MODIS Instrument Operations Status

Terra Flight Operations

- Terra Spacecraft Status
  - 16+ years of successful operation
  - Safe Mode Occurred 02/18/16 – 02/23/16
  - Solid State Recorder – 32 supersets allocated: 0 lost since last STM
  - Battery – Anomaly on 10/13/09 resulted in loss of 1 cell (out of 54 total). No impact on operations or power availability.
  - Orbit Maneuvers: Drag Make-up #91-96, Inclination Adjustment #42-45

Aqua Flight Operations

- Aqua Spacecraft Status
  - 14 years of successful operations
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – Full data allocation
  - Battery – Fully functional
  - Orbit Maneuvers: Drag Make-up #97-106, Inclination Adjustment #48-51

MODIS Instrument Operations (Terra)

- **Terra MODIS is healthy and operating nominally**

- **Operational Configuration (No change since last STM)**
  - A-side: launch to Oct 30, 2000
  - B-side: Oct 30, 2000 to June 15, 2001
  - A-side: July 02, 2001 to Sept 17, 2002
  - A-side electronics and B-side formatter: Sept 17, 2002 to present
  - BB temperatures set at 290K
  - Cold FPA (SMIR and LWIR) controlled at 83K
  - SD door fixed to “open” position since July, 2003
- **Events**
  - Safe Mode: February 18, 2016 – February 24, 2016
  - Outgas: February 23, 2016 – February 24, 2016
- **Concerns**
  - SSR allocation – further decrease could result in data loss
    - No losses since October 26, 2014

MODIS Instrument Operations (Aqua)

- **Aqua MODIS is healthy and operating nominally**

- **Operational Configuration (No change since last STM)**
  - Same B-side configuration since launch
  - BB temperatures set at 285K
  - Cold FPA (SMIR and LWIR) controlled at 83K
- **Events**
  - None
- **Concerns**
  - Loss of radiative cooler margin – Cold FPA not maintained at 83 K through entire orbit.
  - No CFPA changes planned
    - https://mcst.gsfc.nasa.gov/meetings/aqua-modis-cold-fpa-performance-and-operation

Terra Safe Mode

- On February 18th, 2016 (2016/049) the Terra FOT were executing Inclination Adjust Maneuver (IAM) #43
  - During the execution of IAM #43, prior to the maneuver burn, the slew tables tripped the Fault-Detection Isolation & Response (FDIR)
  - Terra autonomously transitioned into Earth Point Safe-Hold at 049/14:33:17
  - MODIS transitioned to Safe Mode at 049/14:33:30
- Terra spacecraft last transitioned to Earth Point Safe-Hold on December 16th, 2003
  - Terra Inertial Reference Unit saw 5 bad data samples and the Fault Detection Isolation and Recovery made the S/C go into Safe Mode

Terra MODIS Safe Mode Recovery

- MODIS transitioned to Standby Mode at 2016/054 16:41:52

- MODIS preformed Outgas procedure from 2016/054 17:34:43 until 2016/055 19:19:40
    - Total Outgas Duration: 25:44:57

- Space View Door opened at 2016/055 19:22:52

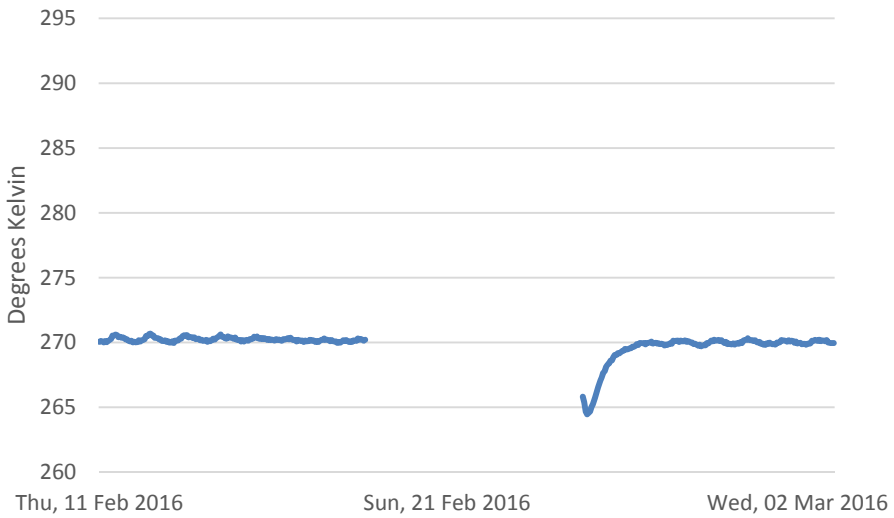
- MODIS transitioned to Science Mode at 2016/055 19:26:34

- Blackbody was turned on (290K) at 2016/055 19:59:21

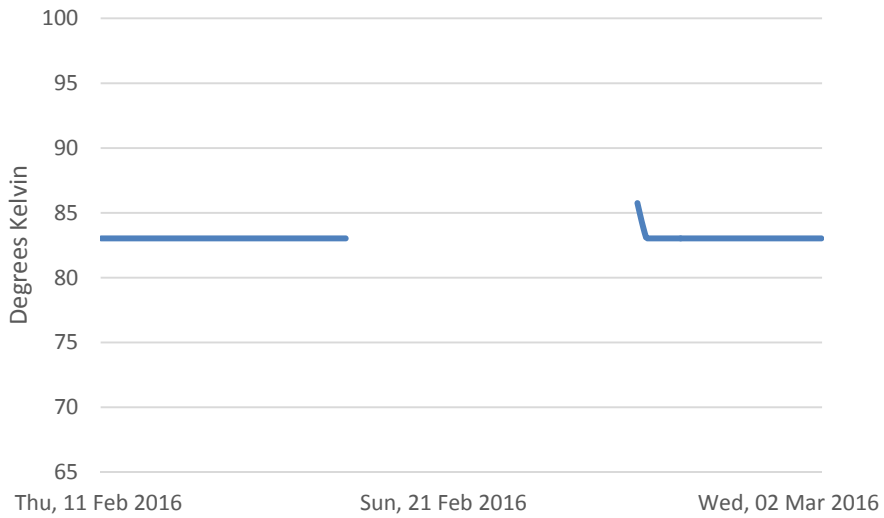
- Nadir Door was opened 2016/055 20:01:32

Terra MODIS Safe Mode Recovery Telemetry

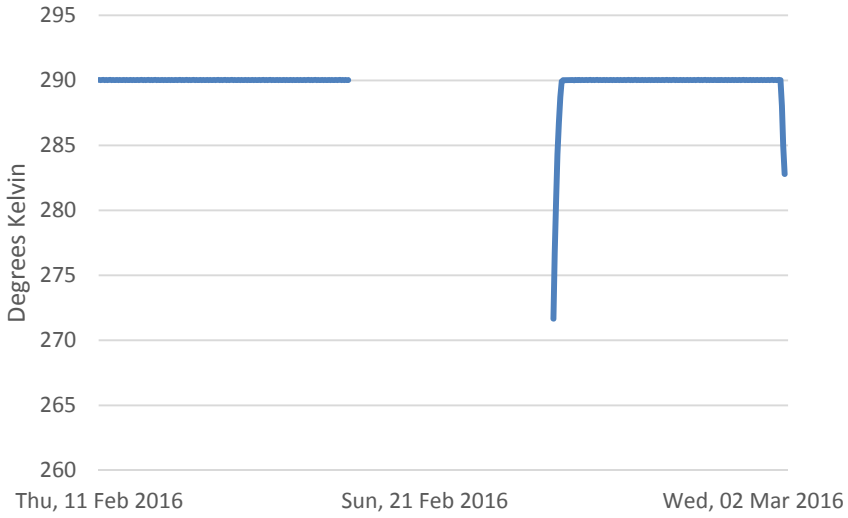
TP_AO_SMIR_OBJ (Instrument Temperature)



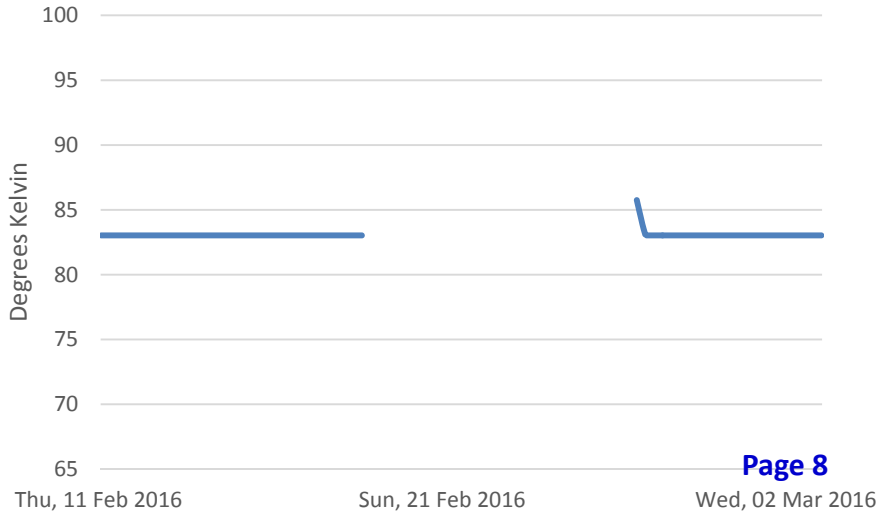
TA_RC_SMIR_CFPAE (SMIR Focal Plane Temperature)



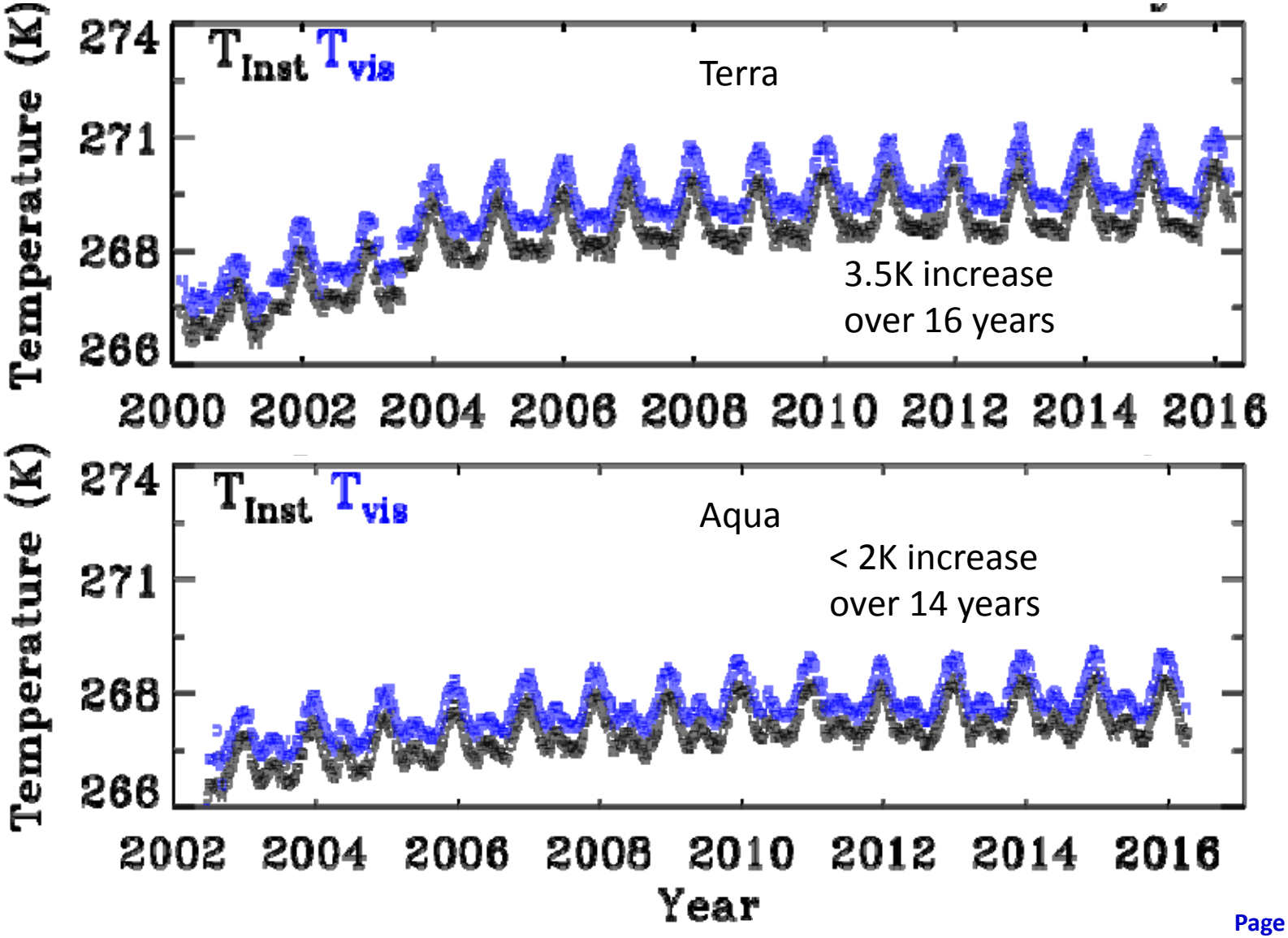
TP_BB_TEMP01 (Blackbody Temperature)



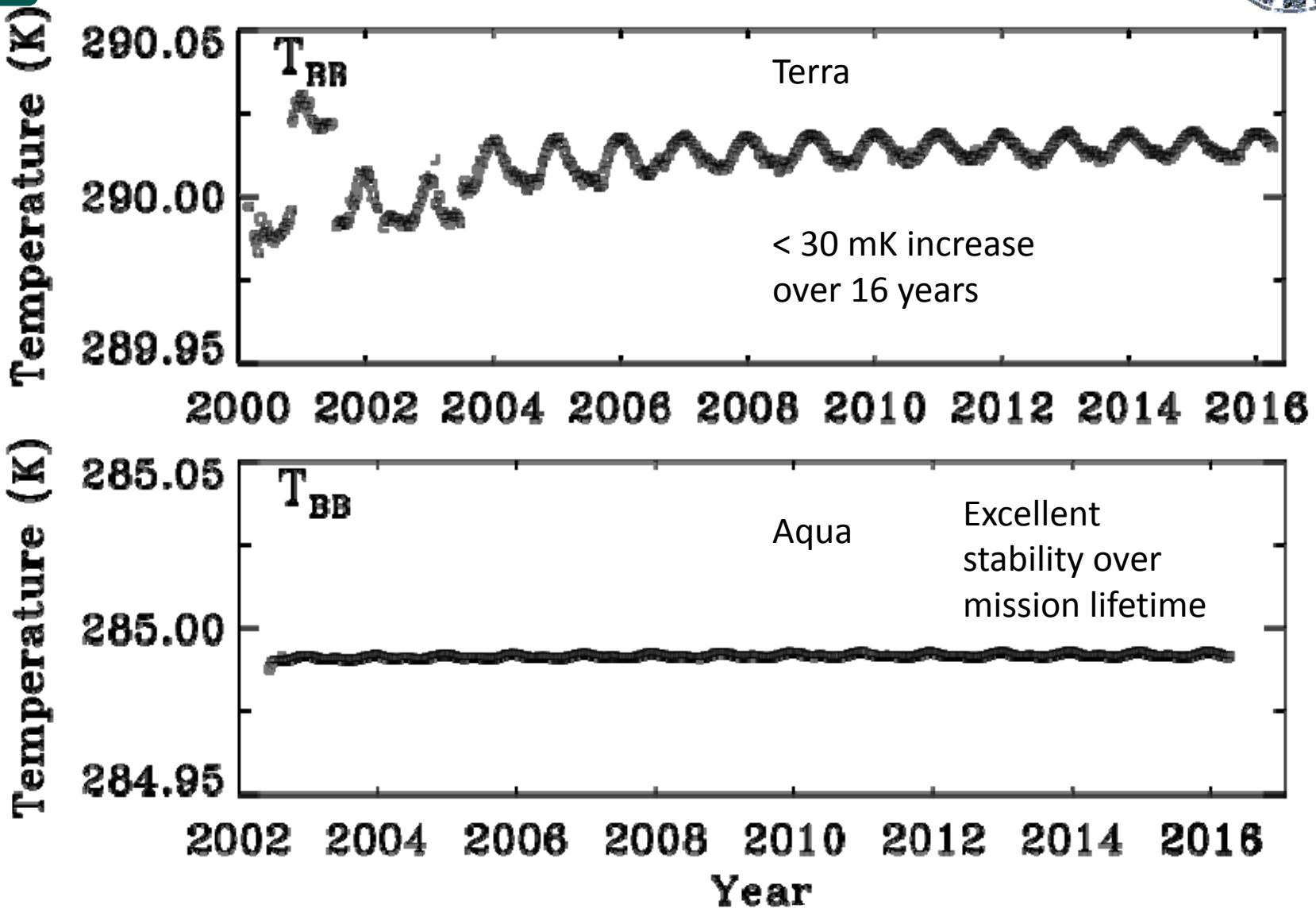
TA_RC_LWIR_CFPAE (LWIR Focal Plane Temperature)



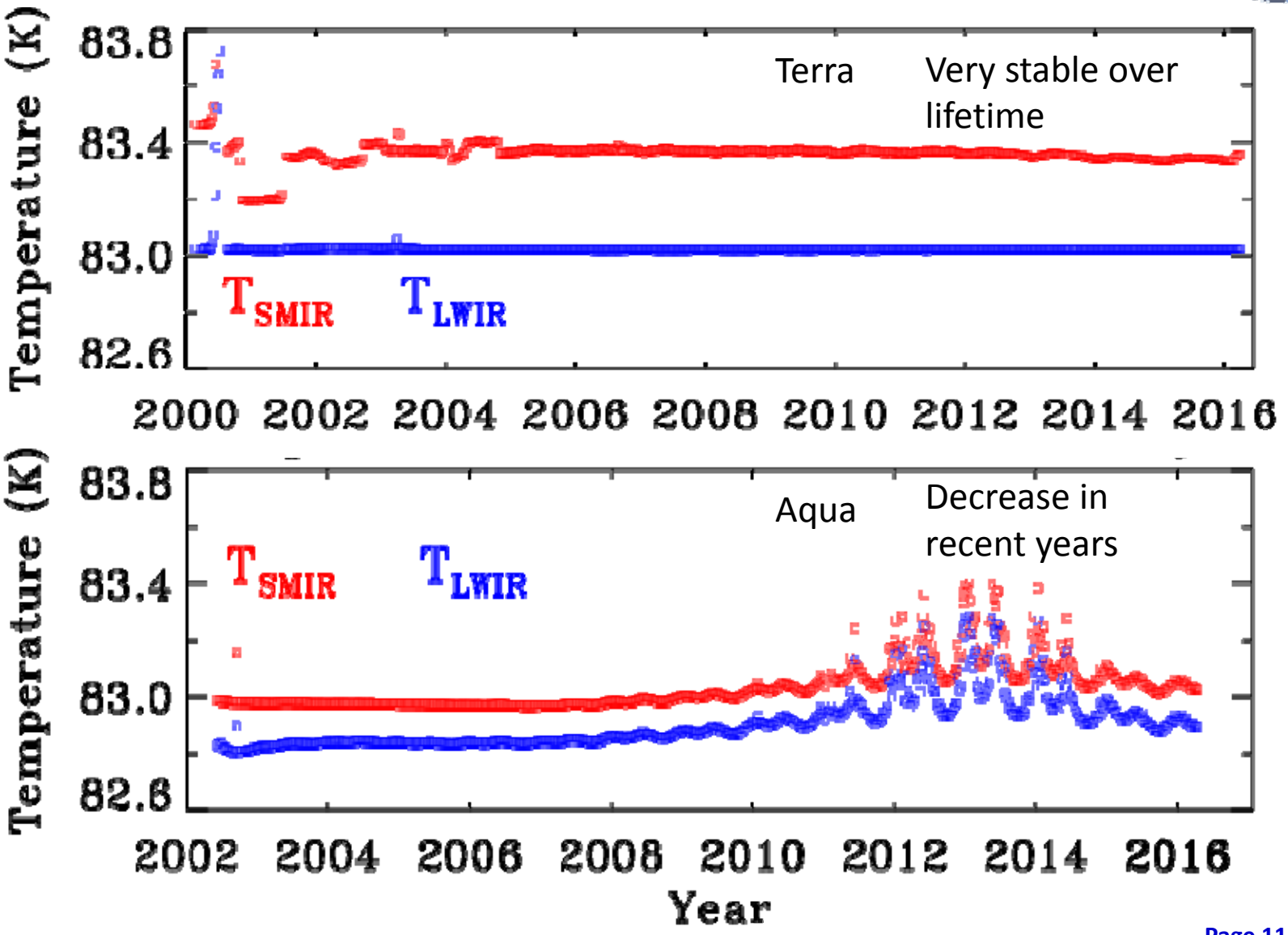
Instrument Temperature Trends



BB Temperature Trends

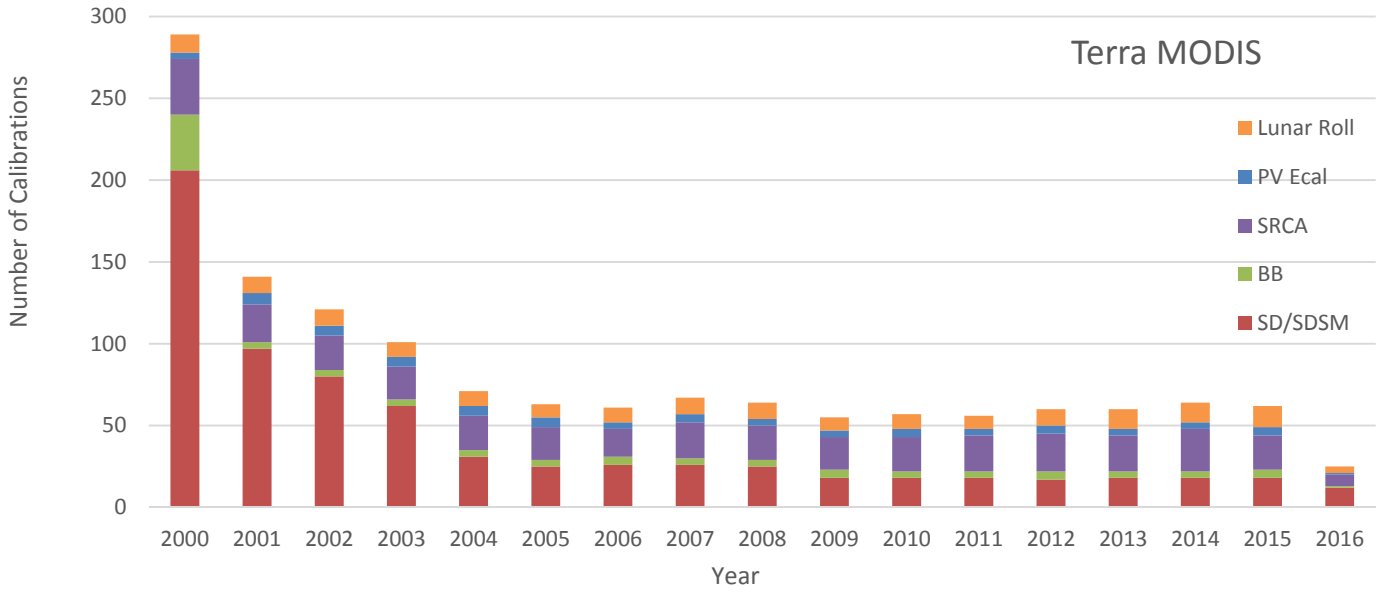


CFPA Temperature Trends

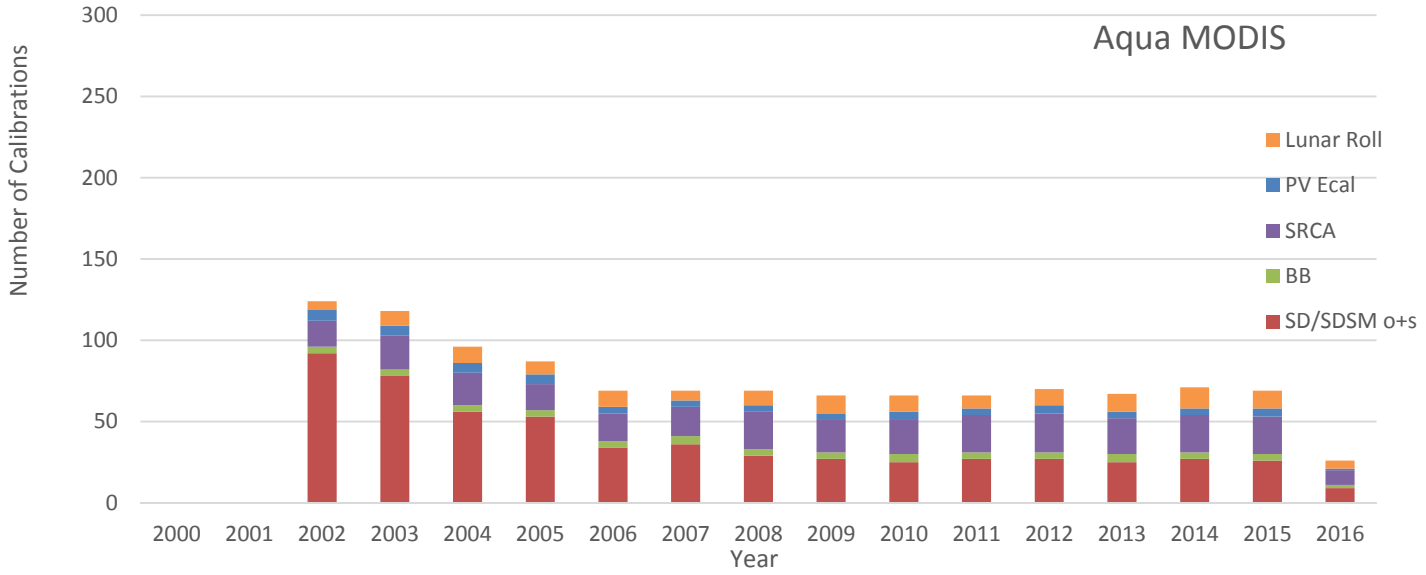


MODIS Calibration Operations

Terra



Aqua



Terra/Aqua MODIS OBC Operations

TERRA

Activity	PL to 06/15	06/15 – present	Total
SD/SDSM[#]	691	24	715
BB WUCD	95	4	99
SRCA*	412	21	433
Electronic Cal	88	4	92
Lunar Roll	150	12	162

AQUA

Activity	PL to 06/15	06/15 - present	Total
SD/SDSM[#]	544	27	571
BB WUCD	57	4	61
SRCA*	289	26	315
Electronic Cal	67	4	71
Lunar Roll	124	12	136

[#] Open & Screened Activities counted independently
* Includes Spatial, Spectral and Radiometric
05/15 = last Science Team Meeting

SRCA Calibrations

- Terra – 433 SRCA Calibrations
- Aqua – 315 SRCA Calibrations
- Please note there was a minor reconciliation of the usage numbers
- Lamps well within lifetime usage margins
- No lamp failures since 2006

Lamp Power		10W				1W	
Lamp #		1	2	3	4	1	2
Terra	Usage (hr)	359.7	172.1	190.3	131.1	587.7	304.6
	Life (hr)	500	500	500	500	4000	4000
	percent	71.9%	Failed on 11-20-2004	Failed on 2-18-2006	26.2%	14.7%	7.6%
Aqua	Usage (hr)	354.3	188.8	205.7	134.5	528.8	294.4
	Life (hr)	500	500	500	500	5000	5000
	percent	70.9%	Failed on 4-14-2003	Failed on 6-28-2005	26.9%	10.6%	5.9%

Future Operational Considerations

- Aqua MODIS CFPA temperature control
  - Currently set at 83K
  - Minimal impact on science data
  - No need for mitigation at this time

- Aqua SD/SDSM door movements
  - Passed projected lifetime limit on movements
  - No change in current frequency of SD calibration activities planned at this time

	PL to 05/14	05/14 to present	Total	Design Lifetime	% Used
Terra*	2146	0	2146	3022	71.01
Aqua+	3218	72	3290	3022	108.87

* As of 07/02/2003, SD Door in fixed 'open' position with screen in place

+ Aqua reached designed lifetime of door movement on DOY 2012/191 (July 2012).

MODIS Level 1B Code and LUT Status

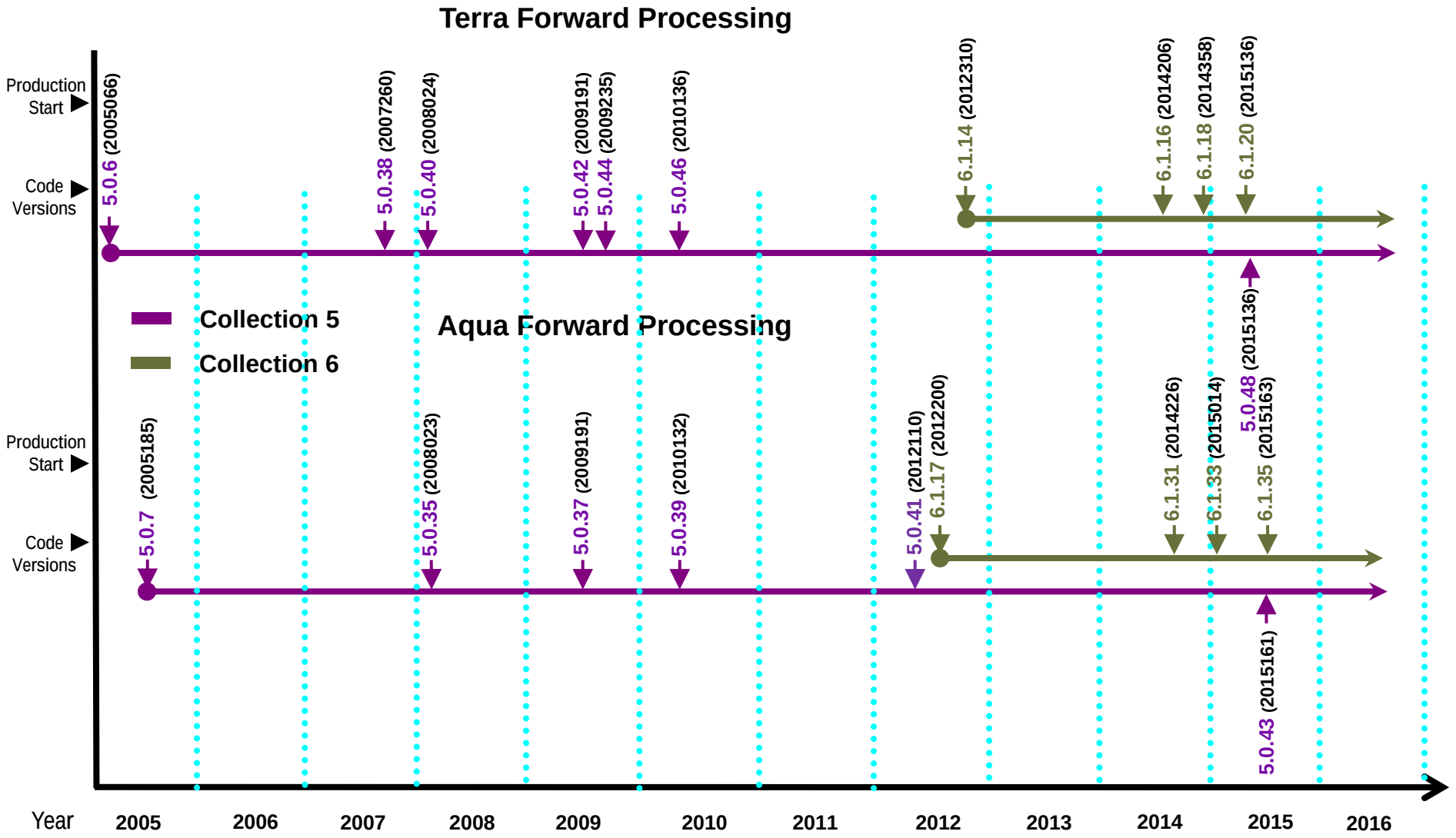
C5/C6 L1B Code and LUT Updates

- **Two separate sets of code and LUT (look-up-table)**
  - Terra MODIS (**MOD02**) and Aqua MODIS (**MYD02**)
  - C5 (2005 – present): Terra V5.0.48; Aqua: V5.0.43
  - C6 (2012 – present): Terra V6.1.20; Aqua: V6.1.35
- **No L1B code updates (since last STM (5/18/2015))**
- **L1B LUT updates (since last STM)**
  - Terra MODIS C5: 16; C6: 16

    Aqua MODIS C5: 14; C6: 16
  - Most LUT updates were driven by gain changes of VIS bands

MODIS MOD_PR02 L1B

Major Production Changes Timeline (C5 & C6)



C5/C6 L1B LUT Updates

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Terra C5	10	14	14	17	19	18	18	21	15	17	17	5
Terra C6	0	0	0	0	0	0	0	5	14	17	17	6
Terra (OBPG)									1	15	17	4
Aqua C5	6	9	11	9	9	13	15	13	11	14	14	7
Aqua C6	0	0	0	0	0	0	0	7	11	15	15	7
Aqua (OBPG)									9	13	13	6
Total	16	23	25	26	28	31	33	46	61	91	93	35

- **C5 Phase out?**
  - C6 = better quality
  - Science products have completed/started C6 reprocessing.

Terra MODIS Safe Mode

- Entered Safe Mode at 049/14:33:30 (02/18/2016)
- Transitioned to Science Mode 055/19:26:34 (02/24/2016)
- Calibrations performed within a week of the recovery
  - A series of SDSM calibrations scheduled starting from 056
  - A black body warm up/cool down calibration was performed between 060 – 062 (2/29/2016 – 3/2/2016).
- L1B LUT update V**6.1.20.14** (**C6**) and V**5.0.48.15** (**C5**)
  - RSB LUT update: m1_table;
  - TEB LUT update: a0_table, a2_table, band_21_b1_table;
  - QA LUT update: detector_quality_flag_values_table.

  The first time stamp after the safe mode: **2016059 00:00:00**
- MODIS data production impact

  No data available between 2016049 11:45:00 and 2016059 00:00:00

Terra MODIS LWIR PV Cross-talk Correction

- Known issue
- Bands involved: 27, 28, **29**, and 30
- Symptom: gain drift, striping, etc.
- Different correction algorithms developed by MCST, and implemented in L1B for test
- Working closely with science teams to evaluate and finalize the cross talk correction algorithm

MODIS RSB Calibration and Performance

Highlights since the last STM (May, 2015)

- Terra MODIS
  - RSB performing nominally after the safe-mode event (Feb, 2016)
  - Out-of-turn calibration events (SD/SDSM) scheduled to monitor the instrument performance after the safe-mode
  - Noticeable gain changes (~2%) for the SWIR bands observed after the safe-mode event. VIS/NIR bands show changes < 1%
  - No new noisy/inoperable detectors since the last STM
- Aqua MODIS
  - No significant events since last STM. Instrument operating nominally with the OBC (SD, SDSM, SRCA) performing normally
  - No new noisy/inoperable detectors since the last STM
  - Need to extend the EV-based RVS approach to bands 1 – 4 [see: MCST Special Topics Talk for details]

On-orbit Calibration Activities

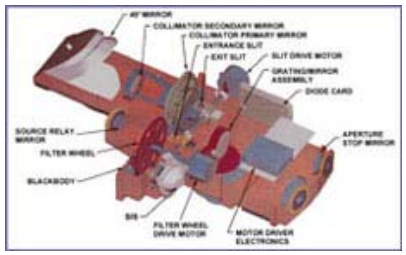
SD/SDSM:
Weekly to tri-weekly

Solar Diffuser

SDSM

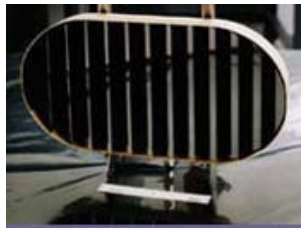
SRCA:
Radiometric: monthly
Spatial: quarterly
Spectral: tri-annual

SRCA



Scan Mirror

Blackbody



BB: quarterly

Space View

Spacecraft maneuvers:
Yaw (SD BRF, VF)
Roll (Moon)

Moon: monthly (nighttime orbits)
0-20° spacecraft roll maneuvers
55° phase angle

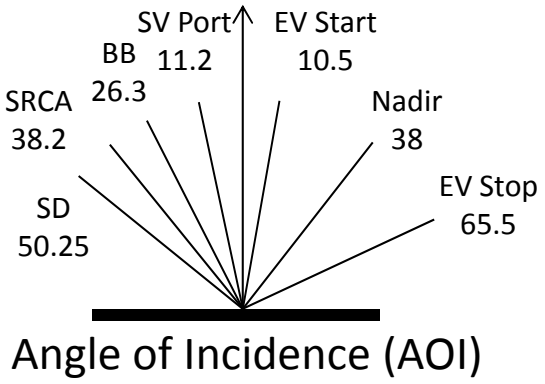
RSB Calibration

- EV Reflectance

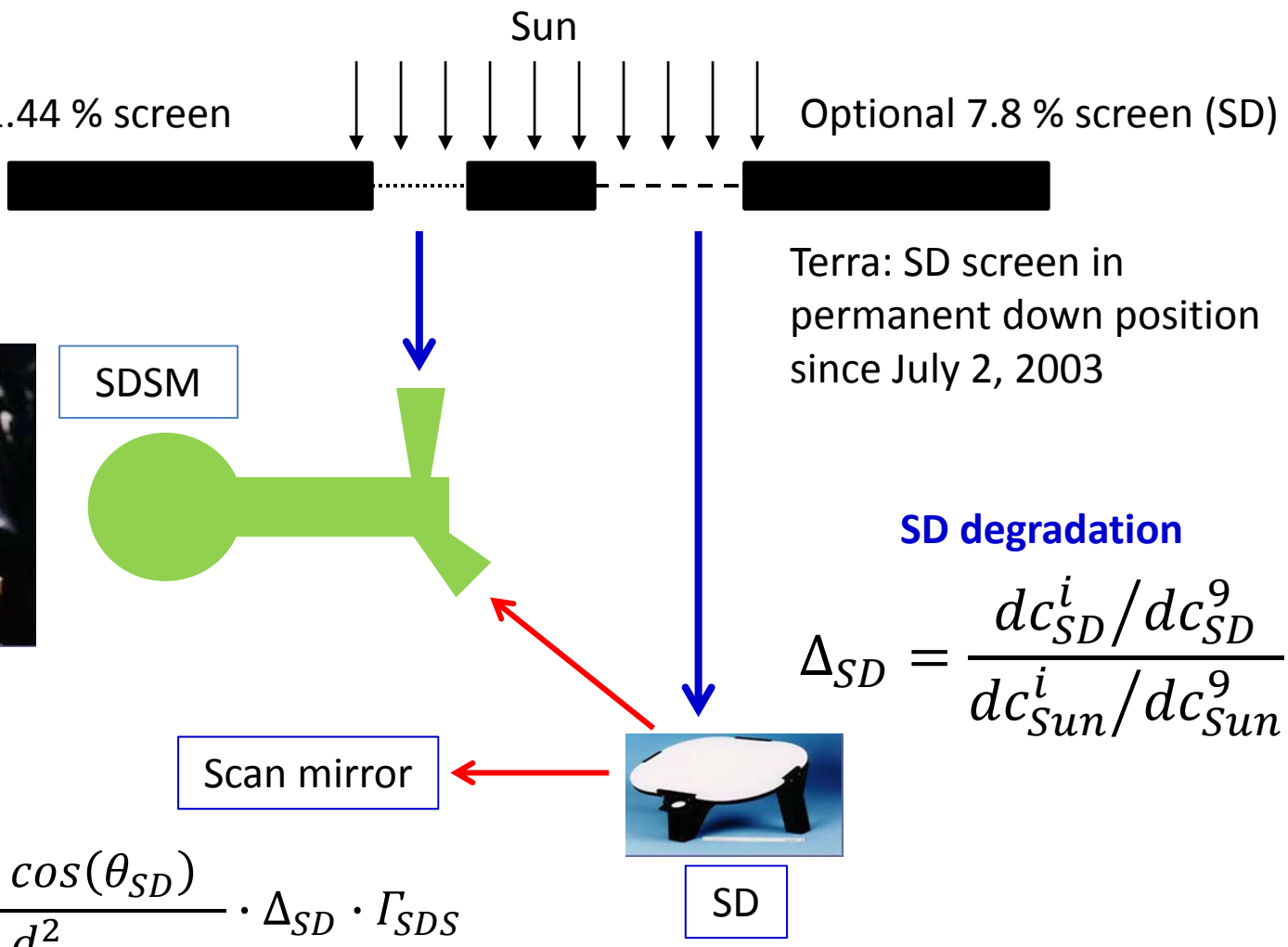
$$\rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS}$$

- 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
  - SRCA and EV mirror side (MS) ratios
  - Response trending from EV targets



RSB SD Calibration



SD degradation

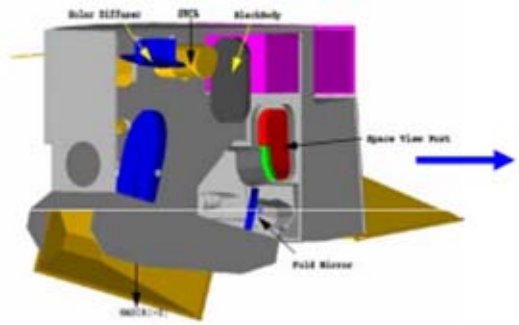
$$\Delta_{SD} = \frac{dc^{i}_{SD}/dc^{9}_{SD}}{dc^{i}_{Sun}/dc^{9}_{Sun}}$$

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

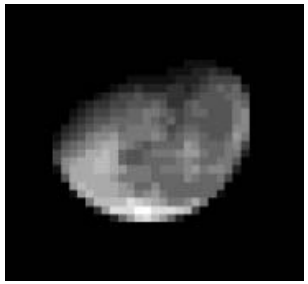
$\rho_{SD} \cdot cos(\theta_{SD}) =$ BRF, dn^{*}_{SD} = Signal from SD (temperature and background corrected), $\Delta_{SD} =$ SD degradation, $\Gamma_{SDS} =$ screen attenuation

RSB Lunar Calibration

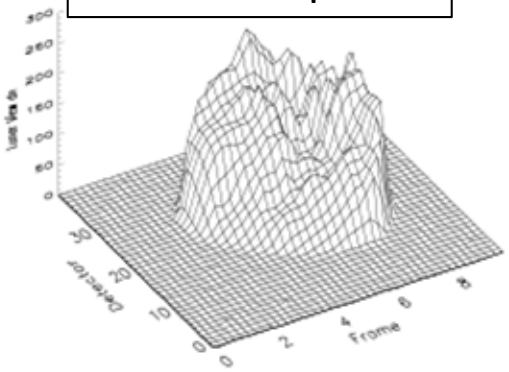
MODIS



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)

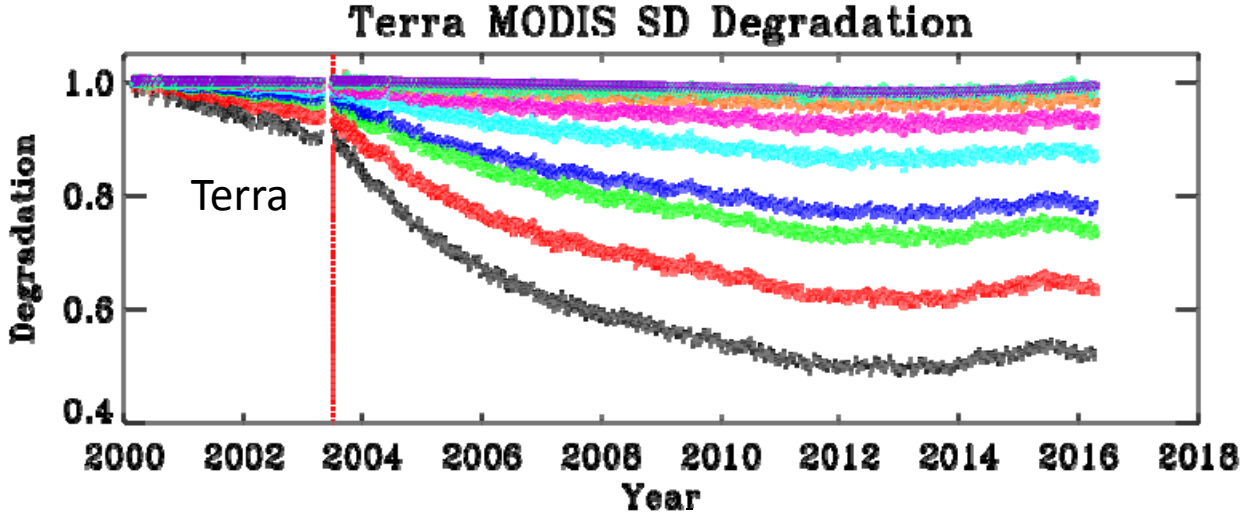
$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

View geometry correction

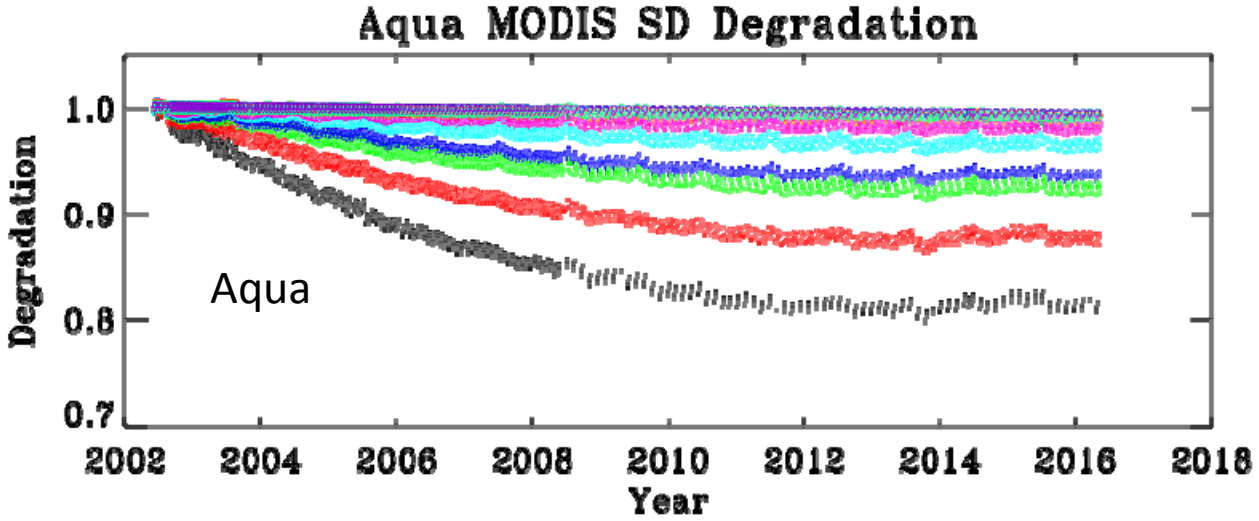
$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

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

MODIS SD Degradation

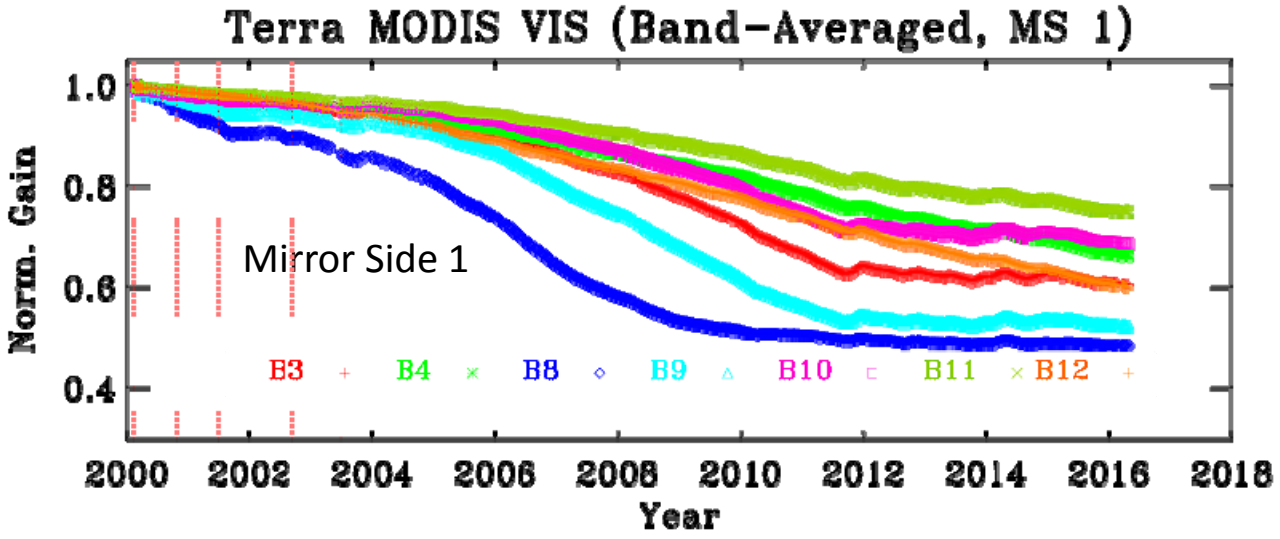


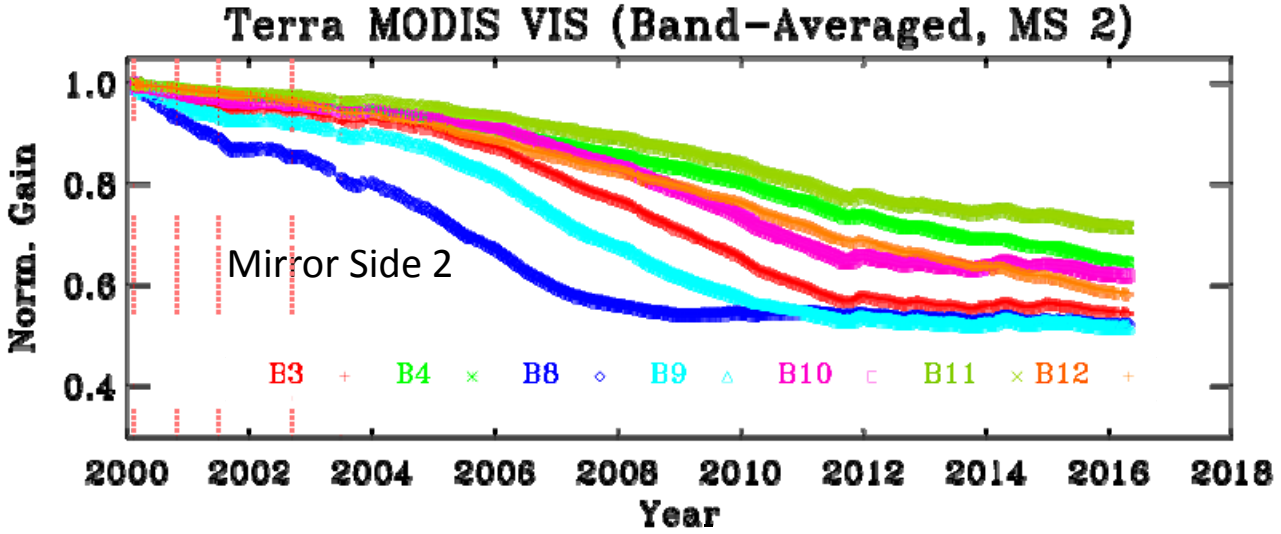
Increased degradation after SD door anomaly on July 2, 2003



Larger SD degradation at shorter wavelengths for both instruments

SD Gain Trending: Terra



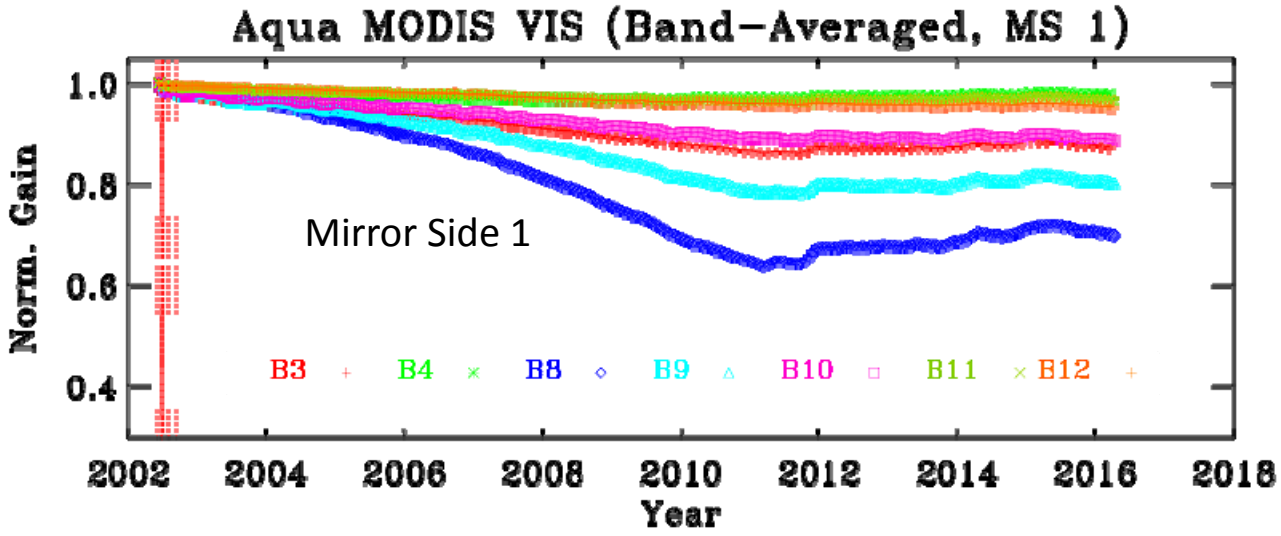


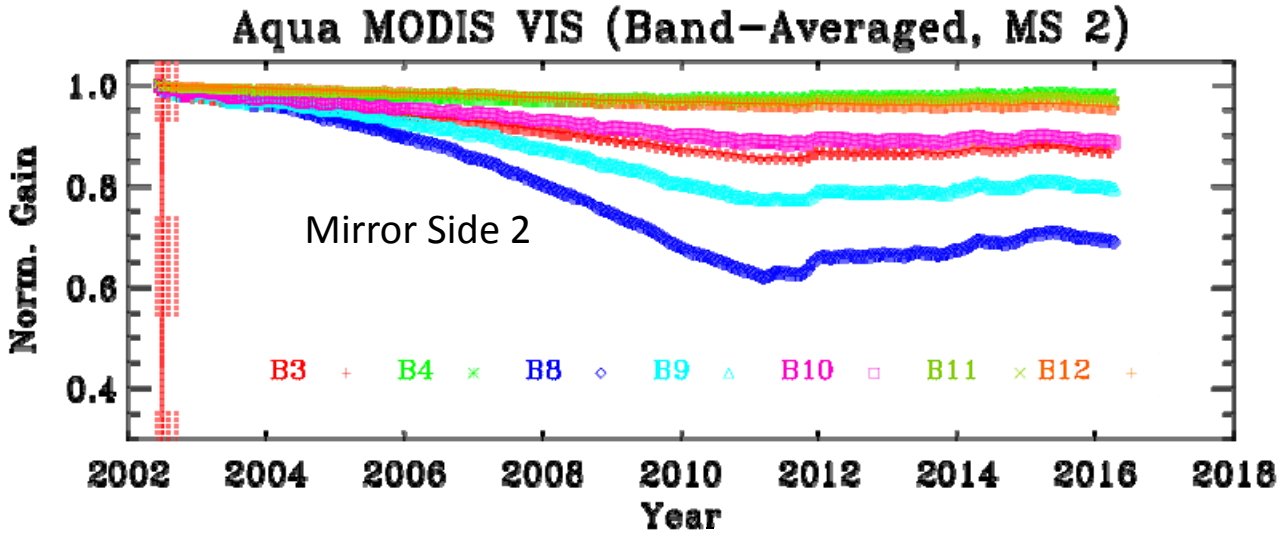
Most change observed for short-wavelength bands

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 3 - .469 µm)

SD Gain Trending: Aqua



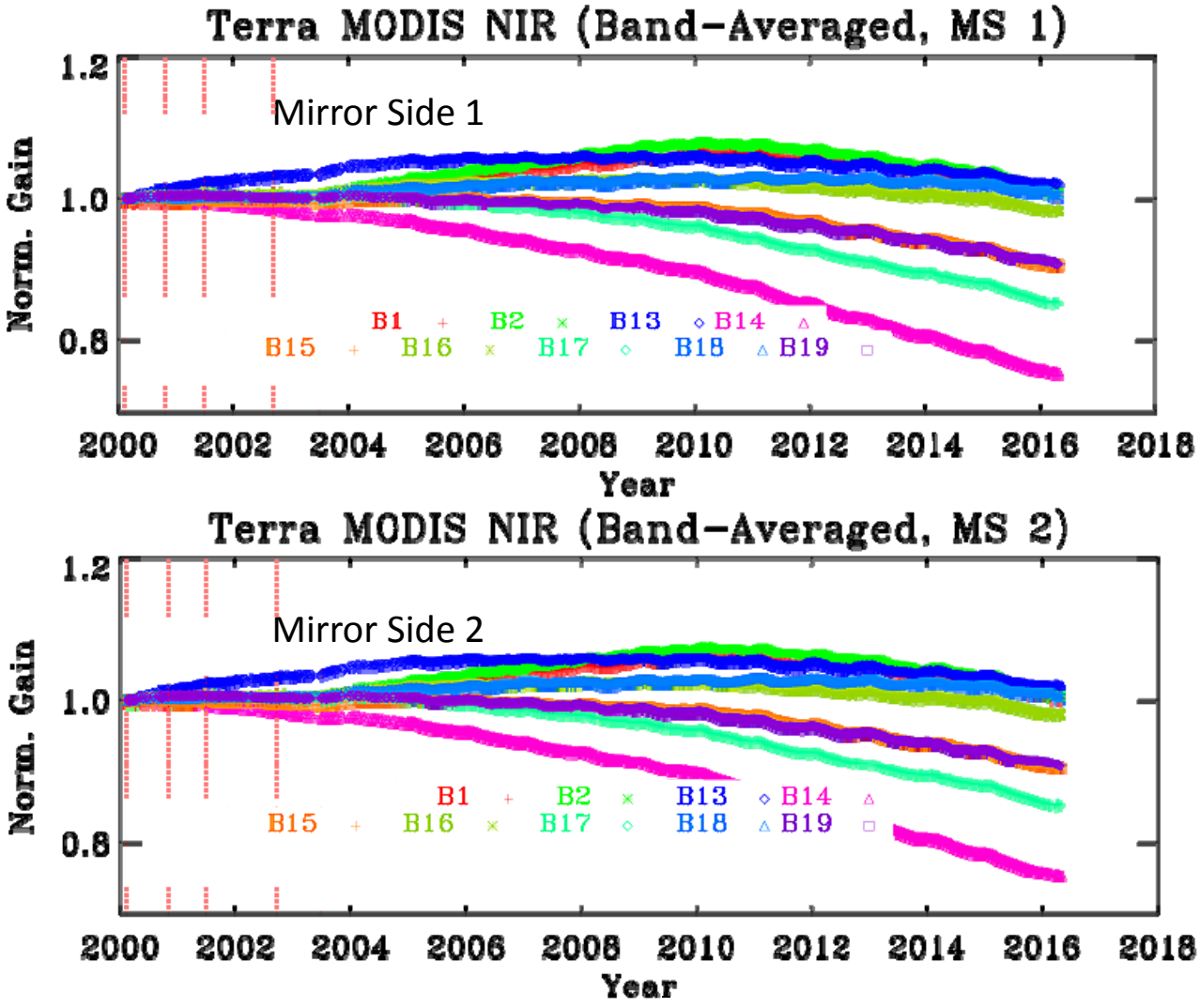


Most change observed for short-wavelength bands

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)

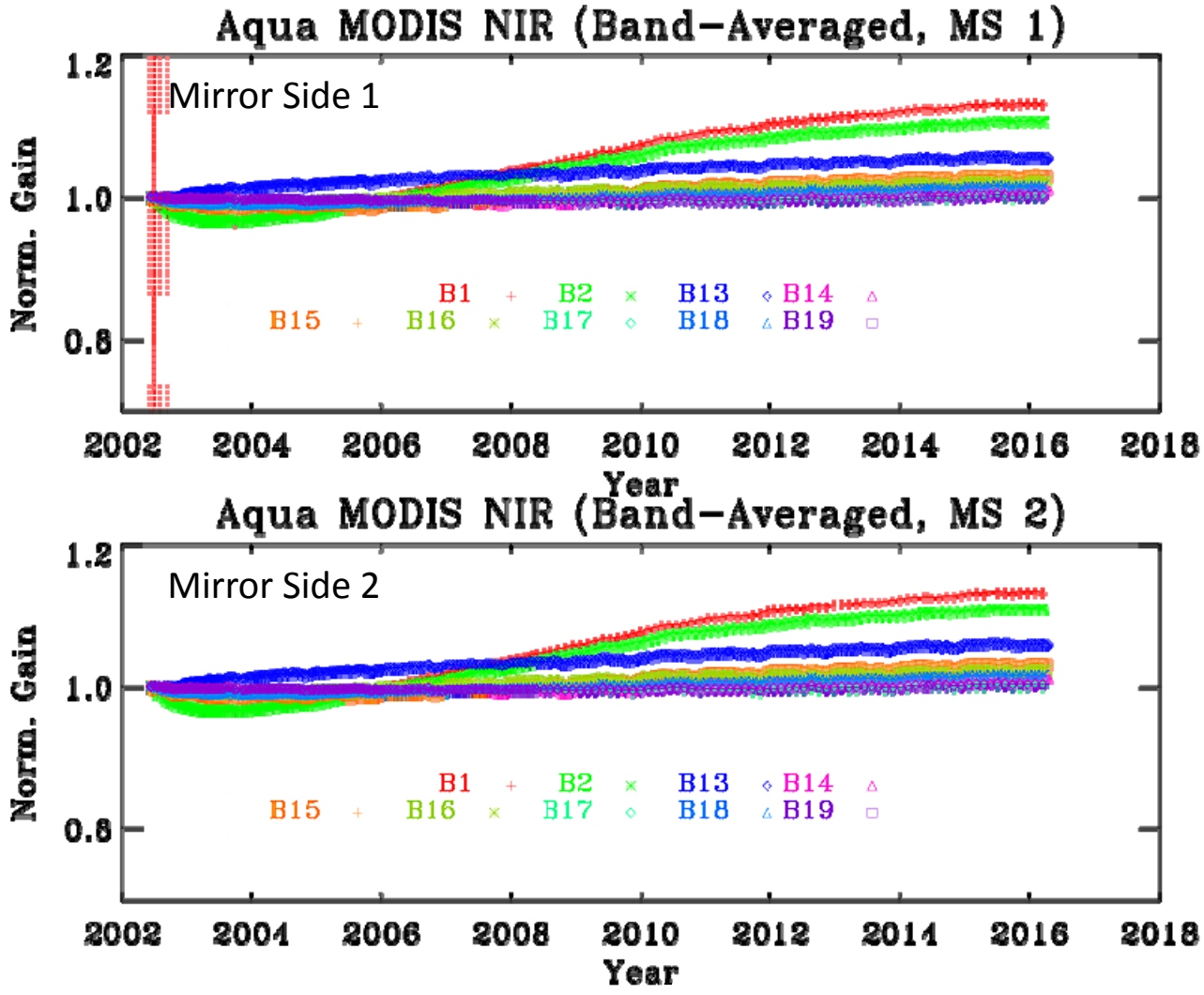
SD Gain Trending: Terra



Changes for most NIR bands are within 10%

Mirror-side differences are <1%

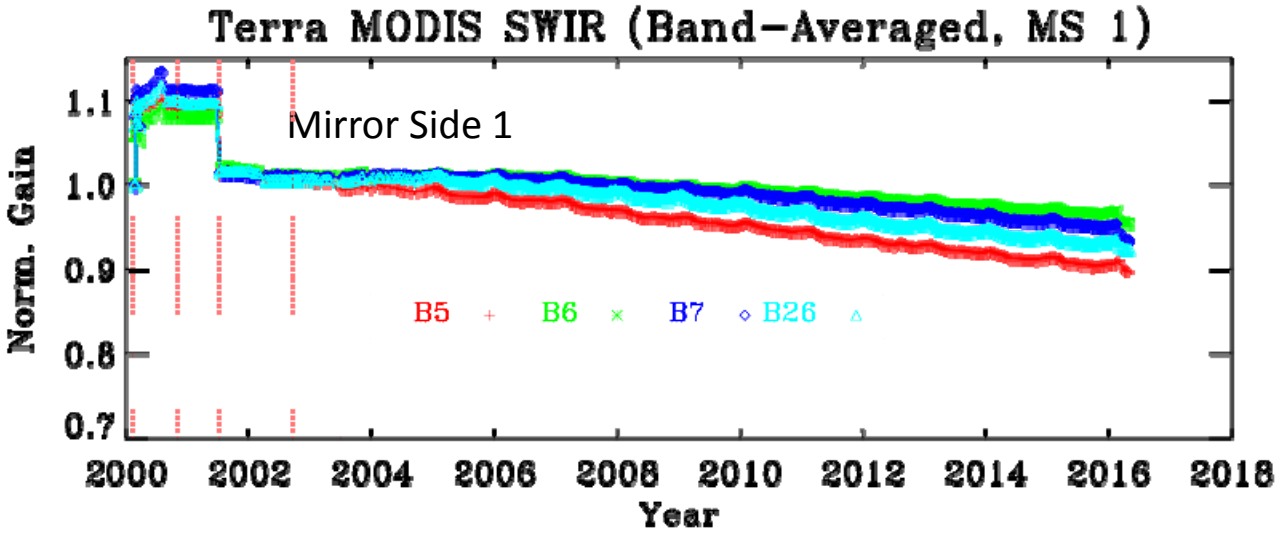
SD Gain Trending: Aqua

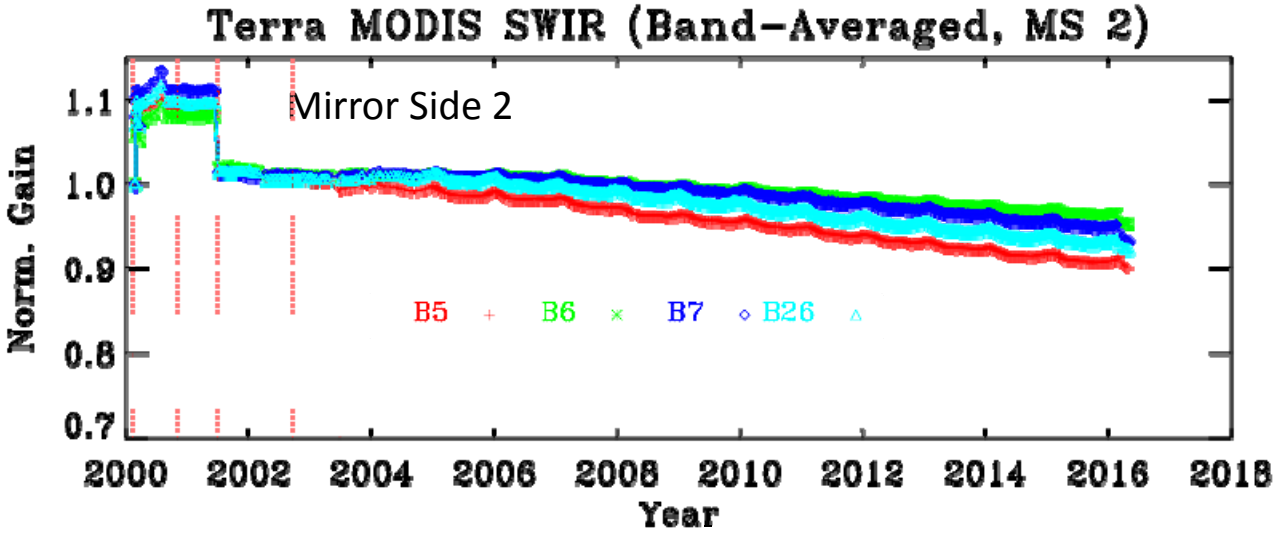


Changes for most NIR bands are within 6%

Mirror-side differences are <1%

SD Gain Trending: Terra



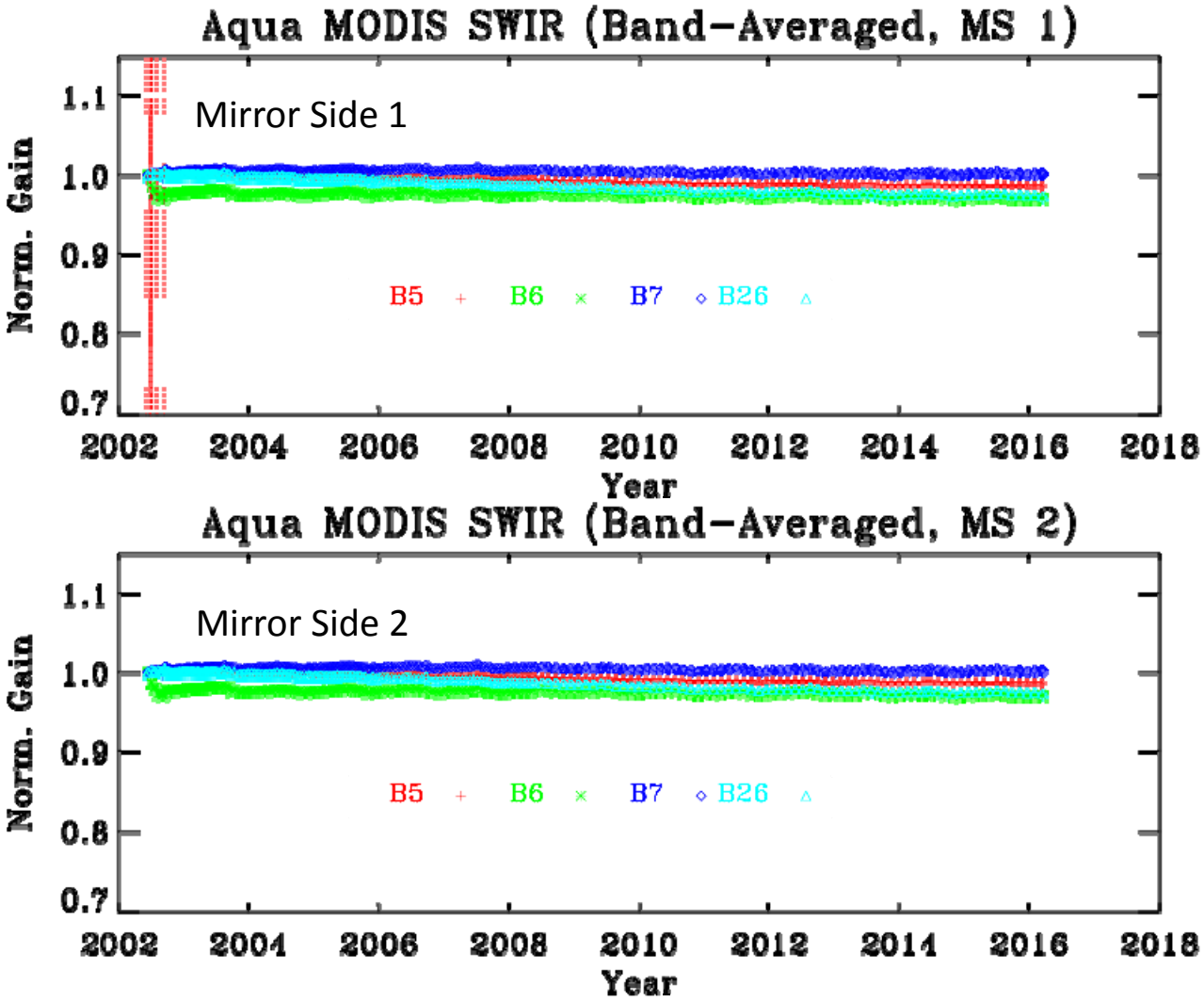


All SWIR bands change by < 10%

Mirror-side differences are <1%

* Noisy and inoperable detectors excluded

SD Gain Trending: Aqua

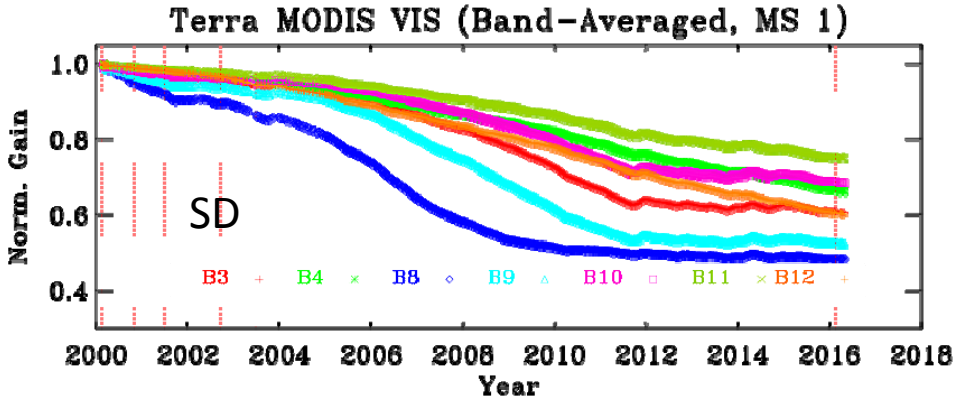


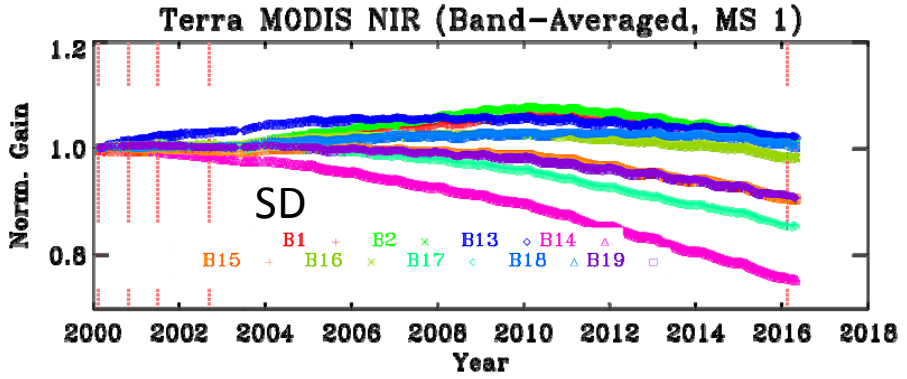
All SWIR bands change by < 3%

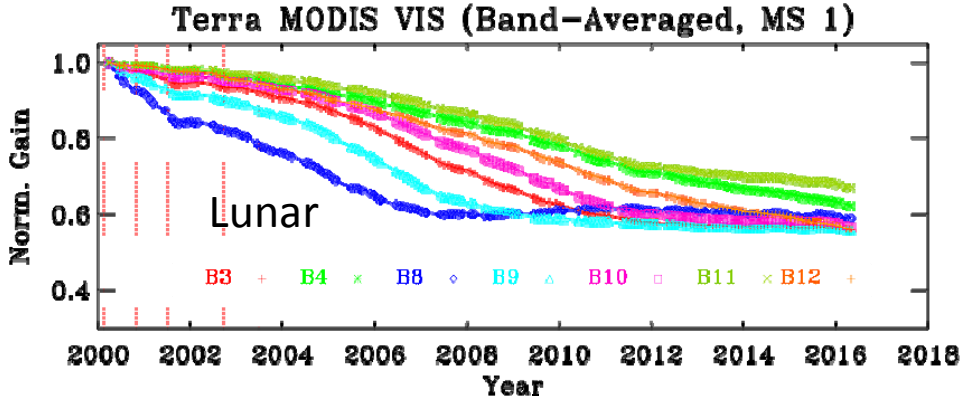
Mirror-side differences are <1%

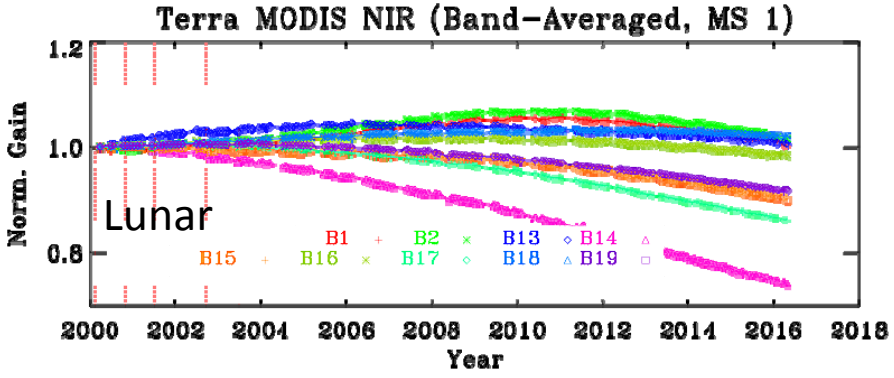
* Noisy and inoperable detectors excluded

Terra MODIS
SD & Lunar Gain Trending





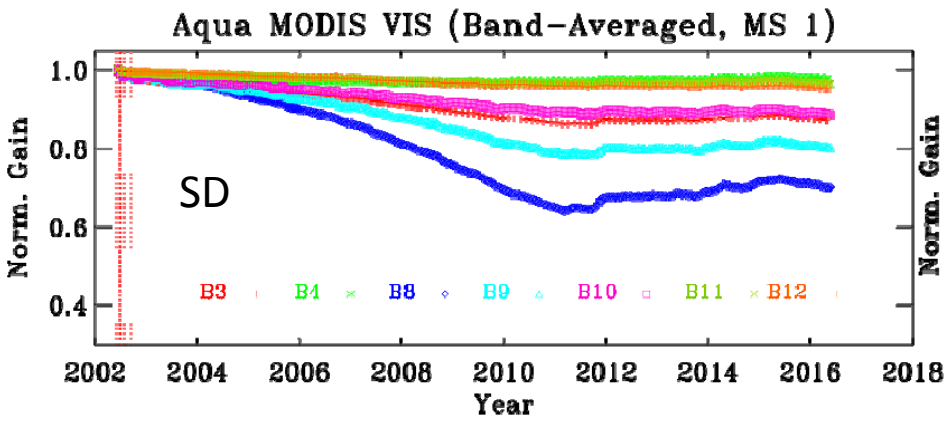


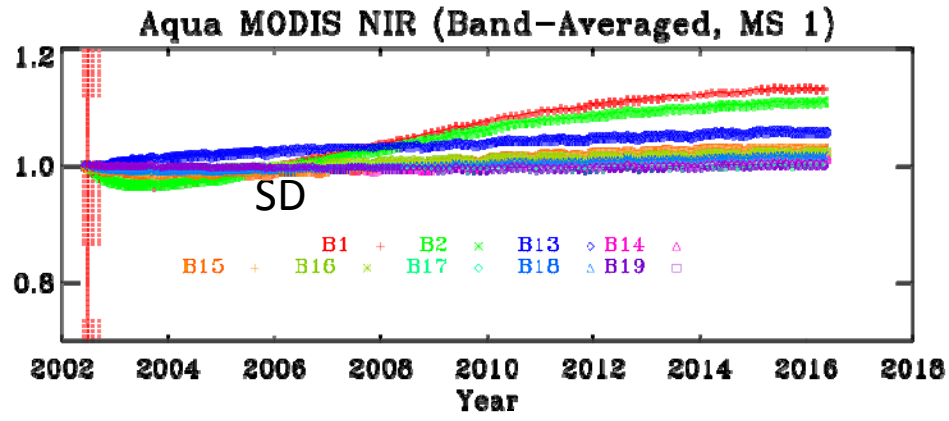


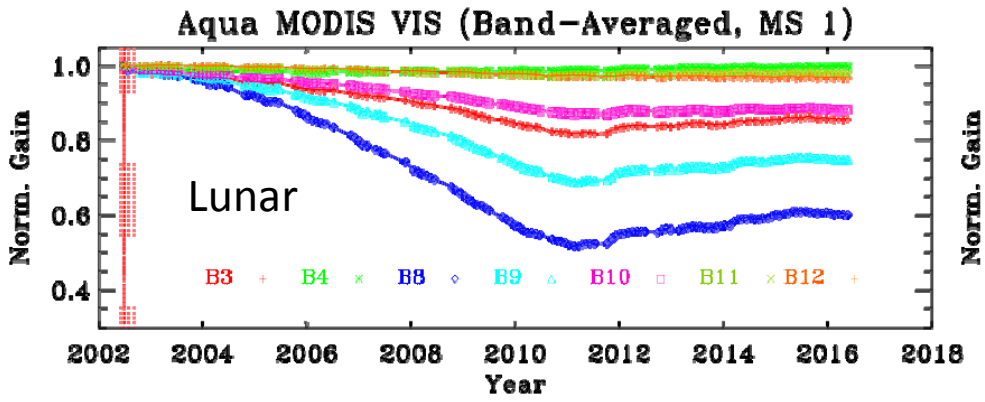
SD & Lunar measurements used to derive the on-orbit RVS change

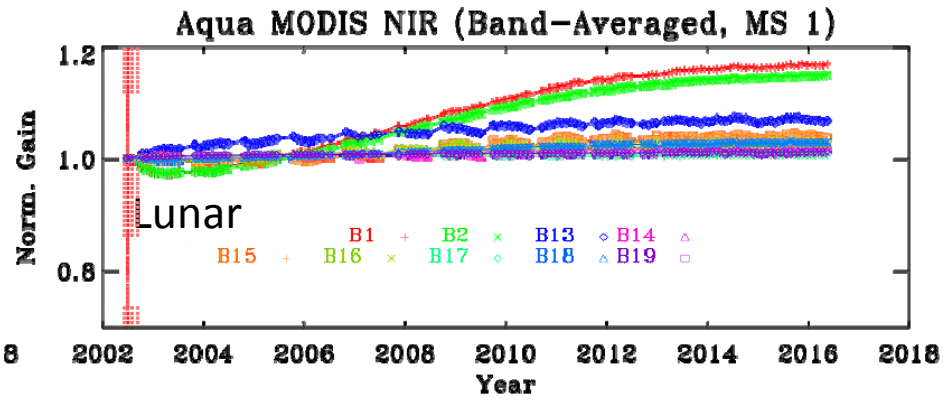
SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

Aqua MODIS
SD & Lunar Gain Trending









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

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

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, 8-9 and Aqua 8-9)
    - Applied to Terra Band 10, starting in July 2014 (with history unchanged)
    - Aqua Bands 1-4 EV-based RVS algorithm:
- Successful recovery from the Terra safe-mode event
  - RSB continue to perform nominally after the safe-mode
  - Noticeable gain changes (~2%) for the SWIR bands observed after the safe-mode event. VIS/NIR bands show changes < 1%
- 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%
- Challenges:
  - Degradation of the solar diffusers
  - Changes in the RVS
  - Impacts of polarization

MODIS TEB Performance

MCST Workshop at MST Meeting (June 6, 2016)

Outline

- Introduction of TEB On-orbit Calibration
- TEB Radiometric Performance
  - Telemetry temperatures trends
  - Detector gain coefficient trends
  - Detector NEdT trends and QA table
  - Uncertainty trending
- Impact of Recent Terra Safe Mode Anomaly
  - Increased b1 and NEdT (mostly for detectors of bands 27-30)
  - a0 and a2 recalibrated by BB WUCD, QA table updated
  - Negative radiance values in some band 27 L1B granules
- Summary

TEB Design Specifications

Band	CW	Ttyp	NEdT	UC (%)	UC (K)	Primary Use
20	3.75	300	0.05	0.75	0.18	Surface/cloud temperature
21	3.96	335	0.20	1	0.31	
22	3.96	300	0.07	1	0.25	
23	4.05	300	0.07	1	0.25	
24	4.47	250	0.25	1	0.19	Atmosphere temperature
25	4.52	275	0.25	1	0.24	
27	6.72	240	0.25	1	0.27	Water vapor
28	7.33	250	0.25	1	0.32	
29	8.55	300	0.05	1	0.53	Cloud properties
30	9.73	250	0.25	1	0.42	Ozone
31	11.03	300	0.05	0.5	0.34	Surface/cloud temperature
32	12.02	300	0.05	0.5	0.37	
33	13.34	260	0.25	1	0.62	Cloud top altitude
34	13.64	250	0.25	1	0.59	
35	13.94	240	0.25	1	0.55	
36	14.24	220	0.35	1	0.47	

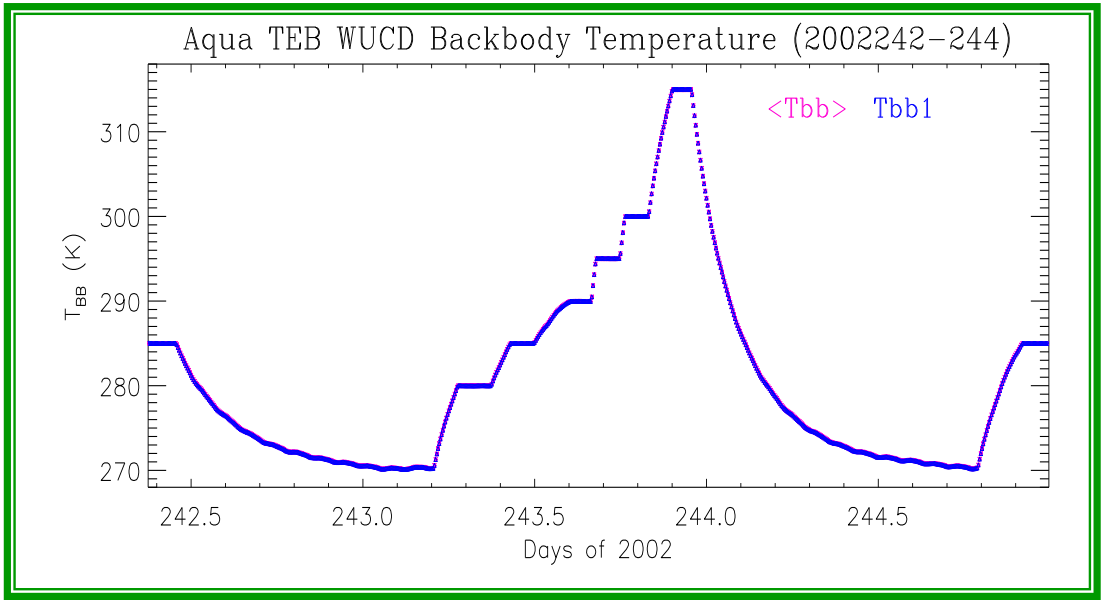
CW: center wavelength in micron;
Ttyp: typical scene temperature in K;
NEdT: noise equivalent temperature difference in K

On-orbit Calibration Methodologies

EV Radiance: $$L_{EV} = \frac{1}{RVS_{EV}}\left(a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 - \left(RVS_{SV} - RVS_{EV}\right) \cdot L_{SM}\right)$$

Calibration Coefficients:

$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$



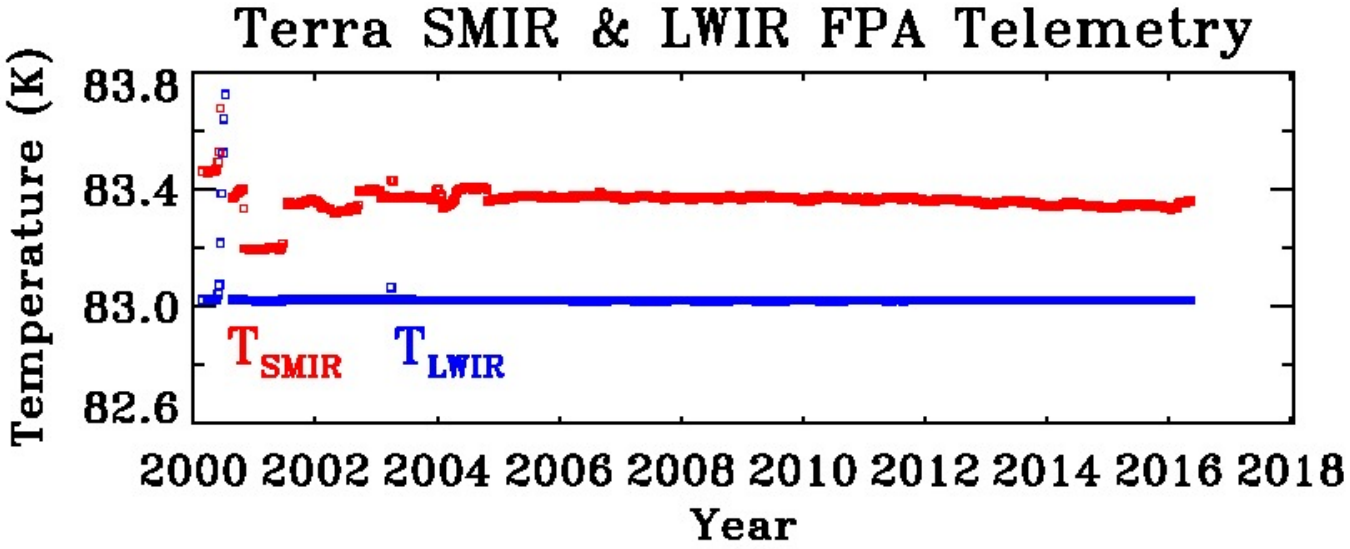
RVS: response versus scan-angle
e: emissivity
***L*: spectral band integrated radiance**
***dn*: digital count with background corrected**
a0 & a2: non-linear gain coefficients
b1: linear gain coefficient

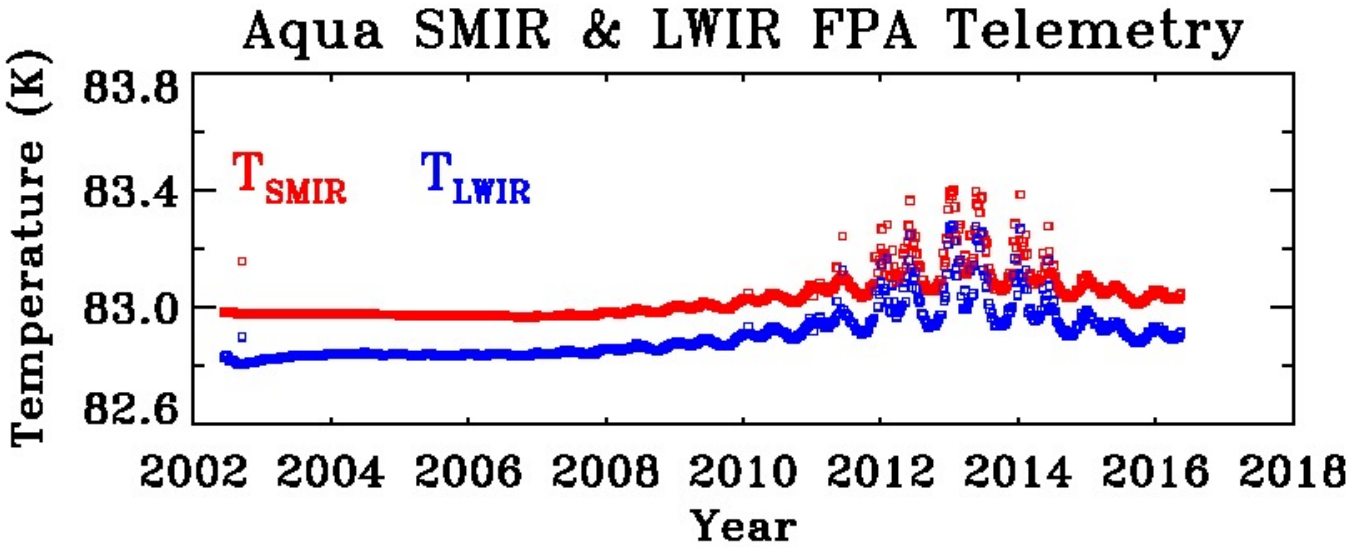
WUCD T_{BB}: ~270 K to 315 K

On-orbit Calibration Methodologies

- Regular BB Calibration
  - Compute linear gain coefficient b1 on a scan-by-scan basis; 40-scan running average used to generate L1B product
- Periodic BB Warm-up and Cool-down (WUCD) Activities
  - Compute nonlinear gain coefficients a0 and a2
  - Derive fixed linear gain coefficients b1 for band 21
- Special Calibration Issues
  - Characterization of RVS
  - Aqua CFPA temperature fluctuation
  - Aqua default b1 and EV image saturation for bands 33, 35 and 36
  - Terra PC (bands 32-36) and PV (bands 27-30) crosstalk
  - Uncertainty
- Calibration Stability Monitoring (Results Not Covered)
  - EV scene (Dome C, Ocean, etc.)
  - Lunar surface

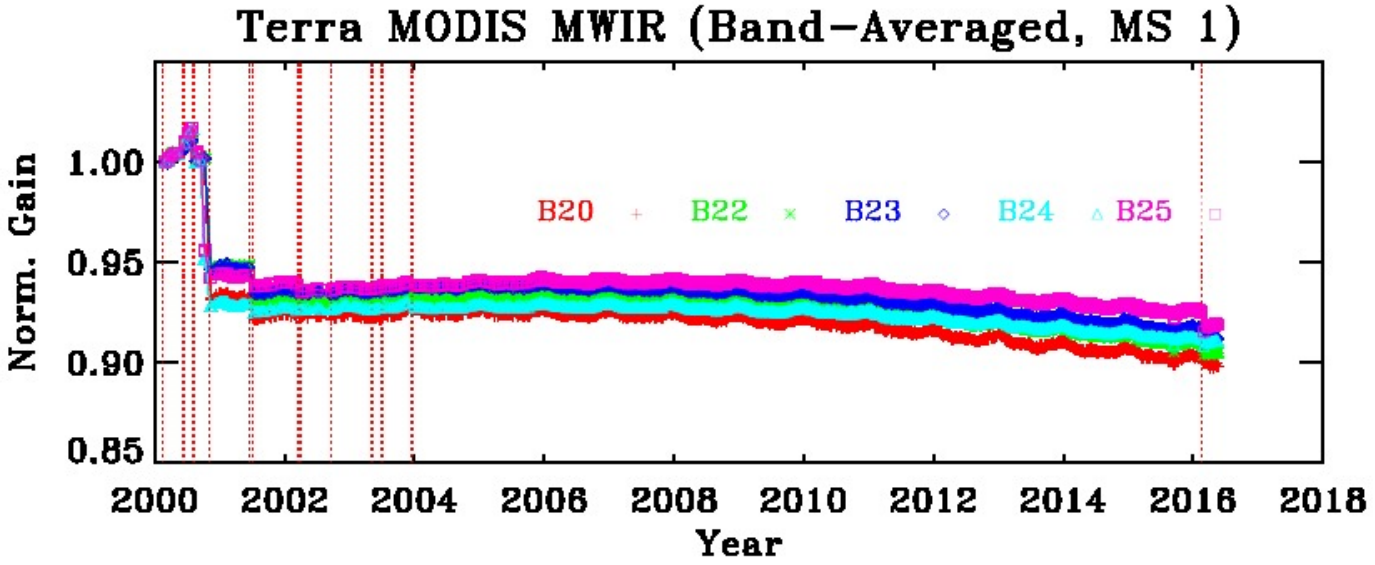
Key Telemetry Temperatures

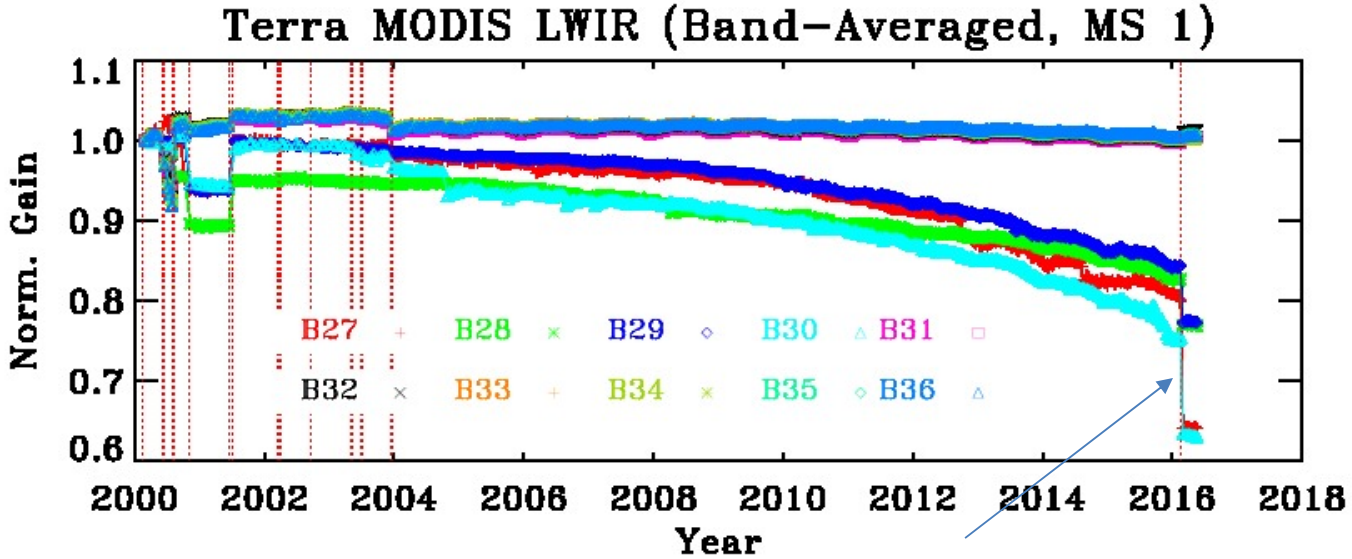




Weekly averaged mitigating CFPA temperature fluctuation

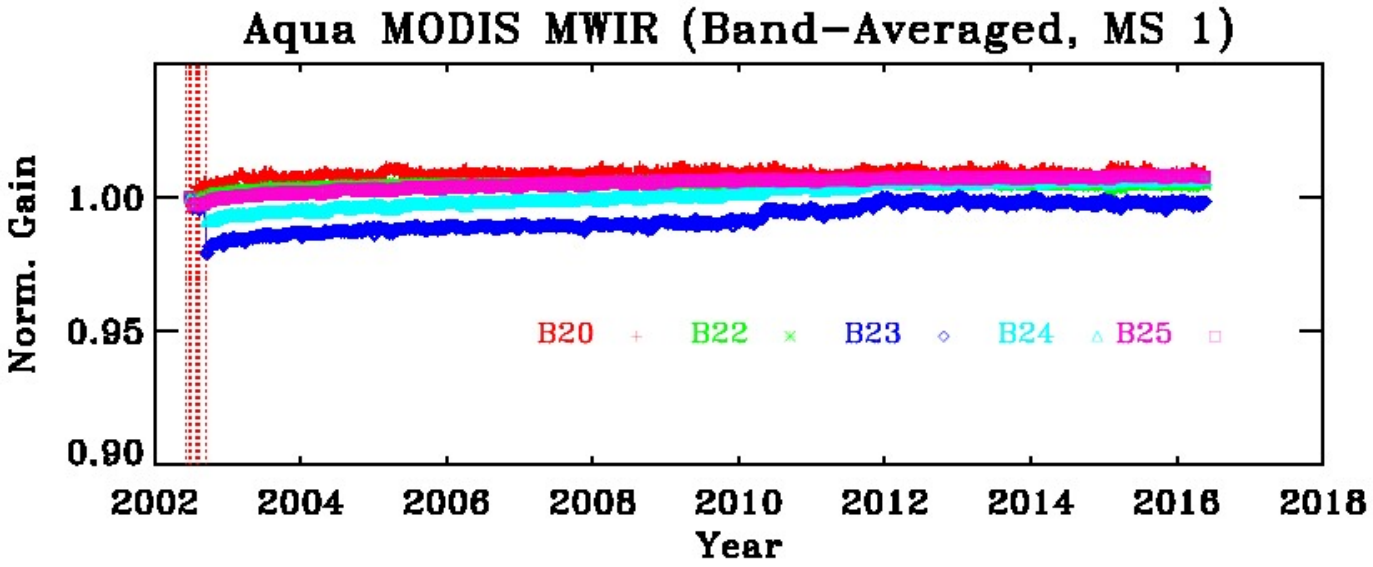
Terra TEB Gain Trending

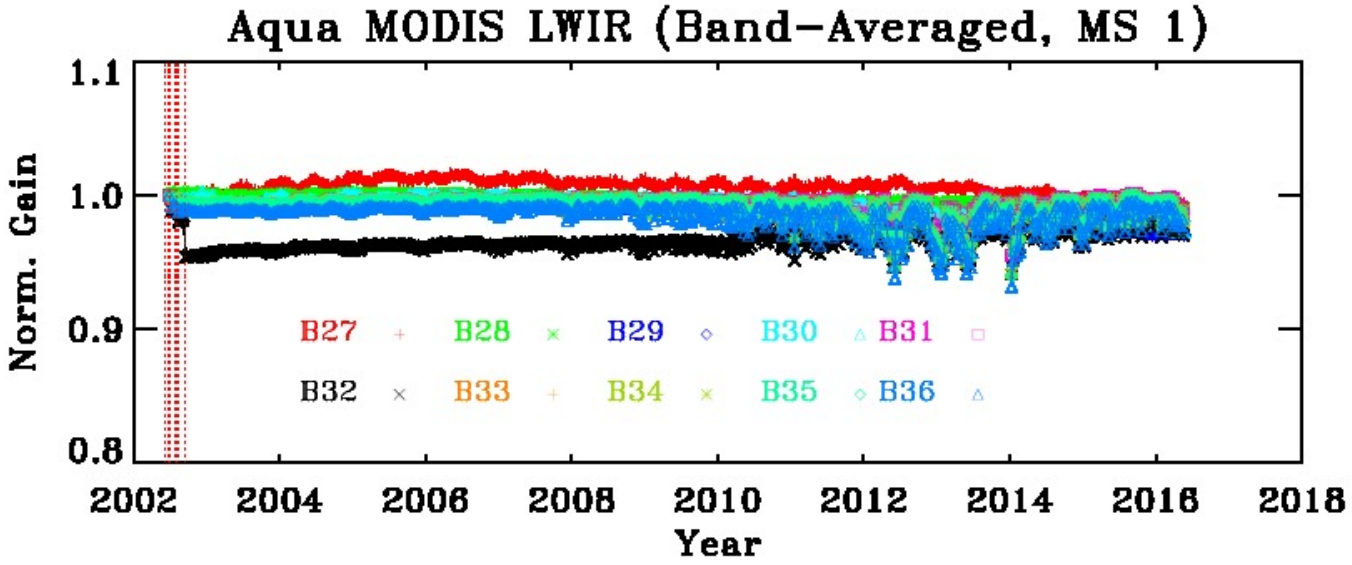




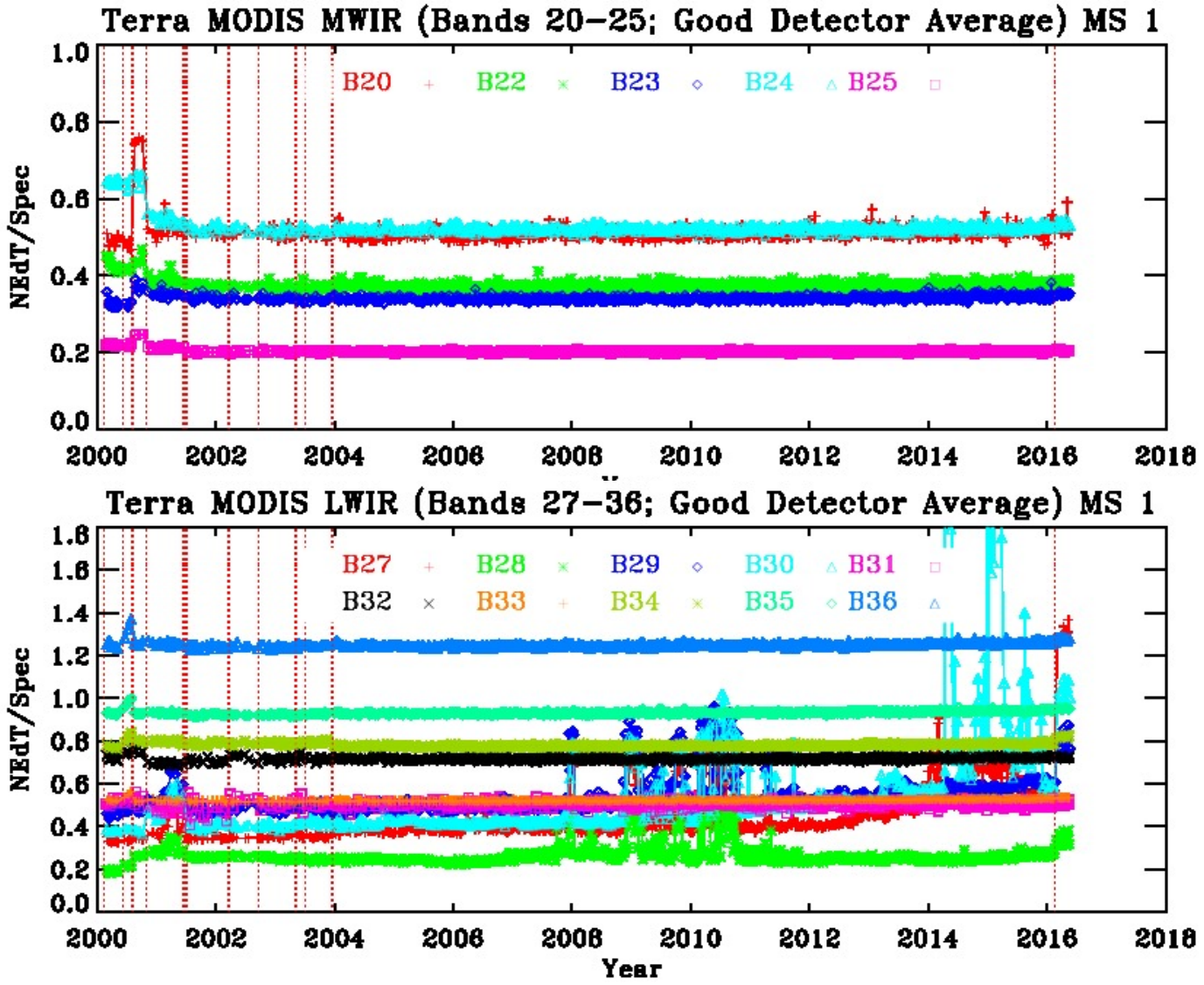
Terra safe mode anomaly 2016049-2016055

Aqua TEB Gain Trending



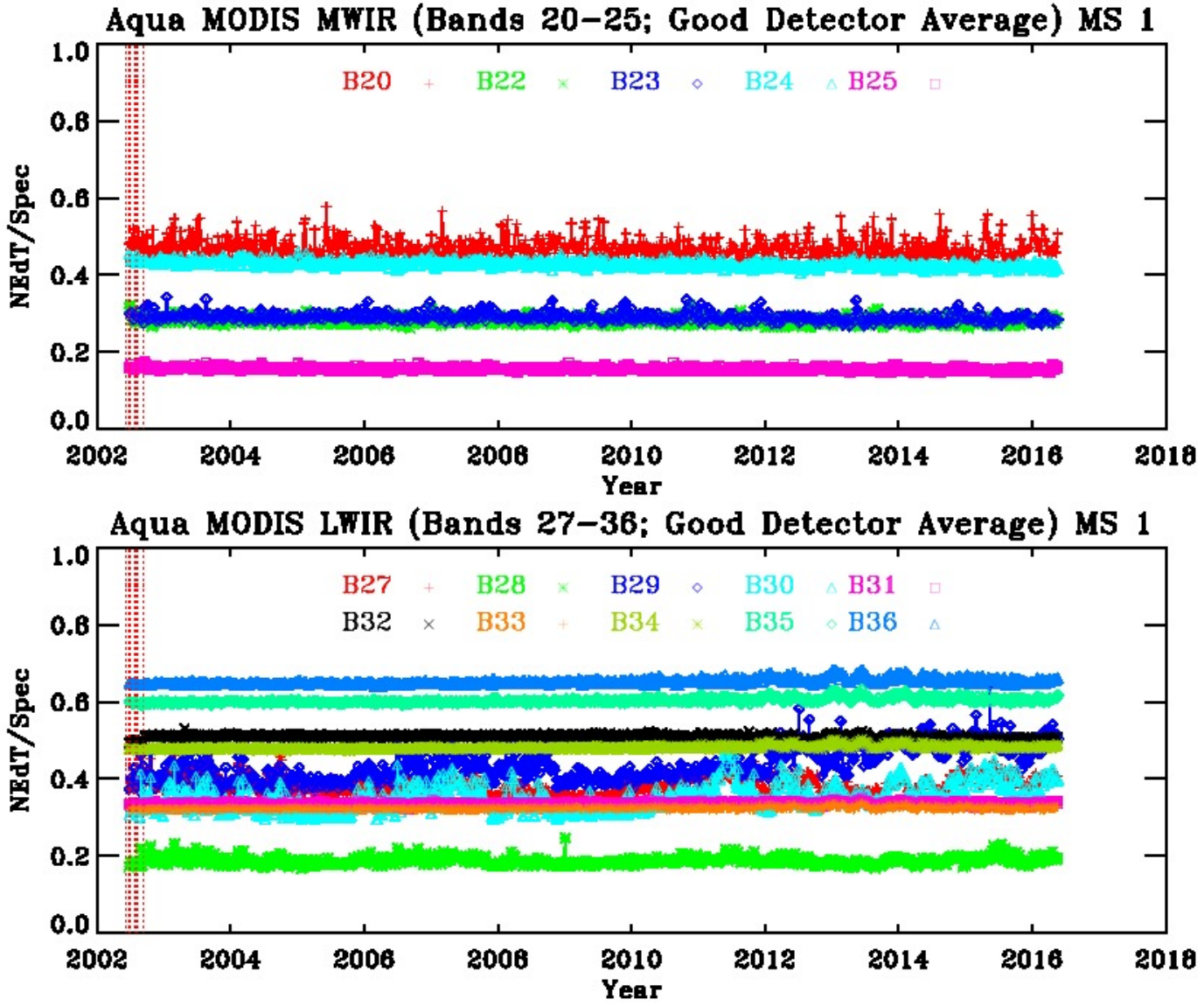


Terra TEB Noise Trending & QA



QA: noisy detector: 31 (5 new); inoperable detector: 4 (1 new)

Aqua TEB Noise Trending & QA

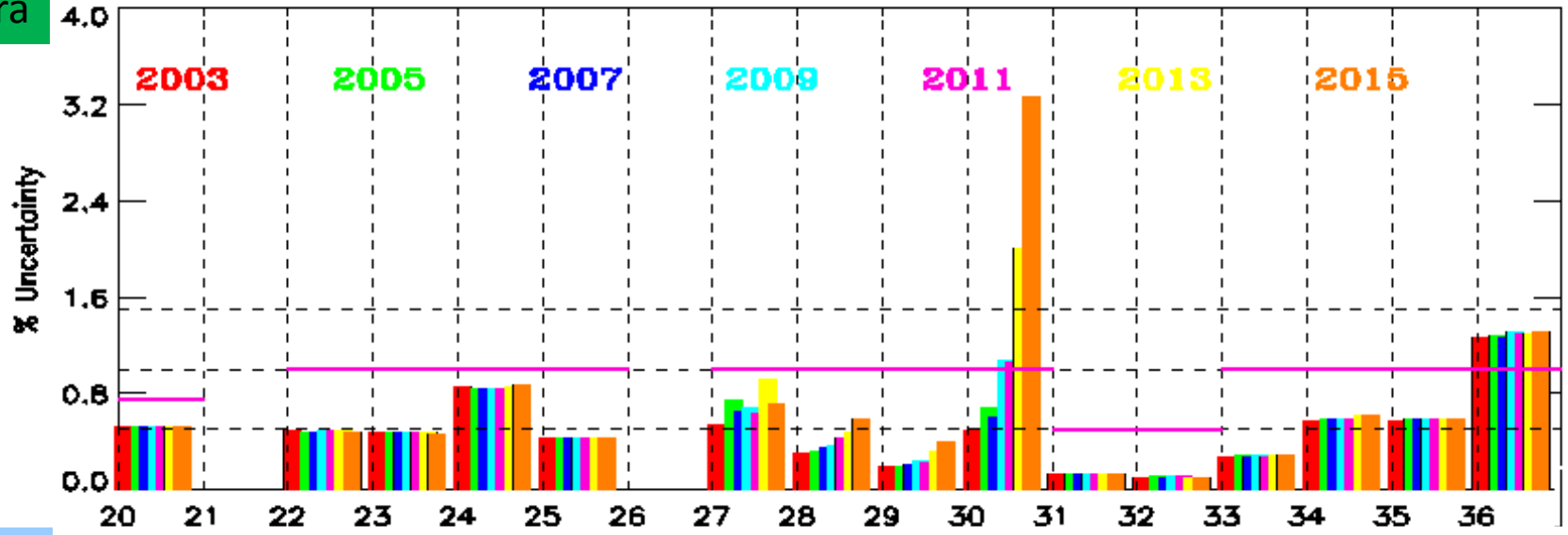


QA: noisy detector: 7; inoperable detector: 1

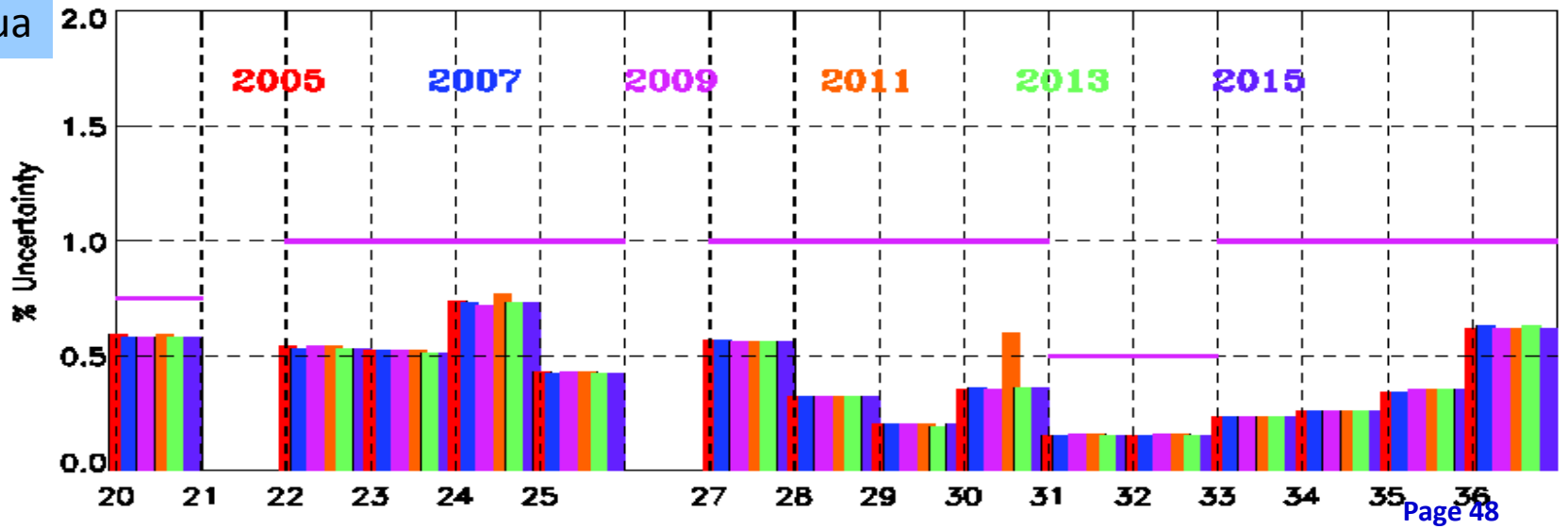
TEB Yearly Uncertainty Trend

Uncertainty evaluated at L_{typ} and at 'nadir' AOI

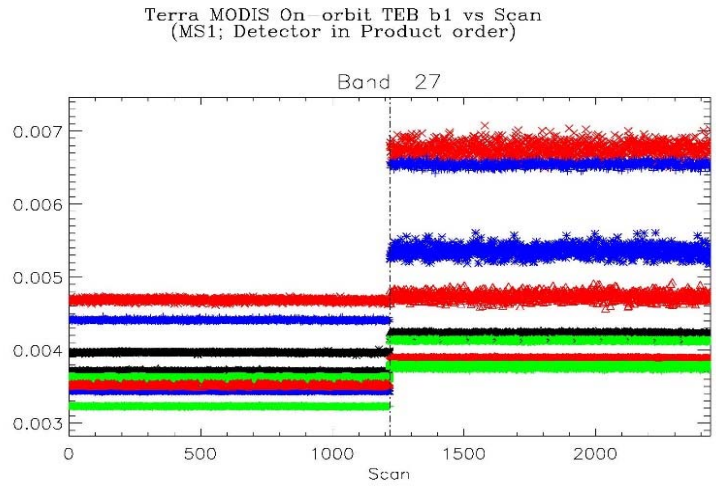
Terra

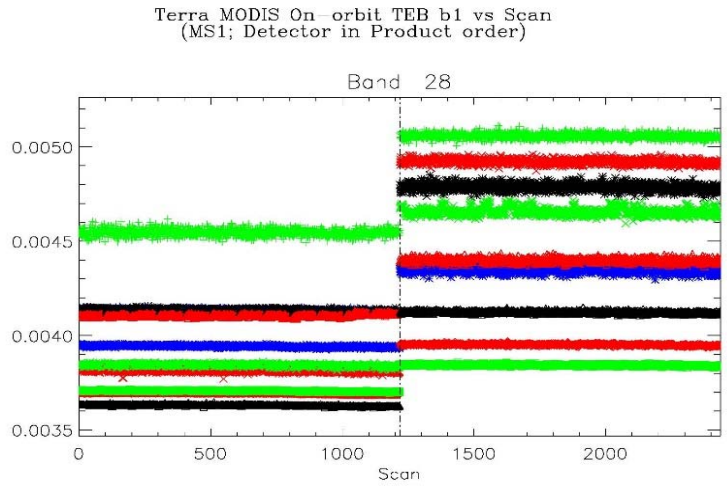


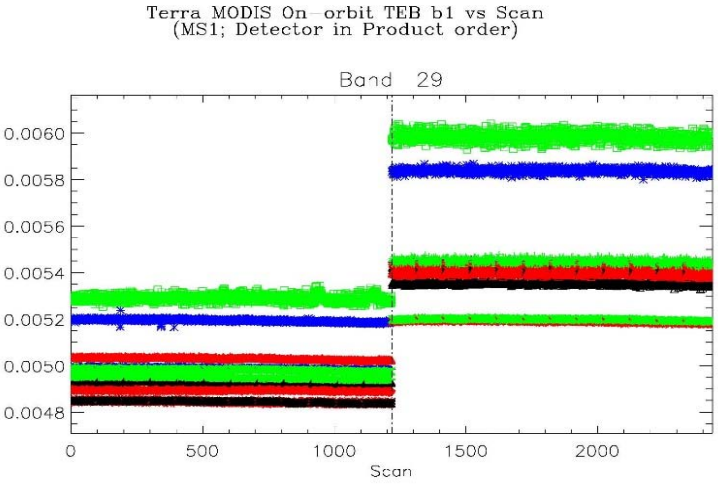
Aqua

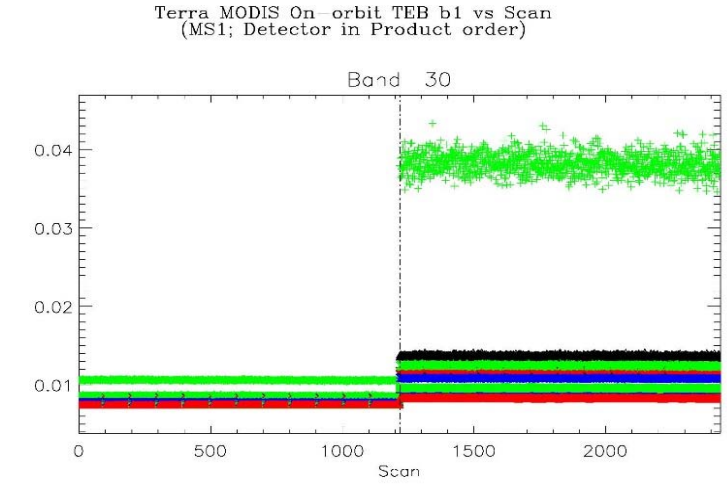


b1 Before and After the Safe Mode





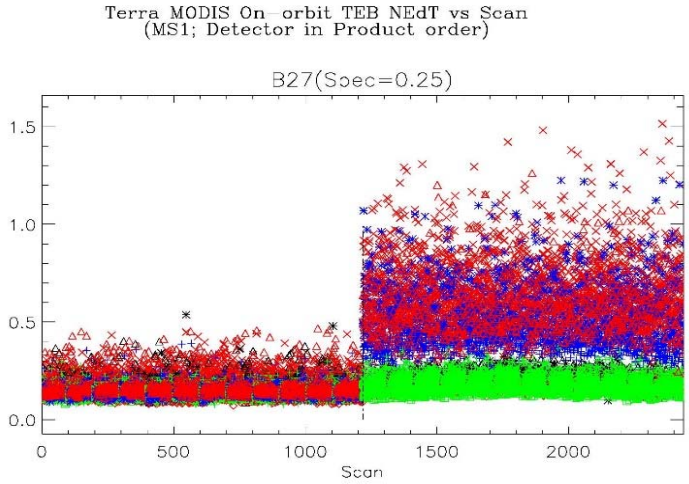


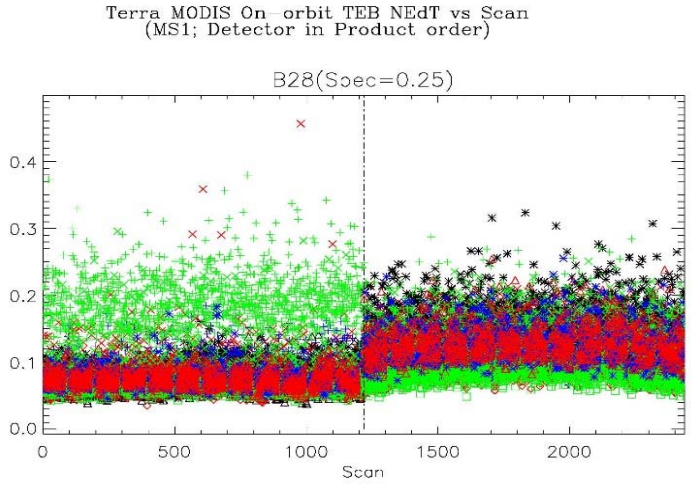


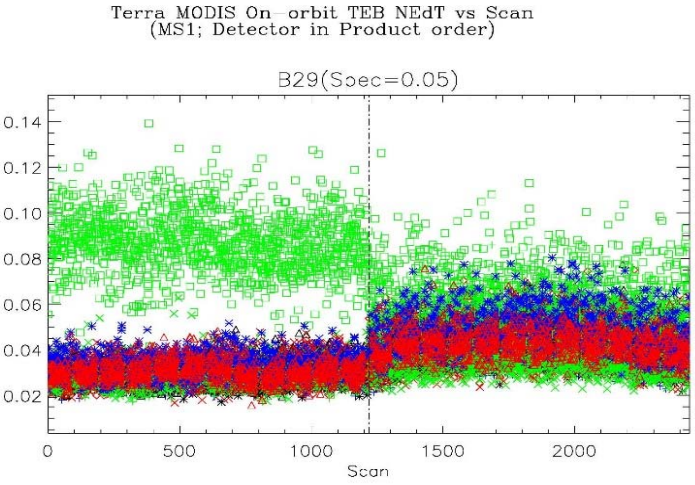
Ch1:Rec x Ch2:Blu + Ch3:Blk * Ch4:Blk Δ Ch5:Rec ◇ Ch6:Grn □ Ch7:Grn x Ch8:Grn + Ch9:Blu * Ch10:Red Δ
Data collected time:P2016049.1050-P2016049.1145;P2016068.1745-P2016068.1840
ltwk/Vdet = 79/190

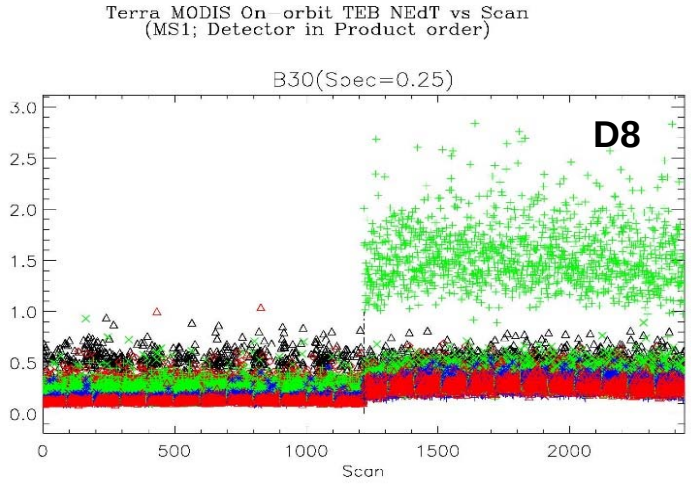
Ch1:Rec x Ch2:Blu + Ch3:Blk * Ch4:Blk Δ Ch5:Rec ◇ Ch6:Grn □ Ch7:Grn x Ch8:Grn + Ch9:Blu * Ch10:Red Δ
Data collected time:P2016049.1050-P2016049.1145;P2016068.1745-P2016068.1840
ltwk/Vdet = 79/190

NEdT Before and After the Safe Mode

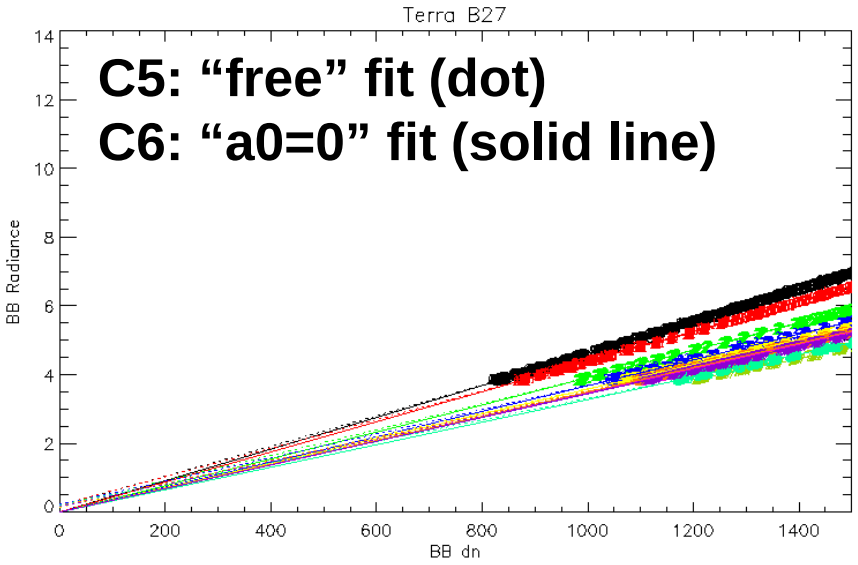


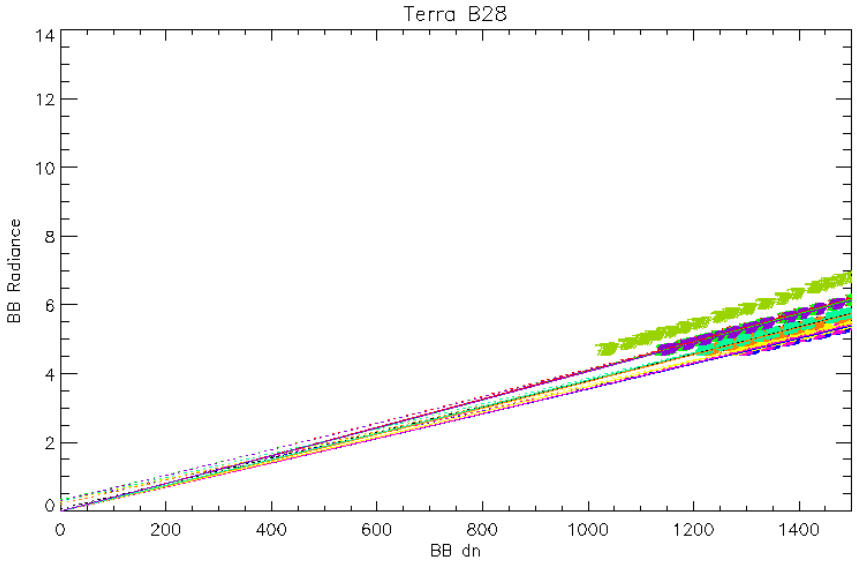


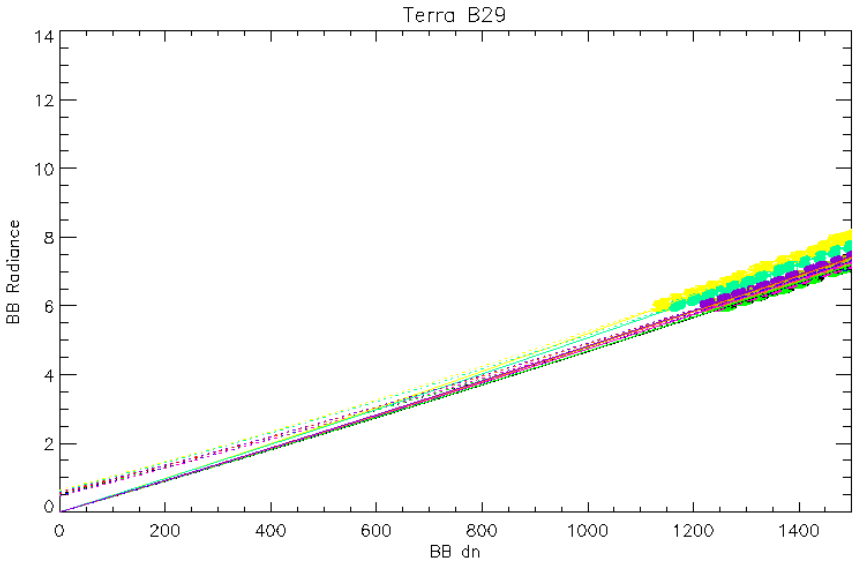


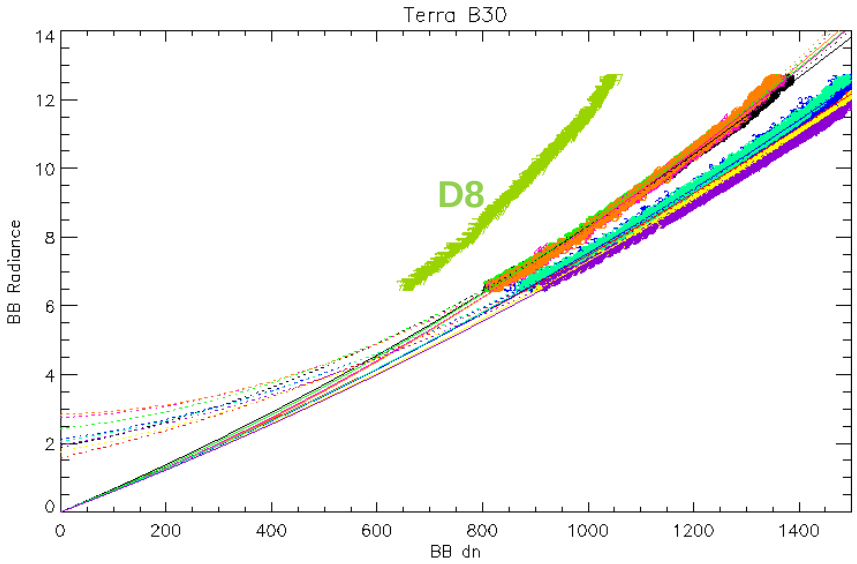


a0/a2 Fitting Before the Safe Mode

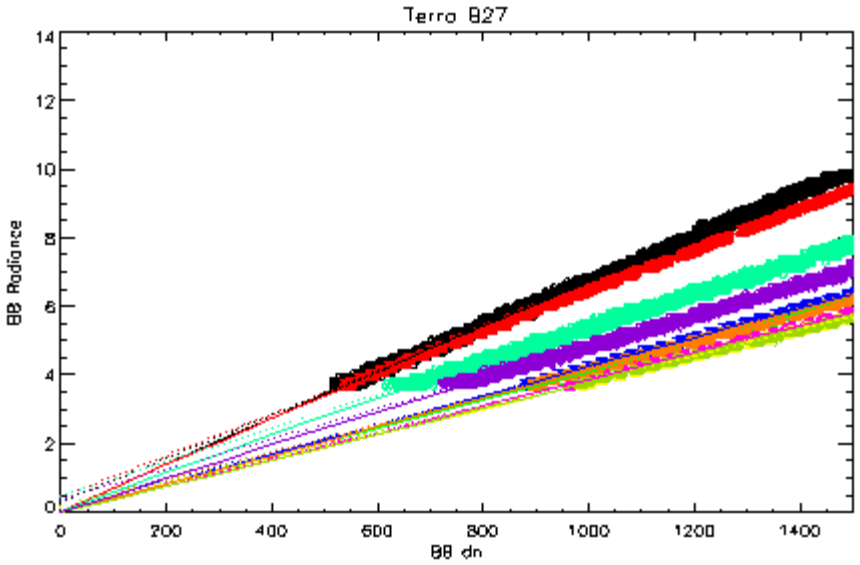


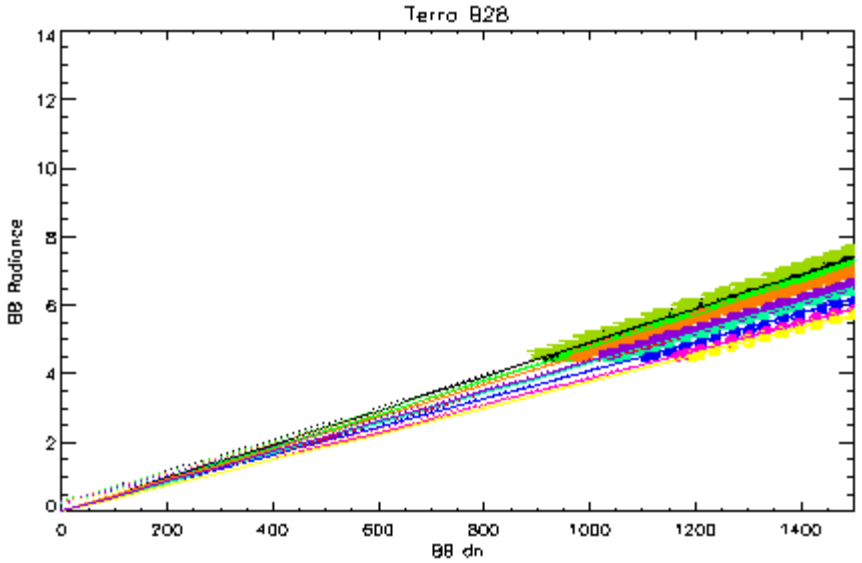




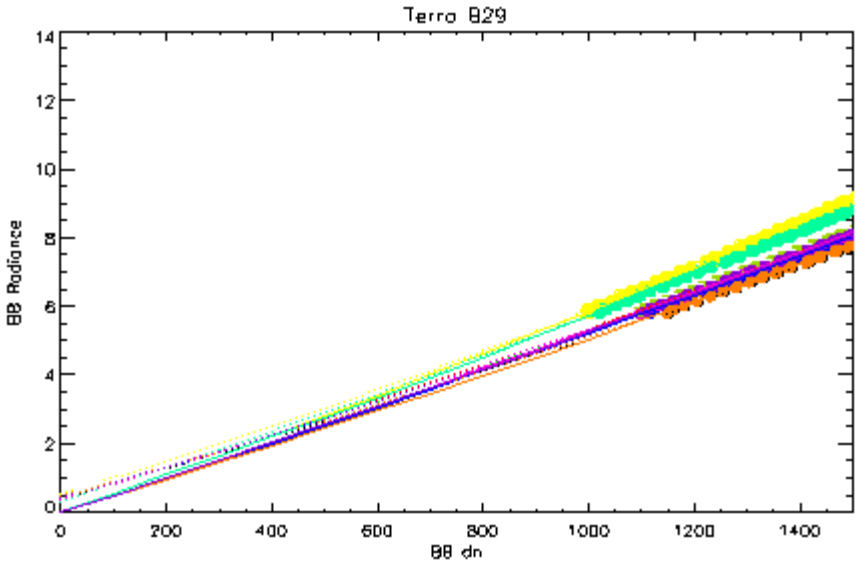


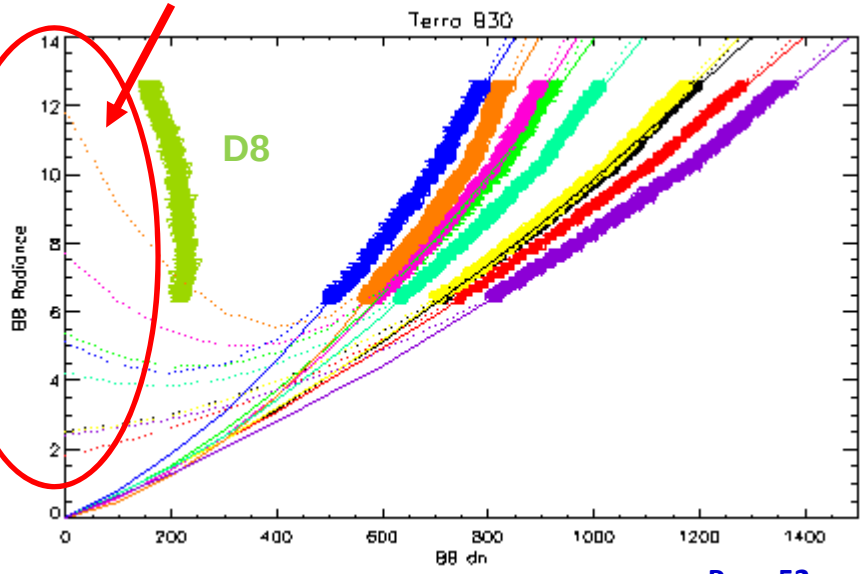
a0/a2 Fitting After the Safe Mode





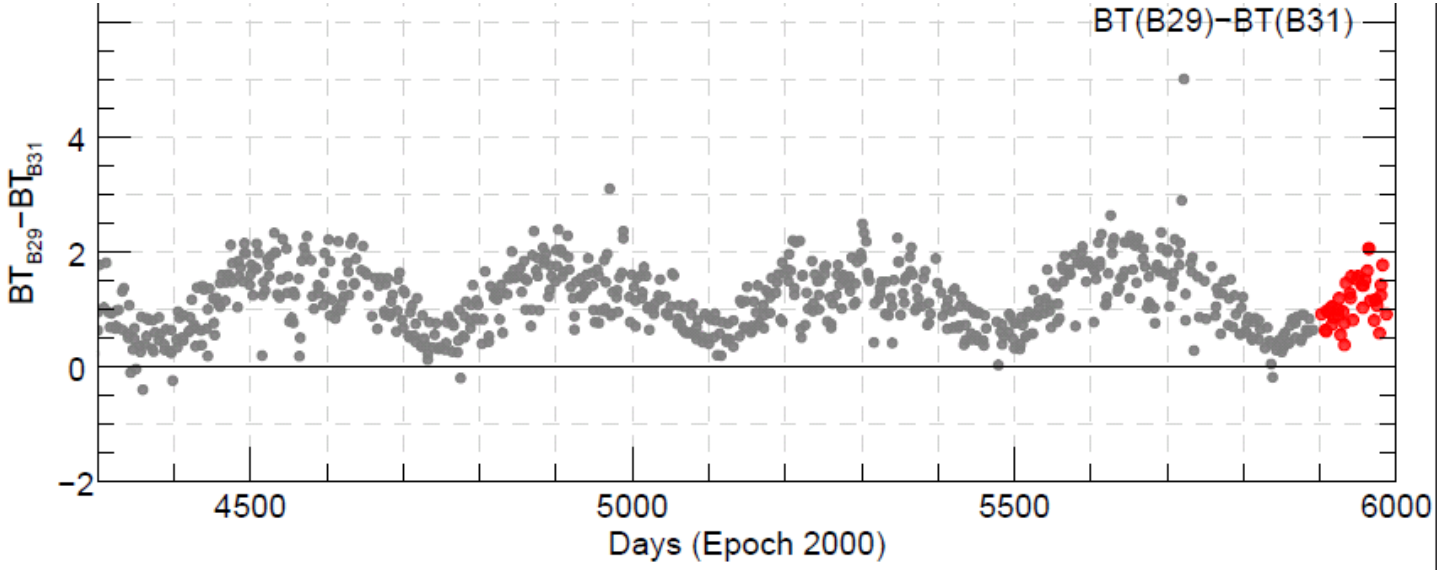
a0 from ‘free’ fit is too large in C5

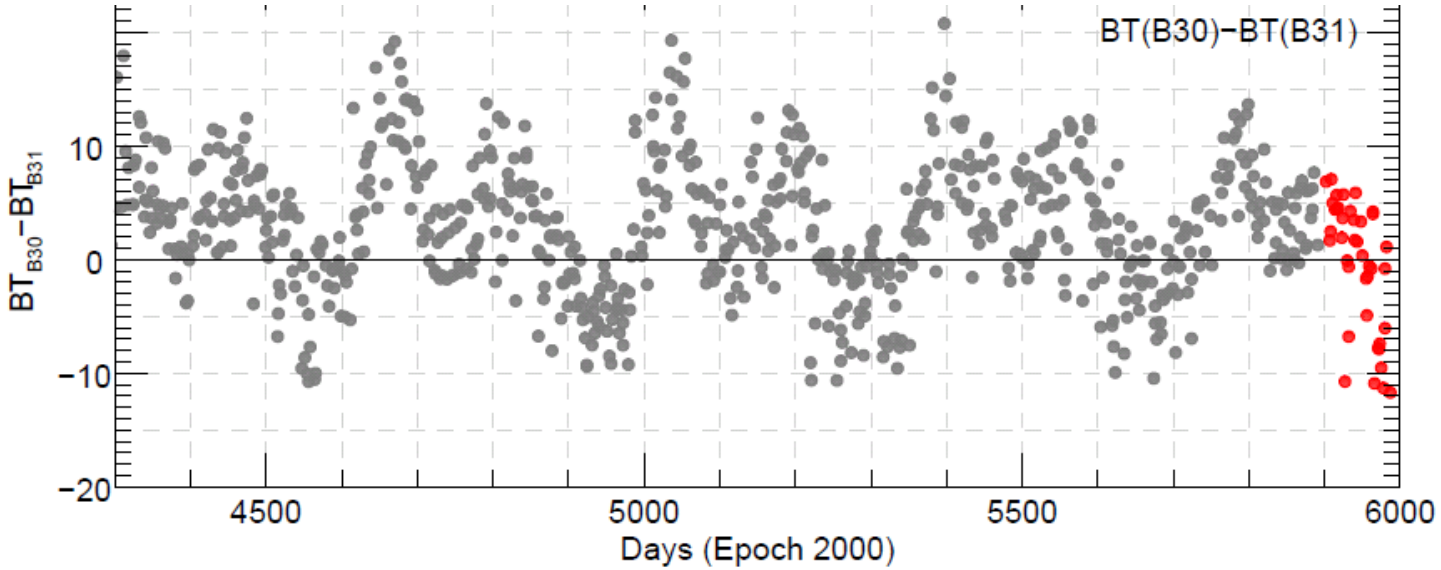




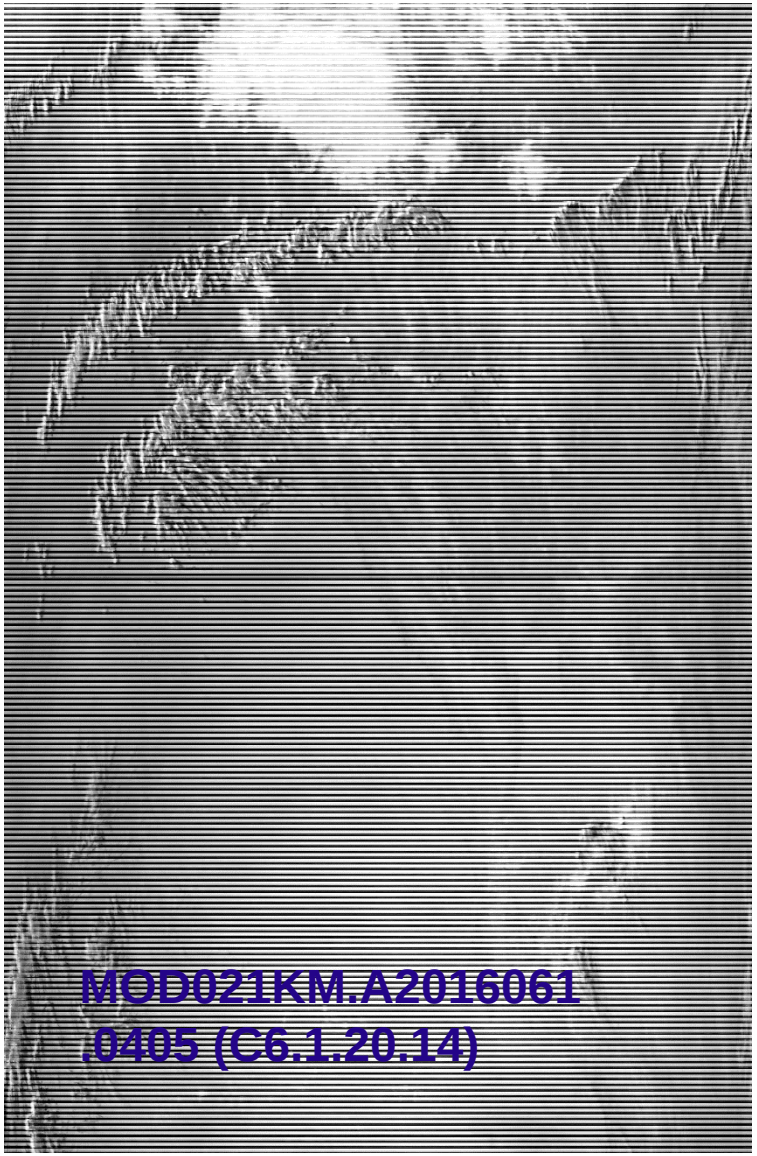
a0, a2 for band 30 (C5): ‘free’ fit -> ‘a0=0’ fit

Initial Assessment of L1B Product

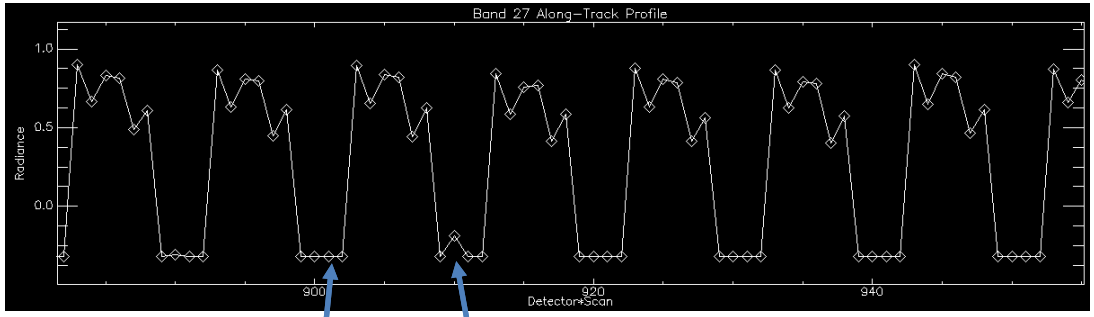




Band 27 Image Negative Radiance



At low radiance, detectors 1, 2, 9 and 10 of band 27, which are flagged noisy in C6 QA (delivered after the safe-mode anomaly), show negative radiance for several earth-scene images



The phenomenon has been presented and discussed at a MsWG meeting. Agreed to continuously flag these detectors as noisy since they work well at higher radiance

These detectors could be flagged as inoperable if the impact is significant on the downstream science products

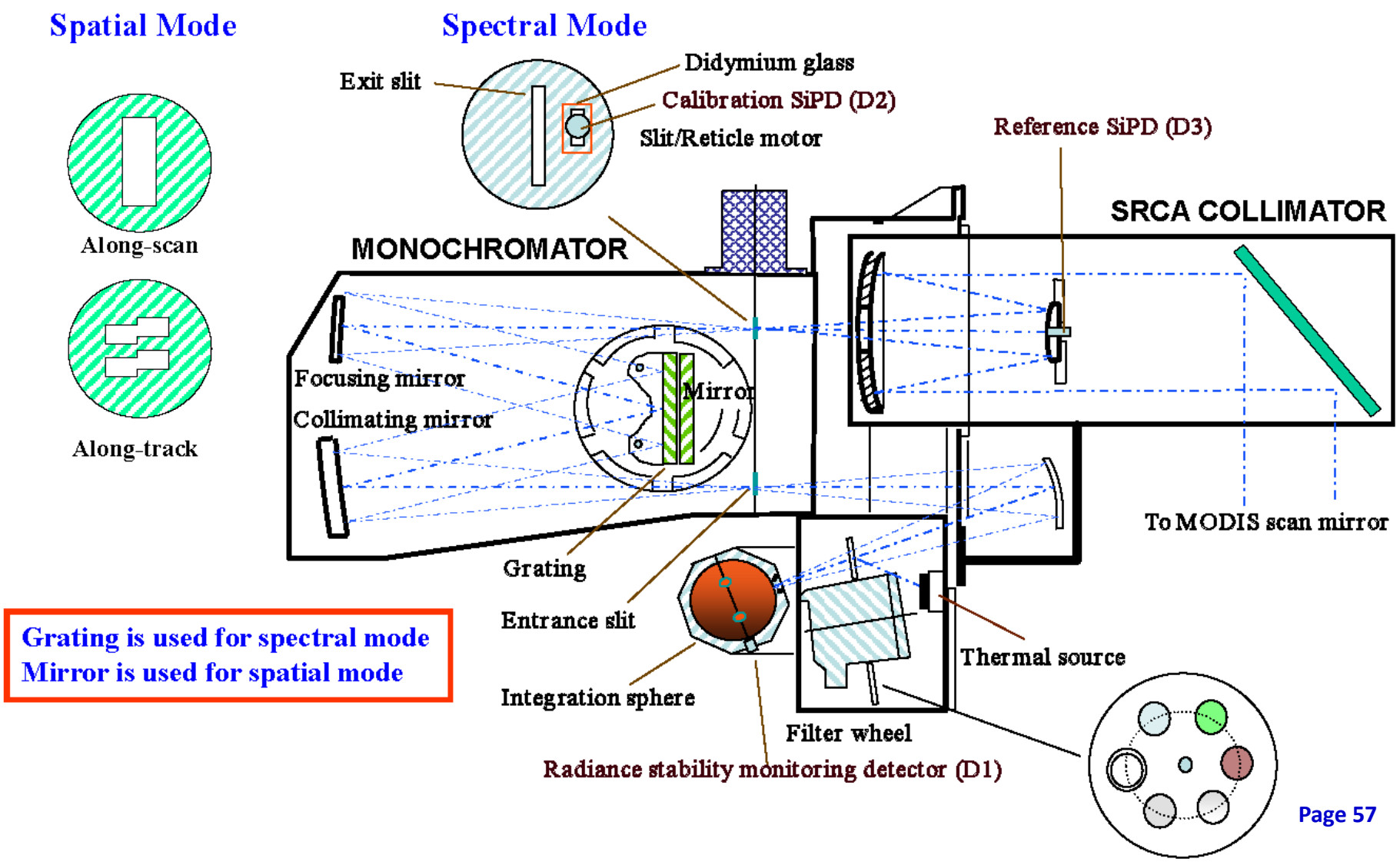
Summary

- TEB performance had been stable for Terra MODIS until the safe-mode anomaly in Feb. 2016
- The gain coefficients and NEdT changed noticeably, especially for detectors of bands 27-30
- The impact to L1B (C5 & C6) product is minor after the re-calibration of the gain coefficients
  - Band 30 C5 a0 & a2 fitting algorithm is updated
- Most bands 27 and 30 detectors are noisy or inoperable
- TEB performance has been stable for Aqua MODIS
  - CFPA temperature fluctuation decreases

MODIS Spatial and Spectral Performance

MCST Workshop at MST Meeting (June 6, 2016)

SRCA Background

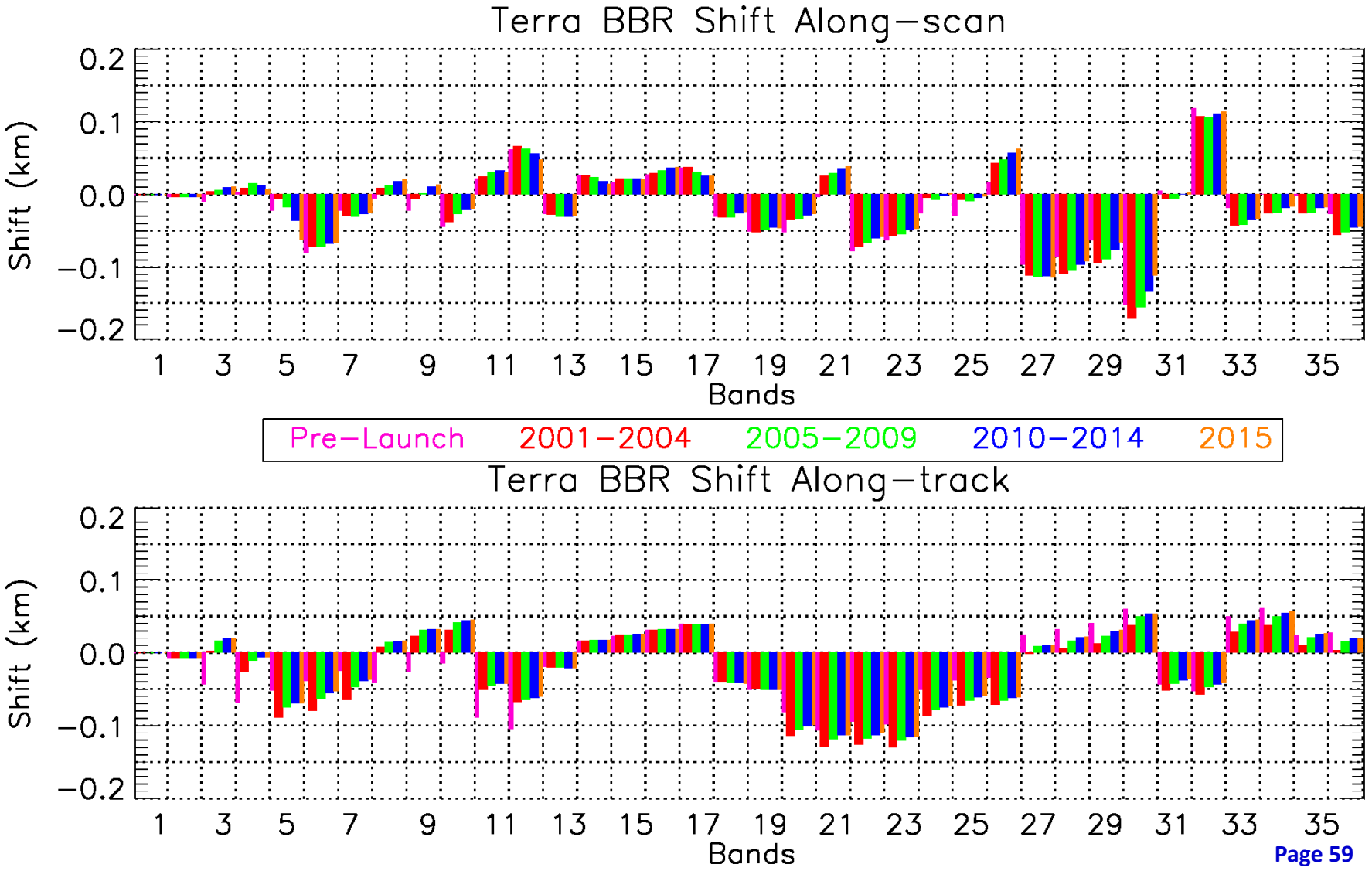


Grating is used for spectral mode
Mirror is used for spatial mode

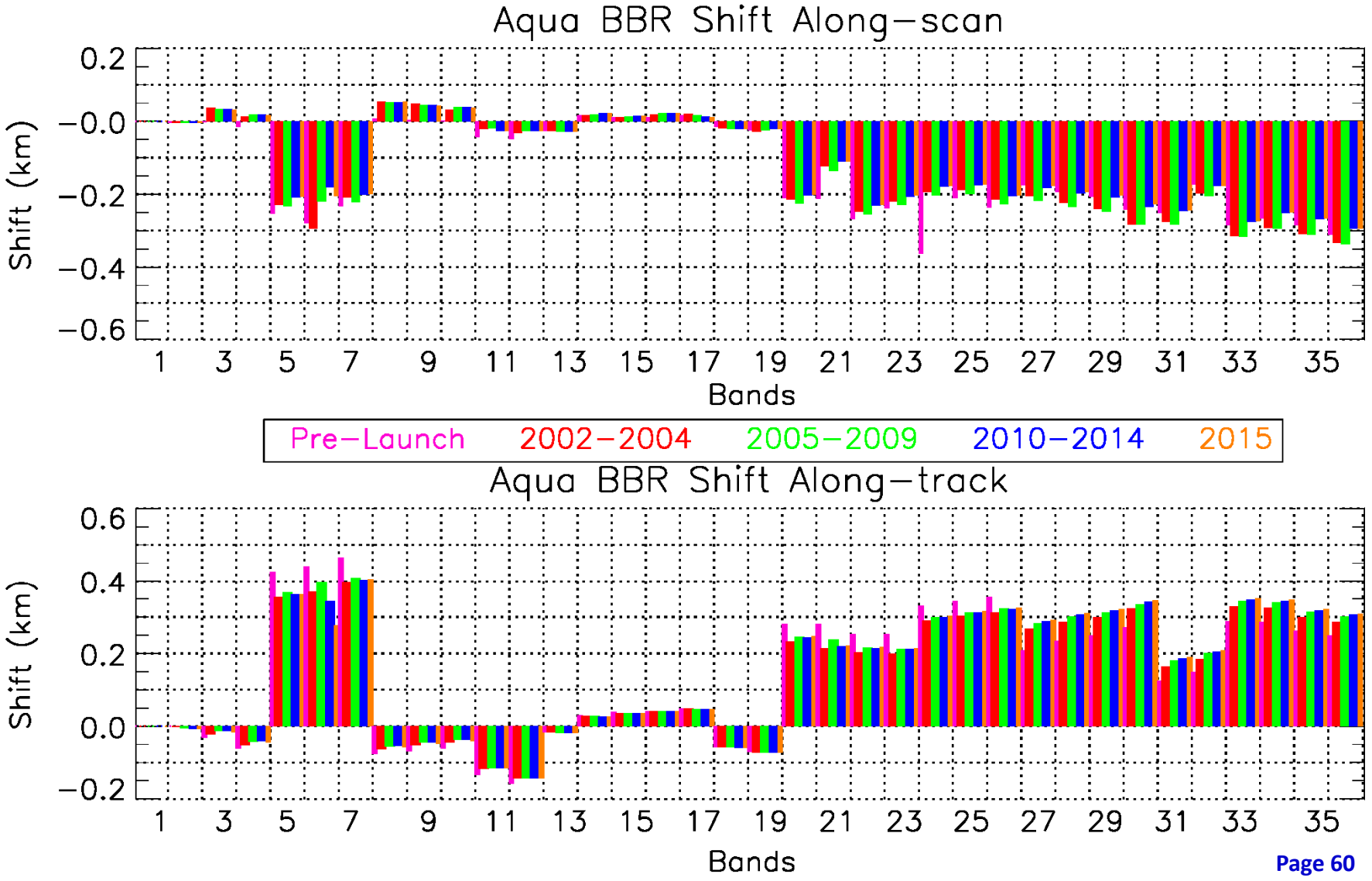
MODIS Spatial Performance

- Spatial calibrations are scheduled every 12 weeks for each instrument
- MODIS BBR design specification is < 200 meters in both directions
- A shift between the cold and warm focal planes in scan and track directions was measured for Aqua MODIS pre-launch
- On-orbit performance for both instruments has remained stable

Spatial Performance



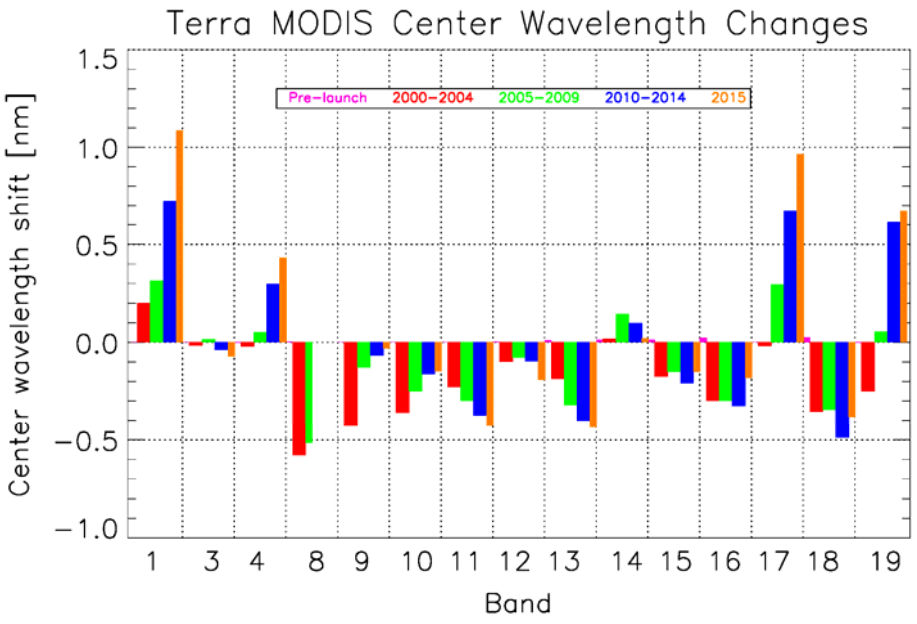
Spatial Performance

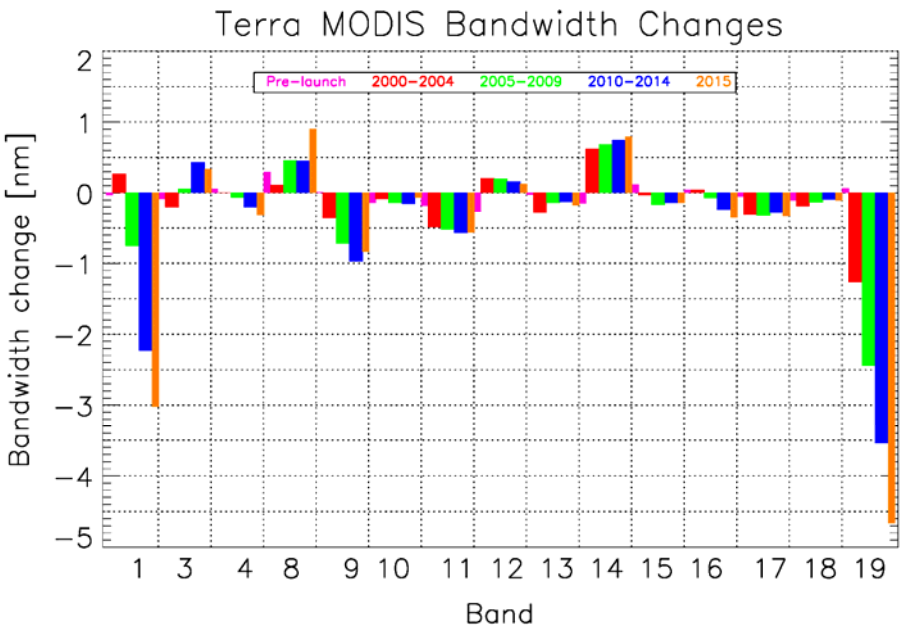


MODIS Spectral Performance

- Spectral calibrations are scheduled every 16 weeks for each instrument
- Measures RSR for select RSB with center wavelengths from 412 nm – 940 nm
- MODIS spectral specifications
  - Stability of center wavelength and bandwidth for VIS bands: 2 nm
  - Other bands: 1% of center wavelength
- All bands continue to operate within specifications

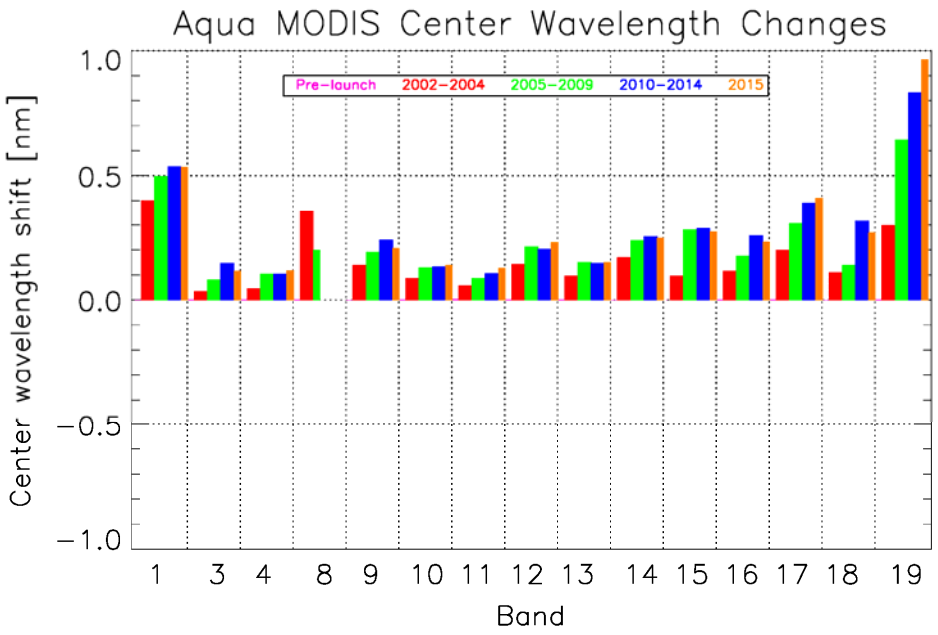
Spectral Performance

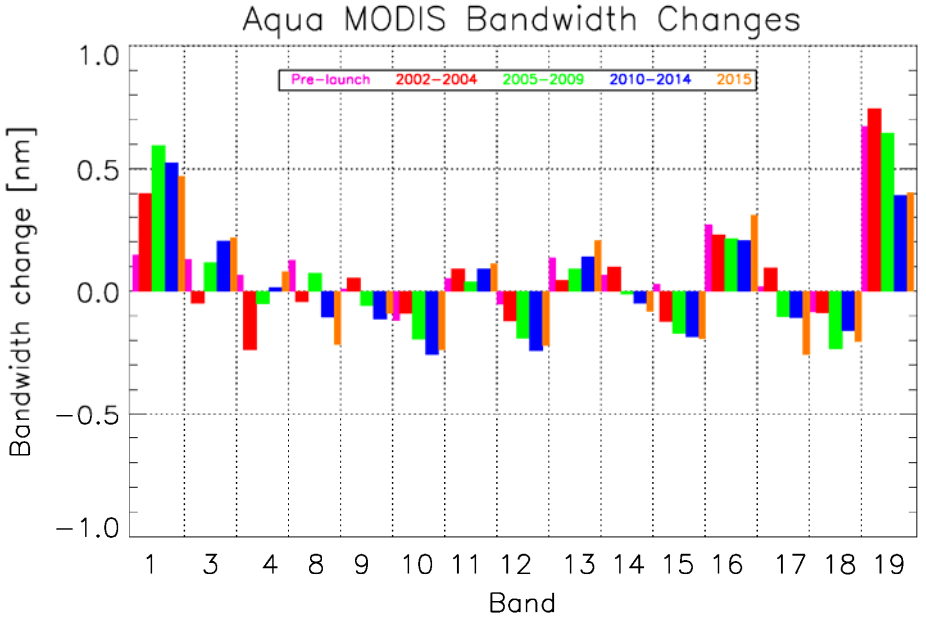




- Largest changes seen in bands 1 (645 nm), 17 (905 nm), and 19 (940 nm), these bands have large bandwidths (30-50 nm) compared with other RSB (10 -20 nm)
- The scheduled spectral calibration for March 2016 was waived due to Terra safe-hold.

Spectral Performance





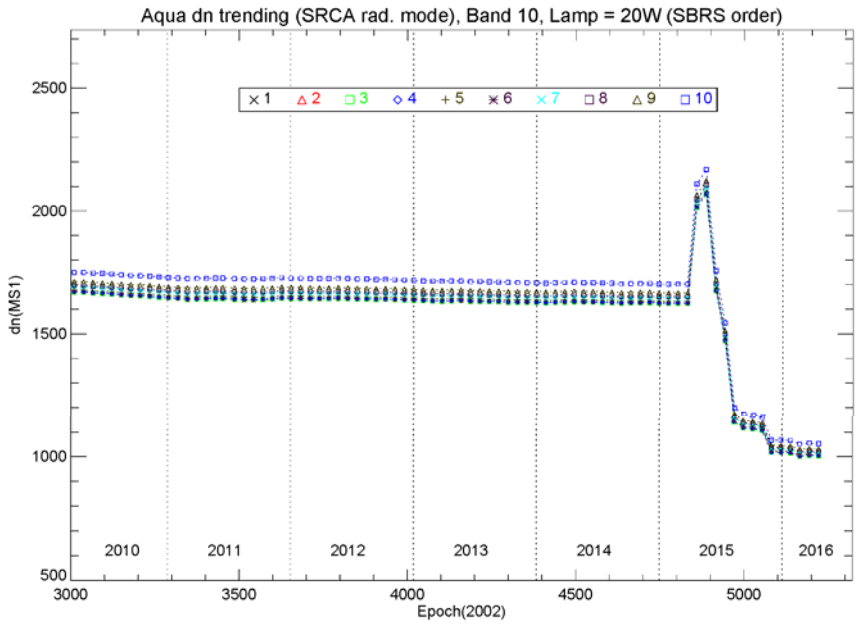
- Largest changes seen in bands 1 (645 nm), 17 (905 nm), and 19 (940 nm), these bands have large bandwidths (30-50 nm) compared with other RSB (10 -20 nm)

SRCA Lamps

- Currently, both MODIS SRCA instruments are operating with
  - Lamps #1 (10W), #4 (10W), and #5 (1W)
  - Lamps #2 (10W) and #3 (10W) are out of service
  - Lamp #6 (1W) is held in reserve

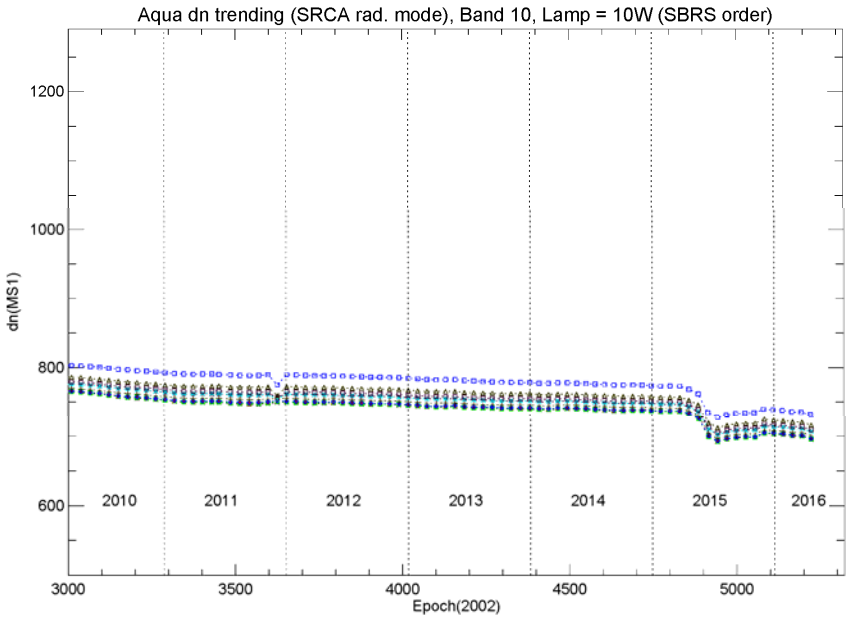
Aqua 10W Lamp #4

- Monthly radiometric calibrations on 2015/110 and 2015/138 showed increased signal from 10W lamp #4
- Lamps are in constant current mode with changes in voltage
- Aqua bands that use 20W calibration results:
  - 1, 3, 4, 8, 9, 10



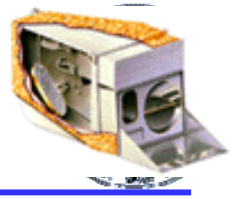
Impact SRCA Calibrations

- Performance of 10W Lamp #1 is only slightly affected
- Reduced signal levels have no affect on spatial and spectral calibrations



Terra Safe Mode Impact

- Spatial Calibrations performed
  - 2016/039 Before Safe Mode
  - 2016/123 After Safe Mode
  - Largest measured change 18 meters for selected detectors
- Spectral Calibrations performed
  - 2015/322 Before Safe Mode
  - 2016/069 Waived due to Safe Mode
  - 2016/181 Planned



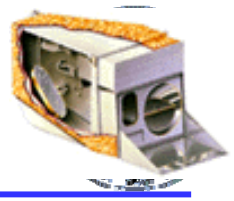
Update of Terra/Aqua EV-based RVS for RSB

MODIS Characterization Support Team

06/06/2016

MCST Workshop at MST Meeting (June 6, 2016)

Overview



- **MODIS Collection-6 (C6) L1B began in Nov. 2011 for Aqua and Feb. 2012 for Terra.**

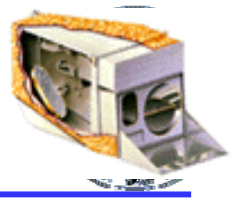
- **Major changes from C5 to C6 for RSB include**

  - **EV reflectance trends at 12 representative AOI from the CEOS endorsed pseudo-invariant desert sites (Libya 1, 2, and 4) are used to account for the inadequacies of a linear approximation of RVS on-orbit change and make additional gain adjustment**

  - **The EV-based RVS adjustments are applied to bands 1-4 and 8-10 on Terra and 8-9 on Aqua**

  - **There is detector-dependent RVS for VIS bands (8-12) and time-dependent RVS for ocean bands (13-16)**

Overview



- **A noticeable downward drift ~ 1% is observed near nadir for Aqua bands 1-2 based on EV reflectance trends (desert, Dome C and DCC).**

- **The EV-based RVS approach, previously applied to Aqua bands 8-9, is extended to bands 1-4 and has been extensively tested for science product and recently approved to be implemented in the forward processing.**

- **For Terra bands 1-2, the observed upward drifts ~1% as reported in the last MODIS STM were due to errors in LUT forward update. A corresponding adjustment in the update procedure works reasonably well.**

RSB Calibration

- EV Reflectance

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

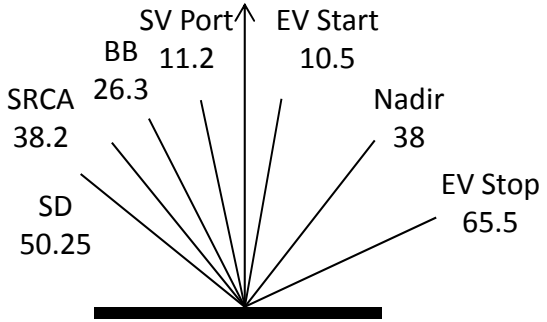
- Look-Up-Tables (LUTs) updated regularly for RSB
  - m_1: Inversely proportion to gain at the AOI of SD
  - RVS : Sensor Response versus Scan angle (normalized to SD AOI)

$$RVS = RVS^{pl}(B,M,F)\ RVS^{on\text{-}obt}(B,M,F,t) \qquad (2)$$

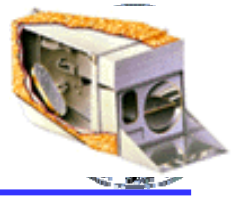
where $RVS^{on\text{-}obt}(B,M,F,0) = 1$ at time t=0

$$RVS^{on\text{-}obt}(B,M,F,t) = \sum_{i=0}^{n} c_i(B,M,t)\ F^i \qquad (3)$$

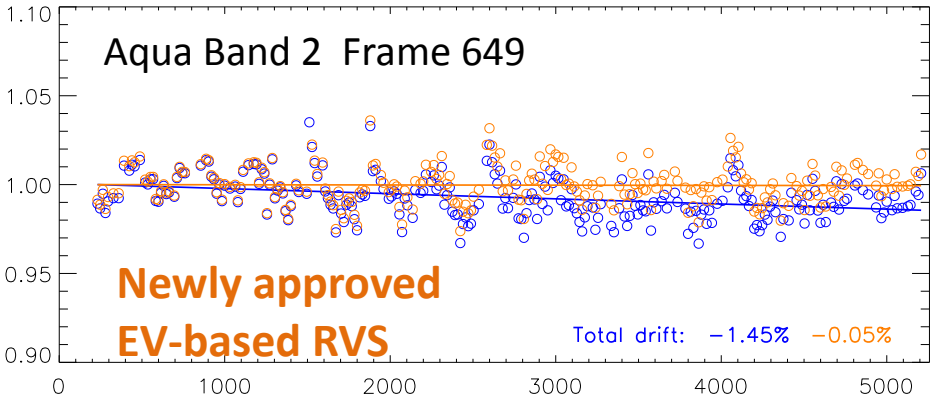
n is 2 or 4 depending on band (B1-4, 8-10)
Additional correction for D to D difference

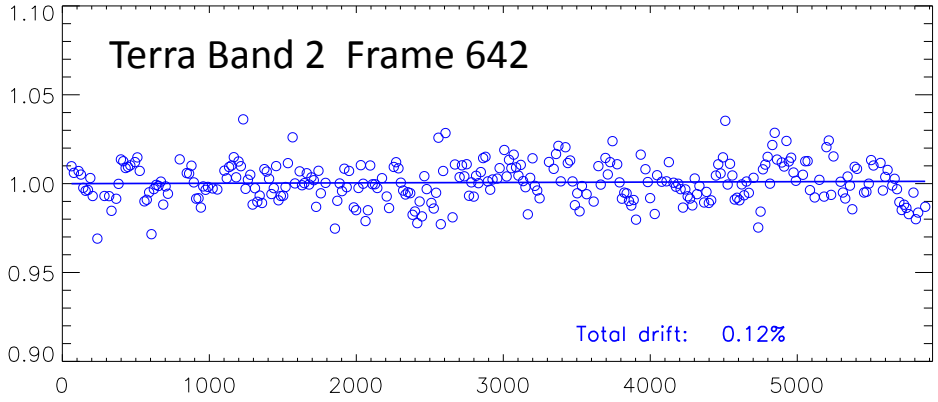


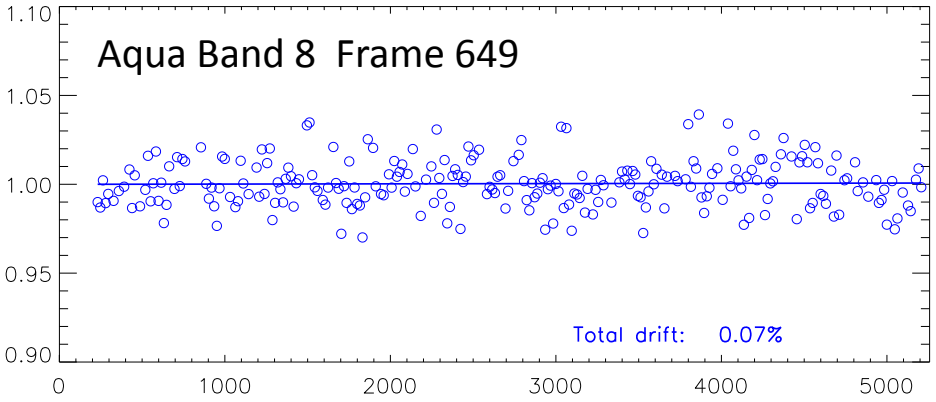
Terra and Aqua TOA reflectance trending from desert around nadir

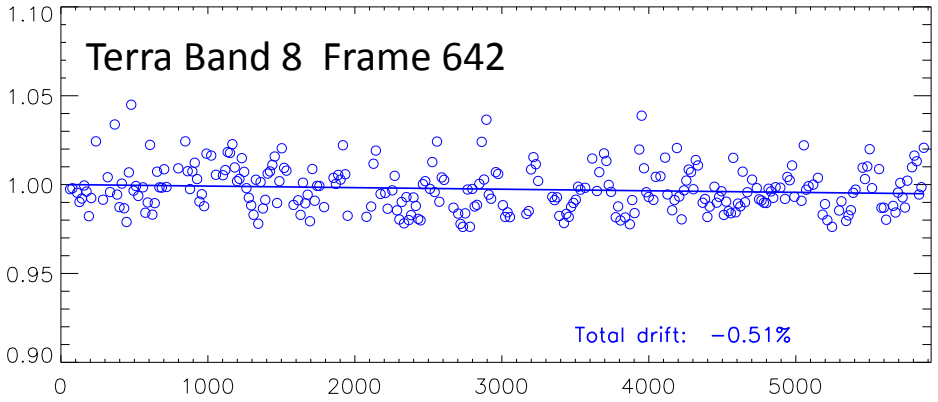


MODIS Collection-6 performance

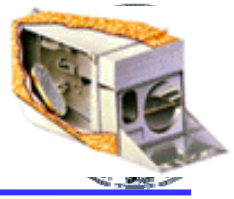




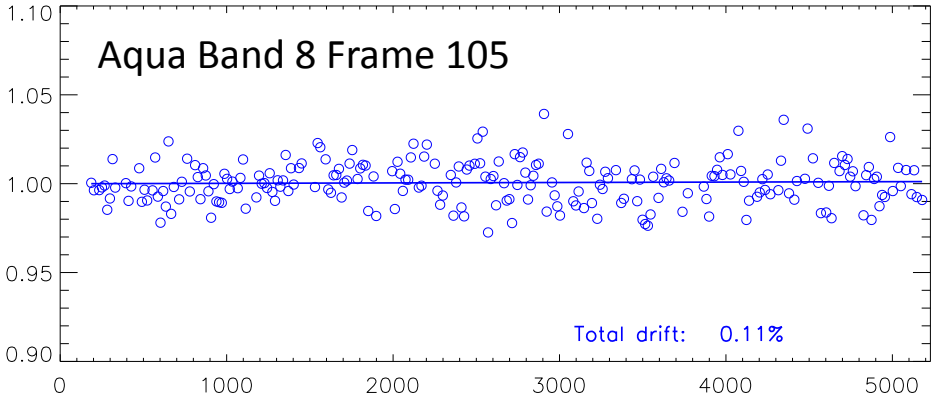


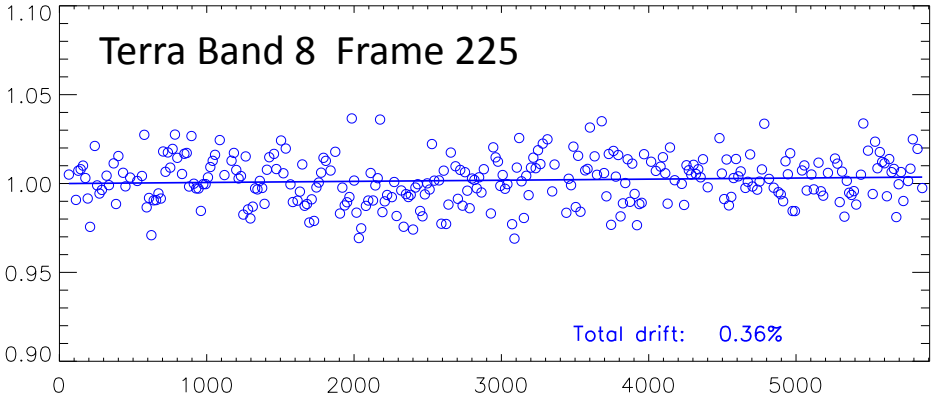


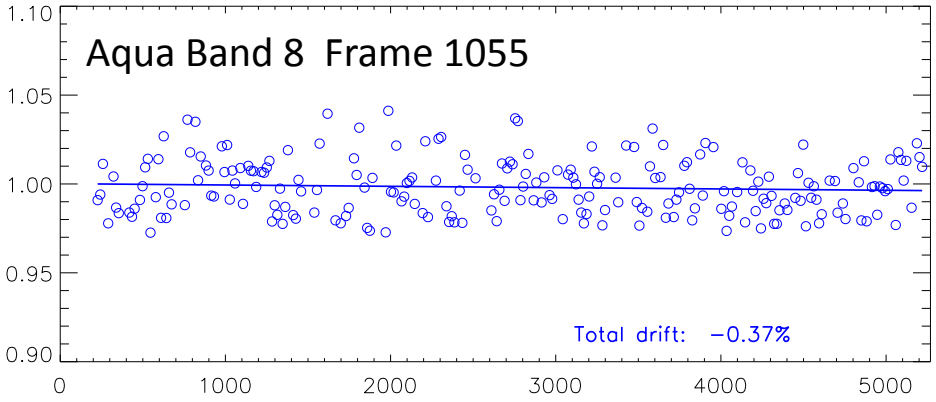
Terra and Aqua TOA band 8 reflectance trending from desert off nadir

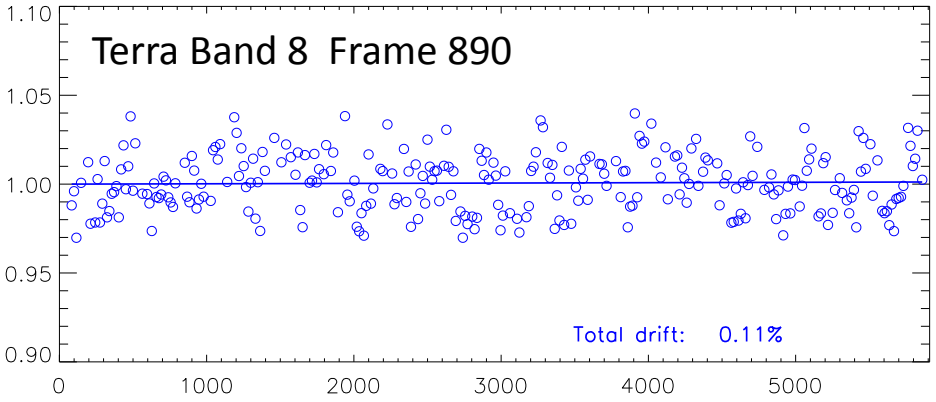


MODIS Collection-6 performance

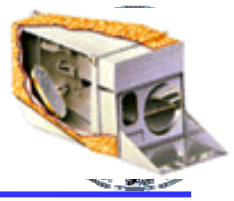




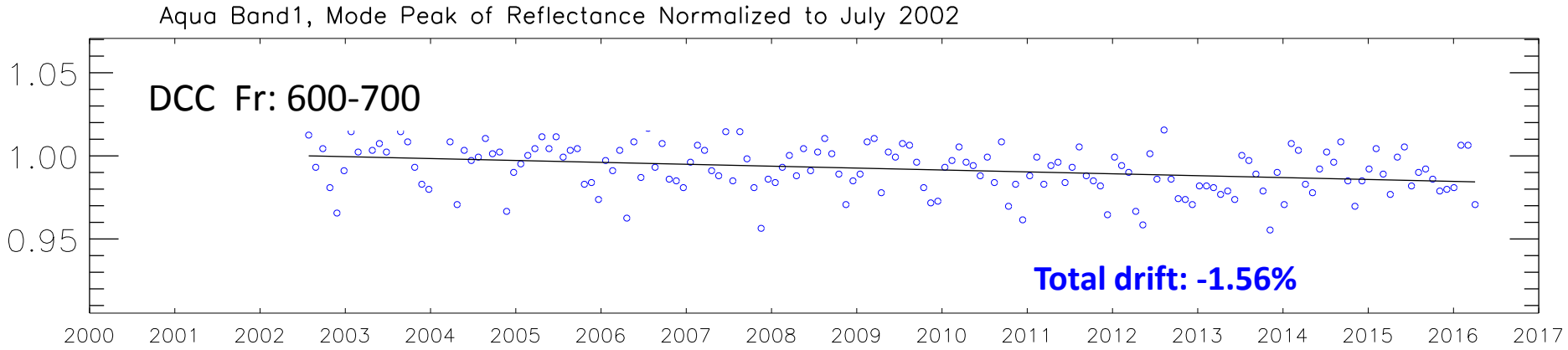


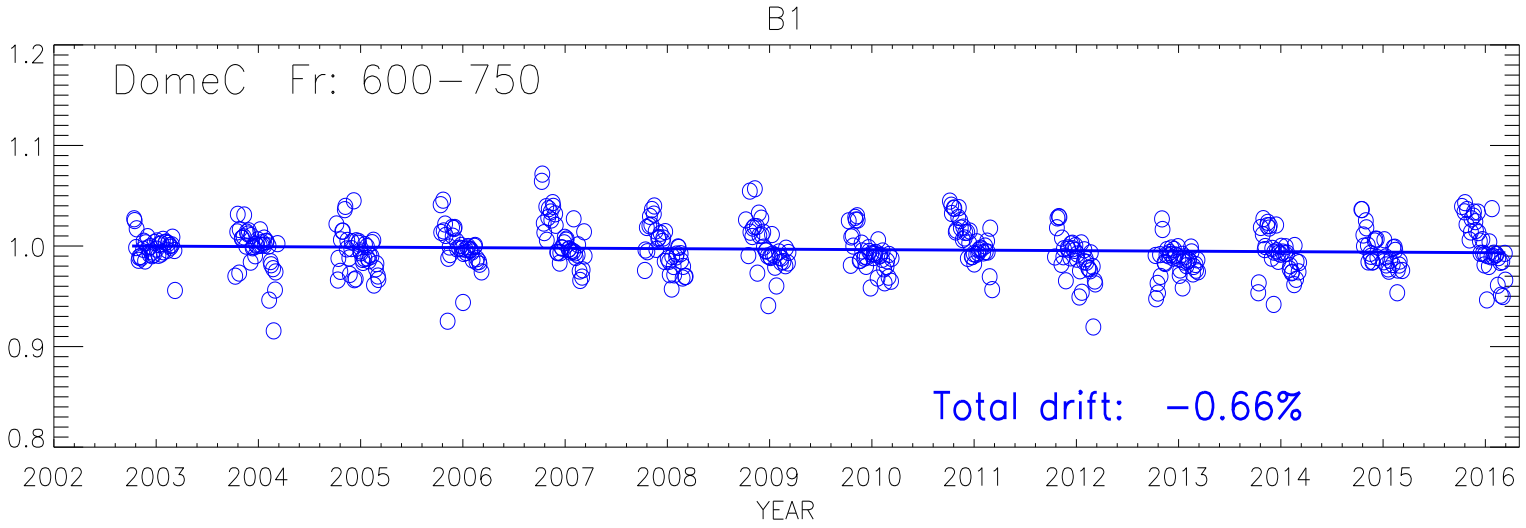


Aqua TOA band 1 reflectance trending from DCC and Dome C (nadir)

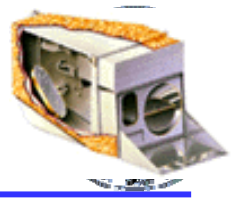


MODIS Collection-6 performance





Summary



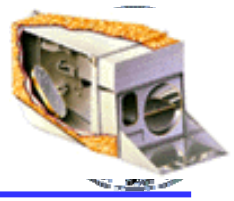
- **The EV-based RVS approach for Aqua bands 1-4 has been extensively tested for science product and is recently approved for the forwarding LUT processing.**

- **Long-term trends (desert, Dome C, DCC) for both Terra/Aqua bands 1-4 and 8-9 show no observable deviation for more than ±1% if the EV-based reflectance trends are applied.**

Tracking MODIS on-orbit polarization sensitivity

MODIS Characterization Support Team
06/06/2016

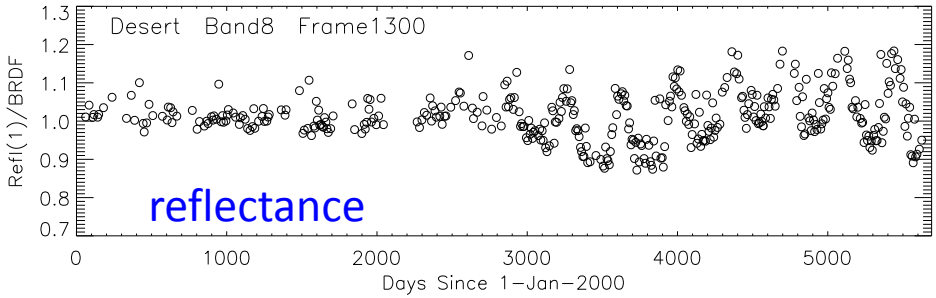
Overview

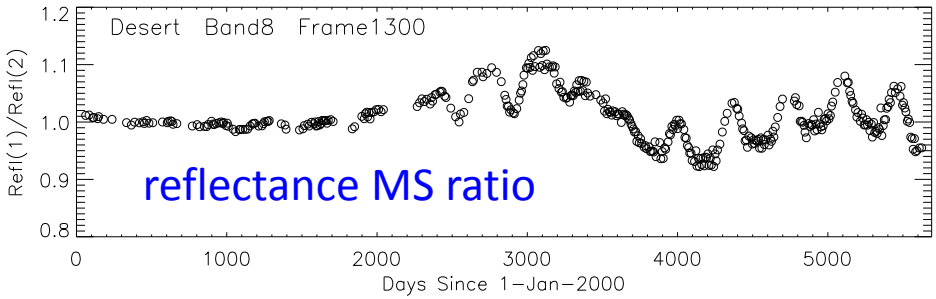


- MODIS visible bands are known to be sensitive to the polarization of incident light and pre-launch tests showed there is an impact of up to 5% at the end of scan.
- There is a significant increase in polarization sensitivity on Terra after 2007, as indicated in the reflectance and mirror-side ratio trends.
- Science teams use their own scene-dependent polarization corrections, based on the OBPG provided parameters.
- MCST developed its algorithm to track on-orbit polarization sensitivity based on measured reflectances from the desert sites and the 6SV modeled at-sensor signals. Recently, this approach is extended to ocean sites.

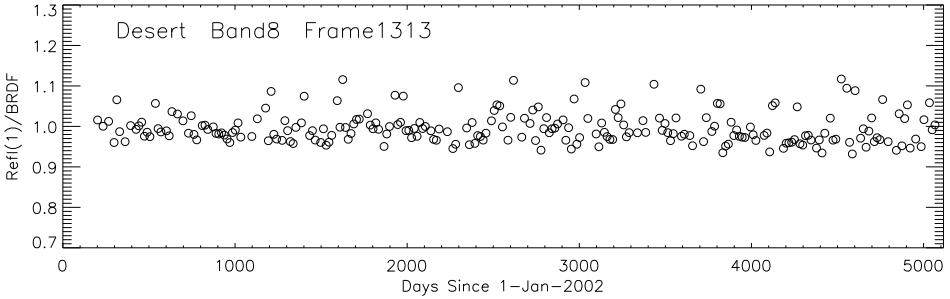
Terra and Aqua TOA reflectance and mirror-side ratio trends at end of scan

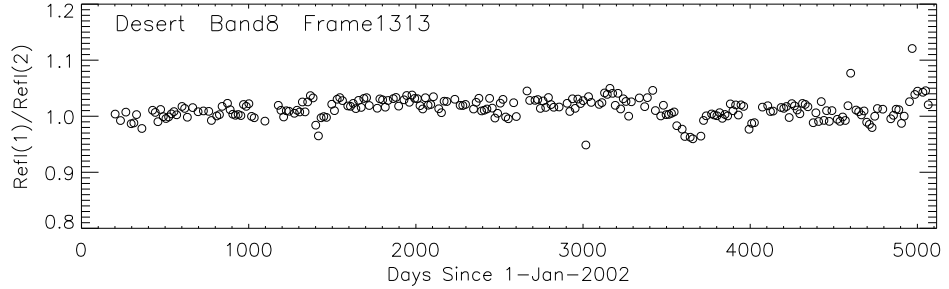
Terra B8 Frame 1300





Aqua B8 Frame 1313





Methodology

Standard polarization correction based on the Mueller matrix after ignoring the circular component

$$L_m / L_t = M11 * (1 + m12 * Q_t / L_t + m13 * U_t / L_t)$$

L_m, L_t : measured and true TOA radiance/reflectance

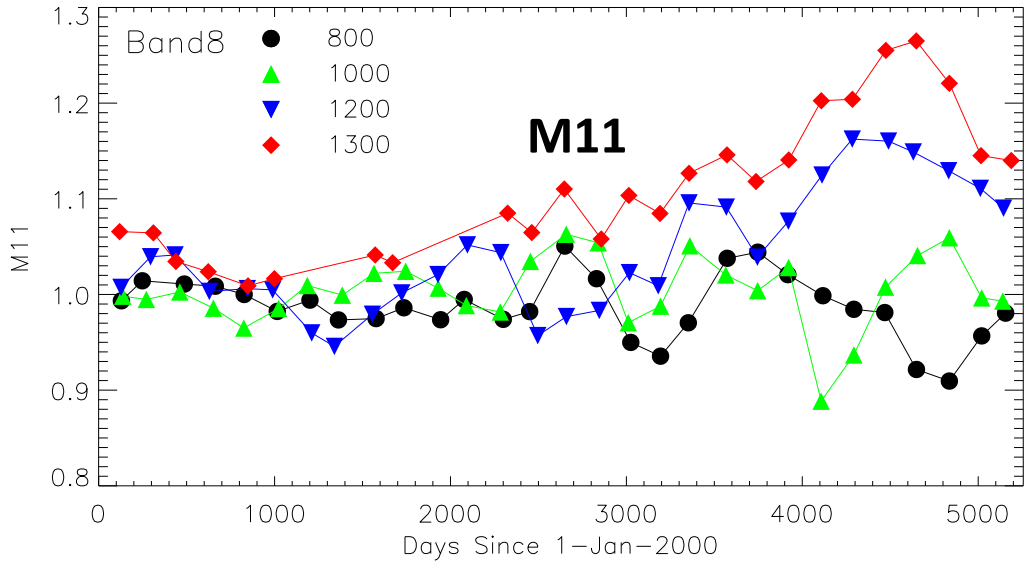
Q, U, I : linear Stokes components, modeled from 6SV

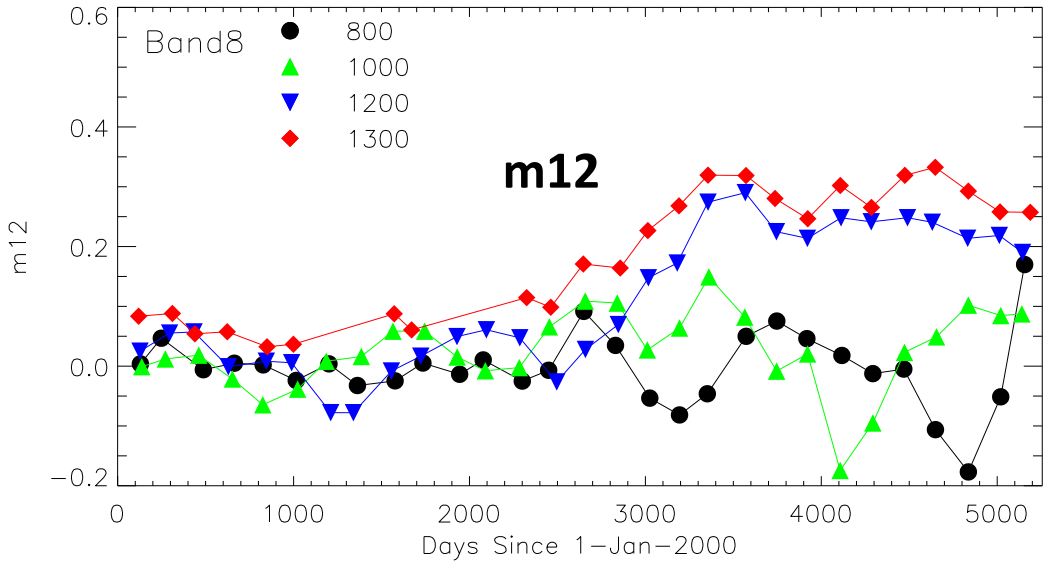
M11 is the instrument gain adjustment

m12 and m13 are the polarization sensitivity parameters.

It is assumed that relative changes such as Q_t/L_t and U_t/L_t can be derived more accurately by model than the absolute values. L_m/L_t is replaced with the reflectance trends normalized with the initial value.

Trends of Terra B8 M11 and m12 at different frames for MS1 (800 to 1300)

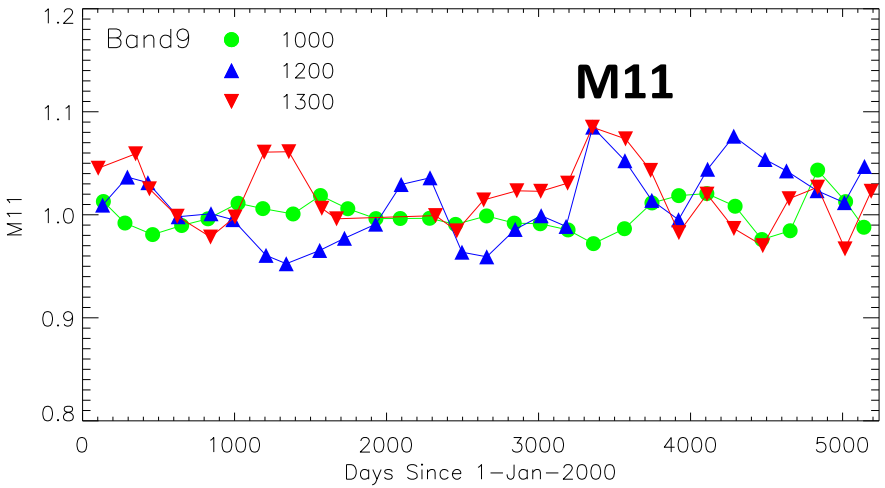


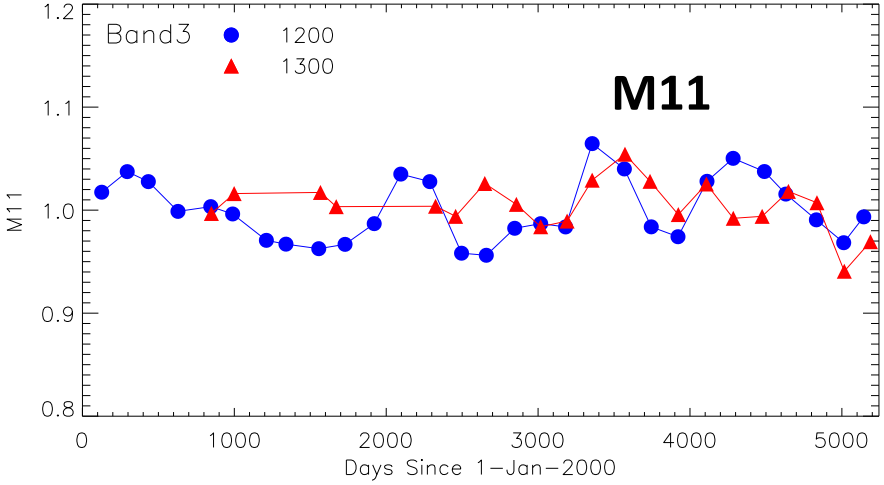


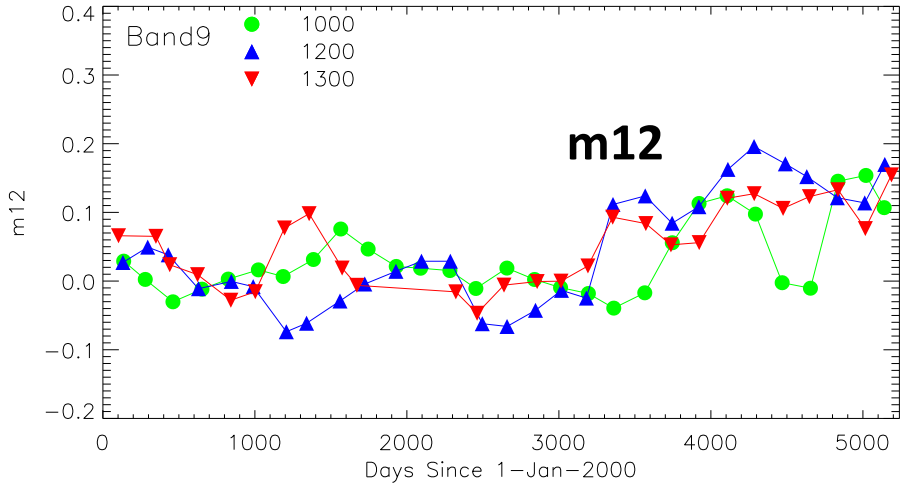
- Polarization contribution of the surface to TOA is neglected.
- L_m/L_t is replaced with the reflectacnes normalized by the early mission BRDF
- M11, m12 and m13 are determined by regression within a yearly moving window.

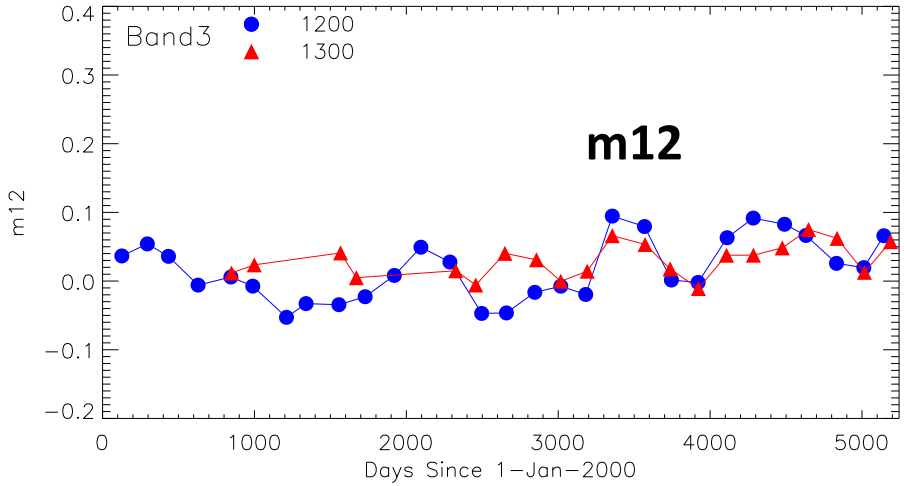
← 35%

Trends of Terra B3 and B9 M11 and m12 at different frames for MS1

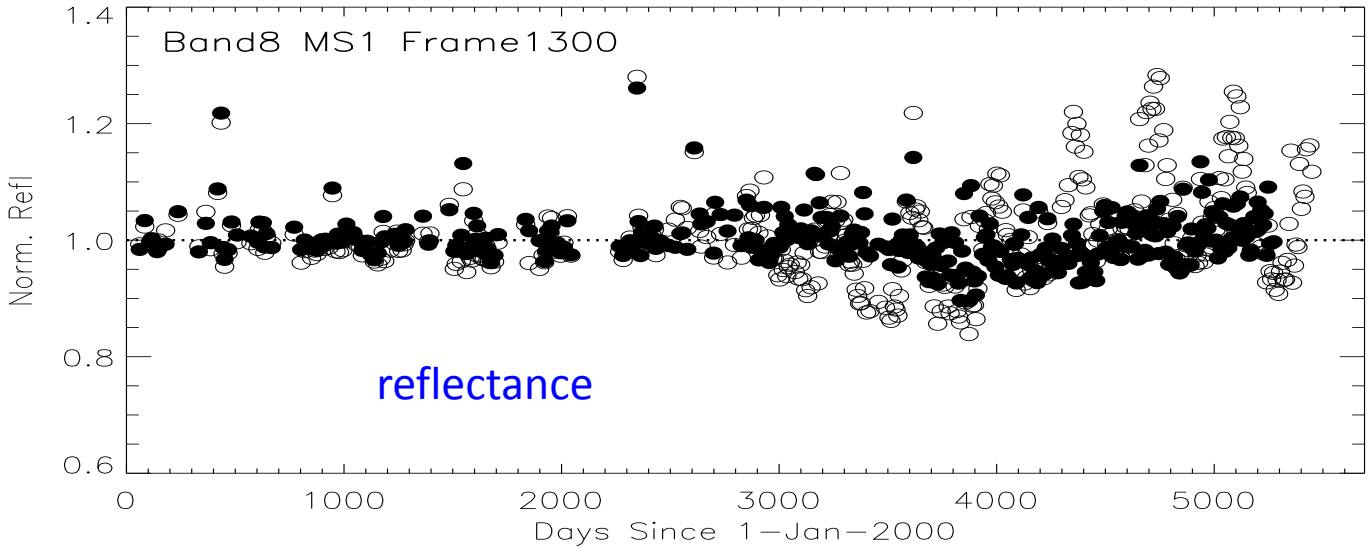


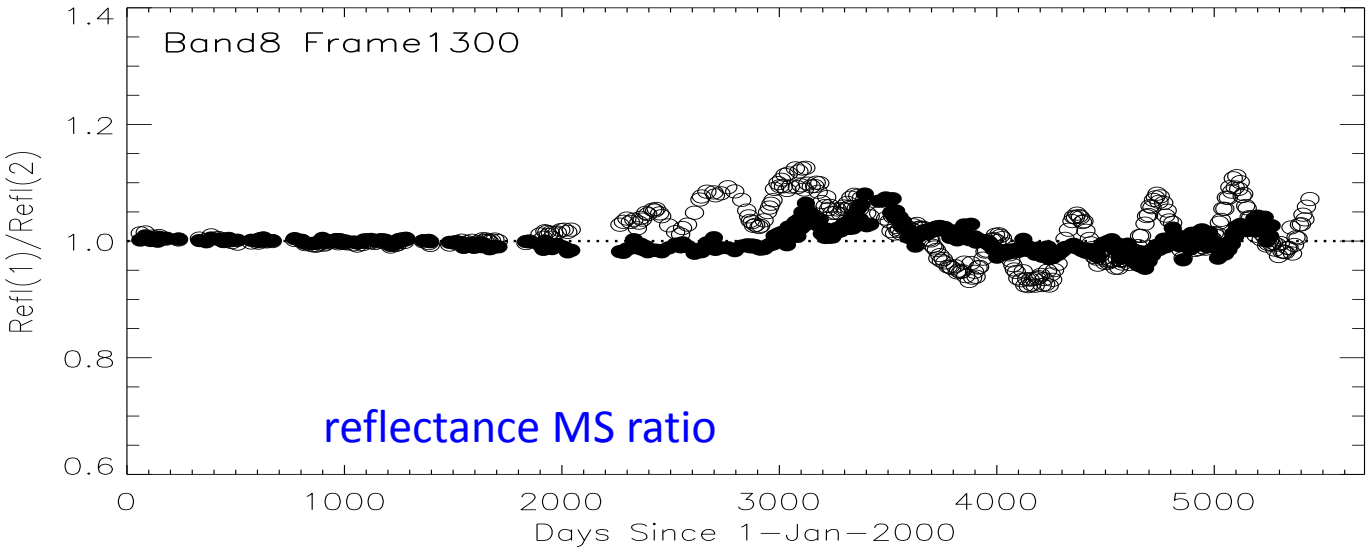




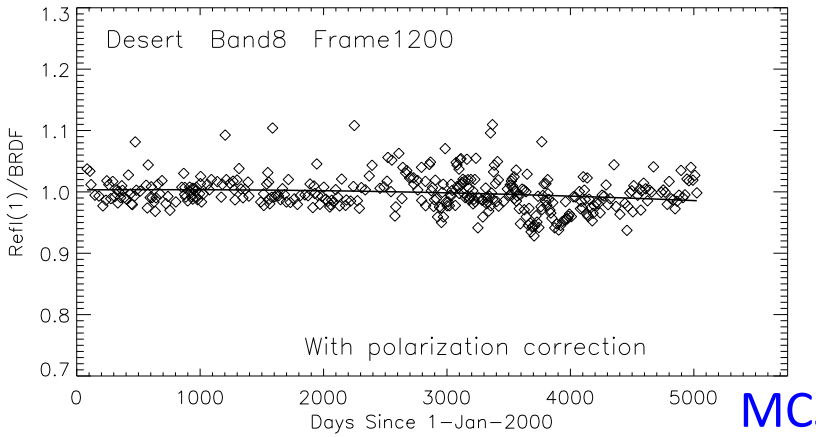


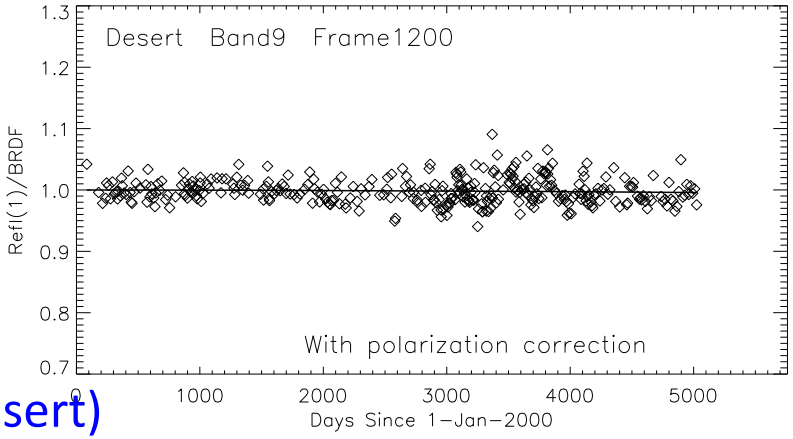
Trends of Terra B8 reflectance before and after polarization correction



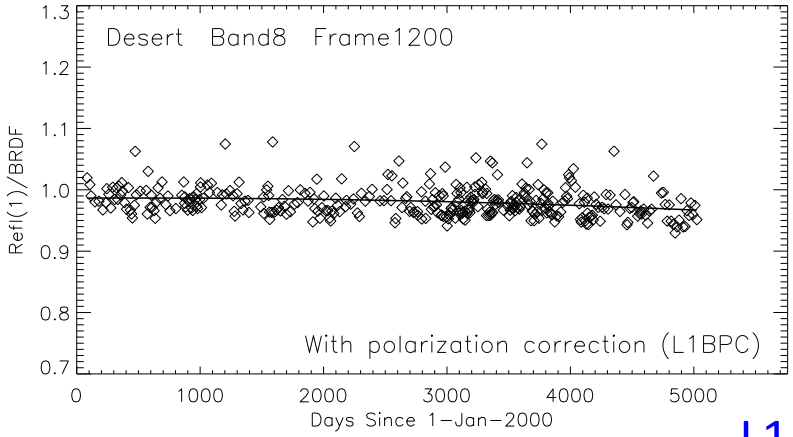


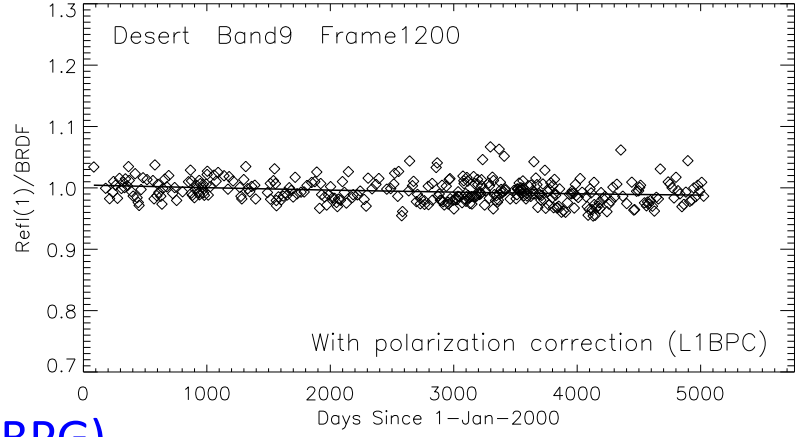
Comparison of polarization correction for desert sites (B8 & 9, frame 1200)





MCST (desert)

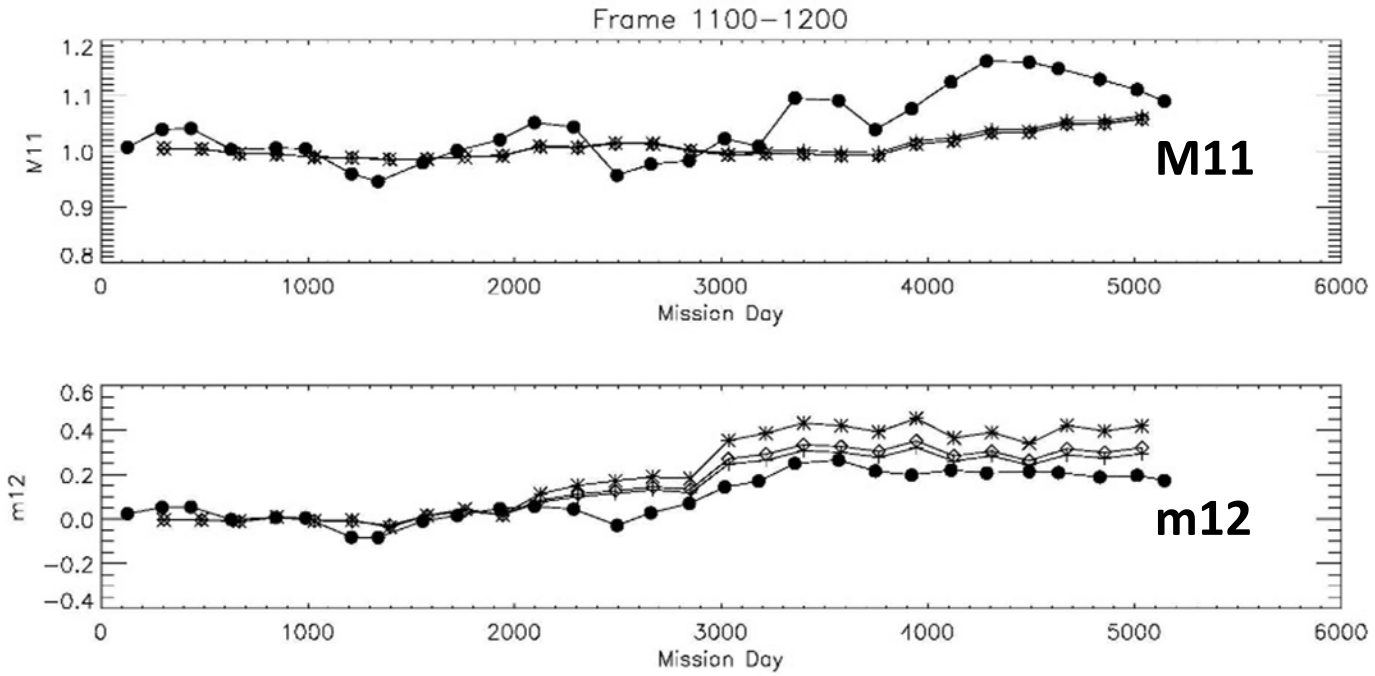




L1BPC (OBPG)

**L1B polarization corrected testing data was provided by Sadashiva Devadiga (SSAI) from MODIS Land Data Operational Product Evaluation (LDOPE)*

Trends of Terra B8 M11 and m12 from desert and ocean sites



- desert
+ ocean 23^{O}N
* ocean 23^{O}S
◊ average

- Ocean reflectances are normalized by BRDF derived using observations from 1st 1000 days of the mission
- Three unknowns (M11, m12 and m13) are determined from a 1-yr interval containing about 100 points with m13 set to zero

Summary

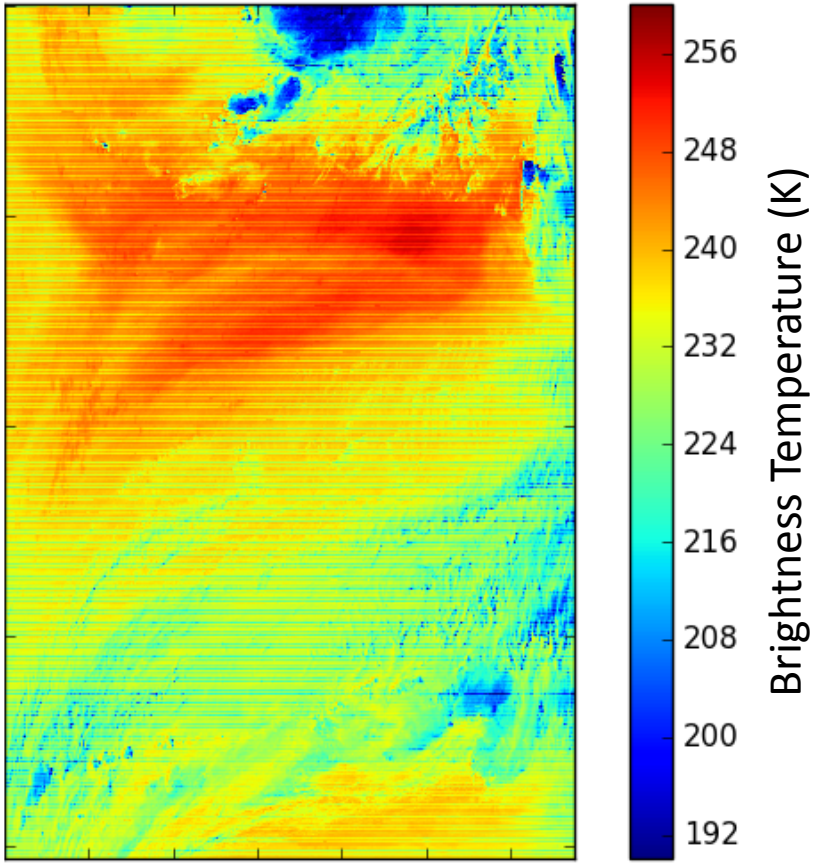
- Polarization sensitivity reaches a peak over 35% at 0.41 μm near the end of 2009 and all three sensitive bands (8, 9 and 3) show a stable performance since then.
- A general good agreement is found between MCST and OBPG polarization corrected (PC) reflectances over desert sites, indicating the simplified approach can work effectively in characterizing the polarization impact.
- The PC data sets can help reduce the uncertainty at large AOI in the calculation of the EV-based RVS

Terra MODIS LWIR PV Crosstalk Status

MCST Workshop at MST Meeting (June 6, 2016)

Crosstalk Background

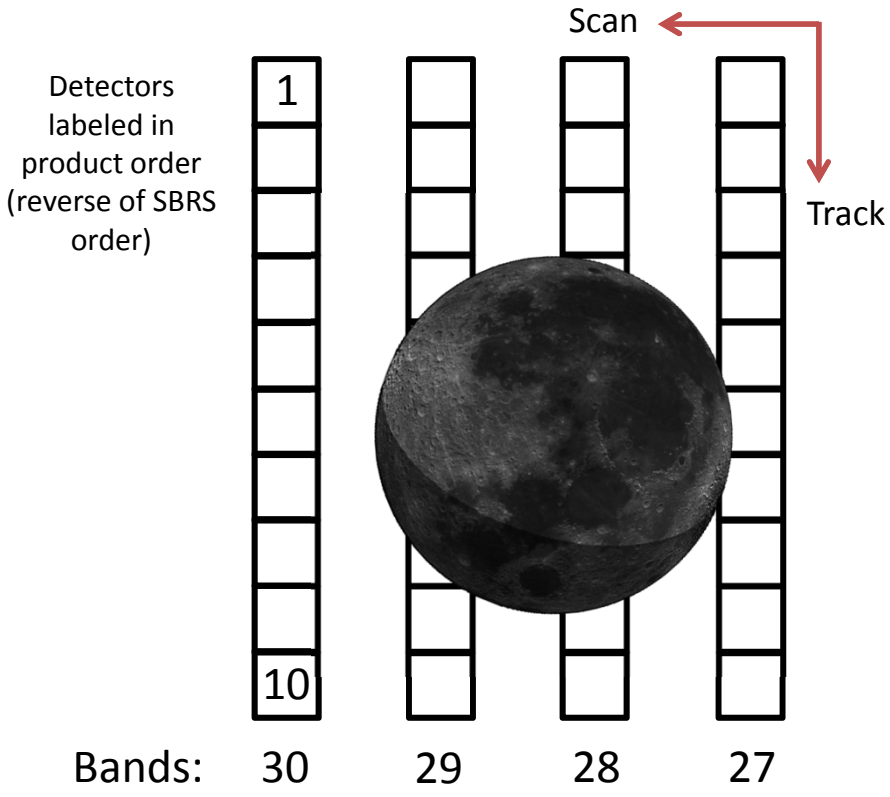
- **Bands 27-30 on the LWIR focal plane are sampled by the same set of electronics, with 4 subsamples of each detector being averaged for each frame.**
- **For detectors/bands being sampled by the same electronics, there is potential for signal "leakage" from detector to detector.**
- **This crosstalk signal can lead to land feature misidentification, false cloud detection, and poor quality images (seen on the right).**
- **Previous work using lunar based approach:**
  - **J. Sun *et al,* Remote Sensing 8 (3), 249, 2016.**
  - **J. Sun *et al*, Proc. SPIE 9607, Earth Observing Systems XX, 96070V, 2015.**
  - **J. Sun *et al*, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 52, NO. 3, MARCH 2014.**



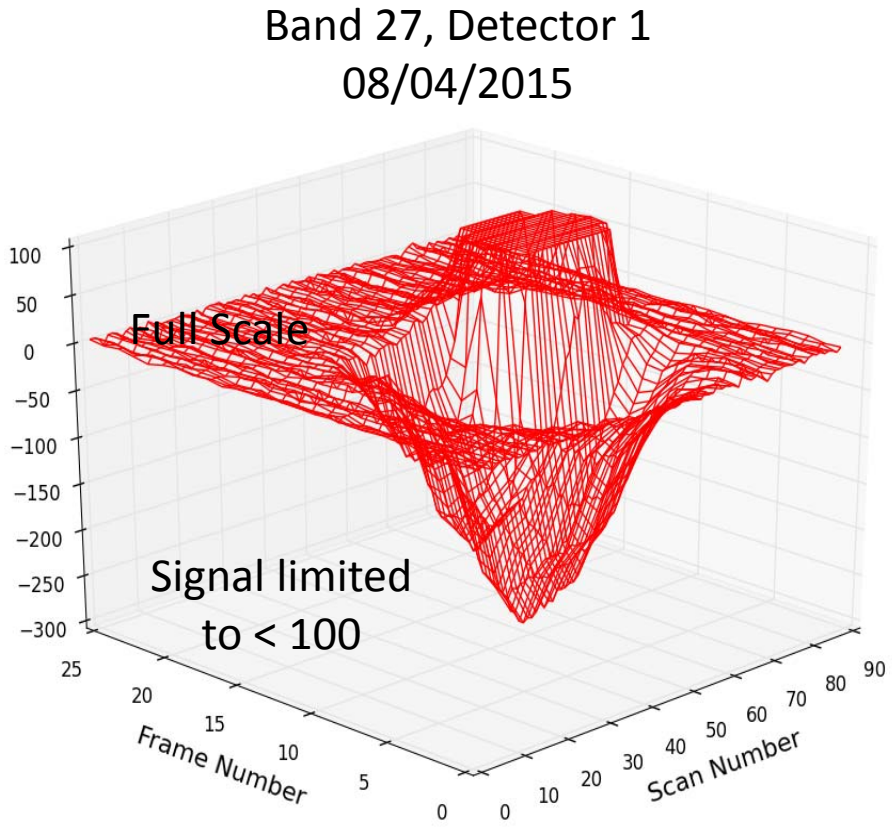
Band 27, Granule 2015182.1345

Using the Moon for Crosstalk Characterization

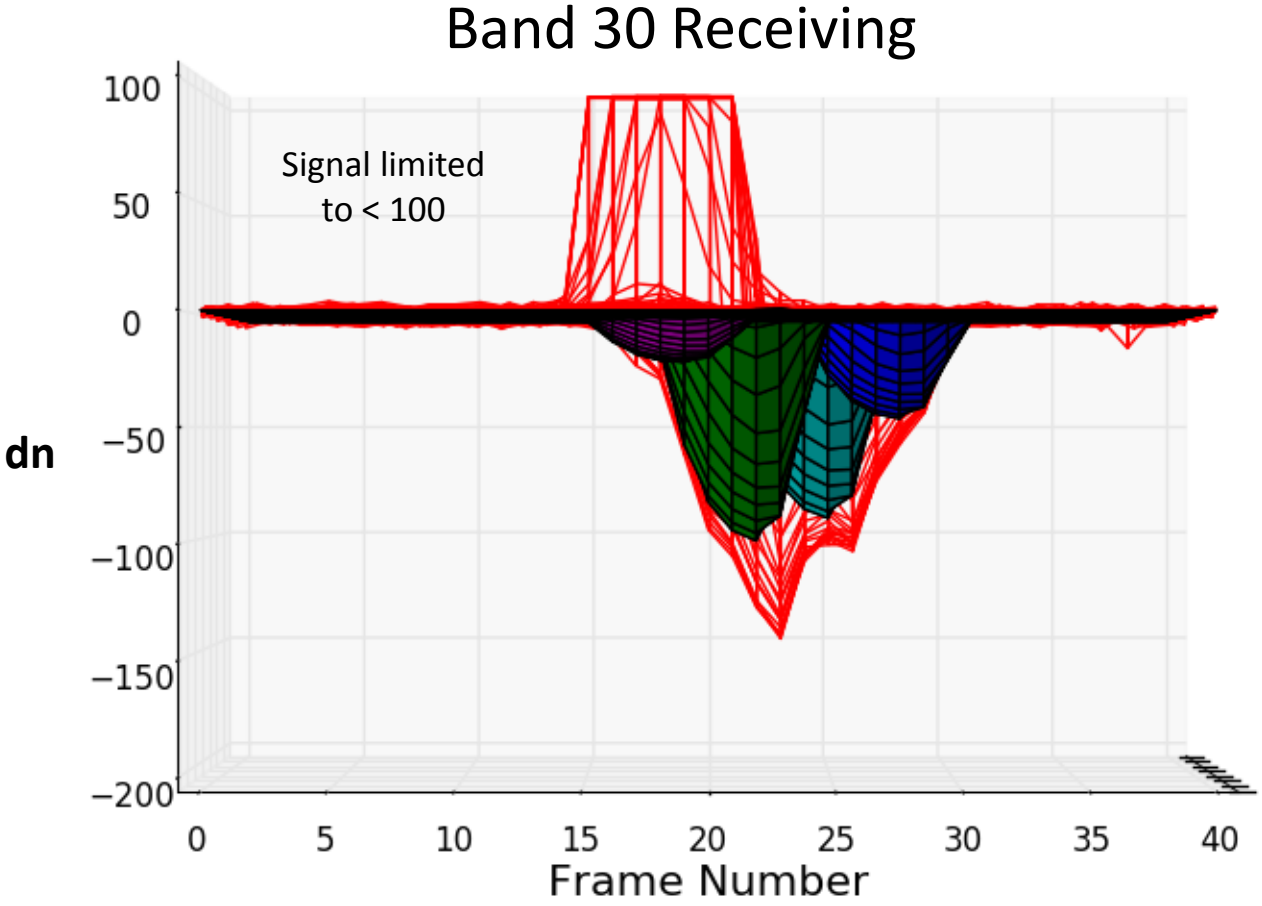
- **The moon is a bright target against a dark background. Each band/detector observe the moon at slightly different times (scans/frames)**



Each band is separated by 3 frames.



Determining the Sending Signal



Sending Signals

Band 27
Band 28
Band 29
Band 30

- **As expected, the sending signal corresponds to the bands that share the same electronics, including other detectors within the same band.**
- **The sending signal is scaled to show alignment, and is shown after a saturation correction has been applied to the sending data using Band 31 as a reference.**

Algorithm

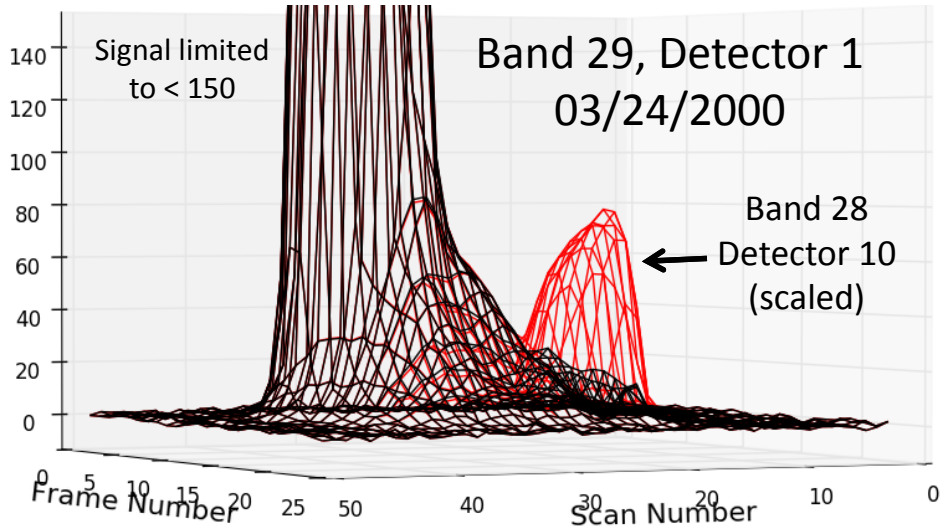
- **The crosstalk sending signal is assumed to be linearly proportional to the measured signal after background subtraction.**

$$dn_i(S,F) = dn_i^*(S,F) - \underbrace{\sum_j c_{i,j}\, dn_j^*(S, F + \Delta F_j)}_{dn_x(S,F)}$$

- **Here, *i* and *j* are the detector indices for the receiving and sending detectors respectively, and range between 1-40 for each detector in bands 27-30. *S* and *F* are scan/frame pairs. The * represents the contaminated signal. Here, $c_{i,j} = 0$ for $i = j$.**

$c_{i,j}$ Matrix

- We are testing two different approaches for $c_{i,j}$:
  - **Band Averaged:**
    - The coefficients in each sending band are fixed to the same value within the band
    - For the receiving band, the receiving detector coefficient is set to 0
  - **Semi-Detector Dependent:**
    - Non-neighboring bands to the receiving band have detector dependent coefficients.
    - For Bands 28-30, receiving detector 1, there is a separate sending signal from bands 27-29, detector 10 respectively (product order). This coefficient is treated separately from the band average in the neighboring band.

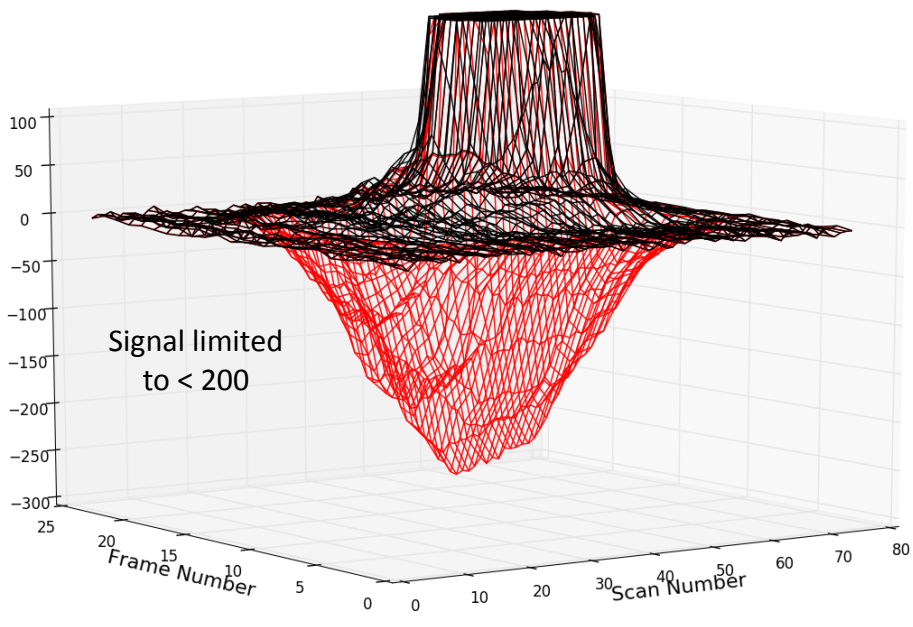


- **The sampling of these two detectors happens consecutively, and there must be some issue with switching between bands (band 27 is sampled last, and has no issue)**
- **This is prevalent throughout the whole mission.**

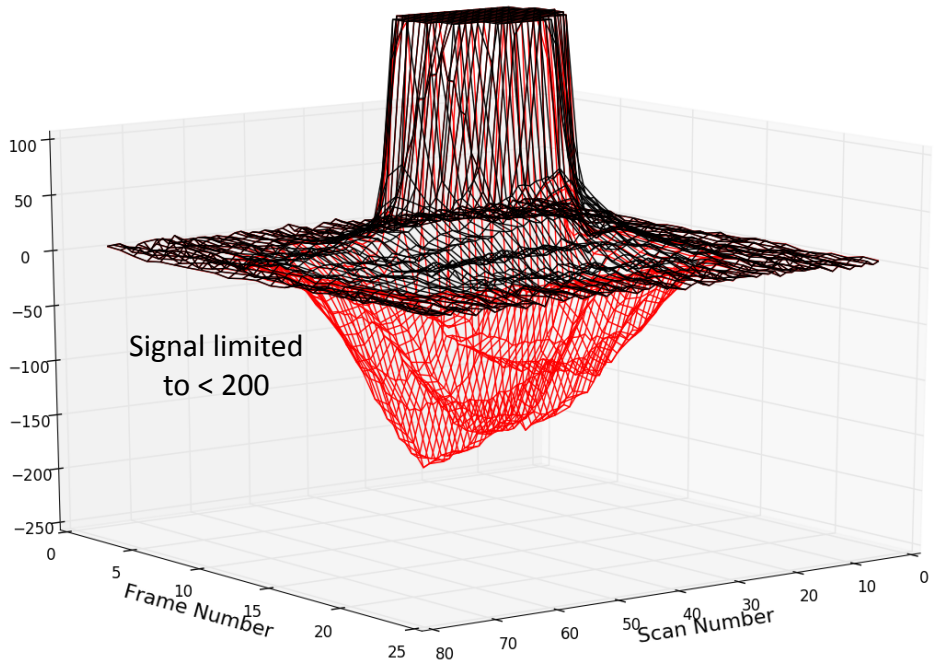
Example Correction of Contaminated Data

- **The red data represents the contaminated signal. The black data is the signal after the correction coefficients are found and applied.**

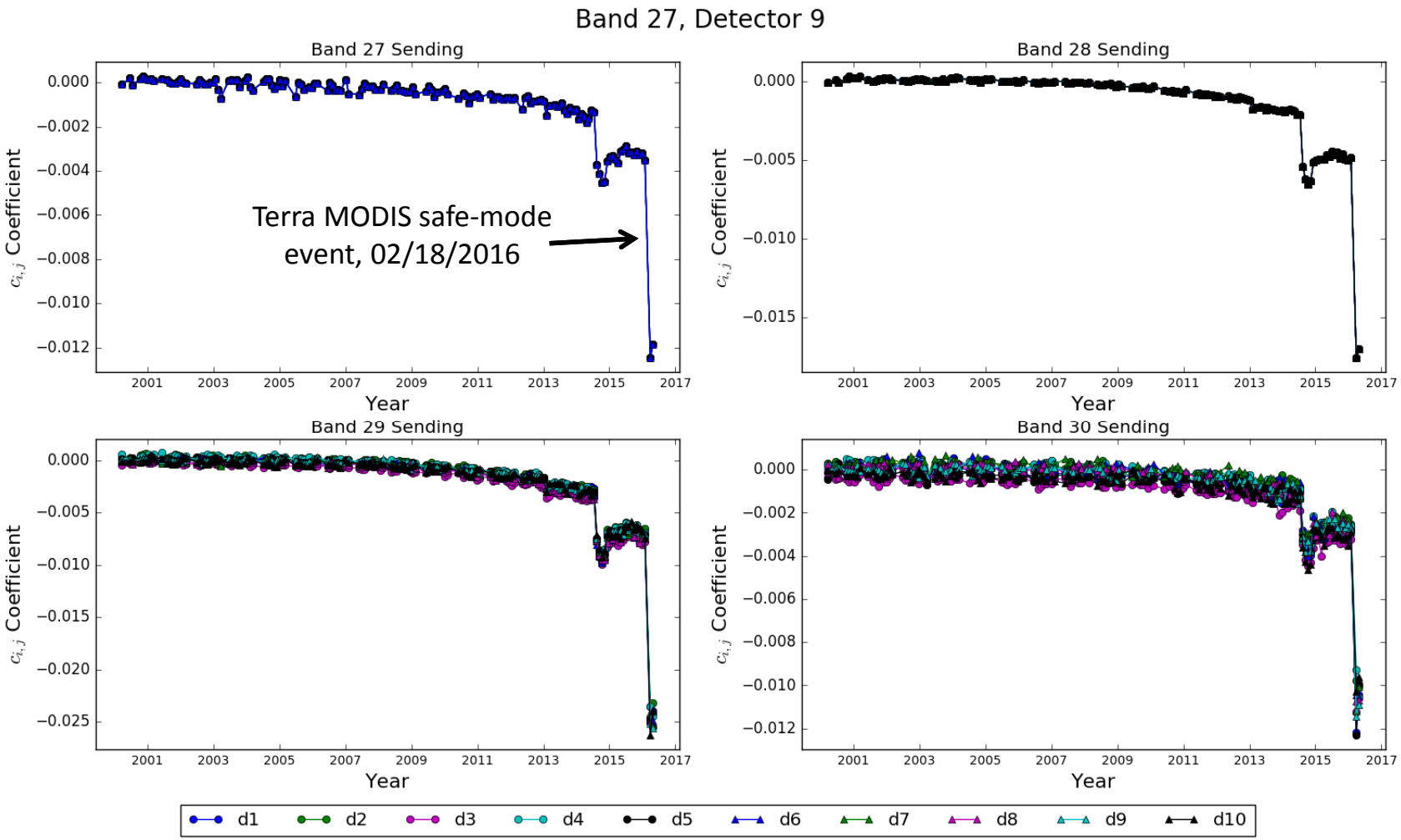
Band 27, Detector 1
08/04/2015



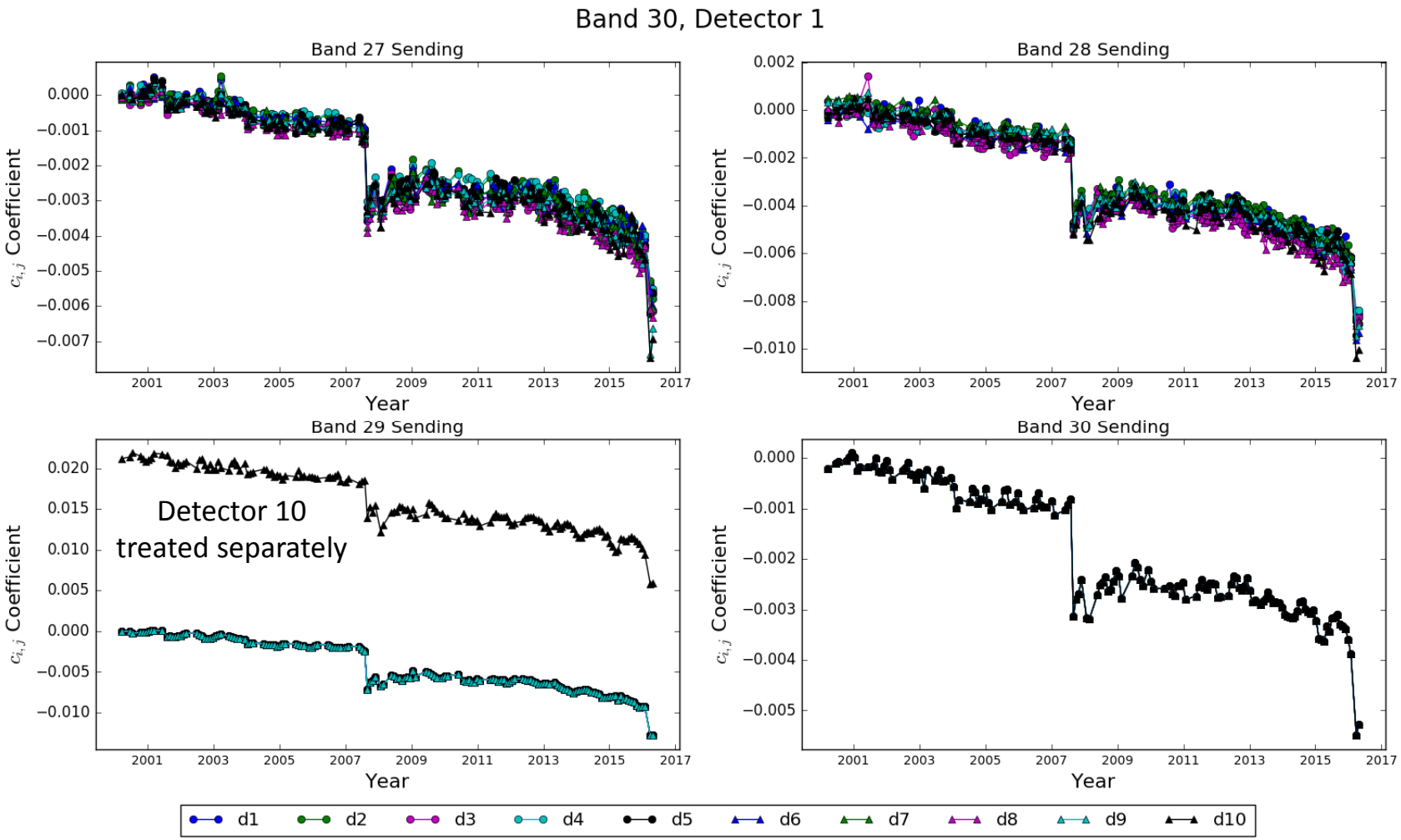
Band 30, Detector 9
08/04/2015



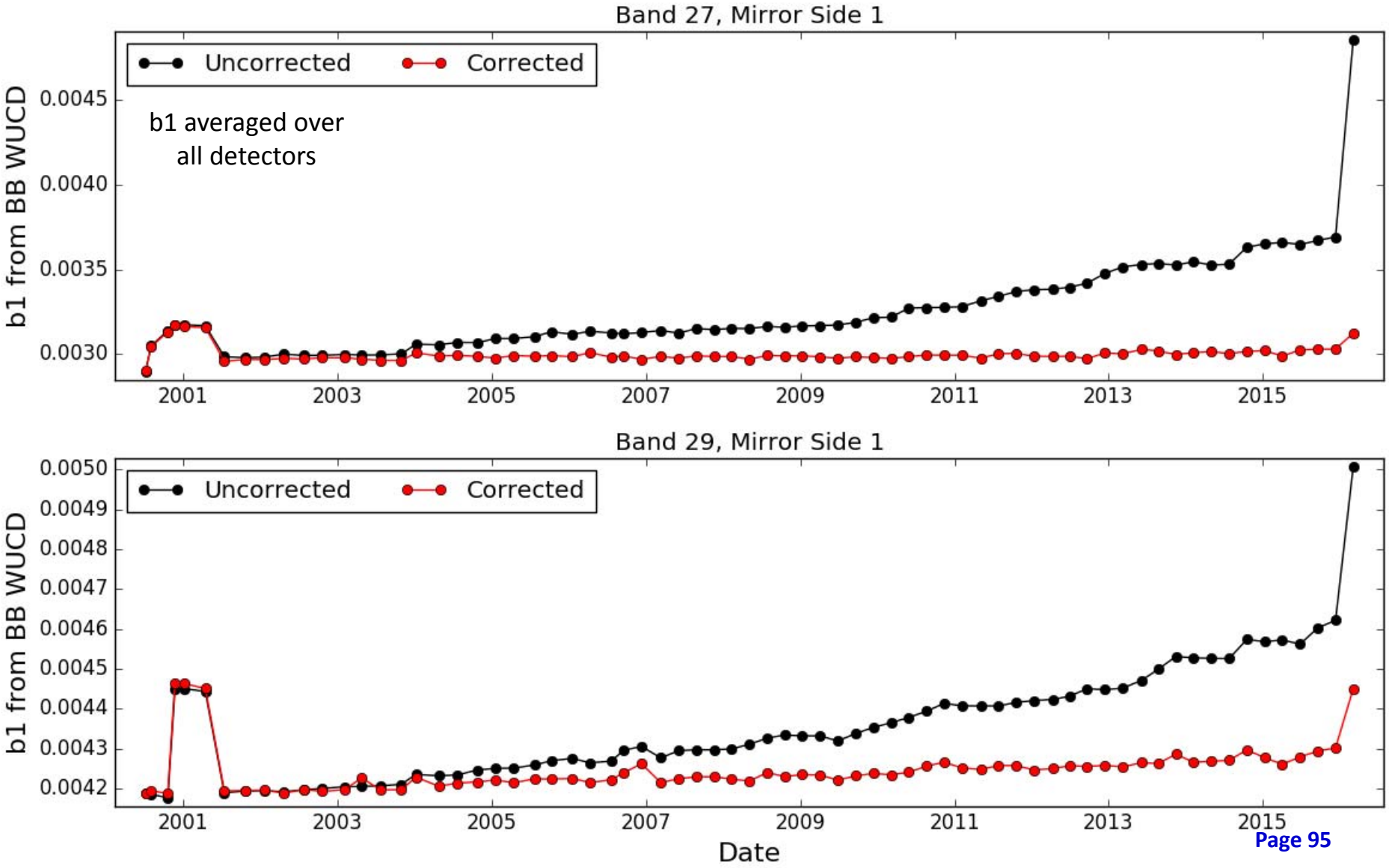
Example Trending Coefficients



Example Trending Coefficients

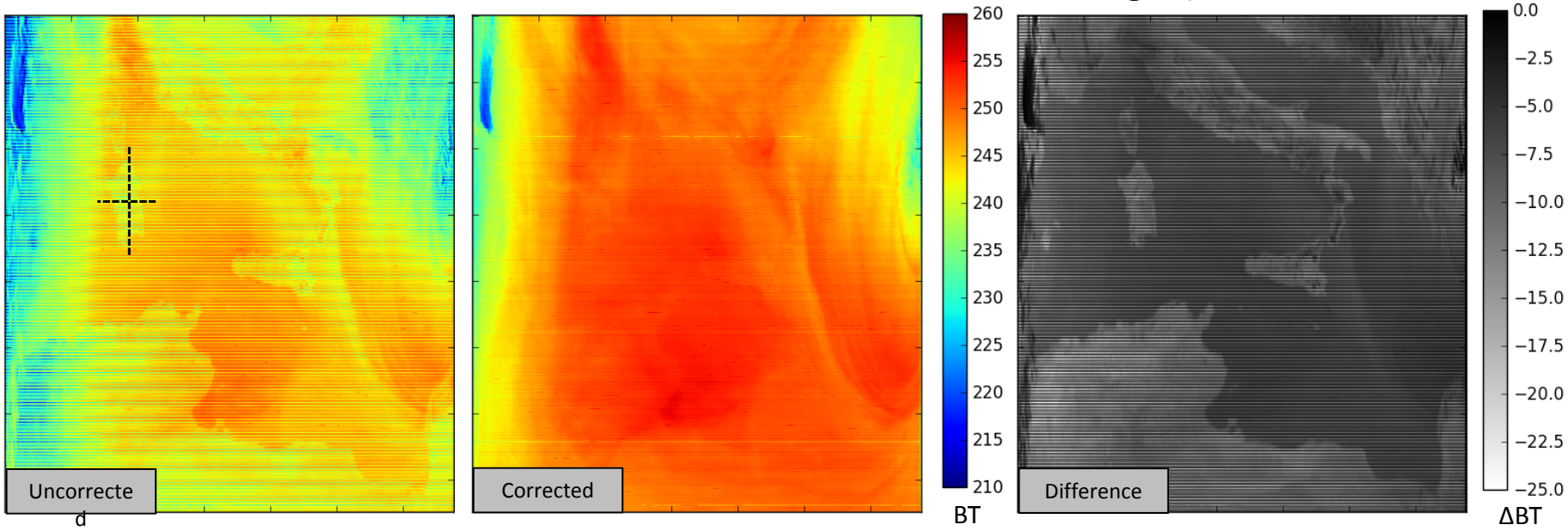


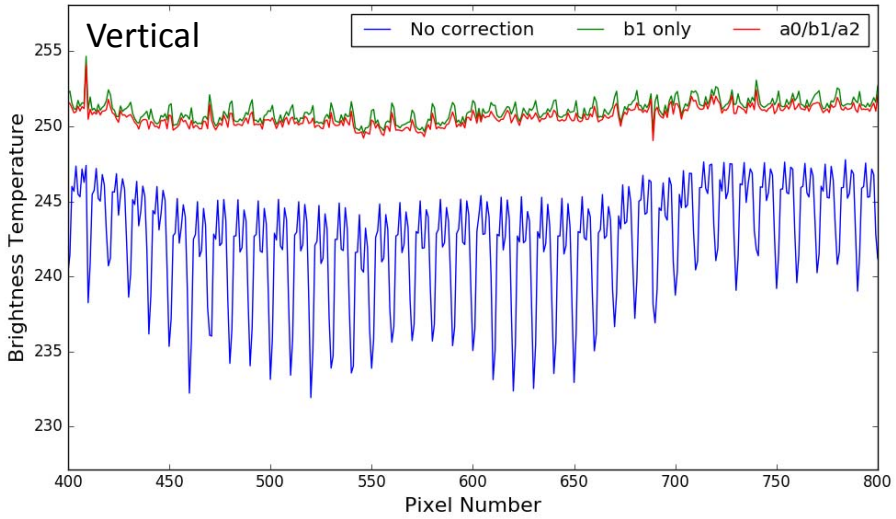
Trending Gain Coefficients

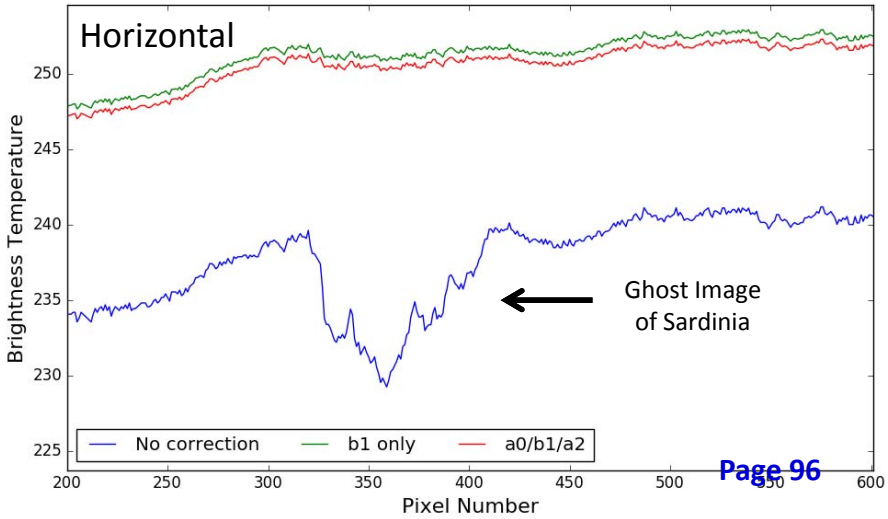


False Land Features in Band 27

Band 27, Granule 2015183.1005 (Band Averaged)

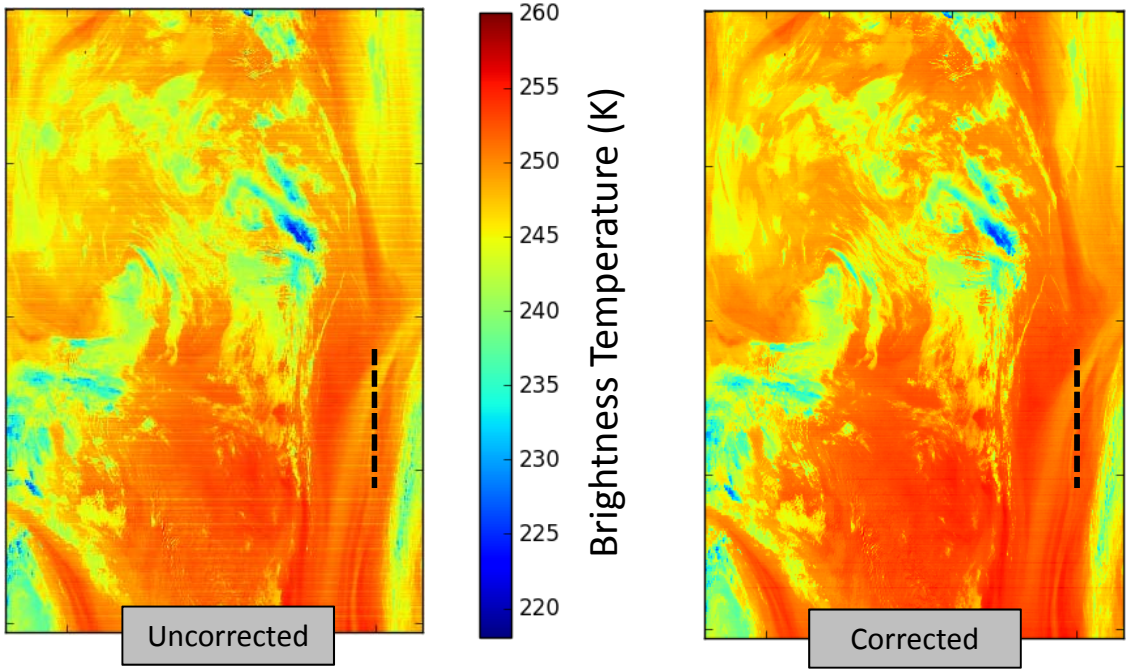


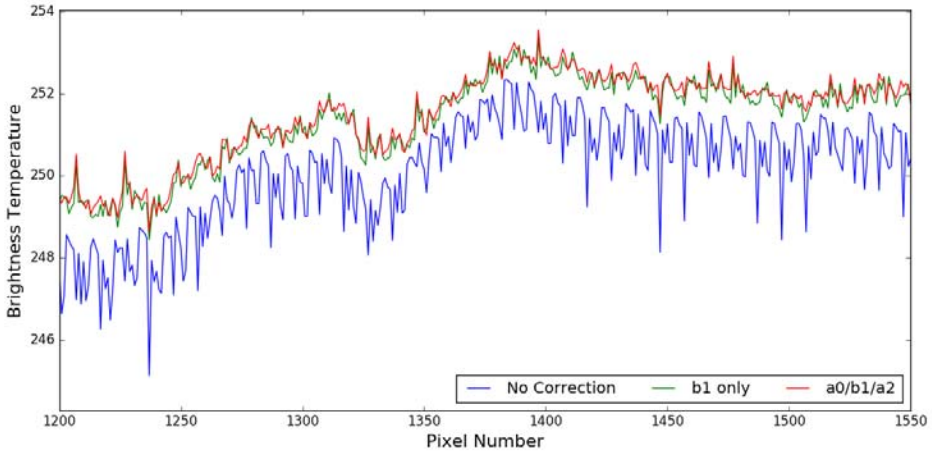


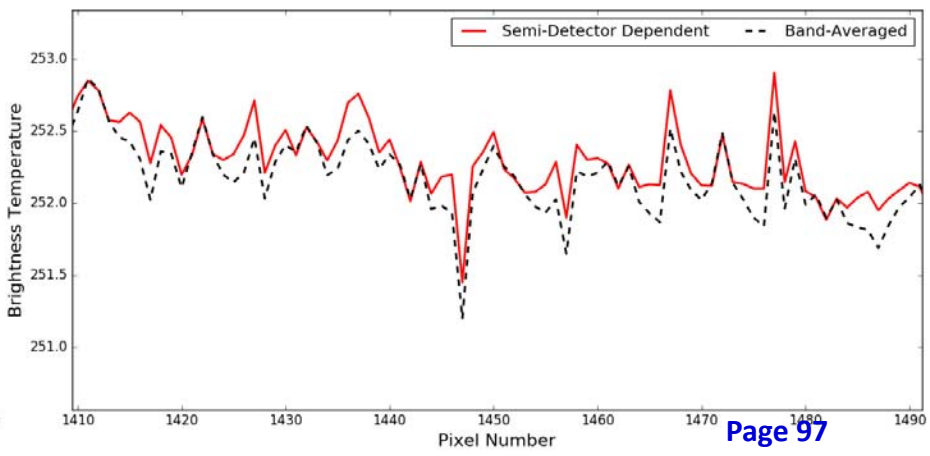


Correction of Image Striping in Band 28

Band 28, Granule 2015182.1405

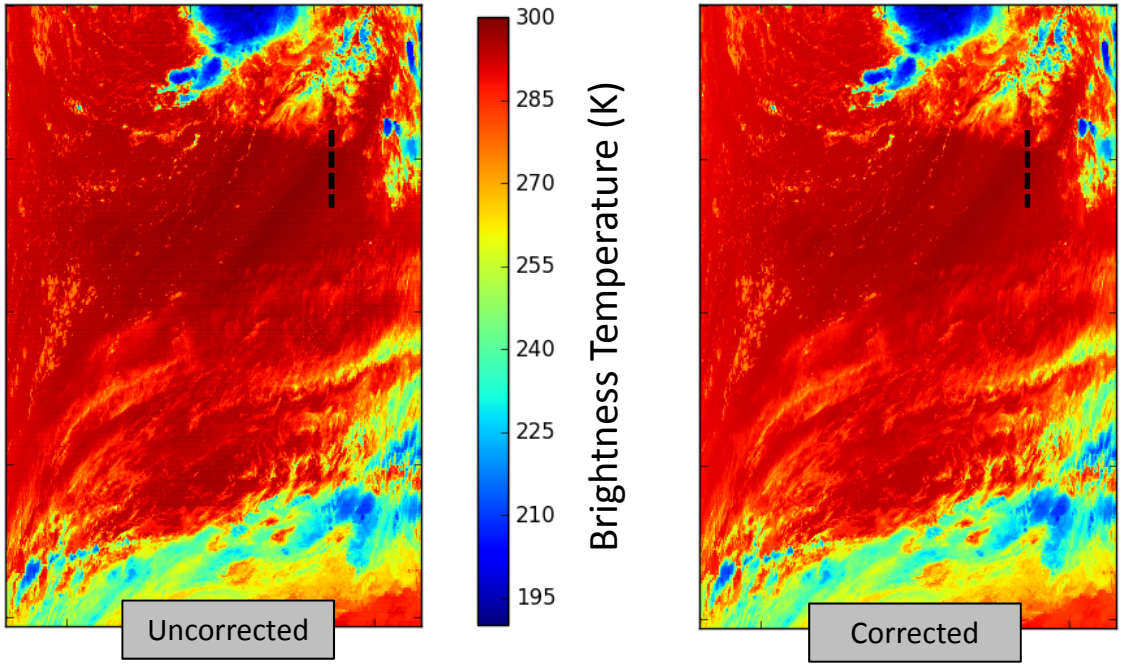


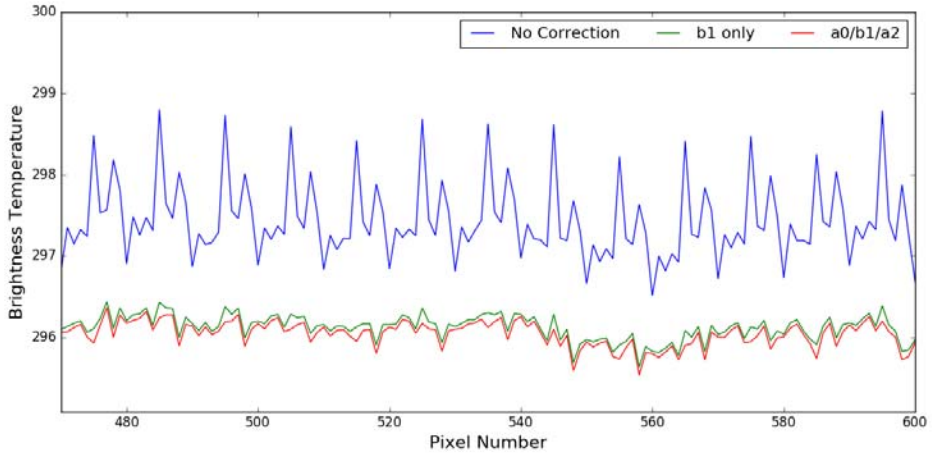


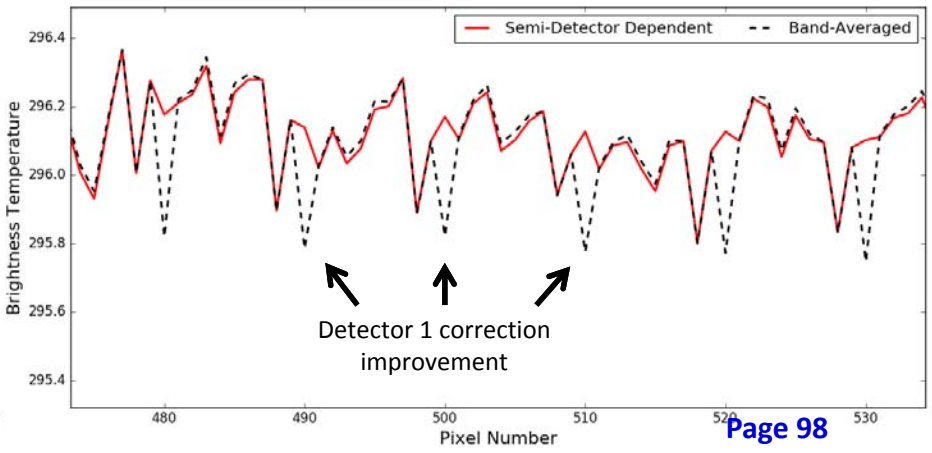


Correction of Image Striping in Band 29

Band 29, Granule 2015182.1345

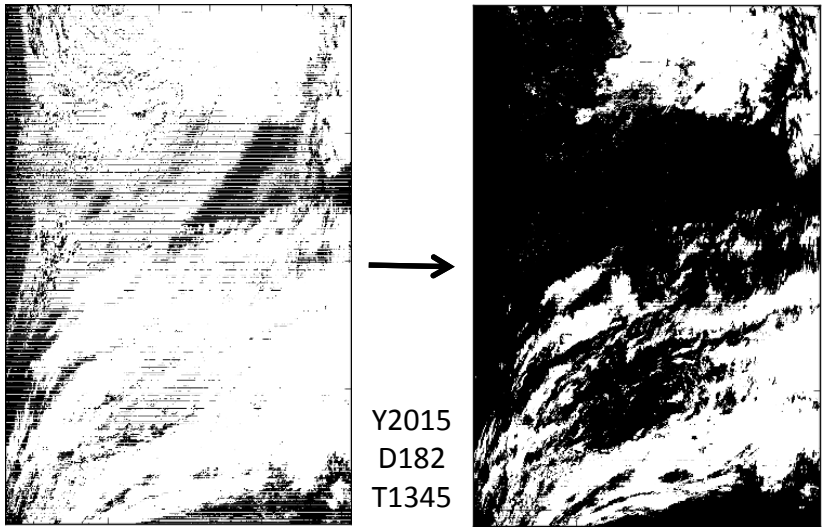




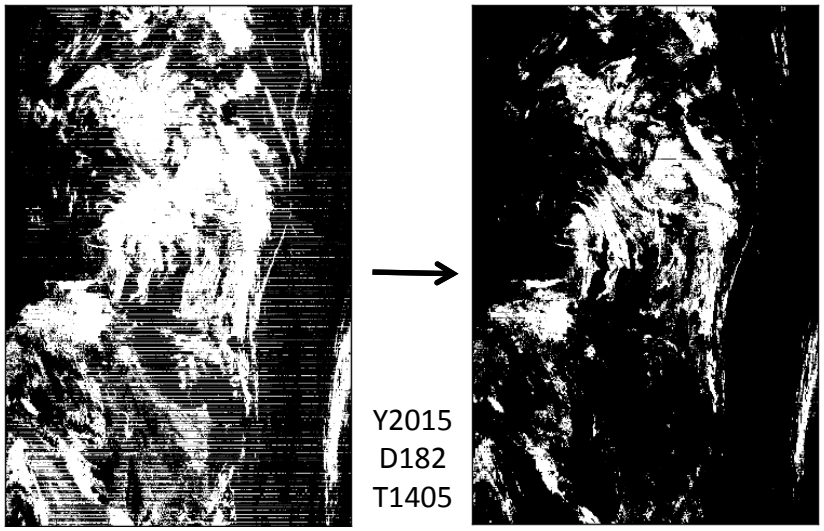


B29 – B31 Cloud Mask

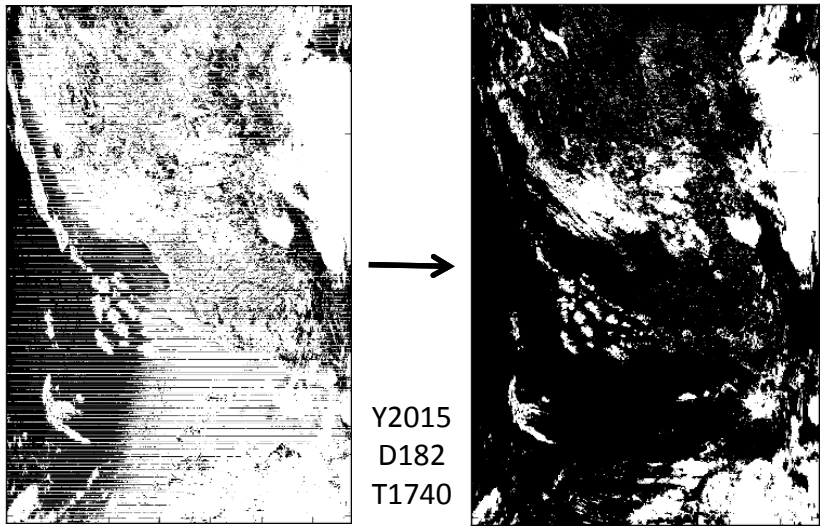
Threshold set at $\Delta BT_{B29-B31}$ = -0.5 K



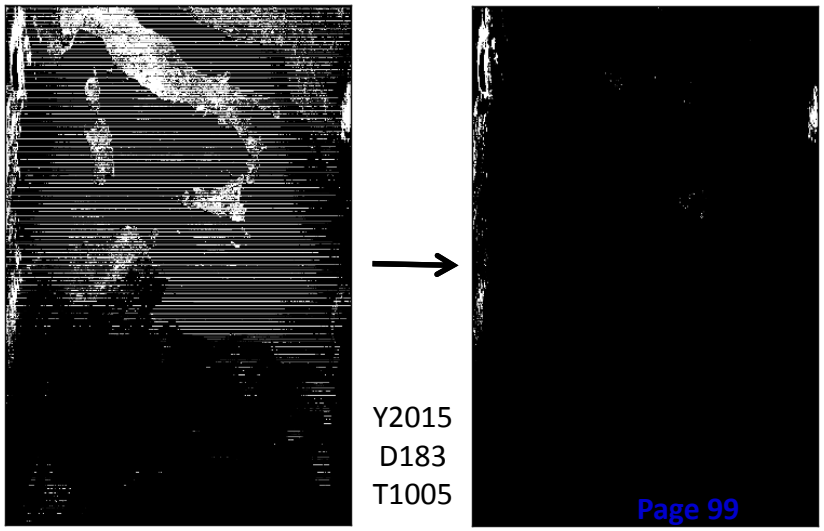
Y2015
D182
T1345



Y2015
D182
T1405



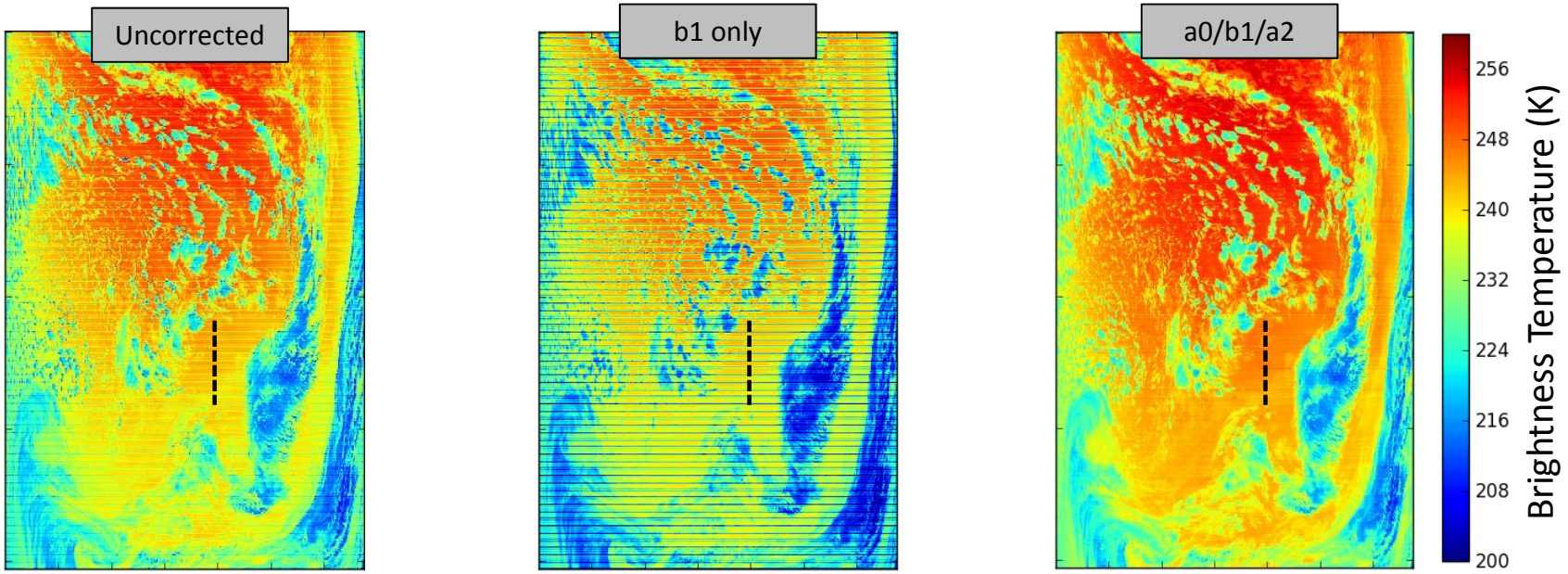
Y2015
D182
T1740



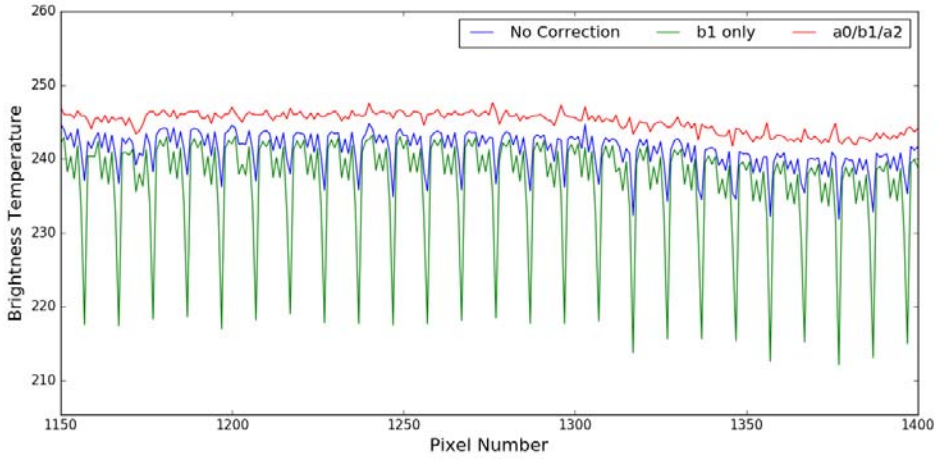
Y2015
D183
T1005

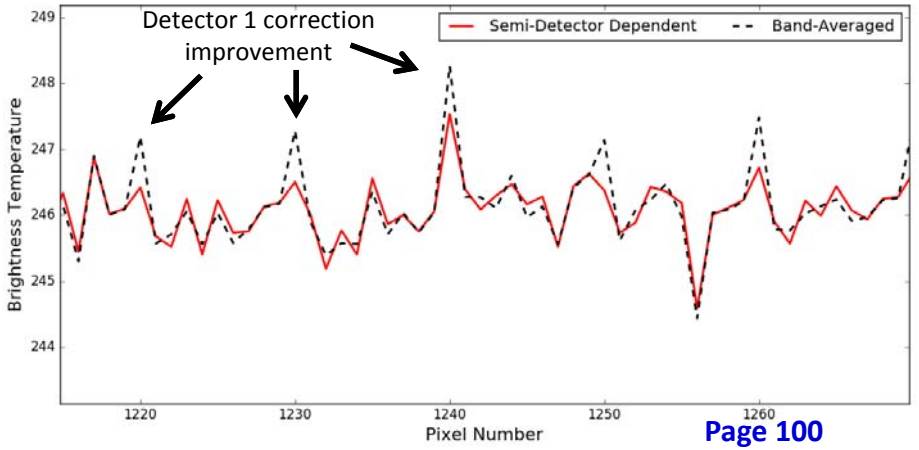
Correcting a0/b1/a2 for Band 30

Band 30, Granule 2015182.1345



The difference in the "b1" correction vs "a0/a2" correction has also been observed in *Sun et. al., Remote Sens.* ***2016****, 8(3), 249.*





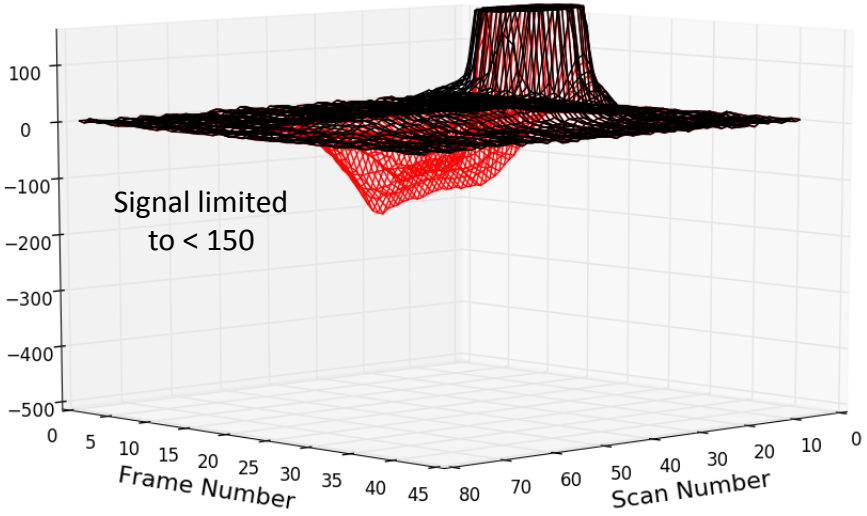
Conclusions

- **Lunar Based Approach**
  - Using the lunar-based crosstalk correction, we are able to derive correction coefficients for Bands 27-30
  - Applying these coefficients corrects a drift the the gain over the course of the mission
  - Testing on L1B granules shows a significant reduction in the striping of images, and the removal of many image artifacts.
- **Other Approaches**
  - We are working to develop an empirical model based on observed temperature drifts between other bands and sensors to provide a correction
  - We are also working to develop another physics based model to provide corrections to the data and check for consistency with the lunar based approach

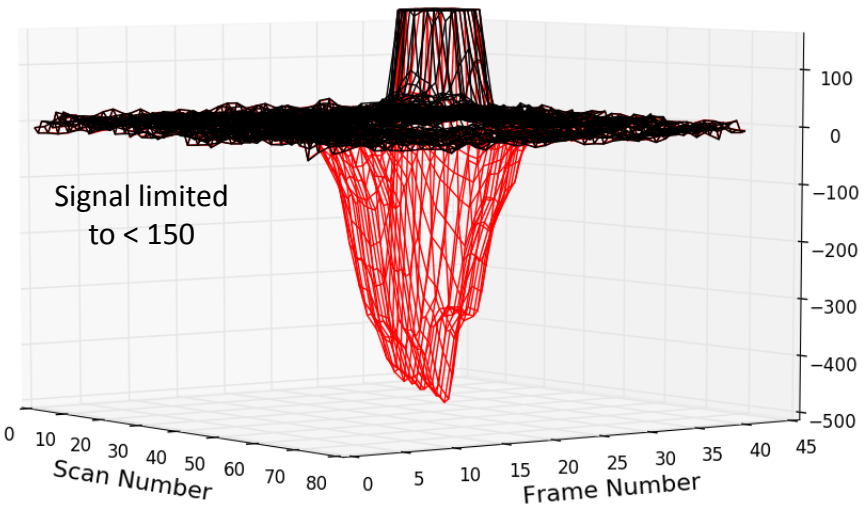
Auxiliary Slide: Impact of Safe-Mode

- **The red data represents the contaminated signal. The black data is the signal after the correction coefficients are found and applied.**

Band 27, Detector 9
01/28/2016

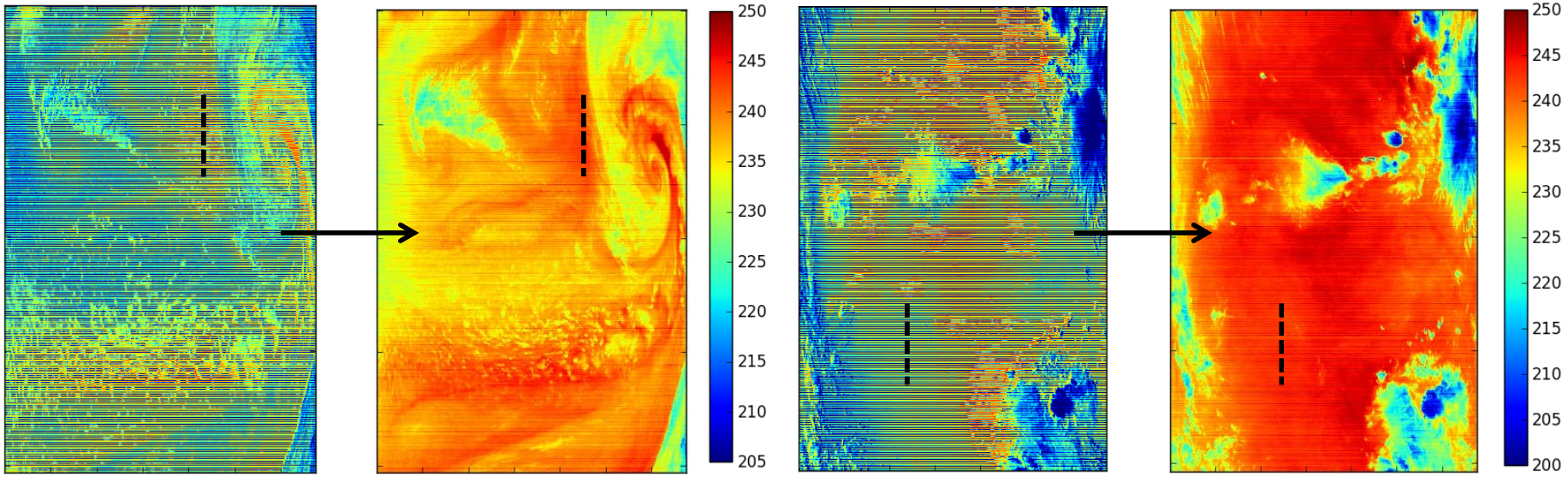


Band 27, Detector 9
03/28/2016



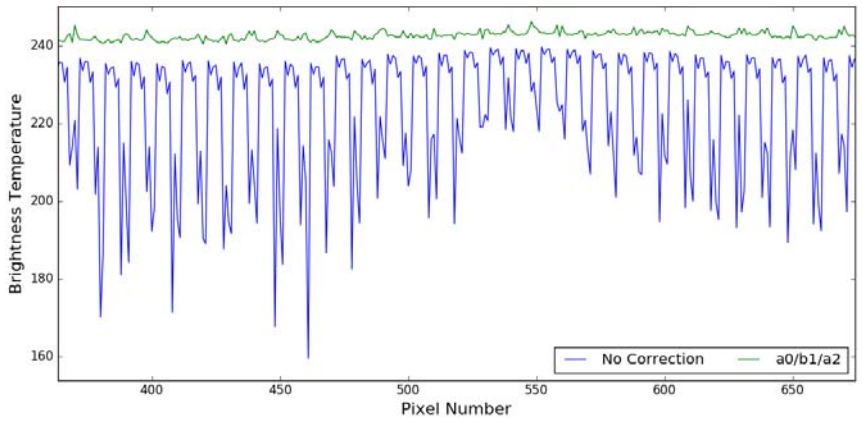
- **The contaminating signal increases by more than a factor of 2 for some detectors.**
- **The background noise for some detectors also increases, leading them to be flagged as noisy. This is one such case.**

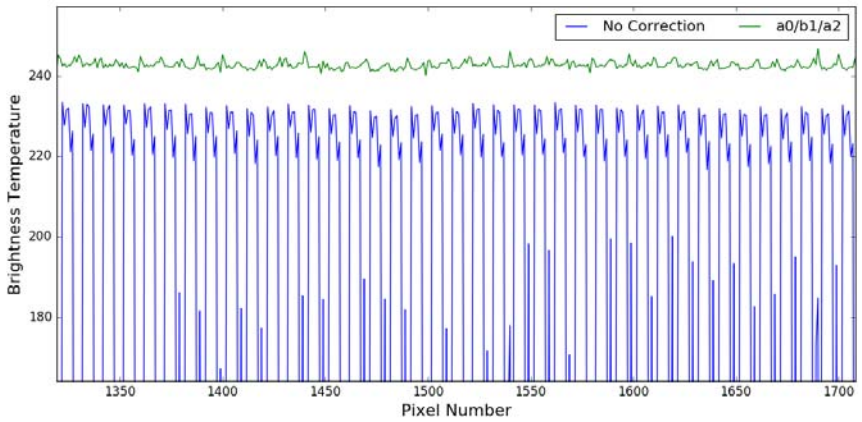
Auxiliary Slide: Impact of Safe-Mode, Band 27



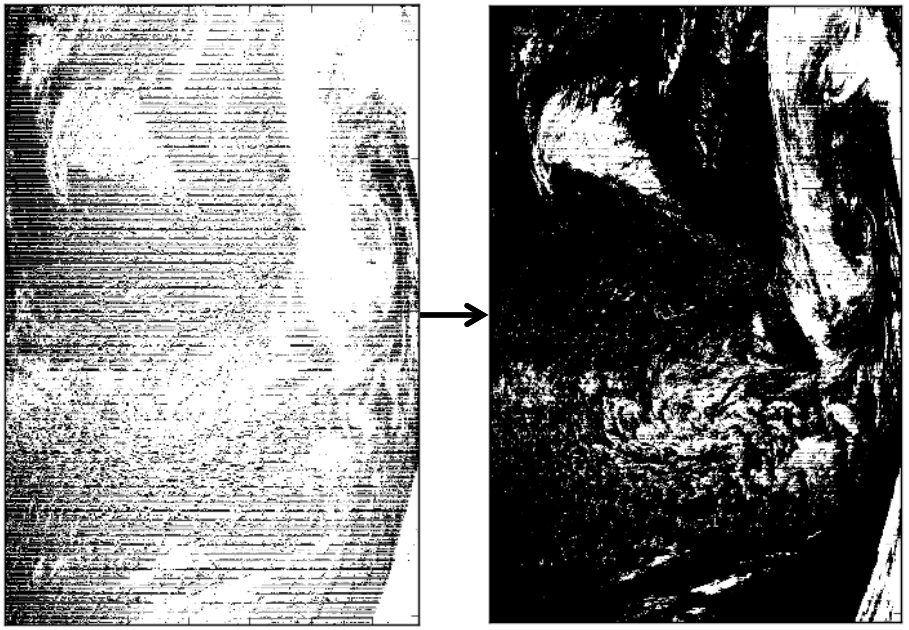
2016088.1150 2016088.1840

Many pixels before correction are below the background level (as much as 12% of the image), leading to negative radiance.

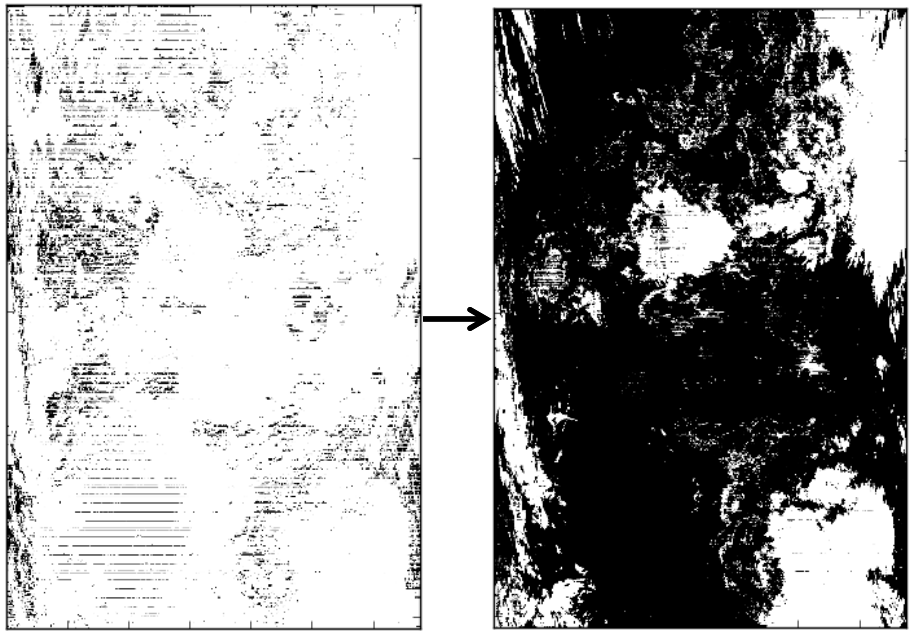




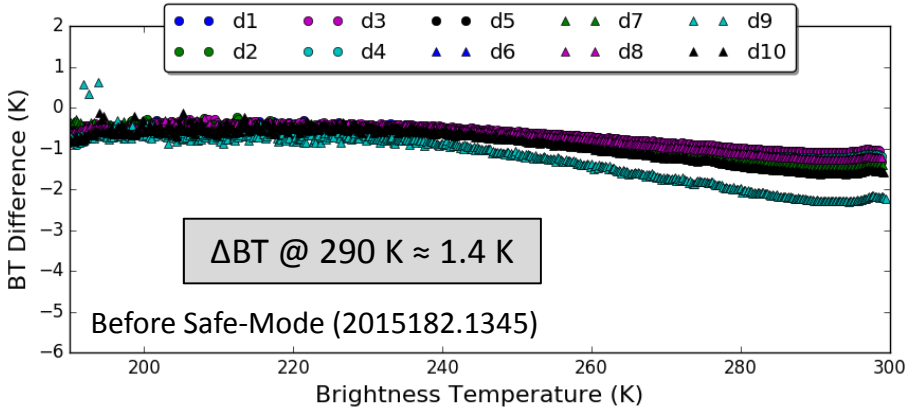
Auxiliary Slide: Impact of Safe-Mode, Band 29

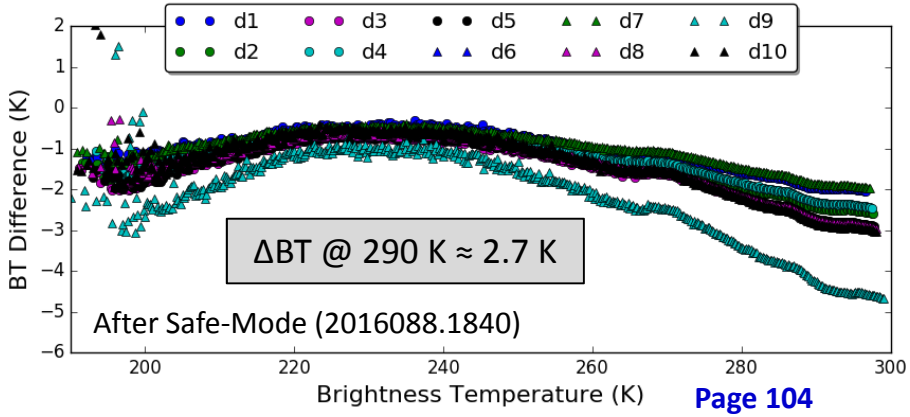


2016088.1150



2016088.1840





Auxiliary Slide: Comparison with Previous Approach

Band 27, Granule 2012159.1820