CLARREO Inter-Calibration Ability in Solar: Sampling Requirement

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CLARREO/Solar instrument baseline:

- Radiance measurements (CLARREO/TSIS) with accuracy 0.3%(2\(\sigma\)) for the time of the mission, uncertainty due to sensitivity to polarization included.
- Wavelength range from 320 to 2300 nm wavelength (combined in 3 modules).
- Spectral sampling of 2 nm in VIS (800 nm), and of 4 nm in NIR (1600 nm).
- Spatial resolution 0.5\(\times\)0.5 km (75% of signal).
- Pointing ability.
- Polarization Distribution Models to provide polarization information.

**CLARREO Inter-Calibration Event:** orbits crossing of CLARREO with sensor to be calibrated that allows time/angle/space matched inter-calibration.

**CLARREO/Solar Field-Of-View:** 100x100 km area observed by CLARREO near instantaneously.

**CLARREO/Solar Inter-Calibration Sample:** area of 20 km scale (for reduction of spatial matching noise to 1%).

**CLARREO/Solar Pixel:** 1x1 km observed area (95% of signal).
# CLARREO Inter-Calibration Goal

## 1) CLARREO Inter-Calibration Goal: CERES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time scale</th>
<th>Variable</th>
<th>Accuracy, $2\sigma$ (%)</th>
<th>Sampling Requirement *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>seasonally</td>
<td>VZA</td>
<td>0.3</td>
<td>N1 samples per bin</td>
</tr>
<tr>
<td>Gain</td>
<td>monthly</td>
<td>All Data</td>
<td>0.3</td>
<td>N2 samples globally</td>
</tr>
<tr>
<td>SRF Degradation</td>
<td>seasonally</td>
<td>Scene Type</td>
<td>0.3 (eff. gain)</td>
<td>N3 samples Clear Ocean</td>
</tr>
<tr>
<td>Gain Non-Linearity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity to DOP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* At noise level $\approx 1\%$ (sources: instrument + matching)

## 2) CLARREO Inter-Calibration Goal: MODIS/VIIRS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time scale</th>
<th>Variable</th>
<th>Accuracy, $2\sigma$ (%)</th>
<th>Sampling Requirement *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>monthly</td>
<td>All Data</td>
<td>0.3</td>
<td>N4 samples globally</td>
</tr>
<tr>
<td>Baseline Gain</td>
<td>monthly</td>
<td>DOP</td>
<td>0.3</td>
<td>N5 samples per bin</td>
</tr>
<tr>
<td>Sensitivity to DOP</td>
<td>annually</td>
<td>DOP, VZA</td>
<td>0.3 (eff. gain)</td>
<td>N6 samples per bin</td>
</tr>
<tr>
<td>SRF CW Shift</td>
<td></td>
<td></td>
<td></td>
<td>Validation Annually, Accuracy $0.3%(2\sigma)$</td>
</tr>
<tr>
<td>Gain Non-Linearity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* At noise level $\approx 1\%$ (sources: instrument + matching)
CLARREO Inter-Calibration Sampling:
number of samples per year

◆ Number of CLARREO inter-calibration Events per spacecraft per year varies depending on orbit choice (Studies by P. Speth, C. Roithmayr, D. MacDonnell)

◆ Increase of matched FOV from CLARREO pointing ability varies on orbit choice (Studies by P. Speth, C. Roithmayr, D. MacDonnell)

◆ For Imager (MODIS/VIIRS): Cookie-cutting to 75% overlapping circles of 20 km in diameter from CLARREO 100 km FOV. Different boundary pixels provide independent samples of spatial noise. Increases CLARREO sampling: 
   
   \( T_d = \text{duration time} \)

   - Factor 125 for \( T_d = 1 \) s \((33 \times 100 \text{ km})\)
   - Factor 250 for \( T_d = 2 \) s \((66 \times 100 \text{ km})\)
   - Factor 400 for \( T_d \geq 3 \) s \((100 \times 100 \text{ km})\)

◆ For CERES (all FOVs, 20 km at nadir):

   - 10 CERES footprints for \( T_d = 1 \) s \((33 \times 100 \text{ km})\).
   - 20 CERES footprints for \( T_d = 2 \) s \((66 \times 100 \text{ km})\).
   - 30 CERES footprints for \( T_d \geq 3 \) s \((100 \times 100 \text{ km})\).

\[
N_{\text{match}} = N_{\text{orbit}} \times N_{\text{pointing}}(T_d) \times N_{20\text{km}}(T_d)
\]
CLARREO Inter-Calibration Sampling
with NPOESS orbit over 365 days
P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 90°:
Distribution of Inter-calibration FOVs (11,195) in lon / lat.

CLARREO Orbit at 600 km, 90°:
Duration Time of Inter-calibration FOVs (11,195).
CLARREO Inter-Calibration Sampling:

5 min time / 1° angle match with instrument on NPOESS orbit
matching noise = 1% (Wielicki et al., IGARSS 2008)

◆ 600 km altitude orbits, Annual Inter-Calibration Sampling:

<table>
<thead>
<tr>
<th>Inclination (°)</th>
<th>IC Events</th>
<th>IC FOVs (total)</th>
<th>IC FOV (Td &lt; 3 s)</th>
<th>Sampling For Imager</th>
<th>Sampling For CERES</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>496</td>
<td>10,231</td>
<td>5,200</td>
<td>2.85 M</td>
<td>225 K</td>
</tr>
<tr>
<td>83</td>
<td>533</td>
<td>13,519</td>
<td>7,000</td>
<td>3.64 M</td>
<td>280 K</td>
</tr>
<tr>
<td>90</td>
<td>463</td>
<td>11,195</td>
<td>5,750</td>
<td>3.05 M</td>
<td>230 K</td>
</tr>
</tbody>
</table>

◆ 1000 km altitude orbits, Annual Inter-Calibration Sampling:

<table>
<thead>
<tr>
<th>Inclination (°)</th>
<th>IC Events</th>
<th>IC FOVs (total)</th>
<th>IC FOV (Td &lt; 3 s)</th>
<th>Sampling For Imager</th>
<th>Sampling For CERES</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>435</td>
<td>5,311</td>
<td>1,710</td>
<td>1.75 M</td>
<td>133 K</td>
</tr>
<tr>
<td>83</td>
<td>443</td>
<td>7,614</td>
<td>2,500</td>
<td>2.43 M</td>
<td>184 K</td>
</tr>
<tr>
<td>90</td>
<td>380</td>
<td>5,980</td>
<td>1,900</td>
<td>1.93 M</td>
<td>146 K</td>
</tr>
</tbody>
</table>

◆ From inter-calibration sampling point of view, the 84° and 90° orbits at 600 km altitude have advantage over other orbit choices. But the difference between these two is not dramatic.
CLARREO Sampling:
Fractions of Scene Types

- Based on near-nadir CERES/MODIS/Aqua data (VZA < 10°, 20 km FOV).
- SZA < 75°.
- Sigmoid distribution weighted in latitude similar to CLARREO-NPOESS inter-calibration sampling (Studies by Speth, Roithmayr, MacDonnell)

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Tropic Clear (%)</th>
<th>Non-Tropic Clear (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>2.145</td>
<td>0.829</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>0.093</td>
<td>0.146</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>0.057</td>
<td>0.235</td>
</tr>
<tr>
<td>Shrubs &amp; Crops</td>
<td>1.127</td>
<td>0.784</td>
</tr>
<tr>
<td>Dark Desert</td>
<td>0.598</td>
<td>0.255</td>
</tr>
<tr>
<td>Bright Desert</td>
<td>0.926</td>
<td>0.088</td>
</tr>
<tr>
<td>Snow</td>
<td>0.039</td>
<td>5.809</td>
</tr>
</tbody>
</table>

CLEAR SKY: Cloud fraction < 0.1%.
## CLARREO Sampling:
Fraction of Water Clouds scene

<table>
<thead>
<tr>
<th>2005 CERES SSF, Fraction of WATER CLOUDS ( % ):</th>
<th>THIN</th>
<th>MED</th>
<th>THICK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCL</td>
<td>6.271</td>
<td>1.348</td>
<td>0.000</td>
</tr>
<tr>
<td>MCL</td>
<td>3.666</td>
<td>3.510</td>
<td>0.011</td>
</tr>
<tr>
<td>OVC</td>
<td>0.216</td>
<td>8.024</td>
<td>1.181</td>
</tr>
<tr>
<td><strong>Land</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCL</td>
<td>1.381</td>
<td>1.002</td>
<td>0.002</td>
</tr>
<tr>
<td>MCL</td>
<td>0.417</td>
<td>1.306</td>
<td>0.035</td>
</tr>
<tr>
<td>OVC</td>
<td>0.008</td>
<td>0.871</td>
<td>0.296</td>
</tr>
<tr>
<td><strong>Snow</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCL</td>
<td>0.533</td>
<td>0.171</td>
<td>0.001</td>
</tr>
<tr>
<td>MCD</td>
<td>0.294</td>
<td>0.623</td>
<td>0.004</td>
</tr>
<tr>
<td>OVC</td>
<td>0.043</td>
<td>2.301</td>
<td>0.135</td>
</tr>
</tbody>
</table>

**PCL:** 0.1 < Cloud Fraction < 40%
**MCD:** 40 < Cloud Fraction < 99%
**OVC:** 99 < Cloud Fraction < 100%

**THIN:** OD < 3.35
**MED:** 3.35 < OD < 22.63
**THICK:** OD > 22.63
Distribution of DOP (CLARREO matching global)

- PARASOL Level-1 data: 12 days of 2006 (1 day per month, “cross-track” sampling)
- Sigmoid distribution weighted in latitude similar to CLARREO-NPOESS inter-calibration sampling *(D. MacDonnell, P. Speth, C. Roithmayr)*
- SZA < 75°.

DOP = linear degree of polarization

<table>
<thead>
<tr>
<th>DOP Range</th>
<th>&lt; 0.05</th>
<th>&lt; 0.1</th>
<th>&lt; 0.2</th>
<th>&lt; 0.3</th>
<th>&lt; 0.4</th>
<th>&lt; 0.5</th>
<th>&lt; 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Data (%)</td>
<td>24.2</td>
<td>55.0</td>
<td>79.8</td>
<td>89.5</td>
<td>94.6</td>
<td>97.6</td>
<td>99.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOP Range</th>
<th>&lt; 0.05</th>
<th>&lt; 0.1</th>
<th>&lt; 0.2</th>
<th>&lt; 0.3</th>
<th>&lt; 0.4</th>
<th>&lt; 0.5</th>
<th>&lt; 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Data (%)</td>
<td>46.4</td>
<td>71.8</td>
<td>87.3</td>
<td>93.9</td>
<td>97.2</td>
<td>98.9</td>
<td>99.77</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOP Range</th>
<th>&lt; 0.05</th>
<th>&lt; 0.1</th>
<th>&lt; 0.2</th>
<th>&lt; 0.3</th>
<th>&lt; 0.40</th>
<th>&lt; 0.5</th>
<th>&lt; 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Data (%)</td>
<td>65.6</td>
<td>81.6</td>
<td>91.5</td>
<td>96.1</td>
<td>98.4</td>
<td>99.5</td>
<td>99.98</td>
</tr>
</tbody>
</table>

* Refer to *Lukashin et al., CLARREO Telecon 2009.04* for more detailed information on data stratification in DOP.
CLARREO/CERES Inter-Calibration

Major Points:

◆ CERES is broadband instrument, spectral range is from 0.3 to 5.0 $\mu$m in SW channel.

◆ Not sensitive to polarization by CERES design.

◆ Scan position dependent electronic offsets.

◆ Degradation of spectral response function below 0.6 $\mu$m wavelength. This optics contamination is a common issue for most solar instruments.

◆ Instrument noise (1σ) is about 0.2% for all-sky mean (0.5% for clear-sky ocean).

Imposed requirements:
Broad spectral range, adequate sampling, spatial resolution.
CERES SR Degradation Test
(SCIAMACHY data used)

Plots:

- **Top:** CERES FM1 pre-launch SR and 3 cases of degraded SR.
- **Bottom:** Amount of degradation

\[
D(\lambda) = 1 - \exp(-\alpha \lambda)
\]

- \(\alpha = 13.8155 \quad (D=0.999 \ @ \ \lambda=0.5 \ \mu m)\)
- \(\alpha = 11.5129 \quad (D=0.999 \ @ \ \lambda=0.6 \ \mu m)\)
- \(\alpha = 9.8155 \quad (D=0.999 \ @ \ \lambda=0.7 \ \mu m)\)
CERES RSR Degradation Test
(no Offset or Gain difference)
clear ocean (N = 800) and marine clouds scenes (N = 2500)

CERES RSR Degradation:
\[ \alpha = 9.8155 \, (D=0.999 \, @ \, \lambda=0.7 \, \mu m) \]

Plots:
- **Top:** Relative difference between CLARREO and CERES versus CLARREO signals.
- **Middle:** Relative difference between CLARREO and CERES versus CLARREO signals with 1% matching noise.
- **Bottom:** Relative difference between CLARREO and CERES signals with noise reduced by averaging.

OFFSET + GAIN + NOISE:

<table>
<thead>
<tr>
<th>Scene</th>
<th>OFFSET (Wm$^{-2}$sr$^{-1}$)</th>
<th>GAIN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLRO</td>
<td>-0.183 ± 0.028</td>
<td>-0.31 ± 0.18</td>
</tr>
<tr>
<td>MCLD</td>
<td>0.021 ± 0.108</td>
<td>-0.73 ± 0.10</td>
</tr>
</tbody>
</table>

* **CLRO:** Offset error (2σ) = 0.21%
* **MCLD:** Offset error (2σ) = 0.10%
CLARREO/CERES Inter-Calibration Steps

**Step 1:** Stratify all available cloudy footprints (70%) in VZA (10° bin width) and derive scan dependent offset and gain corrections. Gain should be the same for all VZA. **SEASONALLY:**
- 83° (600 km) orbit: N = 9,200 IC Samples
- 90° (600 km) orbit: N = 8,000 IC Samples

**Step 2:** Using derived offsets from Step 1, combine all cloudy data (70%) and derive gain correction. **MONTHLY:**
- 83° (600 km) orbit: N = 16,000 IC Samples
- 90° (600 km) orbit: N = 13,000 IC Samples

**Step 3a:** Generate a series of candidates for degradation of CERES SR function in orbit.

**Step 3b:** Select clear-sky ocean (3%) and medium-thick cloud scenes (20%) from CLARREO and CERES matched sampling. Noise reduction by averaging.

**Step 3c:** Use CERES offset and gain from steps 1 and 2. Select the best SRF candidate for which offset and gain difference are **zero** for both scene types. **SEASONALLY CLEAR-SKY OCEAN:**
- 83° (600 km) orbit: N = 2,100 IC Samples
- 90° (600 km) orbit: N = 1,725 IC Samples
Major Points:

- Narrowband imagers, band width varies from 10 nm to 50 nm in solar bands. Spatial resolution = 0.25 – 1.0 km.

- MODIS sensitive to DOP is 2 - 4% depending on wavelength and viewing geometry (ground). VIIRS sensitivity to DOP is 2.5 - 3.5 % (from VIIRS Team).
  Optic sensitivity to DOP sensitivity results in additional factor to effective gain (Sun and Xiong, 2007)

- MODIS optics spectral response functions on orbit are known well, CW shifts uncertainty << 1 nm (Xiong et al., 2006 & 2009)

- MODIS instrument noise depends on its band: from 0.1% for band 14 (678 nm), 2% for band 18 (936 nm).

**Imposed requirements:** adequate sampling, polarization information, spatial and spectral resolution.
**CLARREO/MODIS Calibration**

**MODIS Band 1 RSR, 620 – 670 nm**

- Reported MODIS SRF central wavelength shifts for Band 1 are within 0.3 nm for MODIS/Terra and 0.6 nm for MODIS/Aqua. Uncertainty of the CW shifts $\ll 1$ nm (*Xiong et al., 2006 and 2009*)

- Detailed study on CLARREO sensitivity to SRF CW shifts by *X. Xiong and B. Wenny* (using SCIAMACHY spectral data), mapping all MODIS bands for 4 scene types:
  - Sensitivity trend changes sign for clear ocean and desert in VIS bands.
  - Climate science bands (surface albedo, cloud properties, aerosols) do have specific signature to detect CW shifts.
CLARREO/MODIS Calibration

For any configuration of matched data stratified in DOP and VZA:

MODIS Band 1: 620 – 670 nm, Simulation of
CW Shift = 0.5 nm, Gain diff. = 1%, Offset diff. = 0.02 Wm⁻²sr⁻¹band⁻¹, Noise = 1%
Refer to definition of simulated parameter (C. Lukahin, 2009.10)

1) N inter-cal. samples = 665

| CLARREO Nadir: 665 FOV | | |
| OFFSET (Wm⁻²sr⁻¹) | GAIN (%) | |
| 0.020 ± 0.005 | 1.03 ± 0.12 | |

* Gain error $2\sigma = 0.12\%$
* Offset error $2\sigma = 0.25\%$
  (relative to mean radiance)

* Offset relative error increases as radiance decreases.

2) N inter-cal. samples = 25,435

| CLARREO Pointing: 25,435 FOV | | |
| OFFSET (Wm⁻²sr⁻¹) | GAIN (%) | |
| 0.021 ± 0.001 | 0.960 ± 0.024 (-0.03 CW Shift) |

* Noise reduction by averaging in 0.15 Wm⁻²sr⁻¹band⁻¹ bins, N > 100 FOV.
* Gain error $2\sigma = 0.024\%$
* Offset error $2\sigma = 0.05\%$
  (relative to mean radiance)
CLARREO/MODIS Inter-Calibration Steps

**Step 1:** Select matched data with low DOP applying PDMs (24% 490 nm). Derive baseline gain and offset corrections in 7 VZA bins (10°).

**MONTHLY:**
- 83° (600 km) orbit: N = 10,400 IC Samples
- 90° (600 km) orbit: N = 8,700 IC Samples

**Step 2:** Use PDMs to stratify matched data in DOP (bin width 0.05 – 0.1) and VZA (10°). Map gain corrections due to sensitivity to polarization. Critical sampling case: 0.5 < DOP < 0.6 (490 nm), fraction of matched data ≈ 1% and 7 VZA bins (10°).

**ANNUALLY:**
- 83° (600 km) orbit: N = 5,200 IC Samples
- 90° (600 km) orbit: N = 4,300 IC Samples

* Radiometric error due to variation in DOP (0.1) is small (0.025%)

**Testing the narrowband CW shifts (validation priority):**

**Step 1:** Select data with scenes types which should be sensitive to CW shifts depending on band *(study by X. Xiong and B. Wenny)*
- Noise reduction by averaging.

**Step 2:** Perform SRF CW shift tests until offset and gain differences with CLARREO are *zero* for both scene types.
**Conclusion:** Single CLARREO/Solar instrument with pointing ability provides adequate inter-calibration sampling for instruments in NPOESS orbit to achieve CLARREO accuracy goal.

**Note:** Conclusion is reached for CLARREO/Solar instrument baseline configuration and space/angle/time matching noise limited to 1% (100 km, 5 min time, 1° angle).

**Critical Requirement:** at least 2 K of CLARREO matched samples for every inter-calibration configuration.

**Critical Requirement:** CLARREO/Solar pointing ability to inter-calibrate imager sensitivity to polarization (VZA).

**Non-critical Requirement:** 83° and 90° inclination orbits have inter-calibration sampling advantages over other orbit choices. The difference between these two is not critical.
Backup Slides
CLARREO Inter-Calibration Sampling with NPOESS orbit over 365 days

P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 90°:
Distribution of Inter-calibration Events (463) in Ion / lat.

CLARREO Orbit at 600 km, 90°:
Distribution of Inter-calibration Events (463) in time and latitude.
CLARREO Inter-Calibration Sampling
with NPOESS orbit over 365 days
P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 90°:
Distribution of Inter-calibration FOVs (11,195) in lon / lat.

CLARREO Orbit at 600 km, 90°:
Duration of Inter-calibration FOVs (11,195).
CLARREO Inter-Calibration Sampling
with NPOESS orbit over 365 days
P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 82°:
Distribution of Inter-calibration Events (533) in lon / lat.

CLARREO Orbit at 600 km, 82°:
Distribution of Inter-calibration Events (533) in time and latitude.
CLARREO Inter-Calibration Sampling with NPOESS orbit over 365 days

P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 82°:
Distribution of Inter-calibration FOVs (13,519) in lon / lat.

CLARREO Orbit at 600 km, 82°:
Duration of Inter-calibration FOVs (13,519).
CLARREO Inter-Calibration Sampling
with NPOESS orbit over 365 days
P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 74°: Distribution of Inter-calibration Events (496) in lon / lat.

CLARREO Orbit at 600 km, 74°: Distribution of Inter-calibration Events (496) in time and latitude.
CLARREO Inter-Calibration Sampling
with NPOESS orbit over 365 days
P. Speth, C. Roithmayr, D. MacDonnell

CLARREO Orbit at 600 km, 74°:
Distribution of Inter-calibration FOVs (10,231) in lon / lat.

CLARREO Orbit at 600 km, 74°:
Duration of Inter-calibration FOVs (10,231).