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Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission
Code 427.0

PACE Mission Requirements Document (MRD)

Goddard Space Flight Center
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National Aeronautics and Space Administration

PACE Mission Requirements Document (MRD)
Signature/Approval Page

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Preface

This document is under Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission configuration control. Changes to this document require prior approval of the PACE Configuration Control Board (CCB) Chairperson or designee. Submit proposed changes to the PACE Configuration Management Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Change History Log

Revision	Effective Date	Description of Changes (Reference the CCR & CCB/ERB Approval Date)
Revision -	12/22/2016	Baseline Release following the approval of PACE-CCR-0046
Revision A	01/10/2017	Updated following the approval of PACE-CCR-0081
Revision B	12/08/2017	Updated following the approval of PACE-CCR-0173
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Revision D	08/28/2018	Updated following the approval of PACE-CCR-0404
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Revision G	01/22/2020	Updated following the approval of PACE-CCR-0771
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Revision I	03/08/2022	Updated following the approval of PACE-CCR-1159, PACE-CCR-1176 and PACE-CCR-1200
Revision J	04/14/2022	Updated following the approval of PACE-CCR-1220
Revision K	08/15/2022	Updated following the approval of PACE-CCR-1250
Revision L	04/03/2023	Updated following the approval of PACE-CCR-1299

Deviations/Waivers Record

Section # / Requirement	Deviation / Waiver #	CCR #	Date Approved	Title	Mission

Table of TBDs/TBRs

Item No.	Location	Summary	Individual/ Organization	Due Date

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1 INTRODUCTION

1.1 Purpose

This Plankton, Aerosol, Cloud, ocean Ecosystems (PACE) Mission Requirements Document (MRD) specifies the Level 2 functional, performance, test, and delivery requirements for the PACE Space Segment, PACE Ground Segment, PACE Science Data Segment, and PACE Project Science in support of PACE mission objectives delineated in the Appendix Y Earth Systematic Mission Program Plan.

1.2 Scope

This MRD specifies the Level 2 mission requirement, requirement rationale, and segment/sub-segment allocation for the PACE mission. Links to the Level-1 requirements document are also identified.

1.3 PACE Mission Overview

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is a strategic climate continuity mission that was defined in the 2010 document *Responding to the Challenge of Climate and Environmental Change: NASA's Plan for Climate-Centric Architecture for Earth Observations and Applications from Space* (referred to as the "Climate Initiative"). The Climate Initiative complements NASA's implementation of the National Research Council's Decadal Survey of Earth Science at NASA, NOAA, and USGS, entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*.

PACE will extend the high quality ocean ecological, ocean biogeochemical, cloud, and aerosol particle data records begun by NASA in the 1990s, building on the heritage of the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging SpectroRadiometer (MISR), and the Visible Infrared Imaging Radiometer Suite (VIIRS). The mission will be capable of collecting radiometric and polarimetric measurements of the ocean and atmosphere, from which these biological, biogeochemical, and physical properties will be determined. PACE data products will not only add to existing critical climate and Earth system records, but also answer new and emerging advanced science questions related to Earth's changing climate.

PACE is classified as a Category 2 mission, per the criteria in NASA Procedural Requirement (NPR) 7120.5E, NASA Space Flight Program and Project Management Requirements. The mission classification is C according to NPR 8705.4B, Risk Classification for NASA Payloads.

The PACE observatory is comprised of three instruments, an Ocean Color Instrument (OCI) and two polarimeters, the Hyper-Angular Rainbow Polarimeter 2 (HARP-2) and the Spectro-Polarimeter for Exploration (SPEXone). The OCI is the primary instrument on the observatory and is being developed at Goddard Space Flight Center (GSFC). The OCI is a hyper-spectral scanning (HSS) radiometer designed to measure spectral radiances from the ultraviolet to shortwave infrared (SWIR) to enable advanced ocean color and heritage cloud and aerosol particle science.

The HARP-2 and SPEXone are secondary instruments on the PACE observatory, acquired outside of GSFC. The HARP-2 is multi-spectral, wide swath (supporting atmospheric correction of OCI) and hyper angular (good for clouds). The SPEXone is narrow swath and hyperspectral, better for characterizing aerosol microphysical properties.

This three-instrument PACE mission has the following multiple scientific goals:

- Extending key systematic ocean biological, ecological, and biogeochemical climate data records and cloud and aerosol climate data records;
- Making global measurements of ocean color data products that are essential for understanding the global carbon cycle and ocean ecosystem responses to a changing climate;
- Collecting global observations of aerosol and cloud properties, focusing on reducing the largest uncertainties in climate and radiative forcing models of the Earth system; and,
- Improving our understanding of how aerosols influence ocean ecosystems and biogeochemical cycles and how ocean biological and photochemical processes affect the atmosphere.

The PACE satellite is planned for a launch in 2022-2023. The PACE project office at NASA's GSFC is responsible for the satellite development, launch and operations. The mission is planned for launch into a Sun synchronous polar orbit at 676.5 km with an inclination of 98 degrees and a 1 pm local ascending node crossing time. The spacecraft bus will host the OCI, HARP-2, and SPEXone instruments. The GSFC PACE Project office will oversee the mission and the development of the satellite, launch vehicle, mission operations control center, and operations. The Headquarters Program Science will separately fund the science data processing system and competed science teams, which will include field-based vicarious calibration and data product validation efforts to support the Project science team.

NASA Headquarters has directed the mission development to be guided by a Design-to-Cost (DTC) process. All elements of the mission, other than the cost, are in the DTC trade space. At the heart of the DTC process are the mission studies, performed across all the mission elements. The mission studies will be used to define appropriate approaches within and across elements while maximizing science capabilities at a high cost confidence. Mission baseline requirements development is also embedded within the DTC process, as these requirements were not established at the onset of the mission concept development. Baseline mission requirements will be a product of the mission studies and will be defined by the project office as part of the DTC process.

The PACE mission consists of four major segments: space segment (SS), ground segment (GS), science data segment (SDS), and the launch segment (LS).

- The space segment consists of the spacecraft bus, the OCI, and two polarimeters. The spacecraft and OCI are being developed and integrated at GSFC. The polarimeters are contributed instruments. The spacecraft and instruments will be integrated as the PACE observatory at GSFC.
- The GS and associated Mission Operations Center (MOC) will be developed, integrated, and operated at GSFC. The GS provides for the command and control and health and safety monitoring of the PACE observatory on-orbit, as well as ensuring the science data

are accounted for and delivered to the SDS. The MOC will house the flight operations team (FOT) and is being managed by the PACE project through observatory commissioning. After commissioning, the FOT will be managed by the GSFC Earth Science Mission Operations (ESMO) project. The MOC performs all real time operations and off-line operations functions, including planning and scheduling, orbit and attitude analysis, housekeeping telemetry data processing, monitoring/managing the spacecraft and instruments, first line health/safety for the instruments, and housekeeping archiving and analysis.

- The SDS will be located at GSFC, but managed (separately from the project) by the NASA Headquarters Earth Sciences Division. The SDS will ingest, apply calibration and science algorithms, and process the science data, provide science software development and algorithm integration, act as the science data interface to the science team, and deliver of all science data products to the NASA-assigned Distributed Active Archive Center (DAAC).
- The LS is planned for a launch vehicle to be selected and procured by the NASA Launch Services Program at Kennedy Space Center (KSC).

In addition to utilizing GSFC institutional capabilities, the project will utilize the NASA/GSFC institutional capabilities such as the Flight Dynamics Facility (FDF), Near Earth Network (NEN), Ocean Biology Processing Group (OBPG), Space Network (SN), and NASA Integrated Services Network (NISN). PACE plans to generate 3.5 Terabits of science data daily. The data are downlinked from the observatory during 12-14 daily contacts via Ka-band communications to the NEN's ground stations. The observatory will also receive ground commands and transmit real-time housekeeping telemetry via an S-band 2-way link through the NEN during nominal operations. The observatory also has the capability of receiving ground commands and transmitting real-time housekeeping telemetry, via S-Band, through the SN during critical or contingency operations.

1.4 Related Documentation

1.4.1 Applicable Documents

The PACE Mission will comply with NASA agency and NASA/GSFC programmatic and technical requirements as listed below. In case of conflict, the PACE Level 1 Requirements will prevail, followed by the requirements of this Level 2 document. The following documents will apply for all NASA related design, development, production, integration and test, and operational activities. PACE will access the latest revision in effect and update as appropriate.

Document Number	Title
Appendix Y: Earth Systematic Mission Program Plan	Program Level Requirements for the Plankton, Aerosol, Cloud, ocean Ecosystem Project
GPR 1280.1	The GSFC Quality Manual
GPR 1410.2	Configuration Management
NPR 2810.1A	NASA IT Security Standard
GPD 7120.1	Space Asset Protection Policy

GSFC-STD-1000	Rules for the Design, Development, Verification, and Operation of Flight Systems
GSFC-STD-7000	General Environmental Verification Standard (GEVS) For GSFC Flight Programs and Projects
NPR 7120.5E	NASA Space Flight Program and Project Management Requirements
PACE-SMA-REQ-0002	PACE Mission Assurance Requirements (MAR)
CCSDS 133.0-B-1 (with TC 1 & 2)	Consultative Committee for Space Data Systems (CCSDS) Recommendation for Space Data System Standards – Space Packet Protocol (with Technical Corrigendum 1 & 2)
NPD 8610.7	Launch Services Risk Mitigation Policy for NASA-Owned and/or NASA-Sponsored Payloads/Missions
NPR 8715.6 Section 3.8	NASA Procedural Requirements for Limiting Orbital Debris
NASA-STD 8719.14	Process for Limiting Orbital Debris, Appendices A and B
NASA-STD 8719.24	NASA Expendable Launch Vehicle Payload Safety Requirements with Annex
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
NASA-STD-8719.13	Software Safety Standard
NPR 7150.2B	NASA Software Engineering Requirements

1.4.2 Reference Documents

Document Number	Title
GPR 8705.4	Risk Classification Guidelines and Risk-Based SMA Practices for GSFC Payloads and Systems
NPD 8720.1	NASA Reliability and Maintainability Program Policy
NPD 8705.4	Risk Classification for NASA Payloads
NPR 8715.3	NASA General Safety Program Requirements
NPR 8715.7	Expendable Launch Vehicle (ELV) Payload Safety Program
NPD 2570.5	NASA Electromagnetic (EM) Spectrum Management
NPD 8010.2	Use of the SI (Metric) System of Measurement in NASA Programs
PACE-SYS-REQ-0017	PACE Environmental Requirements Document (ERD)
PACE-SYS-REQ-0018	PACE Radiation Requirements Document (RRD)
PACE-SYS-PLAN-0032	PACE Software Management Plan (SMP)
PACE-SYS-PLAN-0030	PACE Project Materials & Processes Selection, Control & Implementation Plan (MPSCIP)
PACE-SYS-PLAN-0019	PACE Contamination Control Plan (CCP)
PACE-SYS-SPEC-0007	PACE General Systems Design Specification Document (GSDS)
PACE-LV-ICD-0008	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) to Falcon 9 Interface Control Document

2 PACE PROJECT PROGRAMMATIC REQUIREMENTS

2.1 Mission Level Requirements

MRD-19 The PACE Mission management shall comply with the requirements specified in NPD 7120.5E NASA Engineering and Program/Project Management Policy, with the following exceptions on the use of metric:
* Heritage Hardware: Hardware that has been previously qualified, or of similar design heritage, may be specified in English units where use of metric equivalents would lead to additional risk and cost to the program.
* Propulsion System Components: Components used in the construction of spacecraft propulsion systems (tanks, valves, and tubing) may be procured using English units where use of metric equivalents will lead to additional costs to the program.
* Fasteners: Use of US customary fasteners is permitted.

Rationale: NASA Level 1 requirement: NPD 7120.5E is mandatory, but allows exceptions. Significant cost & risk increase if we force the adoption of complete SI compliance.

MRD-20 The PACE mission shall comply with the GSFC Gold Rules, GSFC-STD-1000, Revision G.

Rationale: Per the GOLD Rules 1000 document

MRD-21 The PACE Mission risk classification shall be Class C, as per NPR 8705.4 Risk Classification for NASA Payloads.

Rationale: NASA Level 1 requirement. The PACE Polarimeter(s) are designated as "Do No Harm" instrument(s) per GPR 8705.4.

MRD-22 The PACE Space Segment shall be launched on an expendable launch vehicle of risk Category 2 (medium risk) or Category 3 (low risk) per NASA Policy Directive (NPD) 8610.7.

Rationale: NASA Level 1 requirement

MRD-23 The PACE Space segment shall be compatible with the launch vehicle requirements defined in the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) to Falcon 9 Interface Control Document (PACE-LV-ICD-0008)

Rationale: NASA Level 1 requirement

MRD-24 The launch readiness date shall be as documented in the project's latest Directorate Program Management Council (DPMC) Decision Memorandum.

Rationale: NASA Level 1 requirement; Project schedule reflects the compliance to this requirement

MRD-25 The PACE mission shall implement NASA security requirements as documented in the NASA IT Security Standard NPR 2810.1A.

Rationale: NASA standard that is required to be met by the project; IT security implemented in I&T plans for the space segment and ground segment

2.2 Mission Lifetime

MRD-27 The PACE on-orbit mission life shall be 3 years plus 60 days.

Rationale: 60 days is for in-orbit checkout. Level-1 requirement is 18 + 2 months, however a mission of 36 + 2 months results in a more complete science data set at minimal cost. Polarimeter instrument(s) are classified as Do No Harm, and do not have lifetime requirements.

MRD-28 The PACE mission shall complete the In-Orbit Check-out (IOC) period within 60 days after launch.

Rationale: Assuming direct injection, commissioning can be completed within this allocation; Same duration as similar SC

MRD-29 The PACE mission shall meet all mission requirements including mission lifetime at the completion of an Observatory Integration and Test phase lasting up to 2 years.

Rationale: I&T duration is different for each component due to delivery schedules and delays. Worst-case assumed for everything.

MRD-30 The PACE mission shall support mission and science operations for the observatory testing, launch and early orbit support, checkout period, the nominal science operations and decommissioning.

Rationale: Need to provide spacecraft and instrument operations for the life of the mission (will trace to the MOC and the SDS)

2.3 Mission Orbit

MRD-32 The PACE mission science orbit shall be sun-synchronous with the following parameters (Brouwer-Lyddane J2 element values):
Geodetic Height above WGS-84 ellipsoid: 675 km (minimum) to 710 km (maximum)
Eccentricity: 0.0012 ± 0.0004
Argument of Perigee: 90 ± 20 degrees
MLTAN: 13:00:00 ± 10:00 minutes

Rationale: The mission science orbit is a sun-synchronous orbit that (1) provides high illumination intensities of the relatively dark ocean, (2) minimizes atmospheric path lengths for ocean color atmospheric correction, (3) minimizes the range of scattering angles for simplification of atmospheric correction and surface bidirectional reflectance effects, (4) maximizes repeat observations of high latitudes to improve probabilities of viewing cloud-free scenes each day, and (5) provides 2-day coverage of the entire Earth. The minimum geodetic height is driven by the nominal OCI nadir pixel size of 1 km and provides the minimum recommended overlap of the OCI along-track ground footprint over the spin-to-spin footprint center spacing. The maximum geodetic height is derived from the maximum nadir pixel size of 1.1 km. Eccentricity and argument of perigee create a frozen orbit condition that stabilizes oscillations of the eccentricity vector and allows for easier enforcement of the geodetic height range.

MRD-34 The PACE mission shall maintain the mission orbit equatorial crossing time to within +/- 10 minutes of the nominal equatorial crossing time

Rationale: Required to maintain proper global coverage and Sun glint mitigation, and maintain solar beta angle between 7 and 23 degrees allowing a cold side of the Observatory.

MRD-35 The Mission System geodetic latitude and longitude shall be based on the WGS-84 world reference geoid (ellipsoid).

Rationale: Standard for Earth remote sensing missions

2.4 Mission Assurance and Reliability

MRD-37 The PACE Mission shall comply with the requirements defined in the PACE Mission Assurance Requirements (PACE-SMA-REQ-0002) document.

Rationale: Requirements defined for a Class C mission

2.5 Safety Assurance

MRD-39 The PACE mission shall comply the NASA-STD-8719.24 (with Annex) NASA Expendable Launch Vehicle Payload Safety Requirements

Rationale: Safety document Observatory design and GSE must comply with

2.6 Mission Coordinate Reference Frame

MRD-41 The PACE mission shall use the Spacecraft on-orbit coordinate system which uses a right-hand, orthogonal, body-fixed XYZ coordinate system as follows (see Figure 2.6-1): the +Z-axis is downward towards geodetic nadir, the Y-axis is normal to the orbit plane (+Y is opposite the orbital angular momentum), and the X-axis is along the Spacecraft velocity vector (+X toward the direction of Spacecraft travel).

Rationale: Utilize project lexicon for common terminology. Components with unique Coordinate systems (such as star trackers) shall determine a coordinate transform and verify a coordinate transform.

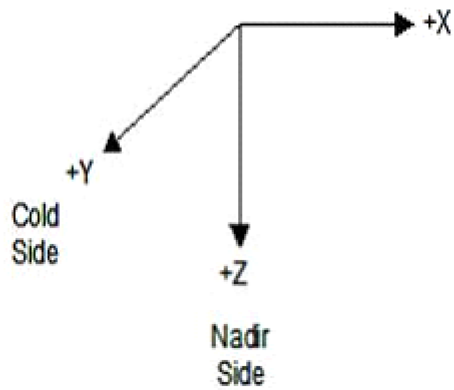

Figure 2.6-1 On-Orbit Coordinate System

2.7 Contamination Control Requirements

MRD-44 The PACE mission shall comply with the contamination control processes defined within the Contamination Control Plan (CCP) per PACE-SYS-PLAN-0019

Rationale: Need to follow a stringent process to protect the instruments from harmful contamination during ground operations and on-orbit

2.8 Orbital Debris

MRD-46 The PACE Space Segment shall limit orbital debris generation per NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris.

Rationale: NASA Level 1 requirement

MRD-47 The PACE Mission shall perform a controlled reentry to comply with NPR 8715.6.

Rationale: Preliminary orbital debris estimates and comparisons to other program estimates indicate that the debris exceeds that allowed for an uncontrolled reentry

MRD-48 The PACE mission shall preserve adequate fuel to meet the observatory controlled reentry deorbit requirements.

Rationale: Requires tank sizing and fuel budgeting for 10 year prop load for maintenance + deorbit

MRD-49 The PACE spacecraft shall have a Probability of Success (Ps) of greater than 0.85 at end of mission (EOM) for performing the controlled reentry.

Rationale: Based on an estimate of the Debris Casualty Area (DCA) for the observatory, the spacecraft requires a Ps to meet NPR 8715.6. DCA is allocated to SC, OCI, and Polarimeter(s) per the Technical Allocations and Resources (TAR) Requirements Document (PACE-SYS-REQ-0020).

2.9 Use of CCSDS Standards

MRD-51 The PACE Mission shall use CCSDS standards for communications between the Space segment and Ground segment per the Observatory to Ground ICDs, Vol I (PACE-SYS-ICD-0005), Vol II (PACE-SYS-ICD-0010), and Vol III (PACE-SYS-ICD-0038).

Rationale: Standard protocols for supporting space-ground communications with operational heritage on many GSFC missions. (GOLD Rule 1.48)

MRD-2052 The PACE Mission shall incorporate DTN BP (bundle protocol) for Housekeeping file return from the Space Segment to the Ground Segment via NEN S-Band for the S-band rates per the Technical Allocations and Resources (TAR) Requirements Document (PACE-SYS-REQ-0020; #7, #28).

Rationale: DTN technology infusion is desired at an Agency level to demonstrate high rate science data transfer through the ground networks using DTN protocols but is not required for PACE science data files. To this end, a parallel effort will enable the NEN to demonstrate DTN BP high rate transfer without incurring additional costs on the PACE GS. This technology infusion will be funded by GSFC Code 450. There are two types of Spacecraft housekeeping files: 1) "HK" files, consisting of housekeeping & significant event packets, which are ~4MB in size and 2) "Event" files, consisting of significant event packets (which are duplicates of the event packets in the "HK" files). The much smaller "Event" files were specifically created as they can be downlinked during LDR rates to assess Spacecraft health & safety. A single "HK" files would take ~6 hrs to downlink at LDR rates, so should only be downlinked at HDR or MDR rates.

2.10 Telemetry Data Transmission

MRD-53 The PACE Mission shall implement CCSDS File Delivery Protocol (CFDP) Class 2 for downlinking of Housekeeping (HK) files.

Rationale: Enables data completeness and HK recorder management activities to be satisfied during unstaffed, autonomous operations.

MRD-2059 The PACE Mission shall use CCSDS File Delivery Protocol (CFDP) Class 1 for downlinking of Science data files.

Rationale: CFDP Class 1 provides a standard protocol for sending of files. The PACE Science data files transfer is defined in Observatory to Ground Data Interface Requirement/Control Document, Volume III: Ka-Band CFDP Specification (PACE-SYS-ICD-0038).

2.11 Mission Time

MRD-55 The PACE mission shall use Universal Time Coordinated (UTC) as the time reference for ground data processing and operations planning.

Rationale: Standardize the time convention for the GS and SDS

2.12 Operational Availability

MRD-57 The PACE mission shall operate in Normal Operations State 96% of the time per month on average, after commissioning is complete, over the required spacecraft lifetime.

Rationale: Based on operational availability budgets of other earth science missions. Also addresses data completeness. Allows for safehold, orbit maintenance, SEUs within the instruments. Budget allocations to instruments and spacecraft allocated in the TAR (PACE-SYS-REQ-0020).

2.13 Science Data Recovery

MRD-59 The PACE mission shall provide to the SDS greater than 94% of the available Level-0 OCI science data on a monthly basis.

Rationale: The mission can tolerate up to 2 days of data loss per month. This equates to 6.67% allowable loss of Level-0 data. This is allocated to the OCI, spacecraft, and the ground segment, including the effects of the space segment availability (MRD-57) for the 94% data completeness. Compliance is shown through the following equation:
*(MRD-57) * (SRD-346) * (MRD-701) * (OCI 99%) = 0.94*

2.14 Space Segment General Design Requirements

MRD-731 The PACE Space Segment shall comply with the design requirements defined within the General System Design Specification (PACE-SYS-REQ-0007)

Rationale: Single document required to define design requirements to Space Segment

2.15 Space Segment Environmental Requirements

2.15.1 Environmental Test Requirements

MRD-62 The PACE Space Segment shall comply with the environmental requirements defined in the Environmental Requirements Document (ERD: PACE-SYS-REQ-0017)

Rationale: Single document required to define test requirements to Space Segment, which tailors GEVS to the program

2.15.2 Radiation Environment Requirements

MRD-64 The PACE Space Segment shall comply with the radiation environment requirements defined in the Radiation Requirements Document (RD: PACE-SYS-REQ-0018)

Rationale: Single document required to define radiation requirements to Space Segment for defined mission and orbit

2.16 Space Segment Launch Vehicle Interface Requirements

MRD-68 The PACE Space Segment shall comply with the requirements defined in the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) to Falcon 9 Interface Control Document (PACE-LV-ICD-0008)

Rationale: LSIDD envelopes the LVs defined by HQ for potential use for PACE mission

MRD-69 The PACE Space Segment shall have a total mass no greater than 1835 kg, including the spacecraft side of the LV payload adapter.

Rationale: The current observatory estimate specifies an observatory of 1835 kg or less, such that a specific propulsion tank may be used. This includes the OCI and DNH polarimeter(s).

2.17 Space Segment Operations

MRD-71 The PACE Mission flight hardware and mission operations shall be designed to allow observatory flight software modifications after launch.

Rationale: The mission needs to provide the capability to generate and upload new FSW loads, patches tables, for the instrument and spacecraft FSW and components.

MRD-72 The PACE mission shall operate in nominal mode autonomously (without ground intervention) for at least 96 hours in response to command sequences loaded to the spacecraft by the MOC.

Rationale: To support lights out operations or minimum ops staffing during weekends and holidays. Uplinks/reloads can take place as frequently as needed.

MRD-73 The PACE mission shall provide long-term trend analyses of observatory performance.

Rationale: Required to support mission operations and to identify potential observatory problems or degradations that may be occurring over the mission. Includes pre-flight trending

2.18 Mission Calibration/Validation

MRD-75 The PACE Mission shall implement a Calibration Program (documented in a Calibration Plan) to ensure that the uncertainty requirements for the science products produced using the PACE flight data meet the PACE Level-1 requirements.

Rationale: Direct flow down from L1, science team is still developing the Calibration plan

MRD-76 The PACE Mission shall implement a post-launch validation program (documented in a PACE Validation Plan) that uses ground data to evaluate that the science products produced using the PACE flight data meet the PACE Level 1 requirements.

Rationale: Direct flow down from L1, science team is still developing the Validation plan

MRD-77 Evaluation of science data products shall be completed by the end of the first year, to assess mission performance in meeting science objectives.

Rationale: Direct flowdown from L1

2.19 Mission Error Budget Allocations

The Level-1 uncertainty is defined as the root sum squared of geophysical algorithm (model), systematic, and random errors. These allocated errors are presented in the following requirements.

MRD-1993 The PACE Mission shall meet the water-leaving reflectance uncertainty allocations as defined in Table 2.19-1.

Rationale: The requirement allocates the PLRA water-leaving uncertainty to systematic, random, and algorithm uncertainties

Table 2.19-1 PACE Allocated Data Product Water-Leaving Reflectance Uncertainties.

Water-leaving reflectance*	Threshold absolute uncertainty	Threshold relative uncertainty	Baseline absolute uncertainty	Baseline relative uncertainty
$\rho_w(350)$	0.0083	30%	0.00465	20%
$\rho_w(360)$	0.0083		0.00408	
$\rho_w(385)$	0.0083		0.00314	
$\rho_w(412)$	0.0024	6%	0.00228	5%
$\rho_w(425)$	0.0024		0.00201	
$\rho_w(443)$	0.0024		0.00175	
$\rho_w(460)$	0.0024		0.00155	
$\rho_w(475)$	0.0024		0.00141	
$\rho_w(490)$	0.0024		0.00129	
$\rho_w(510)$	0.0024		0.00116	
$\rho_w(532)$	0.0024		0.00104	
$\rho_w(555)$	0.0024		0.00094	
$\rho_w(583)$	0.0024		0.00090	
$\rho_w(617)$	0.00084	12%	0.00058	10%
$\rho_w(640)$	0.00084		0.00052	
$\rho_w(655)$	0.00084		0.00046	
$\rho_w(665)$	0.00084		0.00047	
$\rho_w(678)$	0.00084		0.00045	
$\rho_w(710)$	0.00084		0.00041	
Ocean data products to be derived from the above				
Concentration of chlorophyll-a				
Fluorescence line height				
Diffuse attenuation coefficients (in the range 400-600 nm)				
Phytoplankton absorption (in the range 400-600 nm)				
Non-algal particle plus dissolved organic matter absorption (in the range 400-600 nm)				
Particle backscattering (in the range 400-600 nm)				

Note: These baseline requirements are defined for 50% or more of the observable deep ocean (depth>1000 m) at level 2. Threshold performance allocations that comply with PLRA threshold requirements are provided in Appendix A.

Table 2.19-2 PACE Systematic Uncertainty Requirements by Wavelength (Ocean Science)

Top of Atmosphere Radiance Systematic Uncertainty, Ocean Science (L_{low} - L_{high}) 1-sigma, EOL												
A. TOA Radiance Systematic Uncertainty	0.62%	0.54%	0.49%	0.79%	0.56%	0.53%	1.19%	0.83 %	1.39%	1.68%	3.09%	3.59%
Band	UV 350nm-400nm	VIS 400nm-550nm	VIS 555nm	VIS 583nm	VIS 610nm-710nm	NIR 748nm	NIR 820nm	NIR 865nm	NIR 1038nm	NIR 1250nm HG	SWIR 1615nm HG	SWIR 2260nm Ocean
Mission Allocation	0.23%	0.15%	0.15%	0.15 %	0.17%	0.16%	0.58%	0.11%	1.24%	1.26%	1.46%	1.63%
F. Post Launch Absolute Gain Uncertainty(K1)	0.20%	0.10%	0.10%	0.10%	0.10%	0.10%	0.57%	0.00%	1.24%	1.26%	1.45%	1.63%
G. Post Launch Relative Gain Uncertainty(K2)	0.12%	0.12%	0.11%	0.11%	0.13%	0.13%	0.12%	0.11%	0.11%	0.11%	0.12%	0.14%
B. OCI TOA Radiance Systematic Relative Uncertainty	0.46%	0.42%	0.47%	0.64%	0.43%	0.41%	0.80%	0.68%	0.63%	0.61%	2.12%	2.49%

The requirements associated with spectral radiometric accuracy presented in Tables 2.19-2 are discussed in section 3.7.

MRD-2034 The PACE Mission shall meet the aerosol and cloud uncertainty allocations as defined in Table 2.19-4.
PACE Systematic Uncertainty for Atmosphere Science (Top of Atmosphere Radiance Uncertainty, Atmosphere Science, Llow to Lhigh, 1 sigma, EOL) will be 5% for all wavelengths from 350nm to 2260nm.

Rationale: The requirement allocates the PLRA aerosol and cloud data product uncertainty to systematic and algorithm uncertainties

Table 2.19-3 PACE Allocated Data Product Aerosol and Cloud Data Product Uncertainties.

	Range	Uncertainty
Total aerosol optical depth at 380 nm	0.05 to 5	0.06 or 40%
Total aerosol optical depth at 440, 500, 550 and 675 nm over land	0.05 to 5	0.06 or 20%
Total aerosol optical depth at 440, 500, 550 and 675 nm over oceans	0.05 to 5	0.04 or 15%
Fraction of visible aerosol optical depth from fine mode aerosols over oceans at 550 nm	0.05 to 1	±25%
Cloud layer detection for optical depth > 0.3	NA	40%
Cloud top pressure of opaque (optical depth > 3) clouds	100 to 1000 hPa	60 hPa
Optical thickness of liquid clouds	5 to 100	25%
Optical thickness of ice clouds	5 to 100	35%
Effective radius of liquid clouds	5 to 50 μm	25%
Effective radius of ice clouds	5 to 50 μm	35%
Atmospheric data products to be derived from the above		
Water path of liquid clouds		
Water path of ice clouds		
Shortwave radiation effect		

The requirements are defined for 65% or more of the observable atmosphere at level 2 for all products except shortwave radiation effect. Each requirement is defined as the maximum of the absolute and relative values when both are provided. Table 2.19-3 represents threshold aerosol and cloud data products, all of which can be produced by OCI alone. The shortwave radiation effect is for a seasonal, hemispheric average since that is the temporal/spatial domain over which it can be validated against other sensors/observational networks.

3 OCEAN COLOR INSTRUMENT (OCI)

3.1 Global Coverage

MRD-80 For Ocean Color science, the PACE OCI shall achieve two-day global coverage of science measurements to solar zenith angle of 75 degrees and sensor view zenith angles not exceeding 60 degrees.

Rationale: Direct flow from L1

MRD-81 The PACE OCI shall acquire data at two different tilt angles along the in track direction without obstruction from any spacecraft structure: -20 deg or +20 deg from nadir

Rationale: Tilt angles mitigate Sun glint. Instrument observes -20 deg in southern hemisphere and + 20 deg in northern hemisphere. Tilt angles are consistent with the SeaWIFS ocean observing instrument

3.2 OCI Mission Data Spatial Resolution and Pointing Knowledge

MRD-84 The PACE mission maximum spatial resolution of the OCI science pixels (i.e. Ground Sample Distance or GSD) for global coverage shall be 1 km^2 (1 ± 0.1km x 1 ± 0.1km) at nadir for all ocean color radiometry and atmospheric science bands.

Rationale: Direct flow from L1

MRD-85 The PACE mission shall produce ocean color measurements with science pixel location knowledge uncertainty of less than 0.3 IFOV (3-sigma).

Rationale: Science Definition Team report requested pointing knowledge for OCI science products (referenced at nadir). Allocation to SC and OCI per the TAR (PACE-REQ-SYS-0020).

MRD-86 The PACE mission shall point the ocean color instrument boresight on the ground cross track and in-track with an accuracy of 2 IFOV (3-sigma).

Rationale: Science Definition Team report requested pointing knowledge for OCI science products (referenced at nadir). Allocation to SC and OCI per the TAR (PACE-REQ-SYS-0020).

MRD-87 The PACE mission shall control the ocean color instrument boresight pointing stability to 54 arcsec/sec (3 sigma) averaged over one second.

Rationale: Science Definition Team report requested pointing stability for OCI science products. Allocation to SC and OCI per the TAR (PACE-REQ-SYS-0020).

3.3 Spectral Wavelength Requirements

MRD-89 PACE OCI shall provide spectral bands for the retrieval of normalized water-leaving reflectances in open-ocean, clear-water conditions and standard marine atmospheres over the center-to-center wavelength range 350 - 865 nm with 5nm +/- 1 nm resolution.

Rationale: Wider range selected based on ability of hyperspectral detector technology being able to meet performance out to 865 nm. Visible spectral range enables geophysical retrievals for PACE science products.

MRD-92 PACE OCI shall provide spectral bands centered on 940, 1038, 1250, 1378, 1615, 2130, and 2260 nm.

Rationale: 865 nm captured in hyperspectral range; SWIR spectral range enables geophysical retrievals for PACE science products

3.4 Visible Band Spectral Over-Sampling

MRD-99 The PACE OCI shall provide the capability for spectral subsampling over the center-to-center wavelength range 350 - 865 nm.

Rationale: Science team request for OCI spectral subsampling at half, quarter, or eight of the visible spectral resolution; will allow for improvement in threshold science products

3.5 Radiometric Dynamic Range

MRD-103 OCI shall operate over a dynamic range that extends from the noise floor to L_{max}, and meet radiometric precision from Ltyp to L_{max}.

Rationale: Operation at Lmax is required for the on-orbit measurement of clouds (to be used in a stray light correction algorithm), operation at the noise floor is required for prelaunch characterization measurements. Avoiding saturation over clouds and land allows research by the cloud, aerosol, and land science communities.

3.6 Image Quality

MRD-1965 The OCI Modulation Transfer Function (MTF) in both track and scan direction shall equal or exceed:
Fraction of Nyquist GSD Sample Frequency (MTF Req)
0.00 (1.0), 0.25 (0.9), 0.50 (0.7), 0.75 (0.5), 1.00 (0.3)

Rationale: As used here, MTF applies to the on-orbit sensor performance and includes contributions from diffraction, optical aberrations, detector field-of-view, integration drag, aggregation, TDI, crosstalk, electronic response, jitter disturbances, and charge transfer efficiency.

3.7 Radiometric Accuracy

MRD-1982 PACE OCI shall comply with a pre-launch Absolute Gain uncertainty per Table 3.7-1 over the entire operating temperature range, traceable to NIST standards, and be established at Ltyp for unpolarized light during prelaunch measurements.

Rationale: Pre-launch absolute gain uncertainty required in order to meet EOL performance

Table 3.7-1 OCI Pre-Launch Absolute Gain Uncertainty

Band	UV	VIS	NIR	NIR	NIR	NIR	NIR	NIR	NIR	NIR	SWIR	SWIR	SWIR	SWIR	SWIR
	350nm - 400nm	400nm - 710nm	748nm	820nm	865nm	940nm	1038nm	1250nm HG	1250nm SG	1378nm	1615nm HG	1615nm SG	2130nm	2260nm Ocean	2260nm Cloud
OCI Pre-Launch Absolute Gain Uncertainty	2.00%	2.00%	2.00%	2.00%	2.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%

MRD-2005 PACE OCI shall comply with the baseline water-leaving reflectance systematic error requirements per wavelength (Table 2.19-1) by meeting the baseline mission Top of Atmosphere (TOA) Radiance Systematic EOL uncertainty per Table 2.19-2 (Line-B).

Rationale: OCI allocation of the mission level systematic error requirement referenced to the top-of-atmosphere

MRD-2007 PACE OCI shall comply with the post-launch Absolute Gain uncertainty (K1) per Table 2.19-2 through the use of a post-launch solar calibration.

MRD-2008 PACE OCI shall comply with the post-launch Relative Gain uncertainty (K2) per Table 2.19-2 through the use of a post-launch solar and lunar calibration.

3.8 Spectral Stability

MRD-113 On orbit spectral Monitoring: On-Orbit, After Launch, OCI shall characterize the spectral accuracy to 0.5 nm, over the center-to-center wavelength range 350 - 865 nm (including BW accommodation)

Rationale: On-Orbit Radiometric Response Trending

MRD-114 Long Term Spectral Stability: On-Orbit, After Launch, OCI Long Term Spectral Stability shall be 0.5 nm per year with a characterization accuracy of 0.5 nm, over the center-to-center wavelength range 350 - 865 nm (including BW accommodation)

Rationale: On-Orbit Radiometric Response Trending

MRD-115 Mission Spectral Stability: On-Orbit, After Launch, OCI Mission Spectral Stability shall be 1 nm over 3 years with a characterization accuracy of 0.5 nm, over the center-to-center wavelength range 350 - 865 nm (including BW accommodation)

Rationale: On-Orbit Radiometric Response Trending

MRD-1983 The maximum variation of the OCI center wavelength over the whole range of expected on-orbit instrument temperatures shall be less than 0.5nm during science and calibration data collection

Rationale: Spectral shifts reduce the radiometric accuracy and long term calibration trending curves

3.9 Navigation and Registration

MRD-1967 OCI temporal measurement (simultaneity) of all bands within one IFOV shall be less than 0.02 seconds (20 milliseconds).

Rationale: To enable an accurate account of all spectral content in time at a particular ground scene

MRD-1968 OCI spatial band-to-band registration between any two bands shall be greater than 70% of one IFOV.

Rationale: It is desired for each band to be taken at the same time on the same place on earth

3.10 Calibration

MRD-117 The PACE OCI shall provide the capability to expose all of the optical and detector elements to diffused solar illumination for characterization of the degradation of the elements

Rationale: Derived from L1 requirement requiring daily on-board calibrations. Program chose solar calibration vs an on-board light source.

3.11 Operational Availability

MRD-120 The PACE OCI shall operate in nominal science mode 98% of the time, after commissioning is complete, over the required spacecraft lifetime.

Rationale: Based on operational availability budgets of other earth science missions. Allows for instrument radiation environment impacts, SEUs, etc. Budget allocations to instruments and spacecraft allocated in the TAR (PACE-SYS-REQ-0020).

3.12 OCI Technical Budgets

MRD-122 The PACE OCI shall comply with the NTE mass allocation per the TAR (PACE-SYS-REQ-0020).

Rationale: Allocation of limited SC Resource - Mass

MRD-123 The PACE OCI shall comply with the NTE power allocation per the TAR (PACE-SYS-REQ-0020).

Rationale: Allocation of limited SC Resource - Power

MRD-124 The PACE OCI shall comply with the SpaceWire (SpW) bandwidth allocation per the TAR (PACE-SYS-REQ-0020).

Rationale: Allocation of limited SC Resource - BW to recorder

3.13 Products for Project Science/SDS

MRD-128 A prescription for the application of all necessary calibration coefficients to the digital number (DN) output of the OCI shall be provided to the PACE Project Science.

Rationale: Required to support calibration and to generate sensor data records that meet Level-1, Level-2, and Level-3 data product requirements.

MRD-129 A prescription for the determination of the OCI pointing with regard to the time reference shall be provided to the PACE Project Science.

Rationale: Required to support geo-location of the science pixels; includes tilt angle, scan rotation angle wrt pixels, etc

MRD-2088 The OCI engineering team shall deliver to the OB.DAAC (via SDS) an OCI instrument description document as outlined in Section 3.1.1 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

MRD-2089 The OCI engineering team shall deliver to the OB.DAAC (via SDS) OCI pre-flight/pre-operational calibration data as outlined in Section 3.1.1 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

4 PACE POLARIMETER(S)

The polarimeter(s) to be flown on PACE are classified per GPR 8705.4 as Do-No-Harm (DNH). At Level-1 there are no performance requirements for the polarimeter(s), therefore there are no performance requirements in the MRD. The interface and programmatic requirements are flowed through the polarimeter(s) contractual and interface control documents.

PACE is presently planning on having the Hyper-Angular Rainbow Polarimeter (HARP2), and SPEXOne polarimeter as DNH payloads.

MRD-2090 The HARP2 engineering team shall deliver to the OB.DAAC (via SDS) an HARP2 instrument description document as outlined in Section 3.1.1 of the “NASA Earth Science Data Preservation Content Specification” document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

MRD-2091 The HARP2 engineering team shall deliver to the OB.DAAC (via SDS) HARP2 pre-flight/pre-operational calibration data as outlined in Section 3.1.1 of the “NASA Earth Science Data Preservation Content Specification” document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

MRD-2092 The SPEXone engineering team shall deliver to the OB.DAAC (via SDS) an SPEXone instrument description document as outlined in Section 3.1.1 of the “NASA Earth Science Data Preservation Content Specification” document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

MRD-2093 The SPEXone engineering team shall deliver to the OB.DAAC (via SDS) SPEXone pre-flight/pre-operational calibration data as outlined in Section 3.1.1 of the “NASA Earth Science Data Preservation Content Specification” document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

5 SPACECRAFT REQUIREMENTS

5.1 Operational Requirements

5.1.1 Autonomy of Science Operations

MRD-292 The PACE Spacecraft shall be capable of storing and retrieving at least 9 days of commands for execution by the Spacecraft bus and instruments.

Rationale: Allows for weekly uploads to the SC, with 2 days of overlap in the command schedule

5.1.2 Space Segment States

MRD-294 At a minimum, the PACE Space Segment shall be capable of supporting the following states:

1. Power off
2. Launch State
3. Safe Hold State
4. Engineering State
5. Normal Operations State

Rationale: A state is defined as the functional configuration of the observatory. Additional states may be implemented to permit operations in different configurations.

5.1.2.1 Power OFF

The spacecraft bus and all instruments are powered off. This state is only available on the ground

5.1.2.2 Launch State

The Spacecraft bus and all instruments are configured for launch. This state is also used for launch pad checkout and ascent

5.1.2.3 Safe Hold State

This state is used to preserve the health and safety of the Spacecraft and instruments in the event of an anomalous condition or hazardous attitude orientation. This state can also be used to null tip-off rates, acquire the sun post LV separation or after an attitude anomaly, and deploy the solar array.

MRD-301 The PACE Space Segment shall have a Safe Hold state used to maintain a power-positive and thermally-safe orientation to be autonomously entered in observatory emergencies.

Rationale: Safe Hold is needed to provide a simplified ACS & power mode that protects the observatory in the event of serious but non-fatal errors. Comply with GSFC GOLD Rule number 1.17

MRD-1971 The PACE Spacecraft shall only exit the Safe Hold State by Ground command.

Rationale: Safe Hold is maintaining the observatory safety, and exit from it must be by ground operations only

5.1.2.4 Engineering State

The Engineering state provides for test of specific instrument and subsystem configurations to allow evaluation of instrument or Spacecraft subsystem health and status. This state can also be used to perform propulsive maneuvers.

MRD-305 The Spacecraft shall be capable of achieving and maintaining the mission orbit after separation from the LV.

Rationale: S/C needs to be able to perform propulsive maneuvers to achieve the mission orbit post-separation and to maintain the orbit over the life of the mission

MRD-306 The PACE Spacecraft shall perform posi-grade and retro-grade, and inclination maneuvers as required.

Rationale: Need the flexibility and capability for orbit maneuvers

5.1.2.5 Normal Operations

The Normal Operations State is the state in which science operations is performed

MRD-309 The PACE Spacecraft bus shall be capable of operating spacecraft subsystems, the OCI, and the Polarimeter(s) simultaneously and continuously in Normal Operations State.

Rationale: Need to be able to operate full compliment of instruments and bus nominally without any operational constraints.

MRD-310 The PACE Spacecraft shall enter the Normal Operations State only by Ground command

Rationale: The Ground is required to configure the subsystems to support Normal operations. This state is not entered autonomously.

5.1.3 Operational Availability

MRD-312 The PACE Spacecraft shall operate in Normal Operations State 98% of the time, after commissioning is complete, over the required spacecraft lifetime.

Rationale: Based on operational availability budgets of other earth science missions. Allows for radiation environment impacts, SEUs, etc.

5.1.4 Data Storage

MRD-314 The PACE Spacecraft shall be capable of acquiring and storing up to a minimum of 7 orbits of science mission data at the maximum orbital average data rates given in the TAR (PACE-SYS-REQ-0020).

Rationale: The spacecraft memory is sized for 7 orbits of storage, or about 11.5 hrs, and affords the spacecraft sufficient memory to stage science data during the occasional scenario when spacecraft does not see Alaska, Svalbard, or Punta Arenas for 2.7 orbits or ~4.1 hrs. It also allows for the missed contacts.

MRD-315 For anomaly resolution, the PACE Spacecraft shall be capable of acquiring and independently storing up to 24 hours of Spacecraft and instrument housekeeping data at the maximum orbital average data rates given in the TAR (PACE-SYS-REQ-0020).

Rationale: Provide sufficient storage margin to support contingency science operations. An anomaly will be responded to in less than 24 hours since we are scheduling a minimum of 14 passes per day.

5.2 Instrument Accommodations

5.2.1 Instrument Interface Control Documents

MRD-318 The PACE Spacecraft shall accommodate the Ocean Color Instrument (OCI) per the Spacecraft-to-OCI Interface Control Document (PACE-SYS-ICD-0006).

Rationale: Comply with Instrument Accommodation requirements in Level 1 (threshold and baseline), along with the standard requirements for mass, power, FOV's, thermal interface, thermal/mechanical stability, data interface, jitter, uncompensated momentum, etc.

MRD-319 The PACE Spacecraft shall accommodate the Hyper-Angular Rainbow Polarimeter (HARP2) per Spacecraft-to-HARP2 interface control document: PACE-SYS-ICD-0048.

Rationale: Accommodate a full instrument complement, along with the standard requirements for mass, power, FOV's, thermal interface, thermal/mechanical stability, data interface, jitter, etc.

MRD-2038 The PACE Spacecraft shall accommodate the SpectroPolarimeter for Planetary Exploration (SPEXOne) per Spacecraft-to-SPEXone interface control document: PACE-SYS-ICD-0047.

Rationale: Accommodate a full instrument complement, along with the standard requirements for mass, power, FOV's, thermal interface, thermal/mechanical stability, data interface, jitter, etc.

5.2.2 Instrument Data Rates

The PACE instrument's orbit average data rate is defined to be the total data for one orbit divided by the orbit period. The instrument peak data rate is defined as the maximum value over any 1-second period.

MRD-325 The PACE Spacecraft shall be capable of collecting, storing, and retransmitting to the ground, instrument data at the data rates specified in the TAR (PACE-SYS-REQ-0020).

Rationale: Current instrument allocations.

5.2.3 OCI Instrument Glint Mitigation

MRD-2032 The PACE Spacecraft shall perform a re-positioning of the OCI tilt platform of 40 degrees (-20 to +20), and regain pointing accuracy and stability within 60 seconds.

Rationale: Required to minimize the impact to global coverage. 60 seconds selected based on trade between coverage impact and required capability of tilt system for a 9% coverage loss. The tilt change occurs twice per orbit, near the subsolar point (60 seconds applies) and on the dark side (60 seconds does not apply) of the orbit. The operation of the tilt maneuver on subsequent orbits/days is staggered. For reference, SeaWIFS instrument tilt requirement was 30 seconds.

5.3 Space-to-Ground Interface

MRD-327 The PACE Spacecraft shall comply with the applicable National Telecommunications and Information Administration (NTIA) requirements for the space to ground RF interface.

Rationale: Required for all space-to-ground RF interfaces

MRD-328 The PACE Spacecraft shall comply with the applicable International Telecommunications Union (ITU) requirements for the space to ground RF interface.

Rationale: Required for all space-to-ground RF interfaces

5.3.1 RF Interface

MRD-330 The PACE Spacecraft shall provide downlink capacity to provide real-time health and safety data to monitor Spacecraft and instrument operation.

Rationale: Provide mission operations capability.

MRD-331 The PACE Mission shall utilize the NASA Near Earth Network (NEN) S-band ground stations for housekeeping telemetry downlink.

Rationale: Use current capability for s-band telemetry downlink.

MRD-332 The PACE Mission shall utilize the NASA Near Earth Network (NEN) S-band ground stations for command uplink.

Rationale: Use current capability for s-band command uplink

MRD-333 The PACE Mission shall utilize the NASA Near Earth Network (NEN) Ka-band ground stations for science data downlink.

Rationale: Use the NASA NEN for the science downlink. Ka-band required for predicted science data volume

MRD-334 The PACE Mission shall utilize the NASA Space Network (SN) S-band for housekeeping telemetry for launch and early orbit, observatory contingencies, and for coverage of mission critical events as necessary

Rationale: SN support for telemetry downlink is required to meet IOC timelines and for maneuvers and other mission critical events outside of the NEN ground station sites

MRD-335 The PACE Mission shall utilize the NASA Space Network (SN) S-band for bent pipe commanding for launch and early orbit, observatory contingencies, and for coverage of mission critical events as necessary

Rationale: Provide coverage for launch, early orbit & critical events

MRD-336 The PACE Spacecraft and GS shall support simultaneous operation of the S-band and Ka-band downlink, and S-band uplink.

Rationale: S-band downlink is used for state-of-health (SOH) transmission, whereas Ka-band is for the science downlink

MRD-337 The PACE Mission shall support the command and telemetry RF data rates defined in the TAR (PACE-SYS-REQ-0020).

Rationale: Current allocations

5.4 Command Functions

MRD-339 The PACE Mission shall command and control the observatory.

Rationale: Command and control required from MOC & SOC to Spacecraft & instruments

MRD-1975 The PACE Mission shall implement command link encryption.

Rationale: Command encryption required to protect the observatory from external threats per NASA HQ direction per PACE-SYS-CORR-0016.

MRD-2115 The command uplink throughput rate shall not exceed 8.8 kbps when using the 32 kbps RF uplink

Rationale: When actively commanding the Spacecraft at the 32 kbps RF uplink rate the uplink rate needs to be limited due to spacecraft implementation constraint.

5.5 Telemetry Functions

MRD-342 The PACE Spacecraft shall collect, monitor, store on-board, and provide for downlink to the Ground Segment telemetry relevant to the health, safety, and performance of the Observatory systems.

Rationale: Standard mission requirement

MRD-344 The PACE Spacecraft shall generate and provide to the Ground Segment ancillary data consisting of, but not limited to real-time attitude, position, velocity, and time telemetry.

Rationale: Ancillary telemetry required to geo-locate the science pixels

5.6 Space Segment Timing

MRD-346 The PACE Space Segment shall use International Atomic Time (TAI) as the time reference on-board

Rationale: Heritage FSW is baselined

MRD-347 The PACE Spacecraft shall provide a common timing reference for the spacecraft and instruments.

Rationale: Geo-location of science pixels requires accurate and common SC timing and reference to minimize errors

MRD-348 The PACE Space Segment shall have time knowledge with regard to the time reference of less than 2 msec.

Rationale: Geo-location of science pixels requires accurate time synchronization to minimize errors

5.7 Attitude Control Requirements

MRD-351 The PACE Spacecraft shall include on-board capability for orbit determination and clock maintenance that does not require interaction with the ground.

Rationale: Requirement drives the use of a GPS receiver, which is required to support geo-location of pixels

MRD-352 The PACE Spacecraft shall be capable of operations by propagating a ground-based ephemeris update.

Rationale: Operations without GPS at reduced mission performance

MRD-353 The PACE Spacecraft shall be capable of autonomously canceling observatory body rates imparted by the launch vehicle per the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) to Falcon 9 Interface Control Document (PACE-LV-ICD-0008)

Rationale: 3-sigma without thrusters

MRD-354 The PACE Spacecraft shall maintain its normal attitude with the accuracy specified in the TAR (PACE-SYS-REQ-0020).

Rationale: Spacecraft maintains nadir pointing for science operations, except during tilt operations for glint avoidance

MRD-355 The PACE Spacecraft attitude knowledge shall be in accordance with the TAR (PACE-SYS-REQ-0020).

Rationale: This requirement allocation includes the contributions of the ACS pointing knowledge, jitter, and the thermal/mechanical interface between the ACS attitude reference and the OCI interface.

MRD-356 The PACE Space Segment shall have on-board position knowledge better than 50 meters, 3-sigma in-track, cross-track, and radial.

Rationale: Low position knowledge error is required in order to meet the OCI pixel geo-location knowledge budget. Requires a GPSR in order to meet this requirement

MRD-357 The PACE Spacecraft shall maintain pointing accuracy during lunar calibration scans per the TAR (PACE-REQ-SYS-0020).

Rationale: Lunar calibration scans are used to radiometrically calibrate ocean color imager, and pointing knowledge is required for accurate knowledge of imager scan pointing

MRD-2112 The PACE Spacecraft shall maintain pointing accuracy during lunar calibration "stare" per the TAR (PACE-REQ-SYS-0020).

Rationale: Lunar calibration "stare" is required to calibrate SDA recovery time to an input pulse, and pointing accuracy is required for lunar targeting

MRD-2033 The PACE OCI shall recover nominal science pointing within 15 seconds after the SC platform tilt is complete.

Rationale: OCI requires recovery time for any attitude transient caused by the platform tilt. Excessive recovery will result in unnecessary loss of science data following tilt.

MRD-2047 The PACE spacecraft shall actively yaw-steer (rotate about the Z-axis) over the portion of the orbit that SPEXOne science is collected to compensate for the earth rotation.

Rationale: In order to perform robust atmospheric polarimetry the forward and aft looking SPEXOne pixels are required to view the same ground location (and hence the same atmospheric column)

5.8 Propulsion Requirements

MRD-360 The PACE Spacecraft shall provide a propulsion subsystem to perform propulsive corrections for 3-sigma LV orbit injection dispersions, 3 years of orbit maintenance, and a controlled deorbit.

Rationale: Requirement is to capture all drivers for propulsion sizing. 3 years of maintenance driven by MRD mission life requirement (MRD-27)

MRD-732 The PACE Spacecraft shall provide a propulsion tank that is able to accommodate enough propellant to perform propulsive corrections for 3-sigma LV orbit injection dispersions, 10 years of orbit maintenance, and a controlled deorbit.

Rationale: 10-year maintenance required by HQ. Only applies to the propulsion tank sizing.

5.9 Power Management Requirements

MRD-363 The PACE Spacecraft shall provide a power management capability for observatory operations as well as fault detection, fault clearance, and load shedding in all states, during sunlight and eclipse periods.

Rationale: Power system standard requirements

MRD-364 The PACE Spacecraft shall provide a power management capability for observatory operations that is energy balanced for each Normal Operations State science collection orbit, excluding those with a lunar calibration.

Rationale: Nominal science operations need to show energy balance at EOL

MRD-365 The PACE Spacecraft shall provide a power management capability for observatory operations that is energy balanced for a Normal Operations State nominal science collection orbit, including those with a lunar calibration, over 2 orbits.

Rationale: Lunar calibration maneuvers are separated by at least 2 days, and should not be a power system sizing scenario

5.10 Lunar Calibration

MRD-367 The PACE Space Segment shall perform 2 monthly lunar calibrations of the OCI to characterize the detector and optical component changes.

Rationale: 2 maneuvers are selected pre- and post-full moon at equivalent absolute phase angles for maximum characterization for an 18 month mission

MRD-368 The PACE Space Segment shall perform the OCI lunar calibration maneuver without impacting OCI science collection (maneuver must start after solar zenith angle of 75 degrees)

Rationale: Maneuvers are restricted the period in the orbit where required OCI science collection is not impacted (maintains science availability)

MRD-369 The PACE Space Segment shall perform two OCI lunar calibration maneuvers each month, with one maneuver being performed at a lunar phase angle of +7 deg +/- 0.5 deg, and the other being performed at a lunar phase angle of -7 deg +/- 0.5 deg.

Rationale: Need to perform the 2 lunar calibrations at the same lunar phases to obtain the same lunar radiance input into the instrument. Note: The +/- 0.5 degrees will drive each maneuver to be done on a particular orbit, and the two maneuvers will be approximately 1 day apart.

MRD-370 The PACE Space Segment shall perform the OCI lunar calibration maneuver scans at a fixed OCI FOR scan angle (+/- 1 deg) moving perpendicular to the scan direction to obtain full lunar disk coverage.

Rationale: Month-to-month comparison of lunar calibration data requires errors be minimized and full disk coverage obtained

MRD-2113 The PACE Space Segment shall perform the OCI lunar calibration "stare" targeting at the same fixed OCI FOR scan angle as the lunar calibration scans.

Rationale: Lunar calibration "stare" is required to calibrate SDA recovery time to an input pulse, and pointing accuracy is required for lunar targeting. The OCI radiator constraints for lunar calibration apply to the lunar stare.

MRD-371 The PACE Space Segment shall perform the OCI lunar calibration maneuver scans at a lunar sweep rate of 7.5 arcmin/sec, with a rate stability of better than 0.075 arcmin/sec (1-sigma).

Rationale: Over-sampling of the lunar disk by 4X required to obtain the maximum accuracy for measuring the degradation of the instrument. The defined rate assumes 2 sweeps per maneuver.

MRD-1988 The PACE Spacecraft shall provide rate telemetry accurate to 0.2% of the lunar cal SC slew rate.

Rationale: Rate knowledge required to meet lunar calibration error budget allocation

MRD-1989 The Spacecraft shall have the rotation axis of the lunar calibration slew (during lunar scanning) aligned within 1 degree of an axis that is in the OCI Y-Z plane and perpendicular to the OCI scan angle specified for the lunar view.

Rationale: A deviation of the rotation axis from the slew axis would affect the sweep rate, so the rotation axis should be maintained within 1 degree of the slew axis to minimize the effective lunar sweep rate.

5.11 Solar Calibration

MRD-373 The PACE Space Segment shall perform daily solar calibrations of the OCI to characterize the detector and optical component changes.

Rationale: Solar calibration desired on a daily basis to compliment the lunar calibrations (Threshold lunar cal requirement is 1 lunar calibration per month). L1 baseline is 1 solar cal maneuver per day, with a single day per lunar cycle requiring 3 solar cal maneuvers.

MRD-374 The PACE Space Segment shall perform the OCI solar calibration maneuvers without violating OCI coverage requirements.

Rationale: Maneuvers are restricted to orbit periods so that OCI science collection is not impacted (maintains science availability)

MRD-375 The PACE Space Segment shall perform the OCI solar calibration maneuver by pointing the boresight of the solar calibration aperture at the sun for between 30 and 120 seconds.

Rationale: Duration is driven by the science data required, and the target pointing minimizes the effects of off-boresight reflections, attenuation, etc.

MRD-2114 The PACE spacecraft shall collect solar calibration data through the SDA Pulse Calibration Assembly (SPCA) for a maximum of 120 seconds.

Rationale: Duration is driven by the science data required, and the target pointing minimizes the effects of off-boresight reflections, attenuation, etc.

MRD-1990 The PACE Space Segment shall maintain pointing control and knowledge during solar calibration per the TAR (PACE-REQ-SYS-0020).

5.12 Fault Management

MRD-377 The PACE Space Segment shall be designed to detect, identify, and correct failures through autonomous or ground-controlled reconfiguration.

Rationale: FDC required for failures so that they do not endanger the safety of the observatory

MRD-378 The PACE Spacecraft shall prevent the sun from entering the instrument Keep-out-Zones (KOZs) during Engineering and Normal Operations States as required in the spacecraft-to-instrument interface control documents.

Rationale: The instrument can't meet performance requirements with sun within KOZ.

MRD-380 The PACE Spacecraft safe attitude for non-critical failures (i.e., power-off of instrument for a temperature out of limit) shall be nadir pointing (Engineering State)

Rationale: Safe Hold State needs to be thermally safe & power positive for non-critical failures, while maintaining nadir pointing for non-critical failures.

MRD-381 The PACE Spacecraft safe attitude for critical failures (i.e., solar array drive failure) shall be solar inertial with the array drive inhibited and the array normal to the sun.

Rationale: Safe Hold State needs to be thermally safe & power positive for critical failures.

MRD-382 The PACE Spacecraft shall provide load fault isolation to prevent power fault propagation.

Rationale: Fusing and circuit breakers required to prevent circuit shorts from being Single-point failures

MRD-383 The Spacecraft shall allow the contingency use of thrusters to gain control of Spacecraft rates should higher than worst-case tip-off rates occur at launch vehicle separation.

Rationale: Contingency capability to be executed by ground operations

6 SCIENCE DATA SEGMENT

The development of geophysical products of sufficient quality for climate research from spaceborne radiometric observations requires significant efforts in sensor calibration, product validation, software development, and data systems. These elements must be closely coordinated, as the process to improve and verify product quality is inherently iterative and computationally intensive. This process requires an integrated team of scientists, calibration and data systems engineers, software developers, and scientific analysts that fully understand the measurement science and have access to the complete mission archive and significant processing resources. Improvements in sensor calibration knowledge and proposed enhancements to processing algorithms must be implemented and evaluated on global, life-of-mission scales to assess impact to the time series and agreement with field measurements. Results of these analyses then provide feedback for further improvement.

Table 6-1 Science Data Product Level Definitions

Data Level	Data Product
Level 0	Lowest level science data (e.g., Consultative Committee for Space Data Systems packets)
Level 1A	Uncalibrated science data in archive format (e.g., Network Common Data Form)
Level 1B	Calibrated, geolocated science data as observed
Level 1C	Calibrated, geolocated, co-registered (resampled) science data
Level 2	Science products derived from Level-1B/C
Level 3	Temporally and spatially composited science products

The latency is measured from the arrival of the data to SDS until delivery to the specified DAAC.

6.1 SDS General Requirements

MRD-628 The PACE Science Data Segment (SDS) shall utilize and augment the existing facilities of the Ocean Biology Processing Group (GSFC code 616) for the production of science data products, science product calibration and validation processing support, and the planning and monitoring of science instrument operations.

Rationale: Directed by NASA HQ

6.2 SDS Interfaces

MRD-630 The PACE SDS and PACE Mission Operations Center (MOC) shall interface per the PACE MOC-to-SDS Interface Control Document.

Rationale: Comply with interface requirements for data transfer, planning products, etc

MRD-2082 The NEN and the PACE SDS shall interface per the NEN to UMGS Interface Control Document (ICD)/PACE-GS-ICD-0037 for receipt of Science Data Files received via Ka-band.

Rationale: PACE will baseline using a secured file transfer protocol from the ground stations to the MOC/Science Data Segment as defined in the NEN to UMGS Interface Control Document (ICD)/PACE-GS-ICD-0037.

MRD-633 The PACE SDS shall interface with the OB.DAAC for science data product deliveries, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products, per the SDS-to-OB.DAAC Interface Control Document.

Rationale: Comply with interface requirements for science data product deliveries

MRD-2094 The SDS shall deliver to the OB.DAAC the data preservation products as outlined in Sections 3.2.1, 3.2.2, 3.3.3, 3.4.2, 3.5, and 3.8 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

MRD-2095 The SDS shall deliver to the OB.DAAC a deliverables checklist as outlined in Section 3.9 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA. Initially maintained and managed by PACE MSE, then transferred to the MOC post-launch. The MOC will then manage remaining deliverables to OB.DAAC.

6.3 SDS Software and Data Production Requirements

MRD-2058 The PACE SDS computer components shall be specified and configured to support the System and Information Integrity Family of Security Controls defined in NIST Special Publication 800-53, for a Low Impact IT Security Posture for science data.

Rationale: Required for safe-guarding observatory science data.

MRD-635 The PACE science data and processing software, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products, shall be managed and delivered to an ESD-assigned Distributed Active Archive Center (DAAC) in accordance with the NASA Earth Science Data and Information Policy specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/.

Rationale: NASA ESD policy. No period of exclusivity, all software source code and coefficients used in the processing will be in public domain (delivered to the DAAC).

MRD-2084 Public release of the data and software delivered to the DAAC shall conform to the NASA Earth Science Data and Information Policy specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/.

Rationale: Standard NASA policy, and driven by PLRA.

MRD-2085 There shall be no period of exclusive access to the data and software delivered to the DAAC.

Rationale: Standard NASA policy, and driven by PLRA.

MRD-2086 The source code shall be delivered to the DAAC(s) at the time of the initial data delivery specified in Table 6-1.

Rationale: Standard NASA policy, and driven by PLRA.

MRD-2087 Updated source code shall be delivered to the DAAC(s) throughout the lifetime of the project as new versions of software are developed.

Rationale: Standard NASA policy, and driven by PLRA.

MRD-636 The PACE SDS shall produce all higher-level science products in a portable and self-describing format that follows one of the EOSDIS format standards as specified at https://earthdata.nasa.gov/user-resources/standards-and-references

Rationale: NASA ESD policy.

MRD-1998 The PACE SDS science 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: Use of a standard format required to allow general and scientific community access

MRD-1999 For all standard data products that can be meaningfully represented as images, the PACE SDS shall generate full-resolution browse products, as defined in https://earthdata.nasa.gov/about/science-system-description/eosdis-components/global-imagery-browse-services-gibs.

Rationale: Use of a standard format required to allow general and scientific community access

MRD-637 The PACE SDS shall be responsible for all processing software needed to convert PACE science data from Level-0 to higher level science products.

Rationale: Software must be acquired or developed to convert raw sensor observations to calibrated and geolocated measurements and geophysical products.

MRD-638 The PACE SDS shall be responsible for implementation of the science data processing algorithms provided by Project Science.

Rationale: The science algorithms provided by Project Science must be implemented in operational data processing software.

MRD-639 The PACE SDS shall ingest all PACE science, housekeeping, command logs and telemetry data it receives from the Ground Segment.

Rationale: Science and housekeeping data are required for science data processing; housekeeping data is required for monitoring and trending of instrument performance.

MRD-640 The PACE SDS shall produce from the OCI Level-0 science data the higher-level science data products listed in Tables 2.19-1, 2.19-3, and defined in Table 6-1.

Rationale: Data acquisition and processing capabilities must be developed and operated over the mission lifetime or developed to convert raw sensor observations to calibrated and geolocated measurements and geophysical products.

MRD-2046 The PACE SDS shall process all Level-0 polarimeter science data to Level-1C per Table 6-1.

Rationale: Data acquisition and processing capabilities must be developed and operated over the mission lifetime or developed to convert raw sensor observations to calibrated products.

MRD-1987 The PACE SDS shall process all Level-2 science products to Level-3 global daily and monthly composite products as defined in Table 6-1.

MRD-641 The PACE SDS shall be capable of periodic full-mission reprocessing of the higher-level science products, while also maintaining the acquisition and processing of new science data

Rationale: Periodic reprocessing is required to support the evaluation of calibration and algorithm advancements, and to incorporate verified improvements into updated data products for transfer to DAAC.

MRD-642 The PACE SDS shall deliver all Level-0 and higher-level science data products to the ESD-assigned DAAC

Rationale: NASA ESD policy. This includes all versions of the processed data

6.4 SDS Instrument Operations Support

MRD-647 The PACE SDS shall generate daily activity schedules for the PACE science instruments, including nominal operations and calibration events, and provide those schedules to the MOC.

Rationale: A schedule of instrument activities is required to identify when to start/stop imaging, when to tilt (OCI), when to initiate calibration sequences such as lunar or solar calibration.

MRD-648 The PACE SDS shall monitor and trend science instrument state of health telemetry.

Rationale: Changes in instrument telemetry can provide insight into the drivers of sensor radiometric performance degradation and potential avenues for correction.

6.5 SDS Mission Time

MRD-653 The PACE SDS shall support Space Segment time stamps that use International Atomic Time (TAI).

Rationale: Heritage FSW uses TAI

7 GROUND SEGMENT (GS)

7.1 GS Interface Requirements

7.1.1 Science Data Segment Interface

MRD-658 The PACE GS shall make available all science and housekeeping data files to the SDS within 12 hours of receipt of the data at the ground station.

Rationale: GS Design needs to be able to pass data to prevent cascading backups.

MRD-659 The PACE GS shall stage science and housekeeping data files for delivery to the SDS for up to 30 days after receipt from the spacecraft.

Rationale: Required to recover from ingest errors at SDS, initial transmission errors from MOC/SDS interface, or catastrophic data losses at SDS.

MRD-660 The PACE GS shall receive daily instrument activity schedules from the SDS per the PACE MOC-to-SDS Interface Control Document.

Rationale: From operations concept document.

MRD-661 The PACE GS shall provide mission planning products to the SDS per the PACE MOC-to-SDS Interface Control Document.

Rationale: SDS requires certain planning and scheduling information from the MOC to provide key information which could affect SDS operations

MRD-662 The PACE GS shall provide all health and status telemetry, command logs, and mission science data to the Science Data Segment for long-term trending and archival.

Rationale: SDS forwards all data to the DAACs

MRD-2108 The MOC shall deliver to the SDS for delivery to the OB.DAAC a deliverables checklist as outlined in Section 3.9 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Once the observatory has started the mission (L+60 days), the MOC receives from the MSE the deliverables checklist. The MOC maintains this list through the completion of the mission, and deliverers updates to SDS as-required.

7.1.2 Space Segment Interface

MRD-664 The PACE GS shall interface with the Space Segment per the PACE Observatory-to-Ground Data Interface Requirement/Control Documents, Vol I (PACE-SYS-ICD-0005), Vol II (PACE-SYS-ICD-0010), Vol III (PACE-SYS-ICD-0038) and Vol IV (PACE-SYS-ICD-0051).

Rationale: MOC and Ground Stations must be compatible for the observatory data formats defined within the Data IRCDs.

MRD-665 The PACE GS shall interface with the Space Segment and Ground Segment per the Radio Frequency Interface Control Document (PACE-GS-ICD-0020).

Rationale: NEN and SN interfaces with the Space Segment need to be compatible

7.1.2.1 SN Services

MRD-667 The SN shall provide scheduled forward and return S-band link service to the PACE Observatory.

Rationale: SN scheduled for Launch and Early operations support and critical observatory events, such as initial propulsion maneuvers.

MRD-668 The SN shall provide contingency forward and return S-band link service to the PACE Observatory.

Rationale: SN required for emergency contacts due to observatory anomalies and subsequent investigations

MRD-669 The SN shall send real-time housekeeping telemetry data to the PACE mission operations center (MOC).

Rationale: Standard requirement. Delivery format is electronic using the available bandwidth from a particular ground station site.

MRD-670 The SN shall send real-time commands from the PACE mission operations center (MOC) to the PACE Observatory

Rationale: MOC needs to be compatible for the observatory data formats defined within the ICD; CCSDS formats

7.1.2.2 NEN Services

MRD-672 The Near Earth Network (NEN) shall provide scheduled forward and return S-band link service to the PACE Observatory.

Rationale: From PACE operations concept. To support launch and early orbit, nominal operations, special operations and contingency operations.

MRD-673 The Near Earth Network (NEN) shall provide scheduled return Ka-band link service from the PACE observatory.

Rationale: To support science downlink to the MOC

MRD-2053 The NEN shall provide scheduled return Ka-band link from the ground stations using a secure file transfer protocol as defined in the NEN to UMGS Interface Control Document (ICD)/PACE-GS-ICD-0037.

Rationale: PACE will baseline using a secured file transfer protocol from the ground stations to the MOC/Science Data Segment as defined in the NEN to NMGS Interface Control Document (ICD)/PACE-GS-ICD-0037.

MRD-2054 The NEN shall provide PACE science data files received via Ka-band to the PACE MOC/Science Data Segment, formatted as files, as defined in the NEN to UMGS Interface Control Document (ICD)/PACE-GS-ICD-0037.

Rationale: PACE will baseline using CFDP Class 1 for nominal science file return.

MRD-674 The NEN shall send recorded science and housekeeping telemetry data to the PACE mission operations center (MOC).

Rationale: Standard requirement. Delivery format is electronic using the available bandwidth from a particular ground station site.

MRD-675 The NEN shall send real-time housekeeping telemetry data to the PACE mission operations center (MOC).

Rationale: Standard requirement. Delivery format is electronic using the available bandwidth from a particular ground station site.

MRD-2055 The NEN shall send real-time and recorded housekeeping (S-band) telemetry from the ground stations to the MOC using standard housekeeping data protocols.

Rationale: PACE will baseline using both CFDP Class 2 and DTN BP technology for nominal HK file return.

MRD-676 The NEN shall send real-time commands from the PACE mission operations center (MOC) to the PACE Observatory

Rationale: MOC needs to be compatible for the observatory data formats defined within the ICD; CCSDS formats

MRD-677 The NEN shall provide science and housekeeping data files to the MOC as requested, to recover lost data within 7 days of original transmission.

Rationale: Required to recover from ingest errors at SDS, initial transmission errors from MOC/SDS interface, or catastrophic data losses at SDS.

7.1.3 Launch Site Interface

MRD-679 The PACE GS shall interface with the PACE Observatory on the launch vehicle at the launch site, for the purpose of receiving telemetry and sending commands.

Rationale: Best practice for mission operations systems.

7.1.4 I&T Interface

MRD-681 The PACE GS shall interface with the PACE observatory in the I&T facility, for the purpose of receiving telemetry and science data, and sending commands.

Rationale: Best practice for mission operations systems.

7.1.5 Miscellaneous Interfaces

MRD-683 The PACE GS shall utilize the GSFC Flight Dynamics Facility (FDF) for launch and early orbit activities and contingency activities as necessary

Rationale: Need to use FDF until the GPS has been activated and validated and if necessary for any special planning during ops

MRD-684 The PACE GS shall utilize the GSFC Conjunction Assessment Risk Analysis (CARA) group to ensure that the PACE spacecraft doesn't impact another object on orbit

Rationale: Conjunction assessment is required to ensure that the life of the mission is not compromised by collision with space debris

MRD-2039 The PACE GS shall interface with the Space Asset Protection Program (SAPP) for events that can be detected by the PACE observatory on-orbit that are relevant for space asset protection.

Rationale: Interface with SAPP required for threat event identification and notification between GS and SAPP.

7.2 Security Requirements

MRD-686 The PACE GS computer components shall be specified and configured to support the System and Information Integrity Family of Security Controls defined in NIST Special Publication 800-53, for a Moderate Impact IT Security Posture.

Rationale: Required for safe-guarding observatory operations. ESMO derivation from NPR 7120.5E.

7.3 GS Mission Time

MRD-690 The PACE GS shall support Space Segment time stamps that use International Atomic Time (TAI).

Rationale: Heritage FSW uses TAI

7.4 Operations Requirements

MRD-692 The PACE GS shall be able to concurrently support PACE Observatory operations during any maintenance, and test activities.

Rationale: Standard requirement common to all Mission operations systems.

MRD-693 The PACE GS shall monitor the health and maintain the safety of the PACE Observatory for mission life after launch and checkout.

Rationale: Standard requirement common to all Mission operations systems.

MRD-694 The PACE GS shall produce predicted and definitive orbit information, maintain the orbit altitude, and verify spacecraft attitude as required, for the PACE Observatory.

Rationale: Standard requirement common to all mission operations systems

MRD-695 The PACE GS shall be designed for handover to Earth Science Mission Operations (ESMO) at L+60 Days

Rationale: ESMO will be performing the operations for the mission after IOC

7.5 Ground System

MRD-697 The PACE GS shall be responsible for all command load generation, validation, and upload to the observatory

Rationale: This includes all nominal operations (science collection, lunar cal and solar cal maneuvers, downlinks, file management) and propulsive maneuvers

MRD-698 The PACE GS shall be responsible for the daily command scheduling and monitoring of the Observatory.

Rationale: GS needs to plan spacecraft bus command loads, and incorporate command loads for instruments

MRD-699 The PACE GS shall have the capability of planning and executing Observatory instrument calibration slews and maneuvers.

Rationale: Includes 2 lunar cal maneuvers per lunar cycle, and 1 solar cal maneuver per day, with a single day per lunar cycle requiring 3 solar cal maneuvers.

MRD-1976 The PACE GS shall have the capability of planning and executing Observatory Delta-V and Delta-H maneuvers.

Rationale: Propulsive maneuver planning required for post-launch orbit insertion, mission orbit maintenance, and controlled de-orbit.

MRD-700 The PACE GS shall have the capability of generating predictive acquisition data to the NEN and SN.

Rationale: Required for orbit maintenance maneuver planning, daily planning, etc

MRD-701 The GS shall receive from the Spacecraft and make available to the SDS at least 99.5% of the OCI sensor data collected from the operational instrument over the mission lifetime.

Rationale: Applied to data already stored on mass memory for OCI instrument. Requires enough scheduled Ka antenna passes to cover missed/lost ground station.

MRD-2083 The GS shall provide additional Ka-band receive from the Spacecraft and make available to the SDS at least 94% of the sensor data collected from the operational instruments over the mission lifetime.

Rationale: Applied to data already stored on mass memory for OCI, HARP2 and SPEXOne instruments. Requires enough scheduled Ka antenna passes to cover missed/lost ground station. Long term loss of a single ground station is not included in the calculations for all 3 instruments.

7.6 Ground Segment Availability

MRD-703 The PACE GS shall have an operational availability of 99% of the time for real-time observatory operations (command and telemetry functions), measured on a monthly basis.

Rationale: Ground system facilities, networks, MOC need high availability to achieve mission availability requirements and safe operation of system

MRD-704 The PACE GS shall support mission operations 24hrs/7 days, with staffing 8hrs/5 days (except federal holidays)

Rationale: Minimum staffed operations; remaining operations requires automation in GS for lights-out operations

8 PROJECT SCIENCE REQUIREMENTS

8.1 Project Science Interfaces

MRD-707 The PACE Project Science and SDS shall interface for science algorithm transfers, calibration, validation, and operations support per the PACE Project Science-to-SDS Interface Control Document.

Rationale: Provide for algorithm transfers, calibration, validation, and operations support

MRD-2096 PACE Project Science shall deliver to the OB.DAAC (via SDS) the data preservation products as outlined in Sections 3.3.1, 3.3.2, 3.3.4, 3.3.5, 3.3.6, 3.4.1, 3.6, and 3.7 of the "NASA Earth Science Data Preservation Content Specification" document published at http://earthdata.nasa.gov/about-eosdis/requirements.

Rationale: Mission data preservation requirement flowed down from PLRA.

8.2 Algorithm Requirements

MRD-2001 PACE Project Science shall provide models/algorithms to achieve the uncertainty requirements represented in Table 2.19-1.

Rationale: In order to meet the level-1 uncertainty requirements, the algorithms must meet the allocations specified.

MRD-2002 PACE Project Science shall document in Algorithm Theoretical Basis Documents (ATBDs) the science algorithms used to generate the standard science data products listed in Table 6-1.

Rationale: Provide detailed algorithm documentation for general scientific community usage

8.3 Vicarious Calibration

MRD-733 PACE Vicarious Calibration Team shall provide a Vicarious Calibration System that meets the following requirements:

a) Spectral coverage and resolution equivalent to OCI in the ultraviolet to near-infrared region,

b) NIST-traceable spectral and radiometric calibration and temporal stability to support meeting baseline ocean reflectance requirements,

c) Data collection coincident with PACE overflights, and

d) Deployment beginning pre-launch and extending through mission design life

Rationale: Vicarious calibration is critical to ensure the overall radiometric accuracy of the OCI.

8.4 Model Incorporation

MRD-723 The PACE Project Science shall provide the thermal/mechanical models of the observatory for use in the product algorithms

Rationale: Required to reduce the pointing errors due to thermal/mechanical distortions between the instruments and the spacecraft bus

8.5 Phase E Support

MRD-725 PACE Project Science shall assess data product performance over the life of the mission.

Rationale: Project Science has overall responsibility for the science operations plan.

Appendix A

The data product water-leaving reflectance uncertainties shown in Table A-1 are the minimum allocations that allow the mission to comply with the PLRA threshold science data product uncertainty requirements in Table 1. As such, these levels cannot be violated if a reduction is made to the baseline uncertainties per Table 2.19-1.

Table A-1 PACE Threshold Allocated Data Product Water-Leaving Reflectance Uncertainties.

Water-leaving reflectance*	Threshold absolute uncertainty	Threshold relative uncertainty	Baseline absolute uncertainty	Baseline relative uncertainty
$\rho_w(350)$	0.0083	30%	0.00465	20%
$\rho_w(360)$	0.0083		0.00408	
$\rho_w(385)$	0.0083		0.00314	
$\rho_w(412)$	0.0024	6%	0.00228	5%
$\rho_w(425)$	0.0024		0.00201	
$\rho_w(443)$	0.0024		0.00175	
$\rho_w(460)$	0.0024		0.00155	
$\rho_w(475)$	0.0024		0.00141	
$\rho_w(490)$	0.0024		0.00129	
$\rho_w(510)$	0.0024		0.00116	
$\rho_w(532)$	0.0024		0.00104	
$\rho_w(555)$	0.0024		0.00094	
$\rho_w(583)$	0.0024		0.00090	
$\rho_w(617)$	0.00084	12%	0.00058	10%
$\rho_w(640)$	0.00084		0.00052	
$\rho_w(655)$	0.00084		0.00046	
$\rho_w(665)$	0.00084		0.00047	
$\rho_w(678)$	0.00084		0.00045	
$\rho_w(710)$	0.00084		0.00041	
Ocean data products to be derived from the above				
Concentration of chlorophyll-a				
Fluorescence line height				
Diffuse attenuation coefficients (in the range 400-600 nm)				
Phytoplankton absorption (in the range 400-600 nm)				
Non-algal particle plus dissolved organic matter absorption (in the range 400-600 nm)				
Particle backscattering (in the range 400-600 nm)				

The top of atmosphere systematic uncertainties captured within Table A-2 are the minimum allocations that allow the mission to comply with the threshold science data product uncertainty requirements in PLRA Tables 1 and 2. As such, these levels cannot be violated if a reduction is made to the baseline uncertainties per Tables 2.19-2.

Table A-2 PACE Threshold Top of Atmosphere Radiance Systematic Uncertainty

Top of Atmosphere Radiance Systematic Uncertainty, 1-sigma, EOL															
A. Threshold Ocean Science TOA Radiance Systematic Uncertainty (Llow - Lhigh)	1.40%	0.60%	2.00%	2.00%	2.00%	5.00%	-	-	5.00%	5.00%	-	5.00%	5.00%	-	5.00%
C. Threshold Atmosphere Science TOA Radiance Systematic Uncertainty (Lhigh - Lmax)	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	-	-	5.00%	5.00%	-	5.00%	5.00%	-	5.00%
E. OCI Pre-Launch Absolute Gain Uncertainty	2.00%	2.00%	2.00%	2.00%	2.00%	5.00%	-	-	5.00%	8.00%	-	5.00%	5.00%	-	5.00%
Band	UV 350nm 400nm	VIS 400nm 710nm	NIR 748nm	NIR 820nm	NIR 865nm	NIR 940nm	-	-	NIR 1250nm	NIR 1378nm	-	SWIR 1615nm	SWIR 2130nm	-	SWIR 2260nm Cloud