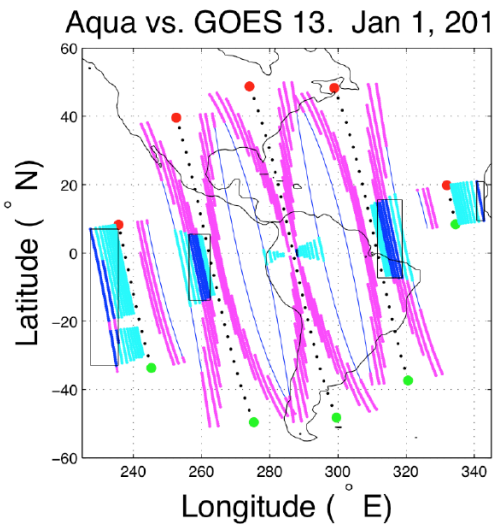
CLARREO Pathfinder Overview

Constantine Lukashin
NASA Langley Research Center, Hampton, VA

CLARREO Pathfinder Overview: Presentation Outline

- Inter-calibration of sensors: background
- Mission Requirements & Success Criteria
- On-orbit pointing approach for inter-calibration
- Instrument Field-of-Regard from ISS location
- Other Inter-calibration opportunities
- Inter-calibration event prediction & sampling
- Inter-calibration data products
- Publications

Inter-Calibration of Sensors in RS: Current



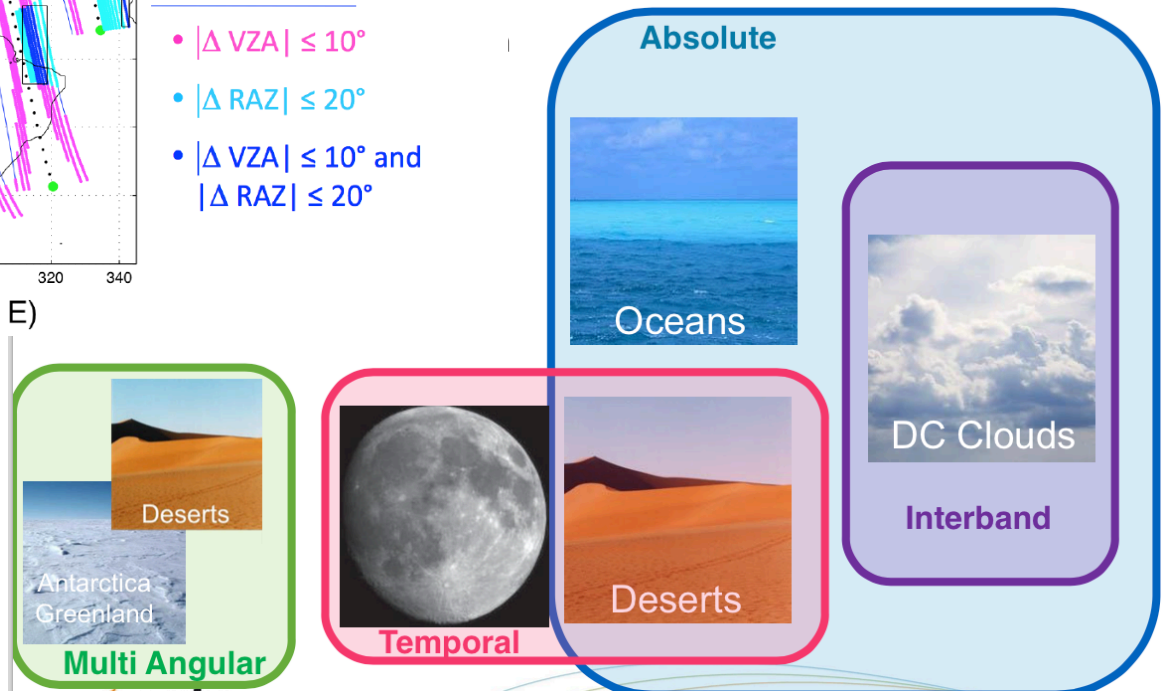
Results from C. Roithmayr

Temporal matching: 30 minutes

• • • Aqua ground track

Aqua swath

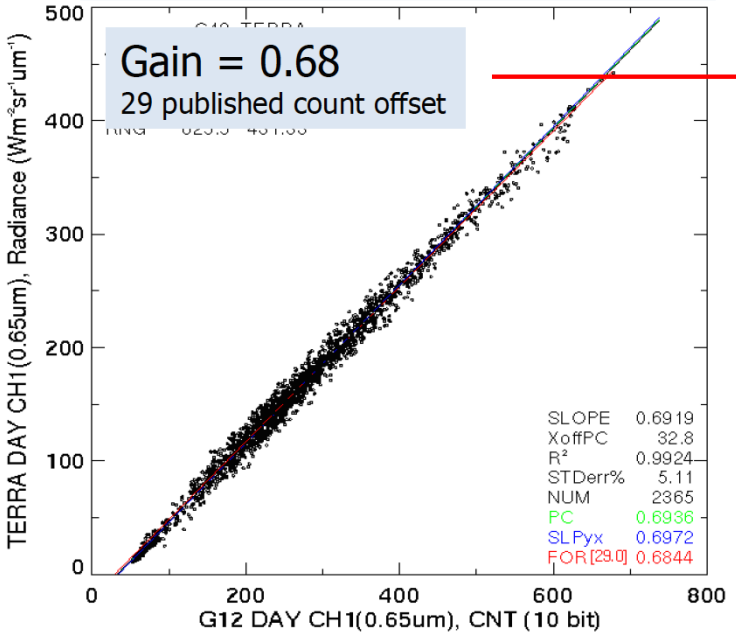
- $|\Delta \text{VZA}| \leq 10°$
- $|\Delta \text{RAZ}| \leq 20°$
- $|\Delta \text{VZA}| \leq 10°$ and $|\Delta \text{RAZ}| \leq 20°$



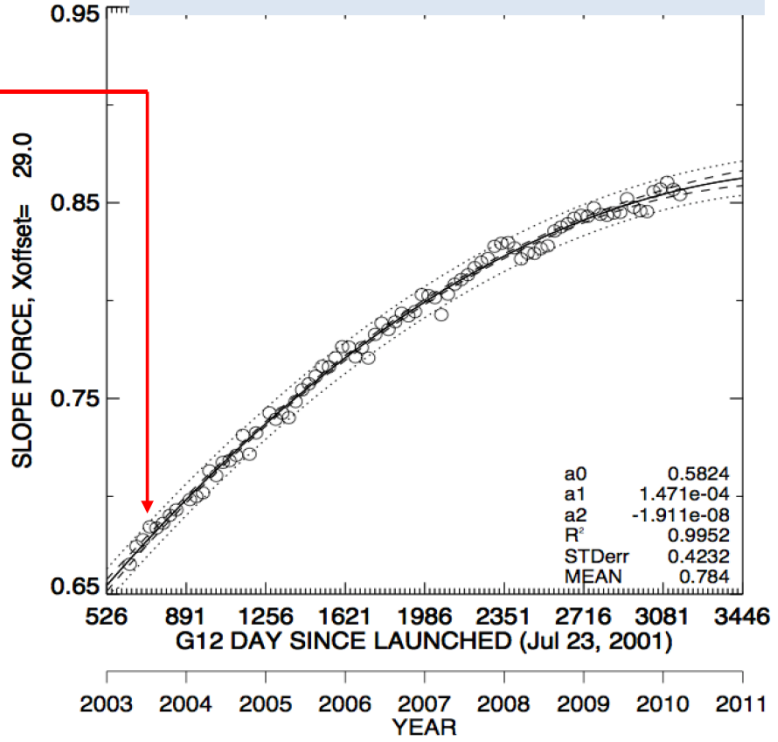
- LEO and GEO data matching when available (e.g. MODIS and GOES-13).
- Uniform and stable surface sites.
- Instrument stability by observing the Moon (e.g. SeaWIFS).
- Deep Convective Clouds, clear ocean & deserts: involve RT modeling.

Inter-Calibration of Sensors in RS: Current

GOES-12/Terra-MODIS
July 2003



GOES-12 gain
based on Terra-MODIS



Results from the GSICS

Fundamental limitation of current approach

Inter-calibration of gain:

- Type A uncertainty (random) is 5.11% (k=1): due to data matching.
- Type B uncertainty (not random) is defined by the MODIS accuracy of 2% (k=1) [pre-launch].
- Spectral Type B uncertainty: due to difference in spectral response.

CLARREO Pathfinder Project Overview

- CLARREO Pathfinder is a directed mission through the NASA Science Mission Directorate – Earth Science Division
  - *NASA Langley has overall project management responsibility*
- CLARREO Pathfinder is a *risk reduction mission* for a potential future full CLARREO Mission
  - *Two primary mission objectives:*
    1. Demonstrate on orbit, high accuracy, SI-Traceable calibration
    2. Demonstrate ability to transfer this calibration to other on-orbit assets
- Project scope consists of formulation, implementation, launch, operation, and analysis of measurements from a Reflected Solar (RS) Spectrometer, launched to the International Space Station (ISS)
- Category 3 (NPR 7120.5E) / Class D Mission (NPR 8705.4), nominal 1-year mission life + 1 year science data analysis
- Targeted for launch in late CY2020 – early CY2021
- Authority to Proceed received April 11, 2016

Inter-Calibration Requirements & Objectives

CERES / RBI and VIIRS are the *required* instruments for demonstrating inter-calibration capability:

- *CERES / RBI Short Wave Channel*
- *VIIRS Reflectance Bands*
- *Inter-Calibration possibilities include CERES / VIIRS on Suomi NPP and JPSS-1, and RBI / VIIRS on JPSS-2*

CLARREO Pathfinder project *objective* is to have the capability to acquire the data necessary to demonstrate inter-calibration with other Earth-observing instruments:

- *The objective is intended to get as much scientific value out if this risk reduction mission as possible within the available budget and schedule*
- ***Acquisition of data** for demonstrating inter-calibration with instruments other than CERES/RBI and VIIRS will be as events of opportunity*
- ***Processing the data** for demonstrating inter-calibration with instruments other than CERES/RBI and VIIRS is not within current CLARREO Pathfinder project scope / budget*

We welcome the opportunity to work with other projects to arrange / advocate for the necessary funding

Draft Level-1 Requirement Summary

Demonstration Parameter	Measurement Uncertainty	
	Baseline Objective*	Threshold Requirement**
Spectrally-Resolved Earth Reflectance (350 – 2300 nm): SI-Traceable, referenced to spectral solar irradiance	≤ 0.3% (k = 1)	≤ 0.6% (k = 1)
Spectrally-Integrated Earth Reflectance (350 – 2300 nm): SI-traceable broadband (350 - 2300 nm) spectrally-integrated Earth reflectance with spectral accuracy weighted using global average Earth spectrally reflected energy	≤ 0.3% (k = 1)	≤ 0.6% (k = 1)
On-Orbit Inter-Calibration*:** Demonstrate the ability to Inter-Calibrate with CERES/RBI short wave channel and VIIRS reflectance bands	≤ 0.3% (k = 1)	≤ 0.6% (k = 1)

* *Baseline Objective is within a factor of 2 of full CLARREO Tier-1 Decadal Survey Mission Requirements*

** *Threshold requirement is a factor of 2 (CERES) to 4 (VIIRS) better than current capabilities.*

*** *Inter-calibration uncertainty are contributions from data matching noise.*

CLARREO Pathfinder Project Status

CLARREO Pathfinder is currently in Formulation Phase A:

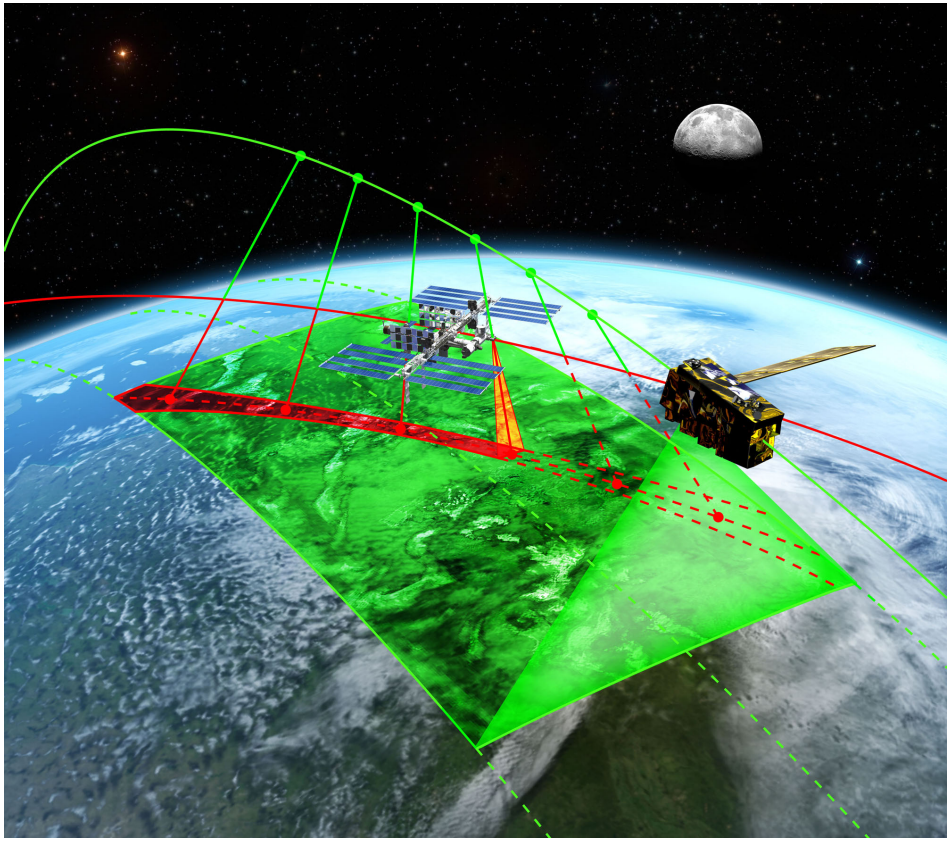
- *Successful Mission Concept Review on August 24-26, 2016*
- *Key Decision Point-A (KDP-A) gate review passed on January 12, 2017*

CLARREO Pathfinder is a recognized International Space Station (ISS) payload and is listed on the MiPROM (MiPROM = ISS payload schedule planning tool):

- *Instrument payload is planned to be accommodated on the ISS at Express Logistics Carrier #1 (ELC-1) Site #3*
- *ISS has planned for an 18-month occupancy for the CLARREO Pathfinder payload (October 2020 through March 2022)*
- *Includes 2-month commissioning period + 12 months prime mission operations*

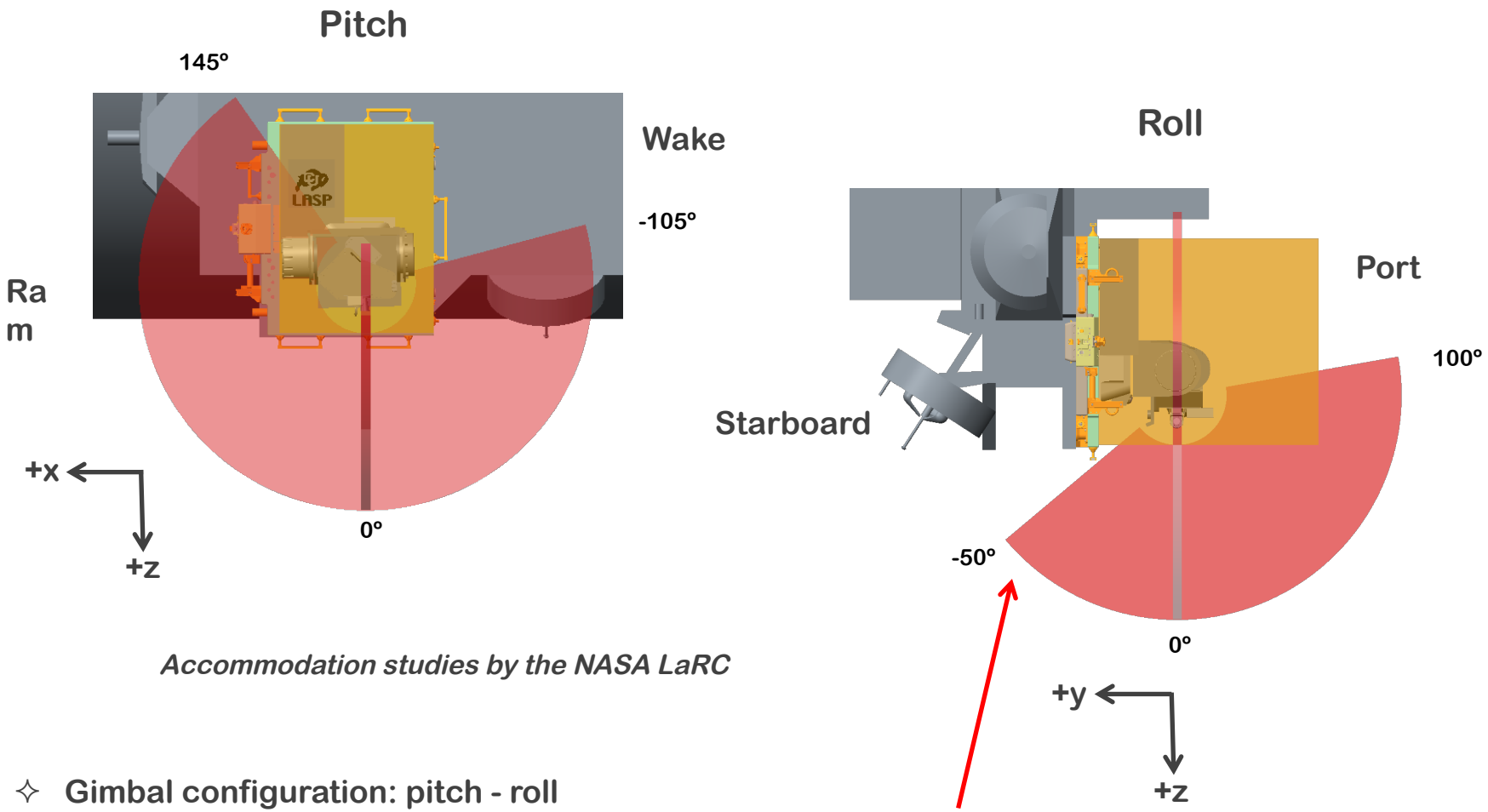
Project is currently performing the necessary work to establish contracts and partnerships during the Formulation phase of the project.

Inter-Calibration Concept: CERES & VIIRS



- CLARREO Pathfinder Instrument provides high-accuracy reference on orbit.
- CLARREO Pathfinder Instrument has 2D pointing ability for real-time data matching.
- CLARREO Pathfinder data matching with CERES and VIIRS on JPSS: temporal matching within 10 minutes, on-orbit angular/spacial matching.
- CLARREO Pathfinder location on ISS: ELC-1 Site 3.

RS Instrument Field-of-Regard



Accommodation studies by the NASA LaRC

- Gimbal configuration: pitch - roll
- Approximate gimbal range of motion at ISS ELC-1 Site 3.
- Not all pointing angles are available due to ISS accommodation.
- Refine analysis for ISS components affecting RS instrument view in Phase-A.

Inter-Calibration Event Prediction

- Approach: Inter-calibration by real-time pointing off-nadir !
- Inter-calibration on-orbit operations are planned ahead of time !

(1) Inter-calibration of Sensors:

- Prediction by orbital modeling
- Filter out events with instrument FOV obscured by ISS fixed and rotating structures
- Assess the value for every event by modeling
- Deliver event parameters to instrument operations team

(2) Calibration of Lunar Spectral Reflectance:

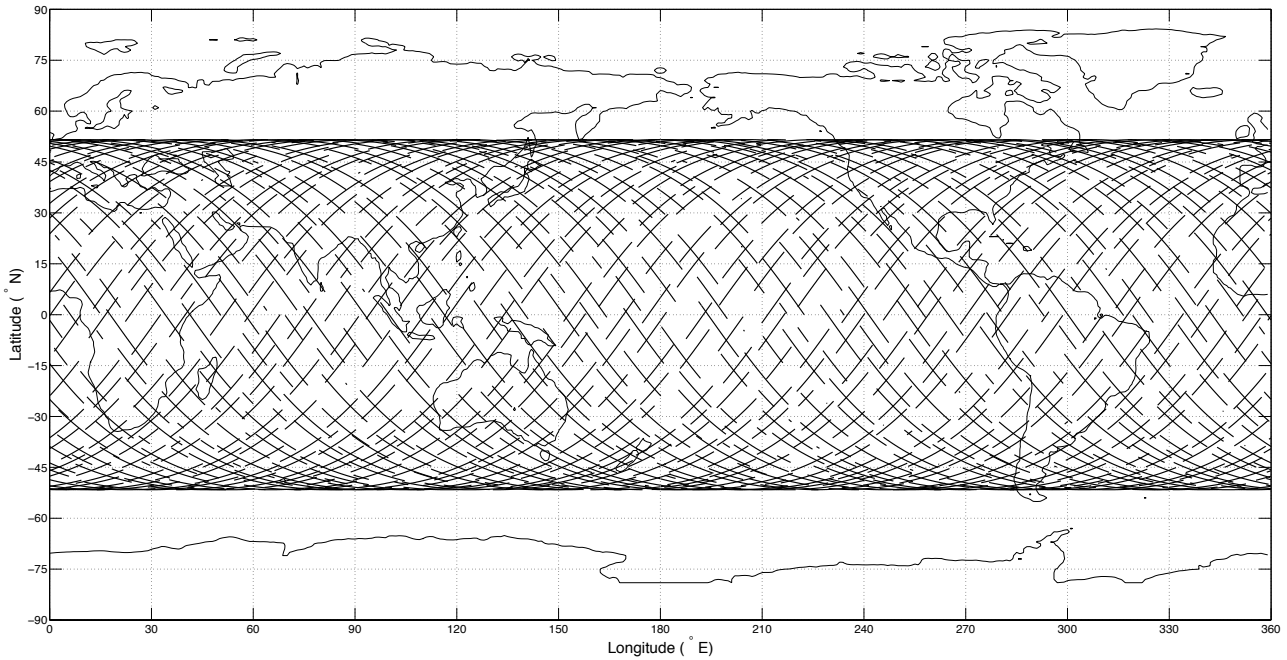
- Prediction of Moon viewing by orbital modeling
- Filter out events with instrument FOV obscured by ISS fixed and rotating structures
- Assess the value for every lunar geometry by modeling
- Coordinate with the instrument calibration team
- Deliver event parameters to instrument operations team

(3) Characterization of Surface Sites:

- Prediction by orbital modeling
- Filter out events with instrument FOV obscured by ISS fixed and rotating structures
- Assess the value for every event by modeling
- Deliver event parameters to instrument operations team

Inter-Calibration Events: Geolocation

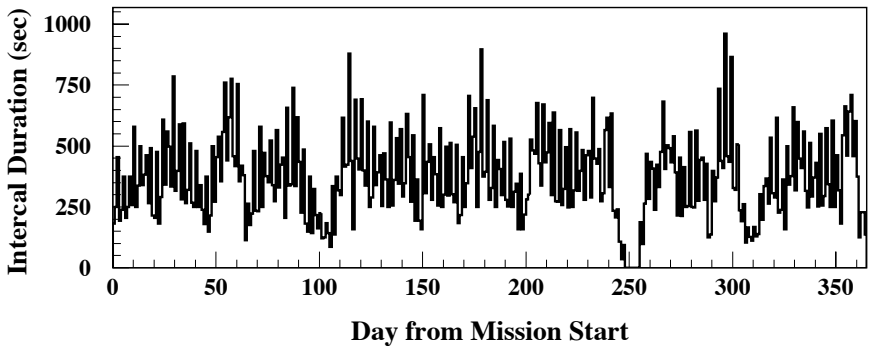
Results from C. Roithmayr

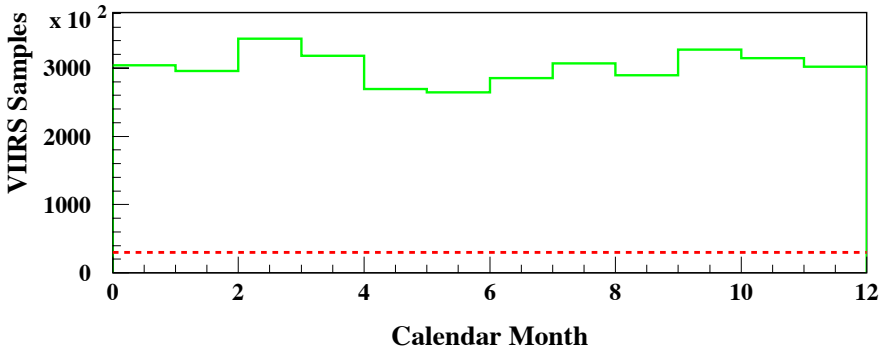


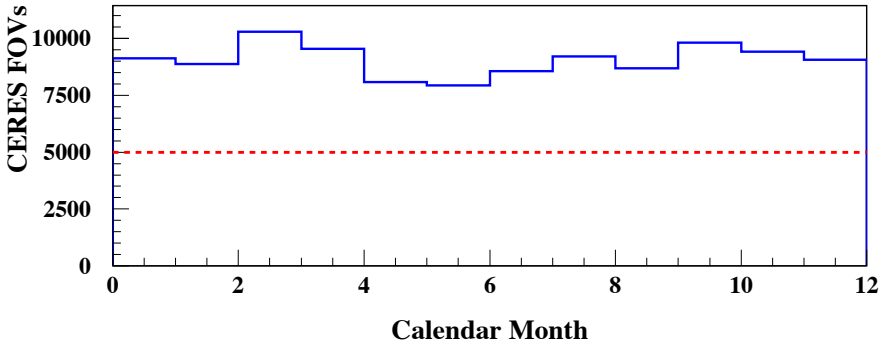
Geolocation of the ISS ground track during each opportunity to take measurements for inter-calibrating JPSS cross-track sensors (CERES and VIIRS).

- Instrument FOV = 10°
- Time matching +/- 10 minutes
- 1308 inter-calibration opportunities over 1 year

Inter-Calibration: Sampling & Margin







Simulation ISS ELC-1 Site 3:

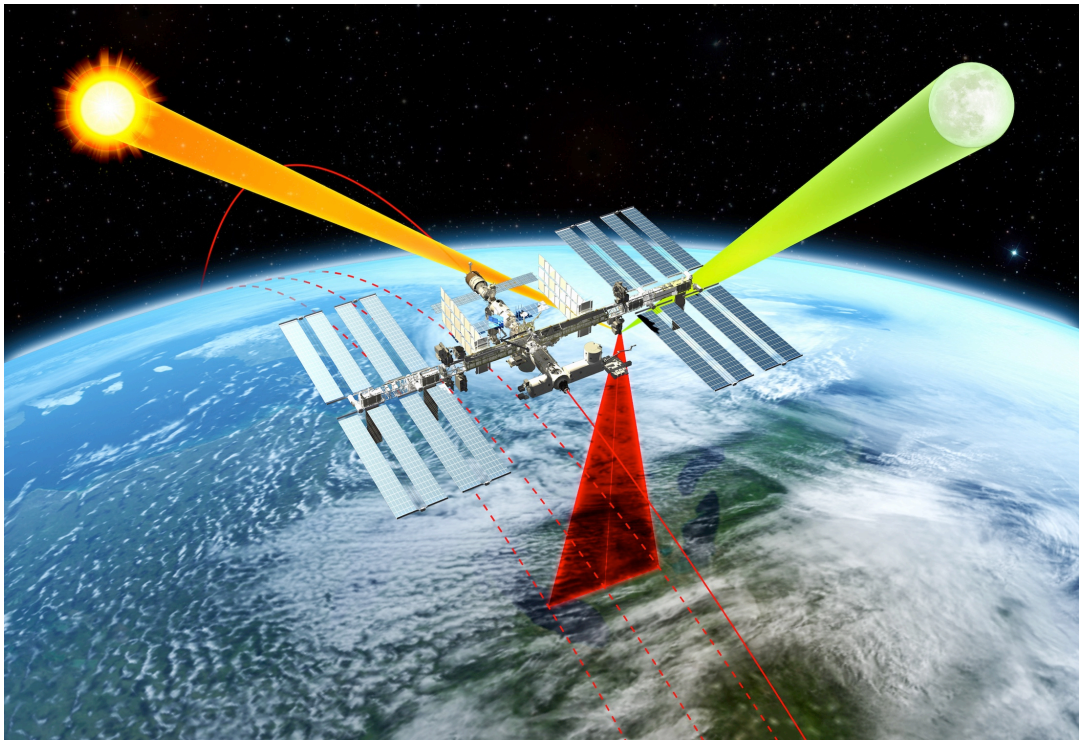
- 10 minutes time matching
- Instrument field-of-regard
- Instrument FOV = 10°
- Instrument FOV obscuration = 0%
- Event duration > 30 seconds
- SZA < 75°
- N good events = 1163

VIIRS:
100 samples every 5 seconds (imager re-sampling)

CERES:
3 FOVs every 5 seconds (large FOV)

Margin at 44% for operations not-available on average !

Other Inter-Calibration Opportunities



SENSORS:

- GEO imagers:
  NOAA ABI on GOES-16
  EUMETSAT
  ESA GERB
- Land imagers:
  USGS Landsat
  ESA Sentinel-2A/B

CALIBRATION TARGETS:

- Instrumented and not-instrumented Surface Sites (deserts)
- Moon: improve accuracy of lunar spectral reflectance

Inter-Calibration Data Products

Product	Contents	Resolution	Granule
Level-1 Products for VIIRS CERES GEO (NOAA, ESA, etc.) Landsat (USGS) Surface Sites Moon	Calibrated and geo-located CPF observations.	Full spectral and spatial resolution of the CPF RS Instrument.	Each granule contains single CPF inter-calibration event.
Level-4 Products for VIIRS CERES	Collections of CPF (Level-1), VIIRS, and CERES matched data (Level-1 & Level-2).	CLARREO (Level-11) and VIIRS (Level-1 & Level-2, Clouds and Aerosols) data spatially convolved over IC sample. CLARREO Spectral re-sampling. CLARREO (Level-1) spatially convolved over CERES FOV's PSF. CLARREO conversion to broadband reflectance. Scene ID from the CERES SSF.	Data processed by the CPF inter-calibration events.
Level-4 Products for VIIRS CERES	Inter-calibration results: Constraints on effective offset, gain, non-linearity, sensitivity to polarization, and spectral degradation.	N/A	N/A

- Additional data analysis – by a separately funded science team

CLARREO Inter-Calibration: Key Publications

Roithmayr, C.M., and P.W. Speth, 2012: "Analysis of opportunities for intercalibration between two spacecraft," Advances in Engineering Research Vol. 1, Chapter 13, Edited: V.M. Petrova, *Nova Science Publishers*, Hauppauge, NY, pp. 409 - 436.

Lukashin, C., B. A. Wielicki, D. F. Young, K. Thome, Z. Jin, and W. Sun, 2013: "Uncertainty estimates for imager reference inter-calibration with CLARREO reflected solar spectrometer," *IEEE Trans. on Geo. and Rem. Sensing, special issue on Intercalibration of satellite instruments*, 51, n. 3, pp. 1425 – 1436.

Roithmayr, C. M., C. Lukashin, P. W. Speth, G. Kopp, K. Thome, B. A. Wielicki, and D.F. Young, 2014a: "CLARREO Approach for Reference Inter-Calibration of Reflected Solar Sensors: On-Orbit Data Matching and Sampling," *IEEE TGRS*, v. 52, 10, pp. 6762 - 6774.

Roithmayr, C. M., C. Lukashin, P. W. Speth, D.F. Young, B.A. Wielicki, K. J. Thome, and G. Kopp, 2014b, "Opportunities to Intercalibrate Radiometric Sensors from International Space Station," *J. of Atm. and Oce. Tech.,* DOI: 10.1175/JTECH-D-13-00163.1.

Wu, A., X. Xiong, Z. Jin, C. Lukashin, B.N. Wenny, J.J. Butler, 2015: "Sensitivity of Intercalibration Uncertainty of the CLARREO Reflected Solar Spectrometer Features," IEEE TGRS, v. 53, 4741 - 4751, 10.1109/TGRS.2015.2409030

Sun W., C. Lukashin, and D. Goldin, 2015: "Modeling polarized solar radiation for CLARREO inter-calibration applications: Validation with PARASOL data," *J. Quant. Spectrosc. Radiat.*, v. 150, pp. 121 - 133.

Sun, W., R.R. Baize, C. Lukashin, and Y. Hu, 2015: "Deriving polarization properties of desert-reflected solar spectra with PARASOL data," *Atmos. Chem. Phys.*, 15, 7725 - 7734, doi: 10.5194/acp-15-7725-2015.