

CLARREO Pathfinder Mission Overview

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& CPF Team

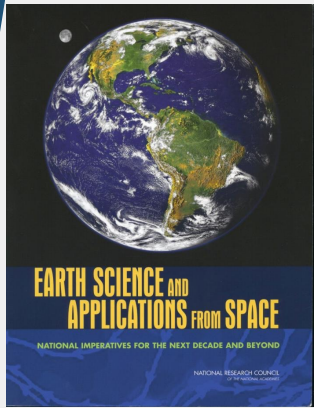
November 2, 2021



A Brief History: The Path to Pathfinder



Climate Absolute Radiance and Refractivity Observatory



2007: Decadal Survey Recommended CLARREO as Tier 1 Mission

2010: CLARREO passed Mission Concept Review

2011: CLARREO Mission was pulled back into Pre-formulation "indefinitely"

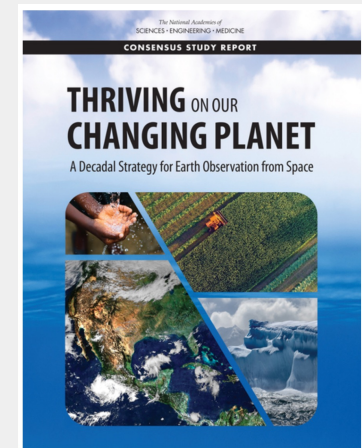
2016: RS CLARREO Pathfinder on ISS mission started!

2017: 2nd Decadal Survey supported continuation of CPF



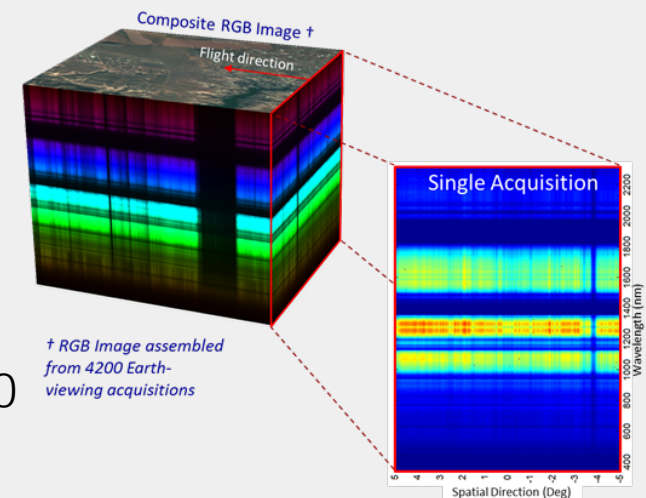
Full CLARREO Purpose: To address critical need for high accuracy climate change observations and establish a climate benchmark.

Scope: 5-year mission with RS and IR spectrometers, GNSS-RO receivers for climate benchmarking and inter-calibration



- **Core Mission Objectives:** Demonstrate ability to achieve climate-critical high accuracy reflectance measurements of Earth reflectance and inter-calibration with CERES (broadband) & VIIRS (multi-spectral)
- LASP-Led Payload & Reflected Solar Spectrometer (350 – 2300 nm)
- Category 3, Class D Mission
- *Nominal* 1-year mission operations + 1-year science data analysis
- Currently in Phase C – Passed [Virtual] CDR in March 2020
- Launch Estimated in Late CY 2023

Spectrally-Resolved Earth Reflectance





CLARREO Pathfinder Schedule



Key

Pre-Phase A

Phase A

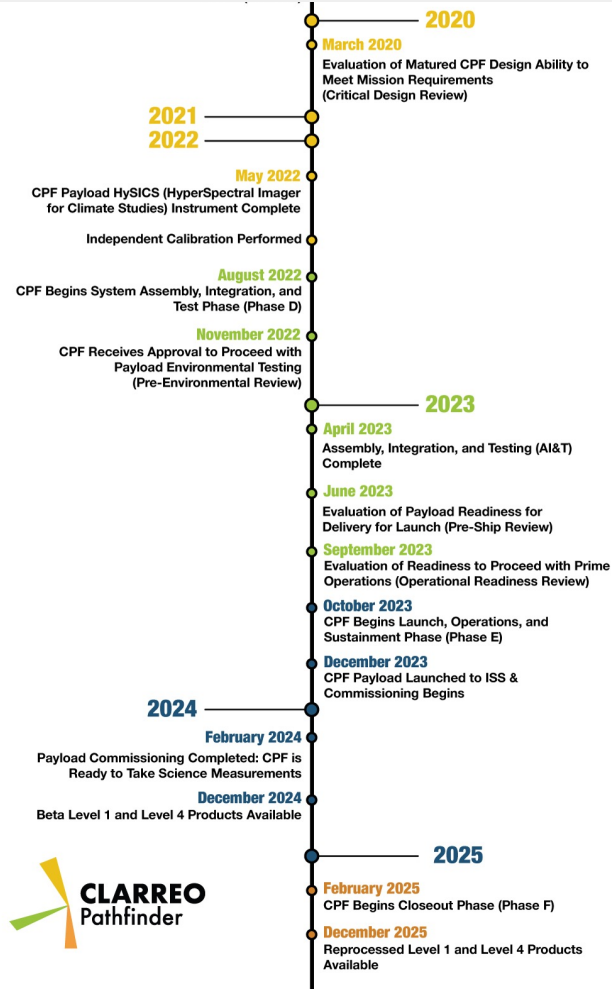
Phase B

Phase C

Phase D

Phase E

Phase F



• Key Dates – Prime Mission

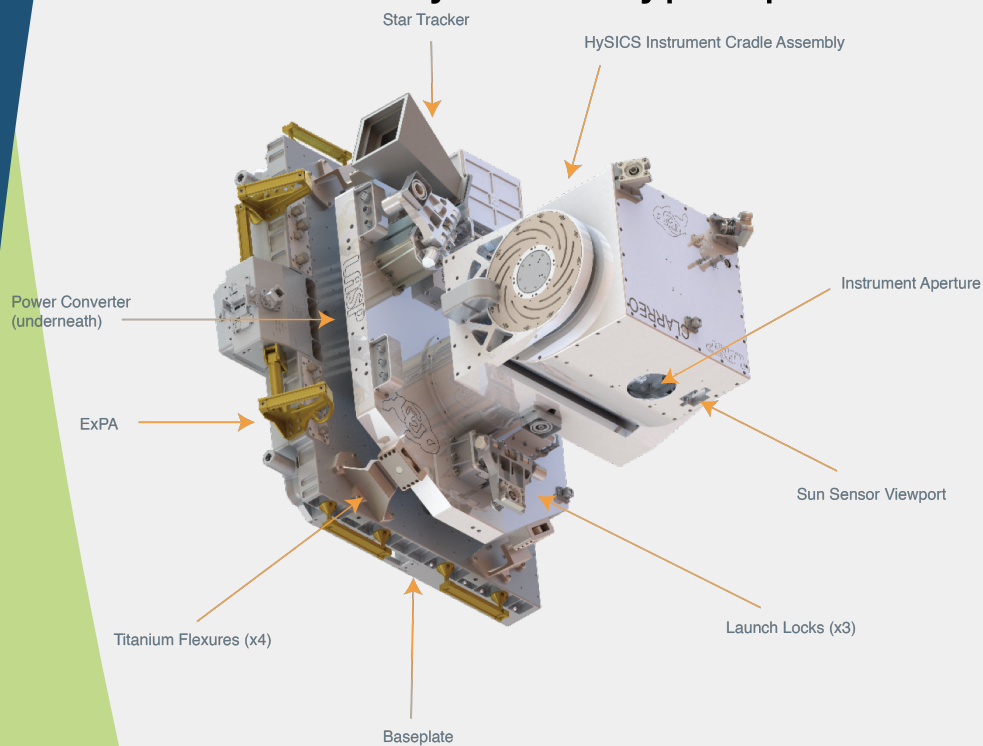
- ~December 2023: Launch!
- February 2024: Start Science Operations
- October 2024: Beta L1 Data Products Available
- December 2024: Beta L4 Data Products Available
- December 2024: Estimated start timeframe of CPF Science Team

• Possible Extended Mission

- ISS Occupancy through 2027
- Tentative ISS Occupancy through 2030



HySICS: Hyperspectral Imager for Climate Science



Radiometric Uncertainty

0.3% (1-sigma)

Spectral Range

350 nm – 2300 nm

Spectral Sampling

3 nm

Swath Width

10° (70 km nadir)

Spatial Sampling

0.5 km

Sampling Rate

15 Hz

Kopp et al 2017



CLARREO Pathfinder is Critical for Observing Climate



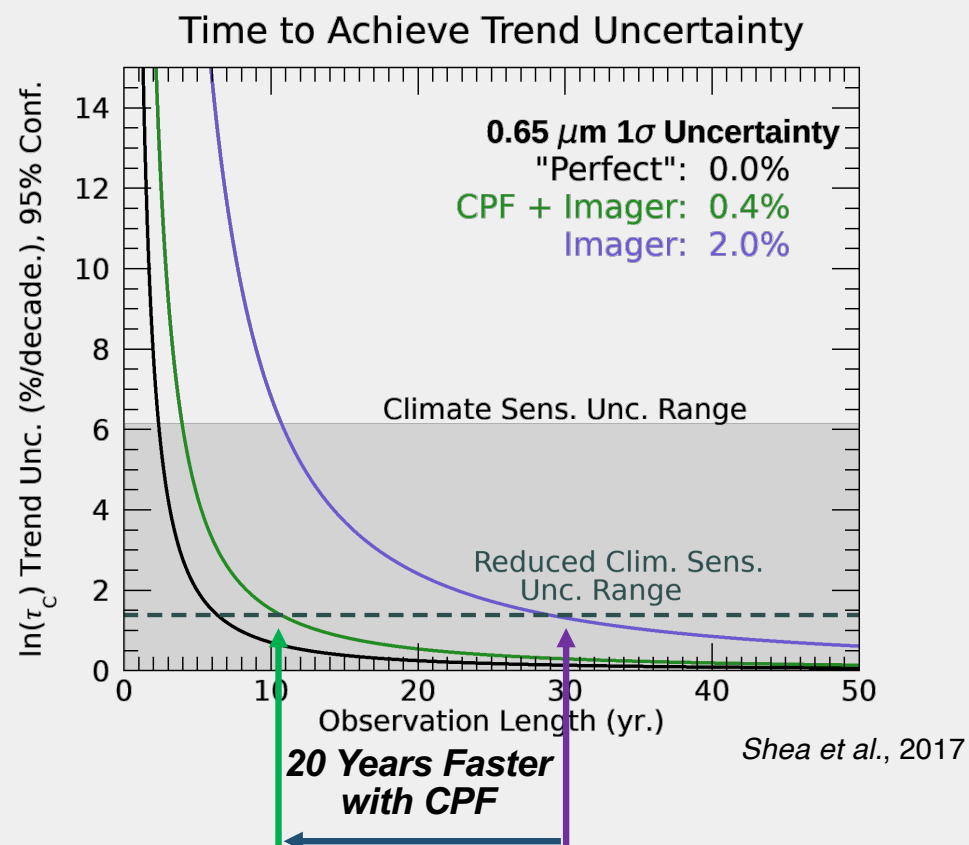
High accuracy, information-packed measurements are critical for both detecting climate change and identifying what is driving Earth's changing climate.

High Accuracy Benefits (4-8x better than current sensors)

- Provides an on-orbit reference for other sensors (via Inter-calibration)
- Gap Resistance for Earth observations
 - Calibration with SI-traceability reduces risks of potential gaps in monitoring Earth's climate
- Enables the beginning of climate benchmark

Inter-calibration Benefits

- Studies show that *CPF + Imager* Inter-calibration enables *faster detection of essential climate variable trends* as shown on the right (e.g.)
- Enables reduced on-orbit calibration uncertainty of other Earth-observing instruments, thus offering the potential to also improve their data product quality

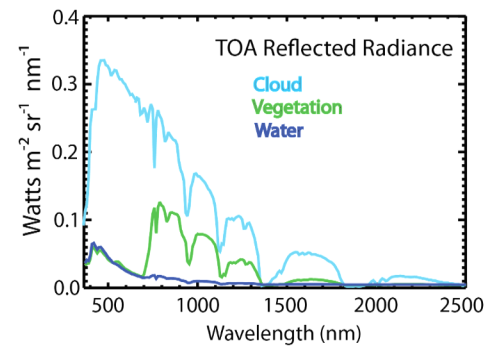
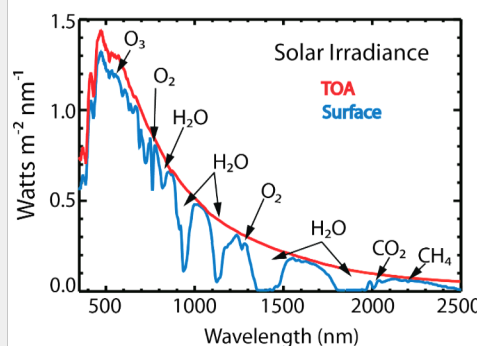
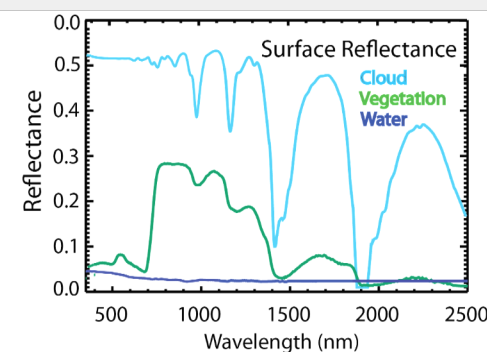
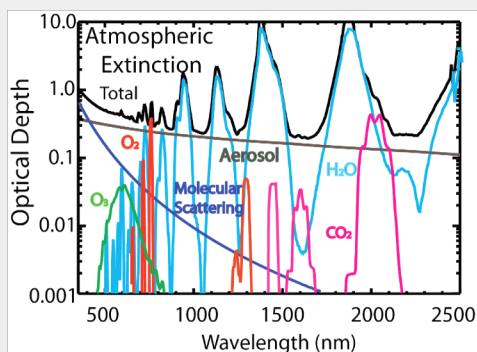


Nadir CPF Hyperspectral Measurements

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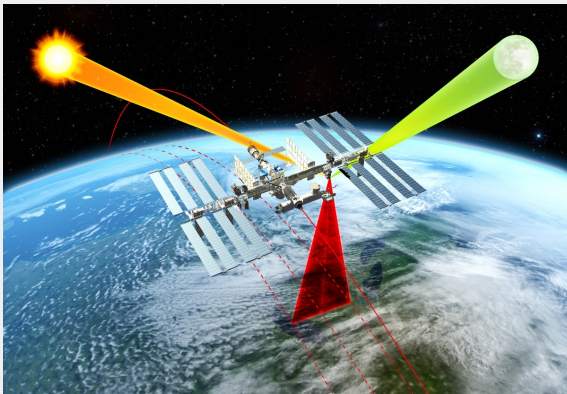
Hyperspectral Benefits (350-2300 nm)

- Several key geophysical variables have slowly varying spectral signatures
- The spectral information enables novel studies
 - Develop hyperspectral geophysical retrieval algorithms (e.g. getting vertical info of cloud effective particle size [*Zhang & Platnick, 2011*])
 - Augment Information in existing retrieval algorithms [*Coddington et al., 2012; 2017*]
 - TOA Hyperspectral Scene Classification Studies [e.g. *Roberts et al., 2011*]
 - Development of a climate benchmark prototype



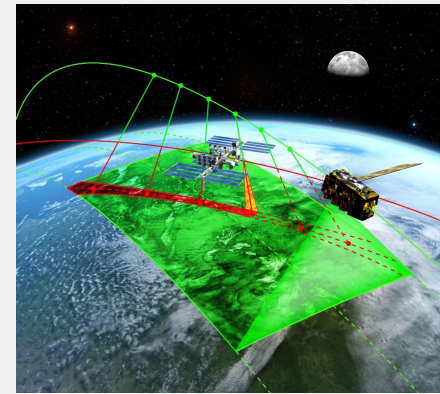
CPF Science Objectives

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

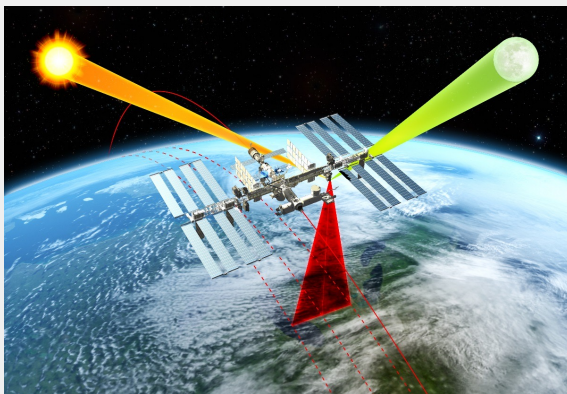


Demonstrate ability to transfer calibration other key RS satellite sensors by inter-calibrating with CERES & VIIRS.

	Objective #1	Objective #2
Uncertainty	Spectrally-resolved & broadband reflectance: $\leq 0.3\%$ (1σ)	Intercalibration Methodology Uncertainty: $\leq 0.3\%$ (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

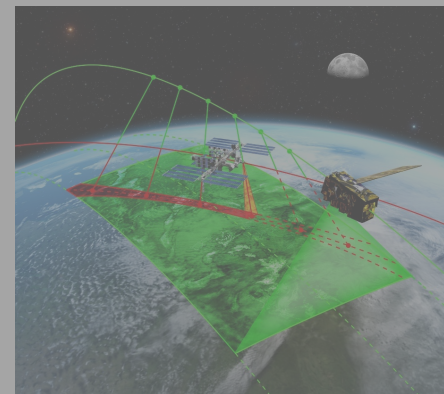
CLARREO Pathfinder Objectives

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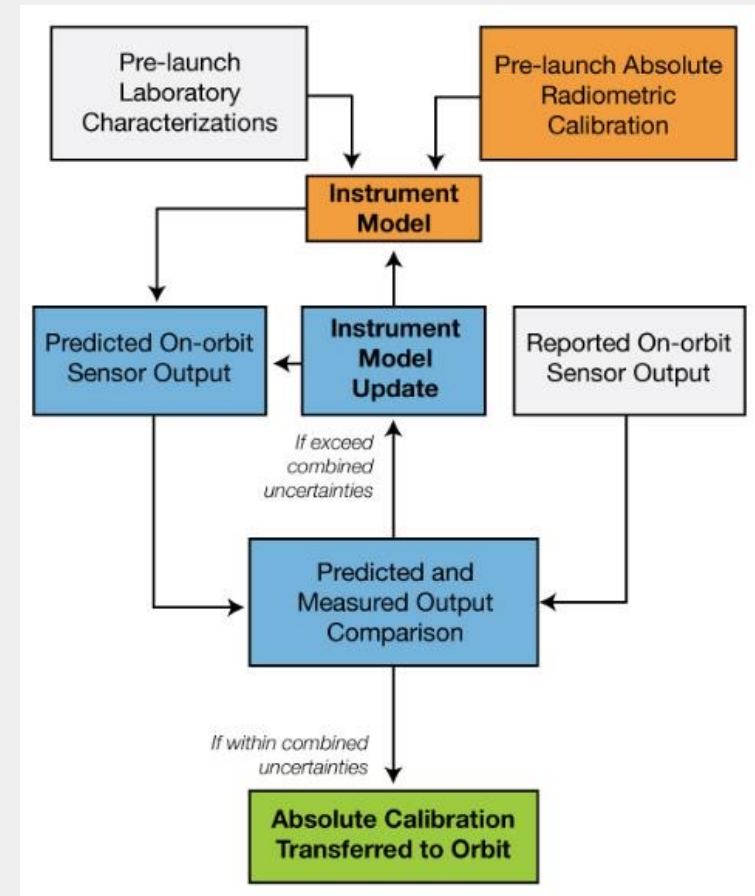


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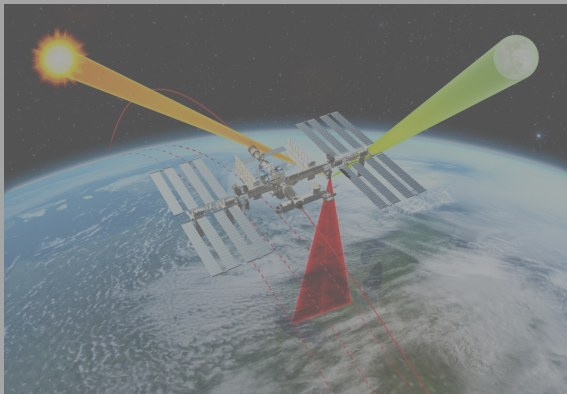
Objective #2
Inter-calibration Data Matching: $\leq 0.3\%$ (1σ)
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- Science community needs demonstration that the ratioing radiometer approach provides CLARREO-level accuracy
- An independent calibration traceability relying on the traditional pathway using a laboratory & detector-based absolute radiometric calibration
- Provides an independent test of CPF's calibrated product with minimal cost and schedule impact to project
 - Strong collaborative effort between instrument developer (CU/LASP) and project
 - Requires a multi-agency and multi-center efforts to be successful



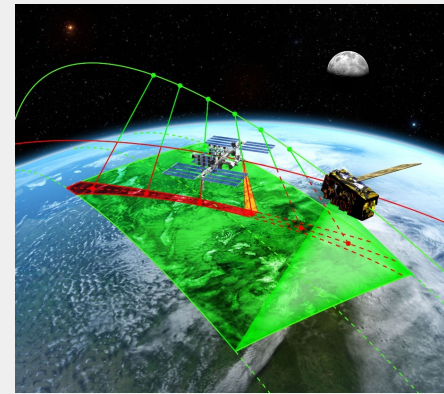
CLARREO Pathfinder Objectives

Objective #1: High Accuracy SI-Traceable Reflectance Measurements



Demonstrate on-orbit calibration ability to reduce radiance 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 other key RS satellite sensors by inter-calibrating with CERES & VIIRS.

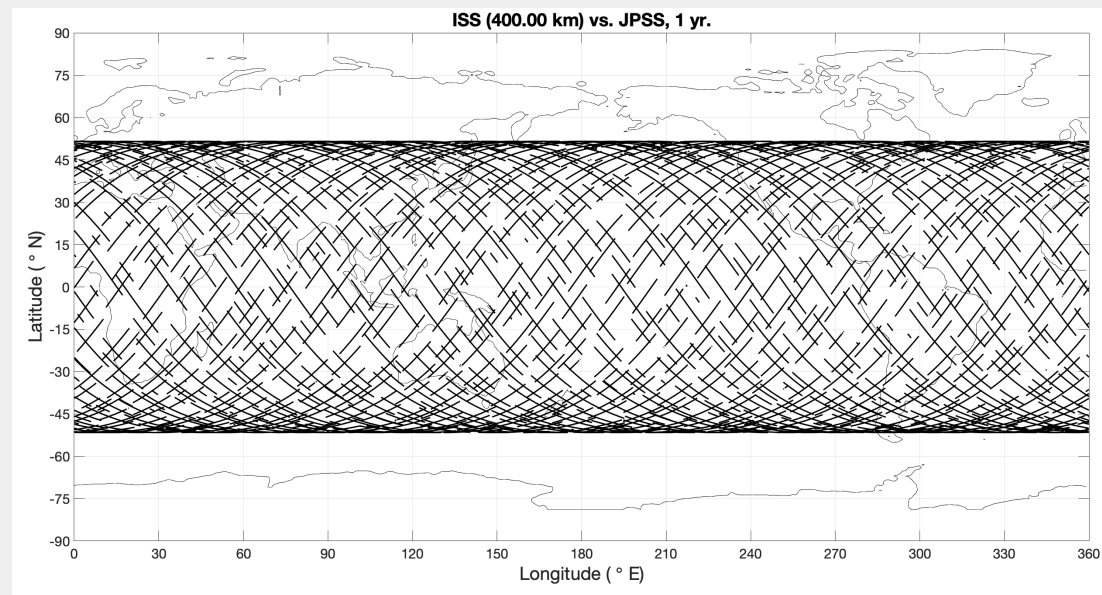
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Planned Pointing & Scanning Ops For Improved IC Statistics

- 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



Versatility in CPF Observations

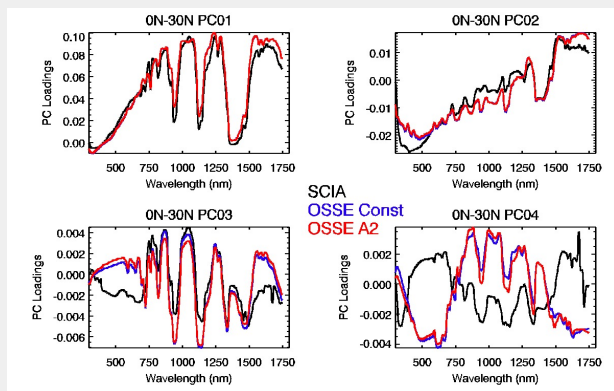
Launch-Ready: Late 2023

Prime Mission Ops

Extended Mission Ops (?)

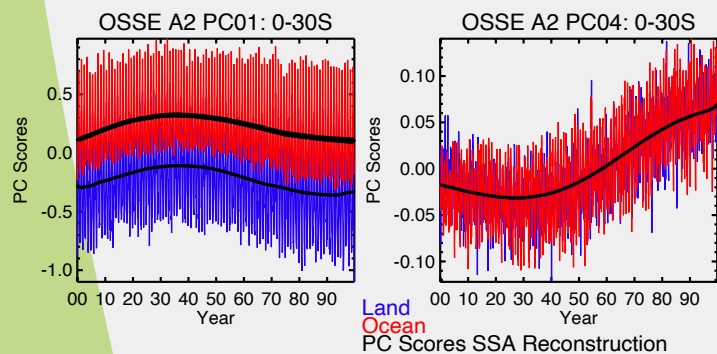
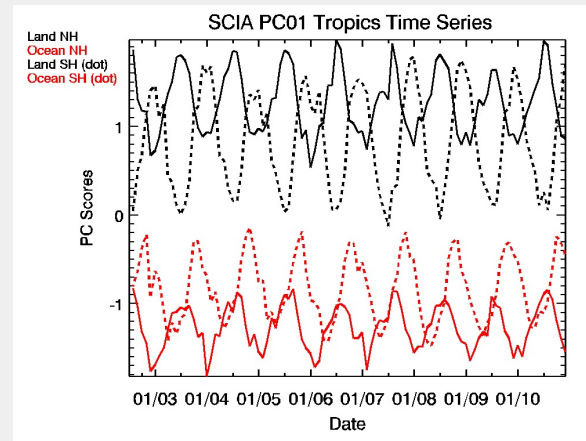
Observation Type	1-Year Mission	1+ Years
On-orbit Instrument Calibration	Demonstrate success of calibration approach over 1 year	Confirm success of calibration approach over longer period
Earth Reflectance and Radiance Nadir Spectra	Will be used to demonstrate achieved calibration, geolocation, etc requirements	- Develop partial (nearly-global) climate benchmark prototype - Potential for overlap with TRUTHS - Additional opportunities for use in science studies
LEO On-orbit Inter-calibration	- Measurements and data analysis for CERES and VIIRS Only - Potential Landsat measurements	Additional flexibility to inter-calibrate other on-orbit LEO sensors (e.g. PACE, Sentinel, commercial sensors)
GEO On-orbit Inter-Calibration	Demonstration measurements with 1 GEO	Expand GEO inter-calibration measurements (e.g. TEMPO, GOES, GERB, Himawari series, GeoCarb)
Enhanced Land/DCC Pseudo-Invariant Calibration Site (PICS) Characterization	Measurements over high priority PICS	Additional PICS added with additional viewing opportunities
Improved characterization of the Moon	Leveraging existing ops mode to cover libration and phase angles available	Additional sampling within libration and phase angles to further make lunar models more robust

Studies on Spectral and Temporal Variability



Temporal Variability of Dominant spectral variables from SCIAMACHY & OSSE simulations

- What would these spectral variables look like from CPF? Would the differences be indicative of a climate shift? Instrument differences? Something else? What observable trends can we identify with the spectral trends of the PCs from SCIA (2002-2012) and CPF (2024-??) data?
- For a short period of time (~1-5 years) are the dominant modes comparable? If not, why not?



Despite PC spectral shape not necessarily exhibiting clear signature of the physical drivers, the time series gave clues regarding physical drivers of variability.

PC1: Aerosol Optical Depth Temporal Variability

PC4: Total Column Precipitable Water Temporal Variability

