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

Mohan Shankar

CERES Instrument Working Group

CERES Fall Science Team Meeting
Oct 1, 2024

CERES Instrument Working Group

CERES Instrument Working Group

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

Instrument Operations	Data Management	Cal/Val
B. Mike Tafazoli	Denise Cooper	Nathaniel Smith
Janet Daniels	Dale Walikainen	Nitchie Smith
Alexander Brown	A. Thomas Grepiotis	Alexander Jarnot
Ethan Ames	Dianne Snyder	
Carol Kelly		

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.
    - No further noise events observed in the SW channel after May 2024.
      - *Noise events were observed in the SW channel between Nov 2023 and Feb 2024.*
    - There was no impact to the L1-L3 data products.
  - SNPP/FM5 is currently operating in Crosstrack 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 Aug 2024.
  - S-NPP/FM5 Edition 2 gains and SRFs have been delivered through Jul 2024.
  - Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through Jul 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	XTK	Operated in BIAX mode from Oct 1, 2019, to Oct 9, 2023.
Aqua	FM4	XTK	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 :

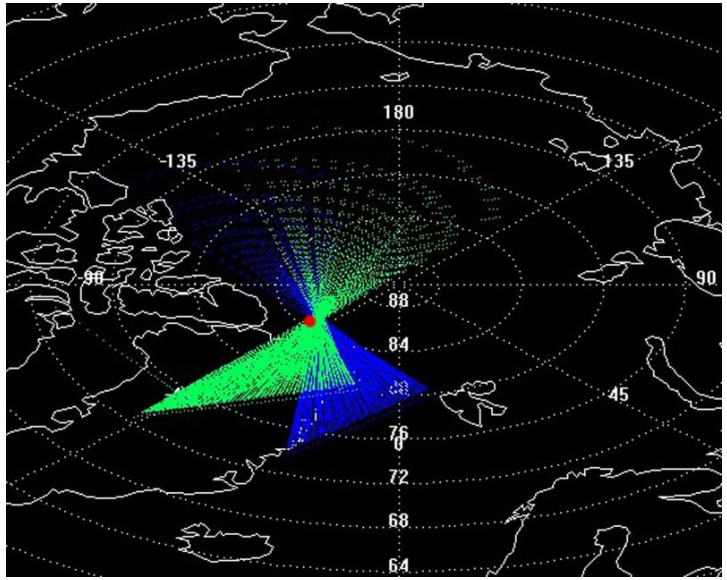
- For 5 days spaced evenly through the month, scan plane of CERES is aligned with a GEO imager for a few orbits.
- Target a different GEO imager each day.
- Instrument is operated in XTK for the rest of the day.

CERES Instrument Operations Summary Cont'd

- **Inter-comparison operations completed 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

  } 70^0 N

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



CERES/ARCSIX- Targeted Scanning of buoy (red dot) by CERES FM2

NOAA-20/FM6 Instrument Status

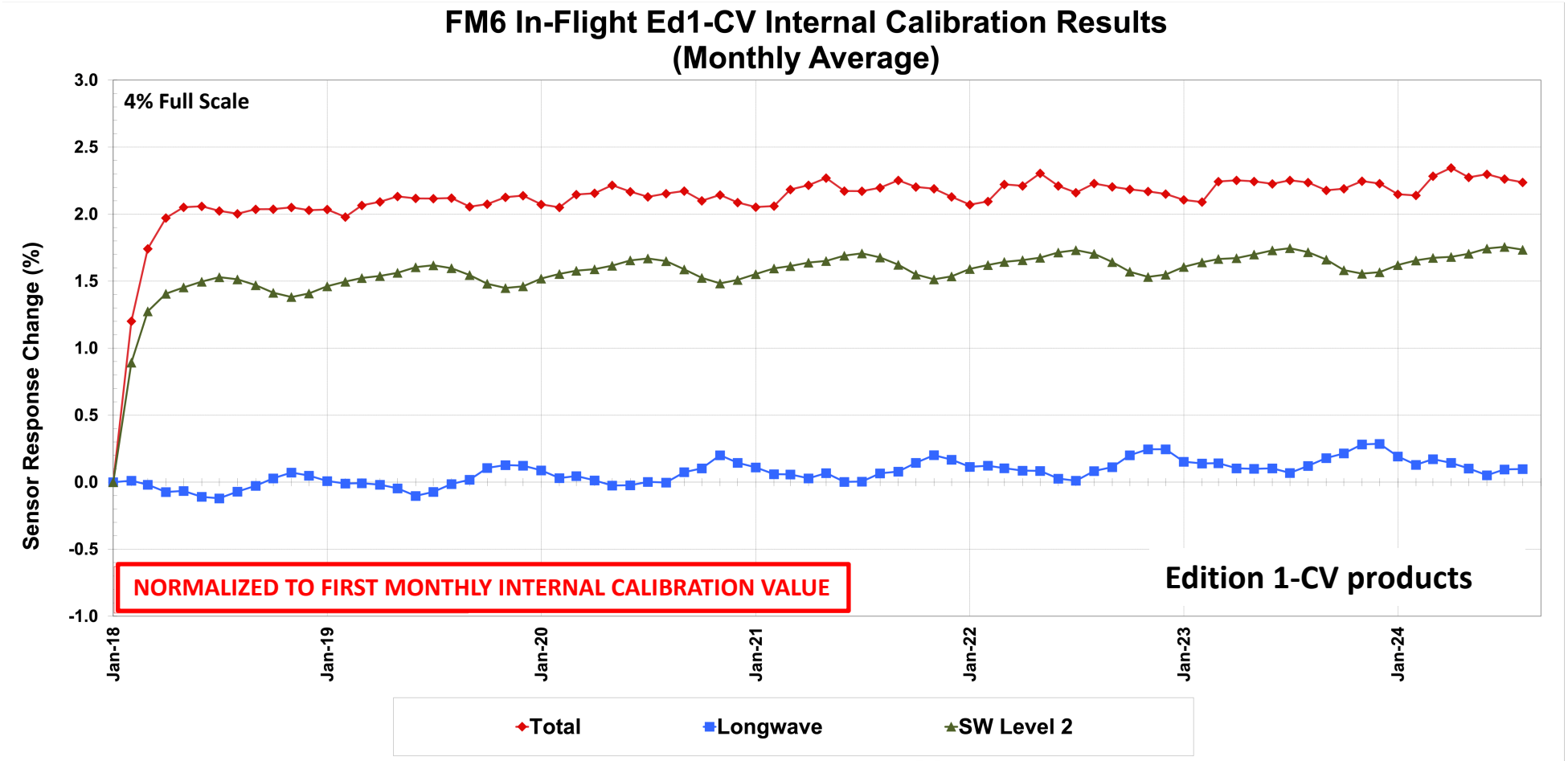
FM6 SW Noise events : Summary

- Noise spikes were observed in the FM6 SW channel between Nov. 2023 and Feb. 2024.
  - Occurrences were random, uncorrelated to instrument or spacecraft parameters.
  - Occurrences of these SW noise events reduced to about 1 per month through May 2024, and no occurrences since then.
- Tiger team was established to identify root cause.
  - Developed a 'fish-bone' diagram of potential causes
  - One likely cause identified as radiation environment, particularly, the effect of radiation on specific electronic components.
- Since the noise events are no longer occurring, the Tiger team is not actively working the issue.
  - Awaiting the report of the findings.
- CERES IWG closely monitoring the instrument telemetry and performance.

FM6 Calibration/Validation

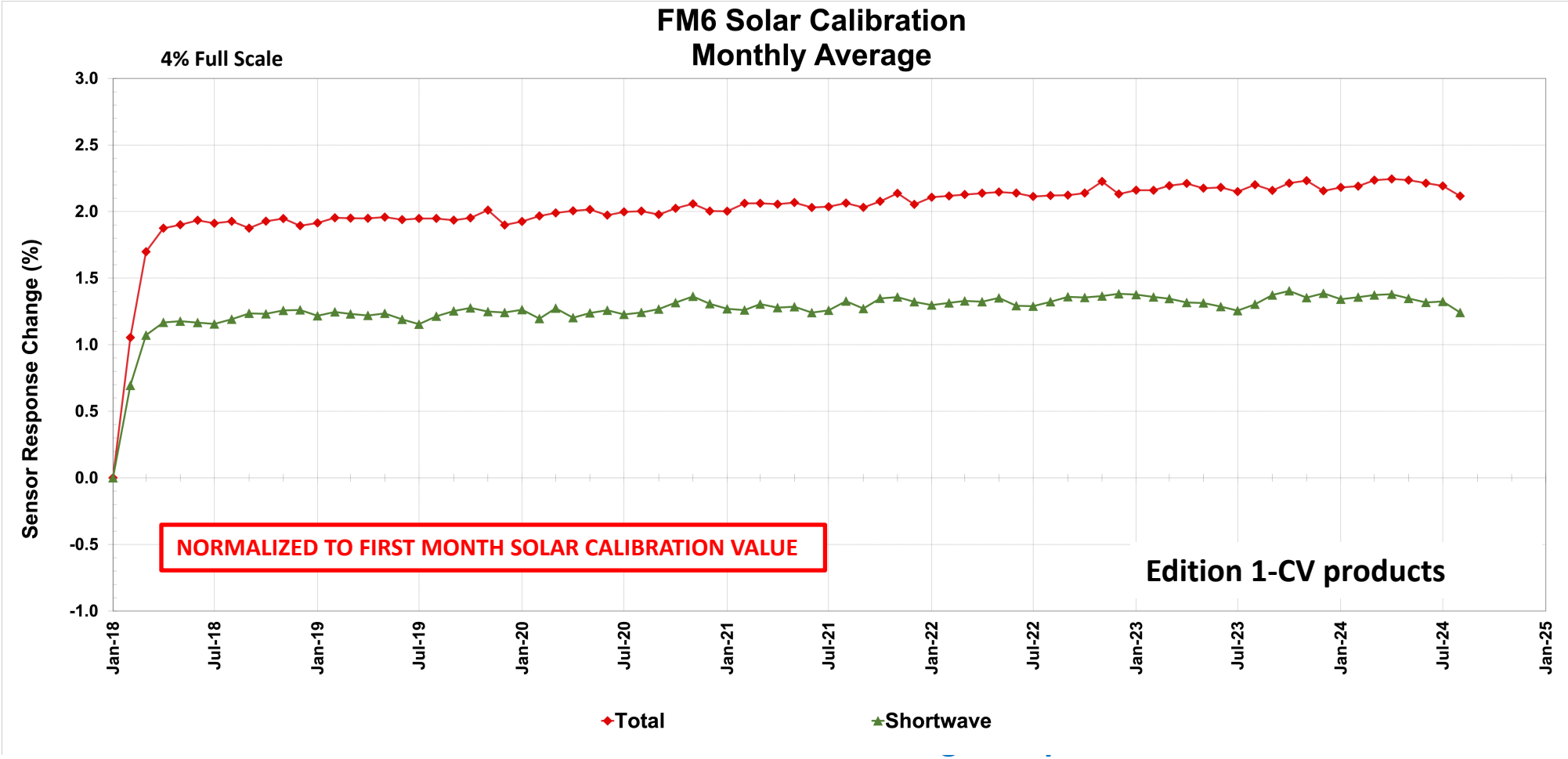
FM6 Internal Calibration

- For SW and TOT channels, the responses to the on-board sources continue to be quite stable (<0.3%) after the initial rise of ~1.5% (SW) and ~2% (TOT) since start of mission.
- LW Channel shows very little change (<0.2%).



FM6 Solar Calibration

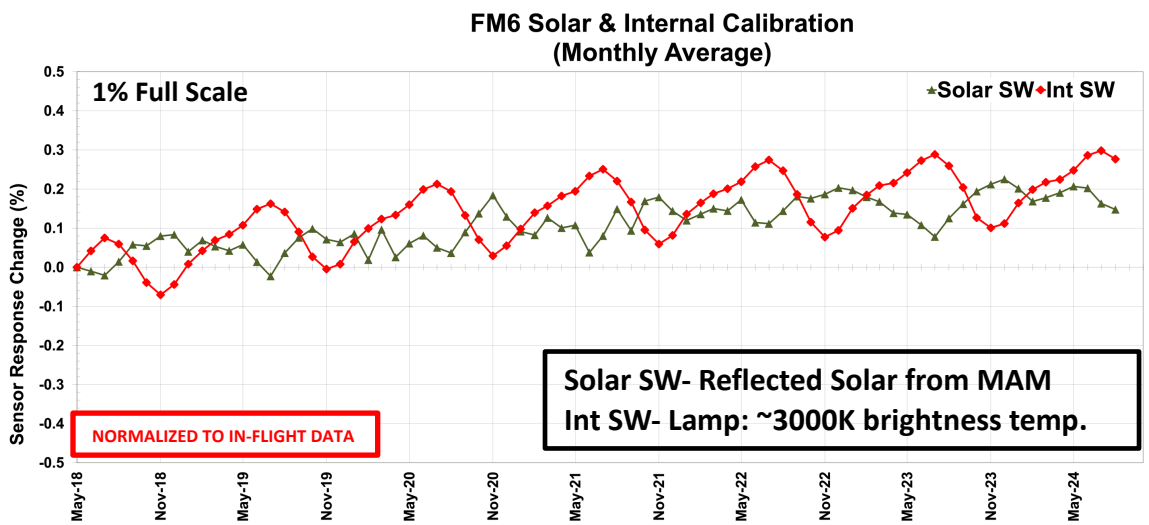
- Response of the SW and TOT channels while viewing the MAM that is illuminated by the sun.
- For SW, after the initial rise of ~1.2% for SW response shows very little change (~0.1%).
- For the TOT, after the initial rise of ~2% for TOT, the response shows about 0.3% change.



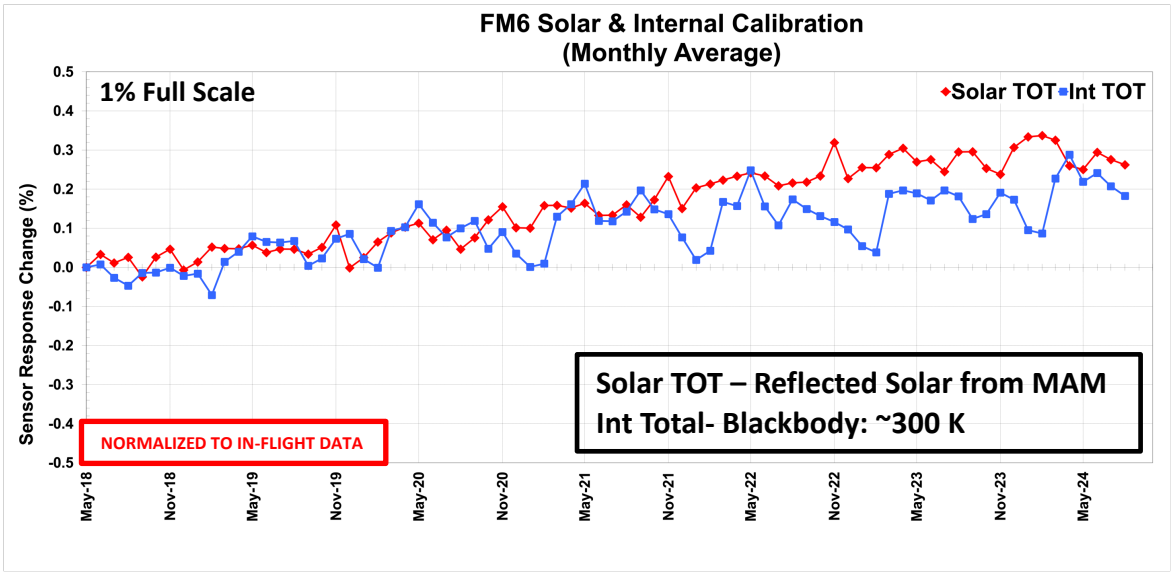
FM6 Calibration- Internal and Solar Cal Since May 2018

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

SW Channel



TOT Channel



Edition 1-CV products

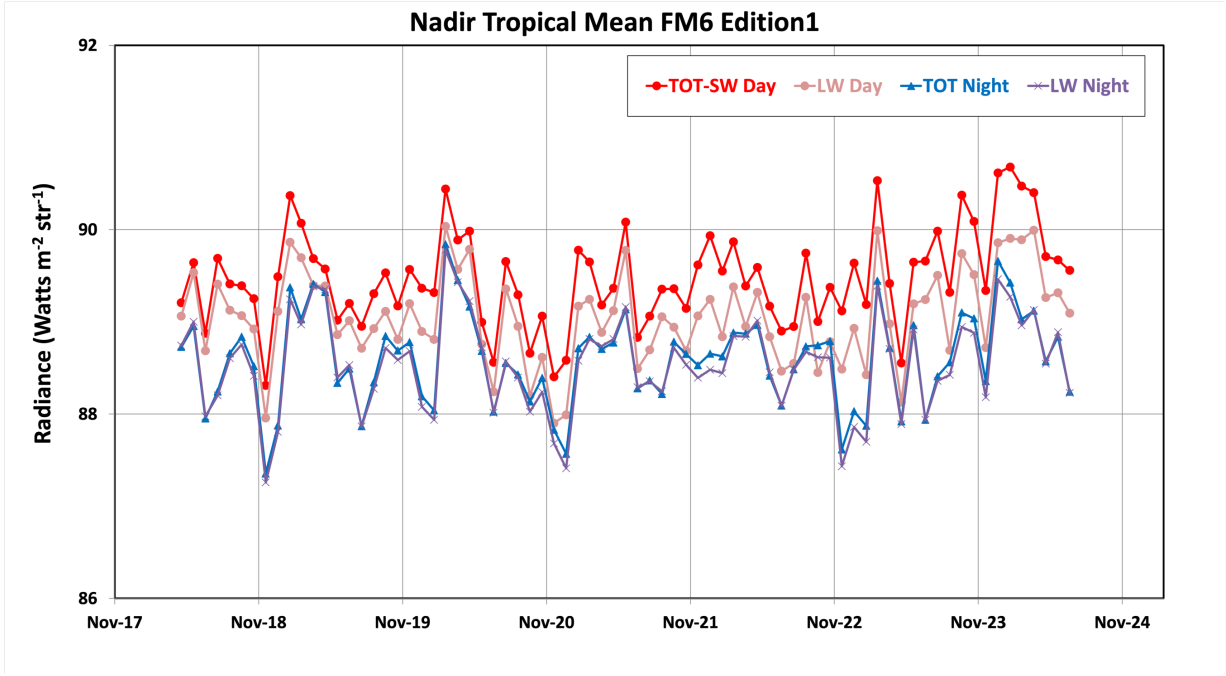
Validation – FM6 Tropical Mean (TM)

- 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

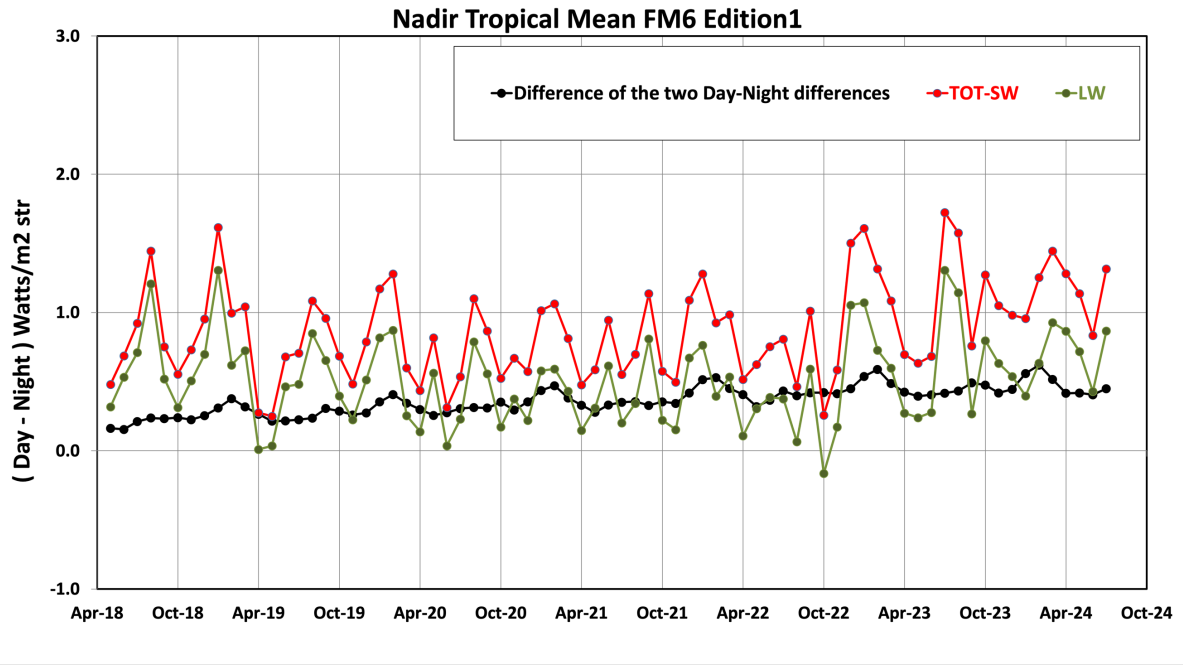
    $DN = TM_D(TOT\text{-}SW) - TM_N(TOT)$
  - LW sensor *(Observations from the LW channel)*

    $DN = TM_D(LW) - TM_N(LW)$
- Trends of the difference in the two DN values highlight any inconsistencies in the response between the three channels.

Validation- FM6 Tropical mean Day-Night



Day-Night Difference



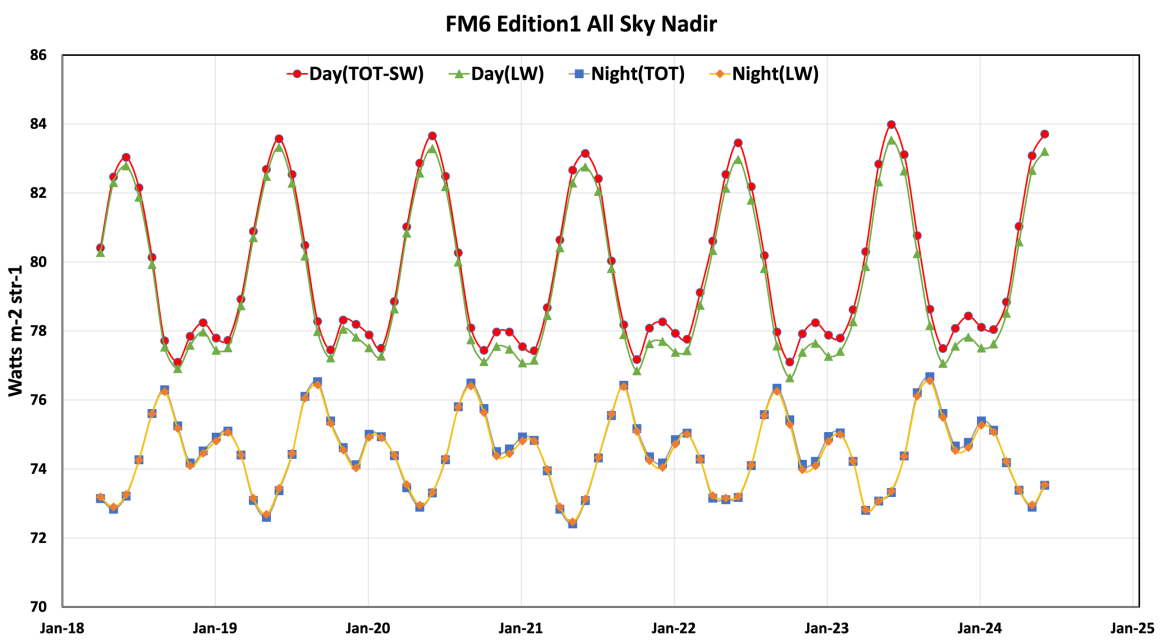
Edition 1 ES-8 products

FM6 3-channel Consistency check- ES-8 All-sky Global Day-Night Differences

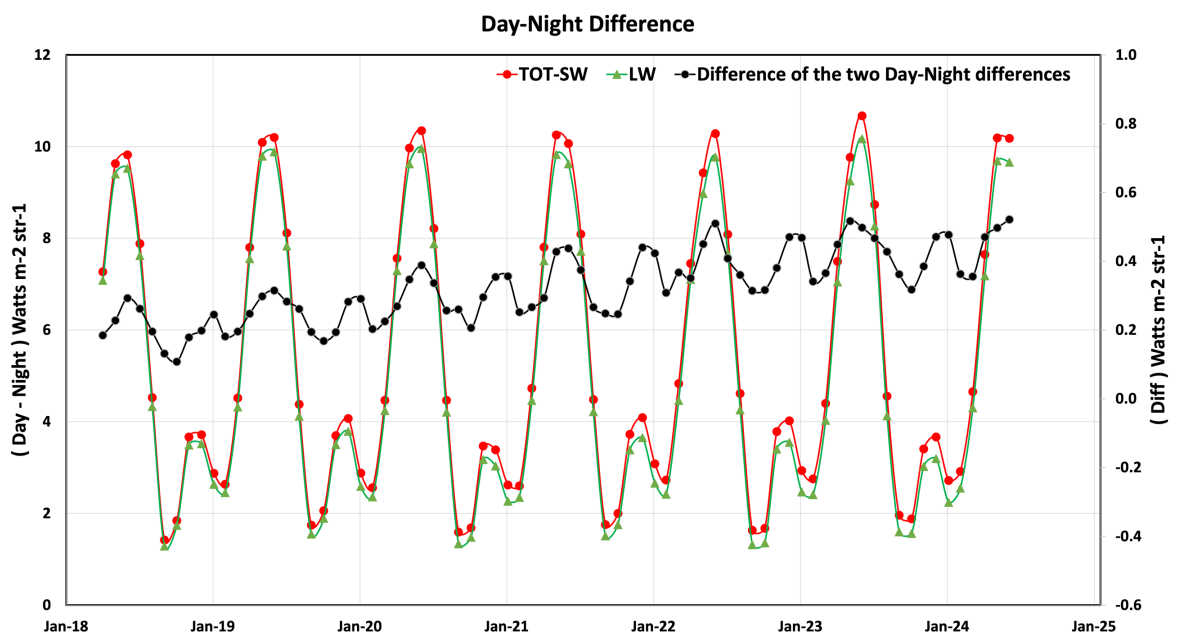
May 2018 - Jul 2024

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

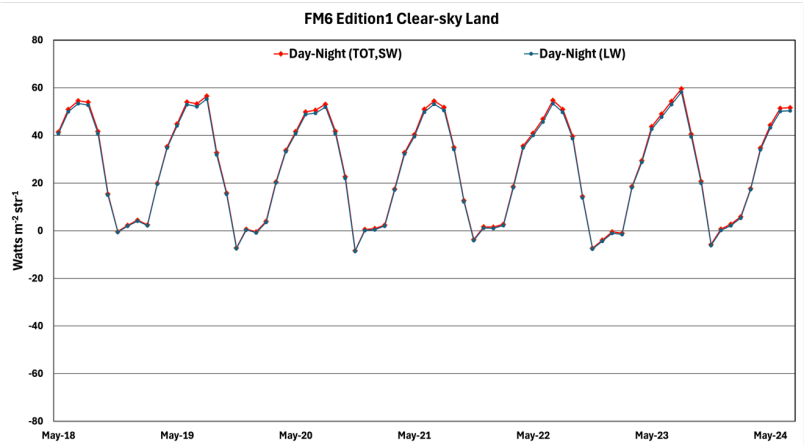
FM6 Edition 1 Global Mean LW radiance

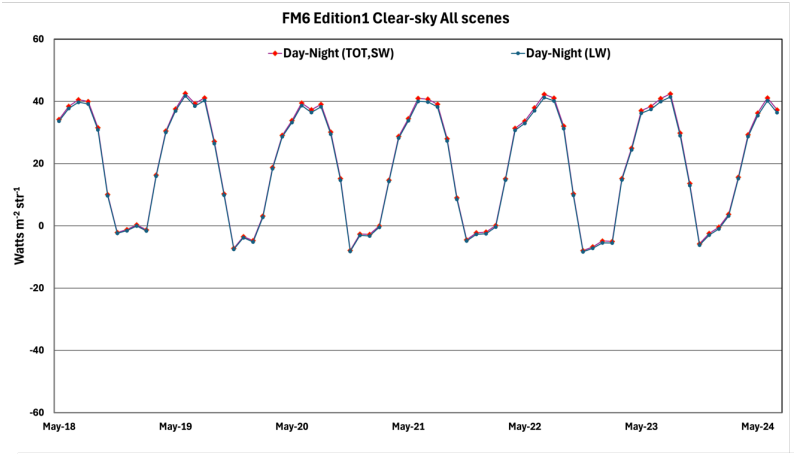


Day-Night Difference



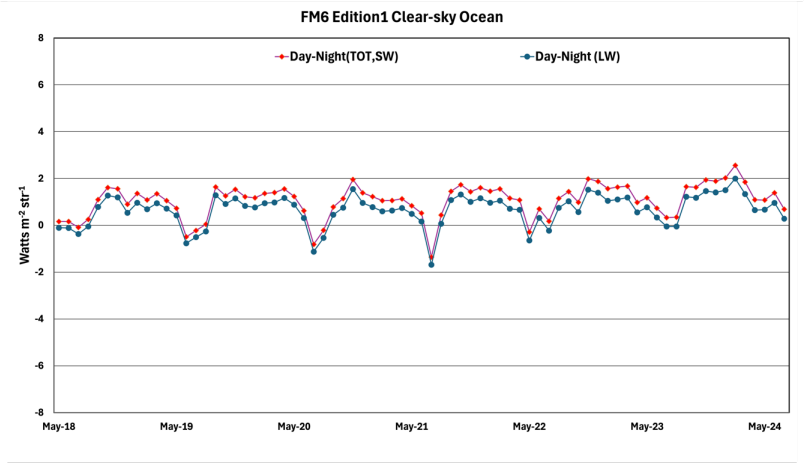
FM6 3-channel Consistency check- SSF Global Clear-sky Day-Night Differences

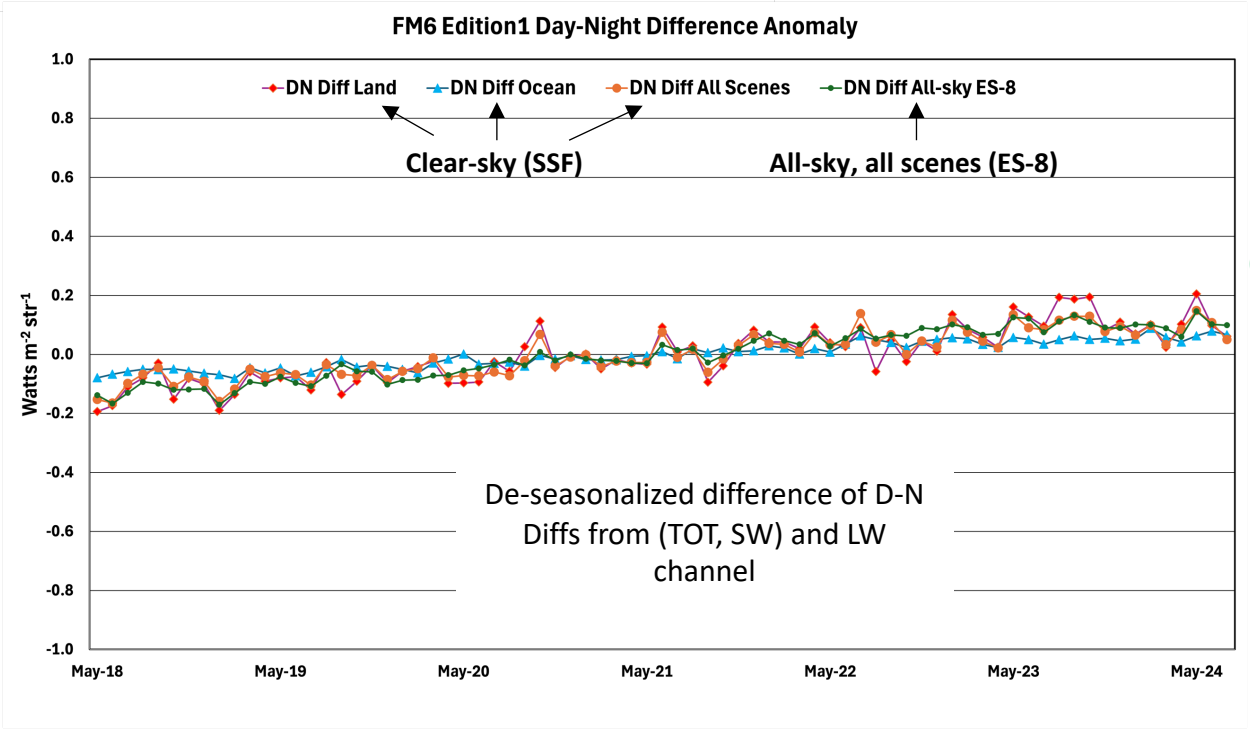




SSF Edition1 Clear Sky Nadir footprints Day-Night Differences

May 2018 - Jul 2024





Consistent Day- Night Difference trends for Clear-sky and All-sky scenes

NOAA-20: CER_SSF1deg-Month_NOAA20-VIIRS_Edition1

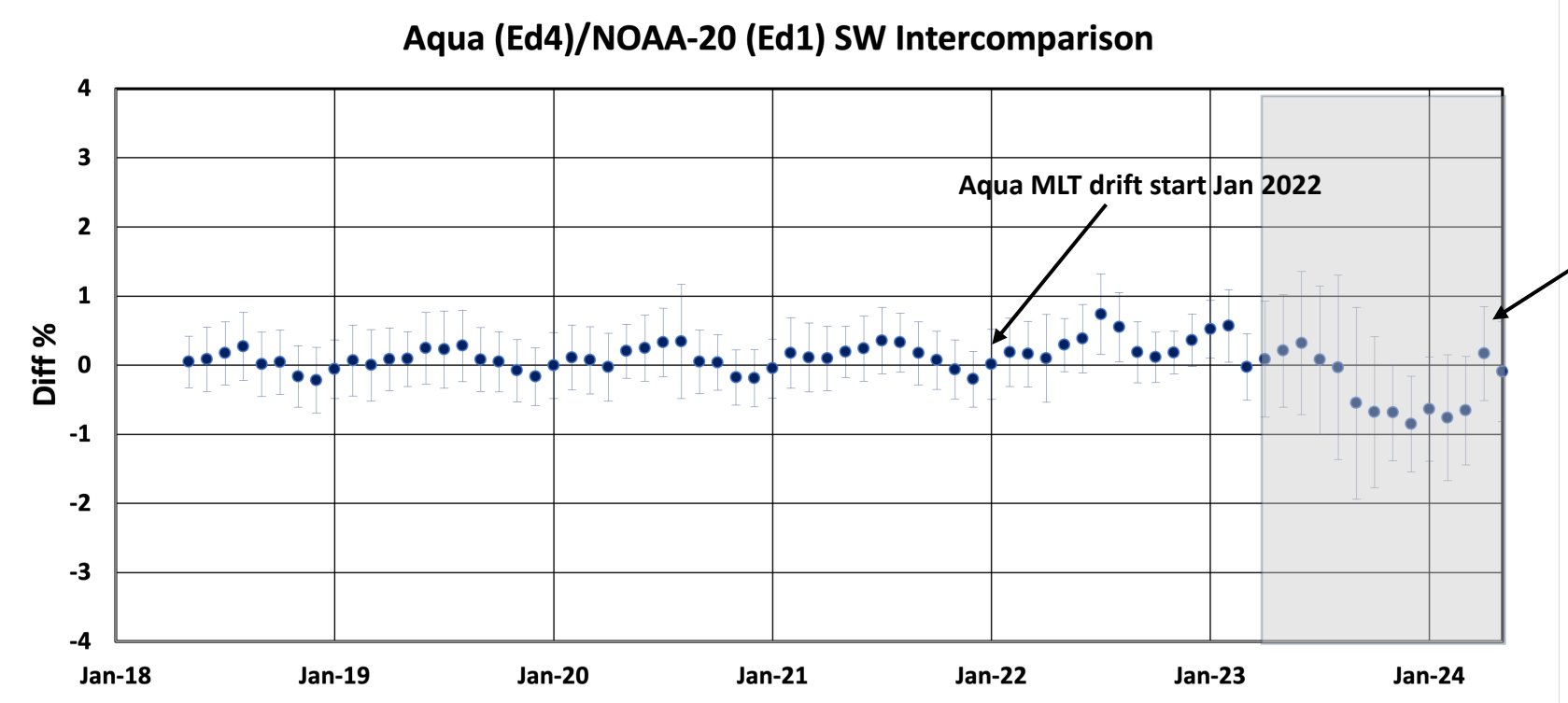
Aqua/NOAA-20 Intercomparisons

- 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 on days with orbital crossovers.
- 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 < **2.0^0**
  - 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.
- *Note:*
  - *Original analysis considered samples in the two-hour window around the orbital crossover times.*
  - *Since FM3 started operating in biaxial scan mode, the number of matched footprints drastically reduced.*
  - *To counteract the reduced sampling, footprint matches for a full day considered (during the biax period) instead of just around the cross-over times on the days that crossovers occur.*

FM3/FM6 SW All-sky Inter-comparisons: May 2018- May 2024

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

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



Radiometric scaling of FM6 to FM3 done in May 2018.

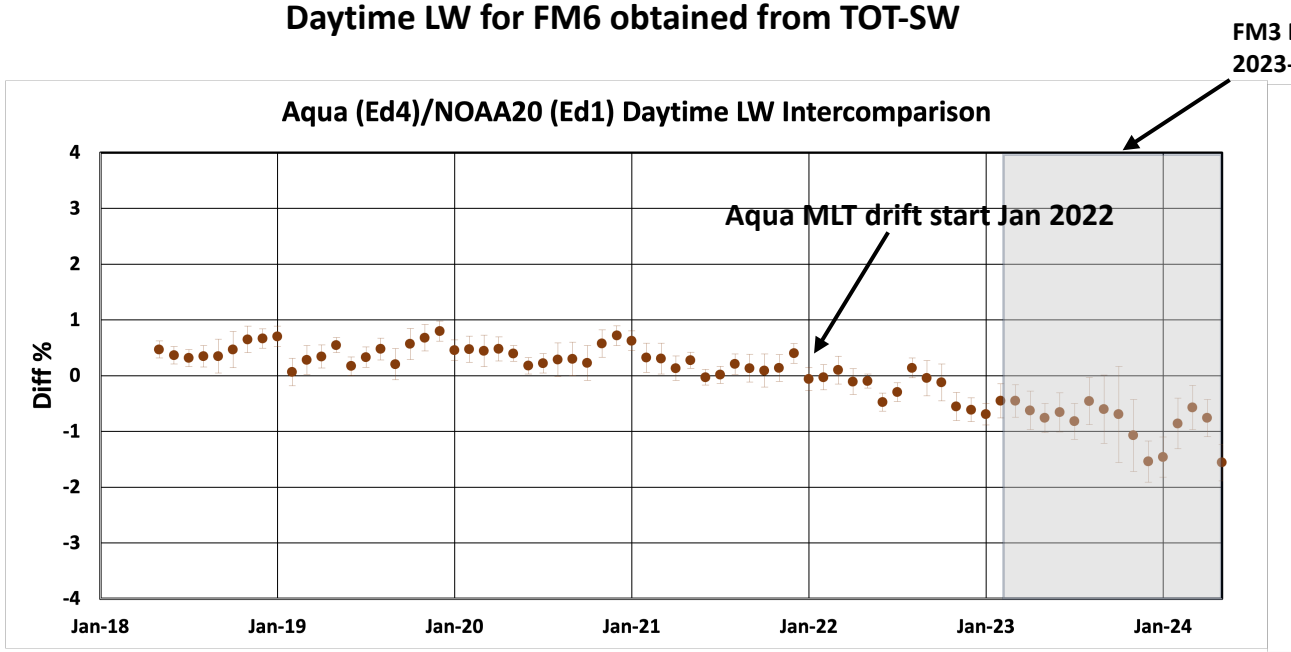
Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM6-VIIRS_Edition1B

Deviation from the long-term trend in the later years due to the impact on the sampling as a result of Aqua's orbital drift and FM3 operating in Biaxial mode.

FM3/FM6 LW All-sky Inter-comparisons: May 2018- May 2024

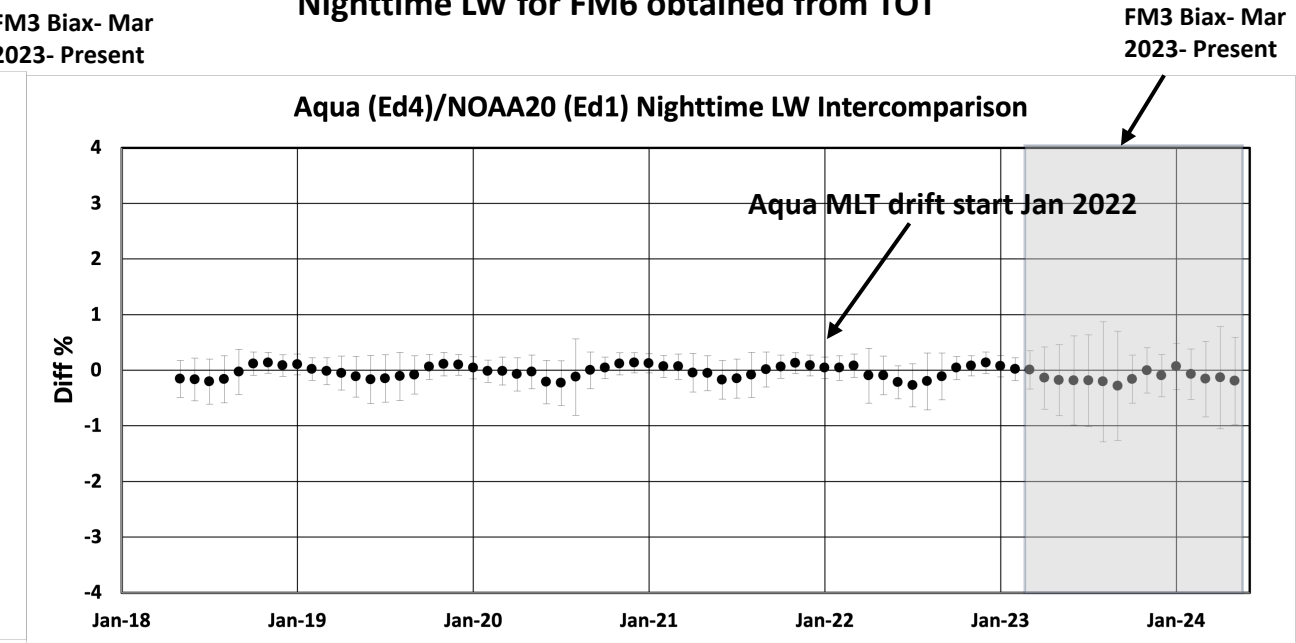
Difference of Daytime Radiance: FM3-FM6 %, 95% CI

Daytime LW for FM6 obtained from TOT-SW



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

Nighttime LW for FM6 obtained from TOT



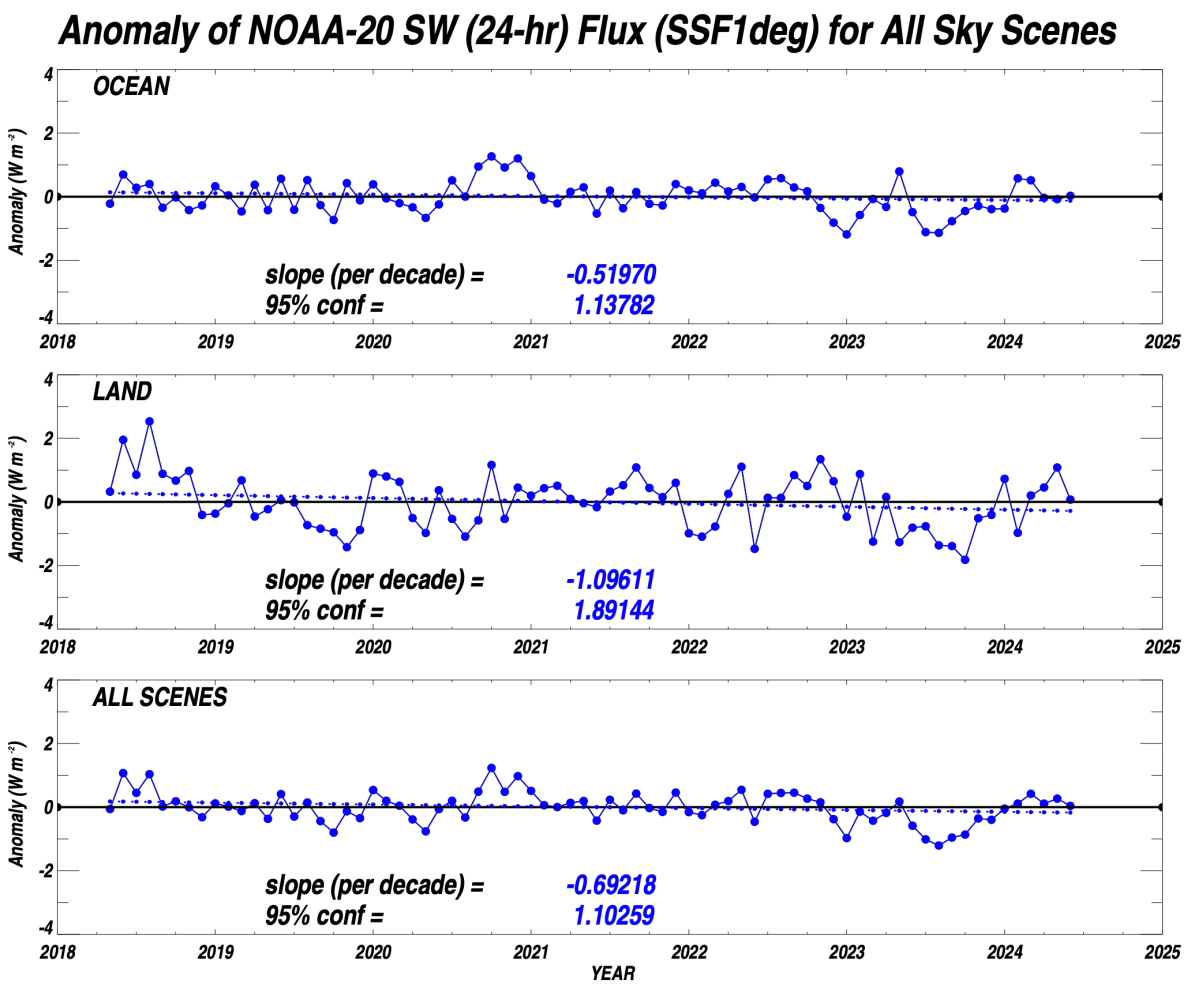
Radiometric scaling of FM6 to FM3 done in May 2018.

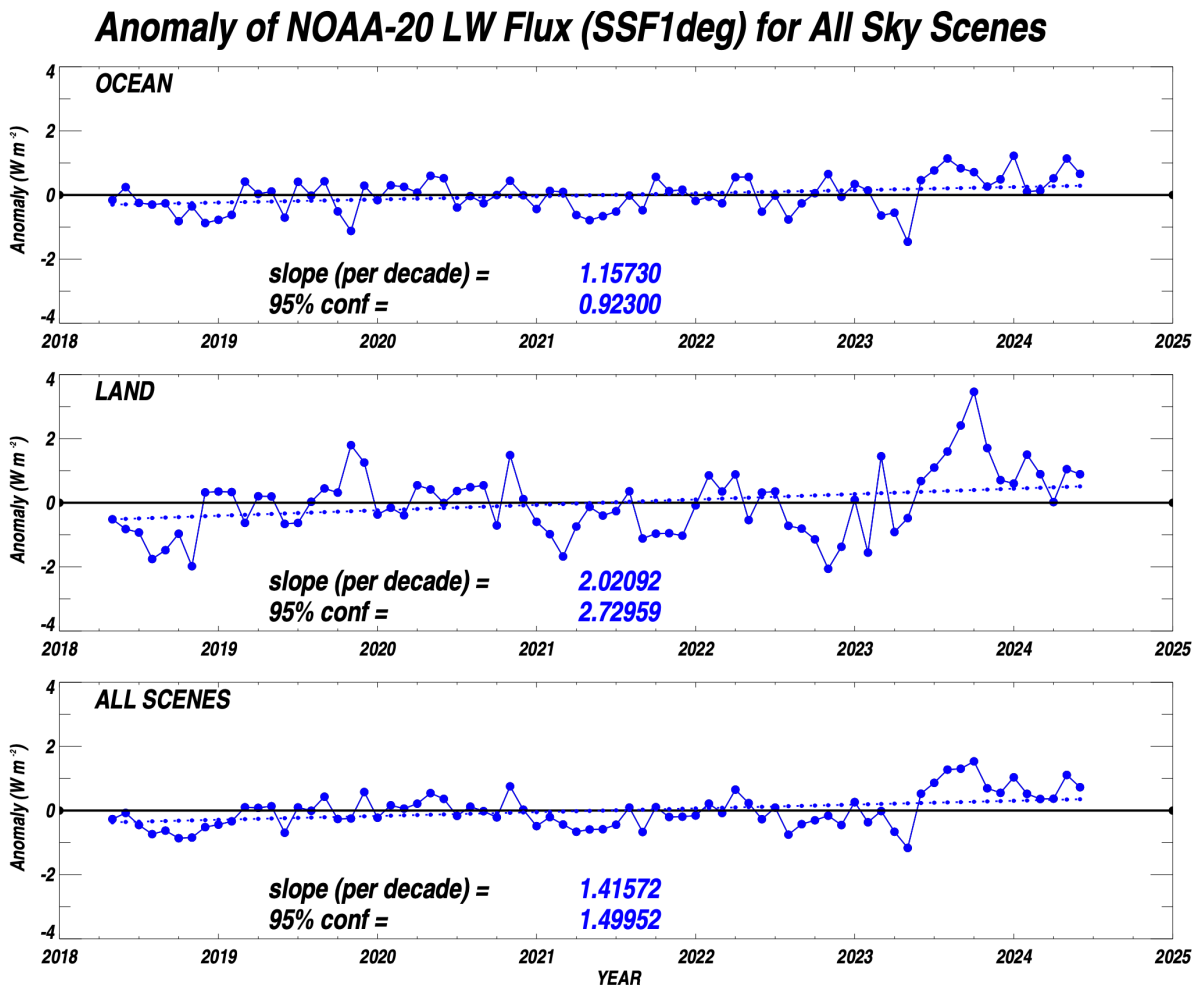
Data:
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_NOAA20-FM6-VIIRS_Edition1B

Deviation from the long-term trend in the later years due to the impact on the sampling as a result of Aqua's orbital drift and FM3 operating in Biaxial mode.

CERES Instrument Working Group

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



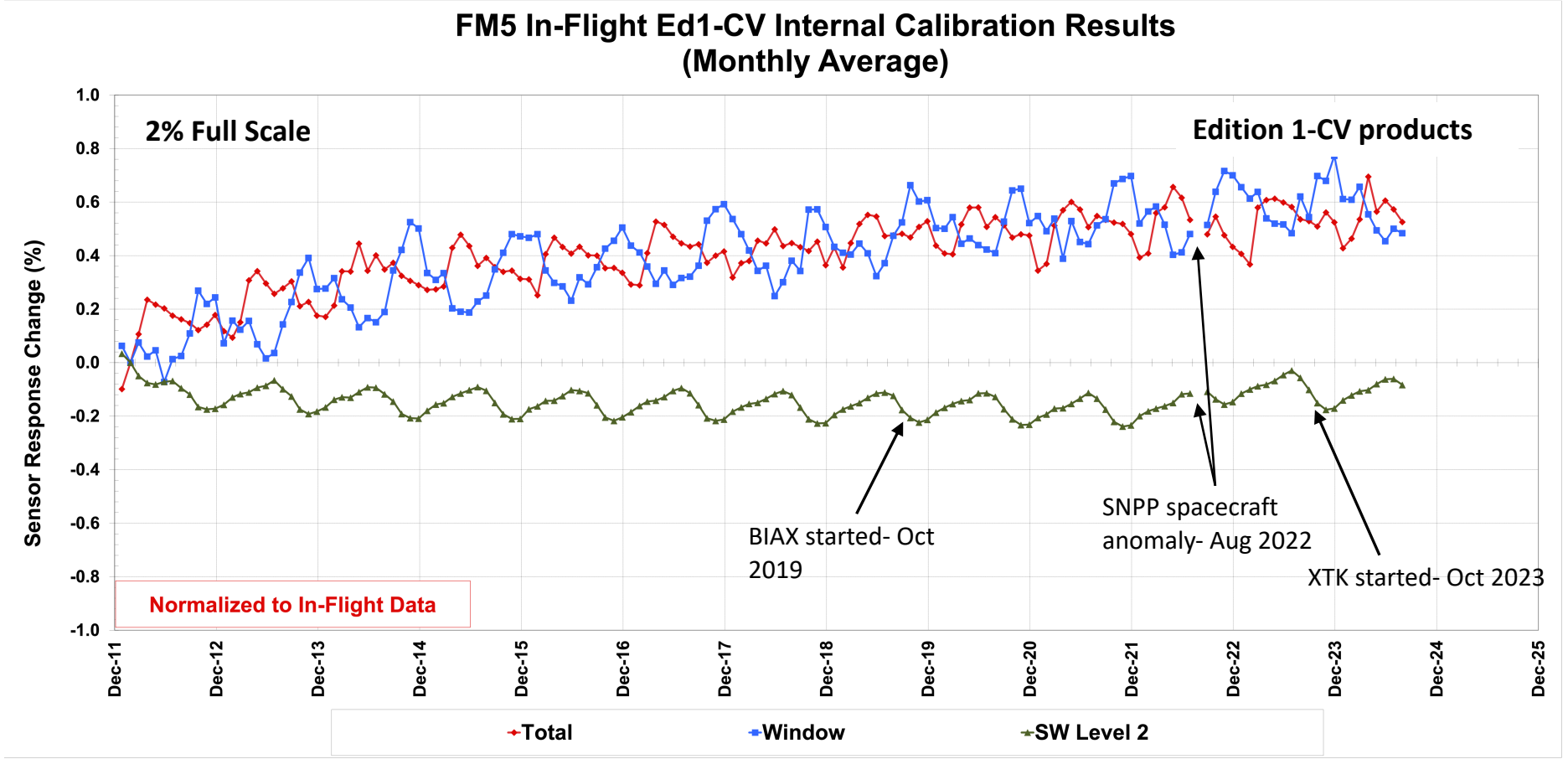


NOAA-20: CER_SSF1deg-Month_NOAA20-VIIRS_Edition1

S-NPP/FM5 Instrument Status

FM5 Internal Calibration

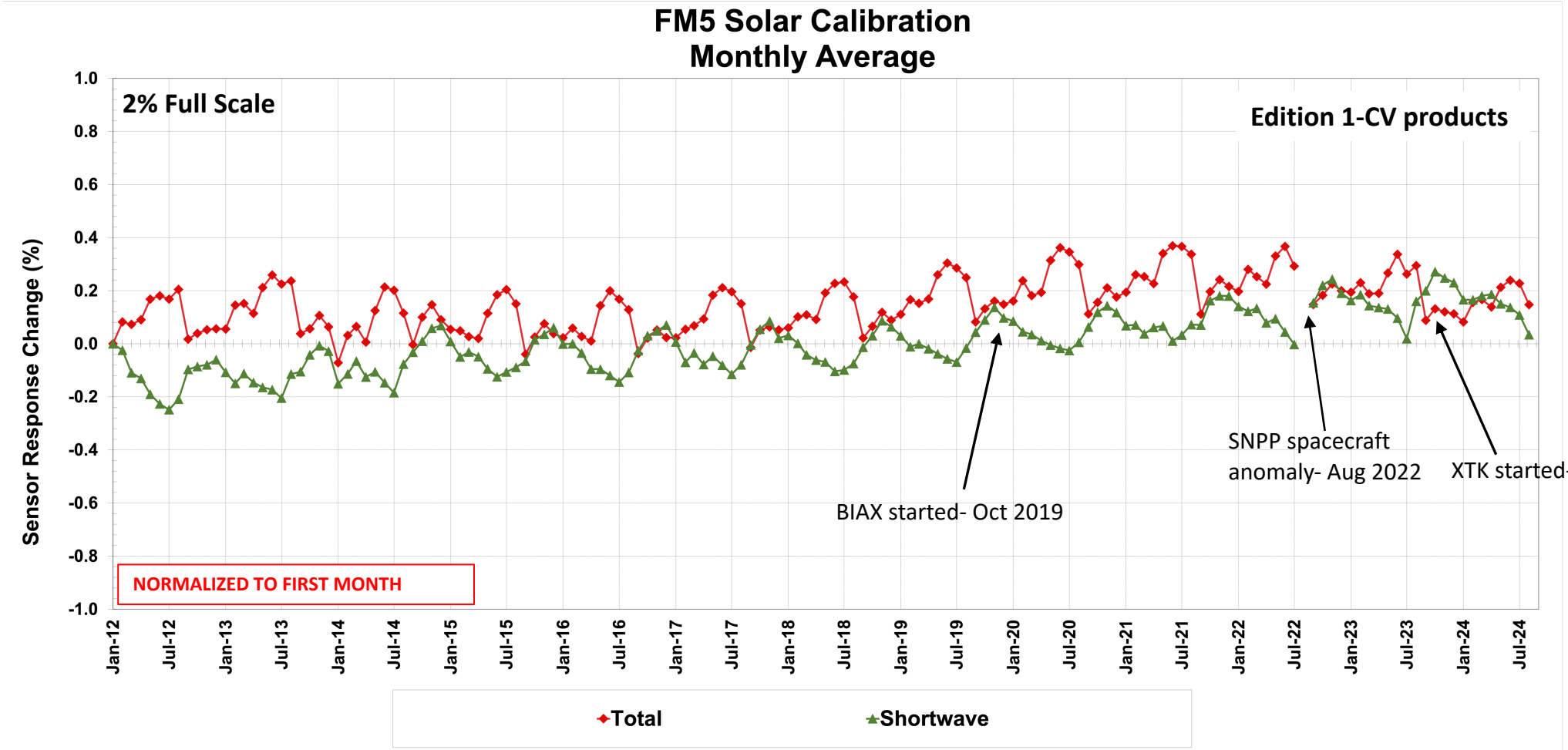
- In response to the blackbodies, the FM5 TOT and WN sensors settled at 0.6% since start of mission.
- SW channel's response to the SWICS is stable at < 0.2% since start of mission.



CERES Instrument Working Group

FM5 Solar Calibration

- FM5 Solar calibration results show the MAMs are very stable- <0.4% change since Start of mission for both SW and TOT channels.



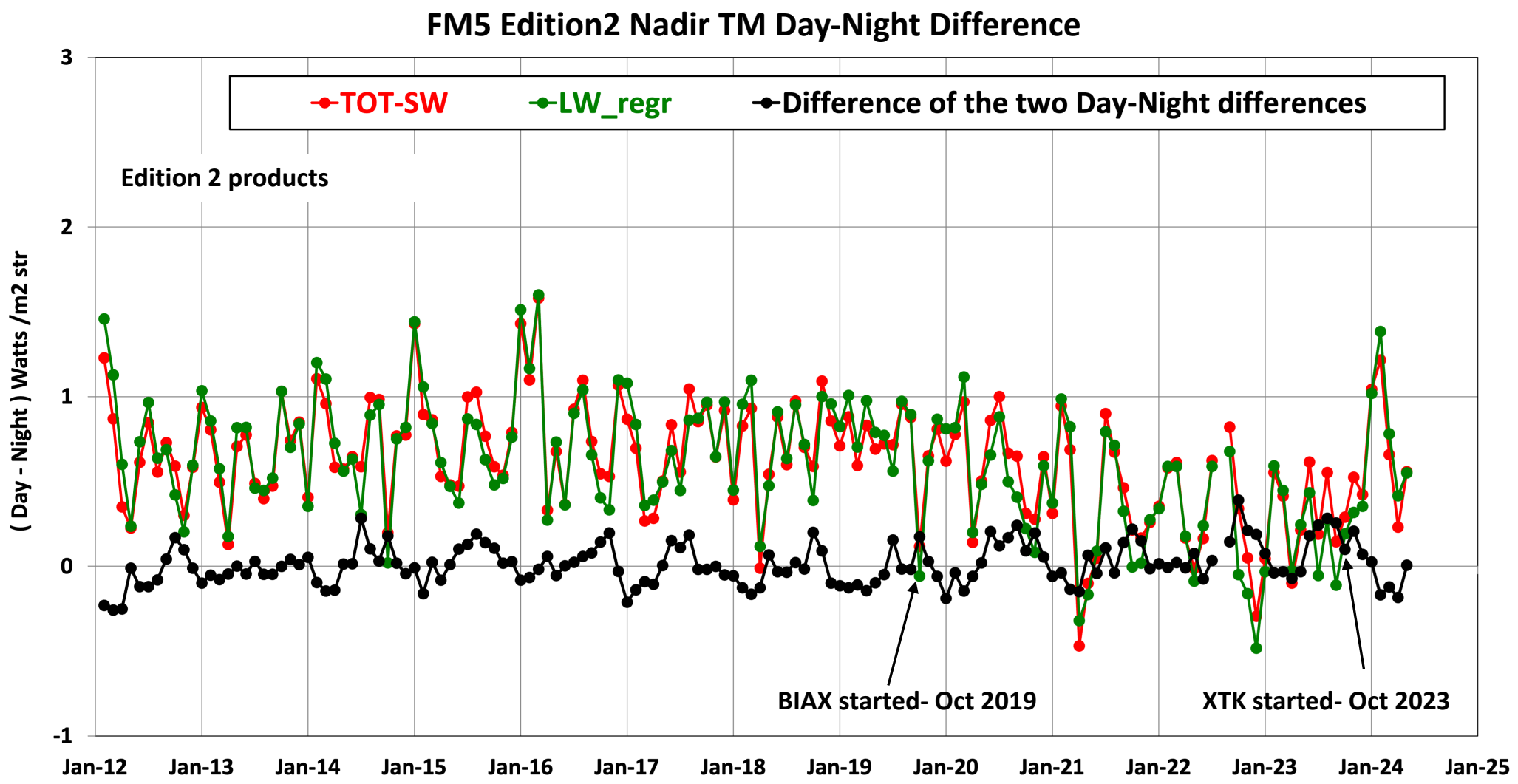
Validation – Tropical Mean (TM)

- 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 *(Uses 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



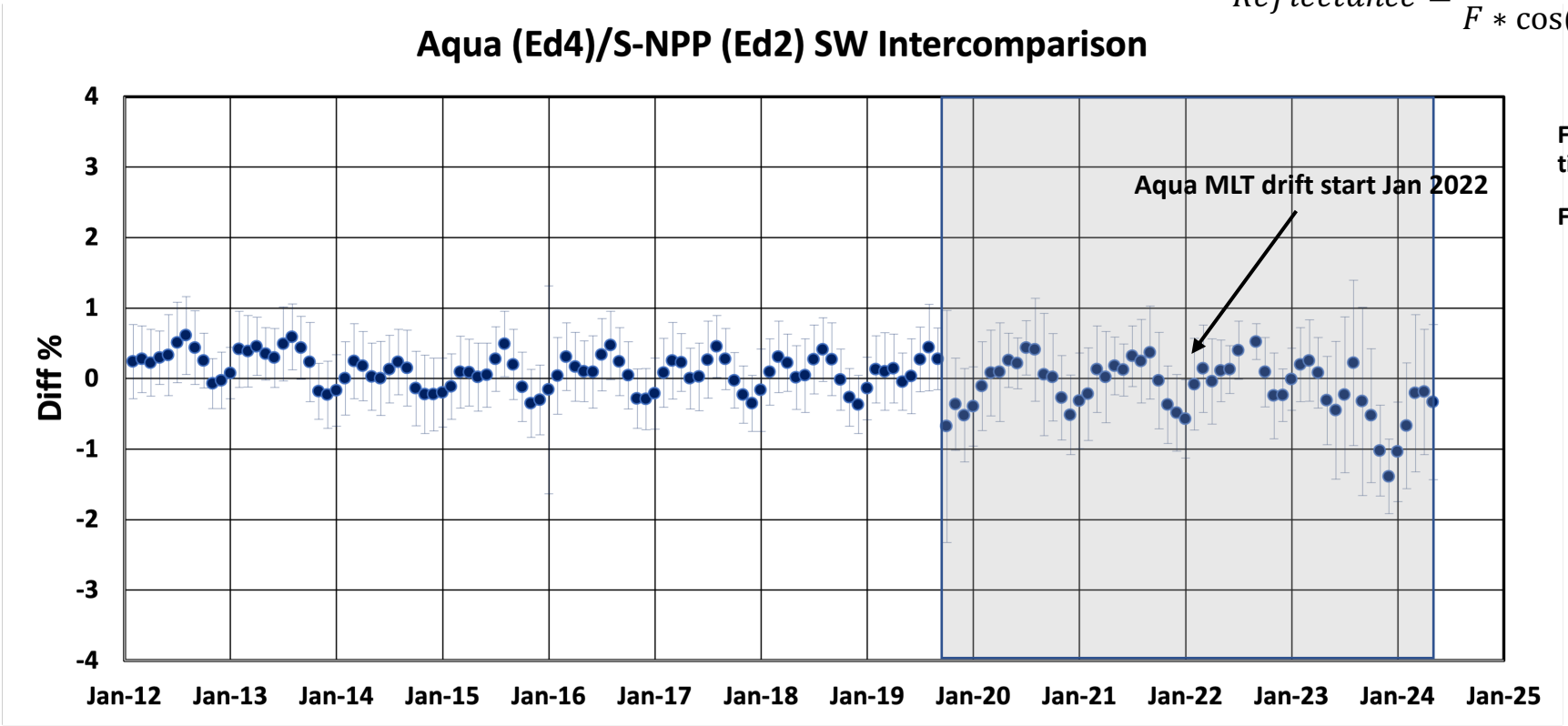
Aqua/S-NPP Intercomparisons

- The 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 < **2.0^0**
  - RAZ difference < **5^0**
  - Distance between footprints **< 7 km**
- Obtain monthly all-sky SW reflectance and LW radiance differences using the matched footprints.
- *Note:*
  - *Original analysis considered samples in the two-hour window around the orbital crossover times.*
  - *When either (or both) instruments are operating in Biaxial mode, the number of matched footprints is drastically reduced.*
  - *To counteract the reduced sampling, footprint matches for a full day considered (during the biax period) instead of just around the cross-over times on the days that crossovers occur.*

FM3/FM5 SW All-sky Inter-comparisons: Feb 2012- May 2024

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

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



FM5 in BIAX from Oct 2019 till Oct 2023

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

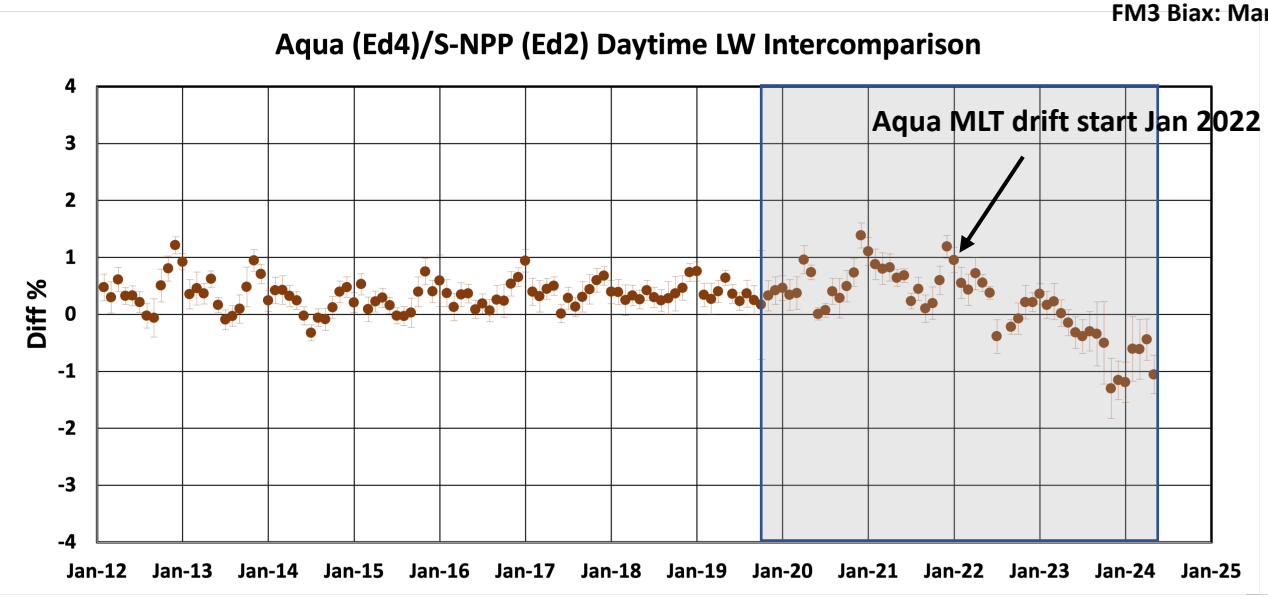
Larger variability observed in the later years due to the impact on the sampling as a result of Aqua's orbital drift and FM3 and FM5 operating in Biaxial mode.

CERES Instrument Working Group

FM3/FM5 LW All-sky Inter-comparisons: Feb 2012- May 2024

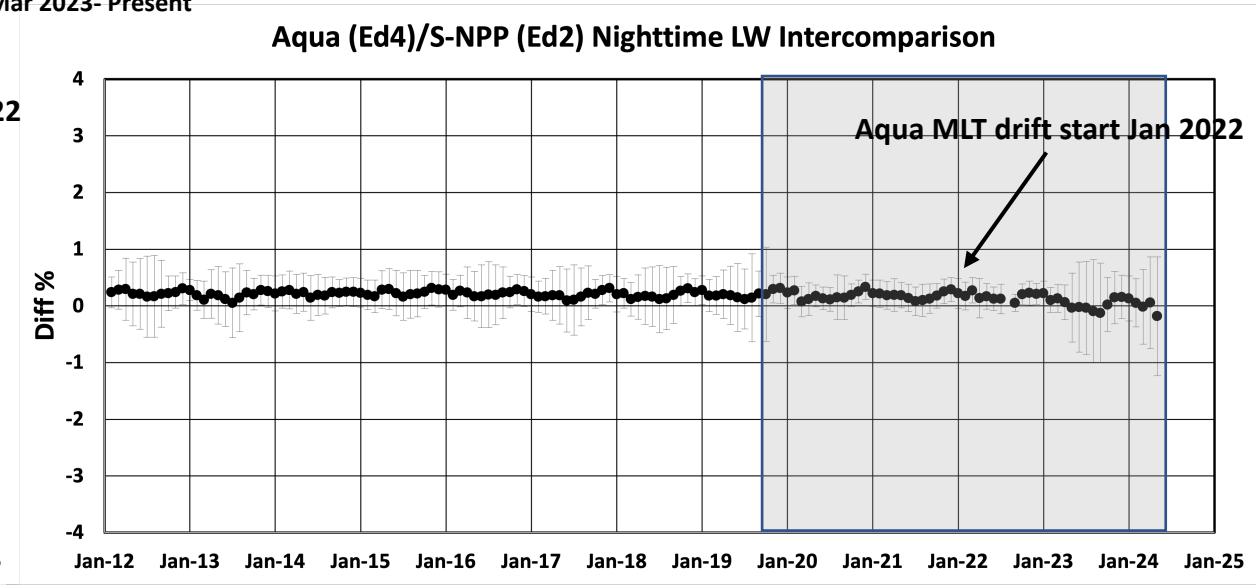
Difference of Daytime Radiance: FM3-FM5 %, 95% CI

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



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

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



2014 data used for the radiometric scaling FM5 to FM3.

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

Larger variability observed in the later years due to the impact on the sampling as a result of Aqua's orbital drift and FM3 and FM5 operating in Biaxial mode.

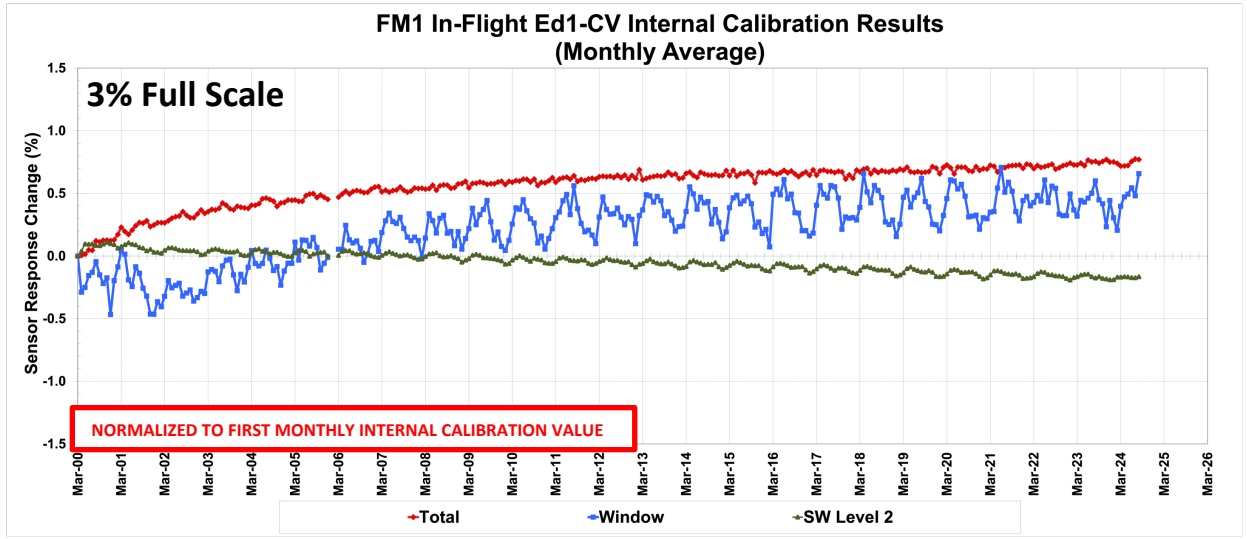
CERES Instrument Working Group

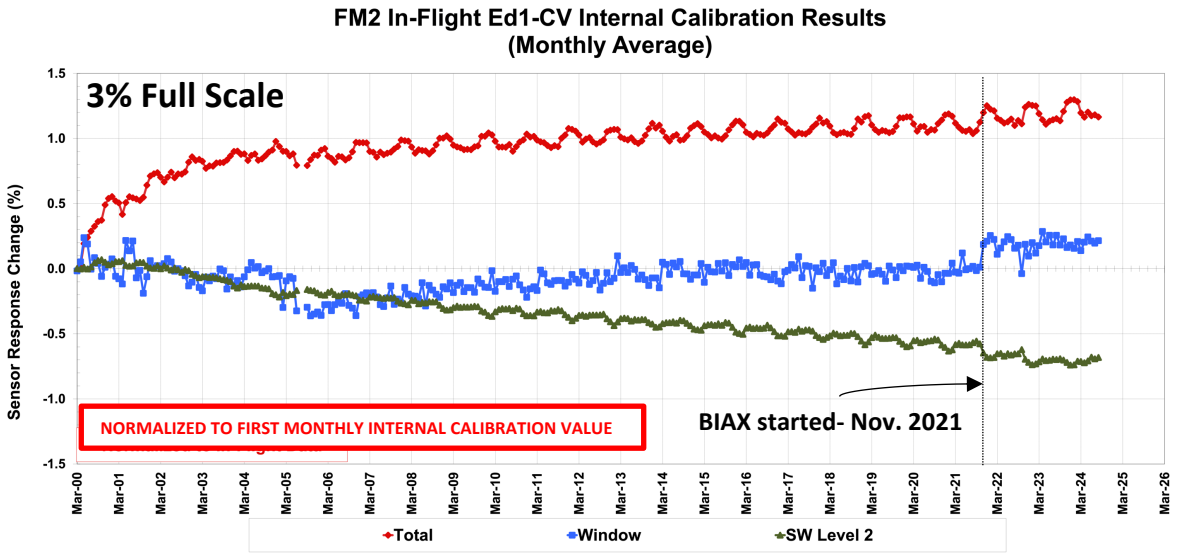
Terra & Aqua
FM1-FM4 Instruments' Status

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 no change until the transition to BIAX in Nov. 2021.

Edition 1-CV products

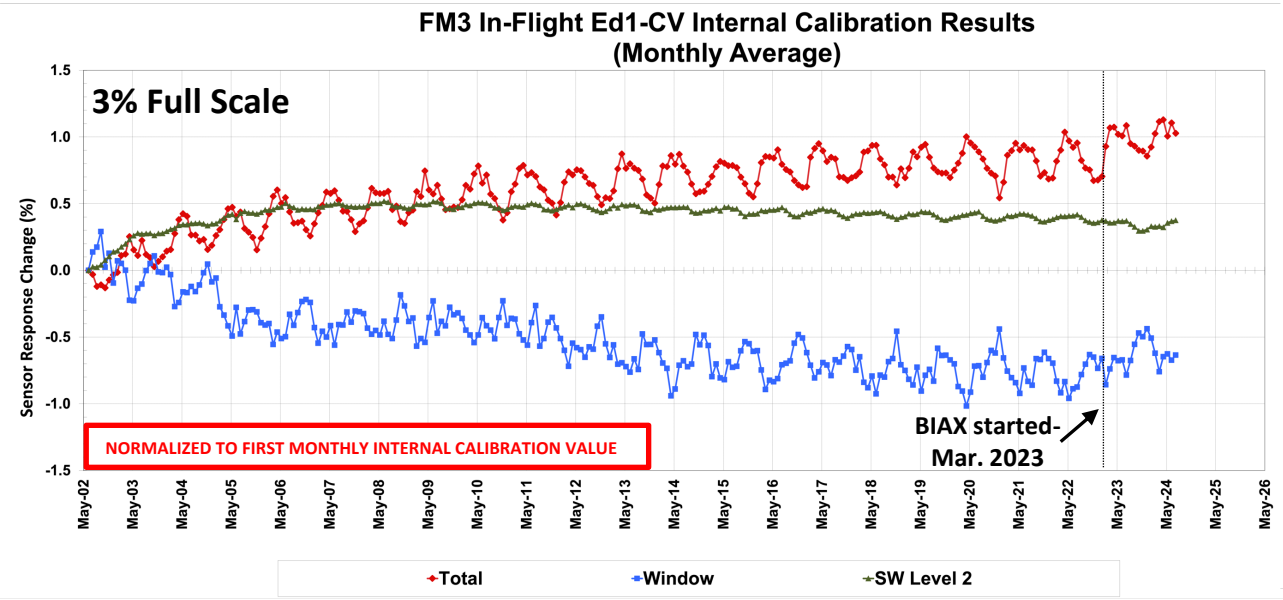


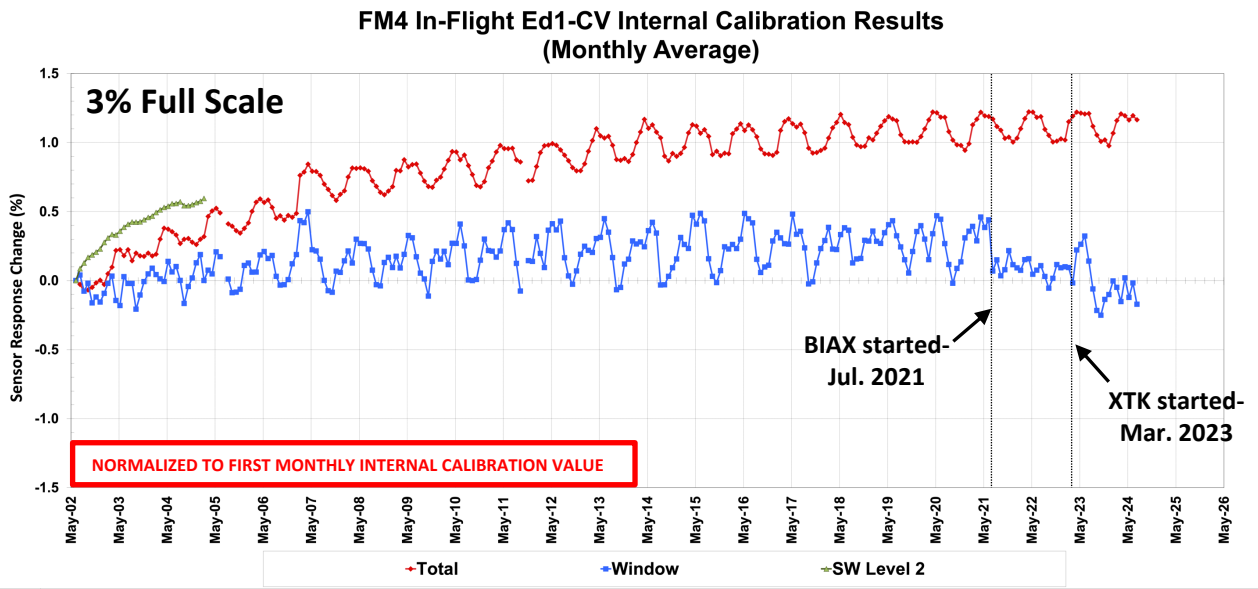


Total, WN- Blackbody: ~300 K
SW- Lamp: ~3000K brightness temp.

Aqua- FM3 and FM4 Internal Calibration

- For FM3, TOT channel shows ~1% 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 till the transition of operational modes.

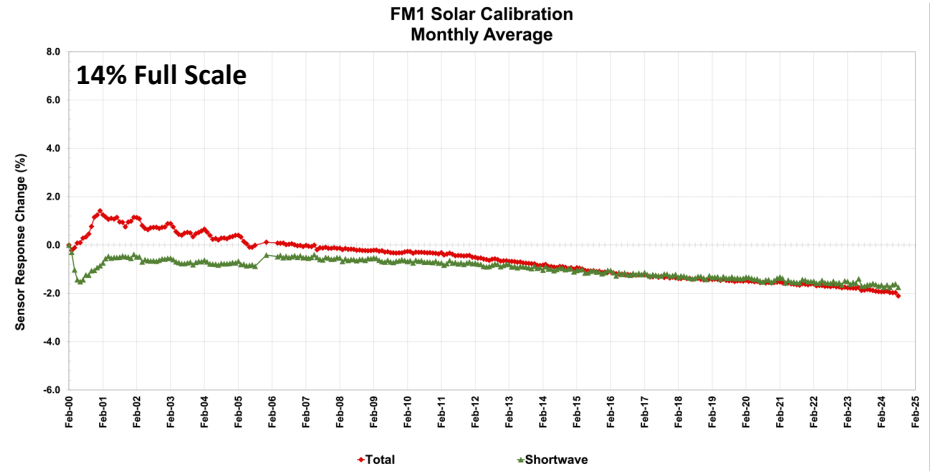


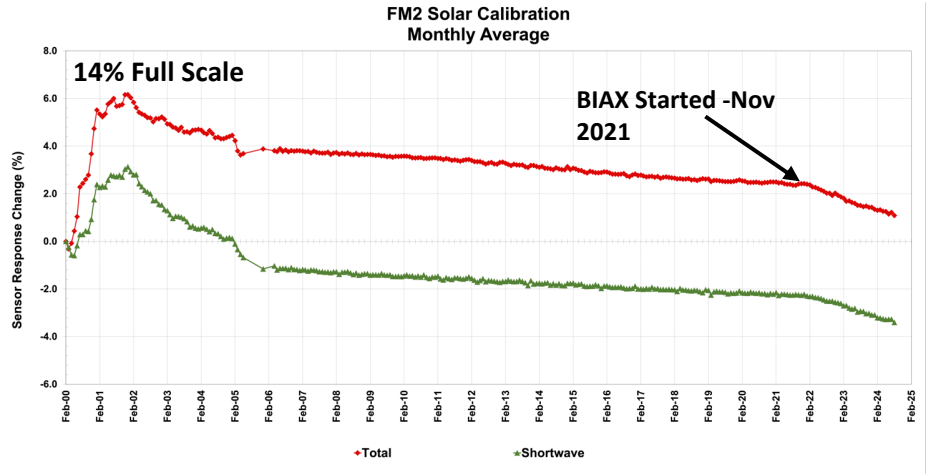


Total, WN- Blackbody: ~300 K
SW- Lamp: ~3000K brightness temp.

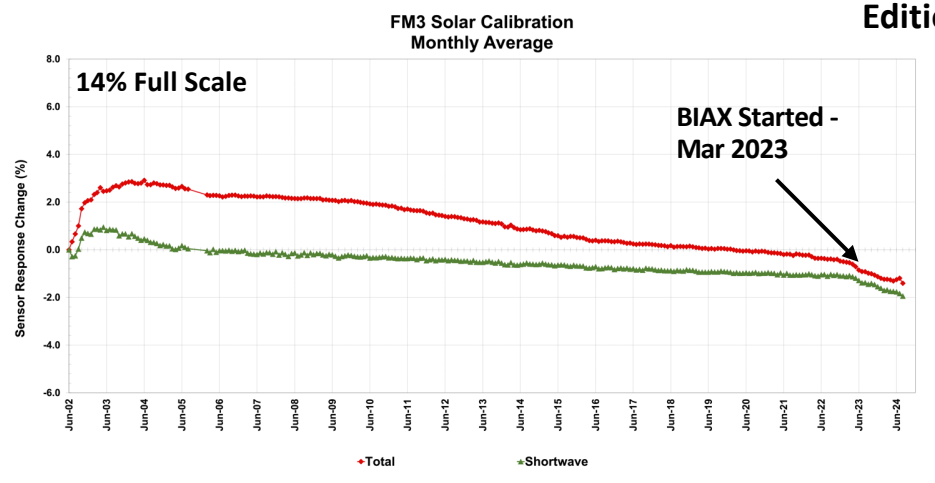
Terra & Aqua Solar Calibration

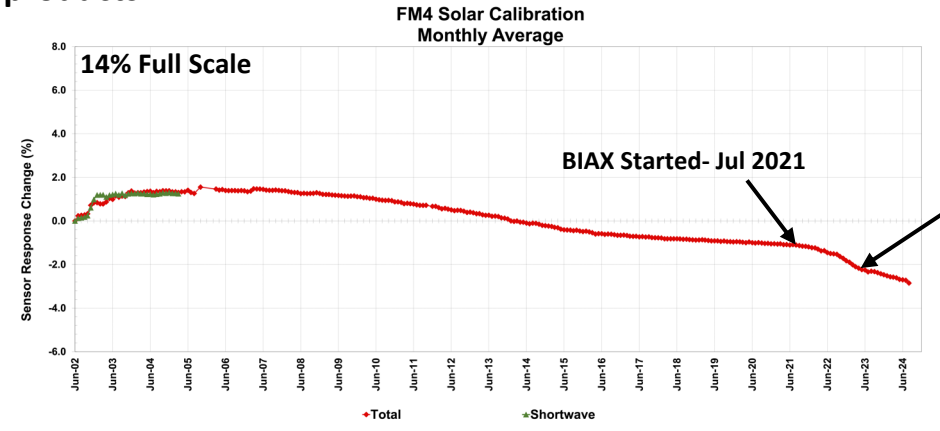
Since the start of BIAX, the TOT and SW channels on FM2 shows a drop in response of ~1.3%, FM3 drops by ~0.9%. TOT channel on FM4 showed a drop of ~1.2% while in BIAX.





Edition 1-CV data products





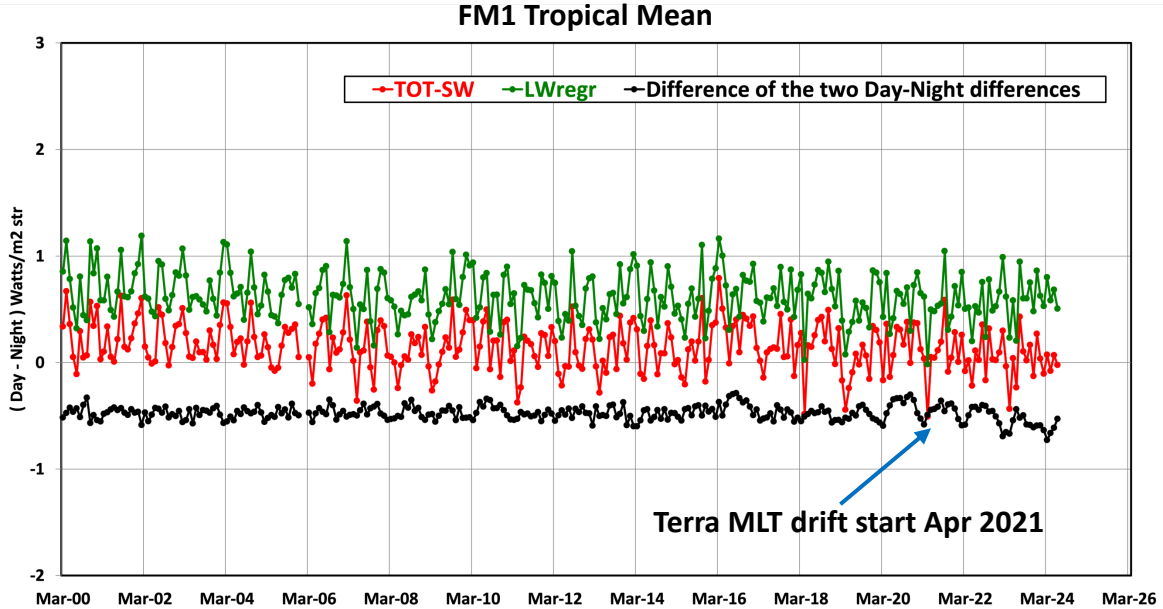
Validation – Tropical Mean (TM)

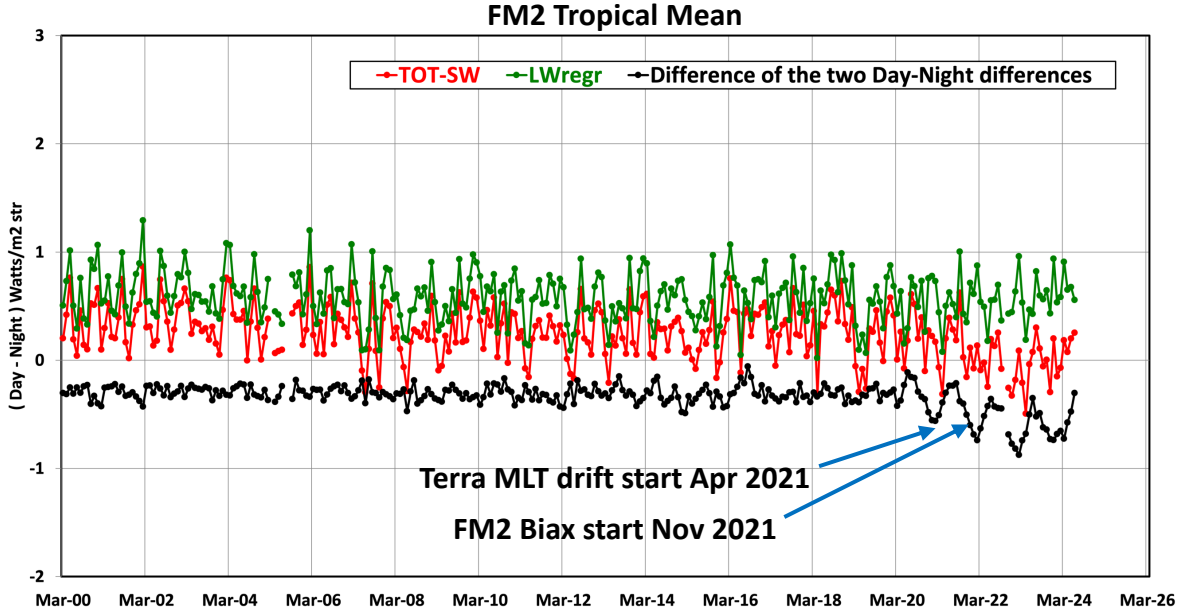
- Average of the ES-8 Nadir radiances over Tropical ocean (20^0N-20^0S) scenes under All-sky conditions.
  - Uses latest version of data products - All calibration updates have been applied.
- Two sets of TM Day-Night Differences (DN) are calculated:
  - TOT and SW sensors

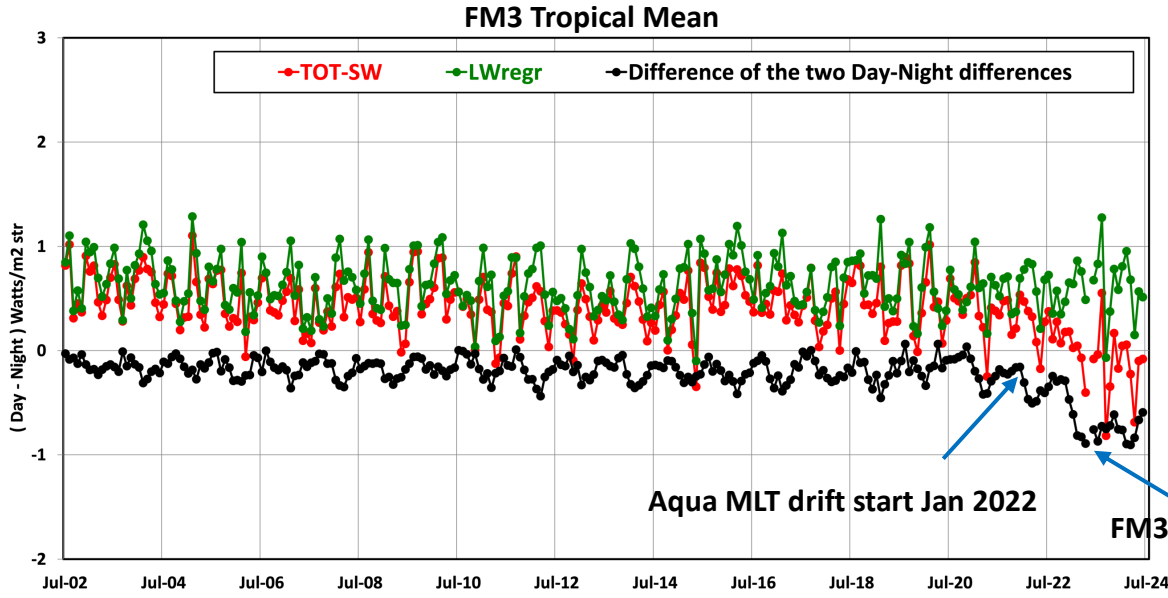
    $DN = TM_D(TOT\text{-}SW) - TM_N(TOT)$
  - LW_r *(Uses a 'trained' WN- Narrow to BB regression)*

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

Validation- Terra and Aqua Tropical Mean



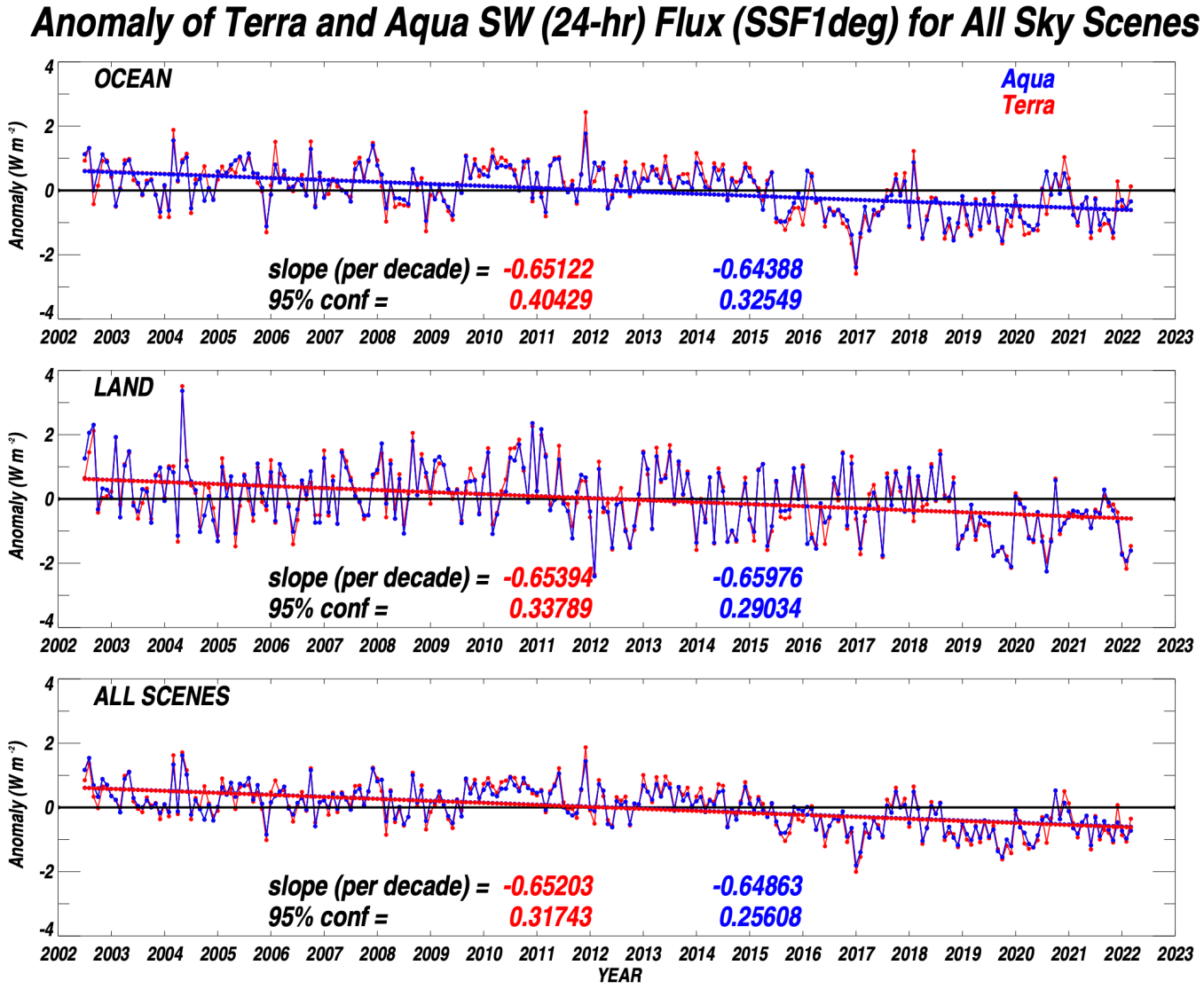




Uses Edition 4 ES-8 data products

Validation: Terra and Aqua Ed-4 SW Flux Anomalies

Level 3
Edition 4 products



Jul 2002-Mar 2022

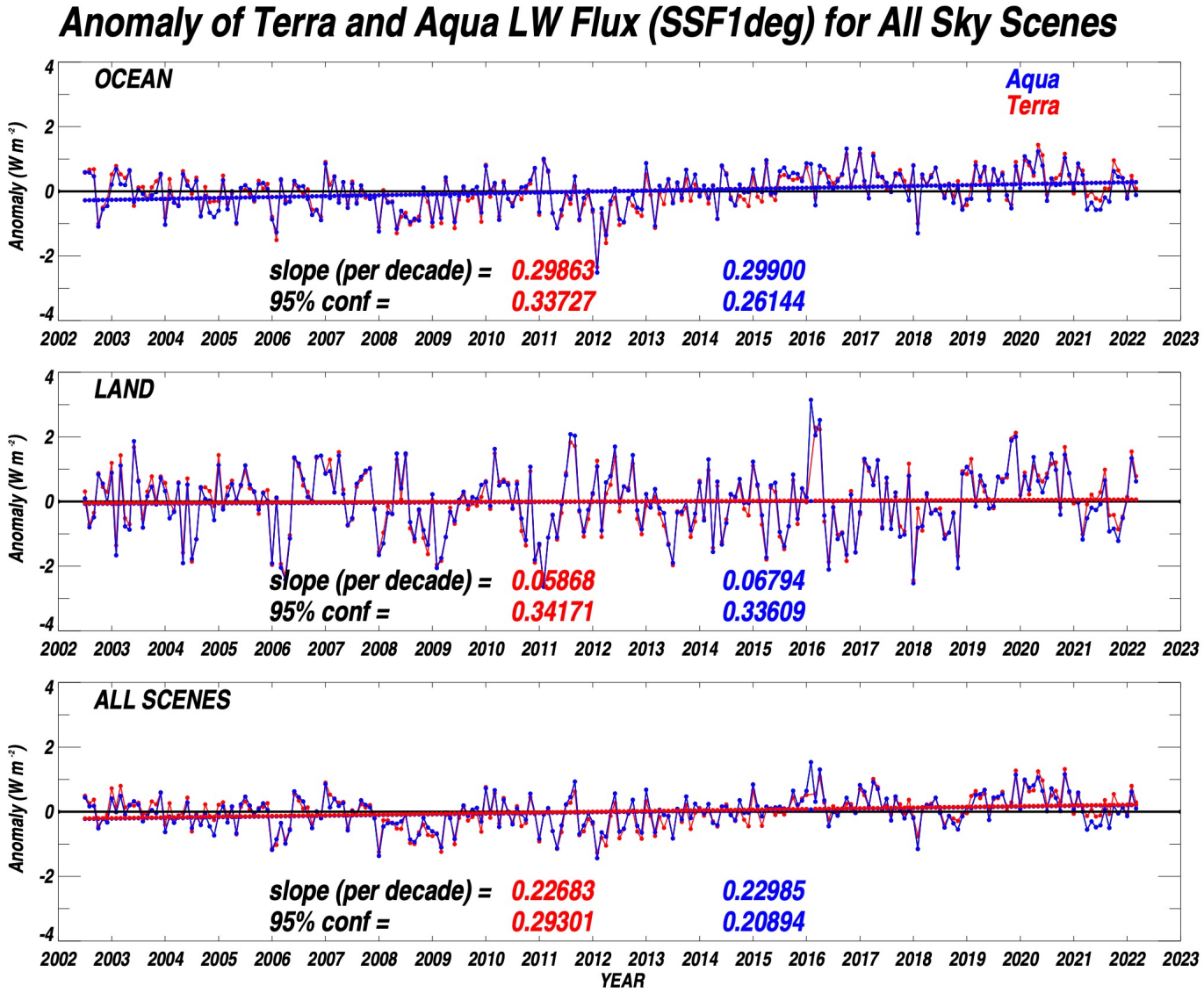
Terra started drifting to earlier MLT in Apr 2021. Aqua started drifting to later MLT in Jan 2022.

CERES Instrument Working Group

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

Validation: Terra and Aqua Ed-4 LW Flux Anomalies

Level 3
Edition 4 products



Jul 2002-Mar 2022

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

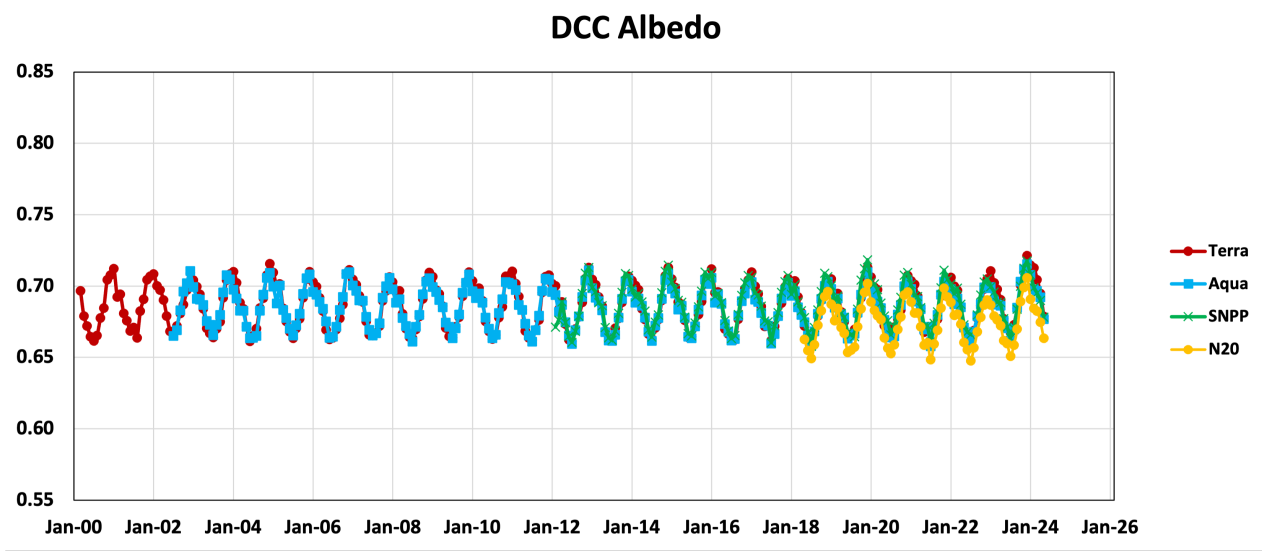
CERES Instrument Working Group

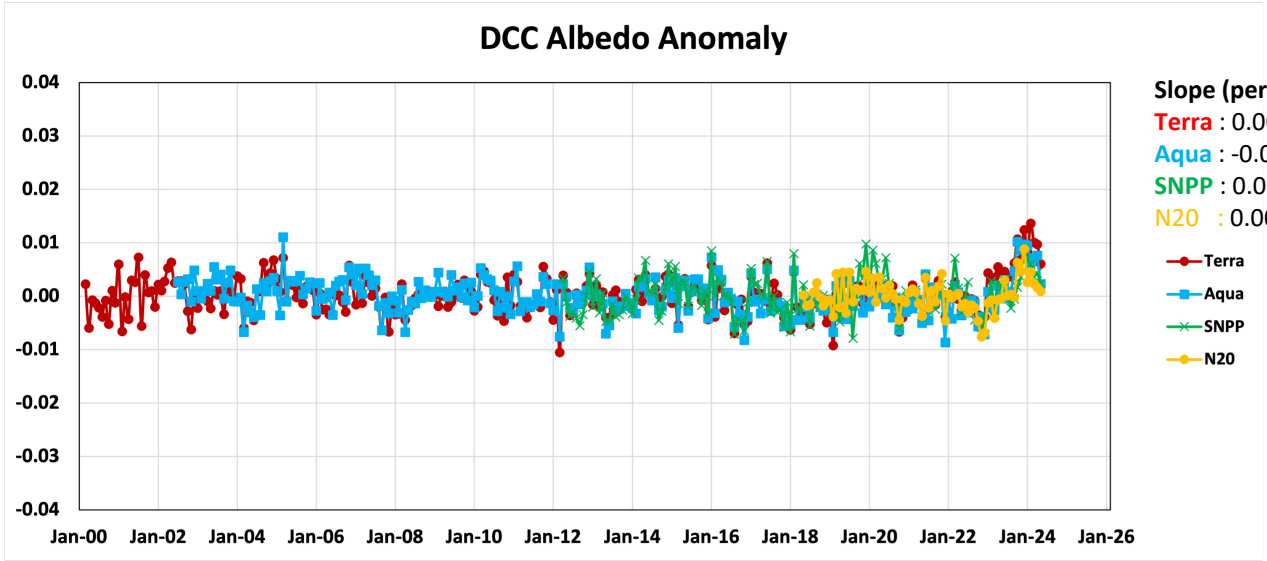
Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A
Aqua: CER_SSF1deg-Month_Aqua-MODIS_Edition4A

Deep Convective Cloud (DCC) Albedo

- Observe the long-term trends of DCC albedo.
  - Uses Level-2 products (SSF), calculate monthly means of DCC footprints.
  - Trend the DCC albedos for instruments on Terra, Aqua, S-NPP, NOAA20.
- Criteria for selecting DCC:
  - Consider all footprints with VZA, SZA < 40 deg.
  - Latitude bands: 30^0 N-S.
  - Cloud Fraction= 100%.
  - Use MODIS/VIIRS 11um channel to identify footprints with brightness temperature <210K.
  - WN channel filtered radiance (Terra, Aqua, SNPP) < 1 $Wm^{-2}sr^{-1}um^{-1}$.

DCC Albedo





Slope (per decade) ± 95% CI
Terra : 0.0005 ± 0.0010
Aqua : -0.0007 ± 0.0010
SNPP : 0.0029 ± 0.0034
N20 : 0.0008 ± 0.0092

Data Series:
Terra: Mar 2000- May 2024
Aqua: Jul 2002- May 2024
SNPP: May 2012- May 2024
N20: May 2018- May 2024

DCC trends show that CERES instruments on Terra, Aqua, SNPP, and N20 are very consistent with each other, with no significant long-term trends.

CERES Instrument Working Group

Data:
CER_SSF_Terra-FM1-MODIS_Edition4A
CER_SSF_Terra-FM2-MODIS_Edition4A
CER_SSF_Aqua-FM3-MODIS_Edition4A
CER_SSF_Aqua-FM4-MODIS_Edition4A
CER_SSF_NPP-FM5-VIIRS_Edition2A
CER_SSF_NOAA20-FM6-VIIRS_Edition1B

Edition 5 Instrument Updates

- For Edition 4, in the generation of the time-varying Spectral Response Functions (SRFs) for the Total channel for Terra and Aqua instruments, a mid-stream change was made in Mar 2017, which involved the MODIS imager.
  - The mid-stream change was made because constraints applied to a few MODIS parameters used in sub-setting the cloudy scenes in the SSF were too restrictive, causing a discrepancy in the sampling between the daytime and night-time scenes in the process of selection of the optimal SRF.
  - The updated algorithm removes these constraints entirely.
  - All SRFs selected after Mar 2017 used this updated algorithm, leaving all prior SRFs unchanged.
- Edition 5 will run with the consistent criteria from the Beginning of mission (BOM) to obtain new time varying SRFs.
  - Currently the team is running analysis using the new SRFs on the Level 2 data products.

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 have now stopped.**
  - **SNPP/FM5 has transitioned back to crosstrack scan mode and continues to perform nominally.**
  - **Terra and Aqua instruments' performance continue to be monitored as their orbits drift- studies indicate that all instruments are performing well.**
- **Level 1 Data products**
  - **NOAA-20/FM6 Edition 1 gains have been delivered through Aug 2024.**
  - **S-NPP/FM5 Edition 2 gains and SRFs have been delivered through Jul 2024.**
  - **Terra and Aqua instruments' Edition 4 gains and SRFs have been delivered through Jul 2024.**
- **IWG continues to support Libera Cal-Val and Ops meetings.**

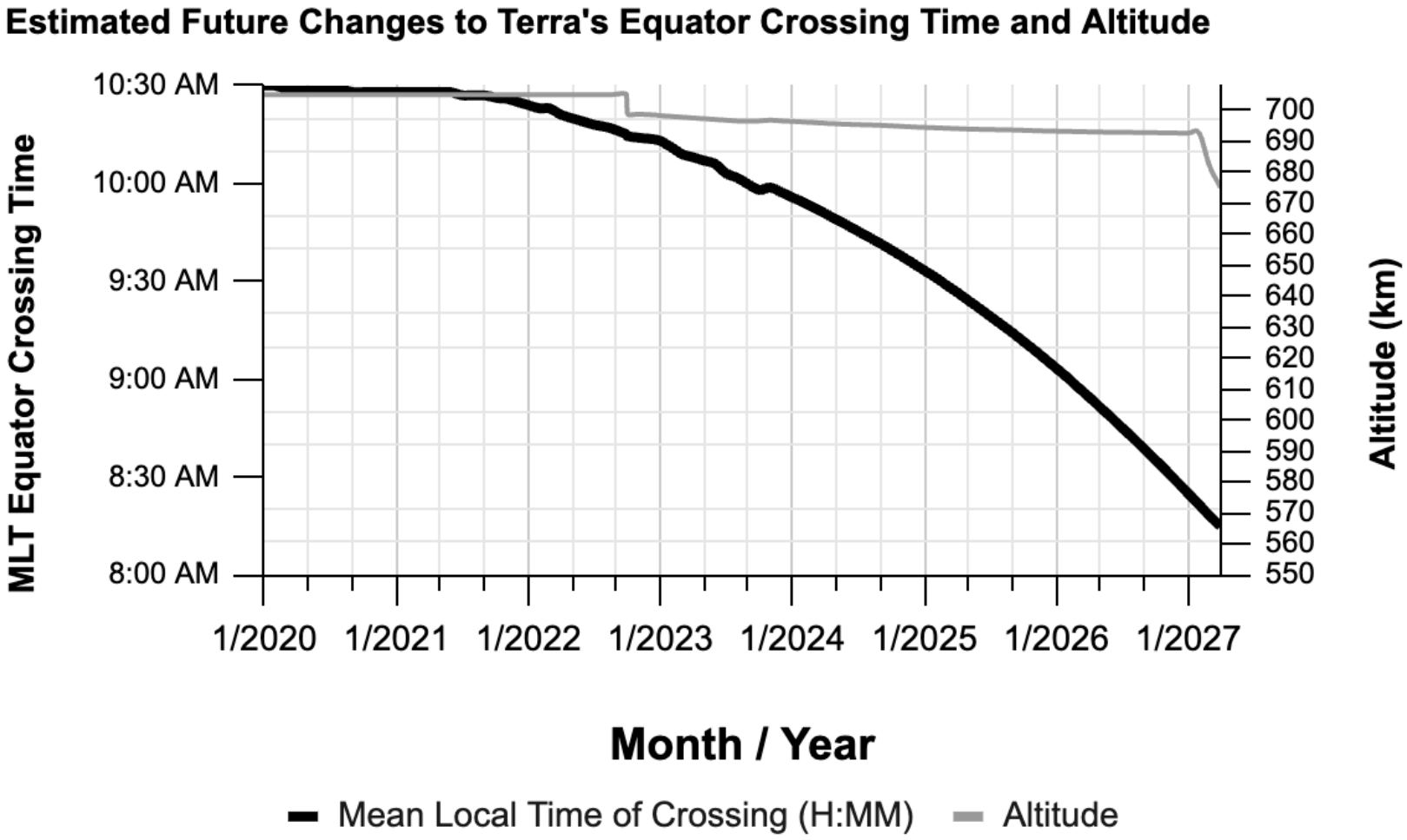
Backup

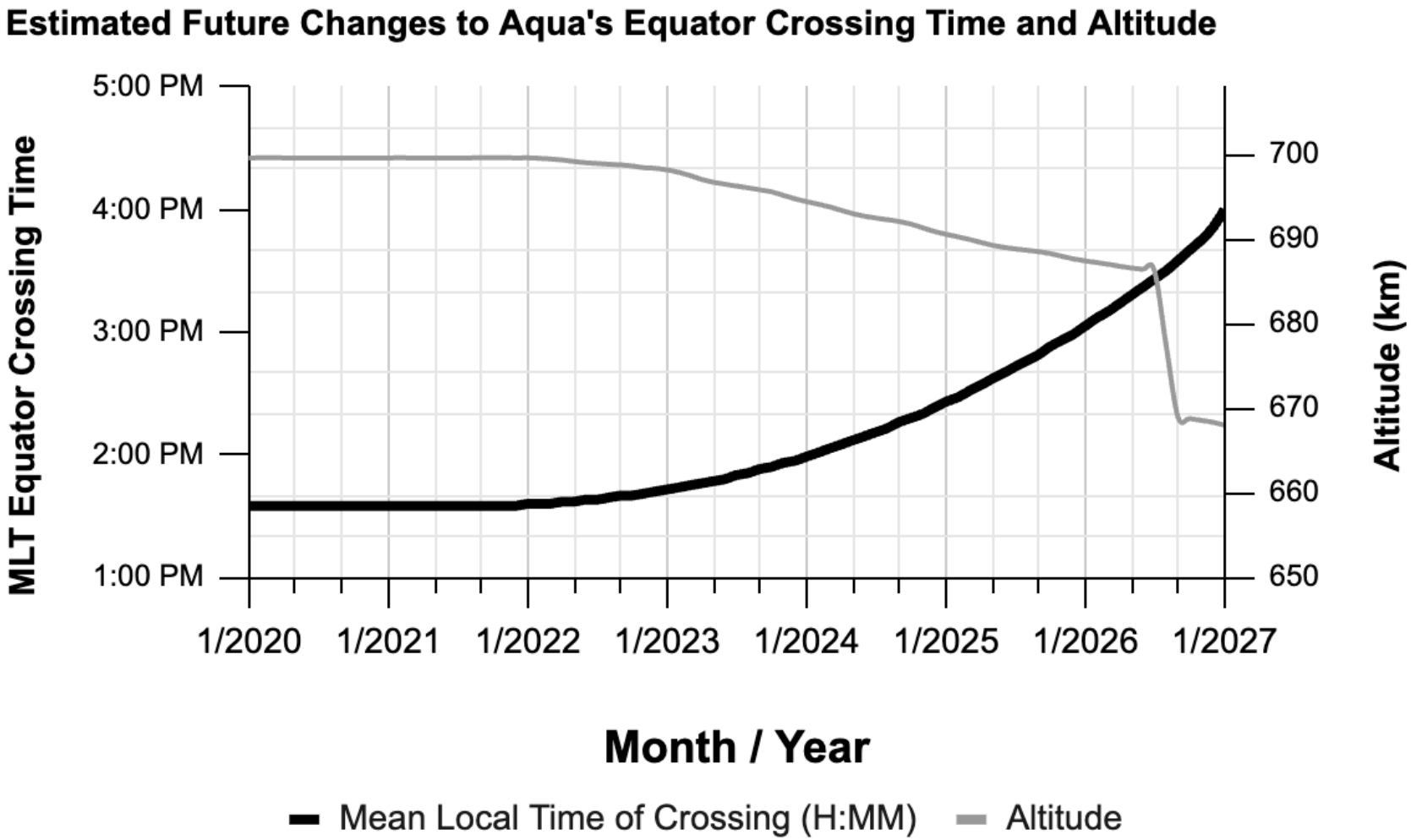
Instrument Product-line definitions

- **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.


Estimated Future Changes to Terra's Equator Crossing Time and Altitude
MLT Equator Crossing Time
10:30 AM
10:00 AM
9:30 AM
9:00 AM
8:30 AM
8:00 AM
1/2020
1/2021
1/2022
1/2023
1/2024
1/2025
1/2026
1/2027
Month / Year
Altitude (km)
700
690
680
670
660
650
640
630
620
610
600
590
580
570
560
550
Mean Local Time of Crossing (H:MM)
Altitude


Estimated Future Changes to Aqua's Equator Crossing Time and Altitude
MLT Equator Crossing Time
5:00 PM
4:00 PM
3:00 PM
2:00 PM
1:00 PM
Altitude (km)
700
690
680
670
660
650
1/2020
1/2021
1/2022
1/2023
1/2024
1/2025
1/2026
1/2027
Month / Year
Mean Local Time of Crossing (H:MM)
Altitude