Reference Inter-calibration Ability of CLARREO Reflected Solar Spectrometer and JPSS Sensors

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1. CLARREO RSS as Calibration Reference

CLARREO Reflected Solar Spectrometer (RSS) Accuracy Goal:
0.18% (k=1) over reflected solar broadband.

CLARREO RSS Reference inter-calibration (RI) uncertainty goal:
0.15% (k=1) error contribution over autocorrelation time period of 18 months *(Leroy, 2006)*. Random error, from data matching noise.

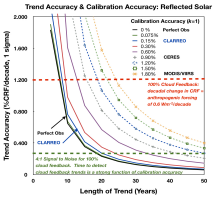
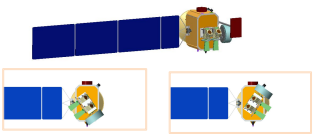


Figure 1. Climate Trend accuracy and calibration accuracy.

2. CLARREO RSS Pointing Ability

CLARREO RSS Pointing Ability will provide RI coincident data matched in RAZ and VZA (scan) angles.

Angular matching:
- Yaw S/C maneuver allows to match azimuth angle.
- Gimbal "Roll" allows to match scan/VZA angle



OFF Nadir, Scan = -55° OFF Nadir, Scan = +55°

Figure 2. CLARREO RSS Pointing ability.

3. CLARREO RSS Spectral Range & Sampling

Spectral range: CLARREO RSS will make observations with required accuracy from 320 nm to 2300 nm wavelength to allow reference inter-calibration of CERES SW broadband measurements.

Spectral Sampling: CLARREO RSS will have 4 nm wavelength spectral sampling to be able to resolve 8 nm bandwidth for imaging radiometer.

4. CLARREO RSS Spatial Coverage - Swath

CLARREO RSS Swath: 100 km (at nadir) to provide sufficient inter-calibration sampling.

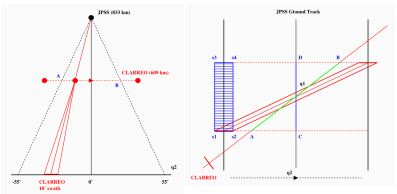


Figure 3. Diagrams of CLARREO/JPSS Inter-calibration Event

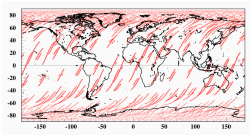


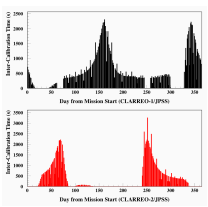
Figure 4. Simulation of inter-calibration opportunities with JPSS for one year of CLARREO in 90° polar orbit with RAAN = 0°.

Goal: Time/space/angle matching to obtain ensemble of samples with data matching noise ≤ 1% *(Wielicki et al., IGARSS 2008)*

Matching requirements:
- Within 5 minutes within JPSS passing
- Viewing Zenith Angle match within 1.4°, RAZ within 0.5°, and SZA < 75°
- At least 10 km effective width of CLARREO swath, q1 < 84°

5. CLARREO RSS Preferred Orbit

CLARREO RSS Preferred Orbit:
90° Polar orbit, 609 km altitude, RAAN = 0° or 180° (+/- 10°)



CLARREO RS Mission START 1: Autumn Equinox, P90 orbit, RAAN = 0- (orbital plane parallel to Earth-Sun direction)

CLARREO RS Mission START 2: Autumn Equinox, P90 orbit, RAAN = 90- (orbital plane perpendicular to Earth-Sun direction).

Figure 5. Inter-Calibration Time per Day: CLARREO RSS is matched to JPSS in 833 km sun synch orbit at 1:30 PM.

6. CLARREO RSS RI Sampling

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

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

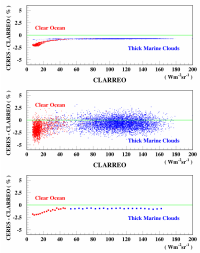
Parameter	Time scale	Variable	RI Error, k=1 (%)
Effective Offset	monthly	All Data	≤ 1.2
Effective Gain	monthly	All Data	≤ 1.2
SRF Degradation	seasonally	Scene Type (clro)	≤ 0.7
Non-Linearity	Validation Annually, RI Error 0.3%(k=2)		
Sensitivity to Polarization	Not Sensitive, Validation Annually, RI Error 0.3%(k=2)		

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

Parameter	Time scale	Variable	RI Error, k=1 (%)
Effective Offset	monthly	VZA(7), DOP, HAM	≤ 1.2
Effective Gain	monthly	VZA(7), DOP, HAM	≤ 1.2
Sensitivity to Polarization	seasonally	VZA(7), DOP, χ (9), HAM	≤ 0.7
SRF CW Shift	Validation Annually, RI Error 0.3 %(k=2)		
Non-Linearity	Validation Annually, RI Error 0.3%(k=2)		

Example: CERES SRF Degradation Test

Clear ocean (N = 1800) and marine clouds scenes (N = 7000)



CERES RSR Degradation:
α = 9.5155 (D=0.999 @ λ=0.7 μm)

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

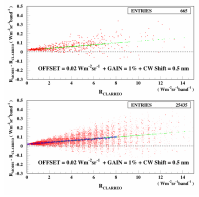
FIT RESULTS:		
Scene	OFFSET (Wm⁻²sr⁻¹)	GAIN (%)
CLRO	-0.183 ± 0.028	-0.31 ± 0.18
MCLD	0.021 ± 0.108	-0.73 ± 0.10

* **CLRO:** Offset error (k=2) = 0.21%
* **MCLD:** Offset error (k=2) = 0.10%

Figure 6. CERES SRF degradation test (simulation using SCIMACHY data)

Example: MODIS Band 1: 620 – 670 nm

0.5 nm CW Shift, Gain 1% , Offset 0.02 Wm⁻²sr⁻¹band⁻¹ 1% Noise, nadir-only and pointing samples



CLARREO Nadir = 665 FOV	
OFFSET (Wm⁻²sr⁻¹)	GAIN (%)
0.0198 ± 0.0051	1.03 ± 0.12

* Formula PAR: 8 00% CL. (k=2)
* Noise reduction by averaging in 0.10 Wm⁻²sr⁻¹band⁻¹ bins, N >100 FOV.

CLARREO Pointing = 25,435 FOV	
OFFSET (Wm⁻²sr⁻¹)	GAIN (%)
0.021 ± 0.001	0.960 ± 0.024

Figure 7. Difference between MODIS band 1 and CLARREO signals plotted versus CLARREO signal for CW shift of 0.5, gain 1%, offset 0.02 $Wm^{-2}sr^{-1}$ difference and matching noise of 1%. TOP: CLARREO nadir-only sampling, BOTTOM: CLARREO pointing sampling. Numbers in corresponding tables show the offset and gain from linear fit.

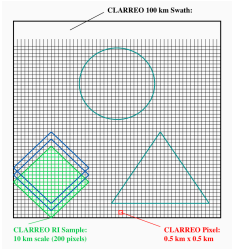
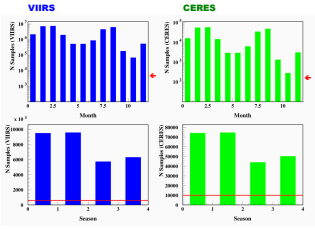


Figure 8. Reference Inter-calibration sampling method.

Sampling Summary for CLARREO RSS/JPSS

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



Red Arrows: Required number of samples for RI monthly error contribution 1.2% (k=2)

Red Lines: Required number of samples for RI seasonal error contribution 0.7% (k=2)

Figure 9. Summary of RI sampling estimates for CERES and VIIRS on JPSS. CLARREO Sampling monthly and seasonal requirements are shown with red arrows and lines, respectively.

7. Numeric Uncertainty Estimates

Imager calibration model:
(for every scan and polarization angle)

$$\rho^{sensor} = (1 + mP)\,\rho_0$$

Degree of linear polarization:

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

Polarization angle:
(relative to view plane)

$$\chi = \begin{cases} tan^{-1}(U/Q)/2 \\ tan^{-1}(U/Q)/2 + \pi/2 \end{cases} \quad \text{if } Q < 0.$$

Inter-Calibration Constraints:

$$\begin{cases} \rho^{clarreo} = \rho_0 & \text{if } P = 0. \\ \rho^{clarreo} = (1 + mP)\,\rho_0 & \text{if } P > 0. \end{cases}$$

Linear Regressions:

$$\begin{cases} \rho_0 - \rho^{clarreo} = A_0 + G_0\rho^{clarreo} & \text{if } P = 0. \\ \rho^{sensor} - \rho^{clarreo} = A_p + G_p\rho^{clarreo} & \text{if } P > 0. \end{cases}$$

Inter-Calibration of sensitivity to polarization:

$$G_p - G_0 = mP \;\rightarrow\; m = \frac{(G_p - G_0)}{P} = \frac{\Delta G}{P}$$

$$\frac{\sigma_m}{m} = \sqrt{\left(\frac{\sigma_{\Delta g}}{\Delta G}\right)^2 + \left(\frac{\sigma_p}{P}\right)^2} \qquad \frac{\sigma_{\Delta g}}{\Delta G} = \frac{\sqrt{\sigma_{g_0}^2 + \sigma_{g_p}^2}}{\Delta G}$$

RI Imager Radiometric Uncertainty:

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

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

	Purpose	m	σ_{gain}	σ_{g0}	σ_{gp}	$\sigma^{clarreo}$	σ^{sensor}
1	RS RI Goal	3	5	0.05	0.10	0.15	0.10
2	PRM Error (σ_{prm})	3	5, 10, 15	0.10	0.15	0.15	0.10
3	Sampling Error (σ_{ref})	3	5	0.05, 0.1, 0.15	0.15	0.15	0.10
4	Sensitivity to P	3, 5, 10	5	0.10	0.15	0.15	0.10

Table 1. Numerical computations of resulting RI Imager uncertainty

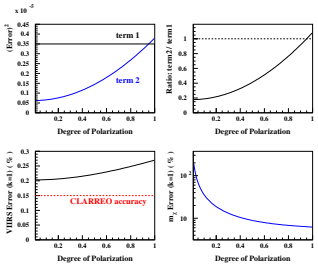


Figure 10. Calculation 1: CLARREO goal – excellent sampling, sensitivity to polarization measured independently 2 times.

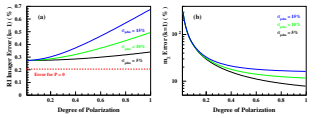


Figure 11. Calculation 2: CLARREO nominal sampling, variable uncertainty of polarization knowledge.

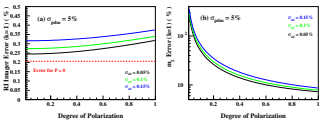


Figure 12. Calculation 3: Variable Inter-Calibration sampling

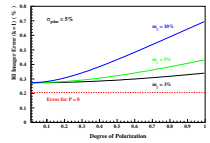


Figure 13. Calculation 4: Variable sensitivity of polarization of target Imager.

8. Summary

- With required accuracy of 0.15%(k=1) and 2-D pointing ability CLARREO RSS will be able to perform reference inter-calibration of CERES and VIIRS sensors on JPSS with expected average accuracy of 0.3%(k=1).
- The parameters of inter-calibration constraint:
  - Effective offset
  - Effective gain
  - Non-linearity of instruments response
  - Month-to-month sensor stability
  - Sensitivity to polarization (VIIRS)
  - Degradation of Spectral Response (CERES)