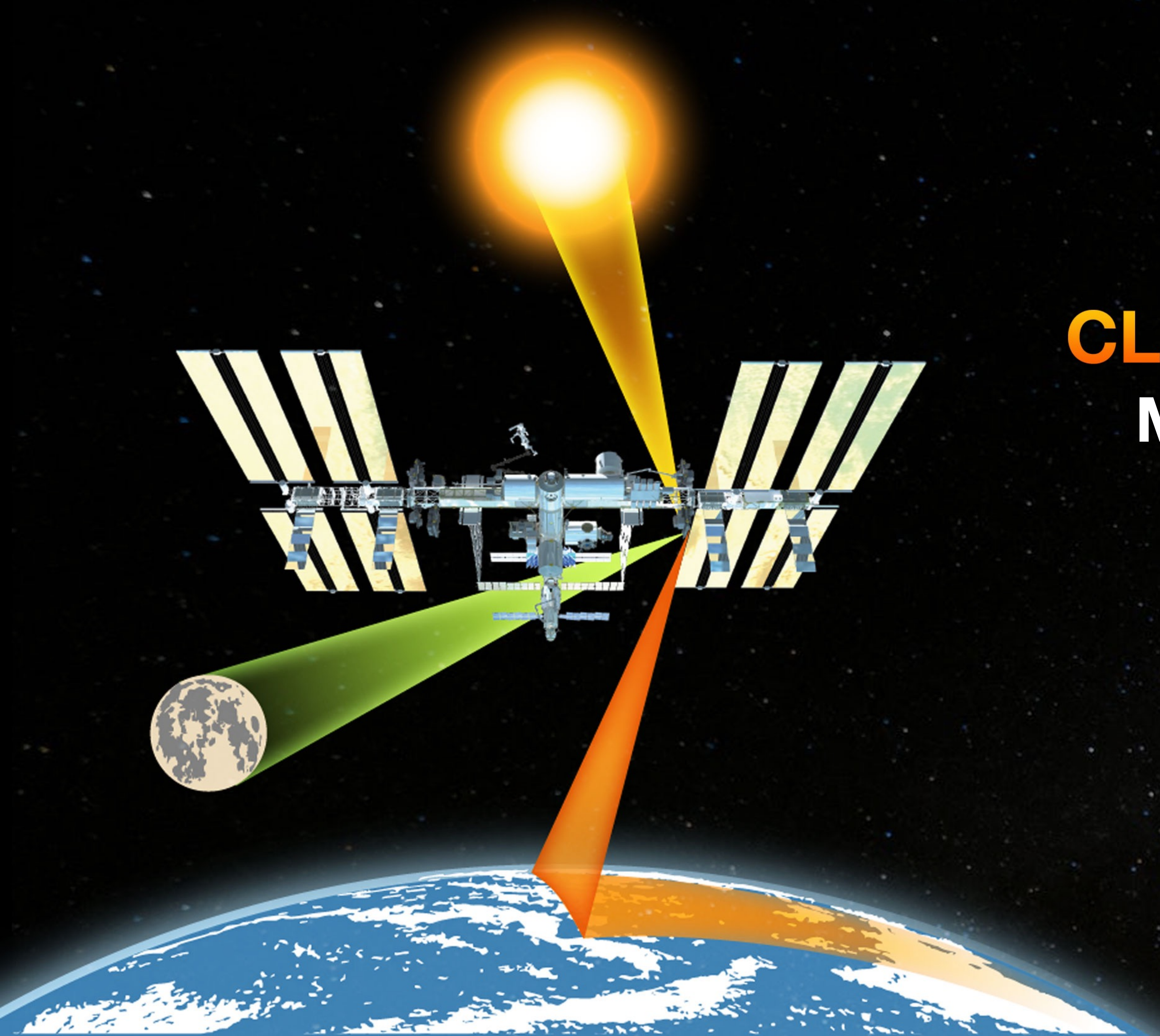


National Aeronautics and Space Administration

NASA

CLARREO Pathfinder

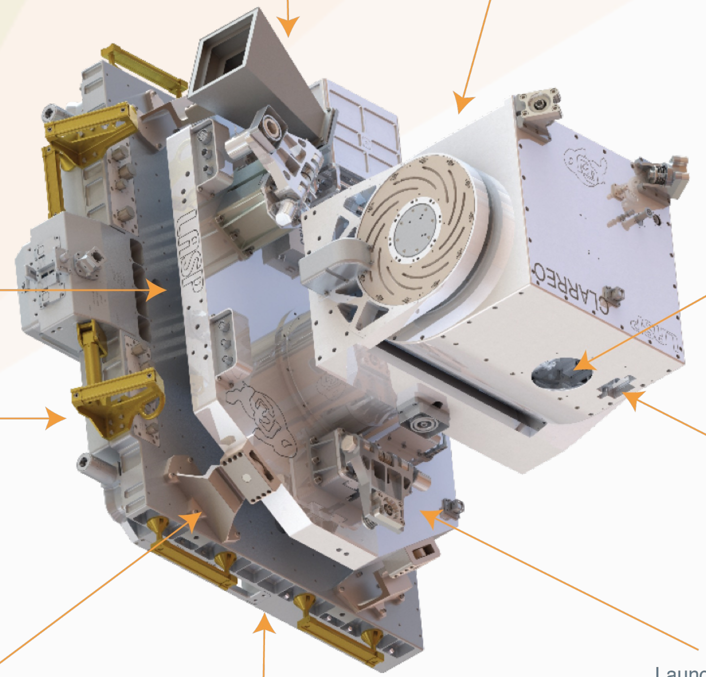
Mission Overview and its Intercalibration Capabilities

Raj Bhatt, Yolanda Shea
and CPF Team
NASA Langley Research Center

GSICS Annual Meeting 2024
Darmstadt, Germany
Mar 11-Mar 15, 2024

CLARREO Pathfinder Payload

HySICS: HyperSpectral Imager for Climate Science



Launch: No earlier than Feb 2026

Push-broom spectrometer

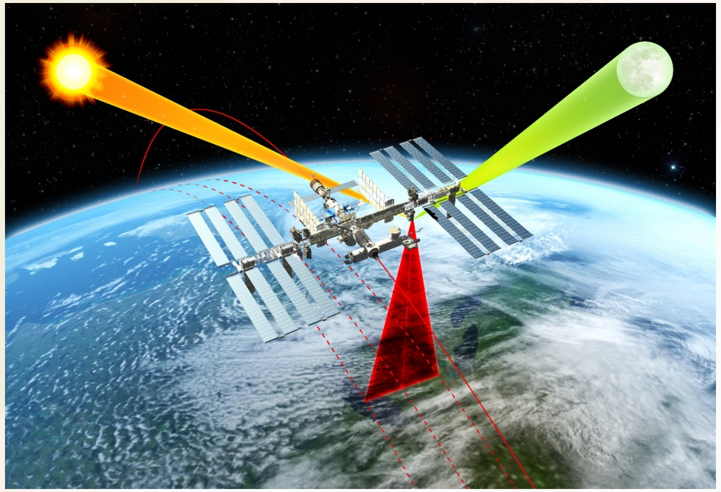
Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Radiometric Uncertainty	0.3% (1-sigma)
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Platform	ISS

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

CPF Science Objectives

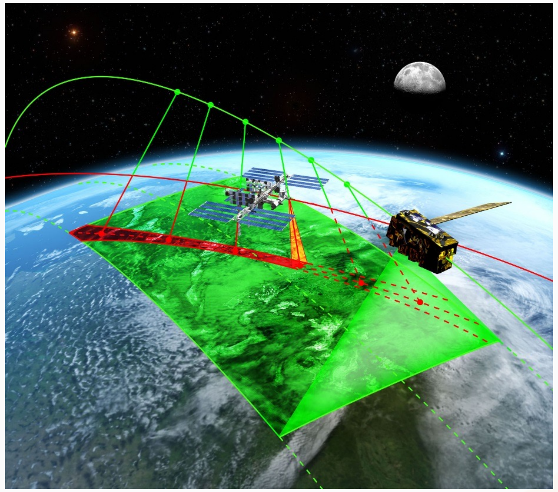
CLARREO Pathfinder

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.

	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

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

LASP

Intercalibration: *A multidimensional data matching challenge!*

Spatial/Temporal Matching

- Spatial pixel resolution difference
- Non-zero temporal gap
- Mitigation: Use larger intercalibration footprints

Spectral Differences

- Scene dependent biases
- Accurate SBAF estimates needed for correction
- Hyperspectral measurements with <4nm sampling desired

Viewing/Solar Geometry

- May induce systematic biases
- Scene dependent corrections

Polarization Sensitivity

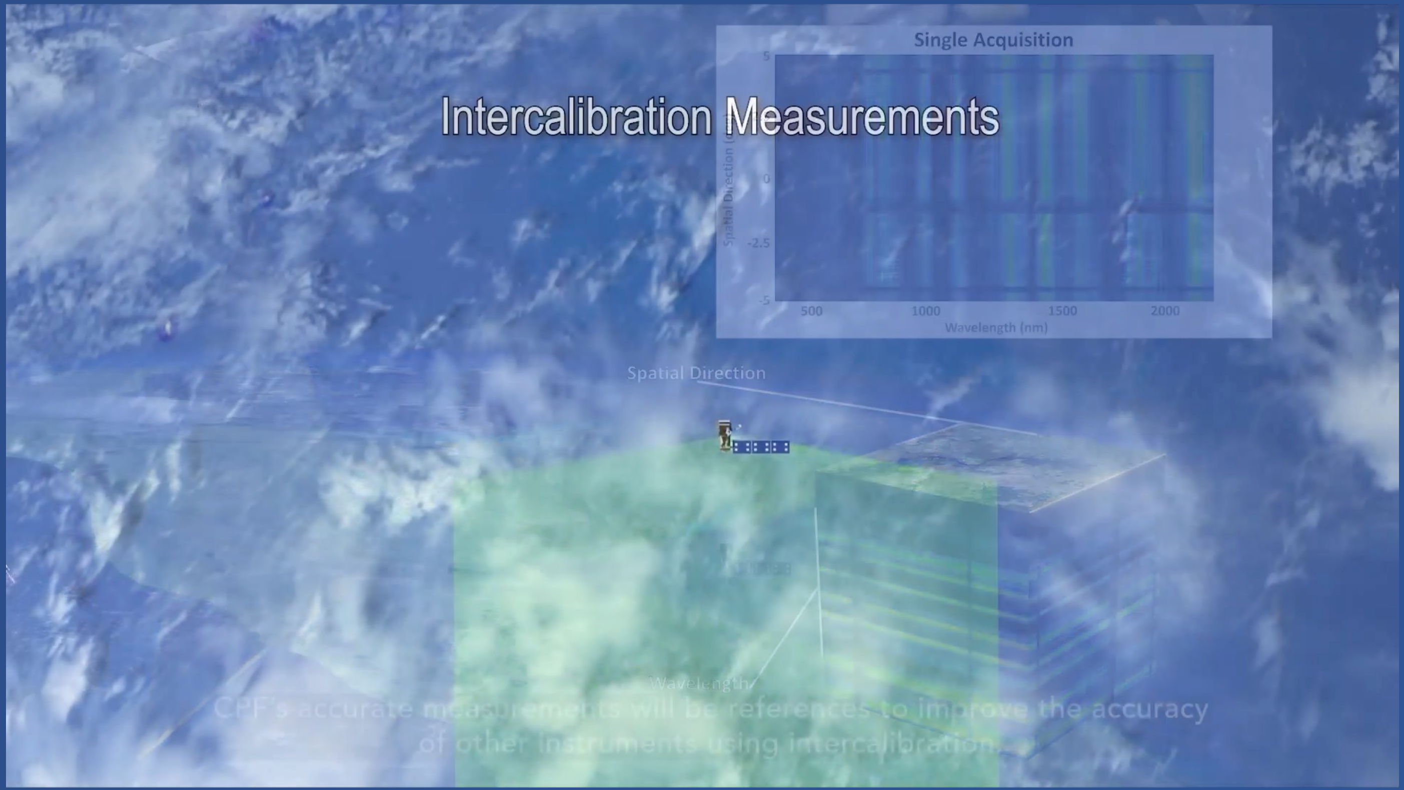
- Differing polarization sensitivity between Reference and Target
- Results in additional uncertainty in measuring polarized radiances
- Scene- and angle dependent

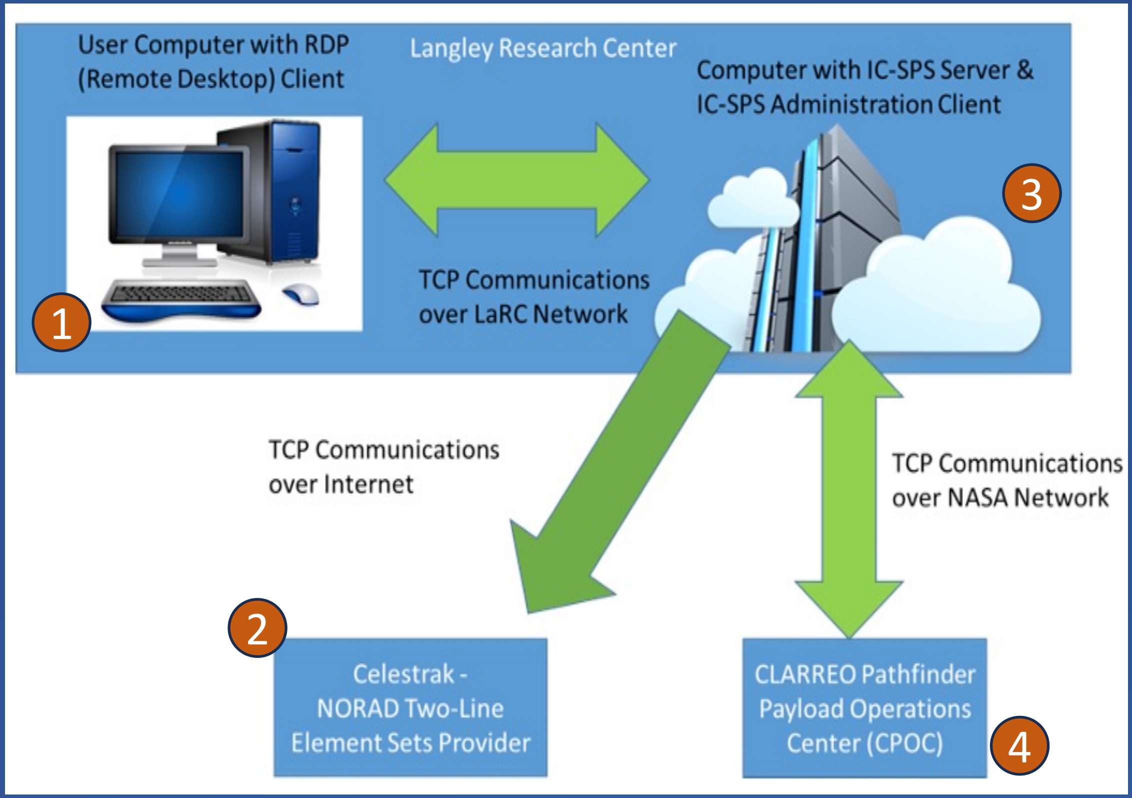
Miscellaneous

- Disparity in usage of reference solar spectra
- Scan-angle calibration dependency
- Sensor non-linearity

- In an idealized intercalibration setup, both the reference and target satellite instruments would acquire measurements that perfectly match in ***time***, ***space***, ***spectral response***, and ***viewing and solar geometry***
- CPF's ***2-axis pointing capability*** and ***novel algorithms*** to ***systematically analyze data matching uncertainties*** and ***substantially mitigate their impacts*** result in an ***unprecedented intercalibration accuracy***

Intercalibration Science Planning System (IC-SPS)

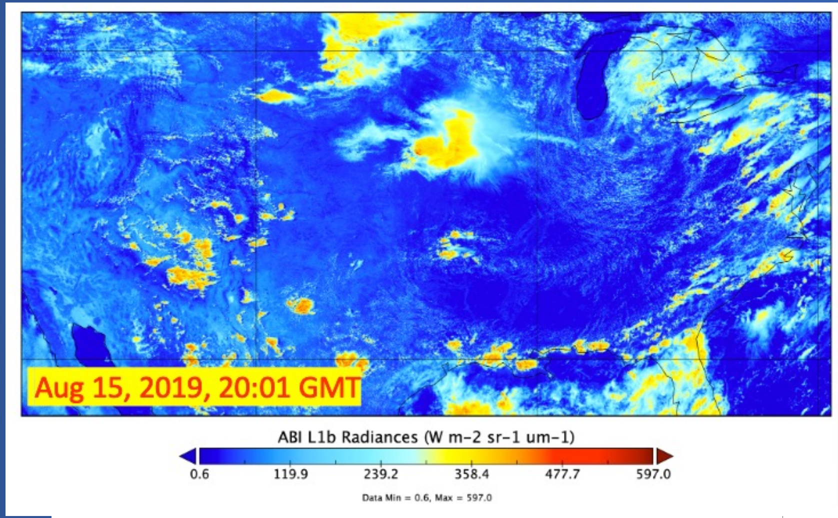


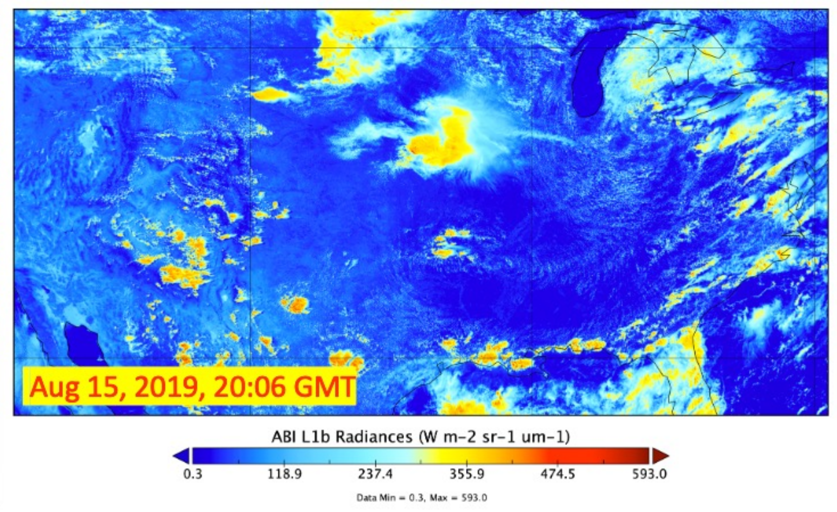


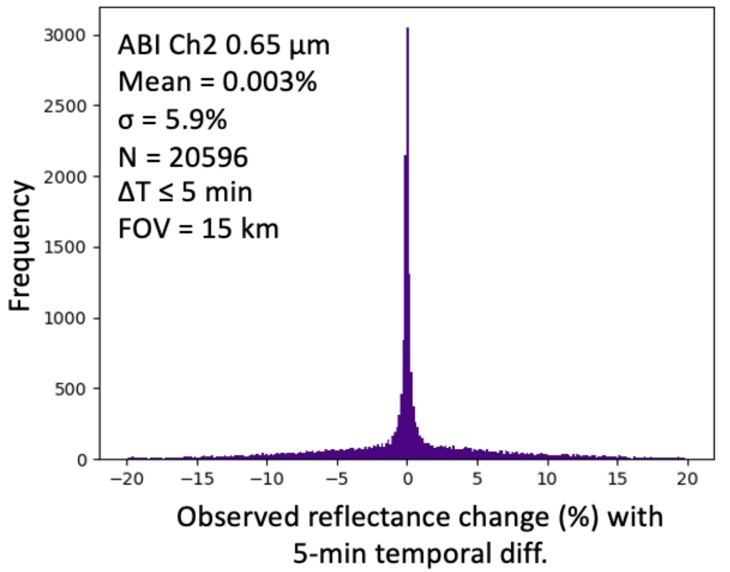
- IC-SPS is a custom developed software tool at LaRC to accurately predict intercalibration opportunities and provide that information to CPF Operations Center

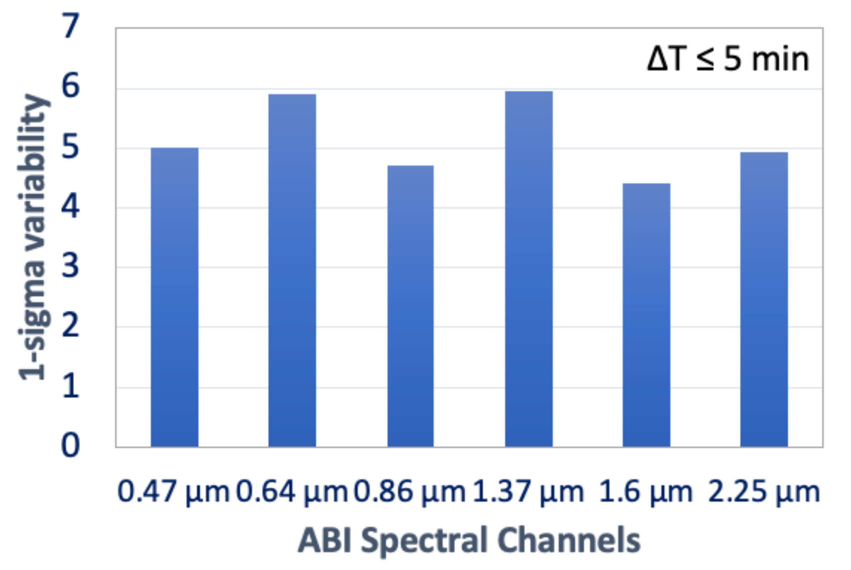
Spatial/Temporal Data Matching Strategy

- Comprehensive and systematic evaluation of spatial and temporal matching uncertainties, considering spatial footprint size, scene homogeneity, and spectral channels as variables
- Extension of 2008 Wielicki et al. study





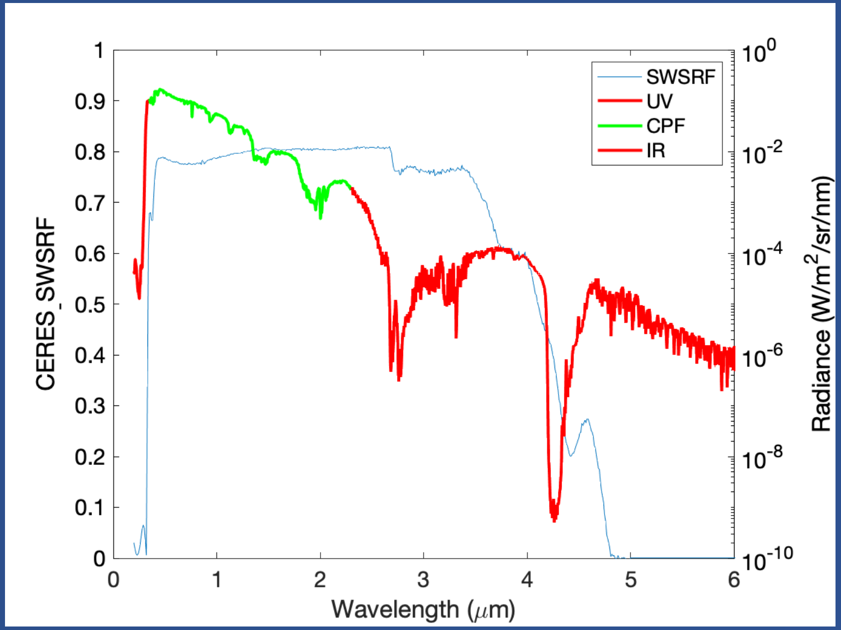




$$u = \frac{\sigma}{\sqrt{N}}$$

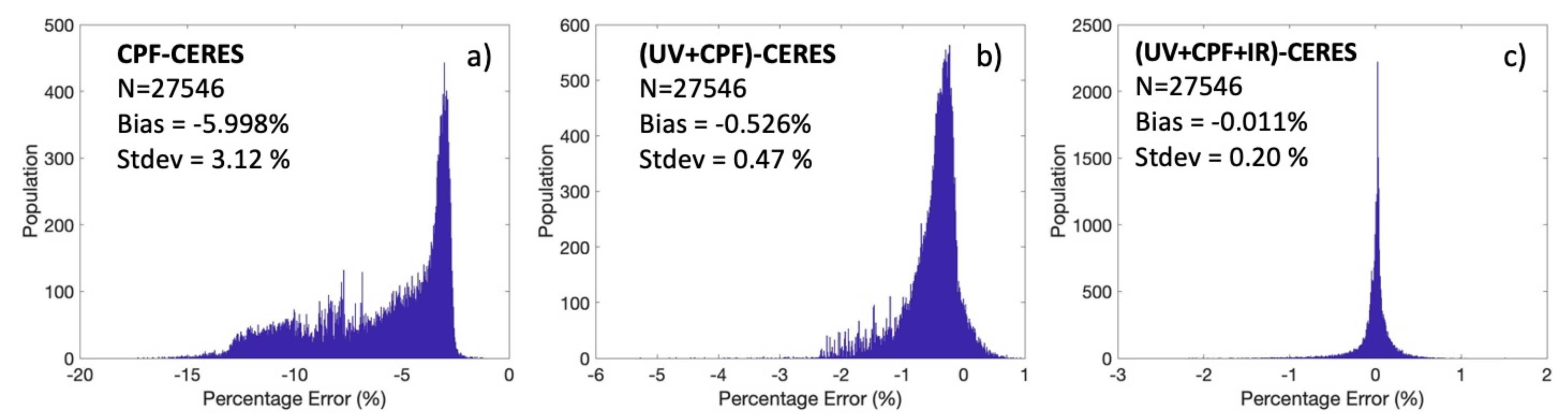
σ determines req. num. of intercal samples to limit data matching uncertainty below a given threshold (targeted u = 0.1%)

PCRTM-based Spectral Extension

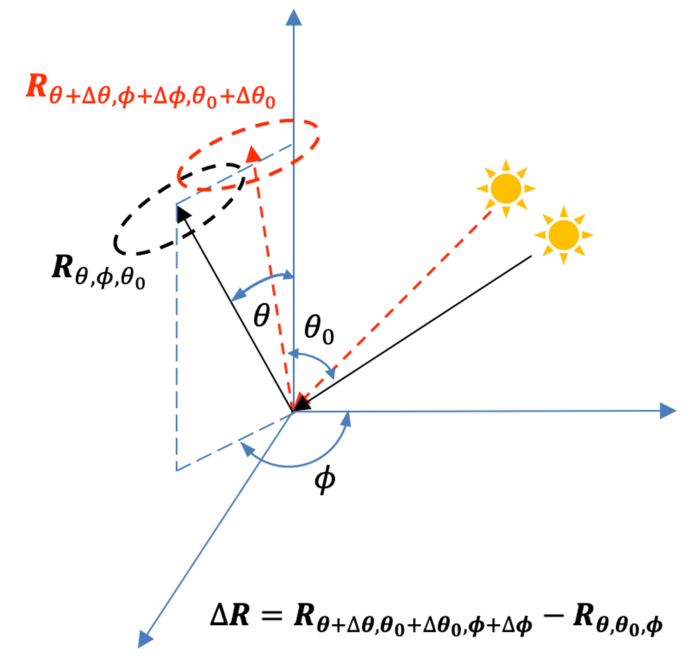


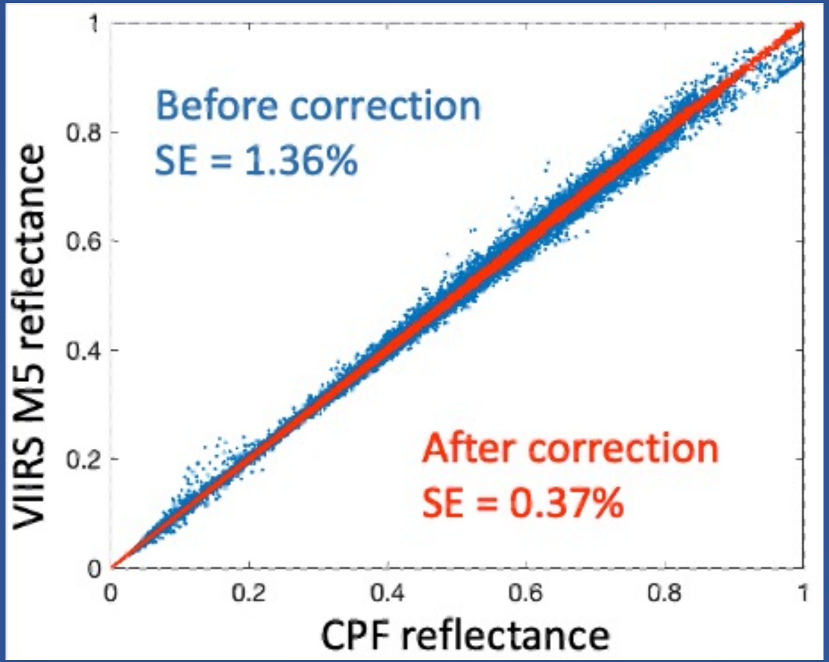
- CPF measurements must be extended to 200 nm – 5 μm to intercalibrate CERES SW channel
- Leverages spectrally redundant information available in the CPF-measured portion using Principal Component Analysis and utilize pre-established *spectral correlation relationships* among wavelengths to extend the CPF spectrum below 350 nm and above 2300 nm
- Anticipated *1-σ uncertainty < 0.1%*

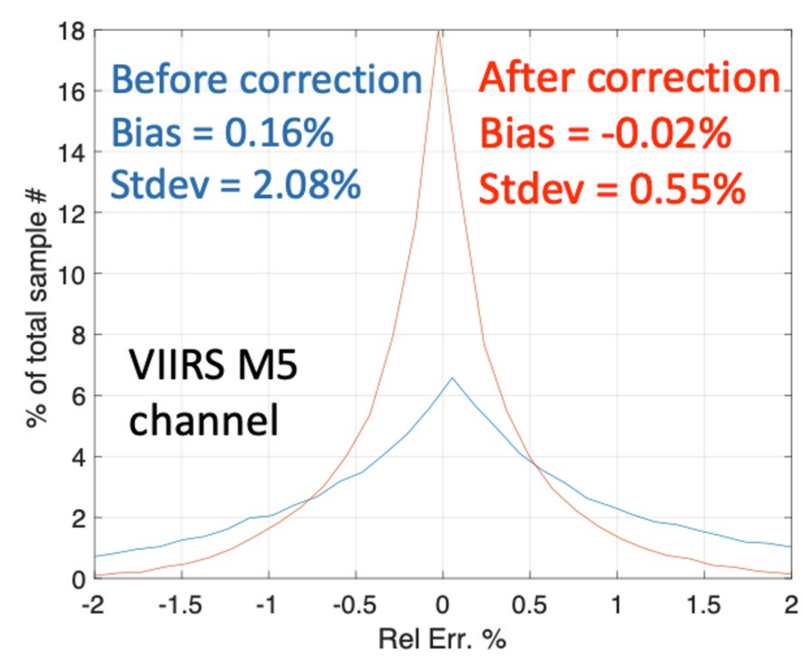
Yang et al. (2016)
Liu et al. (2016)



PCRTM-based Angular Correction



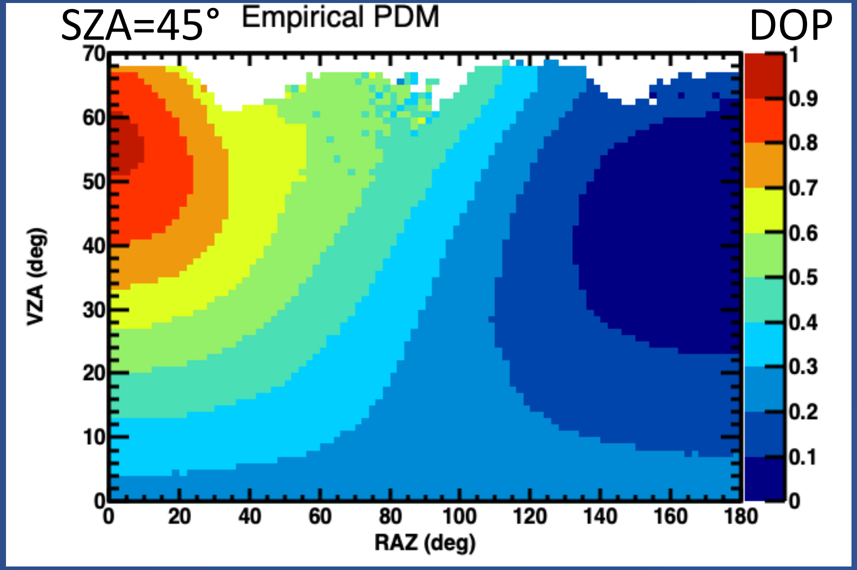


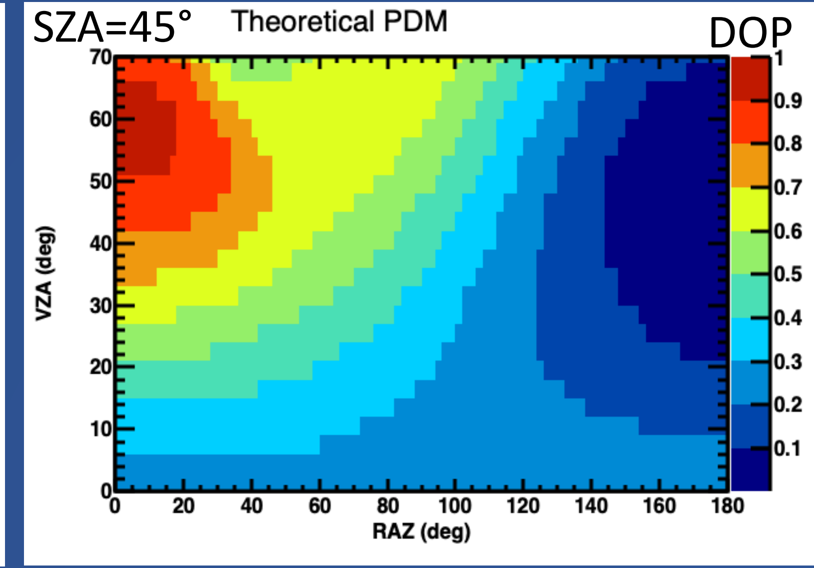


Wu et. al (2024)

- CPF team has developed a PCRTM-based algorithm for angular adjustment
- Extensive training database consisting of millions of CPF-like spectral radiances encompassing diverse surface types and atmospheric conditions and SZA-VZA-RAA combinations that cover the entire range of possible viewing and solar angles
- Leverages ***spectral correlation relationship*** to account for differences between observations acquired at slightly different sun-view geometries
- Significant reduction of bias and noise after angular correction (uncertainty goal = 0.1%)

Novel Polarization Distribution Models (PDMs)





Disparity between diattenuation coefficient of CPF and VIIRS result in differing reflectance measurements

- Contribute to random and systematic uncertainty
- PDMs will be used for identifying low polarized intercalibration footprints

Empirical PDM for Clear-Sky Ocean (0.67 μm)

- Constructed using PARASOL/POLDER Data
- 3 wavelengths: 490, 670, and 865 nm

Theoretical PDM for Clear-Sky Ocean (0.67 μm)

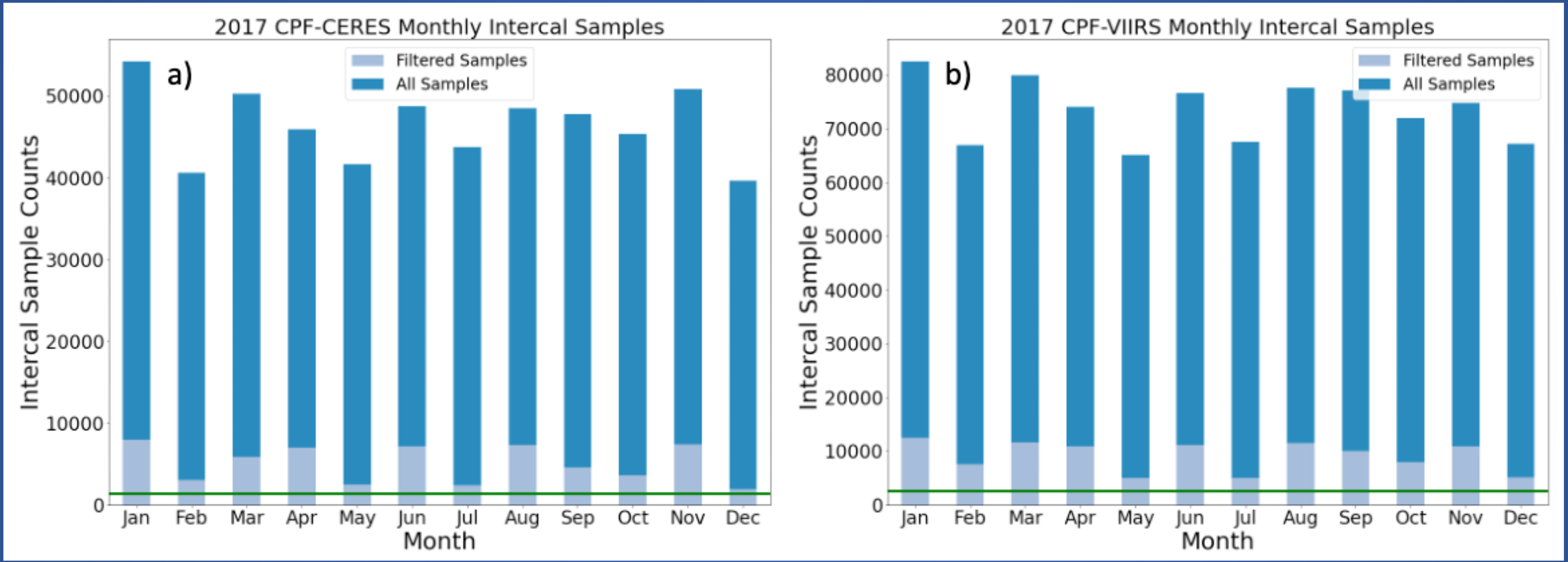
- Simulated using Adding-Doubling Radiative Transfer Model
- Covers all VIIRS bands

Goldin and Lukashin (2016)
Goldin et al. (2019)
Sun et al. (2018)
Sun et al. (2015)

PDM Application Module

- Uses VIIRS scene characterization info from L2 files, identifies correct PDM LUT and retrieves DOP/AOLP estimates from ePDMs & tPDMs
- Can be used to support several applications outside the CPF project

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

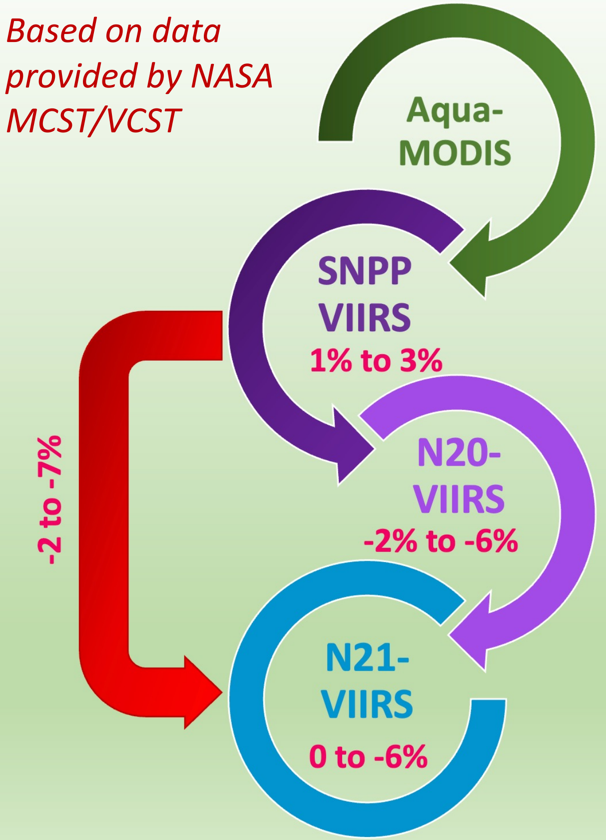


Green line represents minimum required sample size to meet uncertainty threshold

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

CPF Benefits to Intercalibration Community

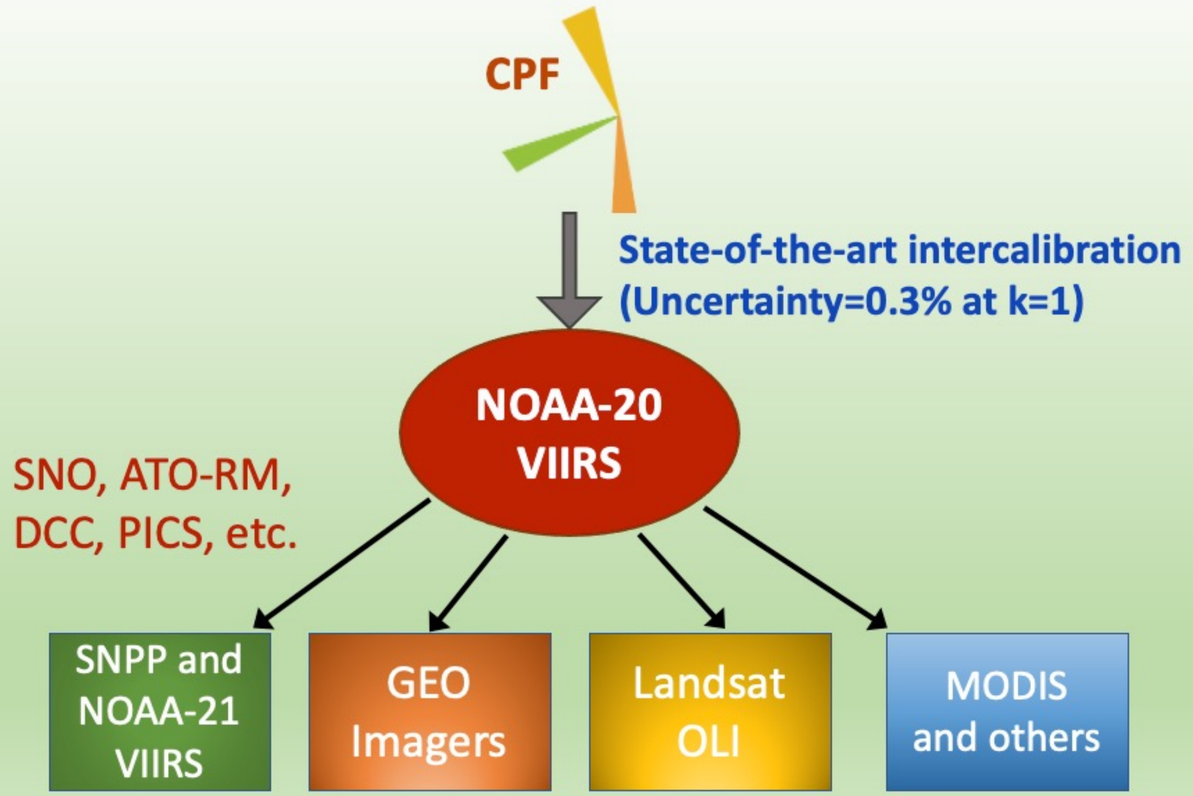


Served as the GSICS calibration reference for reflective solar bands until 2021

SNPP VIIRS observes brighter reflectance than MODIS

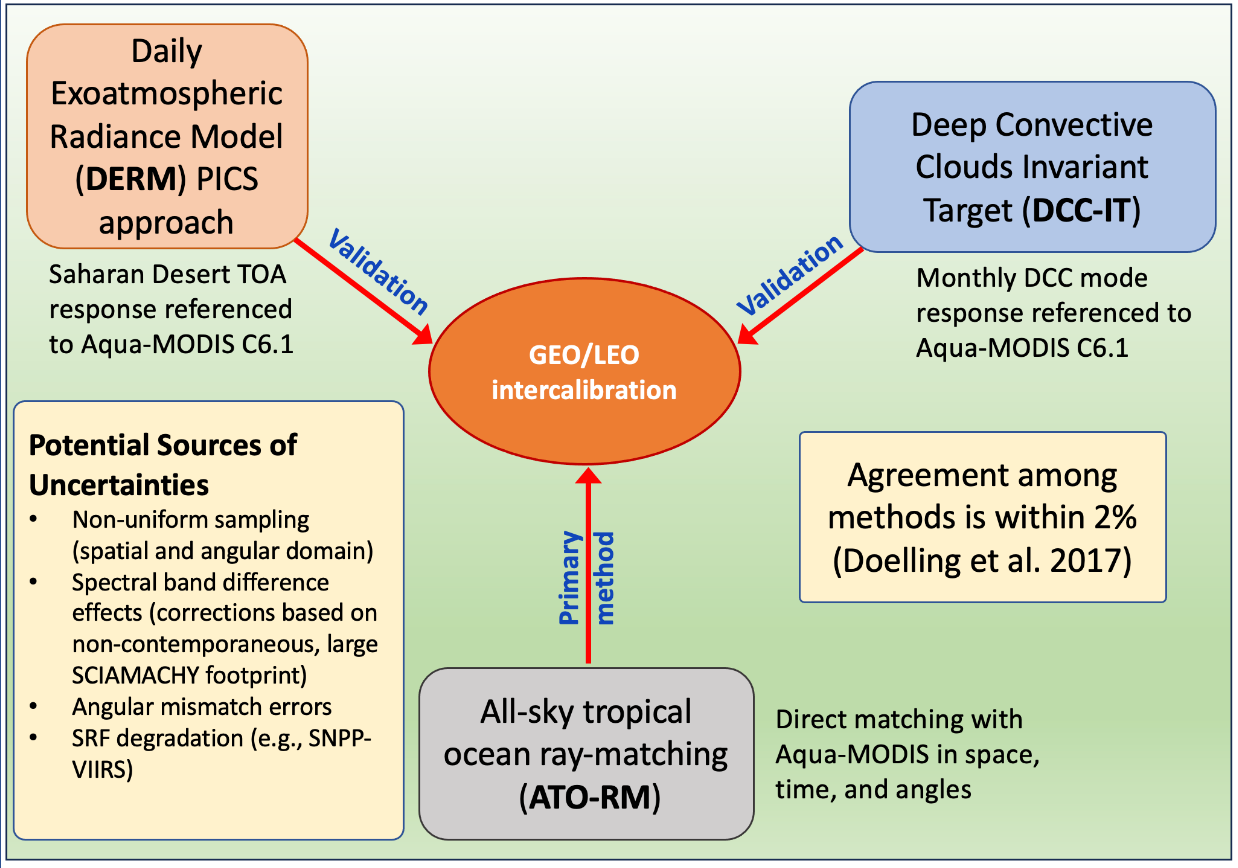
Current GSICS calibration reference
Exhibits darker spectral reflectance than SNPP

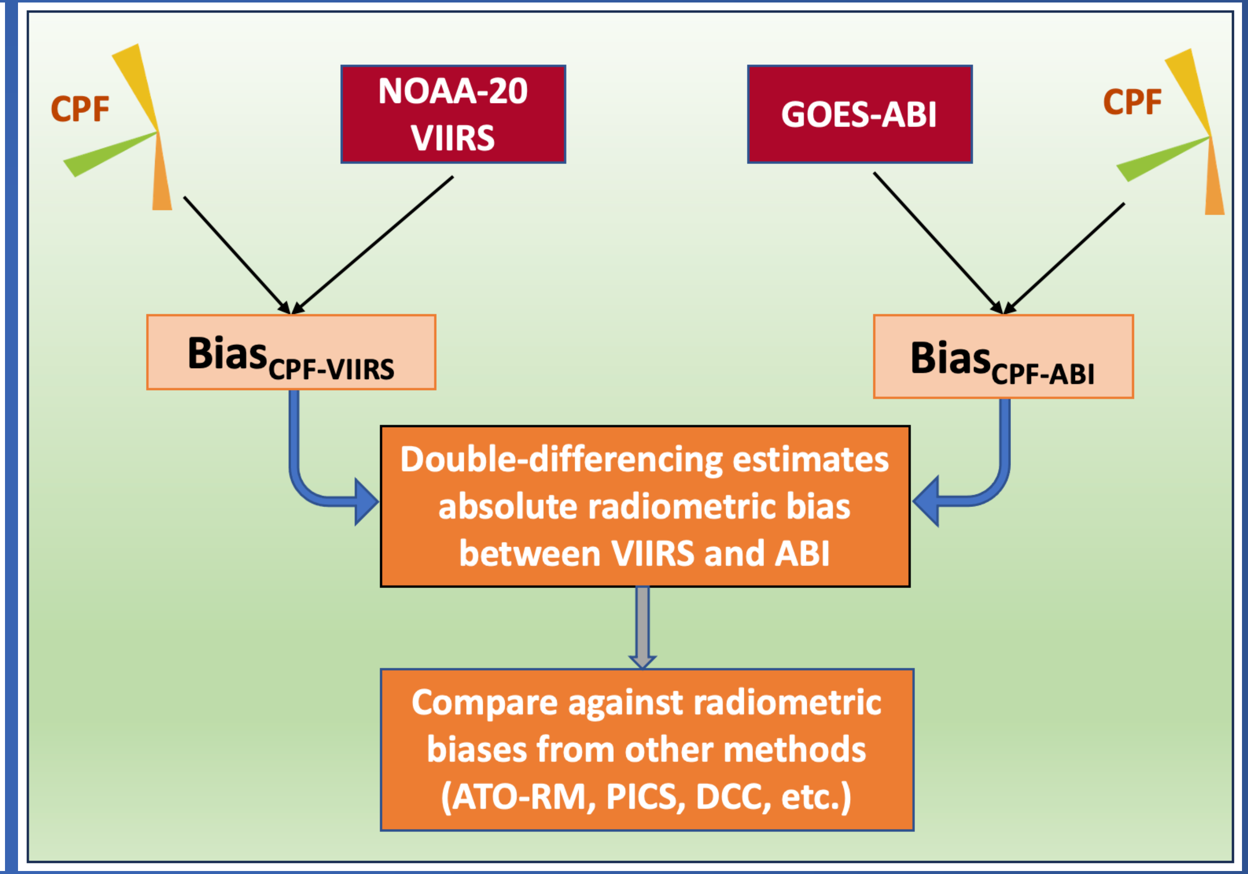
The most recent within the VIIRS sensor series
Exhibits similar or darker spectral reflectance than N20



- Improved reference instrument for satellite intercalibration community:
  - Will enable other Earth observing missions to surpass their original capabilities
  - Independent assessment of the radiometric accuracy of VIIRS sensors (SNPP, NOAA-20, and NOAA-21)
- CPF calibration transfer to several other orbiting sensors (including MODIS) via direct approach or using VIIRS as a transfer radiometer
- Assist improved radiometric characterization of PICS, DCC, Lunar calibration targets

CPF supports validation of existing methods





- Existing intercalibration methodologies can be validated by concurrently (same month) calibrating two instruments against CPF
- CPF will help split uncertainty sources and optimize intercalibration methods for different wavelengths
- Ultimately, these methods can be used to transfer CPF reference to future as well as past instruments

Summary and Path Forward

CPF stands out for cutting-edge fusion of spectral coverage, spectral/spatial resolution, and radiometric accuracy

CPF's innovative approaches to address the challenges of multidimensional data mismatching between CPF and target enables the attainment of intercalibration accuracy that was previously unprecedented

*Maintain collaboration with GSICS and advocate for global adoption of CPF as **preferred reference***

Expand the utilization of CPF's innovative intercalibration methods/tools (LASICS, PDMs) to additional sensors and use cases

Enhance the spectral and radiometric characterization of Pseudo-Invariant Earth Targets (e.g., key desert sites, Deep Convective Clouds)Aid in the enhancement of the Lunar Calibration models by supplying high-accuracy Lunar reflectance measurements obtained from CPF -

Anchor existing NASA Investments (e.g., MODIS) with the SI-traceable Calibration Standard of CPF, leading to an enhanced multi-decadal climate data record