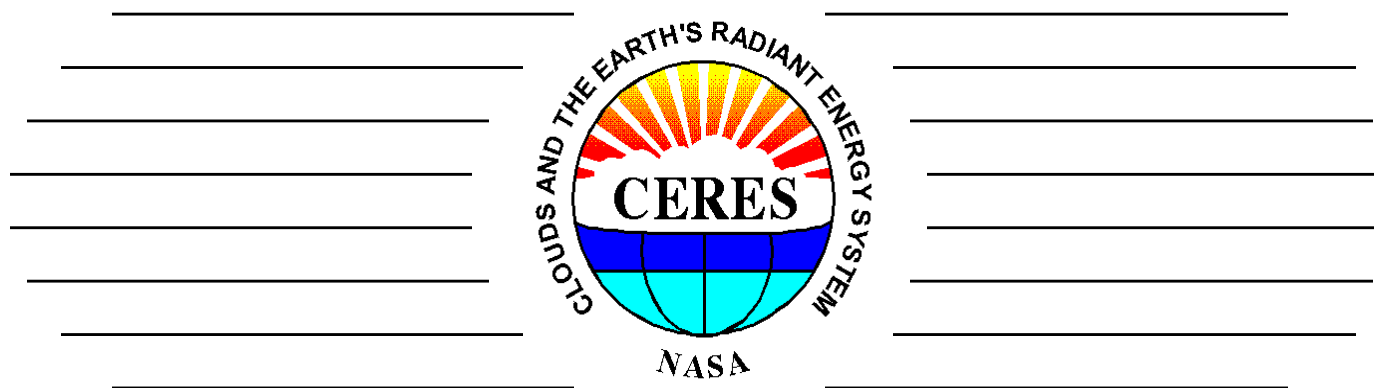


# CERES Instrument Status: Flight Models 1-6 (FM1-FM6)

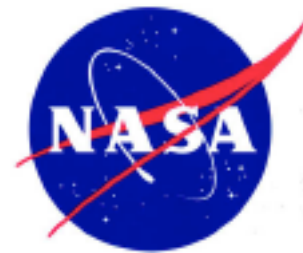


**Mohan Shankar**

**CERES Instrument Working Group**

**CERES Fall Science Team Meeting  
October 17, 2023**

**CERES Instrument Working Group**



# CERES Instrument Working Group

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**Project Scientist (PS): Kory Priestley**  
**Deputy PS/IWG Lead: Mohan Shankar**  
**Tech Lead: Susan Thomas**

## Instrument Operations

B. Mike Tafazoli  
Janet Daniels  
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Alexander Brown  
Ethan Ames  
Carol Kelly

## Data Management

Denise Cooper  
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A. Thomas Grepiotis  
Dianne Snyder

## Cal/Val

Hyung Lee  
Nathaniel Smith  
Nitchie Smith  
Z. Peter Szewczyk



# CERES Instrument Status Summary

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- **All CERES instruments continue to demonstrate stable performance.**
  - NOAA-20/FM6 instrument continues to perform nominally.
  - SNPP/FM5 is currently operating in *Crosstrack* scan mode.
    - *No evidence of degradation of instrument performance when it was operated in biaxial mode.*
  - Terra and Aqua 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 September 2023.
  - S-NPP/FM5 Edition 2 gains and SRFs have been delivered through July 2023.
  - Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through July 2023.



# CERES Instrument

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- **CERES measures the radiation at the Earth's top of atmosphere from the visible through the far IR spectral regions**
  - 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)
- **Instrument was designed, built, and tested by TRW (acquired by NGAS).**
- **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.**
- **Six currently operational instruments on four spacecraft:**
  - Terra: FM1 and FM2
  - Aqua: FM3 and FM4
  - S-NPP: FM5
  - NOAA-20: FM6



# CERES Instrument Operations Summary

Spacecraft	Instrument	Operational Mode	Notes
NOAA20	FM6	XTK	
SNPP	FM5	XTK	Operated in BIAX mode from Mar 23, 2020, till Oct 9, 2023.
Aqua	FM4	XTK	Operated in BIAX from Jul 14, 2021, till 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)

## 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.

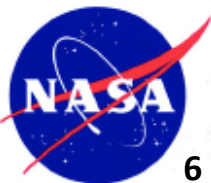


# CERES Instrument Operations Summary Cont'd

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- **Inter-comparison operations conducted in summer 2023:**

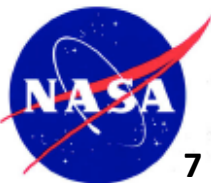
- Terra/FM1 – S-NPP/FM5: May 1 – Jul 31, 2023
  - Terra/FM1 – NOAA-20/FM6: May 1 – Jul 31, 2023
  - Terra/FM1 – Aqua/FM3: Jun 1 – 30, 2023
  - Terra/FM2 – GERB: Jun 1 – 30, 2023
- } 70° N



# NOAA-20/FM6 Instrument Status

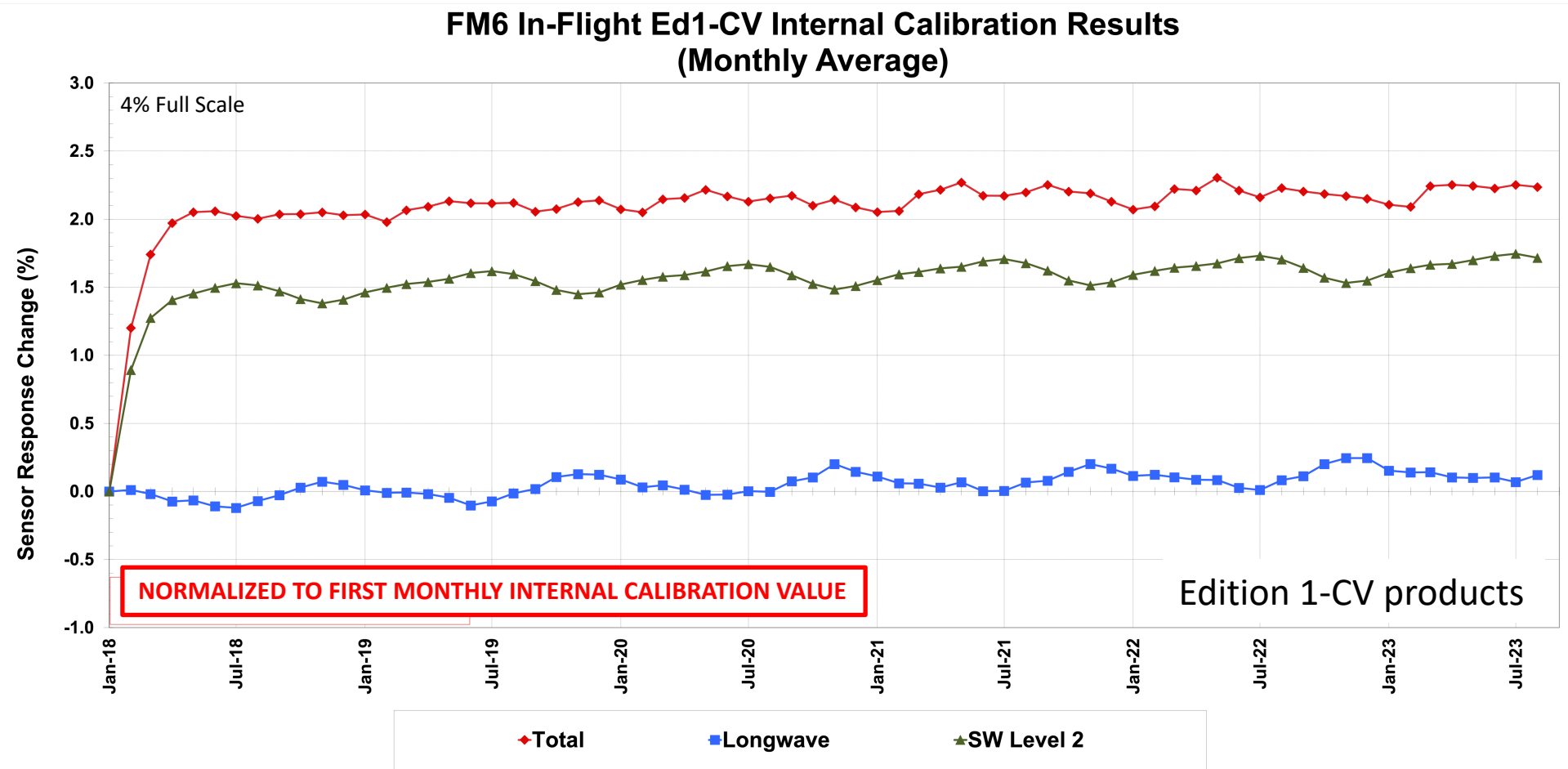


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# FM6 Internal Calibration

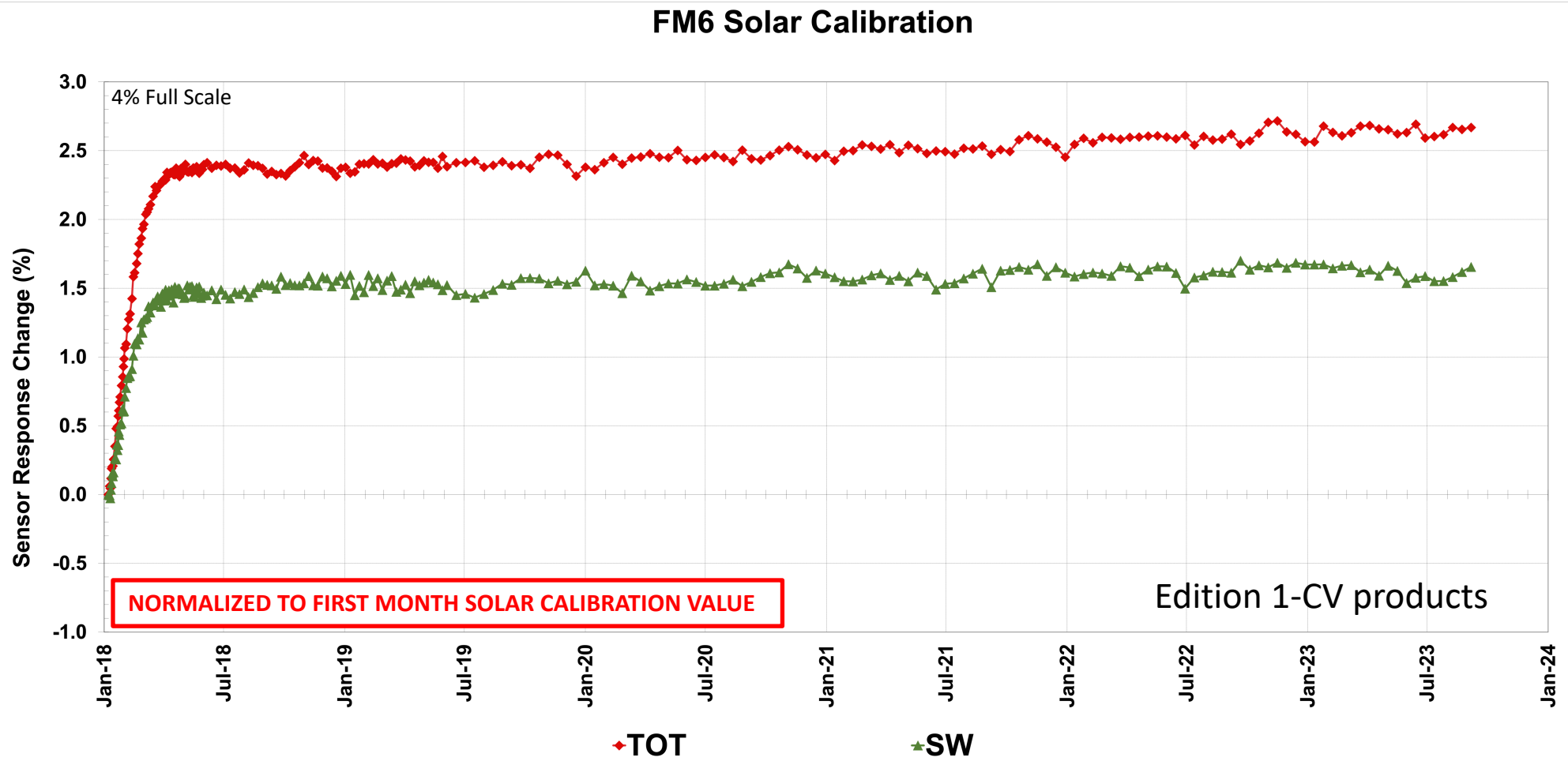
- For SW and TOT channels, the responses to the on-board sources (SWICS lamp and Blackbodies) continue to be quite stable (<0.2%) after the initial rise of ~1.5% (SW) and ~2% (TOT) since start of mission.
- LW Channel (calibrated using blackbody) continues to show very little change.





# 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.



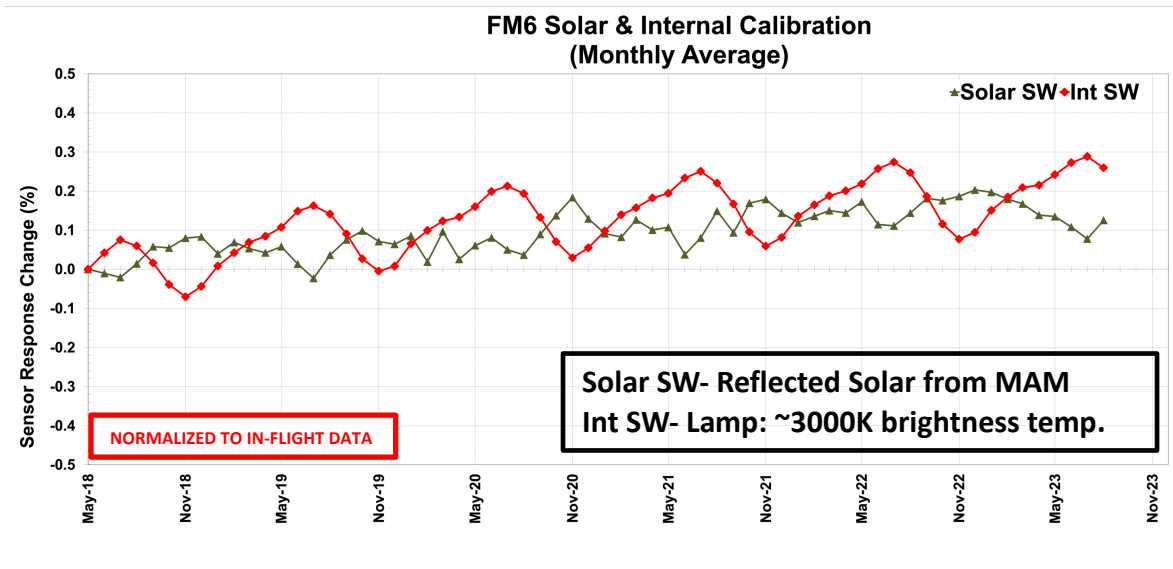
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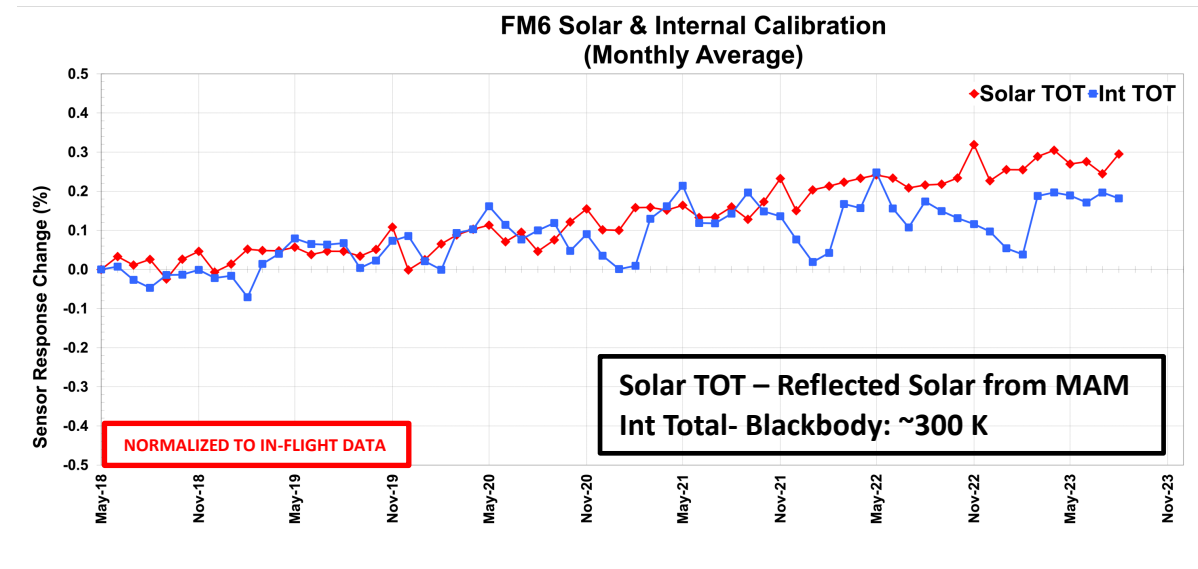
# FM6 Calibration- Internal and Solar Cal Since May 2018

FM6 Internal and solar calibration results consistently show  $<0.3\%$  change since May 2018, demonstrating that the MAM is very stable.

## SW Channel



## TOT Channel



Edition 1-CV products



# Validation – FM6 Tropical Mean

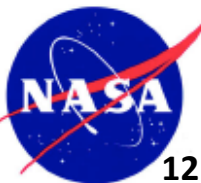
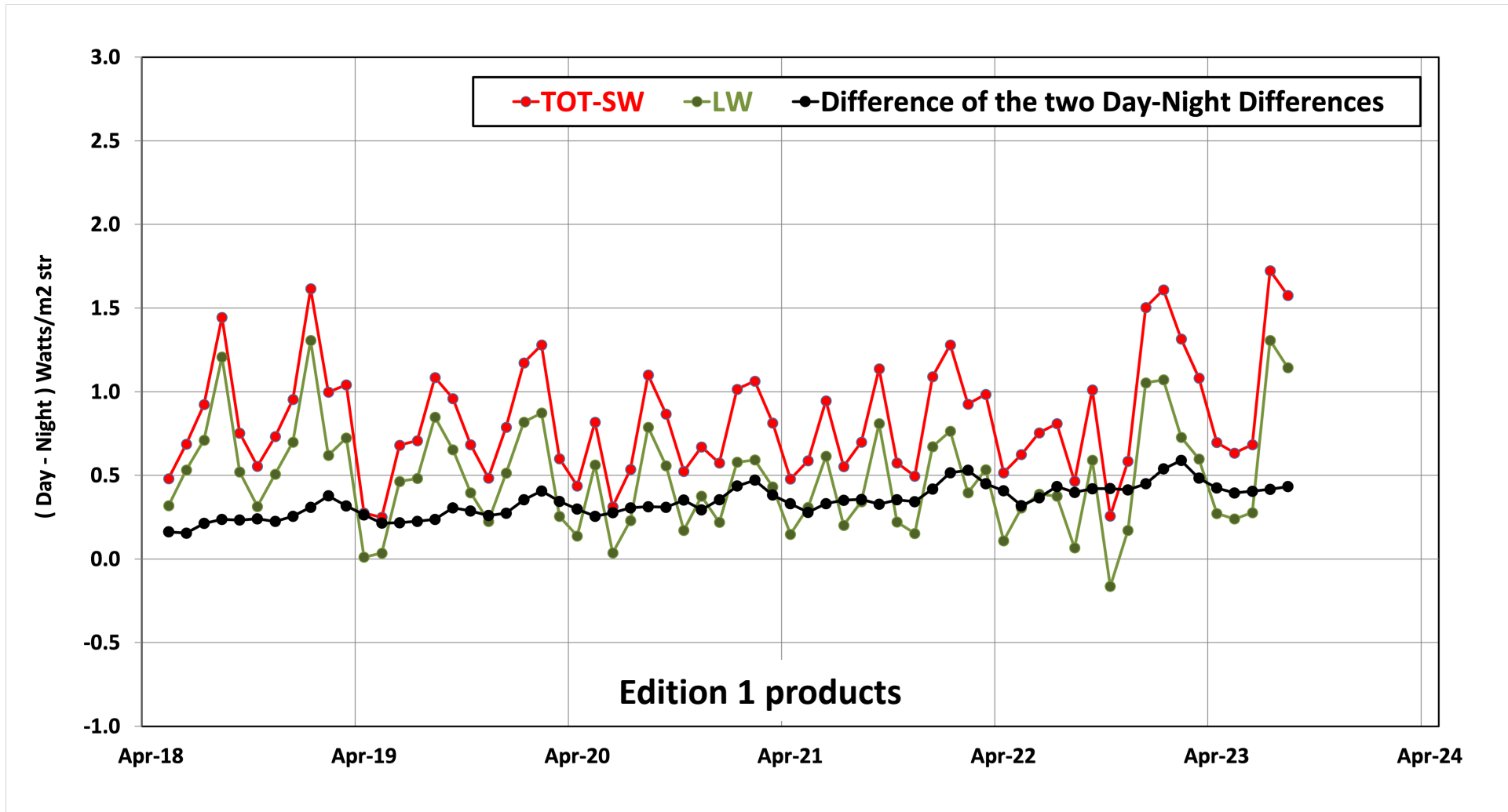
---

- Average of the Nadir radiances over Tropical ocean (20<sup>0</sup>N-20<sup>0</sup>S) scenes under All-sky 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 Tropical mean Day-Night

FM6 Nadir TM Day-Night Difference

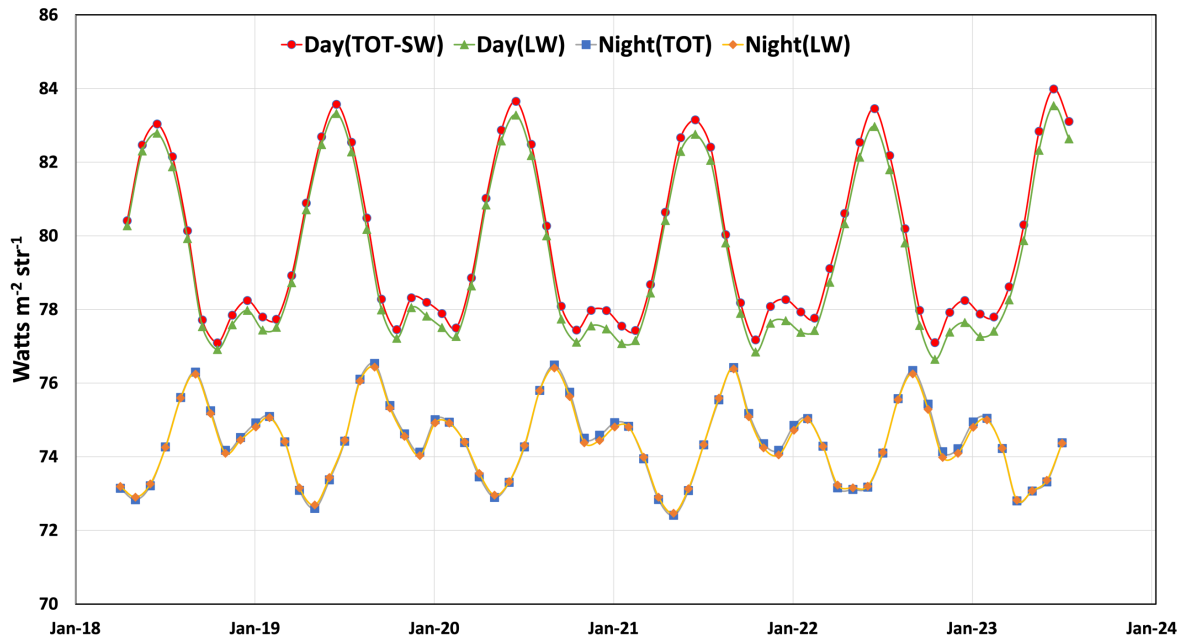


# FM6 3-channel Consistency check- Global Day-Night Differences

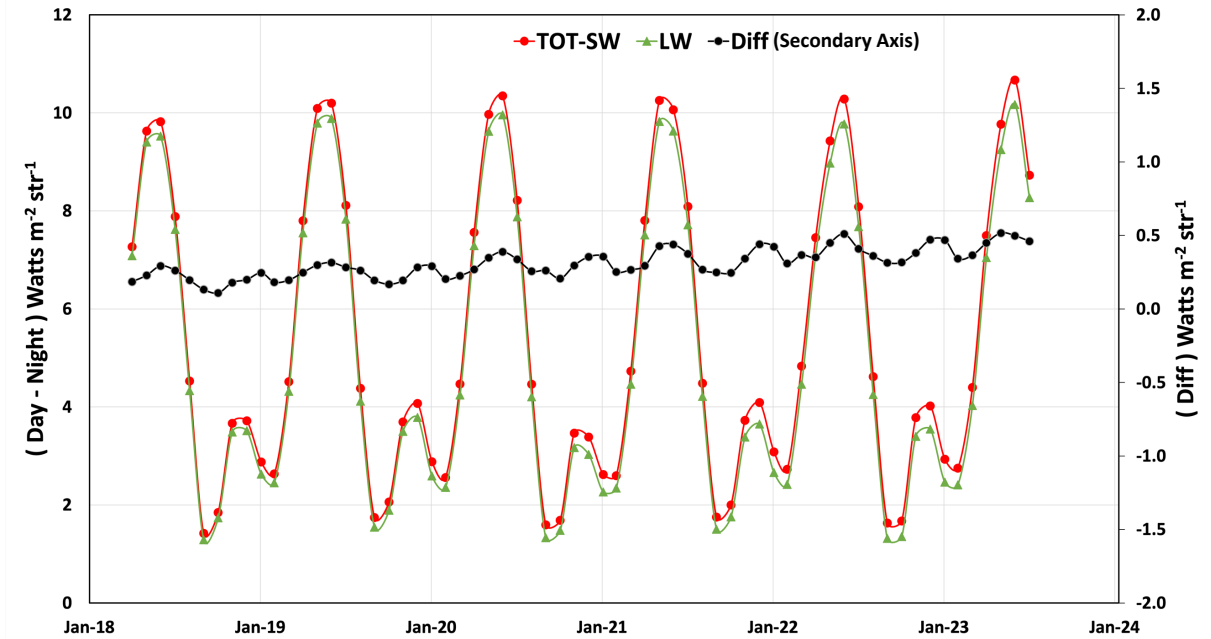
May 2018 - Aug 2023

Edition 1 ES-8, Global, All-sky, Nadir Radiance

### FM6 Edition 1 Global Mean LW radiance



### Day-Night Difference



Edition 1 data products

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# Aqua/NOAA-20 Intercomparisons

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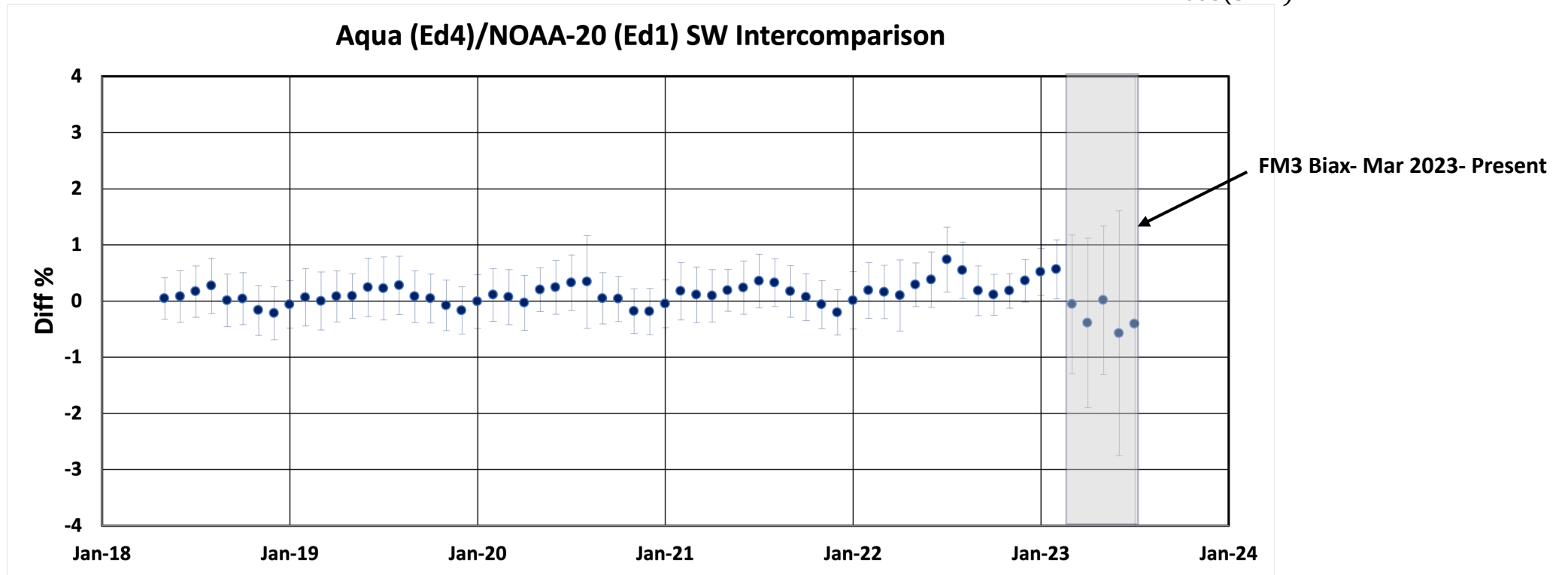
- The nominal orbital geometries for Aqua and NOAA-20 are such that orbital overlaps occur every ~64 hours.
- Obtain spatially and temporally matched observations during every crossover.
- No special operations are conducted to match viewing geometries; Instruments continue operating in their nominal mode:
  - *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 < **5°**
  - Distance between centroid of footprints < **7 km**
- Obtain monthly all-sky SW reflectance and LW radiance differences using the matched footprints.
- *Since FM3 was operating in biaxial scan mode, the number of matched footprints drastically reduced.*



# FM3/FM6 SW All-sky Inter-comparisons: May 2018- Jul 2023

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

$$\text{Reflectance} = \frac{SW_{rad} * \pi}{F * \cos(SZA)} \quad F=1361 \text{ W/m}^2$$



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.

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

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

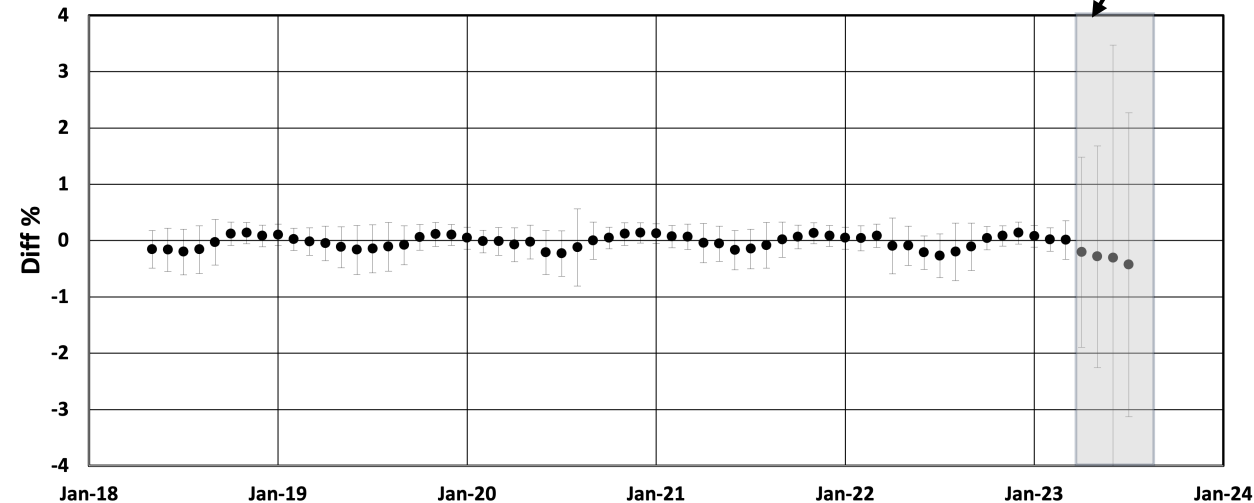
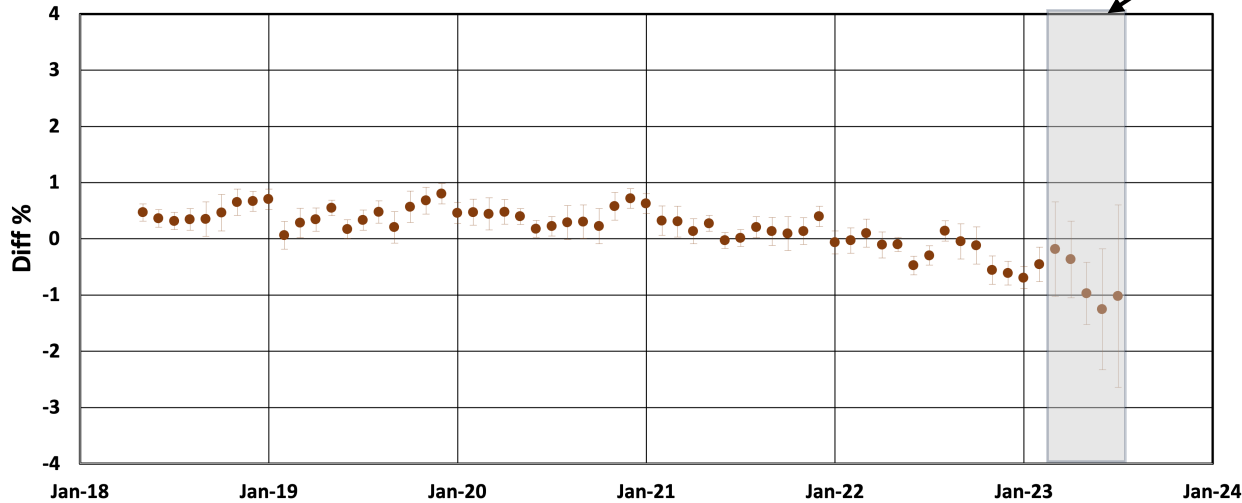
Difference of Nighttime Radiance:  
FM3-FM6 %, 95% CI

Daytime LW for FM6 obtained from TOT-SW

Nighttime LW for FM6 obtained from TOT

Aqua (Ed4)/NOAA20 (Ed1) Daytime LW Intercomparison

Aqua (Ed4)/NOAA20 (Ed1) Nighttime LW Intercomparison



Radiometric scaling of FM6 to FM3 done in May 2018.

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

Data:  
CER\_SSF\_Aqua-FM3-MODIS\_Edition4A  
CER\_SSF\_NOAA20-FM6-VIIRS\_Edition1B



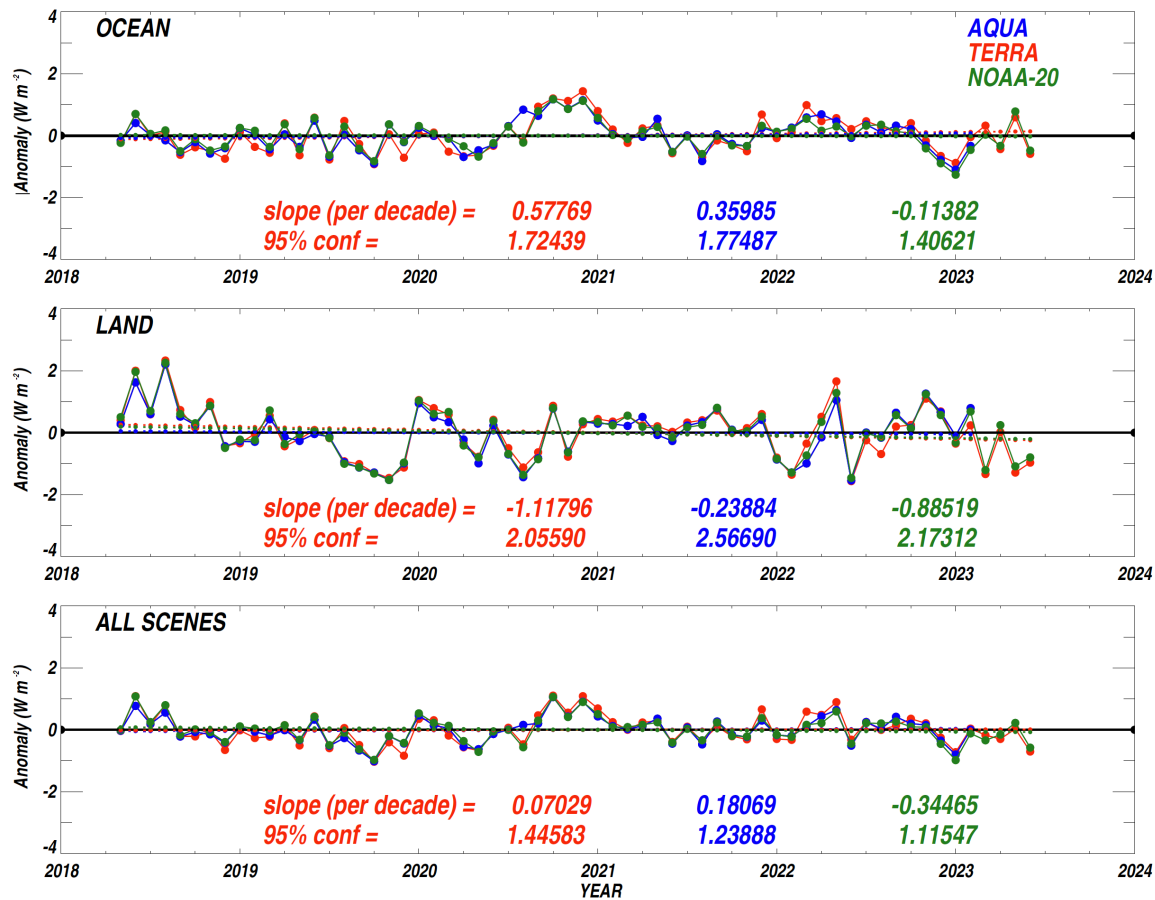
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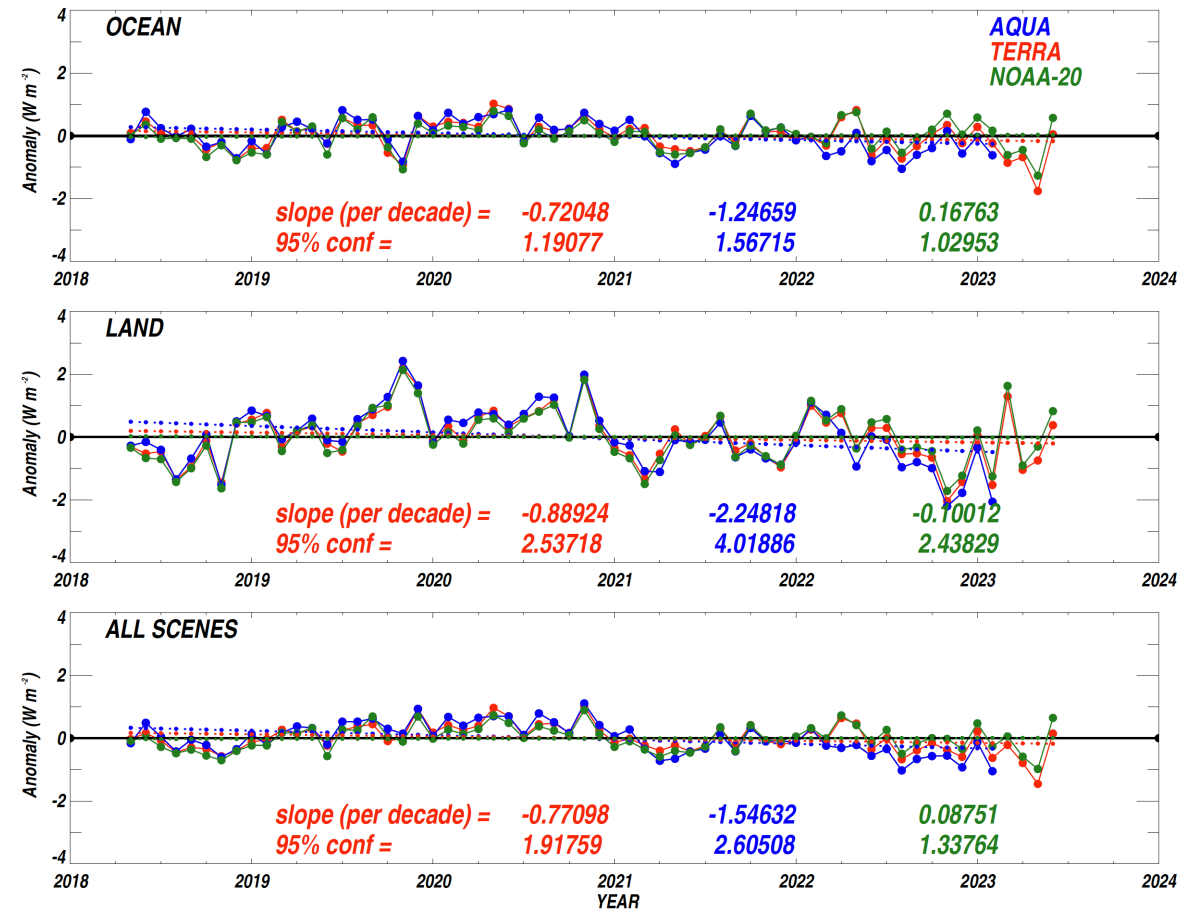


# NOAA-20 SW and LW Flux Anomaly (Level 3)

Anomaly of Terra, Aqua and NOAA-20 SW Flux (SSF1deg) for All Sky Scenes



Anomaly of Terra, Aqua and NOAA-20 LW Flux (SSF1deg) for All Sky Scenes



Terra, Aqua and NOAA20 flux anomalies are consistent

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NOAA20: CER\_SSF1deg-Month\_NOAA20-VIIRS\_Edition1  
 Terra: CER\_SSF1deg-Month\_Terra-MODIS\_Edition4A  
 Aqua: CER\_SSF1deg-Month\_Aqua-MODIS\_Edition4A



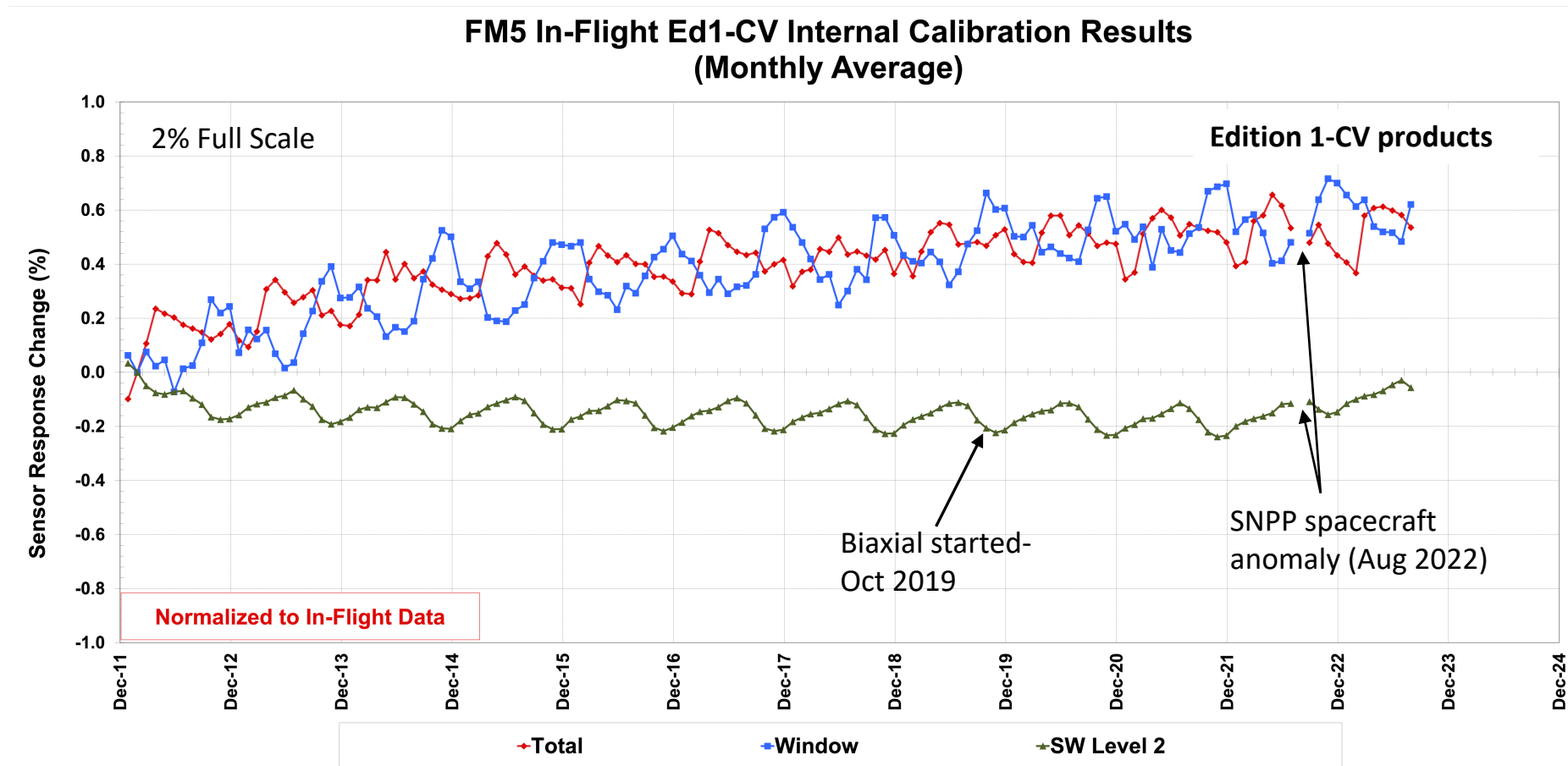
# S-NPP/FM5 Instrument Status



# FM5 Internal Calibration

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

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

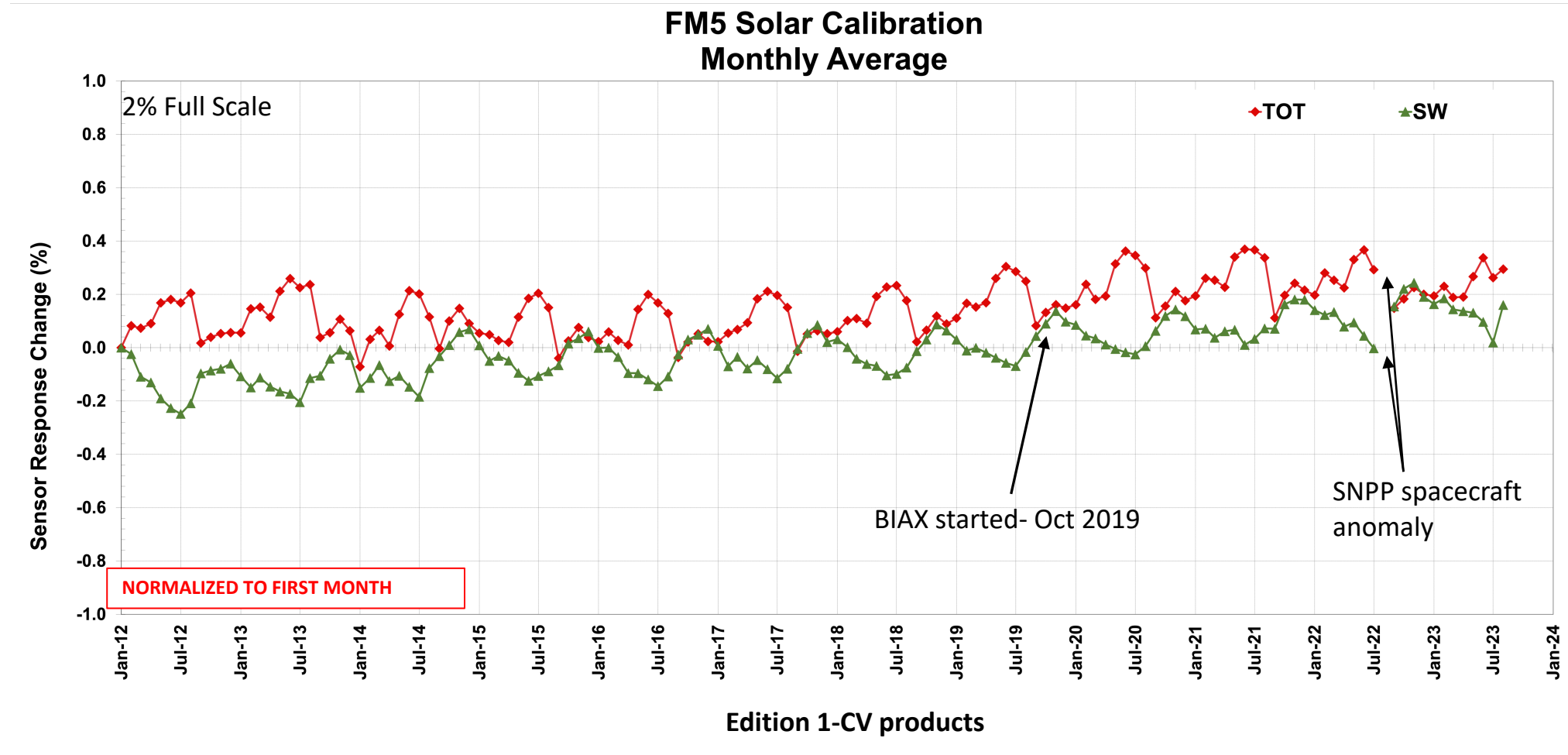


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# FM5 Solar Calibration

- FM5 Solar calibration results show the MAMs are very stable.
- TOT and SW responses show a small upward trend in latter part of mission.



# Validation – Tropical Mean (FMs 1-5)

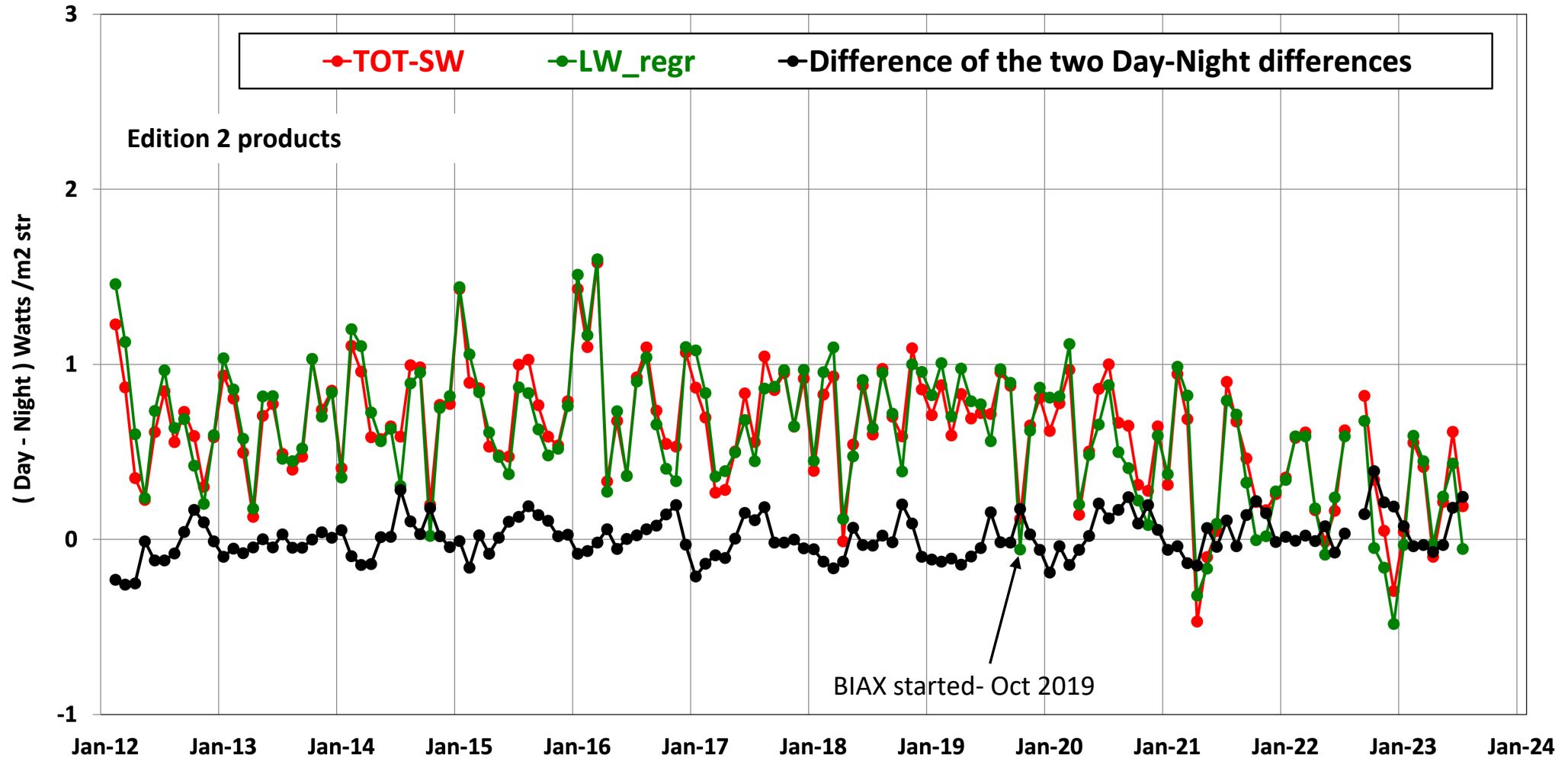
---

- Average of the ES-8 Nadir radiances over Tropical ocean (20<sup>0</sup>N-20<sup>0</sup>S) scenes under All-sky conditions.
  - Uses latest version of data products- All calibration updates have been applied.
- Two sets of TM Day-Night Differences (DN) are calculated:
  - TOT and SW sensors
$$\text{DN} = \text{TM}_D(\text{TOT-SW}) - \text{TM}_N(\text{TOT})$$
  - LW<sub>r</sub> (FMs 1-5 use a 'trained' WN- Narrow to BB regression)
$$\text{DN} = \text{TM}_D(\text{LW}) - \text{TM}_N(\text{LW}_r)$$
- 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  $\sim 64$  hours.
- Obtain spatially and temporally matched observations during every crossover.
- No special operations conducted;
  - *FM5 operated in biaxial mode till Oct 2023; FM3 operates in biaxial mode since Mar 2023.*
- Use matching criteria to subset the data:
  - SZA, VZA difference  $< 2.0^\circ$
  - RAZ difference  $< 5^\circ$
  - 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.*

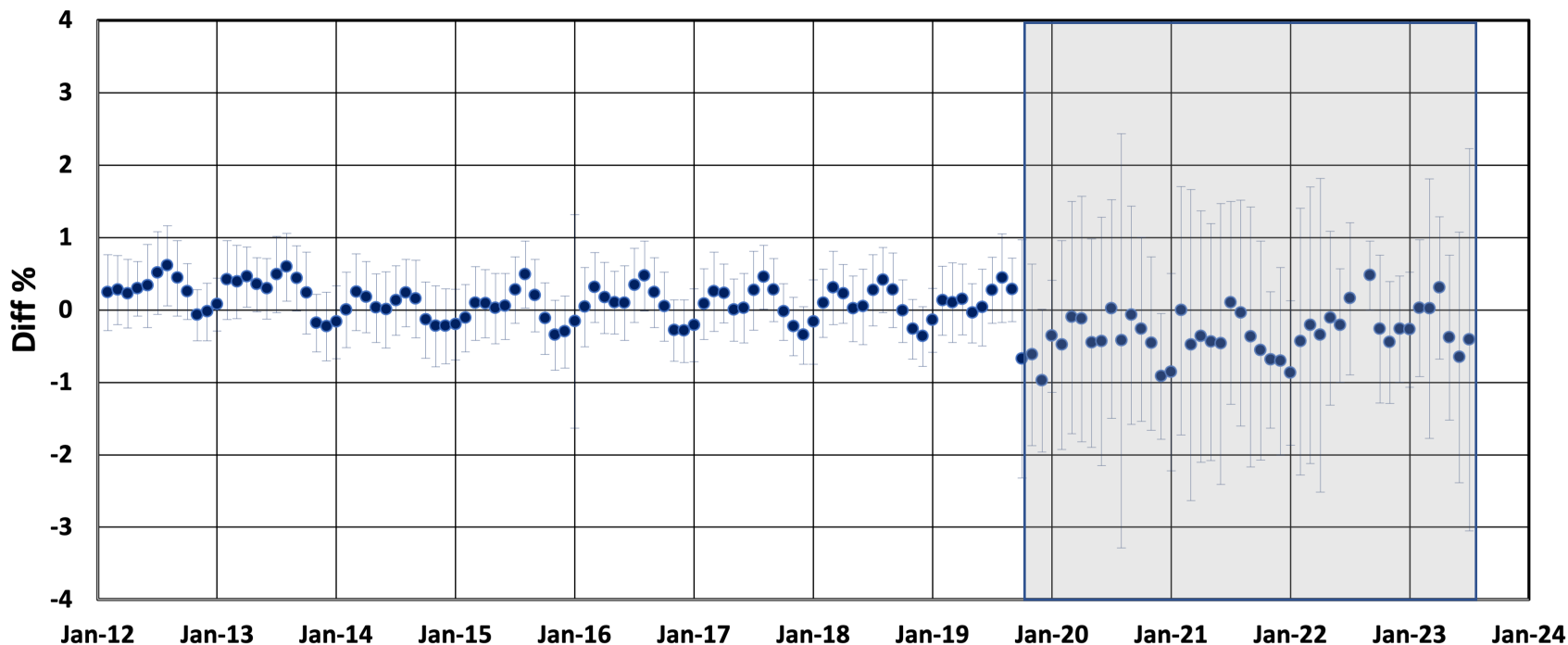


# FM3/FM5 SW All-sky Inter-comparisons: Feb 2012- Jul 2023

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

$$Reflectance = \frac{SW_{rad} * \pi}{F * \cos(SZA)} \quad F=1361 \text{ W/m}^2$$

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



FM5 in BIAX since Oct 2019

FM3 in BIAX since Mar 2023

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.

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

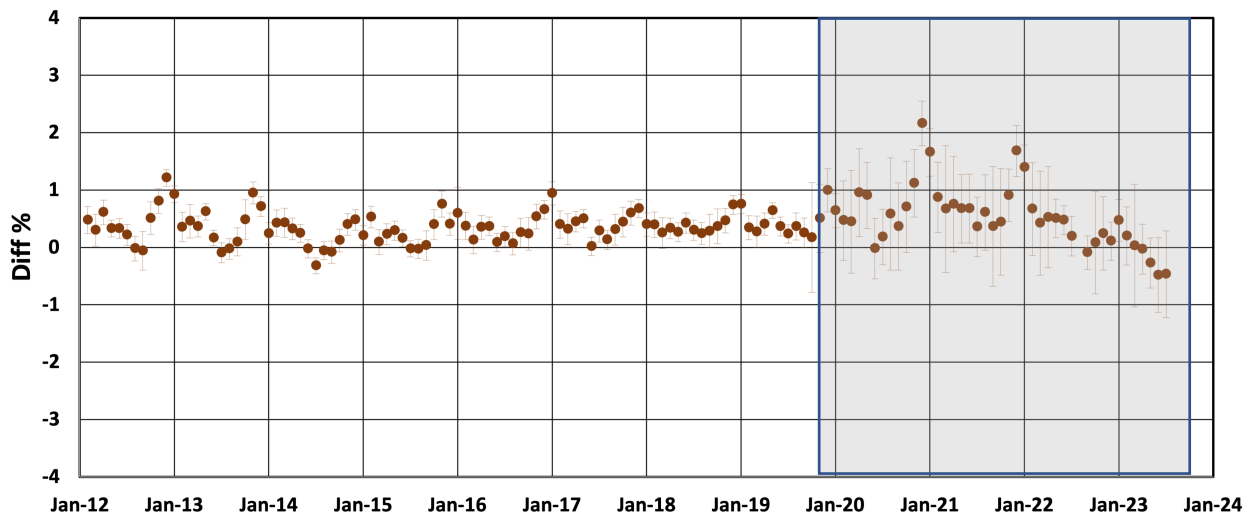
**Difference of Daytime Radiance:  
FM3-FM5 %, 95% CI**

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

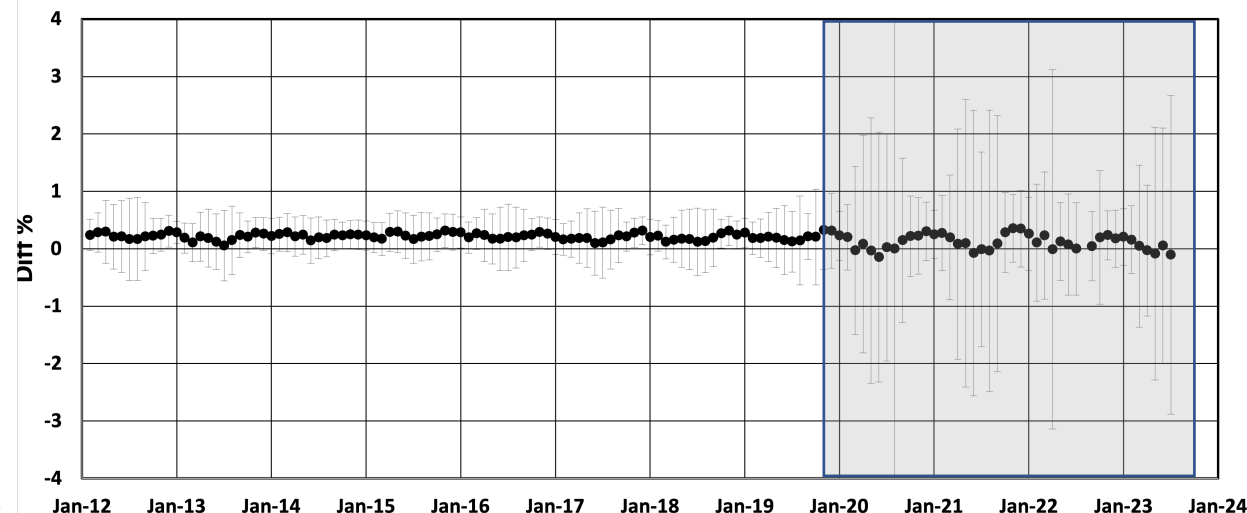
FM5 Biax: Oct 2019- Present  
FM3 Biax: Mar 2023- Present

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

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



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.**



**CERES Instrument Working Group**



# Terra & Aqua FM1-FM4 Instruments' Status

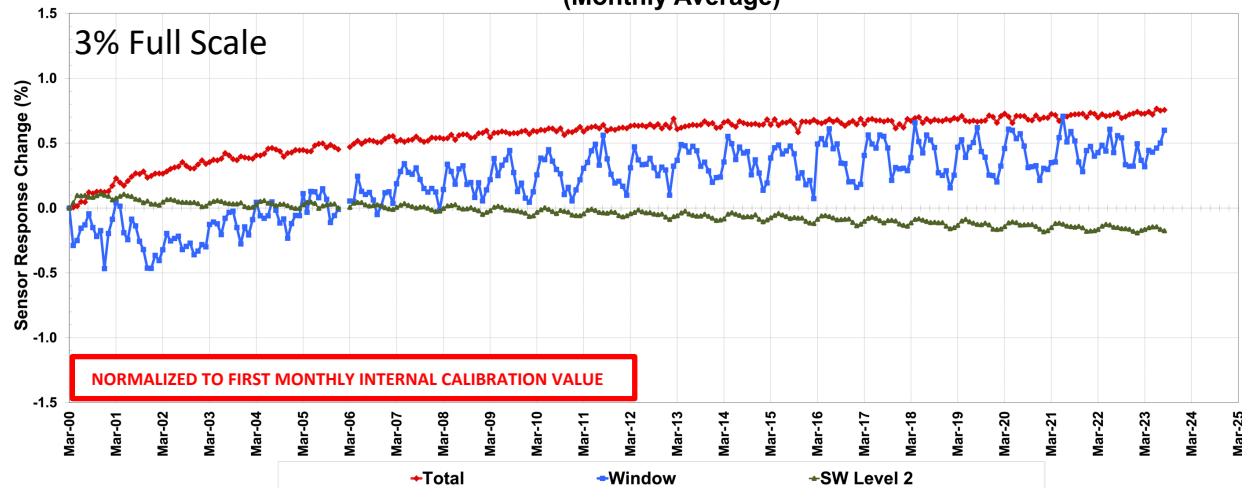


# Terra- FM1 & FM2 Internal Calibration

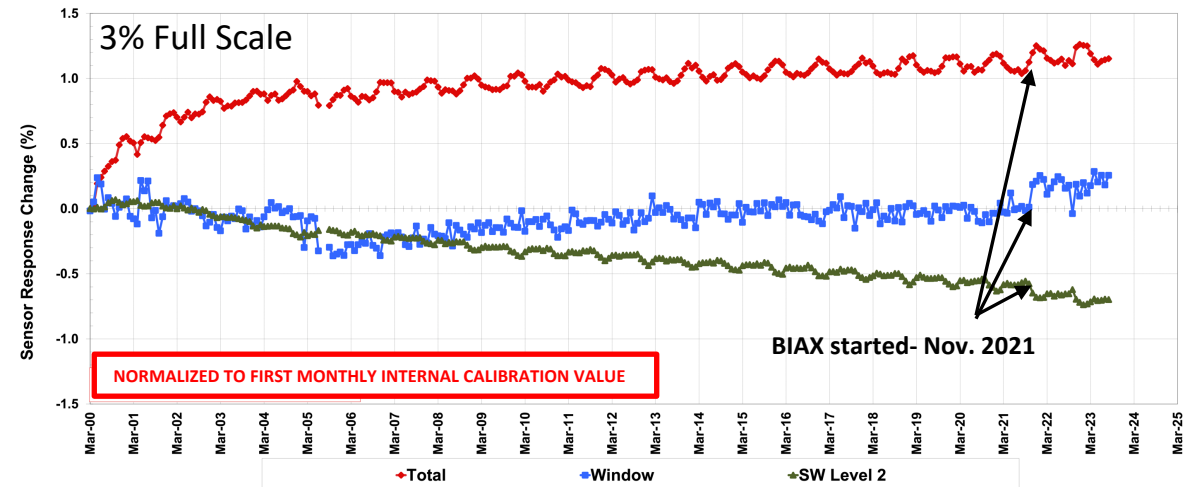
- For FM1, TOT channel shows ~0.7% rise, SW channel shows ~0.2% drop, and WN channel shows a rise of ~0.4% since start of mission.
- For FM2, TOT channel shows ~1.25% rise, SW channel shows ~0.7% drop since start of mission. WN channel shows ~0% change until the transition to BIAx in Nov. 2021.

## Edition 1-CV products

FM1 In-Flight Ed1-CV Internal Calibration Results (Monthly Average)



FM2 In-Flight Ed1-CV Internal Calibration Results (Monthly Average)

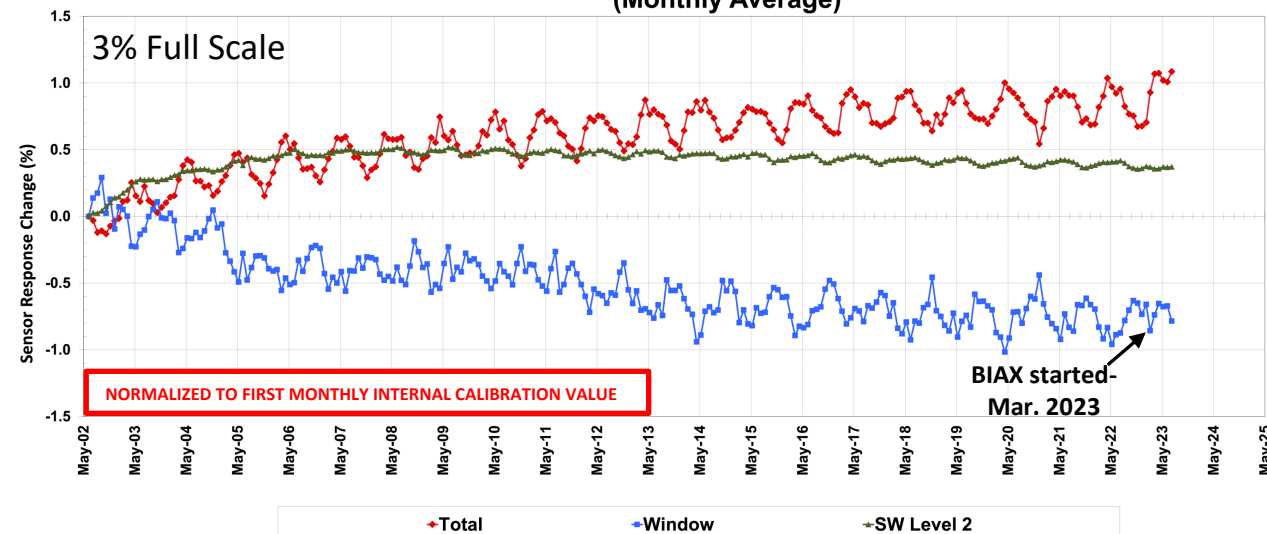


Total, WN- Blackbody: ~300 K  
SW- Lamp: ~3000K brightness temp.

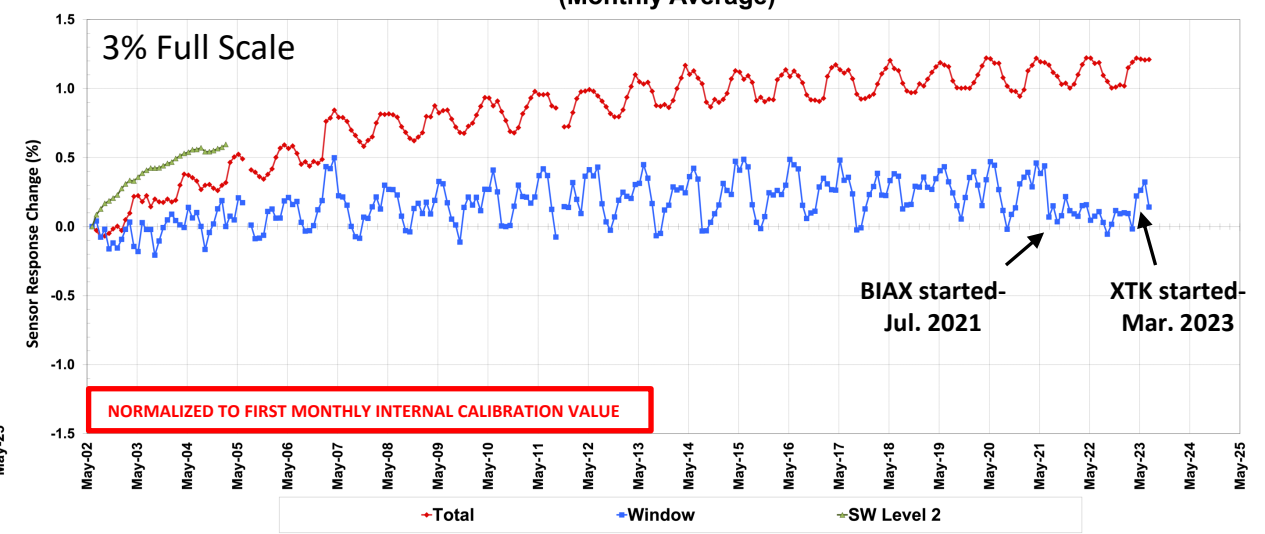
# Aqua- FM3 and FM4 Internal Calibration

- For FM3, TOT channel shows ~0.8% rise, SW channel shows ~0.4% rise, and WN channel shows ~0.8% drop since start of mission.
- For FM4, TOT channel shows ~1.2% rise, while WN channel shows ~0.25% rise since start of mission.

FM3 In-Flight Ed1-CV Internal Calibration Results  
(Monthly Average)

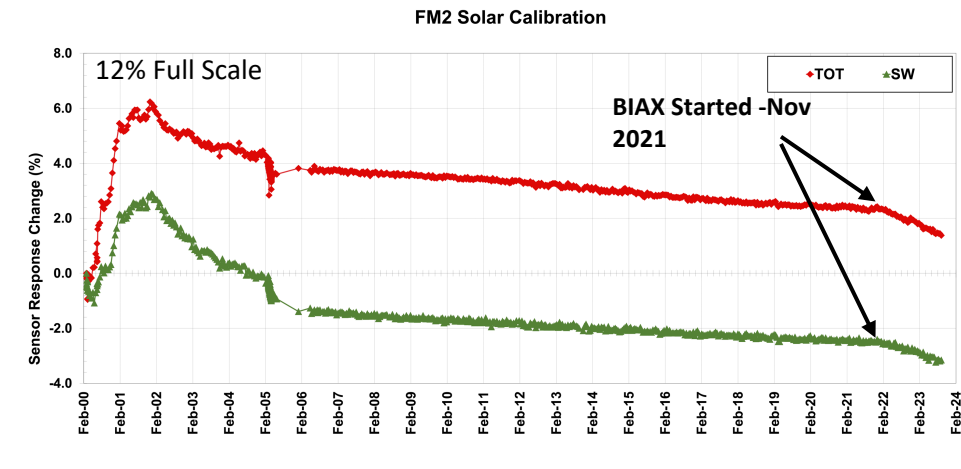
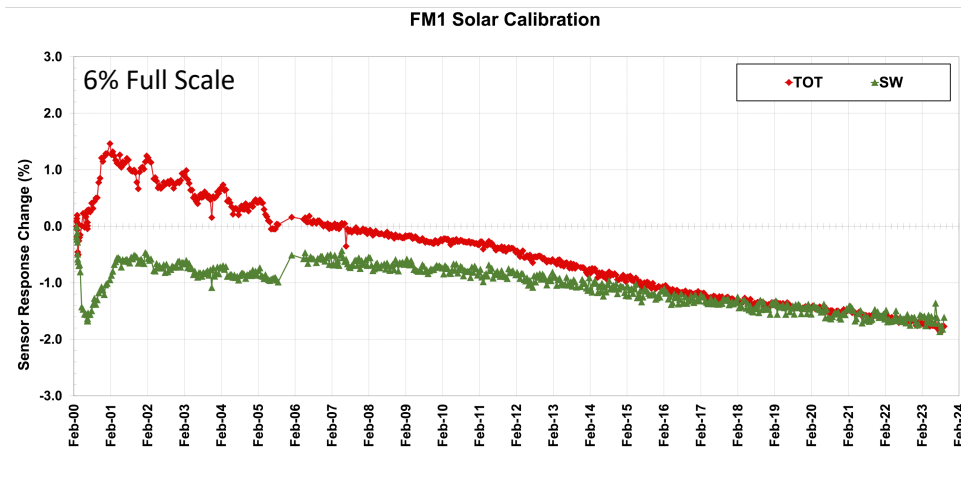


FM4 In-Flight Ed1-CV Internal Calibration Results  
(Monthly Average)

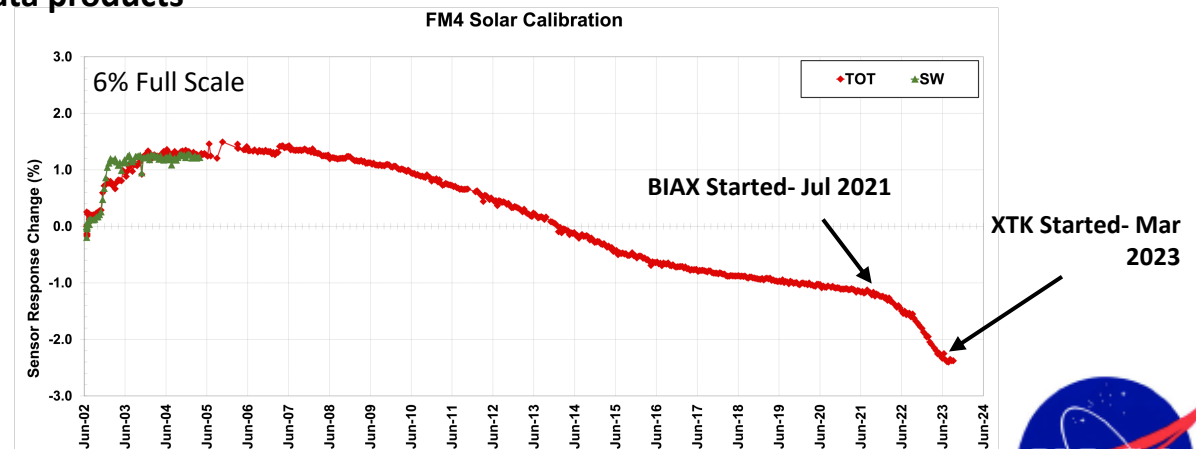
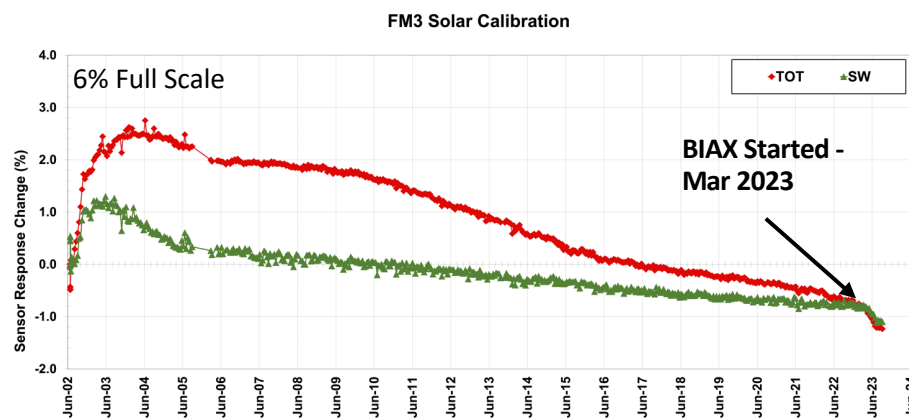


# Terra & Aqua Solar Calibration

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.

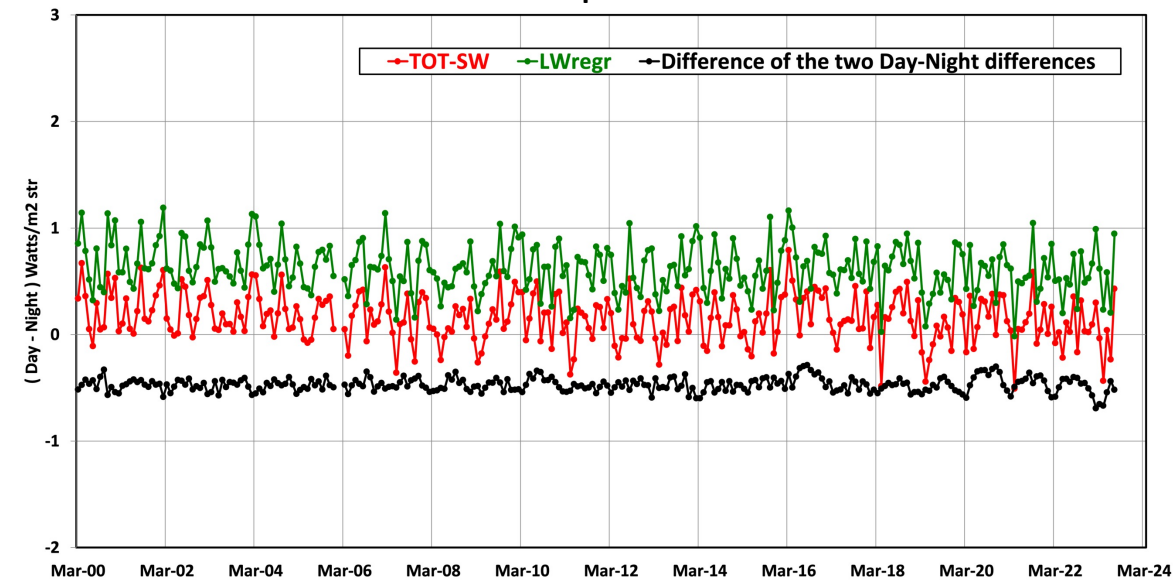


Edition 1-CV data products

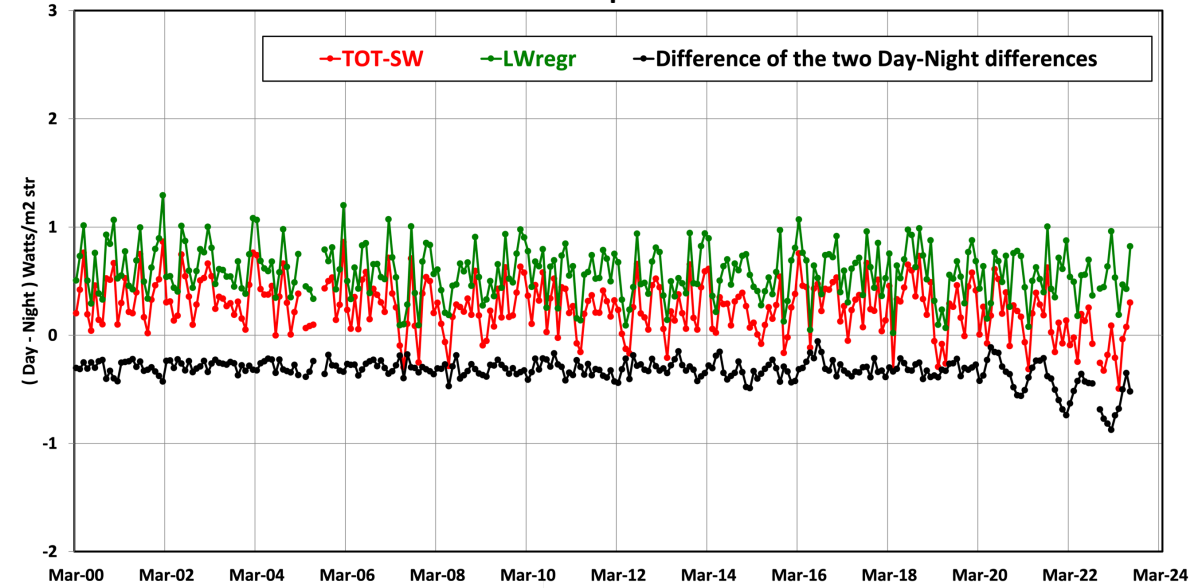


# Validation- Terra and Aqua Tropical Mean

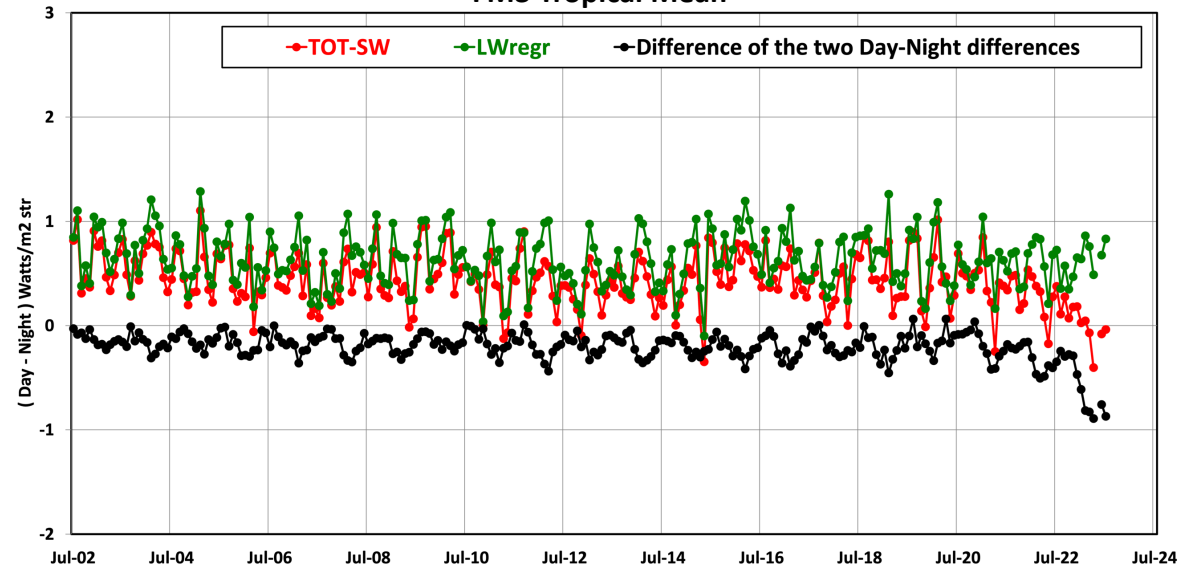
FM1 Tropical Mean



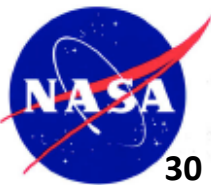
FM2 Tropical Mean



FM3 Tropical Mean

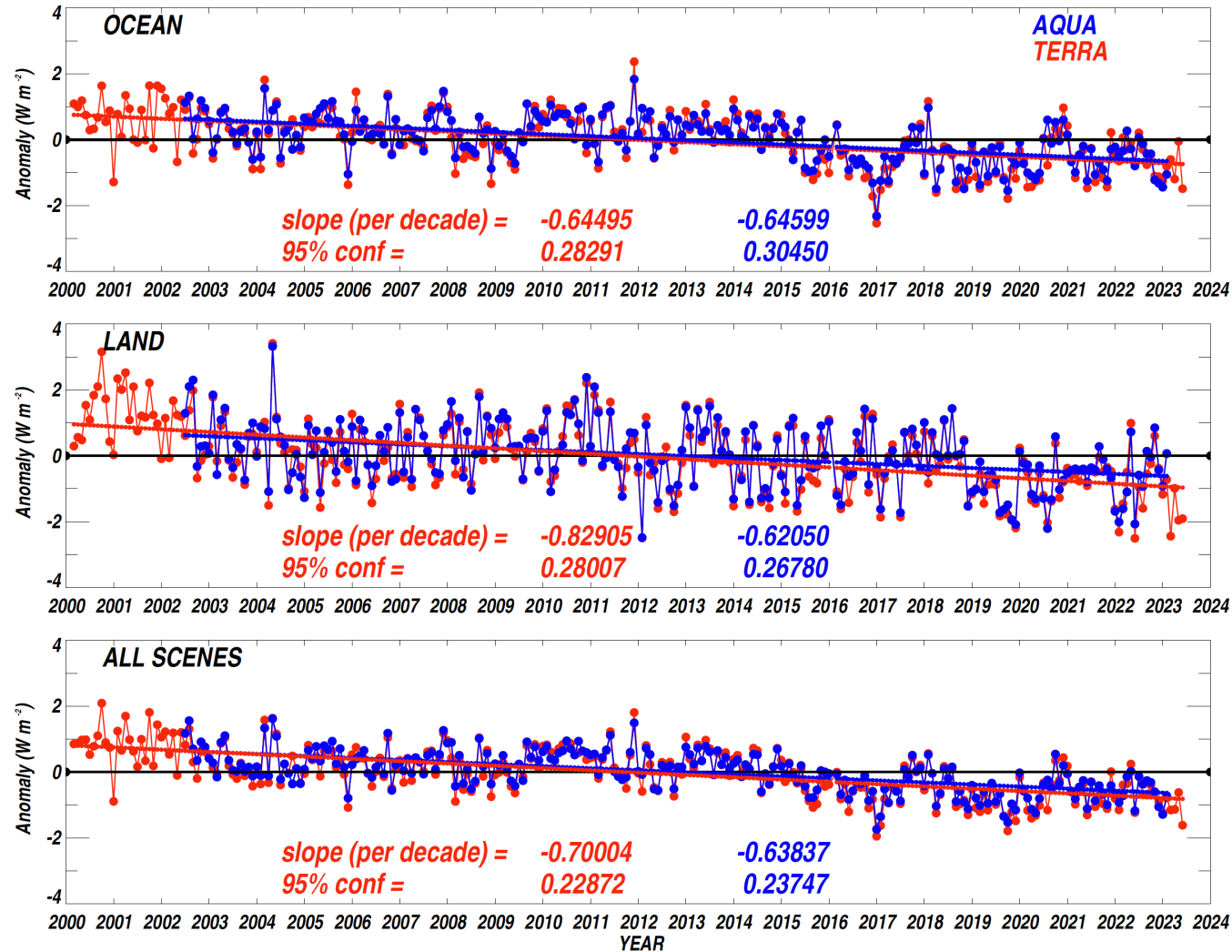


Uses Edition 4 ES-8 data products



# Validation: Terra and Aqua Ed-4 SW Flux Anomalies

## Anomaly of Terra and Aqua SW Flux (SSF1deg) for All Sky Scenes



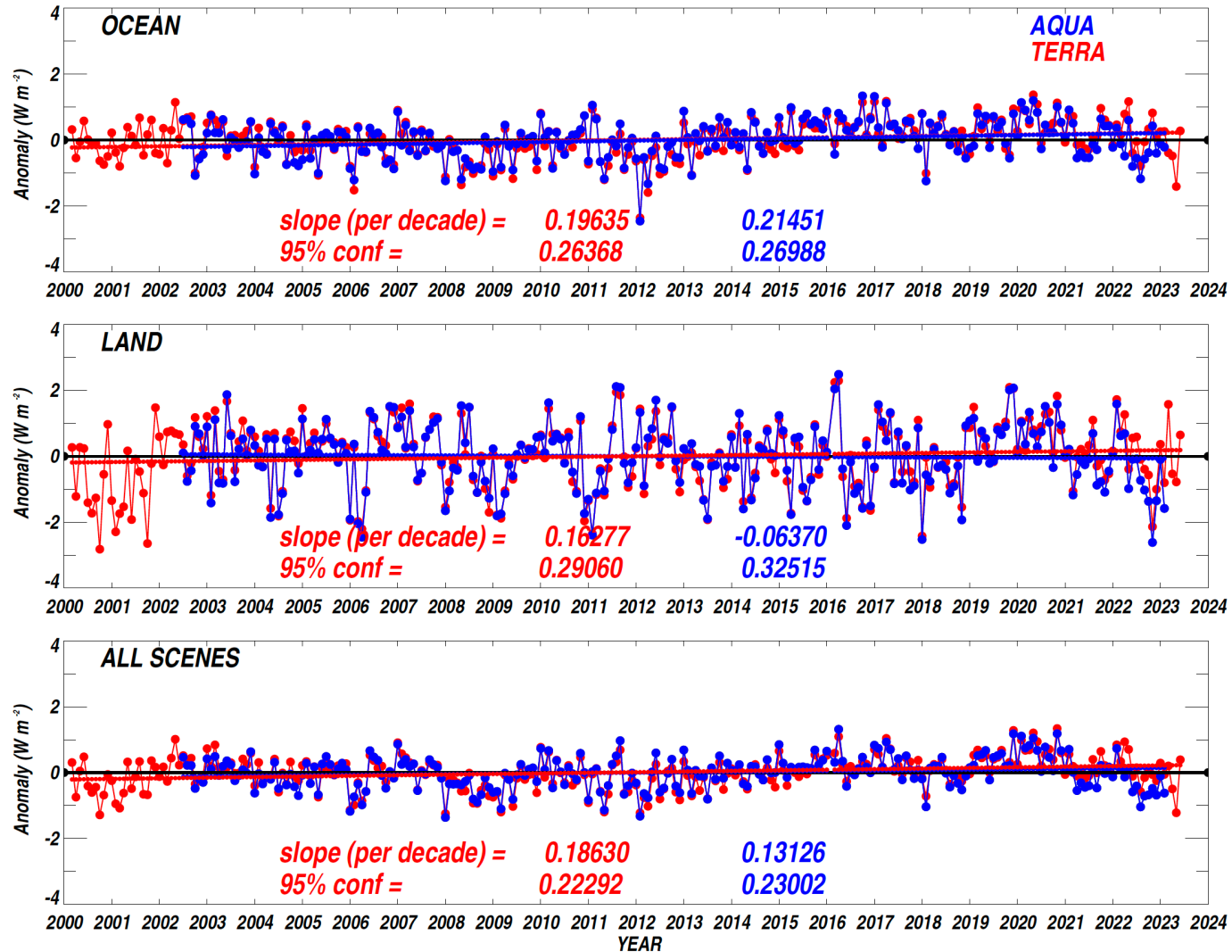
Level 3  
Edition 4 products

SW flux anomalies  
show similar  
trends for Terra  
and Aqua



# Validation: Terra and Aqua Ed-4 LW Flux Anomalies

## Anomaly of Terra and Aqua LW Flux (SSF1deg) for All Sky Scenes



Level 3  
Edition 4 products

LW flux anomalies  
show similar trends  
for Terra and Aqua.





# Terra-Aqua Intercomparisons

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- Terra and Aqua ground tracks cross nominally  $\sim 70^{\circ}$  N at local noon and  $\sim 70^{\circ}$  S at local midnight.
- Inter-comparison data analyzed for the Northern Hemisphere summer months (June, July and August).
- Use matching criteria to subset the data:
  - SZA, VZA difference  $< 2.0^{\circ}$
  - RAZ difference  $< 5^{\circ}$
  - Distance between footprints  $< 7$  km
- Differences computed on the subset are combined into a single average value for each year.

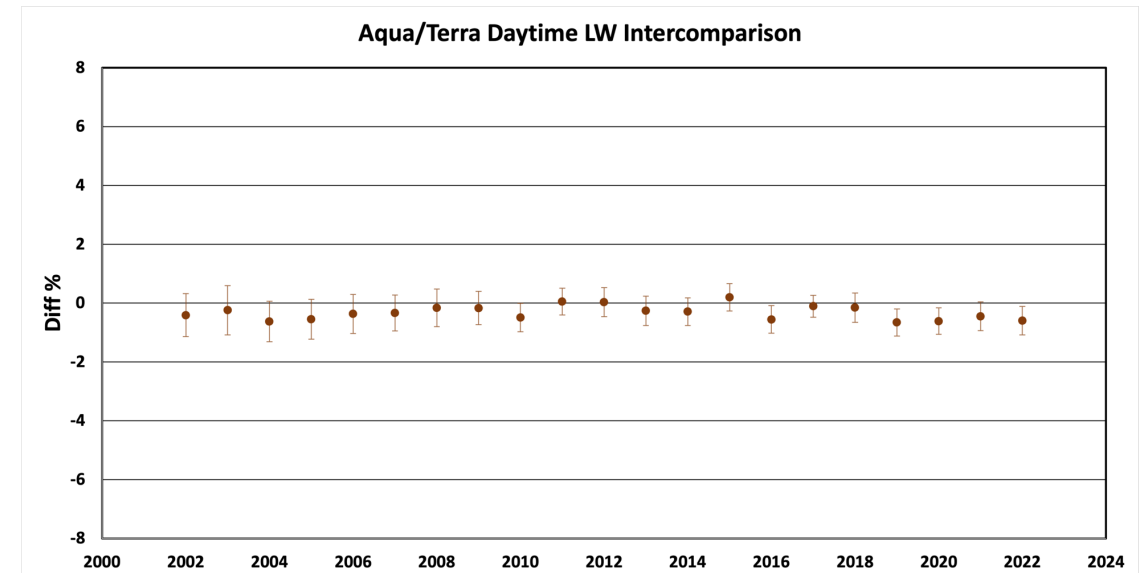
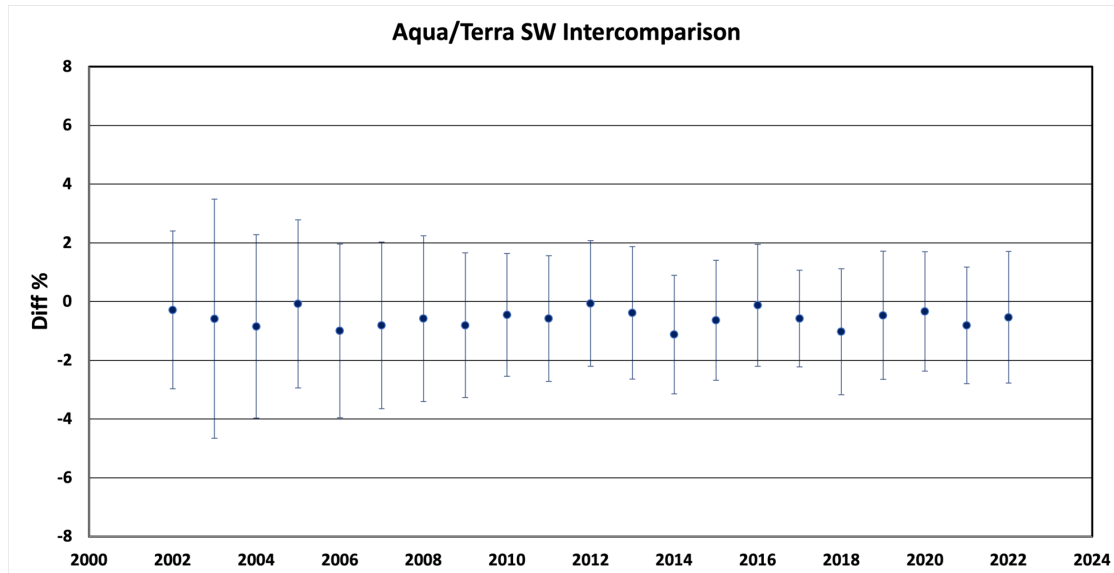


# Terra-Aqua All-sky Inter-comparisons: 2002- 2022

**Difference of Reflectance:  
Aqua-Terra %, 95% CI**

$$Reflectance = \frac{SW_{rad} * \pi}{F * \cos(SZA)} \quad F=1361 \text{ W/m}^2$$

**Difference of Daytime LW Radiance:  
Aqua-Terra %, 95% CI**



**Edition 4 Data products**

**Radiometric scaling of Aqua to Terra done in July 2002.**

**Data:**

CER\_SSF\_Aqua-FM3-MODIS\_Edition4A  
CER\_SSF\_Terra-FM1-MODIS\_Edition4A



**CERES Instrument Working Group**



# SUMMARY

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- 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; on-board calibrations continue to show the sensors' stable performance after the initial response rise.
  - SNPP/FM5 has transitioned back to crosstrack scan mode.
    - *No evidence of deviation of instrument performance while operating in biaxial mode.*
  - Terra and Aqua instruments' performance are monitored through validation studies as well as inter-comparisons with other CERES instruments.
- Level 1 Data products
  - NOAA-20/FM6 Edition 1 gains have been delivered through September 2023.
  - S-NPP/FM5 Edition 2 gains and SRFs have been delivered through July 2023.
  - Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through July 2023.
- Team is currently working on making necessary updates for the Edition 5 Data products.



# Backup



CERES Instrument Working Group



# Instrument Product-line definitions

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- **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.

