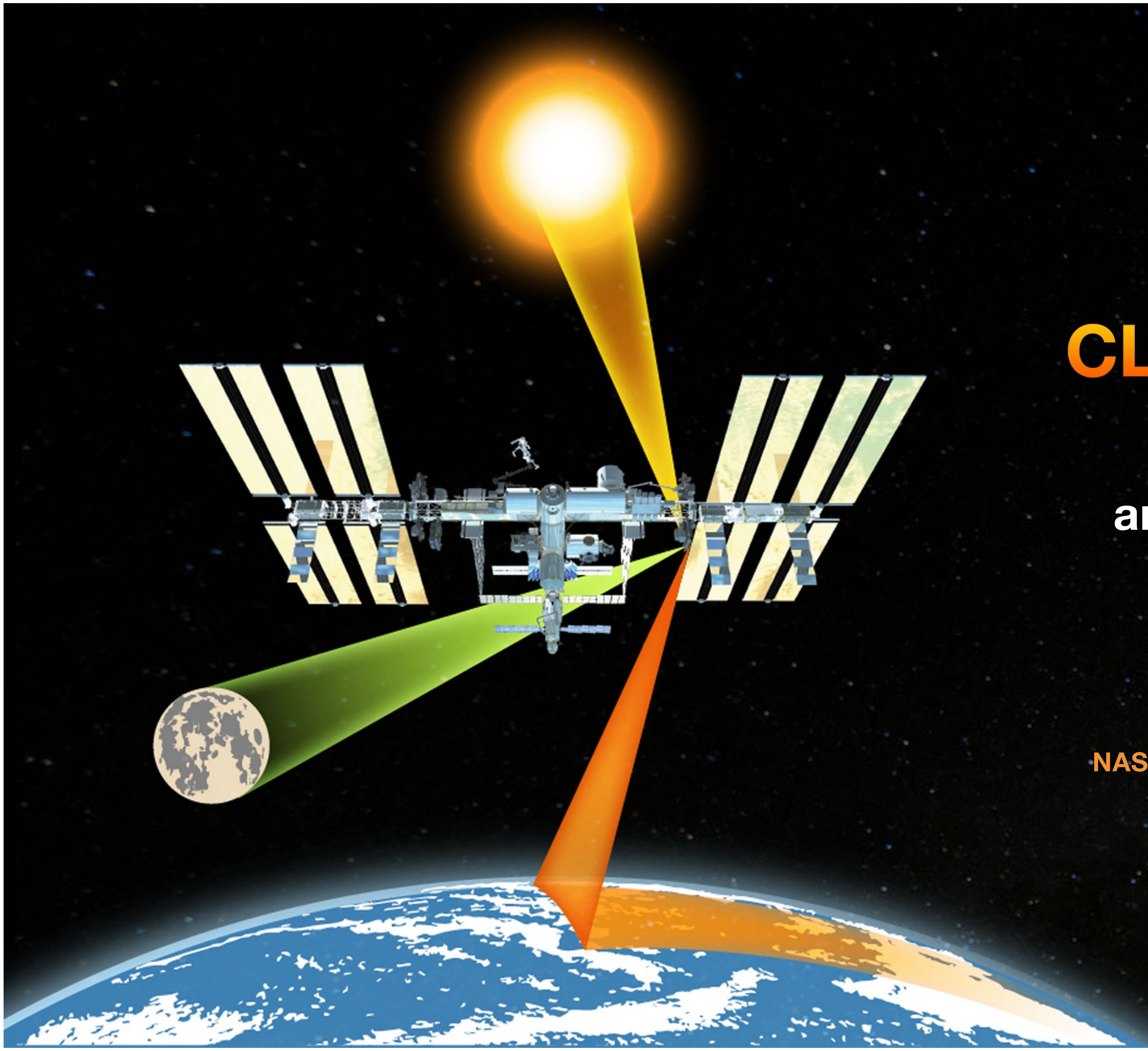

National Aeronautics and Space Administration

CLARREO Pathfinder

Intercalibration processes and strategies: Lessons from CLARREO Pathfinder

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(and the CLARREO Pathfinder team!)

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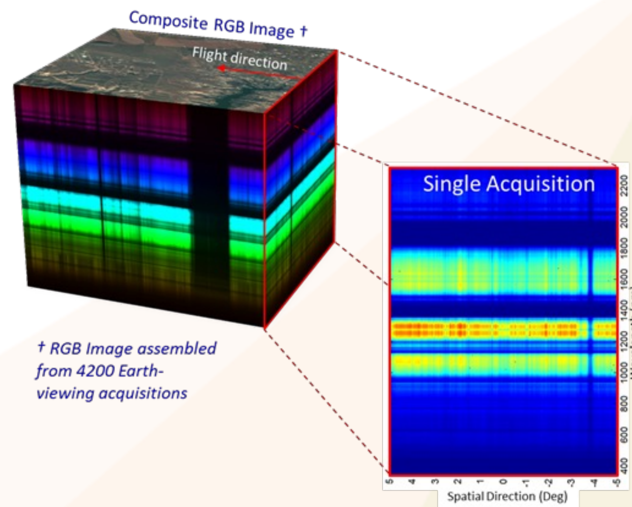
CLARREO Pathfinder on ISS: Summary

- **Mission Purpose:** Take climate-critical high accuracy measurements of Earth reflectance and intercalibrate with CERES (broadband) & VIIRS (multi-spectral) shortwave channels
- LASP-Led Reflected Solar Spectrometer (350 – 2300 nm) & Payload
- Nominally 1-year mission operations (but hopefully more!) + 1-year science data analysis
- Launch Readiness: ~Late 2024
- Currently: In Payload-level Environmental Testing
- Launch: TBD (No Earlier Than Early 2026) **->** In the meantime, the payload will go into storage

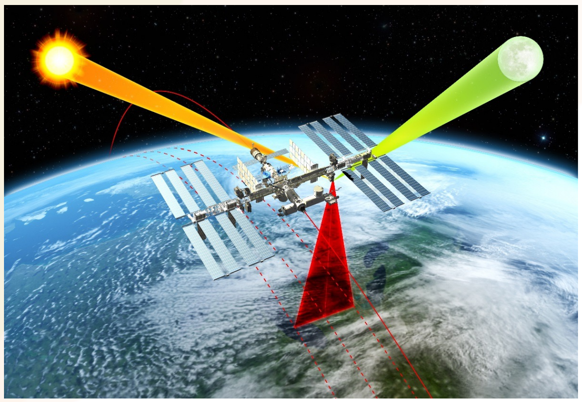
Spectrally-Resolved Earth Reflectance



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

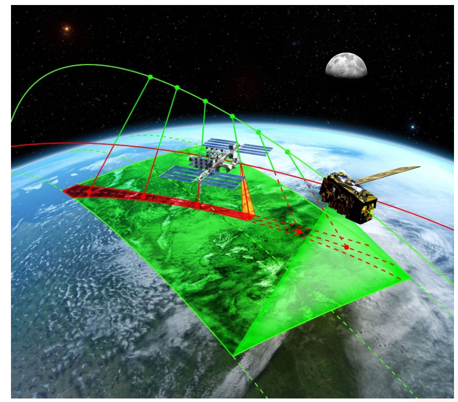
CPF Science Objectives

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: Intercalibration Capabilities



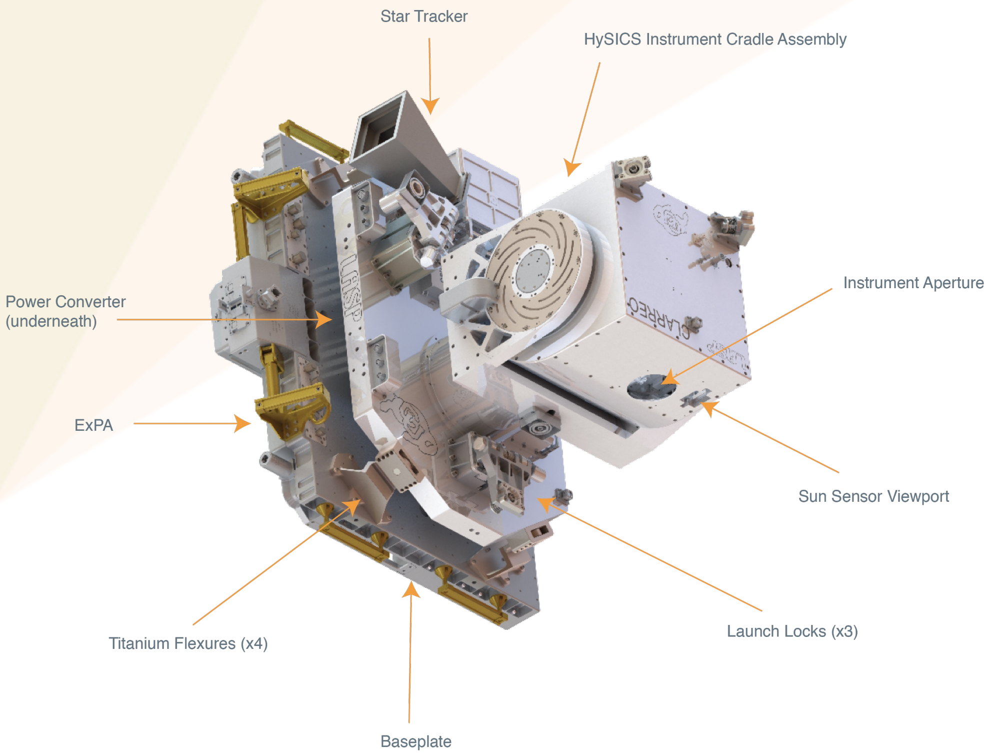
Demonstrate ability to transfer calibration to other key RS satellite sensors by intercalibrating with CERES & VIIRS.

	Objective #1	Objective #2
Uncertainty	Spectrally-resolved & broadband reflectance: 0.3%-0.6% (1σ)	Intercalibration methodology uncertainty: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for intercal, 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 intercal. Merged data products including all required info for intercal analysis

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

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
Platform	ISS

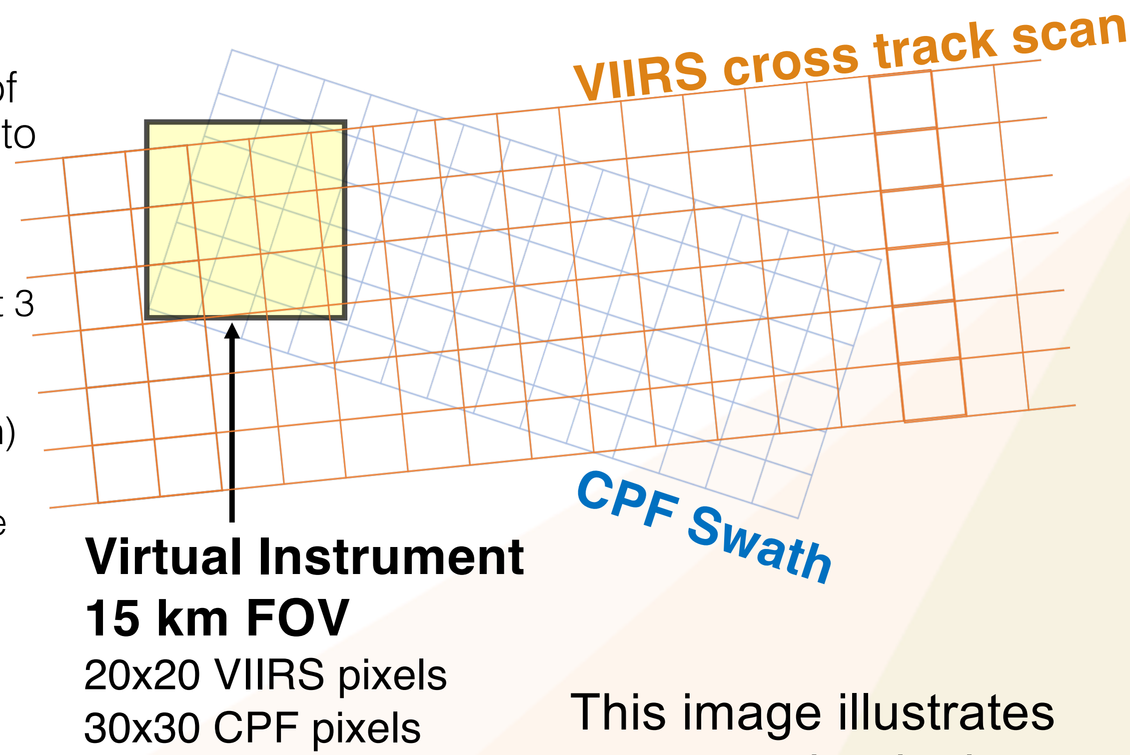
https://clarreo-pathfinder.larc.nasa.gov/

Intercalibration:
A Multi-dimensional data matching challenge

Spatial & Temporal Matching	Spectral Differences	Sun-view Geometry	Polarization Sensitivity	Monthly Target Variability
• Spatial resolution difference, geolocation uncertainties • Differing intercal sample acquisition times	• Scene dependent biases due to differences in spectral range, resolution, and sampling	• Solar: driven by difference in acquisition times • Viewing: from imperfectly aligned samples	• Reference & Target polarization sensitivity differences	• Expected monthly target sensor calibration variability

Spatial matching noise

- Spatial mismatching is one of largest contributors to uncertainty budget
- For VIIRS, intercal samples are made up of CPF & VIIRS footprints spatially averaged to 15 km (at nadir) FOV
- 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)
  - **Limitation:** This study was limited to homogenous Arctic scenes to accommodate AVHRR overlaps
- Based on study conducted by CPF Team, spanning CONUS to represent anticipated variety of CPF-Target scenes
  - Average spatial-temporal matching noise for single intercal sample:
  - CPF-VIIRS: ~%6
  - CPF-CERES: ~4%



This image illustrates one snapshot in time.

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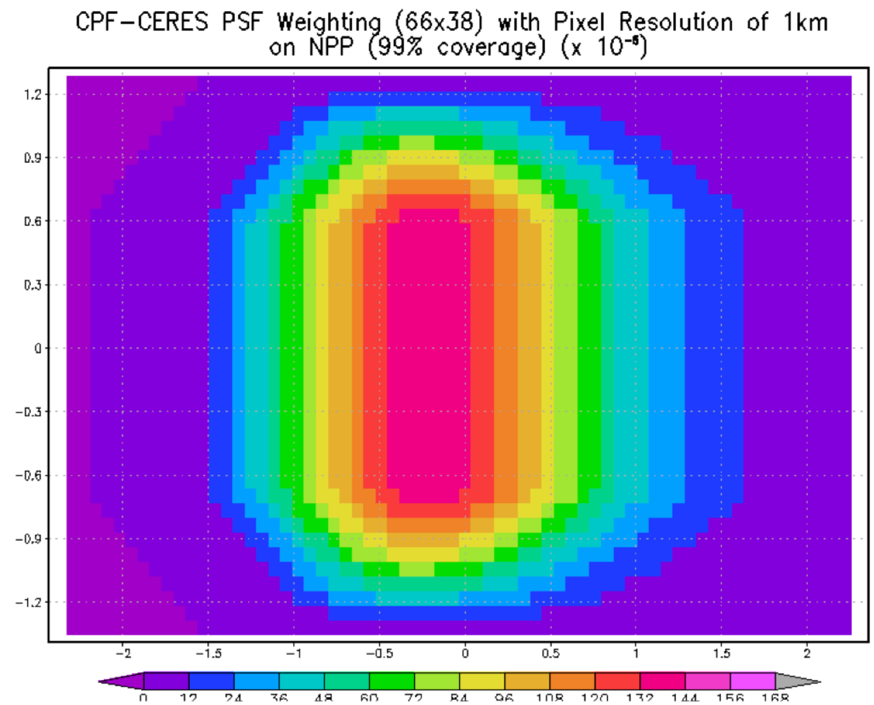
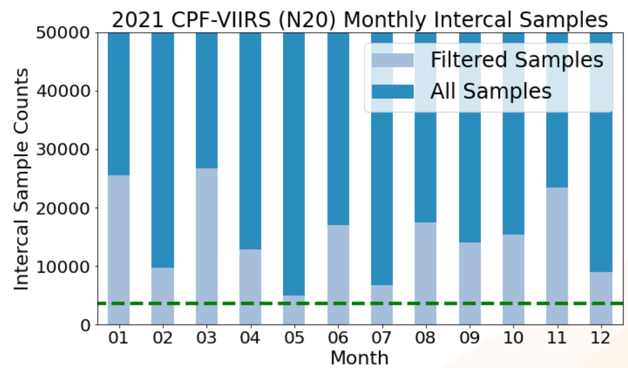
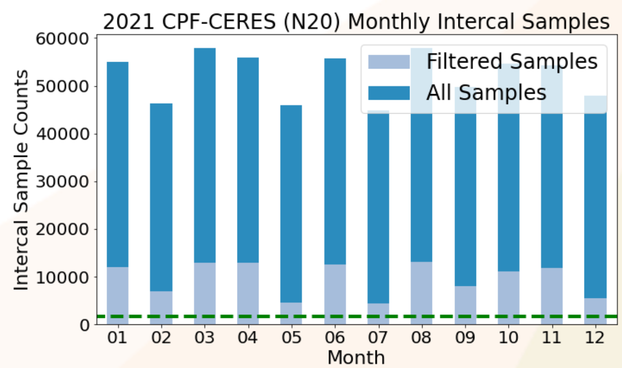


Intercalibration Sampling Estimates

Can we expect at least 5,000 samples monthly?

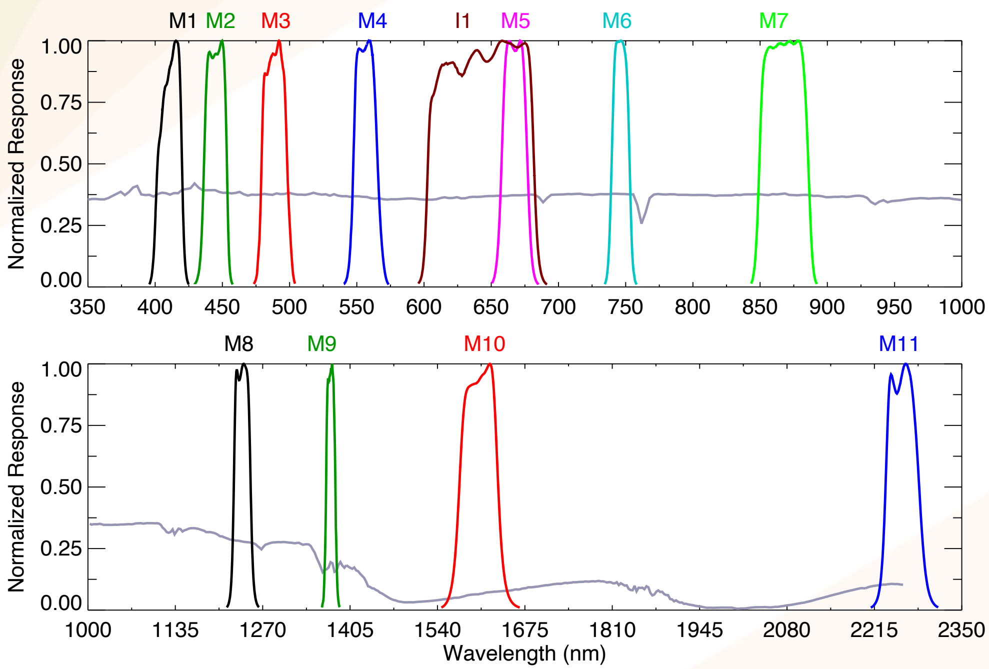
- Intercalibration Sample Filtering Criteria Reduce number of samples included in monthly CPF-Target comparison
  - At least 95% coverage of CPF & Target footprints
  - Sun-view geometry limits (SZA<60, VZA<60, 5<RAZ<175)
  - Low probability of sun glint
  - VIIRS only: Scenes with small DOP
  - Homogeneity Factor <0.2
- 10% Reduction due to ISS maneuvers prohibiting Earth View during IC events

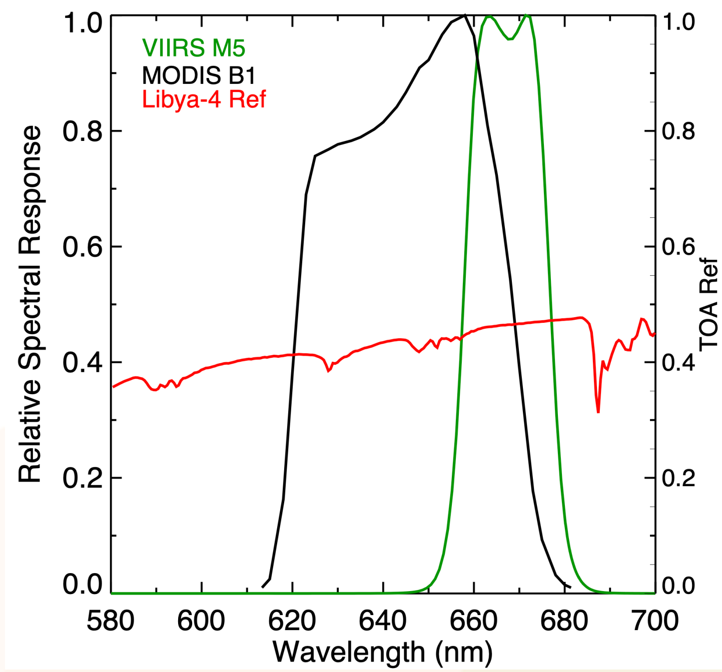




Spectral wavelength matching

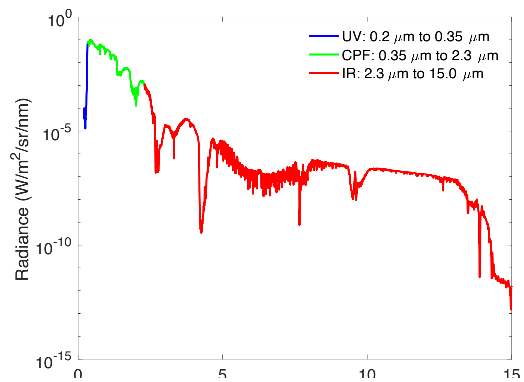
- Spectral mismatch between reference and target sensors results in scene-dependent intercalibration results (e.g., MODIS and VIIRS)
- Hyperspectral measurements from reference sensor substantially mitigates the spectral difference issue
- At 4 nm spectral sampling, the impact is within 0.1% for MODIS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

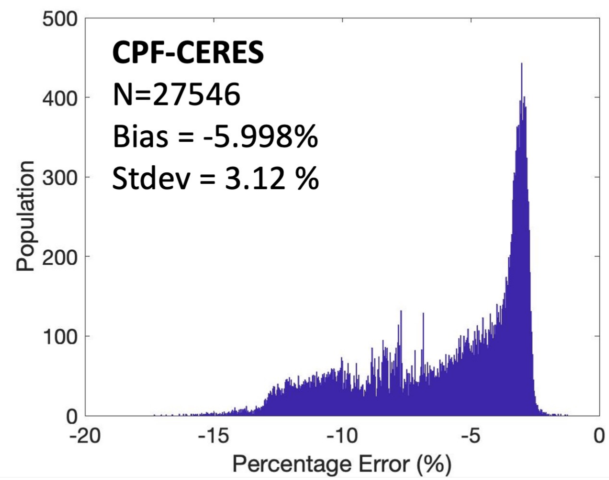




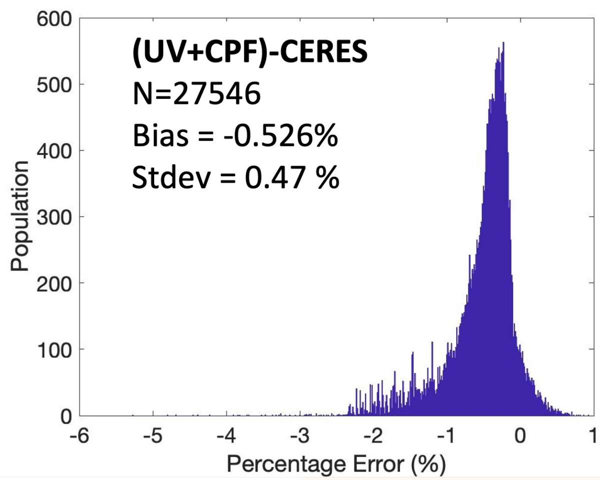
CPF-CERES Spectral range extension

- CPF spectral range (350-2300 nm)
- CPF measurements must be extended to 200 nm – 15 um to account for CERES unfiltered radiance definition
- PCRTM-based spectral gap filling algorithm
- Required **1-σ uncertainty < 0.1%**
- A flexible algorithm that can be used for Intercal with other sensors

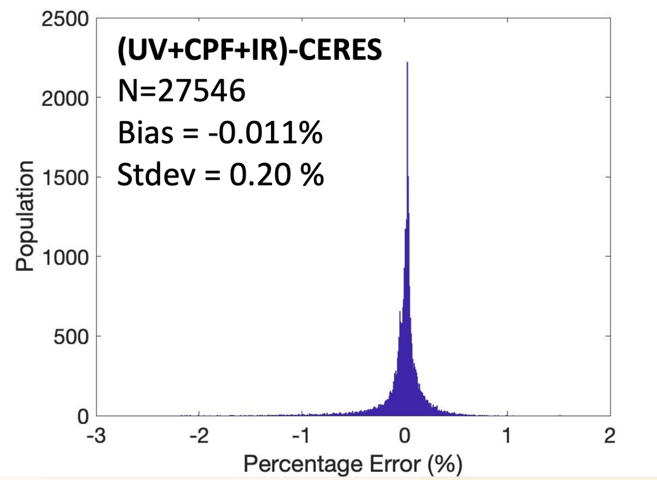




Without any spectral gap-filling between CPF & CERES



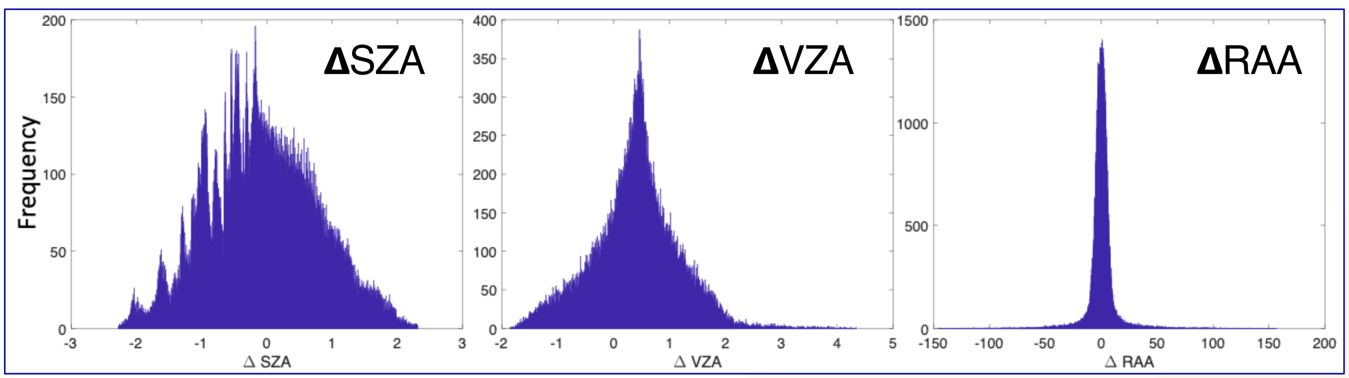
Only spectral gap-filling in UV (200-350nm)

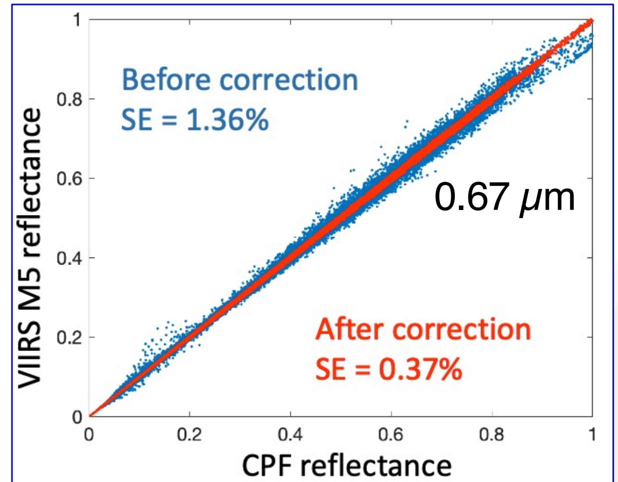


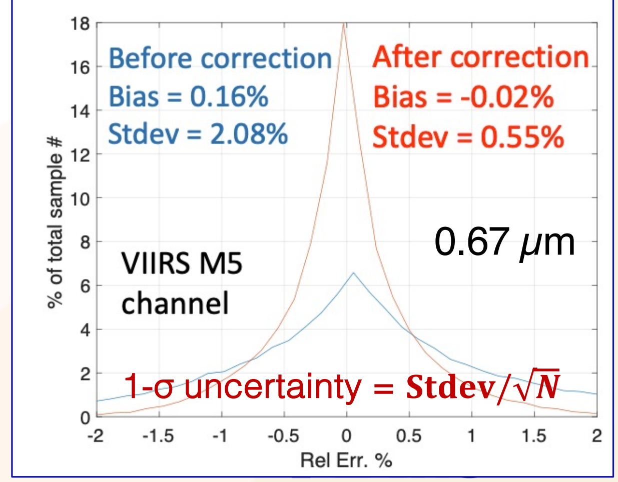
Spectral Gap-Filling in both UV & IR

Angular differences and adjustment

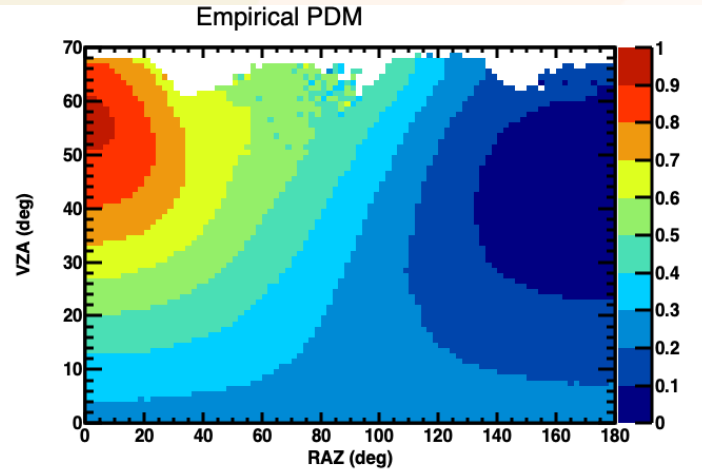
- Angular differences can result in systematic bias and random noise
- A PCRTM-based algorithm for angular adjustment of CPF measurements
- For **CPF-VIIRS intercalibration**
  - Before angular adjustment (Blue),
    - Error from angular mismatch is up to 10%
    - Bias of ~0.2%
  - After angular adjustment (Red),
    - Bias reduces by a factor of 10
    - Noise reduces by a factor of 4
    - **Anticipated 1-σ uncertainty after angular corrections =~0.01% (5k samples)**
- A flexible algorithm that can be used for Intercal with other sensors



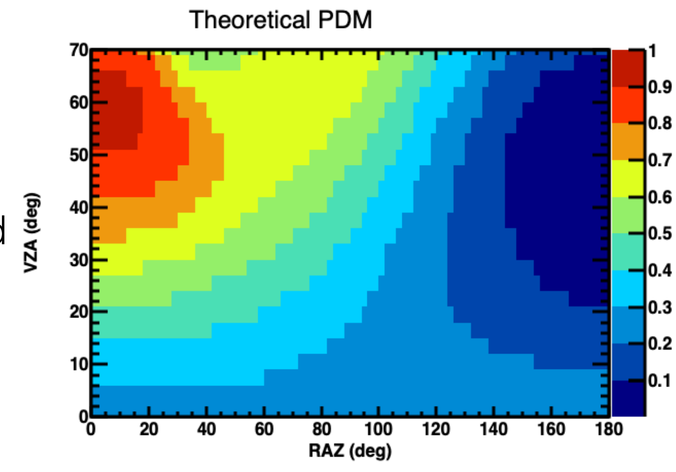




Polarization Distribution Model (PDM) Look-up Tables



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



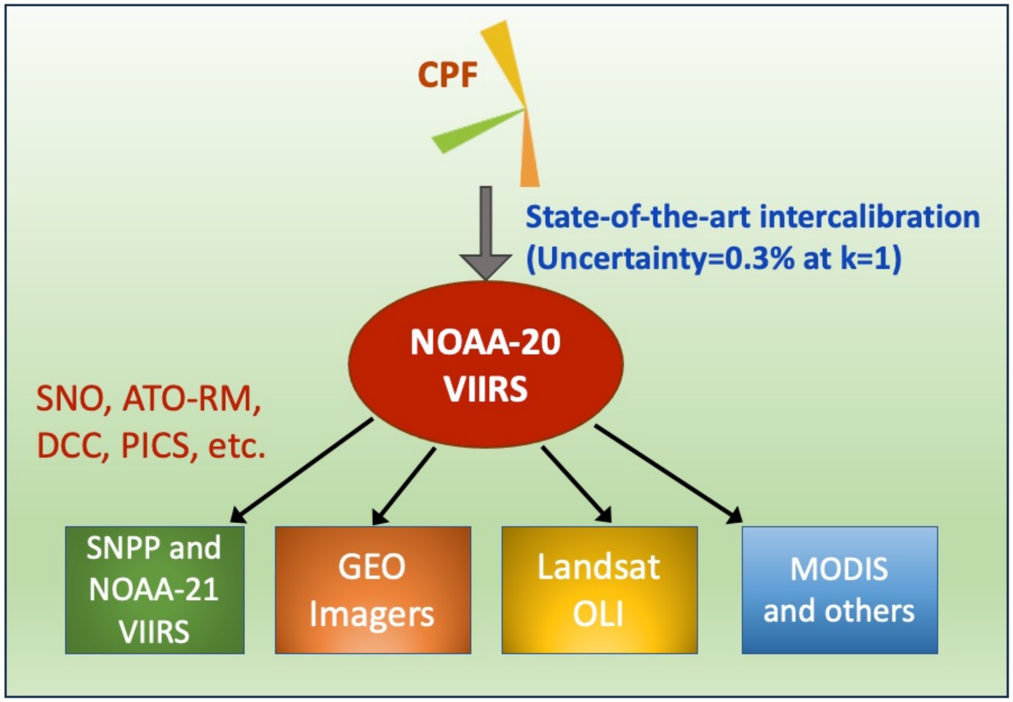
Empirical PDMs: Constructed from PARASOL/POLDER Data

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

CPF will enable other Earth observing missions to surpass their original capabilities



- CLARREO Pathfinder will take concurrent measurements with CERES & VIIRS on NOAA-20 and at least one GEO (although initially L4 data products will only be generated for CPF-CERES & CPF-VIIRS intercalibration).
- CPF will also take measurements of pseudo-invariant calibration targets (the Moon, key land sites, DCCs) to improve hyperspectral characterization of these PICTs
- GSICS has identified N20 VIIRS as its on-orbit reference for reflective solar bands.
- Radiometrically tying N20 VIIRS calibration to CPF calibration in turn can support sensors that use N20 VIIRS as a reference

Additional CPF Intercalibration Applications

CLARREO Pathfinder

- Serve as a reference for Targets Beyond Core Mission Direct Targets (with and without direct intercal measurements)
- Independent Verification of Radiometric Consistency among multiple flight models (e.g. CERES, VIIRS)
- Improvement of Climate Data Records -- e.g. MODIS/VIIRS Aerosol, Cloud Continuity Products (20+ year records!)
- Improved Lunar Reflectance Characterization to support inputs to lunar calibration models
- Hyperspectral, multi-angle, high accuracy measurements of Pseudo-Invariant Earth Targets (e.g. key desert sites, Deep Convective Clouds)

LASP

Intercalibration: A Multi-dimensional data matching challenge

CLARREO Pathfinder

Spatial & Temporal Matching
- Spatial resolution difference, geolocation uncertainties
- Differing intercal sample acquisition times

Spectral Differences
- Scene dependent biases due to differences in spectral range, resolution, and sampling

Sun-view Geometry
- Solar: driven by difference in acquisition times
- Viewing: from imperfectly aligned samples

Polarization Sensitivity
- Reference & Target polarization sensitivity differences

Monthly Target Variability
- Expected monthly target sensor calibration variability

Additional Science with CPF High Accuracy Spectra

CLARREO Pathfinder

- Predecessor & Complement to Several Missions (e.g. ESA TRUTHS mission)
- Develop novel hyperspectral retrievals for cloud, aerosol, water vapor, and surface properties
- Developing a Climate Benchmark Prototype for climate change monitoring and climate model constraints
- Development of Novel Climate Change Attribution Techniques (e.g. spectral fingerprinting)
- Evaluating temporal variability of spectral radiation (e.g. How has spectral reflectance changed in the past 20 years?)

e.g. Dr. Jeffrey Mast, a NASA Postdoctoral Program fellow, is developing a hyperspectral ice cloud retrieval algorithm.

LASP

Some Things to Think About…

- Intercalibrating additional sensors – (Can CPF intercalibrate [insert your favorite sensor here])?
  - CERES & VIIRS on J1 are the top priority to demonstrate meeting mission requirements
  - For other sensors, it's not a "no" – but some thought needed to
  - What are the needed intercalibration methodology uncertainty requirements for other sensors?
    - What is the objective of intercalibrating the target? – Tracking stability? Evaluating consistency with another Flight Model?
    - Target Teams & communities need to consider what the sampling requirements are to meet intercal goals –
  - Additional intercal operations needs to be balanced with other observation goals (e.g. maximizing nadir observations, calibration modes)
- Intercalibrating additional surface sites
  - We will start with limited number of land sites (which ones are TBD)
  - CPF can plan observations for more Land Surface PICS – this is a programmatic matter, not a performance limitation
- Extended Occupancy on ISS – Main justification provided was for potential overlap with TRUTHS
  - **Potential Limitation:** End of ISS is currently 2030
- Lunar Scans Included in nominal CPF Operations Plan – working closely with Tom Stone (USGS)