CLARREO: Reference Inter-Calibration on Orbit with Reflected Solar Spectrometer

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Presentation outline

- CLARREO RSS Inter-calibration approach, mission requirements, and *on-orbit matched-data sampling*.

- CLARREO RSS inter-calibration *approach to sensor’s sensitivity to polarization*, estimates for resulting radiometric uncertainty.
CLARREO Reflected Solar Spectrometer (RSS)
Science Implementation Strategy

1) CLARREO will create benchmark climate data records using two complementary approaches:

(a) Direct benchmark observations by CLARREO RSS: spectral fingerprinting techniques.
(b) Enabling Climate Benchmark using CLARREO for reference inter-calibration of existing operational sensors.

2) CLARREO Reference Inter-calibration (RI) will be used to determine and correct operational sensors for:
   - Effective sensor offset and gain.
   - Spectral response function change on orbit.
   - Sensitivity to Polarization.
   - Non-linearity.

3) CLARREO RSS RI goal: uncertainty contribution $\leq 0.15\%$ (k=1) over autocorrelation time period $\leq 0.8$ year (*Wielicki et al., BAMS 2013*)
CLARREO RSS Mission Requirements

(1) CLARREO RS accuracy 0.15% (k=1) for measuring reflected radiation.

B. Wielicki et al. (BAMS, 2013)

(2) High Priority RI Targets:

- Sensors: CERES & VIIRS/JPSS, AVHRR/Metop, Landsats, ESA Sentinels (optical), GEO imagers (all)
- Surface: Dome C, Desert sites.
- Space: Lunar spectral reflectance

(3) Uncertainty contribution from RI method: $\leq 0.15\%$ (k=1) over climate autocorrelation time period 0.8 year.

RI error is considered to be random (data matching noise).
CLARREO RSS Reference Inter-calibration Objectives

RI Method: Sensor measurements compared to high accuracy reference on orbit (CLARREO RSS observations). The method is statistical, approach is different from sensor to sensor depending on its calibration model.

Requirement: On-orbit matched data sampling is required to reduce random noise from data matching by averaging. Data matching in Time & Viewing geometry in orbit.

Note: Requirements are set for limiting instantaneous data matching noise to 1% (k=1).

1) CLARREO RSS Inter-Calibration Objectives: Broadband Radiometers (CERES)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time scale</th>
<th>Variable</th>
<th>RI Error, k=1 (%)</th>
<th>N Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Offset</td>
<td>monthly</td>
<td>Scan angle</td>
<td>≤ 0.45</td>
<td>2.5 \times 10^3</td>
</tr>
<tr>
<td>Effective Gain</td>
<td>monthly</td>
<td>Scan angle</td>
<td>≤ 0.45</td>
<td>2.5 \times 10^3</td>
</tr>
<tr>
<td>RSR Degradation</td>
<td>seasonally</td>
<td>Scene Type</td>
<td>≤ 0.25</td>
<td>30 \times 10^3</td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>Validation Annually</td>
<td></td>
<td>Validation Annually, RI Error 0.15% (k=1)</td>
<td></td>
</tr>
<tr>
<td>Sensitivity to Polarization</td>
<td>Not Sensitive, Validation Annually</td>
<td>RI Error 0.15% (k=1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) CLARREO RSS Inter-Calibration Objectives: Imaging Radiometers (VIIRS)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time scale</th>
<th>Variable</th>
<th>RI Error, k=1 (%)</th>
<th>N Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Offset</td>
<td>monthly</td>
<td>Scan angle, DOP, HAM</td>
<td>≤ 0.45</td>
<td>7 \times 10^3</td>
</tr>
<tr>
<td>Effective Gain</td>
<td>monthly</td>
<td>Scan angle, DOP, HAM</td>
<td>≤ 0.45</td>
<td>7 \times 10^3</td>
</tr>
<tr>
<td>Sensitivity to Polarization</td>
<td>seasonally</td>
<td>Scan Angle(7), DOP, χ (9), HAM</td>
<td>≤ 0.25</td>
<td>1.2 \times 10^6</td>
</tr>
<tr>
<td>RSR Center Wavelength Shift</td>
<td>Validation Annually</td>
<td></td>
<td>Validation Annually, RI Error 0.15% (k=1)</td>
<td></td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>Validation Annually</td>
<td></td>
<td>Validation Annually, RI Error 0.15% (k=1)</td>
<td></td>
</tr>
</tbody>
</table>
CLARREO RSS Requirement - 2D Pointing Ability

Studies by CLARREO Engineering Team, K. Thome, and C. Lukashin

Requirement:
Ability to provide RI coincident data, matched in both RAZ and VZA angles.

Requirement implies at least 2D pointing ability in orbit.

Yaw & Roll pointing: roll +/- 55°, and yaw +/- 84° range.

Comments:

- Yaw & Roll pointing option is preferred from RI point of view: RAZ is matched accurately, matching with GEO imagers is more effective.

- Hyperspectral image has directional definition of swath: RAZ (or Yaw).
CLARREO RSS On-Orbit Pointing Operations

CLARREO RSS 2D pointing option:

1) Yaw (azimuth angle) match = constant (matching within 0.4°).
2) Continuous Gimbal Roll (scan angle) match \( \rightarrow \) a function of time.

Note: yaw could also be varied continuously
CLARREO RSS in Polar 90° Orbit – Orbital Modeling

Inter-calibration with sensors on the JPSS

Goal:
- Time/space/angle matching to obtain ensemble of samples with data matching noise ≤ 1%

_Wielicki et al., IGARSS 2008_

Matching requirements:
- Within +/- 5 min of the JPSS passing.
- VZA match within 1.4° (CLARREO RSS 100 km swath).
- SZA < 75°.
- At least 10 km effective width of CLARREO swath.

Figure: CLARREO RSS boresight locations, which matched JPSS cross-track data over one year time period.
Sampling Estimates and Restrictions

◆ Sampling for VIIRS/AVHRR is nadir equivalent 10×10 km area in angular space, 1° CLARREO elevation angle. To estimate number of samples with independent spatial noise 1 km shift (0.1° in elevation angle) is required from one sample to the next in both spatial directions (along and perpendicular to the ground track). With CLARREO spatial resolution of 0.5×0.5 km the 1 km shift ensures that only 2 boundary pixels are common.

- This approach to CLARREO/VIIRS RI sampling does not allow the inter-calibration on detector-by-detector basis. Relative calibration of VIIRS detectors to each other requires the use of VIIRS data alone, and would be performed using common histogram equalization, or overlapping field-of-view methods.

◆ For CERES sampling is estimated taking into account CERES FOV size of 25 km at nadir (from JPSS orbit, 2.5° in CLARREO elevation angle), and data acquisition rate 330/180 = 1.8 footprints per degree of scan angle every 3.3 seconds.

General Restrictions:

- SZA < 75°;
- CLARREO RSS effective swath > 10 km (VIIRS), and > 25 km (CERES).
- VZA difference < 1.4°.
CLARREO RSS / Target Sensor - RI Sampling

Summary: Monthly (top) and seasonal (bottom) RI sampling (RAAN = 0°)

VIIRS

CERES

Red Lines: Required number of samples for RI monthly error contribution 0.45% (k=1)

Red Lines: Required number of samples for RI seasonal error contribution 0.25% (k=1)
Summary: Daily (left) and monthly (right) RI sampling (CLARREO orbit RAAN = 0°)

GEO: GOES-East (longitude = 75° W)

Note on time matching: future GEO imagers will have shorter duty cycle (about 10 min).
CLARREO RSS on ISS / Target Sensor - RI Sampling

Summary: Monthly and seasonal RI sampling (CLARREO on ISS)

CLARREO RSS boresight locations matching JPSS cross-track data over one year time period.

Note: This is concept from GSFC and LaRC teams (2012). No obscuration from ISS.
Summary on CLARREO RSS Inter-Calibration Sampling

(1) CLARREO RSS instrument radiometric accuracy at 0.15% (k=1).

(2) CLARREO RSS 2-D data matching on-orbit (azimuth and elevation): constant in azimuth and varying in elevation within matching tent.

(3) All reference inter-calibration goals are feasible from sampling point of view CLARREO RSS instrument in polar 90° inclination orbit or the ISS orbit provides adequate sampling monthly, seasonally and annually for inter-calibration of sensors on the JPSS, MetOP, and in GEO satellites.

References:


CLARREO RSS Approach to Account for Imager Sensitivity to Polarization on Orbit

(a) Polarization factors for Aqua Band 8.  
(b) Detector-averaged polarization factors for Aqua.


Objective: Take into account MODIS/Terra/Aqua & VIIRS/JPSS sensitivity to polarization in orbit by providing Polarization information on as function of viewing geometry and scene type.

Impact: Accuracy of Level-1B data (intercal), Ocean Color and Level-2 Aerosol data products.
Imager Calibration Model (MODIS as an example)

MODIS calibration model, reflectance factor *(Xiong et al., 2003, 2006)*

\[ \rho_{EV} \cos (\theta_{EV}) = m_1 d_{n_{EV}} d_{E_S}^2 (1 + k_{inst} \Delta T) / RVS_{EV} \]

\( \theta_{EV} \) - solar zenith angle
\( m_1 \) - factor from solar calibration (Solar Diffuser and its Monitor)
\( d_{n_{EV}} \) - detector response to earth radiance
\( d_{E_S} \) - sun-to-earth distance
\( k_{inst} \) - temperature correction coefficient
\( \Delta T \) - temperature difference from reference value
\( RVS_{EV} \) - Response Versus Scan angle (gain dependence)

Simplified RI Imager calibration model with polarization factor in:

\[ \rho_{sensor} = \frac{\rho_0}{(1 + mP)} \]

*Consistent with Sun and Xiong 2007.*

\( m \) - sensitivity to polarization, it is function of \( \theta \) and \( \chi \)
\( \rho_0 = \rho_{EV} \) (not-polarized reflectance)
Degree of linear polarization ($P$ or DOP):

$$P = \frac{L_p}{L} = \frac{\sqrt{Q^2 + U^2}}{L} = \frac{\rho_p}{\rho}.$$  

Polarization angle, defined relative to viewing plane (PARASOL definition, range from $-45^\circ$ to $135^\circ$):

$$\chi = \begin{cases} 
\tan^{-1} \left( \frac{U}{Q} \right) / 2 & \text{if } Q > 0, \\
\tan^{-1} \left( \frac{U}{Q} \right) / 2 + \pi / 2 & \text{if } Q < 0. 
\end{cases}$$

**Note:** The $\chi$ should be $90^\circ$ for scattering in principle plane.
Polarization Data from PARASOL (2006.04.01)

PARASOL data:
Simulated cross-track sampling, $1^\circ \times 1^\circ$ lon/lat grid,
670 nm wavelength.

DOP is color scale.

Cumulative sampling for PARASOL Polarization bands
Examples of Empirical PDMs (12 days of PARASOL data)

$40^\circ < \text{SZA} < 50^\circ$, 670 nm wavelength.

**DOP:**

**Polarization angle:**

a) Clear-sky ocean: $\text{WS} < 2.5 \text{ m/s}$

b) Overcast water clouds over ocean: $5 < \text{OD} < 10$

c) Overcast ice clouds over ocean: $5 < \text{OD} < 10$

**Note:** DOP patterns are strongly dependant on scene type, but the Polarization angle is very similar.
Examples of Theoretical PDMs (clear-sky ocean)

Calculations by Wenbo Sun

The total reflectance and DOP at the principal plane calculated with the ADRTM at a wavelength of 670 nm. Pristine clear atmosphere with the mid-latitude summer atmospheric profile is assumed. The solar zenith angle is 33.3°. Wind direction is at 0°. Wind speeds are 5.0 m/s, 7.5 m/s, 10.0 m/s, and 15.0 m/s, respectively.
CLARREO/Imager Inter-Calibration: Resulting Radiometric Uncertainty

For fixed $\theta$ and $\chi$ values, assuming no correlation, reflectance variance:

$$(\sigma_{\text{sensor}})^2 = (1 + mP)^2 \sigma_0^2 + (m\rho_0)^2 \sigma_p^2 + (P\rho_0)^2 \sigma_m^2$$

Then, relative radiometric uncertainty:

$$\frac{\sigma_{\text{sensor}}}{\rho_{\text{sensor}}} = \sqrt\left(\frac{\sigma_0}{\rho_0}\right)^2 + \frac{P^2\sigma_m^2 + m^2\sigma_p^2}{(1 + mP)^2}$$

First term is uncertainty for non polarized reflectance. Second term is from polarization effects.

$$\frac{\sigma_0}{\rho_0} = \sqrt\left(\frac{\sigma_{\text{clarreo}}}{\rho_0}\right)^2 + \left(\frac{\sigma_{\text{intercal}}}{\rho_0}\right)^2 + \left(\frac{\sigma_{\text{sensor}}}{\rho_0}\right)^2$$

The first term is combined accuracy of CLARREO, RI random error, and remaining Imager uncertainty (e.g. month-to-month stability).
Numerical Estimates of Inter-Calibrated Imager Uncertainty:

Single measurement of $m$ on orbit

Inputs for calculation:

\[ m = 3\% \ (k=1) \]
\[ \sigma_{pdm} = 5\%, \ 10\%, \ 15\% \ (k=1) \leftrightarrow \text{Uncertainty in Polarization} \]
\[ \sigma_{g0} = 0.10\% \ (k=1) \]
\[ \sigma_{gp} = 0.15\% \ (k=1) \]
\[ \sigma_{clarreo} = 0.15\% \ (k=1) \]
\[ \sigma_{residue} = 0.10\% \ (k=1) \]
Summary on CLARREO RSS Polarization Approach

(1) CLARREO RSS instrument radiometric accuracy at 0.15\% (k=1).

(2) CLARREO RSS 2-D data matching on-orbit (azimuth and elevation): constant in azimuth and varying in elevation within matching tent.

(3) Polarization Distribution Models are required for inter-calibrating sensor’s sensitivity to polarization, and further its stand-alone operation. A global all-sky set of models should be built for DOP and polarization angle $\chi$.

References:

