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Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder

Science and Mission Requirements Document (SMRD)

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TBD	Expected POIC to CPOC interface requirements document	32
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1.0 Introduction

1.1 Purpose and Scope

This document establishes the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder science and mission requirements. The document includes the functional and performance requirements. The requirements are derived from the Program-Level Requirements for the CLARREO Pathfinder (CPF) Project, which are captured in the Earth Systematic Missions Program Plan, Appendix Z.

1.2 Document Organization

Section 2 lists applicable and reference documents. Section 3 provides an overview of the CPF science objectives and mission segments. Section 4 contains the functional and performance requirements. Appendices A and B provide acronyms and definitions.

2.0 Documents

This section identifies documents that are applicable to this document and assumes the current version unless otherwise noted. Reference documents are for information only.

2.1 Applicable Documents

Document Number	Document Title
420–01–01	Earth Systematic Missions Program Plan, Appendix Z – CLARREO Pathfinder Program Level Requirements
CPF–01–013	CLARREO Pathfinder Statement of Work
CPF–02–002	CLARREO Pathfinder Systems Engineering Management Plan
CPF–02–009	CLARREO Pathfinder Mission Concept of Operations
CPF–03–001	CLARREO Pathfinder Mission Assurance Requirements
SSP 51700	Payload Safety Policy and Requirements for the International Space Station
SSP 57003	External Payload Interface Requirements Document

2.2 Reference Documents

Document Number	Document Title
152–TP–003–003	Glossary of Terms for the EOSDIS Core System Project
CPF–04–014	CLARREO Pathfinder Data Management Plan
GSFC–423–SPEC–001	NASA Earth Science Data Preservation Content Specification
Lukashin et al, IEEE 2013	Uncertainty Estimates for Imager Reference Inter–calibration with CLARREO Reflected Solar Spectrometer
NPR 7120.5	NASA Space Flight Program and Project Management
NPR 7123.1	NASA Systems Engineering Processes and Requirements
NASA SP–2016–6105 Rev 2	NASA Systems Engineering Handbook
Wielicki et al, IGARS 2008	Climate Quality Broadband and Narrowband Solar Reflected Radiance Calibration Between Sensors in Orbit
Wu et al, IEEE 2015	Sensitivity of inter–calibration uncertainty of the CLARREO reflected solar spectrometer features

2.3 Document Control

This document is managed by the CPF Project and, after initial approval, will be placed under configuration control using the change management processes defined in the CLARREO Pathfinder Configuration Management Operating Procedure (CPF-01–005).

2.4 Order of Precedence

The Program-Level Requirements and Project-Level plans listed in the applicable documents section take precedence over the Science and Mission Requirements Document (SMRD). The

SMRD takes precedence over all lower level requirement documents. Nothing in this document, however, supersedes applicable laws and regulations.

3.0 System Description

This section describes the system architecture for the CPF mission and provides context for requirements in Section 4. Refer to CLARREO Pathfinder Mission Concept of Operations, CPF-02–009, for a more thorough description of the mission functions and operations.

3.1 Mission Description

CLARREO is a Tier 1 mission recommended by the 2007 National Research Council Decadal Survey entitled “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond.” The foundation of CLARREO is the ability to produce highly accurate climate records to test climate projections in order to improve models and enable sound policy decisions. The CLARREO mission accomplishes this critical objective through accurate Système Internationale (SI)-traceable decadal observations that are sensitive to many of the key climate parameters such as radiative forcings, climate responses, and feedbacks. Uncertainties in these parameters drive uncertainty in current climate model projections. In 2016, the CLARREO Project received funding for a Pathfinder mission to demonstrate essential measurement technologies for the RS portions of the CLARREO Tier 1 Decadal survey mission, to include on-orbit high accuracy SI-traceable calibration and the ability to transfer that calibration to other on-orbit assets. The appropriated funds support the flight of an RS spectrometer hosted on the International Space Station (ISS) in the calendar year 2022 time frame. Prime mission operations on ISS are planned for one year, with an additional year of data analysis support following the end of the prime mission.

CPF is a NASA-directed mission executed under the direction of the Science Mission Directorate – Earth Science Division. CPF is a Category 3 mission per NPR 7120.5E and a Class D payload risk classification per NPR 8705.4. The mission has two baseline mission objectives:

1. Demonstrate the ability to conduct on-orbit, SI-traceable calibration of measured scene spectral reflectance, with an advance in accuracy over current on-orbit sensors; and
2. Demonstrate the ability to use that improved accuracy to serve as an in orbit reference spectrometer for advanced inter-calibration of other key satellite sensors across most of the reflected solar spectrum (350 – 2300 nm).

The CPF advances in accuracy and inter-calibration of satellite sensors will demonstrate techniques and technologies that, when applied on future missions, can significantly reduce the time needed to detect climate change trends using reflected solar earth remote sensing observations. It will also serve to much more rapidly reduce the uncertainty in societally critical research areas such as climate sensitivity and cloud feedback.

3.2 Science Objectives

The CPF science objectives, as defined in section 4.1.1 of the PRLA, are the following:

1. Spectrally-resolved Earth Reflectance: The CPF objective is to acquire on-orbit SI-traceable spectrally-resolved Earth reflectances referenced to spectral solar irradiance with average uncertainty <= 0.3% (k=1) for the 350 - 2300 nm wavelength range.
2. Spectrally Integrated Earth Reflectance: The CPF objective is to acquire on-orbit SI-traceable broadband (350 - 2300 nm) spectrally-integrated Earth reflectance with uncertainty <= 0.3% (k=1), with spectral accuracy weighted using global average Earth spectrally reflected energy.
3. On-Orbit Reference Inter-Calibration: The CPF objective is to demonstrate the ability to use the reflected solar spectrometer as an in-orbit transfer standard for intercalibration of the reflectance bands of the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument and the Clouds and Earth's Radiant Energy System (CERES) or Radiation Budget Instrument (RBI) instruments' shortwave channel. The inter-calibration uncertainties should be equal to or less than the spectrometer calibration uncertainties listed above.

3.3 System Architecture

The CPF Project system architecture is composed of the four mission segments required to successfully measure, collect, analyze, and distribute the CPF science data. The CPF mission segments, as shown in Figure 3.3-1 below and described in later sections are the Space Segment, Science Segment, Ground Segment, and Launch Segment. The University of Colorado Laboratory for Atmospheric and Space Physics (LASP) is responsible for elements shown in yellow while Langley Research Center (LaRC) is responsible for elements shown in green. Elements shown in orange are external to the Project.

3.4 Segment Definition

3.4.1 Space Segment

The Space Segment is that portion of the architecture that flies in space and maintains the communication links between space and ground. It comprises the CLARREO Pathfinder Reflected Solar Payload (CPRSP) and the ISS. The CPRSP, as shown in Figure 3.4-1, consists of: the HyperSpectral Imager for Climate Science (HySICS) instrument, the HySICS Instrument-Spacecraft Interface Electronics (HISIE), the HySICS Pointing System (HPS), and the ExPRESS Pallet Adapter (ExPA), which is supplied by the ISS Program. The ISS comprises the orbiting Space Station, all of its crew, visiting vehicles, attached non-CLARREO Pathfinder payloads, and associated communications systems.

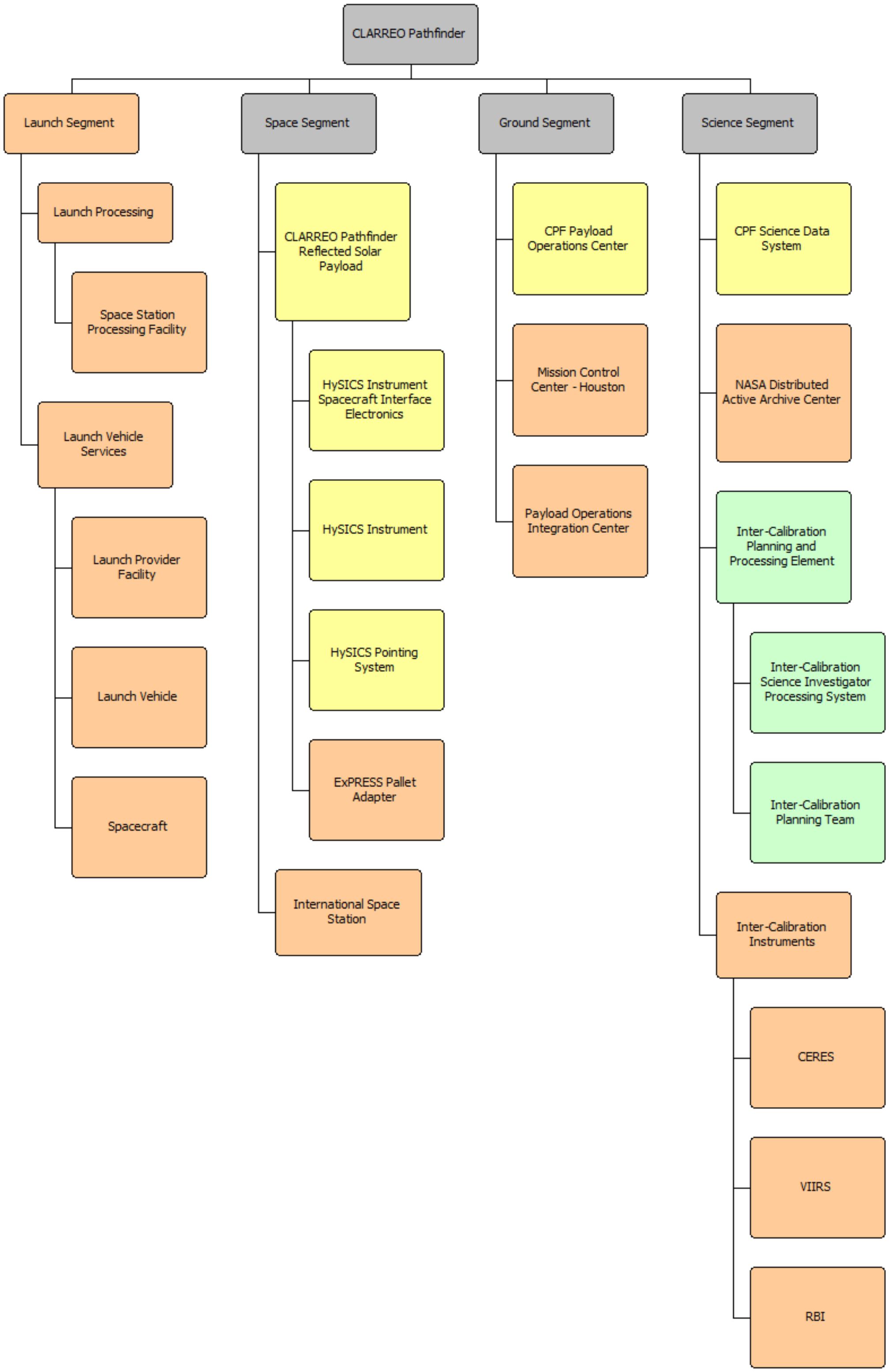

Figure 3.3-1: CPF System Architecture

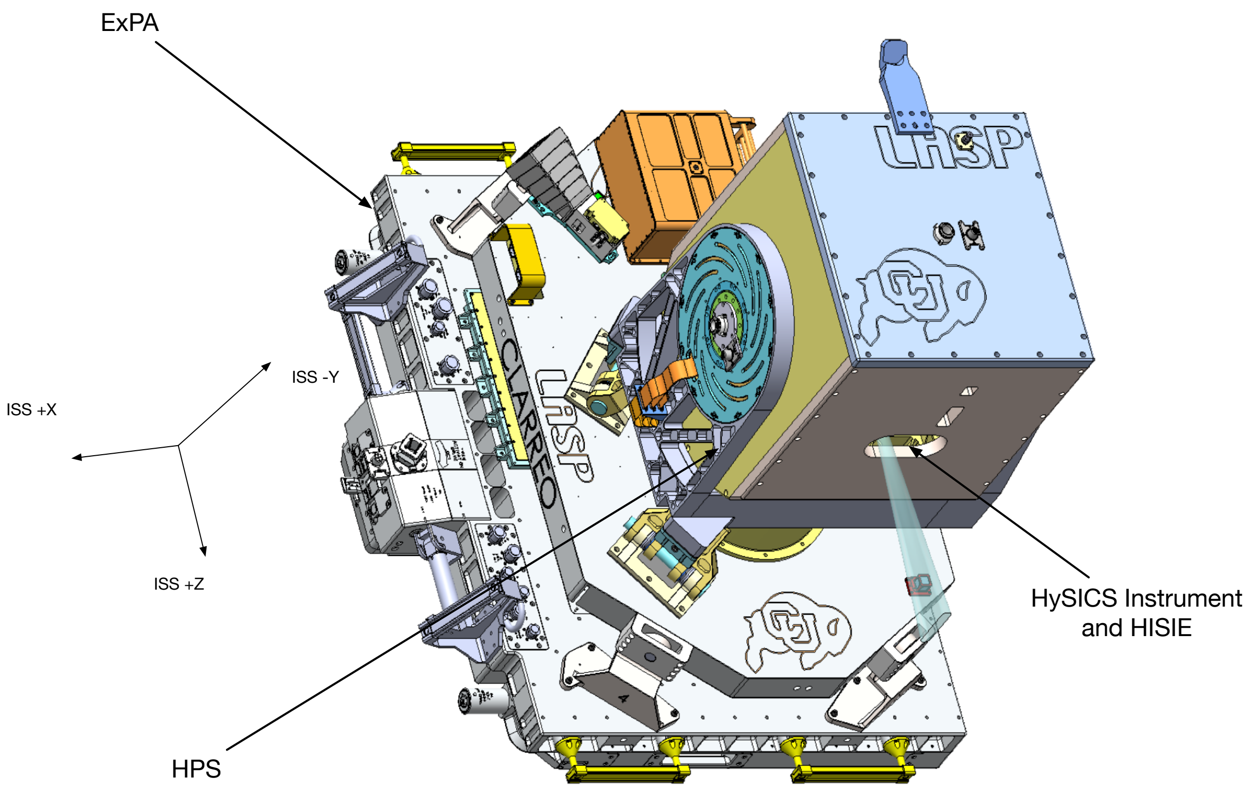

Figure 3.4-1: CLARREO Pathfinder Reflected Solar Payload

3.4.2 Science Segment

The Science Segment includes all of the systems and facilities required to process, analyze (including calibration and validation of data), archive, and distribute the CPF science data and data products. The Science Segment consists of four elements: the CPF Science Data System (CSDS) at LASP, a NASA Distributed Active Archive Center (DAAC), the Inter-Calibration Planning and Processing element (ICPP) element at LaRC, and the Inter-Calibration Instruments. The Inter-Calibration Instruments are CERES, RBI, and VIIRS—the instruments specified by the On-Orbit Reference Inter-Calibration science objective. The NASA DAAC will make the data products listed in the Standard Science Data Products table publicly available in accordance with NASA Earth Science Data and Information Policy with no period of exclusive access.

3.4.3 Ground Segment

The Ground Segment is the portion of the ground-based architecture that does not generate science products, and its primary role is to provide the monitoring, command, and control of the CPRSP. It also processes and forwards the data received from the Space Segment to the Science Segment. It comprises the CPF Payload Operations Center (CPOC) at LASP, Mission Control

Center-Houston (MCC-H) at Johnson Space Center (JSC), and the Payload Operations Integration Center (POIC) at Marshall Space Flight Center (MSFC).

3.4.4 Launch Segment

The Launch Segment is responsible for preparing the CPRSP for flight and delivering it to the ISS. The Launch Processing portion of the architecture prepares the CPRSP, having completed final integration at Kennedy Space Center (KSC), to function as an ISS external payload. It includes the Space Station Processing Facility (SSPF) at KSC. Launch Vehicle Services is the portion of the architecture responsible for transporting the CPRSP from the Earth to the International Space Station. It comprises the Launch Provider Facility (LPF), Spacecraft, and Launch Vehicle. The LPF prepares and integrates the CPRSP into the Spacecraft and the Spacecraft into the Launch Vehicle. It then prepares the Launch Vehicle for flight. The Launch Vehicle and Spacecraft transport the CPRSP to the ISS. At this time, the identity of the Launch Vehicle Services provider and their associated requirements are not yet determined.

4.0 Requirements

This section contains technical requirements, which define either what CPF must do or a quality that the CPF must have. The convention used in this document to distinguish among requirements, goals, and statements of facts, is as follows:

Shall: Used to indicate a binding requirement with LASP

Should/May: Used to indicate a desired goal

Will: Used to indicate a statement of fact that the government will complete

Every requirement containing a "shall" is binding and will be verified. Goals are non-binding, while statements of fact are binding in that an expectation of certainty is established. Goals are included to guide trade studies and will be addressed at design reviews and technical interchange meetings. Values in this document listed as TBD or TBR are pending confirmation.

4.1 Science Requirements

[RS.21004] Spectrally Resolved Earth Reflectance

The CLARREO Pathfinder shall acquire on-orbit SI-traceable spectrally-resolved Earth reflectances referenced to spectral solar irradiance with average uncertainty <= 0.3% (k=1) for the 350 - 2300 nm wavelength range.

Rationale: *To demonstrate on-orbit accuracy required for establishing climate change record.*

Verification Method: Analysis

Verification Description: LASP will analyze an uncertainty budget of the spectrally-resolved reflectance.

Success Criteria: The verification will be successful when the error budget shows that the radiometric uncertainty is less than or equal to 0.3% at k=1.

[RS.21005] Broadband Earth Reflectance

The CLARREO Pathfinder shall acquire on-orbit SI-traceable broadband reflectance (350 - 2300 nm) of Earth scenes with uncertainty <= 0.3% (k=1).

Rationale: *To demonstrate on-orbit accuracy required for establishing climate change record*

Verification Method: Analysis

Verification Description: LASP will analyze an uncertainty budget of the broadband reflectance.

Success Criteria: The verification will be successful when the error budget shows that the radiometric uncertainty is less than or equal to 0.3% at k=1.

[RS.21050] Inter-Calibration Samples

The CLARREO Pathfinder shall collect inter-calibration sampling with CERES or RBI and VIIRS sufficient to limit uncertainty contribution within 1 year of operations as specified in requirements RS.21004 and RS.21005.

Rationale: *This specifies the need to perform inter-calibration with sufficient sampling to achieve the science requirements within a one year time frame. The surface target matching need is derived from the pointing accuracy, angular matching, and temporal matching requirements (RS.21010, RS.21011, and RS.21012). Inter-Calibration sampling refers to acquiring measurements of the surface radiance that coincides with the ground track of where CERES or RBI and VIIRS acquired their data from the Earth's surface.*

Verification Method: Analysis

Verification Description: LaRC will analyze the number and distribution of available inter-calibration samples with CERES or RBI and VIIRS in a representative one-year period.

Success Criteria: The verification will be successful when the analysis identifies the number and distribution of inter-calibration samples necessary to limit the contribution to uncertainty within 1 year of operations, as specified in requirements RS.21004 and RS.21005.

Verification Method: Analysis

Verification Description: LASP will analyze the number of available inter-calibration samples that the CPRSP can perform in a representative one-year period.

Success Criteria: The verification will be successful when the analysis shows that the CPRSP can acquire the number and distribution of inter-calibration samples specified by V.RS.21050.A

4.2 Mission Requirements

4.2.1 Space Segment Requirements

[RS.21000] Wavelength

The CPRSP wavelength range for the instrument shall be 350 - 2300 nm.

Rationale: *Values cover the range needed to observe changes in clouds, cloud phase, water vapor, aerosol, and land surface features. The upper limit is chosen due to loss of signal from reduced solar irradiance and strong water vapor and carbon dioxide absorption at longer wavelengths. The wavelength limits are chosen to provide sufficient spectral range for accurate intercalibration of the CERES broadband shortwave channels. Reference: Wu et al., 2015.*

Verification Method: Test

Verification Description: LASP will test the instrument by generating optical signals to stimulate every channel across the wavelength range.

Success Criteria: The verification will be successful when the CPRSP responds to each channel over the range of 350–2300 nm.

[RS.21010] Pointing Accuracy for Instrument Calibration

The CPRSP shall have the ability to perform pointing operations viewing Sun and Moon with sufficient accuracy to achieve uncertainty requirements RS.21004 and RS.21005.

Rationale: *The pointing requirement is driven by the along slit (flat field scan) of the sun and moon to consistently look at the same feature throughout the calibration.*

Verification Method: Analysis

Verification Description: LASP will analyze the contribution of measured CPRSP pointing errors when viewing the Sun and Moon.

Success Criteria: The verification will be successful when the contribution of pointing errors does not exceed the budget allocation associated with RS.21004 and RS.21005.

[RS.21011] Angular Matching for Inter-Calibration

The CPRSP shall perform Inter-Calibration sampling by directing the HySICS Instrument boresight to within 0.7 degree (k=1) of a time-varying direction that is determined by the line of sight from the Inter-Calibration Instrument (at some instant of time consistent with the temporal matching requirement) to the HySICS Instrument.

Rationale: *To limit inter-calibration noise due to differences in viewing-zenith angles in HySICS and Inter-Calibration Instrument measurements. Wielicki et al., IGARSS 2008, specifies that at a point on Earth's surface within the Inter-Calibration Instrument's field of view, the viewing-zenith angles to that instrument and to HySICS should not differ by more than 1 degree. Measurements at the HySICS boresight meet this constraint when the boresight is aimed within 0.7 degrees of the time-varying line of sight. Reference CPF-SER-008.*

Verification Method: Analysis

Verification Description: LASP will analyze the CPRSP's ability to track the lines of sight representative of a set of inter-calibration event geometries by programming the lines of sight and commanding the CPRSP to track them.

Success Criteria: The verification will be successful when the error between the Inter-Calibration Instrument line of sight and the HySICS Instrument boresight is less than 0.7 degrees (k=1) throughout the inter-calibration event.

[RS.21012] Temporal Matching for Inter-Calibration

The CPRSP shall perform inter-calibration operations viewing Earth within 10 minutes of Low Earth Orbit (LEO) Inter-Calibration Instruments (CERES/RBI and VIIRS) data acquisition events.

Rationale: *For limiting inter-calibration noise due to time difference over viewed scene. Reference: Wielicki et al., IGARSS 2008.*

Verification Method: Analysis

Verification Description: LASP will perform analysis to show that the CPRSP can execute an inter-calibration event. LaRC will have to do the planning, but LASP will have to perform analysis showing the instrument can meet the requirement.

Success Criteria: The verification will be successful when the analysis shows that the CPRSP can execute the inter-calibration within 10 minutes of CERES, RBI, and VIIRS.

[RS.21015] Spectral Sampling

The CPRSP shall sample at a spectral precision of 3 nm or finer, equivalent to a 6 nm full width half maximum Gaussian bandwidth.

Rationale: *Spectral sampling required to ensure < 0.2% error from spectral resampling for inter-calibrating imager bands (VIIRS). Reference: Wu et al., 2015.*

Verification Method: Test

Verification Description: LASP will test the CPRSP using multiple sources at varying wavelengths to ensure it can distinguish between the sources.

Success Criteria: The verification will be successful when the CPRSP can distinguish between sources separated by 3 nm across the entire spectral range.

[RS.21020] Single Spectrum Precision for Inter-Calibration

The CPRSP shall have a single spectrum precision of <= 3% (k=1) relative to reflectance of 0.3 at solar zenith angle = 75 degrees. (This precision is at the scale of a single instantaneous 0.5 km field of view.)

Rationale: *The noise specification is set to enable clear versus cloudy screening and lunar calibration measurements.*

Verification Method: Test

Verification Description: LASP will test the precision of a CPRSP single spectrum measurement relative to a test signal with a reflectance of 0.3 at a solar zenith angle of 75 degrees.

Success Criteria: The verification will be successful when LASP conducts a test that proves that the CPRSP single spectrum measurement, relative to test signal with a reflectance of 0.3 at a solar zenith angle of 75 degrees, has a precision of 3% (k=1) or better.

[RS.21025] Along-track Field of View (FOV)

The CPRSP shall measure RS radiation continuously along-track with a field of view less than or equal to 0.5 km at nadir.

Rationale: *This requirement is driven by the uncertainty budget for inter-calibration to limit noise from spatial data mapping, and the emphasis is gapless coverage along track. The actual instrument angular FOV, pixel size, and array geometry can be derived from this as well as the ISS altitude.*

Verification Method: Inspection

Verification Description: LASP will inspect the CPRSP design to determine the FOV at ISS altitude.

Success Criteria: The verification will be successful when the along-track field of view of the CPRSP is less than or equal to 0.5 km.

[RS.21030] Along-track Ground Sampling Distance

The CPRSP shall measure RS radiation continuously along-track with a ground-sampling distance less than or equal to 0.5 km at nadir.

Rationale: *The instrument enables the CLARREO continuous spatial sampling and matching required for inter-calibration, and the emphasis is along-track resolution. The actual instrument sampling rate, frame overlap, angular FOV, pixel size, and array geometry can be derived from this as well as the ISS altitude.*

Verification Method: Analysis

Verification Description: LASP will analyze the CPRSP sampling rate at ISS altitude to determine the distance between resolved pixels.

Success Criteria: The verification will be successful when the distance between two pixels is 0.5 km or less.

[RS.21031] Cross-track Ground Sampling Distance

The CPRSP shall measure RS radiation continuously cross-track with a ground-sampling distance less than or equal to 0.5 km at nadir.

Rationale: *The instrument enables the CLARREO continuous spatial sampling and matching required for inter-calibration. The actual instrument sampling rate, frame overlap, angular FOV, pixel size, and array geometry can be derived from this as well as the ISS altitude.*

Verification Method: Inspection

Verification Description: LASP will inspect the CPRSP design to show that when the pixels are averaged in the downlink that there will be sufficient surface resolution for inter-calibration in the cross track direction at nadir at ISS altitude.

Success Criteria: The verification will be successful when the inspection shows the CPRSP can resolve two targets separated in the cross-track direction by an angle equivalent to 0.5 km.

[RS.21035] Instrument Sensitivity to Polarization

The CPRSP shall measure the RS radiation in the reflected solar spectra as a reference calibration to relevant climate sensors with polarization sensitivity less than 1% (k=1) in wavelength range from 350 - 1800 nm and less than 2% (k=1) from 1800 - 2300nm.

Rationale: *This requirement ensures that the uncertainty contribution form instrument sensitivity to polarization is limited. Simulations were carried out to determine the distribution of spectrally dependent polarization using global PARASOL multi-angle, multi-spectral polarization measurements. The data were used to simulate the polarization distributions across a full range of scene conditions and climate regions that CLARREO would see for its nadir reflectance spectra, as well as for the scattering angles that it would use to provide Reference Intercalibration to CERES or RBI and VIIRS. Reference: Lukashin et al., 2013.*

Verification Method: Test

Verification Description: LASP will test the difference in response of the CPRSP to a polarized signal versus a non-polarized signal.

Success Criteria: The verification will be successful when the difference in response in the polarized signal versus the non-polarized signal is less than 1% (k=1) in wavelength range from 350 - 1800 nm and less than 2% (k=1) from 1800 - 2300nm.

[RS.21040] Prime Mission Operations Period

The CPRSP shall operate over a prime mission operation period of 1 year following commissioning activities.

Rationale: *CLARREO Pathfinder is a directed mission with 1 year of operations.*

Verification Method: Analysis

Verification Description: LASP will analyze the expected CPRSP operational lifetime.

Success Criteria: The verification will be successful when the analysis shows the expected operational lifetime is greater than or equal to 1 year.

[RS.21041] On-Orbit Commissioning Period

The CPRSP shall complete commissioning activities within 60 days of installation to the ISS.

Rationale: *Two months provide sufficient time for functionality tests of the CPRSP.*

Verification Method: Analysis

Verification Description: LASP will analyze the expected duration of all required CPRSP commissioning activities.

Success Criteria: The verification will be successful when the analysis shows the CPRSP commissioning activities can be completed within 60 days.

[RS.21045] Decommissioning

The CPRSP shall be capable of completing decommissioning activities within three months following the end of the science mission.

Rationale: *The three-month measure establishes a time limit for the CPRSP to be configured for disposal.*

Verification Method: Analysis

Verification Description: LASP will analyze the expected duration of all required CPRSP decommissioning activities.

Success Criteria: The verification will be successful when the analysis shows the CPRSP decommissioning activities can be completed within three months.

[RS.21055] Inter-Calibration Swath Width

The CPRSP shall be capable of aiming the instrument boresight to match the full CERES, RBI, and VIIRS instrument swath width (plus or minus 55°) when not obscured by ISS structure.

Rationale: *This enables sufficient inter-calibration sampling with instruments flying in JPSS-like orbits. The reference is to the ISS body axes instead of the ISS ground track, due to the contribution of ISS attitude excursions to ground-referenced lines of sight. Reference: MCR Inter-Calibration Approach presentation (Section 10.0).*

Verification Method: Analysis

Verification Description: LASP will analyze the FOR of the CPRSP pointing capability, with typical ISS attitude excursions.

Success Criteria: The verification will be successful when the analysis shows that the FOR can accommodate the CERES, RBI, and VIIRS instrument swath width when not obscured by ISS structure.

[RS.21060] Geolocation of Earth-View Data

The CPRSP shall have sufficient pointing knowledge such that the CSDS can determine the Earth viewing pixel geolocation to within 250 m (k=1) nadir equivalent.

Rationale: *This enables the CSDS to generate geolocated data at a precision of 250 m, which is one half of a single pixel's footprint; maintaining this performance ensures that the target point falls within the pixel's actual footprint. This limits the inter-calibration noise due to spatial difference over the viewed scene. Reference: Wielicki et al., IGARSS 2008*

Verification Method: Analysis

Verification Description: LASP will verify by analysis.

Success Criteria: The verification will be successful when the analysis shows that the CPRSP has sufficient pointing knowledge such that the CSDS can determine pixel geolocation within 250 m.

[RS.21110] Swath Width

The CPRSP shall measure RS radiation with a cross-track width greater than or equal to 70 km when centered at nadir.

Rationale: *The specific spatial extent is required to ensure sufficient inter-calibration spatial sampling with relevant instruments. Reference: science study report: SS-2002f-01; Wielicki et al., IGARSS 2008.*

Verification Method: Analysis

Verification Description: LASP will document the CPRSP design.

Success Criteria: The verification will be successful when the inspection shows that the CPRSP's nadir field-of-view footprint is greater than or equal to 70 km.

[RS.21150] Inter-Calibration Operations

The CPRSP shall be capable of performing 1 Inter-Calibration operation per orbit. An Inter-Calibration operation is defined as one of the following:

- Measurement of spectral reflectance over entire lunar disk
- Inter-Calibration of space-borne instruments in low Earth orbit (LEO)
- Inter-Calibration of space-borne instruments in geostationary Earth orbit (GEO)
- Characterization of land site

Rationale: *To ensure that there will be adequate pointing capability in the HPS to perform all of the Inter-Calibration operations during the mission life. The intent of this requirement is that if there is an opportunity for an Inter-Calibration measurement during an orbit, the CPRSP should be able to acquire the data. This requirement in not intended to drive the CPRSP to add additional hardware.*
Science Rationale: There will be approximately 1300 inter-calibration opportunities with JPSS instruments (CERES or RBI and VIIRS) per year. The CPRSP needs to be capable of taking data for every opportunity.

Verification Method: Analysis

Verification Description: LASP will analyze the pointing system of the CPRSP to make sure that the design supports the number of Inter-Calibration operations.

Success Criteria: The verification will be successful when the analysis shows that the CPRSP can perform at least one representative inter-calibration pointing event per orbit over the one year primary mission without exceeding the designed system's expected service life.

[RS.22000] Compliance with Launch Vehicle Requirements

The CPRSP shall satisfy the launch vehicle requirements.

Rationale: *Compliance with LV requirements maximizes probability of successful integration with the LV and mission success. (SSP-50833)*

Verification Method: Inspection

Verification Description: LASP will inspect all Launch Vehicle Services-levied requirements to ensure compliance.

Success Criteria: The verification will be successful when the Launch Vehicle Services-levied requirements have been successfully verified.

[RS.22005] Compliance with ISS Requirements

The CPRSP shall satisfy ISS requirements.

Rationale: *Compliance with ISS requirements maximizes probability of successful integration with the ISS and mission success.*

Verification Method: Inspection

Verification Description: LASP will inspect all ISS-levied requirements to ensure compliance.

Success Criteria: The verification will be successful when the ISS-levied requirements have been successfully verified.

[RS.22025] Measurements and Data Routing

The CPRSP shall send science measurements and data to the CPOC.

Rationale: *The CPRSP will send raw (unprocessed) science measurements, health and status data, contamination, disturbance, and ancillary data via the ISS. The POIC will forward all data to the CPOC.*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the CPRSP can properly send science measurements and data back to the CPOC.

Success Criteria: The verification will be successful when the CPRSP has completed the demonstration.

[RS.22035] Response to Ground Commands

The CPRSP shall have the capability to accept ground commands.

Rationale: *The CPRSP operates using time-tagged sequences or real-time commands uploaded from the CPOC. Reference: CPF-02–009, Section 6.3 (29AUG2017)*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the CPRSP can receive commands from the CPOC through the ExPRESS Logistics Carrier (ELC) simulator at KSC.

Success Criteria: The verification will be successful when the CPRSP has completed the demonstration.

[RS.22040] On-orbit Reprogramming

The CPRSP shall have the capability of being reprogrammed while on orbit.

Rationale: *On-orbit reprogramming allows flight controllers and command controllers to update the CPRSP's behavior to accommodate unexpected demands of the operating environment.*

Verification Method: Demonstration

Verification Description: LASP will demonstrate the CPRSP reprogrammability capability by transmitting a CPRSP software update at the CPOC and identifying the software load of the CPRSP at the ELC simulator.

Success Criteria: The verification will be successful when the CPRSP software load matches the update transmitted at the CPOC.

4.2.2 Science Segment Requirements

4.2.2.1 Science Segment Requirements - LASP

[SCI.24000] Data Product Delivery

The CSDS shall deliver all Level 0 and Level 1B data products to the NASA DAAC within the timelines specified for each data product in the Standard Science Data Products table.

Rationale: *References: 152-TP-003–003 and GSFC 423-SPEC-001.*

Verification Method: Test

Verification Description: LASP will test that the CSDS can deliver Level 0 and Level 1B data products to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of Level 0 and Level 1B data.

Table 4.2-1: Standard Science Data Products

Data Product	**Description**	**First Data Delivery after IOC**	**Maximum data latency after first release**[1]
Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.	4 months	48 hours
Level 1B	Calibrated and geolocated observations at full resolution, annotated with ancillary information such as radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris).	8 months	1 month
Level 4	Time/angle/space matched inter–calibration data for reference (CPF) and target sensors (CERES or RBI and VIIRS), scene information from target sensors (CERES or RBI and VIIRS), modeled parameters for estimated polarization and radiometric corrections.	10 months	6 months

[1] Data latency is defined as the elapsed time from the downlink to the availability of processed data products to the public.

[SCI.24015] Public Release of Data

The CSDS shall make the Level 0 and Level 1B data listed in the Standard Science Data Products table, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products publicly available conforming to the NASA Earth Science Data and Information Policy (http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/).

Rationale: *References: 152-TP-003–003 and GSFC 423-SPEC-001.*

Verification Method: Test

Verification Description: LASP will test that the CSDS can deliver the Level 0 and Level 1B data, scientific source code for algorithm software, coefficients, and ancillary data used to generate these data products to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the Level 0 data, Level 1B data, science source code, coefficients, and ancillary data.

[SCI.24017] Science Data Product Formats

The CSDS shall format all Level 1B data products to conform to the HDF5 standard.

Rationale: *This enables compliance with the NASA Earth Science Data and Information Policy.*

Verification Method: Inspection

Verification Description: LASP will inspect the Level 1B data product format.

Success Criteria: The verification will be successful when the inspection shows that the Level 1B data products conform to the HDF5 standard.

[SCI.24018] Long Term Knowledge Preservation

The CSDS shall transfer to the NASA DAAC all the information and documentation required for long-term preservation of knowledge about the Level 0 and Level 1B data products as defined in the NASA Earth Science Data Preservation Content Specification document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: *This enables compliance with the NASA Earth Science Data Preservation Content Specification document published at http://earthdata.nasa.gov/about-eosdis/requirements.*

Verification Method: Test

Verification Description: LASP will test that the CSDS can deliver the required set of information and documentation to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the information and documentation.

[SCI.24020] Mission Lifetime - LASP

The CSDS shall be designed to support 60 days of commissioning, a prime mission operation period of 1 year, and 1 year of science post processing following the prime mission operation period.

Rationale: *Science Segment operations and hardware must be designed to support operations throughout the mission duration.*

Verification Method: Inspection

Verification Description: LASP will inspect LASP CSDS operational planning documentation on personnel, schedule, and funding.

Success Criteria: The verification will be successful when the LASP CSDS operational planning documentation identifies the commitment of key personnel, sufficient funding, and facilities supporting CPF science for a duration of at least two years following commissioning activities.

[SCI.24031] Post Processing Geolocation for Earth-View Data

The CSDS shall determine the geolocation of the Earth viewing pixels within 250 m (k=1) nadir equivalent.

Rationale: *The LASP CLARREO Science Data System (CSDS) shall determine the geolocation of the Earth viewing pixels within 250 m (k=1) nadir equivalent. Reference: Wielicki et al., IGARSS 2008*

Verification Method: Analysis

Verification Description: LASP will analyze the CSDS's capability to geolocate the Earth viewing pixels.

Success Criteria: The verification will be successful when the analysis shows the CSDS can geolocate the Earth viewing pixels within 250 m (k=1).

[SCI.24035] Data Latency

The CSDS shall deliver all required data to the NASA DAAC within the timeframe specified in the Standard Science Data Products table.

Rationale: *The DAAC is the architectural element responsible for ingesting and archiving CPF data products, and the timeframe ensures efficient public dissemination.*

Verification Method: Inspection

Verification Description: LASP will inspect their mission operations requirements for compliance with the data delivery timeline given in the table.

Success Criteria: The verification will be successful when LASP shows data will be delivered according to Table 1.

[SCI.24040] Earth Science Data and Information System (ESDIS) Compliance

The CSDS Level 0 and Level 1B data products metadata shall conform to ISO 19115 Geographic Information - Metadata standards and adhere to the Metadata Requirements — Base Reference for NASA Earth Science Data Products document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: *The NASA Earth Science Data and Information Policy is specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/. Items include Algorithm Theoretical Basis Documents and science algorithm source code.*

Verification Method: Test

Verification Description: LASP will verify by test that the CSDS can deliver metadata conforming to ISO 19115 to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the metadata.

[SCI.24050] Full Resolution Browse Products

The CSDS shall deliver to the NASA DAAC full-resolution browse products for all science data.

Rationale: *Full-resolution browse products enable users to search for specific scenes generated from CLARREO Pathfinder Reflected Solar Payload data. The specification of "science data" refers to data that is destined to the DAAC for science purposes, as opposed to data collected for engineering analysis.*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the CSDS can deliver browse products to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports the receipt of the browse products.

4.2.2.2 Science Segment Requirements - LaRC

[SCI.24100] Data Product Delivery

The ICPP will deliver all Level 4 data products to the NASA DAAC within the timelines specified for first data delivery associated with each data product in the Standard Science Data Products table.

Rationale: *References: 152-TP-003–003 and GSFC 423-SPEC-001.*

Verification Method: Test

Verification Description: LaRC will verify by test that the ICPP can deliver Level 4 data products to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of Level 4 data products.

[SCI.24115] Public Release of Data

The ICPP will make the Level 4 data listed in the Standard Science Data Products table, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products publicly available conforming to the NASA Earth Science Data and Information Policy (http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/).

Rationale: *References: 152-TP-003–003 and GSFC 423-SPEC-001.*

Verification Method: Test

Verification Description: LaRC will test that the ICPP can deliver the Level 4 data, scientific source code for algorithm software, and the coefficients and ancillary data used to generate these data products to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the Level 4 data, science source code for algorithm software, coefficients, and ancillary data used to generate these products.

[SCI.24117] Science Data Product Formats

The ICPP will format all Level 4 data products to conform to the HDF5 standard.

Rationale: *This enables compliance with the NASA Earth Science Data and Information Policy.*

Verification Method: Inspection

Verification Description: LaRC will inspect the Level 4 data product format.

Success Criteria: The verification will be successful when inspections show that the Level 4 data products conform to the HDF5 standard.

[SCI.24118] Long Term Knowledge Preservation

The ICPP will transfer to the NASA DAAC all the information and documentation required for long-term preservation of knowledge about the Level 4 data products as defined in the NASA Earth Science Data Preservation Content Specification document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: *This enables compliance with the NASA Earth Science Data and Information Policy.*

Verification Method: Test

Verification Description: LaRC will test that the ICPP can deliver the required set of information and documentation to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the information and documentation.

[SCI.24120] Mission Lifetime - LaRC

The ICPP will be designed to support 60 days of commissioning, a prime mission operation period of 1 year, and 1 year of science post processing following the prime mission operation period.

Rationale: *Science Segment operations and hardware must be designed to support operations throughout the mission duration.*

Verification Method: Inspection

Verification Description: LaRC will inspect the LaRC ICPP operational planning documentation on personnel, schedule, and funding.

Success Criteria: The verification will be successful when LASP ICPP operational planning documentation identifies the commitment of key personnel, sufficient funding, and a facility dedicated to CPF science for a duration of at least two years following commissioning activities.

[SCI.24126] Inter-Calibration Planning

The ICPP will provide the inter-calibration planning data to the CPOC according to the CPOC interface control document.

Rationale: *The ICPP identifies and prioritizes the expected inter-calibration events and passes the list of prioritized inter-calibration targets to the CPOC. Reference: CPF-02–009, Section 6.2.1 (29AUG2017)*

Verification Method: Test

Verification Description: LaRC will verify by test that the ICPP can deliver the inter-calibration planning data to the CPOC according to the CPOC interface control document

Success Criteria: The verification will be successful when the CPOC reports receipt of inter-calibration planning data.

[SCI.24130] Inter-Calibrate Science Data

The ICPP will inter-calibrate CLARREO Pathfinder science data with VIIRS.

Rationale: *The ICPP retrieves VIIRS Level 1B and Level 2 data from the LAADS at GSFC and applies inter-calibration algorithms to produce Level 4 data products. Reference: CPF-02–009, Section 10.4 (27AUG017)*

Verification Method: Analysis

Verification Description: LaRC will perform the inter-calibration analysis using a set of VIIRS data products from the Level-1 and Atmosphere Archive and Distribution System (LAADS) DAAC and a set of internally-generated CPF Level 1B data.

Success Criteria: The verification will be successful when the analysis shows the inter-calibration requirements have been met.

[SCI.24131] Inter-Calibrate Science Data

The ICPP will inter-calibrate CLARREO Pathfinder science data with CERES/RBI.

Rationale: *The ICPP retrieves CERES and RBI Level 2 data from the ASDC at LaRC and applies inter-calibration algorithms to produce Level 4 data products. Reference: CPF-02–009, Section 10.4 (27AUG017)*

Verification Method: Analysis

Verification Description: LaRC will perform the inter-calibration analysis using a set of CERES and RBI data products from the Atmospheric Sciences Data Center (ASDC) DAAC and a set of internally-generated CPF Level 1B data.

Success Criteria: The verification will be successful when the analysis shows the inter-calibration requirements have been met.

[SCI.24140] ESDIS Compliance

The ICPP Level 4 data products metadata will conform to ISO 19115 Geographic Information - Metadata standards and adhere to the Metadata Requirements — Base Reference for NASA Earth Science Data Products document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: *The NASA Earth Science Data and Information Policy is specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/. Items include Algorithm Theoretical Basis Documents and science algorithm source code.*

Verification Method: Test

Verification Description: LaRC will test that the ICPP can deliver metadata conforming to ISO 19115 to the NASA DAAC.

Success Criteria: The verification will be successful when the DAAC reports receipt of the metadata.

4.2.3 Ground Segment Requirements

[GS.23000] POIC Interface

The CPOC interfaces with the ISS POIC shall comply with the CPOC to POIC ICD (TBD).

> Rationale: *Nominally, all CPRSP commands flow from the CPOC through the POIC, and all Raw TLM and Science data flow through the POIC to the CPOC. Reference: CPF-02–009, Section 5.3 (29AUG2017). The ISS Program will furnish a future document that will specify the CPOC to POIC interface.*
>
> Verification Method: Test
>
> Verification Description: LASP will test the CPOC to POIC interface.
>
> Success Criteria: The verification will be successful when all of the CPOC to POIC interface requirements have been met.

[GS.23005] Generate Instrument Commanding

The CPOC shall generate instrument commands and command loads for the execution of all CPRSP functions on orbit.

> Rationale: *The CPOC generates all of the commands sent to the CPRSP. Reference: CPF-02–009, Section 4.3.1 (29AUG2017)*
>
> Verification Method: Demonstration
>
> Verification Description: LASP will demonstrate that the CPOC can properly format CPRSP commands.
>
> Success Criteria: The verification will be successful when the CPOC has shown that it can properly format commands for transmission to the CPRSP.

[GS.23010] Transfer Command Information

The CPOC shall transfer commands and command loads to the POIC for upload to the ISS.

> Rationale: *The CPOC sends commands and any file uploads to the POIC for transfer to the Space Segment. Reference: CPF-02–009, Section 5.3 (29AUG2017)*
>
> Verification Method: Demonstration
>
> Verification Description: LASP will demonstrate that the CPOC can send CPRSP commands to the POIC.

Success Criteria: The verification will be successful when the POIC receives commands and command loads from the CPOC.

[GS.23015] Validate Commands and Command Loads

The CPOC shall validate commands and command loads prior to sending them to the POIC for uploading to the CPRSP.

Rationale: *CPOC validation of commands and command loads ensure that they have the intended effect on the CPRSP and do not risk the health or safety of the CPRSP. Reference: CPF-02–009, Section 6.3 (29AUG2017)*

Verification Method: Test

Verification Description: LASP will test the CPRSP command responses prior to transmission to the POIC.

Success Criteria: The verification will be successful when testing shows that commands are validated before sending to the POIC.

[GS.23020] Generate Instrument Software Loads

The CPOC shall generate instrument software loads to support CPRSP operations.

Rationale: *CPOC generation of instrument software loads enables the On-orbit reprogramming specified in RS.22040.*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the Ground Segment can generate valid software that can be loaded onto the CPRSP.

Success Criteria: The verification will be successful when the Ground Segment produces a valid software load.

[GS.23030] Health Maintenance of the Space Segment

The CPOC shall monitor the health and safety of the CPRSP and generate advisories of potentially unsafe conditions.

Rationale: *One of the primary functions of the CPOC is to employ state of health monitoring of the CPRSP on a daily basis. Reference: CPF-02–009, Section 6.4 (29AUG2017)*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that advisories will be generated for potentially unsafe CPRSP conditions.

Success Criteria: The verification will be successful when the CPOC generates the advisories.

[GS.23035] Science Event Measurement Planning

The CPOC shall have the capability of planning CPRSP flight operations.

Rationale: *The CPOC planning process uses information from various sources in order to generate the necessary command products for the CPRSP. Reference: CPF-02–009, Section 6.2 (29AUG2017)*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the CPOC can plan flight operations.

Success Criteria: The verification will be successful when the Ground Segment can generate a plan flight operations for all science events.

[GS.23040] Prime Mission Operational Lifetime

The CPOC shall be designed to operate over a prime mission operation period of 1 year following commissioning activities.

Rationale: *Ground Segment operations and hardware must be designed to support nominal operations throughout the baseline duration.*

Verification Method: Inspection

Verification Description: LASP will inspect CPOC operational planning documentation on personnel, schedule, and funding.

Success Criteria: The verification will be successful when the CPOC operational planning documentation identifies the commitment of key personnel, sufficient funding, and facilities supporting CPOC operations for a duration of at least one year following commissioning activities.

[GS.23045] On-orbit Commissioning Period

The CPOC shall complete CPRSP commissioning activities within 60 days of installation to the ISS.

Rationale: *Two months provide sufficient time to command and evaluate the functionality tests of the CLARREO Pathfinder payload, instrument, and its performance.*

Verification Method: Analysis

Verification Description: LASP will analyze the expected duration of all required CPOC commissioning activities.

Success Criteria: The verification will be successful when analysis shows the CPRSP commissioning activities can be completed in 60 days.

[GS.23050] Data Processing

The CPOC shall be designed to receive and process all science, H&S, and ancillary data delivered from the ISS.

Rationale: *The CPOC interfaces with the POIC to receive CPRSP telemetry in either real-time telemetry delivery, or non-real-time playback and/or file delivery. Reference: CPF-02–009, Section 6.4 (29AUG2017)*

Verification Method: Demonstration

Verification Description: LASP will demonstrate that the CPOC can receive and process data from the POIC.

Success Criteria: The verification will be successful when the CPOC receives and processes the CPRSP data.

[GS.23055] Data Storage

The CPOC shall store CLARREO Pathfinder data received from the ISS until it has been successfully transferred to the DAAC.

Rationale: *CPRSP telemetry data are received by the CPOC, processed, and stored in a mission-specific database. Reference: CPF-02–009, Section 10.1 (29AUG2017)*

Verification Method: Analysis

Verification Description: LASP will verify by analysis that the Ground Segment has sufficient data storage capacity such that no data is lost from the time data is received until it is transferred to the DAAC.

Success Criteria: The verification will be successful when sufficient storage is available to support the analysis results.

4.2.4 Launch Segment Requirements

The launch vehicle is provided by the ISS Program Office, and requirements for the launch vehicle are outside the scope of the CPF system. Requirements levied from the launch vehicle originate from TBD and are allocated to each segment, element, and subsystem directly through the allocations made by LASP.

APPENDIX A

Acronyms and Abbreviations

Acronym	Complete Term
ASDC	Atmospheric Sciences Data Center
CERES	Clouds and Earth's Radiant Energy System
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CPF	CLARREO Pathfinder
CPOC	CPF Payload Operations Center
CPRSP	CLARREO Pathfinder Reflected Solar Payload
CSDS	CPF Science Data System
DAAC	Distributed Active Archive Center
ELC	ExPRESS Logistics Carrier
EOSDIS	Earth Observing System Data and Information System
ESDIS	Earth Science Data and Information System
ExPA	ExPRESS Pallet Adapter
FOV	Field of View
GSFC	Goddard Space Flight Center
HISIE	HySICS Instrument-Spacecraft Interface Electronics
HPS	HySICS Pointing System
HySICS	HyperSpectral Imager for Climate Science
ICPP	Inter-Calibration Planning and Processing element
ISS	International Space Station
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAADS	Level-1 and Atmosphere Archive and Distribution System
LaRC	Langley Research Center
LASP	The University of Colorado Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
LPF	Launch Provider Facility
MCC-H	Mission Control Center-Houston
MSFC	Marshall Space Flight Center
POIC	Payload Operations Integration Center
RBI	Radiation Budget Instrument
RS	Reflected Solar
SI	Système Internationale
SMRD	Science and Mission Requirements Document
SSPF	Space Station Processing Facility
VIIRS	Visible Infrared Imaging Radiometer Suite

APPENDIX B

Glossary

Term	Definition
analysis	the technical evaluation process of using techniques and tools such as mathematical models and computer simulation, historical/design/test data, and other quantitative assessments to calculate characteristics and verify specification compliance. Analysis is used to verify requirements compliance where established techniques are adequate to yield confidence or where testing is impractical.
collect	to acquire data
demonstration	the qualitative determination of compliance with requirements by observation during actual operation or simulation under preplanned conditions and guidelines.
inspection	a physical measurement or visual evaluation of equipment and associated documentation. Inspection is used to verify construction features, drawing compliance, workmanship, and physical condition.
measure	to look at a target and collect the radiation
point	to orient sensor towards a target
sample	to collect an ensemble of measurements
test	an actual operation of equipment, normally instrumented, under simulated or flight equivalent conditions or the subjection of parts or equipment to specified environments to measure and record responses in a quantitative manner.