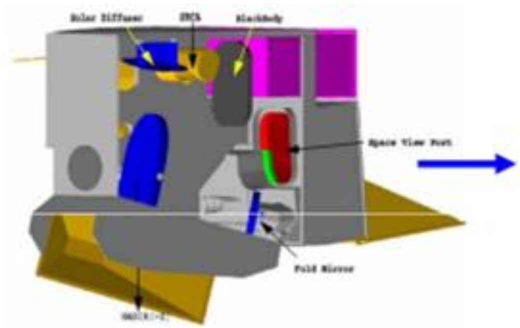
$$\Delta_{SD} = \frac{dc_{SD}^{i} / dc_{SD}^{9}}{dc_{Sun}^{i} / dc_{Sun}^{9}}$$

$$m_1 = \frac{\rho_{SD} \cdot cos(\theta_{SD})}{dn_{SD}^{*} \cdot d_{Earth\_Sun}^{2}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}$$

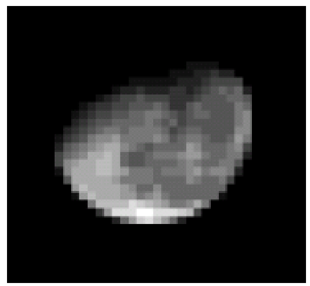
$\rho_{SD} \cdot cos(\theta_{SD}) = \mathrm{BRF}$, dn_{SD}^{*} = Signal from SD (temperature and background corrected),
$\Delta_{SD} =$ SD degradation, $\Gamma_{SDS} =$ screen attenuation

RSB Lunar Calibration

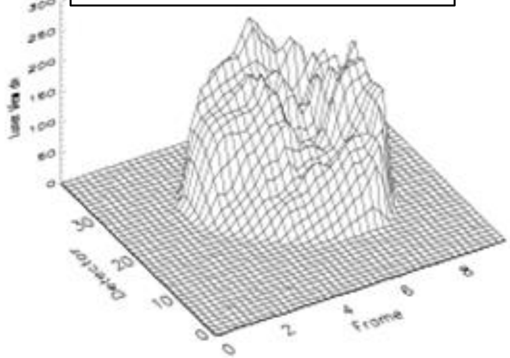
MODIS



Moon



MODIS Response



Near-monthly calibration
Phase angles between 55°- 56°

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

$$m_1^{moon} = \frac{f_{vg}}{< dn^*_{moon} >}$$

Bands 13-16 (saturated)

$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

View geometry correction

$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

Oversampling effect also needs to be corrected if multiple scans are used

Highlights since the last STM (Oct, 2018)

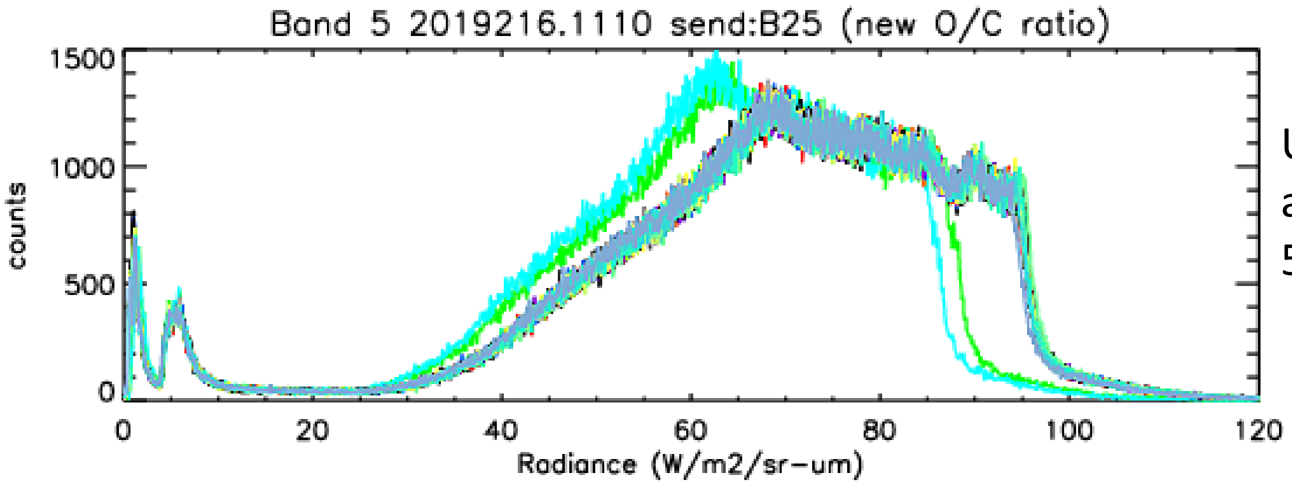
- Terra MODIS
  - RSB continue to perform nominally
  - B3,4,8,10-12 perform nominally after Ideal BB updates
  - B5 D3 and D5 have been designated as “out-of-family” in the QA LUT since March 2019
- Aqua MODIS
  - RSB continue to perform nominally
  - No new noisy/inoperable detectors
  - SDSM “fixed” mode calibrations

Terra Ideal BB table change

- Terra MODIS VIS bands ADC shows tendency to ‘stick’ at odd multiples of 64 (bands 3-4, 8-12).
- Behavior affects all data sectors, but impact is most significant when the SV DN is near one of the sticking values (e.g. 64). Sticking can cause an error in the scan-average SV DN of a few DN.
- Previously, corrections have been used in calculation of SD m_1 to mitigate the impact of inaccurate SV DN values.
- In 2017-2018, new ideal BB tables were uploaded to move the SV DN out of sticking range
  - B3 updated on 2017/347
  - B4, 8, 10-12 updated on 2018/100
- Since the ideal BB updates, the SV DN continue to trend normally. The impacts of inaccurate SV DN on m_1 calibration are reduced, simplifying the calibration procedure.

Terra band 5 QA change

- Terra band 5 inoperable detector (D4 product order) has higher dn and larger variations in recent years with a notable change around October 2017.
- The detector appears to be having a negative impact on the two neighboring detectors (3 and 5):
  - m_1 trends show out-of-family behavior
  - Increased striping in L1B images
- Terra Band 5 detectors 3 and 5 flagged as 'out-of-family gain' in QA LUT starting in March 2019 (QA table time-stamp 2017/296).
- Note that this is a ***separate issue*** from the SWIR OOB/crosstalk effects.

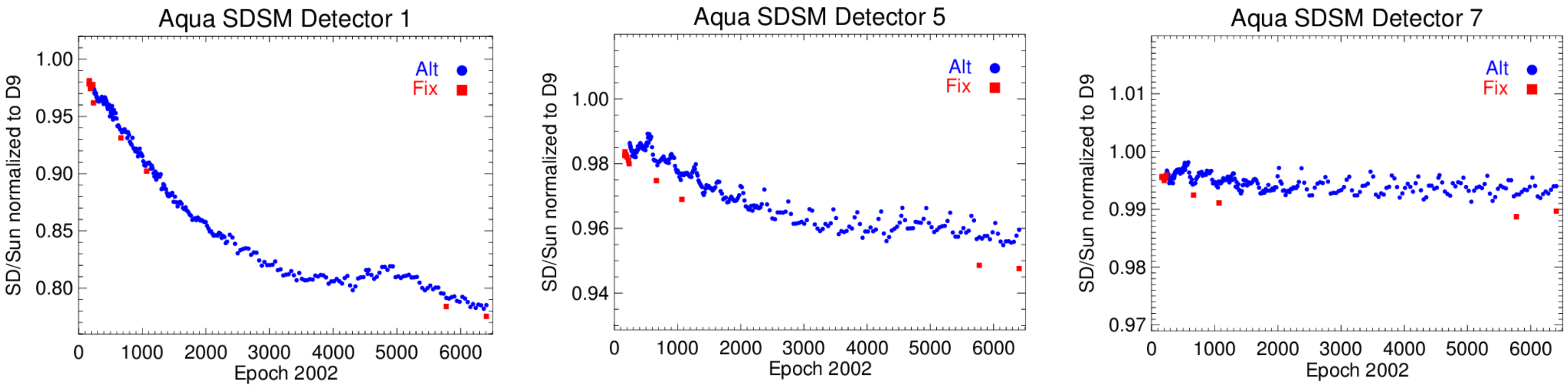


Using new OOB/crosstalk algorithm, detectors 3 and 5 are still out-of-family

Special calibration analysis

- Aqua SDSM performed two ‘fixed mode’ calibrations in recent years:
  - October 2017 and July 2019
  - Previously, Aqua SDSM was run in fixed mode for only 8 (successful) calibrations in early mission: 2002-2004.
- Purpose: Test stability of SDSM calibration in fixed mode and help improve understanding of possible systematic uncertainties in operational calibration.

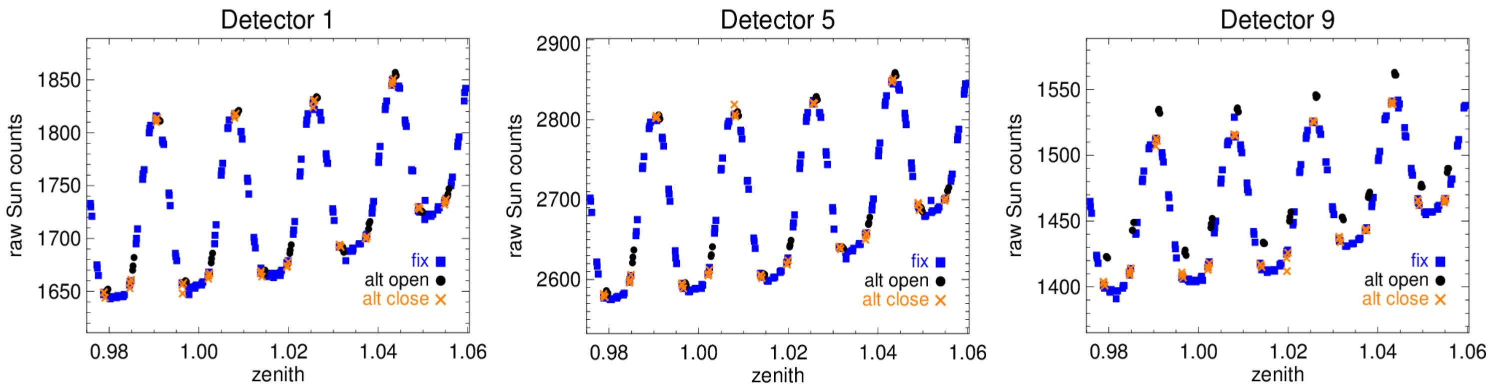
- Results show an offset between ‘fix’ and ‘alt’ mode results, but offset is consistent with calibrations from early mission.



Special calibration analysis

- On both dates, a set of ‘alternate mode’ calibrations was also run as usual.
- These near-coincident calibrations give a good opportunity to analyze and understand the difference between the fix and alt mode results.

Sun view DN

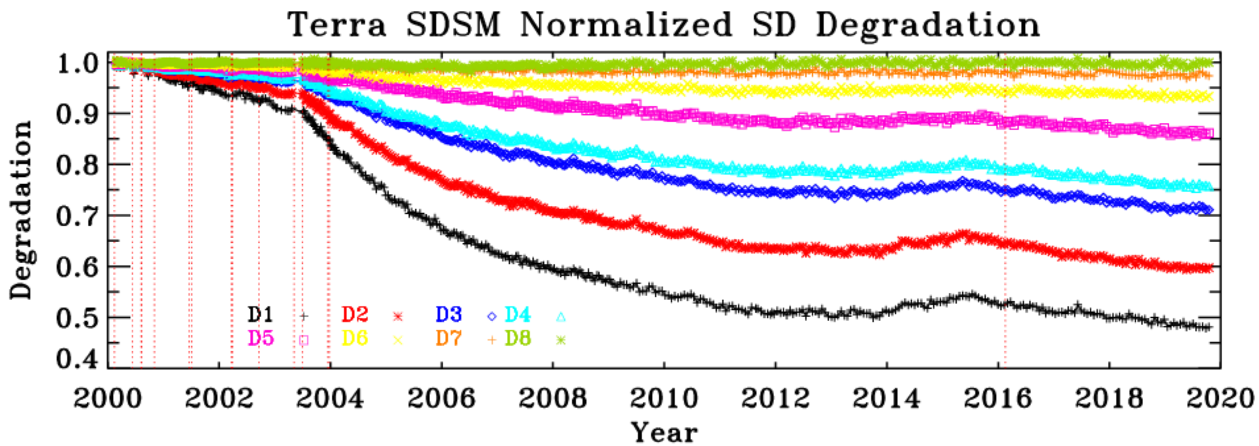


- SD view DN are in good agreement between fix and alt modes.
- But Sun view DN are larger for Alt-open mode compared to fix mode for the NIR detectors, with discrepancies up to 1.5% at D9 (936 nm).

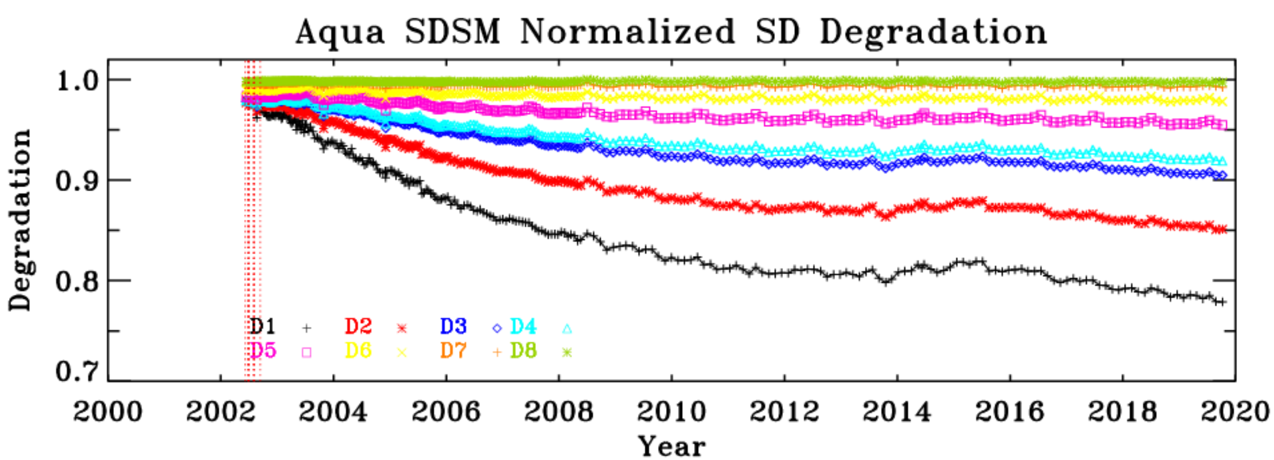
No major concerns for SD degradation used in L1B calibration. This data analysis may be used to improve calibration in next Collection, but impact would be $\leq 0.5\%$.

K. Twedt, A. Angal, H. Chen, X. Xiong, Proc. SPIE **11127**, 1112728 (2019)

MODIS SD Degradation

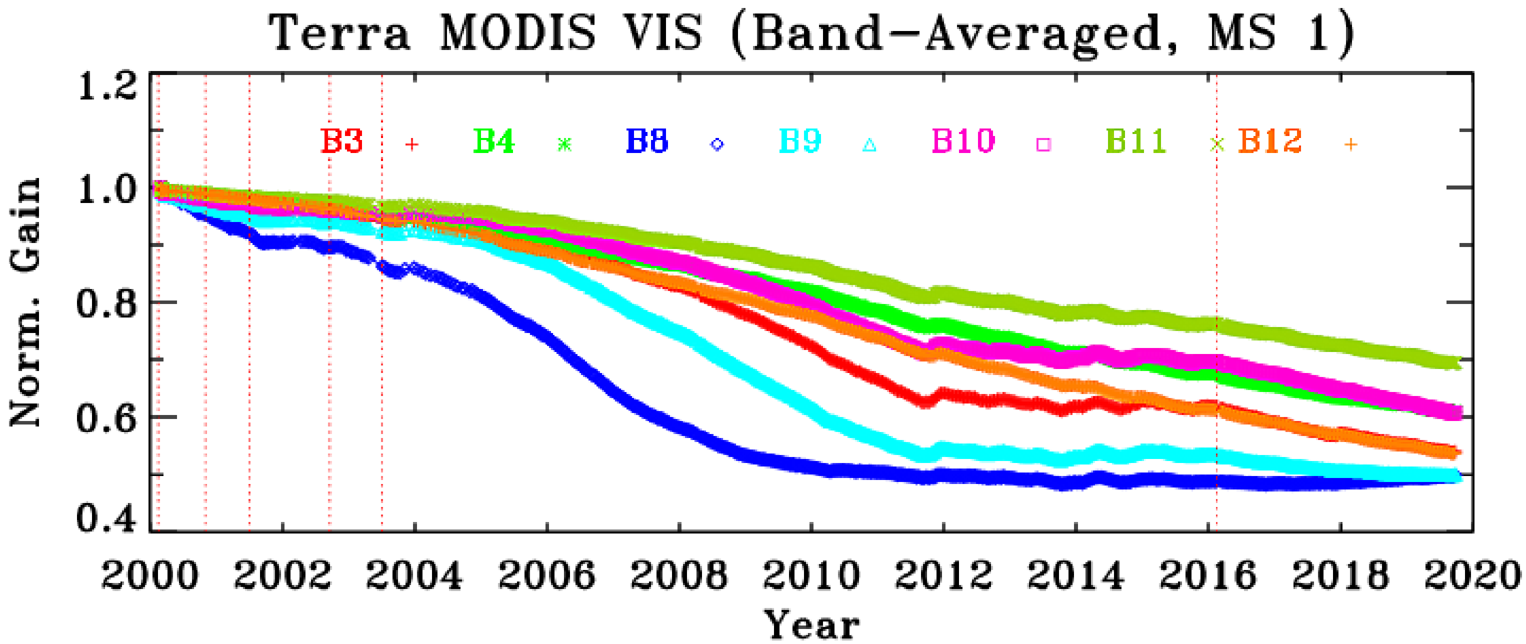


Increased degradation after Terra SD door anomaly on July 2, 2003. Larger SD degradation at shorter wavelengths for both instruments



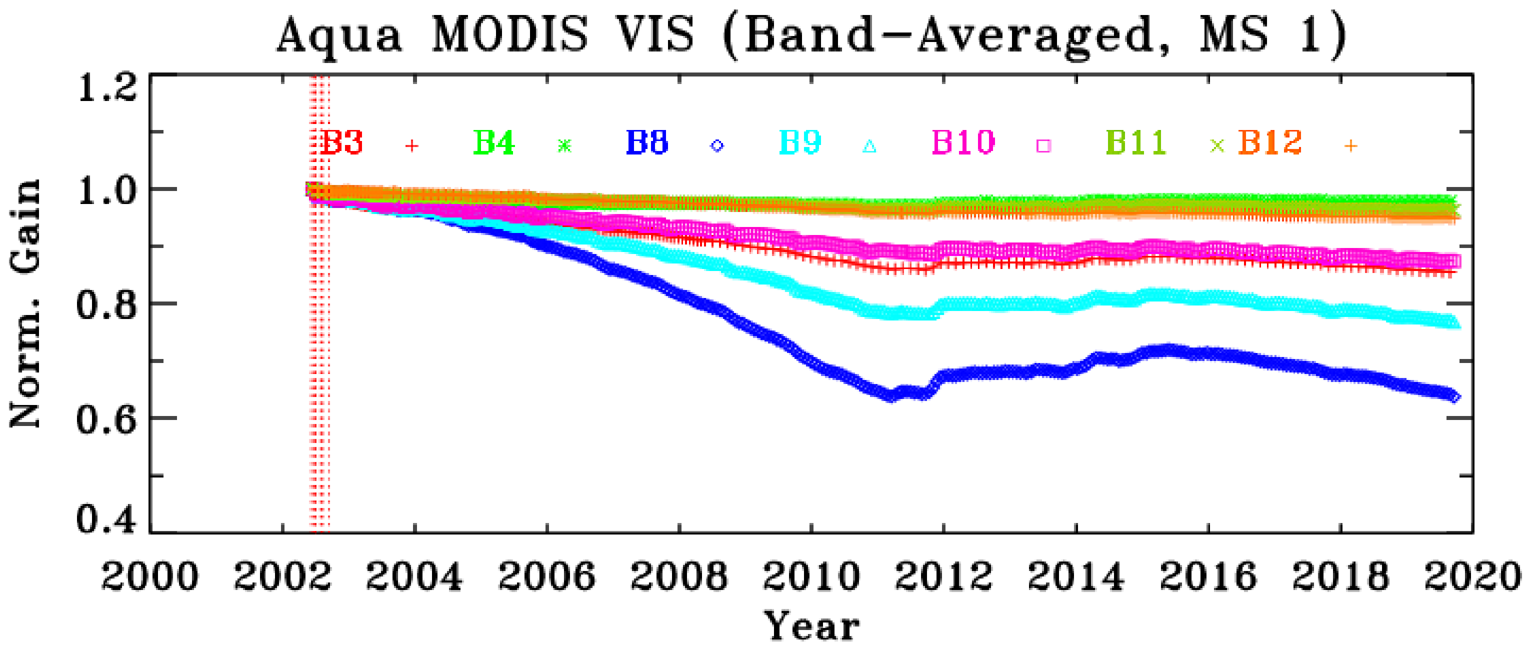
A special “fix” mode operation was performed for Aqua MODIS SDSM to verify the results observed in previous years

Terra VIS Gain Trending from SD



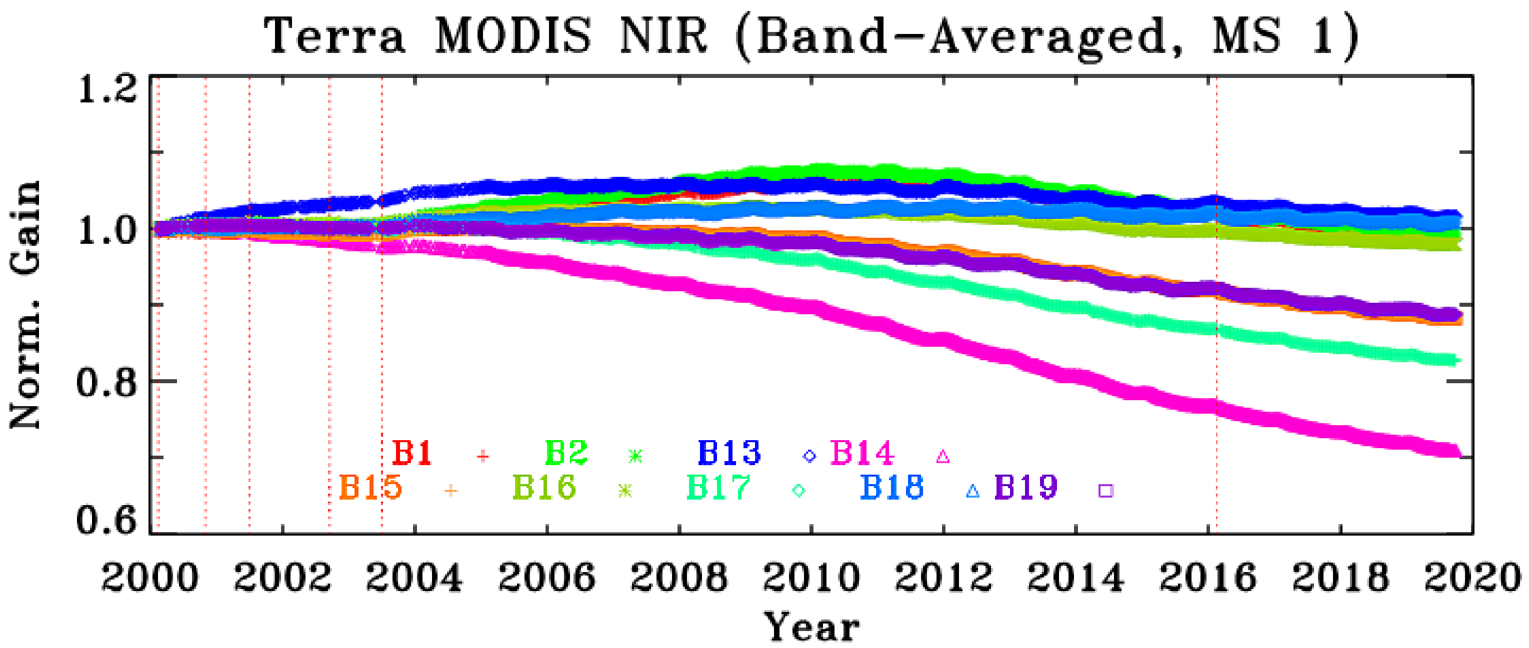
- Most change observed for short-wavelength bands
- Band 8 (.412 µm) changes by over 50%
- Terra VIS bands have a maximum mirror-side difference of about 11% at the SD AOI (Band 10 - .488 µm)

Aqua VIS Gain Trending from SD



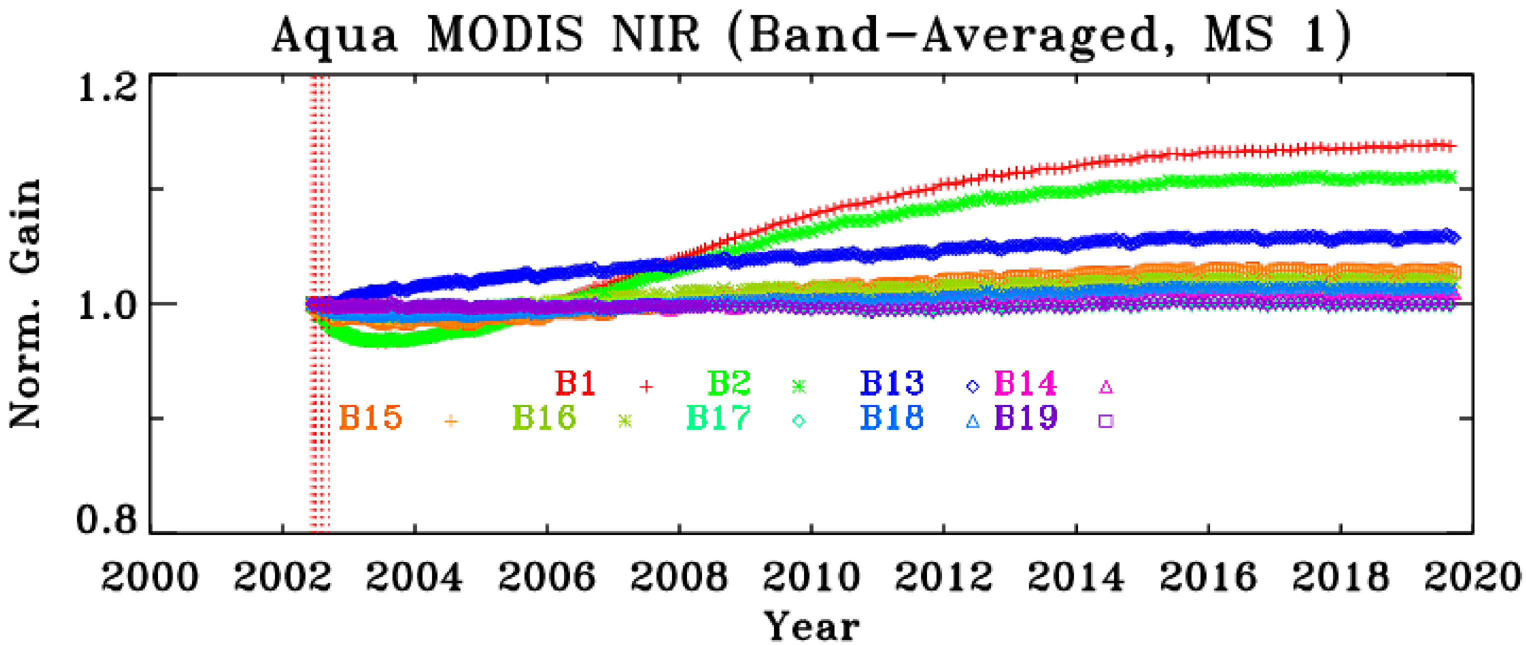
- Most change observed for short-wavelength bands
- Band 8 (.412 μm) maximum change is ~40%
- Aqua VIS bands have a maximum mirror-side difference of about 3% at the SD AOI (Band 8)

Terra NIR Gain Trending from SD



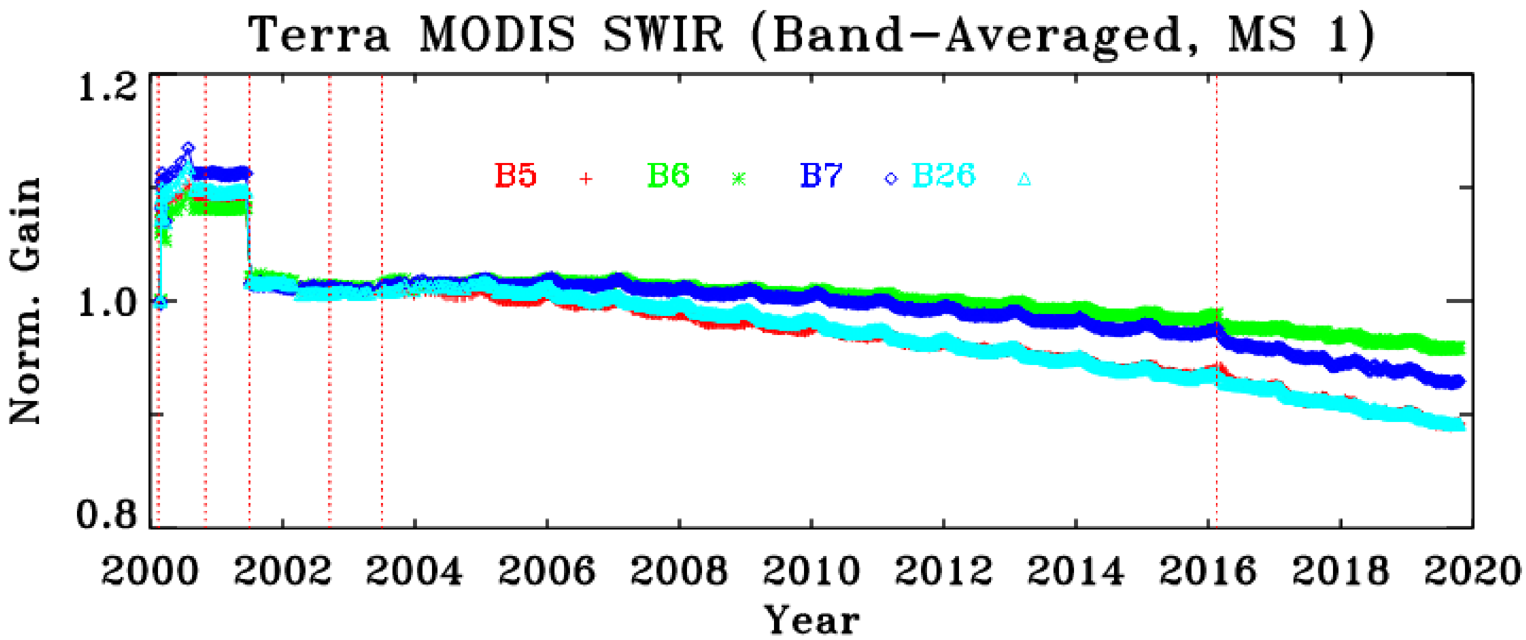
- Changes for most NIR bands are within 10%
- Mirror-side differences are <1%

Aqua NIR Gain Trending from SD



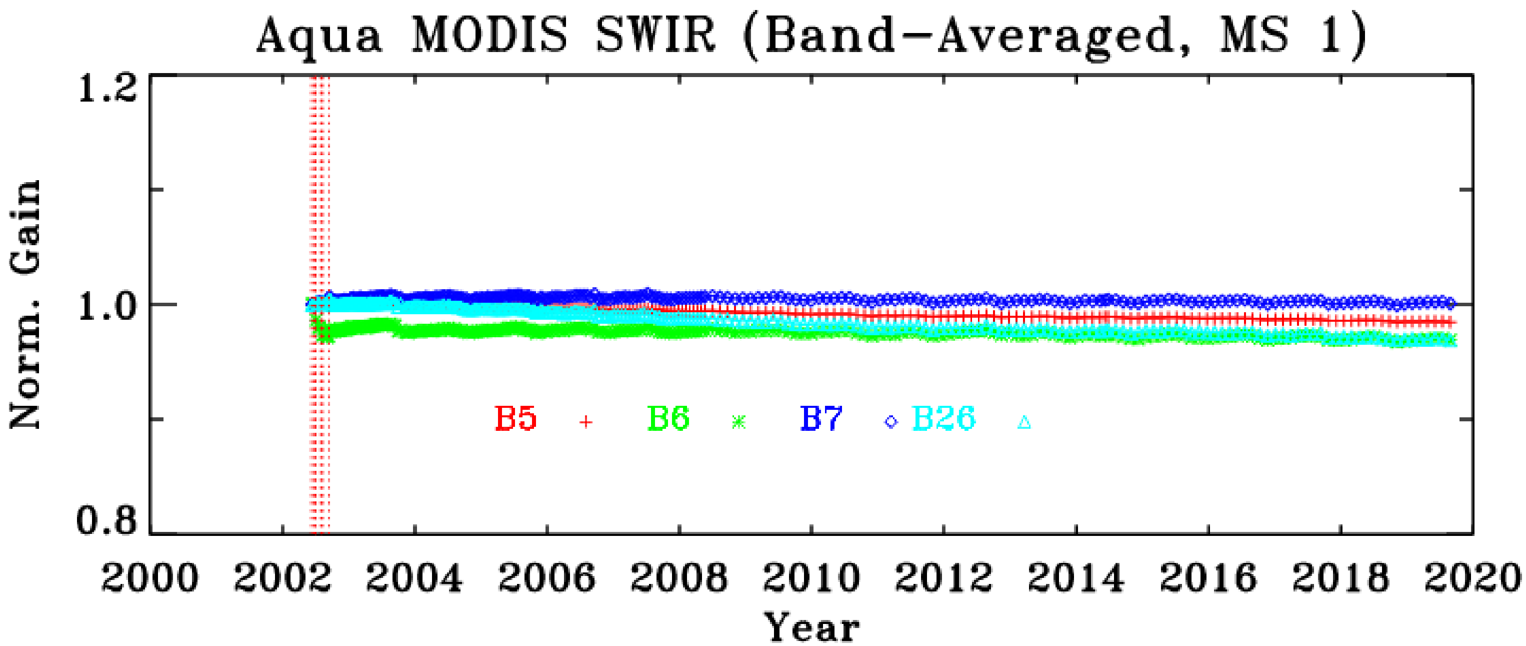
- Changes for most NIR bands are within 6%
- Mirror-side differences are <1%

Terra SWIR Gain Trending from SD



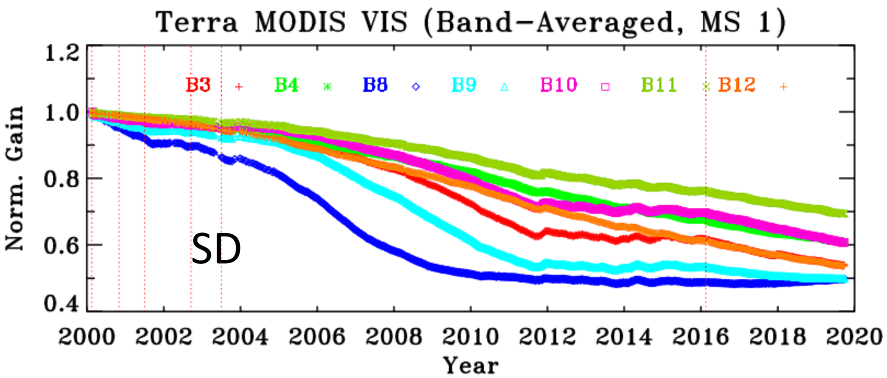
- All SWIR bands change by < 11%
- Mirror-side differences are <1%
- * Noisy and inoperable detectors excluded

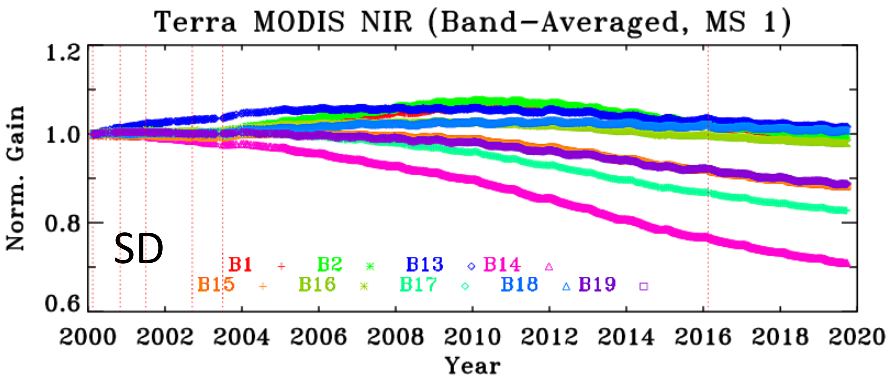
Aqua SWIR Gain Trending from SD

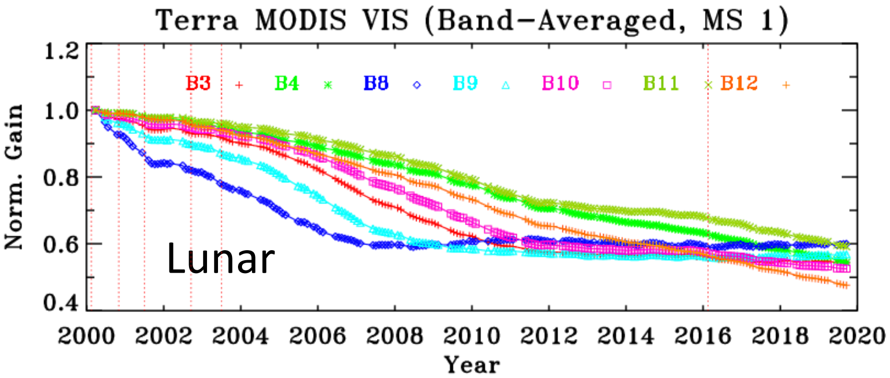


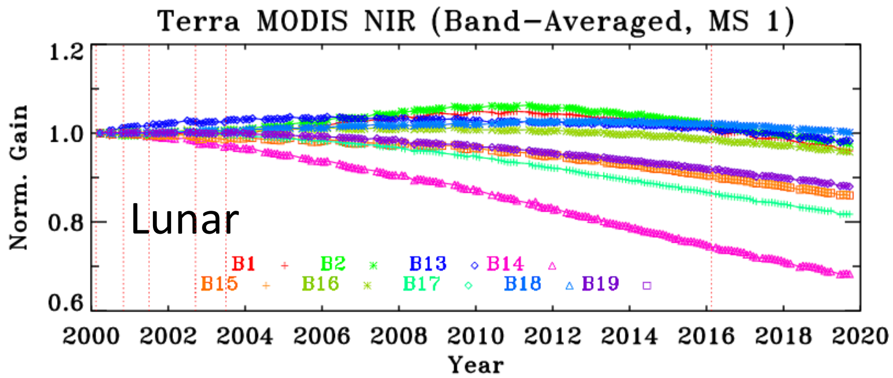
- All SWIR bands change by < 3%
- Mirror-side differences are <1%
- * Noisy and inoperable detectors excluded

Terra MODIS
Gain Trending from SD and Lunar





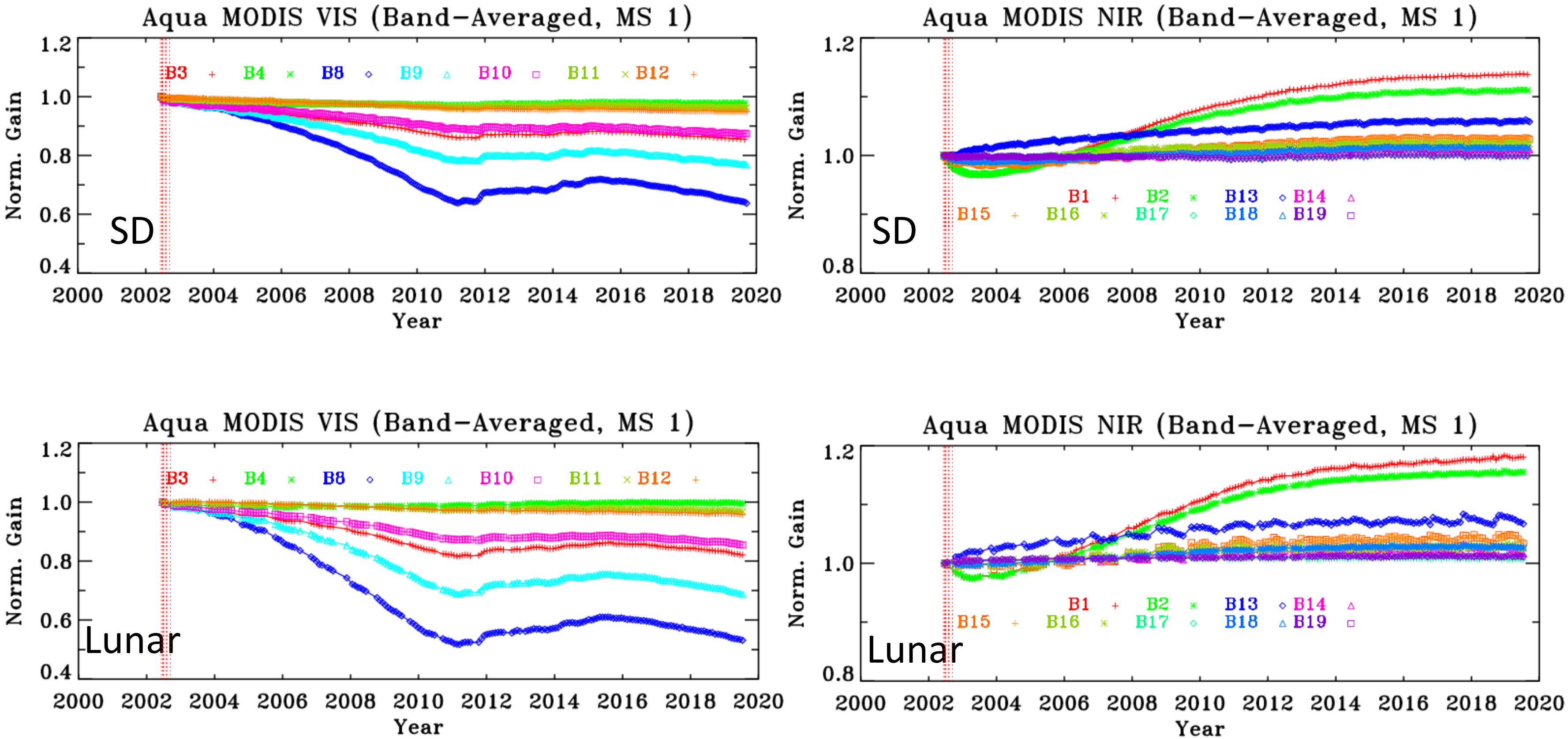




SD & Lunar measurements used to derive the on-orbit RVS change

SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

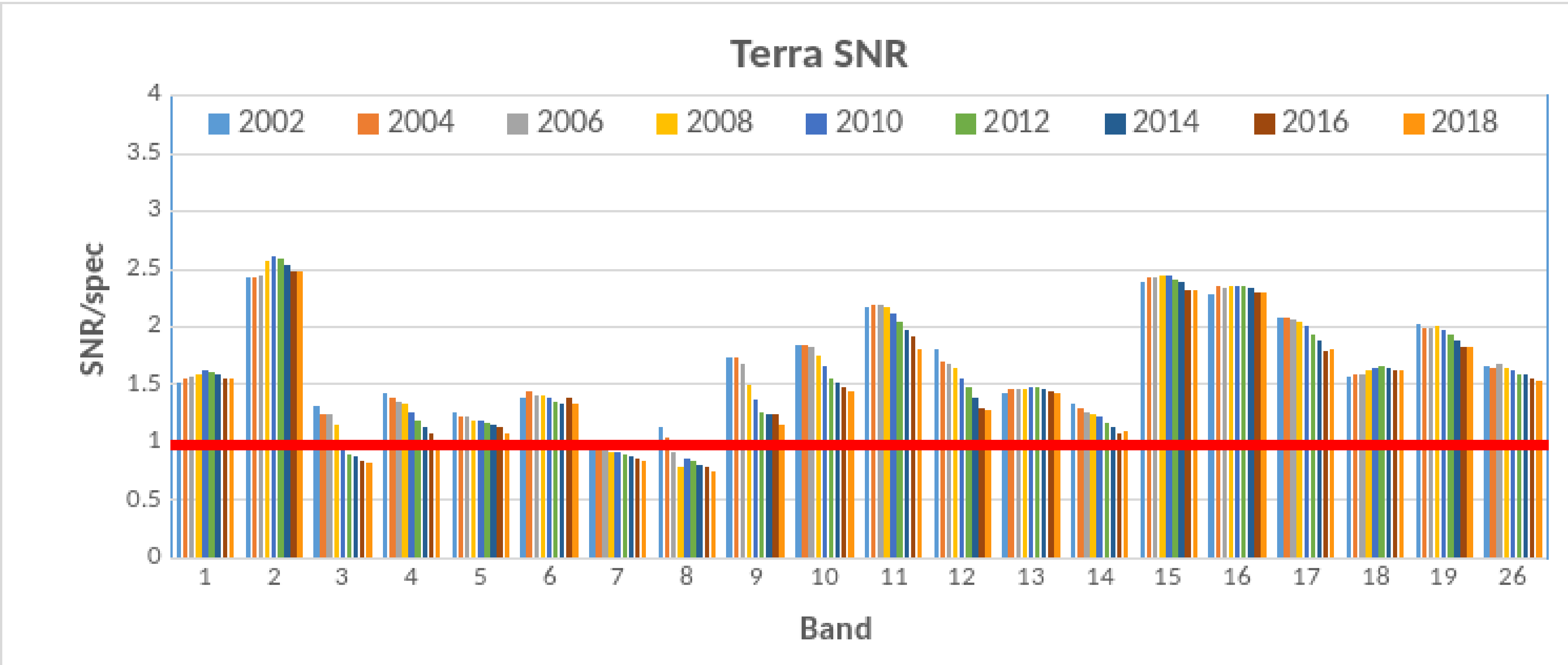
Aqua MODIS
Gain Trending from SD and Lunar



SD & Lunar measurements used to derive the on-orbit RVS change

SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

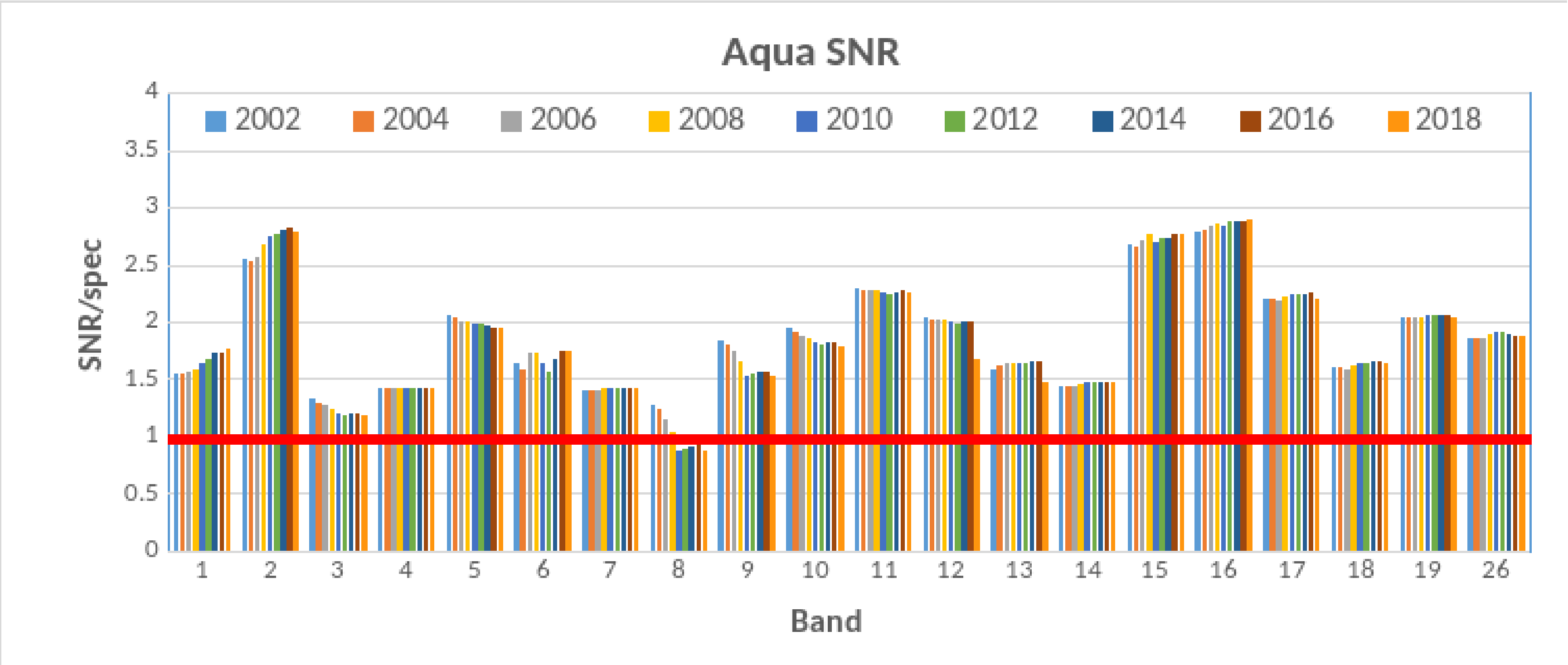
MODIS RSB SNR Bar-Charts



Most bands continue to meet the specification.

- Decreased responsivity for some short wavelength RSB (Terra bands 8, 9, 3)
- Terra band 7 SNR known to be below specification since launch

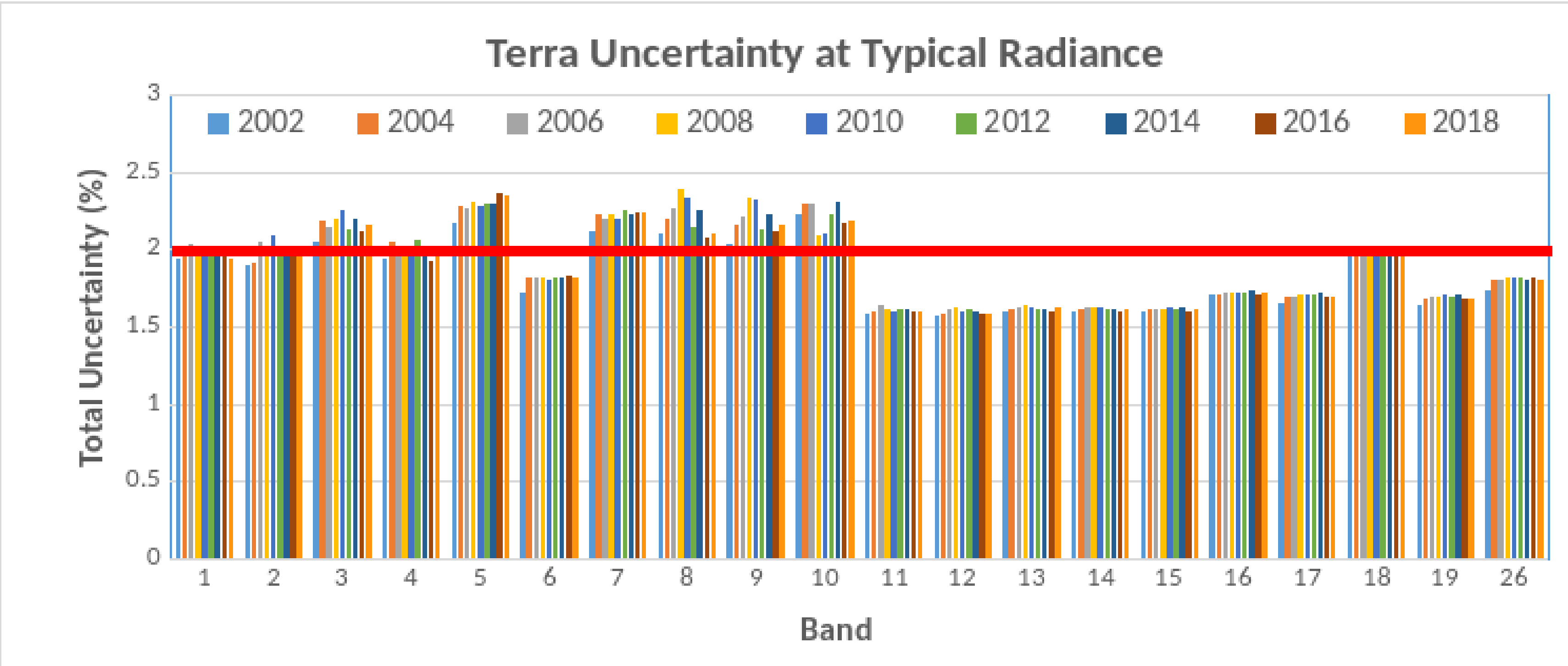
MODIS RSB SNR Bar-Charts



Most bands continue to meet the specification.

- Decreased responsivity for some short wavelength RSB (Aqua band 8)
- Known issues with the inoperable/noisy detectors in Aqua band 6.

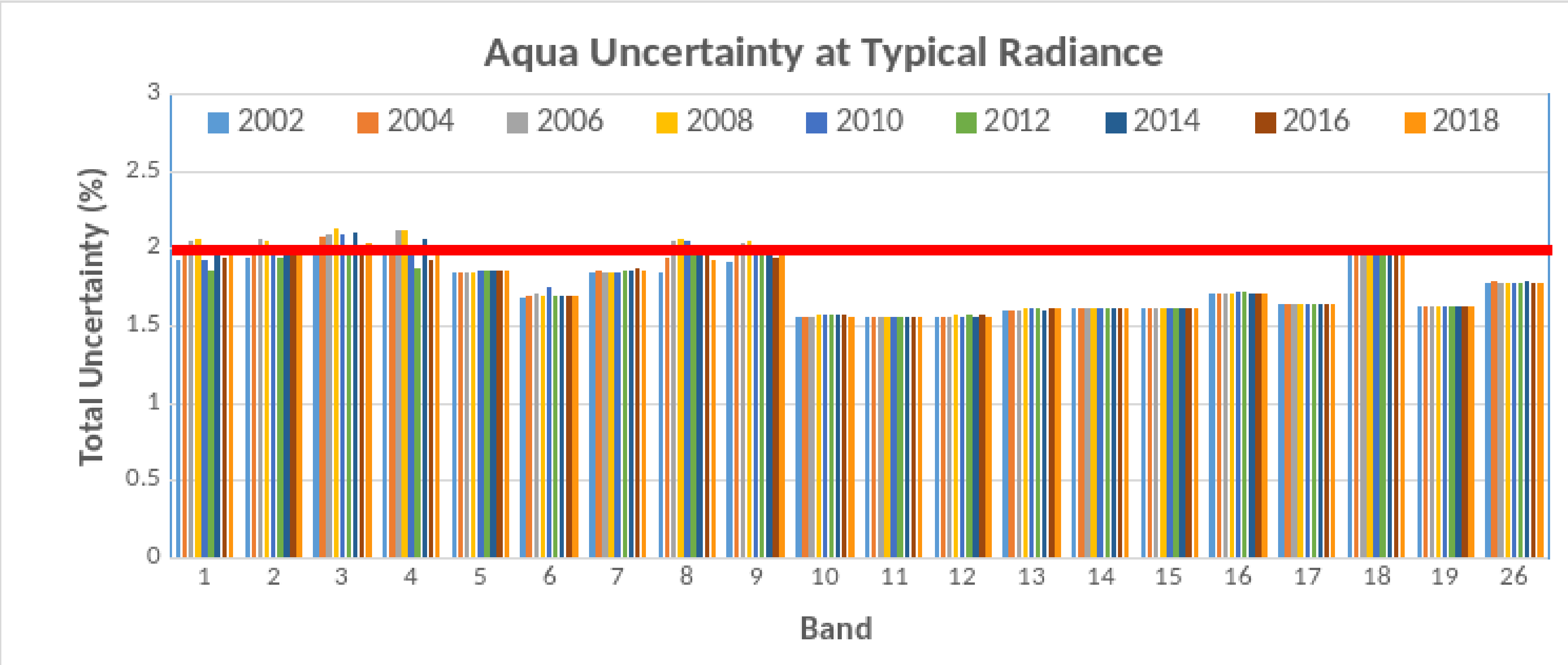
MODIS RSB Uncertainty Trends



Most bands continue to meet the specification.

- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Terra bands 1-4, 8-10)
- On-orbit changes in the polarization sensitivity is also a contributing factor.

MODIS RSB Uncertainty Trends



Most bands continue to meet the specification.

- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Aqua bands 1-4, 8,9)

RSB Calibration Special Topics

Recent MCST activities to improve RSB calibration:

- Improvements to OOB/crosstalk correction algorithm for Terra SWIR bands
  - **Implemented in forward Terra C6/C6.1 LUT starting June 2019. Will be used from mission beginning in next Collection.**
- Improvements in on-orbit RVS characterization:
  - Apply polarization correction for Terra VIS bands to improve gain derivation at large scan angles.
  - Use an inter-band approach that relies on relative trends of ocean data to derive RVS for Terra bands 11 and 12.
  - **Both planned for inclusion in next Collection.**
- Potential lunar calibration improvements
- Mission re-processed RSB LUTs (Terra and Aqua) are available for testing

Terra SWIR improvements

MODIS SWIR bands (5-7 and 26) have a known issue related to electronic crosstalk and out-of-band (OOB) optical leak identified during prelaunch characterization

- A correction to m_1 and L1B dn based on night-time-day-mode acquisitions has been applied since early mission.

Starting in June 2019, a change to forward C6/C6.1 LUTs was made to use band 25 as the reference band for Terra MODIS instead of band 28

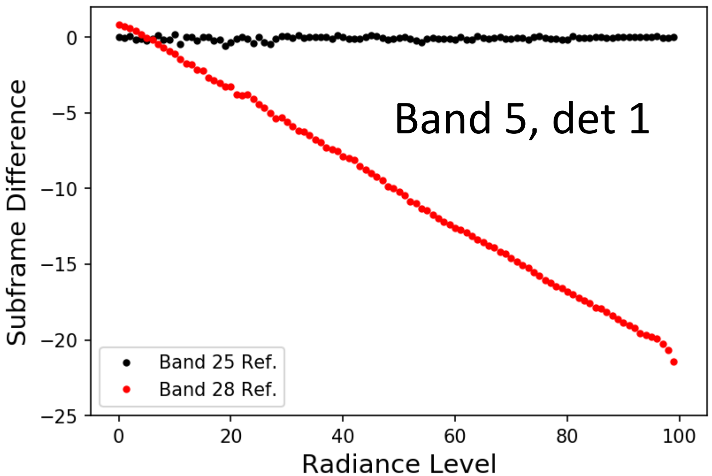
- After the Feb 2016 safe mode, the Terra MODIS PV LWIR bands showed increased impacts due to electronic crosstalk. The un-corrected B28 signal was previously being used to correct the SWIR OOB/crosstalk, which was impacting the quality of the SWIR correction.
- To improve Terra SWIR performance, we switched the reference band from B28 to B25 and also derived new time-dependent OOB/xtalk correction coefficients.
- Result is smoother gain trending, significantly reduced detector and subframe striping, and improved long-term trending.

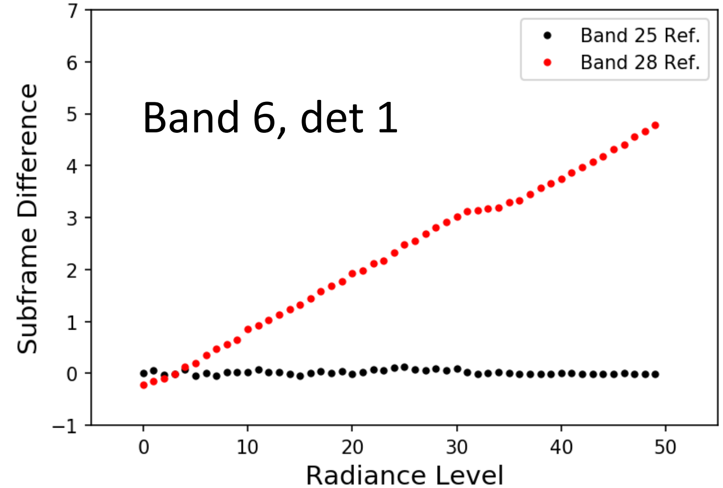
X. Xiong, A. Angal, Y. Li, Proc. SPIE **10781**, 1078151 (2018)

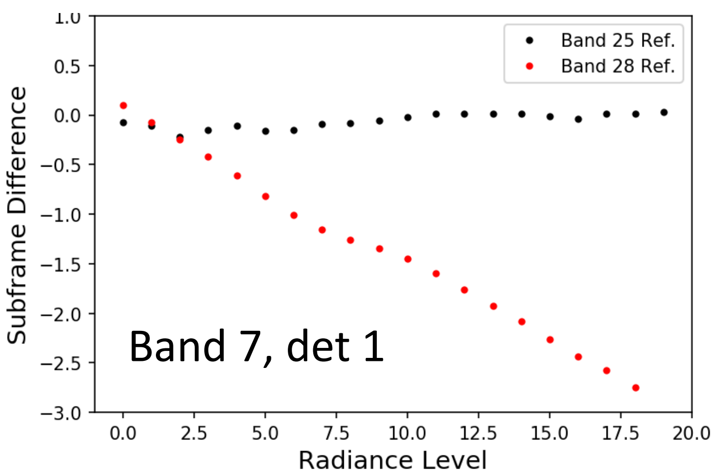
Terra SWIR improvements

Significant reduction in subframe striping

- Plots are radiance difference between the two SFs as a function of radiance.
- B25-based SF difference is small (<2% in most cases) and stable over mission







Black: New algorithm (B25)

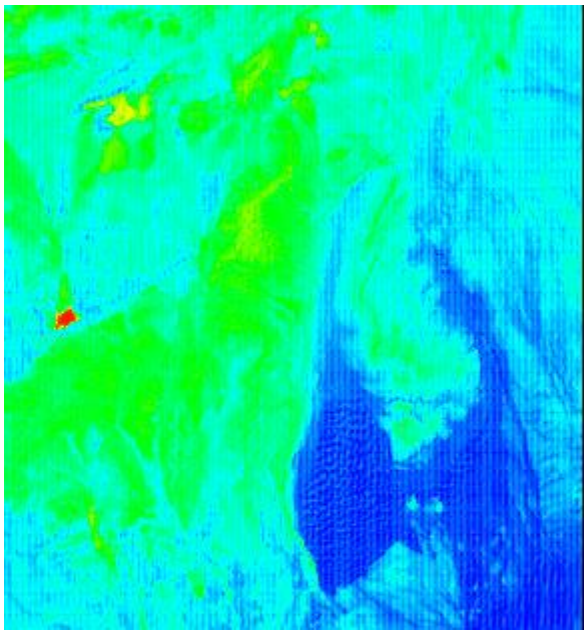
Red: previous C6.1 algorithm (B28)

One orbit test granules from **2019/216**

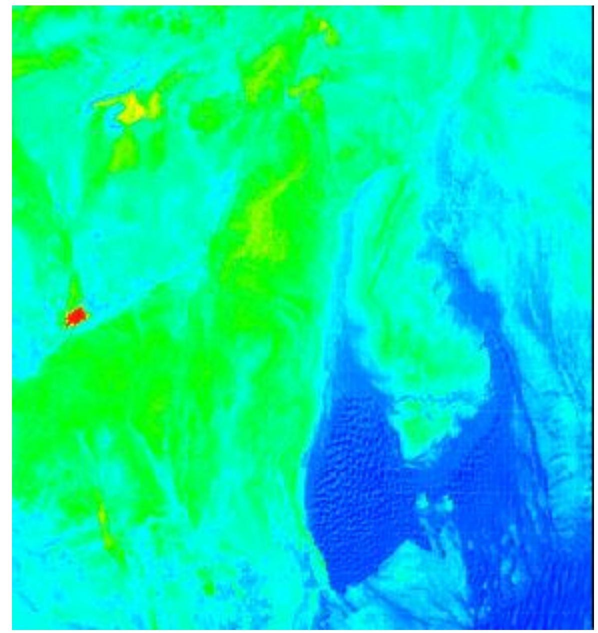
Terra SWIR improvements

Granule: 2016098.1055

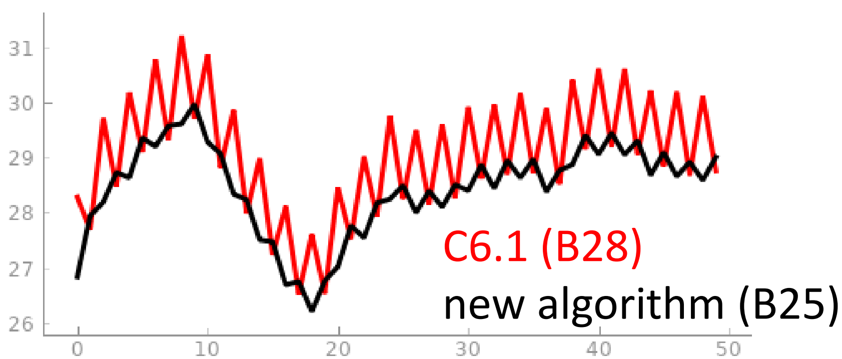
Band 6; C6.1 (B28 reference)



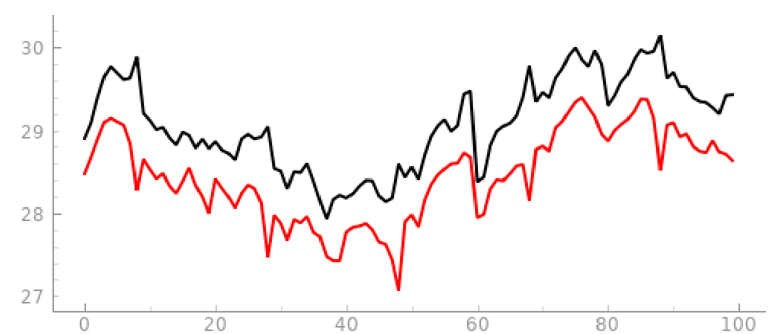
Band 6; new algorithm (B25 reference)



Horizontal line scan



Vertical line scan

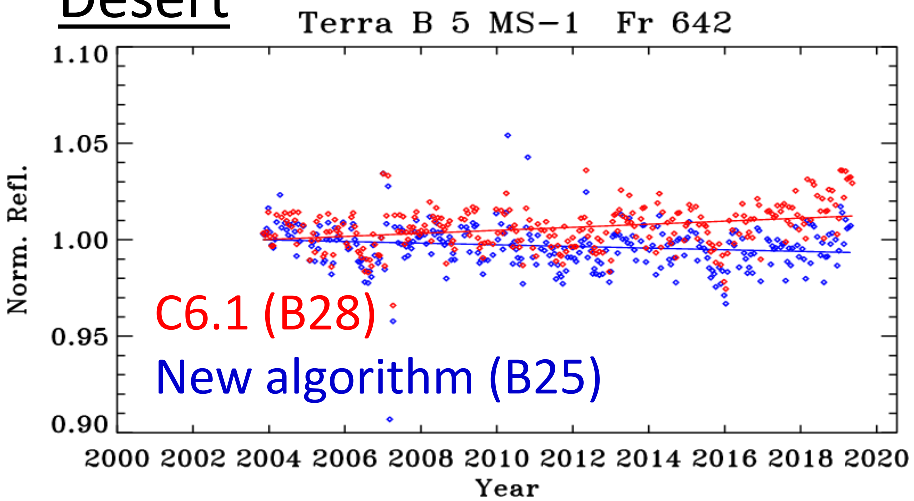


Terra SWIR improvements

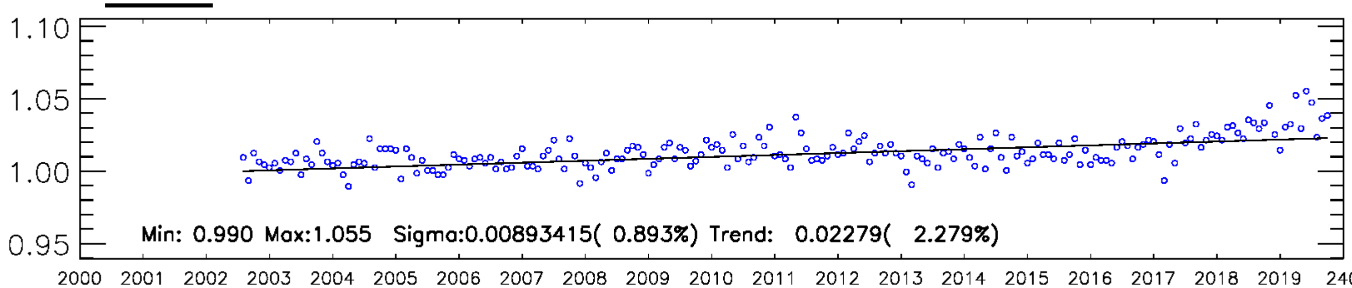
Long-term reflectance trends

- Plots: Band 5, MS1, near nadir
- C6.1 has an increase in reflectance after 2016; improved in the re-processed trend.
- Potential long-term changes in RVS require more investigation.

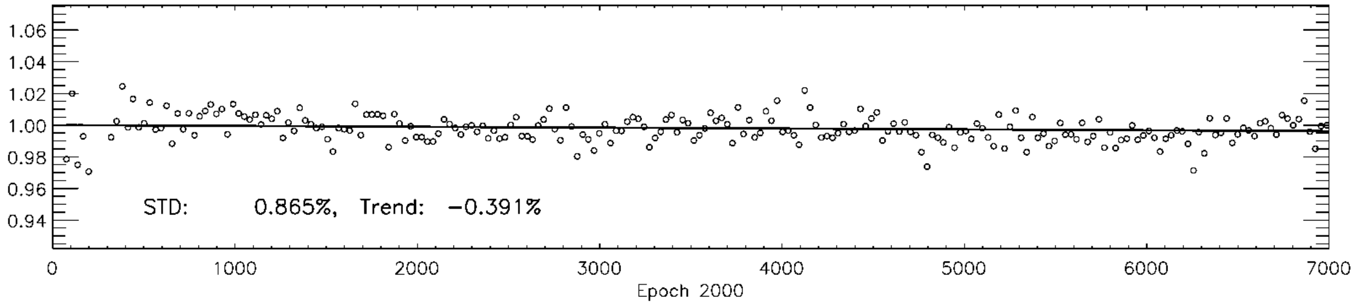
Desert



DCC



C6.1 (B28)



C6.1 with gain from new algorithm (B25)

Terra SWIR improvements

- Terra SWIR improvements are implemented in forward production of C6/C6.1 L1B LUTs starting in June 2019 (SF striping improvement added in August 2019)
  - Forward LUT updates will now include updated x_oob_1 coefficients after every new NTDM data collection
- The same algorithm will be used from mission beginning in the next Collection
- We are also investigating the potential need to update the LUT to correct B26 striping based on scaling of B5 reflectance
  - with Chris Moeller

Terra Polarization correction

The polarization sensitivity of scan mirror has impacted performance of Terra MODIS short-wavelength RSB

- C6/C6.1 L1B does not include any correction for polarization effects

Current mitigation strategy for L2 products

- NASA OBPG has derived polarization correction coefficients from a cross-cal with SeaWIFS/Aqua MODIS over ocean targets
- For land products, use the OBPG polarization coefficients to generate a L1B_PC product followed by de-trending to correct gain for desert sites

MCST activities for next Collection

- Apply polarization correction in derivation of gain from desert sites for Terra bands 8, 9, 3.
- **Goal: Improve accuracy of L1B product and forward-predicted gain. Reduce the magnitude of downstream gain (M_{11}) and de-trending corrections. Note that this effort will improve the instrument gain calibration only; there will still be scene-dependent impacts from polarization in the L1B product.**

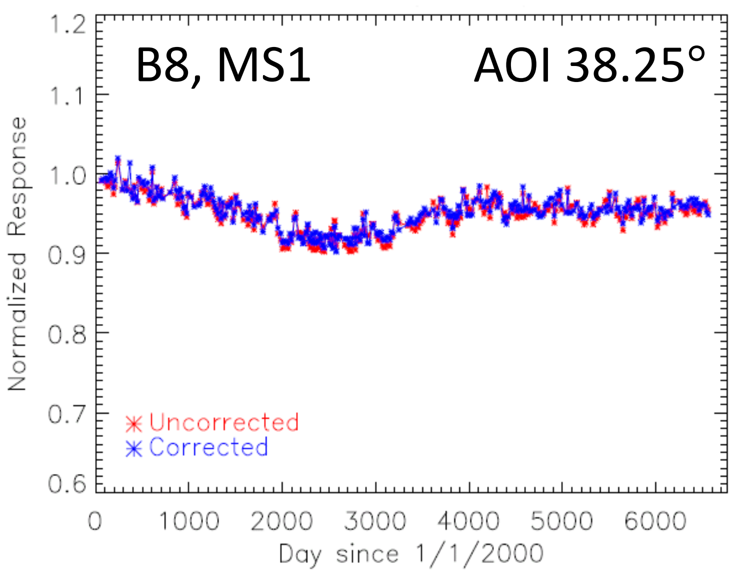
Terra Polarization correction

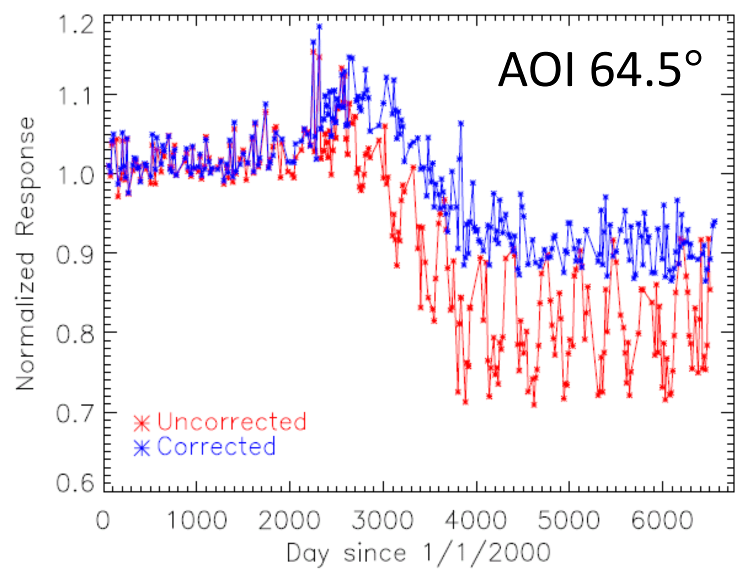
MCST approach for next Collection

Calibrated gains (m_1/RVS) derived from desert trends

- Derive BRDF corrected reflectance, ρ_{BRDF}, for desert using first few years of data and the time-dependent OPBG polarization coefficients m_{12} and m_{13}
- Then derive the gain from the measured dn^* and the polarization and BRDF corrected desert reflectance

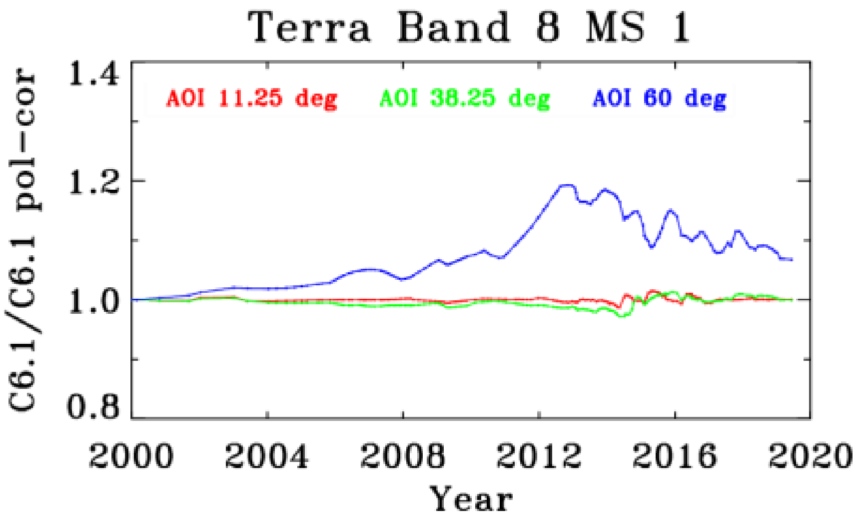
$$gain = \frac{dn^* \, d_{ES}^2 / \cos(\theta)}{\rho_{BRDF} + m_{12}Q + m_{13}U}$$

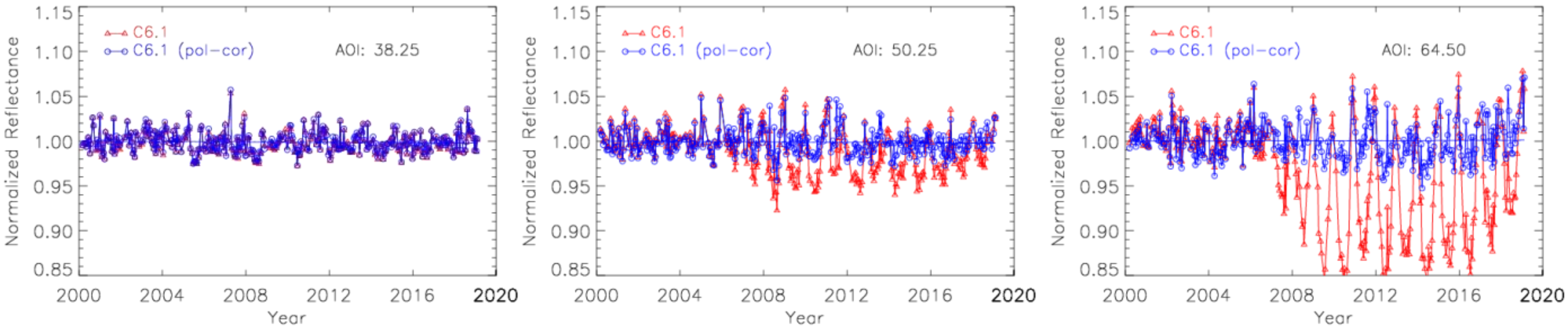




Terra Polarization correction

- Improved gain derivation has largest impact at large scan angles →
- Will result in improved long-term L1B reflectance trending; smaller corrections needed in downstream processing

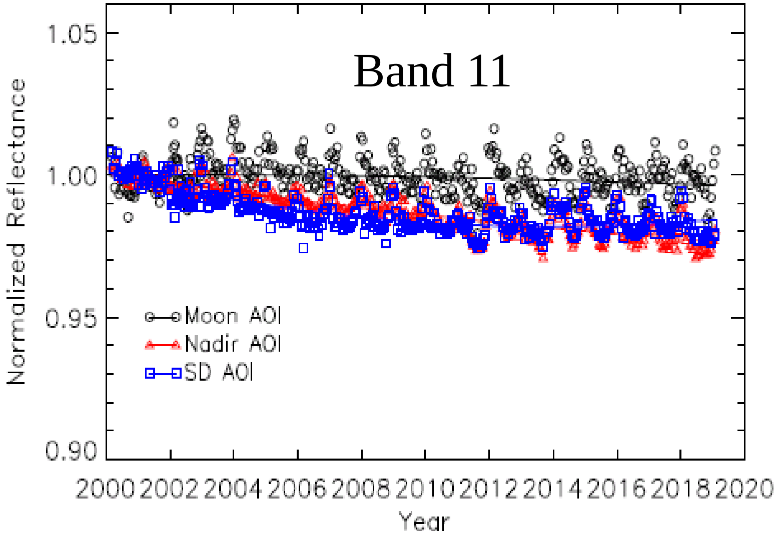


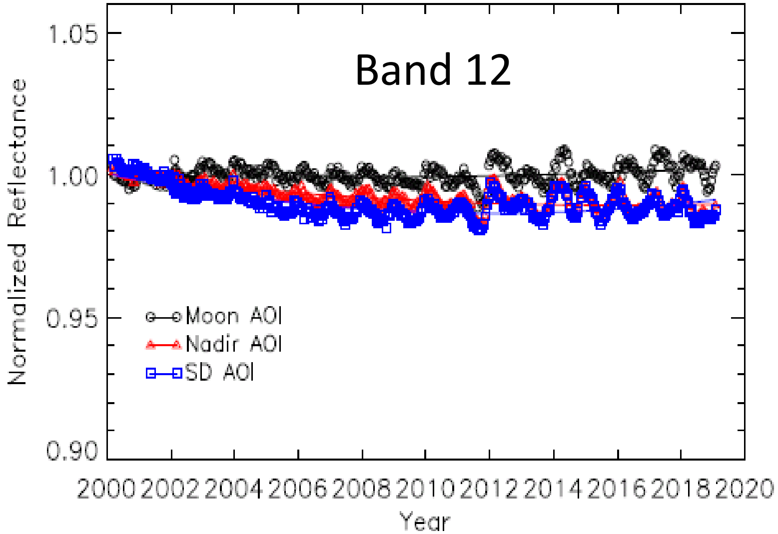


Terra B11-12: Inter-band approach

- C6/C6.1 L1B currently uses EV-based m_1 and RVS for Terra bands 1-4, 8-10. This approach utilizes desert measurements to supplement the on-orbit gain derived from the solar and lunar measurements
  - This approach is necessary for an accurate characterization of the RVS, therefore eliminating the long-term reflectance drifts observed in previous versions
- As the gain continues to degrade, we would like to extend the EV-based approach to other RSB, e.g. bands 11 and 12
  - The desert-based approach is not viable for these (and other high-gain ocean bands) as they saturate while viewing the high-radiance desert.
  - Using ocean targets to derive direct trends is challenging because the response is dominated by Rayleigh scattering and a comprehensive need for atmospheric correction is required
- We have tested an inter-band calibration approach using band 4 (spectrally overlapping) as a reference to monitor the long-term reflectance for bands 11 and 12.
  - The band 4 gain is calibrated from desert PICS approach, and reflectance comparisons with b11 and b12 over ocean granules are used to derive gain for b11 and b12.

Terra B11-12: Inter-band approach





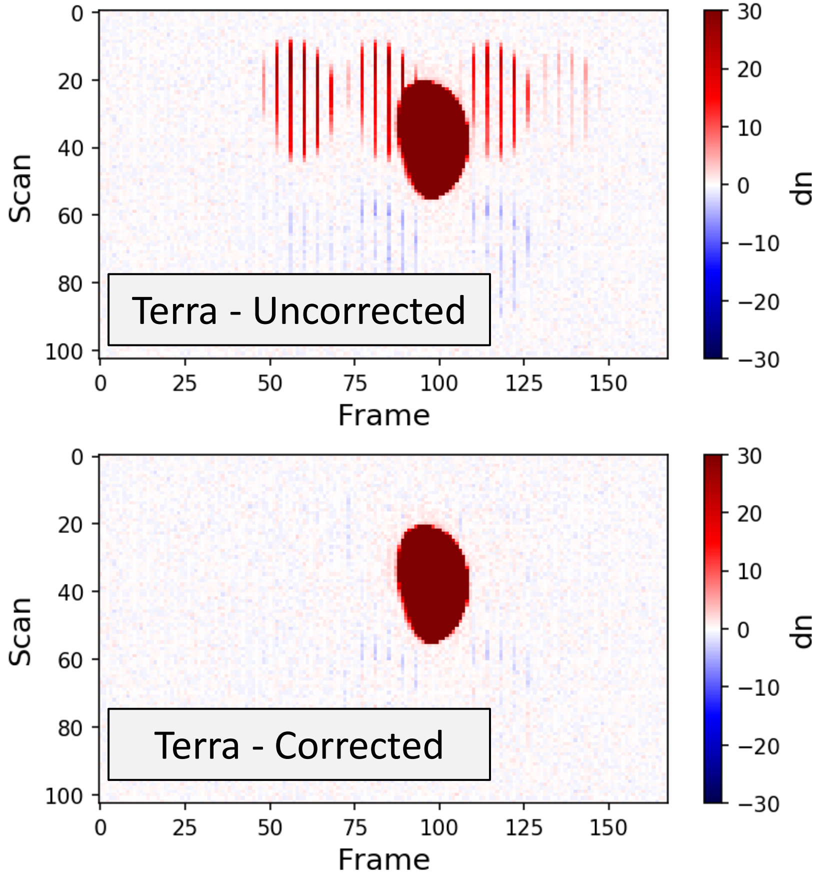
- Long-term drift observed at nadir and SD AOIs for both bands with band 11 showing up to 2% drift, demonstrating the need for EV-based calibration of these bands.
  - No impact expected on the OBPG products as M_{11} factor in the polarization correction accounts for any observed residual drifts.
- Planned for inclusion in next Collection LUT

X. Geng, A. Angal, Y. Li, K. Twedt, X. Xiong, Proc. SPIE **11151**, 1115124 (2019)

Lunar calibration improvements

- Bands 1 and 2 crosstalk correction.
  - Improved detector differences, spatial characterization.
- SWIR bands (5-7, 26) crosstalk correction.
  - Removes large oscillations from the trending lunar m1.
- Lunar Libration oscillation correction.
- Selected Full Disk Scans Method.
  - Like VIIRS, no oversampling.

Example crosstalk correction for Terra MODIS band 2 detector 30.



T. Wilson, X. Xiong, Proc. SPIE **11127**, 111271X (2019)

Test re-processed mission LUTs are ready

Terra

- Changes from C6.1
  - New SWIR OOB/crosstalk algorithm using band 25 applied for the entire mission
  - Polarization-corrected EV data used to derive RVS for B3,8,9
  - Interband calibration used to derive RVS for B11,B12
  - Desert data used for RVS calibration of B10 for entire mission (C6 started using desert data in B10 calibration in 2014)
  - Careful re-investigation of data inputs and data fitting/smoothing methods to provide more accurate and stable LUTs
- Impact on L1B
  - SWIR bands have significantly reduced detector and subframe striping and improved reflectance trending stability
  - More accurate and stable RVS of bands 3, 8-12. Impact is most significant at edge of scan for B8.
  - Re-processing will smooth out variations from forward prediction

Test re-processed mission LUTs are ready

Aqua

- Changes from C6.1
  - Improved SD screen transmission function used for ocean bands 8-16

    Z. Wang, X. Xiong, and W. L. Barnes, Proc. SPIE **8153**, 815307 (2011)

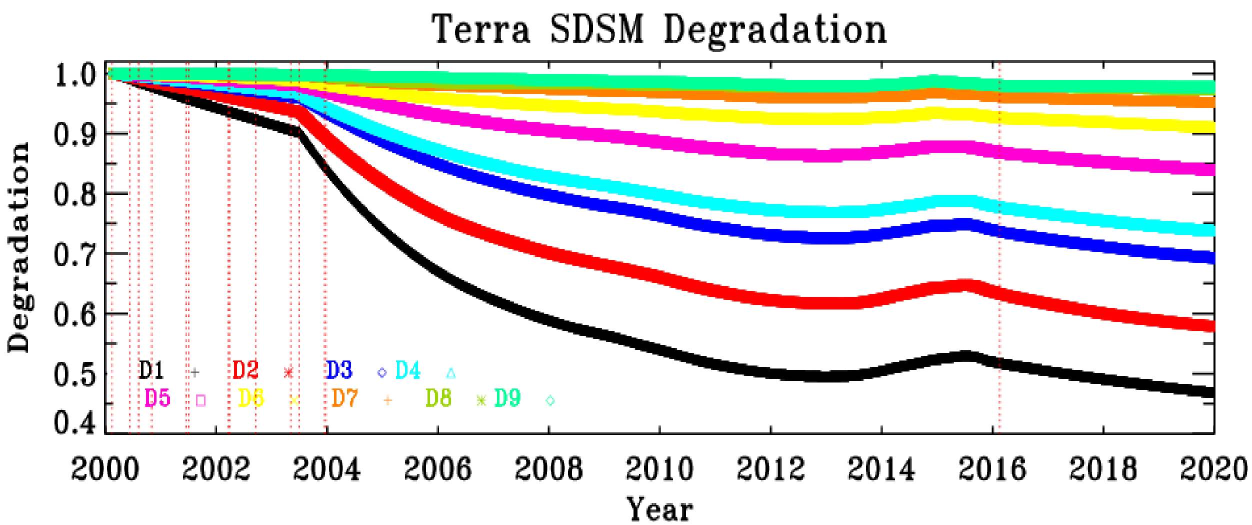
  - Careful re-investigation of data inputs and data fitting/smoothing methods to provide more accurate and stable LUTs
- Impact on L1B
  - Bands 8-16 will have up to 1.3% difference in absolute L1B reflectance/radiance due to new screen transmission function
  - Re-processing will smooth out variations from forward prediction
  - No major impacts expected to long-term on-orbit trends for Aqua

RSB Summary

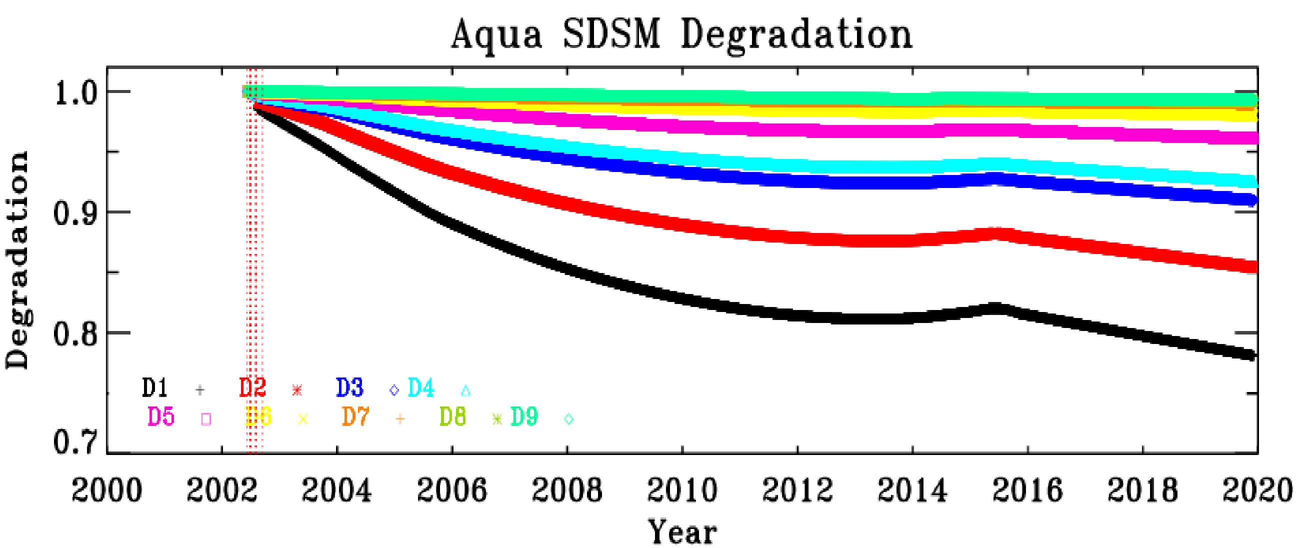
- SD/SDSM and lunar observations are used to track RSB on-orbit gain change
  - Additional information from EV response from desert sites are used for select RSB (Terra 1-4, 8-10 and Aqua 1-4, 8-9)
- Shorter wavelength VIS Bands show larger degradation (strong wavelength, mirror-side, and scan-angle dependence)
  - Gain change over 50% seen in Terra Band 8 (.412 µm) at the AOI of SD (50.25°)
- NIR bands gain change generally within 10%
- SWIR bands gain change within 10%
- Update of Terra SWIR OOB/crosstalk correction
  - Implemented in C6/C6.1 starting in June 2019
  - Major reduction in detector and sub-frame striping and improved reflectance stability
- Challenges for future calibration:
  - Continued degradation of the solar diffusers and changes in RVS may impact gain accuracy of more bands, forcing more reliance of EV-based calibration
  - Correcting for impacts of changes in polarization sensitivity

BACKUP

MODIS SD Degradation (fitted)



Increased degradation after Terra SD door anomaly on July 2, 2003. Larger SD degradation at shorter wavelengths for both instruments

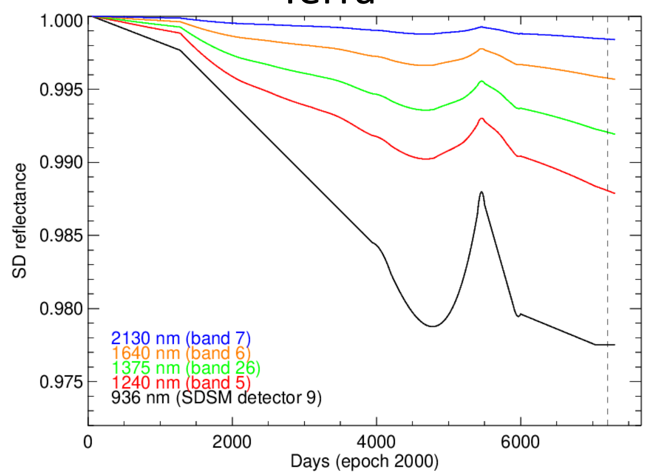


A special "fix" mode operation was performed for Aqua MODIS SDSM to verify the results observed in previous years

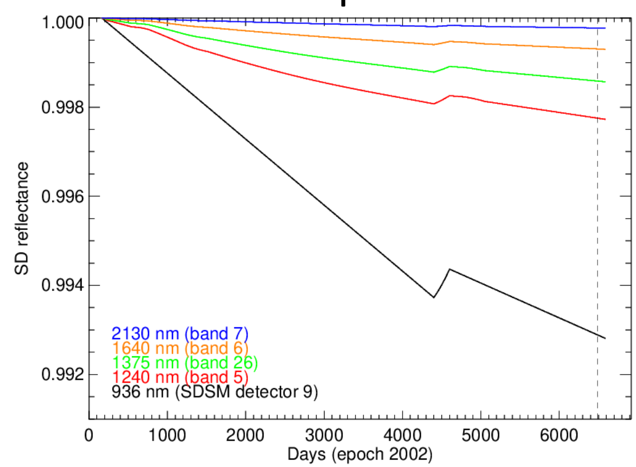
MODIS SD Degradation at SWIR wavelengths

- The solar diffuser degradation at SWIR band wavelengths is not tracked by the SDSM, but can be significant (e.g. >1% for Terra band 5). Starting with January 2018 LUT updates, MCST updated the SD degradation at SWIR wavelengths.
- Previous Collection 6/6.1:
  - The long term reflectance trends of Earth targets were used to derive a linear correction coefficient for Terra band 5 (using desert sites) and Terra band 26 (using DCC). The other SWIR bands did not have any SD degradation applied.
- Forward Collection 6/6.1:
  - We estimate SD degradation at SWIR by performing a power law fit to the SD degradation calculated from SDSM detectors and extrapolating to the SWIR.

Terra

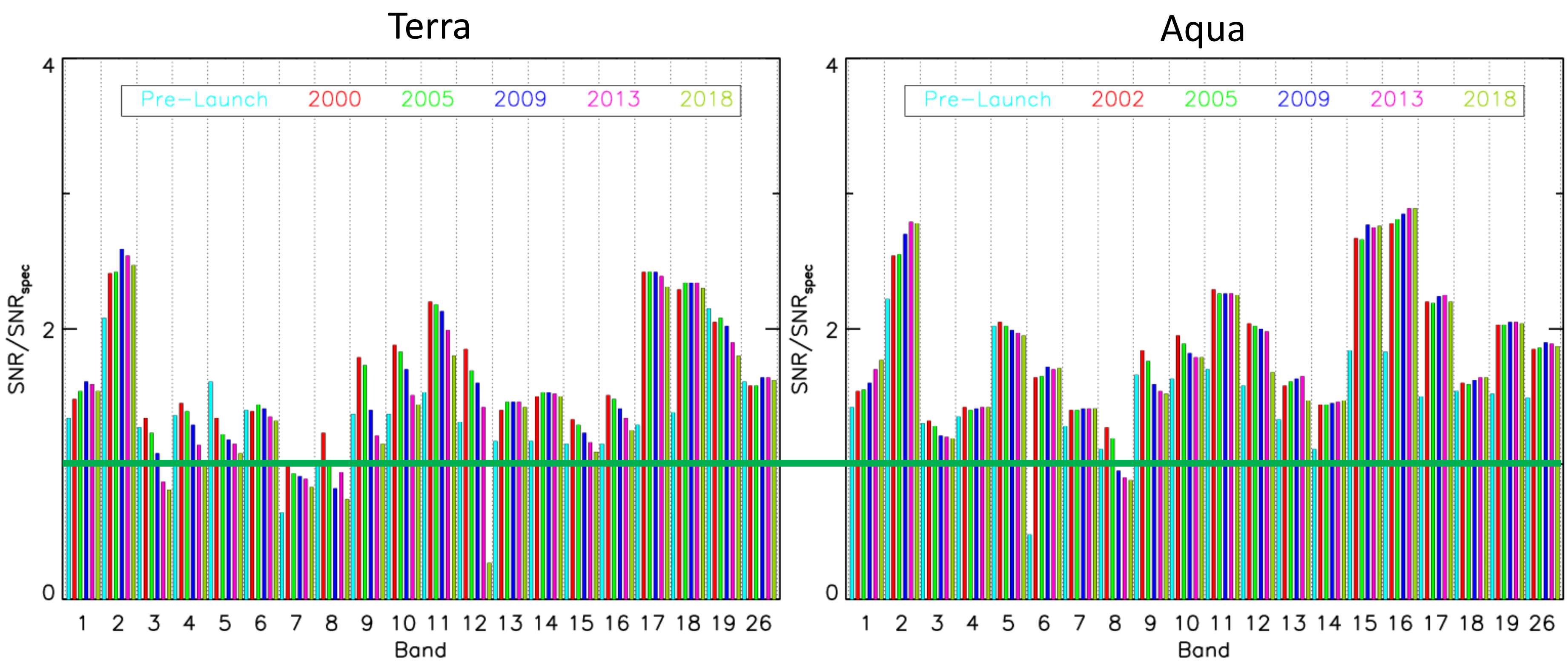


Aqua



K. A. Twedt, A. Angal, X. J. Xiong, X. Geng, and H. Chen, "MODIS solar diffuser degradation at short-wave infrared band wavelengths," in *Proceedings of SPIE*, 2017, vol. 10402, p. 104022K.

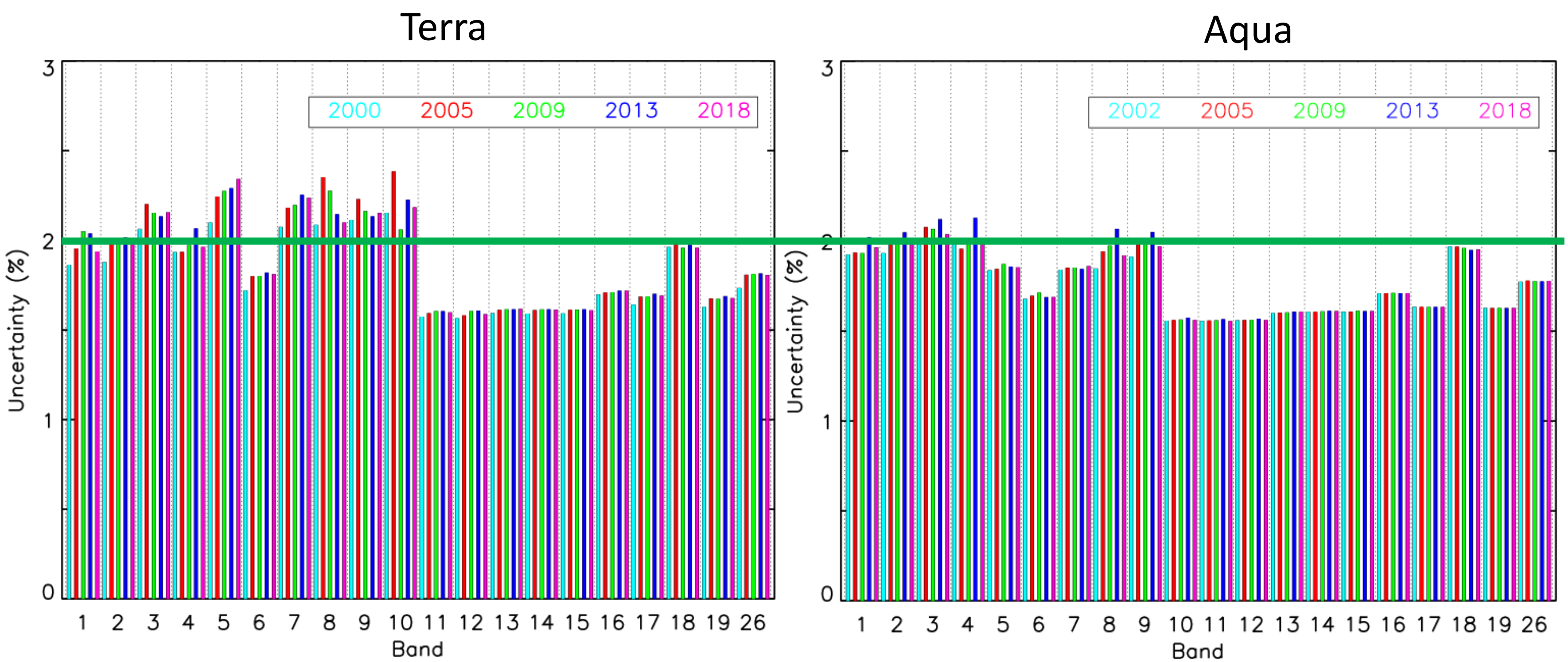
MODIS RSB SNR Bar-Charts



Most bands continue to meet the specification.

- Known issues with the inoperable/noisy detectors in Aqua band 6.
- Decreased responsivity for some short wavelength RSB (Terra bands 8, 9, 3, Aqua band 8
- Terra band 7 SNR known to be below specification since launch

MODIS RSB Uncertainty Trends



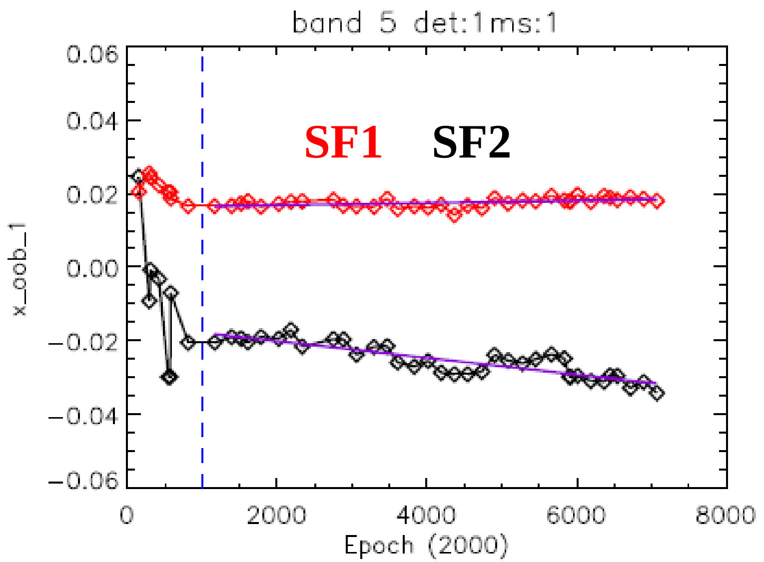
Most bands continue to meet the specification.

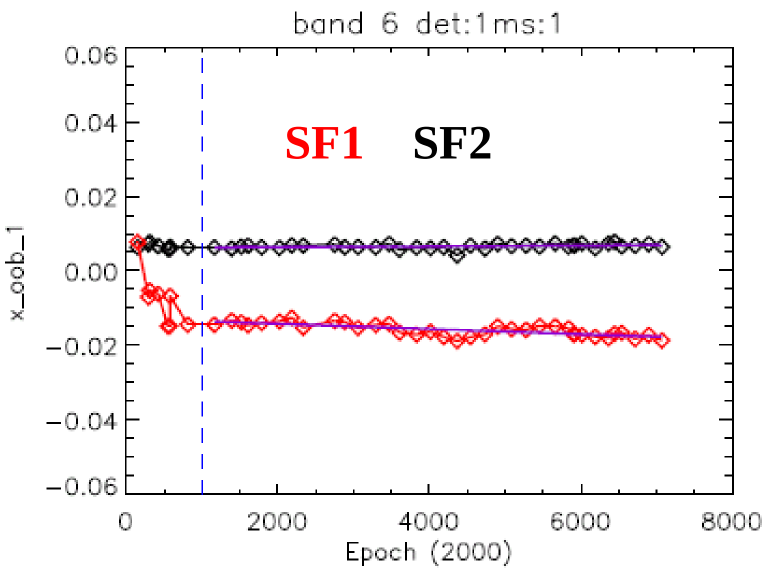
- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Terra bands 1-4,8-10 and Aqua bands 1-4, 8,9)
- On-orbit changes in the polarization sensitivity is also a contributing factor.

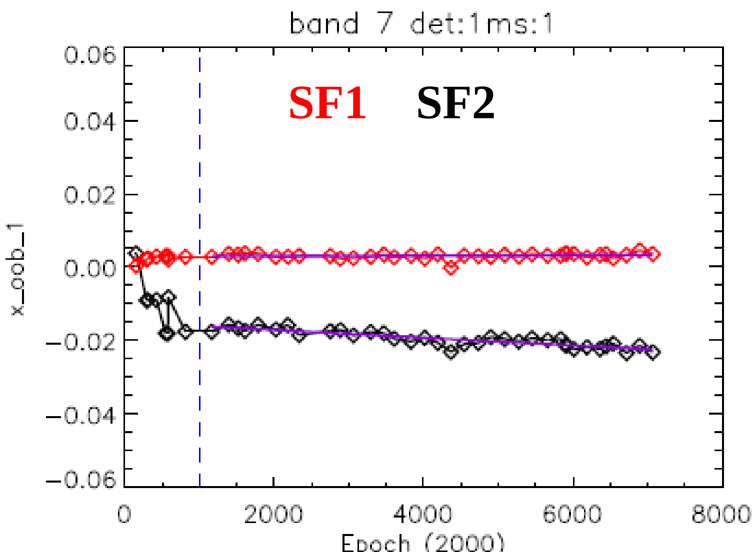
Terra SWIR improvements

X_oob_1 coeffs derived from night-time-day-mode (NTDM) data collections using B25 as the reference band.

- Significant changes in early mission due to configuration changes.
- Gradual drift after day 1000. Fit data to get a smooth time-dependent x_oob_1 LUT in this time range.
- X_oob_1 used to adjust SD and EV dn.



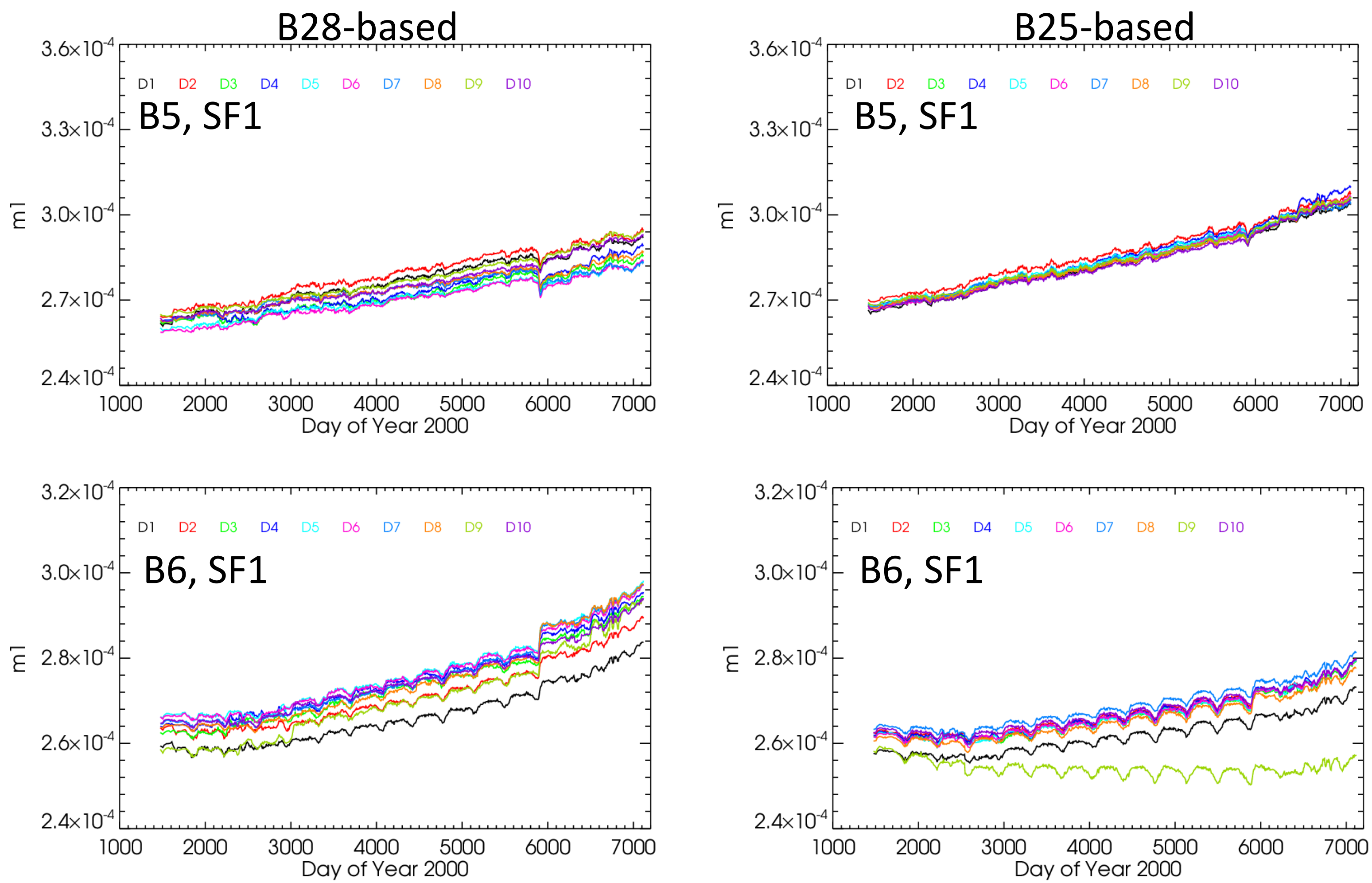




Terra SWIR improvements

Smoother m1 trending after 2016-Feb safe mode

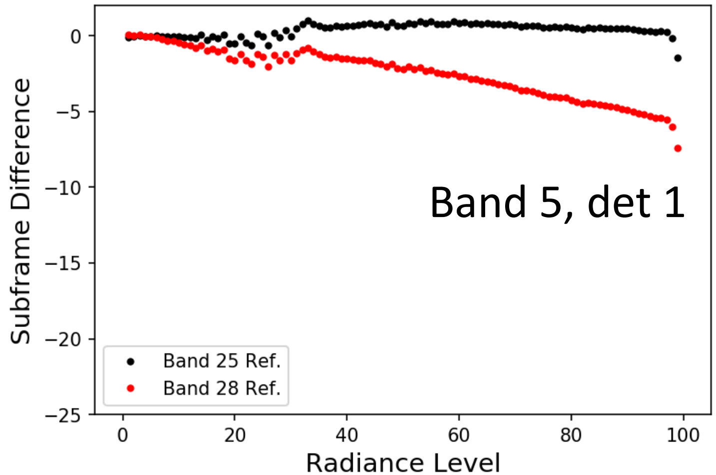
- Re-derived open-to-close scaling ratio applied to data after day 1279

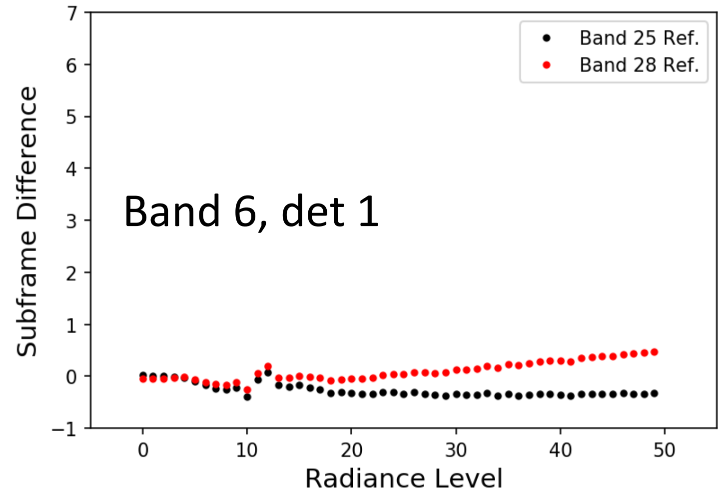


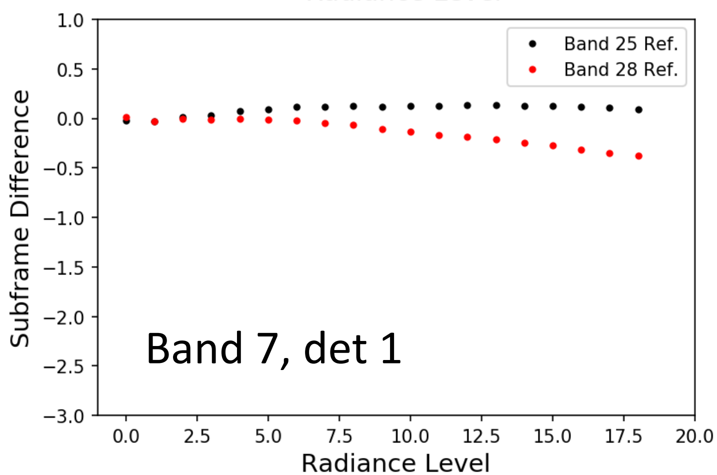
Terra SWIR improvements

Significant reduction in subframe striping

- Plots are radiance difference between the two SFs as a function of radiance.
- B25-based SF difference is small (<2% in most cases) and stable over mission







Black: New algorithm (B25)

Red: previous C6.1 algorithm (B28)

One orbit test granules from **2006/100**

Terra SWIR improvements

Significant reduction in detector striping