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

Mohan Shankar

CERES Instrument Working Group

CERES Spring Science Team Meeting
May 9, 2023

CERES Instrument Working Group

CERES Instrument Working Group

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Janet Daniels	Dale Walikainen	Hyung Lee
Christopher Brown	A. Thomas Grepiotis	Nathaniel Smith
Alexander Brown	Dianne Snyder	Nitchie Smith
Ethan Ames		Z. Peter Szewczyk
Carol Kelly		Robert Wilson

CERES Instrument Status Summary

- **All CERES instruments continue to demonstrate stable performance.**
  - **NOAA-20/FM6 instrument continues to perform nominally.**
  - **SNPP/FM5 is currently operating in full biaxial mode.**
    - ***No evidence of deviation of instrument performance since transitioning to biaxial mode.***
  - **Terra and Aqua instruments are conducting Cross-track, biaxial, and GEOSAT scans.**
    - **Validations show that all instruments are performing consistently.**

- **Level 1 Data products**
  - **NOAA-20/FM6 Edition 1 gains have been delivered through March 2023.**
  - **S-NPP/FM5 Edition 2 gains and SRFs have been delivered through January 2023.**
  - **Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through February 2023.**

CERES Instrument Operations Summary

Spacecraft	Instrument	Operational Mode	Notes
NOAA20	FM6	XTK	
SNPP	FM5	BIAX	Full BIAX mode started on Mar 23, 2020
Aqua	FM4	XTK	Operated in BIAX from Jul 14, 2021, till Mar 22, 2023
Aqua	FM3	BIAX + GEOSAT	GEOSAT started on Feb 1, 2023; BIAX started on Mar 22, 2023
Terra	FM2	BIAX	BIAX started on Nov. 1, 2021
Terra	FM1	XTK + GEOSAT	GEOSAT started on Feb 1, 2023

XTK: Cross-track
BIAX: Biaxial (RAP)

GEOSAT :

- 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.

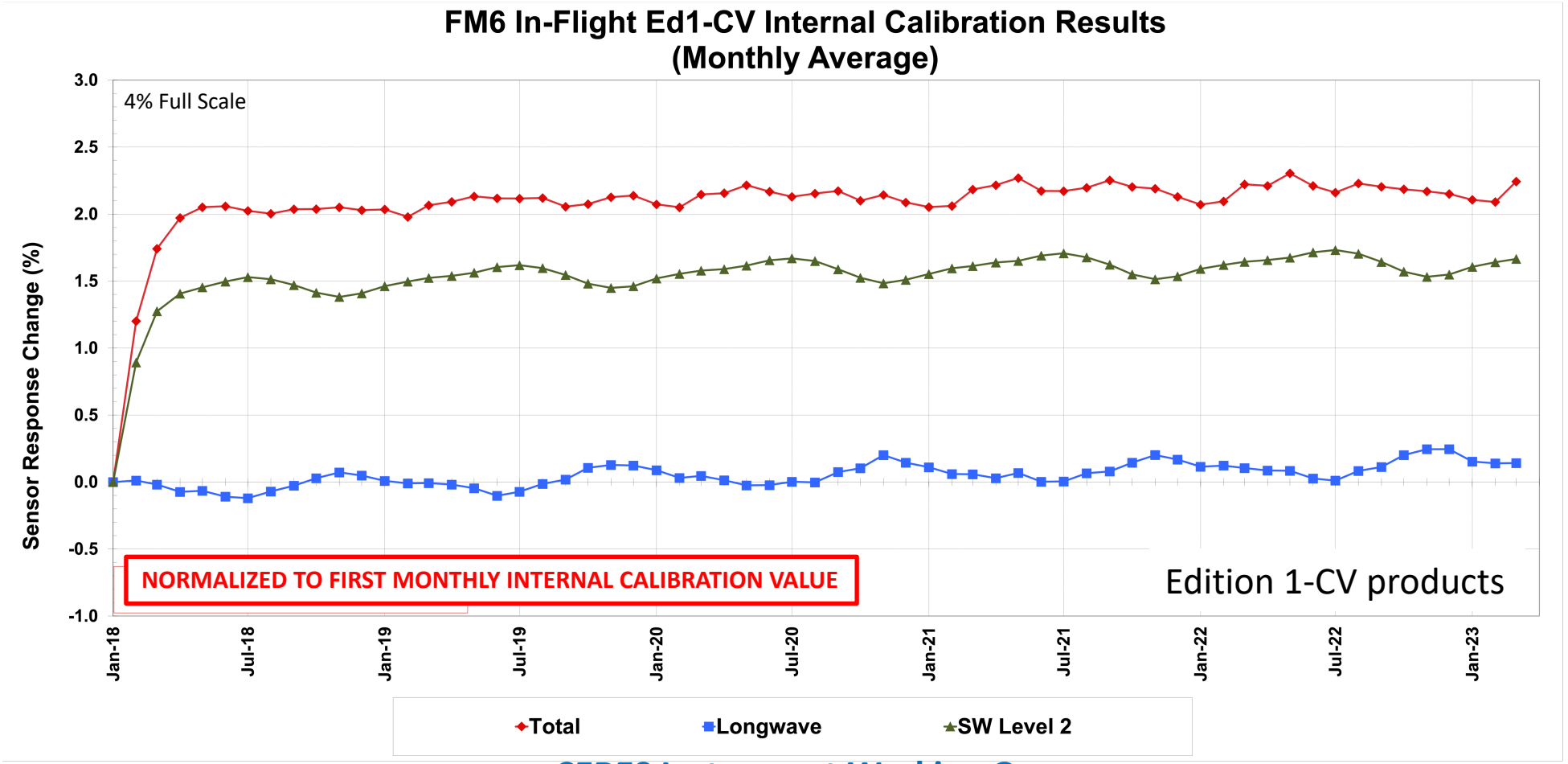
CERES Instrument Operations Summary Cont'd

- **Inter-comparison operations planned in summer 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

NOAA-20/FM6 Instrument Status

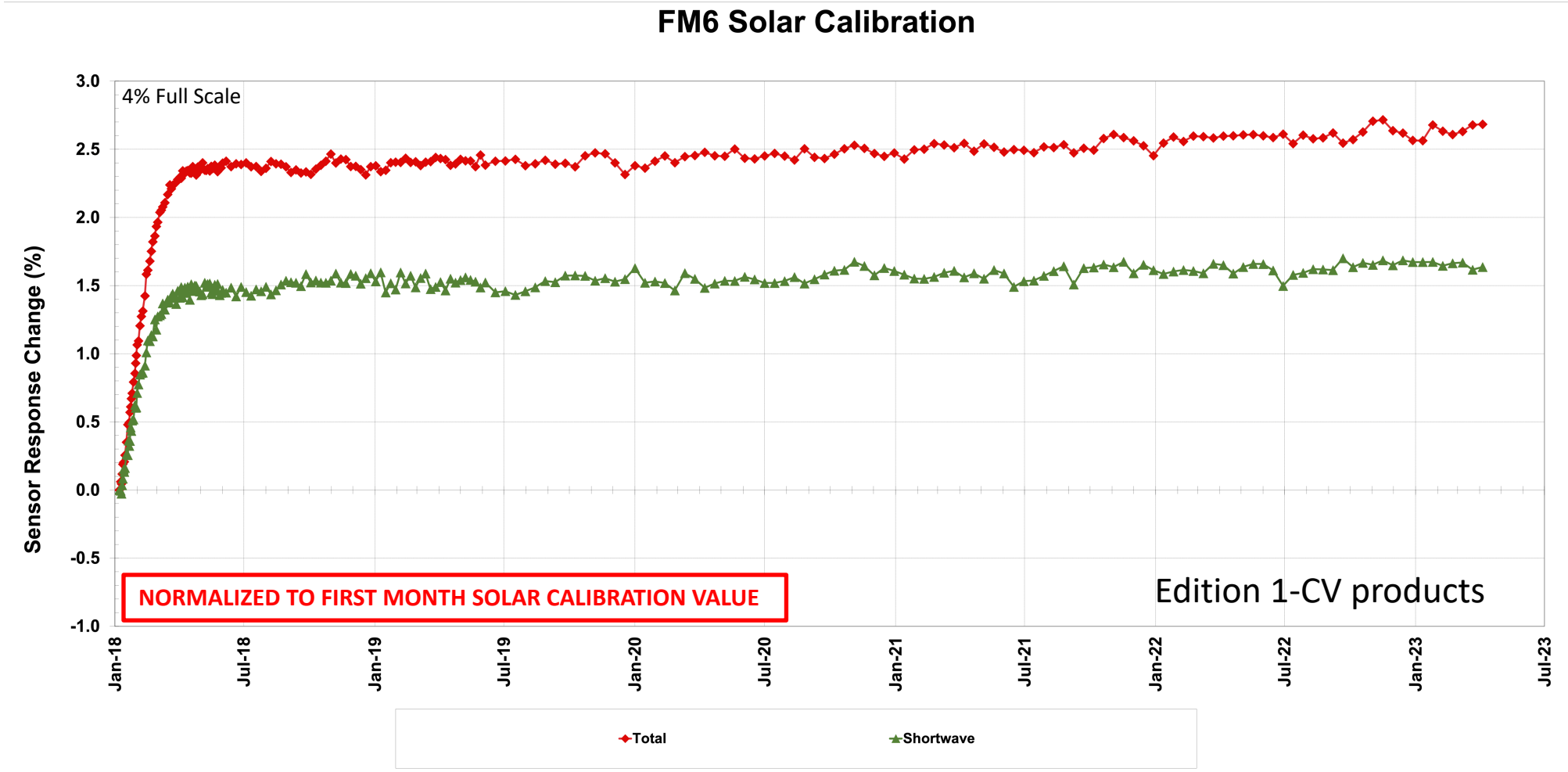
FM6 Internal Calibration

- **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.**



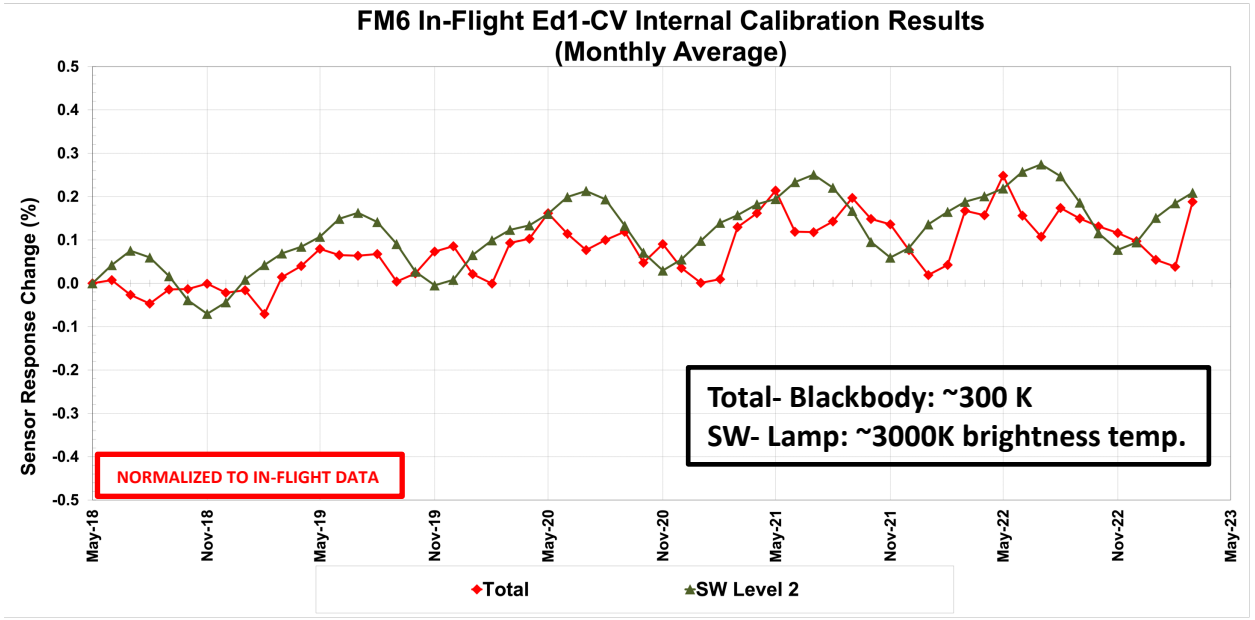
FM6 Solar Calibration

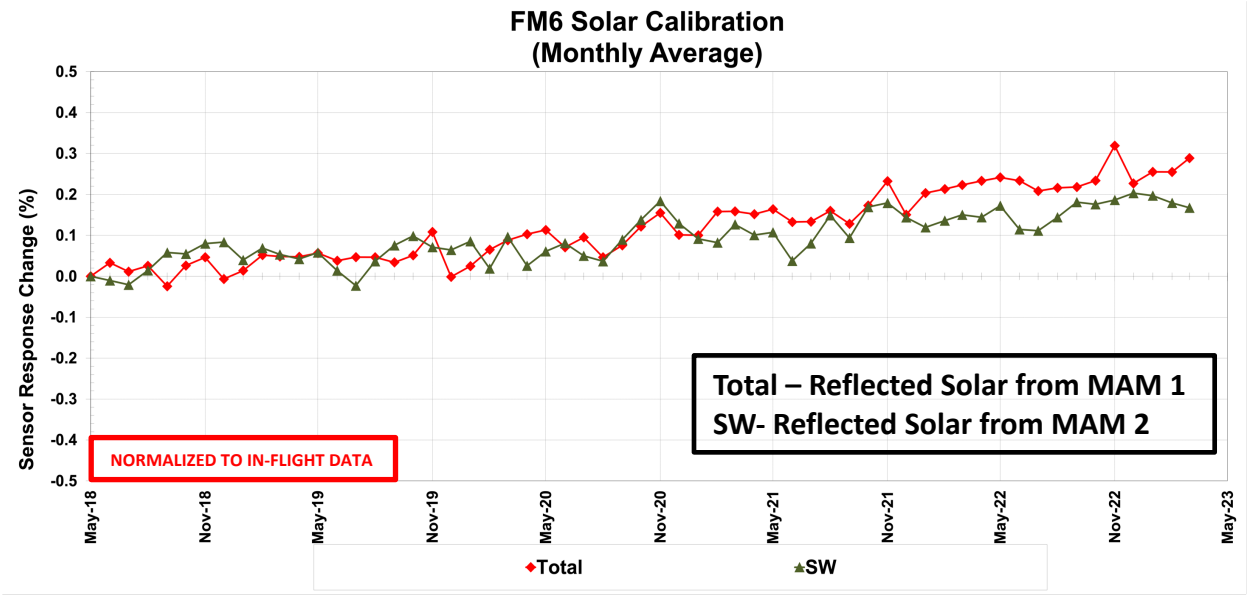
- **Response of the SW and TOT channels while viewing the MAM that is illuminated by the sun.**
- **After the initial rise of ~1.5% for SW, and ~2.3% for TOT, the response is quite stable.**



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.





Edition 1-CV products

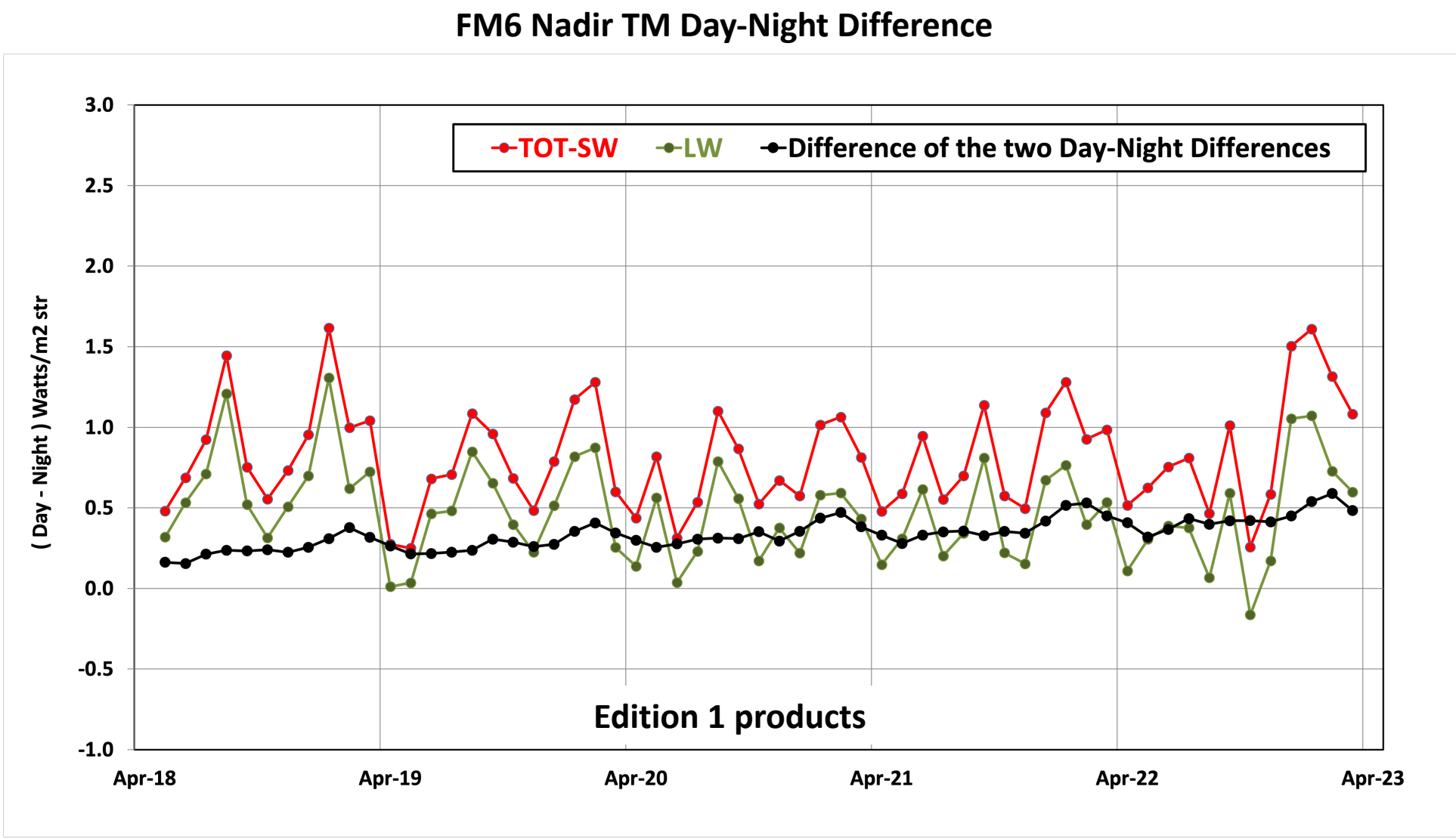
Validation – FM6 Tropical Mean

- Average of the Nadir radiances over Tropical ocean (20^0N-20^0S) 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

    $DN = TM_D(TOT\text{-}SW) - TM_N(TOT)$
  - 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

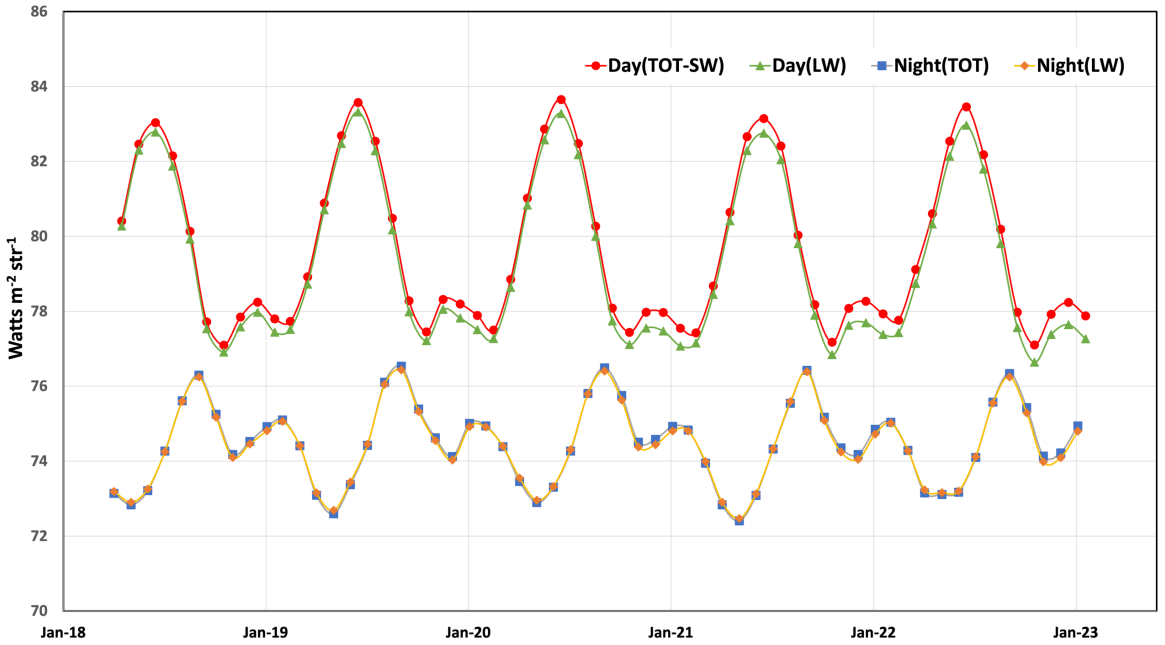


FM6 3-channel Consistency check- Global Day-Night Differences

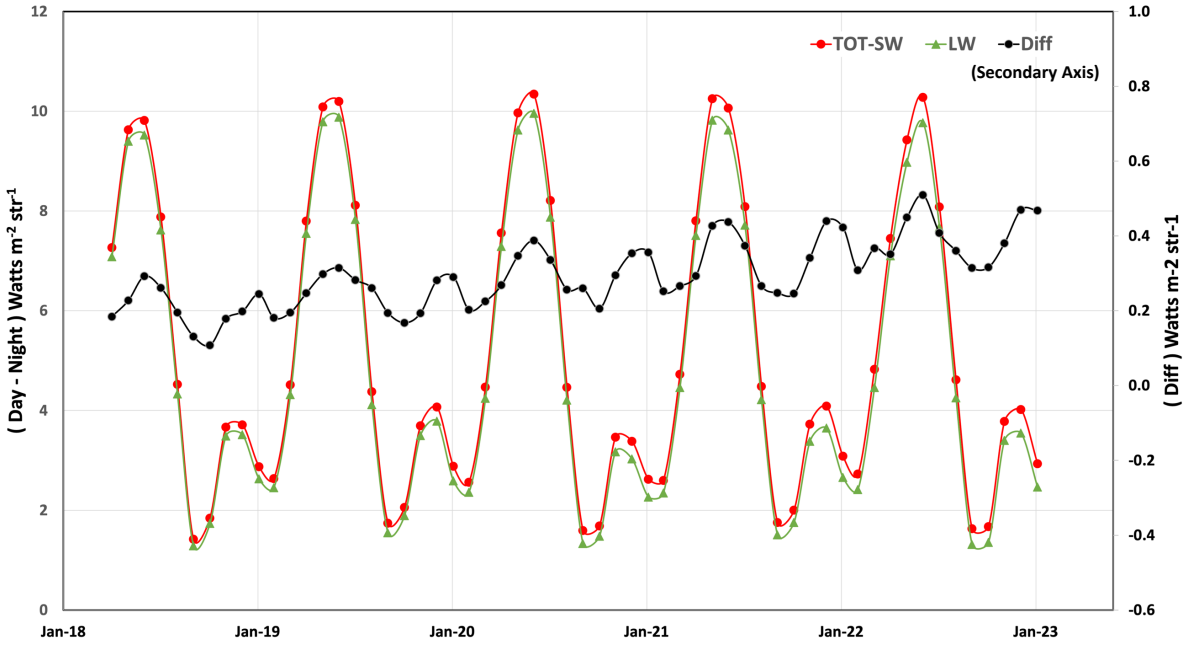
May 2018 - Jan 2023

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

FM6 Edition 1 Global Mean LW radiance



Day-Night Difference



Edition 1 data products

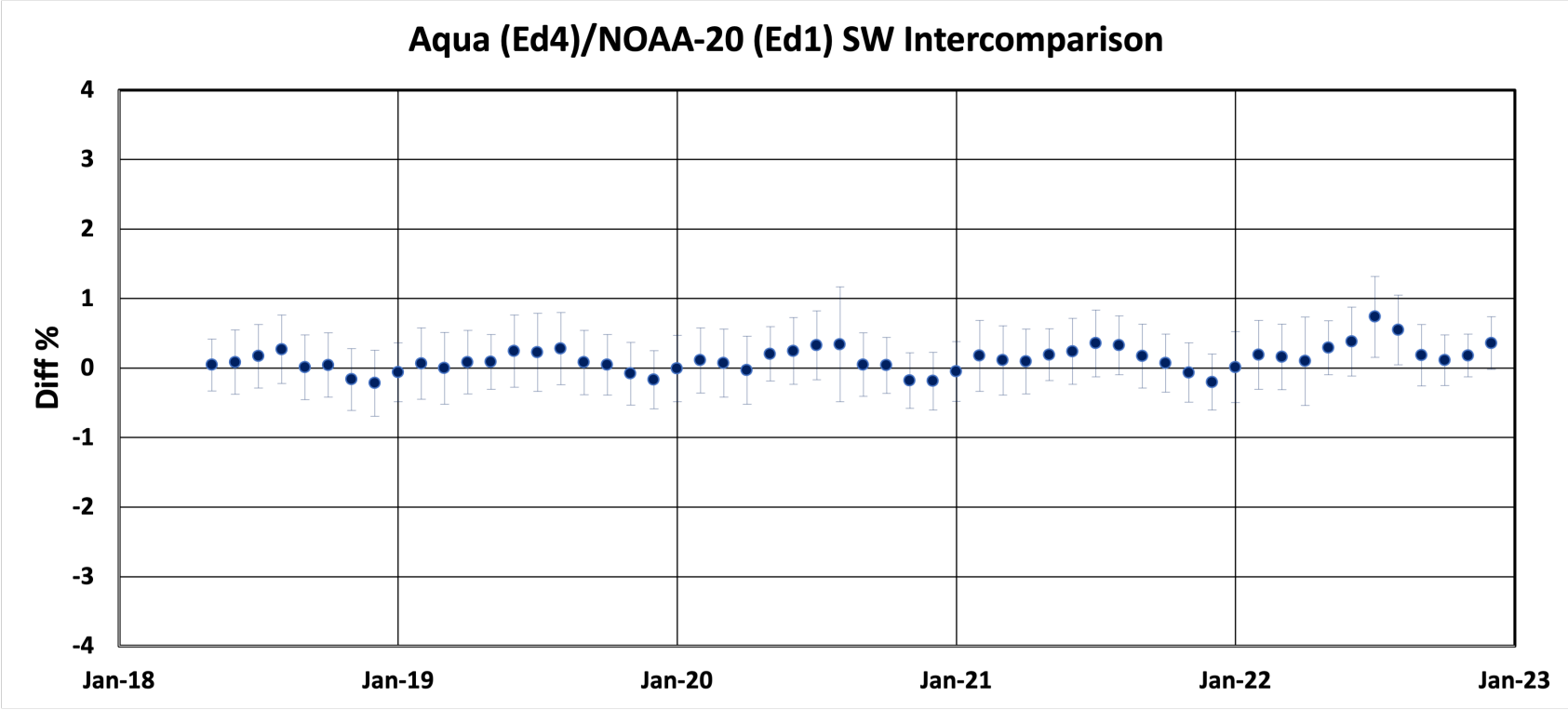
Aqua/NOAA-20 Intercomparisons

- The 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; Both instruments continue operating in cross-track mode.
- Use matching criteria to subset the data:
  - SZA, VZA difference < **2.0^0**
  - RAZ difference < **5^0**
  - Distance between centroid of footprints **< 7 km**
- Obtain monthly all-sky SW reflectance and LW radiance differences using the matched footprints.

FM3/FM6 SW All-sky Inter-comparisons: May 2018- Dec 2022

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

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



Edition 1 Data products

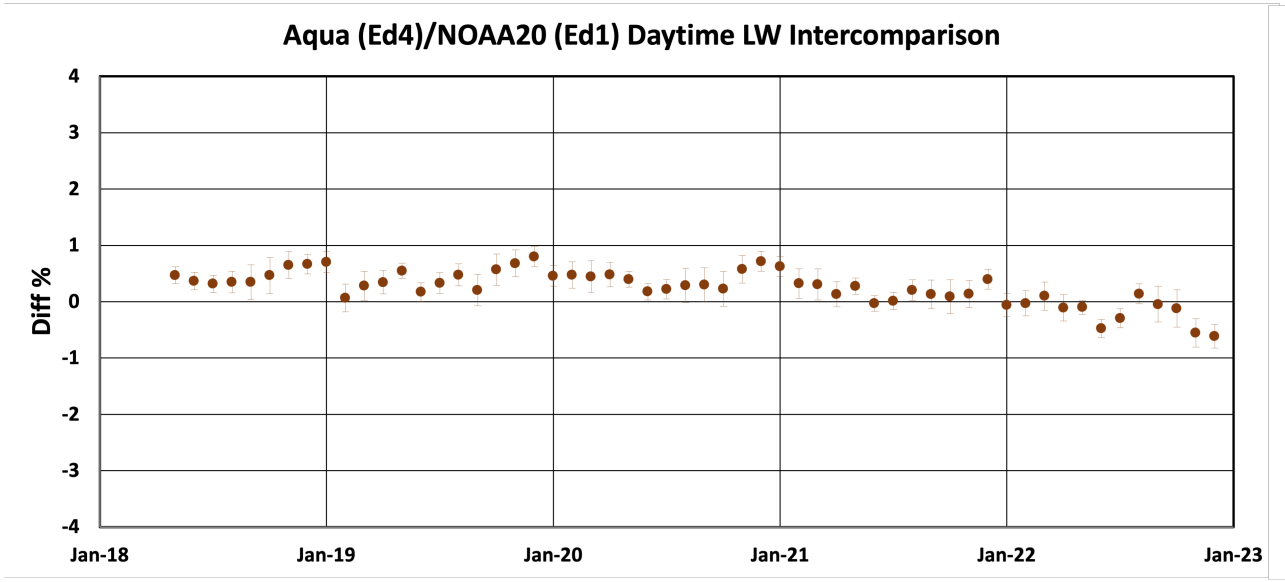
Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM6-VIIRS_Edition1B

Radiometric scaling of FM6 to FM3 done in May 2018.

FM3/FM6 LW All-sky Inter-comparisons: May 2018-Dec 2022

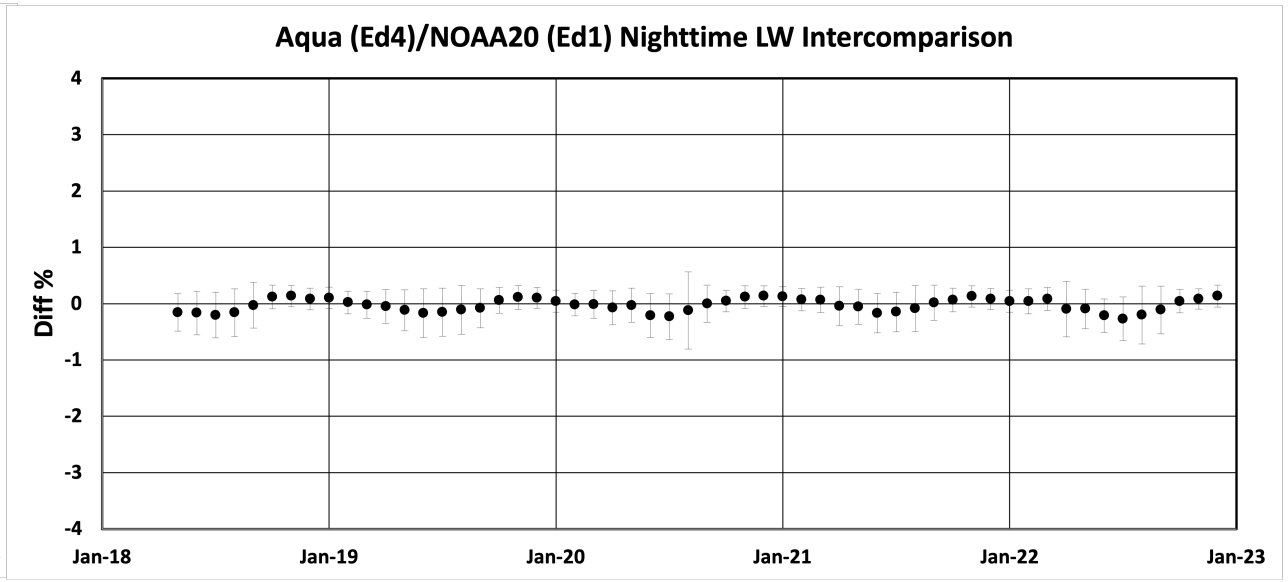
Difference of Daytime Radiance: FM3-FM6 %, 95% CI

Daytime LW for FM6 obtained from TOT-SW



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

Nighttime LW for FM6 obtained from TOT

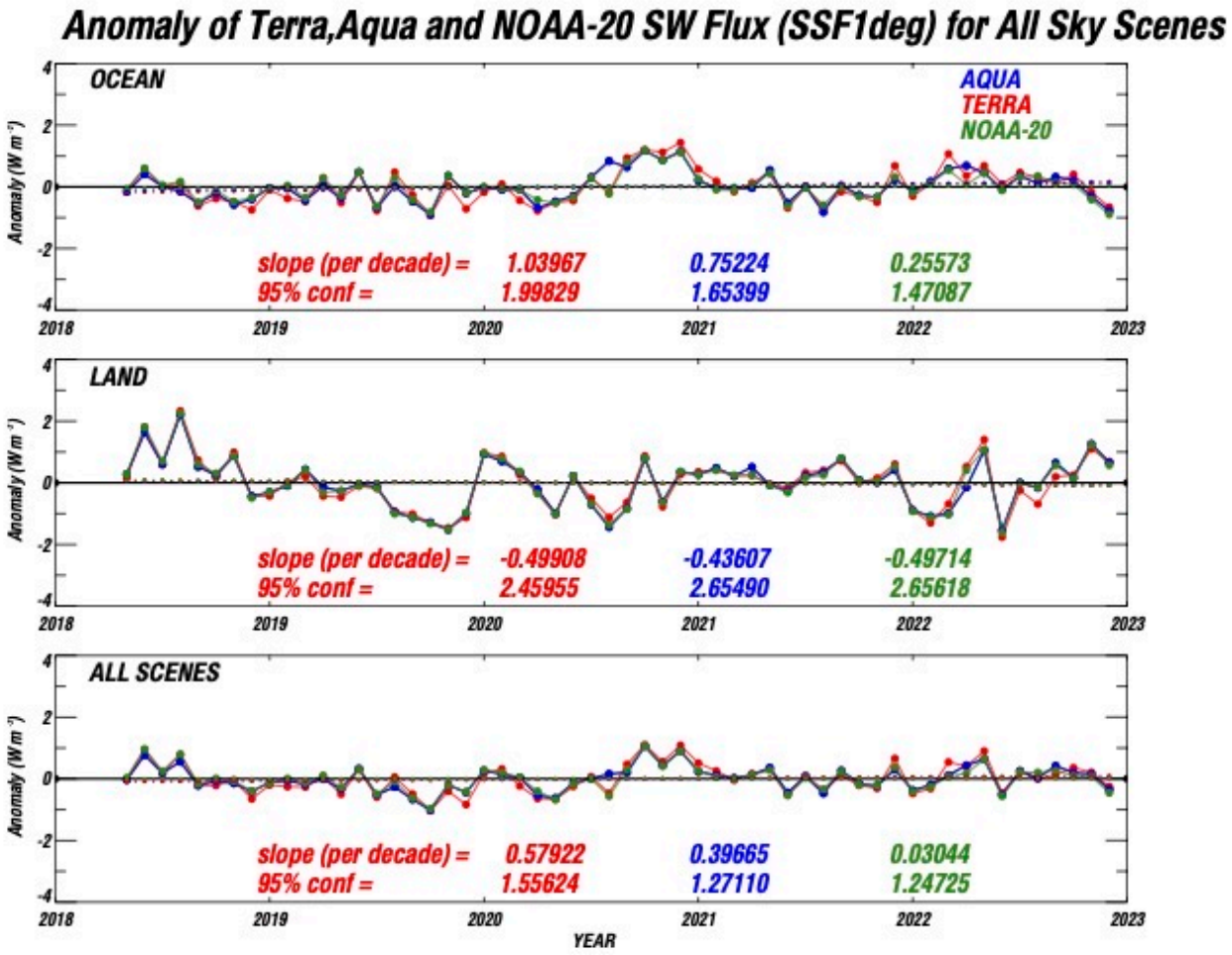


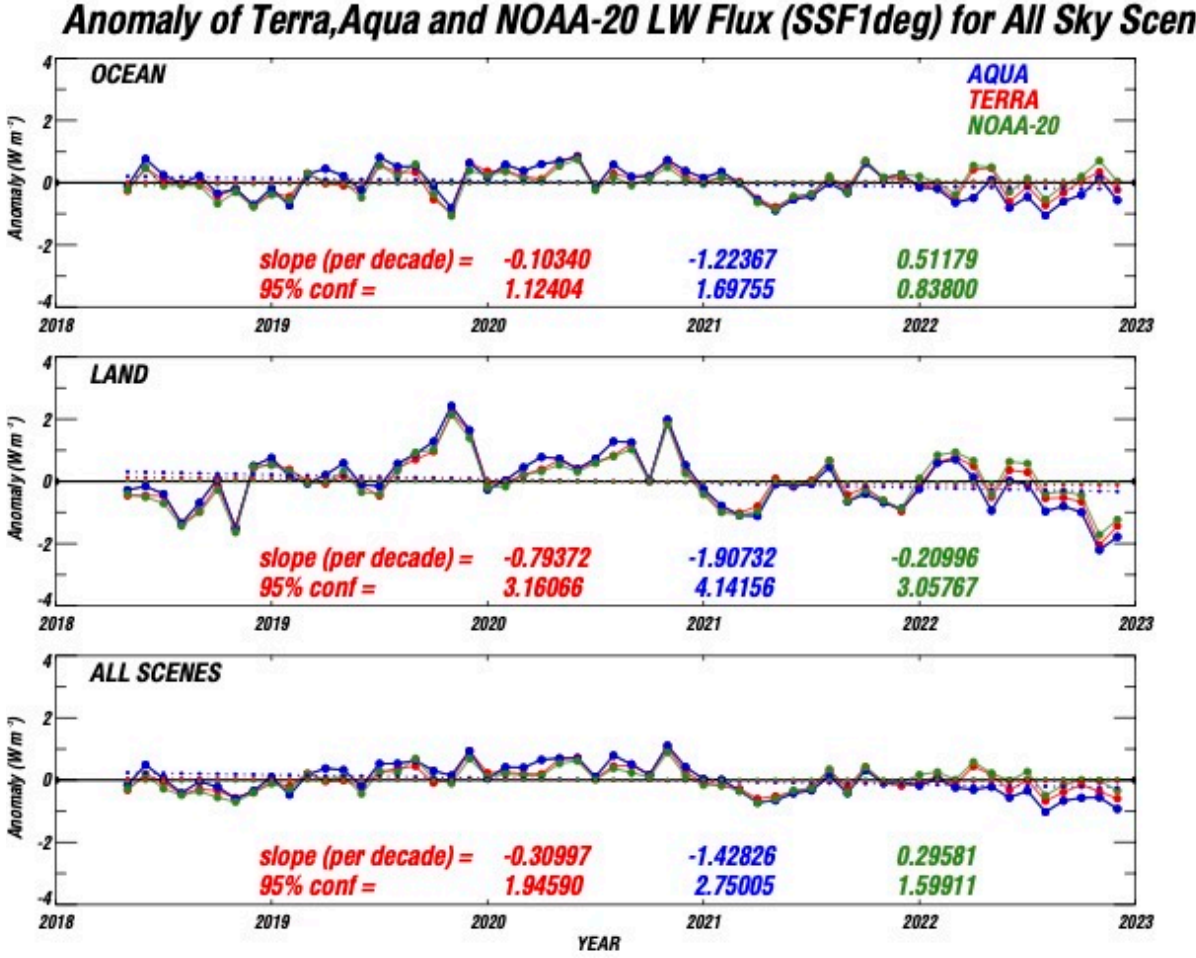
Edition 1 Data products

Radiometric scaling of FM6 to FM3 done in May 2018.

Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM6-VIIRS_Edition1B

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





Terra, Aqua and NOAA20 flux anomalies are consistent

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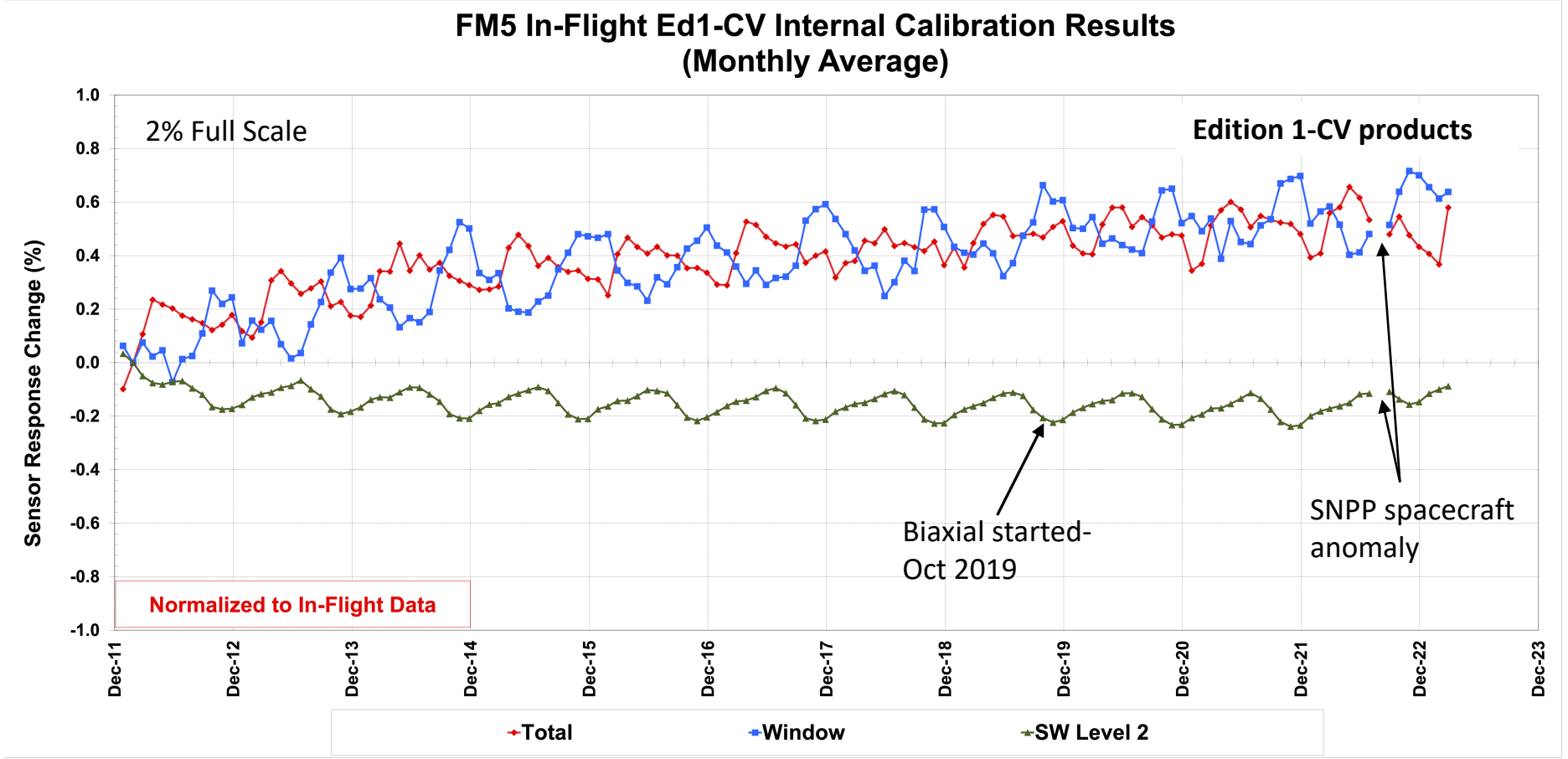
NOAA20: CER_SSF1deg-Month_NOAA20-VIIRS_Edition1
Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A
Aqua: CER_SSF1deg-Month_Aqua-MODIS_Edition4A

S-NPP/FM5 Instrument Status

FM5 Internal Calibration

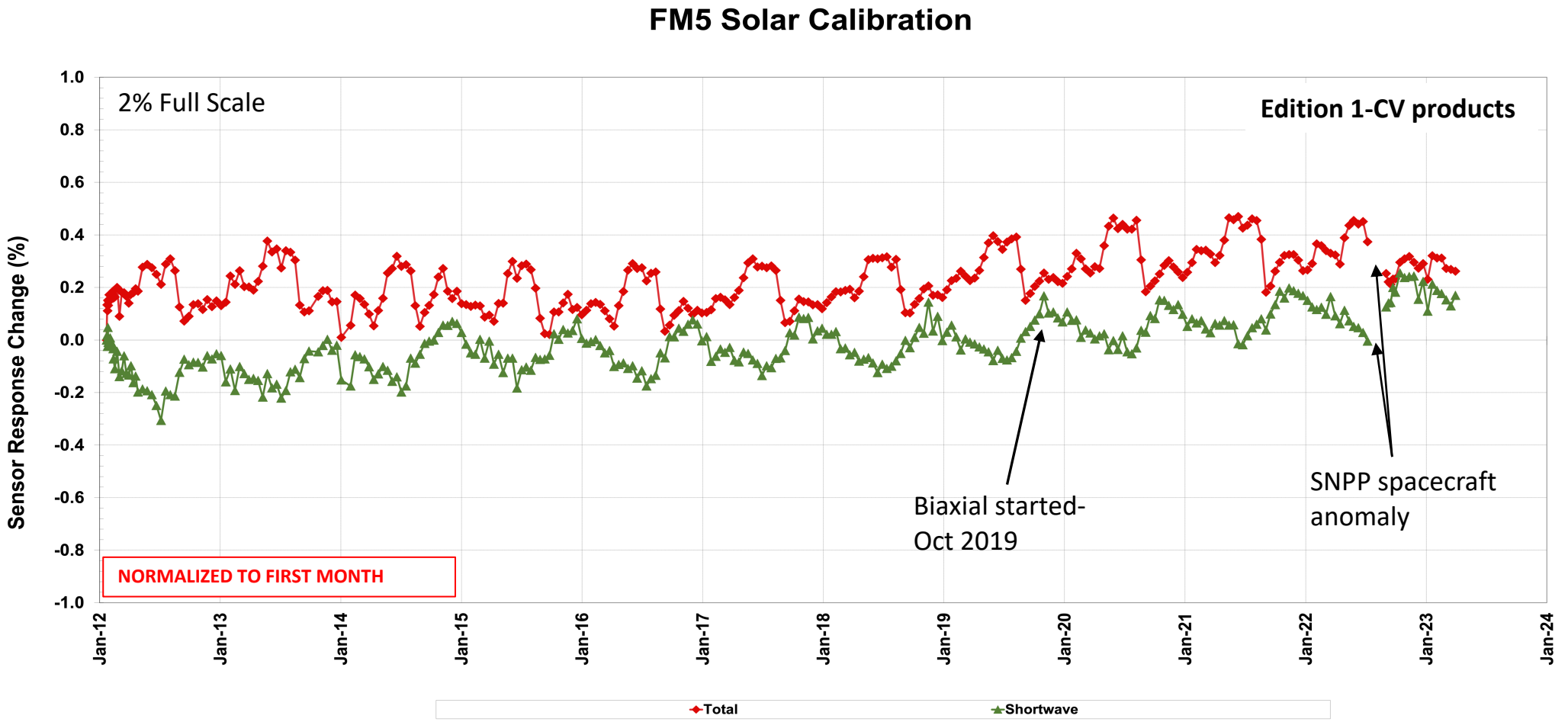
In response to the blackbodies, the FM5 TOT and WN sensors show a ~0.6% rise since start of mission.

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



FM5 Solar Calibration

- **FM5 Solar calibration results show the MAMs are very stable.**
- **SW response shows a slight upward trend in latter part of mission.**



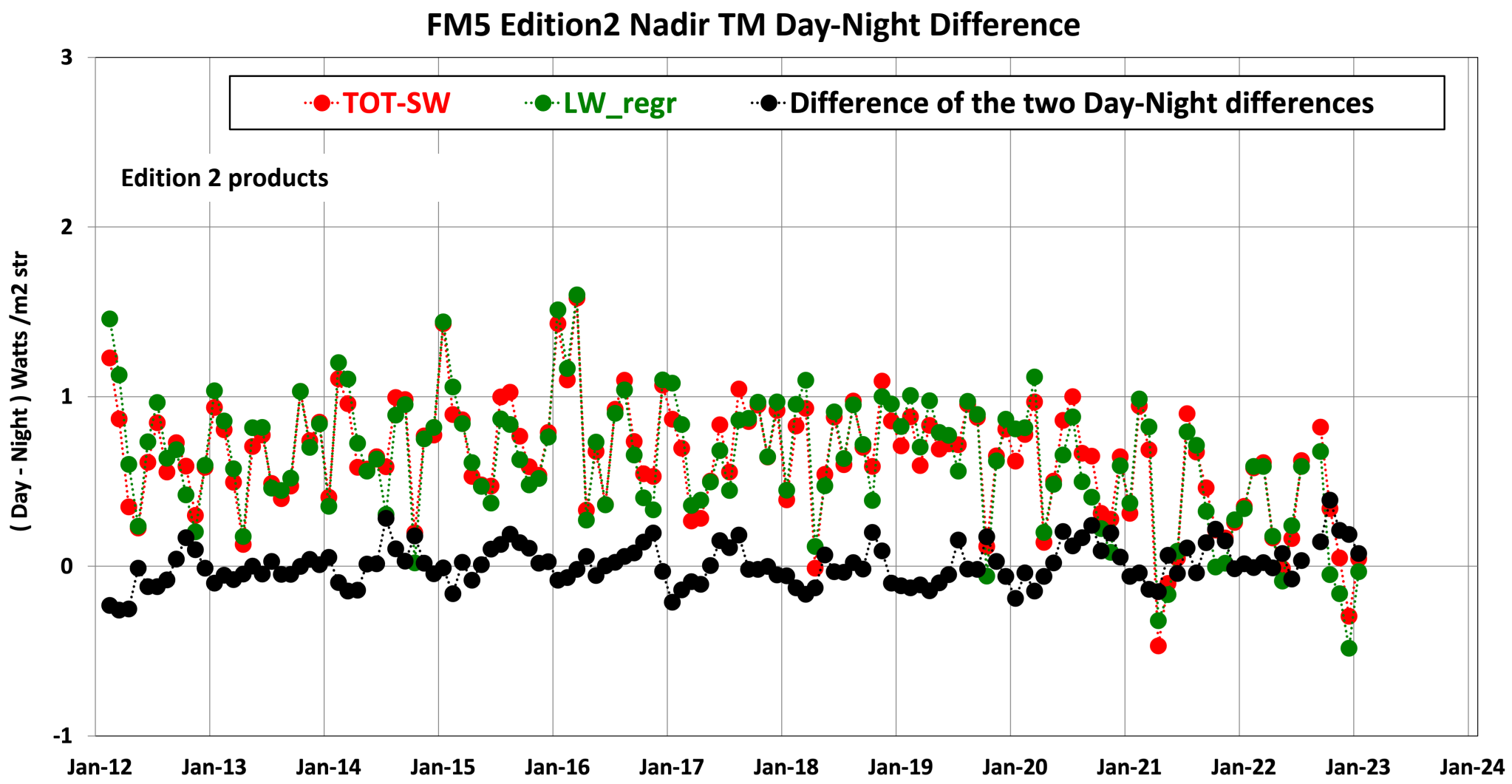
Validation – Tropical Mean (FMs 1-5)

- Average of the ES-8 Nadir radiances over Tropical ocean (20^0N-20^0S) 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

    $DN = TM_D(TOT\text{-}SW) - TM_N(TOT)$
  - 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



Aqua/S-NPP Intercomparisons

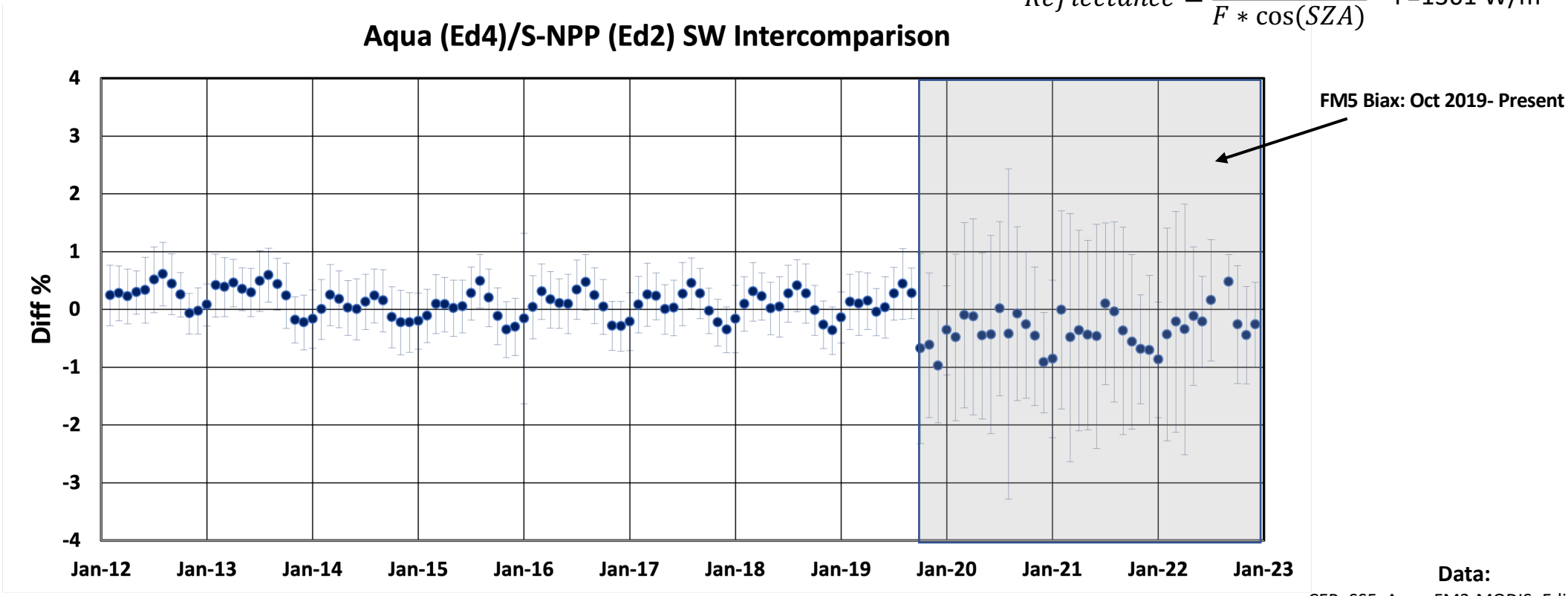
- The orbital geometries for Aqua and S-NPP are such that orbital overlaps occur every ~64 hours.
- Obtain spatially and temporally matched observations during every crossover.
- No special operations conducted; FM5 continues operating in biaxial mode.
- Use matching criteria to subset the data:
  - SZA, VZA difference < **2.0^0**
  - RAZ difference < **5^0**
  - Distance between footprints **< 7 km**
- Obtain monthly all-sky SW reflectance and daytime LW radiance differences using the matched footprints.
- *Since FM5 is operating in biaxial mode, the number of matched footprints has drastically reduced.*

FM3/FM5 SW All-sky Inter-comparisons: Feb 2012- Dec 2022

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



2014 data used for the radiometric scaling FM5 to FM3.

Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM5-VIIRS_Edition2A

Larger uncertainties after FM5 switched to biaxial mode are driven by the drastic reduction in number of spatially and temporally matched observations.

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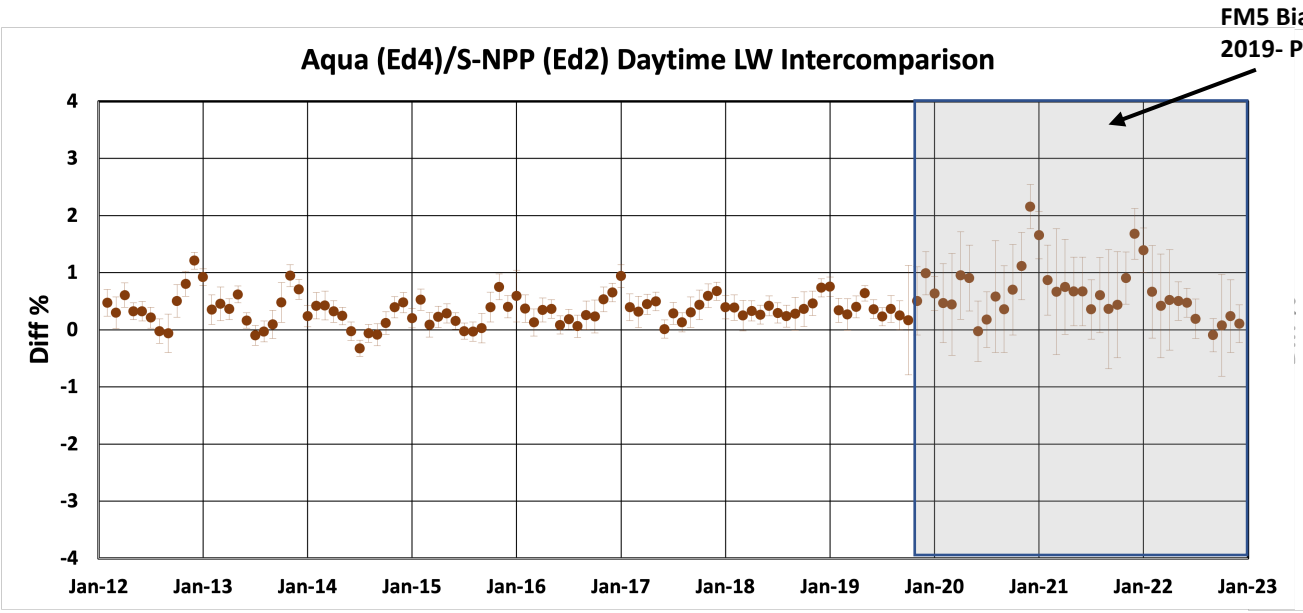
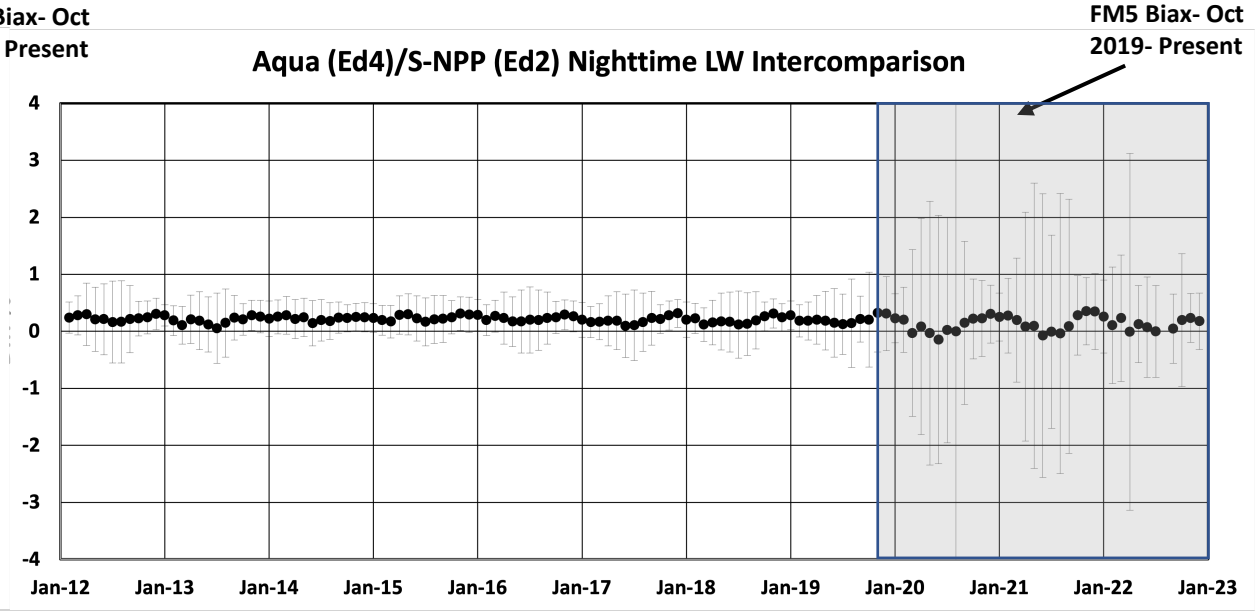
FM3/FM5 LW All-sky Inter-comparisons: Feb 2012- Dec 2022

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



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



2014 data used for the radiometric scaling FM5 to FM3.

Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM5-VIIRS_Edition2A

Larger uncertainties after FM5 switched to biaxial mode are driven by the drastic reduction in number of spatially and temporally matched observations.

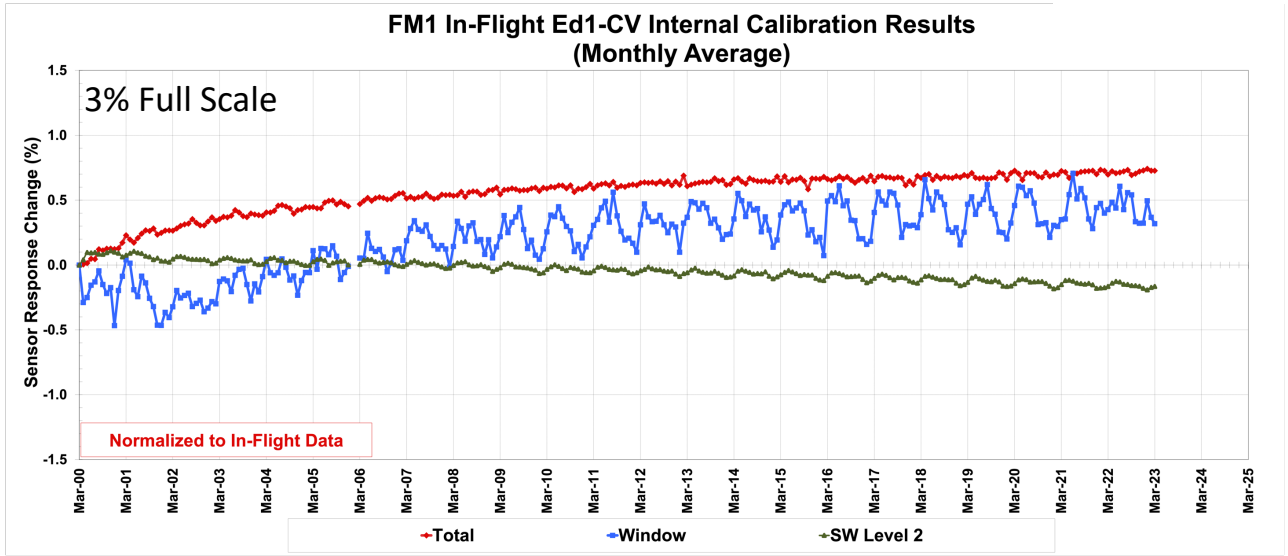
CERES Instrument Working Group

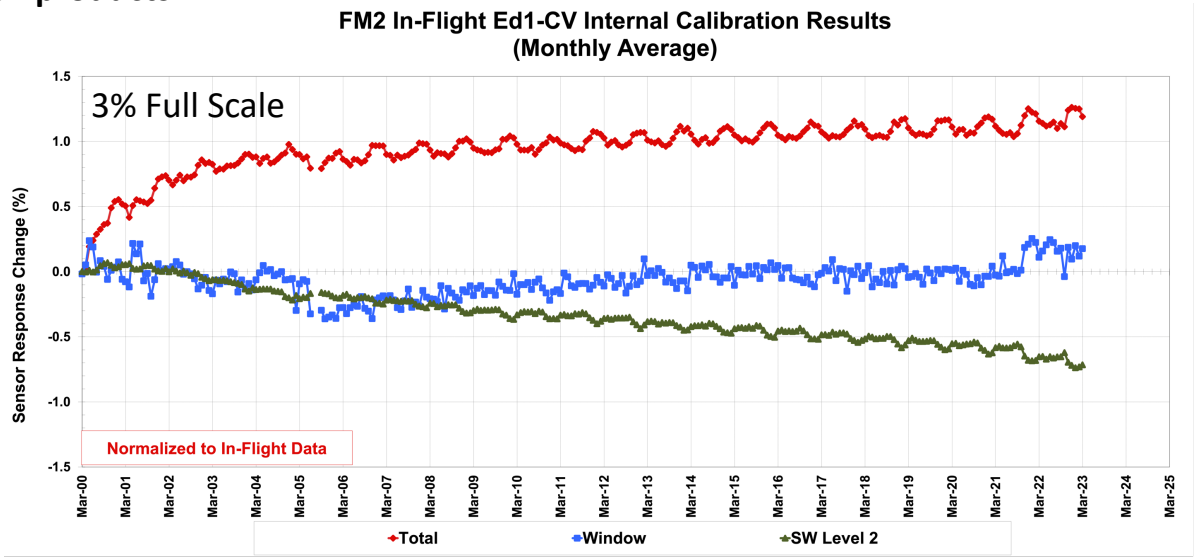
Terra & Aqua
FM1-FM4 Instruments' Status

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

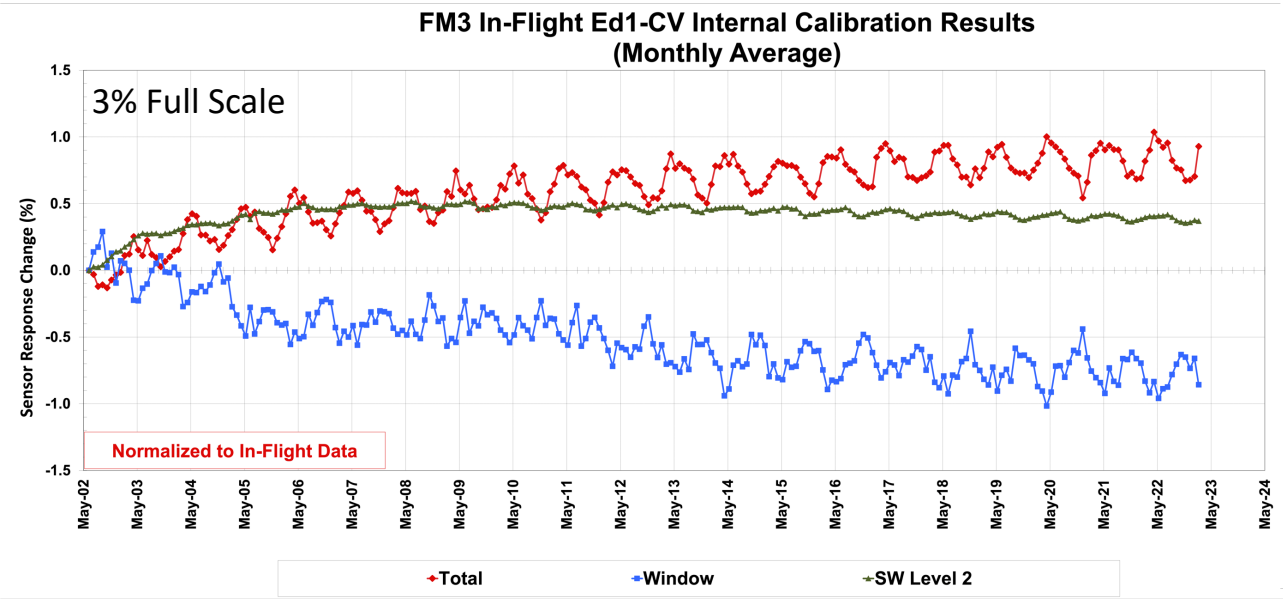


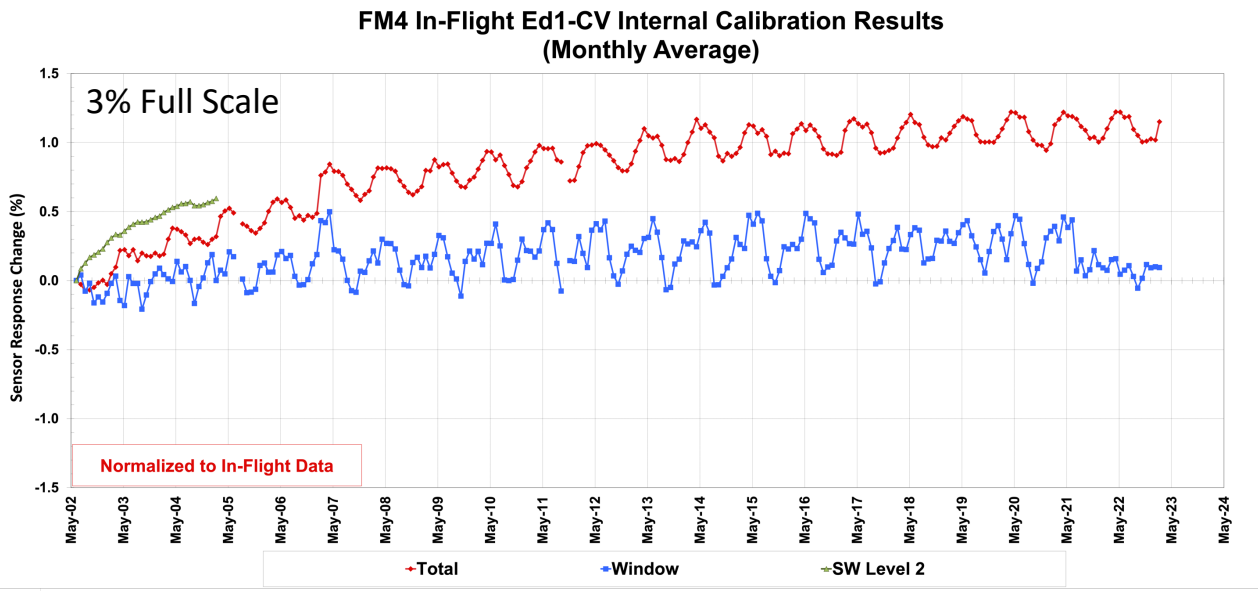


Total, WN- Blackbody: ~300 K
SW- Lamp: ~3000K brightness temp.

Aqua- FM3 and FM4 Internal Calibration

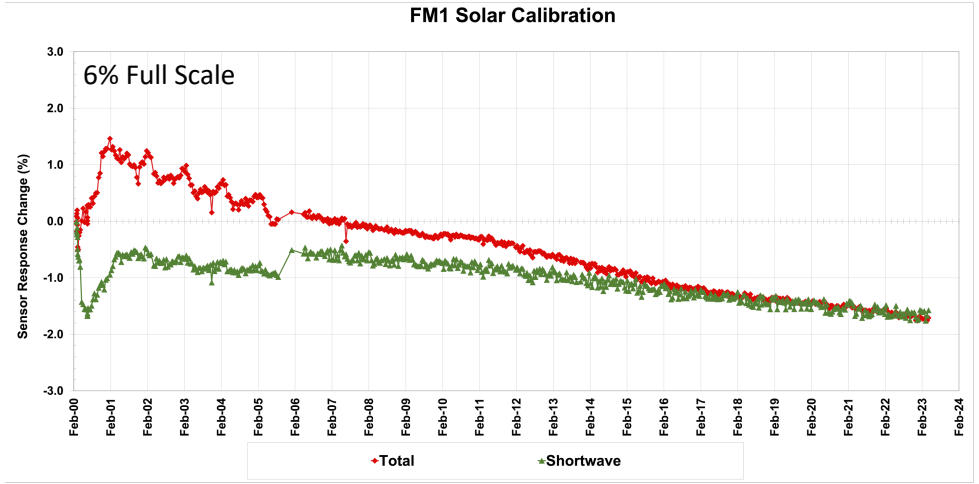
- **For FM3, TOT channel shows ~0.8% rise, SW channel shows ~0.4% rise, and WN channel shows ~0.8% drop since start of mission.**
- **For FM4, TOT channel shows ~1.2% rise, while WN channel shows ~0.25% rise since start of mission. FM4 transitioned to BIAX in Jul 2021, back to XTK in Mar 2023.**

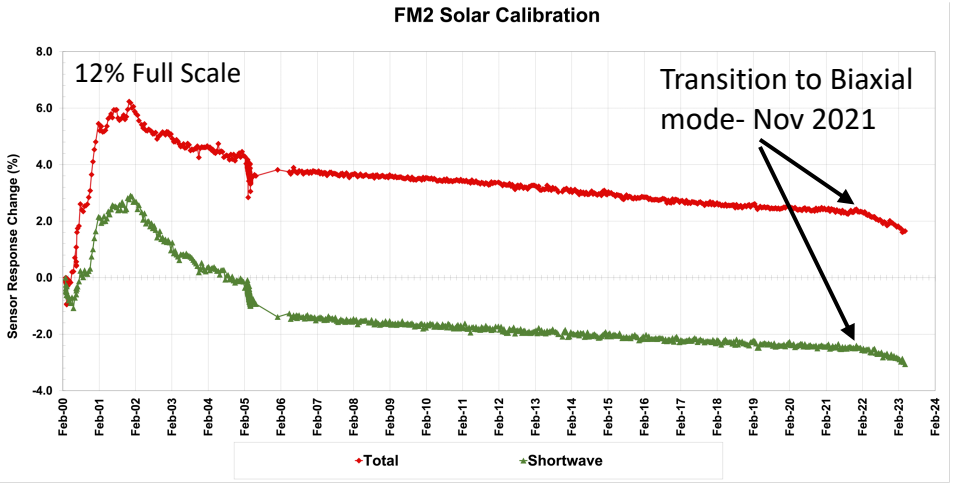




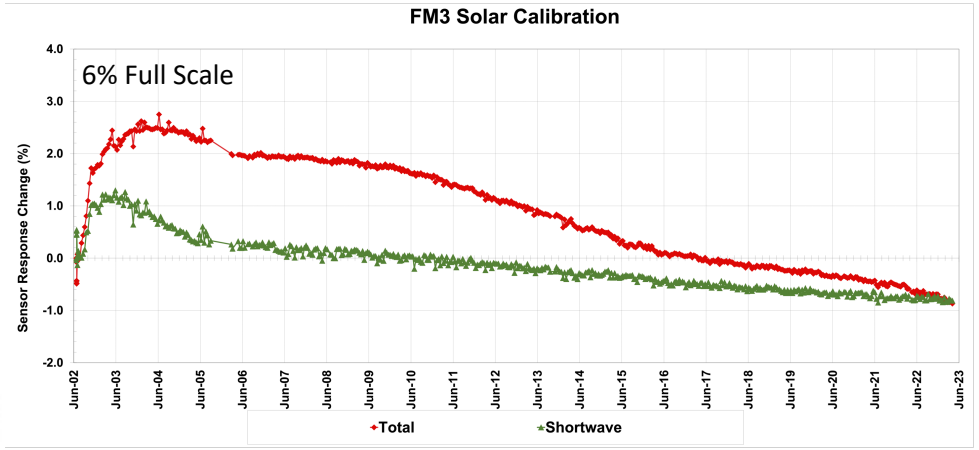
Terra & Aqua Solar Calibration

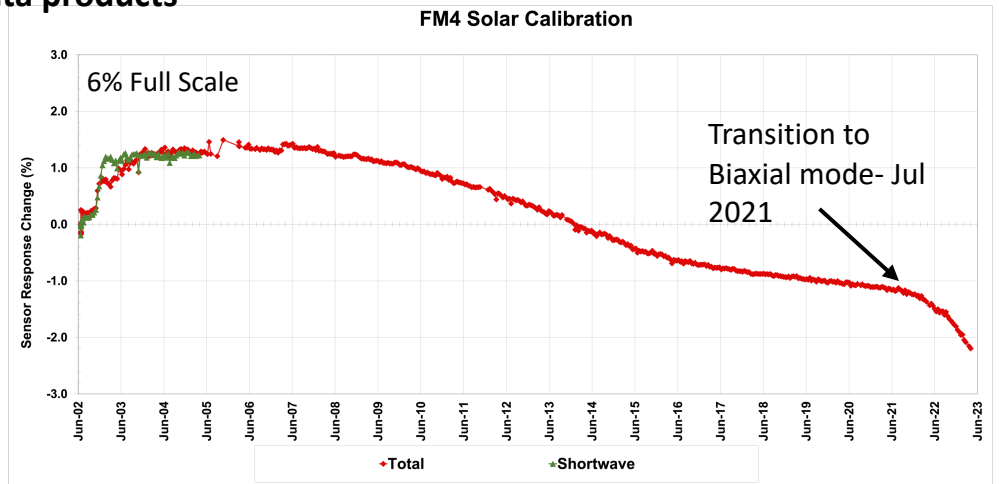
Since the transition to biaxial scanning, the TOT and SW channel on FM2 shows a drop in response of ~0.5%, while the TOT channel on FM4 shows a drop of ~0.8%.



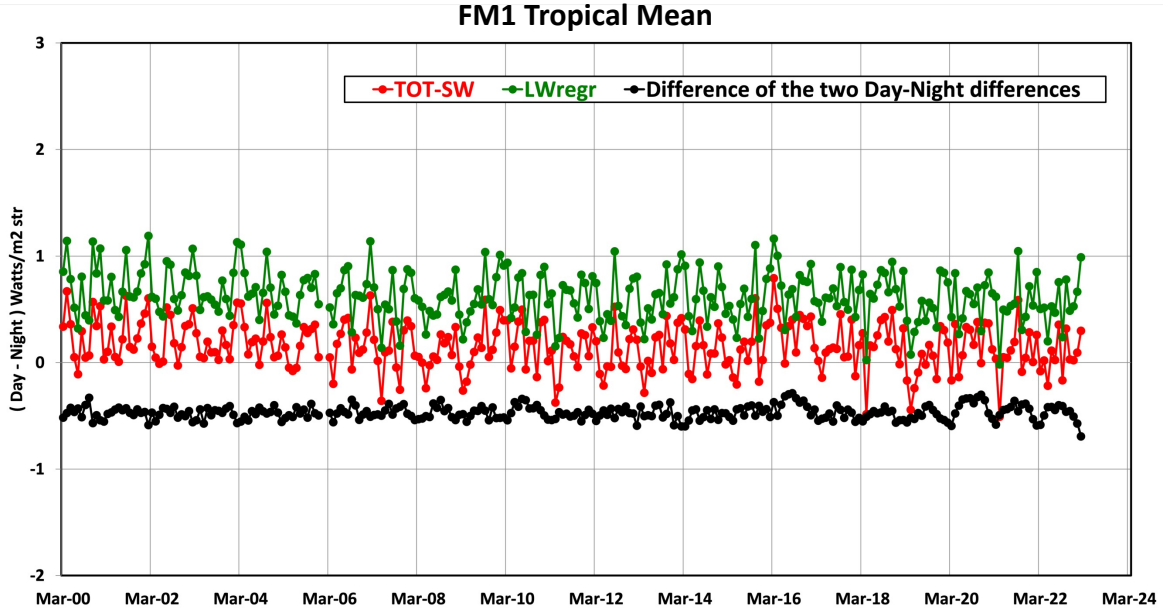


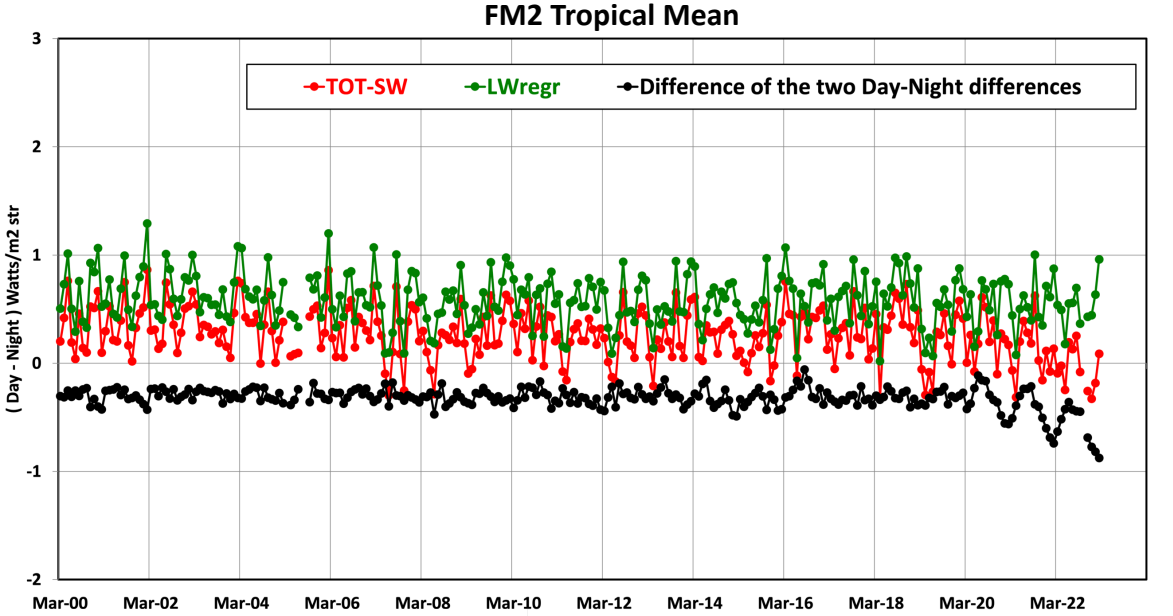
Edition 1-CV data products

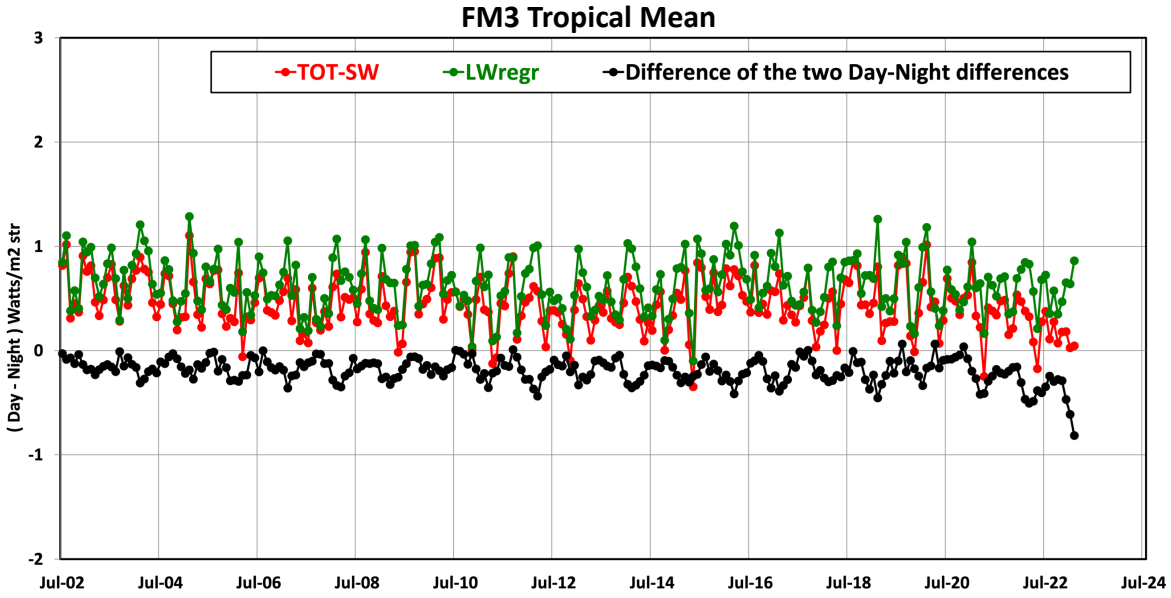




Validation- Terra and Aqua Tropical Mean



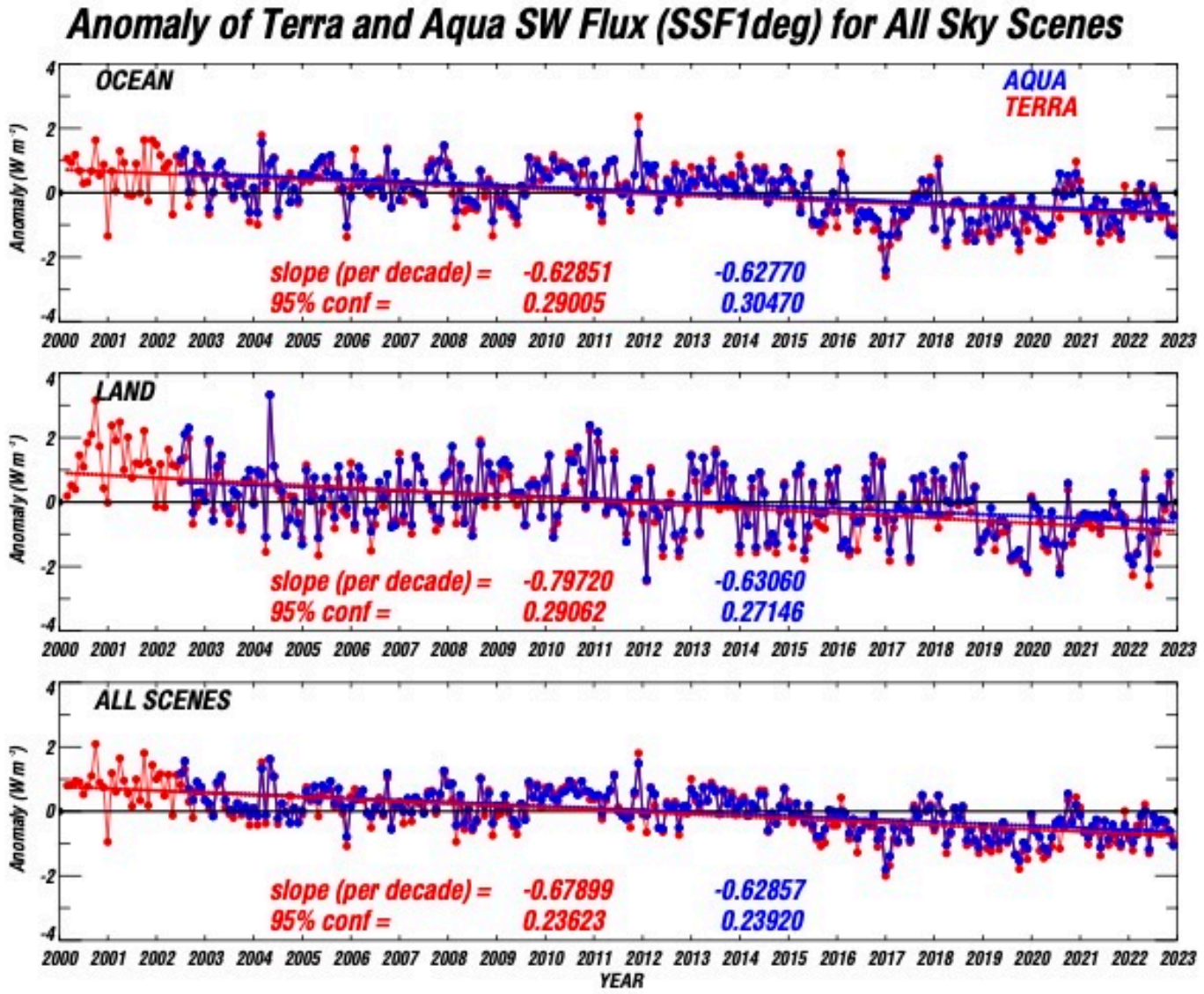




Uses Edition 4 data products

Validation: Terra and Aqua Ed-4 SW Flux Anomalies

Edition 4 products



SW flux anomalies show similar trends for Terra and Aqua

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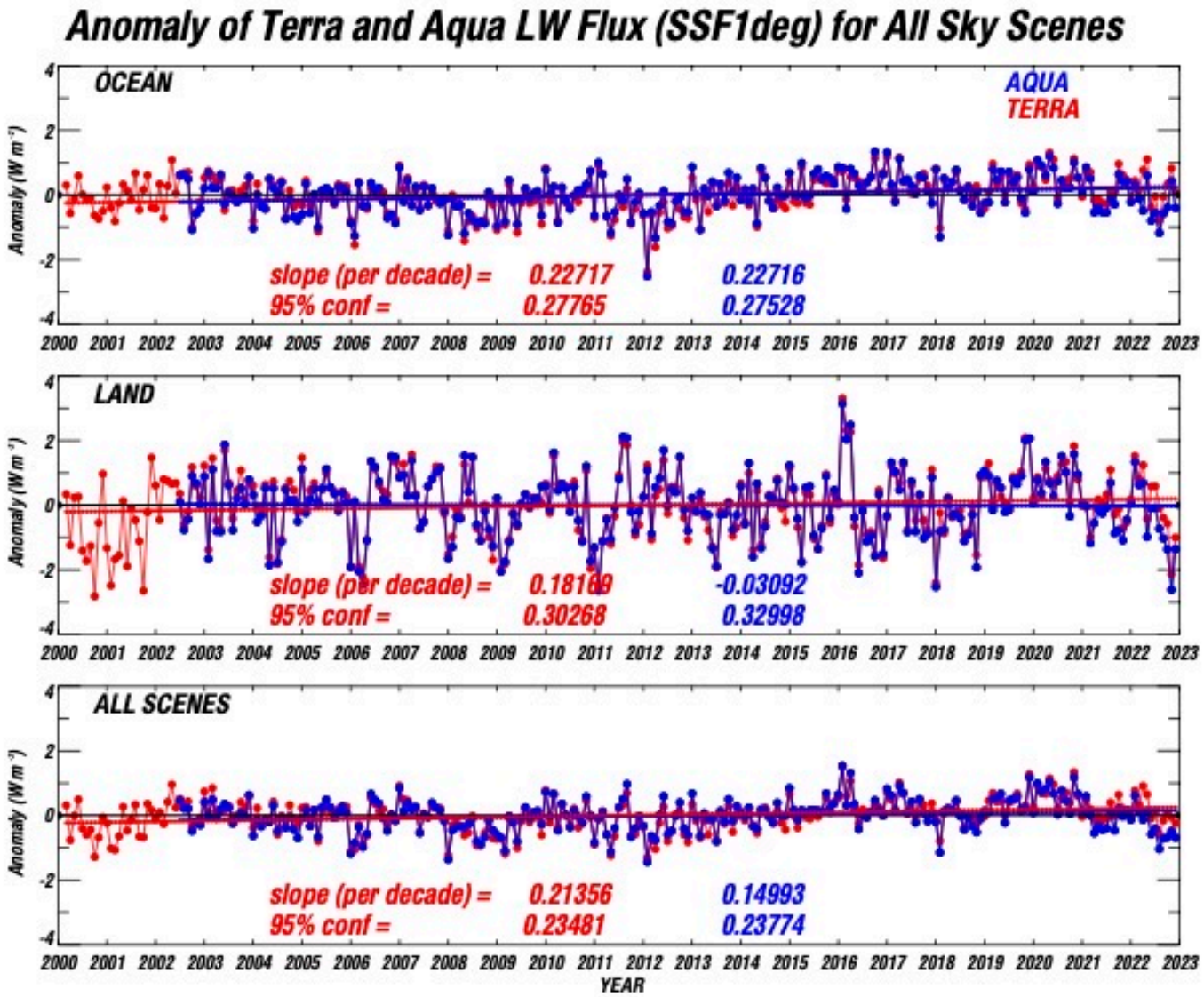
Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A
Aqua: CER_SSF1deg-Month_Aqua-MODIS_Edition4A

Validation: Terra and Aqua Ed-4 LW Flux Anomalies

Edition 4 products



LW flux anomalies show similar trends for Terra and Aqua.

CERES Instrument Working Group

Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A
Aqua: CER_SSF1deg-Month_Aqua-MODIS_Edition4A

SUMMARY

- **CERES instruments on Terra and Aqua have started operations to support scientific studies as the orbit drifts.**
- **All CERES instruments continue to perform nominally.**
  - **NOAA-20/FM6 instrument on-board calibrations continue to show the sensors' stable performance after the initial response rise.**
  - **SNPP/FM5 is currently operating in full biaxial mode.**
    - ***No evidence of deviation of instrument performance since transitioning to 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 Mar 2023.**
  - **S-NPP/FM5 Edition 2 gains and SRFs have been delivered through Jan 2023.**
  - **Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through Feb 2023.**
- **Members of the IWG continue to engage with the Libera team through bi-weekly Cal/Val Working group meetings.**

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.

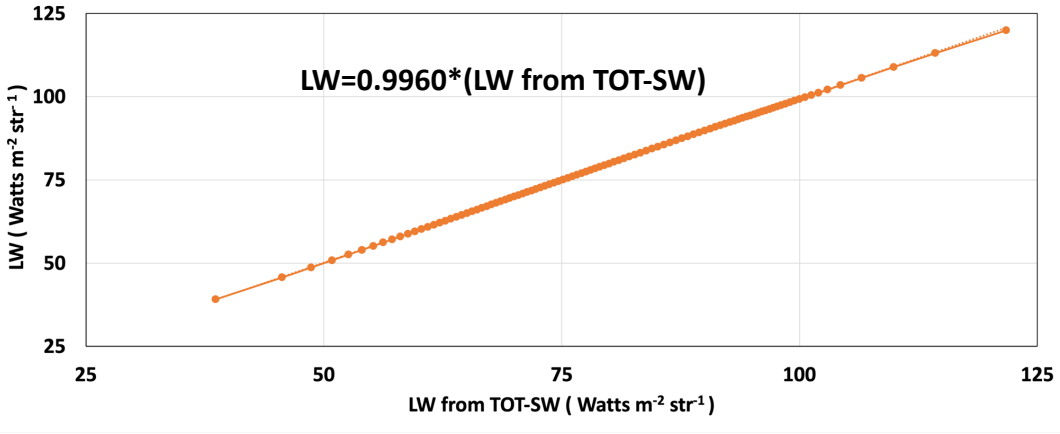
- **S-NPP**:
  - *Edition 1-CV*: Products without any on-orbit instrument calibration corrections applied.
  - *Edition 2*: Incorporates the most up-to-date calibration corrections, radiometric scaling to Aqua, and time varying SRF adjustments to TOT channel.

- **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.

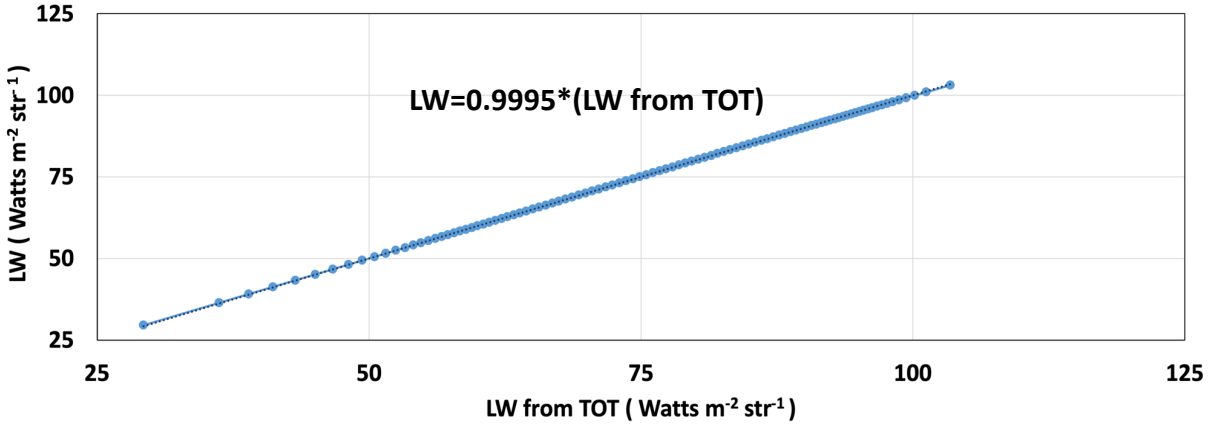
FM6 3-channel Consistency check- Global LW Day and Night

May 2018 - Jan 2022

Daytime Global Edition 1 ES-8 Nadir
TOT- SW vs. LW sensor



Nighttime Global Edition 1 ES-8 Nadir
LW from TOT vs. LW sensor



Daytime
LW_{TOT-SW} - LW_{LWc}= 0.4%

Nighttime
LW_{TOT} - LW_{LWc}= 0.05%

Validation: DCC 3-Channel Inter-comparison

- Compare the radiances from the three sensors of the instrument when viewing Deep Convective Clouds (DCC).
- Two sets of longwave (LW) radiances obtained:
  - TOT and SW sensors
  - Trained WN sensor
- Monitor the trend between the difference of the two LW radiances in relation to the SW radiance.
- Highlights any inconsistencies in the SW sensor or the shortwave part of the TOT sensor.

Validation- DCC 3-Channel Intercomparison