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

**Susan Thomas**
**CERES Instrument Working Group Team**

**Earth Radiation Budget Workshop**
**National Center for Atmospheric Research (NCAR)**
**Boulder, Colorado**
**September 10-13, 2018**

# Instrument Working Group

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# CERES Instrument Operations: FM1 - 6

**CERES Instruments, Flight Models 1- 6 (FM1 – FM6) are primarily operating in cross-track mode.**

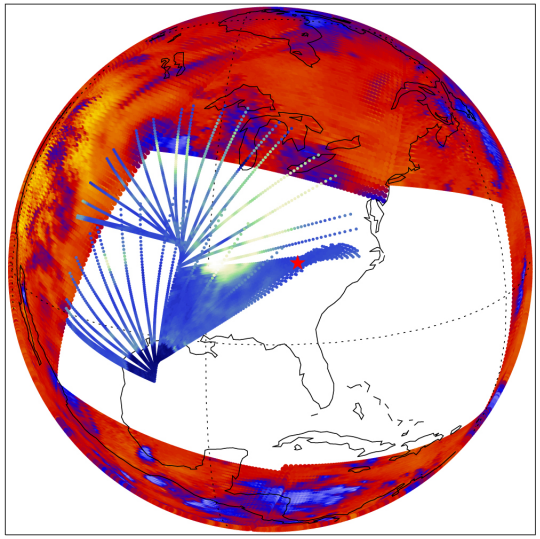
**Inter-comparison Operations: Summer 2018**

- **Data Collect at over-pass region of 70 degree N**
  - **CERES Terra/FM1 – S-NPP/FM5: May 1 – July 31, 2018.**
  - **CERES Terra/FM1 – JPSS-1/FM6: May 1 – July 31, 2018.**
  - **CERES Terra/FM1 – Aqua/FM3: June 1 – 30, 2018**
- **Data collect 60 N – 0 (Equator)**
  - **CERES Terra/FM2 – GERB: June 1 – June 30, 2018**

# CERES Homage to Dr. Barkstrom: Aug 16, 2018

CERES ES8 FM1 SW flux at TOA Data Range: 17:01:36 - 17:04:21
CERES ES8 FM2 LW flux at TOA Data Range: 12:49:54 - 20:20:01

**TERRA**



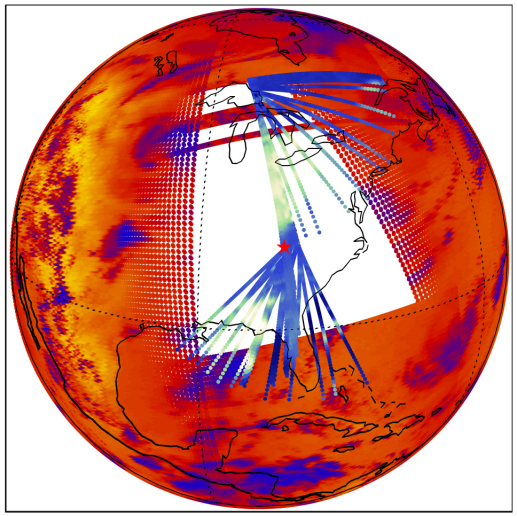
LW
77 88.3 99.7 111 122.4 133.8 145.1 156.5 167.8 179.2 190.6 201.9 213.3 224.6 236 247.4 258.7 270.1 281.4 292.8 304.2 315.5 326.9

SW
61 95.3 129.6 163.9 198.2 232.6 266.9 301.2 335.5 369.8 404.2 438.5 472.8 507.1 541.4 57

Watts per square meter

CERES ES8 FM3 SW flux at TOA Data Range: 18:38:29 - 18:42:14
CERES Ed-1 FM4 WN Counts Data Range: 16:52:00 - 21:05:00

**AQUA**



LW
-198 -175 -152 -129 -106 -83 -60 -37 -14 9 32 55 78 101 124 147 170 193 216 239 262 285 308 33

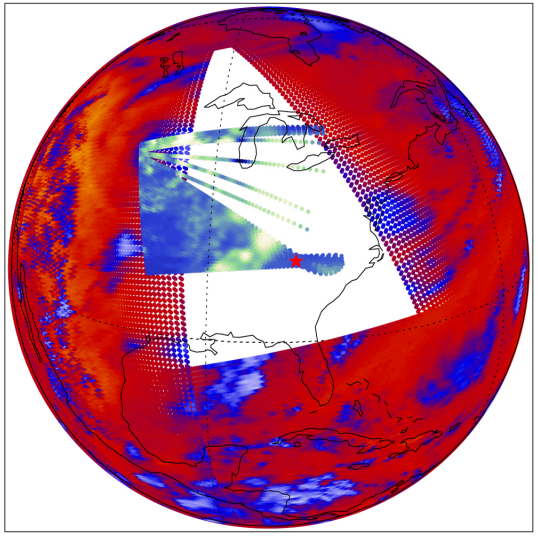
Counts

SW
59 90.2 121.4 152.6 183.8 215 246.2 277.4 308.6 339.8 371 402.2 433.4 464.6 495.8 527 558.2 589.4 620.6 651.8 683 714.2 745.4 77

Watts per square meter

CERES ES8 FM5 SW flux at TOA Data Range: 19:21:54 - 19:24:45
CERES ES8 FM6 LW flux at TOA Data Range: 14:39:54 - 22:06:04

**S-NPP**
**JPSS-1**

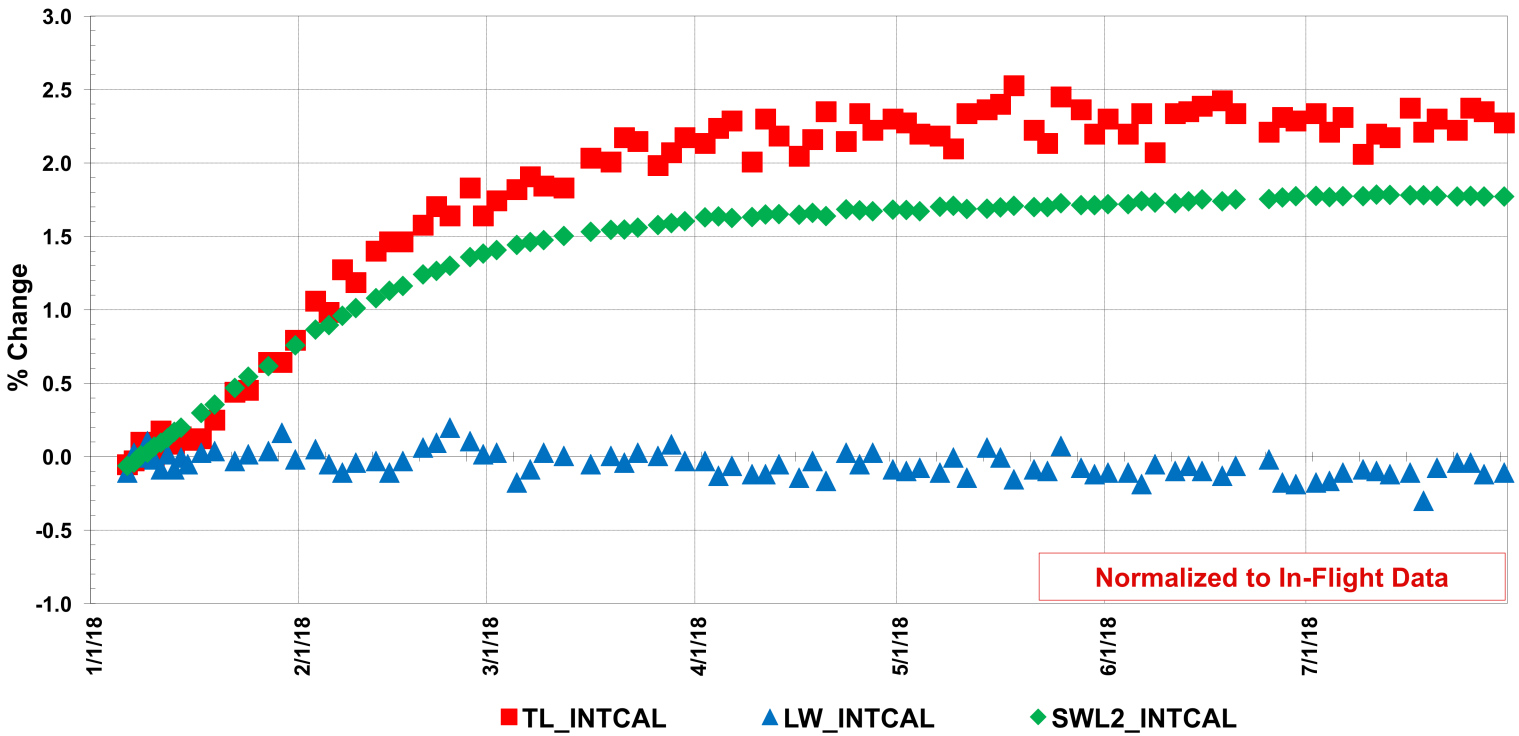


LW
70 83.4 96.8 110.3 123.7 137.2 150.6 164 177.5 190.9 204.4 217.8 231.2 244.7 258.1 271.6 285 298.4 311.9 325.3 338.8 352.2 365.6 387

# JPSS-1/ CERES FM6 INSTRUMENT STATUS

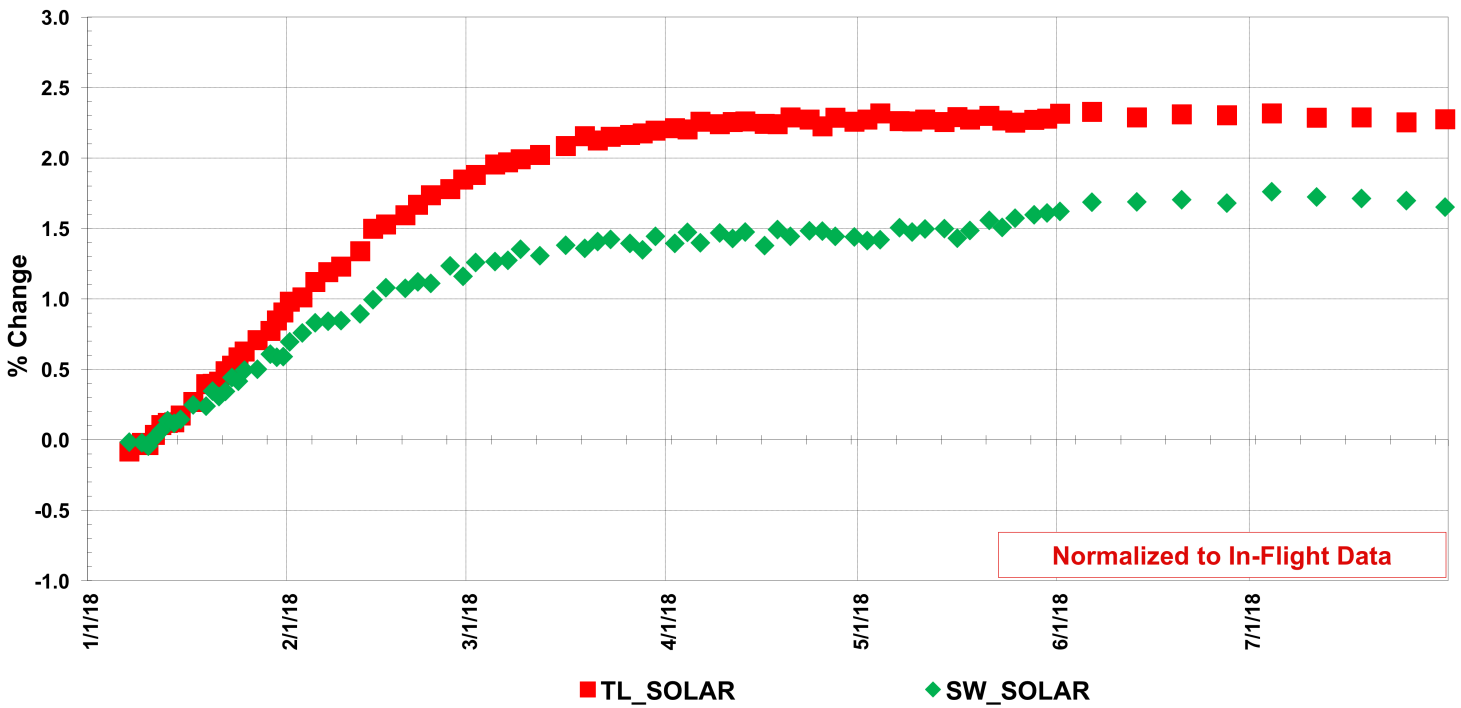
# JPSS-1/CERES FM6 Instrument Calibration

**Calibration results using on-board sources (Blackbodies and SW Lamp) show a response increase of 2.5% for Total and 1.8% for Shortwave sensors. Response from Longwave sensor do not show much variation.**



# JPSS-1/CERES FM6 Instrument Calibration (Solar)

**Solar calibration results using the Solar diffuser – Mirror Attenuator Mosaic (MAM) show similar trend in response as observed with on-board calibration sources. Total sensor response increased by 2.5% and Shortwave sensor increase is 1.8%.**

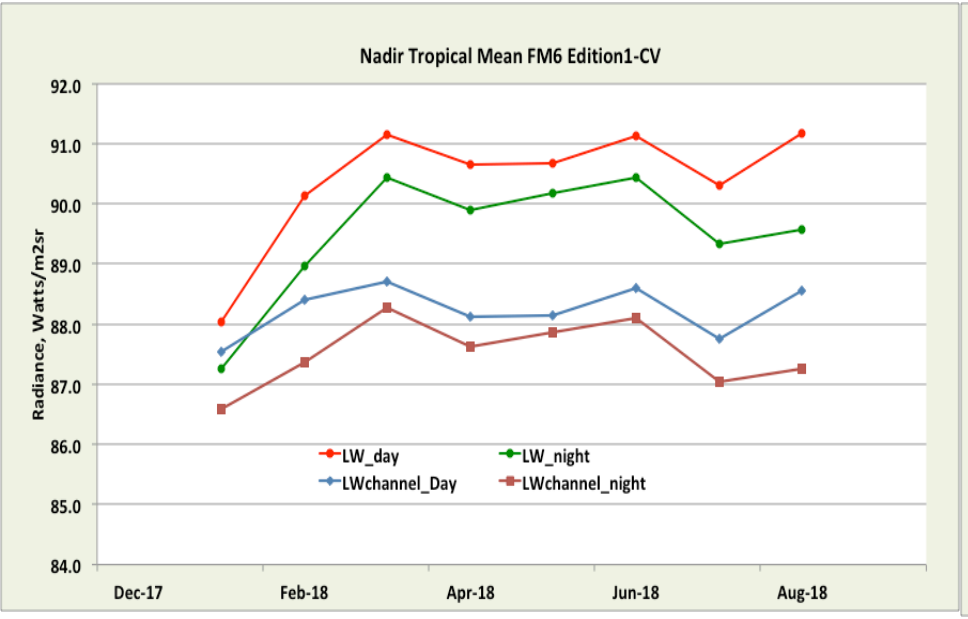


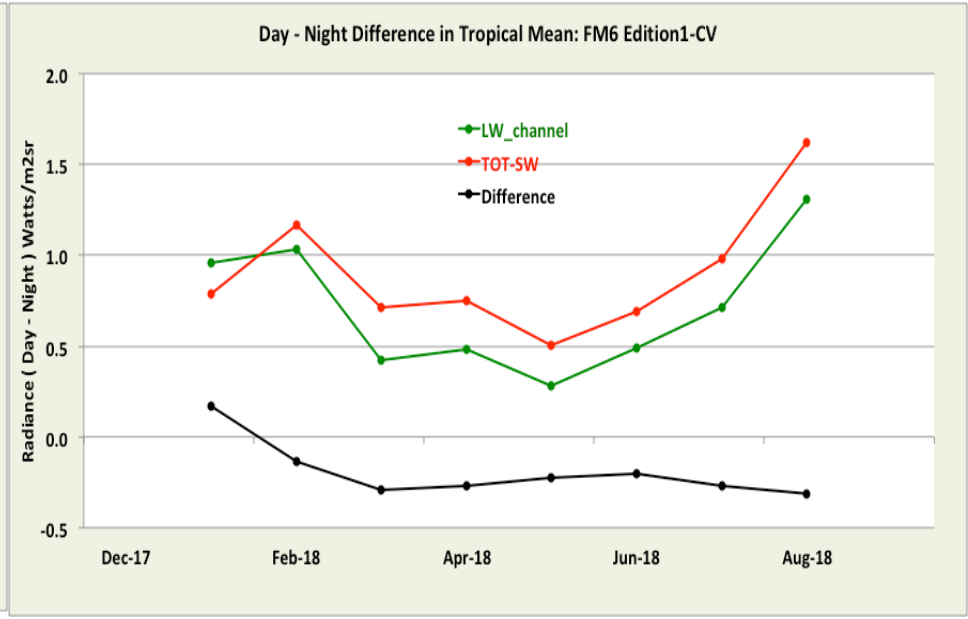
# JPSS-1/CERES FM6 Validation – Tropical Mean

**Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude.**

**Day and Night TM values from both Total and Longwave channels are trended.**

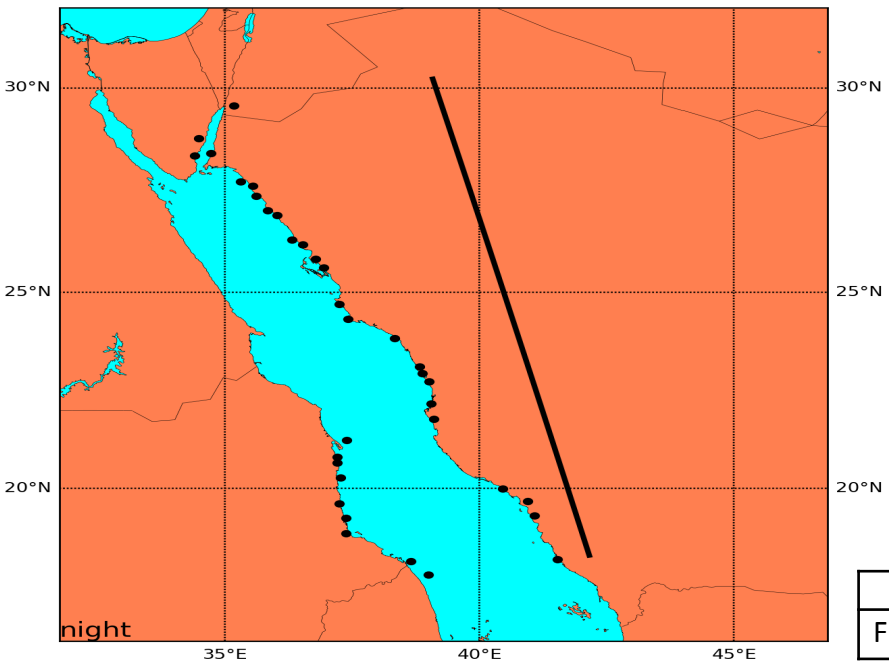
**Changes in SW/TOT channel is monitored through Day-Night (DN) Difference comparison between LW measurements from Total sensor and LW sensor.**

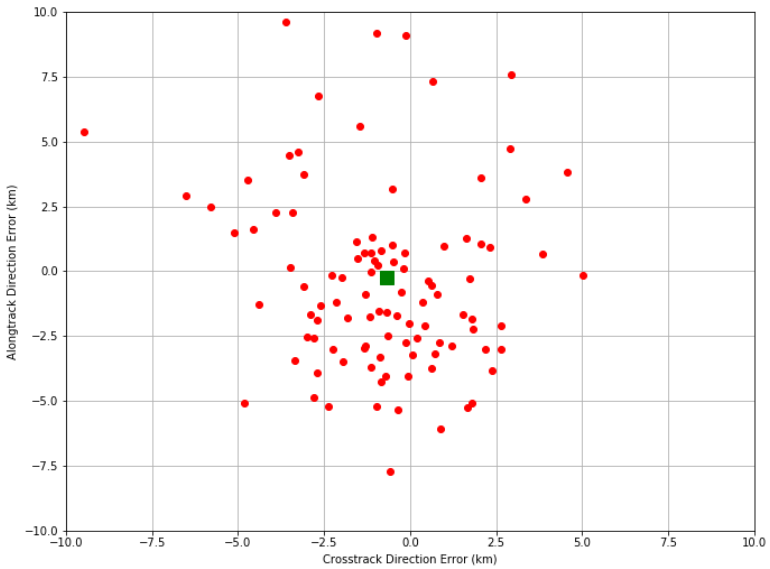


# JPSS-1/CERES FM6 Validation – Pointing Accuracy

**Coast Line Detection is used to validate pointing accuracy of CERES instrument. Detects inflection points where sharp temperature gradients occur like a warm land scene (desert) next to a cold ocean or lake.**
**Difference between detected location and expected location highlights errors in pointing accuracy.**




| | XT ERROR (km) | XT STDERR (km) | AT ERROR(km) | AT STDERR (km) |
|---|---|---|---|---|
| FM6 | -0.69 | +/- 0.50 | -0.26 | +/- 0.77 |

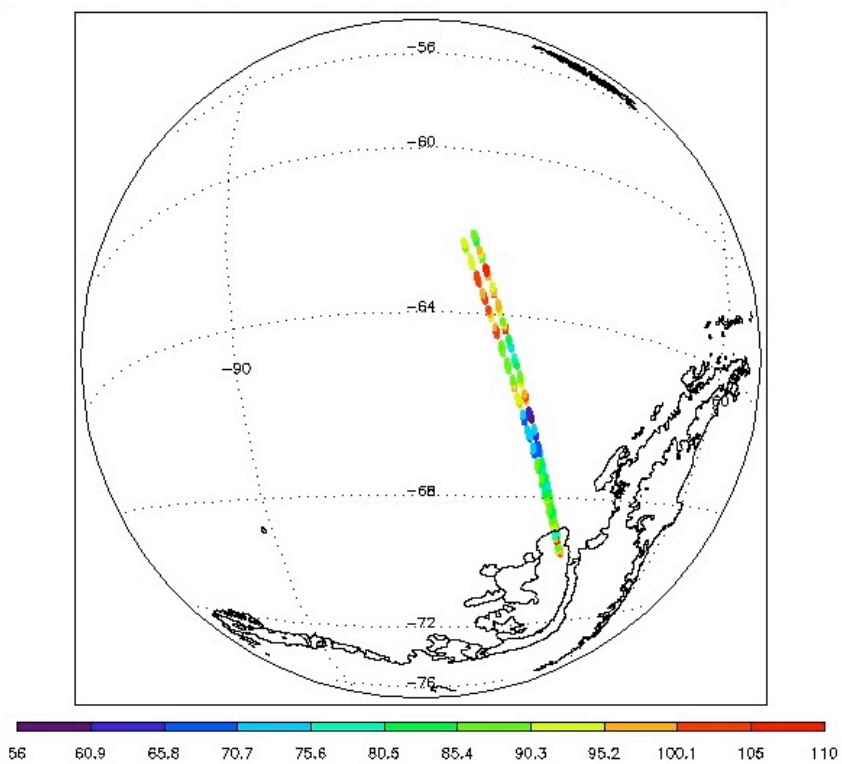
# JPSS-1/FM6 Intercomparisons

**Two Nadir dwell operations with Aqua/FM3 close to Antarctica**

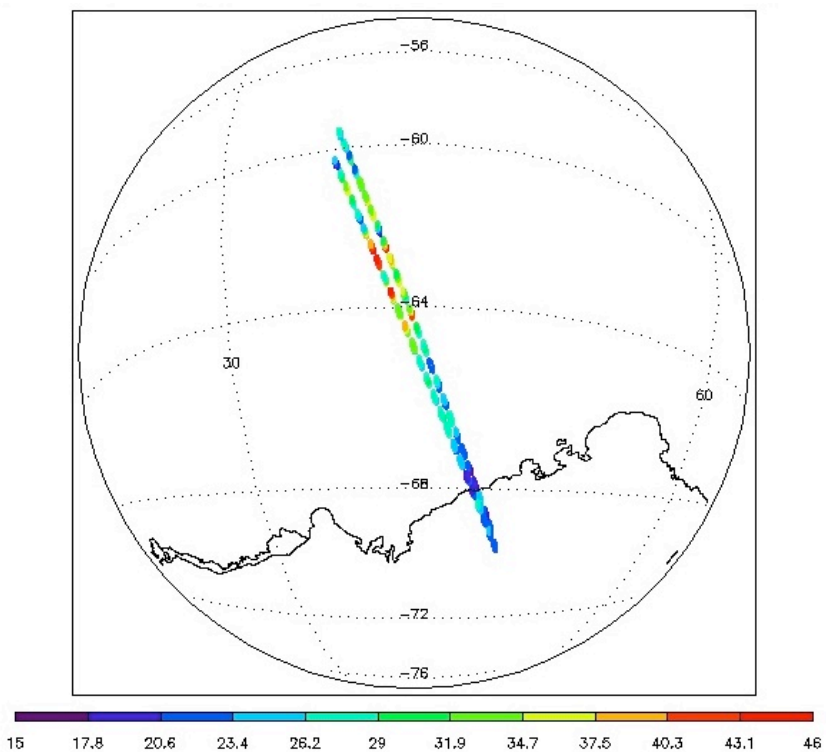
**$\Delta T < 5$ minutes; $\Delta lat < 0.5°$, $\Delta lon < 2°$**

**Each scanner takes 330 measurements along a ground-track within a full scan**

March 9, 2018




April 13, 2018

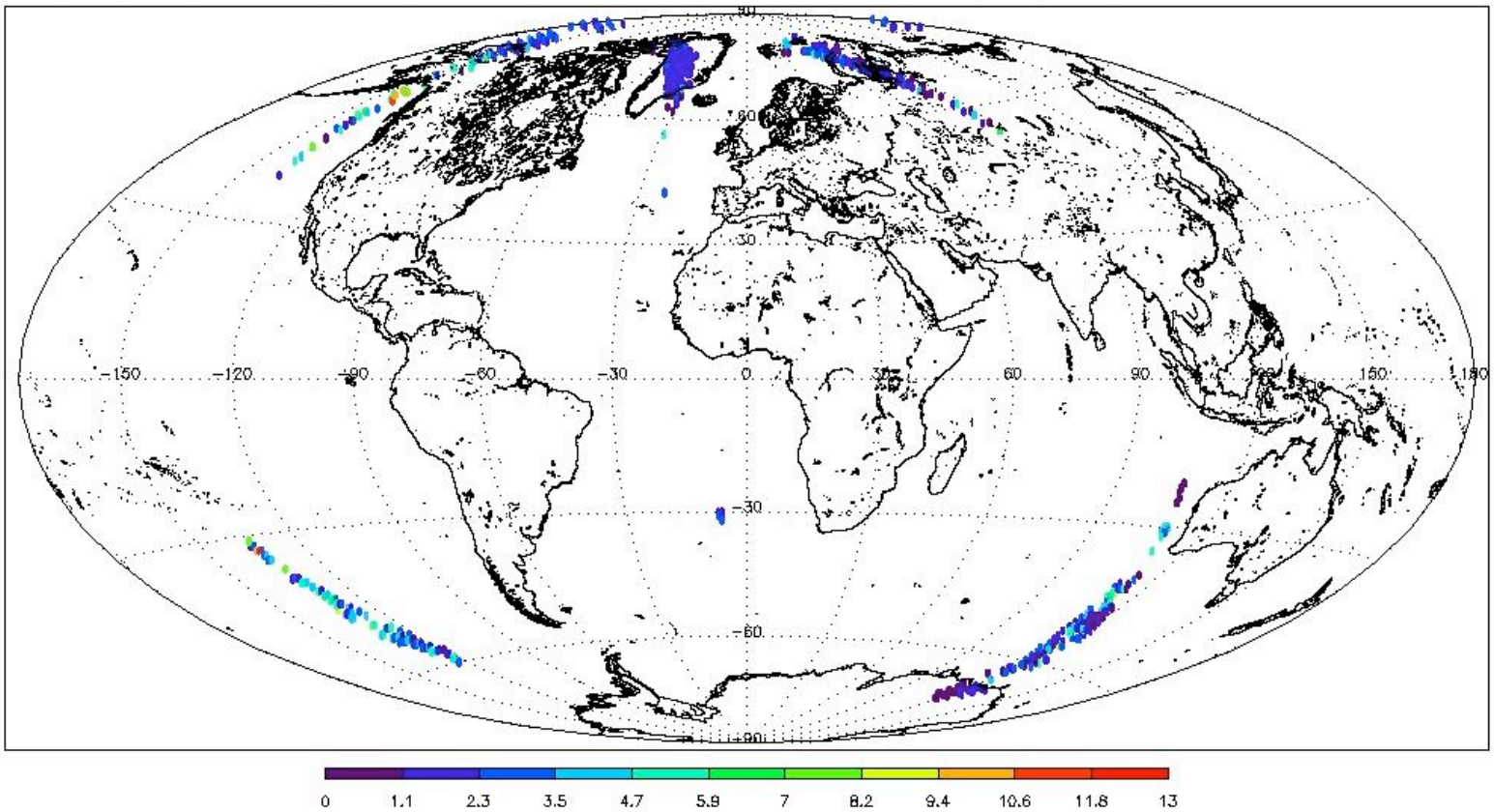


# JPSS-1/FM6 Intercomparisons

**Simultaneous Earth observation with Aqua/FM3 every 64 hours - fly in "tandem"**

**- A comparison region is defined by ΔT<15sec - ~20 min of data**

## Preliminary results of SW comparisons for March and April 2018



# JPSS-1/FM6 Intercomparisons

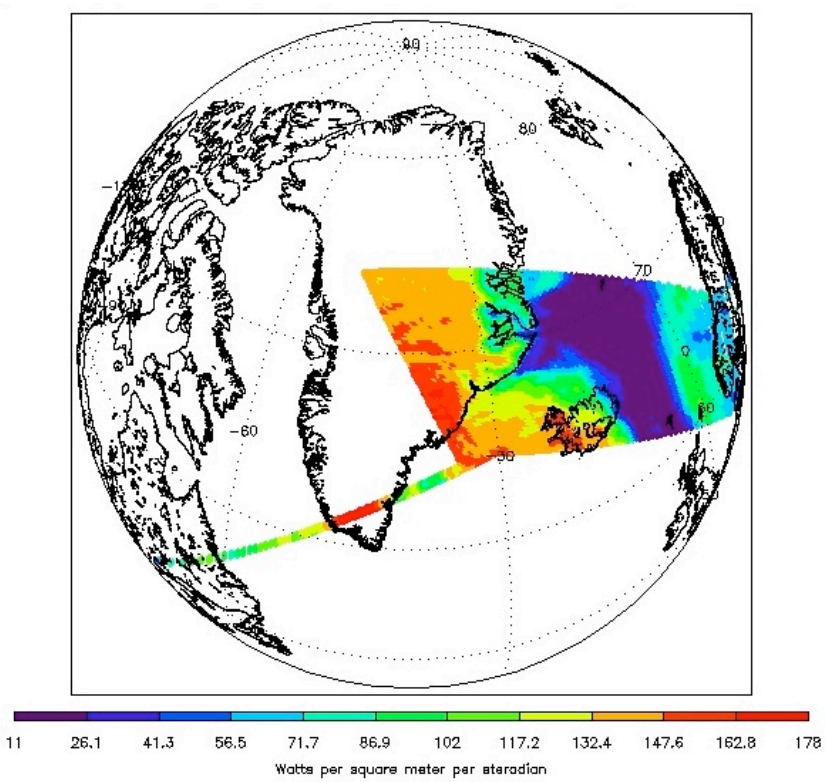
## Minor Plane Radiance Measurement:

**FM1 and FM6 align their scans in a plane perpendicular to local solar plane.**

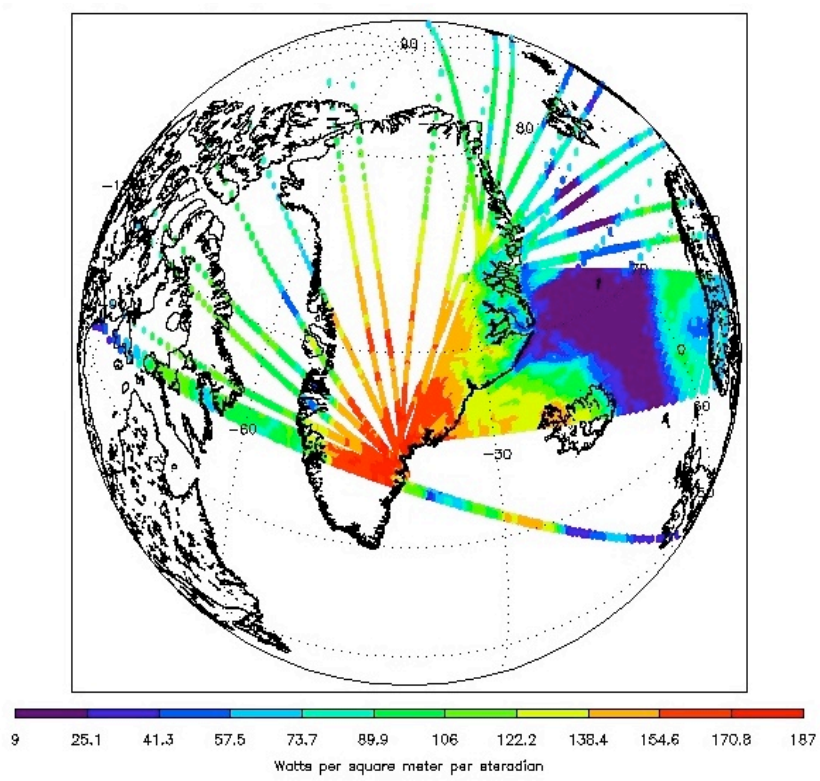
**Location: 70º N  Time differential for FM1 - FM6 < 5min every 64 hours.**

### Scanning Pattern in the Minor Plane on June 21, 2018

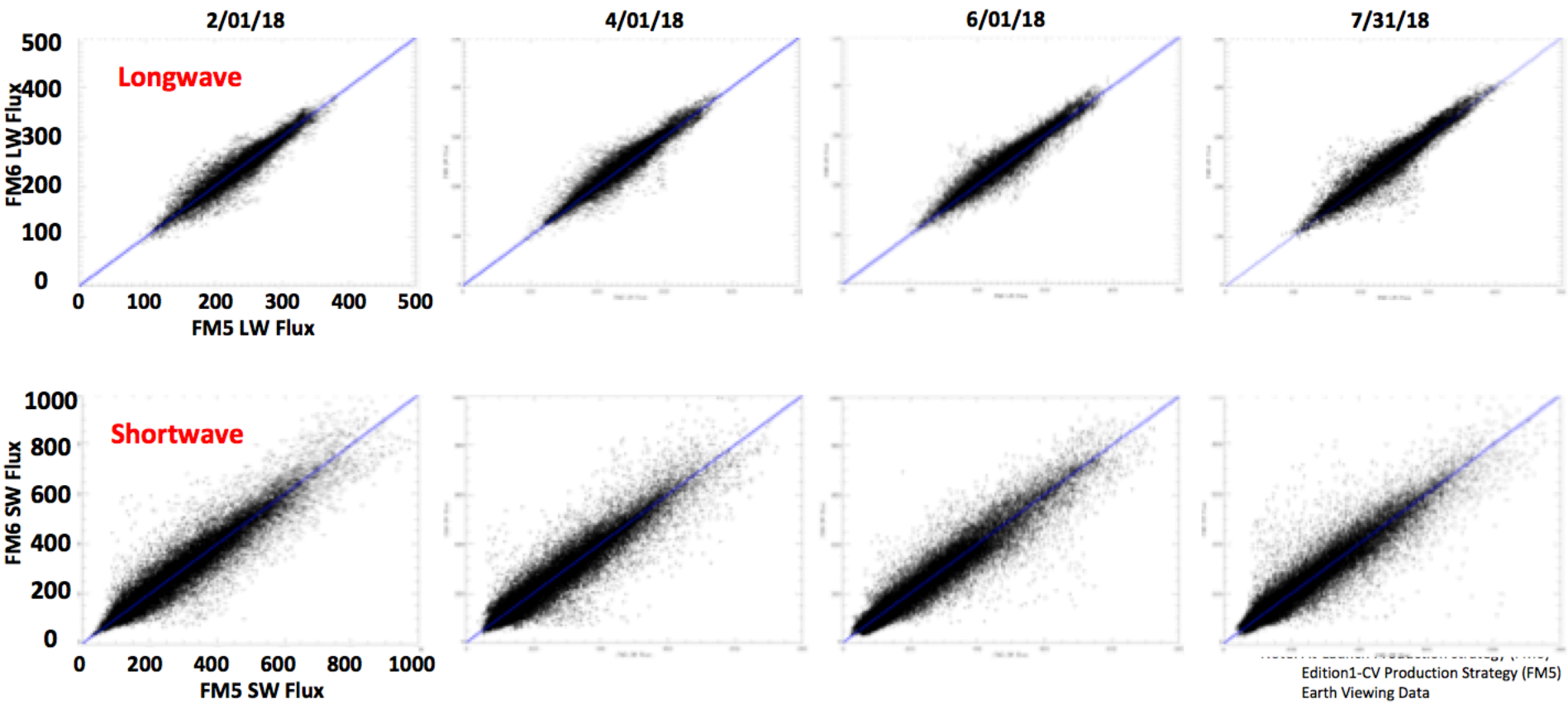
FM6




FM1



# JPSS-1/FM6 to S-NPP/FM5 TOA Flux Daily Comparison

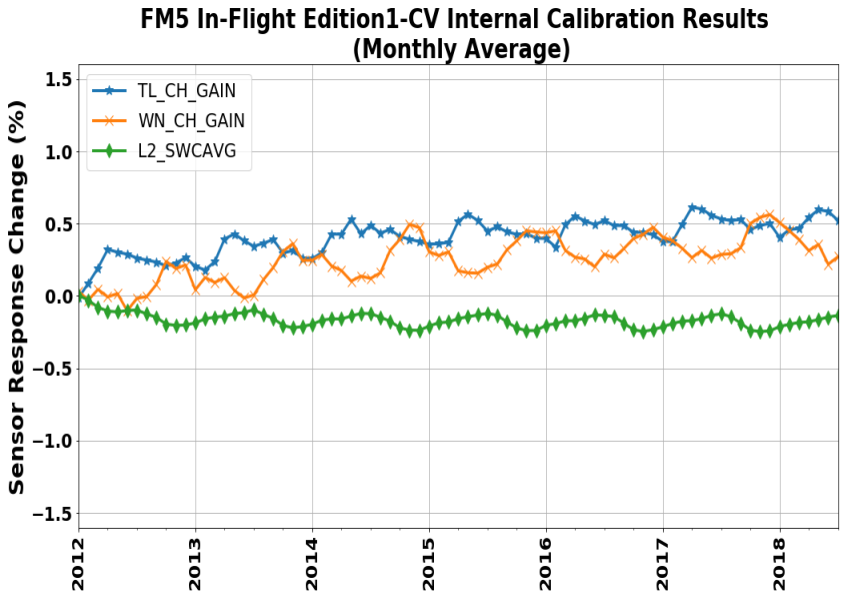


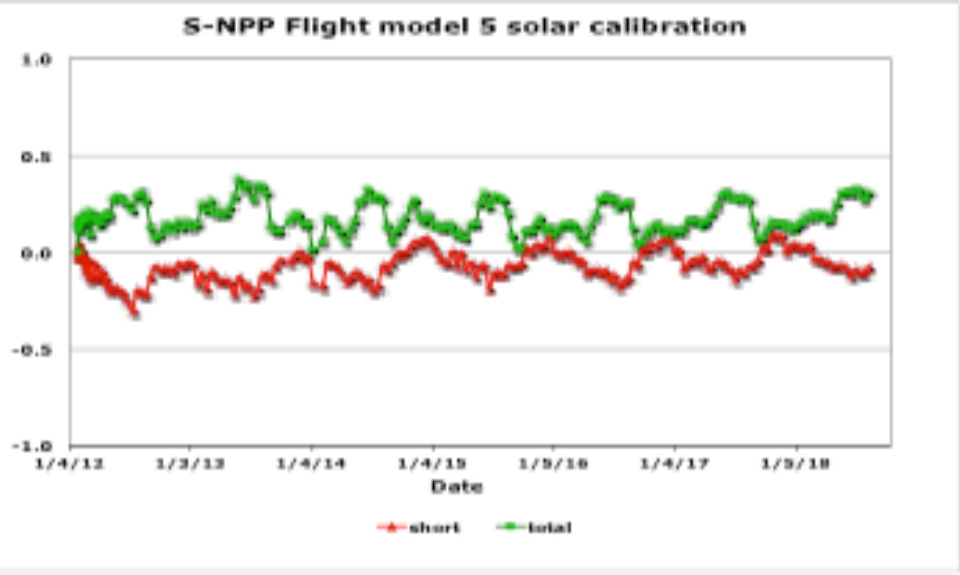
# S-NPP/ CERES FM5 INSTRUMENT STATUS

# S-NPP CERES FM5 Instrument Calibration

**ICM calibrations show a response increase of 0.6% for Total and 0.5% for Window sensor. SW sensor shows a drop of 0.25%**

**Solar calibration results: SW sensor shows slight rising trend. Total sensor is steady**

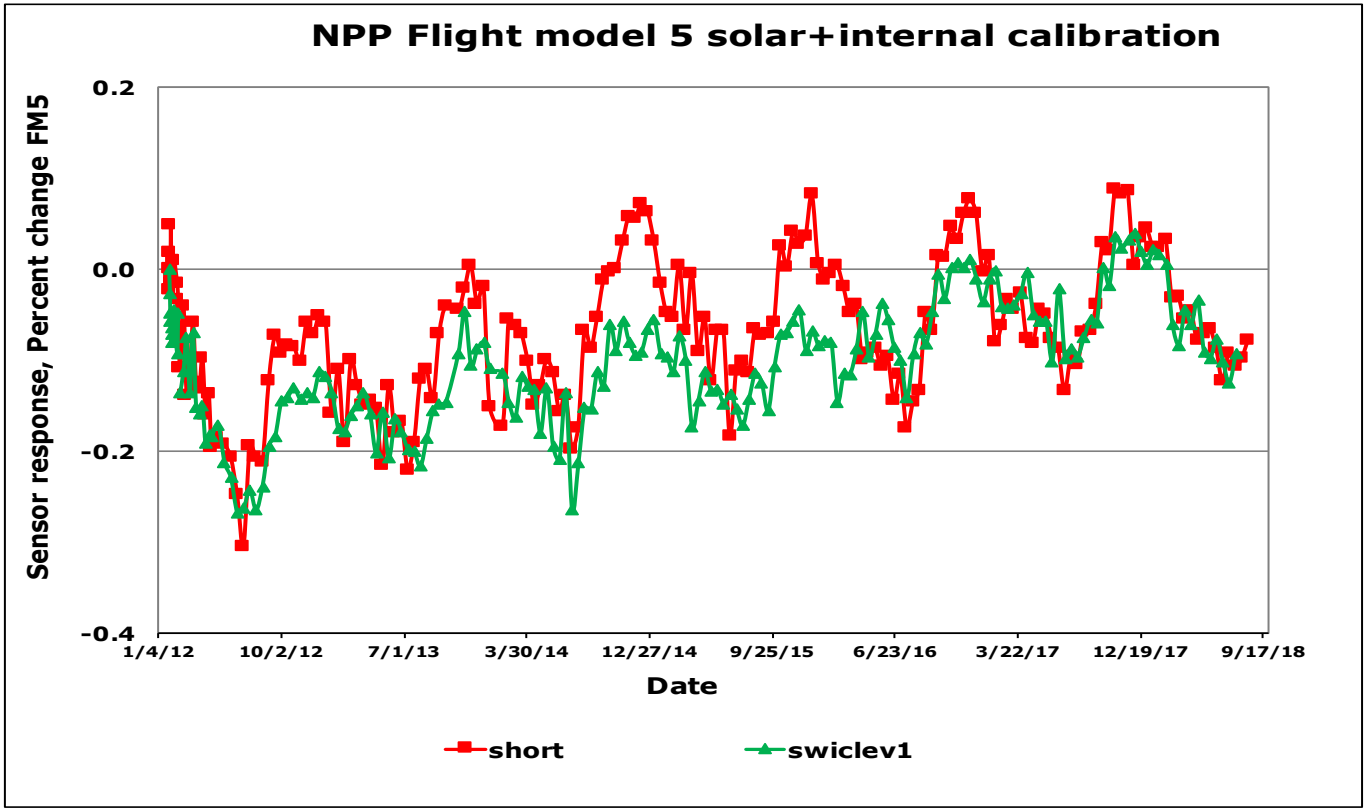



**Sensor gain corrections based on ICM calibrations are applied to Edition1 data products.**

# S-NPP/CERES FM5 Instrument Calibration

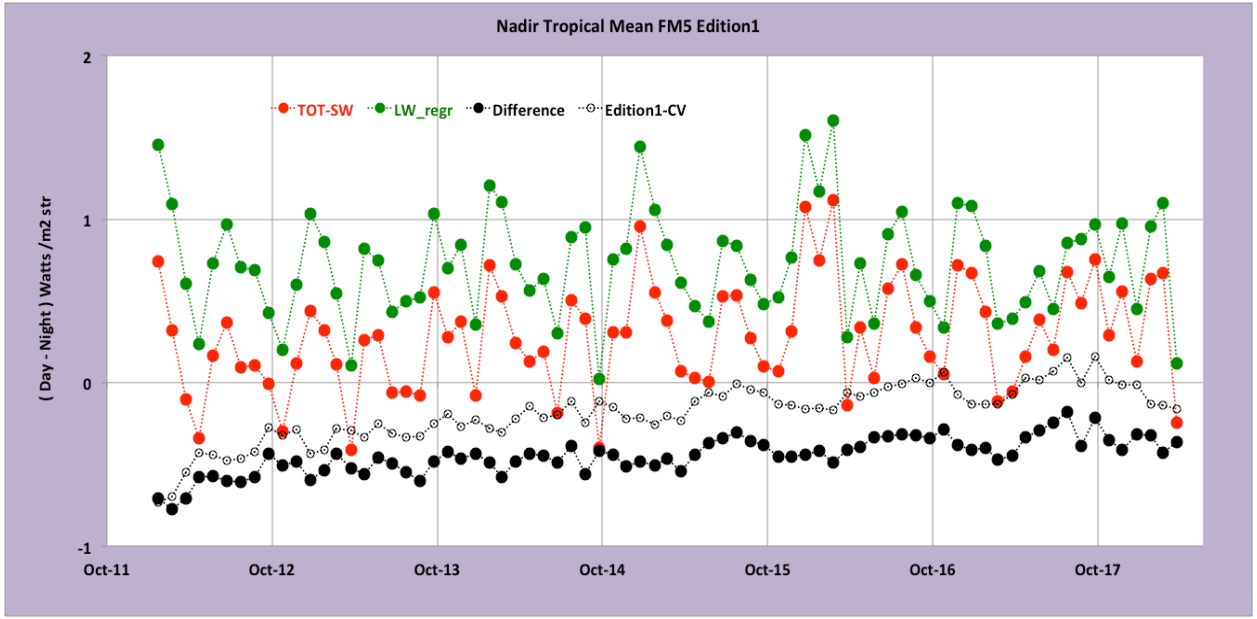
**Comparison of calibration results from SWICS (Level1) and MAM showed similar trends in the SW sensor.**



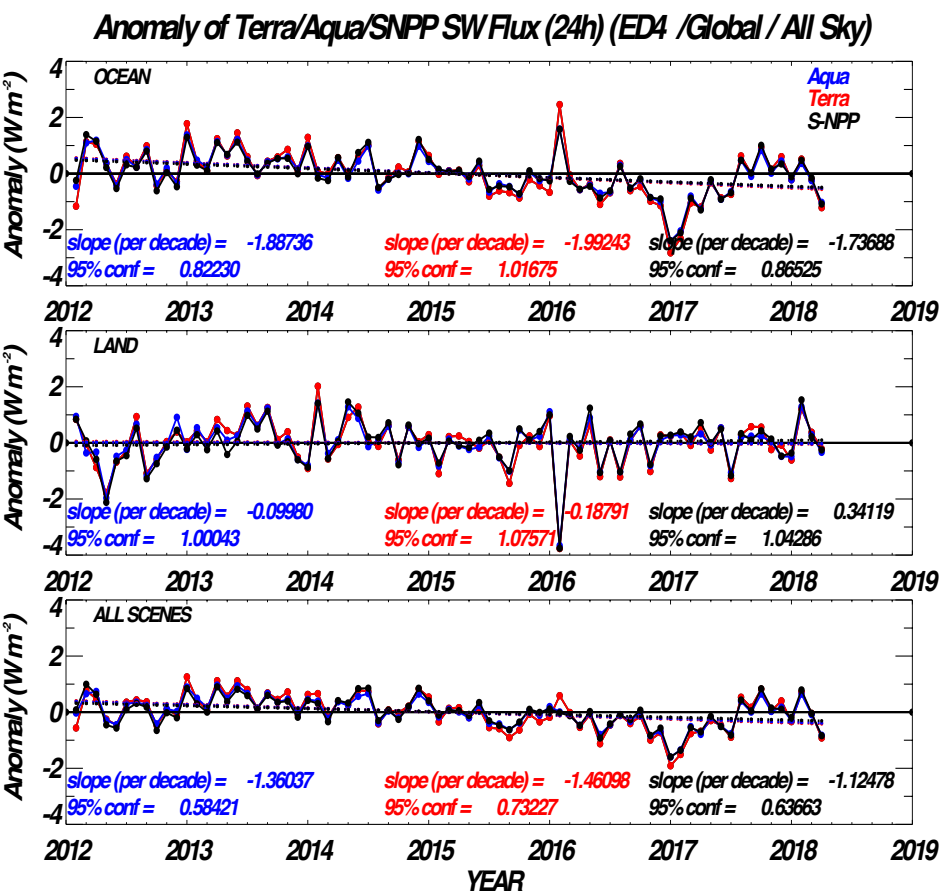
# S-NPP/CERES FM5 Validation Results

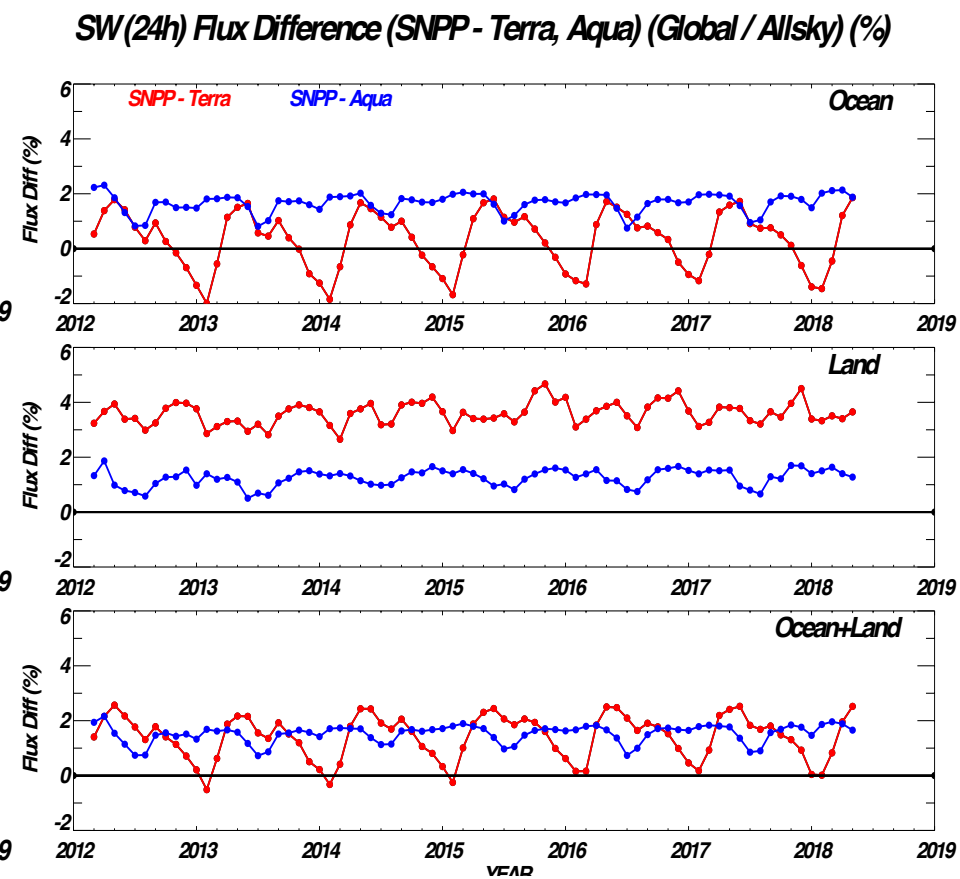
**Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude. Day-Night (DN) Difference comparison between LW and Simulated LW from Window measurements is used to monitor changes in SW portion of TOT sensor.**

**DN Difference radiance of FM5 Edition1 show a positive trend of < 0.001 W/m$^2$sr per year, which can attribute to minor changes in SW/TOT sensor.**



# S-NPP/FM5, TERRA & AQUA COMPARE: SW

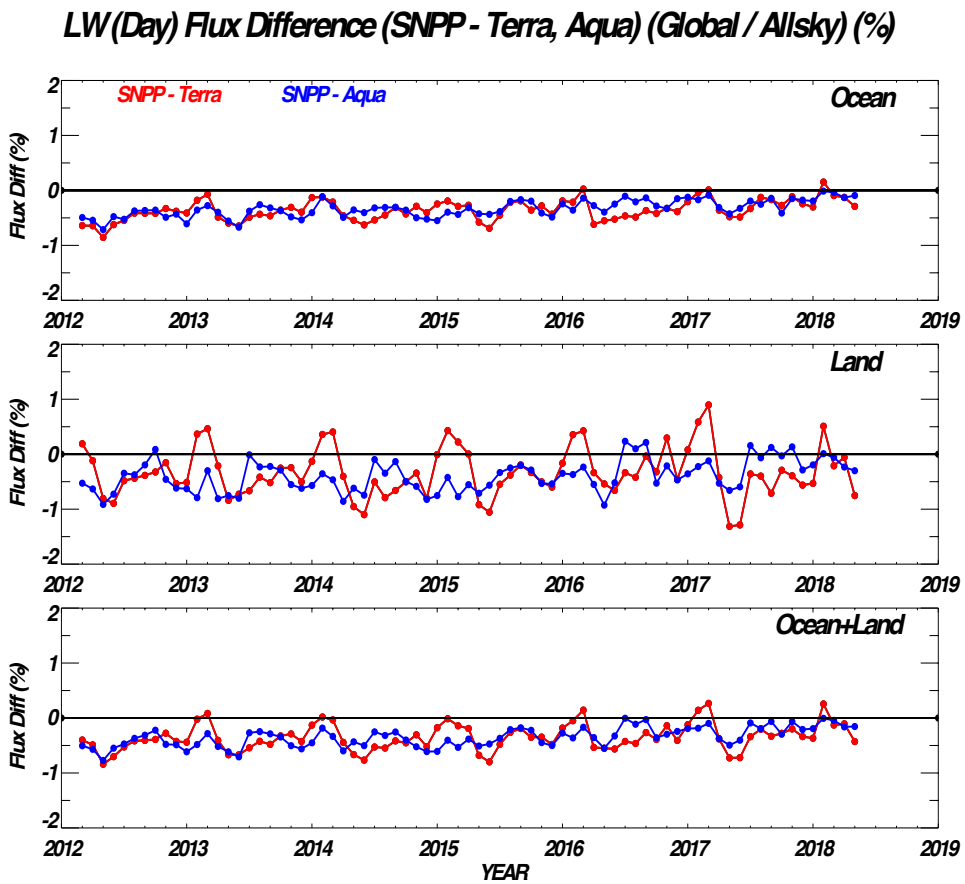


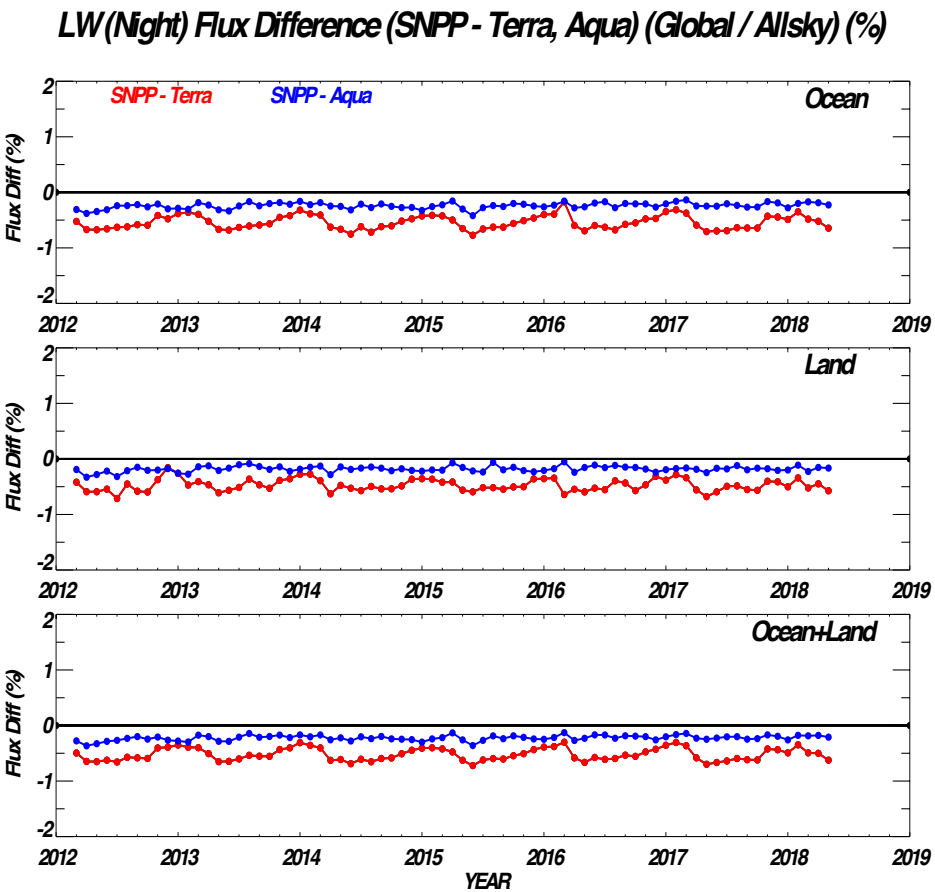




SW Flux anomaly for all scenes show similar trend for all instruments.

S-NPP/FM5 SW difference between Terra/FM1 and Aqua/FM3 remain stable.

# S-NPP/FM5, TERRA & AQUA COMPARE: LW_Ed1




LW-Day Flux Difference between S-NPP/FM5 with FM1 and FM3 show slight increase in trend.
LW-Night Flux Differences are relatively steady over time.

# S-NPP/FM5 Edition2 Activities

- The intercomparison results between S-NPP/FM5 and Aqua/FM3 showed that SW radiances are higher for FM5 instrument.
- Re-evaluate the pre-launch Shortwave calibration at narrow-band spectral regions for the Start of mission SW Spectral Response Function (SRF) for FM5 instrument.
- The SW reflectance for FM5 instrument with the new SW SRF is calculated.
- Intercomparison with FM3 SW reflectance to determine the overall scaling factor for FM5 to correct NPP/FM5 and Aqua/FM3 differences.
- A Lagrange multiplier based optimization is applied on FM5 SRF to determine the necessary corrections for bringing S-NPP/FM5 and Aqua/FM3 to common radiometric scale.

# S-NPP/FM5 SRF Evaluation

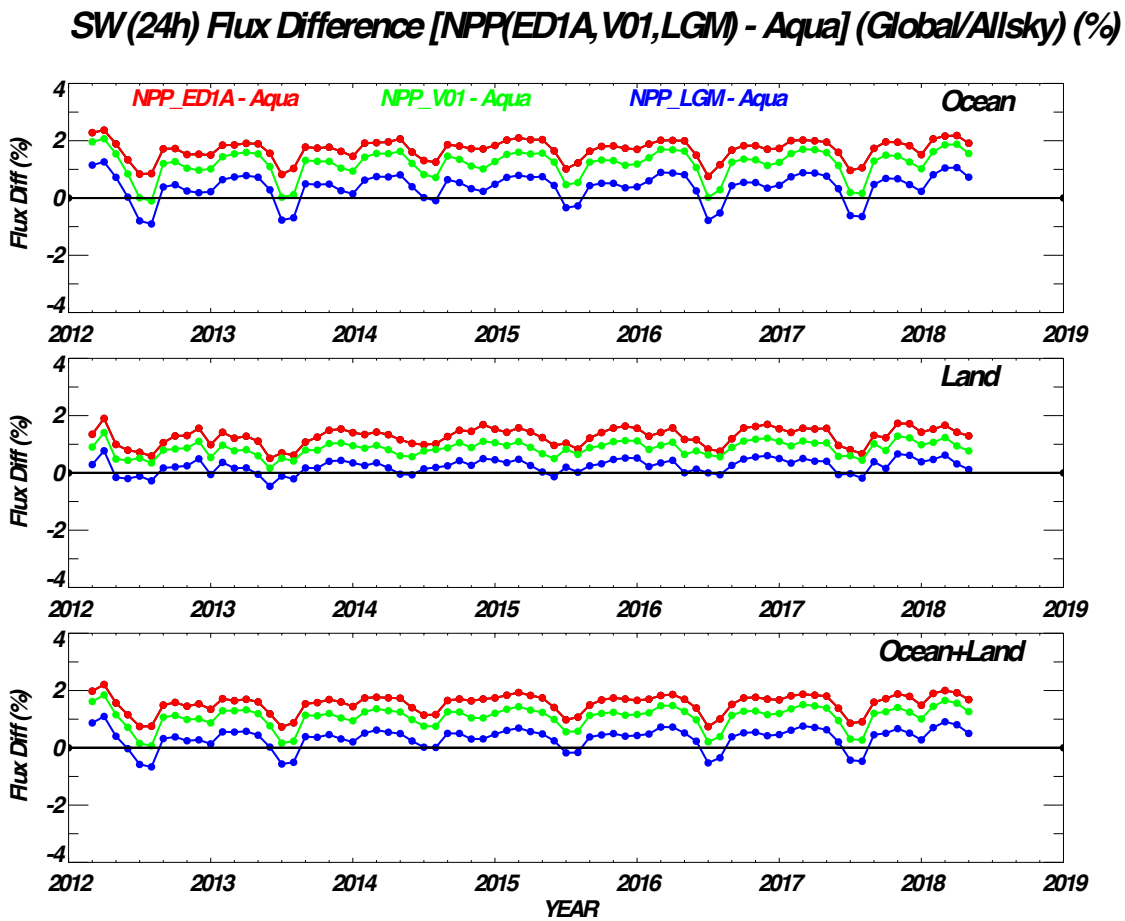
## Impact of Lagrange solution SRF to reflectance

| V01 | Year | N | Aqua | NPP (V01) | Abs Dif | Rel Dif |
|---|---|---|---|---|---|---|
| All-Sky | 2014 | 144 | 0.29357 | 0.29578 | 0.00221 | **0.746%** |
| Clear Ocean | 2014 | 123 | 0.06061 | 0.06133 | 0.00072 | **1.168%** |
| Clear Land | 2014 | 79 | 0.21812 | 0.21911 | 0.00098 | **0.449%** |

| LSolution | Year | N | Aqua | NPP (Lgrg) | Abs Dif | Rel Dif |
|---|---|---|---|---|---|---|
| All-Sky | 2014 | 144 | 0.29357 | 0.29363 | 0.00006 | **0.020%** |
| Clear Ocean | 2014 | 123 | 0.06061 | 0.06026 | -0.00036 | **-0.594%** |
| Clear Land | 2014 | 79 | 0.21812 | 0.21774 | -0.00038 | **-0.174%** |

# S-NPP/FM5 Edition2

## Impact of Lagrange solution SRF to reflectance

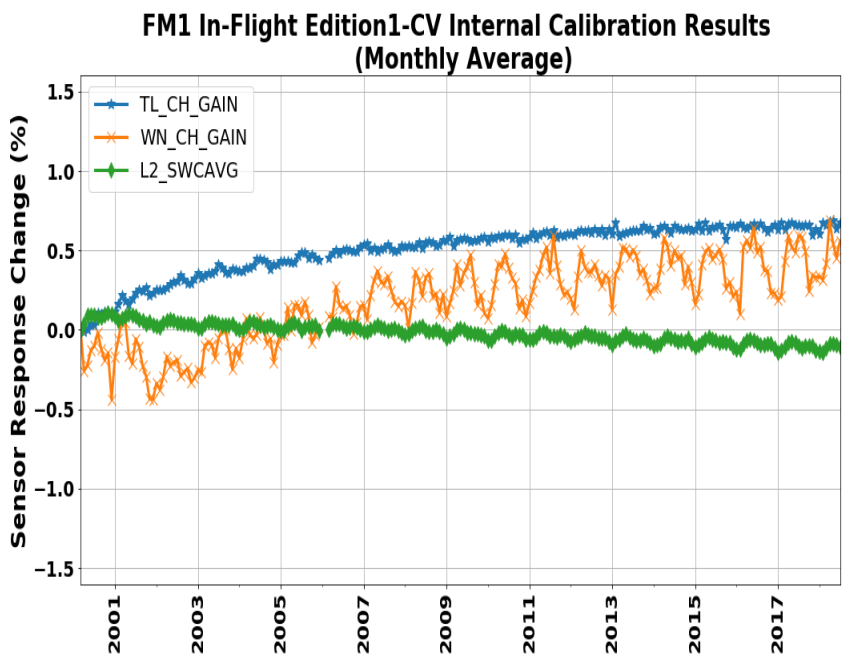


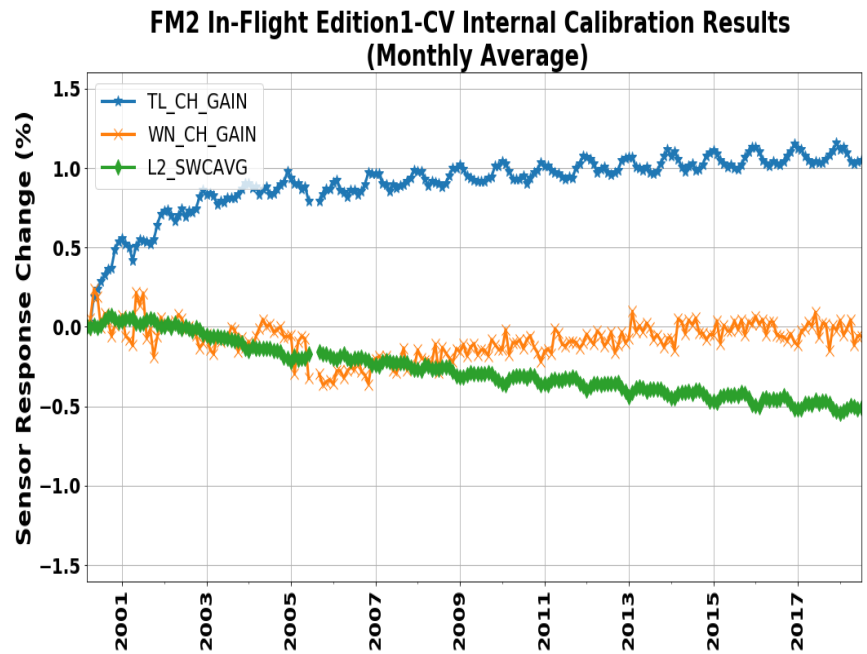
# TERRA & AQUA INSTRUMENT STATUS

# [CERES FM1 – FM4]

# Terra CERES FM1 & FM2 Instrument Calibration

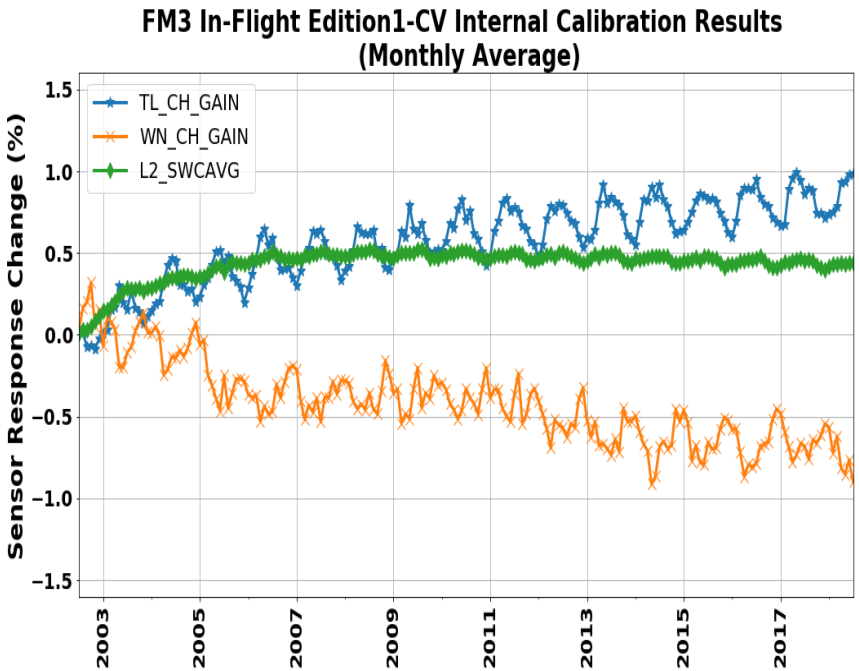
- **Increase in response for Total and Window sensors**
- **Drop in response for SW sensors.**

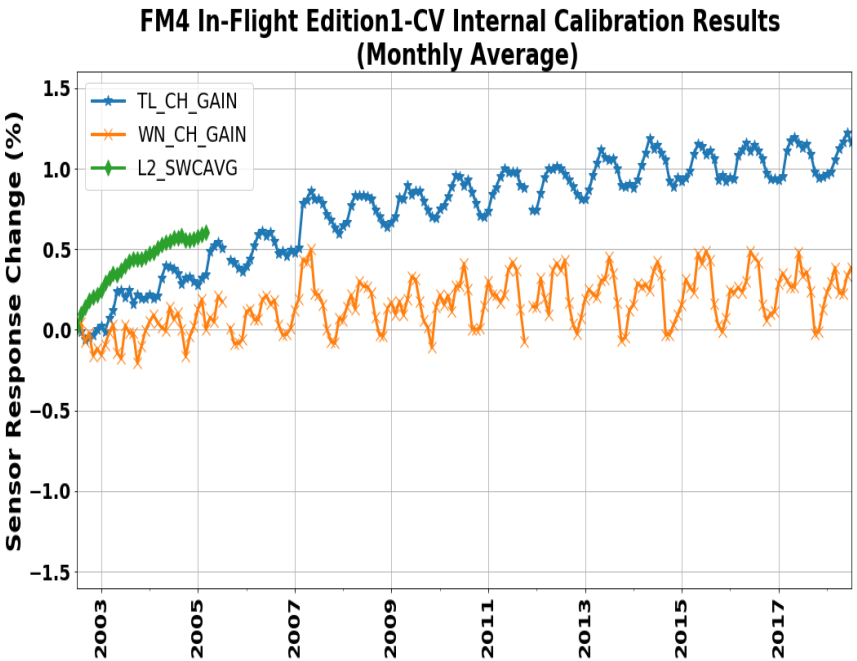


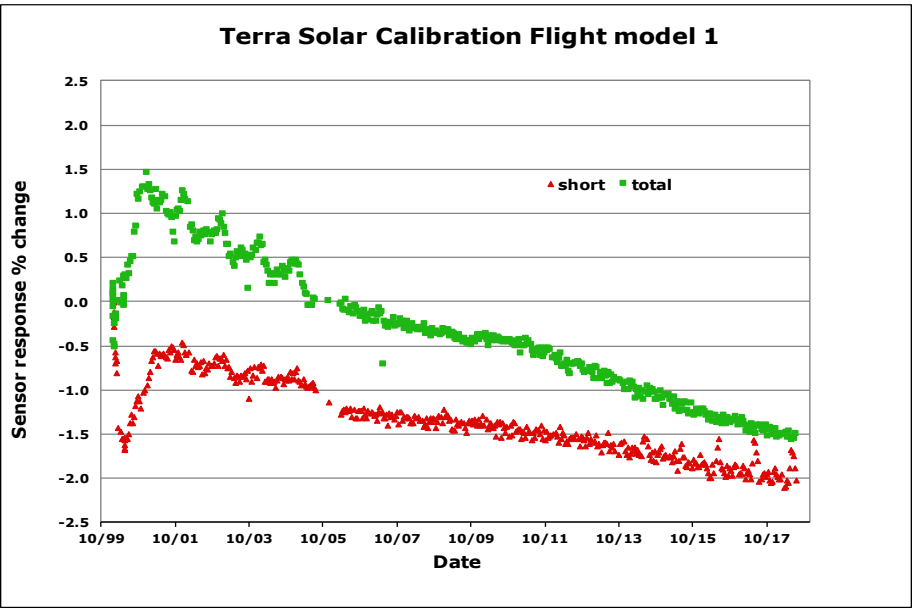
# Aqua CERES FM3 & FM4 Instrument Calibration

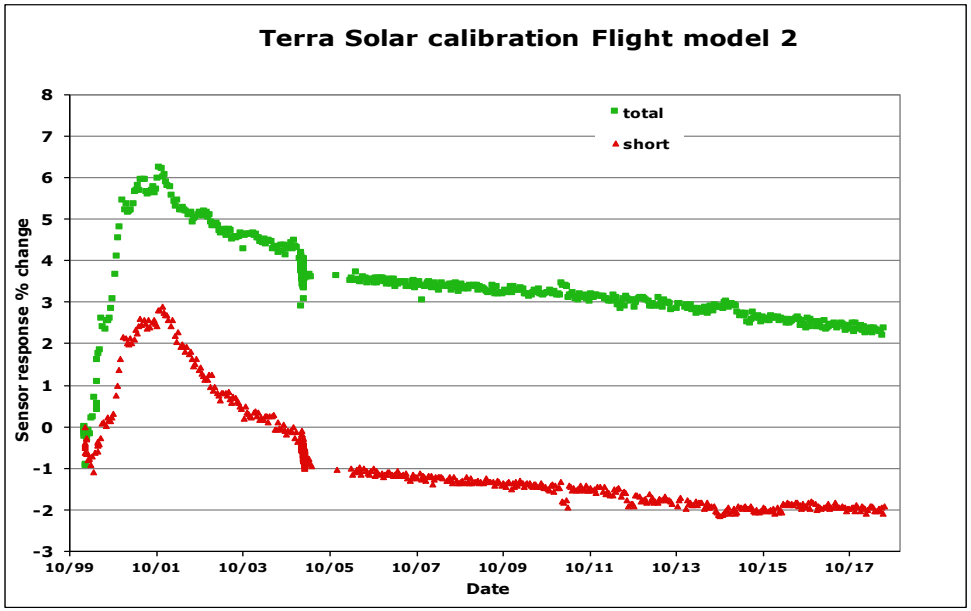
- **Increase in response for Total and SW sensors.**
- **Window sensor on FM3 showed a drop where as FM4 response show slight upward trend, similar to FM1 and FM2 instruments.**



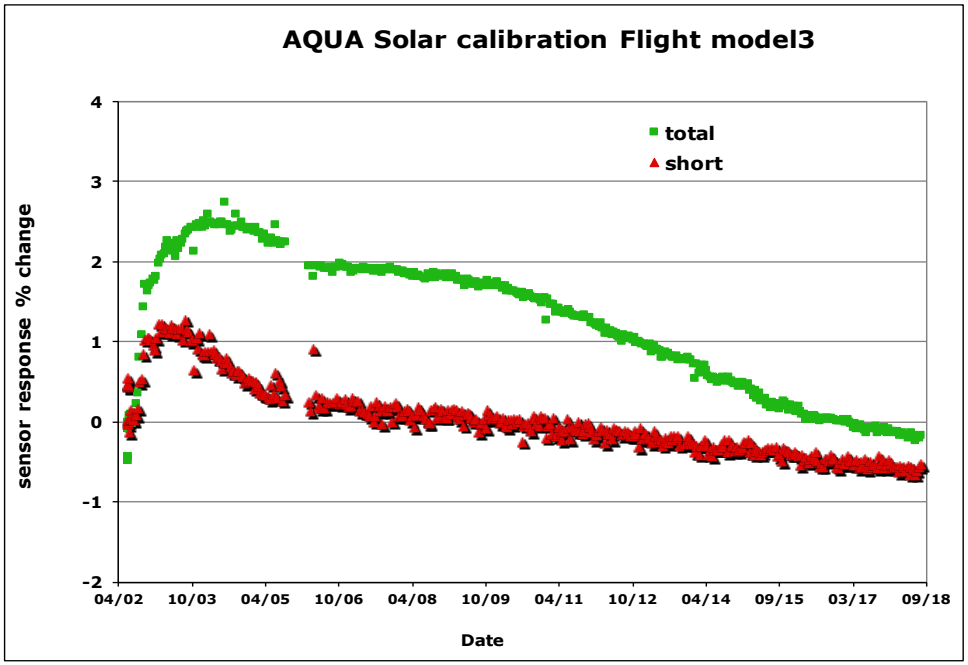
# Terra FM1 & FM2 Solar Calibration Results

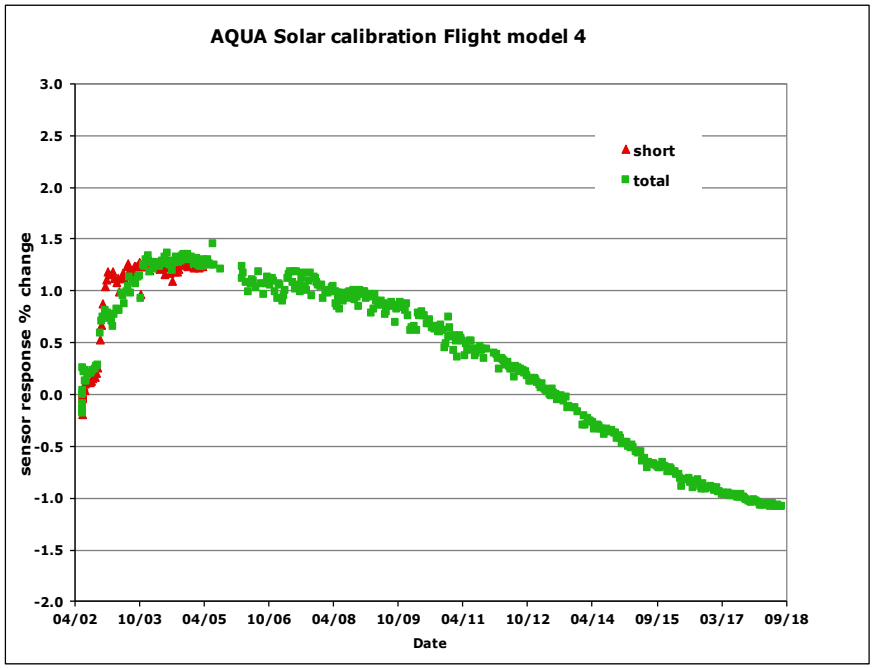



- **After rapid throughput change in first 4 years, Mirror Attenuator Mosaics (MAMs) on FM1 & FM2 instruments show slower rate of change.**
- **After the new solar raster scan calibration sequence starting Dec 2005, the MAMs showed similar rate of change in both instruments.**

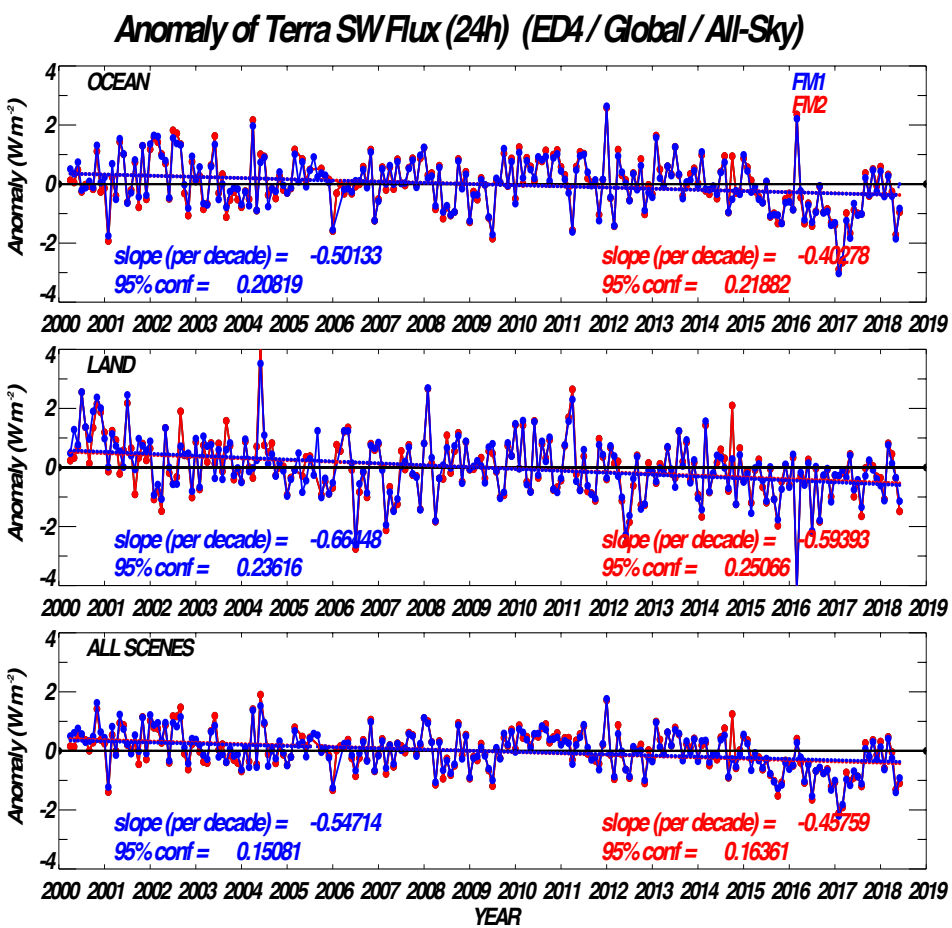
# Aqua FM3 & FM4 Solar Calibration Results

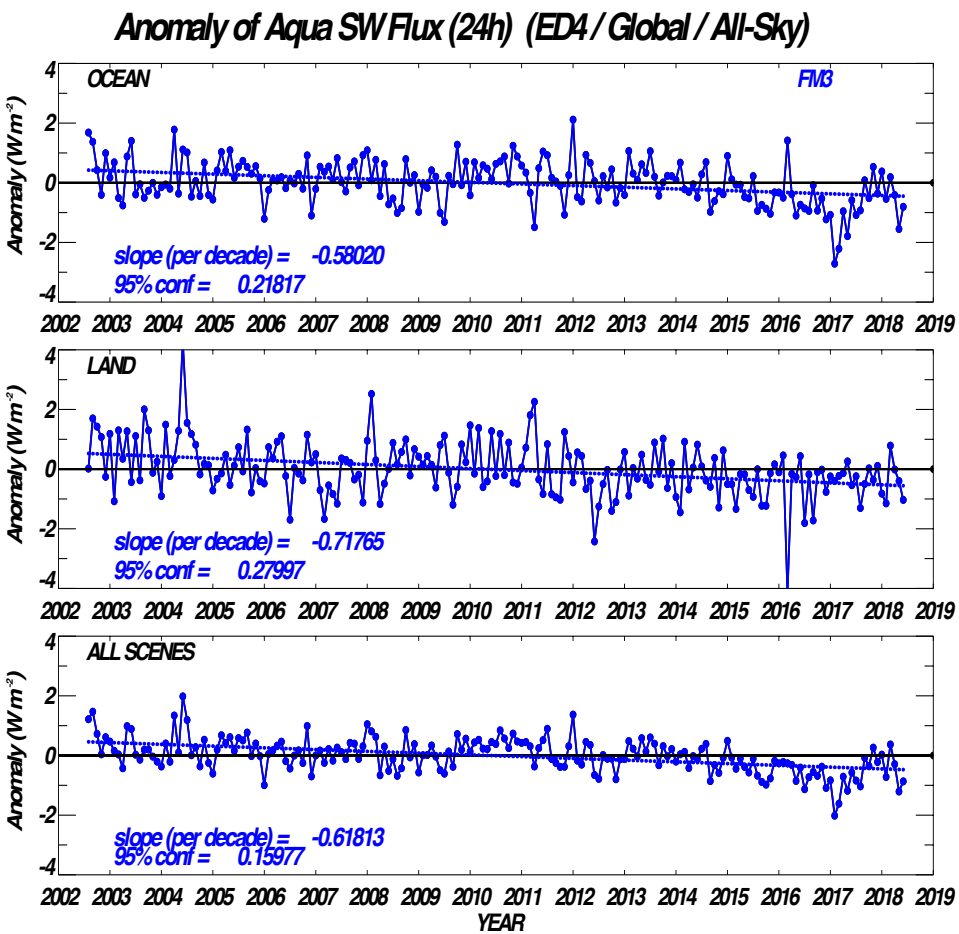


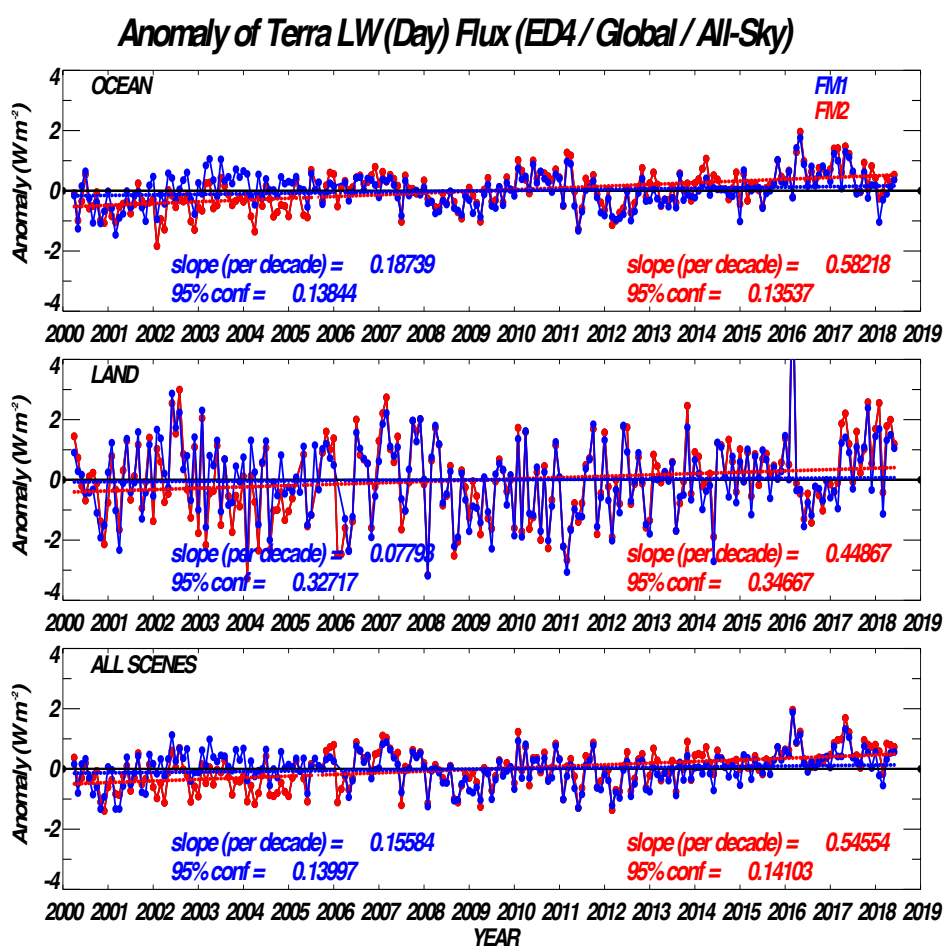

- **Mirror Attenuator Mosaics (MAMs) on FM3 & FM4 instruments also showed increase in throughput for first 18 months in Mission.**
- **The total sensor responses on both instruments showed a drop of 2 percent after the new solar raster scan calibration sequence started in Dec 2005.**
- **SW sensor on FM3 instrument showed about one percent drop in response.**

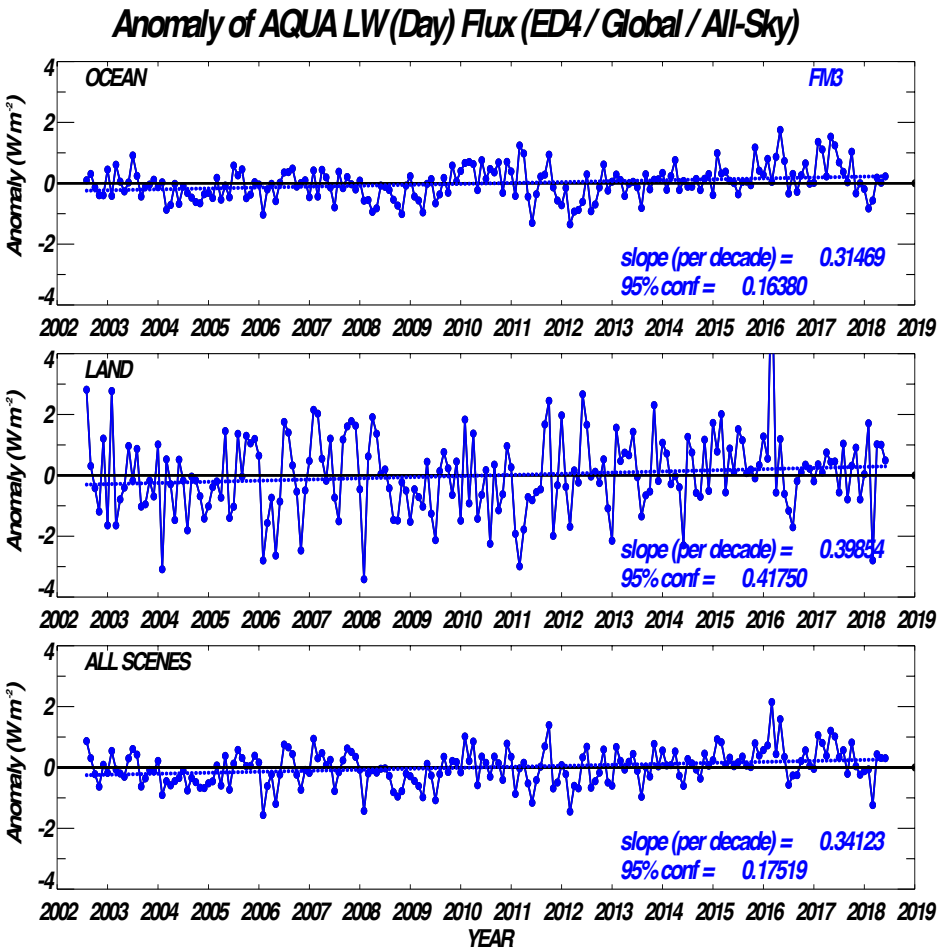
# EDITION-4 Validation: TERRA & AQUA SW Sensors



# EDITION-4 Validation: TERRA & AQUA LW_Day Flux




LW Flux anomaly for all scenes show similar trend for all instruments.

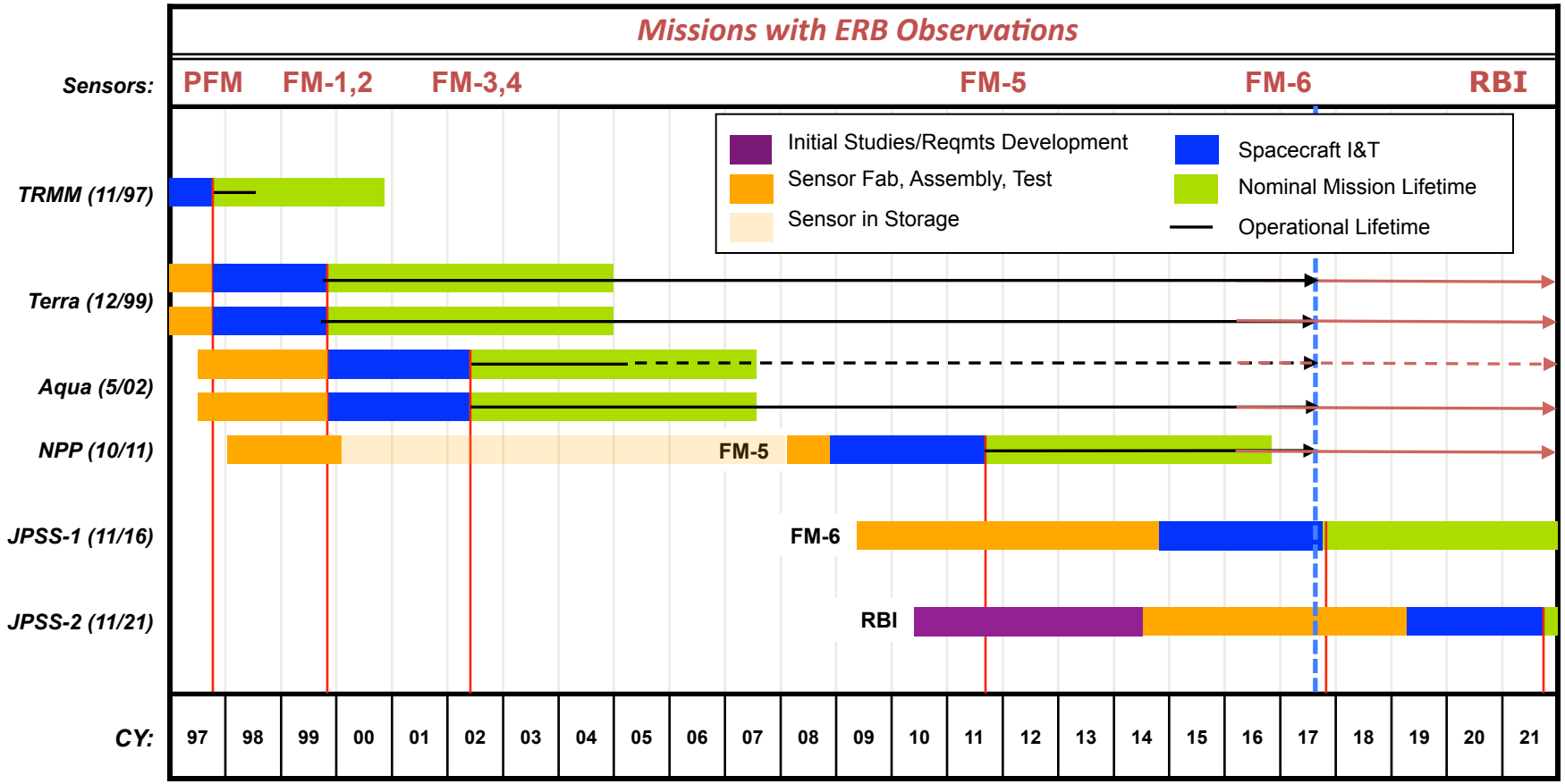
# SUMMARY

- CERES FM6 instrument performance is nominal after the initial sensor response increase in Total and Shortwave sensor.
- The ICM and Solar calibration results show good agreement on both Total and Shortwave sensor.
- CERES FM5 Start of Mission Spectral Response Function (SRF) was re-evaluated. A Lagrange optimization method was used to determine the necessary corrections for bringing S-NPP/FM5 and Aqua/FM3 to common radiometric scale.
- The Terra and Aqua Instruments' Gains and Spectral Response Functions for Edition4 processing were delivered through May 2018. Validation results of Terra/Aqua Edition-4 data show consistent trends in SW and LW measurement among the three CERES instruments (FM1 – FM3).

# BACK UP SLIDES

# Climate Data Record Continuity

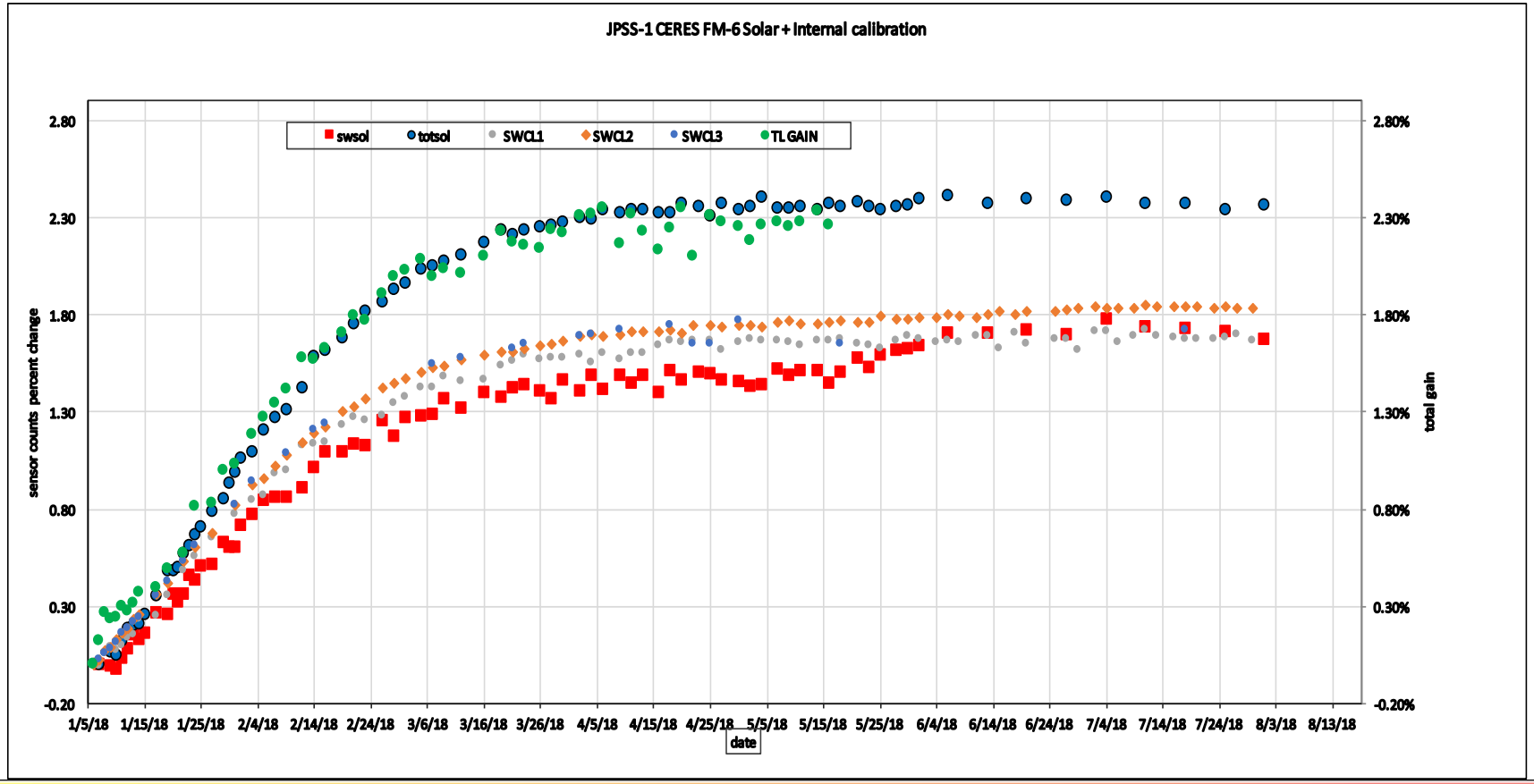
## CERES/RBI Flight Schedule



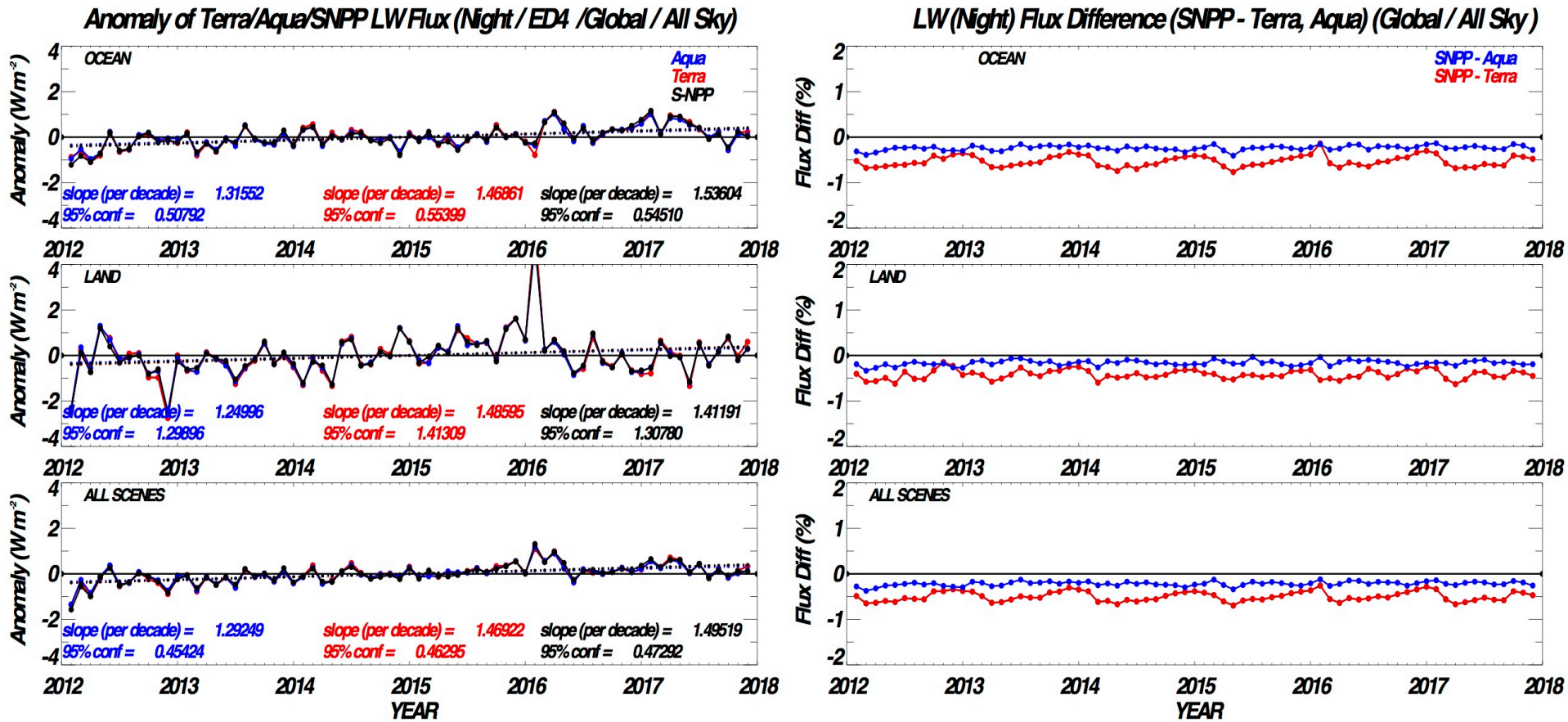

***We now have over 69 years of flight experience with the CERES instruments***

# JPSS-1/CERES FM6 Instrument Calibration

**Internal Calibration Module (ICM) and Solar calibration results for Total and Shortwave sensors show similar trends.**



# S-NPP/FM5, TERRA & AQUA COMPARE: LW Night




LW-Night Flux anomalies show similar positive trend on all 3 instruments.
Difference comparison of S-NPP/FM5 with FM1 and FM3 measurement remain stable.

# FM5/FM3 Differences for 2014

| All Sky | Year | N | Aqua | NPP | Dif Std | Abs Dif | Rel Dif |
|---|---|---|---|---|---|---|---|
| Ed1 | 2014 | 136 | 0.2939 | 0.2979 | 0.0011 | 0.0040±0.0002 | 1.37±0.06% |
| **Ed2-V01** | 2014 | 136 | 0.2939 | 0.2960 | 0.0009 | 0.0022±0.0002 | **0.74±0.05%** |

| Clear Ocn | Year | N | Aqua | NPP | Dif Std | Abs Dif | Rel Dif |
|---|---|---|---|---|---|---|---|
| Ed1 | 2014 | 111 | 0.0615 | 0.0633 | 0.0009 | 0.0018±0.0002 | 2.97±0.29% |
| **Ed2-V01** | 2014 | 111 | 0.0615 | 0.0623 | 0.0009 | 0.0008±0.0002 | **1.34±0.28%** |

| Clear Lnd | Year | N | Aqua | NPP | Dif Std | Abs Dif | Rel Dif |
|---|---|---|---|---|---|---|---|
| Ed1 | 2014 | 71 | 0.2222 | 0.2242 | 0.0015 | 0.0021±0.0004 | 0.94±0.16% |
| **Ed2-V01** | 2014 | 71 | 0.2222 | 0.2231 | 0.0014 | 0.0010±0.0003 | **0.43±0.15%** |

# Direct compare of FM5 and FM3

## FM5–FM3 "simultaneous Earth" observation

2012/2013/2014/2015/2016

ΔTime < 1min; ΔRAZ < 10°; ΔVZA <10°

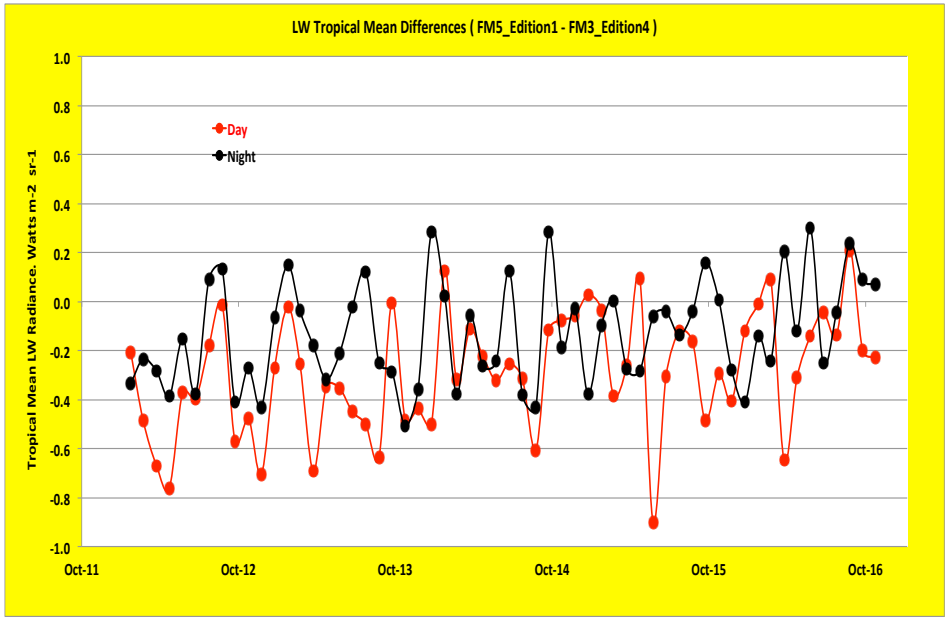
All-sky

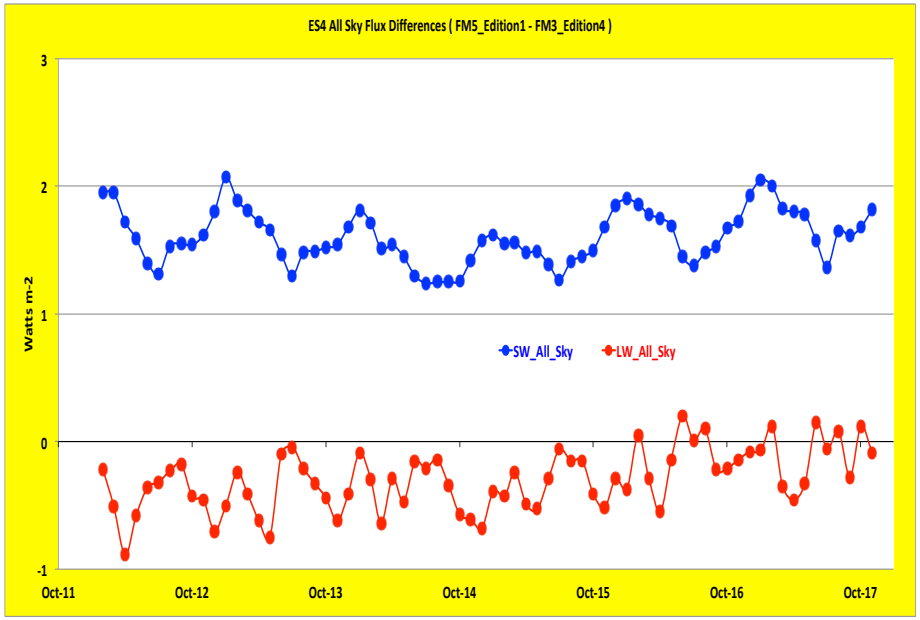
Shown differences are statistically significant

| (FM5-FM3)/ FM5 | FM5 Radiance [W $m^{-2}$ $sr^{-1}$] | Relative Error [%] | α-confidence [95%] | Number of samples |
|---|---|---|---|---|
| Shortwave | 79 /85 /77 /81 /80 | **3.3 / 2.7 / 1.0/ 1.7 /2.6** | .4 /.3 /.4 /.4 /.3 | 65/86/91/85/91 |
| LW daytime | 76 /74 /77 /77 /76 | **-1.1 /-1.3 /-0.6 /-0.9 /-1.0** | .1 /.1 /.1 /.1 /.1 | 69/89/91/85/91 |
| LW nighttime | 66 /65 /68 /66 /66 | **-0.3 /-0.3 /0.0 /-0.2 /-0.3** | .1 /.1 /.1 /.1 /.1 | 87/105/106/105/111 |

- Shown differences are computed as "average of differences" to avoid error cancellation

# CERES S-NPP/FM5 – Aqua/FM3 Comparison



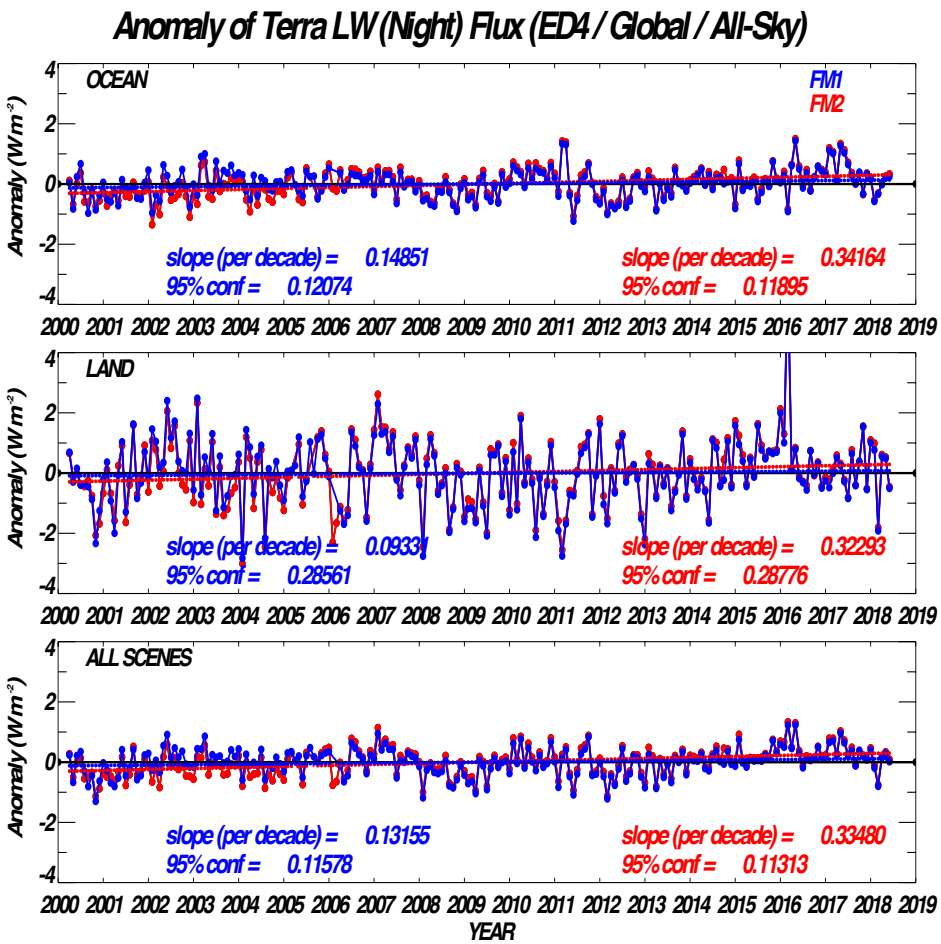
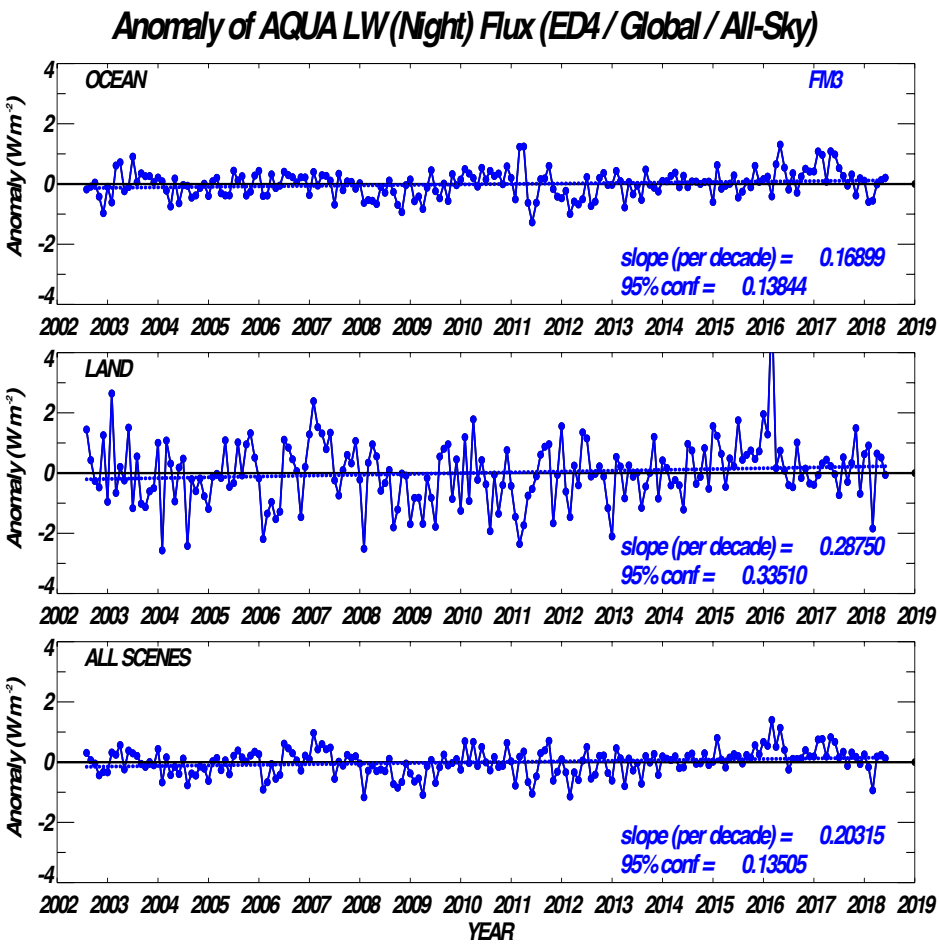

**Tropical Mean LW Radiances (Day and Night) show minimal differences.**
**Global Flux Differences show that FM5 SW measurements are higher by ~1.5 Wm-2 and LW measurements lower by ~0.5 Wm-2.**

# TERRA/AQUA Edition4 GAIN and SRF

- Edition4 Gains and Spectral Response Functions (SRF) :

  Terra and Aqua - Start of Mission to May 2018

- The monthly Gain values for the Total, Window and Shortwave sensors are based on in-flight ICM calibrations.

- With both instruments on the spacecraft operating in crosstrack mode, the current monthly SRF corrections for SW sensor remain constant.
- SRF correction in SW/TOT sensor is calculated monthly using All-sky Ocean and Land measurements of LW and Window sensors.

# EDITION-4 Results: TERRA & AQUA LW_Night Flux