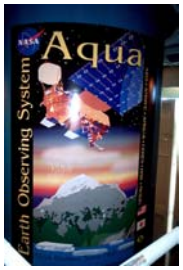
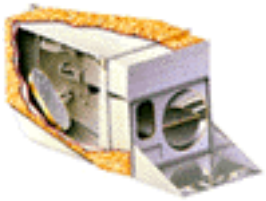


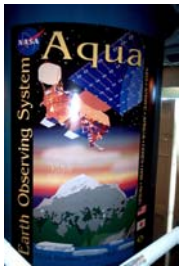

# Status of EOS Terra and Aqua MODIS
## (Sensors, Calibration, and Level 1B / LUTs)

*Jack Xiong*
*Code 614.4, Sciences and Exploration Directorate, NASA/GSFC*

*MODIS Characterization Support Team (MCST)*

*Bill Barnes*
*University of Maryland at Baltimore County (UMBC)*

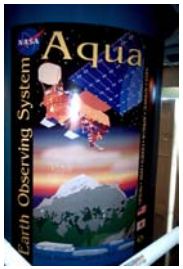





# Outline

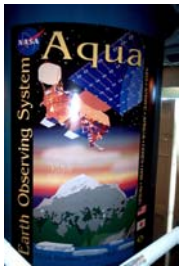
- Introduction
  - Instrument Background
  - Overview of Calibration and Characterization
- Status of Instruments
- Level 1 and LUT Updates
- Instrument On-orbit Performance
- Challenging Issues (Concerns)
- Summary

# Introduction




Acknowledgements:

- All members of MCST (contractors: SSAI, SAIC, STGI)
- Science Team representatives
  - MODIS Science Team (Vince Salomonson, Team Leader)
  - Land (Eric Vermote and Zhengming Wan)
  - Ocean (Bob Barnes … and Bob Evans)
  - Atmosphere (Chris Moeller)
  - Cal/Val (Stuart Biggar and Kurt Thome)
- SBRS
  - Roger Drake and Jim Young
- Other NASA members
  - Eugene Waluschka, Bruce Guenther, and Robert Wolfe



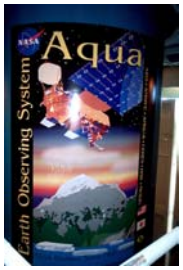

# Introduction

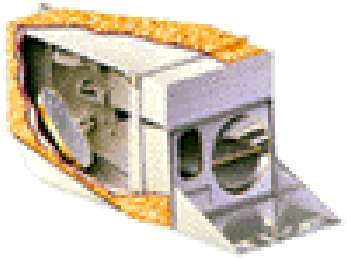
MCST (Jack Xiong and Bill Barnes)

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

- Instrument Operation Team (Bryan Breen and Tony Salerno)
- Calibration Team (Vincent Chiang, Junqiang Sun, and Xiaobo Xie)
  - Thermal Emissive Bands (TEB) routine and special calibration and characterization (BB), algorithms, science support, testing, etc.
  - Reflective Solar Bands (RSB): routine and special calibration and characterization (SD/SDSM), algorithms, calibration and characterization using SRCA and Moon, science support, testing, etc.
  - LUTs preparation and testing (challenges for RSB)
- L1B Team (James Kuyper and Liqin Tan)
- Budget reduction impact on tasks, responses, and science support
  - 35% staff reduction (FY03-05)

# Instrument Background



PFM

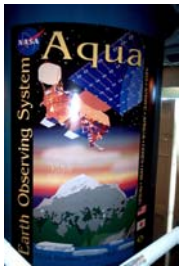
FM1

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

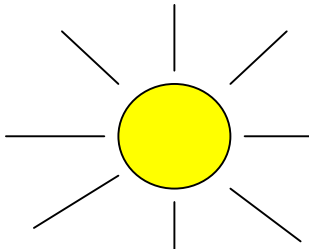
Aqua (EOS-PM):
Launched on 05/04/02
First light 06/24/02

- 2-sided Paddle Wheel Scan Mirror
  - (10km by 2330 km swath per 1.478 sec)
  - Day data rate: 10.6 Mbps, night data rate: 3.3 Mbps (100% duty cycle, 50% day and 50% night)
- 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

# Calibration and Characterization



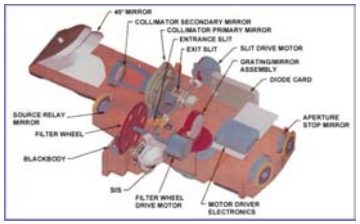

SDSM



Solar Diffuser

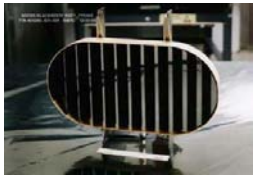
SDSM

SRCA



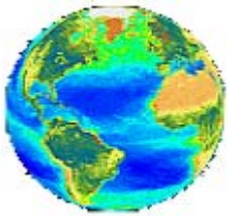
Blackbody

Scan Mirror



Space View

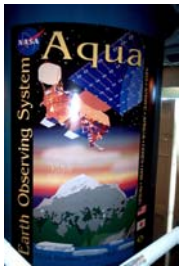
Moon

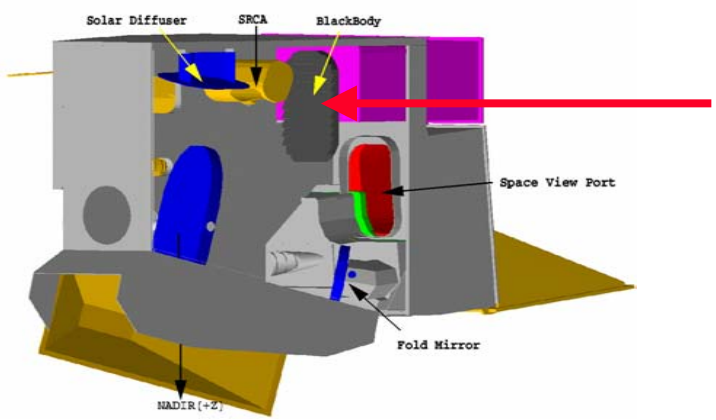


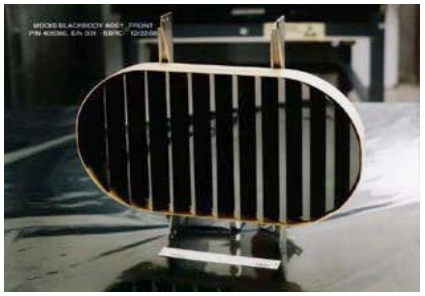
**BB** (quarterly)
**SD/SDSM** (weekly first year to bi-weekly)
**SRCA** (monthly radiometric, bi-monthly spatial, quarterly spectral)
Maneuvers (roll: monthly **Moon**; yaw: 2 for Terra and 1 for Aqua; pitch: 2 for Terra)

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

# 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

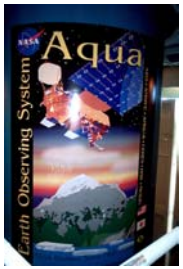
**L:** Spectral band averaged radiance

**dn:** Digital count with background corrected

*Calibration coefficient, b1, from BB*

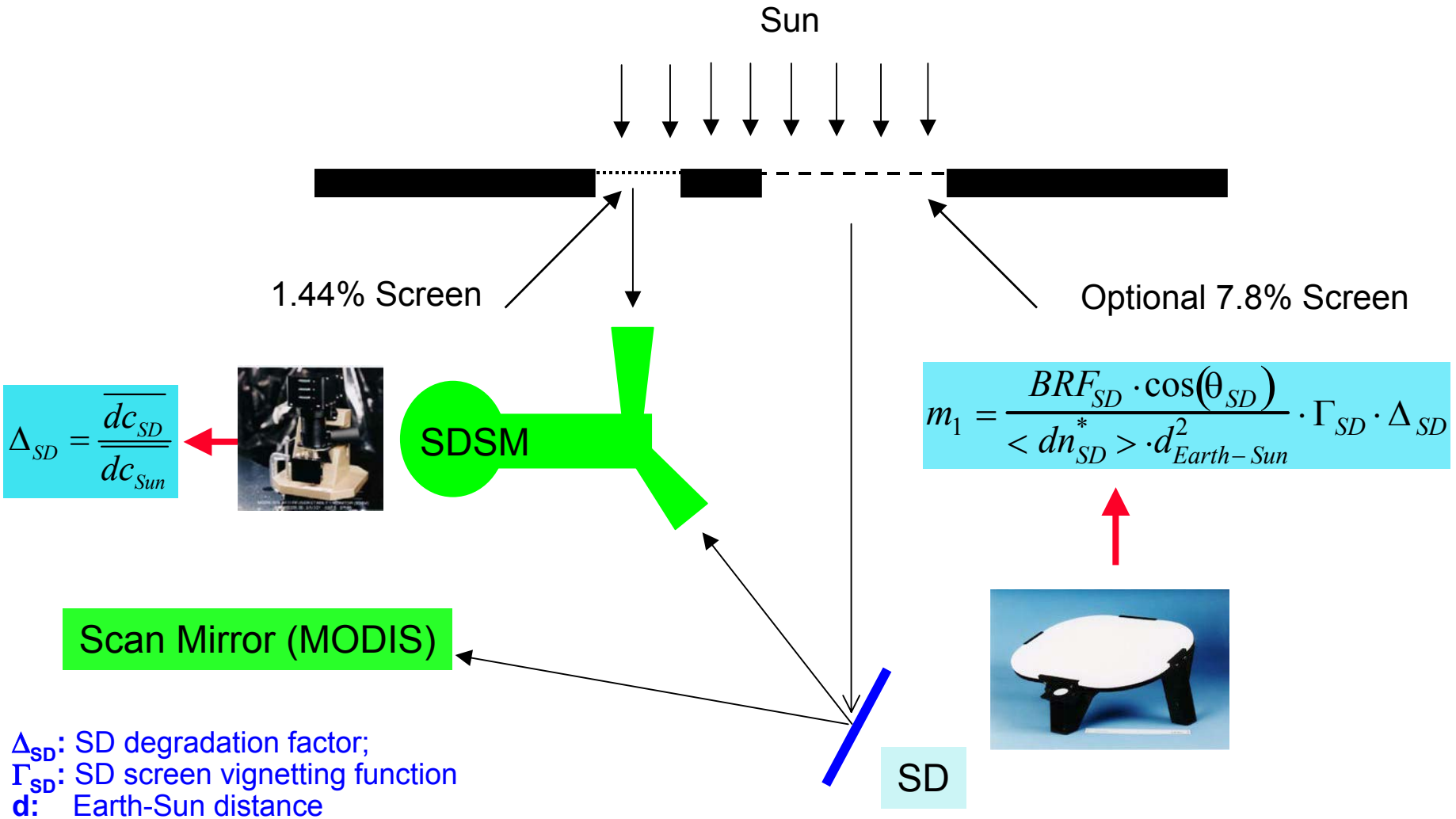
$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$

# MODIS RSB Calibration Using SD/SDSM




*Reflectance Factor*

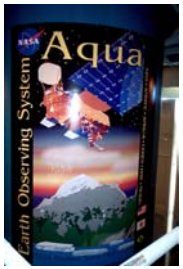
$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$$




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

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

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




# Status of Instruments

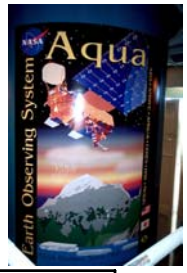
## Terra MODIS (over 5 years)

- 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
  - No concerns for the other doors' movements and SRCA lamps life constrain
  - Recent anomalies (since last MST workshop in July 2004)
    - Spacecraft Science Formatting Equipment (SFE) shutdown on December 24, 2004
    - Small data drops (a few scans each time) when S/C over and near SAA region

## Aqua MODIS (over 2.5 years)

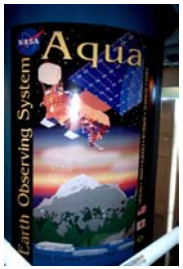
- Stable and Normal Operation
  - Same configuration used for the entire mission (currently B conf.)
  - 2342 (712 on-orbit) of 3022 SD door movements
    - Careful planning of SD CAL if want another set of Yaws and 6+ years of mission
  - Recent anomalies
    - None

# 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 is re-enabled |
| 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) |
| Jan 15, 2004 | SFE Recycled | SFE Side-A was recycled |
| Feb 18, 2004 | SFE Anomaly | SFE autonomously shuts down while passing through the SAA (Back to science mode on Feb 19) |
| 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) |

new




# Aqua MODIS Operational Configurations

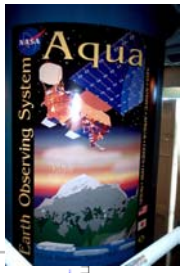
## *Same Configuration Used for the Entire Mission*

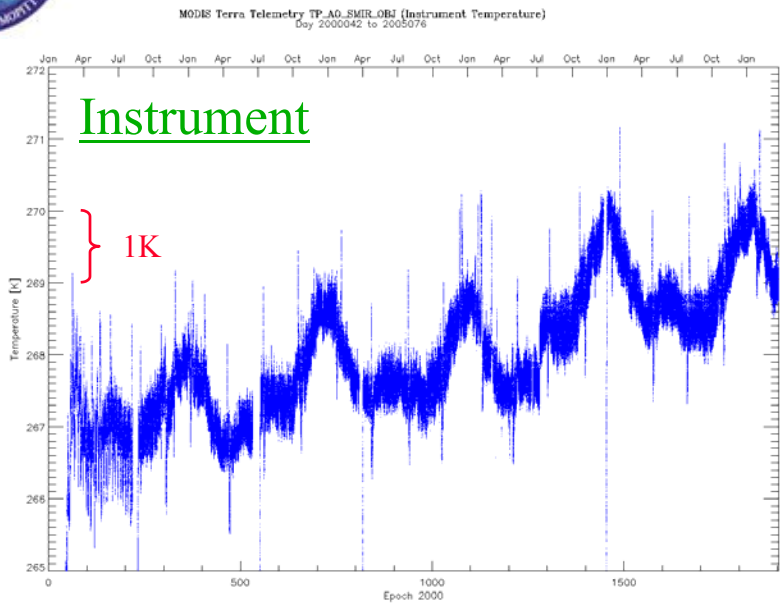
| Date | Events | Description |
|---|---|---|
| May 4, 2002 | Launch | Launched successfully |
| June 7, 2002 | Science Mode | MODIS started science mode on B-side (SMIR Itwk/Vdet = 102/184) |
| June 24, 2002 | Nadir Door Open | Aqua MODIS First Light |
| June 27, 2002 | S/C Safe Hold | Aqua spacecraft Single Event Upset (SEU)<br>SMIR Itwk/Vdet was left at 102/136 (Returned to 102/184 on July 8)<br>MODIS returned to science mode on July 2 |
| July 29, 2002 | S/C Safe Hold | S/C ground pointing management anomaly<br>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<br>S/C recovered to Fine Pointing Mode same day |

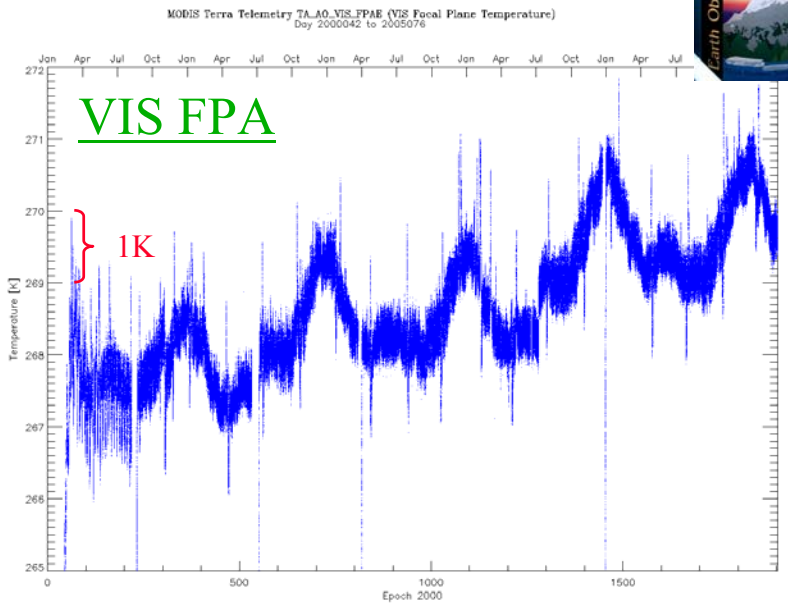
**MCST IOT document: MODIS Instrument Operations**

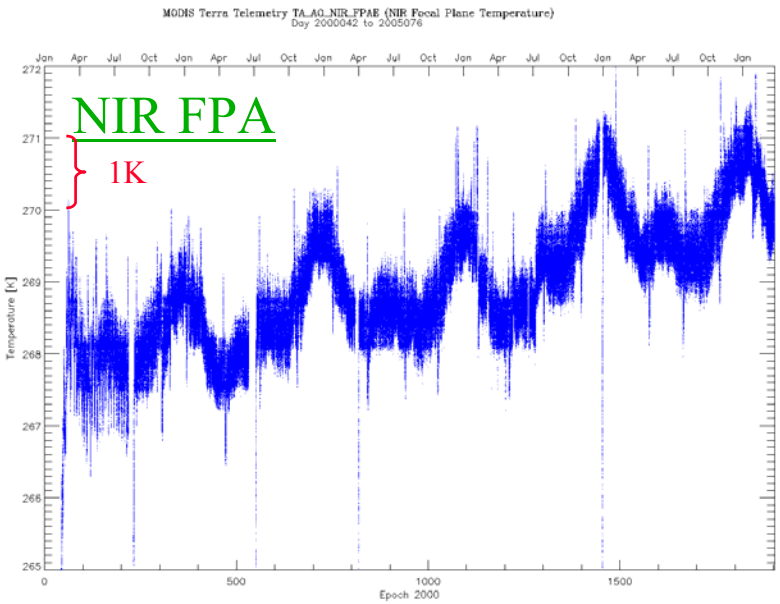
**MCST WEB: Operation configuration changes and instrument reset events impact on science data**

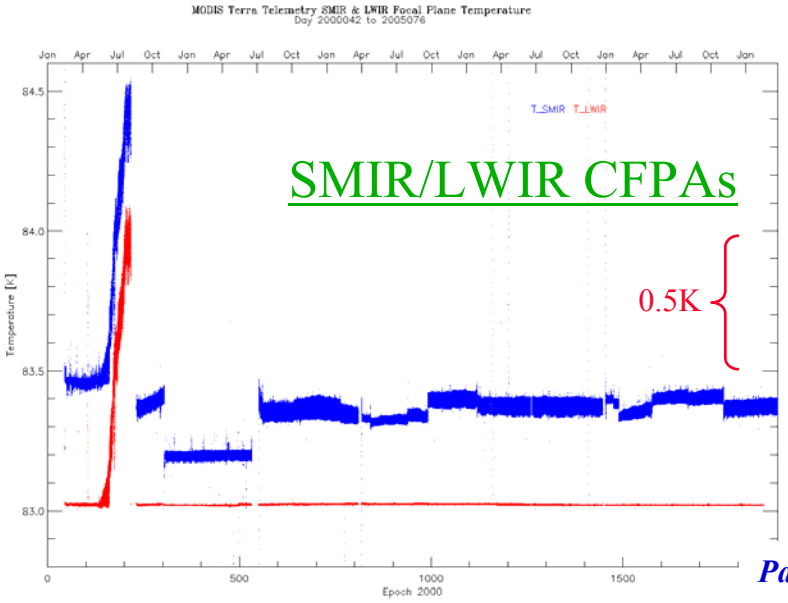
# Instrument and FPA Temperatures (Terra)



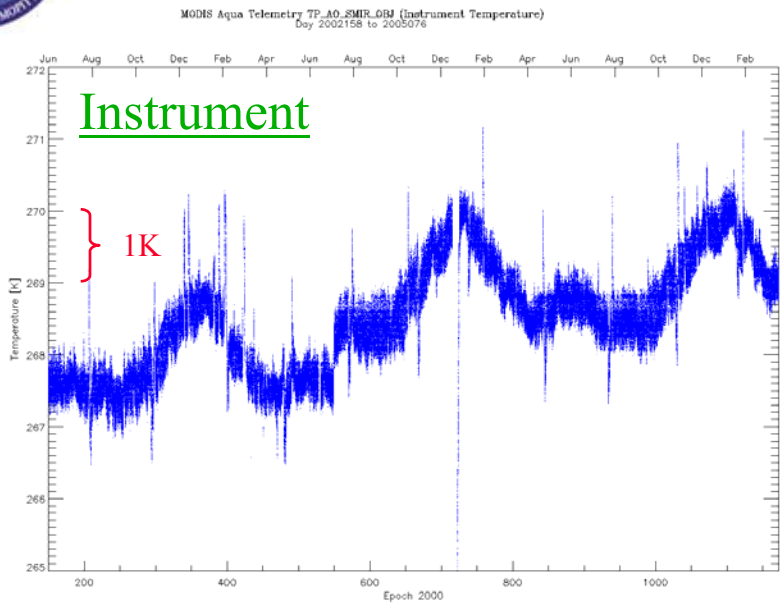



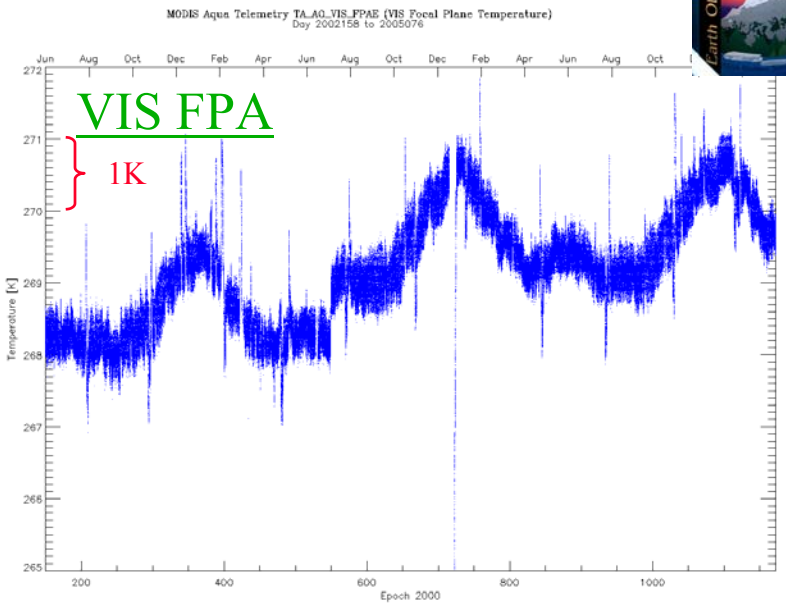



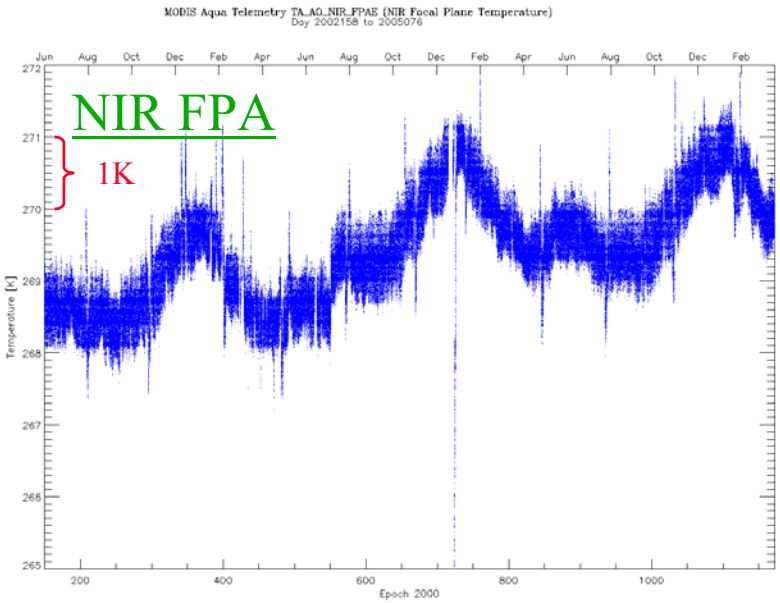



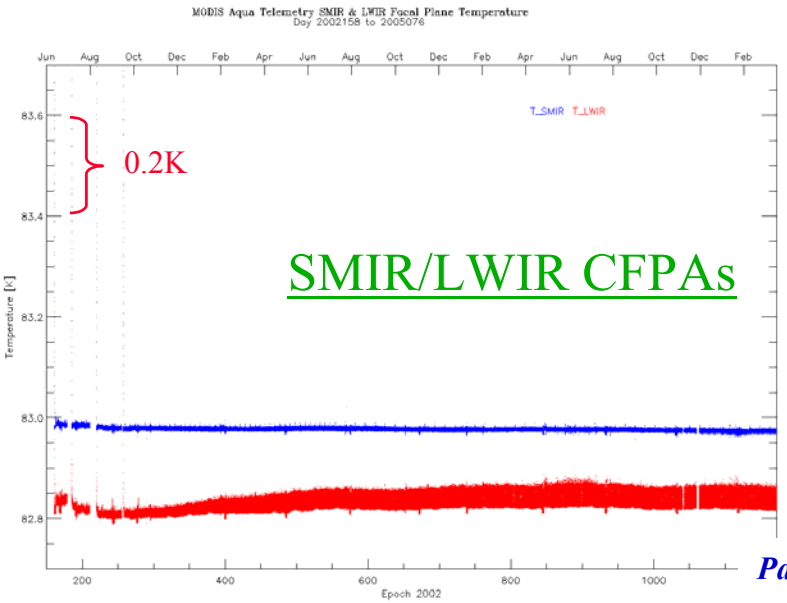




# Instrument and FPA Temperatures (Aqua)

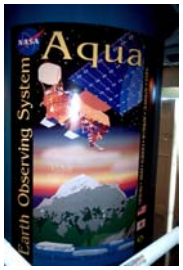


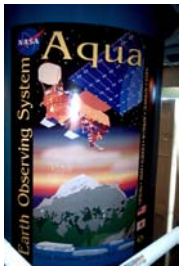

# L1B / LUT Updates



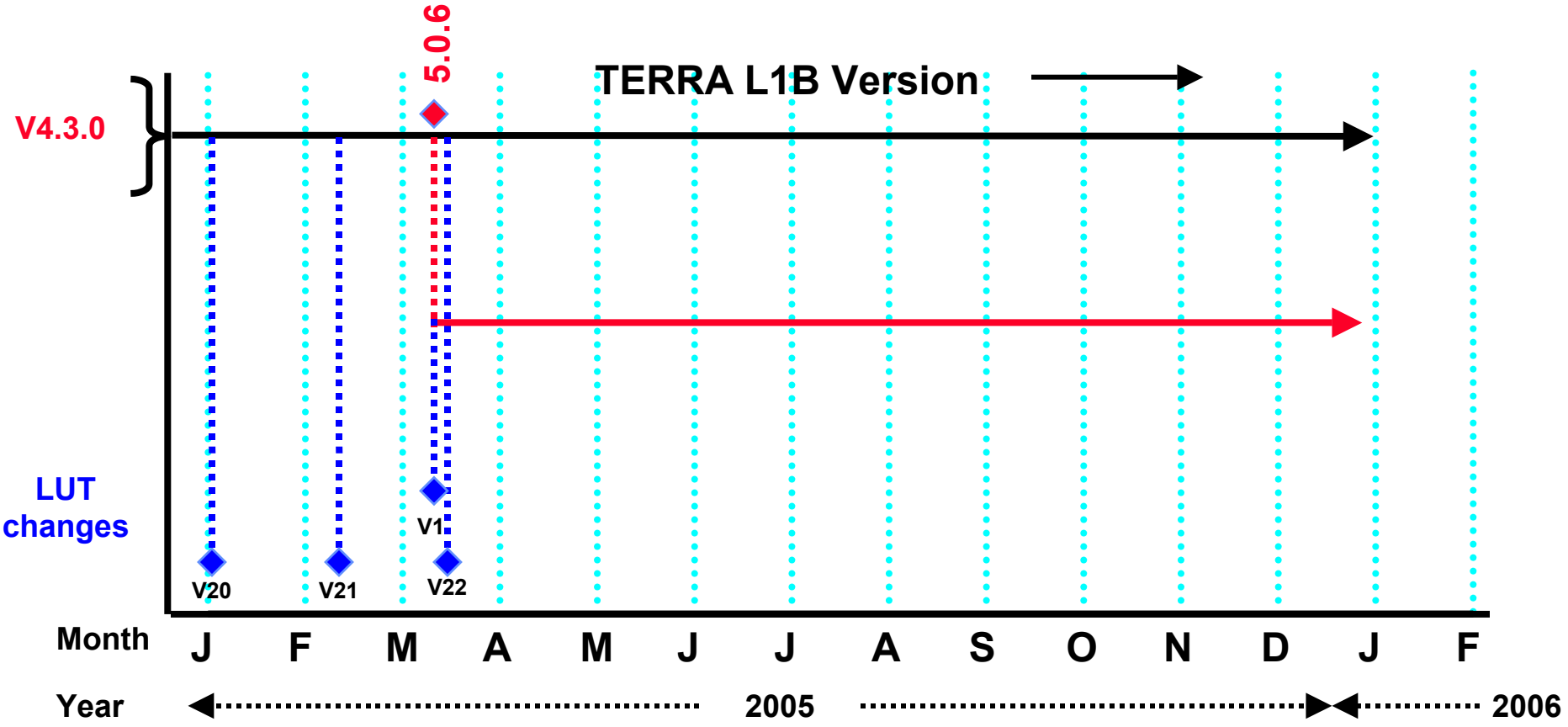

## Collection 5 (Terra and Aqua MODIS)

- Code
  - Add a new LUT for SWIR correction with detector dependency
  - Enable B21 calibration with mirror side dependency (LUT)
  - Fix code version recording
  - Improve code portability and comply with ESDIS guideline
  - Correct dimension mapping offset setting for 250m band data
  - Add HDFEOS_FractionalOffset
- LUTs
  - Add new LUTs due to algorithm and code changes
  - Update calibration coefficients (consistently processed) and QA table (detector quality flags)
  - Update dn_sat values (bands with or without pre-saturation)
  - Use predicted calibration coefficients for RSB forward production
  - DSM RVS for TEB (Terra only)

# L1B / LUT Updates

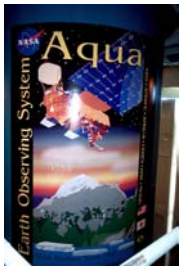



**SWIR OOB correction detector dependency**
**Band 21 calibration with mirror side dependency**
**HDFEOS Offset**

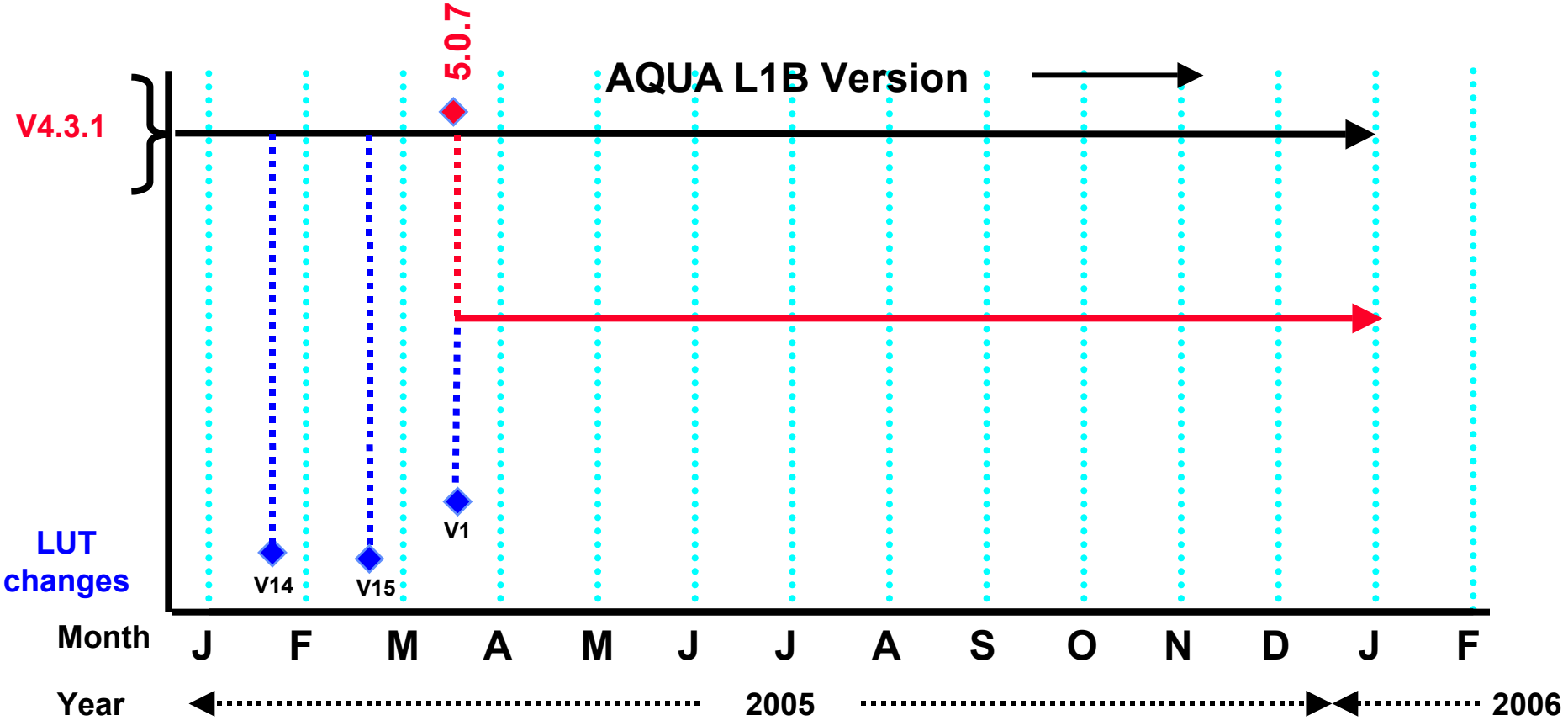



**V5.0.6_Terra: production began on 03/07/05 (2005066)**

# L1B / LUT Updates

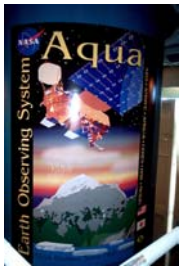



**SWIR OOB correction detector dependency**
**Band 21 calibration with mirror side dependency**
**HDFEOS Offset**



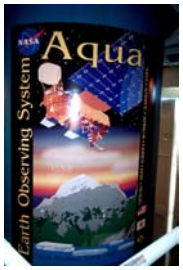

**V5.0.7_Aqua: production begin on TBD**


# Instrument On-orbit Performance



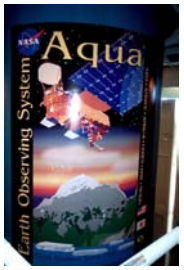

- Thermal Emissive Bands (16 bands and 160 detectors)
  - Terra MODIS
    - Stable short-term and long-term response trending (excluding sensor configuration change and instrument reset events)
    - 24 (10 in B36 from pre-launch, 2 since last STM) noise detectors and 0 inoperable detectors
  - Aqua MODIS
    - Better response trending than Terra MODIS
    - 4 (3 in B21 from pre-launch, 1 since last STM ) noise detectors and 0 inoperable detectors
- Reflective Solar Bands (20 bands and 330 detectors)
  - Terra MODIS
    - Noticeable optics degradation (wavelength dependent, mirror side dependent); small gain changes after configuration changes or instrument reset events; SDSM works well with normalization approach
    - 21 (20 from pre-launch, band 7) noise detectors and 0 inoperable detectors; no changes since last STM
  - Aqua MODIS (more stable)
    - Noticeable optics degradation (wavelength dependent); SDSM works well with normalization approach
    - 3 noise detectors and 15 (13 in B 6 from pre-launch) inoperable detectors; no changes since last STM
  - Applications of Lunar Response Trending (Relative Calibration)

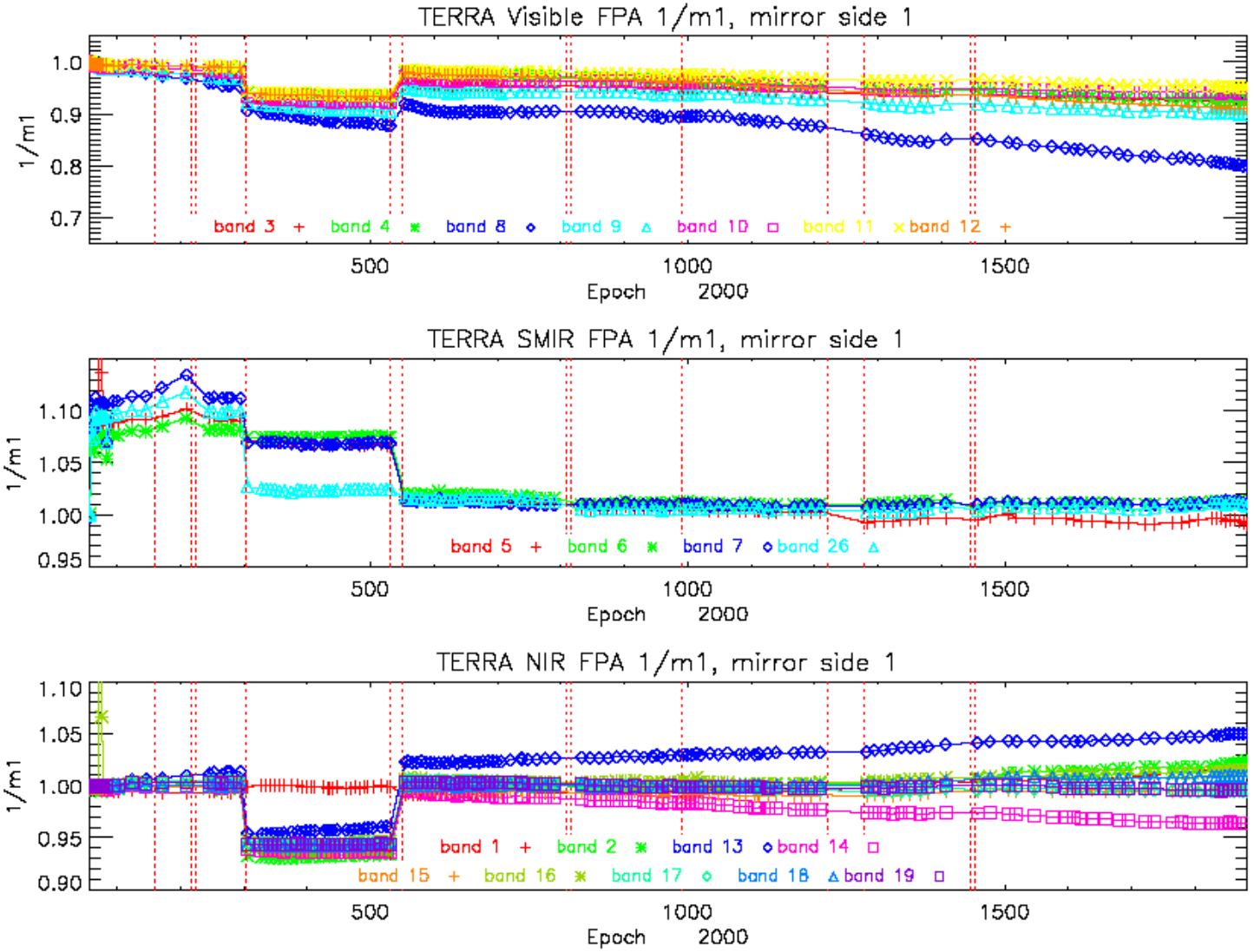

# Instrument On-orbit Performance



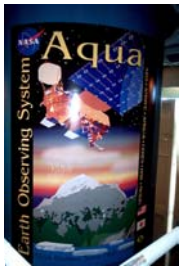

- Spectral (RSB only)
  - Terra MODIS
    - Center wavelength shifts (relative to pre-launch) are less than 0.5nm for most RSB (except 0.6nm for B8); On-orbit drifts are less than 0.2nm for all bands
  - Aqua MODIS
    - Center wavelength shifts (relative to pre-launch) are less than 0.5nm for most RSB (except 1nm for B2); On-orbit drifts are less than 0.2nm for all bands
- Spatial (RSB and TEB)
  - Terra MODIS
    - BBR in specification in along scan direction
    - BBR in specification in along track direction, except 2 bands slightly out specification
  - Aqua MODIS
    - BBR in specification for bands within VIS/NIR and bands within SMIR/LWIR
    - 300m along scan shifts and 350m along track shifts for SMIR and LWIR FPAs (relative to NIR FPA); one of Aqua MODIS problems identified pre-launch
    - Post launch BBR are relatively stable

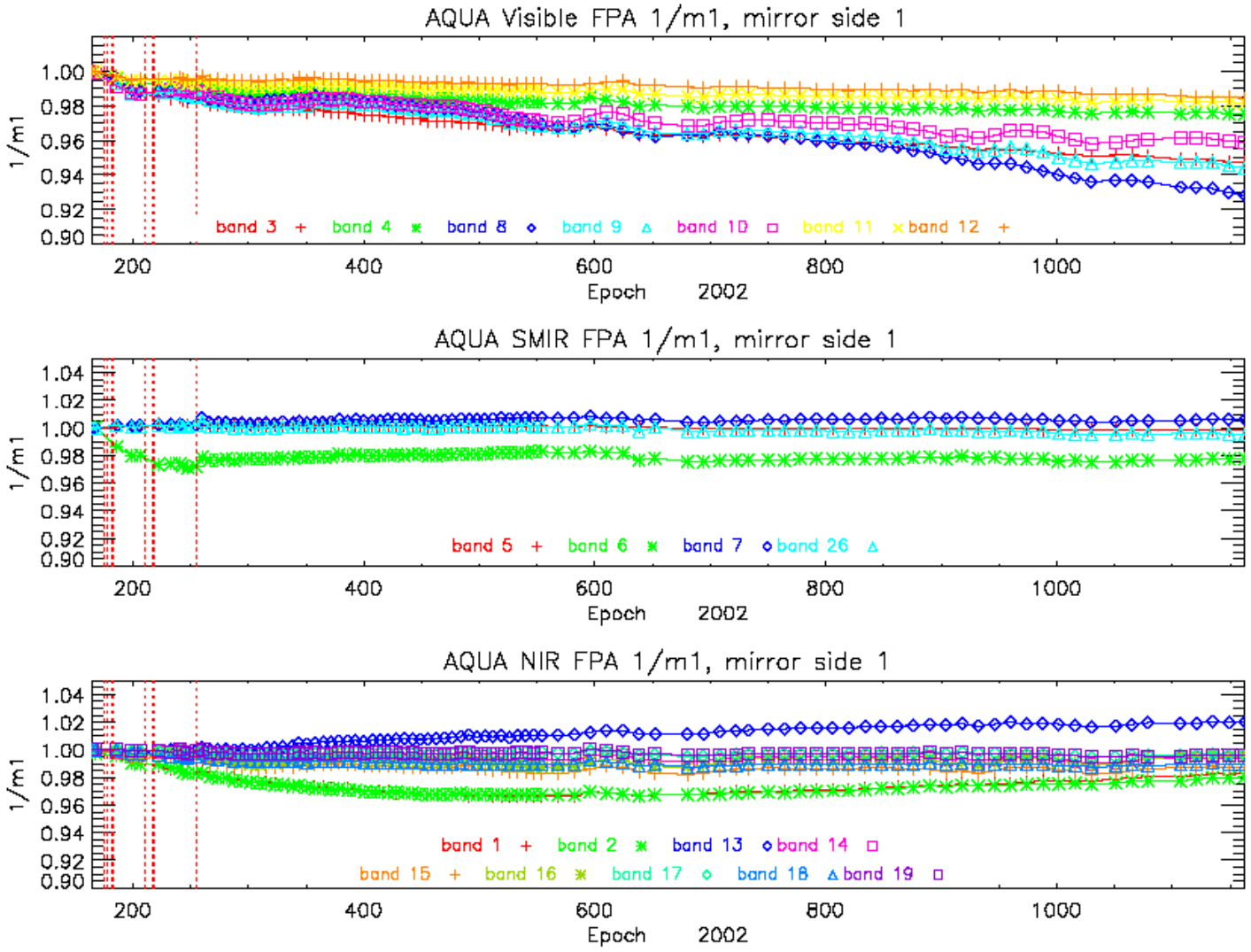
# MODIS RSB Response Trending



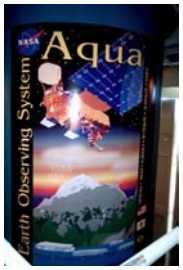



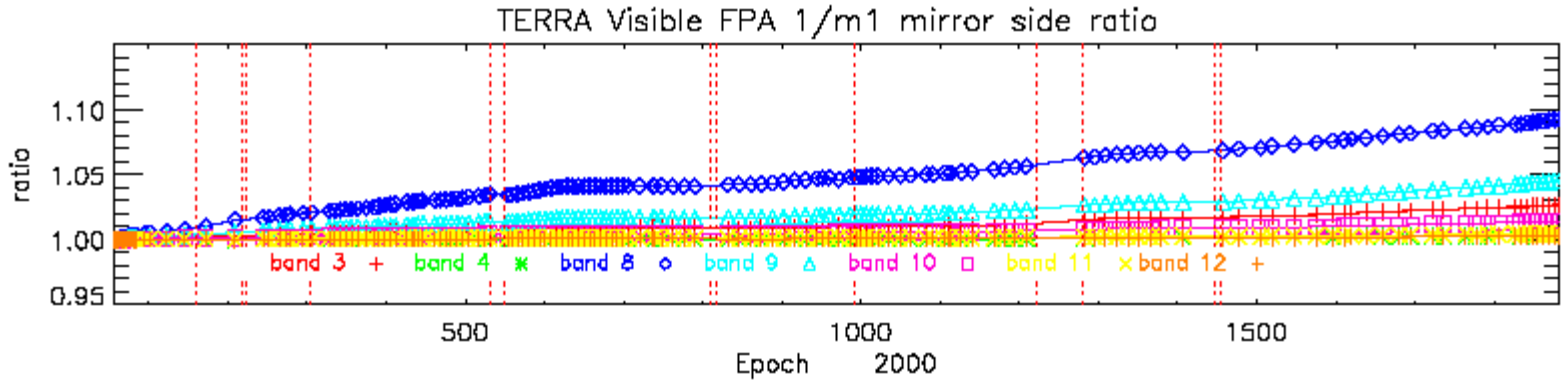
# MODIS RSB Response Trending

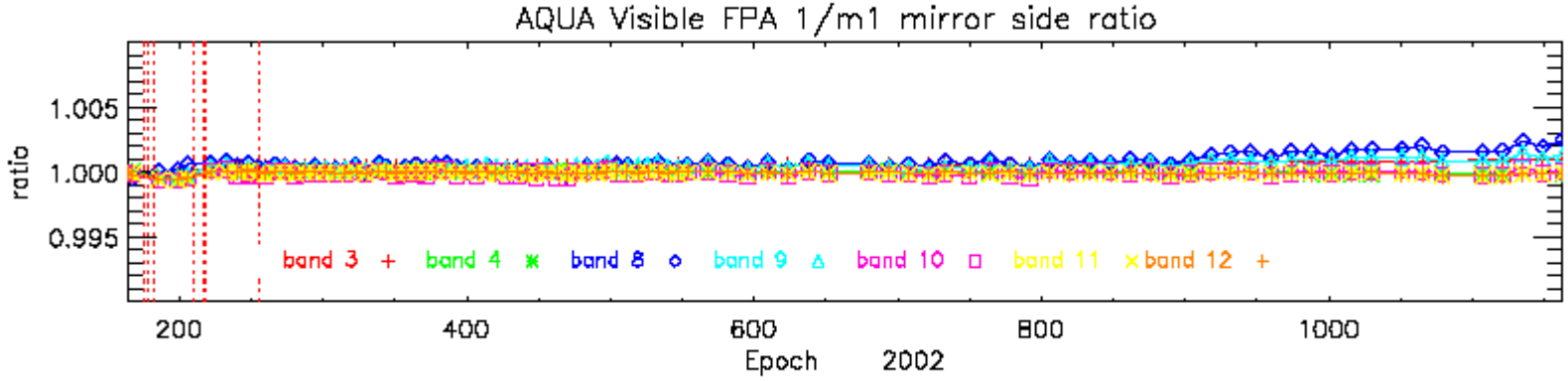


# MODIS RSB Response Trending

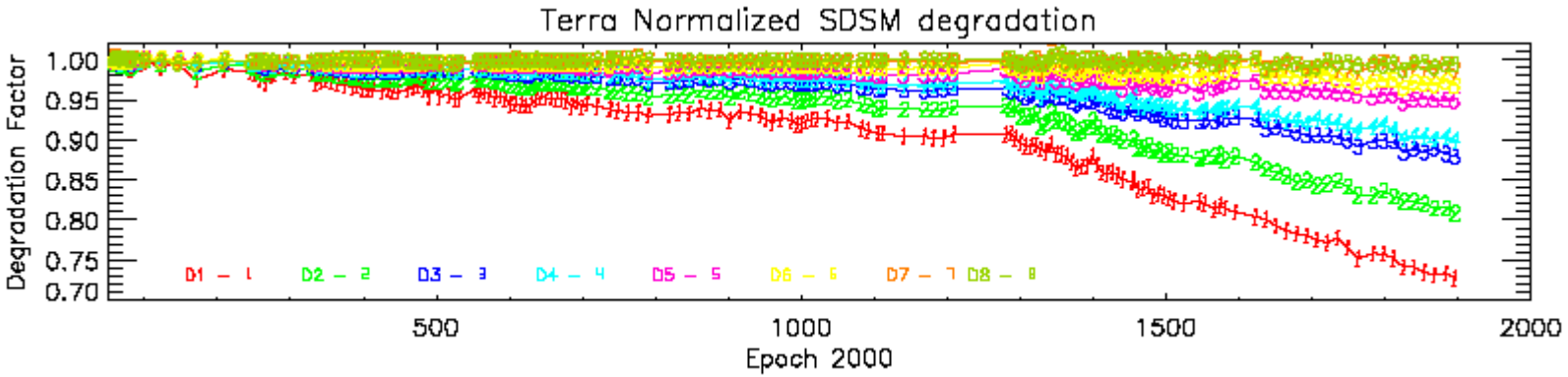


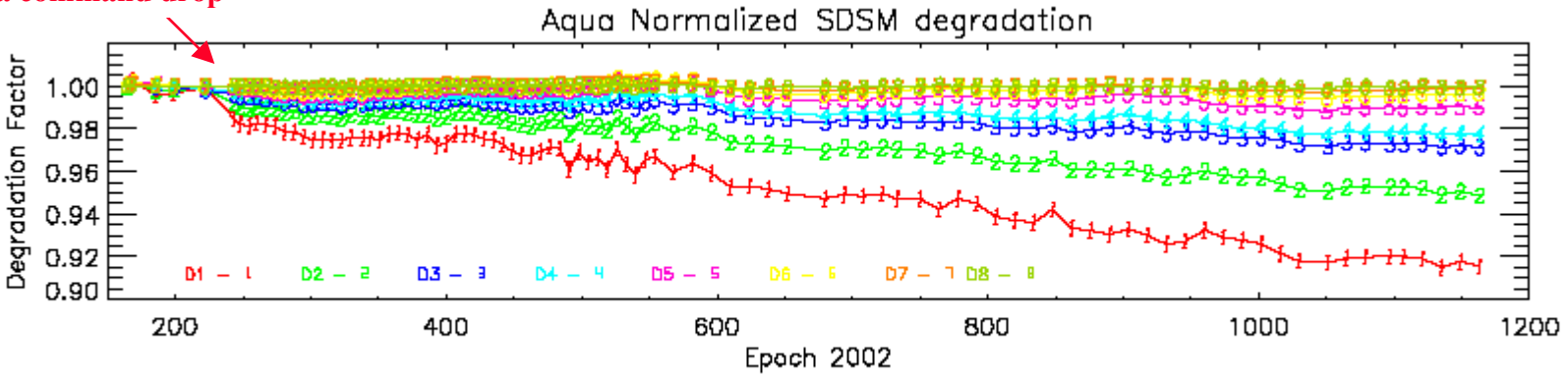




**Mirror side difference in Aqua MODIS is extremely small**

# MODIS SD Degradation Trending

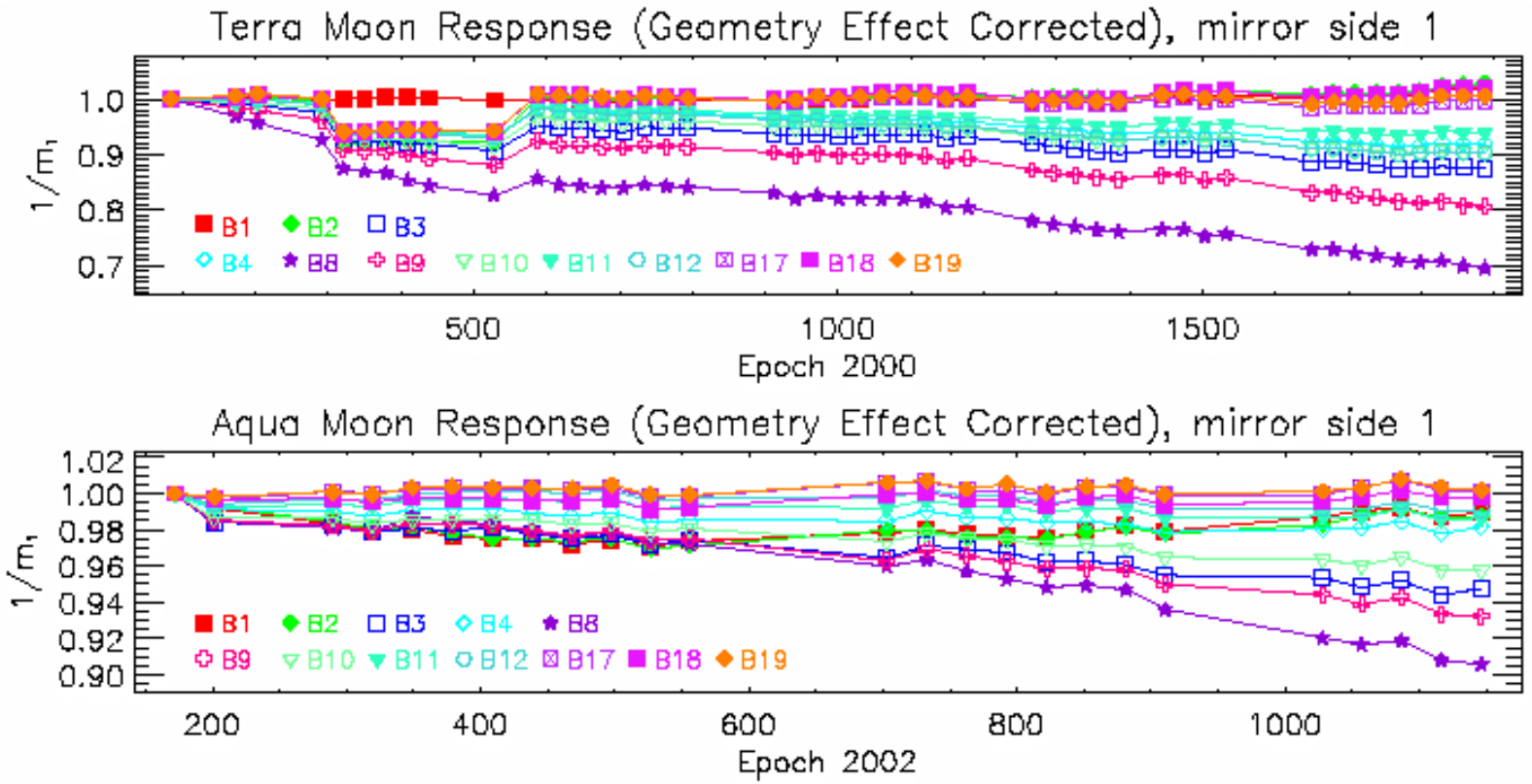



**SD door left open for 5 days due to a command drop**

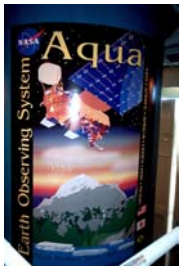


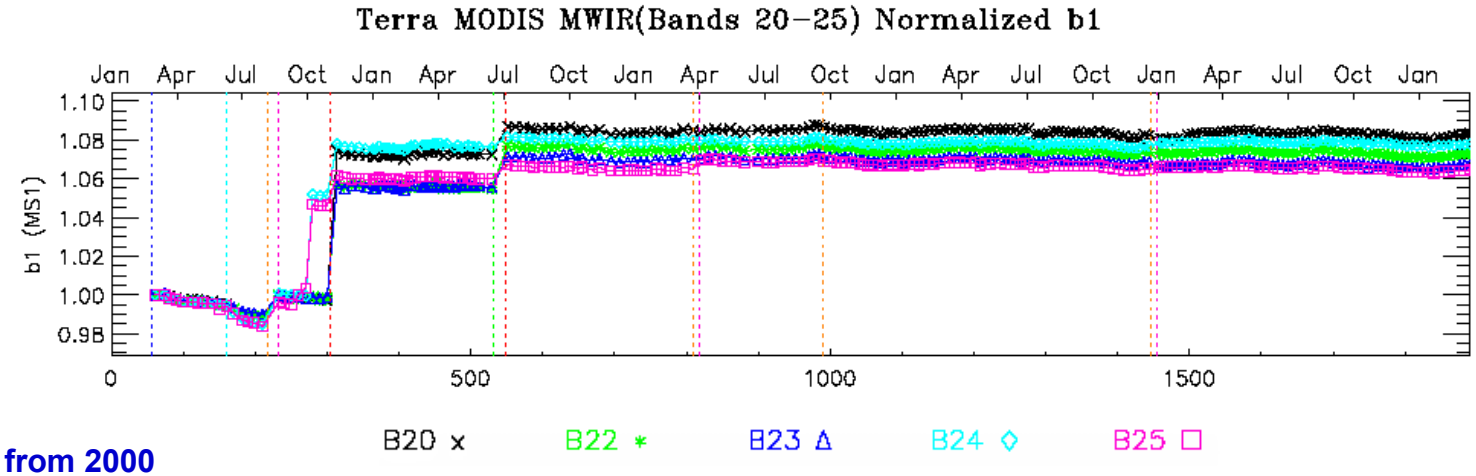

**Similar SD degradation in Terra and Aqua MODIS**

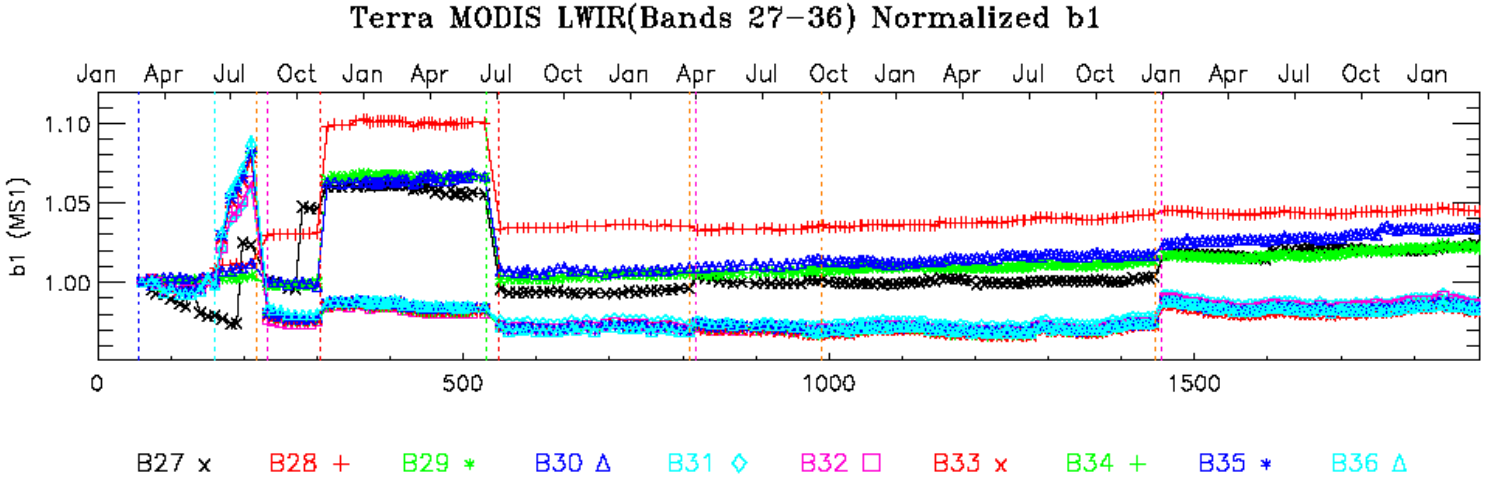
# MODIS Lunar Response Trending



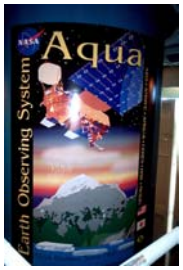
# MODIS TEB Response Trending

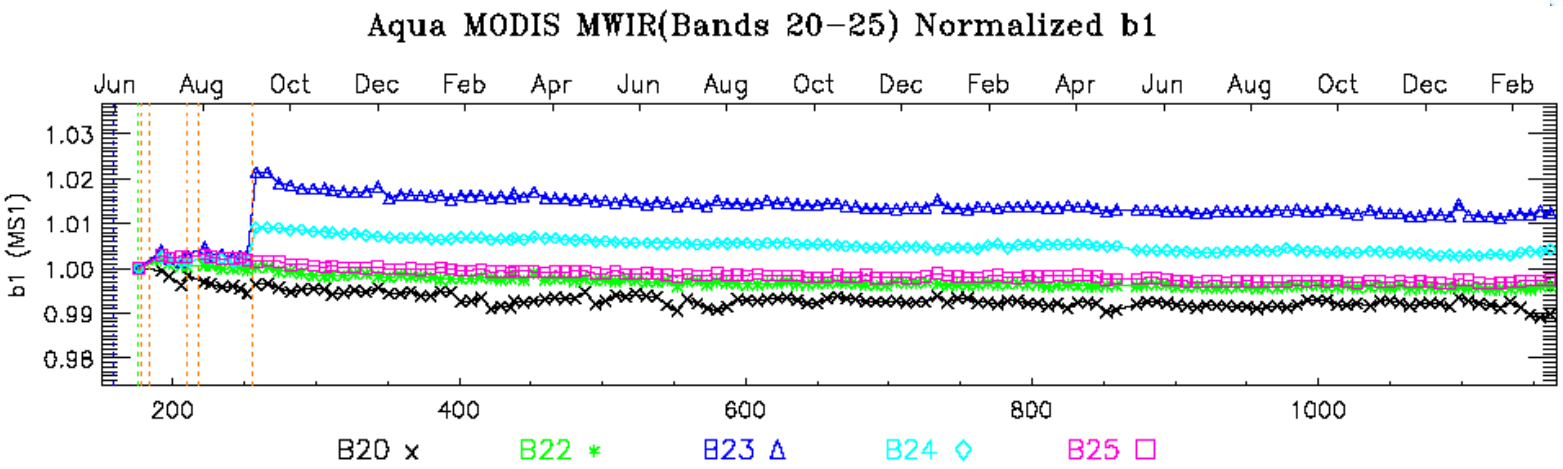


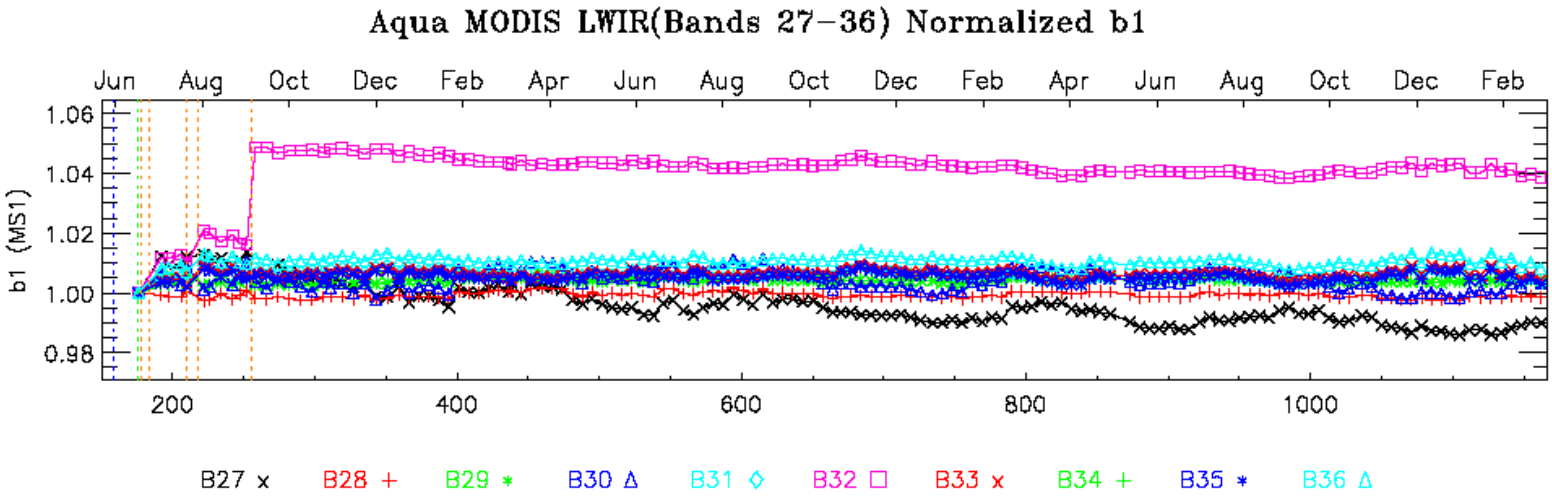



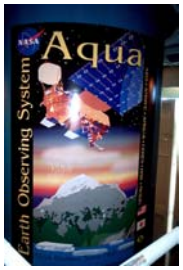
# MODIS TEB Response Trending




**Days from 2002**






# Terra MODIS Noisy Detector History

**Detectors in Product Order**

TEB

| 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 | 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 | 0.08 | 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 | 0.10 | 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 | 0.11 | 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 | 0.12 | 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 | 0.10 | 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 | 0.10 | 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 | 0.10 | 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 | 0.10 | 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 | 0.10 | 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 | 0.14 | 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 | 0.17 | 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 | 0.17 | 0.31 | 0.39 | 0.26 | 0.21 | 0.28 | 0.31 | 0.31 | 0.43 |

new

[1]Spacecraft Deep Space Maneuver

In Spec  Near the Spec  Out of Spec

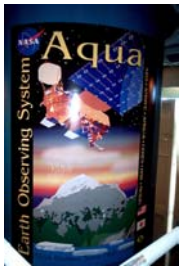
**Detectors in Product Order**

RSB

| Day/Year | Band | 5 | | | | | | | | | | 6 | | | 7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SNR Spec | 74 | | | | | | | | | | 275 | | | 110 | | |
| | Detector | 2 | 4 | 6 | 11 | 13 | 16 | 17 | 18 | 19 | 20 | 3 | 7 | 8 | 1-10 | 11-13,15-20 | 14 |
| 055/2000 | Nadir Dorr Open | 0 | 0 | 60 | 80 | 0 | 30 | 0 | 0 | 80 | 0 | 0 | 0 | 100 | 100 | 110 | 0 |
| 160/2000 | CFPA Lost Control | 95 | 95 | 60 | 80 | 80 | 30 | 80 | 80 | 80 | 80 | 0 | 0 | 100 | 100 | 110 | 0 |
| 232/2000 | Back from FPA recyle | 75 | 95 | 50 | 0 | 80 | 50 | 80 | 0 | 70 | 0 | 0 | 0 | 100 | 100 | 110 | 0 |
| 304/2000 | B Side | 85 | 20 | 85 | 80 | 80 | 60 | 80 | 80 | 80 | 80 | 350 | 350 | 275 | 90 | 100 | 100 |
| 183/2001 | A Side | 95 | 10 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 380 | 380 | 380 | 100 | 110 | 110 |
| 259/2002 | A Side B Formatter | 100 | 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 380 | 380 | 380 | 100 | 110 | 110 |

In Spec  Near Spec  Out Spec

# Aqua MODIS Noisy Detector History




**Detectors in Product Order**

TEB

| 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 |

new

[1]Spacecraft Deep Space Maneuver

In Spec  Near the Spec  Out of Spec

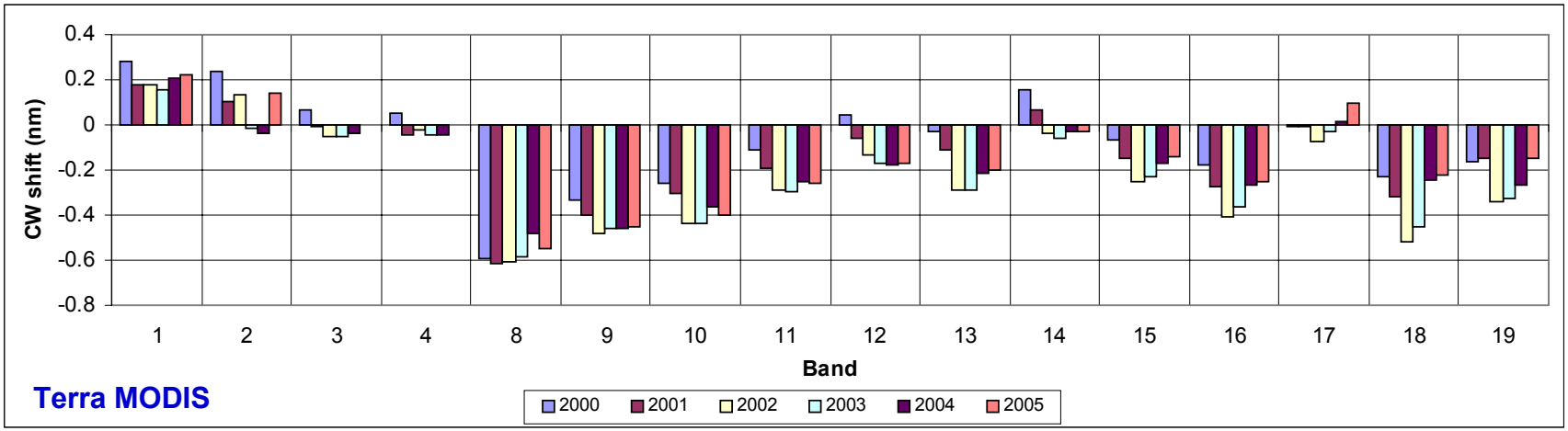
RSB

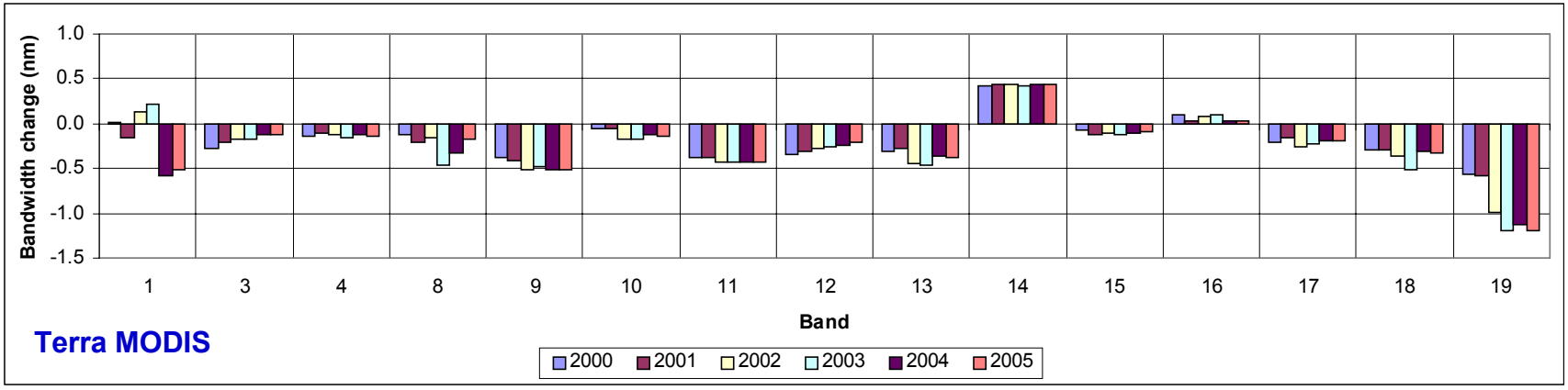
| | Detector | 20 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 12-16 | 17 | 18-20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 175/2002 | Nadir Dorr Open | 0 | 0 | 0 | 0 | 0 | 470 | 470 | 0 | 0 | 100 | 0 |
| 189/2002 | Back from Safe Mode | 0 | 0 | 470 | 470 | 0 | 470 | 470 | 0 | 0 | 470 | 0 |
| 255/2002 | Back from Safe Mode | 0 | 0 | 0 | 0 | 0 | 470 | 470 | 0 | 0 | 470 | 0 |
| 266/2002 | Back from Safe Mode | 0 | 0 | 0 | 0 | 0 | 150 | 400 | 0 | 0 | 470 | 0 |
| 110/2003 | | 0 | 0 | 0 | 0 | 0 | 260 | 470 | 0 | 0 | 320 | 0 |
| 160/2003 | | 0 | 0 | 0 | 0 | 0 | 290 | 400 | 0 | 0 | 470 | 0 |
| 265/2003 | | 0 | 0 | 150 | 0 | 0 | 290 | 400 | 0 | 0 | 275 | 0 |
| 360/2003 | | 0 | 0 | 200 | 0 | 0 | 290 | 275 | 0 | 0 | 270 | 0 |

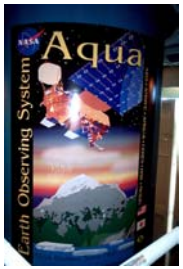
In Spec  Near Spec  Out Spec

# MODIS Spectral Performance

## Terra MODIS Center Wavelength Shifts and Bandwidth Changes

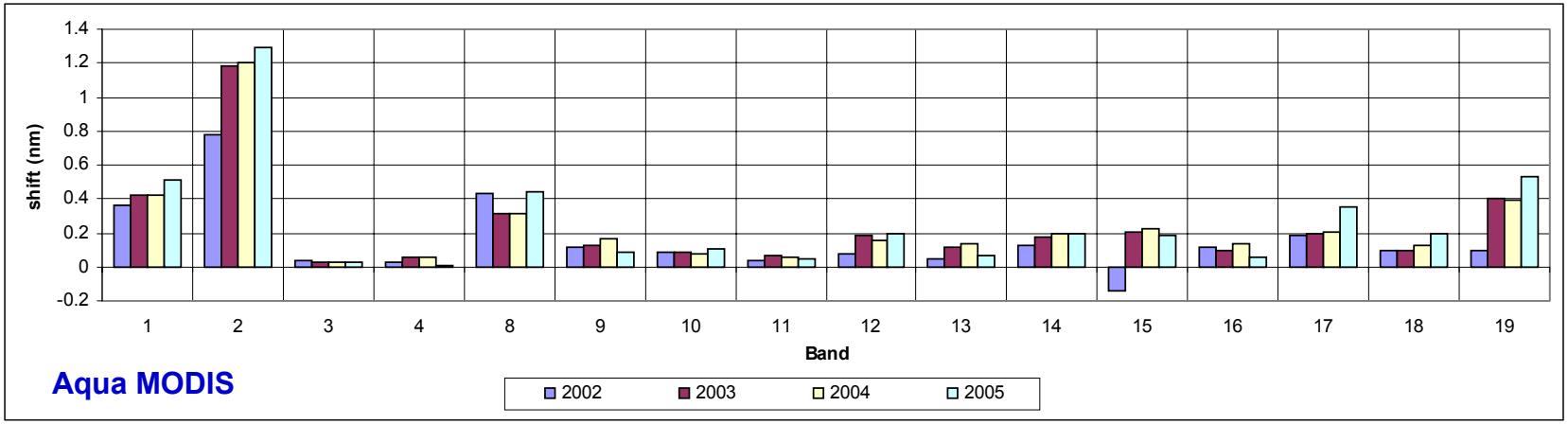


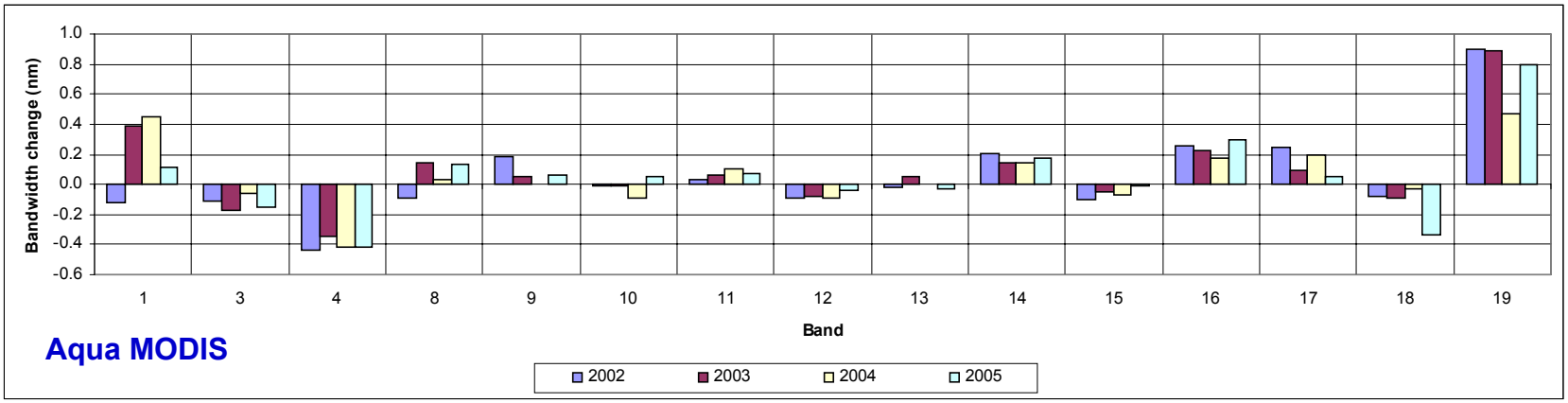





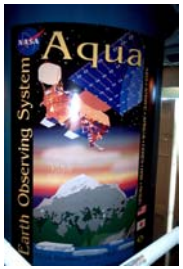

# MODIS Spectral Performance

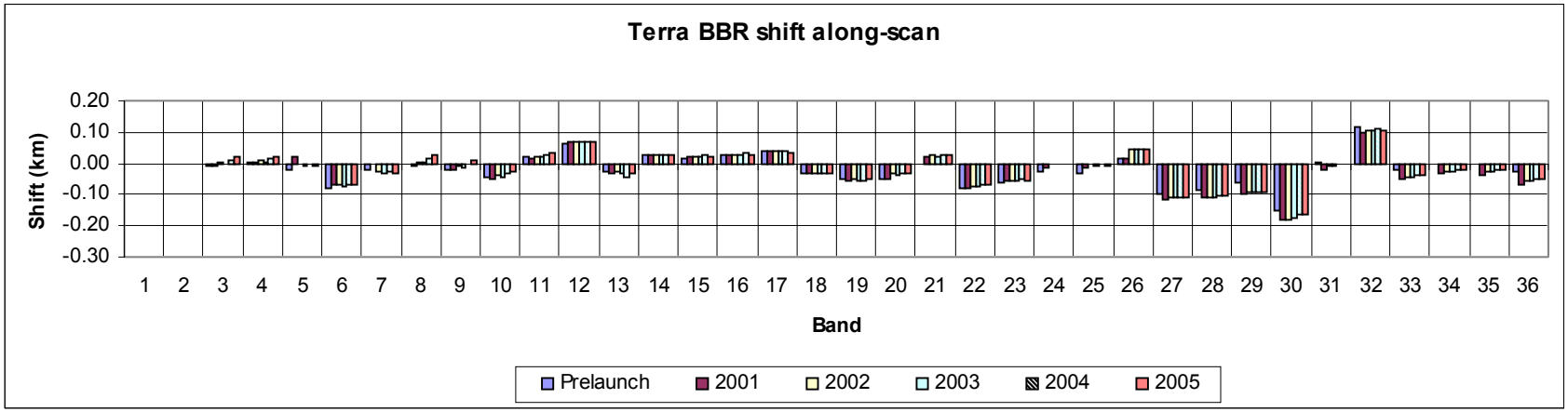
## Aqua MODIS Center Wavelength Shifts and Bandwidth Changes

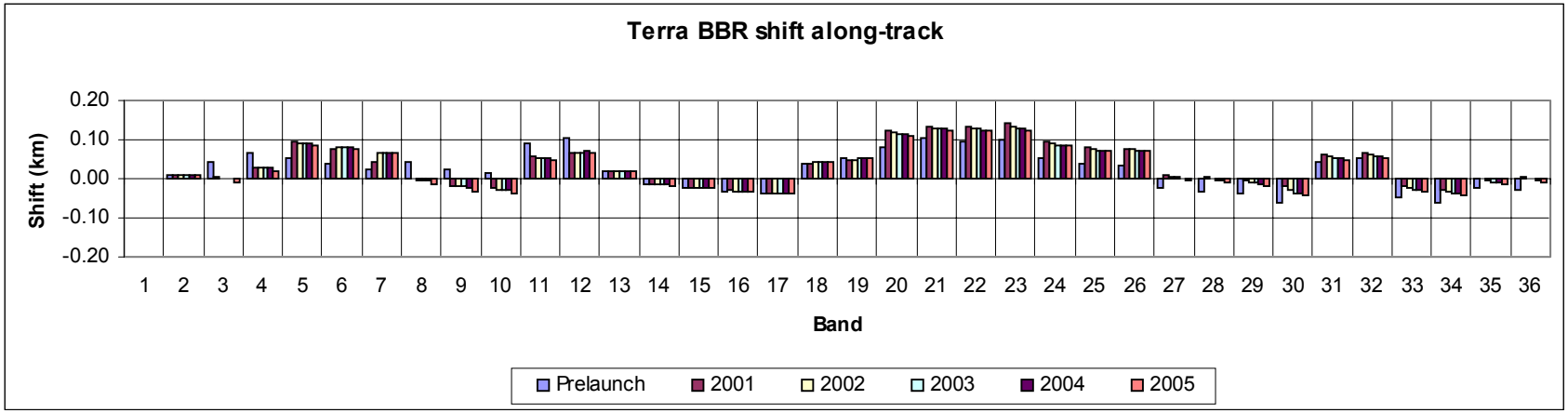


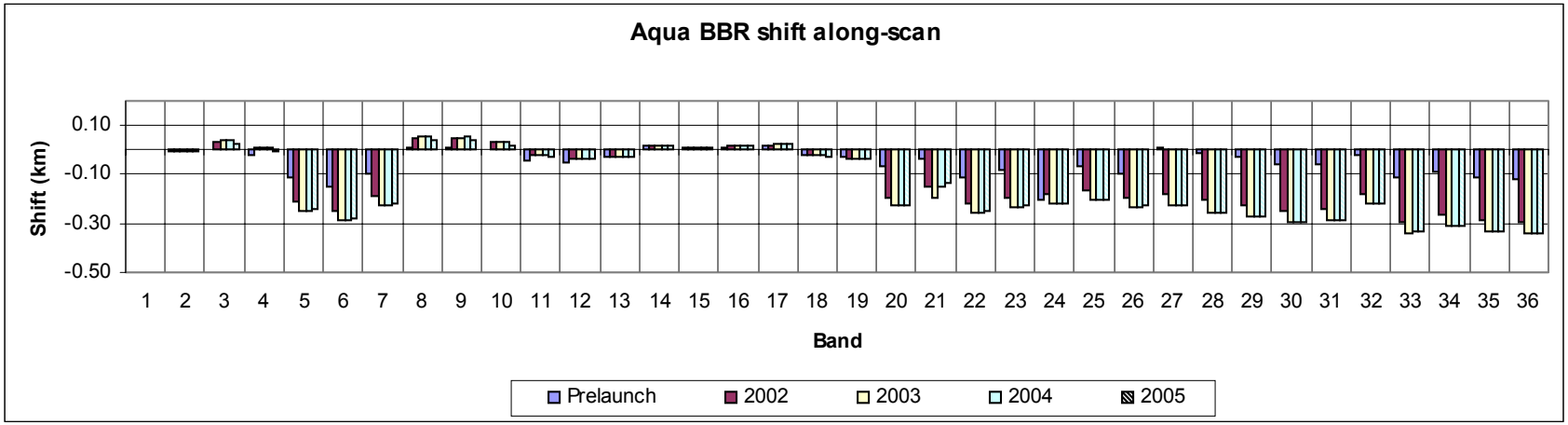
# MODIS Spatial Performance

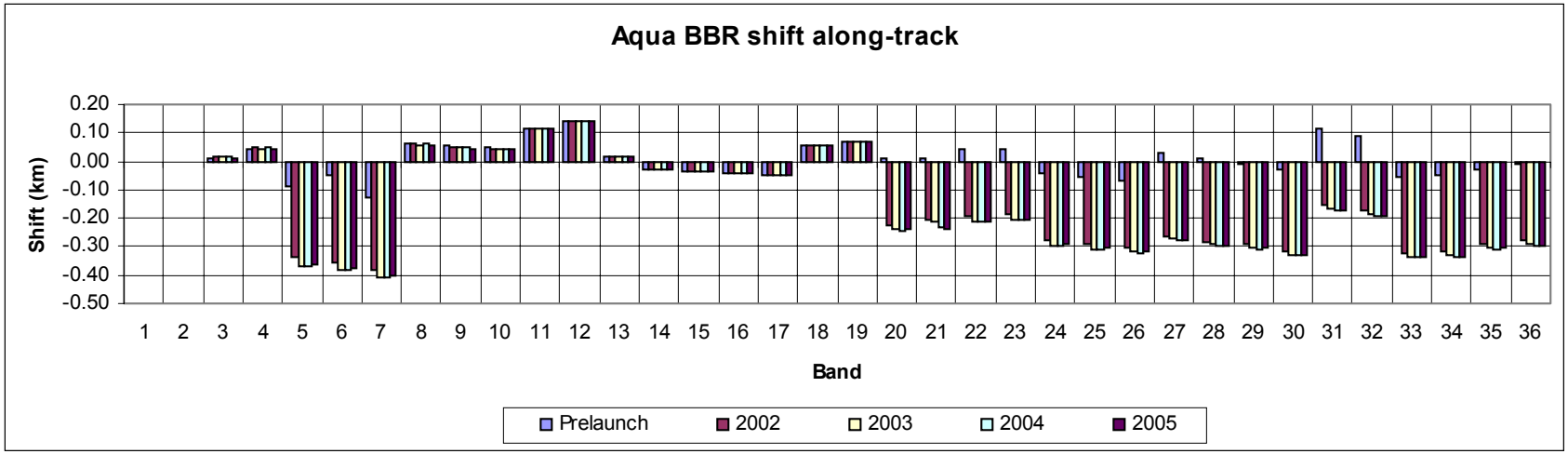


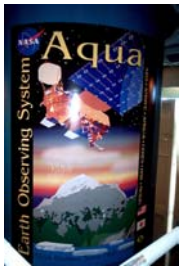



# MODIS Spatial Performance

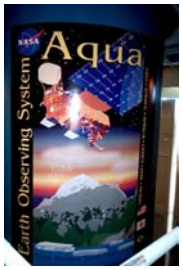



# Challenging Issues

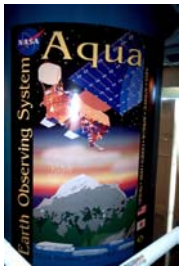



- ✓ No valid pre-launch measurements for Terra MODIS TEB RVS
  - – At-launch RVS derived from witness sample reflectance and parameters from Aqua MODIS RVS measurements
  - – C-NAD relative RVS to improve imagery; DSM RVS to improve radiometry
  - – Studying MSCN impact (especially for bands 33-36; working with C. Moeller)
- ✓ SDSM sun view signal ripples caused by a design error
  - – Modeling and simulation; alternative approach
  - ✓ Analysis shows that the normalization approach is adequate
- ✓ Terra MODIS PC optical leak
  - – Lunar observations
  - ✓ Analysis shows correction is adequate and stable
- ✓ SWIR crosstalk (thermal leak and electronic crosstalk)
  - – Improvement with a linear correction algorithm; uncertainty and striping
  - ✓ New code/LUT changes add correction flexibility (detector dependency)
  - – Continuing efforts (working with C. Moeller and E. Vermote)
  - ✓ B13H and B14H calibration
    - Ratioing approach through B13 L and B14L




# Challenging Issues

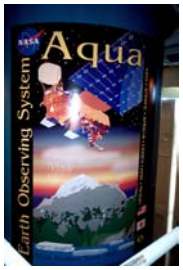
- SD calibration uncertainty
  - ✓ RSB BRF pre-launch characterization uncertainty
    - Non-spatial uniformity can cause annual oscillation in response trending
    - ✓ MCST on-orbit observations show < 0.3% non-uniformity (SBRS PL estimate of 0.7%)
  - ✓ No SD vignetting function characterized pre-launch
    - Yaw maneuvers (on-orbit)
    - ✓ Overall agreement between observations and results from optical ray tracking simulation (MCST and Waluschka); difference within design and measurement uncertainty
    - ✓ Meetings held with ocean groups on VF (det. dep. vs single VF); agreement on using a single VF for all bands (0.5% uncertainty assigned for the VF)
  - ✓ RSB response changes (mirror side, AOI, detector, temporal)
    - Challenges for ocean color bands
  - – Noisy detectors
    - Uncertainty and striping
  - ✓ Earthshine impact (SBRS uncertainty budget: 0.3%; Wolfe: < 0.3%)
    - ✓ MCST estimate < 0.5% impact (with averaged and fitted m1)
    - Support for the modeling efforts (Wolfe); study of spectral dependency
  - – Calibration difference (bias) among detectors
    - Continue studying using the Moon, SD, and EV data




# Challenging Issues

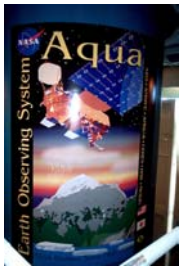
- ✓ RSB RVS (ocean)
  - – Continuing efforts (SRCA lamps' degradation and stability concern; SD and Moon angles to cover the entire range; more demanding and challenges for Terra MODIS)
- • MWIR crosstalk (electronic crosstalk) and B21 calibration
  - ✓ New code/LUT changes add mirror side dependency for B21
- • Mirror side correlated noise (MSCN)
  - – Impact on the TEB and RVS correction (see TEB RVS)
- • Polarization correction (ocean)
  - ✓ Efforts made for completing modeling and simulation (Miami, MCST, and Waluschka); lessons for future sensors (have all the optics information before or during testing)
- • Calibration consistency between Terra and Aqua MODIS
  - ✓ TEB (inter-comparison with other sensors, such as AVHRR)
  - – RSB (inter-comparison with other sensors and the Moon)
- • Uncertainty Analysis
  - ✓ Completed internal review (then and now, numbers and approaches)
    - ✓ a number of action items assigned
  - – **Review items and other technical issues with MsWG members**
  - – **Update TEB and RSB calibration uncertainty**


# Summary




- Instruments performed well according to design specifications
  - Terra (5+ years) and Aqua (2.5+ years); Aqua better than Terra in a number of areas (except B6 and BBR problems)
- Constant efforts made to maintain and improve instrument calibration and characterization
  - MCST continues working closely with science groups (representatives), instrument vendor (SBRS), and other expertise for all key issues
  - Attention on instrument aging issues, such as the impact due to noise detectors
  - Online documents: L1B user guide, product data dictionary, ATBD (under review)
  - L1B code and LUTs change history, workshop materials, and publications
    - *http://www.mcst.ssai.biz/mcstweb/index.html*
- Lessons learned for future sensors

# Useful Documents




Guenther B, Xiong X, Salomonson VV, Barnes WL and Young J, "On-orbit Performance of the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) and the Attendant Level 1-B Data Product," *Remote Sensing of the Environment*, 83, 16-30, 2002

Xiong X., K. Chiang, J. Esposito, B. Guenther and W.L. Barnes, MODIS On-orbit Calibration and Characterization, *Metrologia* 40, 89-92, 2003

Barnes W.L., X. Xiong and V.V. Salomonson, Status of Terra MODIS and Aqua MODIS, *J. of Advances in Space Research*, 32/11, 2099-2106, 2003

Xiong X., W.L. Barnes, B. Guenther and R.E. Murphy, Lessons Learned from MODIS Calibration and Characterization, *J. of Advances in Space Research*, 32/11, 2017-2122, 2003

Xiong X, Sun J, Esposito J, Guenther, and Barnes WL, "MODIS Reflective Solar Bands Calibration Algorithm and On-orbit Performance," *Proceedings of SPIE – Optical Remote Sensing of the Atmosphere and Clouds III*, 4891, 95-104, 2003

Xiong X, Chiang, Guenther, and Barnes WL, "MODIS Thermal Emissive Bands Calibration Algorithm and On-orbit Performance," *Proceedings of SPIE – Optical Remote Sensing of the Atmosphere and Clouds III*, 4891, 392-401, 2003

Wu A., C. Cao and X. Xiong, "Inter-comparison of the 11mm and 12 mm Bands of Terra and Aqua MODIS Using AVHRR/NOAA-16/17", *Proceedings of SPIE – Earth Observing Systems VIII*, 5151, 384-394, 2003

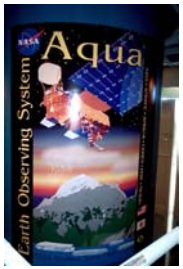
Isaacman A., G. Toller, B. Guenther, W.L. Barnes and X. Xiong, "MODIS Level 1B calibration and data products", *Proceedings of SPIE – Earth Observing Systems VIII*, 5151, 552-562, 2003

Chiang, K., X. Xiong, A. Wu, and W. Barnes, "MODIS Thermal Emissive Bands Calibration Uncertainty Analysis," *Proceedings of SPIE – Earth Observing Systems IX*, 5542, 437-447, 2004

Esposito, J., X. Xiong, A. Wu, J. Sun, and W. Barnes, "MODIS Reflective Solar Bands Uncertainty Analysis," *Proceedings of SPIE – Earth Observing Systems IX*, 5542, 448-458, 2004

# *Backup Charts*

# 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

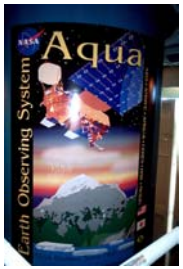
| Primary Use | Band | Bandwidth[1] | Spectral Radiance[2] | Required NEΔT(K)[4] |
|---|---|---|---|---|
| Surface/Cloud Temperature | 20 | 3.660 - 3.840 | 0.45 (300K) | 0.05 |
| | 21 | 3.929 - 3.989 | 2.38 (335K) | 0.2 |
| | 22 | 3.929 - 3.989 | 0.67 (300K) | 0.07 |
| | 23 | 4.020 - 4.080 | 0.79 (300K) | 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 |

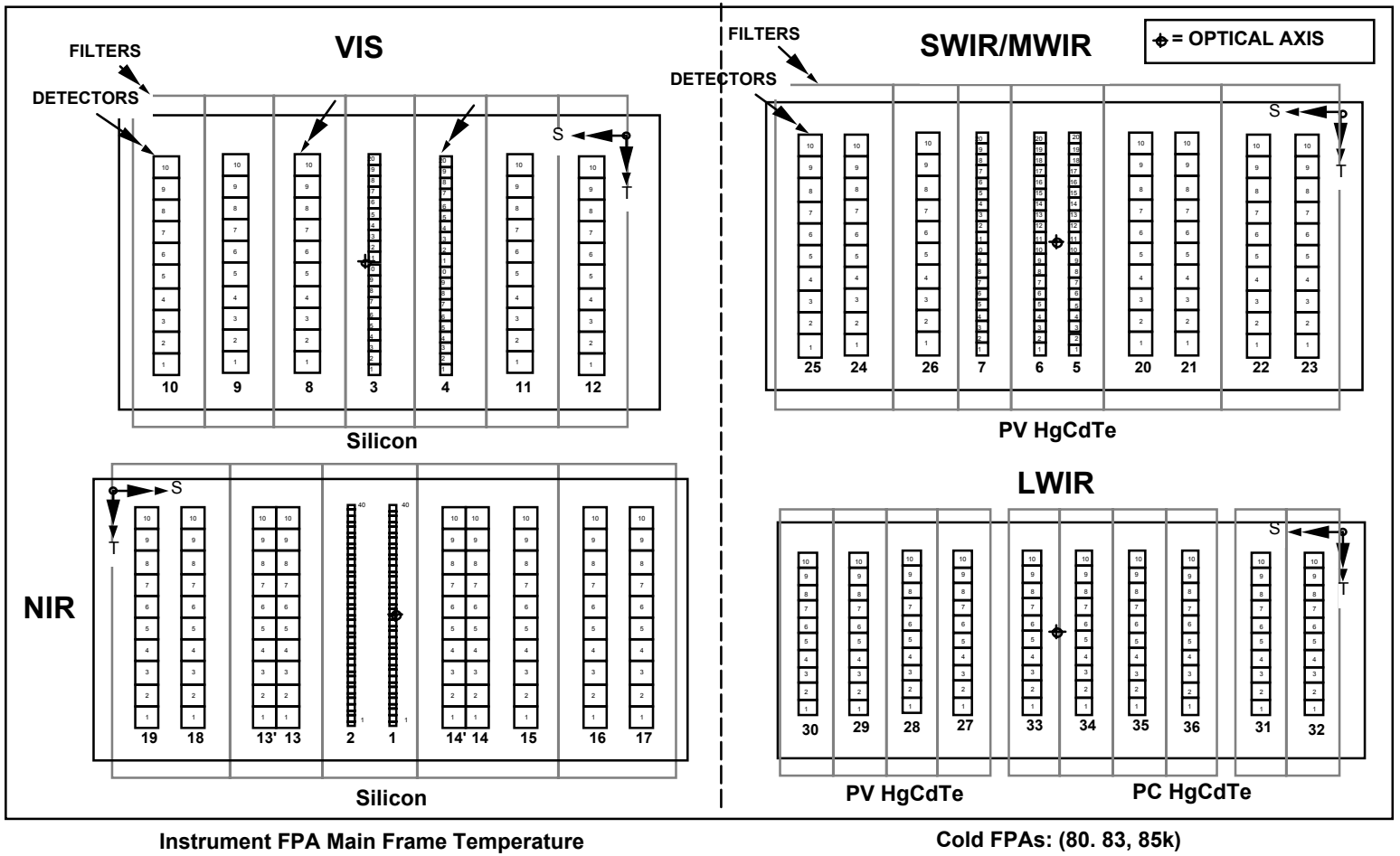
[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in μm

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

[4] NEΔT = Noise-equivalent temperature difference

# MODIS Focal Plane Assemblies (FPA)

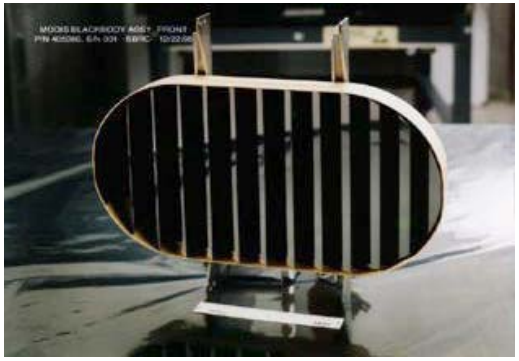



**S: scan direction; T: track direction**

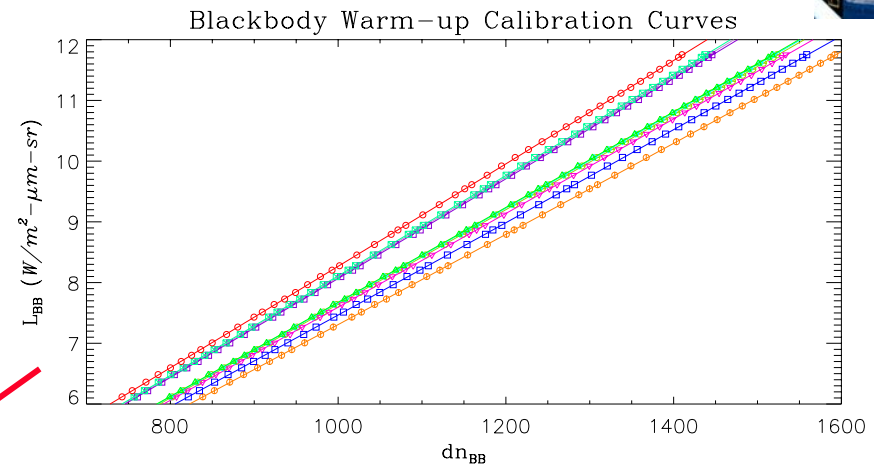
**B13 and B14 have 2 columns of detectors for TDI high and low gain output**

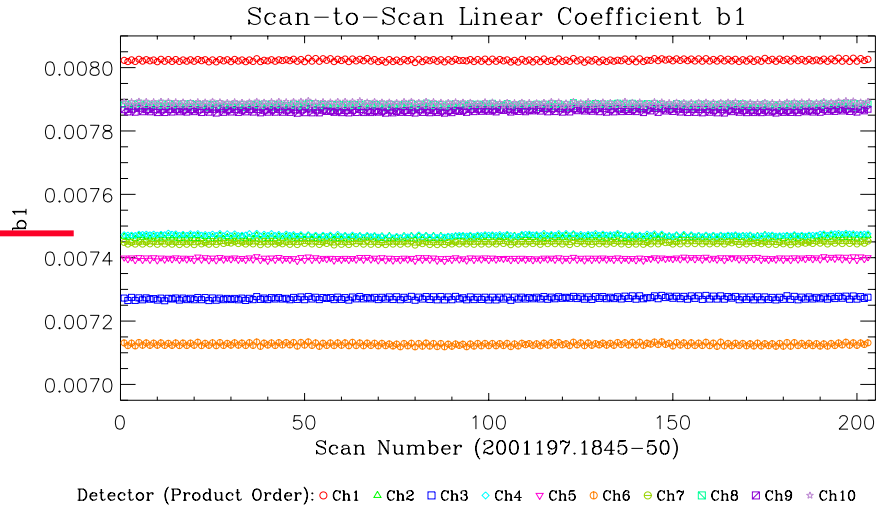
# MODIS TEB Calibration Using Blackbody



*BB from 270-317K provides a0 and a2*

*BB at T_BB provides b1 on a scan by scan basis*



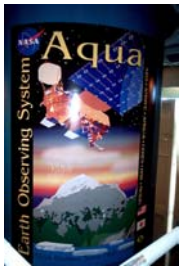

*Other Calibration Issues:*

*B21 (Terra/Aqua) – Now MS Dependent*

*PC Xtalk (Terra)*

*B33,35,36 (Aqua) at high T_BB*

# MODIS RSB Calibration Using SD/SDSM




*EV Radiance:*

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

*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*

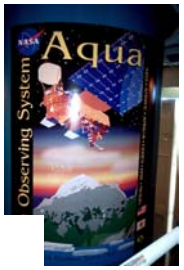
*Others:*

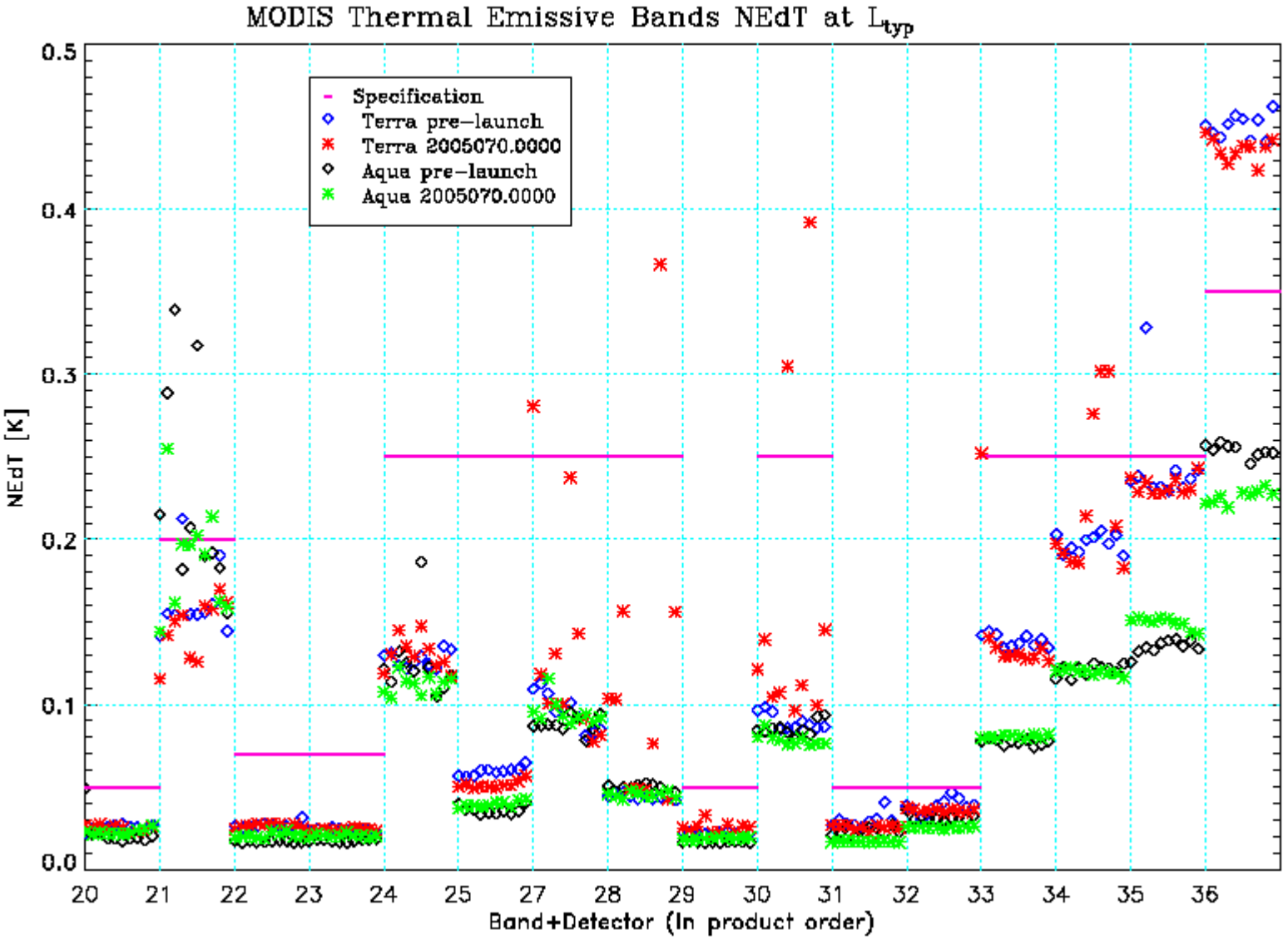
*Thermal leak applied for SWIR bands (B5-7, B26)*

*Leak coefficients determined from EV night time data*

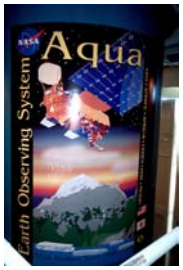
*B26 de-striping algorithm added (from C. Moeller of Wisconsin)*

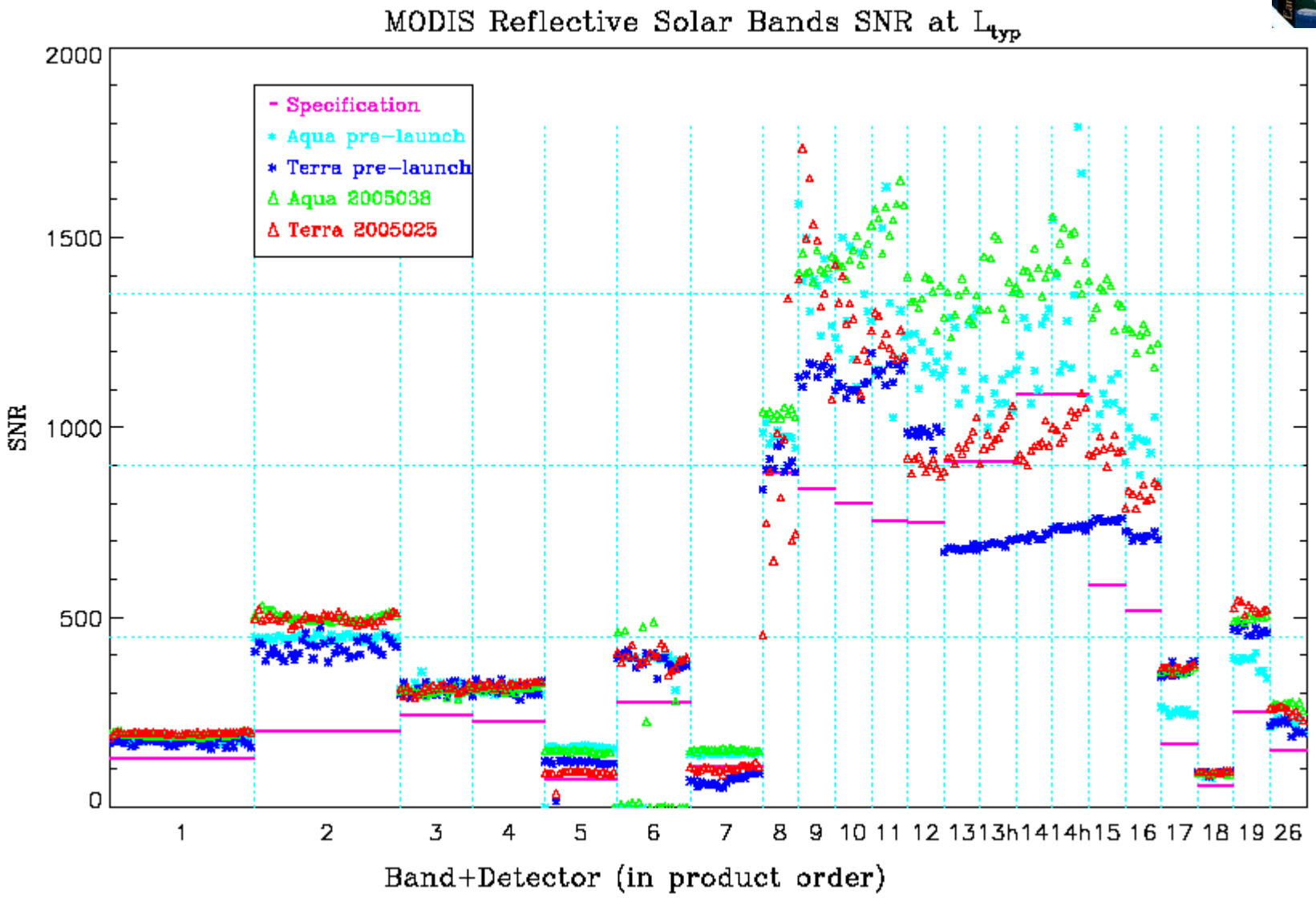
# MODIS TEB NEdT



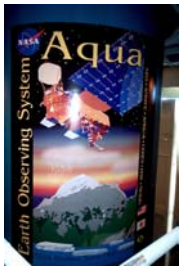
# MODIS RSB SNR

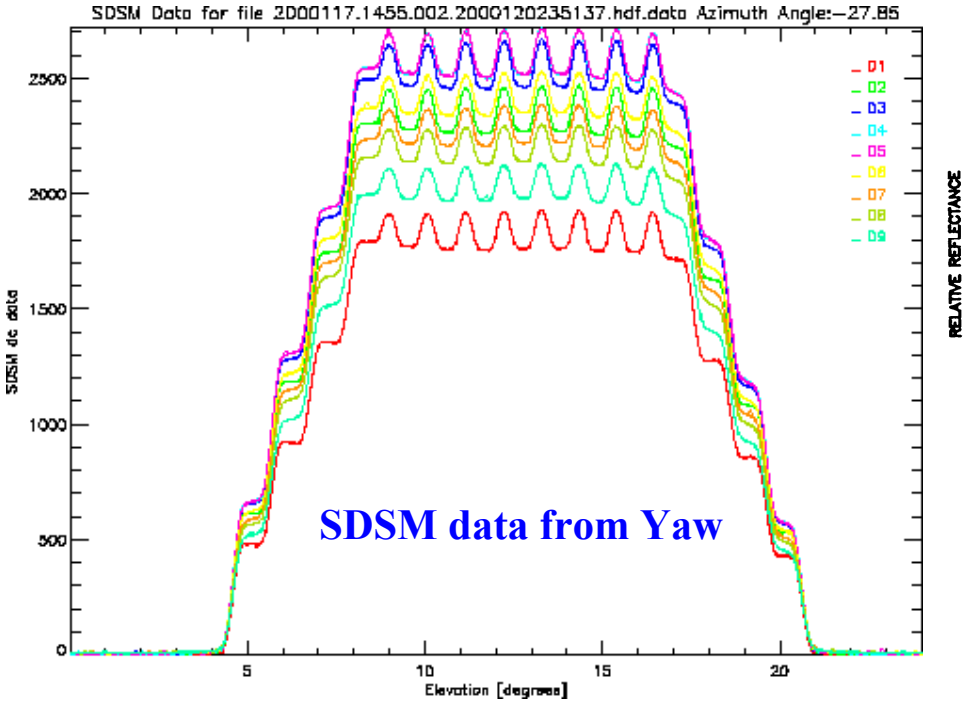


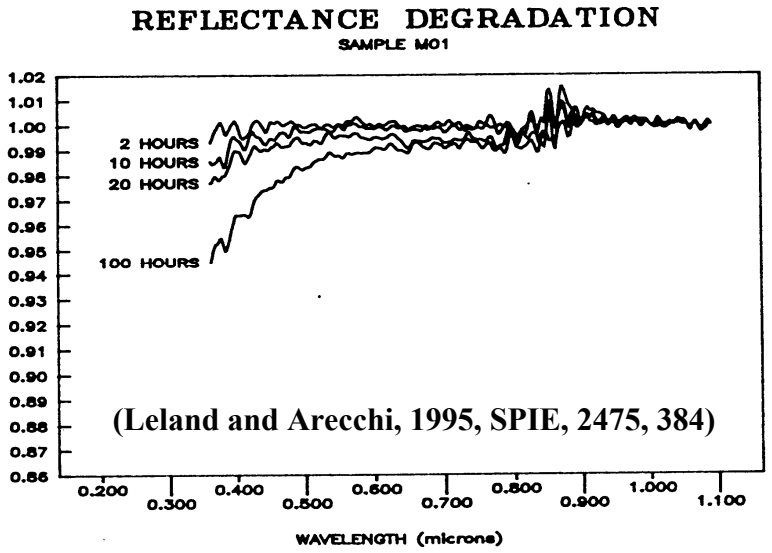



# SDSM for SD Degradation

**Normalize to SDSM D9 is adequate**



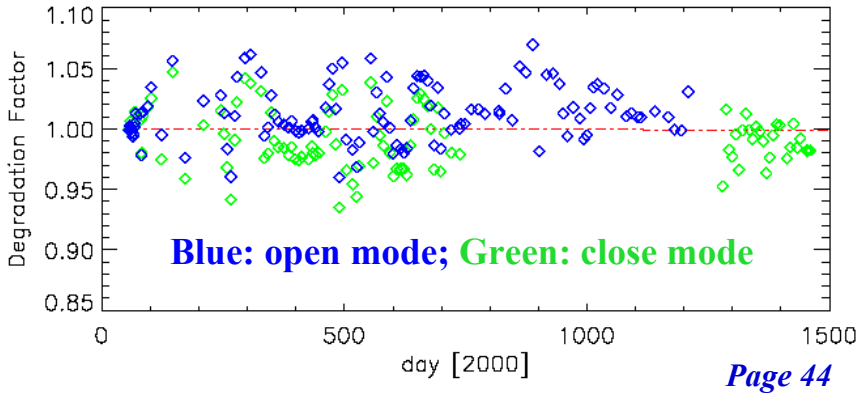



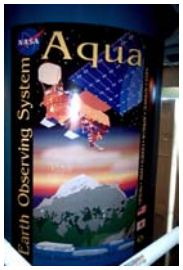

**Terra MODIS SDSM D9 show no obvious degradation from over five years' on-orbit trending (observations)**

**Normalize to SDSM D9 at 936nm**

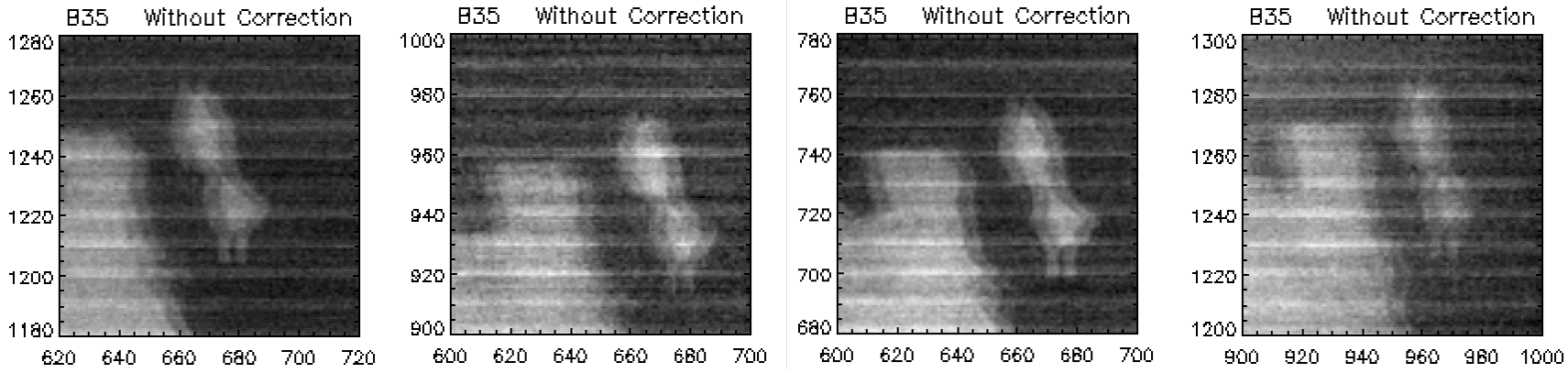
$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{dc_{Sun}} \Rightarrow \left\{ \frac{dc_{SD\_view}^{D1} / dc_{Sun\_view}^{D1}}{dc_{SD\_view}^{D9} / dc_{Sun\_view}^{D9}} \right\}$$

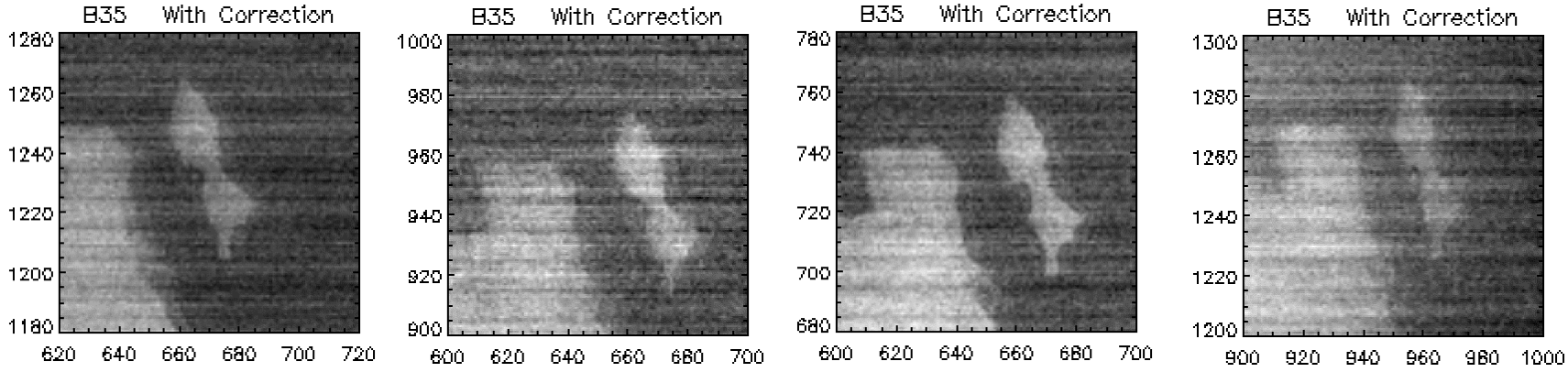


# Terra PC Optical Leak Correction is Stable



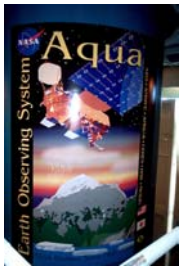

**2002092.0645** **2003079.0645** **2004082.0645** **2005034.0655**



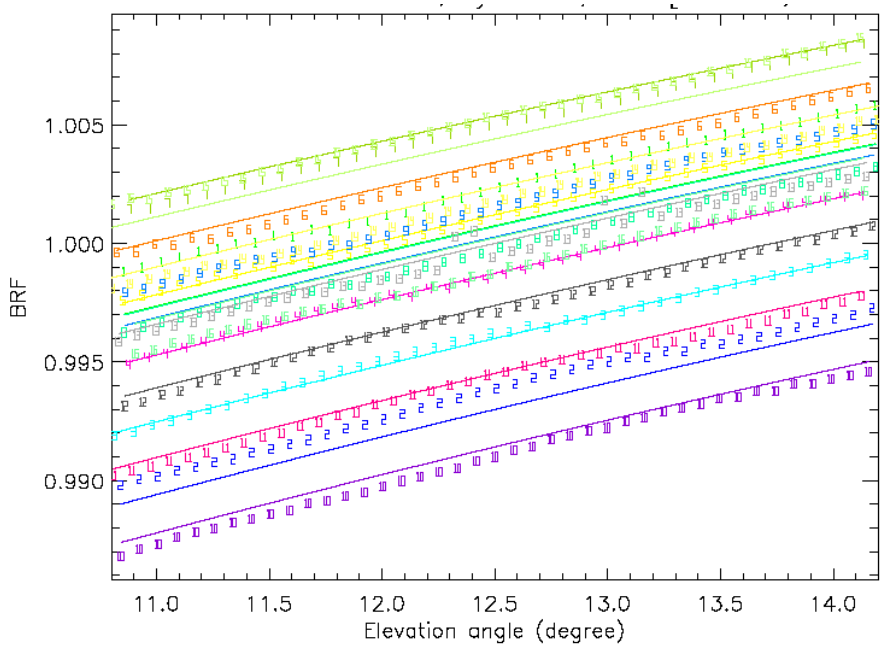

(Images shown are over Oman/Arabian-Sea)

# Solar Diffuser BRF Validation (on-orbit)



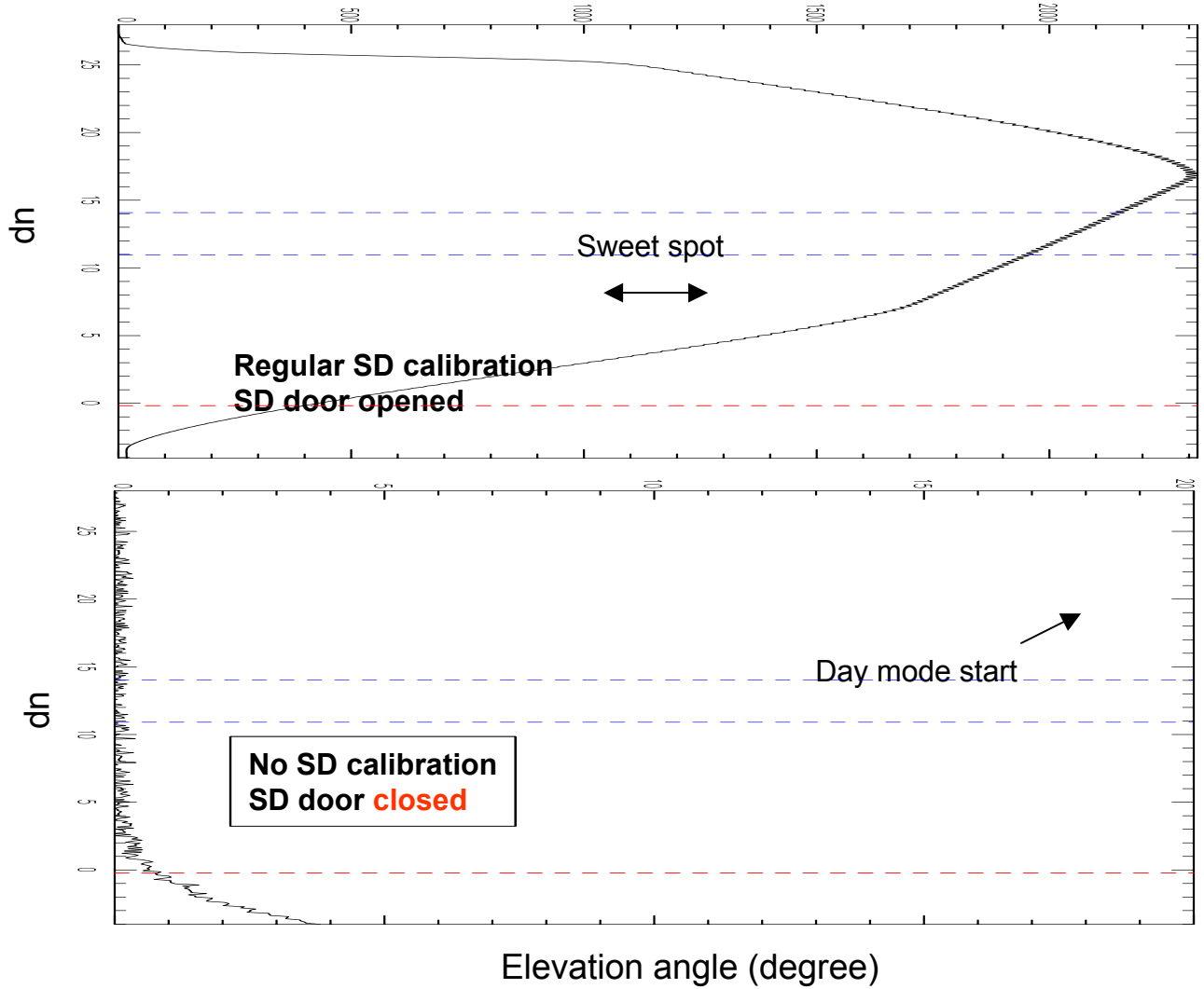

- On-orbit BRF validation performed (yaw maneuvers)
- Bands 1-4 and 17-19 used to validate the BRF (bands 8-16 saturate without SD screen, SWIR bands have xtalk)
- Pre-launch BRF curves used to fit the observations
- Measurements (Terra MODIS) agree with pre-launch values to within ±0.25%* (consistency checked among different detectors within a band; * B2 min/max difference is -0.22%/0.41%
- Pre-launch BRF is used in the m1 calculation

Terra MODIS B3 BRF
fitting (solid line); on-orbit data (symbols)



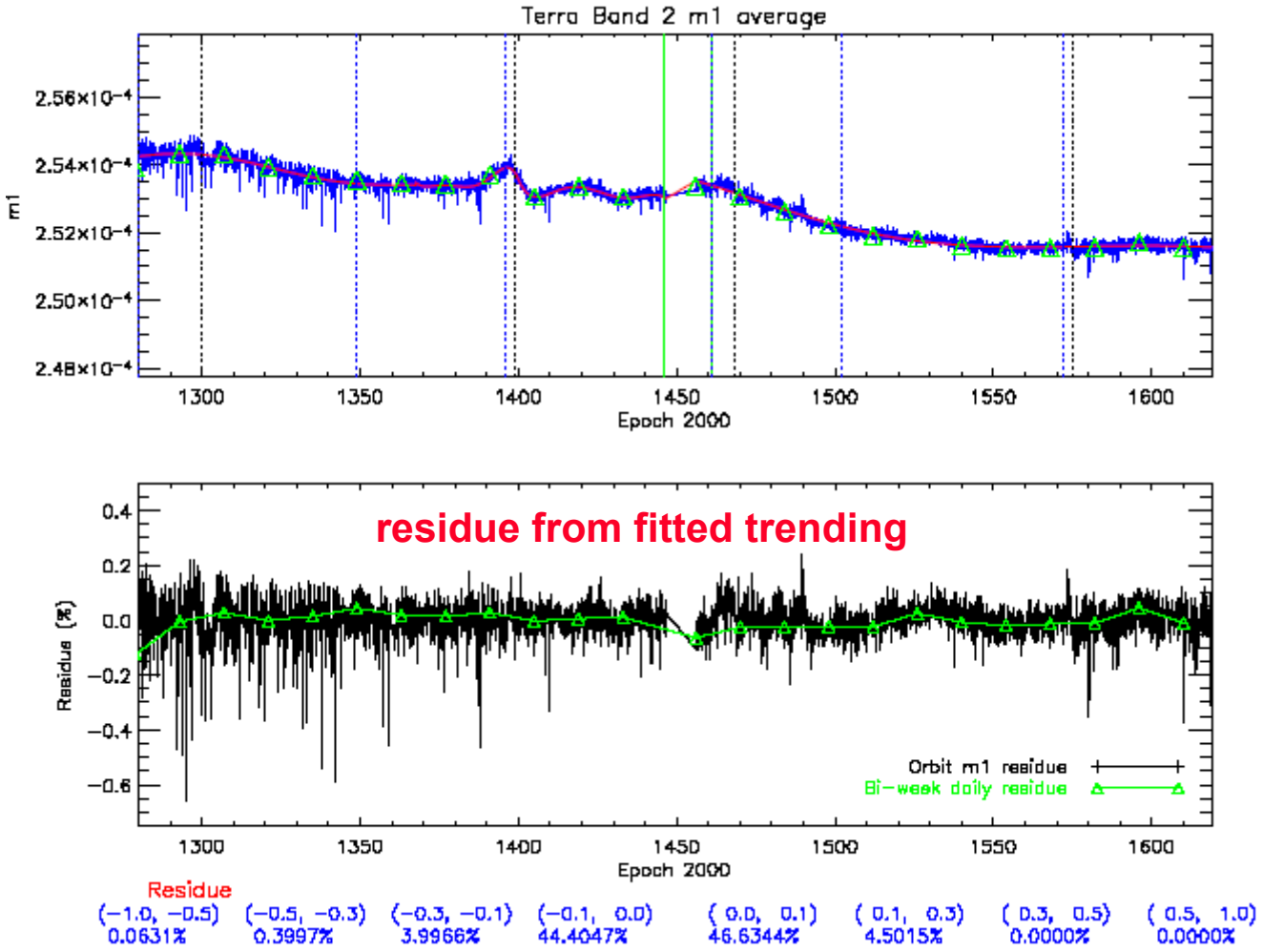

| Band | Min_Diff | Max_Diff |
|---|---|---|
| 1 | -0.1309 | 0.2413 |
| 2 | -0.2172 | 0.4130 |
| 3 | -0.1624 | 0.1933 |
| 4 | -0.1332 | 0.1747 |
| 17 | -0.2045 | 0.2705 |
| 18 | -0.1385 | 0.2491 |
| 19 | -0.1590 | 0.2552 |

# Earthshine Impact on SD Calibration

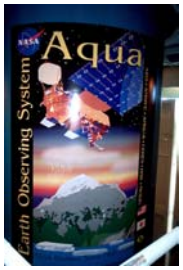



**Impact of Earthshine from nadir aperture door is extremely small <0.1%**

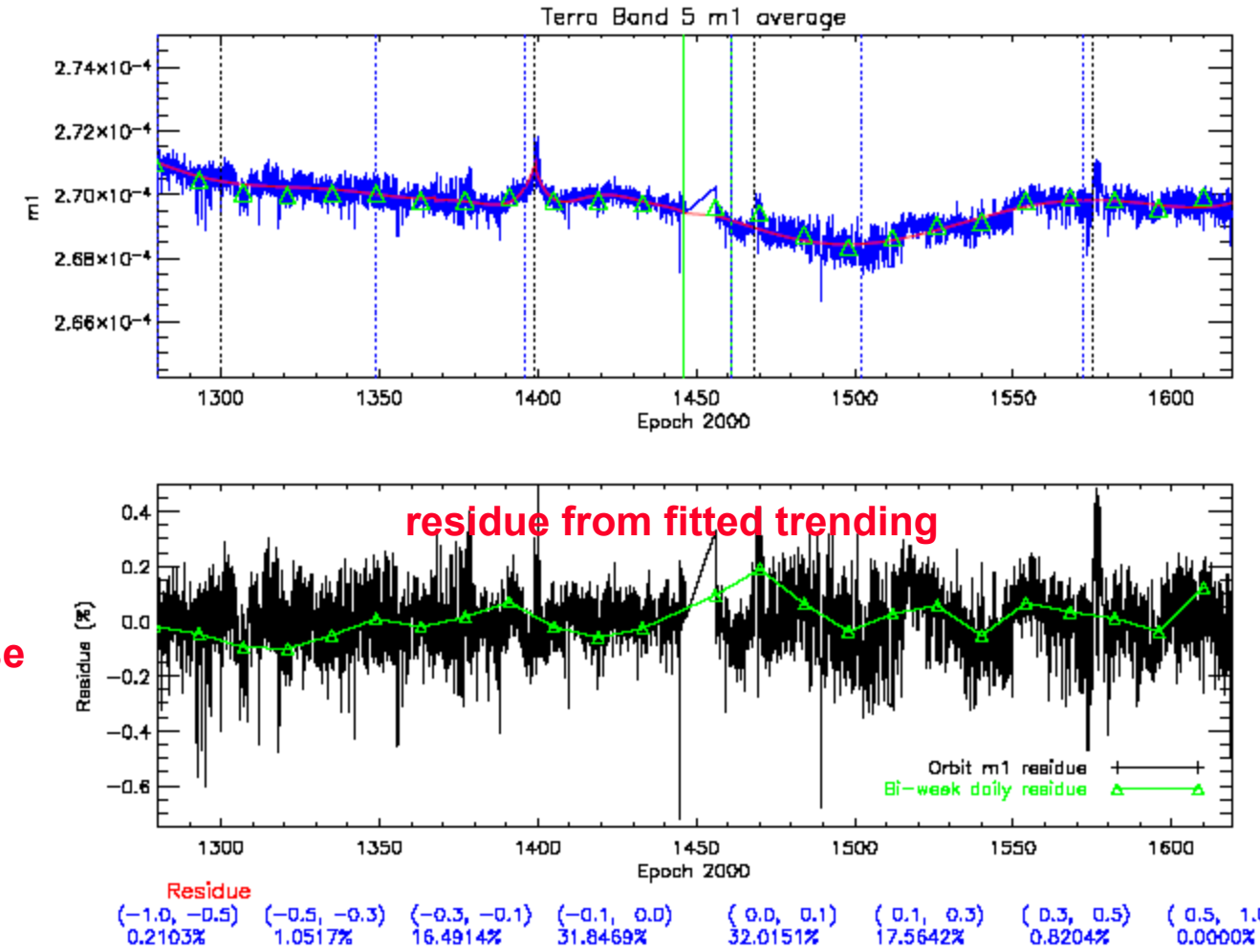
# Earthshine Impact on SD Calibration




**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).**



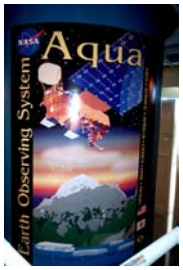

# Earthshine Impact on SD Calibration




**Worst Case**

**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).**

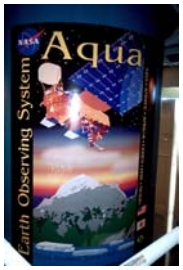

# Earthshine Impact on SD Calibration



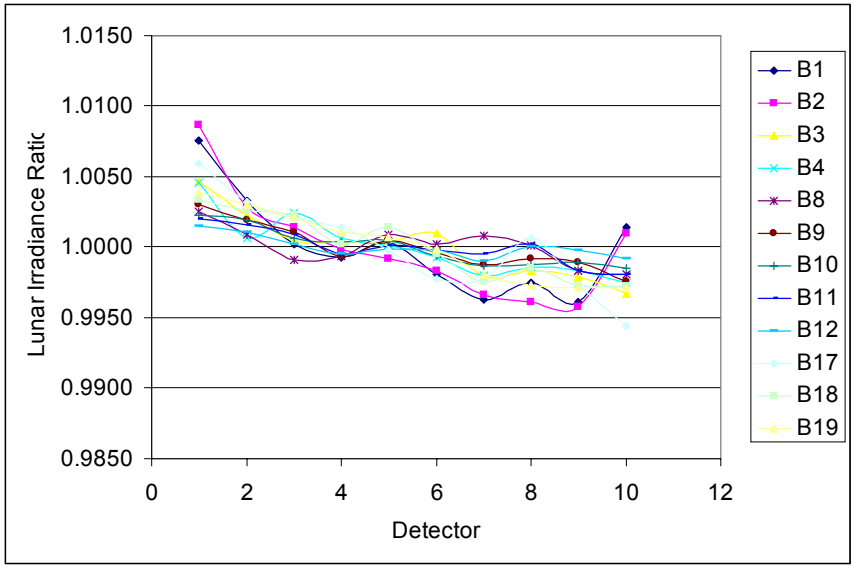

## Summary of Earthshine Impact from SD Aperture Door (all bands)

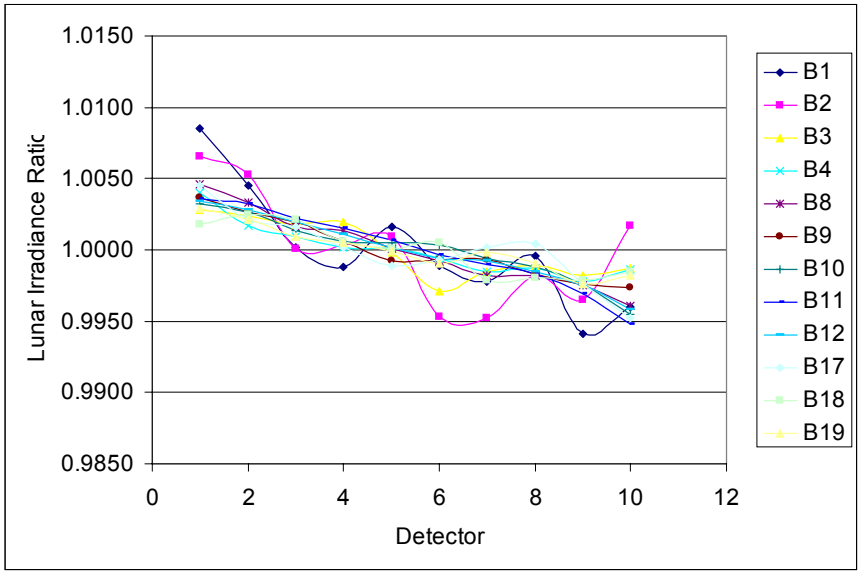
| Band | <-1.% | (-1%,-0.5%) | (-0.5%,-0.3%) | (-0.3%,-0.1%) | (-0.1%,0%) | (0%,0.1%) | (0.1%,0.3%) | (0.3%,0.5%) | (0.5%,1%) | >1.0% |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 0.00 | 1.45 | 48.09 | 49.16 | 1.30 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.06 | 0.40 | 4.00 | 44.40 | 46.63 | 4.50 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 4.29 | 45.60 | 46.23 | 3.87 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 1.94 | 47.77 | 49.37 | 0.93 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.21 | 1.05 | 1.05 | 31.85 | 32.02 | 17.56 | 0.82 | 0.00 | 0.00 |
| 6 | 0.00 | 0.23 | 0.67 | 0.67 | 37.67 | 39.38 | 12.24 | 0.08 | 0.00 | 0.00 |
| 7 | 0.00 | 0.17 | 0.69 | 0.69 | 34.62 | 38.30 | 13.71 | 0.06 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.17 | 7.26 | 42.09 | 43.44 | 7.05 | 0.00 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 3.32 | 47.92 | 44.55 | 4.21 | 0.00 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 1.09 | 49.45 | 48.23 | 1.22 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.65 | 49.94 | 48.72 | 0.69 | 0.00 | 0.00 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.55 | 50.72 | 48.06 | 0.67 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 1.09 | 47.18 | 51.39 | 0.34 | 0.00 | 0.00 | 0.00 |
| 13h | 0.00 | 0.00 | 0.00 | 1.09 | 47.14 | 51.43 | 0.34 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 0.04 | 1.24 | 46.72 | 51.77 | 0.23 | 0.00 | 0.00 | 0.00 |
| 14h | 0.00 | 0.00 | 0.04 | 1.24 | 46.72 | 51.77 | 0.23 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.15 | 1.96 | 44.01 | 53.43 | 0.46 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.06 | 0.38 | 2.71 | 40.70 | 55.28 | 0.86 | 0.00 | 0.00 | 0.00 |
| 17 | 0.00 | 0.00 | 0.06 | 1.47 | 46.07 | 51.68 | 0.72 | 0.00 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 1.68 | 45.71 | 52.02 | 0.59 | 0.00 | 0.00 | 0.00 |
| 19 | 0.00 | 0.00 | 0.04 | 2.36 | 46.32 | 49.98 | 1.30 | 0.00 | 0.00 | 0.00 |
| 26 | 0.00 | 0.06 | 0.25 | 12.33 | 34.85 | 40.96 | 11.40 | 0.15 | 0.00 | 0.00 |

# Calibration Bias Among Detectors



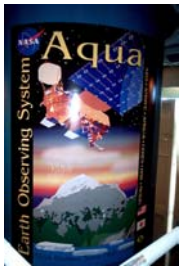

Ratios (averaged) of **lunar irradiance** measured by individual detector to the band-averaged value for Aqua MODIS (left) and Terra MODIS (right) bands 1-4, 8-12, and 17-19.



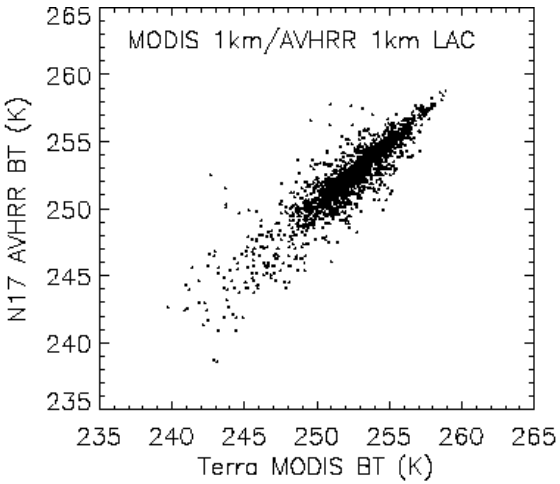



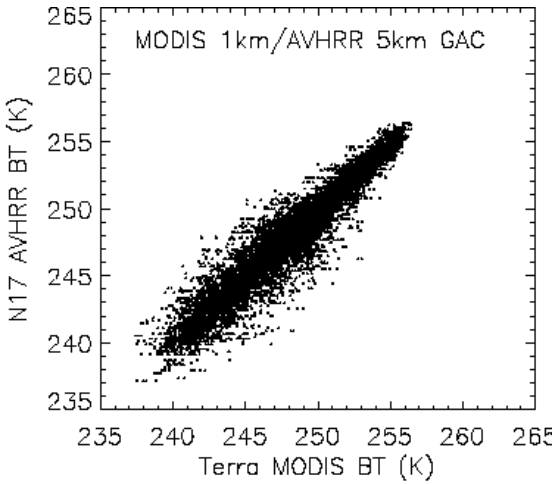

Comparison study using **MISR** for Terra MODIS (TOA radiance) also show small and similar detector to detector difference.

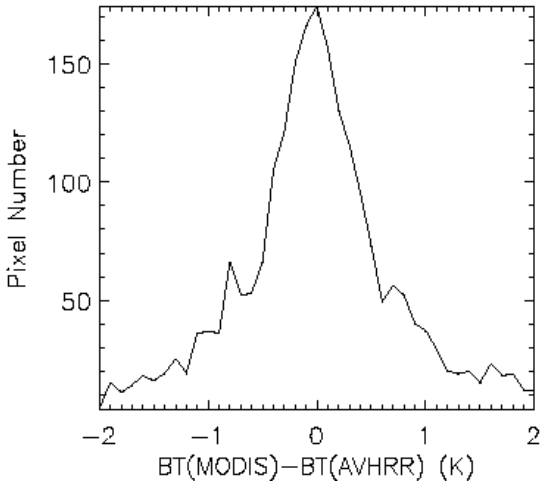
# Inter-comparison Study and Progresses

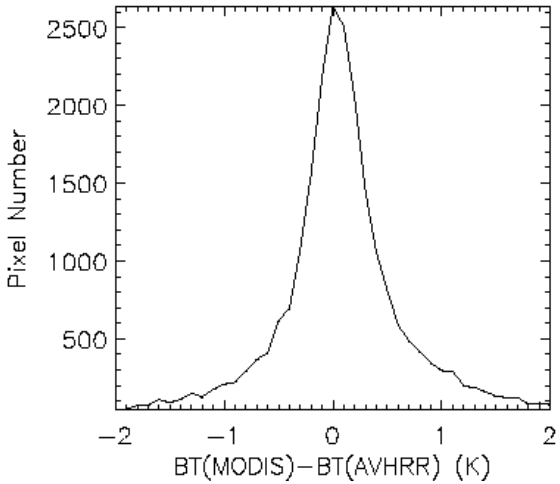



## Terra MODIS and AVHRR (17) in the 11μm band on Nov 25, 2002
## Left: LAC data; Right: GAC data



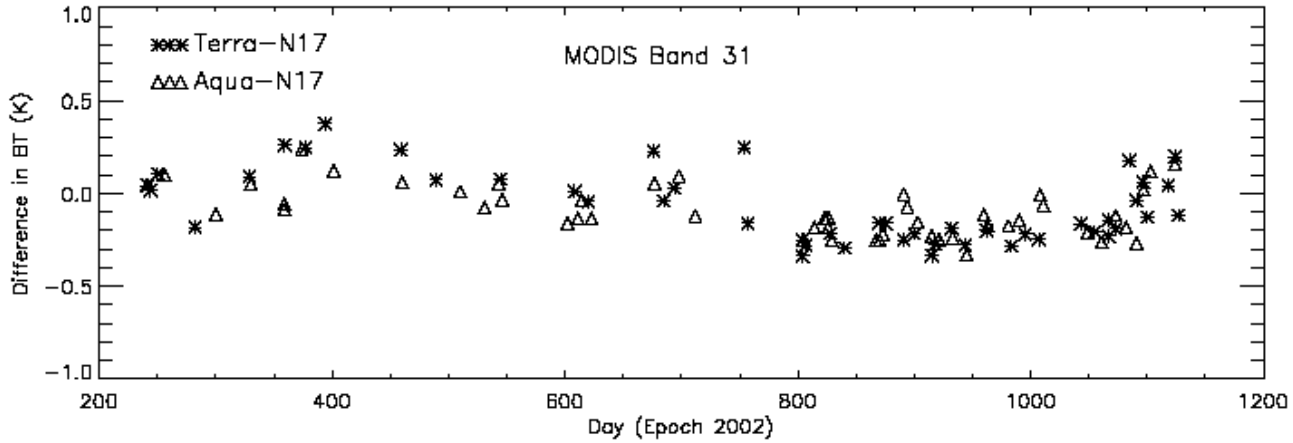



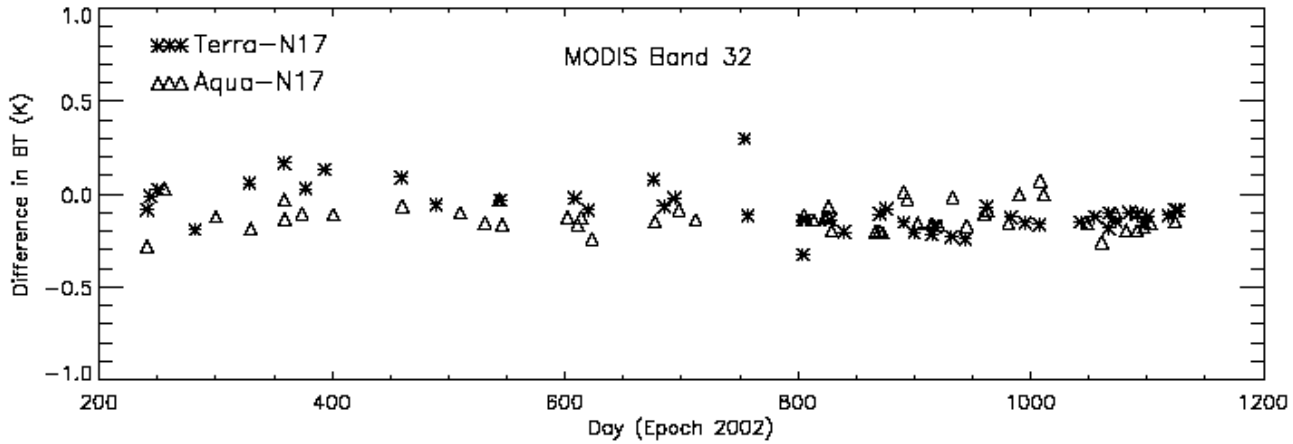
# Inter-comparison Study and Progresses

MODIS Band 31 and 32

Uncertainty: 0.35K; NEdT = 0.05K at 300K

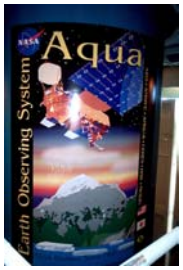



$\Delta BT < 0.08 \pm 0.15K$




$\Delta BT < 0.14 \pm 0.12K$


# Uncertainty Analysis (RSB)

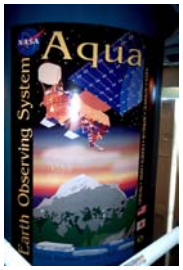



Current MODIS RSB Reflectance Calibration Uncertainty (1)

| | | SBRS/JY | MCST/JX-1 |
|---|---|---|---|
| 1 | NIST reference: | 0.50% | 0.50% |
| 2 | Characterization of SBRS scattering goniometer: | 0.70% | 0.70% |
| 3 | Transfer of NIST BRF scale to MODIS SD reference: | 0.50% | 0.50% |
| 4 | MODIS SD characterization: | 0.50% | 0.50% |
| 5 | SD spatial non-uniformities: | 0.70% | 0.70% |
| 6 | Interpolation angular / spectrally: | 0.10% | 0.10% |
| 7 | Pre-launch to on-orbit SD BRDF change: | 0.50% | 0.50% |
| 8 | SD screen: | 0.20% | 0.50% |
| 9 | SDSM solar 2% attenuation and SDS impact: | 0.50% | 0.50% |
| 10 | Solar illumination of the SD surrounds (stray light) | 0.30% | 0.30% |
| 11 | Earthshine through the SD door | 0.30% | 0.50% |
| 12 | Earthshine through nadir aperture door | 0.10% | 0.10% |
| | RSS | 1.57% | 1.69% |
| | RSS (non-ocean without SDS) | 1.56% | 1.61% |

**Continuing efforts made to update based on sensor's on-orbit performance over time**

# Uncertainty Analysis (RSB)




## Current MODIS RSB Reflectance Calibration Uncertainty (2)

| B | BRF | dn_SD | T_inst | K_inst | SWIR | Δ | RVS | RVS(*) | dn_EV | RSS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.69% | 0.05% | 0.01% | 0.05% | 0.00% | 0.37% | 0.18% | 0.50% | 0.54% | 1.89% |
| 2 | 1.69% | 0.06% | 0.03% | 0.12% | 0.00% | 0.25% | 0.01% | 0.50% | 0.19% | 1.80% |
| 3 | 1.69% | 0.04% | 0.01% | 0.13% | 0.00% | 0.47% | 0.05% | 0.50% | 0.31% | 1.86% |
| 4 | 1.69% | 0.04% | 0.01% | 0.02% | 0.00% | 0.42% | 0.04% | 0.50% | 0.30% | 1.84% |
| 5 | 1.69% | 0.09% | 0.01% | 0.02% | 1.00% | 0.20% | 0.03% | 0.50% | 0.62% | 2.13% |
| 6 | 1.69% | 0.04% | 0.00% | 0.04% | 1.00% | 0.20% | 0.03% | 0.50% | 0.21% | 2.05% |
| 7 | 1.69% | 0.07% | 0.01% | 0.01% | 1.00% | 0.20% | 0.03% | 0.50% | 0.68% | 2.15% |
| 8 | 1.69% | 0.20% | 0.03% | 0.01% | 0.00% | 0.50% | 0.05% | 0.50% | 0.09% | 1.85% |
| 9 | 1.69% | 0.11% | 0.01% | 0.09% | 0.00% | 0.48% | 0.04% | 0.50% | 0.07% | 1.83% |
| 10 | 1.69% | 0.08% | 0.01% | 0.03% | 0.00% | 0.46% | 0.07% | 0.50% | 0.07% | 1.83% |
| 11 | 1.69% | 0.07% | 0.01% | 0.04% | 0.00% | 0.43% | 0.06% | 0.50% | 0.06% | 1.82% |
| 12 | 1.69% | 0.06% | 0.01% | 0.01% | 0.00% | 0.42% | 0.06% | 0.50% | 0.07% | 1.82% |
| 13 | 1.69% | 0.04% | 0.01% | 0.01% | 0.00% | 0.35% | 0.30% | 0.50% | 0.07% | 1.82% |
| 14 | 1.69% | 0.04% | 0.01% | 0.01% | 0.00% | 0.35% | 0.28% | 0.50% | 0.07% | 1.82% |
| 15 | 1.69% | 0.05% | 0.02% | 0.02% | 0.00% | 0.31% | 0.01% | 0.50% | 0.07% | 1.79% |
| 16 | 1.69% | 0.06% | 0.01% | 0.07% | 0.00% | 0.24% | 0.01% | 0.50% | 0.07% | 1.78% |
| 17 | 1.69% | 0.02% | 0.01% | 0.01% | 0.00% | 0.22% | 0.03% | 0.50% | 0.26% | 1.80% |
| 18 | 1.69% | 0.04% | 0.02% | 0.05% | 0.00% | 0.20% | 0.03% | 0.50% | 1.31% | 2.21% |
| 19 | 1.69% | 0.03% | 0.00% | 0.01% | 0.00% | 0.20% | 0.01% | 0.50% | 0.20% | 1.78% |
| 26 | 1.69% | 0.04% | 0.01% | 0.08% | 1.00% | 0.20% | 0.03% | 0.50% | 0.44% | 2.08% |

SWIR crosstalk impact error of 1% was used here. Exact numbers should be evaluated with comprehensive science test (a correction algorithm applied in the L1B and in m1 calculation).