MODIS TEB Calibration and Performance

MODIS Characterization Support Team, NASA GSFC
(presented by Tiejun Chang)
Outline

- MODIS TEB and on-orbit calibration
- TEB calibration performance
- TEB C7 algorithm improvements
- Summary
## TEB Design Specifications

<table>
<thead>
<tr>
<th>Band</th>
<th>CW (μm)</th>
<th>Ttyp (K)</th>
<th>NEdT (K)</th>
<th>UC (%)</th>
<th>UC (K)</th>
<th>Primary Use</th>
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<tr>
<td>20</td>
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<tr>
<td>23</td>
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<td>1.00</td>
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<td>Water vapor</td>
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<td>28</td>
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<td>11.03</td>
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<td>0.50</td>
<td>0.34</td>
<td>Surface/cloud temperature</td>
</tr>
<tr>
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<td>12.02</td>
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<td>0.37</td>
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<td>35</td>
<td>14.24</td>
<td>220</td>
<td>0.35</td>
<td>1.00</td>
<td>0.47</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- **CW:** Center wavelength in micron;
- **Ttyp:** Typical scene temperature in K;
- **NEdT:** Noise equivalent temperature difference in K
**On-orbit Calibration Methodologies**

**EV Radiance:**

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

**Calibration Coefficients:**

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

RVS: response versus scan-angle
\( \varepsilon \): emissivity
\( L \): spectral band integrated radiance
\( dn \): digital count with background corrected
\( a_0 \) & \( a_2 \): non-linear gain coefficients
\( b_1 \): linear gain coefficient

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

- **Regular BB Calibration**
  - Compute linear gain coefficient \( b_1 \) on a scan-by-scan basis
  - 40-scan running average used in the L1B product

- **Quarterly BB Warm-up and Cool-down (WUCD) Activities**
  - Compute nonlinear gain coefficients \( a_0 \) and \( a_2 \)
  - Derive fixed linear coefficients for band 21
  - Aqua default \( b_1 \) for bands 33, 35 and 36

- **Special Calibration Issues**
  - Characterization of response versus scan angle
  - Aqua CFPA temperature fluctuation
  - Terra PV LWIR bands 27-30 electronic crosstalk
  - Terra PC bands 32-36 optical cross-talk
  - Uncertainty
  - QA

- **Calibration Assessments and Monitoring**
  - Gain trending, NEdT trending, Ecal and saturation monitoring
  - EV scene (Dome-C, Ocean, DCC/qDCC)
  - Inter-comparisons with IASI and CrIS, Terra - Aqua, and MODIS - VIIRS.
MODIS TEB Performance

- **Terra MODIS TEB**
  -- Overall performance is stable.
  -- PV LWIR bands 27-30 electronic cross-talk has been corrected for calibration and EV measurement.
  -- BB temperature was changed from 290K to 285K after April 23 to April 25, 2020 WUCD.
  -- NEdT and uncertainty meet specifications, except band 36.
  -- One more noisy detector since last STM (band 28 detector 1)
    (https://mcst.gsfc.nasa.gov/calibration/time-dependent-list-non-functional-or-noisy-detector, )

- **Aqua MODIS TEB**
  -- Overall performance is stable.
  -- NEdT and uncertainty meet specifications.
  -- Increase of CFPA radiative cooler margin and CFPA temperature control improved since 2013.
  -- No noisy detector added since last STM
In the Terra BB temperature trending plot, the temperature is shifted 5K for matching the temperature trending. No impact on the CFPA temperature.

- Aqua SMIR CFPA actively controlled (83K), insufficient radiative cooler margin starting ~2006
  -- Increase of radiative cooler margin and improvement of temperature control since 2013
Before 2004, the gain changes are due to configuration changes.

Safe mode event of Feb 2016 caused gain changes for some bands, especially for PV LWIR bands.

No impact from the BB temperature 290-285K change.
MWIR bands are stable over the mission

CFPA temperature impacts on gain for LWIR bands.
Safe mode event of Feb 2016 caused NEdT changes for some bands, especially for PV LWIR bands.
No impact from the BB temperature 290-285K change
Band 36 NEdT is above the specification
Aqua TEB NEdT Trending

- NEdT meets the specification and stable over the mission
- Band 21 NEdT is close to the specification and overall meet the specification.
MODIS TEB electronic cross-talk corrections

Example image correction for band 27 of Terra MODIS on August 27, 2020. The image shows Hurricane Laura making landfall on the Gulf coast.

- Cross-talk corrections have been implemented in C6.1 for Terra PV LWIR bands 27-30.
- Corrections for selected detectors of Terra MWIR, Aqua MWIR and LWIR are recommended for future calibration improvement.

These plots are sending band averaged coefficients.

- Dots are coefficients from scheduled lunar observation and the lines are the LUT coefficients.
- Safe mode (Feb 2016) caused the jump of the cross-talk. Increased effects of crosstalk after safe mode.
MODIS TEB C7 algorithm improvements

Terra
(1) MWIR bands cross-talk correction for selected detectors
(2) Band 30 algorithm change to improve stability
(3) Bands 20 and 29 a0 correction and a2 re-processing for cold scene bias correction
(4) Early mission PC bands a0 correction for mirror side difference correction

Aqua
(1) MWIR and LWIR bands cross-talk correction for selected detectors
(2) Entire mission a0 correction and a2 re-processing for mirror side difference correction

Detailed analysis and test results were presented on May 13, 2020 at MSWG and November 18, 2020 meetings.
Terra MWIR bands cross-talk corrections

- A correction was applied to the Terra PV LWIR bands 27-30 in Collection 6.1. The mid-wave infrared bands in Terra MODIS, 20 – 25, also show noticeable electronic cross-talk contamination for selected detectors. The impact can be seen during Moon observations, along with some striping in the Earth images.

- A cross-talk correction for selected detectors of the Terra MWIR bands will be applied in C7.

- The selection of the detector for correction depends on the impact on L1B product and image quality.

- The cross-talk coefficients have been processed for entire mission. The crosstalk are stable and show a slight downward trend for some detectors.

<table>
<thead>
<tr>
<th>Band</th>
<th>Detector</th>
<th>Contamination Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>8</td>
<td>Large striping over ice cloud scenes and water scenes (~0.5K).</td>
</tr>
<tr>
<td>23</td>
<td>1,10</td>
<td>Large striping over ice cloud scenes and water scenes (~0.5K).</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>Striping over ice cloud scenes and 0.5 -1 K change over ocean scenes</td>
</tr>
</tbody>
</table>

Reference:
Electronic cross-talk contamination can also be seen in lunar images. Striping can be observed in the Earth images.

A cross-talk correction for selected detectors of the Aqua MWIR and LWIR bands will be applied in C7.

The selection of the detector for correction depends on the impact on L1B product and image quality.

Mission-long cross-talk coefficients have been processed for the Aqua MWIR and LWIR bands.

The cross-talk coefficients are stable and a slight downward trend for some detectors.

<table>
<thead>
<tr>
<th>Band</th>
<th>Detector</th>
<th>Contamination Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1</td>
<td>Striping over some scenes (~0.15K).</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>Striping over some scenes (~0.20K).</td>
</tr>
<tr>
<td>23</td>
<td>1</td>
<td>Large striping over ice cloud scenes and water scenes (~0.5K).</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>Striping over low BT scenes during daytime.</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>Striping over some scenes (~0.20K).</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>Large striping over some scenes (~0.80K).</td>
</tr>
<tr>
<td>29</td>
<td>1,2,6</td>
<td>Striping over some scenes (~0.3K).</td>
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<tr>
<td>30</td>
<td>1</td>
<td>Striping over some scenes (~0.45K).</td>
</tr>
</tbody>
</table>

Aqua band 24 cross-talk correction

The cross-talk correction has been tested for multiple granules. The L1B data changes are as expected. Band 24 detector 1 displays the largest image striping impact for cold scenes. The striping is greatly reduced after correction. Histograms show detector back in-family after correction.
Terra Bands 20 and 29 a0 correction and C7 algorithm

- Terra-IASI comparison (is from 2007 to 2019) shows BT-dependent bias. Lower BT scenes show larger biases.

- The trending from qDCC (~200K) analyzed for bands 20 and 29 for entire mission.

- The BT bias and drift over qDCC, derived combining Terra-IASI comparison and qDCC trending, are used for a0 correction

- For each WUCD event, apply the a0 correction for both mirror sides and derive a2.

Terra band 30 C7 algorithm

- Earth view trending results over Dome-C (cold scene), qDCC, and the ocean (warm scene) also exhibit these biases (decreasing trend). This bias is larger for low BT scenes.
- For C7, use a0 and a2 from 2003 LUT (after last configuration change) to re-process Terra MODIS band 30 for entire mission.
- For both the Dome-C site and an ocean location in the Bahamas, one month’s worth of EV data for every year of the Terra MODIS mission was re-processed using the a0 and a2 calibration coefficients from C7 LUT.
- Comparison tests between this trial and C6.1 demonstrate significant bias corrections for both the Dome-C (cold) and ocean (warm) Earth scenes.
Summary

- Overall performance is stable for both Terra and Aqua MODIS TEB
- Terra BB temperature was changed to 285K after April 23 to April 25, 2020 WUCD.
  -- The instrument performance is as expected. No impact on noise performance (NEdT).
  -- No noticeable impact on calibration coefficients and on EV L1B products.
- Since last STM, one noisy detector added to Terra and no noisy detector add for Aqua.
- Increase of Aqua CFPA temperature control since 2013.
- In C7, the crosstalk correction will be applied for selected detectors for Aqua PV bands and for Terra MWIR bands.
- C7 calibration algorithm improvement for Terra bands 20, 29, and 30 to improve stability.
- C7 calibration algorithm improvement for Aqua TEB a0a2 to improve mirror side consistence.
Backup
Terra BB temperature change

- Terra BB temperature was changed to 285K after April 23 to April 25 WUCD (April 25 02:00)
- The instrument telemetry temperatures, instrument response, and impact on Earth L1B measurements are monitored and analyzed.

  ✓ The instrument performance is as expected. The instrument temperatures decrease slightly and CFPA temperature is stable.

  ✓ Calibration coefficients change is insignificant. Mini-L1B, Semi-L1B, and analytical modeling show negligible impact on L1B product

  ✓ No impact on instrument Noise performance (NEdT)

  ✓ No significant change in EV BT (Dome-C, Ocean, and Terra-IASI comparison, no change were observed above the noise and method uncertainties).
Collection 6.1 TEB QA Table

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</table>

- Current QA table
- Terra band 28 detector 1 added
- Product order

**Terra**

**Aqua**

Noisy data points are marked in yellow, and inoperable data points are marked in red.
### MODIS TEB C6.1 Calibration Algorithm

<table>
<thead>
<tr>
<th>Band</th>
<th>Aqua</th>
<th>Terra</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calibration model</strong></td>
<td><strong>Calibration algorithm</strong></td>
<td><strong>Cross-talk correction</strong></td>
</tr>
<tr>
<td>20</td>
<td>PL $a_0$</td>
<td>$a_{0_ms1} = 0$</td>
</tr>
<tr>
<td>22</td>
<td>PL adjusted CD $a_2$</td>
<td>$a_{0_ms2} = a_{0_ms1} - a_{0_ms1} \cdot \text{free-fit}$</td>
</tr>
<tr>
<td>23</td>
<td>(CD: cooldown)</td>
<td>CD $a_2$</td>
</tr>
<tr>
<td>24</td>
<td>PV LWIR electronic cross-talk</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>PC LWIR optical cross-talk</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>$a_0 = 0$, CD $a_2$</td>
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</tr>
<tr>
<td>28</td>
<td>$a_0 = 0$, CD $a_2$</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>$a_0 = 0$, CD $a_2$</td>
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</tr>
<tr>
<td>30</td>
<td>$a_0 = 0$, CD $a_2$</td>
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### MODIS TEB Recommended C7 Calibration Algorithm

<table>
<thead>
<tr>
<th>Band</th>
<th>Aqua</th>
<th>Terra</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calibration model</strong></td>
<td><strong>Calibration algorithm</strong></td>
<td><strong>Cross-talk correction</strong></td>
</tr>
<tr>
<td>20</td>
<td>PL $a_0$</td>
<td>$a_{0_ms1} = 0$</td>
</tr>
<tr>
<td>22</td>
<td>PL with MS correction</td>
<td>$a_{0_ms2} = a_{0_ms1} \cdot \text{free-fit}$</td>
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<tr>
<td>23</td>
<td>CD $a_2$</td>
<td>CD $a_2$</td>
</tr>
<tr>
<td>24</td>
<td>PV LWIR electronic cross-talk</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Electronic cross-talk corrections for selected detectors</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Corrected $a_0$; CD $a_2$</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>2003 $a_0a_2$; $a_{0_ms1} = 0$</td>
<td></td>
</tr>
</tbody>
</table>

### MODIS TEB C6.1 and C7 Algorithms Comparison

- **MODIS TEB C6.1**
  - PL $a_0$
  - PL adjusted CD $a_2$
  - CD $a_2$
  - PV LWIR electronic cross-talk
  - PC LWIR optical cross-talk

- **MODIS TEB C7**
  - PL $a_0$ with MS correction
  - Electronic cross-talk corrections for selected detectors
  - Corrected $a_0$; CD $a_2$
  - 2003 $a_0a_2$; $a_{0\_ms1} = 0$
  - Early mission: MS corrected $a_0$
  - Since 2003: $a_0 = 0$, CD $a_2$
  - PC LWIR optical cross-talk
Based on the bias trend derived from the Terra-IASI comparison and qDCC trending, derive the a0 correction for each month.

- The a0 correction for C7 LUT and deriving a2 is the yearly sliding window averaged.
- Years 2000-2003 had a few configuration and setting changes. For band 20: use the average a0 correction from 2003-2004 to avoid discontinuity.
- For each WUCD event, apply the a0 correction for both mirror sides and derive a2. Use C7 TEB a0 and a2 LUT procedure to generate a0 and a2 LUTs.
- The Dome-C, ocean, and desert measurements will also be used as reference to monitor broader BT range.

![Band 20 calibration correction](image1)

![Band 29 calibration correction](image2)
The cross-talk coefficients have been processed for the Terra MWIR bands from 2003 to present. The algorithm is described in the reference.

- Band 23 detector 1 cross-talk coefficient from sending band 25 detector 10 is stable
- Band 24 detector 1 cross-talk coefficient from sending band 26 detector 10 shows downward trend
- Band 22 detector 8 and band 23 detector 10 contamination comes from multiple bands. The cross-talk coefficients are stable
- These coefficients will be used in C7 LUTs
Aqua MWIR and LWIR bands cross-talk corrections

Mission-long cross-talk coefficients have been processed for the Aqua MWIR and LWIR bands. An in-depth description of the algorithm can be found in the reference below.

- Bands 20, 22, 23, and 25 detector 1 cross-talk coefficients from sending bands 22, 23, 25, and 24 detector 10, respectively, are quite stable.
- Band 24 detector 1 cross-talk coefficient from sending band 26 detector 10 shows a slight downward trend.
- Bands 27 (from band 30 detectors 1 and 10) and 30 (from band 29 detector 10) detector 1 have small decreasing trends.
- These coefficients will be used for C7 LUTs generation.
- Update monthly with lunar event. All the coefficients for each detector are saved.

- The black is for LUT.

- The Terra PC optical cross-talk updated for each scheduled moon data to monitor the PC cross-talk stability for each detector.

Terra MODIS PC_XT yearly averages (+s are standard deviations)