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Earth System Science Pathfinder (ESSP)
Program Plan

ESSP Program Office (ESSPPO)

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1.0 PROGRAM OVERVIEW

1.1 Introduction

The Earth System Science Pathfinder (ESSP) Program is a science-driven Program designed to advance Earth science research innovatively by providing periodic opportunities to solicit, select, and implement projects, including full orbital missions, instruments as missions of opportunity, and suborbital investigations. To ensure a robust portfolio with a regular cadence of selections, project costs are capped. To this end, the ESSP objective is to ensure the success of each project within its programmatic and schedule constraints. ESSP projects support a variety of Earth science goals, by conducting science driven research concerning the atmosphere, oceans, land surface, polar ice regions, and solid Earth. ESSP projects encompass the entire life cycle from definition, through design, development, integration and test, launch or deployment, operations, science data analysis and distribution. While solicitation, evaluation, and selection of individual ESSP projects are conducted by the Earth Science Division (ESD) of the Science Mission Directorate (SMD) at NASA Headquarters, the ESSP Program is responsible for the management, direction, and implementation of the selected opportunities.

The projects within the ESSP program include: a small number of legacy orbital projects, non-competitive directed projects that are designed to meet unique needs, and the Earth Venture (EV) series of uncoupled, relatively low-to-moderate cost, small to medium-sized, competitively selected, orbital and suborbital projects that are built, tested and delivered or launched within five years of selection and initiation. Project teams may include academia, industry, Government, Federally Funded Research and Development Centers (FFRDC), and international and domestic partners. For PI-led missions, the PI identifies the project team as part of the proposal. For directed missions that are executed within the ESSP program, NASA provides the definition, composition, and organization of the project teams to the ESSP Program Office.

Minor changes to this document will be considered Class II changes and thus will not be subject to formal approval as described in ESSPPO-0003, *ESSP Configuration Control Board Charter*.

1.2 Goals and Objectives

ESSP Program goals and objectives trace to Agency needs, goals, and objectives via SMD and ESD strategic planning. The *NASA Strategic Plan 2018* specifies strategic goals for the Agency, including Strategic Goal 1: “Expand Human knowledge through new scientific discoveries.” SMD is responsible for defining, planning, and overseeing NASA’s space and Earth science programs to enable the Agency’s Strategic Objective 1.1: “Understand the Sun, Earth, solar system, and universe."

The *NASA 2014 Science Plan* details how SMD will turn NASA’s science vision into scientific discovery. NASA addresses the issues and opportunities of climate change and environmental sensitivity by answering the following key science questions through our Earth science program:

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

As explained in the *NASA 2014 Science Plan*, these science questions translate into seven overarching science goals to guide the Earth Science Division's selection of investigations and other programmatic decisions:

1. Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition (Atmospheric Composition)
2. Improve the capability to predict weather and extreme weather events (Weather)
3. Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle (Carbon Cycle and Ecosystems)
4. Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change (Water and Energy Cycle)
5. Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system (Climate Variability and Change)
6. Characterize the dynamics of Earth's surface and interior, improving the capability to assess and respond to natural hazards and extreme events (Earth Surface and Interior)
7. Further the use of Earth system science research to inform decisions and provide benefits to society

The following six Earth Science Research Program Science Focus Areas correspond to the goals identified in the *2014 NASA Science Plan*: atmospheric composition, weather, carbon cycle and ecosystems, water and energy cycle, climate variability and change, and Earth surface and interior.

The goal of the ESSP Program is to stimulate new scientific understanding of the global Earth system through the development and operation of remote-sensing instruments and orbital missions and the conduct of investigations utilizing data from these projects to address unique, specific, highly focused requirements in Earth science research.

The ESSP Program objectives to achieve this goal are to:

- Provide frequent periodic opportunities for competitively selected, PI-led projects addressing NASA's high-priority Earth system science goals
- Contain project and mission costs through commitment to, and control of, design, development, and operational costs within the risk and technical standards established by the Agency

ESSP projects pursue science investigations in one or more of the six Earth Science Research Program Science Focus Areas to address the science goals listed above. By addressing the Science Focus Areas in innovative ways, the Earth science community can understand variability, forcing, and response mechanisms from new perspectives. ESSP provides flexible opportunities to stimulate new scientific understanding by encouraging increased participation by small project teams and creativity in all aspects of project development—the implementation of which can lead to new strategies for acquiring and distributing datasets. ESSP projects also demonstrate measurement techniques for application on future Earth science operational missions.

The following ESSP Program Office objectives guide the implementation approach for the program:

- Ensure each program element (suborbital, orbital, instrument) is managed to achieve its cost, schedule, technical, and risk objectives by using the appropriate management approach.
- Ensure success by continually performing assessments of ESSP projects and applying lessons learned and best practices.
- Promote decision making based upon clearly established cost, schedule, technical, and risk parameters for each project.

1.3 Program Architecture

The ESSP Program is composed of a series of uncoupled, cost-capped, orbital, and suborbital projects that are either competitively selected or directed by ESD. These projects have independent science objectives, mission requirements, and/or technical interdependencies, and yet are integrated in the program through a common funding and management structure. The projects may provide synergistic, coincident, science measurements with other NASA projects (ESSP or non-ESSP) that enhance the overall science return.

Table 1-1 identifies the projects in the ESSP Program and their current status.

Table 1-1: ESSP Project Portfolio

Project	Date	Category/Class	Phase	Status
Orbital Missions	Launch**			
GRACE	March 2002	3/*	Phase E	Extended Operations
CALIPSO	April 2006	3/*	Phase E	Extended Operations
CloudSat	April 2006	3/*	Phase E	Extended Operations
Aquarius	June 2011	2/C	Phase F	Close Out
OCO-2	July 2014	2/C	Phase E	Operations
CYGNSS	December 2017	3/D	Phase E	Implementation
TROPICS	TBD	3/D	Phase B	Formulation
GeoCARB	TBD	3/D	Phase B	Formulation
Instrument Missions of Opportunity	Delivery to Host***			
OCO-3	May 2018	3/C	Phase C	Implementation
TEMPO	March 2018	3/C	Phase C	Implementation
ECOSTRESS	August 2019	3/D	Phase C	Implementation
GEDI	March 2019	3/C	Phase C	Implementation
MAIA	TBD	3/C	Phase B	Formulation
Sub-Orbital Investigations	Initial Deployment			
AirMOSS	August 2012	N/A	Phase F	Complete
ATTREX	September 2012	N/A	Phase F	Complete
CARVE	April 2011	N/A	Phase F	Complete
DISCOVER-AQ	July 2011	N/A	-	Complete
HS3	Aug 2012	N/A	Phase F	Complete
ACT-America	July 2016	N/A	Phase C	Implementation
Atom	July 2016	N/A	Phase C	Implementation
CORAL	September 2016	N/A	Phase C	Implementation
NAAMES	November 2015	N/A	Phase C	Implementation
OMG	March 2016	N/A	Phase C	Implementation
ORACLES	August 2016	N/A	Phase C	Implementation

*Category/class was not defined during mission implementation

**For orbital mission projects in Implementation (Phase C/D) the launch date is the Agency Baseline Commitment (ABC). For orbital projects in Formulation, the launch date is the high end of the range identified at Key Decision Point (KDP)-B.

***Instrument mission of opportunity projects shows delivery of the instrument to the host mission. ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) is an exception and uses launch as its ABC.

In addition to these projects, the ESSP Program implements special studies and activities to support ESD. Studies can pertain to areas such as mission feasibility and instrument accommodations. For example, the Common Instrument Interface (CII) activity is a sustained effort that supports the

Earth Venture Instrument (EVI) strand of the Earth Venture project series. The CII activity defines instrument-to-spacecraft interfaces to facilitate the accommodation of EVI projects on missions of opportunity and is intended to control the costs of instrument-to-spacecraft interface design and implementation.

1.3.1 Program Interfaces

The ESSP Program Office interfaces and interacts with many, varied organizations within and outside NASA to support ESSP projects. Examples of such organizations include: NASA's Launch Services Program (LSP), Space Communications and Navigation (SCaN) Program, Rapid Spacecraft Development Office (RSDO), Airborne Science Program (ASP), and the United States Air Force. The ESSP Program Office can facilitate interactions between ESSP projects and these organizations to ensure timely implementation of agreements.

The ESSP Program Manager attains programmatic authority from the ESD and therefore maintains an interface with that organization. In support of the Programmatic Technical Authority defined in Section 3.1.3, the Program Manager also interfaces with the Office of the Chief Engineer at various NASA Centers, and also with the Jet Propulsion Laboratory's (JPL's) Earth Science and Technology Directorate.

1.4 Stakeholder Definition

ESD and the Earth science community are the ESSP Program's immediate stakeholders. ESD provides the ESSP Program with its operating budget, programmatic guidelines, and scientific goals and objectives. Members of the Earth science research and applications development communities are the principal users of data resulting from ESSP projects, and they provide the intellectual guidance and rationale for the measurements and science investigations. Project data are also utilized by commercial users; federal, state, local, and international public sector users; the educational community; public media; and technology users. All NASA Earth science data is archived and distributed by the Earth Observing System Data and Information System (EOSDIS).

Stakeholder advocacy for the ESSP Program is achieved through interactions with the Earth science research and applications development communities and with the general public interested in Earth science. These interactions involve the NASA ESD, the NASA Advisory Council's (NAC) Science Advisory Committee's Earth Science and Applications Subcommittee (ESAC), Project Scientists, PIs, Advisory Committees, and non-scientific user groups.

The ESSP Program Office engages the Earth science community through formal and informal interactions. Formal interactions include the release of solicitations for proposals to work with NASA and participation in solicitation pre-proposal conferences, PI forums, project science meetings, and advisory committee meetings. Informal interactions include periodic lessons-learned workshops to solicit feedback on program processes.

Helping the public understand Earth science and the activities of ESSP is important to NASA. The Program Office engages the public by supporting invitations to speak at community educational forums, community events that include Earth science venues, and at nearby schools. The ESSP Program Office also seeks out forums in professional communities such as those conducted by the Institute of Electrical and Electronics Engineers (IEEE), the American Institute of Aeronautics and Astronautics (AIAA), and the American Geophysical Union (AGU).

1.5 Program Authority, Management Approach and Governance Structure

ESSP program management authority is delegated by the SMD Associate Administrator (AA) through ESD to the ESSP Program Manager located at Langley Research Center (LaRC). The Agency Program Management Council (APMC) is the governing PMC for the ESSP Program, while the Science Mission Directorate Program Management Council PMC (DPMC) governs the scientific and strategic management of the individual ESSP projects.

The ESSP Program follows program governance and implementation guidelines for space projects consistent with NASA Procedural Requirement (NPR) 7120.5, *NASA Space Flight Program and Project Management Requirements* and with the *SMD Management Handbook*. For suborbital projects, ESSP follows NPR 7120.8, *NASA Research and Technology Program and Project Management Requirements*. The program uses best practices and the requirements of implementing NASA centers as sources of guidance for all ESSP projects.

1.5.1 <u>Management Approach</u>

The *ESSP Program Plan* describes the authority and structure of the ESSP Program including the SMD AA through the ESSP project managers. The plan also captures the responsibilities of the ESSP Program Office and the implementation of program management responsibilities delegated to the ESSP Program Manager. Roles and responsibilities of the directorate-level positions are described in the *SMD Management Handbook*. Roles and responsibilities for the positions in the ESSP Program Office are described in the *ESSP Organizational Plan* (ESSPPO-0009, Rev. A) provided in Appendix U.

The ESSP Program management structure consists of three principal levels of authority:

- The SMD AA is the Selecting Official and the Decision Authority (DA) for ESSP projects. The SMD AA designates the ESD Director as the senior Agency official who serves as the SMD focal point for ESSP scientific and strategic management.
- ESSP program implementation is managed by the ESSP Program Manager located at LaRC. The LaRC Center Director is responsible for providing resources (facilities, infrastructure, and personnel) required to execute the program office functions. Programmatic authority is delegated from the SMD AA to the ESD Director to the ESD Associate Director for Flight Programs to the ESSP Program Manager. The Program Office oversees project implementation to ensure technical, cost, and schedule commitments are met, and advocates as appropriate for projects with ESD and SMD. The ESSP Program Manager is responsible for planning and implementing the ESSP Program consistent with top-level policies, strategies, requirements, and funding established by NASA Headquarters. The ESSP Program Manager assigns a Mission Manager (MM) to each project or investigation. ESSP Program Office MM functions as the Program Manager's day-to-day point of contact and advocate for all assigned projects. They perform technical and programmatic management functions on behalf of the Program Manager, ensuring the Program Manager maintains an awareness of the project status and that the programmatic needs of the assigned projects are being adequately addressed. The Mission Manager also coordinates with the ESD Program Executive. ESSP Program Analysts and Schedule Analysts provide analysis and expertise to the Mission Manager. The Mission Manager and Program Executive advocate for the project with stakeholders and monitor progress/issues to ensure an accurate understanding of project status.

- Management authority for each ESSP competed project resides with the PI named in the selected proposal. An ESSP PI may delegate project management responsibilities to a project manager. Management authority for non-competitive, directed ESSP projects resides with a project manager, to be appointed by the implementing institution and approved by NASA SMD. Each PI or project manager is responsible for the overall success and safety of the project and is accountable to the SMD AA for scientific success, and to the ESSP Program Manager for programmatic success. A PI's NASA Center and/or home institution provides facilities, staff, and technical expertise. For the remainder of this document, references to the responsibilities of the project manager only apply to directed ESSP projects.

To achieve an unambiguous line of direction and reporting within these levels, all formal direction from SMD to the ESSP Program flows from the ESD Director to the ESD Associate Director for Flight Programs to the ESSP Program Manager. Similarly, to ensure an unambiguous line of direction and reporting with ESSP projects, all formal direction from the Program to a project flows from the ESSP Program Manager to the PI (or project manager for ESSP directed projects).

To ensure effective day-to-day dialogue between ESD and the ESSP Program Office, and to execute responsibilities held by ESD, the ESD Director selects ESD staff members to represent SMD and ESD to the Program. ESD staff members who ensure this timely exchange include Program Executives (PE), Program Scientists (PS), Program Applied Scientists (PAS), and Program Analysts (PA). Similarly, the ESSPPO assigns staff members, including the Mission Manager (MM); Program, Planning and Control (PP&C) representative; Program Chief Engineer (CE); and Safety and Mission Assurance (SMA) representative to coordinate project activities at the program level. Together the Program Office and the ESD staff members form a team charged with managing and coordinating the entire suite of activities necessary to implement ESSP projects. This team follows established processes for communicating progress, issues, and problems regularly to the ESD management.

Each ESSP Program Venture element (Earth Venture Instrument (EVI), Earth Venture Mission (EVM), and Earth Venture Suborbital (EVS)) has a unique management approach documented in Appendix T.

1.5.2 Formulation

To date all competitively selected ESSP projects have been chosen through a single step process therefore, no down-selection or Concept Study Report has been required. As a result, the KDP-A event is the selection decision and the project proceeds into formulation phase immediately after selection. The first formal gate review is at KDP-B, after which the project continues formulation activities.

During formulation, the ESSP Program Office, working with the Technical Authority, will coordinate and document any tailoring of NASA requirements to successfully meet mission requirements. A Formulation Authorization Document (FAD) and Formulation Agreement (FA) are created to document the formulation expectations between the ESD, the ESSP Program Office and the project.

1.5.3 Implementation

For orbital mission and instrument projects, the approval to proceed into implementation marks the point at which NASA makes an external commitment regarding the cost, schedule, and performance of the mission as defined in the KDP-C Decision Memorandum (DM) and Program Level Requirements Appendix (PLRA). For sub-orbital projects, these commitments are captured in the KDP-C DM and Project Implementation Plan (PIP). The project enters the implementation phase after successfully completing a KDP-C (also known as the confirmation review).

1.5.4 Termination

The ESSP Program Office conducts regular assessments of project performance. If at any time the assessment reveals that the project is highly likely to not meet its cost, schedule and technical commitments then the Program Office may recommend that ESD organize and convene a mission Termination Review.

If the recommendation for a Termination Review is accepted, and the mission is currently in on-orbit operational phase, then the ESSP Program Office and the project will proceed in accordance with NPR 7120.5 and *Notification of Intent to Decommission or Terminate Operating Space Systems and Terminate Missions* (NASA Policy Directive (NPD) 8010.3

1.6 Implementation

Suborbital ESSP projects are managed according to NPR 7120.8, with the individual implementation approach documented in the project implementation plan during formulation.

ESSP Spaceflight projects are managed according to NPR 7120.5. Individual tailoring of NPR 7120.5 requirements will be conducted during Phase A of the project and documented in the FA and project plan.

All ESSP projects also comply with NPR 7123.1, *NASA Systems Engineering Processes and Requirements,* and the NPD 1000.5, *Policy for NASA Acquisition*.

When orbital projects are preparing to transition to Phase E (operations), the Project Plan may be revised to reflect any changes to the project (e.g., management structure, budget, reporting, etc.), as deemed appropriate by the Program Manager.

At the transition point from Phase E to Phase F, the ESSP Program will evaluate the readiness of the project to conduct closeout activities including final delivery of remaining project deliverables and safe decommissioning of space flight systems and other project assets.

2.0 PROGRAM BASELINE

Each ESSP project follows the implementation policies and practices cited in the respective Internal Task Agreement (ITA), grant, task, or contract Statement of Work (SOW); these documents are based on Center or Agency procedures, or both. The ESSP Program Office negotiates the procedures to be cited in the ITA, grant, or contract SOW and implemented with project management.

2.1 Requirements Baseline

The ESSP Program Commitment Agreement (PCA) documents Agency and SMD requirements that flow down to the program. The ESSP Program level requirements are:

1) The ESSP Program will manage and execute its project within the approved individual project cost cap.

2) ESSP projects will use a cost-effective, domestic, flight-proven Expendable Launch Vehicle (ELV), unless specifically directed otherwise by NASA. Each ESSP Announcement of

Opportunity (AO) describes the launch vehicle details or appropriate access to space. SMD provides access to space and launch vehicle funding and suborbital platforms. These funds are part of the total cost cap for each EVM project and are provided as part of the overall mission cost cap for EVI selections. Foreign launch vehicles may be utilized if contributed by the foreign organization as part of a substantive scientific partnership and on a no-exchange-of-funds basis, and if the launch vehicle meets NASA quality and reliability standards.

3) For each spaceflight project, the primary planned launch date will be within the time period specified at the time of project award, unless extended by mutual agreement of the ESSP Program Office, ESD, and the project and documented in a DM.
4) For each suborbital investigation, science objectives will determine flight operations requirements and operations completed within the timeframe specified in the solicitation, unless extended by mutual agreement of the ESSP Program Office, ESD, and the project and documented in a DM.

Due to the diversity of projects in ESSP, the performance commitments are managed at the project level. The ESSP Program is responsible for ensuring the smooth execution of the projects as they mature through the mission development life cycle. This process includes the timely execution of the annual budget development process, the careful tracking of project performance against plan, and the evaluation and assessment of the projects' performance and reporting to the ESD management.

At the initiation of each competitively selected mission or investigation, ESD will define the baseline science requirements to achieve the entire set of scientific objectives, as well as the threshold science requirements that are the requirements to achieve the minimum science below which the project will not be considered justifiable for the proposed cost. These requirements, as well as other technical parameters (e.g., orbit parameters, lifetime, and altitude), shall be documented in a project-unique Program Level Requirements Appendix (PLRA) (or PIPs for suborbital investigation projects) to the ESSP Program Plan. These requirements shall be baselined at KDP-B and updated and approved at KDP-C. These requirements are controlled by NASA SMD and can be changed only with approval of the PLRA approval signatories. Individual project plans (or PIP for suborbital investigation projects) describe how each project will meet the science and programmatic requirements of performance, cost, and schedule.

Development, distribution and archive of data products shall be in compliance with the NASA Earth Science Data and Information Policy specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/ ,

2.1.1 Project Requirements Baseline

After proposal selection for orbital and suborbital projects, project-specific programmatic requirements (commonly referred to as Level 1 Requirements) are set forth in a PLRA document for orbital projects or PIPs for suborbital investigation projects. The PLRAs and PIPs for the current projects can be found in the Appendices of this program plan. Table 2-1 identifies sources of requirements for ESSP projects typically included in the solicitation used to select the investigation.

Table 2-1: ESSP Requirements Sources

Type Requirement	Where Created	Where Documented	Applicable to	Compliance Verified By	Conduit to Performer				
					PCA	Solicitation	Contract SOW	NPD NPR	Program Plan
Program High-Level	HQ	Program Plan	Program	HQ	√	-	-	-	√
Programmatic (Level 1)	HQ	PLRA / PIP / DM	Individual Project	HQ/ Program	-	-	-	-	√
Management Process	HQ	HQ NPD/ NPG	Program	HQ	-	-	-	√	-
Management Process	HQ	HQ NPD/ NPR	All projects	Center	-	√	√	√	-
Center Management Process	Center	Center	All projects	Center	-	√	√	-	-
All requirements trace back to the NASA Strategic Plan									

The following sections specify programmatic requirements levied on all ESSP projects.

2.1.1.1 Project Science Requirements

ESSP projects will achieve their science requirements while meeting their project-specific cost cap, as specified in their PLRA or as documented in the Project Implementation Plan (for suborbitals). The PLRA documents the baseline and the threshold science requirements based on the selected proposal and according to the following definitions:

- Baseline Science Requirements - That mission which, if fully implemented, accomplishes the entire set of scientific objectives identified at the initiation of the mission.
- Threshold Science Requirements - The minimum scientific requirements below which the investigation is not considered justifiable for the proposed cost.

The PI (or project manager for directed projects) may recommend descoping the project-level science requirements from the baseline to the threshold science requirements in incremental fashion as delineated in the approved proposal. These descopes are a means for mitigating cost and schedule risks associated with cost-caps and are documented in an update to the PLRA. Projects without significant descope options during formulation and implementation may be considered at greater risk. The PLRA signatories will approve any descope that reduces the project performance below the baseline science requirements before that option is exercised.

2.1.1.2 Project Cost Requirements

All competed ESSP projects are cost-capped at a level defined in the applicable solicitation. The cost cap is established through the proposal/formulation process and formally documented in the KDP-C DM.

The cost cap will apply to the full life cycle cost for all elements needed by the investigation. The solicitation will identify whether launch vehicle costs will be included in the cost cap.

The cost cap will include all reserves held by the project. Each project is required to show a budget reserve posture at the end of phase B commensurate with the risk associated with implementation (excluding the cost of the launch vehicle). An appropriate cost reserve for Phase E is also included within the cost cap.

For directed projects, the cost requirements are established at KDP-C and documented in the DM.

Current approved NASA accounting practices will be used in developing the total cost.

2.1.1.3 Project Verification and Validation

Individual projects will verify performance of ESSP orbital, suborbital, and ground elements through a combination of analysis, inspection, demonstration, simulation, and test, with particular emphasis on incremental, integrated, and concurrent testing. For orbital mission projects, the launch vehicle supplier will be responsible for physical integration of the spacecraft with the launch vehicle and for verification of system integrity. For instrument projects, ESSPO will establish the responsibility for integration with the host platform. For suborbital investigations, the aircraft provider will be responsible for the physical integration of the payload and for verification of system integrity. The project will be responsible for the end-to-end flight/ground system performance verification, preferably by test rather than by analysis.

2.1.1.4 Project Implementation Requirements

Each project will develop a unique project plan, based on NPR 7120.5 or NPR 7120.8 as appropriate, that defines the implementation approach. Implementation requirements specific to ESSP projects are found below.

As applicable, earned value management is implemented for the Phase C and D development activities of ESSP projects, compliant with NPR 7120.5 and NPD 9501.3, *Earned Value Management.* Because of their lower total life cycle cost, earned value management is not required for EVS projects.

Each ESSP project will have an effective Safety and Mission Assurance (SMA) program as required by NPD 8700.1, *NASA Policy for Safety and Mission Success* and document it in its Project SMA Plan. Section 3.2 addresses project-level SMA requirements. Projects that reside at institutions that currently have a NASA-approved SMA program may utilize those institutional practices.

Each ESSP project will deliver science data to an ESD assigned Distributed Active Archive Centers (DAAC) for public distribution at the interval specified in the PLRA or PIP for suborbital investigation projects. All data and the standard science data products, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products shall be delivered to the designated 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/. There shall be no period of exclusive access. The source code shall be delivered to DAAC at the time of the initial data delivery. Updated source code shall be delivered to DAAC throughout the lifetime of the project as new versions of software are developed.

Science algorithms used to generate the standard science data products listed in the PLRA or PIP will be documented in Algorithm Theoretical Basis Documents (ATBDs) and delivered to the DAAC at the time of the initial data delivery. Updated ATBDs will be delivered to the DAAC throughout the lifetime of the project.

Within three months of the end of the prime mission, each ESSP project will prepare and deliver to the ESSP Program Office a final report that documents the status of the Level 1 requirements and identifies how science and technical requirements have been met by the mission.

Any new technology transfer, exchange, or partnership agreements for ESSP projects will comply with all laws and regulations regarding export control and the transfer of sensitive proprietary technologies, including the requirements of NPR 2190.1, *NASA Export Control Program* and the provisions of 22 Code of Federal Regulations (CFR) International Traffic In Arms Regulations (ITAR).

2.2 Work Breakdown Structure Baseline

The ESSP Program is uncoupled and therefore does not implement a program Work Breakdown Structure (WBS) baseline. Each ESSP project develops and implements a specific WBS structure that best fits the project's organization and mission design concept.

2.3 Schedule Baseline

The ESSP Program Office develops and maintains a master schedule (Appendix D) that provides a snapshot of the current ESSP Program and project milestones.

Each ESSP project develops and maintains its own integrated master schedule, including all critical milestones, major events, and Agency and project reviews throughout the life cycle. These schedules identify any interdependencies for the critical milestones and the critical paths and are tied to the resources required to complete each task and meet critical milestones.

2.4 Resource Baseline

Because the ESSP Program consists of independent, uncoupled projects that are primarily the result of a competitive selection process, program resource and workforce levels vary as projects end and new projects are selected. The schedule for existing projects is contained in Appendix D and the schedule of future projects is contained in Appendix Q. Table E-1 in Appendix E contains the ESSP Program budget as presented in the President's Budget request. Appendix E also provides the Program Office workforce plan that supports fulfillment of the program. Each ESSP project is responsible for the development of its own PPBE budget request. The ESSP Program Office conducts PPBE budget reviews with each project to ensure that the budget request is aligned with the remaining scope and the ESD guidance.

LaRC provides facility, administrative, and technical infrastructure to support the ESSP Program Office. Individual projects are provided with facility, administrative, and technical infrastructure by the NASA Center or institution that serves as their host. Infrastructure requirements for acquisition, real property/facilities, aircraft, personal property, and information technology (IT) are fulfilled from existing capabilities.

2.5 Joint Cost and Schedule Confidence Level

Because ESSP is an uncoupled program, program-level Joint Cost and Schedule Confidence Level (JCL) analysis and budgeting is not performed. ESSP projects with total life cycle cost (LCC) of greater than $250M perform a JCL analysis that is used to formulate Agency internal and external financial commitments. Projects with LCC less than $250M must perform an integrated cost and schedule confidence assessment using an approach that is defined by the project and coordinated with the ESSP Program Office and the ESD.

3.0 PROGRAM CONTROL PLAN

3.1 Technical, Schedule, and Cost Control Plan

Once an ESSP project is approved to enter formulation, the ESSP Program Office engages in frequent formal and informal communication with the project to ensure continued compliance with ESSP Program requirements; timely identification of issues or areas of technical, schedule, or cost risk; and the application of appropriate mitigation or recovery activities.

The PLRA (or PIP for suborbital investigation projects) documents ESSP program-level requirements specific to each project such as science requirements, mission success criteria, launch requirements, and data requirements. Cost and schedule requirements, consistent with the proposal, are documented in the KDP-C Decision Memo.

The PI/Implementing Organization develops a unique project plan (or PIP for suborbital investigation projects) for each ESSP project that tailors NASA/institutional processes, as appropriate, and defines the implementation approach. The Program Manager approves each project plan (or PIP for suborbital investigation projects).

3.1.1 Program Office Roles to Control Technical, Schedule and Cost

The ESSP Program Mission Manager is the primary Control Technical, Schedule and Cost point of contact for insight into the technical, schedule, and cost status of each ESSP project. Through regular formal and informal communication with the Principal Investigator/Project Manager, the MM maintains cognizance of the project performance against the project Integrated Master Schedule (IMS), cost cap, and performance requirements, as well as any emerging risks. The Program Office regularly reviews the status and projected ability of each project to meet its approved PLRA (or PIP for suborbital investigation projects). The project plan documents the reporting and management processes. The MM obtains project status updates via the project's existing institutional processes and reviews (e.g., project's monthly and quarterly management status reviews), available EVM data for projects in Phase C/D development, and weekly teleconferences. This practice allows the MM to maintain cognizance of the project's performance while minimizing the impact on the project.

The ESSP Program Planning & Control Group supports the MM to analyze and evaluate project performance. For additional insight and support, the MM collaborates with the ESD PE and PS, the ESSP Chief Engineer (CE), and SMA Lead. The ESSP MM may obtain expertise from NASA, academia, or industry to gain additional risk-based insight into a particular area for a project. The Program Office risk-based assessment of ESSP projects will occur throughout the project life cycle.

3.1.2 Approach to Control Technical, Schedule, and Cost

The ESSP schedule includes program milestones for the projects. Monthly schedule status reviews are held to monitor the ESSP Master Schedule and track schedule performance. The ESSP Program Office and ESD are responsible for coordination of project schedule milestones, such as KDPs and launch dates, with the appropriate NASA organizations. While the program office recommends changes to the project's level 1 schedule milestones, the SMD AA approves the changes.

The project is evaluated for performance against the project IMS monthly and at scheduled life cycle reviews or special reviews as requested by the program or SMD. The evaluation includes a detailed assessment of project schedules for overall implementation strategy and credibility, project budgets through prime mission operations and data analysis, and the approach for contractor/subcontractor management and coordination. ESSP makes recommendations to projects regarding the use of schedule margin as well as corrective actions, based on the program office analysis and assessments.

ESSP project budgets are initially estimated in the acquisition process as part of the original project proposal (or KDP-A for directed projects). The total cost to NASA for all phases of an ESSP project, including the definition, development, launch service, mission operations (including communications costs) and data analysis, and reserves is included in the project budget. Independent cost estimates and/or independent review boards may be used to verify estimates provided by the implementing organization at the discretion of the ESSP Program Manager. Each ESSP project is required to document its budget Basis of Estimate (BoE).

Each orbital mission or instrument project is required to show a budget reserve posture at the end of phase B, commensurate with the risk associated with the implementation of the mission. Typically, the reserve should be no less than 25% of cost-to-go for costs through the end of Phase D (excluding the cost of the launch vehicle). An appropriate cost reserve for Phase E must be included. The PI and project manager have full discretion in applying the cost reserve in a given fiscal year within the approved project budget. Additional cost reserves may be held at ESD and not at the ESSP program level. The ESSP Program Office recommends the disposition of any SMD held Unallocated Future Expenses (UFE) to ESD. Program office analyses and assessments support recommendations to ESD and projects regarding the use of reserves, as well as corrective actions. Cost control will incorporate monthly tracking metrics such as reserve status, liens and encumbrances, reserve percentage of cost-to-go, obligations and commitments—plan versus actual, and labor—plan versus actual.

SMD does not require ESSP to implement program-level EVM. The ESSP projects will implement EVM for phase C/D scope, as required per NPR 7120.5, with the exception of the Earth Venture Suborbital investigations.

Table 3-1 lists the weekly, monthly, and quarterly reporting activities.

Table 3-1: ESSP Program Office Reporting

Report/Activity	Content	Customer	Frequency	Format
Program Office Status Review	Program/Projects Status. Recent Events. Near-term activities. Technical, schedule, cost, and risk assessment review	ESSP Program Manager	Monthly	Presentation, face-to-face meeting and telecon
CMC Monthly Review	Program/Projects Status	LaRC Center Director and CMC	Quarterly	Face-to-face meeting with presentation
Program Office Staff Meeting	Program Office updates, highlights and actions	Internal to ESSP Program Office	Weekly	Meeting with agenda, notes
Program Weekly Tag-Up	Program/Projects Status (technical, schedule, cost and risk)	ESD	Weekly	Teleconference
Flight Projects Review	Program/Projects Status (technical, schedule, cost and risk)	ESD	Quarterly	Presentation, face-to-face meeting and telecon
Project Status Report	Technical, cost, schedule and risk	ESSP Program Office, SMD, Center	Monthly	Written report & presentation
Project Weekly Report	Accomplishments for Week	ESSP Program Office, PE	Weekly	Written report
Project Tag-Up	Project issues and status (technical, schedule, cost and risk)	ESSP MM, PE	Weekly	Teleconference

3.1.3 Technical Excellence and Technical Authority Implementation

3.1.3.1 Technical Excellence

ESSP technical excellence integrates the program, project, engineering, and SMA personnel and emphasizes cooperation and shared ownership regarding mission success. The ESSP Program Office facilitates technical excellence for a wide range of issues, which vary in complexity. For less complex issues, the ESSP Program Chief Engineer (CE) may leverage subject matter experts (SME) at LaRC or other centers and arrange for the SMEs to be available to the program and projects. For more complex issues, the Program CE may participate directly in tiger teams or may identify expertise for inclusion in the tiger team.

ESSP projects typically have a Chief Engineer who serves as the Technical Authority for the project. The ESSP Program CE leverages project CE capabilities to maintain a cognizance of the technical excellence activities within a project and exercise technical authority as appropriate. For projects implemented at non-NASA institutions, the Program CE or the civil servant assigned by LaRC to serve as the NASA project CE retains technical authority while working closely with the project engineering organization to delegate an appropriate level of insight responsibility to the non-NASA center’s engineering authority. The Program SMA technical authority serves as the SMA technical authority for projects implemented at non-NASA institutions. Any issues that are identified are resolved at the lowest appropriate level of authority.

In the case where a center or JPL has established an office that coordinates multiple project activities, the ESSP Program CE would also maintain cognizance and exercise technical authority through that organization's CE in addition to the project CE. The ESSP Program CE collaborates and coordinates with the respective CEs to ensure program office perspectives are communicated across the ESSP projects and supports the elevation of technical authority issues from a program perspective.

3.1.3.2 Technical Authority

A clear separation of programmatic and technical authority is maintained for the ESSP Program; each designated technical authority (TA) is organizationally and financially independent from the ESSP programmatic path of authority. The engineering and SMA technical authorities for the ESSP Program are matrixed from and report directly to the LaRC Engineering (Figure 3-1) and SMA Directorates (Figure 3-2), respectively. The ESSP Program leverages and interfaces with the existing Health and Medical Authority established at the center that hosts each project as necessary.

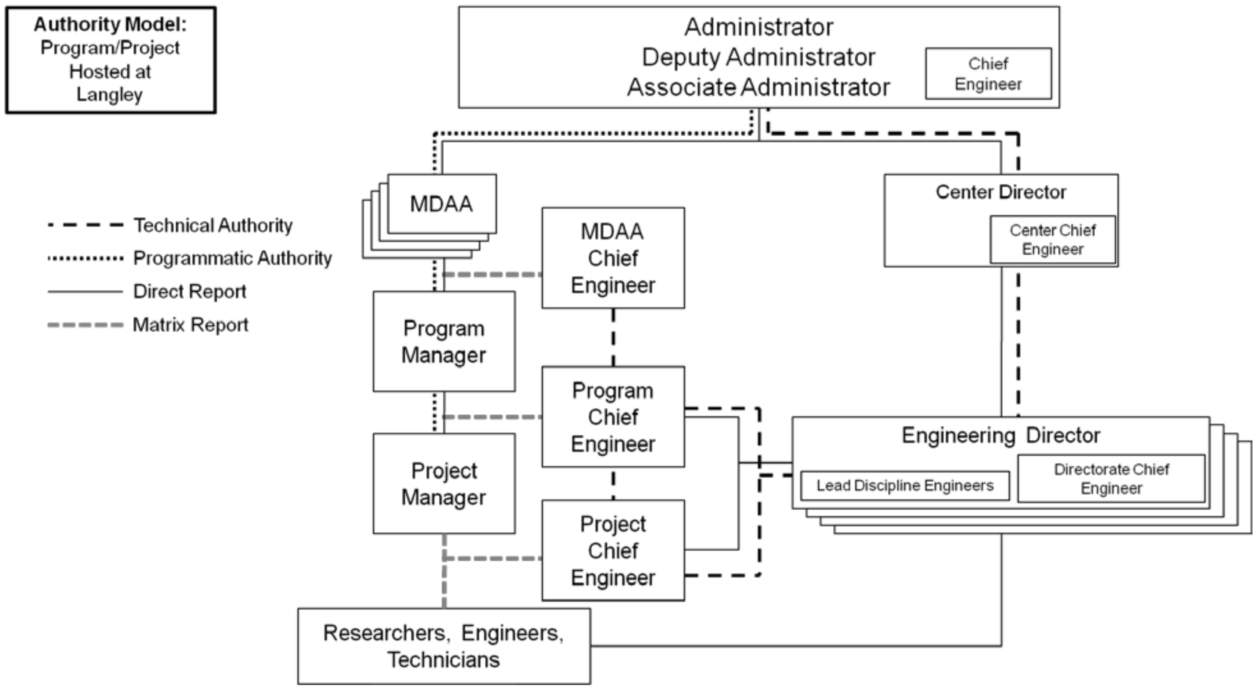


Figure 3-1: Flow of Engineering Technical Authority

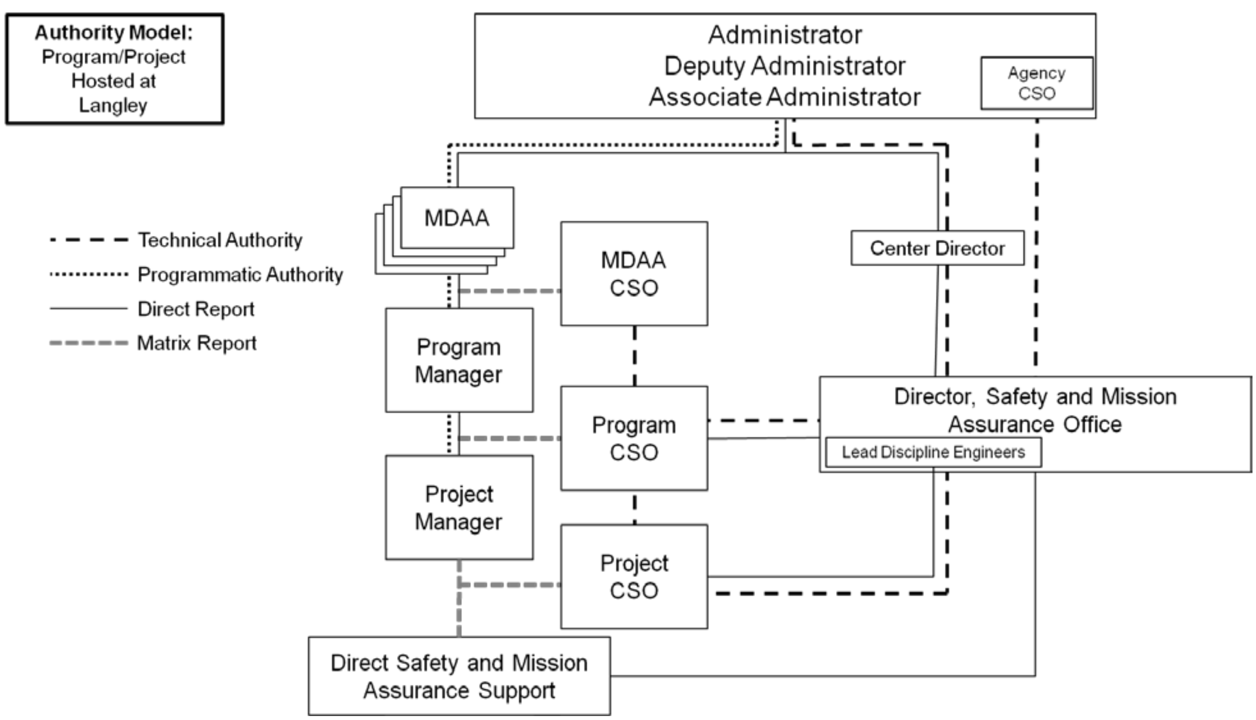


Figure 3-2: Flow of SMA Technical Authority

3.1.3.3 Tailoring, Waivers, Deviations, and Dissenting Opinions

The methods the ESSP program and orbital mission and instrument projects use for tailoring, waivers, deviations, and dissenting opinions adhere to the processes, forms, and authorities explicitly prescribed in NPD 7120.4, *NASA Engineering and Program/Project Management Policy*, NPR 7120.5, NPR 7123.1, and applicable center policies and procedures. ESSP suborbital project tailoring, waivers, deviations, and dissenting opinions adhere to the processes, forms, and authorities explicitly prescribed in NPD 7120.4, NPR 7120.8, NPR 7123.1, and applicable center policies and procedures. Tailoring of the implementation of NASA policies is approved in the Formulation Agreement. Projects develop necessary waivers in coordination with the ESSP Program Office. The Program Office ensures waivers are compliant with task agreements and programmatic guidelines, and coordinates with SMD to forward waiver requests through responsible authorities. Waivers against center practices do not require directorate approval. Waivers against NPDs and NPRs are advanced by the ESD and the directorate.

3.1.4 Performance Measures

The ESSP Program Office assesses its program performance in two ways: quarterly against the objectives set out in section 1.2 of this plan and periodically through the conduct of Program Implementation Reviews (PIR).

The ESSP Program assesses the relevant project performance at key points during project execution. The basis of assessment is documented in the PLRA (or PIP for suborbital investigation projects). The requirements are objective, quantifiable, and measurable, and traceable to the ESSP Program's four Key Performance Parameters

1) Approval for projects to proceed to implementation phase at KDP-C.
2) Achievement of the threshold science performance criteria as established in the PLRA (or PIP for suborbital investigation projects) for each operating spaceflight mission.
3) Delivery of mission science data, meeting latency and performance objectives for each approved science data system during primary mission phase.
4) Definition and implementation of project management practices tailored appropriately to the individual projects, and employment of a continuous improvements process to update and refine the best practices.

The project's PLRA (or PIP for suborbital investigation projects) documents the science requirements, mission and spacecraft performance, launch requirements, ground system requirements, mission requirements, and cost management. If at any time during implementation of an ESSP project, the estimated cost-at-complete exceeds the firm mission cost cap, the project is subject to a termination review. For specific project performance measures, refer to the project PLRA in the appendices.

3.2 ESSP Safety and Mission Assurance Plan

The Program Office ensures that ESSP projects implement thorough and robust SMA activities commensurate with the payload classification and/or risk classification. The goal of these SMA activities is to help ensure investigation success by applying NASA policies and procedures for safety, reliability, software assurance and quality assurance. Table 3-2 lists the governing documents from which project SMA Requirements are derived and the ESSP Program Office's role in implementing these requirements. Since all SMA activities are implemented at the project level, a program SMA plan is not required.

The Program Office assesses the projects' efforts to ensure that the Mission Assurance program being implemented is valid, complete, and effective. The focus of the program's assessment will be the degree to which investigation success is enhanced by processes such as redundancy, management, configuration management, reliability analysis, fault protections, etc. The ESSP Program Office will ensure project compliance with SMA requirements by reviewing SMA plans that are stipulated in the solicitations (or project SMA documentation for directed projects), and by participating at project reviews. Participation at milestone reviews includes compliance checking on SMA deliverables and activities commensurate with the milestone being reviewed.

The SMA requirements are based on a project SMA life cycle process perspective. Specific SMA disciplines are applied to each project life cycle phase through application of the Agency SMA requirements. These applicable Agency documents, shown in Table 3-2, allow for tailoring processes and requirements based on the payload classifications and risk considerations.

Table 3-2: Critical SMA Disciplines

Discipline	Document No.	Document Title
Safety	NPR 8715.3	*NASA General Safety Program Requirements*
Quality Assurance	NPD 8730.5	*NASA Quality Assurance Program Policy*
	NPR 8735.2	*Management of Government Quality Assurance Functions for NASA Contracts*
Compliance Verification, Audit, SMA Reviews, and SMA Process Maps	NPR 8705.6	*Safety and Mission Assurance Audits, Reviews, and Assessments*
Reliability and Maintainability	NPD 8720.1	*NASA Reliability and Maintainability (R&M) Program Policy*
Software Safety and Assurance	NASA-STD-8719.13	*NASA Software Safety Standard*
	NASA-STD-8739.8	*NASA Software Assurance Standard*

To ensure compliance with all Occupational Safety and Health Administration (OSHA) and NASA SMA requirements, ESSP projects are required to plan and implement a comprehensive mission assurance program early in the formulation stage for all flight and ground hardware, software, Ground Support Equipment (GSE), and mission operations. This responsibility extends to all partners, prime contractors, subcontractors, and suppliers. Since ESSP is not a tightly coupled or a single-project program, a Closed Loop Problem Reporting and Resolution System is not required. Projects will utilize Problem Reporting, Analysis, and Corrective Action (PRACA) systems as prescribed by the implementing Center's requirements. For projects not completed at a NASA Center, equivalent practices will be allowed and documented in the project plan. The ESSP Program Office reviews PRACA systems for anomalies and non-conformances that have potential for causing similar issues on other ESSP projects.

For ESSP projects that involve aircraft, an independent Airworthiness Safety Review will be conducted for all aspects of the flight project, including mission operations, as specified by the aircraft host Center processes. Range Safety Review processes or Airworthiness Safety Reviews from organizations outside of NASA may be utilized if the sponsoring NASA Center approves such reviews. Requirements for an aviation safety program for each respective flight activity are set forth in NPR 7900.3, *Aircraft Operations Management*.

NPR 8715.6, *NASA Procedural Requirements for Limiting Orbital Debris* requires routine conjunction assessments for all NASA orbital assets with maneuvering capability. The project management staff for each operational orbital payload will establish tasks and appropriate lines of communication with the Conjunction Assessment Risk Analysis (CARA) Program, located at Goddard Spaceflight Center (GSFC), to meet this policy requirement and to communicate any indicated risks. Final plans, including demonstrations, should be implemented at least three months prior to launch. A foreign partner providing operational services must sign a standard Conjunction Assessment Risk Analysis (CARA) Non-Disclosure Agreement (NDA).

3.3 Risk Management Plan

NPR 8000.4, *Agency Risk Management Procedural Requirements* requires the ESSP Program Office and each ESSP project to implement Continuous Risk Management (CRM) to perform Risk-Informed Decision Making (RIDM). Each ESSP orbital project is required to develop a stand-alone Risk Management Plan (RMP). Suborbital projects (EVS-1, 2, etc.) are not required to have a RMP, but will capture their risk management approach in their project plans. Project managers are expected to elevate to the ESSP Program Office those risks that have the potential to impact program milestones or that require additional technical or programmatic resources beyond those available at the project level.

The RMP for each ESSP project will conform to NASA risk management requirements for all phases of the project life cycle. Projects may use their choice of risk management tools, provided these are consistent with the risk scoring, reporting, and format in NPR 8000.4. Each ESSP project will identify risk areas encountered while executing requirements management, design and development, integration, and test activities under the constraints allocated by project level 1 requirements as documented in the corresponding PLRA (or PIP for suborbital investigation projects). Additional risk management guidance may be found in the *NASA Risk Management Handbook* (NASA/SP-2011-3422)

Oversight and reporting is established to detect unmanageable risks that might threaten program or project baseline milestones, failures to meet KPPs or level 1 requirements, and dangerous trends that might threaten project success.

The ESSP Risk Management Board (RMB) addresses and mitigates program-owned risks.

The ESSP-0008, *ESSP Program Risk Management Plan* details the Program's risk management approach.

The ESSP Program Office also participates in the ESD Flight Program Risk Board.

In general, the ESSP Program Office:

- Identifies and tracks program-owned risks
- Assesses significant project-owned risks through ESSP management processes
- Identifies project-owned risks that need to be elevated to the program Risk Management Board
- Identifies risks that need to be elevated to the ESD Flight Program Risk Board.
- Searches for crosscutting programmatic risk areas that impact multiple ESSP projects

The results of these activities form the basis for an overall implementation of RIDM at all levels of the ESSP organization. CRM at the program level includes RIDM recommendations to NASA Headquarters.

3.4 Acquisition Plan

The ESSP Program acquisition strategy for constituent competed projects is to release open and competitive solicitations on a regular and frequent cadence. The program conducts a peer review of the science, technical, management, and cost elements of a proposal to select projects for award.

Solicitation development, proposal evaluation, and PI/investigation selection are the responsibility of SMD and are carried out to meet the requirements of the Federal Acquisition Regulation (FAR) and the NASA FAR Supplement (NFS). The ESSP Program Office, at the request of NASA Headquarters or the Science Office for Mission Assurance (SOMA), assists with the definition of the scope and strategy for the draft solicitation to ensure program requirements and lessons learned are incorporated.

For directed projects, NASA SMD will establish an acquisition strategy in Phase A. This will be documented in the Formulation Authorization Document, Formulation Agreement, and Project Plan.

3.5 Technology Development Plan

The ESSP Program and its constituent projects are designed to use mature technology at Technology Readiness Level (TRL) 6 or higher. A program Technology Development Plan is not required, because no hardware or software is developed. ESSP projects are strongly encouraged to utilize mature and low-risk technologies. These technologies are typically matured through other technology development programs (e.g. Earth Science Technology Office's [ESTO] Instrument Incubator Program [IIP]), to reduce program and project risks.

3.6 Systems Engineering Management Plan

The ESSP Program does not perform program system design and product realization processes, but does oversee the project performance of these functions. As a result, no Systems Engineering Management Plan (SEMP) is required at the program level. The ESSP Program Office ensures each project implements a SEMP that is consistent with the payload classification and/or risk classification of the project.

3.7 Product Data and Life-Cycle Management Plan

The ESSP Program is not a tightly coupled or a single-project program therefore NPR 7120.9 does not apply.

3.8 Verification and Validation Plan

The ESSP Program is not a tightly coupled or a single-project program therefore NPR 7123.1 does not apply at the Program level.

3.9 Information Technology Plan

3.9.1 <u>Knowledge Capture</u>

The ESSP Program captures knowledge by documenting lessons learned and best practices and socializing tacit knowledge throughout the entire Program. Program processes are developed and shared to ensure efficient office operations. Papers published by the ESSP program office comply with NPD 2200.1, *Management of NASA Scientific and Technical Information* and NPR 2200.2, *Requirements for Documentation, Approval and Dissemination of NASA Scientific and Technical Information*.

3.9.2 Electronic Library

An electronic document library provides the ESSP Program Office an interactive way to collaborate, view, and archive information in a secure manner. The ESSP Program Office Configuration/Data Manager maintains an electronic document library and data integrity is managed through access control.

The ESSP Program Office utilizes a document library (known as Windchill) that operates behind the NASA firewall for internal and business-related documentation and is designated as the official record repository for ESSP. Windchill is a secure system and complies with *NPR 1600.1, NASA Security Program Procedural Requirements* and NPR 2830.1, *NASA Enterprise Architecture Procedures.*

3.9.3 Information Technology

Sensitive but unclassified (SBU) documents will be marked in accordance to *NPR 1600.1, NASA Security Program Procedural Requirements.* Documents designated as SBU are the responsibility of the document owner. SBU documents uploaded to Windchill will be clearly marked and the appropriate metadata tags will be applied.

Requirements and processes for identification/definition, preparation, control, and disposition (storage, access, and records) of ESSP Program data and defined in *ESSPPO-0002, ESSP Program Configuration and Data Management Plan*.

3.10 Review Plan

The ESSP Program and its projects participate in periodic reviews throughout their life cycles to assess performance and decide on continuation.

3.10.1 Program Reviews

At the program level, a Standing Review Board (SRB) conducts an independent Program Implementation Review approximately every two years to validate the program’s conformance to the terms of the program requirements. The Conflict of Interest (COI) procedures detailed in the *NASA Standing Review Board Handbook* will be strictly adhered to. The Terms of Reference (ToR) established by the convening authorities for the review include gate products, success criteria, special assessments to be performed, and reporting of results. Because the ESSP Program is uncoupled and in its implementation phase, other typical life cycle reviews (Preliminary Design Review (PDR), Critical Design Review (CDR), etc.) are not applicable.

3.10.2 Project Reviews

Each project’s review plan is based on NPD 7120.4 and NPRs 7120.5, 7120.8 and 7123.1. The ESSP Program Office will provide ESD with recommendations regarding selection of the review chair and team members. The convening authorities will approve the chair and review team members.

A ToR establishes reporting requirements for each project life cycle review (LCR).

For all LCRs, the project manager, review board chair, ESSP Program Manager, an SMD designee, and a center director designee (for the project lead center) review project readiness for entry to the life cycle review 30-90 days prior to that review.

Within 3 business days of the LCR, the review chair submits a quicklook report to the convening authorities and other key stakeholders to provide an assessment of the degree to which the success criteria were met and any outstanding critical deficiencies. A detailed summary of the review board's findings from the LCR is provided at the subsequent KDP.

At a minimum, orbital missions and instruments in Phase E must plan for the following formal reviews: Post-Launch Assessment Review (PLAR), bi-annual Senior Reviews, End of Prime Mission Review (EPMR), and Decommissioning Review (DR).

3.11 Mission Operations Plan

The ESSP Program does not require a Mission Operations Plan.

ESSP operations occur only at the project level, and each ESSP mission operates independently. Technical management processes are directed towards the successful operation of each independent project.

ESSP missions operating within the Morning or Afternoon Constellations must ensure that the spacecraft can move safely out of the constellation when desired or required. Performing this operation requires that the mission follow the Constellation Contingency Procedures and the Constellation Operations Coordination Plan.

3.12 Environmental Management Plan

An ESSP Program Environmental Management Plan is not required since the National Environmental Policy Act (NEPA) checklist indicates that the ESSP Program Office performs no activities with potential environmental impact.

ESSP projects will prepare standalone Environmental Management Plans to comply with NPR 8580.1, *NASA National Environmental Policy Management Requirements* if activities indicate potential environmental impact. The program office assesses project activities associated with NPR 8580.1 and inserts any critical milestones associated with complying with NEPA regulations into the program schedule.

3.13 Integrated Logistics Support Plan

A Logistics Plan for the ESSP Program is not required.

Development and operations occur only at the project level, and each ESSP project operates independently.

Integrated logistics management supporting development and operations activities is planned and executed at the project level. The program office assesses scope and content of project-developed logistics plans, metrics, and reports for adequacy and conformance with policy directives. At a minimum, logistics planning is assessed at formal milestone reviews.

Each ESSP project will summarize its logistics plan in its project plan. If a standalone logistics plan is required because of the detail and volume of material in the plan, it will comply with NPD 7500.1, *Program and Project Life-Cycle Logistics Support Policy*.

3.14 Science Data Management Plan

A Science Data Management Plan (SDMP) for the ESSP Program is not required.

Each ESSP project is responsible for all science-related aspects throughout the project life cycle. Each ESSP project develops a preliminary SDMP and delivers it to the Earth Science Data Systems PE and the PS in time to permit review before KDP-C. The project updates the SDMP and delivers it to the Earth Science Data Systems PE and the PS in time for baselining before the Operations Readiness Review. The plan should describe the tasks, staffing, schedules, software testing, and software development (algorithms) required prior to beginning operations, as well as data products development required after beginning operations. Typically, the SDMP is a standalone control plan, which is summarized in the project plan, and addresses the approach for creating and releasing scientific and technical information (STI) publications.

3.14.1 Policies

The SDMP shows how a project plans to implement NASA policies regarding scientific openness, data-sharing, and timely dissemination of results, while preventing inappropriate release of SBU, proprietary, or export-controlled data.

The ESSP Program and its projects comply with the NASA Earth Science Data and Information Policies, and Mission Data System Requirements, which can be accessed via http://science.nasa.gov/earth-science/earth-science-data.

ESSP projects are required to make use of the approved data system standards that apply to their science data systems and products. A common set of definitions and nomenclature to assist in complying with the NASA Data and Information Policy is available on the following website: https://earthdata.nasa.gov/user-resources/standards-and-reference.

3.14.2 Science Data Processing Software Development

All project software developed for or by NASA, including software for science data processing, reduction, inversion, and visualization, must comply with the Software Engineering (SWE) Requirements deemed applicable for that specific software effort. For projects led by a NASA center, NPR 7150.2 applies to science data processing software development regardless of whether it is governed by NPR 7120.5, NPR 7120.8, or another project management procedure. Section 3.10 of this program plan details how the ESSP Program Office will assess its projects' software development performance.

3.14.3 Science Data vs. Information

The SDMP addresses processes and plans for two distinct classes of science data: "Science Data" and "Information." The distinction is important, because the two classes are governed by different Agency documents and are archived separately by distinct organizations. However, note that the term "data" is often used collectively to refer to both classes. In fact, the Data & Information Policy defines science data in the following manner:

> Science Data include raw and processed data sets that represent collections of measurements made by science instruments. These may be raw data counts, or values that have undergone calibration, geographical registration, or conversion to engineering units. Also included are higher level Science Data Products (SDPs) derived from the measurement data. This class includes the software, its documentation, and the ancillary, engineering, and other data required to recreate the various products, locate and subset data, read the files, and visualize

and understand their contents. Science Data includes artifacts that would be submitted to a NASA DAAC.

Information is referred to by the Agency as "STI", which has a precise meaning:

"the results (the analyses of data and facts and resulting conclusions) of basic and applied scientific, technical, and related engineering research and development."

STI includes the scientific results that are published in peer-reviewed journals or released to public media and is governed by NPD 2200.1, *Management of NASA Scientific and Technical Information* and by NPR 2200.2, *Requirements for Documentation, Approval, and Dissemination of NASA Scientific and Technical Information***.** All STI is archived in the NASA Aeronautics and Space Database. The subset of STI that is not restricted or limited in any way is released to the general public via the NASA Technical Reports Server.

3.15 Configuration Management Plan

Requirements and processes for identification/definition, preparation, control, and disposition (storage, access, and records) of non-scientific ESSP Program data are defined in ESSPPO-0002, *ESSP Program Configuration and Data Management Plan* (). Change control for the ESSP Program and project documentation is consistent with NASA change control policies and procedures to enable visibility into all interactions and interdependencies within the program.

ESSP projects will manage all non-scientific data, including IT assets, in a cost-effective manner that ensures an appropriate level of integrity, confidentiality, and availability of information. They will follow Agency and center policies, procedures, and requirements to protect NASA information and IT systems in a manner that is commensurate with the sensitivity, value, and criticality of the information.

3.16 Security Plan

The ESSP Program Office implements plans to address security, technology protection, and emergency response requirements.

3.16.1 Security Requirements

The ESSP Program is committed to a safe and secure work environment and to ensuring that: property is protected from vandalism, illegal intrusion, theft, and fire; personnel are protected from injury; appropriate investigations are carried out; and findings are coordinated with designated management and law enforcement organizations. The ESSP Program Office adheres to NPR 1600.1, *NASA Security Program Procedural Requirements* and NPD 1600.2, *NASA Security Policy* and works with the LaRC Center Chief of Security (CCS) to verify adequacy of security implementation.

While the ESSP Program Office does not store classified national security information (CNSI), it does handle SBU materials. As part of its information security implementation, the ESSP Program Office also follows Langley Procedural Requirement (LPR) 1620.1, *Information Security Program Management Procedures and Guidelines* in designating, identifying, marking, controlling, storing, accessing, disclosing, protecting, transmitting, and destroying SBU information when no longer needed.

Industrial security pertains to contracts, grants, cooperative agreements, and other binding transactions in which performance will require access to CNSI by the contractor, supplier, grantee, or its employees. The ESSP Program Office has no industrial security interfaces.

3.16.2 Information Technology Security Requirements

The ESSP Program adheres to NPR 2810.1, *Security of Information Technology* and complies with the IT practices of NPD 2810.1, *NASA Information Security Policy*. ESSP projects will develop IT Security Plans, as required.

3.16.3 Emergency Response Requirements

The ESSP Program Office has no NASA Mission-Essential Infrastructure (MEI). Therefore, Emergency Response is limited to program documentation/information and personnel. All mission-essential program documentation/information is maintained electronically on the ESSP electronic repository, a central server that is backed up periodically and retained in accordance with *NASA Record Retention Schedules* (NRRS 1441.1). Procedures for weather- or facility-related emergencies are announced by LaRC. For other types of emergencies, the ESSP Program Office follows the emergency policies and directives of LaRC. After normal duty hours, emergency instructions are provided through the news media. All emergency response processes and procedures are implemented in accordance with NASA emergency policies and requirements, including NPR 1040.1, *NASA Continuity of Operations Planning (COOP) Procedural Requirements*, LPR 1046.1, *NASA Langley Research Center Emergency Plan* , and LPR 1040.3, *Continuity of Operations (COOP) Plan*.

3.17 Threat Summary

The ESSP Program follows Agency and SMD policy for threat assessments in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements. Each individual project in the program portfolio coordinates with Agency threat assessment representatives to determine the threat environment and the need for a Project Protection Plan.

3.18 Technology Transfer Control Plan

An ESSP Export Control Plan is not required because all export control activity occurs within individual ESSP projects.

Each ESSP project implements an export control process compliant with the requirements of NPR 2190.1. For competed projects, requirement compliance is flowed to the projects through the solicitation process. During the solicitation process, proposers are required to disclose and discuss any international participation, either through involvement of non-U.S. nationals and/or involvement of non-U.S. entities. The ESSP Program Office regularly monitors and reviews this activity at the project level to ensure its compliance with the NPR 2190.1.

3.19 Education Plan

When required through an AO, the ESSP Program ensures its constituent projects meet Agency goals as defined in the NASA 2018 Strategic Plan to engage with the public, educators, and students to provide opportunities to participate in our mission, foster innovation, and contribute to a strong national economy. ESSP Program and project education efforts are aimed at raising public awareness and fostering collaboration between the program and the projects to increase the impact of project activities.

3.20 Communications Plan

Effective communication is an important element to program success. The ESSP Program is committed to ensuring that ESSP projects communicate effectively with stakeholders, the public, and with other NASA teams.

Each ESSP project will describe their communication plan in the project plan or a standalone document. The focus of a project's communication plan is to raise awareness of, and interest in, NASA, Agency goals, missions and programs and to develop an appreciation for, exposure to, or involvement in, STEM or STEM studies and careers. The communication plan must reflect SMD's communication practices and align with Agency strategies.

3.21 Knowledge Management Plan

The ESSP Program Office takes a "Pause and Learn" approach to knowledge management by gathering lessons learned after major events such as reviews and solicitations. The ESSP Configuration/Data Manager captures the ESSP Program Office's lessons learned using requirements established by NPD 7120.4 and as described in NPR 7120.6, *Knowledge Policy on Programs and Projects*.

The ESSP Program Office conducts forums, workshops, and project reviews to share knowledge. Mission Managers disseminate the captured knowledge to each project through day-to-day meetings and reviews, as well as special lessons-learned discussions at the start of each development phase

ESSP's lessons learned are documented and maintained on Windchill.

3.22 Human Rating Certification Package (HRCP)

For ESSP projects manifested on ISS or other human-rated spacecraft, the project will develop an HRCP, as necessary.

4.0 WAIVERS AND DEVIATIONS LOG

The ESSP Program waiver log, located in Table 4-1, is consistent with the requirements of NPR 7120.5.

An ESSP project documents its waivers in its project plan. The ESSP Program Office reviews these waivers and approves them on a case-by-case basis.

Waiver/ Deviation Number	Project	Date submitted	Submitted By	Waiver/ Deviation Description; NPR 7120.5 Requirement Waived	Action Taken	Date of Action

Table 4-1: Waivers and Deviations Log

5.0 CHANGE LOG

The ESSP Program Manager monitors NASA policies, directives, and requirements for changes affecting the ESSP Program. Updates required for key top-level program or project documentation are identified immediately, and generally included in annual updates. Table 5-1 documents Program Plan changes.

The ESSP Program Manager annually evaluates the need for modifications of this Program Plan due to project changes and other activities within the ESSP Program, or as driven by the above NASA documentation changes.

Document Version	Effective Date	Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	• Section 1.1 updated to reflect PCA updates. • All existing appendices were updated. • Added appendices: GG (MAIA); FF (TROPICS); II (GeoCarb). • Superseded appendix U “Education and Public Outreach Policy with “ESSP Organizational Plan.” • Added text about KDP-F in section 1.6. • Updated to comply with most recent 7120.5 Program Plan template.

Table 5-1: Change Log

Appendix A: Acronyms and Abbreviations

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify the correct version before use.

Change Log

Version	**Date**	**Change Description**
Baseline	03/29/2011	Initial release of acronyms and abbreviations
A	11/01/2017	Updated list to reflect changes throughout the Program Plan

Note: Acronyms with * are project specific.

AA	Associate Administrator
AAOES	Associate Administrator for the Office of Earth Science *(GRACE)
ABC	Agency Baseline Commitment
ACAM	Airborne Compact Atmospheric Mapper *(CARVE)
ACT-America	Atmospheric Carbon and Transport - America
AGU	American Geophysical Union
AIAA	American Institute of Aeronautics and Astronautics
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AO	Announcement of Opportunity
APG	Annual Performance Goal *(Aquarius)
APMC	Agency Program Management Council
ARC	Ames Research Center
ASM	Acquisition Strategy Meeting
ASP	Airborne Science Program
ATBD	Algorithm Theoretical Basis Document *(OCO-2/MAIA)
ATom	Atmospheric Tomography Mission
ATTREX	Airborne Tropical Tropopause Experiment
BARCA	Balanço Atmosférico Regional de Carbono na Amazôni *(CARVE)
BoE	Basis of Estimate
BrO	Bromine oxide
BrO_3-	Bromate ion
Cal/Val	Calibration/Validation
CALIPSO	Cloud Aerosol LIDAR and Infrared Pathfinder Satellite Observations
CARA	Conjunction Assessment Risk Analysis
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CCS	Center Chief of Security
CDR	Critical Design Review
CE	Chief Engineer
CFR	Code of Federal Regulations
CH2O	Formaldehyde
CH_4	Methane
CI	Configuration Item
CII	Common Instrument Interface
CIL	Critical Items List
CLIVAR	Climate Variability *(Aquarius)
CMC	Center Management Council
CN	Condensation Nuclei
CNES	Centre National d'Études Spatiales *(CALIPSO)
CNSI	Classified National Security Information
CO	Carbon monoxide; Contracting Officer
CO_2	Carbon Dioxide
COI	Conflict of Interest
COM	Center of Mass *(GRACE)

CONAE	Comisión Nacional de Actividades Espaciales *(Aquarius)
COOP	Continuity of Operations
CORAL	COral Reef Airborne Laboratory
COTS	Commercial-Off-The-Shelf
CPL	Cloud Physics LIDAR *(ATTREX, HS3)
CRM	Continuous Risk Management
CSA	Canadian Space Agency; Configuration Status Accounting
CYGNSS	Cyclone Global Navigation Satellite System
DA	Decision Authority
DAAC	Distributed Active Archive Center
DFRC	Dryden Flight Research Center
Dir	Directorate
DLH	Diode Laser Hygrometer *(ATTREX)
DLR	Deutsche Forschungsanstalt für Luft und Raumfahrt - German Space Agency *(GRACE)
DM	Decision Memo
DMP	Data Management Plan
DMT	Droplet Measurement Technologies *(CARVE)
DOAS	Differential Optical Absorption Spectrometer *(ATTREX)
DPAF	Dual Payload Attach Fitting *(CALIPSO/CloudSat)
DPMC	Directorate Program Management Council
DR	Decommissioning Review
EAR	Export Administration Regulation
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EIA	Electronics Industries Alliance
ELV	Expendable Launch Vehicle
EODIS	Earth Observing System Data and Information System
EPMR	End of Prime Mission Review
ESD	Earth Science Division
ESDS	Earth Science Data System
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
ETA	Engineering Technical Authority
EV	Earth Venture
EVI	Earth Venture Instrument
EVM	Earned Value Management
EVM-x	Earth Venture Mission-#
EVS	Earth Venture Suborbital
FA	Formulation Agreement
FAD	Formulation Authorization Document
FAR	Federal Acquisition Regulation
FC	Fully Comply
FFRDC	Federally Funded Research and Development Center
FRR	Flight Readiness Review

FTS	Fourier Transform Spectrometer *(CARVE)
FWHM	Full Width at Half Maximum *(CloudSat)
FY	Fiscal Year
G, Y, R	Green, Yellow, Red
GCM	General Circulation Model *(CloudSat)
GEDI	Global Ecosystem Dynamics Investigation Lidar
GeoCARB	Geostationary Carbon Cycle Observatory
GFZ	GeoForschungZentrum *(GRACE)
GIDEP	Government-Industry Data Exchange Program
GRACE	Gravity Recovery and Climate Experiment
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSOC	German Space Operations Center *(GRACE)
H_2O	Water
HAIRS	High Accuracy Inter-satellite Ranging System *(GRACE)
HAMSR	High Altitude MMIC sounding radiometer *(HS3)
HDF	Hierarchical Data Format *(MAIA)
HIRAD	Hurricane Imaging Radiometer *(HS3)
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Radar *(HS3)
HMA	Health and Medical Authority
HNO3	Nitric acid
HOPE	Hands On Professional Experience
HQ	Headquarters
HRCP	Human Rating Certification Package
HS3	Hurricane and Severe Storm Sentinel
HSRL	High Spectral Resolution LIDAR *(DISCOVER-AQ)
IBPD	Integrated Budget and Procurement Document
ICE	Independent Cost Estimate
ICR	Investigation Concept Review
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IFOV	Instantaneous Field of View *(CloudSat)
IIP	Instrument Incubator Program
IIR	Imaging Infrared Radiometer *(CALIPSO)
IMS	Integrated Master Schedule
INVAP	Argentine manufacturer of SAC-D spacecraft *(Aquarius)
IO	Iodine monoxide
IOC	In-Orbit Checkout
IR	Infrared
ISGA	In situ Gas Analyzer *(CARVE)
ISO	International Standards Organization
I&T	Integration and Test
IT	Information Technology
ITA	Internal Task Agreement

ITAR	International Traffic in Arms Regulations
JCL	Joint Cost and Schedule Confidence Level
JPL	Jet Propulsion Laboratory
JSG	Joint Steering Group *(Aquarius)
KDP	Key Decision Point
KPP	Key Performance Parameters
KSC	Kennedy Space Center
LaRC	Langley Research Center
LCC	Life Cycle Cost
LI-COR	Manufacturer of gas analyzer *(DISCOVER-AQ)
LIDAR	LIght Detection And Ranging
LPD	LaRC Policy Directive
LPR	LaRC Procedural Requirements; Lawful Permanent Resident
LRR	Launch Readiness Review
MAIA	Multi-Angle Imager for Aerosols
MCR	Mission Concept Review
MDR	Mission Definition Review
MEI	Mission-Essential Infrastructure
MM	Mission Manager
MMIC	Monolithic Microwave Integrated Circuit *(HS3)
MMS	Meteorological Measurement System *(ATTREX)
MOA	Memorandum of Agreement
MoO	Mission of Opportunity
MOS	Mission Operations System
MOU	Memoranda of Understanding
MSFC	Marshal Space Flight Center
MTP	Microwave Temperature Profiler *(ATTREX)
N_2O	Nitrous oxide
N&ASD	NASA Aeronautics and Space Database
N/A	Not Applicable; Not Available
NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NDA	Non-disclosure Agreement
NEPA	National Environmental Policy Act
NFS	NASA FAR supplement
NO_2	Nitrogen dioxide
NOA	New Obligation Authority
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NRA	NASA Research Announcement
NV	Non-volatile *(DISCOVER-AQ)

NWP	Numerical Weather Prediction *(CloudSat)
NX	LaRC Document Management System
O_2	Molecular Oxygen
O_3	Ozone
OClO	Chlorine dioxide
OCE	Office of Chief Engineer
OCO	Orbiting Carbon Observatory
OMG	Oceans Melting Greenland
ONERA	Office Nationale d'Études et de Recherces Aérospatiales *(GRACE)
ORACLES	ObseRvations of Aerosols Above Clouds and Their IntEractionS
ORR	Operations Readiness Review
OSHA	Occupational Safety and Health Administration
P-3B	Designation of NASA Orion aircraft used for DISCOVER-AQ
PA	Program Analyst
PALS	Passive Active L-band System *(CARVE)
PB	President's Budget
PCA	Program Commitment Agreement
PCRS	Picarro Cavity Ring-Down Spectrometer *(ATTREX)
PDR	Preliminary Design Review
PE	Program Executive
PFP	Programmable Flash Pack *(CARVE)
PI	Principal Investigator
PIR	Program Implementation Review
PLAR	Post-Launch Assessment Review
PLRA	Program-Level Requirements Appendix
PM	Program Manager
PMC	Program Management Council
POC	Point of contact
PPBE	Planning, Programming, Budgeting and Execution
PRACA	Problem Reporting, Analysis, and Corrective Action
Proteus	High altitude long-endurance aircraft built by Scaled Composites *(CALIPSO)
PS	Program Scientist
PSLA	Project Service Level Agreement
PSR	Project Status Review
R&M	Reliability and Maintainability
Reps	Representatives
RIDM	Risk Informed Decision Making
RMB	Risk Management Board
RMP	Risk Management Plan; Risk Mitigation Phase
RR	Radiance Research *(DISCOVER-AQ)
RSDO	Rapid Spacecraft Development Office
SAC-D	Satélite de Aplicaciones Científicas *(Aquarius)
SALMON	Stand-Alone Mission of Opportunity Notice
SBU	Sensitive But Unclassified

SCaN	Space Communications and Navigation
SDMP	Science Data Management Plan
SDP	Science Data Product
SEMP	Systems Engineering Master Plan
SF_6	Sulfur hexafluoride
S-HIS	Scanning High-resolution Interferometer Sounder *(HS3)
SIR	System Integration Review
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active and Passive *(AirMOSS)
SMD	Science Mission Directorate
SME	Subject Matter Expert
SFMR	Stepped Frequency Microwave Radiometer
SO2	Sulfur dioxide
SOMA	Science Office for Mission Assessments
SOW	Statement of Work
SP	Special Publication
SPD	SMD Policy Document
SR	Senior Review; Status Review
SRB	Standing Review Board
SRR	System Requirements Review
SS/L	Space Systems Loral *(GRACE)
SSFR	Solar Spectral Flux Radiometer *(ATTREX)
SSMAP	Systems Safety and Mission Assurance Program
SSS	Sea Surface Salinity
STA	Safety and Mission Assurance Technical Authority
STD	Standard
STI	Scientific and Technical Information
SuperSTAR	High-precision accelerometer manufactured by ONERA/CNS *(GRACE)
SWE	Software Engineering
S/P	Spacecraft / Platform
TA	Technical Authority
TBD	To Be Determined
TCCON	Total Column Carbon Observing Network *(OCO-3)
TEMPO	Tropospheric Emissions: Monitoring of Pollution
ToR	Terms of Reference
TPM	Technical Performance Measure
TRL	Technology Readiness Level
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats
TSGC	Texas Space Grant Consortium *(GRACE)
TTCP	Technology Transfer Control Plan
TWiLiTE	Tropospheric Wind LIDAR Technology Experiment *(HS3)
UAS	Uninhabited Aerial System
UAV	Uninhabited Aerial Vehicles

UAVSAR	UAV Synthetic Aperture Radar *(AirMOSS)
UCATS	UAS *Chromatograph* for Atmospheric Trace Species *(ATTREX)
UFE	Unallocated Future Expenses
UHF	Ultrahigh Frequency
ULH	UAS Laser Hygrometer *(ATTREX)
USSTRATCOM	US Strategic Command
UTCSR	University of Texas Center for Space Research *(GRACE)
V&V	Verification and Validation
WB-57	NASA aircraft used for high altitude missions
WBS	Work Breakdown Structure
WYE	Work Year Equivalent
X_{CO2}	Column Average Carbon Dioxide Dry Air Mole Fraction *(OCO-2)

Appendix B: Definitions

Earth System Science Pathfinder Program Office

NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	3/29/2011	Initial Release
A	11/01/2017	Updated definitions associated with Program Plan

Acquisition. The acquiring by contract with appropriated funds of supplies or services (including construction) by and for the use of the Federal Government through purchase or lease, whether the supplies or services are already in existence or must be created, developed, demonstrated, and evaluated. Acquisition begins at the point when Agency needs are established and includes the description of requirements to satisfy Agency needs, solicitation and selection of sources, award of contracts, contract financing, contract performance, contract administration, and those technical and management functions directly related to the process of fulfilling Agency needs by contract.

Aquarius. ESSP Project designed to measure Sea Surface Salinity.

Ascending Node. The point in the orbit where a satellite crosses the Earth's equatorial plane in passing from the southern hemisphere to the northern hemisphere.

A-Train or Afternoon Constellation. A group of Earth-orbiting satellites with synergistic science objectives in similar sun-synchronous orbits and with the satellites distributed along the orbit in close proximity, such that they over-fly the same geographic region within seconds to minutes of each other. Their ascending node equator crossings are near 13:30 hours Mean local time. These satellites maintain their relative positions and control boxes by actively, but independently, maneuvering. Individual satellites remain in the "orbital train" so long as they maintain their assigned position in the train and are acquiring the required science measurements.

Baseline (Document Context). An agreed to set of requirements, designs, or documents that will have changes controlled through a formal approval and monitoring process. Implies the expectation of a finished product, though updates may be needed as circumstances warrant. All approvals required by Center policies and procedures have been obtained.

Baseline (general context). An agreed-to set of requirements, cost, schedule, designs, documents, etc. that will have changes controlled through a formal approval and monitoring process.

Baseline Schedule. The original approved plan plus or minus approved scope changes.

Baseline Science Requirements. The investigation performance requirements necessary to achieve the entire set of science objectives identified at the initiation of the mission. (Also see Threshold Science Requirements.)

Center Management Council (CMC). The advisory body tp the Center Director that performs oversight of programs and projects by evaluating all program and project work executed at that Center.

CloudSat. An ESSP Project that observes vertical distribution of cloud systems and their ice and water contents.

Commitment Baseline. Establishes and documents an integrated set of project requirements, cost, schedule, technical content, and an agreed-to JCL that forms the basis for NASA's commitment with the external entities of OMB and Congress. Only one official baseline exists for a NASA program or project and it is the commitment Baseline.

Compliance Verification. Compliance verification includes: 1) verifying that appropriate technical and process requirements are in place (requirements flow-down verification), 2) verifying that documented SMA requirements are in place and capable, and 3) observing work activities and products to verify process implementation and compliance with process and technical requirements (e.g., on-site in-process audits and reviews for verification of work discipline.)

Conjunction Assessment. An analysis done to predict the closest point of approach of two space objects based on their orbital parameters.

Continuous Risk Management (CRM). A systematic and iterative process that efficiently identifies, analyzes, plans, tracks, controls, communicates, and documents risks associated with implementation of designs, plans, and processes.

Convening Authority. The management official(s) responsible for convening a program/project review, establishing the terms of Reference, including review objectives and success criteria, appointing the SRB chair, concurring on SRB membership, and receiving documented results of the review.

Decision Authority (DA). The individual responsible for evaluating independent assessments and program and project Governing Body recommendations, assessing program and project deliverables, and making the decision at a KDP that authorizes a program or project to transition to the next life cycle phase.

Derived Requirement. Arise from constraints, consideration of issues implied but not explicitly stated in the high-level direction provided by NASA HQ and Center institutional requirements, factors introduced by the selected architecture, and the design. These requirements are finalized through requirements analysis as part of the overall systems engineering process and become part of the program/project requirements baseline. They are established by and are the responsibility of the Programmatic Authority.

Deviation. . A documented authorization intentionally releasing a program or project from meeting a requirement before the requirement is put under configuration control at the level the requirement will be implemented. .

Earned Value Management (EVM). A tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution of the project. EVM provides quantification of technical progress, enabling management to gain insight into project status and project completion costs and schedules. Two essential characteristics of successful EVM are EVM system data integrity and carefully targeted monthly EVM data analyses (i.e., risky WBS elements).

Earned Value. The sum of the budgeted cost for tasks and products that have actually been produced (completed or in progress) at a given time in the schedule.

Environmental Evaluation. An environmental evaluation is the analysis of the environmental effects of proposed actions, including alternative proposals. The analyses are carried out from the very earliest of planning studies for the action in question and are the materials from which the more formal environmental assessments, environmental impact statements, and public record of decisions are made.

Environmental Impact. The direct, indirect, or cumulative beneficial or adverse effect of an action on the environment.

Environmental Management. The activity of ensuring that program and project actions and decisions that potentially impact or damage the environment are assessed/evaluated during the formulation/planning phase and reevaluated throughout implementation. This activity must be performed according to all NASA policy and Federal, state and local environmental laws and regulations.

Expedition. A series of crewed or uncrewed aircraft flights, generally focused on a specific geographic area, designed to gather scientific measurements of Earth characteristics over a period of time.

Factor of Safety. Ratio of the design condition to the maximum operating conditions specified during design.

Foreign National. (For the purpose of general security protection, considerations of national security and access accountability.) Any person who is not a citizen of the US. Includes lawful permanent resident (i.e., holders of green cards) or persons admitted with refugee status to the US.

Formulation Phase. The first part of the NASA management life cycle where system requirements are baselined, feasible concepts are determined, a system baseline is baselined for the selected concept (s), and preparation is made for progressing to the implementation phase.

Functional Redundancy. A situation where a dissimilar device provides safety backup rather than relying on multiple identical devices.

GIDEP. This acronym stands for "Government-Industry Data Exchange Program". GIDEP is a cooperative information-sharing program between the US and Canadian governments and industry participants. The goal of GIDEP is to ensure that only reliable and conforming parts are in use on all Government programs and operations. GIDEP members share technical information essential to the research, design, development, production, and operational phases of the life cycle of systems, facilities, and equipment.

Ground Support Equipment. Ground-based equipment used to store, transport, handle, test check out, service and control aircraft, launch vehicles, spacecraft, or payloads.

Implementation Phase. The part of the NASA management life cycle where the detailed design of system products is completed and the products to be deployed are fabricated, assembled, integrated, and tested and the products are deployed to their customers or users for their assigned use or mission.

Independent Assessment. The general term referring to an evaluation of a program or project conducted by experts outside the advocacy chain. Specifically, a review or evaluation that results in an assessment of the program's or project's readiness (technical, schedule, cost, risk) to proceed to the next phase in the life cycle that is reported to a program or project governing body and DA..

Independent Cost Estimate. An independent program/project cost estimate prepared by an office or other entity that is not under the supervision, direction, advocacy, or control of the program/project (or its chain of command) that is responsible for carrying out the development or acquisition of the program/project. An ICE is bounded by the program/project scope (total life cycle through all phases), schedule, technical content, risk, ground rules, and assumptions and is conducted with objectivity and the preservation of integrity of the cost estimate. ICEs are generally developed using parametric approaches that are tailored to reflect the design, development state, difficulty, and expertise of team members.

Information System. The term "information system" means a discrete set of information resources organized for the collection, processing, maintenance, use, sharing, dissemination, or disposition of information. Information systems are also referred to as IT systems.

Information Technology (IT). Any equipment, or interconnected system(s) of subsystem(s) of equipment, that is used in the automatic acquisition, storage, analysis, evaluation, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of data or information by the Agency

Integrated Baseline. The project's technical performance and content, technology application, schedule milestones and budget. The integrated baseline includes the WBS, WBS dictionary, integrated master schedule, preliminary life cycle cost estimate, and workforce estimate, consistent with the program requirements on the project.

Integrated Master Schedule (IMS). An integrated set of schedule data that reflects the total project scope of work as discrete and measureable tasks/milestones that are time phased through the use of task durations, interdependencies, and date constraints and is traceable to the WBS. The highest level schedule is the Master Schedule supported by Intermediate Level Schedules and by lowest level detail schedules.

International Traffic in Arms Regulations (ITAR). US Export Control Regulations that require limited availability for technical data that pertain to commodities, technology, and software listed on the US Munitions List. NASA STI reports subject to restriction under this regulation are often referred to as ITAR documents.

Joint Cost and Schedule Confidence Level (JCL). (1) The probability that cost will be equal to or less than the targeted cost and schedule will be equal to or less than the targeted schedule date. (2) A process and product that helps inform management of the likelihood of a project's programmatic success. (3) A process that combines a project's cost, schedule, and risk into a complete picture. JCL is not a specific methodology (e.g., resource loaded schedule) or a product from a specific tool (e.g., @RISK).

Key Decision Point (KDP). The event at a point in time in the program or project life cycle, usually at the end of a program or project life cycle phase, when the program or project DA makes the decision (or not) to authorize the program or project to transition to its next life cycle phase. Program KDPs are designated with roman numerals, e.g., KDP II, and project KDPs are designated with letters, e.g., KDP B.

Key Performance Parameters (KPP). Quantitative metrics selected by the Project Manager in order to measure the effectiveness of the project in achieving their goals and related mission success criteria.

Lesson Learned. The significant knowledge or understanding gained through past or current programs and projects that is documented and collected to benefit current and future programs and projects.

Life Cycle Cost (LCC). The LCC of a project or system can be defined as the total cost of ownership over the project's or system's life cycle from Formulation through Implementation. The total of direct, indirect, recurring, nonrecurring, and other related expenses incurred, or estimated to be incurred, in the design, development, verification, production, deployment, operation, maintenance, support and disposal of a project.

Mission Assurance. Providing increased confidence that applicable requirements, processes, and standards for the mission are being fulfilled.

Mission Manager. Member of the Program Office staff responsible for ensuring Program Office support for each ESSP constituent Project. Specifically, this includes establishing and maintaining effective working relations with the Projects, leading the analysis of Project performance and leading the analysis of mission implementation processes.

Mission Operations. All activities executed by the spacecraft; includes design mission, prime mission, secondary mission, extended mission, and disposal.

Principal Investigator (PI). A person who conceives an investigation and is responsible for carrying it out and reporting its results. In some cases, PIs from industry and academia act as project managers for smaller development efforts with NASA personnel providing oversight.

Program-Level Requirements Appendix (PLRA). The document that establishes the baseline for project implementation, including the Level 1 requirements as well as the agreements among the Program Executive, Program Scientist, cognizant SMD Division Director, managing Center Director, implementing Center Director, and Program Manager. This document is an appendix to the Program Plan under whose management authority it reports at the NASA Center.

Risk. The combination of the probability that a program or project will experience an undesired event and the consequences, impact, or severity of the undesired event, was it to occur. The undesired event may come from technical or programmatic sources (e.g., a cost overrun, schedule slippage, safety mishap, health problem, malicious activities, environmental impact, failure to achieve a needed scientific or technological objective, or success criterion). Both the probability and consequences may have associated uncertainties.

Risk Management. Risk management includes risk-informed decision making and continuous risk management in an integrated framework. This is done in order to foster proactive risk management, to better inform decision making through better use of risk information, and then to more effectively manage implementation risks by focusing the CRM process on the baseline performance requirements emerging from the RIDM process. (See NPR 8000.4).

Risk Management Board. Formally established groups of people assigned specifically to review risk information. Their output is twofold: (1) to improve the management of risk in the area being reviewed and (2) to serve as an input to decision-making bodies in need of risk information.

Risk-Informed Decision Making (RIDM). A risk-informed decision making process uses a diverse set of performance measures (some of which are risk-based risk metrics)) along with other considerations without a deliberative process to inform decision making.

Sensitive But Unclassified (SBU). Information, data, or systems that require protection due to the risk and magnitude of the harm or loss that could result from unauthorized disclosure, alteration, loss or destruction but has not been designated as classified for national security purposes.

Software Assurance. Providing a measure of increased confidence that applicable requirements, processes, and standards are being fulfilled. Grounds for confidence that the other four security goals (integrity, availability, confidentiality, and accountability) have been adequately met by a specific implementation. "Adequately met" includes (1) functionality that performs correctly, (2) sufficient protection against unintentional errors (by users or software), and (3) sufficient resistance to intentional penetration or bypass.

Stakeholder. An individual or organization that is materially affected by the outcome of a decision or deliverable but is outside the organization doing the work or making the decision. A group or individual who is affected by or is in some way accountable for the outcome of an undertaking. The term "relevant stakeholder" is a subset of the term "stakeholder" and describes the people identified to contribute to a specific task. There are two main classes of stakeholders (see "Customers" and "Other Interested Parties"

Standing Review Board (SRB). The entity responsible for conducting independent reviews (life cycle and special) of the program/project. The reviews are conducted in accordance with approved ToR and the life cycle requirements per NPR 7120.5 and NPR 7123.1. The SRB is advisory and is chartered to objectively assess the material presented by the program/project at a specific review.

Success Criteria. That portion of the top-level requirements that define what must be achieved to successfully satisfy NASA Strategic Plan objectives addressed by the program/project. Specific accomplishments that must be successfully demonstrated to meet the objectives of a technical review so that a technical effort can progress further in the life cycle. Standards against which the program/project will be deemed a success. Success criteria are documented in the corresponding technical review plan. Success criteria may be both qualitative and quantitative, and may cover mission cost, schedule and performance results, as well as actual mission outcomes.

Tailoring. The process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific task or activity (e.g., program or project). The tailoring process results in the generation of deviations and waivers depending on the timing of the request.

Technical Authority (TA). Technical Authorities are part of NASA's system of checks and balances and provide independent oversight of programs and projects in support of safety and mission success through the selection of individuals at selected levels of authority. These individuals are the Technical authorities. Technical authority delegations are formal and traceable to the Administrator. Individuals with Technical authority are funded independently of a program or project.

Technical Performance Measures. The set of critical or key performance parameters that are monitored by comparing the current actual achievement of the parameters with that anticipated at the current time and on future dates. Used to confirm progress and identify deficiencies that might jeopardize meeting a system requirement. Assessed parameter values that fall outside an expected range around anticipated values indicate a need for evaluation and corrective action. Technical performance measures are typically selected from the defined set of measures of performance.

Terms of Reference (ToR). A document specifying the nature, scope, schedule, and ground rules for an independent review or independent assessment.

Threshold (or Minimum) Science Requirements. The minimum performance requirements necessary to achieve the minimum science acceptable for the investment. In some solicitations used for competed missions, threshold science requirements may be called the "science floor" for the mission. This is the KPP threshold.

Validation. Proof that the product accomplishes the intended purpose based on stakeholder expectations. May be determined by a combination of test, analysis, demonstration, and inspection.

(1) An evaluation technique to support or corroborate safety requirements to ensure necessary functions are complete and traceable; or (2) the process of evaluating software at the end of the software development process to ensure compliance with software requirements.

Variance. In program control terminology, a difference between actual performance and planned cost or schedule status.

Verification. Proof of compliance with design solution specifications and descriptive documents. May be determined by a combination of test, analysis, demonstration, and inspection. (1) The process of determining whether the products of a given phase of the software development cycle fulfill the requirements established during the previous phase; or (2) formal proof of program correctness; or (3) the act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether items, processes, services, or documents conform to specified requirements.

Waiver. A documented authorization intentionally releasing a program or project from meeting a requirement. (Some Centers use waivers during the life cycle implementation phase, and deviations for the period prior to implementation.

Work Breakdown Structure (WBS). A product-oriented hierarchical division of the hardware, software, services, and other tasks that organizes, displays, and defines the products to be developed and or produced and relates the elements of the work to be accomplished to each other and the end product(s). The WBS should reflect the way in which program/project costs, schedule, technical and risk data are to be accumulated, summarized, and reported. The WBS should be accompanied by a text document referred to as a WBS Dictionary that describes the work content of each element of the WBS in detail.

Appendix C: ESSP Compliance Matrix

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify the correct version before use.

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release of ESSP Program Plan Glossary
A	11/01/2017	Glossary deleted and replaced with NASA Compliance Matrix

Products	Formulation		Implementation	Comply?	Status
	KDP I		KDP 2 - n		
	SRR	SDR	PIR		
1. FAD	Baseline			N/A	N/A
2. PCA	Preliminary	Baseline		FC	Available
3. Program Plan	Preliminary	Baseline	Update	FC	ESSPPO-0001
3.a. Mission Directorate requirements and constraints	Baseline	Update		FC	ESSPPO-0001
3.b. Traceability of program-level requirements on projects to the Agency strategic goals and Mission Directorate requirements and constraints	Preliminary	Baseline		FC	ESSPPO-0001
3.c. Documentation of driving ground rules and assumptions on the program	Preliminary	Baseline		N/A	N/A
4. Interagency and international agreements	Preliminary	Baseline		FC	PCA Section 10.0
5. ASM minutes		Final		N/A	N/A
6. Risk mitigation plans and resources for significant risks	Initial	Update	Update	FC	Available
7. Documented Cost and Schedule Baselines	Preliminary	Baseline	Update	FC	Appendix D
8. Documentation of Basis of Estimate (cost and schedule)	Preliminary	Baseline	Update	FC	Monthly EPSR

Products	Formulation		Implementation	Comply?	Status
	KDP I		KDP 2 - n		
	SRR	SDR	PIR		
9. Documentation of Performance against plan/baseline, including status/closure of formal actions from previous KDP.	Summary	Summary	Summary	FC	Monthly EPSR
10. Plans for work to be accomplished during Implementation		Plan	Plan	FC	PLRA's
Program Plan Control Plans[2]					
1. Technical, Schedule, and Cost Control Plan	Preliminary	Baseline		FC	PLRA's
2. Safety and Mission Assurance Plan	Preliminary	Baseline		FC	ESSPPO-0001
3. Risk Management Plan	Preliminary	Baseline		FC	ESSPPO-0008
4. Acquisition Plan	Preliminary	Baseline		FC	ESSPPO-0001
5. Technology Development Plan	Preliminary	Baseline		N/A	N/A
6. Systems Engineering Management Plan	Preliminary	Baseline		N/A	N/A
7. PDLM Plan		Initial	Update annually	N/A	N/A
8. Review Plan	Baseline	Update		FC	ESSPPO-0001
9. Environmental Management Plan		Baseline		N/A	N/A
10. Configuration Management Plan		Baseline		FC	ESSPPO-0004
11. Security Plan		Baseline		FC	ESSPPO-0001
12. Threat Summary		Baseline	Update annually	FC	ESSPPO-0001
13. Technology Transfer (formerly Export) Control Plan		Baseline		FC	ESSPPO-0001
14. Education Plan		Baseline		FC	ESSPPO-0001
15. Communications Plan		Baseline		FC	ESSPPO-0001
16. Lessons Learned Plan	Preliminary	Baseline		FC	ESSPPO-0001

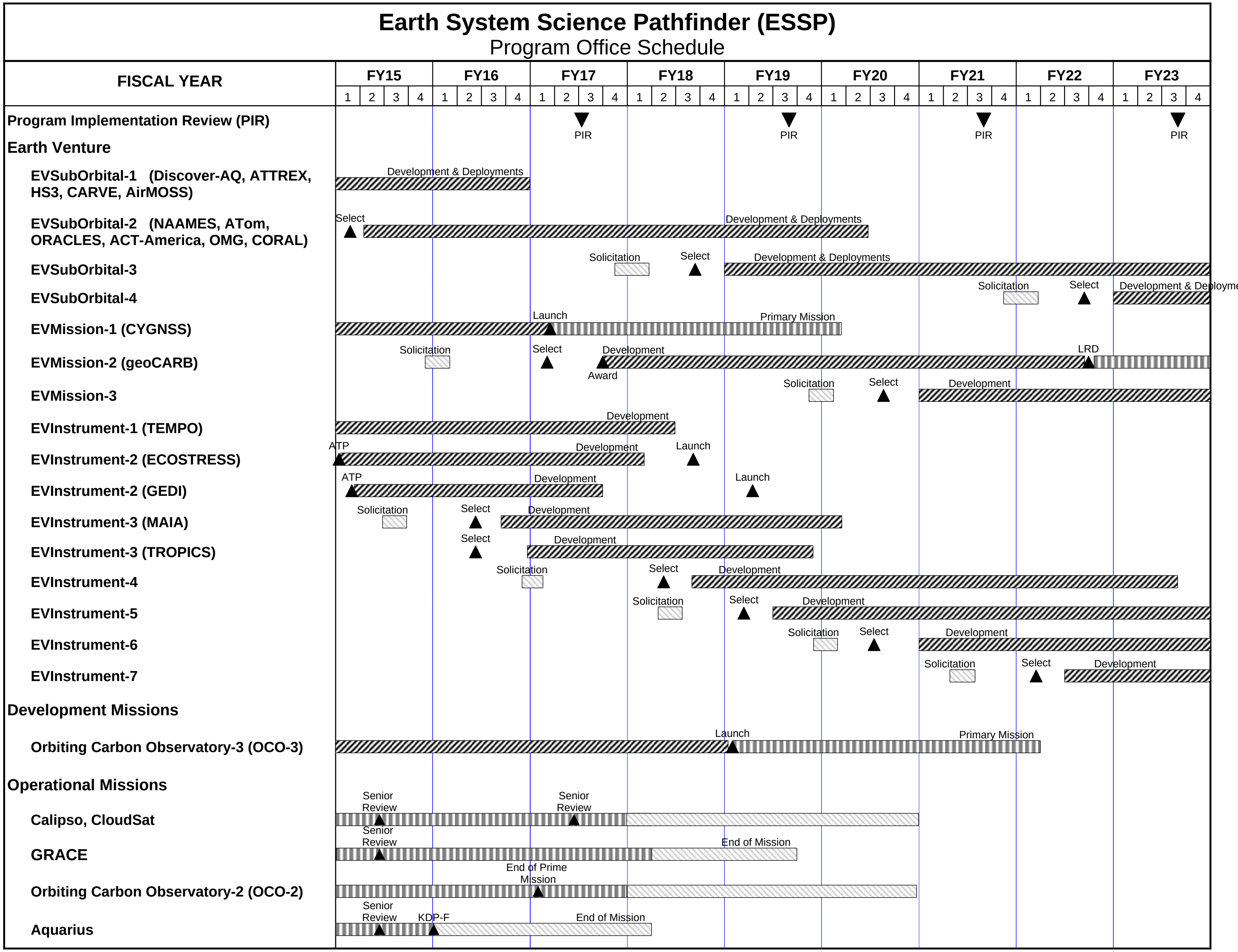
Appendix D: Schedule Baseline

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	Updated schedule through FY23

*The Science Office for Mission Assessment (SOMA) maintains the official solicitation schedule. Future projects (shown as unnamed on this schedule) are notional and used for internal planning purposes only.



Earth System Science Pathfinder (ESSP)
Program Office Schedule
FISCAL YEAR
FY15 FY16 FY17 FY18 FY19 FY20 FY21 FY22 FY23
1 2 3 4
Program Implementation Review (PIR)
PIR
Earth Venture
EVSubOrbital-1 (Discover-AQ, ATTREX, HS3, CARVE, AirMOSS)
Development & Deployments
EVSubOrbital-2 (NAAMES, ATom, ORACLES, ACT-America, OMG, CORAL)
Select
Development & Deployments
EVSubOrbital-3
Solicitation
Select
Development & Deployments
EVSubOrbital-4
Solicitation
Select
Development & Deployme
EVMission-1 (CYGNSS)
Launch
Primary Mission
EVMission-2 (geoCARB)
Solicitation
Select
Development
Award
LRD
EVMission-3
Solicitation
Select
Development
EVInstrument-1 (TEMPO)
Development
EVInstrument-2 (ECOSTRESS)
ATP
Development
Launch
EVInstrument-2 (GEDI)
ATP
Development
Launch
EVInstrument-3 (MAIA)
Solicitation
Select
Development
EVInstrument-3 (TROPICS)
Select
Development
EVInstrument-4
Solicitation
Select
Development
EVInstrument-5
Solicitation
Select
Development
EVInstrument-6
Solicitation
Select
Development
EVInstrument-7
Solicitation
Select
Development
Development Missions
Orbiting Carbon Observatory-3 (OCO-3)
Launch
Primary Mission
Operational Missions
Calipso, CloudSat
Senior Review
Senior Review
GRACE
Senior Review
End of Mission
Orbiting Carbon Observatory-2 (OCO-2)
End of Prime Mission
Aquarius
Senior Review
KDP-F
End of Mission

Appendix E: ESSP FY2016 Budget and Workforce Plans

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	02/01/2017	• Updated to reflect FY2016 Execution Plans and PPBE FY18 • Added projected budgets for new projects

$M	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Venture Class Missions*	12.0	70.0	124.3	121.9	145.7	171.6
Earth Venture Management	8.3	6.3	6.1	5.8	4.2	1.8
OCO-3	33.1	26.3	9.5	4.2	6.6	6.8
ECOSTRESS	4.6	12.8	5.7	0.4	0.0	0.0
GEDI	50.4	34.8	10.9	5.1	0.4	0.0
Earth Venture Sub-Orbital-2	36.9	37.0	31.5	16.7	3.2	0.0
CYGNSS	26.8	20.8	4.8	2.5	0.4	0.0
CALIPSO	7.0	5.1	7.1	7.1	7.2	7.3
OCO-2	9.4	10.2	10.0	10.4	10.0	10.2
TEMPO	12.1	12.5	16.3	22.2	30.4	26.4
Small Satellite Constellation Initiative	0.0	30.0	0.0	0.0	0.0	0.0
Aquarius	2.7	3.0	0.0	0.0	0.0	0.0
GRACE	5.3	5.4	2.3	1.3	0.0	0.0
CloudSat	8.3	8.5	4.1	2.0	0.0	0.0
ESSP Program Office	5.4	5.6	5.5	5.8	5.8	5.8
ESSP Program Total $M	222.3	288.3	238.1	205.5	214.0	229.9

Table E-1: ESSP Budget based on PPBE18 Program Requirements Guidance

*This line includes the 2016 selections (MAIA, TROPICS and GeoCARB) and all future selections in this timeframe

	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
ESSP Program Office FTE	12	12	12	12	12	12

Table E-2: ESSP Program FY16 Workforce Plan

Note: With no approved FY17 budget, tables presented below are accurate for FY16 and projected for FY17-FY21. The projected budget for the newest projects are:

$M	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
GeoCARB	0	10,881	34,835	41,535	26,649	17,409
MAIA	7,978	25,178	31,308	23,126	10,214	14,157
TROPICS	2,868	12,148	11,045	8,616	3,822	2,760

Table E-3: ESSP Projected Budget for New Projects

Appendix F: ESSP Program Level Agreements

Earth System Science Pathfinder Program Office

NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	01/23/2014	Added items 8 & 9
B	11/01/2017	• Removed DISCOVER-AQ, ATTREX, HS3, CARVE, AirMOSS, and Aquarius • Removed FAST ROSE MOU

Item Number	Type of Agreement	Organizations	Agreement Subject	Approval Date
9	MOA	ESD & AF SMC	For Hosted Payload activities	01/03/2014

Appendix G: Gravity Recovery and Climate Experiment (GRACE)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	05/28/2013	Updated section G.1
B	11/01/2017	Updated section G.1 and G.3 (PLRA Dated 12/1/2000)

G.1 GRACE DESCRIPTION

GRACE was implemented with twin satellites launched on 17 March 2002. The GRACE satellites make detailed measurements of the Earth's gravity field at monthly intervals that are leading to discoveries about the spatial and temporal changes in the Earth's natural systems. GRACE contributes to:

- Oceanography (enabling a better understanding of surface and deep ocean currents and mass and heat transport)
- Climate (through mass exchange in the interactions of the oceans, land and cryosphere,)
- Solid Earth (mass and gravity changes in subduction zones in areas of post-glacial rebound)
- Glaciology (observing the changing mass of ice sheets)
- Hydrology (tracking changes in the storage of water on and beneath Earth's surface)
- Geodesy (defining an improved reference frame for defining position, better calculation of orbits for geodetic satellites, a more accurate equipotential surface to which land elevations can be referenced)
- Other components of the Earth system.
- In an aeronomy co-experiment, GRACE provides atmospheric temperature and water vapor measurements and point measurements of atmospheric neutral density.

GRACE successfully completed its primary five-year mission and is currently in an extended mission phase. GRACE underwent Senior Reviews in 2007, 2009, 2011, 2013 and 2015 which extended the mission through FY 2017. Currently both twin satellites are operating and stable, but GRACE 2 is near the threshold of safe and effective science operations, The GRACE Joint Steering Group is monitoring the mission’s health and will passivate the mission once it is unable to maintain science mode pointing. Because of the mission’s health, GRACE will not submit a 2017 Senior Review Proposal. GRACE is a joint partnership between NASA in the United States and Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) in Germany. The PI is from the University of Texas Center for Space Research (UTCSR). The Co-PI is from the GeorfuschungZentrum Potsdam (GFZ). The PI delegated project management responsibility to JPL.

G.2 GRACE LEVEL 1 REQUIREMENTS

Level 1 Requirements for the Gravity Recovery and Climate Experiment (GRACE) Mission

1. SCOPE

This appendix to the Earth Science Enterprise (ESE) Program plans identifies the mission, science and programmatic (funding and schedule) requirements imposed on the University of Texas Center for Space Research (UTCSR) and the Jet Propulsion Laboratory (JPL), having prime responsibility for the development and operations of the Gravity Recovery and Climate Experiment (GRACE) of the Earth System Science Pathfinder Program.

This document serves as the guideline for mission assessments conducted by NASA Headquarters during the Implementation Subprocess and is an aid in the determination of science mission success during mission operations. The Mission Definition and Requirements Agreement (MDRA) under contract NAS5-97213 is the authoritative document for the evaluation of mission success.

Program authority is delegated from the Associate Administrator for the Office of Earth Science (AA/OES) through the Goddard Space Flight Center (GSFC) Center Director to the Earth Probes Program Manager within the Flight Projects Directorate at GSFC.

The Principal Investigator (PI) at UTCSR is responsible for the overall success of the GRACE Mission and is accountable to the AA/OES for the scientific success and to the GSFC Center Director for the programmatic success. The GSFC Program Management Council (PMC) is the governing PMC for the GRACE Mission. The GSFC Center Director is responsible for certifying GRACE flight readiness to the Associate Administrator for Earth Science. The PI at UTCSR is responsible for the JPL effort in the design, development, test, and launch phases of the GRACE Mission, as well as coordinating the efforts of the Co-PI and the co-investigators. On-orbit operations conducted by DLR/GSOC will be responsive to the PI. The PI will use the set of approved co-investigators reflected in the proposal for the scientific investigation and data verification tasks. Any changes to this science team will be coordinated with the ESSP Project Office.

Changes to information or requirements contained in this document require approval by the Office of Earth Science, NASA Headquarters.

2. SCIENCE DEFINITION

2.1 Baseline Science Objectives

The primary goal of the GRACE Mission is to obtain accurate global and high resolution models for both the static and the time variable components of the Earth's gravity field. This goal will be achieved by making accurate measurements of the inter-satellite range and range rate between two co-planar, low altitude and polar orbiting satellites, using a micro-wave tracking system. In addition, each satellite will carry geodetic quality Global Positioning System (GPS) receivers, a laser retro-reflector for satellite laser ranging and high accuracy accelerometers to enable accurate estimation of gravity field models.

The gravity field estimates obtained from data gathered by the GRACE Mission will provide, with unprecedented accuracy, integral constraints on the global mass distribution and its temporal variations. In the oceanographic community, the knowledge of the static geoid, in conjunction with satellite altimeter data, will allow significant advances in the studies of ocean heat flux, long term sea level change, upper oceanic heat content, and the absolute surface geostrophic ocean currents. Further, the estimates of time variations in the gravity field obtained from GRACE, in conjunction with other in-situ data and geophysical models, will help the science community unravel complex processes in oceanography (e.g. deep ocean current change and sea level rise), hydrology (e.g. large scale evapo-transpiration and soil moisture changes), glaciology (e.g. polar and Greenland ice sheet changes), and the solid Earth sciences.

2.2 Science Instrument Summary Description

The GRACE Mission is unique with respect to science instruments. The differential influence of the gravity field is manifested as a difference in the orbital motion of the COM of each GRACE satellite. The distance change, and hence the gravity field variations, must be inferred from the phase change measurements made between the respective antenna phase centers on the two satellites using the K-Band Ranging Instrument. In essence, the two satellites themselves become the instrument.

The High Accuracy Inter-satellite Ranging System (HAIRS) provides measurements of the distance change. In addition, the SuperSTAR Accelerometers are used to measure the non-gravitational accelerations acting on the satellites. The Star Camera Assembly is used to measure satellite orientation. The GPS Turbo-Rogue Receiver and the Instruments Processing Unit (IPU) are used for digital signal processing, as well as measuring the distance change relative to the GPS satellite constellation. The Laser Retro-Reflector Assembly provides measurements of the GRACE satellite orbits relative to terrestrial tracking networks. In addition, the GPS Receiver is also used for secondary atmospheric occultation experiments.

3. PROJECT DEFINITION

3.1 Project Organization & Management

The GRACE Principal Investigator (PI), Prof. Byron Tapley of the University of Texas, Austin Center for Space Research (UTCSR), has established teaming arrangements with a Co-Principal Investigator, Prof. Christoph Reigber of the GeoForschungZentrum (GFZ), Germany; the Deutsche Forschungsanstalt fur Luft und Raumfahrt (DLR), Germany; the Jet Propulsion Laboratory (JPL), Space Systems Loral (SS/L), the Astrium, GmbH, the Applied Physics Laboratory (APL) at Johns Hopkins University, Office National d'Études et de Recherches Aérospatiales (ONERA) and the Langley Research Center (LaRC) to implement the GRACE Mission.

3.2 Project Acquisition Strategy

The PI will have overall responsibility for the total mission, including the instrument, spacecraft, ground system, mission planning and operations, data processing and analysis, and data distribution. Prof. Tapley will be supported by experienced management and engineering teams, which have established close and efficient working relationships. The DLR and GFZ will work under an International Memorandum of Understanding (IMOU) between NASA and DLR in a no-exchange of funds agreement. The DLR/GSOC will provide mission operations. DLR will provide the launch vehicle and launch services. GFZ will provide the German Science Data Systems and the Co-PI who will lead the German science implementation effort and coordinate all elements of the German contributions. JPL provides project management and systems engineering through the launch and early orbit checkout phases. (Astrium GmbH) provides the spacecraft buses and environmental testing under contract to JPL. Space Systems Loral (SS/L) provides the Ka-band ranging system, attitude control algorithms and operations planning support under contract to JPL. ONERA provides the SuperSTAR accelerometer under contract to JPL.

4. PROGRAMMATIC REQUIREMENTS

4.1 Science Requirements

4.1.1 Primary Objectives

The primary goal of the GRACE mission is to provide, with unprecedented accuracy, estimates of the global high-resolution models of the Earth's gravity field for a period of up to 5 years. A temporal sequence of approximately monthly estimates of the gravity field provides the mean (or static) gravity field, as well as a time history of its temporal variability. An additional science objective of the GRACE mission is to provide several hundred globally distributed profiles each day of the excess delay, or bending angle of the GPS measurements due to the ionosphere and the atmosphere, using GPS limb sounding.

During mission operations, the GRACE science data shall be made available to the scientific community in an EOS compatible format, shortly after calibration and validation. The Level-1 data products include line of sight range change between the satellites measured using the K-band ranging instrument, the non-gravitational accelerations measured using the accelerometer, the GPS navigation data, as well as related ancillary data. The Level-2 data products include the coefficients of the geopotential fields, the satellite position and velocity, as well as excess delay and refractivity estimates from GPS limb sounding.

4.1.2 Typical Science Applications

The estimates of the Earth gravity field from GRACE, in conjunction with other space-based measurements, in-situ data and geophysical models, will be used to discriminate time varying changes in the mass of the Earth's dynamical system due to different geophysical processes. Examples include the discrimination of effects due to sea level rise, continental water storage, ice sheet changes and other geophysical phenomena. Additionally, atmospheric model studies will benefit by the recovery of refractivity (and the derived quantities of temperature and water vapor) from the use of GPS limb sounding. Furthermore, limited GPS sounding of the ionosphere beginning at altitudes in the region of 100 km will be available for studying fine ionospheric structure.

As an example, Table 1 summarizes the areas in Earth System Science which will benefit from the geopotential field models estimated using GRACE measurements and other in-situ data and geophysical models. For each scientific application, the principal spatial, and where appropriate, the temporal scales of associated geoid variability are given for which GRACE is expected to have an impact. The accuracy of these determinations will depend on the methods of solution of complex geophysical inverse problems, taking into account not only the GRACE measurement errors but also the errors in the ancillary geophysical model and in-situ data (e.g. atmospheric or ocean tide models).

Table 1 Science Applications Summary

APPLICATION	RESOLUTION	TIME SCALE	COMMENTS
STATIC GRAVITY FIELD			
Oceanic Heat Flux	> 1000 km		
Ocean Currents	> 1000 km		
Solid Earth Sciences	> 300 km		
TIME VARIABLE GRAVITY FIELD			
Oceanic Heat Flux	> 1000 km	Seasonal	30 day estimate
Ocean Bottom Pressure	> 500 km	Seasonal	30 day estimate
Deep Ocean Currents	> 500 km	Seasonal	30 day estimate
Sea Level Rise	> 700 km	Secular	5 year estimate
Evapo-Transpiration	> 300 km	Seasonal	30 day estimate
Greenland/ Antarctic Ice		Secular Seasonal	5 year estimate yearly estimate

4.1.3 Baseline Science Mission Requirements

In the Baseline Science Mission definition, the Earth's geopotential field is characterized by the coefficients of a spherical harmonic expansion. These coefficients will be estimated to degree and order 160 or more for the long term mean part, and to degree and order 100 or less for the time variable part. The temporal variability will be characterized by mean values of the coefficients over 30 days or less. In addition, approximately 200 GPS atmospheric profile soundings per day shall be acquired, subject to data system limitations.

The science data, in conjunction with ancillary data, will be used to obtain estimates of spherical harmonic coefficients of the Earth's gravitational potential. A typical 30 day span of data, collected in a 475 km altitude polar orbit, shall have a global root mean square (rms) geoid height error due to the measurement system errors as specified in Table 2.

Table 2 Geoid Height Error over 30 days

Harmonic Degree	Geoid Height Error Per Degree (mm)	Geoid Height Error Cumulative (from n=3) (mm)
N = 2	< 0.10	--
$3 \leq n \leq 10$	< 0.01	< 0.02
$10 \leq n \leq 70$	< 0.15	< 0.40
$70 \leq n \leq 100$	< 1.50	< 3.50
$100 \leq n \leq 150$	< 65.0	< 200

4.1.4 Minimum Science Mission Requirements

As a minimum objective for a successful mission, the GRACE measurements shall provide for at least an order of magnitude improvement in the mean global geoid. This improvement in the marine geoid will enhance dramatically the recovery of the general ocean circulation and ocean heat flux from satellite altimetry. Such improvement is a current requirement of both Earth Observation System (EOS) and World Ocean Circulation Experiment (WOCE).

For the Minimum Science Mission, the mean geopotential model will be characterized by a spherical harmonic model to at least degree and order 100. The cumulative contribution to global geoid height error from harmonic coefficients to degree and order 70 shall not exceed 1 cm rms. No atmospheric and ionospheric occultation data products will be available.

4.1.5 Science Measurement Objectives

The data required to realize the science goals are defined in Table 3, which establishes the primary measurement objectives for GRACE.

Table 3 Science Measurement Objectives

Science	Measurement	Instrument	Spacecraft
Earth Gravity Field	Inter-Satellite Range Change	K-Band Ranging m-wave link	2
	Non-Grav. Accelerations	Accelerometer	2
	GPS Tracking Data	GPS Receiver	2
Atmospheric Occultation	GPS-to-GRACE phase change	GPS Receiver	1

4.2 Mission and Spacecraft Performance Requirements

The two GRACE spacecraft shall be designed for a five-year lifetime. The two GRACE satellites shall be in co-planar orbits at approximately 300-500 km altitude, at an inclination of 89 degrees, separated along track by approximately 100-500 km.

The data rates will be up to 20 Mb/day for the gravity field, and 20-40 Mb/day for the occultation experiment. Orbit maneuvers will be required every 30-60 days in order to maintain the separation between the satellites, in addition to the occasional calibration and altitude make-up maneuvers.

4.3 Launch Requirements

The GRACE Mission is planned to launch in November 2001 from the Plesetsk Cosmodrome in Russia. There is no science window for the GRACE Mission.

The GRACE spacecraft will be launched into a near 500 km circular orbit at an inclination of 89 degrees.

4.4 Ground Systems Requirements

The GRACE Mission Operations System shall be capable of acquiring and processing an average of at least 50 Mbytes of science and housekeeping data per day for each satellite.

5.2 Cost Management and Scope Reduction

The GRACE Mission has undergone extensive studies during Phase B and developed comprehensive risk mitigation strategies for key technical and programmatic risk items. In addition, the PI and PM have built an acceptable cost reserve pool to be used, when needed, to preserve the Baseline Science Mission. Use of this cost reserve is at the discretion of the PI, without further NASA approval. Should it become necessary to descope the Baseline Science Mission, the PI and his mission team will consult with the ESSP Project Office and NASA Headquarters before implementation. The Risk Management Plan and Descope Plan are fully described in the GRACE Cooperative Project Plan.

6. MULTI-MISSION NASA FACILITIES

The GRACE Mission will utilize the PODAAC at JPL or another acceptable archive for science data archiving, as well as several NASA ground stations for launch, early orbit and contingency operations support.

7. EXTERNAL AGREEMENTS

The DLR and GFZ are working on the GRACE Mission under the auspices of an International Memorandum of Understanding between NASA and the DLR. Both the DLR and GFZ confirmed that all necessary funds and resources have been committed for the GRACE Mission.

8. PUBLIC OUTREACH AND EDUCATION

The GRACE Mission has developed and shall execute an Education and Public Outreach Plan. The outreach efforts are coordinated by the Texas Space Grant Consortium (TSGC).

9. SPECIAL INDEPENDENT EVALUATION

The GRACE Mission has successfully completed the Mission Design Review and Mission Confirmation Review. Both of these reviews were staffed with reviewers independent of the GRACE Mission. The GRACE Systems Review Plan includes several independent reviews throughout the Implementation Subprocess.

10. TAILORING

The GRACE Cooperative Project Plan (GRACE Project 327-100) details all tailoring of NPG 7120.5.

11. REQUIRED APPROVALS

Byron Tapley
GRACE Principal Investigator
University of Texas Center for Space Research

Richard J. Fitzgerald
GRACE Mission Manager
Goddard Space Flight Center

Nicholas Chrissotimos
Project Manager
Earth System Science Pathfinder
Goddard Space Flight Center

Nicholas Chrissotimos
Acting, Earth Probes – G Program Manager
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John Campbell
Director
Flight Programs and Projects Directorate
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Al Diaz
Center Director
Goddard Space Flight Center

Dr. Ghassem Asrar
Associate Administrator for Earth Science
NASA Headquarters

G.3 GRACE 2015 SENIOR REVIEW

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

SEP 1 8 2015

Reply to Attn of: SMD/Earth Science Division

mike

TO: GRACE Principal Investigator

FROM: Director, Earth Science Division

SUBJECT: Results from the 2015 Senior Review of Earth Science Operating Missions

This letter provides programmatic direction for the Gravity Recovery and Climate Experiment (GRACE) project for FY2016-2019, based on the findings of the 2015 Earth Science Division (ESD) Senior Review.

The ESD Senior Review consisted of a series of comprehensive reviews of the missions' science quality, operational utility, and continued engineering/cost performance. A full description of the evaluation process, the factors used by the review panels, and their findings for all missions, may be found in the Senior Review Final Report, located at URL http://science.nasa.gov/earth-science/missions/operating/.

The review panel's findings for GRACE are:

Adjectival Summary Science Score	Utility Score	Technical Risk	Cost Risk
Excellent	High	Medium-High	Medium-Low

Since launch in 2002 the GRACE mission has produced a series of over 140 global gravity models, providing an unprecedented view of mass redistribution within the Earth system on monthly to inter-annual time scales. These gravity variations result primarily from transport of water between the oceans, land, cryosphere and atmosphere, making GRACE a unique and important component of NASA's climate measurement capability; it was one of the climate missions listed in the 2010 ESD Climate Initiative. GRACE is a valuable resource for basic science investigations, providing a unique view of the coupled Earth system, and shedding light on fundamental oceanographic, hydrologic, and cryospheric processes and interconnections. Through assimilation, mission data are also helping to improve model hind-casts and improving predictive skill in several areas of application. A follow-on mission is planned for launch in fall 2017. A core rationale for extension of the GRACE mission is to maintain continuity of the climate record, and provide sufficient overlap with the follow-on for calibration and validation of the new mission.

There are significant risks to the mission over the coming years due to the technical health and status of the two spacecraft. If the K-band ranging is lost, the mission proposes to continue to produce time variable gravity fields with GPS tracking of a GRACE satellite, in combination with other LEO satellites. The mission is studying the feasibility of this approach, but preliminary assessments do not yet demonstrate that such solutions would be of sufficient quality to maintain the climate record. The mission should continue these studies, in cooperation with international collaborators and the science community, to further develop and evaluate the feasibility of the single GRACE satellite solution approach.

I have used the panel's assessment in formulating the mission programmatic directions for the FY2016-2019 period. These new guidelines, together with the scope of activities defined in this letter, constitute the new project requirements for the extended mission.

Your response to this direction should be in the form of a letter; the letter should include your project's response to the technical guidance below, and a rationale to address any budget reductions.

Specific guidance for the GRACE project is as follows:

> The GRACE Project is directed to implement the sustainable mission extension proposal for FY16-17, or as long as both satellites are operating. Overlap with GRACE Follow-On for calibration/validation of the new mission is a priority. Mission extension will be reconsidered should loss of one satellite reduce the mission to a single satellite instead of a pair; the mission team will be expected to support a Mission Reconfiguration Review should that occur.
>
> Budget is reduced in the out-years, but may be restored contingent on:
> - Health of both satellites
> - Operating performance of GRACE Follow-On
> - Projected orbit (GRACE re-entry is currently predicted for early CY2018)
> - 2017 Senior Review Proposal
>
> The Mission Capabilities for the GRACE mission are unchanged.

All projects are requested to review their Project Plan and their End of Mission Plan, and deliver an updated plan to the ESSP Program Office and SMD/ESD by March 30, 2016. If a review of either document determines that an update is not necessary, the Project may submit instead a memorandum to that effect, including the rationale supporting the conclusion. The Project is also requested to hold an Annual Mission Operations Review, and report results, findings and actions to ESD and the cognizant Program Office by the end of FY2016. Please coordinate review content and date with your Program Office and include this information in your response to this guidance letter.

Funding Direction

Funding guidelines for the GRACE project are below. These numbers are in real year $K and represent the new Headquarters guidance for the sum of the traditional mission operations and core data analysis lines, including civil servant labor funds.

FY16	FY17	FY18	FY19
5,295	5,419	2,302	1,304

It is our intention that the guidelines provided are the funds that will be made available to you in FY16 and FY17, but we note that changes in available resources and the requirements placed on us require revisiting budget allocations annually, or more frequently as circumstances warrant. If for some reason we believe that the resources to be available will differ from those indicated above, we will let you know as soon as we can. Guidelines for FY18 and FY19 should be considered preliminary, to be revisited during the 2017 ESD Senior Review.

I congratulate you and your team on the positive review results, and look forward to your response on October 30. Any questions may be directed to Ms. Cheryl Yuhas, 202-358-0758, Cheryl.Yuhas@nasa.gov.

Michael H. Freilich

cc:
LaRC/Earth System Science Pathfinder Program Office
JPL/Earth Science and Technology Directorate

Appendix H: Cloud Aerosol LIDAR and Infrared Pathfinder Satellite Observations (CALIPSO)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	05/28/2013	Updated section H.1
B	11/01/2017	Updated section H.1 and H.3 (PLRA Rev A; 3/12/2005)

H.1 CALIPSO Description

The CALIPSO mission is the culmination of a decade-long and continuing collaboration between NASA and the French Space Agency Centre National d'Études Spatiales (CNES). Since launch on April 28, 2006, CALIPSO has been providing nearly continuous measurements of the vertical structure and optical properties of clouds and aerosols in the Earth's atmosphere. These measurements provide new information and unique insights that are improving our understanding of the distribution and properties of clouds and aerosols. In addition, this information and insight is being used to markedly improve the performance of a variety of models ranging from regional chemical transport and weather forecast models to global circulation models used for climate prediction. The CALIPSO instrument suite consists of a two-wavelength polarization–sensitive LIDAR, a three-channel infrared imaging radiometer, and a single channel wide-field-of-view camera. CALIPSO is flying in the Afternoon Constellation (A-Train constellation) and provides complementary, near-simultaneous, observations with the other active and passive instruments in the A-Train. CALIPSO has completed its primary 3-year mission and is currently in its extended mission phase. CALIPSO underwent Senior Reviews in 2009, 2011, 2013 and 2015. CALIPSO plans to submit a 2017 Senior Review Proposal to extend the mission through 2019. The PI is from NASA Langley Research Center (LaRC). The Co-PI is from the Institut Pierre Simon Laplace (IPSL) and leads French mission responsibilities and provides scientific guidance on the IIR and mission objectives. LaRC is responsible for project management.

H.2 CALIPSO Level 1 Requirements

LEVEL I REQUIREMENTS

for the

CALIPSO MISSION

June 18, 2002

Revision A
March 12, 2005

Document Revision Record

Revision	Date	Description of Change	Approved By
A	2005/03/12	Title Page: Added Revision A and generation date Section 1.1:Changed references to Earth Science Enterprise to the Science Mission Directorate. Section 2.1: Changed the total cost of the mission from $151M to $199M. This includes two separate replans, one for the increase in the Spring of 2004, from $151M to $186.6M, and the second in the Spring of 2005, to $199M. The first increase also included adjustments required to convert to full cost accounting. Section 2.2: Changed the "Launch Readiness Date from 04/04 to Summer 2005. Section 2.2: Changed the Distribution of Cal/Val Data from 12/05 to Spring 2007. Section 3.1, Table 1: Deleted the two data products for Surface LW fluxes and Atmospheric LW fluxes. These products required the delivery of CERES data products to CALIPSO. Earth science R&A budget reductions eliminated the incoming CERES analyses, and the CALIPSO project could not accommodate the increase. Section 3.3: Changed the launch ready date from April 2004 to Summer 2005. Section 3.6: Added mission success criteria. Section 5: Changed Ghassem Asrar to Alphonso Diaz as the responsible AA, and replaced references to the Earth Science directorate to the Science Mission Directorate	
	2005/05/25	Section 2.2: Added a distribution of calibrated level 1b and level 2a data products by Launch + 180 days to the requirements.	

LEVEL I REQUIREMENTS
FOR THE
CALIPSO MISSION

1. OVERVIEW

1.1 SCOPE

This document identifies the mission, science and programmatic requirements imposed on CALIPSO mission. This document establishes Headquarters' requirements for the implementing center. It serves as the basis for mission assessments conducted by NASA Headquarters during the Implementation Subprocess and provides the baseline for the determination of science mission success during mission operations.

Changes to the requirements specified in this document must be made through the following methods:

- Changes to scientific/technical/cost content require Science Mission Directorate (SMD) Directorate Program Management Council (DPMC) approval.
- Changes to cost requirements may be handled as a part of the POP process.
- Changes to the baseline launch readiness date require SMD DPMC approval and a letter of direction from the Associate Administrator for the Science Mission Directorate (AA/SMD).

Program authority is delegated from the Associate Administrator for Science Mission Directorate (AA/SMD) through the Goddard Space Flight Center (GSFC) Center Director to the Earth Explorers Program Manager for the successful implementation of the mission.

1.2 PROJECT DEFINITION

CALIPSO is a satellite mission designed to provide global measurements of aerosols and clouds required for better understanding of their role in the climate system and to improve our ability to predict long-term climate change and seasonal-to-interannual climate variability.

1.3 SCIENCE OBJECTIVES

The primary science goal of CALIPSO is to acquire a global set of aerosol and cloud observations over a period of three years which, by themselves and in combination with coincident observations from the Aqua and CloudSat platforms, will allow significant advances in our understanding of the role of aerosols and clouds in the climate system. The mission has defined four primary science objectives and one secondary science objective.

- Provide a global suite of measurements from which the first observationally based estimates of direct aerosol forcing, and its certainty, can be made.
- Enable the first global observationally-based assessment of indirect aerosol radiative forcing.
- Improve the accuracy of satellite estimates of longwave radiative fluxes at the surface of the Earth and longwave heating rates within the atmosphere by a factor of 2.
- Provide a new ability to assess cloud feedback in the climate system, including thin cirrus, polar clouds, and multi-layered cloud systems, all of which are poorly determined by passive radiometers alone.

A secondary objective is to provide a set of simultaneous coincident data with which to validate and improve data retrievals from NASA's Earth Observing System (EOS) Aqua mission.

2 PROGRAM REQUIREMENTS

2.1 BUDGET REQUIREMENTS

The total cost for the CALIPSO mission is $199M, and includes NASA mission development, science, operations, and launch costs.

2.2 SCHEDULE REQUIREMENTS

Milestone	Completion Date
Launch Readiness Date	Summer 2005
Distribution of calibrated level 1b and 2a data products (lidar profiles, IIR and WFC radiances, meteorological profiles, lidar aerosol/cloud browse images and backscatter profiles, aerosol layer and cloud height/thickness)	Launch + 180 days
Distribution of Cal/Val Data	Spring 2007

2.3 EXTERNAL AGREEMENT REQUIREMENTS

In accordance with Article III of the NASA/CNES MOU, and in summary, CNES is responsible for providing science team participation, IIR algorithm development, the PROTEUS platform, satellite engineering, Imaging Infrared Radiometer, payload-to-platform integration and test, the command and control data uplink for the satellite, the satellite operations and control center, and support satellite-to-launch vehicle integration and test.

2.4 MULTI-MISSION FACILITIES REQUIREMENTS

The CALIPSO mission will use the LaRC Distributed Active Archive Center (DAAC) for data processing, archive and distribution. Funding for data processing and archive activities is included in the CALIPSO budget.

2.5 CONSTRAINTS

N/A

3. PERFORMANCE REQUIREMENTS

3.1 MISSION REQUIREMENTS

The science objectives will be achieved by flying the lidar, the Imaging Infrared Radiometer (IIR), and a wide field camera (WFC) in formation with Aqua for a three-year mission life. Science requirements can still be met if the IIR and/or WFC are operated discontinuously during the third year of the on-orbit mission to meet power constraints, if required.

The CALIPSO orbit requirements of 705 km altitude with a 1:30 pm equator crossing time are derived from the science requirement for coincident measurements with Aqua and the Aqua orbit. Constellation flying with Aqua will be implemented to ensure science objectives are met, and to ensure safe operations with Aqua and other missions in the proposed Aqua train.

The science data products and associated measurement uncertainties required to realize the mission objectives are defined in Table 1.

Table 1. Science Products and Uncertainties

Data Product	Measurement Capabilities and Uncertainties
	Aerosols
Height, thickness	For layers with $\tau > 0.005$
τ, σ (z)	40%**
	Clouds
Height	For layers with $\tau > 0.01$
Thickness	For layers with $\tau < 5$
τ, σ (z)	Within a factor of 2 for $\tau < 5$
Ice/water phase	Layer by layer
Ice cloud emissivity, ε	$\pm$0.03
Ice particle size	$\pm$50% for $\varepsilon > 0.2$

τ - optical depth
σ (z) – profile of extinction cross-section
**assumes 30% uncertainty in backscatter-to-extinction ratio

3.2 INSTRUMENT INFORMATION

The CALIPSO instrument suite and measurements required to achieve the science baseline objectives are described below:

- The lidar acquires vertical profiles of elastic backscatter at 532 and 1064 nm from a near nadir viewing geometry during day and night segments of the orbit. Two orthogonal polarization components (parallel and perpendicular to polarization plane of the transmitted beam) are measured at 532 nm. The lidar profiles provide information on the vertical distributions of aerosols and clouds, cloud particle phase (via the ratio of signals in the two orthogonal polarization channels at 532 nm), and classification of aerosol size (via wavelength dependence of backscatter).
- The IIR provides medium spatial resolution, nadir-viewing images at 8.65 μm, 10.6 μm, and 12.05 μm. The IIR operates continuously, night and day, providing information on cirrus cloud particle size and infrared emissivity, and allows nighttime verification of the co-registration of CALIPSO observations with those of Aqua.
- The WFC is a digital camera that collects high spatial resolution imagery in the 620-nm to 670-nm wavelength range during the daylight segments of orbit. The WFC spectral band is matched to MODIS channel 1. WFC data will be used for ascertaining cloud homogeneity to provide overall meteorological context, and to aid IIR retrievals. Also, the WFC images will be used for highly accurate daytime co-registration of CALIPSO observations with those of Aqua.

3.3 LAUNCH REQUIREMENTS

CALIPSO shall be launch-ready in Summer 2005 in a dual launch configuration with the CloudSat satellite. The launch vehicle will be the Boeing Delta II 7420-10C launch vehicle with a Dual Payload Attach Fitting (DPAF) with CALIPSO in the upper berth. CALIPSO and CloudSat shall be launched from Vandenberg Air Force Base (VAFB) in California.

3.4 MISSION OPERATIONS REQUIREMENTS

The CALIPSO satellite and ground systems shall be designed for a three-year on-orbit lifetime.

3.5 SCIENCE DATA SYSTEM REQUIREMENTS

CALIPSO shall use the LaRC DAAC to perform science Standard Products data processing, distribution, and archive.

3.6 MISSION SUCCESS CRITERIA

Success for CALIPSO is defined as a significant improvement over our current knowledge of the global characteristics of multi-layer cloud structure and the vertical distribution of aerosols. CALIPSO observations will produce:

1) The first high resolution (60 m) global profiles of clouds and aerosols with a backscatter sensitivity of at least 1 x 10^{-3}/km/sr at 532 nm.
2) The first global high resolution (60 m) profiles of cloud ice/water phase.
3) A comprehensive data set including seasonal cloud and aerosol properties to be acquired over periods including 3 months each during summer and winter (Jun-Aug and Dec-Feb), and 2 additional months (April, October) in the spring and the fall.

As CALIPSO will be flying as part of the A-train, all measurements are expected to be coincident with other A-train satellite observations for the data to be available for processing and modeling efforts outside of the CALIPSO project.

4. PUBLIC OUTREACH AND EDUCATION REQUIREMENTS

The CALIPSO project shall develop and execute an Education and Public Outreach Plan. Activities will focus on communicating the CALIPSO mission and scientific results through informal and formal venues. These activities will include creation of CALIPSO content materials, development of education programs that amplify the efforts of CALIPSO and stimulate broad awareness and understanding, and the identification of new applications required to incorporate the rewards of CALIPSO into the fabric of our everyday life.

5. APPROVAL

Original signed by G. Asrar for A. Diaz

____
A. V. Diaz
Associate Administrator for
Science Mission Directorate

H.3 CALIPSO Senior Review

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

SEP 18 2015

Reply to Attn of: SMD/Earth Science Division

TO: CALIPSO ~~Principal~~ Investigator David

FROM: Director, Earth Science Division

SUBJECT: Results from the 2015 Senior Review of Earth Science Operating Missions

This letter provides programmatic direction for the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission for FY2016-2019, based on the findings of the 2015 Earth Science Division (ESD) Senior Review.

The ESD Senior Review consisted of a series of comprehensive reviews of the missions' science quality, operational utility, and continued engineering/cost performance. A full description of the evaluation process, the factors used by the review panels, and their findings for all missions, may be found in the Senior Review Final Report, located at URL http://science.nasa.gov/earth-science/missions/operating/.

The review panel's findings for CALIPSO are:

Adjectival Summary Science Score	Utility Score	Technical Risk	Cost Risk
Excellent	High	Medium-Low	Medium-Low

CALIPSO provides a unique set of data products that are not currently available from any other satellite platform. The L1 products have reached a level of maturity that enables climate quality analysis based on the nearly 10-year dataset. The L2 products are widely used by the scientific community, and gridded L3 aerosol and cloud products are in active development. The project continues to innovate, and has recently produced an estimate of ocean sub-surface phytoplankton concentration. Synergistic use of CALIPSO data in combination with CloudSat, MODIS, and CERES observations has led to the development of robust multi-instrument cloud, aerosol, and radiative heating products. More than 500 peer reviewed publications have utilized CALIPSO data since the 2013 Senior Review. CALIPSO aerosol vertical profiles are used in data assimilation tests at the US Naval Research Laboratory, the European Centre for Medium Range Weather Forecasts, and the Japanese Meteorological Agency. Detection of volcanic ash plumes by CALIPSO is used in support of commercial aviation operations. The US Environmental Protection Agency and several state agencies are using CALIPSO data to assess air quality and develop strategies to mitigate pollution-induced reduction to visibility. Specifically, the EPA notes that 10-20% of its data downloads consist of CALIPSO data. The CALIPSO spacecraft and all instruments are in excellent health and the mission is supporting transformative science.

I have used the panel's assessment in formulating the mission programmatic directions for the FY2016-2019 period. These new guidelines, together with the scope of activities defined in this letter, constitute the new project requirements for the extended mission.

Your response to this direction should be in the form of a letter; the letter should include your project's response to the technical guidance below, and your approach to address the budget reduction in FY2017.

Specific guidance for the CALIPSO mission is as follows:

> The CALIPSO Project is directed to implement its baseline proposal for extended mission operations and data analysis.
>
> The CALIPSO Project is also directed to:
> 1) Continue experiments to determine if and how the backup laser can be returned to service when the current laser hits the corona region;
> 2) Maintain high priority for release of Version 4 Level 2 and Level 3 products;
> 3) Report to ESD either in your response to this direction or a short, concurrently submitted white paper on the potential of developing an ocean subsurface product, including feasibility, outstanding questions, impacts on instrument operations and production of other data products, and estimated costs.
>
> The Mission Capabilities for the CALIPSO mission are unchanged.

All projects are requested to review their Project Plan and their End of Mission Plan, and deliver an updated plan to the ESSP Program Office and SMD/ESD by March 30, 2016. If a review of either document determines that an update is not necessary, the Project may submit instead a memorandum to that effect, including the rationale supporting the conclusion. ESD's requirement for an Annual Mission Operations Review will be satisfied by the annual Review of Exploitation (REVEX) conducted by our partner Centre National d'Études Spatiales; report results, findings and actions from the REVEX (presumed to occur in May 2016) to ESD and the cognizant Program Office by the end of FY2016.

Funding Direction

Funding guidelines for the CALIPSO mission are below. These numbers are in real year $K and represent the new Headquarters guidance for the sum of the traditional mission operations and core data analysis lines, including civil servant labor funds.

FY16	FY17	FY18	FY19
7,038	5,086	7,086	7,086

It is our intention that the guidelines provided are the funds that will be made available to you in FY2016 and FY2017, but we note that changes in available resources and the requirements placed on us require revisiting budget allocations annually, or more frequently as circumstances warrant. If for some reason we believe that the resources to be available will differ from those indicated above, we will let you know as soon as we can. Guidelines for FY2018 and FY2019 should be considered preliminary, to be revisited during the 2017 ESD Senior Review.

I congratulate you and your team on the positive review results, and look forward to your response on October 30. Any questions may be directed to Ms. Cheryl Yuhas, 202-358-0758, Cheryl.Yuhas@nasa.gov.

Michael H. Freilich

cc:
LaRC/Earth System Science Pathfinder Program Office
LaRC/Science Directorate

Appendix I: CloudSat

Table of Contents

Earth System Science Pathfinder Program Office

NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	**Date**	**Change Description**
Baseline	03/29/2011	Initial Release
A	05/28/2013	Updated section I.1
B	11/01/2017	Updated section I.1 and I.2 (PLRA Rev A; 4/12/2005)

I.1 CLOUDSAT DESCRIPTION

CloudSat provides the vertical distribution of cloud systems and their ice and water contents. CloudSat is acquiring the information needed by Numerical Weather Prediction

(NWP) models and General Circulation Models (GCMs) to validate and improve their predictions of clouds. In addition, CloudSat provides the quantitative measurements of optical depth, layer thickness, base height, and ice and liquid water contents of clouds, facilitating accurate determination of the radiative properties of clouds and their roles in the radiative heating of the atmosphere. The knowledge of this heating is critical to improving understanding of cloud-climate feedback phenomena. CloudSat was launched on 28 April 2006 and is flying in the Afternoon Constellation (A-Train constellation). CloudSat has completed its primary two-year mission and is currently in an extended mission phase. CloudSat underwent Senior

Reviews in 2007, 2009, 2011, 2013 and 2015. CloudSat will submit a 2017 Senior Review Proposal to extend the mission through 2019. In addition to NASA, contributing partners to CloudSat include the Canadian Space Agency (CSA), which provided radar components, and the U. S. Air Force Advanced Systems and Development Directorate at Kirtland Air Force Base, which provides the ground station network and conducts ground control of the satellite. The PI is from JPL, and JPL is responsible for project management.

I.2 CLOUDSAT LEVEL 1 REQUIREMENTS

LEVEL I REQUIREMENTS

for the

CloudSat MISSION

August 14, 2002

Revision A
March 12, 2005

**LEVEL I REQUIREMENTS
FOR THE
CloudSat MISSION**

1. OVERVIEW

1.1 SCOPE

This document identifies the mission, science and programmatic requirements imposed on CloudSat mission. This document establishes Headquarters' requirements for the implementing center. It serves as the basis for mission assessments conducted by NASA Headquarters during the Implementation Subprocess, and it provides a basis for determining science mission success during mission operations.

Changes to the requirements specified in this document must be made through the following methods:
- Changes to scientific/technical/cost content require Science Mission Directorate (SMD) Directorate Program Management Council (DPMC) approval.
- Changes to cost requirements may be handled as a part of the POP process.
- Changes to the baseline launch readiness date require SMD DPMC approval and a letter of direction from the Associate Administrator for the Science Mission Directorate (AA/SMD).

Program authority is delegated from the Associate Administrator for Science Mission Directorate (AA/SMD) through the Goddard Space Flight Center (GSFC) Center Director to the Earth Probes Program Manager for the successful implementation of the mission.

1.2 PROJECT DEFINITION

CloudSat is a space-mission experiment intended to measure the vertical structure of clouds with a radar from an earth-orbiting spacecraft. This radar is a millimeter-wave radar (94 GHz) capable of detecting a range of clouds from very thin cirrus to thick, precipitating thunderstorms. CloudSat will fly in a near-earth sun-synchronous orbit, in formation with CALIPSO and in a constellation other cloud-measuring satellites (viz. Aqua, Aura).

1.3 SCIENCE OBJECTIVES

The primary science goal of CloudSat is to advance our understanding of the feedback between clouds and climate. Research investigations that utilize CloudSat data will be carried out through NASA NRA funded proposals and through contributions by other USA and non-USA organizations. The following are the science objectives that support the goal:

1. Quantitatively evaluate the representation of clouds and cloud processes in global atmospheric circulation models
2. Quantitatively evaluate the relationship between the vertical profiles of cloud liquid water and ice content and the radiative heating of the atmosphere and surface by the various cloud systems. This involves the following types of studies:
   - Evaluating the connection between cloud liquid water and ice contents and radiative properties
   - Comparing the heating rates derived with CloudSat data to those derived from the classes of models used to address Objective 1
   - Evaluating current approaches in estimating surface radiation fluxes
3. Evaluate cloud properties retrieved from other satellite systems, in particular those of Aqua

The Level 2 CloudSat Science Requirements document shall contain detailed measurements and measurement accuracy requirements.

2. PROGRAM REQUIREMENTS

2.1 BUDGET REQUIREMENTS

The total cost for the CloudSat mission is $173M, and includes NASA mission development, science, operations, and launch costs.

2.2 SCHEDULE REQUIREMENTS

Milestone	Completion Date
Launch Readiness Date	Summer 2005
First release of validated Data	On or before Spring 2006

2.3 EXTERNAL AGREEMENT REQUIREMENTS

The Canadian Space Agency (CSA) is providing radar components to the CloudSat mission in accordance with government-to-government agreement between the United States and Canada. The USAF is providing ground network and mission operations services under a MOA between NASA GSFC and the USAF. Under a Cooperative Agreement with the PI, the DoE ARM Program is providing ground and airborne measurements to support the algorithm development and measurement validation activities.

2.4 MULTI-MISSION FACILITIES REQUIREMENTS

The CloudSat mission will not use any NASA multi-mission facilities.

2.5 CONSTRAINTS

N/A

3. PERFORMANCE REQUIREMENTS

3.1 MISSION REQUIREMENTS

The science objectives are to provide from space the first global survey of cloud profiles and cloud physical properties, with seasonal and geographical variations, needed to evaluate the way clouds are parameterized in global models, thereby contributing to predictions of weather, climate and the cloud-climate feedback problem.

The spacecraft will be placed into a circular, sun-synchronous earth orbit for 22 months of continuous cloud observations, giving coverage over all latitudes (to within 8.2° of the poles) for 22 months. In addition, CloudSat will be flown on-orbit as part of the Aqua constellation.

The science data products required to realize the mission objectives are defined in Table 1.

Table 1. CloudSat Data Products

Standard Data Product	Measurement Accuracy
Cloud classification & geometrical profile (Radar-only)	Detect all single-layer ice clouds with optical depth $\geq$1.0 and all single-layer water clouds with optical depth $\geq$ 3.0; Vertical resolution $\leq$ 550 m from the surface to 25m above the mean geoid.
Ice Water Content (Radar-only)	Ice content of non-precipitating clouds to +100%, -50% error, in $\leq$ 550m vertical layers;
Liquid water content (Radar-only)	Liquid content of clouds to $\leq$ 50% error in $\leq$ 550m layers.
Radiative fluxes & heating rates	Estimates of in-cloud heating for each observed 550m cloud layer to within 1K day-1, km-1; Radiative forcing of clouds on longwave, downward, instantaneous radiative fluxes to $\leq$10Wm-2 (1-sigma).

These measurement accuracies are those achievable by CloudSat as a standalone mission. CloudSat will fly in formation with and use data from Aqua and

CALIPSO, which is expected to improve the measurement accuracy of CloudSat's data products.

3.2 INSTRUMENT REQUIREMENTS

3.2.1 Cloud Profiling Radar (CPR) Performance

The vertical (range) resolution of the radar measurements will be 500 ± 50 meters, The radar shall detect reflected signals with a sensitivity of ≤ -26 dBZ at end-of-life. The radar shall be calibrated to ±2.0 dBZ pre-launch. The instantaneous radar footprint (IFOV) on the ground (FWHM) shall be ≤ 2km along-track and ≤ 2 km cross-track. Radar sensitivity performance shall be based on a "science footprint" that is ≤ 5 km along-track and ≤ 2 km crosstrack (FWHM).

3.3 LAUNCH REQUIREMENTS

CloudSat shall be launch-ready in Summer 2005 in a dual launch configuration with the CALIPSO satellite. The launch vehicle will be the Boeing Delta II 7420-10C launch vehicle with a Dual Payload Attach Fitting (DPAF) with CloudSat in the lower berth. CALIPSO and CloudSat shall be launched from Vandenberg Air Force Base (VAFB) in California.

3.4 MISSION OPERATIONS REQUIREMENTS

The CloudSat satellite and ground systems shall be designed for a two-year on-orbit lifetime.

3.5 SCIENCE DATA SYSTEM REQUIREMENTS

CloudSat shall provide science data processing, including levels 1-N data processing, distribution, and data storage during the operational phase of the mission.

CloudSat will store Level 0-2 data products, along with the supporting ancillary data, and will transfer the CloudSat data set to the LaRC DAAC using the EOS-DIS HDF format at the conclusion of the mission.

3.6 MISSION SUCCESS CRITERIA

The first set of global cloud measurements will be complete after one 16-day repeat of the groundtrack orbit. Each subsequent 16-day repeat cycle adds statistical information for cloud system types and seasonal changes. There are an estimated 40 such cycles in the 22 months of operations. Success for CloudSat is defined as the acquisition and processing of cloud radar measurements that will be used to greatly improve understanding of cloud physical properties and global characteristics of multi-layered cloud structures. To do this, CloudSat observations will produce on a global scale a significant improvement over current observational capability in these areas:

1. The first vertically resolved measurements and estimates of ice mass in clouds, with 500 m resolution an accuracy of 50% or better.
2. The first vertically resolved measurements and estimates of the liquid water content of clouds, with 500 m resolution and an accuracy of 30%.
3. The first estimates of the fraction of clouds producing precipitation, including all precipitation types (light or heavy, solid or liquid phase) as well as the clouds in which they occur.
4. The first resolved characteristics of vertical cloud structure.
5. The first observationally based estimates of vertical radiative heating by clouds, with 500 m vertical resolution, and to 1K/day.

4. PUBLIC OUTREACH AND EDUCATION REQUIREMENTS

The CloudSat project shall develop and execute an Education and Public Outreach Plan. Activities will focus on communicating the CloudSat mission and scientific results through informal and formal venues. These activities will include creation of CloudSat content materials, development of education programs that amplify the efforts of CloudSat and stimulate broad awareness and understanding, and the identification of new applications required to incorporate the rewards of CloudSat into the fabric of our everyday life.

5. APPROVAL

- signed -
Alphonso Diaz
Associate Administrator for
Science Mission Directorate

I.3 CLOUDSAT 2015 SENIOR REVIEW

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

SEP 18 2015

Reply to Attn of: SMD/Earth Science Division

TO: CloudSat ~~Principal~~ Graeme Investigator

FROM: Director, Earth Science Division

SUBJECT: Results from the 2015 Senior Review of Earth Science Operating Missions

This letter provides programmatic direction for the CloudSat mission for FY2016-2019, based on the findings of the 2015 Earth Science Division (ESD) Senior Review.

The ESD Senior Review consisted of a series of comprehensive reviews of the missions' science quality, operational utility, and continued engineering/cost performance. A full description of the evaluation process, the factors used by the review panels, and their findings for all missions, may be found in the Senior Review Final Report, located at URL http://science.nasa.gov/earth-science/missions/operating/.

The review panel's findings for CloudSat are:

Adjectival Summary Science Score	Utility Score	Technical Risk	Cost Risk
Excellent	High	Medium-Low	Low

CloudSat's nine years of operations as part of the A-train constellation is an outstanding achievement. CloudSat's single instrument, the Cloud Profiling Radar (CPR) has enabled detailed mapping of the vertical structure of clouds, hydrometeors and precipitation with unprecedented sensitivity, especially for snowfall and light rain. Integrated with the A-train satellites as well as the recently launched GPM, CloudSat observations are instrumental for elucidating fundamental climate processes such as cloud-radiation feedbacks, including aerosol-cloud-rainfall interactions, and the linkages between the water cycle and radiative forcing. CloudSat data can also be used for the evaluation of existing parameterizations of moist processes in numerical weather prediction models, and for the development of new parameterizations of microphysical processes and convection. The continuity of these data products is highly desirable for the scientific community, governmental agencies and the international operational user community. Hundreds of science publications and millions of downloads of CloudSat products, in particular L2 products, attest to their importance and utility. The importance of CloudSat observations to elucidating the global climatology of clouds and to understand their climate role was highlighted by the IPCC AR5 report. By taking advantage of the long data records and the rich suite of L2 and L3 products, the extended mission allows the science to focus on studying moist processes in the context of multi-annual modes of climate variability, a WCRP grand challenge, and ultimately to improve their representation in numerical weather prediction and climate models. While operating in DO-OP (Daylight-Only Operations) mode due to battery issues, the spacecraft and the radar instrument are in good health, and appear to be able to continue to work well during the proposed mission extension.

I have used the panel's assessment in formulating the mission programmatic directions for the FY2016-2019 period. These new guidelines, together with the scope of activities defined in this letter, constitute the new project requirements for the extended mission.

Your response to this direction should be in the form of a letter; the letter should include your project's response to the technical guidance below, and a rationale to address any budget reductions.

Specific guidance for the CloudSat mission is as follows:

> The CloudSat Project is directed to implement the sustainable proposal for extended mission operations for FY16-17. Budget is reduced in the out-years, but may be restored if Cloudsat continues in good health. A 2017 Senior Review proposal is expected.
>
> The Project is also directed to synthesize from the peer-reviewed literature a summary report of CloudSat uncertainties, and to make this available to the user community, in order to enhance the data product documentation for a broader user community.
>
> The Mission Capabilities for the CloudSat mission are unchanged.

All projects are requested to review their Project Plan and their End of Mission Plan, and deliver an updated plan to the ESSP Program Office and SMD/ESD by March 30, 2016. If a review of either document determines that an update is not necessary, the Project may submit instead a memorandum to that effect, including the rationale supporting the conclusion. The Project is also requested to hold an Annual Mission Operations Review, and report results, findings and actions to ESD and the cognizant Program Office by the end of FY2016. Please coordinate review content and date with your Program Office and include this information in your response to this guidance letter.

Funding Direction

Funding guidelines for the CloudSat mission are below. These numbers are in real year $K and represent the new Headquarters guidance for the sum of the traditional mission operations and core data analysis lines, including civil servant labor funds.

FY16	FY17	FY18	FY19
8,275	8,519	4,103	2,000

It is our intention that the guidelines provided are the funds that will be made available to you in FY2016 and FY2017, but we note that changes in available resources and the requirements placed on us require revisiting budget allocations annually, or more frequently as circumstances warrant. If for some reason we believe that the resources to be available will differ from those indicated above, we will let you know as soon as we can. Guidelines for FY2018 and FY2019 should be considered preliminary, to be revisited during the 2017 ESD Senior Review.

I congratulate you and your team on the positive review results, and look forward to your response on October 30. Any questions may be directed to Ms. Cheryl Yuhas, 202-358-0758, Cheryl.Yuhas@nasa.gov.

Michael H. Freilich

cc:
LaRC/Earth System Science Pathfinder Program Office
JPL/Earth Science and Technology Directorate

Appendix J: Aquarius

Table of Contents

Earth System Science Pathfinder Program Office

NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	**Date**	**Change Description**
Baseline	03/29/2011	Initial Release
A	11/01/2017	Updated section J.1 (PLRA 3.0; 4/14/2011)

J.1 AQUARIUS DESCRIPTION

Aquarius collected pioneering space-based measurements of Sea Surface Salinity (SSS) with the precision, resolution, and coverage needed to characterize salinity variations in the surface oceans and investigate the linkage between ocean circulation, the Earth's water cycle, and climate variability. Salinity is required to determine seawater density, which in turn helps govern ocean circulation. SSS variations in the ocean are governed by freshwater fluxes, precipitation, evaporation, runoff, and the freezing and melting of ice. The Argentine Comisión Nacional de Actividades Espaciales (CONAE) was a partner on the project and is providing the SAC-D spacecraft bus, secondary science instruments, as well as the Mission Operations Center and Ground Station for data acquisition and commanding. Aquarius was launched on 10 June 2011 and entered Phase-E operations December 2011. Aquarius completed its primary three-year mission December 2014. Aquarius underwent the 2015 Senior Review which extended the mission through FY 2017. However, on 7 June 2015 the SAC-D spacecraft experienced a failure and communications with the spacecraft and Aquarius instrument were lost. Aquarius successfully completed KDP-F and is in the mist of mission closeout by 30 December 2017. The PI is from Earth and Space Research and is responsible for the scientific integrity of the mission. The PI delegated responsibility for project management to JPL during implementation, launch and commissioning and GSFC assumed project management at the transition to Phase-E.

J.2 AQUARIUS LEVEL 1 REQUIREMENTS

Aquarius Project

A NASA Earth System Science Pathfinder (ESSP) Mission

Level 1 Requirements and Mission Success Criteria

(Appendix J-2 to the ESSP Program Plan)

Version: 3.0
Date: 14 April 2011

Change Log

Revision	Date	Sections Changed	Author
2.0	11/10/09	2.2 – Clarified text; 3.1 – Clarification; 3.2 – Added information on the Operations Phase organization. 4.1.1 – Changed "ice-free oceans" to "open ocean"; 5.1 – Updated to currently approved funding level; 5.2.1.1 – Added to capture mission duration descope direction; 5.3 – Updated to currently approved launch readiness date; Figure 1 – Clarification; Figure 2 added. Approval/concurrence signatures updated.	E. Ianson
3.0	4/14/11	Updates to life-cycle cost and launch readiness date; updated MOU amendment date; updated concurrence/approval list	E. Ianson

Table of Contents

1. Scope

This document describes the Level 1 science, mission, schedule, and cost requirements governing the Earth System Science Pathfinder (ESSP) Aquarius mission. Level 1 Requirements serve as the basis for mission assessments conducted by NASA during the development period and provide the baseline for determining science mission success during the operational phase.

The Aquarius Principal Investigator (PI) is responsible for the overall success of the Aquarius Project, and is accountable to the Associate Administrator of the Science Mission Directorate (SMD). The Aquarius PI delegates the project implementation authority to the Director of the Jet Propulsion Laboratory (JPL), and the JPL Director has delegated this authority to the JPL Earth Science and Technology Directorate (ESTD) and the Aquarius Project Manager. The PI delegates operational phase responsibilities to the Director, Goddard Space Flight Center (GSFC). The Governing Program Management Committee is the NASA SMD Program Management Council.

The Aquarius mission is implemented jointly with the Argentina Comisión Nacional de Actividades Espaciales (CONAE). The CONAE mission is called SAC-D. This joint undertaking is referred to as the Aquarius/SAC-D Mission. Throughout this document, reference to Aquarius will specifically apply to the NASA ESSP Aquarius mission. Reference to Aquarius/SAC-D applies to the integrated NASA-CONAE mission. The implementation of Aquarius/SAC-D is governed by a Memorandum of Understanding (MOU) (see Section 5.4.1).

The Aquarius Level 1 requirements must remain consistent with the MOU. Any changes to the Level 1 requirements specified in this document must be approved by NASA SMD.

2. Science Definition

2.1. Science Objectives

The ESSP Aquarius Project will implement an Exploratory Measurement Mission designed to make pioneering space-based measurements of Sea Surface Salinity (SSS) with the precision, resolution, and coverage needed to characterize salinity variations and investigate the linkage between ocean circulation, the Earth's water cycle, and climate variability. Salinity is required to determine seawater density, which in turn governs ocean circulation. SSS variations are governed by freshwater fluxes due to precipitation, evaporation, runoff and the freezing and melting of ice. The Aquarius SSS measurements will be used to address two key areas of NASA's Earth Science research strategy described ESSP-3 Announcement of Opportunity (AO-01-OES-01):

Earth System Variability and Trends: How are global precipitation, evaporation, and the cycling of water changing?

Earth System Responses and Feedback Processes: How can climate variations induce changes in the global ocean circulation?

In meeting these objectives, Aquarius will also validate a space-based measurement approach and analysis concept that could be used for future systematic SSS monitoring missions.

2.2. Implementation Approach

Space-based SSS measurements are required to provide systematic global mapping because the existing compilation of *in situ* ship and buoy observations is inadequate to meet the science objectives. The *in situ* spatial and temporal sampling is sparse, irregular and largely confined to shipping lanes and the summer season. About 25% of the world oceans have never been sampled, including vast regions of the southern hemisphere. More than 73% of the world oceans have fewer than 10 observations per one-degree square, insufficient to resolve the annual water cycle, interannual variability, or the spatial fronts, eddies and current systems that affect oceanographic circulation processes.

Aquarius will retrieve SSS by microwave remote sensing of surface brightness temperature at L-band, which is governed by the surface salinity, temperature and roughness (due to wind and waves). An integrated L-band microwave radiometer/scatterometer will be developed and deployed as the salinity measuring instrument, consisting of three beams in a pushbroom configuration. The radiometers will measure the L-band microwave surface brightness temperature and the radar scatterometer measurements will be used to derive the brightness temperature correction due to surface roughness. Ancillary measurements of surface temperature, surface wind and other geophysical corrections needed to convert brightness temperature to salinity will be obtained from other satellite observing systems and operational models. Aquarius will provide global sampling on an orderly, comprehensive, spatial and temporal pattern from a low earth orbiting satellite over the open ocean (defined in these requirements as the ocean regions where the microwave emissions are not significantly contaminated by land and ice surfaces which have much higher brightness temperature than the ocean). The observatory will be in a sun-synchronous orbit with the sensors oriented away from the sun to minimize contamination by the L-band solar radiation. Independent calibration and validation will be applied to verify SSS retrieval accuracy. SSS measurements will be provided in practical salinity units (psu) according the international standard Practical Salinity Scale (1978), which is based on seawater electrical conductivity, and is a very near approximation of salt concentration in g/kg.

The open ocean SSS range is ~32-37 psu, and the scale of seasonal-to-inter-annual variations can be as much as 1-2 psu in key regions. Modeling studies show that mapping the mean annual SSS to 0.2 psu accuracy over multiple seasonal cycles on spatial scales of 150 km x 150 km will, at a minimum, enable us to substantially reduce the large uncertainties in the mean global net air-sea freshwater flux, which constitutes ~80% of the global water cycle, and to quantify the associated links to oceanic mean circulation. The Baseline Science Mission enables study of the relevant oceanic processes on intraseasonal to interannual time scales by resolving the SSS with 0.2 psu accuracy on monthly time scales for at least three years. The Minimum Science Mission enables the study of these processes over an annual cycle by resolving the SSS with 0.2 psu accuracy on seasonal time scales for at least one year.

3. Project Definition

3.1. Project Organization and Management

The Aquarius/SAC-D Project includes US institutional partners that are funded by NASA and the international CONAE partnership that is without exchange of funds:

- NASA JPL responsibilities include the Aquarius mission implementation phase project management, Aquarius Project System Engineering; Aquarius Safety and Mission Assurance; Aquarius Instrument, including the scatterometer, antenna, command, data, and power subsystems; Aquarius Instrument integration and test; and data archive.
- NASA GSFC responsibilities include managing the Aquarius PI contract; Aquarius operations phase Project Management; Aquarius instrument radiometer subsystem; science algorithms, calibration and validation; and development and operations of the Aquarius ground data system including NASA-CONAE ground system interfaces.
- NASA Kennedy Space Center (KSC) is responsible for the launch services.
- CONAE responsibilities include development, integration, test and mission operations of the Aquarius/SAC-D observatory; SAC-D service platform; CONAE and third party instruments.

The Aquarius and SAC-D organizations for the implementation phase are shown in *Figure 1*. Key NASA and CONAE management and engineering interfaces for the Aquarius/SAC-D joint implementation are identified. The operational phase organizational changes are reflected in Figure 2. A Joint Steering Group, consisting of senior project and agency officials from both parties, provides overall guidance to the Project and decides any matters that affect the mission launch schedule, Level 1 mission requirements, and other implementation issues not resolved by the respective Project Managers.

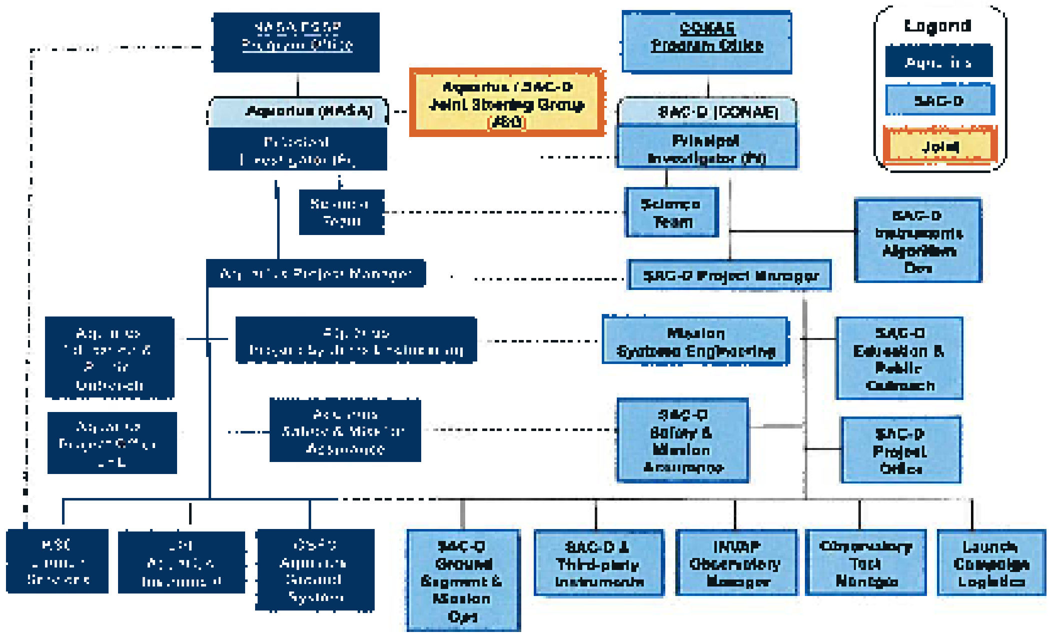

Figure 1: Block diagram showing the Aquarius and SAC-D organizations and their technical/programmatic interfaces during mission implementation phase

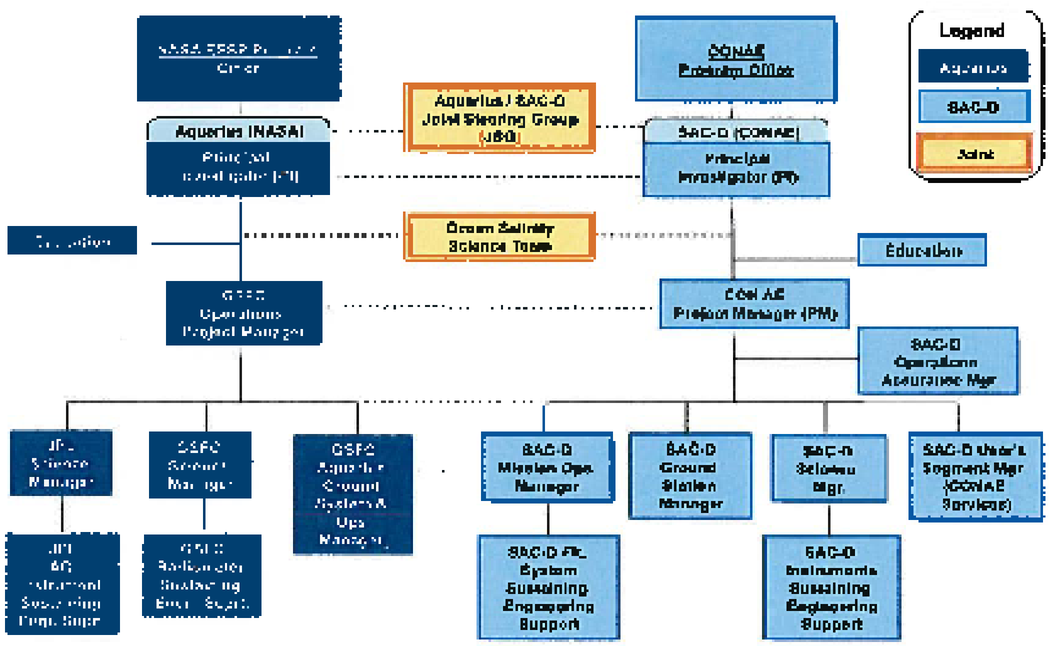

Figure 2: Block diagram showing the Aquarius and SAC-D organizations and their technical/programmatic interfaces during mission operation phase.

3.2. Project Acquisition Strategy

The Aquarius/SAC-D project will be conducted using an observatory made up of the NASA provided Aquarius instrument, SAC-D science instruments, and the SAC-D spacecraft bus (service platform) contributed by CONAE. CONAE's SAC-D requirements are technically and scientifically compatible with Aquarius. The Aquarius/SAC-D mission operations will be conducted using an integrated mission operations system consisting of the CONAE observatory operations control center in Argentina, the GSFC Aquarius science planning and data processing center, and the JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC) for data archive and distribution.

4. Performance Requirements

4.1. Science Requirements

4.1.1. Requirement: The Aquarius Mission shall collect the space-based measurements to retrieve SSS with global root-mean-square (rms) random errors and systematic biases no larger than 0.2 psu on 150 km by 150 km scales over the open ocean;

4.1.2. Requirement: The Baseline Science Mission shall:
- Be at least 3 years in duration.
- Collect data sufficient to produce monthly mean estimates of SSS according to Requirement 4.1.1.

4.1.3. Requirement: The Minimum Science Mission shall:
- Be at least 1 year in duration.
- Collect data sufficient to produce seasonal (3-month) mean estimates of SSS according to Requirement 4.1.1.

4.2. Instrument Requirements

4.2.1. Requirement: The Aquarius instrument radiometers shall operate in the L-band frequency within the Earth Exploration Satellite Service (EESS) passive allocation 1400-1427 MHz.

4.2.2. Requirement: The Aquarius instrument scatterometer shall operate in the L-band frequency EESS active allocation at 1.26 GHz.

4.3. Observatory and Mission Operations Requirements

4.3.1. Requirement: The Aquarius/SAC-D observatory shall fly in a sun synchronous polar Earth orbit that provides coverage to meet the science requirements in Section 4.1.

4.3.2. Requirement: The Aquarius mission shall complete the In-Orbit Checkout (IOC) period within 90 days after launch, and then begin operations according to the science requirements in Section 4.1.

4.4. Launch Requirements

4.4.1. Requirement: NASA shall provide for the launch of the Aquarius/SAC-D observatory from the Vandenberg Air Force Base in California on a dedicated Delta 7320-10 launch vehicle.

4.4.2. Requirement: The launch vehicle and launch services will be procured by NASA through the NASA Kennedy Space Center (KSC).

4.5. Science Measurement Validation Requirements

4.5.1. Requirement: The Aquarius validation program shall assemble and analyze conventional surface *in-situ* measurements from regional and global arrays for instrument calibration and data validation.

4.5.2. Requirement: The *in situ* SSS measurements provided freely by the international Climate Variability (CLIVAR), Global Ocean Observing System (GOOS) Programs or other sources shall be obtained and used. These measurements are available in the public domain and require no external agreements between NASA and other institutions.

4.5.3. Requirement: The Aquarius validation program shall demonstrate that retrievals of SSS meet the science requirements in Section 4.1.

4.6. Data Product Requirements

The Aquarius Data Products are defined in Table 1.

Table 1. Aquarius Data Products

Data Product	Description
Level 1a	Reconstructed Unprocessed Instrument Data
Level 1b	Calibrated Sensor Units
Level 2	Derived Geolocated SSS
Level 3	Time-space averaged SSS on a standard Earth Projection.

4.6.1. Requirement: No later than twelve (12) months after the end of the IOC period, the Aquarius Project shall deliver the first release of data products (containing at least six (6) months of data) in Table 1 to a NASA Distributed Active Archive Center (DAAC).

4.6.2. **Requirement:** After the first release of validated Aquarius data, the Aquarius data products shall be delivered to the DAAC as soon as the validated data are available, but no later than six months after measurements are taken in orbit.

4.6.3. **Requirement:** The final data products produced by the Aquarius Project shall be delivered to the DAAC within six (6) months after the end of the prime mission.

5. Program Requirements

5.1. Budget Requirements

5.1.1. **Requirement:** The total NASA cost for the Aquarius mission shall include the formulation, implementation, launch, operations, calibration, validation, and science data analysis costs to generate the products in Table 1.

5.1.2. **Requirement:** The total direct NASA cost for the Aquarius mission shall not exceed $287.7M.

5.1.3. **Requirement:** The Aquarius mission science investigations shall be augmented by an Ocean Salinity Science Team, funded through a NASA Research Announcement, no later than one year before launch. Funding for the Ocean Salinity Science Team shall not be included in the total NASA mission cost.

5.2. Cost Management and Scope Reduction

5.2.1. **Requirement:** Provided that due consideration has been given to the use of budgetary and schedule reserves, the Aquarius Project shall pursue scope reduction to control cost and mitigate risk. Any potential scope reductions that reduce the science capability from the Baseline Science Mission (section 4.1.1) shall be implemented only with the concurrence of NASA Headquarters and the ESSP Program Office.

5.3. Schedule Requirements

5.3.1. **Requirement:** The Aquarius Project shall target a Launch Readiness Date of June 2011.

5.4. External Agreement Definition

5.4.1. **Requirement:** The Aquarius mission shall be conducted in conjunction with the Argentina space agency, CONAE, which will provide specific mission elements and services identified in an MOU between NASA and CONAE (signed 2 March 2004; amended 21 June 2010).

5.5. Multi-Mission Facilities Requirements

5.5.1. **Requirement:** NASA shall make available the NASA Near Earth Network for coverage of Aquarius/SAC-D launch, critical flight activities in-flight anomaly resolution, and back-up to the CONAE ground station.

5.6. Safety Requirements

5.6.1. **Requirement:** The Aquarius project shall implement a safety and mission assurance plan.

6. Education and Public Engagement Requirements

Requirement: The Aquarius Project shall develop and execute an Education and Public Engagement Plan that utilizes unique scientific and/or engineering aspects of the mission to inspire and motivate the Nation's students and teachers as well as to engage and educate the public. The activities shall aim to stimulate broad awareness and understanding of the role of ocean salinity in the Earth's climate and the links between ocean circulation and the water cycle. The plan shall be optimized for educational and cost effectiveness and build upon the resources and capabilities that NASA has accrued in education and public engagement.

7. Mission Success Criteria

7.1. The Aquarius Mission will be considered fully successful if it:

- Meets the baseline science requirements (see Section 4.1)
- Meets the data product requirements (see Section 4.6)

7.2. The Aquarius Mission will be considered minimally successful if it:

- Meets the minimum science requirements (see Section 4.1)
- Meets the data product requirements (see Section 4.6)

8. Approvals

Edward Weiler — Date: 5-23-11
Associate Administrator, Science Mission Directorate
NASA Headquarters

Charles Elachi — Date: 5-5-11
Director, Jet Propulsion Laboratory

Robert Strain — Date: 5/13/11
Director, Goddard Space Flight Center

Frank Peri — Date: 9 May 2011
Program Manager
Earth System Science Pathfinder Program

9. Concurrences

Gary Lagerloef — Date: 5/3/2011
Principal Investigator, Aquarius Mission
Earth and Space Research

Amit Sen — Date: 5/3/2011
Project Manager for Development, Aquarius Mission
Jet Propulsion Laboratory

Diane Evans — Date: 5/3/11
Director, Earth Science and Technology Directorate
Jet Propulsion Laboratory

Gene Feldman — Date: 12 May 2011
Project Manager for Operations, Aquarius Mission
Goddard Space Flight Center

Nicholas White — Date: 5/12/2011
Director, Science and Exploration Directorate
Goddard Space Flight Center

James Wells — Date: 5/9/11
Mission Manager
Earth System Science Pathfinder Program

Eric Lindstrom — Date: 5/16/11
Program Scientist
Science Mission Directorate, NASA Headquarters

Eric Ianson — Date: 5/16/11
Program Executive
Science Mission Directorate, NASA Headquarters

Steve Volz — Date: 5/23/2011
Associate Director for Flight Projects, Earth Science Division
Science Mission Directorate, NASA Headquarters

Michael Freilich — Date: 17 May 2011
Director, Earth Science Division
Science Mission Directorate, NASA Headquarters

Ken Ledbetter — Date: 5/18/11
Chief Engineer
Science Mission Directorate, NASA Headquarters

Mike Luther — Date: 5/20/11
Deputy Associate Administrator for Programs
Science Mission Directorate, NASA Headquarters

Chuck Gay — Date: 5/23/11
Deputy Associate Administrator
Science Mission Directorate, NASA Headquarters

J.3 AQUARIUS COMMITMENT BASELINE

The following section details the Aquarius Project commitments as proposed to Congress in the 2011 President's Budget Request.

Project Commitments

Project commitments include major mission architecture elements and the organization responsible for providing that element. The primary responsibility for ESSP is to enable successfully delivery of the JPL Aquarius instrument to CONAE.

Table 01 summarizes Aquarius Project commitments.

Table 01: Aquarius Project Commitments

Project Element	Provider	Description	FY 2010 PB Request	FY 2011 PB Request
Aquarius Instrument (integrated radiometer/ scatterometer)	JPL	L-band microwave radiometer at 1.413 GHz; scatterometer at 1.26 GHz; SSS measurements with root-mean-sq. random errors and systematic biases ≤ 0.2 psu on 150 km sq. scales over ice-free oceans.	Same	Same
Spacecraft	CONAE	SAC-D	Same	Same
Launch Vehicle	Boeing	Delta II	Same	Same
Data Management	GSFC	N/A	Same	Same
Operations	CONAE	Command and telemetry	Same	Same

Schedule Commitments

The Aquarius mission entered a Risk Mitigation Phase (RMP) in July 2002. Following the RMP, the Project was authorized to proceed to a formulation phase in December 2003. The Aquarius Project was authorized by the NASA SMD to proceed to development on October 12, 2005. In November 2007, the NASA Science Directorate Program Management Council (DPMC) approved a rebaseline of Aquarius, including a launch delay to May 2010. In December 2009, the NASA Science DPMC approved another rebaseline of Aquarius, including a launch delay manifesting the Aquarius/SAC-D mission for a January 2011 launch. The Aquarius schedule commitments are summarized in Table 02 and Table 03 for the second rebaseline. Table 04 summarizes development cost through the second rebaseline.

Table 02: Aquarius Schedule Commitments

Milestone Name	Confirmation Baseline	FY 2010 PB Request	FY 2011 PB Request
Development			
Project Confirmation Review	September 2005	September 2005	September 2005
Project CDR	August 2007	July 2008	July 2008
Aquarius Instrument Pre-ship Review [FY 2008 APG]	May 2008	May 2009	May 2009
Launch	March 2009	May 2010	January 2011

Table 03: Aquarius Development Cost and Schedule Summary

Project	Base Year	Base Year Development Cost Estimate ($M)	Current Year	Current Year Development Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Date	Current Year Milestone Date	Milestone Change (months)
Aquarius	2007	192.6	2010	222.6	16	Launch Readiness	07/2009	01/2011	18

Table 04: Aquarius Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Delta
Total:	192.6	222.6	30.0
Payloads	55.4	96.1	40.7
Launch Vehicle/Services	78.9	79.4	0.5
Ground Systems	5.5	5.5	0.0
Science/Technology	10.9	11.8	0.9
Other Direct Project Cost	41.9	29.8	-12.1

Project Management

The Jet Propulsion Laboratory is responsible for project management. The Science DPMC is responsible for program oversight. The ESD Director is the responsible official. Table 5 summarizes responsibilities for Aquarius Project elements.

Table 5: Aquarius Project Element Responsibilities

Project Element	Project Management Responsibility	NASA Center Performers	Cost-Sharing Partners
Launch Vehicle	KSC	KSC	None
Ground System	JPL	GSFC	None
Aquarius Instrument	JPL	JPL	None
Spacecraft	CONAE	None	CONAE
Radiometer	JPL	GSFC	None
Data management	GSFC	GSFC/JPL	None
Mission operations	CONAE	None	CONAE

J.4 AQUARIUS 2015 SENIOR REVIEW

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

SEP 1 8 2015

Reply to Attn of: SMD/Earth Science Division

TO: Aquarius Principal Investigator

FROM: Director, Earth Science Division

SUBJECT: Results from the 2015 Senior Review of Earth Science Operating Missions

This letter provides programmatic direction for the Aquarius mission for FY2016-2019, based on the findings of the 2015 Earth Science Division (ESD) Senior Review, as modified by the subsequent events of June 7, 2015.

The ESD Senior Review consisted of a series of comprehensive reviews of the missions' science quality, operational utility, and continued engineering/cost performance. A full description of the evaluation process, the factors used by the review panels, and their findings for all missions, may be found in the Senior Review Final Report, located at URL http://science.nasa.gov/earth-science/missions/operating/.

The review panel's findings for Aquarius are:

Adjectival Summary Science Score	Utility Score	Technical Risk	Cost Risk
Excellent	High	Low	Low (Blue)

Aquarius successfully completed its primary 3-year mission phase in November 2014, demonstrating that the hardware, mission operations, and data science and data product development approaches are combining to yield all new weekly to monthly sea surface salinity (SSS) datasets that further the overall objectives of NASA's Earth Science program. The global SSS data products in swath and gridded form have already been made openly available to the broader science community in a well-documented fashion. The project calibration and validation team has been active in developing the tools needed to assess the salinity data against Argo buoy, climatology, and model products. The project has achieved success in refining the data product accuracy and rms errors to achieve the monthly

SSS 0.2 psu rms error level by end of prime mission. The new version4 datasets for science applications, reflecting latest refinements, will be released in the coming months. New scientific results are already forthcoming, with 111 publications to date, that address ocean circulation dynamics and prediction, land-ocean exchange of freshwater, cyclone impacts on the upper ocean, and atmosphere-ocean coupling associated with freshwater fluxes.

Given this positive assessment by the panel, the loss of the Aquarius mission due to the premature failure of its host platform is unfortunate. The panel was unanimous in providing a post-review comment on the importance and value of the Aquarius data products, and encouraging the production of a final archival dataset for the community.

I have used the panel's assessment in formulating the mission programmatic directions for the FY2016-2019 period. Specific guidance for the Aquarius mission is as follows:

> The Aquarius Project is directed (1) to prepare a Phase F plan that will deliver within two years a final dataset that meets the ESDIS Data Preservation Specification, and (2) to support a KDP-F on October 5, 2015.

Funding Direction

Preliminary funding guidelines for the Aquarius mission are below. These numbers are in real year $K and represent the sum of the traditional mission operations and core data analysis lines, including civil servant labor funds.

FY16	FY17	FY18	FY19
5,538	4,357	-	-

These are not-to-exceed numbers, and may change based on the decisions from the KDP-F on October 5, 2015. Your response to this direction will be the Project's Phase F plan as presented in the October 5, 2015 KDP-F, and documented in your signature on the Decision Memorandum from that review. No other response will be required.

My appreciation to your team for the mission's excellent performance during its lifetime, and I look forward to your response on October 5. Any questions may be directed to Ms. Cheryl Yuhas, 202-358-0758, Cheryl.Yuhas@nasa.gov.

Michael H. Freilich

cc:
LaRC/Earth System Science Pathfinder Program Office
GSFC/Sciences & Exploration Directorate
JPL/Earth Science and Technology Directorate

Appendix K: Orbiting Carbon Observatory-2 (OCO-2)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	Updates to Section K.1 and PLRA 2.0; 1/16/2013

K.1 OCO-2 DESCRIPTION

The original Orbiting Carbon Observatory was launched on February 24, 2009, but was lost after the launch vehicle payload fairing failed to separate. OCO-2 was successfully launched July 2, 2014. Like its predecessor, OCO-2 was designed to return the space-based measurements needed to provide global estimates of atmosphere carbon dioxide (CO_2) with the sensitivity, accuracy, and sampling density needed to quantify regional scale carbon sources and sinks and characterize their behavior over the annual cycle. For its successful two-year prime mission, OCO-2 flew in the Afternoon Constellation (A-Train constellation) in a Sun-synchronous orbit that provides near global coverage of the sunlit portion of the Earth with a 16-day repeat cycle. Its single instrument incorporates three high-resolution grating spectrometers that are designed to measure the near-infrared absorption of reflected sunlight in CO_2 and molecular oxygen (O_2) absorption bands. OCO-2's prime mission validated a space-based measurement approach and analysis concept that can be used for future systematic CO_2 monitoring projects. OCO-2 will submit a 2017 Senior Review Proposal to extend the mission through 2019. The Project Manager leads the JPL Project team and is responsible to NASA for scientific integrity and project management.

K.2 OCO-2 LEVEL 1 REQUIREMENTS

Appendix K - Earth System Science Pathfinder Program Plan

Program-Level Requirements for the Orbiting Carbon Observatory – 2 Project

Version: 2.0
Date: 16 January 2013

Change Log

Revision	Date	Sections Changed	Author
1.0	9/24/2010	Initial Release	E. Ianson
2.0	1/16/2013	4.3 – Revised launch date; 4.5.1 – revised data management requirements to be compliant with updated JPL-ESD agreement; 4.6 – revised mission success criteria; 5.1 - revised LCC estimate; updated signatories; added header and footer; updated ToC	S. Volz

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1.0 SCOPE

This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on the Jet Propulsion Laboratory (JPL) for the development and operation of the Orbiting Carbon Observatory – 2 (OCO-2) Project of the ESSP Program. Requirements begin in Section 4. Sections 1, 2 & 3 are intended to set the context for the requirements that follow.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division within SMD to the ESSP Program Manager at Langley Research Center. Project management will be conducted at JPL. See Section 3.1.

JPL is responsible for scientific success, design, development, test, mission operations, and data verification tasks and shall coordinate the work of all contractors and science team members.

The NASA Earth Science Division will select the investigators that will compose the OCO-2 Science Team through a competitive process.

Changes to information and requirements contained in this document require approval by the Science Mission Directorate (SMD), NASA Headquarters by the officials that approved the original.

OCO-2 is based on the original OCO mission, which was developed under the NASA Earth System Science Pathfinder (ESSP) Program Office and launched from Vandenberg Air Force Base on February 24, 2009. Before spacecraft separation, a launch vehicle anomaly occurred that prevented the spacecraft from reaching injection orbit. The spacecraft was destroyed during re-entry and was unrecoverable.

2.0 SCIENCE DEFINITION

2.1 Baseline Science Objectives

The ESSP OCO-2 Project will implement an exploratory science mission designed to collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO2}, with the precision, resolution, and coverage needed to improve our understanding of surface CO_2 sources and sinks (fluxes) on regional scales (≥1000 km) and the processes controlling their variability over the seasonal cycle. This mission will also validate a space-based measurement approach and analysis concept that could be used for future systematic CO_2 monitoring missions.

2.2 Science Instrument Summary Description

The OCO-2 instrument incorporates three near-infrared spectrometers designed to measure reflected sunlight in CO_2 and molecular oxygen (O_2) absorption bands. Soundings, consisting of coincident CO_2 and O_2 spectra, are analyzed with a remote sensing retrieval algorithm to yield spatially-resolved estimates of X_{CO2}. The spectrometer optical design, spectral range, and resolving power were selected to optimize measurement precision and minimize bias. Spectra collected at wavelengths near 1.61 microns are most sensitive to variations in the CO_2 concentration near the surface. Coincident measurements from the O_2 A-band and the CO_2 band near 2.06 microns minimize X_{CO2} errors associated with pointing uncertainties and scattering by thin clouds and aerosols. The small ($\leq 3\ km^2$) sounding footprint is expected to yield > 100 cloud-free soundings on regional scales over > 80% of range of latitudes on the sunlit hemisphere at monthly intervals.

The precision and bias of space-based X_{CO2} retrievals can only be validated at locations where X_{CO2} is well characterized by other methods. OCO-2 results will be validated through comparisons with X_{CO2} retrievals from selected ground-based spectrometers in the Total Column Carbon Observing Network (TCCON). Retrievals from TCCON stations designated as OCO-2 "primary ground validation sites" have been validated against in situ CO_2 profiles collected during aircraft overflights of the station, using measurement techniques traceable to World Meteorological Organization standards for atmospheric CO_2 measurements. OCO-2 can acquire > 100 soundings in the vicinity of a TCCON station in a single cloud-free overflight. At least once each season, space-based X_{CO2} retrievals from cloud-free overflights of ≥ 3 of the primary ground validation sites will be compared with TCCON retrievals to validate the OCO-2 measurement precision and to identify global-scale systematic biases in its space-based X_{CO2} product.

3.0 PROJECT DEFINITION

3.1 Project Organization & Management

The OCO-2 Project Manager shall report to NASA according to Figure 1.

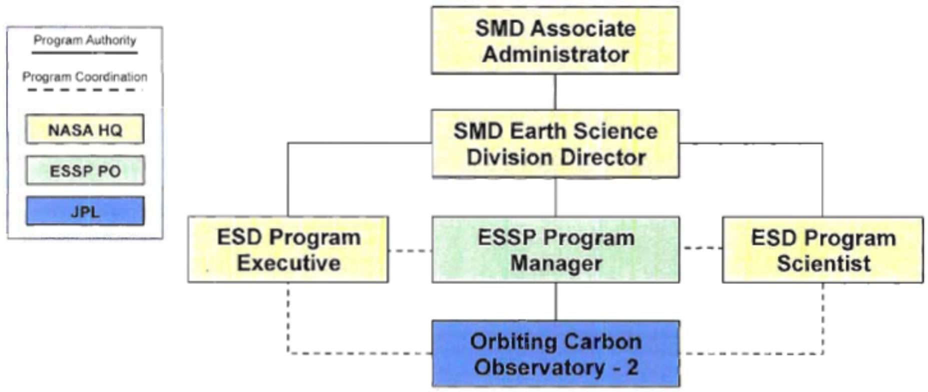

Figure 1. OCO-2 Programmatic Lines of Authority and Coordination

The OCO-2 Project Manager has overall management responsibility for the success of the project. The OCO-2 Project Scientist has overall management responsibility for the science elements of the project. Specific assigned roles and responsibilities are:

- JPL is responsible for providing: the Project Scientist; project management; system engineering and mission design; safety and mission assurance; the instrument; spacecraft; mission operations and the associated mission operations ground data system; science data processing and delivery of calibrated/validated science data products to an archive for public distribution.

- NASA is responsible for providing a launch vehicle and launch services for OCO-2 and access to the SN (Space Network) for S-band uplink and downlink and Near Earth Network (NEN) for S-band uplink and downlink and X-band downlink compatible with the OCO-2 mission. The Goddard Earth Sciences Data and Information Services Center (GES DISC) is responsible for public distribution of OCO-2 data and long-term science data archiving.

3.2 Project Acquisition Strategy

JPL will implement an in-house development of the instrument, utilizing commercial vendors for parts and assemblies. However, the instrument cryocoolers will be obtained from the GOES-R (Geostationary Operational Environmental Satellite, R-Series) Program through an inter-agency transfer between NASA and NOAA (National Oceanic and Atmospheric Administration). Orbital Science Corporation (OSC) is contracted to provide the spacecraft development, integration, test, launch operations, and mission operations support. NASA's Launch Services Program at Kennedy Space Center will provide the launch vehicle. Sole source justifications will be implemented based on the past experience on OCO.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA and the Earth Science Community.

4.1 Science Requirements

4.1.1 Baseline Science Requirements

a) Retrieve estimates of the column-averaged CO_2 dry air mole fraction (X_{CO2}) on regional scales (≥1000 km) from space-based measurements of the absorption of reflected sunlight by atmospheric CO_2 and O_2, collected in cloud-free scenes over ≥ 80% of the range of latitudes on the sunlit hemisphere at monthly intervals for 2 years.

b) Compare space-based and ground-based X_{CO2} retrievals from soundings collected during overflights of ≥ 3 primary ground validation sites at least once each season to identify and correct global-scale systematic biases in the space-based X_{CO2} product and to demonstrate a precision of ≤ 0.3% for collections of ≥100 cloud-free soundings.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the GES DISC for use by the scientific community.

d) Validate a space-based measurement approach and analysis concept that could be used for future systematic CO_2 monitoring missions.

4.1.2 Threshold Science Requirements

a) Retrieve estimates of the column-averaged CO_2 dry air mole fraction (X_{CO2}) on regional scales (≥1000 km) from space-based measurements of the absorption of reflected sunlight by atmospheric CO_2 and O_2, collected in cloud-free scenes over ≥ 80% of the range of latitudes on the sunlit hemisphere at monthly intervals for ≥ 1 year.

b) Compare space-based and ground-based X_{CO2} retrievals from soundings collected during overflights of ≥ 3 primary ground validation sites at least once each season to identify and correct global-scale systematic biases in the space-based X_{CO2} product and demonstrate a precision of ≤ 0.5% for collections of ≥100 cloud-free soundings.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the GES DISC for use by the scientific community.

d) Validate a space-based measurement approach and analysis concept that could be used for future systematic CO_2 monitoring missions.

4.1.3 Science Instrument Requirements

a) The space-based instrument shall be capable of acquiring coincident measurements of reflected sunlight in the CO_2 bands centered at wavelengths near 1.61 and 2.06 μm and in the O_2 A-band centered near 0.765 μm.

b) The spectral range and resolving power of the space-based instrument shall be selected to resolve individual absorption lines from the underlying continuum throughout each CO_2 and O_2 band to retrieve estimates of X_{CO2} that meet the Science Requirements (Section 4.1).

c) The OCO-2 instrument shall be capable of acquiring CO_2 and O_2 soundings with a footprint size ≤ 3 km^2 at nadir to facilitate the acquisition of cloud-free scenes in at least 10% of the soundings collected over the sunlit hemisphere on monthly time scales.

4.2 Mission and Spacecraft Performance

a) The OCO-2 project shall be Category 2 per NPR 7120.5E, and the payload class shall be C per NPR 8705.4.

b) The OCO-2 mission shall complete the In-Orbit Checkout (IOC) period within 90 days after launch, and then begin operations consistent with the science requirements in Section 4.1.1.

c) The Observatory shall fly in a sun-synchronous low Earth orbit that provides access to ≥90% of the range of latitudes on the sunlit hemisphere at least once a month.

d) After IOC, the Observatory's orbit nodal crossing time shall be between 11AM and 2PM, and vary by less than 15 minutes during the science mission as defined in Section 4.2(e).

e) The OCO-2 mission lifetime is 2 years baseline (1 year threshold) following completion of IOC.

4.3 Launch Requirements

a) The Observatory shall be launched on an expendable launch vehicle of Risk Category 2 or 3, per NPD 8610.7C with a payload isolation damping system, if needed.

b) The OCO-2 project shall target a Launch Readiness Date in July 2014.

4.4 Ground System Requirements

The OCO-2 project shall develop a ground system to meet the performance requirements in section 4.1 and the reprocessing and data latency requirements in section 4.5.

4.5 Mission Data Requirements

4.5.1 Science Data Management

a) The OCO-2 Project shall produce the standard science data products listed in Table 1.

b) All data and the standard science data products listed in Table 1, along with the coefficients and ancillary data used to generate these products, will be delivered to the GES DISC in accordance with the NASA Earth Science Data and Information (ESD&I) Policy specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/. Public release of these data shall also conform to the NASA ESD&I Policy. There shall be no period of exclusive access. An Algorithm Specification Document (ASD) that provides information to validate the data products generated by the computer software, to the same extent that is provided by the computer software source code, shall be developed and delivered. Requests for Algorithm Specification Documents or computer software source code for the purpose of validation of the data products generated by the software shall be addressed in conformance with the existing JPL Prime Contract.

c) Science algorithms used to generate the standard data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).

d) The OCO-2 Project will coordinate with the GES DISC the release of product versions, to ensure completeness and accuracy of quality information, validation status, and metadata of the OCO-2 science data products.

e) The OCO-2 Project will coordinate with GES DISC regarding the data and information to be transferred at OCO-2 Project closeout.

4.5.1.1 Science Data Requirements

a) OCO-2 Level 1 and Level 2 science data product formats shall conform to the Hierarchical Data Format (HDF5) standard.

b) The metadata for the OCO-2 standard data products listed in Table 1 shall conform to the Earth Observing System (EOS) Clearinghouse (ECHO) Science Metadata Model.

c) The OCO-2 Project shall transfer to the GES DISC all the information and documentation required for long-term preservation of knowledge about the products resulting from OCO-2 using the *NASA Earth Science Data Preservation Content Specification* document published at http://earthdata.nasa.gov/about-eosdis/requirements as guidance.

d) The OCO-2 Project shall deliver reprocessed data products which meet the science requirements in Section 4.1 within 6 months after completion of the science mission as specified in Paragraph 4.2.e.

e) X_{CO2} products mapped on a uniform spatial grid shall be produced by the OCO-2 Project.

Table 1. OCO-2 Data Products

Data Product	Description	Initial Availability to NASA DAAC	Subsequent Validated data deliveries to NASA DAAC after initial release
Level 0	Raw collected telemetry	Within 24 hours of receipt from EDOS*	Within 24 hours of receipt from EDOS*
Level 1	Calibrated Geolocated Spectral Radiances	3 months after IOC**	3 weeks**
Level 2	X_{CO2}	3 months after Level 1 data products are available	6 weeks**

* EDOS: (Earth Observing System) Data and Operations System
**Delivery latency after ground receipt

4.5.2 Applied Science Data Requirements

Beginning in Phase C, the OCO-2 Project shall participate in an OCO-2 data product application workshop annually. The workshop will share information on OCO-2 science data applications and define potential applications that can be supported with existing OCO-2 data requirements. Results of the workshop will be provided to the OCO-2 science team and at other OCO-2 workshops and meetings.

4.6 Mission Success Criteria

The OCO-2 Project will implement an exploratory science mission to collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO2}. Specifically, the OCO-2 Project will:

a) Collect global space-based measurements of atmospheric carbon dioxide (CO_2) with the precision, resolution, and coverage needed to improve understanding of CO_2 sources and sinks and quantify their variability over an annual cycle.
b) Validate a space-based measurement approach and analysis concept for future systematic CO_2 monitoring missions.
c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the GES DISC for use by the scientific community.

5.0 NASA MISSION COST REQUIREMENT

5.1 Cost

The OCO-2 life cycle cost (LCC), without HQ UFE, shall not exceed $437.7 M. The LCC includes the cost for the formulation, implementation, launch, operations, calibration, validation, science data analysis costs to generate the products in Table 1, and $10M (a not-to-exceed figure) for the two cryocoolers obtained from the NOAA GOES-R Program.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the OCO-2 project shall pursue scope reduction and risk management as a means to control cost. The Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised.

Scope reductions from baseline science requirements (Section 4.1.1) to threshold science requirements (Section 4.1.2) or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of document.

6.0 MULTI-MISSION NASA FACILITIES

a) The NASA Near Earth Network (NEN) shall be made available by NASA for S-band uplink and downlink and X-band downlink compatible with the OCO-2 Mission.

b) The SN, also known as the NASA Tracking and Data Relay Satellite System (TDRSS) shall be made available by NASA for rapid communications between the spacecraft and ground during the IOC, orbit correction maneuvers, and emergencies.

7.0 EXTERNAL AGREEMENTS

a) The OCO-2 mission shall include no flight hardware or flight software contributions from organizations outside of NASA, precluding the need for external agreements for flight hardware or software contributions.

b) The OCO-2 Project shall reimburse NOAA (National Oceanic and Atmospheric Administration) for the two GOES-R (Geostationary Operational Environmental Satellite, Series R) Program cryocoolers per the countersigned inter-agency transfer MOA (Memorandum of Agreement).

c) The scope of the contributions from the international or interagency partners on the OCO-2 Science Team, validation activities, or data sharing shall be described in formal agreements between NASA and these organizations.

8.0 PUBLIC OUTREACH AND EDUCATION

The OCO-2 project shall develop and execute an Education and Public Outreach Plan.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the OCO-2 Project.

10.0 WAIVERS

The OCO-2 Project was granted Agency approval to complete a tailored formulation phase that reduced that number of KDP gates, gate product versions, and technical reviews during this period.

11.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS

John M. Grunsfeld — Date: 1/13/13
Associate Administrator, Science Mission Directorate
NASA Headquarters

Charles Elachi — Date: 1/4/13
Director, Jet Propulsion Laboratory

Frank Peri — Date: 1/8/13
Program Manager, Earth System Science Pathfinder Program
NASA Langley Research Center

CONCURRENCES

[signature] 1/4/2013
Ralph Basilio Date
Project Manager, OCO-2 Mission
Jet Propulsion Laboratory

[signature] 1/4/2013
Michael Gunson Date
Project Scientist, OCO-2 Mission
Jet Propulsion Laboratory

[signature] 1/4/13
Diane Evans Date
Director, Earth Science and Technology Directorate
Jet Propulsion Laboratory

[signature] 1/7/13
Jim Wells Date
Mission Manager, Earth System Science Pathfinder Program Office
NASA Langley Research Center

[signature] 1/14/2013
Ken Jucks Date
Program Scientist
Science Mission Directorate, NASA Headquarters

CONCURRENCES, Continued

Stephen Volz — Date: 12/21/12
OCO-2 Program Executive (Acting)
Science Mission Directorate, NASA Headquarters

Stephen Volz — Date: 12/21/12
Associate Director for Flight Programs, Earth Science Division
Science Mission Directorate, NASA Headquarters

Michael Freilich — Date: 4 Jan 13
Director, Earth Science Division
Science Mission Directorate, NASA Headquarters

Tristram (Tupper) T. V. Hyde — Date: 8 Jan 13
Science Mission Directorate Chief Engineer
Office of the Chief Engineer, NASA Headquarters

Marc Allen — Date: 1/15/12
Chief Scientist
Science Mission Directorate, NASA Headquarters

Mike Luther — Date: 1/16/12
Deputy Associate Administrator for Programs
Science Mission Directorate, NASA Headquarters

Chuck Gay
Deputy Associate Administrator
Science Mission Directorate, NASA Headquarters

1/19/13
Date

K.3 OCO-2 COMMITMENT BASELINE

Management commitment; the Program Manager and Mission Directorate agree that the Project can be completed within the External (External to NASA) Commitment as listed in the right column in the table above.

NASA SMD Program Management Council
Project KDP Decision Agreement

Summary: The Science Mission Directorate Program Management Council met on September 24, 2010 and evaluated the Orbiting Carbon Observatory – 2 (OCO-2) project's Key Decision Point C of the life cycle as defined in NASA Procedural Requirement 7120.5: Space Flight Program and Project Management Requirements. The DPMC determined that the project is ready to proceed to Phase C.

Decision: Based on this review and the project readiness documents, the Decision Authority for the OCO-2 project grants approval for the project's Phase C with the content, schedule, and cost profile specified in the attached summary and reflected in Table 1, below. The OCO-2 project has significantly leveraged the experience from OCO and has been funded appropriately (both total LCC and phasing) to put the project an excellent position to succeed. This decision includes the actions specified below.

Table 1: KDP-C Cost and Schedule Baseline Commitments

	Management (Internal to Project) [1]	**Agency Baseline Commitment** (Reported External to NASA) [2]
Cost – LCC (Phases A through F) Commitment	$325.9M	$349.9M
Cost – Development (Phases C & D) Commitment	$227.0M	$249.0M
Schedule (LRD)	February 2013	February 2013
Years/Months of Operations	24 months	24 months
Joint Confidence Level (Cost and Schedule)	>50%	>70%

Notes:
- The JCL was performed for Phases C & D, excluding project managed Unallocated Future Expenses (UFE), JPL fees, launch services, and low-level fixed cost activities at GSFC (Exploration and Space Communications, EOS Data and Operations System, Flight Dynamics Facility, and NASA Integrated Services Network)
- The Development Commitment includes all activities for Phases C & D
- Months of operation is after the In-Orbit Checkout (IOC) Period

[1]Includes the UFE and schedule margin to be managed by the project, project labor, and project CoF.
[2]Includes all project UFE and schedule margin, including UFE and margin to be managed above the project. Also includes legacy indirect costs.

Concurrence

Project/Mission Manager	Date		
Program Manager	Date	Program Executive	Date
MD Division/Theme Director	Date	Center Director	Date
Chief Engineer designee	Date	Chief Financial Officer designee	Date

Approval

MD Associate Administrator   Date

During formulation, the Project Manager agrees that the ensuing phase can be completed within the Management commitment. During implementation, the Project Manager agrees that the project lifecycle can be completed within the

Appendix L: Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	**Date**	**Change Description**
Baseline	03/29/2011	Initial Release
A	11/01/2017	• PLRA removed • AirMOSS project completed 3/31/2016 • KDP-F added

G.4 AIRMOSS DESCRIPTION

North American ecosystems are critical components of the global carbon cycle, exchanging large amounts of carbon dioxide and other gases with the atmosphere. Root-zone soil measurements can be used to better understand these carbon fluxes and their associated uncertainties on a continental scale. The goal of the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) investigation is to provide high-resolution observations of root-zone soil moisture over regions representative of the major North American climatic habitats (biomes), quantify the impact of variations in soil moisture on the estimation of regional carbon fluxes, and extrapolate the reduced-uncertainty estimates of regional carbon fluxes to the continental scale of North America.

AirMOSS will use an airborne ultra-high frequency synthetic aperture radar to penetrate through substantial vegetation canopies and soil to depths down to approximately 1.2 meters. For AirMOSS, NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) will be flown on a Gulfstream-III aircraft. Extensive ground, tower, and aircraft in-situ measurements will validate root-zone soil measurements and carbon flux model estimates. The surveys will provide measurements at 100 meter spatial resolution and at sub-weekly, seasonal, and annual time scales.

AirMOSS responds directly to challenges set down by the NASA Carbon Cycle Science and the North American Carbon Program. Additionally, AirMOSS data provide a direct means for validating root-zone soil measurement algorithms from the Soil Moisture Active & Passive (SMAP) mission and assessing the impact of fine-scale heterogeneities in its coarse-resolution products.

The UAVSAR instrument operating for the first time at UHF band will provide measurements of root zone soil moisture, net ecosystem exchange, CO_2, CH_4, H_2O, soil moisture, temperature and water potential profile. The tower sites will use Fluxnet sensors and provide soil moisture, temperature, vegetation characteristics and water and carbon flux. The in-situ aircraft instrument will be the Piccaro spectrometer, which will measure CO_2, CH_4, and H_2O. The Piccaro instrument will be flown on the Purdue Airborne Laboratory for Atmospheric Research (ALAR) aircraft, which is a Beechcraft 76. Tower and aircraft instruments have been used in numerous missions over several years.

The PI is from the University of Southern California, Los Angeles, CA, and JPL is responsible for project management.

Cost: $25.9M over five years (2010-2015)

G.5 KDP-F DECISION MEMO

NASA Earth Science Division Program Management Council
AirMOSS KDP-F Review Decision Memorandum

Summary: The Earth Science Division Program Management Council (ESD PMC) met on February 23rd, 2016 and evaluated the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) investigation results to date as measured against the Program-Level Requirements & Investigation Success Criteria and the investigations readiness to enter the closeout phase of the investigation. The AirMOSS Principal Investigator, Dr. Mahta Moghaddam, and the AirMOSS Project Manager, Ms. Yunling Lou, presented a summary of the investigations science findings and accomplishments against their requirements. The $25.857M investigation will meet all PLRA requirements by investigation closeout.

Decision: Based on this review the Decision Authority for the AirMOSS Investigation grants approval for the project's closeout activities and successful completion of KDP-F.

Concurrence:

Principal Investigator	2/23/2016 Date
Program Scientist	Feb 23, 2016 Date
Earth System Science Pathfinder (ESSP) Program	23 Feb 16 Date
Program Executive	23 Feb 16 Date
Resource Management Division	2-24-16 Date
ESD Associate Director, Research	2/23/16 Date
ESD Associate Director, Flight	2/23/16 Date

Approval:

Earth Science Division Director	2/24/16 Date

Appendix M: Airborne Tropical Tropopause Experiment (ATTREX)

Table of Contents

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	• PLRA removed • ATTREX project completed 07/20/2016 • KDP-F added

M.1 ATTREX DESCRIPTION

The Stratospheric water vapor has large impacts on the Earth's climate and energy budget. Future changes in stratospheric humidity and ozone concentration in response to changing climate are significant climate feedbacks. While the tropospheric water vapor climate feedback is well represented in global models, predictions of future changes in stratospheric humidity are highly uncertain because of gaps in our understanding of physical processes occurring in the region of the atmosphere that controls the composition of the stratosphere, the Tropical Tropopause Layer. Uncertainties in the Tropical Tropopause Layer region's chemical composition also limit our ability to predict future changes in stratospheric ozone. By improving our understanding of the processes that control how much water vapor gets into this region from lower in the atmosphere, the ATTREX investigation will directly address these uncertainties in our knowledge of the climate system.

The proposed instruments will provide measurements to trace the movement of reactive halogen-containing compounds and other important chemical species, the size and shape of cirrus cloud particles, water vapor, and winds in three dimensions through the Tropical Tropopause Layer. In particular, bromine-containing gases will be measured to improve our understanding of stratospheric ozone. ATTREX will consist of four NASA Global Hawk Unmanned Aircraft System (UAS) campaigns deployed from NASA's Dryden Flight Research Center (DFRC) in Edwards, CA, Guam, Hawaii, and Darwin, Australia taking place in Boreal summer, winter, fall, and summer, respectively.

The proposed investigation fills several significant gaps in atmospheric science identified in the 2007 Decadal Survey involving climate change, stratospheric ozone, and stratosphere-troposphere exchange.

ATTREX uses a Cloud Physics LIDAR (CPL) to provide aerosol/cloud backscatter. The ATTREX instrument is a copy of one which first deployed in 2000 and is currently awaiting its first flight. An absorption photometer measures ozone and has flown on several WB-57 missions. An Advanced Whole Air Sampler (AWAS) measurers tracers with varying lifetimes and will need to be modified for this series of missions. A UAS Chromatograph for Atmospheric Trace Species (UCATS) measures O_3, CH_4, N_2O, SF_6, H_2O, and CO and has flown on multiple missions. A Picarro Cavity Ring-Down Spectrometer (PCRS) will measure CO and CO_2. The hardware flew as a prototype in 2009 and is considered to be TRL 7 and 8. A UAS Laser Hygrometer (ULH) and a Diode Laser Hygrometer (DLH) measure H_2O. The DLH has flown for 15 years while the ULH predecessor flew in 2007. Hawkeye measures ice crystal properties. The Solar Spectral Flux Radiometer (SSFR) measures radiation fluxes and has flown on many missions. The Meteorological Measurement System (MMS) measures temperature and winds and has flown for two decades. The Microwave Temperature Profiler (MTP) measures temperature profile and has flown on five airborne platforms, but has not yet flown on Global Hawk. The Differential Optical Absorption Spectrometer (DOAS) measures BrO_3^-, NO_2, OClO, and IO and is a new instrument.

The PI is from Ames Research Center (ARC), and ARC is responsible for project management.

Cost: $29.3M over five years (2010-2015)

M.2 KDP-F DECISION MEMO

NASA Earth Science Division Program Management Council
ATTREX KDP-F Review Decision Memorandum

Summary: The Earth Science Division Program Management Council (ESD PMC) met on Oct 1, 2015 and evaluated the Airborne Tropical TRopopause EXperiment (ATTREX) investigation results to date as measured against the Program-Level Requirements & Investigation Success Criteria and the investigations readiness to enter the closeout phase of the investigation. The ATTREX Principal Investigator, Dr. Eric Jensen, and the ATTREX Project Manager, Mr. Dave Jordan, presented a summary of the investigations science findings and accomplishments against their requirements. The $29.26M investigation met all PLRA requirements with the exception of Boreal summer measurements and was granted a no cost one year extension until 20 July 2016, to complete all analysis and data archiving.

Decision: Based on this review the Decision Authority for the ATTREX Investigation grants approval for the project's closeout activities and successful completion of KDP-F.

Concurrence:

Eric Jensen — 10/01/15
Principal Investigator — Date

[signature] — 1 Oct 15
Program Scientist — Date

[signature] — 1 Oct 15
Earth System Science Pathfinder (ESSP) Program — Date

Bruce [signature] — 1 OCT 15
Program Executive — Date

[signature] — 10-1-15
Resource Management Division — Date

[signature] — 10/1/15
ESD Associate Director, Research — Date

[signature] — 10/1/15
ESD Associate Director, Flight — Date

Approval:

M. [signature] — 21 Oct 2015
Earth Science Division Director — Date

Appendix N: Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)

Table of Contents

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	3/29/2011	Initial Release
A	11/01/2017	• PLRA removed • CARVE project completed 03/31/2016 • KDP-F added

N.1 CARVE DESCRIPTION

The carbon budget of Arctic ecosystems is not known with confidence since fundamental elements of the complex Arctic biological-climatologic-hydrologic system are poorly quantified. CARVE will collect detailed measurements of important greenhouse gases on local to regional scales in the Alaskan Arctic and demonstrate new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle-climate processes. Ultimately, CARVE will provide an integrated set of data that will provide unprecedented experimental insights into Arctic carbon cycling.

CARVE will use a C-23 Sherpa aircraft to fly an innovative airborne remote sensing payload. It includes an L-band radiometer/radar and a nadir-viewing spectrometer to deliver the first simultaneous measurements of surface parameters that control gas emissions (i.e., soil moisture, freeze/thaw state, surface temperature) and total atmospheric columns of carbon dioxide, methane, and carbon monoxide. The aircraft payload also includes a gas analyzer that links greenhouse gas measurements directly to World Meteorological Organization standards. Deployments will occur during the spring, summer, and early fall when Arctic carbon fluxes are large and change rapidly. Further, at these times, the sensitivities of ecosystems to external forces such as fire and anomalous variability of temperature and precipitation are maximized. Continuous ground-based measurements provide temporal and regional context as well as calibration for CARVE airborne measurements.

CARVE science fills a critical gap in Earth Science knowledge and satisfies high priority objectives across NASA's Carbon Cycle & Ecosystems, Atmospheric Composition, and Climate Variability & Change focus areas as well as the Air Quality and Ecosystems elements of the Applied Sciences program. CARVE complements and enhances the science return from current NASA and non-NASA satellite sensors.

An infrared camera provides measurements of, inundation state, surface freeze-that state and surface temperature. . A Tsukuba airborne Fourier Transform Spectrometer (FTS) measures the total column of CO_2, CH_4 and CO. An In situ Gas Analyzer (ISGA) provides measurements of CO_2, CH_4 and CO and was demonstrated in the Balanço Atmosférico Regional de Carbono na Amazôni (BARCA) campaign. A Programmable Flash Pack (PFP) provides CO_2, CH_4 and CO. Both the ISGA and the PFP are COTS instrumentation.

The PI is from JPL, and JPL is responsible for project management.

Cost: $27.9M over five years (2010-2015)

N.2 KDP-F DECISION MEMO

NASA Earth Science Division Program Management Council
CARVE KDP-F Review Decision Memorandum

Summary: The Earth Science Division Program Management Council (ESD PMC) met on January 28th, 2016 and evaluated the Carbon in Arctic Reservoir Vulnerability Experiment (CARVE) investigation results to date as measured against the Program-Level Requirements & Investigation Success Criteria and the investigations readiness to enter the closeout phase of the investigation. The CARVE Principal Investigator, Dr. Charles Miller, and the CARVE Project Manager, Steve Dinardo, presented a summary of the investigations science findings and accomplishments against their requirements. The $27.875M investigation met all PLRA requirements and will provide a new EAC and plan for a one year no-cost extension (through September 28th, 2016) by March 1st, 2016.

Decision: Based on this review the Decision Authority for the CARVE Investigation grants approval for the project's closeout activities and successful completion of KDP-F.

Concurrence:

Principal Investigator	28 Jan 16 — Date
Program Scientist	28 Jan 16 — Date
Earth System Science Pathfinder (ESSP) Program	28 Jan 16 — Date
Program Executive	28 Jan 16 — Date
Resource Management Division	1-29-16 — Date
for J. Kaye — ESD Associate Director, Research	28 Jan 16 — Date
ESD Associate Director, Flight	1/28/16 — Date

Approval:

Earth Science Division Director	1/28/16 — Date

Appendix O: Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release PLRA
A	11/01/2017	• PLRA removed • DISCOVER AQ project completed 9/30/2015 • KDP-F added

O.1 DISCOVER-AQ DESCRIPTION

The overarching objective of the DISCOVER-AQ investigation is to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. To diagnose air quality conditions from space, reliable satellite information on aerosols and ozone precursors needs to be compared to surface- and aircraft-based measurements at highly-correlated times and locations. DISCOVER-AQ will provide an integrated dataset of airborne and surface observations relevant to the diagnosis of surface air quality conditions from space.

DISCOVER-AQ will provide systematic and concurrent observations of column-integrated, surface, and vertically-resolved distributions of aerosols and trace gases relevant to air quality as they evolve throughout the day. This will be accomplished with a combination of two NASA airborne platforms (B-200 and P-3B) sampling in coordination with re-locatable and fixed surface networks. One aircraft will be used for extensive in-situ profiling of the atmosphere while the other will conduct both passive and active remote sensing of the atmospheric column extending below the aircraft to the surface. These aircraft will repeatedly overfly instrumented surface locations continuously monitoring both column and surface conditions for select variables throughout the day.

DISCOVER-AQ will focus on NASA's goals to study the Earth from space to increase fundamental understanding and to enable the application of satellite data for societal benefit. DISCOVER-AQ aligns with priorities for both the Atmospheric Composition Focus Area and the Applied Sciences Air Quality Program at NASA. Fundamentally, DISCOVER-AQ will provide data needed to critically examine the ability to determine surface air quality conditions from space.

The P-3B in-situ trace gas measurement techniques are: thermal disassociation, laser induced fluorescence, chemiluminescence, IR absorption spectrometer, LI-COR 6252, diode laser spectrometer, and hygrometer and proton transfer reaction-mass spectrometer. Measurements are NO_2, peroxynitrates, alkyl nitrates, HNO_3, O_3, NO_x, CH_2O, CO_2, CO, CH_4, H_2O, methanol, acetaldehyde, acetone, isoprene, acetonitrile, benzene, toluene, C8 aromatics, and C9 aromatics.

The P-3B airborne in situ aerosol measurement techniques are: condensation particle counter, mobility particle sizers, Droplet Measurement Technologies (DMT) spectrometer, optical particle counter, aerodynamic particle sizer, condensation nuclei counter, nephelometer, soot absorption photometer, Radiance Research (RR) nephelometer, DMT particle soot photometer, particle into liquid sampler chromatograph and total organic carbon. Measurements are ultrafine NV CN; particle size; CN spectra; scattering at 450, 550, and 700nm; absorption at 467, 530, and 660 nm; humidity dependence of scattering; black carbon; soluble ion composition; and water soluble organic carbon.

The P-3B meteorological measurements are: pressure, wind speed, ground speed, temperature, dew/frost point, and NO_2 photolysis frequency.

The ground station instruments are: Pandora, Cleo, and Native. The measurements are: O_3 total column, NO_2, CH_2O, SO_2, H_2O, BrO, O_3 profile, NO_2 profile and aerosol properties.

The B-200 remote sensing instruments are: High Spectral Resolution LIDAR (HSRL) and Airborne Compact Atmospheric Mapper (ACAM). The measurements are: aerosol backscatter at

532 and 1064 nm, aerosol extinction at 532 nm, aerosol optical depth at 532 nm, O_3, NO_2, and CH_2O.

All instrumentation is in the TRL-9 category and has a flight heritage of a decade or longer.

The PI is from LaRC, and LaRC is responsible for project management.

Cost: $30.0M (2010-2015)

O.2 KDP-F DECISION MEMO

NASA Earth Science Division Program Management Council
Discover AQ KDP-F Review Decision Memorandum

Summary: The Earth Science Division Program Management Council (ESD PMC) met on Aug 11, 2015 and evaluated the Deriving Information on Surface Conditions from Column and VERtically Resolved Observations Relevant to Air Quality (Discover-AQ) investigation results to date as measured against the Program-Level Requirements & Investigation Success Criteria and the investigations readiness to enter the closeout phase of the investigation. The Discover-AQ Principal Investigator, Dr. James Crawford, and the Discover-AQ Project Manager, Mary Kleb, presented a summary of the investigations science findings and accomplishments against their requirements. The $30M investigation met all PLRA requirements.

Decision: Based on this review the Decision Authority for the Discover-AQ Investigation grants approval for the project's closeout activities and successful completion of KDP-F.

Concurrence:

	Date
[signature] Principal Investigator	11 AUG 2015
[signature] Program Scientist	11 AUG 2015
[signature] Earth System Science Pathfinder (ESSP) Program	11 Aug 15
Bruce A Tagg [signature] Program Executive	11 AUG 2015
Resource Management Division	
[signature] ESD Associate Directer, Research	8/11/15
[signature] ESD Associate Director, Flight	8/11/15

Approval:

	Date
[signature] Earth Science Division Director	8/11/2015

Appendix P: Hurricane and Severe Storm Sentinel (HS3)

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	**Date**	**Change Description**
Baseline	3/29/2011	Initial Release
A	11/01/2017	• PLRA removed • HS3 project completed 08/03/2016 • KDP-F added

P.1 HS3 DESCRIPTION

Close to 100 million Americans now live within 50 miles of a coastline, thus exposing them to the potential destruction caused by a land-falling hurricane. While hurricane track prediction has improved in recent decades, improvements in hurricane intensity prediction have lagged, primarily as a result of a poor understanding of the processes involved in storm intensity change. The Hurricane and Severe Storm Sentinel (HS3) is a five-year project targeted to enhance our understanding of the processes that underlie hurricane intensity change in the Atlantic Ocean basin. HS3 will determine the extent to which either the environment or the processes internal to the storm are significant to intensity change.

The investigation objectives will be achieved using two Global Hawk (GH) Uninhabited Aerial Systems (UAS) with separate comprehensive environmental and over-storm payloads. The high Global Hawk flight altitudes allow over-flights of most vertical storm convection and sampling of upper-tropospheric winds. Deployments from NASA's Wallops Flight Facility and 26-hour flight durations will provide access to unrestricted air space, coverage of the entire Atlantic Ocean basin, and on-station times up to 10-24 hours depending on storm location. Deployments will be from mid-August to late-September 2012-2014, with up to ten 26-hour flights per deployment, providing an unprecedented and comprehensive data set for approximately nine to twelve hurricanes.

HS3 is focused on the fundamental NASA Earth Science goal to "Study Earth from space to advance scientific understanding and meet societal needs" and NASA's Research Objective to "enable improved predictive capability for weather and extreme weather events." HS3 complements NASA's Weather Focus Area and Hurricane Science Research Program.

A Scanning High-resolution Interferometer Sounder (S-HIS) will provide temperature and relative humidity and has flown on four different platforms since 1998. A Tropospheric Wind LIDAR Technology Experiment (TWiLiTE) Doppler LIDAR will provide continuous wind profiles when it flies in 2014.. An Airborne Vertical Atmosphere Profiling System (AVAPS) dropsonde will provide wind, temperature and humidity profiles.. A Cloud Physics Lidar (CPL) will provide aerosol and cloud layer vertical structure and was first deployed in 2000. A High-Altitude Imaging Wind and Rain Airborne Radar (HIWRAP) scanning Doppler radar will provide 3-D wind and precipitation fields and was designed for GH in 2007. A Hurricane Imaging Radiometer (HIRAD) hurricane imaging multi-frequency interferometric radiometer will provide surface winds and rainfall and is based on the stepped frequency microwave radiometer (SFMR) and flew on the WB-57 at the end of 2009 for the first time. A High Altitude MMIC sounding radiometer (HAMSR) will provide temperature, water vapor, liquid water profiles, total precipitated water, sea surface temperature, and vertical precipitation profiles first flew in 2001.

The PI and the relevant Center Management Council are at GSFC; the Project Manager and project management responsibilities are at ARC.

Cost: $29.7M over five years (2010-2015)

P.2 KDP-F DECISION MEMO

NASA Earth Science Division Program Management Council
HS3 KDP-F Review Decision Memorandum

Summary: The Earth Science Division Program Management Council (ESD PMC) met on July 29, 2015 and evaluated the Hurricane and Severe Storm Sentinel (HS3) investigation results to date as measured against the Program-Level Requirements & Investigation Success Criteria and the investigations readiness to enter the closeout phase of the investigation. The HS3 Principal Investigator, Dr Scott Braun, and the HS3 Project Manager, Marilyn Vasques, presented a summary of the investigations science findings and accomplishments against their requirements.

Decision: Based on this review and completion of the action items by the assigned dates, the Decision Authority for the HS3 Investigation grants approval for the project's closeout activities and successful completion of KDP-F.

Actions:

1. **Program:**
   a. How was the mission implementation different from what was proposed?
   b. What are the top discoveries?
2. **Impact:**
   a. What was HS3's 'nucleation potential'?
   b. Highlight that NOAA used GH dropsonde data in their forecasts.
3. **Budget:**
   a. Highlight/discuss use of reserves.
   b. Show full budget by team. Separate data acquisition from data analysis, theory, forecasting; was the split about right? Separate out management overhead. Budget per instrument team.
4. **Level 1:**
   a. Make it clear that TWiLiTE was part of baseline, not threshold.
   b. Need a crisp answer to: Did we succeed (threshold)?
5. **Data:**
   a. Make our documentation discoverable.
   b. Our slide understates data delivery; update that.
6. **Project info:**
   a. List team members.
   b. # flight hours per flight and per storm.

Action Deliverable schedule:
Draft responses to all actions to Bruce Tagg for review 9/14/15
Final version delivered 9/28/15

Concurrence:

Scott Braun 9/1/15

Principal Investigator Date

Ramesh Kakar 9/14/15

Program Scientist Date

Greg Stover 25 Sept 15

Earth System Science
Pathfinder (ESSP) Program Date

9/1/15

Program Executive Date

9/1/15

Resource Management Division Date

9/15/15

ESD Associate Director, Research Date

9/22/15

ESD Associate Director, Flight Date

Approval:

9/30/15

Earth Science Division Director Date

Appendix Q: Future Earth Venture (EV) Projects

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	Deleted Table Q-1; updated website and references.

Q.1 PROJECTS DESCRIPTION

The 2007 Decadal Survey first characterized the Venture class missions, describing them as follows:

> *"Priority would be given to cost-effective, innovative missions rather than those with excessive scientific and technological requirements. The Venture class could include stand-alone missions that use simple, small instruments, spacecraft, and launch vehicles; more complex instruments of opportunity flown on partner spacecraft and launch vehicles; or complex sets of instruments flown on suitable sub-orbital platforms to address focused sets of scientific questions. These missions could focus on establishing new research avenues or on demonstrating key application-oriented measurements. Key to the success of such a program will be maintaining a steady stream of opportunities for community participation in the development of innovative ideas, which requires that strict schedule and cost guidelines be enforced for the program participants."*

In response to this recommendation, NASA established the EV portfolio of investigations and assigned the investigations to the ESSP Program. All selected projects/investigations to date are listed on the ESSP Program website (https://essp.nasa.gov/projects).

Future EV investigations will be competed annually (depending on funding) and are broadly categorized as either Orbital, Sub-orbital or Instrument investigations.

- Orbital: EV Mission (EVM) investigations are stand-alone investigations that use simple, small instruments, spacecraft, and launch vehicles. EV five-year orbital investigations will be competed every four years, and will be cost-capped at approximately $166M.

- Sub-orbital: EV Sub-orbital (EVS) five-year investigations are composed of complex sets of instruments flown on suitable sub-orbital platforms to address focused sets of scientific questions. EV sub-orbital investigations will be competed every four years, and will be cost-capped at approximately $150M total for up to five selections. Each individual selection will be cost-capped at approximately $30M, and the NRA procurement process is expected to occur in one step.

- Instrument: EV Instrument (EVI) investigations are composed of more complex instruments of opportunity flown on partner spacecraft and launch vehicles. EV instrument investigations will be competed every year, and will be cost-capped at approximately $90M total. The Stand-Alone Mission of Opportunity Notice (SALMON) procurement process will occur in one step, resulting in one or more selections. Each selection will be for a duration of five years, which does not include flight operations or science data activities.

Appendix D provides the schedule for EV solicitations during the next several years.

Appendix R: References

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	**Date**	**Change Description**
Baseline	03/29/2011	Initial Release
A	11/01/2017	• Deleted: “Functional Assignments for ESSP Personnel” and replaced it with “References”; NPD 9501.3, *Earned Value Management;* NPR 1441.1 “*NASA Records Management Program Requirements”*; NPR 7900.3 to “*Aircraft Operations Management Manual”* • Renamed: 7120.6 to “Knowledge Policy on Programs and Projects”; NPD 7500.1 to *“Program and Project Life-Cycle Logistics Support Policy”;* NPR 2190.1 to “*NASA Export Control Program”*; NPR 8580.1 to *“NASA National Environmental Policy Management Requirements”* • Added NPD 1001.0, *2014 NASA Strategic Plan;* NRRS 1441.1, *NASA Records Retention Schedule* • Updated: “ESSP Program Office Documents” and “Related References” • Replaced “SPD-18” with “SPD-26A” • Updated version of SMD Management Handbook (2008 to 2013)

NASA Policy Directives

NPD 1000.0, NASA Governance and Strategic Management Handbook
NPD 1000.5, Policy for NASA Acquisition
NPD 1001.0, 2014 NASA Strategic Plan
NPD 1600.2, NASA Security Policy
NPD 2200.1, Management of NASA Scientific and Technical Information
NPD 2810.1, NASA Information Security Policy
NPD 7120.4, NASA Engineering and Program/Project Management Policy
NPD 7500.1, Program and Project Life-Cycle Logistics Support Policy
NPD 8010.3, Notification of Intent to Decommission or Terminate Operating Space Systems and Terminate Missions
NPD 8700.1, NASA Policy for Safety and Mission Success
NPD 8720.1, NASA Reliability and Maintainability (R&M) Program Policy
NPD 8730.5, NASA Quality Assurance Program Policy

NASA Procedural Requirements

NPR 1040.1, NASA Continuity of Operations Planning (COOP) Procedural Requirements
NPR 1600.1, NASA Security Program Procedural Requirements
NPR 2190.1, NASA Export Control Program.
NPR 2200.2, Requirements for Documentation, Approval, and Dissemination of NASA Scientific and Technical Information
NPR 2810.1, Security of Information Technology
NPR 7120.5, NASA Space Flight Program and Project Management Requirements (see also NM 7120-81)
NPR 7120.6, Knowledge Policy on Programs and Projects
NPR 7120.8, NASA Research and Technology Program and Project Management Requirements
NPR 7123.1, NASA Systems Engineering Processes and Requirements
NPR 7150.2, NASA Software Engineering Requirements
NPR 8000.4, Agency Risk Management Procedural Requirements
NPR 8580.1, NASA National Environmental Policy Management Requirements
NPR 8705.6, Safety and Mission Assurance (SMA) Audits, Reviews, and Assessments
NPR 8715.3, NASA General Safety Program Requirements
NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris
NPR 8735.2, Management of Government Quality Assurance Functions for NASA Contracts

NASA Standards

NASA-STD-8719.13, NASA Software Safety Standard
NASA-STD-8739.8, NASA Software Assurance Standard

NASA Langley Research Center Policy Directives and Procedural Requirements

LPR 1040.3, Continuity of Operations (COOP) Plan
LPR 1046.1, NASA Langley Research Center Emergency Plan
LPR 1620.1, Information Security Program Management Procedures and Guidelines

ESSP Program Office Documents

ESSPPO-0001, ESSP Program Plan
ESSPPO-0002, ESSP Program Office Configuration Management Plan
ESSPPO-0009, ESSP Roles and Responsibilities

Related References

NASA 2014 Science Plan.
Federal Acquisition Regulation (FAR)
International Traffic In Arms Regulations (22 CFR 120-130)
NASA Earth Science Data and Information Policy
NASA FAR Supplement (NFS)
NASA Records Retention Schedule (NRRS 1441.1)
NASA Risk Management Handbook (NASA/SP-2011-3422)
NASA Schedule Management Handbook (NASA/SP-2010-3403)
NASA Systems Engineering Handbook (NASA/SP-2007-6105, Rev1)
Policy and Requirement for SMD Communications for Flight Missions, (SPD-26A) Science Mission Directorate Management Handbook (SMD Management Handbook), 2013.

Web Site References

ESSP Program Office. **https://essp.nasa.gov/**

NASA Federal Acquisition Regulations (FAR) Supplement (NFS). **http://www.hq.nasa.gov/office/procurement/regs/nfstoc.htm**

NASA Online Directives System (NODIS). **http://nodis3.gsfc.nasa.gov/**

NASA Science Earth Data & Information Policy. **http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/**

NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES). **http://nspires.nasaprs.com/external/**

ScienceWorks. **https://scienceworks.hq.nasa.gov/**

Appendix S: Hands-On Professional Experience (HOPE) Program Level Requirements

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Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify the correct version before use.

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release of "Project Information Needed for Monthly Assessments and Reporting"
A	11/01/2017	Supersedes Appendix S: "Project Information Needed for Monthly Assessments and Reporting" with HOPE Project information • HEROS PLRA removed; project completed 2013 • Rad-X project completed 2016 • EPOCH PLRA (dated 01/06/2017) added

S.1 HOPE DESCRIPTION

The HOPE Program provides an opportunity for a team of early-entry NASA employees to propose, design, develop, build, and launch a suborbital flight project over the course of 18 months. The purpose of the program is to enable practitioners in the early years of their careers to gain the knowledge and skills necessary to manage NASA's future flight projects. The Science Mission Directorate (SMD), in collaboration with the Space Technology Program (STP) and the Office of the Chief Engineer (OCE)/Academy of Program/Project and Engineering Leadership (APPEL), are stakeholders in the HOPE Program. Calls for proposals are distributed as a Training Opportunity and selections are made based on available funding. HOPE projects are NASA lead projects to develop an in-house Project Team that will fly an Earth or space science or technology payload on any suborbital-class platform including sounding rocket, balloon, aircraft (piloted, unmanned, or parabolic), CubeSat, or commercial suborbital reusable launch vehicle. The Centers are encouraged to embrace this training opportunity for early career hires and interleave it with the Center's own training program in order to develop future program and project leaders.

The primary goal of HOPE is:

To provide a hands-on Training project to enhance the technical, leadership, and project knowledge, skills and abilities for the selected NASA in-house Project Team. This goal is expected to be accomplished (i) by developing a comprehensive Training Plan for an appropriately experienced team of early career NASA personnel representing the broad diversity of functions of the center (science, technology, engineering, training, business, administration), and (ii) with structured coaching and mentoring by Center experts, and (iii) supported by just-in-time informal and formal training targeted toward individual team member learning needs that support the success of the project, and (iii) with lessons learned and knowledge sharing for the Center and the Agency.

The secondary goal of this solicitation is:

To fly an Earth or space science payload having a useful purpose for SMD, or to mature or develop a space related technology having a useful purpose to either SMD or to STP.

This appendix houses all the Program Level Requirements for each HOPE project. Each HOPE project will be assigned a dash number to designate the appendix number and will be superseded once completed.

S.2 EAST PACIFIC ORIGINS AND CHARACTERISTICS OF HURRICANES (EPOCH) DESCRIPTION

The EPOCH project will directly contribute to the SMD science goal of improving capabilities to predict weather, especially extreme weather events. The EPOCH project consists of three payload instruments carried on a Global Hawk UAS – the EXRAD radar, HAMSR radiometer, and AVAPS dropsonde system – that are ideally suited for the study of hurricanes in the East Pacific.

The main goal of the EPOCH science flight is to understand hurricane genesis and intensity change in the East Pacific using the combined observational data from these three instruments and augmented with data from multiple NASA satellites and computer simulations. The first-time integration of the EXRAD radar with the Global Hawk is critical to improve retrievals of the vertical wind component for 3-D wind estimates. In addition, the NOAA AVAPS system is critical to the HOPE EPOCH project because it will provide the only in situ measurements within the hurricane to validate HAMSR data.

S.3 EPOCH PROGRAM LEVEL REQUIREMENTS

APPENDIX P.1 EPOCH PROGRAM-LEVEL REQUIREMENTS
ESSP PROGRAM PLAN & INVESTIGATION SUCCESS CRITERIA

East Pacific Origins and Characteristics of Hurricanes (EPOCH)

A NASA Hands On Project Experience (HOPE) Project

Program-Level Requirements and Investigation Success Criteria

Version: Final
Date: January 6, 2017

1

Change Log

Revision	Date	Sections Changed	Author
V1	05/13/2016	First Draft	A. Emory
V2	06/10/2016	Update from discussion with SE G. DeAmici	A. Emory
V3	06/20/2016	Edits from Mentor S. Braun and EXRAD PI M. McLinden	A. Emory
V4	06/23/2016	Edits from HQ Program Scientist K. Jucks	A. Emory
V5	09/12/2016	Edits to include descope option of using another aircraft	A. Emory
V6	01/06/2017	Edits to include edits requested by ESSP PO	A. Emory

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APPENDIX P.1 TO THE EARTH SYSTEM SCIENCE PATHFINDER PROGRAM PLAN
PROGRAM-LEVEL REQUIREMENTS FOR THE EAST PACIFIC ORIGINS AND CHARACTERISTICS OF HURRICANES PROJECT

1.0 SCOPE

This appendix to the ESSP Program Plan identifies the investigation, science and programmatic (funding and schedule) requirements imposed on the Principal Investigator and the Goddard Space Flight Center (GSFC) for the development and operation of the Hands On Project Experience (HOPE) East Pacific Origins and Characteristics of Hurricanes (EPOCH) Project of the ESSP Program. Requirements begin in Section 4. Sections 1, 2 & 3 are intended to set the context for the requirements that follow.

This document serves as the basis for investigation assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

ESSP Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division (ESD) within SMD to the ESSP Program Manager at NASA Langley Research Center. HOPE authority is delegated from the AA/SMD through the Deputy Associate Administrator for Research (DAAR) within SMD to the ESSP Program Manager. Investigation management will be conducted as described in Section 3.1.

The Principal Investigator (PI) at GSFC is responsible for the scientific and technological success of the EPOCH Project, including the design, development, integration and testing, investigation operations, and data verification tasks, and shall coordinate the work of all contractors and co-investigators.

Changes to information and requirements contained in this document require approval by the DAAR, SMD, and by the officials that approved the original.

2.0 SCIENCE DEFINITION

2.1 SCIENCE OBJECTIVES

Over the past five years, tropical activity in the East Pacific has increased, while decreasing in the Atlantic Basin. In addition, during El Niño years, warmer than average sea surface temperatures further increase the likelihood of tropical cyclone formation in the East Pacific. Hurricane field campaigns used the Ku-/Ka-band High-Altitude Wind and Rain Airborne Profiler (HIWRAP) radar on the Global Hawk (GH) unmanned aircraft, in GRIP (Genesis and Rapid Intensification Processes 2010), HS3 (Hurricane and Severe Storm Sentinel 2012-2014), and the 2015 NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) field campaign. Although originally designed for the GH, the X-band High altitude RADar (EXRAD) has yet to be integrated and flown on an unmanned aerial vehicle (UAV). EXRAD will provide data with less attenuation of signal over deep convection as well as better estimates of three-dimensional (3-D) winds with its nadir-pointing beam. As part of the HOPE Training Opportunity, the EPOCH team will fly a GH aircraft with the EXRAD radar, the High Altitude MMIC Sounding Radiometer (HAMSR), and the NOAA AVAPS dropsonde system to investigate genesis and rapid intensification (RI) of an East Pacific hurricane by measuring both the environment and interior structures.

The EPOCH science objectives are:

1) To obtain critical remote sensing measurements of tropical cyclogenesis and intensification in the East Pacific and to understand tropical cyclone response to large-scale synoptic features like troughs, jetstreams, and AEWs.
2) To observe and understand the evolution of cloud and frozen/liquid precipitation structure during hurricane intensification to characterize rapidly evolving cloud and precipitation structures.

Important science questions that EPOCH will address include:

a) What impact does the large-scale environment of the East Pacific have on intensity change, including both storm formation and intensification?
b) What is the role of storm internal processes, such as those associated with deep convective towers, in storm formation and intensification?

2.2 SCIENCE IMPLEMENTATION SUMMARY

2.2.1 Investigation Overview

The EPOCH project science objectives will be addressed with an airborne science investigation designed to collect observations in the environment of and within developing and mature tropical cyclones in the East Pacific Ocean. EPOCH will coordinate flight planning with scientists from other government agencies that are also sampling East Pacific tropical cyclones or the tropical environment. This will be accomplished through joint forecasting and flight planning discussions with NOAA through the EPOCH project Co-I Gary Wick. EPOCH measurements will be used to identify specific weaknesses in current hurricane forecasting models, to support improvement in the representation of modeled storm development processes, and to produce a comprehensive data set to characterize the hurricane environment and internal structures.

2.2.2 Investigation Instrument Payload and Platform

A developing and/or mature tropical cyclone will be sampled using one high-altitude long-duration Global Hawk with an over-storm payload. The over-storm payload includes a Doppler radar, a sounding radiometer, and dropsondes with *in situ* measurement capabilities of atmospheric state variables and winds to account for parts of the tropical environment that could affect the development of a tropical cyclone. These instruments measure profiles of temperature, pressure and water vapor in cloudy regions, and measure tropospheric and surface wind and precipitation structure where there is precipitation. Specific measurement requirements are listed in Section 4.1.3.

3.0 INVESTIGATION DEFINITION

3.1 INVESTIGATION ORGANIZATION & MANAGEMENT

EPOCH is a Principal Investigator-led investigation. The Principal Investigator is responsible for investigation success. She delegates authority for day-to-day implementation of the investigation to the Project Manager. The PI and PM will be in close communications with the EPOCH team to direct and track key activities. Planning documentation will be made available to all investigation personnel and NASA program personnel on the Mission Tools Suite (MTS; mts.nasa.gov). The Principal Investigator is at GSFC and the Project Manager resides at the Wallops Flight Facility (WFF). EPOCH's management structure and lines of reporting are shown in Figure 1.

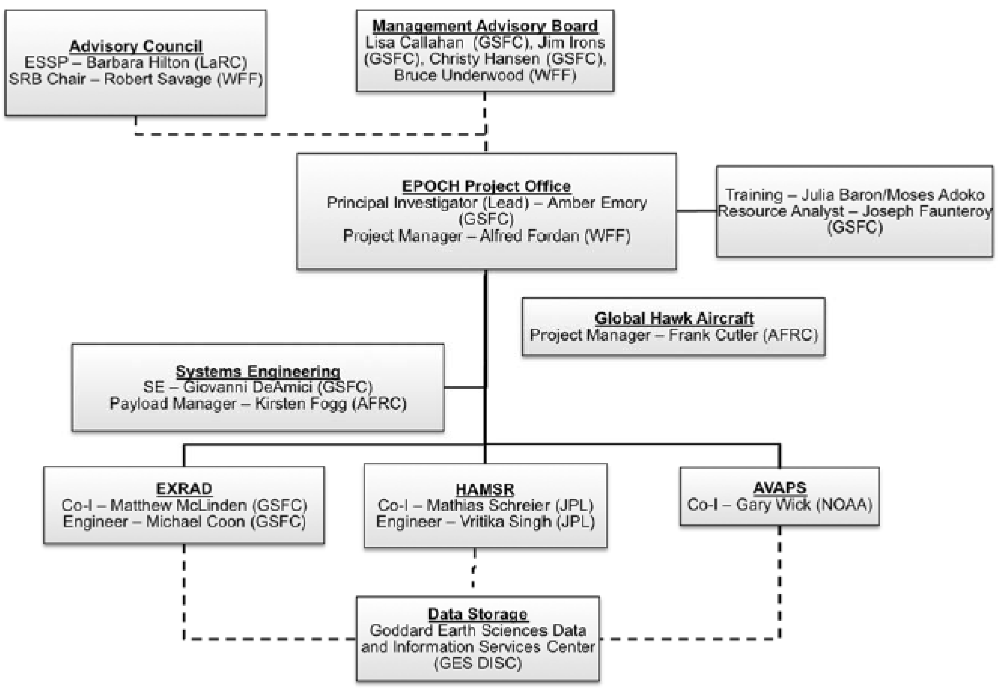

Figure 1. EPOCH Organizational Chart, Lines of Authority and Coordination

Specific assigned roles and responsibilities are:

- NASA DAAR is responsible for providing: the Program Scientist; program management and decision authority for confirmation through the ESSP Program Office; coordination with relevant NASA projects and programs
- NASA GSFC is responsible for: the Principal Investigator and Science Team Lead; Investigation Systems Engineer; investigation success and

science oversight; the payload; the science team; system engineering and mission design; distributed ground data system and science data processing and delivery of calibrated/validated science data products for public distribution within 6 months of science flight(s).

- NASA WFF is responsible for providing the Project Manager; investigation management; investigation operations.

- NASA AFRC is responsible for providing aircraft; aircraft hangars, pilots, service, maintenance, logistics, safety and mission assurance, and aircraft deployment operations. The EPOCH Project provides funding for required flight hours. NASA AFRC is responsible for NASA flight safety and mission assurance requirements, airworthiness and flight readiness reviews, per NPR 7900.3B and/or NPD 7900.4C; the payload integration and test; investigation aircraft operations and associated ground control system. NASA AFRC will also provide the science deployment site and facilities.

- Each of the NASA Centers involved is responsible for providing training and mentoring to their respective EPOCH team members.

3.2 INVESTIGATION ACQUISITION STRATEGY

Science Instruments:
The Investigation will execute subcontracts and grants with the home institutions of all co-investigators through existing GSFC business infrastructure. The instruments have been built and will be provided by GSFC, by JPL through a NASA task agreement, and by NOAA via an interagency agreement.

Platform: EPOCH will acquire flight hours on one high-altitude long duration Global Hawk Unmanned Aircraft System (UAS) that meets the specifications in Section 4.3 from NASA AFRC.

Science Team: The Investigation will execute subcontracts and grants with the home institutions of all co-investigators through existing GSFC business infrastructure.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 are achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA and the Earth Science Community.

4.1 SCIENCE REQUIREMENTS

4.1.1 BASELINE SCIENCE REQUIREMENTS

To provide measurements to address influences on hurricane formation and intensification from the environment and internal processes, the EPOCH Project shall:

a) conduct one (1) science flight lasting at least 24 hours with 10 hours spent over a developing, intensifying, or dissipating tropical cyclone in the East Pacific Ocean

b) conduct science flight deployment(s) in the time window of August 1-30, 2017

c) measure precipitation structure and wind structure in precipitating tropical cyclones with the measurement characteristics as outlined in Section 4.1.3

d) record, validate, publish and deliver science data records and calibrated geophysical data products to the scientific community as described in Section 4.5

4.1.2 THRESHOLD SCIENCE REQUIREMENTS

To provide measurements to address influences on hurricane formation and intensification from the environment and internal processes, the EPOCH Project shall:

a) conduct three (3) science flights, each lasting 8 hours with 2 hours spent over a developing, intensifying, or dissipating tropical cyclone.

b) conduct the science flight during the 2017 hurricane season.

c) sample at least one (1) developing, intensifying, or dissipating tropical depression or tropical cyclone.

d) measure precipitation and wind structure in a tropical cyclone with the measurement characteristics in Section 4.1.3, bullet point (b)

e) record, validate, publish and deliver science data records and calibrated geophysical data products to the scientific community as described in Section 4.5

4.1.3 BASELINE SCIENCE MEASUREMENT REQUIREMENTS

To meet the science requirements in Sections 4.1.1 or 4.1.2 for the EPOCH Project, science instruments shall:

a) measure nadir vertical profiles of temperature and humidity with 1-3 km vertical and at least 20 km horizontal resolution, with the following precisions: 2 K for temperature and 30% for humidity

b) measure profiles of precipitation and wind structure within precipitating regions with 1 km vertical and 1 km horizontal resolution and precisions of 2 dBZ for reflectivity and 2 m s^{-1} for Doppler vertical velocity and 5 m s^{-1} for Doppler horizontal velocity

4.2 SCIENCE INSTRUMENT REQUIREMENTS

EPOCH science instruments shall operate either autonomously or by remote control.

4.3 AIRCRAFT PERFORMANCE AND SAMPLING REQUIREMENTS

To meet the baseline science objectives for the EPOCH Project, an airborne platform shall:

a) operate from the West Coast of the United States with the ability to fly down to the Gulf of Tehuantepec

b) operate by remote control

c) maintain flight altitudes greater than 13.7 km (45 kft) for environmental sampling and 16.8 km (55 kft) for over-storm sampling

d) have a minimum flight duration capability of 24 hours

e) carry the science payloads as specified in Section 4.1.3

4.4 GROUND SYSTEM REQUIREMENTS

To meet the baseline science objectives of the EPOCH Project, the ground system shall:

a) include a complete onsite ground station for controlling aircraft during science deployments if UAS deployment occurs.

b) ingest and store meteorological data for flight-planning during the campaign periods.

c) ingest and geolocate all data from the science payload.

d) process raw data to provide the standard data products listed in Table 4.5.1.

4.5 INVESTIGATION DATA REQUIREMENTS

4.5.1 SCIENCE DATA MANAGEMENT

a) The EPOCH Project shall produce the standard science data products listed in Table 4.5.1.

b) The EPOCH Project standard science data products and associated metadata shall be made publicly available with the latencies given in Table 4.5.1.

c) Science algorithms and calibration procedures used to generate the standard data products listed in Table 4.5.1 shall be described in documents that are accessible to users after the latencies given in Table 4.5.1.

d) By the Investigation Closeout, the EPOCH Project shall deliver all data products and ancillary data used to generate these products, and the algorithm and calibration documentation to the Goddard Earth Sciences Data and Information Services Center (GES DISC).

e) All terms and conditions of the transfer of data products and associated information to GES DISC shall be documented in a Data Management Plan (EPH-D1-0100 Section 3.14) that has been approved by the Earth Science Data and Information System Project.

Instrument	Data Product	Description	**Preliminary** Latency Not to Exceed	**Final** Latency Not to Exceed
Standard Science Products				
Doppler Radar	Level 1	Calibrated reflectivity, Doppler velocity	3 months	9 months
Doppler Radar	Level 2	Radial coordinate products including VAD	6 months	9 months
Doppler Radar	Level 3	Gridded reflectivities, winds	6 months	Investigation Closeout
Microwave Sounder	Level 1	Calibrated radiances	3 months	9 months
Microwave Sounder	Level 2	Retrieved temperature and humidity, precipitation profiles	6 months	9 months
Supplemental Science Products				
Dropsonde	Level 1	Quality controlled profiles of temperature, humidity, winds	3 months	9 months

Table 4.5.1. EPOCH Data Products

4.5.2 SCIENCE DATA REQUIREMENTS

a) The EPOCH science data product formats shall conform to one of the ESD-approved Data System Standards.

b) The EPOCH science data products shall have accompanying spatial, temporal and product metadata that conform to ESD-approved metadata specifications.

4.5.3 TRAINING REQUIREMENT

a) All EPOCH team ECH will complete a self-assessment with feedback from their mentor(s).

b) A training plan for each ECH will be formulated with the help of the Training Professional at GSFC.

c) Each ECH will provide Lessons Learned after each major review with feedback provided by their mentor(s) and at the end of the EPOCH project.

4.6 INVESTIGATION SUCCESS CRITERIA

The EPOCH Project shall be successful if it

a) trains a next generation of Airborne Science Program (ASP) and spaceflight leadership

b) samples a tropical system using an instrumented UAS during the 2017 hurricane season

c) observes the three-dimensional mesoscale and convective-scale internal structures of tropical disturbances and cyclones

d) improves understanding of hurricane intensity change

e) delivers calibrated science data and geophysical data products for use by the scientific community

5.0 NASA INVESTIGATION COST REQUIREMENTS

5.1 COST

a) The EPOCH Project life cycle cost (LCC) shall not exceed $1.55M. The LCC includes the cost for the formulation, implementation, operations, calibration, validation, and science data analysis costs to generate the products in Table 4.5.1. Specifically, this cost includes all operations of the GH, project management, funding of three instrument teams (including integration, travel, spare parts, and data analysis), flight facilities, science team activities, and approximately 10% reserves held at GSFC and managed by the PI and Project Manager.

5.2 COST MANAGEMENT AND SCOPE REDUCTION

a) Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the EPOCH Project shall pursue scope reduction and risk management as a means to control cost.

b) The Investigation Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the

Investigation Project Plan may be exercised.

c) Scope reductions from Baseline Science requirements (Section 4.1.1) to Threshold Science requirements (Section 4.1.2) or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of this document.

5.3 SCHEDULE AND INVESTIGATION CLOSEOUT

a) EPOCH science operations shall begin no later than August 1, 2017.

b) The EPOCH Project Closeout shall occur within 24 months from the Project Initiation Conference held on March 23, 2016.

c) Final verification of the EPOCH Level 1 Requirements and Investigation Success Criteria shall be delivered at the Investigation Closeout.

6.0 MULTI-INVESTIGATION NASA FACILITIES

EPOCH will make use of NASA AFRC for integration and flight tests as well as for science operations.

7.0 EXTERNAL AGREEMENTS

a) EPOCH includes the National Oceanographic and Atmospheric Administration's dropsonde system. Their commitment to the project and the scope of their contributions are described in the interagency memorandum of agreement.

b) The EPOCH project includes the Jet Propulsion Laboratory's HAMSR instrument. Their commitment to the EPOCH Project and the scope of their contributions are described in a NASA Internal Task Agreement.

8.0 PUBLIC OUTREACH AND EDUCATION

As part of the instrument integration and science flight to take place at AFRC in Summer 2017, the EPOCH team will host a day of middle school students from the local Palmdale School District to explain the science and technology behind the project to inspire the next generation of scientists and engineers.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the EPOCH Project.

11.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS:

Approval on File SMD DAAR (J. Newmark)	Date
ESSP Program Manager (G. Stover)	11 JAN 17 Date
Principal Investigator (A. Emory)	1/9/2017 Date
EPOCH Project Manager (A. Fordan)	1/11/17 Date

CONCURRENCES:

EPOCH Mission Manager (B. Hilton)	1/11/2017 Date
GSFC Airborne Sciences Manager (C. Hansen)	1/9/17 Date

Appendix T: Management Approaches for Earth Venture Elements of NASA's ESSP Program

TABLE OF CONTENTS

Earth System Science Pathfinder Program Office

NASA Langley Research Center

Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release
A	11/01/2017	• Expanded management approach for each ESSP element • Removed content that is already contained in main document. Included cubesats in the Mission Accommodations section.

T.1 INTRODUCTION

There three elements of ESSP Earth Venture. The EV Suborbital (EVS) element includes suborbital and/or airborne investigations with 5-year duration and managed to NPD 7120.8. The EV Mission (EVM) element comprises small complete cost-capped missions launched within 5 years of initiation, managed to NPD 7120.5 as Class D missions per NPD 8705.4. The EV Instrument (EVI) element develops spaceborne instruments and cubesats for flight as missions-of-opportunity (MoO). These cost-capped instruments and cubesats are managed to NPD 7120.5 according to Class C or Class D (as appropriate) per NPD 8705.4, and are limited to 5-year development duration. NASA separately secures and funds the access to space for these instruments.

The following sections describe the general management approach for each EV element. The management approach is designed to support the PI's role to perform project management and science trade-offs while ensuring NASA programmatic and risk requirements are realized. To ensure the success of EV, the management approach of each element is tailored according to the specific needs of the project or investigation following selection.

T.2 EV SUBORBITAL

The EV Suborbital (EVS) element includes airborne and/or suborbital, competitively selected, PI led investigations to conduct innovative, integrated, hypothesis, or scientific question driven approaches to pressing earth science issues.

Earth Venture Suborbital investigations have the following characteristics:

- Sustained, science-based data acquisition – Investigations advance earth science objectives through temporally sustained regional- or larger-scale measurements sufficient and necessary to prove/disprove a scientific hypothesis or address scientific questions.
- Mature technology – Investigations must use mature system technology where, at a minimum, there has been a system/subsystem model or prototype demonstration in a relevant environment.
- Cost and schedule constraints – Each suborbital investigation must have a life cycle duration of less than or equal to five years with total investigation cost not to exceed $30 million.

T.2.1 PRINCIPAL INVESTIGATOR RESPONSIBILITY

An EVS PI is wholly responsible to accomplish the investigation objectives using his/her own management processes, procedures, and methods. The PI is responsible for all planning and documentation for the investigation, including science goals and objectives, baseline and threshold science requirements and investigation implementation approach.

T.2.2 RISK MANAGEMENT

For EVS investigations the PI identifies potential risks to successful achievement of investigation objectives within resource and schedule constraints. The PI specifies risk mitigation plans including descopes, if appropriate. Generally, the nature of suborbital investigations allows for an aggressive risk posture compared to spaceflight missions. For example, investigations occur during deployments of equipment to a field location with a schedule established for taking measurements that has some margin, i.e. extra days built in. If any equipment exhibits anomalous operations or failure, the PI's team can, in some cases, perform repairs on the equipment without impacting the deployment schedule. As such, subsystem redundancy is not required, for example.

T.2.3 NASA OVERSIGHT

The PI has a large degree of freedom and responsibility to accomplish the science objectives. NASA's oversight ensures that the investigation is responsive to requirements and the constraints of NPR 7120.8 for the risk that is acceptable for suborbital investigations.

The ESD Program Scientist provides the primary oversight of the science implementation of the project and science stakeholders. The ESD Program Executive provides the primary oversight of implementation, external interfaces and all stakeholders. The ESSP Mission Manager provides the primary programmatic interface to the PI.

Key elements of how the ESSP Mission Manager provides direct insight/oversight for the assigned EVS investigations are described as follows:

- Interact with the PI and their team on a regular basis to maintain a current awareness of investigation execution and issue development
- Assess each investigation's progress through verbal communication, written reports, and status reviews
- Participate in the Investigation Reviews (defined in T.2.4)
- Identify areas where additional insight/oversight is required or where additional technical expertise can be provided (through the investigation risk management process)
- As a minimum, establish necessary insight levels to ensure investigations are following agreed to processes and practices
- Identify potential investigation liens and threats against the investigation budget and schedule

T.2.4 EVS REVIEWS

EVS investigations have a streamlined review structure that includes the following:

<u>Investigation Confirmation Review (ICR)</u>

The ICR generally occurs within one year of investigation selection after the PI and ESD agree upon investigation requirements, the PI matures the investigation implementation approach, and the major risks to completion of the proposed investigation have been addressed. The original proposal forms the baseline for the assessment. Following the assessment, the PI presents their investigation and responses to the assessment to ESD. The ICR will be complete when the ESD approves the investigation to continue with implementation.

<u>Flight Readiness Review (FRR)/Operations Readiness Review (ORR)</u>

The FRR/ORR is conducted according to NASA policies and procedures to ensure the instrumentation and aircraft are ready and safe for flight. All aircraft operations, including those for commercially acquired aircraft, shall be reviewed in accordance with NPR 7900.3. This review does not generally assess the performance of the instrumentation.

<u>Project Status Review (PSR)</u>

PSRs are conducted quarterly by the investigation team and ESSP to examine the progress to date against the approved cost, schedule, and performance of the investigation.

Science Review

The purpose of the Science Review is to measure progress toward meeting the baseline and threshold requirements listed in the Level 1 Requirements documented in the investigation Project Implementation Plan, and is conducted at least annually.

T.3EV MISSION

The Earth Venture Mission (EVM) element develops spaceflight missions to conduct innovative integrated, hypothesis or scientific question-driven approaches to pressing earth science issues. They are PI led and encompass all measurements required to achieve the scientific objectives. The Associate Administrator of the SMD is the Decision Authority and is supported by the Directorate Program Management Council that recommends approval or disapproval to the Decision Authority for entry to the next phase at Key Decision Points (KDP).

T.3.1 PRINCIPAL INVESTIGATOR RESPONSIBILITY

An EVM PI is responsible for accomplishing the proposed mission objectives. The PI defines the technical implementation and the project management approach that drives the risk posture. The PI can exercise decisions to accomplish requirements within a trade space that includes performance margins, quality assurance, and reliability. The PI is responsible for defining and describing in the formulation agreement (Phase A/B) and project plan (Phase C/D/E/F) the standards, processes and practices for mission assurance, the mission implementation (approach & execution), the approach for performance/cost/schedule/risk management and the approach for peer reviews.

T.3.2 RISK MANAGEMENT

Because EVM projects are classified as Class D, the risk tolerance is typically higher than other earth science missions (most of which are Class C). The PI implements a rigorous and accountable risk management process that identifies any risk that is accepted (rather than mitigated). EVM projects are allowed to proceed to launch with some unmitigated yellow risks (those with likelihood greater than 3).

T.3.3 NASA OVERSIGHT

The PI has a large degree of freedom and responsibility to accomplish the proposed science objectives and implement the mission. NASA's oversight ensures that the project is performing to applicable standards. While Class D missions are required to comply with the requirements of NPR 7120.5 and NPR 7123, the PI may propose to tailor NASA processes or use their institution's processes. NASA exercises only essential oversight to ensure implementation is responsive to requirements and constraints of NPR 7120.5 for the risks that are acceptable for Class D implementations.

The ESD Program Scientist provides the primary oversight of the science implementation of the project and science stakeholders. The ESD Program Executive provides the primary oversight of implementation, external interfaces and all stakeholders. The ESSP Mission Manager will provide the primary programmatic NASA interface to the PI.

Key elements of how the ESSP Mission Manager provides direct insight/oversight for the assigned EVM project are described as follows:

- Interact with the project team on a frequent basis to maintain a current awareness of project execution and issue development
- Review and assess each project's weekly, monthly, and quarterly reports
- Participate in the Mission's System Reviews (e.g. PDR and CDR)
- Participate in various project reviews (SIR and Critical Events Readiness Reviews, Risk Reviews, Delivery Reviews, etc.)
- Identify areas where additional insight/oversight is required or where additional technical expertise can be provided (through the project risk management process)
- As a minimum, establish necessary insight levels to ensure projects are following agreed to processes and practices
- Identify potential project liens and threats against the project budget and schedule

T.3.4 EVM REVIEWS

EVM reviews will be conducted as specified in NPR 7120.5 and NPR 7123.1. As a Category 3 activity with LCC < $250M, an independent review team is established to conduct the design reviews that precede KDP events. EVM mission reviews (except KDP's) are led by a NASA Center. For missions selected that are not led by a NASA Center, LaRC will serve as the host NASA center with responsibility to satisfy Agency Technical Authority requirements.

A Terms of Reference (ToR) document is developed and proposed by the PI and review Chair in advance of the first major review. The ToR captures entrance and exit criteria that are updated prior to each review. The ToR is concurred with and signed by the Program Office, Project, and implementing Center organization and is approved by the Decision Authority.

The PI can propose tailored technical reviews subject to approval through the ToR. The scope of tailoring can include products from technical review entrance and success criteria found in NPR 7123.1, Appendix G, and/or expected product maturity (preliminary, baseline, updates) found in NPR 7120.5, Tables 4-3 & 4-4.

An independent review team will be established by the lead NASA Center. The chair of the review team will report the findings to the PI, lead NASA Center, Program Office, and HQ. The independent review team is only involved in major reviews not day-to-day implementation. The review team may participate in project peer reviews at the discretion of the review team chair.

T.3.5 EXPECTATIONS TO ACHIEVE A SUCCESSFUL CLASS D MISSION

The successful implementation of a Class D mission requires acceptance of principles and practices by a community that traditionally expects a lower risk tolerance than that allowed on Class C missions. In order to be successful, different constituencies must be cognizant of the

Class D management approach and its goals. The following are some key ways the constituents contribute to success:

Stakeholders

- Ensure the Class D characteristics are applied to all reviews and evaluations
- Ensure the cost cap criteria of the program is maintained as a parameter of the project

NASA Headquarters (ESD) and Program Office

- Maintain Class D risk posture through launch
- Encourage innovative implementations
- Maintain vigilance against requirements creep and risk suppression
- Encourage innovative implementations

Principal Investigator

- Keep open communications on implications of Class D risk management process and mission implementation
- Recognize that termination for excessive cost is real

These Class D principles are consistent with section "5.9 Class D Tailoring" of the *NASA Headquarters SMD Management Handbook; Version V1 (2017)*.

T.4 EV INSTRUMENT

The Earth Venture Instrument (EVI) element develops instruments for participation on a NASA-arranged spaceflight mission of opportunity to conduct innovative, integrated, hypothesis or scientific question-driven approaches to pressing earth science issues. The NASA funded PI retains a central role on the instrument or instrument package development, integration and testing, calibration, and science operations. The Associate Administrator of the SMD is the Decision Authority and is supported by the Directorate Program Management Council that recommends approval/disapproval to the Decision Authority regarding entry to next phase at Key Decision Points.

T.4.1 PRINCIPAL INVESTIGATOR RESPONSIBILITY

An EVI PI is responsible for accomplishing the proposed mission objectives. The PI defines the technical implementation and the project management approach that drives the risk posture. The PI can exercise decisions to accomplish requirements within a trade space that includes performance margins, quality assurance, and reliability. The PI is responsible for defining and describing in the formulation agreement (Phase A/B) and project plan (Phase C/D/E/F) the standards, processes and practices for mission assurance, the mission implementation (approach & execution), the approach for performance/cost/schedule/risk management and the approach for peer reviews.

Costs that are within the PI Managed responsibility:

- Instrument development
- Functional algorithms and ground processing system

- Science team
- Calibration/validation activities
- Operations, product generation, data analysis
- Key management and engineering staff during Phase D

Costs that are outside the PI Managed responsibility:

- Integration to NASA selected platform
- Required funding to cover the gap between instrument delivery and start of platform I&T
- Access to space

T.4.2 RISK MANAGEMENT

For EVI projects the risk tolerance is consistent with typical earth science projects that are Class C. The PI will implement a rigorous and accountable risk management process that identifies any consequences of risk that are accepted. The PI identifies the risks and the mitigations while NASA examines consistency with the risk tolerance for a Class C instrument development.

T.4.3 NASA OVERSIGHT

The PI has a large degree of freedom and responsibility to accomplish the proposed science objectives. NASA's oversight ensures that the project is performing to applicable standards. NASA uses its standard policy and processes to evaluate the PI established management processes to ensure the rigor required for success. NASA exercises only essential oversight to ensure project implementation is responsive to requirements and constraints of NPR 7120.5 for the risk that are acceptable for Class C implementations.

The ESD Program Scientist provides the primary oversight of the science implementation of the project and science stakeholders. The ESD Program Executive provides the primary oversight of implementation, external interfaces and all stakeholders. The ESSP Mission Manager provides the primary programmatic NASA interface to the PI.

Key elements of how the ESSP Mission Manager provides direct insight/oversight for the assigned EVI project are described as follows:

- Interact with the project team on a frequent basis to maintain a current awareness of project execution and issue development
- Review and assess each project's weekly, monthly, and quarterly reports
- Participate in the System Reviews (e.g. PDR and CDR)
- Participate in various project reviews (SIR and Critical Events Readiness Reviews, Risk Reviews, Delivery Reviews, etc.)
- Identify areas where additional insight/oversight is required or where additional technical expertise can be provided (through the project risk management process)
- As a minimum, establish necessary insight levels to ensure projects are following agreed to processes and practices
- Identify potential project liens and threats against the project budget and schedule

T.4.4 EVI REVIEWS

EVI reviews will be conducted as specified in NPR 7120.5 and NPR 7123.1. As a Category 3 activity with LCC less than $250M, an independent review team is established. EVI reviews (except KDP's) will be led by a NASA Center. For missions selected that are not led by a NASA Center, the LaRC will serve as the host NASA center with responsibility to satisfy Agency Technical Authority requirements.

A Terms of Reference (ToR) will be developed and proposed by the PI and review Chair in advance of the first major review. The ToR will capture clearly defined entrance and exit criteria that are updated prior to each review. The ToR is concurred with and signed by Program Office, Project, and implementing Center Organization and is approved by the Decision Authority.

The PI can propose tailored technical reviews subject to approval through the ToR. The scope of tailoring can include products from technical review entrance and success criteria found in NPR 7123.1, Appendix G, and/or expected product maturity (preliminary, baseline, updates) found in NPR 7120.5, Tables 4-3 & 4-4.

An independent review team will be established by the lead NASA Center. The chair of the review team will report the findings to the PI, lead NASA Center, Program Office, and HQ. The independent review team is only involved in major reviews not day-to-day implementation. The review team may participate in project peer reviews at the discretion of the review team chair.

A successful Class D instrument will follow the same general principles outlined in Section T.3.5.

T.4.5 MISSION ACCOMMODATIONS

NASA is responsible to identify and arrange for the accommodation of the investigation/instrument/cubesat(s) on a S/C. NASA will establish a team to address system level accommodation requirements that include consideration for the instrument, S/C, and ground systems that will make up the elements necessary for the PI to achieve their investigation requirements. This team will examine system implementations and determine solutions for interface and integration requirements. It is expected that once an appropriate platform is determined (preferably before the Preliminary Design Review) minor changes to the selected instrument may be required.

The success of the EVI element hinges on the necessity to mitigate the most critical instrument development risks prior to making an external commitment with stakeholders on the life-cycle cost and launch date.

T.5 HOPE MANAGEMENT APPROACH

The ESSP PO has been designated by SMD to serve as the HOPE Training Program Office that will support the SMD through implementation phases of the effort. During the development and implementation phase the ESSP PO will serve as the training program interface between the selected project and NASA HQ. This will include oversight of the selected project through all phases to data analysis and reporting. The ESSP PO will also plan and implement the independent life cycle reviews. These reviews will be led by the HOPE Standing Review Board (SRB) and Terms of Reference for the reviews will be developed by the Review Board Chair as appropriate. The ESSP PO will work with the selected project in order to define the most appropriate board membership and review protocol in order to develop an efficient review process considering the project reviews and normal SRB run reviews. If the carrier is provided by WFF, the ESSP PO will support WFF in the conduct of the MRR and other WFF-lead reviews. In addition to the standard role of providing the training program interface for the project, the ESSP PO will support the project in order to help the project succeed. The ESSP PO monitors actions from the review boards and provides monthly monitoring of the project. Through continued reports, the ESSP PO will maintain an awareness of the project progress and issues and will follow up with the appropriate actions. It will maintain awareness of the project interfaces in order to insure efficient operation. It will resolve issues and concerns that are outside of the project and Center jurisdiction. It will fund the members to the review boards who in turn, will also mentor and support the project's efforts.

T.6 AUTHORITY AND COMMUNICATIONS

Management authority for each ESSP investigation is assigned to a respective PI. Each PI is responsible for the overall success and safety of his/her investigation and is accountable to the SMD AA for the scientific success and to the ESSP PM for the programmatic success. An ESSP PI may delegate management responsibilities to a project manager who may also report to the ESSP PM.

To achieve an unambiguous line of direction and reporting within these levels, all formal direction from SMD to the ESSP Program flows from the ESD Associate Director for Flight Programs to the Program Manager. Similarly, to ensure an unambiguous line of direction and reporting with ESSP Projects, all formal direction from the Program to the Investigation flows from the Program Manager to the PI. This is discussed in detail in Program Plan section 1.51.

In order to ensure effective day-to-day dialogue between the PI and NASA, ESD staff members and Program Office staff members form a team to represent SMD to the PI. The team follows established processes for communicating progress, issues, and problems regularly to the ESD management. The principal NASA team members and their roles are:

Program Scientist Roles and Responsibilities (All functions coordinated with PE and MM):

- Provides assessment of projects scientific and programmatic implementation
- Lead on developing science portion of Level I Requirements
- Coordinates directly with the PI on discussions of mission science
- Verification and tracking of progress on meeting level 1 requirements
- Monitors science management and project execution
- Participate in selected Project reviews

Program Executive Roles and Responsibilities (All functions coordinated with PS and MM):

- Supports the HQ Program Director
- Interfaces with Principle Investigator, Project Manager and ESSP PO MM
- Steward of Program-Level Requirements
- Maintains current knowledge of Project's status
- Monitors/reviews project implementation of technical requirements
- Conduct independent assessment of project for ESD, as required

- Participates in selected Project reviews

Program Office Roles and Responsibilities

- Program Manager issues formal direction to the PI
- Mission Manager (MM) is delegated Program Office authority and responsibility for EVM to accomplish the following:
    - Serve as the primary interface between the PO and PI team
    - Monitor/review project implementation of technical requirements
    - Coordinate funding according to an agreed upon plan as identified in most recent PPBE
    - Review and evaluate risk mitigation approaches to PI-identified risks
    - Assess budget reserve usage
    - Coordinate development of PPBE products
    - Capture and then pass along lessons learned

Appendix U: ESSP Organizational Plan (ESSPPO-0009)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	03/29/2011	Initial Release of ESSP Education and Public Outreach Policy
A	11/01/2017	This appendix version supersedes the baseline Education and Public Outreach Policy dated 03/29/2011

National Aeronautics and Space Administration	**Document Number:**	**ESSPPO-0009**
	Revision:	**Baseline**
	Effective Date:	**June 6, 2016**

Earth System Science Pathfinder Program Office (ESSPPO)

ESSP Organizational Plan

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

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Earth System Science Pathfinder Program Office: ESSP Organizational Plan		
Doc No. ESSPPO-0009	Effective Date: June 6, 2016	Version: Baseline Page: 2 of 13

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6/6/2016
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Date

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Change Log

Version	Date	Change Description
Baseline	06/06/2016	Initial Release

Table of Contents

Table of Figures

1.0 Purpose

This document outlines the ESSP organization and describes the roles and responsibilities for the positions within the ESSP Program Office.

2.0 ESSP Organization

ESSP Program Office is an extension of, and implementation office for the Earth Science Division (ESD). ESSPPO at NASA Langley Research Center (LaRC) is responsible for pathfinder and Venture-Class missions through Announcements of Opportunity (AOs).

Figure 1-1 presents the current ESSP Program Office organization chart.

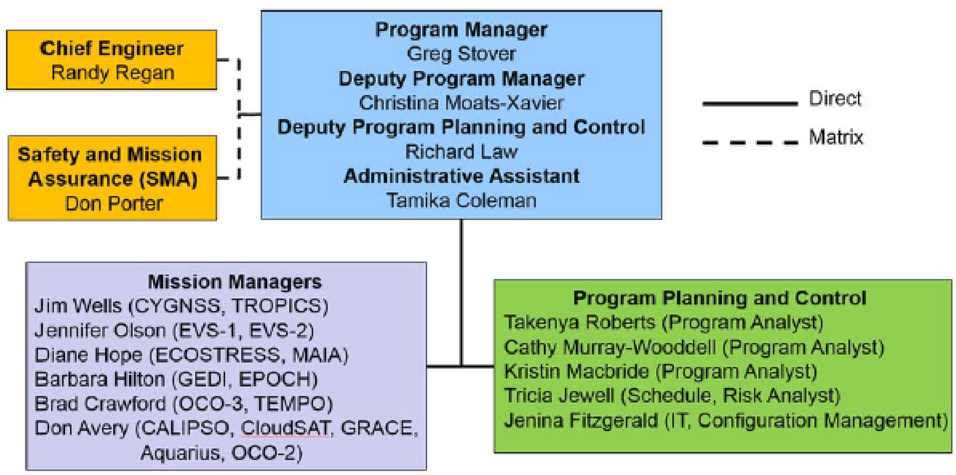

Figure 1-1 ESSP Program Office Organization

3.0 ESSP Program Office Roles and Responsibilities

3.1 ESSP Program Manager

The ESSP Program Manager is responsible for planning and implementing the ESSP Program consistent with top-level policies, strategies, requirements, and funding established by NASA HQ. The Programs Manager's Roles and Responsibilities are discussed in detail in the SMD Handbook. For the ESSP Program, these include but are not limited to:

- ✧ Implementing the ESSP Program for the SMD-selected investigations
- ✧ Ensuring open communications with ESSP Program customers and communicating program customer needs to SMD
- ✧ Developing and managing program-level metrics to assess the performance and health of the Program

- Maintaining the ESSP Program Plan in accordance with NPR 7120.5
- Independently evaluating and assessing program and project technical, schedule, and cost performance, and mitigating risk as appropriate
- Providing program technical experts as required to support the Projects
- Managing the ESSP Program implementation budget. Developing detailed program Operating Plans and Cost Phasing Plans for the implementation budget. Monitoring distribution of funds to implementing organizations
- Assessing the Program for Project liens and threats which could impact the ESSP Futures Budget
- Assigning a Program Office Mission Manager (MM) to each mission
- Conducting disposition of mission flight and ground hardware
- Assessing Program and Project readiness and recommending whether they should proceed past Key Decision Points (KDPs)
- Supporting SMD in the initiation and preparation of ESSP solicitations
- Planning, coordinating, and implementing an outreach program
- Communicating Project status to the ESD Associate Director for Flight Programs
- Recommending options to solve Program and Project challenges to the ESD Associate Director for Flight Programs

3.2 Deputy Program Manager

The ESSP Deputy Program Manager is responsible for supporting the Program Manager in planning and implementing the ESSP Program consistent with top-level policies, strategies, requirements, and funding established by NASA HQ. For the ESSP Program, these include but are not limited to:

- Supporting the Program Manager to meet all of the Program requirements.
- Leading all new small special project initiatives.
- Ensuring that internal documentation and guidance is appropriate and sufficient.
- Assessing the value provided by the program.
- Proposing initiatives, analysis, and/or ideas to increase the value of the Program.

3.3 ESSP Deputy for Program Planning and Control

The ESSP Deputy for Program Planning and Control performs financial and programmatic management functions on behalf of the Program Manager, ensuring the Program Manager maintains an awareness of Project financial status and performance vs. plan, and that the financial needs of the Projects are being adequately addressed.

The Program Planning and Control manager's responsibilities include, but are not limited to:

- ✧ Establishing and performing resources management oversight of Project contracts and task orders
- ✧ Independently evaluating Project schedule, management, and cost data and issues for the Program Manager
- ✧ Identifying Project liens and threats that could result in cost cap breaches
- ✧ Coordinating Project funding requirements
- ✧ Coordinating with the PA to ensure consistent budget direction between SMD and the Program Office
- ✧ Ensuring that appropriate Program resources are provided to the Projects in a timely manner
- ✧ Leading the Program Office planning and implementation of Planning, Programming, Budgeting, and Execution (PPBE) activities. Preparing information requests for all Projects and the Program Office and a schedule for submittal to the Program Manager
- ✧ Providing monthly assessments of project performance by documenting commitments, obligations, and costs and explaining variances that exceed ± 10%
- ✧ Providing monthly assessments of each Project's projected cost at the end of the FY vs. New Obligation Authority (NOA) anticipated at the end of the FY as well as total cost for all Projects vs. Total NOA to be provided to all Projects and the Program Office
- ✧ Alerting the Program Manager at any time a Project's cumulative commitments, obligations, or costs are expected to exceed 95% of the NOA available
- ✧ Maintaining the program milestones/events calendar with at least monthly updates to reflect all significant Project and Program Office events
- ✧ Leading the Program Office regular reporting activities, including transmitting after report finalization and review, negotiating format, receiving and distributing project-level input, and assigning section drafting and submission schedules

3.4 ESSP Program Chief Engineer

The ESSP Program Chief Engineer (CE) is assigned systems technical authority for communicating technical excellence and exercising technical authority for the ESSP Program. The ESSP Program CE, in partnership with the ESSP Program Manager, ensures an atmosphere of "checks and balances" within the ESSP Program and Projects. For Projects assigned to NASA Centers and the Jet Propulsion Laboratory (JPL), the Technical Authority for these Projects is delegated from the NASA Office of Chief Engineer directly to the engineering management at that Center. For any Projects assigned to non-NASA centers, the ESSP Program CE has NASA technical authority. The ESSP Program CE responsibilities include:

- Identifying and utilizing technical expertise from across NASA, industry, and academia to ensure investigation success and technical excellence through risk-based technical insight into the ESSP Projects
- Monitoring project execution and issue resolution
- Serving as a review team member
- For ESSP Projects assigned to NASA Centers and JPL, working to seek resolution of identified issues. If resolution of the issues cannot be done at lower levels, then the CE communicates to the next level of Center or Agency technical authority
- For ESSP Projects assigned to non-NASA centers, retaining technical authority while working closely with the project-level engineering organization to delegate an appropriate level of insight responsibility to the non-NASA center's engineering authority. The CE resolves any identified issues at the lowest level of authority. Major unresolved issues shall be elevated to the next level of Center or Agency technical authority

3.5 ESSP Mission Managers

ESSP Program Office MMs function as the Program Manager's day-to-day point of contact and advocate for all assigned Projects. They perform technical and programmatic management functions on behalf of the Program Manager, ensuring the Program Manager maintains an awareness of the Project status and that the programmatic needs of the assigned Projects are being adequately addressed. The MMs' responsibilities include:

- Serving as the NASA point of contact (POC) for Projects within the Program
- Interfacing directly with the PIs and Project Managers to develop inputs for program planning, integration, and project issue resolution
- Establishing and performing technical management oversight of project contracts and task orders
- Independently evaluating project metrics, schedule, cost data, management, and issues for the Program Manager
- Independently assessing Projects to identify risks and mitigations
- Identifying Project liens and threats that could result in cost cap breaches
- Providing a monthly project assessment to the Program Manager
- Coordinating with the PE to ensure the clear understanding of programmatic direction between SMD and the Program Office
- Serving as the Program Office representative among NASA, other U.S. governments agencies, and foreign participants on behalf of assigned investigations

- Serving as the Program Office advocate to NASA management, the Public, and other government entities for assigned Projects
- Leading the development of decision packages or products that are fully coordinated within the ESSP Program and with the related PIs and Project Managers
- Participating in Investigation Reviews, or ensuring ESSP PO is thoroughly briefed on the outcome of reviews

3.6 ESSP Program Safety and Mission Assurance Lead

The ESSP Program Safety and Mission Assurance (SMA) Lead (*i.e.* Chief Safety and Mission Assurance Officer) is assigned systems SMA authority for communicating SMA excellence and exercising SMA authority for the ESSP Program. The ESSP Program SMA Lead, in partnership with the ESSP Program Manager, ensures an atmosphere of "checks and balances" with the ESSP Program and Projects. For Projects assigned to NASA Centers and JPL, the SMA authority is delegated from the NASA SMA Office directly to the SMA group at that Center. For Projects assigned to non-NASA centers, the ESSP Program SMA Lead has NASA SMA authority. The ESSP Program SMA Lead responsibilities include:

- Ensuring mission success and safety through risk-based technical insight into the ESSP Projects
- Monitoring project execution and SMA issue resolution
- Serving as a review team member
- For ESSP Projects assigned to NASA Centers and JPL, working to seek resolution of identified issues. If the issue is not resolved at lower levels, the SMA Lead communicates it to the next level of the Center or Agency SMA authority
- For ESSP Projects assigned to non-NASA centers, the ESSP Program SMA Lead retains SMA authority while working closely with the Project SMA organization to delegate an appropriate level of insight responsibility to the non-NASA center's SMA authority. The SMA Lead resolves any identified issues at the lowest level of authority

3.7 ESSP Program Consultants/Subject Matter Experts (SME)

ESSP Program Consultants and SME's provide technical and management expertise in support of Mission Managers, the Chief Engineer, the SMA Lead, and the management team. The ESSP Program Consultant/SME responsibilities include:

- Identifying risks within the ESSP Program Office.
- Identifying risks in project execution.
- Consulting and supporting, as needed, in any of the ESSP PO activities.

3.8 ESSP Program Analysts

The ESSP Program Analysts perform financial and programmatic management functions supporting the Deputy for PP&C, the Program Manager, Deputy Program Manager and MMs, ensuring an awareness of Project financial status and performance vs. plan, and that the financial needs of the Projects are being adequately addressed.

The Program Analyst's responsibilities include, but are not limited to:

- ✧ Establishing and performing resources management oversight of Projects
- ✧ Providing programmatic oversight to program office held contracts/tasks for their assigned projects
- ✧ Independently evaluating cost performance with strong coordination with Schedule Analyst and Risk Analyst
- ✧ Identifying Project liens and threats that could result in cost cap breaches
- ✧ Coordinating Project funding requirements
- ✧ Ensuring that appropriate Program resources are provided to the Projects in a timely manner
- ✧ Leading the Planning, Programming, Budgeting, and Execution (PPBE) activities for their assigned projects.
- ✧ Providing monthly assessments of project performance by documenting commitments, obligations, and costs and explaining variances that exceed ± 10% for their assigned projects

3.9 ESSP Schedule Analyst

The ESSP Schedule Analyst (SA) maintains the overall ESSP schedule, which includes key milestones and tasks of the ESSP Projects, Headquarters events and ESSP events. The ESSP schedule is a historical record of milestone completion for the Program Office and for the investigations/missions in the ESSP portfolio. The schedule is also a planning tool for staffing plans, solicitations, and budgets, and is updated each year to reflect the PPBE guidance. The SA is also responsible for reviewing and assessing the schedules received from the projects, particularly in support of ESSP recommendations to HQ. The SAs' responsibilities include:

- ✧ Maintaining the ESSP schedule and updating as project schedules are received; PPBE guidance is received; solicitations are selected
- ✧ Maintaining the program milestones/events calendar with monthly updates to reflect all significant Project and Program Office events
- ✧ Teaming with MMs in performing the program level schedule management function for projects/investigations, including evaluating project metrics

- Advising program and mission managers in the planning and implementation of projects/investigations
- Providing monthly assessments of projects/investigations' performance using a variety of tools and techniques
- Preparing schedule related reports for MM's, the Deputy for Program Planning and Control, the Deputy Program Manager and the Program Manager
- Working with the project/investigations' schedule analyst to prepare baseline-ready schedules prior to PDR/KDP-C
- Working with the project/investigations' schedule analyst to document schedule variances post KDP-C
- Coordinating with the ESSP Program Analysts to prepare integrated cost and schedule reporting for the MM, the Deputy for Program Planning and Control, the Deputy Program Manager and the Program Manager

3.10 ESSP Risk Manager

The ESSP Risk Manager is responsible for the ESSP Risk Management processes. The RM maintains the ESSP Risk Database, and works with the Mission Managers to support the project/investigation risk management processes. The RM's responsibilities include:

- Facilitates the Risk Management Board
- Administers the Program risk management process
- Works with the risk originators and Risk Owners to capture risk information
- Tracks risks and generates reports
- Enters risk data and maintains the risk database
- Maintains the Risk Management Plan
- Responsible agent to prepare and present Program risks at reviews as required
- Ensures that all mitigation plans are monitored, tracked, and updated, and presented to the Program Manager
- Conducts risk analysis with Risk Owner
- Supports risk status meetings and reviews
- Supports the Program Manager regarding risk scoring, categorization and prioritization
- Reviews all risks

3.11 ESSP Configuration Manager

APPENDIX A: Acronym List

AO	Announcements of Opportunity
CE	Chief Engineer
CM	Configuration Manager
ESD	Earth Science Division
ESSP	Earth System Science Pathfinder
ESSPPO	Earth System Science Pathfinder Program Office
HQ	NASA Headquarters
JPL	Jet Propulsion Laboratory
KDP	Key Decision Point
LaRC	NASA Langley Research Center
MM	Mission Manager
NOA	New obligation authority
PDR	Preliminary Design Review
POC	Point of contact
RM	Risk Manager
SA	Schedule Analyst
SMA	Safety and Mission Assurance
SME	Subject Matter Expert

Appendix V: Tropospheric Emissions: Monitoring of Pollution (TEMPO)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (PLRA Version 2.0 dated July 2014)

Appendix V - Earth System Science Pathfinder Program Plan

Program-Level Requirements for Tropospheric Emissions: Monitoring of Pollution

Version: 2.0
Date: July 2014

Change Log

Revision	Date	Sections Changed
1.0	Nov 2013	Initial Release for KDP-B
2.0	July 2014	1. Remove the following measurements: SO_2, $C_2H_2O_2$ (glyoxal), aerosols (including aerosol optical depth), and UV-B radiation (this change results in changes through the document in sections 2 and 4) 2. Change reference in section 3.2 from 'data downlink to IOC' to 'data delivery to IOC'. 3. Change Field of Regard from 18°N to 19°N and from 58°N to 57.5°N 4. Change the orbital longitude range from 75°W-137°W to 80°W-115°W 5. Minor wording changes regarding the delivery of the science data products (section 4.5.1) 6. Removed references to the specific cost and delivery schedule for the instrument and inserted a reference to the most current KDP DM and Datasheet (sections 4.2 and 5.1)

REQUIRED APPROVALS AND CONCURRENCES
APPROVALS

[signature] 25 Nov 14

John Grunsfeld
Associate Administrator
Science Mission Directorate
NASA Headquarters

Date

[signature] 24 July 2014

Charles Alcock
Director
Smithsonian Astrophysical Observatory

Date

[signature] 7/29/14

Frank Peri
Program Manager
Earth System Science Pathfinder Program Office
NASA Langley Research Center

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Stephen G. Jurczyk
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Date

CONCURRENCES

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Mission Project Manager
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Diane L. Hope — 7/29/14
Diane Hope
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Michael Freilich
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20 Aug 2014
Date

Tupper Hyde
Science Mission Directorate Chief Engineer
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8/21/2014
Date

Geoffrey Yoder
Deputy Associate Administrator for Programs
Science Mission Directorate
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24/Jul/2014
Date

Charles Gay
Deputy Associate Administrator
Science Mission Directorate
NASA Headquarters

24/Jul/2014
Date

2.0 SCIENCE DEFINITION

TEMPO will measure air pollution over North America, at high spatial and temporal resolutions, from GEO. TEMPO spectroscopic measurements in the ultraviolet (UV) and visible (Vis) will provide a measurement suite that includes the key gas variables of tropospheric air pollution chemistry: ozone (O_3), nitrogen dioxide (NO_2), and formaldehyde (H_2CO), and cloud parameters. TEMPO thus will measure the major components, directly or by proxy, of the diurnal tropospheric O_3 chemistry cycle. Multi-spectral observations will provide sensitivity to O_3 in the lowermost troposphere. A small spatial footprint will resolve pollution sources and distributions at sub-urban scale. Together, TEMPO's high temporal and spatial resolution will improve emission inventories, monitor population exposure, and enable effective emission-control strategies.

2.1 Science Objectives

TEMPO is designed to collect the space-based measurements needed to quantify variations in the temporal and spatial emissions of gases important for air quality evaluation with the precision, resolution, and coverage needed to improve our understanding of greater North American pollutant sources and sinks (fluxes) on regional scales and the processes controlling their variability over the diurnal and seasonal cycles.

2.2 Science Instrument Summary Description

The TEMPO instrument is a dispersive spectrometer that measures solar back-scattered light in the UV and Vis spectral ranges. The TEMPO instrument draws from low Earth orbit instrument subassembly heritage and adapts it to GEO operations. A scan mirror steps the spectrometer slit from East to West. A telescope images the scene onto the slit of an Offner-type spectrometer. Spectra are imaged onto a commercially available focal plane array. The instrument's thermal and structural design ensures stability over the full temperature range incurred in the GEO orbit. Instrument control electronics provide all the functionality necessary to operate the instrument, manage data, and interface to the host spacecraft.

TEMPO will provide air quality products that will be made available publicly to allow demonstration of the utility of the products for potential use in near-real time air quality management. TEMPO is expected to operate concurrently with the European Sentinel 4 mission and the Asian Geostationary Environmental Monitoring Spectrometer (GEMS) on the GEO-KOMPSAT-2B mission, which will allow it to be a component of an international GEO constellation for pollution monitoring.

3.0 PROJECT DEFINITION

3.1 TEMPO Roles and Responsibilities

Programmatic lines of authority and lines of information exchange and coordination are shown in Figure 1.

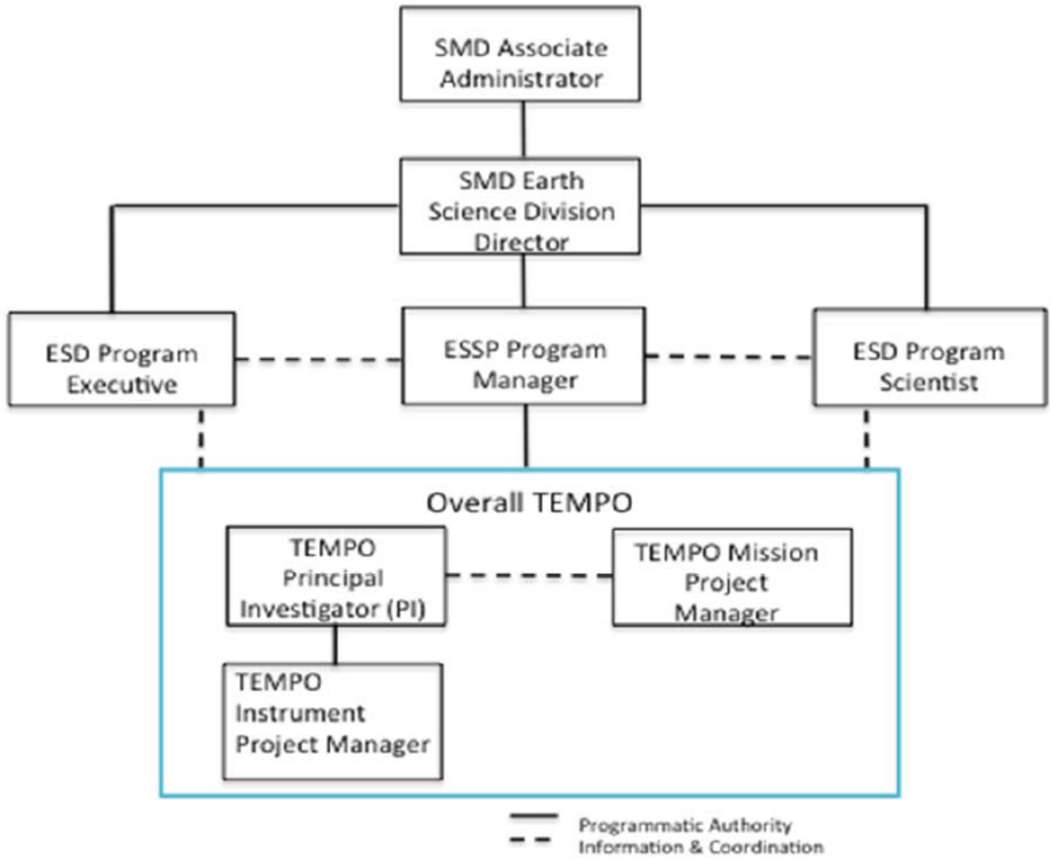

Figure 1. TEMPO Programmatic Lines of Authority and Coordination

The roles and responsibilities for each entity in Figure 1 are described below:

The TEMPO PI and his Institution, SAO, are responsible for overall science leadership; instrument design, development and test (both pre-launch and on-orbit); the Instrument Operations Center (IOC), science data processing and public distribution of data during Phase E; communication and public engagement; and delivery of calibrated/validated science data products to an archive for long-term preservation. The PI is also responsible for coordinating the work of all TEMPO Instrument contractors and Science Team (ST) members.

Instrument Project management is delegated by the PI to NASA LaRC. The TEMPO Instrument Project Manager leads this team and conducts day-to-day management of the TEMPO Instrument Project while coordinating with the TEMPO PI and TEMPO Mission Project Manager.

The TEMPO Mission Project has been directed by the Earth Science Division to the LaRC. The TEMPO Mission Project Manager has responsibility for procurement of accommodations on a GEO host spacecraft; integration of the TEMPO instrument to the host spacecraft (including funding any required engineering support from the instrument development contractor); systems engineering and mission design; support for launch activities, data delivery to the IOC and NASA assigned Data Center, and the ground system to transfer the telemetry and instrument commands between the TEMPO instrument and the TEMPO Instrument Operations Center (IOC).

The initial members of the TEMPO ST were identified in the TEMPO proposal. The ST is composed of scientists with expertise spanning all necessary disciplines and will be managed by the PI. The role of the ST is to provide algorithms for data products, validate the TEMPO data, perform geophysical analysis of the data, and use the data in scientific research. During the lifetime of the instrument, the TEMPO PI may propose changes to the ST membership with the changes subject to the approval and concurrence of the ESD Program Scientist.

The SMD/ESD will designate a Data Center as the Distributed Active Archive Center (DAAC) for long-term preservation of TEMPO data products (See Section 4.5). NASA SMD is responsible for providing access to communications networks necessary for the transfer of science data products from SAO to the DAAC for long-term preservation.

The TEMPO Instrument Project and TEMPO Mission Project shall coordinate systems requirements definition; agree upon systems requirement allocations (as defined in the Systems Engineering Management Plan or SEMP) to each project; communicate status of each project; and participate in each other's risk management processes.

3.2 Project Acquisition Strategy

The PI delegated the responsibility for procurement of the TEMPO instrument to the Instrument Project Manager at LaRC who contracted with Ball Aerospace and Technologies Corporation (BATC) for design, development, testing and delivery of the TEMPO instrument to NASA.

TEMPO will be accommodated on a host spacecraft in GEO. The TEMPO Mission Project will acquire the host accommodation for the TEMPO instrument. NASA ESD is partnering with United States Air Force (USAF) Space and Missile Systems Center (SMC) Hosted Payload Solutions (HoPS) office to award study contracts with prospective vendors using the USAF Indefinite Delivery/Indefinite Quantity (IDIQ) contract. After the study phase completes, procurement of the hosting service will be conducted either using the USAF IDIQ contract vehicle or by NASA LaRC procurement.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, however the baseline science requirements provide substantially more value to NASA and the Earth science community. The requirements in this section encompass the overall TEMPO project. The requirements in section 4.1 are specifically levied on the TEMPO Instrument Project. The requirements in the other subsections of section 4 include those levied on both the Instrument Project and the Mission Project (and are so identified in those sections as appropriate). These requirements are flowed down to the appropriate subsidiary documents.

4.1 Science Requirements

The requirements specified herein are derived from the achievable science identified in the TEMPO instrument proposal submitted by SAO to NASA.

4.1.1 Baseline Science Requirements

a) Retrieve estimated geophysical products with temporal revisit as shown in Table 1 across Greater North America (to include all of the contiguous lower 48 United States and Canada at latitudes below 57.5ºN, all of Central America above 19ºN, the Caribbean islands north of 19ºN and west of 72.75ºW, and the Pacific Ocean north of 19ºN and East of 120ºW) on urban-regional spatial scales (≤ 60 km^2 at the center of the Field of Regard (FOR)) to resolve diurnal changes in pollutant distributions in cloud-free scenes with a geo-location accuracy of at least 4 km and for twenty (20) months subject to instrument availability as defined in Section 4.3.

Table 1: Baseline Science Requirements

Species/Products	Required Precision	Temporal Revisit
Tropospheric O_3	10 ppbv	1 hour
0-2 km O_3 Selected scenes	10 ppbv	2 hour
Total O_3	3%	1 hour
Tropospheric NO_2	1.0×10^{15} molecules cm^{-2}	1 hour
Tropospheric H_2CO	1.0×10^{16} molecules cm^{-2}	3 hour

b) Compare space-based and ground-based retrievals of products using correlative data collected from daytime (solar zenith angles <70° for all products) observations at least one month each season from at least three (3) ground validation sites in the US to identify and correct regional-scale and diurnal systematic biases in the space-based products and to demonstrate required precisions in polluted clear-sky scenes to the levels listed in Table 1. At the validation sites, Pandora solar spectral-radiometer measurements will be the primary source of correlative data for trace gas column densities. Ozonesondes will contribute to the validation of the O_3 mixing ratio on a best effort basis.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to a NASA SMD/ESD-assigned DAAC for archive. Fully characterize the accuracy of all publically delivered and archived science data. The SAO Science Data Processing Center (SDPC) shall perform public distribution of data products for use by the scientific community during operations.

4.1.2 Threshold Science Requirements

a) Retrieve estimated geophysical products with temporal revisit as shown in Table 2 across Greater North America (19°N to 55°N near 100°W, 67°W to 125°W near 42°N) on urban-regional spatial scales (≤ 300 km^2 at the center of the FOR) to resolve diurnal changes in pollutant distributions in cloud-free scenes with a geo-location accuracy of at least 4 km and for twelve (12) months subject to instrument availability as defined in Section 4.3.

Table 2: Threshold Science Requirements

Species/Products	Required Precision	Temporal Revisit
Tropospheric O_3	10 ppbv	1 hour
Total O_3	3%	1 hour
Tropospheric NO_2	1.0×10^{15} molecules cm^{-2}	1 hour
Tropospheric H_2CO	1.0×10^{16} molecules cm^{-2}	3 hour

b) Compare space-based and ground-based retrievals of products using correlative data collected from daytime (solar zenith angles <70° for all products) observations at least one month during the North American Summer from at least three (3) ground validation sites in the US to identify and correct regional-scale and diurnal systematic biases in the space-based products and to demonstrate required precisions in polluted clear-sky scenes to the levels listed in Table 2. At the validation sites, Pandora solar spectral-radiometer measurements will be the primary source of correlative data for trace gas column densities. Ozonesondes will contribute to the validation of the O_3 mixing ratio on a best effort basis.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to a NASA SMD/ESD-assigned DAAC for archive. Fully characterize the accuracy of all publically delivered and archived science data. The SDPC shall perform public distribution of data for use by the scientific community during operations.

4.1.3 Science Instrument Requirements

The space-based instrument shall be capable of acquiring spatially imaged measurements of the wavelength-dependent atmospheric reflectance spectrum in the UV/Vis portions of the spectrum for solar zenith angles <70° that meet the Baseline Science Requirements (Section 4.1.1).

a) The spectral range and resolving power of the space-based instrument shall be selected to resolve individual absorption bands for O_3, NO_2, and H_2CO.

b) The TEMPO instrument shall acquire measurements with a pixel footprint area of ≤ 15 km^2 at the center of the FOR to facilitate resolution of urban-scale air quality events over the contiguous United States on seasonal time scales.

4.2 Launch and Installation Requirements

a) The calibrated and validated TEMPO instrument shall be provided by the PI ready for integration on a NASA-selected host spacecraft for launch to GEO.

b) The TEMPO instrument shall be installed on the nadir deck of a GEO host with an acceptable longitude range of 80°W to 115°W.

c) The TEMPO Instrument Project shall target the instrument delivery date as documented in the most current KDP Decision Memo and Datasheet.

d) The TEMPO instrument shall be controlled by the SAO IOC utilizing the host Spacecraft Operations Center (SOC) data uplink/downlink.

e) The TEMPO Mission Project shall transfer the data, telemetry, and commanding between the host SOC and the TEMPO IOC.

4.3 TEMPO Performance

a) TEMPO shall be Category 3 per NASA Procedural Requirement (NPR) 7120.5E.

b) The TEMPO instrument and any hardware and/or software required for accommodations shall be Class C per NPR 8705.4.

c) TEMPO Instrument Project shall complete the On-Orbit Checkout (OOC) period within 90 days after power-on at the operational orbit location and then begin operations consistent with the science requirements in Section 4.1.1.

d) The TEMPO instrument lifetime is twenty (20) months baseline (12 months threshold) following completion of OOC.

e) The TEMPO Mission Project shall reserve accommodations to support TEMPO operations on the host for at least twenty (20) months after OOC. Extended investigation operations beyond the nominal investigation length are subject to approval through the ESD Senior Review process and negotiations with the host spacecraft. The TEMPO Mission Project will conduct these negotiations with the host spacecraft provider.

f) The TEMPO instrument shall produce data products from at least 75% of available measurement opportunities for baseline (at least 50% for threshold). Available measurement opportunities are those times at which the solar zenith angle within Greater North America is less than 70 degrees.

g) The TEMPO instrument shall be capable of operating >95% of the time that the Host satellite is not in eclipse and >80% of the time during eclipse.

4.4 Ground System Requirements

a) The TEMPO Instrument Project shall develop and operate the IOC and SDPC ground systems to meet the performance requirements in Section 4.1 and the data requirements in Section 4.5.

b) The TEMPO Mission Project shall deliver L0 data and satellite ancillary data to the IOC within 24 hours of the data being generated by the TEMPO Instrument and the Host spacecraft.

4.5 Mission Data Requirements

4.5.1 Science Data Management

a) The TEMPO Instrument Project shall produce the standard science data products above Level 0 that are listed in Table 3. The SDPC shall perform public distribution of these standard science data products, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products, for use by the scientific community during the mission according to latencies expressed in Table 3. Public release of these data shall conform to the NASA Earth Science Data and Information Policy. There shall be no period of exclusive access.

b) The L0 reconstructed, unprocessed instrument data shall be delivered to the NASA SMD/ESD-assigned DAAC and to the TEMPO IOC. The TEMPO PI will coordinate with the DAAC to provide all appropriate information and documentation necessary to enable the scientific community to access and use the L0 instrument data.

Table 3. TEMPO Data Products

Data Product	Description	Time beyond On-Orbit Checkout (OOC) to deliver initial data	Maximum data latency after first release for ≥ 80% of products
Level 0	Reconstructed, Unprocessed Instrument Data	2 months	Within 2 hours of receipt at SAO
Level 1b	Calibrated, Geolocated Radiances	4 months	Within 3 hours of Level 0 and ancillary data receipt at SAO
Level 2	Derived Geophysical Data Products	6 months	Within 24 hours of production of Level 1 at SAO
Level 3	Derived Gridded Geophysical Data Products	6 months	1 month after completion of data accumulation required for individual geophysical products

c) Science algorithms used to generate the standard science data products listed in Table 3 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).

d) All original observation data and standard science data products listed in Table 3, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products, shall be delivered to the designated NASA SMD/ESD-assigned DAAC within six months of completion of the prime mission.

e) The TEMPO Instrument Project shall coordinate with the NASA SMD/ESD-assigned DAAC regarding the release of product versions to ensure completeness and accuracy of quality information, validation status, and metadata of the TEMPO science data products.

f) The TEMPO Instrument Project shall coordinate with the NASA SMD/ESD-assigned DAAC on the data and information to be transferred at TEMPO closeout.

4.5.1.1 Science Data Requirements

a) TEMPO science data product formats shall conform to the HDF-EOS5 standard, selected from the published list of NASA SMD/ESD-approved Data System Standards.

b) TEMPO 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* published at http://earthdata.nasa.gov/about-eosdis/requirements, and TEMPO shall baseline to a specific initial version before launch.

c) TEMPO shall transfer to the NASA SMD/ESD-assigned DAAC all the information and documentation required for long-term preservation of knowledge about the products resulting from the project, as defined in the *NASA Earth Science Data Preservation Content Specification* document published at http://earthdata.nasa.gov/about-eosdis/requirements, and shall baseline to a specific initial version before launch.

d) The TEMPO Instrument Project will document the approach to the final reprocessing of all instrument data in the End of Mission Plan.

4.5.2 Applied Science Requirements

TEMPO shall organize and host a TEMPO data product application workshop six months prior to launch (with appropriate follow-on meetings) and participate in the appropriate NASA SMD/ESD mission applications meeting(s). The workshop or meeting will share information on TEMPO science data products and define potential applications that can be supported or developed within existing TEMPO data requirements. TEMPO shall provide results of the workshop(s) and meeting(s) to the TEMPO ST and make available information about potential or actual applications at other TEMPO workshops and meetings and to the public.

4.6 Mission Success Criteria

TEMPO will be considered successful if it:

a) Collects space-based measurements of tropospheric O_3 column amounts, total O_3 column amounts, NO_2, and H_2CO with the precision, resolution, and coverage needed to assess the spatial and temporal variability of pollutant distributions over a diurnal cycle over at least half of the contiguous United States for a total of 30 days including at least three 7-day periods of contiguous daylight operations.

b) Records, validates, publishes, and delivers the science data records and calibrated geophysical data products to a NASA SMD/ESD-assigned DAAC for archive.

5.0 TEMPO COST REQUIREMENTS

5.1 Cost Requirements

a) The TEMPO Instrument Project lifecycle costs and the phasing of the costs are documented in the most recent KDP Decision Memo and Datasheet. Costs that are within the PI-Managed Instrument Cost include: instrument delivery ready for integration onto the selected spacecraft (Phases A-C); development and delivery of functional algorithms and ground processing system (Phases B-D); supporting a science team that will contribute directly to the successful implementation of the investigation (Phases A-F); required calibration and validation activities (Phases C-E); instrument operations, data product generation and distribution, and data analysis during the proposed prime investigation lifetime (Phases E); and close out of the investigation once the investigation has been concluded (Phase F).

b) TEMPO Mission Project costs are outside the PI-Managed Cost and include integration of the TEMPO instrument to the NASA selected host spacecraft (Phase D); supporting the integration of the host satellite with the launch vehicle and launch (including funding any required engineering support from the instrument development contractor); ensuring TEMPO ground system compatibility with host ground systems; costs due to any potential gap between the delivery of the completed instrument (end of Phase C) and the start of integration of the instrument to the designated spacecraft (start of Phase D); and host spacecraft on-orbit operations services including transponder lease for data downlink. The TEMPO Mission Project's costs are documented in the most recent KDP Decision Memo and Datasheet. Unallocated Future Expenses (UFE) funding is maintained at the SMD level.

5.2 Cost Management and Scope Reduction

a) Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the TEMPO Instrument Project shall pursue scope reduction and risk management as a means to control cost.

b) The TEMPO Instrument Project Plan shall include potential scope reduction and risk management as a means to control cost. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised.

c) Scope reductions from baseline science requirements (Section 4.1.1) to threshold science requirements (Section 4.1.2) or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of this document.

d) The TEMPO Instrument Project and Mission Project shall coordinate technical and programmatic trades with each other without changing the PI-managed cost cap.

   a. The TEMPO Instrument Project shall identify cost and schedule margin to enable them to make design modifications in the event of a schedule incompatibility between the instrument development and host selection.

   b. The TEMPO Mission Project shall identify the budget to find suitable host accommodations for the instrument.

   c. The TEMPO Instrument and Mission Project Managers may together consider design and implementation options that affect the budget allocations for each. The SMD PMC retains the sole decisional authority to alter the TEMPO Instrument Project cost cap and the TEMPO Mission Project budget allocation.

6.0 MULTI-MISSION NASA FACILITIES

TEMPO shall rely on the NASA SMD/ESD-assigned DAAC and other EOSDIS infrastructure for science data archive at the end of the prime mission and receipt of L0 data. The SMD/ESD provides access to these resources as documented herein.

7.0 EXTERNAL AGREEMENTS

There is no non-NASA financially contributing partner in TEMPO.

8.0 COMMUNICATION AND PUBLIC ENGAGEMENT

The TEMPO Instrument Project shall develop and execute a Communication and Public Engagement Plan that utilizes unique scientific and/or engineering aspects of the investigation to inspire and motivate the nation's students and teachers as well as to engage and educate the public. The activities aim to stimulate broad awareness and understanding of the role of tropospheric emissions in air quality and the Earth's climate. The plan should optimize educational and cost effectiveness and coordinate with NASA's communication and public engagement activities to build upon the resources and capabilities NASA has accrued in education and public outreach.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for TEMPO.

10.0 WAIVERS

None at this time.

Appendix W: Cyclone Global Navigation Satellite System (CYGNSS)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	11/01/2013	Initial Release (PLRA dated 8/20/2012)
A	11/01/2017	Updated PLRA (3.0; 4/15/2016)

Appendix W - Earth System Science Pathfinder Program Plan

Program-Level Requirements for the Cyclone Global Navigation Satellite System (CYGNSS) Project

Version: 3.0
Date: May 11, 2016

Change Log

Revision	Date	Sections Changed	Author
	20 Aug 2012	**Initial Release**	Bonniksen
2.0	1 Nov 2013	**3.2:** Update of Deployment Module Provider **4.3:** Standardization of Launch Vehicle requirements 4.1.1 (f) Clarification of requirement 4.1.2 (f) Clarification of requirement **4.1.3:** Removal of section – redundant with sections 4.1.1 and 4.1.2 **4.5:** Designation of selected DAAC Table 1: Removal of TBR designation 5.1: Change PI controlled funding from FY 14 Base Year total to Real Year Total **5.1:** Clarification of NASA launch vehicle cost base **6:** Removal of TBR requirement **10:** Addition of waiver process language	Bonniksen
3.0	15 April 2016	**4.3.c** Change of LRD from Oct to November to be consistent with current Decision Memorandum Management Agreement Date **4.5.1.1.** Clarification of Level 1, 2 and 3 science data product definitions. **4.5.1.1.d** Addition of non-standard data product.	Bonniksen

Table of Contents

1.0 SCOPE

This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed upon the Regents of the University of Michigan for the development and operation of the Cyclone Global Navigation Satellite System (CYGNSS) Project of the ESSP Program. Requirements begin in section 4. Sections 1, 2 & 3 are intended to set the context for the requirements that follow.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division within SMD to the ESSP Program Manager at Langley Research Center (LaRC). Project management will be conducted at Southwest Research Institute. See Section 3.1.

The Principal Investigator is responsible for scientific success, design, development, test, mission operations, and data verification tasks and shall coordinate the work of all contractors and science team members.

Changes to information and requirements contained in this document require approval by the Science Mission Directorate (SMD), NASA Headquarters, and the University of Michigan by the officials that approved the original.

2.0 SCIENCE DEFINITION

The CYGNSS Project will implement a spaceborne earth observation mission designed to collect measurements of ocean surface winds through variations in the direct vs reflected Global Positioning System signals. The observatory portion of this mission consists of a constellation of eight satellites. CYGNSS measurements will yield a critical data set that will enable science and applications users to understand processes that link the ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics in terrestrial water, energy and carbon cycles;

The CYGNSS mission will investigate whether a space-based measurement approach could be used for future Tropical Cyclone monitoring missions.

Storm Definitions:

Tropical Storm: A tropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) ranges from 17 m/s to 33 m/s.

Tropical Cyclone: A warm-core non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects).

2.1. Baseline Science Objectives

The CYGNSS science is enabled by meeting the following objectives:

- Measure ocean surface wind speed in most naturally occurring precipitating conditions, including those experienced in the tropical cyclone eyewall.
- Measure ocean surface wind speed in the tropical cyclone inner core with sufficient frequency to resolve genesis and rapid intensification.

2.2 Science Instrument Summary Description

The baseline CYGNSS instrument is a Delay Doppler Mapping Instrument (DDMI) that resides on each observatory in the constellation. The DDMI is a Global Navigation Satellite System (GNSS) Receiver-Remote sensing Instrument. Each instrument will use one or more nadir pointing antennas for collecting reflected GNSS signals and a zenith facing antenna to collect direct GNSS signals. The GNSS transmission frequency enables the instrument to operate as a passive sensor while providing data during most precipitation conditions. These measurements are autonomously processed to provide a pixel map based on the cross-correlation of the direct received signal with the analysis of the reflected signal generated based on time delay and Doppler shift.

3.0 PROJECT DEFINITION

3.1 Project Organization & Management

The Principal Investigator shall report to NASA according to Figure 1.

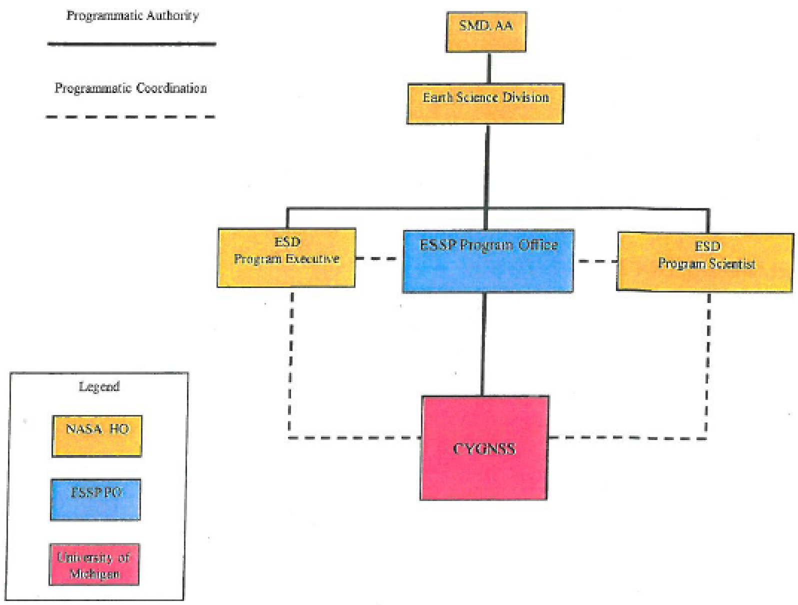

Figure 1. CYGNSS Lines of Authority and Coordination

The Principal Investigator and his institution (The University of Michigan) has overall management responsibility for the success of the project mission and science objectives.

3.2 Project Acquisition Strategy

The University of Michigan (UM) serves as a prime contractor to NASA for CYGNSS. UM will contract with Southwest Research Institute (SwRI) for development and integration of all spacecraft systems including deployment module. NASA will acquire launch services for the CYGNSS Project to include any required launch service interagency agreements.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA.

4.1 Science Requirements

4.1.1 Baseline Science Requirements

a) The baseline science mission shall provide estimates of ocean surface wind speed over a dynamic range of 3 to 70 m/s as determined by a spatially averaged wind field with resolution of 5x5 km.

b) The baseline science mission shall provide estimates of ocean surface wind speed during precipitation rates up through 100 millimeters per hour as determined by a spatially averaged rain field with resolution of 5x5 km.

c) The baseline science mission shall retrieve ocean surface wind speed with a retrieval uncertainty of 2 m/s or 10%, whichever is greater, with a spatial resolution of 25x25 km.

d) The baseline science mission shall collect space-based measurements of ocean surface wind speed at all times during the science mission with the following temporal and spatial sampling: 1) temporal sampling better than 12 hour mean revisit time; and 2) spatial sampling 70% of all storm tracks between 35 degrees north and 35 degrees south latitude to be sampled within 24 hours.

e) The CYGNSS project shall conduct a calibration and validation program to verify data delivered meets the requirements in sections 4.1.1a, 4.1.1b, 4.1.1c and 4.1.1d within individual wind speed bins above and below 20 m/s.

f) The CYGNSS Project shall provide Level 2 Data Products in support of the operational hurricane forecast community assessment of CYGNSS data in retrospective studies of new data sources.

4.1.2 Threshold Science Requirements

a) The threshold science mission shall provide estimates of ocean surface wind speed over a dynamic range of 3 to 40 m/s as determined by a spatially averaged wind field with resolution of 5x5 km.

b) The threshold science mission shall provide estimates of ocean surface wind speed during precipitation rates up through 100 millimeters per hour as determined by a spatially averaged rain field with resolution of 5x5 km.

c) The threshold science mission shall retrieve ocean surface wind speed with a retrieval uncertainty of 2 m/s or 10%, whichever is greater, with a spatial resolution of 50x50 km.

d) The threshold science mission shall collect space-based measurements of ocean surface wind speed at all times during the science mission with the following temporal and spatial sampling 1) temporal sampling better than 12 hour mean revisit time and 2) spatial sampling 60% of all storm tracks between 35 degrees north and 35 degrees south latitude to be sampled within 24 hours.

e) The CYGNSS project shall conduct a calibration and validation program to verify data delivered meets the requirements in sections 4.1.2a, 4.1.2b, 4.1.2c and 4.1.2d within individual wind speed bins above and below 20 m/s.

f) The CYGNSS Project shall provide Level 2 Data Products in support of the operational hurricane forecast community assessment of CYGNSS data in retrospective studies of new data sources.

4.2 Mission and Flight Element Performance

a) The CYGNSS project shall be Category 3 per NPR 7120.5E, and the mission class shall be D per NPR8705.4.

b) The CYGNSS mission shall complete the In-Orbit Checkout (IOC) period within 60 days after launch, and then begin operations according to the science requirements in section 4.1.

c) The CYGNSS Constellation orbital deployment shall be designed for minimum inter-Observatory conjunction of 200 m (3σ) (TBR).

d) The CYGNSS science mission lifetime is 2 years baseline (14 months threshold) following completion of IOC.

e) The CYGNSS mission shall be capable of completing decommissioning activities within 1 month following the end of the science mission.

4.3 Launch Requirements

a) This payload shall be launched on an expendable launch vehicle.

b) The CYGNSS constellation shall be launched in a nominally circular orbit which will support a constellation revisit time of not more than 12 hours between 35° N and 35°S latitude.

c) The CYGNSS project shall target a Launch Readiness Date of November 2016.

4.4 Ground System Requirements

The CYGNSS project shall develop a ground system to meet the science requirements in section 4.1 and the data requirements in section 4.5.

4.5 Mission Data Requirements

4.5.1 Science Data Management

a) The CYGNSS Project shall produce the standard science data products listed in Table 1.

b) The standard science data products listed in Table 1, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products shall be made publically available. Public release of these data shall conform to the NASA Earth Science Data and Information Policy (http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/). There shall be no period of exclusive access.

c) Science algorithms used to generate the standard science data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).

d) By the end of Prime Mission, the CYGNSS Project shall deliver all standard science data products, along with the scientific algorithm software, coefficients, and ancillary data used to generate these products, to the PO.DAAC.

e) The CYGNSS Project will coordinate with the PO.DAAC on the data and information to be transferred at CYGNSS closeout.

4.5.1.1 Science Data Requirements

a) The CYGNSS Project science data product formats shall conform to the NetCDF standard.

b) The CYGNSS 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, and the CYGNSS Project shall baseline to a specific initial version before launch.

c) The CYGNSS Project shall transfer to PO.DAAC all the information and documentation required for long-term preservation of knowledge about the products resulting from CYGNSS Project, as defined in the *NASA Earth Science Data Preservation Content Specification* document published at http://earthdata.nasa.gov/about-eosdis/requirements, and shall baseline to a specific initial version.

Table 1. CYGNSS Data Products[1]

Data Product	Description	First Data Delivery after IOC	Maximum data latency after first release[2]
Level 1a	Calibrated DDMs of received power (watts), calibrated using on-board cal load measurements	2 months	6 days
Level 1b	Calibrated DDMs of scattering cross section (meters^2), calibrated using CYGNSS and GPS spacecraft attitude and location knowledge and Earth geoid model	2 mo	6 days
Level 2a	Wind speed in ungridded Observatory coordinate system and serial time stamp without precision geolocation	2 mo	6 days
Level 2b	Mean square slope (surface roughness) in ungridded Observatory coordinate system and serial time stamp without precision geolocation	2 mo	6 days
Level 3a	Gridded wind speed with	2 mo	6 days

	precision geolocation		
Level 3b	Gridded ocean surface roughness with precision geolocation	2 mo	6 days

[1] The NASA HQ Archive will be at the PO.DAAC.

[2] Data latency is defined as the elapsed time from the downlink of raw data to the availability of processed Level 2 data products to the public.

d) A non-standard science data product, Level 4 Data Assimilation Wind Field, will be produced for each of the Atlantic hurricanes for which the operational HWRF product is generated by NOAA. It is a gridded basin-scale product based on the assimilation of CYGNSS and all other available wind and other environmental data into a hurricane weather research and forecasting model framework. The CYGNSS Project shall deliver this product, along with its ATBD, to the PO.DAAC. The product shall be delivered within one month after the end of each Atlantic hurricane season.

4.5.2 Applied Science Support Requirements

Beginning in Phase C, the CYGNSS Project will coordinate with the Applied Science Program on jointly hosting an annual CYGNSS data product application workshop. The content and goals of the application workshops are to be determined by CYGNSS Project and Applied Science leads.

4.6 Mission Success Criteria

Collect global space-based measurements from not less than four spacecraft to provide estimates of ocean surface wind speed over a dynamic range of 3 to 40 m/s and during precipitation rates up through 100 millimeters per hour, as determined respectively by spatially averaged wind and rain fields with a resolution of 5x5 km. Wind speed retrieval uncertainty shall be 2 m/s or 10%, whichever is greater, with a spatial resolution of 50x50 km. The measurements will need to be collected for not less than 6 months after checkout is complete. This time period provides the minimal time needed to determine if collected measurements meet the threshold requirements (per section 4.1.2) during a single Tropical Cyclone season. This number of spacecraft provides for 50% coverage of historical storm tracks every 24 hours.

5.0 NASA Mission Cost Requirement

5.1 Cost

The CYGNSS funding allocation is $102.8M for the design, development, and operation of the mission (phase A through E). Additionally, Launch Services based on the requirements in section 4.3 will be provided by NASA; costs associated with changes outside this scope will be borne by the project.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the CYGNSS project shall pursue scope reduction and risk management as a means to control cost. The Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised. Scope reductions from baseline science requirements to threshold science requirements or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of the document.

6.0 MULTI-MISSION NASA FACILITIES

No Multi-Mission NASA facilities are used for CYGNSS.

7.0 EXTERNAL AGREEMENTS

All agreements between NASA and each non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of International and Interagency Relations prior to KDP-C. All funding for external participation will be performed under the cost cap.

8.0 PUBLIC OUTREACH AND EDUCATION

The CYGNSS project shall develop and execute an Education and Public Outreach Plan consistent with SMD requirements for the class of project.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the CYGNSS Project.

10.0 WAIVERS

Any waivers to NPR 7120.5 Class D implementation requirements or processes shall be approved in accordance with existing University of Michigan, Southwest Research Institute and NASA processes for category A waiver approval.

11.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS

Geoffrey L. Yoder — 6/20/2016
Date
Acting Associate Administrator, Science Mission Directorate
NASA Headquarters

Chris Ruf — 27 April 2016
Date
Principal Investigator, CYGNSS Mission
University of Michigan

Greg Stover — 7 Jun 16
Date
Program Manager, Earth System Science Pathfinder Program
NASA Langley Research Center

CONCURRENCES

4/27/16

John Scherrer
Project Manager, CYGNSS Mission
Southwest Research Institute

Date

6/7/16

James Wells
Mission Manager, Earth System Science Pathfinder Program Office
NASA Langley Research Center

Date

Ramesh Kakar

4/25/16

Ramesh Kakar
Program Scientist
Science Mission Directorate, NASA Headquarters

Date

7 Jun 16

Christine Bonniksen
Program Executive
Science Mission Directorate, NASA Headquarters

Date

6-13-16

Joe Pellicciotti
Science Mission Directorate, Chief Engineer
Date

6/7/2016

Michael H. Freilich
Director, Earth Science Division
Science Mission Directorate, NASA Headquarters
Date

6/14/16

Greg Robinson
Deputy Associate Administrator for Programs
Science Mission Directorate, NASA Headquarters
Date

Appendix X: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (PLRA 6.0; 10/19/2015)

Contents

1.0 SCOPE

The Science Mission Directorate (SMD) at NASA Headquarters selected the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) investigation on July 30, 2014 in response to the Second Stand Alone Mission of Opportunity Notice (SALMON-2), Program Element Appendix (PEA) M: Earth Venture Instrument-2, NNH12ZDA0060-EVI2. This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on the Jet Propulsion Laboratory (JPL) for the development and operation of the ECOSTRESS Project. The ECOSTRESS Principal Investigator (PI) from JPL is responsible for the complete science investigation and for ECOSTRESS development and activities necessary to deliver the science as agreed to in this Program Level Requirements Appendix (PLRA). The PI is responsible for scientific success, design, development, test, mission operations, and data verification tasks and will coordinate the work of all contractors and science team members. The ECOSTRESS instrument will be accommodated on the ISS.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Requirements begin in Section 4. Sections 1, 2 and 3 set the context for the requirements that follow.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division (ESD) within SMD to the ESSP Program Manager at the Langley Research Center (LaRC). Project management will be conducted at JPL. See Section 3.1.

Any changes to the Level-1 requirements contained in this document must be approved by the officials that approved the original requirements.

2.0 SCIENCE DEFINITION

2.1 Science Objectives

ECOSTRESS will answer critical scientific questions on plant–water dynamics and the potential for future ecosystem changes with climate and allow us to address the following science objectives:

1. Identify critical thresholds of water use and water stress in key climate sensitive biomes;

2. Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle; and,

3. Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy.

2.2 Science Instrument Summary Description

ECOSTRESS will use thermal infrared (TIR) brightness temperature measurements made from the International Space Station (ISS) to address the science objectives. The ECOSTRESS payload is a stand-alone instrument built using the Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) instrument, with additional elements as required to accommodate installation and operation on the ISS. The ECOSTRESS instrument is a multispectral thermal infrared radiometer that can support up to 6 spectral bands. The ECOSTRESS instrument uses an actively cooled mercury cadmium telluride (MCT) detector and operates in a whiskbroom mode with a continuously rotating scan mirror. The ECOSTRESS data are calibrated with one or more blackbodies, which are viewed with each mirror scan.

3.0 PROJECT DEFINITION

3.1 Project Organization and Management

The ECOSTRESS Principal Investigator will report to NASA according to Figure 1.

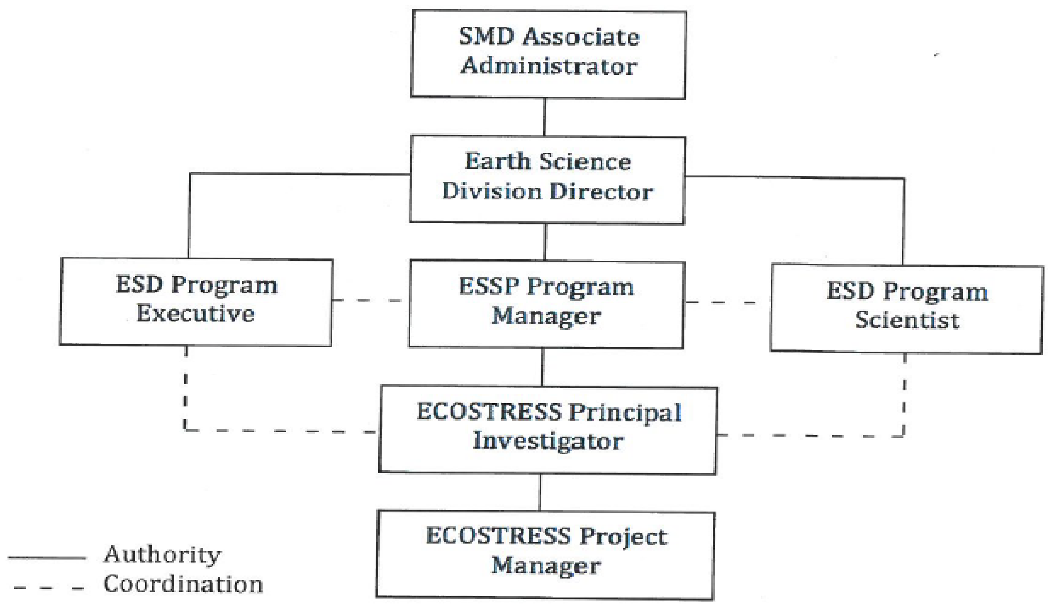

Figure 1. ECOSTRESS Programmatic Lines of Authority and Coordination

The ECOSTRESS Principal Investigator (PI) is responsible for overall mission success within the committed schedule and cost. The PI has delegated formulation and implementation management responsibility to the Project Manager at JPL. Specific assigned roles and responsibilities are:

- The PI and JPL are responsible for ensuring the scientific success of the mission and providing project management; system engineering and mission design;

safety and mission assurance; the ECOSTRESS instrument; mission operations and the associated mission operations ground data system; science data processing and delivery of calibrated/validated science data products to an archive for public distribution.

- The Human Exploration and Operations Mission Directorate (HEOMD) ISS Program Office (ISSPO), specifically the ISSPO Research Integration Office (RIO), provides the launch and launch services, the site and supporting interfaces on the ISS Japanese Experiment Module Exposed Facility (JEM-EF), the robotic installation of the ECOSTRESS payload to the ISS, and payload disposal at the end of mission. The ISSPO RIO is also responsible for providing access to ground communication network(s) for uplink and downlink compatible with the ECOSTRESS mission.
- NASA SMD/ESD has designated the Land Processes Distributed Active Archive Center (LP DAAC) to be responsible for public distribution of ECOSTRESS data and long-term science data archiving.
- The ECOSTRESS Project, working together with the ISSPO, will identify potential accommodations required to comply with the Program Level Requirements that are not defined within the PI-managed cost cap nor specifically provided by the ISSPO RIO (including funding any required engineering support from the instrument development contractor). The ESSP Program Manager is responsible for the adjudication, approval and funding of accommodations.

3.2 Project Acquisition Strategy

JPL will implement an in-house development of the instrument, supplemented by commercial vendors and/or other NASA centers for parts and assemblies as required, and inheriting, as applicable, ISS-relevant designs developed previously by the Orbiting Carbon Observatory-3 (OCO-3) project. The ISSPO RIO will provide the launch services and the ground network.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by the science requirements listed herein.

4.1 Science Requirements

a) The ECOSTRESS mission shall measure the Brightness Temperature at sensor of the surface of the Earth from the ISS with an accuracy of 1K and a precision of 0.3K at 300K. The measurements will be made at different times over the diurnal cycle, with coverage of CONUS on average once per week over a growing season.

b) The ECOSTRESS mission shall acquire the brightness temperature in 4.1.a at a ground sampling distance of 100 meters over a continuous ground swath width of at least 360 km from the expected 385 to 415 km ISS altitude range.

c) The ECOSTRESS mission shall record, validate, publish, and deliver science data records and calibrated geophysical data products to the LP DAAC for use by the scientific community.

For the ECOSTRESS investigation, the baseline and threshold science requirements are the same and hereafter are referred to as the science requirements.

4.2 Science Instrument Requirements

The ECOSTRESS Thermal Infrared Radiometer instrument shall acquire coincident thermal infrared emission measurements of the Earth surface in a minimum of 3 separate spectral bands, covering the 8.0 to 12.5 microns wavelength range, over a temperature range of 270 to 335K to the accuracy and precision specified in the science requirements.

4.3 Launch, Installation and Disposal Requirements

a) The ECOSTRESS payload shall be launched on a launch vehicle provided by ISSPO RIO.

b) The ECOSTRESS payload shall be installed on the Japanese Experiment Module Exposed Facility (JEM-EF) Unit #10 of the ISS and controlled via NASA's Payload Operations Integration Center (POIC).

c) The ECOSTRESS payload shall be disposed of at the end of the mission by NASA ISS RIO.

d) The ECOSTRESS project shall target instrument delivery for integration onto the Launch Vehicle as specified in the most current NASA SMD DPMC ECOSTRESS Project Decision Agreement.

4.4 Mission Performance

a) The ECOSTRESS mission shall complete the In-Orbit Checkout (IOC) period within 30 days after installation and power-on, and then begin operations consistent with the science requirements in Section 4.1.

b) The ECOSTRESS mission lifetime shall be at least 1 year following completion of IOC.

c) The ECOSTRESS project shall be Category 3 as defined in NPR 7120.5E.

d) The ECOSTRESS payload shall be designated Risk Class D, per NPR 8705.4

e) Extended mission operations beyond 1 year after IOC are subject to approval through the ESD Senior Review process, in consultation with the ISS program.

f) The ECOSTRESS mission shall acquire at least 75 percent of available measurement opportunities for each of: CONUS; twelve 1,000 km x 1,000 km key climate zones; and twenty-seven FLUXNET sites.

g) Science operations on the ISS shall be planned to accommodate operational constraints unique to the ISS environment. Unique ISS operational constraints include but are not limited to: Crew and/or EVA operations; visiting vehicles; elevated contamination flux due to out-gassing and/or thrusters; and ISS configuration changes.

h) The ECOSTRESS operations team shall schedule science measurements when operationally possible with acceptable risk as determined by the operations team using approved flight rules based on the operational status of the ISS.

4.5 Ground System Requirements

The ECOSTRESS project shall develop a science data processing system to meet the science requirements in Section 4.1 and the reprocessing and data latency requirements in Section 4.6.

4.6 Mission Data Requirements

a) The ECOSTRESS Project shall produce the standard science data products listed in Table 1.

b) All data and standard science data products listed in Table 1, along with the coefficients and ancillary data used to generate the products shall be delivered to the LP DAAC. There shall be no period of exclusive access.

c) Science algorithms used to generate the standard data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).

d) The ECOSTRESS Project shall coordinate with the LP DAAC on the release of product versions to ensure completeness and accuracy of quality information, validation status, and metadata of the ECOSTRESS science data products.

e) The ECOSTRESS Project shall coordinate with the designated LP DAAC on the data and information to be transferred at project closeout.

f) An Algorithm Specification Document (ASD) that provides information to validate the data products generated by the computer software, to the same extent that is provided by the computer software source code, shall be developed and delivered. Requests for Algorithm Specification Documents or computer software source code for the purpose of validation of the data products generated by the software shall be addressed in conformance with the existing JPL Prime Contract.

Table 1. ECOSTRESS Data Products

Data Product	Description	Initial Availability to NASA DAAC	Median Latency in Product Availability to NASA DAAC after Initial Delivery	NASA DAAC Location
Level 0	Raw collected telemetry	6 months after IOC	12 weeks	LP DAAC
Level 1	Calibrated Geolocated Radiances	6 months after IOC	12 weeks	LP DAAC
Level 2	Surface temperature and emissivity	6 months after Level 1 data products are available	12 weeks*	LP DAAC
Level 3	Evapotranspiration	2 months after Level 2 data products are available	12 weeks*	LP DAAC
Level 4	Water use efficiency and evaporative stress index	2 months after Level 3 data products are available	12 weeks*	LP DAAC

*Delivery latency after ground receipt

4.7 Science Data Requirements

ECOSTRESS Level 1 and Level 2 science data product formats shall conform to the Hierarchical Data Format (HDF5) standard.

4.8 Mission Success Criteria

The ECOSTRESS mission will be considered successful if it:

a) Collects space-based measurements of TIR brightness temperatures (BT) of the Earth from the ISS over a growing season in either hemisphere.

b) Records, validates, publishes, and delivers the science data records and calibrated geophysical data products to the LP DAAC for use by the scientific community.

5.0 MISSION REQUIREMENTS

5.1 Cost Requirements

a) For the ECOSTRESS Project, costs that are within the PI-Managed Mission Cost include: instrument delivery ready for integration onto the Launch Vehicle (Phases

A-C); development and delivery of functional algorithms and ground processing system (Phases B-D); supporting a science team that will contribute directly to the successful implementation of the investigation (Phases A-F); required calibration and validation activities (Phases C-E); operations, product generation, and data analysis during the proposed prime mission lifetime of the investigation (Phases E); and close out of the investigation once the investigation has been concluded (Phase F). The PI-Managed Mission Cost also includes the cost of the science team and of key management, instrument, and engineering staff during Phase D. For support of the science team and key management and engineering during Phase D, a two-year duration should be assumed for budgeting purposes.

b) Costs that are outside the PI-Managed Mission Cost include integration to the ISS (Phase D); and investigation costs during any potential gap between the delivery of the completed instrument (end of Phase C) and the start of integration of the instrument to the launch vehicle (start of Phase D).

c) The total NASA cost and associated budgetary phasing are given in the most current NASA SMD DPMC ECOSTRESS Project Decision Agreement.

d) The ECOSTRESS Project shall coordinate technical and programmatic trades for payload integration not included in the proposal with the ISSPO RIO using accommodation funding.

   a. Accommodation of ECOSTRESS instrument for integration to the Japanese Experiment Module –Exposed Facility (JEM-EF) on the ISS includes costs for studies and implementation in areas that require further refinement (e.g., aperture cover and WiFi) and costs to ensure ECOSTRESS ground system compatibility with ISS ground systems. The ECOSTRESS instrument has been proposed as an ISS JEM-EF payload, with appropriate enclosures and interfaces included in the proposed payload design. While ISS interfaces and requirements are defined, it is expected that modest instrument changes may be required as a result of changes in ISS and or launch vehicle (LV) requirements throughout the integration process. Such changes (i.e., those resulting from modified ISS/LV interface requirements) are part of accommodations.
   b. The ECOSTRESS Project shall design and build a payload that meets the Program Level Requirements within the confines of the ISSPO RIO host allocated resources.
   c. The ECOSTESS Project shall identify host accommodations (outside the defined PI-managed cost cap) needed to comply with the Program Level Requirements that are not provided by ISSPO RIO.
      i. The scope and cost for these accommodations shall be submitted to the ESSP Program for consideration.
      ii. The ESSP Program Manager shall adjudicate these accommodations requests and disposition resources to preserve

the payload's ability to comply with the Program Level Requirements.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the ECOSTRESS project shall pursue scope reduction and risk management as a means to control cost. No scope reduction will be exercised that prevents achievement of the science requirements in Section 4.1.

6.0 MULTI-MISSION NASA FACILITIES

a) NASA ground communication network(s) shall be made available by the ISSPO RIO for uplink and downlink compatible with the ECOSTRESS Mission, including any ground lines or interfaces required between JPL and other NASA centers or facilities.

b) ISS Program resources and services shall be provided by the ISSPO RIO as documented in the Payload Integration Agreement. These resources include the Mission Control Center–Houston at Johnson Space Center, the POIC at NASA Marshall Space Flight Center (MSFC), the space network, and other operational infrastructure used to operate and maintain the ISS. The POIC shall facilitate ECOSTRESS remote payload operations by routing ECOSTRESS payload commands to the ISS, retrieving and temporarily archiving payload data and ISS data such as attitude and ephemeris, and by performing mission critical payload health and status monitoring.

c) Data archival shall be provided by the LP DAAC.

7.0 EXTERNAL AGREEMENTS

All agreements between NASA and each non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of International and Interagency Relations (OIIR).

8.0 PUBLIC OUTREACH AND EDUCATION

No specific Education and Public Engagement Plan is required for the ECOSTRESS Project.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the ECOSTRESS Project.

10.0 WAIVERS

Any waivers to NPR 7120.5 requirements or processes shall be processed and approved in accordance with the existing JPL and NASA processes for Category A waiver approval.

Tailoring of NPR 7120.5E for ECOSTRESS is outlined in a memo from the ESSP Program Manager to the ECOSTRESS PI dated January 22, 2015, in accordance with the NASA Associate Administrator letter of September 26, 2014, entitled "Guidance and Expectations for Small Category 3, Risk Classification D (Cat 3/Class D) Space Flight Projects with Life-Cycle Cost Under $150M." See OCE tab in NODIS under Other Policy Documents at http://nodis3.gsfc.nasa.gov/OCE_docs/OCE_25.pdf.

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10/21/15
Date

JPL ID D-94058
ECOSTRESS PLRA Rev. 6.0 19 Oct 2015

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Deputy Associate Administrator
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ECOSTRESS PLRA Rev. 6.0 19 Oct 2015

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Appendix Y: The Global Ecosystem Dynamics Investigation Lidar (GEDI)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (Version 2.17; 06/09/2016)

Appendix Y - Earth System Science Pathfinder Program Plan

Program-Level Requirements for the Global Ecosystem Dynamics Investigation Lidar Project

Version: 2.17
Date: June 9, 2016

Change Log

Revision	Date	Sections Changed
1.0	Jan 15	Initial Release
2.0	02 Feb 15	Dubayah modified (Requirements section)
2.1	05 Feb 15	Dubayah/Jucks modified (Requirements section)
2.2	05 Feb 15	Dubayah changed data table
2.3	12 Feb 15	Pontius clarified 5 percent downtime assumption (p. 8)
2.4	31 Mar 15	Dubayah edited L1 requirements; MTS suggested changes
2.5	01 Apr 15	Dubayah added small edits and strikethroughs
2.6	07 Apr 15	Dubayah removed strikethroughs (deleted the text)
2.7	17 Apr 15	PO delineated accommodations Sec 3.1 & 5.1 d)
2.8	21 Apr 15	Dubayah made minor heading change (4.5.1 and 4.5.2) and automated numbering
	01 May 15	Dutta made changes/clarifications
	03 May 15	Dubayah made minor changes; did not accept 4.2.c and reverted to original text in v. 2.2
2.9	04 May 15	Dutta accepted all changes including changes from May 1 after clarification with Dubayah
	05 May 15	Edits captured from ESD review
	06 May 15	Dubayah/Jucks modified Sections 4.1 & 4.3-No other sections touched (so does not reflect other comments from walk-thru
2.10	14 May 15	Bullock update with comments from ESD walkthrough
2.11	29 May 15	Dutta update with minor edits left over from ESD walkthrough and accepting all changes
2.12	10 June 15	Dutta update sections 4.5.1b and 5.1a
2.13	16 Oct 15	Editorial changes made by GSFC (spelling out of acronyms)
2.13-3	16 Feb 16	KJ and RD made minor changes that reflect two year mission and others that are highlighted
	02-Mar 16	RD changed data table to reflect 2-year mission
	18-Mar-16	RD modified Mission Success Criteria
2.14	31-Mar-16	RD created new version 2.14. All changes are included in the GEDI PLRA From / To table.
2.15	03-May-16	JP created new version 2.15. All changes are included in the GEDI PLRA From / To table.
2.16	11-May-16	Dutta created new version 2.16 with edits from Kevin Murphy in section 4.5. Concurred by PI, PM, PS, PE.
2.17	9-June-16	Dutta update on page 8 in Baseline and Threshold Science Requirements and in Mission Success Criterion: all "up to about" changed to "up to" and "about 98%" to "97%" in section 4.1.1.b).

Contents

1. SCOPE

The Global Ecosystem Dynamics Investigation (GEDI) Lidar instrument was selected by NASA's Science Mission Directorate (SMD)/Earth Science Division (ESD) on July 30, 2014, in response to the Second Stand Alone Mission of Opportunity Notice - 2, Program Element Appendix M: Earth Venture Instrument-2, NNH12ZDA0060 solicitation, and has been awarded to the principal investigator (PI) Professor Ralph Dubayah from the University of Maryland. The PI is responsible for the GEDI instrument development and activities necessary to deliver the science as proposed. The PI partnered with Goddard Space Flight Center (GSFC) for the development and implementation of the GEDI instrument necessary to deliver the science objectives of GEDI. The GEDI instrument will be flown on the International Space Station (ISS) on the Japanese Experimental Module – Exposed Facility (JEM-EF). Access to the ISS for GEDI will be the responsibility of NASA's ESD.

This appendix to the Earth System Science Pathfinder (ESSP) program plan identifies the mission, science, and programmatic (funding and schedule) requirements imposed on the PI for the development and operation of the GEDI project. GSFC implements the mission for the PI in full compliance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, through project management, systems engineering, discipline engineering, integration and test, and a significant science contribution. GSFC also manages the interface to the ISS and to any other organizations relevant for payload accommodation and operation onboard the ISS. In this document, requirements begin in Section 4. Sections 1, 2, and 3 are intended to set the context for the requirements that follow.

GEDI project is managed under the ESSP program for which the authority is delegated from the Associate Administrator (AA) for the SMD through the ESD to the ESSP program manager at Langley Research Center. Project management will be conducted at GSFC in accordance with the lines of authority shown in Section 3.1. The PI is responsible for leading the project and delivering its science results within the budgetary and schedule constraints indicated in the solicitation. The PI is supported by an instrument project manager (IPM) from GSFC who is accountable for mission implementation including technical performance, acquisition, regulatory compliance, risk management, and major cost and schedule decisions.

This document serves as the basis for mission assessments to be conducted by NASA Headquarters during the development and implementation period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Changes to information and requirements contained in this document require approval by the officials that approved the original document.

2. SCIENCE DEFINITION

2.1. Baseline Science Objectives

GEDI is designed to collect measurements of forest vertical structure using waveform Lidar. These waveform data are used to derive canopy height, canopy profile, biomass, ground elevation, and other metrics. GEDI data are designed to address four science objectives: (1) Quantify the distribution of above-ground forest carbon at fine spatial resolution; (2) Quantify changes in carbon resulting from forest disturbance and recovery; (3) Quantify the carbon sequestration potential of forests through time under changing land use and climate using ecosystem models initialized with GEDI data; and (4) Quantify the spatial distribution of habitat structure and its relationship to habitat quality and biodiversity.

2.2. Science Instrument Summary Description

The GEDI Lidar instrument is a self-contained multi-beam laser altimeter based on a mature, high signal-to-noise ratio, full-waveform measurement approach. Three lasers are used to generate a complement of ground tracks at high spatial resolution within a 2-year mission, with the capability of penetrating the densest canopy cover.

An active, single-axis pointing control system provides cross-track pointing control of the laser ground tracks to eliminate the significant measurement gaps that would otherwise result from the ISS orbit and attitude variations. Over the 2-year mission, the laser tracks are methodically and evenly spaced around the Earth between ± 51.6 degrees latitude (i.e., the orbital range of ISS).

A composite optical bench provides precise and stable mechanical coupling of the lasers, transmit optics, receiver telescope assembly, inertial measurement unit, and star trackers to ensure on-orbit optical alignment stability. The receiver system has multiple channels, and the individual fields of view for each beam are coupled to the return pulses for their respective detector channels.

3. PROJECT DEFINITION

3.1. Project Organization and Management

The GEDI PI shall report to NASA according to Figure 1.

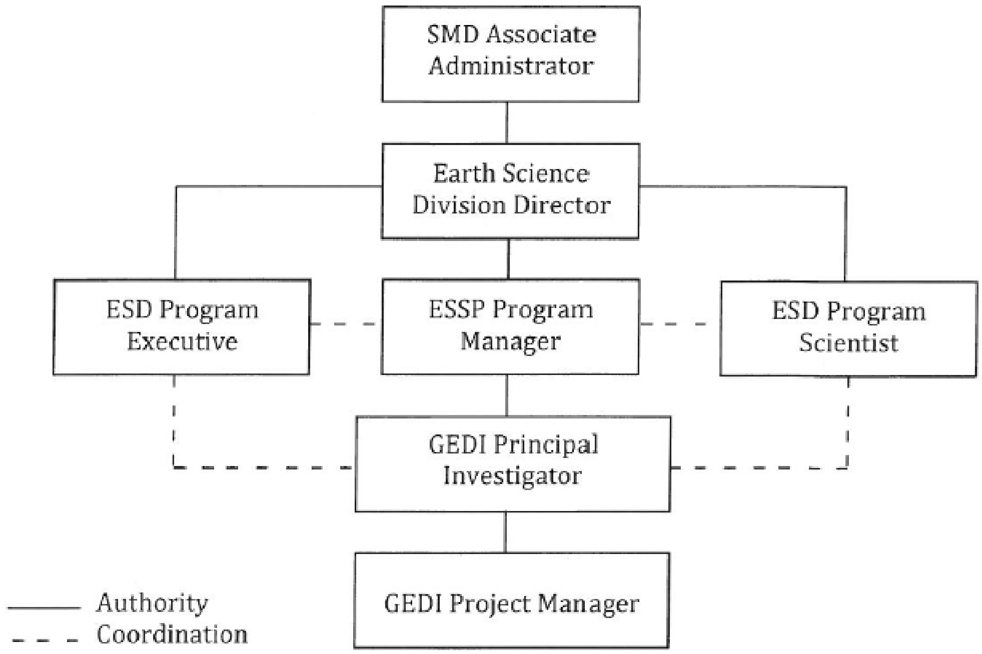

Figure 1. GEDI Programmatic Lines of Authority and Coordination

The GEDI PI has overall responsibility for the success of the project. Specific assigned roles and responsibilities are:

- The PI delegated the responsibility and authority to manage the day-to-day implementation of the instrument project to NASA's GSFC. GSFC is responsible for providing project management, systems engineering and mission design, safety and mission assurance, the instrument, mission operations and the associated mission operations ground data system, science data processing, and delivery of calibrated/validated science data products to an archive for public distribution. NASA's GSFC designated a project manager to execute these delegated responsibilities. NASA's GSFC provides necessary oversight to establish, implement, and maintain a management system of planning, organizing, controlling, and reporting of the integrated scientific, technical and costing objectives of the project.
- The GEDI PI has overall responsibility for the success of the project, including the responsibility for the science elements of the project. The PI is responsible for supporting the science team, implementing the ground systems, performing instrument operations, developing the science data processing system, performing

science data processing and distributing the science data products. More specifically concerning the data products, the PI will be responsible for production and analysis of the mission data necessary to achieve the proposed science objectives, delivery of products to a NASA-selected distributed active archive center (DAAC), and timely publication of initial scientific results in refereed scientific journals as part of the mission operations (Phase E) or closeout (Phase F) activities.

- SMD's ESD will designate NASA's DAAC as the facility for public distribution and eventual long-term preservation of GEDI data products (see Section 4.5).
- The Human Exploration and Operations Mission Directorate (HEOMD) ISS program provides significant enabling contributions to the GEDI mission on the ISS. The HEOMD ISS program provides the launch and launch services and robotically installs the GEDI payload to the ISS. The HEOMD ISS program also provides mission operations of the GEDI instrument payload using commands provided by GSFC, downlink and capture of health and status, science telemetry, and mission critical operations support. The HEOMD ISS program is responsible for payload disposal at the end of mission.
- NASA's SMD is responsible for providing access to voice and data communications networks necessary for the operation and transfer of science data for the GEDI mission as identified in 6.0.
- The GEDI project, working together with the ISS program office (ISSPO), will identify potential accommodations required to comply with the Program Level Requirements that are not defined within the PI-managed cost cap nor specifically provided by the Research Integration Office (RIO) of the ISSPO. The ESSP program manager is responsible for the adjudication, approval, and funding of accommodations.

The role of the GEDI science team will be to execute the GEDI science objectives. The GEDI science team will be responsible for development and testing of required science algorithms, pre- and post-launch calibration and validation of GEDI observations, and the delivery and validation of GEDI data products.

3.2. Project Acquisition Strategy

GSFC will implement an in-house development of the instrument, supplemented by commercial vendors and/or other NASA centers for parts and assemblies, as required.

4. PROGRAMMATIC REQUIREMENTS

GEDI science objectives can be achieved by either the baseline or threshold science mission requirements listed below. The baseline mission provides substantially more Lidar transect observations resulting in finer spatial resolution of gridded data products and, consequently, greater science value to NASA and the Earth science community.

4.1. Science Requirements

4.1.1. Baseline Science Requirements

a) Acquire Lidar canopy vertical profile data required to estimate aboveground woody carbon density for the Earth's global tropical and temperate forests within the ISS orbital coverage at ≤ 1 km resolution. At the end of 2 years after on-orbit checkout, at least 80 percent of the 1 km cells shall have an accuracy of 20 percent standard error, or 20 Mg/ha, whichever is greater subject to instrument availability as defined in Section 4.3.

b) Acquire transects (that is, near contiguous, along-track laser footprint observations) of tropical and temperate forest canopy vertical profiles from the top of canopy to the ground. Instrument performance must be sufficient to acquire profiles in conditions of up to 95 percent canopy cover for all beams. At least one laser beam must have sufficient power to acquire profiles in conditions of up to 97 percent canopy cover.

c) Record, validate, publish, and deliver science data records (L0-L1B) and validated data products and model outputs (L2-L4) to the DAAC designated by NASA for use by the scientific community.

4.1.2. Threshold Science Requirements

a) Acquire Lidar canopy vertical profile data required to estimate aboveground woody carbon density for the Earth's global tropical and temperate forests within the ISS orbital coverage at ≤ 2 km resolution. At the end of 2 observation years, at least 80 percent of the 2 km cells shall meet an accuracy within 20 percent standard error, or 20 Mg/ha, whichever is greater.

b) Acquire transects of tropical and temperate forest canopy vertical profiles from the top of canopy to the ground. Instrument performance must be sufficient to acquire profiles in conditions of up to 95 percent canopy cover for all beams.

c) Record, validate, publish, and deliver science data records (L0-L1B) and validated data products and model outputs (L2-L4) to the DAAC designated by NASA for use by the scientific community.

Note: The term "20 percent standard error" means that the standard error of the biomass estimate in the cell (that is its uncertainty) is less than or equal to 0.2 × the estimate of the cell.

4.1.3. Mission Success Criteria

The GEDI mission shall be considered successful if it:

a) Acquires one billion vertical profiles over the land surface from the top of canopy to the ground in conditions of up to 95 percent canopy cover.

b) Records, validates, publishes, and delivers the science data records and calibrated data products to an SMD/ESD-assigned DAAC for use by the scientific community.

Meeting these criteria will result in an order of magnitude increase in suitable land

Meeting these criteria will result in an order of magnitude increase in suitable land observations over the existing space-based Lidar archive.

4.2. Launch and Installation Requirements

a) The GEDI payload shall be launched on a launch vehicle provided by HEOMD-ISSPO.

b) The GEDI payload shall be installed on the JEM-EF Unit #6 of the ISS and controlled via NASA's Payload Operations Integration Center (POIC).

c) The GEDI payload shall be disposed of at the end of the mission by NASA's ISS RIO.

d) The GEDI project shall target instrument delivery for integration onto the launch vehicle as specified in the most current NASA SMD DPMC GEDI Project Decision Agreement.

4.3. Mission Performance

a) The GEDI project shall be Category 3 per NPR 7120.5, NASA Space Flight Program and Project Management Requirements.

b) The GEDI payload shall be Class C per NPR 8705.4, Risk Classification for NASA Payloads.

c) The GEDI mission shall complete the In-Orbit Checkout (IOC) period within 30 days after installation and power-on and then begin operations consistent with the baseline science requirements in Section 4.1.1.

d) The GEDI mission lifetime shall be at least 2 years of observations following completion of IOC.

e) Extended mission operations are subject to approval through the ESD's Senior Review process, in consultation with the ISS program.

f) Science operations on the ISS shall be planned with acceptable risk as determined by the operations team to accommodate operational constraints unique to the ISS environment. Unique ISS operational constraints include but are not limited to: crew and/or extra vehicular activities operations; visiting vehicles; power and coolant availability; elevated contamination flux due to outgassing and/or thrusters; and ISS configuration changes, e.g., changes in attitude that prevent required near-nadir (< 5 degrees) observations.

g) Analyses of operation time on the ISS in its present configuration indicate that the instrument will be able to acquire data no less than 60 percent of the time over a 2-year period with a priority during the northern hemisphere growing season. The instrument shall acquire data during 90 percent of the measurement opportunities outside the time required to accommodate ISS operational constraints for baseline performance.

4.4. Ground System Requirements

The GEDI project shall accomplish science data processing to meet the science data requirements in Section 4.5 and the reprocessing and data latency requirements in Table 1.

4.5. Mission Data Requirements

4.5.1. Science Data Requirements

a) The GEDI project shall produce the standard science data products listed in Table 1. Public release of GEDI data products shall conform to NASA's ESD Data & Information (ESD&I) Policy. There shall be no period of exclusive access. Data product creation, calibration, and validation results in initial and subsequent release latencies are noted in Table 1.

b) The GEDI data products shall be generated in standard formats (e.g., HDF5, ESDS RFC-007) in conformance with NASA's ESD&I policy specified at http://earthdata.nasa.gov/about-eosdis/requirements.

c) The GEDI science data products metadata shall adhere to the *Metadata Requirements – Base Reference for NASA Earth Science Data Products* document published at http://earthdata.nasa.gov/about-eosdis/requirements, and the GEDI project shall baseline to a specific initial version by the project Preliminary Design Review (PDR).

d) The GEDI Project shall transfer to NASA's specified DAAC(s) all the information and documentation required for long-term preservation of knowledge about the products resulting from the GEDI project as defined in the *NASA Earth Science Data Preservation Content Specification* document published at http://earthdata.nasa.gov/about-eosdis/requirements and shall baseline to a specific initial version by the project PDR.

4.5.2. Science Data Management

a) The GEDI mission shall obtain L0 data from the ISS Payload Operations Integration Center. The GEDI Science Data Processing Center (SDPC) located at GSFC shall generate the L1 through L4 data products.

b) All data and the standard science data products listed in Table 1, along with the coefficients, ancillary data and scientific source code (or in the case of COTS software, the specific programs) used to generate these products, shall be delivered to a NASA specified DAAC(s) for archiving and public distribution in accordance with the ESD&I Policy.

c) An Algorithm Theoretical Basis Document (ATBD) shall be developed, reviewed and delivered for each data product. An ATBD describes the specific algorithms used in generating each GEDI data product and forms the basis of the science data product generation software code. An ATBD, therefore, provides the necessary algorithm detail to validate the data products generated by the SDPC computer software. Reviewed ATBDs shall be provided to the selected DAAC(s) for archival and public distribution.

d) The GEDI project shall coordinate with NASA's specified DAAC(s) the release of product versions to ensure completeness and accuracy of quality information, validation status, and metadata of the GEDI science data products.

e) The GEDI Project shall coordinate with NASA's specified DAAC(s) on the data and information to be transferred at GEDI closeout in accordance with https://earthdata.nasa.gov/standards/preservation-content-spec. GEDI shall baseline to a specific initial version of this document before launch.

Table 1. GEDI Data Products

Data Product	Description	First Data Delivery after IOC	Maximum Data Latency After First Release	NASA DAAC Location
Level 0	Raw collected telemetry including Lidar return profiles, global positioning system, star-tracker and gyro data	Within 24 hours of receipt at GSFC	Within 24 hours of receipt at GSFC	NASA specified DAAC
Level 1	Calibrated geolocated Lidar waveforms	First 2 months of L1 released 6 months after IOC	4 months in monthly intervals*	NASA specified DAAC
Level 2	Footprint level canopy height and profile metrics	First 2 months of L2 released 6 months after IOC	4 months in monthly intervals*	NASA specified DAAC
Level 3	Gridded canopy height metrics and variances	Populated with first 2 months of L2 data. Released 6 months after IOC	4 months in monthly intervals*	NASA specified DAAC
Level 4	Model investigative outputs: above ground carbon	17 months after IOC constructed from first 12 months of L3	6 months after completion of global sampling required to satisfy L1 requirements. Product created for full mission.	NASA specified DAAC

*Delivery latency after ground receipt

5. MISSION REQUIREMENTS

5.1. Cost Requirements

a) For the GEDI project, costs that are within the PI-managed mission cost include instrument delivery ready for integration onto the launch vehicle (Phases A-D); development and delivery of functional algorithms and ground processing system (Phases B-D); supporting a science team that will contribute directly to the successful implementation of the investigation (Phases A-F); required calibration and validation activities (Phases C-E); operations, product generation, and data analysis during the proposed prime mission lifetime of the investigation (Phase E); and close out of the investigation once the investigation has been concluded (Phase F). The PI-managed instrument Phase D cost will also include four months of staffing, with appropriate levels of reserves for launch site activities and in-orbit checkout.

b) Costs that are outside the PI-managed mission cost include integration to the ISS (Phases A-D), investigation costs during any potential gap between the delivery of the completed instrument and the start of integration of the instrument to the launch vehicle.

c) The total NASA cost and associated budgetary phasing are given in the most current NASA SMD Directorate Program Management Council GEDI Project Decision Agreement.

d) The project direct cost shall be based on a launch on a TBD launch vehicle after delivery as per Section 4.2a. Other mission enabling contributions funded for and provided by the ISS program are documented in the Payload Integration Agreement.

e) The GEDI project shall coordinate technical and programmatic trades for payload integration not included in the proposal with the ISSPO RIO using accommodation funding.

  a. Accommodation of GEDI instrument for integration to the JEM-EF on the ISS includes costs for studies and implementation in areas that require further refinement and costs to ensure GEDI ground system compatibility with ISS ground systems. The GEDI instrument has been proposed as an ISS JEM-EF mountable payload with appropriate enclosures and interfaces included in the proposed payload design. While ISS interfaces and requirements are defined, it is expected that modest instrument changes may be required as a result of changes in ISS and or launch vehicle requirements throughout the integration process. Such changes (i.e., those resulting from modified ISS/launch vehicle interface requirements) are part of accommodations budget.

  b. The GEDI project shall design and build a payload that meets the Program Level Requirements within the confines of the ISSPO RIO host allocated resources.

  c. The GEDI project shall identify host accommodations (outside the defined PI-managed cost cap) needed to comply with the Program Level Requirements that are not provided by the ISSPO RIO.

    i. The scope and cost for these accommodations shall be submitted to the ESSP program for consideration.

    ii. The ESSP PM shall adjudicate these accommodations requests and disposition resources to preserve the payload's ability to comply with the Program Level Requirements.

5.2. Cost Management and Scope Reduction

a) Provided that Program Level Requirements are preserved and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the GEDI project shall pursue scope reduction and risk management as a means to control cost.

b) The project plan shall include potential scope reduction and risk management as a means to control cost. If other methods of cost containment are not practical, the reductions identified in the project plan may be exercised.

c) Scope reductions from baseline science requirements (Section 4.1.1) to threshold science requirements (Section 4.1.2) or potential scope reductions affecting these program requirements shall be agreed to by the officials represented on the approval page of the document.

6. MULTI-MISSION NASA FACILITIES

The GEDI project shall rely on the following multi-mission NASA facilities and infrastructure which are funded outside the project:

a) ISS program resources and services shall be provided by the HEOMD as documented in the Payload Integration Agreement. These resources include the Mission Control Center–Houston at Johnson Space Center, the Payload Operations Integration Center (POIC) at NASA Marshall Space Flight Center (MSFC), the Space Network, and other operational infrastructure used to operate and maintain the ISS. The POIC shall facilitate GEDI remote payload operations by routing GEDI payload commands to the ISS, retrieving and temporarily archiving payload data and ISS data, such as attitude and ephemeris, and by performing mission critical payload health and status monitoring.

b) NASA's terrestrial communications resources and services shall be provided by NASA Integrated Services Network as documented in the project service level agreement for voice and data communications between NASA's GSFC and Marshall Space Flight Center.

c) The GEDI project utilizes NASA's DAAC(s) and other Earth Observing System Data and Information System infrastructure for science data archive and distribution. SMD/ESD provides access to these resources as documented herein.

7. EXTERNAL AGREEMENTS

There are no non-NASA partners in the GEDI mission.

8. PUBLIC OUTREACH AND EDUCATION

GEDI does not require an education and/or public engagement plan.

9. SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the GEDI project.

10. WAIVERS

None.

11. REQUIRED APPROVALS AND CONCURRENCES

APPROVALS

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NASA Headquarters

6/6/2016
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Ralph Dubayah
Principal Investigator
University of Maryland

7 April 2016
Date

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Appendix Z: COral Reef Airborne Laboratory (CORAL)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release

Z.1 DESCRIPTION

The goal of the COral Reef Airborne Laboratory (CORAL) is to provide critical data and new models needed to analyze the status of coral reefs and to predict their future. CORAL will provide the most extensive picture to date of the condition of a large portion of the world's coral reefs from a uniform data set. The data will reveal trends between coral reef condition and biogeophysical forcings, both natural and those arising from human activities. With this new understanding of reef condition, we can better predict the future of this global ecosystem and provide policy makers.

CORAL acquires airborne spectral image data using the Portable Remote Imaging Spectrometer (PRISM) instrument installed in a commercial airplane Gulfstream-IV (G-IV) from Tempus Applied Solutions. In situ data are obtained to validate the remote observations. For each reef, the spectral image data are processed to provide the reef "condition" described by measurable quantities of benthic cover of coral, algae, and sand; primary productivity; and calcification. These three reef condition parameters are analyzed quantitatively against ten key biogeophysical parameters using new models to understand reef conditions today and predict reef conditions in the future.

CORAL addresses key science questions of the Carbon Cycle and Ecosystems Focus Area of NASA's Earth Science Division, including: "How are global ecosystems changing?", "How do ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change?", "What are the consequences of climate change and increased human activities for coastal regions?", and "How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?"

CORAL science will focus on key reef areas in the Pacific Ocean: Hawaii, the Mariana Islands, Palau, and the Great Barrier Reef. The Florida Reef Tract will serve as a testing area for operations readiness. Data acquisition is currently planned for 2016, with science analysis in following years.

Some aspects of the CORAL project are considered to be ITAR as well as proprietary and are tightly controlled. If access to project data is needed please go to http://coral.jpl.nasa.gov/ for contact information.

Appendix AA: North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release

Approved By:

Mr. Greg Stover, Program Manager
Earth Systems Science Pathfinder Program Office
NASA Langley Research Center

13 Aug 15
Date

Dr. Lynda Ciuffetti, Department Head
Department of Botany and Plant Pathology
Oregon State University

8/11/15
Date

Dr. Michael Freilich, Director
Earth Science Division, Science Mission Directorate
NASA Headquarters

13 Aug 15
Date

Concurrences:

Dr. Mary Kleb
NAAMES Project Manager
NASA Langley Research Center

8/13/15
Date

Dr. Michael Behrenfeld
NAAMES Principal Investigator
Oregon State University

8-11-15
Date

Mr. Kevin Murphy, Program Executive
Earth Science Data Systems
Earth Science Division, Science Mission Directorate
NASA Headquarters

8/14/2015
Date

Concurrences Continued:

Ms. Holly Degn, Earth Science Budget Lead
Science Mission Directorate
NASA Headquarters

9-1-15
Date

Mr. Bruce Tagg, EVS2 Program Executive
Earth Science Division, Science Mission Directorate
NASA Headquarters

12 AUG 2015
Date

Dr. Paula Bontempi, NAAMES Program Scientist
Earth Science Division, Science Mission Directorate
NASA Headquarters

8.17.15
Date

Dr. Hal Maring, EVS2 Program Scientist
Earth Science Division, Science Mission Directorate
NASA Headquarters

19 Aug 2015
Date

Dr. Jack Kaye, Associate Director for Research
Earth Science Division, Science Mission Directorate
NASA Headquarters

8/20/15
Date

Mr. Eric Ianson, Associate Director for Flight Programs
Earth Science Division, Science Mission Directorate
NASA Headquarters

8/28/15
Date

1 Objectives

Plankton ecosystems of the global ocean profoundly affect climate and life on Earth. NASA's ocean color satellite record tells us that these invaluable ecosystems are highly responsive to climate variability, with changes in ocean production impacting food production, uptake of atmospheric CO_2, and emission of climate-regulating aerosols. Intergovernmental Panel on Climate Change climate simulations suggest that surface ocean temperatures will warm globally over the 21st century, with major consequences on the physical properties of the surface ocean where plankton populations thrive. The pressing question is, how will these changes alter plankton production, species composition, and aerosol emissions? Today, even the sign of these potential changes remains unresolved. Our ability to predict Earth System consequences of a warming ocean and develop realistic mitigation and adaptation strategies depends on resolving conflicting hypotheses regarding factors controlling plankton ecosystems and biogenic aerosol emissions.

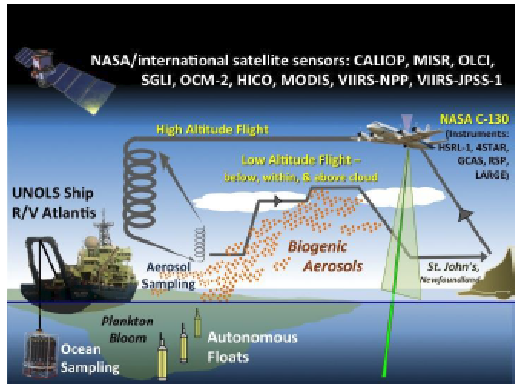

Figure 1-1. ***NAAMES*** *combines ship, aircraft, satellite, autonomous sensor, and modeling data to address knowledge gaps on ocean plankton and their biogenic aerosol emissions.*

The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) is an interdisciplinary investigation designed to address fundamental measurement and knowledge gaps that currently restrict understanding of ocean ecosystem functioning, linkages to atmospheric aerosols, and implications on climate. NAAMES focuses on characterizing ocean ecosystem and aerosol properties in the climate-sensitive North Atlantic, which is an ideal location for resolving key processes common to many other ocean regions. Specific NAAMES Science Objectives are:

1. **Characterize plankton ecosystem properties during primary phases of the annual cycle in the North Atlantic and their dependence on environmental forcings**

2. **Determine how primary phases of the North Atlantic annual plankton cycle interact to recreate each year the conditions for an annual bloom**

3. **Resolve how remote marine aerosols and boundary layer clouds are influenced by plankton ecosystems in the North Atlantic**

Four field campaigns constitute the core of the NAAMES mission, with each campaign aligned to a specific event, or 'ecosystem state', in the annual plankton cycle (**Fig. 1-2**). The four key ecosystem states are (1) the *initiation transition*, which demarks the beginning of annual bloom, (2) the *increasing phase*, which encompasses the duration of biomass accumulation during the bloom, (3) the *climax transition*, which represents the end of the blooming phase and a change in sign for plankton predator-prey relationships, and (4) the *declining phase*, which continues to late fall and 'resets' the system for the following spring bloom (**Fig. 1-2**). Each state of the plankton annual cycle is associated with different aerosol emission properties. The NAAMES field campaigns will characterize ecosystem trophic relationships during each state of the annual cycle and determine how these characteristics relate to biogenic aerosol emissions. Importantly, the timing of the four ecosystem states varies with latitude. The NAAMES mission benefits from this latitudinal variability because it allows multiple states to be sampled within a single field campaign and because it provides schedule flexibility and decreased risk for achieving mission objectives. In addition, the four ecosystem states can be characterized in any sequence, which adds flexibility to the NAAMES schedule.

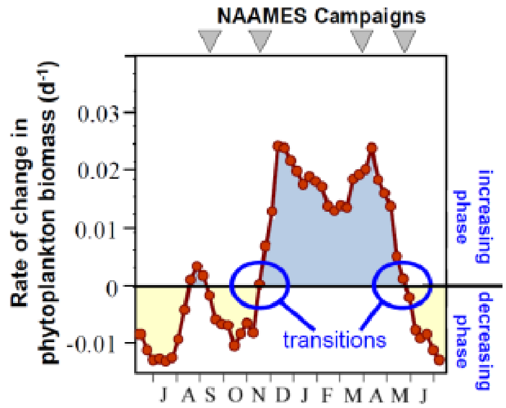

Figure 1-2. *Contrasting states of the subarctic Atlantic annual plankton cycle. Red symbols and line show satellite-observed specific rates of change in phytoplankton biomass, with blue and yellow shaded areas corresponding to periods of increasing and decreasing biomass, respectively. Shifts between primary increasing and decreasing phases define transition states.*

During each field campaign, ship-based measurements provide detailed characterization of plankton stocks, rate processes, and community composition. Ship measurements also characterize seawater volatile organic compounds, their processing by ocean ecosystems, and the concentration and properties of gases and particles in the overlying atmosphere. These data are extended over broader spatial scales through parallel airborne remote sensing measurements and in situ aerosol sampling. The airborne data link observed local-scale processes to properties quantified at the basin-scale through satellite remote sensing. Satellite data and in-water autonomous sensor measurements provide the sustained observational record for evaluating climate-ecosystem model results. Field campaign results further contribute to the testing and refinement of detailed processes captured by the models. Through this integration of ship, airborne, modeling, and sustained satellite and autonomous sensor approaches, NAAMES will resolve key mechanisms underlying the annual plankton cycle and primary ecological determinants of biogenic aerosol emissions. Thus, predictions of ocean ecosystem and aerosol changes in a future warmer ocean will be improved.

It is expected that NAAMES ship-based measurements will be conducted on University-National Oceanographic Laboratory System (UNOLS) research vessels, although alternative research vessels can be used if scheduling conflicts arise [e.g., *R/V Revelle* (Scripps), *R/V Thompson* (Univ. Washington), *R/V James Clark Ross* (UK), *R/V L'Atlante* (France)]. The first NAAMES campaign ship measurements will be conducted from November 6 to December 1, 2015 on the UNOLS R/V *Atlantis* and based out of Woods Hole, MA. Airborne measurements will be performed on a

NASA C-130 aircraft, primarily stationed at St. John's Bay, Canada, but potentially with some suitcase flights based from Lajes Field in the Azores to allow more aircraft time on station near the ship at the southern end of the cruise track (below 42.5°N Lajes is actually closer than St. John's Bay). NAAMES ship, aircraft, and autonomous in situ measurements employ mature instruments with extensive field deployment histories. NAAMES airborne remote sensing measurements also employ mature instruments with extensive deployment histories. These remote sensing instruments are the NASA Langley Research Center (LaRC) High Spectral Resolution Lidar-1 (HSRL-1), the NASA Goddard Institute for Space Studies (GISS) Research Scanning Polarimeter (RSP), the NASA Ames Research Center (ARC) Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR), and the NASA Goddard Space Flight Center (GSFC) GEO-CAPE Airborne Simulator (GCAS).

1.1 Relevance to Program, Agency, Beneficiaries, and Stakeholders

Earth Venture Suborbital 2 (EVS-2) program objectives identified by the EVS-2 Call for Proposals and met by NAAMES are:

- Models: Integration of in situ and remote sensing measurements with Earth system modeling, with observations improving model performance and modeling used to inform interpretations of field and remote sensing data and forecast change
- Phenomena and Change: Improved understanding of (1) climate-sensitive controls of ecosystem annual cycles, (2) food web interactions underlying plankton blooms, and (3) links between plankton ecosystem structure and biogenic aerosol burdens and characteristics
- Interdisciplinary: Investigation design, science team, and measurement suite reflect the interdisciplinary and inseparable nature of atmosphere and ocean processes
- Relevance: Project science objectives are relevant to NASA's Carbon Cycle and Ecosystems, Atmospheric Composition, and Climate Variability and Change focus areas.

NASA's Agency Vision and Mission are to "*Reach New Heights and Reveal the Unknown for the Benefit of Humankind*" and "*Drive Advances in Science, Technology, Aeronautics, and Space Exploration to Enhance Knowledge, Education, Innovation, Economic Vitality, and Stewardship of Earth*", respectively (NPD 1001.0 NASA Strategic Plan). Within this overarching Vision and Mission umbrella, the NAAMES project contributes to the Agency's objectives to:

- Improve understanding on causes of Earth system changes
- Improve predictions of Earth system changes in the future

These contributions are achieved by (1) addressing unresolved mechanisms linking ocean plankton communities and productivity to physical forcings that will be impacted by climate change and (2) providing quantitative evaluations of linkages between ocean biological properties and the production and fate of the biogenic aerosols that strongly impact atmospheric energy budgets over the remote marine environment.

A key beneficiary of a successfully implemented NAAMES project will be the Earth system modeling community, through the improved understanding gained on ocean ecosystem functioning, linkages to atmospheric aerosols, and implications on climate. In addition, the advanced in situ and remote sensing measurements are highly relevant to NASA's upcoming PACE and ACE satellite missions. It is expected that the extensive observational dataset collected during NAAMES will transcend the project duration and inform model and remote sensor retrieval algorithm development efforts that will be carried out over the next decade.

2 Level 1 Mission Requirements and Science Traceability Matrix

NAAMES science objectives are achieved by either the baseline or threshold science mission requirements as defined in **Table 2-1** below. The baseline mission provides substantially more value to NASA and the Earth Science community. The baseline mission provides (1) airborne remote sensing measurements with reduced uncertainties, (2) sustained in situ autonomous measurements with a complete characterization of initial conditions, (3) a field observation data set encompassing a wider range of ecosystem-aerosol-environmental conditions, and (4) a greater assurance that all four ecosystems states will be encountered during the deployments. The Threshold mission constitutes the minimum success criteria for the project. The reduced requirements of the Threshold mission decrease remote sensing data quality, diminish the science value added from autonomous in situ sensor assets, limit the range of environmental conditions under which field observations are conducted, and increase risk of incomplete coverage of the plankton ecosystems states during the annual cycle.

The mapping between the Threshold Mission Requirements and Descope Options (Section 9.0) are as follows: Threshold Requirements A and D map to Descope Option 1, Threshold Requirement C maps to Descope Option 2, and Threshold Requirement F maps to Descope Option 3.

Table 2-2 presents the NAAMES mission Science Traceability Matrix (STM), which reflects requirements for the Baseline mission. The STM provides a flow-through summary linking science objectives to mission measurement, instrument, and investigation requirements. As noted in Section 1, latitudinal variability in the timing of ecosystem events and the ability to conduct field campaigns in any sequence provides considerable flexibility to the NAAMES schedule.

Table 2-1. *Summary of NAAMES Level 1 Mission Requirements*

Baseline Mission Requirements	Threshold Mission Requirements
a. Conduct ***four*** field campaigns between 2015 and 2019 in the plankton bloom-forming region of the North Atlantic.	a. Conduct ***two*** field campaigns between 2015 and 2019 in the plankton bloom-forming region of the North Atlantic.
b. Acquire science data on plankton stocks and rate processes and biogenic aerosols from ship-based and aircraft measurements during each field campaign.	b. Same as baseline.
c. Acquire in situ autonomous science data on plankton properties using optical instruments on profiling floats deployed during each field campaign.	c. Acquire in situ autonomous science data on plankton properties using optical instruments on profiling floats ***provided solely through non-NAAMES floats deployed as part of the international BioArgo consortium.***
d. Measure plankton properties (see Table 3-2 for a summary of the NAAMES targeted Ocean Ecosystem Measurements) during the four primary ecosystem states of the annual cycle (Fig. 1-2), with each of the four campaigns targeting a specific ecosystem state.	d. Same as baseline, ***but extend duration of each campaign and target two ecosystem states during each deployment***.
e. Sample above-water aerosols and in-water aerosol precursors during the four primary ecosystem states of the annual cycle (Fig. 1-2), with each of the four campaigns targeting a specific ecosystem state. (See Table 3-3 below for a summary of the NAAMES targeted Aerosol-Related Measurements).	e. Same as baseline.
f. Measure plankton, aerosol, and cloud properties at different locations to assess spatial variability during the four primary ecosystem states of the annual cycle (Fig. 1-2). (See Table 3-1 below for a summary of the NAAMES targeted Airborne Remote Sensing Measurements.)	f. Same as baseline, ***except without the 4STAR aircraft instrument***.
g. Use satellite observations to assess spatial and temporal variability in plankton and aerosol properties across the subarctic Atlantic basin	g. Same as baseline.
h. Compare contemporary ocean ecosystem and aerosol model results to NAAMES ship, aircraft, and autonomous measurement data and satellite remote sensing data.	h. Same as baseline.
i. Record, validate, publish, and deliver science data and calibrated geophysical data products to the science community. Archive data on NASA DAAC.	i. Same as baseline.

Table 2-2. NAAMES science traceability matrix. *Science Objectives (1st column) define Measurement Requirements (2nd column), which are each given a color coded number. This number system allows Measurement Requirements to be aligned with Instrument Functional Requirements (3rd column) and Investigation Functional Requirements (4th column), as indicated below the two orange arrows.*

Science Objectives & Questions	Scientific Measurement Requirements	Instrument Functional Requirements	aligns with	Investigation Functional Requirements	aligns with
Science Objectives: • Characterize plankton ecosystem properties during primary states of the annual cycle in the North Atlantic and their dependence on environmental forcings • Determine how primary states of the North Atlantic annual plankton cycle interact to recreate each year conditions for an annual bloom **Question #1:** How do environmentally-driven changes in phytoplankton growth rate and seasonal changes in ecosystem interactions create the spring bloom, and what does the relative importance of these two processes imply about future change? **Question #2:** How are seasonal changes in community composition linked to bloom formation?	1 (green) Continuous, mission-long plankton ecosystem properties from satellite ocean color data (e.g., VIIRS, MODIS, HICO, OCM-2, OCLI, SGLI)	1. Autonomous measurements of water column optical and physical properties at 5 m vertical resolution and sustained over annual cycle	2 (green)	1. Field campaigns targeting biomass increasing/ decreasing states and transition states of the annual plankton cycle	6 (green)
	2 (green) Continuous, in situ mission-long plankton ecosystem properties through the water column at distributed locations in N. Atlantic	2. Ship-based ecosystem and optical measurements as specified in Table 3-2	3 (green)	2. Geographically co-located ship and airborne measurements and long-range, transport-scale airborne measurements during each field campaign .	1, 2, 3 (red); 3, 4 (green)
	3 (green) In situ measurements of mixed layer plankton concentrations, species composition, POC, cDOM, and phytoplankton growth, accumulation, total loss, and grazing loss rates	3. Ship- and aircraft-based in situ aerosol, aerosol-precursor, trace-gas, and cloud measurements as specified in Table 3-3	1, 2, 3, 4 (red)	3. Field measurements of the North Atlantic gradient in ecosystem and aerosol properties	5 (green)
	4 (green) UV-to-NIR airborne radiometric measurements linking local-scale analytical data (item 3 above) to satellite remote sensing resolution	4. Passive airborne remote sensing of mixed layer plankton and cDOM properties as specified in Table 3-1	1, 4 (green)	4. Autonomous sensor deployment along latitudinal gradient to sustain in situ observations of annual cycle	2 (green)
	5 (green) Field measurements in items 3 and 4 above conducted over a wide dynamic range in ecosystem properties and encompassing differences in seasonal timing of ecosystem annual cycle events	5. Active airborne remote sensing of subsurface particles as specified in Table 3-1	5 (green)	5. Airborne transects including below, in, and above cloud in-situ sampling and remote sensing at high altitude during each campaign.	2 (red)
	6 (green) Field measurements in items 3 and 4 above conducted during contrasting states of the annual plankton cycle	6. Passive airborne remote sensing of column-averaged aerosol properties from surface to aircraft level as specified in Table 3-1	2, 3 (red)	6. Basin-scale retrievals of aerosol and ecosystem properties from existing/upcoming satellites	5 (red)
Science Objective: • Resolve how remote marine aerosols and boundary layer clouds are influenced by plankton ecosystems in the North Atlantic **Question #3:** How do ocean-ecosystem emissions alter remote marine aerosol burden, spatial distribution, and properties? **Question #4:** How do these biogenic aerosols affect cloud condensation nuclei abundance and, in turn, cloud microphysical properties?	*Ecosystem and optical properties as in 1-4 above plus the following with spatial-temporal coverage as in 5-6:*	7. Active airborne remote sensing of aerosols between surface and aircraft levels as specified in Table 3-1	2 (red)	7. Central data archive	
	1 (red) Measurements of surface air concentrations of aerosols (e.g., sea salt, POA, SOA) and trace gases (e.g., VOCs, DMS)	8. Active and passive airborne remote sensing of clouds as specified in Table 3-1	2 (red)	8. Climate-ecosystem modeling to (1) optimize field campaign design, (2) understand mechanisms of observed ecosystem variability, (3) forecast change in ecosystem properties, with relevance to aerosols	
	2 (red) Measurements of aerosol concentration, size distribution, composition, optical properties and CCN activity below, above, and between clouds	9. Passive airborne remote sensing of spectral aerosol optical depth above the aircraft as specified in Table 3-1	2 (red)		
	3 (red) In situ and remote sensing measurements of cloud droplet number density, size, and liquid water content				
	4 (red) In situ measurements of seawater volatile organics and their production and consumption rates				
	5 (red) Continuous, mission-long record of passive-sensor, satellite-derived aerosol and cloud properties				

NASA Earth Science Division Program Management Council
NAAMES Investigation Confirmation Decision Agreement

Summary: The Earth Science Division Program Management Council (ESD PMC) met on Aug 28, 2015 and evaluated the North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) Investigation's readiness to proceed into the implementation phase. The NAAMES Principal Investigator, Michael Behrenfeld, and the NAAMES Project Manager, Mary Kleb, presented a summary of NAAMES Science and Implementation. The Chair of the ESSP assessment team, Greg Stover, presented the assessment team findings and recommendation.

Decision: Based on this review and the NAAMES Project Implementation Plan (PIP), the Decision Authority for the NAAMES Investigation grants approval for the project's implementation with the content, schedule, and cost profile as specified in the NAAMES Project Implementation Plan and summarized in Table 1, below.

Table 1: NAAMES Cost and Schedule Baseline Commitments

	Baseline Commitment
Cost – LCC Commitment	$29.96M
Investigation Duration	1/15/2015-1/14/2020
Years/Months of Operations	60 months

Actions: None

Concurrence

Principal Investigator — Date: 8/28/15

Program Scientist — Date: 8.28.15

Earth System Science Pathfinder (ESSP) Program — Date: 28 Aug 15

Program Executive — Date: 28 AUG 15

Resource Management Division — Date: 8-28-15

ESD Associate Director, Research — Date: 8/28/15

ESD Associate Director, Flight — Date: 8/28/15

Approval:

Earth Science Division Director — Date: 8/28/15

Appendix BB: Oceans Melting Greenland (OMG)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

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Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release

BB.1 DESCRIPTION

Global sea level rise will be one of the major environmental challenges of the 21st Century. Oceans Melting Greenland (OMG) will pave the way for improved estimates of sea level rise by addressing the question: To what extent are the oceans melting Greenland's ice from below? Over a five-year campaign, OMG will observe changing water temperatures on the continental shelf surrounding Greenland, and how marine glaciers react to the presence of warm, salty Atlantic Water. The complicated geometry of the sea floor steers currents on the shelf and often determines whether Atlantic Water can reach into the long narrow fjords and interact with the coastal glaciers. Because knowledge of these pathways is a critical component of modeling the interaction between the oceans and ice sheet, OMG will facilitate improved measurements of the shape and depth of the sea floor in key regions as well.

OMG will use NASA's G-III to fly the Glacier and Ice Surface Topography Interferometer (GLISTIN) in order to generate high resolution, high precision elevation measurements of Greenland's coastal glaciers during the spring. Annual surveys by GLISTIN will measure glacier thinning and retreat over the preceding season. A second aircraft, the NASA S-3, will be deployed each year to release over 200 expendable temperature and salinity probes along the continental shelf to measure the volume, extent, of warm, salty Atlantic Water. These data, along with fundamental new and critical observations of airborne marine gravity and ship-based observations of the sea floor geometry will provide a revolutionary data set for modeling ocean/ice interactions and lead to improved estimates of global sea level rise.

Beyond addressing the scientific questions on Greenland posed by the 2007 NASA Earth Science Decadal Survey, the campaign will provide observations connected to the overall NASA Earth Science Question from the NASA 2010 Science Plan: How is the Earth changing and what are the consequences for life on Earth? It will also directly address 3 of the 4 sub-components of this question (Characterize, Understand and Predict changes in the Earth system).Jet Propulsion Laboratory (JPL) is a Federally Funded Research and Development Center (FFRDC) managed and operated by Caltech under a contract from NASA.

Some aspects of the OMG project are considered to be ITAR and are tightly controlled. If access to project data is needed please go to https://omg.jpl.nasa.gov/portal/ for contact information.

Appendix CC: ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

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Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (Version 1.0; 3/22/2016)

ORACLES Project Implementation Plan
Version 1.0
March 22 2016

Approved By:

21 March 16

Mr. Greg Stover, Program Manager
Earth Systems Science Pathfinder Program Office
NASA Langley Research Center

Date

2016.03.17

Dr. Michael D. Bicay
Director for Science
NASA Ames Research Center

Date

8 April 2016

Dr. Michael Freilich, Director
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

ORACLES Project Implementation Plan

Version 1.0

March 22 2016

Concurred By:

Bernadette Luna — March 22, 2016

Dr. Bernadette Luna, Project Manager
ORACLES
NASA Ames Research Center

Date

3/22/16

Dr. Jens Redemann, Principal Investigator
ORACLES
NASA Ames Research Center

Date

3/22/2016

Mr. Kevin Murphy, Program Executive
Earth Science Data Systems
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

3/23/16

Ms. Holly Degn, Earth Science Budget Lead
Science Mission Directorate
NASA Headquarters

Date

____________________________ Mr. Bruce Tagg, EVS2 Program Executive Earth Science Division, Science Mission Directorate NASA Headquarters	_______________ Date
____________________________ Dr. Robert Swap, ORACLES Program Scientist Earth Science Division, Science Mission Directorate NASA Headquarters	_______________ Date
____________________________ Dr. Hal Maring, EVS2 Program Scientist Earth Science Division, Science Mission Directorate NASA Headquarters	_______________ Date
____________________________ Dr. Jack Kaye, Associate Director for Research Earth Science Division, Science Mission Directorate NASA Headquarters	_______________ Date
____________________________ Mr. Eric Ianson, Associate Director for Flight Programs Earth Science Division, Science Mission Directorate NASA Headquarters	_______________ Date

1.0 Objectives

The proposed ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) study area in the SE Atlantic is influenced by biomass-burning (BB) aerosols from neighboring southern Africa that account for almost one-third of the Earth's BB emissions. These produce optically-thick aerosol layers that are routinely transported across the entire South Atlantic basin. The South East (SE) Atlantic is also home to one of the Earth's three semi-permanent subtropical stratocumulus (Sc) cloud decks and plays a key role in the energetic balance of the region. The physical processes governing the feedbacks between sea surface temperature and cloud properties are poorly represented in climate models.

ORACLES overarching science goals are 1) to determine the impact of African BB aerosol on cloud properties and the radiation balance over the South Atlantic, using state of the art in situ and remote sensing instruments to generate data sets that can also be used to verify and refine current and future observation methods, and, 2) to acquire a process-level understanding of aerosol-cloud-radiation interactions and resulting cloud adjustments that can be applied in global models. These goals align with NASA's Strategic Goal 2: "Advance understanding of Earth and develop technologies to improve the quality of life on our home planet." and with the NASA Mission to "Drive advances in science, technology and aeronautics that enhance knowledge, education, economic vitality, and stewardship of Earth".

NASA assets, namely the P-3 and ER-2 planes and airborne instruments, will be applied to address the following three science questions: 1) What is the direct radiative effect of the African BB aerosol layer in clear and cloudy conditions over the southeast Atlantic? 2) How does absorption of solar radiation by African BB aerosol change atmospheric stability, circulation, and ultimately cloud properties? and 3) How do BB aerosols affect cloud droplet size distributions, precipitation and the persistence of clouds over the southeast Atlantic? The combination of remote sensing instrumentation on the ER-2 provides a testbed for the ACE (Aerosol Cloud Ecosystems) Decadal Survey Mission. The ER-2 observations enhance satellite-based remote sensing by resolving smaller-scale variability and in combination with the P-3 in-situ measurements, guide the development of new and improved remote sensing techniques. ORACLES also contributes to the Earth System Science Pathfinder Program by focusing on the role of shortwave-absorbing aerosols in climate, an internally-recognized scientific priority. ORACLES is a strong partner in an international collaboration with the United Kingdom, South Africa and Namibia, and with the US National Science Foundation and Department of Energy (DOE) agencies.

The science questions addressed by ORACLES support NASA Objective 2.2: "Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet. " NASA assets will provide unprecedented insight into the Earth system and environmental change. ORACLES is also contributing to Objective 2.4, namely to "Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets.". ORACLES is a joint project involving five NASA centers, a DOE laboratory, and nine US universities, and is developing strong relationships with stakeholders in Namibia, South Africa, Angola and Botswana.

Global aerosol forcing assessments show large inter-model differences for the southeast Atlantic and aerosols and clouds remain the most significant contributors to uncertainties in predictions of the Earth's climate. These have implications for predicting shifts in regional precipitation patterns. The main customers/beneficiaries and stakeholders of the investigation therefore, besides the scientists and personnel infrastructure directly involved, encompass a much larger process-level and climate modeling community. The increased understanding resulting from the ORACLES investigation will improve future Intergovernmental Panel on Climate Change (IPPC) assessments and predictions for the impact of aerosols, clouds, and their interactions on climate.

2.0 Level 1 Mission Requirements

2.1 Distinction between Baseline and Threshold Science Mission

The basic premise for the development of ORACLES science mission requirements is that the statistics of important observed aerosol and cloud properties, given sampling and measurement uncertainties, need to be sufficiently constrained to quantitatively distinguish between the climate models that were used in the AeroCom model intercomparison [Myhre et al., 2013; Stier et al., 2013]. For this, we assume that the variability in aerosol properties at model-relevant scales (100 km^2) can be extrapolated from the results by Shinozuka and Redemann [2011] to be less than 20%, and that such variability is well below the inter-model differences on such scales.

The ORACLES baseline science mission captures aerosol-radiation interactions due to scattering and absorption of solar radiation (SO1-1 to SO1-3), the semi-direct aerosol effects on clouds, i.e., cloud adjustments in response to changes in atmospheric heating (SO2-1 to SO2-3), and the indirect aerosol RF on clouds due to microphysical interactions between aerosol and cloud particles (SO3-1 to SO3-3), including differences in these effects due to seasonal changes in aerosol and cloud properties. Aerosol-cloud interactions over the southeast Atlantic are expected to take place at greater distances from the African shore and are hence more difficult to explore with airborne assets. We therefore consider the exploration of the direct and semi-direct effects as the ORACLES threshold science, and the indirect effects as part of the baseline mission only.

2.2 Baseline and Threshold Science Mission Requirements

As described in section 3, we will spend half (~7-8 flights) of the available flight hours in each campaign for routine flights along a constant latitude between 10-15°S to facilitate comparisons with climate models and to ensure sampling of a wide range of aerosol loadings and cloud conditions. The required flight time for the threshold science mission was estimated in the following fashion. Because most physical processes studies in ORACLES depend on aerosol loading we considered the frequency of occurrence of MODIS derived AOD in September 2001. Specifically, we calculated the normalized PDF (probability distribution function) of MODIS daily 1x1 degree-averaged AOD between 10-20S and 5W-5E for September 2001. We then randomly subsampled the roughly 3000 1x1 deg MODIS AOD boxes and found that 200 random subsamples generally resulted in a PDF that yielded a good representation of the parent population of MODIS AOD.

We conclude that at a rate of 5 observed 1x1 deg grid boxes per flight hour, a total of 40 flight hours is adequate to compile a PDF of aerosol properties in 200 climate model grid boxes, that permits assessments of climate model differences at these spatial scales. We will spend the other half of flight hours in each campaign on targets of opportunity as detailed in Table 1.

2.3 Derivation of Scientific Measurement Requirements

Instrument measurement requirements are derived using the aforementioned target that the ORACLES instruments must be able to assess aerosol and cloud radiative properties with an accuracy that allows for a quantitative distinction between the models that were used in the AeroCom model intercomparison [Myhre et al., 2013; Stier et al., 2013]. Stier et al. (2013) indicate an inter-model standard deviation of 1Wm^{-2} in the annual all-sky TOA radiative forcing. This translates to a standard deviation in instantaneous radiative forcing of 8 Wm^{-2} (after multiplying by a factor of four for seasonal averaging and by a factor of two for diurnal averaging). For ORACLES observations to be useful to discriminate between models, individual measurements need to permit the calculation of instantaneous solar irradiance at the top of the atmosphere to within half the standard deviation between the models, i.e., 4 Wm^{-2}.

2.4. ORACLES Driving Science Questions and Investigation Objectives

2.4.1. Direct Effects

Science Question 1: What is the direct radiative effect of the African biomass burning (BB) aerosol layer in clear and cloudy sky conditions over the southeast Atlantic?

- Science Objective SO1-1: Determine the evolution of the BB aerosol microphysical and spectral radiative properties as the aerosol is transported across the South Atlantic.
- Science Objective SO1-2: Measure aerosol-induced spectral radiative fluxes as a function of cloud albedo and aerosol properties.
- Science Objective SO1-3: Assess the key factors that control the seasonal variation in aerosol direct effects.

2.4.2. Semi-Direct Effects

Science Question 2. How does absorption of solar radiation by African BB aerosol change atmospheric stability, circulation, and ultimately cloud properties?

- Science Objective SO2-1: Determine the seasonally varying relative vertical distributions of aerosol and cloud properties as a function of distance from shore.
- Science Objective SO2-2: Constrain aerosol-induced heating rates for aerosol layers above, within and below cloud.
- Science Objective SO2-3: Investigate the sensitivity of cloud structure and condensate to aerosol-induced heating rates.

2.4.3. Indirect Effects

Science Question 3: How do BB aerosols affect cloud droplet size distributions, precipitation and the persistence of clouds over the southeast Atlantic?

- Science Objective SO3-1: Survey the location and extent of aerosol mixing into the BL and its seasonal variation.
- Science Objective SO3-2: Measure changes in cloud microphysical properties, albedo and precipitation as a function of aerosol mixing into the BL.
- Science Objective SO3-3: Investigate the sensitivity of cloud structure and condensate to aerosol-induced suppression in precipitation.

Table 2.3-1. Investigation Requirements to address baseline and threshold mission objectives

	Investigation Performance Requirements
Threshold Science	**As related to Science Objectives SO1-1 to SO1-3, and SO2-1 to SO2-3:**
	A minimum of 2 flight campaigns using the P-3 aircraft, with a **total of 128 successful† science flight hours** collecting data for the following constellations:
	A minimum of 80 hrs in "routine" flights along a constant latitude between 10-15°S, sampling mid-visible AOD in the range of 0.1-0.7 in clear sky and aerosol above cloud conditions, to facilitate comparison with global and regional models
	A minimum of 48 hrs in "target of opportunity" flights:
	24 flight hours observing aerosol evolution in quasi-Lagrangian experiments to study changes in aerosol properties and aerosol-induced irradiance changes during long-range transport (**SO1**)
	24 flight hours observing changes in the spatiotemporal distribution of aerosol properties and processes potentially affecting heating rates and cloud properties for a range of Sc cloud fractions (SO2)
	A minimum **6-week range of observations** between the two campaigns to observe intraseasonal variations in aerosol and cloud properties
Baseline Science	**As related to all Science Objectives, SO1-1 to SO1-3, SO2-1 to SO2-3, and SO3-1 to SO3-3:**
	A **total of 3 flight campaigns with the P-3** aircraft, **one** of which coordinated **with the ER-2**, with an average of 96 flight hours per campaign for the P-3, and a minimum of 64 ER-2 flight hours
	An **ER-2 remote sensing data set** to advance remote sensing retrievals of mixed aerosol and cloud scenes using combined polarimeter, lidar and imager observations from state-of-the-art airborne simulator instruments
	A **9-week range of observations** between the three campaigns to observe intraseasonal variations in aerosol and cloud properties
	In the P-3 flight campaigns, **a total of 240 successful† research flight hours** (an average of 10x8hrs=80hrs per campaign) collecting data for the following constellations:
	A total of 120 hrs in "routine" flights along a constant latitude between 10-15°S, sampling mid-visible AOD in the range of 0.1-0.7 in clear sky and aerosol above cloud conditions, with varying cloud fractions, to facilitate comparison with global and regional models
	A total of 120 hrs in "target of opportunity" flights:
	40 flight hours observing aerosol evolution in quasi-Lagrangian experiments to study changes in aerosol properties and aerosol-induced irradiance changes during long-range transport (**SO1**)
	40 flight hours observing changes in the spatiotemporal distribution of aerosol properties and processes potentially affecting heating rates and cloud properties for a range of Sc cloud fractions (SO2)
	40 flight hours showing evidence of aerosol mixing into Sc cloud deck (**SO3**)

†Successful research flight hours are defined as hours in which **at least one instrument providing the key observable** for the targeted science objective (as defined in the STM) was operational for the majority of time.

Note: A total of 115 science flight hours are budgeted for the P-3 per campaign - the estimated 128 flight hours to address SO1 and SO2 in the threshold science mission constitute about 55% of the available science flight hours in two threshold deployments; the estimated 240 total flight hours to address the baseline science mission constitute about 70% of the available science flight hours.

We use simple parametric RT calculations with the expressions derived by Russell et al. [1997], and a baseline state characterized by AOD = 0.4, SSA = 0.9, surface+cloud albedo = 0.4, to assess the required accuracies in aerosol and cloud properties to permit instantaneous forcing calculations to within 4 Wm^{-2}. The individual accuracy requirements are summarized in the STM, Table 2 below.

To allow meaningful validation of the remote sensing instruments for aerosols above clouds [e.g., Knobelspiesse et al., 2013], more stringent accuracy requirements are applied to AOD and AAOD; required accuracies for aerosol spectral refractive index and chemical composition are formulated to allow distinction of major aerosol types [e.g., Russell et al., 2010]; aerosol size and number concentration are required to permit a detection of the effect of increasing CCN concentrations on cloud properties [e.g., Fridlind and Ackerman, 2011]. Precipitation rate accuracy is determined by a requirement of quantifying instantaneous latent heating with an accuracy of 10 Wm^{-2}, at which precipitation becomes energetically significant compared with ~100 Wm^{-2} cloud top cooling and surface fluxes. The required accuracy of carbon monoxide (CO) is set using the AOD accuracy requirement above and typical ratios of AOD/CO for the region. The instruments that appear in bold type in the STM have been shown to meet or exceed the accuracy requirements; their measurement uncertainties are indicated in parentheses. The relevant references that demonstrate these accuracies are given in the original proposal.

Table 2.3-2. ORACLES Science Traceability Matrix (in the last column, "A" means all three objectives for that set)

Priority	Science Objectives	Scientific Measurement Requirements: Parameter	Scientific Measurement Requirements: Accuracy	Instrument Functional Requirements (**bold** indicates instruments that are required to address threshold science objectives)	Investigation Functional Requirements
Threshold	Aerosol direct effects: O1-1 (Aerosol spatial evolution) O1-2 (Aerosol-induced radiative fluxes) O1-3 (Seasonal aerosol variation) Aerosol semi-direct effects: O2-1 (Relative vertical distribution) O2-2 (Aerosol-cloud heating rates) O2-3 (Cloud changes due to aerosol-induced heating)	**Aerosol:**			**Observations:** Intensive, multi-aircraft field campaigns [A] [A] [A] Measurements on routine flight track along 15°S, sampling at least 40hrs (~200 100km² model grid boxes) to enable statistical comparisons to climate models [O1-1] [O3-1] Sampling that permits assessments of variability in aerosol and cloud properties within climate model grid cells (100km²) for multiple adjacent cells [A] [A] [A] 3 airborne campaigns in different months of BB season [O1-3] [O2-1] [O3-1] In situ and remote sensing obs of aerosol layers above (and entrained into) low-level Sc deck [A] [A] [A] Coincident obs of underlying cloud macro- and microphysical properties [A] [A] Measurement of FT-to-PBL mixing [O3-1]
		AOD at UV-VIS-SWIR	±0.02 or 5%	**4STAR (0.01-0.02)**, RSP(0.02), AirMSPI, HSRL-2(0.01), eMAS, AERONET(0.01-0.02) [O1-1] [O1-2]	
		AAOD at UV-VIS-SWIR	±0.02 for AOD>0.1	**4STAR+SSFR (0.02)**, RSP, AirMSPI, HSRL-2,eMAS,HiGEAR,AERONET(0.02) [O1-1] [O1-2] [O2-2]	
		Aerosol spectral refractive index at UV-VIS-SWIR	±0.02 for real part	**4STAR+SSFR**, RSP, AirMSPI, HSRL-2, eMAS, **AERONET(0.02)** [O1-1]	
		Aerosol/CCN size distribution, r_{eff}	±0.07μm±7%	**HiGEAR(10% number, 5% size)**, CCN, RSP [O1-1] [O3-1]	
		Aerosol number conc.	50%	**HiGEAR(10%)**, HSRL-2 [O1-1] [O3-1]	
		Chemical composition	Speciation (BC, volatile, refract.)	**HiGEAR-AMS(35%), SP2(25%)**, RSP [O1-1] [O3-1]	
		Aerosol extinction / absorption profile	±0.025 km⁻¹ in ext	**HiGEAR(0.005 in ext), HSRL-2(0.01 in ext), PTI (0.003 in abs)**, 4STAR [O1-1] [O2-1]	
		Single scattering albedo (profile or layer), ϖ_o	±0.028	**HiGEAR (0.03)**, HSRL-2, RSP, AirMSPI, 4STAR+SSFR (0.02 in midvis), AERONET(~0.03) [O1-1] [O1-2] [O2-1] [O2-2]	
		Gases:			
		CO, CO2, H2O, O3	10 ppbv CO	COMA(2ppbv CO), Facility, HiGEAR [O3-1] [O1-1]	
		Cloud/Drizzle/Precipitation:			
		Cloud fractional cover	±0.05	eMAS (0.05), ACR+APR-2, AirMSPI (0.05), **MODIS/SEVIRI (0.05)** [O2-3] [O1-2]	
Baseline	Aerosol indirect effects: O3-1 (Mixing survey) O3-2 (Cloud changes due to aerosol mixing) O3-3 (Cloud changes due to aerosol-suppressed precipitation)	Cloud top/bottom height	±100m	**APR-3 (60m),** HSRL-2 (33m), AirMSPI [A] [O1-2]	
		Droplet Size Distribution	20%	**CAPS-CAS, PDI (20%)**, CDP [O3-2] [O2-2] [O2-3]	**Modeling:** Large eddy simulations to integrate observations for process scale understanding of aerosol-cloud interactions. [A] [A] Regional chemistry-aerosol climate modeling for field planning, to integrate observations to constrain direct, semi-direct and indirect effects, and to separate aerosol and meteorological effects on clouds [A] [A] [A] Global climate modeling to determine impacts of BB aerosols on radiation budget and global circulation [A] [A] [A]
		COD	10%	eMAS(5-10%),**SSFR**, RSP, AirMSPI, 4STAR [O2-1] [O2-2] [O3-2] [O3-3]	
		r_{eff}	20%	eMAS (10-20%), RSP, AirMSPI, SSFR, 4STAR, **in situ probes (20%)**	
		Liquid water content/path (LWC/LWP)	0.05 gm⁻³ / 10 gm⁻²	**King probe, CAPS-LWC, PDI (20%LWC), APR-3+AMPR (10gm⁻²LWP)** [O2-3] [O3-2] [O3-3]	
		Winds & Thermodynamics	±0.3 m/s (vertical)	**TAMMS (±0.2 m/s)**, Facility [O3-1]	
		Precipitation microphysics/ rate	0.4 mm/day (rate)	**2D-S, CAPS-CIP (0.2mm/day)**, eMAS+APR-3 (0.2mm/day) [O3-3]	
		Radiation:			
		Spectral Solar Flux	3%	**SSFR (3%, 0.5-1% for differentials)** [O1-1] [O2-1]	
		Visible-SWIR Degree of Linear Polarization	0.5%	RSP (0.2%), AirMSPI (0.5%) [O1-2] [O2-1] [O2-2]	
		Visible, SWIR, Thermal IR Radiance / Brightness T	5-10% in radiance, 0.5K for IR	eMAS (5% in radiance, 0.5K for mid- and window-IR, 1-2K for 13+ μm) [O2-3]	

NASA Earth Science Division Program Management Council
ORACLES Investigation Confirmation Decision Agreement

Summary: The Earth Science Division Program Management Council (ESD PMC) met on March 22nd, 2016 and evaluated the ObseRvations of Aerosols above Clouds and their intEractionS (ORACLES) readiness to proceed into the implementation phase. The ORACLES Principal Investigator, Dr. Jens Redemann, and Project Manager, Ms. Bernadette Luna, presented a summary of ORACLES Science and Implementation. The Mission Manager for the investigation, Jennifer Olson, presented the assessment team findings and recommendation.

Decision: Based on this review and the ORACLES Project Implementation Plan (PIP), the Decision Authority for the ORACLES Investigation grants approval for the project's implementation with the content, schedule, and cost profile as specified in the ORACLES Project Implementation Plan and summarized in Table 1, below.

Table 1: ORACLES Cost and Schedule Baseline Commitments

	Baseline Commitment
Cost – LCC Commitment	$29.971M
Investigation Duration	2/1/2015-1/31/2020
Years/Months of Operations	60 months

Actions: None

Concurrence

Principal Investigator — Date: 3/22/16

Program Scientist — Date: 3/22/16

Jennifer Olson
Earth System Science Pathfinder (ESSP) Program — Date: 3/22/16

Program Executive — Date: 3/22/16

Resource Management Division — Date: 3/23/16

ESD Associate Director, Research — Date: 3/22/16

ESD Associate Director, Flight — Date: 3/22/2016

Approval:

Earth Science Division Director — Date: 3/23/16

Appendix DD: Atmospheric Carbon and Transport America (ACT-America)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (Version 1; dated 09/30/2015)

National Aeronautics and
Space Administration

Document Number: Investigation CM
Version: 1
Effective Date: 9/30/2015

Atmospheric Carbon and Transport (ACT) – America
Project Implementation Plan

A NASA Earth Venture Suborbital (EVS-2) Mission

Approved By:

Mr. Greg Stover, Program Manager
Earth Systems Science Pathfinder Program Office
NASA Langley Research Center

28 Sept 15
Date

Dr. John R. Hellmann
Associate Dean for Graduate Education and Research
College of Earth and Mineral Sciences
The Pennsylvania State University

September 25, 2015
Date

Dr. Michael Freilich, Director
Earth Science Division, Science Mission Directorate
NASA Headquarters

10 Oct 2015
Date

Concurred By:

Dr. Kenneth J. Davis
The Pennsylvania State University
Investigation Principal Investigator

28 September, 2015
Date

Dr. Bing Lin
NASA Langley Research Center
Investigation Project Scientist

28 September, 2015
Date

Dr. Michael D. Obland
NASA Langley Research Center
Investigation Project Manager

28 September, 2015
Date

Mr. Kevin Murphy, Program Executive
Earth Science Data Systems
Earth Science Division, Science Mission Directorate
NASA Headquarters

9/22/2015
Date

Ms. Holly Degn, Earth Science Budget Lead
Science Mission Directorate
NASA Headquarters

9/30/15
Date

Mr. Bruce Tagg, EVS2 Program Executive
Earth Science Division, Science Mission Directorate
NASA Headquarters

9/17/15
Date

Concurrences Continued:

18 Sep 2015

Dr. Ken Jucks, ACT-America Program Scientist
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

17 Sept 2015

Dr. Hal Maring, EVS2 Program Scientist
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

9/30/15

Dr. Jack Kaye, Associate Director for Research
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

9/28/15

Mr. Eric Ianson
Associate Director for Flight Programs
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

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1.0 Mission Objectives

Overarching goal: The overarching goal of the Atmospheric Carbon and Transport-America (ACT-America) mission is to improve regional (~10^6 km^2) to continental scale diagnoses of carbon dioxide (CO_2) and methane (CH_4) sources and sinks over North America.

Achievement of this goal will advance society's ability to predict and manage future climate change by enabling policy relevant quantification of the contemporary carbon cycle. This mission will enable and demonstrate a new generation of atmospheric inversion systems for quantifying regional CO_2 and CH_4 sources and sinks.

Significant progress quantifying the carbon cycle has been made at the global scale and at the scale of flux tower footprints (~1 km^2), but we currently lack the ability to diagnose CO_2 and CH_4 sources and sinks with regional (~10^6 km^2) resolution. Accurate and precise diagnoses of CO_2 and CH_4 fluxes that are ongoing, possess regional and annual resolution, span the globe, and encompass decades, are needed. Atmospheric inversion models are data analysis systems that can be used to convert these measurements of atmospheric CO_2 and CH_4 mole fractions into estimates of CO_2 and CH_4 sources and sinks. Inversions have the potential to provide accurate and precise diagnoses of CO_2 and CH_4 fluxes at the requisite spatial and temporal scales.

The new generation atmospheric inversion systems enabled by ACT-America will be the first ever with the precision, accuracy, and resolution needed to 1) evaluate and improve terrestrial carbon cycle models at continental scales; and 2) monitor carbon fluxes to support climate-change mitigation efforts. This will be achieved with an airborne mission that will improve our understanding of regional, seasonal CO_2 and CH_4 sources and sinks, atmospheric transport of these gases, and satellite column CO_2 observations. Applications of the inversion systems beyond the conclusion of this mission will improve diagnoses of the contemporary carbon cycle across the globe for decades. The ACT-America investigation will demonstrate this uncertainty reduction in CO_2 and CH_4 flux estimates for North America.

The overarching goal will be achieved via three synergistic mission objectives, in order of priority.

Objective 1: Quantify and reduce transport uncertainty for temperate latitude atmospheric inversions.

Objective 2: Provide regional-scale, top-down constraint on seasonal CH_4 emissions and biogenic CO_2 fluxes. Reduce uncertainty in the prior estimates of CO_2 and CH_4 fluxes used for atmospheric inversions.

Objective 3: Evaluate the sensitivity of satellite-based passive measurements of CO_2 from OCO-2 to regional variability in tropospheric CO_2.

These objectives will be met by airborne flight campaigns focused on determining carbon fluxes and atmospheric transport of CO_2 and CH_4, model-data comparisons, and comparisons between airborne and OCO-2 CO_2 column observations. ACT-America's mission spans 5 years and includes five 6-week field campaigns using the NASA C-130 and B-200 aircraft, and covering all 4 seasons and 3 regions of the central and eastern United States. The aircraft will measure the 3-dimensional distribution of carbon dioxide and methane (hereafter C) at synoptic spatial scales, focused on the atmospheric boundary layer (ABL) and lower free troposphere (FT) and including both fair and stormy weather. Ensembles of flux, atmospheric transport, and C data assimilation models provide a comprehensive modeling and analysis system. The science team includes experts from all relevant disciplines.

The Atmospheric Carbon and Transport (ACT) – America mission aligns with NASA's Strategic Goal 2 "Advance understanding of Earth and develop technologies to improve the quality of life on our home planet." Specifically the science questions answered by ACT-America are in support of Objective 2.2 of the Goal 2: "Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet." The research communities involved in determining C sources and sinks from atmospheric measurements, including the satellite CO_2 and CH_4 observation communities, are the most immediate beneficiaries of ACT-America. The improved inversion modeling methods developed by ACT America will be employed by these research scientists to improve ongoing diagnosis of CO_2 and CH_4 fluxes. These improved C flux estimates will provide the climate modeling and prediction communities the ability to evaluate and improve terrestrial carbon cycle models at regional to continental scales. The resulting improvements in terrestrial carbon cycle models will significantly reduce uncertainties in predictions of the future terrestrial carbon cycle, climate forcing and climate change, and will advance society's ability to manage future climate change. Improved atmospheric inversion modeling will also support C emissions management efforts by enabling accurate and precise quantification of regional carbon sources and sinks.

2.0 Level 1 Science Requirements

The first two science objectives in Section 1 are achieved by either the baseline or threshold science investigation requirements listed herein. The baseline investigation provides substantially more value to NASA and the Earth Science Community, and adds the third objective.

The ACT-America Investigation shall be considered successful if it meets the Threshold Science and Investigation Requirements defined in Section 2.2.

Note that in the following discussion, "stormy" weather refers to conditions dominated by a low-pressure system, also known as a synoptic storm or mid-latitude cyclone. "Fair" weather is any condition dominated by high pressure. Since the mission goal is to study C transport by typical mid-latitude weather, every day has atmospheric conditions that fall within this desired range of weather – a spectrum from stormy to fair conditions.

2.1 Baseline science and investigation requirements.

Throughout SR and IV refer to the science and investigation requirements, respectively, in the science traceability matrix (Table 1).

a) Conduct five campaigns to measure tropospheric CO_2 and CH_4 distributions, with each campaign covering three regions within the continental U.S., and occurring during each of the four seasons. [SR1.1, SR2.1, IV1.1, IV2.1]

b) Measure mid to lower tropospheric CO_2 and CH_4 distributions during weather conditions ranging from synoptic storms to fair weather in each study region and in each season of the year. [SR1.2, SR2.3, SR2.4, IV1.2, IV2.1]

c) Conduct 10 under-flights of the OCO-2 satellite measuring the CO_2 distribution below the satellite and obtain related atmospheric and surface properties from A-train satellites in the OCO-2 orbit. [SR3.1, IV3.1, IV3.2].

d) Obtain measurements of CO_2 and CH_4 during fair weather conditions over altitudes from within the atmospheric boundary layer to at least 3 km above ground level, encompassing a significant cross-wind fraction of fair weather systems and a distribution of C sources and sinks (cross-wind flight legs of at least 300 km), with data both upwind and downwind of CO_2 and CH_4 sources and sinks, and with horizontal measurement resolution of at least 20 km along the flight legs. [SR1.4, SR2.1, SR2.3, SR2.4, IV 1.3, IV2.2]

e) Obtain measurements of CO_2 and CH_4 during stormy weather over altitudes from within the boundary layer to the mid to upper troposphere and covering both along-front and cross-frontal conditions, with horizontal measurement resolution of at least 20 km along the flight track. [SR1.5, IV1.3]

f) Obtain coincident measurements of atmospheric physical properties (boundary layer height, temperature, horizontal wind speed and direction, pressure) and of atmospheric gases (H_2O, O_3, CO, COS, $^{14}CO_2$) that can be used to differentiate flux versus transport errors in simulations of CO_2 and CH_4 distributions. [SR1.3, SR2.2, SR2.5]

g) Compare OCO-2 data and airborne CO_2 observations from the OCO-2 underflights, and evaluate the dependence of this comparison on atmospheric CO_2, land surface topography and reflectivity, and atmospheric aerosol distributions. [SR3.2, IV3.4, IV3.5]

h) Conduct model ensemble simulations of CO_2 and CH_4 transport over the flight domains. [IV1.4, IV3.3].

i) Use the atmospheric simulations and the observations of CO_2 and CH_4 to estimate seasonal CH_4 emissions and biogenic CO_2 fluxes. [IV2.3]

j) Identify transport model ensemble members with the lowest CO_2 and meteorological model-data mismatch errors and minimal bias. [IV1.5, IV1.6]

k) Demonstrate a multi-year, regional atmospheric GHG inversion using the improved prior CO_2 and CH_4 flux estimates and improved atmospheric transport ensemble, and OCO-2 observations with improved uncertainty quantification. [IV1.7, IV2.4, IV3.6]

2.2 Threshold science and investigation requirements.

Changes from the baseline are indicated with text strikeouts followed, when appropriate, by the modifications for the threshold requirements.

a) Conduct ~~five~~ two campaigns to measure tropospheric CO_2 and CH_4 distributions, with each campaign covering ~~three regions within~~ at least the southeast and one other region of the continental U.S., and occurring during ~~each of the four seasons~~ both growing season and biologically dormant conditions. [SR1.1, SR2.1, IV1.1, IV2.1]

b) Measure mid to lower tropospheric CO_2 and CH_4 distributions during weather conditions ranging from synoptic storms to fair weather in each study region and in ~~each season of the year~~ both growing season and biologically dormant conditions. [SR1.2, SR2.3, SR2.4, IV1.2, IV2.1]

~~c) Conduct 10 under-flights of the OCO-2 satellite measuring the CO_2 distribution below the satellite and obtain related atmospheric and surface properties from A-train satellites in the OCO-2 orbit. [SR3.1, IV3.1, IV3.2].~~

d) Obtain measurements of CO_2 and CH_4 during fair weather conditions over altitudes from within the atmospheric boundary layer to at least 3 km above ground level, encompassing a significant cross-wind fraction of fair weather systems and a distribution of C sources and sinks (cross-wind flight legs of at least 300 km), with data both upwind and downwind of CO_2 and CH_4 sources and sinks, and with horizontal measurement resolution of at least 20 km along the flight legs. [SR1.4,

SR2.1, SR2.3, SR2.4, IV 1.3, IV2.2]

e) Obtain measurements of CO_2 and CH_4 during stormy weather over altitudes from within the boundary layer to the mid to upper troposphere and covering both along-front and cross-frontal conditions, with a horizontal measurement resolution of at least 20 km along the flight track. [SR1.5, IV1.3]

f) Obtain coincident measurements of atmospheric physical properties (~~boundary layer height,~~ temperature, horizontal wind speed and direction, pressure) and of atmospheric gases (H_2O, ~~O_3,~~ CO, ~~COS, $^{14}CO_2$~~) that can be used to differentiate flux versus transport errors in simulations of CO_2 and CH_4 distributions. [SR1.3, SR2.2, SR2.5]

~~g) Compare OCO-2 data and airborne CO_2 observations from the OCO-2 underflights, and evaluate the dependence of this comparison on atmospheric CO_2, land surface topography and reflectivity, and atmospheric aerosol distributions. [SR3.2, IV3.4, IV3.5]~~

h) Conduct model ensemble simulations of CO_2 and CH_4 transport over the flight domains. [IV1.4, ~~IV3.3~~]

i) Use the atmospheric simulations and the observations of CO_2 and CH_4 to estimate seasonal CH_4 emissions and biogenic CO_2 fluxes. [IV2.3]

j) Identify transport model ensemble members with the lowest CO_2 and meteorological model-data mismatch errors and minimal bias. [IV1.5, IV1.6]

k) Demonstrate a ~~multi-year~~ one-year, regional atmospheric GHG inversion using the improved prior CO_2 and CH_4 flux estimates and improved atmospheric transport ensemble~~, and OCO-2 observations with improved uncertainty quantification~~. [IV1.7, IV2.4~~, IV3.6~~]

2.3 Instrument requirements.

The science traceability matrix (STM, Table 1) presents the instrument requirements associated with the baseline science and investigation requirements.

Table 1: Science traceability matrix for threshold and baseline science requirements.

Mission Objectives	**Science Requirements**	**Instrument Requirements**	**Investigation Requirements**
Objective 1: Reduce transport uncertainty for temperate latitude GHG inversion studies. [MO1.1] Reduce transport uncertainty for inverse estimates of net annual biogenic N. American CO_2fluxes. [MO1.2] Reduce transport uncertainty in regional (10^6 km^2) net annual biogenic CO_2 flux estimates.	[SR1.1] Observe multiple high-pressure and low-pressure systems spanning growing-season and biologically dormant conditions, and spanning different regions of the U.S. [SR1.2] Observe atmospheric CO_2 with sufficient precision to distinguish differences (3-10 ppm hourly in the midday ABL) among transport models. [SR1.3] Observe properties that differentiate flux vs. transport errors: ABL depth, winds, CO, H_2O, O_3, COS, $^{14}CO_2$. [SR1.4] Fair weather: Measure from the ABL to 3-4 km AGL spanning a significant cross-wind extent of system area (300 km) with sufficient resolution (20 km) to detect within-system structure. [SR1.5] Storms: Measure a significant portion of along-front and cross-frontal structure from the ABL to the mid- to upper-troposphere with sufficient resolution (20 km) to detect within-system structure.	[IR1.1] Accuracy of CO_2 measurements: 1 ppm. <u>Airborne instruments:</u> [IR1.2] Temporal resolution: 130 sec (20 km at 150 m/s). [IR1.3] Precision for a 20km (130 sec) average: CO_2: 1 ppm; CO: 15 ppb; O_3: 8 ppb; H_2O: 0.5 g/kg; COS: 10 ppt; $^{14}CO_2$: 2 per mil; ABL depth: 100 m; Altitude above ground: (5 m); Ambient air temperature: 0.5°C; Horizontal wind speed: 1.0 m/s; Horizontal wind direction: 5°; Ambient air pressure: 0.5 mb. CO_2 column (from surface to 3km AGL) precision of 0.125%. <u>Ground instruments:</u> [IR1.4] CO_2: 1-ppm hourly accuracy and precision.	[IV1.1] Conduct campaigns spanning growing season and biologically dormant conditions, and two to three regions of the eastern U.S. [IV1.2] Sample low-pressure and high-pressure systems within each season and study region. [IV1.3] Conduct flight patterns whose spatial dimensions meet the fair and stormy weather science requirements. [IV1.4] Conduct model simulations of atmospheric CO_2 and CH_4. [IV1.5] Use field data to identify and quantify CO_2 errors in atmospheric transport models. [IV1.6] Identify transport model ensembles with reduced CO_2 model-data mismatch errors and minimal bias. [IV1.7] Implement identified transport ensemble for continental inversions.
Objective 2: Provide regional-scale top-down constraint on CH_4 emissions and seasonal CO_2 fluxes across the study regions in the eastern half of the U.S. [MO2.1] Determine regional CH_4 emissions for the period of the flight campaign with <20% uncertainty. [MO2.2] Determine regional biogenic CO_2 fluxes for the period of the flight campaign to <20% uncertainty.	[SR2.1] Resolve regional, fair-weather, ABL CH_4 enhancements (20-100 ppb) and CO_2 changes (10-20 ppm) with a precision of <20%. [SR2.2] Sample trace gases (CO, COS, $^{14}CO_2$) that identify CO_2 sources/sinks. [SR2.3] Measure upwind and downwind of C sources/sinks and laterally to encompass sources/sinks (at least 300 km), encompassing growing and biologically dormant seasons. [[SR2.4] Measure the C content of the free troposphere. [SR2.5] Measure ABL depth, wind, temp, H_2O.	[IR2.1] Same instrument capabilities noted for Goal 1 with the addition of CH_4 and no requirement for O_3. [IR2.2] Accuracy and precision of airborne CH_4 measurements: 4 ppb for a 20 km (130 sec) average. <u>Ground instruments:</u> [IR2.3] The same CO_2 requirements as for Objective 1. CH_4: 4 ppb hourly accuracy and precision.	[IV2.1] Conduct multiple fair weather aircraft flights in CH_4 and CO_2 source/sink regions and encompassing growing season and biologically dormant conditions. [IV2.2] Collect CO_2 and CH_4 measurements upwind of the source regions. [IV2.3] Estimate regional CH_4 and CO_2 sources/sinks via atmospheric inversions. [IV2.4] Use airborne data to improve flux priors for continental-scale inversions that utilize the long-term C observing network.
Objective 3: Evaluate the sensitivity of satellite-based passive measurements of CO_2 from OCO-2 to regional variability in tropospheric CO_2 content. [MO3.1] Quantify biases in OCO-2 CO_2 measurements that are greater than 0.5 ppm with a spatial resolution of 20 km.	[SR3.1] Measure tropospheric CO_2 distributions with 0.125% (0.5 ppm) precision and 20 km spatial resolution coincident in time and space with OCO-2. [SR3.2] Quantify temporal and spatial variably in column CO_2 along track resulting from different surface reflectances and aerosol distributions within the OCO-2 footprint.	[IR3.1] Measure column CO_2 from surface to 8 km AGL with 0.125% precision and 20 km spatial resolution. [IR3.2] Measure spatial location to within 500 m, and altitude above ground level to within 5 m, at 0.2 km spatial resolution (1.3 sec). [IR3.3] Measure ABL depth, air pressure as for Objective 1. [IR3.5] Measure aerosol distribution and surface reflectance variability at 0.2 km. resolution.	[IV3.1] Collect airborne CO_2 on multiple flights centered in time around the OCO-2 overpass and on OCO-2 track, over a variety of continental surfaces and aerosol conditions. [IV3.2] Obtain cloud, aerosol and land surface properties with A-train satellite instruments (CALIPSO, MODIS). [IV3.3] Compute column CO_2 above 8 km with inversion systems. [IV3.4] Compare OCO-2 and ACT-America column CO_2 amounts at 2.25 km and 20 km resolution. [IV3.5] Diagnose causes of OCO-2 and ACT-America column CO_2 differences.

			[IV3.6] Utilize OCO-2 high res data with improved uncertainty quantification in continental inversions.

3.0 Technical Approach

ACT-America's mission spans 5 years and includes five 6-week field campaigns using the NASA C-130 and B-200 aircraft covering all 4 seasons and 3 regions of the central and eastern United States. The aircraft will measure the 3-dimensional distribution of carbon dioxide and methane (hereafter C) at synoptic spatial scales, focused on the atmospheric boundary layer (ABL) and lower free troposphere (FT) and including both fair and stormy weather. Ensembles of flux, atmospheric transport, and C data assimilation models provide comprehensive modeling and analysis systems. The science team includes experts from all relevant disciplines.

First year preparations include the procurement, calibration, and installation of tower-based and airborne, commercial, off-the-shelf in situ instruments, drafting aircraft flight plans and securing necessary permission within the 3 flight regions, and preparing and optimizing the airborne remote sensors for multi-year deployment. The ensemble modeling system will be assembled, exchange of data among modeling systems will be tested, and platforms for model-model and model-data comparison and assimilation will be constructed.

Years two through four include five airborne campaigns, scheduled for the summer of 2016 (FY 16), winter of 2017 (FY 17), summer of 2017 (FY 17), fall of 2017 (FY 18), and spring of 2018 (FY 18), covering all four seasons and with redundant sampling of the most active biological season, summer. Each campaign will consist of deployments for 2 weeks to each of the three study regions. Four science flights are scheduled for each regional deployment, allowing for approximately two fair and two stormy-weather flights per region. Two OCO-2 underflights are desired during each campaign. The mission will thus include a total of approximately 30 fair-weather flights, 30 stormy-weather flights, and 10 OCO-2 underpass flights. This measurement density achieves the repeated realizations of flux and weather conditions required by the investigation requirements. Schedule options that do not compromise the scientific mission include delaying the summer 17 or fall 17 campaigns by one year if necessary.

The final year will focus on integration of the findings from Objectives 1 through 3 to improve continental-scale atmospheric inversions of C fluxes over North America for the past decade. All capital gain equipment purchased (Picarro and 2B Technologies instruments) will be returned to NASA Langley. Data archives will be finalized and a final report will be issued. Key findings from this mission will be disseminated through both scientific conference reports and peer-reviewed journal articles. Funds have been allocated for multiple publications per research group. It is expected that the ACT-America mission will provide data that will be used for research and publication by other interested research groups outside of the ACT-America science team.

3.1 Science Instrumentation

The C-130 payload includes two remote sensing instruments: the Multi-Functional Fiber Laser Lidar (MFLL, Dobler *et al.* 2013), a Laser Absorption Spectrometer (LAS) for measuring CO_2 column number density weighted to the near surface atmosphere as well as range to the surface and surface reflectance, and the Cloud Physics Lidar (CPL, McGill et al. 2002), an aerosol backscatter lidar for measuring ABL depth and aerosol distributions (Table 2). The C-130 also carries a comprehensive suite of in situ sensors measuring CO_2, CH_4, carbon monoxide (CO), ozone (O_3), and H_2O (water), and flasks that measure CO_2 and CH_4 as well as GHG tracers, particularly CO, COS, and $^{14}CO_2$. The B-200 has an identical suite of in situ sensors and flask sampling capability (Table 2). In situ sensor redundancy for CO_2, CH_4 and CO on each aircraft provides the opportunity to evaluate in flight performance of the measurements. Both aircraft are also equipped to provide high accuracy and precision meteorological measurements. All instruments (c.f., Table 2) meet or exceed the precision and accuracy levels required by the STM over the requisite averaging scale. Most instruments exceed the STM requirements at their native resolutions, which are higher than those required by the STM (see Table 2).

Table 2. *The ACT-America instruments provide the necessary measurements and measurement precisions required to achieve the mission objectives.*

Instrument	Platform	Technique	TRL	Species/ Parameter	Instrument Precision (Averaging Time)	STM Precision Requirement [over 20 km (~130 sec) unless otherwise noted]
MFLL	C-130	LAS[1]	8	CO_2 Column Density[4]	≤0.08% (10 sec)	0.1%
		Pseudorandom Number Altimetry		Range to ground	< 1m (0.1 sec)	5 m (0.2 km)
CPL	C-130	Pulsed Lidar	9	ABL Height[5]	≤ 100 m (10 sec)	100 m
Picarro G2401-m	C-130, B-200	CRDS[2]	9	CO_2	≤ 0.15 ppm (5 sec)	1 ppm
				CH_4	≤ 1 ppb (5 sec)	4 ppb
				CO	≤ 30 ppb (5 sec)	15 ppb
				H_2O	≤ 0.12 g/kg (5 sec)	0.5 g/kg
2B Technologies Model 205	C-130, B-200	Laser Spectrometer	9	O_3	1 ppb (10 sec)	8 ppb
Picarro G2301	Tower	CRDS[2]	9	CO_2	≤ 0.07 ppm (5 sec)	1 ppm hourly
				CH_4	≤ 0.5 ppb (5 sec)	4 ppb hourly
Flasks	C-130 B-200	GC/ MS[3]	9	CO_2, CH_4, CO, $^{14}CO_2$, COS	0.2 ppm CO_2;1 ppb CH_4; 2 per mil $^{14}CO_2$;2 ppt COS; (all 10 sec)	1 ppm CO_2; 4 ppb hourly CH_4; 2 per mil $^{14}CO_2$; 10 ppt COS
Environmental Parameters Suite	C-130 B-200	INS[3] or DGPS[6]	9	Wind Speed and Direction	1 m/s; +/- 5 degrees (10 sec)	1 m/s; 5 degrees
	C-130 B-200	Various		Pressure	0.25 mbar (0.015 sec)	0.5 mbar
				Temperature	0.2 deg Celsius (0.15 sec)	0.5 degrees Celsius
		Chilled mirror hygrometer		Water vapor	0.1 g/kg (5 sec)	0.5 g/kg

[1]LAS = Laser Absorption Spectroscopy; [2]CRDS = Cavity Ring-Down Spectroscopy; [3]GC/MC = Gas Chromatography/Mass Spectroscopy; [3]INS = Inertial Navigation System; Note that location, altitude, air speed, and aircraft pitch, roll, and yaw, are also provided and recorded by onboard aircraft systems. [4]MFLL also provides surface reflectance variability. [5]CPL also provides aerosol distribution variability. [6]differential geographic positioning system.

Remote Sensing Instruments

MFLL: The MFLL is a suite of Continuous-Wave (CW) lidar instruments consisting of: 1) an intensity modulated multi-frequency single-beam synchronous-detection Laser Absorption Spectrometer (LAS) operating at 1571 nm for measuring the column CO_2 number density and range between the aircraft and the surface or cloud tops, and surface reflectance; and 2) a Pseudo-random Noise (PN) altimeter at 1596 nm for measuring the path length from the aircraft to the scattering surface and/or cloud tops.

The LAS instrument, developed by Exelis, Inc. (now part of Harris Corp.) in 2004 (Dobler, *et al.*, 2013, Lin, *et al.*, 2013, Dobbs *et al.*, 2007, 2008a), has been extensively evaluated in 1000+ hours of ground testing and in 14 multi-day flight campaigns conducted over a variety of meteorological conditions and surface types during both days and nights (Browell *et al.*, 2008, 2009, 2012). The LAS CO_2 column measurements have a precision of 0.08% for a 10-s horizontal average (~1.5 km on C-130) over land. The precision value is equivalent to a CO_2 mole fraction precision of about 0.30 ppm. Absolute comparisons of CO_2 remote and in situ measurements showed an absolute accuracy of 0.65 ppm of CO_2 (Dobler, *et al.*, 2013, Browell *et al.*, 2012), meeting the 1 ppm CO_2 accuracy requirement. Based on this extensive flight-testing, the LAS instrument meets the CO_2 column measurement requirements of the mission and is considered to be at TRL-8.

CPL: The CPL is an airborne lidar system designed specifically for studying clouds and aerosols (McGill et al., 2002), and has participated in nearly 30 science measurement campaigns (e.g. McGill et al., 2003, and McGill et al., 2004). It also has been used extensively for satellite validation (e.g., McGill et al., 2007 and Vaughan et al., 2010). The Cloud Physics Lidar provides a complete battery of cloud physics information, greatly surpassing the measurement requirements for ACT-America, especially for ABL height measurements. Data products include:

- Cloud profiling with 30 m vertical and 200 m horizontal resolution at 1064 nm, 532 nm, and 355 nm, providing cloud location and internal backscatter structure.
- Aerosol, boundary layer, and smoke plume profiling at all three wavelengths.
- Depolarization ratio to determine the phase (e.g., ice or water) of clouds using the 1064 nm output.
- Cloud particle size determined from a multiple field-of-view measurement using the 532 nm output (off-nadir multiple scattering detection).
- Direct determination of the optical depth of cirrus clouds (up to ~OD 3) using the 355 nm output.

The CPL uses photon-counting detectors with a high repetition rate laser to maintain a large signal dynamic range. This dramatically reduces the time required to produce reliable and complete data sets. The goal of the CPL analysis is to provide data within 24 hours of a flight including the cloud and aerosol quick-look pictures, cloud boundaries, ABL height, and depolarization information. The final data release shall be within 4 months for the mission.

Airborne* In Situ *Instruments

Picarro continuous $CO_2/CH_4/H_2O/CO$: The C-130 and B-200 both have Picarro instruments. The Picarro instruments have been extensively tested on aircraft flights (Karion *et al.*, 2013a, b; Mays *et al.*, 2009; Turnbull *et al.*, 2011). Picarro analyzers are based on Wavelength-Scanned Cavity Ring Down Spectroscopy (WS-CRDS), a time-based measurement utilizing a near-infrared laser to measure a spectral signature of molecular absorption. Gas flows through a 35-cc optical cavity with an effective path length of up to 20 km and pressure of 140 Torr. Extremely stable and high-precision measurements are achieved through cavity temperature, pressure, and laser frequency control to better than 0.002 °C, 0.00003 atm and 1 MHz, respectively. Aircraft instruments are similar to surface-based sensors, but use faster flow rates, solid-state data storage, and additional vibration isolation. These instruments exceed the precision requirements of the STM for all four gases (Table 2, Karion et al., 2013a). Accuracies of 0.2 ppm for CO_2 and 2 ppb for CH_4 (Karion et al., 2013a) also exceed mission accuracy requirements of 1 ppm for CO_2 and 4 ppb for CH_4.

2B Technologies Continuous O_3: The Model 205 O_3 monitor uses two ultraviolet beams in two cells to simultaneously measure O_3-scrubbed air and unscrubbed air. This model has been approved by the Environmental Protection Agency as a Federal Equivalent Method (FEM) and is the fastest UV-based O_3 monitor available. The O_3 monitor has been previously flown on tropospheric chemistry field missions and meets the accuracy and precision requirements laid out in the STM (Bertschi et al. 2004).

Flask Measurement System: The NOAA Earth System Research Laboratory (ESRL) carbon cycle group has developed programmable flask packages (PFP) used in their aircraft network since 2003 and the tall tower measurement network since 2006. The PFPs hold twelve 0.7-L silicate glass flasks that can be triggered manually or automatically at specific altitudes, times or locations. Measurements of CO_2, CH_4, CO and other trace gases are made on one of two nearly identical automated analytical systems; the same systems are used in the ESRL ground, tall tower, and aircraft networks (Conway *et al.*, 1994; Dlugokencky *et al.*, 1994; Novelli *et al.*, 1998). COS (and hydrocarbons and halocarbons) will be measured via Gas Chromatography/Mass Spectrometry measurements. PFP flask sample responses are calibrated against whole air working reference gases, which, in turn, are calibrated with respect to gravimetric primary standards. At selected times, duplicate flasks will be collected and analyzed for $^{14}CO_2$. Accuracy and precision for these measurements are 0.2 ppm for CO_2, 2 ppb for CH_4 (Karion *et al.*, 2013a), 2 ppb for CO (Novelli et al., 1998), 2 ppt for COS (Montzka et al., 2007), and 2 per mil for $^{14}CO_2$, matching or exceeding the STM accuracy and precision requirements.

Environmental Parameters Suite: Water vapor, pressure, and ambient temperature are measured on both aircraft. Wind direction and speed will be measured on the C-130 and B-200. Water vapor will be measured using a 3-stage chilled mirror hygrometer to make dew/frost point measurements with an accuracy of 0.2 °C. Ambient temperature will be derived using a Rosemount non-deiced model 102 total air temperature probe with a precision of 0.2 °C. Horizontal and vertical winds on board the C-130 are calculated from high precision pressure transducers and aircraft position and attitude data generated by Honeywell inertial navigation positioning systems, and from pressure transducers and a differential GPS on the B-200. Wind speed direction will be measured to within 5 degrees while horizontal winds will have a precision of ±1 m/s, both at 10 second resolution. Both measurements are made at 10-Hz intervals.

Surface Measurements

ACT-America will install two Picarro $CO_2/CH_4/H_2O$ instruments on existing communications towers and maintain three others (already deployed for other limited-duration projects), filling gaps that exist in or near our three study regions in the existing tower CO_2/CH_4 measurement network. The current plan calls for one mid-Atlantic site, two Gulf coast sites, and two sites at the western edges of the Midwest and southern study areas. Specific towers will be selected in science-critical locations based on tall tower and local Ethernet or cell phone data connection availability. Data will be collected at 100 m above ground level (AGL) or higher. Daily, automated data transfer to the Langley Atmospheric Science Data Center will allow remote monitoring of instrument status and investigation planning. The tower-based investigators continuously operated five similar tower installations in the Midwest from 2007-2009 (Richardson *et al.*, 2012b; Miles *et al.*, 2012) and are currently operating 12 such installations around the city of Indianapolis (Miles *et al.*, 2013). Additional measurements that will be used in this study include NOAA moorings along the East and Gulf coasts, the Total Carbon Column Observing Network (TCCON) sites at Park Falls, Wisconsin (WLEF) and the Department of Energy-Atmospheric Radiation Measurement (DOE-ARM) Central Facility, OK sites, and the NOAA Aircraft (biweekly vertical profiles) and Tall Tower networks. These data are all accessible to the public. ACT-America investigators have extensive background working with these networks and the responsible investigators and programs.

Table 3. ACT-America science instruments.

Instrument (Platform)	Variables Measured	Sampling Frequency	Data Latency (Archiving)	Purpose of measurement
MFLL (C-130)	Column CO_2 number density, altimetry, surface reflectance	10 Hz	1 day (≤6 months)	Core GHG CO_2 measurement & ranging capability
CPL (C-130)	ABL height, aerosol distribution	2 Hz, 30m vertical resolution	1 day (≤4 months)	Transport model constraint, OCO-2 validation
Picarro Air (C-130 & B-200)	CO_2, CH_4, CO, H_2O mole fraction	1 Hz	1 day (≤4 months)	Core GHG measurements, combustion & airmass tracer
2-B Tech. (C-130 & B-200)	O_3 mole fraction	1 Hz	1 day (≤4months)	Airmass tracer
Atm. state and nav. (C-130, B-200)	GPS Lat.-Lon, Wind speed, direction, Pressure, Temp., H_2O	1 Hz or higher	1 day (≤6 months)	Evaluate atmospheric transport models
Flasks (C-130 & B-200)	Multiple trace gases.	12 flasks / aircraft / flight	1 month (≤6 months)	Core GHG measurements, GHG source tracers.
Picarro Ground	CO_2, CH_4, H_2O mole fraction	1 Hz	1 day (≤6 months)	Core GHG measurements.

3.2 Science Platforms

Two aircraft are needed to cover domains of hundreds of kilometers at multiple altitudes within the hours (roughly 10-18 Local Standard Time) when the ABL is well mixed. Two aircraft also benefit science objective 3 by providing both column CO_2 from aircraft to surface or cloud top and in situ ABL measurements that will enhance our ability to identify sources of column CO_2 variability.

The airborne platforms selected for the ACT-America mission are the NASA Wallops C-130 and NASA Langley B-200. The C-130 is selected as the remote sensing and in situ measurement platform because of its endurance (> 8 hours), thus ability to fly within and above the ABL, and payload capacity, thus ability to host remote and in situ instruments. The B-200 is selected for in situ measurements. The NASA C-130 and B-200 aircraft will field nearly identical in situ instrument suites, as noted in Table 3. Tower-based instruments will be deployed on communications towers (Richardson et al., 2012b).

3.3 Investigation operations

Each of the five ACT-America flight campaigns consists of measurements in three regions: the Northeast with bases at NASA Wallops Flight Facility (the home of the C-130) and NASA Langley Research Center (the home of the B-200), the Midwest basing out of Sioux City, Iowa, and the South basing out of Shreveport, Louisiana. Utilizing the home airfields for one of the regions reduces travel costs, risks, and logistical efforts. Sioux City and Shreveport have all the necessary maintenance facilities required to operate successfully the C-130and B-200 while deployed, including fuel, hangar space, and runway length, and both locations were vetted and selected by the C-130 and B-200 Aircraft Managers at NASA Wallops and NASA Langley. A site survey of each location will be completed prior to the first flight campaign. While basing out of the NASA centers, both aircraft will have access to their full complements of maintenance personnel, consumables, and spares. While deployed to the other two regions, the streamlined deployment team nominally consists of the Logistics Officer, Principal Investigator (PI), Project Manager (PM), Project Scientist (PS), Instrument Scientists, and a minimum number of scientists and technicians traveling with the aircraft. Critical consumables and spares are deployed with each aircraft and other spares and equipment are shipped to each location via the C-130 cargo bay or ground transportation. The ACT-America team spends about 2 weeks in each region, performing four to five science flights in that time, allowing for flexibility in coordinating flight schedules with the weather systems moving through each region. Daily teleconferences are held with the ACT-America science team and with mission meteorologists to plan, execute, and discuss the results of each science flight. Internet connections and office space are procured at each deployment location so that preliminary field data can be processed, uploaded to servers at the Langley Atmospheric Sciences Data Center (ASDC), and provided the next day to the field flight planning team.

3.4 Flight Plans

Three notional flight plans will be used in the investigation: fair-weather, stormy-weather (synoptic), and OCO-2 intercomparison flights. Data from the **fair-weather flights** are intended to quantify regional CO_2 and CH_4 fluxes (Objective 2), and to evaluate fair weather atmospheric C transport processes (Objective 1). The flight pattern (Figure 1) is designed to provide extensive sampling of the ABL and lower FT in source/sink regions, meeting the requirements for the fair weather investigation. The C-130 aircraft will fly a U-shape pattern with flight legs perpendicular to the wind, sampling FT and ABL properties upwind and downwind of the sources and sinks of C. The C-130 will fly at roughly two times the midday ABL depth, (~3-4 km AGL) with periodic descents and ascents (5 to 10 times in a 6-8-hr flight) to sample the ABL. Although clear sky conditions will be targeted, the C-130 will conduct more low-level flight legs if low-altitude clouds interfere with the remote sensors. The B-200 aircraft will partake in two flights per day and will sample a subset of the C-130 flight path focusing on long transects in the ABL with periodic ascents to the FT. A nominal flight plan is shown in Figure 1. The time stamps denote the transit time between waypoints. The level of complexity of the fair-weather flights is low as the flight patterns are simple geometric shapes whose waypoints and exact dimensions can be moved to adapt to weather and air traffic. The two aircraft will operate over the same time period, but precise coordination is not required.

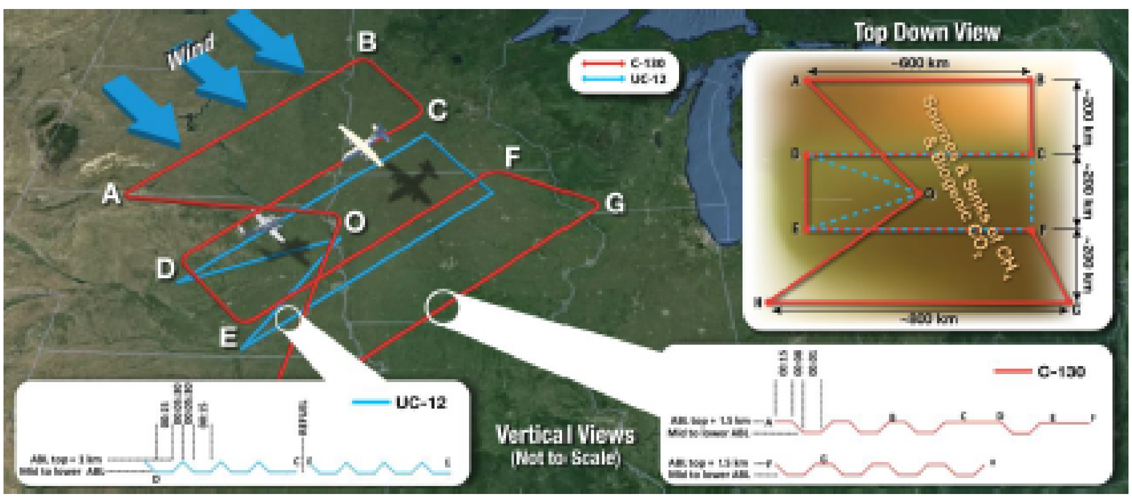

Figure 1. Fair-weather flights will provide data needed to determine regional CO_2 and CH_4 sources and sinks (Objective 2) and evaluate fair weather atmospheric transport (Objective 1). Each flight will provide extensive sampling of ABL and FT C mole fractions and meteorological conditions in the vicinity of regional C sources and sinks. Precise flight dimensions will be adapted to weather conditions and C source and sink distributions in each region. (Note, the P-3B has been replaced

with the C-130, and the UC-12 with the B-200.)

Data from **stormy-weather flights** will be used in combination with the data from fair-weather flights to evaluate the transport of C in the mid-latitudes (Objective 1). The flight plans (Figure 2) include flight legs parallel to and crossing frontal boundaries at two or more altitudes, and crossing the frontal zone at two or more locations, meeting the requirements for the stormy-weather investigation.

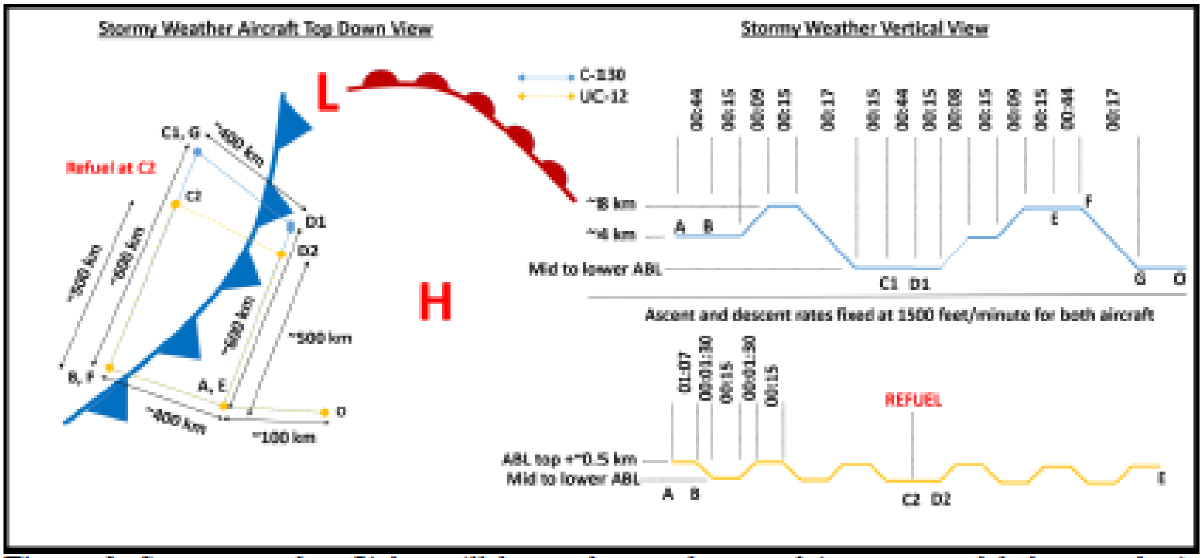

Figure 2. Stormy-weather flights will be used to evaluate and improve modeled atmospheric transport of CO_2 and CH_4 by mid-latitude cyclones. Flight plans will sample CO_2, CH_4, meteorological variables and trace gases across frontal structures responsible for transport of GHGs. Flights may cover both cold and warm fronts if allowed by storm location and structure.

The two aircraft will navigate in a structured, but not highly restrictive flight pattern around frontal structures using onboard navigation tools and, guidance on weather and aircraft hazard from air traffic control as well as from meteorologists and the project scientist/staff at the aircraft base location. The science goals do not require precise waypoints and altitudes; these can be adjusted during flight. The C-130 will focus on the upper altitudes using in situ instruments and, when cloud cover allows, remote sensors. The B-200 will sample a subset of the C-130 flight track and focus on level legs within the ABL with periodic profiling to the FT. The two aircraft will operate in the same time window, but precise coordination is not required. These flights will avoid convective cores, eliminating substantial flight risks.

The pattern for the **OCO-2 inter-comparison flights** (Figure 3) is designed to obtain data to evaluate the degree to which OCO-2 column CO_2 measurements capture true spatial variability in column CO_2 content over the continents. Two OCO-2 underflights will be conducted during each campaign and will be selected to cover varying surface reflectance, topography, and aerosol and cloud cover, all possible sources of bias in the OCO-2 measurements. The C-130 flights will be roughly 1000 km in length and flown at 8 km (28 kft) altitude to maximize the fraction of the atmospheric column sampled by the MFLL. The B-200 aircraft will sample a shorter (~360 km) leg in the ABL, often the largest source of variability in column CO_2. The B-200 flight will be centered with the C-130 and both aircraft will be vertically stacked during the OCO-2 overpass. On flights where vertical structure in CO_2 is of more interest than the horizontal variability, a vertical in situ profile will be flown in the center of the track with one or both aircraft. Suitable OCO-2 ground tracks are abundant, since the satellite tracks are approximately N-S lines spaced every 120 km (though not sampled sequentially). The resulting airborne measurement of column integrated CO_2 number density up to 8 km will be combined with ACT-America reanalyses of atmospheric CO_2 above 8 km and compared to OCO-2 column CO_2 estimates at 2.25 km resolution, satisfying the requirements for Objective 3.

Science data summary. The mission proposed yields 70 science flights per aircraft, 528 hours for the C-130 and 396 hours for the B-200, dedicated in a roughly 3:3:1 ratio across the 3 flight patterns. The amount of high-quality lower FT C data would exceed any past campaign by a factor of 2-3. A total of approximately 23 Terabytes of airborne- and ground-based data will be collected. These instruments, flight hours and plans satisfy the investigation requirements for the baseline science objectives. The threshold science objectives can be met while eliminating the one redundant summer and transient season campaigns and the OCO-2 flights. CPL, the ozone sensor, and some flask sampling can also be de-scoped without sacrificing the threshold science objectives.

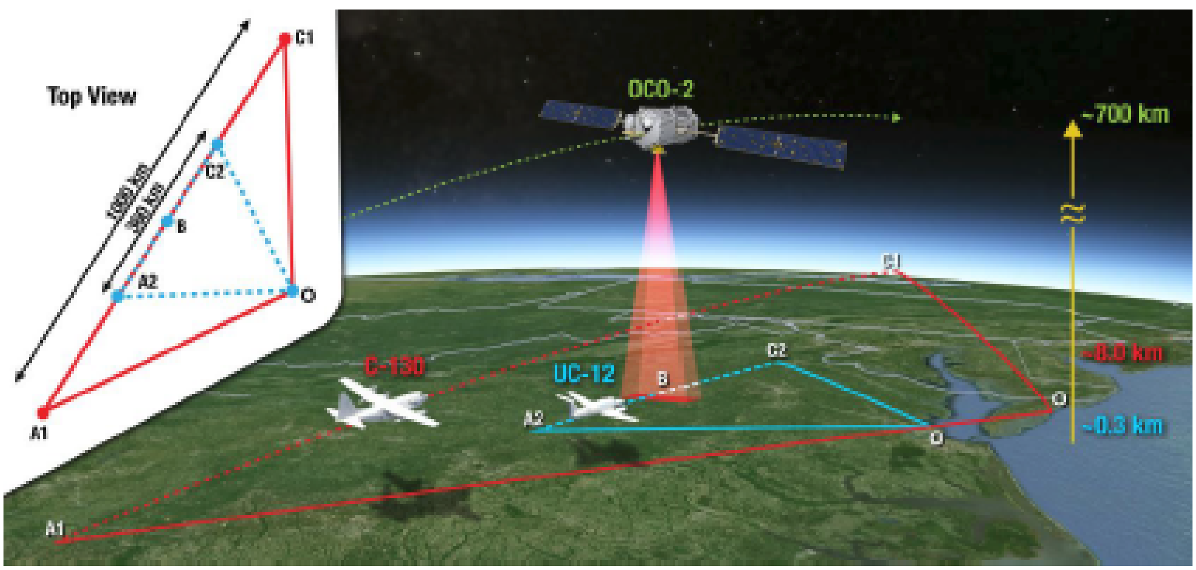

Figure 3. Underflights of OCO-2 will provide high-precision, high-spatial-resolution measurements of the majority of the atmospheric CO_2 column. These data will be used to evaluate OCO-2 measurements of high-resolution spatial structure in column CO_2 over continental surfaces.

3.5 Numerical Modeling and Model-Data Synthesis

The Penn State regional inversion and ensemble modeling system (Lauvaux *et al.*, 2012a; Diaz *et al.*, 2013; Nomile *et al.*, 2013) is the centerpiece of our analysis system. It will be used for regional inversions using aircraft data (Objective 2), to create atmospheric C ensemble predictions required for model evaluation (Objective 1), to provide CO_2 reanalyses in the upper troposphere (Objective 3) and to integrate mission progress on all three objectives into a next-generation North American inversion (overarching goal). This system utilizes the Weather Research and Forecast model (WRF, Skamarock and Klemp, 2008) for atmospheric transport, the Lagrangian Particle Dispersion Model (LPDM; Uliasz, 1994) for computing influence functions, and a Bayesian inversion framework for optimizing fluxes (Lauvaux *et al.* 2012a). This system will be run in forward (ensemble atmospheric C predictions) and inverse (solve for C sources and sinks) modes. The WRF model will be 1) implemented with a wide variety of land-surface, cloud physics, cloud convection, and planetary boundary layer schemes to create model physics ensembles (Diaz *et al.*, 2013); 2) run at multiple spatial resolutions from cloud-resolving up to the scale of global inversion systems; and 3) run with different meteorological initial and boundary conditions to create transport ensembles. Data assimilation algorithms (Rogers *et al.*, 2013) will use operational (Objectives 1, 2 and 3) and ACT-America airborne meteorological data (Objectives 2, 3) to improve transport fidelity.

The Penn State regional system requires surface C fluxes and atmospheric C boundary and initial conditions, both of which will also be varied in ensemble fashion. The Penn State system has already been coupled to output from two of the three global inversion systems participating in this project and all of the surface flux algorithms. The flux model ensembles, C boundary condition ensembles (from global inversions) and transport ensemble will be combined to create atmospheric C mole fraction ensembles, which include the ability to track C sources (e.g., fossil vs. biogenic CO_2).

Biogeochemical and emissions inventory models. The Carnegie-Ames-Stanford Approach-Global Fire Emissions Database (CASA-GFED) is our source for biogenic CO_2 flux ensembles. CASA-GFED includes physiological processes involved with uptake of CO_2 by photosynthesis and the release of CO_2 through respiration and fires (Randerson *et al.*, 1996; van der Werf *et al.*, 2006; 2010). An ensemble will be constructed by varying model parameters. Vulcan (Gurney *et al.*, 2009), the satellite-derived Open-source Data Inventory for Anthropogenic CO_2 (ODIAC) product (Oda *et al.*, 2011) and the Carbon Dioxide Information Analysis Center (CDIAC) inventory will provide CO_2 fossil fuel emissions estimates. Emission Database for Global Atmospheric Research (EDGAR) will provide CO_2 and CH_4 emissions estimates.

Global carbon inversion systems. This project utilizes four global inversion systems, each of which includes its own flux and atmospheric transport models and performs an inversion using atmospheric C mole fraction observations to optimize fluxes. These systems provide a comparison to our regional transport modeling (Objective 1), provide boundary conditions for our regional analyses (Objectives 1 and 2), and provide upper atmospheric column CO_2 estimates needed to complete our OCO-2 evaluation (Objective 3). These four systems are 1) Carbon Tracker CO_2 (Peters, *et al.*, 2007), 2) Carbon Tracker CH_4 (Bruhwiler *et al.*, submitted), 3) the NASA Carbon Monitoring System (CMS) flux pilot product (Liu *et al.* 2013), and 4) the Colorado State/ Parameterized Chemistry Transport Model (PCTM) 4DVar system (Baker *et al.*, 2006b 2010). These systems span the state of the science, use both remote and in situ C observations, and include the primary quasi-operational systems in the U.S.

The project will also test an alternative inversion approach, the regional Geostatistical Inverse Model (GIM) system (e.g., Miller *et al.*, 2013) and alternative meteorological simulations via the U. Oklahoma "Spring Project" and the Colorado State University "super-parameterization" Community Earth System Model.

4.0 Management Approach

Because there is no new instrument development that needs to be accomplished for this mission, management resources are dedicated to the logistics, integration, operations, and science activities required to meet mission objectives. ACT-America is implemented by a multi-center, multi-disciplinary integrated teaming arrangement and is led by Dr. Kenneth Davis (PI) and supported by Dr. Michael Obland (PM), Dr. Thomas Lauvaux (Deputy PI), Dr. Chris O'Dell (Deputy PI), and Dr. Bing Lin (PS) along with highly experienced members from each supporting organization. Detailed descriptions of roles and duties are discussed below.

Principal Investigator (Dr. Kenneth Davis) – The Principal Investigator (PI) has final authority for all investigation decisions, and is ultimately responsible for the ACT-America project scientific deliverables and investigation success. Dr. Davis is aided by two Deputy PIs for flux inversions (Dr. Thomas Lauvaux) and satellite measurements (Dr. Chris O'Dell). In consultation with the management team as well as the larger science team, Dr. Davis is the final authority for leading the science investigation, managing the Science Team, and delivering the science data, and for scope changes and key decisions. Dr. Davis will be materially involved in both the deployment execution and post-deployment analysis of observations.

Project Manager (Dr. Michael Obland) – The PI delegates authority to the PM for the successful planning and implementation of all ACT-America activities, including monitoring of project resources, schedule, and performance risks. The PM and PI work closely to meet all technical characteristics and performance objectives to ensure the overall project is completed on schedule and within the allotted budget by coordinating across all project WBS levels. The PM is responsible for tracking budget, schedule, and overall project progress, and reports these metrics to the PI and PS during frequent teleconferences and meetings. The PM is the primary contact with each Co-investigator and collaborating NASA center or institution concerning disposition and distribution of funds. The PM role includes oversight and monitoring for scheduling and preparation for programmatic reviews and aircraft safety reviews. The PM is responsible for compliance with all safety, reliability and quality process requirements and all applicable NASA standards. Responsibilities also include managing cost/schedule reserves allocated to the discretion of the PM, not to exceed the delegated scope. Cost and schedule reserves have been established based on the level of risk associated with each element of the project. The PM will monitor the status of each project element and in concert with the PI allocate cost and schedule reserves as required to address specific issues.

Project Scientist (Dr. Bing Lin) – The Project Scientist reports directly to the PI and is responsible for implementing the tasks required to achieve the science objectives. The PS is responsible for assisting the PI in refining the mission design and coordination of the Science Team activities. The PS is primarily responsible for designing and implementing flight plans and ensuring that instruments and flights meet measurement and science requirements. The PS assesses the progress towards achieving the ACT-America science goals and works with the deputy PIs and PI to coordinate collaboration among instrument, analysis, and modeling teams on post-deployment data assessments. The PS is the science liaison to the PM and provides day-today consultation on management decisions. The PS also serves as the Airborne Deployment Lead.

Aircraft Manager (Mr. Byron Meadows) – The Aircraft Manager is the primary interface for both the Langley and Wallops aircraft personnel, and is responsible for tracking progress on aircraft modifications and tasks required for aircraft deployments. The Aircraft Manager is also the primary interface between the aircraft engineers and the instrument teams, and is responsible for communicating instrument requirements to the aircraft personnel. The Aircraft Manager facilitates coordination between instrument Co-Is and Aircraft Points of Contact at WFF and Langley and tracks progress on integration and deployment. Due to the aircraft modifications needed for the switch to the C-130 from the P-3B aircraft, weekly teleconferences are conducted with WFF personnel, the ACT-America instrument Co-Is, and the aircraft modifications prime contractor to ensure steady progress and prompt addressing of any issues that arise.

Instrument Scientist (Dr. Amin Nehrir) – The Instrument Scientist works in conjunction with the Aircraft Manager to ensure that instrument requirements are appropriately tracked, communicated, and met by the aircraft platforms. The Instrument Scientist also aids in data interpretation and flight planning.

Science Data Managers (SDMs: Dr. Gao Chen and Dr. Robert Cook) – Data management is the responsibility of data managers at Langley (Dr. Gao Chen, for airborne and tower measurement data) and ORNL (Dr. Bob Cook, model output, model documentation, and model-data syntheses). The SDMs share responsibility for developing the Data Management Plan, setting up and managing the ACT-America science data archives (as discussed in Section 8), and developing the ACT-America web sites that serve as the archive interface for project information to the team and the public. Both data websites will prominently note the presence of the other data website and of the project outreach website (http://act-america.larc.nasa.gov). Dr. Cook is also responsible for managing the ORNL DAAC where ACT-America data will be archived, while Dr. Chen will be responsible for management of observational data and transfer to the ORNL DAAC. The SDMs are also responsible for ensuring Science Team compliance in meeting data delivery schedules and data format requirements. See Section 8.0 for additional data management details.

Aircraft Points of Contact and Deployment Logistics (Mr. John Valliant and Mr. Mike Wusk) – Each aircraft has a primary contact (John Valliant for C-130 and Mike Wusk for B-200). These engineers are responsible for logistics planning for the aircraft, aircraft hangars and facilities, shipments of equipment, and travel logistics for the field team. The Aircraft POCs and the Aircraft Manager conduct site surveys in advance of the deployments to arrange support for facilities (e.g., office, lab, supplies, security, bonded storage, IT resources and hangar space), communications (e.g., phone and network support), logistics (e.g. shipping of equipment; critical supplies to include cryogens and compressed gases), and negotiated support from local providers. The Aircraft POCs also ensure that required aircraft modifications, instrument integration, and flight plans meet safety requirements, including conducting the required Airworthiness Safety Review Board (ASRB) and engineering/configuration reviews prior to each deployment (see Section 10).

Each airborne and ground instrument has a primary contact who is responsible for instrument readiness, integration, deployment, and data archive. Each science team member is responsible for the particular analysis tasks of his research group, and reports directly to the PI.

Any problems/issues that arise concerning schedule, budget, safety, science goals, or risk are reported to the PI, PM, PS, Aircraft Manager, and Instrument Scientist. The issues are investigated with the appropriate individuals and a mitigation plan decided upon. Ultimate responsibility in resolving issues belongs to the PI.

The management structure is shown in Figure 4. The PI and Project Manager report to NASA HQ and NASA Langley officials during a number of reviews and reports (see Section 10 for review schedule and description). Several working groups are set up within the investigation, including an executive working group consisting of the PI, PM, PS, Deputy PIs, Aircraft Manager, Instrument Scientist, and ex-officio advisors Dr. Edward Browell and Dr. James Crawford. The executive working group meets weekly at a minimum.

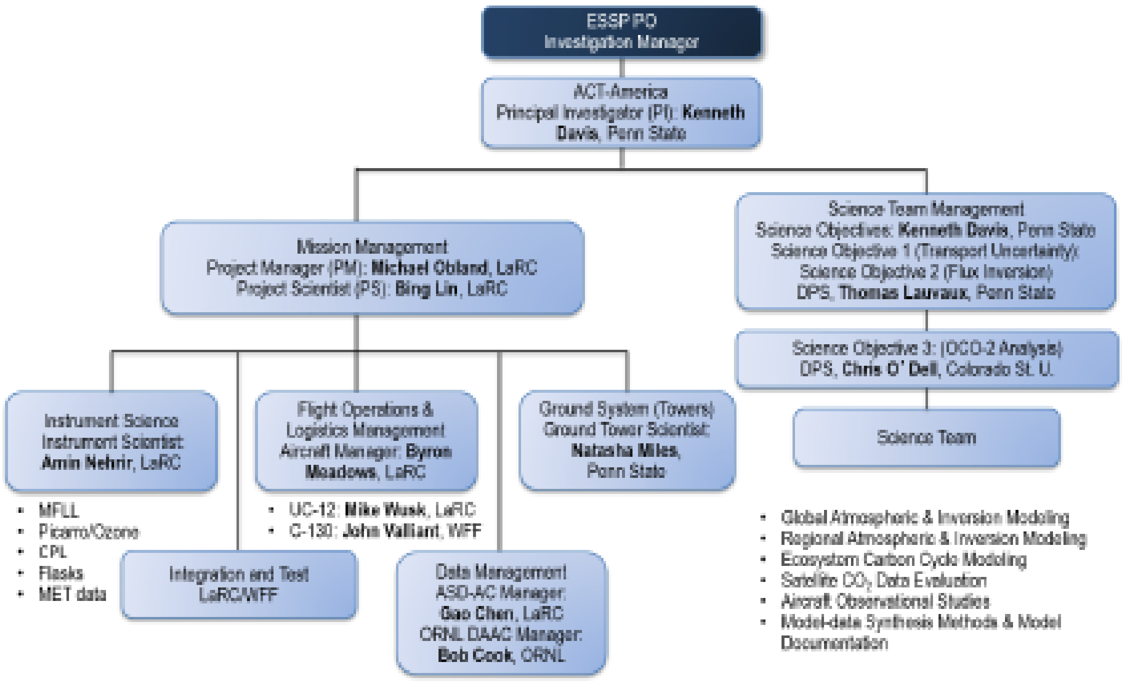

Figure 4. The management structure of ACT-America

Program Tools and Support: Budget tracking is provided through the financial office of the Science Directorate at NASA Langley (Marie Avery), which furnishes monthly spreadsheets providing detailed information on obligation, commitment, and costing of funds. The PM is responsible for reconciling this information with the required rates of expenditure and identifying situations where funding may be reallocated or if reserve funds are necessary to fulfill mission requirements.

Management tools used in support of planning and controlling the investigation include Microsoft Excel (budgeting, schedule) and NASA Business Objectives (spending, labor, travel). Budget is tracked through monthly summaries of commitments, obligations, and costing. Large deviations from the plan are investigated further (to NASA center and if necessary by individual investigator WBS). At LaRC, approximately bi-weekly summaries are provided by the Science Directorate Resource Management Team summarizing commitments, obligations, and costing by WBS for procurement, labor, and travel allotments. In addition, monthly labor and civil servant travel summaries are provided to ensure accurate and appropriate labor and travel charging.

The ACT-America master schedule is tracked using Microsoft Excel and updated monthly at a minimum. The overall mission calendar, including teleconferences, meetings, reviews, and integration/deintegration/deployment dates, is tracked and made available to the Co-investigators using Google Calendar. Schedules for higher-risk mission elements are tracked with higher frequency (e.g. C-130 aircraft modifications). The aircraft schedule for instrument integration takes into account engineering and safety reviews, check flights, etc. prescribed by Wallops Flight Facility and Langley Research Center to ready the aircraft for scheduled science flights. Periodic updates are provided as the aircraft reviews progress and also through informal conversations as necessary. Instrument co-investigators are expected to provide the necessary information to the integration engineers to facilitate integration and safety reviews. All aircraft instrument coinvestigators have successfully participated in airborne campaigns such that additional reporting requirements are deemed unnecessary at this point. Other schedules are tracked through conversations with responsible parties. For example, a schedule has been defined in the statement of work for the C-130 modification, with deliverable dates and weekly telecons held to track progress. No further action is necessary until there is a deviation from the agreed upon schedule.

The ACT-America project is staffed as described above (management and grantees) and in Section 12: Relationship to Other Projects and Organizations. Any changes involving a management team member or co-investigator require notification to and approval by the project Principal Investigator.

The Principal Investigator, Project Manager, and Project Scientist coordinate the development of the principal documents of the investigation. The PI, PM, and PS work together to develop and approve (and thus concur on) all major investigation documents.

Property acquired during the ACT-America investigation will be used or disposed of according to Government regulations at the end of the investigation. Final data archival is described in the Data and Knowledge Management and Distribution Plan (Section 8.0).

5.0 Resource Requirements

The ACT-America overall budget is shown in Tables 4A through 4E by WBS element, NASA Center, Science Team member, instrument group, and aircraft. Funds are distributed according to the mechanisms given in Tables 13 and 14 in Section 12. Descriptions of each WBS element are found in Section 7.0. Funding by WBS is included in Section 5.1.

5.1 Funding Requirements

WBS 1, Project Management, includes all project management activities, including labor and deployment travel.

WBS 4, Science Team, carries science team funds. Each co-investigator has funds allocated for multiple publications, as well as travel to scientific conferences and ACT-America science team meetings for dissemination and discussion of research results.

WBS 5, Instruments, include funds necessary to cover travel and labor for integration, flight campaigns, deintegration, and required data analysis and archival activities, and are distributed directly to each team. Instrument and equipment shipping costs are included in instrument team budgets where appropriate, but most equipment needed during campaigns will be carried by the C-130 since the aircraft has a large amount of cargo capacity well above the requirements of the ACT-America science requirements.

WBS 7, Investigation Operations, includes aircraft-related costs. The C-130 aircraft is dedicated to the investigation throughout the duration of the mission. The B-200 or UC-12 is scheduled via flight requests with the Langley hangar. Funding for these aircraft, including labor, deployment travel costs, and modification costs as necessary are sent directly to their respective flight organizations (Wallops for the C-130 and Langley for the B-200/UC-12). Campaign facilities and the labor required to organize campaign logistics are also carried under WBS 7: Investigation Operations. Since all five ACT-America campaigns visit the same two deployment locations every campaign, only one site visit trip is expected prior to the first campaign. Logistics for deployed researchers, aircraft, and equipment are the responsibility of operations engineers from Langley and Wallops who are experienced with prior flight campaign deployments.

WBS 9, Ground Systems, includes funding for data archival activities. Note that funding for the ground tower instruments is carried under *WBS 4, Science Team*.

No instrument development is planned for this investigation. Instruments will be integrated onto the aircraft according to the schedule in Section 6.0.

Table 4A. Total investigation budget by WBS element.

WBS	WBS Description	FY15	FY16	FY17	FY18	FY19	FY20	Grand Total
1	Project Management	$100.2	$285.5	$293.1	$225.8	$131.5	$50.9	**$1,087.00**
4	Science	$2,277.2	$2,271.2	$2,373.6	$2,378.1	$2,299.0	$114.1	**$11,713.2**
5	Instruments	$1,714.6	$1,451.3	$1,504.6	$1,133.0	$165.9	$14.1	**$5,983.5**
7	Investigation Operations	$479.2	$2,628.4	$2,826.9	$1,497.1	$30.4	$0	**$7,462.0**
9	Ground Systems	$146.6	$256.0	$340.0	$346.0	$360.0	$0	**$1,448.6**
	Reserves	$207.4	$734.4	$748.8	$462.5	$134.4	$10.4	**$2,297.9**
	PI Managed Mission Cost to NASA ($K)	**$4,925.2**	**$7,626.8**	**$8,087.0**	**$6,042.5**	**$3,121.2**	**$189.5**	**$29,992.2**

Table 4B. Investigation budget by NASA Center. Note that reserves are not included here and funding for the JPL task is included in the Langley budget.

Budget ($K)	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Grand Total
TOTAL	**4,717.82**	**7,192.41**	**7,638.29**	**5,904.98**	**2,986.74**	**179.12**	**27,694.35**
Procurement	4,257.82	5,947.80	6,429.27	4,865.66	2,612.34	70.02	24,182.92
Travel	9.80	283.20	255.78	185.88	21.98	13.80	770.44
Labor	450.21	961.42	953.23	853.43	352.42	95.29	3,665.99
LANGLEY	**4,355.45**	**5,265.52**	**5,484.74**	**4,645.37**	**2,831.70**	**172.21**	**22,754.99**
Procurement	3,967.00	4,222.63	4,508.85	3,755.61	2,518.58	70.02	19,042.70
Travel	9.80	269.51	241.70	178.64	21.98	13.80	735.43
Labor	378.65	773.38	734.19	711.13	291.14	88.38	2,976.87
GODDARD	**362.38**	**1,626.89**	**1,853.55**	**934.60**	**155.04**	**6.91**	**4,939.36**
Procurement	290.82	1,425.17	1,620.42	785.05	93.76	0.00	4,215.22
Travel	0.00	13.69	14.09	7.24	0.00	0.00	35.01
Labor	71.56	188.03	219.04	142.31	61.27	6.91	689.13

Table 4C. Investigation budget by science team group. Co-investigators are shown in parenthesis.

Budget ($K)	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Grand Total
SCIENCE TOTAL	**2,277.16**	**2,271.20**	**2,373.58**	**2,378.07**	**2,299.00**	**114.11**	**11,713.12**
Science Team	59.37	89.06	91.20	93.39	95.63	32.64	461.282

Management (Lin)							
PSU (Davis, Lauvaux, Keller, Zhang)	965.79	1,032.18	1,116.92	1,104.45	1,069.52	0.00	5288.853
CSU (Baker, Schuh, Trudeau)	117.58	109.98	101.81	112.29	102.72	0.00	544.385
CSU (Denning)	86.01	88.79	92.05	94.64	99.64	0.00	461.1381
CSU (O'Dell)	82.29	88.44	84.78	90.58	89.95	0.00	436.029
NOAA ESRL/CU (Sweeney, Petron, Miller)	579.21	340.82	346.28	272.77	196.81	0.00	1735.88
Carnegie (Michalak)	5.78	82.09	85.28	128.24	132.00	0.00	433.379
Carnegie (Berry)	73.01	75.10	5.78	2.55	2.63	0.00	159.053
U of Oklahoma (Moore, Xue, Hu)	0.00	0.00	32.38	66.71	68.71	0.00	167.808
Langley (Browell, Science analyst CON)	219.59	263.67	271.63	272.61	273.62	74.56	1,375.67
GSFC (Collatz, Pawson, Ott)	30.39	37.29	38.66	40.14	41.72	6.91	195.11
JPL (Bowman)	41.14	48.80	53.91	48.43	57.53	0.00	249.81

Table 4D. Investigation budget by instrument team. Co-investigators and collaborators are listed in parenthesis.

Budget ($K)	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Grand Total
MFLL Instrument (Dobler)	1027.39	824.387	967.368	594.79	0	0	3413.935
Picarro/O3 instruments (Yang)	576.1083	301.7021	259.4306	245.8308	0	0	1383.072
CPL (McGill)	40.861	255.906	206.89	218.565	113.316	0	835.538
Met and Nav (Barrick, NSERC)	46.77333	32.1536	32.92529	33.71549	11.50822	0	157.0759
Ground Towers (Miles,	17.00	7.00	15.00	15.00	17.50	0.00	71.50

Richardson)							

Table 4E. Investigation budget by aircraft platform.

Budget ($K)	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Grand Total
UC-12 Operations (Langley)	0	933.902	841.002	445.66	0	0	2220.564
C-130 Operations (Wallops)	291.12	1633.688	1907.999	1000.901	0	0	4833.708

5.2 Instrument Development/Integration

There is no instrument development for the ACT-America project. Instrument integration costs are included in WBS 7.1 for instruments on the C-130 and WBS 7 for instruments aboard the two aircraft.

5.3 Publication of Science Results

Funding for publication of science results are included in the individual co-investigators' budgets.

5.4 Logistics/Shipping

Project logistics/payload manager costs are carried under WBS 1.0 (Project Management). Limited logistical support (some shipping, deployment related purchases/consumables) will be provided under a task with a support service contractor (managed at LaRC). Instrument co-investigators are responsible for shipping their instrument(s)/supplies to the integration location (costs included in individual WBS). Most equipment needed during campaigns will be carried by the C-130 since the aircraft has a large amount of cargo capacity well above the requirements of the ACT-America science requirements.

5.5 Travel

Travel for integration, deployment and science team meetings is carried under WBS 7.3 (Project Travel). Travel will be administered through WBS 7.3 directly for civil servant travelers and through the Science Directorate support contract for other travelers. Any other travel (reviews and site surveys for project management and conferences for science team) has been budgeted by management or each co-investigator and is included in their respective WBS elements.

5.6 International Agreements

No flights into foreign airspace are planned for ACT-America and therefore there are no international agreements required for the execution of the ACT-America investigation.

6.0 Schedule/Milestone

The ACT-America schedule includes significant flexibility in the order and timing of its airborne measurement campaigns. Test flights of the fully-instrumented C-130 aircraft and a simulation of the go/no-go decision making and flight planning will occur prior to the first campaign to reduce risks associated with the flight campaigns. Lessons-learned meetings will occur after these risk-reduction events and after the completion of the flight campaigns. As all instruments have aircraft flight heritage, the integration and deintegration times are sufficient for these efforts based on prior airborne campaigns. Major milestones leading to the first investigation campaign are listed in Table 5. The baseline campaign schedule is shown in Table 6.

Table 5. ACT-America Schedule Milestones

Date	Milestone
February 1, 2015	Project Start Date
February 3, 2015	Project Kickoff Meeting
June 26, 2015	C-130 modification begins
July-September, 2015	Complete aircraft mods at contractor facility
August 12-13, 2015	Science Team Meeting / HQ Science Review
August 14, 2015	ESSPPO Confirmation Assessment Review
September 30, 2015	SMD Confirmation Review
October, 2015	C-130 returns to Wallops (nadir portals and research power complete)
October, 2015	Complete instrument mounts and science instrument fit checks
November 30, 2015 – March 6, 2016	Schedule margin
Spring 2016	Simulation – 1-week campaign go/no-go decision making and flight planning.
Spring 2016	Lessons-learned meeting with entire team to discuss simulation of campaign go/no-go decision making and flight planning
March 7 – April 15, 2016	Science instrument upload (C-130 only)
April 18, 2016	Final Installation and Inspection Review (FIIR)
April 19, 2016	Flight Readiness Review (FRR)
May 2, 2016	Airworthiness Test Flight (ATF) (approx. 3 flight hours)
May 2 – 13, 2016	Project Test Flights (added to mitigate risks of change to modified C-130 aircraft)
May 16, 2016	Lessons-learned meeting with entire team to discuss test flights
May 17 – June 17, 2016	Resolution of issues specific to C-130
Deployment 1 (FY16)	
June 20 – 30, 2016	Science instrument upload (B-200)
July 6, 2016	Final Installation and Inspection Review (FIIR) (contingency)
July 7, 2016	Airworthiness Test Flight (approx. 3 flight hours, contingency) (ATF)
July 8, 2016	Flight Readiness Review (FRR) (contingency)
July 11, 2016	Mission Readiness Review (MRR)
July 12-15, 2016	Project Test Flights (approx. 8 flight hours)
July 18 – August 28, 2016	ACT-America Campaign #1 (Summer)
August 29 – September 2, 2016	Science instrument download and ship
Fall 2016	Lessons-learned meeting with entire team to discuss first campaign
Fall 2016	Science Team Meeting / HQ Science Review
Deployment 2 (FY17)	
January 4-13, 2017	Science instrument upload (C-130 &B-200)
January 17, 2017	Final Installation and Inspection Review (FIIR)

January 19, 2017	Flight Readiness Review (FRR)
January 20, 2017	Airworthiness Test Flight (ATF) (approx. 3 flight hours)
January 23-25, 2017	Project Test Flights (approx. 8 flight hours)
January 26, 2017	Mission Readiness Review (MRR)
January 30 – March 12, 2017	ACT-America Campaign #2 (Winter)
March 13 – 17, 2017	Science instrument download and ship
Spring 2017	Lessons-learned meeting with entire team to discuss second campaign
Deployment 3 (FY17)	
June 19-29, 2017	Science instrument upload
July 5, 2017	Final Installation and Inspection Review (FIIR)
July 6, 2017	Flight Readiness Review (FRR)
July 7, 2017	Airworthiness Test Flight (ATF) (approx. 3 flight hours)
July 10- 13, 2017	Project Test Flights (approx. 8 flight hours)
July 14, 3017	Mission Readiness Review (MRR)
July 17 – August 27, 2017	ACT-America Campaign #3 (Summer)
August 28- 30, 2017	No download, button up in prep for next campaign
Fall 2017	Lessons-learned meeting with entire team to discuss third campaign
Fall 2017	Science Team Meeting / HQ Science Review
Deployment 4 (FY17-18)	
September 12-15, 2017	Instrument check out
September 18, 2017	Final Installation and Inspection Review (FIIR)
September 19, 2017	Flight Readiness Review (FRR)
September 21, 2017	Airworthiness Test Flight (approx. 3 flight hours) (ATF)
September 25-28, 2017	Project Test Flights (approx. 8 flight hours)
September 29, 2017	Mission Readiness Review (MRR)
October 2 – November 12, 2017	ACT-America Campaign #4 (Fall)
November 13-16, 2017	Science instrument download and ship
Deployment 5 (FY18)	
March 5 -14, 2018	Science instrument upload
March 15, 2018	Final Installation and Inspection Review (FIIR)
March 16, 2018	Flight Readiness Review (FRR)
March 20, 2018	Airworthiness Test Flight (ATF) (approx. 3 flight hours)
March 21-23, 2018	Project Test Flights (approx. 8 flight hours)
March 29, 2018	Mission Readiness Review (MRR)
April 2 – May 13, 2018	ACT-America Campaign #5 (Spring)
May 14 -18, 2018	Science instrument download and ship
Summer 2018	Lessons-learned meeting with entire team to discuss fourth campaign
Summer 2018	Science Team Meeting / HQ Science Review
Winter 2019	Lessons-learned meeting with entire team to discuss fifth campaign
Summer 2019	Science Team Meeting / HQ Science Review
November 1, 2018 – January 31, 2020	Analysis and Project Closeout
Winter/Spring 2020	HQ/ESSPPO Closeout Review

Table 6. ACT-America baseline campaign schedule and an example backup campaign schedule option.

Season	F 15	W 16	Sp 16	Su 16	F 16	W 17	Sp 17	Su 17	F 17	W 18	Sp 18	Su 18	F 18
Baseline Schedule				X		X		X	X		X		
Example Backup Schedule				X		X			X		X	X	

7.0 Work Breakdown Structure

Each of the investigation WBS elements are shown in Table 7. The WBS does not follow standard NASA WBS designations, and was instead custom designed by the Project Manager to track the ACT-America expenses most efficiently. For example, each instrument team has their own individual WBS. The expenses for the two aircraft are likewise separated into individual WBS elements. The WBS dictionary is as follows:

Langley WBS 388982.05.01.01.XX:

WBS 1.0, Project Management, includes labor and travel for the project manager.

WBS 2.0, C-130 Modifications Labor Tracking, is used to track the estimated additional labor to the investigation due to the use of the C-130 aircraft in place of the P-3B. Systems engineering tasks that would normally be carried under WBS 2.0 are distributed throughout the program and are minimal since there is not instrument development work in ACT-America.

WBS 3.0 is reserved for future use (not currently funded). The management and directing of safety and mission assurance, particularly all Airworthiness and Flight Safety Reviews along with the associated hazard and risk packages for each of the deployments, are included in WBS 1 and WBS 7.

WBS 4.0, Science Team, contains labor and travel for the project scientist and grant funding for the science team co-investigators who are primarily involved with modeling work.

WBS 5.0, Instruments, provides funding (labor, travel, and procurement) for the co-investigators who are providing instruments, as well as labor for the instrument scientist.

WBS 6.0 is reserved for future use (not currently funded).

WBS 7.0, Investigation Operations, includes labor funding for the aircraft manager, operational costs for deploying the Langley B-200/UC-12 aircraft, funds for ground tower operational costs, funds for non-civil servant travel expenses to meetings and field campaigns, and science team publication costs.

WBS 8.0 is reserved for future use (not currently funded).

WBS 9.0, Ground Systems, includes funds for the data archival efforts at NASA Langley and at Oak Ridge National Laboratories. Note that funding for the ground tower instruments is carried under *WBS 4, Science Team*.

WBS 10.0 is reserved for future use (not currently funded). All integration & test costs are contained within the instrument investigator's budgets in WBS 5. Integration and test costs for Wallops and Langley aircraft efforts are captured in WBS 7.

Goddard WBS 388982.05.01.02.XX:

WBS 1.0, GSFC Modeling, includes funding (labor, travel, and procurement) to support the Goddard science team co-investigator and his team.

WBS 2.0, C-130 Operations, includes operational costs for deploying the Wallops C-130 aircraft, as well as funds to support the C-130 modifications.

WBS 3.0, CPL, includes funding (labor, travel, and procurement) to support the Goddard co-investigator who is providing the Cloud Physics Lidar instrument.

JPL WBS 388982.05.01.03.XX:

There is a single WBS element to fund the research efforts of the science team co-investigator from JPL.

Table 7. Work Breakdown Structure

WBS Element	WBS Name (Co-investigator)
388982.05.01.01	Langley Research Center
388982.05.01.01.01	Project Management (Obland)
388982.05.01.01.02	C-130 Modifications Labor Tracking
388982.05.01.01.03	(Reserved)
388982.05.01.01.04	Science Team
388982.05.01.01.04.01	Science Team Management (Lin)
388982.05.01.01.04.02	Science Team (Davis, Baker, Denning, O'Dell, Sweeney, Michalak, Berry, Moore, Lin)
388982.05.01.01.05	Instruments
388982.05.01.01.05.01	Payload Management (Nehrir)
388982.05.01.01.05.02	MFLL (Dobler)
388982.05.01.01.05.03	Picarro/Ozone (Yang)
388982.05.01.01.06	(Reserved)
388982.05.01.01.07	Investigation Operations
388982.05.01.01.07.01	Investigation Ops Management (Meadows)
388982.05.01.01.07.02	B-200/UC-12 Operations (Wusk)
388982.05.01.01.07.03	Project Travel, Publications, and PRs
388982.05.01.01.08	(Reserved)
388982.05.01.01.09	Ground Systems
388982.05.01.01.09.01	Langley Data Archive (Chen)
388982.05.01.01.10	(Reserved)
388982.05.01.02	Goddard Space Flight Center
388982.05.01.02.01	GSFC Modeling (Collatz)
388982.05.01.02.02	C-130 Operations (Valliant)

388982.05.01.02.03	CPL (McGill)
388982.05.01.03	Jet Propulsion Laboratory (Bowman)

8.0 Data and Knowledge Management and Distribution

Introduction:

ACT-America will produce two broad categories of data: Aircraft and ground-based *observations* of atmospheric properties, and *numerical model output* including atmospheric properties and surface fluxes of CO_2 and CH_4. The *observational* data includes in situ tower GHG measurements, airborne continuous trace gas measurements, flask samples, backscatter lidar observations (CPL), and CO_2 lidar observations (MFLL). *Numerical model output* includes simulations of meteorological variables and atmospheric C mole fractions matching the time and space domains of the research flights, simulations of C fluxes at the earth's surface, and estimates of C fluxes at the earth's surface derived from atmospheric C observations. While the numerical model output is critical to ACT-America analyses, the observations collected by the ACT-America investigation are the focus of the data management plan. We first present the observational data management plan, focusing on the transition of observational data from field data collection to archival at the ORNL DAAC. Second, we include a supplementary section describing our plan for integration of observations and numerical models needed to achieve our level 1 science requirements.

Overall data management (observation and modeling) will be governed by a working group, led by Deputy PI Lauvaux, and reporting to the PI. The working group includes representatives from science team representatives from observational and numerical data producers, and from project data management experts. Data management experts will include Gao Chen, lead for the NASA Langley Research Center Airborne Science Data for Atmospheric Composition (ASD-AC) group, and Robert Cook, lead for Oak Ridge National Lab's Distributed Active Archive Center (ORNL DAAC). Chen and ASD-AC will direct the *observational* data management. Cook plays two roles. As a funded science team member, he will direct ORNL's work to support ACT-America's *numerical* data management and model-data syntheses. The ORNL DAAC has also been selected as the project data archive, thus Cook will also work with ACT-America to facilitate the long-term archiving and distribution of project data.

Data management will refer to both stages of data preparation, and data processing levels. Data preparation stages include "preliminary," and "final" data. Preliminary data are typically produced within a day of a research flight, and are used for field and flight planning. Data processing may be approximate in order to enable rapid assessment for field work. Preliminary data are not suitable for public release. Final data have been fully-quality checked, and data processing methods and algorithms have been finalized. These data are suitable for public release and long-term archival.

Data processing levels will conform to NASA EOSDIS standards (http://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products/) with the exception that most project observations are time-series data, not spatially gridded observations. Aircraft and tower observations that have been processed to geophysical variables and are at full resolution will be designated level 2. Level 3 data will be further processed and segmented to enable comparison or syntheses with other data sources (e.g. aircraft leg-averaged observations, matching leg-averaged model output; gridded model output; temporally-averaged tower measurements); and level 4, value-added products derived from original project observations (e.g. inverse C flux estimates derived from atmospheric C measurements). Most data sources will not include all 5 data levels.

Our data archiving strategy will follow past earth and atmospheric sciences campaigns in that *observational* data will be fully archived, including all levels and algorithms and associated metadata. This process will be facilitated and led by Co-I Chen and ASD-AC, which has successfully managed many past airborne atmospheric field campaigns. *Numerical model output* will be archived primarily by *publications* of model-data syntheses and analyses that accomplish the project research objectives, and the archival of model output that is required to document those published results. This process will be facilitated by Co-I Cook and ORNL.

Observational data management.

8.1 Science Data Flow

The schematic in Figure 5 includes the end-to-end data flow for the observational level one science data products from initial acquisition of airborne and ground-based measurements to archival at ORNL DAAC and distribution to the public. Table 8 lists instrument groups and data delivery schedules. The instrument Co-Is will be primarily responsible for operating their instruments, processing data, and submitting data to the ASD-AC group according to project schedules and requirements. Instrument Co-Is are responsible for assuring that both preliminary and final data conforms to the data file format requirements, including the metadata requirements. The distribution and use of preliminary data will be limited to the ACT-America science team and collaborators. Final data will be made available to the science team, collaborators, and the public with caveats concerning the potential for re-processing of the data, but enabling broad science community access to project data. The final data will be available to the public and transferred to ORNL DAAC starting in the fourth project year.

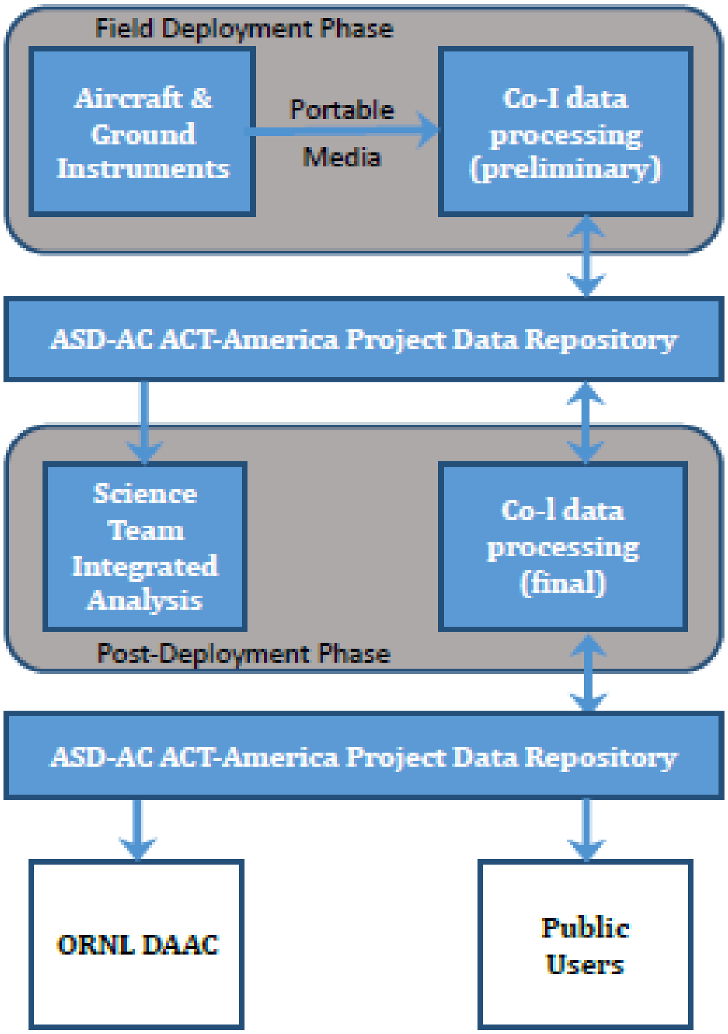

Figure 5. ACT-America observational data flow diagram. Preliminary data will be used for short-term flight planning and field instrument performance analyses, and will typically be available within 24 hours of a research flight. Final data will be available within 6 months of field operations. These data are suitable for public release, and will be suitable for long-term archival at the ORNL DAAC.

8.2 Science Data Generation and Documentation Requirements

As part of ACT-America, each Co-I has budgeted sufficient financial, computational, and staffing resources necessary to process their instrument data and generate science data products. The data processing procedure will convert instrument measurements to data products quantitatively describing atmospheric chemical and physical states, e.g., trace gas mixing ratio (or concentration). The data processing algorithms will be refined through detailed instrument characterization and calibration (if applicable) to ensure data quality in terms of accuracy and precision.

The ACT-America instrument Co-Is will be required to preserve sufficient raw data sets (instrument primary output and ancillary data sets) and documentation for each of the funded measurements to retain reprocessing capability. The primary goals of this requirement are: 1) to maintain data reprocessing capability, 2) to maintain transparency of the data processing, and 3) to facilitate users' understanding and use of data. The content of documentation files should consist of an instrument description and certain specific explanation of the actual measurements in the data products and ancillary data sets that are needed for reprocessing. The instrument description should include the measurement principle, instrument description, calibration procedures and standards (if applicable), data processing procedure (including software if necessary), data validation (if applicable), data revision records, and uncertainties/detection limits. Since much of the information can often be found in peer-reviewed publications, relevant publications can be used as references. The documentation itself should primarily be focused on the details or modifications specific to the instrument operation for each of the ACT-America field deployments. The data management working group (which includes the PI, project data management experts, and a representative from the ORNL DAAC) and the instrument Co-Is, working with the ORNL DAAC, will determine the appropriate documentation requirements for each instrument on a case-by-case basis.

Table 8. Summary of ACT-America observational data products, submission schedules, responsible Co-Is, data formats, and sampling platforms. Final data will be transferred to the ORNL DAAC beginning in year 4 of the mission.

Data product	Data Latency		Co-I	Data Format	Platform
	Preliminary	Final			
Column CO_2	1 day	6 mo.	Dobler/ Lin	HDF 5	C-130
ABL Height	1 day	6 mo.	McGill	HDF 5	C-130
CO_2, CH_4, CO	1 day	6 mo.	Yang	ICARTT	C-130
O_3	1 day	6 mo.	Yang	ICARTT	C-130
CO_2, CH_4, CO, ^{14}CO2, COS	1 mo.	6 mo.	Sweeney/ Miller	ICARTT	C-130
Lat, lon, Alt, T, P, Winds, H_2O	1 day	6 mo.	NSERC	ICARTT	C-130
CO_2, CH_4, CO	1 day	6 mo.	Yang	ICARTT	B-200
O_3	1 day	6 mo.	Yang	ICARTT	B-200
CO_2, CH_4, CO, ^{14}CO2, COS	1 mo.	6 mo.	Sweeney/ Miller	ICARTT	B-200
Lat, lon, Alt, T, P, Winds, H_2O	1 day	6 mo.	Barrick	ICARTT	B-200
CO_2, CH_4, H_2O	1 day	6 mo.	Miles	ICARTT	Ground

The ACT-America airborne and ground-based observational data will be recorded during the field deployment periods. The preliminary data for airborne measurements will be submitted to the project data repository, typically within 24 hours after each flight (Table 8). Rapid submission is required because the preliminary data are used by the PI, PM, and PS to monitor project progress and to formulate plans for follow-up flights. Exceptions may be granted when flights are scheduled for consecutive days. The flask trace gas measurements are exempt since flask samples require substantially more time for analysis.

Final data will be submitted to the project data repository at ASD-AC within 6 months after the end of each field deployment, provided that the time between deployments is greater than 6 months (including aircraft integration time). This 6-month period will provide the time for Co-Is to reprocess their data, using final calibrations, and conduct full QA/QC checks. These data will be used for ongoing science team integrated interpretive analysis and comparison with models. The final observational data will be made available to the public through a data interface.

A downloadable version of data scanning software will be made available at the data repository for use by the Co-Is to help them check if their data files are in compliance with the data format standards. As a part of the data submission process to the ASD-AC ACT-America project data repository, all incoming data files will be scanned upon delivery to ensure that the data format requirements are met. Table 8 summarizes ACT-America observational data products, submission schedules, responsible Co-Is, data formats, and sampling platforms.

In addition to the instrument co-I submitted observational data, merged data products will be generated by ASD-AC for both preliminary and final data. The merged data files associate all of the airborne measurements with the sampling location and meteorological environment, and thus offer a means to readily analyze the co-variance of the common platform atmospheric measurements. Nominally, 1-second and 10-second merged data files will be created for the NASA C-130 and B-200 science flights. Special merged data files requested by Co-Is or partners will be accommodated. The preliminary merged data files will be generated during the deployment phase. Final merged data files will be updated as data are revised by instrument Co-Is.

8.3 Science Data Storage and Distribution

The project observational data repository (Figure 5) will be set up at http://www-air.larc.nasa.gov/missions/ACT-America/index.html to host airborne and ground-based preliminary and final data. The access to preliminary data will be limited to science team and collaborative partners. The final data will be open to the public. During the project lifecycle, ASD-AC will be responsible for providing public access to final data at the ACT-America observational data repository. The distribution metrics will be compiled and submitted to the ESDIS Metrics System (EMS). Anticipated observational data volumes are in Table 9.

Table 9: Anticipated data volumes for one campaign (aircraft) or one year (towers) of field operations. The C-130 data volume includes a breakout of the two lidar (MFLL and CPL) data streams.

Platform	Data products (GB)	Raw data (TB)
C-130 total	23.5	3.8
MFLL	8	3.6
CPL	13	0.03
B-200 total	0.5	0.1
Towers	0.003	0.04

ACT-America final data will be transferred to the ORNL-DAAC by the ASD-AC group in cooperation with the instrument Co-Is, including all necessary metadata in compliance with NASA science data policy. The transfer of final data to the ORNL DAAC will begin in the fourth project year. At the same time, the ASD-AC will work with ORNL to facilitate the process for submission of documentation files by measurement Co-Is to ORNL.

8.4 Post-mission Stewardship and Access

The ORNL DAAC will provide long-term archive and post-mission access to ACT-America data products. The transfer of raw and final science data and associated documentations to ORNL DAAC will be a joint effort between ASD-AC group, the ORNL DAAC, and project modeling and instrument Co-Is. Specifics of the data and transfer mechanisms will be defined in an Interface Control Document (ICD), which will be developed collaboratively by ORNL DAAC and ASD-

AC group beginning in the fourth project year.

At or prior to year 4 of the investigation, the ORNL DAAC and ASD-AC will complete a successful transfer of representative data and ancillary information as a testing mechanism to prove that data meets the format, metadata, and ancillary information requirements of the DAAC, to support long-term usability. NASA's ESDIS will be involved in this activity.

8.5 Data Format and File Naming

The ACT-America science data products will conform to NASA Earth Science Division approved data system standards. The *in situ* observational data products will be archived in the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) data format, i.e., ESDS-RFC-019. A detailed description can be found at: https://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc/esds-rfc-019. The ACT-America remote sensing data products will be archived in the Hierarchical Data Format (HDF 5) data format, which is described at http://www.esdswg.org/spg/rfc/ese-rfc-007. All ACT-America observational data will be reported with Coordinated Universal Time (UTC) (ISO 8601) for the time record. The instrument Co-Is are required to use UTC time by synchronizing their instruments with the UTC time used by the GPS. For the time stamp variables, the instrument Co-Is are required to use "start", "stop", and "mid" as keywords to clearly indicate if the time stamp variable corresponds to the beginning, end, or middle of the sampling time period, respectively.

A downloadable version of data scanning software will be made available at the data repository for use by the Co-Is to help them check if their ICARTT data files are in compliance with the data format standards. As a part of the data submission process to the ASD-AC ACT-America project data repository, all incoming data files will be scanned upon delivery to ensure that the data format requirements are met.

The ACT-America project has a specific file naming convention to promote the usability of the ACT-America data. The ACT-America file naming convention is derived from the ICARTT file naming convention. The ACT-America file names are limited to 127 characters or less and are defined as follows:

dataID_locationID_YYYYMMDD_R#

The only allowed characters are: a-z A-Z 0-9_.- (that is, upper case and lower case alphanumeric, underscore, period, and hyphen). Fields are described as follows:

dataID: an identifier of measured parameter/species, instrument, or model (e.g., O_3; NxOy; and Flask). For ACT-America data files, the Co-Is are required to use "ACTAmerica-" as prefixes for their DataIDs, e.g, ACTAmerica-CO2.

locationID: an identifier of airborne platform or ground station, e.g., C-130. Specific locationIDs for each deployment will be provided on the ACT-America website.

YYYY: four-digit year

MM: two-digit month

DD: two-digit day (for flight data, the date corresponds to the UT date at takeoff)

R#: data revision number. For preliminary data, revision number will start from letter "A", e.g., RA, RB, … etc. Numerical values will be used for the final data, e.g., R1, R2, R3 … etc.

extension: "ict" will be the file extension for ICARTT files, "h5" will denote HDF 5 files.

For example, the filename for the C-130 Picarro CO_2 measurement made on July, 1, 2016 flight may be: ACTAmerica-Picarro-CO2_C130_20160701_R1.ict

The date in the file name gives the date at which the data within the data file began. For aircraft files, the date always refers to the UTC date of take-off or launch. Multiple flights or launches within the same calendar day can be accommodated by addition of a volume number in the file name. For ground sites, the data within a data file should correspond to a calendar day based on local time, although the timestamp in the file should still utilize UTC to report time.

8.6 Metadata Format and Requirements

The ACT-America metadata requirements are designed to meet the Distributed Active Archive Center (DAAC) collection level and granule level metadata requirements. It is noted that these requirements largely overlap with the ICARTT data file format protocol but are an additional requirement for Co-Is who opt to use the HDF-5 format. A metadata file equivalent to the ICARTT file header is required to accompany each HDF-5 data file. This will ensure the consistency in metadata collection for all measurements.

Platform and associated location data: Geographic location and altitude will be embedded as part of the data or provided via a link to the archival location of the aircraft navigational data.

Data Source Contact Information: phone number, mailing information, and e-mail address shall be given for the instrument Co-I and one alternate contact.

Data Information: Clear definition of measured quantities will be given in plain English, avoiding the use of undefined acronyms, along with reporting units and limitation of data use if applicable.

Measurement Description: A simple description of the measurement technique with reference to readme file and relevant journal publication.

Measurement Uncertainty: The minimum requirement is to provide overall uncertainty. Ideally, precision and accuracy will be provided explicitly. The confidence level associated with the reported uncertainties will also need to be specified if it is applicable. The measurement uncertainty can be reported as constants for entire flights or as separate variables. It is noted that measurement uncertainty is required by the ICARTT data file format.

Data Quality Flags: definition of flag codes for missing data (not reported due to instrument malfunction or calibration) and detection limits.

Data Revision Comments: Provide sufficient discussion about rationale for data revision. The discussions should focus on highlighting issues, solutions, assumptions, and impact.

Numerical model data management.

8.7 Science data flow

Figure 6 shows the data flow encompassing the entirety of the ACT America mission, including external data, numerical modeling systems, and ACT America observations. The figure shows schematically how this variety of data sources, both observational and numerical, will flow into the analytic systems of the ACT America science team, then out to numerical products stored at ORNL (not the DAAC) and made available to the public in a way very similar to the way that observational data will be made available to the public via ASD-AC. Thus ACT-America will provide public access to numerical modeling products prior to archival at the ORNL DAAC in an effort to more fully and rapidly involve the external scientific community in the evaluation of both observational and numerical output from the mission. As with the observational data, numerical data distribution metrics will be provided to the ESDIS Metrics System (EMS) during the time the data reside at the ORNL data repository for ACT-America outputs.

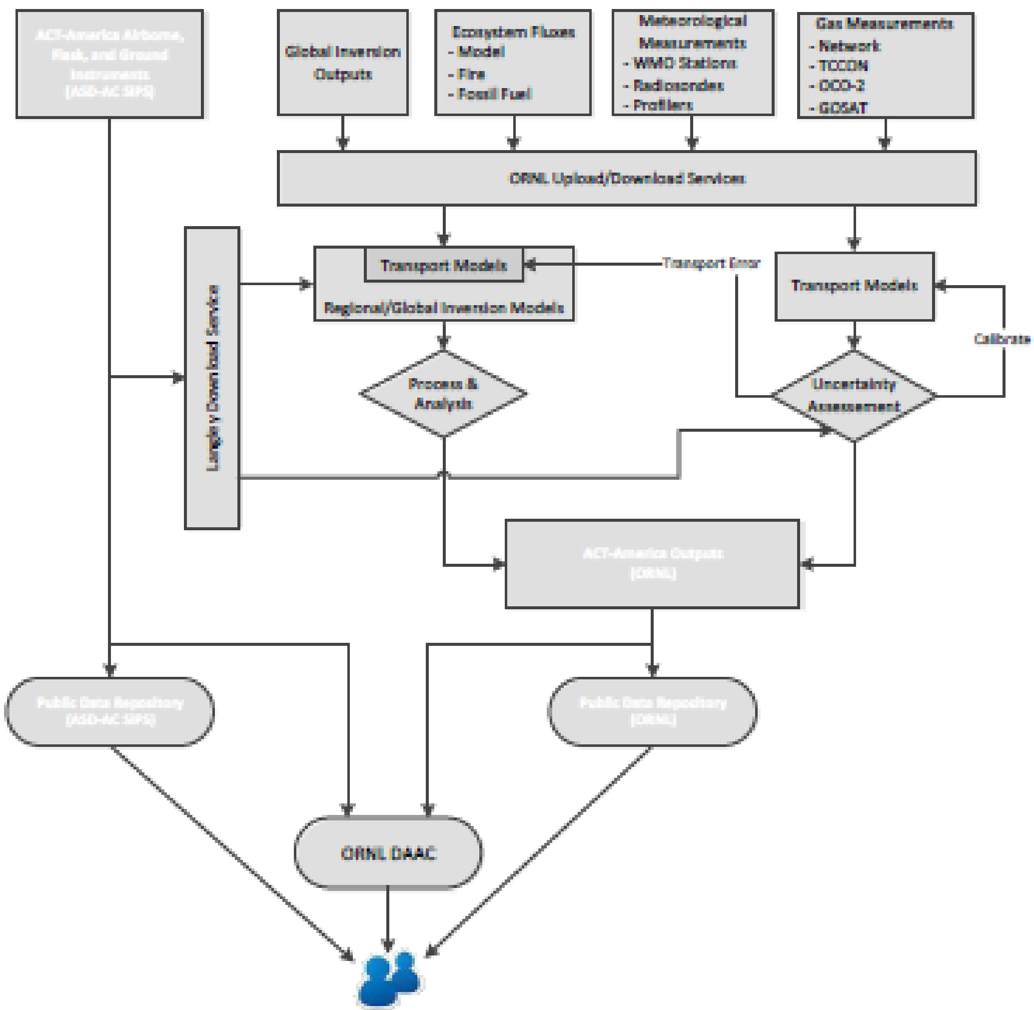

Figure 6. Overall project data flow including project *observational* data management (purple), project *numerical model* management (blue), final archive and public data interfaces, numerical modeling systems (gray), external data sources (beige), and internal data management centers (ORNL and ASD-AC). Analyses by ACT America science team members are collaborators are within the gray boxes and blue diamonds.

Levels 0 and 1 *numerical* model outputs will be maintained by modeling Co-Is. ORNL (Figure 6) will host more processed numerical model outputs (levels 2-4) needed for model-data comparisons and analyses. Examples of these data include global atmospheric C simulations to be used in regional atmospheric C modeling systems, or flux predictions to be used within regional C modeling systems.

Model output and analyses will be documented primarily via publications, but key model outputs will be archived with the ORNL DAAC as required for publication, and as deemed beneficial for the broader scientific community. These products will also be transferred to the ORNL DAAC by the ORNL group in collaboration with science team Co-Is beginning in the fourth year of the project. This archive effort will focus on level 3 and 4 model outputs and published documentation of the analysis methods and algorithms.

9.0 Risk Management

Cost and schedule reserves have been established based on the level of risk associated with each element of the project. The PM will monitor the status of each project element and in concert with the PI allocate cost and schedule reserves as required to address specific issues.

Several significant risks to the investigation were identified during the proposal stage. Since the investigation was awarded, new risks have been identified and some risks have been retired. Table 10 summarizes the cost and schedule related risks and proposed mitigations.

Previously identified risks include aircraft availability, instrument failures, unsuitable weather for science flights, unplanned cost increases, and an OCO-2 satellite delay or failure. The investigation was granted sole use of a NASA C-130 aircraft for the duration of the mission, so aircraft availability for the C-130 is no longer a risk. There is still availability risk for the use of the Langley B-200 aircraft, but the investigation can either use the Langley B-200 or UC-12 aircraft, so having two aircraft to choose from mitigates this risk. The investigation project management is also in close communication with the aircraft managers since we are all located at Langley.

While all instruments are mature (TRL-8 or -9) and have flown on multiple previous campaigns, instrument failures are a risk during our aircraft integration efforts and flight campaigns, To mitigate this risk, instruments will be integrated at the base of operations for each aircraft involved (Langley for the B-200 and Wallops for the C-130) before deployments. These same locations serve as the base of operations for the first two weeks of each deployment, which reduces cost and risk by making adjustments or repairs to the instruments easier to accomplish versus being deployed away from these sites. Each instrument has also budgeted for spare parts while on deployment to minimize the risk of flight delays due to instrument failures. Each instrument mitigates instrument performance risks at deployment sites with judicious budgets for spare parts on deployments. The instruments budget includes a full spare Picarro and ozone airborne instrument. The Picarro and ozone instruments have already been purchased and flown during the 2015 SARP campaign and 2015 ACES test flight campaign to test their airborne performance prior to the first ACT-America campaign. MFLL component replacement parts and critical spares will be purchased to ensure reliability over the course of the mission. All other instruments require only calibration and pre-flight testing before deployment.

Unsuitable weather is another risk that applies only during the flight campaigns. To mitigate this risk, a simulation of forecasting and fly/no-fly decisions using real weather systems moving through our flight campaign regions will be conducted prior to the first campaign to help the investigation better plan for the weather events that are expected during our campaigns. Reserve funds and schedule reserve can be used to add some flights to each campaign if needed to further mitigate this risk.

OCO-2 successfully launched in July, 2014, and is operating nominally so the launch and operations risk is retired. There is still a risk of satellite failure during the investigation campaign, however, a failure of the OCO-2 satellite does not affect ACT-America's Threshold Science and Investigation Requirements.

All of the newly identified risks are due to the investigation being granted the use of the C-130 aircraft in place of the proposed P-3B aircraft. The investigation science instruments have not previously flown on the C-130, so new instrument mounts are being constructed and testing will have to be performed to verify instrument performance on the aircraft prior to the beginning of the science flight campaigns. Furthermore, the C-130 is new to the NASA aircraft fleet, and must undergo major modifications to accommodate the science campaign. These modifications add schedule and cost risk to the investigation. The cost of the aircraft is higher than the proposed P-3B, primarily due to the investigation having to purchase fuel for the aircraft. This adds the risk of fuel prices increasing to an unaffordable level. The instrument operations risks are being mitigated by executing two test flights of the fully-instrumented C-130 aircraft about two months prior to the first science campaign to allow time to identify and resolve any discrepancies introduced into the instrument data products due to the C-130 environment. Funds are being held in reserve to mitigate the risks associated with changes in the aircraft flight costs and expected fuel cost increases. The largest commodity risk is the cost of fuel to fly the aircraft. Note that most of the modification costs themselves are covered by NASA HQ, so the risk of modification costs themselves increasing is not a significant risk to the investigation; however, associated schedule slip due to delays in the modifications schedule is a risk to the investigation. This schedule risk is mitigated by having several months of schedule margin built into the aircraft modification schedule. Furthermore, the ACT-America flight campaigns dates are flexible and can be moved to accommodate unexpected changes in the schedule without sacrificing the mission science objectives. Individual campaigns can be postponed until later in the project if needed as there is no science requirement to fly during any certain season in a given year. Although ACT-America has been granted a C-130 aircraft for the duration of the mission, the availability of crew for flight campaign is a new risk owing to dual C-130 aircraft and multiple suborbital missions which was not a case during proposal time. To reduce this risk, a careful mission schedule to avoid conflicts on campaign schedules and to ensure the availability of crew is designed.

The initial set of investigation risks were taken from the investigation proposal and updated by the team. It is appropriate for anyone to raise a risk with the PI and/or PM. It is the responsibility of the PM to evaluate all identified risks with input from the PI and team members knowledgeable about the factors influencing each risk. It is also the responsibility of the PM to retire a risk when it has been eliminated. Risks are evaluated and updated monthly and included in the ESSP monthly reports.

Table 10. Cost Risks and Mitigation Approach

Risk Statement	L	C	R	Pot. Cost (% of Total Reserves)	ACT-America Mitigation Approach
Risks identified during proposal stage					
Aircraft availability (B-200/UC-12)	L	M	L	$100 K (4%) per campaign	B-200/UC-12 aircraft both available for use; Schedule Reserve; flexibility for deployment timing
Instrument Failures	L	M	L	Instrument dependent	Cost Reserve; funded spare components
Unsuitable Weather	L	L	L	$100 K (4%) per week during deployment	Cost Reserve and 1 week funded Schedule Reserve per deployment

Unplanned cost increases (instruments and science)	L	M	M	Inflation rate dependent	Cost Reserve
OCO-2 Failure	L	L	L	N/A	Delay or Descope OCO-2 underflights
Risks identified since investigation start					
C-130 modifications and impact to schedule	M	L	L	N/A	HQ/Wallops responsibility for modifications; schedule reserve; flexibility for deployment timing
Total costs of expected fuel increases ($4.60/gal at 820 gal/hr)	H	L	M	$751.8 K (33%)	Cost reserve; negotiations of fuel rates with suppliers
Instrument incompatibility with C-130 vibration/thermal environment	M	M	M	$50 K (2%) for two 4-hour test flights plus instrument dependent costs	Test flights prior to first science campaign; lessons learned from previous C-130 campaigns
Unplanned cost increases (aircraft)	M	L	M	$515 K (22%)	Cost reserve
Retired Risks					
Aircraft availability (C-130)	NA	NA	NA	NA	Investigation has exclusive use of aircraft throughout mission
Pot. Cost – Potential Cost to the mission should this risk occur L – Likelihood judged as Low (L), Medium (M), High (H) C – Consequence judged as Low (L), Medium (M), High (H) R – Risk Rating judged as Low (L), Medium (M), High (H)					

ACT-America has identified costed descope options which can be exercised with the approval of the PI throughout the mission to control costs and do not jeopardize meeting the threshold mission science requirements. The descope plan provides a structured approach to maximizing the science return while controlling investigation costs. Individual descope options are shown in Table 11. The sum of the potential descopes reflect the difference between the baseline and threshold mission science (Table 12). Descopes can be exercised late in the project with significant savings. The PI is the ultimate decision authority for exercising descope options.

Table 11. Descope Options and Cost Savings Associated with Each. Threshold requirements can still be met if these descopes are enacted.

Descope Option	FY2015	FY2016	FY2017	FY2018	FY2019	Total
Remove one of three measurement campaign regions for a single campaign (e.g. from FY2018 campaign)	$0	$0	$0	$363.6K	$0	**$363.6K**
Remove one campaign (e.g a FY2018 campaign, aircraft costs only)	$0	$0	$0	$1,822.1K	$0	**$1,822.1K**
Remove OCO-2 underflights, if OCO-2 fails.	$0	$96.3K	$207.3K	$218.1 K	$0K	**$521.7K**
Eliminate CPL	$40.86 K	$255.91K	$206.89K	$218.57K	$113.32K	**$835.55K**
Reduce Flask sampling	$0	$85.2 K	$84.2 K	$44.7 K	$0	**$214.1K**

Table 12. Total cost savings of descoping from baseline to threshold mission.

Descope Option	FY2015	FY2016	FY2017	FY2018	FY2019	Total
Remove one of three measurement campaign regions for each campaign	$0	$321.1 K	$691.0 K	$727.1 K	$0	**$1,739.2 K**

Remove three campaigns (these costs are representative and include aircraft costs only; actual cost savings depend on which campaigns are descoped)	$0	$0	$3,126.9 K	$1,822.1 K	$0	**$4,949.1 K**
Remove OCO-2 Underflights, if OCO-2 fails	$0	$96.3 K	$207.3 K	$218.1 K	$0K	**$521.7 K**
Eliminate CPL	$40.86 K	$255.91K	$206.89K	$218.57K	$113.32K	**$835.55K**
Reduce Flask sampling	$0	$85.2 K	$84.2 K	$44.7 K	$0	**$214.1K**
Total	**$41 K**	**$758 K**	**$4,316 K**	**$3,030 K**	**$113 K**	**$8,259 K**

10.0 Investigation Evaluation

The proposed review process is in accordance with NPR 7120.8 and LPR 7130. The Baseline plan is submitted by the Review Manager, and approved by the convening authority at the LaRC Center Director's Office. Prior to approval by the convening authority, concurrences are obtained from

- The LaRC Director of the Science Directorate
- The LaRC Chief Engineer

All those approving and concurring on this baseline plan request notification and copies of all Addendum related to the LaRC EVS-2 investigations, but otherwise delegate formal approval authority for future Addendum to the Review Manager. This delegation is revocable at any time by any of the convening authority.

The life cycle reviews (including those that are carried out by ESSPPO and the Langley Independent Review Team (IRT)) are listed in Table 13. The LaRC IRT reviews (items in green and yellow in Table 13) complement the Investigation Confirmation Review Process instituted by ESSPPO (see Figure 7). The two key factors that drive the proposed plan are (1) The Life Cycle Cost for the subsystems for which LaRC has primary responsibility, and (2) There is very little development work as all instruments have been deployed on previous airborne missions. Using the Langley Tailoring guideline for NPR7123_1B, it is proposed that the project should be classified as Type E under $10M life cycle cost. We propose to use the LaRC Engineering Project and Task Review (EPTR) as the forum for certain periodic reviews, and the Director of the Science Directorate, or designee, is the Designated Governing Authority (DGA) to approve the project implementation plan (see LPR 7123.-1).

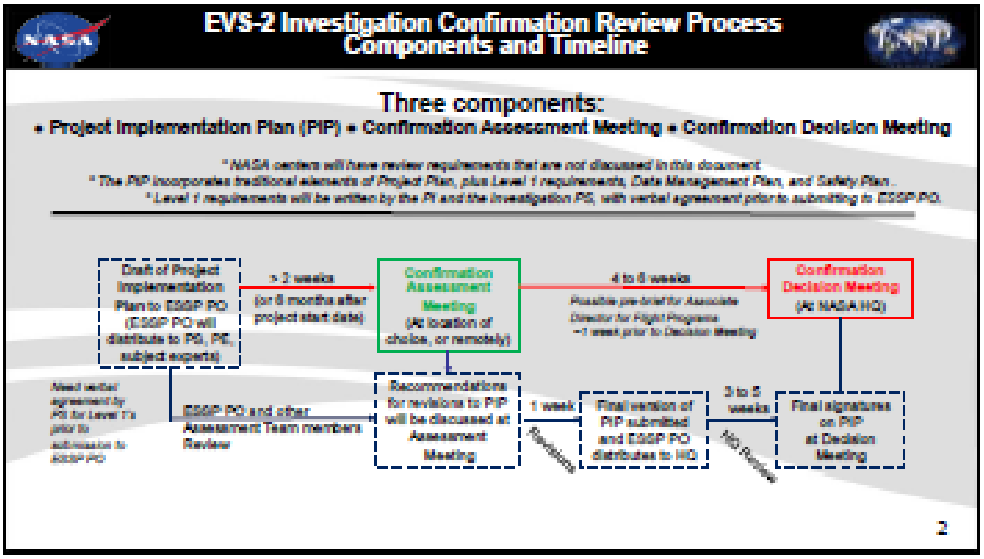

Figure 7: Investigation Confirmation Process instituted by ESSPPO

Table 13: Review Plan.

Time	Review	Description
7/23/2015	Project Status Review	Monthly status review with ESSPPO until Confirmation review
8/10/2015	Table Top Review of the Project Implementation Plan	Review convened by the LaRC IRT Review Manager
8/12-8/13/2015	Science Review	Science team meeting to serve as science review with Program Managers from NASA HQ.
8/14/2015	ESSPPO Confirmation Assessment Review [1]	The project will preview the materials to be presented at the HQ Confirmation Review.
8/27/2015	Project Status Review	Monthly status review with ESSPPO until Confirmation review
9/3/2015	Post ESSPPO Confirmation Assessment Review [2]	The Project Chief Engineer will present the findings from the Confirmation Assessment Review to the LaRC EPTR
9/30/2015	Confirmation Decision Meeting	To demonstrate to the Director of Earth Science Division that the investigation is ready to proceed into the implementation/deployment phase
Quarterly	Project Status Review	Quarterly status review with ESSPPO after Confirmation review
60 days Before Deployment #1	Status update on cost schedule, project reserve, and logistics for the upcoming deployment	Project Manager will present at the LaRC EPTR
As needed per schedule for integration	Air Safety	LaRC Airworthiness and Safety Review Board (ASRB) for the B-200/UC-12; Wallops ASRB for the C-130
	Flight Readiness Review	Langley: B-200/UC-12; Wallops: C-130
	Operation Readiness Review	Conducted by Wallops ASRB for both aircraft
6 months after Deployment	Post Deployment Assessment Review	Project Manager will present at the LaRC EPTR
Annually	Science Review	Science team meeting to serve as science review with Program Managers from NASA HQ.

[1] ESSPPO organizes the review. The LaRC DGA shall attend.
[2] Based on the review, LaRC will confirm (or not confirm) the project's readiness to proceed with the HQ Confirmation Review.

11.0 Safety and Mission Assurance

NASA Air Worthiness and Flight Safety Review Board meetings will be held according to the schedule described in Section 10 to address safety and mission assurance related to the use of the C-130 and B-200/UC-12 aircraft. The PM has ultimate responsibility for ensuring prompt scheduling of these reviews. All laser instruments are required to submit laser safety plans to their respective laser safety organizations: the MFLL laser safety plan is reviewed and approved by the Langley Non-ionizing Radiation Safety Committee, and the CPL laser safety plan is reviewed and approved by the corresponding review board at Goddard. Letters of Non-Objection are obtained from the FAA where required.

12.0 Relationships to Other Projects and Organizations

12.1 Internal Relationships: The ACT-America investigation has internal relationships with three NASA centers, Langley Research Center, Goddard Space Flight Center, and Wallops Flight Facility, as shown in Table 14. Funding is made available to each of the Langley groups on their own individual WBS elements by the Project Manager at Langley upon approval of a fiscal year budget by ESSPPO. Funding to the other NASA centers flows directly from NASA HQ to the centers with the approval and authorization of the Project Manager at Langley. While these funds will be sent directly to those centers by NASA HQ, costing of those funds will be reported by the centers to the ACT-America project office at LaRC where all costs will be actively managed by the PM.

Langley's responsibilities include managing the project, contributing to the science team, providing in situ instruments, managing data, and providing the B-200 aircraft. Goddard's responsibilities include contributing to the science team and providing the Cloud Physics Lidar (CPL) instrument. Wallops' responsibilities include providing the C-130 aircraft. Each group has provided statements of work for their funding.

Table 14. Internal relationships and funding mechanisms

Institution	Co-investigator	Purpose	Agreement Type	Approval Date
Goddard Space Flight Center	Collatz	Science Team	Direct funding from NASA HQ with Langley Research Center PM approval	4/8/2015
Goddard Space Flight Center	McGill	Science Team/Cloud Physics Lidar (CPL) Instrument		4/8/2015
Wallops Flight Facility	Cropper	C-130 aircraft		4/8/2015
Langley Research Center	Obland	Project Management	Direct funding from Langley	4/8/2015
Langley Research Center	Lin	Science Team		4/8/2015

Langley Research Center	Yang	Science Team/in situ instruments	Research Center	4/8/2015
Langley Research Center	Chen	Data management		4/8/2015
Langley Research Center	Fisher	B-200 aircraft		4/8/2015

12.2 External Relationships: The ACT-America investigation has external relationships with Jet Propulsion Laboratory, Oak Ridge National Laboratory, Exelis, Inc. (now part of Harris Corp.), SSAI, Inc., and several universities (Table 15). The PI institution, PSU, as well as most of the investigation co-investigators are funded via grants through the NASA Shared Services Center (NSSC). The grant to the PI institution is initiated by the ESSPPO mission manager who acts as the technical monitor for that grant. All grants are for one year and are to be renewed on an annual basis. Each grantee is required to submit an annual report for review prior to grant renewal. Continuation of the grants is subject to documented progress with the tasks defined in each co-investigator's grant statement of work. Oak Ridge National Laboratory's responsibility is for data management and their work is funded via Interagency Agreement with DOE. Exelis, Inc., will provide the Multifunctional Fiber Laser Lidar (MFLL) instrument and are funded via a contract through Langley. SSAI is funded via a task order on the existing STARSS II contract with Langley Research Center. All other external institutions provide contributions to the investigation science team. The ACT-America Project Manager serves as the technical monitor for all grants, agreements, contracts, and tasks except the grant to the PI institution.

Table 15. External relationships and funding mechanisms

Institution	Co-investigator	Purpose	Agreement Type	Agreement Number	Approval Date
Pennsylvania State University	Davis	Principal Investigator	Grant	NNX15AG76G	04/10/2015
Colorado State University	Baker	Science Team	Grant	NNX15AJ07G	05/06/2015
Colorado State University	Denning	Science Team	Grant	NNX15AJ09G	05/27/2015
Colorado State University	O'Dell	Science Team	Grant	NNX15AI97G	04/23/2015
Colorado University	Sweeney	Science Team	Grant	NNX15AJ06G	06/10/2015
Carnegie Institute	Michalak	Science Team	Grant	NNX15AJ42G	05/22/2015
Carnegie Institute	Berry	Science Team	Grant	NNX15AJ43G	05/14/2015
University of Oklahoma	Moore	Science Team	Grant	Not yet assigned	Work to start in

					project year 2
Harris, Corp. (previously Exelis Inc.)	Dobler	Science Team/Multi-functional Fiber Laser Lidar (MFLL) instrument	Cost Plus Fixed-Fee Contract	NNL15AA01B	9/15/2015
Oak Ridge National Laboratory	Cook	Data Management	Interagency Agreement	NNL15AA10I	6/8/2015
Jet Propulsion Laboratory	Bowman	Science Team	Task Order	NNN12AA01C	6/17/2015
SSAI, Inc.	McBride	Travel Support	Task Order	STARSS II	5/29/2015

13.0 Waivers

No waivers have been granted to the ACT-America investigation. Waivers for civil servant 30-day travel limitations are not anticipated to be needed because the research teams will most likely switch their field team personnel within the 30-day limit and each flight campaign will move its base to different regions within 2 to 3 weeks. A data delivery waiver may be needed if two ACT-America field campaigns occur within a six-month window (including instrument integration). Waivers to these limitations will be applied for if necessary.

14.0 Change Log

Changes to the Investigation Implementation Plan are documented in Table 16 below. To expedite the processing of changes, approval for all changes, other than those related to the Level 1 science and investigation requirements, only require the signatures of the ESSP Program Office and the Principal Investigator. All signatories will be provided a copy of the updated plan. Changes to the Level 1 science and investigation requirements requires the approval of all the signatories.

Table 16. Project Implementation Plan Change Log

Revision	Date	Sections Changed	Author
Version 1	07/31/2015	Initial Release	K.J. Davis
Version 2	09/16/2015	All sections edited after ESSPPO Assessment Review	K.J. Davis

15.0 References

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Appendix EE: Atmospheric Tomography Mission (ATom)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release • PIP Version 0.0, dated 02/16/2016 • Section 8.0 – Version 1.0, dated 06/06/2016

National Aeronautics and
Space Administration

Version 0.0
Effective Date: 02/16/16

Earth Venture Suborbital-2 (EVS-2)

Atmospheric Tomography Experiment

(ATom)

Project Implementation Plan

Atmospheric Tomography Experiment (ATom)
Project Implementation Plan
Effective date: 02/16/16

Approved by:

[signature] 12 Feb 16

Mr. Greg Stover
Program Manager
Earth Systems Science Pathfinder Program Office
NASA Langley Research Center

Date

[signature] 23 Feb 16

Dr. Michael Freilich
Director
Earth Science Division, Science Mission Directorate
NASA Headquarters

Date

Atmospheric Tomography Experiment (ATom)
Project Implementation Plan
Effective date: 02/16/16

CONCURRED BY:

Mr. Dave Jordan
Investigation Project Manager
NASA Ames Research Center

2/22/16
Date

Dr. Steven Wofsy
Investigation Principal Investigator
Harvard University

22 Feb 2016
Date

Mr. Kevin Murphy
Program Executive, Earth Science Data Systems
Earth Science Division, Science Mission Directorate
NASA Headquarters

2/12/2016
Date

for

Ms. Holly Degn, Earth Science Budget Lead
Science Mission Directorate
NASA Headquarters

2/22/16
Date

Atmospheric Tomography Experiment (ATom)
Project Implementation Plan
Effective date: 02/16/16

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1. Science Objectives

The Atmospheric Tomography (ATom) experiment is an Earth Venture Suborbital-2 project providing data and analyses contributing to NASA's objectives to understand the Earth's composition and climate. The overarching goal of the mission is to carry out near-continuous airborne vertical profiling on a global scale to quantify key atmospheric chemical processes and loss rates for the short-lived climate forcing agents methane (CH4), ozone (O3), and aerosols (including black carbon or BC). ATom uses in situ airborne measurements along long latitudinal transects in low-risk airspace over the Atlantic and Pacific oceans to provide information on atmospheric processing relevant to more than 60% of the total reactivity of the global atmosphere. ATom is tightly linked to satellites measuring atmospheric chemical composition and to global chemistry-climate models (CCMs). ATom further addresses important secondary questions linked to climate forcing by aerosols and longer-lived greenhouse gases (GHGs) and to ozone depleting substances (ODSs).

The primary science objectives (denoted Tier 1 objectives) of the ATom Mission are to address the connection between the following scientific and societal questions:

- What are the chemical processes that control the short-lived climate forcing agents CH_4 and O_3 in the atmosphere?
- How is the global scale chemical reactivity of the atmosphere affected by anthropogenic emissions?
- How can we improve chemistry-climate simulations of these processes?

ATom focuses on O_3 because it is a principal driver for tropospheric photochemical processes, is a short-lived climate forcer, and is a major ground-level pollutant. ATom focuses on CH_4 because it is a major source of O_3 and a medium-lifetime climate forcer. Both are greenhouse gases (GHGs) whose concentrations have risen significantly since the industrial revolution. O_3 and CH_4 are the second and third most important GHGs after CO_2. Both CH_4 and O_3 control concentrations of the hydroxyl radical (OH), which in turn destroys other key pollutants including volatile organic compounds (VOCs) and hydrofluorocarbons (HFCs).

The secondary science objectives (denoted Tier 2 objectives) are to address the questions linked to climate forcing by aerosols and longer-lived GHGs and Ozone Depleting Substances (ODSs):

- In remote areas, what are the distributions of BC and other aerosols that are important as short-lived climate forcers?
- What are the sources of new particles in the remote troposphere? In regions far from pollution sources, how do aerosols evolve and become more active in cloud processes from formation to precipitation? How well are these processes represented in CCMs?

To address these questions ATom quantifies BC and aerosol composition to provide key constraints on growth and removal processes in models. ATom also maps out new particle formation and the evolution of particle size distributions in under-sampled atmospheric regions that are highly sensitive to indirect cloud radiative forcing. ATom further addresses the questions:

- What are the vertical and horizontal gradients of GHGs and ODSs over remote ocean regions?
- How can we use the observed gradients to help identify the human influences on photochemical reactivity in air parcels, validate satellite data for these gases, and refine knowledge of sources and sinks?

ATom's "fingerprint tracers" help identify the origins of anomalies in photochemical reactivity and concentrations of aerosols, GHGs and ODSs, for which budgets and source identification have significant scientific and decision-support value.

Further ATom objectives come from the project's tight link to satellites measuring atmospheric chemical composition and to global chemistry-climate models (CCMs). ATom will use satellite data to extend its airborne *in situ* observations to global scale and will in turn provide unique validation and calibration data for Orbiting Carbon Observatory (OCO)-2, both in terms of global profile data and by making measurements over TCCON sites around the globe. ATom also provides validation and calibration data for the Global Ozone Monitoring Experiment 2 (GOME-2), Tropospheric Ozone Monitoring Instrument (TROPOMI), Greenhouse gases Observing SATellite (GOSAT), and satellites in the Geostationary Monitoring Constellation. ATom will also directly engage CCM groups and deliver a single, large-scale, contiguous *in situ* data set for model evaluation and model improvement.

2. Level 1 Requirements

2.1. Goals and Objectives

The Tier 1 objective for ATom is founded on delivering atmospheric measurements and related chemical rate computations for a statistical ensemble of air parcels widely distributed over the globe. ATom measures the chemical species required to compute the chemical reactivity of the atmosphere: $\langle P\text{-}O_3 \rangle$, $\langle L\text{-}O_3 \rangle$, $\langle L\text{-}CH_4 \rangle$, where $\langle P \rangle$ and $\langle L \rangle$ denote the 24-hour averaged production and loss rates for ozone (O_3) and methane (CH_4). The goal is to define these controlling chemical rates in the vast remote regions of the atmosphere, to quantify the diffuse effects of global anthropogenic emissions and to assess the influence of diffusely distributed, human-caused emissions on global chemical rates, especially for CH_4 and O_3. The sampling strategy is therefore global and the observations and computations provide a measure of the contrast between the Northern and Southern Hemispheres in multiple seasons and between Pacific and Atlantic Ocean basins over a wide range of latitudes. The sampling is also dense enough to provide statistics covering the high- and low-end probability distributions of reactivity over the ocean basins.

2.2. Scientific Design

ATom's direct, point-to-point flight plans include frequent vertical profiles that provide sampling of air parcels that will be as unbiased as possible with respect to prior human influence or meteorological regime. Sampling takes place from the lowest accessible altitudes (0.15 km over the ocean, 0.5 km over land) to the aircraft's flight ceiling of ~12 km. Restrictions imposed by air traffic control and weather (visibility, icing, storms) may limit the sampling to 0.5 to 8 km altitude over portions of the ocean basins.

ATom's core measurements include the necessary precursors to initiate 24-hour chemical model integrations to compute, from the observations, the chemical production (*P*) and loss (*L*) rates in the Tier I objectives. The desired species to constrain *P* and *L* are: **CH_4, CO, H_2CO, HOOH, CH_3OOH, NOx (NO + NO_2), HNO_4, PAN and O_3 plus meteorological and aircraft data and diagnostic tracers of transport (CO_2, SF_6, or other long-lived species).** The ATom Science Traceability Matrix (**Table 2.2**) is based on the proposal and is presented together with a new detailed mapping for the NOx measurement (**Table 2.2.3**).

In addition ATom core data may include other volatile organic compounds (VOCs) and aerosol surface area where abundances are high enough to impact overall reactivity, for example, in polluted air masses encountered over the sea. The short-lived radicals and photolysis rates are important observations but not required for the threshold mission; these parameters provide an instantaneous check on the chemical models but do not constrain the diurnal cycle for an air parcel, which must integrate over varying sun angles and cloud cover.

"Air parcels" used in this computation are defined at 10 – 30 second sampling intervals (approximately 2 – 8 km along the track and 300 – 1000 m in the vertical). The computation directly uses *in* situ data acquired at high rates (> 0.1 Hz). For those measurements made at slower rates, binning, smoothing, and covariance analyses are used to interpolate species information to shorter intervals as required for each computation. The air parcel measurement and computational data are grouped into statistically robust ensembles by aggregating over altitude and latitude domains.

Table 2.2 ATom Science Traceability Matrix

Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Investigation Functional Requirements
• Acquire global scale tomographic data for reactive gases and aerosols •Determine the rates of chemical processes that control short-lived climate forcing agents **CH_4, O_3, and black carbon** in the atmosphere. • Evaluate the impacts of pollutants from emerging economies on global chemistry and composition. •Improve chemistry-climate simulations of these processes **Tier 1: Methane and tropospheric ozone** • Quantify the chemical processes and rates controlling CH_4 and tropospheric O_3 abundances. • Determine how CH_4 and O_3 are affected by urban, industrial, agricultural, and natural emissions from major source regions. **Tier 2: Aerosols** • Determine the large-scale distributions and size spectra of different aerosol species: BC, OA. • Determine the mechanisms primarily responsible for new particle formation in the remote atmosphere. • Determine how aging that occurs during transport affects aerosol removal from the atmosphere. **Tier 2: Greenhouse gases and ozone-depleting substances** • Measure greenhouse gases and ozone depleting substances to help identify pollution influences on photochemical reactivity; refine models of global sources and sinks. **Satellite validation and synthesis** Measure numerous vertical profiles for validation of data from 8 satellites, and assimilate satellite data into ATom analysis.	**• Comprehensive measurement payload:** *In situ* measurements of reactive and long-lived gases, aerosols, radiation, and meteorological parameters. **• Specific measurements (Table 8.2.1):** - Reactive nitrogen species (e.g., NO, NO_2, HNO_3, HNO_4, PAN, $RONO_2$, NO_y…) - Volatile organic compounds (VOCs) (e.g., C–C alkanes, C– C aromatics, …) - Photoproducts and oxygenates (.e.g, O_3, HCHO, HOOH, $CH_3C(O)CH_3$, CH_3CH_2OH,…) - Aerosols (e.g, 0.004 to 50 μm size and number, black carbon, organics, cations and anions, …) - Greenhouse gases and ozone-depleting substances (e.g., CO_2, CH_4, N_2O, SF_6, CFCs, HCFCs, …) - Tracers and other species (e.g., CO, CH_3CN, HCN, H_2O, SO_2, OCS, …) - Spectrally resolved actinic flux (280 to 650 nm) - Meteorological data (e.g., P, T, 3D winds, turbulence) **• Airborne sampling:** - Tomographic, global-scale sampling achieved by continuous airborne profiling from near-surface to 12 km altitude along flight tracks that reach nearly pole-to-pole in the Pacific and Atlantic Ocean basins. - Repeated deployments over 4 years to sample in each of four seasons.	• Continuous or near continuous sampling of reactive and long-lived gases and aerosols with calibrated *in situ* sensors. • High sample rates for most species to provide a spatial resolution of 250 m in the horizontal and 10 m in the vertical during profiles. • Lower sample rates from 1–15 minutes for key species measured with calibrated gas chromatographic and filter collection techniques. • Spectrally resolved radiation measurements at 0.3 Hz. • Meteorological state parameters (pressure and temperature at 1 Hz and 3D winds at 20 Hz) • Mature instruments with Technology Readiness Levels (TRLs) of 7 or greater and suitable for attended or unattended operation for up to 11 hr flight durations and for minimal servicing and maintenance between sustained series of flights. ____________ • Measurement accuracy, precision, and sampling rate requirements for tomographic sampling are met or exceeded by the payload as listed in **Table 8.2.1.**	**• Platform requirements and specifications** - Execution of up to 11-hr flight plans in the remote Pacific and Atlantic Ocean basins, continuously profiling from near-surface to 12 km, from 85°N to 65°S, along meridians in the Pacific and Atlantic basins. - Range > 9000 km - Endurance > 10 hours - Cruise altitudes <200 m through 12 km - Payload > 25,000 lbs - Global operations with long overwater capability - Air Traffic Control clearance via CPDLC to maximize altitude flexibility in remote regions • Four separate airborne deployments (one per Northern Hemispheric season between 2015 and 2018) **• Analysis tools** - Model analyses constrained by the fine-grained, simultaneous, observational datasets. - Lagrangian trajectory modeling using analyzed wind fields to quantify transport history of each 500 m x 16x16 km air parcel - Footprints from trajectory modeling to quantify source contributions to each air parcel - Global modeling using *in situ* observations to derive time-integrated chemical reaction rates in each sampled air parcel - Global-scale chemistry-transport modeling to quantitatively assess CCM fidelity on appropriate spatial and temporal scales - Global, vertical profiles used to evaluate and improve retrieval methods used by current and future satellite sensors. -Close collaboration with CCM teams to ensure ATom data sets are infused into improved models.

Table 2.2.3 NOx Measurement Mapping

Science Goal	Science Objectives	Meas. Requirements		Instrument Functional Requirements		Projected Performance	Mission Functional Requirements (Top Level)
		Observables	Quantities				
Validate ozone tendency predictions in global-scale chemistry-climate models	Determine production rate of O_3 (P-O3), its meridional, seasonal, and vertical variability, and its dependence on transported anthropogenic emissions	NOx = NO + NO_2	Mixing ratio	Spatially and temporally resolved data during vertical profiles along flight track	30-second averages	1-second averages	Repeated vertical profiles from 200m to 10 km altitude Flight tracks sampling latitudinal cross-sections in low-risk airspace in remote Pacific and Atlantic air basins
				Vert. Resol.	450 m	8 m	
				Horiz. Resol.	7500 m	250 m	
				Temp. Resol.	30 seconds	1 second	Deployment in spring, summer, fall, winter
				Precision	±10 ppt in 30s	±15 ppt in 1s; ±5 ppt in 30s	
				Accuracy	±10 %	±6%	

2.3. Level 1 Threshold and Baseline Requirements

ATom's unique contribution to atmospheric chemistry lies in making instantaneous chemical measurements that can be used to model the reactivity of globally distributed air parcels over the 24 hours following the measurement. We define an "air parcel" as a segment of the flight path covering ~ 12 km along track and/or 1000m in the vertical. We will provide measurements of 1,200 independent air parcels per 10-hour flight. ATom has a unique flight plan that focuses on sampling the large remote regions of the troposphere over the ocean basins. The intent is to determine the natural variability and the extent of human influence on chemical reactivity in the most remote regions of the atmosphere.

For each air parcel the key reactivities that ATom will derive are: **production of ozone, loss of ozone and loss of methane**. Most Tier-1 core measurements are made at 1-second (250 m) intervals, and if variability in some regions occurs on time scales that short, and if there are sufficient data to initialize the reactivity model calculations, then higher resolution air parcels will be reported. Air parcels pass the Level 1 requirement if all the species listed above (Section 2.2) are either measured directly, or filled using observed correlation patterns, providing initial conditions for (at least) two global chemistry models to integrate the 3 key reactivity rates over the daily period. *The outputs from these constrained model computations, combined with the underlying measurements, represent the deliverables against which the Level 1 requirements are to be measured.* The statistical distributions of reactivity versus the key initiating species are accumulated into ensembles over latitude-height domains and compared with results from global chemistry models' unconstrained simulations.

2.3.1. Level 1 Threshold Requirements

The Level 1 Threshold Mission defines the set of requirements necessary to achieve the minimum science return acceptable for the investment. ATom's unique flight plan allows us to determine the natural variability and the extent of human influence on chemical reactivity in the most remote regions of the atmosphere. Threshold Mission requirements are:

- **Attain core goals of ATom in a limited domain representative of air with highest reactivity and a broad range of human impacts.**
- ***Domain: Tropics / subtropics, Pacific and Atlantic.***
- ***Sampling: Systematic, profiles from 0.3 - 9 km.***
- ***Species complement:***
- ***Species complement a subset of the priority species:***

Reactants and tracers: CH_4, CO, O_3.
Odd-nitrogen (NOx, NOy) : NOx (=NO+NO_2) + 1 (minimum) reservoir species.
Odd-hydrogen (HOy) precursors: one or more of: HCHO, H_2O_2, CH_3OOH.

- ***Model synthesis:*** *Calculate the reactivity along the flight track, constrained by ATom measurements, compare with reactivity statistics in a global model.*

2.3.2. Level 1 Baseline Requirements

The Level 1 Baseline Mission requirements are defined to achieve the complete set of Tier I science objectives. ATom's full contribution to atmospheric chemistry will be met if the mission delivers an extensive, robust statistical measure of the reactivity of air parcels over the central Pacific and Atlantic Ocean basins and these statistics are compared with those predicted by the leading U.S. chemistry-climate models. Further, we expect to be able to partition the activity of the most reactive air parcels (e.g., those with high rates of methane loss and ozone production) in remote regions to natural sources versus human pollution. The Baseline Mission includes all of the threshold requirements above in addition to the following:

- ***Attain the core goals of ATom globally, including direct observation of seasonal shifts, NOx- and hydrocarbon-limited, wide range of human influence.***
- ***Domain: 80N – 65 S, Pacific and Atlantic.***
- ***Sampling: Systematic, profiles from 0.3 – 9 km, some 0.15 - 12 km, remote oceans + some coastal; TCCON overflights.***
- ***Seasons:*** *four seasons, or three with a repeat of one. At least one high-sun boreal summer (Jun-Jul-Aug) to capture the highest impacts of human pollution on reactivity.*
- ***Species complement: a subset of the priority species***

Reactants and tracers: CH_4, CO, O_3
Odd-nitrogen (NOx, NOy) : NOx (=NO+NO_2) + 2 reservoir species.
Odd-hydrogen (HOy) precursors: one or more of: HCHO, H_2O_2, HNO_4.
Tracers: fingerprint processes and regions controlling diffuse pollution: biomass burning tracers, CO_2, N_2O, industrial gases, solvents.
GHGs and ODSs: Global cross sections for satellite validation and source model analysis.
Aerosol: Global Atlantic / Pacific cross sections of BC; global new particle and accumulation mode data; elemental composition.

- ***Model synthesis:*** *Calculate the reactivity along the flight track, strongly constrained by ATom measurements, compare with reactivity statistics in a global model.*
- ***Species complement: reactive gases*** *to measure reactivity: CH_4, CO, O_3.*
- ***Tracers:*** *fingerprint processes and regions controlling diffuse pollution: biomass burning tracers, CO_2, N_2O, industrial gases, solvents.*
- ***GHGs and ODSs:*** *Global cross sections for satellite validation and source model analysis.*
- ***Aerosol:*** *Global Atlantic / Pacific cross sections of BC; global new particle and accumulation mode data; elemental composition.*
- ***Model synthesis:*** *Calculate the reactivity along the flight track, strongly constrained by ATom measurements, compare with reactivity statistics in a variety of global models, quantitatively assess strengths and weaknesses.*

3. Technical Approach

ATom is a 5-year project. The central components of the project are four deployments of the NASA AFRC DC-8 aircraft; each deployment will last ~ 35 days. The four deployments will be conducted over three years with each deployment conducted during a different season. Each deployment includes 10 flights to acquire Pacific and Atlantic cross sections, along a repeated, prescribed flight path (**Figure 3.1, ATom Flight Path**) from 85°N to 65°S. Nearly continuous vertical profiling (from 0.15 (over water) or .5 (over land) through 12 km) en route provides approximately 144 equally spaced profiles for each deployment with a climb or descent being initiated every 20-30 minutes. With this plan the project will acquire approximately 576 total vertical profiles from the four deployments. All deployments originate at NASA Armstrong Flight Research in Palmdale, California. The first flight is a round trip flight from/to Palmdale along a meridian in the tropical east Pacific to capture as much as possible of the chemical differences between the central and eastern Pacific induced by the Walker circulation and distance from pollution sources. Any latent issues with the payload can be addressed in Palmdale after this flight as there are two down days prior to departure on the remainder of the 9 flight global circuit.

The deployments then proceed to the Western Arctic and North Pole vicinity, transect the Pacific southward, cross the South Pacific, then proceed northward over the Atlantic and return to California via the Canadian High Arctic and central US. Planned stops include Anchorage, Alaska; Kona, Hawaii; Pago Pago, American Samoa; Christchurch, New Zealand; Punta Arenas, Chile; Ascension Island, British Overseas Territory; Azore Islands, Portugal and, for the last three deployments, Thule, Greenland. The first deployment will stopover in Kangerlussuaq , Greenland due to work that will be taking place on the runway at Thule. ATom uses low-risk airspace to provide a contiguous, global scale data set sampling remote ocean basins. All stopover locations have been used for previous NASA Airborne Science missions and all will have been visited, during dedicated site surveys, prior to the commencement of the ATom-1 deployment. Alternate locations are available and will be investigated should, for some unforeseen reason, one or more of the originally identified sites be unavailable or unusable. Divert sites, should they be needed due to an inflight emergency, will be identified by the flight crew prior to all departures.

ATom tracks provide snapshots of the integrated effects of pollution outflow from Asia, Europe, North and South America, Africa and Australia. Most instruments sample the atmosphere every second resulting in ~ 10 m vertical and ~ 250 m horizontal resolution. At latitudes above 50° ATom samples through the upper troposphere into the lower stratosphere; at lower latitudes and in the tropics the 12-km aircraft ceiling is sufficient to sample into the upper troposphere (**Figure 4.2, ATom Flight Strategy**).

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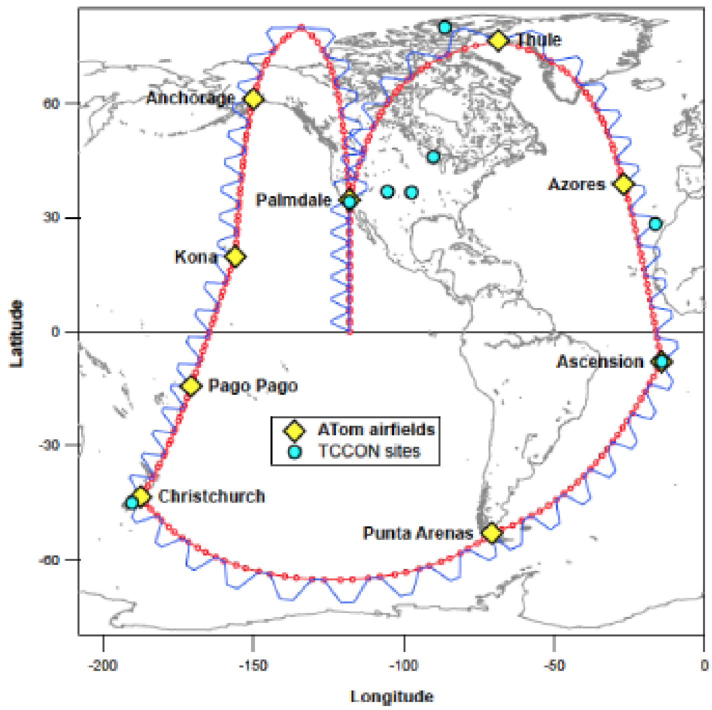

Figure 3.1 ATom Flight Path

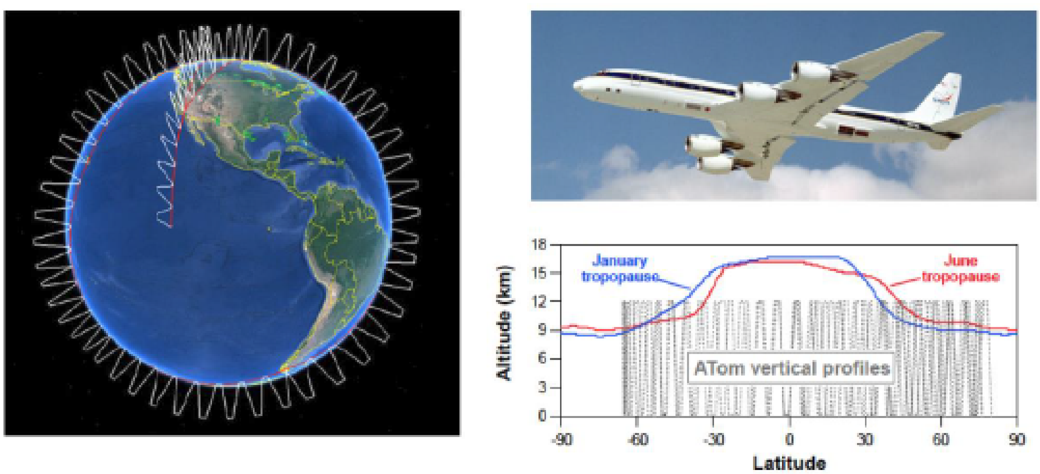

Figure 3.2 ATom Flight Strategy

Figure 3.3, Palmdale/Palmdale Flight Plan, shows the current flight plan for the Palmdale/Palmdale flight that will begin each deployment. The figure shows the Flight Information Region (FIR) boundaries that the flight will cross, Total Carbon Column Observing Network (TCCON) sites (a number of which ATom will directly overfly to obtain collaborative measurements) and typical vertical profile maneuvers.

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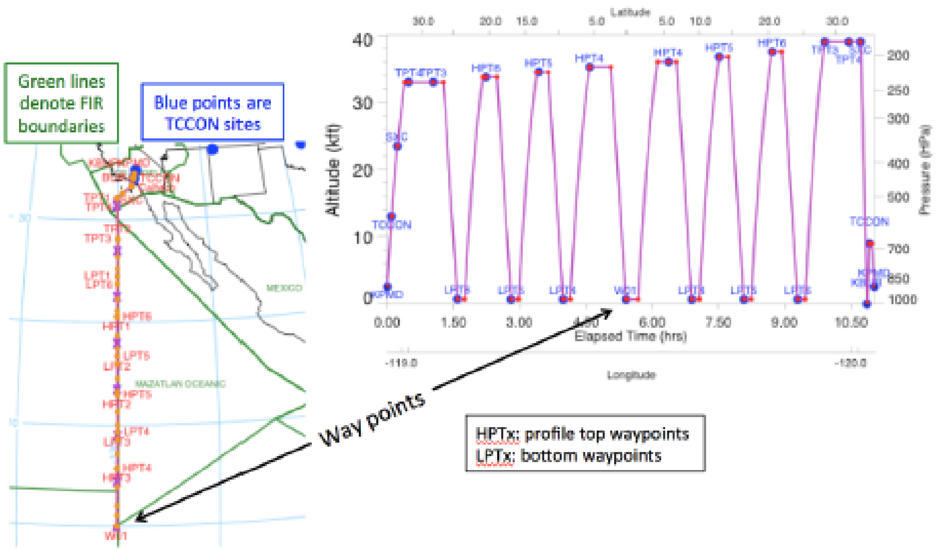

Figure 3.3 Palmdale/Palmdale Flight Plan

ATom defines the chemical and microphysical atmospheric state for comparison to models in terms of both probability distributions and as specific realizations at the times of ATom observations. ATom expects to encounter distinct plumes of continental pollution, stratospheric intrusions, and biomass burning in both ocean basins, representing the high tails of probability distributions for many species concentrations. The systematic sampling in very remote areas guarantees characterization of the "background" median and low tails as well.

Data from HIPPO Pacific flights showed that probability distributions of short-lived species such as PAN were very similar for repeated transects two weeks apart, demonstrating that the statistics over long latitudinal transects are relatively insensitive to the particulars of episodic transport events encountered in a given deployment. ATom deployments capture the seasonal dependence of natural and anthropogenic emissions sources, transport, and atmospheric sinks. ATom will quantify the different influences of dry and wet season fires, winter and summer anthropogenic emissions, and El Niño–Southern Oscillation (ENSO) phase (if one occurs; 2016 looks very promising as of this writing) and assesses the fidelity of simulations by global chemistry-climate models. ATom instruments have all operated in "point-to-point" flights away from a fixed base of operations, helping to ensure successful participation in ATom and reducing risk. Periods between deployments afford the PIs, science teams, and the public time for data analysis, model evaluation, synthesis and publication of results (**Figure 6.1, ATom Project Schedule**).

ATom flight planning is relatively straightforward. Systematic sampling dictates a flight strategy that avoids flying into unsafe weather, but otherwise follows a pre-determined pattern with minimal deviation (e.g., a permitted deviation might place the DC-8 closer to a satellite overpass). "Plume chasing" will be avoided to reduce sampling bias. Following a forecast, weather briefing and 3-hour instrument preflight, ATom flights will generally launch early morning local time (or choose a flight time for convenience to both takeoff and landing) with flights lasting from approximately 6 to 11 hours. Science data will be taken from launch to landing. At least one day is scheduled between successive flights to provide time for the PI and science team to evaluate instrument performance, upload data and undertake flight preparations and maintenance before continuing on the circuit. AFRC management has approved the waiver of the requirement of an aircraft crew wide "hard down" day every 8th day. Adequate rest will be provided to the aircraft crew using a schedule of individual down days. Additional days are included in the schedule and will be used for crew rest or to avoid weather problems.

3.1. Platform System Capabilities

The NASA DC-8 has the payload capacity (30,000 lb.), flight endurance (up to 12 h, with a 5,400 NM range), and altitude range (boundary layer to 12km) that are well suited for the ATom mission. Furthermore, the DC-8 has sufficient sampling and exhaust ports for the ATom instrumentation suite and adequate seating, cargo capacity, and room to allow mission and instrument PIs to monitor their instruments during flight. The large payload capacity of the DC-8 reduces risk to ATom science goals by permitting a full onboard complement of trained science personnel to promptly identify and address any instrument issues, and on-board transportation of instrument consumables and hardware spares for each sensor. The aircraft will also carry aircraft spares of critical components. The ATom instruments have been reviewed by the NASA Armstrong Flight Research Center Building 703 engineering staff and do not require any major structural or instrumental modifications to be integrated into the DC-8. The requirements needed and the sequence used to upload instruments onto the aircraft will be developed and coordinated through the DC-8 Payload Engineer, Project and Deputy Project Managers and the individual instrument teams. The AFRC engineering staff has developed an instrument loading floor plan that integrates the science payload onto the DC-8 to best address power, inlet performance and center of gravity considerations (**Figure 3.1, ATom DC-8 Floorplan**). The DC-8 supports the ATom payload space, weight, and power with substantial margins (**Table 3.1, ATom Payload Instrument Summary**) while simplifying the logistics and reducing mission risk. Additionally the DC-8 cargo capacity provides the space required for the needed aircraft parts and tools so that when a/c schedule based maintenance is required the work can be performed at any of the remote deployment sites, thereby further reducing mission risk. The DC-8 altitude range and flight speeds, coupled with the ATom instrumentation sampling characteristics, will provide science-quality data with horizontal and vertical spatial resolution that meet or exceed the key ATom science measurement goals (**Table 8.2, ATom Airborne Measured Data Products**).

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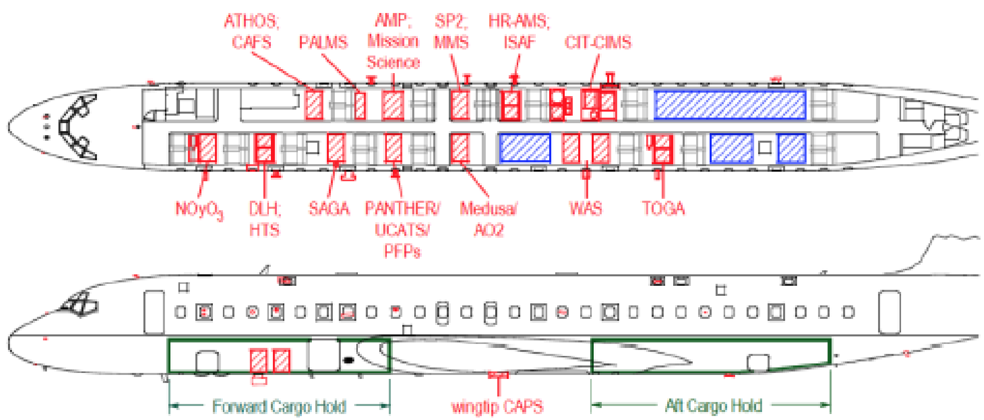

Figure 3.1 ATom DC-8 Floorplan

Table 3.1 ATom Payload Instrument Summary

Instrument	Mass (lb.)	Volume (ft^3)	Power (kW) 60 Hz	Power (kW) 400 HZ
AMP	275	16	0.5	-
AO2	298	17	1.0	-
ATHOS	1000	88	2.0	2.8
CAFS	60	8	0.5	-
CIT-CIMS	860	65	5.0	-
DLH	70	4	0.2	-
HR-AMS	520	36	0.8	0.2
ISAF	100	9	0.6	0.6
Medusa	211	17	-	.4
MMS	150	7	0.3	1.5
$NOyO_3$	850	55	0.4	5.0
PALMS	613	39	.9	.4
PANTHER/UCATS	280	35	0.3	-
PFP	21	1	.5	-
HTS	425	55	0.4	0.6
SAGA	760	40	2.3	0.2
SP2	130	12	0.3	-
TOGA	680	40	1.3	0.2
WAS	650	72	1.2	-
TOTALS	**7953**	**616**	**18.5**	**11.9**
DC-8 Maxima	30000	10,370	41	55
Margin	**22047**	**9754**	**22.5**	**43.1**

3.2. Hazard Avoidance

The DC-8 employs equipment, systems design, and system redundancy to mitigate potential operational hazards. Four engines, and related subsystems, provide positive margins in any flight phase even after total loss of an engine. Among other safety features the DC-8 carries onboard oxygen systems and smoke masks for all individuals, modern weather radar to identify and avoid severe weather, radar altimeters for positive situational awareness of ground proximity, a Traffic Collision Avoidance System for aircraft avoidance, and satellite communications for relaying continuous aircraft position and status information to team personnel on the ground.

3.3. Communications

Standard commercial aircraft communication onboard the DC-8 is augmented by INMARSAT and IRIDIUM satellite communications systems. These systems provide global coverage, including the polar regions, as well as real-time mission tracking, document sharing, and real time text messaging (IRC X-Chat) via the mission-specific website on the NASA Airborne Science Programs Mission Tools Suite. The IRC X-Chat permits interaction with mission participants worldwide. The DC-8 communications suite has been recently modernized to include Controller-Pilot Data Link Communications (CPDLC), which is part of the new Future Air Navigation System upgrade to worldwide air traffic control. CPDLC provides Air Traffic Control (ATC) text communications through a satellite link and ensures clear and prompt ATC requests and clearances. CPDLC permits efficient course and altitude change requests and clearances anywhere on the globe, especially outside of ATC radar coverage. This capability will enable ATom vertical profiles through 12 km altitude in the remote ocean basins.

3.4. Contingencies

The DC-8 aircraft systems are completely separate from the science payload; a science instrument failure cannot affect the flight systems. In the event of a flight systems issue, the DC-8 will land at the nearest safe location for repairs. All flight participants complete safety training prior to flying on the DC-8 at either AFRC or in the field. The ATom payload has been reviewed and notionally approved by AFRC staff. The entire mission payload must still undergo final review by AFRC Center subject matter experts prior to installation on the DC-8.

3.5. Science Instrumentation

The ATom instruments are all part of an integrated mission design. The ATom proposal contained a suite of 16 instruments. Since the proposal was selected three instruments have been added to the proposed suite: the Airborne Oxygen instrument (AO2)/ Medusa whole air sampler, the Particle Analysis by Laser Spectrometry (PALMS) and the Programmable Flask Package (PFP) whole air sampler. These instruments will be provided at no cost to the project for the ATom-1 deployment. The additional instruments were selected on the basis of their scientific contribution to ATom goals. Sixteen of the twenty ATom instruments have flown previously on the NASA DC-8. The remaining four will have been through both a 4.5 and 6.5-hour test flight prior to the first deployment flight. The first deployment flight is a round trip flight from/to Palmdale followed by two days of instrument access. These fights, and instrument access time, should provide the instrument teams ample opportunity to prepare the instruments for the following deployment flights. Engineering characteristics of all instruments are listed in **Table 3.1, ATom Payload Instrument Summary**, and measurement performance is listed in **Table 8.2.1, ATom Airborne Measured Data Products.** Many of the ATom instruments are regularly calibrated while in flight using known gas-phase standards added to the air sampling probes to characterize instrument performance under authentic flight conditions. All instruments are rigorously calibrated in the PI laboratories before and after each deployment, according to standards developed for each instrument and published in the peer-reviewed literature. Short instrument descriptions follow.

3.5.1. AO2: Airborne Oxygen Instrument (B. Stephens, NCAR)

(http://www.eol.ucar.edu/homes/stephens/AO2) AO2 measures O_2 concentration using a vacuum-ultraviolet absorption technique. AO2 is based on earlier ship-board and laboratory instruments using the same technique, but has been designed specifically for airborne use to minimize motion and thermal sensitivity and with a pressure and flow controlled inlet system. To achieve the high levels of precision needed, AO2 switches between sample gas and air from a high-pressure reference cylinder every 2.5 seconds. Atmospheric O_2 concentrations are typically reported in units of one part in 1,000,000 relative deviations in the O_2/N_2 ratio, which are referred to as "per meg." AO2 has a 1-sigma precision of ± 2 per meg on a 5 second measurement. For comparison, this is equivalent to detecting the removal of one O_2 molecule from 2.5 million molecules of air. The instrument includes an internal single-cell CO_2 sensor (LI-840), which is used to correct the O_2 measurements for dilution by CO_2 and for limited scientific purposes. To minimize inlet surface effects, the pressure in the inlet line is actively controlled at the aircraft bulkhead. The sample air is cryogenically dried in a series of electropolished stainless steel traps immersed in a dry ice Fluorinert slurry. The AO2 system consists of a pump module, a cylinder module, an instrument module, and a dewar.

3.5.2. AMP: Aerosol Microphysical Properties (C. Brock, NOAA)

AMP consists of three instruments to measure aerosol and cloud droplet concentration as a function of size at 1-second intervals. The nucleation-mode aerosol size spectrometer (NMASS) consists of five custom-built condensation particle counters (CPCs) operating in parallel; each CPC counts particles larger than a specific geometric diameter, providing size distribution information on particles from 4 to 55 nm diameter in 5 size intervals. The ultra-high sensitivity aerosol spectrometer (UHSAS) measures particles from 70-1000 nm in diameter in 100 size intervals. A cloud droplet probe (CDP) measures liquid and mixed-phase number as a function of size for cloud droplets and aerosol particles from 2-50 µm in diameter, providing sizing information on the coarse aerosol mode which is expected to be dominated by dust and sea-salt particles in the ATom measurements.

3.5.3. ATHOS: Airborne Tropospheric Hydrogen Oxides Sensor and OH Reactivity (W. Brune, PSU)

ATHOS uses laser-induced fluorescence to measure OH and HO_2 simultaneously, with data reported as 5-second averages. Ambient air is sampled into low-pressure detection cells, where OH is both excited and detected by a tunable UV laser; ambient HO_2 is converted using reagent NO to form OH that is then detected with LIF. The OH reactivity channel measures the total atmospheric loss rate of OH and provides an upper limit reference to compare with the sum of reaction rates calculated from measured concentrations of CO, CH_4, NO_2, VOCs and other reactants.

3.5.4. CAFS: CCD Actinic Flux Spectroradiometers (S. Hall, NCAR)

The CAFS provide spectrally-resolved in situ measurements of up- and down-welling ultraviolet and visible actinic flux from 280-650 nm at 3-second intervals. Photolysis frequencies for O_3, NO_2, HONO, HNO_3, HNO_4, PAN, H_2O_2, CH_2O, CH_3OOH and many other species are derived from the wavelength-resolved actinic flux measurements.

3.5.5. CIT-CIMS: Caltech Chemical Ionization Mass Spectrometers (P. Wennberg, Caltech)

The Caltech CIMS instrument incorporates two mass spectrometers that provide measurements at 1-second intervals of a suite of acids, peroxides, and organic nitrates. Inorganic acids (HNO_3, HNO_4) and organic acids (e.g., CH_3CO_2H, $CH_3CH_2CO_2H$) are detected by selective chemical ionization via fluoride transfer from the CF_3O^- reagent anion:

$$CF_3O^- + HX \rightarrow HF{\bullet}X^- + CF_2O$$

CF_3O^- is also used to ionize less acidic species (e.g., HCN, H_2O_2, CH_3OOH, $CH_3C(O)OOH$ (peroxyacetic acid)) via a clustering reaction:

$$CF_3O^- + HX \rightarrow CF_3O^-{\cdot}HX$$

3.5.6. DLH: Diode Laser Hygrometer (G. Diskin, NASA LaRC)

The DLH is an open-path tunable diode laser-based instrument, operating in the near-IR spectral region, measuring the atmospheric gas-phase H_2O mixing ratio by wavelength-modulated differential absorption at 1-second intervals. The DLH absorption path is external to the DC-8, and is formed between a laser transceiver and a retro-reflecting panel. The combination of external path and normalized second-harmonic detection yields an accurate measurement even in the presence of clouds and precipitation, and it is insensitive to interferences caused by the DC-8 itself (e.g., vaporization of condensed phase H_2O, cabin leaks, etc.).

3.5.7. HR-AMS: High Resolution Aerosol Mass Spectrometer (J. Jimenez, CU Boulder)

HR-AMS measures total submicron non-refractory particle composition by low-pressure vaporization of ambient particles on a tungsten vaporizer operated at 600°C, followed by electron impact ionization and time-of-flight mass spectrometric analysis. Size-segregated information is obtained by measuring particle arrival times at the vaporizer. HR-AMS provides 1-second data on particulate SO_4^{2-}, NO_3, Cl^-, NH_4^+, and organic mass concentrations, and measures mass spectral markers for organic acids, hydrocarbon-like organic aerosol, and biomass burning organic aerosol in real time. Post-flight data reduction generates derived products such as aerosol particle O/C, H/C, organic mass/organic carbon (OM/OC) ratios and organic nitrate ($RONO_2$) mass.

3.5.8. HTS: Harvard Tracer Suite (B. Daube, Harvard)

HTS is composed of two instruments based on absorption of near-infrared laser radiation in high-finesse optical cavities. A Picarro G2401-m analyzer based on wavelength-scanned cavity ring-down spectroscopy (CRDS) measures CO_2, CH_4, and CO concentrations at 2-second intervals. An Aerodyne Quantum Cascade Laser spectrometer measures N_2O and CO concentrations at 1-second intervals. Extensive modifications have been applied to these commercial analyzers for flight and include vibration isolation, temperature control, additional flow control and pumping capacity for high-altitude sampling, sample drying, and in-flight calibrations using WMO-traceable compressed gas standards to verify stable and accurate performance throughout the full DC-8 flight envelope.

3.5.9. ISAF: In Situ Airborne Formaldehyde (T. Hanisco, NASA GSFC)

ISAF detects formaldehyde in situ using laser-induced fluorescence. Ambient air is sampled into the instrument using a particle-rejecting inlet and formaldehyde is detected at 1-second intervals using a pulsed tunable fiber laser at a single rotational transition at 353.16 nm. The resulting fluorescence is detected with a photon counting photomultiplier tube. The laser is pulsed to aid in removing background signal, and the laser wavelength is tuned on and off resonance throughout the flight to ensure specificity in the detection of formaldehyde.

3.5.10. Medusa Whole Air Sampler (R. Keeling, UCSD)

Medusa collects 32 cryogenically dried, flow and pressure-controlled samples per flight. An automated sampler collects the samples in 1.5 L glass flasks that integrate over 25-s (1 e-fold) periods. Medusa provides discretely sampled comparisons for onboard in situ O_2/N_2 ratio and CO_2 measurements and unique measurements of Ar/N_2 plus the ^{13}C, ^{14}C, and ^{18}O isotopologues of CO_2. The complementary measurements of O_2/N_2 and CO_2 provide a check of onboard instrument calibrations. Isotope and argon measurements provide additional information about land and ocean controls over the carbon cycle, and about the age and source of the air sampled. Medusa consists of an onboard computer, two pressure controllers, two pumps, three multi-position selector valves, and a host of other hardware that control and direct the air samples. All air is dried by passing it through traps immersed in a -78°C dry ice bath, adjusted to match atmospheric pressure at sea level, and then isolated in flasks. The Scripps O_2 Program at Scripps Institution of Oceanography analyzes Medusa flasks using a sector-magnet mass spectrometer and a LiCor non-dispersive infrared CO_2 analyzer.

3.5.11. MMS: Meteorological Measurement Systems (T. Bui, NASA ARC)

MMS provides calibrated, high-resolution meteorological parameters (pressure, temperature, turbulence index, and the 3-dimensional wind vector) at 20 samples per second. MMS consists of three major systems: (1) an air motion sensing system to measure the air velocity with respect to the DC-8, (2) a motion sensing system to measure the DC-8 velocity with respect to the earth, and (3) a data acquisition system to sample, process and record the measured quantities. MMS provides accurate and precise measurements of ambient pressure, temperature, horizontal and vertical wind vectors, potential temperature, true airspeed, turbulence, GPS position, aircraft velocities, accelerations, pitch, roll, heading, angles of attack and sideslip, dynamic and total pressure, and total temperature.

3.5.12. NOyO3: Nitrogen Oxides and Ozone (T. Ryerson, NOAA)

The NOyO3 4-channel chemiluminescence (CL) instrument measures NO, NO_2, total reactive nitrogen oxides (NOy), and O_3. It provides fast-response, specific, high-precision, and calibrated measurements at high spatial resolution. Detection is based on gas-phase chemiluminescence reaction of NO with O_3 at low pressure, resulting in photoemission from electronically excited NO_2. Photons are detected using pulse counting techniques, providing ~10 part-per-trillion (ppt molecules per 10^{12} air molecules) precision at 1-second intervals. One CL channel is used to measure ambient NO directly, a second channel is equipped with a UVLED converter at 385 nm to selectively photo dissociate ambient NO_2 to NO, and a third channel is equipped with a heated gold catalyst to reduce ambient NOy species to NO. Reagent ozone is added to these sample streams to drive the CL reactions with NO. Ambient O_3 is detected in the fourth channel by adding reagent NO.

3.5.13. PALMS: Particle Analysis by Laser Mass Spectrometry (K. Froyd, NOAA)

The NOAA PALMS instrument measures single-particle aerosol composition using UV laser ablation to generate ions that are analyzed with a time-of-flight mass spectrometer. The PALMS size range is approximately 150 to >3000 nm and encompasses most of the aerosol volume. Particle mass spectra allow individual aerosol particles to be classified into broad compositional categories: sulfate-organic mixtures, biomass burning, elemental carbon, mineral dust, sea salt, meteoric, industrial, and oil combustion. The size-dependent composition data will be combined with aerosol counting instruments from the Aerosol Microphysical Properties (AMP) group to generate quantitative, composition-resolved aerosol number and volume. Background tropospheric concentrations of climate-relevant aerosol including mineral dust, sea salt, and biomass burning particles are the primary foci for the ATom campaigns. PALMS also provides a variety of compositional tracers to identify aerosol sources, probe mixing state, track particle aging, and investigate convective transport and cloud processing.

3.5.14. PANTHER/UCATS: PAN and other Trace Hydrohalocarbon ExpeRiment / Unmanned aircraft systems Chromatograph for Atmospheric Trace Species (J. Elkins, NOAA)

PANTHER is a 6-channel gas chromatograph (GC) that uses 4 electron capture detectors (ECDs), each sampling for 3 seconds every 1-2 minutes depending on the channel, and 2 mass selective detectors sampling for 150 seconds every 3 minutes, to permit parallel analysis of ambient air for halocarbons, greenhouse gases, molecular hydrogen, and sulfur compounds. UCATS is an independent 2-channel gas chromatograph with 2 ECDs, each sampling for 3 seconds every 2 minutes. UCATS also includes a modified commercial UV photometer to quantify atmospheric O_3 every 5 seconds and a commercial tunable diode laser spectrometer to quantify atmospheric H_2O every second, providing some redundancy for the primary measurements of these species.

3.5.15. PFP: Programmable Flask Package Whole Air Sampler (Steve Montzka and Colm Sweeney, NOAA/CU)

The PFP whole air sampler provides a means of automated or manual filling of glass flasks, twelve per PFP, with two PFPs sampled per flight. The sampler is designed to compress ambient air into 700 cm^3 flasks after removing excess water vapor. Flasks are analyzed at NOAA's Global Monitoring Division laboratory for trace gases and at

INSTAAR's Stable Isotope Lab for the ^{13}C isotopologue of methane. More than 60 trace gases are measured at mole fractions ranging from parts-per-million (10^{-6}), e.g., carbon dioxide) down to parts-per-quadrillion (10^{-15}, e.g., HFC-365mfc and CH_3I). The chemical species monitored include N_2O, SF_6, H_2, OCS, CO_2, CH_4, $^{13}CH_4$, CO, and multiple CFCs, HCFCs, HFCs, perfluorocarbons, methyl halides, solvents and other hydrocarbons.

3.5.16. SAGA: Soluble Acidic Gases and Aerosol (J. Dibb, UNH)

SAGA is composed of two related instruments: a mist chamber/ion chromatograph (MC/IC) system that provides on-line data for selected soluble species (**Table 8.2.1**), and a bulk aerosol system that collects atmospheric particles ≤5 microns in diameter onto filters for offline analysis. The MC/IC system alternates between 2 channels; one is always collecting a 90-second integrated air sample while the other channel is analyzing its previous sample. Paired filter samples are continuously acquired for 5 minutes at altitudes below 15,000 feet and for 10 minutes above this altitude. Changing both filters in the dual probe system requires 2 minutes.

3.5.17. SP2: Single-Particle Soot Photometer (J. Schwarz, NOAA)

SP2 is a laser-induced incandescence instrument that measures black carbon (BC) mass content of individual atmospheric particles at 1-second intervals, and thus delivers detailed information on BC mass loadings and size distributions, even in exceptionally clean air. Ambient air is drawn through an intense intra-cavity laser at 1.064 µm wavelength. Aerosol particles enter the laser beam singly, and scatter laser light according to their size and composition. When a BC-containing particle enters the laser, it is heated to vaporization (~3500K), emitting blackbody radiation (incandescent light) in quantities directly related to its BC mass content, regardless of particle morphology or mixing state. SP2 also identifies the presence of coatings via a custom-built detector system that provides optical size information on BC-containing particles before they are perturbed by laser heating. This allows quantification of the amount of non-BC material associated with each BC core, and its impact on the optical properties of the BC component.

3.5.18. TOGA: Trace Organic Gas Analyzer (E. Apel, NCAR)

TOGA provides an on-line, in situ measurement of a variety of VOCs, including non-methane hydrocarbons, oxygenated VOCs, halogenated VOCs, acetonitrile, and alkyl nitrates in the C1–C10 range. A custom-made gas chromatograph is coupled to a quadrupole mass spectrometer operated in single ion mode for selective trace gas detection at ppt to sub-ppt mole fractions in the atmosphere. A custom–made gas standard is coupled to an on-board dynamic dilution system for in-flight instrument calibration by overflowing the inlet. TOGA samples are acquired by collecting ambient air for 30 seconds every 2 minutes during flight.

3.5.19. WAS: Whole Air Sampler (D. Blake, UCI)

WAS consists of multiple sets of 24 linked, 2-liter stainless steel air sampling canister assemblies ("snakes"), a pump and associated sample tubing. WAS canisters take between 15 and 90 seconds to fill, depending on altitude. ATom carries 100 canisters per flight, providing one WAS sample approximately every 6 minutes on a typical 10-hour flight. Following a flight, onboard full WAS snakes are replaced with new ones. Each filled canister is returned to the Blake laboratory at UC-Irvine and analyzed on the 6 column–6 detector GC system for a variety of trace gases including C2-C10 alkanes, C2-C5 alkenes, C6-C9 aromatics, C1-C2 halocarbons, C1-C5 alkyl nitrates, and selected sulfur compounds. WAS analyses also provide a back-up capability for in situ measurements of CO and CH_4. Canisters still contain 4 liters of residual ambient air following chromatographic analysis at UCI. This residual is sufficient for additional analyses (e.g., for stable isotopologues of CH_4 or N_2O) but these analyses are not included in the core ATom data products.

3.6. Global Chemistry Models

The ATom model-derived products are basically the 24-hour integrated rates of reactivity (loss of CH_4, production of O_3, loss of O_3, plus formation of aerosol sulfate and organic matter) and will be produced using a range of global chemistry-climate models (CCMs) and chemistry-transport models (CTMs). These computations will be done by the global modeling team (Michael Prather, UC Irvine; Arlene Fiore, Columbia U.; Jean-Francois Lamarque, NCAR; Jose Rodriguez, NASA GSFC) using a range of CCM/CTMs available at the time: e.g., UCI CTM, GFDL AM3, GEOSChem, GSFC GEOS CCM, and NCAR CESM CAM/WACCM.

4. Management Approach

The ATom management team (**Figure 4.1, ATom Management Organization Chart**) will manage the project in accordance with NPR 7120.8: NASA Research and Technology Program and Project Management Requirements. Overall scientific and technical leadership and direction, including the development of the science requirements and flight planning, will be established by Dr. Steven Wofsy, Principal Investigator. Dr. Michael Prather, Deputy Principal Investigator, will assist Dr. Wofsy in overall scientific and technical leadership and direction of the project. The Principal Investigator is also responsible for ensuring ATom's science goals are met on time and within budget.

Mr. Dave Jordan, as Project Manager, is responsible for the Project Implementation Plan, schedule development and tracking, deployment operational planning, project cost tracking and risk management and mitigation planning and reporting. The Project Manager is also the Technical Officer for all ATom Cooperative Agreements with the exception of the Cooperative Agreement for Harvard, for which Jennifer Olson of the ESSP is the Technical Officer. Mr. Erin Czech, as Deputy Project Manager, is responsible for assisting the PM in project and deployment organization, coordination and conduct and schedule and risk tracking. The PM will make project documents available to team members through an ESPO-managed website. Bi-weekly management team teleconferences will be held during the life of the project with the frequency increasing to weekly approximately 3 months ahead of deployments. Full project team teleconferences will be held monthly over the life of the project with the frequency increasing to twice monthly approximately 3 months ahead of deployments. Project directions and plans, including detailed plans for the deployments, will be formulated by the management team and discussed and refined during management team teleconferences. The directions and plans will then be communicated to the entire project team during the full project team teleconferences. After the commencement of deployment instrument upload activities management and full project team meetings will be held, as required, to communicate direction and plans as well as issues, problems and project risks. The project will be managed as a flat organizational structure in order to promote open communication between all team members.

Reporting to the ESSP Program Office will be in the form of teleconferences and documents as requested. Lessons learned will be collected and compiled at the end of each deployment, reviewed at a subsequent science team meeting (in person or via teleconference) and applied to subsequent deployments.

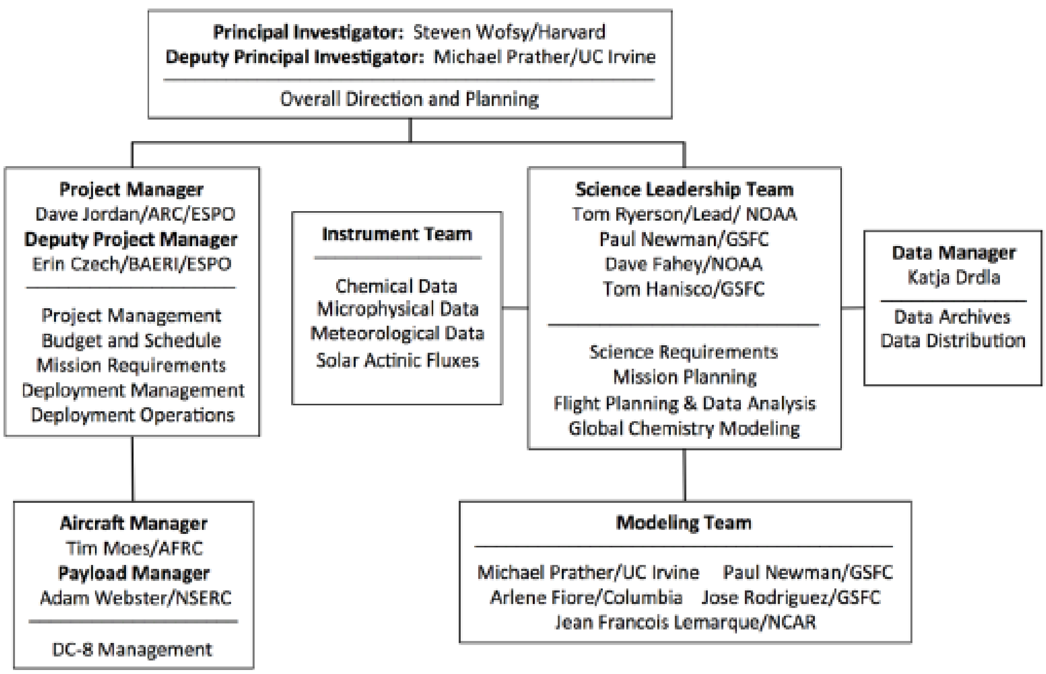

Figure 4.1 ATom Management Organization Chart

4.1. Deployment Management

Prior to the first ATom deployment site surveys of all of the deployment stopover sites will be conducted to ensure that each site can fulfill all project requirements (adequate runways, airport security, air traffic control, aircraft supplies, ground handlers, instrument consumable vendors, lodging, transportation, medical services, etc.). One orientation document will be developed, and will be distributed to the project's participants prior to departure from Palmdale, that will cover all layover locations. Due to the unique nature of the ATom project deployments, i.e., a sequential series of stopovers along a round trip loop, the management of the deployments will be achieved using a team of five ESPO Site Managers. The site surveys will include, at a minimum, the Project Manager and Deputy Project Manager (who will also function as Site Managers and, as such, will cover four of the eight stopover sites) except for the Punta Arenas, Chile site survey. The DC-8 has been in Punta Arenas, for Operation Ice Bridge (OIB), many times. The ATom Site Manager that is responsible for the Punta Arenas stopover for ATom-1 is the current OIB Deployment Manager, Mr. Jhony Zavaleta. The ATom Project Management decided that due to Mr. Zavaleta's familiarity and experience operating the DC-8 from Punta Arenas it wasn't necessary to have others involved in the Punta Arenas site survey. Mr. Zavaleta will conduct the ATom Punta Arenas site survey while he is there for the 2015 OIB project's deployment. For all other site surveys the Site Manager will be included in the dedicated site survey. The ATom Project Management believes experienced gained in ATom-1 will allow flexibility, with reduced risk, in Site Manager assignments over the remainder of the project. The site surveys ensure that all necessary arrangements, contracts, etc. are in place before the DC-8 arrives.

All required diplomatic clearances will be obtained working through NASA's Office of International and Interagency Relations. The OIIR Point of Contact is Judy Dove. The U.S. State Department, through the Bureau of Political/Military Affairs (PM/ISO) has recently (the ATom project was notified on January 27th, 2016) instructed NASA to request diplomatic aircraft clearances through use of the Department of Defense Automated Aircraft and Personnel Clearance System (APACS). Starting in March the OIIR will be responsible for the submission of diplomatic clearance requests via the APACS. NASA will use this new approach on a trial basis. The initial effect is that more project specific information (i.e., entry and exit points and at what approximate times will the aircraft be within the airspace of each country listed in the itinerary, passengers/crew and nationalities, fuel and logistics requirements and payment type information, exact dates of planned flights, etc.) will be required for the clearance submission. It is not known, at this time, if the process will be faster or slower than the process that has been used in the past. APACS has been used for clearances required to fly into/out of U.S. military installations. It remains to be seen how it will apply to flying into/out of commercial airports. The OIIR has requested all information required for the submission of ATom clearances be provided to them no later than April 1, 2016.

A Mission Scientist and a deputy, usually the ATom PI or Deputy PI, will be onboard the aircraft for each flight of each deployment. The Mission Scientist and deputy represent the entire payload. They will review and perform quick-look QA/QC on data from each flight. The Mission Scientist is responsible for all scientific decisions affecting flights and schedules in the field and is the principal interface with the Mission manager and Operations for the deployment.

A Site Manager will arrive at each deployment stopover location 2-3 working days prior to the aircraft's arrival. The Site Manager will contact airport officials, the aircraft ground handler, immigration and customs officials (if applicable), lodging and transportation representatives and the local instrument consumable vendor(s) to ensure preparedness to fulfill project requirements. After the aircraft's arrival the Site Manager will function as the liaison between project personnel, aircraft and science, and the local service providers. After the aircraft's departure the Site Manager will remain at the stopover site for 1-2 business days to ensure proper close out of all support tasks.

5. Resources Required

Table 5.1, ATom Budget Manpower Requirements by NASA Center, shows the ATom budget, covering the entire life cycle of the investigation, by procurement, travel and labor full cost dollars. The Ames Research Center budget includes the Project Manager and Deputy Project Manager, funding for the MMS instrument and all 11 NASA/University Co-operative Agreements as well as mission peculiar costs. The funding for the Deputy PI is included in the NASA/University of California, Irvine cooperative agreement. The Armstrong Flight Research Center budget includes all DC-8 integration and operation activities. The Langley Research Center includes funding for the PI and HTS sensor as well as the DLH instrument, the NASA HQ budget includes funding for the NOAA Interagency Transfer and the Goddard Space Flight Center budget includes funding for three Co-Investigators and the ISAF instrument. Table 6.1 represents the baseline budget. The phasing of this baseline budget may be modified during the annual Planning, Programming, Budgeting and Execution (PPBE) process. If an adjustment is required between budget inputs it will need approval by the ESSP Program Office.

Table 5.1 ATom Budget and Manpower Requirements by NASA Center

Total Direct Budget	Category	Total ($K)	FY15 ($K)	FY16 ($K)	FY17 ($K)	FY18 ($K)	FY19 ($K)	FY20 ($K)
Total	Direct $	**29852.0**	**2373.9**	**6652.4**	**10130.0**	**6624.6**	**3110.7**	**960.4**
	Proc	**23701.7**	1994.6	5084.7	7902.3	5291.0	2587.4	841.7
	Travel	**671.4**	92.7	144.0	269.3	141.6	16.1	7.6
	Labor	**2435.2**	183.9	545.4	705.1	602.3	348.3	50.4

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	Reserve	**3043.7**	102.8	878.4	1253.2	589.7	158.9	60.8
	FTE	**11.53**	**0.95**	**2.69**	**3.33**	**2.74**	**1.50**	**0.32**
	WYE	**9.17**	**0.61**	**2.07**	**2.34**	**2.05**	**1.61**	**0.49**
Total Direct Budget	**Category**	**Total ($K)**	**FY15 ($K)**	**FY16 ($K)**	**FY17 ($K)**	**FY18 ($K)**	**FY19 ($K)**	**FY20 ($K)**
HQ	Direct $	**3439.6**	**439.2**	**684.5**	**1004.6**	**741.5**	**413.6**	**156.2**
	Proc	**3439.6**	439.2	684.5	1004.6	741.5	413.6	156.2
	Travel	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
	Labor	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
	FTE	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
	WYE	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
ARC	Direct $	**13772.7**	**1218.9**	**2813.3**	**4218.2**	**3035.3**	**1757.4**	**729.5**
	Proc	**12138.2**	1027.9	2456.6	3686.9	2647.0	1634.3	685.5
	Travel	**310.4**	53.8	58.9	120.7	62.4	6.9	7.6
	Labor	**1324.1**	137.1	297.9	410.6	325.9	116.2	36.4
	FTE	**6.15**	0.70	1.45	1.90	1.45	0.50	0.15
	WYE	**4.75**	0.41	0.95	1.25	0.95	0.70	0.49
AFRC	Direct $	**5542.0**	**100.0**	**1361.0**	**2720.0**	**1361.0**	**0.0**	**0.0**
	Proc	**5161.0**	70.0	1273.0	2545.0	1273.0	0.0	0.0
	Travel	**270.0**	30.0	60.0	120.0	60.0	0.0	0.0
	Labor	**111.0**	0.0	28.0	55.0	28.0	0.0	0.0
	FTE	**0.49**	0.00	0.12	0.25	0.12	0.00	0.00
	WYE	**0.16**	0.00	0.08	0.00	0.08	0.00	0.00
LaRC	Direct $	**2478.0**	**446.0**	**543.0**	**554.0**	**500.0**	**421.0**	**14.0**
	Proc	**2213.4**	418.0	493.3	492.7	438.1	371.2	0.0
	Travel	**12.6**	3.0	2.3	2.4	2.5	2.6	0.0
	Labor	**252.0**	25.0	47.4	58.9	59.4	47.2	14.0
	FTE	**1.42**	0.15	0.28	0.34	0.33	0.25	0.07
	WYE	**1.05**	0.10	0.26	0.31	0.24	0.14	0.00
GSFC	Direct $	**1576.0**	**67.1**	**372.2**	**380.0**	**397.0**	**359.8**	0.0
	Proc	**749.5**	39.4	177.2	173.2	191.3	168.4	0.0
	Travel	**78.4**	5.9	22.9	26.3	16.7	6.6	0.0
	Labor	**748.1**	21.8	172.1	180.6	188.9	184.8	0.0
	FTE	**3.47**	0.10	0.84	0.84	0.84	0.75	0.10
	WYE	**3.21**	0.10	0.78	0.78	0.78	0.77	0.00

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6. Schedule/Milestones

The current lifecycle schedule for the ATom project is shown in **Figure 6.1, ATom Project Schedule.** The green rectangles represent the four ATom deployments. With the exception of ATom-1 (**Figure 6.2, ATom-1 Schedule**) the remaining deployments do not have to be flown in the sequence shown, thus providing schedule margin and flexibility. Additionally there is more than a year remaining after the last planned deployment that, if needed, could be used for a deployment that had serious schedule conflicts. The ATom-2, -3 and -4 deployments are already on the DC-8 master schedule and, with the exception of scheduled aircraft maintenance in 2017 and 2018 and the Student Airborne Research Project in June of 2018, there are currently no competing requirements for the aircraft. Science Meetings are denoted with red arrows. Science Meeting #4 will be via teleconference due to the short interval between ATom-3 and -4.

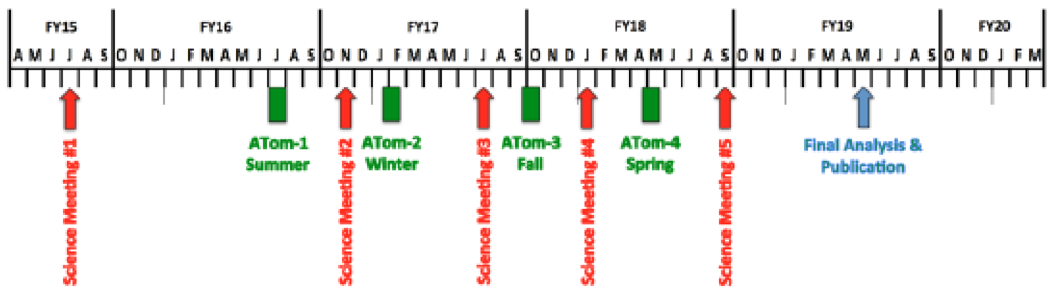

Figure 6.1 ATom Project Schedule

The following are the ATom Project's significant milestones.

<u>ATom Project Milestones:</u>

10/1/2015	Project Implementation Plan Due
1/21/2016	Confirmation Assessment
2/16/2016	Confirmation Decision Meeting
4/1/2016	Submission of flight clearance request for first deployment
6/15/2016	KORUS project ends
6/16/2016	KORUS initial download begins
6/17-18/2016	SARP project DC-8 flights (2 flights)
6/20/2016	KORUS final download begins
6/22/2016	ATom instrument upload begins
6/30/2016	ATom Technical Brief (AFRC)
7/11/2016	ATom shakedown flight

7/12/2016	4.5-hour test flight
7/13/2016	ATom problem resolution period begins
7/14/2016	ATom Operational Readiness Review (AFRC)
7/23/2016	ATom problem resolution period ends
7/26/2016	6.5-hour test flight
7/28/2016	ATom-1 deployment begins (PMD/PMD flight)
8/22/2016	ATom-1 deployment ends (SFJ/PMD flight)
8/23/2016	Atom-1 download begins
10/26/2016	Approval of flight clearances for second deployment
1/9/2017	Instrument upload for second deployment
1/26/2017	Second deployment departure date
6/28/2017	Approval of flight clearances for third deployment
9/11/2017	Instrument upload for third deployment
9/28/2017	Third deployment departure date
1/26/2018	Approval of flight clearances for fourth deployment
4/9/2018	Instrument upload for fourth deployment
4/26/2018	Fourth deployment departure date

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Activity Name	Duration (Days)	Start Date	Finish Date
ATom-1	66.00	6/22/16	8/26/16
Integration	34.00	6/22/16	7/26/16
Upload	18.00	6/22/16	7/9/16
Technical Brief	1.00	6/30/16	6/30/16
Shakedown	0.00	7/11/16	7/11/16
4.5-hr Test	0.00	7/12/16	7/12/16
Operational Readiness Review	1.00	7/14/16	7/14/16
Problem Resolution Period	11.00	7/13/16	7/23/16
6.5-hr Test	0.00	7/26/16	7/26/16
Flights	25.00	7/28/16	8/22/16
PMD - PMD	0.00	7/28/16	7/28/16
PMD - ANC	0.00	7/31/16	7/31/16
ANC - KOA	0.00	8/3/16	8/3/16
KOA - PPG	0.00	8/6/16	8/6/16
PPG - CHC	0.00	8/8/16	8/8/16
CHC - PUQ	0.00	8/12/16	8/12/16
PUQ - ASI	0.00	8/15/16	8/15/16
ASI - TER	0.00	8/17/16	8/17/16
TER - SFJ	0.00	8/20/16	8/20/16
SFJ - PMD	0.00	8/22/16	8/22/16
Download	4.00	8/23/16	8/26/16

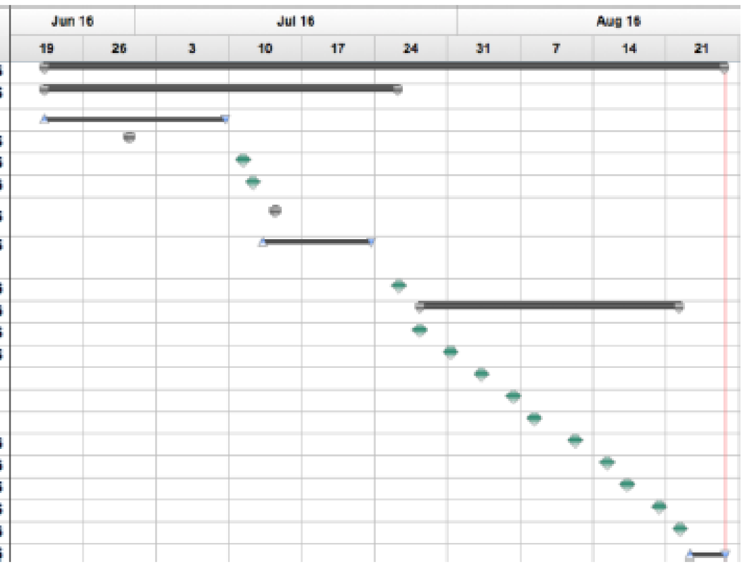

Figure 6.1.2 ATom-1 Schedule

7. Work Breakdown Structure

Figure 7.1, ATom Work Breakdown Structure, displays the Work Breakdown structure of the ATom project. Harvard's participation (Principal Investigator and HTS instrument) is funded directly from the Earth Science System Pathfinder (ESSP) office at Langley Research Center and NOAA's participation is funded directly through an Inter Agency Transfer (IAT) between NASA headquarters and NOAA's Earth System Research Laboratory (ESRL) in Boulder, Colorado.

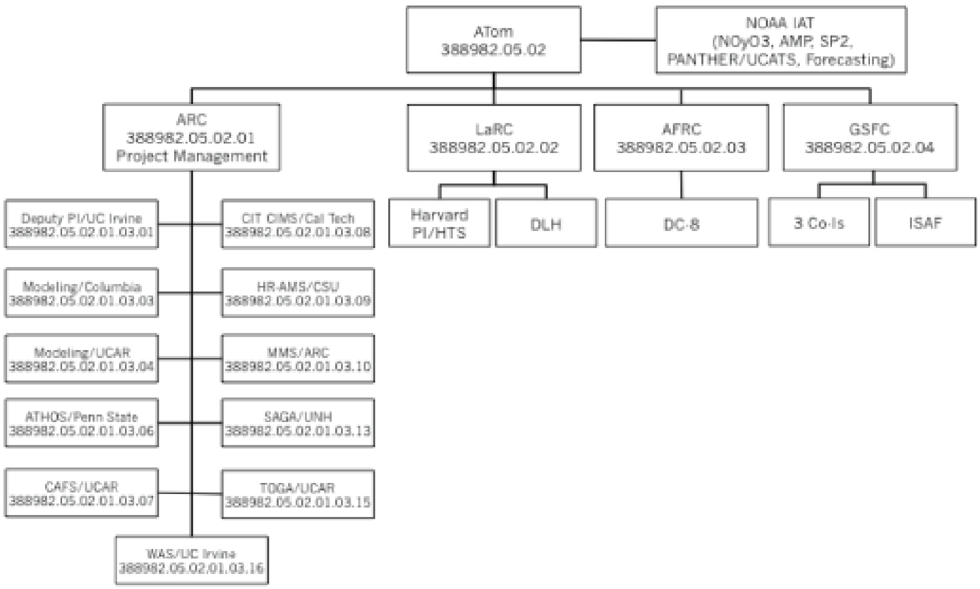

Figure 7.1 ATom Work Breakdown Structure

8. Data and Knowledge Management and Distribution

The goals of the ATom data management plan are to: 1) Ensure prompt data availability for in-field science team use, 2) Enable seamless interchange and gridding between observations and model simulations and analyses, 3) Provide timely public access to the final data archive and promote broader scientific use of the ATom data in addressing issues related to the statistical distribution of key species and reactivity/climate-forcing of air parcels. Data from each deployment will be released through a DOI address permanently registered at the NASA Langley Distributed Active Archive Center (DAAC). It may physically reside at the ATom data center, which will house all the active data sets during the deployments. At the end of the ATom mission all public release data sets will be transferred to the DAAC for archive without change of DOI.

8.1 ATom Science Data Flow

Figure 8.1, ATom Science Data Flow, illustrates the end-to-end data flow from initial acquisition of airborne measurements to archival storage at the Langley DAAC and distribution to users at large. The NASA Ames Earth Science Project Office (ESPO) archive will be the project-specific data repository to facilitate the project data exchange needs and interface with the Langley DAAC and with users. Instrument Co-Is will be primarily responsible for operating research-grade instruments, processing their measurements, and submitting the data representing a time stream of geophysical quantities according to project schedules and format requirements. As shown in **Figure**

8.1, ATom Science Data Flow, the ATom project data processing will occur in two phases: 1) preliminary data generated during the field deployment and 2) final, post deployment data resulting from post-deployment processing and analysis. The final, post deployment data will be transferred to the Langley DAAC for archiving with provision for updating or revising as needed. Pamela Rinsland is the Liaison for Operations and User Services. Ms. Rinsland will provide support for required documentation such as Data Management Plans, Interface Control Documents and Operations Agreements. She will also provide support for any reviews or reporting that requires the status of DAAC activities and environments and the identification of additional documentation for preservation. Brandi Quam is the Deputy Head of the DAAC and the IT Security Lead. Ms. Quam will provide IT Security documentation and activities at the DAAC in support of ATom. She will also coordinate activities at the DAAC to ensure ATom tasks are given appropriate resources and priority. Lastly Lindsay Parker is the SSAI DAAC Manager and will coordinate ATom support at technical levels for metadata formats, ingest workflows and public web pages. The ATom PI, data management team, and ATom Co-Is have gained valuable experience from participation in past NASA, NOAA and NSF airborne studies where similar data flow schemes have been successfully implemented.

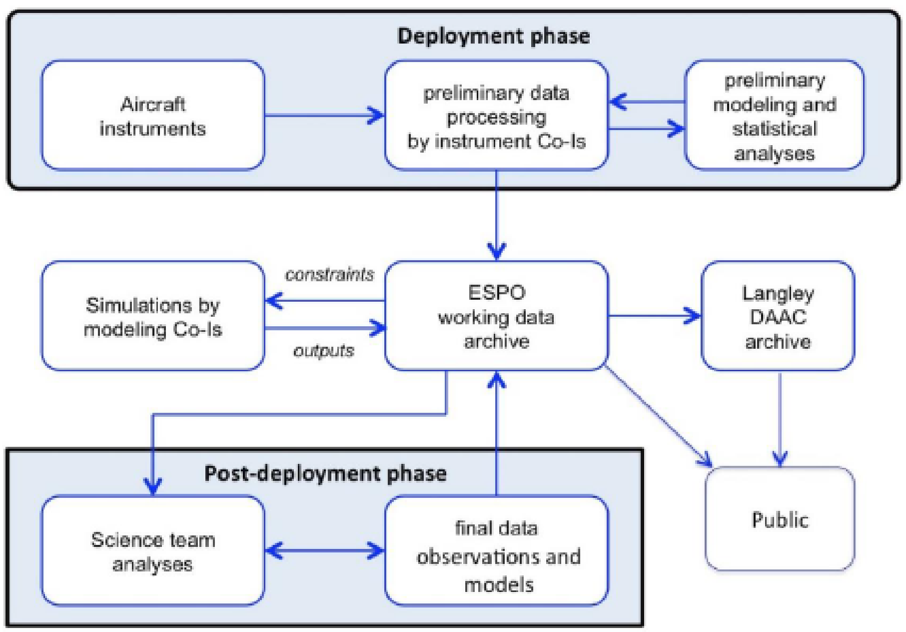

Figure 8.1 ATom Science Data Flow.

The shaded boxes denote the ATom project data management components. Initial QA/QC, modeling and statistical analyses will be done in the field, with the majority of model-derived products completed as the data sets reach the final/release version.

ATom airborne observational data will be recorded during each of four field deployments. Preliminary, Level 1, airborne data will be submitted to the ESPO working data archive – the ATom project-specific data repository – within 24 hours of each flight from instruments that do not require extensive post-flight analysis. The working archive is accessible via ftp. The team will facilitate transfer by slow internet connections from the field by uploading all data through a single local computer that accomplishes most of the communication with the Ames-ESPO working archive. All preliminary data must be aligned with the aircraft time stamp before posting by instrument Co-Is, to facilitate prompt data merging in the field. Merged data products and quick-look QA/QC will be produced within 48 hours of collection under the direction of the science leadership team. This product initially receives weather and chemical forecasts, and will be updated as new observations and data products are generated or updates received. First-cut model-derived products, such as the statistical patterns of species and estimated reactivity of air parcels, will be added to the working data archive as soon as available.

Timely submission of the preliminary data ensures that they are available for the PI, PM, and Mission Scientist to monitor project progress and to evaluate payload readiness. Exceptions may be granted when flights are scheduled for consecutive days or if there are instrument problems. In these cases, the ATom PI and PM must be notified. In addition, instrument Co-Is may seek prior approval from both the ATom PI and PM for an exception if the data submission period appears too stringent in consideration of labor intensive data processing procedures. The distribution and use of preliminary data will be limited to the ATom science team and collaborators. Rapid generation of preliminary data is not possible for a few instruments that require extensive post-flight analysis (e.g. the Whole Air Sampler (WAS)).

Within 7 to12 months of the end of each phase of ATom, the fully calibrated, level 2, observational data and their assigned uncertainties will be submitted to the ESPO working data archives and the Langley DAAC and made available to the public in compliance with NASA science data policy. Instrument Co-Is are responsible for assuring these data conform to the file format and metadata requirements. For attribution purposes, the data sets shall be referenced using the ATom DOI, generated by the Langley DAAC:

10.5067/Aircraft/ATom/TraceGas_Aerosol_Global_Distribution

In addition to data from each sensor, the PI and Deputy PI will provide merged datasets and model products, to be delivered to the ESPO archive and Langley DAAC within 9 months of the end of each deployment. Merged datasets (level 3) include two types: (a) time series of all available observations at 1s, 10s, and flask sampling intervals; and (b) data organized by each vertical sounding. Model-product datasets include: (a) time series of the 24-hour average chemical reactivity of key gases and aerosols for all observed air parcels (level 3); plus statistical, integrated products for latitude-height domains including representativeness of the entire ocean basin and uncertainties (level 4).

Acceptable data formats will be ICARTT or NetCDF. Version control will be applied to updates to these data and merged products.

At the end of the five-year EV mission, the final datasets will be uploaded to the NASA Langley DAAC. The ESPO public site will remain available, and will be updated as revised or new data and model products are submitted. These changes will be mirrored by the DAAC in a coordinated fashion to ensure that only one version of the data is presented to the public at any time.

8.1.1. Science Data Generation and Documentation Requirements

As described earlier, the instrument Co-Is are responsible for data processing for their respective measurements. This processing will convert the primary instrument outputs to data products quantitatively describing atmospheric chemical and microphysical states, e.g., trace gas mole fractions or concentrations, aerosol and cloud drop number distributions, and aerosol chemical composition. The data processing algorithms will be refined through detailed instrument characterization and calibration (if applicable) to ensure data quality in terms of accuracy and precision. The data processing methods are well established, reflecting the fact that all instruments selected for the ATom study have successfully been deployed in previous airborne studies and described in the peer-reviewed literature.

As part of the ATom proposal, each instrument Co-I has budgeted sufficient financial, computational, and staffing resources necessary to process their instrument data and generate science data products and is required to fully comply with NASA data policy.

ATom instrument Co-Is will archive, or reference public information, complete documentation for each of the measurements held at the ESPO Archive and the Langley DAAC. The goals of the documentation requirement are: 1) to maintain data reprocessing capability, 2) to maintain transparency of the data processing, and 3) to facilitate understanding and use of data. This documentation will include an instrument description, primary instrument output data and any ancillary data needed for reprocessing. The instrument description will include the measurement principles, sensor description, calibration procedures and standards (if applicable), data processing procedure (including software if necessary), data validation (if applicable), data revision records, and uncertainties/detection limits. Peer-reviewed publications containing relevant information can be used as references, but the online material should be self-contained. The documentation will specify any details specific to the instrument operation for the ATom field deployments and include references to the pre-ATom instrument.

The PI and PM (Project Manager), in consultation with the Co-I, will determine the documentation requirements for each sensor. As shown in Table 8.1.3 documentation materials will be submitted to the ESPO Archive and Langley DAAC, along with fully QA/QC data, within 7 – 12 months of the end of each deployment. Modeling Co-Is are expected to provide similar documentation of the model and version used to calculate the modeled products, and to submit this information along with the products themselves within 9 months of the end of each deployment.

8.1.2 Science Data Format and Metadata Requirements

The ATom observational data products will conform to NASA Earth Science Division approved data system standards. The in-situ data are required to be archived in the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) data format, i.e., ESDS-RFC-019. A detailed description of the data format protocol can be found at http://www-air.larc.nasa.gov/missions/etc/IcarttDataFormat.htm. All ATom observational data will be reported with universal time (UT) for the time record. Instrument Co-Is are required to synchronize their instruments to GPS time. In addition to the format standards, the ATom project has a specific file naming convention and set of metadata content requirements. These additional requirements are intended to promote the usability of the ATom data.

The ATom model products will generate reactivity and related information for each of the air parcels defined by the observational products. They will use a similar format as above, or Net CDF. In addition, model products will look at chemical data on a standard latitude-height grid for calculated statistics and integrated products that will be documented in the metadata of the NetCDF files used to archive these products.

8.1.2.1. ATom Metadata Requirements

The ATom metadata requirements are developed to meet NASA DAAC collection level and granule level metadata requirements.
Platform and associated location data: Geographic location and altitude will be embedded as part of the data file or provided via a link to the data location. The PI will create a merged data product giving this information uniformly for all compatible data records. For regularly timed/spaced data, the grid indexing will be defined.
Data Source Contact Information: phone number, mailing information, and e-mail address shall be given for the instrument Co-I and one alternate contact.
Data Information: Clear definition of measured quantities will be given in plain English, avoiding the use of undefined acronyms, along with reporting units and limitations in data applicability if needed.
Measurement Description: A simple description of the measurement technique with reference to readme file and relevant journal publications.
Model Description: For derived or corollary data products, a simple description of the modeling technique with reference to readme file and relevant journal publications.
Measurement Uncertainty: Reporting measurement uncertainty is a metadata requirement for ATom and is required by the ICARTT file format. Overall uncertainty will need to be given and, if possible, precision and accuracy will be provided explicitly for each datum. The confidence level associated with the reported uncertainties will also need to be specified for the reported uncertainties if it is applicable. The measurement uncertainty can be reported as constants for entire flights or as separate timeline variables.

Data Quality Flags: definition of flag codes for missing data (not reported due to instrument malfunction or calibration) and detection limits (if applicable).
Data Revision Comments: Provide sufficient discussion about reasons that data are being revised, focused on highlighting issues, solutions, assumptions, and impact.

8.1.2.2 ATom Datafile Naming Convention

ATom will use the ICARTT file naming convention and format for all ASCII-format files. File names can be no more than 127 characters and are defined as follows:

dataID_locationID_YYYYMMDD_R#.ext
The only allowed characters are: a-z A-Z 0-9_.- (that is, upper case and lower case alphanumeric, underscore, period, and hyphen). Fields are described as follows:

dataID: an identifier of measured parameter/species, instrument, or model (e.g., DLH-H2O), selected by the PI and approved by the project.

locationID: an identifier of airborne platform or ground station. DC8 will be used for all data collected on the DC-8 aircraft; appropriate identifiers will be selected for corollary data from non-DC-8 platforms or models..
YYYY: four-digit year
MM: two-digit month
DD: two-digit day (for flight data, the date corresponds to the UT date at takeoff)
R#: numerical data revision identifier
ext: "ict" will be the file extension for ICARTT-format (ASCII plain text files) and "nc" for NetCDF files.

For example, the filename for preliminary Diode Laser Spectrometer H_2O data taken on the DC-8 on an August 1, 2015 flight would be **DLH-H2O_DC8_20150801_R0.ict**

Reported parameters must be consistently named in all data files, for all flights. Parameters measured by more than one instrument on ATom should have the sensor ID in the name, e.g. "DLH-H2O", ensuring that no two parameters are given the same name. The names appear in the body of the data header as required, and then again in a comment line directly preceding the start of the data set. The parameter names should be consistent throughout the ATom mission.

8.1.3 Science Data Storage and Distribution

During the project life cycle, ATom science data products (a detailed list defined in section 3) will be archived at the ESPO working data archive. A science team data archive for ATom will be set up at http://espoarchive.nasa.gov/archive/browse/ATom for access to airborne preliminary and first public release data.

Table 8.1.3 ATom Data Submission Schedule and Access

Data Products	Data Provider	Submission Schedule	Data Access (Location)
Preliminary observed in situ data (Level 1, 2)	Instrument Co-I	24 hours after flight	Science team (ESPO archives)
Preliminary merged data product (Level 2)	PI or on-board mission scientist	48 hours after flight	Science team (ESPO archives)
Preliminary model/statistical analyses (Level 1)	PI & Deputy PI	96 hours after flight	Science team (ESPO archives)
QA/QC in situ data (Level 2)	PI & Instrument Co-I	7 - 12 months after end of deployment	Public (ESPO archives and Langley DAAC)
Merged Data Products	PI & Instrument Co-I	9 - 14 months after end of deployment	Public (ESPO archives and Langley DAAC)
Model-derived products from merged observations (Levels 3 & 4)	Deputy PI & Model Co-I	9 - 14 months after end of deployment	Public (ESPO archives and Langley DAAC)
QA/QC flask/filter data (Level 2)	PI & Instrument Co-I	12 months after end of deployment	Public (ESPO archives and Langley DAAC)
End of mission data	ESPO	End of mission (2020)	Langley ASDC

Table 8.1.3, ATom Data Submission Schedule and Access, summarizes the ATom science data flow illustrated in **Figure 8.1, ATom Science Data Flow**. Also given is the data archive location. The ATom end of mission public data along with documentation materials will be transferred to the Langley DAAC at the end of five-year EV mission.

All Co-Is are required to submit their data files in standard format defined in section 3. An online version of the scanning software is available at the ESPO archive and can be used by the Co-Is to help them prepare their data files. The ESPO archive scans all incoming archive ICARTT-format data files upon delivery to ensure that the data format requirements are met. Account-based access control on the ESPO archive limits data sharing to the ATom science team participants for all preliminary data. In addition to the archive function, the ESPO archive will be responsible for transferring data to the Langley DAAC.

8.1.4. Post-Mission Stewardship and Access

The ESPO archive and the Langley DAAC will provide post-mission access to final ATom data products. The ATom science team is committed to the timely release of "publication quality" data products for public use in scientific research. The transfer of final science data and associated documentation to the Langley DAAC will be a joint effort between the Ames ESPO archive and the Langley DAAC. Specifics of the data and transfer mechanisms will be defined in an Interface Control Document (ICD), which is being developed collaboratively between the ATom Data Manger (K. Drdla) and senior personnel at the NASA Langley Atmospheric Science Data Center (ASDC, Gao Chen). The primary goal is to perform accurate and timely ingestion of the ATom science data products into the Langley data archive and distribution system.

The ESPO archive will initiate execution of the data transfer plan, which includes the data format, file types, and metadata requirements. By working with the instrument Co-

Is, the ESPO archive will take the responsibility to provide the NASA Langley DAAC with a reasonable estimate of the total size of the archive, including both science data products and associated documentation.

Prior to delivery, the ESPO archive will work closely with the Langley DAAC to create collection, granule, and browse metadata files. ATom metadata will be exported to EOSDIS Common Metadata Repository (CMR) and archive and distribution metrics will be provided to the ESDIS Metrics System (EMS). After delivery of data and documentation, the ESPO archive will work with the Langley DAAC to generate and submit CMR DIF (Directory Interchange Format) for ATom science data products. These activities are to ensure the ATom science data and appropriate ancillary records are properly ingested into the Langley DAAC archive and distribution system to support long-term usability. The DAAC will be properly configured and fully functional at the time of the first data release.

Revisions to the public data sets will take place as needed, with documentation of the version number and changes from the previous release. All public release versions will remain available, because the full cycle statistical and model analysis of the coupled data may not be updated if single measurements are revised after the end of mission. The dataset submitted to the Langley DAAC will include the most up-to-date revisions at the time of the submission. Further revisions past that date will be permitted on the ESPO Archive and will be mirrored at the Langley DAAC.

8.2 ATom Data Products

This section defines a list of measurement data products that will be archived to fulfill the ATom observational data product requirements. Items specifically provided here are definitions of the measured quantities, spatial and/or temporal resolutions of the reported data, and instruments/techniques. The measured quantities are named in generic terms to be consistent with Global Change Master Directory when applicable. The temporal resolution is given to indicate the interval at which the data will be continuously reported.

8.2.1. ATom Airborne Measured Data Products

Table 9.2.1 summarizes the measurements to be taken from the NASA DC-8. All data will be delivered in the ICARTT format. The data volume for science data files and associated documentation is estimated to be less than 1 TB for each field deployment.

Table 8.2.1 ATom Airborne Measured Data Products

Species	Instrument(s)	Sampling interval	Data Quality
Reactive nitrogen			
Nitric oxide (NO)	NO_yO_3	1 s	6 ppt + 3%
Nitrogen dioxide (NO_2)	NO_yO_3	1 s	15 ppt + 5%
NO_x ($NO + NO_2$)	NO_yO_3	30 s	10 ppt +5%
Nitric acid (HNO_3)	SAGA MC/IC	1.5 min	5 ppt + 10%
Nitric acid (HNO_3)	CIT-CIMS	1 s	50 ppt + 30%
Pernitric acid (HNO_4)	CIT-CIMS	1 s	50 ppt + 30%
Total reactive nitrogen (NO_y)	NO_yO_3	1 s	40 ppt + 12%

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Species	Instrument(s)	Sampling interval	Data Quality
VOCs			
C_2–C_4 alkanes	PFP	15-30 s every 25 min*	2 ppt + 10%
Benzene	PFP	15-30 s every 25 min*	2 ppt + 10%
Ethane (C_2H_6), Ethene (C_2H_4)	WAS	15-90 s every 6 min‡	3 pptv or 2% (whichever is larger) precision, 5% accuracy
i-Butane (C_4H_{10}), Toluene (C_7H_8)	WAS	15-90 s every 6 min‡	3 ppt, 3% (whichever is larger) precision, 10% accuracy
Ethyne (C_2H_2), Propane (C_3H_8), Propene (C_3H_6), n-Butane (C_4H_{10}), n-Pentane (C_5H_{12}), i-Pentane (C_5H_{12}), Isoprene (C_5H_8), Benzene (C_6H_6)	WAS	15-90 s every 6 min‡	3 ppt, 2% (whichever is larger) precision, 10% accuracy
trans-2-Butene, cis-2-Butene, 1-Butene, i-Butene, Neopentane, 1,3-Butadiene, 1-Pentene, Isoprene, 2,3-Dimethylbutane, 2-Methylpentane, 3-Methylpentane, n-Hexane, Heptane, Ethylbenzene, m-Xylene, o-Xylene, α-Pinene, β-Pinene	WAS	15-90 s every 6 min‡	3 ppt or 2% (whichever is larger) precision, 10% for accuracy
Benzene	TOGA	30 s every 2 min	± 15% or 2 pptv
Toluene	TOGA	30 s every 2 min	± 15% or 1 pptv
Ethylbenzene+m-/p-Xylene	TOGA	30 s every 2 min	± 20% or 0.6 pptv
o-Xylene	TOGA	30 s every 2 min	± 20% or 0.4 pptv
Isobutene+1-Butene	TOGA	30 s every 2 min	± 50% or 2 pptv
Isoprene	TOGA	30 s every 2 min	± 15% or 2 pptv
Propane (C_3H_8)	TOGA	30 s every 2 min	± 30% or 20 pptv
i-Butane, n-Butane, i-Pentane	TOGA	30 s every 2 min	± 15% or 2 pptv
n-Pentane	TOGA	30 s every 2 min	± 15% or 4 pptv
2-Methylpentane, 3-Methylpentane, n-Hexane,	TOGA	30 s every 2 min	± 15% or 1 pptv
n-Heptane	TOGA	30 s every 2 min	± 30% or 6 pptv
Photoproducts and oxygenates			
Ozone (O_3)	NO_yO_3	1 s	0.2 ppb + 2%
Ozone (O_3)	UCATS	5 s	2 ppb + 2%
Formaldehyde (HCHO)	ISAF	1 s	20 ppt + 10%
Formaldehyde (HCHO)	TOGA	30 s every 2 min	± 40% or 40 pptv
Acetone (CH_3COCH_3)	TOGA	30 s every 2 min	± 20% or 40 pptv
Methyl ethyl ketone, MEK, ($CH_3COC_2H_5$), MVK, Methacrolein	TOGA	30 s every 2 min	± 20% or 2 pptv
Methanol (CH_3OH)	TOGA	30 s every 2 min	± 30% or 40 pptv
Ethanol (C_2H_5OH)	TOGA	30 s every 2 min	± 30% or 20 pptv
α-Pinene	TOGA	30 s every 2 min	± 30% or 0.4 pptv
β-Pinene	TOGA	30 s every 2 min	± 30% or 1 pptv
Acetaldehyde, Propanal	TOGA	30 s every 2 min	± 20% or 10 pptv
Butanal, Acrolein	TOGA	30 s every 2 min	± 30% or 2 pptv
Methyl t-butyl ether (MTBE)	TOGA	30 s every 2 min	± 20% or 2 pptv
Ethyl Nitrate ($C_2H_5ONO_2$)	TOGA	30 s every 2 min	± 30% or 2 pptv
i-Propyl Nitrate ($iC_3H_7ONO_2$)	TOGA	30 s every 2 min	± 15% or 2 pptv
2-Butyl Nitrate + n-Butyl Nitrate	TOGA	30 s every 2 min	± 30% or 2 pptv
Hydrogen peroxide (HOOH)	CIT-CIMS	10 s	50 ppt + 30%
Methyl peroxide (CH_3OOH)	CIT-CIMS	10 s	50 ppt + 30%
Formic acid (HCOOH)	CIT-CIMS	1 s	100 ppt + 30%
Acetic acid (CH_3COOH)	CIT-CIMS	10 s	100 ppt + 30%
Hydroxyl radical (OH)	ATHOS	30 s	0.02 ppt + 20%
Hydroperoxyl radical (HO_2)	ATHOS	30 s	0.2 ppt + 20%
OH loss rate	ATHOS	30 s	1 s^{-1} + 10%
Methyl nitrate (CH_3ONO_2), Ethyl nitrate ($C_2H_5ONO_2$), i-Propyl nitrate ($C_3H_7ONO_2$), n-Propyl nitrate ($C_3H_7ONO_2$), 2-Butyl nitrate ($C_4H_9ONO_2$), 2-Pentyl nitrate ($C_5H_{11}ONO_2$), 3-Pentyl nitrate ($C_5H_{11}ONO_2$)	WAS	15-90 s every 6 min‡	0.02 pptv or 3% (whichever is larger) precision, 20% accuracy
Aerosols			

Species	Instrument(s)	Sampling interval	Data Quality
Particle distribution (4–1000 nm)	NMASS; UHSAS	1 s	Number: 8 cm^{-3}, 9% Surface Area: 2 $\mu m^2 cm^{-3}$, 26% Volume: 0.1 $\mu m^3 cm^{-3}$, 36%
Cloud drop distribution (2–50 µm)	CDP	1 s	TBD
Black carbon mass and coating state	SP2	1 s	12 ng/kg + 30%
SO_4^{2-}, NO_3^-, Cl^-, NH_4^+	HR-AMS	1 s	0.1 $\mu g/m^3$ ± 34%
Organic aerosol	HR-AMS	1 s	0.5 $\mu g/m^3$ ± 38%
Particle O/C	HR-AMS	1s	± 25%
Particle H/C	HR-AMS	1s	± 15%
Particle OM/OC	HR-AMS	1s	± 20%
Single particle composition (200-4000 nm). Particle type fractions for sulfate/organic/nitrate, biomass burning, elemental carbon, sea salt, mineral dust, meteoric, oil combustion	PALMS	3 min	0 +15%
Particle type vol concentration	PALMS	5 min	0.1 μm^3 cm^{-3} +30%
Sub micron SO_4^{2-}	SAGA MC/IC	1.5 min	0.05 $\mu g/m^3$ + 10%
Bulk Cl^-, Na^+, Ca^{2+}	SAGA filters	5 - 15 min	0.05 $\mu g/m^3$ + 10%
Bulk SO_4^{2-}, NO_3^-, Br^-, $C_2O_4^{2-}$, NH_4^+, K^+, Mg^+	SAGA filters	5 - 15 min	0.02 $\mu g/m^3$ + 10%
^7Be	SAGA filters	5 – 15 min	25 fCi/m^3 + 5%
^{210}Pb	SAGA filters	5 – 15 min	0.5 fCi/m^3 + 10%
GHGs and ODSs			
Carbon dioxide (CO_2)	HTS	2 s	± 0.1 ppm, ± 0.02 ppm
Carbon dioxide (CO_2)	AO2	1 s	0.2 ppm
Carbon dioxide (CO_2)	MEDUSA	32 flasks/flight	0.1 ppm
Carbon dioxide (CO_2)	PFP	15-30 s every 25 min[†]	0.2 ppm
Methane (CH_4)	HTS	2 s	± 1 ppb, ± 0.5 ppb
Methane (CH_4)	PANTHER/UCATS	3 s sample every 2 min	5 ppb + 0.5%
Methane (CH_4)	PFP	15-30 s every 25 min[†]	1.5 ppb [a]
Methane (CH_4)	WAS	15-90 s every 6 min[‡]	0.1%, 1%
Nitrous oxide (N_2O)	HTS	1 s	± 0.2 ppb, ± 0.10 ppb
Nitrous oxide (N_2O)	PANTHER/UCATS	3 s sample every 1 min	1 ppb + 0.5%
Nitrous oxide (N_2O)	PFP	15-30 s every 25 min[†],	0.5 ppb [a]
Sulfur hexafluoride (SF_6)	PANTHER/UCATS	3 s sample every 1 min	0.05 ppt + 0.5%
Sulfur hexafluoride (SF_6)	PFP	15-30 s every 25 min[†]	0.06 ppt [a]
CFCs	PANTHER	3 s sample every 1 min	1 ppt + 0.5%
HCFCs and HFCs	PANTHER	2.8 min sample every 3 min	0.5 ppt + 1.5%
CFCs, HCFCs, and HFCs	PFP	15-30 s every 25 min[†]	0.1 to 5%, depending on chemical
C_1 halides	PFP	15-30 s every 25 min[†]	0.2 to 10%, depending on chemical
Halons: H-1211, H-1301, H-2402	PFP	15-30 s every 25 min[†]	1 to 2% depending on chemical
Halon H-1211	PANTHER	3 s sample every 1 min	0.05 ppt + 1%
Chloromethane (CH_3Cl), Methylbromide (CH_3Br)	PANTHER	2.8 min sample every 3 min	0.1 ppt + 2%
Other halogenated hydrocarbons: CH_3CCl_3, CCl_4, C_2Cl_3, $CHCl_3$, C_2Cl_4, $CHBr_3$, CH_2Br_2, CF_4, C_2F_6	PFP	15-30 s every 25 min[†]	0.2 to 10% depending on chemical
CFC-11	WAS	15-90 s every 6 min[‡]	1% precision, 2% accuracy
CFC-113	WAS	15-90 s every 6 min[‡]	2% precision, 2% accuracy
CFC-12	WAS	15-90 s every 6 min[‡]	1% precision, 2% accuracy
CFC-11	TOGA	30 s every 2 min	± 20% or 10 pptv
CFC-113	TOGA	30 s every 2 min	± 20% or 2 pptv
HCFC-22	WAS	15-90 s every 6 min[‡]	3% precision, 5% accuracy
H-1211 ($CBrClF_2$)	WAS	15-90 s every 6 min[‡]	0.1 pptv or 3% (whichever is larger) precision, 5% accuracy
CFC-114, HCFC-142b, HCFC-141b, HFC-134a	WAS	15-90 s every 6 min[‡]	3% precision, 10% accuracy
HFC-152a	WAS	15-90 s every 6 min[‡]	5% precision, 20% accuracy
H-2402, H-1301	WAS	15-90 s every 6 min[‡]	5% precision, 10% accuracy
Methyl bromide (CH_3Br)	WAS	15-90 s every 6 min[‡]	3% precision, 5% accuracy

Species	Instrument(s)	Sampling interval	Data Quality
Dibromethane (CH_2Br_2)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 10% accuracy
Bromoform ($CHBr_3$)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 20% accuracy
Chloroform ($CHCl_3$)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 10% accuracy
Methyl chloride (CH_3Cl)	WAS	15-90 s every 6 min‡	5 pptv or 3% (whichever is larger) precision, 5% accuracy
Methyl iodide (CH_3I)	WAS	15-90 s every 6 min‡	0.01 pptv or 3% (whichever is larger) precision, 10% accuracy
Dichloromethane (CH_2Cl_2)	WAS	15-90 s every 6 min‡	0.3 pptv or 4% (whichever is larger) precision, 20% accuracy
Trichloroethylene (C_2HCl_3)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 20% accuracy
Bromodichloromethane ($CHBrCl_2$), Dibromochloromethane ($CHBr_2Cl$)	WAS	15-90 s every 6 min‡	0.1 pptv or 10% (whichever is larger) precision, 20% accuracy
Carbon tetrachloride (CCl_4)	WAS	15-90 s every 6 min‡	2% precision, 5% accuracy
Tetrachloroethene (C_2Cl_4)	WAS	15-90 s every 6 min‡	0.05 pptv or 3% (whichever is larger) precision, 10% accuracy
Methyl chloroform (CH_3CCl_3)	WAS	15-90 s every 6 min‡	1 pptv or 3% (whichever is larger) precision, 5% accuracy
1,2-dichloroethene	WAS	15-90 s every 6 min‡	1 pptv, 5% precision, 50% accuracy
Methyl bromide (CH_3Br)	TOGA	30 s every 2 min	± 20% or 2 pptv
Dibromomethane (CH_2Br_2)	TOGA	30 s every 2 min	± 15% or 0.06 pptv
Bromoiodomethane (CH_2BrI)	TOGA	30 s every 2 min	± 30% or 0.06 pptv
Chloroform ($CHCl_3$)	TOGA	30 s every 2 min	± 15% or 2 pptv
Bromoform ($CHBr_3$)	TOGA	30 s every 2 min	± 30% or 0.4 pptv
Bromodichloromethane ($CHBrCl_2$)	TOGA	30 s every 2 min	± 20% or 0.06 pptv
Dibromochloromethane ($CHBr_2Cl$)	TOGA	30 s every 2 min	± 15% or 0.06 pptv
Chloroiodomethane (CH_2ClI)	TOGA	30 s every 2 min	± 20% or 0.14 pptv
Diiodomethane (CH_2I_2)	TOGA	30 s every 2 min	± 40% or 0.1 pptv
Chlorobenzene (C_6H_5Cl)	TOGA	30 s every 2 min	± 15% or 0.2 pptv
Tetrachloroethylene (C_2Cl_4)	TOGA	30 s every 2 min	± 15% or 0.6 pptv
Tracers and other species			
Carbon monoxide (CO)	HTS	1 s	± 3.5 ppb, ± 0.15 ppb
Carbon monoxide (CO)	PANTHER/UCATS	3 s every 2 min	3 ppb + 2%
Carbon monoxide (CO)	PFP	15-30 s every 25 min^{+}	1.2 ppb
Carbon monoxide (CO)	WAS	15-90 s every 6 min‡	3% precision, 5% accuracy
Acetonitrile (CH_3CN)	TOGA	30 s every 2 min	± 40% or 2 pptv
DMS (CH_3SCH_3)	TOGA	30 s every 2 min	± 15% or 1 pptv
Oxygen (O_2/N_2)	AO2	1 s	3 per meg
Oxygen (O_2/N_2)	MEDUSA	32 flasks/flight	3 per meg
Argon (Ar/N_2)	MEDUSA	32 flasks/flight	6 per meg
Hydrogen cyanide (HCN)	CIT-CIMS	1 s	50 ppt + 30%
Hydrogen cyanide (HCN)	TOGA	30 s every 2 min	± 50% or 20 pptv
Water vapor (H_2O)	DLH	1 s	0.2 ppm + 10%
Water vapor (H_2O)	UCATS	1 s	1 ppm + 5%
Hydrogen (H_2)	PANTHER/UCATS, PFP	3 s sample every 2 min, 15-30 s every 25 min^{+}	2 ppb + 1%, 4 ppb
Sulfur dioxide (SO_2)	CIT-CIMS	1 s	250 ppt + 30%
Carbonyl sulfide (OCS)	PFP	15-30 s every 25 min^{+}	1%
Carbonyl Sulfide (OCS)	WAS	15-90 s every 6 min‡	3% precision, 10% accuracy
Carbonyl sulfide (OCS)	PANTHER	2.8 min sample every 3 min	2 ppt + 1.5%
DMS (CH_3SCH_3)	WAS	15-90 s every 6 min‡	0.5 ppt or 1% (whichever is larger) precision, 10% accuracy
DMDS (CH_3SSCH_3)	WAS	15-90 s every 6 min‡	0.1 ppt or 3%, (whichever is larger) precision, 20% accuracy
Methyl iodide (CH_3I), Carbon disulfide (CS_2)	PANTHER	2.8 min sample every 3 min	TBD
Isotopes: $\delta^{13}CH_4$	PFP	15-30 s every 25 min^{+}	0.1 per mil
Solar radiation			
Spectrally-resolved actinic flux (280-650 nm)	CAFS	3 s	$5 \times 10^{-5} s^{-1}$ + 12% for jNO_2

Species	Instrument(s)	Sampling interval	Data Quality
Meteorological data			
Static P, static T, 3D winds; turbulence	MMS	0.05 s	0.3 mb, 0.3K, 1 m/s

‡WAS sampling interval is based on 100 canisters and a nominal 10-hour flight time.
+PFP sampling interval based on 24 flasks being filled during a nominal 10-hour flight, though actual sampling will most likely be triggered at specific pressure/altitude points.
#These values represent the sum of repeatability plus reproducibility.

8.2.2. ATom Airborne Modeled and Merged Data Products

Table 8.2.2, ATom Modeled and Merged Data Products, summarizes the modeled and merged data products based on ATom direct measurements to be delivered in a suitable format (ICARTT or NetCDF). The data volume for these files and associated documentation is estimated to be less than 1 TB for each field deployment.

Table 8.2.2 ATom Modeled and Merged Data Products

Data Products	Data	Comments
Merged data streams		
Synced merged streams	All observations	1 s and 10 s intervals defining air parcels with slower measurements interpolated or filled by measured correlations. (10 s is about 2.5 km at cruise)
Smoothed merged streams	All observations	Averages to match whole-air flask and chromatographic sampling times.
Profiles and statistics	All observations	Profiles including variability & extremes at 0.1 - 0.5 km vertical resolution separately for each ascent and descent.
Model-derived products		
Gas-phase reactivity	Loss of CH_4; Production of O_3; Loss of O_3.	Modeled reactivity by integrating 30 s air parcels (15 km at cruise) for 24 hours in global 3D models using model meteorology for cloud cover.
Aerosol reactivity	Oxidation, growth, coagulation of particles.	ibid
Integrated reactivity & statistical analysis of air parcels	Gas phase or aerosol reactivity as above	Over latitude-height domains (e.g., 500-800 hPa x 20N-40N; final domains TBD) along each oceanic transect, derive integrated reactivity and characterize air parcels that dominate this reactivity.
Representative sampling of each ocean basin	Latitude-Height domain average	Use global models to assess how representative the ATom transect latitude-height domains are compared to other ocean transects and other days of the month, by producing a range of ATom-equivalent transects.

9. Risk Management and Scope Reduction Options

ATom is an intrinsically low-risk mission due to the combination of airborne platform maturity, a proven science payload consisting of TRL 7 or higher instrumentation (most have flown on the DC-8 already), schedule flexibility, and a team with experience in several successful NASA deployments at the international level as well as at most of the remote locations along the selected ATom track. This combination, along with close-knit and highly experienced science and management teams, positions ATom for success.

9.1. Risk Management

The team leverages science and management experience from multiple successful NASA, NSF, and NOAA projects. Residual risks inherent to the ATom proposal have been identified and will be tracked continuously and reported accordingly throughout the life of the project (**Table 9.1, ATom Risk, Mitigation and Science Impact, Table 9.2 ATom Risk Legend** and **Figure 9.1, ATom Risk Matrix**). The risk management approach is tailored from NPR 8000.4A, Agency Risk Management Procedural Requirements, which explains the thoughts behind and use of Risk Informed Decision Making (RIDM) and Continuous Risk Management (CRM). The steps of the ATom CRM shall include: 1) identification of the risks, 2) analysis of the risk probability, impact/severity, and time frame, 3) decision on the risk disposition and handling and development of risk mitigation plans and determination of what to track, 4) tracking the risk, 5) controlling and monitoring the risk, and 6) communicating and documenting the process and decisions. CRM will be incorporated into the existing technical and management meetings to ensure the communication of risk information to all parties. An integral part of the success of risk management is communication. An atmosphere of free exchange will be promoted on the ATom project to ensure all concerns, regarding even perceived risks, are voiced. Table 9.1 has the current set of ATTREX risks. The risk scale for probability and impact are based on a 5x5 matrix.

The Risk Management activities for the DC-8 comply with Armstrong Risk Management Guidelines and are covered in the System Safety Handbook DCP-S-002.

Table 9.1 ATom Risk, Mitigation and Science Impact

No.	Risk	Background	Response/Mitigation	Science Impact
1	Given that the DC-8 could suffer an incident during a deployment that required major maintenance there is the possibility that the remainder of the deployment would be cancelled thereby losing the science of the remaining portion of the deployment.	NASA has only one DC-8 aircraft. The DC-8 is an old, though well maintained, workhorse. Maintenance issues can cause long-term groundings.	The deployment during which the incident occurred would be terminated. The a/c crew and science team would travel home.	Any issue that causes early termination of a deployment could have significant science impact.
2	Given that the DC-8 could suffer an incident close to the beginning of an ATom deployment that required major maintenance there is the possibility that the deployment would have to be	NASA has only one DC-8 aircraft. The DC-8 is an old, though well maintained, workhorse. Maintenance issues can cause long-term groundings.	The ATom schedule is flexible. The 4 seasonal deployments can occur in any order. The current schedule has deployments completed in 2018 but a deployment could slip to FY19 to	Rescheduling a deployment would have minimal science impact.

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No.	Risk	Background	Response/Mitigation	Science Impact
	rescheduled.		accommodate a major aircraft issue.	
3	Given that the project could suffer a short term schedule delay during a deployment (a/c maintenance, weather, labor disruptions, etc.) there is the possibility that the aircraft would have to remain on the ground 2-3 days longer than scheduled and the remainder of the deployment would be delayed.	Aircraft maintenance issues, weather and ground support labor disputes could cause short-term schedule delays.	During site visits discussions were held with airport officials, aircraft ground handling and lodging providers that included a discussion of possible 2-3 day schedule slippage. All indicated that they would be willing and could accommodate 2-3 day arrival/departure slippage.	A delay of 2-3 days during a deployment would have minimal science impact.
4	Given the number of required stopover sites there is the possibility that one or more would be unavailable and an alternate site(s) will have to be selected.	Due to the scope of the project global coverage the project requires on eight deployment stopover sites.	Discovery during a deployment that a stopover site is unavailable will result in a pilot identified divert site to have to be used.	Utilization of a divert sight, for planned stopover sights other than New Zealand, would have minimal science impact. Not being able to stopover at New Zealand (our major resupply stop) would have larger implications for some instruments.
5	Given that the cost of required items (i.e., fuel, travel, etc.) could change during the life of the project there is the possibility that actual costs could exceed estimated costs.	Since the project is cost capped and is to be conducted over five years increases in fuel and travel costs and changes in team travel requirements may occur.	Costs for the project were developed including a 3%/year inflationary cost growth for fuel, travel and local support. Above that the AFRC budget also includes a $2/gallon fuel reserve.	Overall cost growth up to 3% and fuel costs up to $2/gallon above that should have no science impact. Cost growth above that would require resorting to scope reduction options. Exercising scope reduction options #1-#4 would still satisfy Level 1 Baseline requirements and exercising option #5 would still satisfy Level 1 Threshold requirements.

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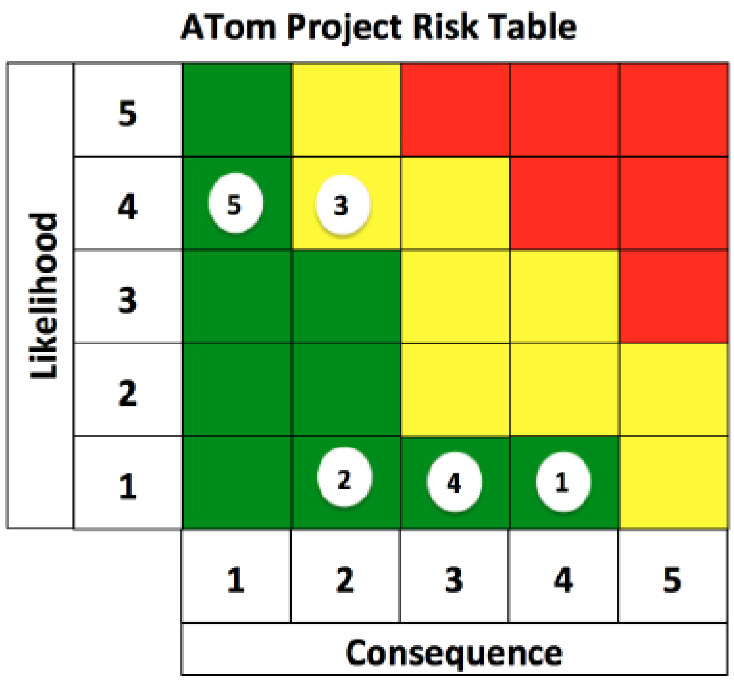

Figure 9.1 ATom Risk Matrix

Table 9.2 ATom Risk Legend

Legend

- ↓ Decreasing (Improving)
- ↑ Increasing (Worsening)
- → Unchanged
- Action: Research, Accept, Watch, Mitigate
- Timeframe; Near, Mid, Far
- ▲ PO Risk
- ◆ Top Project Risk (TProjR)

Cost Legend

1	$0-$100K
2	$100-$200K
3	$200K-$300K
4	$300K-$400K
5	$400K-$500K

ID	Trend	Description	Likelihood	Consequence: Safety	Consequence: Technical	Consequence: Schedule	Consequence: Cost	Action	Timeframe
1	→	DC-8 unavailable (long term in the field)	1			4	2	A	F
2	→	DC-8 unavailable (long term at AFRC)	1			2		A	F
3◆	→	Short term (2-3 day) deployment schedule slip	4		2	2	1	A	F
4	↓	Deployment stopover site unavailable	1		3		1	M	F
5	→	Cost increases	4				1	W	F

9.2. Scope Reduction Options

ATom has a $3M cost reserve and incorporates technical and schedule margins that minimize the possibility of requiring a reduction in scope of the proposed mission. The management team has reviewed the science objectives and determined the instruments most critical to the mission goals and the resulting scope reduction options (**Table 9.2, ATom Descope Options**) that provide additional cost margins while minimizing the impacts on the science returns. The first major reduction in scope option keeps two full Pacific and Atlantic circuit deployments, in boreal Summer FY16 and Winter FY17, but reduces the scope of the Fall FY17 and Spring FY18 deployments to Pacific-only circuits. A Pacific-only circuit would return to Palmdale after Christchurch (via Pago-Pago and Kona). This option would shorten the deployment by 7 days and result in a reduction of the mission cost by $0.5M (by reducing travel, flight hours and other support costs for each of the two years). The second and third options remove science instruments; first MMS and then, if needed, HR-AMS. If exercised option two would save the project $737K and three would save the project $1.2M. The DC-8 aircraft instrumentation provides a backup measurement capability for P, T, and vector winds in the event that the MMS instrument was removed from the ATom instrument suite. The SAGA measurements of particle composition provide a limited backup in the event that the HR-AMS instrument was removed from the suite. The fourth scope reduction option drops a full deployment in the Spring of FY18 and saves the project $2.2M. The fifth scope reduction option would drop the Spring FY18 and Fall FY17 deployments and save the project $4.3M.

If exercised scope reduction options #1 through #4 would still allow the project to achieve the ATom Level 1 Baseline requirements. If exercised scope reduction option #5 would still allow the project to achieve the ATom Level 1 Threshold requirements.

The team has also defined a Level 1 Threshold mission (see Section 3) in which the completion of one fully operational Pacific loop to Christchurch and back (not necessarily on the same deployment), plus Atlantic basin data would provide sufficient new statistics and model analysis on reactivity to justify the ATom science goals.

Table 9.2 ATom Scope Reduction Options

Descope Options:	FY15	FY16	FY17	FY18	FY19	FY20	Option Total
#1: Change 2 Pacific-Atlantic loops to Pacific only loop	$0	$244	$250	0	0	0	$494
#2: Drop MMS instrument	$54	$141	$254	$151	$80	$56	$737
#3: Drop HR-AMS instrument	$180	$183	$281	$207	$220	$123	$1,195
#4: Drop complete Spring FY18 deployment	0	0	0	$2171	0	0	$2171
#5: Drop Spring and Fall deployments	0	0	$2010	$2171	0	0	$4281

10. Investigation Evaluation

Over the life of the ATom project the following reviews will be conducted in an effort to help ensure the project will successfully fulfill its Level 1 requirements, manage and mitigate project risks and do so while staying within the project fiscal restraints.

10.1. Investigation Confirmation Review (ICR)

The ICR shall be conducted prior to the first ATom deployment (ATom-1) and will cover the ATom investigation concept and requirements. The ICR, a two-part review, is the mechanism through which the project will receive approval to proceed to the implementation phase. The first part of the ICR is the Investigation Confirmation Assessment. The Investigation Confirmation Assessment will involve the Earth System Science Pathfinder Program Office, the Program Scientist and the ATom Project Principal Investigator and Project Manager. The PI and PM will present pertinent information from the Project Implementation Plan and address any new issues. The full content of the presented materials will be coordinated between the Principal Investigator, the ESSP Project Office, the Program Scientist and Executive. The ESSP Project Office, the Program Scientist and Executive and the Project Principal Investigator will use results from the Investigation Confirmation Assessment to develop a decision package in preparation for the second part of the ICR review; the Confirmation Decision Meeting. The decision package is in turn presented to the Earth Science Directorate at NASA Headquarters at the Confirmation Decision Meeting. After the project has successfully completed the Confirmation Decision Meeting the project will be given approval to proceed to the project implementation phase.

10.2. Project Status Reviews

Project Status Reviews, between the ESSP and ATom project management, are conducted by teleconference. These reviews are held twice monthly prior to the Confirmation Review and quarterly post Confirmation Review and are based upon monthly/quarterly reports submitted from the project to the ESSP Program Office. The status reviews include discussions of progress against the proposal (pre-Confirmation Review) or Project Implementation Plan (post Confirmation Review) costs, schedule and performance.

10.3. Science Reviews

The ATom project will hold annual Science Review/Team Meetings. The ATom project's entire team of participants, representatives of the ESSP Program Office and NASA Headquarters' Program Scientist will attend the Science Review/Team Meetings. One Science Team meeting will be held prior to the first ATom deployment. Subsequent reviews will be conducted after the completion of a deployment and prior to the next deployment. The Science Reviews will concentrate on data acquired during the previous deployment and planning for the subsequent deployment. Included will be discussions of what went well, during the previous deployment, and what didn't and changes that should be incorporated in an effort to improve the conduct of the subsequent deployment.

10.4. Safety and Mission Assurance

The ATom Safety and Mission Assurance review requirement will be satisfied through the Technical Brief and Flight Readiness/Operational Readiness Reviews that will be conducted at AFRC.

10.4.1. Technical Brief

The Technical Brief is a component of the overall Armstrong Flight Research Center's Air Worthiness and Flight Safety Review (AFSRB) process. The Technical Brief ensures that projects present goals and plans for peer review and that the AFRC Management Team receives updates to current project goals, plans and risks. The Technical Brief is a review by various designated Senior Management personnel to assure readiness for a research/science flight or block of flights.

Those whose attendance is mandatory at the Technical Brief are:

- Project Manager
- Project Chief Engineer
- Project Pilot
- Project Operations Engineer
- AFRC Chief Engineer (Chair)
- AFRC Director for Engineering
- AFRC Director for Flight Operations
- AFRC Director for Aerospace Projects
- AFRC Director for the Office of Safety & Mission Assurance
- AFRC Chief Pilot

Subjects to be reviewed include:

- Past flight conduct and results
- Objective of the proposed flight or flight block
- Flight plan
  - Maneuvers
  - Flight profiles
- Aircraft status
  - Maintenance status
  - Time Compliance Technical Order (TCTO), Technical Directive (TD), Airworthiness Directive (AD) and Safety Bulletin (SB) status
  - Instrument status
  - Instrument structural analyses for new installations
- Configuration
  - Configuration changes
  - Status of Configuration Management documentation
  - Open waivers

- Hazard review
  - List of all identified hazards
  - Hazard Action matrix (HAM) charts
  - Accepted risk list, including mitigations and mitigation type for each
- Mandatory mission requirements
  - Go/No Go list, with changes highlighted
  - Mission rules, with changes highlighted
  - Weather constraints
  - Operating limitations
  - Test-specific emergency procedures
  - Required documentation
- AFRC range, facility and information technology requirements
  - Normal operations
  - Effect of scheduled outages
  - Contingency plan for unscheduled outages
- Open items from AFSRB, if required

10.4.2. Operational Readiness Review

An Operational Readiness Review (FRR) shall be conducted at AFRC prior to each ATom deployment in accordance with NASA policies (NPR 7900.3) and procedures. The ORR is a 3 to 5 member NASA convened, Operational Readiness Review Panel. The task of the ORR is to review the total mission readiness for each mission prior to flight. The ORR will review the Mission Description, Science Requirements and Success Criteria. The ORR will also review the aircraft readiness with regard to maintenance readiness and will review a summary of the aircraft's airworthiness. The ORR will also review the qualification of the flight crew and will ensure that all are qualified and current. The project's operations plans will be reviewed with regard to the flight plan and logistics plan. Finally the Safety Plan will be reviewed to ensure that all risks have been identified and analyzed and either have the necessary mitigations in place or are lower level risks that can be accepted. The ORR will ensure that a safety briefing will be given to all project personnel that will fly on the aircraft and that a Mishap Preparedness & Contingency plan is in place.

11. Relationships to other projects and organizations

The conduct of the ATom project relies heavily on numerous relationships with institutions and organizations both internal and external to NASA.

11.1. Internal Relationships

The ATom project requires participation from and coordination with Program Scientists and Executives, Mission Managers, Science and Instrument Co-Investigators, aircraft operations, data archives, project management and contracting personnel from a host of NASA centers. The NASA centers include Langley Research Center, Goddard Space Flight Center, Armstrong Flight Research Center, Ames Research Center, the NASA Shared Services Center. The ATom project also requires participation with and support from NASA Headquarters. Regular communications between participants from all of the NASA centers will include phone calls, e-mails, teleconferences and meetings. There are no formal internal agreements required between any of the NASA organizations.

11.2. External Relationships

The ATom project has both funded and unfunded relationships with a number of organizations external to NASA. The Principal and Deputy Principal Investigators, Science and Instrument Co-Investigators participate through funded relationships between NASA and their institutions. These institutions include Harvard University, the University of California at Irvine, the Earth System Research Laboratory (ESRL), Boulder, of the National Oceanic and Atmospheric Administration (NOAA), the University Corporation for Atmospheric Research (UCAR), Pennsylvania State University, the University of New Hampshire, Durham, Columbia University, the University of Colorado, Boulder and the California Institute of Technology. The Principal Investigator, along with the Harvard HTS instruments' Co-Investigator participation, is through a cooperative agreement between Harvard University and Langley Research Center (through the NASA Shared Services Center (NSSC)). The Deputy Principal Investigators' participation, as well as a subset of the Science and Instrument Co-Investigators' participations, are funded through cooperative agreements between Ames Research Center (through the NSSC) and their respective educational institutions or the University Corporation for Atmospheric Research. The other subset of the Science and Instrument Co-Investigators' participations are through an Interagency Transfer (IAT) between NASA Headquarters and the NOAA. Travel for all cooperative agreement participants will be administered through the Fully Integrated Lifecycle Mission Support Services (FILMSS) support service contract (NNA14AB82C). The project is also supported (i.e., the Deputy Project Manager's position and general support) through a cooperative agreement between Ames Research Center and the Bay Area Environmental Research Institute (BAERI). All of these cooperative agreements, as well as the NASA/NOAA IAT, have been approved and are in place. Additionally there are unfunded collaborators from the Smithsonian Institution/Smithsonian Astrophysical Observatory, the Jet Propulsion Laboratory, the University of Bremen, the Norwegian Meteorological Institute, the Japanese National Institute for Environmental Studies and the Royal Netherlands Meteorological Institute. There are no formal external agreements required between the ATom project and these project collaborators' institutions.

ATom will also have a number of external relationships, commercial and otherwise, with service providers at each of the deployment stopover locations. The service providers range from the United States and Royal Air Force to providers of aircraft fuel, aircraft ground handling services, lodging, rental vehicles, etc.

12. Waivers

At the time of the writing of this plan there was one waiver that the project has been granted and one other that may be required. The waiver that has been granted by AFRC releases the project from the requirement to have an aircraft crew wide "hard down day" every 8th consecutive workday during deployments. The waiver was approved by Tom Grindle, Aircraft Maintenance Division Chief. The project will achieve the crew rest requirement, that the "hard down day" ensures, by scheduling rolling, individual aircraft crew member "down days" that ensure aircraft crew members do not work more than 7 consecutive days. There is one other waiver that the project may need to pursue. The other waiver would be from NASA-STD-8719.11 which states that NASA hangars and hangars that are used to house NASA aircraft must be protected in accordance with the requirements of NFPA409. The only stopover location where a hangar would be required is Anchorage, AK, and the thought is that that would only be for the winter 2017 deployment. The only hangar at Ted Stevens International Airport that is large enough to house the DC-8 is a hangar that is leased by Fed Ex. During the site survey to Anchorage we had discussions with Fed Ex regarding the use of the hangar. While we haven't yet received word from Fed Ex confirming our ability to use the hangar it is equipped with a fire detection/suppression system, and as such, the waiver should not be required. If we are not able to use the Fed Ex hangar and have to go elsewhere we may still need the waiver.

13. Change Log

Change Log

Version	Date	Description

Appendix FF: Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats (TROPICS)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Release (Ver. 1.0; 1/19/2017)

Appendix FF - Earth System Science Pathfinder Program Plan

Program-Level Requirements for the

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats **(TROPICS)**

Version: 1.0
Date: Jan 19, 2017

Change Log

Revision	Date	Sections Changed	Author
	7 Nov 2016	**Initial Release**	Bonniksen

Table of Contents

1.0 SCOPE

This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on MIT Lincoln Laboratory (MIT LL) for the development and operation of the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Project of the ESSP Program. Requirements begin in Section 4. Sections 1, 2 & 3 are intended to set the context for the requirements that follow.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

For purposes of the TROPICS project, the term "CubeSat" is defined as one payload and one spacecraft bus.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division within SMD to the ESSP Program Manager at Langley Research Center (LaRC).

The Principal Investigator is responsible for scientific success, design, development, test, mission operations, and data verification tasks and shall coordinate the work of all contractors and science team members.

Changes to information and requirements contained in this document require approval by the officials that signed the original document.

2.0 SCIENCE DEFINITION

The TROPICS Project will implement a spaceborne Earth observation mission designed to collect measurements over the tropical latitudes to observe the environmental thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems' lifecycles. The measurements will provide nearly all-weather observations of 3D temperature and humidity, as well as cloud ice, precipitation horizontal structure and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the CubeSat constellation, are needed to better understand the TC lifecycles and the environmental factors that affect the intensification of TCs.

Definitions:

Tropical Storm: A tropical cyclone in which the maximum sustained surface wind speed (using 1-minute average) ranges from 17 m s^{-1} to 33 m s^{-1}.

Tropical Cyclone: A warm-core non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this way, they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects).

Precipitation Horizontal Structure: Precipitation Horizontal Structure is defined as mesoscale or smaller regions of enhanced scattering (brightness temperatures depressions) in the temperature (118 GHz) and water vapor (183 GHz) channels that are associated with small to large precipitating ice particles. Within tropical cyclones, precipitation structure is related to regions of the eyewall and cyclonically curving rainbands outside of the eyewall.

Minimum Sea-Level Pressure: A measure of tropical cyclone intensity given by the minimum surface pressure at the center of a storm.

Maximum Sustained Wind Speed: A measure of tropical cyclone intensity given by the maximum estimated 1-minute average wind speed at 10 meters above the surface within the storm.

Measurement Definitions

a) Spatial (horizontal) resolution is expressed as the geometric mean of the minor and major axes of the ellipse resulting when the antenna half-power beam contour is projected onto the Earth's surface.

b) Latitude-weighted revisit time is defined as the observatory revisit time as a function of latitude weighted by historical storm frequency as a function of latitude.

2.1. Baseline Science Objectives

The TROPICS science is enabled by meeting the following objectives:

- Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated storm intensity changes
- Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilate microwave radiances and/or retrievals in mesoscale and global numerical weather prediction models to assess impacts on storm track and

intensity

2.2 Science Instrument Summary Description

The baseline TROPICS instrument is a cross-track scanning multiband passive microwave radiometer in an approximately 1U payload on a 3U CubeSat. Each Cubesat will carry one instrument and the initial plan is for 12 CubeSats in 3 orbital planes. The radiometer comprises an ultra-compact dual-feed offset-fed reflector antenna with integrated G-band front-end mixer electronics, W/F-band receiver front-end electronics, electronic calibration modules, ultra-compact intermediate frequency processor modules, control and data handling electronics, and voltage regulation electronics. Radiometric observations are in one channel near 90 GHz, 7 (TBC) channels near the 118.75-GHz oxygen absorption line, 3 (TBC) channels near the 183.31-GHz water vapor line, and one channel near 206 GHz.

3.0 Project Definition

3.1 Project Organization & Management

The Principal Investigator shall report to NASA according to Figure 1.

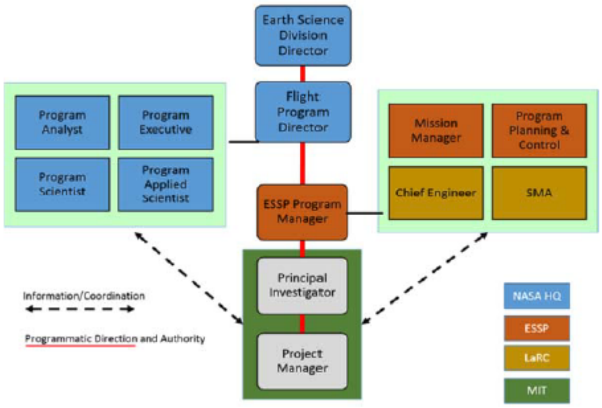

Figure 1. TROPICS Lines of Authority and Coordination

The Principal Investigator and his institution, MIT Lincoln Laboratory (LL), have overall management responsibility for the success of the CubeSats once orbited and science objectives.

3.2 Project Acquisition Strategy

MIT LL serves as a TROPICS prime contractor for NASA. NASA will acquire the launch services for the TROPICS Project to include any required launch service interagency agreements.

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA.

4.1 SCIENCE REQUIREMENTS

4.1.1 BASELINE SCIENCE REQUIREMENTS

a) The baseline science mission shall provide estimates of atmospheric temperature profiles in non-precipitating conditions with average horizontal resolution of 50 km and average RMS profile error less than 2 K averaged over 3 km vertical layers from 0-20 km altitude.

b) The baseline science mission shall provide estimates of the atmospheric moisture profiles in non-precipitating conditions with average horizontal resolution of 25 km and average RMS profile error less than 25% averaged over 3 km vertical layers from 0-10 km altitude.

c) The baseline science mission shall collect space-based measurements of brightness temperature with temporal sampling not greater than one hour as measured by the latitude-weighted median revisit time over latitudes observed by the constellation.

d) The baseline science mission shall provide estimates of instantaneous surface rainfall rate with average horizontal resolution of 25km. These estimates shall be validated on a spatially and temporally aggregated grid to a relative accuracy compared to IMERG of 25% at a resolution of 2.5-deg x 2.5-deg on weekly time scales.

e) The baseline science mission shall provide estimates of Minimum Sea-Level Pressure with RMS error less than 10 hPa and Maximum Sustained Wind Speed with RMS error less than 6 m s^{-1}.

4.1.2 THRESHOLD SCIENCE REQUIREMENTS

a) The threshold science mission shall provide estimates of atmospheric temperature profiles in non-precipitating conditions with average horizontal resolution of 65 km and average RMS profile error less than 2.5 K averaged over 3 km vertical layers from 0-20 km altitude.

b) The threshold science mission shall provide estimates of the atmospheric moisture profiles in non-precipitating conditions with average horizontal resolution of 40 km and average RMS profile error less than 35% averaged over 3 km vertical layers from 0-10 km altitude.

c) The threshold science mission shall collect space-based measurements of brightness temperature with temporal sampling not greater than two hours as measured by the latitude-weighted median revisit time over latitudes observed by the constellation.

d) The threshold science mission shall provide estimates of instantaneous surface rainfall rate with average horizontal resolution of 25km. These estimates shall be validated on a spatially and temporally aggregated grid to a relative accuracy compared to IMERG of 50% at a resolution of 2.5-deg x 2.5-deg on monthly time scales.

e) The threshold science mission shall provide estimates of Minimum Sea-Level Pressure with RMS error less than 12 hPa and Maximum Sustained Wind Speed with RMS error less than 8 m s^{-1}.

4.2 Mission and Flight Element Performance

a) The TROPICS project shall be Category 3 per NASA Space Flight Program and Project Management Requirements, NPR 7120.5E, and the mission class shall be D per Risk Classification for NASA Payloads, NPR 8705.4.

b) The TROPICS mission shall complete the In-Orbit Checkout (IOC) period within 30 days after the final launch. Science Operations will begin 30 days after the final launch according to the science requirements in section 4.1.

c) The TROPICS Constellation orbital deployment shall be designed for minimum inter-CubeSat conjunction of 200 m (3σ) (TBR).

d) The TROPICS baseline science mission lifetime is one year following completion of IOC for the CubeSat constellation.

e) The TROPICS threshold science mission lifetime requirement is 6 months following completion of IOC for the CubeSat constellation.

f) The TROPICS mission shall be capable of completing decommissioning activities within 3 months following the end of the science mission.

4.3 Launch Requirements

a) The TROPICS CubeSats shall be launched on one or more NASA provided expendable launch vehicles as either the primary or secondary payload.

b) All CubeSats will be launched within a 60-day window.

c) The TROPICS constellation shall be launched in a nominally circular orbit which will support the CubeSats reaching a final constellation latitude-weighted median revisit time of not more than 2 hours between 35° N and 35°S latitude.

d) The TROPICS project shall target CubeSat completion and readiness for integration with a launch vehicle on or before a date of March 2020. This date will be updated as appropriate, via the most current Decision Memorandum.

4.4 Ground System Requirements

The TROPICS project shall develop and operate a ground system to meet the science requirements in section 4.1 and the data requirements in section 4.5.

4.5 Mission Data Requirements

4.5.1 Science Data Management

a) The TROPICS Project shall produce the standard science data products listed in Table 1. Standard data products are fully validated against Level 1 requirements.

b) The standard science data products listed in Table 1, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products shall be made publicly available*. Public release of these data shall conform to the NASA Earth Science Data and Information Policy (http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/). There shall be no period of exclusive access.

* Although not a formal requirement, if possible, the public release of data products will be through the NASA DAAC designated for project archiving

c) Science algorithms used to generate the standard data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs) and be available to the public through the same source as the mission science data. The ATBD will be maintained through the life of the project.

d) The TROPICS Project shall coordinate with the [NASA Identified DAAC] or selected public release source on the release of product versions, to ensure completeness and accuracy of quality information, validation status, and metadata of the TROPICS science data products.

e) By the end of Prime Mission, the TROPICS Project shall deliver all standard science data products, along with the scientific algorithm software, coefficients, and ancillary data used to generate these products, to the [NASA Identified DAAC].

f) The TROPICS Project will coordinate with the [NASA Identified DAAC] on the data and information to be transferred at TROPICS closeout.

4.5.1.1 Science Data Requirements

a) The TROPICS Project science data product formats shall conform to the HDF5/netCDF4 standard.

b) The TROPICS 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, and the TROPICS Project shall baseline to a specific initial version before launch.

c) For all standard data products that can be meaningfully represented as images, TROPICS shall generate full-resolution browse products. Specific products will be identified prior to confirmation.

d) The TROPICS Project shall transfer to the [NASA Identified DAAC] all the information and documentation required for long-term preservation of knowledge about the products resulting from the TROPICS Project, as defined in the *NASA Earth Science Data Preservation Content Specification* document published at http://earthdata.nasa.gov/about-eosdis/requirements, and shall baseline to a specific initial version.

Table 1. TROPICS Standard Science Data Products[1]

Data Product	Description	First Data Delivery after IOC	Maximum data latency after first release[2]
Level 1a	Geolocated & calibrated antenna temperatures (kelvins)	3 months	4 days (TBC)
Level 1b	Geolocated & calibrated, and intercalibrated brightness temperatures (kelvins)	6 months	4 days (TBC)
Level 2a	Spatially resampled brightness temperatures (kelvins) to a Unified Resolution (L2a-UR)	6 months	4 days (TBC)
Level 2b	Atmospheric Vertical Temperature Profile (kelvins) Atmospheric Vertical Moisture Profile (mass mixing ratio)	6 months	4 days (TBC)
Level 2b	Surface rain rate (mm hr^{-1}) Maximum sustained wind speed (m s^{-1}) Minimum sea-level pressure (hPa)	9 months	4 days (TBC)

[1] The NASA HQ Archive will be at the TBD.DAAC.
[2] Data latency is defined as the elapsed time from the downlink to the availability of processed level 2 data products to the

public.

4.5.2 Applied Science Support Requirements

Beginning in Phase C, the TROPICS Project will coordinate with the Applied Science Program to jointly host an annual TROPICS data product application workshop. The content and goals of the application workshop are to be determined by the TROPICS Project and Applied Science leads.

The TROPICS Project shall interact with the operational hurricane forecast community assessment of TROPICS data in retrospective studies of new data sources.

4.6 Mission Success Criteria

Collect global space-based simultaneous measurements from no fewer than two CubeSats in each of two orbital planes for 3 months to provide measurements that individually support the threshold science requirements of section 4.1.2 items a, b, c, and d.

5.0 NASA MISSION COST REQUIREMENT

5.1 Cost

The TROPICS PI-managed mission is cost capped at $30.2M in real year (RY) dollars. This cost includes all development and execution costs for Phases A through F of the proposed mission.

Access to space is outside the PI-managed cost cap and will be provided by NASA along with all integration costs to the launch service. The NASA procured launch services will be based on the requirements in section 4.3. The cost of the launch service includes, but is not limited to, procurement of the launch service, integration onto the selected launch service, and investigation costs during any potential gap between the time the TROPICS CubeSats are complete and the start of the first Launch service integration.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the TROPICS project shall pursue scope reduction and risk management as a means to control cost. The Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised. Scope reductions from baseline science requirements to threshold science requirements or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of this document.

6.0 MULTI-MISSION NASA FACILITIES

No Multi-Mission NASA facilities are used for TROPICS.

7.0 EXTERNAL AGREEMENTS

All agreements between NASA and each non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of International and Interagency Relations prior to KDP-C. All funding for external participation will be performed under the cost cap.

8.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the TROPICS Project.

9.0 WAIVERS

Any waivers to NPR 7120.5 Class D implementation requirements or processes shall be approved in accordance with existing MIT LL, and NASA processes for category A waiver approval.

10.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS

____________________________________ ___________
Thomas H. Zurbuchen, Ph.D. Date
Associate Administrator, Science Mission Directorate
NASA Headquarters

____________________________________ ___________
William Blackwell Date
Principal Investigator, TROPICS Mission
MIT Lincoln Laboratory

____________________________________ ___________
Greg Stover Date
Program Manager, Earth System Science Pathfinder Program
NASA Langley Research Center

_______________________________________ ____________

Greg Robinson Date

Deputy Associate Administrator for Programs

Science Mission Directorate, NASA Headquarters

Appendix GG: Program Level Requirements Appendix (PLRA) for the Multi-Angle Imager for Aerosols (MAIA) Project

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	4/14/2017	Initial Release

Earth System Science Pathfinder Program

Program-Level Requirements Appendix (PLRA) for the Multi-Angle Imager for Aerosols (MAIA) Project

April 2017

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1 SCOPE

This appendix to the Earth System Science Pathfinder (ESSP) Program Plan describes the Level 1 science, mission, schedule, and cost requirements governing the Multi-Angle Imager for Aerosols (MAIA) investigation. Level 1 requirements serve as the basis for mission assessments conducted by NASA during the development period and provide the baseline for determining science mission success during the operational phase.

The MAIA investigation was selected by the Science Mission Directorate (SMD) at NASA Headquarters on 10 March 2016 in response to the Second Stand Alone Mission of Opportunity Notice (SALMON-2), Program Element Appendix (PEA) P: Earth Venture Instrument-3, NNH12ZDA0060-EVI3. The MAIA Principal Investigator (PI) from the Jet Propulsion Laboratory (JPL) is responsible for scientific success, design, development, test, mission operations, and data verification tasks and will coordinate the work of all contractors and science team members, consistent with this Program Level Requirements Appendix (PLRA). Costs covered within the PI-Managed Mission Cost (PIMMC) (§5.1.1) are capped as described in §5.1.3. The MAIA instrument will be accommodated on a host platform to be determined by NASA. It is recognized that achieving the investigation requirements detailed herein involves certain performance trades between the instrument, host platform, and orbit selected for the MAIA investigation. NASA will work with the PI to ensure the requirements developed to support the host selection process remain responsive to investigation requirements. Accommodations costs are outside of the PIMMC, as described in §5.1.2.

As described in §3.1, program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division (ESD) within SMD to the Earth System Science Pathfinder (ESSP) Program Manager at the Langley Research Center (LaRC). Project management is conducted at JPL.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Changes to information and requirements contained in this document require approval by the officials that approved the original.

2 SCIENCE DEFINITION

2.1 Science Objectives

Particulate air pollution imposes serious health risks upon much of the world's population. Airborne particulate matter (PM) is a well-known cause of heart disease, cardiovascular and respiratory illness, low birth weight, and lung cancer. The Global Burden of Disease Study ranks ambient PM as the top environmental risk factor worldwide, causing more than 4 million premature deaths per year. Numerous studies have demonstrated that PM exposure increases the risks of mortality (death) and morbidity (illness). However, ambient PM is a complex mixture of particles that vary in size, shape, and chemical composition. Our understanding of the relative toxicity of different PM types—mixtures having different size distributions and compositions—is relatively poor. According to the US Environmental Protection Agency, "[T]he evidence is not yet sufficient to allow differentiation of those constituents or sources that may be more closely related to specific health outcomes."

The primary objective of the Multi-Angle Imager for Aerosols (MAIA) investigation is to assess the impact that different size and compositional mixtures of PM have on adverse birth outcomes, cardiovascular and respiratory diseases, and premature deaths. Surface PM monitors alone cannot do this because they are too sparsely distributed, expensive to install and maintain, and non-existent in many parts of the world where air pollution health impacts are greatest. Observation from space offers the only practical means of acquiring frequent, high spatial resolution maps of PM concentrations in major population centers around the world. Airborne particles of interest to MAIA are those near the surface, where they impact human health. The MAIA investigation aims to address the following science questions:

- For which PM types is maternal exposure during pregnancy linked to adverse birth outcomes such as restricted intrauterine growth, preterm delivery, and low birth weight?
- For which PM types is short-term (daily to monthly) exposure linked to acute illness events (e.g., asthma flare-ups) and premature death?
- For which PM types is chronic (multi-year) exposure linked to cardiovascular and respiratory disease?

The secondary objectives of the MAIA investigation are to (a) collect multi-angle spectropolarimetric imagery over targets of interest to the air quality and climate science communities, such as cities with elevated pollution (besides those observed to meet the primary objective), aerosol source regions, and climatically important cloud regimes including those affected by aerosol pollution, volcanic eruptions, major wildfires, dust storms, or other episodic events; and (b) serve as a technology demonstration for a future spaceborne multi-angle spectropolarimetric imager capable of achieving global coverage.

2.2 Investigation Approach

In air pollution research, airborne particle sizes are specified by their aerodynamic diameter, which is the diameter of a sphere with density = 1 g cm^{-3} that has the same terminal settling velocity under gravity as the airborne particle considered. PK° refers to particles having aerodynamic diameters < 10 jam. PM2.5 refers to particles having aerodynamic diameters < 2.5 [tin. For MAIA, the PM components of interest include two size classes, coarse and fine. Coarse PM consists of particles with aerodynamic diameters in the 2.5 pm to 10 ium size range. Fine PM consists of particles having aerodynamic diameters less than or equal to 2.5 pm. The concentration of fine particles is further partitioned into mixtures of inorganic, organic, elemental carbon, mineral dust, and other components. PM type is defined by the fractional masses of the components making up a particle mixture.

Near-surface PM is generally heterogeneous in spatial distribution. The Code of Federal Regulations (CFR) Part 58, Appendix D introduces the "spatial scale of representativeness," which is described in terms of the physical dimensions of an air parcel (quantity of air with homogeneous properties) throughout which actual pollutant concentrations are reasonably similar. The US

Environmental Protection Agency (EPA) states that representative information about air quality trends and compliance with National Ambient Air Quality Standards (NAAQS) is best provided at the neighborhood scale, corresponding to areas where people commonly live and work for extended periods. This is the relevant scale for PM mapping by MAIA, and is associated with relatively uniform land use having dimensions in the 0.5 to 4.0 km range.

The primary MAIA investigation integrates data from chemical transport models (CTMs), the MAIA satellite instrument, and geostatistical regression models derived from collocated surface and MAIA measurements to determine near-surface concentrations of coarse, and fine PM, as well as components of fine PM. Geocoded birth, death, and hospital records and established epidemiological methodologies are used to examine the association between these PM metrics and adverse health outcomes.

2.3 Science Instrument Summary Description

The MAIA instrument measures the radiance and polarization of sunlight scattered by atmospheric aerosols, from which the abundance and characteristics of ground-level PM are derived. The instrument design includes a pushbroom spectropolarimetric camera system capable of providing multi-angle imagery for a selected set of globally distributed Primary Target Areas (PTAs). PTAs are regions specifically designated for conducting the MAIA particulate-matter health investigation. They are observed on a routine basis throughout the mission. The PTAs are selected to include major population centers covering a range of PM concentrations and particle types, surface-based aerosol sunphotometers, PM size discrimination and chemical speciation monitors, and access to health datasets associated with location identifiers such as home addresses, postal codes, census block groups, or similar.

The requirement for multi-angle viewing makes low Earth orbit the appropriate orbit choice for MAIA. The scan (along-track) axis provides multi-angle viewing using a "step and stare" observing sequence. The pan (cross-track) axis allows access to targets that are not directly situated on the sub-spacecraft track.

The spectral range of the MAIA camera system spans the ultraviolet (UV), visible and near-infrared (VNIR), and shortwave infrared (SWIR) regions of the electromagnetic spectrum. VNIR and SWIR spectral bands help discriminate particle size because the wavelengths are comparable to the mean particle radii. The VNIR bands are most sensitive to fine aerosols while the SWIR is sensitive to coarse aerosols. Extending measurements into the UV provides sensitivity to aerosol absorption. Multi-angle radiance observations are powerful because oblique views enhance the aerosol signal relative to surface reflection and are sensitive to the aerosol scattering phase functions, which are governed by particle size and shape. This enables separation of anthropogenic aerosols from dust. Multi-angle polarimetry is sensitive to particle size and compositional proxies such as refractive index.

In addition to the PTAs, the MAIA investigation defines other types of target areas to be observed by the spaceborne instrument. These include Secondary Target Areas (STAs), regions of general interest for aerosol and cloud science; Calibration/Validation Target Areas (CVTAs), areas observed routinely for instrument vicarious calibration and aerosol/particulate matter validation;

and Targets of Opportunity (TOOs), regions where observations are scheduled as a result of an episodic or potentially calamitous event, such as a volcanic eruption, major wildfire, dust storm, or industrial accident.

3 PROJECT DEFINITION

3.1 Project Organization and Management

The MAIA Principal Investigator (PI) will report to NASA according to Figure 3.1.

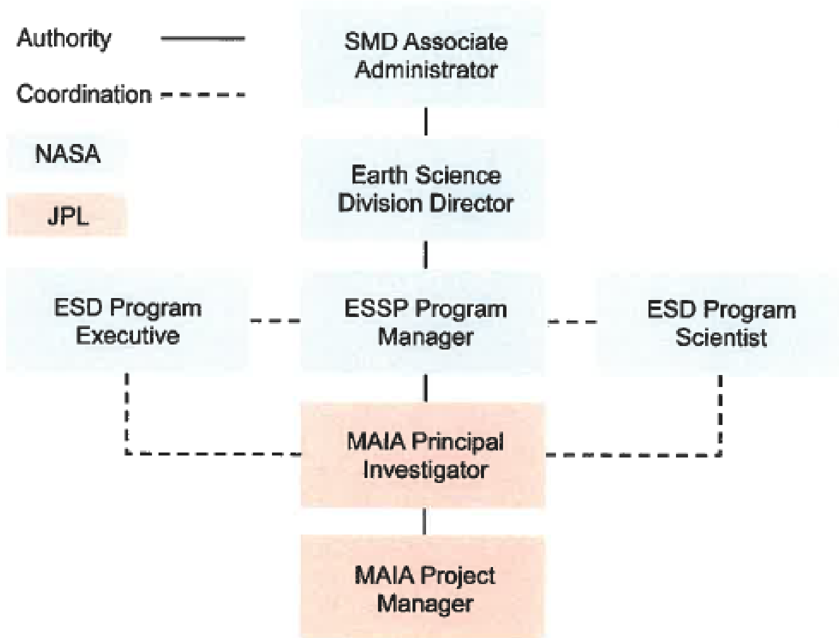

Figure 3.1. MAIA programmatic lines of authority and coordination.

The PI is responsible for overall investigation success within the committed schedule and cost. The PI has delegated formulation and implementation management responsibility to the Project Manager at JPL. Specific assigned roles and responsibilities are:

- The PI and JPL are responsible for ensuring the scientific success of the mission and providing project management; system engineering and mission design; safety and mission assurance; the MAIA instrument; instrument operations; science data system algorithm and software development; and working with the MAIA Science Team to obtain geocoded health records for the PTAs from state and national Vital Statistics reports, Medicare, Medicaid, local hospitals, relevant cohort studies, and/or other health record providers.
- Using science data product generation software delivered by the PI, the NASA LaRC Atmospheric Science Data Center (ASDC) is responsible for ground data processing and delivery of calibrated/validated science data products to one or more NASA-designated Distributed Active Archive Centers (DAACs) for public distribution.

3.2 Project Acquisition Strategy

JPL will implement the development of the MAIA instrument, supplemented by commercial vendors for parts and assemblies as required. The ESSP Program Office will work with the MAIA Project to identify potential accommodations required to comply with the Program Level Requirements that are not defined within the PI-managed cost cap. The ESSP Program Office will provide host services to the MAIA Project with the required capabilities and interfaces necessary for achieving the science requirements delineated in §4.1 and §4.2. The ESSP Program Manager is responsible for the adjudication, approval, and funding of accommodations.

4 PROGRAMMATIC REQUIREMENTS

The science objectives in §2.1 can be achieved by either the Baseline or Threshold science investigation requirements listed herein, but the Baseline investigation provides substantially more value to NASA and the Earth science community

4.1 Science Requirements

4.1.1 Baseline science requirements

(a) The Baseline mission duration shall be three years.

(b) During the Baseline mission, MAIA satellite instrument observations shall be acquired over at least 10 globally distributed Primary Target Areas (PTAs) representing a variety of particulate matter (PM) concentrations and particle types.

(c) Each PTA shall contain an estimated human population level that provides the requisite statistical power for associating PM exposure and human health response.

(d) The MAIA investigation shall deliver, for days and locations coincident with cloud-free MAIA satellite instrument observations of a given PTA, daily-averaged concentrations of coarse PM, fine PM, and fine PM components on a spatial sampling grid of 2000 m x 2000 m or finer, over the spatial extent of each PTA.

(e) Within each PTA, PM concentrations shall be derivable at one or more point locations from ground stations and mapped over the entire target area (with dimensions of 300 km x 150 km or larger) using spatiotemporally integrated results derived from the ground stations, the MAIA instrument, and/or a chemical transport model (CTM).

(f) The MAIA Science Team shall be responsible for epidemiological conclusions about the human health impacts of exposure to different PM size classes and components within the PTAs.

(g) By the end of the mission, the delivered PM concentration data, characterized in part by the regression slopes compared to collocated surface monitor data, shall support the epidemiological studies.

(h) Calibrated and validated instrument imagery and PM data products shall be delivered to the NASA-designated DAAC(s) for use by the MAIA Science Team and the broader scientific community.

4.1.2 Threshold science requirements

(a)The Threshold mission duration shall be two years.

(b) During the Threshold mission, MAIA satellite instrument observations shall be acquired over at least 10 globally distributed Primary Target Areas (PTAs) representing a variety of particulate matter (PM) concentrations and particle types.

(c)Each PTA shall contain an estimated human population level that provides the requisite statistical power for associating PM exposure and human health response.

(d) The MAIA investigation shall deliver, for days and locations coincident with cloud-free MAIA satellite instrument observations of a given PTA, daily-averaged concentrations of coarse PM, fine PM, and fine PM components on a spatial sampling grid of 2000 m x 2000 m or finer, over the spatial extent of each PTA.

(e) Within each PTA, PM concentrations shall be derivable at one or more point locations from ground stations and mapped over the entire target area (with dimensions of 150 km x 150 km or larger) using spatiotemporally integrated results derived from the ground stations, the MAIA instrument, and/or a chemical transport model (CTM).

(f) The MAIA satellite observations shall support epidemiological studies about the human health impacts of exposure to different PM size classes and components within the PTAs.

(g) By the end of the mission, the delivered PM concentration data, characterized in part by the regression slopes compared to collocated surface monitor data, shall support the epidemiological studies.

(h) Calibrated and validated instrument imagery and PM data products shall be delivered to the NASA-designated DAAC(s) for use by the MAIA Science Team and the broader scientific community.

4.2 Science Instrument Requirements

(a) To provide sensitivity to aerosol absorption and to distinguish fine and coarse PM, the MAIA instrument shall acquire radiance measurements in a set of discrete spectral bands including ultraviolet, visible, near-infrared, and shortwave-infrared (SWIR) wavelengths.

(b) To provide complementary sensitivity to particle size and refractive index, the instrument shall measure the linear polarization Stokes parameters in a subset of the spectral bands, including the visible and SWIR.

(c) The instrument's spectral complement shall include bands that facilitate the screening of water and ice clouds from the PM retrievals.

(d) During a single overpass of a given Earth target, the instrument shall be capable of acquiring imagery of the target at multiple and selectable along-track view angles.

(e) The instrument shall enable observing each PTA with a frequency, averaged over a season, having a mean value of at least 3 revisits per week.

(f) The MAIA instrument shall be capable of meeting the science requirements at orbital parameters as defined in §4.4.

4.3 Mission Success Criteria

The MAIA mission shall be considered successful if:

(a) The satellite instrument collects space-based radiometric and polarimetric measurements.
(b) The science data system retrieves column aerosol properties sufficient to provide at least 150 collocated matchups with ground-based sunphotometers.

(c) The resulting calibrated and georectified image and aerosol products are delivered to the NASA-designated DAAC(s).

4.4 Mission Performance Requirements

(a) The MAIA Project shall be Category 3 per NASA Space Flight Program and Project Management Requirements, NASA Procedural Requirement (NPR) 7120.5E. The MAIA instrument shall be Class C per Risk Classification for NASA Payloads, NPR 8705.4.

(b) The MAIA instrument shall be available for integration onto the selected host platform by March 31, 2021.

(c) Instrument in-orbit checkout (IOC) shall be completed within 90 days after instrument activation.

(d) The MAIA instrument shall be hosted on a NASA-selected spacecraft with an orbit that shall be Sun-synchronous with an altitude between 600 and 850 km. The mean local time of equator crossing shall be between 9:00 am and 3:00 pm, exclusive of 11:30 am to 12:30 pm.

4.5 Ground System Requirements

The MAIA Project shall develop and operate an instrument operations system and science data processing system to meet the science requirements in §4.1 and the reprocessing and data latency requirements in §4.6.

Level	Description	First data release at DAAC(s)	Median data latency after first release
0	Downlinked instrument telemetry	6 months after instrument IOC	Within 8 weeks from receipt of telemetry
1	Calibrated and georectified Stokes parameters describing radiance and linear polarization View and solar geometry Latitude and longitude	6 months after instrument IOC	Within 12 weeks from receipt of telemetry
2	Cloud mask and cloud-screened total and fractional aerosol particle properties at time of satellite overpass 24-hr averaged concentrations of coarse PM, fine PM, and fine PM components on days and locations coincident with cloud-free and quality-controlled instrument observations of the MAIA PTAs	12 months after instrument IOC	Within 8 weeks of completion of Level 1 processing
3	N/A, as spatial gridding is performed at Level 1	MAIA has no Level 3 products	
4	Spatially and temporally gap-filled 24-hr averaged concentrations of daily coarse PM, fine PM, and fine PM components over the MAIA PTAs	18 months after instrument IOC	Within 8 weeks of completion of Level 2 processing

Table 4.1. MAIA data products.

4.6 Science Data Management

(a) The MAIA Project shall generate the standard data products as shown in Table 4.1.

(b) The ASDC at NASA LaRC is responsible for ground data processing and shall deliver the standard science data products listed in Table 4.1, along with the coefficients and ancillary data used to generate them, to the NASA-designated DAAC(s) in accordance with the NASA Earth Science Data and Information (ESD&I) Policy specified at *http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/.*

(c) Public release of these data shall also conform to the NASA ESD&I Policy.

(d) There shall be no period of exclusive access.

(e) Algorithm Specification Documents (ASDs) that provide information to validate the data products generated by the computer software, to the same extent that is provided by the computer software source code, shall be developed and delivered to the DAAC(s) at the time of the initial data deliveries associated with each of the Level 1 and higher products specified in Table 4.1.

(f) Requests for computer software source code used to generate data products shall be addressed in conformance with the existing JPL Prime Contract.

(g) The MAIA Project shall baseline to a specified version number of the NASA ESD&I Policy at the project Preliminary Design Review (PDR).

(h) The science algorithms used to generate the standard data products listed in Table 4.1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs) and delivered to the NASA-designated DAAC(s) at the time of initial data delivery.

(i) Updated ATBDs shall be delivered to the DAAC(s) throughout the lifetime of the project.

(j) The MAIA Project shall coordinate with the ASDC and NASA-designated DAAC(s) on the release of product versions to ensure completeness and accuracy of quality information, validation status, and metadata of the MAIA science data products.

(k) The MAIA Project shall coordinate with the NASA-designated DAAC(s) on the data and information to be transferred at project closeout.

4.7 Science Data Requirements

a) Publicly available MAIA data products shall be distributed in standardized formats (e.g., HDF-5 and/or netCDF-4), in conformance with NASA ESD-approved Data System Standards published at http://earthdata.nasa.gov/about-eosdis/requirements.

b) MAIA 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. The MAIA Project shall baseline the metadata format before PDR.

(c) For all standard data products that can be meaningfully represented as images, the MAIA Project shall generate full-resolution browse products, as defined in https://earthdata.nasa.gov/about/science-system-description/eosdis-components/global-imagerybrowse-services-gibs.

(d) The MAIA Project shall transfer to the NASA-designated DAAC(s) all the information and documentation required for long-term preservation of knowledge about the products resulting from the MAIA investigation, as defined in the NASA Earth Science Data Preservation Content Specification document published at http://earthdata.nasa.gov/about-eosdis/requirements. The MAIA Project shall baseline to a specific version of this document before PDR.

5 MISSION REQUIREMENTS

5.1 Cost Requirements

5.1.1 Costs covered within the PI-Managed Mission Cost

For the MAIA Project, costs that are within the PI-Managed Mission Cost (PIMMC) include:

- Instrument delivery ready for integration onto the host spacecraft (Phases A-C).
- Development and delivery of functional algorithms and ground processing system (Phases BD).
- Supporting a science team that will contribute directly to the successful implementation of the investigation (Phases A-F).
- Required calibration and validation activities (All phases).
- Cost of the science team and of key management, instrument, and engineering staff during Phase D. For support of the science team and key management and engineering during Phase D, a two-year duration is assumed for budgeting purposes.
- Post-launch instrument commissioning during the instrument IOC period.
- Operations, product generation, and data analysis during the prime mission lifetime of the investigation (Phase E).
- Completion and close out of the investigation once the space-based data collection period has been concluded (Phase F).

5.1.2 Costs outside of the PI-Managed Mission Cost

Costs that are outside the PIMMC include:

- Technical and programmatic trades and development efforts for accommodation of the MAIA instrument on the host platform (Phases A-D). The MAIA Project shall identify host accommodations efforts needed to comply with the Program Level Requirements. The scope and cost for these accommodations efforts shall be submitted to the ESSP Program Office for consideration. The ESSP Program Manager shall adjudicate these accommodations requests and disposition resources to preserve the payload's ability to comply with the Program Level Requirements.
- Investigation costs during any potential gap between the delivery of the completed instrument (end of Phase C) and the start of integration of the instrument to the spacecraft (start of Phase

D). A planning budget of up to four years is assumed, on a per-year basis.

- Integration to the NASA-designated host platform (Phase D).
- Investigation costs during any extension of Phase D beyond two years caused by spacecraft development schedules, launch schedules, spacecraft IOC, or associated schedule delays that are outside the MAIA Project's control.
- Costs for access to space (launch vehicle and launch services).
- Costs for data downlink from the host spacecraft and delivery of error-checked MAIA instrument telemetry and time-stamped spacecraft attitude and navigation data to the MAIA science data processing system.
- Costs for archival and public distribution of MAIA standard data products by the NASA-designated DAAC(s).
- The costs for the Student Collaboration activities (Phase E).
- Costs for a Communication program (All phases).

5.1.3 Total costs

The MAIA Project shall design and build a payload that meets the Program Level Requirements within the confines of the allocated resources. Costs covered within the PIMMC (§5.1.1) are capped. The total NASA cost and associated budgetary phasing are given in the most current NASA SMD Directorate Program Management Council (DPMC) MAIA Project Decision Memorandum.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the MAIA Project shall pursue scope reduction and risk management as a means to control cost. No scope reduction shall be exercised that prevents achievement of the Threshold science requirements in §4.1.2.

6 MULTI-MISSION NASA FACILITIES

Services from multi-mission NASA facilities to be utilized by the MAIA investigation will be documented in accordance with the requirements of the facility. Such facilities include:

- The NASA LaRC ASDC, which is responsible for ground data processing and delivery of calibrated/validated science data products.
- One or more NASA-designated DAACs, to which MAIA standard data products will be delivered for archival and public distribution.
- Ground communication network(s) or interfaces required between NASA centers or facilities relevant to the MAIA investigation, including JPL.

7 EXTERNAL AGREEMENTS

Any agreements between NASA and any non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of International and Interagency Relations (0IIR).

8 EDUCATION AND PUBLIC OUTREACH

As stated in the SALMON-2 PEA P: Earth Venture Instrument-3, NNH12ZDA0060-EVI3, no specific Education and Public Outreach (E/PO) Plan is required for the MAIA Project.

9 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the MAIA Project.

10 WAIVERS

Any waivers to NPR 7120.5 requirements or processes shall be processed and approved in accordance with the existing JPL and NASA processes for Category A waiver approval.

11 ACRONYMS

AA	Associate Administrator
AOD	Aerosol Optical Depth
ASD	Algorithm Specification Document
ASDC	Atmospheric Science Data Center
ATBD	Algorithm Theoretical Basis Document
CFR	Code of Federal Regulations
CTM	Chemical Transport Model
CVTA	CalibrationNalidation Target Area
DAAC	Distributed Active Archive Center
DOLP	Degree of Linear Polarization
DPMC	Directorate Program Management Council
EPA	Environmental Protection Agency
E/PO	Education and Public Outreach
ESD	Earth Science Division
ESD&I	Earth Science Data and Information
ESSP	Earth System Science Pathfinder
EVI	Earth Venture Instrument
HDF	Hierarchical Data Format
IOC	In-Orbit Checkout
JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center
MAIA	Multi-Angle Imager for Aerosols
MLT	Mean Local Time (of Equator-Crossing)
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
netCDF	Network Common Data Form
NPR	NASA Procedural Requirement
OIIR	Office of International and Interagency Relations
PDR	Preliminary Design Review

PEA Program Element Appendix

PI Principal Investigator

PIMMC PI-Managed Mission Cost

PLRA Program Level Requirements Appendix

PM Particulate Matter

PSLA Project Service Level Agreement

PTA Primary Target Area

SALMON-2Second Stand Alone Mission of Opportunity Notice

SMD Science Mission Directorate

STA Secondary Target Area

SWIR Shortwave Infrared

TOO Target of Opportunity

UV . Ultraviolet

VNIR Visible/Near-Infrared

12 REQUIRED APPROVALS AND CONCURRENCES

12.1 Approvals

5/4/17
Date

Thomas H. Zurbuchen, Ph.D.
Associate Administrator
Science Mission Directorate
NASA Headquarters

4/27/17
Date

Michael Watkins
Director
Jet Propulsion Laboratory

14Apr17
Date

Greg Stover
Program Manager
Earth System Science Pathfinder Program Office
NASA Langley Research Center

12.2 Concurrence

David J. Diner
Principal Investigator
Jet Propulsion Laboratory

4/25/2017
Date

Kevin A. Burke
Project Manager
Jet Propulsion Laboratory

5/4/2017
Date

Elizabeth C. Edwards
Program Executive
Earth Science Division
NASA Headquarters

25 April 2017
Date

Hal B. Maring
Program Scientist
Earth Science Division
NASA Headquarters

25 Apr 2017
Date

Eric E. Ianson
Associate Director, Flight Programs
Earth Science Division
NASA Headquarters

4/26/17
Date

Michael H. Freilich
Division Director
Earth Science Division
NASA Headquarters

5/3/17
Date

Joseph W. Pellicciotti
Chief Engineer
Science Mission Directorate
NASA Headquarters

5/10/17
Date

Gregory L. Robinson
Deputy Associate Administrator for Programs
Science Mission Directorate
NASA Headquarters

5/17/17
Date

Dennis J. Andrucyk
Deputy Associate Administrator
Science Mission Directorate
NASA Headquarters

6/15/17
Date

Appendix HH: Orbiting Carbon Observatory 3 (OCO-3)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Change Log

Version	Date	Change Description
Baseline	11/01/2017	Initial Program Plan Release (May 2016; Version 3.0)

Contents

HH.1 SCOPE

This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on the Jet Propulsion Laboratory (JPL) for the development and operation of the Orbiting Carbon Observatory–3 (OCO-3) Project of the ESSP Program. The OCO-3 payload will be flown on the International Space Station (ISS) on the Japanese Experiment Module-Exposed Facility. Requirements begin in Section 4. Sections 1, 2 and 3 are intended to set the context for the requirements that follow.

This document serves as the basis for mission assessments to be conducted by NASA HQ during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division (ESD) within SMD to the ESSP Program Manager at the Langley Research Center. Project management will be conducted at JPL in accordance with the lines of authority shown in Section 3.1.

JPL is responsible for scientific success, design, development, test, mission operations, and data verification tasks and shall coordinate the work of all contractors and science team members.

The NASA ESD will select the investigators that will compose the OCO-3 Science Team through a competitive process.

Changes to information and requirements contained in this document require approval by the Science Mission Directorate (SMD), NASA Headquarters.

HH.2 SCIENCE DEFINITION

HH.2.1 Baseline Science Objectives

The ESSP OCO-3 Project is designed to collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO2}, with the precision, resolution, coverage and temporal stability needed to improve our understanding of surface CO_2 sources and sinks (fluxes) on regional scales (≥1000 km) and the processes controlling their variability over the seasonal cycle.

HH2.2 Science Instrument Summary Description

OCO-3 is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added as required to accommodate installation and operation on the International Space Station (ISS).

The OCO-3 instrument incorporates three near-infrared spectrometers designed to measure reflected sunlight in the CO_2 and molecular oxygen (O_2) absorption bands. Soundings, consisting of coincident CO_2 and O_2 spectra, are analyzed with a remote sensing retrieval algorithm to yield spatially-resolved estimates of X_{CO2}. The spectrometer optical design, spectral range, and resolving power were selected to optimize measurement precision and minimize bias. Spectra collected at wavelengths near 1.61 microns are most sensitive to variations in the CO_2 concentration near the surface of the Earth. Coincident measurements from the 0.76 micron O_2 A-band and the CO_2 band near 2.06 microns minimize X_{CO2} errors associated with pointing uncertainties and scattering by thin clouds and aerosols.

The core of the proposed OCO-3 instrument, the optical bench assembly, will be assembled from OCO-2 instrument flight spares, and is expected to have similar sensitivity and performance characteristics as the OCO-2 instrument. Mission unique components are used to adapt the OCO-3 instrument for operation on the ISS. These include a pointing mechanism, polarization mechanism, and structural enclosure and adapters to interface to the ISS structure and avionics.

The precision and bias of space-based X_{CO2} retrievals can only be validated at locations where X_{CO2} is well characterized by other methods. OCO-3 results will be validated through comparisons with X_{CO2} retrievals from selected ground-based spectrometers in the Total Column Carbon Observing Network (TCCON). These TCCON stations have been validated against in situ CO_2 profiles collected during aircraft or balloon over-flights of the station, using measurement techniques traceable to World Meteorological Organization standards for atmospheric CO_2 measurements. OCO-3 can acquire more than 100 soundings in the vicinity of a TCCON station in a single cloud-free over-flight. At least once each season, space-based X_{CO2} retrievals from cloud-free over-flights of each of three or more ground validation sites will be compared with TCCON retrievals to validate the OCO-3 measurement precision and to identify regional-scale systematic biases in its space-based X_{CO2} product.

HH.3 PROJECT DEFINITION

HH.3.1 Project Organization and Management

The OCO-3 Project Manager shall report to NASA according to Figure 1.

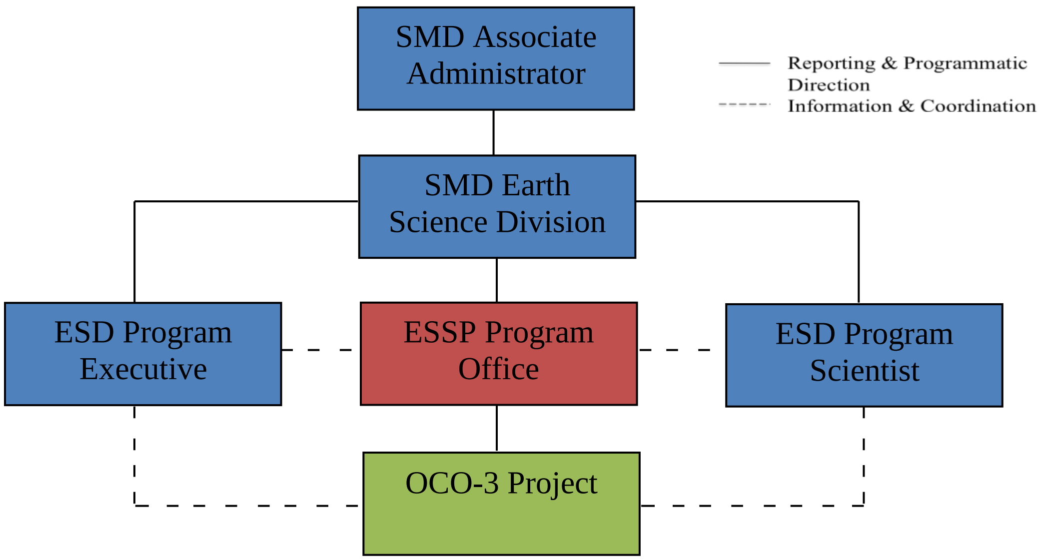

Figure 1. OCO-3 Programmatic Lines of Authority and Coordination

The OCO-3 Project Manager has overall management responsibility for the success of the project. The OCO-3 Project Scientist has overall management responsibility for the science elements of the project. Specific assigned roles and responsibilities are:

- JPL is responsible for providing: project management; system engineering and mission design; safety and mission assurance; the instrument; mission operations and the associated mission operations ground data system; science data processing and delivery of calibrated/validated science data products to an archive for public distribution.
- The SMD ESD has designated the NASA GSFC Distributed Active Archive Center (DAAC) as the facility for public distribution and eventual long-term preservation of OCO-3 data products (see Section 4.5).
- The Human Exploration and Operations Mission Directorate (HEOMD) – International Space Station (ISS) Program provides significant enabling contributions to the OCO-3 mission on the ISS. The HEOMD ISS Program provides the launch and launch services, and robotically installs the OCO-3 payload to the ISS. The HEOMD ISS Program also provides mission operations of the OCO-3 instrument payload using commands provided by JPL, downlink and capture of health and status, science telemetry, and mission critical operations support. The HEOMD ISS Program is responsible for payload disposal at the end of mission.

- NASA OCIO is responsible for providing access to voice and data communications networks necessary for the operation and transfer of science data for the OCO-3 mission, as identified in 6.0.

The Science Team (ST) will be composed of scientists with expertise spanning all necessary disciplines, competitively selected by NASA HQ. The role of the ST will be to validate the OCO-3 data, perform geophysical and geochemical analysis of the data, and achieve end-use research exploitation thereof.

HH.3.2 Project Acquisition Strategy

JPL will develop the instrument in-house, utilizing the spare OCO-2 flight instrument, supplemented by commercial vendors and/or other NASA centers for parts and assemblies as required.

HH.4 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA and the Earth science community.

HH.4.1 Science Requirements

HH.4.1.1. Baseline Science Requirements

a) Retrieve estimates of the column-averaged CO_2 dry air mole fraction (X_{CO2}) at monthly intervals, on regional scales (≥1000 km) from space-based measurements of the absorption of reflected sunlight by atmospheric CO_2 and O_2, collected in all cloud-free scenes in the sunlit regions for 3 years subject to instrument availability as defined in Section 4.3.

b) Compare space-based and ground-based X_{CO2} retrievals from soundings collected during over-flights of each of at least 3 ground validation sites at least once each season to identify and correct regional-scale systematic biases in the space-based X_{CO2} product and to demonstrate a precision of better than 0.3% for collections of more than 100 cloud-free soundings.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the GSFC DAAC for use by the scientific community. Fully characterize the accuracy of all publically delivered and archived science data.

HH.4.1.2 Threshold Science Requirements

a) Retrieve estimates of the column-averaged CO_2 dry air mole fraction (X_{CO2}) at monthly intervals, on regional scales (≥1000 km) from space-based measurements of the absorption of reflected sunlight by atmospheric CO_2 and O_2, collected in all cloud-free scenes in the sunlit regions for 1 year subject to instrument availability as defined in Section 4.3.

b) Compare space-based and ground-based X_{CO2} retrievals from soundings collected during over-flights of each of at least 3 ground validation sites at least once each season to identify and correct regional-scale systematic biases in the space-based X_{CO2} product and demonstrate a precision of better than 0.5% for collections of more than 100 cloud-free soundings.

c) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the GSFC DAAC for use by the scientific community. Fully characterize the accuracy of all publically delivered and archived science data.

HH.4.1.3 Mission Success Criterion/Criteria

The OCO-3 mission shall be considered successful if it augments the OCO-2 record with data of similar precision and accuracy over 50% of the available observation time for three (3) months after instrument on-orbit commissioning while also providing unique observations, taken at various times of the day, and broader spatial coverage in areas of interest for local emission sources (e.g., large urban areas).

HH.4.1.4 Science Instrument Requirements

a) The space-based instrument shall be capable of acquiring coincident measurements of reflected sunlight in the CO_2 bands centered at wavelengths near 1.61 and 2.06 μm and in the O_2 A-band centered near 0.765 μm.

b) The spectral range and resolving power of the space-based instrument shall be selected to resolve individual absorption lines from the underlying continuum throughout each CO_2 and O_2 band to retrieve estimates of X_{CO2} that meet the Science Requirements (Section 4.1).

c) The OCO-3 instrument shall acquire CO_2 and O_2 soundings with a footprint area of $\leq$ 4.5 km^2 at nadir to facilitate the acquisition of cloud-free scenes in at least 10% of the soundings collected over the sunlit hemisphere on monthly time scales.

HH.4.2 Launch and Installation Requirements

a) The OCO-3 payload shall be launched on a launch vehicle provided by the HEOMD ISS Program.

b) The OCO-3 payload shall be installed on the Japanese Experiment Module-Exposed Facility (JEM-EF) of the ISS and controlled via NASA's Payload Operations Integration Center (POIC).

c) The OCO-3 payload shall be disposed of at the end of the mission by the HEOMD ISS Program.

d) The OCO-3 payload shall be completed in March 2018, ready for shipment to the launch site for final processing and integration with the launch vehicle provided by the HEOMD ISS Program.

HH.4.3 Mission Performance

a) The OCO-3 project shall be Category 3 per NASA Procedural Requirement (NPR) 7120.5E.

b) The OCO-3 payload shall be Class C per NPR 8705.4.

c) The OCO-3 mission shall complete the In-Orbit Checkout (IOC) period within 90 days after installation and power-on, and then begin operations consistent with the baseline science requirements in Section 4.1.1.

d) The OCO-3 mission lifetime is 3 years baseline (1 year threshold) following completion of IOC.

e) Accommodations to support OCO-3 operations on the ISS shall be reserved for 3 years after IOC completion. Extended mission operations are subject to approval through the ESD Senior Review process, in consultation with the ISS program.

f) Science operations on the ISS shall be planned with acceptable risk as determined by the operations team to accommodate operational constraints unique to the ISS environment. Unique ISS operational constraints include but are not limited to: Crew and/or EVA operations; visiting vehicles; elevated contamination flux due to out-gassing and/or thrusters; ISS configuration changes; and electrical power availability.

g) OCO-3 shall acquire at least 75% of the measurement opportunities outside the time required to accommodate operational constraints for baseline performance. It shall acquire at least 50% of these measurement opportunities for threshold performance.

HH.4.4 Ground System Requirements

The OCO-3 project shall accomplish science data processing to meet the science requirements in Section 4.1 and the reprocessing and data latency requirements in Section 4.5.

HH.4.5 Mission Data Requirements

HH.4.5.1 Science Data Management

a) The OCO-3 Project shall produce the standard science data products listed in Table 1.

b) All data and the standard science data products listed in Table 1, along with the coefficients and ancillary data used to generate these products, will be delivered to the GSFC DAAC in accordance with the NASA Earth Science Data and Information (ESD&I) Policy specified at http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/. Public release of these data shall also conform to the NASA ESD&I Policy. There shall be no period of exclusive access. An Algorithm Specification Document (ASD) that provides information to validate the data products generated by the computer software, to the same extent that is provided by the computer software source code, shall be developed and delivered. Requests for ASDs or computer software source code for the purpose of validation of the data products generated by the software shall be addressed in conformance with the existing JPL Prime Contract.

c) Science algorithms used to generate the standard data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).

d) The OCO-3 Project will coordinate with the GSFC DAAC the release of product versions, to ensure completeness and accuracy of quality information, validation status, and metadata of the OCO-3 science data products.

e) The OCO-3 Project will coordinate with the GSFC DAAC on the data and information to be transferred at OCO-3 closeout.

HH.4.5.1.1 Science Data Requirements

a) OCO-3 Level 1 and Level 2 science data product formats shall conform to the Hierarchical Data Format (HDF5) standard.

b) The OCO-3 science data products metadata shall conform to ISO 19115-2 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.

c) The OCO-3 Project shall transfer to the GSFC DAAC all the information and documentation required for long-term preservation of knowledge about the products resulting from the OCO-3 project, as defined in the *NASA Earth Science Data Preservation Content Specification* document, original/change 01, January 2013 published at http://earthdata.nasa.gov/about-eosdis/requirements

Table 2. OCO-3 Data Products

Data Product	Description	First Data Delivery after IOC	Maximum Data Latency After First Release	NASA DAAC Location
Level 0	Raw collected telemetry	Within 24 hours of receipt at JPL	Within 24 hours of receipt at JPL	GSFC DAAC
Level 1	Calibrated Geolocated Spectral Radiances	6 months after IOC	3 weeks*	GSFC DAAC
Level 2	X_{CO2}	6 months after Level 1 data products are available	12 weeks*	GSFC DAAC

***Delivery latency after ground receipt

HH.4.5.2 Applied Science Data Requirements

Beginning in Phase C and in coordination with the OCO-2 Mission, the OCO-3 Project shall participate in all scheduled OCO-3 data product application workshops. The workshop will share information on OCO-3 science data applications and define potential applications that can be supported with existing OCO-3 data requirements. Results of the workshop will be provided to the OCO-3 science team and at other OCO-3 workshops and meetings.

HH.5 MISSION REQUIREMENTS

HH.5.1 Cost Requirements

a) The life cycle cost (LCC) for the OCO-3 mission shall include the formulation, implementation, operations, calibration, validation, and generation of science data products (defined in Section 4).

b) The cost associated with any gap between delivery of the OCO-3 payload and the actual start of the launch site processing (i.e., a payload storage period) is outside the OCO-3 LCC.

c) The total NASA SMD cost and associated budget phasing are given in the most current NASA SMD Directorate Program Management Council (DPMC) OCO-3 Project Decision Memorandum.

HH.5.2 Cost Management and Scope Reduction

a) Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the OCO-3 project shall pursue scope reduction and risk management as a means to control cost.

b) The Project Plan shall include potential scope reduction and risk management as a means to control cost. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised.

c) Scope reductions from baseline science requirements (Section 4.1.1) to threshold science requirements (Section 4.1.2) or potential scope reductions affecting these Program Requirements shall be agreed to by the officials represented on the approval page of document.

HH.6 MULTI-MISSION NASA FACILITIES

The OCO-3 Project shall rely on the following multi-mission NASA facilities and infrastructure, which are funded outside the project:

a) ISS Program resources and services shall be provided by the HEOMD as documented in the Payload Integration Agreement. These resources include the Mission Control Center–Houston at Johnson Space Center, the POIC at NASA Marshall Space Flight Center (MSFC), the Space Network, and other operational infrastructure used to operate and maintain the ISS. The POIC shall facilitate OCO-3 remote payload operations by routing OCO-3 payload commands to the ISS, retrieving and temporarily archiving payload data and ISS data such as attitude and ephemeris, and by performing mission critical payload health and status monitoring.

b) NASA's terrestrial communications resources and services shall be provided by the NASA Communications Service Office as documented in the Project Service Level Agreement (PSLA) for voice and data communications between NASA JPL and NASA MSFC.

c) The OCO-3 Project utilizes the NASA GSFC DAAC and other EOSDIS infrastructure for science data archive and distribution. The SMD/ESD provides access to these resources as documented herein.

HH.7 EXTERNAL AGREEMENTS

There are no non-NASA partners in the OCO-3 Mission.

HH.8 PUBLIC OUTREACH AND EDUCATION

OCO-3 shall develop and execute an Education and/or Public Engagement Plan in accordance with approved NASA education and public engagement guidelines.

HH.9 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the OCO-3 Project.

HH.10 WAIVERS

None.

HH.11 REQUIRED APPROVALS AND CONCURRENCES

11.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS

John M. Grunsfeld
Associate Administrator
Science Mission Directorate
NASA Headquarters

5/6/16
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Appendix II: Geostationary Carbon Cycle Observatory (GeoCarb)

Earth System Science Pathfinder Program Office
NASA Langley Research Center
Hampton, VA 23681

Please verify correct version before use.

Change Log

Version	Date	Change Description
Baseline	10/10/2017	Initial Release

Contents

1.0 SCOPE

The Science Mission Directorate (SMD) at NASA Headquarters selected the Geostationary Carbon Cycle Observatory (GeoCarb) mission on December 6, 2016 in response to the NASA SMD Earth Venture Mission-2 (EVM-2) Announcement of Opportunity (AO) NNH15ZDA0110. This appendix to the Earth System Science Pathfinder (ESSP) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on The Board of Regents of the University of Oklahoma (OU) for the development and operation of the GeoCarb mission.

The GeoCarb Principal Investigator (PI) from OU is responsible for the complete science investigation and for the GeoCarb development and activities necessary to deliver the science as agreed to in this Program Level Requirements Appendix (PLRA), also known as the "Level-1 requirements". The PI is responsible for scientific success, design, development, test, launch (via a contractor as a hosted payload), mission operations, data verification tasks, and science and application implementation. The PI will also coordinate the work of all contractors and science team members. The GeoCarb mission will be mounted as a hosted payload on the nadir deck of a geostationary commercial satellite. The hosting service supporting flight of the GeoCarb instrument will be procured by the PI.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Requirements begin in Section 4, while Sections 1, 2 and 3 set the context for the requirements that follow.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division (ESD) within SMD to the ESSP Program Manager at the Langley Research Center (LaRC). Project management will be conducted at OU, as described in Section 3.1.

Any changes to the Level 1 requirements contained in this document must be approved by the officials that approved the original requirements.

2.0 SCIENCE DEFINITION 2.1 Science

Objectives

The GeoCarb mission will develop and deploy a multi-channel, slit-scan spectrometer that will measure absorption spectra in sunlight reflected from the land to retrieve atmosphere-column concentrations of carbon dioxide (CO2), methane (CH4), carbon monoxide (CO) and solar induced fluorescence (SIF) from vegetation from a GEOstationary orbit (GEO). The column concentrations of CO2, CH4, and CO will be used by the PI, the GeoCarb science team, and the science and application communities to increase understanding and impact of terrestrial sources and sinks of CO2 and CH4. The SIF information will enable the community to improve models for agricultural production and yield as well as to detect changes in crop status.

2.2 Science Instrument Summary Description

GeoCarb deploys a 4-channel slit imaging spectrometer that measures reflected near-Infra Red (IR) sunlight at wavelengths 1.61 microns (pm) and 2.06 gm for XCO2, and 2.32 pm for XcH4 and Xco, where X denotes column-integrated average concentration. The fourth channel, 0.76 gm, measures 02 column concentration, SIF, and provides valuable information on aerosol and cloud contamination. The spectrometer will be deployed on a host geostationary satellite in the range of 85° +/- 10° West longitude (baseline). The North/South (N/S) extent of the scan spans a 4.4° field of view (FOV) angle, and projects up to 25° latitude or 2800 kilometer (km) swaths at nadir.

Measurements are acquired with a scanning slit spectrograph that has a 3 km East/West (E/W) slit step size and provides a 6 km FOV at nadir. By exploiting available sunlight reflected from the land, the designated regions (scan blocks) generally will be scanned daily. The scan patterns are flexible; scan blocks can be changed, and the scan strategy can be updated at least weekly to observe areas of greater interest or uncertainty, for calibration/validation (cal/val), or for transient events in a campaign mode.

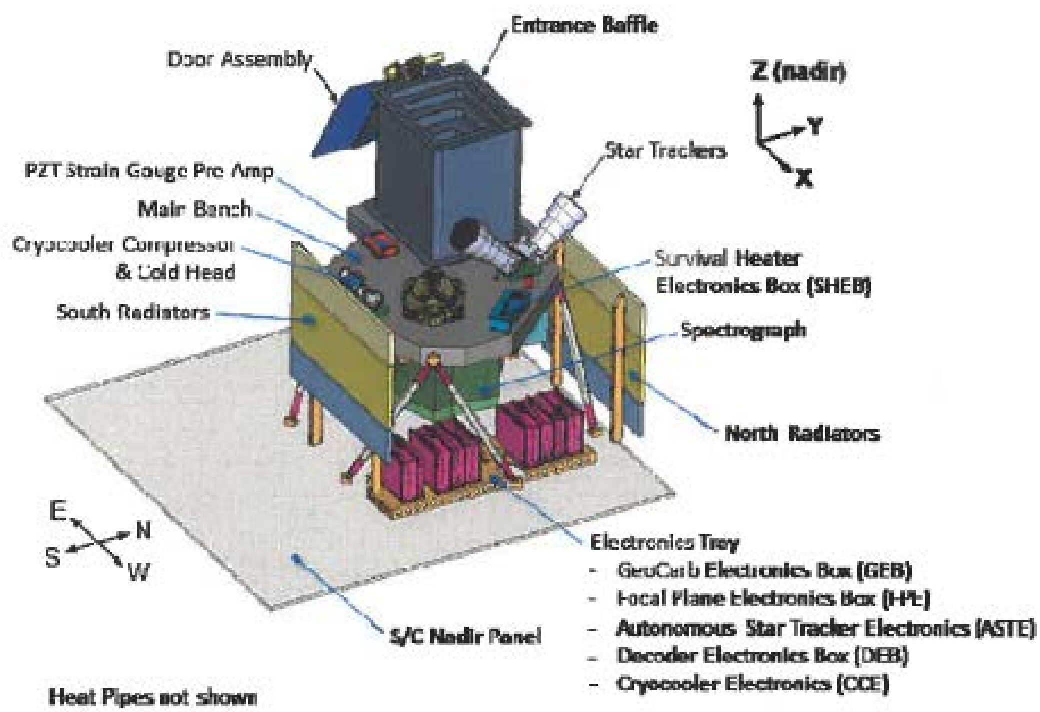

Figure 1. GeoCarb Layout

3.0 PROJECT DEFINITION

3.1 Project Organization and Management

The GeoCarb **PI** shall report to NASA according to Figure 2.

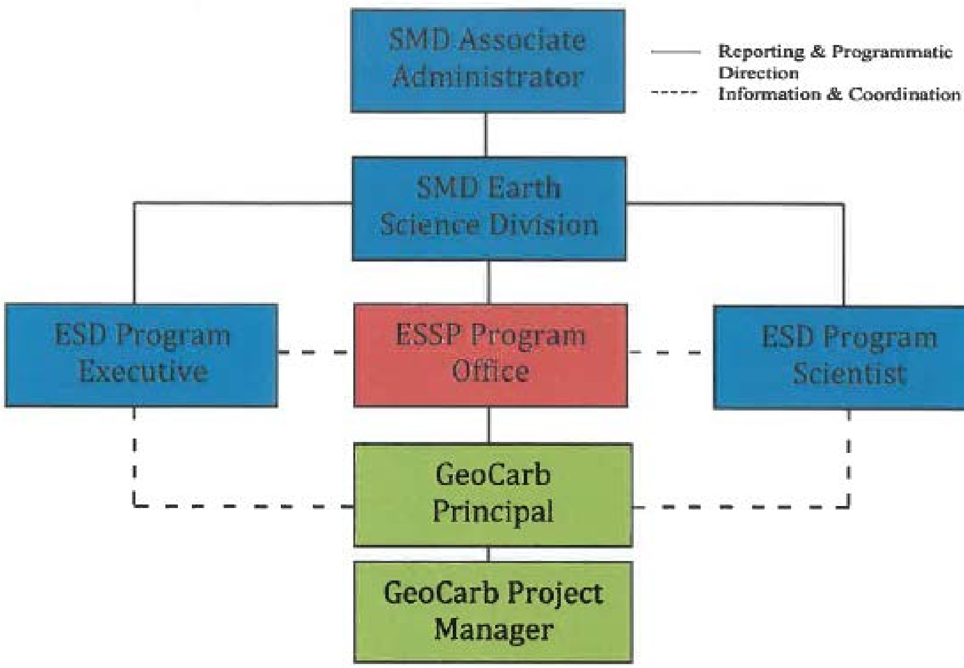

Figure 2. GeoCarb Programmatic Lines of Authority and Coordination

The GeoCarb PI and his institution (OU) are responsible for overall mission success within the committed schedule and cost. Specific assigned roles and responsibilities include:

- Ensuring the scientific success of the mission;
- Providing project management support;
- Ensuring system engineering and mission design development aligns with Level 1 requirments;
- Ensuring safety and mission assurance throughout the entire lifecycle of the project;
- Enuring the GeoCarb payload is successfully mounted as a hosted payload on the nadir deck of a geostationary commercial satellite;
- Procuring hosting services;
- Providing mission operations and the associated mission operations ground data system;
- Ensuring successful processing, delivery, and cal/val of science data products to an archive for public distribution (NASA SMD/ESD will designate the appropriate Distributed Active Archive Centers (DAACs) to be responsible for public distribution of GeoCarb data and long-term data archiving).

3.2 Project Acquisition Strategy

The OU has the prime contract for GeoCarb and is funded by NASA on a Cost Reimbursable (CR) contract. OU has subcontracts with Lockheed Martin Civil Space and Advanced Technology Center (LMATC) for instrument development, and Colorado State University (CSU) for Level 2 algorithms and science. There will also be a Firm Fixed Price (FFP) subcontract with SES Government Solutions (SES-GS) for payload hosting. LMATC is subcontracted by OU with a Cost Plus Fixed Fee (CPFF) contract and CSU is subcontracted with a Cost Reimbursable (CR) contract. NASA Ames Research Center, Goddard Space Flight Center (GSFC), and Jet Propulsion Laboratory (JPL) efforts are overseen by OU and are included in the PI cost cap and funded directly by NASA. The entire mission is cost capped at $170.9 million (M). The responsibilities of the partners are described in Figure 3.

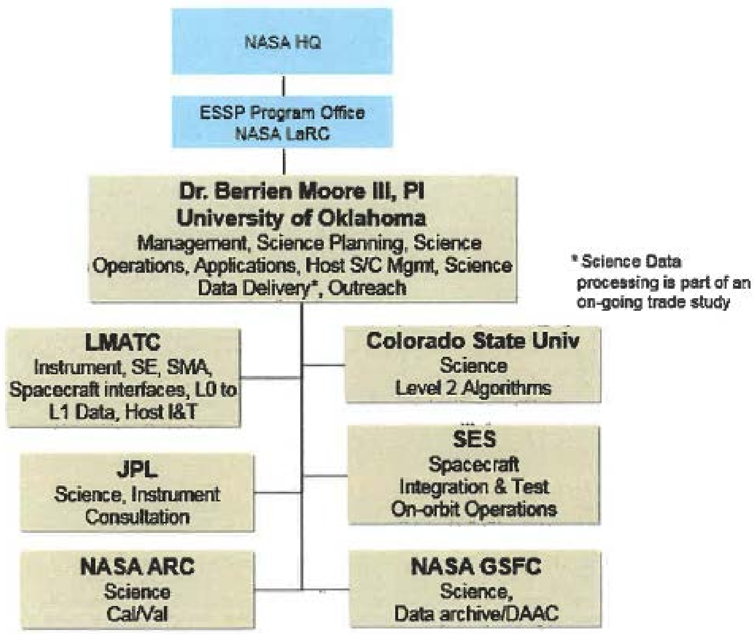

Figure 3. GeoCarb Partners and Responsibilities

4.0 PROGRAMMATIC REQUIREMENTS

The science objectives in Section 2.1 can be achieved by either the baseline or threshold science mission requirements listed herein, but the baseline mission provides substantially more value to NASA and the Earth science community.

4.1 Science Requirements

4.1.1 Baseline Science Requirements

The GeoCarb baseline mission will provide daily high precision measurements of XCO2, XCH4, Xco, and SIF from GEO, which will enable breakthrough improvements in the estimation of CO2 and CH4 terrestrial fluxes and resulting science. The measurement requirements include:

a) Retrieve estimates of the column-averaged dry air mole fractions XCO2, XCH4, XCO and SIF from space-based measurements collected over all available cloud-free (atmospheric scattering opacity less than 0 3 optical depth), terrestrial sunlit regions between 50° N and 50° S latitude and within +/- 40° E-W longitude of the geostationary placement for 3 years.

b) Evaluate space-based and ground-based XCO2, XCH4, and XCO retrievals from cloud-free soundings collected during scans of at least 3 Total Carbon Column Observing Network (TCCON) sites at least once each season. Retrieval products will be compared to TCCON measurements to demonstrate multi-sounding average accuracies better than:

   a. 0.3% for XCO2 as measured against time integrated TCCON observations at multiple sites,
   b. 0.6% for XCH4 as measured against time integrated TCCON observations at multiple sites, and
   c. 10% or 12 parts per billion (ppb) (whichever is greater) for XCO as measured against time integrated TCCON observations at multiple sites.

c) GeoCarb shall retrieve estimates of SIF with a Noise Equivalent Spectral Radiance (NESR) that is better than 0.75 W/m2/sr/pm.

d) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the NASA-assigned DAAC(s) for use by the scientific community. Characterize the precision and accuracy of all publicly delivered and archived science data.

4.1.2 Threshold Science Requirements

a) Retrieve estimates of the column-averaged dry air mole fractions XCO2 and Solar Induced Fluorescence (SIF) from space-based measurements collected over all available cloud-free, terrestrial sunlit regions between 50° N and 50° S latitude and within +/- 40° E-W longitude of the geostationary placement for 1 year.

b) Evaluate space-based and ground-based XCO2 retrievals from cloud-free soundings collected during scans of at least 1 TCCON site at least once each season. Retrieval products will be compared to TCCON measurements to demonstrate multi-sounding accuracies better than 0 3% for XCO2 as measured against time integrated TCCON observations at multiple sites.

c) GeoCarb shall retrieve estimates of SIF with a NESR that is better than 1.0 W/m2/sr/gm.

d) Record, validate, publish, and deliver science data records and calibrated geophysical data products to the NASA-assigned DAAC(s) for use by the scientific community. Characterize the precision and accuracy of all publicly delivered and archived science data.

4.1.3 Mission Success Criterion/Criteria

The GeoCarb mission shall be considered successful if it acquires observations over two seasons which have sufficient quality to improve knowledge of terrestrial fluxes of CO2 over the major geographic areas within the field of regard (e.g., Amazonia, North America). The regions of most intensive observations will depend on the longitude of the satellite.

4.1.4 Science Instrument Requirements

a) The space-based GeoCarb system shall utilize hosting from a commercial geostationary satellite.

b) Instrument lifetime shall be designed for three years of on-orbit observations.

c) The instrument shall acquire soundings with footprint size of 30 km^2 FOV at nadir.

4.2 Applications

The GeoCarb Mission shall provide a data product, SIF, and work with the agricultural community to ensure that it is closely aligned with the needs of that community. The GeoCarb Applications Team shall convene at least three community workshops during Phases D and E to engage potential users, assess data needs and get feedback on methods for disseminating information in the most effective manner.

4.3 Launch Requirements

a) The hosting satellite shall be launched into a baseline geostationary orbit in the range of 85° +/- 10° West longitude. To meet the threshold requirement, the station can be as far west as 100° W +/- 5° or as far east as 70° W +/- 5°, affording a complete view of the Contiguous United States (CONUS) or the Amazon, respectively.

b) The GeoCarb instrument shall be passivated at the end of the GeoCarb mission.

c) The GeoCarb instrument shall be delivered to the host spacecraft to accommodate a launch no later than June 30, 2022.

4.4 Mission Performance

a) The GeoCarb project shall be Category 3 per NASA Procedural Requirement (NPR) 7120.5E: 7120.5: Space Flight and Ground System Program and Project Management Requirements and the mission class shall be D per NPR 8705.4: Risk Classification for NASA payloads.

b) The GeoCarb mission shall complete the In-Orbit Checkout (IOC) period within 60 days of the host initiating instrument operations.

c) The GeoCarb mission lifetime is three years baseline (one year threshold) following completion of IOC.

d) Extended mission operations are subject to approval through the ESD Senior Review process, in consultation with the host.

4.5 Ground System Requirements

The GeoCarb project shall include a ground system to meet the science requirements described in Section 4.1 and the data requirements described in Section 4.6.

4.6 Mission Data Requirements

4.6.1 Science Data Management

a) The GeoCarb Project shall produce the standard science data products listed in Table 1. Standard data products will be fully validated against Level 1 requirements.

b) All data and the standard science data products listed in Table 1, along with the scientific source code for algorithm software, coefficients and ancillary data used to generate these products, will be delivered to the NASA-assigned DAAC(s) in accordance with the NASA Earth Science Data and Information (ESD&I) Policy specified at https://science.nasa. gov/earth-science/earth-science-data/datainformation-policy/. The GeoCarb project shall baseline to the policy above before the Preliminary Design Review (PDR).

c) Public release of these data shall conform to the NASA ESD&I Policy.

d) There shall be no period of exclusive access.

e) The source code shall be delivered to DAAC(s) within 12 months of initial science data collection.

t) Updated source code shall be delivered to DAAC(s) throughout the lifetime of the project as new versions of software are implemented for the released data products.

g) Science algorithms used to generate the standard data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs) and delivered to NASA-assigned DAAC(s) at the time of the initial data delivery.

h) Updated ATBDs shall be delivered to the DAAC(s) throughout the lifetime of the project if the ATBDs are modified.

i) The GeoCarb project shall coordinate with the NASA-assigned DAAC(s) the release of product versions, including browse products, to ensure completeness and accuracy of quality information, validation status, and metadata of the GeoCarb science data products.

j) The GeoCarb project shall coordinate with the NASA-assigned DAAC(s) on the data and information to be transferred at GeoCarb closeout.

4.6.1.1 Science Data Requirements

a) The GeoCarb Level 1 and Level 2 science data product formats (e. g., Hierarchical Data Format (HDF-5)) shall conform to ESD-approved Data System Standards specified at https://earthdata.nasa.gov/about-eosdis/requirements.

b) The GeoCarb science data products metadata shall conform to International Organization for Standardization (ISO) 19115-2 Geographic Information -Metadata standards and adhere to the *Metadata Requirements — Base Reference for NASA Earth Science Data Products* document published at hups://earthdata.nasa.gov/about-eosdis/requirements. The GeoCarb project shall baseline the initial metadata format before the PDR.

c) For all standard data products that can be meaningfully represented as images, GeoCarb will work with the Global Imaging Browse Services (GIBS) team to generate full-resolution browse products, as defined in https://earthdata.nasa.2oviabout/science-system-description/eosdis-components/gjobal-imagery-browse-services-gibs.

d) The GeoCarb project shall transfer to the NASA-Assigned DAAC(s) all the information and documentation required for long-term preservation of knowledge about the products resulting from the GeoCarb project, as defined in the *NASA Earth Science Data Preservation Content Specification* document, original/change 01, January 2013 published at hnps://earthdata.nasa.gov/about-eosdis/requirements. The GeoCarb project shall baseline the initial version before launch.

Table 1. GeoCarb Data Products

Data Product	Description	First Data Delivery after In-Orbit Checkout (IOC)	Maximum Data Latency After First Release	NASA Distributed Active Archive Center(s) DAAC(s) Location
Level 0	Science data, calibration mode data, star tracker, housekeeping, S/C ancillary data.	6 months	30 days*	NASA ASSIGNED DAAC(s)
Level la	Science data , geometric cal data	6 months	30 days*	NASA ASSIGNED DAAC(s)
Level lb	Calibrated/geolocated radiance data	6 months	30 days*	NASA ASSIGNED DAAC(s)
Level 2	Retrieved column averaged concentrations of CO2, CH4**, and CO**, and Solar Induced Fluorescence with associated error bars	9 months	30 days*	NASA ASSIGNED DAAC(s)

*Delivery latency after ground receipt
**Assumes baseline mission

5.0 MISSION REQUIREMENTS

5.1 Cost Requirements

a) The life cycle cost (LCC) for the GeoCarb mission shall include the formulation, implementation, operations, calibration, validation, hosting services, generation of science data products (defined in Section 4) and project closeout. The funding allocation is $170.9M for the support of Phases A through F. Costs that are within the PI-managed mission cost include:

  a. Instrument delivery ready for integration onto the host spacecraft (Phases AC);
  b. Development and delivery of functional algorithms and ground processing system (Phases B-D);
  c. Supporting a science team that will contribute directly to the successful implementation of the investigation (Phases A-F);
  d. Required calibration and validation activities (Phases C-E);
  e. Securing a host and any related accommodations, operations, product generation, and data analysis during the proposed prime mission lifetime of the investigation (Phase E); and
  f. Close out of the investigation once the investigation is concluded (Phase F).

b) The total NASA SMD cost and associated budget phasing are documented in the most current NASA SMD Directorate Program Management Council (DPMC) GeoCarb project Decision Memorandum.

5.2 Cost Management and Scope Reduction

a) Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the GeoCarb project shall pursue scope reduction and risk management as a means to control cost.

b) The Project Plan shall include potential scope reduction and risk management as a means to control cost. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised.

c) Scope reductions from baseline science requirements (described in Section 4.1.1) to threshold science requirements (described in Section 4.1.2) or potential scope reductions affecting program requirements shall be agreed to by the officials represented on the approval page of this document.

6.0 MULTI-MISSION NASA FACILITIES

The GeoCarb Mission shall rely on the following multi-mission NASA facilities and infrastructure, which are funded outside the project:

a) The GeoCarb project utilizes the NASA-Assigned DAAC(s) and other EOSDIS infrastructure for science data archival and distribution. The SMD/ESD provides access to these resources as documented herein.

7.0 EXTERNAL AGREEMENTS

All agreements between NASA and each non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of International and Interagency Relations (0IIR) prior to Key Decision Point-C (KDP-C). All funding for external participation will be performed under the cost cap.

8.0 COMMUNICATIONS AND OUTREACH

GeoCarb shall develop and execute a plan for communications and outreach to include print, electronic and visual media opportunities.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the GeoCarb project.

10.0 WAIVERS

None.

11.0 REQUIRED APPROVALS AND CONCURRENCES

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