A23S-2623

Reference Intercalibration for the Climate Observing System

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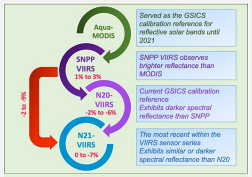
Climate Benchmark Measurements for Intercalibration



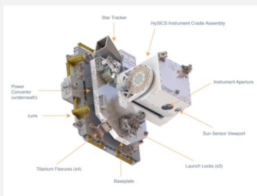
Created with data provided by the MODIS/VIIRS Characterization Support Team. The MCST/VCST is currently reprocessing N21 VIIRS data.

Differences in radiometric calibration uncertainties from multiple sensors such as MODIS and VIIRS (see figure on left) have been found to propagate into the long-term climate data records constructed with measurements from different sensors and must be carefully accounted for (e.g. Meyer et al., 2020; Sayer et al., 2017).

Climate Benchmark Measurements have characteristics (*Goody et al.*, 1998) that can make them ideal candidates to serve as intercalibration references (among plenty of other applications!), particularly their requirements to be global (or nearly so) and regularly calibrated to global absolute standards.

SITSats (SI-Traceable Satellite Sensors), such as CLARREO Pathfinder (CPF) have the needed measurement characteristics to take climate benchmark and intercalibration reference measurements.

CPF Characteristics	
Instrument	HyperSpectral Imager for Climate Science (HySICS)
Spectral Range/Sampling	350 nm – 2260 nm (3 nm)
Uncertainty	0.3% (spatial/spectral avg)
Swath Width	10° (~70 km at nadir)
Spatial Sampling	0.5 km
Sampling Rate	15 Hz



CPF Science Objectives

	Spectral Reflectance	Intercalibration
Objective	Take spectral reflectance measurements with unprecedented uncertainty	Illustrate high accuracy calibration transfer to other RS satellite sensors by inter-calibrating with CERES & VIIRS.
Uncertainty	Spectrally-resolved & broadband reflectance: ≤0.3% (1σ)	Intercalibration **methodology** uncertainty: ≤0.3% (1σ)
Data Products	**Level 1A:** Highest accuracy, best for intercalibration, lunar observations. **Level 1B:** Approx. consistent spectral & spatial sampling, best for most science studies using nadir spectra.	**Level 4:** One each for CPF-VIIRS & CPF-CERES intercal. Merged data products that include all required info for interval analysis.

Key Reference Measurement Characteristics contributing to low intercal methodology uncertainty

- Low polarization sensitivity (<1%, 350-1400 nm)
- Consistent spectral sampling (3 nm across spectral range)
- Moderate spatial sampling (~0.5 km)
- Two-axis pointing capability
- Low radiometric calibration uncertainty

Intercalibration: A multidimensional data matching challenge

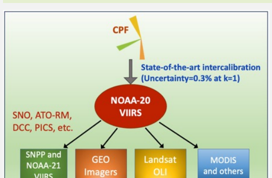
Spatial & Temporal Matching
- Spatial resolution difference, geolocation uncertainties
- Differing intercal sample acquisition times

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

Sun-View Geometry Differences
- Solar geometry differences driven by difference in acquisition times
- Viewing geometry differences from imperfectly aligned samples

Polarization Sensitivity
- Reference & Target polarization sensitivity differences
- Induces uncertainty when comparing polarized radiances

Miscellaneous
- Mainly accounts for monthly target sensor calibration variability, or generally, the timeframe over which intercal analysis is conducted

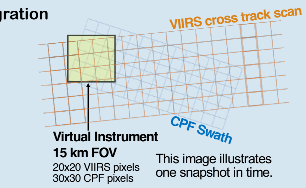


- CLARREO Pathfinder will take concurrent measurements with CERES & VIIRS on NOAA-20 and at least one GEO (although initially L4 data products will only be generated for CPF-CERES & CPF-VIIRS intercalibration).
- CPF will also take measurements of pseudo-invariant calibration targets (the Moon, key land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

CPF-VIIRS Intercalibration

Spatial Integration

- CPF pixels are ~0.5 km at nadir
- VIIRS pixels are 375 m and 750 m for the Imager & Moderate Resolution bands, respectively
- CPF-VIIRS intercalibration samples are defined by an arbitrary "virtual instrument" defined to have a 15 km FOV at nadir
- Intercalibration sample centroids are defined such that the samples overlap 50% in "along-track" and "cross-track" directions to obtain sufficient samples with low polarization sensitivity.

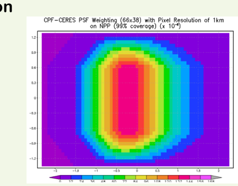


CPF's two-axis pointing system enables CPF-target sensor angular matching throughout intercal events.

CPF-CERES Intercalibration

Spatial Convolution

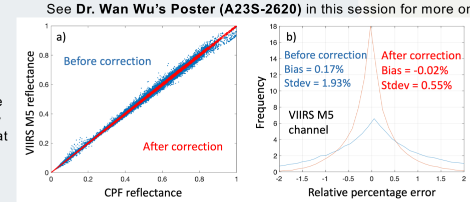
- CPF spectra are spatially convolved using CERES Point Spread Function.
- CERES has a footprint size at nadir of about 20 km² so about 40x40 CPF pixels are spatially convolved over the CERES Point Spread Function to create CPF intercalibration samples
- This reduces the spatial matching noise between CPF & CERES and enables CPF to more closely emulate CERES measurements.
- We have done studies (lunar) that show that the pre-launch CERES PSFs are stable at less then 0.1% level.



Angular Correction

See **Dr. Wan Wu's Poster (A23S-2620)** in this session for more on the Angular Correction algorithm

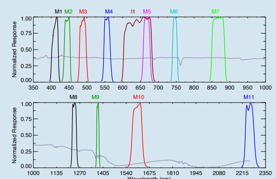
- Goal to reduce angular difference uncertainty to within 0.1% (at least within 0.65 um band)
- Principal Components-Based Radiative Transfer Model (PCRTM)-based correction leverages spectral correlations in CPF spectra to estimate the adjustment that needs to be made to each spatially convolved CPF spectrum such that it emulates what CPF would have measured if it had the same sun-view geometry (SZA, VZA, and RAA) as the target instrument.



- Figure shows the pre-correction and post-correction relative error for the VIIRS M5 moderate
- The differences were computed from PCRTM-simulated CPF/HySICS-like spectra for Jan 2017 CPF-VIIRS simulated intercalibration events.
- The only differences between the two sets of spectra were the sun-view geometries at which they were simulated.
- The same algorithm is implemented for both CPF-CERES and CPF-VIIRS intercalibration because it is applied to spatially convolved CPF spectra prior to any spectral convolution/integration.
- We have estimated (using simulated spectra) that for both the CERES SW band and the VIIRS M-bands, that this adjustment can be done within an uncertainty of 0.1%.

Spectral Convolution

- Unresolved spectral mismatches between reference and target sensors results in scene-dependent intercalibration comparisons.
- Hyperspectral measurements (3 nm sampling) from the reference sensor (CPF) substantially mitigates the spectral differences.
- The CPF 3 nm spectral sampling across its entire spectral range enables the simulation of moderate resolution spectral bands (like MODIS/VIIRS).
- As-built CPF spectral range does not include sufficient measurement coverage of M11 band.
- At 4 nm spectral sampling, the impact is within 0.1% for MODIS bands (**Wu et. al. 2015**).

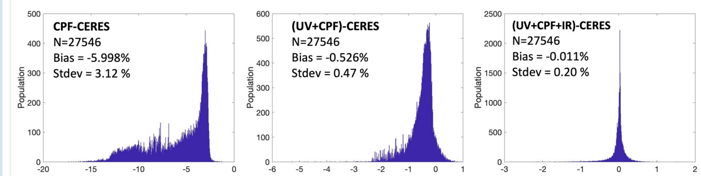


HySICS-like reflectance spectrum (grey) and Spectral Response Functions of VIIRS M1-M11 and I1 bands

Spectral Band Extension/Gap-Filling

See **Dr. Qiguang Yang's Poster (A23S-2621)** in this session for more on the algorithm

- Not accounting for the spectral range difference between the CERES SW band and the CPF spectral range would result in large differences when directly comparing CPF and CERES radiances (see below).



Without any spectral gap-filling between CPF & CERES | Only spectral gap-filling in UV (200-350nm) | Spectral Gap-Filling in both UV & IR

CPF-VIIRS N20 Intercalibration Sampling

Data Filters Applied

Only include samples with
- Solar Zenith Angles <60°
- Viewing Zenith Angles <60°
- Relative Azimuth Angles at least +/- 5° of forward or backward scattering regions
- CPF & VIIRS pixel percent coverage > 95% of sample
- Homogeneity Factor (σ/μ) <0.2
- Degree of Polarization <0.1

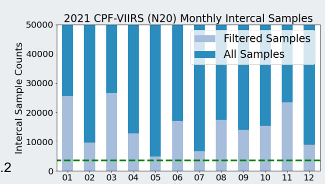


Figure shows current estimate of CPF-VIIRS intercalibration samples that pass filters listed on left.

Green line shows minimum sample counts needed assuming spatio-temporal uncertainty of 6% (see **Matthew Little's Poster (A23S-2622)** next door).

CPF-CERES N20 Intercalibration Sampling

Data Filters Applied

Only include samples with
- Solar Zenith Angles <60°
- Viewing Zenith Angles <60°
- Relative Azimuth Angles at least +/- 5° of forward or backward scattering regions
- CPF pixel percent coverage >= 95% of CERES FOV
- Homogeneity Factor (σ/μ) <0.2

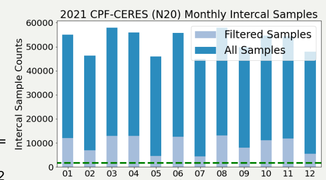


Figure shows current estimate of CPF-CERES intercalibration samples that pass filters listed on left.

Green line shows minimum sample counts needed assuming spatio-temporal uncertainty of 4% (supported by preliminary studies).

CPF-VIIRS Intercalibration Summary

- Spatial-Temporal Matching uncertainty is largest individual uncertainty contribution – According to sample filter analysis (panel above), we have sufficient samples monthly to reduce the spatial & temporal matching uncertainty to <0.1%
- CPF-VIIRS intercalibration algorithms & data analysis applicable to other multi-spectral imagers.
- For target sensors with similar spatial sampling, a similar "virtual instrument" can be created for simple spatial convolution/averaging.

Intercal Methodology Uncertainty Estimates

Combined Uncertainty (current best estimates)	Uncertainty Term	Definition	Combined Uncertainty (current best estimates)
$6/\sqrt{N}$	u_{ST}	Spatial & Temporal Matching	$4/\sqrt{N}$
n/a	u_{PSF}	Point Spread Function Centroid Knowledge	$(0.06^2 + 0.15^2/N)^{0.5}$
0.1	u_{Spec}	Spectral Matching	$(0.01^2 + 0.2^2/N)^{0.5}$
$(0.02^2 + 0.55^2/N)^{0.5}$	u_{Ang}	Angular Adjustment	$(0.01^2 + 0.65^2/N)^{0.5}$
$(0.06^2 + 0.15^2/N)^{0.5}$	u_{Pol}	Polarization Sensitivity Differences	n/a
0.1	u_{misc}	Miscellaneous (target calibration monthly variability)	0.1

Key Systematic Uncertainty | Random Variability | Estimated Combined Uncertainty

CPF-CERES Intercalibration Summary

- Spatial-Temporal Matching uncertainty is largest individual uncertainty contribution – According to sample filter analysis (panel above), we have sufficient samples monthly to reduce the spatial & temporal matching uncertainty to <0.1%
- Similar process could be used to intercalibrate with Libera (CERES follow-on).
- CPF can also be a resource to further validate other consistency studies comparing CERES & Libera measurements

References
- Goody, R., et al. "Testing climate models: An approach." *Bulletin of the American Meteorological Society* 79.11 (1998): 2541-2549.
- Lyapustin, A., et al. "Calibration of the SNPP and NOAA 20 VIIRS sensors for continuity of the MODIS climate data records." *Remote Sensing of Environment* 295 (2023): 113717.
- Meyer, K., et al. "Derivation of shortwave radiometric adjustments for SNPP and NOAA-20 VIIRS for the NASA MODIS-VIIRS continuity cloud products." *Remote Sensing* 12.24 (2020): 4096.
- Sayer, A. M., et al. "Cross-calibration of S-NPP VIIRS moderate-resolution reflective solar bands against MODIS Aqua over dark water scenes." *Atmospheric Measurement Techniques* 10.4 (2017): 1425-1444

Other CLARREO Pathfinder-related posters
- Xu Liu: A23S-2624 A Principal-Component-based Radiative Transfer Model (PCRTM) for Hyperspectral SW and LW Satellite Sensors and Its Applications
- Jeff Mast: A23S-2625 Towards optimal estimation retrieval of cirrus cloud optical and microphysical properties using hyperspectral shortwave instruments and a fast radiative transfer algorithm
- Tracey Morland: IN23B-0594 A Cloud-Native Data Processing Approach for the CLARREO Pathfinder Mission
- Aron Bartle (Friday PM): T53F-0204 Earth Science Data Processing With Nextflow