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

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and

MODIS Characterization Support Team (MCST)
Outline

• Introduction
  – Instrument Background, On-orbit Calibration Activities, and Current Status
• Instrument Operations
• On-orbit Performance
  – Thermal Emissive Bands (TEB)
  – Reflective Solar Bands (RSB)
• Level 1 and LUT Updates
• Challenging and Concerning Issues
• Summary
Introduction

Acknowledgements:

• All MCST members
• MODIS Science Team
  – Science Team Leader (Vince Salomonson)
  – Land (Eric Vermote and Zhengming Wan)
  – Ocean (Barnes et al.)
  – Atmosphere (Chris Moeller)
  – Cal/Val (Stuart Biggar)
• Raytheon / SBRS
  – Roger Drake and Jim Young
• Others
  – Bruce Guenther, Eugene Waluschka, and Robert Wolfe
Introduction

Contact:

- Team leader: Jack Xiong
- Support and coordinate science team issues: Vincent Chiang
- Instrument operation: Bryan Breen
- RSB Calibration: Xiaobo Xie
- TEB Calibration: Aisheng Wu
- L1B and LUT: James Kuyper

**Instrument Background**

- 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

**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
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)

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

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

Terra MODIS (over 6 years)

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

Aqua MODIS (over 3.5 years)

• Stable and Normal Operation
  – Same configuration used for the entire mission (currently B conf.)
  – May 17, 2005: SRCA operation shutdown during 20W spatial calibration due
to failure of lamp # 3. Starting from October 2005, SRCA has been operated
at reduced frequencies using constant current mode without 30W lamp
configuration. No impact on science data.
Status of Instruments: L1B/LUTs

Terra MODIS (over 6 years)
- L1B code: 12 versions
  - V4.3.0 and V.5.0.6 are currently in production
- L1B LUTs: over 110 versions used in production (10 for collection 5)
  - Nearly 20 LUTs delivered (March 05 – present)

Aqua MODIS (over 3.5 years)
- L1B code: 6 versions
  - V4.3.1 and V.5.0.7 are currently in production
- L1B LUTs: over 50 versions used in production (7 for collection 5)
  - Nearly 14 LUTs delivered (March 05 – present)

Note: many versions of code and LUTs have also been developed, tested, and delivered for special applications or for MCST internal testing and research
Terra MODIS (over 6 years)
- Stable Spatial and Spectral Performance On-orbit
- TEB calibration performs well using on-board BB
- RSB calibration LUTs have been regularly updated
  - Tracking SD degradation
  - Constantly tracking RSB stability using lunar observations
  - New RVS approach applied in collection 5

Aqua MODIS (over 3.5 years)
- Stable Spatial and Spectral Performance On-orbit
  - BBR out of specification for all bands between warm and cold FPAs, B6 inoperable detectors (two problems since pre-launch)
- TEB calibration performs well using on-board BB
- RSB calibration LUTs have been regularly updated
  - Similar SD degradation as Terra MODIS under the same conditions
  - Constantly tracking RSB stability using lunar observations
Terra Instrument and FPA Temperatures
Aqua Instrument and FPA Temperatures

MODIS Aqua Telemetry Instrument Temperature
Day 2002/58 to 2005/339

MODIS Aqua Telemetry VIS Focal Plane Temperature
Day 2002/58 to 2005/339

MODIS Aqua Telemetry NIR Focal Plane Temperature
Day 2002/58 to 2005/339

MODIS Aqua Telemetry SMIR & LWIR Focal Plane Temperature
Day 2002/58 to 2005/339
PFM MODIS Operations: Highlights

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

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

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

• Switched Instrument Configuration to B-side
  – October 30, 2000: Transitioned to B-side science

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

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

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

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

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

• Black Body (BB) Taxi Errors
  – July 26, 2002: C&DH gets a lot of TAXI overflow errors (problem is traced to when the BB is at FULL duty cycle and reaches a plateau)
  – October 22, 2002: BB calibration reworked so temperature goes from 290K to 315K at FULL without a plateau
• SD Screen Failure to Open
  – May 6, 2003: SD Screen (SDS) does not open when commanded
  – July 2, 2003: SD Door is opened with the SDS remaining closed (will remain this configuration until further notice)

• 1st Spacecraft Science Formatting Equipment (SFE) Shutdown
  – February 1, 2003: SFE-A HPM-2A board locked up. SFE-A power-cycled.
  – February 18, 2004: SFE-A shuts down inside SAA.
• 2nd Spacecraft Solid State Recorder Anomaly
  – September 24, 2003: PWA in the MODIS buffer fails; MODIS loses 2 superset; now at 34 superset
  – September 25, 2003: Failed superset are removed from active list
  – September 30, 2003: 1 superset reallocated from MISR buffer to MODIS buffer; MODIS now at 35 superset

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

• Terra Direct Broadcast Outage
  – November 30, 2003: SFE-A Direct Broadcast is lost.
  – January 15, 2004: SFE-A recycled; Direct broadcast back online
• **SRCA Lamp #2 Degradation**
  - March-April, 2004: Some degrading of SRCA lamp #2 was noticed
  - April 26 & 27, 2004: 10W radiometric calibrations were performed using lamps 1, 2, and 3.
  - May 25, 2004: SRCA lamp #2 is no longer being used during SRCA calibrations. In its place, lamp #4 is being used.
  - November 22, 2004: SRCA lamp #2 shuts itself off during an extended SRCA calibration.

• **2nd Spacecraft Science Formatting Equipment (SFE) Shutdown**
  - December 24, 2004: SFE-A HPM-2 card error trips TMON-16, shutting off SFE-A

• **4th Spacecraft Solid State Recorder Anomaly (new since last STM)**
PFM MODIS Operations: Status

- 216 SRCA Calibrations
  - 31 Full Spectral, 43 Full Spatial, and 72 Full Radiometric (update)
  - Lamp Usage in hours: total (on orbit)
    10W Lamps, 500hr life: 1) 249.8 (115.6) 2) 172.1 (53.0) 3) 188.4 (60.1) 4) 77.9 (16.4)
    1W Lamps, 4000hr life: 1) 569.2 (26.3) 2) 278.7 (2.4)

<table>
<thead>
<tr>
<th>Lamp Use in Hours</th>
<th>10W #1</th>
<th>10W #2</th>
<th>10W #3</th>
<th>10W #4</th>
<th>1W #1</th>
<th>1W #2</th>
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<tr>
<td>Full Radiometric</td>
<td>0.151</td>
<td>0</td>
<td>0.13</td>
<td>0.13</td>
<td>0.086</td>
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<td>Full Spatial</td>
<td>0.34</td>
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<td>0.34</td>
<td>0.34</td>
<td>0.17</td>
<td>0</td>
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<tr>
<td>Full Spectral</td>
<td>2.38</td>
<td>0</td>
<td>1.172</td>
<td>1.172</td>
<td>0</td>
<td>0</td>
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<tr>
<td>One Year Use with:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Radiometric</td>
<td>10.312</td>
<td>0</td>
<td>6.436</td>
<td>6.436</td>
<td>1.712</td>
<td>0</td>
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<tr>
<td>Quartley Spatial Triannual Spectral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total after 10 years</td>
<td>304.471</td>
<td>172.093</td>
<td>224.216</td>
<td>113.702</td>
<td>580.897</td>
<td>278.715</td>
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</table>
PFM MODIS Operations: Status

- 500 SD/SDSM Calibrations (183 SD Door Open + 317 SD Door Screened)
  - 2146 (1213 on orbit) of 3022 Solar Diffuser Door Movements
- 54 Blackbody Calibrations
- 46 Electronics Calibrations
- 62 Lunar Calibrations, 57 via Roll Maneuver
- 33 Yaw Maneuver SD/SDSM Calibrations
- Nadir Door Operations
  - 538 (9 on orbit) of 1316 Nadir Door Movements
- Space View Door Operations
  - 441 (8 on orbit) of 1316 Space View Door Movements
- Voltages are steady with occasional single-sample spikes
- Focal Plane Heater Voltage
  - PFM LWIR Focal Plane Heater Margin is currently ~34mW
  - Another outgas event may be required, but not in the near future
- Radiative cooler / Outgas Temperatures
  - PFM Intermediate Stage is currently 126.0K and steady
FM1 MODIS Operations: Highlights

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

• 3 Early Spacecraft Safe Mode Events
  – June 27, 2002:
  – July 29, 2002:
  – September 12, 2002:
• Dropped SCS Command Anomaly
  – July 10, 2002: First 2 commands of SCS 154 not executed (SDSM calibration)
  – August 9, 2002: Final command of SCS 153 not executed (Macro 9 command)
  – August 13, 2002: First command of SCS 56 not executed (DAY rate command)
  – August 28, 2002: Fifth and sixth commands of SCS 154 not executed (SDSM calibration)
  – September 2, 2002: Second command of SCS 56 not executed (NIGHT rate command)
  – September 20, 2002: Patch loaded to disable IMOK signal to MODIS in event of s/c SAFE mode
  – October 15, 2002: Patch loaded to swap ISC-to-MODIS and CTC-to-MODIS command slots
  – January 21, 2003: CTC-to-MODIS commands dropped/delayed
  – April 15, 2003: Patch loaded to swap back the ISC-to-MODIS and CTC-to-MODIS command slots, and to delay each command by one sub-minor cycle (32 milliseconds)
• SRCA Lamp #2 Degradation
  – February, 2003: Some degrading of SRCA lamp #2 was noticed
  – March 17 & 18, 2003: 10W radiometric calibrations were performed 4 times using each of the 4 lamps.
  – As of April 14, 2003: SRCA lamp #2 is no longer being used for SRCA calibrations. Lamp #4 is being used in it’s place.

• SRCA Lamp #3 Failure
  – May 17, 2005: During 20W portion of SRCA Full Spatial calibration, SRCA lamps shutdown, SRCA continues to run until normal shutdown.
  – June 28, 2005: Lamps are tested and 10W lamp #3 does not turn on. All other lamps operate nominally. Currently SRCA calibrations limit to 10W, 20W, and 1W.
• 91 SRCA Calibrations
  – 13 Full Spectral, 22 Full Spatial, and 39 Full Radiometric (update)
  – Lamp Usage in hours: total (on orbit)
    10W Lamps, 500hr life: 1) 247.2 (47.0)  2) 188.0 (12.3)
    3) 205.7 (27.2)  4) 83.2 (25.5)
    1W Lamps, 5000hr life: 1) 510.2 (10.7)  2) 271.6 (1.8)

<table>
<thead>
<tr>
<th>Lamp Use in Hours</th>
<th>10W #1</th>
<th>10W #2</th>
<th>10W #3</th>
<th>10W #4</th>
<th>1W #1</th>
<th>1W #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Radiometric</td>
<td>0.15</td>
<td>0</td>
<td>0</td>
<td>0.065</td>
<td>0.085</td>
<td>0</td>
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<tr>
<td>Full Spatial</td>
<td>0.339</td>
<td>0</td>
<td>0</td>
<td>0.169</td>
<td>0.169</td>
<td>0</td>
</tr>
<tr>
<td>Full Spectral</td>
<td>2.38</td>
<td>0</td>
<td>0</td>
<td>1.172</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

One Year Use with:
Monthly Radiometric
Quarterly Spatial
Tri-annual Spectral

<table>
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<tr>
<th>One Year Use</th>
<th>10.296</th>
<th>0</th>
<th>0</th>
<th>4.972</th>
<th>1.696</th>
<th>0</th>
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<tbody>
<tr>
<td>Total after 10 years</td>
<td>335.011</td>
<td>187.983</td>
<td>205.709</td>
<td>125.427</td>
<td>526.827</td>
<td>271.625</td>
</tr>
</tbody>
</table>
FM1 MODIS Operations: Status

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

Calibration algorithms

Instrument performance

Aqua & Terra MODIS inter-comparison

Summary
MODIS TEB Calibration Using Blackbody

Radiance (TOA), $L_{EV}$

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

Calibration coefficient, $b_1$, from BB

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

**RVS**: Response Versus Scan-angle  
**E**: Emissivity  
**L**: Spectral band averaged radiance  
**dn**: Digital count with background corrected
MODIS TEB Calibration Using Blackbody

BB from 270-317K provides $a_0$ and $a_2$

BB at $T_{BB}$ provides $b_1$
on a scan by scan basis

Other Calibration Issues:
B21 (Terra/Aqua) – Now MS Dependent
PC Xtalk (Terra)
B33,35,36 (Aqua) at high $T_{BB}$
Instrument On-orbit Performance

Thermal Emissive Bands (16 bands and 160 detectors)

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

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

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

Terra MODIS MWIR (Bands 20–25) Normalized b1

Terra MODIS LWIR (Bands 27–36) Normalized b1
Aqua MODIS TEB Response Trending

Aqua MODIS MWIR (Bands 20-25) Normalized b1

Aqua MODIS LWIR (Bands 27-36) Normalized b1

Days from 2002
MODIS TEB Short-term Response

Terra MODIS can-by-scan response on 2005281

Aqua MODIS can-by-scan response on 2005290
### Aqua MODIS Noisy Detector History

#### Detectors in Product Order

<table>
<thead>
<tr>
<th></th>
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<tr>
<td></td>
<td>20</td>
<td>0.05</td>
<td>10</td>
<td>-</td>
<td>0.05</td>
<td>0.23</td>
<td>0.23</td>
<td>0.20</td>
<td>0.3</td>
<td>0.03</td>
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<tr>
<td></td>
<td>21</td>
<td>0.20</td>
<td>3</td>
<td></td>
<td>0.16</td>
<td>0.23</td>
<td>0.23</td>
<td>near 0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.25</td>
<td>9</td>
<td>others</td>
<td></td>
<td></td>
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<td></td>
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#### In Spec

#### Near Spec

#### Out of Spec
## Terra MODIS Noisy Detector History

**Detectors in Product Order**

<table>
<thead>
<tr>
<th>Day/Year</th>
<th>Band 21</th>
<th>Band 27</th>
<th>Band 28</th>
<th>Band 29</th>
<th>Band 30</th>
<th>Band 31</th>
<th>Band 32</th>
<th>Band 33</th>
<th>Band 34</th>
<th>Band 35</th>
<th>Band 36</th>
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<tbody>
<tr>
<td></td>
<td>Spec NEdT[K]</td>
<td>0.20</td>
<td>0.25</td>
<td>0.25</td>
<td>0.05</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.05</td>
<td>0.35</td>
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<td>Detector #</td>
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<td>5</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>2</td>
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<tr>
<td>Pre-launch</td>
<td>-</td>
<td>0.20</td>
<td>0.18</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
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<tr>
<td>055/2000 Nadir door open</td>
<td>0.17</td>
<td>0.17</td>
<td>0.09</td>
<td>0.09</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.10</td>
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<tr>
<td>232/2000 Back from FPA recycle</td>
<td>0.16</td>
<td>0.15</td>
<td>0.10</td>
<td>0.24</td>
<td>0.05</td>
<td>0.05</td>
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<td>0.02</td>
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<td>0.03</td>
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<td>030/2001</td>
<td>-</td>
<td>0.15</td>
<td>0.16</td>
<td>0.10</td>
<td>0.27</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
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<td>087/2002 Back from safe mode</td>
<td>0.18</td>
<td>0.25</td>
<td>0.11</td>
<td>0.24</td>
<td>0.06</td>
<td>0.32</td>
<td>0.05</td>
<td>0.04</td>
<td>0.02</td>
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<td>022/2003</td>
<td>-</td>
<td>0.14</td>
<td>0.16</td>
<td>0.10</td>
<td>0.23</td>
<td>0.05</td>
<td>0.30</td>
<td>0.27</td>
<td>0.04</td>
<td>0.02</td>
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<td>086/2003 After DSM¹</td>
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<td>0.15</td>
<td>0.11</td>
<td>0.23</td>
<td>0.05</td>
<td>0.29</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
<td>0.02</td>
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<td>0.16</td>
<td>0.15</td>
<td>0.26</td>
<td>0.26</td>
<td>0.05</td>
<td>0.16</td>
<td>0.36</td>
<td>0.16</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>158/2004</td>
<td>-</td>
<td>0.18</td>
<td>0.17</td>
<td>0.28</td>
<td>0.25</td>
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<td>0.16</td>
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<td>0.21</td>
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<tr>
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<td>-</td>
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<td>0.16</td>
<td>0.26</td>
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<td>0.20</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>175/2004</td>
<td>-</td>
<td>0.15</td>
<td>0.15</td>
<td>0.28</td>
<td>0.26</td>
<td>0.12</td>
<td>0.17</td>
<td>0.35</td>
<td>0.17</td>
<td>0.03</td>
<td>0.02</td>
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<tr>
<td>034/2005</td>
<td>-</td>
<td>0.14</td>
<td>0.15</td>
<td>0.28</td>
<td>0.22</td>
<td>0.10</td>
<td>0.16</td>
<td>0.45</td>
<td>0.16</td>
<td>0.04</td>
<td>0.02</td>
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<tr>
<td>130/2005</td>
<td>-</td>
<td>0.16</td>
<td>0.16</td>
<td>0.31</td>
<td>0.22</td>
<td>0.40</td>
<td>0.15</td>
<td>0.40</td>
<td>0.14</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

¹Spacecraft Deep Space Maneuver

**Legend**
- **In Spec**
- **Near the Spec**
- **Out of Spec**
MODIS Inter-comparison Using a Third Sensor

Aqua MODIS and AVHRR GAC (17) in the 11/12\(\mu\)m band on Nov 24, 2005
T(Aqua) - T(Terra) (N15) = - 0.05K

Band 31

T(Aqua) - T(Terra) (N16) = - 0.12K

T(Aqua) - T(Terra) (N17) = - 0.03K

MODIS Band 31 and 32 Uncertainty: 0.35K; NEdT = 0.05K at 300K
MODIS thermal bands have been performing well according to design specifications for Terra (6+ years) and Aqua (3.5+ years); Aqua performs better than Terra in a number of areas.

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

- Overview of RSB calibration and characterization
- RSB on-orbit performance update
- Earthshine impacts on RSB calibration and improvements
- Summary
MODIS RSB Calibration Using SD/SDSM

Reflectance Factor

\[
\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot d_{n_{EV}}^* \cdot d_{Earth-Sun}^2
\]

\[\Delta_{SD} = \frac{d_{c_{SD}}}{d_{c_{Sun}}}\]

\[m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< d_{n_{SD}}^* > \cdot d_{Earth-Sun}^2} \cdot \Gamma_{SD} \cdot \Delta_{SD} \]

SD degradation factor;  
\(\Gamma_{SD}\): SD screen vignetting function  
\(d\): Earth-Sun distance  
\(d_{n^*}\): Corrected digital number;  
\(d_{c}\): Digital count of SDSM
EV Radiance:

\[
L_{EV} = \frac{E_{Sun} \cdot \rho_{EV} \cdot \cos(\theta_{EV})}{\pi \cdot d_{Earth-Sun(EV)}^2} = \frac{E_{Sun}}{\pi} m_1 \cdot d n_{EV}
\]

Solar Irradiance \(E_{\text{SUN}}\):

- 0.4-0.8 \(\mu\text{m}\) Thuillier et al., 1998;
- 0.8-1.1 \(\mu\text{m}\) Neckel and Labs, 1984;
- Above 1.1 \(\mu\text{m}\) Smith and Gottlieb, 1974

Others:

- Thermal leak applied for SWIR bands (B5-7, B26)
- Leak coefficients determined from EV night time data
- B26 de-striping algorithm added (from C. Moeller of Wisconsin)
RSB On-Orbit Overall Performance

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

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

### Terra

<table>
<thead>
<tr>
<th>Day/Year</th>
<th>Band</th>
<th>SNR Spec</th>
<th>Detector</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74</td>
<td>275</td>
<td>110</td>
</tr>
<tr>
<td>055/2000</td>
<td>Nadir Door Open</td>
<td>0 80 0 0 30 0 80 60 0 0 100 0 0 0 110 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160/2000</td>
<td>CFPA Lost Control</td>
<td>80 80 80 80 30 80 80 60 95 95 100 0 0 0 110 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>232/2000</td>
<td>Back from FPA recycle</td>
<td>0 70 0 80 50 80 0 50 95 75 100 0 0 0 110 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304/2000</td>
<td>B Side</td>
<td>80 80 80 80 60 80 80 85 20 85 275 350 350 100 100 90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>183/2001</td>
<td>A Side</td>
<td>90 90 90 90 90 90 90 90 10 95 380 380 380 110 110 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>259/2002</td>
<td>A Side B Formatter</td>
<td>100 100 100 100 100 100 100 100 10 100 380 380 380 110 110 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Aqua

<table>
<thead>
<tr>
<th>Day/Year</th>
<th>Band</th>
<th>SNR Spec</th>
<th>Detector</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74</td>
<td>275</td>
<td></td>
</tr>
<tr>
<td>175/2002</td>
<td>Nadir Door Open</td>
<td>0 0 100 0 0 470 470 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>189/2002</td>
<td>Back from Safe Mode</td>
<td>0 0 470 0 0 470 470 0 470 470 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>255/2002</td>
<td>Back from Safe Mode</td>
<td>0 0 470 0 0 470 470 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>266/2002</td>
<td>Back from Safe Mode</td>
<td>0 0 470 0 0 400 150 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110/2003</td>
<td>Back from Safe Mode</td>
<td>0 0 320 0 0 470 260 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160/2003</td>
<td>Back from Safe Mode</td>
<td>0 0 470 0 0 400 290 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>265/2003</td>
<td>Back from Safe Mode</td>
<td>0 0 275 0 0 400 290 0 0 150 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360/2003</td>
<td>Back from Safe Mode</td>
<td>0 0 270 0 0 275 290 0 0 200 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Detectors in SBRS order
MODIS RSB Response Trending

TERRA Visible FPA 1/m1, mirror side 1

TERRA SMIR FPA 1/m1, mirror side 1

TERRA NIR FPA 1/m1, mirror side 1
MODIS RSB Response Trending

AQUA Visible FPA 1/m1, mirror side 1

AQUA SMIR FPA 1/m1, mirror side 1

AQUA NIR FPA 1/m1, mirror side 1
MODIS RSB Response Trending

**TERRA Visible FPA 1/m1 mirror side ratio**

**AQUA Visible FPA 1/m1 mirror side ratio**

Mirror side difference in Aqua MODIS is extremely small
Similar SD degradation in Terra and Aqua MODIS
Simplified Solar Diffuser Geometry

Direct Light
- full illumination

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

Terra band 2

~0.4%

Terra band 16

~0.4%

Mirror side 1

SD Screen used for band 16
Earthshine Impacts on RSB Calibration

~0.4%

Terra band 3

~0.8%

Terra band 9

SD Screen used for band 9
Earthshine Impacts on Terra Orbit m1s

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

Terra MODIS B2

- Regular: Average of 40 scans centered at elevation angle 12.5
- Method A: 40 scans used with 20 scans shift ahead
- Method B: 20 scans used with 20 scans shift ahead

Impact of Earthshine from nadir aperture door is extremely small <0.1%
Improvements on Terra m1

Regular Method A Method B

<table>
<thead>
<tr>
<th></th>
<th>&lt;-0.5%</th>
<th>&lt;-0.3%</th>
<th>&gt;-0.3%</th>
<th></th>
<th>&lt;-0.5%</th>
<th>&lt;-0.3%</th>
<th>&gt;-0.3%</th>
<th></th>
<th>&lt;-0.5%</th>
<th>&lt;-0.3%</th>
<th>&gt;-0.3%</th>
</tr>
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<tbody>
<tr>
<td>Band 2</td>
<td>0.08</td>
<td>0.49</td>
<td>99.51</td>
<td>Band 2</td>
<td>0.04</td>
<td>0.32</td>
<td>99.68</td>
<td>Band 2</td>
<td>0.05</td>
<td>0.29</td>
<td>99.71</td>
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<tr>
<td>Band 16</td>
<td>0.09</td>
<td>0.45</td>
<td>99.55</td>
<td>Band 16</td>
<td>0.04</td>
<td>0.30</td>
<td>99.70</td>
<td>Band 16</td>
<td>0.05</td>
<td>0.28</td>
<td>99.72</td>
</tr>
</tbody>
</table>

Residual less than –0.5%: the improvements is about 50%
Residual less than –0.3%: the improvements is more than 30%
• RSB calibration performed well according to the design specifications
  – Terra (6 years !) and Aqua (3.5 years)
  – Noticeable wavelength dependent degradation observed on both instruments, mirror side dependent degradation also observed in Terra MODIS
  – Solar Diffuser degradation tracked by SDSM, both Terra and Aqua show consistent results

• Constant efforts made to maintain and improve RSB calibration and characterization
  – Continues working closely with science groups for key RSB issues
  – Earthshine impacts investigations
## Production Changes to MOD_PR02 TERRA L1B Code

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>Forward Process Begin</th>
<th>Code Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2.3.2_Terra</td>
<td>3/17/2000 (077 2000) 00:00</td>
<td>• Pre-Launch calibration (SMWIR Itwk/Vdet = 79/190).</td>
</tr>
</tbody>
</table>
| V2.4.2_Terra  | 6/19/2000 (171 2000) 00:00 | • Corrected indexing bug affecting emissive bands (this appeared in the product as if something was wrong with RVS).  
• Corrected bug for determining when the moon is in the SVP (sign error)  
• Maximum number of scans raised to 208 (consistent with L1A code) |
| V2.4.3_Terra  | 8/18/2000 (231 2000) 14:00 | • Corrected bug in emissive bands preprocessing for PC bands X-talk.  
• Interpolation of scaled integers for non-functional (dead) detectors.  
• Time-dependent LUTs architecture. |
| V2.4.4_Terra  | 10/13/2000 (287 2000) 19:55 | • New emissive band algorithm to compute $<\text{DNsv}>$ with moon in SVP.  
• Corrected bug in emissive bands preprocessing for the 40 scans preceding or following a sector rotation or Ecal.  
• Corrected indexing bug in SWIR OOB correction (switch remained OFF).  
• Several other bug fixes affecting metadata. |
| V2.5.4_Terra  | 11/23/2000 (328 2000) 15:55 | • Aqua compatible code and metadata  
• Removed obsolete metadata  
• New SWIR OOB algorithm & LUTs (for B-side only) |
| V2.5.5_Terra  | 02/13/2001 (044 2001) 13:55 | • Misregistration of aggregated images corrected.  
• Detector average of Esun used for computation of band-dependent radiancescales. |
Production Changes to MOD_PR02 TERRA L1B Code (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>Forward Process Begin</th>
<th>Code Changes</th>
</tr>
</thead>
</table>
| V3.0.0_Terra  | 05/24/2001 (144 2001) 00:00 | • Piecewise linear LUT capability added.  
• Reflective solar bands (RSBs) now check Space View subtracted values for saturation against lookup table.  
• For SWIR bands, when the moon is in the Space view port, method of computing average background DN same as that used for emissive bands. |
| V3.0.1_Terra  | 2/25/2002 (056 2002) 00:00 | • Production of 250m and 500m resolution night data may be turned off.  
• Various code upgrades/bug fixes. |
| V4.1.2_Terra* | 01/30/2003 (030 2003) 01:55 | • Band 26 Correction using aggregated Band 5 radiances inserted; turned ON  
• RVS correction changed to piecewise linear.  
• New flag TEB_B1_NOT_CALCULATED added.  
• Various code upgrades/bug fixes.  
• Metadata field "ProcessingEnvironment" is filled in from a call to "uname" from within the L1B code  
• R* LUT deleted  
• New OBC MCF files  
• RSB cal. coefficients reworked in LUTs |
| V4.2.0_Terra  | 08/22/2003 (234 2003) 02:00 | • SWIR out-of-band correction “sending” band changed to value determined by LUT  
• Earth-Sun distance calculation corrected  
• NAD open/closed determination changed  
• Nominal platform height corrected  
• ANSI-C compliance |
### Production Changes to MOD_PR02 TERRA L1B Code (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>Forward Process Begin</th>
<th>Code Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>V4.3.0_Terra</td>
<td>12/22/2003 (356 2003) 22:35</td>
<td>• Maneuver flag changed to key on spacecraft attitude</td>
</tr>
</tbody>
</table>
| V5.0.6_Terra  | 03/07/2005 (066 2005) 23:55 | • Add a new LUT to enable the SWIR OOB correction detector dependency  
• Enable Band 21 calibration with mirror side dependency  
• Improve the code portability  
• Comply with the ESDIS guideline  
• Add HDFEOS_FractionalOffset  
• Minor fix for code version recording  
• Correct wrong dimension mapping offset setting for 250m band data |

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

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V2.3.2_Terra  | 3                | • Emissive bands calibration and uncertainty LUTs  
                  • Reflective bands calibration and uncertainty LUTs  
                  • Uncertainty index scaling factors  
                  • Detector quality flag  
                  • “St. Patrick’s Day Update”  
                  • LUTs derived from on-orbit data. SMWIR ltwk/Vdet = 110/226. |
| V2.4.2_Terra  | 0                | • Scientifically same as LUTs v2.3.2.3 |
| V2.4.3_Terra  | 1                | • PC bands X-talk LUTs (from day 084 moon observation)  
                  • Emissive bands calibration LUTs (from day 102 BB cool-down observation)  
                  • RVS (for mirror side 2 only, from day 118 observation of NAD closed)  
                  • L_max for bands 31 and 32 increased  
                  • Reflective bands calibration LUTs (from day 171 solar diffuser observation)  
                  • SWIR OOB leak correction turned OFF  
                  • Detector quality flag – some detectors flagged as dead |
## Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V2.4.4_Terra  | 0, 1, 2           | • Switch to B-side. Final values for SMWIR Itwk/Vdet = 79/110  
• First implementation of time-dependent LUTs (A-side/B-side)  
• A-side calibration LUTs remained the same as before.  
• B-side emissive bands calibration LUTs (from day 305/306 BB observations)  
• Some B-side emissive bands uncertainty coefficient LUTs  
• L_max for several bands increased (both A and B side)  
• B-side reflective bands calibration LUTs (from day 305 solar diffuser observation)  
• B-side reflective bands uncertainty coefficient LUTs  
• Detector quality flag – all B-side detectors are functional.  
• B-side only: SWIR OOB correction switch turned ON and new SWIR LUTs (aimed at improving the first sub-sample of 500m bands) |
| V2.5.4_Terra  | 0                 | • New SWIR OOB LUTs (for B-side only) |
| V2.5.5_Terra  | 1, 2              | • Added Reflective LUT "E_sun_over_pi"; deleted Emissive LUT "Number of overlap scans for temperatures" (No science content affected).  
• 2 detectors marked as non-functioning as of day 2001/019.  
• Time dependent LUT table pieces added to cover day 2000/063. |
Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

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

* For V4.0.7_Terra, LUT V0 delivered but not used and LUT V1 used for reprocess only;  
For V4.0.9_Terra, LUT V0 used for reprocess only.
## Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V4.2.0_Terra  | 3, 4, 5, 6, 7, 8, 9 | - SWIR out-of-band correction “sending” band changed to value determined by LUT  
- Name change for the three LUTs related to the Band 5 to Band 26 correction  
- Continuous Reflective Calibration Coefficient updates |
|               | 1, 2, 3, 4, 5, 6, 7, 8, 9, 11* , 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36 | - LUTs updated from V4.2.0.8  
- Attitude limit LUTs added for maneuver flagging as of Version 1  
- Updates on coefficient for RVS computation  
- Updates on the coefficients for calculating $a_0$ and $a_2$, and on the value of $b_1$ for each Band 21 detectors, derived using the BB warm-up data set from days 007-008, 2004.  
- Detector quality flags QA table: Out-of-family gain” / “Noisy Detector” flag set for two detectors of Band 28 and one detector of Band 29.  
- Updated the SWIR bands correction coefficient.  
- Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, RVS_EefSB) |

*LUT V4.3.0.10 is a special version for U. of Wisconsin only (not shown here).
Production Changes to MOD_PR02 TERRA L1B LUTs (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V5.0.6_Terra  | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 | - Updates on the coefficients for calculating $a_0$ and $a_2$, and on the value of $b_1$ for each Band 21 detectors using the newly developed TEB RVS from Deep Space Maneuver. A new dimension of Mirror Side is added to the band_21_b1 LUT to separate the coefficients of the two mirror sides for Band 21.  
- Added a new LUT to enable the ability of determine the SWIR out-of-band correction "sending" detectors from the "sending" band.  
- Detector quality flags QA table: newly revised flags cover the entire time period since the launch.  
- Updated dn_sat_ev values for presaturating bands. Those which do not exhibit any presaturation are set to 4095 to remove any dn_sat_ev cutoff to make more valid data available.  
- Updated the SWIR bands correction coefficient.  
- Detector quality flags QA table: “Noisy Detector” flag set for one detector of Band 28.  
- Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, RVS_EefSB) |
## Production Changes to MOD_PR02 AQUA L1B Code

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

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>Forward Process Begin</th>
<th>Code Changes</th>
</tr>
</thead>
</table>
| V5.0.7_Aqua   | 07/03/2005 (185 2005) 00:10 | - Add a new LUT to enable the SWIR OOB correction detector dependency  
- Enable Band 21 calibration with mirror side dependency  
- Improve the code portability  
- Comply with the ESDIS guideline  
- Add HDFEOS_FractionalOffset  
- Minor fix for code version recording  
- Correct wrong dimension mapping offset setting for 250m band data |
## Production Changes to MOD_PR02 AQUA L1B LUTs

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V3.1.0_Aqua   | 0, 1, 2, 3        | • Pre-launch LUTs inserted.  
• Several LUTs updated after more Pre-launch analysis  
• New RSB and TEB calibration coefficient LUTs  
• New BB temp. saturation limits  
• Detector quality flags changed  
• SWIR correction switch ON |
| V4.1.1_Aqua   | 0, 1             | • LUTs updated from V3.1.0.3  
• New RSB calibration coefficient LUTs using SD degradation  
• Band 21 b1 table piece added  
• Detector quality flags changed |
| V4.1.3_Aqua   | 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 | • LUTs updated from V4.1.1.1  
• R* LUT deleted  
• Continuous Reflective Calibration Coefficient updates  
• Band 21, Detector 9 (product order) changed to “noisy” as of Version 3 |
### Production Changes to MOD_PR02 AQUA L1B LUTs (continued)

<table>
<thead>
<tr>
<th>PGE02 Version</th>
<th>LUT Patch Version</th>
<th>LUT Changes</th>
</tr>
</thead>
</table>
| V4.2.1_Aqua   | 4, 5, 6, 7, 8     | - LUTs updated from V4.2.1.3, which is parallel to V4.1.3.10  
                  - SWIR correction sending band changed to Band 28 before 2003104, Band 25 after as of Version 4  
                  - Continuous Reflective Calibration Coefficient updates  
                  - LUTs added for Band 26 destriping using aggregated Band 5 data as of V. 4 |
| V4.3.1_Aqua   | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 | - LUTs updated from V4.2.1.8  
                  - Reflective Calibration Coefficients reworked for reprocessing as of Version 1  
                  - Improved SD sun angles used  
                  - BRF and vignetting as a function of SD zenith and azimuth used  
                  - Temperature using Kinst used  
                  - Non-SWIR bands fitted with smooth function  
                  - SWIR bands  
                  - Step functions before 2002255, Linear functions thereafter  
                  - SWIR correction sending band changed to Band 25 for entire mission  
                  - Attitude limit LUTs added for maneuver flagging as of Version 1  
                  - Updates on coefficient for RVS computation and value of EV pixel dn to treat as saturated  
                  - Detector quality flags QA table: “Noisy Detector” flag set for one detector of Band 27.  
                  - Updated the SWIR bands correction coefficient.  
                  - Continuous Reflective Calibration Coefficient updates (m1, Sigma_m1, and/or RVS_RefSB) |
Production Changes to MOD_PR02 AQUA L1B LUTs (continued)

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

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

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

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

• Instruments have performed well and are stable
  – Terra (6+ years) and Aqua (3.5+ years); Aqua better than Terra in a number of areas (except B6 and BBR problems)
  – Noticeable optics degradation identified and corrected in both sensors’ response

• Constant efforts must be made to maintain instrument calibration and data quality
  – Combination of using on-board calibrators and other approaches
  – Input and support from science groups (representatives), instrument vendor (SBRS), and other expertise
  – Consideration of sensor aging impact

• Useful Information (MCST webpage)
  – Online documents: L1B user guide, product data dictionary, and ATBD
  – L1B code and LUTs change history, workshop materials, and publications

• Lessons learned for future sensors
Backup Charts
# MODIS Key Specifications

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

1 Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
2 Spectral Radiance values are (W/m²-µm-sr)
3 SNR = Signal-to-noise ratio
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
## Terra MODIS Operational Configurations

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

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

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

**Same Configuration Used for the Entire Mission**

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

**MCST IOT document: MODIS Instrument Operations**
**MCST WEB: Operation configuration changes and instrument reset events impact on science data**
**MODIS Spatial/Spectral Performance Summary**

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

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

**Useful References:**
2. X. Xiong, N. Che, and W. Barnes, “Terra MODIS on-orbit spectral characterization and performance”, Accepted for Trans. IEEE
Terra MODIS Spectral Performance

Terra MODIS Center Wavelength Shifts and Bandwidth Changes

Unable to track on-

Unable to track on-

2000 2001 2002 2003 2004 2005

2000 2001 2002 2003 2004 2005

Page 77
Aqua MODIS Spectral Performance

Aqua MODIS Center Wavelength Shifts and Bandwidth Changes

Unable to track on-or

Page 78
Note: The along-track shift is opposite in sign from last Workshop due to a change in detector numbering from SBRS to product order during the SRCA spatial computations.
Aqua MODIS Spatial Performance

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