MODIS TEB Calibration and Performance

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MODIS TEB Design Specifications

Band	CW	Ttyp	NEdT	UC (%)	UC (K)	Primary Use
20	3.75	300	0.05	0.75	0.18	Surface/cloud temperature
21	3.96	335	0.20	1	2.97	
22	3.96	300	0.07	1	0.25	
23	4.05	300	0.07	1	0.25	
24	4.47	250	0.25	1	0.19	Atmosphere temperature
25	4.52	275	0.25	1	0.24	
27	6.72	240	0.25	1	0.27	Water vapor
28	7.33	250	0.25	1	0.32	
29	8.55	300	0.05	1	0.53	Cloud properties
30	9.73	250	0.25	1	0.42	Ozone
31	11.03	300	0.05	0.5	0.34	Surface/cloud temperature
32	12.02	300	0.05	0.5	0.37	
33	13.34	260	0.25	1	0.62	Cloud top altitude
34	13.64	250	0.25	1	0.59	
35	13.94	240	0.25	1	0.55	
36	14.24	220	0.35	1	0.47	

CW: center wavelength in micron;
Ttyp: typical scene temperature in K;
NEdT: noise equivalent temperature difference in K

MWIR: 20-25
PV LWIR: 27-30
PC LWIR: 31-36

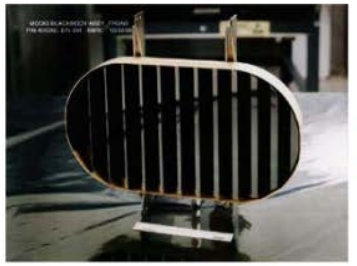
MODIS TEB On-orbit Calibration and Methodologies

- **Regular BB Calibration**
  - Linear gain coefficient b1 on a scan-by-scan basis
  - 40-scan running average b1 for L1B product
- **Quarterly BB Warm-up and Cool-down (WUCD)**
  - Nonlinear gain coefficients a0 and a2
  - Fixed linear coefficients for band 21
- **Special Calibration Issues**
  - PV LWIR bands and MWIR detector electronic crosstalk
  - Terra PC bands 32-36 optical cross-talk
  - Response versus scan angle (RVS)
  - Aqua CFPA temperature fluctuation (till March 2022)
  - Uncertainty and QA
- **Calibration Assessments and Monitoring**
  - Gain, NEdT, uncertainty, and telemetry temperature trending monitoring
  - Ecal and saturation monitoring
  - EV scene (Dome-C, Ocean, qDCC) trending
  - Inter-comparisons with IASI, AIRS, CrIS, and VIIRS Terra/MODIS with Aqua/MODIS,

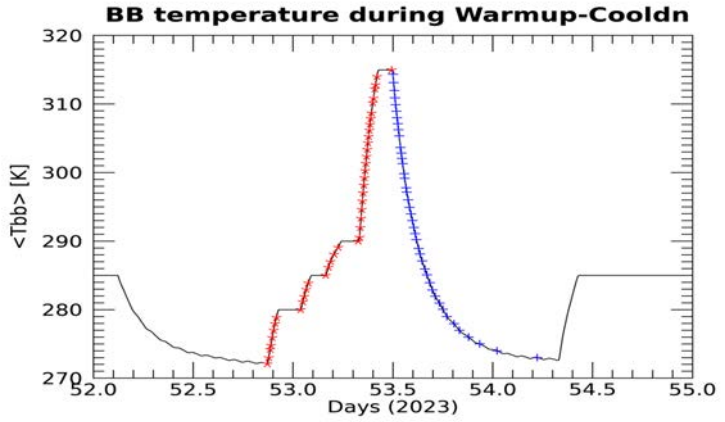
EV Radiance: $L_{EV} = \frac{1}{RVS_{EV}}\left(a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 - \left(RVS_{SV} - RVS_{EV}\right) \cdot L_{SM}\right)$

Calibration Coefficients:

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



Aqua WUCD 2023052



RVS: response versus scan-angle
e: emissivity
L: spectral band integrated radiance
dn: digital count with background corrected
a0 & a2: non-linear gain coefficients
b1: linear gain coefficient

WUCD T_{BB}: ~270 K to 315 K

Terra MODIS TEB calibration performance

Calibration performance

- Overall performance is stable.
- PV LWIR bands 27-30 electronic crosstalk increasing.
- MWIR band select detector electronic crosstalk show slight downward trend.
- NEdT and uncertainty meet specifications, except band 36.
- No noisy detector added since last STM. Currently total 19 noisy and 1 inoperable TEB detectors

Recent events and impacts on calibration

- Terra CP/FP reset (March 2022)

  -- No significant changes to telemetry, gain, noise, and crosstalk contamination

  -- Mirror side difference inverted; calibration offset changes made

- Terra CEM (October 2022)

  -- Gain changes up to 1%

  -- PV LWIR bands crosstalk slight increase

  -- No change in QA

(https://mcst.gsfc.nasa.gov/calibration/time-dependent-list-non-functional-or-noisy-detector)

CP/FP: Command and format processors CEM: Constellation Exit Maneuvers

Aqua MODIS TEB calibration performance

Calibration performance

- Overall performance is stable.
- PV LWIR bands 27-30 electronic crosstalk is increasing, especially in recent three years
- MWIR band select detector electronic crosstalk show slight downward trend.
- NEdT and uncertainty meet specifications.
- Three noisy detectors added since last STM. Currently total 7 noisy and 1 inoperable TEB detectors

Aqua safe mode (March 2022) impacts

-- Gain changes: MWIR bands within 1%; PV LWIR and PC bands 2-3%

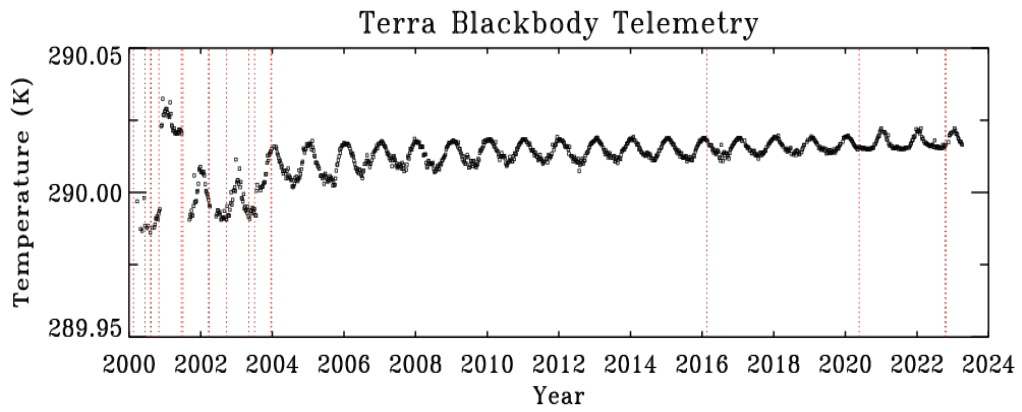
-- PV LWIR bands crosstalk contamination saw significant increase

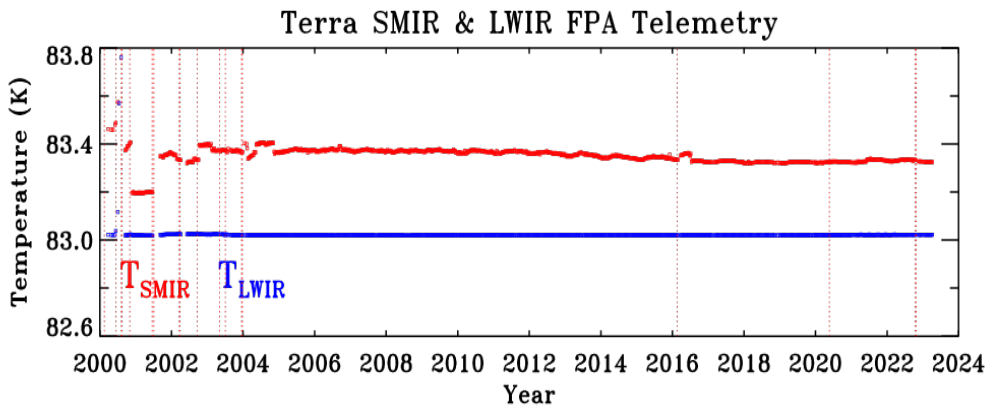
-- B27(1, 3) and B30(1) (P.O.) added as noisy detectors to QA

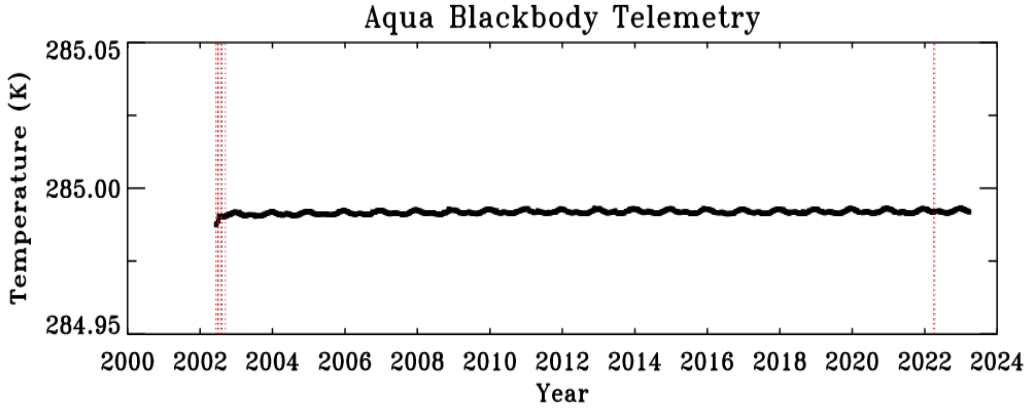
-- Aqua MODIS CFPA temperatures are fully controlled after outgassing

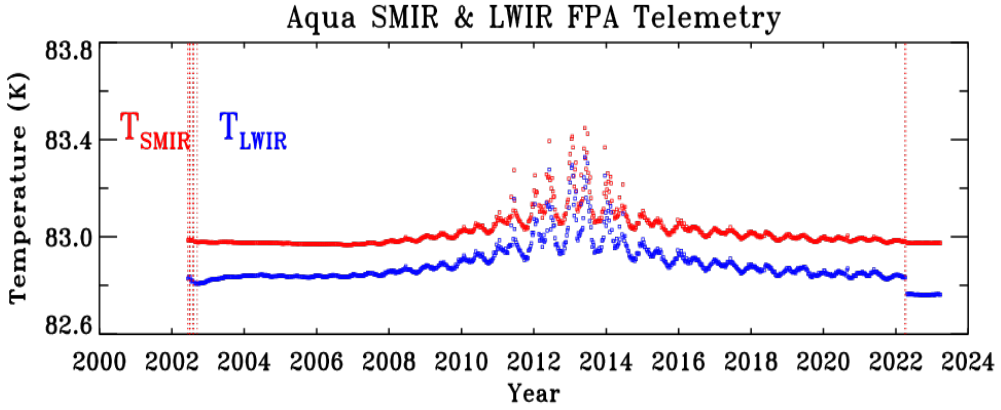
(https://mcst.gsfc.nasa.gov/calibration/time-dependent-list-non-functional-or-noisy-detector)

Key Telemetry Temperatures



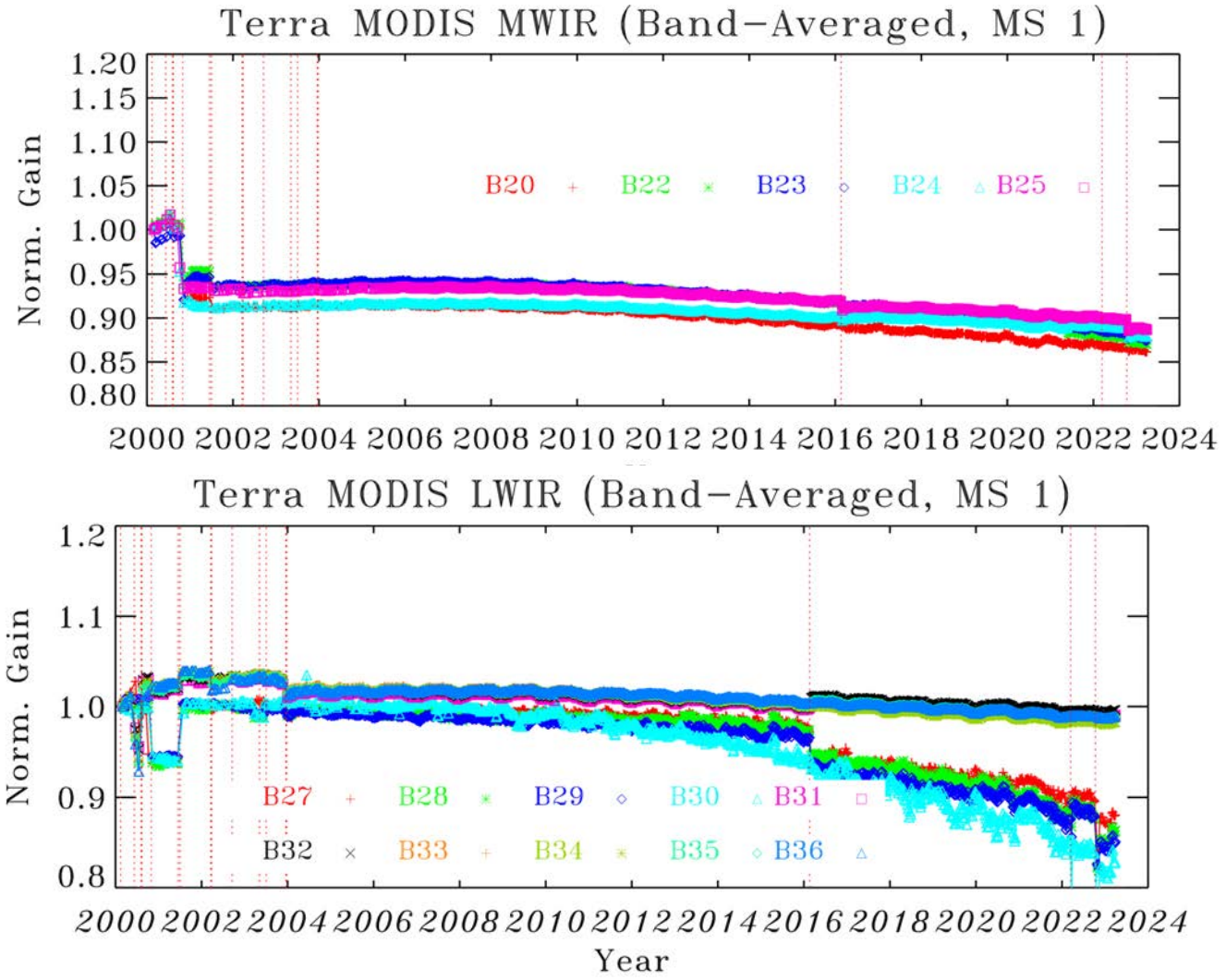






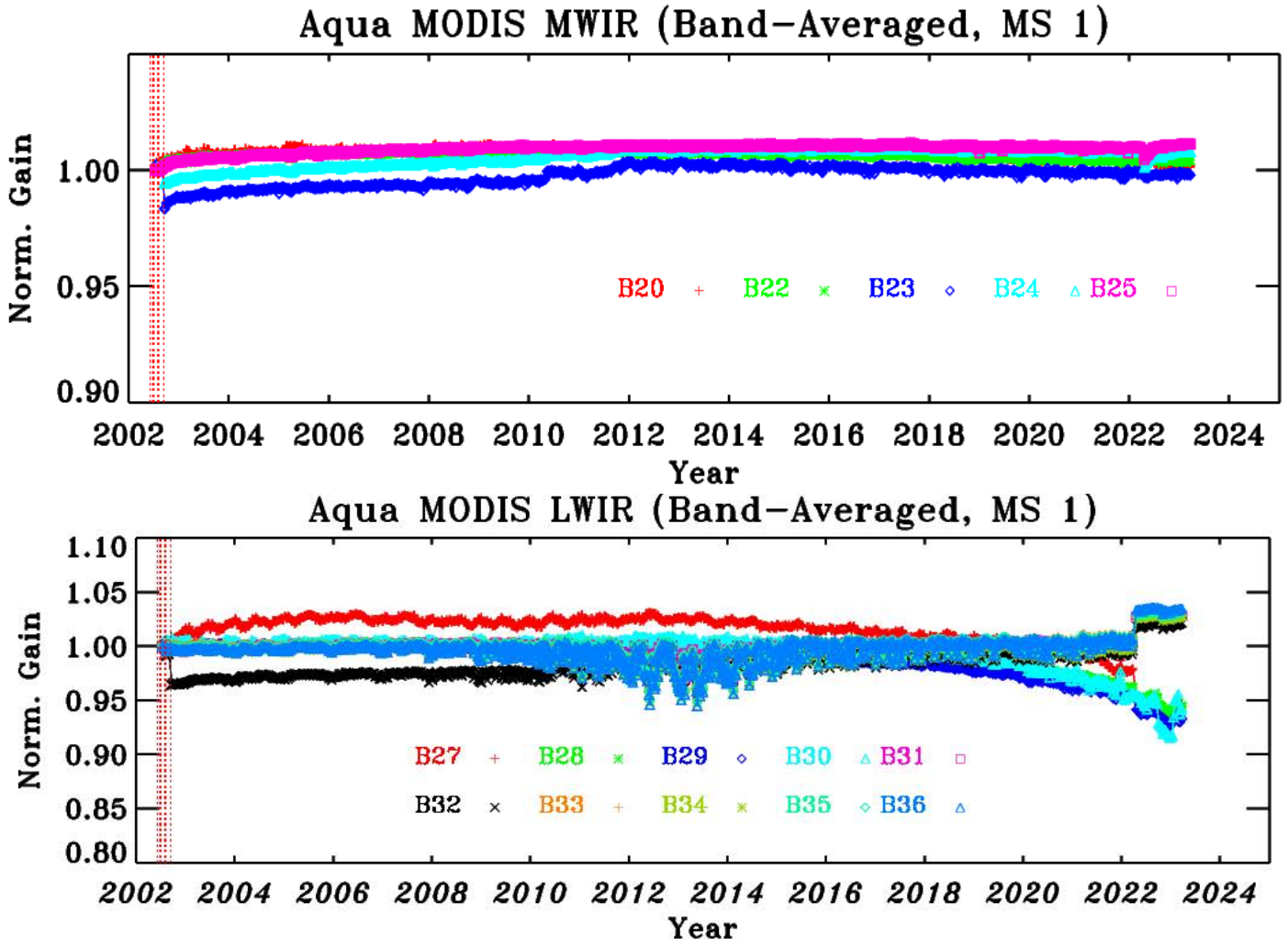
- Terra BB temperature setting is changed to 285K in April 2020. In the Terra BB temperature trending plot, the temperature is shifted 4.96K for matching the temperature trending.
- Aqua SMIR CFPA actively controlled (83K), insufficient radiative cooler margin starting ~2006.
  - -- Increase of radiative cooler margin and improvement of temperature control since 2013
  - -- After outgassing following safe mode, CFPA temperature is fully controlled.

Terra TEB Gain Trending



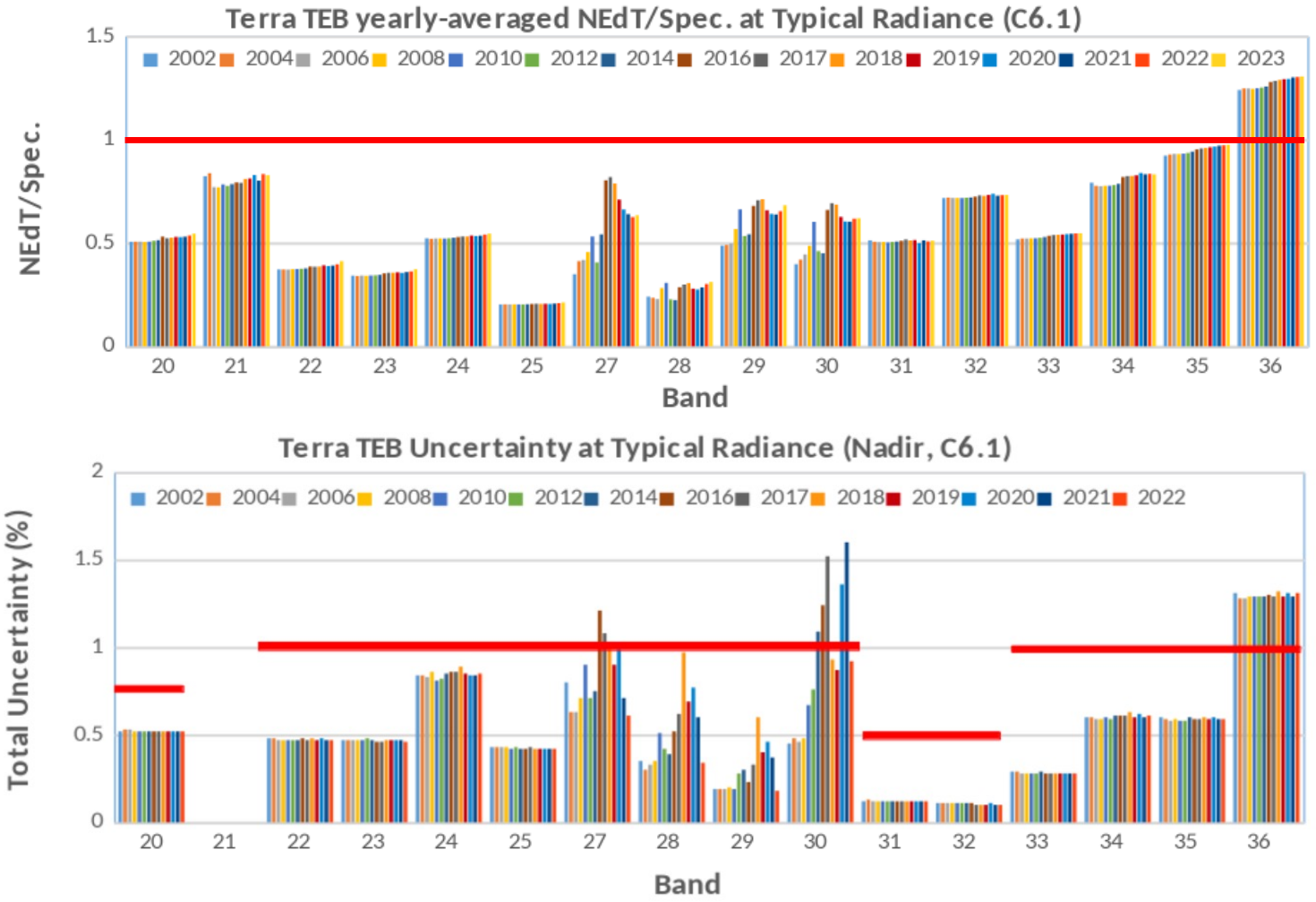
- Safe mode event of Feb 2016 caused gain changes for some bands, especially for PV LWIR bands.
- Slight gain change after CEM.

Aqua TEB Gain Trending



- CFPA temperature impacts on gain for LWIR bands around 2013.
- Safe mode (March 2022) impacts on gains for LWIR bands

Terra TEB NEdT and uncertainty



- Safe mode event of Feb 2016 caused NEdT changes for some bands, especially for PV LWIR bands.
- No impact from Terra 2022 CP/FP reset and CEM
- Band 36 NEdT and uncertainty are above the specification

Aqua TEB NEdT and uncertainty

- NEdT meets the specification and stable over the mission
- Band 21 NEdT is close to the specification and overall meet the specification.
- No significant impact from Aqua 2022 safe mode

MODIS TEB C6.1 and C7 algorithms

Terra C7 improvements

- **MWIR crosstalk correction** – Crosstalk correction applied to selected detectors calibration and EV measurements.
- **PC bands mirror side difference reduction** – Early mission calibration offset a0 correction to reduce mirror side difference.
- **Bands 20 and 29 cold scene biases reduction** – Calibration offset a0 adjustments to reduce cold scene bias
- **Band 30 calibration stability** – Improvement of nonlinear a0 and a2 coefficient algorithm.
- **MWIR and LWIR crosstalk uncertainty** – Improvement on crosstalk uncertainty calculation and propagation to L1B data.

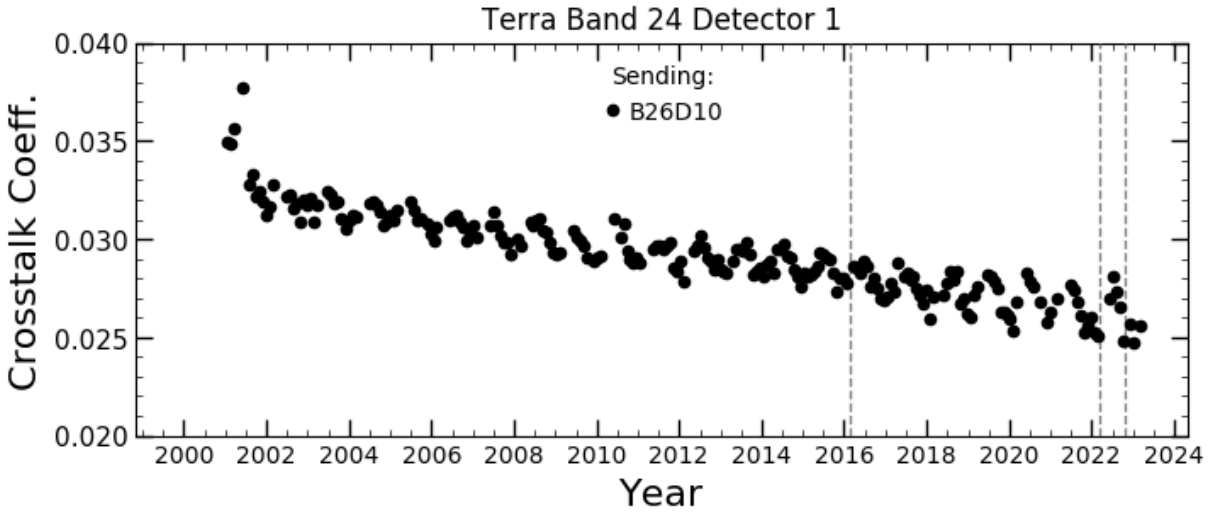
Aqua C7 improvements

- **MWIR crosstalk correction** – Crosstalk correction applied to selected detectors calibration and EV measurements.
- **LWIR crosstalk correction** – Crosstalk correction applied to calibration and EV measurements.
- **Calibration stability improvement** – Application of nonlinear a2 using BB CD data to all bands and a2 adjustment for PV LWIR bands.
- **Mirror-side consistency** - Application of mission-long a0 correction to reduce mirror side difference.
- **MWIR and LWIR crosstalk uncertainty** – Improvement on crosstalk uncertainty calculation and propagation to L1B data.

Terra MWIR bands cross-talk corrections

- MWIR bands crosstalk correction for selected detectors applied to Terra MODIS C7.
- The table lists the receiving band/detector and contamination impact
- Band 24 detector 1 (sending from band 26 detector 10) shows the largest contamination for daytime measurements
- The MWIR crosstalk coefficients are gradually decreasing. The chart shows band 24 detector 1 crosstalk trending.

Band	Det	Contamination Impact
22	8	Striping over ice cloud scenes and water scenes (~0.5K).
23	1,10	Striping over ice cloud scenes and water scenes (~0.5K).
24	1	Striping over ice cloud scenes; 0.5 -1 K change over ocean scenes

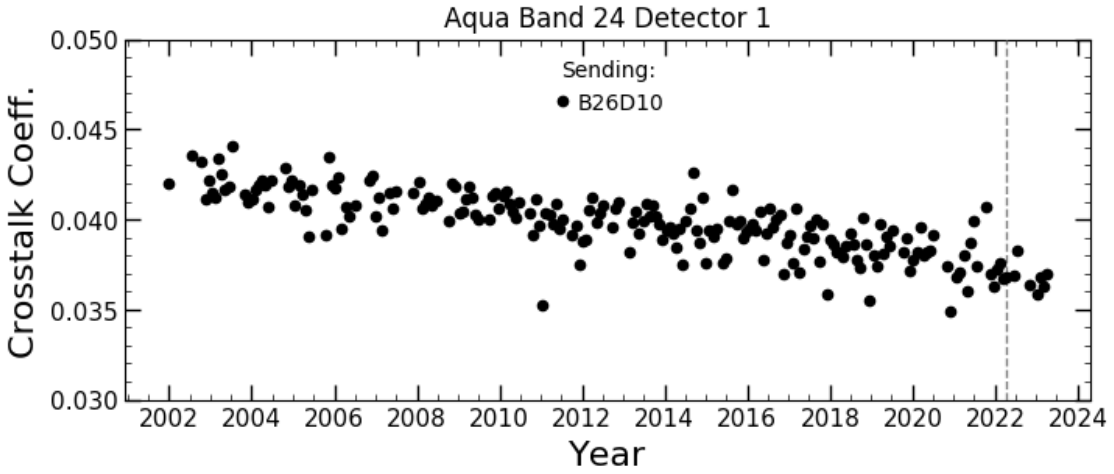


Reference:
(1) Wilson, T., A. Shrestha, and X. Xiong, "Electronic crosstalk impact assessment in the Terra MODIS midwave infrared bands", Proceedings Volume 10423, Sensors, Systems, and Next-Generation Satellites XXI; 104231Z, 2017
(2) https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

Aqua MWIR bands cross-talk corrections

- MWIR bands crosstalk correction for selected detectors applied to Aqua MODIS C7.
- The table lists the receiving band/detector and contamination impact
- Band 24 detector 1 (sending from band 26 detector 10) shows the largest contamination for daytime measurements
- The MWIR crosstalk coefficients are gradually decreasing. The chart shows band 24 detector 1 crosstalk trending.

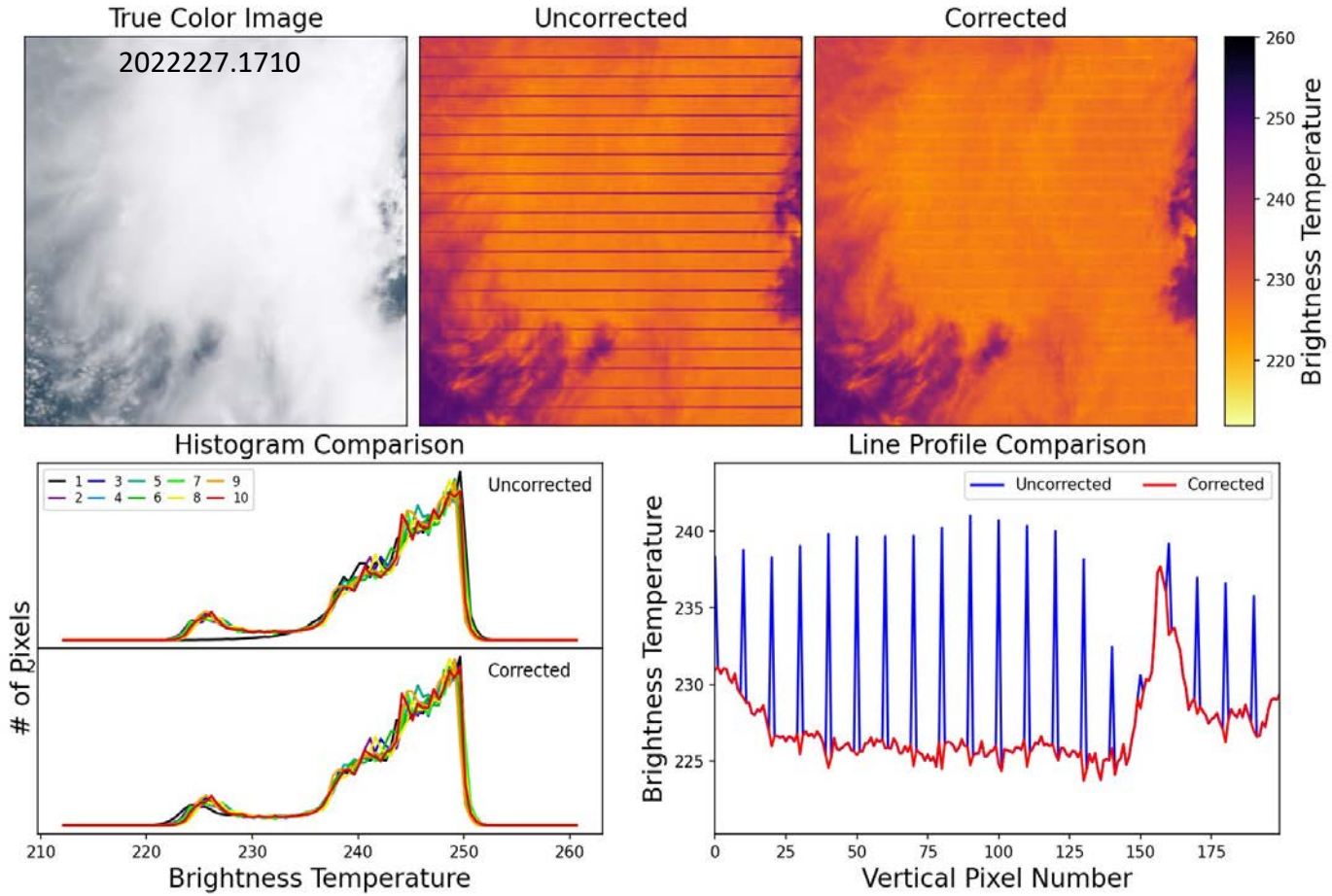
Band	Det	Contamination Impact
20	1	Striping over some scenes (~0.15K).
22	1	Striping over some scenes (~0.20K).
23	1	Large striping over ice cloud and water scenes (~0.5K).
24	1	Striping over low BT scenes during daytime.
25	1	Striping over some scenes (~0.20K).



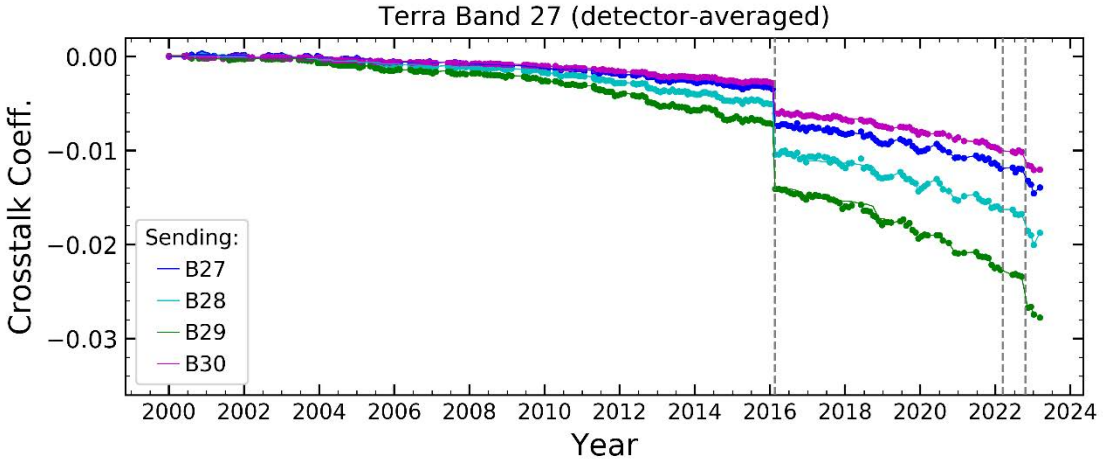
Reference:
(1) Keller, G. R., T. Wilson, X. Geng, A. Wu, Z. Wang and X. Xiong, "Aqua MODIS Electronic Crosstalk Survey: Mid-Wave Infrared Bands," IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 3, pp. 1684-1697, 2019
(2) https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

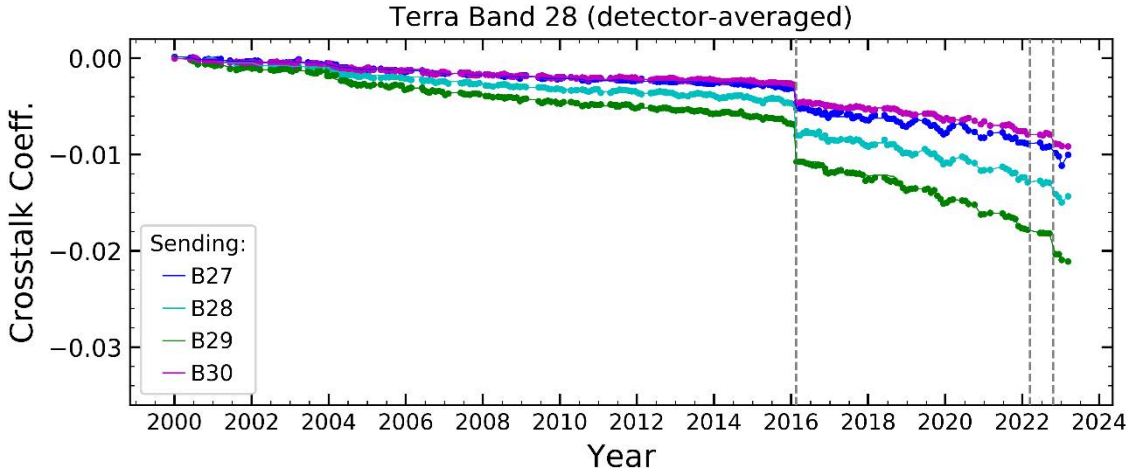
Aqua band 24 cross-talk correction

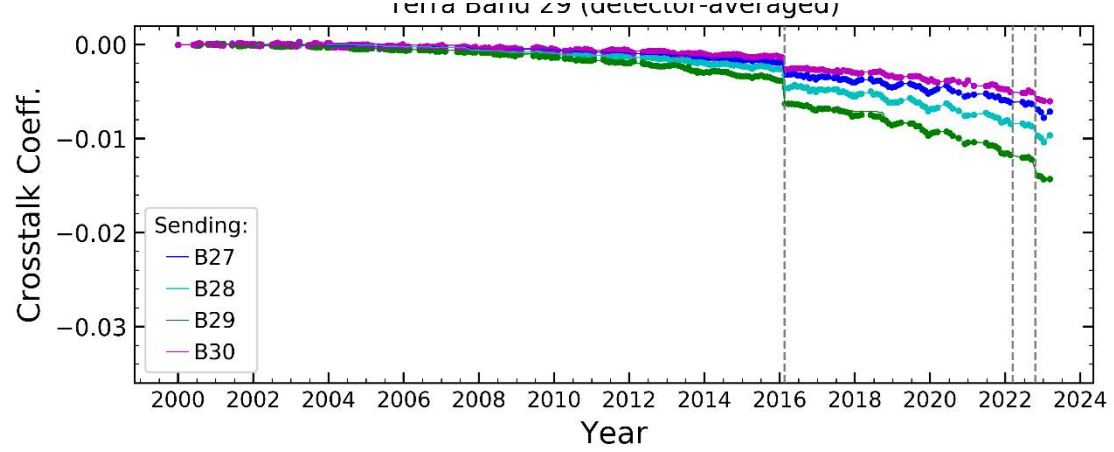
The cross-talk correction has been tested for multiple granules. The L1B data changes are as expected. Band 24 detector 1 displays the largest image striping impact for cold scenes. The striping is greatly reduced after correction. Histograms and BT profile show detector back in-family after correction.

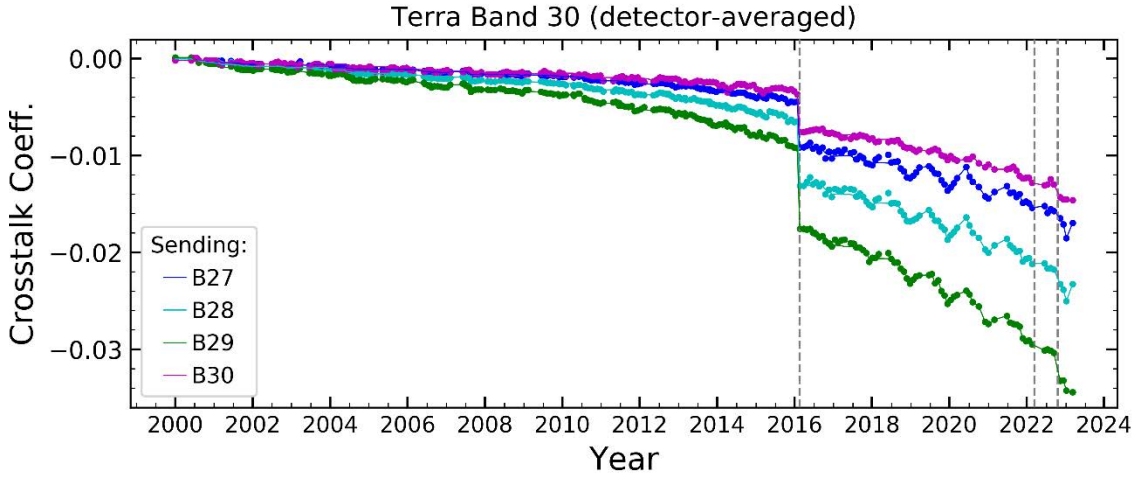


Terra PV LWIR Bands Cross-talk for C6.1/C7



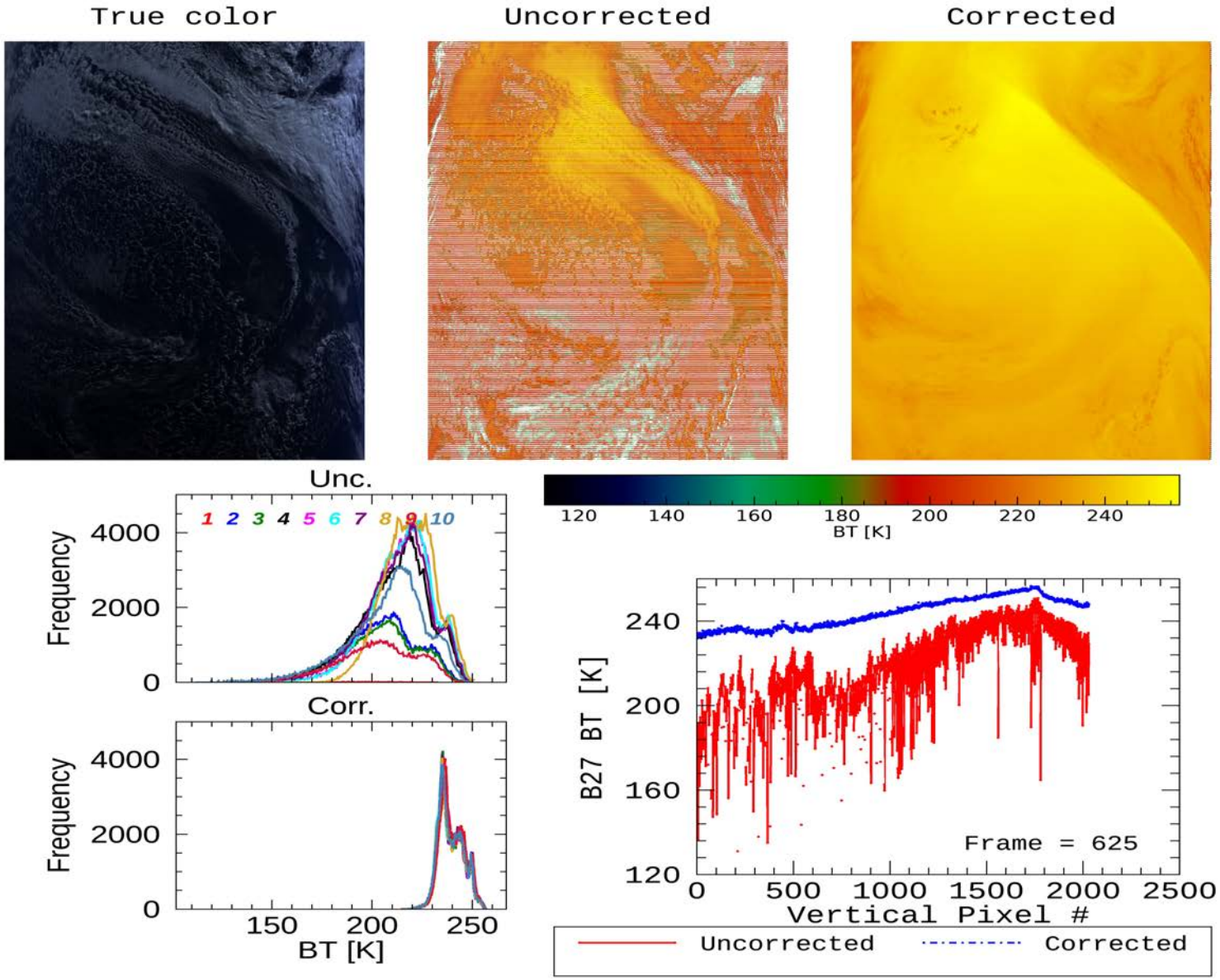






- These plots are sending band averaged coefficients
- Dots are coefficients from scheduled lunar observation and the lines are the LUT coefficients
- Safe mode (Feb 2016) caused the jump of the cross-talk.
- Slightly drop after CEM Oct 2022

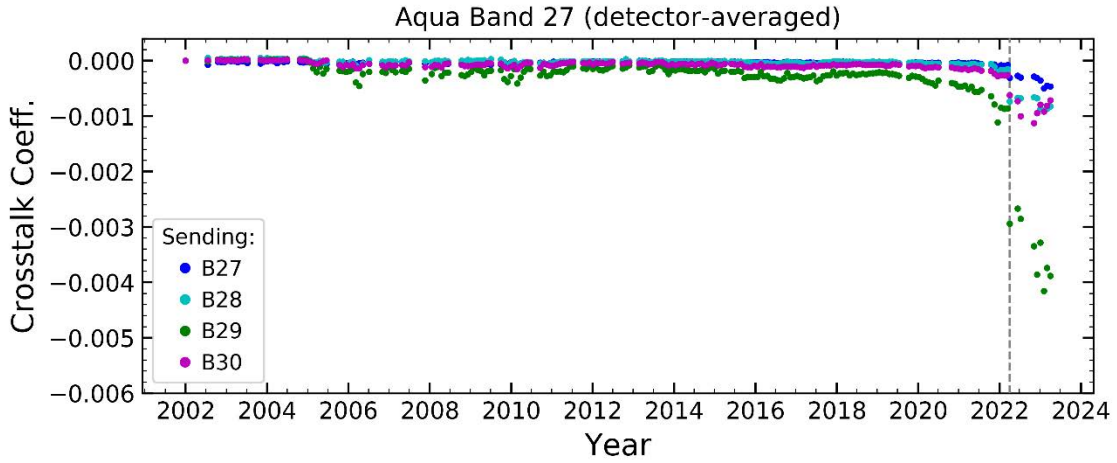
MODIS TEB electronic cross-talk corrections

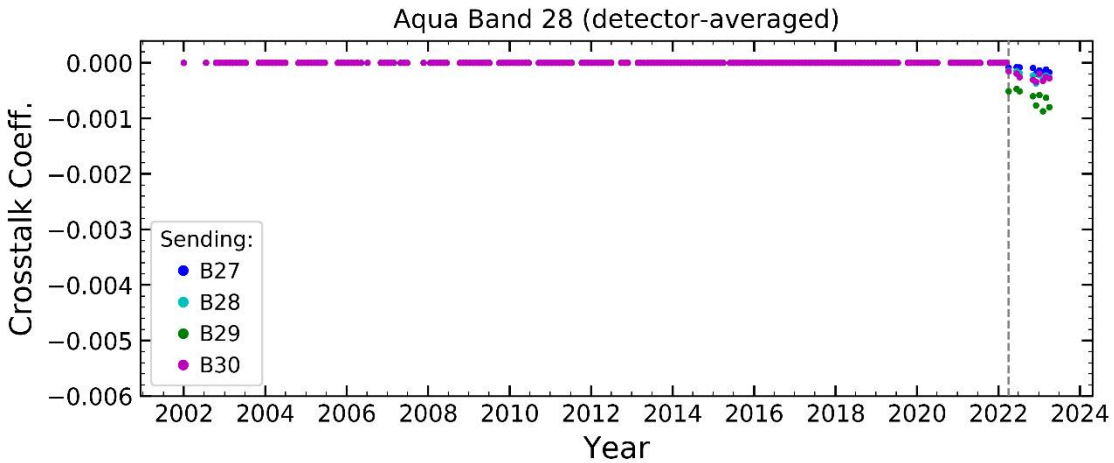


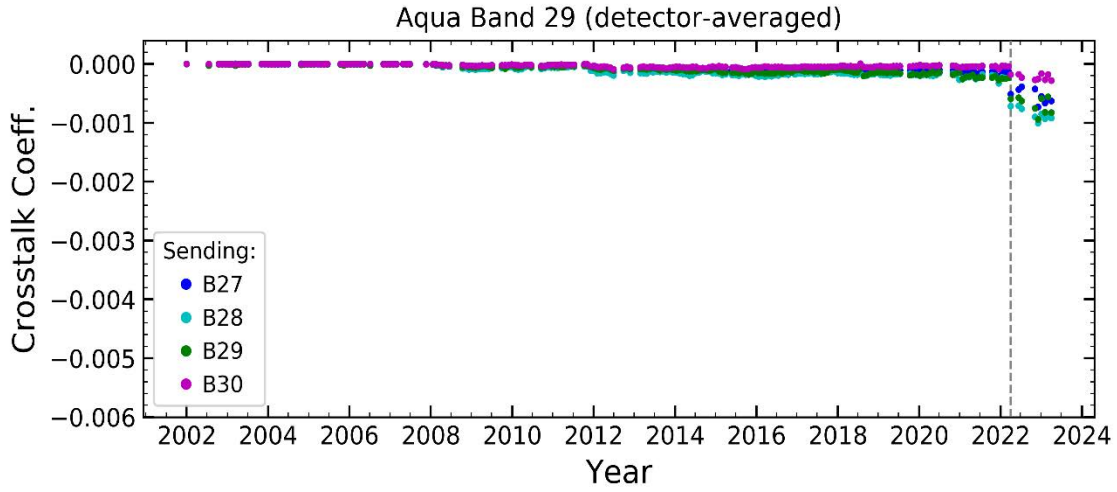
- Cross-talk corrections have been implemented in C6.1/C7 for Terra entire mission.
- Correction example for Terra MODIS band 27 on 2022349.1145.

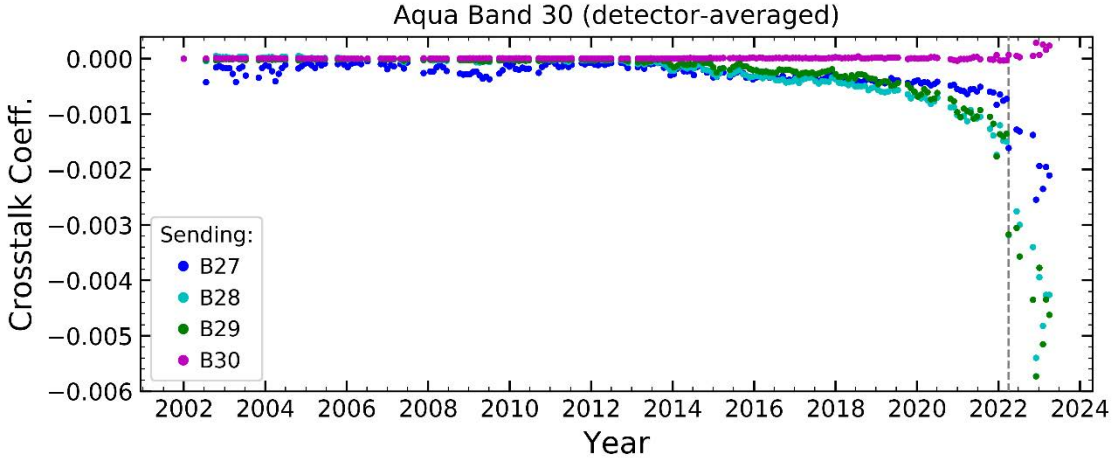
https://mcst.gsfc.nasa.gov/sites/default/files/meetings_files/2018_mcst_xtalk_workshop.pdf.

Aqua PV LWIR Bands Cross-talk



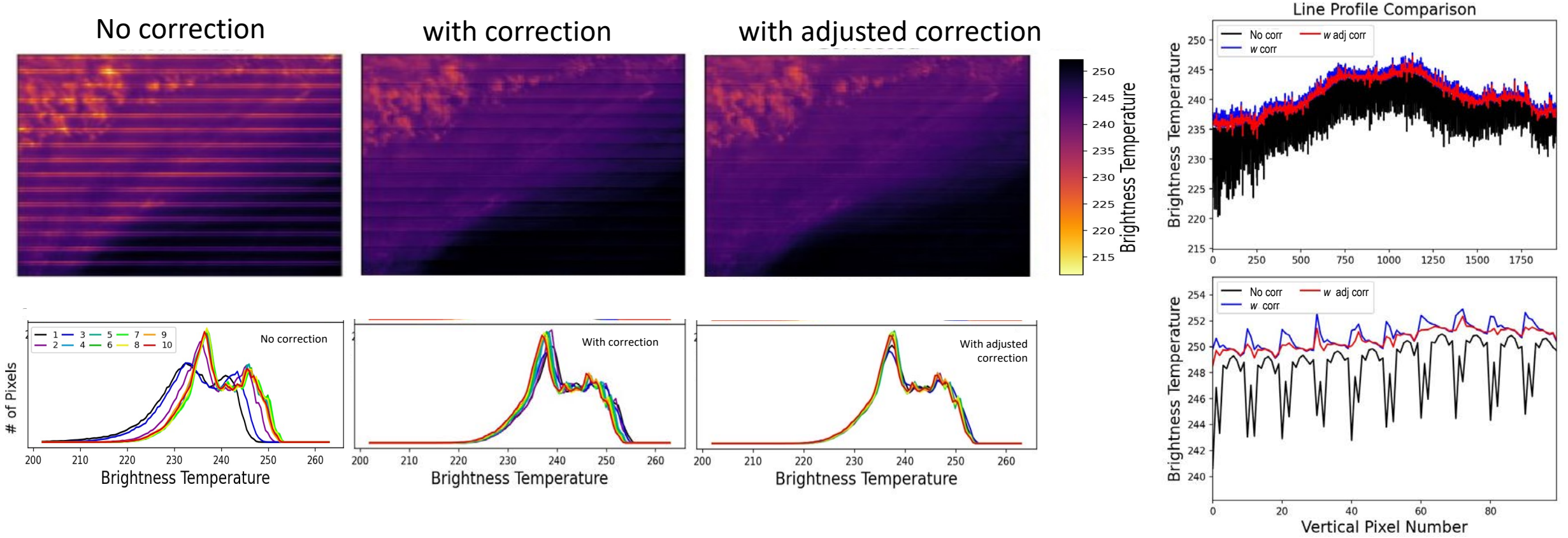






- These plots are sending band averaged coefficients
- Crosstalk correction applied to entire mission for C7 and to after safe mode for C6.1
- Safe mode (March 2022) caused the changes of the cross-talk.

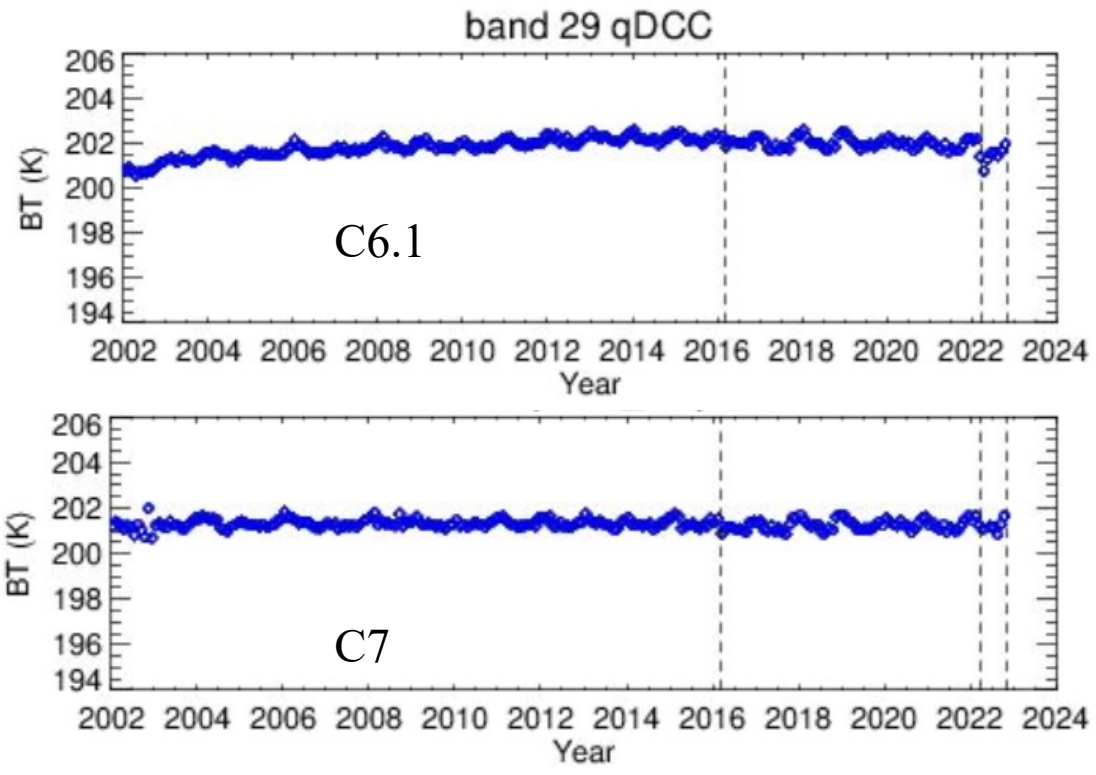
Aqua crosstalk coefficient adjustment and image quality

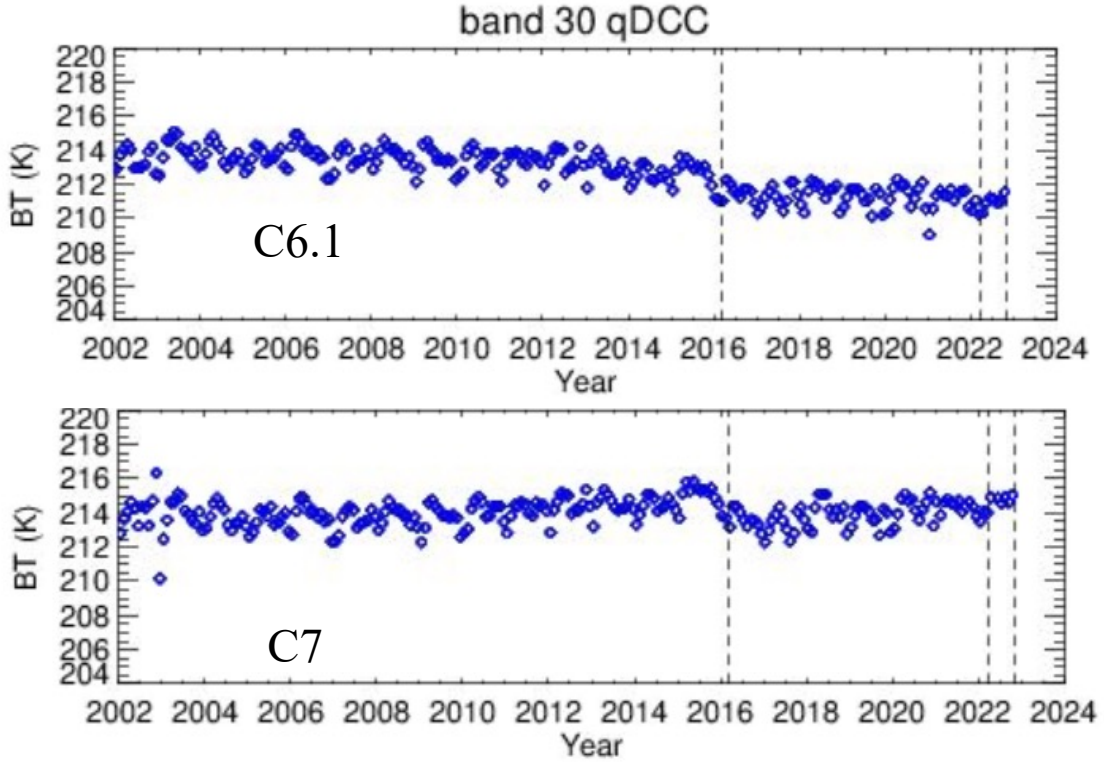


- Aqua PV LWIR crosstalk correction is applied to C7 and C6.1 for band 27 after safe mode March 2022.
- The adjustment of the crosstalk correction using Earth measurement assessment enhance the L1B image quality
- For details, see the poster "Aqua-MODIS TEB C7 electronic crosstalk correction and image quality enhancement"

C7 algorithm example (Terra trending)

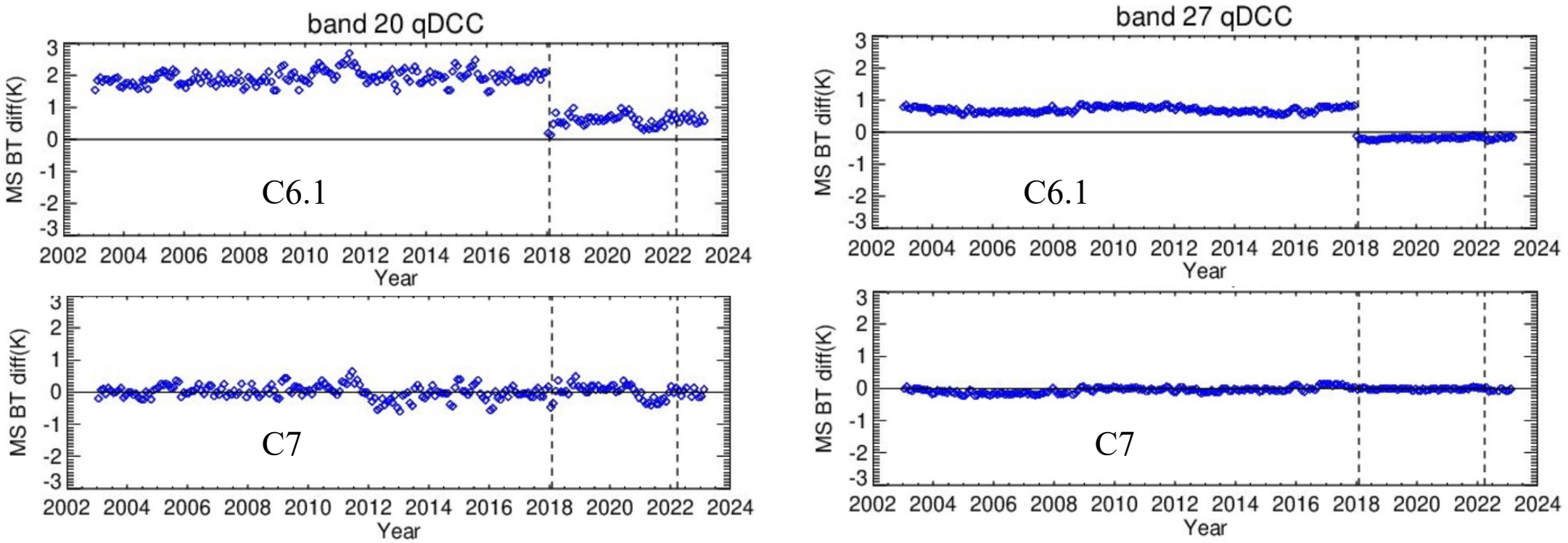
- a0 and a2 correction applied to Terra MODIS C7 for improvement on long-term stability
- The qDCC (~200K) trending assessment for the mirror side difference for C6.1 (top) and C7 (bottom) for bands 29 and 30.





C7 algorithm example (Aqua mirror side difference)

- Mission-long a0 correction applied to Aqua MODIS C7 for improvement on mirror side consistence
- The qDCC (~200K) trending assessment for the mirror side difference for C6.1 (top) and C7 (bottom) for bands 20 and 27.



Reference: Chang, T., X. Xiong, A. Shrestha, and P. C. Diaz, "Methodology development for calibration assessment using quasi-deep convective clouds with application to Aqua MODIS TEB", Earth and Space Science, vol. 7, issue 1, pp. 1-15, 2020.

Backup

MODIS TEB C6.1 and C7 algorithms comparison

MODIS TEB C6.1 calibration algorithm

Band	Aqua	Terra	
	Calibration algorithm	Calibration algorithm	Cross-talk correction
20	PL a_0 PL adjusted CD a_2 (CD: cooldown).	$a_{0\_ms1} = 0$ $a_{0\_ms2} = a_{0\_ms2}^{\text{free-fit}} - a_{0\_ms1}^{\text{free-fit}}$ CD a_2	
22			
23			
24			
25			
27			PV LWIR electronic cross-talk
28			
29			
30			
31	a_0=0, CD a_2	$a_0 = 0$ CD a_2	
32			PC LWIR optical cross-talk
33	a_0=0 PL adjusted CD a_2		
34			
35			
36			

MODIS TEB C7 calibration algorithm

Band	Aqua		Terra	
	Calibration algorithm	Cross-talk correction	Calibration algorithm	Cross-talk correction
20	PL a_0 with MS correction CD a_2	Electronic cross-talk corrections for selected detectors	Corrected a_0; CD a_2	Electronic cross-talk corrections for selected detectors
22			$a_{0\_ms1} = 0$ $a_{0\_ms2} = a_{0\_ms2}^{\text{free-fit}} - a_{0\_ms1}^{\text{free-fit}}$ CD a_2	
23				
24				
25				
27	PL a_0 with MS correction 2012 CD a_2	Electronic cross-talk corrections for all detectors with additional adjustment		PV LWIR electronic cross-talk
28				
29	Corrected a_0; CD a_2		Corrected a_0; CD a_2	
30	MS Corrected a_0 ; 2012 a_2		2003 a_0a_2; $a_{0\_ms1} = 0$	
31	Entire mission MS corrected a_0 CD a_2		a_0 =0 CD a_2	
32				PC LWIR optical cross-talk
33			Early mission: MS corrected a_0 Since 2003: a_0 =0 CD a_2	
34				
35				
36				