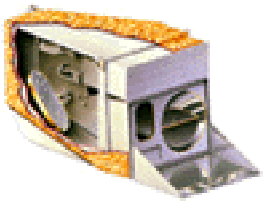
MODIS Operation, Calibration & Performance

Jack Xiong (NASA GSFC)

and

MODIS Characterization Support Team (MCST)

MODIS Science Discipline Representatives



MCST Workshop at MST Meeting (April 17, 2013)

Introduction

- **Acknowledgements**
  - MODIS Characterization Support Team (MCST)
    - Instrument Operation Team (IOT)
    - Level 1B Group
    - Calibration Group (RSB, TEB, LUT delivery)
  - MODIS Sensor Working Group (MsWG)
    - Discipline Representatives (ocean, land, and atmosphere)
  - Others
    - NASA HQ (funding support for both Terra and Aqua missions)
    - MODIS Science Team (science contributions)
    - User Community

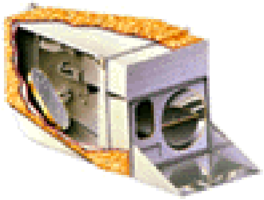
Agenda

<u>MODIS Operation, Calibration, and Performance</u>	
Introduction (Jack Xiong)	08:30 am
MODIS Operation and L1B Status (Brian Wenny)	08:35 am
Thermal Emissive Bands Calibration and Performance (Aisheng Wu)	08:50 am
Reflective Solar Bands Calibration and Performance (Amit Angal)	09:10 am
Special Topics (Junqiang Sun)	09:30 am
MODIS Geo-location Status (Robert Wolfe)	09:50 am
Summary and Plans (Jack Xiong)	10:10 am
Break	10:30 am
<u>Science Discipline Presentations</u>	
Land Discipline Cal/Val Updates – RSB (Eric Vermote)	10:45 am
Land Discipline Cal/Val Updates – TEB (Simon Hook)	11:00 am
Ocean Discipline Cal/Val Updates (Gerhard Meister)	11:15 am
Atmosphere Discipline Cal/Val Updates – RSB (TBD)	11:30 am
Atmosphere Discipline Cal/Val Updates – TEB (Chris Moeller)	11:45 am
Discussions (All)	12:00 pm
Adjourn	12:15 pm

References: ST M Plenary Presentations on MODIS Instrument Status and L1 C6

MODIS Operation, Calibration & Performance

MODIS Characterization Support Team (MCST)



MCST Workshop at MST Meeting (April 17, 2013)

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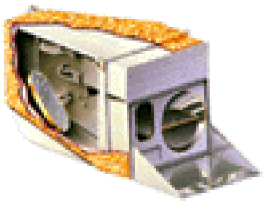
MODIS Instrument Operations Status



MCST Workshop at MST Meeting (April 17, 2013)

Terra Flight Operations

- Terra Spacecraft Status
  - 13+ years of successful operation
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – 33 supersets allocated: no change since June 2007
  - 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 #67-72, Inclination Adjustment #32-34

Aqua Flight Operations

- Aqua Spacecraft Status
  - 11+ years of successful operations
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – Full allocation
  - Battery – Fully functional
  - AMSR-E – antenna operation recovery operation was successful in 12/4/2012 – currently operating at 2 rpm (instead of 40 rpm)
  - Orbit Maneuvers: Drag Make-up #59-70, Inclination Adjustment #35-36

MODIS Instrument Operations (Terra)

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

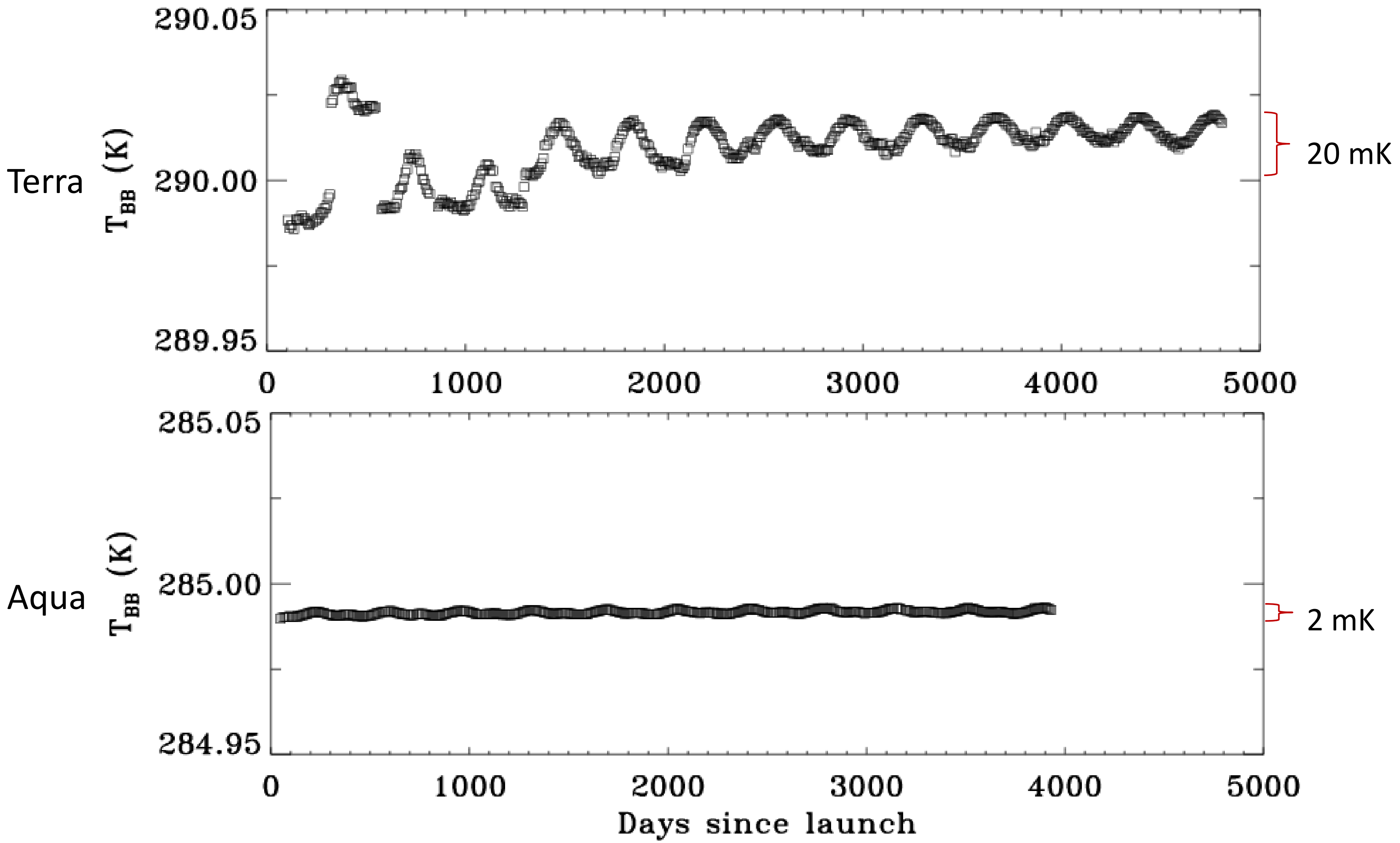
- **Operational Configuration (No change since last STM)**
  – A-side: launch to Oct 30, 2000
  – B-side: Oct 30, 2000 to June 15, 2001
  – A-side: July 02, 2001 to Sept 17, 2002
  – A-side electronics and B-side formatter: Sept 17, 2002 to present
  – BB temperatures set at 290K
  – Cold FPA (SMIR and LWIR) controlled at 83K
  – SD door fixed to "open" position since July, 2003
- **Events**
  – None
- **Concerns**
  – SSR allocation – further decrease could result in data loss

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.

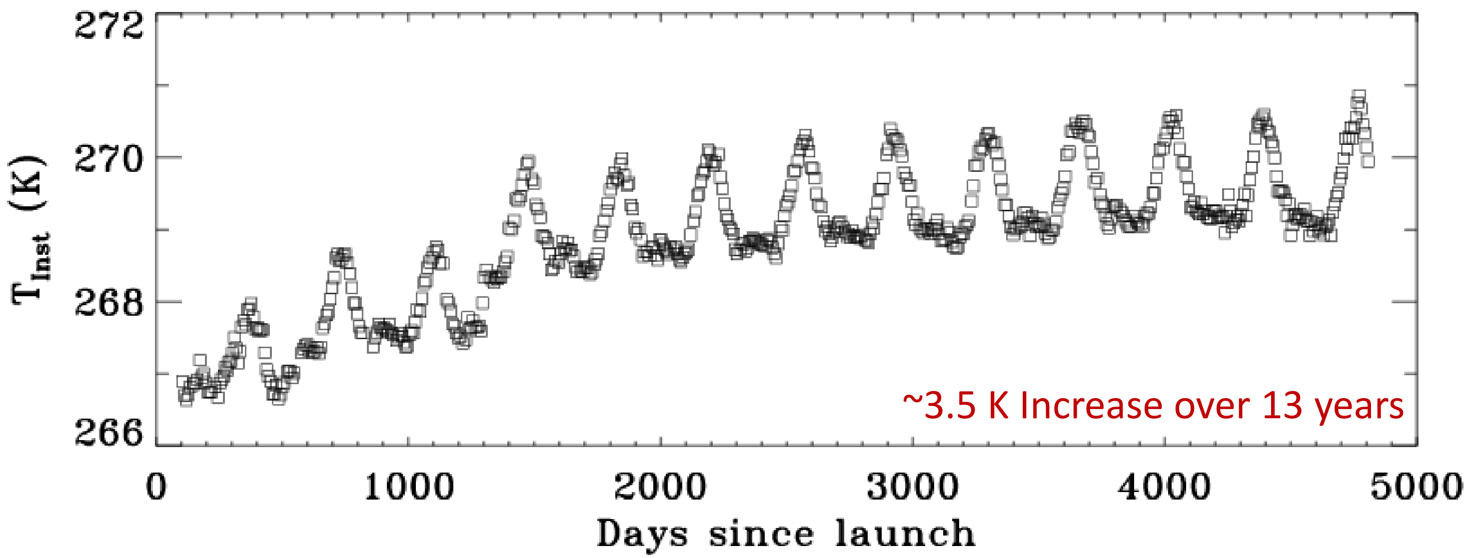
Telemetry Trends (BB)



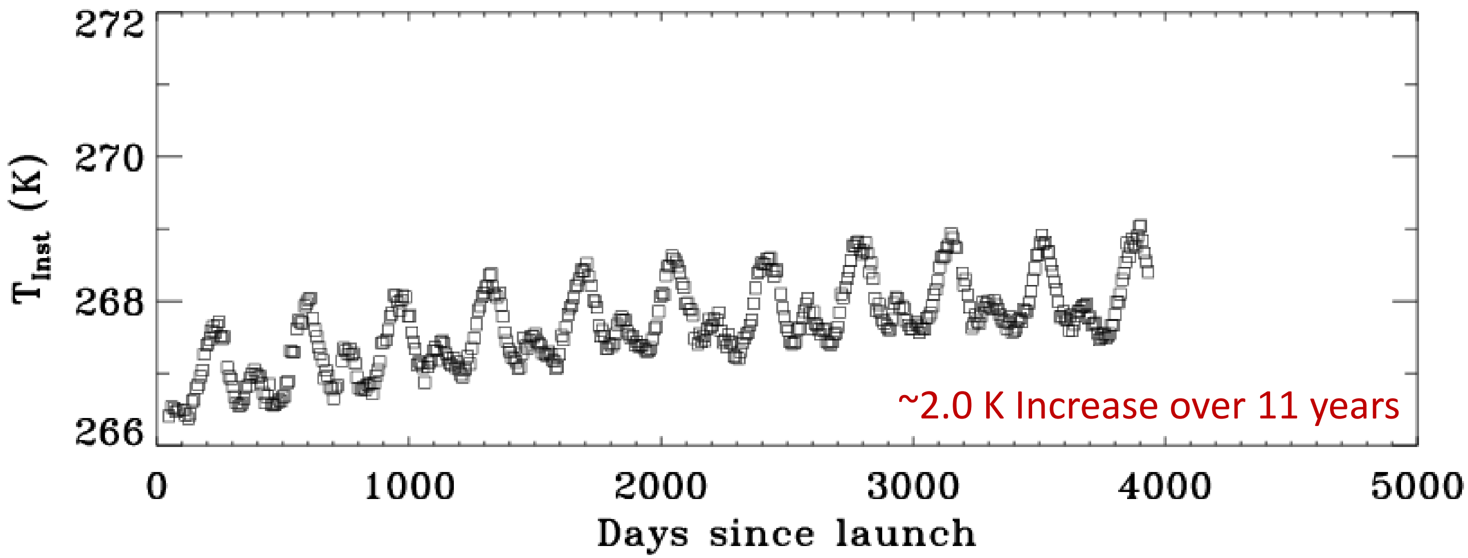
Weekly average (Cal events excluded)

Telemetry Trends (Instrument)

Terra



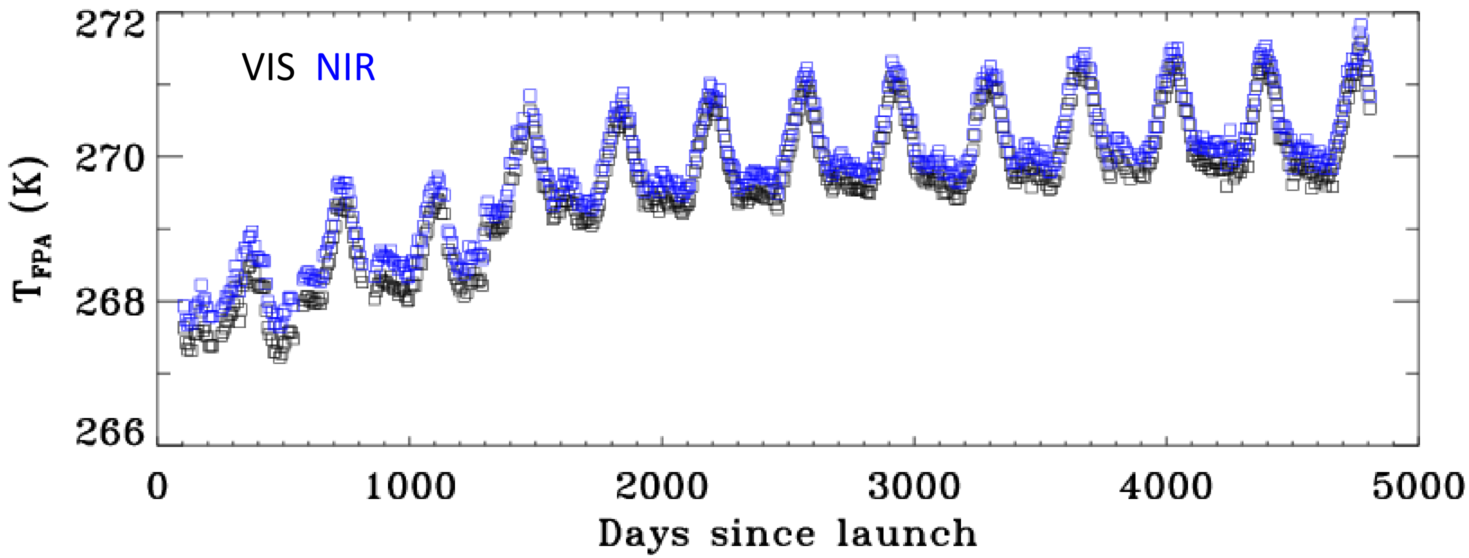
Aqua



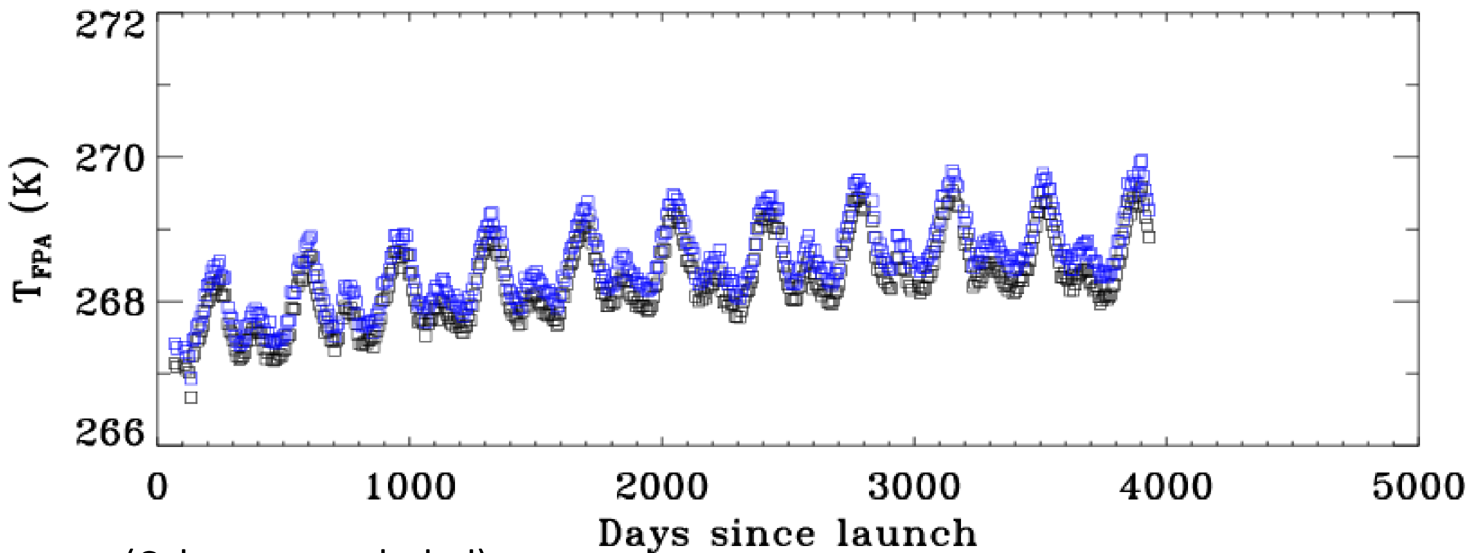
Weekly average (Cal events excluded)

Telemetry Trends (Warm FPA)

Terra



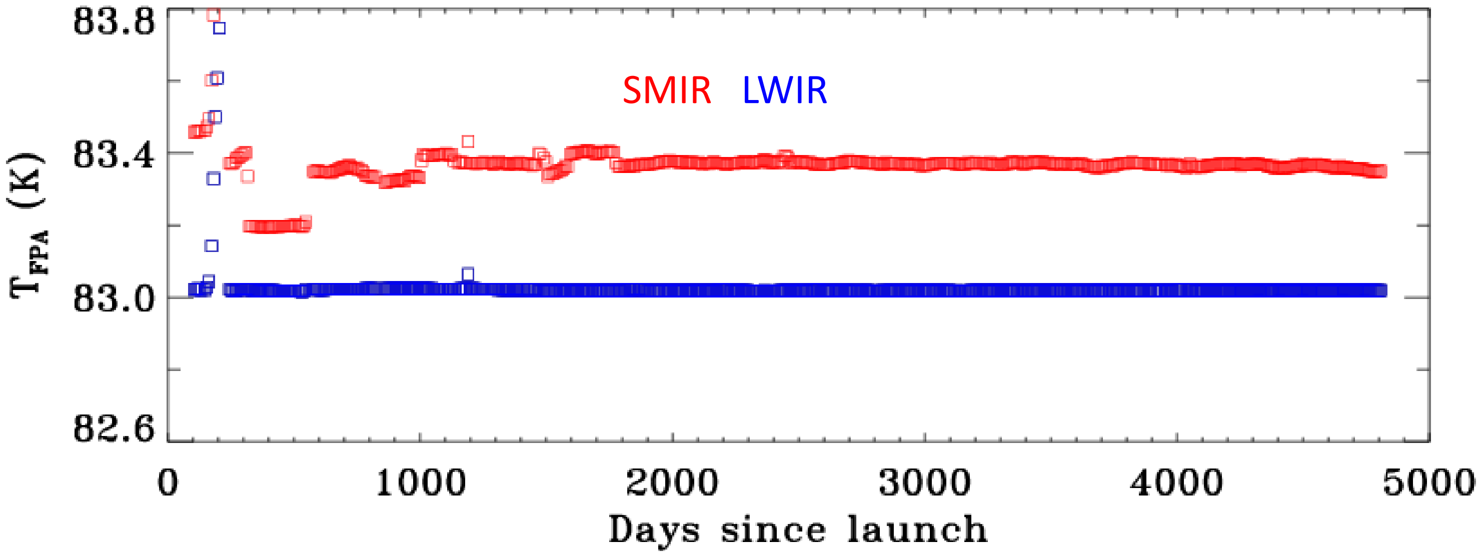
Aqua



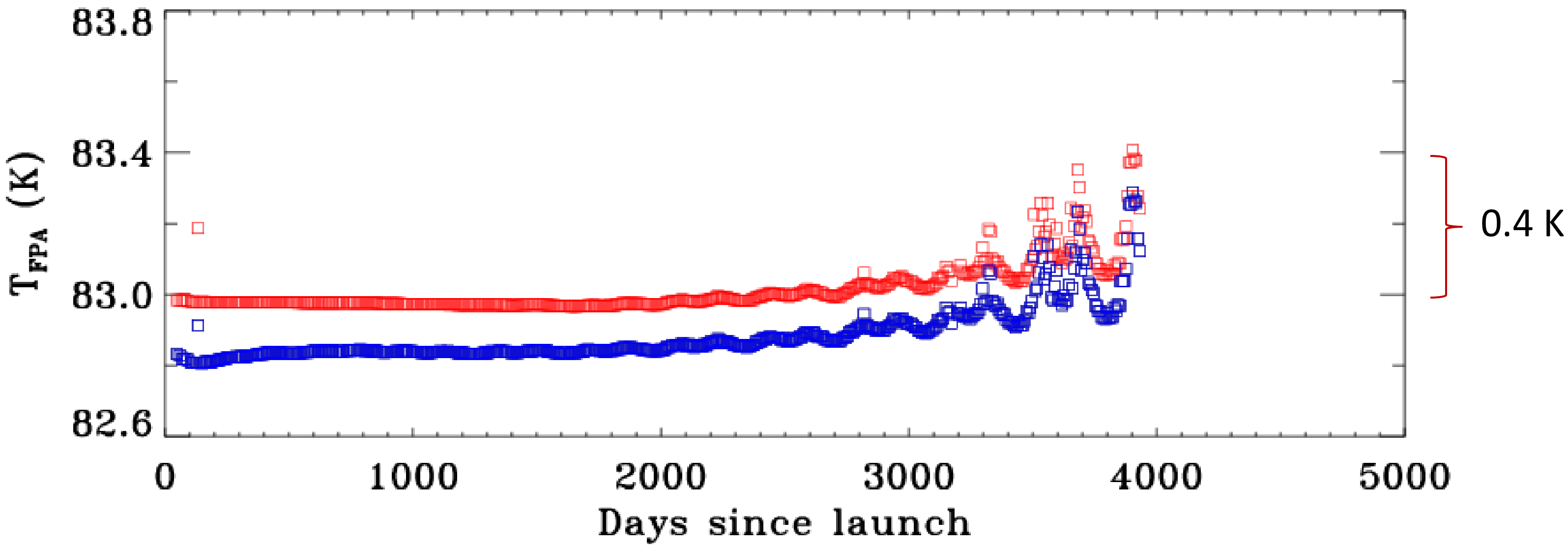
Weekly average (Cal events excluded)

Telemetry Trends (Cold FPA)

Terra

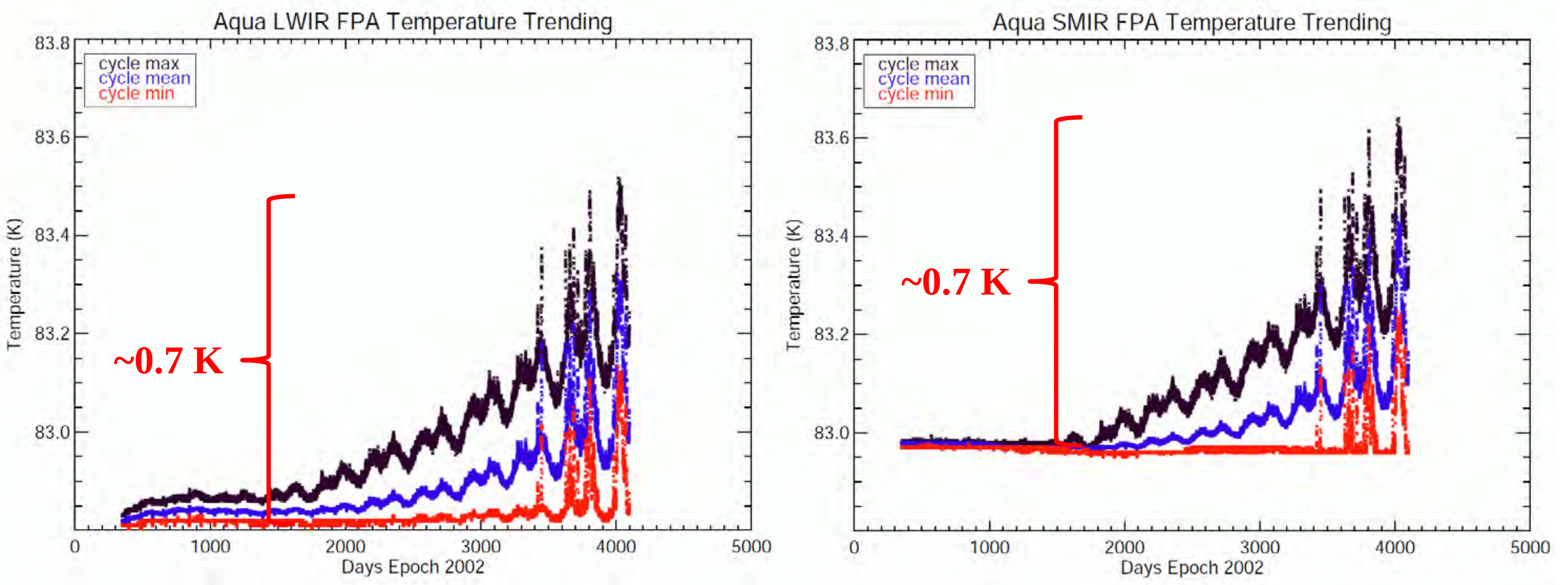


Aqua



Weekly average (Cal events excluded)

Aqua CFPA Oscillations
Long-term trend

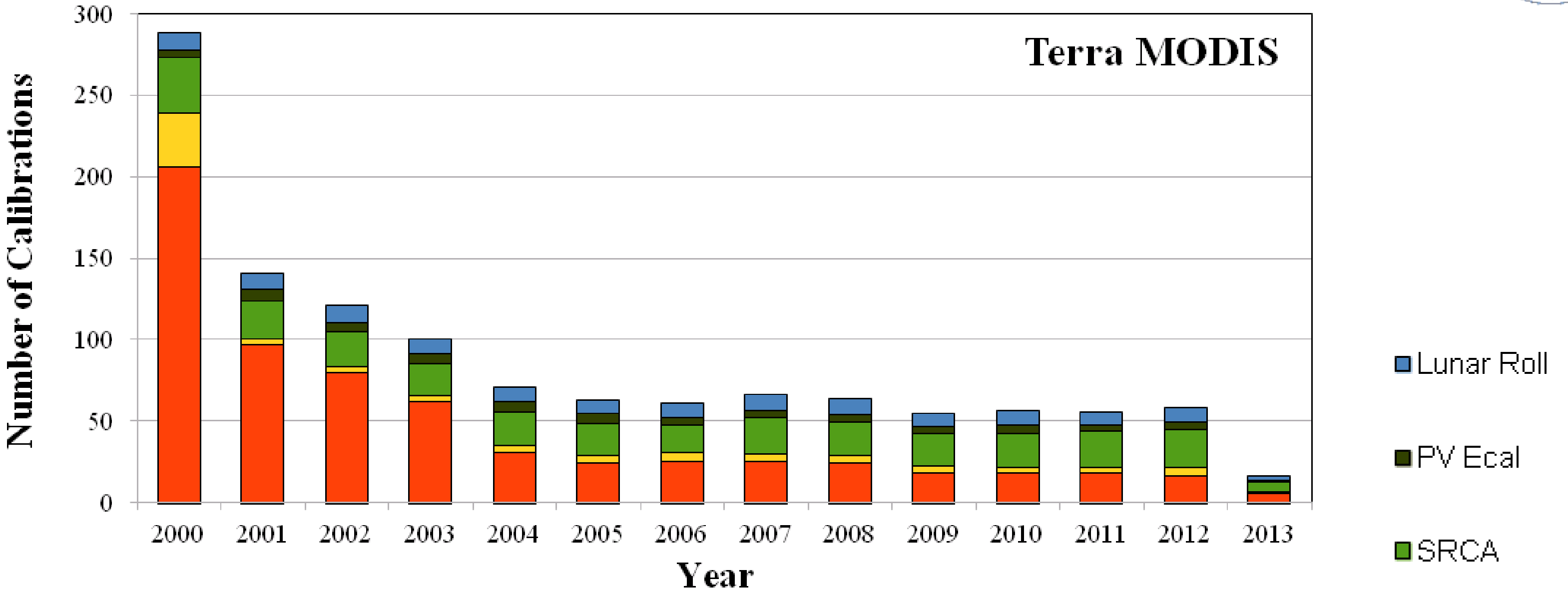


LWIR SMIR

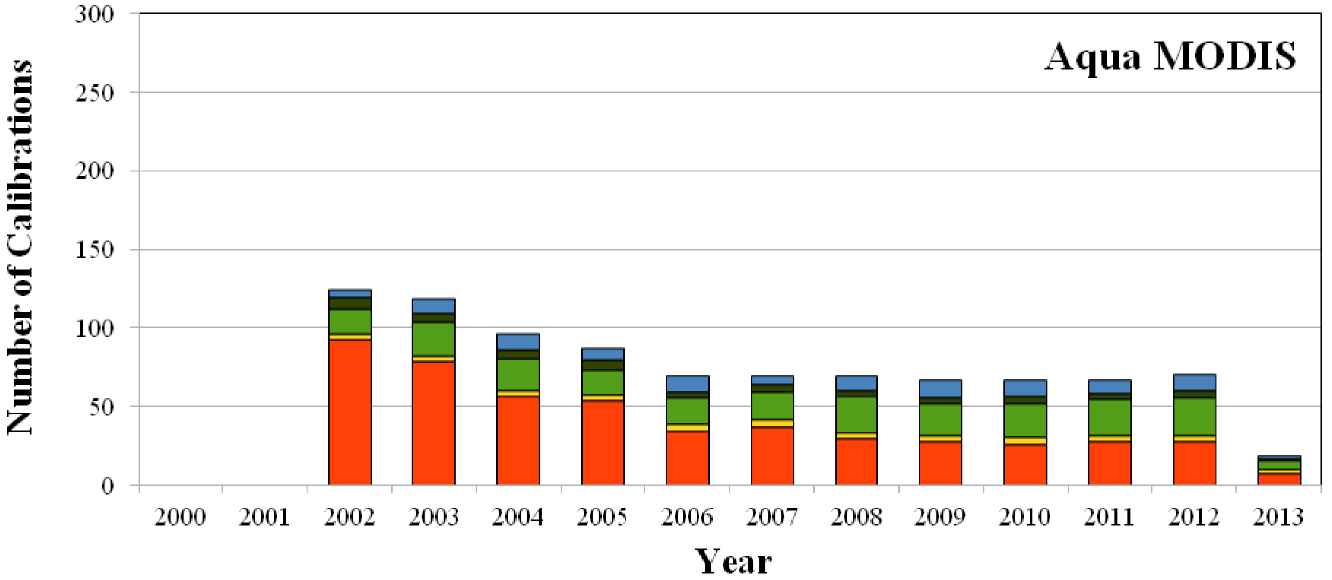
Max/Min of 4 orbits, every 8 hours

MODIS Calibration Operations

Terra



Aqua



Terra/Aqua MODIS OBC Operations

TERRA

Activity	PL to 05/12	05/12 – present	Total
SD/SDSM#	638	18	656
BB WUCD	79	5	84
SRCA*	352	21	373
Electronic Cal	75	5	80
Lunar Roll	112	11	123

AQUA

Activity	PL to 05/12	05/12 - present	Total
SD/SDSM#	466	27	493
BB WUCD	43	5	48
SRCA*	225	23	248
Electronic Cal	55	5	60
Lunar Roll	93	10	103

Open & Screened Activities counted independently

* Includes Spatial, Spectral and Radiometric

05/12 = last Science Team Meeting

SRCA Calibrations

- Terra – 373 SRCA Calibrations
- Aqua – 248 SRCA Calibrations

Lamp Power		10W				1W	
Lamp #		1	2	3	4	1	2
Terra	Usage (hr)	312.9	172.1	190.3	107.5	587.6	282.0
	Life (hr)	500	500	500	500	4000	4000
	percent	62.6%	**Failed on 11-20-2004**	**Failed on 2-18-2006**	21.5%	14.7%	7.1%
Aqua	Usage (hr)	306.6	188.0	205.7	114.8	528.2	274.9
	Life (hr)	500	500	500	500	5000	5000
	percent	61.3%	**Failed on 4-14-2003**	**Failed on 6-28-2005**	23.0%	10.6%	5.5%

Future Operational Considerations

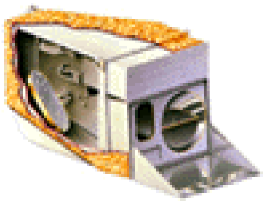
- Aqua MODIS CFPA temperature control
  - Currently set at 83K with observed ~0.4 K orbital oscillation
  - Minimal impact on science data
  - Mitigation options are under investigation
- Aqua SD/SDSM door movements
  - Passed projected lifetime limit on movements
  - No change in current frequency of SD calibration activities planned at this time

	PL to 05/12	05/12 to present	Total	Design Lifetime	% Used
Terra*	2146	0	2146	3022	71.01
Aqua+	3002	68	3070	3022	101.59

* 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 and LUT Status



MCST Workshop at MST Meeting (April 17, 2013)

C5/C6 L1B Code and LUT Updates

- C6 L1B product for both Terra and Aqua have been reprocessed and are available for use by the science community.
- No L1B code changes made since last STM.
- LUT updates for each MODIS forward processing (since the last Science Team Meeting (5/2/2012))
  - Terra MODIS C5: 18; C6: 11; Aqua MODIS C5: 10; C6: 13
  - Additional LUTs generated, tested, and delivered to OBPG (Ocean Biology Processing Group) and Wisconsin University for special investigations
  - Most LUT updates were driven by response changes of VIS bands

Number of MCST L1B Code and LUT Versions

(as of 2013-04-17)

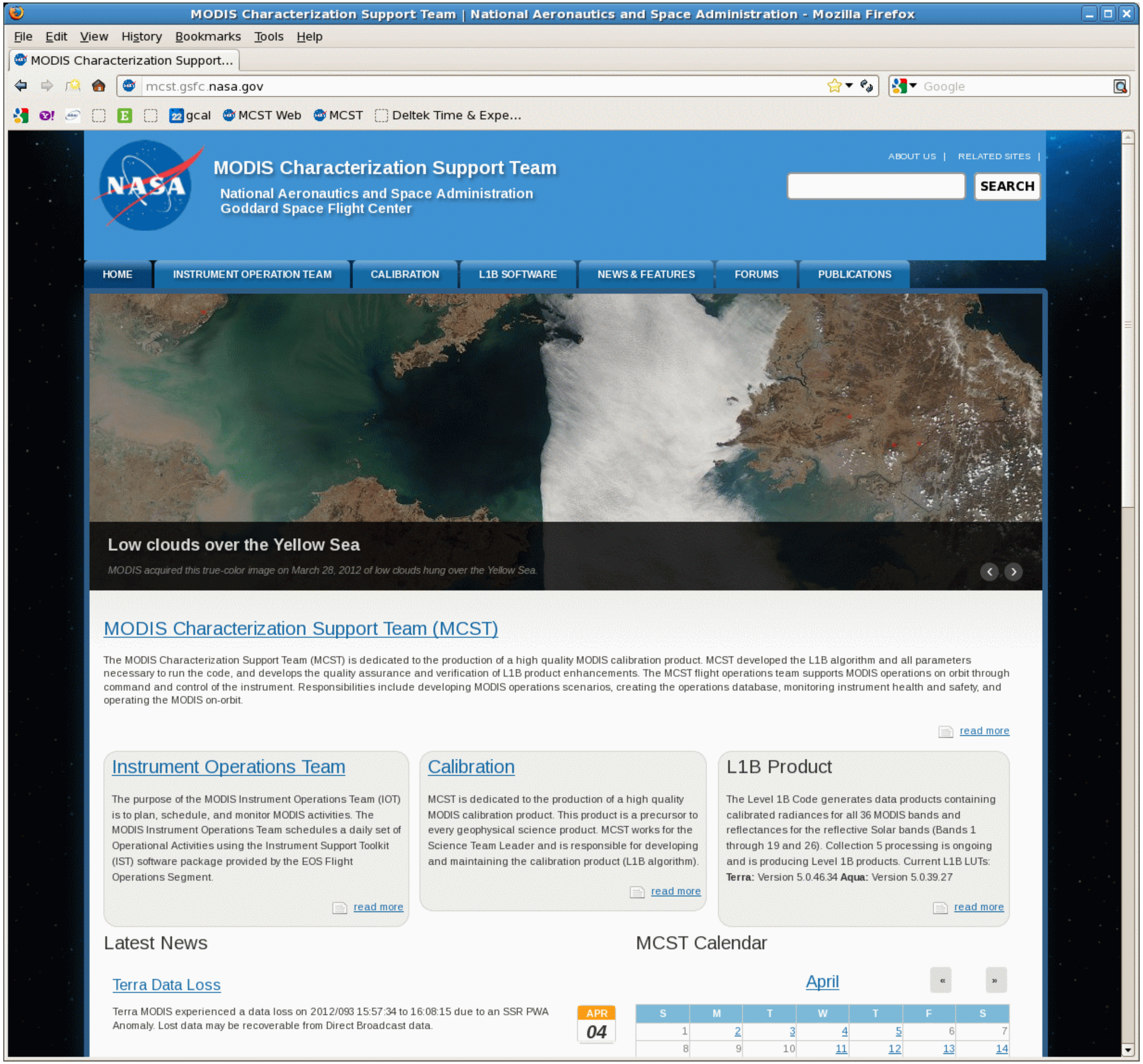
Year	Terra Code Versions	Terra LUTs C2	Terra LUTs C3	Terra LUTs C4	Terra LUTs C5	Terra LUTs C6	Aqua Code Versions	Aqua LUTs C3	Aqua LUTs C4	Aqua LUTs C5	Aqua LUTs C6	Total
2000	5	2	0	0	0	0	0	0	0	0	0	7
2001	3	1	5	0	0	0	0	0	0	0	0	9
2002	3	0	1	0	0	0	3	3	1	0	0	11
2003	3	0	0	19	0	0	3	0	17	0	0	42
2004	1	0	0	17	0	0	1	0	11	0	0	30
2005	2	0	0	18	10	0	2	0	11	6	0	49
2006	0	0	0	20	14	0	0	0	12	9	0	55
2007	1	0	0	1	13	0	0	0	0	11	0	26
2008	1	0	0	0	16	0	1	0	0	8	0	26
2009	2	0	0	0	18	0	1	0	0	8	0	29
2010	1	0	0	0	18	0	1	0	0	13	0	33
2011	1	0	0	0	18	0	2	0	0	15	1	37
2012	1	0	0	0	21	8	1	0	0	13	13	57
2013	0	0	0	0	5	4	0	0	0	2	3	14
Total	24	3	6	75	133	12	15	3	52	85	17	425

Does not include internal deliveries, nor special deliveries to Ocean Color Group or Miami & Wisconsin

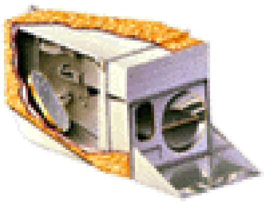
C6 L1B Major Code Changes

- **Interpolation for inoperable detectors no longer applied.**
  - Explicit fill value (SI = 65531) now used in L1B.
- **Noisy/Inoperable detector (sub-sample) QA flag**
  - If sub-sample is inoperable, the scaled integer value will be set to the flag value 65525
- **The sector rotation data handling**
  - A data anomaly is caused by the mismatch of the timing of the instrument command to perform the sector rotation and the reporting of the telemetry point that reports the angle of sector rotation.
  - The same fix was also made to C5 PGE02 on 2010-02-25 in versions 5.0.46 (Terra) and 5.0.39 (Aqua).
- **RVS model for the RSB changed from quadratic to quartic polynomial.**
- **LWIR FPA temperature dependent default b1 algorithm for Aqua bands 33, 35 and 36.**
- **Revised algorithms for calculation of the uncertainty for RSB and TEB**

http://mcst.gsfc.nasa.gov



MODIS TEB Performance



Outline

- Introduction
- TEB Performance
  - Stability & detector noise status
- TEB Collection-6
  - Changes and impacts on L1B
  - Uncertainty
- Summary

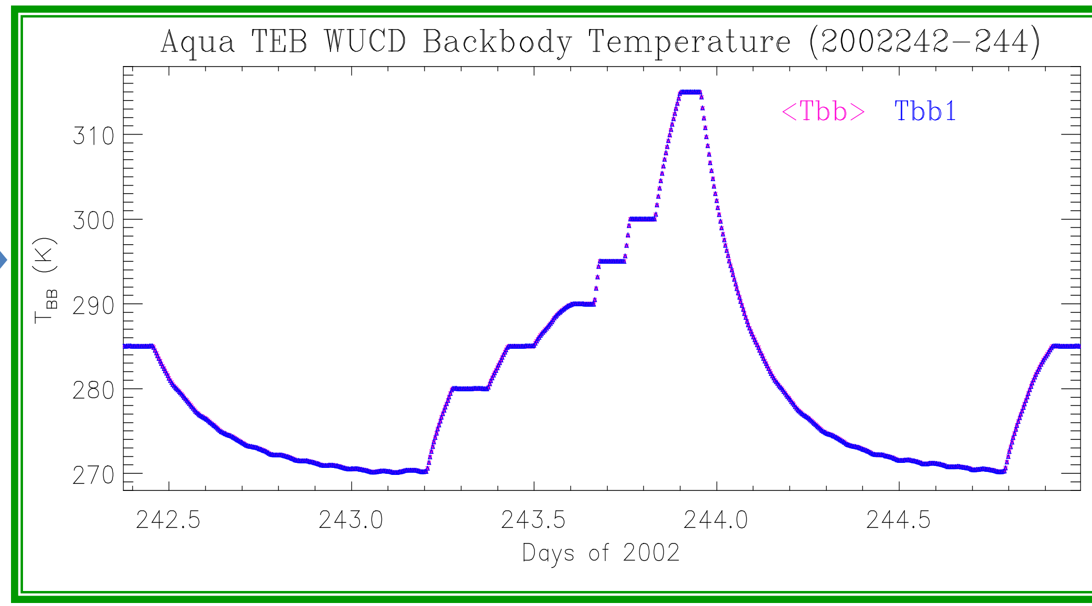
TEB Radiometric Calibration

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:

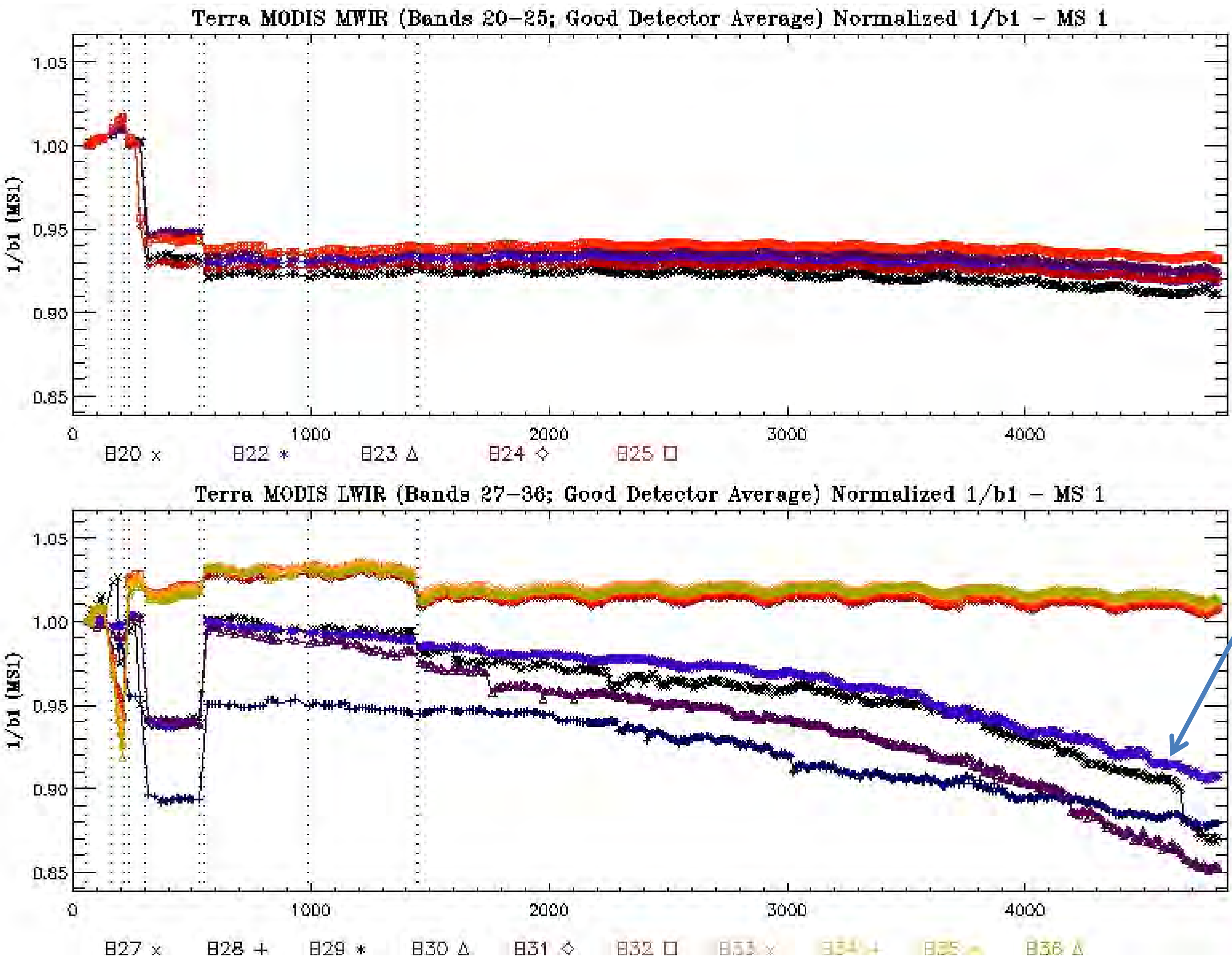
$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$



RVS: Response Versus Scan-angle
e: Emissivity
L: Spectral band averaged radiance
dn: Digital count with background corrected
RSR: Relative Spectral Response

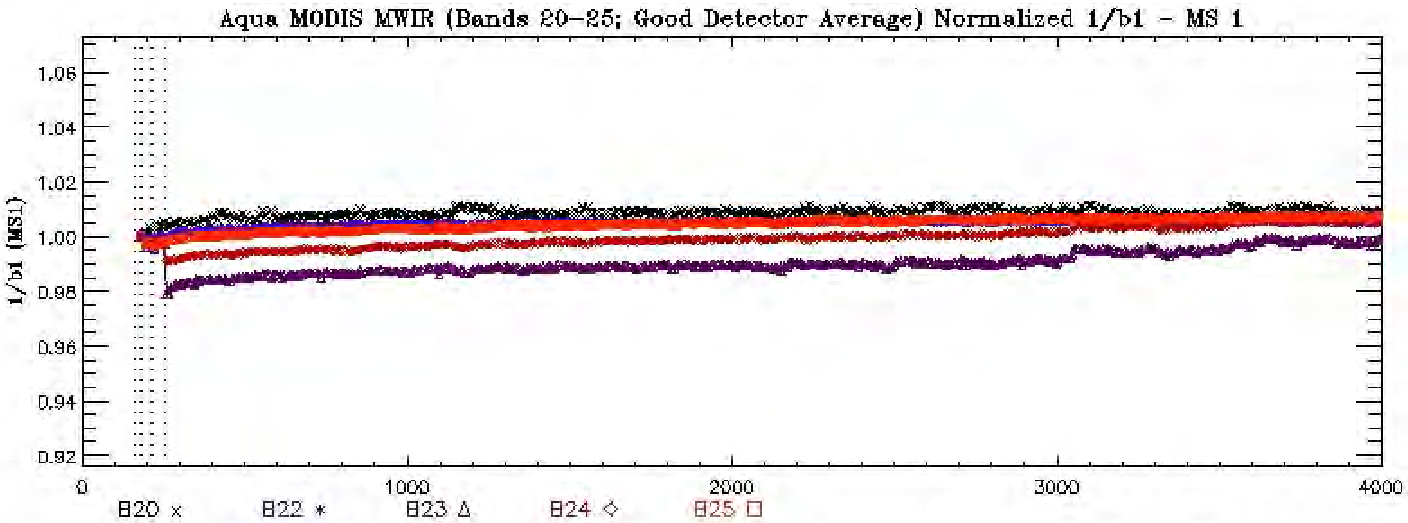
WUCD T_{BB}: 270 to 315K

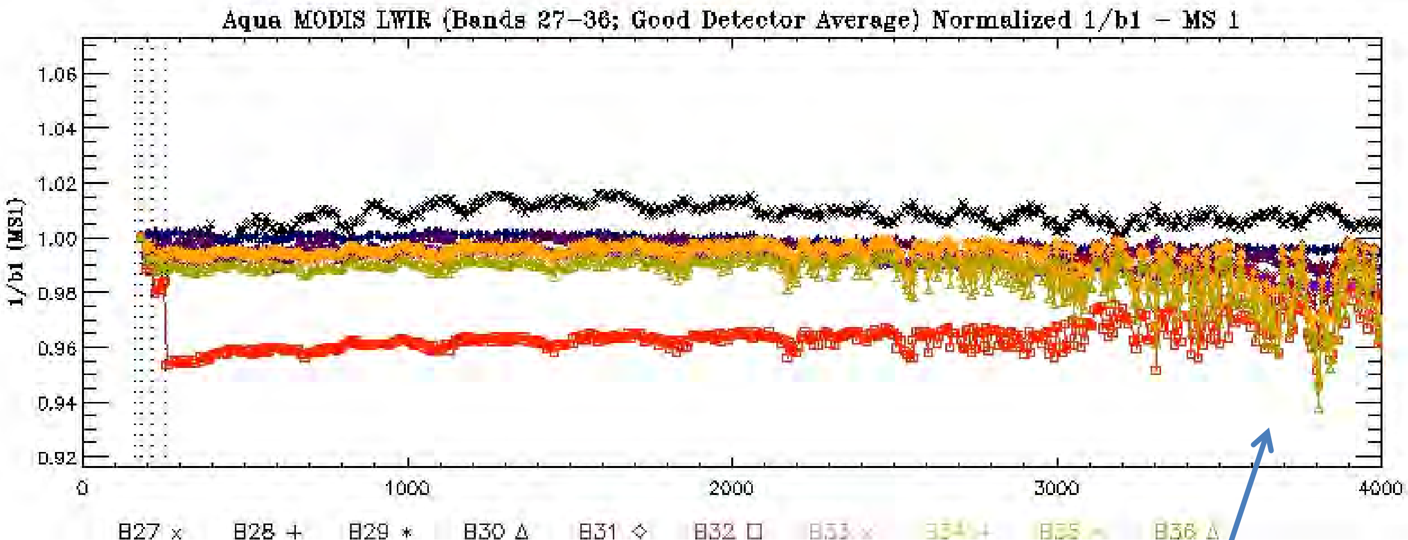
Terra MODIS Gain Trending



Band	Percent Change
20	-1.5
22	-1.5
23	-1.3
24	-0.9
25	-0.7
27	-9.0
28	-8.0
29	-8.0
30	-11.0
31	-0.5
32	-0.5
33	-0.5
34	-0.5
35	-0.3
36	-0.1

Aqua MODIS Gain Trending

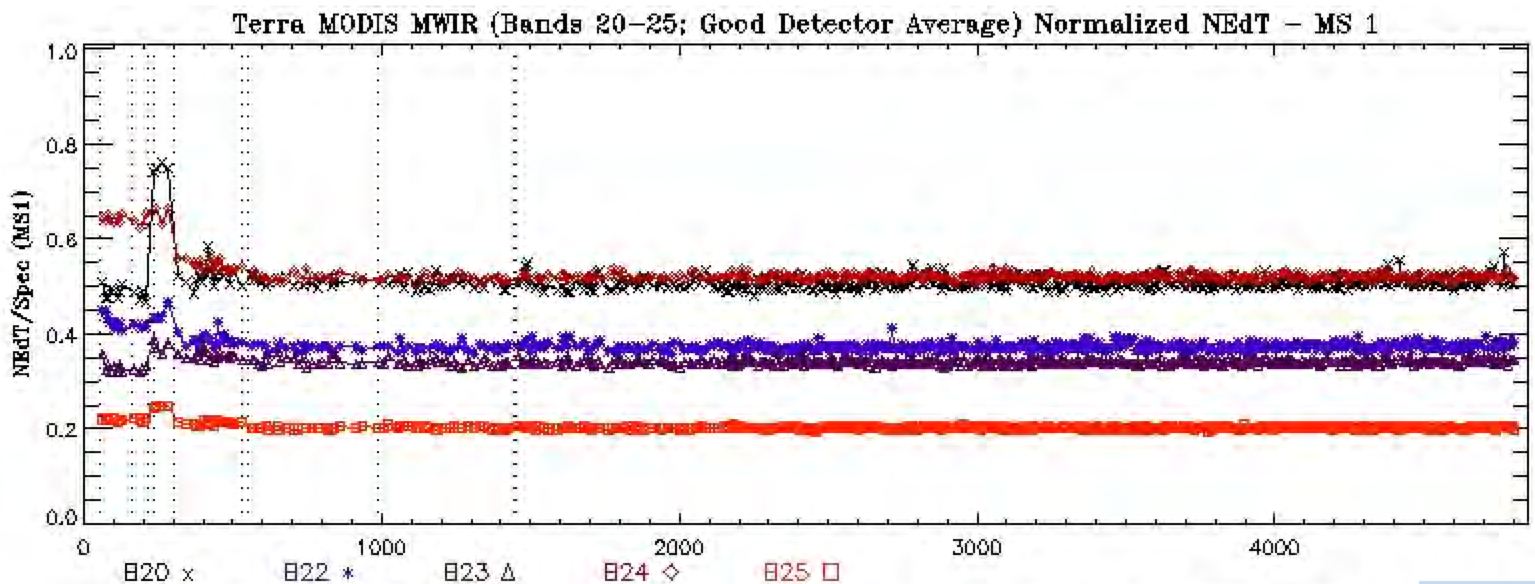


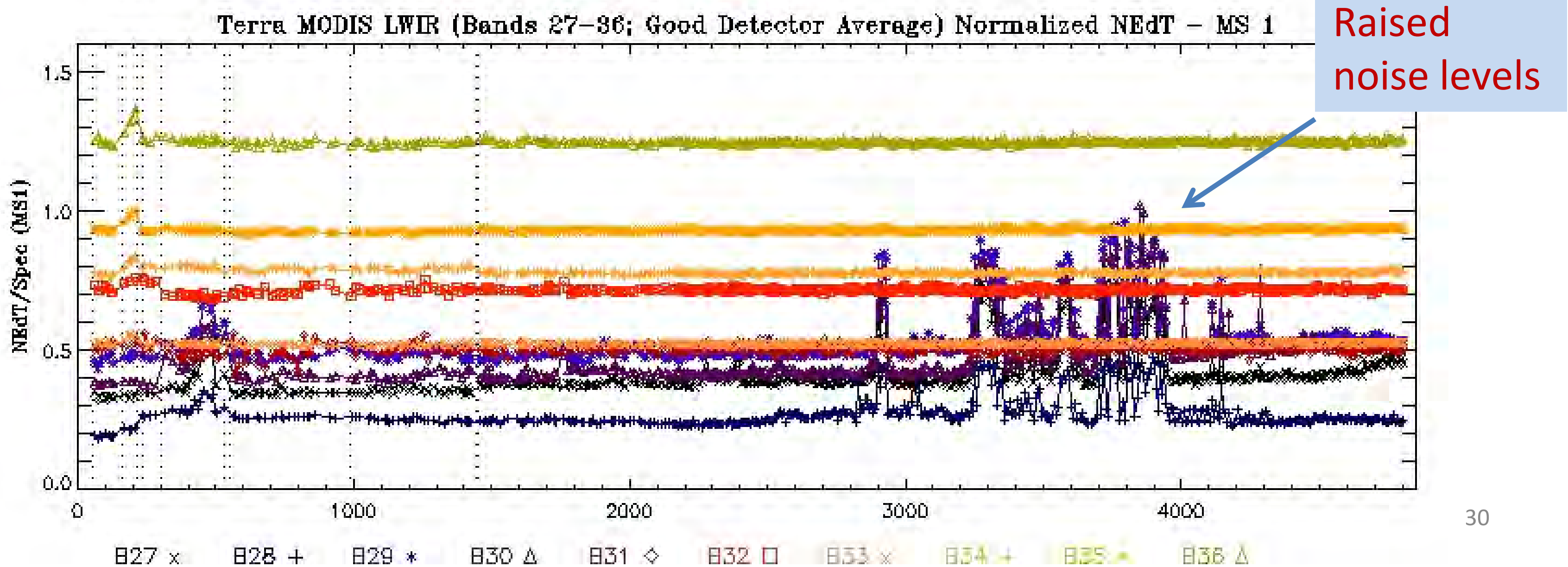


Band	Percent Change
20	0.2
22	0.3
23	1.4
24	1.3
25	0.6
27	-0.0
28	-0.8
29	-1.3
30	-0.7
31	-0.9
32	1.0
33	-1.6
34	-1.6
35	-1.6
36	-1.7

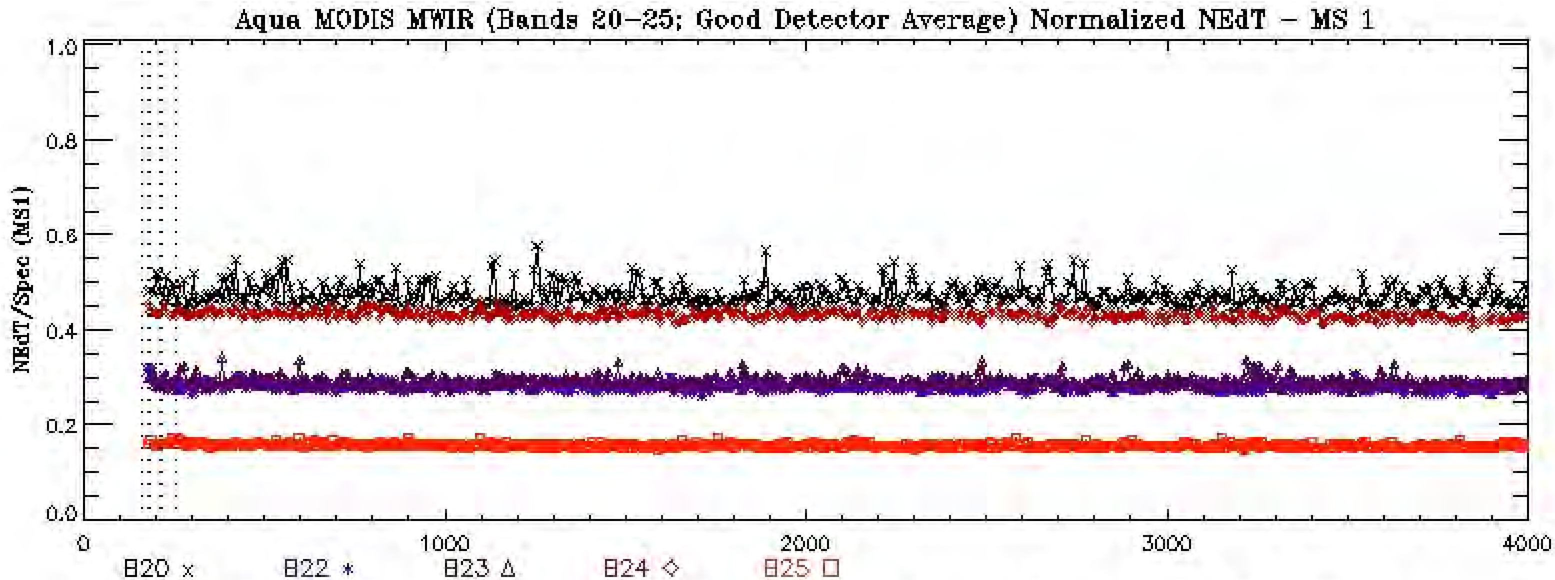
Increasing gain fluctuations

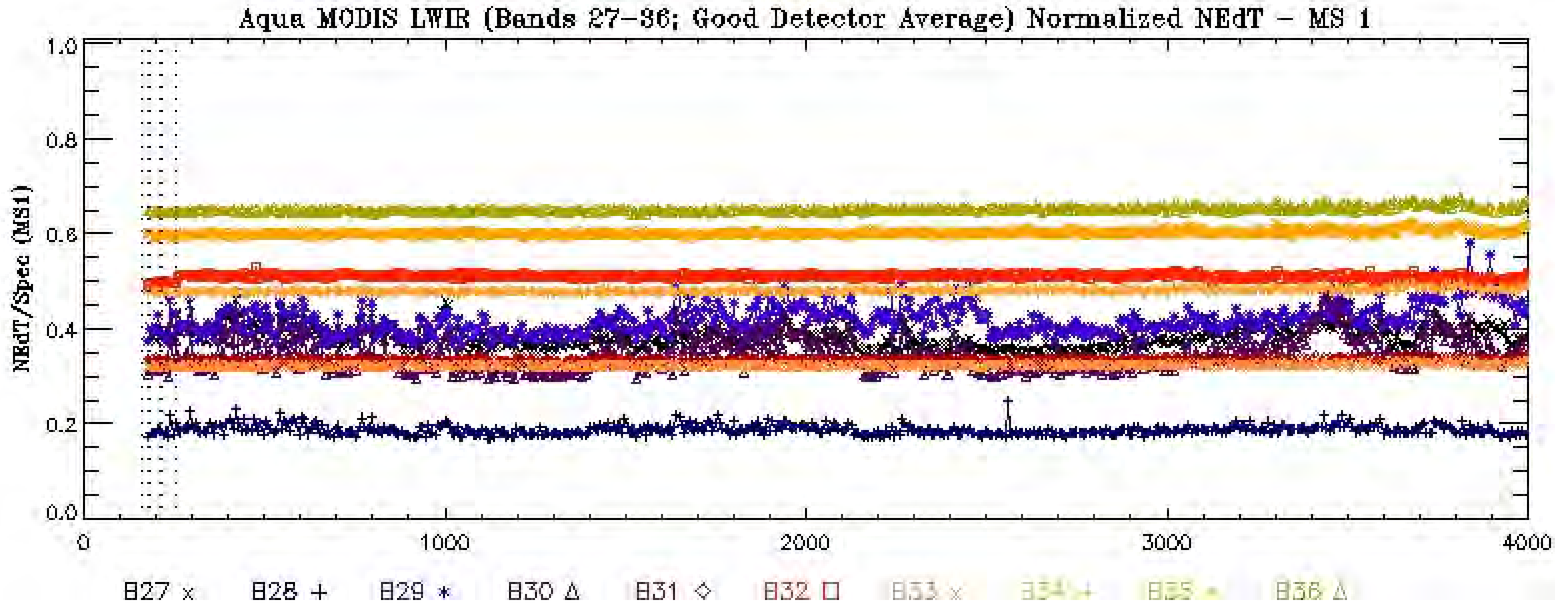
Terra MODIS NEDT Trending





Aqua MODIS NEDT Trending





MODIS Noisy Detector History

Detectors in Product Order

Terra

Band	Detector	Status	Date Classified
27	1	Noisy	Dec-03
	2	Noisy	Nov-08
	3	Noisy	Jul-07
	6	Noisy	Jul-00
	8	Noisy	Feb-06
28	1	Noisy	Jun-04
	8	Noisy	Dec-03
	9	Noisy	Nov-05
	10	Noisy	Apr-04
29	6	Inoperable	Aug-06
30	1	Noisy	Nov-08
	3	Noisy	Jun-06
	5	Noisy	Aug-00
	8	Noisy	Jan-01
33	1	Noisy	at launch
34	6	Noisy	Jun-00
	7	Noisy	at launch
	8	Noisy	at launch
36	1-10	Noisy	Pre- launch

Aqua

Band	Detector	Status	Date Classified
27	3	Noisy	Jan-05
29	2	Noisy	Feb-08
	8	Noisy	Dec-11
	6	**Noisy**	**Feb-12**
36	5	Inoperable	Pre-Launch

Total TEB Detectors = 160

Noisy Detectors:

Terra = 27, Aqua = 4

Inoperable Detectors:

Terra = 1, Aqua = 1

Changes in TEB Collection-6

1. Switched to use Terra and Aqua MODIS BB cool-down data to derive offset (a0) and non-linearity (a2) coefficients
2. Set a0 = 0 for remaining Terra PV bands (20-30)
3. Adjusted Terra PV bands (B20, 22-30) a0 of mirror-side 2 to reduce mirror-side dependent striping
4. Added more a0/a2 LUT timestamps for Terra to reflect early mission changes in configuration
5. Iterative adjustment of Aqua prelaunch a2 for on-orbit drifts

Changes in TEB Collection-6

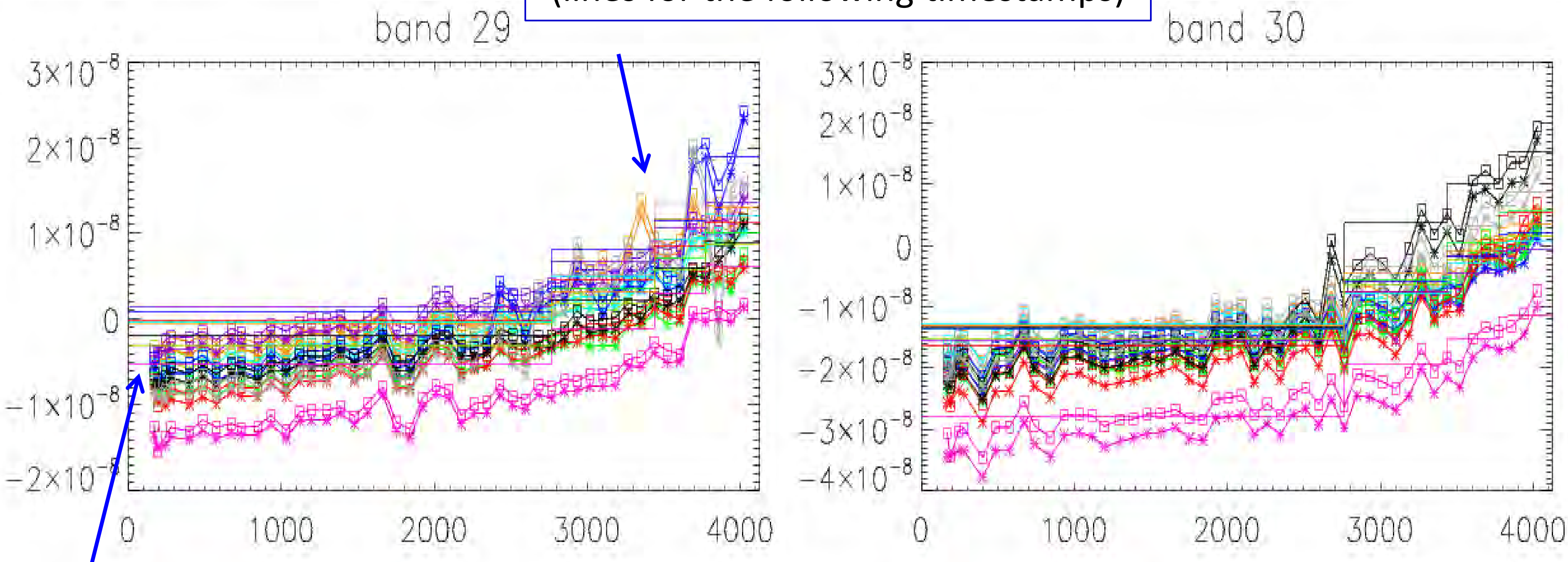
6. Revised approach for default b1 to compensate for Aqua CFPA temperature variations (B33, 35-36)
7. Re-computed TEB uncertainties to include time-dependent contribution of a0/a2, etc.
8. QA handling: filled value for inoperable detectors and flag noisy or inoperable detectors on sub-frame basis
9. L1B code fix for sector rotation data (lunar roll) anomaly

Aqua TEB C6 a0/a2 Update

1. a0/a2 for B31 and 32 are derived using BB cool-down with a0 = 0 (prelaunch coeff. Not used due to gain change)
2. a2 for rest TEB are derived by iteratively adjusting prelaunch a2 to maintain the initial post-launch differences in BT between using prelaunch and the first on-orbit a2
3. Impacts of the adjusted prelaunch a2 are evaluated at typical temperature of each band

Aqua TEB C6 LUT Update by Iteratively Adjusting Prelaunch a2

Iteratively adjusted a2 LUT
(lines for the following timestamps)

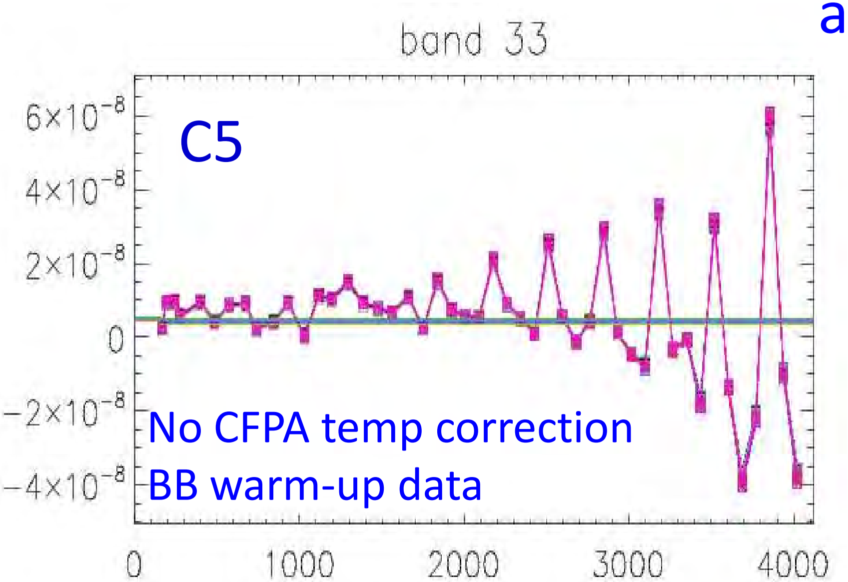


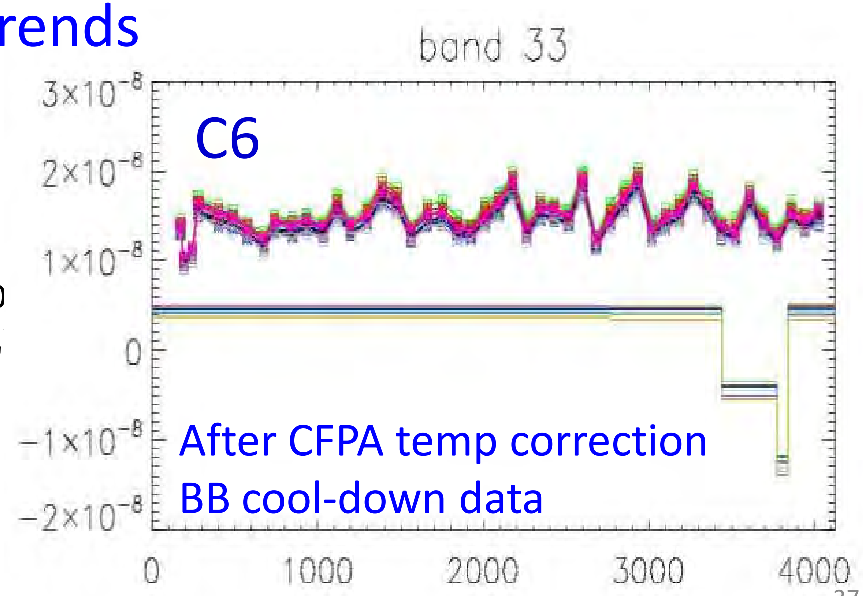
Prelaunch a2 LUT
(lines for the first timestamp)

Aqua TEB C6 LUT Update by Correcting CFPA Temperature Fluctuations

1. Current Aqua CFPA temperature fluctuations are ~0.6K
2. These fluctuations cause increasing uncertainties in the calculation of a0/a2
3. A linear correction for Aqua CFPA temperature is applied to normalize detector responses at the same CFPA temperature of 83K
4. Largest impacts seen for PC bands (B31-36), particularly B33 and no impact on PV bands

a2 Trends



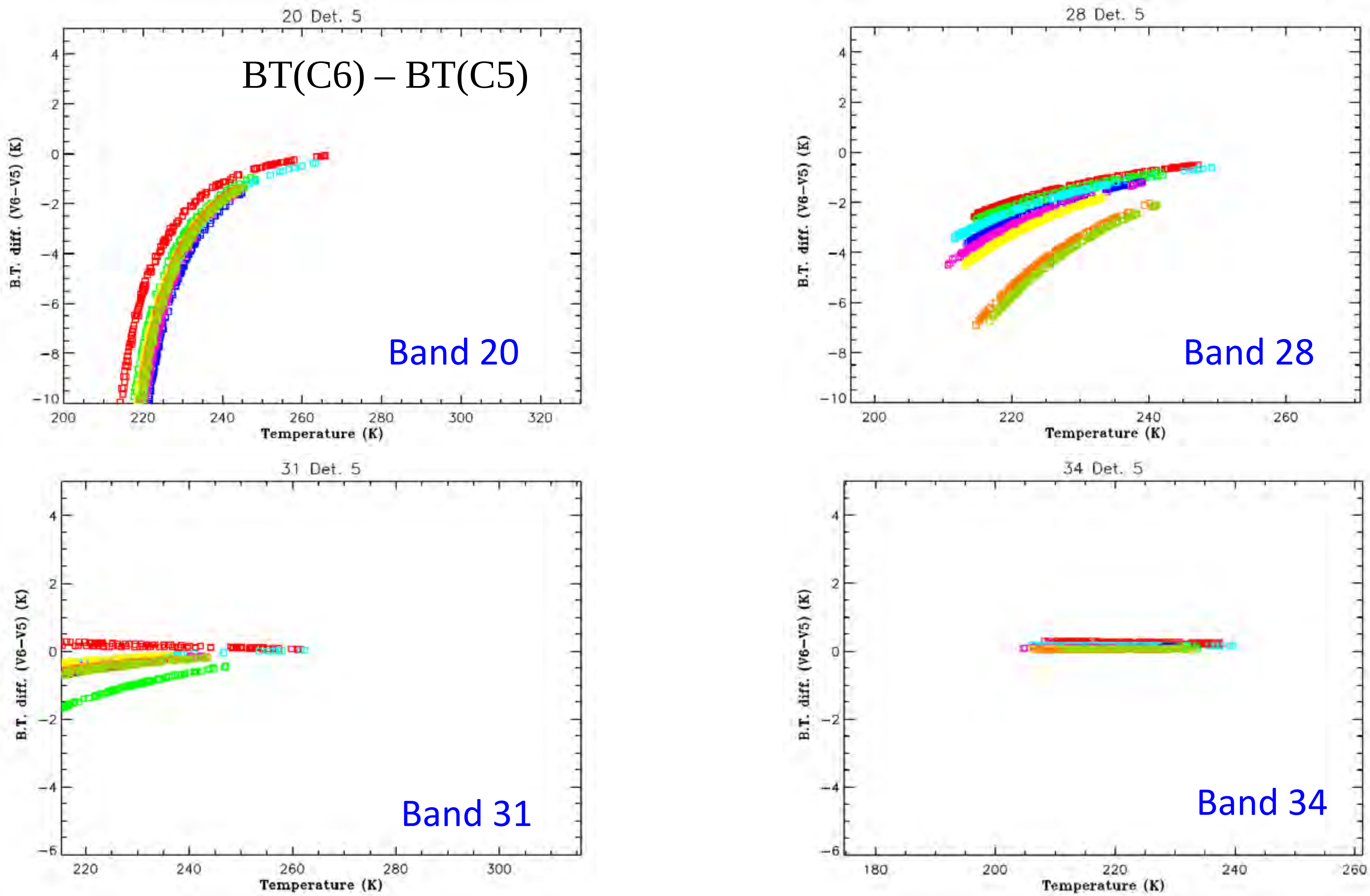


Estimated L1B Impact due to C6

ΔT = BT(V6) – BT(V5) (K) (2013), actual differences are detector and time-dependent

Band	T_{typ}	Terra			Aqua		
		ΔT @ (0.3L_{typ})	ΔT @ (L_{typ})	ΔT @ (0.9L_{max})	ΔT @ (0.3L_{typ})	ΔT @ (L_{typ})	ΔT @ (0.9L_{max})
20	300	-0.11	0.03	0.05	0.02	-0.06	-0.41
22	300	-0.10	0.03	0.04	0.02	-0.06	-0.29
23	300	-0.10	0.03	0.04	0.02	-0.06	-0.28
24	250	-1.70	-0.46	-0.22	0.02	0.02	0.02
25	275	-0.52	-0.09	-0.04	0.02	0.01	0.00
27	240	-2.94	-1.06	-0.15	-0.07	-0.07	-0.05
28	250	-2.94	-0.40	0.05	-0.01	-0.01	0.00
29	300	-1.20	-0.28	-1.21	-0.05	0.04	0.11
30	250	-8.52	-0.13	0.66	-0.14	-0.12	-0.07
31	300	-0.27	-0.03	-0.13	-0.37	-0.02	-0.09
32	300	-0.33	-0.04	-0.14	-0.34	-0.03	-0.12
33	260	0.08	0.05	0.03	0.19	0.12	0.04
34	250	0.06	0.05	0.04	-0.01	-0.01	-0.01
35	240	0.04	0.04	0.04	-0.09	-0.08	-0.07
36	220	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02

Terra TEB C6 Assessment for Dome C

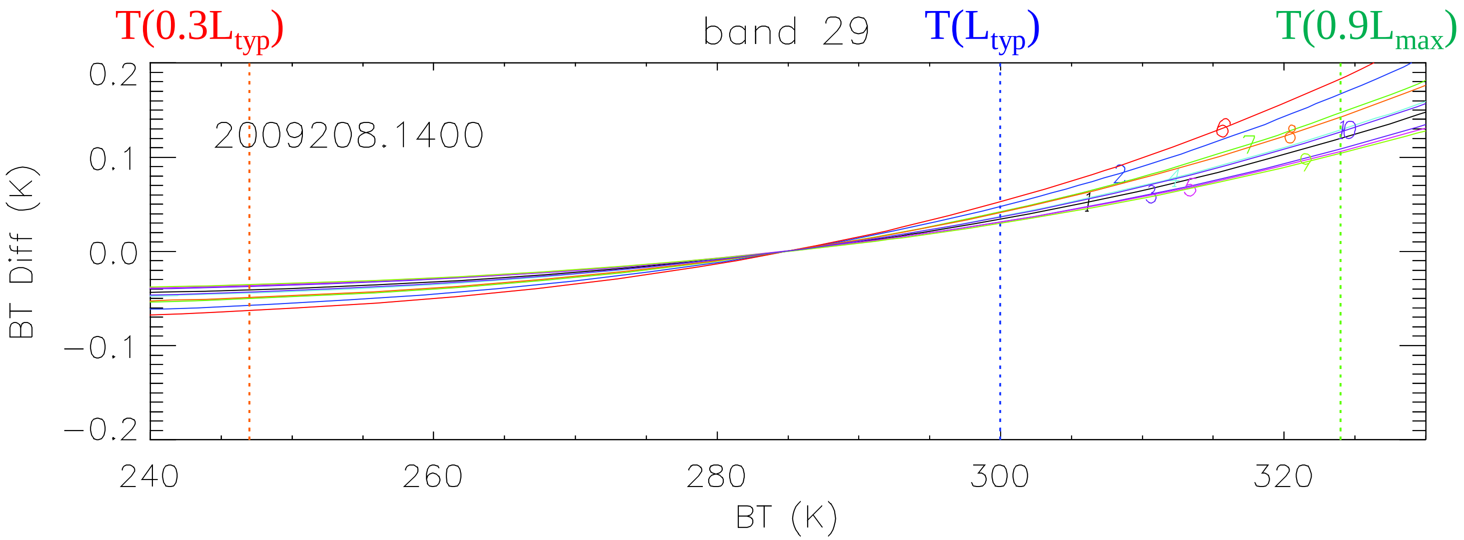


□ 2000 □ 2002 □ 2004 □ 2006 □ 2008 □ 2010 □ 2012 □ 2013

Example shown for Det. 5 for nadir looking frames of EV

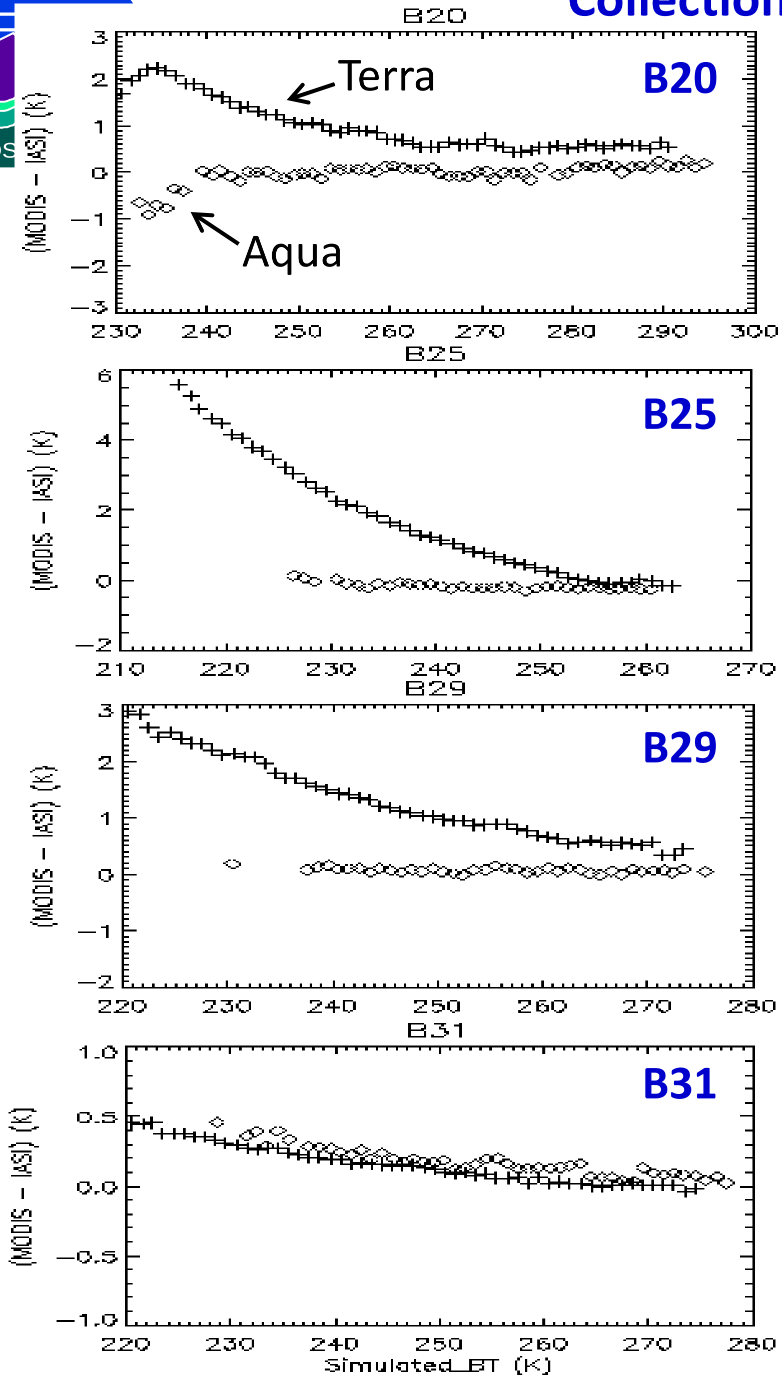
Aqua TEB C6 LT impact – Band 29

C5 – No update C6 – Updated using iteration algorithm

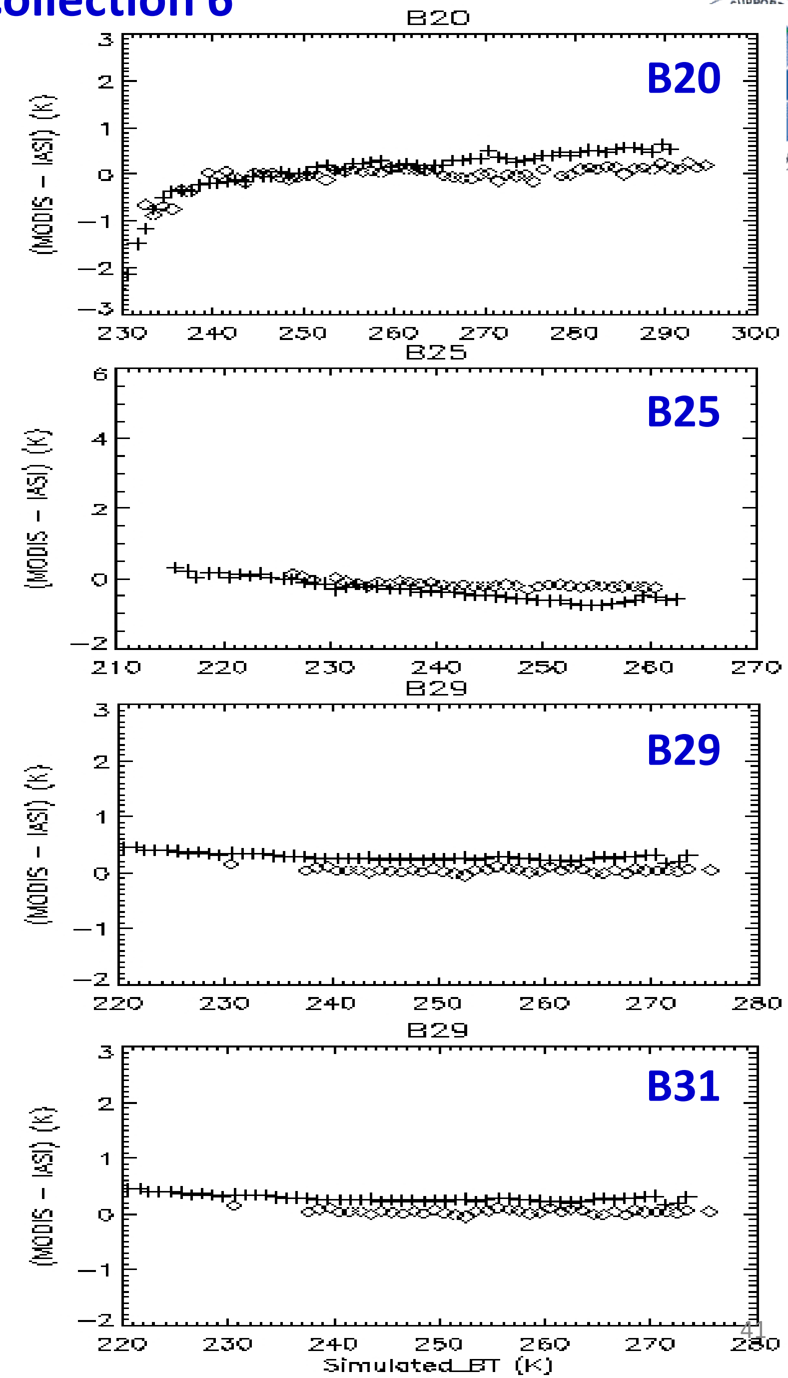


Trends of on-orbit BB WUCD a0/a2 show that there are noticeable drifts in Aqua band 29 and 30. An update example of a2 (2009208) is made using iterative adjustment of prelaunch a2

Collection 5

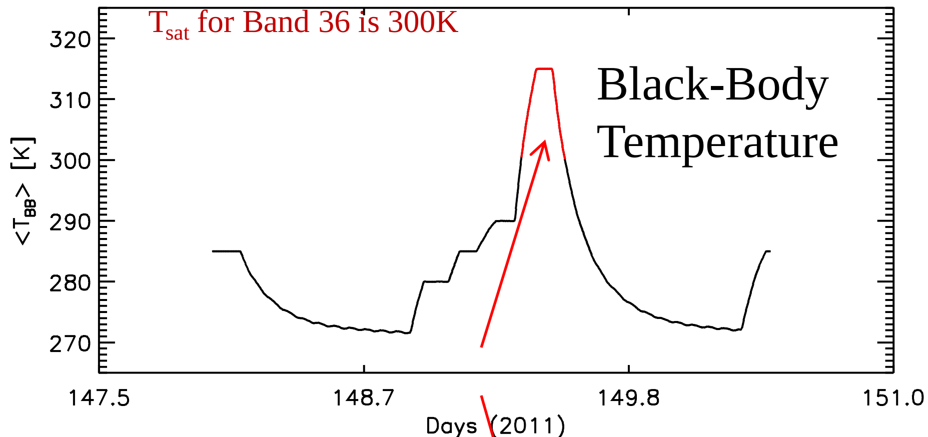


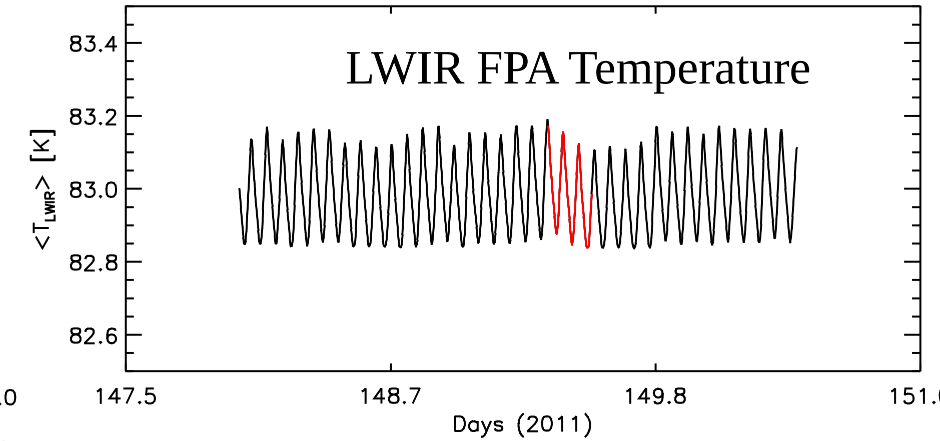
Collection 6



Aqua TEB Default b1

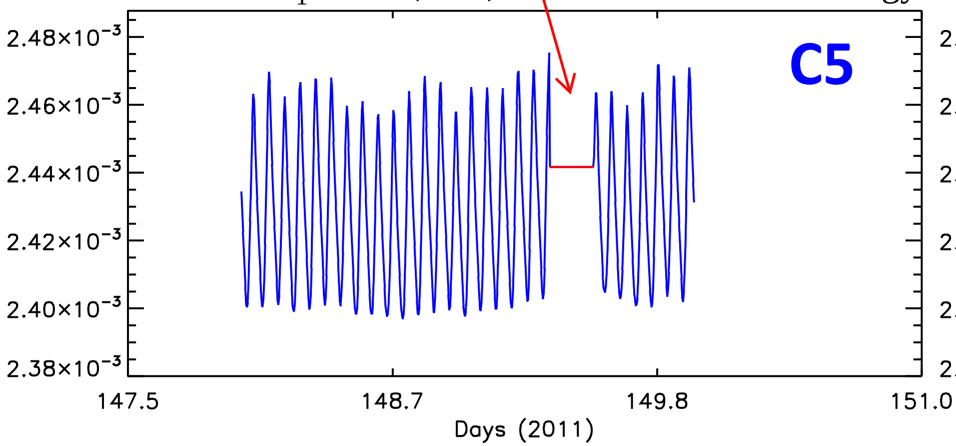
A linear relation between Aqua CPPA temperature and gain (b1) is used to compute default b1



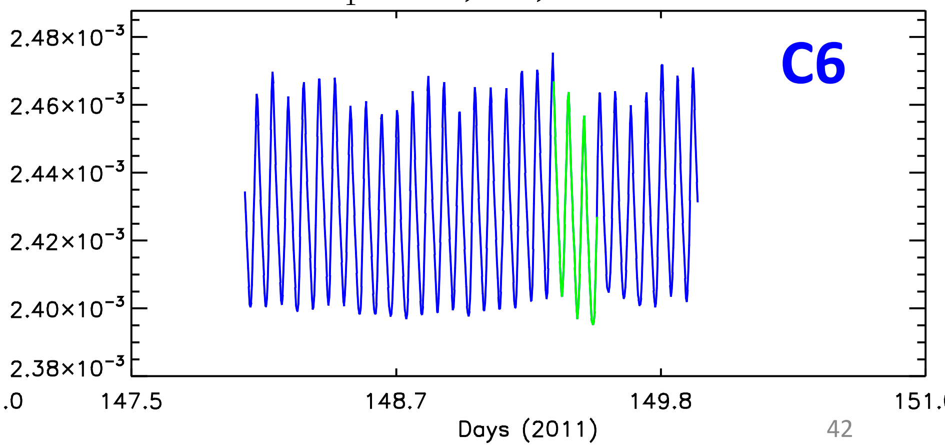


Saturation of detector response (B33, 35&36)

Band 36 b_1 for D1, M1; Previous L1B methodology



Band 36 b_1 for D1, M1; Modified default b1



All Data shown are granule averaged

TEB EV Radiance Retrieval and Uncertainty

- EV TEB Radiance Retrievals:

$$L_{EV} = \frac{1}{RVS_{EV}} \cdot \left\{ \left(a_0 + a_2 \cdot dn_{EV}^2 \right) + \left[RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB} \right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB} \right) \cdot \varepsilon_{CAV} \cdot L_{CAV} - a_0 - a_2 \cdot dn_{BB}^2 \right] \cdot \frac{dn_{EV}}{dn_{BB}} - \left(RVS_{SV} - RVS_{EV} \right) \cdot L_{SM} \right\}$$

- ❖ Special calibration for Band 21 (Terra & Aqua): use fixed linear gain “band_21_b1”; ao & a2 are zero for B21.
- ❖ Special correction for PC bands 32-36 crosstalk (for Terra only; Aqua has no PCX): use Band 31 as sender; Crosstalk coefficients “pc_xt_table” are applied to both BB and EV data.
- ❖ The EV radiance is a function of several parameters determined from pre-launch or on-orbit observations: (Note: $RVS_{BB}=1$ and $\delta RVS_{BB}=0$)

- EV TEB Radiance Uncertainty:

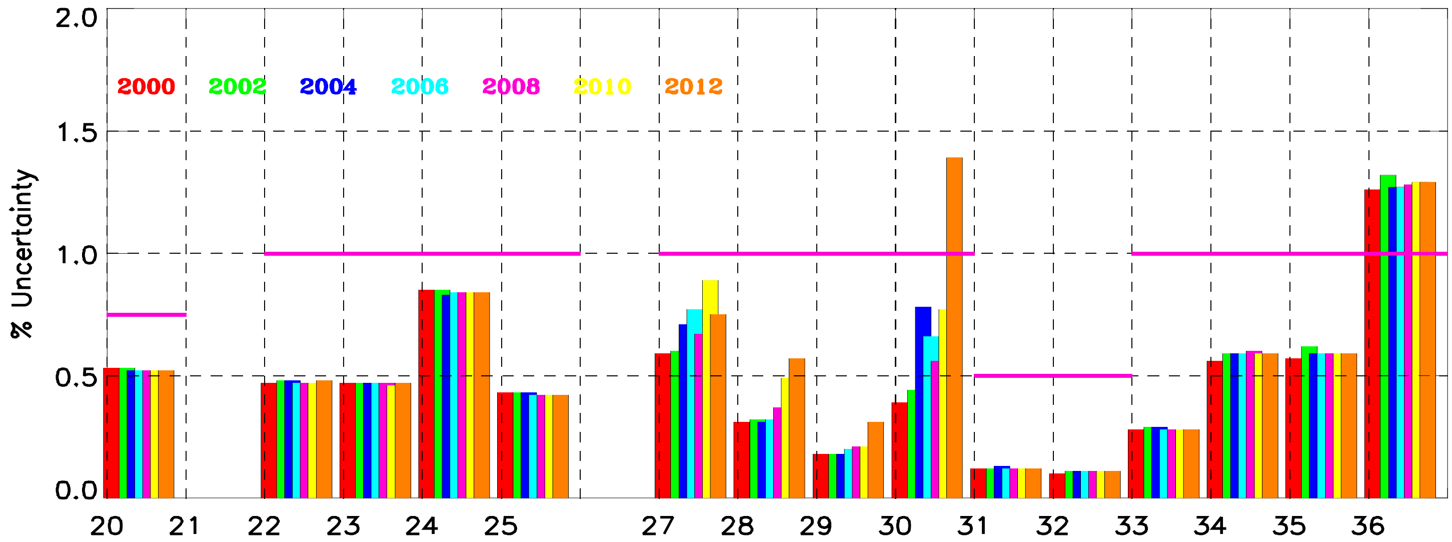
$$L_{EV} = L_{EV}\left(a_0, a_2, RVS_{SV}, RVS_{EV}, \varepsilon_{BB}, \varepsilon_{CAV}, \lambda, T_{BB}, T_{SM}, T_{CAV}, dn_{BB}, dn_{EV}, b1_{B21}, PCX \right)$$

(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14)

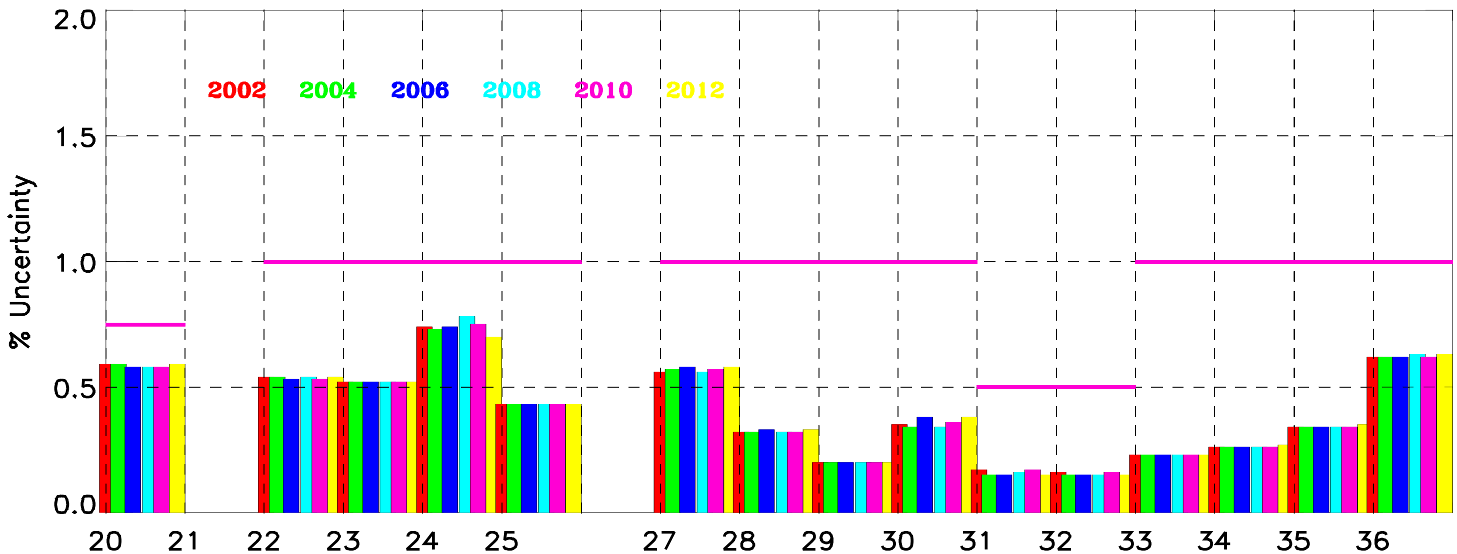
$$\frac{dL_{EV}}{L_{EV}} = \sqrt{\sum_{i=1}^{14} \left(\frac{dL_{EV}^i}{L_{EV}} \right)^2}$$

L1B UI is converted to percent (%)

Terra – Uncertainty at L_{typ}, and Nadir viewing AOI



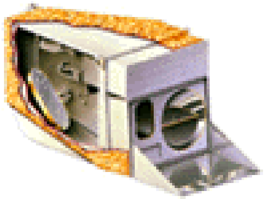
Aqua – Uncertainty at L_{typ}, and Nadir viewing AOI



Summary

- Measured temperatures (i.e., radiances) for cold scenes will be significantly lower in most Terra PV bands (B20, 22-30).
- For both Terra and Aqua bands 31/32, measured temperatures for cold scenes will also be noticeably lower
- C6 significantly reduces Terra/Aqua differences in PV bands
- A simple Aqua default b1 algorithm improves L1B data quality (B33, 35-36) during BB WUCD periods when the detector response saturates
- Mirror-side striping for cold scenes expected to be reduced in C6
- TEB uncertainties are slightly larger than those in C5

MODIS RSB Calibration Performance



MCST Workshop at MST Meeting (April 17, 2013)

Outline

- Introduction
- RSB calibration using SD/SDSM
  - SD degradation performance
  - RSB gain performance
- Lunar calibration
  - RSB gain from lunar measurements
- EV response trending
  - On-orbit RVS change
- Instrument Performance Summary

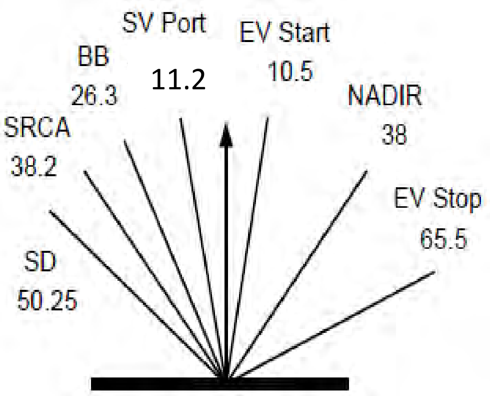
Introduction

- ***EV Reflectance***

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

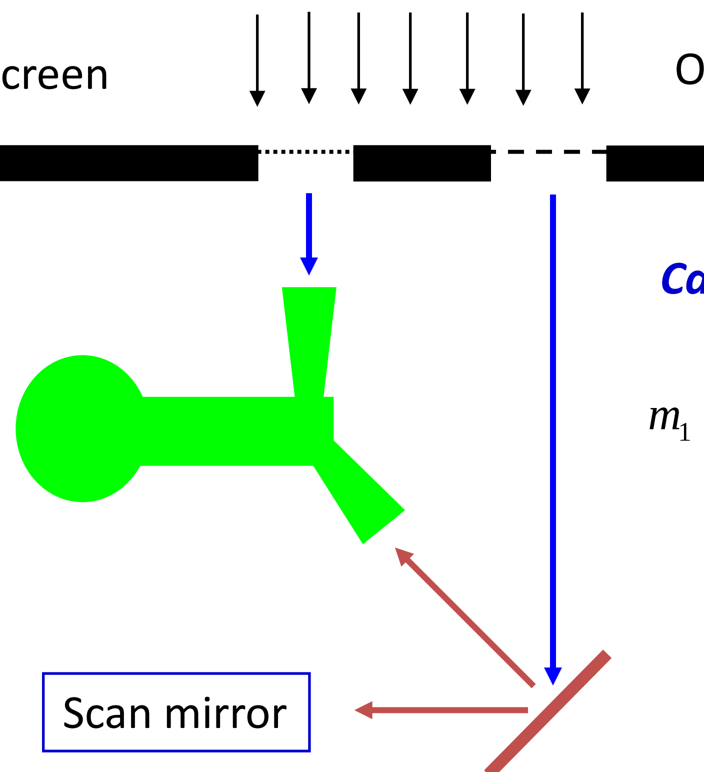
- LUT needing to be updated for RSB
  - m1: Inversely proportion to gain at the AOI of SD
  - RVS: Sensor Response versus Scan angle (normalized to SD view AOI to the scan mirror)
  - Uncertainty Index (UI)
- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - SRCA and EV mirror side (MS) ratios
  - Response trending from EV targets

MODIS scan mirror



Angle of Incidence (AOI)

RSB SD Calibration



Calibration coefficients

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

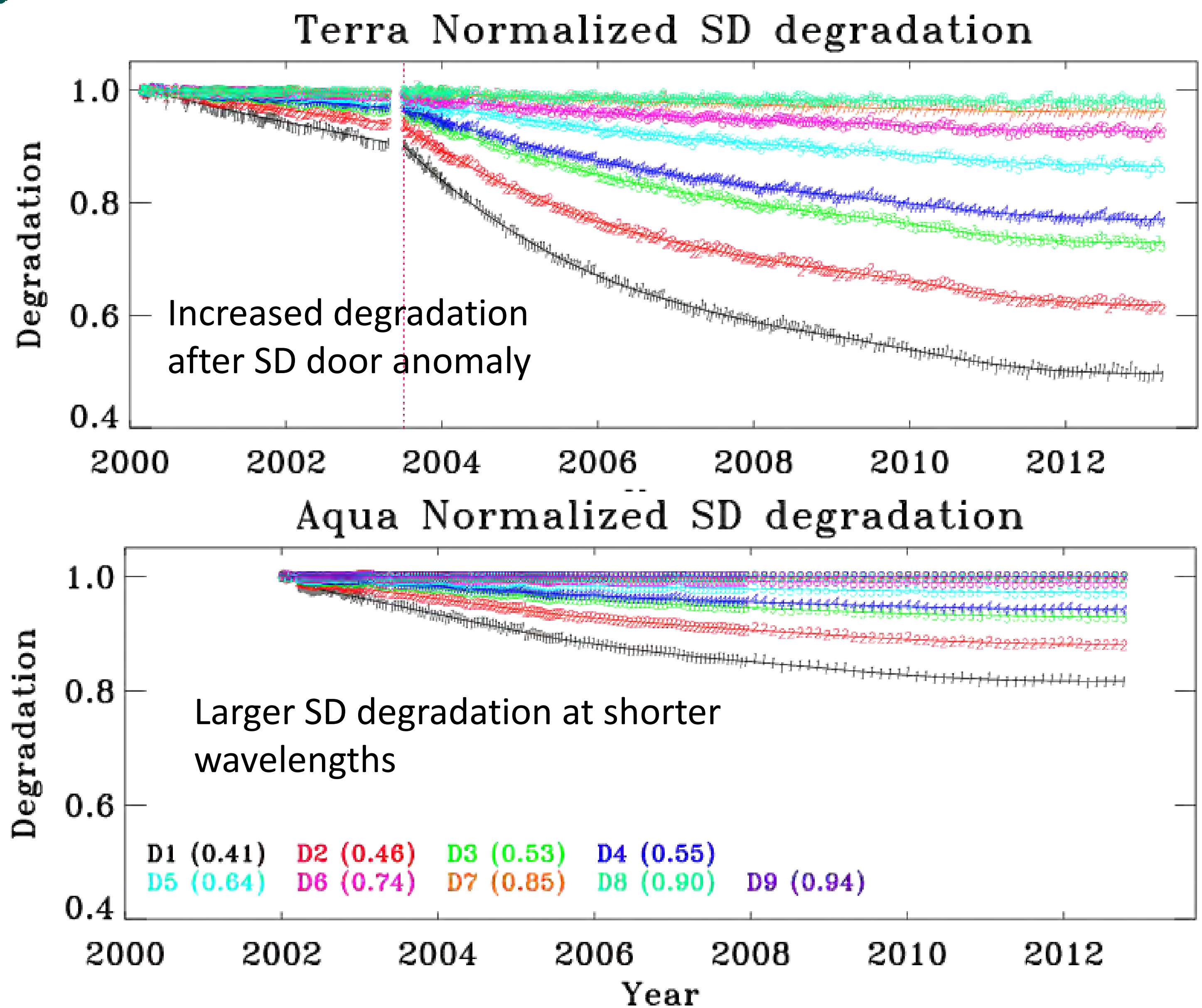
SD degradation

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

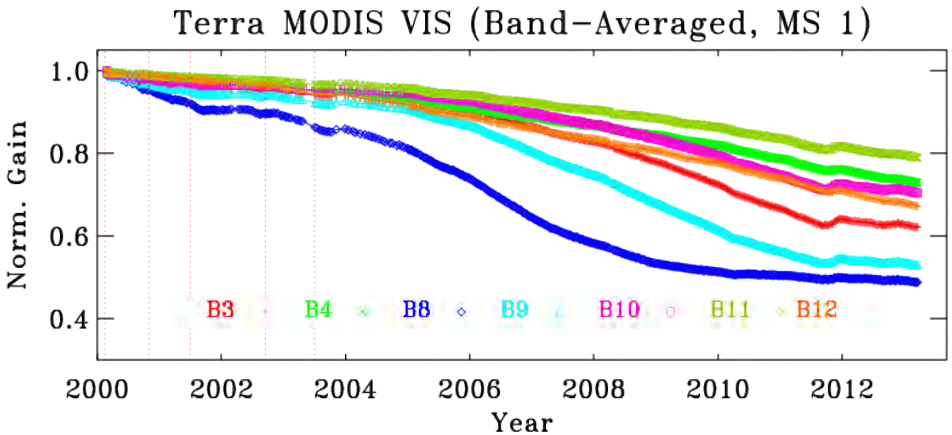
$$\Delta^9_{SD} = dc^9_{SD} / dc^9_{Sun}$$

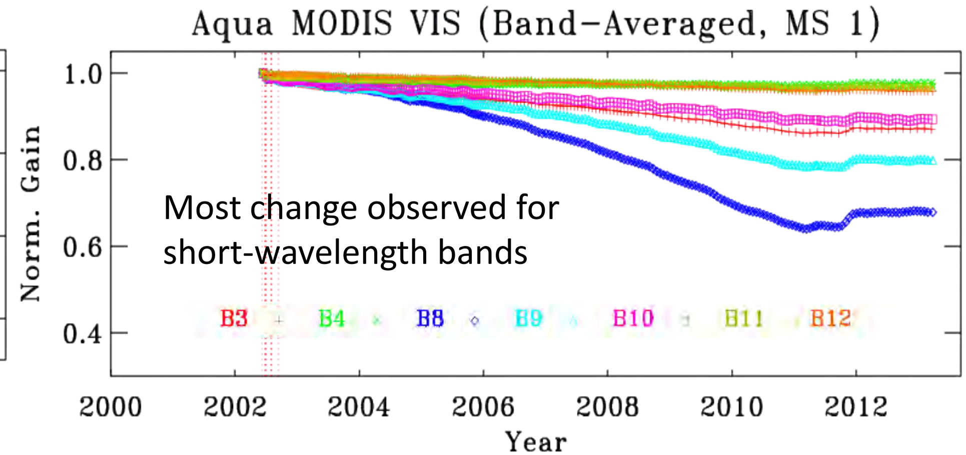
SD degradation at wavelength 936 nm measured by SDSM D9 is included in Collection 6 through the entire mission and also included in Collection 5 for Terra after Jan. 1, 2009 and Aqua after March 1, 2009.

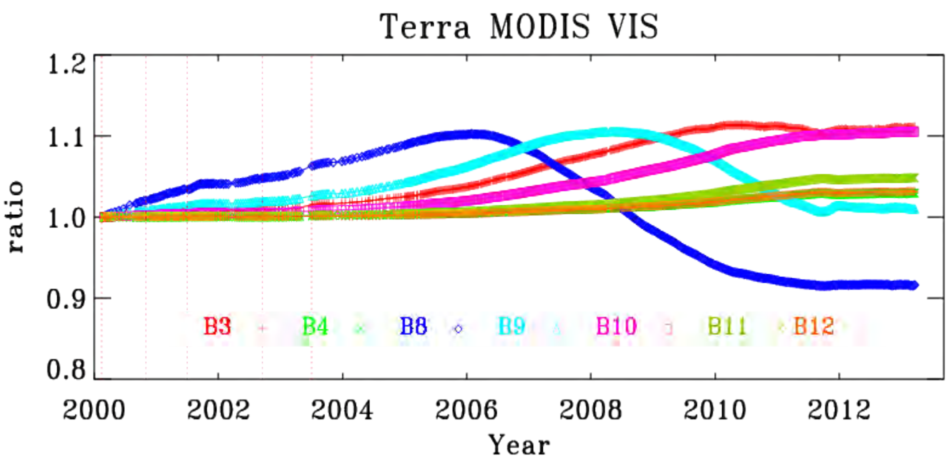
MODIS SD Degradation

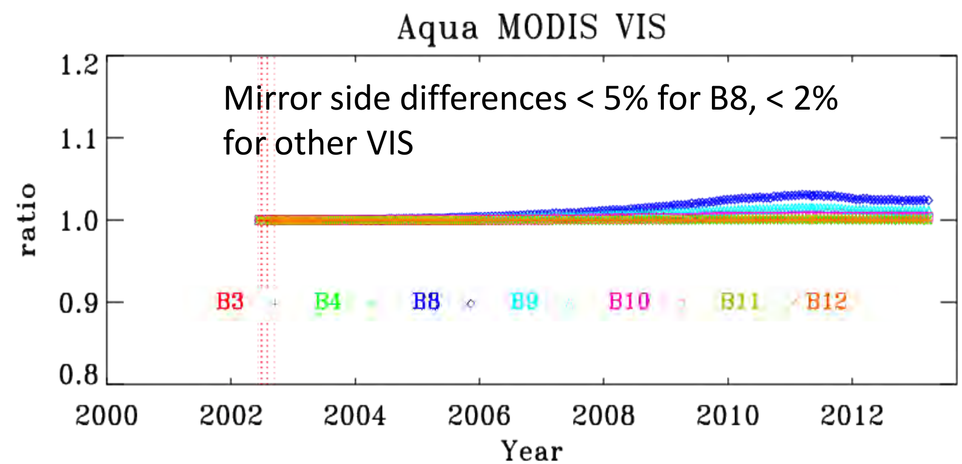


MODIS RSB SD Gain Trending





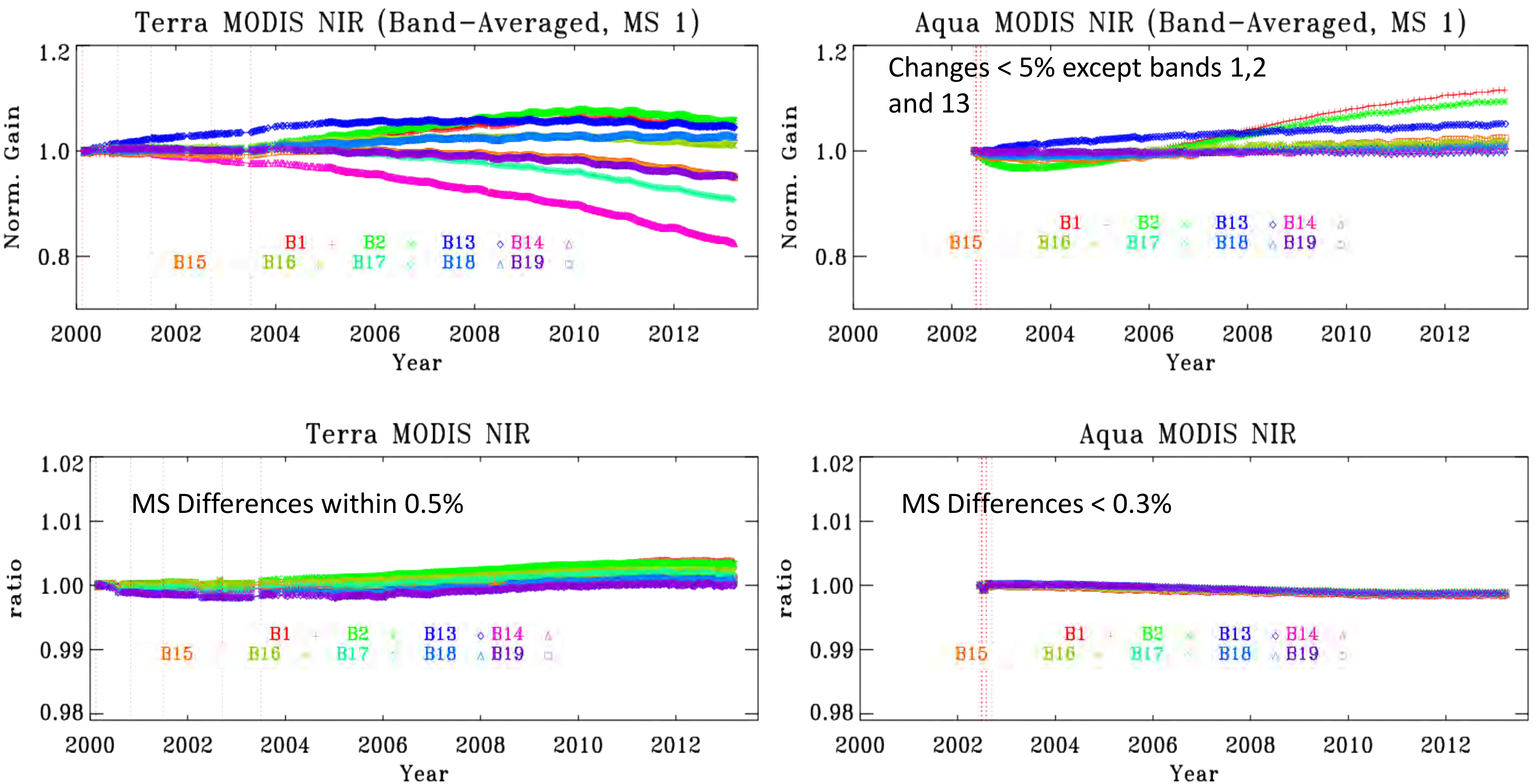




VIS channels for both instruments exhibit large gain change,
50% for band 8 (Terra) and 30% for band 8 (Aqua)

SD AOI: 50.25°

MODIS RSB SD Gain Trending

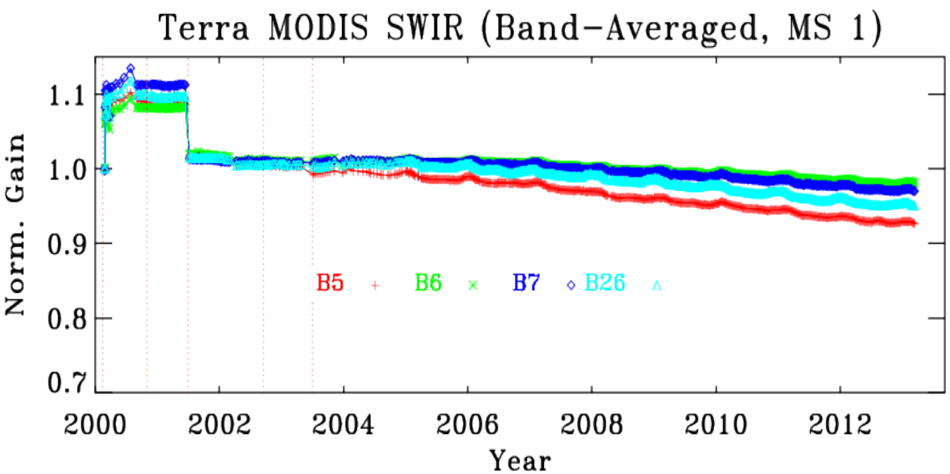


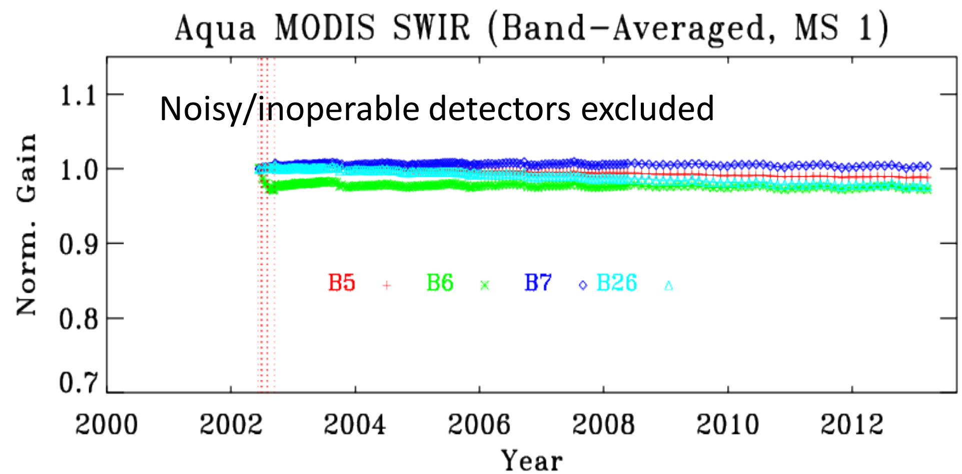
Terra MODIS NIR gain change within 10% (except select ocean bands)

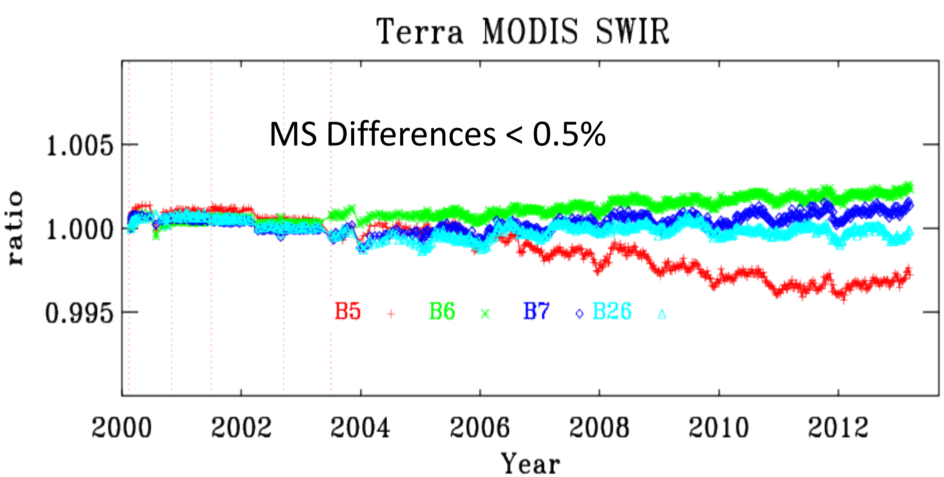
Corresponding Aqua MODIS NIR bands exhibit lesser change

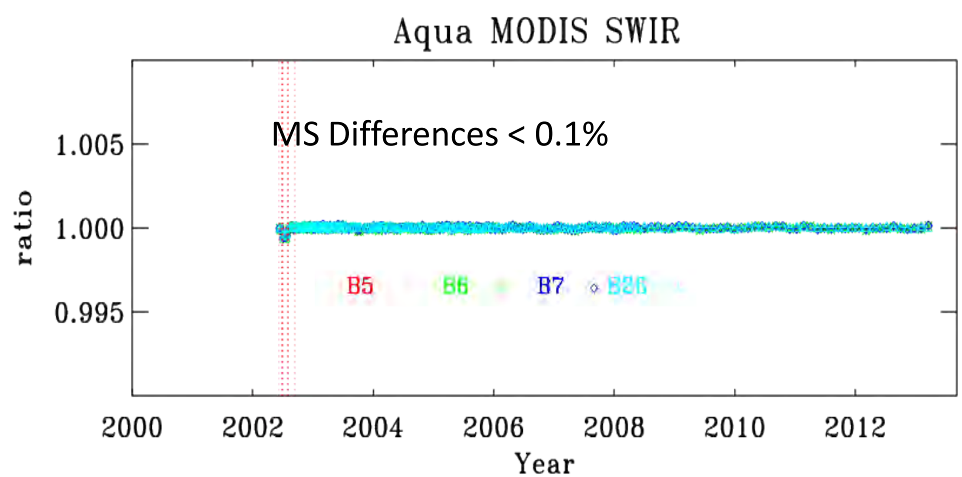
SD AOI: 50.25°

MODIS RSB SD Gain Trending







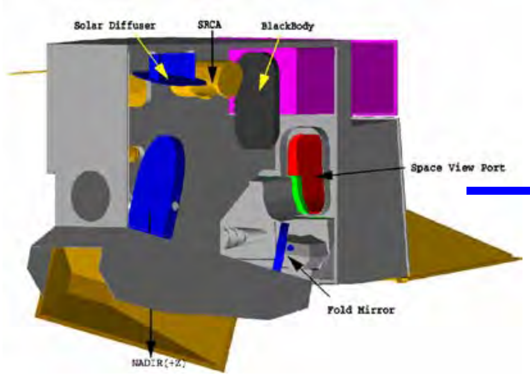


Gain change for Terra SWIR bands < 10% and Aqua SWIR bands < 2%

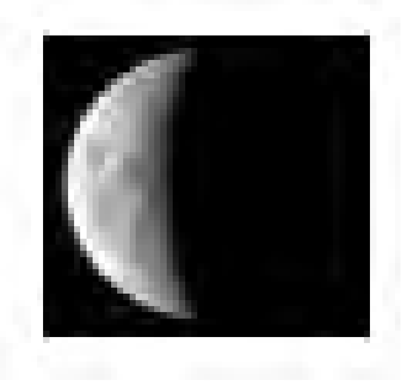
SD AOI: 50.25°

RSB Lunar Calibration

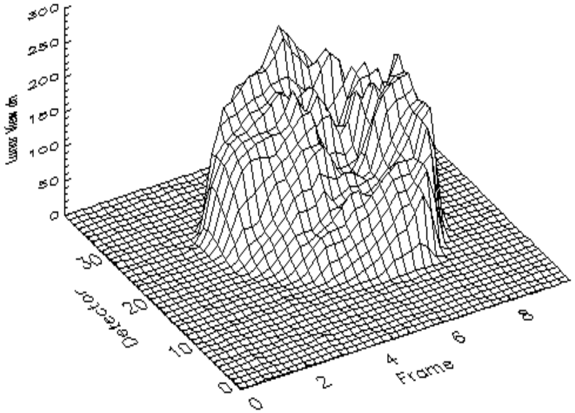
MODIS



Moon



MODIS Response



Lunar calibration coefficients

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

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

Bands 13-16 (Saturated)

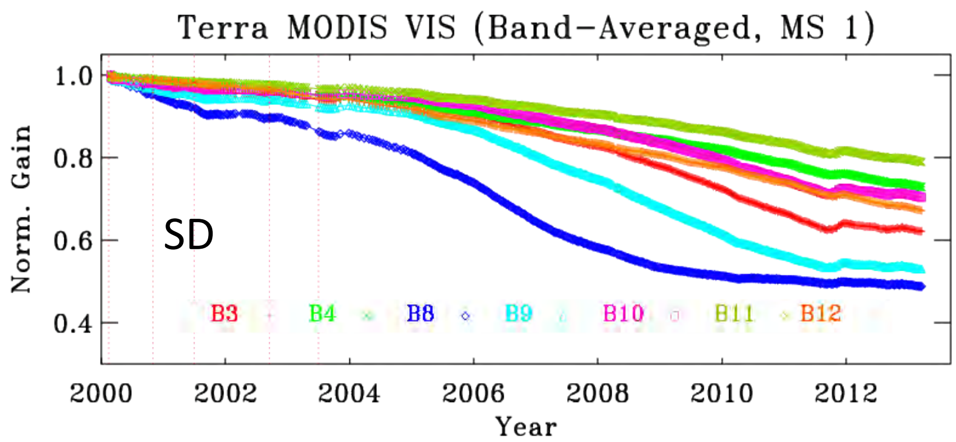
$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

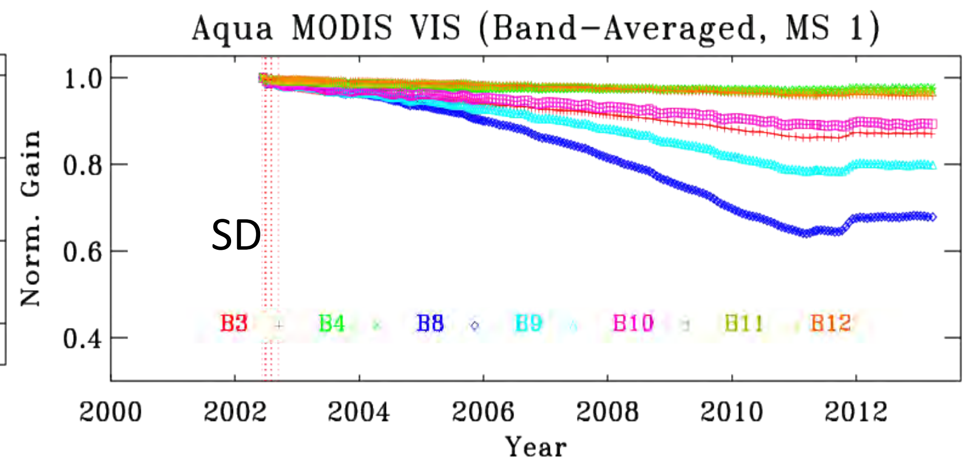
View geometry correction

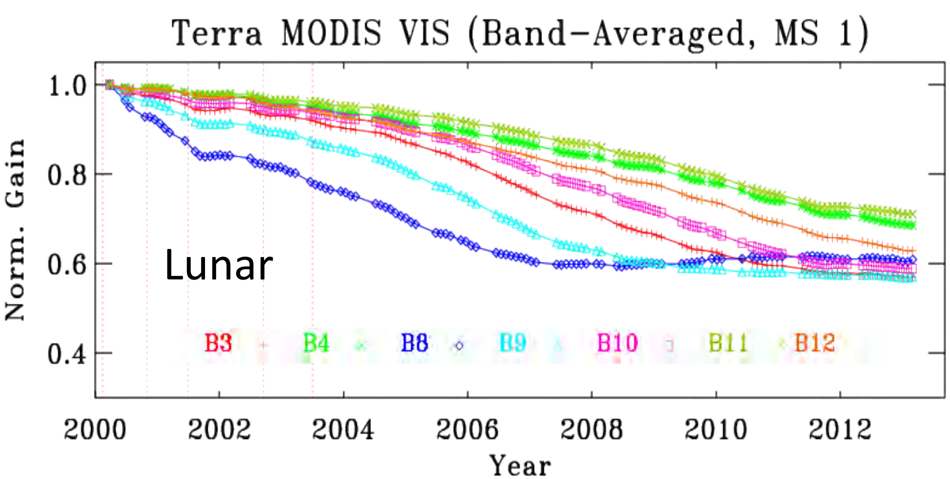
$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

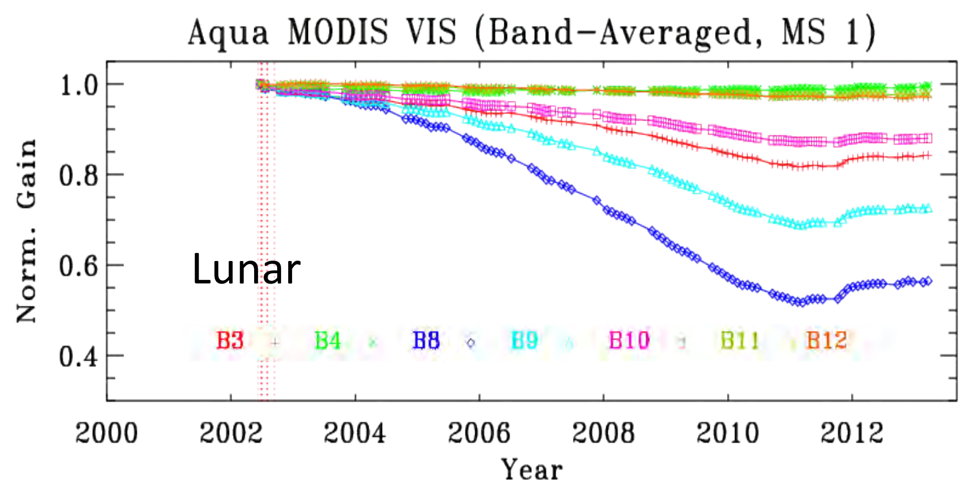
Oversampling effect also needs to be corrected if multiple scans are used

MODIS RSB SD & Lunar Gain Trending





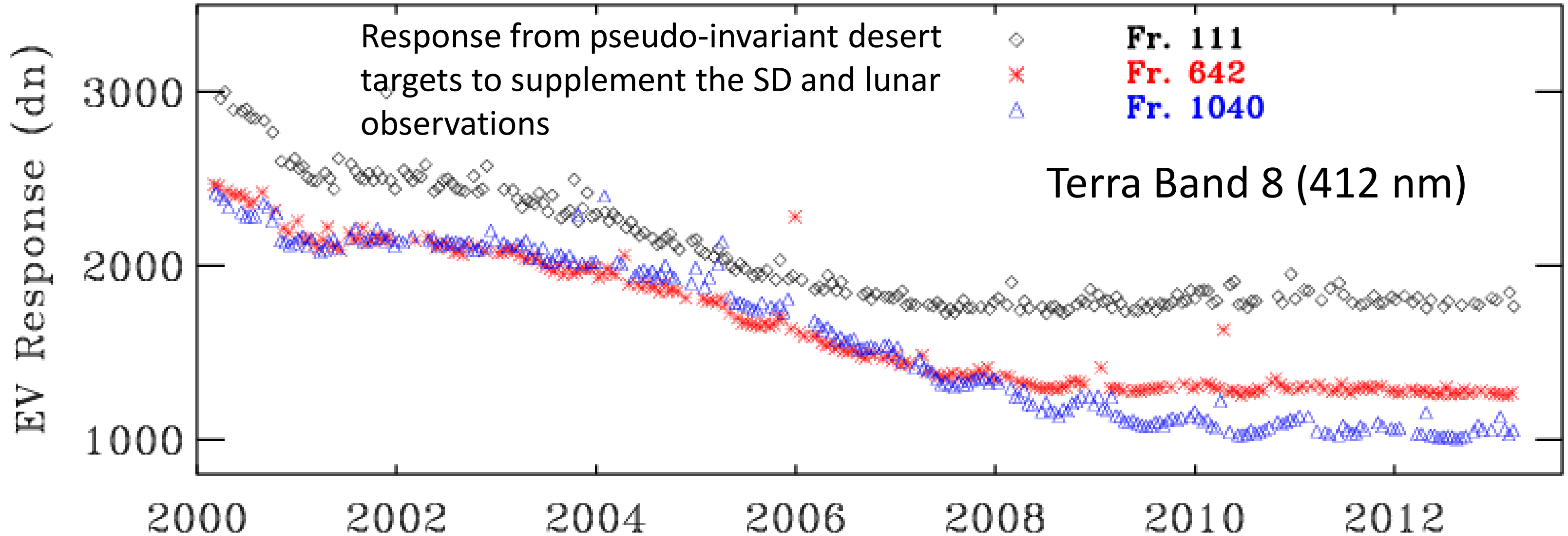


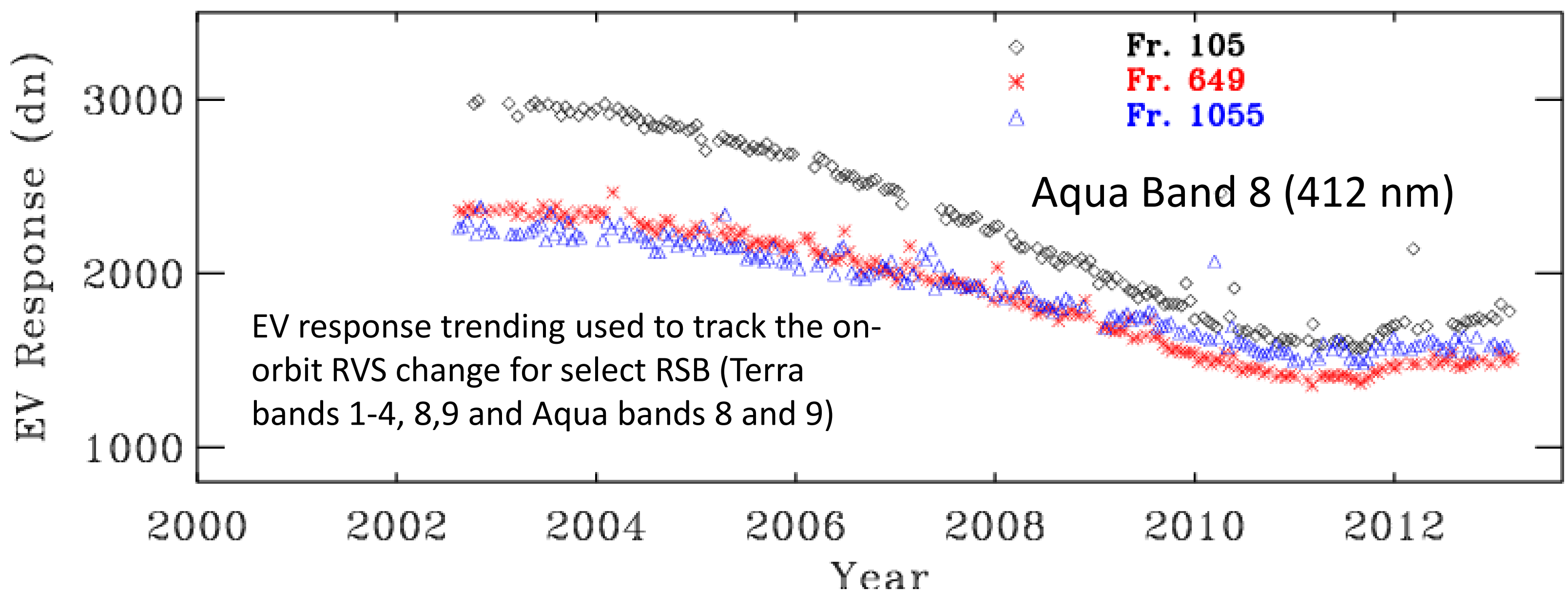


SD & Lunar measurements used to derive the on-orbit RVS change

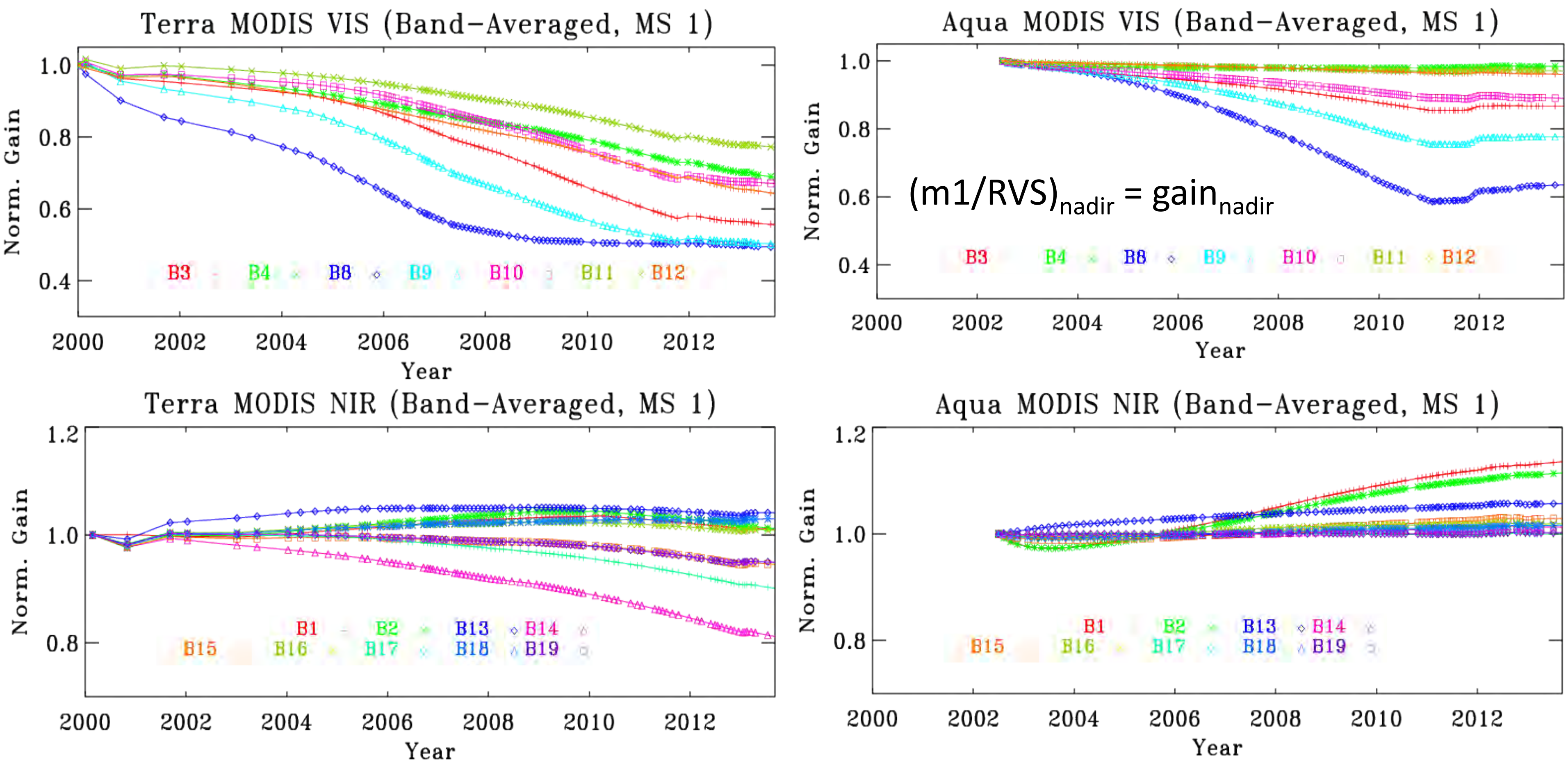
SV AOI: 11.25°

MODIS RSB EV Response Trending





RSB Gain Trending at Nadir



Gain for most RSB derived using on-board measurements from SD & Moon

For select RSB (Terra bands 1-4,8,9 and Aqua bands 8 and 9) gain is derived using on-board calibrators supplemented with EV measurements

Nadir AOI: 38.25°

Collection 6 RSB Changes

- RSB calibration coefficients (m1) and RVS are derived at the same time using observations to the SD, Moon, and "pseudo-invariant" targets at different AOIs
  - Mainly applied to VIS bands (Aqua bands 8 and 9 and Terra bands 1-4, 8, and 9)
- Time dependent RVS applied to bands 13-16
  - Approach developed to monitor bands 13-16 lunar calibration stability (some pixels saturate when viewing the Moon)
- Detector-dependent RVS
  - Mainly applied to VIS bands (Aqua bands 8-12, Terra bands 3,8-12)
- Improved Algorithms for uncertainty calculation
  - Improved characterization for scene, time and AOI dependence

Summary - I

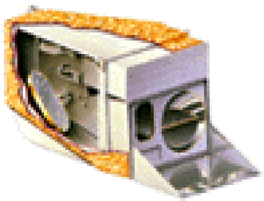
- Terra MODIS (13+ years)
  - No new noisy/inoperable detectors since last STM
  - SD/SDSM, and lunar observations used to track the RSB on-orbit gain change. Additional information from EV response from desert sites used for select RSB (Bands 1-4, 8 and 9)
  - Shorter wavelength VIS bands show larger degradation (strong wavelength, mirror side and scan-angle dependence), gain change of 50% and mirror side differences up to 10% seen in band 8 (412 nm) at the AOI of SD (50.25 °)
  - NIR bands gain change generally within 10% (exception few ocean bands)
  - SWIR bands gain change within 10% and MS difference within 0.5%
  - Challenges: RVS change for other VIS/NIR bands, Polarization, Aging instruments, EV response

Summary - II

- Aqua MODIS (~11 years)
  - No new noisy/inoperable detectors since last STM
  - SD/SDSM, and lunar observations used to track the RSB on-orbit gain change. Additional information from EV response from desert sites used for select RSB (Bands 8 and 9)
  - Shorter wavelength VIS bands show larger degradation (strong wavelength, mirror side and scan-angle dependence), gain change of 35% and mirror side differences up to 5% seen in band 8 (412 nm) at the AOI of SD (50.25 °)
  - NIR bands gain change generally within 5% (except bands 1,2 and 13)
  - SWIR bands gain change within 2% and MS difference within 0.1%
  - Challenges: RVS change for other VIS/NIR bands, Polarization, aging instruments, EV response

MODIS Calibration
Special Topics

MODIS Characterization Support Team (MCST)



Outline

- Terra band 27 crosstalk effect and removal
- Terra band 10 RVS using EV response trending
- “Sticky bin” effect to Terra RSB m1 and its correction
- Polarization effect on MODIS RSB
- Other issues

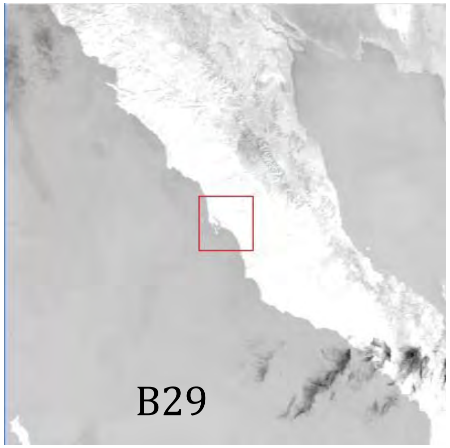
Terra MODIS Crosstalk

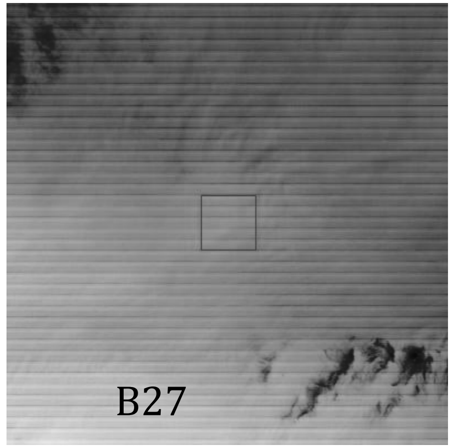
Timeline

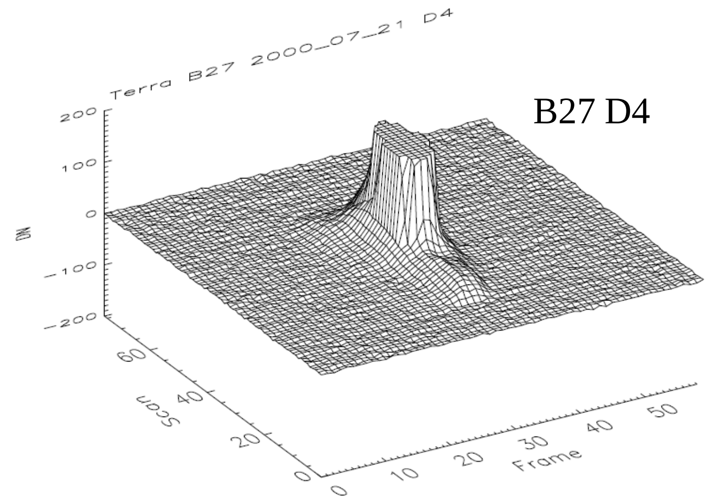
- Terra MODIS SWIR bands (5-7 and 26) crosstalk
  - Identified during prelaunch characterization and also evident in on-orbit observations
  - Developed algorithms to characterize and mitigate the impact
  - Challenging due to the complex nature of the electronic crosstalk characteristic
- Terra MODIS band 2 Crosstalk
  - Predominantly observed during the second half of the Terra mission
  - Developed a linear algorithm to correct the impact of the crosstalk (*J. Sun, X. Xiong, N. Che, and A. Angal, "Terra MODIS band 2 electronic crosstalk: cause, impact, and mitigation", Proc. SPIE **7826**,78261Y, 2010.*)
- Terra band 27 crosstalk
  - MCST received user inquiries regarding possible problems with band 27, which were then discussed at MsWG
  - EV images (Baja Peninsula) show evidence of a change in performance over time – in terms of signal leak and striping
  - Crosstalk effect confirmed by Lunar observations
    - From bands 28-30
  - Crosstalk coefficients characterized from lunar observations
  - Applications of the crosstalk algorithm to both BB calibration and EV imagery
  - *J. Sun, X. Xiong, S. Madhavan, B. Wenny, "Terra MODIS Band 27 Electronic Crosstalk Effect and Its Removal", IEEE geosciences and remote sensing, in press.*

EV Temperatures and Lunar Images

2000355.1850







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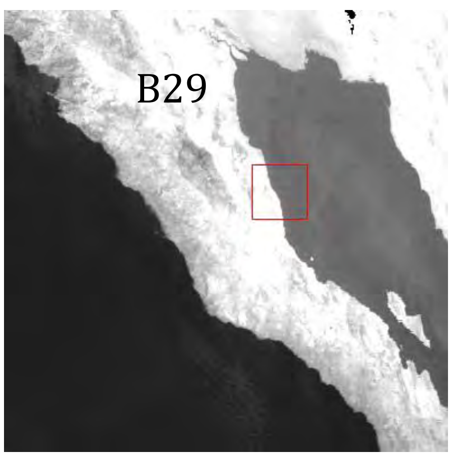
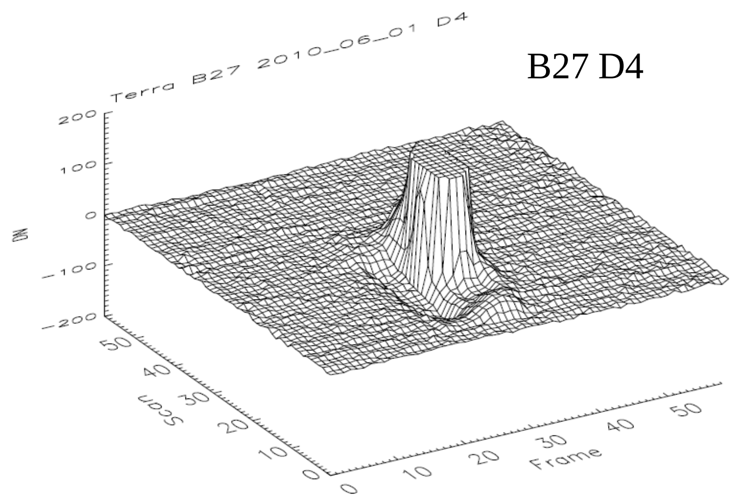




Brightness Temperature (B.T.) L1B images for Baja Peninsula (no stretching applied)

Crosstalk Correction Algorithm

- Linear Algorithm

$$dn_{B27}^{xtalk}(D,F) = \sum_{i,j} c_{ij}(D) dn_{B_i}(D_j, F + \Delta F_i)$$

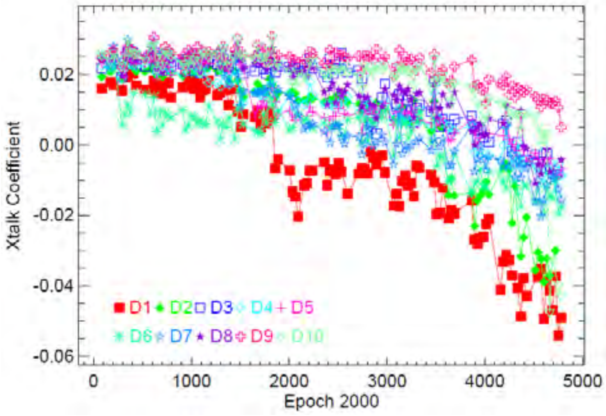
$$dn_{B27}^{corrected}(D,F) = dn_{B27}(D,F) - dn_{B27}^{xtalk}(D,F)$$

$$dn_{B27}^{xtalk}(D,F) = \sum_{i} C_i(D) \left\langle dn_{B_i}(D_j, F + \Delta F_i) \right\rangle_{D_j}$$

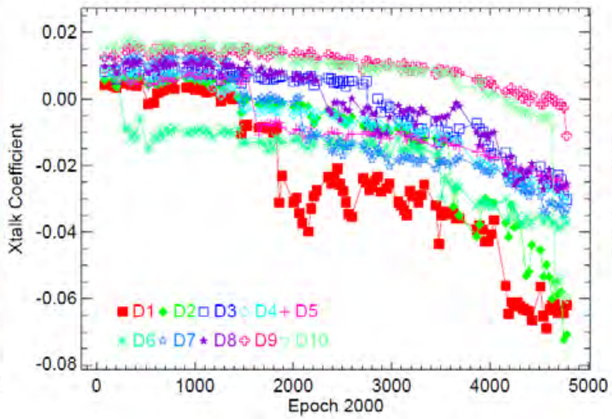
  - D, F: detector, frame
  - B_i, D_j: ith sender band, jth detector
  - ΔF_i: distance between band 27 and the ith sending band on the LWIR focal plane
  - c_{ij}: coefficient for the xtalk from B_i, D_i to B27, D
  - C_i: detector averaged coefficient for the xtalk from B_i to B
- Derive the xtalk coefficients from lunar observations
- Apply them in both Black Body calibration coefficients (b_1) calculation and L1B

B27 Crosstalk Coefficients

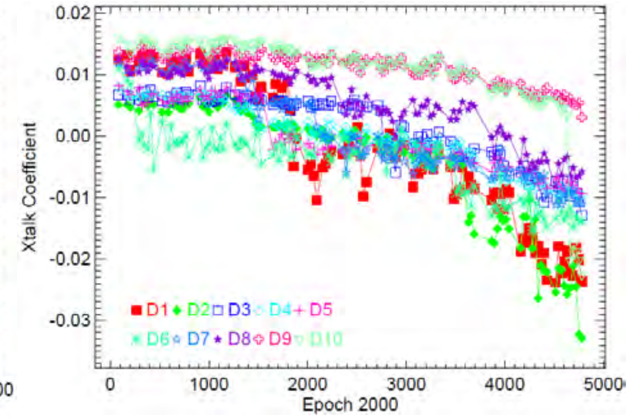
Sending band: B28



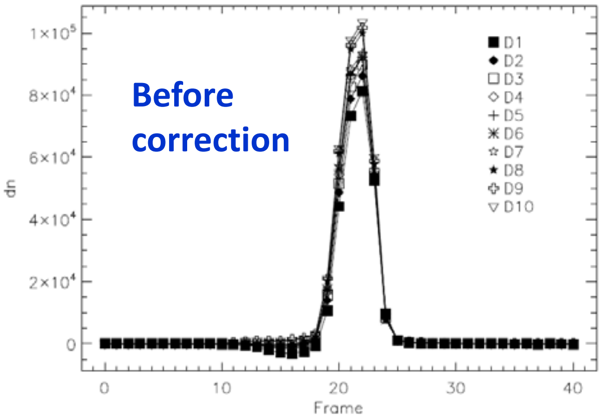
Sending band: B29



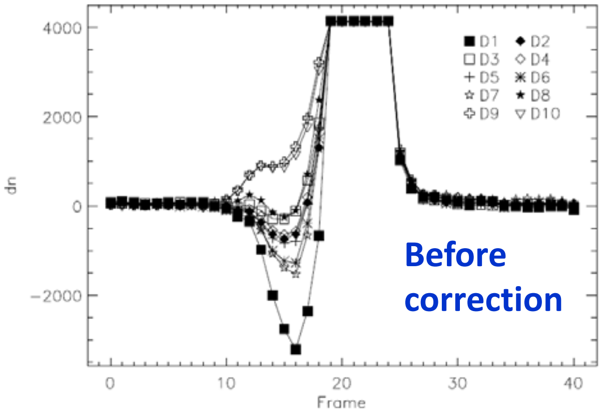
Sending band: B30



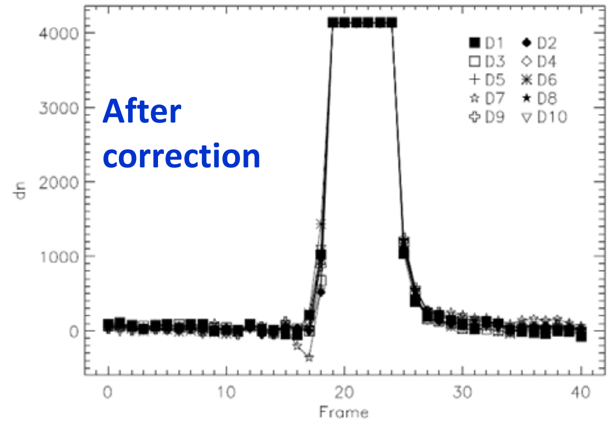
dn summed over scan



dn summed over scan

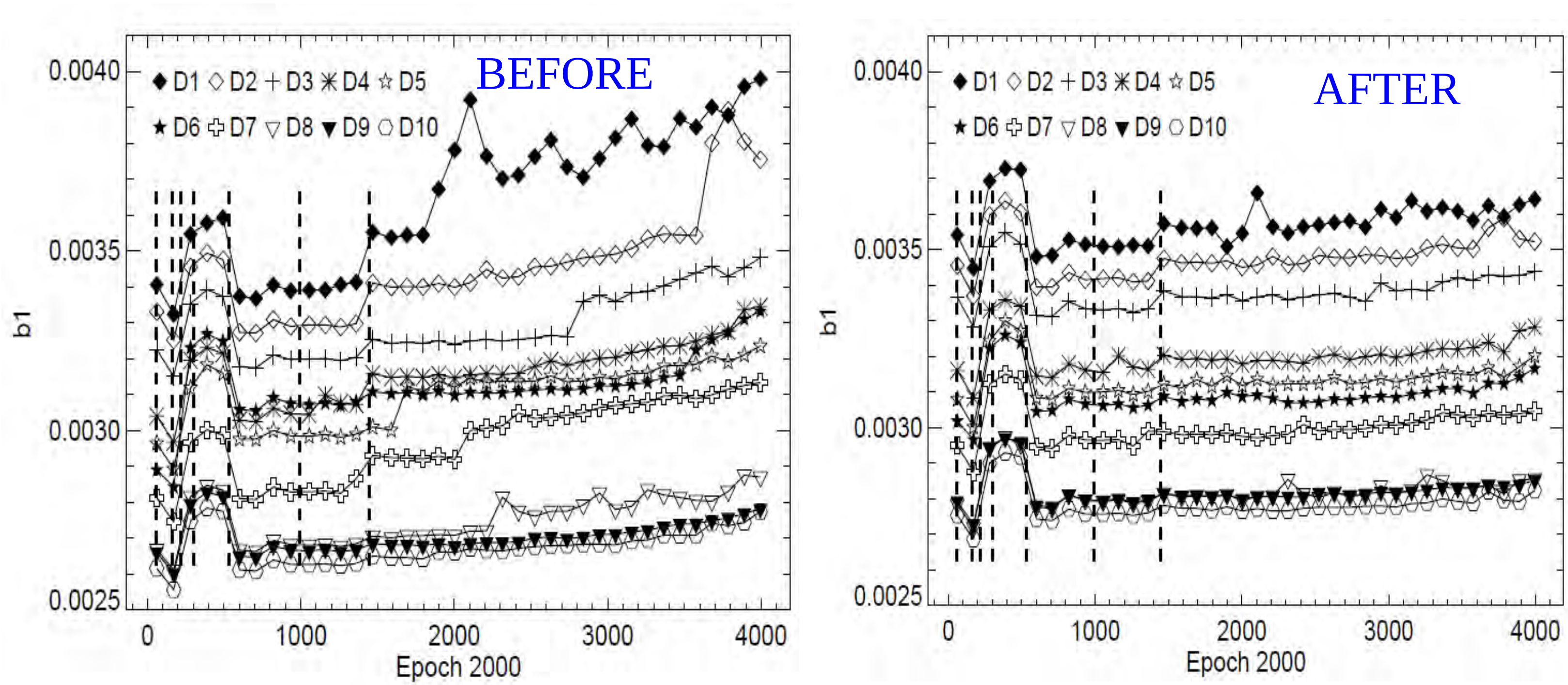


dn summed over scan



Crosstalk Removal

Terra MODIS Band 27 b1 Trending (Product order; T_{BB}@290K)

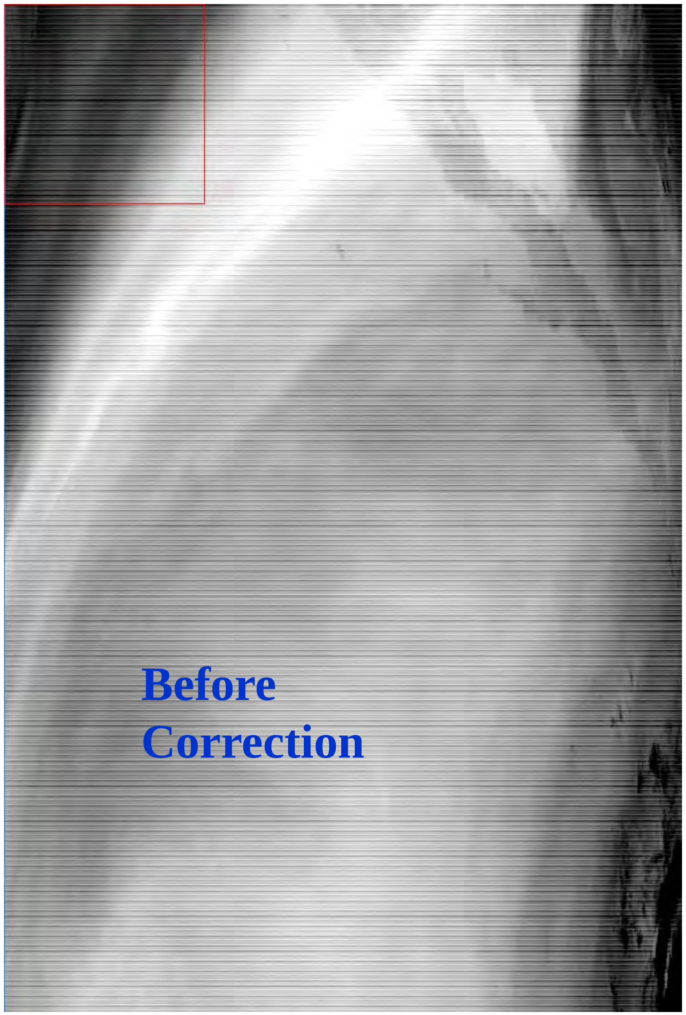


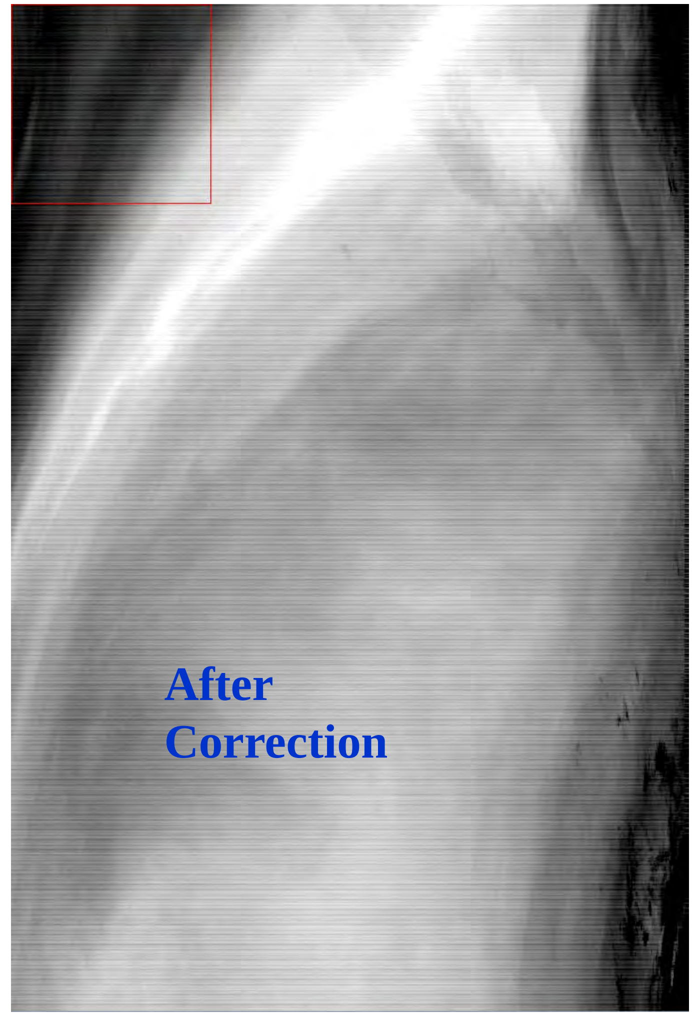
- Vertical dashed lines correspond instrument events
- b_1 relates to the linear coefficient of the TEB Calibration equation
- Detector response equalized after crosstalk correction

Crosstalk Removal

Terra Band 27 EV Temperatures

2010174.1840

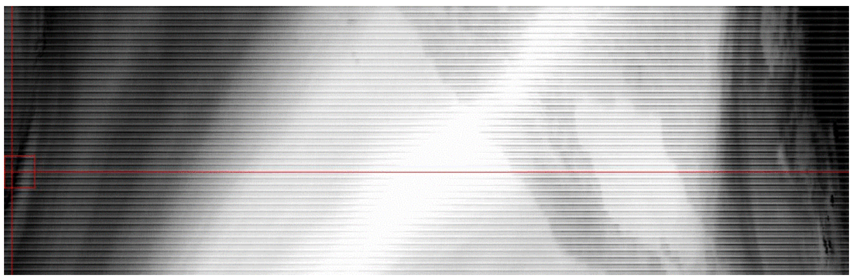


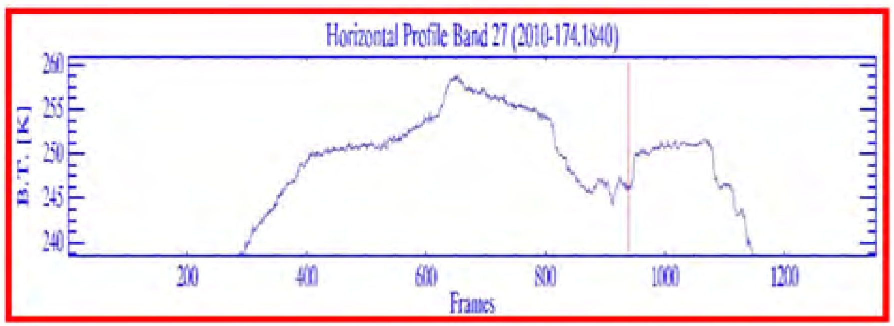


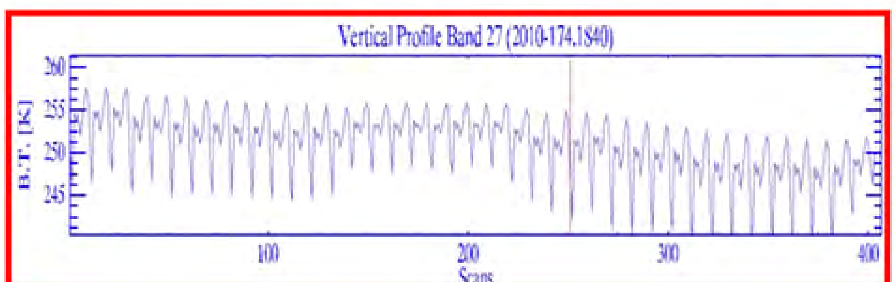
Crosstalk Removal

Terra Band 27 EV Temperatures on zoomed area from Image shown previously ***2010174.1840***

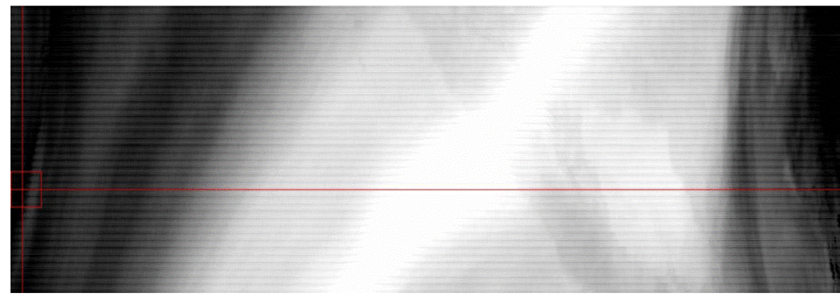
Before Correction

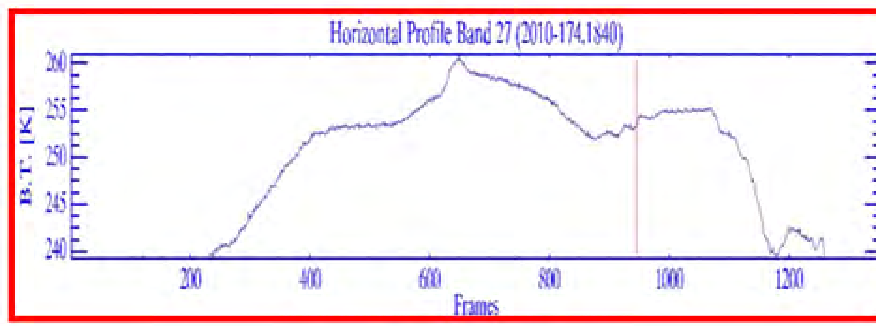






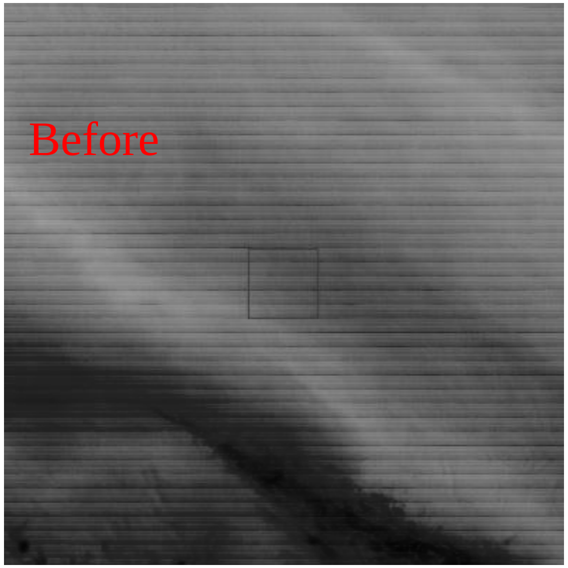
After Correction

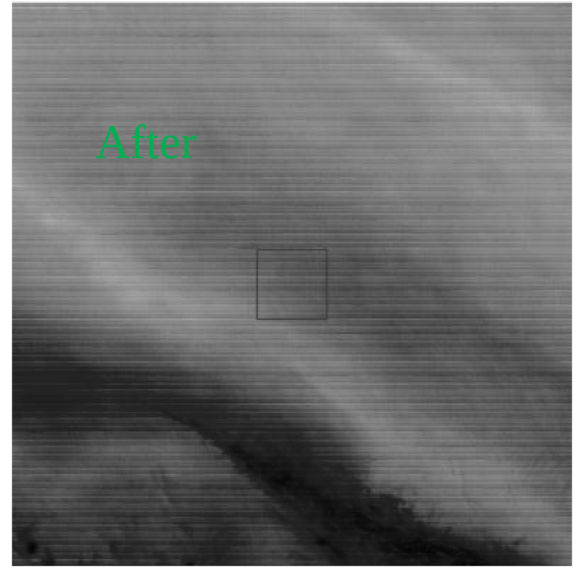


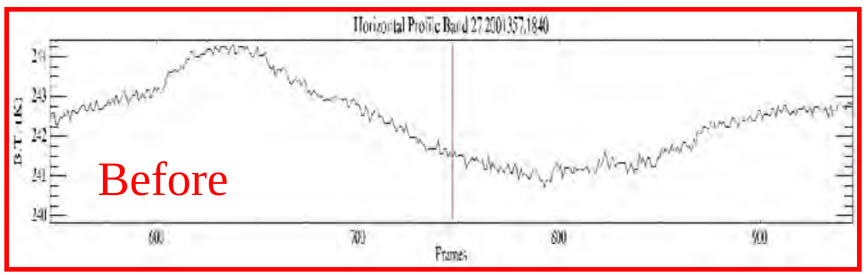


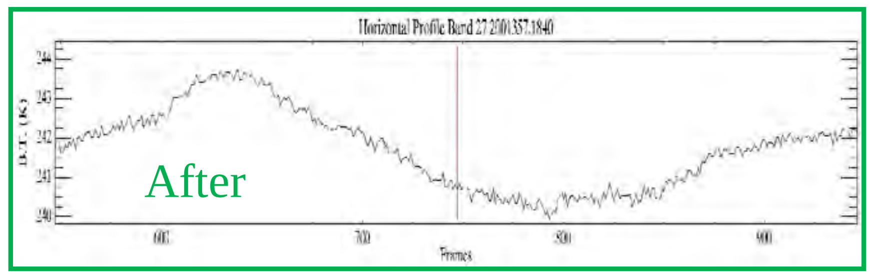
Crosstalk Removal

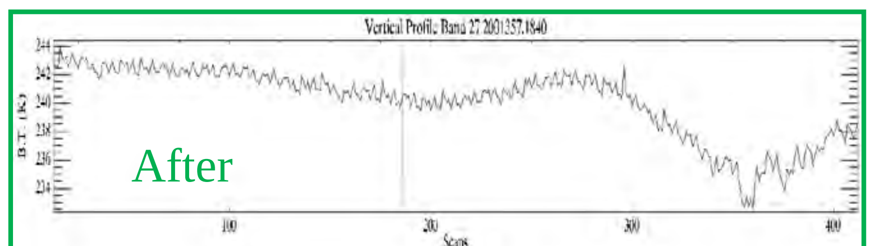
Terra Band 27 EV Temperatures, *2001357.1840 (BAJA)*





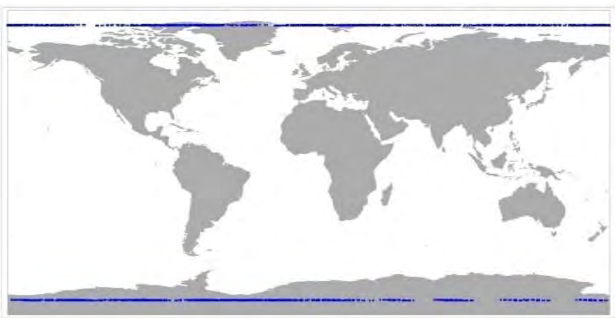


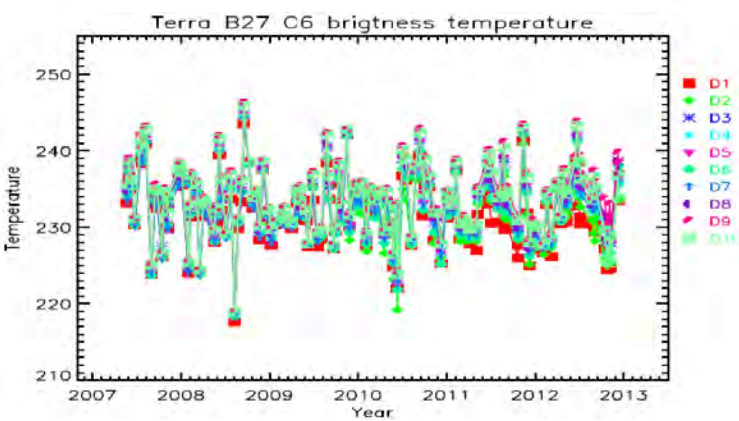




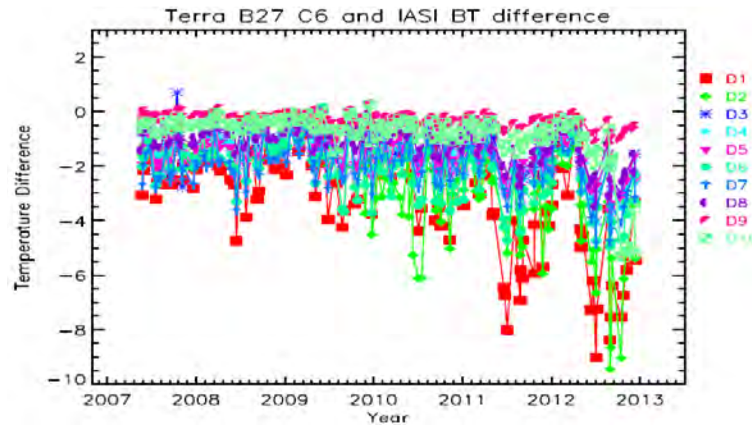
MODIS B27 and IASI SNO Comparison

IASI was launched in 10/19/2006, which has a sun-synchronous polar orbit at an altitude of 819 km and an IFOV of a ground resolution of 12 km at nadir.

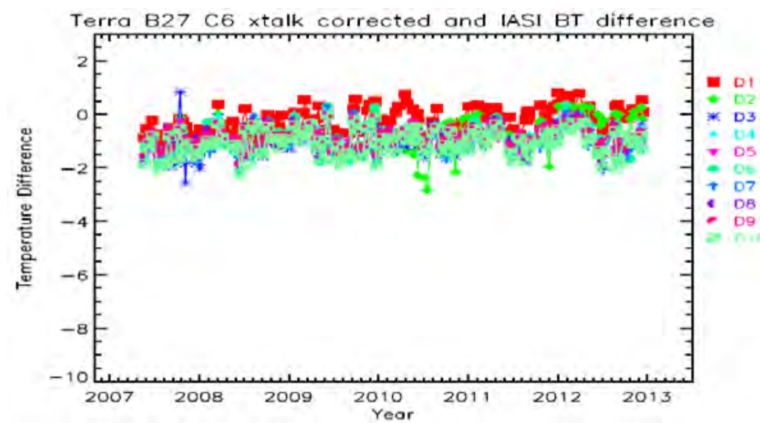




MODIS B27 T_{typ} is 240 K



Differences are detector dependent, increase with time, and can be as large as 10 K

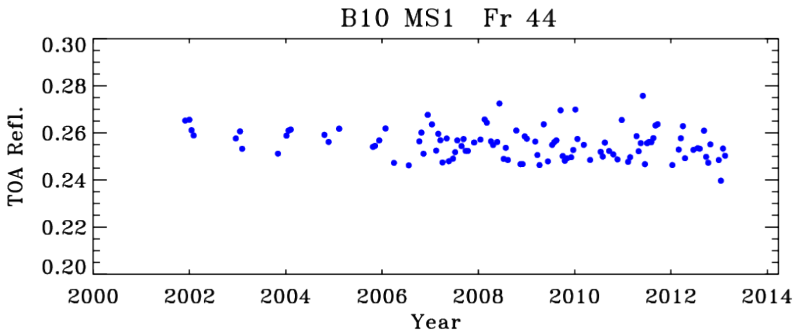


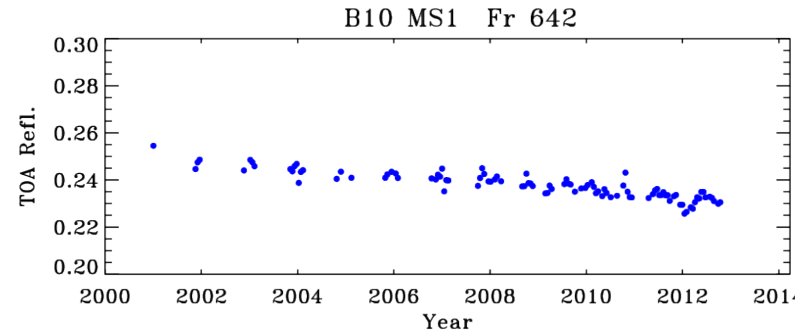
- Terra B27 detector differences are greatly reduced
- The band averaged BT differences between Terra B27 and IASI are much smaller with no observable long-term drift

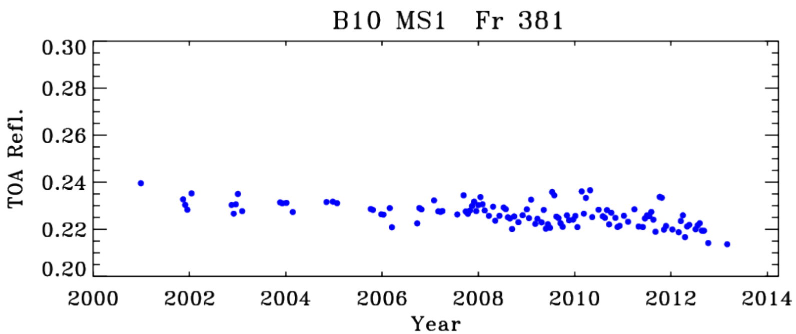
C6 RSB m1 and RVS LUT

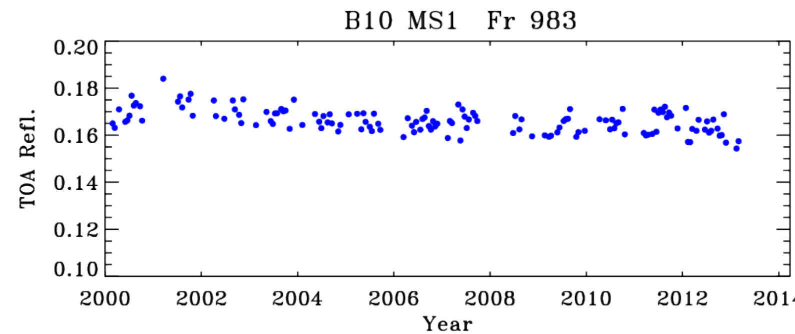
- No time-dependent RVS applied for SWIR bands
- For Terra bands 10-19 and Aqua bands 1-4 and 10-19
  - m1 and RVS are generated from SD and lunar calibration as well as mirror side ratios of Earth ocean sites observations
- For Terra bands 1-4 and 8-9 and Aqua bands 8-9
  - m1 and RVS are generated at same time from SD, lunar, and Earth ocean and desert sites observations
- Constant monitoring of the EV response trending of other RSB
- Next on line to use to on-board calibrators as well as EV response trending to generate LUTs
  - Aqua: Band 3, band 10, etc
    - No noticeable long-term drift seen in EV reflectance
  - Terra: Band 10, band 11, etc
    - Noticeable long-term drift seen in ocean products reported by OBPG, especially in last few years, for band 10

Terra Band 10 C6 EV Reflectance



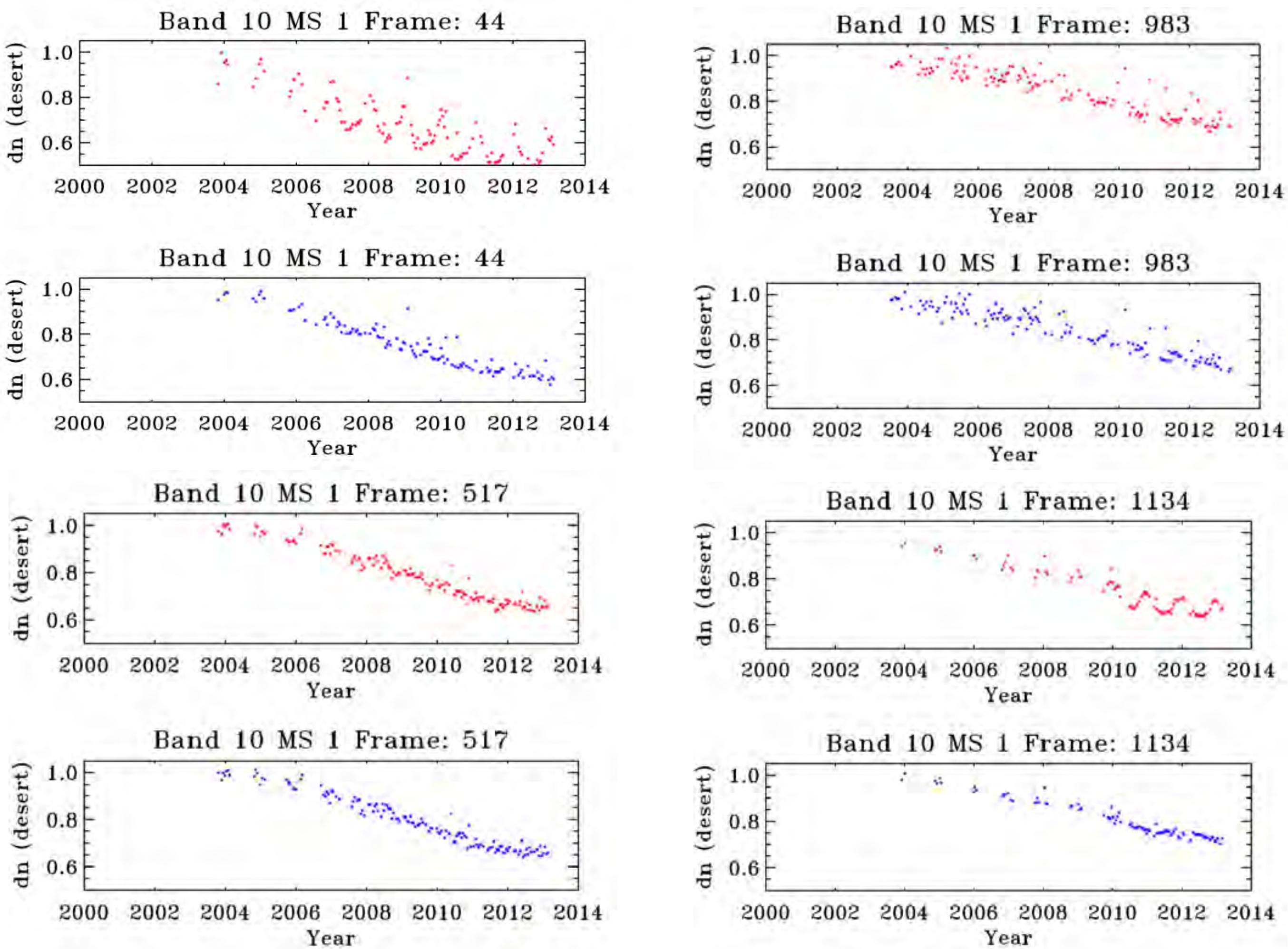






- Terra band 10 reflectance over pseudo-invariant desert sites.
- The band was saturated most time early in the mission.
- The seasonal oscillations have been removed.

Terra Band 10 EV Response Trending

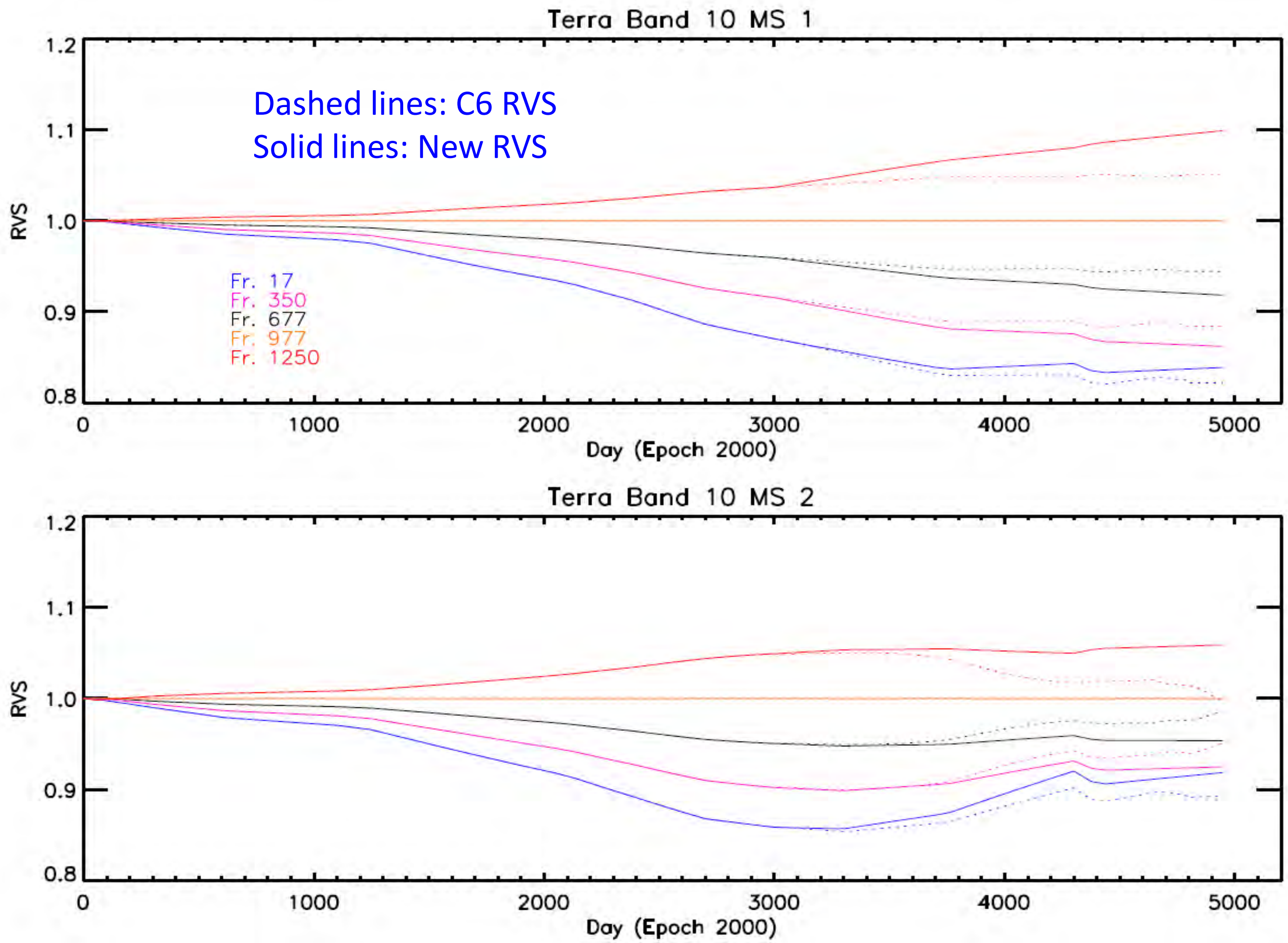


Red: Seasonal oscillations not removed; Blue: the oscillations removed.

Terra Band 10 Proposed RVS Algorithm

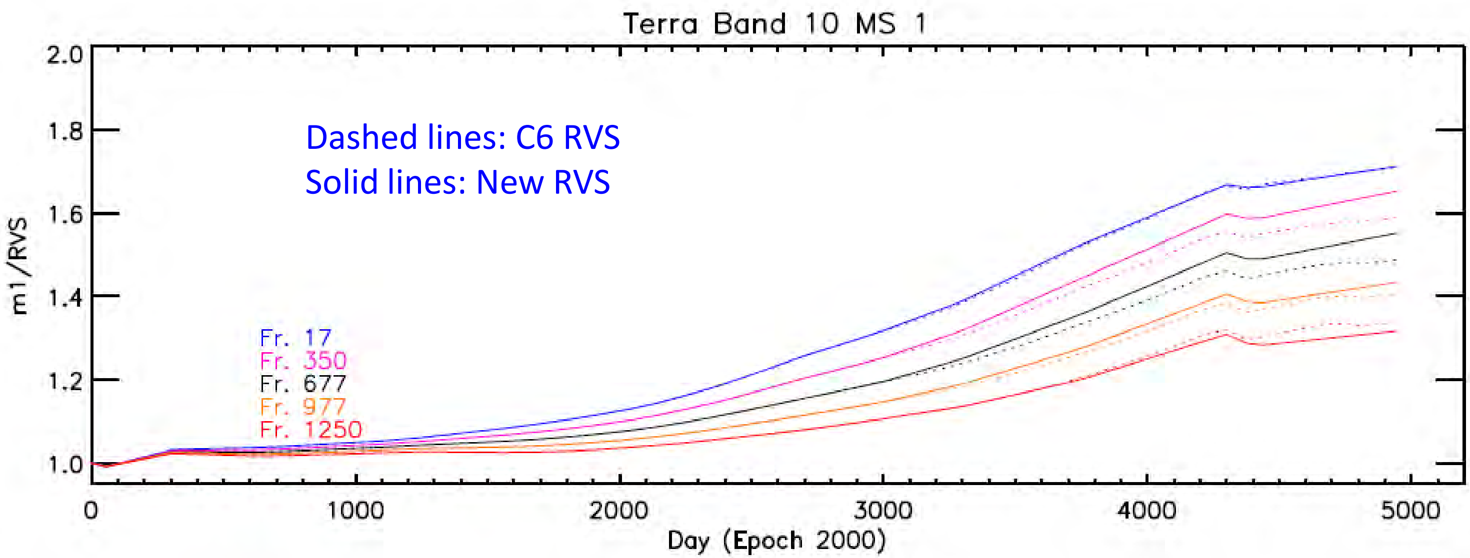
- Lunar view response and Earth view responses at selected AOIs
  - Terra Frames: 17 (lunar), 44, 91, 111, 180, 269, 381, 439, 517, 642, 745, 890, 983, 1134
  - Desert sites: algeria-3, libya-1, libya-2, libya-4
  - For each AOI, the instrument response is fitted to a linear function and the function is normalized at day 3000 (March 18, 2008).
- m1 and RVS before day
  - Derived from SD and lunar observations as well as EV MS ratios, same as current C6 approach for Terra band 10
- m1 and RVS after day 3000
  - Derived from SD and lunar observations and EV response trending over pseudo-invariant desert sites , similar as current C6 approach applied to Terra bands 1-4 and 8-9 with following details
    - The starting time using this approach is day 3000
    - A quadratic polynomial is applied to describe the on-orbit RVS change

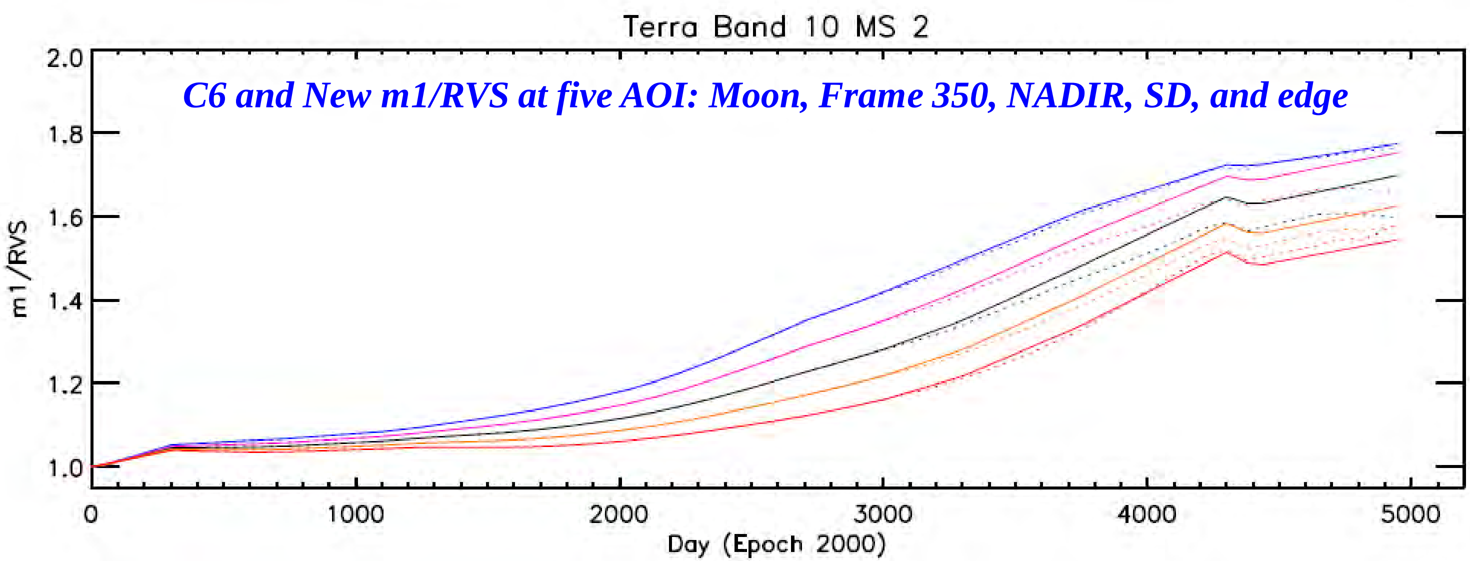
Terra Band 10 RVS



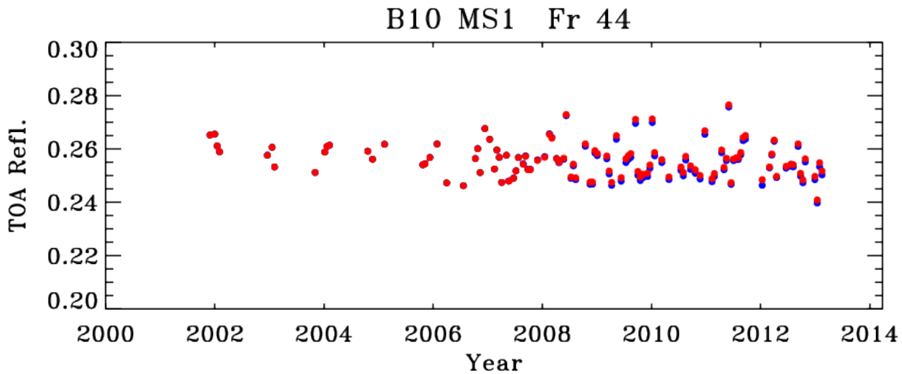
C6 and New RVS at five AOI: Moon, Frame 350, NADIR, SD, and edge

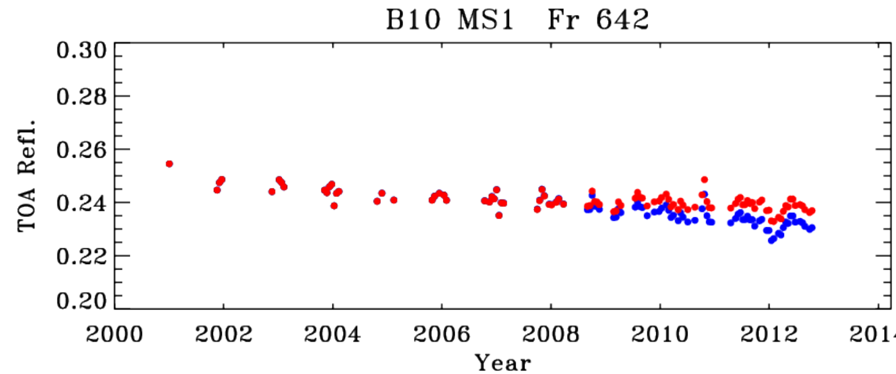
Terra Band 10 m1/RVS

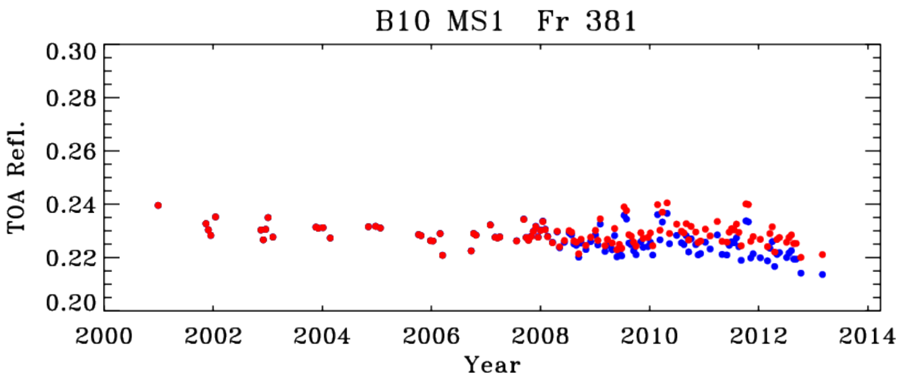


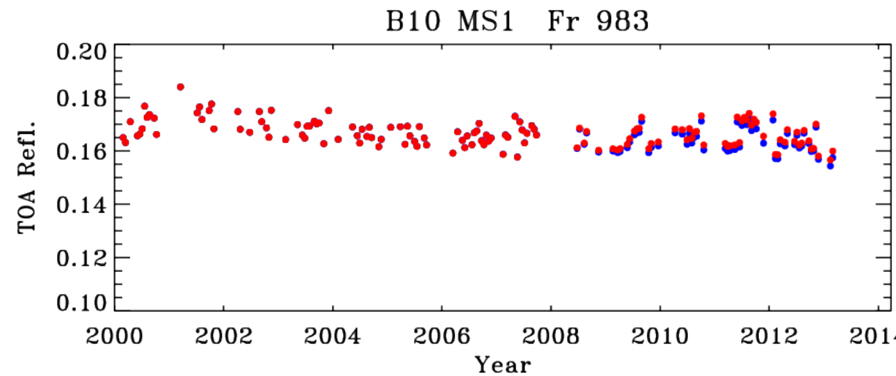


Terra Band 10 EV Reflectance



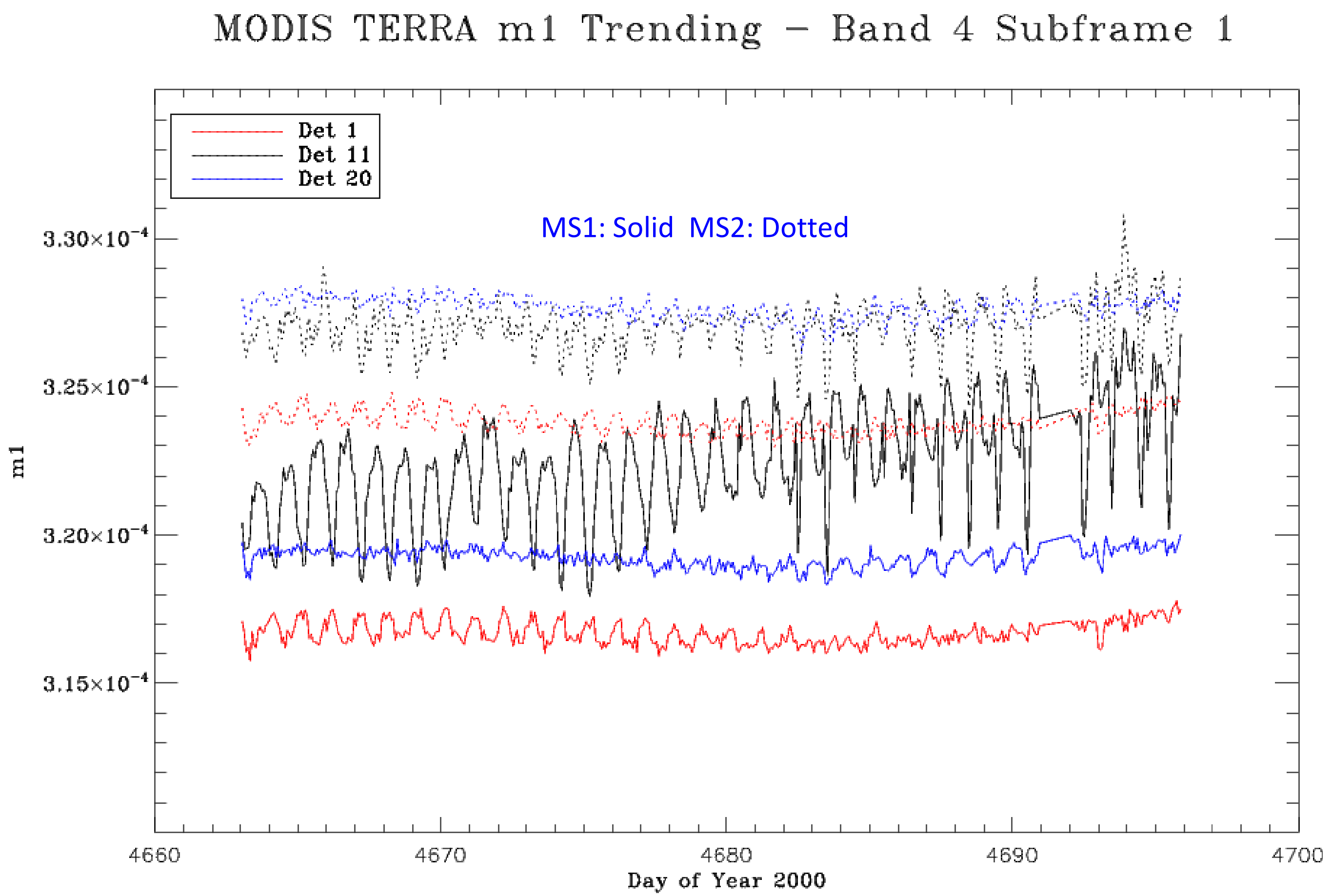






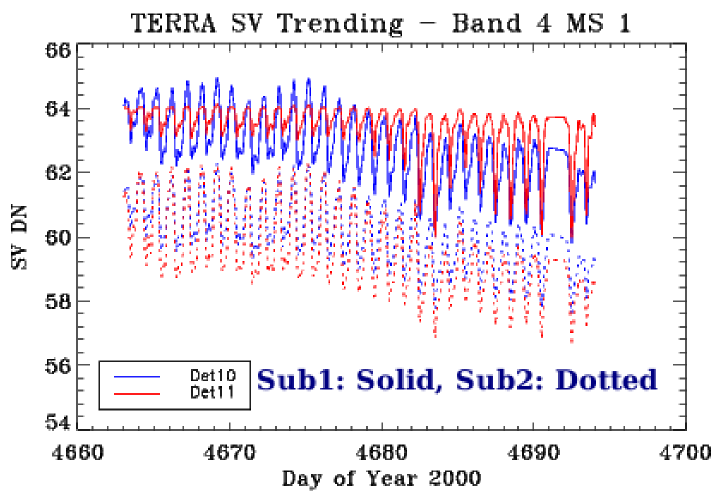
Red: New m1 and RVS; Blue: C6 m1 and RVS.

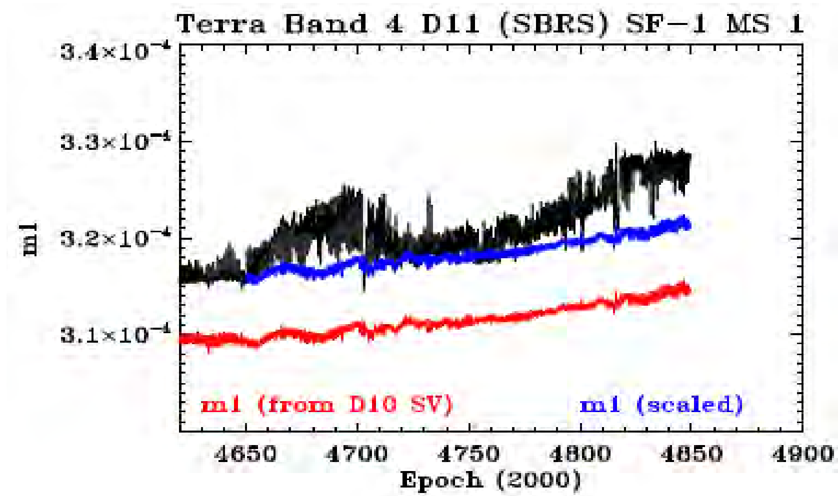
m1 Anomaly due to the "Sticky Bin" Effect

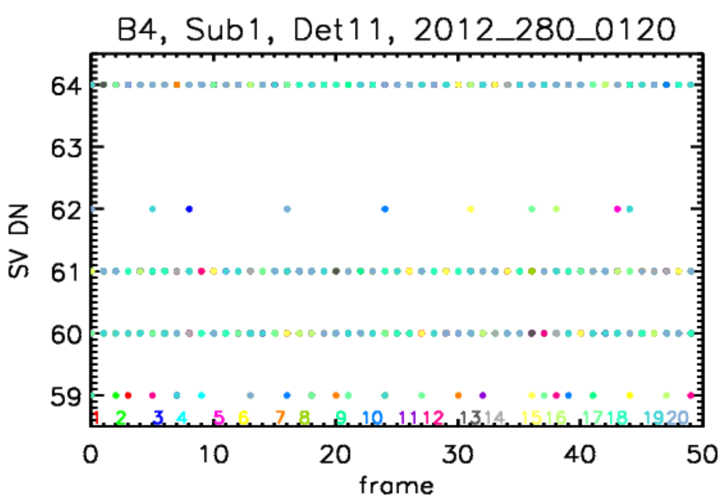


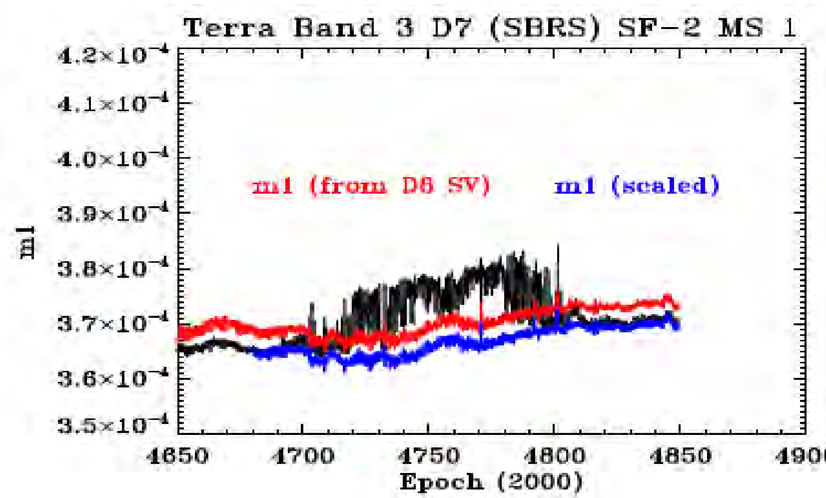
- B4 D11: Fluctuations ~1.5% since ~15, October, 2012
- B3 D7: Fluctuations ~2.5% since December, 2012
- B8 detector 1: Fluctuations ~0.5% very recently

m1 Anomaly due to the "Stick Bin" Effect







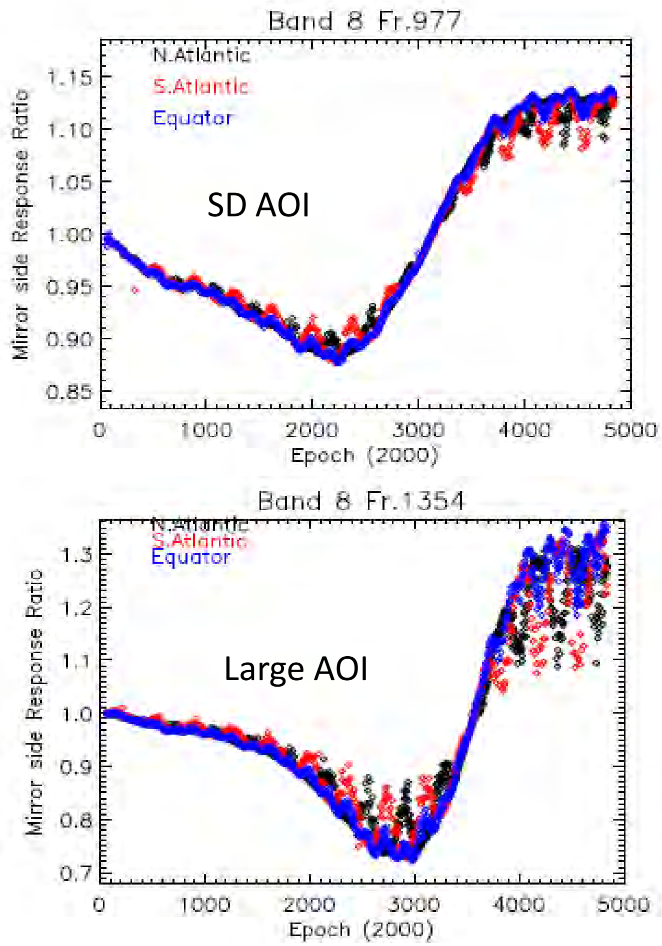


64 is a "sticky bin" for band 4 detector 11.

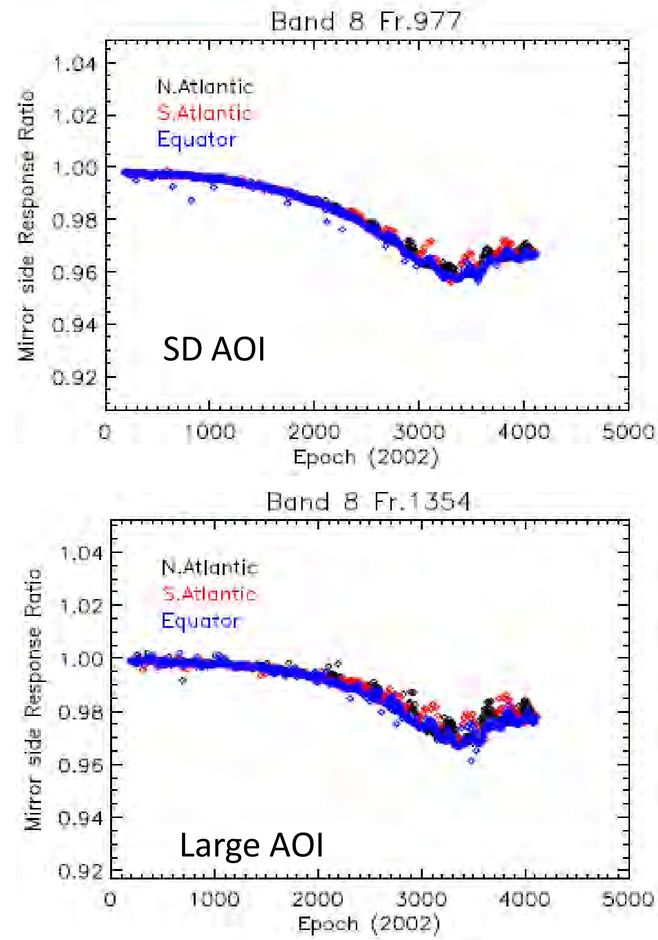
Polarization Effect

Terra and Aqua MS Ratios over ocean sites

Terra band 8



Aqua band 8

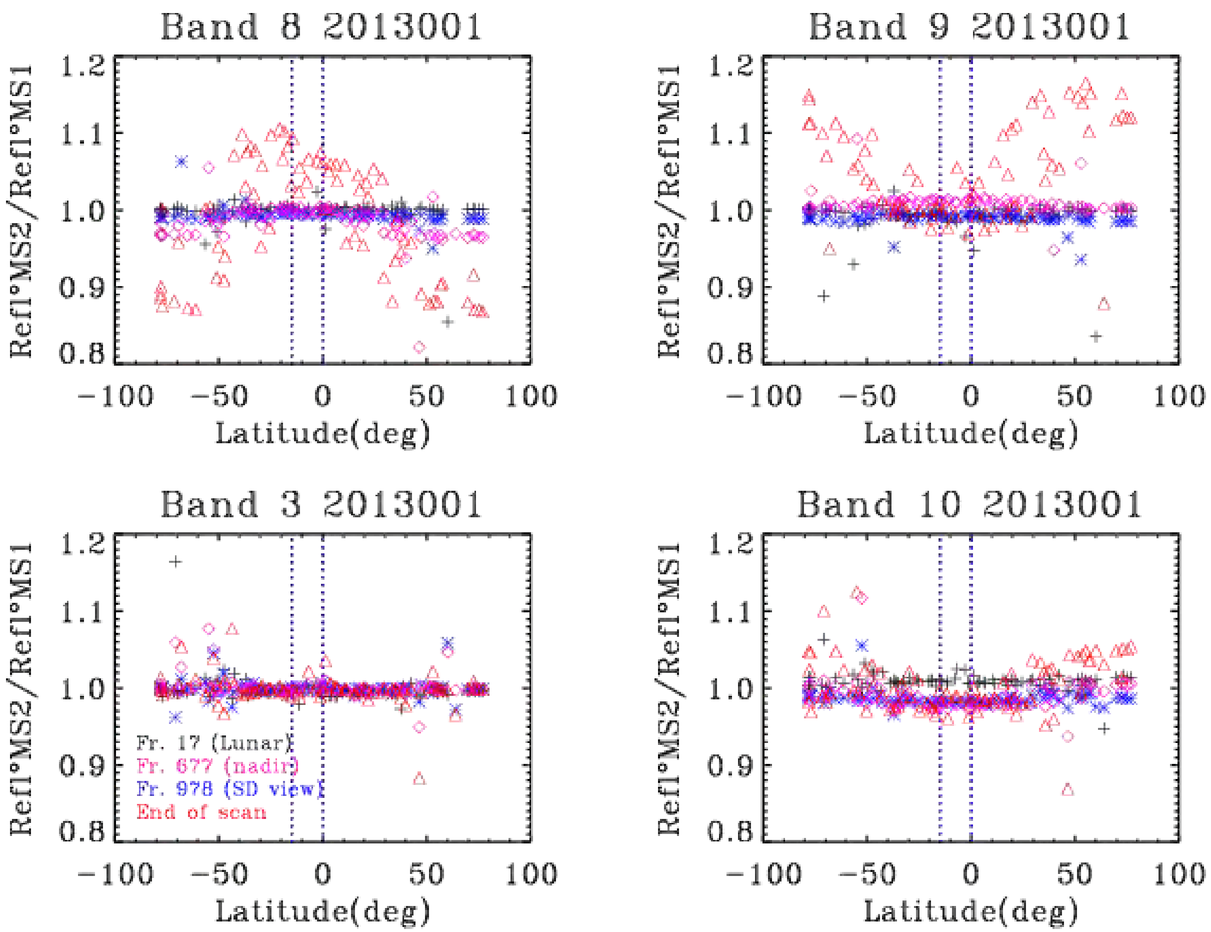


The variation of MS ratio with time at the two AOI is caused by MS difference of the polarization effect

Polarization Effect

Terra MS Ratios in one orbit

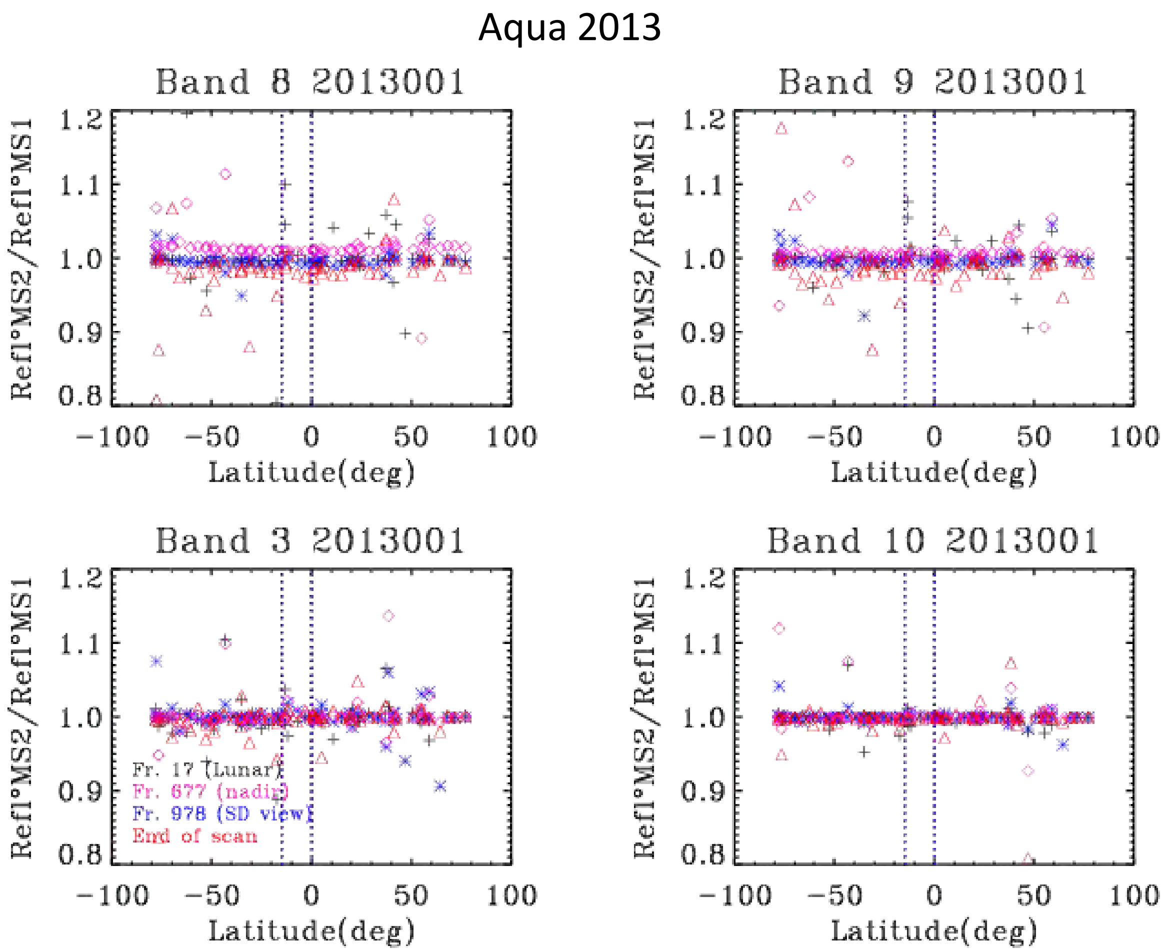
Terra 2013



The MS ratio varies with the latitude at large AOI, which is caused by MS difference of the polarization effect

Polarization Effect

Aqua MS Ratios in one orbit



MS difference of the polarization effect for Aqua band 8 is much smaller that for Terra band 8 but is visible recently.

Issues currently under investigation

- Band 20 Terra/Aqua consistency
  - Aqua band 20 consistently ~0.3 K lower than Terra at typical radiance levels
  - Observed in both Collection 5 and 6 data
  - MCST investigating RSR differences as a possible cause
- Aqua CFPA Temperature control
  - Three workshops have been held and most recent one was held on 3/27/2013 http://mcst.gsfc.nasa.gov/meetings/aqua-modis-cfpa-workshop-mar-27-2013
  - Saturation for bands 33, 35 & 36 during WUCD activities
  - Mitigation approaches under investigation
- Simon Hook reported last year on an increasing Terra/Aqua B29 difference using his Lake Tahoe dataset
  - MCST confirmed the drift using Collection 5 Dome C data using B31 as a reference. [Terra/Aqua B31 difference near 0 and stable over lifetime]
  - Similar trending using Collection 6 dataset removes/reduces the long-term drift in Terra Band 29.
- TEB RVS derivation using Dome C and clear ocean surfaces
  - Under investigation
- Terra bands 1 and 2 lunar and EV response trending difference
  - Lunar response trending match EV response trending over pseudo-invariant desert sites for all RSB bands of both instruments as long as they are not saturated expect Terra bands 1 and 2

Summary

- Both Terra and Aqua MODIS continue to operate normally
- Instrument on-board calibrators remain capable of all design functions
- Overall sensor performance has been satisfactory (very few noisy detectors in recent years)
- Decade long high quality MODIS data products have significantly contributed to a broad range of scientific studies and applications
- Dedicated calibration and characterization effort, including good communication with the science and user community, has become critically important for future improvement

Performance Summary

- Shorter wavelength VIS bands show larger degradation
  - Strong wavelength, mirror side, and scan angle dependence
  - MS difference in Aqua MODIS is much smaller than Terra MODIS
- A few NIR bands show gain increases over time
- Changes in SWIR responses are very small
  - SWIR bands are located on CFPA with MWIR bands
- TEB (MWIR and LWIR) responses have been very stable
  - Less than 2% changes over entire mission, except up to 10% for Terra LWIR PV bands 27-30
- Overall SNR and NEdT performance remains satisfactory
  - Only 1 new noisy detector in last 3 years
- On-orbit spectral and spatial performance remains stable
- Geolocation improvements have been made in C6

Discussions

- **Challenging Issues**
  - Large changes in VIS spectral band/detector response
    - Mirror side, wavelength, and AOI dependent
    - Impact on mirror polarization sensitivity
    - Less predictability for the long-term trend
  - Strong wavelength dependent SD degradation (larger at shorter λ), especially in Terra MODIS
  - Issues identified from science (Cal/Val) presentations

- **Future Work**
  - Examine and mitigate the impact of large SD degradation on SD/SDSM calibration accuracy and potentially on the detector RSR
  - Further reduce calibration impact due to gradual increase of Aqua CFPA temperatures (add temperature dependency for a2)
  - Characterize Terra and Aqua MODIS calibration consistency

- **Future Work (cont'd)**
  - Investigate and resolve bands 1-2 drift
  - Improve RSB RVS
    - Current algorithms: band selections
    - New algorithms: for future applications
  - Improve TEB RVS characterization (update if necessary)
  - Terra/Aqua calibration data product consistency
  - Terra configuration consistency (request of SST group)
  - Spectral correction to PC bands (UWisc)
- **Other Considerations**
  - Calibration and characterization effort at end of the mission
- **Action Items (to be discussed in future MsWG)**