CLARREO Inter-Calibration Ability in Solar: Sampling Requirement

Constantine Lukashin
SSAI, Hampton, VA

Bruce Wielicki
LaRC NASA, Hampton, VA

Paul Speth
LaRC NASA, Hampton, VA

David MacDonnell
LaRC NASA, Hampton, VA

Carlos Roithmayr
LaRC NASA, Hampton, VA

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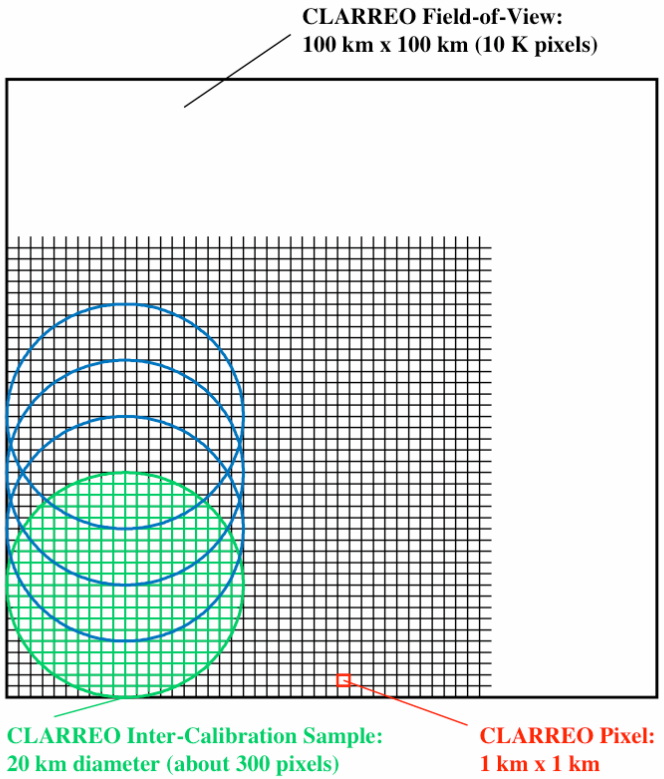
CLARREO/Solar instrument baseline:

- **Radiance measurements (CLARREO/TSIS) with accuracy 0.3%(2σ) 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 0.5×0.5 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

Parameter	Time scale	Variable	Accuracy, 2σ (%)	Sampling Requirement *
Offset	seasonally	VZA	0.3	N1 samples per bin
Gain	monthly	All Data	0.3	N2 samples globally
SRF Degradation	seasonally	Scene Type	0.3 (eff. gain)	N3 samples Clear Ocean
Gain Non-Linearity	Validation Annually, Accuracy 0.3%(2σ)			
Sensitivity to DOP	Not Sensitive, Validation Annually, Accuracy 0.3%(2σ)			

2) CLARREO Inter-Calibration Goal: MODIS/VIIRS

Parameter	Time scale	Variable	Accuracy, 2σ (%)	Sampling Requirement *
Offset	monthly	All Data	0.3	N4 samples globally
Baseline Gain	monthly	DOP	0.3	N5 samples per bin
Sensitivity to DOP	annually	DOP, VZA	0.3 (eff. gain)	N6 samples per bin
SRF CW Shift	Validation Annually, Accuracy 0.3%(2σ)			
Gain Non-Linearity	Not Sensitive, Validation Annually, Accuracy 0.3%(2σ)			

* At noise level ≈ 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)***

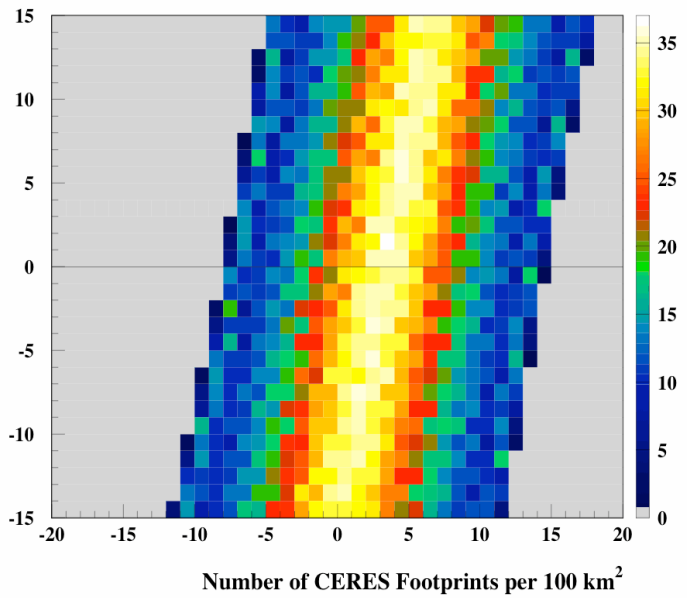
- **For Imager (MODIS/VIIRS): Cookie-cutting to 75% overlapping circles of 20 km in diameter from CLARREO 100 km FOV. Different boundary pixels provide independent samples of spatial noise. Increases CLARREO sampling: (T_d = duration time)**

  - **Factor 125 for T_d = 1 s (33 × 100 km)**
  - **Factor 250 for T_d = 2 s (66 × 100 km)**
  - **Factor 400 for $T_d \geq 3$ s (100 × 100 km)**

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

  - **10 CERES footprints for T_d = 1 s (33 × 100 km).**
  - **20 CERES footprints for T_d = 2 s (66 × 100 km).**
  - **30 CERES footprints for $T_d \geq 3$ s (100 × 100 km).**

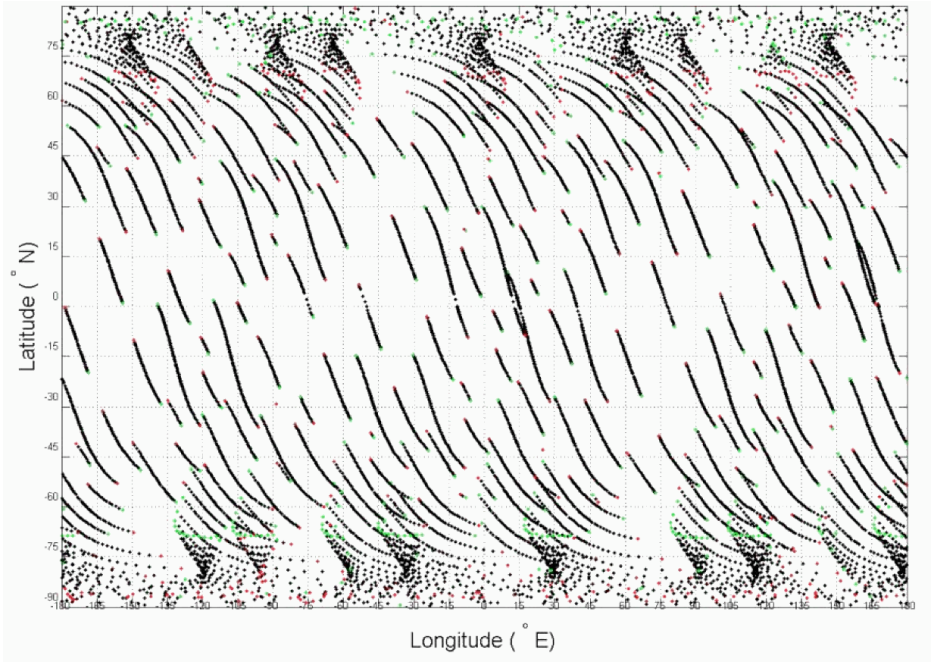
$$N_{match} = N_{orbit} \times N_{pointing}(T_d) \times N_{20km}(T_d)$$



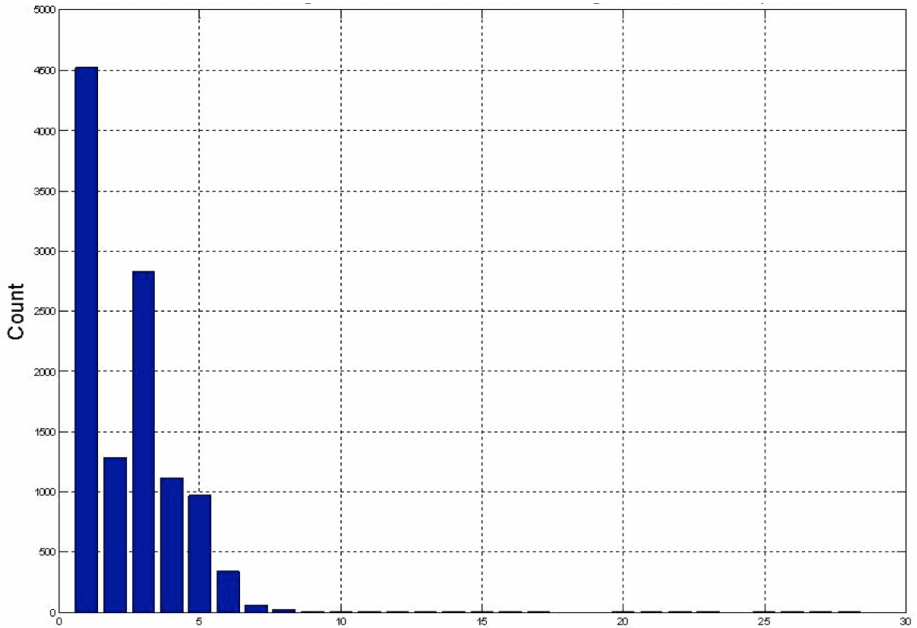
CLARREO Inter-Calibration Sampling

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:**

Inclination (°)	IC Events	IC FOVs (total)	IC FOV (Td < 3 s)	Sampling For Imager	Sampling For CERES
74	496	10,231	5,200	2.85 M	225 K
83	533	13,519	7,000	3.64 M	280 K
90	463	11,195	5,750	3.05 M	230 K

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

Inclination (°)	IC Events	IC FOVs (total)	IC FOV (Td < 3 s)	Sampling For Imager	Sampling For CERES
74	435	5,311	1,710	1.75 M	133 K
83	443	7,614	2,500	2.43 M	184 K
90	380	5,980	1,900	1.93 M	146 K

- **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)*

2005 CERES SSF, Fraction of Clear - Sky:		
Surface Type	**Tropic Clear (%)**	**Non-Tropic Clear (%)**
Ocean	2.145	0.829
Evergreen Forest	0.093	0.146
Deciduous Forest	0.057	0.235
Shrubs & Crops	1.127	0.784
Dark Desert	0.598	0.255
Bright Desert	0.926	0.088
Snow	0.039	5.809

CLEAR SKY: Cloud fraction < 0.1%.

CLARREO Sampling:

Fraction of Water Clouds scene

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

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 < 75º.

DOP = linear degree of polarization

Relative fraction of data (%) with DOP(490 nm) < X (fractional):							
DOP Range	< 0.05	< 0.1	< 0.2	< 0.3	< 0.4	< 0.5	< 0.75
Global Data (%)	24.2	55.0	79.8	89.5	94.6	97.6	99.98

Relative fraction of data (%) with DOP(670 nm) < X (fractional):							
DOP Range	< 0.05	< 0.1	< 0.2	< 0.3	< 0.4	< 0.5	< 0.75
Global Data (%)	46.4	71.8	87.3	93.9	97.2	98.9	99.77

Relative fraction of data (%) with DOP(865 nm) < X (fractional):							
DOP Range	< 0.05	< 0.1	< 0.2	< 0.3	< 0.40	< 0.5	< 0.75
Global Data (%)	65.6	81.6	91.5	96.1	98.4	99.5	99.98

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

CLARREO/CERES Inter-Calibration

Major Points:

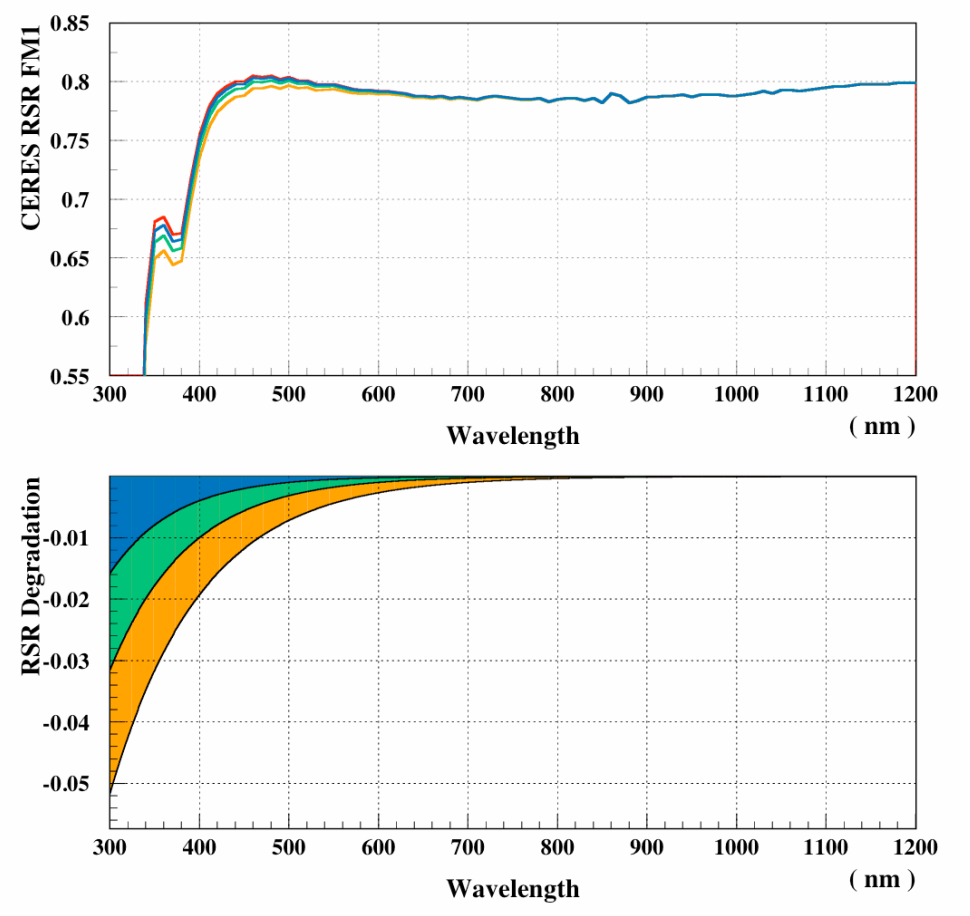
- **CERES is broadband instrument, spectral range is from 0.3 to 5.0 μm in SW channel.**
- **Not sensitive to polarization by CERES design.**
- **Scan position dependent electronic offsets.**
- **Degradation of spectral response function below 0.6 μm wavelength. This optics contamination is a common 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

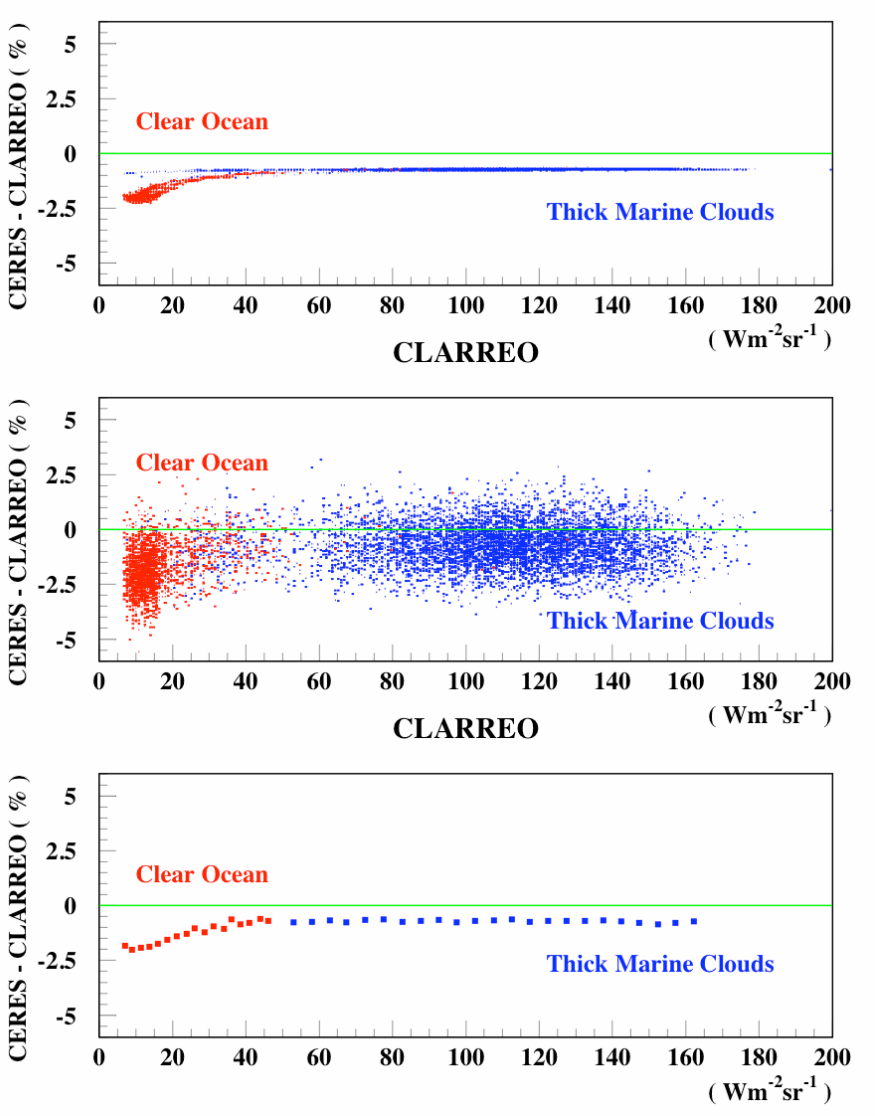
$$D(\lambda) = 1 - \exp(-\alpha\lambda)$$

α = 13.8155 (D=0.999 @ λ=0.5 μm)
α = 11.5129 (D=0.999 @ λ=0.6 μm)
α = 9.8155 (D=0.999 @ λ=0.7 μm)

CERES RSR Degradation Test

(no Offset or Gain difference)

clear ocean (N = 800) and marine clouds scenes (N = 2500)



CERES RSR Degradation:
α = 9.8155 (D=0.999 @ λ=0.7 μm)

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 :		
Scene	OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
CLRO	-0.183 ± 0.028	-0.31 ± 0.18
MCLD	0.021 ± 0.108	-0.73 ± 0.10

* **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

CLARREO/MODIS Inter-Calibration

VIIRS on NPP and NPOESS will be similar

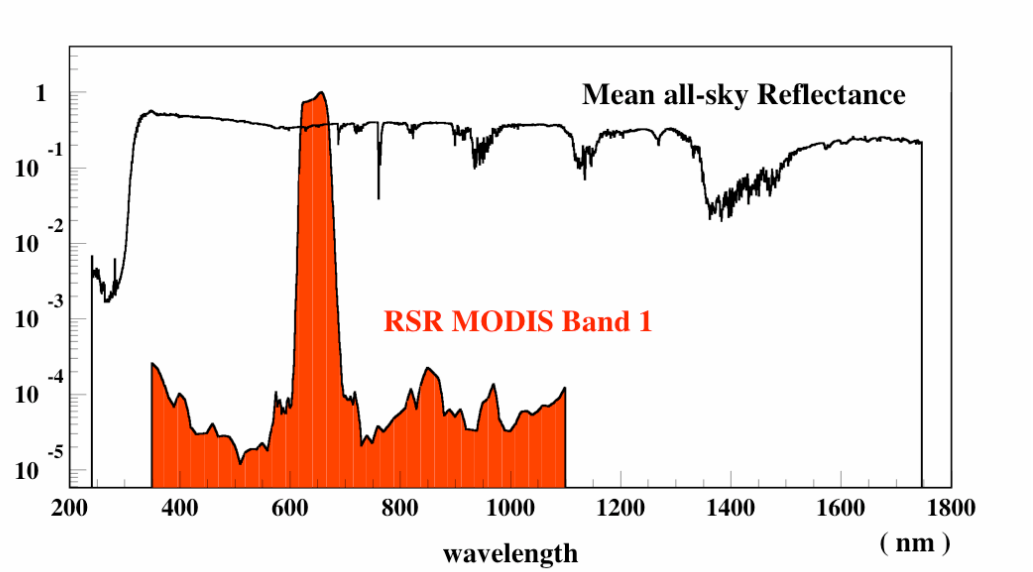
Major Points:

- **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 << 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 $Wm^{-2}sr^{-1}band^{-1}$, Noise = 1%
Refer to definition of simulated parameter *(C. Lukahin, 2009.10)*

1) N inter-cal. samples = 665

CLARREO Nadir: 665 FOV	
OFFSET ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.020 ± 0.005	1.03 ± 0.12

* Gain error 2σ = 0.12%
* Offset error 2σ = 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 ($Wm^{-2}sr^{-1}$)	GAIN (%)
0.021 ± 0.001	0.960 ± 0.024 (-0.03 CW Shift)

* Noise reduction by averaging in 0.15 $Wm^{-2}sr^{-1}band^{-1}$ bins, N > 100 FOV.

* Gain error 2σ = 0.024%
* Offset error 2σ = 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.

CLARREO/Solar Inter-Calibration Sampling:
Conclusions and Requirements

- **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).

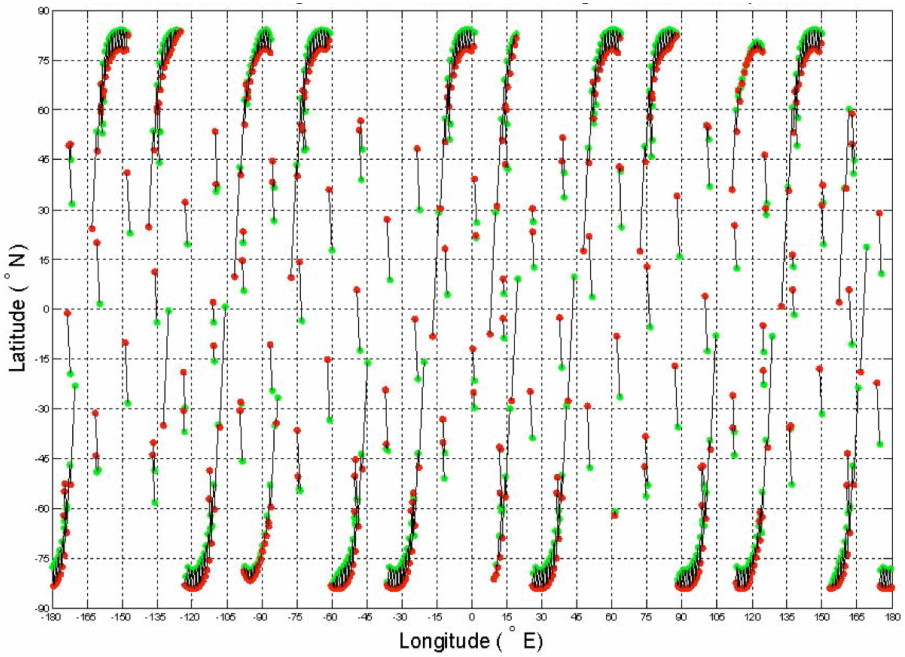
- **Non-critical Requirement:** 83° and 90° inclination orbits have inter-calibration sampling advantages over other orbit choices. The difference between these two is not critical.

Backup Slides

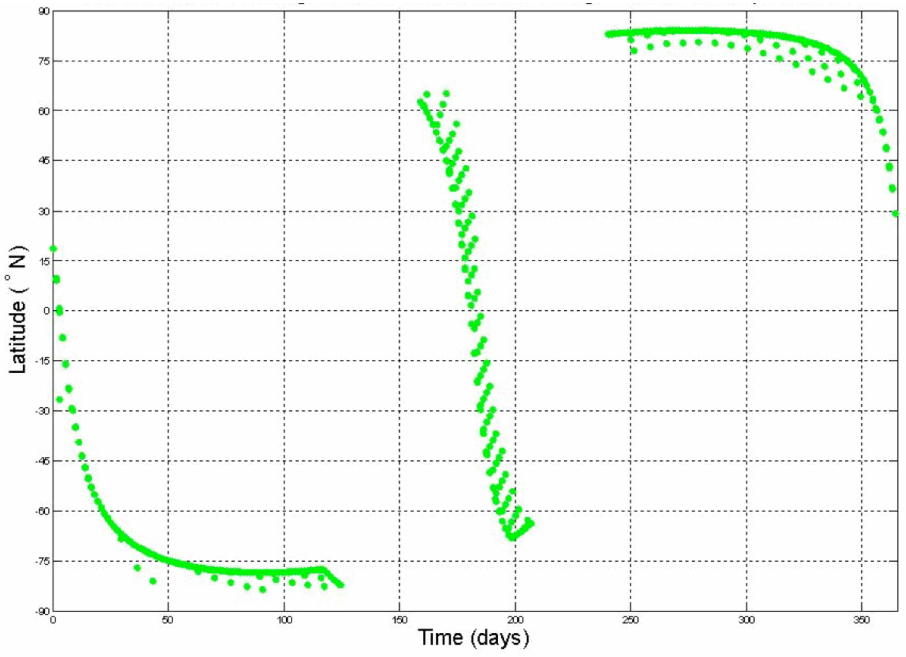
CLARREO Inter-Calibration Sampling

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 lon / lat.

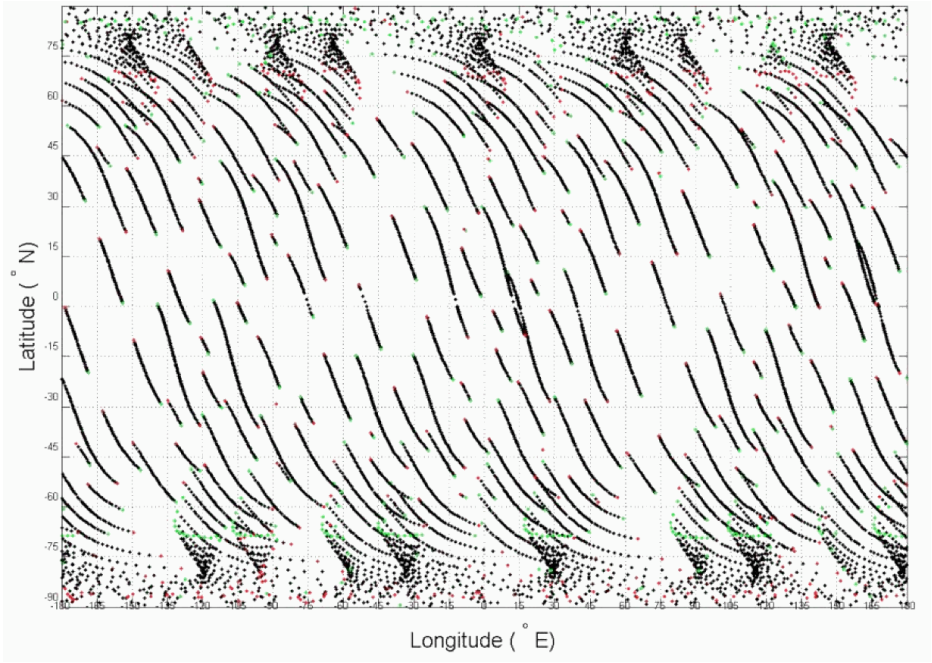


CLARREO Orbit at 600 km, 90°:
Distribution of Inter-calibration Events (463) in time and latitude.

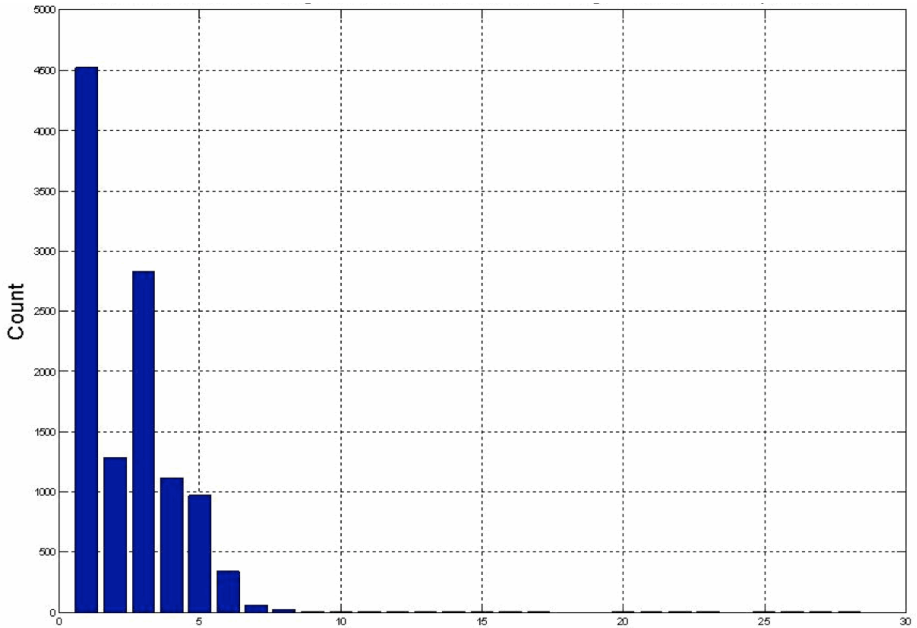
CLARREO Inter-Calibration Sampling

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

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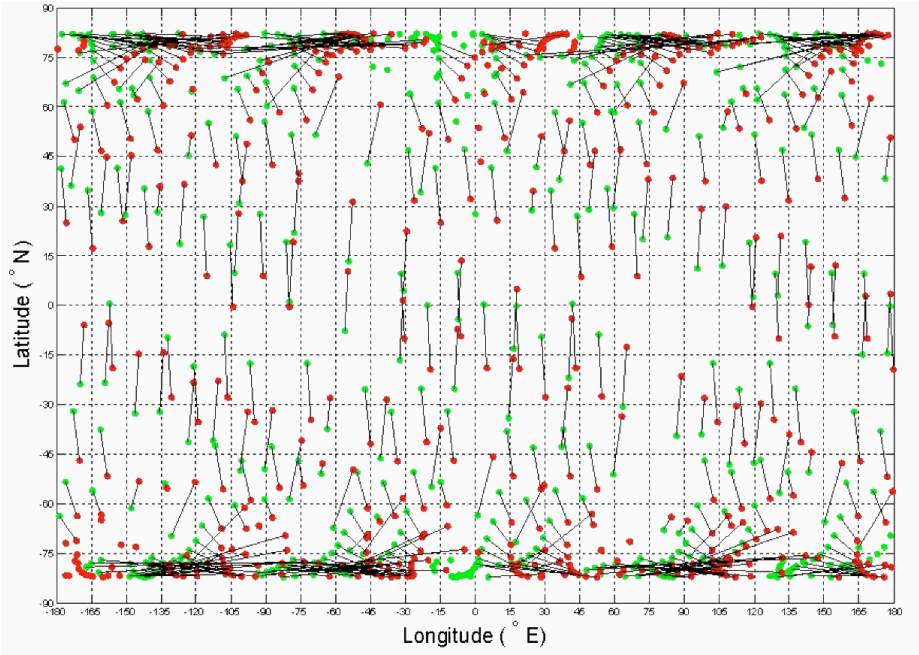
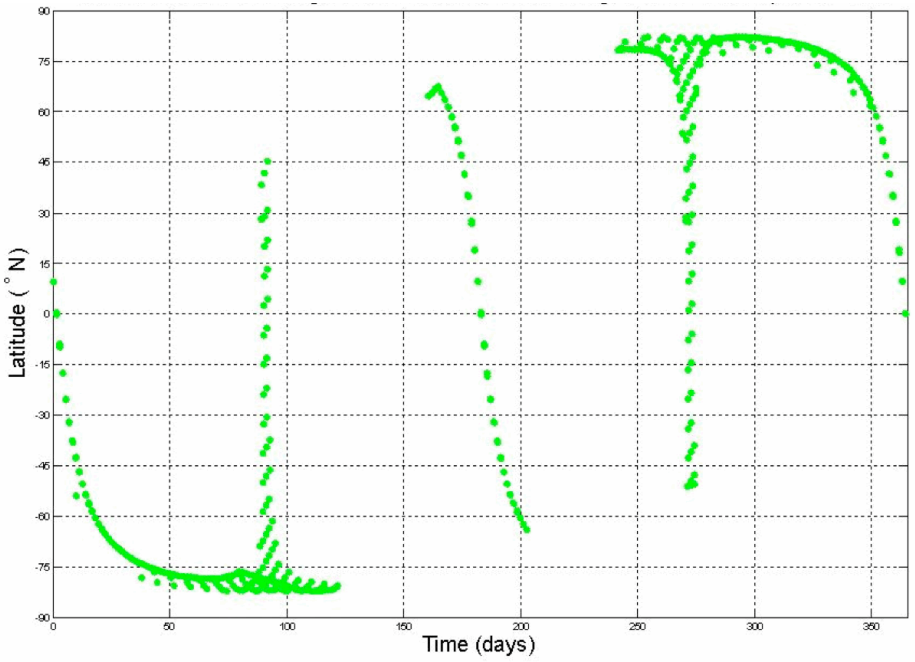


CLARREO Orbit at 600 km, 82°:
Distribution of Inter-calibration Events (533) in lon / lat.

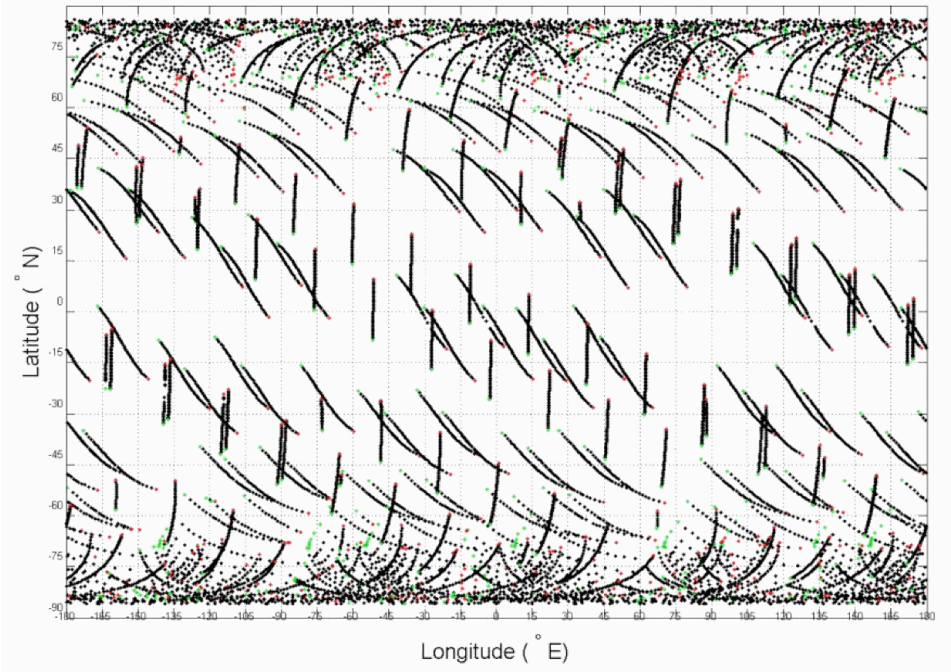


CLARREO Orbit at 600 km, 82°:
Distribution of Inter-calibration Events (533) in time and latitude.

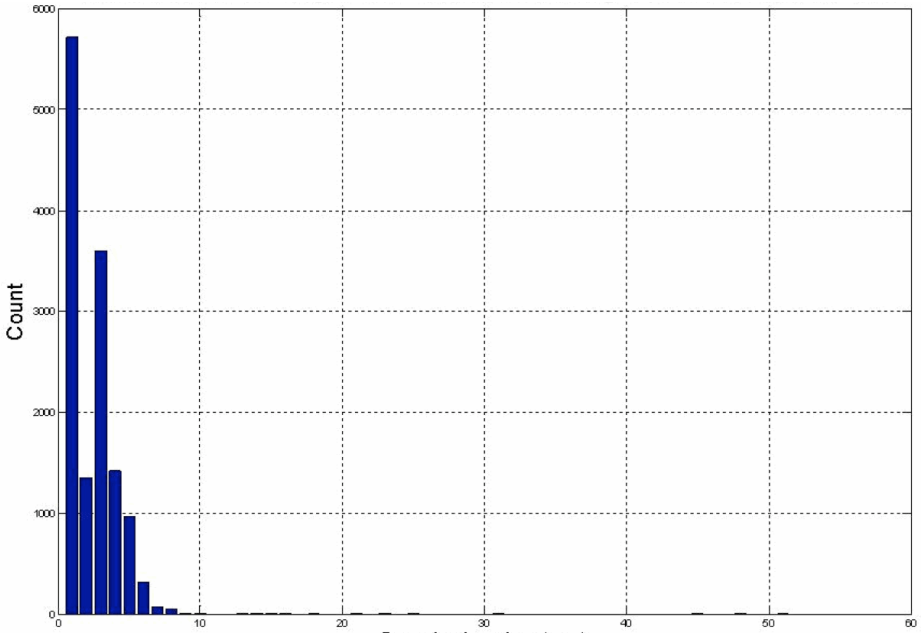
CLARREO Inter-Calibration Sampling

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

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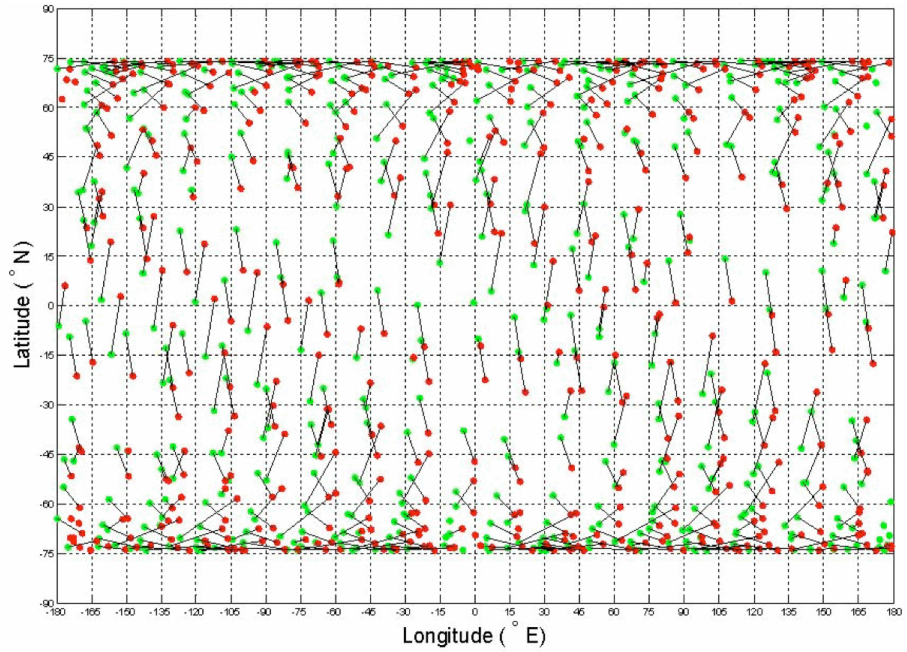
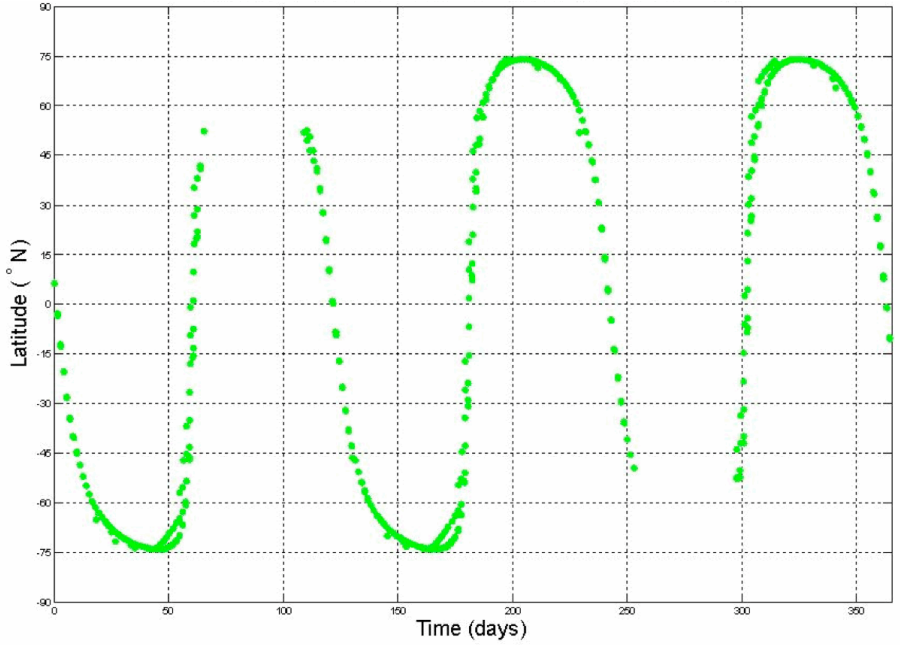


CLARREO Orbit at 600 km, 74°:
Distribution of Inter-calibration Events (496) in lon / lat.

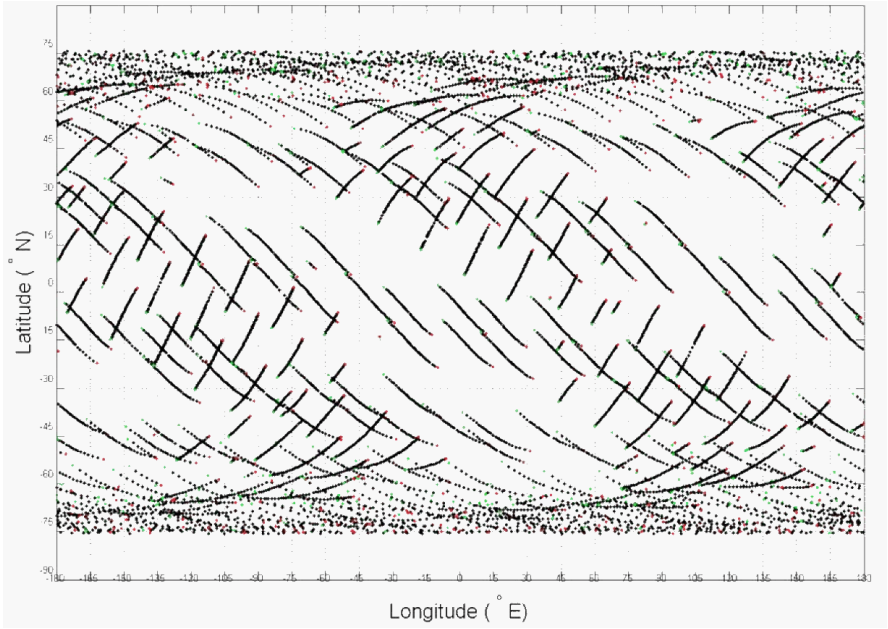


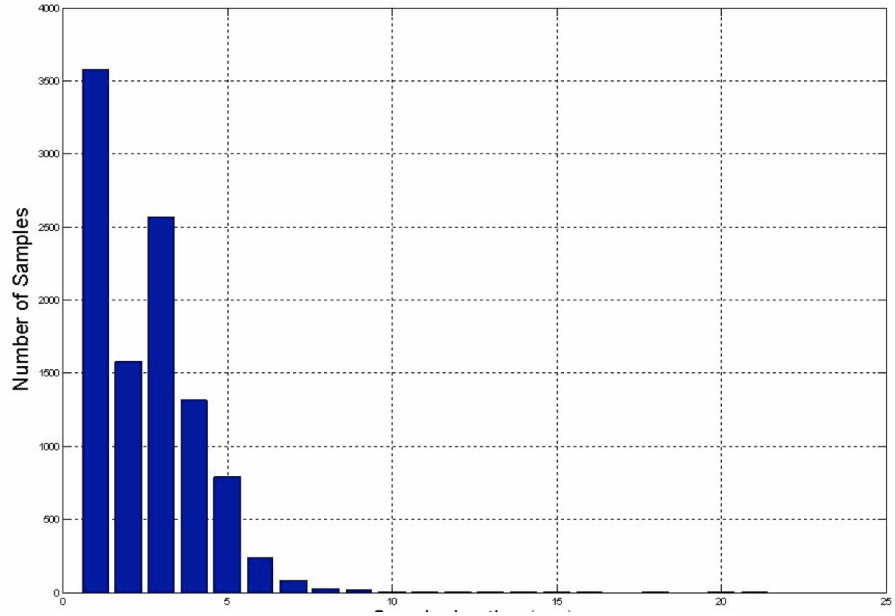
CLARREO Orbit at 600 km, 74°:
Distribution of Inter-calibration Events (496) in time and latitude.

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.

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Duration of Inter-calibration FOVs (10,231).