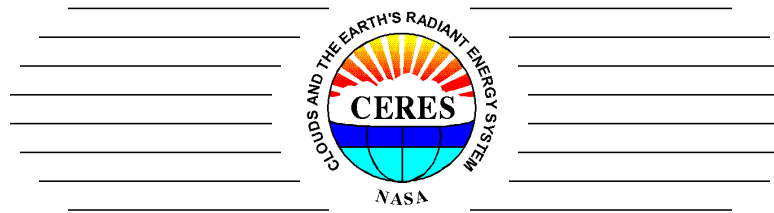


PERFORMANCE EVALUATION OF CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM (CERES) INSTRUMENTS IN GENERATING A STABLE EARTH RADIATION BUDGET MULTI- DECADAL DATA RECORD



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N.M. Smith^c, D. R. Walikainen^b**

a. NASA Langley Research Center

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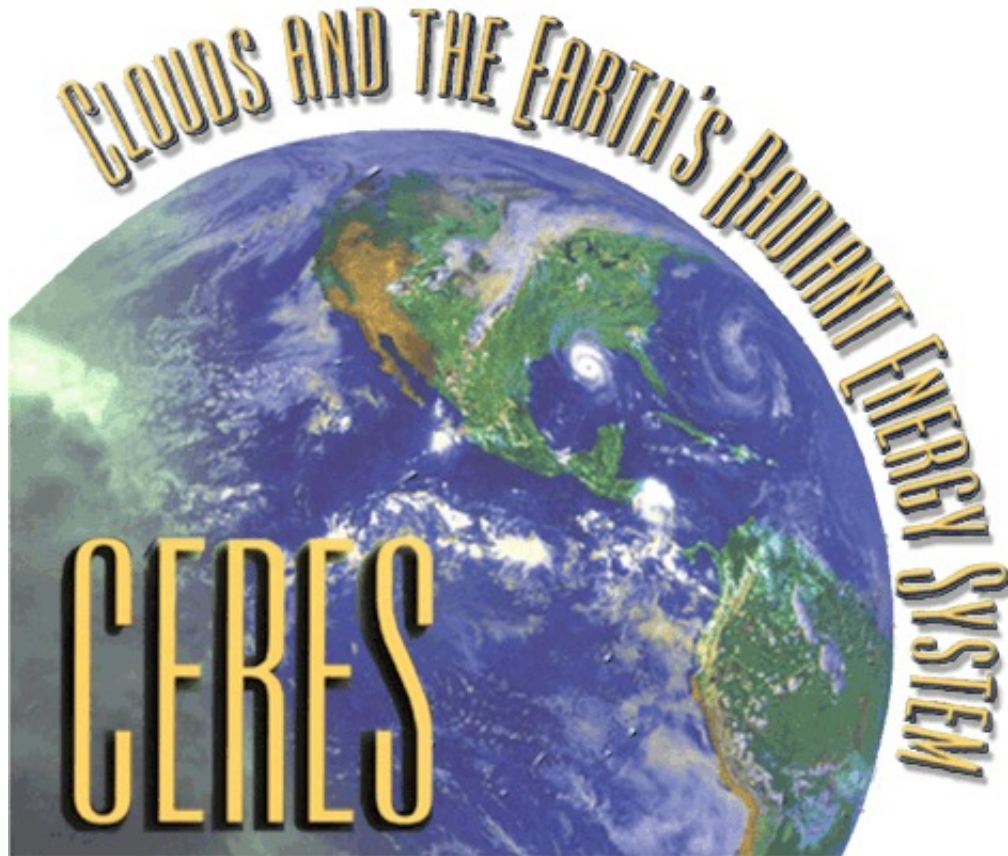
c. Analytical Mechanical Associates

Hampton, Virginia, USA

**IEEE IGARSS 2024, Athens, Greece
July 7 – 12, 2024**



OUTLINE



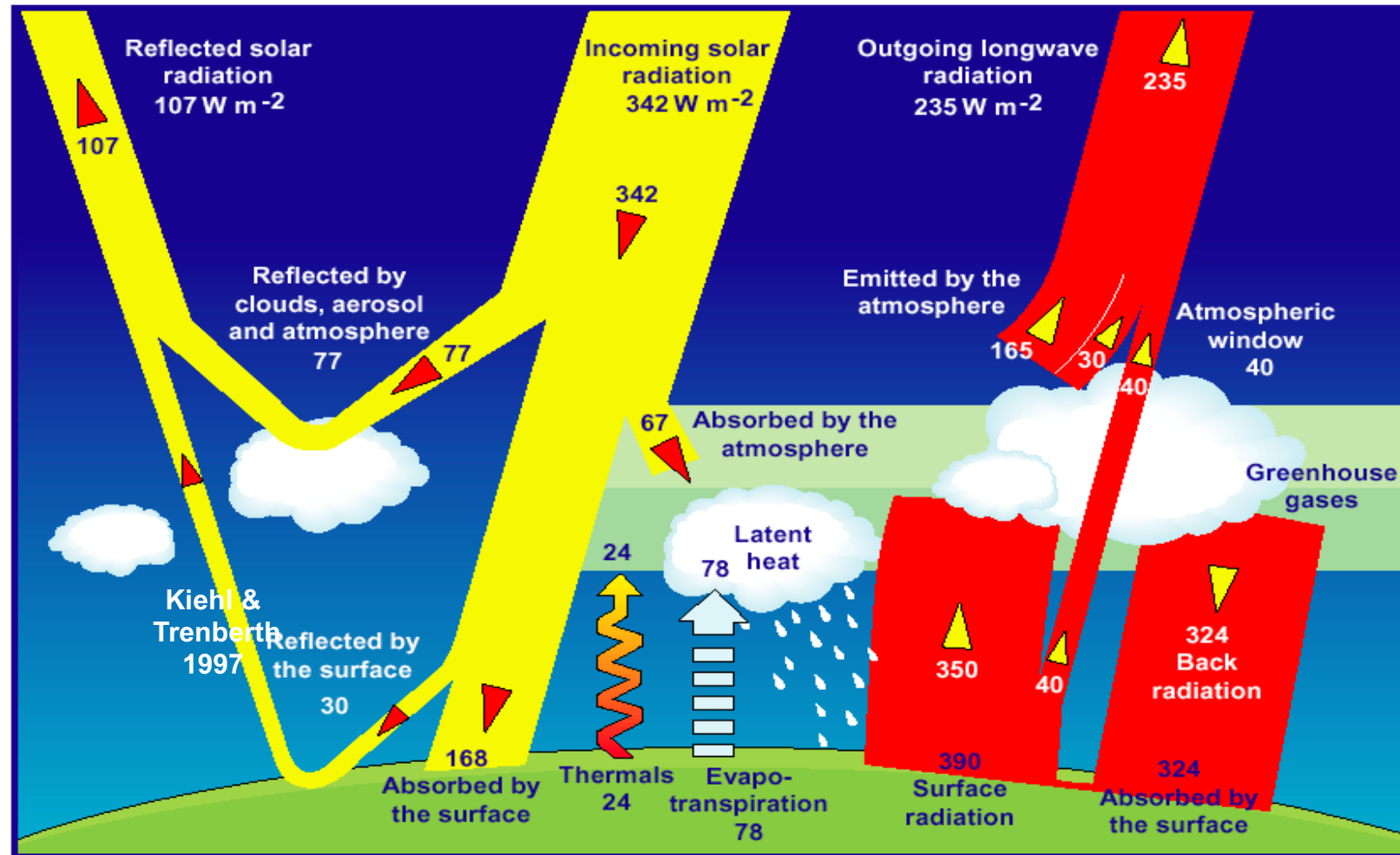
- **CERES OVERVIEW**
- **INSTRUMENT**
- **SENSOR CALIBRATION**
- **VALIDATION STUDIES**
- **INTERCOMPARISONS**
- **SUMMARY**

Earth Radiation Budget Components

CERES

CERES

Top of
Atmosphere

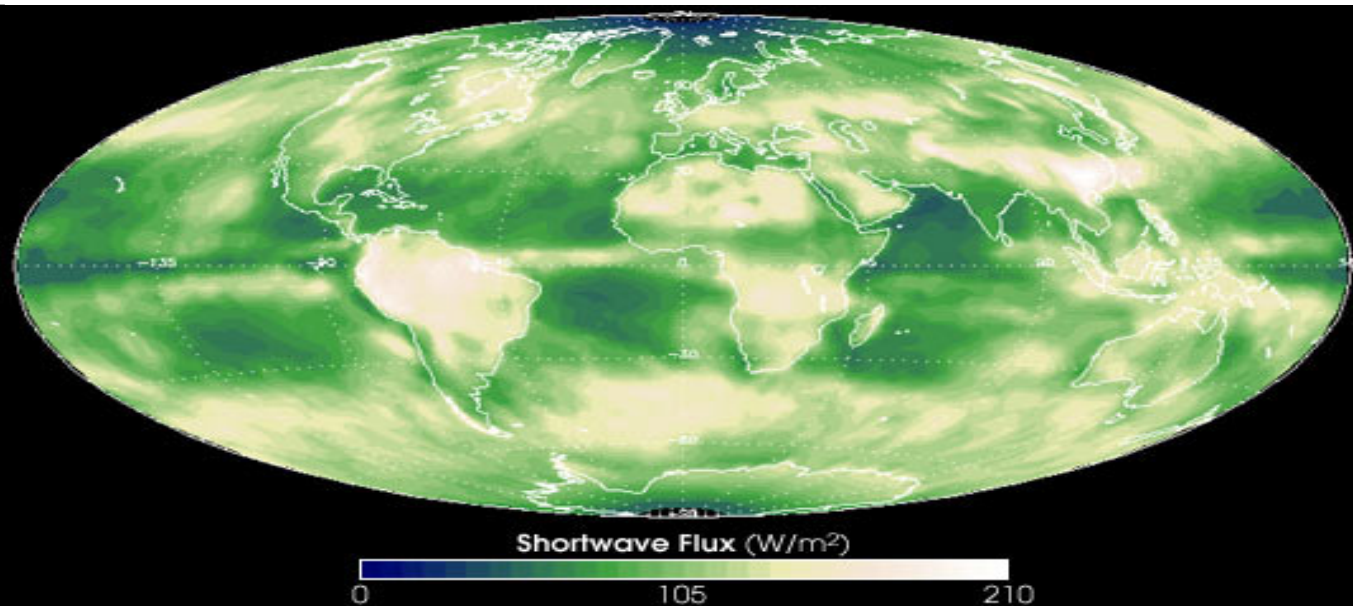




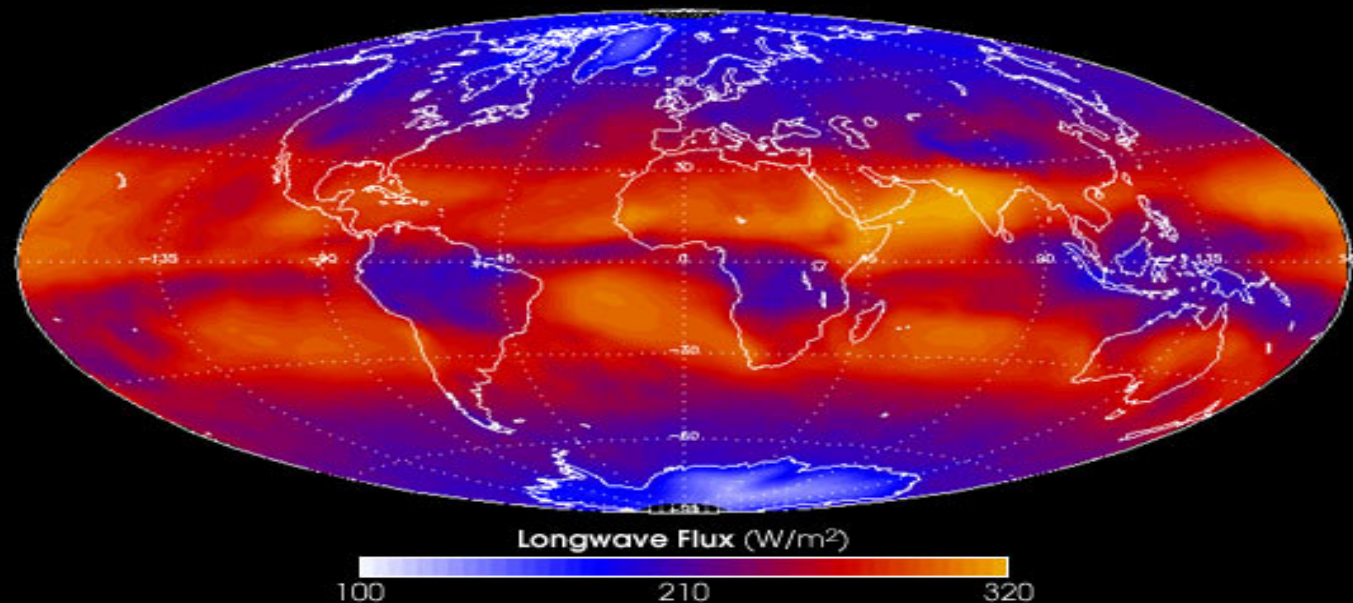
Primary CERES Climate Data Records



**Reflected
Solar Energy**



**Emitted
Thermal
Energy**



CERES INSTRUMENTS

SIX CERES INSTRUMENTS supporting the NASA Earth Observing System (EOS) and NOAA S-NPP & NOAA20 missions.

FLIGHT MODELS 1 & 2 (FM1 & FM2) – TERRA Spacecraft

Launch: December 1999

705 KM - 10:30 AM Orbit. MLT Drift started in April 2021

FLIGHT MODELS 3 & 4 (FM3 & FM4) - AQUA Spacecraft

Launch: May 2002

705 KM - 1:30 PM Orbit. MLT Drift started in Jan 2022

FLIGHT MODEL 5 (FM5) - Suomi-NPP Spacecraft

Launch: October 2011

824 KM - 1:30 PM Orbit

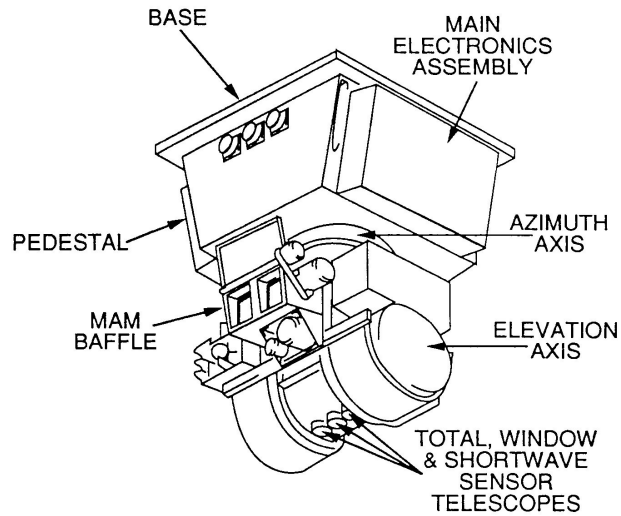
FLIGHT MODEL 6 (FM6) – NOAA20 Spacecraft

Launch: October 2011

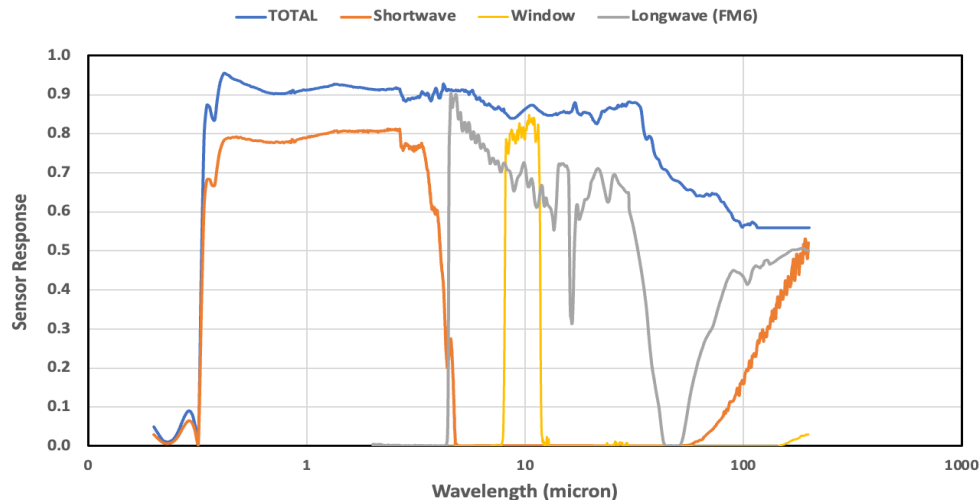
824 KM - 1:30 PM Orbit



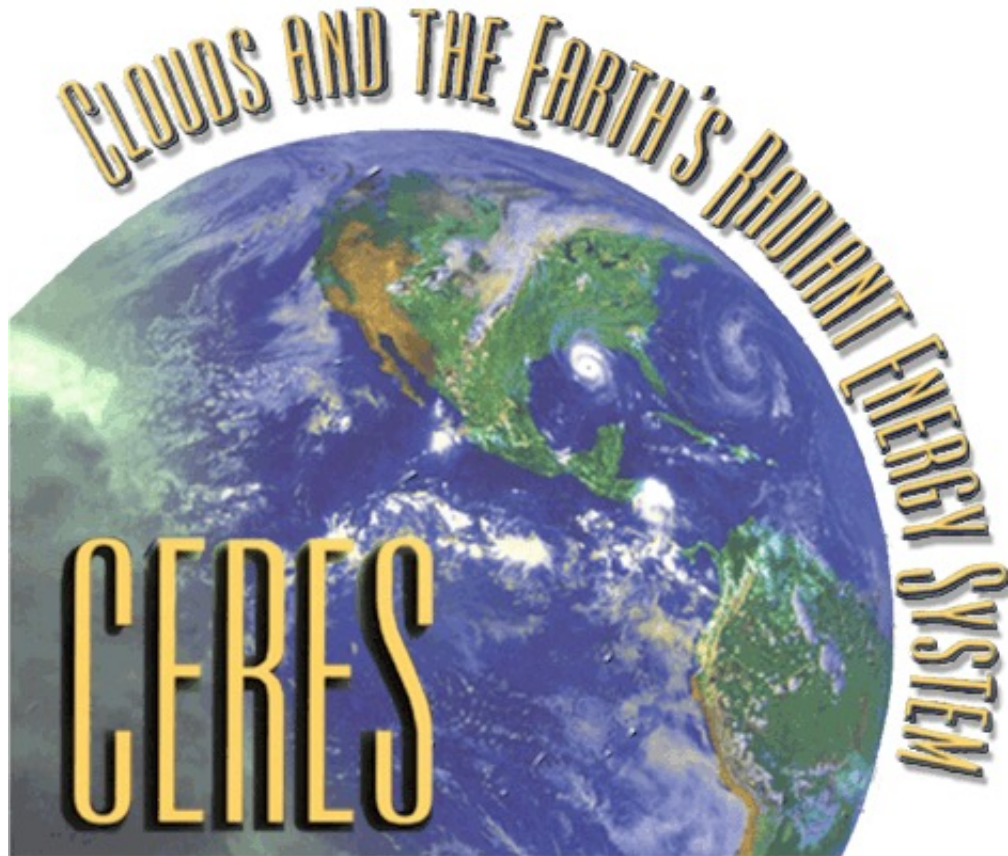
CERES INSTRUMENT



Total: 0.3 - >100 micron
Shortwave: 0.3 – 5.0 micron
Window: 8.0 – 12.0 micron
Longwave: 5.0 – 50 micron



- Three sensor assemblies with cassegrain optics and thermistor bolometer detectors
- Sensors measure thermal radiation in the near-visible through far-infrared spectral region
- Three sensor channels are coaligned and mounted on a spindle which rotates about the elevation axis
- Sensor Assembly Unit rotate about the azimuth axis providing hemispherical sampling of data
- Primary mode of operation is Crosstrack - fixed azimuth perpendicular to orbital path
- Pre-launch Calibration Accuracy Requirements - 0.5% LW, 1.0% SW



- CERES OVERVIEW
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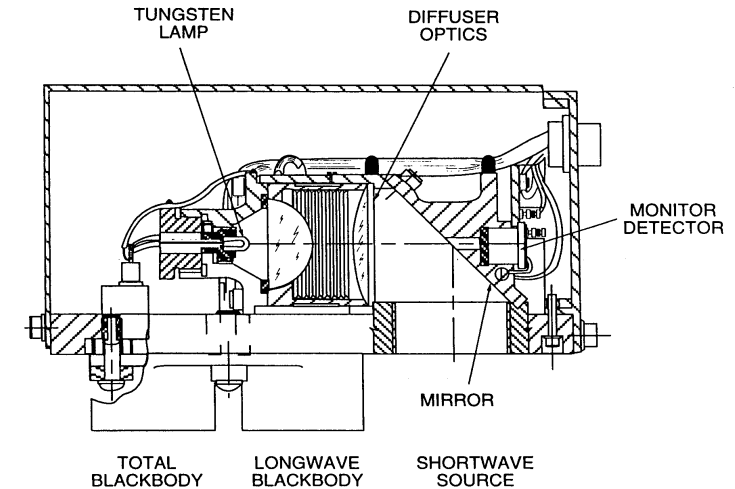
CERES FLIGHT CALIBRATION SYSTEMS

Internal Calibration Module

Total & Window: Blackbody sources

Shortwave: Quartz Tungsten Lamp

ICM Calibration instrumental in pre-launch to in-flight gain shift determination.



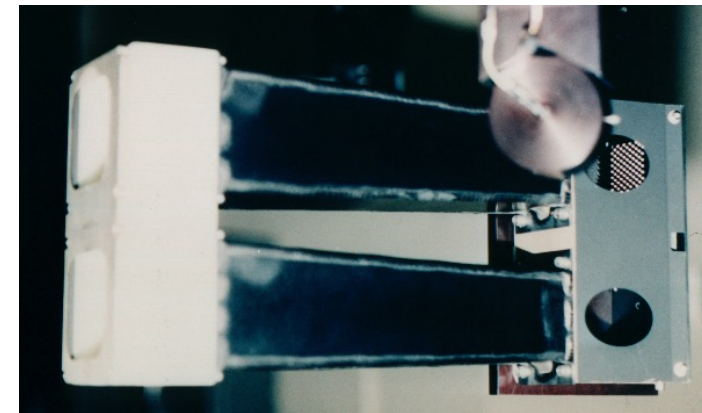
Mirror Attenuator Mosaic (MAM)

Solar Diffuser Plate to calibrate Total and

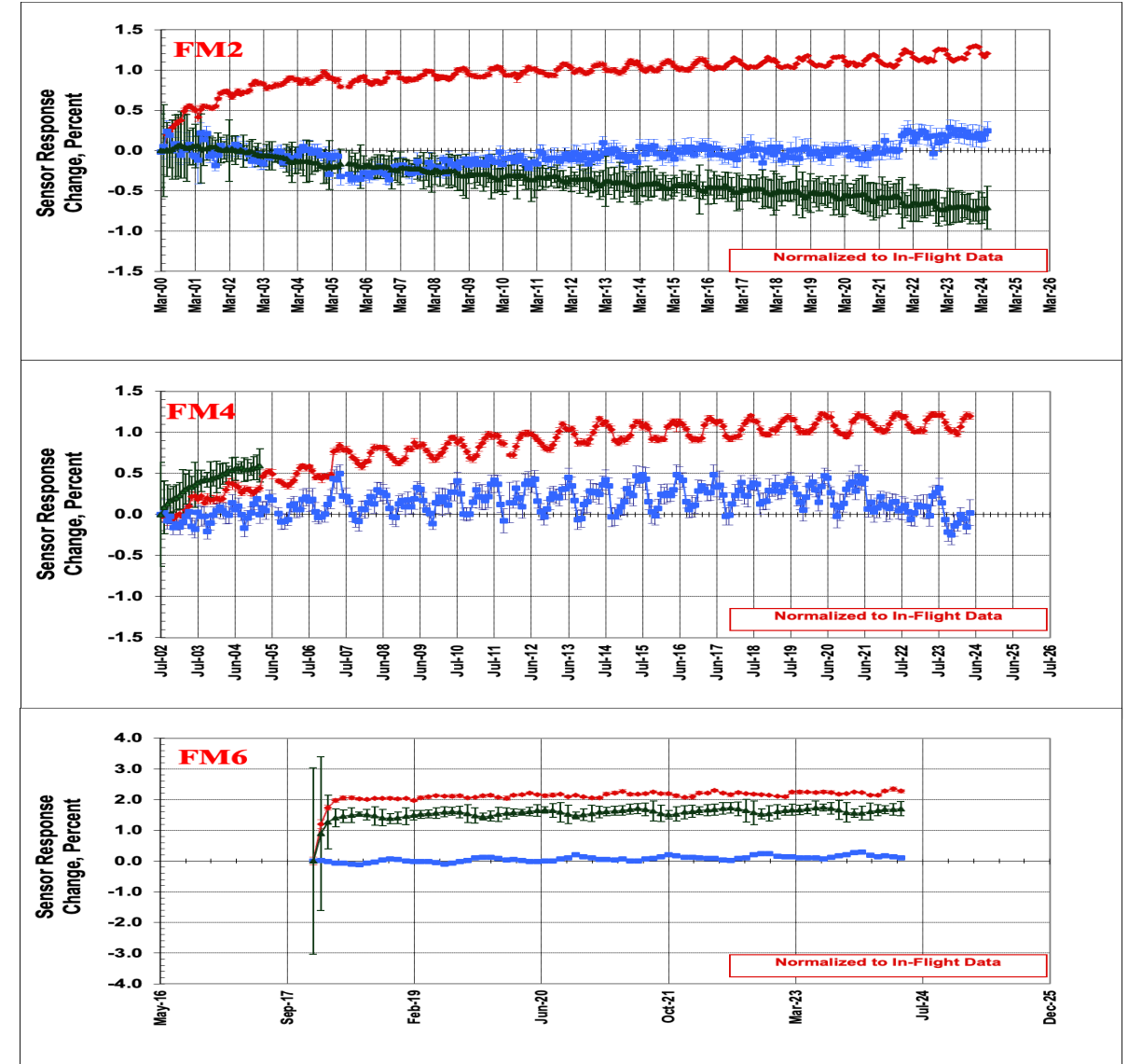
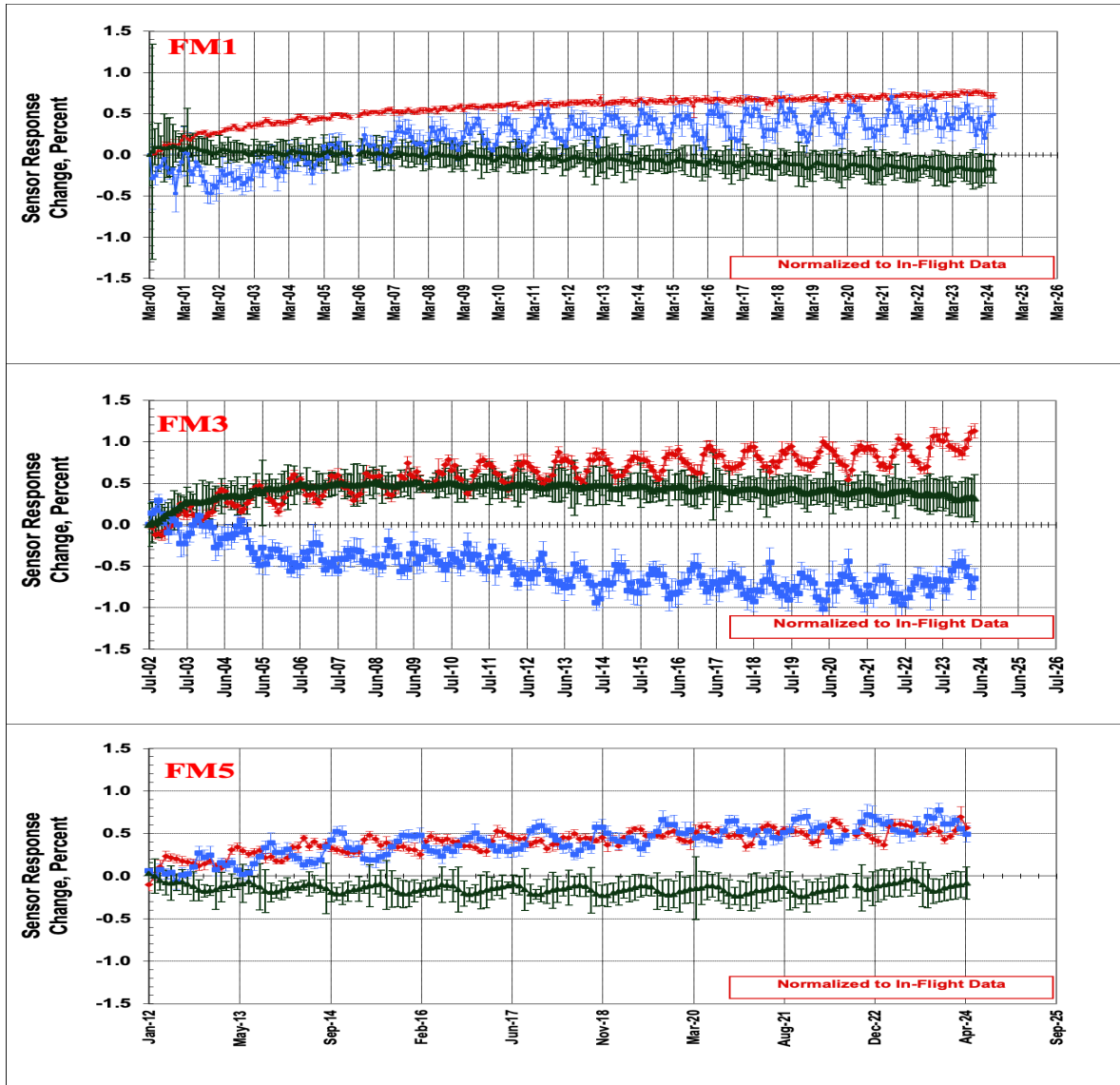
Shortwave sensors

Nickel substrate with Aluminum coated spherical cavities

In-flight gain variability evaluation



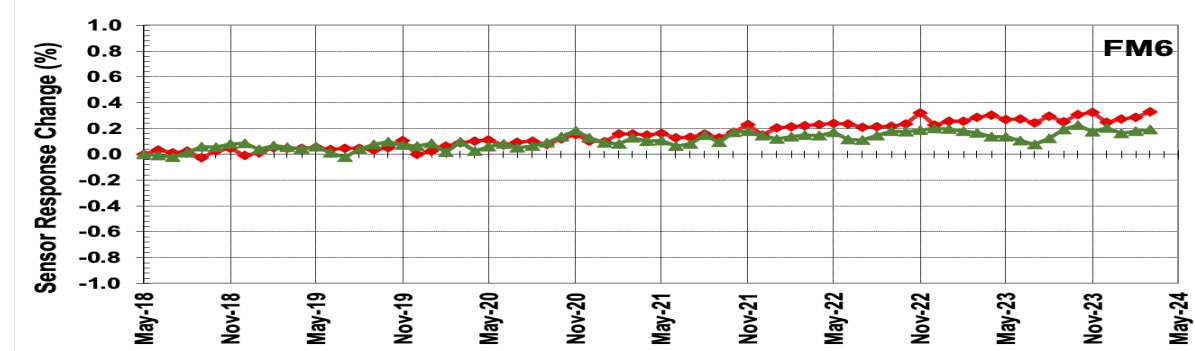
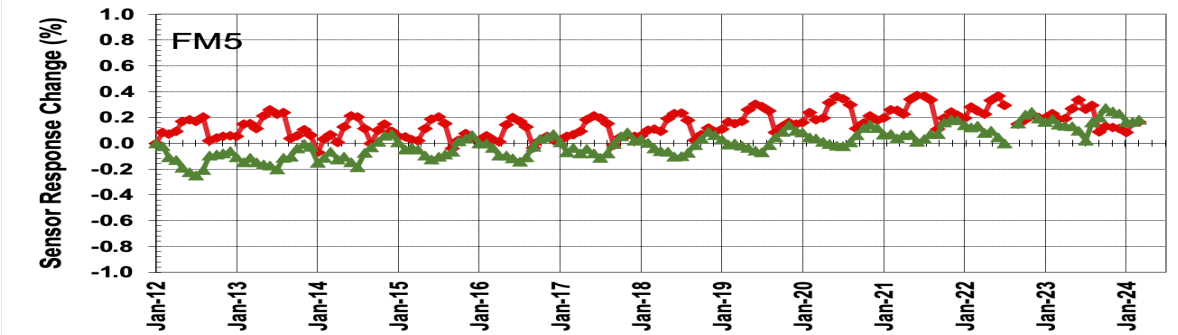
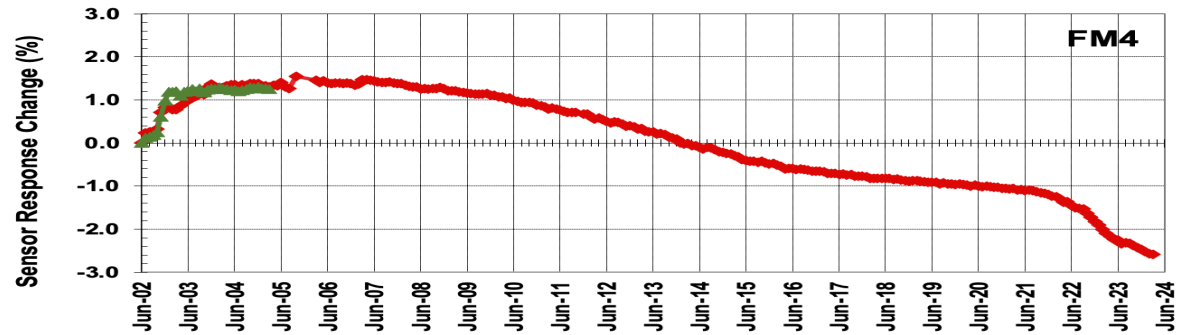
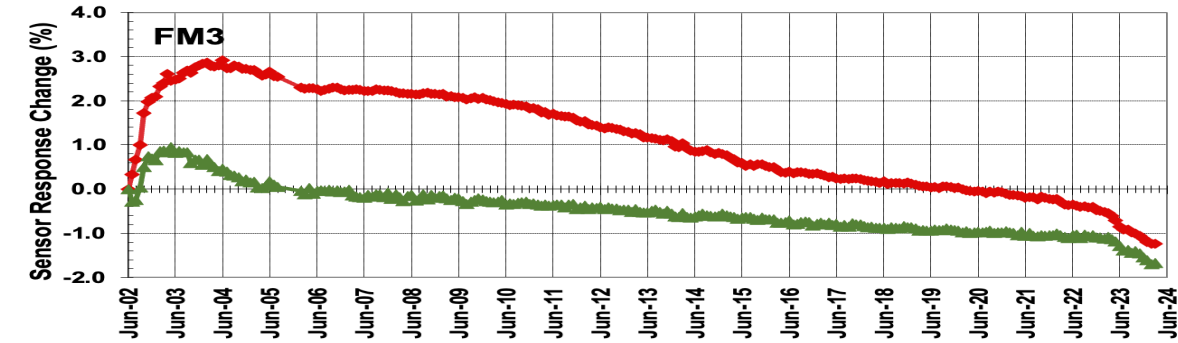
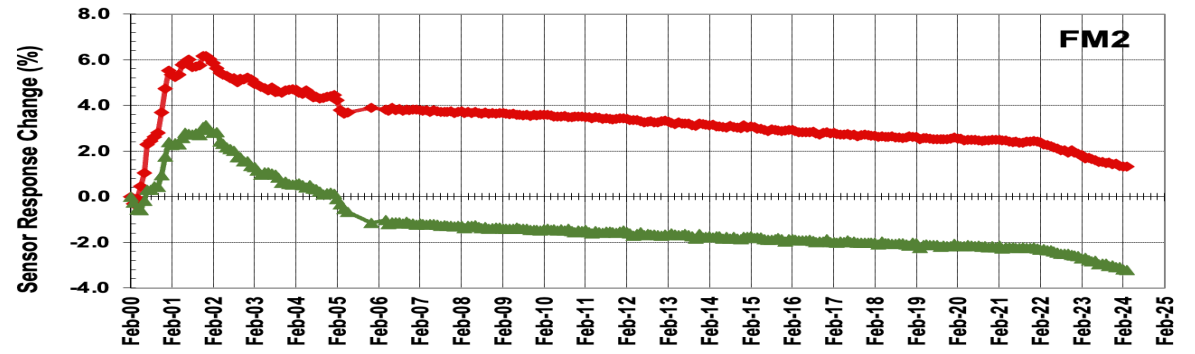
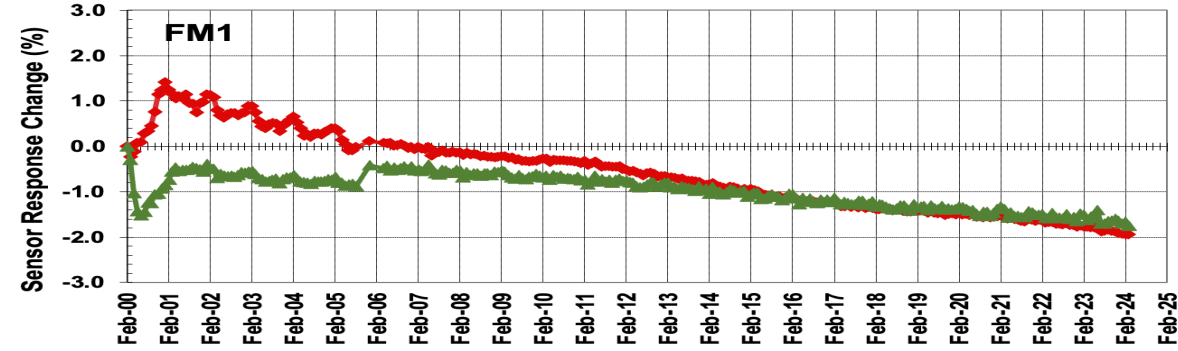
ICM Calibrations: Radiometric Gain



◆ Total • Window / LW ▲ Shortwave

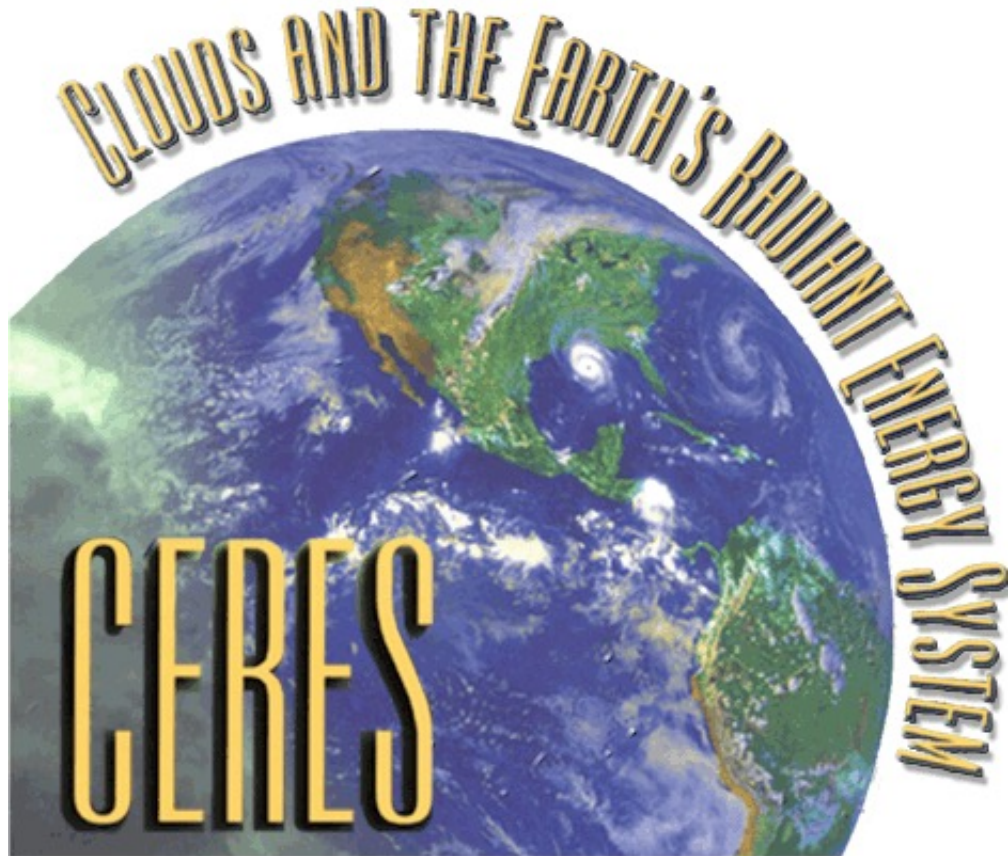


CERES Solar Calibrations



◆ Total ▲ Shortwave





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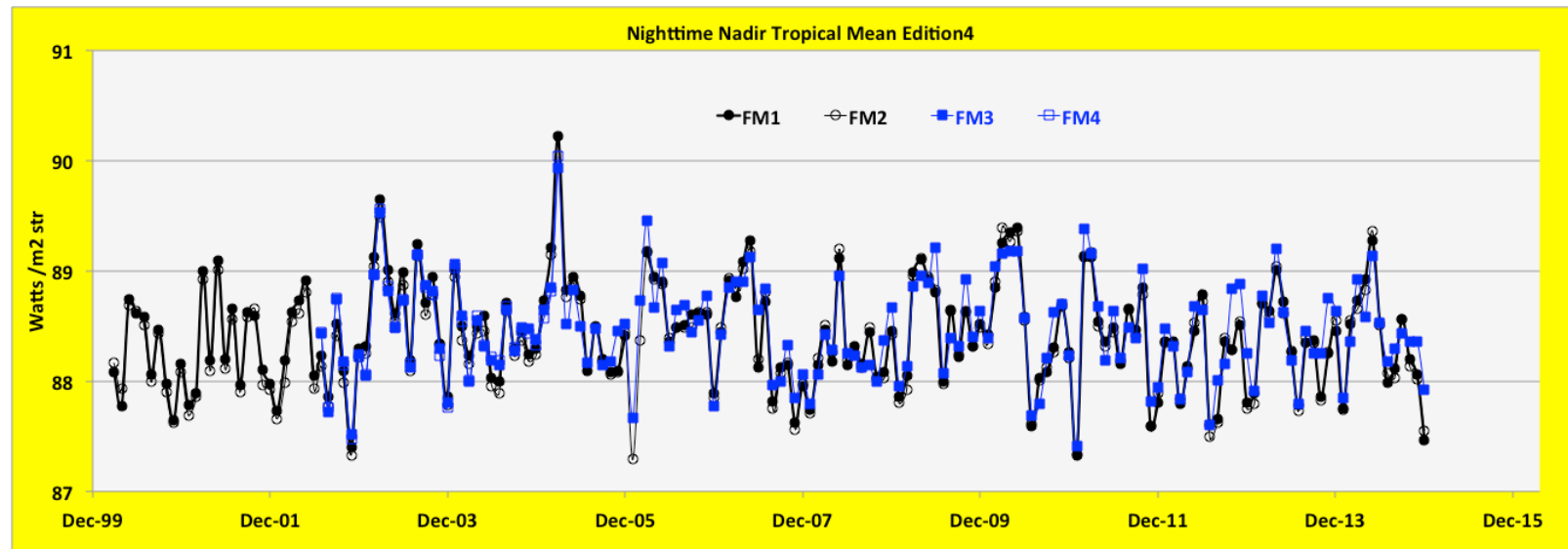


TROPICAL MEAN (TM) EVALUATION

Tropical Mean value is the average of Nadir Longwave (LW) radiances over Tropical ocean (20N – 20S) under All Sky conditions.

TM is relatively stable with low temporal variability.

The TM measurements from different instruments are adjusted for a noon orbit.



The average Night time TM value is $88.42 \pm 0.46 \text{ Wm}^{-2}\text{sr}$



TROPICAL MEAN (TM) EVALUATION

CERES daytime LW Radiance is calculated from Total and Shortwave sensors.

Daytime LW is also derived from trained Window sensor.

TM Day-Night Difference (DN) is derived:

1. TOTAL and SHORTWAVE Sensors

$$\text{DN} = \text{TM}(\text{day}, \text{TOT-SW}) - \text{TM}(\text{night}, \text{TOT})$$

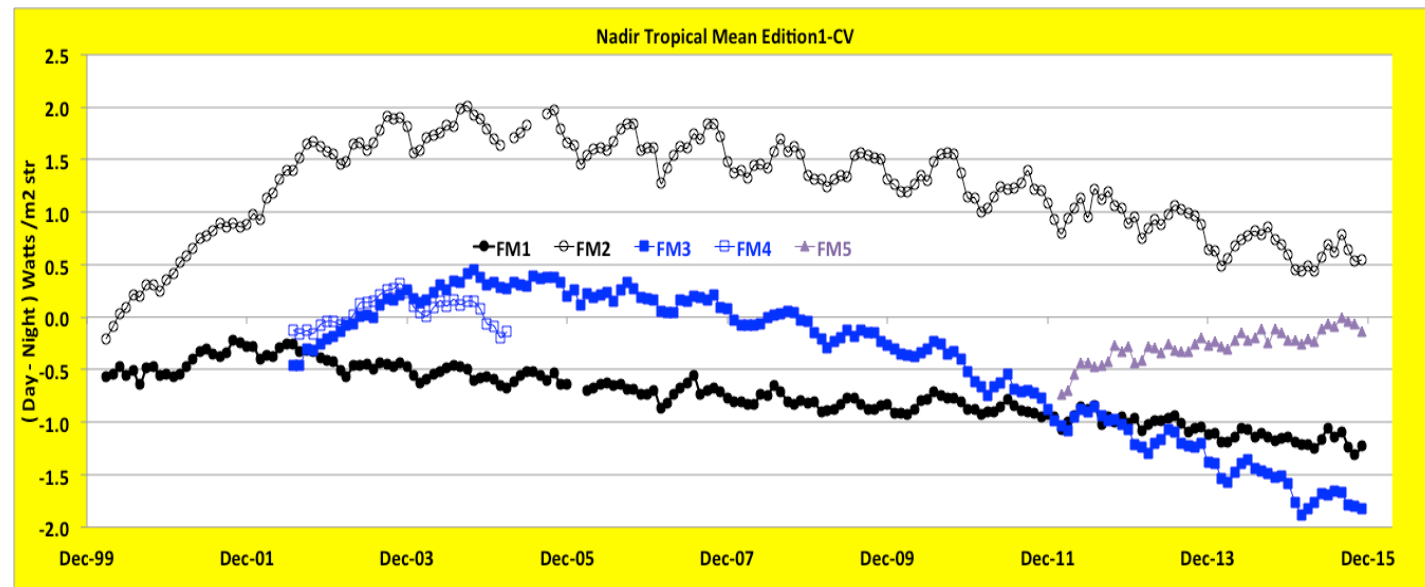
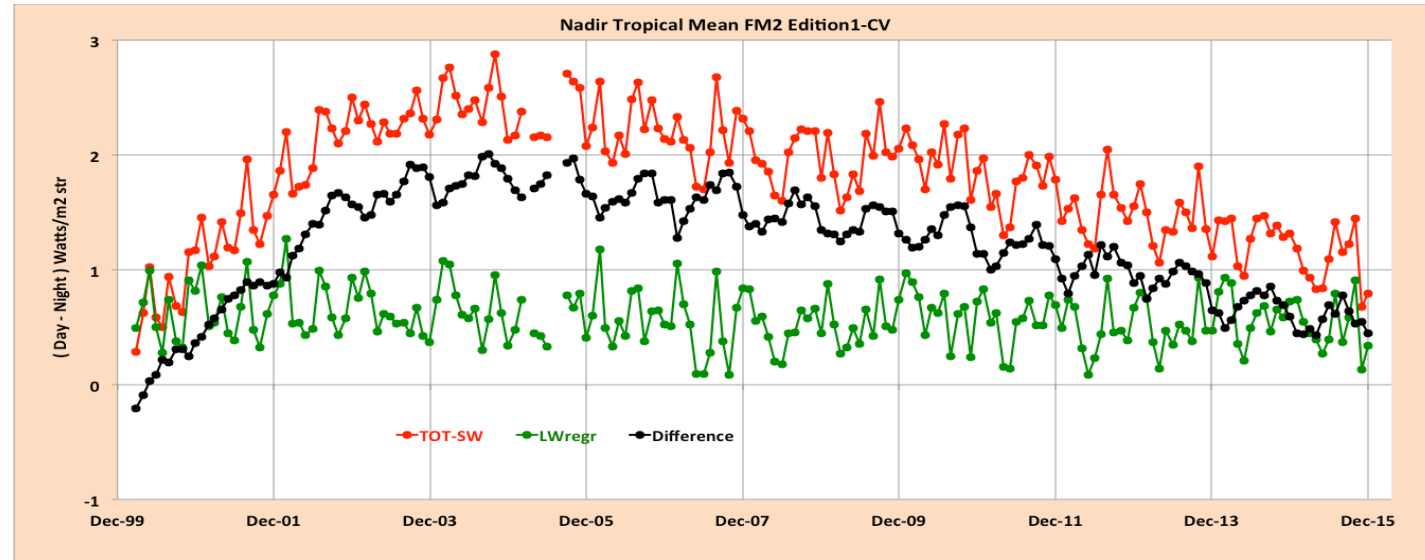
2. LONGWAVE/WINDOW Sensor

$$\text{DN} = \text{TM}(\text{day}, \text{LW}) - \text{TM}(\text{night}, \text{LW})$$

Difference in DN values highlight the discrepancy that may occur in the shortwave spectral region of the Total sensors.



OLR Day-Night Difference Trends: Tropical Mean



Direct Compare: Shortwave Sensor Flux

Comparison of coincident Shortwave sensor measurements from instruments on the same spacecraft.

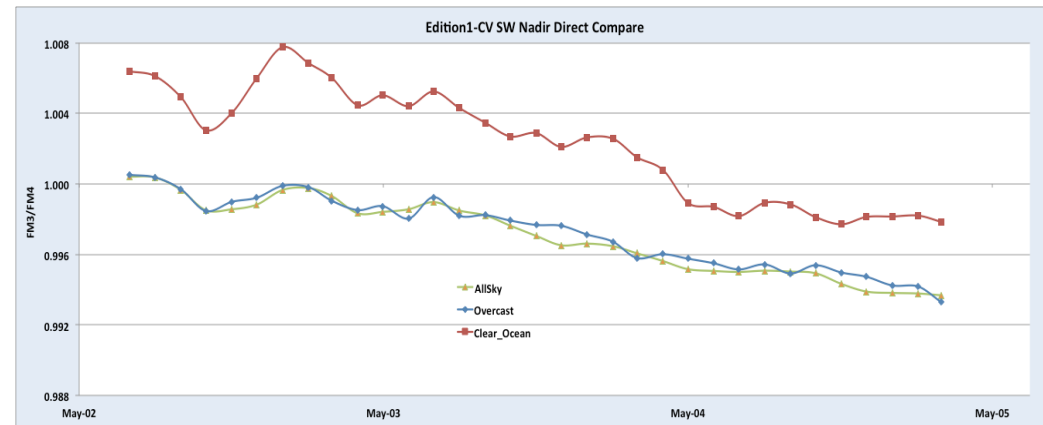
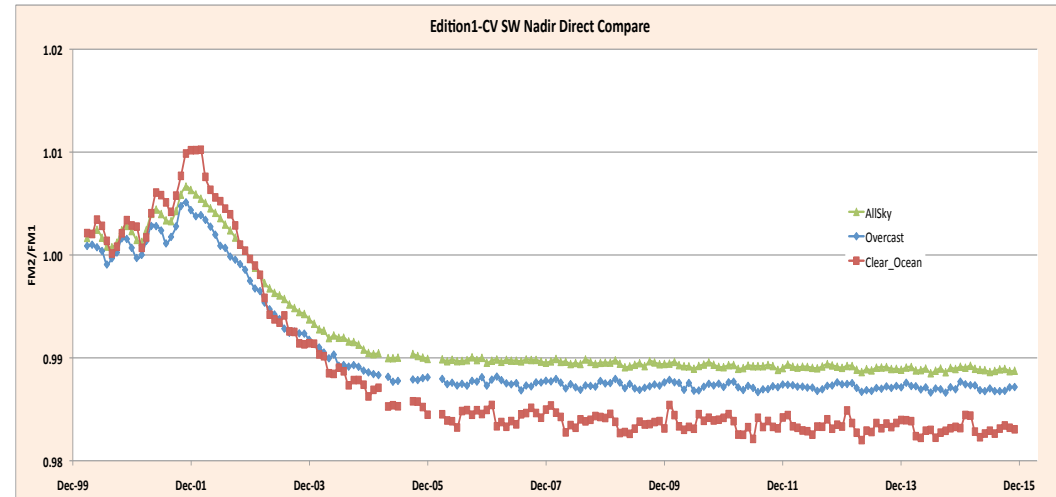
Results are categorized by scenes.

Shortwave measurement changes

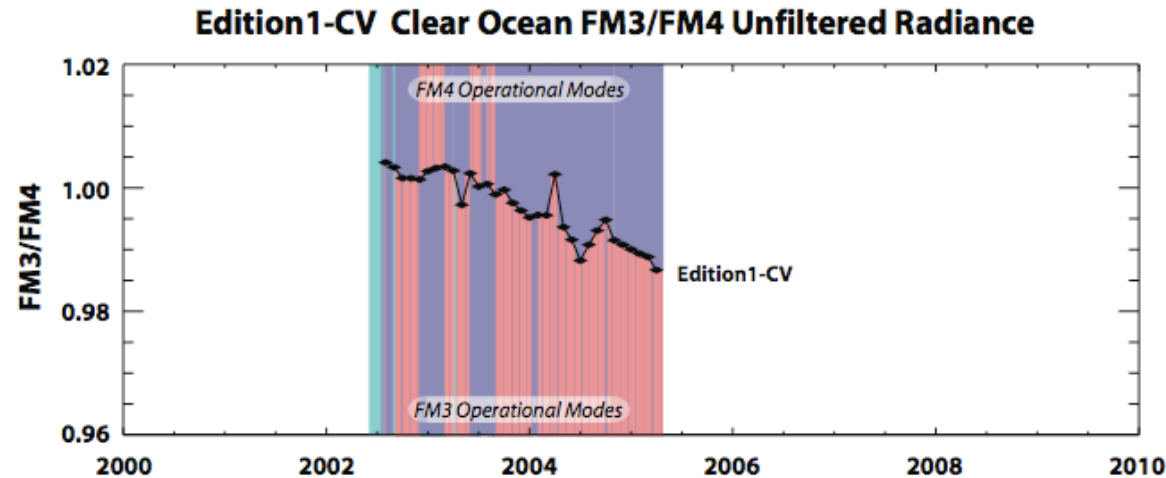
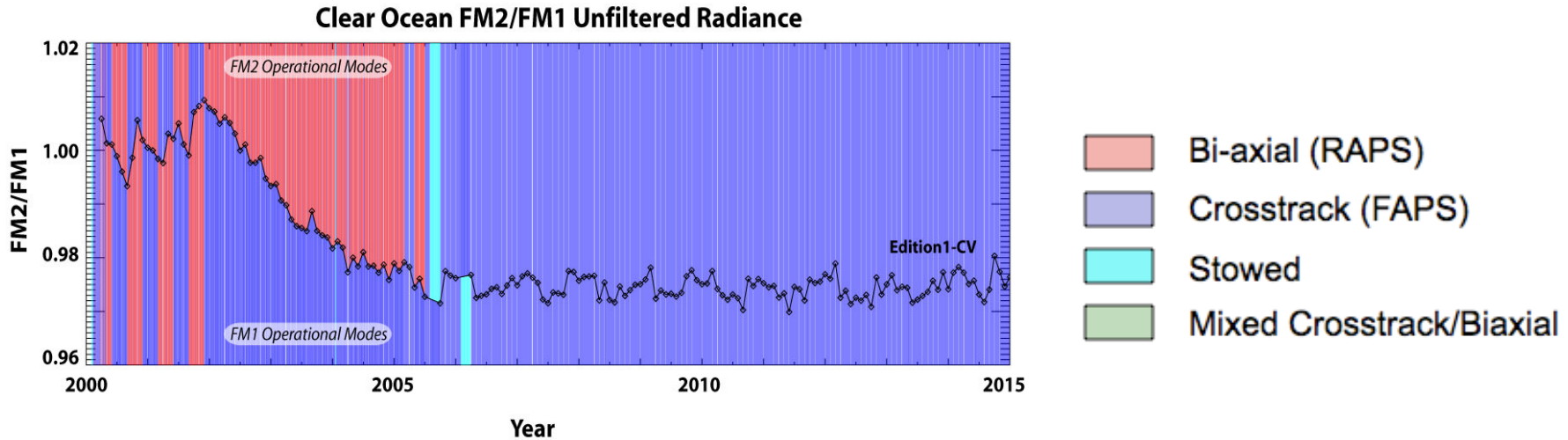
All-sky– 1.5% for Terra & 0.4% for Aqua sensors

Clear Sky Ocean – 2.8% for Terra & 1.0% for Aqua

Spectral Darkening increases for shorter wavelengths.



Operational Mode and Radiance Comparison

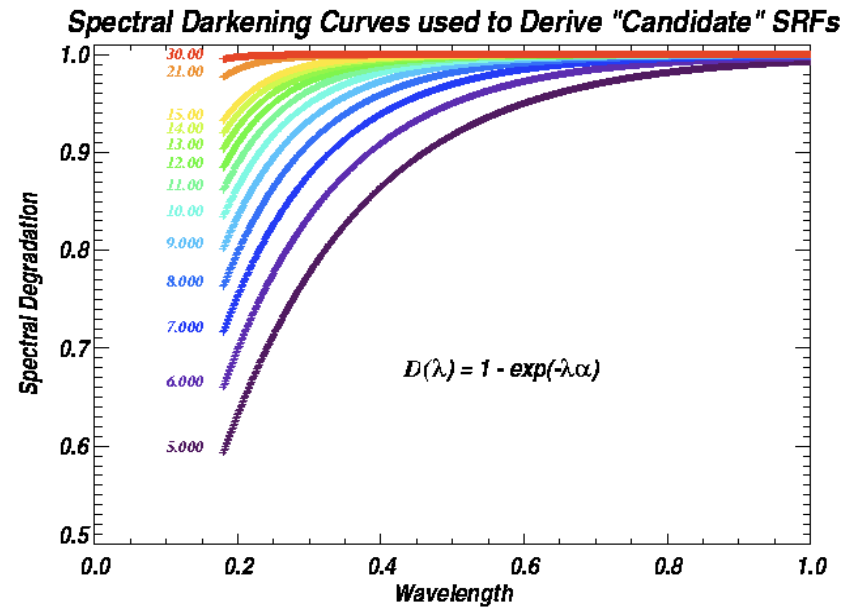


The ratio displays the radiance drop in the instrument operating in RAPS mode



Spectral Darkening Correction

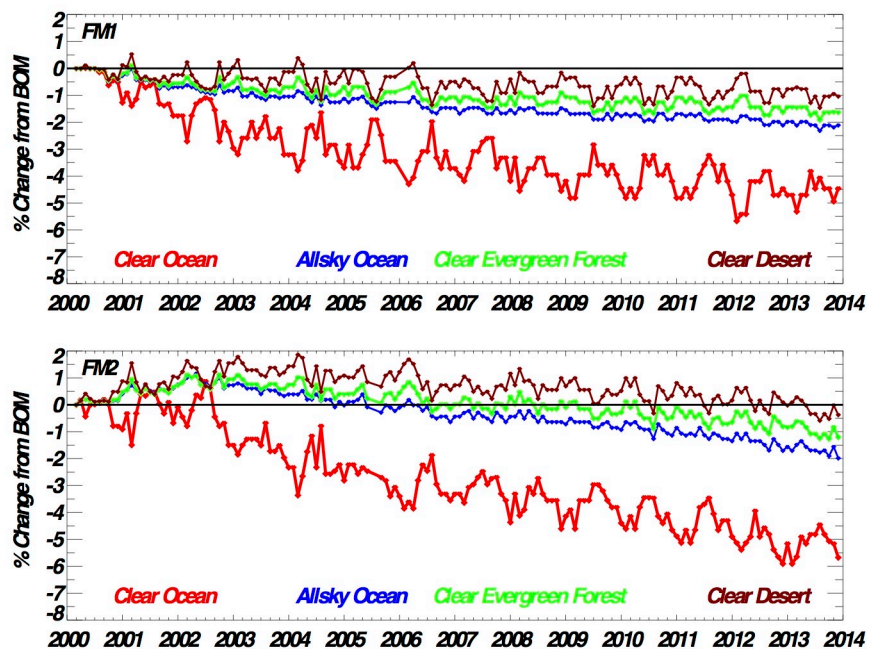
Correction was applied to the spectral response function of the instrument operating in RAPS mode. Applied correction is in exponential form to address the higher drop in shorter wavelength.



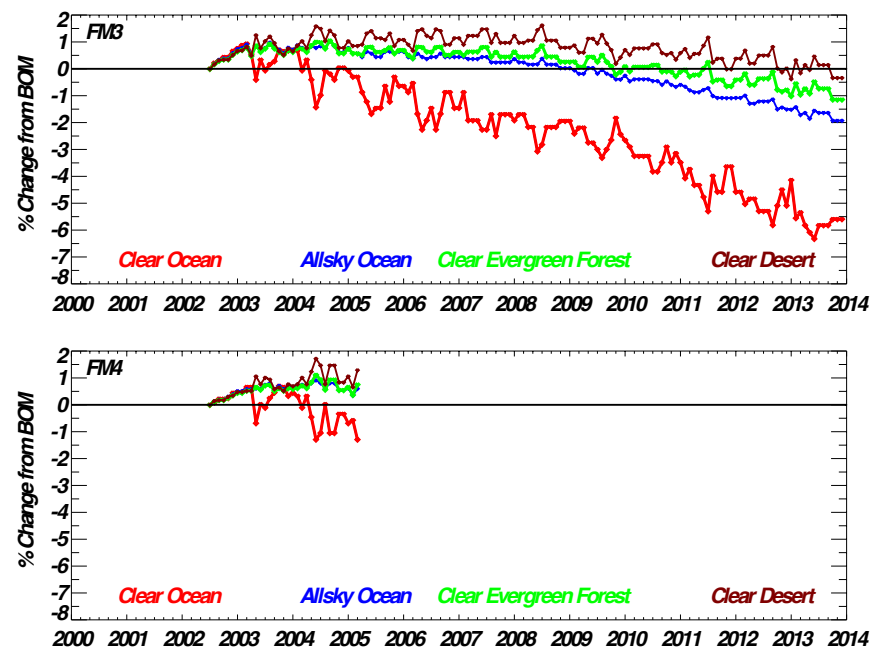
TERRA/AQUA: SW/TOT SENSOR CORRECTIONS

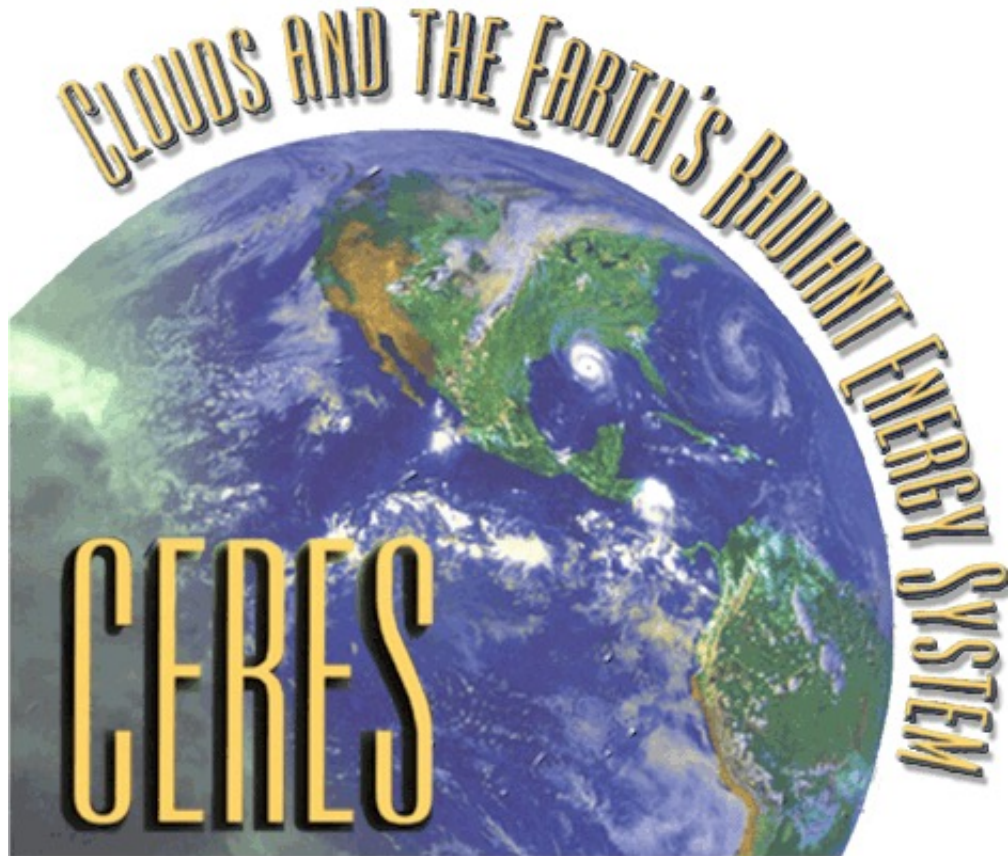
- Correction to SW/TOT sensor is based on the regression between LW(Day-Night) and WN (Day-Night) using Tropical Ocean and Land scenes. The corrections applied to SW/TOT SRF is of the functional form: $D(\lambda) = [1 - e^{-\alpha\lambda}] + \beta$

SW/TOT 'Optimal' Throughput Change for Terra
(Terra SRF with SCIAMACHY Scene Spectra)



SW/TOT 'Optimal' Throughput Change for Aqua
(Aqua SRF with SCIAMACHY Scene Spectra)





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Aqua-NPP Inter-comparisons

CERES FM3 on Aqua

Altitude: 704 km

Inclination: 98.2°

Equatorial Crossing: 1:36 PM

CERES FM5 on S-NPP

Altitude: 824 km

Inclination: 98.7°

Equatorial Crossing: 1:27 PM

Orbital Overlaps every
~64 hours

Matching criteria:

Lat. and Long. difference $\leq 0.05^\circ$

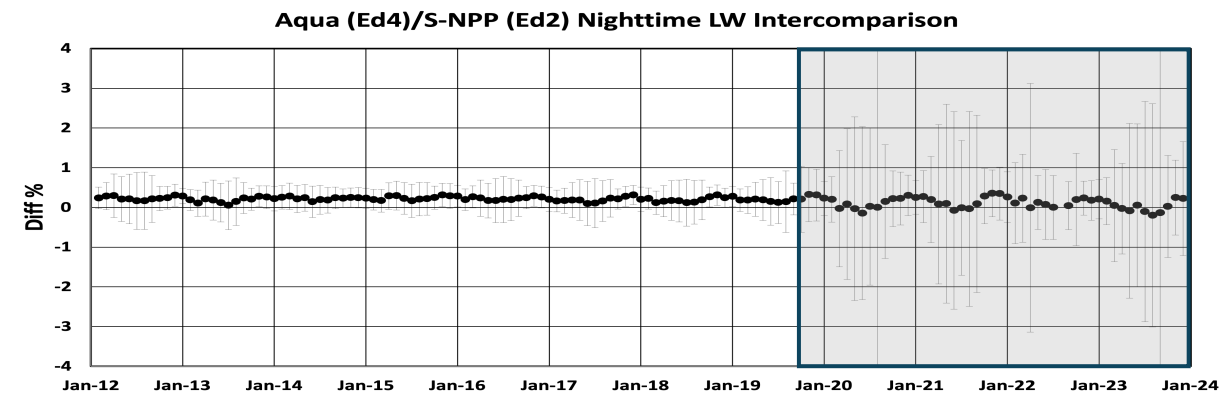
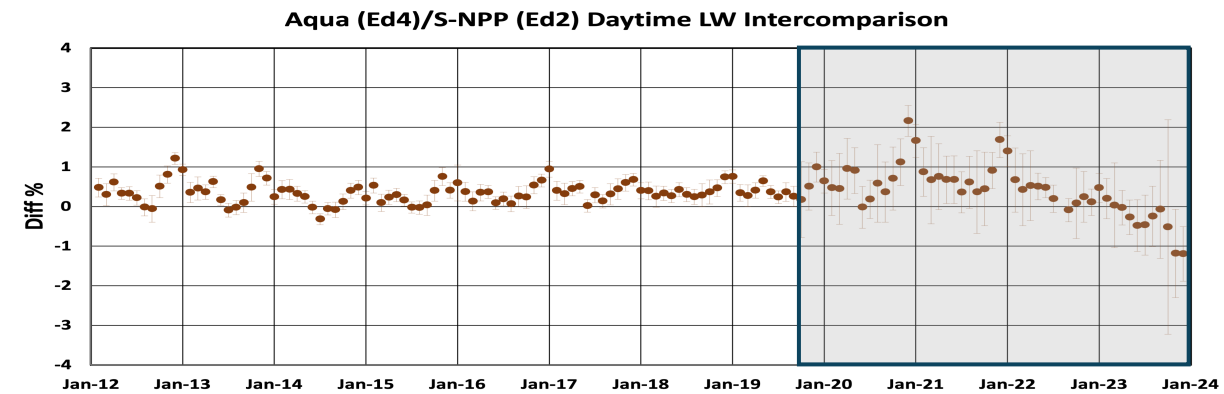
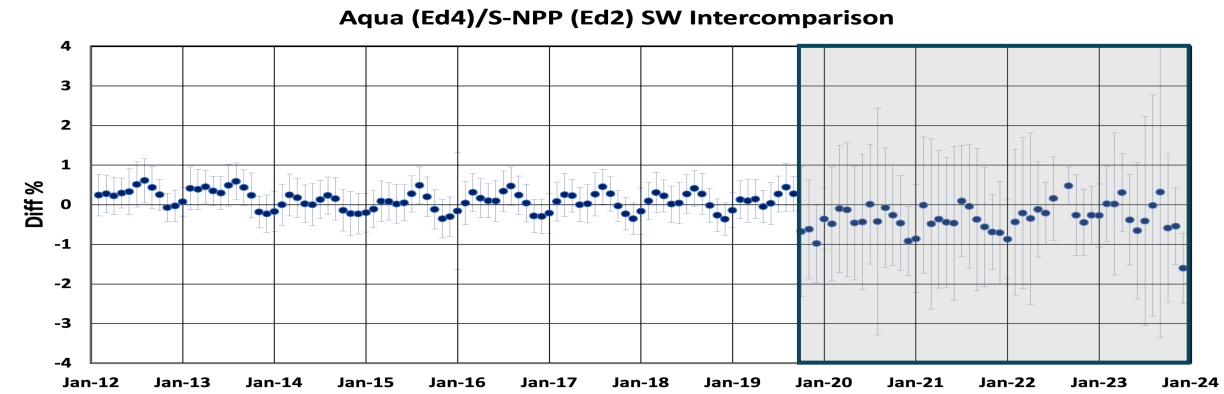
SZA, VZA difference $< 2.0^\circ$

RAZ difference $< 5^\circ$

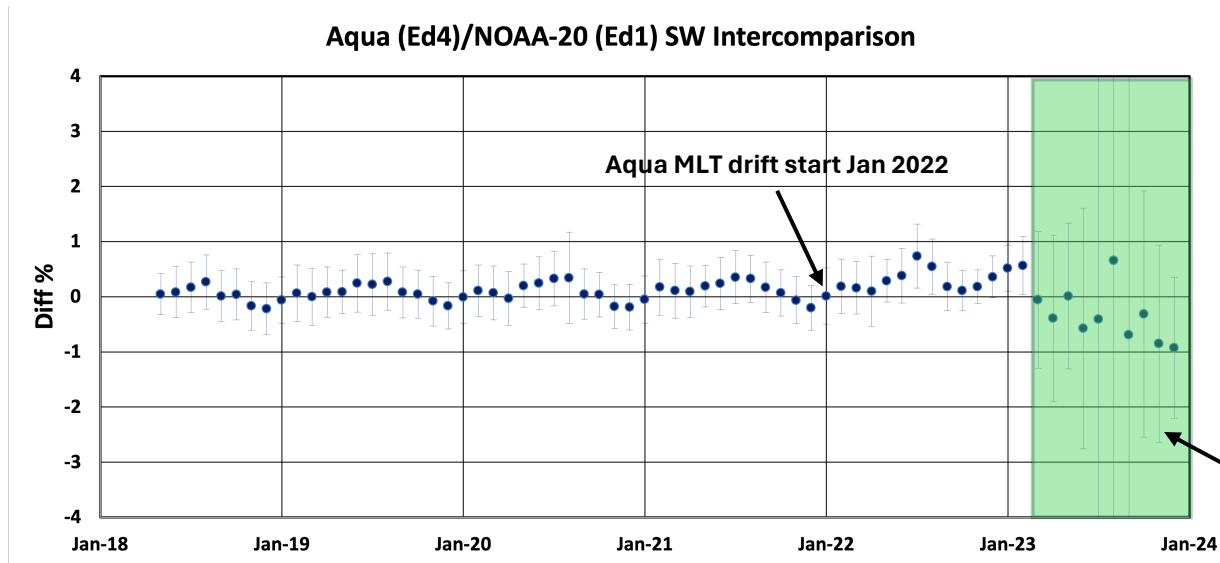
Spatially and
temporally matched
observations

Intercompare Results

- Spatially and temporally matched observations during every crossover.
- Use matching criteria to subset the data:
 - SZA, VZA difference $< 2.0^\circ$
 - RAZ difference $< 5^\circ$
 - Distance between footprints < 7 km
- Monthly all-sky SW reflectance and LW radiance differences were calculated using the matched footprints.
- When the instrument are operated in biaxial mode, there is reduction in the number of matched footprints.



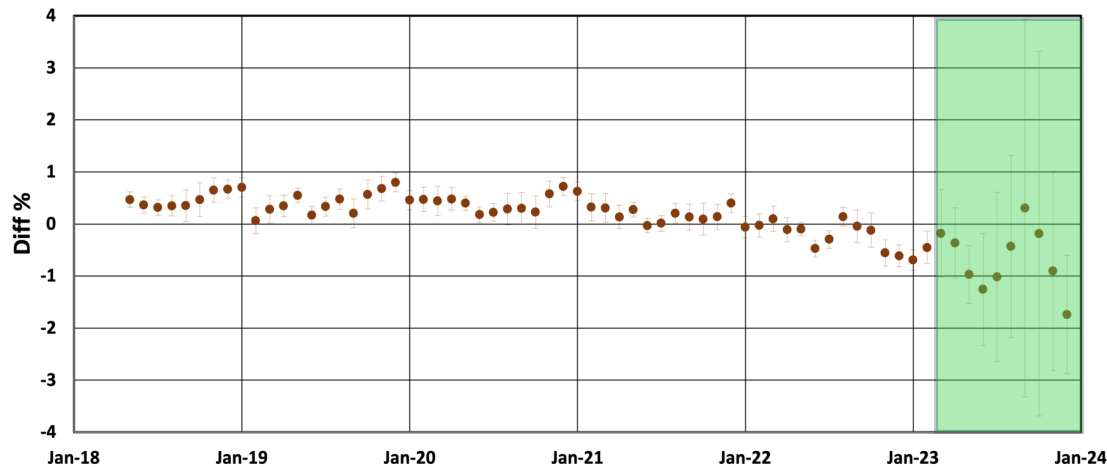
FM3/FM6 SW All-sky Inter-comparisons: May 2018- Dec 2023



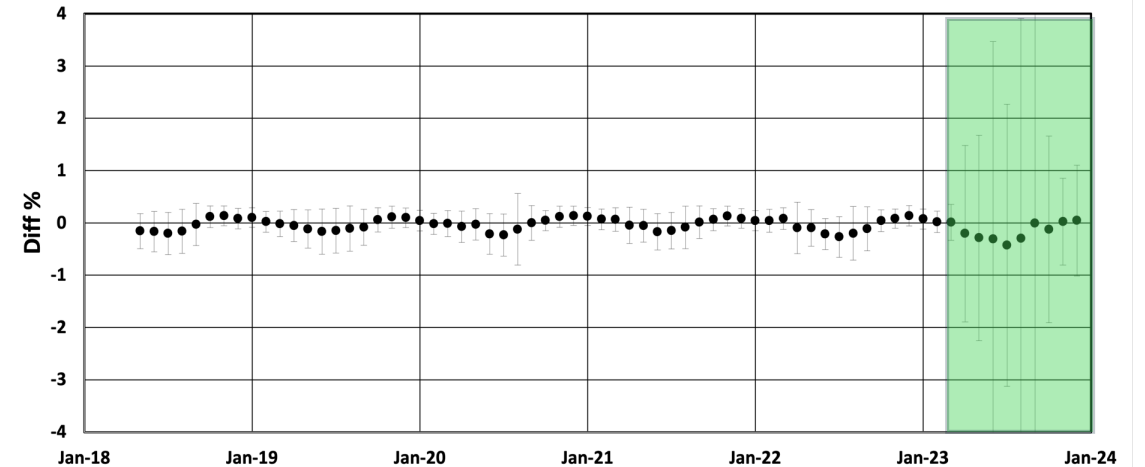
Larger uncertainties after FM3 switched to biaxial mode are driven by the drastic reduction in number of spatially and temporally matched observations.

FM3 Biax- Mar 2023- Present

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

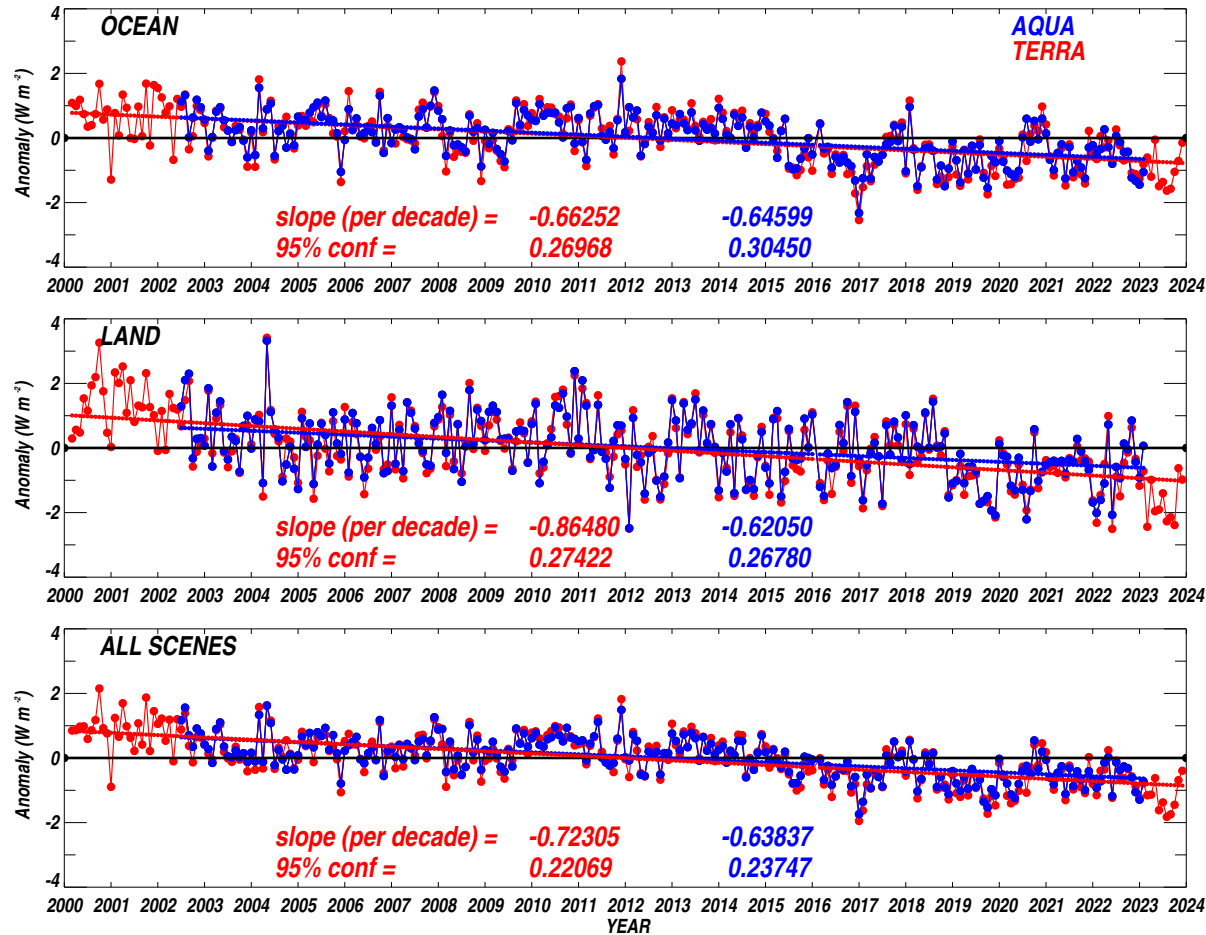


Aqua (Ed4)/NOAA20 (Ed1) Nighttime LW Intercomparison

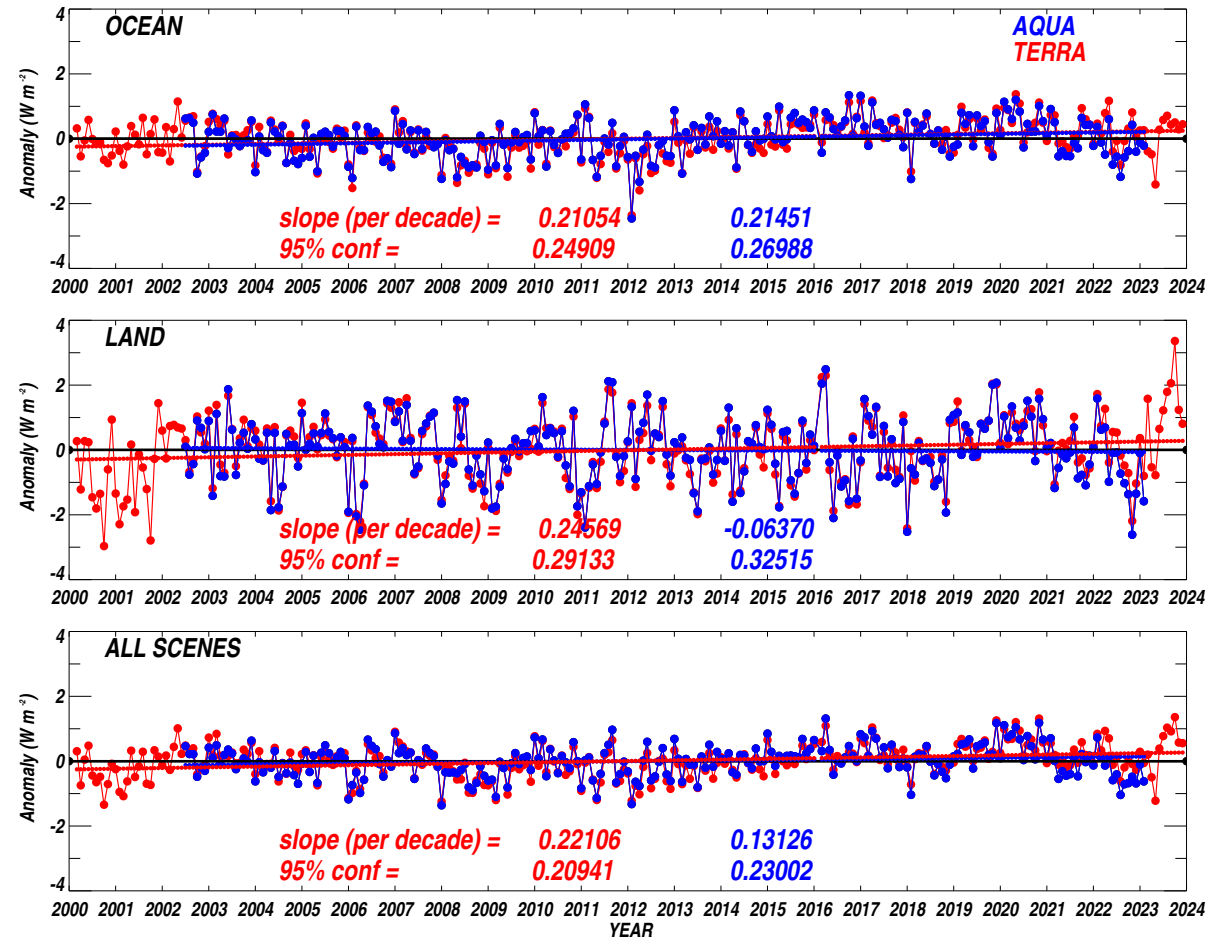


Validation: Terra and Aqua Ed-4 LW Flux Anomalies

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



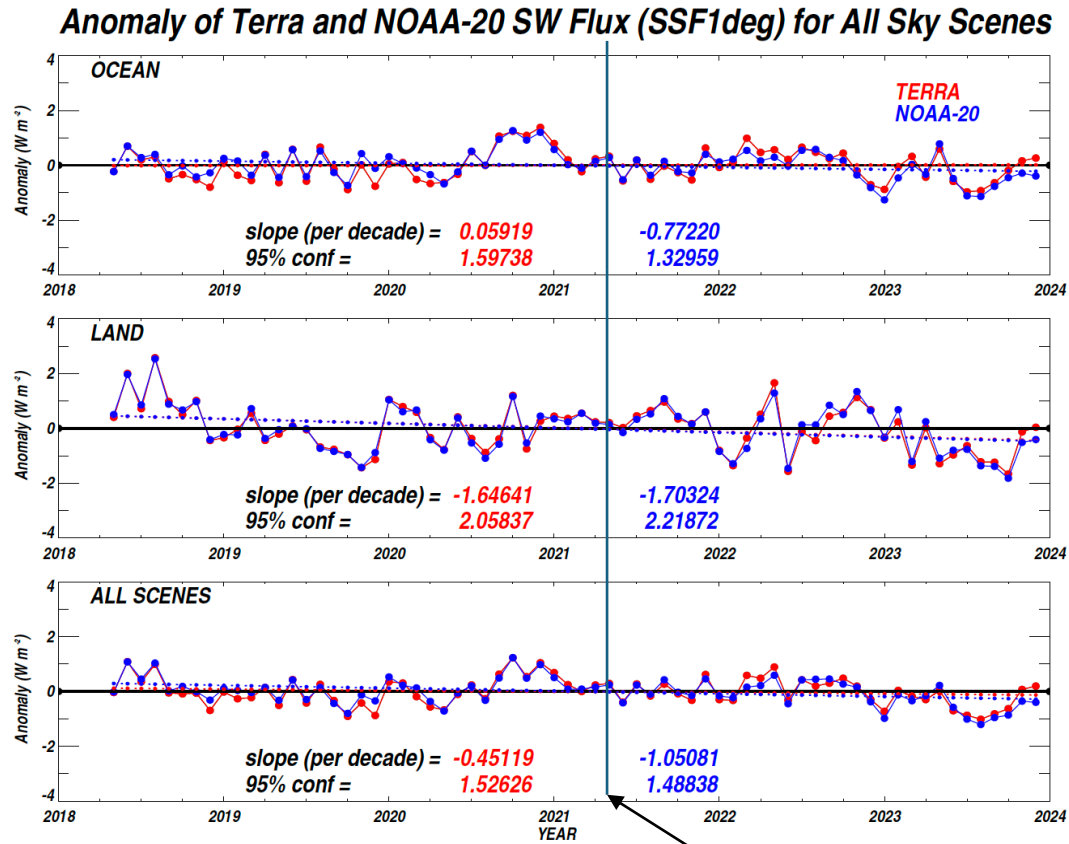
Anomaly of Terra and Aqua LW Flux (SSF1deg) for All Sky Scenes



Terra and Aqua Level 3 Edition 4 products

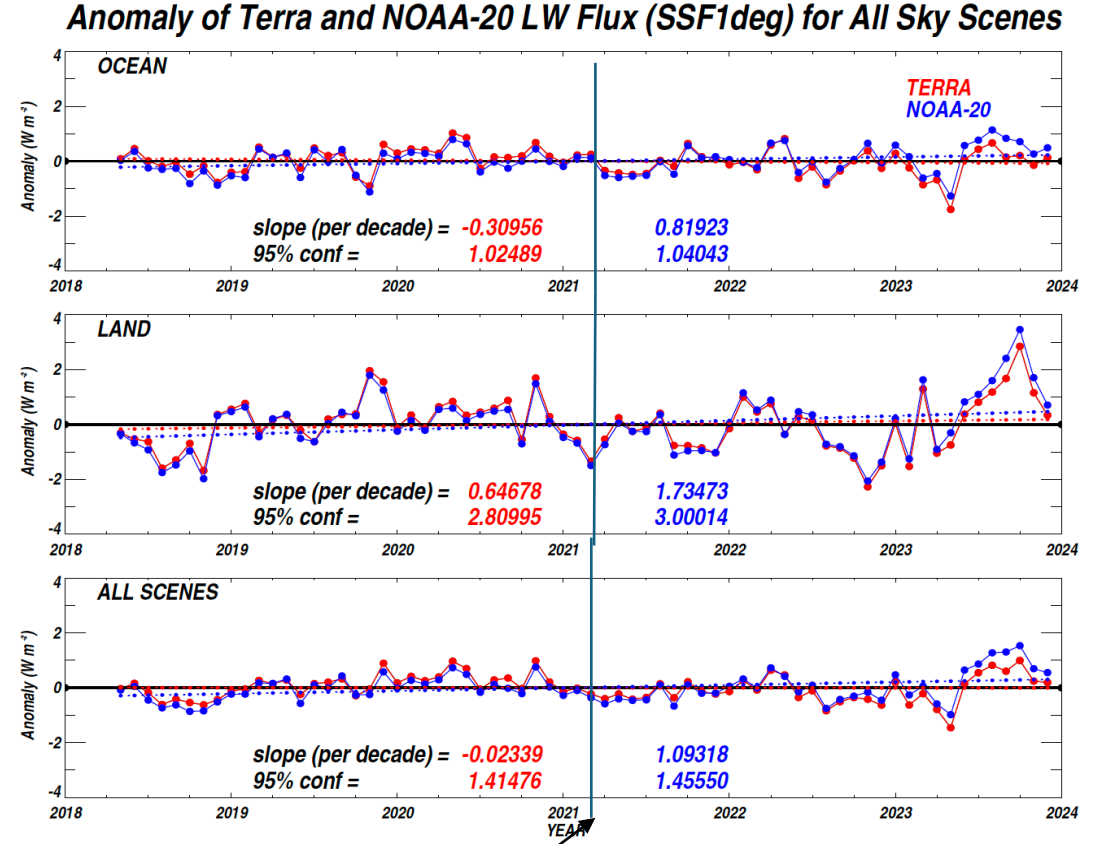
Terra started drifting to earlier MLT in Apr 2021.
Aqua started drifting to later MLT in Jan 2022.

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



Terra started drifting to earlier MLT in Apr 2021

Terra and NOAA20 flux anomalies are consistent



NOAA-20: CER_SSF1deg-Month_NOAA20-VIIRS_Edition1

Terra: CER_SSF1deg-Month_Terra-MODIS_Edition4A

CONCLUSION

- **In-flight ICM calibration results showed the on-orbit sensor gain changes and were used to correct the radiometric gain for radiance calculation.**
- **Validation studies highlight the spectral changes occurring in the reflected solar region of Shortwave and Total sensors on Terra and Aqua missions. Corrections were applied to spectral response functions to account for the spectral darkening.**
- **Intercomparison studies between instruments on different spacecraft show less than +/- 0.5% variation in CERES measurements.**
- **The response changes are incorporated in latest editions of CERES data products.**
- **The gain and SRF updates deliver a stable global record of Top of the Atmosphere (TOA) shortwave and longwave fluxes for the Earth radiation budget climate data record that span over twenty-four years.**

