CERES FM1 – FM6 Instrument Status

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CERES Instrument Working Group Team

Radiation Budget Workshop
ECMWF
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Instrument Working Group

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CERES Instrument Working Group
Discussion Topics

• ERB missions Overview
  • Flight history/future
• Operations
• Instrument Status
  • FM1–4 on Terra/Aqua
  • FM-5 on S-NPP
  • FM-6 on JPSS-1
• Summary
Climate Data Record Continuity

CERES/RBI Flight Schedule

<table>
<thead>
<tr>
<th>Sensors:</th>
<th>PFM</th>
<th>FM-1,2</th>
<th>FM-3,4</th>
<th>FM-5</th>
<th>FM-6</th>
<th>RBI</th>
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<tr>
<td>TRMM (11/97)</td>
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<td>Terra (12/99)</td>
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<td>Aqua (5/02)</td>
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<td>NPP (10/11)</td>
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<td>JPSS-1 (11/16)</td>
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<td>JPSS-2 (11/21)</td>
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Legend:
- Initial Studies/Requirements Development
- Sensor Fabrication, Assembly, Test
- Sensor in Storage
- Spacecraft I&T
- Nominal Mission Lifetime
- Operational Lifetime

CY: 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21
CERES Instruments, Flight Models 1-5 (FM1 – FM5) are primarily in Cross-Track mode of operation.

Inter-comparison campaigns in 2016

CERES Terra/FM2 – ScaRAB: April 1 – May 31, 2016
CERES Terra/FM2 – GERB: June 1 – June 30, 2016
CERES Terra/FM1 – Aqua/FM3: June 1 – 30, 2016
TERRA & AQUA INSTRUMENT STATUS
[CERES FM1 – FM4]
Terra – Aqua Sensor Performance

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Terra – Aqua Solar Calibration Results

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EDITION-4 RESULTS: TERRA & AQUA SW SENSORS

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Terra – Aqua SW Anomaly Trends

SW TOA Flux Anomalies (W/m²/decade)

Trends in CERES Terra Monthly (July 2002 – June 2016)
SW TOA Flux Anomalies (W/m²/decade)

SW TOA Flux Anomalies (W/m²/decade)

Trends in CERES Aqua Monthly (July 2002 – June 2016)
SW TOA Flux Anomalies (W/m²/decade)

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EDITION-4 Results: TERRA & AQUA LW_Day Flux

Anomaly of Terra LW (Day) TOA Flux (ED4 / Global / All-Sky)

- **Ocean**
  - Slope (per decade) = 0.04660
  - 95% confidence = 0.15662
  - Slope (per decade) = 0.32269
  - 95% confidence = 0.41167

- **Land**
  - Slope (per decade) = -0.1664
  - 95% confidence = 0.16367
  - Slope (per decade) = 0.26419
  - 95% confidence = 0.16611

- **All Scenes**
  - Slope (per decade) = -0.1664
  - 95% confidence = 0.16367
  - Slope (per decade) = 0.26419
  - 95% confidence = 0.16611

Anomaly of Aqua LW (Day) TOA Flux (ED4 / Global / All-Sky)

- **Ocean**
  - Slope (per decade) = 0.18334
  - 95% confidence = 0.19118

- **Land**
  - Slope (per decade) = 0.48564
  - 95% confidence = 0.51680

- **All Scenes**
  - Slope (per decade) = 0.27766
  - 95% confidence = 0.21111

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Anomaly Trends of the difference between Day-Night difference of Longwave and Window measurements for 1x1 degree region was performed.

The results show the trends are more pronounced in certain Land scenes of Aqua measurements.
EDITION-4 Results: TERRA & AQUA LW_Night Flux

Anomaly of Terra LW (Night) TOA Flux (ED4 / Global / All-Sky)

- **OCEAN**
  - Slope (per decade) = 0.05380
  - 95% conf = 0.14101

- **FM1**
  - Slope (per decade) = 0.23438
  - 95% conf = 0.13886

- **FM2**
  - Slope (per decade) = 0.12038
  - 95% conf = 0.34618

- **FM3**
  - Slope (per decade) = 0.10595
  - 95% conf = 0.16425

Anomaly of Aqua LW (Night) TOA Flux (ED4 / Global / All-Sky)

- **OCEAN**
  - Slope (per decade) = 0.12038
  - 95% conf = 0.34618

- **LAND**
  - Slope (per decade) = 0.38581
  - 95% conf = 0.34807

- **ALL SCENES**
  - Slope (per decade) = 0.07249
  - 95% conf = 0.13686

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Minor plane radiation measurements

• Annual campaign around summer solstice
  • FM1 and FM3 in June of each year since 2002
    – On all orbits with time differential < 18 minutes
  • FM1 and FM5 May-July each year since 2012
    – A few orbits every 64 hours; ΔT < 5 minutes
• Each data collection lasts 90 sec

• FM1/FM3/FM5 scan in the minor plane
  • Scan orientation is perpendicular to the solar plane
  • Double nadir scan profile to avoid ram directions

• Data collection region is about 70°N
  • Various scene types including Greenland (ice/snow)
Shortwave results for FM3/FM1

Excellent consistency for “all-sky”; $-0.5\% < \Delta SW < 0.2\%$
Longwave results for FM3/FM1

LWN measured; LWD derived: TOT - SW

Good consistency for “all-sky”; - 0.5% < ΔLWday < 0.4%
Better consistency; - 0.25% < ΔLWnight < 0.1%; small upward trend
Direct compare FM2/FM1 (unfiltered radiance)

- Terra CERES in XT since 2005
- Very stable & consistent
- Δ’s plotted for selected years

- SW: FM2 > FM1 by 0.5%
- LW Day: FM2 ≈ FM1
- LW Night: FM2 ≈ FM1

✓ SW:
✓ CLRO FM2 > FM1 by 1.5%
✓ Other scene types < within 1%

✓ LW Day:
✓ All scene types within 1%
TERRA/AQUA DATA AVAILABILITY

Edition3 Gains and Spectral Response Functions (SRF):  
Start of Mission – May 2016

Edition4 Gains and Spectral Response Functions (SRF):  
Terra and Aqua - Start of Mission to May 2016

Start of Mission – September 2016
S-NPP/ CERES FM5 INSTRUMENT STATUS
ICM calibrations show a response increase of 0.4% for Total, 0.5% for Window sensor and a drop of 0.2% in SW sensor. Sensor response trends from solar calibrations remain within ± 0.5%.

Sensor gain corrections based on ICM calibrations are applied to Edition1 data products.
Calibration results from SWICS (Level1) and MAM showed consistent trends in the SW sensor.
Suomi NPP/CERES FM5 Validation Results

Tropical Mean (TM): Nadir LW radiance for All-sky Ocean in ± 20 deg Latitude. Changes in SW/TOT channel is monitored through Day-Night Difference comparison between LW and Window measurements. Three Channel comparison use Deep Convective Cloud (DCC) as target. Trend in monthly slope between delta LW and SW measurements is monitored.
CERES FM-6
JPSS-1 Satellite I&T Overview

• Ball Aerospace & Technologies Corporation (BATC) in Boulder, CO is the JPSS-1 spacecraft provider and satellite integrator.

• JPSS-1/CERES FM6 completed the Environmental Campaign.
  - Vibration: May 2016
  - EMI/EMC: June-July 2016
  - Thermal Vacuum (TVAC): August – October 2016

• JPSS Compatibility Tests and Mission Rehearsals were conducted to evaluate the Instrument post-launch operation capabilities.

• JPSS coordinate launch operations through NASA KSC
  - Launch will be from Vandenberg AFB, CA – NET March 2017
JPSS-1/CERES FM6 TVAC RESULTS

CERES FM6 Internal Calibrations

Sensor Response Change (%)

-3% -2% -1% 0% 1% 2% 3%

Calibration

Instrument Level TVAC

Hot-1
Hot-2
Hot-3
Hot-4

Cold-1
Cold-2
Cold-3
Cold-4

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• Validation results from the Edition-4 datasets show slight negative trend in SW (FM1: -0.24, FM2: -0.22 and FM3: -0.46 W/m²/decade).

• LW-Day anomaly results show positive trends in FM2 (0.26 W/m²/dec) and FM3 (0.28 W/m²/dec) and no trend in FM1 instrument.

• Terra and Aqua Inter-comparison campaign results show good consistency in both SW and LW measurements.

• CERES FM5 calibration results show the performance trends are within expected range.

• CERES FM6 instrument has successfully completed all Spacecraft Level Test Campaign.
BACK UP SLIDES
Mean SW TOA Flux Difference (Latitude: +/-60 degrees)

**CLEAR SKY**

**ALL SKY**
Mean LW (Day) TOA Flux Difference (Latitude: +/-60 degrees)

CLEAR SKY

ALL SKY

YEAR

Mean LW (Night) TOA Flux Difference (Latitude: +/-60 degrees)

CLEAR SKY

ALL SKY

YEAR

(FW1-FM2)/FM1 (%)
The SW sensor Spectral Response Function (SRF) correction is applied based on the Nadir comparison of Clear Ocean SW measurement from two instruments on same spacecraft. The correction is applied to SRF for the instrument operating in RAPS mode.

**SW ‘Optimal’ Throughput Change calculated with SCIAMACHY Clear/All Ocean Spectra**

![Graph showing SW ‘Optimal’ Throughput Change](image)
Correction to SW/TOT sensor of each instrument is based on the regression between LW(Day-Night) and WN (Day-Night) using Tropical Ocean and Land scenes.

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)
Tropical Mean LW comparisons show stable results. Global Flux Differences show that CERES FM5 SW measurements are higher and LW measurements lower than FM3 measurements.
CERES FM5 - FM3 Matched Footprint Comparisons

All-sky 2012/2013/2014/2015
(Rev. 04/19/16)
ΔTime < 1min; ΔRAZ < 10°; ΔVZA <10°

Shown differences are statistically significant

<table>
<thead>
<tr>
<th>(FM5-FM3)/FM5</th>
<th>FM5 Radiance [W m⁻² sr⁻¹]</th>
<th>Relative Error [%]</th>
<th>α-confidence [95%]</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortwave</td>
<td>79.1/84.5/77.2/80.6</td>
<td>3.29 / 2.68 / 1.02/ 1.71</td>
<td>.40/.31/.35/.35</td>
<td>65/86/91/85</td>
</tr>
<tr>
<td>LW daytime</td>
<td>75.7/74.0/76.9/76.6</td>
<td>-1.13/-1.25/-0.57/-0.87</td>
<td>.09/.10/.13/.10</td>
<td>69/89/91/85</td>
</tr>
<tr>
<td>LW nighttime</td>
<td>66.2/64.9/67.5/65.5</td>
<td>-0.31/-0.27/0.01/-0.15</td>
<td>.07/.08/.06/.07</td>
<td>87/105/106/105</td>
</tr>
</tbody>
</table>

- Edition 1 for FM5 and Edition 4 for FM1/FM3 are used
- Shown differences are computed as “average of differences” to avoid error cancellation
Direct compare of FM5 and FM3

Minor Plane Scanning

All-sky 2013/2014/2015

13min < ΔTime < 23min

Differences are not statistically significant

<table>
<thead>
<tr>
<th>(FM5-FM3)/FM5</th>
<th>FM5 Radiance [W m⁻² sr⁻¹]</th>
<th>Relative Error [%]</th>
<th>α-confidence [95%]</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortwave</td>
<td>97.7/108.7/105.7</td>
<td>0.86 / 0.96 / 0.88</td>
<td>0.93/0.90/0.87</td>
<td>39/30/30</td>
</tr>
<tr>
<td>LW daytime</td>
<td>77.8/76.4/75.7</td>
<td>0.15 / -0.03 / -0.14</td>
<td>0.39/0.46/0.38</td>
<td>39/30/30</td>
</tr>
</tbody>
</table>

- Edition 1 for FM5 and Edition 4 for FM3 are used
- The differences are similar to those of FM5/FM1
- Larger uncertainties make differences statistically non-significant
Direct compare of FM5 and FM1
Minor Plane Scanning
All-sky 2012/2013/2014/2015
ΔTime < 5min

Shown differences are statistically significant

<table>
<thead>
<tr>
<th>(FM5-FM1)/FM5</th>
<th>FM5 radiance [W m(^{-2}) sr(^{-1})]</th>
<th>Relative Error [%]</th>
<th>(\alpha)-confidence [95%]</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortwave</td>
<td>87.0/101.6/111.1/108.6</td>
<td>.81/.93/.86/1.00</td>
<td>.26/.17/.14/.17</td>
<td>64/108/123/139</td>
</tr>
<tr>
<td>LW daytime</td>
<td>78.6/76.1/74.8/74.8</td>
<td>-.46 /-.16 /-.81 /-.71</td>
<td>.13/.09/.12/.12</td>
<td>68/112/130/141</td>
</tr>
</tbody>
</table>

- 2012 campaign lasted only 6 weeks
  - June 16 – July 31
- 2013/2014/2015 campaigns lasted 3 months
  - May 1 – July 31
S-NPP/FM5, TERRA & AQUA COMPARE: SW FLUX

Anomaly of Terra/Aqua/SNPP SW TOA Flux (Global / All Sky)

SW TOA Flux Difference (SNPP - T,A) (Global/All Sky)

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

Anomaly of Terra/Aqua/SNPP LW (DAY) TOA Flux (Global / All Sky)

LW (Day) TOA Flux Difference (SNPP - T,A) (Global / All Sky)

YEAR

OCEAN

LAND

ALL SCENES

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

**Anomaly of Terra/Aqua/SNPP LW (NIGHT) TOA Flux (Global/All Sky)**

- **OCEAN**
  - Year: 2012 to 2016
  - Anomaly (W m⁻²)
  - Slope (per decade): 1.07203 (95% conf = 0.77085)
  - Slope (per decade): 1.37849 (95% conf = 0.94465)
  - Slope (per decade): 1.19473 (95% conf = 0.98601)

- **LAND**
  - Year: 2012 to 2016
  - Anomaly (W m⁻²)
  - Slope (per decade): 1.75392 (95% conf = 1.70821)
  - Slope (per decade): 3.23876 (95% conf = 1.88426)
  - Slope (per decade): 3.07744 (95% conf = 1.70069)

- **ALL SCENES**
  - Year: 2012 to 2016
  - Anomaly (W m⁻²)
  - Slope (per decade): 1.53958 (95% conf = 0.70529)
  - Slope (per decade): 1.91108 (95% conf = 0.73833)
  - Slope (per decade): 1.73599 (95% conf = 0.71979)

**LW (Night) TOA Flux Difference (SNPP - T,A) (Global/All Sky)**

- **OCEAN**
  - Year: 2012 to 2016
  - (SNPP - T,A)/SNPP (%)
  - Line plots showing trends over years

- **LAND**
  - Year: 2012 to 2016
  - (SNPP - T,A)/SNPP (%)
  - Line plots showing trends over years

- **ALL SCENES**
  - Year: 2012 to 2016
  - (SNPP - T,A)/SNPP (%)
  - Line plots showing trends over years
CERES FM6 TVAC OPERATIONS

• CERES Instrument conducted 4 Comprehensive Function Tests (CPT) at COLD-1, HOT-1, COLD-4 and HOT-4 Plateaus.
• CERES operates primarily in Cross-Track mode (default on-orbit mode) during TVAC.
• Calibration using the on-board sources are conducted at each Thermal plateau.
• Total and Longwave sensor stability is evaluated using on-board Blackbody sources at each Thermal plateau.