MODIS Calibration Workshop

Jack Xiong (NASA GSFC)

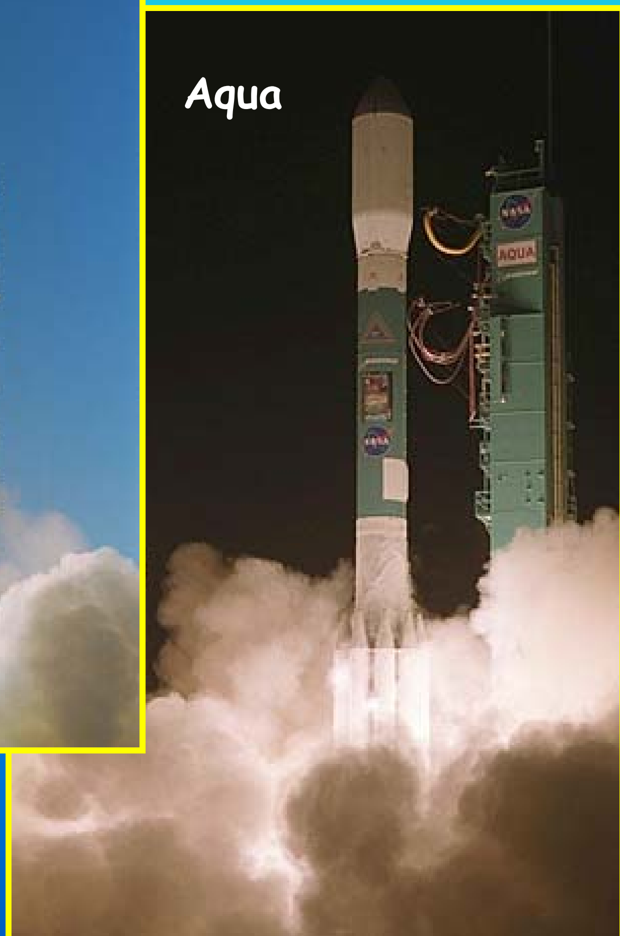
and

MODIS Characterization Support Team

MODIS Science Discipline Representatives

University of Maryland University College, Adelphi, MD 20783 (May 17, 2011)

Terra MODIS: over 11 years of successful operation
Aqua MODIS: over 9 years of successful operation



An unprecedented amount of data products with significant contributions to the broad user and science community

Successful Senior Review for both Terra and Aqua missions

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)
- NASA HQ and MODIS Science Team
  - Continuous Funding Support for both Terra and Aqua Missions
  - Leadership and Science Contributions
- User and Science Community
  - Input and Feedback

Agenda

MODIS Operation, Calibration, and Performance

Introduction (Jack Xiong)	1:30 pm
Instrument Operation Status (Gavin Westenburger)	1:40 pm
Recent L1B Algorithm and LUT Updates (James Kuyper)	1:50 pm
RSB Calibration, Performance, and C6 (Amit Angal, Junqiang Sun)	2:00 pm
TEB Calibration, Performance, and C6 (Sri Madhavan, Aisheng Wu)	2:40 pm
Geo-location Characterization and Performance (Robert Wolfe)	3:05 pm
Coffee Break	3:20 pm
Science Discipline Presentations	
CAL/VAL Presentations (Simon Hook, Chris Moeller)	3:40 pm
Land Presentations (Eric Vermote, Alex Lyapustin)	4:05 pm
Ocean Presentations (Peter Minnett, Gerhard Meister)	4:30 pm
Atmosphere Presentations (Steve Platnick, Rob Levy)	4:55 pm
Summary (Jack Xiong, Brian Wenny)	5:20 pm
Adjourn	5:30 pm

Summary

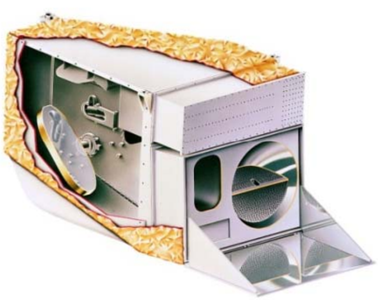
- Part 1: Instrument operation, calibration, performance, and C6 issues
- Part 2: Vicarious calibration and science applications
  - Spectral and spatial performance is provided in the backup slides
  - Recent updates to the L1B Uncertainty Index (UI) is available on the MCST webpage (materials discussed and reviewed at MsWG)
- Both instruments and their on-board calibrators continue to operate normally (no new changes to the instrument operational configurations)
  - Terra MODIS SD door fixed at the "open" position (July 2, 2003), which led to the increase of SD degradation rates
  - Gradual decrease of Aqua MODIS cooler margin has led to small increase of cold FPA temperatures (up to 0.3 K) and orbital/seasonal variations
  - Aqua SD door movements will soon reach the vendor limit (mid 2012), further decrease of Aqua SD calibration frequency is planned

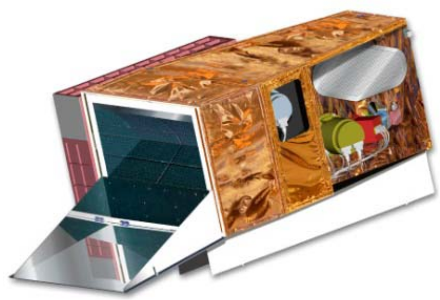
Challenges and Concerns

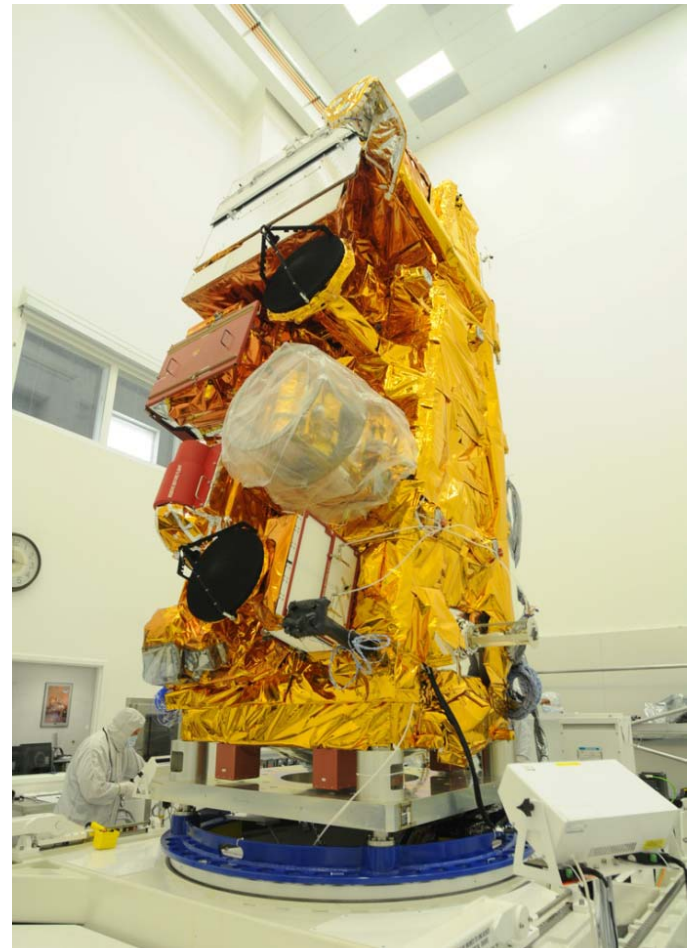
- Large changes in VIS spectral band/detector response
  - Mirror side, wavelength, and AOI dependent
  - Changes in response versus scan-angle (RVS)
  - Changes in scan mirror polarization sensitivity
  - Noticeable impact in bands 8, 9, and 3, and likely in other bands (more in Terra than Aqua MODIS)
- Large SD degradation at short wavelengths
  - More degradation in Terra than Aqua MODIS
- TEB calibration quality over cold targets
  - Improvements made in C6, noticeable effect may still exist
- Calibration consistency between Terra and Aqua MODIS
  - Scene dependent differences (offsets and trends)

Lessons for NPP VIIRS Operation and Calibration

EOS/MODIS to NPP/VIIRS and Beyond







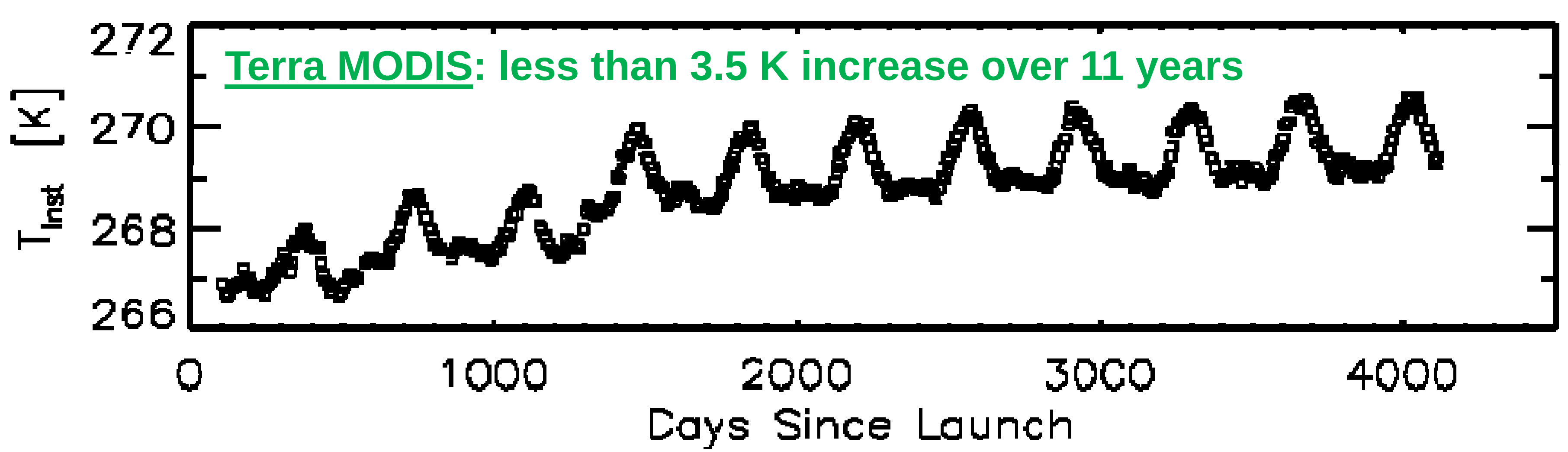
Instrument Operation

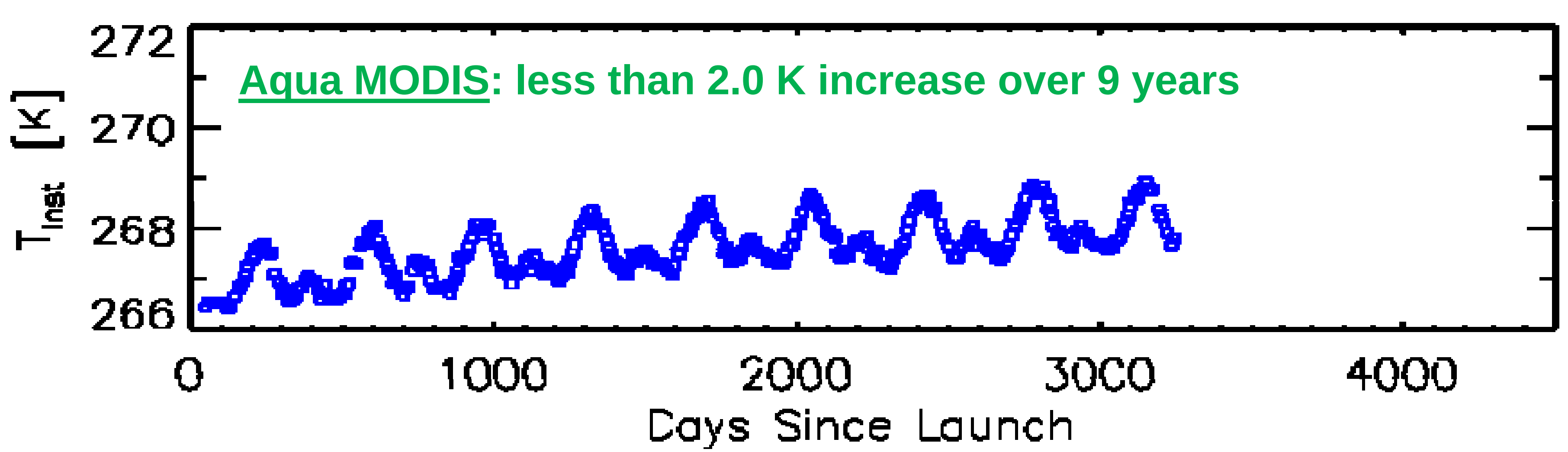
No New Changes to Instrument Operational Configurations

- Terra MODIS
  - 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 at "open" since July, 2003
- Aqua MODIS
  - Same B-side configuration since launch
  - BB temperatures set at 285K
  - Cold FPA (SMIR and LWIR) controlled at 83K

Details of MODIS operational activities available on MCST Webpage

Instrument Temperatures

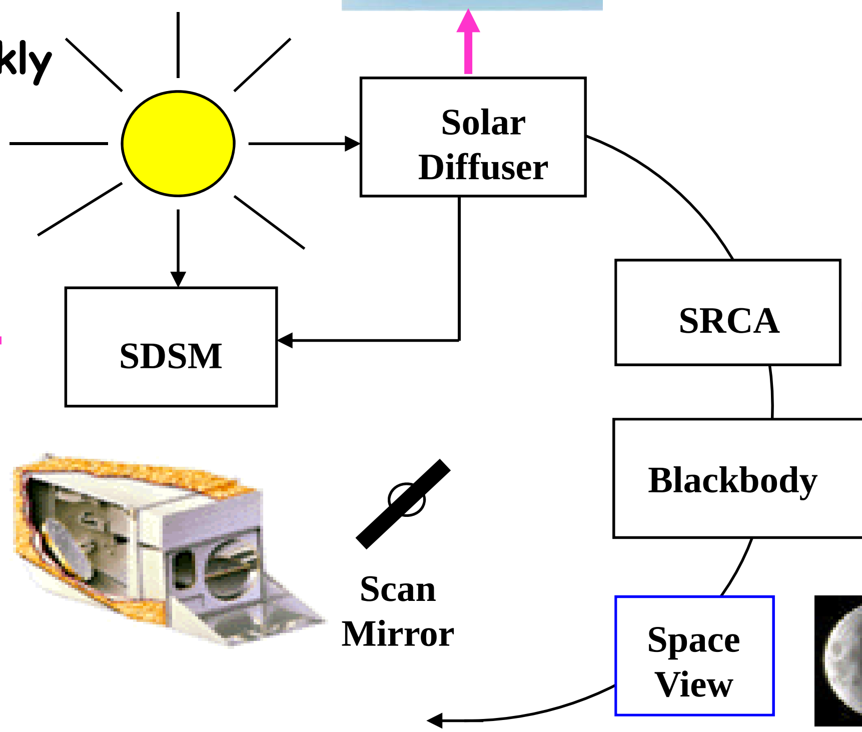




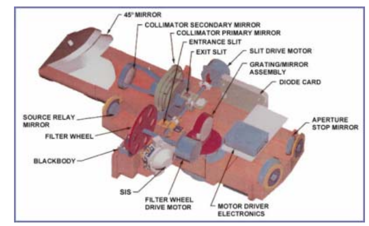
Similar trends for the VIS and NIR FPA temperatures

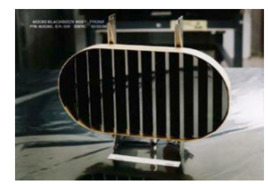
On-board Calibrator On-orbit Calibration

SD/SDSM:
Weekly to tri-weekly

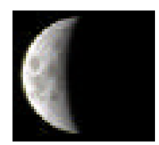


SRCA:
Radiometric: monthly
Spatial: bi-monthly
Spectral: quarterly

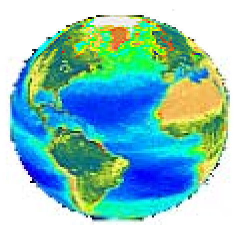




BB: quarterly



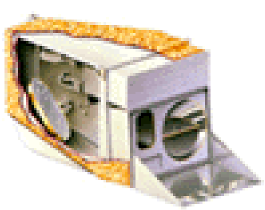
Spacecraft maneuvers:
Yaw (SD BRF, VF)
Roll (Moon)
Pitch (only applied to Terra)



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

MODIS Instrument Operations

MODIS IOT



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MODIS Operational Activities

Operational Activity	Activity	Operational Activity	Activity
OA-01	Initial Checkout	OA-16	SD/SDSM Screened
OA-02	Mode Transition	OA-17	SD Sector Shift
OA-03	Formatter Day Mode	OA-18	SDSM
OA-04	Formatter Night Mode	OA-19	SRCA Full Radiometric
OA-05	Safe/Survival Mode Recovery	OA-20	SRCA 10W Radiometric Continuous
OA-06	Initial Outgas	OA-21	SRCA 1W Radiometric Continuous
OA-07	DC Restore On/Off	OA-22	SRCA Full Spectral
OA-08	S/C Maneuver (Lunar Cal)	OA-23	SRCA Full Spatial
OA-09	S/C Maneuver (SD Scattered Light)	OA-24	SRCA Along-Scan Spatial
OA-10	S/C Maneuver (RVS)	OA-25	SRCA 1W Along-Scan Spatial
OA-11	Constraints on Special Operations (Field Campaign)	OA-26	Blackbody Cycle
OA-12	Table Load (GAO)	OA-27	PV Electronic Calibration
OA-13	Deleted	OA-28	PC Electronic Calibration
OA-14	Sector Rotation	OA-29	End Of Mission
OA-15	SD/SDSM Open		

Recent Events (Terra)

- **Spacecraft Events**
  - SFE-A (2010/065,107,177) – All Anomalies resulted in a data loss of several hours, but there was no detrimental impact to MODIS.
  - Battery Anomaly (2009/286) - possible MMOD (Micro-Meteoroid Orbital Debris)
  - On DOY 2010/181, the FOT erroneously commanded an additional second to the Command and Telemetry Interface Unit (CTIU). Terra Lunar Roll #98 on DOY 2010/182 was waived as a result of the anomaly. This error was corrected on DOY 182 (7/01/10) and there have been no further impacts to the spacecraft or MODIS.
- **Orbit Adjust Maneuvers**
  - Drag Make-Up #58-61
  - Inclination Adjustment #25-28
- **MODIS Events**
  - A few telemetry points slightly exceeded configuration monitor limits, following the SRCA Spectral Calibration on DOY 2011/012. There was no impact to MODIS.

Recent Events (Aqua)

- **Spacecraft Events**
  - No new events
- **Orbit Adjust Maneuvers**
  - Drag Make-Up #40-48
  - Inclination Adjustments #25-30
  - Debris Avoidance Maneuver (2010/362, 2011/002, 039, 060)
- **MODIS Events**
  - Aqua SRCA Spectral Calibration scheduled for DOY 2011/013 was waived due to a miscommunication between the IOT and the new Aqua Flight Software Engineer. The SRCA Spectral activities were successfully completed on DOY 2011/048. There was no impact to MODIS.

Terra/Aqua MODIS OBC Operations

TERRA

Activity	PL to 01/10	01/10 - present	Total
SD/SDSM#	597	24	621
BB WUCD	70	5	75
SRCA*	299	29	328
Electronic Cal	63	5	68
Lunar Roll	95	9	104

AQUA

Activity	PL to 01/10	01/10 - present	Total
SD/SDSM#	408	35	443
BB WUCD	31	5	36
SRCA*	174	29	203
Electronic Cal	44	5	49
Lunar Roll	69	15	84

Open & Screened Activities counted independently
* Includes Spatial, Spectral and Radiometric
01/10 = last Science Team Meeting

SRCA Calibrations

- Terra – 328 SRCA Calibrations
- Aqua – 203 SRCA Calibrations

Lamp Power		10W				1W	
Lamp #		1	2	3	4	1	2
Terra	Usage (hr)	298.0	172.1	190.3	99.7	581.2	282.0
	Life (hr)	500	500	500	500	4000	4000
	percent	59.6%	**Failed on 11-20-2004**	**Failed on 2-18-2006**	19.9%	14.5%	7.1%
Aqua	Usage (hr)	291.6	188.0	205.7	104.0	522.9	274.9
	Life (hr)	500	500	500	500	5000	5000
	percent	58.3%	**Failed on 4-14-2003**	**Failed on 6-28-2005**	20.8%	10.5%	5.5%

Future Operational Considerations

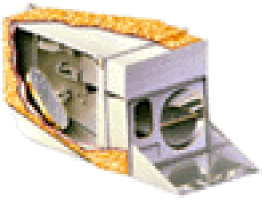
- Aqua MODIS CFPA temperature control
  - Currently set at 83K – two options for mitigation
    - Change set point to 85K
    - Perform outgas (given the opportunity)
      - Preliminary Standard Operating Procedure (SOP) has been produced for an outgas.
- Aqua SD/SDSM door movements
  - Adjust calibration frequency to preserve door movements

	PL to 01/10	01/10 to present	Total	Design Lifetime	% Used
Terra*	2146	0	2146	3022	71.01
Aqua+	2849	95	2944	3022	97.42

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

+ At the current usage rate Aqua will reach designed lifetime of door movement on DOY 2012/191 (July 2012). Plans to reduce SD/SDSM frequency in the future are being considered.

MODIS Level 1B and LUT Status



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Recent Code and L1B Updates

Near-monthly LUT update for each MODIS forward processing

- 96 for Terra MODIS and 60 for Aqua MODIS in Collection 5 since 2005
- Additional LUTs generated, tested, and delivered to OBPG (Ocean Biology Processing Group) for special investigations
- Most LUT updates were driven by response changes of VIS bands

Production Changes to Collection 5 MOD_PR02 TERRA L1B Code

PGE02 Version	Forward Processing Begin	Code Changes
V5.0.6_Terra	3/07/2005 (066 2005) 23:55	• Add a new LUT to enable the SWIR OOB correction detector dependency • Enable Band 21 calibration with mirror side dependency • Improve the code portability • Comply with the ESDIS guideline • Add HDFEOS_FractionalOffset • Minor fix for code version recording • Correct wrong dimension mapping offset setting for 250m band data
V5.0.38_Terra	9/17/2007 (260 2007) 19:35	• Relax the RVS correction limit range from [0.8, 1.2] to [0.4, 2.4].
V5.0.40_Terra	1/24/2008 (024 2008) 00:00	• Changed to set the PGEVersion ECS inventory metadata based upon the MODAPS PGE Version, rather then the obsolete GDAAC PGE Version. • Removed the ScanType of "Mixed" from the code. • Changed for ANSI-C compliance and comments correction.
V5.0.42_Terra	7/10/2009 (191 2009) 00:00	• Added an extension ".NRT" to the LOCALGRANULEID metadata if the ReprocessingActual from pcf is "Near Real Time" to indentify the NRT production.
V5.0.44_Terra	8/23/2009 (235 2009) 00:00	• Only the PGE02 version is changed for correction to a PGE level error.
V5.0.46_Terra	5/16/2010 (136 2010) 00:00	• Fixed the sector rotation anomaly.

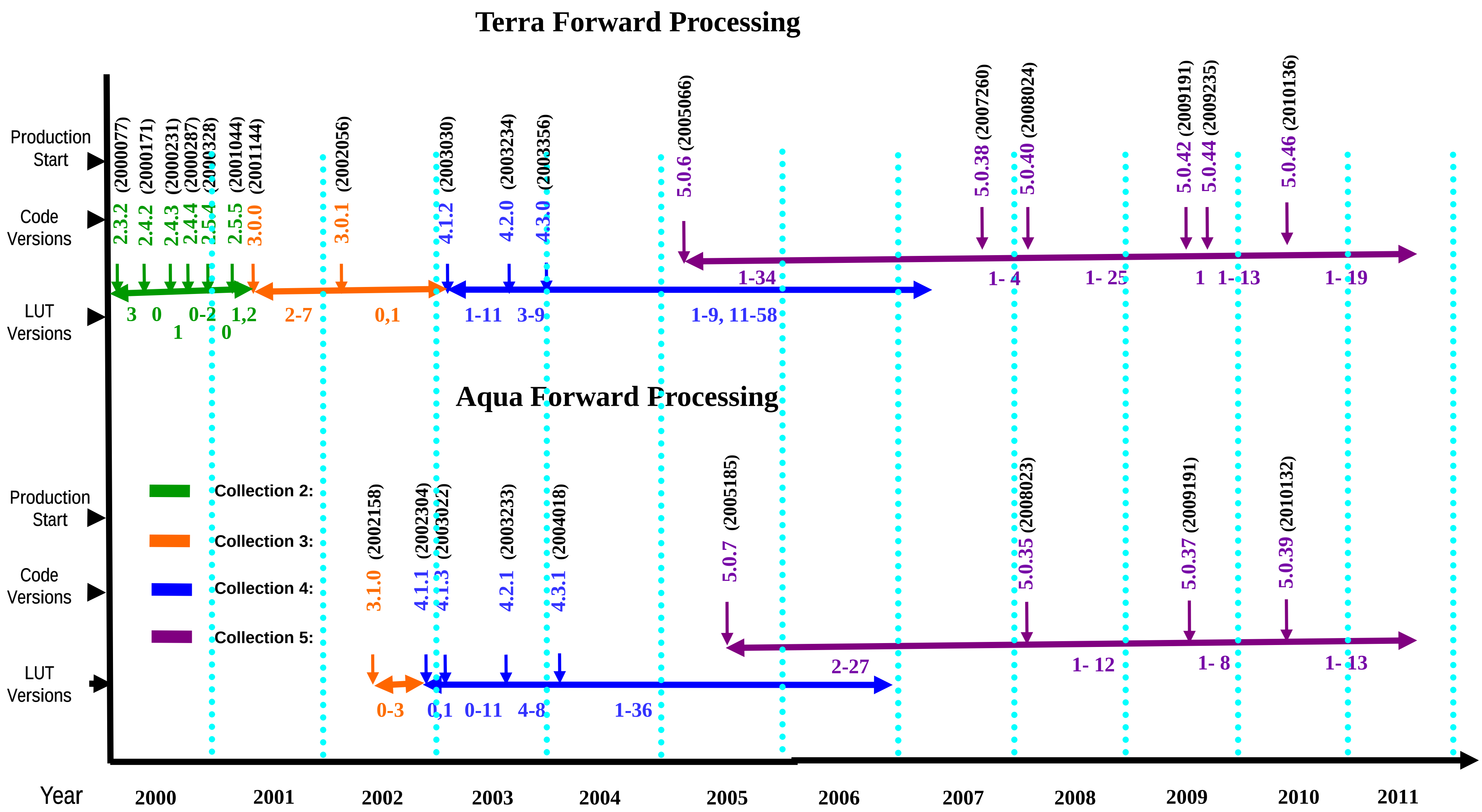
Number of MCST L1B Code and LUT Versions

(as of 2011-05-11)

Year	Terra Code Versions	Terra LUTs C2	Terra LUTs C3	Terra LUTs C4	Terra LUTs C5	Aqua Code Versions	Aqua LUTs C3	Aqua LUTs C4	Aqua LUTs C5	Total
2000	5	2	0	0	0	0	0	0	0	7
2001	2	1	5	0	0	0	0	0	0	8
2002	3	0	1	0	0	2	3	1	0	10
2003	3	0	0	19	0	3	0	17	0	42
2004	1	0	0	17	0	1	0	11	0	30
2005	2	0	0	18	10	2	0	11	6	49
2006	0	0	0	20	14	0	0	12	9	55
2007	1	0	0	1	13	0	0	0	11	26
2008	1	0	0	0	16	1	0	0	8	26
2009	2	0	0	0	18	1	0	0	8	29
2010	1	0	0	0	18	1	0	0	14	34
2011	0	0	0	0	7	0	0	0	4	11
Total	21	3	6	75	96	11	3	52	60	327

Does not include internal deliveries(18), nor special deliveries to Ocean Color Group (31) or Miami & Wisconsin (7)

MODIS MOD_PR02 L1B Code/LUTs Major Production Changes Timeline



Production Changes to Collection 5 MOD_PR02 AQUA L1B Code

PGE02 Version	Forward Processing Begin	Code Changes
V5.0.7_Aqua	7/03/2005 (185 2005) 00:10	• Add a new LUT to enable the SWIR OOB correction detector dependency • Enable Band 21 calibration with mirror side dependency • Improve the code portability • Comply with the ESDIS guideline • Add HDFEOS_FractionalOffset • Minor fix for code version recording • Correct wrong dimension mapping offset setting for 250m band data
V5.0.35_Aqua	1/23/2008 (023 2008) 00:00	• Relax the RVS correction limit range from [0.8, 1.2] to [0.4, 2.4] • Changed to set the PGEVersion ECS inventory metadata based upon the MODAPS PGE Version, rather then the obsolete GDAAC PGE Version. • Removed the ScanType "Mixed" from the code because the L1A "Scan Type" is never "Mixed". • Changed for ANSI-C compliance and comments correction.
V5.0.37_Aqua	7/10/2009 (191 2009) 00:00	• Added an extension ".NRT" to the LOCALGRANULEID metadata if the ReprocessingActual from pcf is "Near Real Time" to indentify the NRT production.
V5.0.39_Aqua	5/12/2010 (132 2010) 00:00	• Fixed the sector rotation anomaly.

Collection 6 Code Changes for L1B-1

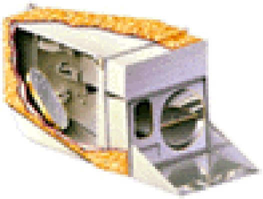
- Change to no longer interpolate the values of inoperable detectors from nearby good detectors.
  - The scaled integer value are now set to a flag value of 65531
- Noisy/inoperable detector (sub-sample) flagging
  - If sub-sample is inoperable, the scaled integer value will be set to the flag value 65525
- The sector rotation timing fix
  - The anomaly is caused by the mismatch of the timing of the instrument command to perform the sector rotation and the recording 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).
- Change in how `ReprocessingActual` ECS metadata is set and used.
  - Previously, value was fixed as "`processed once`"
  - Now the value is controlled by MODAPS operations:
    - "`Near Real Time`" – causes file name to end with "`.NRT.hdf`"
    - "`processed once`"
    - "`reprocessed once`"
  - Also implemented in Collection 5 code.

Collection 6 Code Changes for L1B-2

- PCLW Electronics Side A and Side B on at same time
  - Is one of three systems on spacecraft that can be commanded to have both sides on. (however, that command is incompatible with current hardware configuration)
  - Previously treated as a fatal error, causing loss of entire granule.
  - Corrupted data packets have made it appear to have happened.
  - No longer fatal; only the affected scan is marked as bad.
- New algorithms for calculating the uncertainties for RSB bands
  - The uncertainty in C5 L1B includes 9 terms derived from prelaunch analysis. In C6 L1B, contributions to the uncertainty due to prelaunch measurements as well as on-orbit calibrations are included. They are grouped into 5 terms (u1, u2, u3, u4, and u5). Among the five terms, three are provided by input look up tables which are updated routinely. The other two terms are calculated since they are scene dependent. The parameters used in the calculation are also provided by input look up tables and may need to be updated.
- New algorithms for calculating the uncertainties for TEB bands
  - The perturbation method used to derive UI terms in the C5 L1B is replaced with an analytical expression approach. A few UI terms from prelaunch are replaced with on-orbit values. There are 11 new emissive LUTs added and 5 LUTs rendered obsolete.
- Changed to model RVS for the RSB bands using a quartic polynomial, rather than a quadratic one.

Status of EOS Terra and Aqua MODIS RSB Calibration

MODIS Characterization Support Team (MCST)



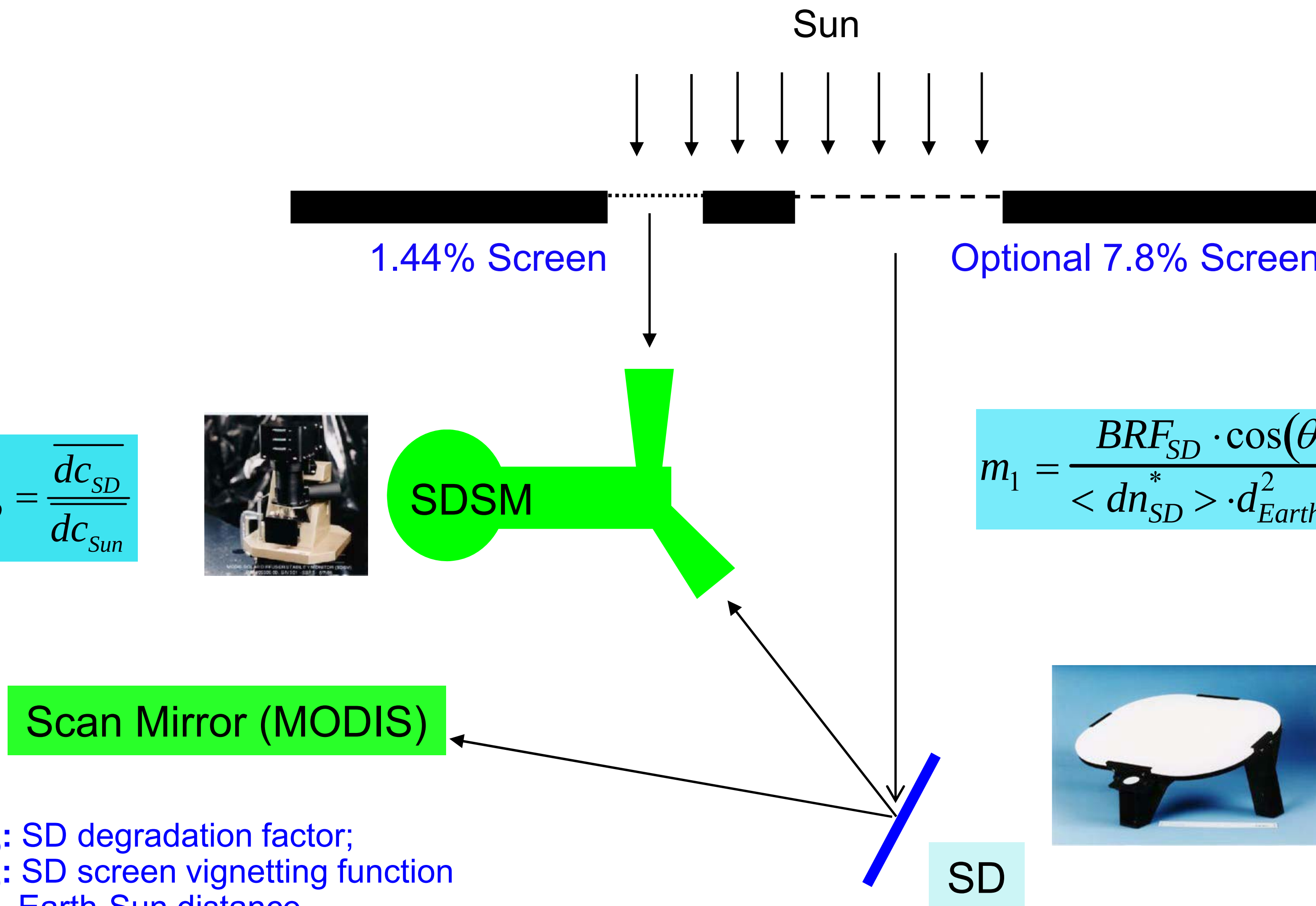
<u>MCST Workshop at MST Meeting (May 17, 2011)</u>

Outline

- Overview of the RSB calibration algorithm
- Noisy & Inoperable RSB detectors
- Solar Diffuser Degradation
- RSB response trending
- Summary of RSB overall performance

MODIS RSB Calibration Using SD/SDSM

Reflectance Factor $\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$



$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$

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

Δ_{SD}: SD degradation factor;
Γ_{SD}: SD screen vignetting function
d: Earth-Sun distance
dn*: Corrected digital number; **dc**: Digital count of SDSM

MODIS RSB Noisy & Inoperable Detectors

Terra

Day/Year	Band	5										6			7		
	SNR Spec	74										275			110		
	Detector	1	2	3	4	5	8	10	15	17	19	13	14	18	7	1-6,8-10	11-20
055/2000	Nadir Door Open	0	80	0	0	30	0	80	60	0	0	100	0	0	0	110	100
160/2000	CFPA Lost Control	80	80	80	80	30	80	80	60	95	95	100	0	0	0	110	100
232/2000	Back from FPA recyle	0	70	0	80	50	80	0	50	95	75	100	0	0	0	110	100
304/2000	B Side	80	80	80	80	60	80	80	85	20	85	275	350	350	100	100	90
183/2001	A Side	90	90	90	90	90	90	90	90	10	95	380	380	380	110	110	100
259/2002	A Side B Formatter	100	100	100	100	100	100	100	100	10	100	380	380	380	110	110	100

Aqua

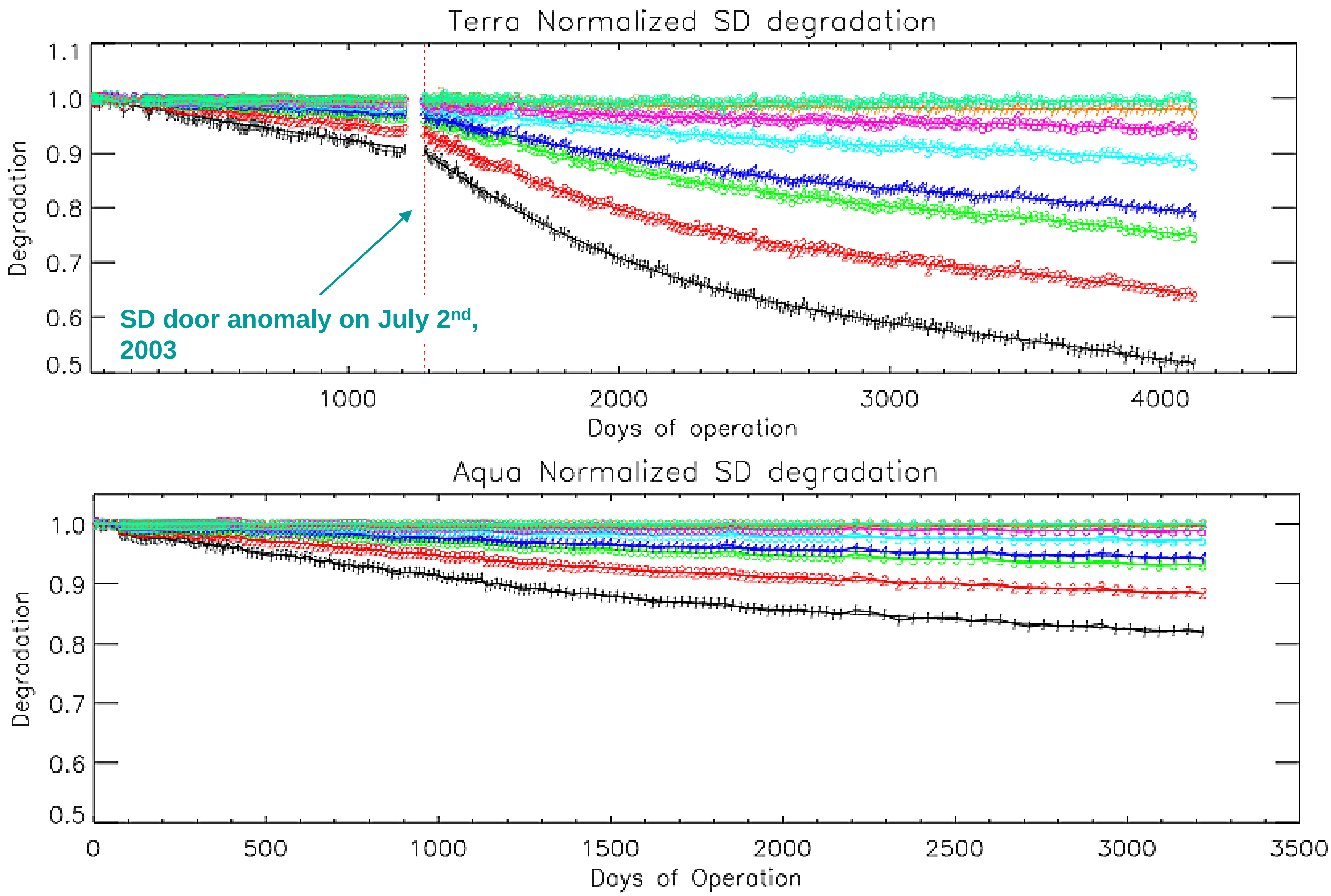
Day/Year	Band	5	6									
	SNR Spec	74	275									
	Detector	1	1-3	4	5-9	11	12	14	15	16	17	19
175/2002	Nadir Door Open	0	0	100	0	0	470	470	0	0	0	0
189/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	470	470	0
255/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	0	0	0
266/2002	Back from Safe Mode	0	0	470	0	0	400	150	0	0	0	0
110/2003		0	0	320	0	0	470	260	0	0	0	0
160/2003		0	0	470	0	0	400	290	0	0	0	0
265/2003		0	0	275	0	0	400	290	0	0	150	0
360/2003		0	0	270	0	0	275	290	0	0	200	0
080/2006		0	0	270	0	0	350	0	0	0	200	0

In Spec | Near Spec | Out Spec | Inoperable

No new inoperable/noisy detectors since the last MST (Jan, 2010)

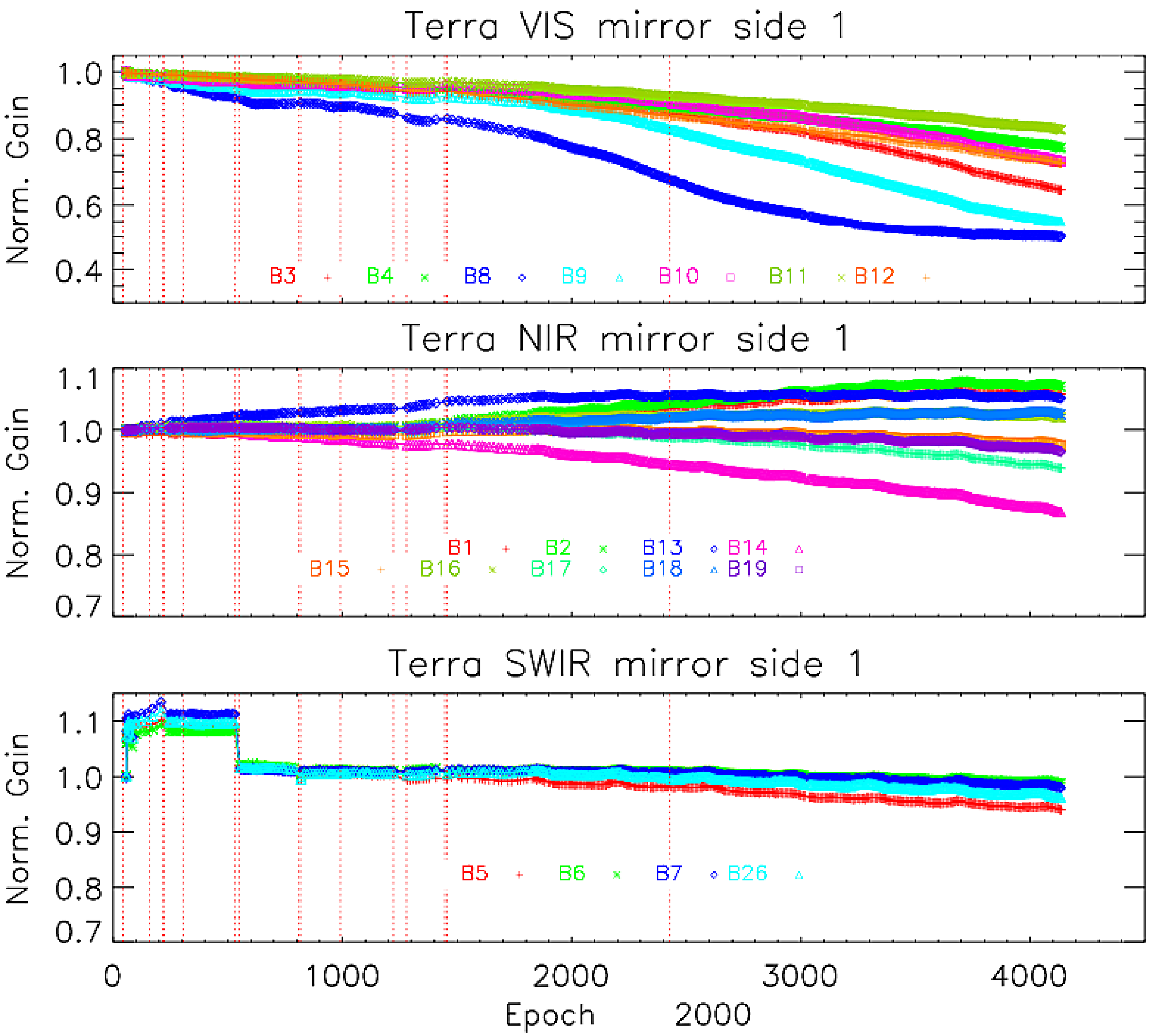
Detectors in SBRS order

MODIS SD Degradation Trending

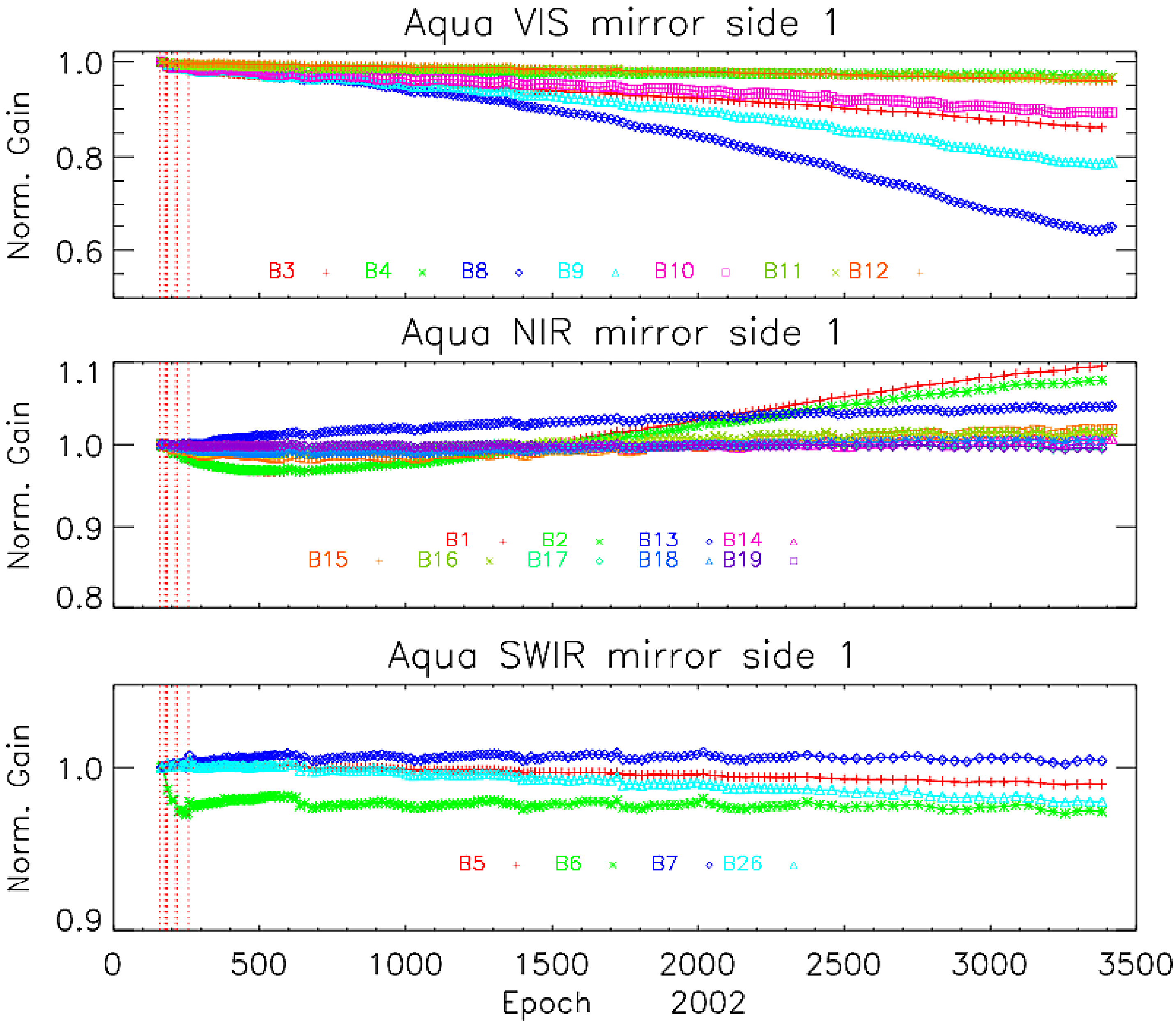


The results are derived from a normalization approach to SDSM D9 (936 nm). An additional correction for the degradation at SDSM D9 wavelength is applied

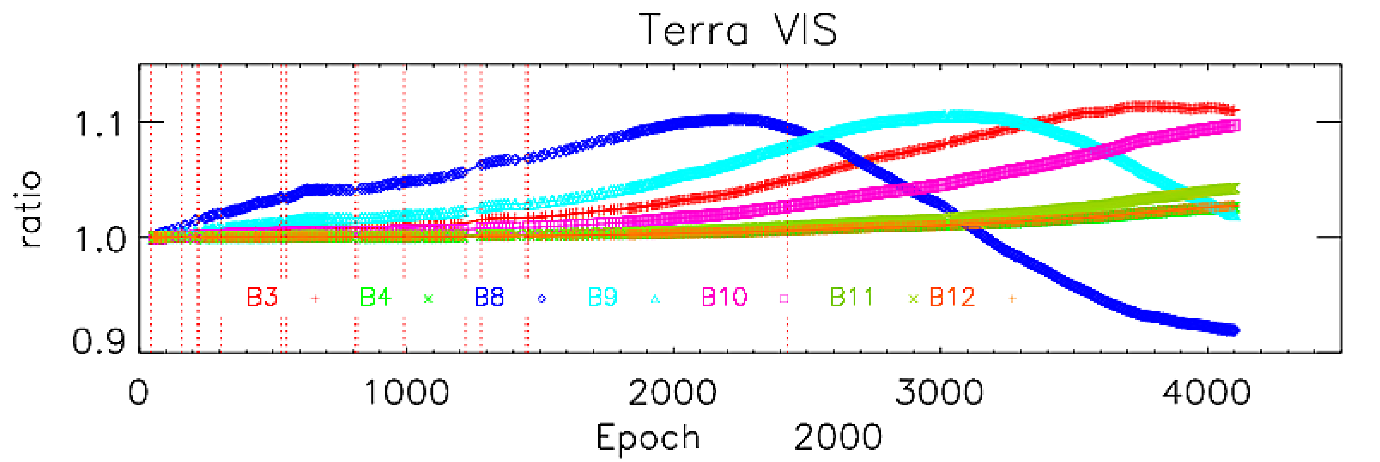
MODIS RSB Response Trending

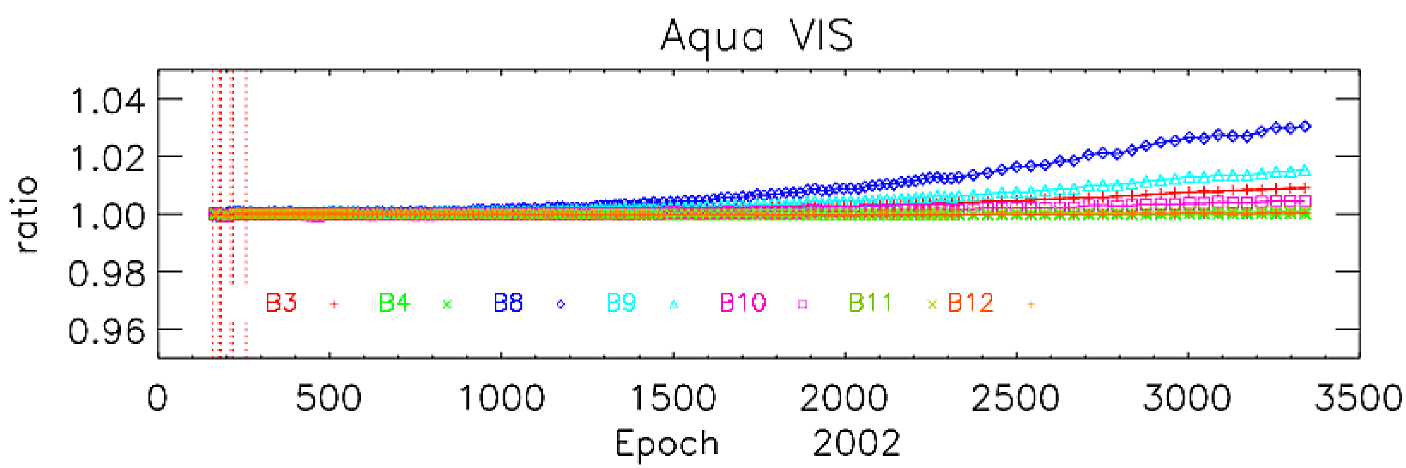


MODIS RSB Response Trending



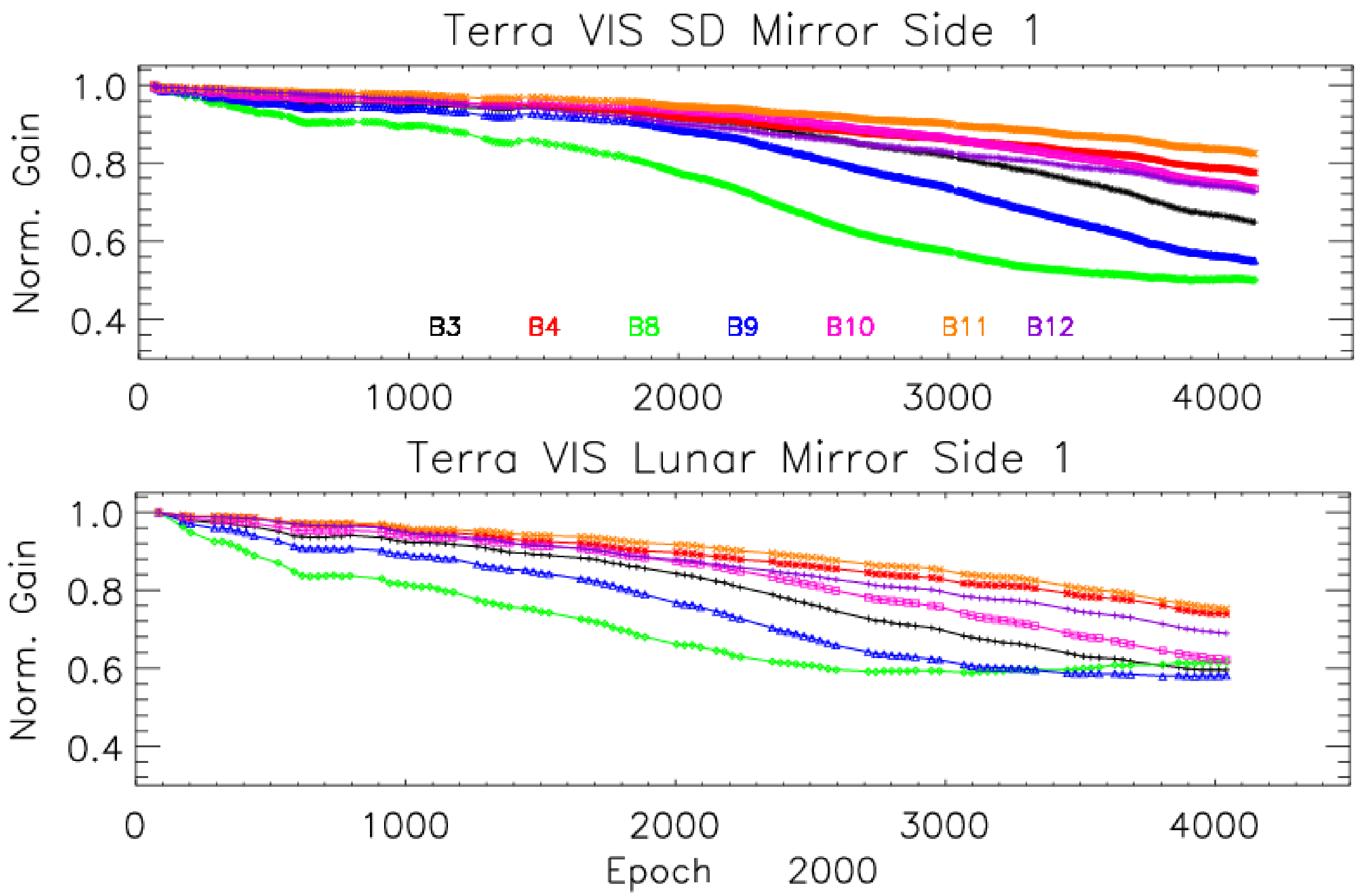
MODIS RSB Response Trending





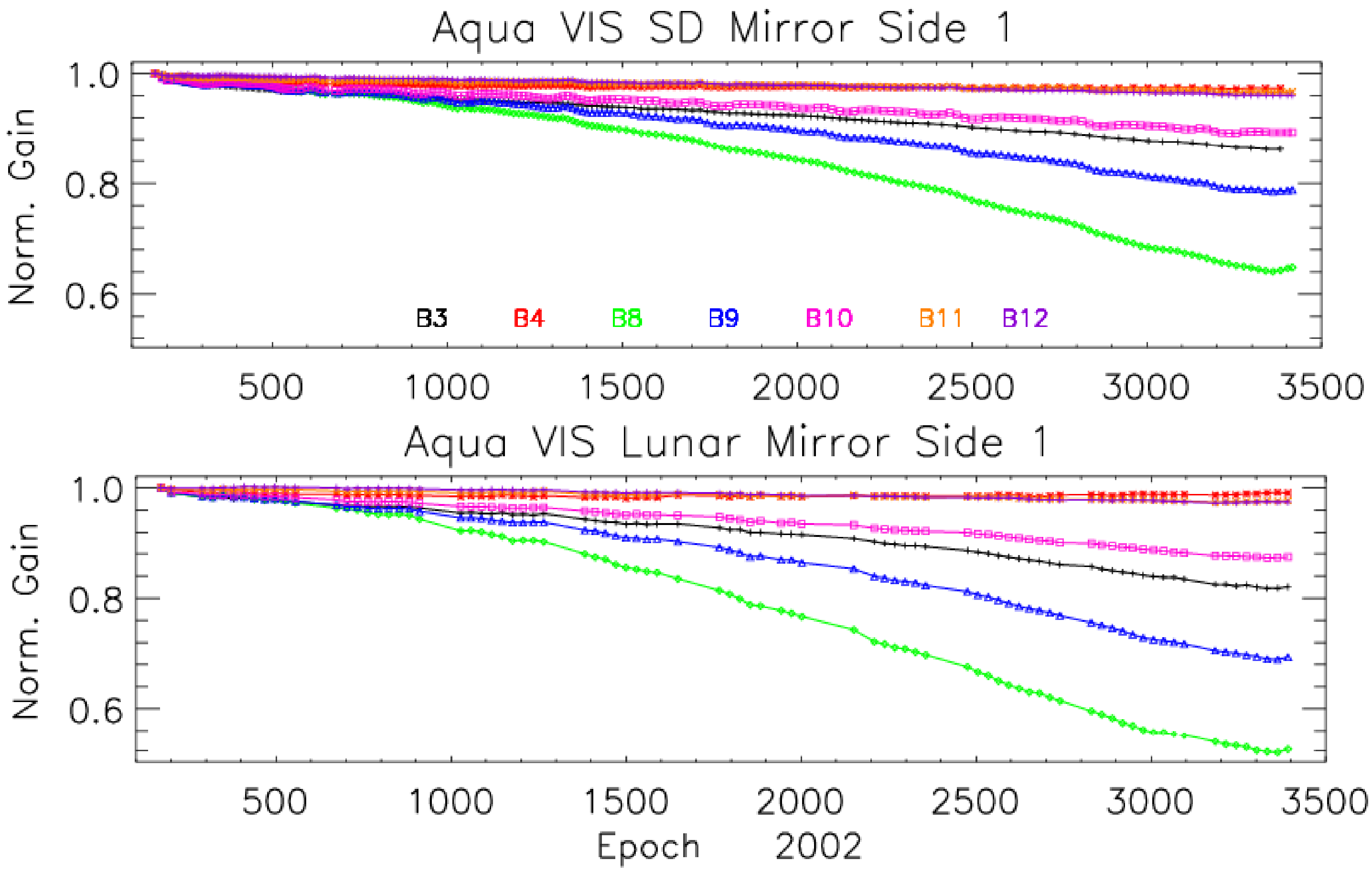
Smaller mirror side differences
observed in Aqua MODIS

MODIS RSB Response Trending



SD/SDSM and lunar observations used to track the on-orbit RSB Response versus Scan Angle (RVS) change

MODIS RSB Response Trending



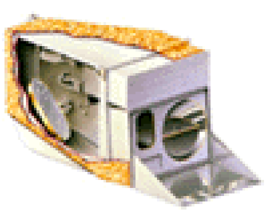
SD/SDSM and lunar observations used to track the on-orbit RSB Response versus Scan Angle (RVS) change

Summary of RSB overall Performance

- **RSB calibration has performed well according to design specifications**
  - Terra (11+ years) and Aqua (9+ years)
  - No new noisy/inoperable detectors since last STM
  - SD/SDSM and the Moon observations are used to track the on-orbit RSB gain change
  - Noticeable optics degradation identified and corrected in both sensors' response
    - Most degradation seen in VIS bands with largest change seen for Band 8 (412 nm) at SD AOI: 50% for Terra and about 35% for Aqua
    - Gain change for NIR and SWIR bands is generally within 10% for both instruments
    - Mirror side differences are smaller in case of Aqua VIS bands (within 5%) as compared to the Terra VIS bands (± 10 %)
    - Mirror side differences in NIR and SWIR bands for both instruments are within ±0.5%

MODIS RSB Collection 6 LUTs

MODIS Characterization Support Team (MCST)



Outline

- Introduction
  - Look Up Tables (LUT)
    - Calibration coefficients (m1)
    - Response versus Scan angle (RVS)
    - Uncertainty Index (UI)
  - Approaches developed for m1 and RVS
- Approach I for m1 and RVS
  - Algorithms and results
  - EV reflectance trending
- Approach II for m1 and RVS
  - Algorithms and results
  - EV reflectance comparison
- Summary and Challenges

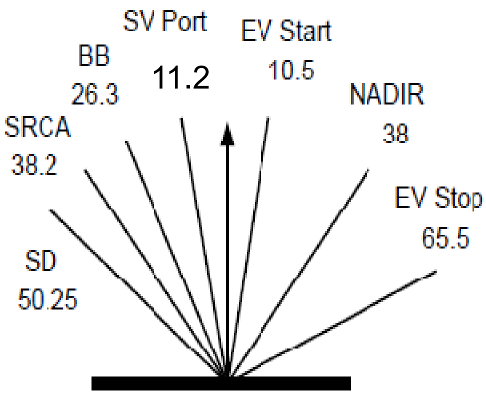
RSB m1 and RVS

- EV Reflectance

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

- LUTs need 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), not be discussed here
- Calibration Source
  - Lunar observation
  - SD/SDSM calibration
  - SRCA and EV mirror side (MS) ratios
  - Selected EV targets

MODIS scan mirror



Angle of Incidence (AOI)

Terra C6 m1 and RVS (Approach I)

- m1 calibration coefficients are generated using SD observations
- Mirror side 1 (MS1) RVS on-orbit variation is tracked using SD and lunar calibration coefficients with a linear approximation for its AOI dependence
- Mirror side 2 (MS2) RVS on-orbit variation is derived from the mirror side ratio of sensor response at multiple AOI (SD, Moon, EV, and SRCA) with a quadratic approximation for the AOI dependence and using MS1 RVS as reference
- No time-dependent RVS applied to bands 5-7 and 26
- Approach I is, in fact, the same as C5 approach with following improvements
    - RVS detector dependence (8-12)
    - Time-dependent RVS for bands 13-16
    - SD degradation at wavelength 936 nm measured by SDSM D9

Terra C6 m1 and RVS (Approach II)

- m1 and RVS are generated using the lunar calibration, SD calibration (absolute calibration at beginning of the mission), and sensor EV response trending at multiple AOI
- Detector differences in both m1 and RVS are identical to the Approach I LUTs, which are obtained using SD and lunar calibration coefficients
- The lunar m1 is used to track the gain change at the AOI of the SV
- A quartic approximation is applied for both MS1 and MS2 AOI dependence of the RVS on-orbit variation.

MODIS RSB RVS Algorithms
Approach I

- RVS is characterized by prelaunch measurement and on-orbit variation

$$RVS(B,D,M,\theta,t) = RVS^{pl}(B,M,\theta)RVS^{oo}(B,D,M,\theta,t)$$

  - B, D, M, θ and t represent band, detector, mirror side, AOI and time
  - pl: pre-launch; oo: on-orbit.

- RVS on-orbit variation at AOI of the SV

$$RVS^{oo}(B,D,M,\theta_{SV},t) = \frac{m_1^{moon}(B,D,M,t_0)m_1(B,D,M,t)}{m_1^{moon}(B,D,M,t)m_1(B,D,M,t_0)}$$

- Mirror side one RVS on-orbit variation – a linear function of AOI

$$RVS^{oo}(B,D,1,\theta,t) = 1 + \frac{\theta - \theta_{SD}}{\theta_{SV} - \theta_{SD}}\left[RVS^{oo}(B,D,1,\theta_{SV},t) - 1\right]$$

- Mirror side two RVS

$$RVS(B,D,2,\theta,t) = \frac{dn(B,D,2,\theta,t)}{dn(B,D,1,\theta,t)}\frac{m_1(B,D,1,t)}{m_1(B,D,2,t)}RVS(B,D,1,\theta,t)$$

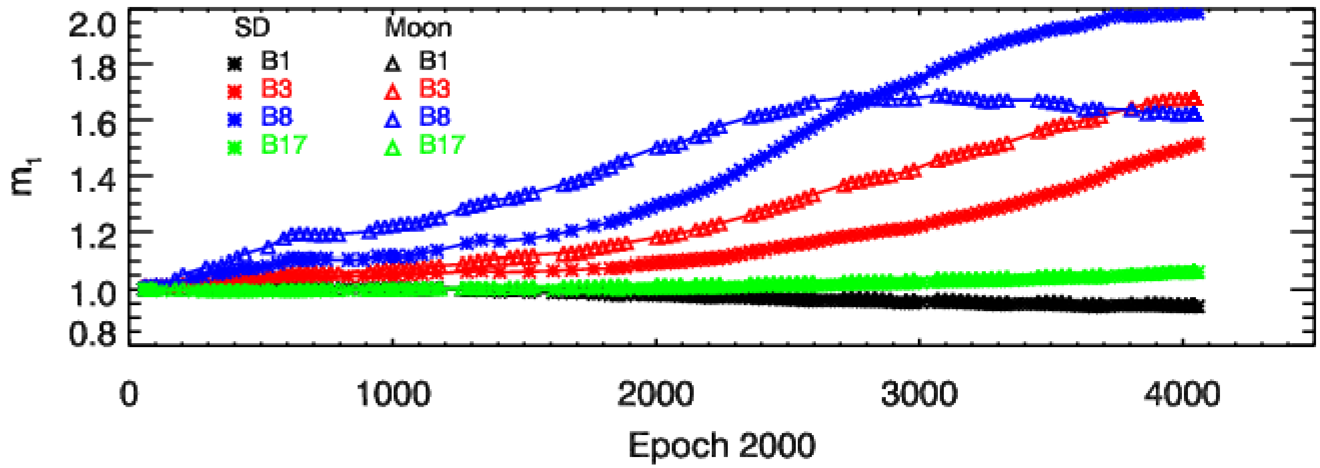
  - Instrument response mirror side ratio is obtained from SD, lunar, SRCA, and EV observations

- The calculated RVS is fitted to a quadratic form of the frame, and the fitted coefficients form a time dependent LUT for MODIS RSB RVS

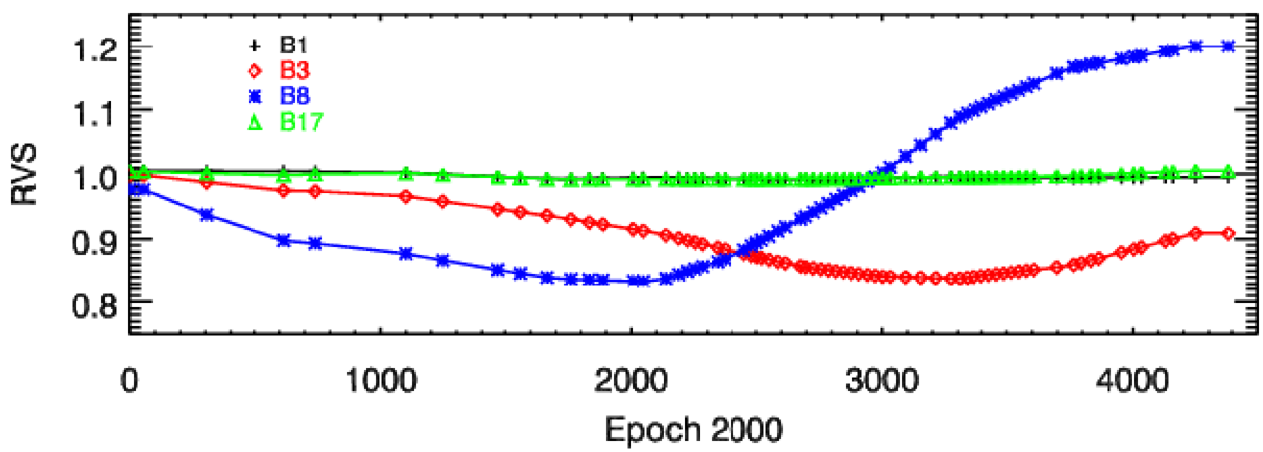
$$RVS^{L1B}(F,t) = c_0(t) + c_1(t)F + c_2(t)F^2$$

  - *F: Frame*

Terra MODIS RSB MS1 RVS

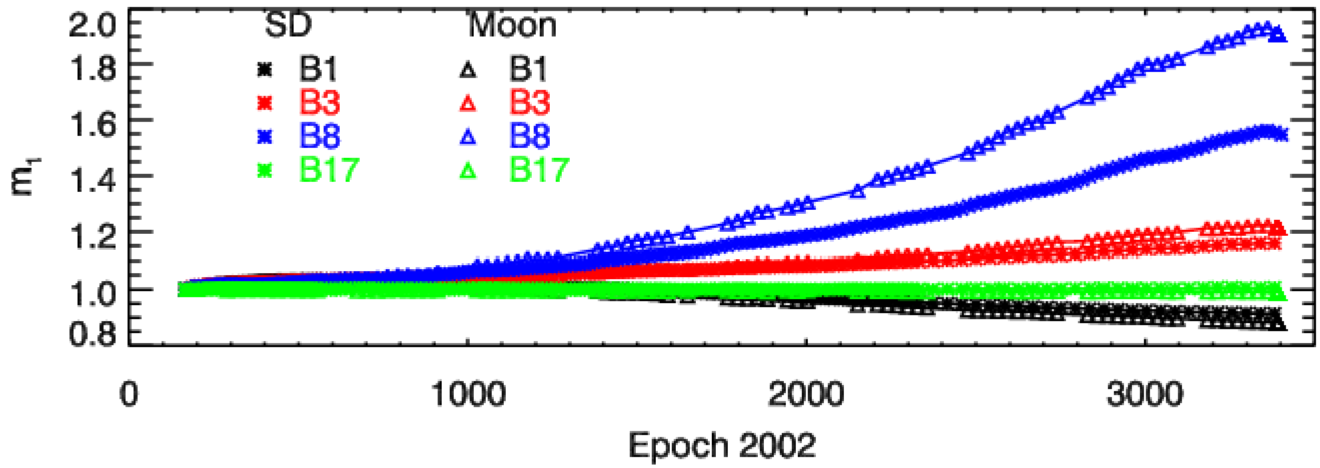


Detector-averaged SD and lunar calibration coefficients for Terra MODIS bands 1, 3, 8, and 17 MS1

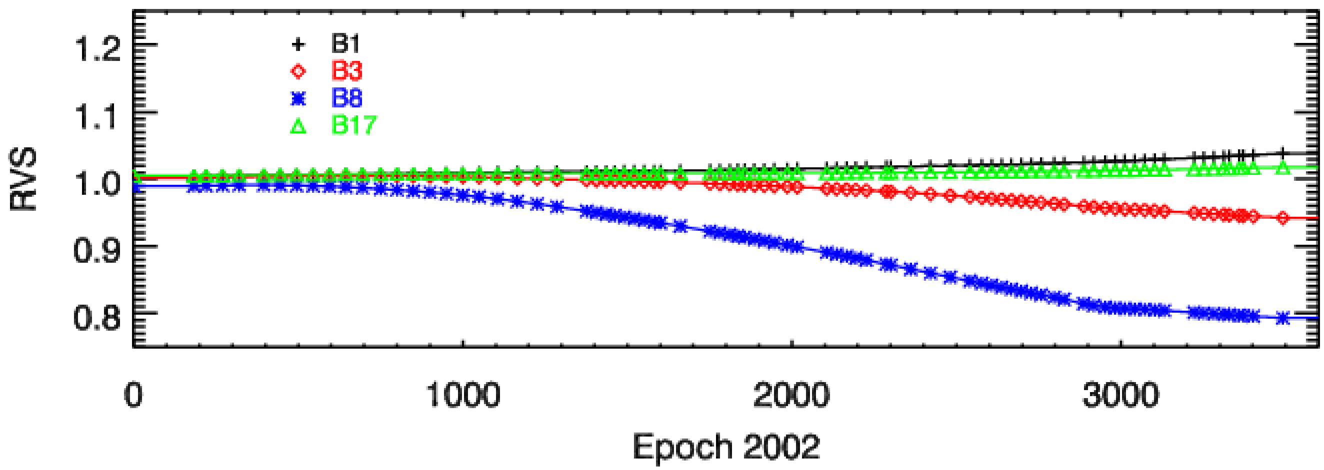


Detector averaged RVS at the SV AOI for Terra bands 1, 3, 8, and 17 MS1

Aqua MODIS RSB MS1 RVS

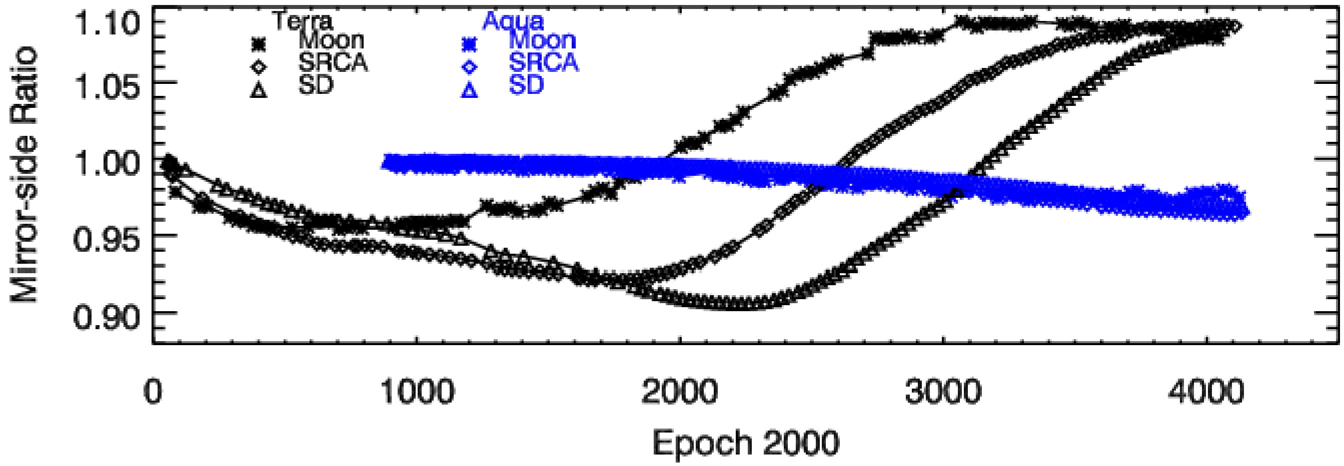


Detector-averaged SD and lunar calibration coefficients for Aqua MODIS bands 1, 3, 8, and 17 MS1

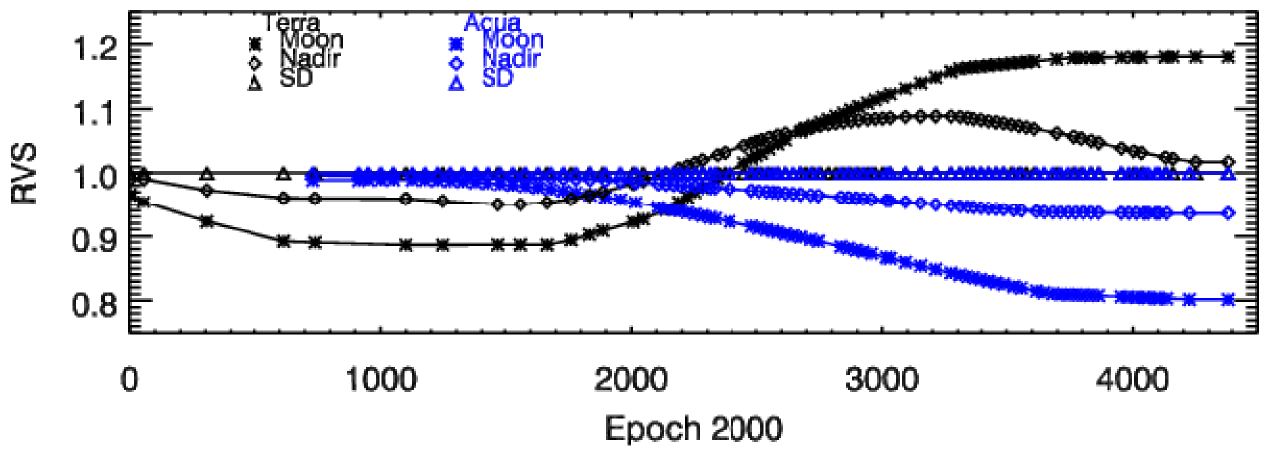


Detector averaged RVS at the SV AOI for Aqua bands 1, 3, 8, and 17 MS1

MODIS RSB MS2 RVS



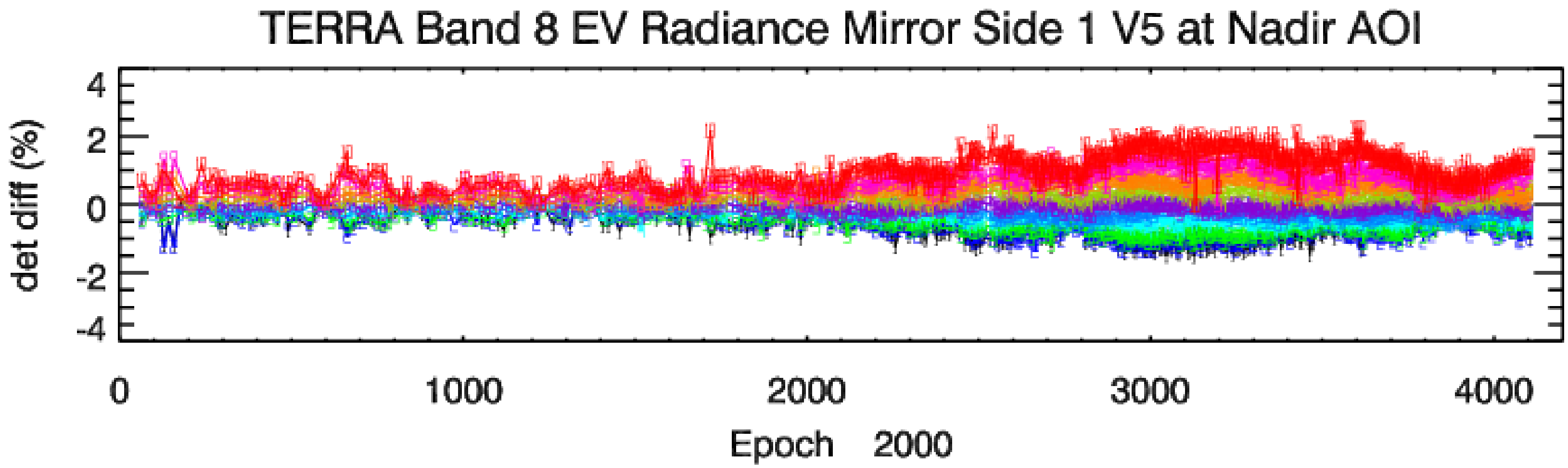
Band 8 mirror side (MS) ratios of the SD, SRCA, and lunar response.



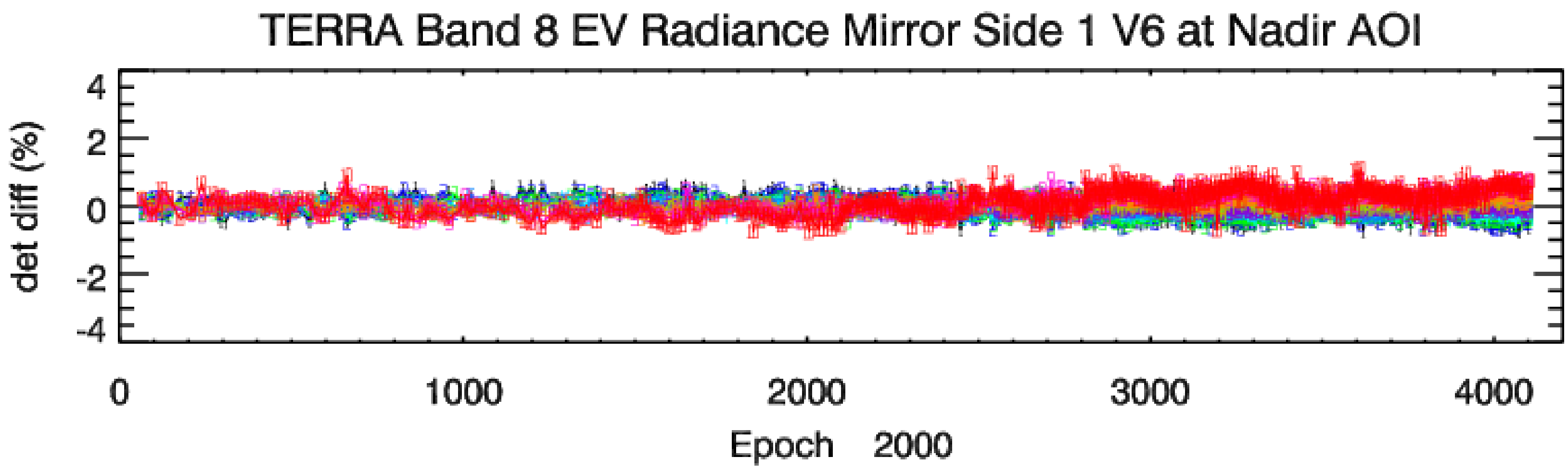
Detector averaged RVS at the SV AOI for Band 8 MS2.

EV Radiance Detector Difference

C5



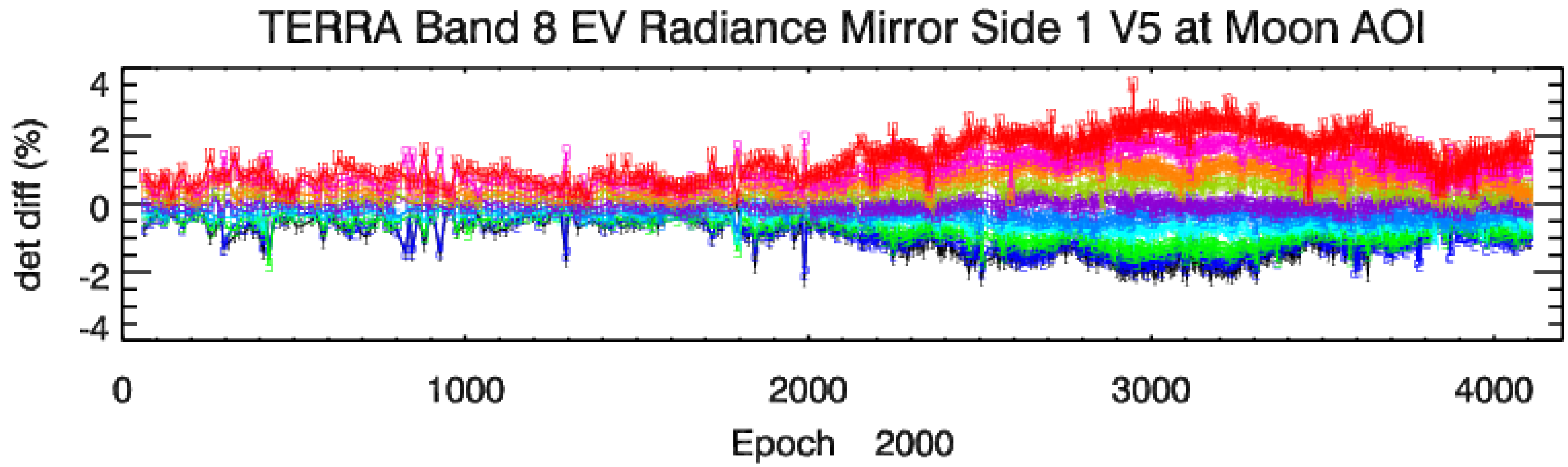
C6



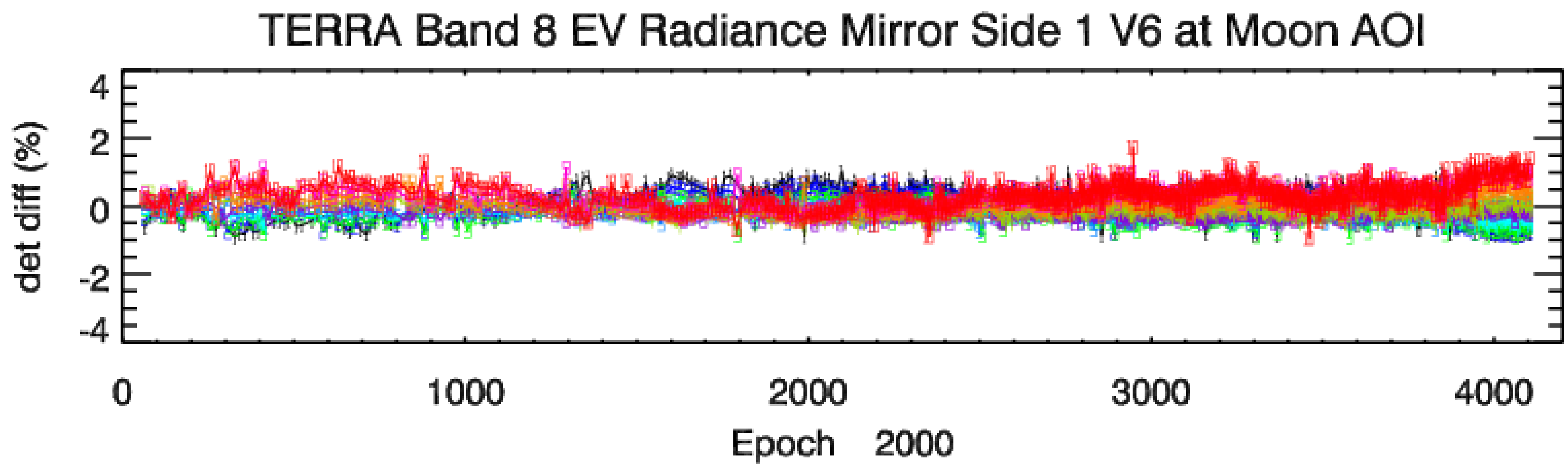
Numbers denote detectors in product order

EV Radiance Detector Difference

C5

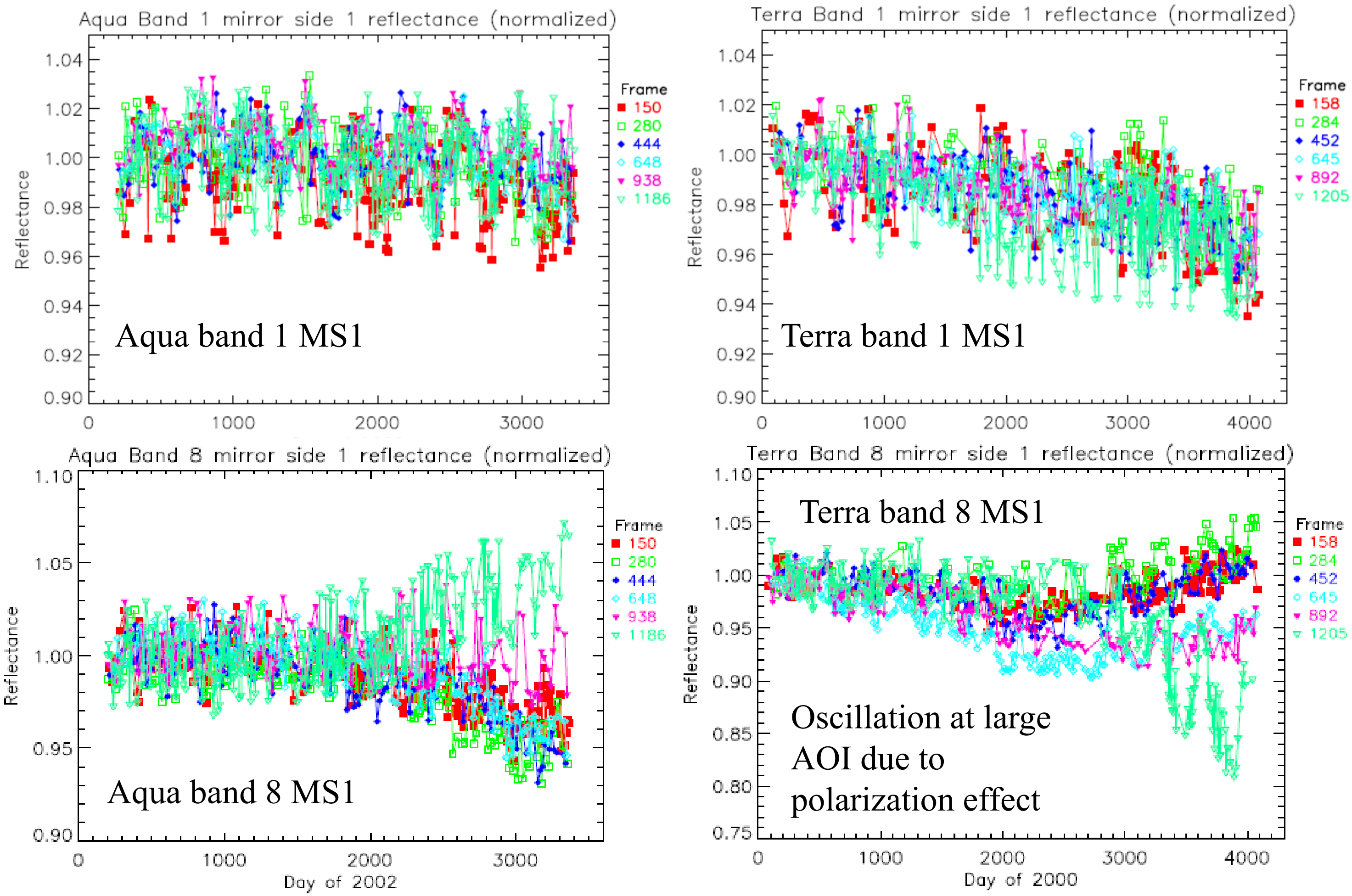


C6



Numbers denote detectors in product order

EV Reflectance



~3% drift in Terra bands 1, 2, and 4 and 2% in Aqua band 9

Much larger drift seen in Terra bands 3 (~5%), 8 (10~15%), and 9 (~8%) and Aqua band 8 (~5%)

MODIS RSB m1 and RVS Algorithms

Approach II

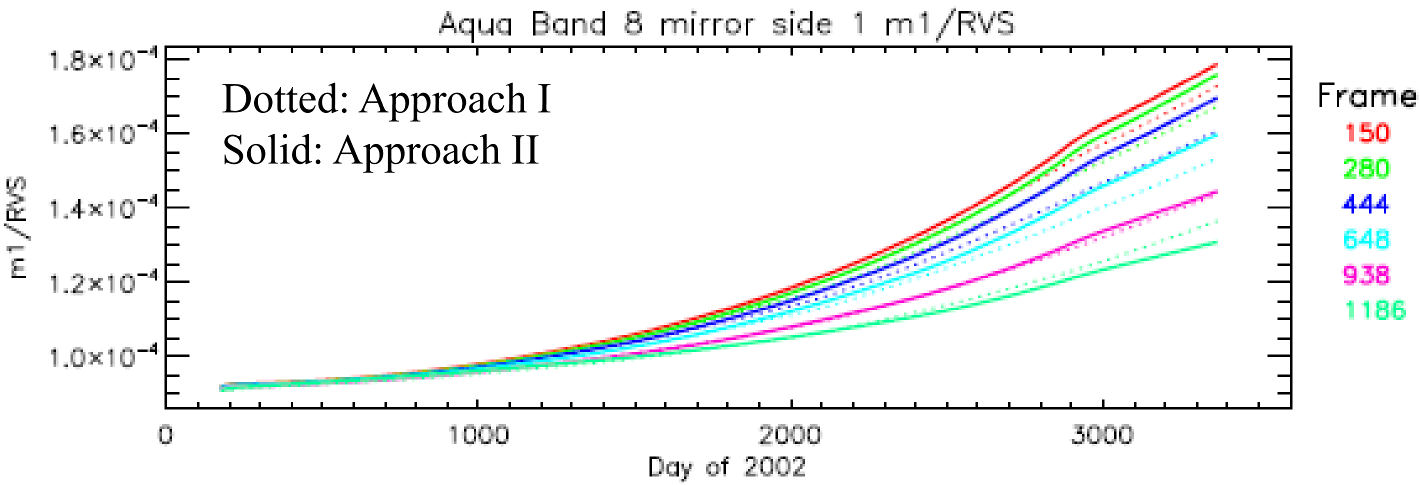
- Summary for Approach I
  - Works reasonably well for all RSB except Aqua bands 8-9 and Terra bands 1-4 and 8-9
    - ~3% drift in Terra bands 1, 2, and 4 and 2% in Aqua band 9
    - Much larger drift seen in Terra bands 3 (~5%), 8 (10~15%), and 9 (~8%) and Aqua band 8 (~5%)
  - Possible Reasons
    - Linear approximation for RVS AOI dependence
    - Accuracy of SD/SDSM calibration
- Pseudo-Invariant Desert Sites
  - Sites: Mauritania 1, Mali 1, Algeria 1, Algeria 3, Niger 1, Libya 1, Libya 2, Libya 4, Egypt 1, Sudan 1, Yemen Desert 1, Arabia 2
  - Detail information for these sites: http://calval.cr.usgs.gov/sites_catalog_map.php
- Justification for the approximation
  - Aqua and Terra MODIS should see similar long-term EV reflectance trending for a given wavelength
  - Reports from various science groups that Aqua MODIS provide better L1B products

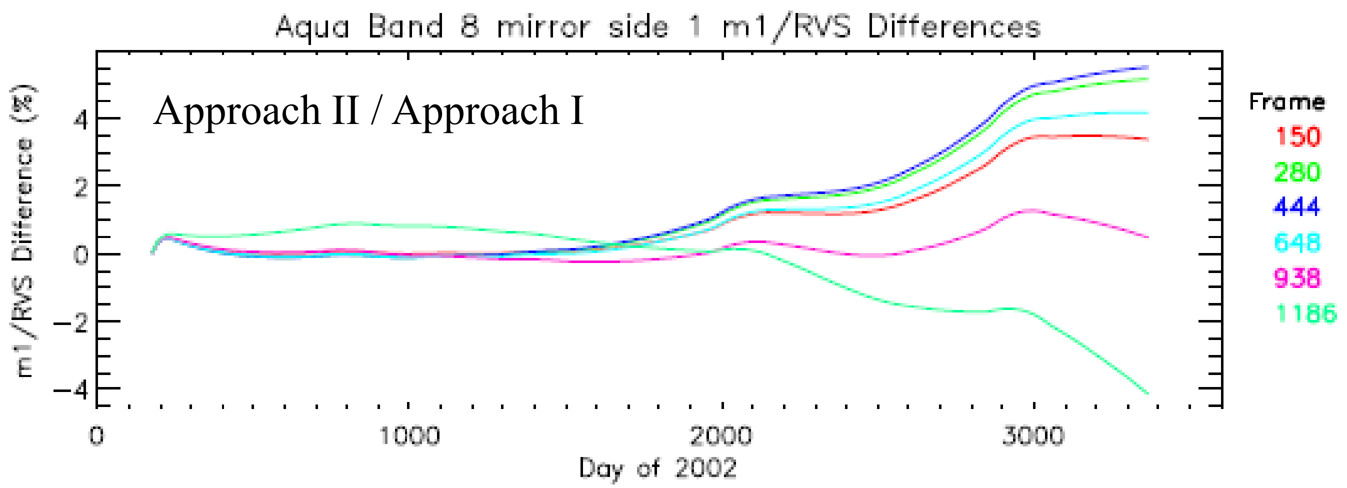
MODIS RSB RVS Algorithms

Approach II

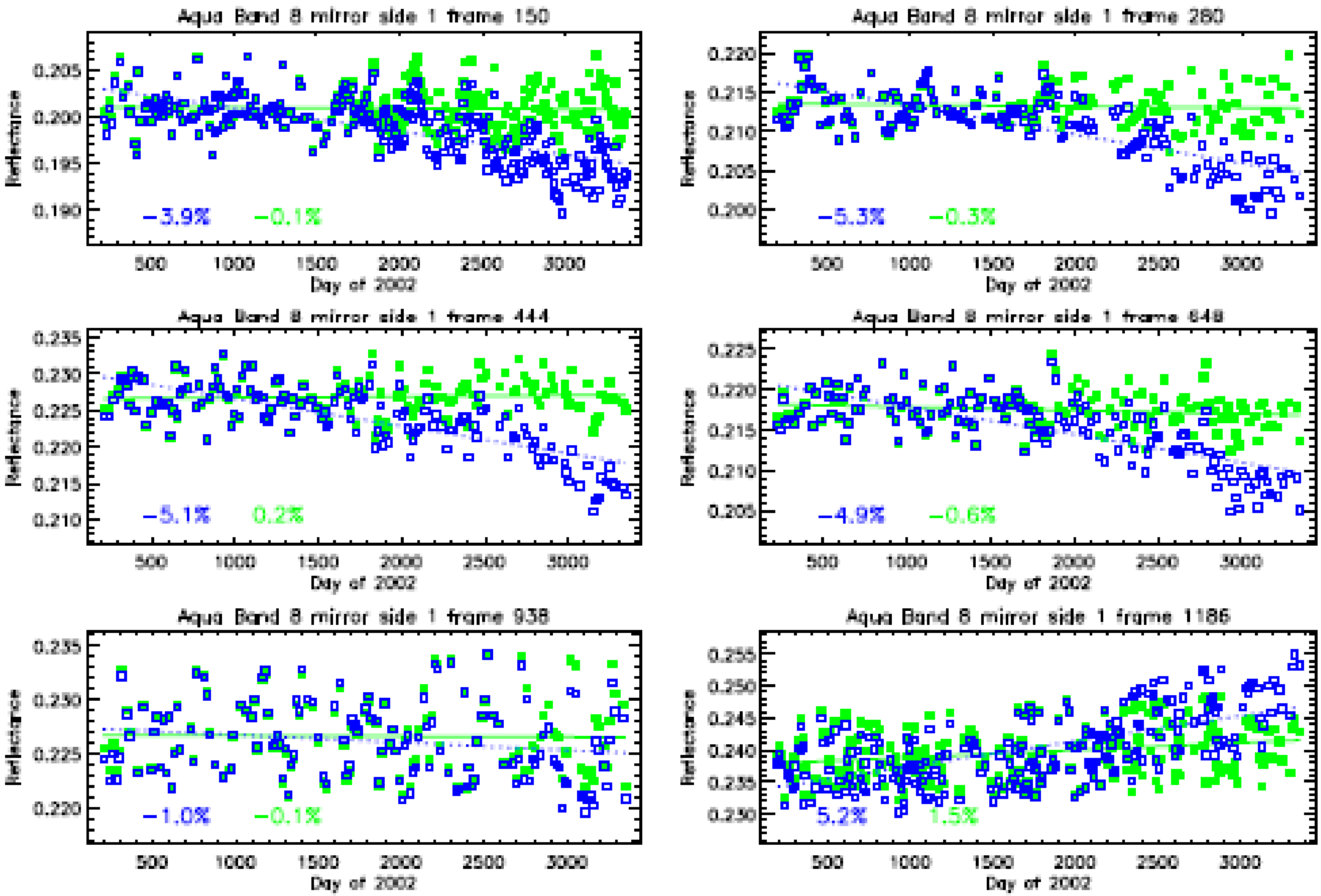
- Lunar view response and Earth view responses at selected AOIs
  - Terra AOIs (degree): 11.2 (lunar), 16.9, 22.0, 23.8, 28.9, 32.6, 36.7, 42.7, 46.7, 53.4, 59.4, 64.2
  - Aqua Frames are slightly different from those of Terra
  - For each AOI, the instrument response is fitted to smoothly connected analytical functions
- Detector-averaged m1 and RVS on-orbit variation
  - The fitted smooth functions are normalized at NADIR door open time for each instrument
  - For any time t, the RVS on-orbit variation for a given band and mirror side is determined by fitting the values of the functions of the band and mirror side to a quartic polynomial of AOI with a constrain that the polynomial passes through the on-board lunar measurement
  - The inverse of the fitted polynomial at AOI of the SD is the detector-averaged m1 on-orbit variation
  - The polynomial normalized by the m1 above is the detector-averaged RVS on-orbit variation

Aqua C6 Band 8 m1 and RVS LUTs



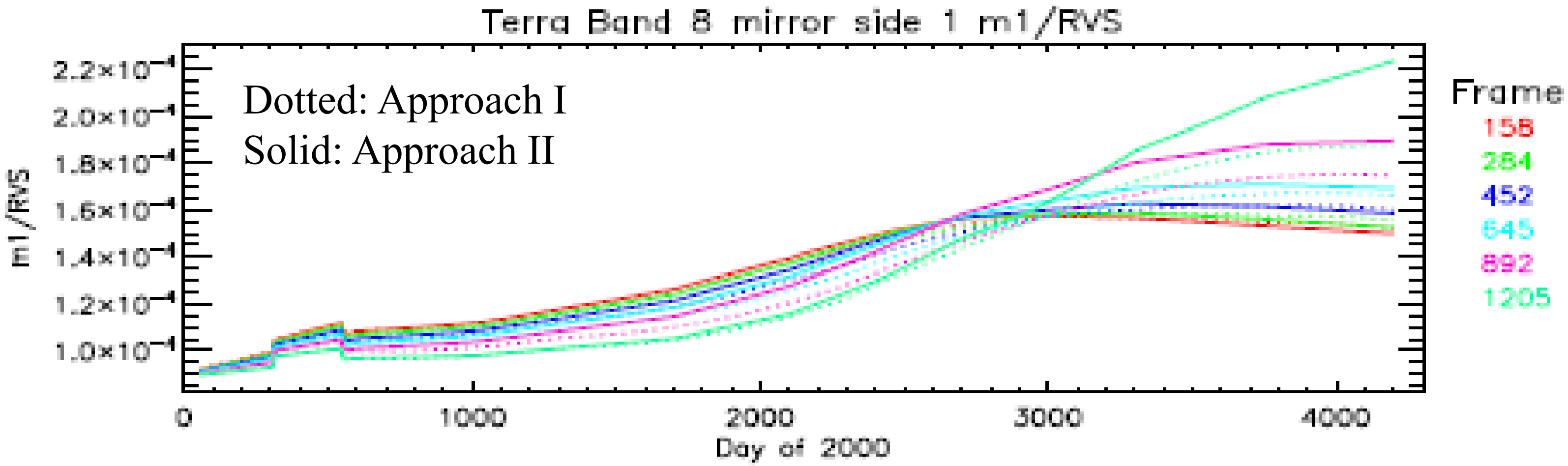


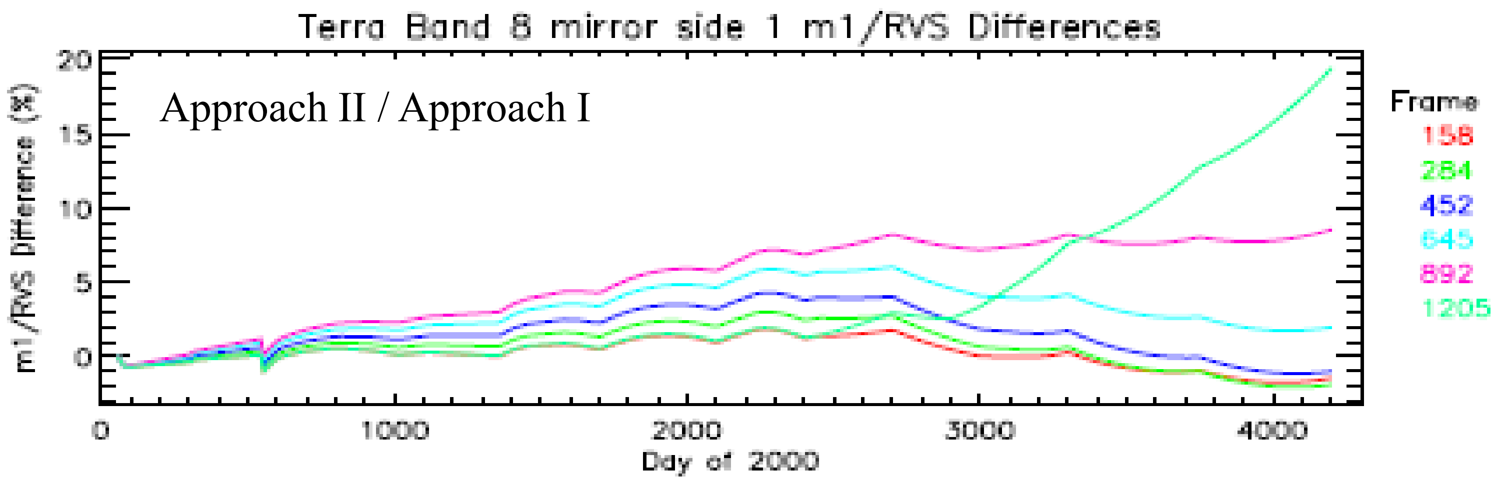
Aqua Band 8 EV Reflectance



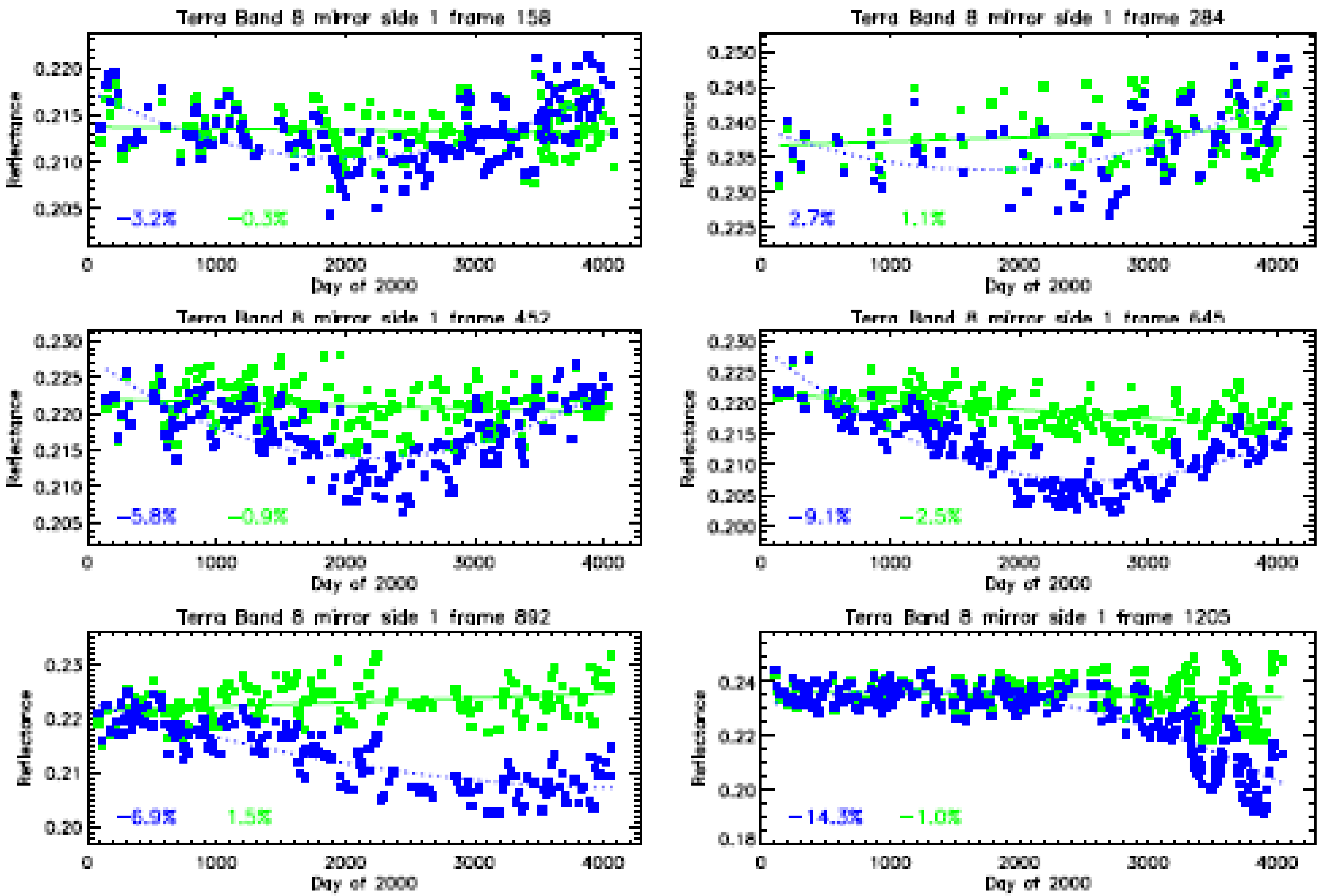
Blue: Approach I; Green: Approach II

Terra C6 Band 8 m1 and RVS LUTs





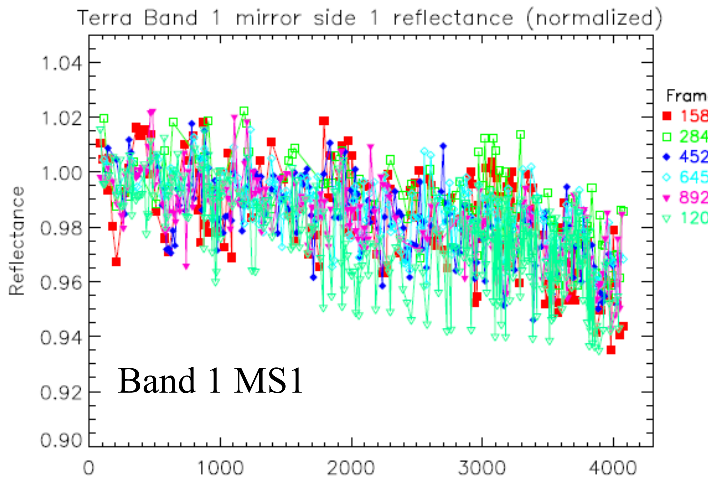
Terra Band 8 EV Reflectance

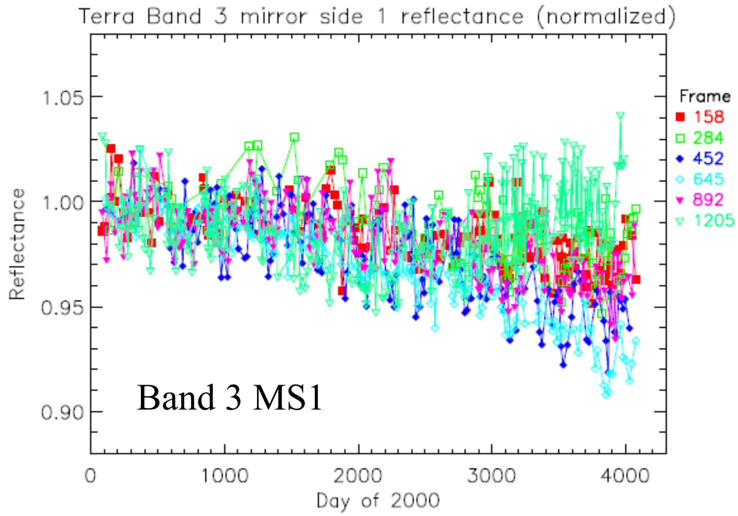


Blue: Approach I; Green: Approach II

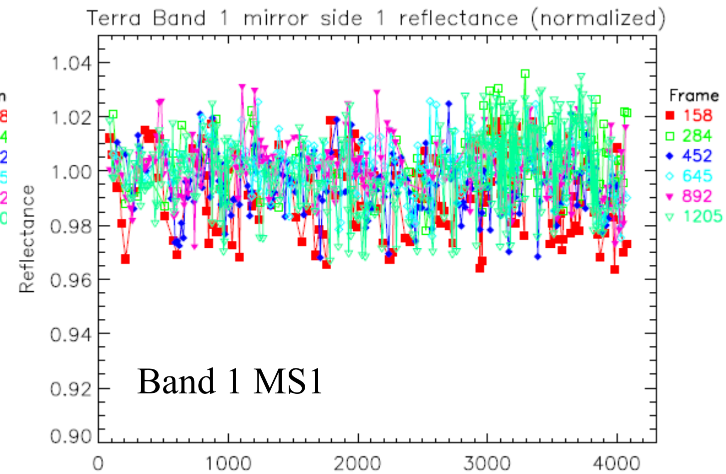
Terra EV Reflectance

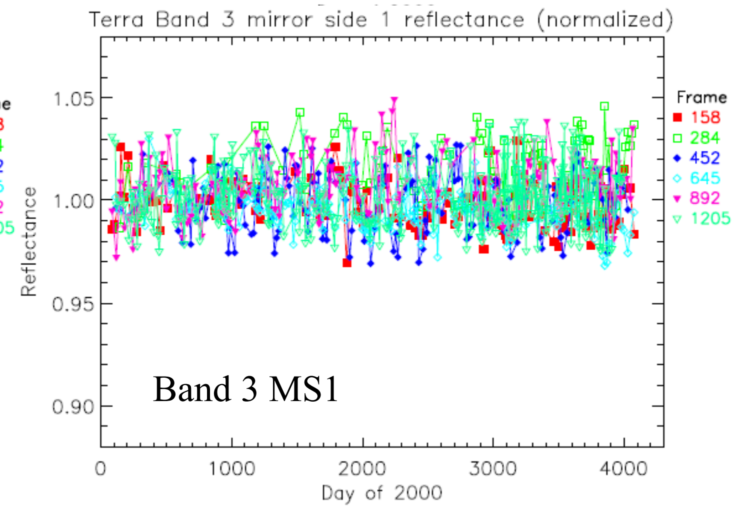
Approach I





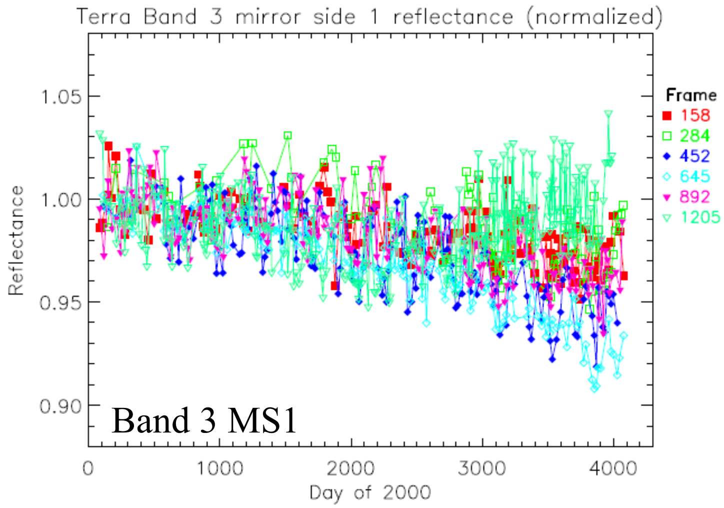
Approach II



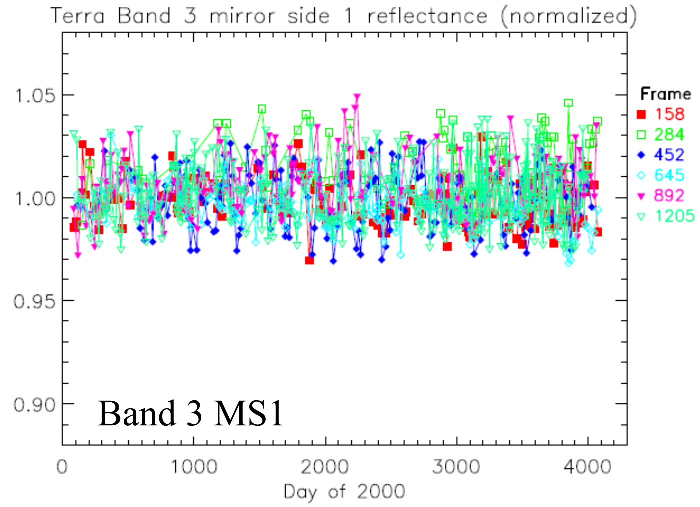


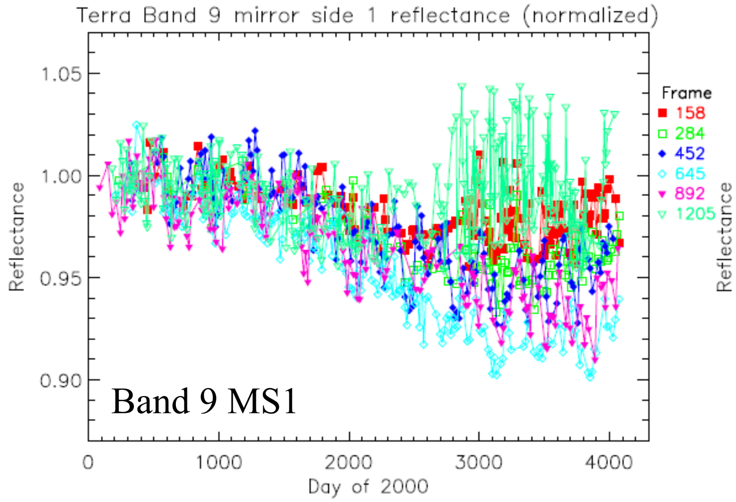
Terra EV Reflectance

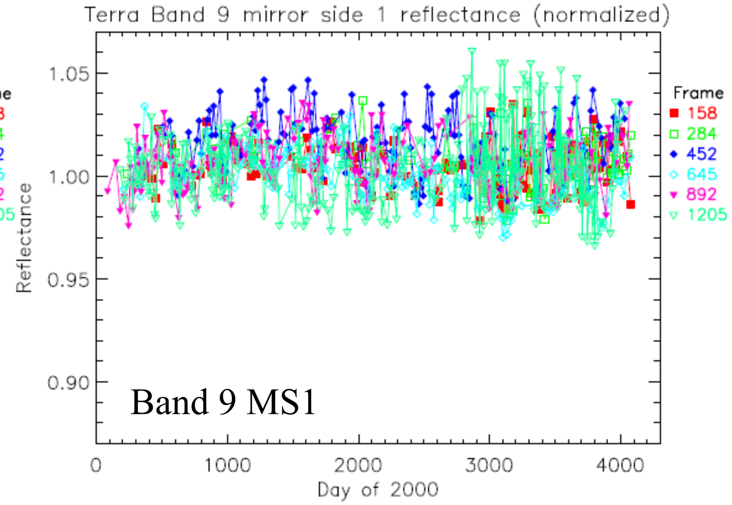
Approach I



Approach II

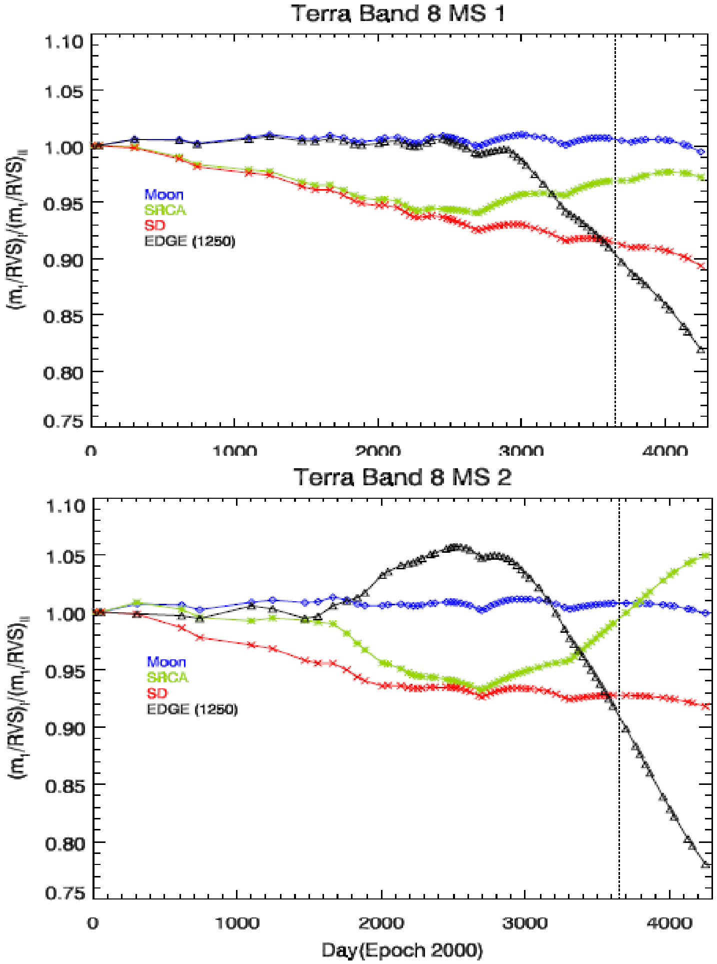




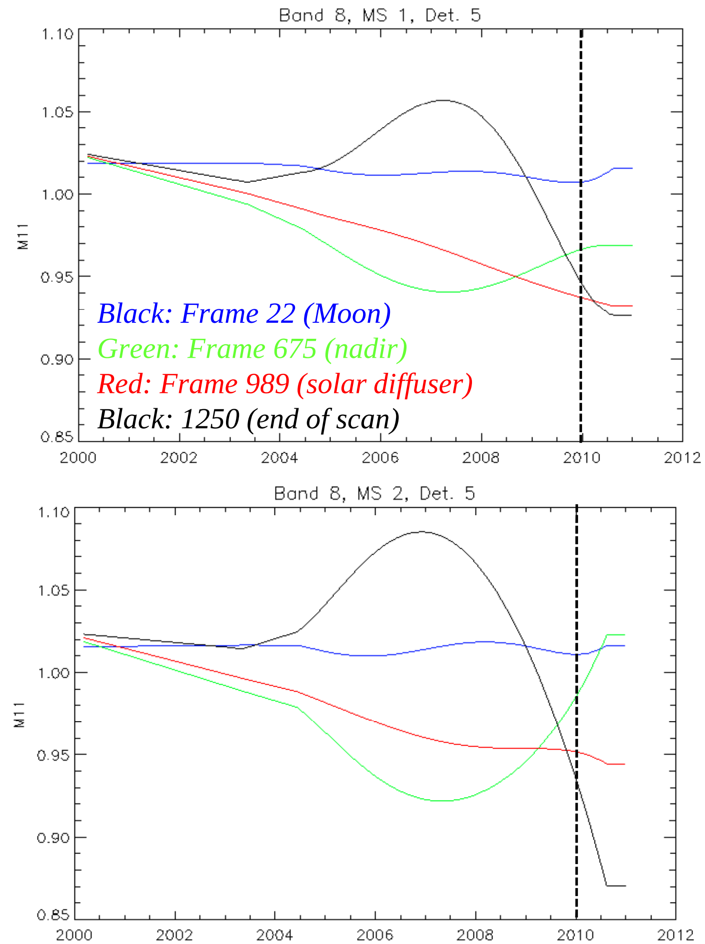


Approach II and OBPG Correction Comparison

Approach I and II difference



OBPG Correction to Approach I



Vertical dashed line denotes 01/01/2010

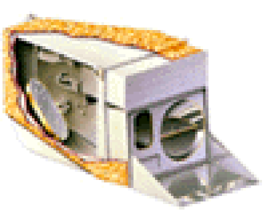
OBPG results provided by Gerhard Meister

Summary and Challenges

- Two approaches were developed to generate MODIS C6 RSB m1 and RVS LUTs
  - Approach I is mainly based on SD calibration and lunar observation
    - Aqua bands 1-7, 10-19, and 26 and Terra bands 5-7, 10-19, and 26
  - Approach II is based on lunar observations and trending using the EV response from pseudo-invariant desert sites.
    - Aqua bands 8-9 and Terra bands 1-4 and 8-9
- Improvements compared to C5
  - Detector differences reduced
  - Time-dependent RVS applied to bands 13-16
  - Long-term drifts observed in Aqua bands 8-9 and Terra bands 1-4 and 8-9 mitigated
- Challenges
  - Aging instruments
    - Terra 11+ years
    - Aqua 9+ years
  - Polarization effect in Terra MODIS
  - Accuracy of SD/SDSM calibration at short wavelengths
  - Recent gain changes in Aqua MODIS short wavelength bands

MODIS Thermal Emissive Bands On-Orbit Performance

MODIS Characterization Support Team (MCST)



MODIS Science Team Meeting (May 17, 2011)

TEB Calibration Performance

- TEB Calibration Algorithm
- Terra and Aqua TEB On-orbit Performance
  - Detector response & NEdT Trending
  - Noisy Detector History

On-orbit Calibration Methodologies and Performance

- Quadratic Algorithm
  - Linear calibration coefficients computed on a scan-by-scan basis; 40-scan running average used in the L1B
  - Fixed coefficients used for B21 (a simple linear algorithm)
  - Fixed coefficients also used for B33, 35, and 36 when T_bb are above T_sat during the warm-up/cool-down BB activities (AQUA ONLY !!!)
- Quarterly BB Warm-up and Cool-down (WUCD) Activities
  - Derive fixed linear coefficients
  - Compute nonlinear coefficients (update if necessary)
- Performance
  - Dedicated short- and long-term monitoring effort (offline)

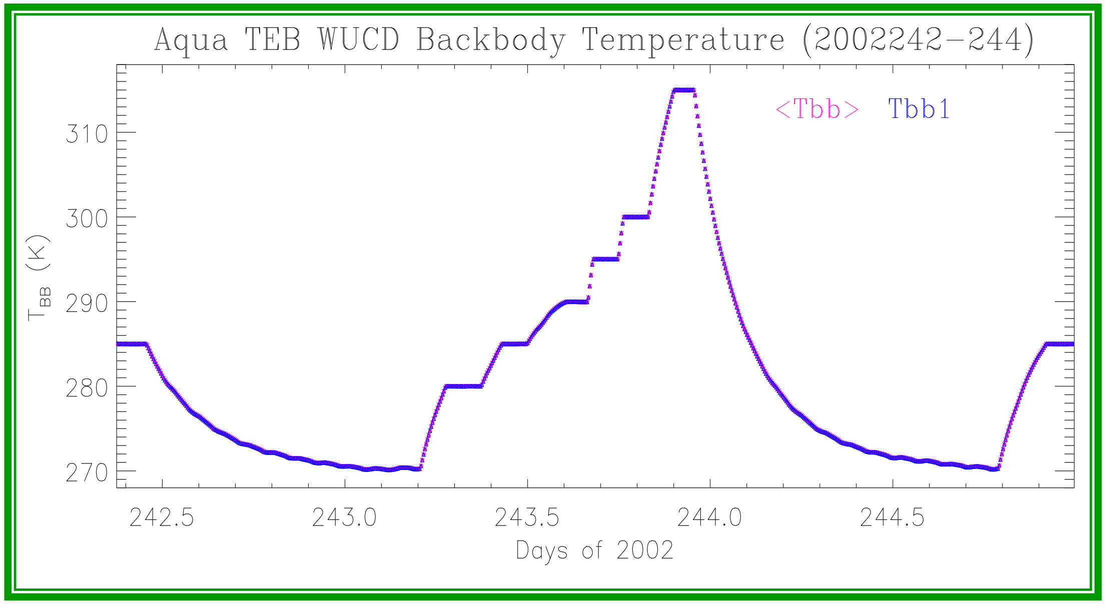
TEB Radiometric Calibration

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:

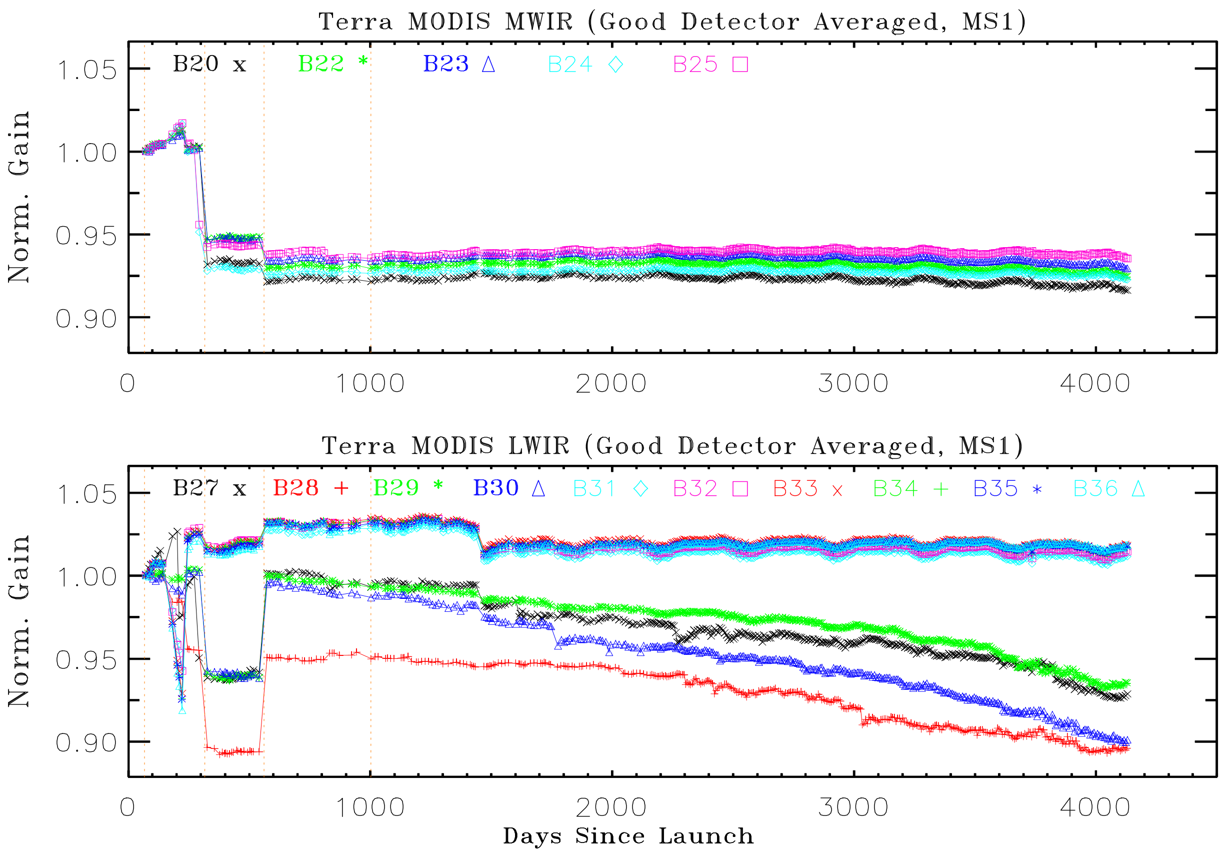
$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$



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

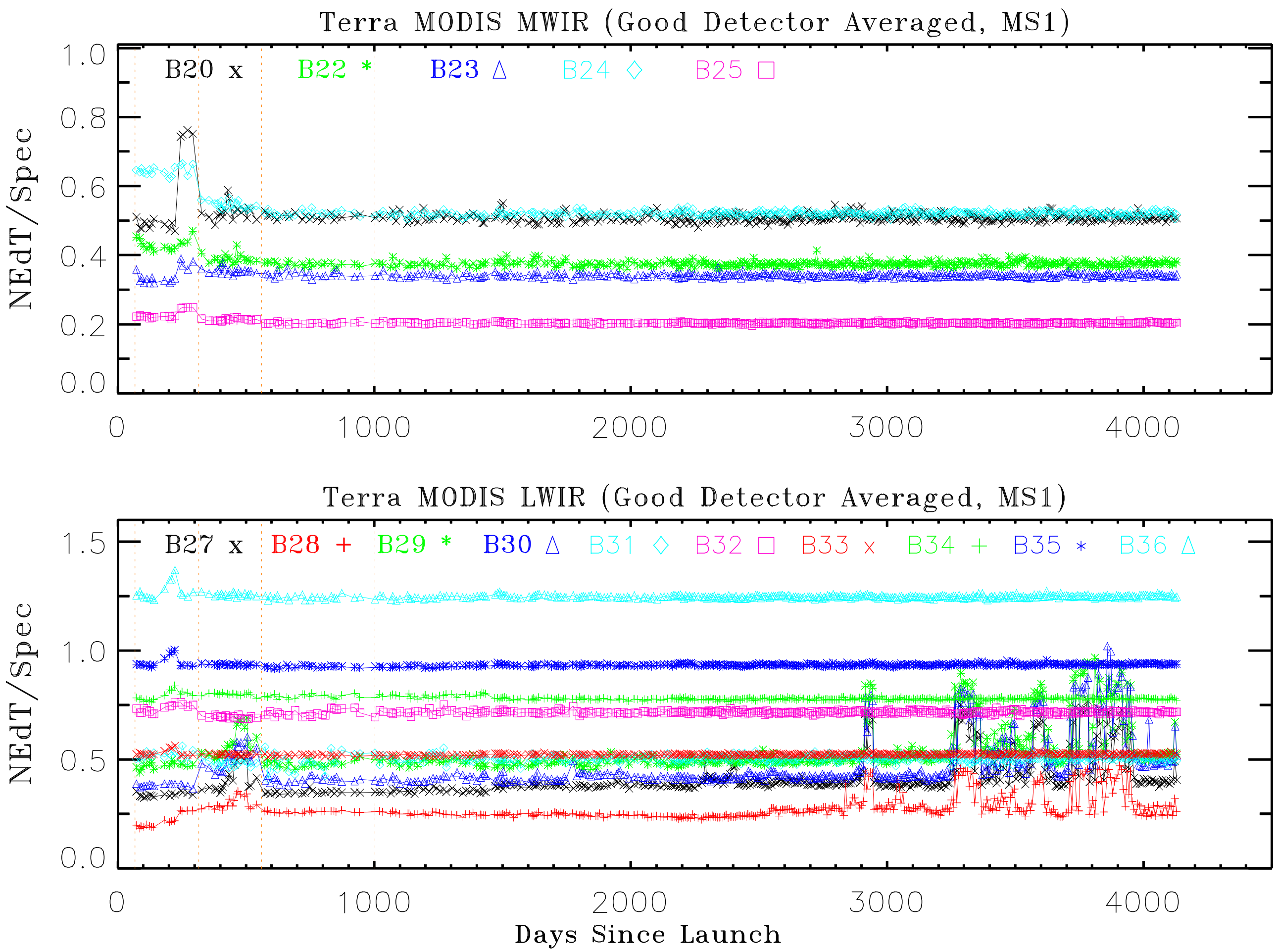
WUCD T_{BB}: 270 to 315K

Terra MODIS TEB Response Trend

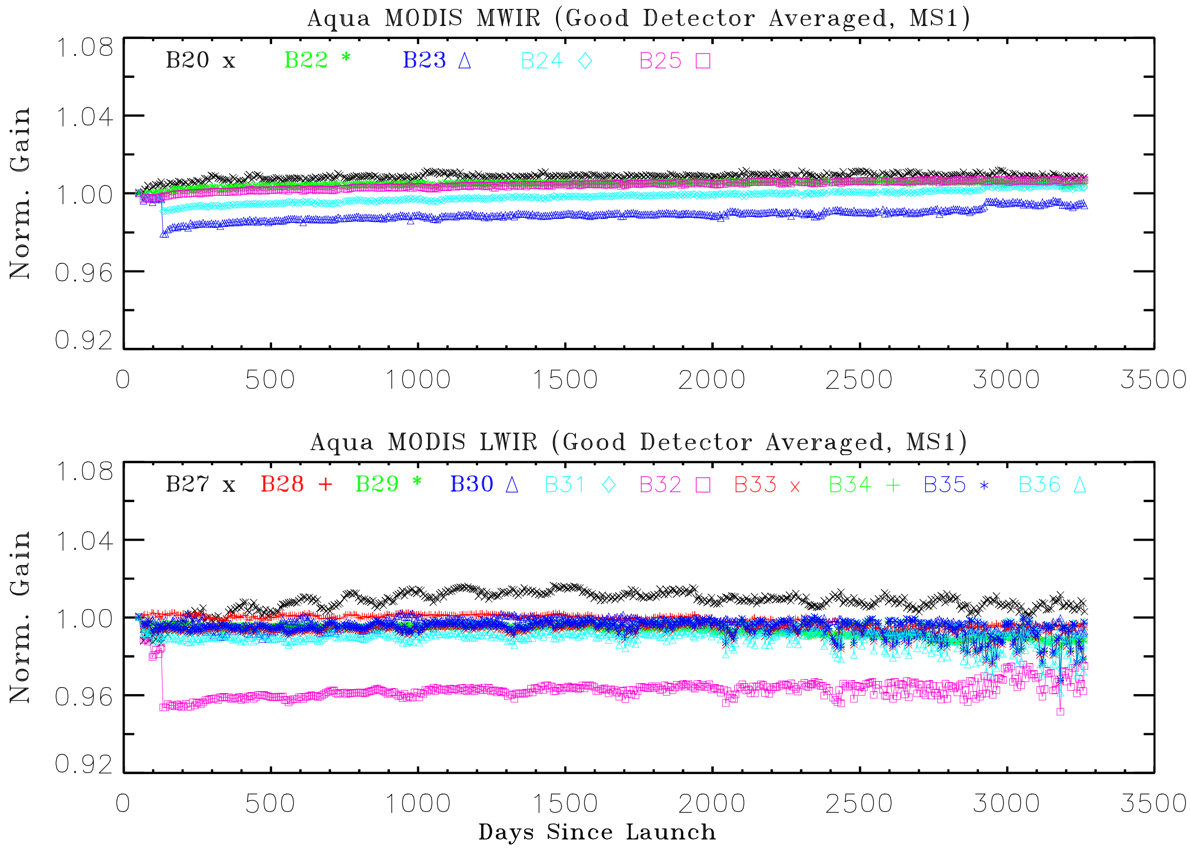


Band	Percent Change
20	-0.80
22	-0.77
23	-0.71
24	-0.42
25	-0.22
27	-4.83
28	-6.36
29	-5.02
30	-7.04
31	-0.20
32	-0.19
33	-0.18
34	-0.10
35	0.02
36	0.18

Terra MODIS TEB NEdT Trend

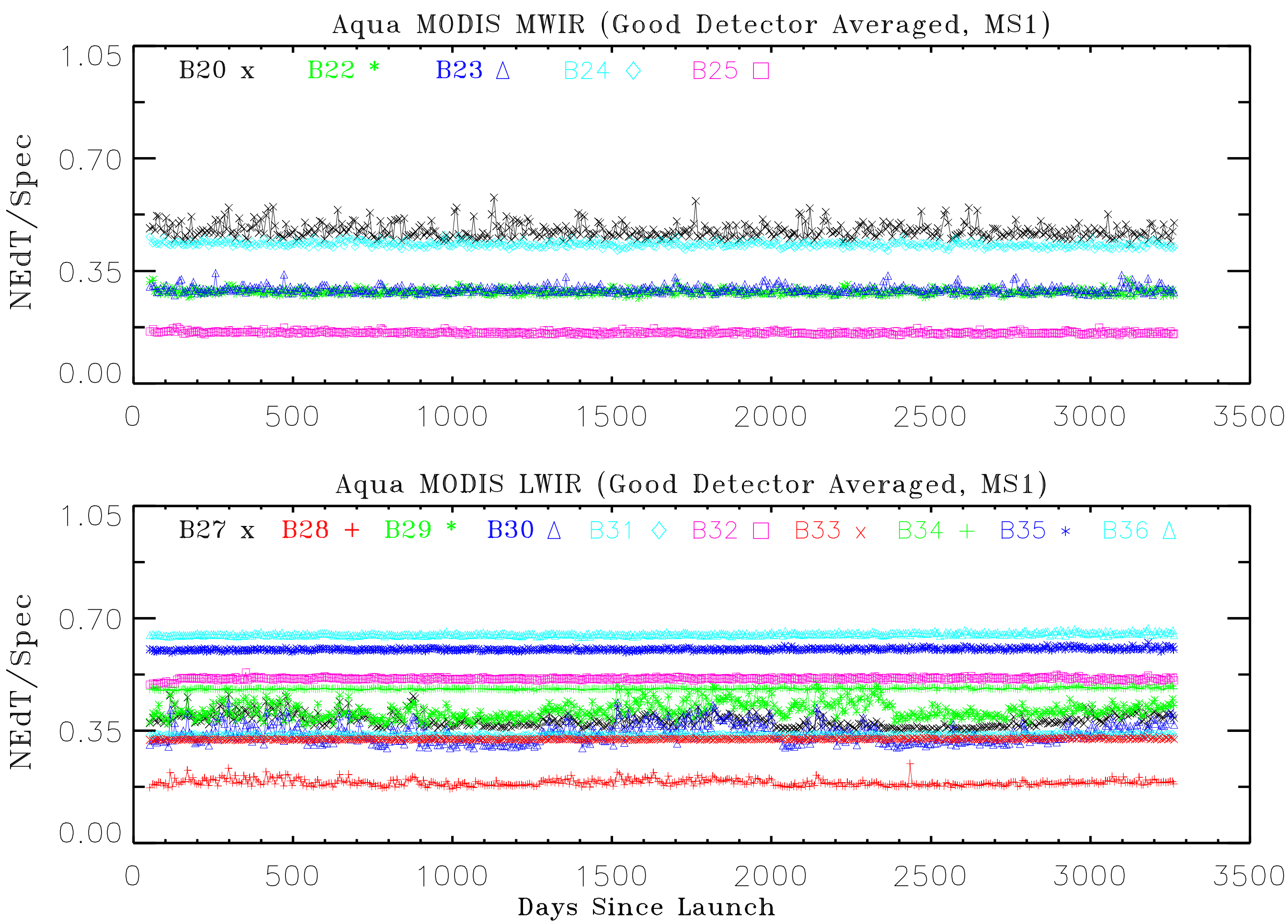


Aqua MODIS TEB Response Trend



Band	Percent Change
20	0.25
22	0.32
23	0.92
24	0.99
25	0.65
27	0.18
28	-0.72
29	-0.78
30	-0.26
31	-0.12
32	0.91
33	-0.53
34	-0.48
35	-0.46
36	-0.54

Aqua MODIS TEB NEdT Trend



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
36	5	Inoperable	Pre-Launch

Total TEB Detectors = 160

Noisy Detectors:

Terra = 27, Aqua = 3

Inoperable Detectors:

Terra = 1, Aqua = 1

No new noisy/inoperable detectors since 01/10

TEB On-orbit Performance Summary

– Stable detector response for both Terra and Aqua (excluding sensor configuration changes and instrument reset events)

Largest Gain Change (in terms of %)

- MWIR PV bands: Terra Band 20 – approx. 0.8% , Aqua Band 24 – approx. 1.0%
- LWIR PV bands: Terra Band 30 – approx. 7.0%, Aqua Band 29 – approx. 0.8%
- LWIR PC bands: Terra Band 31 – approx. 0.2%, Aqua Band 32 – approx. 0.9%

– No new noisy / inoperable detectors since last Science Team Meeting (Jan. 2010)

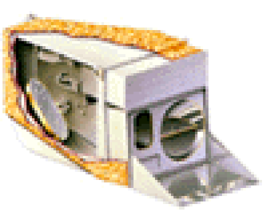
– Terra MODIS has 27 noisy detectors and 1 inoperable detector

- PV Detectors in LWIR Focal plane are getting noisier

– Aqua MODIS has 3 noisy detectors and 1 inoperable detector

MODIS Thermal Emissive Bands Collection 6

MODIS Characterization Support Team (MCST)



MODIS Science Team Meeting (May 17, 2011)

Outline of TEB C6 changes

- ❑ a0/a2 update
- ❑ L1B impact assessment due to a0/a2 change
- ❑ Aqua B33, 35, & 36 default b1 update
- ❑ Terra/Aqua uncertainty index for L1B*

*details will be documented on MCST webpage

TEB C6 LUT – a0/a2 update strategy

Aqua	**C5**	**Changes in C6**
B20, 22-30	PL a0/a2	**Adjust PL a2 based on cool-down***
B21	a0 = 0 and a2 = 0	no change
B31-32	Warm-up a0/a2	**a0 = 0, cool-down a2**
B33-36	a0 = 0, PL a2	**Adjust PL a2 based on cool-down**

Terra	**C5**	**Changes in C6**
B20, 22-30	Warm-up a0/a2	**Cool-down a0/a2**
B21	a0 = 0 and a2 = 0	no change
B29, 31-32	Warm-up a0/a2	**a0 = 0, cool-down a2**
B33-36	a0 = 0, warm-up a2	a0 = 0, **cool-down a2**

- Coefficients derived from quarterly BB Warm-up & Cool-down Activities
- C6 improves TEB performance for low temperature scenes
- C6 has additional early mission time steps to capture instrument configuration change impact

TEB C6 LUT – a0/a2 update strategy for Aqua*

***Bands:** all TEB except for B21, 31 and 32 use prelaunch (PL) a0/a2.

Goal for update:
Maintain the initial differences in BT between PL and the first on-orbit a0/a2

Update method:
Adjustment of PL a2 to maintain nearly constant BT differences over time due to on-orbit drifts in a2 (set a0=PL and fit a2)

Update criteria:
Examine if BT differences exceed two times of NEdT from 0.3Ttyp to Ttyp for two consecutive BB warmup/cooldown events

TEB C6 LUT – a0/a2 update strategy for Aqua*

Algorithm details

1) Calculate initial post-launch BT differences at T_{typ}, ΔT^0_{typ}

$$\Delta T^0_{typ} = BT\,[\text{on-orbit } a0/a2(0)] - BT\,[\text{PL } a0/a2]$$

2) At a given time *t*, calculate the difference, ΔT^t

$$\Delta T^t = \Delta T^t_{typ} - \Delta T^0_{typ}$$

3) Make iterative adjustments of PL a2 with a factor δ

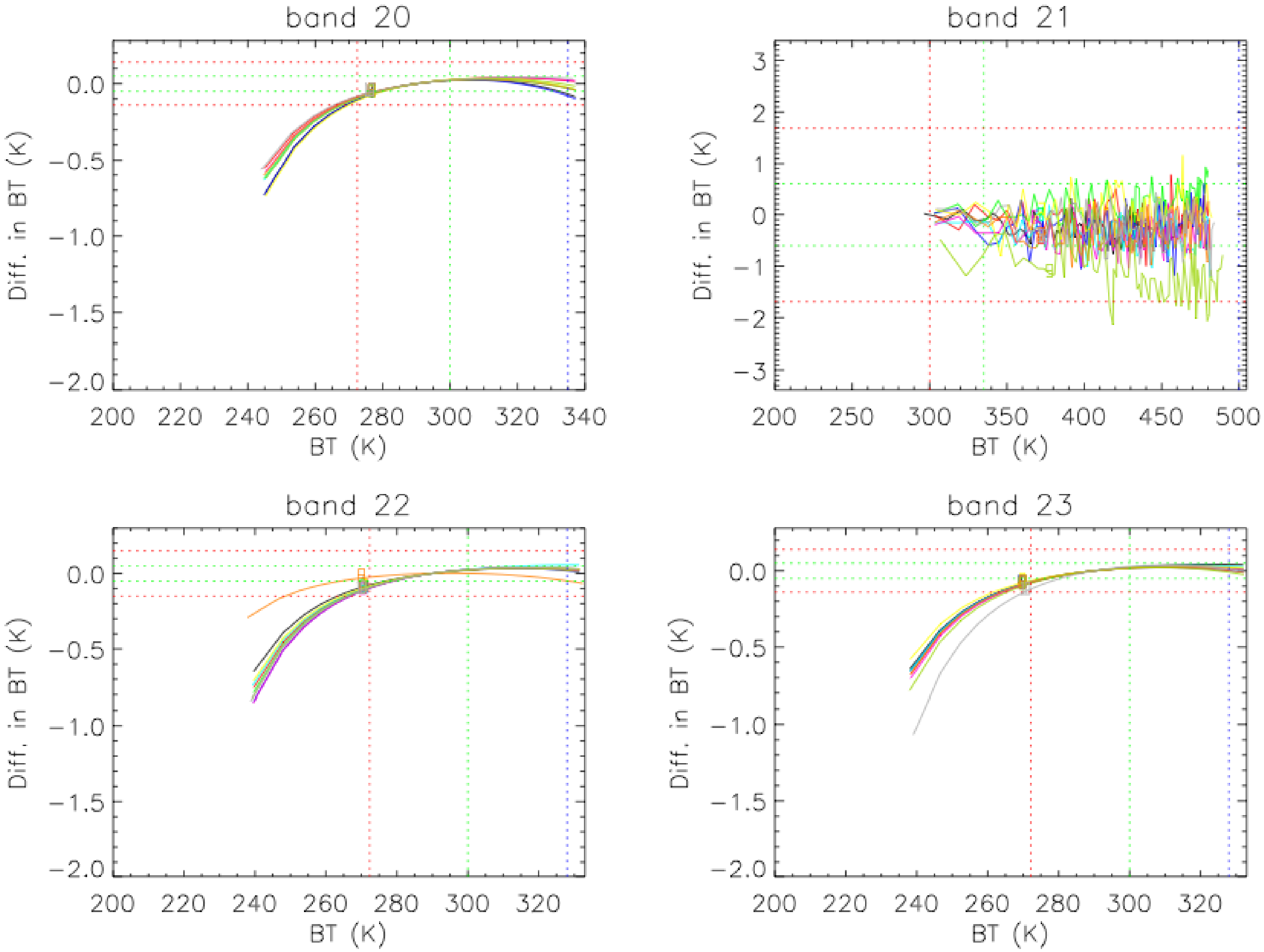
$$a2(i) = a2(i) + \delta a2, \; i = 0, 1, 2, 3 \ldots.$$

4) After the iterative adjustment, a conversion is reached at step i when

$$\Delta T^t\,(i) \leq 0.03 * NEdT$$

TEB C6 LUT impact – Terra B20-23

ΔT = C6 – C5

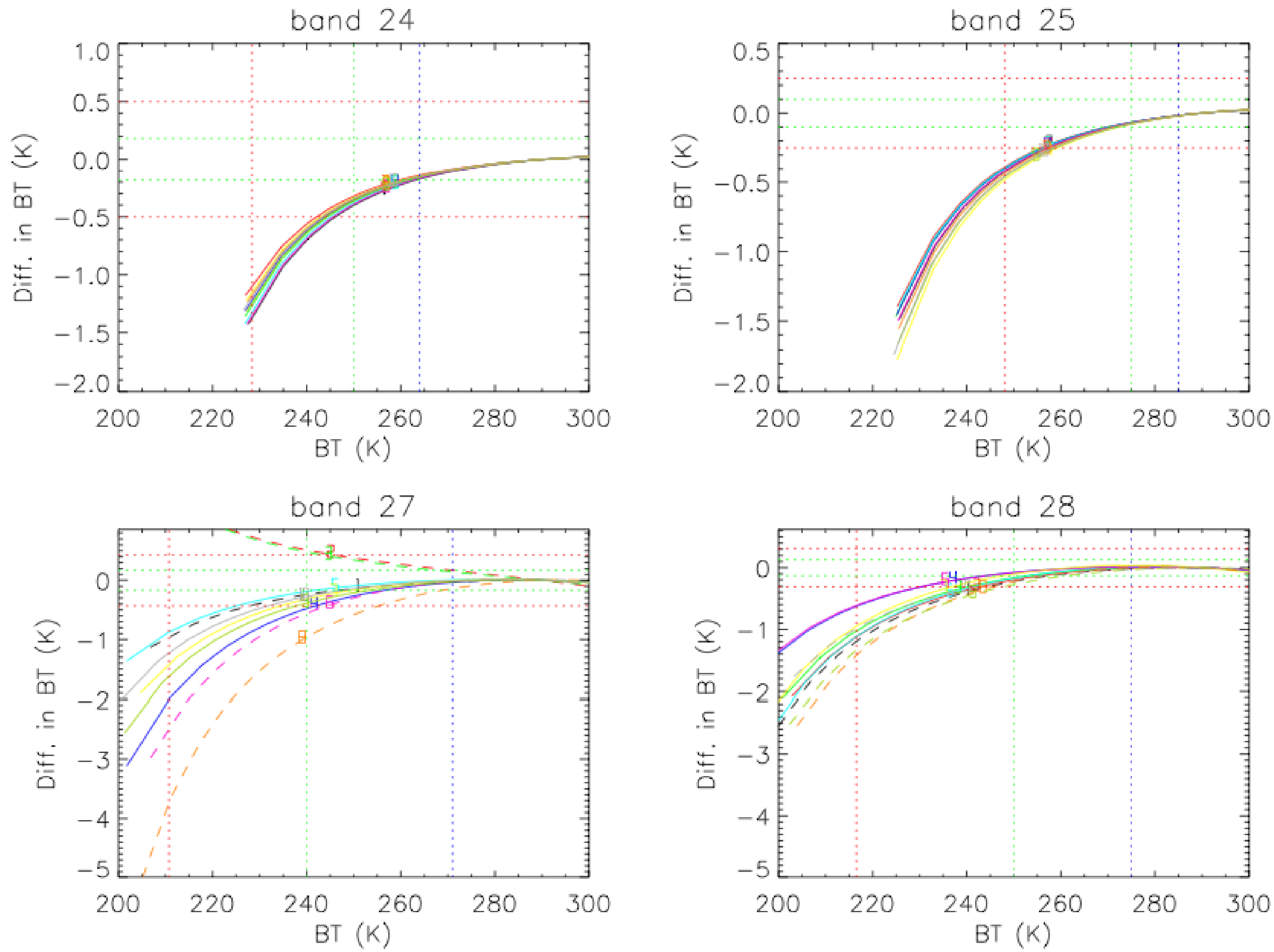


Test Granule = Terra 2011128.1300
Colored lines denote individual detectors

Vertical lines: red = 0.3Ltyp, green = Ltyp, blue = 0.9Lmax
Horizontal lines : green = +/- NEdT at Ltyp, red = +/- NEdT at 0.3 Ltyp

TEB C6 LUT impact – Terra B24-28

ΔT = C6 – C5



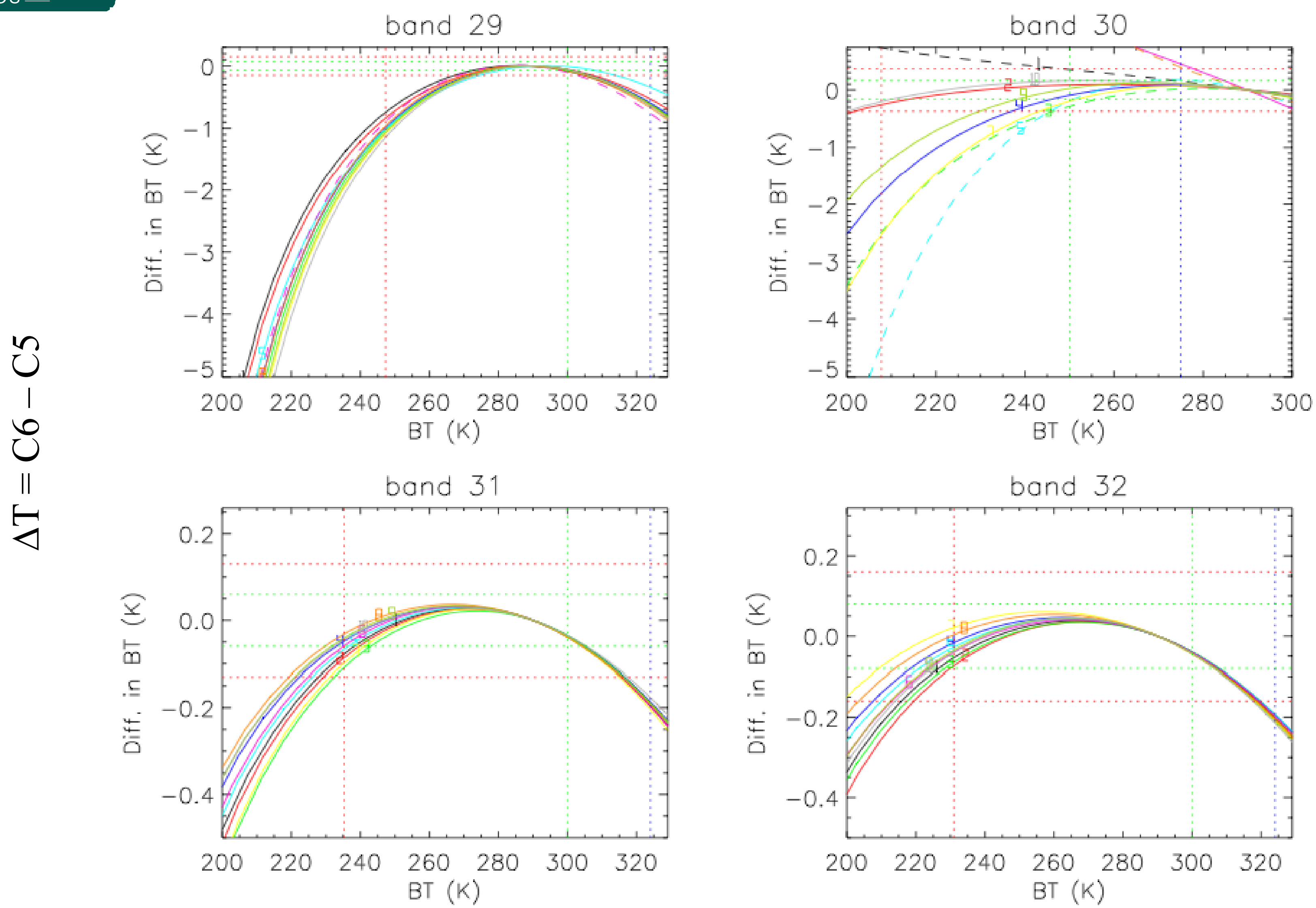
Test Granule = Terra 2011128.1300

Colored lines denote individual detectors

Vertical lines: red = 0.3Ltyp, green = Ltyp, blue = 0.9Lmax

Horizontal lines : green = +/- NEdT at Ltyp, red = +/- NEdT at 0.3 Ltyp

TEB C6 LUT impact – Terra B29-32

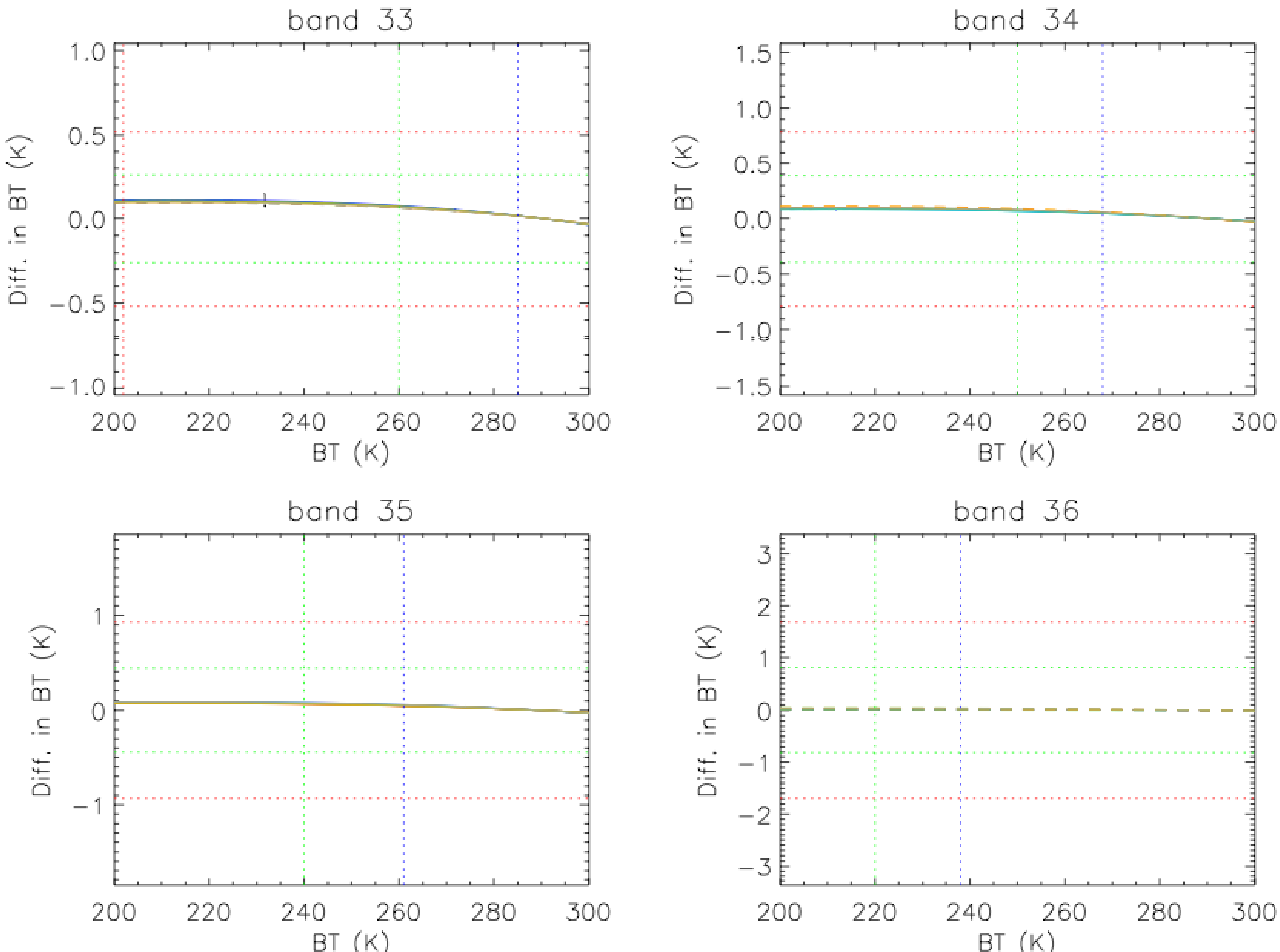


Test Granule = Terra 2011128.1300
Colored lines denote individual detectors

Vertical lines: red = 0.3Ltyp, green = Ltyp, blue = 0.9Lmax
Horizontal lines : green = +/- NEdT at Ltyp, red = +/- NEdT at 0.3 Ltyp

TEB C6 LUT impact – Terra B33-36

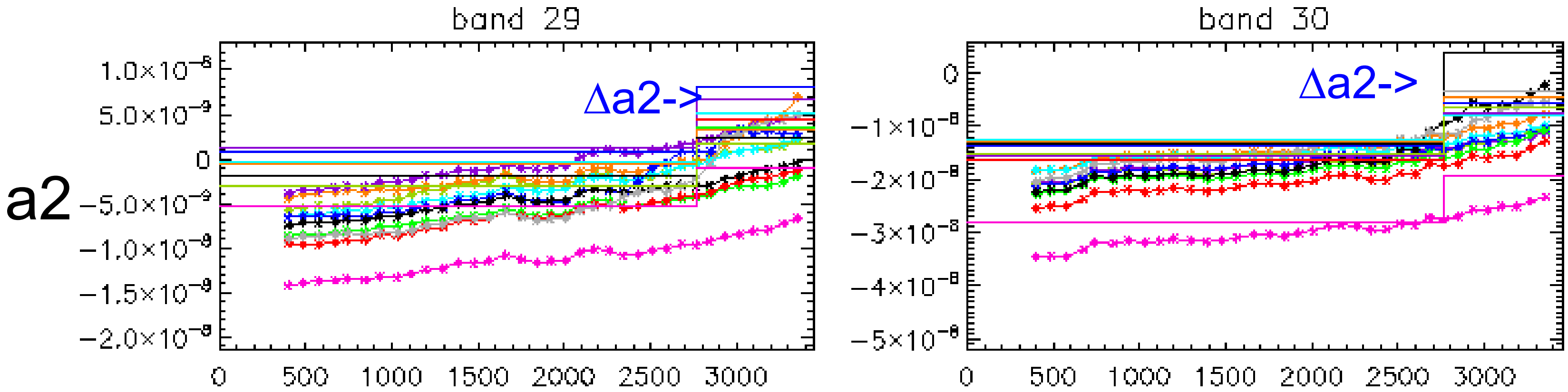
$\Delta T = C6 - C5$

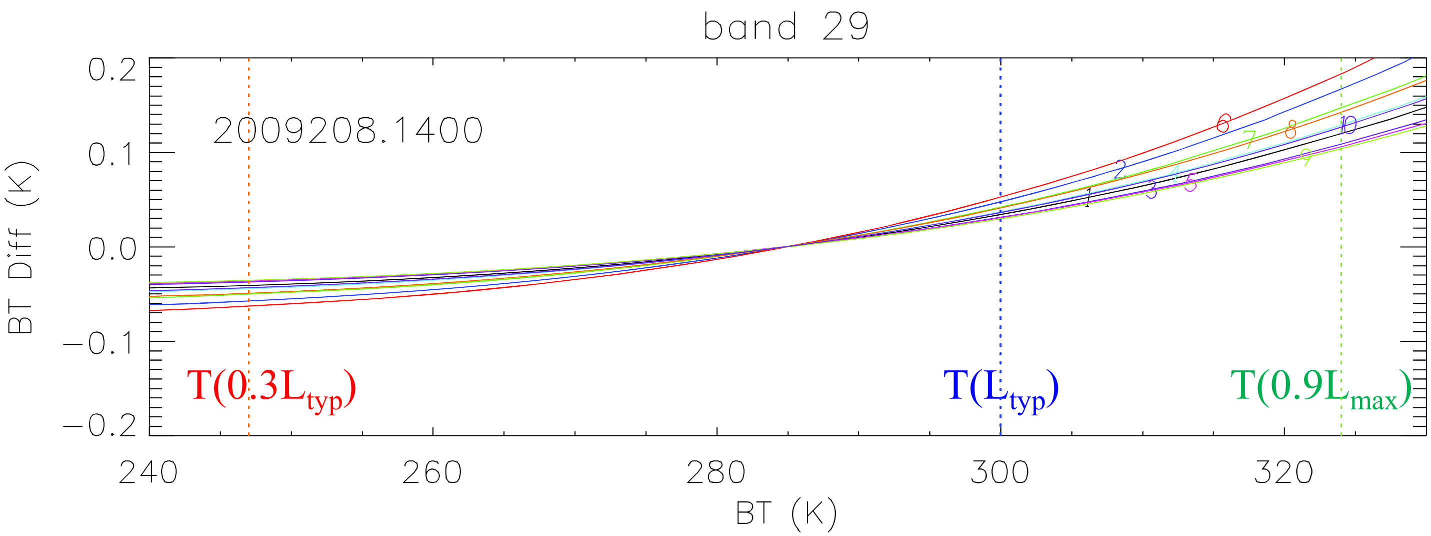


Test Granule = Terra 2011128.1300
Colored lines denote individual detectors

Vertical lines: red = 0.3Ltyp, green = Ltyp, blue = 0.9Lmax
Horizontal lines : green = +/- NEdT at Ltyp, red = +/- NEdT at 0.3 Ltyp

TEB C6 LUT impact – Aqua TEB





Trends of on-orbit BB WUCD a0/a2 show that there are noticeable drifts in Aqua band 29 and 30. An update of a2 (2009208) is made using an iterative adjustment of PL a2 based on ΔT^t (i)

Estimated L1B Impact

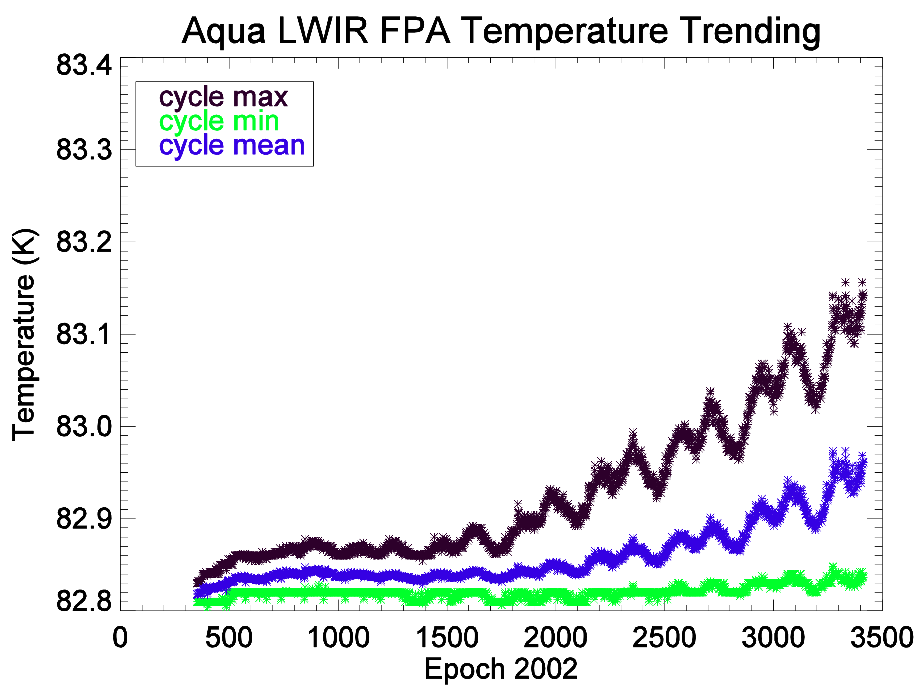
$\Delta T = BT(C6) - BT(C5)$ (K), actual differences are detector and time-dependent

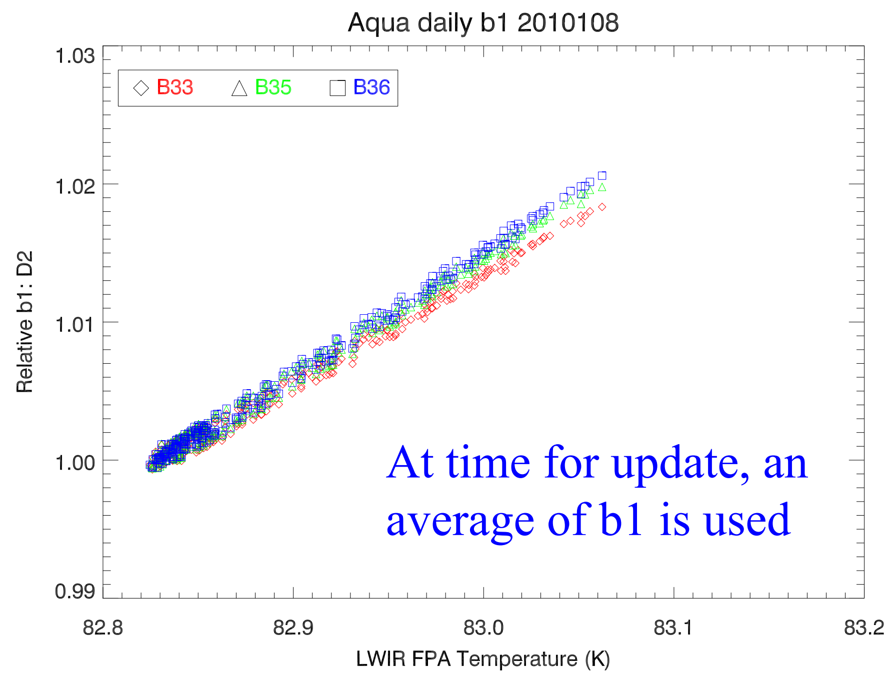
Band	T_{typ}	Terra			Aqua		
		ΔT (0.3L_{typ})	ΔT (L_{typ})	ΔT (0.9L_{max})	ΔT (0.3L_{typ})	ΔT (L_{typ})	ΔT (0.9L_{max})
20	274, 300, 335	- 0.10	+ 0.02	- 0.03	0.00	0.00	-0.03
22	273, 300, 328	- 0.05	+ 0.02	+ 0.01	0.00	0.00	0.00
23	273, 300, 328	- 0.08	+ 0.02	0.00	0.00	0.00	-0.01
24	229, 250, 264	- 1.20	- 0.30	- 0.15	0.00	0.00	0.00
25	250, 275, 285	- 0.40	- 0.08	- 0.04	0.00	0.00	0.00
27	212, 240, 271	- 0.50	- 0.20	- 0.05	-0.02	-0.02	-0.01
28	217, 250, 275	- 0.70	- 0.15	- 0.02	-0.01	-0.01	-0.01
29	247, 300, 324	- 0.55	- 0.03	- 0.20	-0.05	0.04	0.13
30	207, 250, 275	+ 0.40	+ 0.15	+ 0.10	-0.13	-0.11	-0.05
31	235, 300, 324	- 0.20	- 0.04	- 0.14	- 0.40	0.00	- 0.05
32	231, 300, 324	- 0.20	- 0.04	- 0.14	- 0.40	0.00	- 0.05
33	202, 260, 285	+ 0.10	+ 0.08	+ 0.05	0.01	0.00	0.00
34	195, 250, 268	+ 0.10	+ 0.08	+ 0.07	0.00	0.00	0.00
35	187, 240, 261	+ 0.10	+ 0.08	+ 0.07	-0.12	-0.10	-0.07
36	175, 220, 238	+ 0.08	+ 0.08	+ 0.07	0.02	0.02	0.02

Band 21 – Differences are generally within +/- 2K (detector & time dependent)

C6 procedure for default b1 update (b33, 35&36)

b1 variation with CFPA Temperature

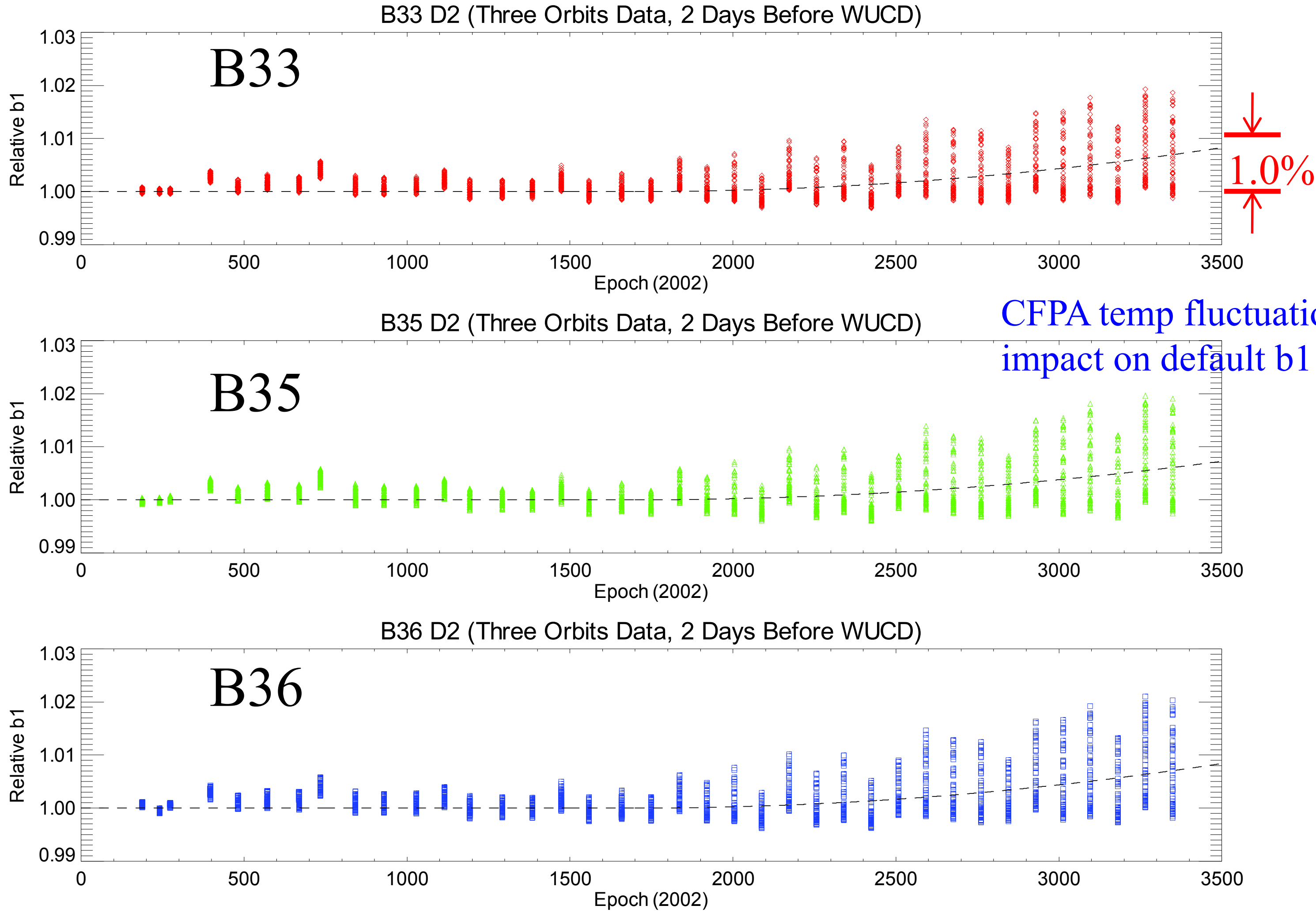




- Rate of Change in b1 due to CFPA temperature variations: ~7.8%/K, ~8.5%/K & ~9.0%/K for B33, 35 & 36
- Default b1 update in C5 became arbitrary depending on CFPA temperature
- Impacts are only limited to the WUCD periods when BB temp are larger than T_{SAT}

C6 procedure for default b1 update (B33, 35&36)

b1 Trending from WUCD



CFPA temp fluctuation's impact on default b1 is 2-3%

Number of Terra/Aqua C5/C6 LUT time stamps

	Terra		Aqua	
	C5	C6	C5	C6
a0/a2	15	22	5	2
B21-b1	15	25	11	10
Default b1	N/A	N/A	5	2

- More Terra C6 a0/a2 time stamps are added for different configurations during early post-launch period
- C5 uses warmup and C6 uses cooldown data
- C6 uses moving average when a0/a2 measurements are available
- Requirements for C6 a0/a2 update are more stringent than those used in C5