MODIS TEB Performance

Outline

- MODIS TEB and on-orbit calibration

- TEB calibration performance

  - ➢ Performance summary

  - ➢ Blackbody and CFPA temperature trends

  - ➢ Detector gain coefficient trends

  - ➢ Detector NEdT trends and QA table

  - ➢ Uncertainty

- TEB electronic cross-talk update and recommendation

- TEB calibration assessment using DCC

- Summary

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	10	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;
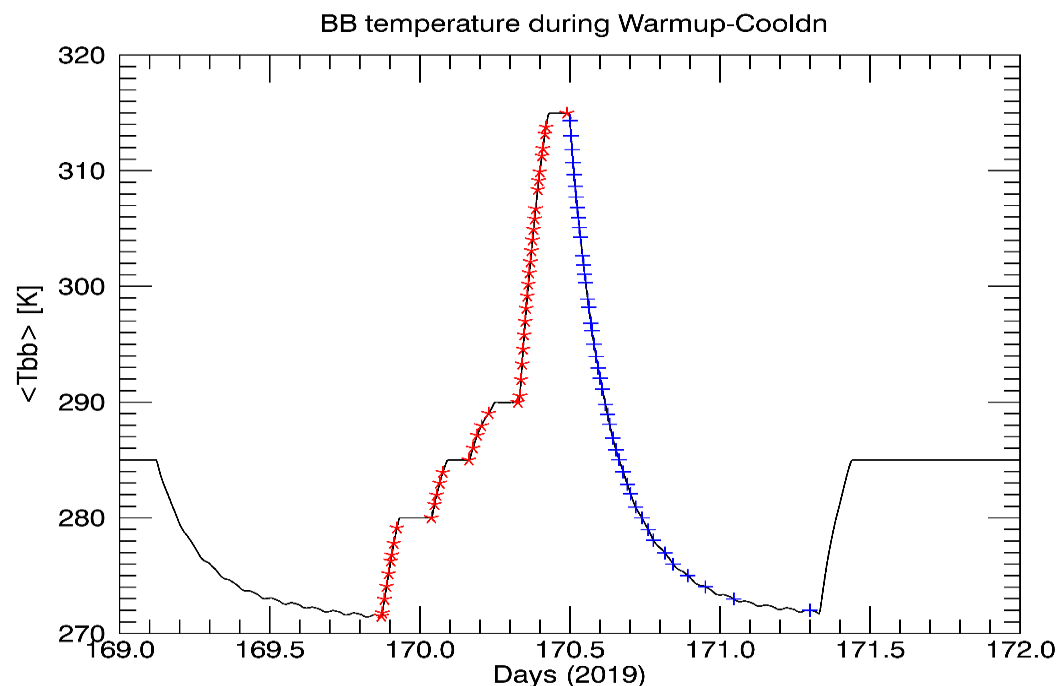NEdT: noise equivalent temperature difference in K

On-orbit Calibration Methodologies

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

Calibration Coefficients:

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

BB temperature during Warmup-Cooldn

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

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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
- **Quarterly BB Warm-up and Cool-down (WUCD) Activities**
  - Compute nonlinear gain coefficients a0 and a2
  - Derive fixed linear coefficients for band 21
  - Aqua default b1 for bands 33, 35 and 36
- **Special Calibration Issues**
  - Characterization of response versus scan angle
  - Aqua CFPA temperature fluctuation
  - Bands 27-30 electronic crosstalk
  - Bands 32-36 optical cross-talk
  - Uncertainty
- **Calibration Assessments and Monitoring**
  - EV scene (Dome-C, Ocean, DCC)
  - Gain trending, NEdT trending, Ecal and saturation monitoring
  - Inter-comparisons with IASI and CrIS, Terra - Aqua, and MODIS - VIIRS.

TEB Performance Summary
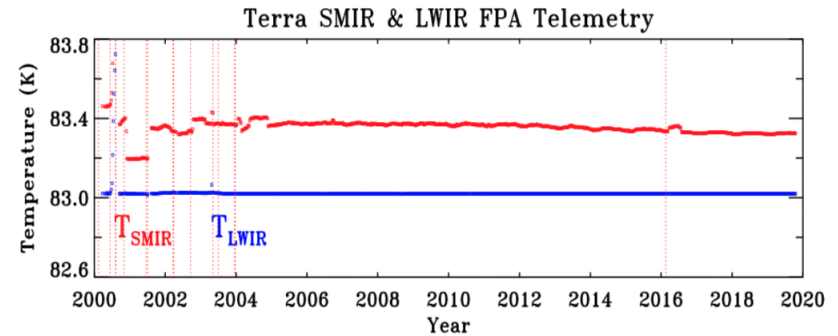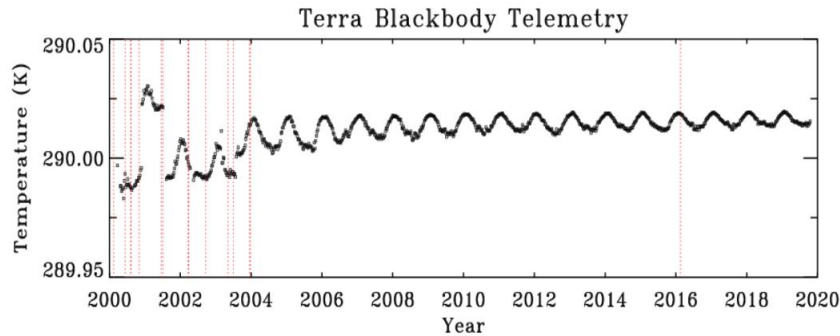
- **Terra MODIS**

  -- Overall performance is stable.

  -- 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, NEdT, and cross-talk, especially for PV LWIR bands 27-30.

  -- a0/a2 delivery procedure improved to catch the response changes.

  -- NEdT and uncertainty meet specifications, except band 36 NEdT and uncertainty.

- **Aqua MODIS**

  -- Overall performance is stable.

  -- NEdT and uncertainty meet specifications.

  -- CFPA temperature fluctuation improved since 2013.

Key Telemetry Temperatures

Terra Blackbody Telemetry

Terra SMIR & LWIR FPA Telemetry

Aqua Blackbody Telemetry

Aqua SMIR & LWIR FPA Telemetry

SMIR FPA Heater Duty Cycle
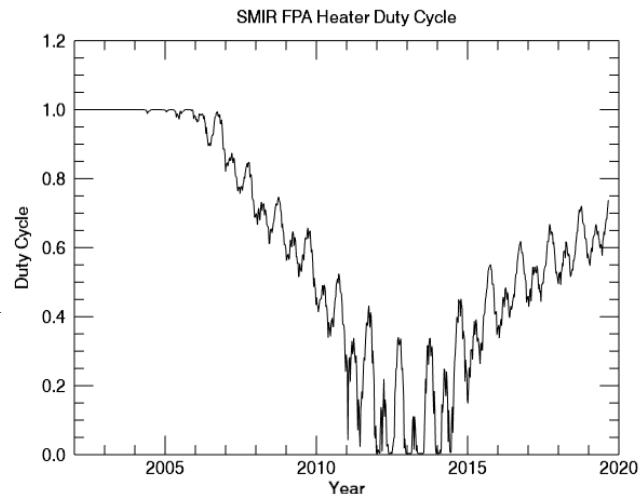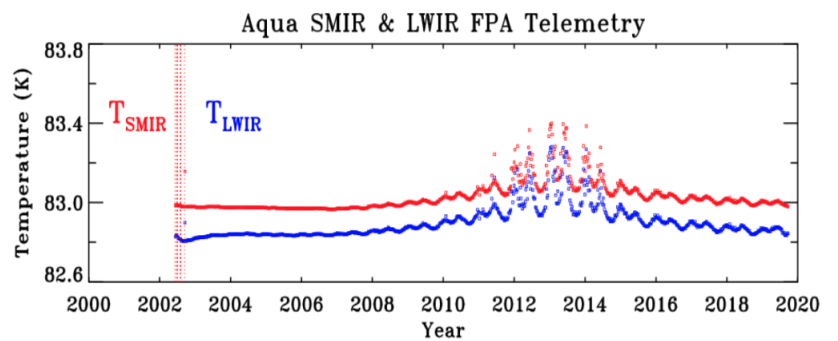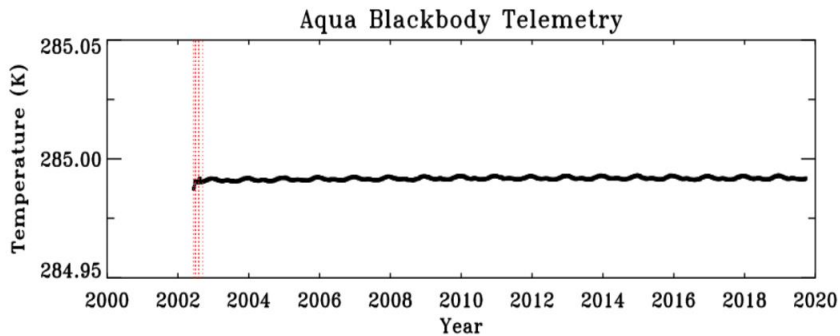
➢ Aqua SMIR CFPA actively controlled (83K), insufficient radiative cooler margin starting ~2006

  -- Improved since 2013 (Increase of radiative cooler margin and improvement of temperature control)
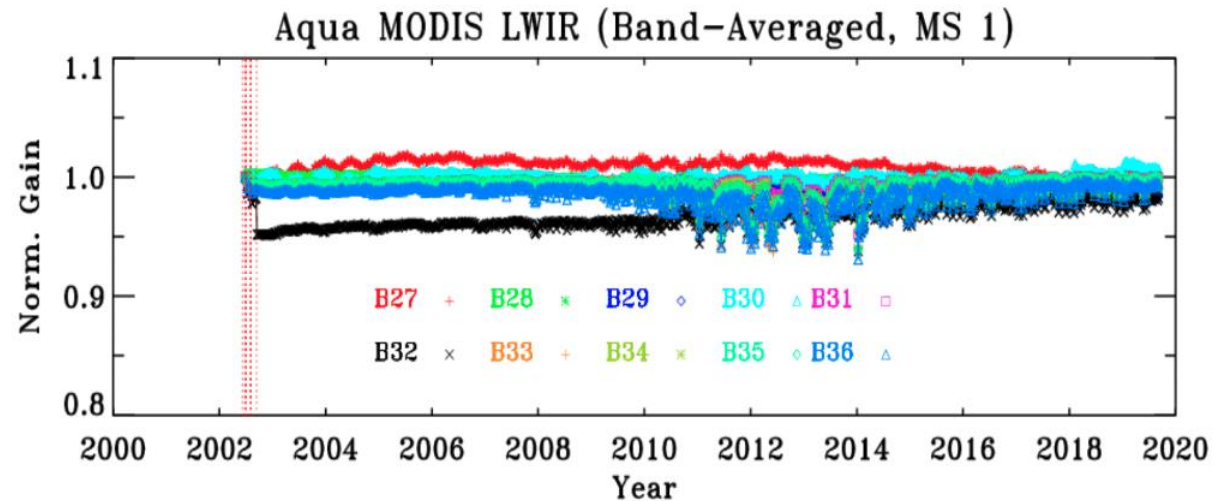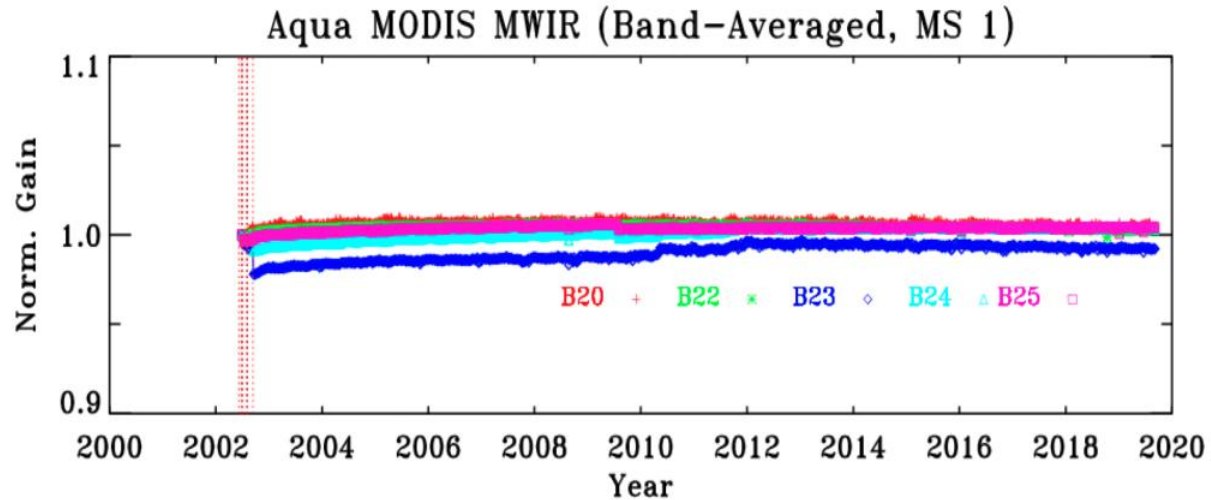
Terra TEB Gain Trending

Terra MODIS MWIR (Band-Averaged, MS 1)

Terra MODIS LWIR (Band-Averaged, MS 1)
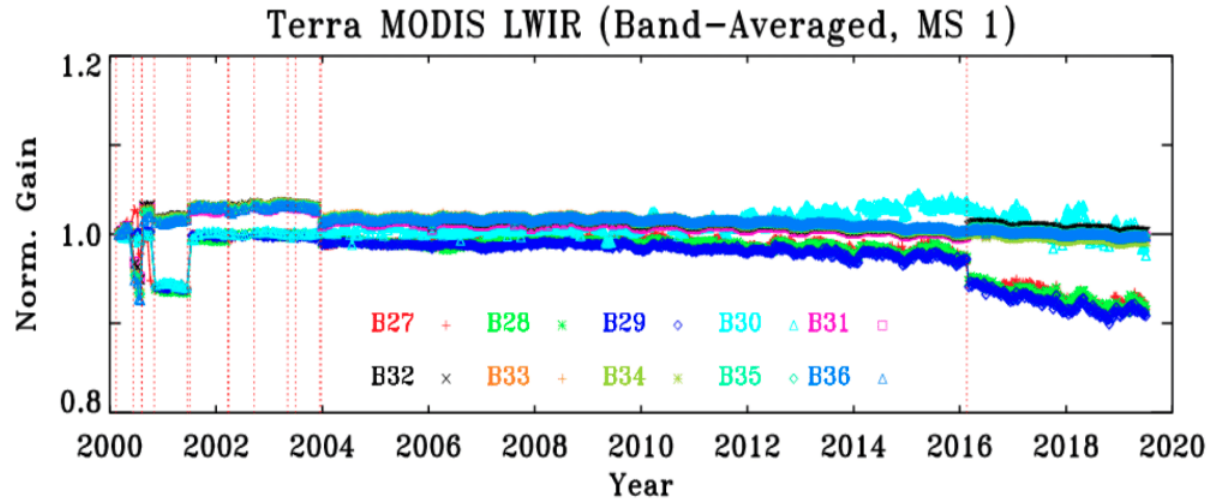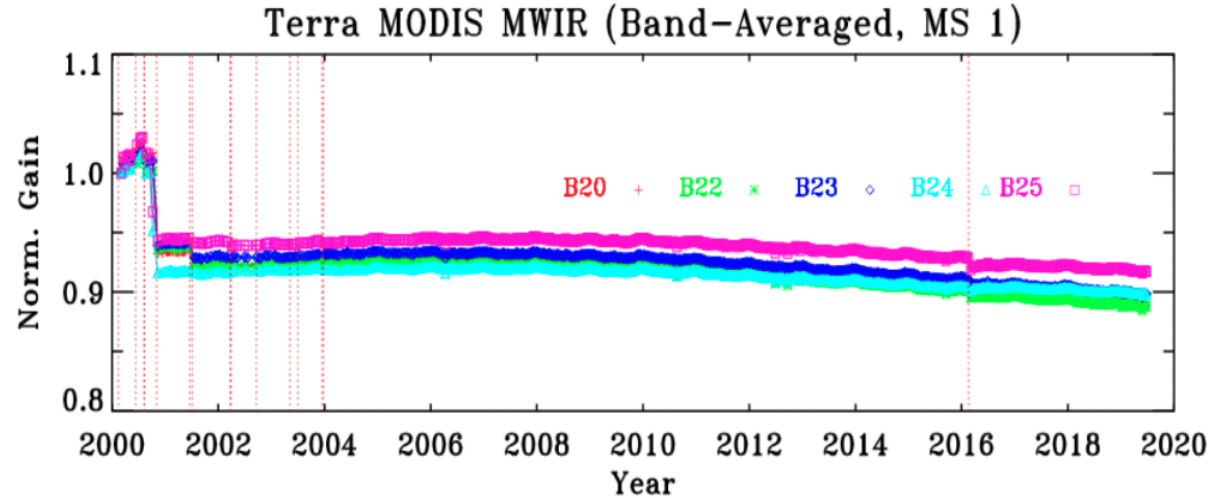
- ➢ **Before 2004, the gain changes are due to configuration changes.**
- ➢ **Safe mode event of Feb 2016 causes gain changes for some bands, especially for PV LWIR bands.**

Aqua TEB Gain Trending

Aqua MODIS MWIR (Band-Averaged, MS 1)

B20 + B22 × B23 ◇ B24 △ B25 □

Aqua MODIS LWIR (Band-Averaged, MS 1)

B27 + B28 × B29 ◇ B30 △ B31 □
B32 × B33 + B34 × B35 ◇ B36 △

➢ **MWIR bands are stable over the mission**
➢ **CFPA temperature impacts gain for LWIR bands. Improvements since 2013**

Collection 6.1 TEB QA Table

Terra

Aqua

➢ **Current QA table**
➢ **Product order**

noisy

inoperable

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Collection 6 TEB QA Table

Terra TEB Yearly NEdT

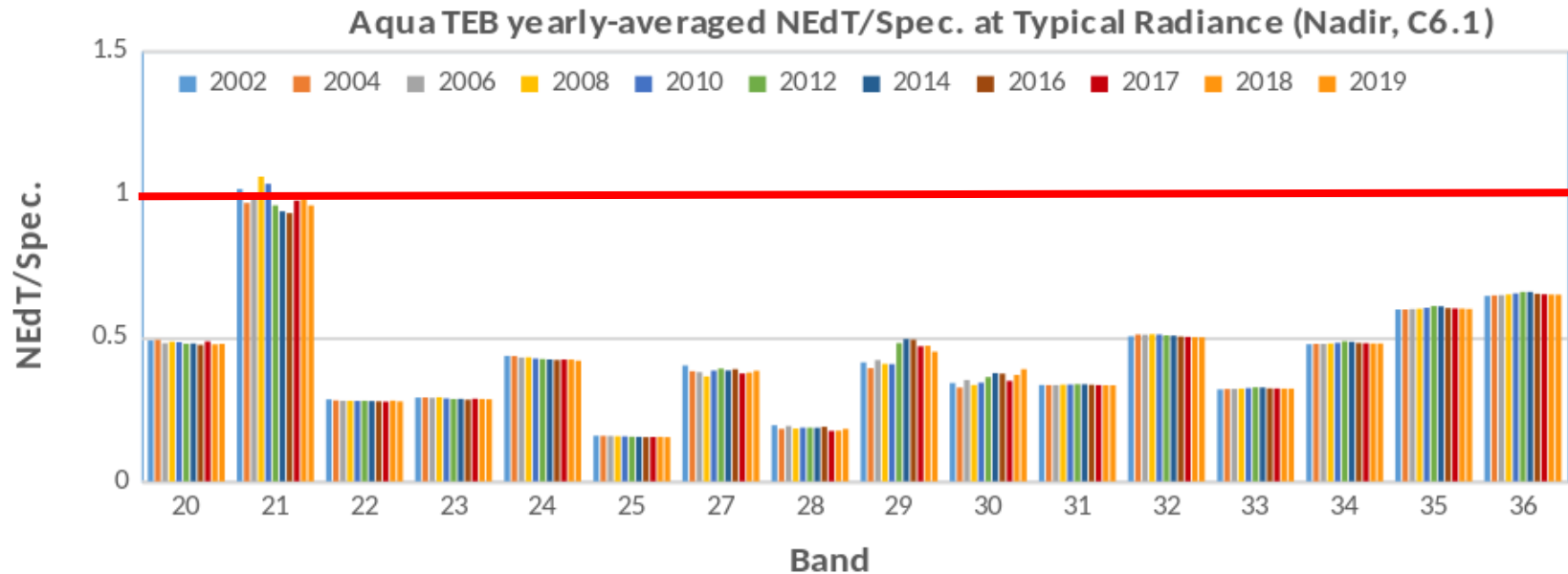Terra TEB yearly-averaged NEdT/Spec. at Typical Radiance (Nadir, C6.1)
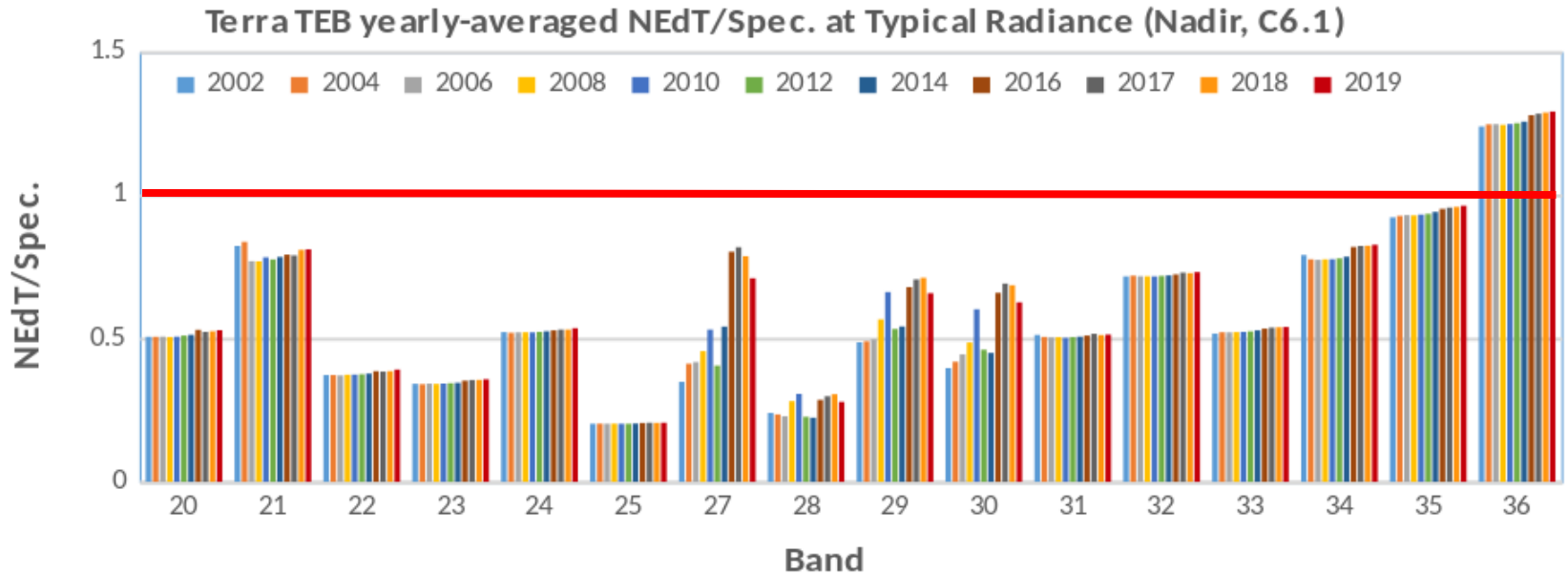
- ➤ **NEdT of PV LWIR bands 27-30 show fluctuation, especially after safe mode. All other bands are stable over the mission**
- ➤ **NEdT meets the specification, except band 36.**
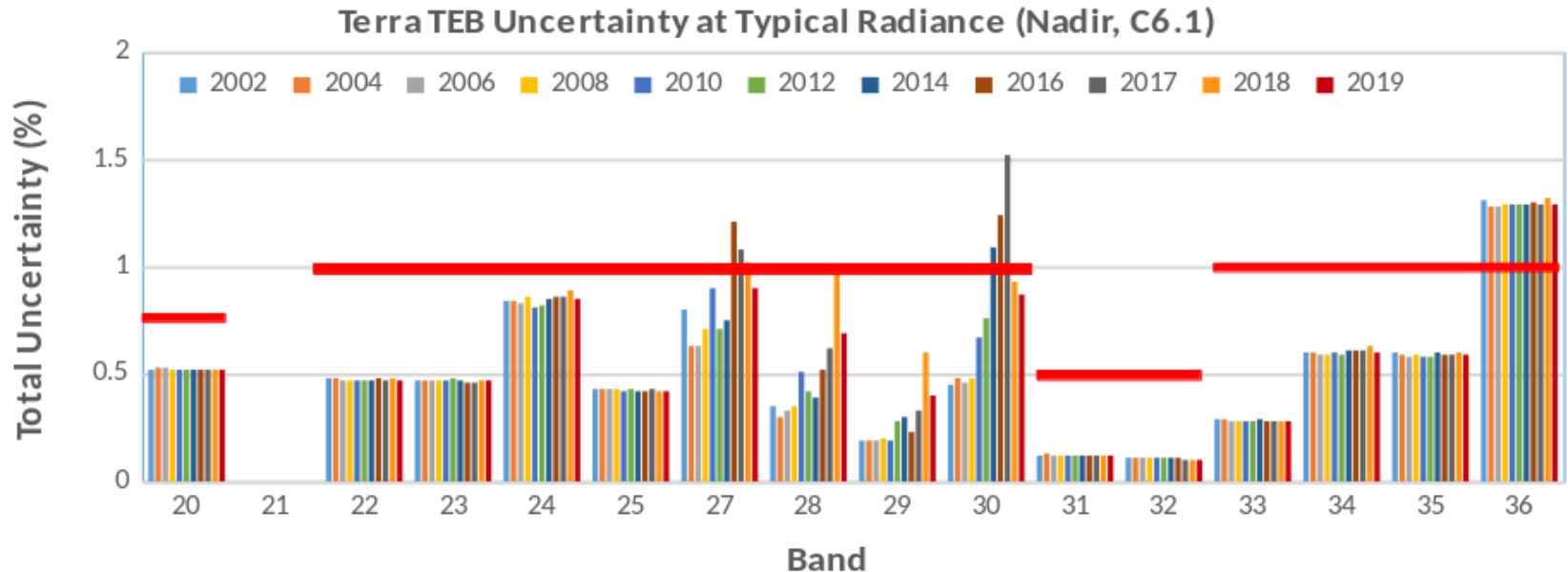- ➤ **Terra band 36 all detectors are noisy**

Aqua TEB Yearly NEdT

Aqua TEB yearly-averaged NEdT/Spec. at Typical Radiance (Nadir, C6.1)

- ➢ **The uncertainty is stable for all TEBs.**
- ➢ **Three detectors of band 21 are noisy.**
- ➢ **All bands meet the NEdT specifications.**

# Terra TEB Yearly Uncertainty

Terra TEB Uncertainty at Typical Radiance (Nadir, C6.1)

- ➢ **Bands 27 and 30 uncertainty are higher than specification for years 2016-2017 and improved in 2018 and 2019**
  (1) LUT recovery after safe mode
  (2) LUT delivery frequency change to catch up the instrument response change.
- ➢ **Terra band 36 all detectors are noisy**

Aqua TEB Yearly Uncertainty

Aqua TEB Uncertainty at Typical Radiance (Nadir, C6.1)
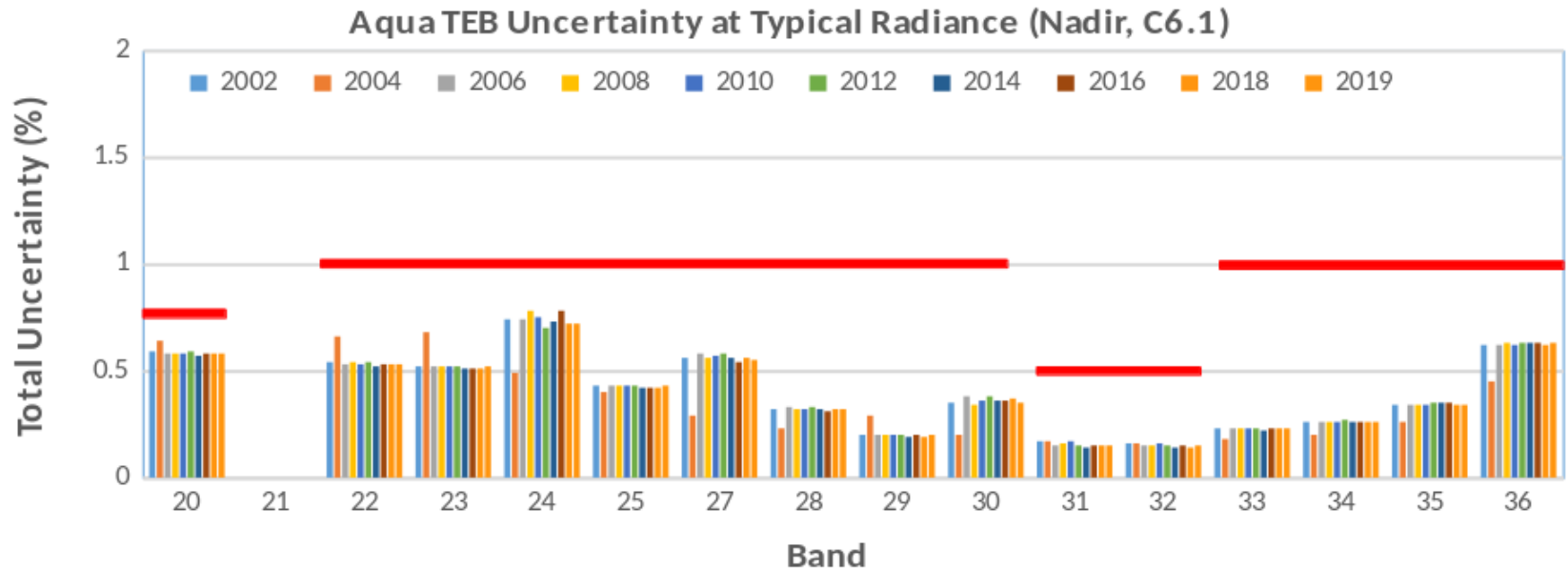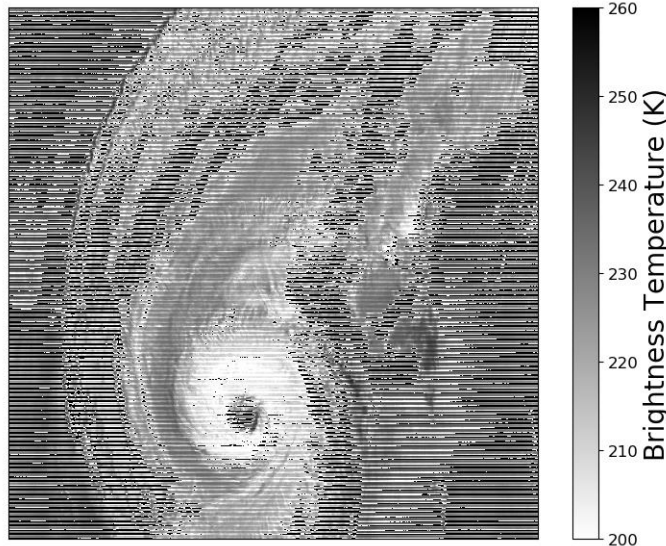
- ➢ **The uncertainty is stable for all TEBs.**
- ➢ **All bands meet the uncertainty specifications.**

MODIS TEB electronic cross-talk trending and corrections

Terra band 27 C6

Terra band 27 C6.1
Sept. 5 2019 Hurricane Dorian
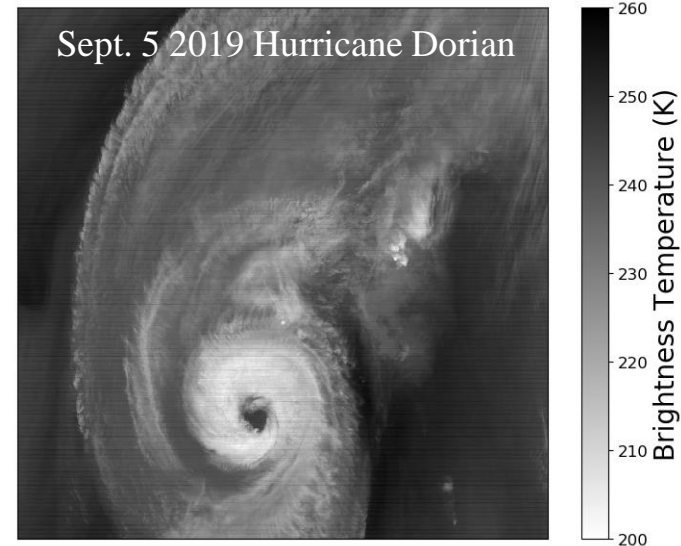
➢ Cross-talk corrections have been implemented in C6.1 for Terra PV LWIR bands 27-30.

➢ Corrections for selected detectors of Terra MWIR, Aqua MWIR and LWIR TEBs are recommended for future calibration improvement.

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Cross-talk Coefficient and Correction

- To derive the coefficients, minimize the contamination relative to a reference signal by varying the values of $c_{i,j}$.

$$\eta_i^2 = \sum_{S,F} \left(dn_i^*(S,F) - dn_{ref,i}(S,F) - \sum_j c_{i,j} \cdot dn_j^*(S, F + \Delta F_j) \right)^2$$

- Use linear correction coefficients, $c_{i,j}$, to correct the background subtracted signal for a given detector, i, in every data sector.

$$dn_i(S,F) = dn_i^* - \sum_j c_{i,j} \cdot dn_j^*(S, F + \Delta F_j)$$
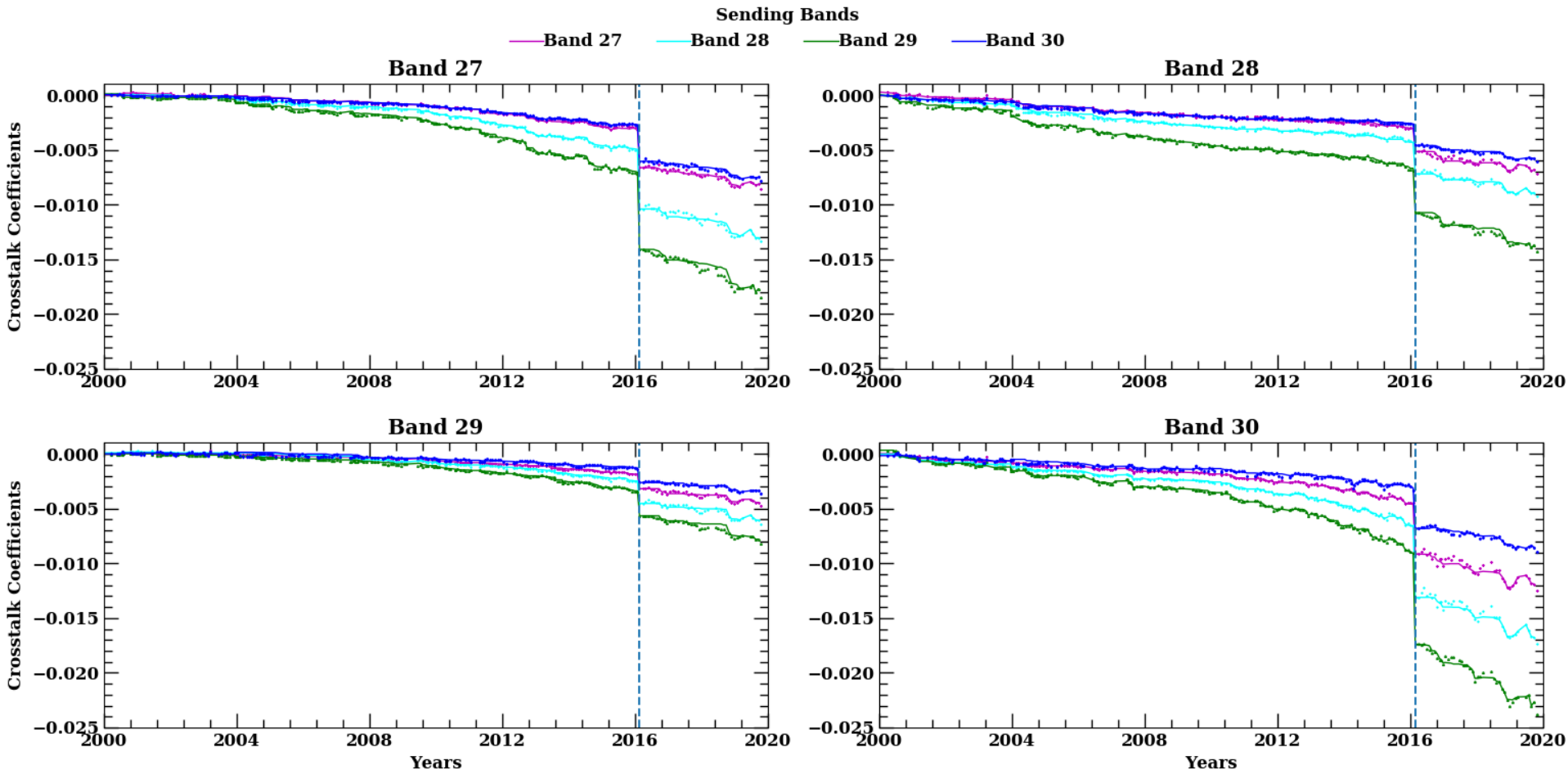
Lunar Profile - Terra

- The reference signal, dn_{ref}, is band 31 for the LWIR bands.

- For the MWIR bands, the lunar signal is sharp enough to reference to the background level.

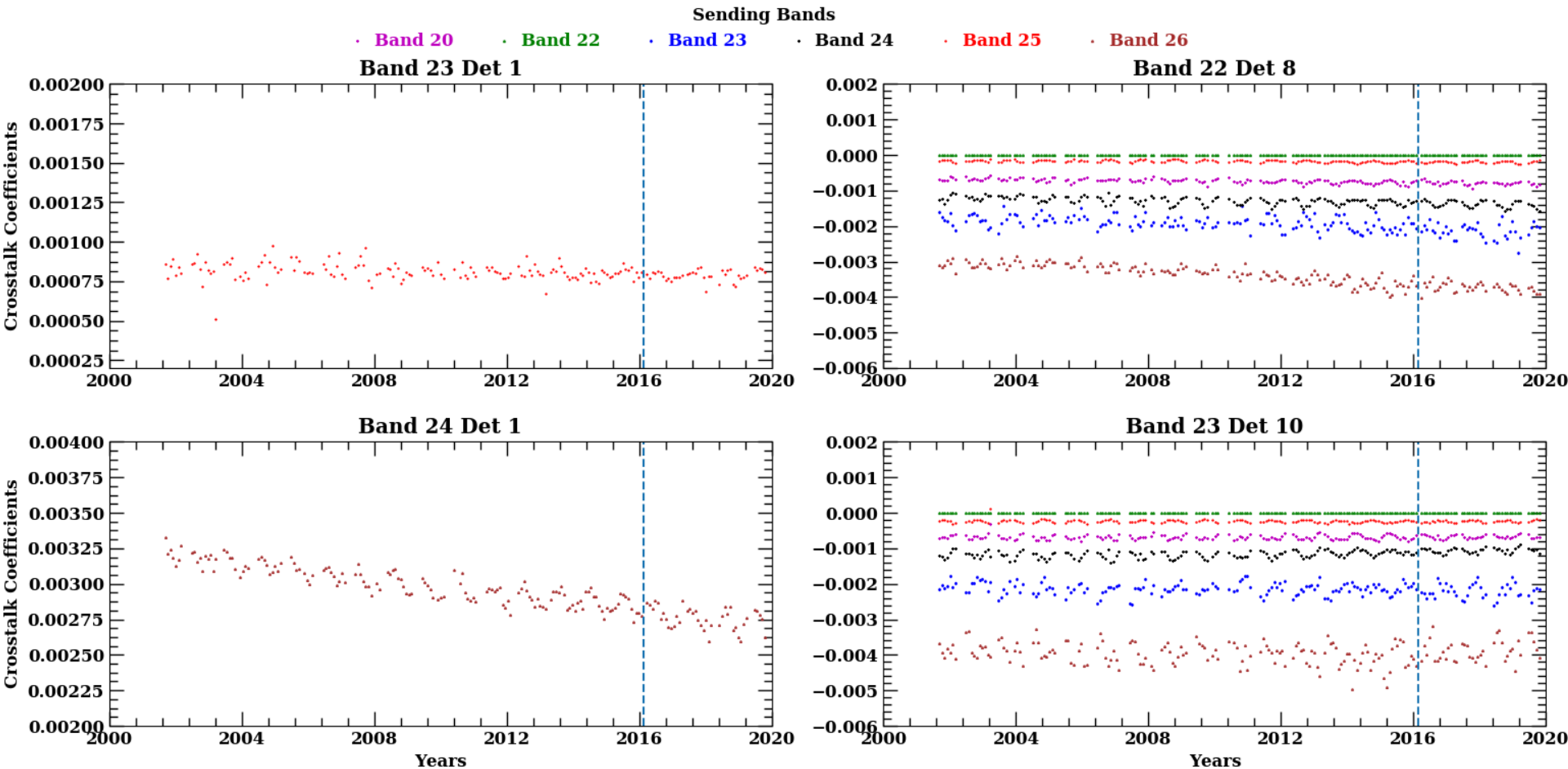- The band 26 sending for the Terra MWIR bands is derived using EV data from ice cloud scenes.
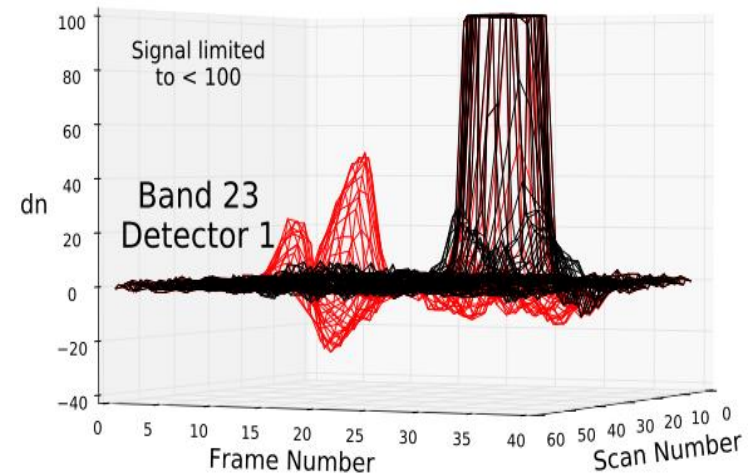
- ➢ These plots are sending band averaged coefficients
- ➢ Dots are coefficients from scheduled lunar observation and the lines are the LUT coefficients
- ➢ In general, the cross-talk increased over the mission
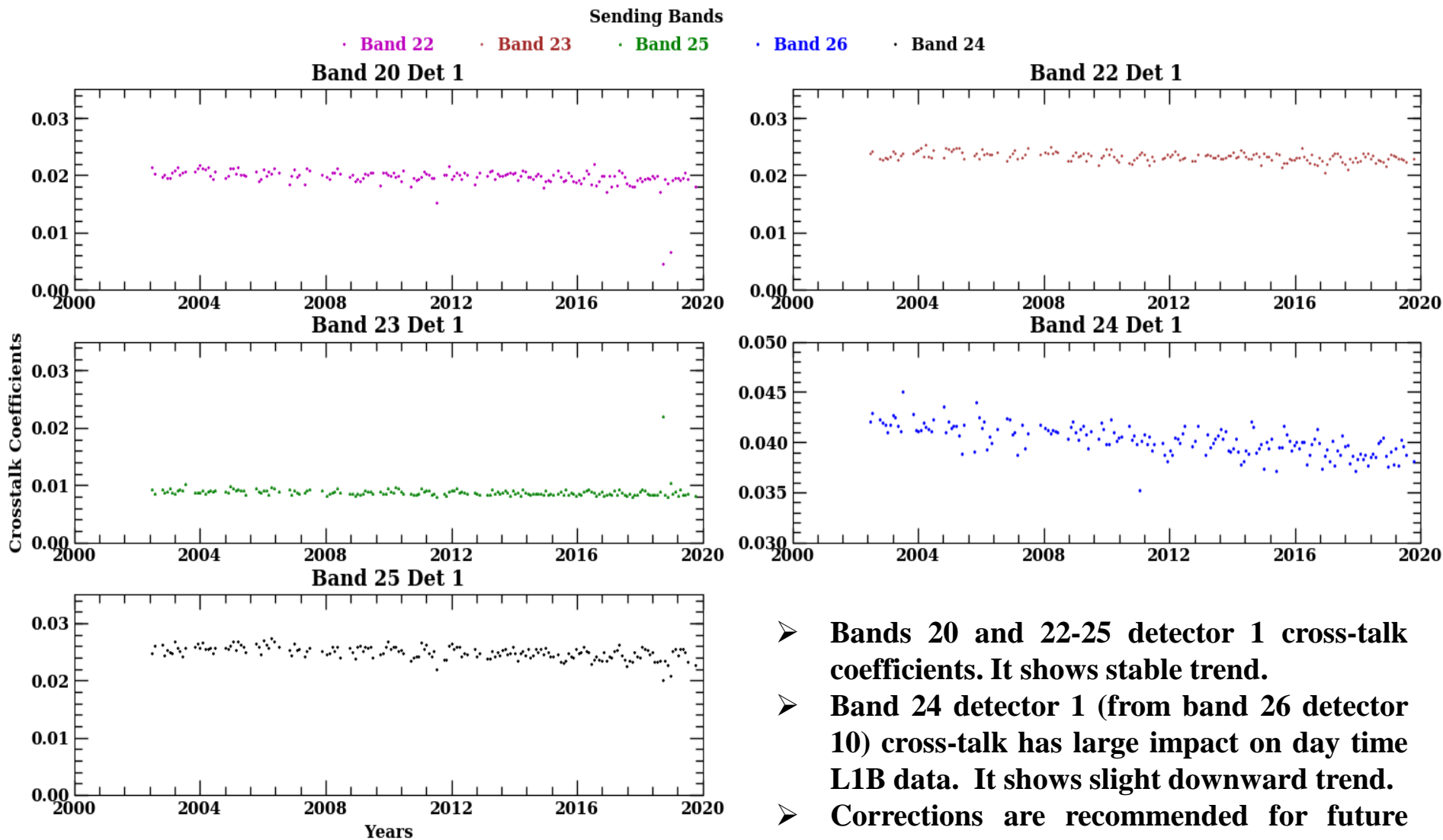- ➢ Safe mode causes the crosstalk jump.

Terra MWIR Bands Cross-talk

- ➢ **No impact from safe mode (vertical dashed line).**
- ➢ **Corrections are recommended for future calibration improvements**

Sending Bands

· Band 22   · Band 23   · Band 25   · Band 26   · Band 24

- ➢ **Bands 20 and 22-25 detector 1 cross-talk coefficients. It shows stable trend.**
- ➢ **Band 24 detector 1 (from band 26 detector 10) cross-talk has large impact on day time L1B data. It shows slight downward trend.**
- ➢ **Corrections are recommended for future calibration improvements**
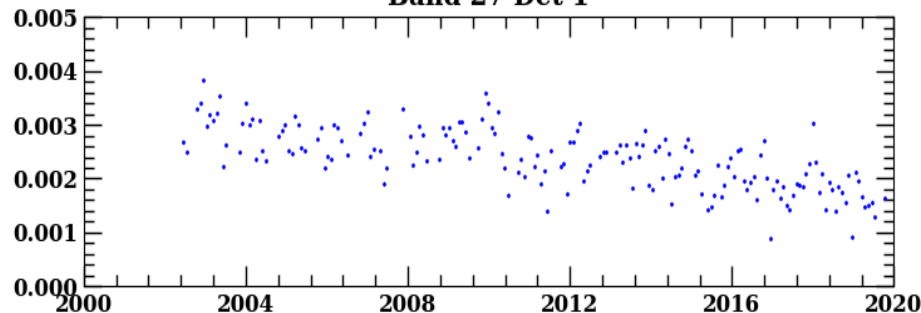
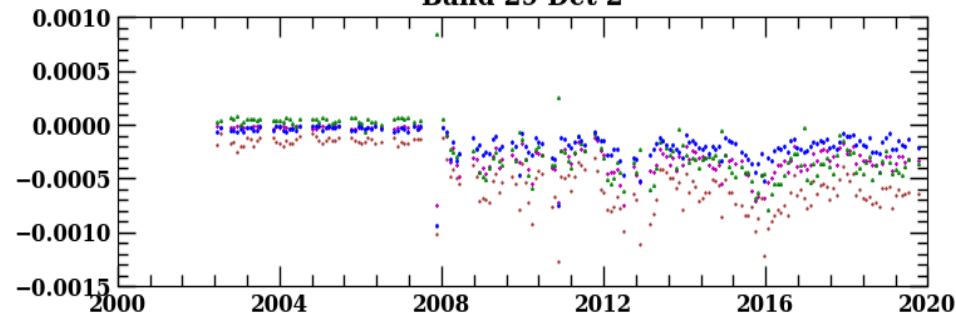Page 19

Aqua PV LWIR Bands Cross-talk
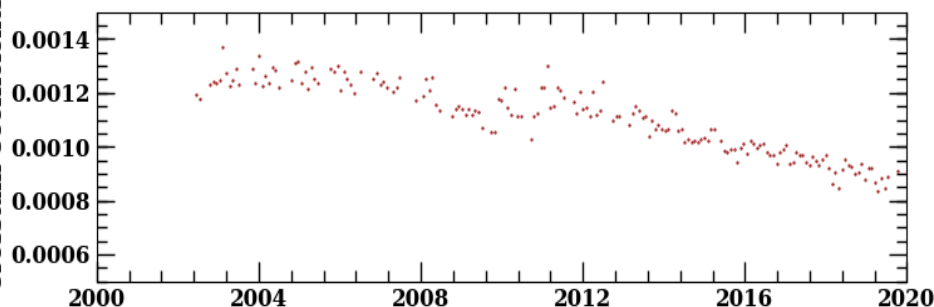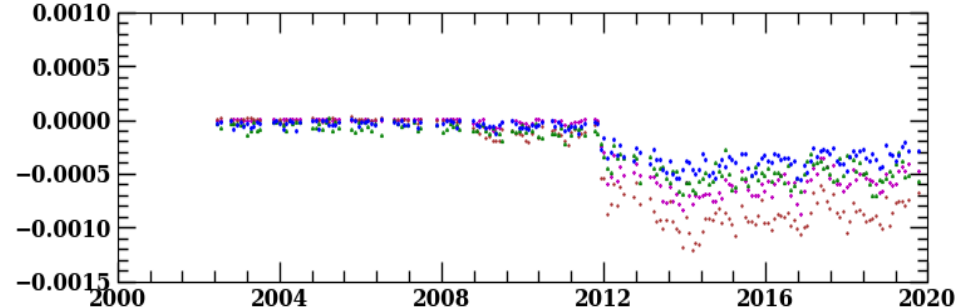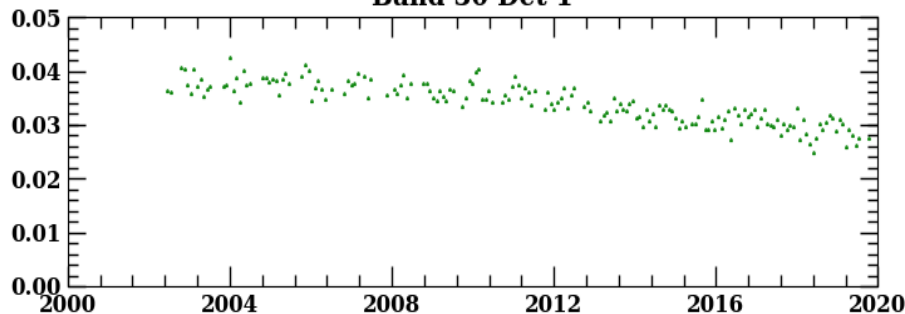
> ➢ **(Left) Bands 27, 29, and 30 detector 1 cross-talk coefficients. Slight downward trend.**
> ➢ **(Right) Band 29 detectors 2 and 6 from sending bands 27-30. Detector 2 cross-talk jumps around 2008. Detector 6 cross-talk jumps around 2012**
> ➢ **Corrections are recommended for future calibration improvements**

# Assessment of Terra and Aqua MODIS TEB calibration using DCC

➢ An invariant and cold target is good for TEB stability and consistency assessments, especially for offset a0 calibration assessment.

➢ TEB assessments from Terra and Aqua entire mission.

➢ Calibration algorithm improvement is recommended.
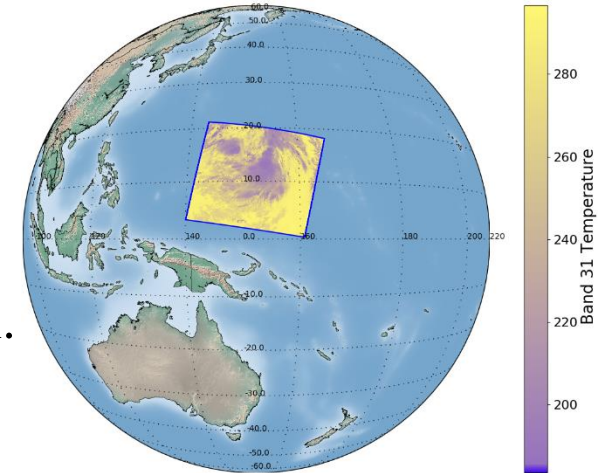
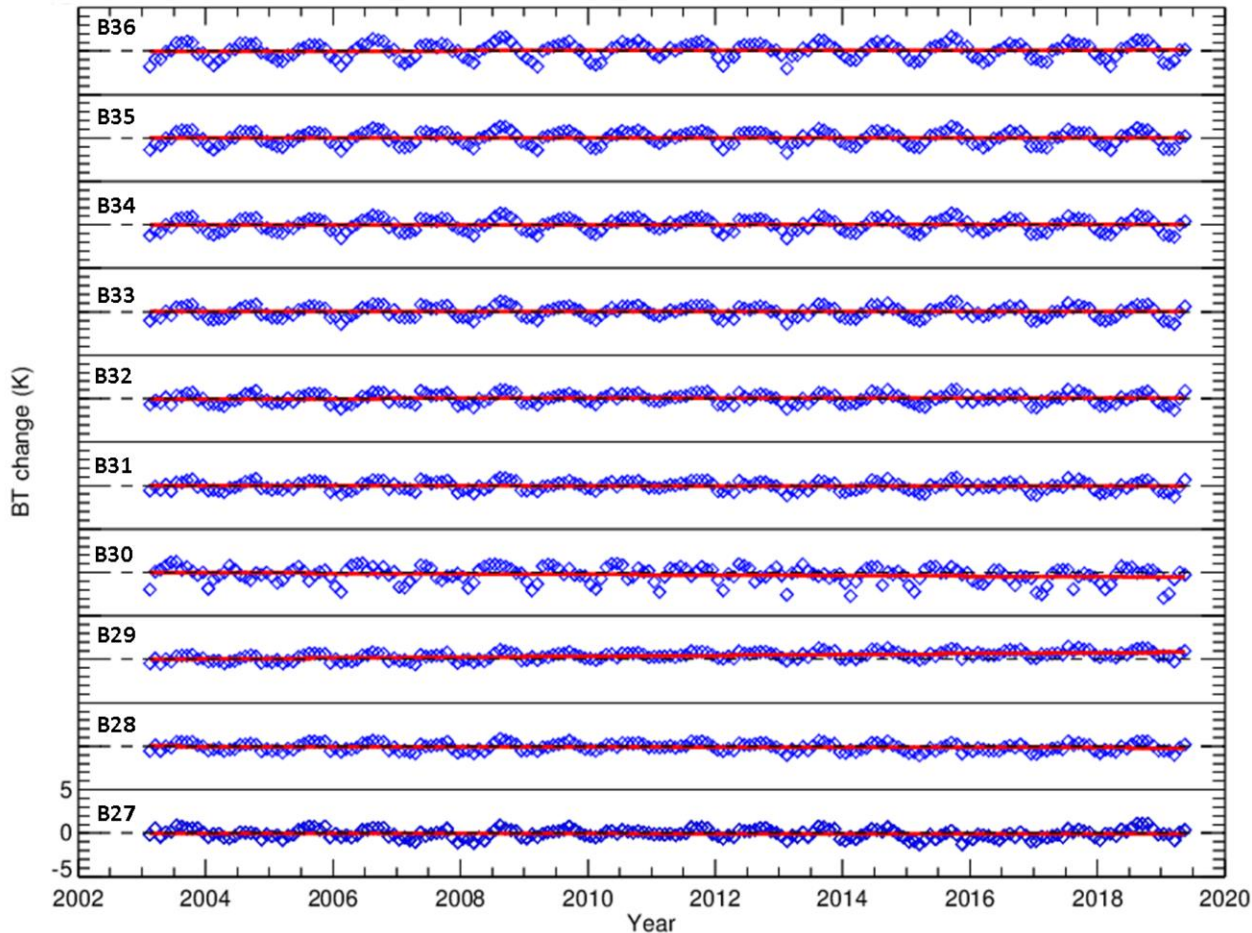DCC: Deep convective clouds

Terra LWIR Stability Assessment
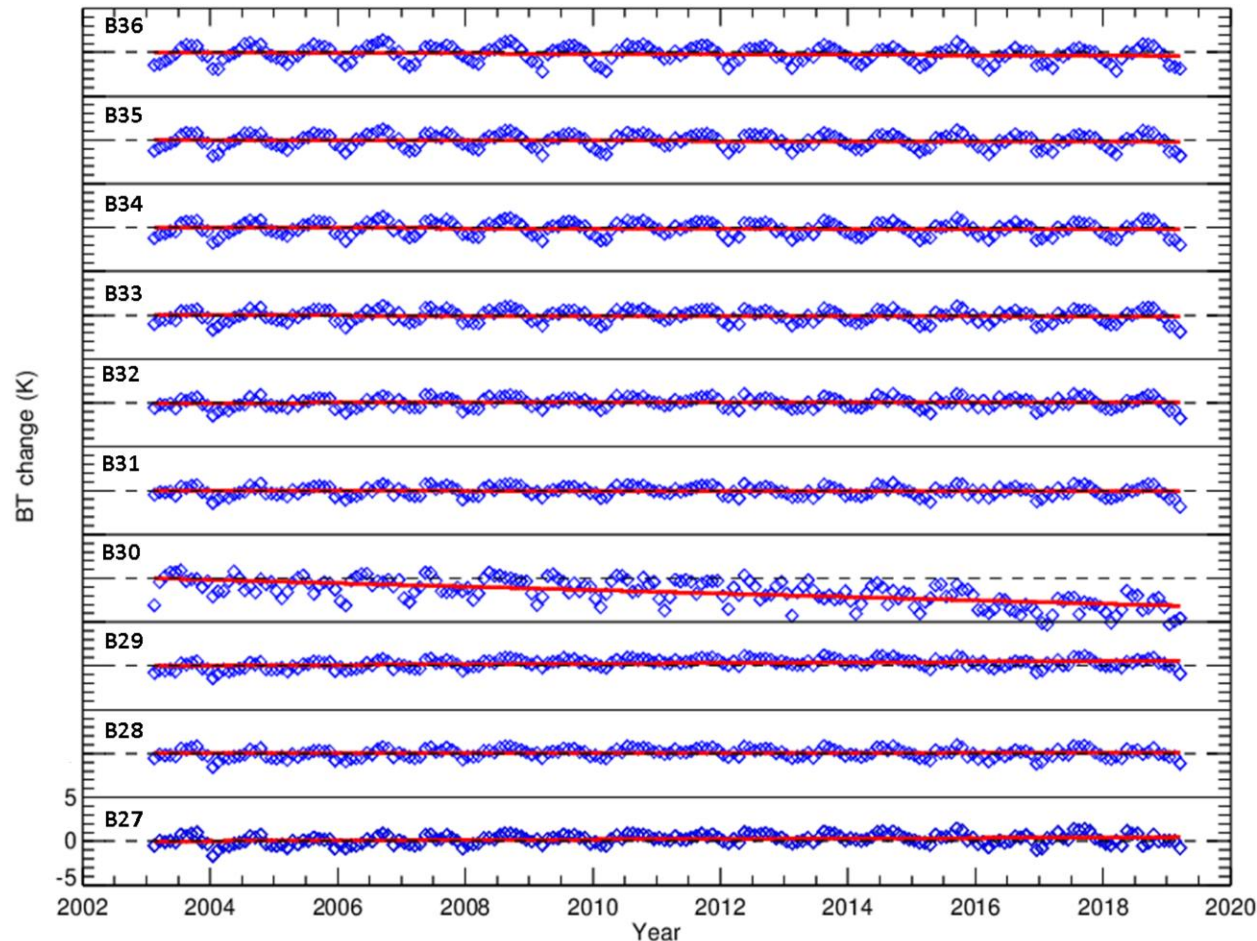
> Band 30: largest change

➢ Terra LWIR band stability assessment using DCC from years 2003 to 2019.
➢ The blue symbols are the monthly averaged BT measurement changes over DCC targets.
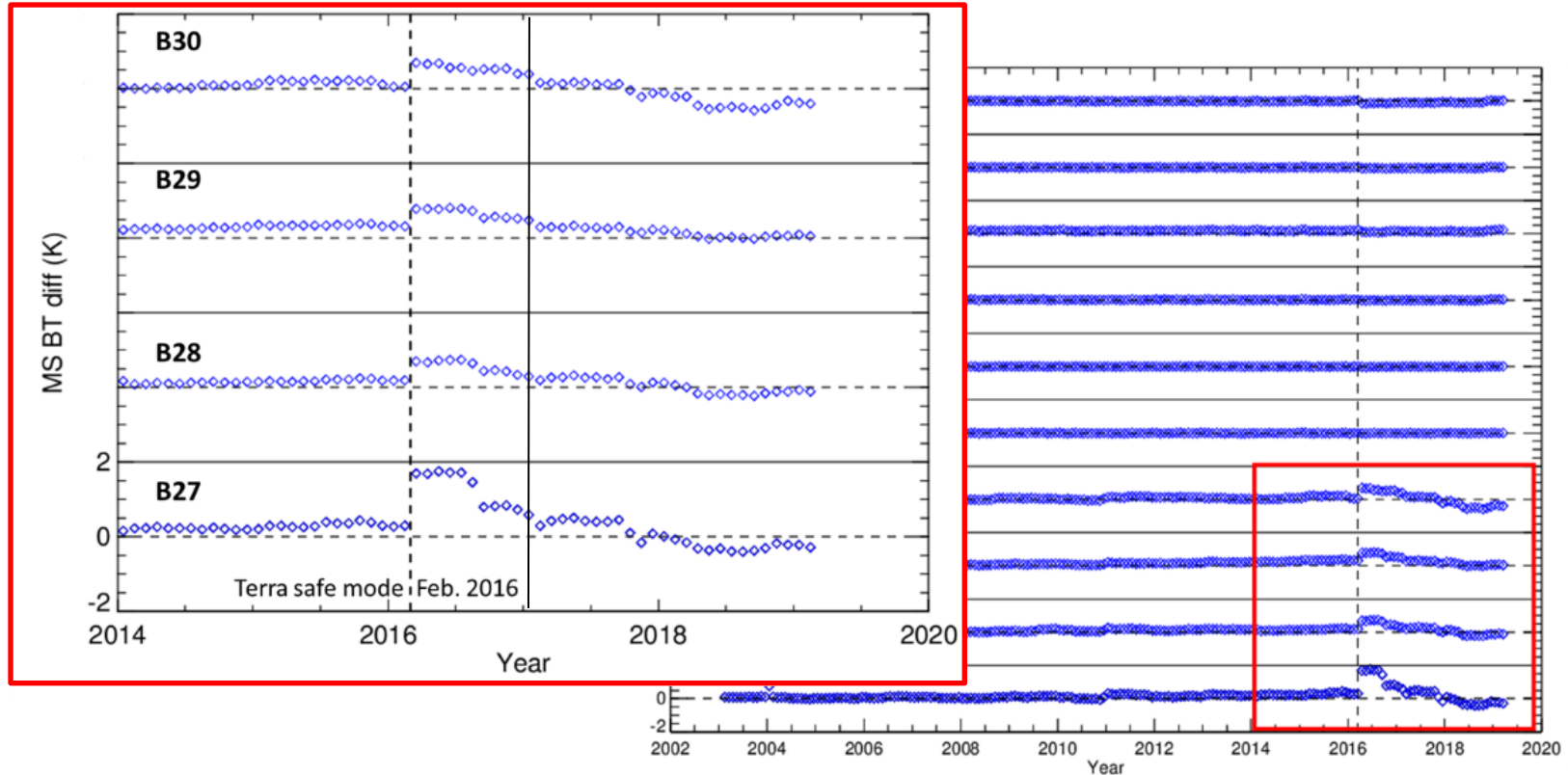➢ The red lines are the linear fit.

Aqua LWIR Stability Assessment

- ➢ Aqua LWIR band stability assessment using DCC from years 2003 to 2019.
- ➢ The blue symbols are the monthly averaged BT measurement changes over DCC targets.
- ➢ The red lines are the linear fits.

Terra Mirror Side Consistency

- ➢ PV LWIR bands (27-30) show mirror side difference after safe mode
- ➢ Terra TEB nonlinearity LUT update uses sliding window average. The nonlinear coefficient LUT has larger uncertainty due to the discontinuity of instrument response and induced the mirror side difference. The vertical line marks the LUT update to catch the instrument change.
- ➢ The LUT one year after safe mode will be updated in reprocessing for future improvements.
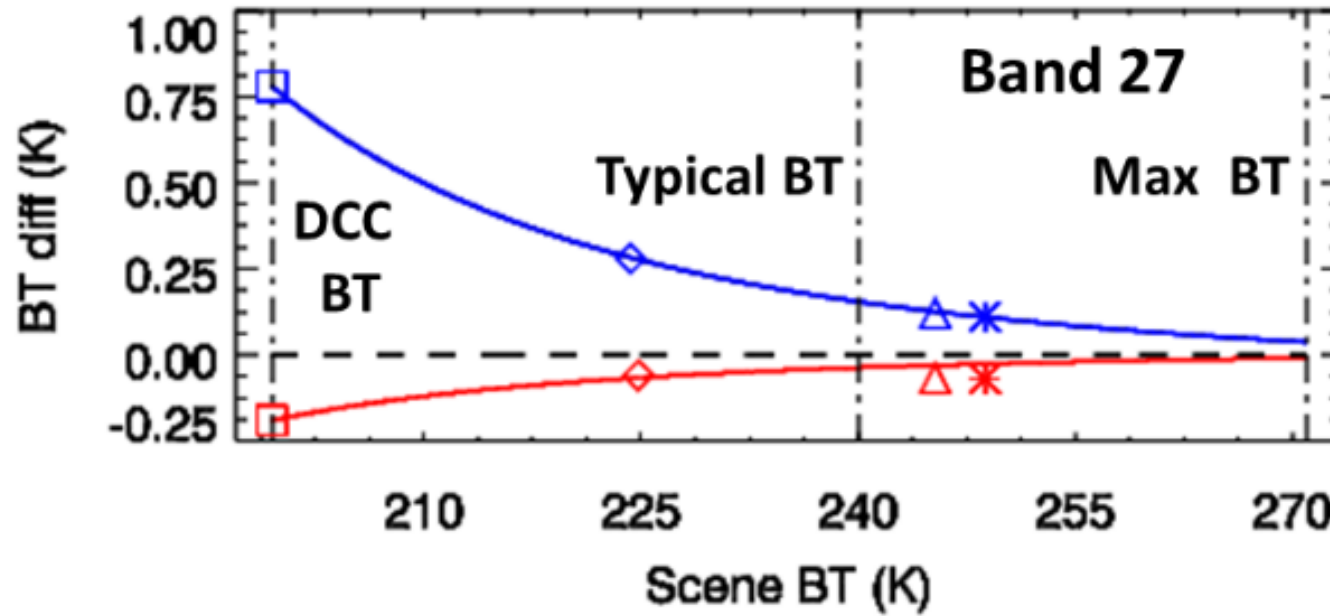
Aqua Mirror Side Consistency
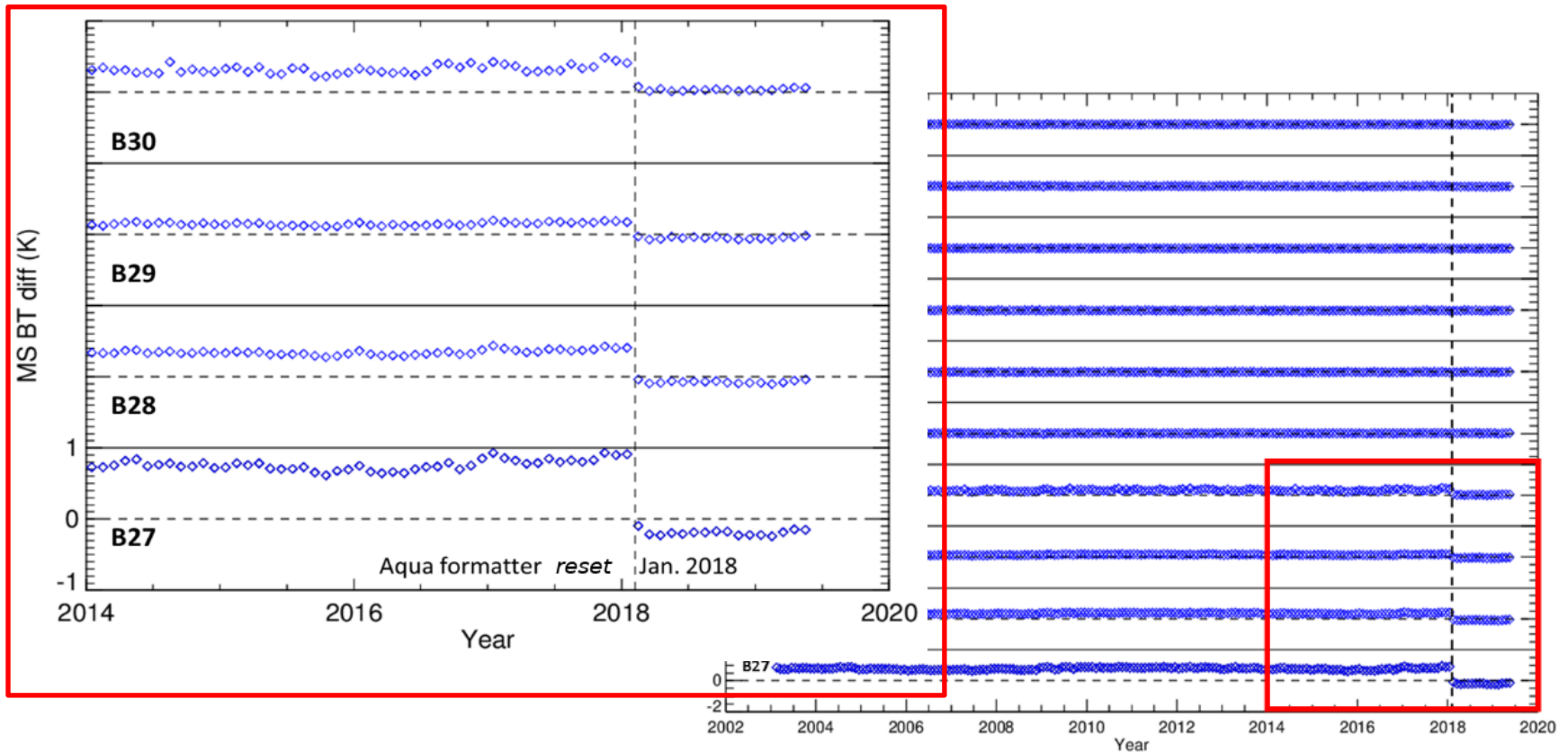
➢ PV LWIR bands (27-30) show mirror side difference change due to the formatter reset.

➢ After reset, the mirror side differences are much smaller.

Aqua Mirror Side Consistency

- ➢ The mirror side brightness temperature difference as a function of EV brightness temperature
  one year before reset: blue
  one year after reset: red
- ➢ DCC: Square
  Dome-C: Diamond/Triangle
  Ocean: Asterisk/Cross
- ➢ The vertical dash-dotted lines are for DCC, typical, and maximum brightness temperatures.

Future Calibration Improvement and Assessment

➢ Continue to monitor TEB performance using earth view targets and inter-comparisons.

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

➢ Implementation of Terra and Aqua TEB electronic cross-talk corrections in addition to Terra PV LWIR bands .

➢ Seek proper EV targets to assess nonlinear effect in cross-talk correction on L1B product, especially on cold targets.