An Overview of MODIS On-orbit Performance
(Sensors, Calibration, and Level 1B / LUTs)

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and

MODIS Characterization Support Team (MCST)

Outline

- ## Introduction
  - Instrument Background, On-orbit Calibration Activities, and Current Status

- ## Instrument Operations

- ## On-orbit Performance
  - Thermal Emissive Bands (TEB)
  - Reflective Solar Bands (RSB)

- ## Level 1 and LUT Updates

- ## Challenging and Concerning Issues

- ## Summary

Introduction

Acknowledgements:

- All MCST members

- MODIS Science Team

  - Science Team Leader (Vince Salomonson)

  - Land (Eric Vermote and Zhengming Wan)

  - Ocean (Barnes et al.)

  - Atmosphere (Chris Moeller)

  - Cal/Val (Stuart Biggar)

- Raytheon / SBRS

  - Roger Drake and Jim Young

- Others

  - Bruce Guenther, Eugene Waluschka, and Robert Wolfe

Introduction

Contact:

- Team leader: Jack Xiong

- Support and coordinate science team issues: Vincent Chiang

- Instrument operation: Bryan Breen

- RSB Calibration: Xiaobo Xie

- TEB Calibration: Aisheng Wu

- L1B and LUT: James Kuyper

MCST (*http://www.mcst.ssai.biz/mcstweb/index.html*)

Instrument Background

PFM **FM1**

Terra (EOS-AM):
Launched on 12/18/99
First light on 02/24/00

Aqua (EOS-PM):
Launched on 05/04/02
First light 06/24/02

- 2-sided Paddle Wheel Scan Mirror
- 3 Nadir Spatial Resolutions
    - 250m (1-2), 500m (3-7), and 1km (8-36)
- 4 Focal Plane Assemblies (FPAs)
    - VIS, NIR, SMIR, and LWIR
- 36 Spectral Bands (490 detectors)
    - Reflective solar bands (1-19, and 26), thermal emissive bands (20-25, 27-36)
- On-Board Calibrators (OBCs):
    - Solar diffuser (SD)
    - SD stability monitor (SDSM)
    - Blackbody (BB)
    - Spectro-radiometric calibration assembly (SRCA)
    - Space view (SV)
- Science Applications
    - Land, oceans, and atmosphere
    - Nearly 40 science products generated and distributed

MODIS Calibration Activities

BB (quarterly)
SD/SDSM (weekly first year to bi-weekly)
SRCA (monthly radiometric, bi-monthly spatial, quarterly spectral)
Maneuvers (roll: monthly **Moon**; yaw: 2 for Terra and 1 for Aqua; pitch: 2 for Terra)

SDSM

Solar Diffuser

SRCA

SDSM

Blackbody

Scan Mirror

Space View

Moon
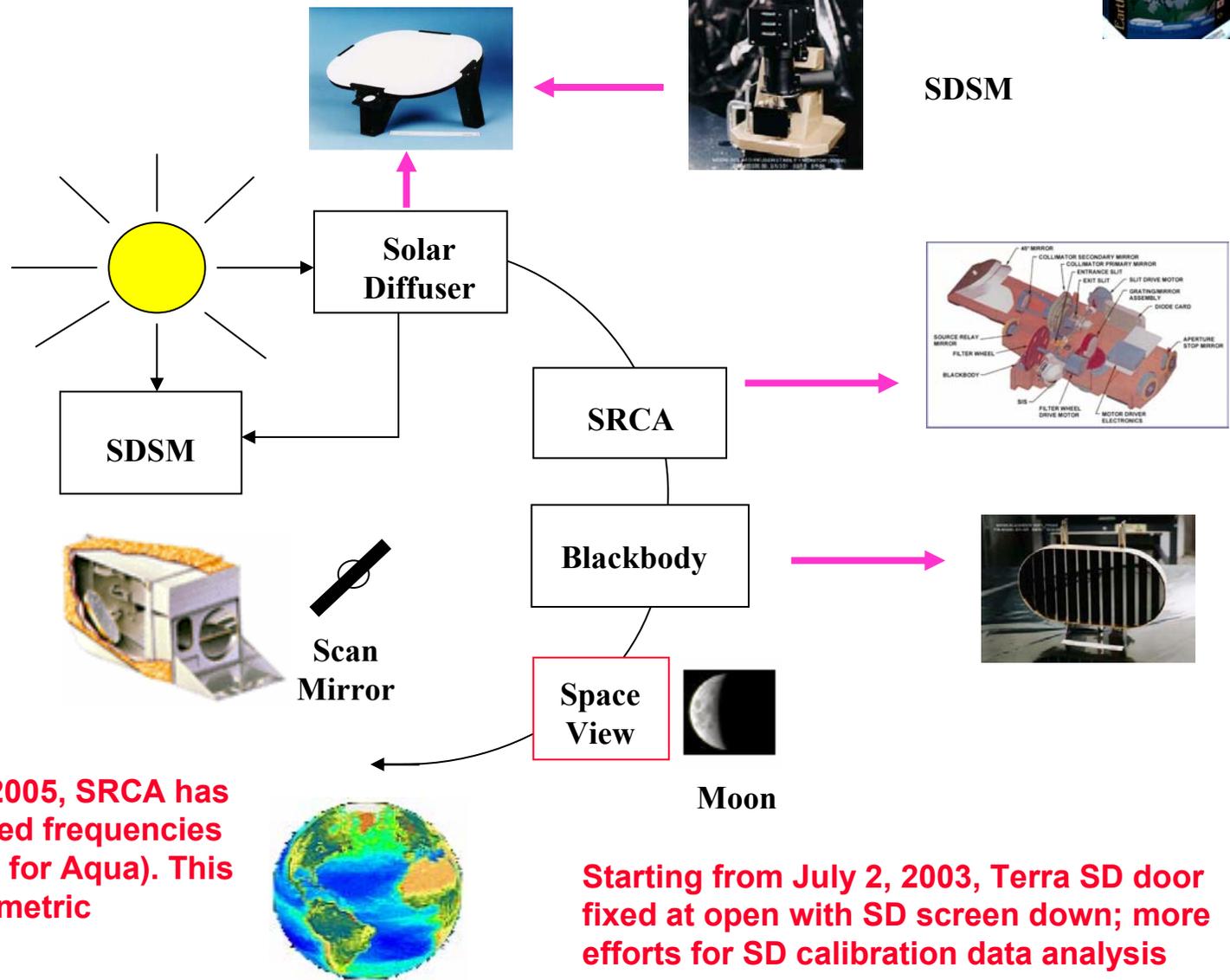
Starting from October 2005, SRCA has been operated at reduced frequencies (no 30W configurations for Aqua). This has no impact on radiometric calibration.

Starting from July 2, 2003, Terra SD door fixed at open with SD screen down; more efforts for SD calibration data analysis

Status of Instruments: Operation

Terra MODIS (over 6 years)

- Stable and Normal Operation
  - No configuration changes since September 2002 (currently A/B conf.)
  - SD door fixed at open with SD screen down since July 2003
  - S/C SSR anomaly (August 26, 2005): PWA in the MODIS buffer fails. MODIS loses 2 supersets (now operated with 32 supersets).
    - Options proposed: change % of day/night orbit; SSR recycling
  - SFE anomaly (September 23, 2005); Returned to normal on the same day.

Aqua MODIS (over 3.5 years)

- Stable and Normal Operation
  - Same configuration used for the entire mission (currently B conf.)
  - May 17, 2005: SRCA operation shutdown during 20W spatial calibration due to failure of lamp # 3. Starting from October 2005, SRCA has been operated at reduced frequencies using constant current mode without 30W lamp configuration. No impact on science data.

Status of Instruments: L1B/LUTs

Terra MODIS (over 6 years)

- L1B code: 12 versions
  - V4.3.0 and V.5.0.6 are currently in production

- L1B LUTs: over 110 versions used in production (10 for collection 5)
  - Nearly 20 LUTs delivered (March 05 – present)

Aqua MODIS (over 3.5 years)

- L1B code: 6 versions
  - V4.3.1 and V.5.0.7 are currently in production

- L1B LUTs: over 50 versions used in production (7 for collection 5)
  - Nearly 14 LUTs delivered (March 05 – present)

Note: many versions of code and LUTs have also been developed, tested, and delivered for special applications or for MCST internal testing and research

Status of Instruments: Calibration

Terra MODIS (over 6 years)

- Stable Spatial and Spectral Performance On-orbit
- TEB calibration performs well using on-board BB
- RSB calibration LUTs have been regularly updated
  - Tracking SD degradation
  - Constantly tracking RSB stability using lunar observations
 - New RVS approach applied in collection 5

Aqua MODIS (over 3.5 years)

- Stable Spatial and Spectral Performance On-orbit
  - BBR out of specification for all bands between warm and cold FPAs, B6 inoperable detectors (two problems since pre-launch)
- TEB calibration performs well using on-board BB
- RSB calibration LUTs have been regularly updated
  - Similar SD degradation as Terra MODIS under the same conditions
  - Constantly tracking RSB stability using lunar observations
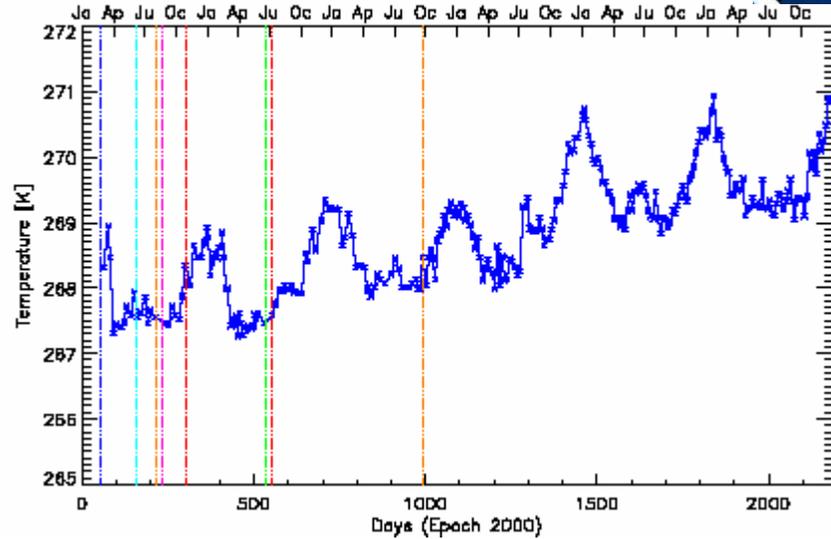
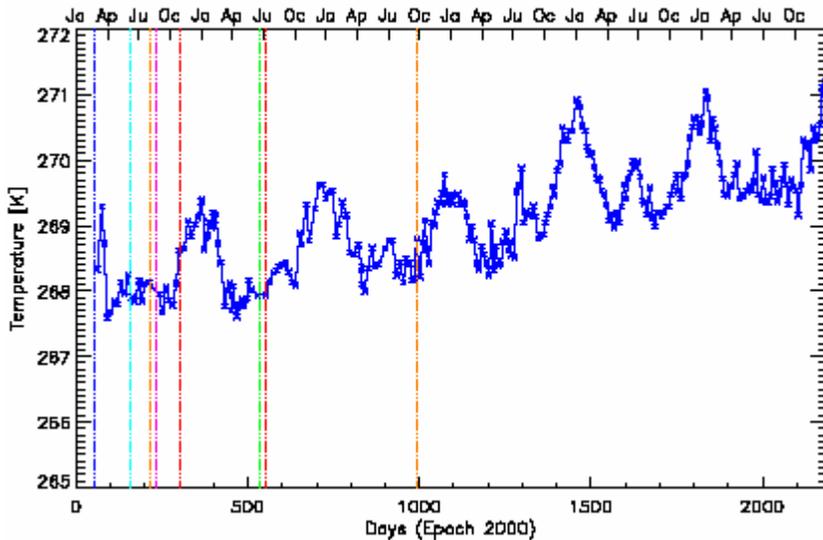# Terra Instrument and FPA Temperatures

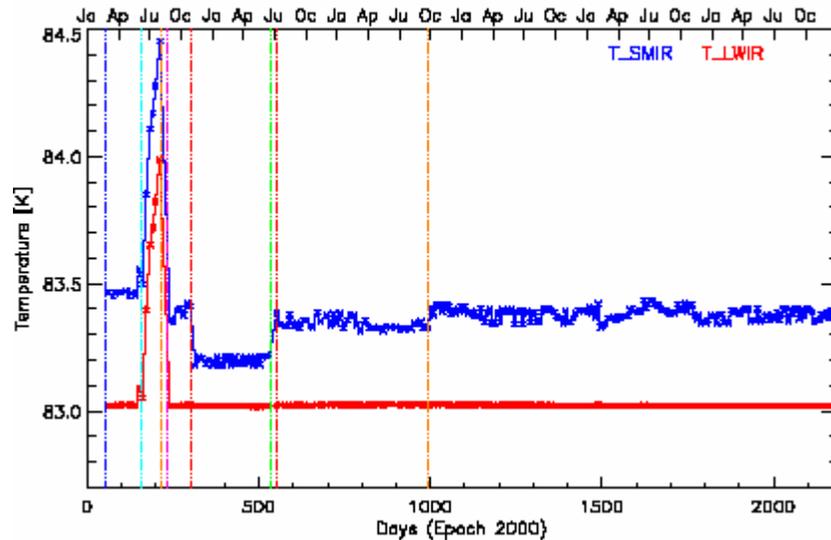Terra Telemetry Instrument Temperature
Day 2000042 to 2005359
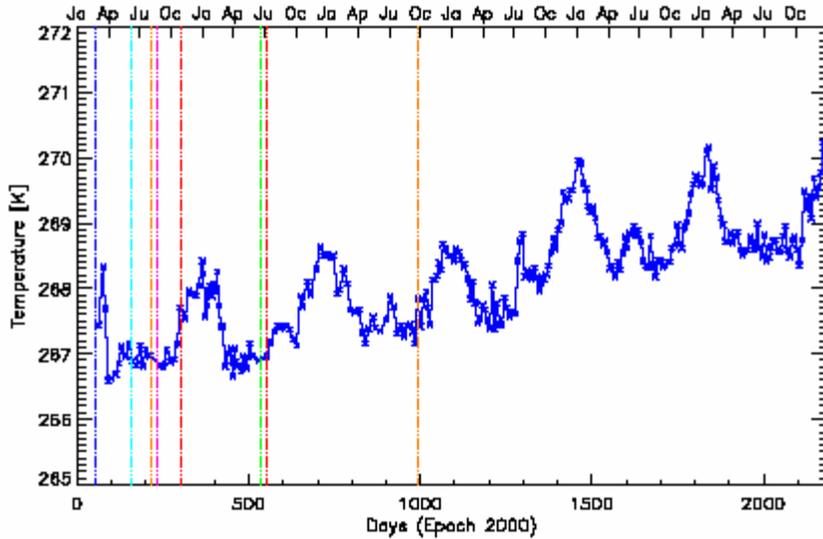
MODIS Terra Telemetry VIS Focal Plane Temperature
Day 2000042 to 2005359

MODIS Terra Telemetry NIR Focal Plane Temperature
Day 2000042 to 2005359

MODIS Terra Telemetry SMIR & LWIR Focal Plane Temperature
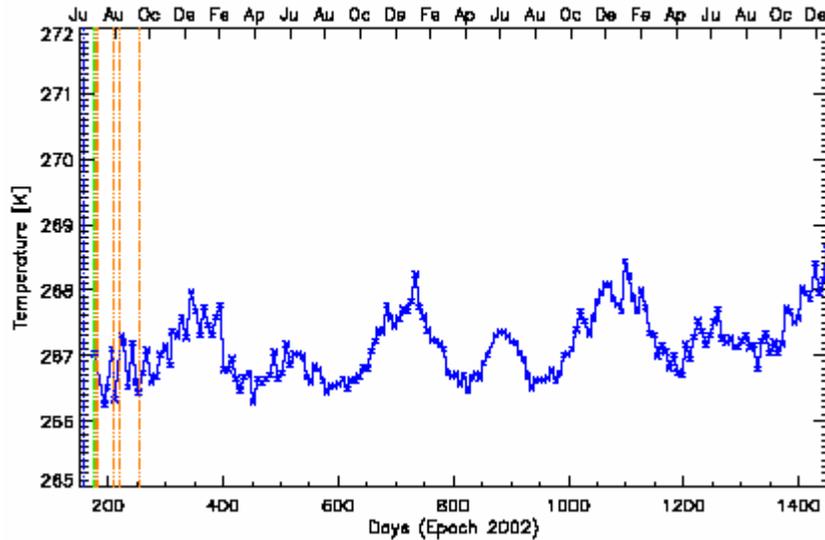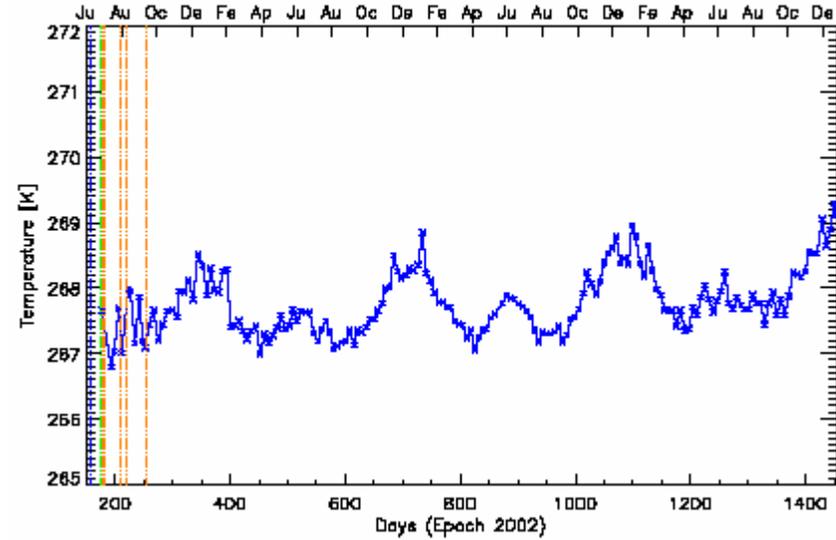Day 2000042 to 2005359
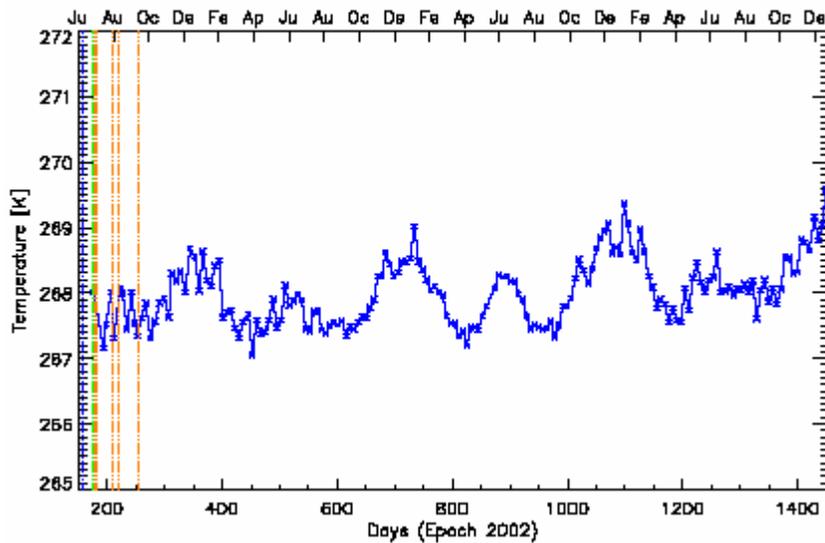
Aqua Instrument and FPA Temperatures

MODIS Aqua Telemetry Instrument Temperature
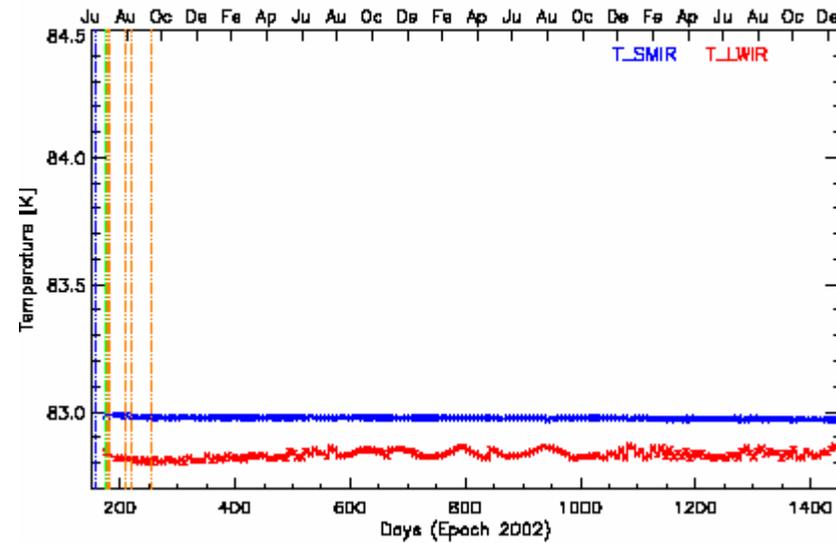Day 2002158 to 2005359

MODIS Aqua Telemetry VIS Focal Plane Temperature
Day 2002158 to 2005359

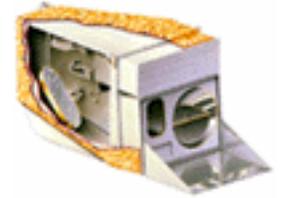MODIS Aqua Telemetry NIR Focal Plane Temperature
Day 2002158 to 2005359

MODIS Aqua Telemetry SMIR & LWIR Focal Plane Temperature
Day 2002158 to 2005359

T_SMIR   T_LWIR

PFM MODIS Operations: Highlights

- Successful Activation of the PFM MODIS Instrument
  – December 18, 1999:   Terra Launch
  – February 11, 2000:   Science Mode
  – February 24, 2000:   Open Nadir Door (First Light)

- Radiative Cooler Temperature Anomaly
  – June 8, 2000:   FPA stopped controlling at 83K
  – August 3, 2000:   Set FPA temperature to 85K
  – August 8-10, 2000:   Performed second active outgas

- 1st Formatter Anomaly
  – June 21, 2000:   First formatter reset
  – August 5, 2000:   Repeated formatter resets
  – August 18, 2000:   Returned to Science Mode with two FR FSW Patches in place

PFM MODIS Operations: Highlights
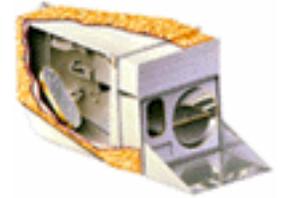
- Switched Instrument Configuration to B-side
  - October 30, 2000:   Transitioned to B-side science

- 1st Spacecraft Solid State Recorder Anomaly
  - May 20, 2001:   Two (MODIS) SSR supersets fail;
                              MODIS down to 33 supersets
  - May 24-25, 2001:   Failed supersets are removed from active list
  - June 17, 2001:   Complete SSR "hang-up"
  - June 20, 2001:   SSR fully recovered, superset allocation
                              adjustment, MODIS gains additional superset
                              (up to 36)

- PS2 Shutdown Anomaly
  - June 15, 2001:   PS2 Shutdown
  - June 28, 2001:   PS1/CPB Startup attempt
  - July 2, 2001:   Returned to A-side science using PS1/CPA

PFM MODIS Operations: Highlights

- 2nd Formatter Anomaly
  - August 15, 2001:   A-side Formatter errors resume
  - July 8, 2002:   20 million errors per day
  - September 10, 2002:   Nearly 70 million errors per day
  - September 17, 2002:   Swapped to formatter B from formatter A; other components remain on the A-side.

- MODIS EEPROM: burned patches
  - March 19, 2002:   Terra transitions to Safe mode
  - March 23, 2002:   MODIS has trouble transitioning to Science Mode due to formatter resets
  - March 28, 2002:   Safe mode recovery
  - May 8, 2002:   EEPROM written to with 1 word patch to prevent formatter resets during formatter startup

PFM MODIS Operations: Highlights

- Nadir Aperture Door (NAD) Micro-switch Failure
  - December 13, 2001:   MOD_CR_DR_NAD_OPEN indicates OPEN when the NAD is closed
  - March 28, 2002:   NAD commanded open after SAFE hold but MOD_CR_DR_NAD_OPEN indicates NOT_OPEN; science data indicates OPEN
  - March 29, 2002:   MOD_CR_DR_NAD_OPEN spontaneously transitions to OPEN
  - December 24, 2003:   NAD commanded open after SAFE hold but MOD_CR_DR_NAD_OPEN indicates NOT_OPEN; science data indicates OPEN

- Black Body (BB) Taxi Errors
  - July 26, 2002:   C&DH gets a lot of TAXI overflow errors (problem is traced to when the BB is at FULL duty cycle and reaches a plateau)
  - October 22, 2002:   BB calibration reworked so temperature goes from 290K to 315K at FULL without a plateau

PFM MODIS Operations: Highlights

- SD Screen Failure to Open
  - May 6, 2003:   SD Screen (SDS) does not open when commanded
  - July 2, 2003:   SD Door is opened with the SDS remaining closed (will remain this configuration until further notice)

- 1st Spacecraft Science Formatting Equipment (SFE) Shutdown
  - February 1, 2003:   SFE-A HPM-2A board locked up. SFE-A power-cycled.
  - February 18, 2004:   SFE-A shuts down inside SAA.
  - February 19, 2004:   SFE-A powered on. Total data loss from 2004/049 14:31:57 - 050 16:11:38

PFM MODIS Operations: Highlights
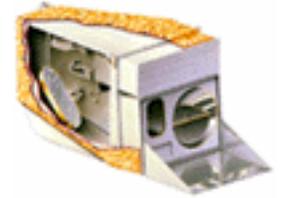
- 2nd Spacecraft Solid State Recorder Anomaly
  - September 24, 2003:   PWA in the MODIS buffer fails; MODIS loses 2 supersets; now at 34 supersets
  - September 25, 2003:   Failed supersets are removed from active list
  - September 30, 2003:   1 superset reallocated from MISR buffer to MODIS buffer; MODIS now at 35 supersets

- 3rd Spacecraft Solid State Recorder Anomaly
  - October 14, 2003:   PWA in the MODIS buffer fails; MODIS looses 2 supersets; now at 33 supersets
  - October 14, 2003:   Failed supersets are removed from active list
  - October 20, 2003:   1 superset reallocated from MISR buffer to MODIS buffer; MODIS now at 34 supersets

- Terra Direct Broadcast Outage
  - November 30, 2003:   SFE-A Direct Broadcast is lost.
  - January 15, 2004:   SFE-A recycled; Direct broadcast back online

PFM MODIS Operations: Highlights

- SRCA Lamp #2 Degradation
    - March-April, 2004: Some degrading of SRCA lamp #2 was noticed
    - April 26 & 27, 2004: 10W radiometric calibrations were performed using lamps 1, 2, and 3.
    - May 25, 2004: SRCA lamp #2 is no longer being used during SRCA calibrations. In its place, lamp #4 is being used.
    - November 22, 2004: SRCA lamp #2 shuts itself off during an extended SRCA calibration.

- 2nd Spacecraft Science Formatting Equipment (SFE) Shutdown
    - December 24, 2004: SFE-A HPM-2 card error trips TMON-16, shutting off SFE-A
    - December 24, 2004: SFE-A powered on. Total data loss from 2004/359 13:52:44 - 20:38:35

- 4th Spacecraft Solid State Recorder Anomaly (new since last STM)
    - August 26, 2005: PWA in the MODIS buffer fails. MODIS loses 2 supersets. Now at 32 supersets.

PFM MODIS Operations: Status

- 216 SRCA Calibrations
  - 31 Full Spectral, 43 Full Spatial, and 72 Full Radiometric (update)
  - Lamp Usage in hours: total (on orbit)

    10W Lamps, 500hr life: 1) 249.8 (115.6) 2) 172.1 (53.0)
        3) 188.4 (60.1)   4) 77.9 (16.4)

    1W Lamps, 4000hr life: 1) 569.2 (26.3)   2) 278.7 (2.4)

| Lamp Use in Hours						
	10W #1	10W #2	10W #3	10W #4	1W #1	1W #2
Full Radiometric	0.151	0	0.13	0.13	0.086	0
Full Spatial	0.34	0	0.34	0.34	0.17	0
Full Spectral	2.38	0	1.172	1.172	0	0
One Year Use with: Monthly Radiometric Quartley Spatial Tri-annual Spectral	10.312	0	6.436	6.436	1.712	0
Total after 10 years	304.471	172.093	224.216	113.702	580.897	278.715

PFM MODIS Operations: Status
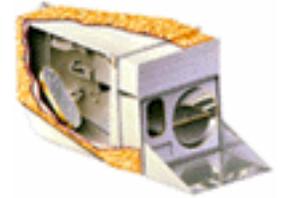
- 500 SD/SDSM Calibrations (183 SD Door Open + 317 SD Door Screened)
  - 2146 (1213 on orbit) of 3022 Solar Diffuser Door Movements
- 54 Blackbody Calibrations
- 46 Electronics Calibrations
- 62 Lunar Calibrations, 57 via Roll Maneuver
- 33 Yaw Maneuver SD/SDSM Calibrations
- Nadir Door Operations
  - 538 (9 on orbit) of 1316 Nadir Door Movements
- Space View Door Operations
  - 441 (8 on orbit) of 1316 Space View Door Movements
- Voltages are steady with occasional single-sample spikes
- Focal Plane Heater Voltage
  - PFM LWIR Focal Plane Heater Margin is currently ~34mW
  - Another outgas event may be required, but not in the near future
- Radiative cooler / Outgas Temperatures
  - PFM Intermediate Stage is currently 126.0K and steady

FM1 MODIS Operations: Highlights
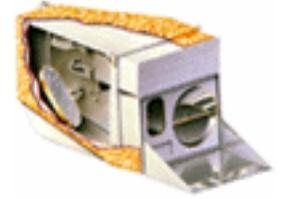
- Successful Activation of the FM1 MODIS Instrument
  - May 4, 2002:   Aqua Launch
  - June 7, 2002:   Science Mode
  - June 24, 2002:   Open Nadir Door (First Light)

- 3 Early Spacecraft Safe Mode Events
  - June 27, 2002:
 - July 29, 2002:
  - September 12, 2002:
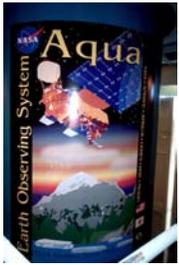
FM1 MODIS Operations: Highlights

- Dropped SCS Command Anomaly
  - July 10, 2002:   First 2 commands of SCS 154 not executed (SDSM calibration)
  - August 9, 2002:   Final command of SCS 153 not executed (Macro 9 command)
  - August 13, 2002:   First command of SCS 56 not executed (DAY rate command)
  - August 28, 2002:   Fifth and sixth commands of SCS 154 not executed (SDSM calibration)
  - September 2, 2002:   Second command of SCS 56 not executed (NIGHT rate command)
  - September 20, 2002:   Patch loaded to disable IMOK signal to MODIS in event of s/c SAFE mode
  - October 15, 2002:   Patch loaded to swap ISC-to-MODIS and CTC-to-MODIS command slots
  - January 21, 2003:   CTC-to-MODIS commands dropped/delayed
  - April 15, 2003:   Patch loaded to swap back the ISC-to-MODIS and CTC-to-MODIS command slots, and to delay each command by one sub-minor cycle (32 milliseconds)
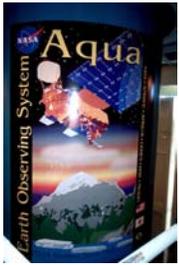
FM1 MODIS Operations: Highlights
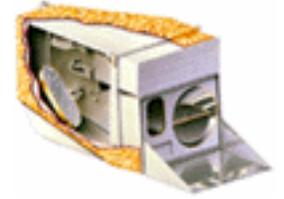
- SRCA Lamp #2 Degradation

  - February, 2003:   Some degrading of SRCA lamp #2 was noticed
  - March 17 & 18, 2003:   10W radiometric calibrations were performed 4 times using each of the 4 lamps.
  - As of April 14, 2003:   SRCA lamp #2 is no longer being used for SRCA calibrations. Lamp #4 is being used in it's place.

- SRCA Lamp #3 Failure

  - May 17, 2005:   During 20W portion of SRCA Full Spatial calibration, SRCA lamps shutdown, SRCA continues to run until normal shutdown.

  - June 28, 2005:   Lamps are tested and 10W lamp #3 does not turn on. All other lamps operate nominally.

    Currently SRCA calibrations limit to 10W, 20W, and 1W.
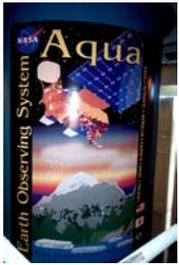
FM1 MODIS Operations: Status

- 91 SRCA Calibrations
  - 13 Full Spectral, 22 Full Spatial, and 39 Full Radiometric (update)
  - Lamp Usage in hours: total (on orbit)

    10W Lamps, 500hr life: 1) 247.2 (47.0)   2) 188.0 (12.3)
    3) 205.7 (27.2)   4) 83.2 (25.5)

    1W Lamps, 5000hr life: 1) 510.2 (10.7)   2) 271.6 (1.8)

Lamp Use in Hours						
	10W #1	10W #2	10W #3	10W #4	1W #1	1W #2
Full Radiometric	0.15	0	0	0.065	0.085	0
Full Spatial	0.339	0	0	0.169	0.169	0
Full Spectral	2.38	0	0	1.172	0	0
One Year Use with: Monthly Radiometric Quarterly Spatial Tri-annual Spectral	10.296	0	0	4.972	1.696	0
Total after 10 years	335.011	187.983	205.709	125.427	526.827	271.625

FM1 MODIS Operations: Status

- 277 SD/SDSM Calibrations (137 SD Door Open + 140 SD Door Screened)
  - 2468 (838 on orbit) of 3022 Solar Diffuser Door Movements
- 16 Blackbody Calibrations
- 26 Electronics Calibrations
- 33 Lunar Calibrations, 32 via Roll Maneuvers
- 29 Yaw Maneuver SD/SDSM Calibrations
- Nadir Door Operations
  - 1053 (7 on orbit) of 1316 Nadir Door Movements
- Space View Door Operations
  - 632 (8 on orbit) of 1316 Space View Door Movements
- Voltages are steady with occasional single-sample spikes
- Focal Plane Heater Voltage
  - FM1 SMIR Focal Plane Heater Margin is currently ~23mW
  - Another outgas event may be required, but not in the near future
- Radiative cooler / Outgas Temperatures
  - FM1 Intermediate Stage is currently 124.5K and steady

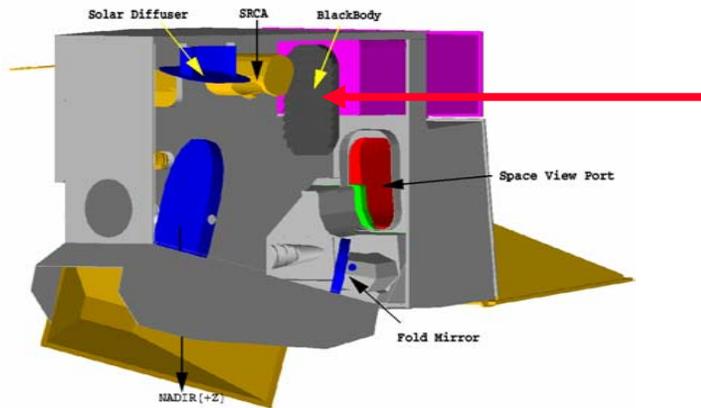# Calibration of MODIS Thermal Emissive Bands

Calibration algorithms

Instrument performance

Aqua & Terra MODIS inter-comparison

Summary

MODIS TEB Calibration Using Blackbody

Radiance (TOA), L_{EV}

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

RVS: Response Versus Scan-angle

ε: Emissivity

L: Spectral band averaged radiance

dn: Digital count with background corrected

Calibration coefficient, b1, from BB

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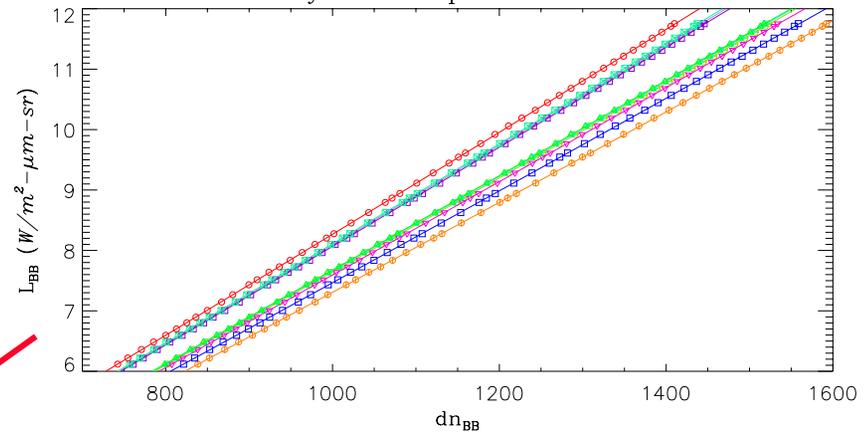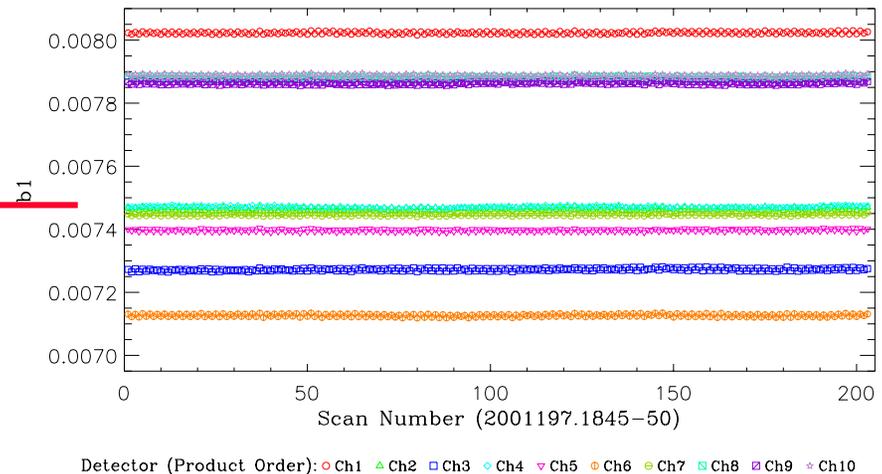
MODIS TEB Calibration Using Blackbody

Blackbody Warm-up Calibration Curves

BB from 270-317K
provides a0 and a2

Scan-to-Scan Linear Coefficient b1

BB at T_BB provides b1
on a scan by scan basis

Detector (Product Order): Ch1 Ch2 Ch3 Ch4 Ch5 Ch6 Ch7 Ch8 Ch9 Ch10

Other Calibration Issues:

B21 (Terra/Aqua) – *Now MS Dependent*

PC Xtalk (Terra)

B33,35,36 (Aqua) at high T_BB

Instrument On-orbit Performance

Thermal Emissive Bands (16 bands and 160 detectors)

- **Terra MODIS**
  - Stable short-term and long-term response trending (excluding sensor configuration change and instrument reset events)
  - 25 (10 in B36 from pre-launch, **1 since last STM**) noisy detectors and 0 inoperable detectors

- **Aqua MODIS**
  - Better response trending than Terra MODIS
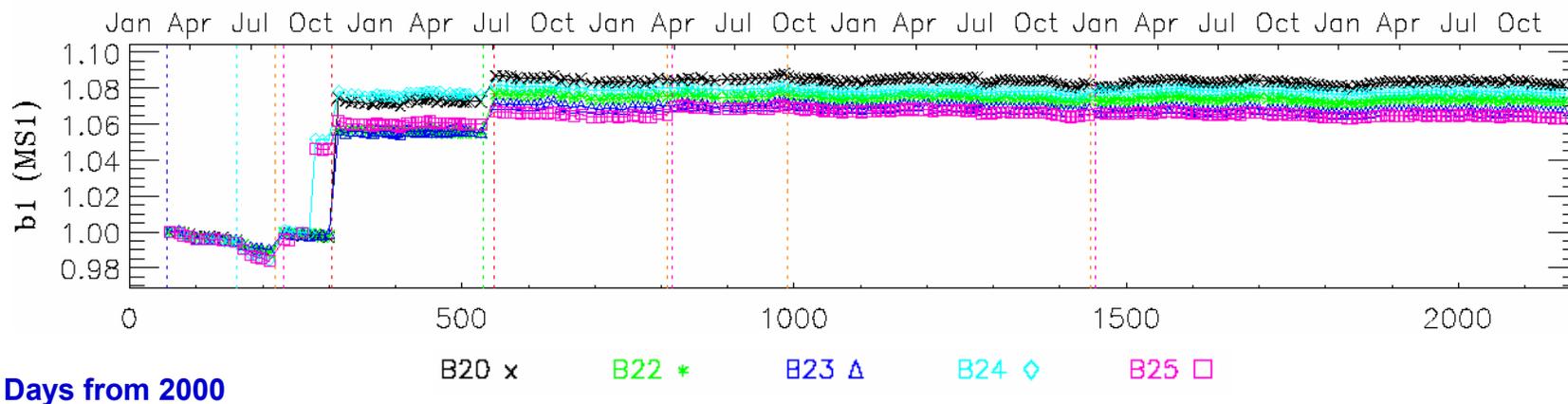 - 4 (3 in B21 from pre-launch, **0 since last STM**) noisy detectors and 0 inoperable detectors

- **Terra MODIS PC Xtalk**
  - Correction applied since launch and PC Xtalk is in stable condition
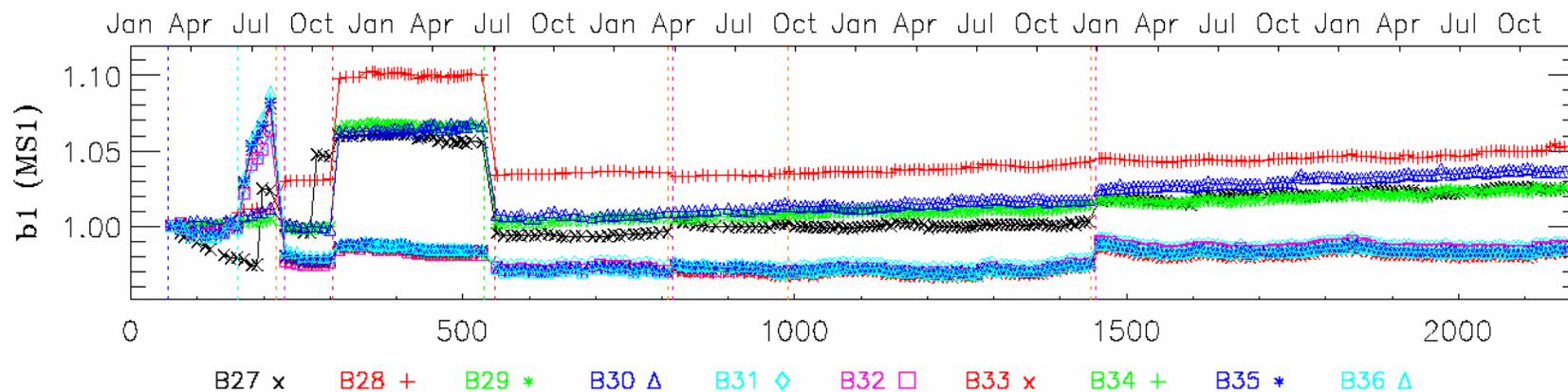
Terra MODIS TEB Response Trending

Terra MODIS MWIR(Bands 20-25) Normalized b1
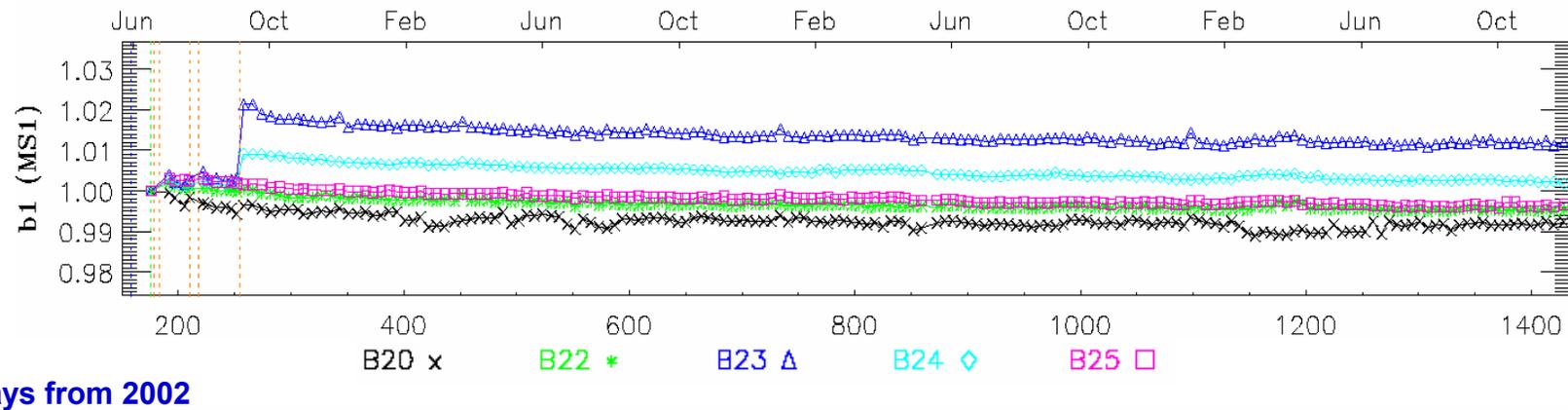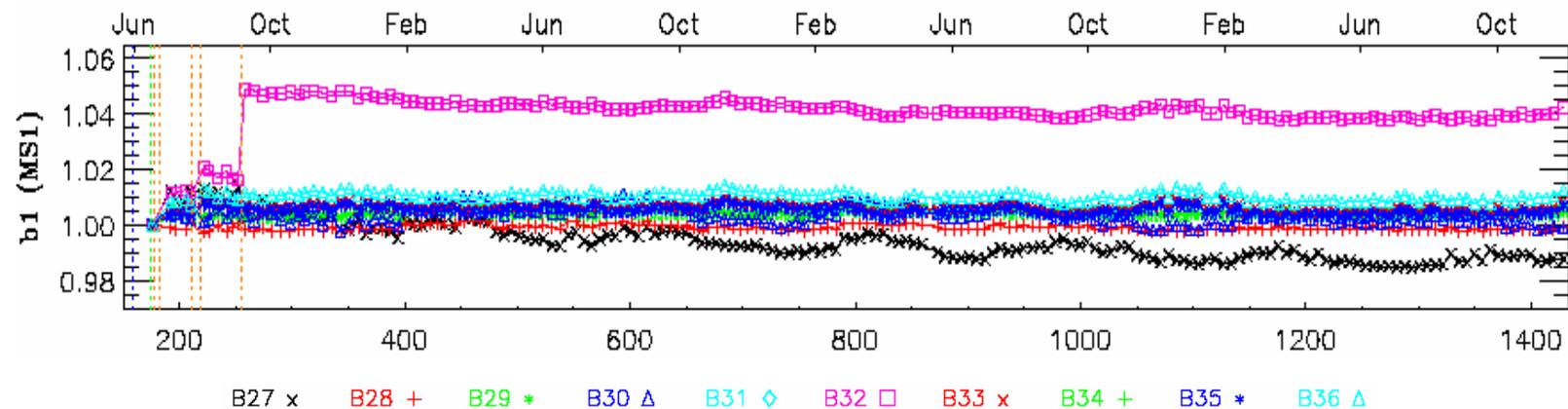
Days from 2000

Terra MODIS LWIR(Bands 27-36) Normalized b1

Aqua MODIS TEB Response Trending

Aqua MODIS MWIR(Bands 20-25) Normalized b1

Days from 2002

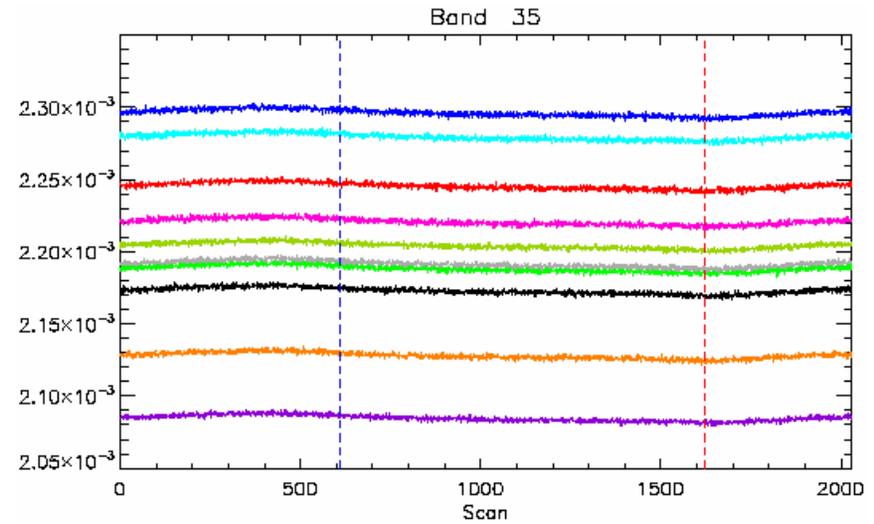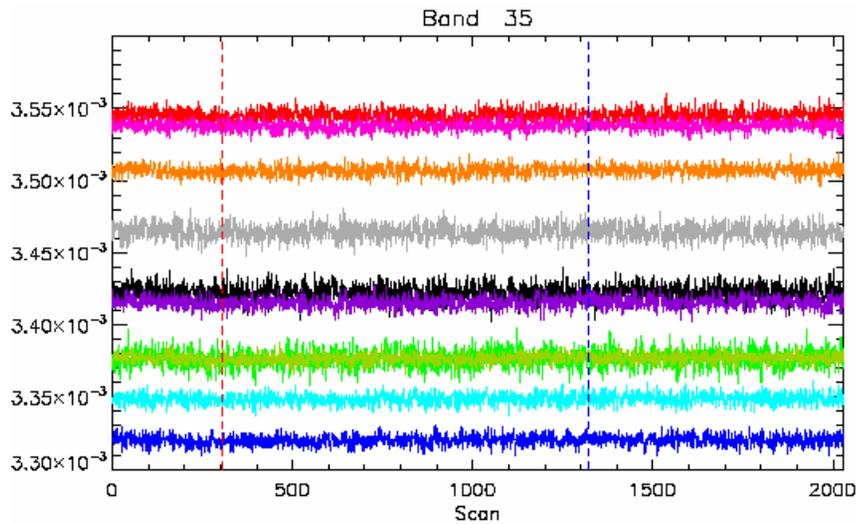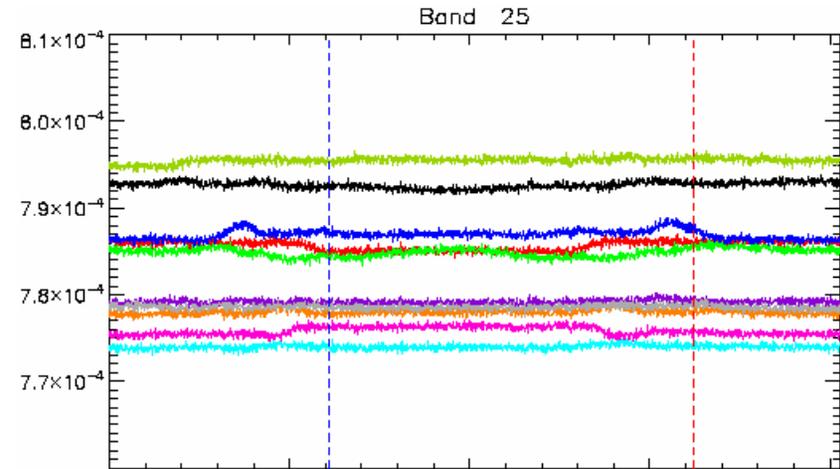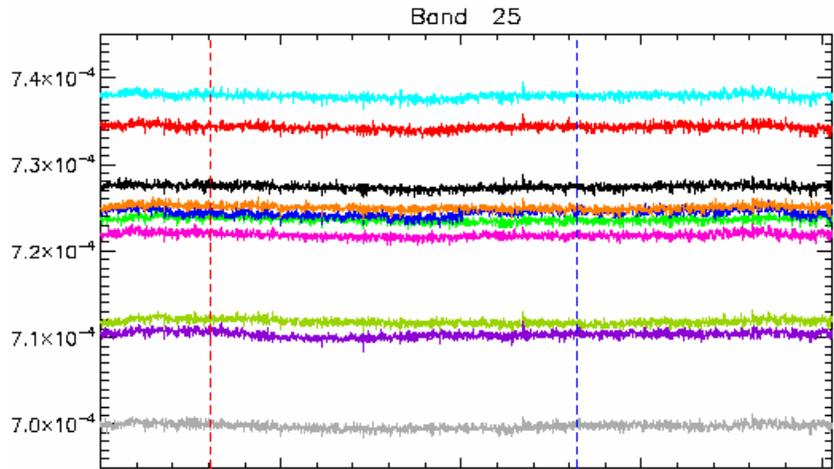Aqua MODIS LWIR(Bands 27-36) Normalized b1

MODIS TEB Short-term Response

Terra MODIS can-by-scan response on 2005281

Aqua MODIS can-by-scan response on 2005290

Ch1 Ch2 Ch3 Ch4 Ch5 Ch6 Ch7 Ch8 Ch9 Ch10
Data collected time: F2005290.0000–F2005290.0135   Red Dashed: Day Mode   Blue Dashed: Night Mode
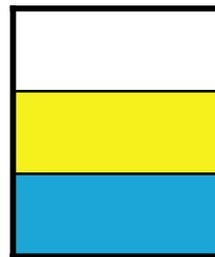
Aqua MODIS Noisy Detector History

Detectors in Product Order

Day/Year	Band	20	21			27
	Spec NEdT [K]	0.05	0.20			0.25
	Detector #	10	3	9	others	3
Pre-launch	-	0.05	0.16	0.28		0.10
175/2002	Nadir door open	0.03	0.23	0.23	near 0.2	0.09
183/2002	Back from safe mode	0.03	0.20	0.25	near 0.2	0.09
218/2002	Back from safe mode	0.03	0.19	0.26	near 0.2	0.09
255/2002	Back from safe mode	0.03	0.23	0.20	near 0.2	0.09
102/2003	-	0.03	0.43	0.19	near 0.2	0.09
201/2003	-	0.03	0.18	0.18	near 0.2	0.09
010/2005	-	0.03	0.17	0.19	near 0.2	0.23

- In Spec
- Near Spec
- Out of Spec

Terra MODIS Noisy Detector History

Detectors in Product Order

Day/Year	Band	21		27		28				29		30			33	34				36
	Spec NEdT[K]	0.20		0.25		0.25				0.05		0.25			0.25	0.25				0.35
	Detector #	4	5	1	6	1	3	8	10	4	6	2	5	8	1	5	6	7	8	1-10
Pre-launch	-	0.20	0.18	0.10	0.10	0.05	0.05	0.04	0.04	0.02	0.02	0.08	0.09	0.09	0.14	0.20	0.20	0.21	0.20	0.45
055/2000	Nadir door open	0.17	0.17	0.09	0.09	0.05	0.06	0.06	0.05	0.02	0.02	0.10	0.11	0.11	0.28	0.23	0.26	0.27	0.29	0.43
232/2000	Back from FPA recycle	0.16	0.15	0.10	0.24	0.05	0.05	0.05	0.05	0.02	0.03	0.11	0.31	0.11	0.27	0.24	0.33	0.37	0.38	0.42
030/2001	-	0.15	0.16	0.10	0.27	0.05	0.06	0.05	0.05	0.02	0.02	0.12	0.29	0.30	0.25	0.24	0.33	0.37	0.37	0.43
087/2002	Back from safe mode	0.18	0.25	0.11	0.24	0.06	0.32	0.05	0.04	0.02	0.02	0.10	0.26	0.64	0.25	0.24	0.29	0.32	0.33	0.43
022/2003	-	0.14	0.16	0.10	0.23	0.05	0.30	0.27	0.04	0.02	0.02	0.10	0.25	0.65	0.27	0.25	0.33	0.37	0.37	0.43
086/2003	After DSM[1]	0.16	0.15	0.11	0.23	0.05	0.29	0.08	0.05	0.03	0.02	0.10	0.47	0.65	0.26	0.24	0.33	0.36	0.36	0.44
118/2004	-	0.16	0.15	0.26	0.26	0.05	0.16	0.36	0.16	0.02	0.03	0.10	0.33	0.41	0.27	0.21	0.29	0.32	0.32	0.43
158/2004	-	0.18	0.17	0.28	0.25	0.05	0.16	0.37	0.21	0.03	0.03	0.10	0.31	0.40	0.27	0.22	0.28	0.31	0.31	0.43
162/2004	-	0.16	0.16	0.26	0.27	0.05	0.16	0.37	0.20	0.02	0.03	0.14	0.32	0.42	0.27	0.22	0.30	0.34	0.34	0.43
175/2004	-	0.15	0.15	0.28	0.26	0.12	0.17	0.35	0.17	0.03	0.02	0.17	0.30	0.41	0.27	0.21	0.28	0.32	0.32	0.43
034/2005	-	0.14	0.15	0.28	0.22	0.10	0.16	0.45	0.16	0.04	0.02	0.17	0.31	0.39	0.26	0.21	0.28	0.31	0.31	0.43
130/2005	-	0.16	0.16	0.31	0.22	0.40	0.15	0.40	0.14	0.03	0.06	0.17	0.40	0.40	0.26	0.21	0.31	0.34	0.34	0.43

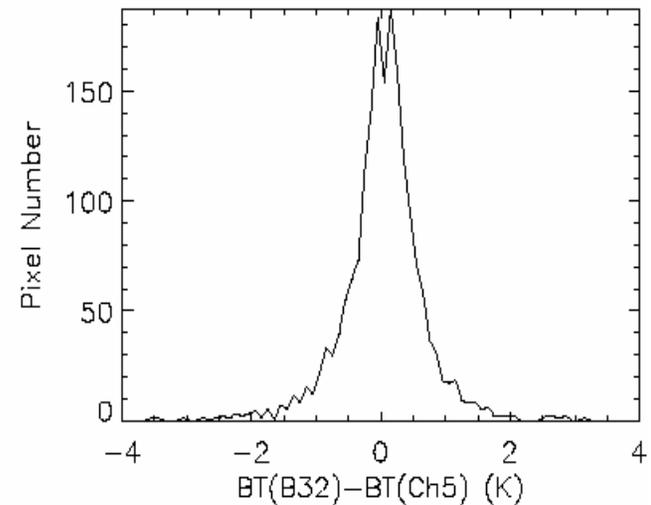**new** →

[1]Spacecraft Deep Space Maneuver
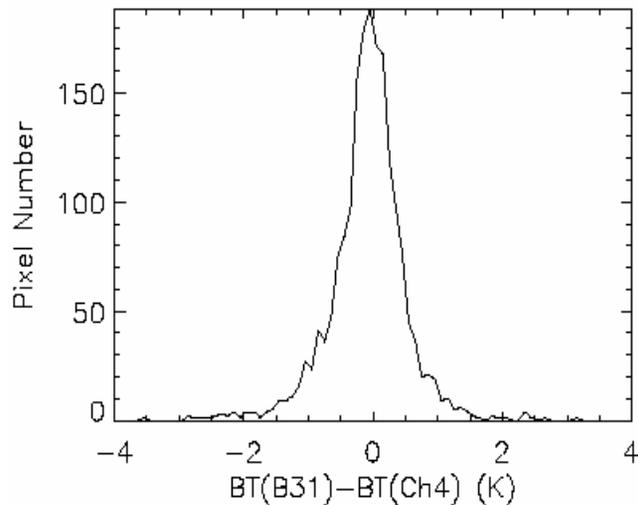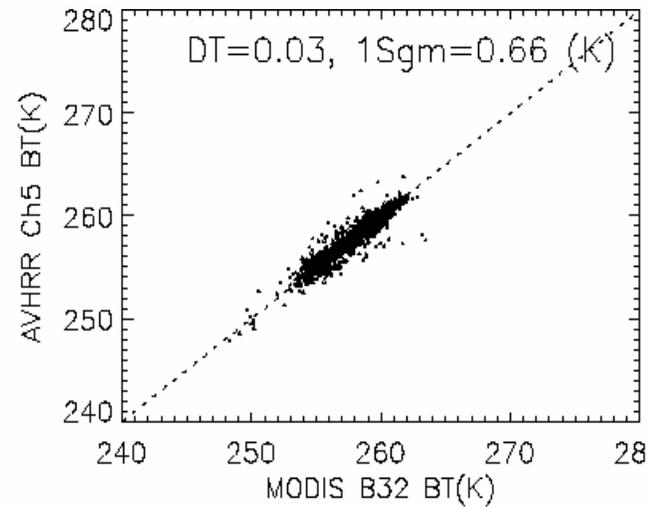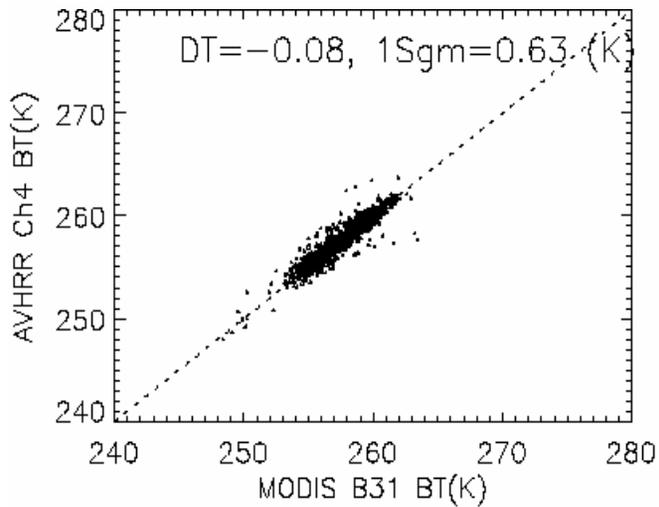
Legend:
- In Spec
- Near the Spec
- Out of Spec

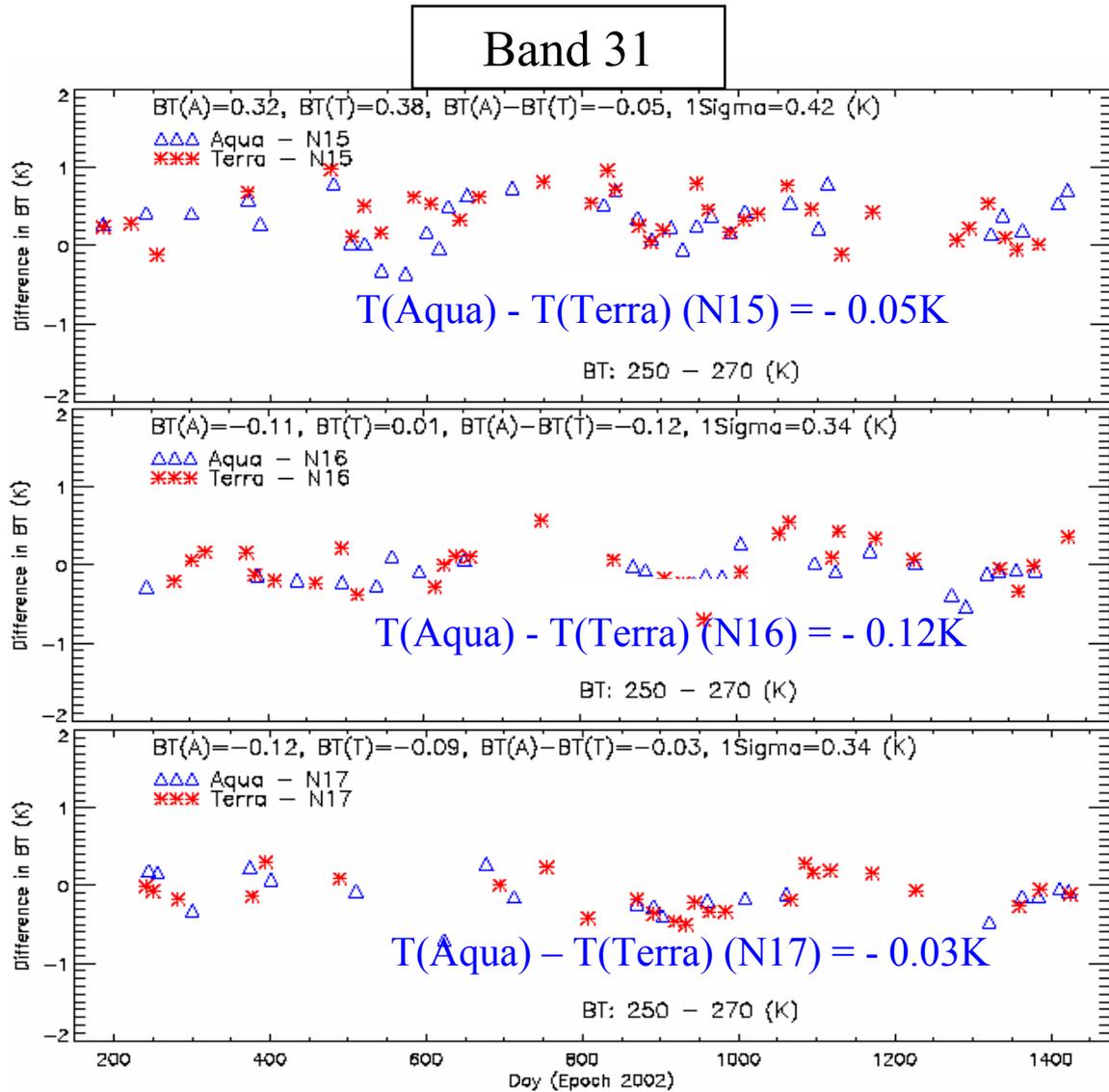# MODIS Inter-comparison Using a Third Sensor

Aqua MODIS and AVHRR GAC (17) in the 11/12μm band on Nov 24, 2005

Aqua/Terra MODIS Inter-comparison

Band 31

MODIS Band 31 and 32 Uncertainty: 0.35K; NEdT = 0.05K at 300K

TEB Performance Summary

MODIS thermal bands have been performing well according to design specifications for Terra (6+ years) and Aqua (3.5+ years); Aqua performs better than Terra in a number of areas.

Inter-comparison shows that Aqua/Terra MODIS differences in 11 and 12µm are within their combined calibration uncertainties.

Status of Terra and Aqua MODIS RSB Calibration

- Overview of RSB calibration and characterization
- RSB on-orbit performance update
- Earthshine impacts on RSB calibration and improvements
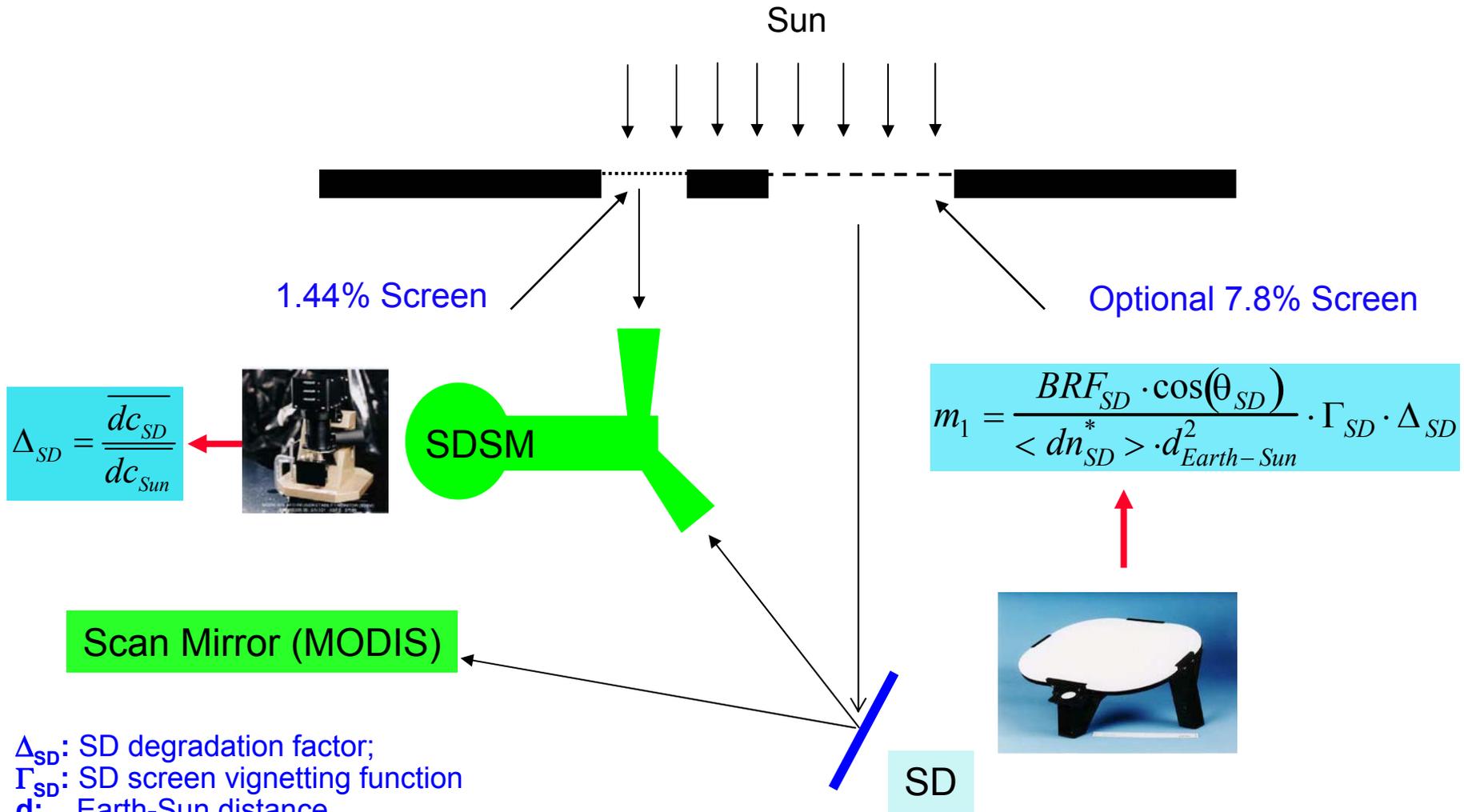- Summary

MODIS RSB Calibration Using SD/SDSM

Reflectance Factor

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

Sun

1.44% Screen

Optional 7.8% Screen

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

SDSM

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

Scan Mirror (MODIS)

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 Calibration Using SD/SDSM

EV Radiance:

$$L_{EV} = \frac{E_{Sun} \cdot \rho_{EV} \cdot \cos(\theta_{EV})}{\pi \cdot d^2_{Earth\_Sun(EV)}}$$

$$= \frac{E_{Sun}}{\pi} m_1 \cdot dn_{EV}$$

Solar Irradiance E_{SUN}:
   0.4-0.8 μm Thuillier et al., 1998;
   0.8-1.1 μm Neckel and Labs, 1984;
   Above 1.1 μm Smith and Gottlieb, 1974

Others:

Thermal leak applied for SWIR bands (B5-7, B26)

Leak coefficients determined from EV night time data

B26 de-striping algorithm added (from C. Moeller of Wisconsin)

RSB On-Orbit Overall Performance

❑ **Terra MODIS**
- ▪ Noticeable optics wavelength & mirror side dependent degradation
- ▪ Small gain changes after configuration changes or instrument reset events
- ▪ SDSM operates bi-weekly to track SD degradation
- ▪ Every orbit SD calibration being monitored to track instrument changes

❑ **Aqua MODIS**
- ▪ Noticeable optics wavelength dependent degradation, but no strong mirror side dependent degradation observed
- ▪ Small gain changes due to instrument resets
- ▪ SDSM operation and SD calibration taken bi-weekly

MODIS RSB Noisy Detector History

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

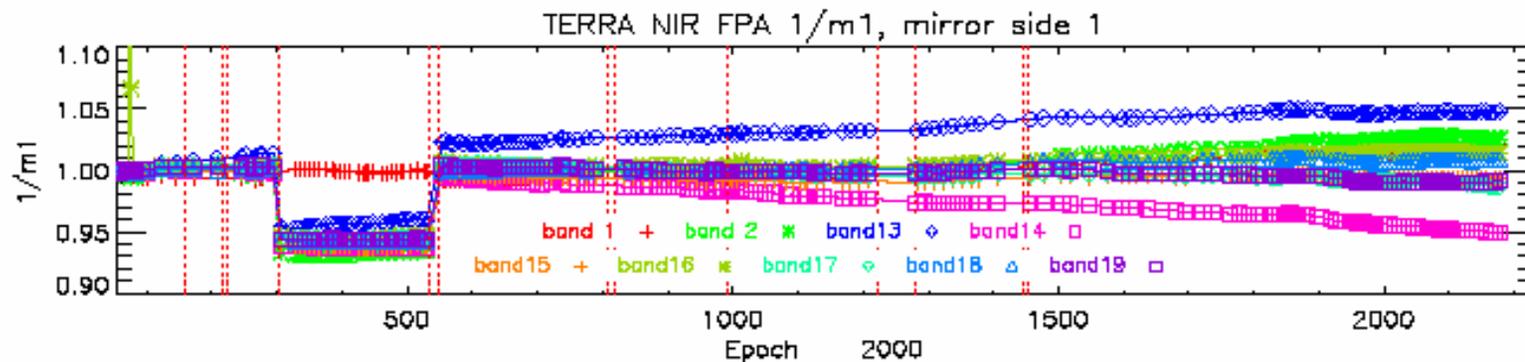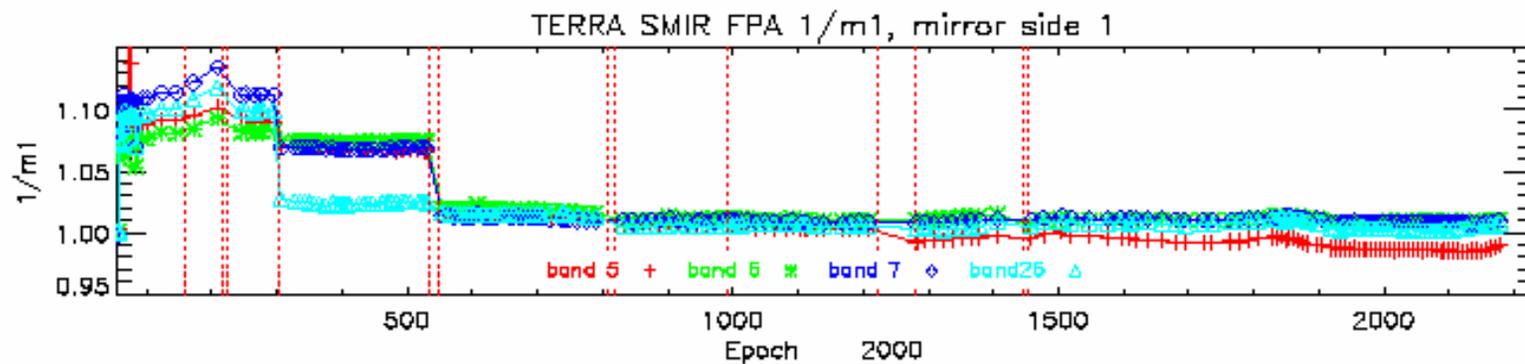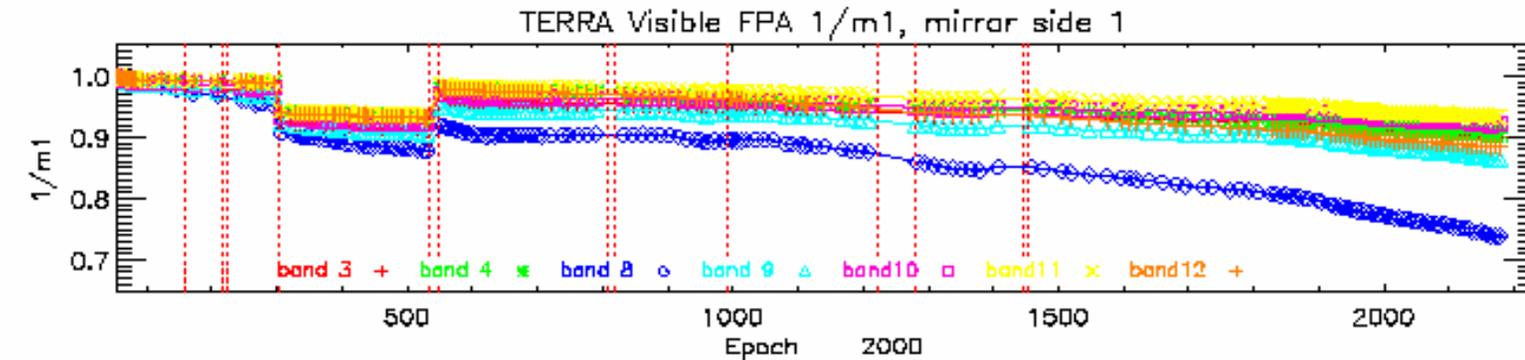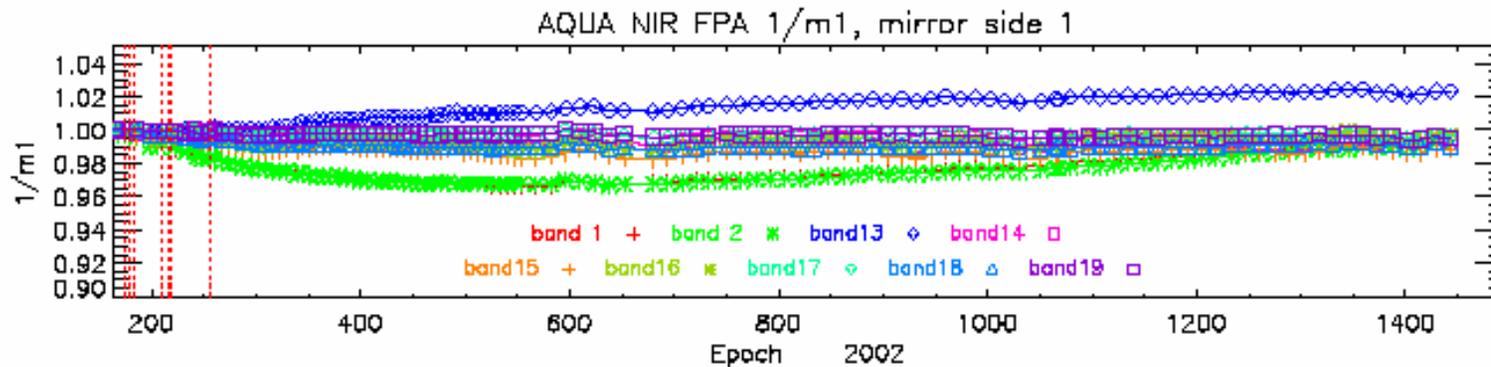| Day/Year	Band	5	6									
	SNR Spec	74	275									
	Detector	1	1-3	4	5-9	11	12	14	15	16	17	19
175/2002	Nadir Door Open	0	0	100	0	0	470	470	0	0	0	0
189/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	470	470	0
255/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	0	0	0
266/2002	Back from Safe Mode	0	0	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

In Spec   Near Spec   Out Spec

Detectors in SBRS order

MODIS RSB Response Trending

TERRA Visible FPA 1/m1, mirror side 1

band 3 +   band 4 ✳   band 8 ○   band 9 △   band10 □   band11 ×   band12 +

TERRA SMIR FPA 1/m1, mirror side 1

band 5 +   band 6 ✳   band 7 ◇   band25 △

TERRA NIR FPA 1/m1, mirror side 1

band 1 +   band 2 ✳   band13 ◇   band14 □
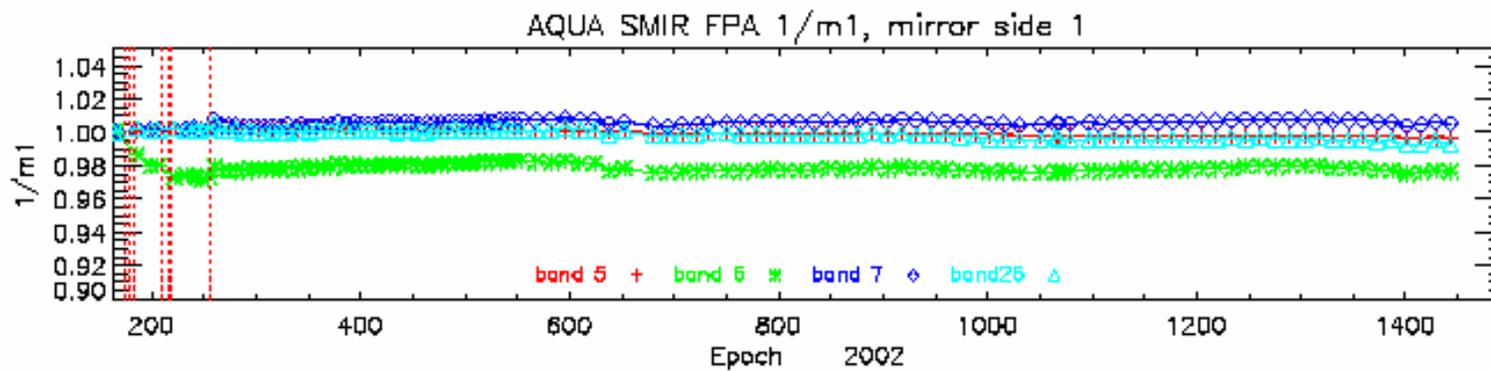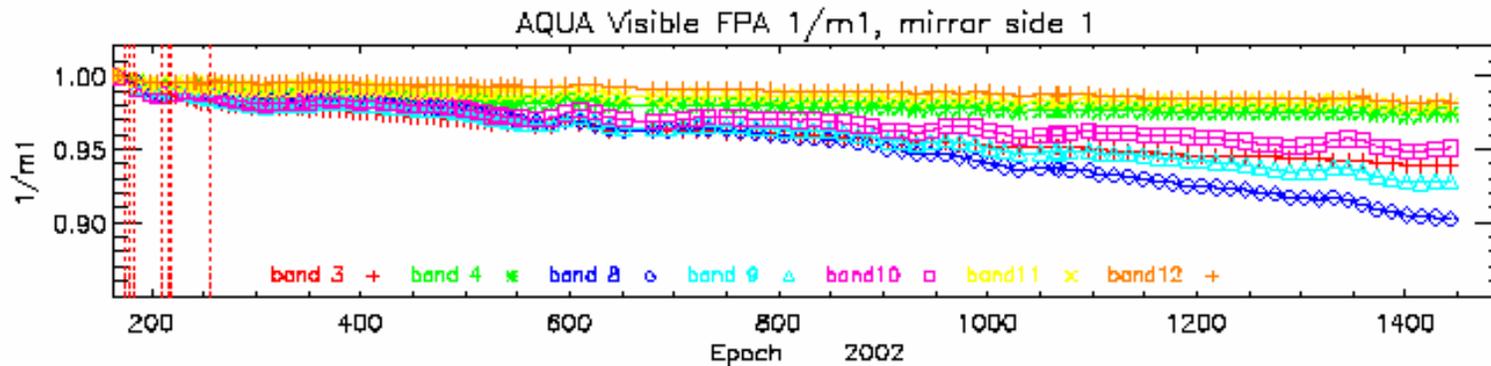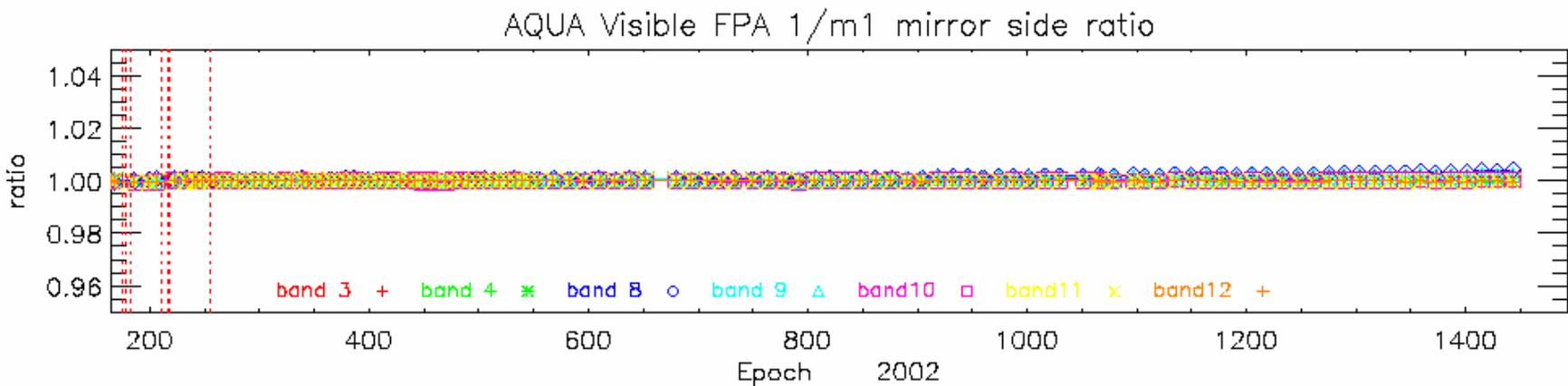band15 +   band16 ✳   band17 ◇   band18 △   band19 □

MODIS RSB Response Trending

MODIS RSB Response Trending

TERRA Visible FPA 1/m1 mirror side ratio

AQUA Visible FPA 1/m1 mirror side ratio
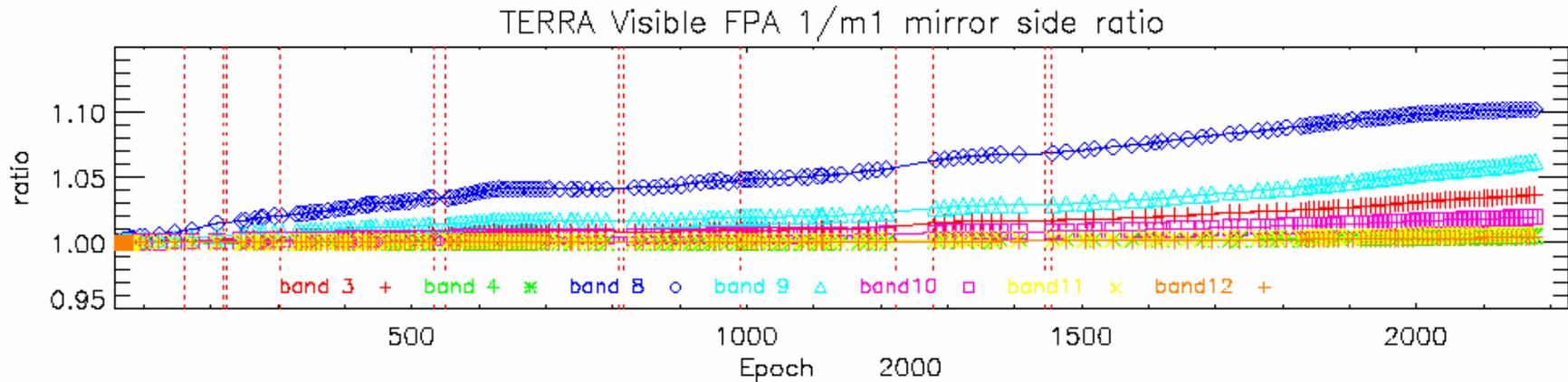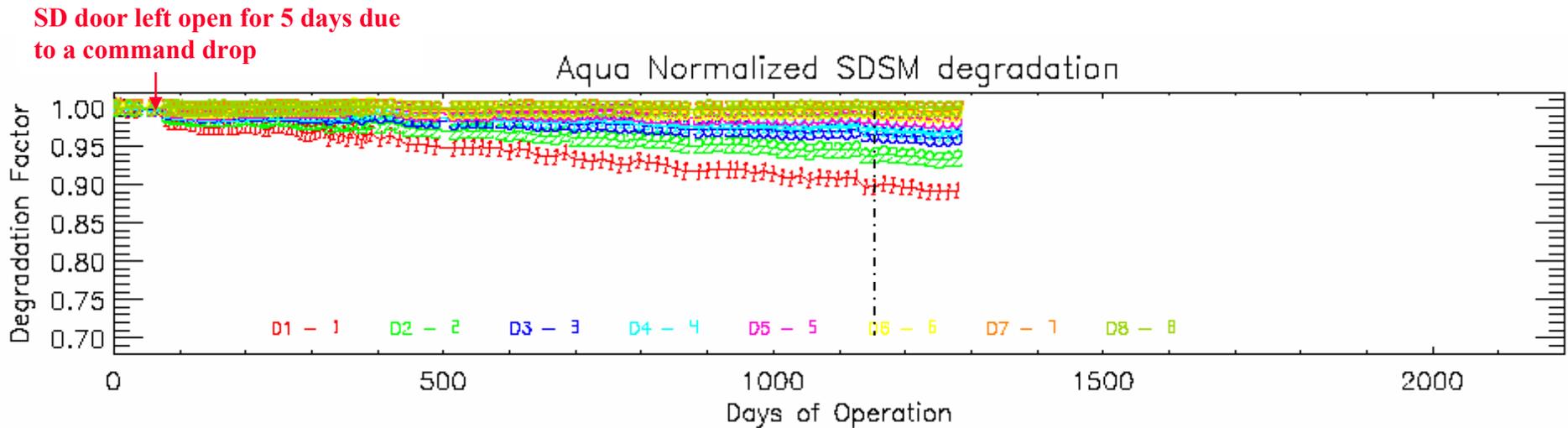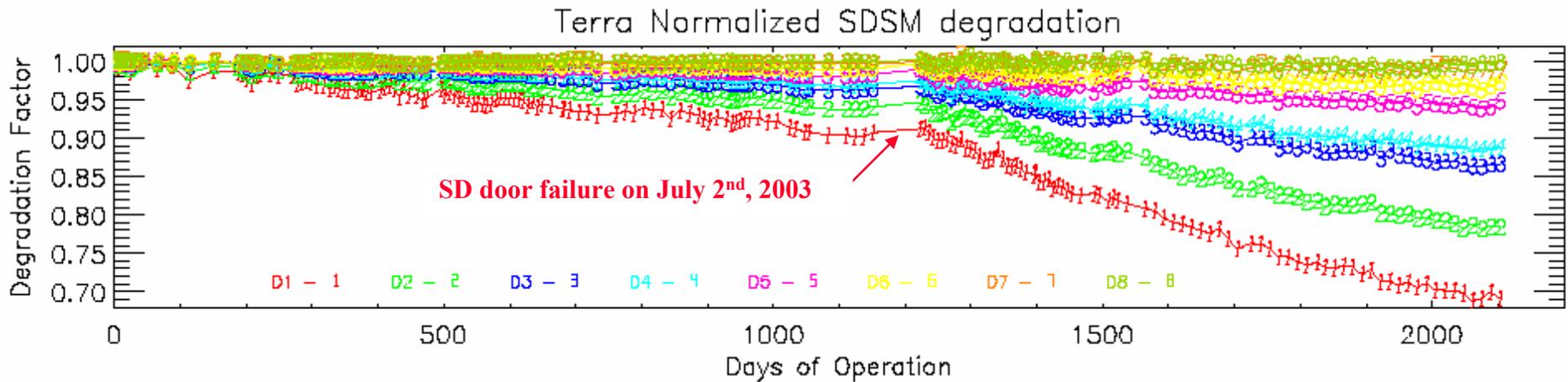
Mirror side difference in Aqua MODIS is extremely small

MODIS SD Degradation Trending

Terra Normalized SDSM degradation

SD door failure on July 2nd, 2003

SD door left open for 5 days due to a command drop
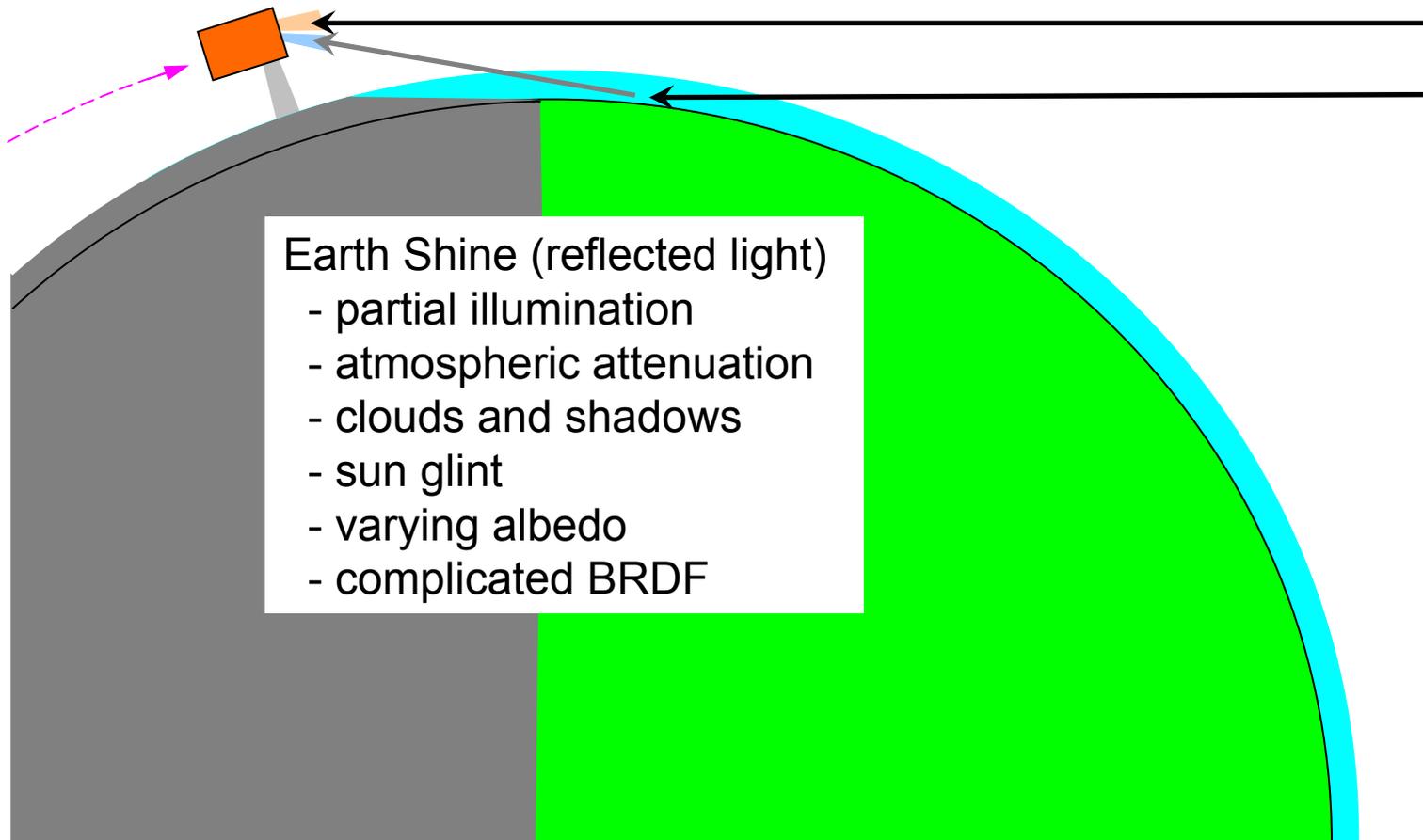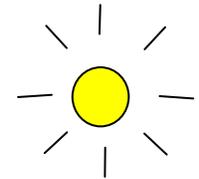
Aqua Normalized SDSM degradation
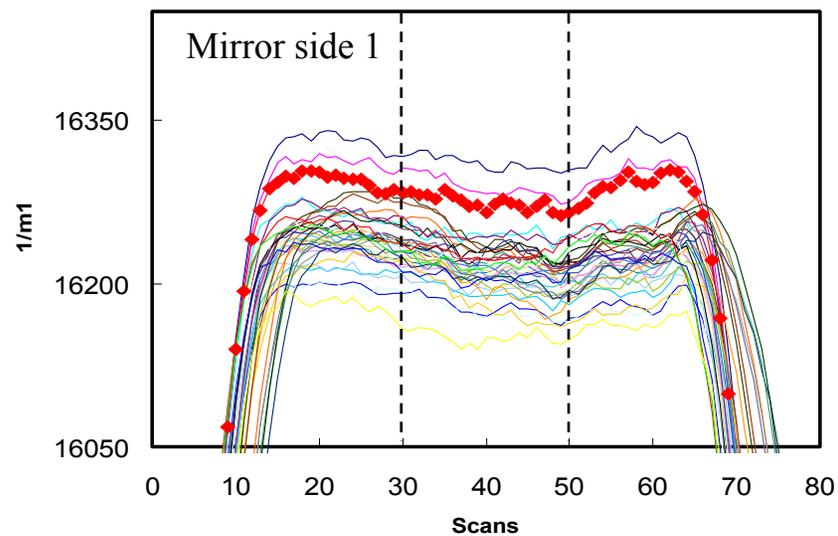
Similar SD degradation in Terra and Aqua MODIS
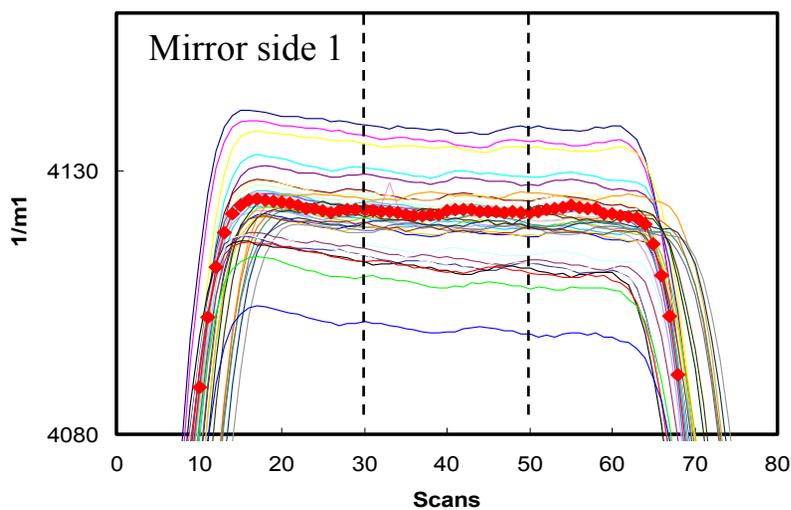
Simplified Solar Diffuser Geometry

Direct Light
- full illumination

Earth Shine (reflected light)
- partial illumination
- atmospheric attenuation
- clouds and shadows
- sun glint
- varying albedo
- complicated BRDF

Earthshine Impacts on RSB Calibration

Terra band 2

~0.4%

Terra band 16

~0.4%

Mirror side 1

Mirror side 1

SD Screen used for band 16

Earthshine Impacts on RSB Calibration

Terra band 3

~0.4%

Terra band 9

~0.8%

Mirror side 1

Mirror side 1
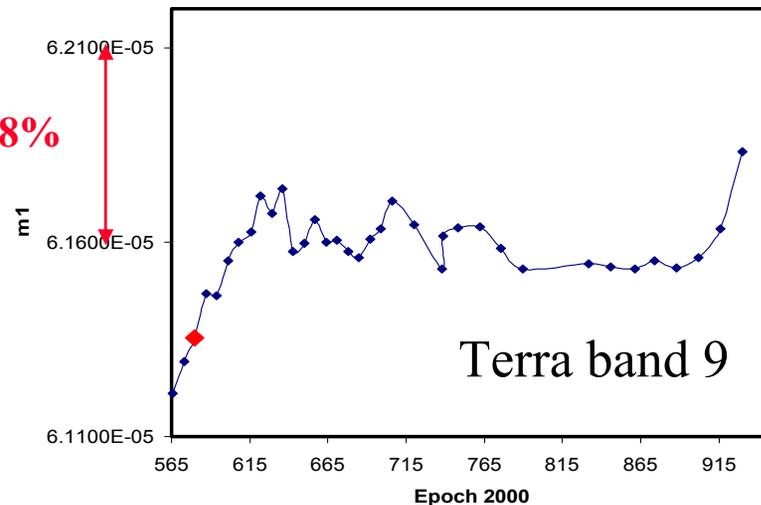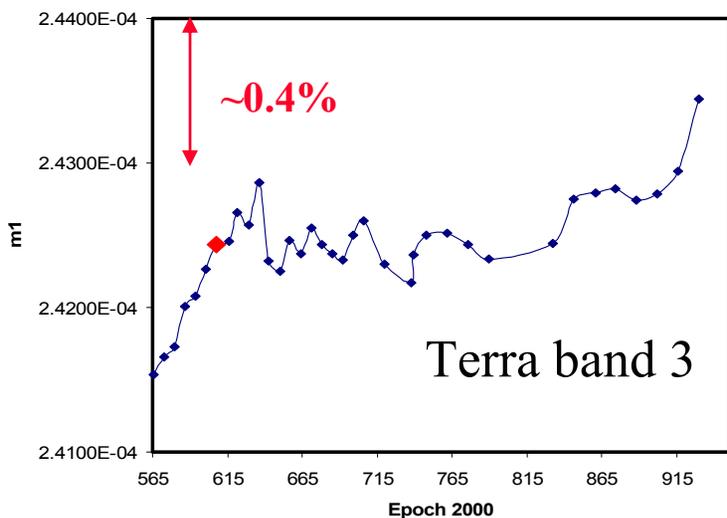
SD Screen used for band 9

Earthshine Impacts on Terra Orbit m1s

Terra Band 16 m1 average
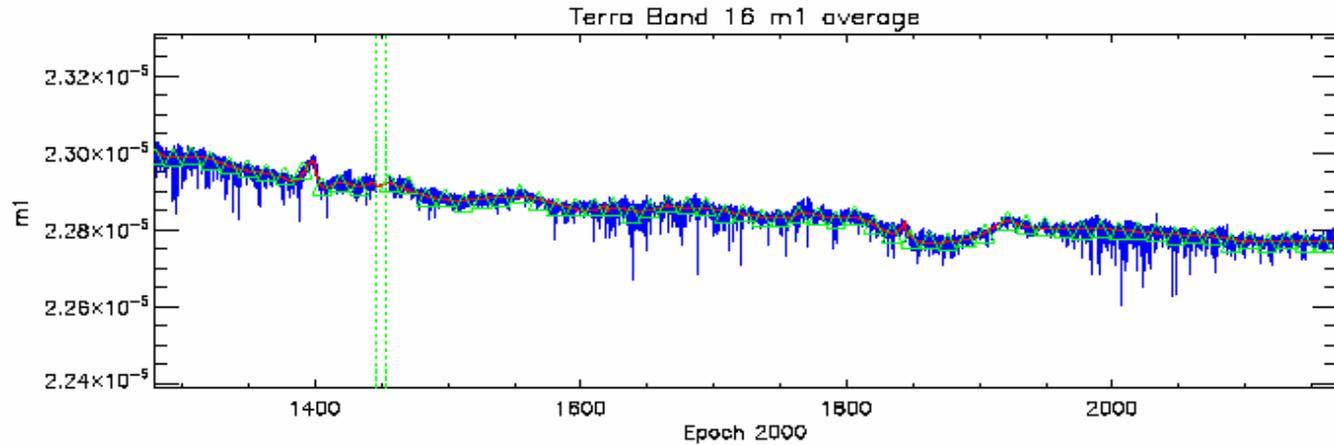
residue from fitted trending
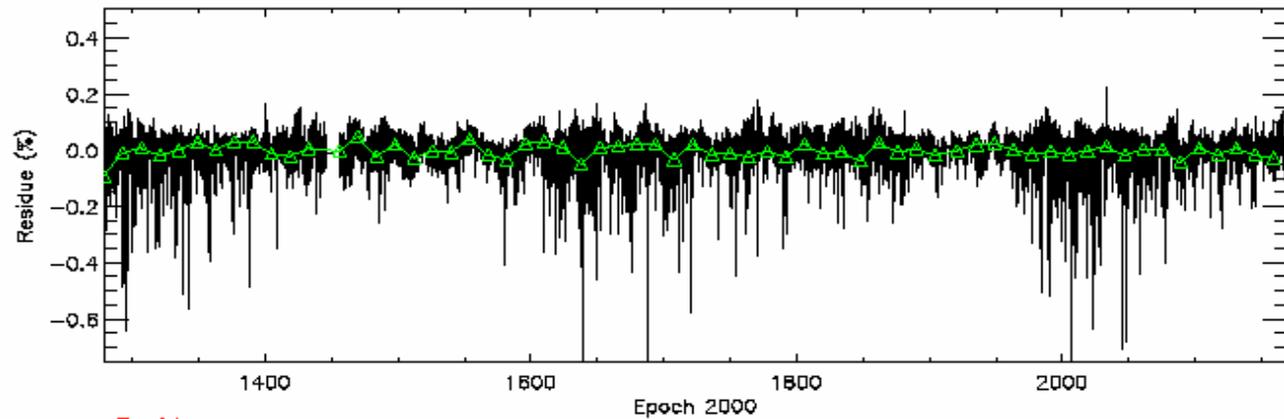
Residue							
(−1.0, −0.5)	(−0.5, −0.3)	(−0.3, −0.1)	(−0.1, 0.0)	(0.0, 0.1)	(0.1, 0.3)	(0.3, 0.5)	(0.5, 1.0)
0.0948%	0.3553%	3.3165%	40.2085%	54.8642%	1.1608%	0.0000%	0.0000%

Earthshine impact from SD aperture door is observed.
The variation of m1 due to Earthshine is reduced substantially in the MODIS L1B LUTs by using averaged m1 (green triangle).

Methods to Reduce Earthshine Impacts

Terra MODIS B2
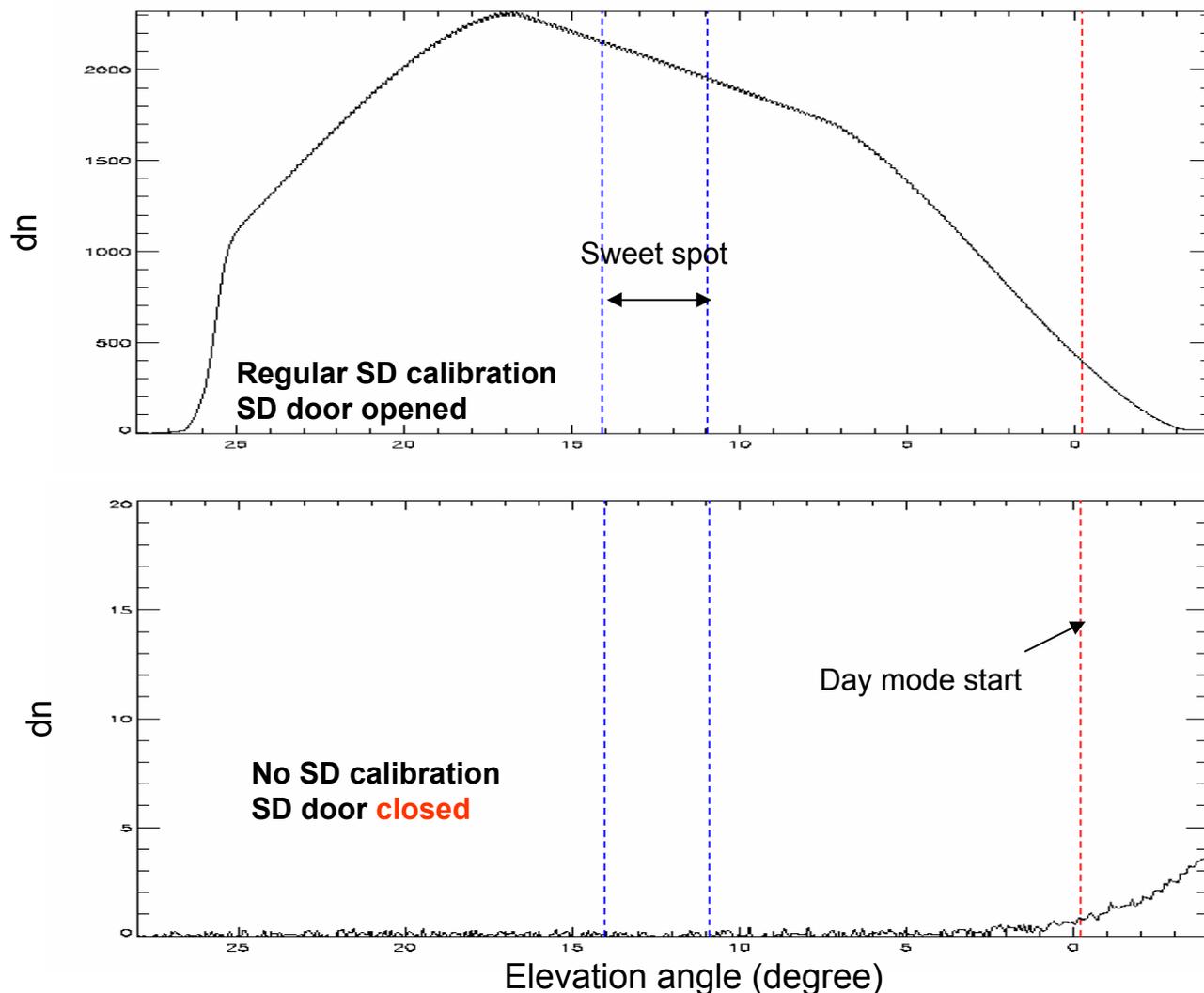
- Regular: Average of 40 scans centered at elevation angle 12.5

- Method A: 40 scans used with 20 scans shift ahead

- Method B: 20 scans used with 20 scans shift ahead

Impact of Earthshine from nadir aperture door is extremely small <0.1%

Improvements on Terra m1

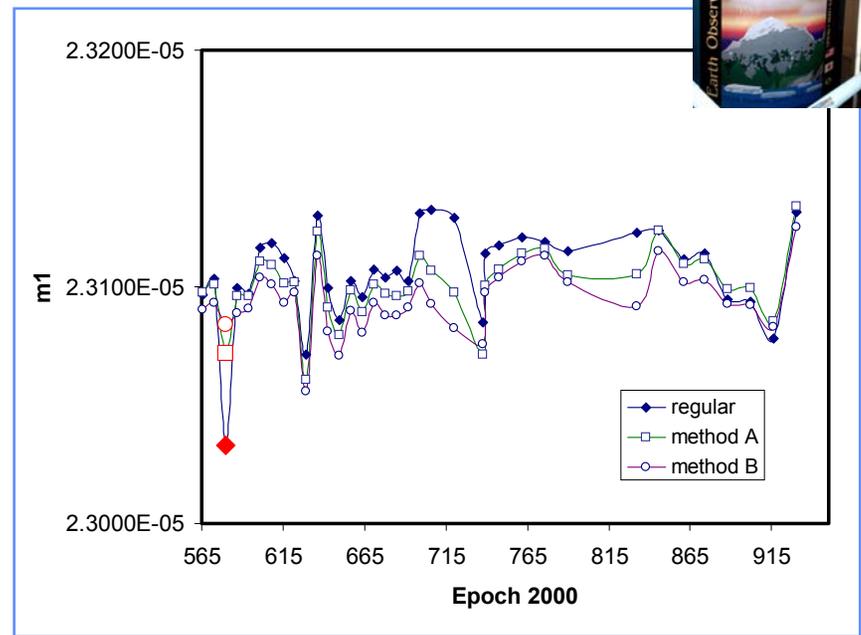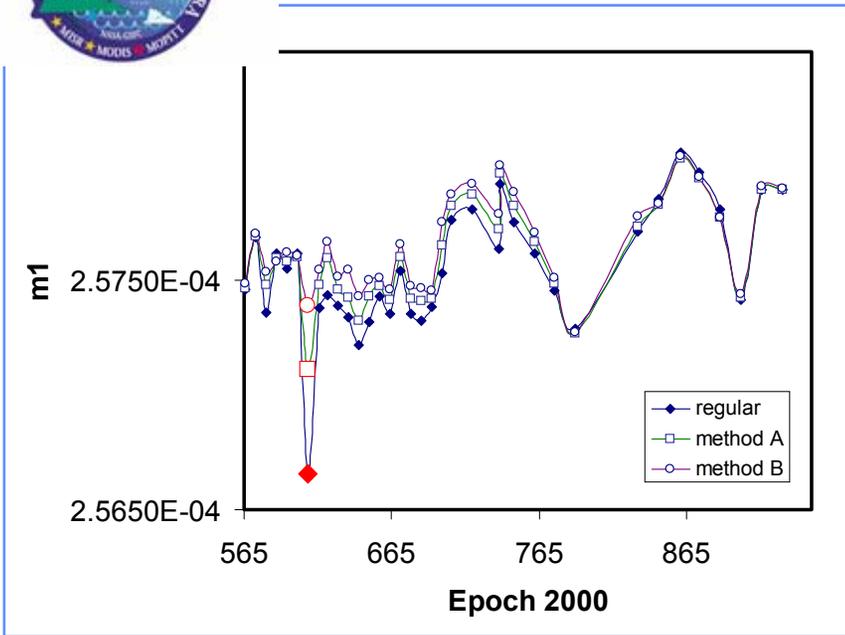| Regular				Method A			Method B		
	<-0.5%	**<-0.3%**	**>-0.3%**	**<-0.5%**	**<-0.3%**	**>-0.3%**	**<-0.5%**	**<-0.3%**	**>-0.3%**
Band 2	0.08	0.49	99.51	0.04	0.32	99.68	0.05	0.29	99.71
Band 16	0.09	0.45	99.55	0.04	0.30	99.70	0.05	0.28	99.72

Residual less than –0.5%: the improvements is about 50%
Residual less than –0.3%: the improvements is more than 30%

RSB Performance Summary

- RSB calibration performed well according to the design specifications
  - **Terra** (6 years !) and **Aqua** (3.5 years)
  - Noticeable wavelength dependent degradation observed on both instruments, mirror side dependent degradation also observed in Terra MODIS
  - Solar Diffuser degradation tracked by SDSM, both Terra and Aqua show consistent results

- Constant efforts made to maintain and improve RSB calibration and characterization
  - Continues working closely with science groups for key RSB issues
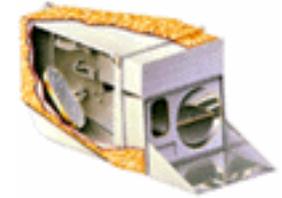 - Earthshine impacts investigations

Production Changes to
MOD_PR02 TERRA L1B Code

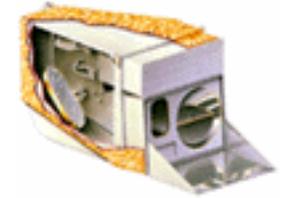| PGE02 Version	Forward Process Begin	Code Changes
V2.3.2_Terra	3/17/2000 (077 2000) 00:00	• **Pre-Launch calibration** (SMWIR ltwk/Vdet = 79/190).
V2.4.2_Terra	6/19/2000 (171 2000) 00:00	• Corrected indexing bug affecting emissive bands (this appeared in the product as if something was wrong with RVS). • Corrected bug for determing when the moon is in the SVP (sign error) • **Maximum number of scans raised to 208** (consistent with L1A code)
V2.4.3_Terra	8/18/2000 (231 2000) 14:00	• Corrected bug in emissive bands preprocessing for PC bands X-talk. • Interpolation of scaled integers for non-functional (dead) detectors. • **Time-dependent LUTs architecture.**
V2.4.4_Terra	10/13/2000 (287 2000) 19:55	• **New emissive band algorithm to compute <DNsv> with moon in SVP.** • Corrected bug in emissive bands preprocessing for the 40 scans preceding or following a sector rotation or Ecal. • Corrected indexing bug in SWIR OOB correction (switch remained OFF). • Several other bug fixes affecting metadata.
V2.5.4_Terra	11/23/2000 (328 2000) 15:55	• **Aqua compatible code and metadata** • Removed obsolete metadata • **New SWIR OOB algorithm & LUTs (for B-side only)**
V2.5.5_Terra	02/13/2001 (044 2001) 13:55	• **Misregistration of aggregated images corrected.** • **Detector average of Esun used for computation of band-dependent radiance_scales.**

Production Changes to
MOD_PR02 TERRA L1B Code
(continued)

PGE02 Version	Forward Process Begin	Code Changes
V3.0.0_Terra	05/24/2001 (144 2001) 00:00	• **Piecewise linear LUT capability** added. • **Reflective solar bands (RSBs)** now **check Space View subtracted values for saturation** against lookup table. • For **SWIR bands,** when the moon is in the Space view port, method of **computing average background DN** same as that used for emissive bands.
V3.0.1_Terra	2/25/2002 (056 2002) 00:00	• **Production of 250m and 500m reso-lution night data may be turned off.** • Various code upgrades/bug fixes.
V4.1.2_Terra*	01/30/2003 (030 2003) 01:55	• **Band 26 Correction** using aggregated Band 5 radiances inserted; turned **ON** • **RVS correction** changed to piecewise linear. • New flag TEB_B1_NOT_CALCULATED added. • Various code upgrades/bug fixes. • Metadata field "ProcessingEnvinronment" is filled in from a call to "uname" from within the L1B code • R* LUT deleted • New OBC MCF files • RSB cal. coefficients reworked in LUTs
V4.2.0_Terra	08/22/2003 (234 2003) 02:00	• **SWIR out-of-band correction "sending" band** changed to value determined by LUT • Earth-Sun distance calculation corrected • NAD open/closed determination changed • Nominal platform height corrected • ANSI-C compliance

Production Changes to MOD_PR02 TERRA L1B Code (continued)

PGE02 Version	Forward Process Begin	Code Changes
V4.3.0_Terra	12/22/2003 (356 2003) 22:35	• **Maneuver flag** changed to key on spacecraft attitude
V5.0.6_Terra	03/07/2005 (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**

* PGE02 V4.0.7 and PGE02 V4.0.9 were delivered to GDAAC but not used for forward process.
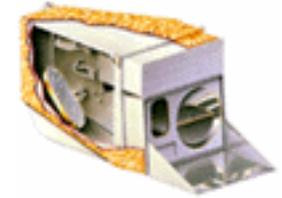
Production Changes to MOD_PR02 TERRA L1B LUTs

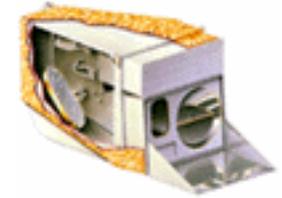| PGE02 Version	LUT Patch Version	LUT Changes
V2.3.2_Terra	3	• Emissive bands calibration and uncertainty LUTs • Reflective bands calibration and uncertainty LUTs • Uncertainty index scaling factors • Detector quality flag • "St. Patrick's Day Update" • LUTs derived from on-orbit data. SMWIR ltwk/Vdet = 110/226.
V2.4.2_Terra	0	• Scientifically same as LUTs v2.3.2.3
V2.4.3_Terra	1	• PC bands X-talk LUTs (from day 084 moon observation) • Emissive bands calibration LUTs (from day 102 BB cool-down observation) • RVS (for mirror side 2 only, from day 118 observation of NAD closed) • L_max for bands 31 and 32 increased • Reflective bands calibration LUTs (from day 171 solar diffuser observation) • SWIR OOB leak correction turned OFF • Detector quality flag – some detectors flagged as dead

Production Changes to
MOD_PR02 TERRA L1B LUTs
(continued)

PGE02 Version	LUT Patch Version	LUT Changes
V2.4.4_Terra	0, 1, 2	• **Switch to B-side.** Final values for SMWIR ltwk/Vdet = 79/110 • First implementation of time-dependent LUTs (A-side/B-side) • A-side calibration LUTs remained the same as before. • B-side emissive bands calibration LUTs (from day 305/306 BB observations) • Some B-side emissive bands uncertainty coefficient LUTs • L_max for several bands increased (both A and B side) • B-side reflective bands calibration LUTs (from day 305 solar diffuser observation) • B-side reflective bands uncertainty coefficient LUTs • Detector quality flag – all B-side detectors are functional. • B-side only: SWIR OOB correction switch turned ON and new SWIR LUTs (aimed at improving the first sub-sample of 500m bands)
V2.5.4_Terra	0	• New SWIR OOB LUTs (for B-side only)
V2.5.5_Terra	1, 2	• Added Reflective LUT "E_sun_over_pi"; deleted Emissive LUT "Number of overlap scans for temperatures" (No science content affected). • 2 detectors marked as non-functioning as of day 2001/019. • Time dependent LUT table pieces added to cover day 2000/063.

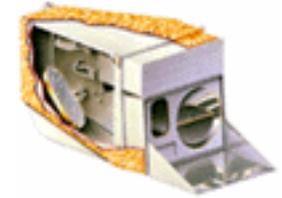# Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

PGE02 Version	LUT Patch Version	LUT Changes
V3.0.0_Terra	1 (Superseded) , 2, 3, 4, 5 (For reprocess only), 6, 7	• **RSB LUT update for Band 5 gain change (day 212/2001):** • **Time stamped table pieces added to RSB calibration tables**. • **Update for SWIR OOB correction on "A" side (after day 183/2001):** • New SWIR OOB correction switch turned ON. • New SWIR OOB correction table piece added. • RSB calibration table pieces reworked for SWIR OOB correction. • **Update to Detector Quality Flags after return to "A" side electronics:** • Detector quality flags QA table: Out-of-family gain flag set for 2 detectors; noisy detector flag set for one detector as of day 183 2001.
V3.0.1_Terra	0, 1	• Slope of fit for Band 3 calibration coefficients adjusted.
V4.1.2_Terra *	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	• New RSB LUT calibration coefficients • Pre-launch SWIR corr. switch "OFF" • R* LUT deleted • RSB cal. coefficients reworked in LUTs • Detector quality flags QA table: noisy detector flag set for one detector as of day 183 2001 and for another detector as of day 086 2003. • Continuous Reflective Calibration Coefficient updates

* For V4.0.7_Terra, LUT V0 delivered but not used and LUT V1 used for reprocess only;
   For V4.0.9_Terra, LUT V0 used for reprocess only.

Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

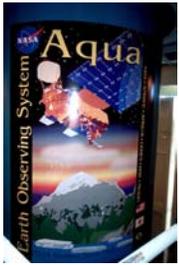| PGE02 Version	LUT Patch Version	LUT Changes
V4.2.0_Terra	3, 4, 5, 6, 7, 8, 9	• **SWIR out-of-band correction "sending" band** changed to value determined by LUT • Name change for the three LUTs related to the Band 5 to Band 26 correction • Continuous Reflective Calibration Coefficient updates •
V4.3.0_Terra	1, 2, 3, 4, 5, 6, 7, 8, 9, 11*, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36	• LUTs updated from V4.2.0.8 • **Attitude limit LUTs added for maneuver flagging** as of Version 1 • Updates on coefficient for RVS computation • Updates on the coefficients for calculating a0 and a2, and on the value of b1 for each Band 21 detectors, derived using the BB warm-up data set from days 007- 008, 2004. • Detector quality flags QA table: Out-of-family gain" / "Noisy Detector" flag set for two detectors of Band 28 and one detector of Band 29. • Updated the SWIR bands correction coefficient. • Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, RVS_EefSB)

*LUT V4.3.0.10 is a special version for U. of Wisconsin only (not shown here).
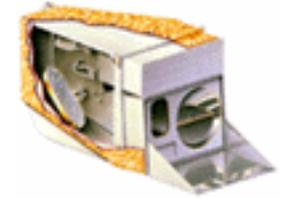
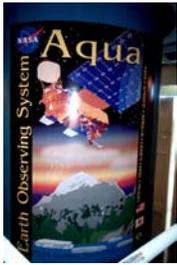| PGE02 Version	LUT Patch Version	LUT Changes
V5.0.6_Terra	1, 2 , 3, 4, 5, 6, 7, 8, 9, 10	• Updates on the coefficients for calculating a0 and a2, and on the value of b1 for each Band 21 detectors using the newly developed TEB RVS from Deep Space Maneuver. A new dimension of Mirror Side is added to the band_21_b1 LUT to separate the coefficients of the two mirror sides for Band 21. • Added a new LUT to enable the ability of determine the SWIR out-of-band correction "sending" detectors from the "sending" band. • Detector quality flags QA table: newly revised flags cover the entire time period since the launch. • Updated dn_sat_ev values for presaturating bands. Those which do not exhibit any presaturation are set to 4095 to remove any dn_sat_ev cutoff to make more valid data available. • Updated the SWIR bands correction coefficient. • Detector quality flags QA table: "Noisy Detector" flag set for one detector of Band 28. • Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, RVS_EefSB)

Production Changes to MOD_PR02 AQUA L1B Code

PGE02 Version	Forward Process Begin	Code Changes
V3.1.0_Aqua	06/07/2002 (158 2002) 18:10	• **Blackbody warmup saturation** corr. • **Aqua temp. conversion** coefficients. • New flag TEB_B1_NOT_CALCULATED added.
V4.1.1_Aqua	10/31/2002 (304 2002) 00:15	• RVS corr. changed to piece-wise linear. • Various code upgrades/bug fixes.
V4.1.3_Aqua	01/22/2003 (022 2003) 09:55	**No Science Changes to the Code** • R* LUT deleted • New OBC MCF files
V4.2.1_Aqua	08/21/2003 (233 2003) 12:00	• **SWIR out-of-band correction "sending" band** changed to value determined by LUT • **Destriping of Band 26** using aggregated Band 5 data added • Earth-Sun distance calc. corrected • NAD open/closed determination changed • Platform height corrected • ANSI-C compliance
V4.3.1_Aqua	01/18/2004 (18 2004) 00:10	• **Used for first reprocessing effort, Collection 4** • **Maneuver flag** changed to key on spacecraft attitude
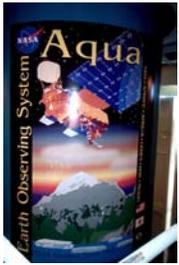
Production Changes to MOD_PR02 AQUA L1B Code (continued)

PGE02 Version	Forward Process Begin	Code Changes
V5.0.7_Aqua	07/03/2005 (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**

Production Changes to MOD_PR02 AQUA L1B LUTs

PGE02 Version	LUT Patch Version	LUT Changes
V3.1.0_Aqua	0, 1, 2, 3	• **Pre-launch LUTs** inserted. • **Several LUTs updated after more Pre-launch analysis** • **New RSB and TEB calibration coefficient LUTs** • **New BB temp. saturation limits** • **Detector quality flags changed** • **SWIR correction switch ON**
V4.1.1_Aqua	0,1	• **LUTs updated from V3.1.0.3** • **New RSB calibration coefficient LUTs using SD degradation** • **Band 21 b1 table piece added** • **Detector quality flags changed**
V4.1.3_Aqua	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	• **LUTs updated from V4.1.1.1** • **R* LUT deleted** • **Continuous Reflective Calibration Coefficient updates** • **Band 21, Detector 9 (product order) changed to "noisy" as of Version 3**

Production Changes to MOD_PR02 AQUA L1B LUTs (continued)

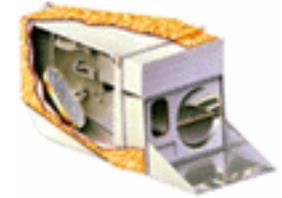| PGE02 Version	LUT Patch Version	LUT Changes
V4.2.1_Aqua	4, 5, 6, 7, 8	• LUTs updated from V4.2.1.3, which is parallel to V4.1.3.10 • **SWIR correction sending band changed to Band 28 before 2003104, Band 25 after** as of Version 4 • Continuous Reflective Calibration Coefficient updates • **LUTs added for Band 26 destriping** using aggregated Band 5 data as of V. 4

V4.3.1_Aqua	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23	• LUTs updated from V4.2.1.8
		• **Reflective Calibration Coefficients reworked for reprocessing** as of Version 1
		 • Improved SD sun angles used
		 • BRF and vignetting as a function of SD zenith and azimuth used
		 • Temperature using Kinst used
		 • Non-SWIR bands fitted with smooth function
		 • SWIR bands
		  • Step functions before 2002255, Linear functions thereafter
		  • **SWIR correction sending band changed to Band 25** for entire mission
		• **Attitude limit LUTs added for maneuver flagging** as of Version 1
		• Updates on coefficient for RVS computation and value of EV pixel dn to treat as saturated
		• Detector quality flags QA table: "Noisy Detector" flag set for one detector of Band 27.
		• Updated the SWIR bands correction coefficient.
		• Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, and/or RVS_RefSB)

Production Changes to MOD_PR02 AQUA L1B LUTs (continued)

PGE02 Version	LUT Patch Version	LUT Changes
V5.0.7_Aqua	1(Superseded) , 2, 3, 4, 5, 6, 7	• Updates on the coefficients for calculating a0 and a2, and on the value of b1 for each Band 21 detectors. A new dimension of Mirror Side is added to the band_21_b1 LUT to separate the coefficients of the two mirror sides for Band 21. • Added a new LUT to enable the ability of determine the SWIR out-of-band correction "sending" detectors from the "sending" band. • Detector quality flags QA table: newly revised flags cover the entire time period since the launch. • Updated dn_sat_ev values for presaturating bands. Those which do not exhibit any presaturation are set to 4095 to remove any dn_sat_ev cutoff to make more valid data available. • Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, and/or RVS_RefSB)

Challenging Issues and Future Work

- ➢ TEB Calibration
  - MSCN impact on PC bands 33-36 (no easy solution)
  - Calibration coefficients (a0/a2) update strategy (TBR)
  - Improvement of B21 calibration (TBR)
  - Study of calibration long-term drifting

- ➢ RSB Calibration
  - Continuing efforts for SWIR bands calibration
  - Overall calibration improvements (considering on-orbit detector dependent BRF and VF) for detector to detector difference (especially VIS bands)
  - Study SDSM sun-view screen and SD screen impact on the SD degradation monitoring
  - Evaluate alternative approaches for tracking RSB RVS (primarily for bands 8,9,3,10) (High Priority)

Challenging Issues and Future Work

- ➢ Others
  - – Noisy detectors
  - – Implement earthshine impact reduction approach in RSB calibration
  - – Calibration difference among detectors
    - • Difference may vary with AOI
  - – Continue efforts for calibration uncertainty assessment (latest version reported in SPIE 2005 Xiong et al.)
    - • Configuration dependent, time dependent, AOI dependent
  - – Support polarization modeling efforts for future sensors
  - – Resolve issues related to Aqua OOB RSR (work with SBRS)
    - • Review SBRS new normalization approach and provide independent derivation

Summary

- Instruments have performed well and are stable
  - Terra (6+ years) and Aqua (3.5+ years); Aqua better than Terra in a number of areas (except B6 and BBR problems)
  - Noticeable optics degradation identified and corrected in both sensors' response
- Constant efforts must be made to maintain instrument calibration and data quality
  - Combination of using on-board calibrators and other approaches
  - Input and support from science groups (representatives), instrument vendor (SBRS), and other expertise
  - Consideration of sensor aging impact
- Useful Information (MCST webpage)
  - Online documents: L1B user guide, product data dictionary, and ATBD
  - L1B code and LUTs change history, workshop materials, and publications
    - *http://www.mcst.ssai.biz/mcstweb/index.html*
- Lessons learned for future sensors

Backup Charts

MODIS Key Specifications

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]	Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NEΔT(K)[4]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128	Surface/Cloud Temperature	20	3.660 - 3.840	0.45 (300K)	0.05
	2	841 - 876	24.7	201		21	3.929 - 3.989	2.38 (335K)	0.2
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243		22	3.929 - 3.989	0.67 (300K)	0.07
	4	545 - 565	29	228		23	4.020 - 4.080	0.79 (300K)	0.07
	5	1230 - 1250	5.4	74	Atmospheric Temperature	24	4.433 - 4.498	0.17 (250K)	0.25
	6	1628 - 1652	7.3	275		25	4.482 - 4.549	0.59 (275K)	0.25
	7	2105 - 2155	1	110	Cirrus Clouds Water Vapor	26	1.360 - 1.390	6	150 [3]
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880		27	6.535 - 6.895	1.16 (240K)	0.25
	9	438 - 448	41.9	838		28	7.175 - 7.475	2.18 (250K)	0.25
	10	483 - 493	32.1	802	Cloud Properties	29	8.400 - 8.700	9.58 (300K)	0.05
	11	526 - 536	27.9	754	Ozone	30	9.580 - 9.880	3.69 (250K)	0.25
	12	546 - 556	21	750	Surface/Cloud Temperature	31	10.780 - 11.280	9.55 (300K)	0.05
	13	662 - 672	9.5	910		32	11.770 - 12.270	8.94 (300K)	0.05
	14	673 - 683	8.7	1087	Cloud Top Altitude	33	13.185 - 13.485	4.52 (260K)	0.25
	15	743 - 753	10.2	586		34	13.485 - 13.785	3.76 (250K)	0.25
	16	862 - 877	6.2	516		35	13.785 - 14.085	3.11 (240K)	0.25
Atmospheric Water Vapor	17	890 - 920	10	167		36	14.085 - 14.385	2.08 (220K)	0.35
	18	931 - 941	3.6	57					
	19	915 - 965	15	250					

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in μm

[2] Spectral Radiance values are (W/m^2-μm-sr)

[3] SNR = Signal-to-noise ratio

[4] NEΔT = Noise-equivalent temperature difference

MODIS Focal Plane Assemblies (FPA)
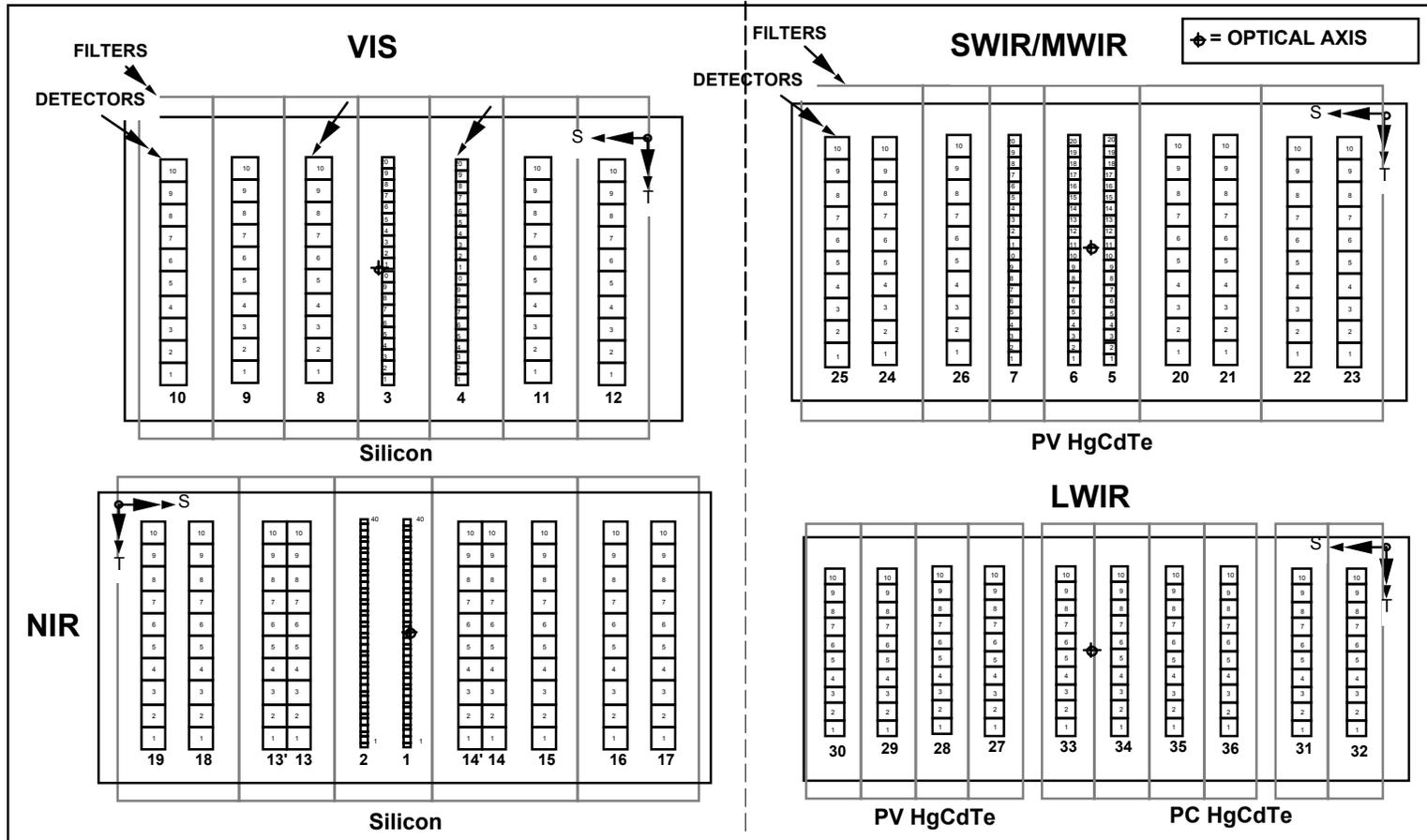
Instrument FPA Main Frame Temperature   Cold FPAs: (80. 83, 85k)

S: scan direction; T: track direction
B13 and B14 have 2 columns of detectors for TDI high and low gain output

Terra MODIS Operational Configurations

Date	Events	Description
Dec 18, 1999	Launch	Launched successfully
Feb 13, 2000	Science Mode	MODIS started science mode on A-side
Feb 24, 2000	Nadir Door Open	Terra MODIS First Light
June 2000	CFPA Lost Control	Ice began to cover radiative cooler surface
Aug 5, 2000	Formatter Anomaly	MODIS entered standby mode then safe mode
Aug 8, 2000	Outgas	Turned on outgas heater for two days (Back to science mode on Aug 19)
Oct 30, 2000	B-side Electronics	Transitioned to science mode on B-side
Jun 15, 2001	PS2 Anomaly	Powered supply 2 (B-side) off passing SAA
Jul 2, 2001	A-side Electronics	Returned to science mode on A-side with PS1
Mar 19, 2002	S/C Safe Hold	Anomaly during inclination maneuver (Back to science mode on Mar 23)
Sep 17, 2002	Formatter B	On A-side but cross-strapped to Formatter B
May 6, 2003	SD Door Failure	Set the SD open with screen down on July 2
May 18, 2003	UART Reset	UART_RESET count increased from 119 to 122
Sep 24, 2003	SSR Anomaly	Science recording shuts down and re-enabled (Lost 2 SS; Assigned 1 SS to MODIS from MISR on Sep 30; total 35 SS for MODIS)
Oct 14, 2003	SSR Anomaly	Another 2 SS failed in SSR PWA (Assigned 1 SS to MODIS from MISR on Oct 20; total 34 SS for MODIS)
Nov 30, 2003	Formatter Anomaly	SFE anomaly Sync errors over SAA
Dec 16, 2003	ACE-B Anomaly	Anomaly to Safe Mode due to Attitude Control Electronics over SAA (Back to science mode on Dec 22; Nadir door opened on Dec 24)

Terra MODIS Operational Configurations

Date	Events	Description
Jan 15, 2004	SFE Recycled	SFE Side-A was recycled to fix DAS-1 errors for DB
Feb 18, 2004	SFE Anomaly	SFE autonomously shuts down while passing through the SAA (Back to science mode on Feb 19)
Apr 13, 2004	SRCA 20W Abnormal	Rad-mode (Apr 26) confirmed 10W lamp #2 failure ; Replaced by lamp #4 (May 25)
Sep 4, 2004	SSR Sync Error	Data was lost due to loss of Sync during SSR playback over SAA
Oct 18, 2004	UART Reset	UART_RESET count increased from 122 to 125
Dec 24, 2004	SFE Anomaly	Science Record was disabled due to SFE anomaly over SAA (Back to science mode on the same day)
Aug 26, 2005	SSR Anomaly	SSR PWA failure of 2 SS (MODIS SS down to 32; SSR recycling recommended !)
Sep 6, 2005	SRCA Ops Change	Starting Const Current Mode (from Const Radiance); Activity freq reduced
Sep 23, 2005	SFE Anomaly	BIT failure turning SSR SFE-A off (SFE back on the same day) over SAA

MCST IOT document: MODIS Instrument Operations
MCST WEB: Operation configuration changes and instrument reset events impact on science data

Aqua MODIS Operational Configurations

Same Configuration Used for the Entire Mission

Date	Events	Description
May 4, 2002	Launch	Launched successfully
June 7, 2002	Science Mode	MODIS started science mode on B-side (SMIR Itwk/Vdet = 102/184)
June 24, 2002	Nadir Door Open	Aqua MODIS First Light
June 27, 2002	S/C Safe Hold	Aqua spacecraft Single Event Upset (SEU); SMIR Itwk/Vdet was left at 102/136 (Returned to 102/184 on July 8); MODIS returned to science mode on July 2
July 29, 2002	S/C Safe Hold	S/C ground pointing anomaly; MODIS science mode resumed on Aug 6
Aug 9-14, 2002	SD Door Open	SDSM calibration command dropped
Sep 12, 2002	S/C Safe Hold	Error in lower fidelity ephemeris; Recovered to Fine Pointing Mode same day
Jan 20, 2003	SRCA 20W Abnormal	Rad-mode (Mar 17) confirmed 10W lamp #2 bad; Replaced by lamp #4 (Apr 14)
May 17, 2005	SRCA 20W Anomaly	20W lamps shutdown during Spat-mode; Test (Jun 28) confirmed 10W lamp #3 broken; Two 10W lamps left (#1 & #4) w/o 30W config for future calibration
Oct 10, 2005	SRCA Ops Change	Starting Const Current Mode (from Const Rad); Activity freq reduced

MCST IOT document: MODIS Instrument Operations
MCST WEB: Operation configuration changes and instrument reset events impact on science data

MODIS Spatial/Spectral Performance Summary

Spectral – Center wavelength and band-width

1. MODIS RSB center wavelengths for both Terra and Aqua are very stable. The center wavelengths shifts are <0.5nm for most reflective solar bands.
2. Band-width is calculated from SRCA recovered RSR profiles.
3. Band 2 is not available due to pre-launch and on-orbit operation difference.

Spatial – Band-to-band

1. The Band-to-band registration is within 0.2km specification for Terra except for few bands in along-track direction. It is out-of-specification for Aqua with mis-registration up to 0.4km between VIS/NIR and MWIR/LWIR FPAs. The Aqua mis-registration was identified pre-launch and has small change on-orbit.
2. Care must be taken when developing product using bands from the both cold and warm FPAs.

Useful References:

1. X. Xiong, N. Che, and W. Barnes, "Terra MODIS on-orbit spatial characterization and performance", Trans. IEEE, Vol. 43, pp.355-365, 2005
2. X. Xiong, N. Che, and W. Barnes, ""Terra MODIS on-orbit spectral characterization and performance", Accepted for Trans. IEEE
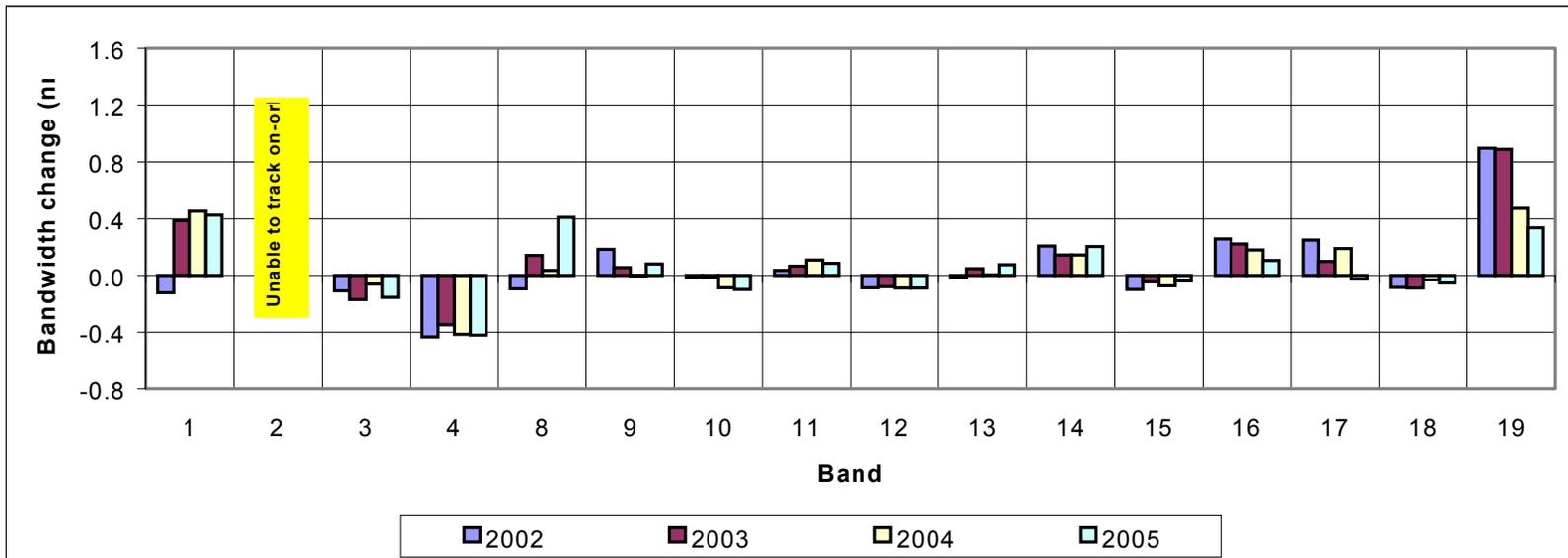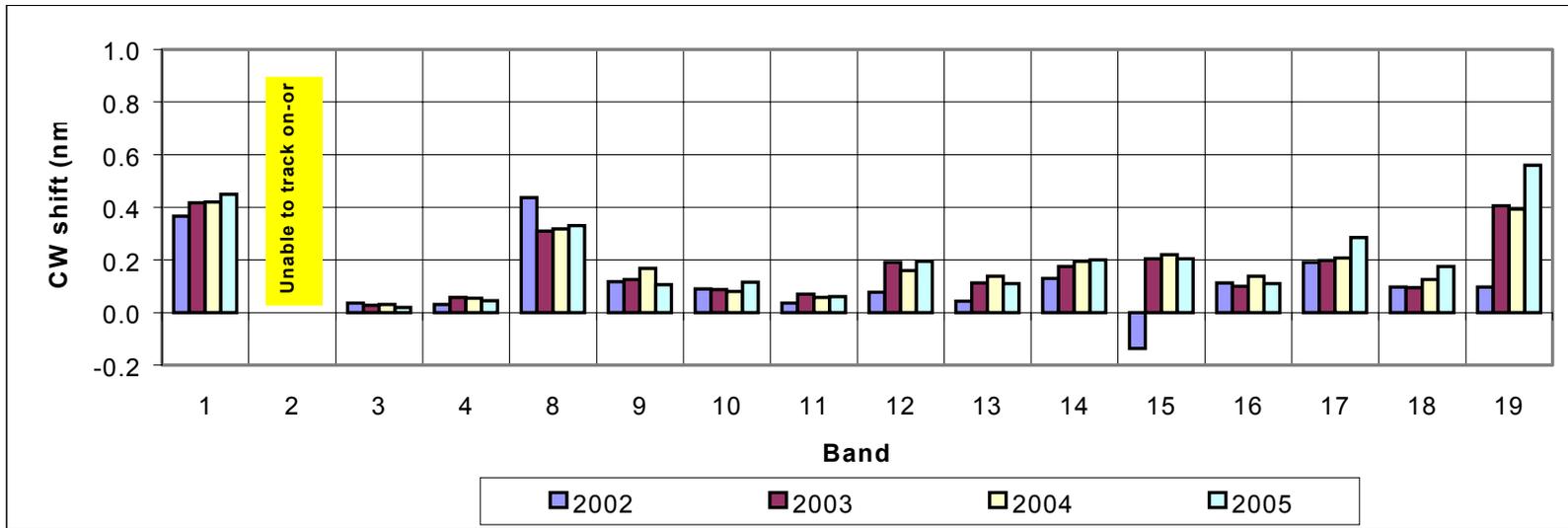
Terra MODIS Spectral Performance

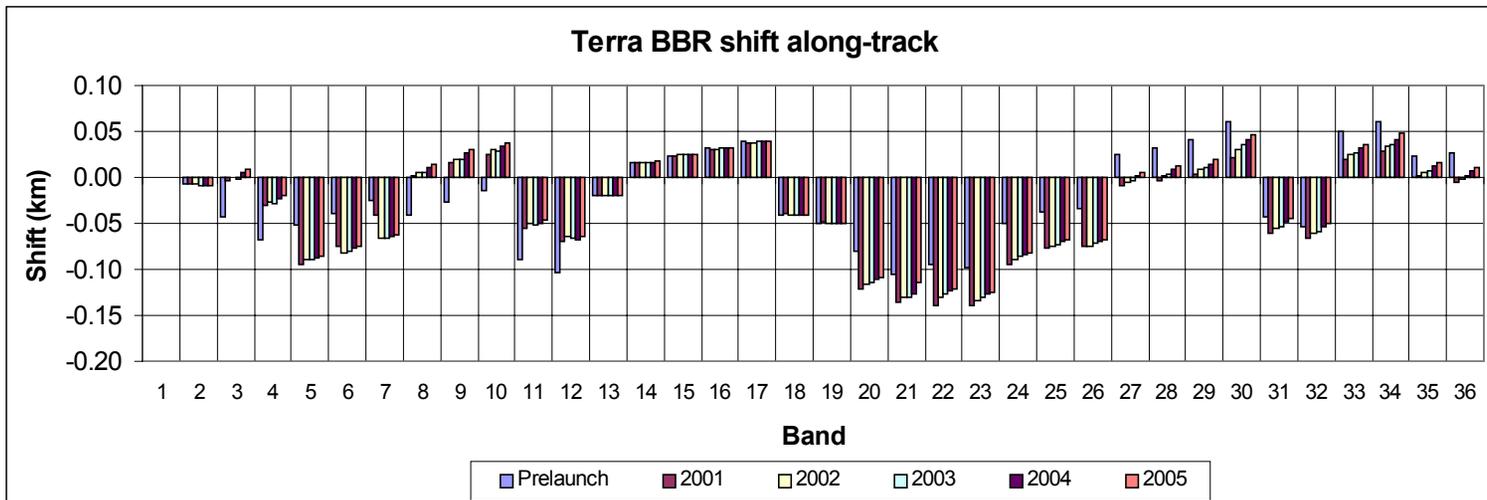## Terra MODIS Center Wavelength Shifts and Bandwidth Changes
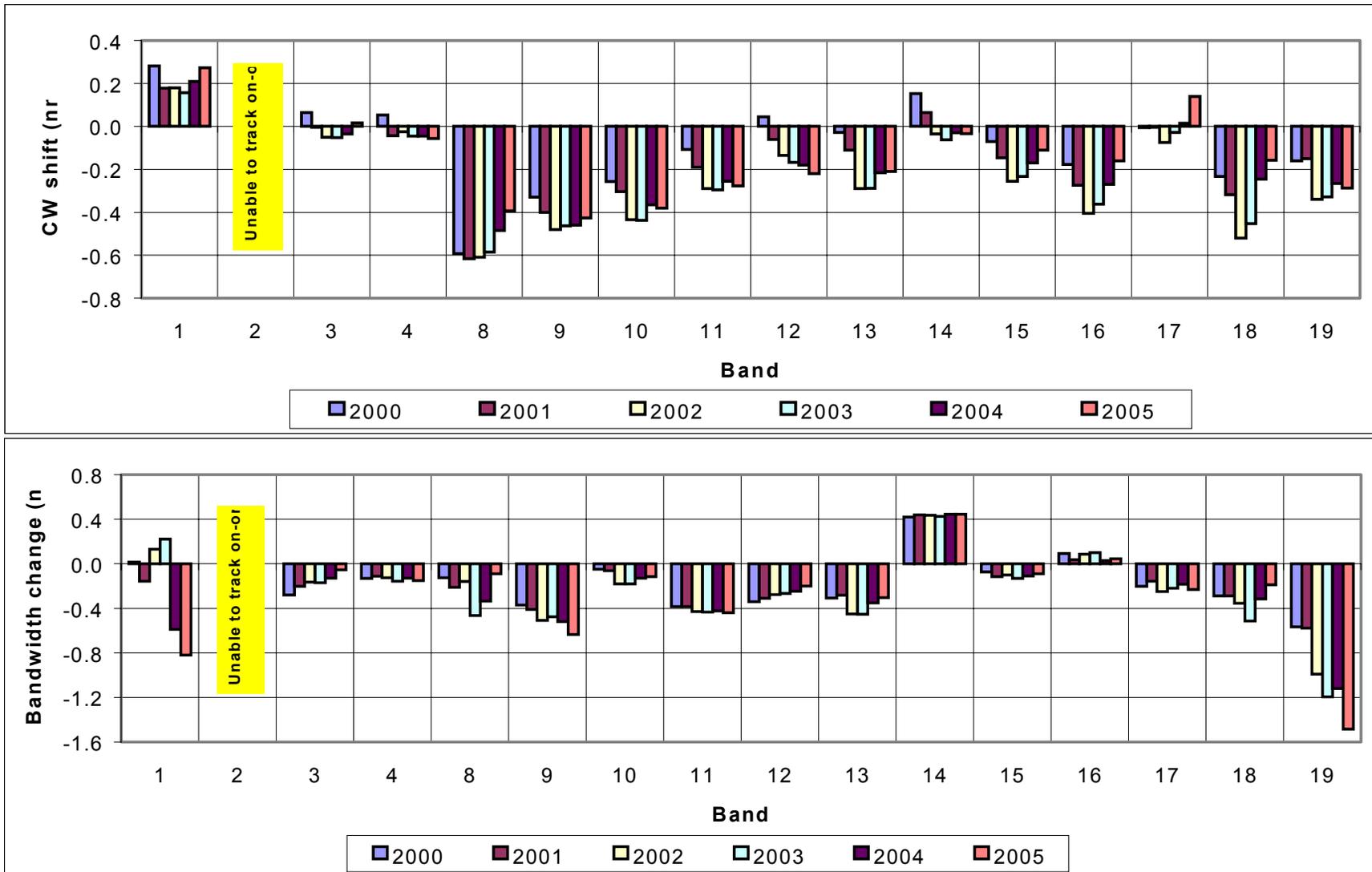
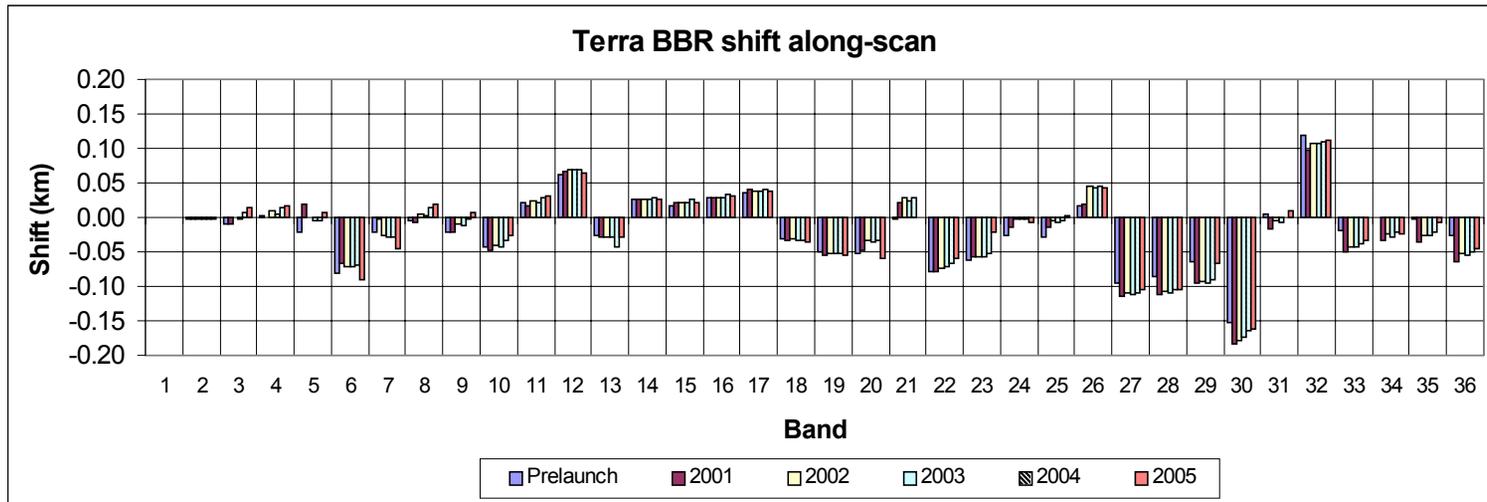# Aqua MODIS Spectral Performance

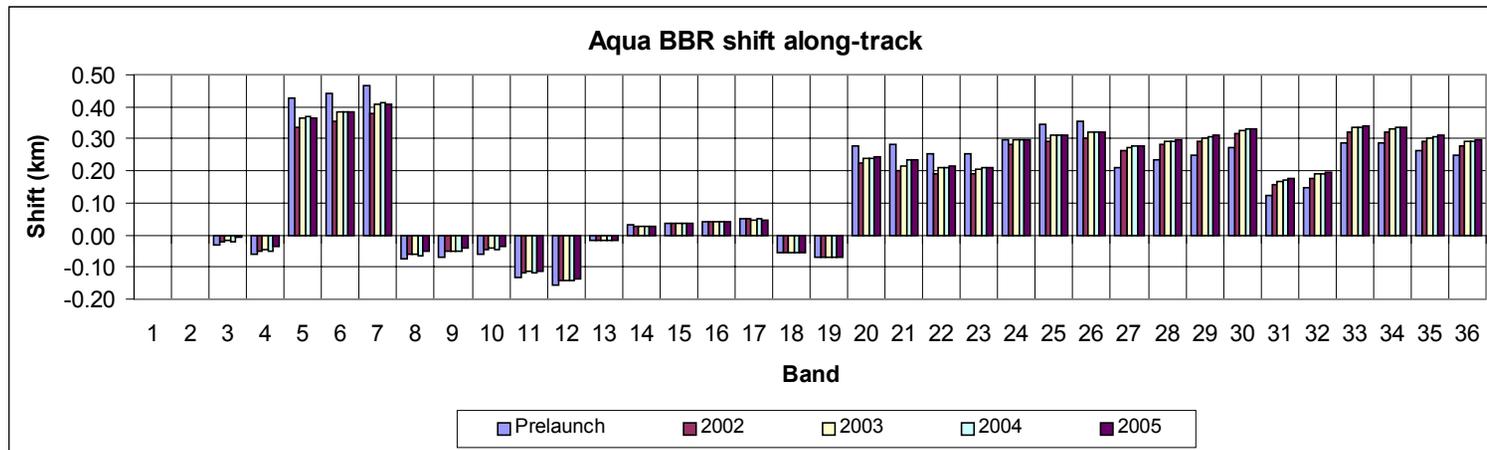## *Aqua MODIS Center Wavelength Shifts and Bandwidth Changes*

Terra MODIS Spatial Performance

Terra BBR shift along-scan

Terra BBR shift along-track

Note: The along-track shift is opposite in sign from last Workshop due to a change in detector numbering from SBRS to product order during the SRCA spatial computations.
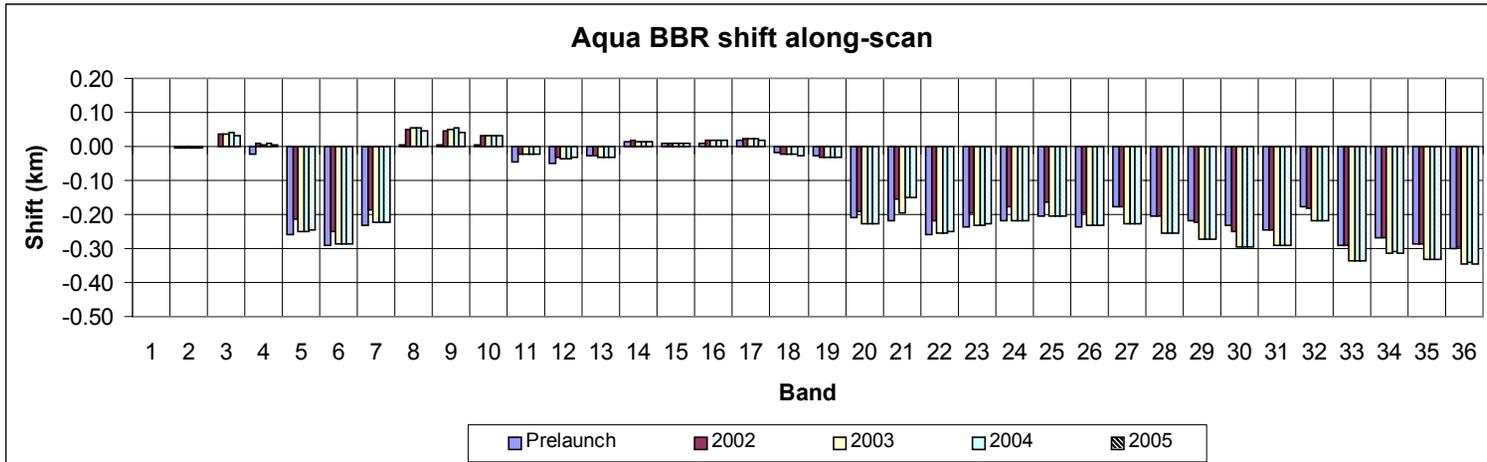
Aqua MODIS Spatial Performance

Note: The along-track shift is opposite in sign from last Workshop due to a change in detector numbering from SBRS to product order during the SRCA spatial computations.
Pre-launch shift is from TV3 data.