MODIS Instrument Operations Status
Terra Flight Operations

- Terra Spacecraft Status
  - 18+ years of successful operation
  - Safe Mode Occurred 02/18/16 – 02/24/16
  - Solid State Recorder – 32 supersets allocated: 0 lost since last STM
  - Battery – Anomaly on 10/13/09 resulted in loss of 1 cell (out of 54 total). No impact on operations or power availability.
  - Orbit Maneuvers: Drag Make-up #97-107, Inclination Adjustment #46-51
Aqua Flight Operations

- Aqua Spacecraft Status
  - 16+ years of successful operations
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – Full data allocation
  - Battery – Fully functional
  - Orbit Maneuvers: Drag Make-up #107-130, Inclination Adjustment #52-61
MODIS Instrument Operations (Terra)

• Terra MODIS is healthy and operating nominally

• Operational Configuration (No change since last STM)
  – A-side: launch to Oct 30, 2000
  – A-side: July 02, 2001 to Sept 17, 2002
  – A-side electronics and B-side formatter: Sept 17, 2002 to present
  – BB temperatures set at 290K
  – Cold FPA (SMIR and LWIR) controlled at 83K
  – SD door fixed to “open” position since July, 2003

• Events
  – Updated Ideal BB Tables
  – Deep Space Calibration – August 2017
  – Standby Mode – September 2018

• Concerns
  – SSR allocation – further decrease could result in data loss or more night rate data collection
MODIS Instrument Operations (Aqua)

• **Aqua MODIS is healthy and operating nominally**

• **Operational Configuration (No change since last STM)**
  – Same B-side configuration since launch
  – BB temperatures set at 285K
  – Cold FPA (SMIR and LWIR) controlled at 83K

• **Events**
  – SRCA Lamp Failure
  – Lunar Roll duration change

• **Concerns**
  – Loss of radiative cooler margin – Cold FPA not maintained at 83 K through entire orbit.
  – Has been improving over past few years
Aqua SRCA Lamp Failure

- 10W Lamp #4 failed on June 30th, 2016
  - During SRCA Spectral Calibration Part 2
  - Confirmed by running separate 10W calibrations with remaining functional lamps

- Now only one remaining 10W Lamp functional
  - Lamp #1

- SRCA Calibrations changed on Aqua to only use 1 lamp
  - SCS for Radiometric and Spatial Calibrations changed
  - Macro 31 load updated for Spectral

- No major impact to instrument calibration
- SRCA calibration frequencies have been reduced to preserve lamp life
Terra performed an accelerated pitch during spacecraft night so that instruments can view the moon and deep space.

Previous maneuvers were performed on March 26, 2003 (no lunar view) and April 14, 2003 (with lunar view)
- No such maneuvers have been performed on Aqua

MODIS was set to Day rate data collection during the event

Moon was visible through Earth-View port

CFPA temperatures increased during calibration
- Returned to nominal temperatures after maneuver completion
Terra Lunar Deep Space Calibration

SMIR Cold Focal Plane Temperature

LWIR Cold Focal Plane Temperature

*2003 Data is from Lunar DSC
Terra Power Supply Alarms

• MOD_VR_PVLW_P30V flagged as RED on July 4, 2017
  – 30 volt power supply for PV LWIR Space-Viewing Analog Module Multiplexer
  – Lasted 60 seconds (1 telemetry update cycle)
  – Lower Limit is 26 V
  – Flagged at 25.7804 V

• Investigation found the alarm had flagged numerous times over the course of the mission

• After consultation with Joe Auchter, it was determined that this temporary low voltage did not pose a health threat to MODIS

• Flight Operations Alarm Threshold Lowered to 24 V
Terra Standby Mode – September 27, 2018

- Terra MODIS transitioned to Standby Mode on 2018/270 at 20:00 GMT
  - Caused by ATC (Automated Time Commands) not being loaded in time
  - Door positions and scan mirror activity remained unchanged
  - Blackbody was turned off
  - All MODIS related inhibit IDs were set
- MODIS returned to science mode on 2018/271 at 00:59 GMT
- The blackbody was powered on 2018/271 at 01:01 GMT
  - It was set to 290 K at 01:03 GMT
- All MODIS related inhibits were cleared by 2018/271 at 15:54 GMT
- There are no instrument health or safety concerns
- Science data remained in trend
DCR Background Information

- The DC Restore adjusts the output from the detector analog-to-digital converter (ADC) to maintain the signal within a specified dynamic range.
- The ADC Responsible for the Terra VIS FPA has shown a tendency to report odd multiples of 64 DN.
  - Referred to as a “sticky bin”, the signal level favors the response at the raw digital number value (DN) of 64.
  - At low signal levels, this can cause a noticeable discontinuity/level-of-error in data.
- The ideal blackbody output table values are compared against the measured blackbody values on a scan-by-scan basis.
  - If the difference is more than 150 DN, the DC restore is incremented.
Terra Band 3 Sticking Behavior

Daily TERRA SV Trending - Band 3 Subframe 2 D 5
Terra Ideal Blackbody Output Table Changes

• The Ideal Blackbody Output Table consists of 1800 words
  – 36 Bands, 50 Temperature values for each band
• Values for bands 3, 4, 8, 10-12 were changed from 200 to 230
  – This changed the dynamic range for these bands from 50-350 to 80-380, thus getting us out of the “sticky bin” range
  – Band 9 has shown no “sticky bin” behavior
• Memory Load to change values for band 3 took place on December 13, 2017
• Memory Load to change values for bands 4, 8, 10-12 took place on April 10, 2018
Band 3 SV after Ideal Blackbody Output Table Change
Calibration Changes

• **Aqua Lunar Roll**
  – Calibration time reduced from 6:46 to 3:46
    • Terra had the same time reduction in 2013
    • No impact on Radiometry

• **PV_Ecal**
  – Both instruments
  – Calibration will only be performed once annually
  – Previously performed quarterly

• **SRCA Calibrations**
  – Both instruments to conserve remaining lamp life
  – Full Radiometric
    • Quarterly, previously monthly
  – Spatial
    • Semi-annually, previously quarterly
  – Spectral
    • Semi-annually, previously tri-annually
Instrument Temperature Trends

Terra Inst. & VIS FPA Telemetry

- Terra: 3.5K increase over 18 years

Aqua Inst. & VIS FPA Telemetry

- Aqua: < 2K increase over 16 years
**BB Temperature Trends**

**Terra Blackbody Telemetry**

- Terra
- < 30 mK increase over 18 years

**Aqua Blackbody Telemetry**

- Aqua
- Excellent stability over mission lifetime
CFPA Temperature Trends
Terra SMIR & LWIR FPA Telemetry

Terra Very stable over lifetime

Aqua SMIR & LWIR FPA Telemetry
Aqua Decrease in recent years
**Terra/Aqua MODIS OBC Operations**

<table>
<thead>
<tr>
<th>Activity</th>
<th>PL to 05/16</th>
<th>05/16 – present</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD/SDSM#</td>
<td>714</td>
<td>42</td>
<td>756</td>
</tr>
<tr>
<td>BB WUCD</td>
<td>99</td>
<td>12</td>
<td>111</td>
</tr>
<tr>
<td>SRCA*</td>
<td>432</td>
<td>24</td>
<td>456</td>
</tr>
<tr>
<td>Electronic Cal</td>
<td>92</td>
<td>7</td>
<td>99</td>
</tr>
<tr>
<td>Lunar Roll</td>
<td>161</td>
<td>27</td>
<td>188</td>
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</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>PL to 05/16</th>
<th>05/16 - present</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD/SDSM#</td>
<td>570</td>
<td>66</td>
<td>636</td>
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<tr>
<td>BB WUCD</td>
<td>61</td>
<td>9</td>
<td>70</td>
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<tr>
<td>SRCA*</td>
<td>314</td>
<td>26</td>
<td>340</td>
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<tr>
<td>Electronic Cal</td>
<td>71</td>
<td>6</td>
<td>77</td>
</tr>
<tr>
<td>Lunar Roll</td>
<td>135</td>
<td>30</td>
<td>165</td>
</tr>
</tbody>
</table>

# Open & Screened Activities counted independently

* Includes Spatial, Spectral and Radiometric

05/16 = last Science Team Meeting
SRCA Calibrations

- Terra – 456 SRCA Calibrations
- Aqua – 340 SRCA Calibrations
- Please note there was a minor reconciliation of the usage numbers
- Lamps well within lifetime usage margins
- Aqua Lamp #4 Failure - 2016

<table>
<thead>
<tr>
<th>Lamp Power</th>
<th>10W</th>
<th>1W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp #</td>
<td>1W</td>
<td>1W</td>
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<tr>
<td>Usage (hr)</td>
<td>375.4</td>
<td>172.1</td>
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<tr>
<td>Life (hr)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>percent</td>
<td>75.1%</td>
<td>75.1%</td>
</tr>
<tr>
<td>Terra</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Failed on 11-20-2004</td>
<td>Failed on 2-18-2006</td>
</tr>
<tr>
<td>Aqua</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Failed on 4-14-2003</td>
<td>Failed on 6-28-2005</td>
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<tr>
<td>Usage (hr)</td>
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<td>188.8</td>
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<tr>
<td>Life (hr)</td>
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<td>500</td>
</tr>
<tr>
<td>percent</td>
<td>73.6%</td>
<td>73.6%</td>
</tr>
</tbody>
</table>
Future Operational Considerations

• Aqua MODIS CFPA temperature control
  – Currently set at 83K
  – Minimal impact on science data
  – Has begun trending in correct direction

• Aqua SD/SDSM door movements
  – Passed projected lifetime limit on movements
  – No change in current frequency of SD calibration activities planned at this time

• SRCA Lamps
  – Aqua currently has 1 working 10 W lamp
  – Frequency of all calibrations has been decreased

<table>
<thead>
<tr>
<th></th>
<th>PL to 05/16</th>
<th>05/16 to present</th>
<th>Total</th>
<th>Design Lifetime</th>
<th>% Used</th>
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</thead>
<tbody>
<tr>
<td>Terra*</td>
<td>2146</td>
<td>0</td>
<td>2146</td>
<td>3022</td>
<td>71.01</td>
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<tr>
<td>Aqua+</td>
<td>3290</td>
<td>174</td>
<td>3464</td>
<td>3022</td>
<td>114.62</td>
</tr>
</tbody>
</table>

* As of 07/02/2003, SD Door in fixed ‘open’ position with screen in place
+ Aqua reached designed lifetime of door movement on DOY 2012/191 (July 2012).
MODIS Level 1B Code and LUT Status
MODIS L1B Major Changes

- **L1B major changes since last STM (6/06/2016)**
    - Code versions: 7 (Terra); 6 (Aqua)
    - LUT versions: 195 (Terra); 142 (Aqua)
  - Release of Collection 6.1
    - Forward processing started since September 2017
    - Reprocessing completed in early 2018

- **Versions in Current Forward L1B Processing**
  - C6.1 (2017 – present): Terra V6.2.2; Aqua: V6.2.1
  - C6 & C6.1 LUT in the **Forward Update**:
    - RSB identical between C6 and C6.1 for Aqua and Terra
    - TEB & QA identical between C6 and C6.1 for Aqua only
C6.1 L1B Improvements

- EV_based gain and RVS calibration extended to mission long Aqua MODIS bands 1-4
- Terra MODIS LWIR crosstalk correction
  Bands: 27 (6.72 μm), 28 (7.33 μm), 29 (8.55 μm), 30 (9.73 μm)

Detector Quality Flag after Safe Mode in 2016 (Terra)

<table>
<thead>
<tr>
<th>Terra MODIS Bands 27-30</th>
<th>Collection 6</th>
<th>Collection 6.1</th>
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</thead>
<tbody>
<tr>
<td>Noisy Detectors</td>
<td>18</td>
<td>5</td>
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<tr>
<td>Inoperable Detectors</td>
<td>3</td>
<td>0</td>
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</tbody>
</table>
Terra C6.1 L1B Improvements

Collection 6

Collection 6.1

Brightness Temperature (K)

Terra Band 27, Baja California, July 3, 2018
L1B Major Production Timeline

Terra Forward Processing

- Collection 6.1
- Collection 6

Year
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019

Production Start

Code Versions

LUT Versions

Aqua Forward Processing

Production Start

Code Versions

LUT Versions

Year
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
## C5, C6 and C6.1 L1B LUT Updates

<table>
<thead>
<tr>
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<tr>
<td>Terra C6</td>
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<td>11</td>
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<td>Aqua C5</td>
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<td>9</td>
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<td>15</td>
<td>3</td>
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<tr>
<td>Aqua C6</td>
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<td></td>
<td>7</td>
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<td></td>
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<td></td>
<td></td>
<td>6</td>
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<tr>
<td><strong>Total</strong></td>
<td>16</td>
<td>23</td>
<td>25</td>
<td>26</td>
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<td>63</td>
<td>63</td>
<td>57</td>
<td>51</td>
<td>48</td>
</tr>
</tbody>
</table>

- MCST also supports science teams by providing special L1B LUTs and/or test granules.
Summary

➢ C6.1 forward processing started September, 2017. The cross talk correction to Terra MODIS LWIR bands greatly improved the data quality of Terra MODIS L1B.

➢ Expected changes in the future collection:
  1. Cross-talk correction to MWIR, LWIR, and SWIR bands.
  2. LUT from improved calibration algorithm.
  3. Data format: HDF4 to NETCDF4/HDF5.
MODIS RSB Calibration and Performance
Highlights since the last STM (June, 2016)

• Terra MODIS
  – RSB continue to perform nominally after the safe-mode event (Feb, 2016)
  – Noticeable gain changes (~2%) for the SWIR bands observed after the safe-mode event. VIS/NIR bands show changes < 1%
  – No new noisy/inoperable detectors since the last STM
  – Ideal BB update has mitigated the impacts due to “sticky bin” in the VIS bands
  – Improved algorithm to estimate the SD degradation at SWIR wavelengths (also implemented for Aqua MODIS)
  – C6.1 L1B reprocessed bands 1 and 2 LUT from 2012-2017.

• Aqua MODIS
  – No significant events since last STM. Instrument operating nominally with the OBC (SD, SDSM, SRCA) performing normally
  – No new noisy/inoperable detectors since the last STM
  – C6.1 L1B reprocess includes EV-based RVS extended to apply to bands 1-4. Mitigated the long-term reflectance drifts
On-orbit Calibration Activities

SD/SDSM:
Weekly to tri-weekly

SRCA (at-launch):
Radiometric: monthly
Spatial: quarterly
Spectral: tri-annual

Solar Diffuser

SDSM

Spacecraft maneuvers:
Yaw (SD BRF, VF)
Roll (Moon)
Pitch (with Moon) for RSB
RVS validation

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

Blackbody

Scan Mirror

Space View

BB: quarterly
RSB Calibration

- EV Reflectance
  \[ \rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d_{Earth-Sun}^2 \cdot d_{n_{EV}} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS} \]

- Look-Up-Tables (LUTs) updated regularly for RSB
  - \( m_1 \): Inversely proportion to gain at the AOI of SD
  - \( RVS \): Sensor Response versus Scan angle (normalized to SD AOI)
  - Uncertainty tables

- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - EV mirror side (MS) ratios
    - SRCA MS ratios (previously used) are not considered due to lamp failures
  - Response trending from EV targets

![Diagram showing Angle of Incidence (AOI)]
RSB SD Calibration

1.44 % screen

Optional 7.8 % screen (SD)

Terra: SD screen in permanent down position since July 2, 2003

\[ \Delta_{SD} = \frac{dc^i_{SD}/dc^9_{SD}}{dc^i_{Sun}/dc^9_{Sun}} \]

\[ m_1 = \frac{\rho_{SD} \cdot \cos(\theta_{SD})}{dn^*_SD \cdot d^2_{Earth\_Sun}} \cdot \Delta_{SD} \cdot \Gamma_{SDS} \]

\[ \rho_{SD} = \text{BRF}, \ dn^*_SD = \text{Signal from SD (temperature and background corrected)}, \ \Delta_{SD} = \text{SD degradation}, \ \Gamma_{SDS} = \text{screen attenuation} \]
RSB Lunar Calibration

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

\[ m_{1}^{\text{moon}} = \frac{f_{vg}}{< d_{n}^{*}\text{moon} >} \]

Bands 13-16 (saturated)

\[ m_{1}^{\text{moon}} = m_{1,B18}^{\text{moon}} \cdot \frac{< d_{n}^{*}\text{Moon,B18} >}{< d_{n}^{*}\text{Moon} >} \]

View geometry correction

\[ f_{vg} = \frac{f_{\text{phase-angle}} \cdot f_{\text{libration}} \cdot f_{\text{oversampling}}}{d_{\text{Sun-Moon}}^{2} \cdot d_{\text{Moon-MODIS}}^{2}} \]

Near-monthly calibration
Phase angles between 55° - 56°
MODIS SD Degradation

Increased degradation after Terra SD door anomaly on July 2, 2003. Larger SD degradation at shorter wavelengths for both instruments

A special “fix” mode operation was performed for Aqua MODIS SDSM to verify the results observed in previous years
MODIS SD Degradation at SWIR wavelengths

- The solar diffuser degradation at SWIR band wavelengths is not tracked by the SDSM, but can be significant (e.g. >1% for Terra band 5). Starting with January 2018 LUT updates, MCST updated the SD degradation at SWIR wavelengths.

- Previous Collection 6/6.1:
  - The long term reflectance trends of Earth targets were used to derive a linear correction coefficient for Terra band 5 (using desert sites) and Terra band 26 (using DCC). The other SWIR bands did not have any SD degradation applied.

- Forward Collection 6/6.1:
  - We estimate SD degradation at SWIR by performing a power law fit to the SD degradation calculated from SDSM detectors and extrapolating to the SWIR.

Most change observed for short-wavelength bands

Band 8 (.412 µm) changes by over 50%

Terra VIS bands have a maximum mirror-side difference of about 11% at the SD AOI (Band 3 - .469 µm)
SD Gain Trending: Aqua

Most change observed for short-wavelength bands

Band 8 (.412 µm) maximum change is ~40%

Aqua VIS bands have a maximum mirror-side difference of about 3% at the SD AOI (Band 8)
SD Gain Trending: Terra

Changes for most NIR bands are within 10%

Mirror-side differences are <1%
SD Gain Trending: Aqua

Changes for most NIR bands are within 6%

Mirror-side differences are <1%
SD Gain Trending: Terra

All SWIR bands change by < 10%

Mirror-side differences are <1%

* Noisy and inoperable detectors excluded
**SD Gain Trending: Aqua**

All SWIR bands change by < 3%

Mirror-side differences are <1%

* Noisy and inoperable detectors excluded
Terra MODIS
SD & Lunar Gain Trending

SD & Lunar measurements used to derive the on-orbit RVS change

SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°
Aqua MODIS
SD & Lunar Gain Trending

SD & Lunar measurements used to derive the on-orbit RVS change
SD AOI = 50.25°  Lunar (SV Port) AOI = 11.2°
Terra MODIS VIS Mirror Side Difference

SD AOI = 50.25°  Lunar (SV Port) AOI = 11.2°

Sharp changes in the MS ratio trends after the S/C safe mode (2016)
Most bands continue to meet the specification.

- Known issues with the inoperable/noisy detectors in Aqua band 6.
- Decreased responsivity for some short wavelength RSB (Terra bands 8, 9, 3, Aqua band 8
- Terra band 7 SNR known to be below specification since launch
Most bands continue to meet the specification.

- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Terra bands 1-4, 8-10 and Aqua bands 1-4, 8,9)
- On-orbit changes in the polarization sensitivity is also a contributing factor.
Recent MCST activities to improve RSB calibration:

• We have been investigating several ways to improve on-orbit RVS characterization:
  – Apply polarization correction for Terra VIS bands to improve gain derivation at large scan angles.
  – Use an inter-band approach that relies on relative trends of ocean data to derive RVS for Terra bands 11 and 12
  – Alternative methods of deriving RVS from desert sites
  – RVS derived from DCC measurements
  – Introduce on-orbit RVS for SWIR bands (which still use pre-launch RVS) using SD and lunar data

• Improvements to OOB/crosstalk corrections for SWIR bands
• Evaluate impact of changing RSR
Terra Polarization correction

The polarization sensitivity of scan mirror has impacted performance of Terra MODIS short-wavelength RSB

• C6.1 L1B does not include any correction for polarization effects

Current mitigation strategy for L2 products

• NASA OBPG has derived polarization correction coefficients from a cross-cal with SeaWIFS/Aqua MODIS over ocean targets
• For land products, use the OBPG polarization coefficients to generate a L1B_PC product followed by de-trending to correct gain for desert sites

MCST activities for next Collection

• Apply polarization correction in derivation of gain from desert sites for Terra bands 8, 9, 3.
• Goal: Improve accuracy of L1B product and forward-predicted gain. Reduce the magnitude of downstream gain ($M_{11}$) and de-trending corrections.
Terra Polarization correction

Current polarization mitigation strategy

For ocean products: NASA OBPG performs a xcal with SeaWiFS/Aqua to Terra L1B to generate the coefficients for Terra polarization correction

\[ L_t = \frac{L_m}{M_{11}} - m_{12}Q - m_{13}U \]

- \( L_t \): true radiance,
- \( L_m \): measured radiance,
- \( M_{11} \): gain correction

Shihyan Lee

For land products:

- Use these \( M_{11}, m_{12}, \) and \( m_{13} \) to correct the long-term reflectance time-series of MODIS RSB from the desert sites: L1B_PC
- The Q and U are site specific
- De-trending applied to correct for residual drifts

Alexei Lyapustun and Yujie Wang
Terra Polarization correction

Current L1B and L1B_PC reflectance trends

- Large oscillations in C6.1 L1B due to uncorrected polarization
- L1B_PC corrects for polarization, but has drift that needs to be corrected using de-trending. Drift may be due to difference between ocean-derived and desert-derived gain.
Terra Polarization correction

MCST approach for next Collection

Calibrated gains \( (m_1/RVS) \) derived from desert trends

- Derive BRDF corrected reflectance, \( \rho_{BRDF} \), for desert using first few years of data and the time-dependent OPBG polarization coefficients \( m_{12} \) and \( m_{13} \)
- Then derive the gain from the measured \( dn^* \) and the polarization and BRDF corrected desert reflectance

\[
gain = \frac{dn^* \ d_{ES}^2/ \cos(\theta)}{\rho_{BRDF} + m_{12}Q + m_{13}U}
\]
Terra Polarization correction

Compare “C7” gain trend with C6.1 gain trend

- Results similar to $M_{11}$ gain trend from OBPG cross-cal

Compare reflectance trends

- C7 L1B better than C6.1 L1B
- C7 L1B_PC has less drift compared to C6.1 L1B_PC
Terra B11-12: Inter-band approach

- C6/C6.1 L1B currently uses EV-based $m_1$ and $RVS$ for Terra bands 1-4, 8-10. This approach utilizes desert measurements to supplement the on-orbit gain derived from the solar and lunar measurements
  - This approach is necessary for an accurate characterization of the RVS, therefore eliminating the long-term reflectance drifts observed in previous versions
- As the gain continues to degrade, we would like to extend the EV-based approach to other RSB, e.g. bands 11 and 12
  - The desert-based approach is not viable for these (and other high-gain ocean bands) as they saturate while viewing the high-radiance desert.
  - Using ocean targets to derive direct trends is challenging because the response is dominated by Rayleigh scattering and a comprehensive need for atmospheric correction is required
- Proposal: An inter-band calibration approach using band 4 (spectrally overlapping) as a reference to monitor the long-term reflectance for bands 11 and 12.
  - The band 4 gain is calibrated from desert PICS approach, and reflectance comparisons with b11 and b12 over ocean granules are used to derive gain for b11 and b12.
Terra B11-12: Inter-band approach

- Long-term drift observed at nadir and SD AOIs for both bands with band 11 showing up to 2% drift, demonstrating the need for EV-based calibration of these bands.
  - No impact expected on the OBPG products as $M_{11}$ factor in the polarization correction accounts for any observed residual drifts.
- Path Forward: MCST has delivered a special LUT including these corrections based on inter-band calibration to OBPG for evaluation and feedback after which a decision will be made to include these in forward production of C6.1.
Alternative RVS algorithms

MCST has investigated various alternative ways to derive RVS using Earth targets

• Alternative algorithm with Libyan desert data
  – Derive AOI-dependence (RVS) from a single desert site, Libya 4. Use moon as anchor point for on-orbit gain change. Tested for MODIS bands 1-4, 8, 9.
  – Using lunar gain reduces reliance on desert site invariance. Single-site approach may be more attractive during future de-orbiting phase of Terra and Aqua missions.
  – Results agree with C6.1 approach to <2%

• DCC-based RVS
  – We have developed our own DCC analysis and used it to derive on-orbit gain for MODIS bands 1, 3, and 4.
  – Signal trends from DCC targets can have lower noise than trends from desert PICS, particularly at large AOI.
  – Results agree with desert approach to <2% in most cases

On-orbit RVS for SWIR bands

C6.1 L1B (and all previous collections) uses pre-launch RVS for SWIR bands

- But recent evaluations with desert and DCC suggest there may be on-orbit changes to RVS for some SWIR bands

MCST plan
Derive on-orbit RVS for SWIR bands using same 2-point approach as NIR bands

- Solar diffuser AOI
  - SD degradation determined by extrapolating SDSM results to longer wavelength using a power-law fit.

- SV AOI
  - Gain at SV AOI derived from scheduled lunar observations using improved algorithm


Evaluate effectiveness of RVS using desert and DCC trends.

Preliminary results are being studied. A challenge is properly correcting for SWIR OOB/xtalk through all mission configuration changes.
MODIS SWIR bands (5-7 and 26) have a known issue related to electronic crosstalk and OOB leak identified during prelaunch characterization

- A correction to $m_1$ based on night-time-day-mode acquisitions has been applied since early mission. Correction employs band 28 as reference band (Aqua MODIS uses band 25 as reference)

After the Feb, 2016 safe mode, the Terra MODIS PV LWIR bands showed increased impacts due to electronic crosstalk.

- Lunar-based correction applied in C6.1 (entire mission) to mitigate the impacts for the PV LWIR bands
- But un-corrected band 28 signal still used to calculate SWIR band $m_1$

We are evaluating multiple options to improve mitigation of SWIR xtalk

- Correction derived from lunar observations
  

- Correct band 28 signal for PV LWIR xtalk before deriving SWIR correction
- **Use band 25 as reference band in Terra MODIS SWIR correction**

Terra SWIR xtalk improvements

- Band 7 shows smoother $m_1$ trends and less detector条状for images after 2016 safe mode
- Bands 5 and 6 show similar improvements
On-orbit RSR changes

Relative spectral response of each band (in-band response and out-of-band response) measured prior to launch.

L1B calibration uses in-band pre-launch RSR only.

RSB RSR can change on orbit. How does changing RSR affect calibration?

1) Consider in-band RSR changes as measured by SRCA

2) Consider broadband RSR changes due to scan mirror degradation (‘modulated RSR’)

SRCA spectral calibration measures in-band RSR on-orbit

- Aqua – All bands show very little on-orbit change.
- Terra – Most bands show very little on-orbit change. Exceptions are bands 1, 4, 17, 19
- Bands 8, 9, 3 not evaluated

Impact of changing RSR on the calibrated radiance is small:

<0.12% for Aqua, <0.4% for Terra.

Impact of changing RSR on Earth scene radiance retrieval may be larger, depending on scene spectrum. Worst case is Terra b19.
On-orbit RSR changes

Out-of-band portion of RSR changes due to broadband degradation of the instrument optics (mostly scan mirror)

Impact for Aqua – Only band 8 has a significant impact; up to 0.5% at SD AOI, larger at small AOI.

Impact for Terra – Similar, but much higher uncertainty

Changing RSR impact could be included in calibrated L1B in future (similar to NASA VIIRS L1B). But Earth product impact must be considered separately.
Summary

• SD/SDSM and lunar observations are used to track RSB on-orbit gain change
  – Additional information from EV response from desert sites are used for select RSB (Terra 1-4, 8-10 and Aqua 1-4, 8-9)

• Shorter wavelength VIS Bands show larger degradation (strong wavelength, mirror-side, and scan-angle dependence)
  – Gain change over 50% seen in Terra Band 8 (.412 µm) at the AOI of SD (50.25°)

• NIR bands gain change generally within 10%

• SWIR bands gain change within 10%

• Successful recovery from the Terra safe-mode event
  – RSB continue to perform nominally after the safe-mode. Noticeable gain changes (~2%) for the SWIR bands observed after the safe-mode event. VIS/NIR bands show changes < 1%

• Challenges for future calibration:
  – Continued degradation of the solar diffusers and changes in RVS may impact gain accuracy of more bands, forcing more reliance of EV-based calibration
  – Correcting for impacts of polarization
  – Changes to SWIR band OOB/xtalk effects
MODIS TEB Performance
Outline

- MODIS TEB and on-orbit calibration
- TEB calibration performance
  - Blackbody and CFPA temperature trends
  - Detector gain coefficient trends
  - Detector NEdT trends and QA table
  - Uncertainty
- TEB calibration assessment using cold targets
- Summary
### TEB Design Specifications

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<th>Band</th>
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**CW:** center wavelength in micron;  
**Ttyp:** typical scene temperature in K;  
**NEdT:** noise equivalent temperature difference in K
**On-orbit Calibration Methodologies**

**EV Radiance:**

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

**Calibration Coefficients:**

\[ b_1 = \left( RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + (RVS_{SV} - RVS_{BB}) \cdot L_{SM} + RVS_{BB} \cdot (1 - \varepsilon_{BB}) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot d_n_{BB} \right) / d_n_{BB} \]

RVS: response versus scan-angle  
\( \varepsilon \): emissivity  
\( L \): spectral band integrated radiance  
\( d_n \): digital count with background corrected  
a0 & a2: non-linear gain coefficients  
b1: linear gain coefficient

**WUCD \( T_{BB} \):** ~270 K to 315 K
On-orbit Calibration Methodologies

- **Regular BB Calibration**
  - Compute linear gain coefficient b1 on a scan-by-scan basis; 40-scan running average used in the L1B product

- **Quaterly BB Warm-up and Cool-down (WUCD) Activities**
  - Compute nonlinear gain coefficients a0 and a2
  - Derive fixed linear coefficients for band 21

- **Special Calibration Issues**
  - Characterization of response versus scan angle
  - Aqua CFPA temperature fluctuation
  - Aqua default b1 and EV image saturation for bands 33, 35 and 36
  - Terra PC (bands 32-36) and PV (bands 27-30) crosstalk
  - Uncertainty

- **Independent calibration stability monitoring**
  - EV scene (Dome-C, Ocean, DCC)
  - Measurement in scheduled lunar events
  - Inter-comparisons
### MODIS Collection 6.1

#### Table: Calibration and Cross-talk Correction for MODIS Bands 20-36

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<td>CFPA temperature: Default $b_1$</td>
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<td>Calibration algorithm: CFPA temperature correction applied in the fitting</td>
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#### Mathematical Formulas:

- $a_{0\_ms1} = 0$
- $a_{0\_ms2} = a_{0\_ms2\_free-fit} - a_{0\_ms1\_free-fit}$
- $a_0 = 0$
- $a_0 = 0$
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- $a_0 = 0$

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- **Page 70**
Key Telemetry Temperatures

- Terra BB temperature 290K, ~10mK fluctuation
- Aqua BB temperature 285K, stable
- Terra LWIR CFPA actively controlled (83K), both stable
- Aqua SMIR CFPA actively controlled (83K), detail next page
Aqua CFPA temperature

- Mitigation since 2013
  -- Increase of radiative cooler margin
  -- Improvement of temperature control
  -- Reduction of EV saturation (bands 33, 35 & 36) instance during WUCD.
- Scan-by-scan calibration captures much of the impact of the CFPA variation
- Improved default b1 algorithm implemented
- Temperature correction to the a0/a2 analysis implemented
Safe model causes gain changes for some bands
Aqua TEB Gain Trending

CFPA temperature impacts on gain for LWIR bands
Terra TEB Noise Trending

Terra MODIS MWIR (bands 20-25) MS1

- Safe model causes NEdT jumps for PV LWIR bands
- Band 30 all detectors are noisy
Aqua TEB Noise Trending

Aqua MODIS MWIR (bands 20-25) MS1

Aqua MODIS LWIR (bands 27-36) MS1
## Collection 6.1 TEB QA Table

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- **Current QA table**
- **Product order**

- Yellow: noisy
- Red: inoperable

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Page 77
- Terra bands 27 and 30 uncertainty are higher than spec in recent years due to cross-talk.
- Terra band 30 all detectors are noisy.
RVS is derived based on detector response to scan mirror’s thermal emission (in case of pitch, $L_{EV} = 0$), which is a function of AOI.

$$RVS_{EV} = 1 - \frac{L_{BB}}{L_{SM}} \left( \frac{dn_{EV} - dn_{EV=BB}}{dn_{BB} - dn_{EV=BB}} \right)$$

$L_{EV}$ is the EV radiance, $L_{BB}$ and $L_{SM}$ are the radiances from the blackbody and scan mirror, respectively.

40 scans used (20 each mirror side)
Terra TEB RVS Verification

- **Pitch 1 2003085**
  - Band 20 to 28
  - Band 29 to 36

- **Pitch 2 2003104**
  - Band 20
  - Band 31
  - Band 36

- **Pitch 3 2017217**
  - Band 20 to 36

- 2017217 pitch maneuver shows stable RVS (Maximum change is 0.3% for band 31 at large AOI)
Performance summary

- **Terra MODIS**
  - Overall performance is stable.
  - NEdT and uncertainty meet specifications, except band 36 NEdT and uncertainty of bands 27, 30, and 36.
  - PV LWIR bands 27-30 electronic cross-talk has been corrected for calibration and EV measurement for Collection 6.1.
  - Safe mode in Feb 2016 has some impacts on TEB gain and NEdT, especially for bands 27-30.
  - a0/a2 delivery procedure improved to catch the response changes.
  - 2017217 pitch maneuver shows stable RVS (Maximum change is 0.3% for band 31 at large AOI)

- **Aqua MODIS**
  - Overall performance is stable.
  - NEdT and uncertainty meet specifications.
  - CFPA temperature mitigated since 2013.
Assessment of Terra MODIS TEB calibration using cold targets and measurements in lunar roll

Reference: T. Chang; X. Xiong; A. Shrestha; A. Wu; N. Chen; Y. Li; Q. Mu “Assessment of Terra MODIS thermal emissive band calibration using cold targets and measurements in lunar roll events” SPIE 10785, Sensors, Systems, and Next-Generation Satellites XXII, 107851C (25 September 2018); doi: 10.1117/12.2325378

DCC: Deep convective clouds
Before safe mode

After safe mode

- $a_{0_{ms1}} = 0$, mirror side two $a_0$ jumps after safe mode (due to 4 time moving averaging not applied)
- The current LUT coefficients are back to pre-safe mode level
- Low BT scene measurements are sensitive to $a_0$
- Calibration consistency of mirror sides can be assessed using low BT measurement
The two mirror side are consistent

- $a_2$ is out of trend after safe mode.
- The current LUT coefficients are back to pre-safe mode level
- Band 30 has slight different pattern after safe mode.
Mirror side difference using Dome-C

- $a_{0\_ms1} = 0$, mirror side two $a_0$ jumps after safe mode
- The mirror side difference jumps after safe mode for these bands
Mirror side difference using Dome-C

- $a_{0\_ms1} = 0$, mirror side two $a_0$ jumps after safe mode
- The mirror side difference jumps after safe mode for these bands
Mirror side difference using DCC

- Band 31 mirror side difference is stable
- Band 27 mirror side difference changes after safe mode
Mirror side difference jumps due to safe mode for band 27. No significant change for Band 31. (Red veridical dash line marks the time of safe mode, purple lines are the LUT update time.)
Calibration consistency assessment using DCC

- $a_{0_{ms1}} = 0$, mirror side two $a_0$ jumps after safe mode
- The mirror side difference jumps after safe mode for these bands
Safe mode impacts on the band averaged BT relative to band 31
The mirror side difference jumps after safe mode for these bands
Future calibration improvement and assessment

- Continue to monitor TEB performance using earth view targets and cavity during lunar event, especially for PV LWIR bands.

- Continue to monitor TEB performance using inter-comparison.

- Model observed bias and estimate calibration correction.

- Propose calibration improvement for future collection by combining the calibration algorithm analysis, observation and comparison results, and analytical modeling.

- Propose Terra and Aqua TEB electronic cross-talk corrections in addition to Terra PV LWIR bands (Truman Wilson’s talk).

- Seek proper EV targets to assess nonlinear effect in cross-talk correction on L1B product, especially on cold targets.
On August 1, 2018, MCST held a special meeting of the MODIS Sensor Working Group (MsWG) to review the status of electronic crosstalk in MWIR and LWIR bands for both Aqua and Terra MODIS.

- The full package is available on the MCST FTP site.

- Today we will just provide a brief review of this workshop.

Electronic crosstalk has been observed in many MODIS bands since before launch. In particular, the MODIS TEBs 20-25 and 27-30 have been significantly impacted. MCST has been monitoring this issue throughout the mission.

- For bands 27-30 in Terra MODIS, a correction has implemented in Collection 6.1. The same methodology has been extended to the rest of the MWIR and LWIR bands in Aqua and Terra.
The Moon has been used extensively for electronic and optical crosstalk characterization and correction for both Aqua and Terra MODIS.
Crosstalk Correction Coefficients

Terra MODIS MWIR D10 to D1

Terra MODIS Band 28, Detector 8

Aqua MODIS MWIR D1

Aqua MODIS Band 29, Detector 6
Crosstalk Correction Example

Terra MODIS Band 27

This correction is implemented in Collection 6.1
Aqua Band 24 Day/Night Difference

Day

Night

Band 24

Day

Night

d1  d2  d3  d4  d5  d6  d7  d8  d9  d10
<table>
<thead>
<tr>
<th>Band</th>
<th>Contamination Impact</th>
<th>Correction Impact</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>No discernable impact.</td>
<td>No Correction Required</td>
<td>No action recommended</td>
</tr>
<tr>
<td>21</td>
<td>D1 and D9 striping over <strong>water scenes</strong>. D1 striping over <strong>desert scenes</strong>. D9 Striping over <strong>ice clouds scenes</strong>.</td>
<td>Some image improvement over water. Limited impact over desert and ice clouds.</td>
<td>No action recommended</td>
</tr>
<tr>
<td>22</td>
<td>D8 striping over <strong>ice cloud scenes</strong> (large) and <strong>water scenes</strong> (~0.5K).</td>
<td>Effectively removes contamination</td>
<td>Apply correction for detector 8</td>
</tr>
<tr>
<td>23</td>
<td>D10 striping over <strong>ice cloud scenes</strong> (large) and <strong>water scenes</strong> (~0.5K).</td>
<td></td>
<td>Apply correction for detectors 1 and 10</td>
</tr>
<tr>
<td>24</td>
<td>D1 striping over <strong>ice cloud scenes</strong>. 0.5 – 1 K change over ocean scenes for all detectors.</td>
<td>Effectively removes D1 striping. Slight increase in detector spread over ocean scenes.</td>
<td>Apply correction for detector 1</td>
</tr>
<tr>
<td>25</td>
<td>No discernable impact</td>
<td>No Correction Required</td>
<td>No action recommended</td>
</tr>
</tbody>
</table>

- The current recommendations are **ready** to be implemented in the Level-1B code
<table>
<thead>
<tr>
<th>Band</th>
<th>Contamination Impact</th>
<th>Correction Impact</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Striping and false land/water boundary features. Significant bias that increases throughout the mission, especially after 2016</td>
<td>Effectively removes contamination</td>
<td>A correction is already implemented in Collection 6.1 for all detectors</td>
</tr>
<tr>
<td>28</td>
<td>Striping and false land/water boundary features. Significant bias that increases throughout the mission.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Increasing bias and striping throughout the mission. Causes false cloud detection in cloud mask tests.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Increasing bias and striping throughout the mission.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Impact Assessment Aqua MWIR

<table>
<thead>
<tr>
<th>Band</th>
<th>Contamination Impact</th>
<th>Correction Impact</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>D1 impact ~0.15K on average. Insignificant impact for others.</td>
<td>Effectively removes contamination</td>
<td>Apply correction for detector 1</td>
</tr>
<tr>
<td>21</td>
<td>Contamination is insignificant.</td>
<td>No Correction Required</td>
<td>No action recommended</td>
</tr>
<tr>
<td>22</td>
<td>D1 impact ~0.2K on average. Insignificant impact for others.</td>
<td>Effectively removes contamination</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>D1 striping over <strong>ice cloud scenes</strong> (large) and <strong>water scenes</strong> (~0.5K).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>D1 striping over low BT scenes during daytime. BT shift at low and high BT scenes</td>
<td>Effectively removes D1 striping over low BT scenes during daytime. Slight increase in detector spread over high BT scenes.</td>
<td>Apply correction for detector 1</td>
</tr>
<tr>
<td>25</td>
<td>D1 impact ~0.2K on average. Insignificant impact for others.</td>
<td>Effectively removes contamination</td>
<td></td>
</tr>
</tbody>
</table>

- The current recommendations are ready to be implemented in the Level-1B code.
Impact Assessment Aqua LWIR

<table>
<thead>
<tr>
<th>Band</th>
<th>Contamination Impact</th>
<th>Correction Impact</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>D1 impact ~0.8K on average</td>
<td>Effectively removes contamination</td>
<td>Apply correction for detector 1</td>
</tr>
<tr>
<td>28</td>
<td>Contamination is insignificant.</td>
<td>No Correction Required</td>
<td>No action recommended</td>
</tr>
<tr>
<td>29</td>
<td>D1 impact ~0.2K</td>
<td>Effectively removes contamination</td>
<td>Apply correction for detectors 1, 2, and 6</td>
</tr>
<tr>
<td></td>
<td>D2 (noisy) ~0.25K since 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D6 (noisy) ~ 0.35K since 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>D1 impact ~0.45K on average</td>
<td>Effectively removes contamination</td>
<td>Apply correction for detector 1</td>
</tr>
<tr>
<td></td>
<td>Insignificant impact for others.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The current recommendations are ready to be implemented in the Level-1B code
MODIS Spatial and Spectral Performance
SRCA Layout

Spatial Mode
- Along-scan
- Along-track

Spectral Mode
- Exit slit
- Calibration SiPD (D2)
- Slit/Reticle motor
- Didymium glass
- Reference SiPD (D3)

MONOCHROMATOR
- Focusing mirror
- Collimating mirror

Grating is used for spectral mode
Mirror is used for spatial mode

SRCA COLLIMATOR
- To MODIS scan mirror
- Thermal source
- Filter wheel
- Radiance stability monitoring detector (D1)
Aqua Lamp #4 Failure

- During the 20W configuration of the Spectral Calibration on 2016/182, the lamp signal, current, and voltage all unexpectedly went to zero.
- Leading explanation is the overvoltage ‘tripped’, causing the lamps to turn off.
- Subsequent testing performed as expected after executing set-up commands.
- As reported at previous science team meeting, Lamp #4 (10W) began exhibiting increased voltage since mid-2015.
Impact on Calibration

• Impact on Processing
  – Bands that previously used results from 20W source now use 10W source instead
  – Spatial bands: 1, 3, 4, 8, 9, 10
  – Spectral bands: 1, 3, 4, 8, 9, 10, 11, 17
  – The 10W source provides enough signal to resolve signal for most bands/calibrations

• Impact on Results
  – Aqua band 3 signal is now also too low to resolve spectral data due to switch from 20W to 10W
    • Aqua/Terra band 8 signal became too low to resolve spectral data after switch from 30W to 20W after lamp failures in 2005/2006
Calibration Plan

- IOT commanding procedures were updated to allow calibrations to continue without 20W capability
- To reduce load on SRCA lamps, the calibration frequency was reduced for both instruments after the Aqua lamp #4 failure

<table>
<thead>
<tr>
<th>SRCA Calibrations per Instrument per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Radiometric</td>
</tr>
<tr>
<td>Spatial</td>
</tr>
<tr>
<td>Spectral</td>
</tr>
</tbody>
</table>
MODIS Spatial Performance

- Spatial calibrations are scheduled every 26 weeks for each instrument
- MODIS BBR design specification is < 200 meters in both directions
- A shift between the cold and warm focal planes in scan and track directions was measured for Aqua MODIS pre-launch
- On-orbit performance for both instruments has remained stable
Band-to-Band Registration

- No bands out of specification
- Only slight drifts observed

B36 along-track data no longer reported, Detector 7 is classified as inoperable
Band-to-Band Registration

- Cold Focal Plane shift measured prelaunch (200 m)
- Only slight drifts observed
Detector-to-Detector Registration

Terra MODIS DDR in Band 1 and MS 1

Aqua MODIS DDR in Band 1 and MS 1
MODIS Spectral Performance

- Spectral calibrations are scheduled every 26 weeks for each instrument
- Measures RSR for most RSB with center wavelengths from 412 nm – 940 nm
- MODIS spectral specifications
  - Stability of center wavelength and bandwidth for VIS bands: 2 nm
  - Other bands: 1% of center wavelength
- All bands continue to operate within specifications
Center Wavelength and Bandwidth

Terra

Terra MODIS Center Wavelength Changes

Terra MODIS Bandwidth Changes
Center Wavelength and Bandwidth

Aqua

Aqua MODIS Center Wavelength Changes

Aqua MODIS Bandwidth Changes
Both SRCA instruments continue to operate on a regular basis to provide on-orbit spatial and spectral characterization of MODIS bands

Coordination between MCST, IOT, and FOT has allowed continued calibrations in light of lamp failures

On-going Analysis

- Investigating uncertainty of spectral calibrations has led to areas of potential improvement (background correction)
- Applying electronic crosstalk correction to PVLWIR band signals in spatial calibration (shift of up to 30 m along-scan)
- Applying a time-dependent RSR into RSB gain calculation