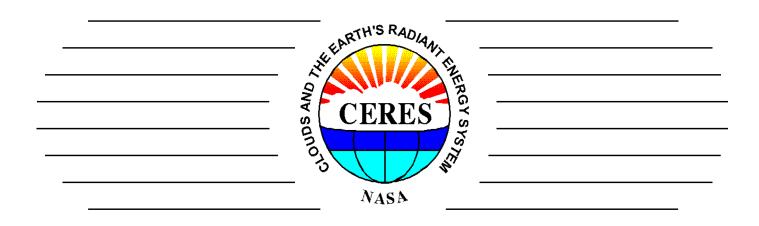
CERES Instrument Status: Flight Models 1-6 (FM1-FM6)



Mohan Shankar

CERES Instrument Working Group

CERES Spring Science Team Meeting May 14, 2024

CERES Instrument Working Group





CERES Instrument Working Group

Project Scientist: Kory Priestley
IWG Lead: Mohan Shankar
Technical Lead: Susan Thomas

Instrument Operations

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Janet Daniels
Alexander Brown
Ethan Ames
Carol Kelly

Data Management

Denise Cooper

Dale Walikainen

A. Thomas Grepiotis

Dianne Snyder

Cal/Val

Nathaniel Smith
Nitchie Smith

Alexander Jarnot





CERES Instrument Status Summary

- All CERES instruments continue to demonstrate stable performance.
 - NOAA-20/FM6 instrument continues to operate in Crosstrack mode and instrument is performing nominally.
 - Noise events were observed in the SW channel between Nov 2023 and Feb 2024.
 - There was no impact on the on-board calibration or the L1-L3 data products.
 - SNPP/FM5 is currently operating in Crosstrack scan mode and continues to perform nominally.
 - Terra and Aqua CERES instruments are conducting Cross-track, biaxial, and GEOSCAN.
 - Validation studies show all instruments are performing consistently.
- Level 1 Data products
 - NOAA-20/FM6 Edition 1 gains have been delivered through Mar 2024.
 - S-NPP/FM5 Edition 2 gains and SRFs have been delivered through Jan 2024.
 - Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through Feb 2024.

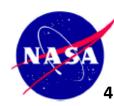


CERES Instrument

- CERES measures the radiation at the Earth's top of atmosphere from the visible through the far IR wavelengths
 - Reflected Solar Radiances (SW channel: 0.3 5 microns)
 - Total Outgoing Radiances (TOT channel: 0.2 100 microns)
 - Outgoing Longwave Radiances (WN channel (FMs 1-5): 8 12 microns; LW channel (FM6): 5-35 microns)
- Three sensor assemblies contain Cassegrain telescopes and thermistor bolometer detectors.
- Sensor assemblies can be rotated in the elevation axis, and instrument can rotate about the azimuth axis.
- On-board Calibration:
 - Blackbodies: TOT channel and WN/LW channel
 - SWICS Lamp- SW channel
 - Mirror Attenuator Mosaic (MAM): Solar Calibration SW and TOT channel







CERES Instrument Operations Summary

Spacecraft	Instrument	Operational Mode	Notes
NOAA20	FM6	XTK	Periodically placed instrument in stow- dwell mode Jan 11-Apr 2, 2024, to evaluate SW channel noise events
SNPP	FM5	ХТК	Operated in BIAX mode from Oct 1, 2019, to Oct 9, 2023.
Aqua	FM4	хтк	Operated in BIAX from Jul 14, 2021, to Mar 22, 2023.
Aqua	FM3	BIAX+ GEOSCAN	GEOSCAN started on Feb 1, 2023; BIAX started on Mar 22, 2023.
Terra	FM2	BIAX	BIAX started on Nov. 1, 2021.
Terra	FM1	XTK + GEOSCAN	GEOSCAN started on Feb 1, 2023.

XTK: Cross-track
BIAX: Biaxial (RAP)

FM6 Stow Dwell

- Stow dwell testing between Jan 11- Apr 2, 2024.
- Extended stow dwell on Jan 18-19, 1-orbit per day from Jan 17-Feb 21, reduced frequency from Feb 22- Apr 2 (about 2-orbits/week)

GEOSCAN:

- For 5 days spaced evenly through the month, scan plane of CERES is aligned with a GEO imager for a few orbits.
- Target a different GEO imager each day.
- Instrument is operated in XTK for the rest of the day.





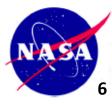
CERES Instrument Operations Summary Cont'd

Inter-comparison operations planned in summer 2024:

```
    Terra/FM1 – S-NPP/FM5: May 1 – Jul 31, 2024
    Terra/FM1 – NOAA-20/FM6: May 1 – Jul 31, 2024
    Terra/FM1 – Aqua/FM3: Jun 1 – 30, 2024
```

- Terra/FM2 GERB: Jun 1 30, 2024
- Terra/FM2 ARCSIX : May 24 Jun 17, 2024, Jul 22 Aug 24, 2024.





NOAA-20/FM6 Instrument Status





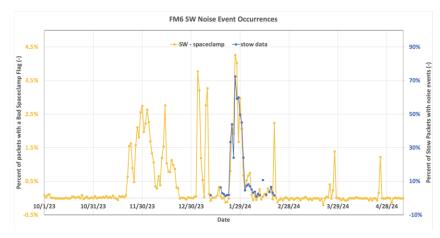
FM6 SW Noise Events

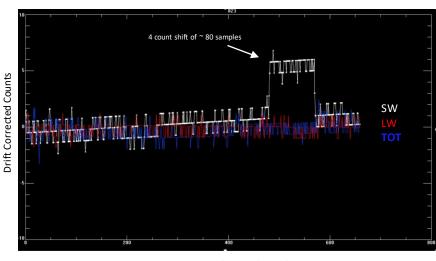


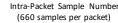


FM6 SW Noise events: Nov 2023- Feb 2024

- Starting late November 2023, SW channel began exhibiting periods of count shifts in SW channel telemetry.
 - Other parameters (engineering, science, or housekeeping) unaffected.
 - Total and LW channels did not exhibit these count shifts.
- This was identified by observing a sudden increase in the number of space view sample averages flagged as 'bad' (exceeded a standard deviation threshold).
- Instrument was put into stow-dwell mode to observe characteristics of the noise events
 - Count shifts remained consistent at ~4 count.
 - Duration of events varied from 1 to 100+ samples (.01 to 1+ seconds).
 - Occurrence was independent of orbital location, beta angle, solar activity.
 - Developed and executed a long dwell Internal calibration sequence which verified that the shifts did not scale with magnitude of signal.
- No similarity to failure of FM4 SW channel in 2005.
- Since mid Feb 2024, noise events reduced frequency to about once per month.
- Several investigations carried out showed no impact of count shifts on the data products.





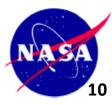




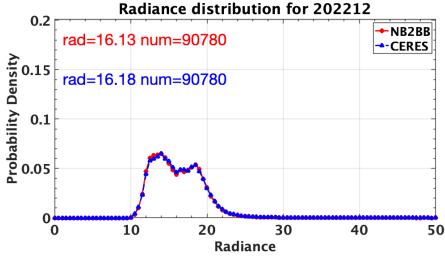
FM6 SW Noise events: Impact to Data products

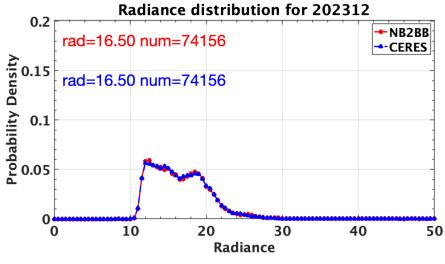
- Compare NOAA20 clear ocean near-nadir (VZA<20) footprint radiance observations with NB2BB computed radiances (Analysis by: Wenying Su)
 - Used NOAA20 Ed1b NB2BB coefficients developed for EBAF processing to derive clear ocean footprint NB2BB radiances.
 - Compare the CERES observed radiance against the NB2BB radiance for tropical regions (30° S to 30° N) and extratropical (30°-60° N/S) region.
 - Data used: Dec 2022 and Dec 2023.

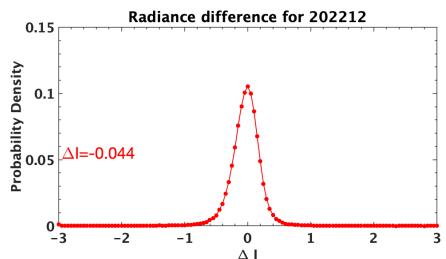


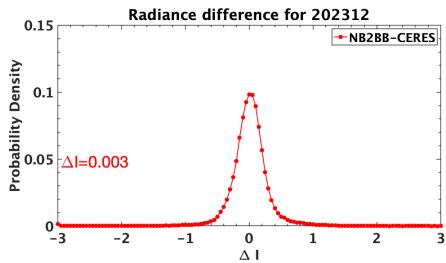


Tropical Region Comparison





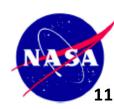




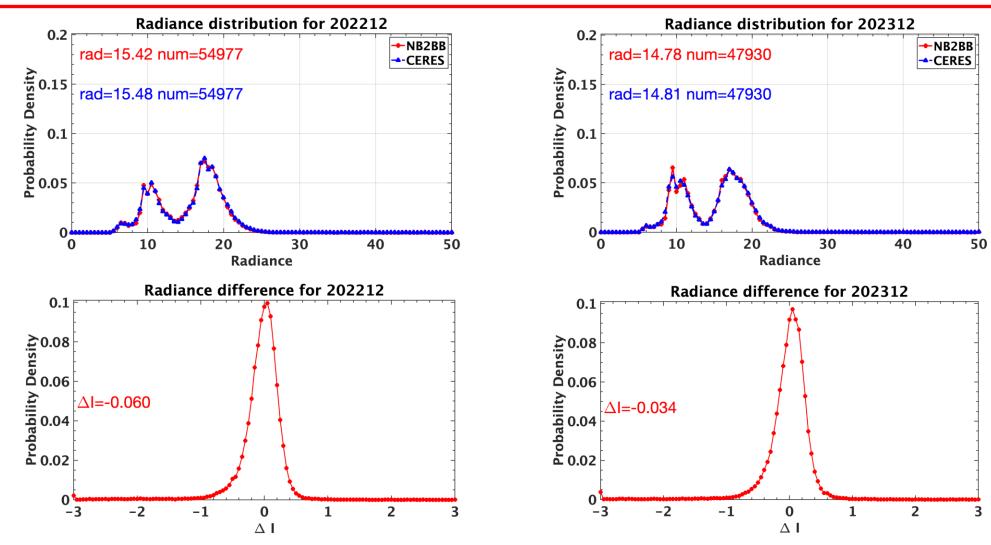


No impact observed due to noise events





Extra-tropical region comparison







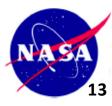




FM6 SW Noise events: Actions/Next steps

- Tiger team currently working to evaluate and determine root-cause.
 - Developed a 'fish bone' table of potential causes.
 - Building circuit models, inspecting instrument build history, studying telemetry and instrument state, and tracking fault occurrences to generate supporting or refuting evidence for those potential causes.
 - Isolated the circuitry where the problem originates from, and continuing to conduct engineering simulations to try and replicate what was observed.
- CERES IWG closely monitoring the instrument telemetry and performance.
 - Occurrences of these SW noise events has reduced to about 1 per month on average over the last few months.





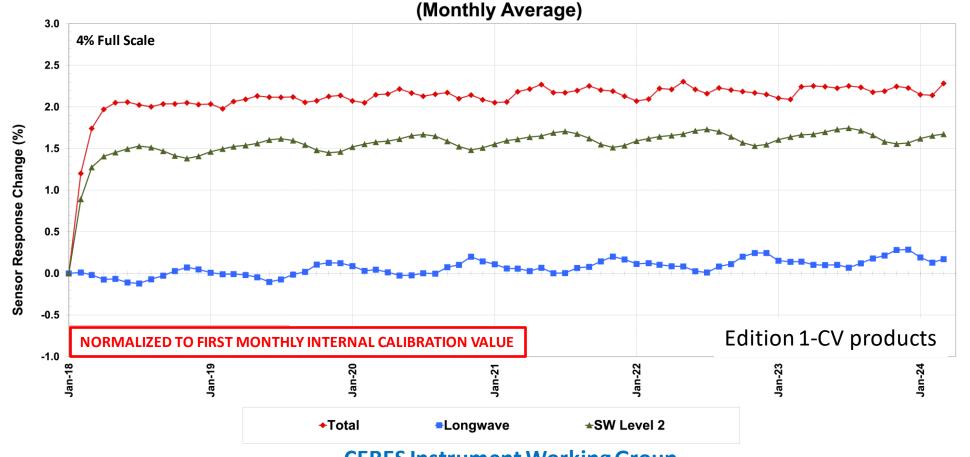
FM6 Calibration/Validation





FM6 Internal Calibration

- For SW and TOT channels, the responses to the on-board sources continue to be quite stable (<0.2%) after the initial rise of ~1.5% (SW) and ~2% (TOT) since start of mission.
- LW Channel shows ~0.2% change.
- Count shifts did not impact the internal calibration data or the process of generating the SW channel gains.
 FM6 In-Flight Ed1-CV Internal Calibration Results



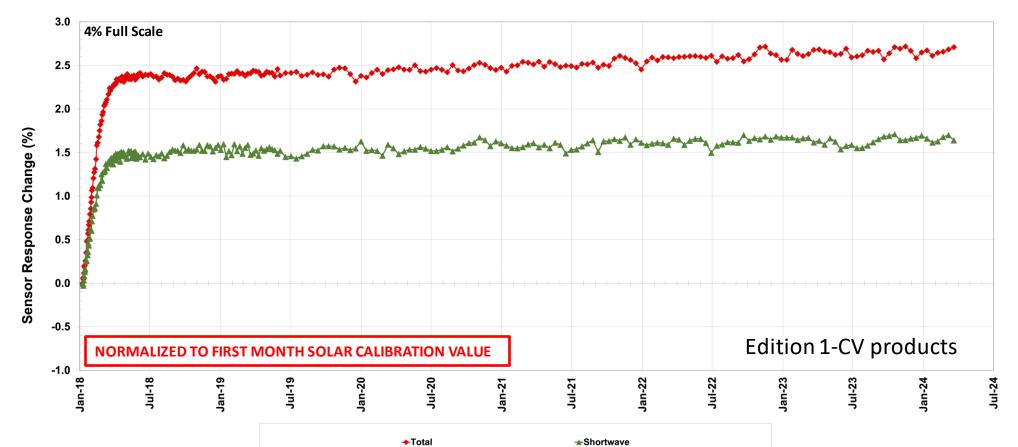




FM6 Solar Calibration

- Response of the SW and TOT channels while viewing the MAM that is illuminated by the sun.
- After the initial rise of ~1.5% for SW, and ~2.5% for TOT, the response is quite stable.

FM6 Solar Calibration

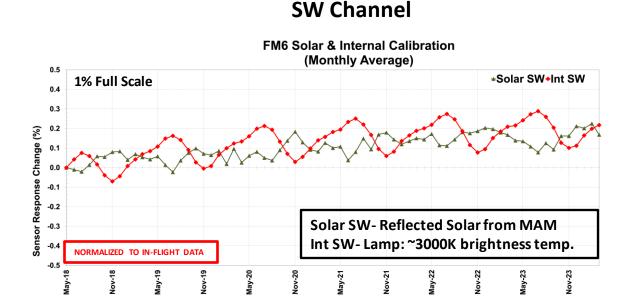


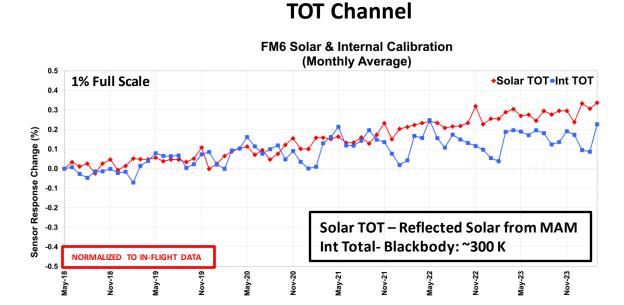




FM6 Calibration-Internal and Solar Cal Since May 2018

FM6 Internal and solar calibration results consistently show < 0.4% change since May 2018, demonstrating that the MAM is very stable.





Edition 1-CV products





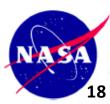
Validation – FM6 Tropical Mean (TM)

- Average of the Nadir radiances over Tropical ocean (20^oN-20^oS) scenes under Allsky conditions.
 - Uses latest version of ES-8 data products (Edition 1) All calibration updates have been applied.
- Two sets of TM Day-Night Differences (DN) are calculated:
 - TOT and SW sensors

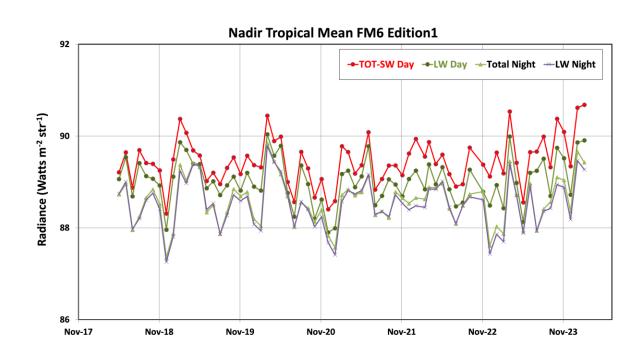
 DN= TM_D(TOT-SW) TM_N(TOT)
 - LW sensor (FM6 has a broadband LW channel)

 DN= TM_D(LW) TM_N(LW)
- Trends of the difference in the two DN values highlight any inconsistencies in the Reflected Solar wavelengths of the TOT and SW sensors.

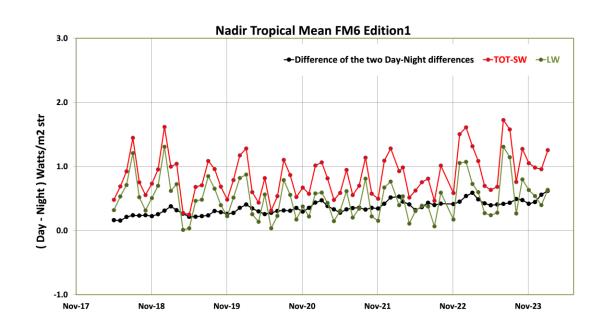




Validation-FM6 ES-8 Tropical mean Day-Night



Day-Night Difference



Edition 1 products

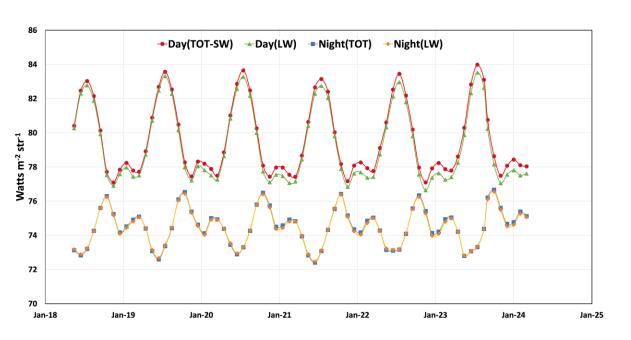




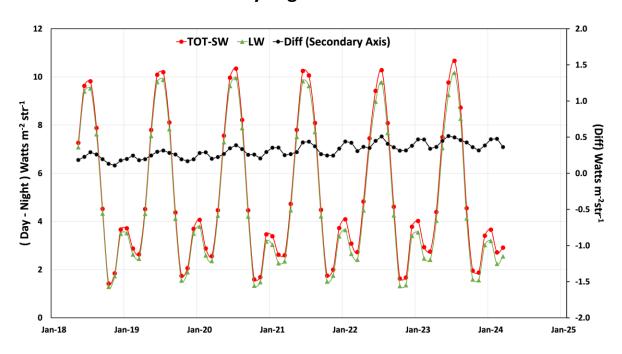
FM63-channel Consistency check-Global Day-Night Differences

May 2018 - Feb 2024 Edition 1 ES-8, Global, All-sky, Nadir Radiance

FM6 Edition 1 Global Mean LW radiance

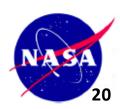


Day-Night Difference









Aqua/NOAA-20 Intercomparisons

- The nominal orbital geometries for Aqua and NOAA-20 are such that orbital overlaps occur every ~64 hours.
 - Aqua's orbit has drifted from its nominal MLT starting Jan 2022.
- Obtain spatially and temporally matched observations during every crossover.
- No special operations are conducted to match viewing geometries; Instruments continue operating in their nominal modes:
 - FM6 in Crosstrack scan mode, FM3 in Biaxial scan mode since Mar 2023.
- Use matching criteria to subset the data:
 - SZA, VZA difference < 2.0°
 - RAZ difference < 5⁰
 - Distance between centroid of footprints < 7 km
- Obtain monthly all-sky SW reflectance and LW radiance differences using the matched footprints.
- Since FM3 started operating in biaxial scan mode, the number of matched footprints drastically reduced.

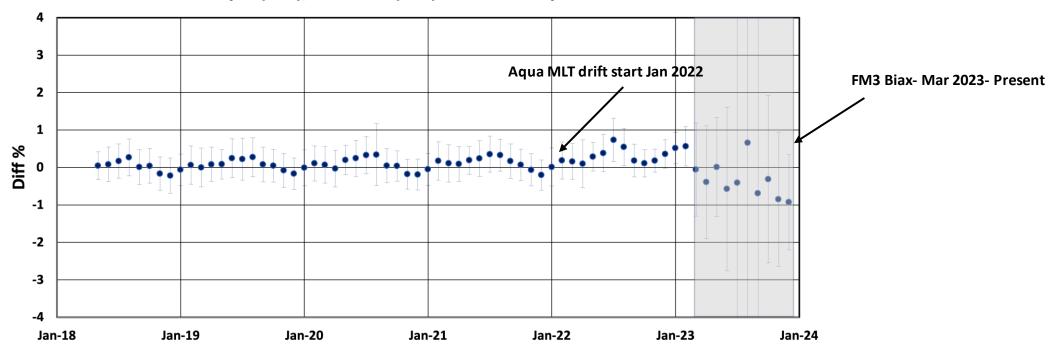


FM3/FM6SW All-sky Inter-comparisons: May 2018- Dec 2023

Difference of Reflectance: FM3-FM6 %, 95% CI

$$Reflectance = \frac{SW_{rad} * \pi}{F * \cos(SZA)}$$
 F=1361 W/m²

Aqua (Ed4)/NOAA-20 (Ed1) SW Intercomparison



Radiometric scaling of FM6 to FM3 done in May 2018.

Data:

CER_SSF_Aqua-FM3-MODIS_Edition4A CER_SSF_NOAA20-FM6-VIIRS_Edition1B



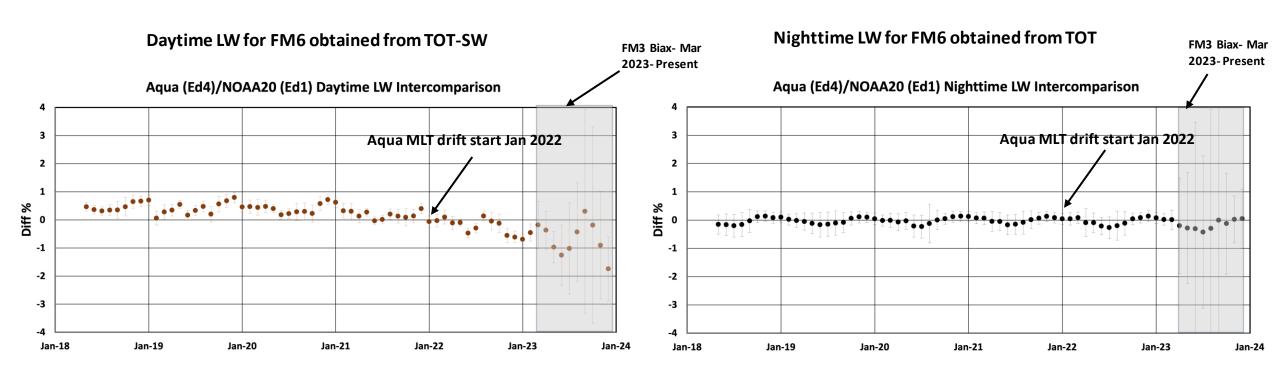
Larger uncertainties after FM3 switched to biaxial mode are driven by the drastic reduction in number of spatially and temporally matched observations.



FM3/FM6 LW All-sky Inter-comparisons: May 2018- Dec 2023

Difference of Daytime Radiance: FM3-FM6 %, 95% CI

Difference of Nighttime Radiance: FM3-FM6 %, 95% CI



Radiometric scaling of FM6 to FM3 done in May 2018.

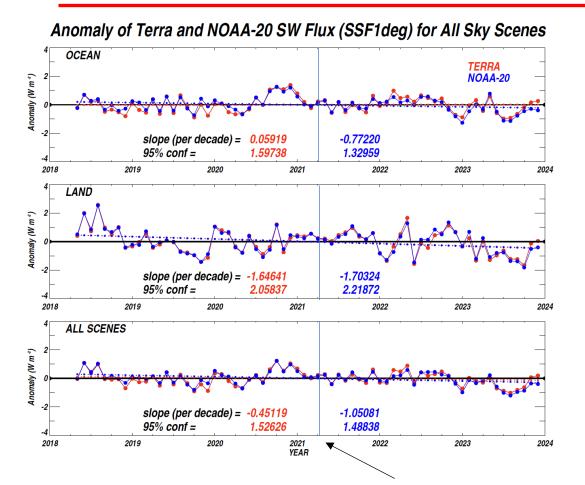
Data:

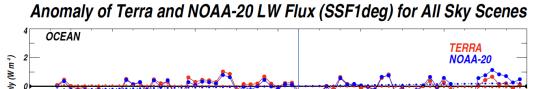
CER_SSF_Aqua-FM3-MODIS_Edition4A CER_SSF_NOAA20-FM6-VIIRS_Edition1B

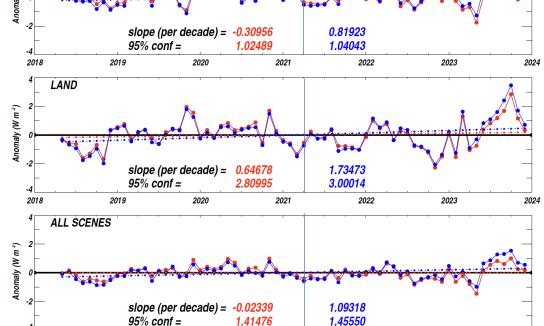


Larger uncertainties after FM3 switched to biaxial mode are driven by the drastic reduction in number of spatially and temporally matched observations.

NOAA-20 SW and LW Flux Anomaly (Level 3)







2020

Terra started drifting to earlier MLT in Apr 2021

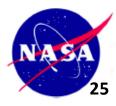


NOAA-20: CER_SSF1deg-Month_NOAA20-VIIRS_Edition1
Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A

2023

S-NPP/FM5 Instrument Status



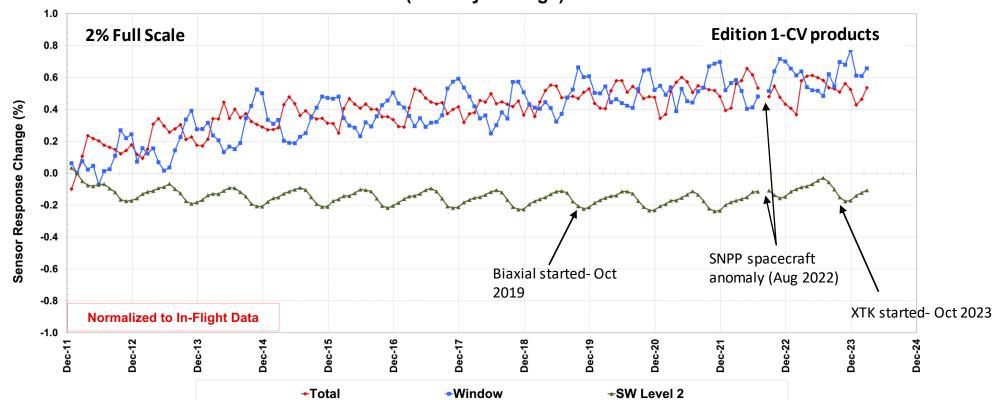


FM5 Internal Calibration

In response to the blackbodies, the FM5 TOT and WN sensors show a ~0.6% rise since start of mission.

SW channel's response to the SWICS is stable at < 0.2% since start of mission.



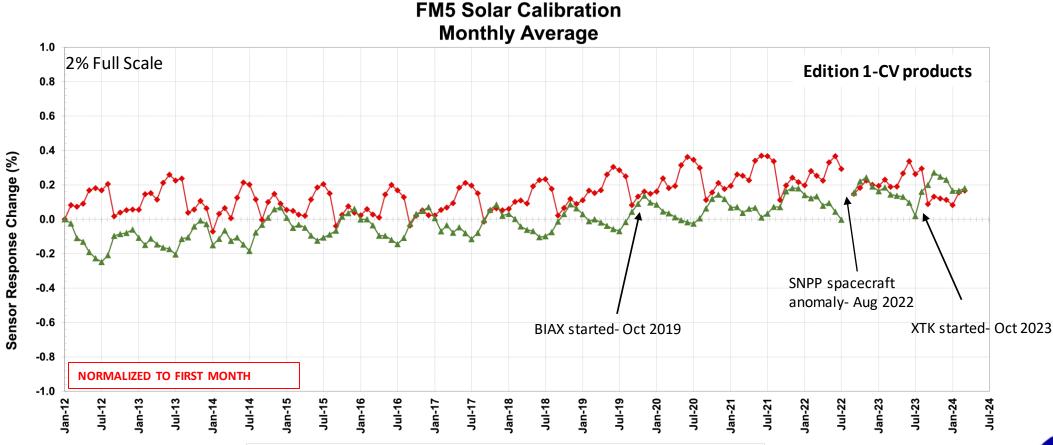




NA SA

FM5 Solar Calibration

FM5 Solar calibration results show the MAMs are very stable - < 0.4% change since Start of mission.





NASA

★Shortwave

◆Total

Validation – Tropical Mean (FMs 1-5)

- Average of the ES-8 Nadir radiances over Tropical ocean (20^oN-20^oS) scenes under All-sky conditions.
 - Uses latest version of data products All calibration updates have been applied (Gains and SRFs).
- Two sets of TM Day-Night Differences (DN) are calculated:
 - TOT and SW sensors

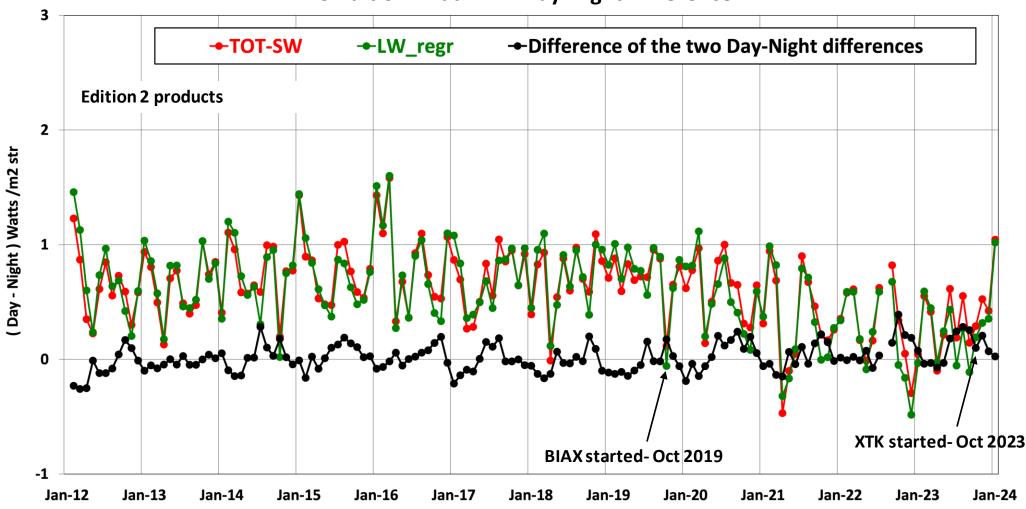
 DN= TM_D(TOT-SW) TM_N(TOT)
 - LW_r (FMs 1-5 use a 'trained' WN- Narrow to BB regression) $DN = TM_D(LW) TM_N(LW_r)$
- Trends of the difference in the two DN values highlight any inconsistencies in the Reflected Solar wavelengths of the TOT and SW sensors.





Validation-FM5 Tropical Mean

FM5 Edition2 Nadir TM Day-Night Difference





Aqua/S-NPP Intercomparisons

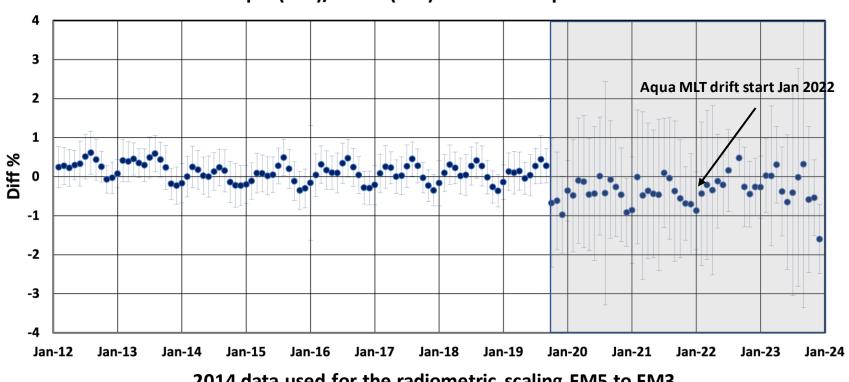
- The nominal orbital geometries for Aqua and S-NPP are such that orbital overlaps occur every ~64 hours.
 - Aqua's orbit has drifted from its nominal MLT starting Jan 2022.
- Obtain spatially and temporally matched observations during every crossover.
- No special operations conducted;
 - FM5 operated in biaxial mode Oct 2019-Oct 2023; FM3 operates in biaxial mode since Mar 2023.
- Use matching criteria to subset the data:
 - SZA, VZA difference < 2.0°
 - RAZ difference < 5⁰
 - Distance between footprints < 7 km
- Obtain monthly all-sky SW reflectance and LW radiance differences using the matched footprints.
- When instruments operated in biaxial mode, the number of matched footprints drastically reduced.

FM3/FM5 SW All-sky Inter-comparisons: Feb 2012- Dec 2023

Difference of Reflectance: FM3-FM5 %, 95% CI

 $Reflectance = \frac{SW_{rad} * \pi}{F * \cos(SZA)}$ F=1361 W/m²

Aqua (Ed4)/S-NPP (Ed2) SW Intercomparison



FM5 in BIAX from Oct 2019 till Oct 2023

FM3 in BIAX since Mar 2023

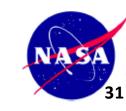
Data:

CER SSF Aqua-FM3-MODIS Edition4A CER SSF NPP-FM5-VIIRS Edition2A

2014 data used for the radiometric scaling FM5 to FM3.



Larger uncertainties when instruments are operated in biaxial mode due to the drastic reduction in number of spatially and temporally matched observations.



FM3/FM5 LW All-sky Inter-comparisons: Feb 2012- Dec 2023

Difference of Daytime Radiance: FM3-FM5 %, 95% CI

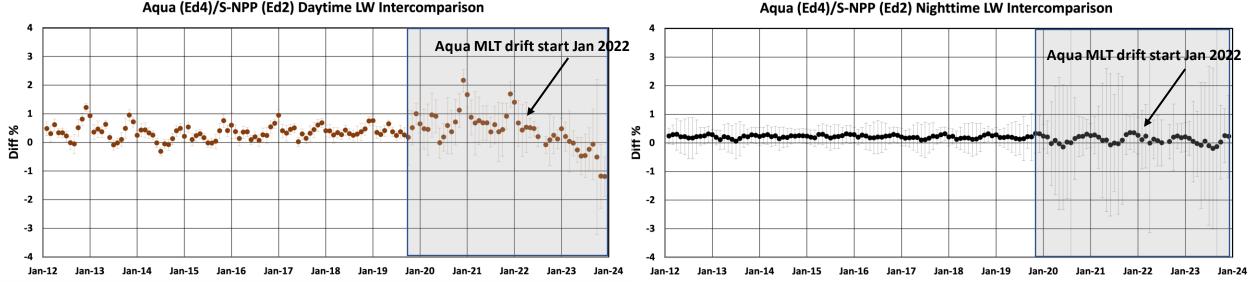
Difference of Nighttime Radiance: FM3-FM5 %, 95% CI

> FM5 Biax: Oct 2019-Oct 2023 FM3 Biax: Mar 2023-Present

FM5 Biax: Oct 2019-Oct 2023

FM3 Biax: Mar 2023-Present

Aqua (Ed4)/S-NPP (Ed2) Nighttime LW Intercomparison



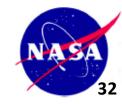
2014 data used for the radiometric scaling FM5 to FM3.

Data:

CER SSF Aqua-FM3-MODIS Edition4A CER SSF NPP-FM5-VIIRS Edition2A

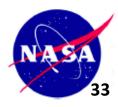


Larger uncertainties when instruments are operated in biaxial mode due to the drastic reduction in number of spatially and temporally matched observations.



Terra & Aqua FM1-FM4 Instruments' Status

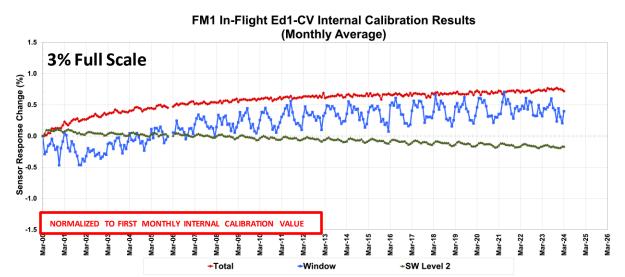


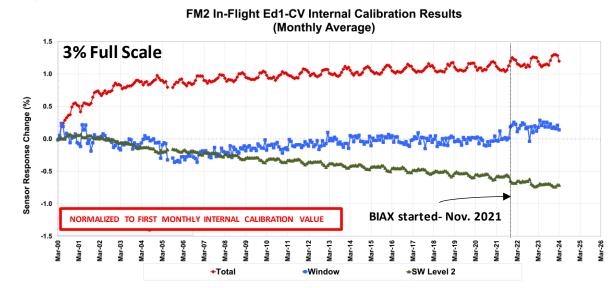


Terra-FM1 & FM2 Internal Calibration

- For FM1, TOT channel shows ~0.7% rise, SW channel shows ~0.2% drop, and WN channel shows a rise of ~0.4% since start of mission.
- For FM2, TOT channel shows ~1.25% rise, SW channel shows ~0.7% drop since start of mission. WN channel shows ~0% change until the transition to BIAX in Nov. 2021.









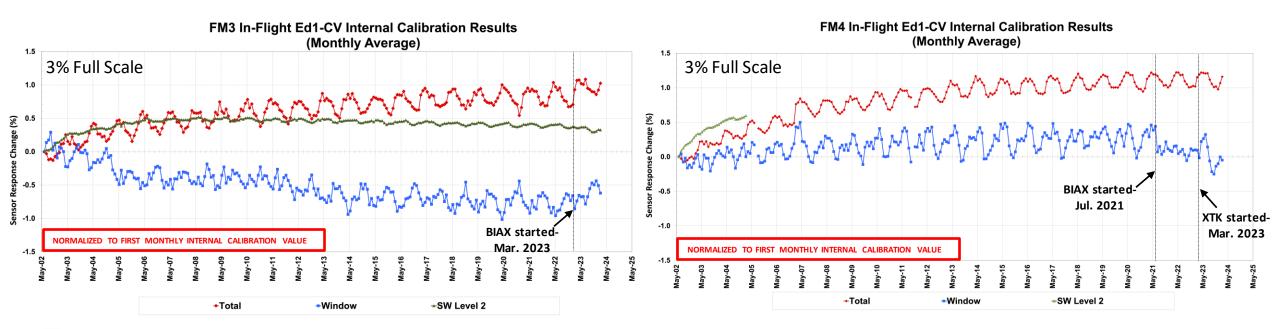
Total, WN-Blackbody: ~300 K

SW-Lamp: ~3000K brightness temp.

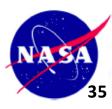


Aqua-FM3 and FM4 Internal Calibration

- For FM3, TOT channel shows ~0.9% rise, SW channel shows ~0.3% rise, and WN channel shows ~0.6% drop since start of mission.
- For FM4, TOT channel shows ~1.2% rise, while WN channel shows ~0.25% rise since start of mission.

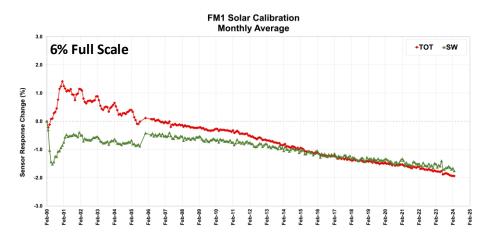


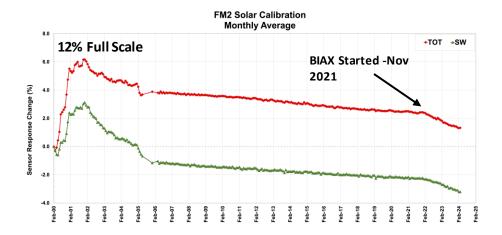


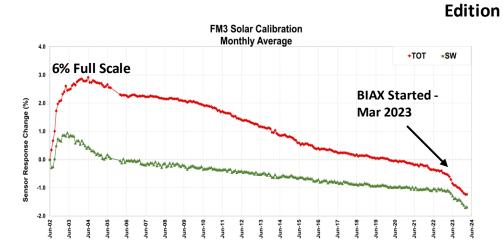


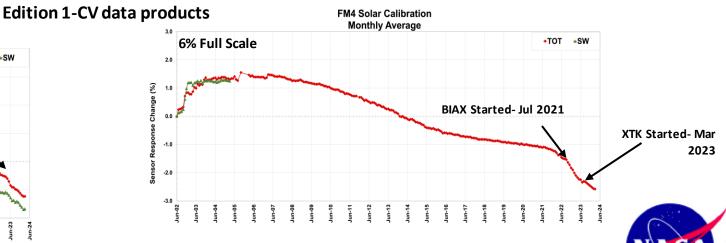
Terra & Aqua Solar Calibration

Since the start of BIAX, the TOT and SW channels on FM2 shows a drop in response of \sim 0.5%, FM3 drops by \sim 0.4%. TOT channel on FM4 showed a drop of \sim 1.2% while in BIAX.



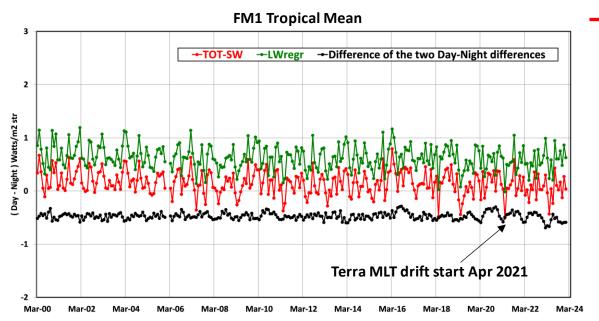


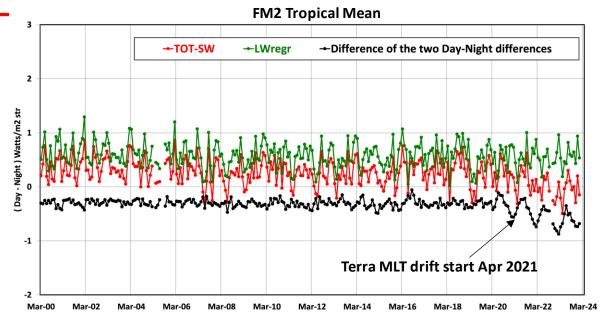


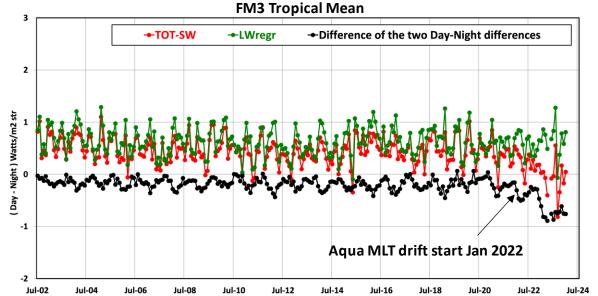




Validation-Terra and Aqua Tropical Mean

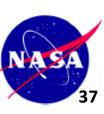






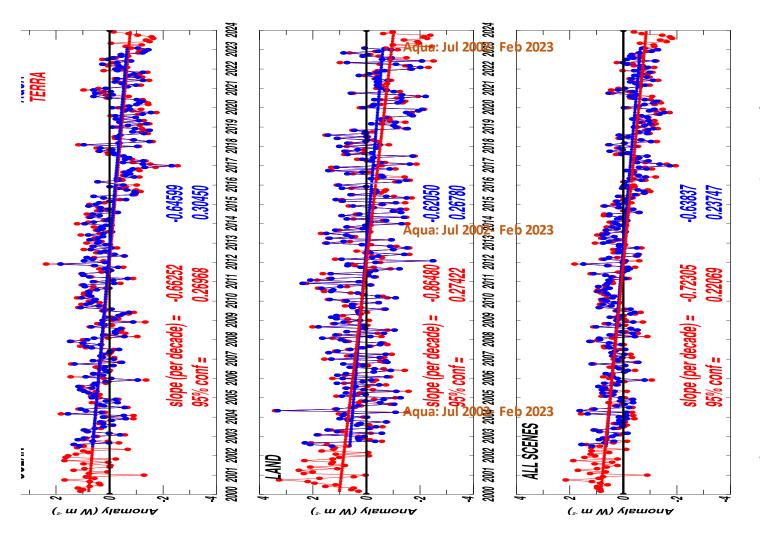
Uses Edition 4 ES-8 data products





Validation: Terra and Aqua Ed-4 SW Flux Anomalies

Level 3
Edition 4 products



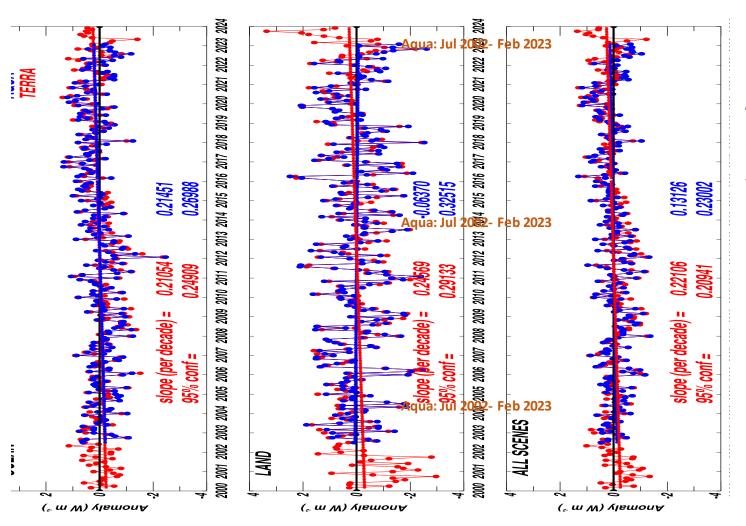
Terra started drifting to earlier MLT in Apr 2021. Aqua started drifting to later MLT in Jan 2022.

Note: Aqua record stops in Feb 2023; FM3 was transitioned to BIAX mode in Mar 2023.



Validation: Terra and Aqua Ed-4 LW Flux Anomalies

Level 3
Edition 4 products



Terra started drifting to earlier MLT in Apr 2021. Aqua started drifting to later MLT in Jan 2022.

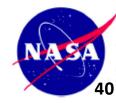
Note: Aqua record stops in Feb 2023; FM3 was transitioned to BIAX mode in Mar 2023.



SUMMARY

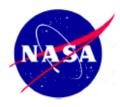
- CERES instruments on Terra and Aqua performing operations to support scientific studies as their orbits drift.
- All CERES instruments continue to perform nominally.
 - NOAA-20/FM6 instrument is operating in crosstrack scan mode;
 - SW Channel noise events during Nov 2023 through Feb 2024 caused no impact to the higher-level data products and their occurrences are now less frequent.
 - IWG continues to closely monitor telemetry for future occurrences.
 - SNPP/FM5 operating in crosstrack scan mode and continues to perform nominally.
 - Terra and Aqua instruments' performance are monitored through validation studies as well as inter-comparisons with other CERES instruments, all studies show instruments are performing consistently.
- Level 1 Data products
 - NOAA-20/FM6 Edition 1 gains have been delivered through Mar 2024.
 - S-NPP/FM5 Edition 2 gains and SRFs have been delivered through Jan 2024.
 - Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through Feb 2024.





Backup





Instrument Product-line definitions

NOAA-20

- Edition1-CV: Products without any on-orbit instrument calibration corrections applied.
- Edition 1: Incorporates the most up-to-date calibration corrections, radiometric scaling to Aqua.

• **S-NPP**:

- Edition 1-CV: Products without any on-orbit instrument calibration corrections applied.
- Edition 2: Incorporates the most up-to-date calibration corrections, radiometric scaling to Aqua, and time varying SRF adjustments to TOT channel.

• Terra/Aqua:

- Edition 1-CV: Products without any on-orbit instrument calibration corrections applied.
- Edition 4: Incorporates the most up-to-date calibration corrections, radiometric scaling and time varying SRF adjustments to SW and TOT channels.



