CPF-CERES Intercalibration: Desirables/Expected Outcome

Mohan Shankar

CERES Instrument Working Group

CPF Science Workshop
CERES Background

• CERES instrument enables measurement of the Reflected Solar and Outgoing LW radiation from the Earth’s Top of the Atmosphere (TOA).

• CERES measures the radiation at the TOA with three channels:
  • SW: 0.3-5 μm
  • TOT: 0.3->100 μm
  • WN: 8-12 μm/LW: 5->50 μm (FM6)

• Three telescopes are co-aligned and mounted on a spindle that can be rotated about the elevation axis.

• Instrument can also be rotated about the azimuth axis.

• Radiometric accuracy: 1% for SW and 0.5% for LW, for k=1.

• There are six CERES instruments currently operational:
  • FMs 1 and 2 on Terra, launched in Dec 1999.
  • FMs 3 and 4 on Aqua, launched in May 2002.
  • FM5 on S-NPP, launched in Oct 2011.
  • FM6 on NOAA-20, launched in Nov. 2017.
CERES Operational Scanning Capabilities

Tracking Capability

Targeted Campaigns

Increased angular sampling

Nominal Science Mode

Fixed (FAPS)

Rotating (RAPS)

Programmable (PAPS)

APS: Azimuth plane Scan

Sensors- TOT, SW, WN or LW (FM6)
CERES spatial sampling characteristics

Cross-track scan spacing driven by Scan Rate
Along-track spacing given by S/C motion and Scan Cycle Time

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Altitude (km)</th>
<th>Equatorial crossing Mean Local Time</th>
<th>Viewing Range limb-to-limb, $\theta$ (deg)</th>
<th>Swath (km)</th>
<th>Scan Spacing at Nadir, 6.6 s interval (km)</th>
<th>Sample interval (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terra</td>
<td>705</td>
<td>1030*</td>
<td>128.4</td>
<td>5739</td>
<td>49.5</td>
<td>7.8-40.2</td>
</tr>
<tr>
<td>Aqua</td>
<td>705</td>
<td>1330</td>
<td>128.4</td>
<td>5739</td>
<td>49.5</td>
<td>7.8-40.2</td>
</tr>
<tr>
<td>S-NPP/NOAA-20</td>
<td>824</td>
<td>1330</td>
<td>124.6</td>
<td>6161</td>
<td>49.1</td>
<td>9.1-41.2</td>
</tr>
</tbody>
</table>

*Currently drifting
# CERES On-orbit Calibration/Validation Protocol

<table>
<thead>
<tr>
<th>Product Level</th>
<th>Spatial Scale</th>
<th>Temporal Scale</th>
<th>Spectral Weighting</th>
<th>Dynamic Range</th>
<th>Latitude Range</th>
<th>Radiometric Metric</th>
<th>Channel</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>On-Board</strong></td>
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<tr>
<td>Internal BB</td>
<td>Filtered Radiance</td>
<td>Full IFOV</td>
<td>Continuous Capability</td>
<td>290-320 K BB</td>
<td>Across</td>
<td>All</td>
<td>Absolute Accuracy, Stability</td>
<td>TOT, WN, LW</td>
</tr>
<tr>
<td>Internal Lamp</td>
<td>Filtered Radiance</td>
<td>Full IFOV</td>
<td>Continuous Capability</td>
<td>17000, 2000, 2300 K BB</td>
<td>Across</td>
<td>All</td>
<td>Absolute Stability</td>
<td>SW</td>
</tr>
<tr>
<td>Solar</td>
<td>Filtered Radiance</td>
<td>Full IFOV</td>
<td>1 per orbit capability</td>
<td>Solar</td>
<td>Fixed, High</td>
<td>N or S Pole</td>
<td>Relative Stability</td>
<td>TOT, SW</td>
</tr>
<tr>
<td><strong>Vicarious</strong></td>
<td></td>
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<tr>
<td>Theoretical Line-by-Line</td>
<td>Filtered Radiance</td>
<td>&gt;20 Km</td>
<td>Instantaneous</td>
<td>Various Earth</td>
<td>Across</td>
<td>N/A</td>
<td>Inter-Channel Theoretical Agreement</td>
<td>TOT, WN, LW</td>
</tr>
<tr>
<td>Unfiltering Algorithm Theoretical Validation</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>TOT, SW, WN, LW</td>
</tr>
<tr>
<td>Inter-Satellite (Direct Comparison)</td>
<td>Unfiltered Radiance</td>
<td>1-deg Grid</td>
<td>1 per crossing</td>
<td>Various Earth</td>
<td>Mid</td>
<td>All</td>
<td>Inter-Instrument Agreement, Stability</td>
<td>TOT, SW, WN, LW</td>
</tr>
<tr>
<td>Tropical Mean Geographical Average</td>
<td>Unfiltered Radiance</td>
<td>20N-20S</td>
<td>Monthly</td>
<td>Tropical Ocean, All Sky</td>
<td>Mid</td>
<td>20N-20S</td>
<td>Inter-Instrument Agreement, Stability</td>
<td>TOT, WN</td>
</tr>
<tr>
<td>DCC Albedo</td>
<td>Unfiltered Radiance</td>
<td>&gt; 40 Km</td>
<td>Monthly</td>
<td>Cloud RS</td>
<td>High</td>
<td>All, Daytime</td>
<td>Inter-Instrument Agreement, Stability</td>
<td>SW</td>
</tr>
<tr>
<td>3-Channel Intercomparison</td>
<td>Unfiltered Radiance</td>
<td>&gt;100 Km</td>
<td>Monthly</td>
<td>Various Earth</td>
<td>Across</td>
<td>All, Daytime</td>
<td>Inter-Channel consistency, Stability</td>
<td>TOT, SW, WN, LW</td>
</tr>
<tr>
<td>Time Space Averaging</td>
<td>Fluxes</td>
<td>Regional, Zonal, Global</td>
<td>Monthly, Yearly</td>
<td>Various Earth</td>
<td>Across</td>
<td>All</td>
<td>Inter-Instrument Agreement</td>
<td>OLR, RS</td>
</tr>
<tr>
<td>Lunar Radiance Measurements</td>
<td>Filtered Radiance</td>
<td>Sub IFOV (7-10%)</td>
<td>1 day per lunar month</td>
<td>Lunar OLR and RS</td>
<td>Fixed, Low</td>
<td>N or S Pole</td>
<td>Relative Stability</td>
<td>TOT, SW, WN, LW</td>
</tr>
</tbody>
</table>

**Fluxes**
CERES Instruments’ Current Operational Status

• **Terra:**
  • FM1 (Cross track mode)
  • FM2 (Biaxial mode since Nov. 1, 2021).

• **Aqua:**
  • FM3 (Cross track mode)
  • FM4 (Biaxial mode since July 2021), SW channel non-functional since Apr 2005.

• **S-NPP:**
  • FM5 (Biaxial mode since October 2019)

• **NOAA-20:**
  • FM6 (Cross track mode)
CPF-CERES Intercalibration: Desirables

Co-located inter-comparisons between CERES and CPF when the orbits cross-over, to validate CERES SW channel performance.

**Desired characteristics of the inter-comparisons**

- Geographically diverse scenes spanning the spectral and dynamic range of the CERES SW channel.
- Span the spectral range of CERES SW channel to evaluate performance in various wavelength domains, including in the UV/blue regions.
- Span the dynamic range to evaluate gain, linearity, offsets.

**Value to CERES**

- Compare/tie NOAA-20/FM6 SW channel observations to the CPF radiometric reference.
- Validate S-NPP/FM5 (and, possibly, Terra/FM2) SW channel performance while operating in RAPS mode.
  - Prior experience with operating in RAPS mode with instruments on Terra and Aqua caused optical degradation to the SW channel due to telescopes pointing in the ram direction.
Independent validation of inter-instrument differences across CERES SW sensors on various spacecraft.

**Challenges with current approach:**
- Inter-comparisons between CERES instruments are obtained from co-located CERES data obtained where the orbits cross-over.
  - For Terra/Aqua, Terra/S-NPP, Terra/NOAA-20, these cross-overs occur North of 70° latitude.
- Direct inter-comparisons between CERES on S-NPP and NOAA-20 are not possible because they are positioned half an orbit apart in the same altitude and inclination.
- Comparisons can be performed with Aqua that under-flies both S-NPP and NOAA-20.

**Value to CERES**
CPF could provide an independent validation of differences being observed between instruments across various spacecraft.
- Between NOAA-20/FM6 and S-NPP/FM5.
- Could these be done directly with Terra or Aqua?