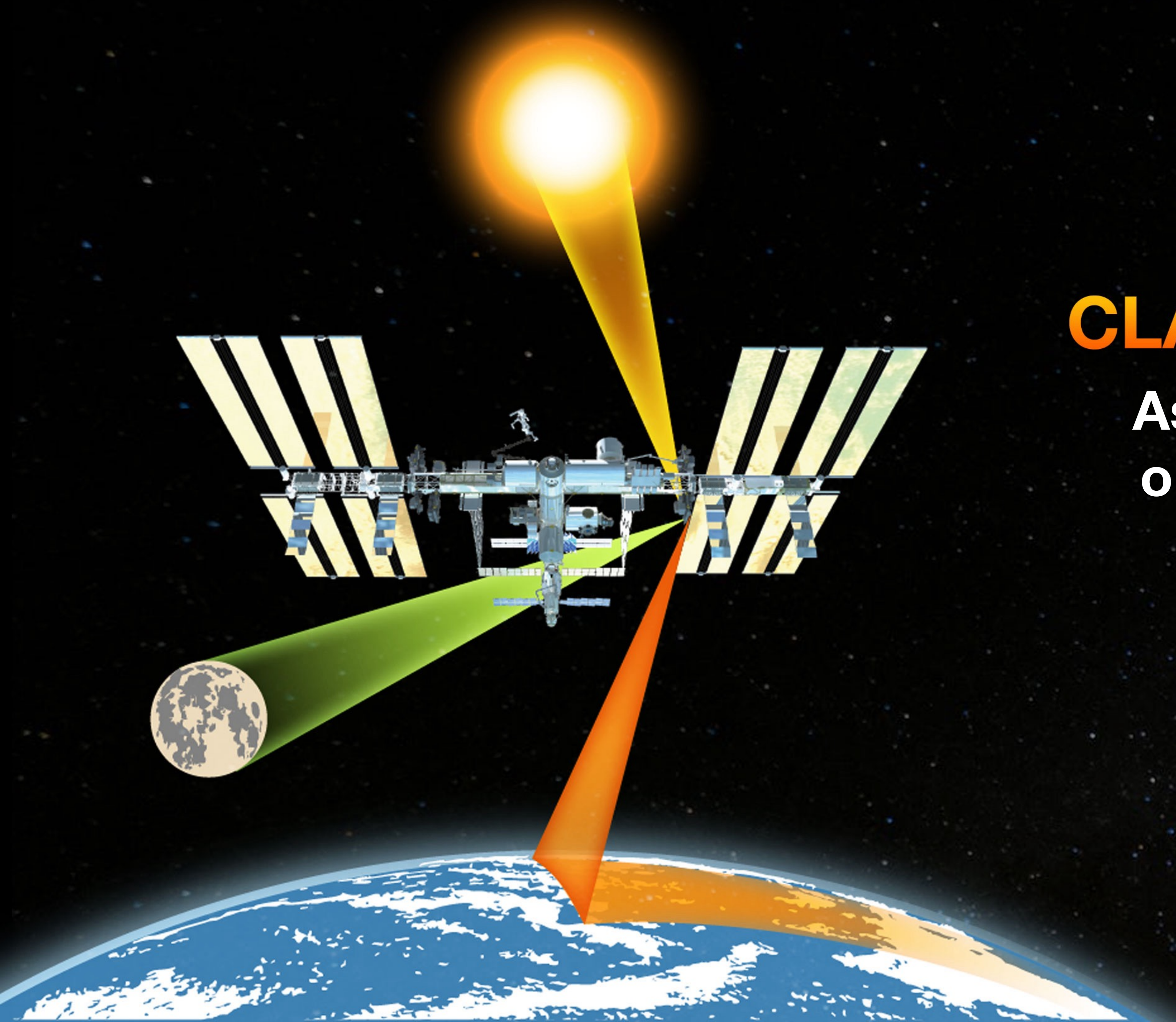


National Aeronautics and
Space Administration

CLARREO Pathfinder

As a Next-generation On-orbit Reference Standard for Reflective Solar Intercalibration

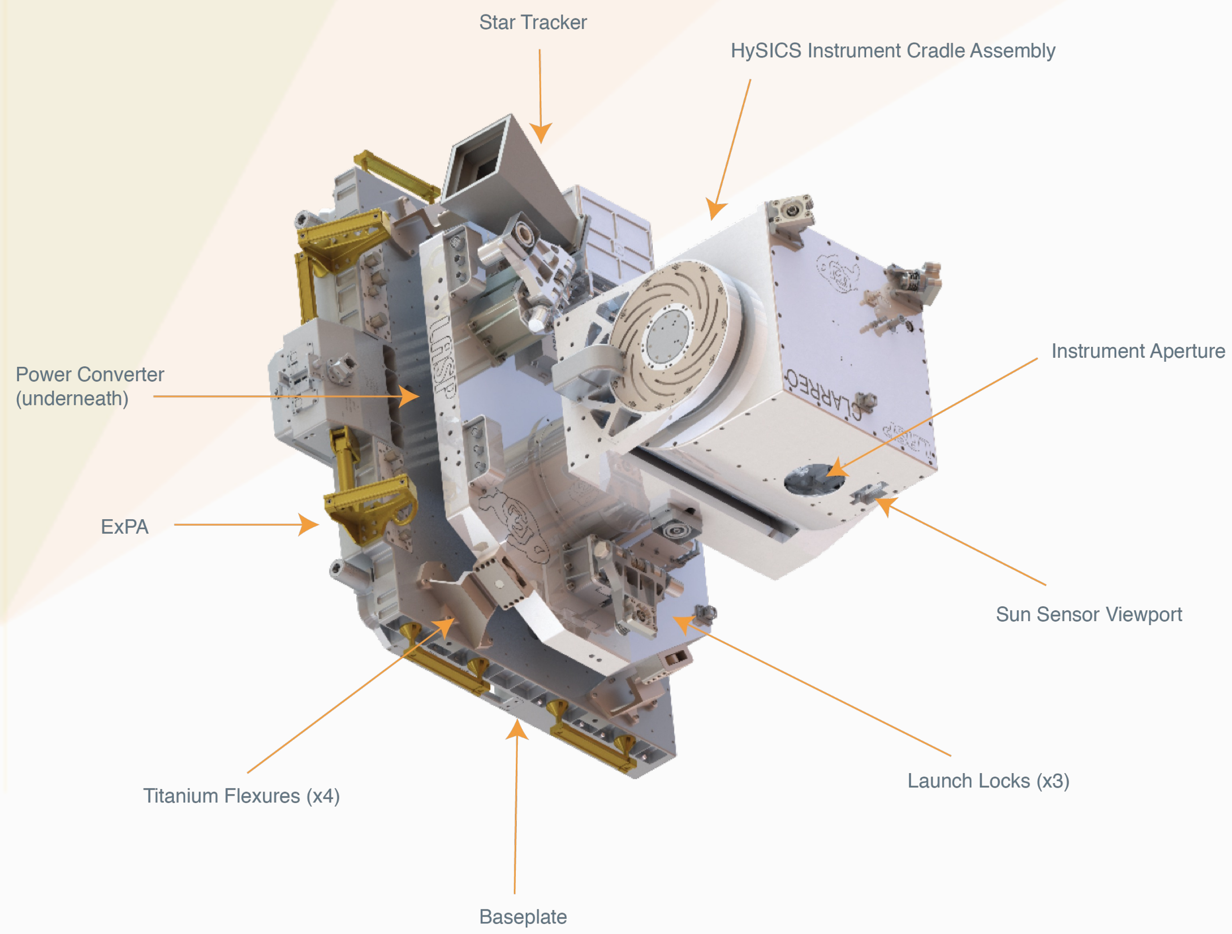
Raj Bhatt
and CPF Team
NASA Langley Research Center

32nd CALCON Technical Meeting
June 12-15, 2023

CLARREO Pathfinder Payload

CLARREO Pathfinder

HySICS: HyperSpectral Imager for Climate Science



Push-broom spectrometer

Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Radiometric Uncertainty	0.3% (1-sigma)
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Platform	ISS

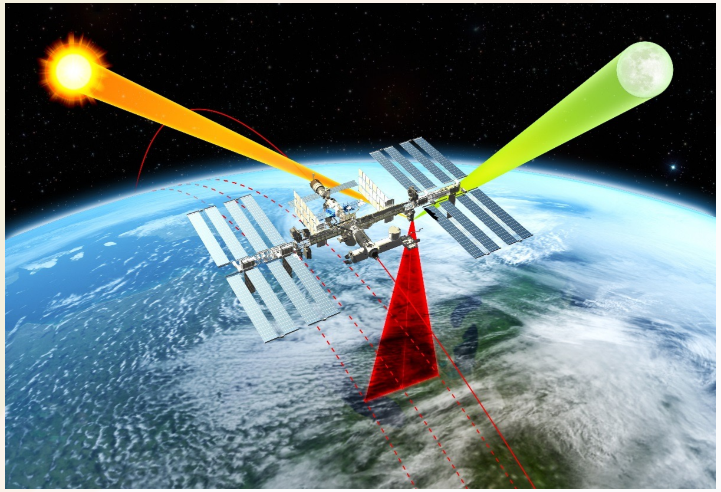
Being built by Laboratory for Atmospheric and Space Physics (LASP) @ University of Colorado

https://clarreo-pathfinder.larc.nasa.gov/

CPF Science Objectives

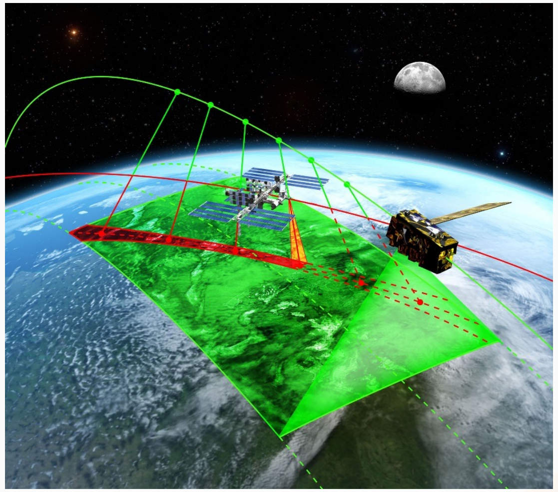
CLARREO Pathfinder

Objective #1: High Accuracy SI-Traceable Reflectance Measurements



Demonstrate on-orbit calibration ability to reduce reflectance uncertainty by a factor of ***5-10 times*** compared to the best operational sensors on orbit.

Objective #2: Inter-Calibration Capabilities



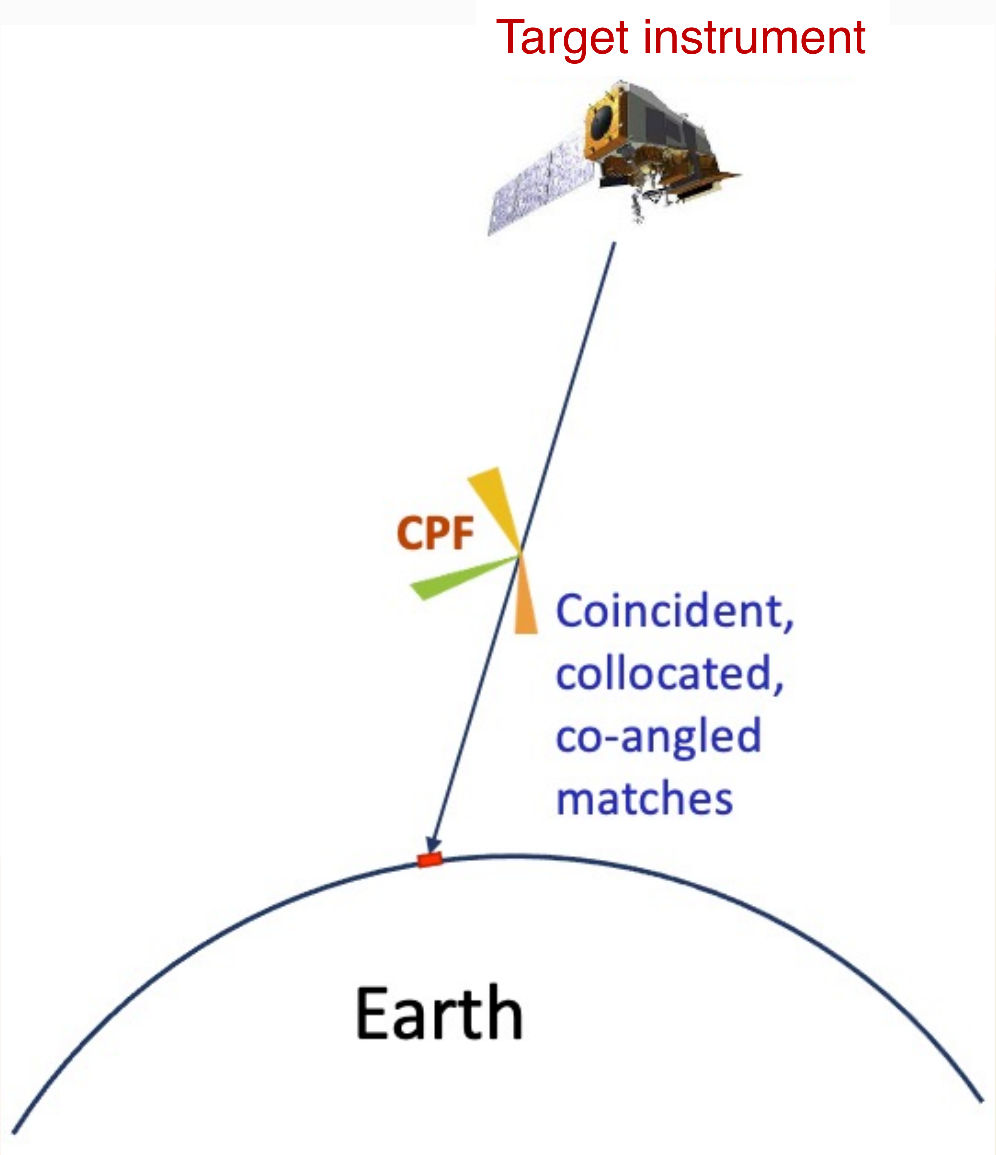
Demonstrate ability to transfer calibration to other key RS satellite sensors by inter-calibrating with CERES & VIIRS.

https://clarreo-pathfinder.larc.nasa.gov/

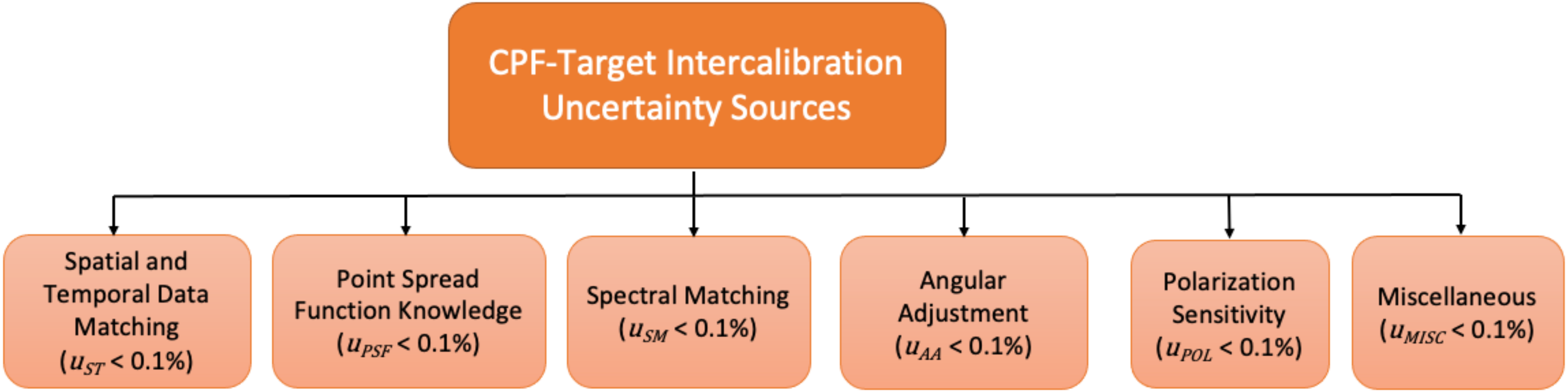
	Objective #1	Objective #2
Uncertainty	Spectrally-resolved & broadband reflectance: ≤0.3% (1σ)	Inter-calibration **methodology** uncertainty: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for inter-cal, lunar obs Level 1B: Approx. consistent spectral & spatial sampling, best for science studies using nadir spectra	Level 4: One each for CPF-VIIRS & CPF-CERES inter-cal. Merged data products including all required info for inter-cal analysis

Intercalibration between CPF and Target Instrument

- An idealized intercalibration setup requires perfectly matched data
  in **time**, **space**, **angles**, and **wavelengths**
- Realistic intercalibration allows finite differences in sampling to define coincident matches, thereby resulting in several sources of uncertainty
  - *Spatial and temporal mismatch*
  - *Angular differences (SZA, VZA, and RAA)*
  - *Spectral band differences*
- CPF will demonstrate a state-of-the-art intercalibration methodology mitigating the uncertainties from imperfect data matching
  - *2-axis pointing capability*
  - *Substantially alleviate impacts from spatial, angular, and spectral mismatches via advanced algorithms*



CPF-Target (CERES or VIIRS) Intercalibration Uncertainty Budget



Spatial convolution of CPF spectra and target instrument measurements within intercalibration footprints

Applicable to CERES only

Difference in spectral coverage between CPF and target instrument

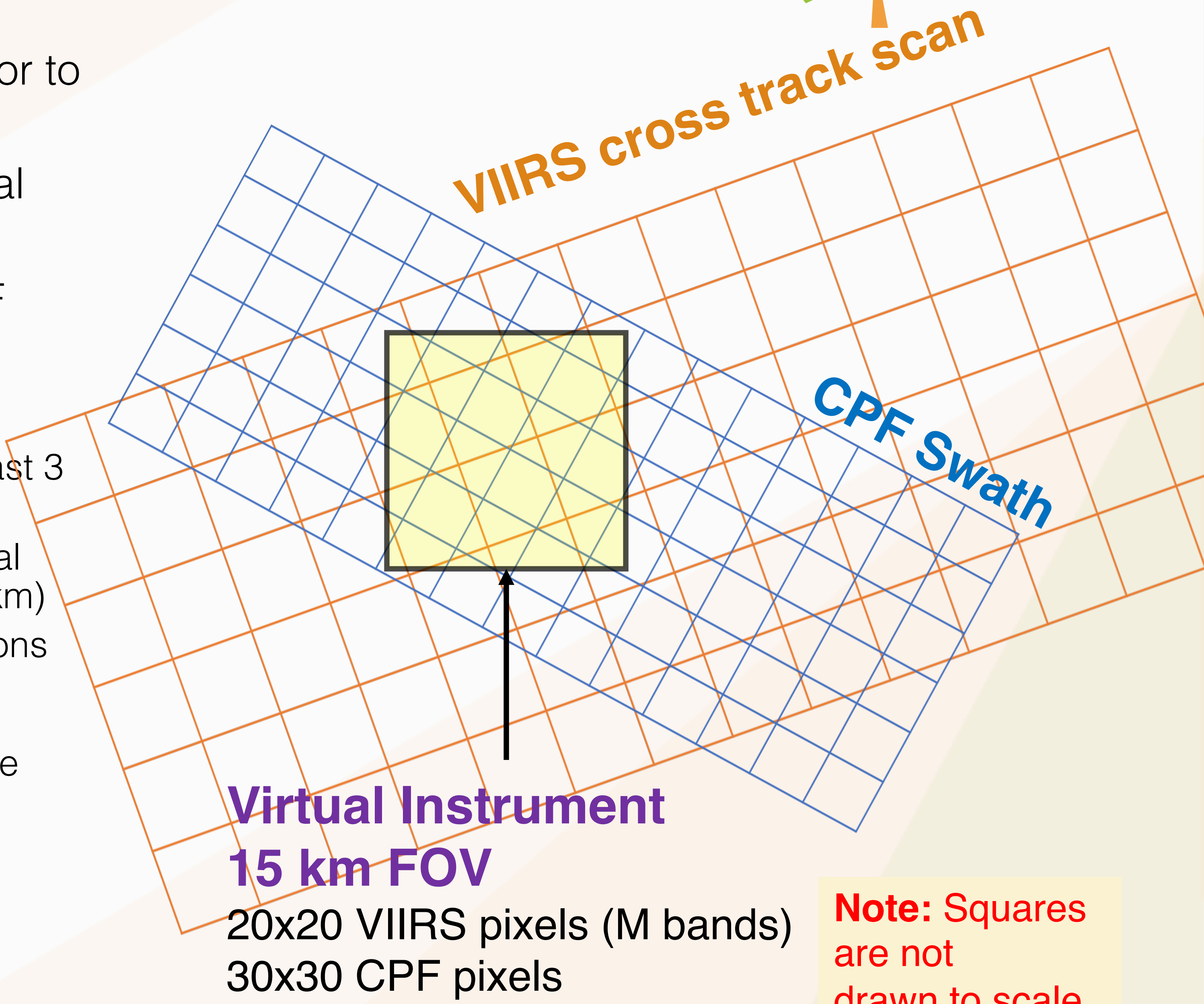
Imperfect angles matching between CPF and target instrument

Uncertainty contribution due to differing polarization sensitivity of CPF and VIIRS

Uncertainty contribution due to any radiometric response variability in the target instrument samples within a month

Temporal and Spatial matching noise

- Spatial mismatching is a prime contributor to uncertainty budget
- For VIIRS, 15 km (at nadir) FOV for spatial convolution
- For CERES, prelaunch PSF used for CPF spatial convolution
- Based on Wielicki et al. (2008)
  - Large intercalibration FOV preferred (at least 3 to 10 times the native spatial resolution)
  - Dependence on time simultaneity is minimal below 6 minutes for larger FOV (e.g., 100 km)
  - Based on AVHRR matches over polar regions
- Revisited the sampling study
  - Emulating scene variability that CPF will see
  - Used GOES-ABI 5-min interval images to estimate temporal matching noise

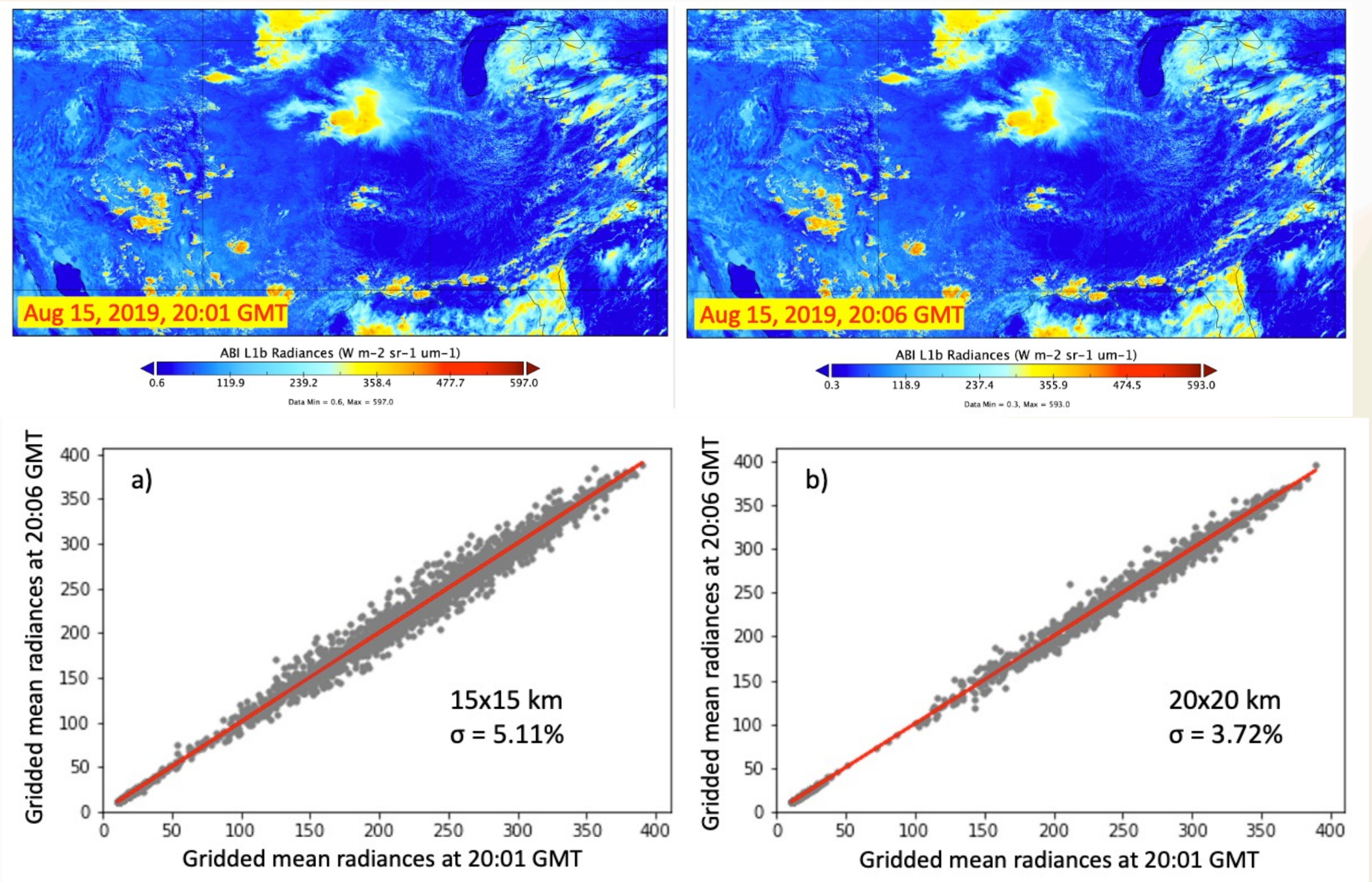


Note: Squares are not drawn to scale

Spatial and Temporal Matching Noise

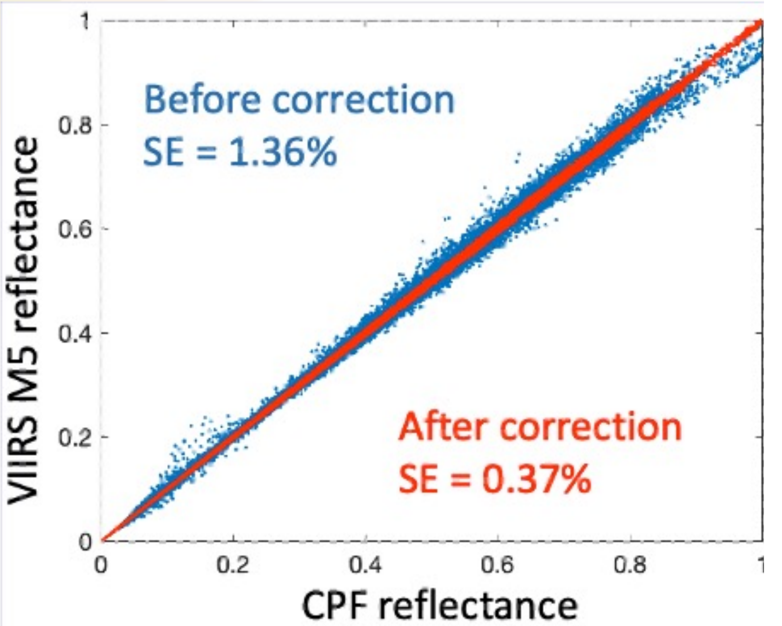
- GOES-16 ABI band 2 consecutive CONUS images (5 min apart)
- Estimated random data matching noise of 5% -> Required samples is 3K/month

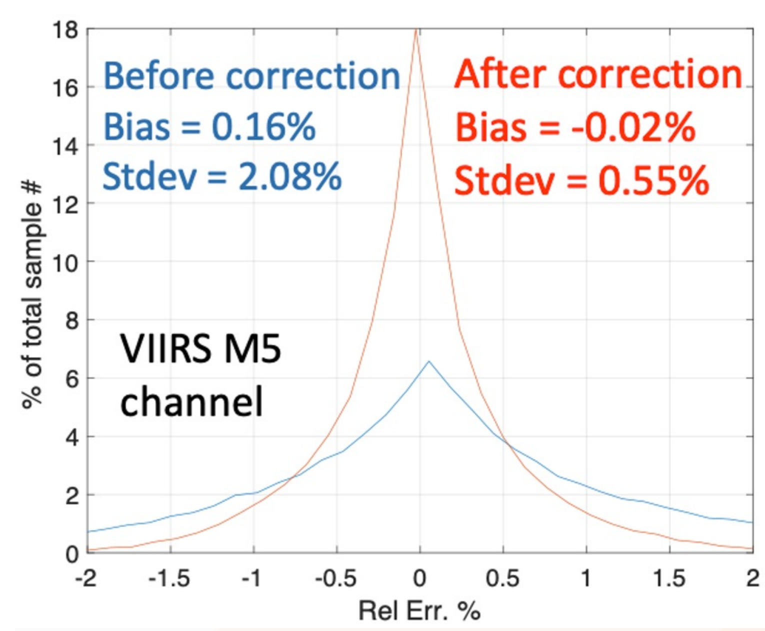
$$u = \frac{\sigma}{\sqrt{N}}$$

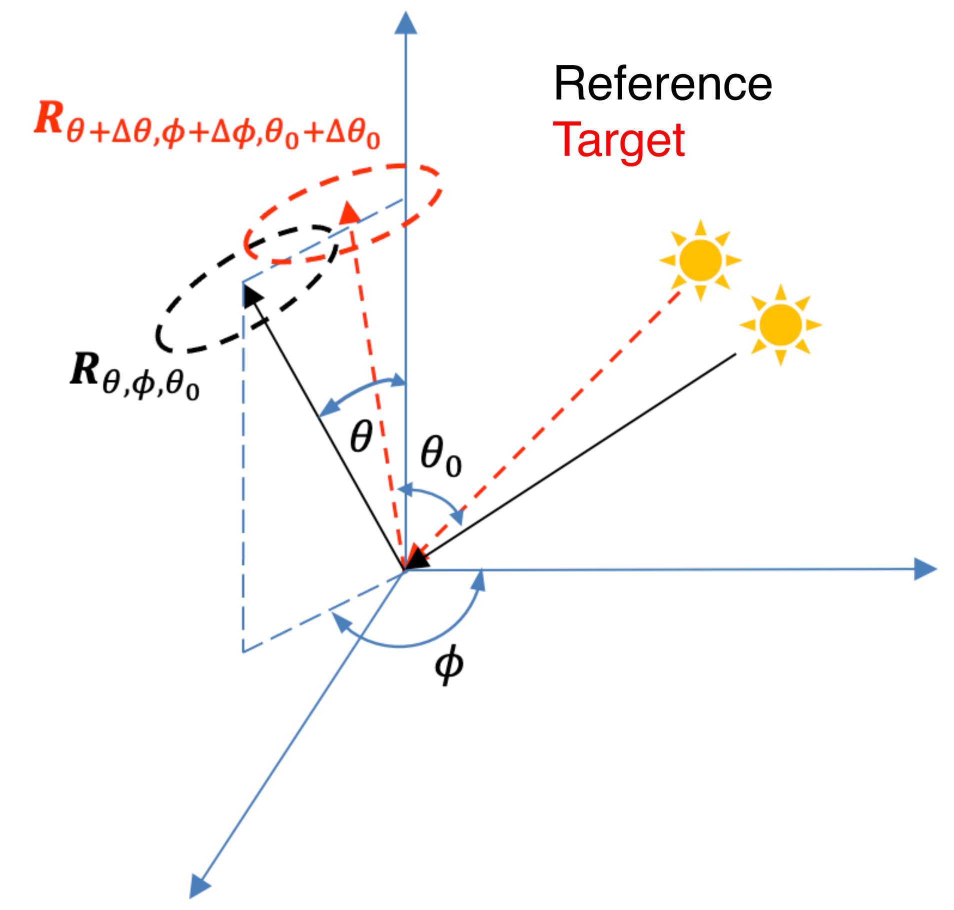


CPF-CERES Angular Adjustment

- CPF IC team has developed a PCRTM-based algorithm for angular adjustment
- Angular correction LUTs generated based on thousands of simulated CPF-like radiance spectra (randomly chosen) at different angular conditions
- Significant reduction of bias and noise after angular correction





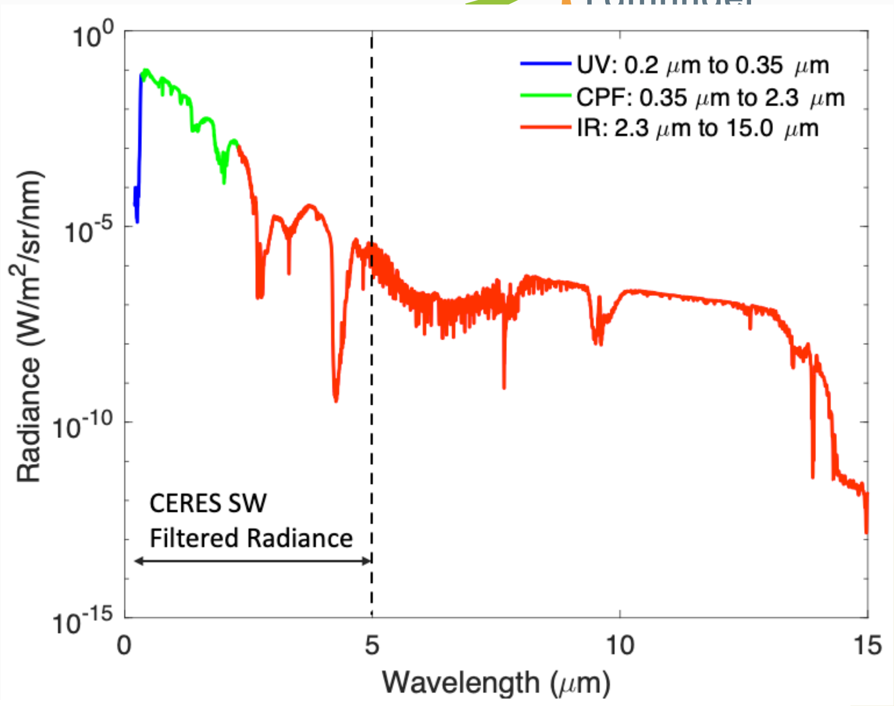


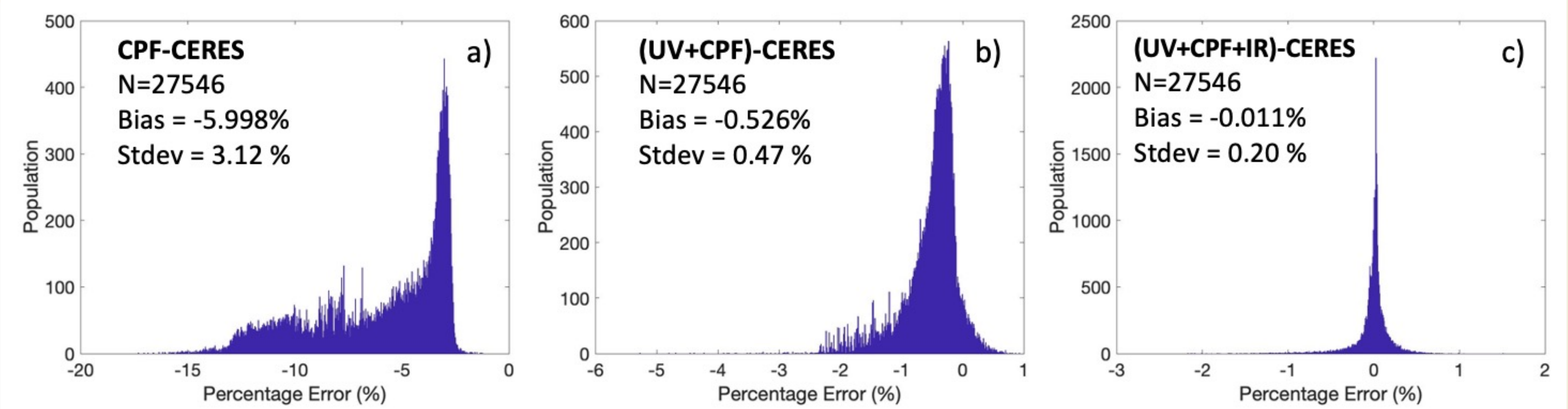
$$\Delta R = R_{\theta+\Delta\theta,\theta_0+\Delta\theta_0,\phi+\Delta\phi} - R_{\theta,\theta_0,\phi}$$

Algorithm Development: *Wan Wu & Xu Liu*

Spectral range extension for CPF-CERES intercalibration

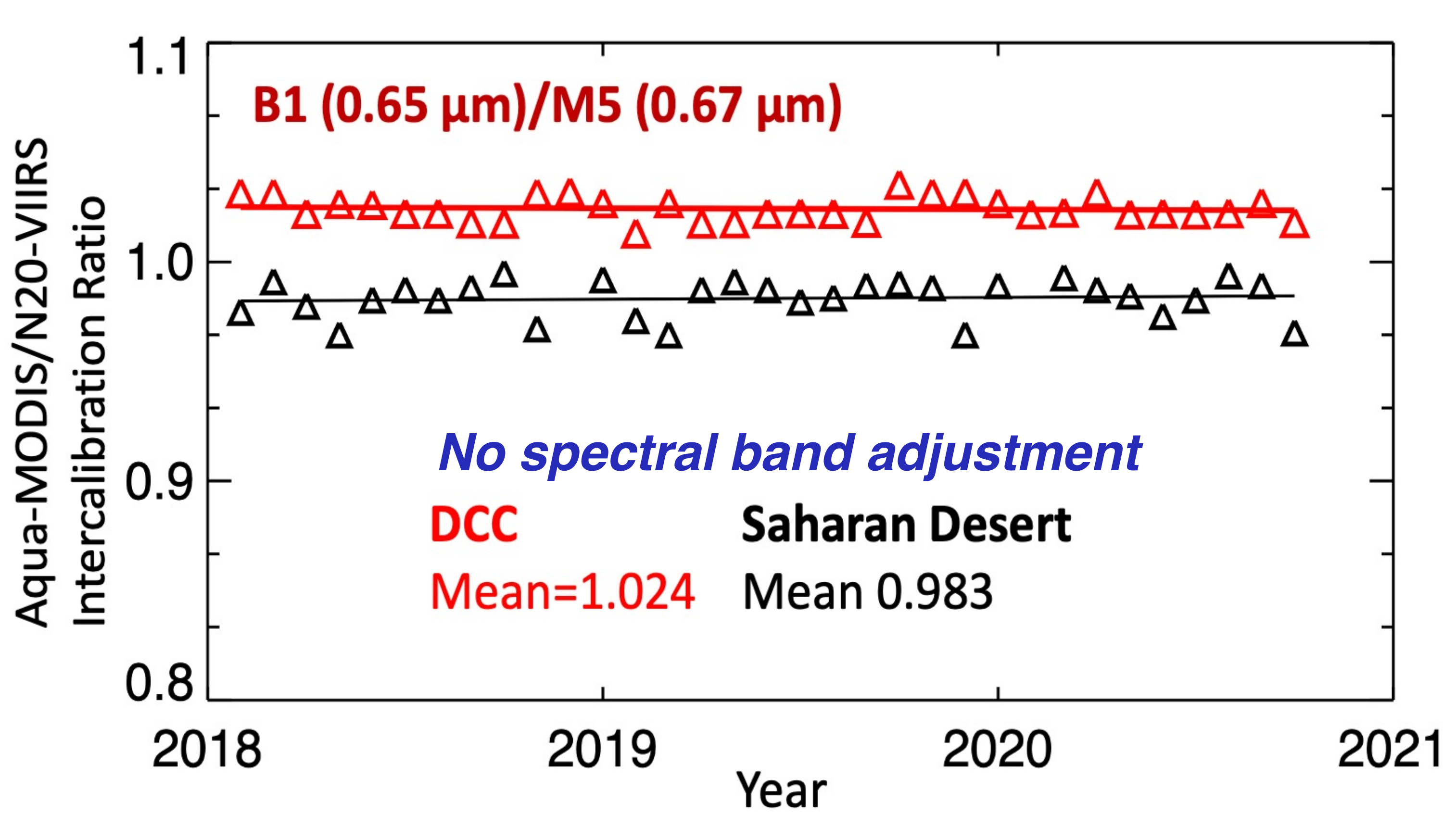
- CPF measurements must be extended to **200 nm – 5 µm** to account for CERES unfiltered radiance definition
- Leverage spectrally redundant information available in the CPF-measured portion and utilize pre-established spectral correlation relationships among wavelengths to extend the CPF spectrum below 350 nm and above 2300 nm
- Anticipated **1-σ uncertainty < 0.1%**

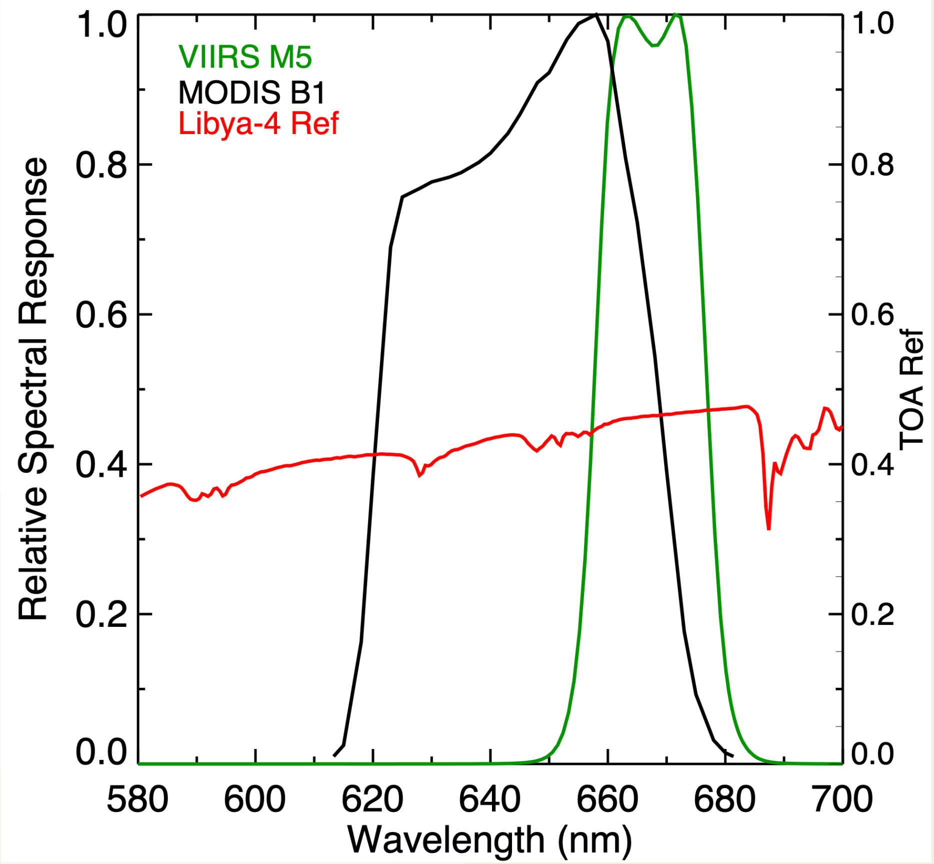




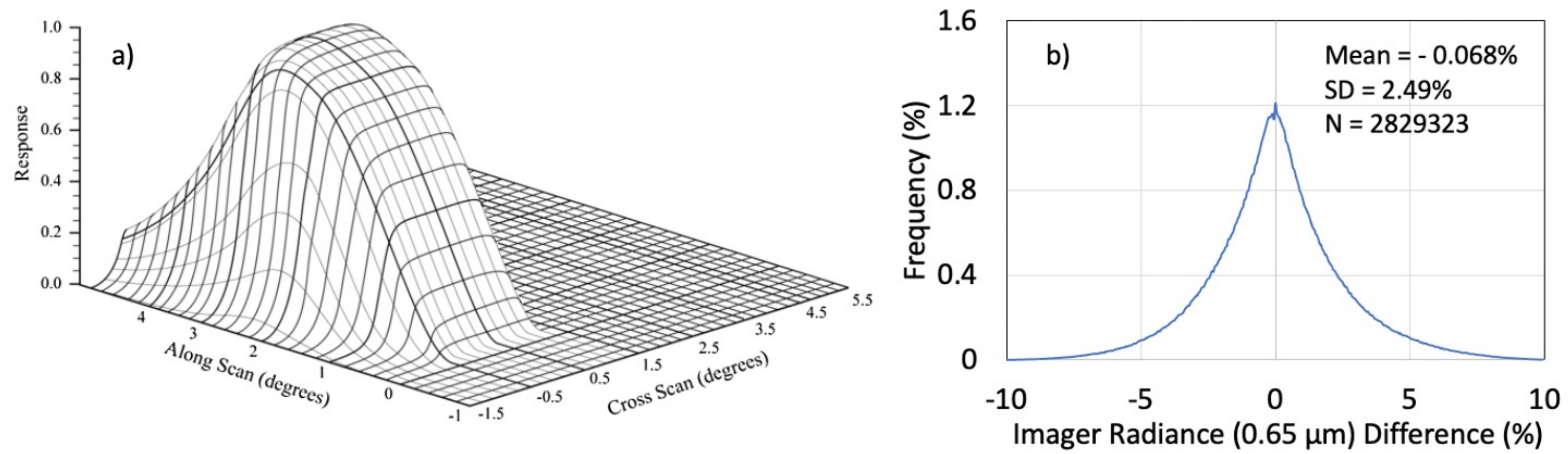
Spectral wavelength matching

- Spectral mismatch between reference and target sensors results in scene-dependent intercalibration results (e.g., MODIS and VIIRS)
- Hyperspectral measurements from reference sensor substantially mitigates the spectral difference issue
- At 4 nm spectral sampling, the impact is within 0.1% for MODIS bands (Wu et. al. 2015)



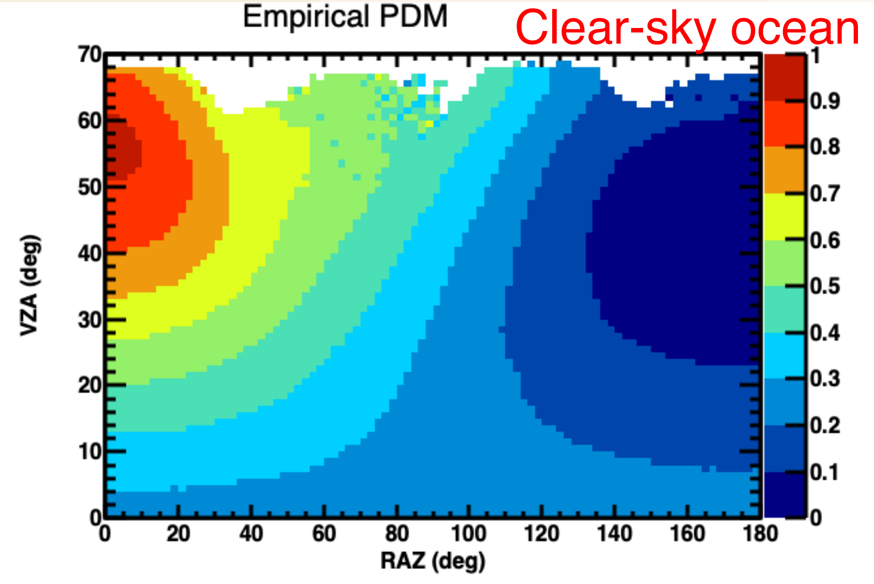


CERES Point Spread Function uncertainty



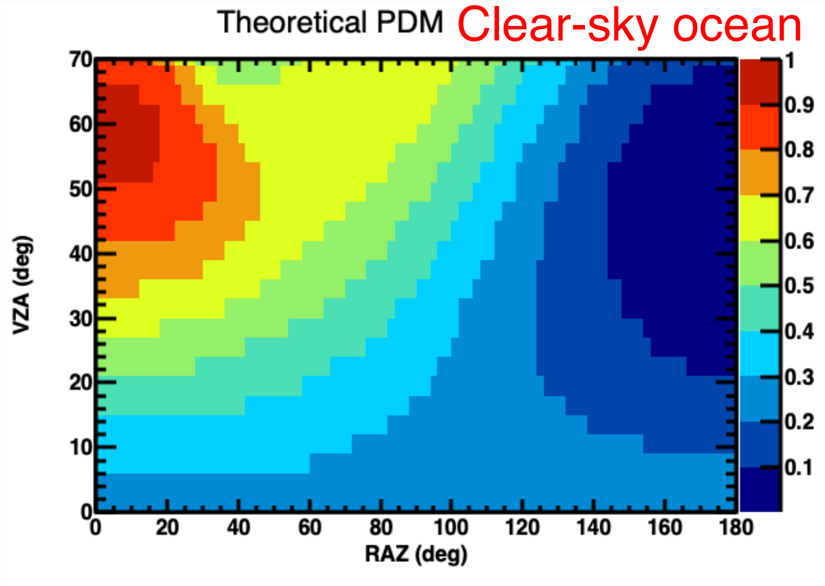
- CPF Level-1B pixel radiances undergo spatial convolution with the CERES PSF to derive CPF intercalibration footprints
- CERES pointing accuracy and PSF centroid verified using Lunar and coastline observations
- Impact of PSF centroid displacement on spatial data convolution studied via artificial perturbation to PSF (shifting centroid along the scan direction by 0.415° degrees)
- Recorded systematic uncertainty of approximately 0.07% and a random variability of around 2.5% over homogeneous footprints

Polarization Distribution Model (PDM) Look-up Tables



PDM Application Module: Using VIIRS scene characterization info from L2 files, identifies correct LUT DOP/AOLP estimates from ePDMs & tPDMs

PDMs will be used to identify low-polarized radiances (DOP<0.1).



Empirical PDM Conditions: Constructed from PARASOL/POLDER Data

- SZA = [40º,50º]
- Band = 670 nm
- AOD = [0.05, 0.1]
- Wind Sp. = [2 m/s,10 m/s]

Developed by: *Daniel Goldin & Costy Lukashin*

Development Lead: *Daniel Goldin*

ePDM
- Based on Polder measurements
- 3 wavelengths: 490, 670, and 865 nm
- Wavelength interpolation

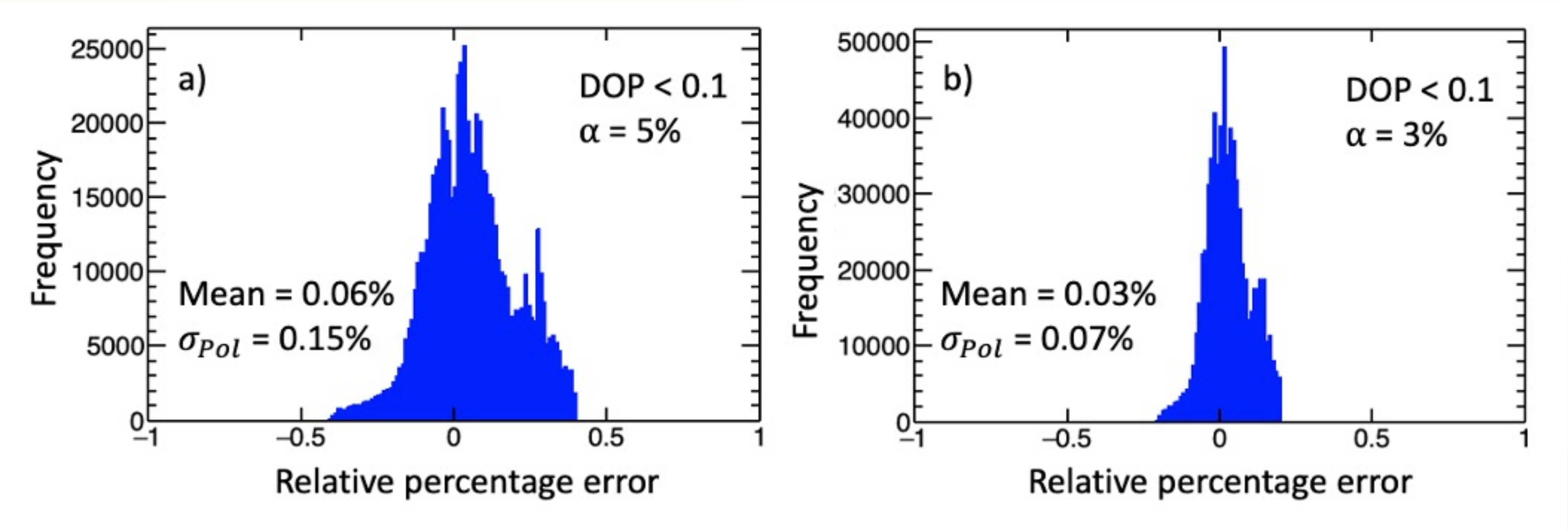
tPDM
- ADRTM simulation
- All wavelengths

Theoretical PDMs: Simulated using Adding-Doubling Radiative Transfer Model

- SZA = 45º
- Band = 672 nm
- AOD = 0.076
- Wind Sp. = 7.5 m/s

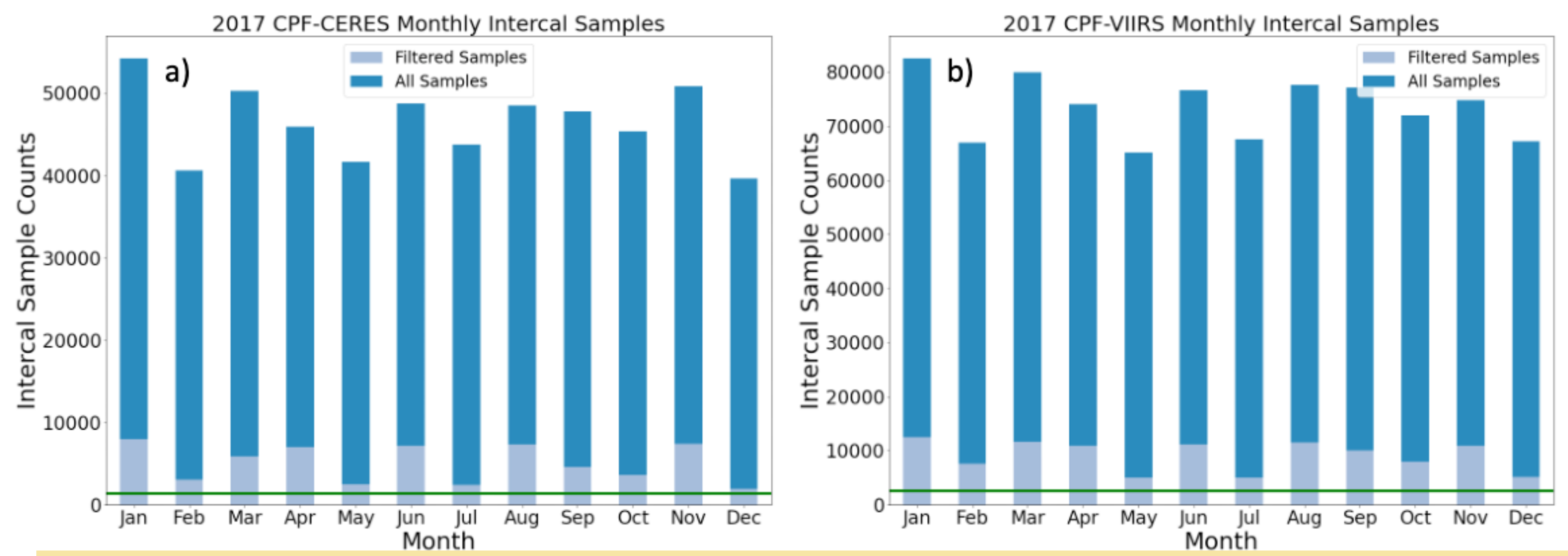
Simulated by: *Wenbo Sun*

Polarization sensitivity difference uncertainty



- VIIRS polarization sensitivity is up to 5% (band averaged diattenuation for M1 band)
- CPF polarization sensitivity is below 1% for wavelengths < 1400 nm
- Frequency distribution of reflectance difference between CPF and VIIRS due to differing polarization sensitivity and limiting the DOP of intercalibration samples from polarized radiances to below 0.1 for (a) M1 band that has the highest band averaged diattenuation coefficient of 5% and (b) remaining other reflective solar bands for which the diattenuation coefficient is less than 3%.

Intercalibration Sampling Estimates from low-fidelity simulation data for year 2017



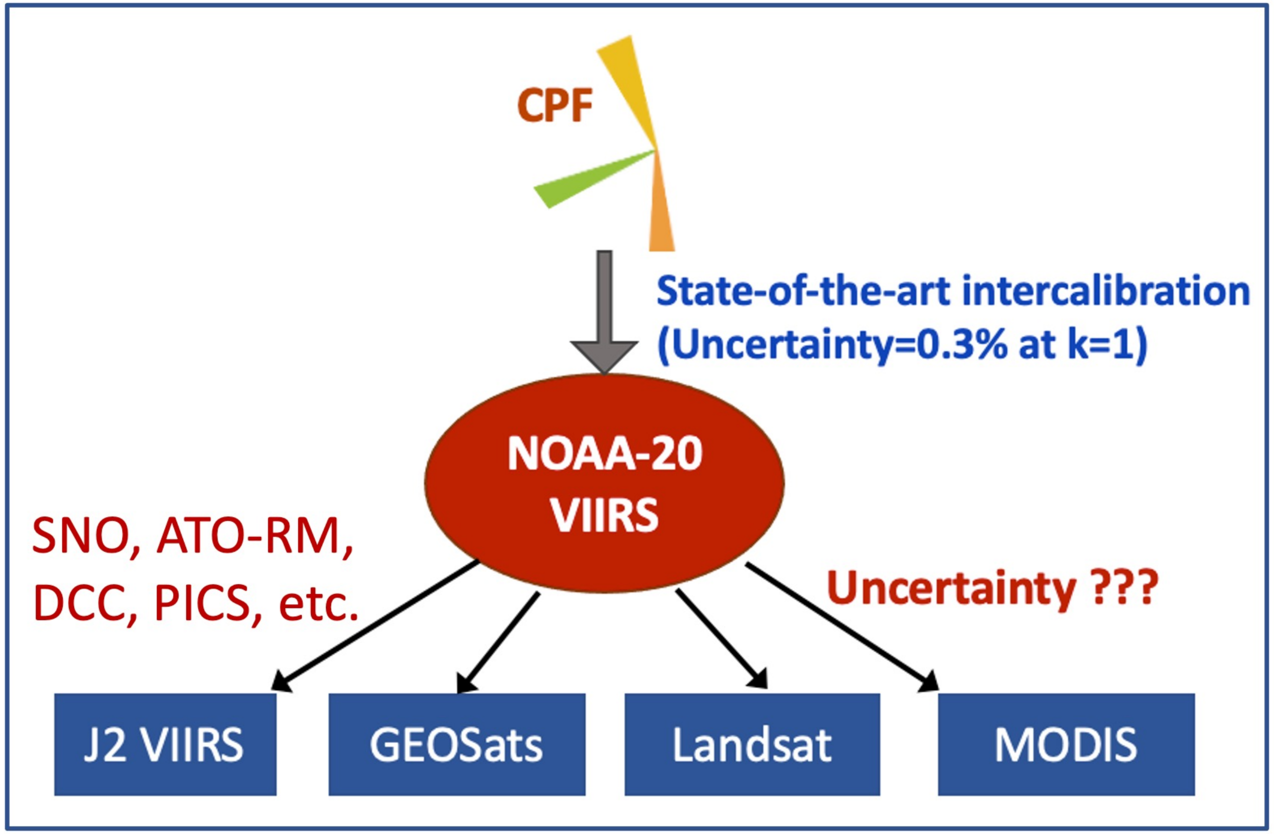
Sample selection criteria

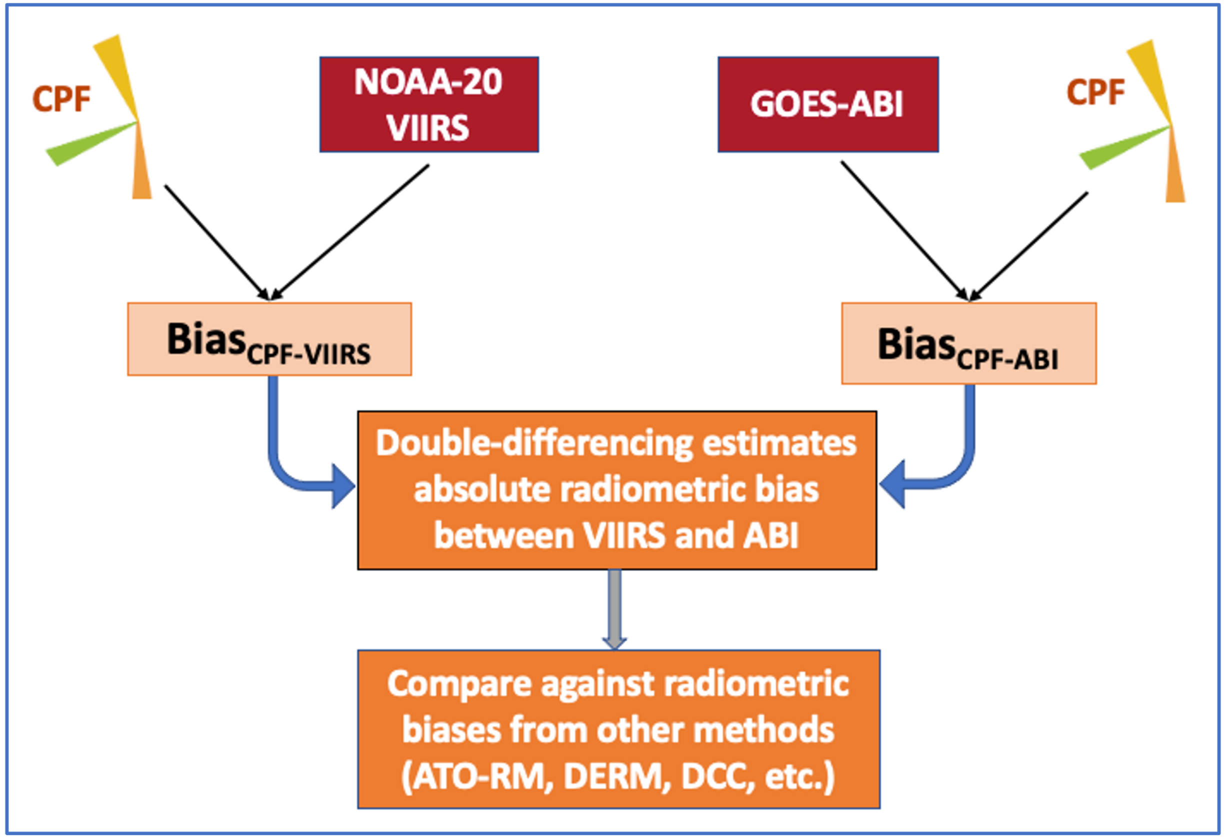
- a) SZA<60° and VZA <60° to ensure high signal-to-noise ratio;
- b) 5°<RAA<175° to avoid hotspot and sun glint conditions;
- c) a spatial homogeneity factor of less than 0.2 for visible wavelength (0.65 μm) to exclude extreme heterogenous scenes;
- d) spatial field of view coverage of greater than 95%;
- e) maximum allowable time difference of 10
- f) DOP<0.1 for VIIRS
- g) Sampling loss due to ISS reboost events 10%

Green line represents minimum required sample size to meet uncertainty threshold

CPF benefits to Intercalibration Community

- Improved reference instrument for satellite intercalibration
- Lunar reflectance characterization
- PICS and DCC characterization at hyperspectral level
- Augmenting existing intercalibration approaches





CPF Timeframe Update

- CPF launch delayed (previous launch date was Dec 2023)
- Payload delivery date: No earlier than Spring 2024
- ISS Schedule : Launch no earlier than late 2025 (TBR)

Conclusions

- CPF will demonstrate a state-of-the-art intercalibration capability (0.3% uncertainty at k=1) by calibrating CERES and VIIRS against high-accuracy CPF measurements
  - Extensive # of intercalibration footprints
  - CPF pointing capability
  - PDMs
  - PCRTM-based angular adjustments and spectral corrections
- These algorithms can be extended to other GEO/LEO imagers

Community Benefits

- Scheduled nadir scans of CPF can be used to intercalibrate other RS imagers in GEO and LEO orbits
- CPF measurements will assist validating GSICS intercalibration methodologies (SNO, PICS, DCC, SBAF etc.)
- Improve Lunar characterization models
- High-accuracy SI traceable CPF can serve as a next-generation calibration standard for on-orbit intercalibration