CLARREO Pathfinder

National Aeronautics and Space Administration

CPF Direct Intercalibration Approach

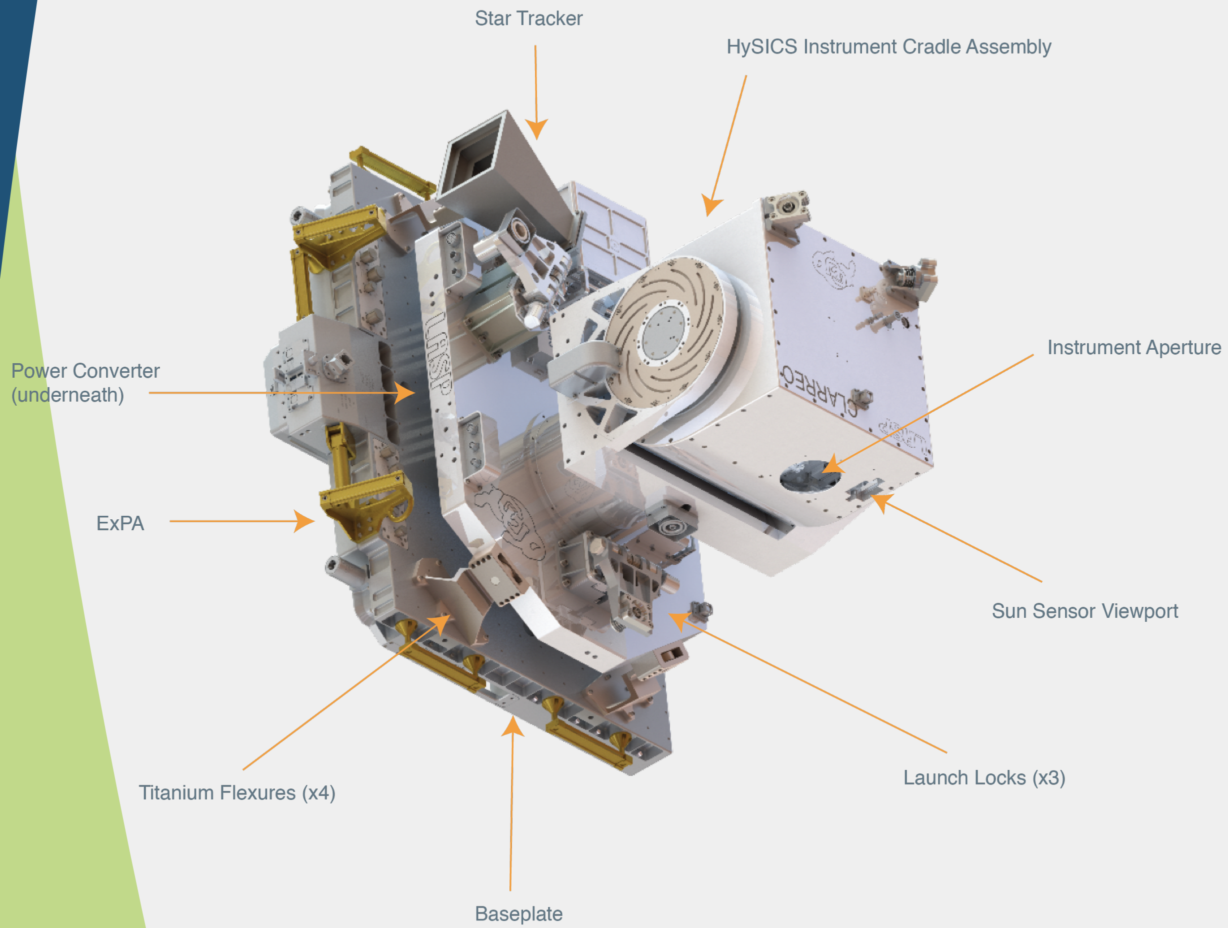
Rajendra Bhatt, Yolanda Shea, and CPF Intercalibration Team

CPF Science Workshop

November 3, 2021

CLARREO Pathfinder Payload

HySICS: HyperSpectral Imager for Climate Science



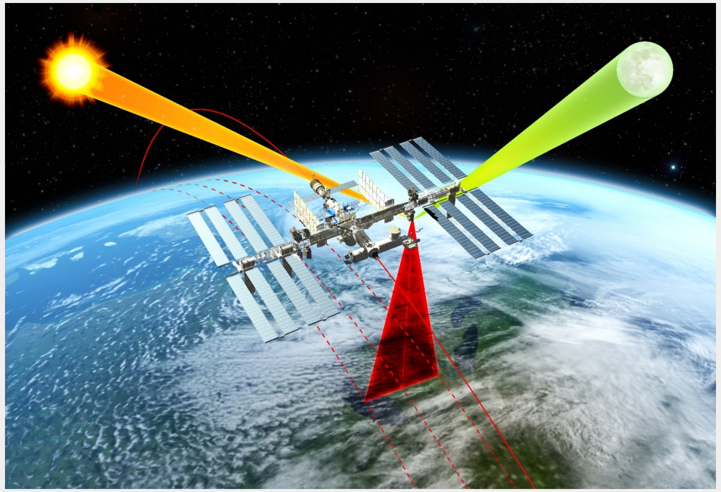
Push-broom spectrometer	
Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Radiometric Uncertainty	0.3% (1-sigma)
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Sampling Rate	15 Hz

Kopp et al 2017

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

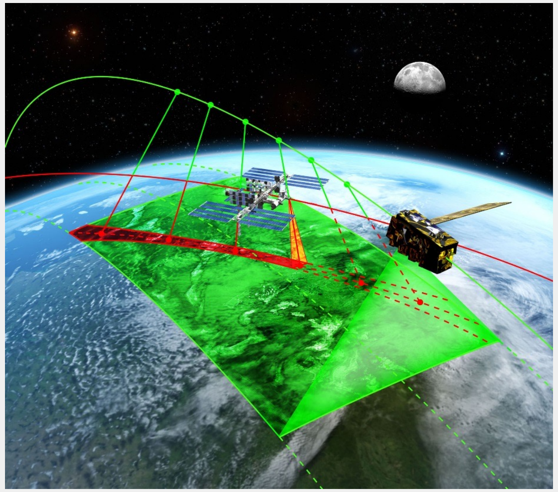
CPF Science Objectives

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/

Versatility in CPF Observations

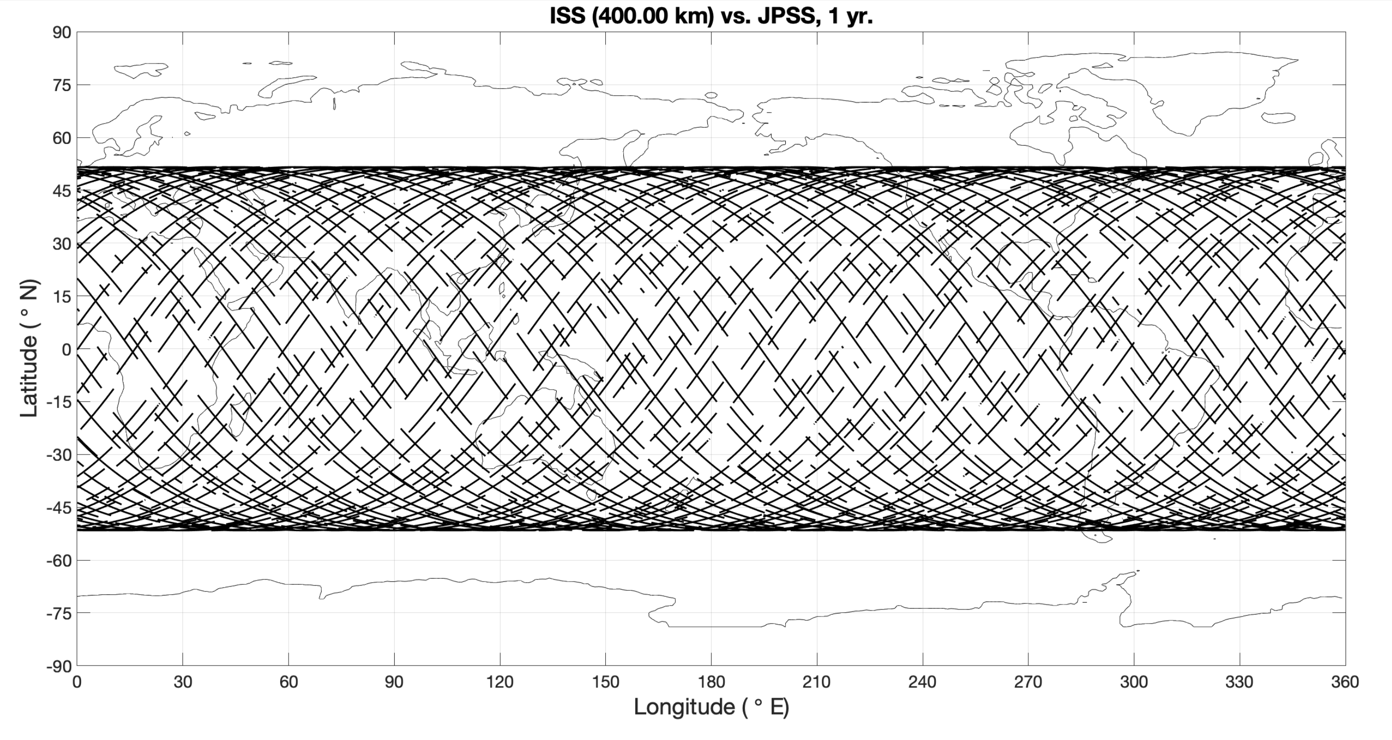
Launch-Ready: Late 2023	Prime Mission Ops	Extended Mission Ops (?)
Observation Type	**1-Year Mission**	**1+ Years**
On-orbit Instrument Calibration	Demonstrate success of calibration approach over 1 year	
Earth Reflectance and Radiance Nadir Spectra	Will be used to demonstrate achieved calibration, geolocation, etc requirements	
LEO On-orbit Inter-calibration	• Measurements and data analysis for CERES and VIIRS Only • Potential Landsat measurements	
GEO On-orbit Inter-Calibration	• Demonstration measurements with 1 GEO	
Enhanced Land/DCC Pseudo-Invariant Calibration Site (PICS) Characterization	• Measurements over high priority PICS	
Improved characterization of the Moon	• Leveraging existing ops mode to cover libration and phase angles available	

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

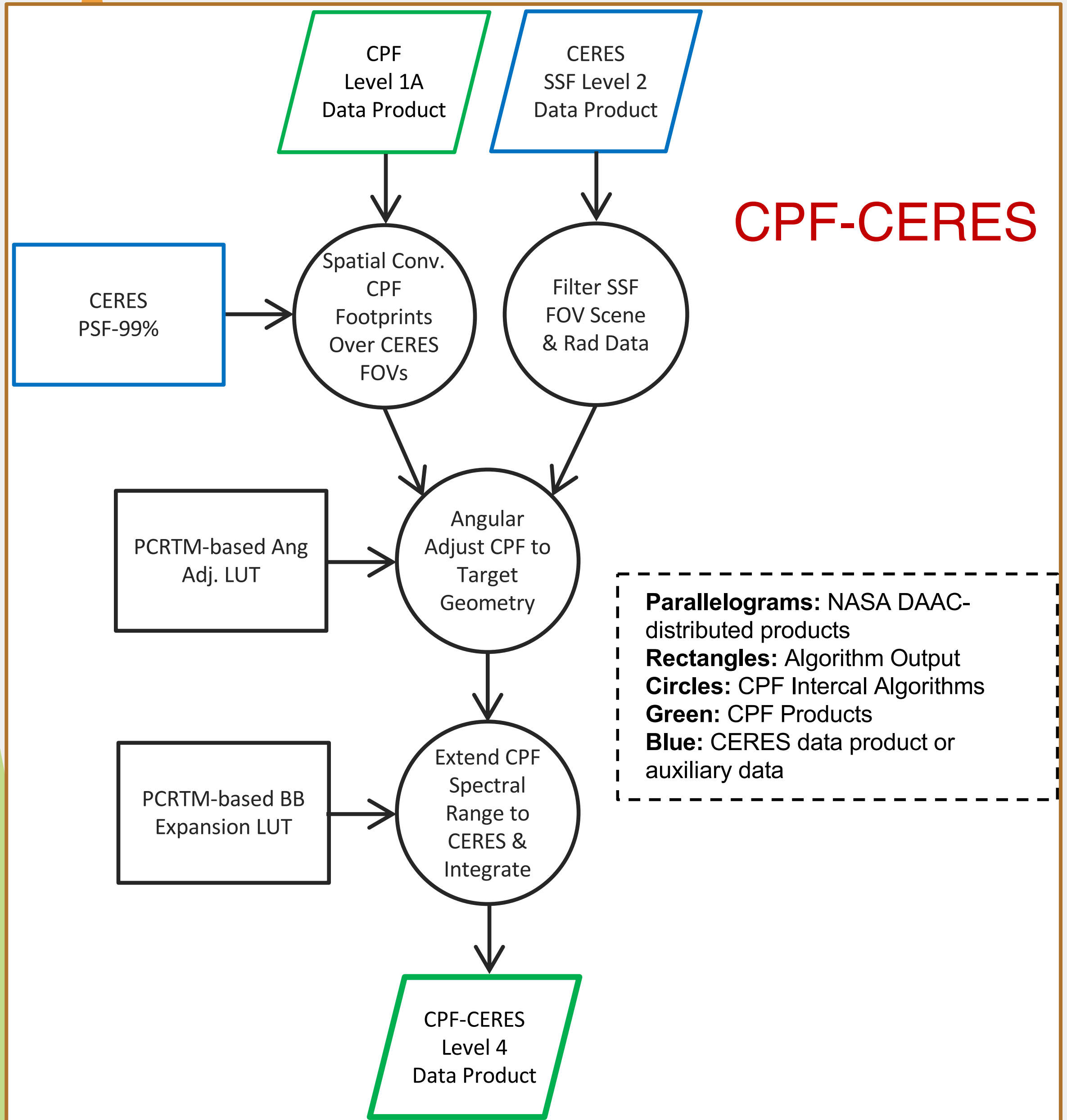
Planned Pointing & Scanning Ops For Improved IC Statistics

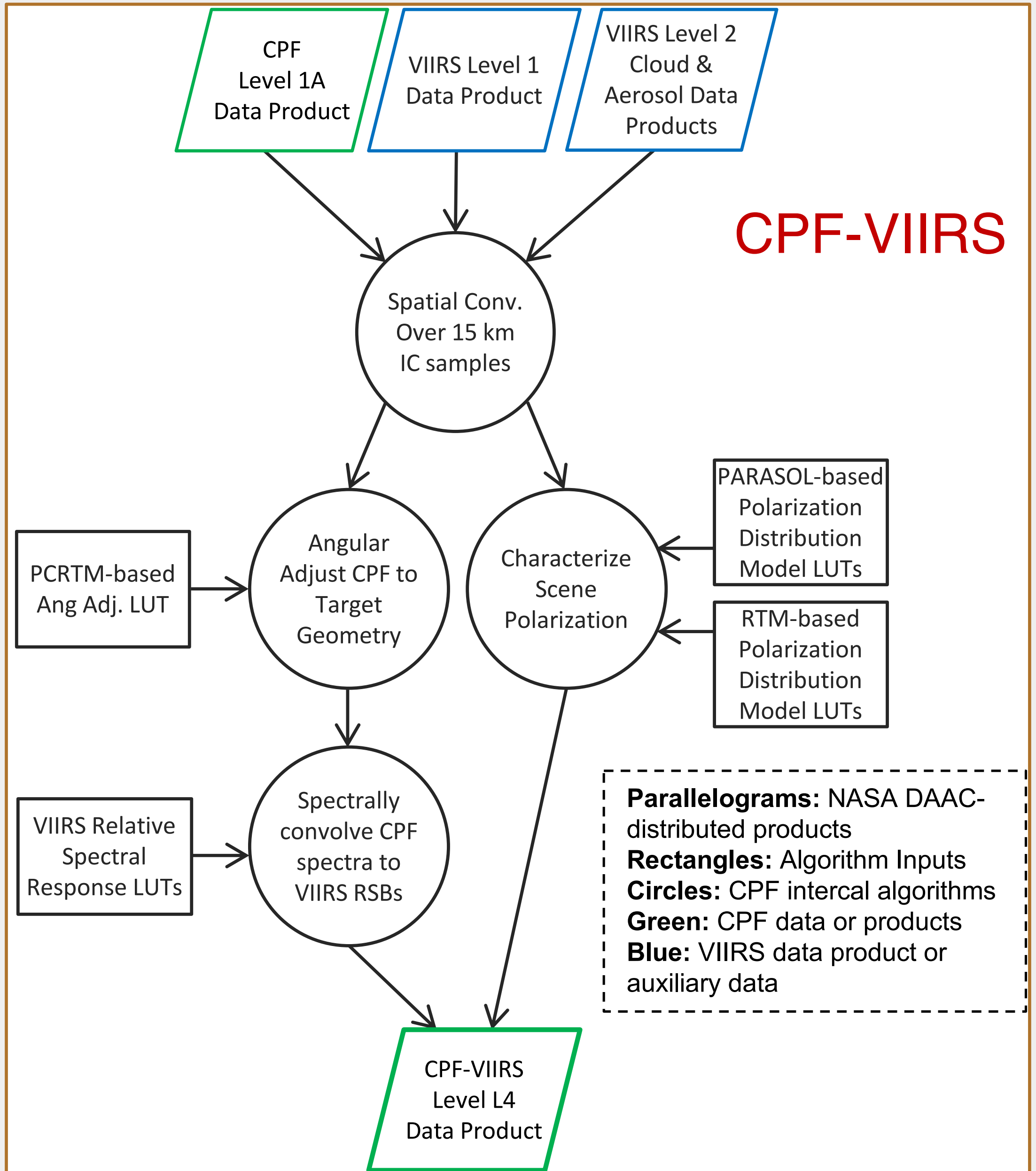
- Inter-calibration sampling difference uncertainty requirements are met (in part) by acquiring and analyzing data from an aggregation of inter-calibration events
- More events improves reduction of data matching noise

Predicted inter-calibration event ISS ground tracks (~1,300) between CLARREO Pathfinder on ISS and JPSS-1 for 1-year of operations



CPF-CERES and CPF-VIIRS intercalibration algorithm flowcharts





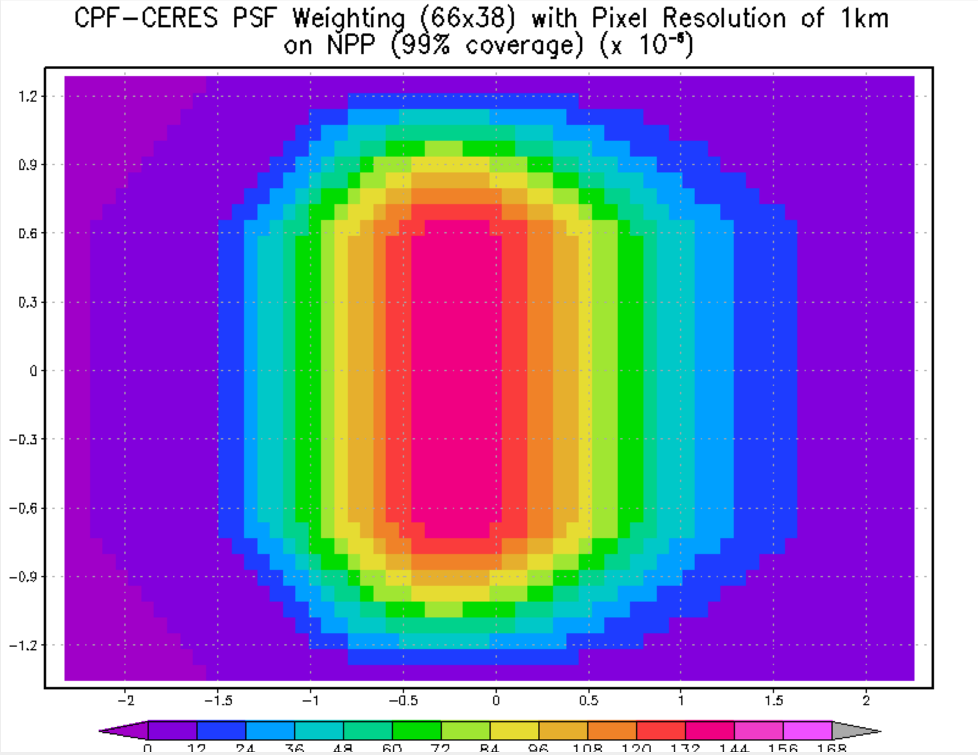
CPF-CERES Intercalibration Uncertainty Budget (Initial Estimates)

CPF-CERES Intercalibration Combined Uncertainty (<0.22%)

- **Spatial Matching (<0.1%)**
  Spatial Data Matching Noise: Convolving 0.5 km CPF spectra to CERES footprints using CERES PSF.
- **CERES Point Spread Function (<0.1%)**
  Uncertainty in CERES PSF knowledge.
- **CPF Spectral Range Extension (0.1%)**
  PCRTM-based Algorithm to Extend CPF spectral range to CERES spectral range (0.2-15um)
- **CPF-CERES Angular Adjustment (0.1%)**
  PCRTM-based Algorithm Angular Correction
- **Unaccounted uncertainty estimate (0.1%)**
  Uncertainty Contribution due to unknown CERES instrument behavior

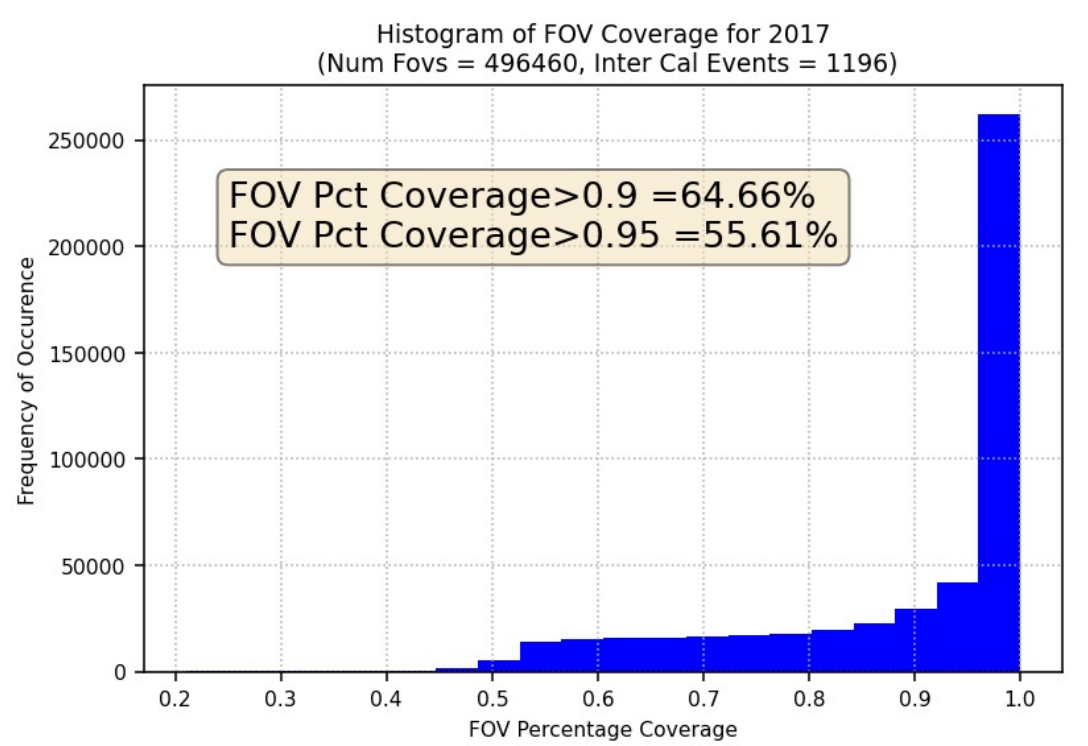
CPF-CERES Spatial Convolution & Sampling Estimates

CERES PSF used for CPF Spectra Spatial Convolution



The DMT, with support from Nitchie & Walt, have implemented the CERES PSF-based spatial convolution

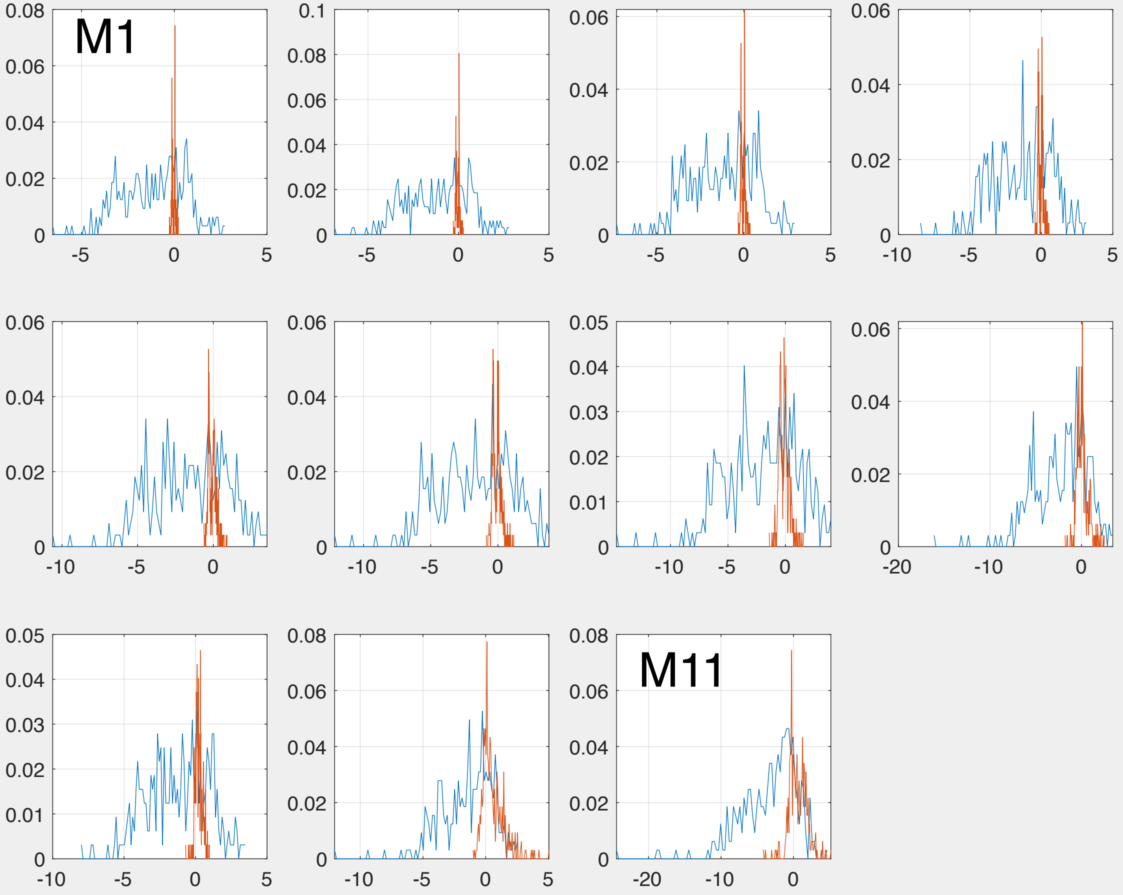
Using 1-year of Low-Fidelity Intercal Simulation Data – Est. CERES Sampling



This suggests that each month on average we can expect about (55.6%*90%(#FOVs))/12 =~ 20K intercal samples >> conservative est of 5K – Study conducted by DMT/Currey

CPF-CERES Angular Adjustment

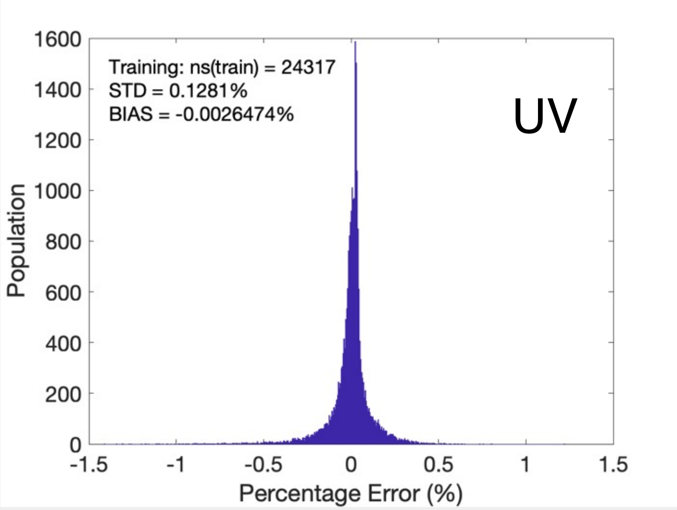
Overview of Angular Correction for 11 VIIRS bands
Clear Sky

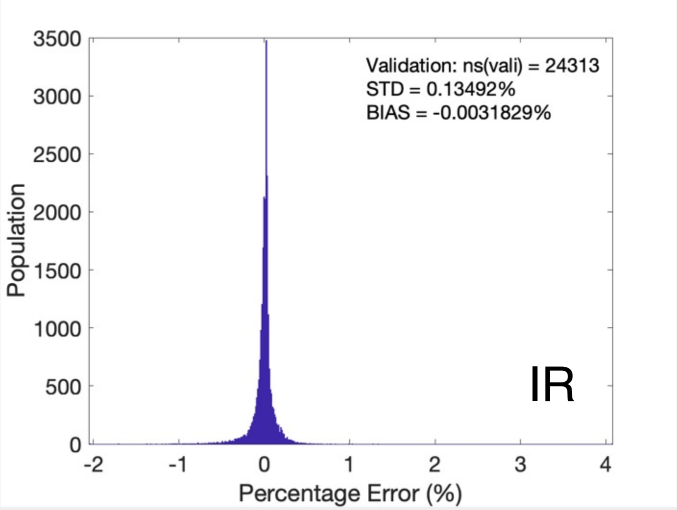


- Note: These are technically results from VIIRS, but same algorithm used for CPF-CERES.
- Among 11 VIIRS bands
  - Before Angular Adjustment (Blue) error from angular mismatch
  - After Angular Adjustment (Red), error from angular mismatch is minimal
- Working toward uncertainty goal of 0.1% from Angular Adjustment Algorithm
  - Mitigate Regression-Prediction Error
  - Improve Interpolation Error from Angular Adjustment LUT
  - Enhance Training Sample sizes Spanning scene types

Algorithm Development: Wan Wu & Xu Liu

CPF-CERES Spectral Range Extension

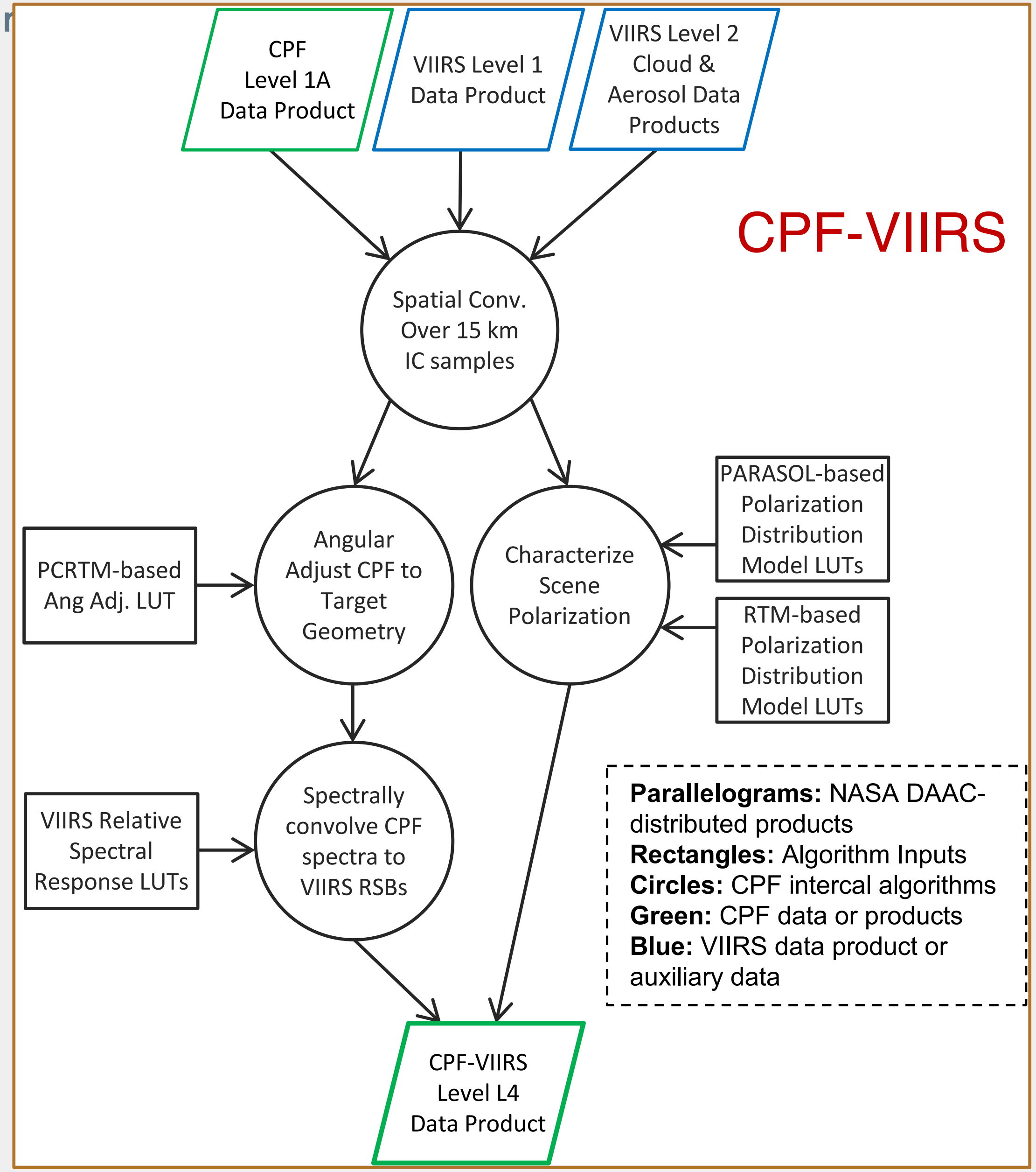




- Estimates what CPF would have measured if it had spectral range of CERES unfiltered radiances – using spectral correlations & constructed LUT
  - CPF spectral range (350-2300 nm)
  - We are extending this to 200 nm – 15 um to account for CERES unfiltered radiance definition
- PCRTM team has developed an improved Hyperspectral Land Surface BRDF model based on PC analysis to reduce errors from spectrally interpolating land surface BRDF between MODIS/VIIRS bands
- Investigating uncertainty contributions to further reduce total uncertainty

Algorithm Development: Qiguang Yang & Xu Liu

CPF-VIIRS Intercal



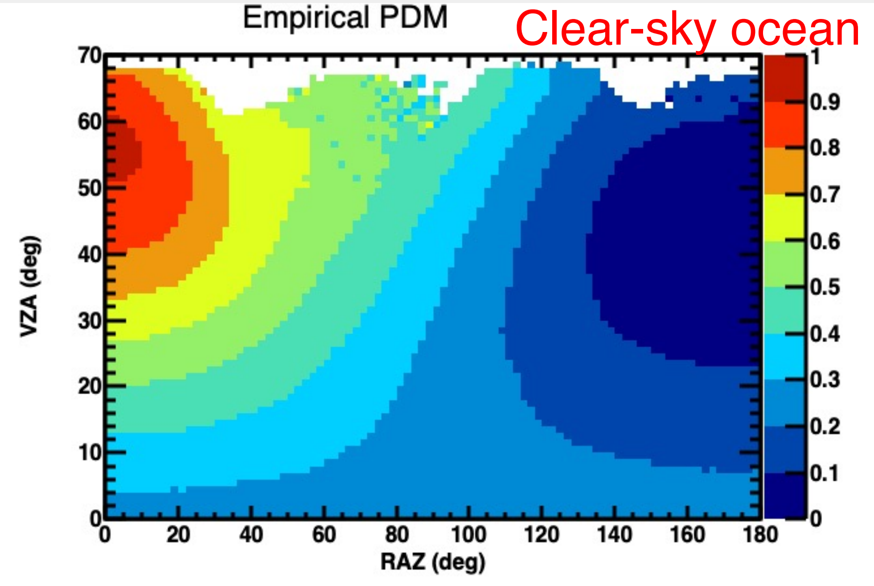
1. Scene characterization with VIIRS Cloud & Aerosol L2 variables
2. Spatial Convolution of CPF & VIIRS variables with Virtual Instrument “PSF”
3. Angular Adjustment of CPF data
4. Spectral Convolution of CPF spectra
5. DOP/AOLP of Intercal Samples (PDM Application Module)

CPF-VIIRS Intercalibration Uncertainty

CPF-VIIRS Inter-calibration Combined Uncertainty (<0.2%)

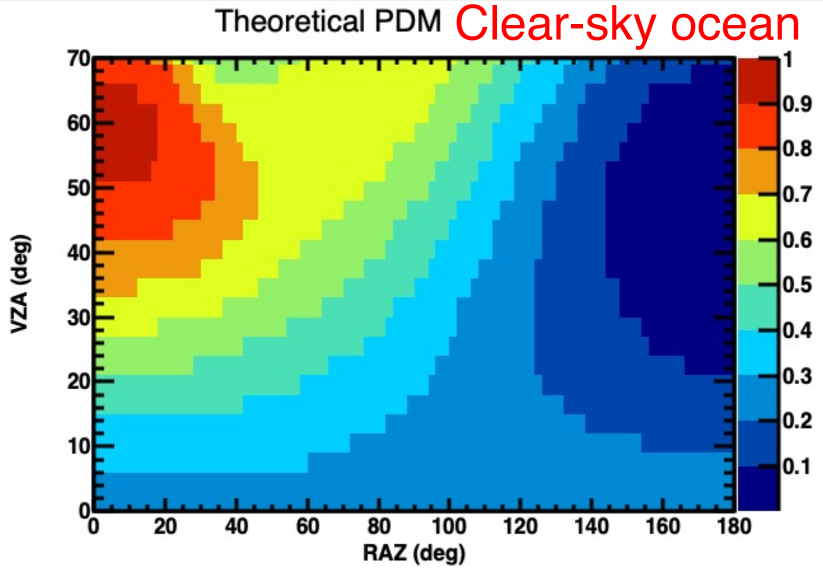
- **CPF & VIIRS Spatial Matching (<0.1%)**
  After spatially convolving CPF and VIIRS data to same 15 km samples, spatial matching noise reduction estimate below 0.1%
- **CPF Spectral Convolution (<0.1%)**
  CPF spectral convolution over VIIRS spectral bands.
- **CPF-VIIRS Angular Adjustment (0.1%)**
  PCRTM-based Algorithm Angular Mis-match Correction
- **Unaccounted Uncertainty Estimate (0.1%)**
  Uncertainty Contribution due to unknown VIIRS instrument behavior

Polarization Distribution Model (PDM) Look-up Tables



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

PDMs will be used for polarization corrections that would be scene/wavelength/angle dependent.



Empirical PDM Conditions: Constructed from PARASOL/POLDER Data

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

Developed by Daniel Goldin & Costy Lukashin

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

tPDM
- ADRTM simulation
- All wavelengths

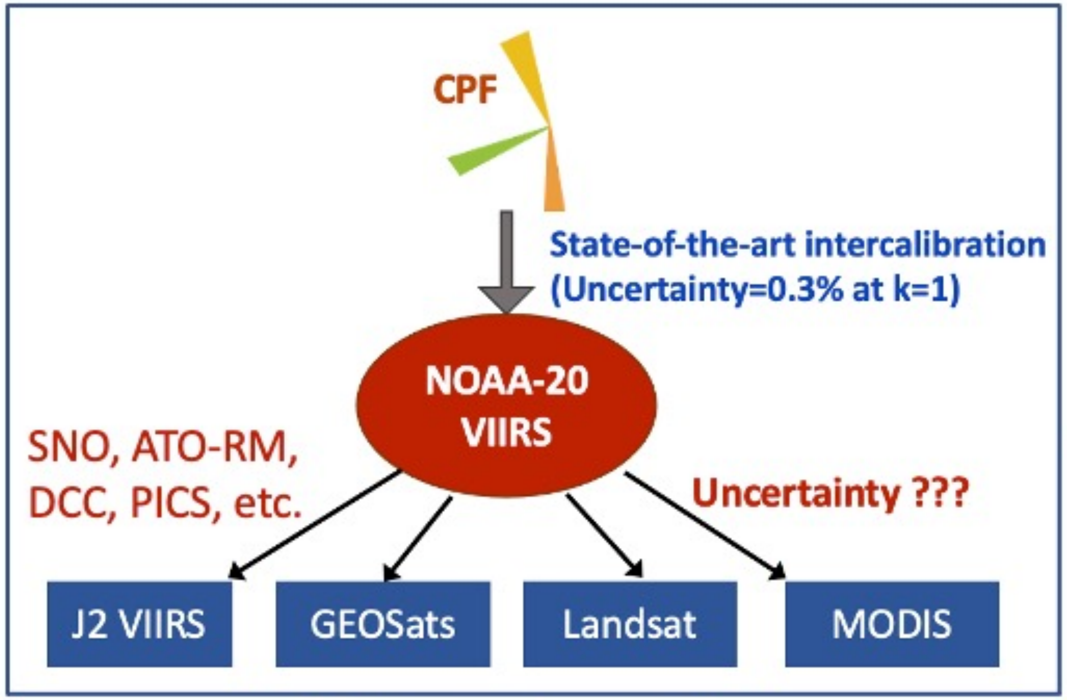
Theoretical PDMs: Simulated using Adding-Doubling Radiative Transfer Model

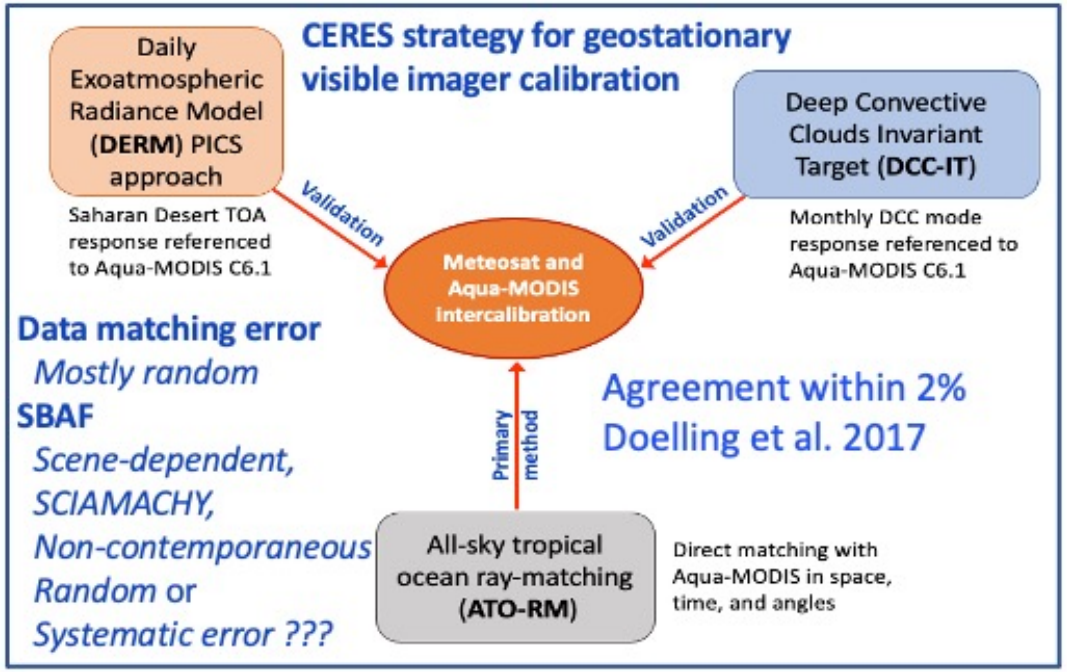
- SZA = 45^o
- Band = 672 nm
- AOD = 0.076
- Wind Sp. = 7.5 m/s

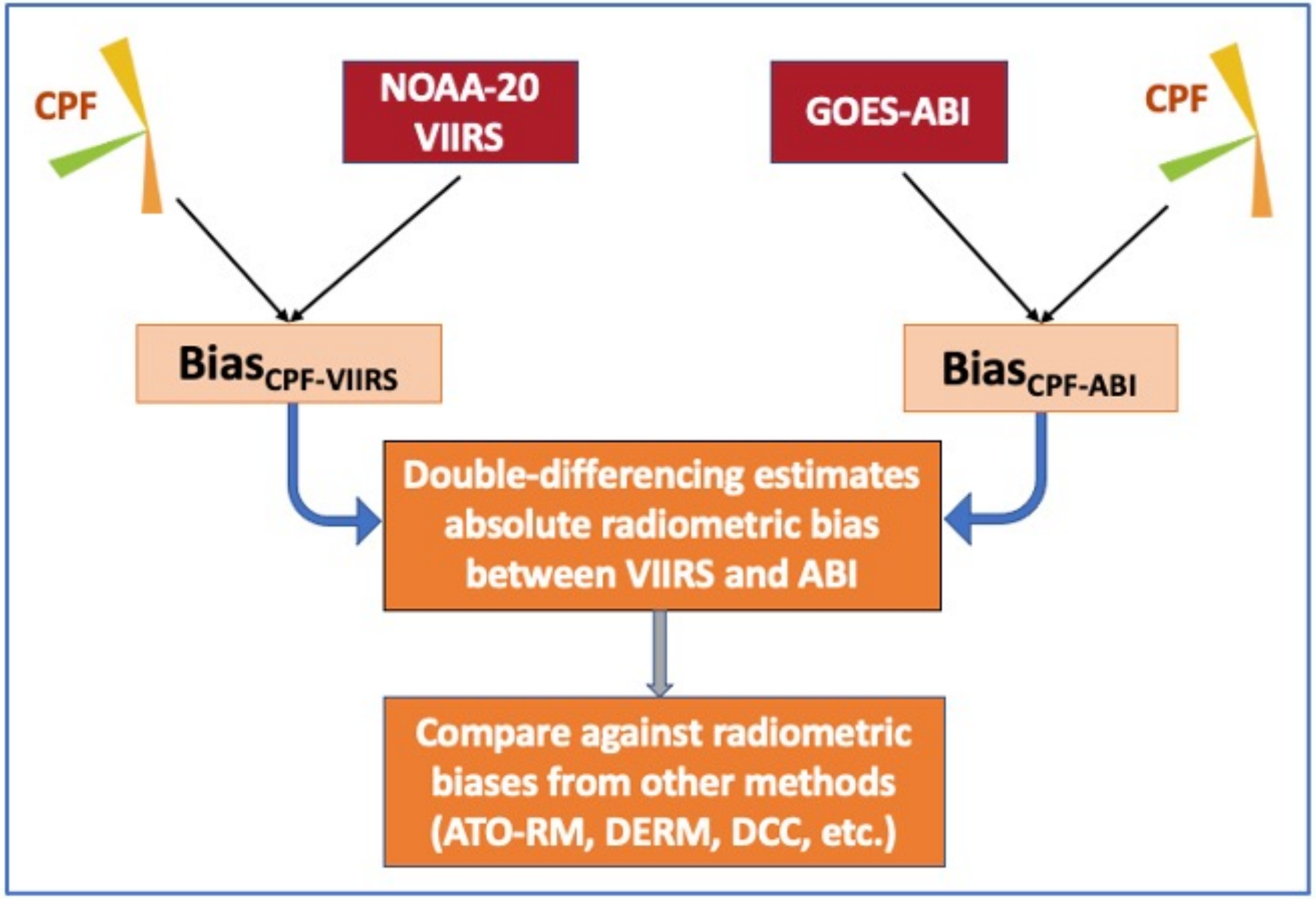
Simulated by Wenbo Sun

Validation of Intercalibration methods

- *Intercalibration methodologies can be validated by concurrently (same month) calibrating two instruments against CPF*
- *Help identify the most optimal intercalibration method for a given wavelength*
- *Ultimately, these methods can be used to transfer CPF reference to future as well as past instruments*







CPF Inter-calibration Data Analysis Components

Target Sensor	IC Parameter	Time Scale	Dependence
CERES	Effective Offset	Monthly	Scan Angle
	Effective Gain		
	Non-linearity	Bi-annually	All Data
	Spectral Response		Scene Type
VIIRS	Effective Offset	Monthly	Scan Angle & DOP
	Effective Gain		
	Non-linearity	Bi-annually	DOP
	Spectral Response		
	Sensitivity to Polarization		Scan Angle, DOP, χ

DOP – Degree of (linear) Polarization
χ – Angle of (linear) Polarization

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 intercal footprints, CPF pointing capability, PDMs, PCRTM angular and spectral corrections
- Scheduled nadir scans of CPF can be used to intercalibrate other RS imagers in GEO and LEO orbits
- CPF measurements will enhance the characterization of invariant Earth targets (DCC, PICS, etc.)
- CPF observations of Moon will improve lunar irradiance models for calibration