CERES and ScaRaB comparison campaigns, method, schedule for rendez-vous and results

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Outline

- CERES & ScaRaB comparisons
- The PAPS campaigns (2012, 2015, 2016)
- Schedule for rendez-vous
- Colocation method
- Comparison results
CERES & ScaRaB comparisons

Objective: To compare CERES & ScaRaB SW and LW radiances in order to
- validate the ScaRaB measurements
- confirm the CERES measurements
- analyse the possible drifts between these instruments

ScaRaB-SW error budget @ 1σ ≈ 1.6%

<table>
<thead>
<tr>
<th>Items</th>
<th>Value</th>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short wave calibration (sphere)</td>
<td>3% @2σ</td>
<td>Biais</td>
<td>1.5%</td>
</tr>
<tr>
<td>Error on spectral response</td>
<td>0.08% /°</td>
<td>Biais</td>
<td>0.4%</td>
</tr>
<tr>
<td>Thermal gain correction</td>
<td>dT= 0.04° @1σ</td>
<td>Random</td>
<td>0.03%</td>
</tr>
<tr>
<td>Thermal leak correction</td>
<td>20% of the thermal leak @1σ</td>
<td>Random</td>
<td>0.04%</td>
</tr>
<tr>
<td>Location</td>
<td>0.06° @1σ</td>
<td>Random</td>
<td>0.4%</td>
</tr>
<tr>
<td>Budget at 1 sigma</td>
<td></td>
<td></td>
<td>1.6%</td>
</tr>
</tbody>
</table>

CERES-FM2-SW error budget @ 1σ ≈ 1%

<table>
<thead>
<tr>
<th>Source</th>
<th>Incoming solar</th>
<th>Outgoing SW</th>
<th>Outgoing LW</th>
<th>Net incoming</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solar irradiance</td>
<td>±0.2</td>
<td>0</td>
<td>0</td>
<td>±0.2</td>
<td>Absolute calibration (95% confidence)</td>
</tr>
<tr>
<td>Filtered radiance</td>
<td>0</td>
<td>±2.0</td>
<td>±2.4 (N)</td>
<td>±4.2</td>
<td>Absolute calibration (95% confidence)</td>
</tr>
<tr>
<td>Unfiltered radiance</td>
<td>0</td>
<td>±0.5</td>
<td>±0.25 (N)</td>
<td>±1.0</td>
<td>Instrument spectral response function</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±0.45 (D)</td>
<td></td>
<td>Unfiltering algorithm</td>
</tr>
</tbody>
</table>

Loeb et al., 2009 [CERES-FM2 error budget @2σ]
They showed that their error budget was consistent with the climate monitoring.

+ errors due to the collocation

- Not the same instrument technologies
- independent measurements

Comparisons between ScaRaB & CERES
(instantaneous comparisons i.e. pixel by pixel).

NB: No in-situ measurements
CERES & ScaRaB comparisons

Intersections + same angular conditions

ScaRaB on MT  →  20° inclination, half-swath: 48.9° - XT mode
CERES on TERRA  →  98.2° inclination, half-swath: 55.2° - XT mode

CERES & ScaRaB crossing ; same angular conditions only near nadir.

2012.04.17 at 02:40 UTC, 100 minutes plotted
CERES & ScaRaB comparisons

CERES/TERRA & ScaRaB/MT
Represented period : 16 days
Temporal colocation : 5’

No co-angular restriction here !
CERES & ScaRaB comparisons

CERES/TERRA & ScaRaB/MT
Represented period: 16 days
Temporal colocation: 5’
Conical aperture = 5°

Angular constraint

LMT (local) 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 hours
The PAPS campaigns

It is required to have measured radiances under the same angular conditions to improve radiances matching for highly anisotropic scenes ➞ inconvenient poorer statistics in XT mode.

To optimize the frequency of co-angular observations: use the CERES others scanning modes.

CERES can change the angle of his axis scan.

PAPS mode: rotating angle is fixed for a required period ➞ Possibility to align CERES and ScaRaB swaths.

CERES in RAPS mode
(Scan angle modified over time)
The **PAPS campaigns**

Alignment of the CERES scan axis with the ScaRaB Scan axis:

**The 3 PAPS campaign**

1. **April/May 2012, 2015 & 2016**
2. Only during daytime (for SW).
3. **Crossing forecasts** (computed with IXION and NORAD data) with durations & PAPS angles sent to NASA.
4. **Advantages**: Increase the collocated pixels between the 2 instruments + all swath pixels has been collocated.

![Diagram showing alignment of scan axes](image)
The rendez-vous

CERES goes to PAPS mode when crossing ScaRaB.
The rendez-vous
Megha-Tropiques
Orbit - Ground track

Recurrence = [14; -1; 7] 97
Time span shown: 102.0 min = 0.07 day

Across track swath (XT mode)

Altitude = 865.5 km
a = 7243.677 km

Inclination = 20.00 °

Period = 101.93 min * Rev/sid.d. = 14.09

Equat. orbital shift = 2892.0 km (26.0 °)

** Half-swath: 48.9° = 1108 km (2.00 min)

Projection: Mercator
Property: Conformal

Project. center: 0.0 ° ; 0.0 °
Aspect: Direct

T.:Cylindrical - Graticule: 10°

Asc. Node: 0.00 ° [00:00 LMT]
Max. attained latit. = 30.0 °

M * LMD

Chomette et al., Earth Radiation Budget Workshop, 18-21 Oct 2016 - Reading
The rendez-vous

Megha-Tropiques
Orbit - Ground track

Recurrence = [14; -1; 7] 97
2015 03 30 16:00:00 UTC >>> 60.0 min = 0.04 day
Across track swath (XT mode)

Altitude = 865.4 km    a = 7243.570 km
Inclination = 19.98 °    e = 0.000997
Period = 101.93 min * Rev/sid.d=14.09
Equat. orbital shift = 2892.0 km (26.0 °)

** Half-swath: 48.9° => 1108 km [1.00 min]

A=61.9
Q=32
=> P=100%
The rendez-vous

Megha-Tropiques
Orbit - Ground track

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Q=32
=> P=100%
The rendez-vous

Megha-Tropiques
Orbit - Ground track

Recurrence = [14; -1; 7] 97
2015 04 17 04:00:00 UTC >>> 60.0 min = 0.04 day
Across track swath (XT mode) ** Terra: -91.0 °

Altitude = 865.4 km
Inclination = 19.98 °
Period = 101.93 min * Rev/sid.d=14.09
Equat. orbital shift = 2892.0 km (26.0 °)
** Half-swath: 48.9° => 1108 km [1.00 min]

Projection: Mercator
PC: 0.0 ° ; 0.0 ° /ZC: 15.0 ° N; 90.0 ° E
Property: Conformal
Aspect: Direct [zoom : 5.14]
⊕ T.:Cylindrical - Graticule: 10°

Asc. Node: 147.38 ° [00:01 LMT]
[NORAD] Revolution: 17477
[NORAD] 2015 03 02 14:11:37 UTC

A=91.0
Q=3
=> P=8%
The rendez-vous

2016 PAPS campaign

March 31
9-15/04 & 23-29/04
No PAPS

May 30
The PAPS campaigns

Ex:
2016 PAPS campaign

2016 PAPS campaign (100 crossings)

Q too small

Q too small
Colocation method

- Comparisons with another ERB instruments
  - Geographical colocation
  - Temporal colocation $\Rightarrow \Delta T = 5'$
  - Angular colocation (because of the anisotropy of the observed scenes). $\Rightarrow \theta_{cône} = 5^\circ$

Spatial colocation

CERES pixels (red) are projected into a ScaRaB pixel (green)

Comparisons between an CERES averaged value and the ScaRaB measurement.
Results

Unfiltered ScaRaB SW Radiances vs. Unfiltered CERES-FM2-PAPS SW Radiances with 5’, 5° & coverage of at least 80% (surface) of the ScaRaB pixel. Daytime data only.

<table>
<thead>
<tr>
<th>PAPS Years</th>
<th>N</th>
<th>SW Radiances</th>
<th>(\frac{\text{ScaRaB}-\text{CERES}}{\text{mean(CERES)}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>2453</td>
<td>2.54 ± 10.48 %</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>2232</td>
<td>2.13 ± 10.96 %</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>2168</td>
<td>1.86 ± 9.89 %</td>
<td></td>
</tr>
</tbody>
</table>
Results

To compare CERES & ScaRaB it’s better to compare homogeneous pixels between them (to be sure that bias & std are not due to the scene heterogeneity)

➤ Statistics over homogeneity index:

\[
\frac{\sigma_{CERES (in each ScaRaB pixel)}}{\text{mean}(CERES)}_{\text{in each ScaRaB pixel}}
\]

<table>
<thead>
<tr>
<th>Homogeneity Index</th>
<th>N</th>
<th>mean</th>
<th>std</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5%</td>
<td>576</td>
<td>2.09</td>
<td>2.92</td>
</tr>
<tr>
<td>5 – 10%</td>
<td>539</td>
<td>2.72</td>
<td>7.32</td>
</tr>
<tr>
<td>10 – 15%</td>
<td>395</td>
<td>1.81</td>
<td>9.12</td>
</tr>
<tr>
<td>15 – 20%</td>
<td>286</td>
<td>3.23</td>
<td>12.51</td>
</tr>
<tr>
<td>20 – 50%</td>
<td>630</td>
<td>3.29</td>
<td>16.19</td>
</tr>
<tr>
<td>50 – 100%</td>
<td>27</td>
<td>-4.54</td>
<td>15.12</td>
</tr>
<tr>
<td>TOTAL (0 – 100%)</td>
<td>2453</td>
<td>2.54</td>
<td>10.48</td>
</tr>
<tr>
<td>0 – 10%</td>
<td>1115</td>
<td>2.38</td>
<td>5.27</td>
</tr>
<tr>
<td>0 – 20%</td>
<td>1796</td>
<td>2.39</td>
<td>7.83</td>
</tr>
</tbody>
</table>

**PAPS 2016** SW Radiances – surface > 0.8 – 5 min – 5°
Results

To compare CERES & ScaRaB it’s better to compare homogeneous pixels between them (to be sure that bias & std are not due to the scene heterogeneity)

⇒ Statistics over the values of

\[ \frac{\sigma_{\text{CERES (in each ScaRaB pixel)}}}{\text{mean(CERES)}_{\text{in each ScaRaB pixel}}} \]

<table>
<thead>
<tr>
<th>SW Radiances ( \frac{\text{ScaRaB - CERES}}{\text{mean(CERES)}} )</th>
<th>surface &gt; 80%</th>
<th>5’ - 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAPS Years</td>
<td>0-5%</td>
<td>0-10%</td>
</tr>
<tr>
<td>2016</td>
<td>2.09 ± 2.92 %</td>
<td>2.38 ± 5.27 %</td>
</tr>
<tr>
<td>2015</td>
<td>2.35 ± 3.80 %</td>
<td>2.18 ± 5.76 %</td>
</tr>
<tr>
<td>2012</td>
<td>1.49 ± 3.74 %</td>
<td>1.87 ± 5.23 %</td>
</tr>
</tbody>
</table>
Results

CERES & ScaRaB are in good agreement.

- bias ≈ 2.5% in SW, with
- error budget ScaRaB≈1.6%, CERES≈1% (at 1 σ)
- + errors brought by the colocation method > 1.5%

Unfiltered SW radiances: 5’ 5° 80% \[ \frac{\sigma_{\text{CERES (in each ScaRaB pixel)}}}{\text{mean(CERES) in each ScaRaB pixel}} \] 0-10%

Comparisons in XT mode
- in black
  - 102 days each
  - 550 px on average

PAPS campaigns in red
- ≈ 60 days each
- 1000 px on average
Results

CERES & ScaRaB are in good agreement.

- bias ≈2.5% in SW, with error budget ScaRaB≈1.6%, CERES≈1% (at 1σ)
- + errors brought by the colocation method > 1.5%

Comparisons in XT mode in black
102 days each
550 px on average

PAPS campaigns in red
≈ 60 days each
1000 px on average

Unfiltered SW radiances : 5’  5°  80% \[
\frac{\sigma_{\text{CERES(in each ScaRaB pixel)}}}{\text{mean(CERES) in each ScaRaB pixel}} \quad \approx 0-10%
\]

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Thank you!

LW Radiances

(ScRaB-CERES)/CERES (in %)

**Colocation method**

**ALL PIXELS**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>N</th>
<th>SW Radiances</th>
</tr>
</thead>
<tbody>
<tr>
<td>5° - 5min</td>
<td>2168</td>
<td>1.86 ± 9.89 %</td>
</tr>
<tr>
<td>5° - 2min</td>
<td>606</td>
<td>0.95 ± 9.99 %</td>
</tr>
</tbody>
</table>

Surface > 80%

2012 PAPS campaign

Restrict the criteria (angular, temporal, « surface », scene homogeneity)

Improve the statistics

But also reduce N

ScaRaB L1A2, XT mode, MT vs.

ScaRaB L1A2, XT mode, MT

SW Radiances

(2545273 colocated pixels)

-0.02 ± 9.38 % (RMS: 9.4%)

Only 20000 pts displayed

Same colocation criteria, same algorithm ➔ No bias but large dispersion.

When comparing same instrument with overlapping pixels with himself, our method brings std.
Colocation method

- Comparisons with another ERB instruments
  
  Pixels colocation: **geographical**, **temporal** and **angular**
  (because of the anisotropy of the observed scenes).

**SW radiances**

Co-angular \((\theta_{\text{zenith}} \pm x^\circ \text{ & } \theta_{\text{azimuth}} \pm x^\circ \text{ or conical aperture with an aperture of } x^\circ)\)

Simultaneous \((\Delta T \pm x \text{ mn})\)

**LW radiances**

Same as SW without the \(\theta_{\text{azimuth}}\) constraint

\[\theta_{\text{cône}} = 5^\circ \text{ et } \Delta T = 5'\]
Colocation method

- Spatial colocation

ScaRaB (green) = master pixel; CERES (red) = slave pixel

Pixels with different sizes, shapes and weighting functions

The deformation of the pixels are taken into account

The PSF-weighted co-location estimates the contribution of each slave (red) pixel inside the master (green) one

Comparisons between an averaged value (CERES pixels into a ScaRaB pixel) and the ScaRaB measurement.

Exemple of ScaRaB PSF