National Aeronautics and
Space Administration

CPF-02-011
REV. C
RELEASE DATE: TBD

Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder

Science and Mission Requirements Document (SMRD)

16 April 2018

Approved for Public Release; Distribution is Unlimited

The electronic version is the official approved document.
The requirements are from a CORE database query dated: 16 April 2018.
Verify this is the correct version before use.

SIGNATURE PAGE

Prepared By:

Craig Hutchinson
Systems Engineer

Concurred By:

Brian Boland
Lead Systems Engineer

Approved By:

James Corliss
Chief Engineer

Gary Fleming
Project Manager

Bruce Wieliecki
Project Scientist

REVISION HISTORY PAGE

Revision No.	Description	Release Date
Baseline	Baseline. See CPF-CR-007	29 June 2017
A	See CPF-CR-011	17 January 2018
B	See CPF-CR-012	14 March 2018
C	See CPF-CR-013	TBD

TBX LIST

Item	Description	Page
TBD	Expected POIC to CPOC interface requirements document	20
TBD	Launch Vehicle Requirement Originator	21

TABLE OF CONTENTS

TABLE OF APPENDICES

TABLE OF TABLES

TABLE OF FIGURES

1.0 Introduction

1.1 Purpose and Scope

This document establishes the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder science and mission requirements, which are derived from the Program-Level Requirements for the CLARREO Pathfinder (CPF) Project and 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 science and mission 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
NASA SP–2016–6105 Rev 2	NASA Systems Engineering Handbook
NPR 7120.5	NASA Space Flight Program and Project Management
NPR 7123.1	NASA Systems Engineering Processes and Requirements
PIP–16–039	Payload Interface Agreement for CLARREO Pathfinder
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 highest three levels of 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 as well as details of lower levels in the architectural hierarchy.

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 will advance the accuracy and inter-calibration of satellite sensors. New techniques and technologies, that when applied on future missions, can reduce the time, relative to the use of existing space-based observations of reflected solar wavelengths, needed to detect climate change trends using reflected solar earth remote sensing observations. It also serves to 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 makes radiometric observations and transmits that information to the CPF Payload Operations Center (CPOC) via its attachment to the ISS. The ISS comprises the orbiting Space Station, all of its crew, visiting vehicles, attached non-CLARREO Pathfinder payloads, and associated communications systems.

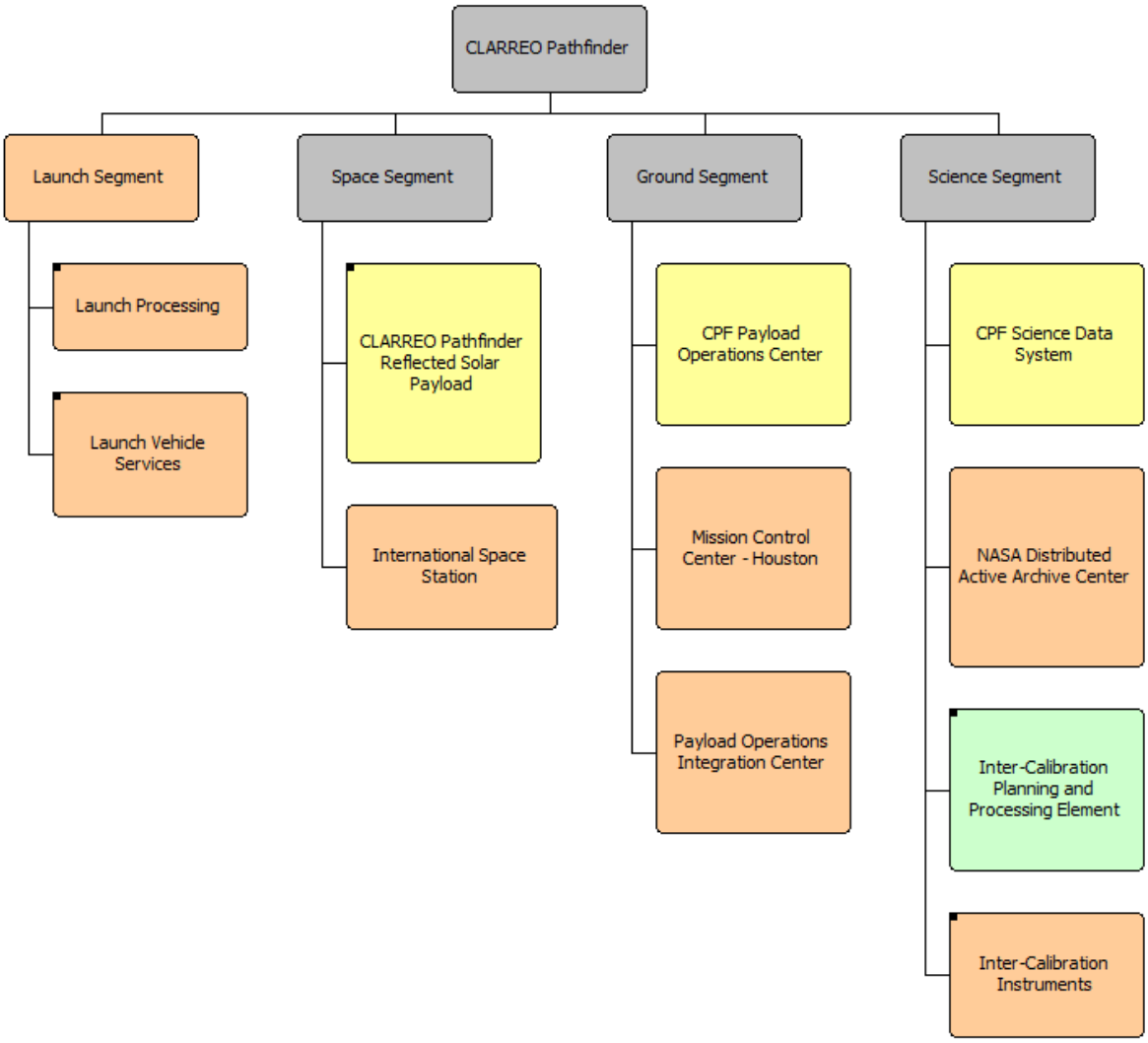

Figure 3.3-1: CPF System Architecture

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 those 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 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. Launch Vehicle Services is the portion of the architecture responsible for transporting the CPRSP from the Earth to the International Space Station. 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. Science Requirements trace directly to PLRA Baseline Science Requirements and specify performance of the overall CPF mission. Mission Requirements allocate the SMRD Science Requirements and PLRA Mission and Flight Element Performance Requirements to the Project-managed elements. The SMRD groups Mission Requirements by segment.

The SMRD distinguishes among requirements, goals, and statements of facts as follows:

Shall: Used to indicate a binding requirement that will be verified

Should/May: Used to indicate a desired goal

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

The SMRD allocates all Mission Requirements containing a “shall” to LASP-managed elements. 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

[CPF.20004] 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.

[CPF.20005] 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).

[CPF.20050] 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 CPF.20004 and CPF.20005.

4.2 Mission Requirements

4.2.1 Space Segment Requirements

[RS.21000] Wavelength

The CPRSP shall measure over the wavelength range of 350–2300 nm.

[RS.21004] Spectrally Resolved Earth Reflectance

The CPRSP 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.

[RS.21005] Broadband Earth Reflectance

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

[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.

[RS.21011] Angular Matching for Inter-Calibration

The CPRSP shall perform Inter-Calibration sampling by directing the HyperSpectral Imager for Climate Science (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.

[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.

[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.

[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.)

[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.

[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.

[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.

[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.

[RS.21040] Prime Mission Operations Period

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

[RS.21041] On-Orbit Commissioning Period

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

[RS.21045] Decommissioning

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

[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.

[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.

[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.

[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)

[RS.22000] Compliance with Launch Vehicle Requirements

The CPRSP shall satisfy the launch vehicle requirements.

[RS.22005] Compliance with ISS Requirements

The CPRSP shall satisfy ISS requirements.

[RS.22010] Compliance with Payload Interface Agreement Resource Allocations

The CPRSP shall meet the resource allocations documented within the CPF to ISS Payload Integration Agreement (PIA).

[RS.22025] Measurements and Data Routing

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

[RS.22035] Response to Ground Commands

The CPRSP shall have the capability to accept ground commands.

[RS.22040] On-orbit Reprogramming

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

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.

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/).

[SCI.24017] Science Data Product Formats

The CSDS shall format all Level 1B data products to 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.

[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.

[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.

[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.

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

The CSDS shall generate Level 0 and Level 1B data products whose metadata 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.

[SCI.24050] Full Resolution Browse Products

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

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.

[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/).

[SCI.24117] Science Data Product Formats

The ICPP will format all Level 4 data products to 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.

[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.

[SCI.24126] Inter-Calibration Planning

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

[SCI.24130] Inter-Calibrate Science Data

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

[SCI.24131] Inter-Calibrate Science Data

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

[SCI.24140] ESDIS Compliance

The ICPP will generate Level 4 data products whose metadata 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.

4.2.3 Ground Segment Requirements

[GS.23000] POIC Interface

The CPOC shall interface with the ISS POIC in accordance with the CPOC to POIC ICD (TBD).

[GS.23005] Generate Instrument Commanding

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

[GS.23010] Transfer Command Information

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

[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.

[GS.23020] Generate Instrument Software Loads

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

[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.

[GS.23035] Science Event Measurement Planning

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

[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.

[GS.23045] On-orbit Commissioning Period

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

[GS.23050] Data Processing

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

[GS.23055] Data Storage

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

[GS.23060] Inter-Calibration Prioritization

The CPOC shall command the CPRSP to execute a sufficient number of inter-calibration events to meet the performance measures specified in CPF.20050.

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
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
EOSDIS	Earth Observing System Data and Information System
ESDIS	Earth Science Data and Information System
FOV	Field of View
GSFC	Goddard Space Flight Center
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
LaRC	Langley Research Center
LASP	The University of Colorado Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
MCC-H	Mission Control Center-Houston
MSFC	Marshall Space Flight Center
PIA	Payload Integration Agreement
POIC	Payload Operations Integration Center
RBI	Radiation Budget Instrument
RS	Reflected Solar
SI	Système Internationale
SMRD	Science and Mission Requirements Document
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
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.