A23S-2622

Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder Intercalibration Data Analysis Strategy

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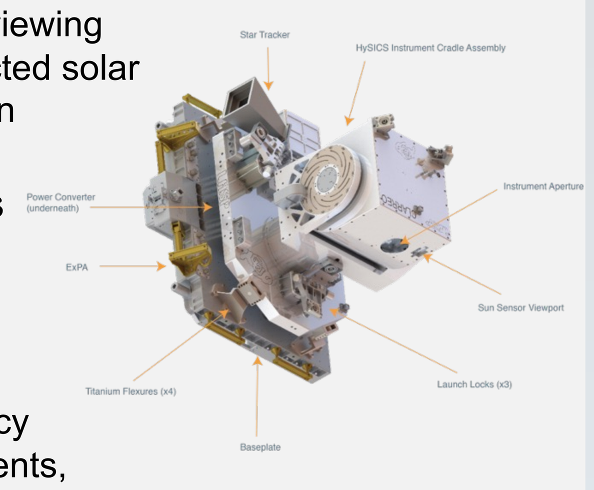
Background

CLARREO Pathfinder

CLARREO Pathfinder mission will launch an Earth-viewing reflected solar spectrometer to measure Earth-reflected solar radiation from the International Space Station with an *SI-traceable radiometric uncertainty of 0.3% (k=1).*



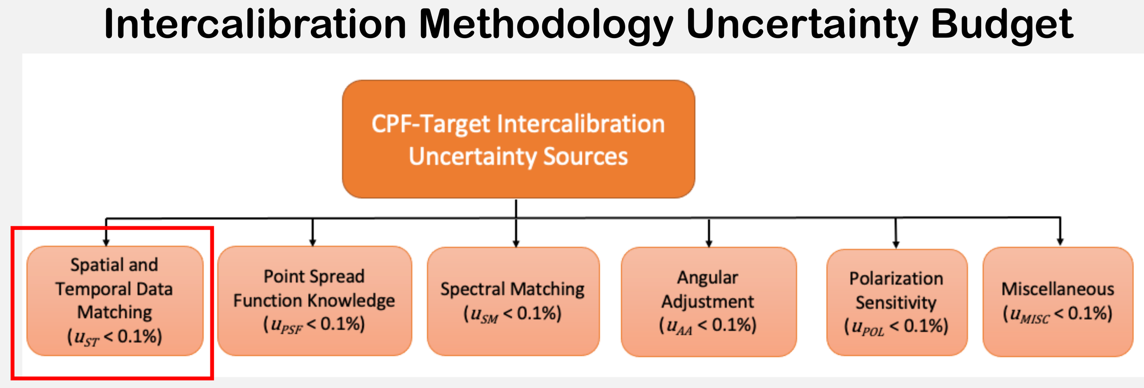
Mission and Intercalibration Objectives

1. Capture highly accurate hyperspectral Earth observations with advanced on-orbit calibration allowing reduced operational measurement uncertainty by 5 – 10 times.
2. Serve as a reference to transfer improved accuracy via intercalibration to other Earth-viewing instruments, as will be demonstrated using CERES and VIIRS.

Intercalibration Problems, Solutions, and Mission Novelty

- Existing on-orbit satellite intercalibration references not SI-traceable.
- *CPF limits uncertainty through hyperspectral, highly accurate measurements by means of a reflected solar spectrometer, the Hyperspectral Imager for Climate Science.*
- Ideal intercalibration config requires matched data in time, space, angles, wavelengths.
  - Does not happen in practice; thus, several sources of uncertainty (e.g., temporal and spatial mismatch, angular differences, spectral band differences).
- *CPF will have state-of-the-art intercalibration methodology mitigating uncertainties from imperfect data matching.*

Intercalibration Methodology Uncertainty Budget



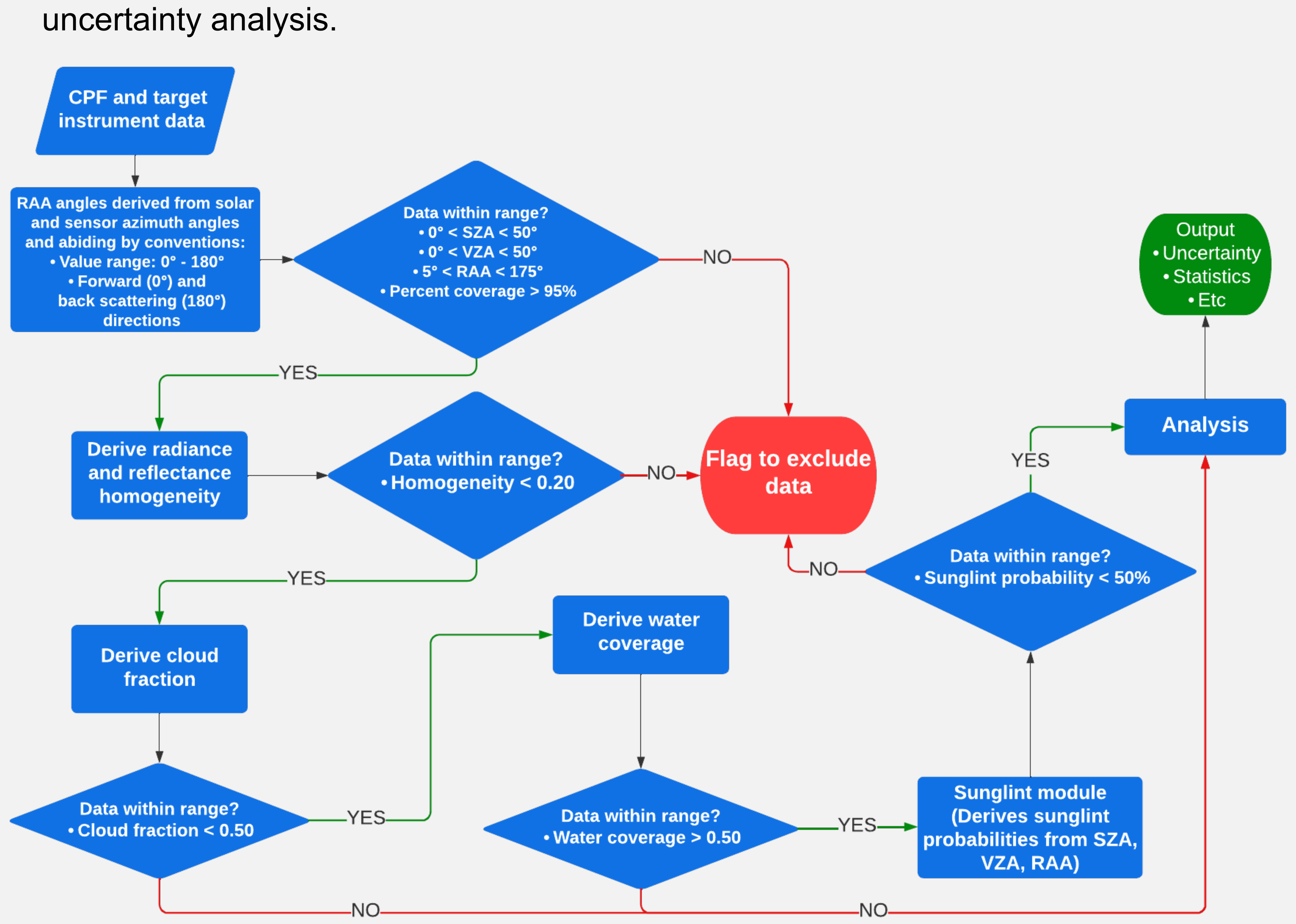
Presentation Focus

In this work, we present a:

- (a) data filtering algorithm to reduce dataset noise to support intercalibration uncertainty analysis in comparing CPF and target instrument data;
- (b) temporal mismatch noise analysis isolating anticipated uncertainty between CPF and VIIRS due to temporal differences in sampling; and
- (c) spatial mismatch noise analysis isolating the anticipated uncertainty between CPF and VIIRS due to resolution differences between instruments and geolocation error.

Data Filtering Algorithm

- Samples collected by CLARREO Pathfinder and target instruments should ideally match well, but data collection methodology, atmospheric conditions (such as cloud cover), or sample target properties contribute to temporal and spatial mismatch noise.
- Data are flagged by filters if they are collected under conditions that unacceptably affecting data reliability.
- Sequence of filters (illustrated below) is configured to efficiently yield a data subset that has the best reduction in noise while not unacceptably affecting confidence in uncertainty analysis.



Temporal Mismatch Noise Analysis

- Temporal and spatial mismatch noise analysis is necessary to quantify estimated intercalibration methodology uncertainty between CPF and target instruments.
  - These sources of noise contribute most to the CPF-target Intercalibration Uncertainty Sources total, in the **Intercalibration Methodology Uncertainty Budget**.
- Temporal mismatch noise results from temporal differences in scan times between target (e.g., VIIRS, CERES) and reference (CPF) instruments.
  - Most of this noise is due to changes in clouds and other atmospheric conditions.
- To simulate temporal mismatch noise, GOES-16 ABI channels 1 through 6, 5-minute CONUS scans are used.
  - 5-minute scans used as average maximum scan time difference.
- For this analysis, a subset area of the CONUS scans is used, bounded by latitude (25° to 50°) and longitude (-85° to -70°), centered on the North American East Coast.

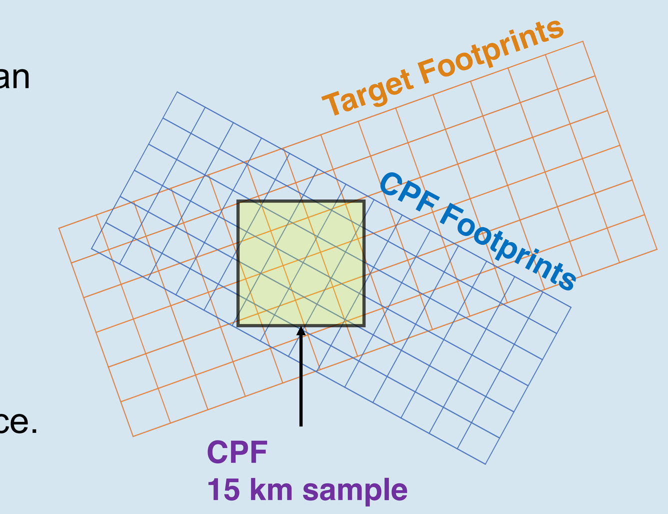
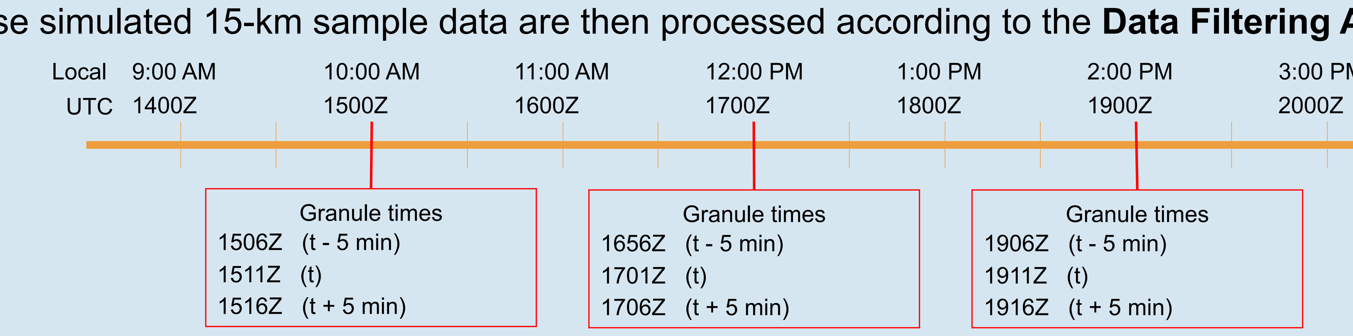
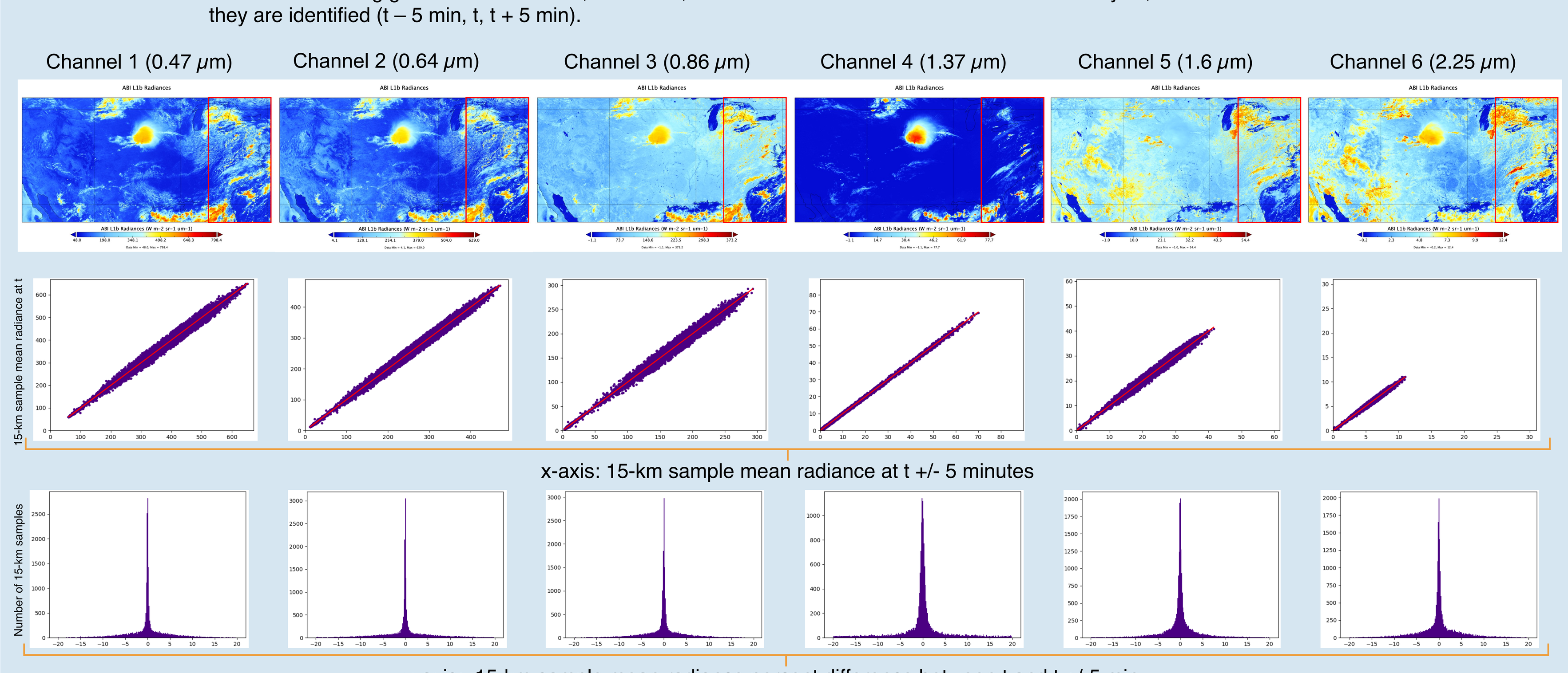


Illustration of temporal and spatial mismatch noise between CPF and a target instrument.

- Three sequential scans are selected for 15 August 2019 before, during, and after local noon (1500Z, 1700Z, and 1900Z), for a total of nine scans per channel, illustrated in the timeline below.
- Radiance values are normalized by solar zenith angles (SZA) at each of these hours:
  - First (t - 5 minutes) and last scans (t + 5 minutes) are normalized to middle scans (t) to reduce radiance bias caused by changing solar position.
- To simulate CPF-VIIRS temporal mismatch noise:
  - Subset area divided into 15-km boxes within which mean radiance is used to simulate a VIIRS sample.
  - These simulated 15-km sample data are then processed according to the **Data Filtering Algorithm**.



Timeline illustrating granules at 10:00 AM, 12:00 PM, and 2:00 PM local time which are used in analysis, and how they are identified (t – 5 min, t, t + 5 min).



Top: GOES-16 ABI CONUS radiance displays (subset analysis area in red box); middle: linear regression analysis using 15-km sample mean radiance, at 0.20 homogeneity threshold; bottom: histogram analysis using 15-km sample mean radiance percent difference between t and t +/-5 min, at 0.20 homogeneity threshold.

15 August 2019	CH 1 (0.47 μm)	CH 2 (0.64 μm)	CH 3 (0.86 μm)	CH 4 (1.37 μm)	CH 5 (1.6 μm)	CH 6 (2.2 μm)
Total 15-km sample count	20,991	**20,596**	21,060	15,377	20,809	20,846
Slope	0.9991	**0.9991**	0.9987	0.9987	0.9984	0.9984
Offset	0.2439	**0.1452**	0.1468	0.0029	0.0193	0.0051
$Slope_{forced}$	0.9991	**0.9991**	0.9987	0.9987	0.9984	0.9984
Mean 15-km sample radiances at t +/- 5 minutes	253.9372	**163.7470**	120.1463	4.8008	12.5846	3.7641
Mean 15-km sample radiances at time t (used in statistics)	253.9602	**163.7437**	120.1360	4.7977	12.5845	3.7632
Mean difference in 15-km sample radiances	0.0071 percent	**-0.0025 percent**	-0.0166 percent	-0.0191 percent	-0.0017 percent	0.0190 percent
Standard deviation of 15-km sample radiance	5.0065 percent	**5.8858 percent**	4.7099 percent	5.9486 percent	4.3932 percent	4.9335 percent
Minimum samples required to meet 0.1% uncertainty requirement	2,506	**3,464**	2,218	3,538	1,930	2,433

Table: Temporal mismatch noise analysis statistics.

Temporal Mismatch Noise Analysis Conclusions

- Channel 2, at 0.64 μm, has the greatest standard deviation, mainly due to high spatial variability, and therefore channel 2 may be used as a good estimate of maximum expected temporal noise between CPF and VIIRS (as seen in standard deviation).
- Channel 4, at 1.37 μm, has low average signal but a large radiance range depending on clouds; temporal noise is therefore high.
- Channels 5 (1.6 μm) and 6 (2.2 μm) have relatively coarse resolutions and are less sensitive to spatial variability, so temporal noise is comparable to other channels (except channel 4).

Spatial Mismatch Noise Analysis

- Spatial mismatch noise occurs when target and reference instruments scan at differing resolutions or when geolocation errors create data mismatches up to 1/2 pixels in distance.
- To simulate spatial mismatch noise, a subset Landsat 9 OLI channel 4 (0.655 μm) granule at 30 m resolution on 12 January 2023 at 1541Z is used, displaying the coastline of North Carolina (shown below).
- From the Landsat 9 OLI pixel reflectance, 375 m, 500 m, and 750 m mean footprint reflectances are calculated to simulate VIIRS I-band, CPF, and VIIRS M-band resolutions, respectively.
- To simulate VIIRS geolocation errors, offsets of ½ I-band and ½ M-band pixel are applied in each direction (illustrated to right), creating four offset scenarios.

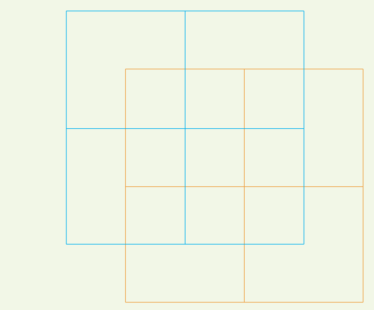
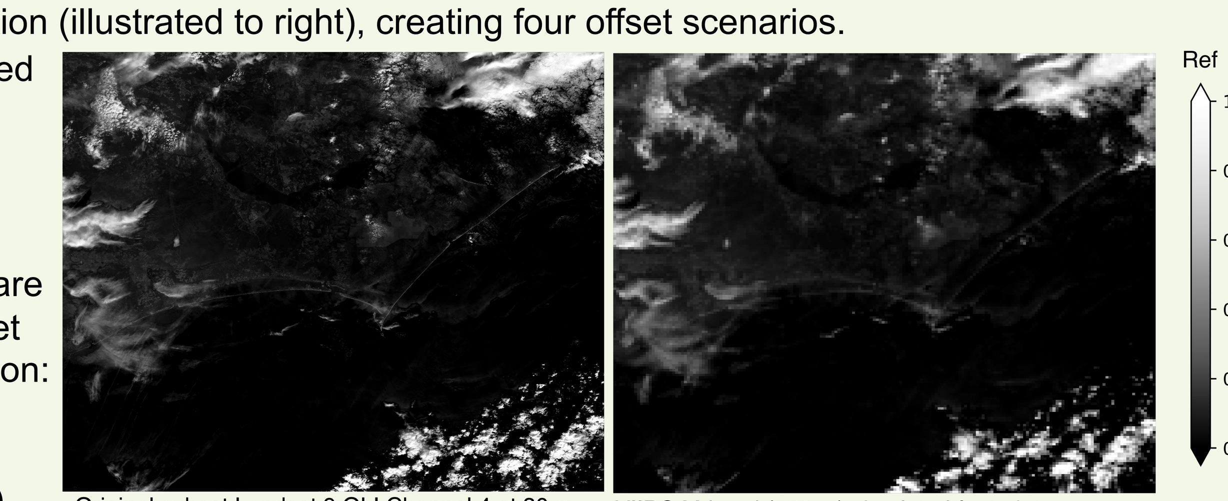
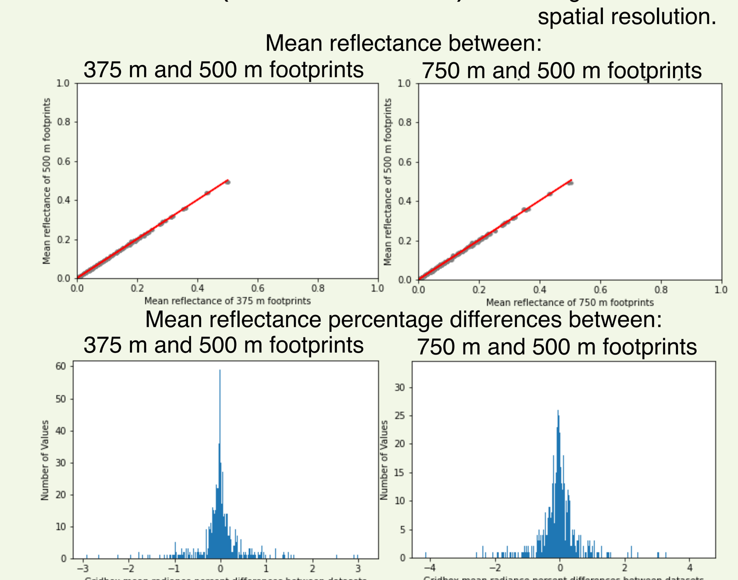


Illustration: offset methodology – Blue pixel grid is offset from orange pixel grid 1/2 pixel up and left.

- 15-km samples are created from mean footprint reflectances in offset scenarios.
- The 15-km samples from the four offset scenarios are combined into one dataset for each footprint simulation:
  - 375 m (VIIRS I-band),
  - 500 m (CPF), and
  - 750 m (VIIRS M-band).



Original subset Landsat 9 OLI Channel 4 at 30 m spatial resolution. VIIRS M-band (750 m) simulated footprints.



Top: linear regression analysis; bottom: histogram analysis.

	15-km samples	
	CPF-VIIRS I-band (375 m & 500 m) footprints	CPF-VIIRS M-band (750 m & 500 m) footprints
Total 15-km sample count	1,260	1,260
Slope	0.9999	1.0021
Offset	0.0001	0
Mean for 375 m footprints	0.0713	
Mean for 500 m footprints	0.0714	0.0714
Mean for 750 m footprints		0.0713
Mean difference in 15-km sample reflectance	-8.4127e-10 percent	-4.1269e-10 percent
Standard deviation of 15-km sample reflectance	0.5071 percent	0.7034 percent
Summing std. dev. in quadrature with temporal analysis ch. 2 std. dev.	5.9076 percent	**5.9279 percent**

Table: Spatial mismatch noise analysis statistics.

Spatial Mismatch Noise Analysis Conclusions

- Spatial mismatch noise (as seen in standard deviation) contributes relatively little to overall uncertainty between CPF and VIIRS I- and M-bands compared to temporal mismatch noise.
- Greater spatial mismatch noise occurs between CPF and VIIRS M-band footprints compared to CPF and VIIRS I-band footprints due to VIIRS M-bands having larger pixels and therefore a greater offset distance.

Temporal and Spatial Noise Analysis Conclusions

- Temporal and spatial matching noise drives the required sample size to meet desired intercalibration uncertainty threshold.
- Total maximum spatial and temporal mismatch noise is about 5.93 percent.
- A minimum of about 3,500 intercalibration samples/month required to satisfy the spatial + temporal mismatch noise requirement of less than 0.1 percent.
- Quantifying uncertainties and minimum samples necessary are essential to meet mission requirements.

$$u = \frac{\sigma}{\sqrt{N}}$$

Future Work and Additional Applications

- Increase subset area and number of days and seasons of data used in temporal mismatch noise analysis.
- Increase scenes used in spatial mismatch noise analysis for larger, more diverse datasets.
- Expand footprints to 20 km footprints to simulate CPF-CERES in temporal and spatial noise analysis.
- CPF will leverage high-accuracy spectral information to advance:
  - Comprehensive Earth observations
  - Climate projection and variability
  - Climate trend detection and timeline
  - Understanding cloud properties

Related Posters in this Session

- **A23S-2620** Leveraging CPF Spectral Information for Effective Angular Corrections in Sensor Inter-calibration Studies. Presented by Dr. Wan Wu.
- **A23S-2621** Training and Real EMIT Spectrum Validation of A Spectral Gap Filling Algorithm for CPF-CERES Inter-calibration. Presented by Dr. Qiguang Yang.
- **A23S-2623** Reference Intercalibration for the Climate Observing System. Presented by Dr. Yolanda Shea.
- **A23S-2624** A Principal-Component-based Radiative Transfer Model (PCRTM) for Hyperspectral Shortwave and Longwave Satellite Sensors and Its Applications. Presented by Dr. Xu Liu.

Acknowledgements and References

- CLARREO Data Management Team
- GOES-R Calibration Working Group
- Conor Haney (NASA LaRC/AMA)
- NOAA for GOES-16 ABI data via AWS
- USGS for Landsat 9 OLI data via EarthExplorer