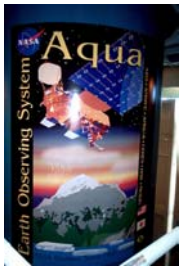
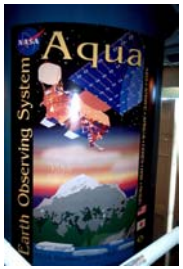


MODIS Calibration and Characterization Workshop

Jack Xiong
Sciences and Exploration Directorate, NASA/GSFC

and

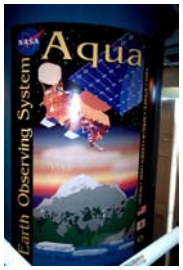
MODIS Characterization Support Team (MCST)



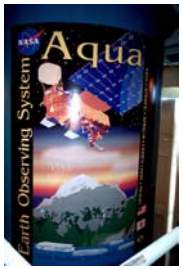
Outline

- Introduction
  - Instrument Background and On-orbit Calibration
- Instrument Operations (Breen)
- Level 1 and LUT Updates (Kuyper)
- RSB On-orbit Performance (Xie)
- TEB On-orbit Performance (Wenny)
- Challenging Issues and Future Work
- Summary

Outline



- Reflectance-based results for Terra and Aqua MODIS (Thome)
- Analysis of image striping due to polarization correction artifacts in MODIS Aqua ocean scenes (Meister)
- LWIR Band Radiometric Performance (Moeller)
- In-Flight Cross Validation of Mid and Thermal Infrared Remotely Sensed Data from MODIS and ASTER Using the Lake Tahoe Automated Validation Site (Hook)

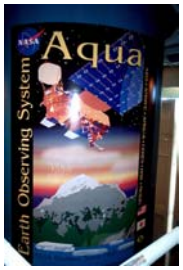


Introduction

Acknowledgements:

- MCST Groups: IOT, L1B/LUT, and Calibration
- MODIS Science Team
  - Science Team Leader (Vince Salomonson)
  - Land (Eric Vermote and Zhengming Wan)
  - Ocean (Meister et al.)
  - Atmosphere (Chris Moeller)
  - Cal/Val (Biggar et. al)
- Raytheon / SBRS MODIS Team
- Others
  - Bill Barnes, Bruce Guenther, Eugene Waluschka, and Robert Wolfe

Introduction

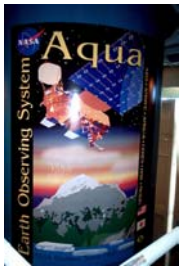


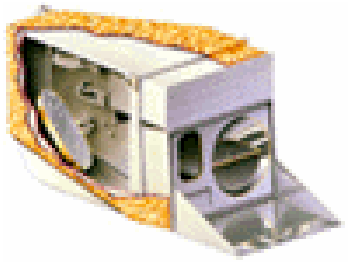
MCST Contact:

- Team leader: Jack Xiong
- Science support: Brian Wenny
- Instrument operation: Bryan Breen
- RSB Calibration: Xiaobo Xie / Junqiang Sun
- TEB Calibration: Brian Wenny / Aisheng Wu
- L1B and LUT: James Kuyper / Liqin Tan

http://www.mcst.ssai.biz/mcstweb/index.html

Instrument Background





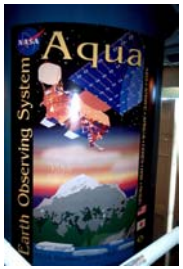
PFM **FM1**

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 Key Specifications



Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10	167
	18	931 - 941	3.6	57
	19	915 - 965	15	250

[3] SNR = Signal-to-noise ratio

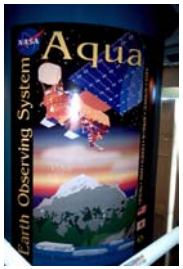
Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE∆T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45 (300K)	0.05
	21	3.929 - 3.989	2.38 (335K)	0.2
	22	3.929 - 3.989	0.67 (300K)	0.07
	23	4.020 - 4.080	0.79 (300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17 (250K)	0.25
	25	4.482 - 4.549	0.59 (275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6	150 [3]
	27	6.535 - 6.895	1.16 (240K)	0.25
	28	7.175 - 7.475	2.18 (250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58 (300K)	0.05
Ozone	30	9.580 - 9.880	3.69 (250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55 (300K)	0.05
	32	11.770 - 12.270	8.94 (300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52 (260K)	0.25
	34	13.485 - 13.785	3.76 (250K)	0.25
	35	13.785 - 14.085	3.11 (240K)	0.25
	36	14.085 - 14.385	2.08 (220K)	0.35

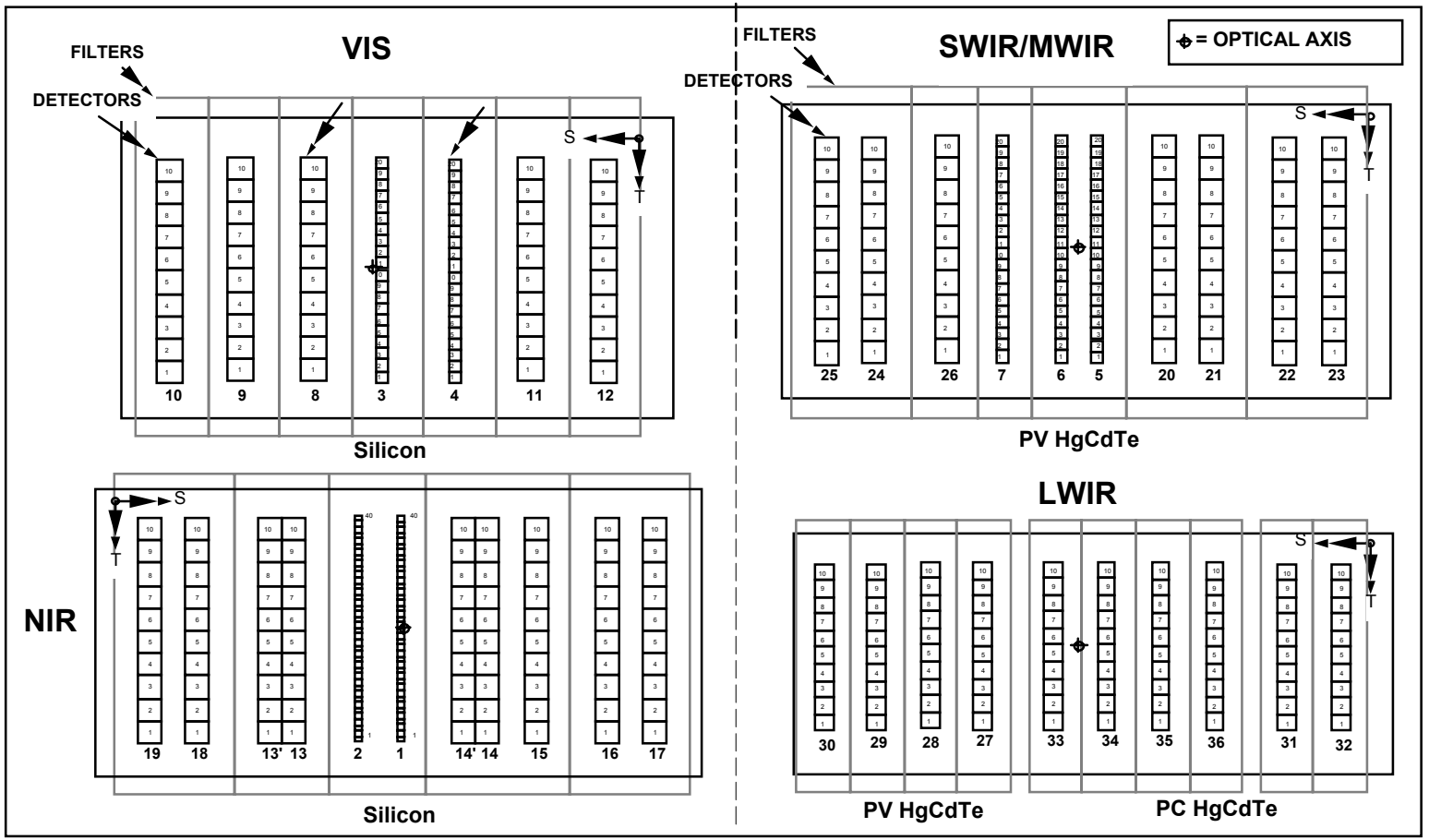
[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm

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

[4] NE∆T = Noise-equivalent temperature difference

MODIS Focal Plane Assemblies (FPA)





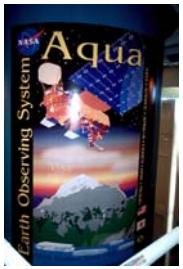
Instrument FPA Main Frame Temperature

Cold FPAs: (80. 83, 85k)

S: scan direction; T: track direction

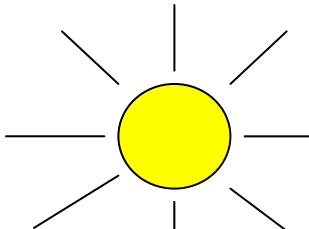
B13 and B14 have 2 columns of detectors for TDI high and low gain output

MODIS Calibration Activities



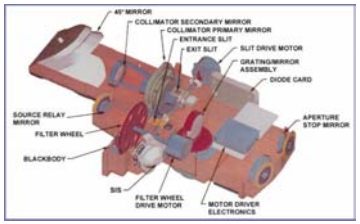
BB (quarterly)
SD/SDSM (weekly first year to bi-weekly)
SRCA (monthly radiometric, bi-monthly spatial, quarterly spectral)
Maneuvers (roll: monthly **Moon**; yaw: 2 for Terra and 1 for Aqua; pitch: 2 for Terra)

SDSM



Solar Diffuser

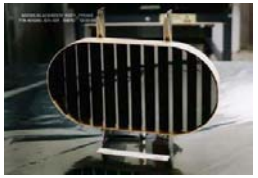
SDSM



SRCA

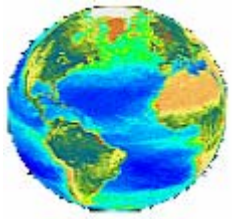
Scan Mirror

Blackbody



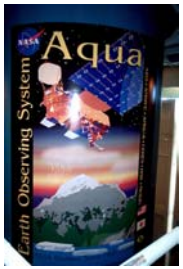
Space View

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



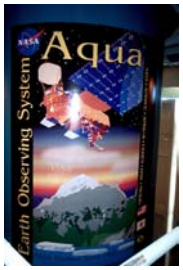
MODIS Instrument Operations

January 2006 - October 2006

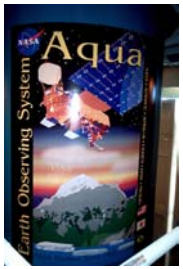
Bryan Breen

Bryan.C.Breen.1@gsfc.nasa.gov

MODIS Operations PFM Highlights

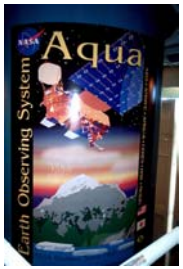


- 4th Spacecraft Solid State Recorder Anomaly
  - August 26, 2005: PWA in the MODIS buffer fails. MODIS loses 2 supersets. Now at 32 supersets.
  - No new events in 2006
    - No change in SSR configuration
    - Current SSR configuration considered “limit” of no loss operations with current TDRSS scheduling
    - Current plan is “wait and see” – FOT ready to perform an SSR recycle if another PWA is lost, NASA HQ has been briefed



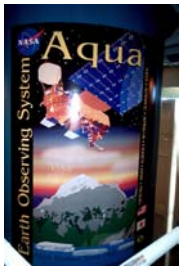
MODIS Operations
PFM Highlights

- NAD/SVD door close incident
  - August 22, 2006 (DOY 234) at 16:37, the NAD and SVD were commanded closed by an ATC activity/IOT error.
  - SMIR and LWIR temps increase to 101.2K.
  - August 22, 2006 at 19:13, SVD commanded OPEN.
  - August 22, 2006 at 19:15, NAD commanded OPEN.
  - August 23, 2006 at approx. 19:20, SMIR and LWIR temps back to normal (83K).
  - NAD Open Switch working again
    - Switch stuck on last NAD movement – December 24, 2003



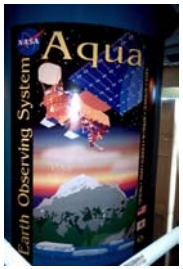
MODIS Operations PFM Highlights

- SRCA Lamp #2 Degradation/Failure
  - Some degrading of SRCA lamp #2 was seen by MCST
  - November 22, 2004: SRCA lamp #2 shuts itself off during an extended SRCA calibration.
- SRCA Lamp #3 Degradation
  - Some degrading of SRCA lamp #3 was seen by MCST
  - February 18, 2006: 10W radiometric tests of 10W lamps #3 and #4 are performed. Lamp #3 is verified to be abnormal. It is taken out of service.
  - Tests since then run in Constant Current mode to lessen load on remaining 10W lamps #1 and #4.



MODIS Operations PFM Highlights

- SRCA Radiometric and Spatial Redesign
  - Small command counts = easy fix
  - CP Macros 15 (Rad.) and 23 (Spat.) replaced by stored commands
  - Both executed multiple times this year
- SRCA Spectral Redesign
  - Reduction to 20W max SRCA lamp configuration required redesign of 30W CP Macros 18 and 19 in ROM
  - Large command counts and precise timing constraints required used of internal MODIS Macro
  - Macros 18 and 19 redesigned and uploaded to Macro 31 in RAM
  - First executed September 28, 2006 (DOY 2006/270)

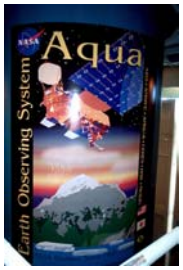


MODIS Operations
PFM SRCA Calibrations

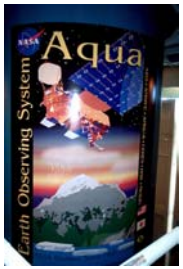
- 233 SRCA Calibrations
  - Including: 33 Full Spectral, 46 Full Spatial, 82 Full Radiometric
- Lamp Usage in hours: total (on orbit)
  - 10W Lamps, 500hr life: 1) 256.9 (122.7) 2) 172.1 (53.0) 3) 190.3 (62.0) 4) 81.8 (20.3)
  - 1W Lamps, 4000hr life: 1) 570.5 (27.6) 2) 278.7 (2.4)

Lamp Use in Hours						
	10W #1	10W #2	10W #3	10W #4	1W #1	1W #2
Full Radiometric	0.15	0	0	0.065	0.086	0
Full Spatial	0.34	0	0	0.17	0.17	0
Full Spectral	2.38	0	0	1.172	0	0
One Year Use with: Monthly Radiometric Quartley Spatial Tri-annual Spectral	10.312	0	0	4.976	1.712	0
Total after 10 years	303.596	172.093	190.307	103.926	581.752	278.715

MODIS Operations
PFM SD/SDSM Calibrations

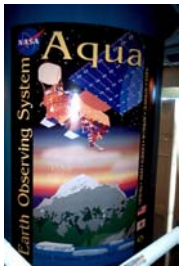


- 520 SD/SDSM Calibrations
  - 183 SD Door Open, 337 SD Door Screened
  - 2146 (1213 on orbit) of 3022 Solar Diffuser Door Movements
  - Note: As of July 2, 2003, the SD Door will remain Open, the SD Screen will remain Screened. No additional door movements are planned.



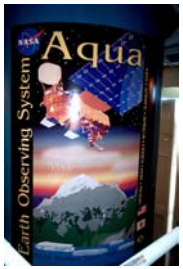
MODIS Operations
PFM Other Doors/Calibrations

- Nadir Door Operations
  - 540 (11 on orbit) of 1316 Nadir Door Movements
- Space View Door Operations
  - 443 (10 on orbit) of 1316 Space View Door Movements
- 58 Blackbody Calibrations (warm/cool cycle)
- 50 Electronics Calibrations
- 68 Lunar Calibrations, 63 via Roll Maneuvers
- 33 Yaw Maneuver SD/SDSM Calibrations



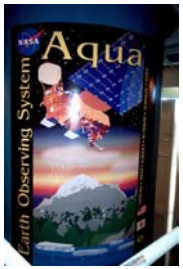
MODIS Operations
PFM Ongoing Operations

- Calibrations
  - SRCA: Monthly full radiometric, quarterly full spatial, and quad-monthly full spectral. All SRCA calibrations will be in constant current feedback mode.
  - SDSM: Performed bi-weekly. No door movements. All SD/SDSM calibrations will be in the screened position.
  - Blackbody: Performed quarterly
  - Ecal: PV Ecal performed quarterly
  - Lunar View: Performed monthly for Roll Angles less than 20 degrees



MODIS Operations
FM1 Highlights

- SRCA Lamp #2 Degradation
  - Some degrading of SRCA lamp #2 was seen by MCST
  - As of April 14, 2003: SRCA lamp #2 is no longer being used during 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.
  - Tests since then run in Constant Current mode to lessen load on remaining 10W lamps #1 and #4.



MODIS Operations
FM1 Highlights

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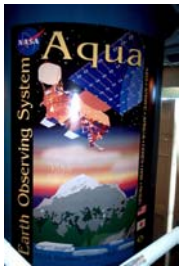
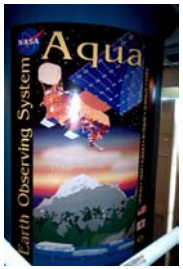
  - Small command counts = easy fix
  - CP Macros 15 (Rad.) and 23 (Spat.) replaced by stored commands
  - Both executed multiple times this year
- SRCA Spectral Redesign
  - Reduction to 20W max SRCA lamp configuration required redesign of 30W CP Macros 18 and 19 in ROM
  - Large command counts and precise timing constraints required used of internal MODIS Macro
  - Macros 18 and 19 redesigned and uploaded to Macro 31 in RAM
  - First executed April 27, 2006 (DOY 2006/117)



MODIS Operations
FM1 SRCA Calibrations

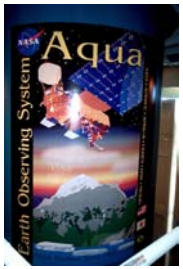
- 106 SRCA Calibrations
  - Including: 15 Full Spectral, 25 Full Spatial, 49 Full Radiometric
- Lamp Usage in hours: total (on orbit)
  - 10W Lamps, 500hr life: 1) 254.4 (54.2) 2) 188.0 (12.3)
    3) 205.7 (27.2) 4) 86.7 (29.0)
  - 1W Lamps, 5000hr life: 1) 511.6 (12.1) 2) 271.6 (1.8)

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	331.901	187.983	205.709	123.798	527.762	271.625



MODIS Operations
FM1 SD/SDSM Calibrations

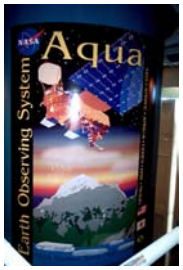
- 307 SD/SDSM Calibrations
  - 152 SD Door Open, 155 SD Door Screened
  - 2558 (928 on orbit) of 3022 Solar Diffuser Door Movements



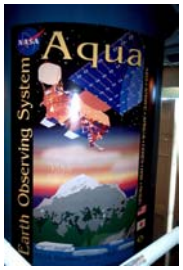
MODIS Operations
FM1 Other Doors / Calibrations

- 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
- 19 Blackbody Calibrations
- 30 Electronics Calibrations
- 40 Lunar Calibrations, 39 via Roll Maneuvers
- 29 Yaw Maneuver SD/SDSM Calibrations

MODIS Operations
FM1 Ongoing Operations



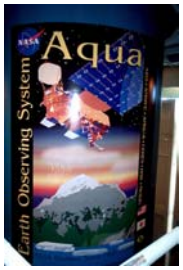
- Calibrations
  - SRCA: Monthly full radiometric, quarterly full spatial, and quad-monthly full spectral. All SRCA calibrations will be in constant current feedback mode.
  - SDSM: Performed tri-weekly
  - Blackbody: Performed quarterly
  - Ecal: PV Ecal performed quarterly
  - Lunar View: Performed monthly for Roll Angles less than 20 degrees



MODIS L1B Code Changes and LUT Updates

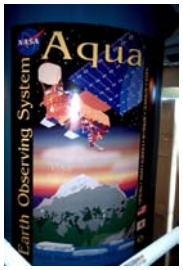
L1B Group

MODIS Level 1B
Updates 2006-01-01 to 2006-10-23



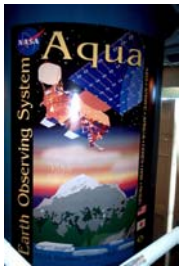
- No changes that had any science impact.
- Most changes were motivated by the GDAAC=>MODAPS transition.
- Few changes were made to the actual L1B process code; most were made to the PGE02 perl scripts that run the L1B process code.

PGE02 Versions
5.0.28 (Terra), 5.0.23 (Aqua)



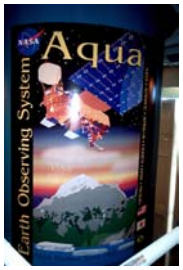
- Triggered by switch from GDAAC to MODAPS: product files distributed by the Level 1 and Atmosphere Archive and Distribution System (LAADS) <http://ladsweb.nascom.nasa.gov/> are required to be internally compressed.
- Total size of L1B products was reduced about 43%.
- Production of compressed files started 2006-04-06.
- Internally compressed files can be read by existing programs and HDF utilities without code modification - the HDF library handles decompression automatically.
- Files can be decompressed using hrepack utility.

PGE02 Versions 5.0.34(Terra), 5.0.29(Aqua)



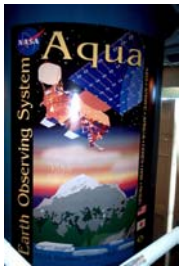
- Depending upon how they are written, programs can run a lot slower when HDF input files are changed to be internally compressed.
- All PGEs running under MODAPS decompress their input files, if necessary, before running process code, so this matters only for files ordered from LAADS and used elsewhere.
- The slow down can be substantially reduced by chunking the SDSs.
- The first L1B products with chunked SDSs were produced 2006-10-04.

PGE02 Versions
5.0.36 (Terra), 5.0.33(Aqua)



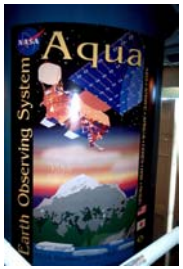
- Low priority internal changes for compliance with EOSDIS coding standards and guidelines, and MODIS SDST requirements and recommendations.
- Change file metadata to match MODAPS PGE Version, rather than GDAAC.
- Correct the chunk size used for the 5km subset Longitude and Latitude in 1KM files from 10x1354 to 16x271.
- Delivered to SDST by 2006-10-31; will go into production after science testing.

MODAPS and GDAAC PGE02 Version numbers



- GDAAC PGE02 version numbers changed only when a change to the L1B code was delivered to the GDAAC.
- MODAPS PGE02 version numbers change whenever there's a change to
  - the L1B process code
  - the PGE02 perl script that runs the L1B process.
- Up until MODAPS versions 4.3.46 (Terra), 4.3.35 (Aqua), 5.0.26 (Terra) and 5.0.21 (Aqua), changes to the PGE02 LUT files required changes to the MODAPS PGE02 perl script.

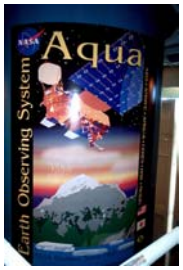
MODAPS PGE02 version changes since last GDAAC version



Collection	4	4	5	5
Satellite	Terra	Aqua	Terra	Aqua
Last GDAAC Version	4.3.0	4.3.1	5.0.6	5.0.7
Delivered	2003-11-13	2003-11-10	2005-02-16	2005-02-16
Code Changes*	2	2	1	1
LUT-only Updates	17	10	10	7
Production changes	4	5	4	5
Current MODAPS Version	4.3.46	4.3.35	5.0.36	5.0.33

* - not delivered to GDAAC

MODIS L1B LUT updates 2006-01-01 to 2006-10-23

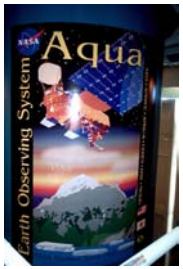


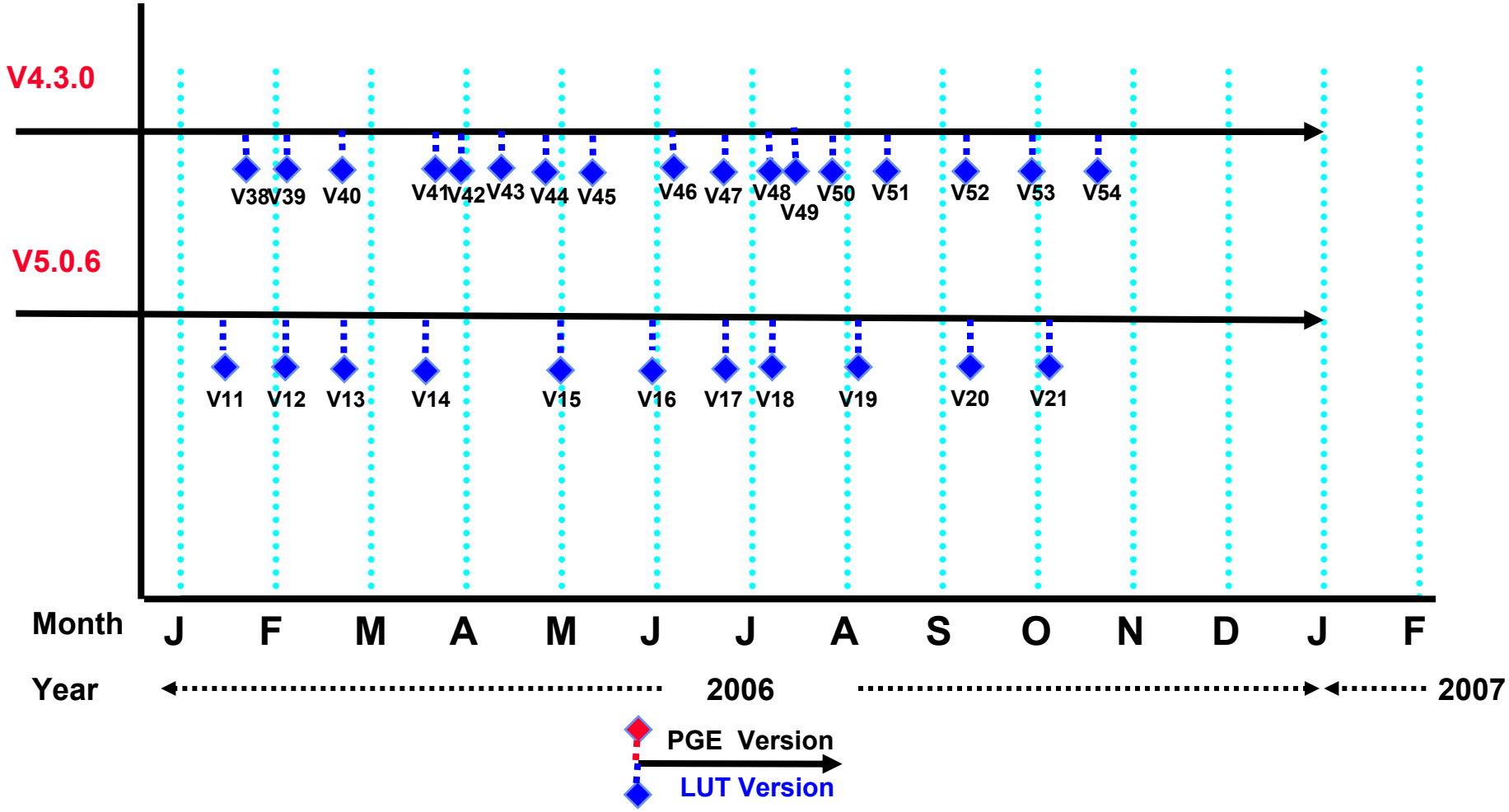
	Collection 4	Collection 5	Total
Terra	17	14*	31*
Aqua	10	7	17
Total	27	21*	48*

* includes 3 special deliveries for Oceans group

2006 Production Changes in MOD_PR02 TERRA L1B Code/LUTs

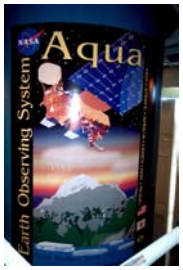
(Forward Processing)

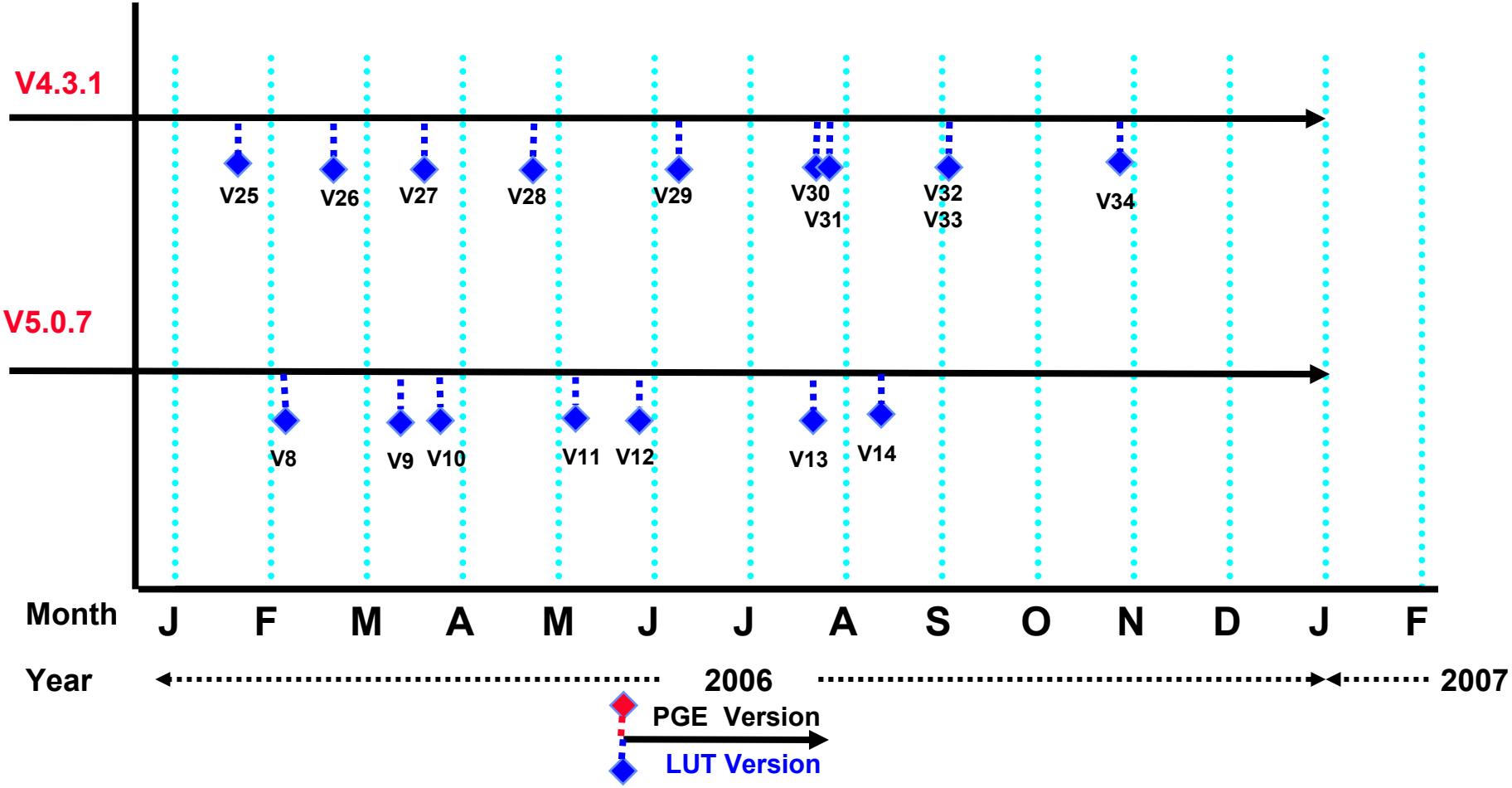


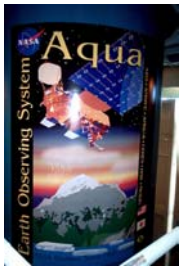


2006 Production Changes in MOD_PR02 AQUA L1B Code/LUTs

(Forward Processing)



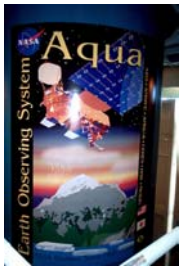




Status of EOS Terra and Aqua MODIS RSB Calibration

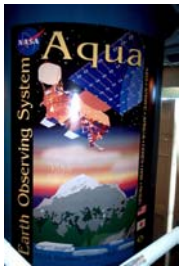
RSB Group

Outline



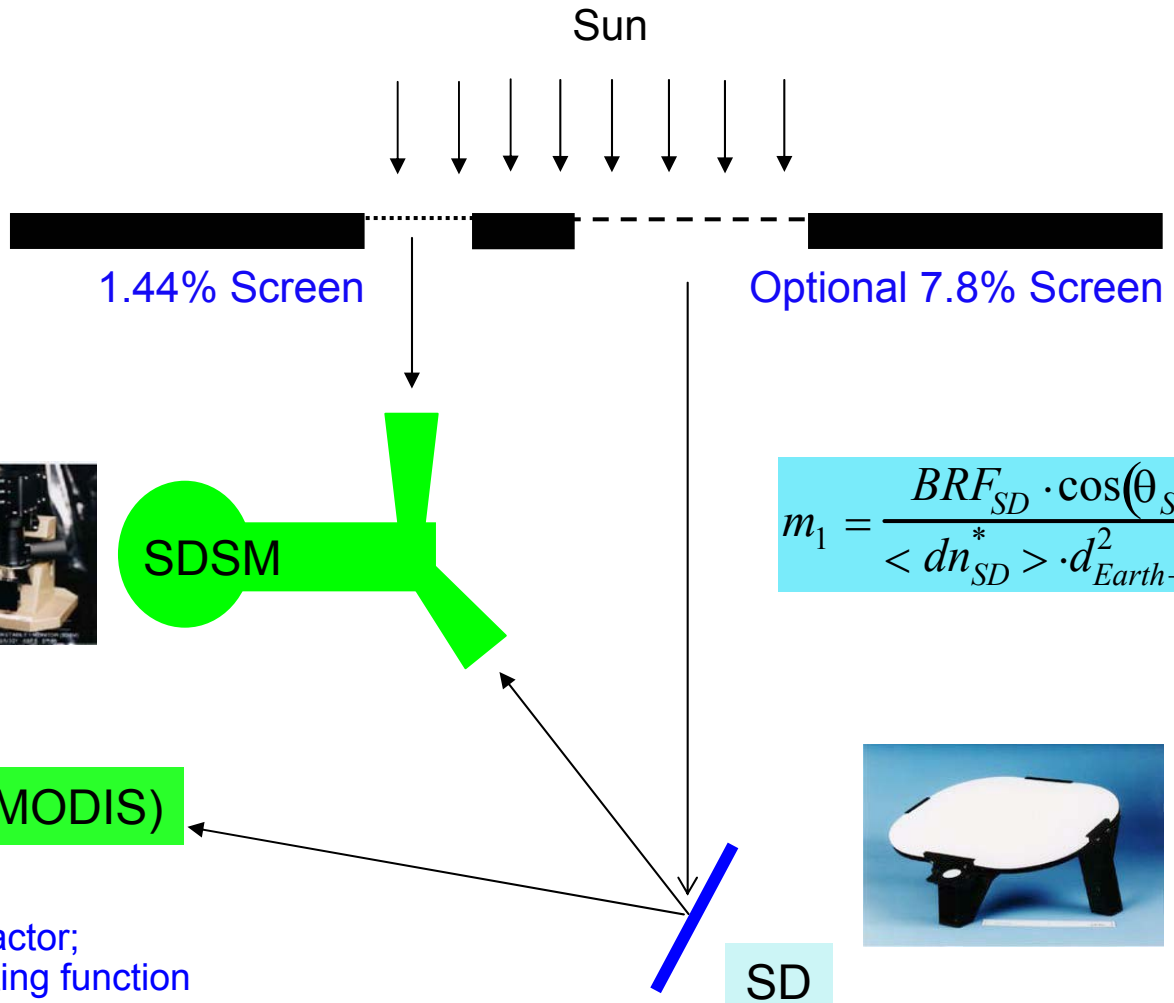
- Overview of RSB calibration
- Noisy & inoperable RSB detectors, SNR updates
- RSB responses trending
- Solar Diffuser degradation
- Summary of RSB overall performance

MODIS RSB Calibration Using SD/SDSM



Reflectance Factor

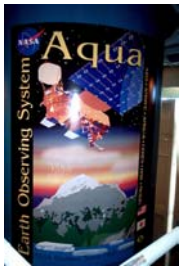
$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$$



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

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

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 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

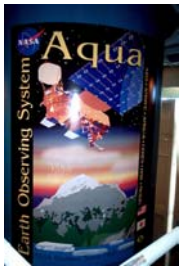
Others:

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)

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

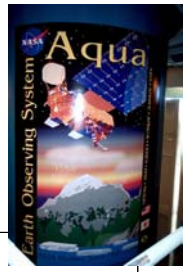
Aqua

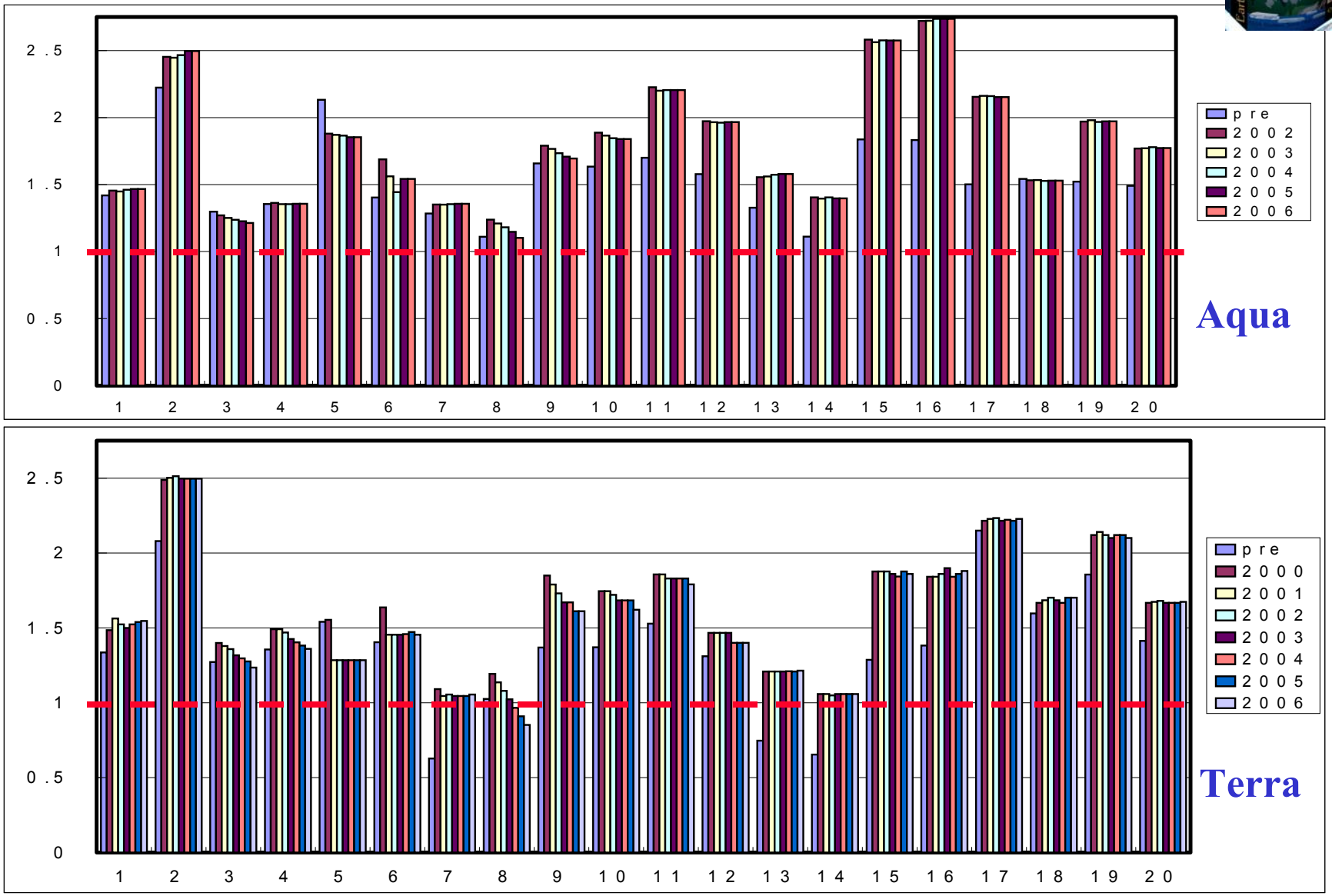
Day/Year	Band	5	6									
	SNR Spec	74	275									
	Detector	1	1-3	4	5-9	11	12	14	15	16	17	19
175/2002	Nadir Door Open	0	0	100	0	0	470	470	0	0	0	0
189/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	470	470	0
255/2002	Back from Safe Mode	0	0	470	0	0	470	470	0	0	0	0
266/2002	Back from Safe Mode	0	0	470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

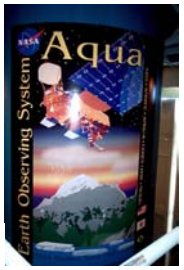
In Spec Near Spec Out Spec Inoperabl

Detectors in SBRS order

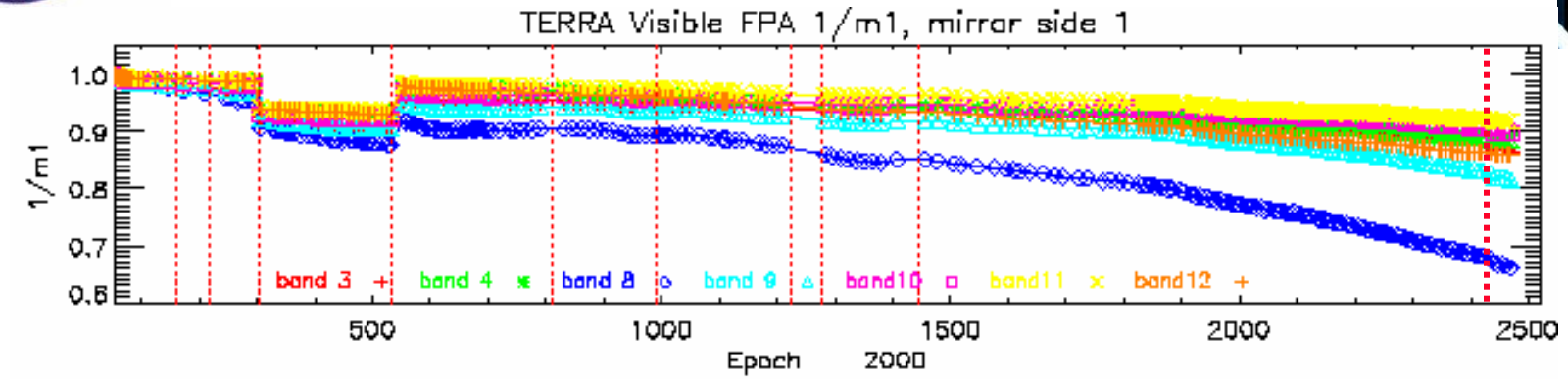
MODIS RSB SNR (Normalized to design specification)

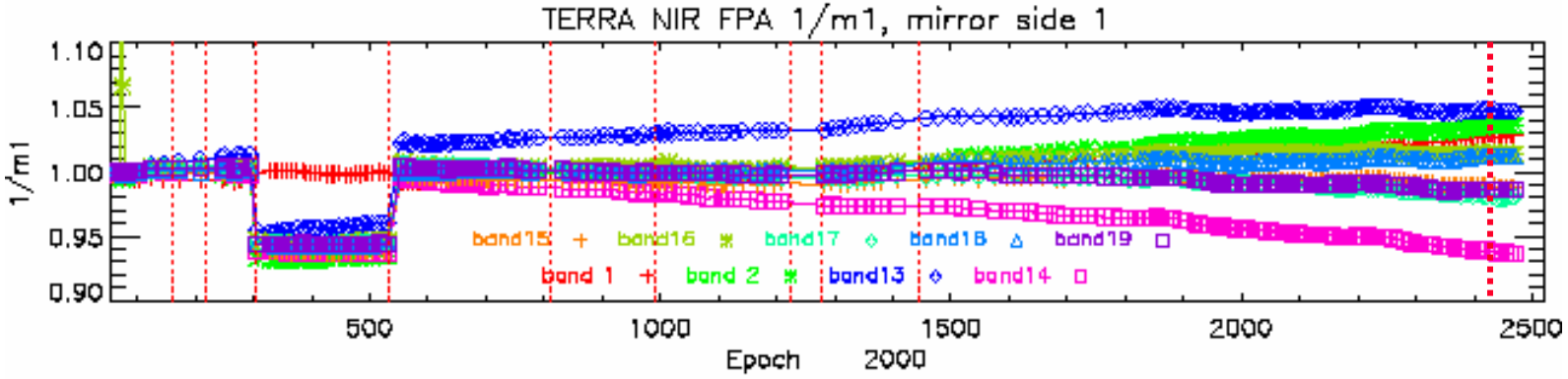


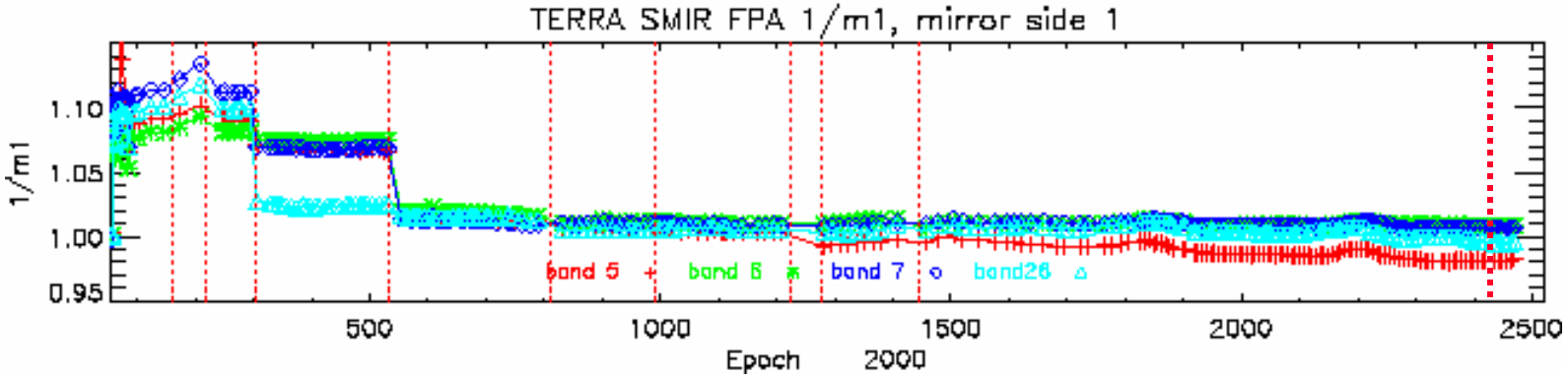


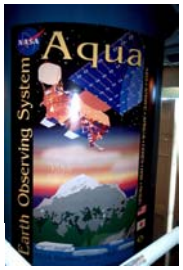


MODIS RSB Response Trending

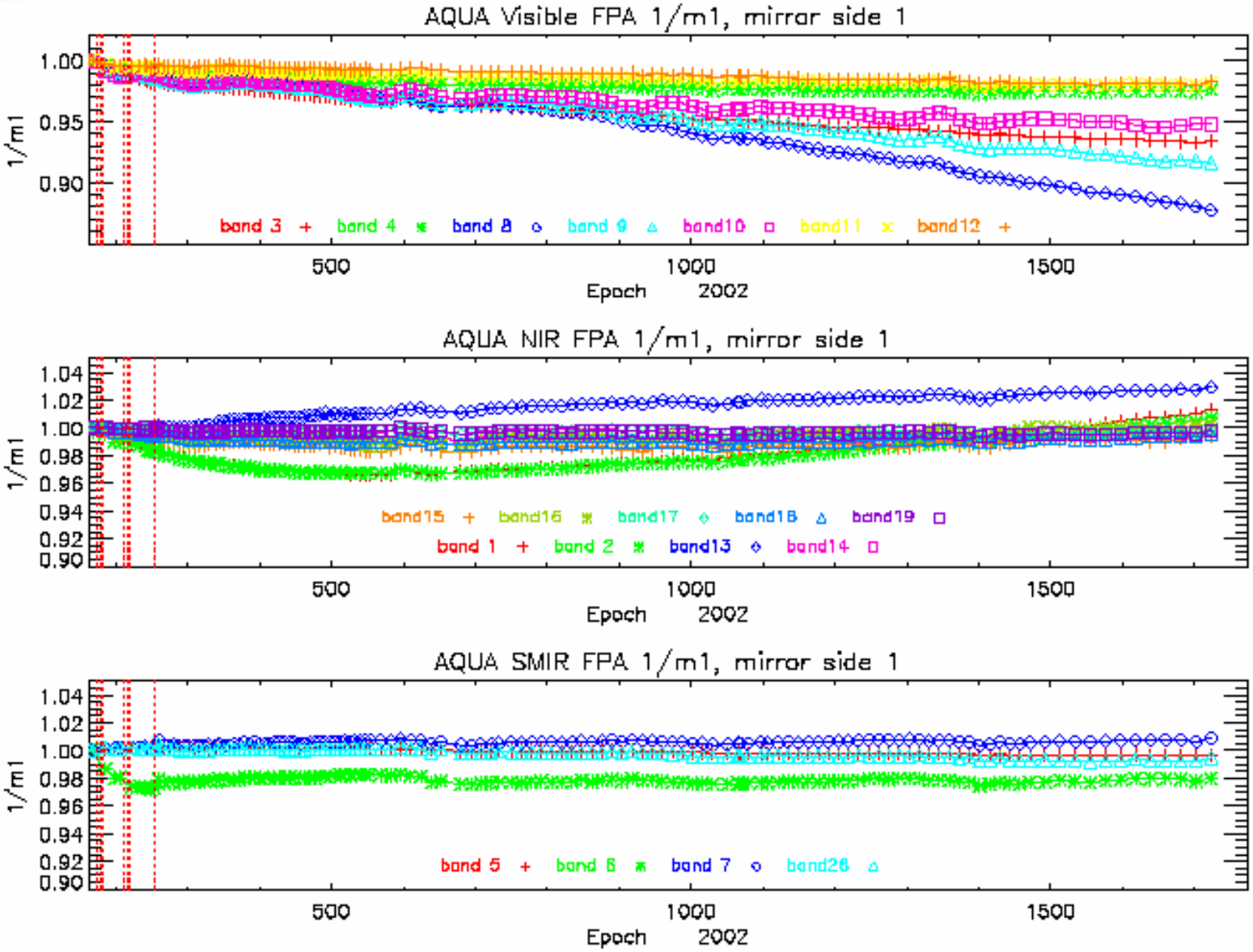




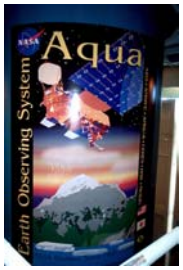


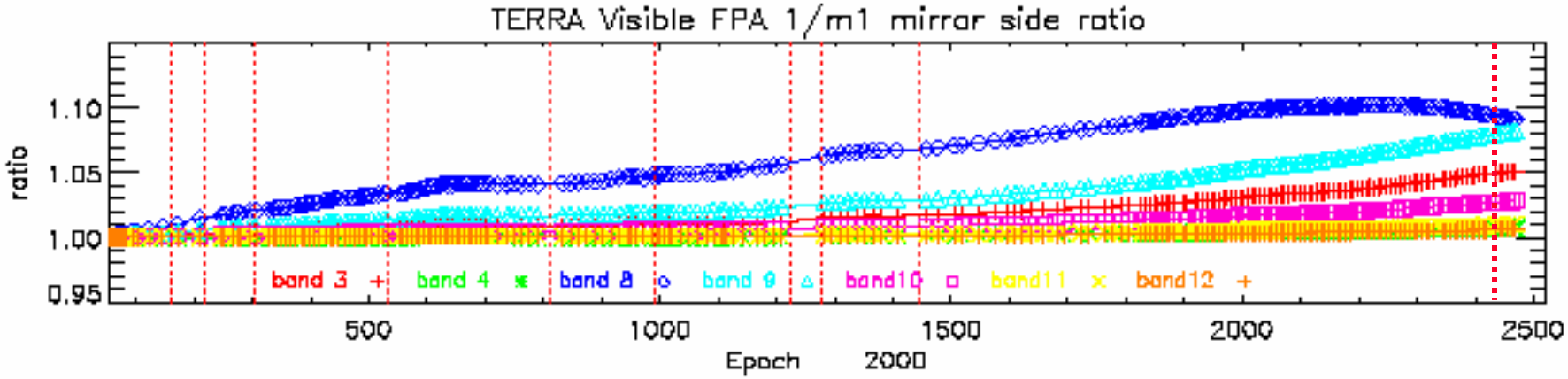


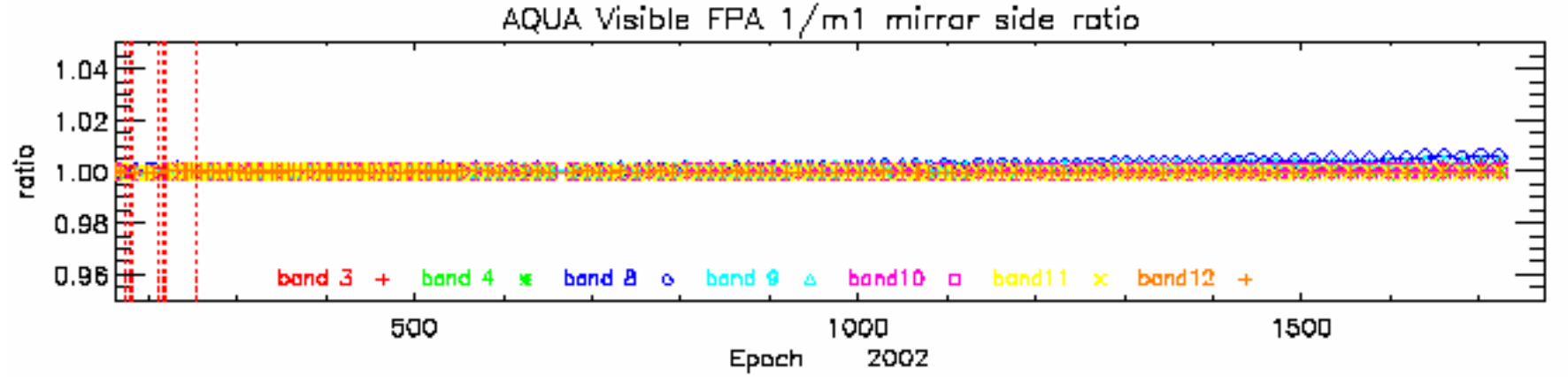
MODIS RSB Response Trending



MODIS RSB Response Trending

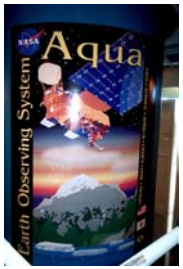


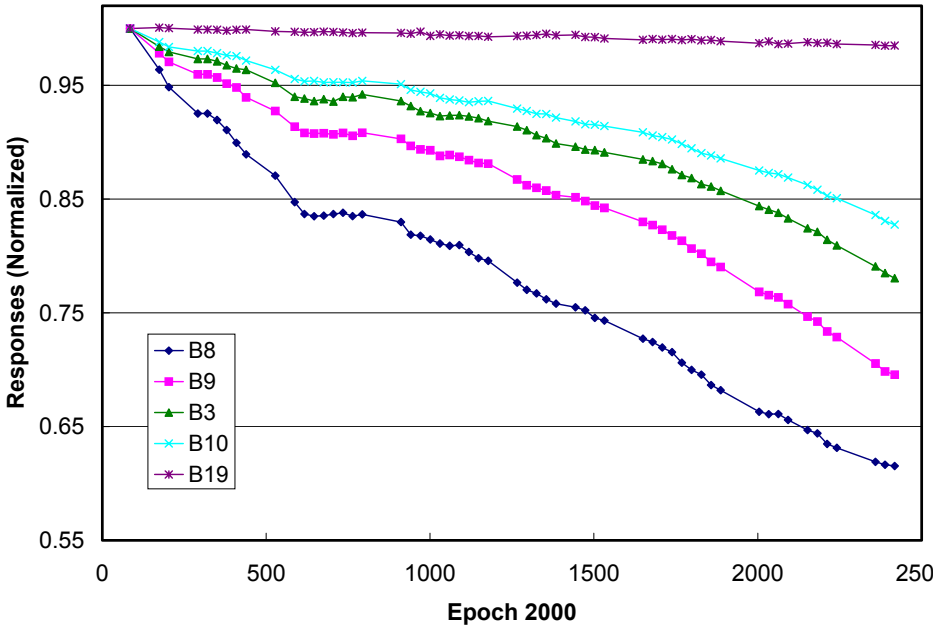




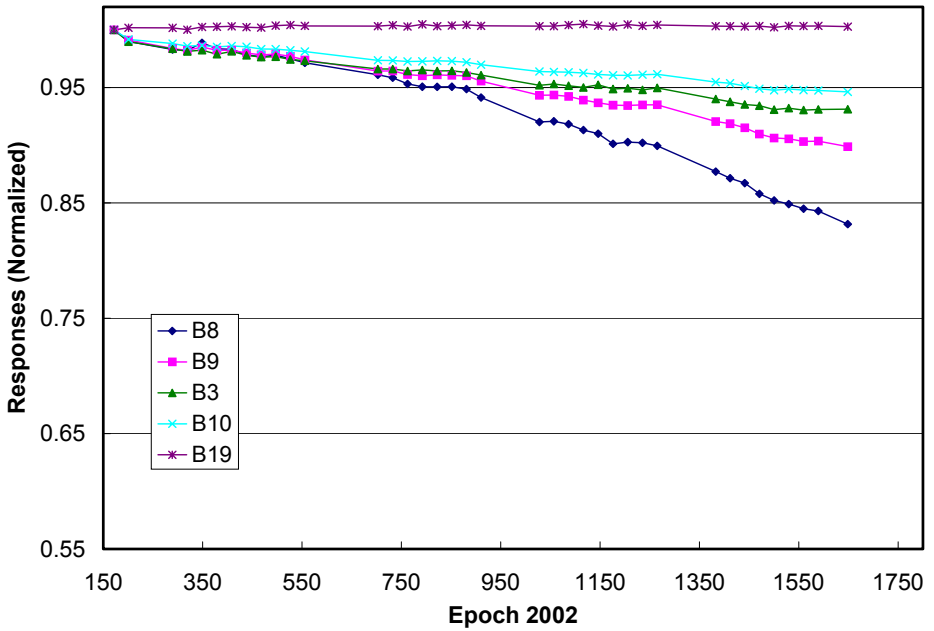
Mirror side difference of Terra band 8 starts to decrease after 6 years operation, while other visible bands still show uprising trend. For Aqua, less than 1% difference noticed for mirror side differences after 4 years operation.

MODIS Lunar trending





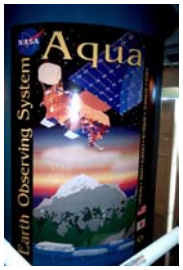
Terra mirror side 1

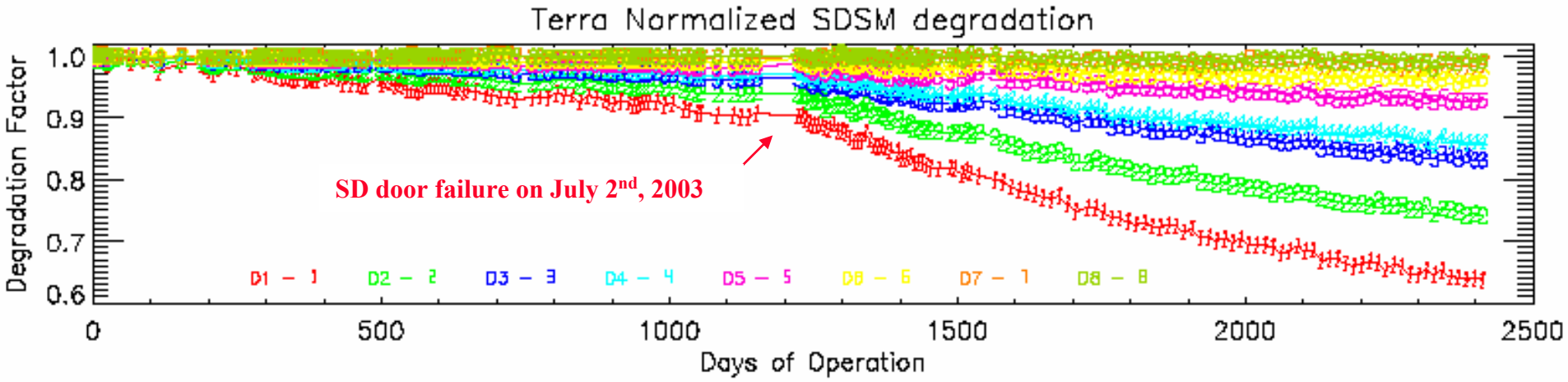


Aqua mirror side 1

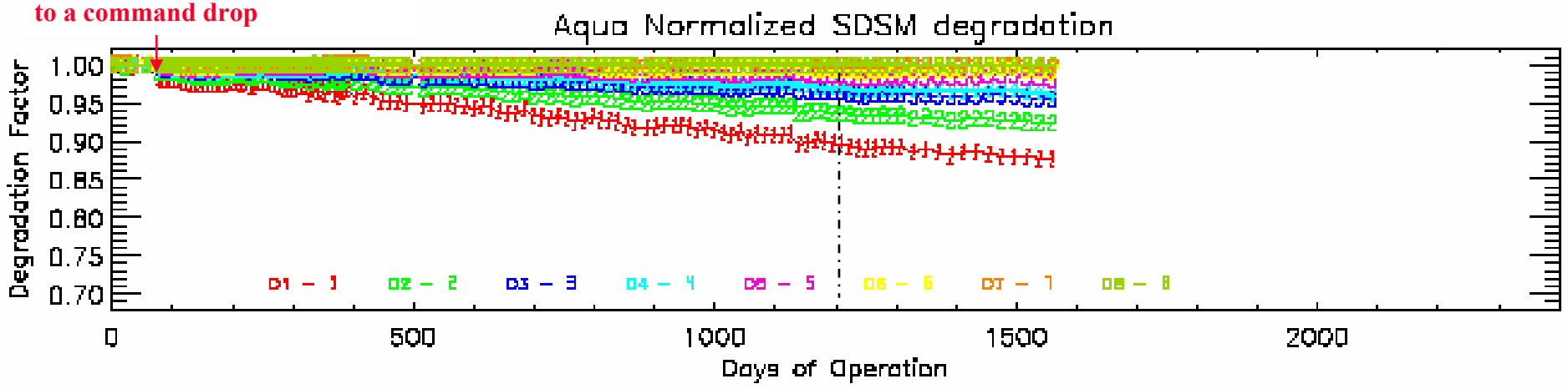
Lunar response (through Space View port) trending primarily used to track MODIS scan mirror RVS (reflection verse scan angle)

MODIS SD Degradation Trending



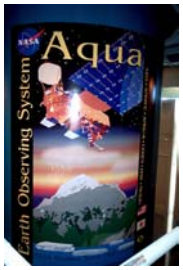


SD door left open for 5 days due to a command drop



Similar SD degradation in Terra and Aqua MODIS

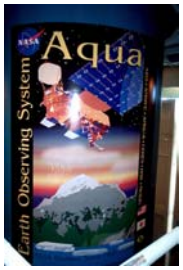
Summary of RSB overall Performance



- **Terra MODIS (6.5 years)**
  - More than 34% change for MODIS band 8 responses (both mirror sides)
  - Mirror side difference of band 8 starts to decrease after 6 years operation
  - SDSM operates bi-weekly to track SD degradation
  - SD performs RSB calibration every orbit since SD door kept open after July 2nd 2003 and this causes more degradation on SD BRF
  - 1 noisy RSB detector, no change since last workshop (01/2006)
  - No significant impacts noticed for RSB calibration caused by Terra day 2006234 NAD & SVD close event

- **Aqua MODIS (4 years)**
  - Maximum response change for band 8 around 12%, less than 5% for NIR & SWIR bands
  - Mirror side differences are very small and less than 1% for all the RSB bands.
  - SDSM operation and SD calibration changed to tri-weekly in order to extend SD door movement lifetime
  - 1 noisy and 14 dead RSB detectors, no change since last workshop (01/2006)

Calibration Status of MODIS Thermal Emissive Bands

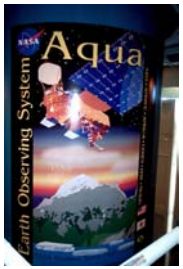


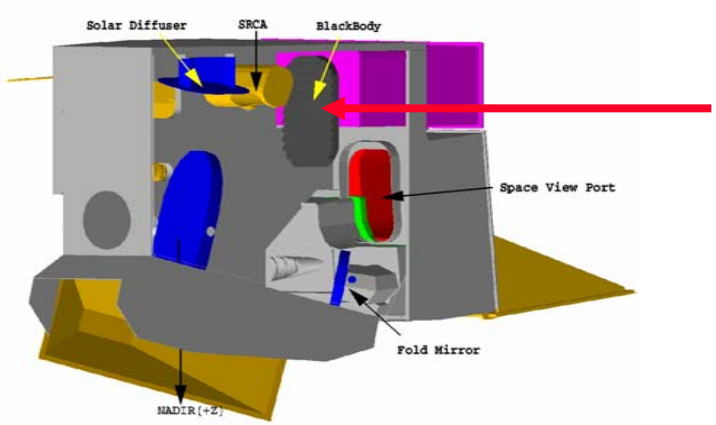
TEB Group

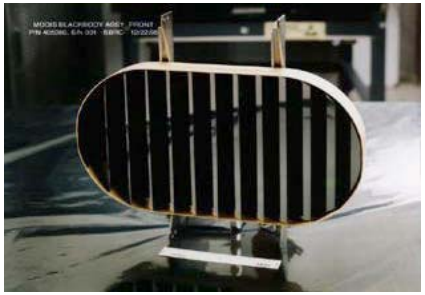
Outline

- **TEB Calibration Algorithm**
- **Terra and Aqua TEB Performance**
- **Current TEB issues**
- **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

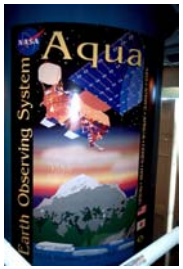
Calibration coefficient, b1, from BB

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

b_1 derived scan-by-scan from BB, a_0 & a_2 derived from periodic warm-up/ cool-down cycles (270-315 K) of the BB

Further details available at: www.mcst.ssai.biz/mcstweb

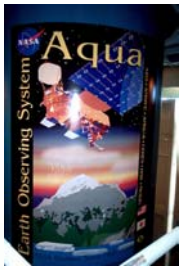
Instrument On-orbit Performance

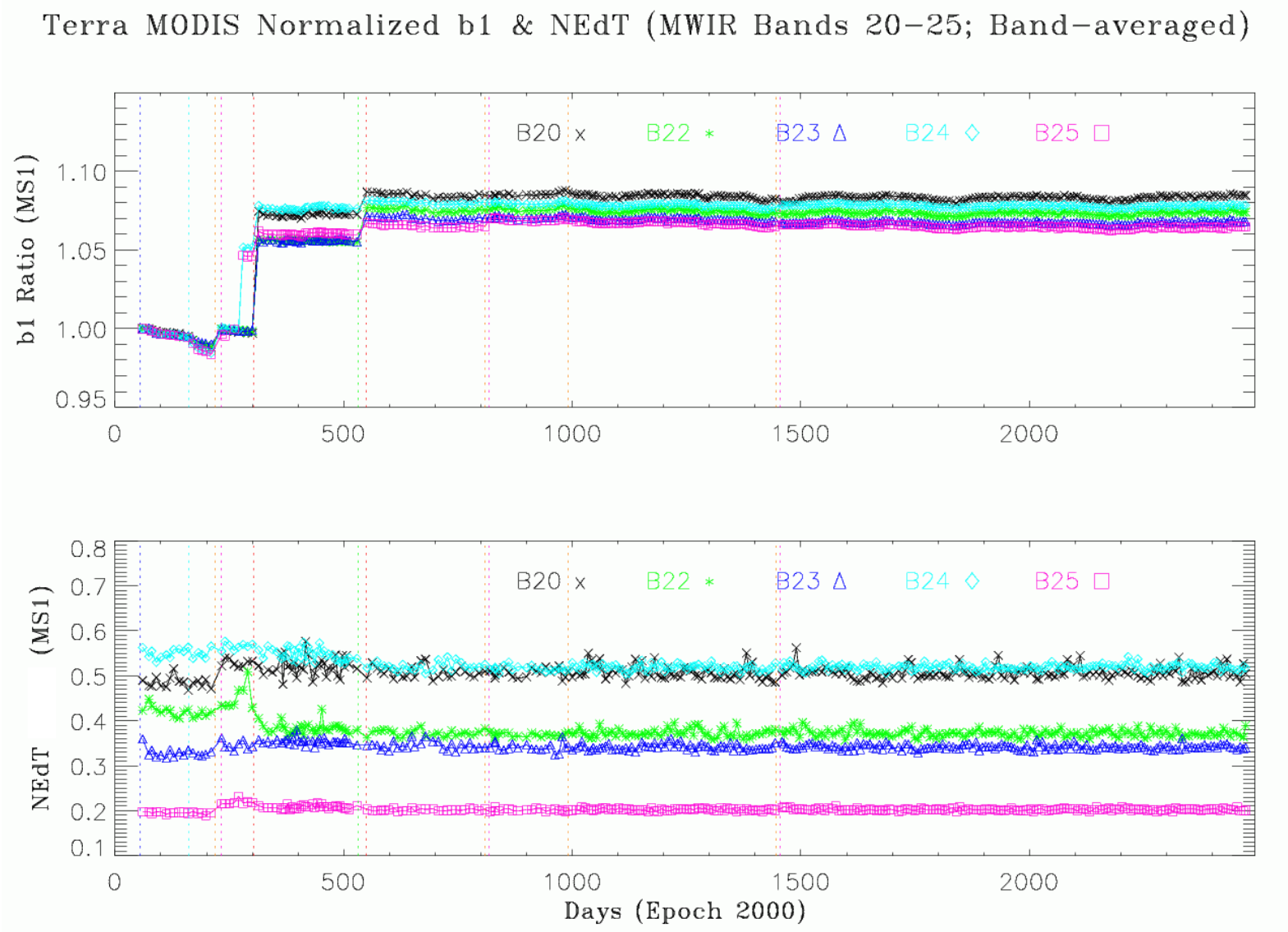


Thermal Emissive Bands (16 bands and 160 detectors)

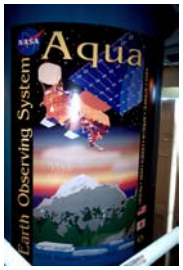
- **Terra MODIS**
  - Stable short-term and long-term response trends (excluding sensor configuration change and instrument reset events)
  - 24 noisy detectors (2 new since last STM), 1 inoperable detector (B29 D6)
- **Aqua MODIS**
  - Stable short-term and long-term response trends
  - 1 noisy detector (B27 D3) and 1 inoperable detector (B36 D5)

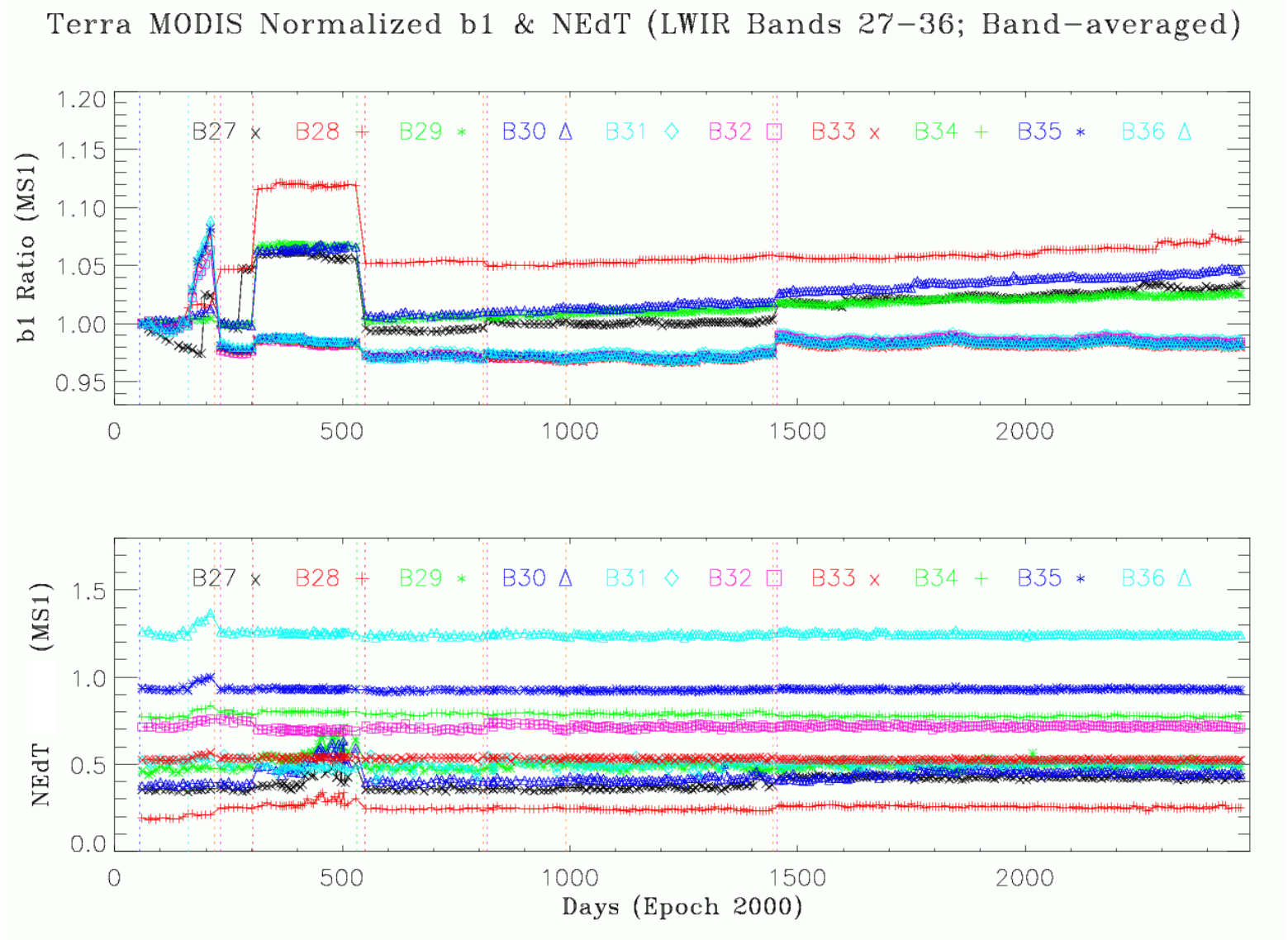
Terra MODIS TEB MWIR Response Trend

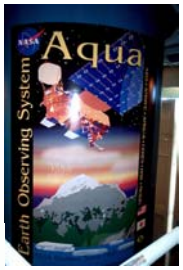




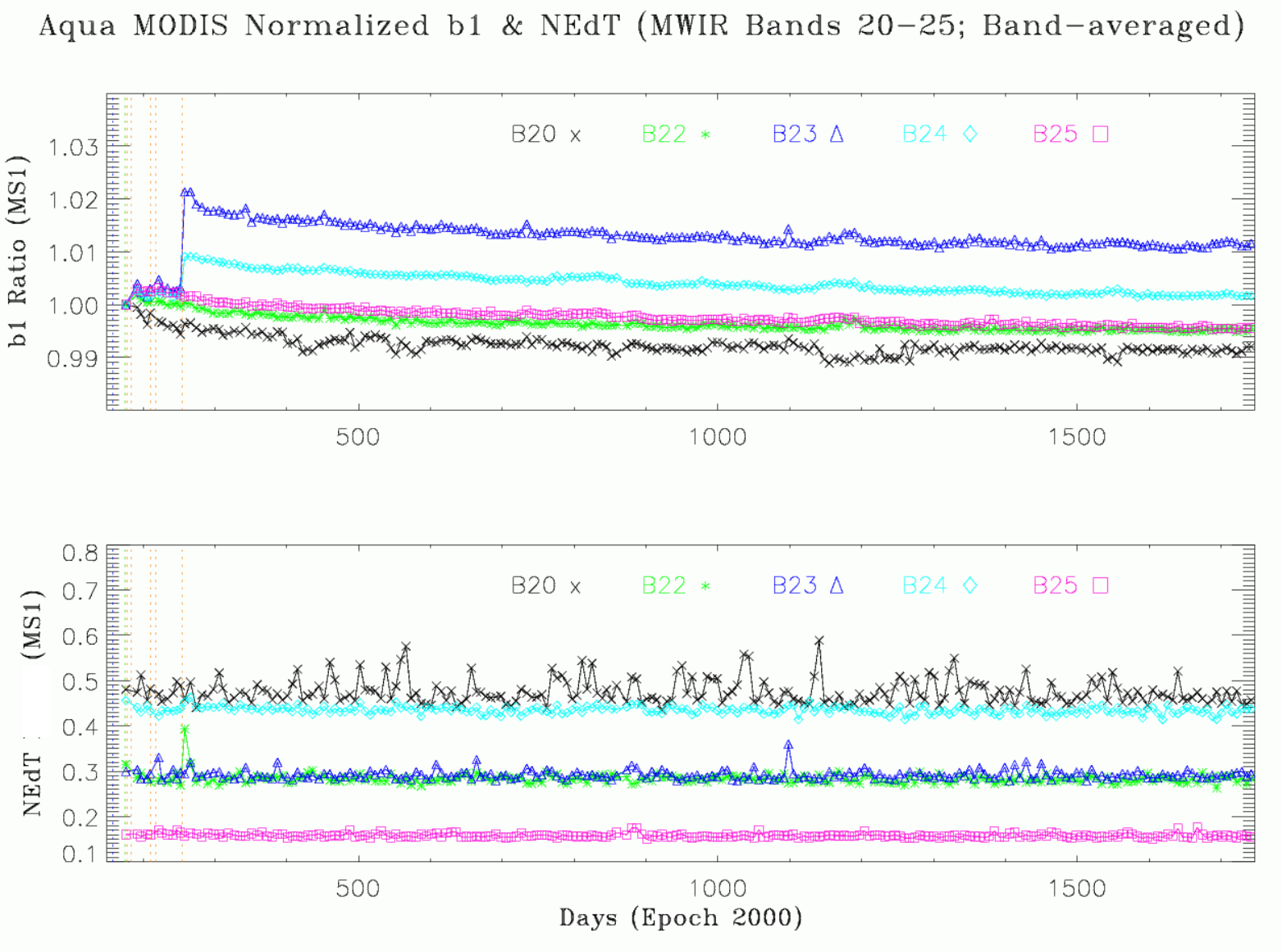
Terra MODIS TEB LWIR Response Trend

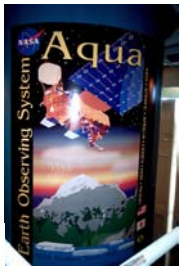




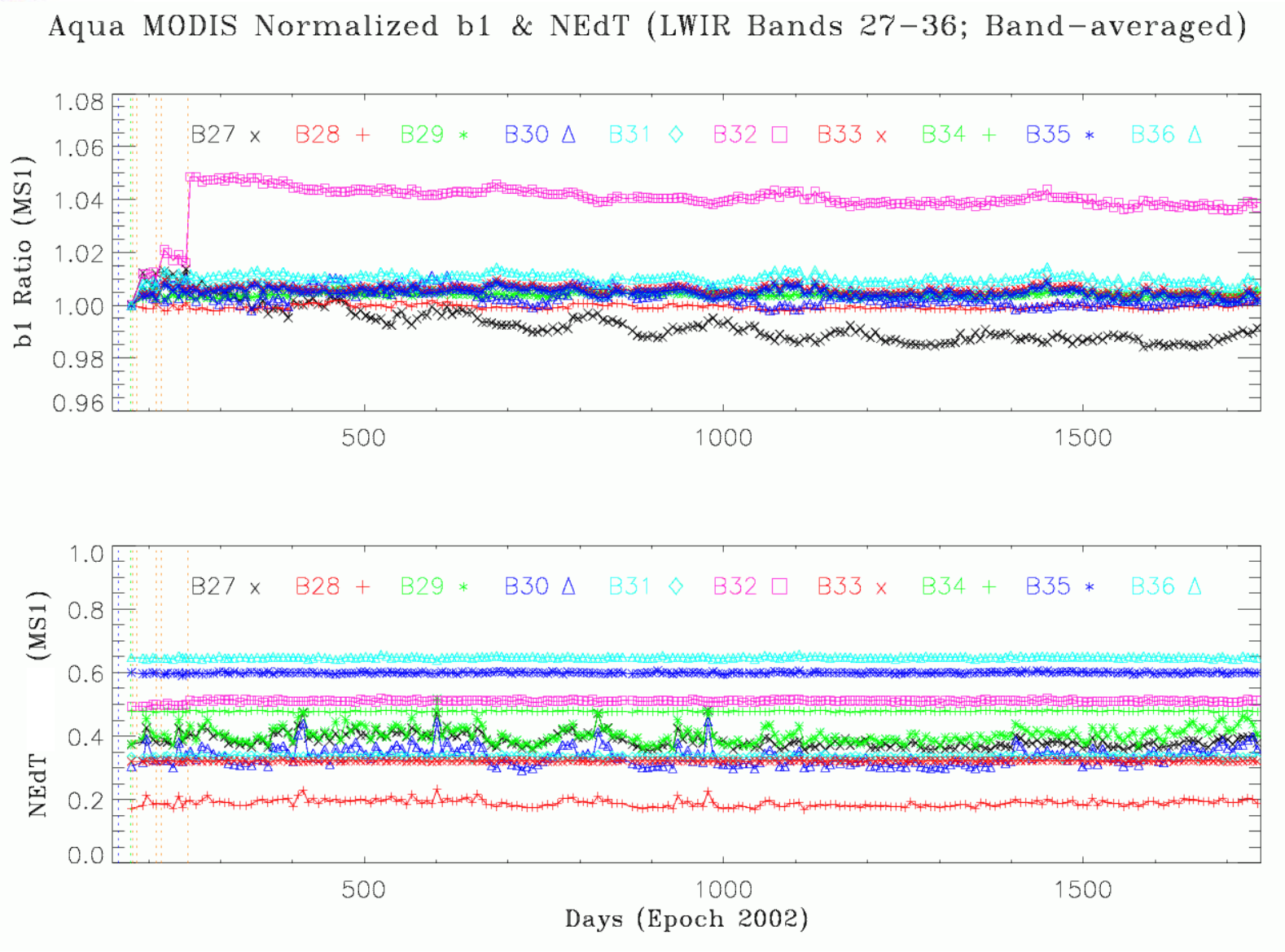


Aqua MODIS TEB MWIR Response Trend



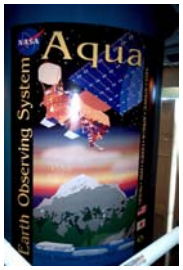


Aqua MODIS TEB LWIR Response Trend



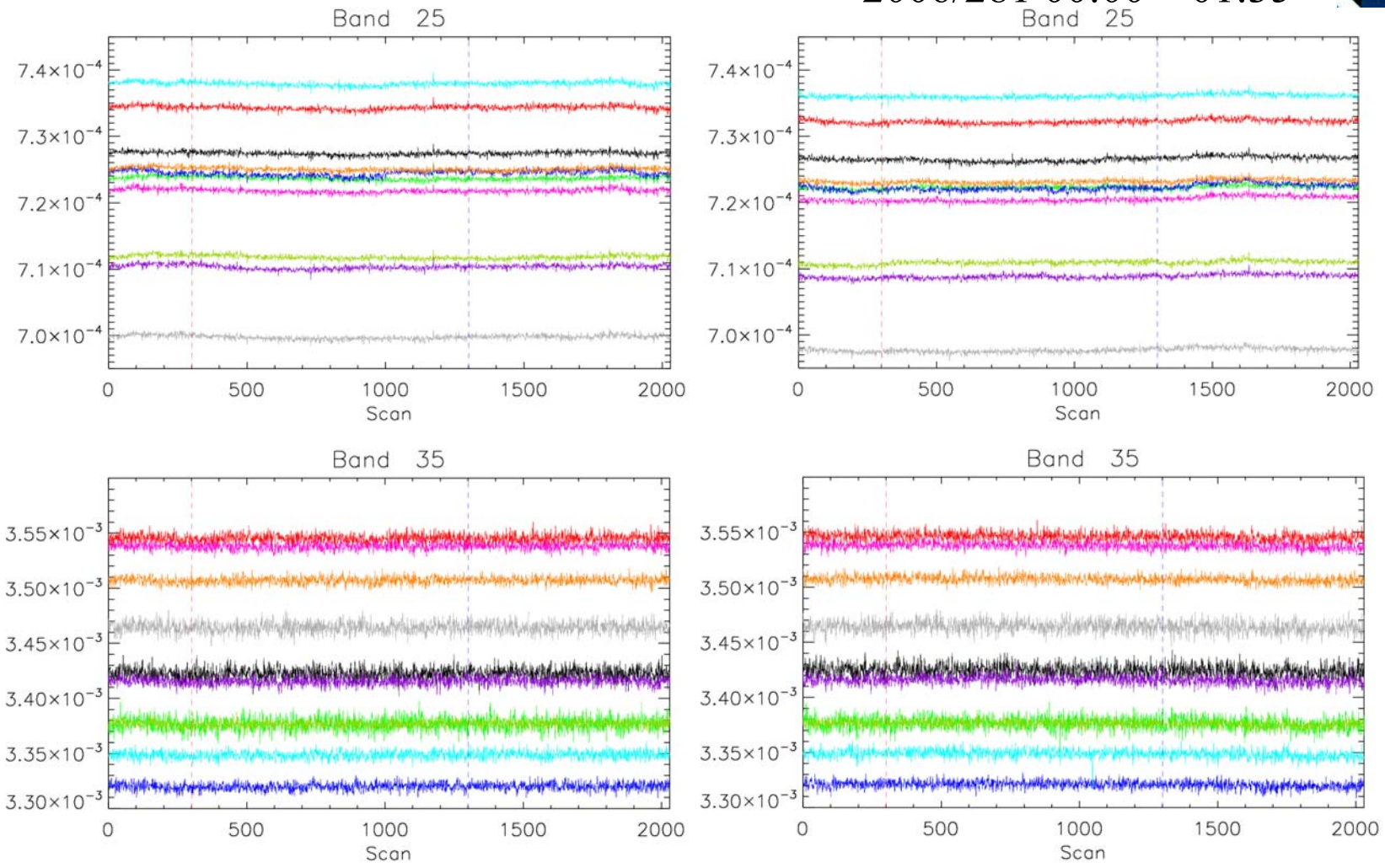
Terra MODIS TEB Short-term Response

Scan-by-scan b1 for one orbit



2005/281 00:00 – 01:35

2006/281 00:00 – 01:35

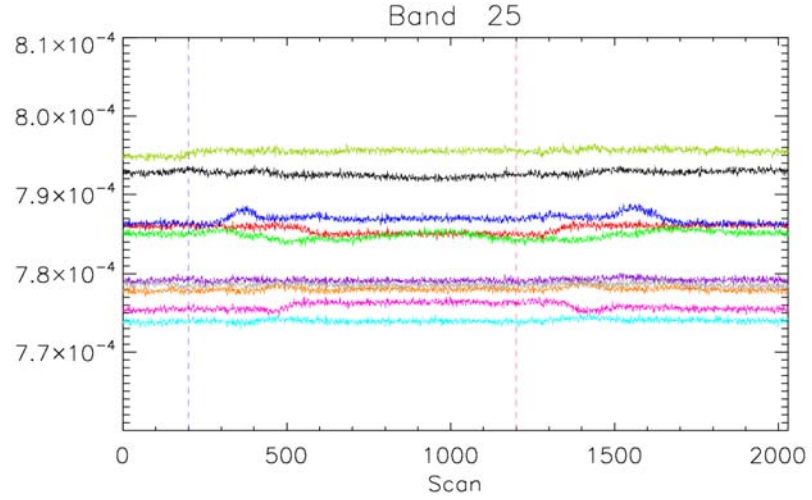


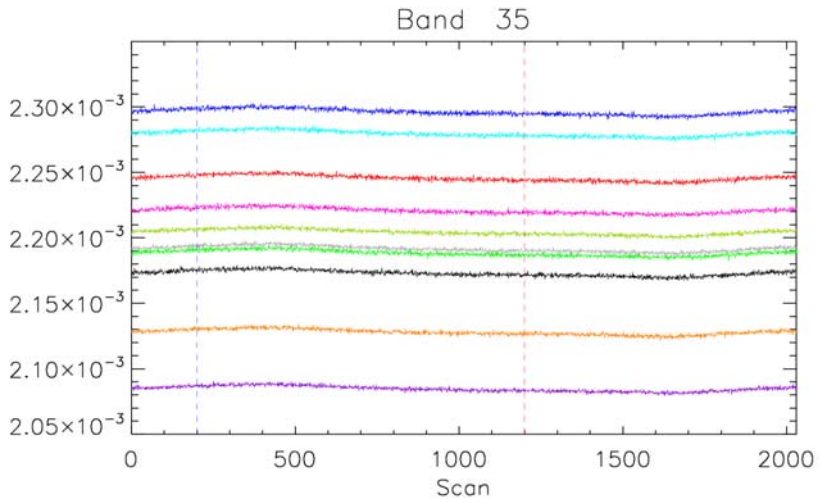
Ch1 Ch2 Ch3 Ch4 Ch5 Ch6 Ch7 Ch8 Ch9 Ch10

Aqua MODIS TEB Short-term Response

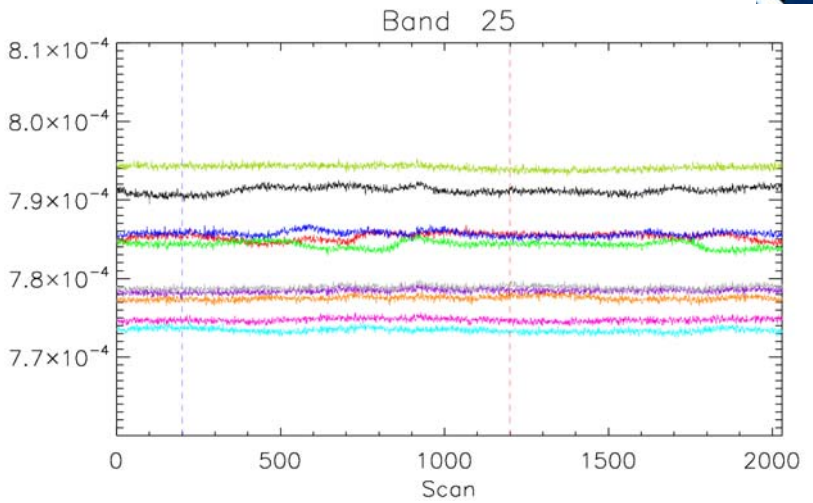
Scan-by-scan b1 for one orbit

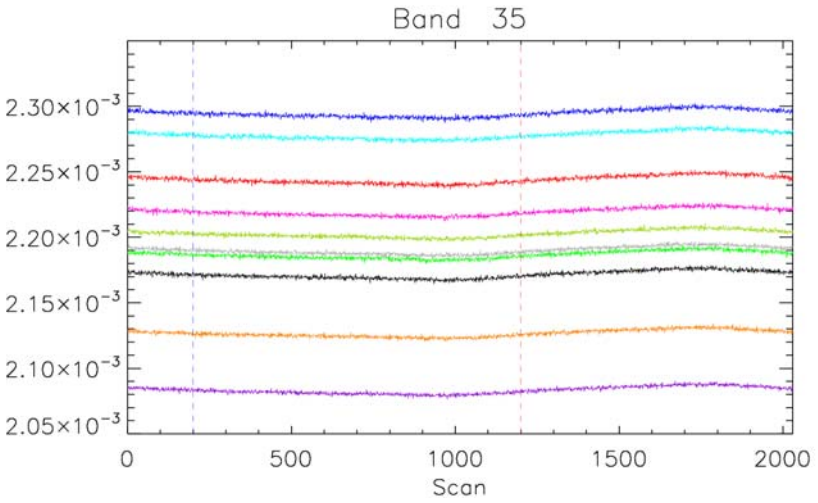
2005/290 00:00 – 01:35





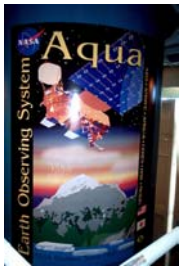
2006/290 00:00 – 01:35





Ch1 Ch2 Ch3 Ch4 Ch5 Ch6 Ch7 Ch8 Ch9 Ch10

Terra MODIS Noisy Detector History



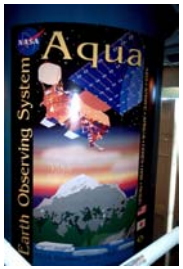
Detectors in Product Order

Day/Year	Band	27			28					29		30				33	34				36
	Spec NEdT[K]	0.25			0.25					0.05		0.25				0.25	0.25				0.35
	Detector #	1	6	8	1	3	8	9	10	4	6	2	3	5	8	1	5	6	7	8	1-10
Pre-launch	-	0.10	0.10		0.05	0.05	0.04	0.05	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	0.09	0.09	0.03	0.05	0.06	0.06	0.05	0.05	0.02	0.02	0.10	0.06	0.11	0.11	0.28	0.23	0.26	0.27	0.29	0.43
232/2000	Back from FPA recycle	0.10	0.24	0.03	0.05	0.05	0.05	0.05	0.05	0.02	0.03	0.11	0.07	0.31	0.11	0.27	0.24	0.33	0.37	0.38	0.42
030/2001	-	0.10	0.27	0.03	0.05	0.06	0.05	0.05	0.05	0.02	0.02	0.12	0.07	0.29	0.30	0.25	0.24	0.33	0.37	0.37	0.43
087/2002	Back from safe mode	0.11	0.24	0.03	0.06	0.32	0.05	0.05	0.04	0.02	0.02	0.10	0.06	0.26	0.64	0.25	0.24	0.29	0.32	0.33	0.43
022/2003	-	0.10	0.23	0.03	0.05	0.30	0.27	0.04	0.04	0.02	0.02	0.10	0.06	0.25	0.65	0.27	0.25	0.33	0.37	0.37	0.43
086/2003	After DSM[1]	0.11	0.23	0.03	0.05	0.29	0.08	0.05	0.05	0.03	0.02	0.10	0.06	0.47	0.65	0.26	0.24	0.33	0.36	0.36	0.44
118/2004	-	0.26	0.26	0.03	0.05	0.16	0.36	0.05	0.16	0.02	0.03	0.10	0.06	0.33	0.41	0.27	0.21	0.29	0.32	0.32	0.43
158/2004	-	0.28	0.25	0.03	0.05	0.16	0.37	0.05	0.21	0.03	0.03	0.10	0.07	0.31	0.40	0.27	0.22	0.28	0.31	0.31	0.43
162/2004	-	0.26	0.27	0.03	0.05	0.16	0.37	0.05	0.20	0.02	0.03	0.14	0.06	0.32	0.42	0.27	0.22	0.30	0.34	0.34	0.43
175/2004	-	0.28	0.26	0.03	0.12	0.17	0.35	0.05	0.17	0.03	0.02	0.17	0.06	0.30	0.41	0.27	0.21	0.28	0.32	0.32	0.43
034/2005	-	0.28	0.22	0.03	0.10	0.16	0.45	0.05	0.16	0.04	0.02	0.17	0.06	0.31	0.39	0.26	0.21	0.28	0.31	0.31	0.43
130/2005	-	0.31	0.22	0.03	0.40	0.15	0.40	0.05	0.14	0.03	0.06	0.17	0.07	0.40	0.40	0.26	0.21	0.31	0.34	0.34	0.43
309/2005	-	0.30	0.21	0.03	0.09	0.14	0.35	0.30	0.18	0.03	0.04	0.18	0.06	0.31	0.40	0.24	0.21	0.27	0.30	0.30	0.43
New → 053/2006	-	0.30	0.21	0.27	0.13	0.15	0.40	0.19	0.16	0.03	0.04	0.16	0.11	0.33	0.39	0.28	0.21	0.28	0.31	0.31	0.43
155/2006	-	0.26	0.21	0.11	0.10	0.14	0.46	0.10	0.15	0.03	0.05	0.14	0.26	0.31	0.41	0.24	0.21	0.28	0.31	0.31	0.44
241/2006	-	0.26	0.22	0.10	0.10	0.14	0.36	0.10	0.11	0.03	1.10	0.15	0.16	0.29	0.39	0.25	0.22	0.28	0.32	0.32	0.43

[1]Spacecraft Deep Space Maneuver

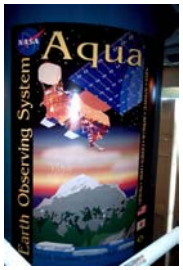
In Spec | Near the Spec | Out of Spec | inoperable

Aqua MODIS Noisy Detector History



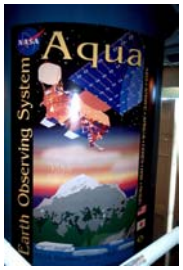
Aqua MODIS TEB Noisy Detector History							
Day/Year	Band	20	21			27	B36
	Spec NEdT [K]	0.05	0.20			0.25	0.35
	Detector #	10	3	9	others	3	5
Pre-launch	-	0.05	0.16	0.28		0.10	1.34
175/2002	Nadir door open	0.03	0.23	0.23	near 0.2	0.09	1.28
183/2002	Back from safe mode	0.03	0.20	0.25	near 0.2	0.09	1.31
218/2002	Back from safe mode	0.03	0.19	0.26	near 0.2	0.09	1.32
255/2002	Back from safe mode	0.03	0.23	0.20	near 0.2	0.09	1.36
102/2003	-	0.03	0.43	0.19	near 0.2	0.09	1.31
201/2003	-	0.03	0.18	0.18	near 0.2	0.09	1.29
010/2005	-	0.03	0.17	0.19	near 0.2	0.23	1.35
	In Spec		Near Spec		Out of Spec		Inoperable

Current TEB Investigations



Issues Raised at last STM

- A0/A2 Calibration coefficient update strategy
- PC-Crosstalk trending
- MSCN impact on PC bands 33-36
- B21 calibration improvement
- TEB calibration long-term drifting

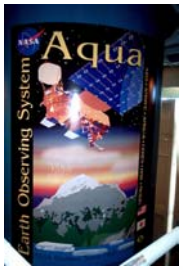


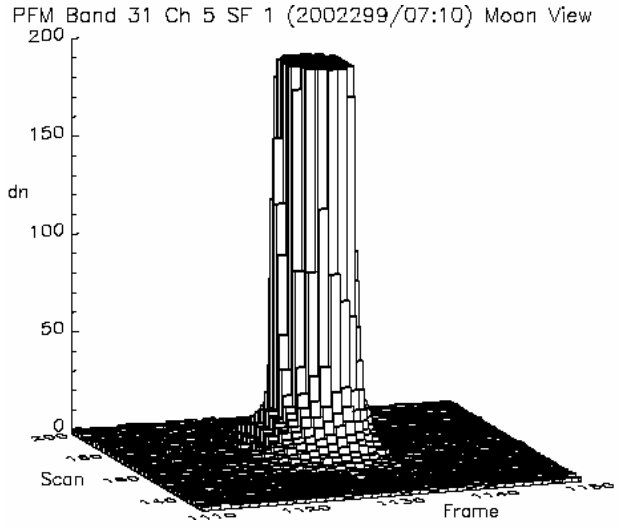
A0/A2 Update Strategy

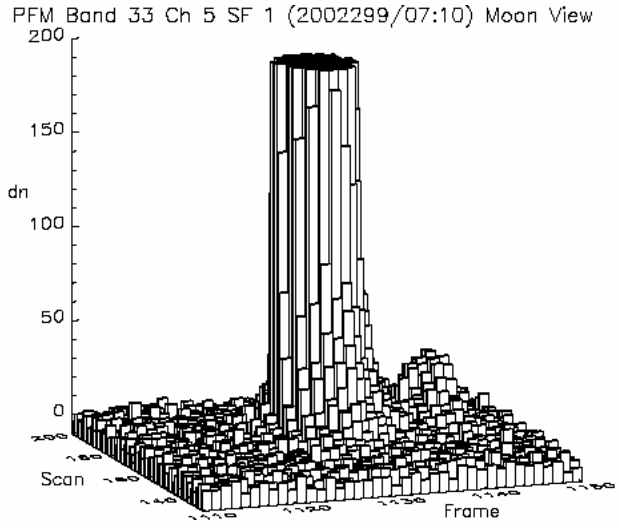
- Current method
  - Terra: B20-25, 27-32: WU cycle, B33-36: A0=0, A2: WU cycle
  - Aqua: B20-25,27-30: Pre-launch, B31-32: WU cycle, B33-36: A0=0, A2: Pre-launch
  - Successful strategy for the typical scene temperature range
    - For (cold) scene temperatures well outside the typical calibration temperature range, the calibration dataset used to derive A0/A2 can cause a bias at these low temperatures (e.g. T_{scene} ~ 200K). This cold scene bias also seen in intercomparison with coincident AIRS measurements.
  - MCST conducted a series of sensitivity tests using all combinations of A0/A2 data sets: Pre-launch, Warm-up, Cool-down, A0=0
    - Preliminary conclusion: The choice of A0=0 and A2 derived from WU or CD yields consistent scene temperatures with the current LUT for the typical Temp range, and reduces the bias seen at cold scene Temps.

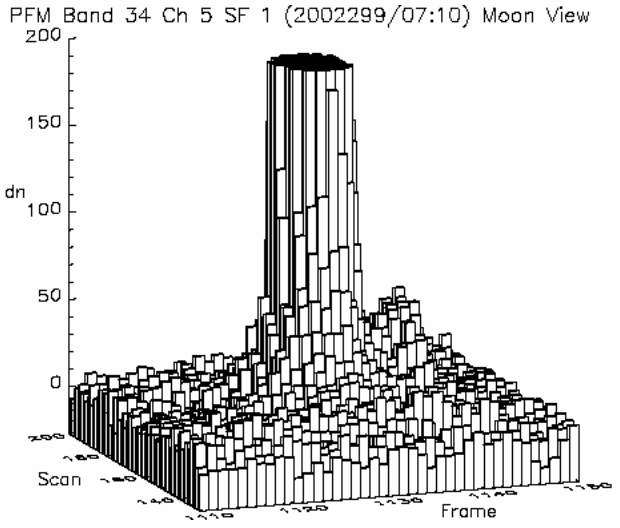
PC-Crosstalk

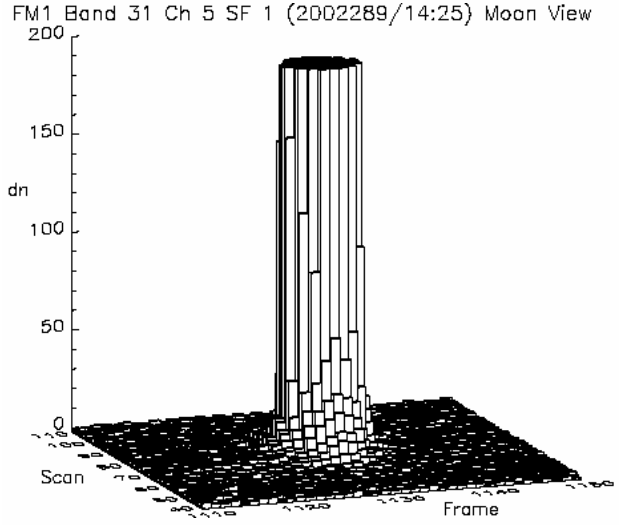
Terra (top) and Aqua (bottom) - B31, 33, and 34

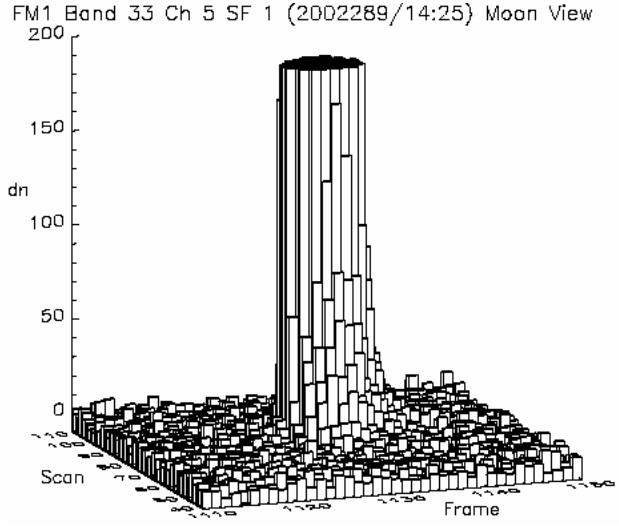


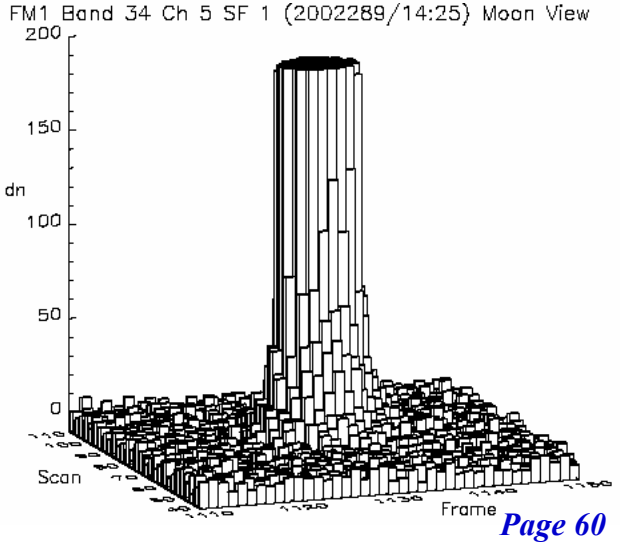




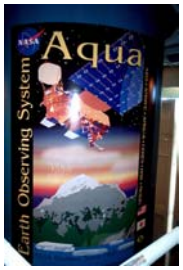


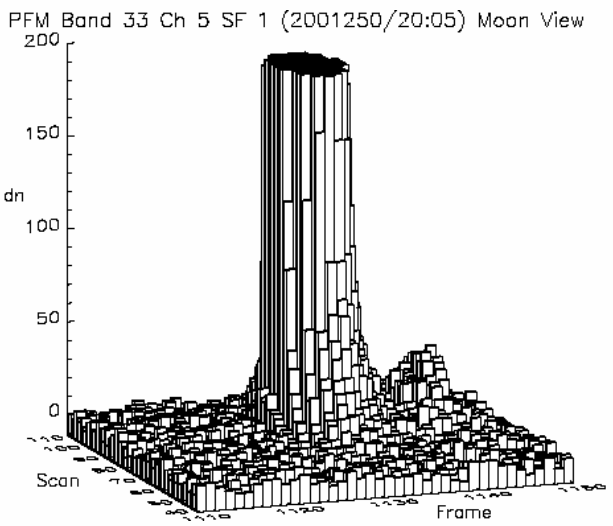


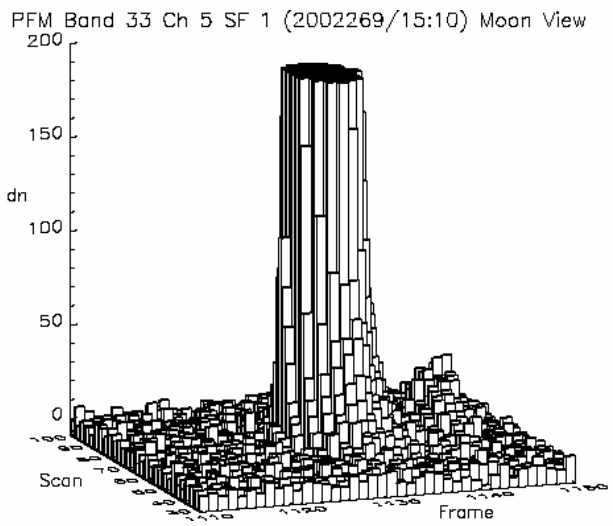


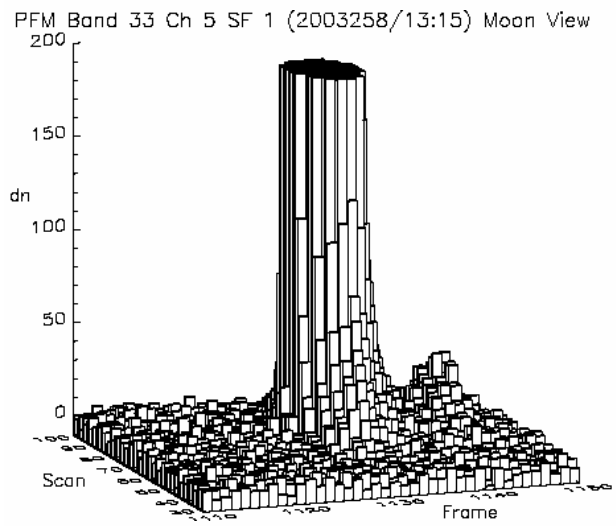


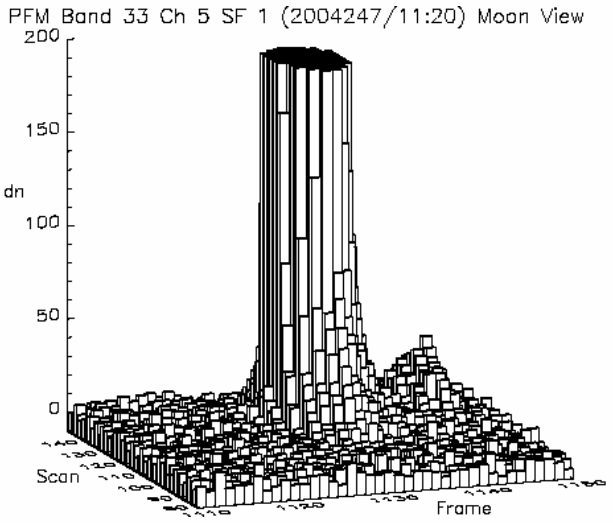
Terra 6-year PC-Crosstalk on-orbit tracking (B33 September lunar view on A-side electronics)

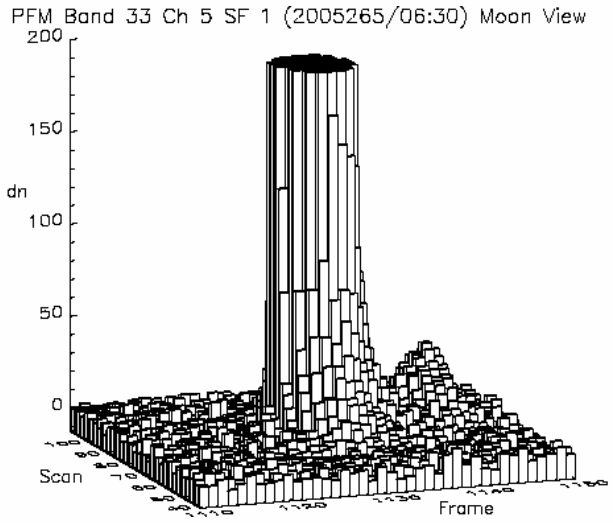


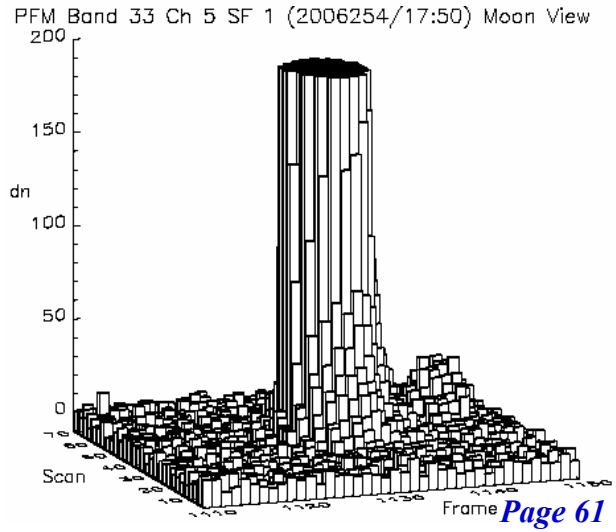


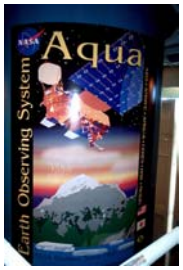






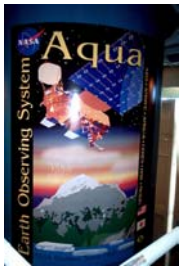






Summary

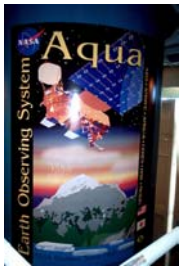
- MODIS TEB calibration has performed well according to design specifications and displays good long-term stability for both instruments: Terra 6.5+ yrs, Aqua 4.5 yrs.
- 2 new noisy detectors & 1 inoperable detector for Terra, none for Aqua.
- TEB issues investigated
  - A0/A2 update strategy
  - PC-Crosstalk
  - B21 calibration improvements
  - Calibration long-term drift



Challenging Issues and Future Work

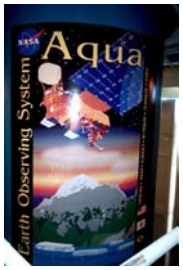
- TEB Calibration
- Calibration coefficients (a0/a2) update strategy (TBR with Chris)
  - Consistency between versions and over the entire mission
- MSCN impact on PC bands 33-36
  - Primarily in Terra MODIS PC bands prior to flight SW patch for reset fix
- Improvement of B21 calibration (TBR)
- Study of calibration long-term drifting (progress made)
  - On-orbit changes of BB temperature and emissivity?
- Absolute calibration accuracy
- Calibration consistency between Terra and Aqua MODIS TEB
- Cross-sensor calibration (approaches developed and reported)
  - CDR and data fusion (measurements from multi-sensors)
  - Paper in SPIE 2006 (Xiong et al.)

Challenging Issues and Future Work



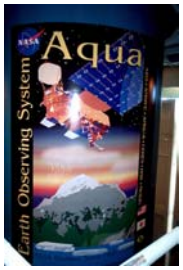
- RSB Calibration

- Continue to monitor and apply corrections for the optics degradation
  - Tracking mirror side difference, detector-to-detector difference, and SD degradation (long-term effect at different viewing angles: calibration and monitoring)
  - Signal drops of VIS bands in SD observations
- Overall calibration improvements
  - On-orbit detector dependent BRF and VF (especially VIS bands)
- Continuing efforts on tracking SWIR bands calibration
  - Correction coefficients derived from NTDM data sets
- Study SDSM sun-view screen and SD screen impact on the SD degradation
  - Primarily in Terra MODIS (effects due to noise and low signals)
- Evaluate alternative approaches for tracking RSB RVS
  - For VIS bands 8,9,3,10 (high priority)
- Calibration consistency (input received from U. AZ)



Challenging Issues and Future Work

- Others
  - Continuous efforts on detector noise characterization (assessments made for TEB, reported in CALCON 2006, Xiong et al.)
  - Implementation of earthshine impact reduction approach in RSB calibration (reported in SPIE 2006 Wolfe et al. and Xie et al.)
  - Investigation of calibration difference among detectors
    - Difference may vary with AOI (more work needed)
  - Continuous efforts on calibration uncertainty assessment (previously reported in SPIE 2005 Xiong et al.) and updates
    - Configuration dependent, time dependent, AOI dependent
  - Support for polarization simulation and modeling work
    - Experience passed to VIIRS work
  - Development of new approaches that are critical to continuously maintaining calibration and data quality
    - Limitations of OBCs
  - Impact due to relocation of SBRS: future support



Summary

- Instruments have performed well and are stable
  - Terra (near 7 years) and Aqua (4.5 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 (larger in Terra, including SD degradation mirror side difference)
  - Stable performance for instrument spectral and spatial characterization
- Continuous 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 (Terra MODIS TEB noisy detectors)
- 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*