PACE Applications Plan

Ver. 1.2

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1 INTRODUCTION

1.1 Purpose

NASA's Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) mission will make global ocean color and atmospheric measurements to provide extended data records on ocean ecology and global biogeochemistry, along with polarimetry measurements to provide advanced systematic observations of aerosols and clouds. In pursuing answers to fundamental science questions about atmospheric properties and ocean ecosystem processes, remarkable technological advancements and breakthroughs in knowledge can be achieved that will form the foundation for innovative practical applications that directly benefit society. The overarching purpose of the NASA Applied Sciences Program is to discover and demonstrate such innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology. Here, we seek to identify and engage potential user communities early in the PACE mission design and development process, to ensure that the product suite and delivery mechanisms maximize the usefulness and societal value of PACE observations. Specific outreach activities, communication strategies such as the use of succinct one-page white papers illustrated in Figure 1, and community engagement approaches are discussed. The objective of these communication strategies is to demonstrate the value of PACE products across a wide range of practical application areas and foster interactions between the PACE Program, Project Team, Science Teams, operational users, resource managers, policy makers and other relevant stakeholders.

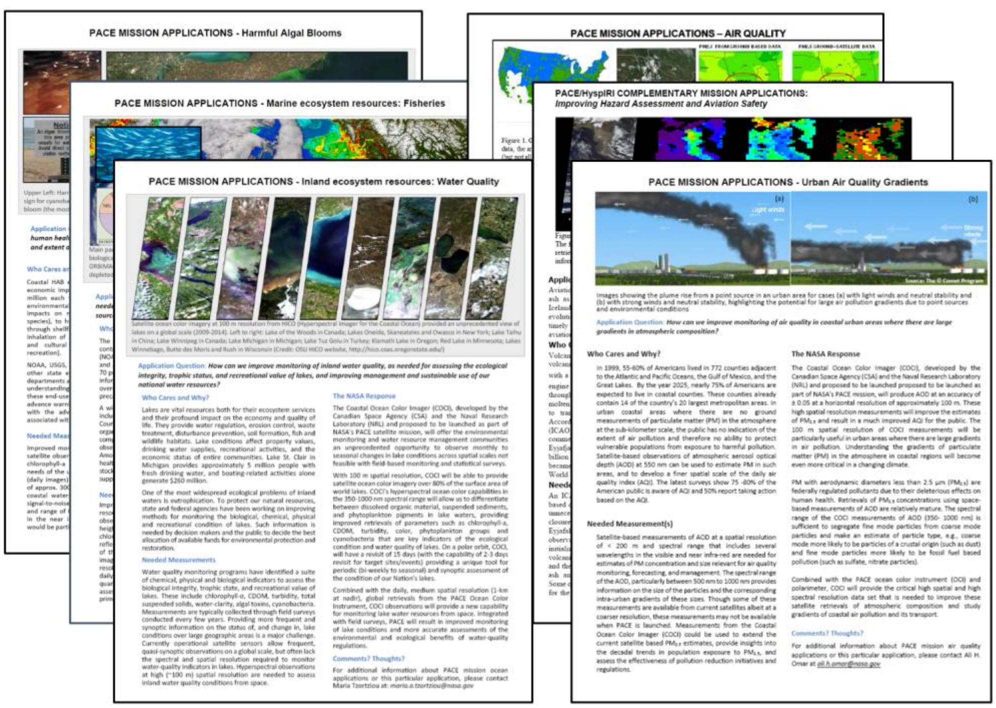

Figure 1. Example PACE applications.

Advanced PACE capabilities will result in new products that will help with many pressing environmental issues such as harmful algal blooms, managing marine fisheries, air quality degradation, smoke and aviation safety (examples of PACE White Papers, papers available on the right side of the PACE Applications web page at https://pace.oceansciences.org/applications.htm).

This Applications Plan follows the NASA HQ Earth Sciences Division (ESD) *Directive on Project Applications Program*, signed in June 2016 (hereafter referred to as the ESD Directive).

1.2 PACE Mission Overview

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

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

The PACE observatory is comprised of three instruments, an Ocean Color Instrument (OCI) and two polarimeters, the Hyper-Angular Rainbow Polarimeter 2 (HARP2) and the Spectro-Polarimeter for Exploration (SPEXone). The OCI is the primary instrument on the observatory and is being developed at Goddard Space Flight Center (GSFC). The OCI is a hyper-spectral scanning (HSS) radiometer designed to measure spectral radiances from the ultraviolet to shortwave infrared (SWIR) to enable advanced ocean color and heritage cloud and aerosol particle science. The HARP2 and SPEXone are secondary instruments on the PACE observatory, acquired outside of GSFC. The Hyper-Angular Rainbow Polarimeter instrument (HARP2) is a wide swath imaging polarimeter that is capable of characterizing atmospheric aerosols for purposes of sensor atmospheric correction as well as atmospheric science. The SPEXone provides atmospheric aerosol and cloud data at high temporal and spatial resolution.

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

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

- Improving our understanding of how aerosols influence ocean ecosystems and biogeochemical cycles and how ocean biological and photochemical processes affect the atmosphere.

The PACE satellite is planned for a launch in 2022-2023. The PACE project office at NASA's GSFC is responsible for the satellite development, launch and operations. The mission is planned for launch into a Sun synchronous polar orbit at 676.5 km with an inclination of 98 degrees and a 1 pm local ascending node crossing time. The spacecraft bus will host the OCI, HARP2, and SPEXone instruments. The GSFC PACE Project office will oversee the mission and the development of the satellite, launch vehicle, mission operations control center, and operations. The Headquarters Program Science will separately fund the science data processing system and competed science teams, which will include field-based vicarious calibration and data product validation efforts to support the Project science team.

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

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

- The space segment consists of the spacecraft bus, the OCI, and two polarimeters. The spacecraft and OCI are being developed and integrated at GSFC. The polarimeters are contributed instruments. The spacecraft and instruments will be integrated as the PACE observatory at GSFC.
- The GS and associated Mission Operations Center (MOC) will be developed, integrated, and operated at GSFC. The GS provides for the command and control and health and safety monitoring of the PACE observatory on-orbit, as well as ensuring the science data are accounted for and delivered to the SDS. The MOC will house the flight operations team (FOT) and is being managed by the PACE project through observatory commissioning. After commissioning, the FOT will be managed by the GSFC Earth Science Mission Operations (ESMO) project. The MOC performs all real time operations and off-line operations functions, including planning and scheduling, orbit and attitude analysis, housekeeping telemetry data processing, monitoring/managing the spacecraft and instruments, first line health/safety for the instruments, and housekeeping archiving and analysis.
- The SDS will be located at GSFC, but managed (separately from the project) by the NASA Headquarters Earth Sciences Division. The SDS will ingest, apply calibration and science algorithms, and process the science data, provide science software development

and algorithm integration, act as the science data interface to the science team, and deliver of all science data products to the NASA-assigned Distributed Active Archive Center (DAAC).

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

2 PACE APPLICATIONS PROGRAM

The overarching goal of the PACE Applications Program is to enhance the applications value and overall societal benefits of the PACE mission.

PACE will deliver the most comprehensive approach to global ocean color measurements in NASA's history. With advanced global remote sensing capabilities, PACE will provide high quality observations that contribute to an extended time series of records on inland, coastal, and ocean ecosystems—all of which have substantial value beyond basic science and research. Global measurements from PACE will be essential for understanding marine and terrestrial biology, biogeochemistry, ecology, as well as cloud and aerosol dynamics. These measurements will enable advanced understanding of delicate ocean ecosystems, monitoring of vulnerable coastal regions, quantification of the atmosphere-ocean carbon cycle, unparalleled characterization of ecosystem change and functioning, improved characterization of clouds and aerosol properties, and cross-disciplinary datasets for studies of terrestrial, atmospheric, and aquatic processes and interactions.

The main objectives of the PACE Applications Program are to:

- Demonstrate the utility of PACE data products and PACE's practical use for societal benefit;
- Identify key stakeholders and Early Adopters to promote the use of PACE products by user communities whose decisions could benefit from the application of PACE data;
- Provide information on and documentation of collaboration with different types of users and communities;
- Identify factors that might increase or decrease the applications value of the PACE mission and provide feedback to the project accordingly;
- Design communication strategies to reach out to new communities—this will include organization of workshops to inform and build user communities, articulate key applications benefits, support applications readiness, and solicit and receive feedback;
- Support new PACE data users, experts, and associated personnel to integrate PACE data into their processes and systems—this will include distribution of relevant simulated PACE data products for testing in decision systems;
- Develop an Early Adopters Program to demonstrate societally relevant applications of proposed data products;
- Foster and facilitate relationships between mission Early Adopter research and the PACE Science Teams and report back to the mission on:
  - how PACE data will be used by PACE end users after launch and
  - challenges identified with data resolution, ingestion, processing, formatting, and access;
- Coordinate with the PACE Communications and Public Engagement personnel and the media to publicize PACE products, users and objectives to help improve the visibility of the mission within the research and applied sciences communities;
- Conduct studies to explore how we can estimate the socioeconomic benefits of PACE data, in accordance with the Earth Science Division (ESD) Directive on Project

Applications Program. This will include socioeconomic analysis of select Early Adopters projects and organization of impact workshops;
- Foster a Community of Practice who can work with the project throughout the mission life cycle; and
- Establish a PACE Applications Working Group (AWG) and develop a PACE Applications Plan (this document).

The PACE Applications Program is guided by a PACE Applications Team, which includes members of the GSFC PACE Project, the HQ PACE Program, the HQ Applied Sciences Program, and the competed PACE Science Team(s).

This PACE Applications Plan is a living document that will be updated continuously as the PACE mission proceeds through its development and operational phases.

Novel applications of PACE data will allow the community to address some of our most pressing environmental issues. The combination of high-quality, global atmospheric and oceanic observations provided by the PACE mission (Table 1) will provide direct benefits to society across a range of applications areas, including marine and coastal resources, disasters, climate, ecological forecasting, ecosystem health, human health, and air quality. PACE science data products will be made available to the public through a NASA-designated Earth science data center, after a 60-day post-launch initial orbit checkout phase, with an expected data latency of 6-12 hours. Latency is defined as the average time under normal operating conditions between data acquisition by the PACE observatory and delivery of the data to the data center.

Table 1. Key PACE data products for applied sciences.

Instrument	Products
OCI	**Standard data products**
	Spectral ocean water-leaving reflectances
	Chlorophyll-a concentrations
	Inherent Optical Properties (absorption and backscattering)
	Photosynthetically available radiation PAR
	Diffuse attenuation coefficient
	Particulate Organic Carbon concentrations
	Particulate Inorganic Carbon concentrations
	Fluorescence Line Height
	Advanced OCI data products
	Phytoplankton community structure
	Phytoplankton physiology parameters
	Photosynthetic pigment concentrations
	Primary/community production
	Dissolved Organic Carbon concentrations
	Particle abundances
	Particle size distributions
	Carbon fluxes & export
	Atmospheric data products
	Spectral aerosol optical depth
	Cloud layer detection
	Cloud top pressure
	Liquid & ice cloud optical depth
	Liquid & ice cloud effective radius
	Liquid & ice cloud water path
	Shortwave radiation effect
	Possible Terrestrial Data Products
	Heritage (non-thermal) data products, including vegetation indices, LAI, PAR, BRDF albedo, Reflectance, GPP & NPP, etc.
	Vegetation stress & nutrient status
	Plant pigments
	Plant functional types
Polarimeter	**Atmospheric data products**
	Aerosol particle size distributions
	Aerosol refractive index
	Aerosol single scattering albedo
	Aerosol shape & non-spherical fraction
	Aerosol layer height
	Cloud optical depth
	Cloud liquid particle size distributions
	Cloud ice particle shape & roughness
	Cloud top & base height

3 PACE APPLICATIONS TEAM AND WORKING GROUP

3.1 PACE Applications team: roles and responsibilities

The PACE Applications Team is comprised of the NASA HQ Applied Sciences Program Applications Lead and Deputy Program Application (DPA) Lead(s) for PACE, the NASA HQ PACE Program Scientist and Deputy Program Scientist(s), the PACE Project Scientist and Deputy Project Scientist(s), and the PACE Project Applications Coordinator (PAC), who serves as the coordinator of the PACE Applications Program. As necessary and available, the PACE Applications Team will also include representatives from the PACE Science Data Segment (SDS) and NASA Distributed Active Archive Center (DAAC) for PACE, as well as the Lead(s) of any standing competed PACE Science Team(s). The roles and responsibilities of the Applications Team members are described in Table 2, adapted from the ESD Directive.

Table 2. PACE Applications Team Roles and Responsibilities.

Team Member	Responsibilities
NASA HQs Program Applications Lead	▪ Provide support and guidance at the program level on goals and objectives for applications.
NASA Headquarters Program Scientist (PS) and Deputy PS	▪ Provide support and guidance regarding communities and opportunities that will help expand the mission user community.
NASA HQs Deputy Program Applications leads (DPAs)	▪ Provide guidance at the program level, and work closely with the Project Applications Coordinator to ensure successful implementation of the Mission Applications Plan. ▪ Act as the liaison between the NASA HQs Program Applications Lead, the PACE Project Scientists, and the competed PACE Science Team. ▪ Develop and refine the PACE Applications Traceability Matrix (ATM), website, and White Papers highlighting new applications foci for the mission. ▪ Develop cross mission activities relevant to applications and identify synergies among different satellite missions relevant to PACE. ▪ Establish and provide guidance for the PACE Applications Working Group to expand applications outreach. ▪ Develop and update the PACE Applications Plan as the mission proceeds through its development and operational phases. ▪ Provide guidance for the PACE Early Adopters Program.
Science Team Leader	▪ Provide guidance and set expectations for project applications.
Project Scientist and Deputy Project Scientists (Ocean, Atmosphere)	▪ Provide guidance at the project level and set expectations for project applications. Manage the PACE Applications Program including its budget and schedule. ▪ Participate in the Early Adopters Program. ▪ Participate in meetings and events, including workshops, focus sessions, and tutorials; Review materials for such events and activities. ▪ Review outreach material for project applications.

Project Applications Coordinator	▪ Applications Program coordinator; responsible for the organization and execution of all applications strategies and activities, as described in the Applications Plan. ▪ Establish, manage and coordinate the Early Adopters Program. ▪ Manage and coordinate PACE applications case studies. ▪ Organize meetings and events, including workshops, focus sessions, and tutorials, and write event reports to enable new communities to understand the objectives of the applications program. ▪ Develop outreach material for project applications. ▪ Provide sustained outreach to the PACE applications community. ▪ Develop and update the PACE Community Assessment Reports including the Early Adopters Program.
Project Science Data Systems Representative	▪ Support project applications efforts by providing feedback about data uses, support of Early Adopters and updates with data access tools.
NASA Distributed Active Archive Centers (DAAC) Representative(s)	▪ Support project applications efforts by providing feedback about data uses, support of Early Adopters and updates with data access tools.

3.2 PACE Applications Working Group

The PACE Applications Working Group (AWG) is the link between the mission and the applications communities relevant to the mission, communicating information about the mission to applications audiences across the range of relevant applications areas, and bringing the interests and concerns of the applications communities back to the PACE Project at GSFC. The PACE AWG is an inclusive group that accepts members through registration on the PACE website, networking, and by invitation. The AWG will evolve with the mission depending on active applications. Three key roles for members of the PACE AWG are: (1) PACE applications development, (2) engagement of the user community, and (3) feedback to the PACE Applications Team. The PACE AWG can achieve these goals through interaction with PACE Science Team members and communication with the PACE Project Applications Coordinator and the PACE DPAs. The objectives of the AWG are to:

- Assess current applications benefits and requirements for PACE products
- Develop a community of end-users that understand PACE capabilities and are interested in using PACE products in their applications
- Recruit early adopters who can work with the PACE project during the pre-launch period, particularly to assess impacts on their applications
- Provide information about PACE and its products to the user communities
- Provide guidance to leverage future opportunities

Two main user groups in the PACE AWG are defined and categorized by their use of PACE data in their operations and activities. These are:

Community of Practice - users who are familiar with NASA products, have a well-defined need for mission data products, and will partner with the PACE Science Teams to optimize their use of PACE products, possibly even before launch as part of the PACE test-bed activities and PACE calibration/validation. This group includes the Early Adopters Program.

Community of Potential - users who are unfamiliar with PACE capabilities, but have the potential to benefit from PACE products in their applications.

3.3 Interactions between the PACE AWG and the PACE mission

Whenever possible and without placing undue burden and constraints on the Project, the PACE mission will assist with facilitating access to existing simulated and evaluation PACE data products generated both pre- and post-launch via the PACE SDS and/or DAAC.

In turn, the PACE AWG will assist the PACE mission in conducting the preliminary feasibility studies required to promote the use of PACE data products in previously identified applications, demonstrate the potential use of PACE in new applications, and provide input on the applications value of proposed products and feedback from a functionality perspective. These studies will refine our current understanding of the application requirements for PACE data products.

Special data or assistance requests beyond the opportunities listed above should be submitted to the PACE Mission as a white paper on the PACE application that would include: (1) application description; (2) data currently used in application; (3) desired PACE data product(s); (4) key personnel; (5) ancillary data needs; (6) requested simulated data products and/or field experiment demonstration; (7) potential implementation strategy; (8) next steps (deadlines/timelines); (9) how to integrate into future projects; and (10) product output format. This would assist the PACE mission in determining the magnitude of the effort required and the return on staff investment.

4 PACE APPLICATIONS PLAN IMPLEMENTATION STRATEGY

The user engagement strategy will follow a pathway from simple knowledge of the PACE data configuration and availability to actively using the data in the user system or process. Figure 2 shows the general strategy for engagement of users.

To facilitate implementation of these steps, the PACE Project Applications Coordinator (PAC) will report to PACE Project Science and serve as a liaison between the GSFC PACE Project, the HQ PACE Program, the HQ Applied Sciences Program, and NASA center Applications Programs (as possible). The PAC will engage with the data end users to define data attributes that would best enable the PACE data products to be captured within operational frameworks. This relationship with relevant users (federal and international agencies, operational users, policy implementers, the commercial sector, scientists and educators, etc.) will foster case-examples and demonstrations of the operational uses of PACE data sets. The PAC will also work with PACE Science Team members to refine mission data products to meet applications needs.

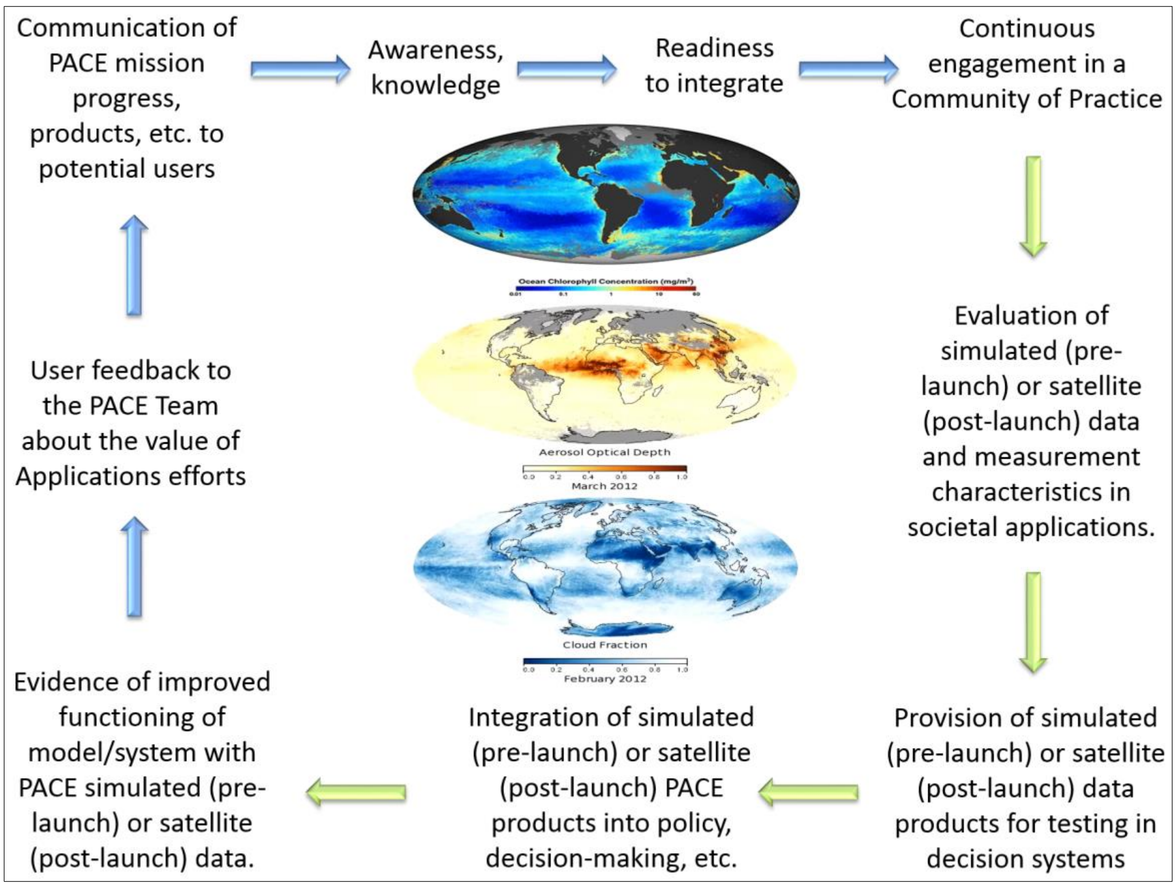

Figure 2. Flow of user engagement.

Flow of engagement of users from passive awareness to actively using PACE data once it becomes available (blue arrows are generally applicable, not dependent on whether it is pre- or post-launch; green arrows split the following description into pre- vs. post-launch).

4.1 Engagement with Early Adopters

The main goal of the PACE Early Adopter (EA) Program is to promote pre-launch applied research to facilitate feedback on PACE products *pre-launch*, and accelerate the use of PACE products *post-launch*. PACE Early Adopters are defined as those groups and individuals who have a direct or clearly defined need for PACE-like ocean color, aerosol, cloud or polarimetry data, have an existing application or new ideas for novel PACE-related applications, and are planning to apply their own resources (funding, tools, personnel, facilities, etc.) to demonstrate the utility of PACE data for their particular system or model**.** The goal of this designation is to accelerate the use and integration of PACE products into policy, decision-making and scientific support settings by providing specific guidance to Early Adopters who commit to engage in pre-readiness studies that incorporate PACE data in their applications. Early Adopters will connect to the PACE project through an informal letter of interest.

In the framework of the Early Adopter program, each Early Adopter will provide an early adopter research project title with the end user clearly identified, and a short abstract describing the societal benefit of the project. After selection, each Early Adopter will be partnered with a Science Team member who can provide guidance and information on project data and product development. Through this partnership, the Early Adopter Program will be beneficial to both the PACE end users and the mission, as the Early Adopters will receive access to developmental products and interaction with the product developer enabling them to be among the first to integrate the new PACE products into their systems. The Science Team members will gain a partner who can evaluate products and offer feedback from a functionality perspective as well as potential calibration and validation information. The Early Adopter will provide the PACE Applications Team quantitative metrics and testimonials that explain how the use of a product will improve a policy or decision relevant to their organizational goals and objectives.

Through interactions with the PACE Science and Applications Teams, the Early Adopters will: (1) get access to and resolve issues with PACE pre-launch simulated data products and (2) report on the Early Adopters Program successes, challenges and progress during PACE Science Team and Applications Working Group meetings.

An impact workshop will be held with members of the Early Adopters Program and other key stakeholders and user communities at the start of Phase E, to establish metrics upon which quantitative assessments of the impact of project products on decision-making can be compared. A key output of the workshop will be a report documenting how each participant could benefit from integrating PACE data into his or her research or operational tools. The report will be shared with the PACE Project as feedback for how mission data was applied to specific societal applications.

4.2 Applications Plan Notional Schedule

Applications activities will be planned and conducted during the different development phases of the PACE mission (Table 3) based on the maturity of mission products with respect to the project objectives for product applications, and in accordance with the ESD Directive. To prepare for post-launch Senior Review(s), the Applications Team will work with the PACE Project leadership to document the national interest activities that are realized due to the PACE products. Quantification of these benefits through socio-economic studies will be included in the societal benefits section of the Senior Review proposal. These will include, but are not limited to, case studies, peer-reviewed journals, press releases, articles/interviews in the popular press, and testimonial accounts of the use of PACE products in decision support systems.

Table 3 is adopted from the ESD Directive. The PACE mission Applications Program began in Phase B and, as such, will retrospectively follow Table 3 on a best-effort basis. At the time of this writing, the PACE web site (https://pace.gsfc.nasa.gov) hosts an Applications page that includes white papers and an Applications Traceability Matrix (Phase A activities).

Table 3. PACE applications by development phase.

Mission Phase	Applications Activity
Pre-phase A	Assessment of the community of practice. Description of potential applications from the PACE data using the requirements established by the Science Definition Team (SDT).
Phase A	Applications website establishment. Database of user community individuals begins. Applications Plan written and posted to website. Applications white papers developed and posted to the website. Applications Traceability Matrices developed and posted to the website. Applications Working Group established.
Phase B	Newsletters, articles, posters, and other communications developed to expand the community of potential. Early Adopters Program initiated.
Phase C/D	Workshop conducted with targeted science communities to communicate key model, observation and Applied Sciences opportunities and requirements. Annual workshop focused on results from Early Adopters. Description of validation datasets to the community of practice. Conference presentations and papers; newsletters and journal articles on user interaction to expand the community of potential. Data workshops, short courses, focus sessions, tutorials. Interaction with NASA HQ Applied Sciences to prepare funding opportunities. Early Adopters Program established.
Phase E	Documenting decision support provided by mission data. Newsletter, journal articles, conference presentations of applications of data. Community interaction and support of data reprocessing and improvement. Calibration/validation of data quality, format, issues. Conduct Impact Workshop to assess success of Applications implementation. Conduct a Quantitative PACE Data Societal Benefit Value Assessment. Information for Senior Review Submissions.

PACE Application Questions & Concepts

What is the air quality forecast of particulate matter (PM) predicted from PACE measurements of the aerosol optical depth (AOD) in regions where there are no direct measurements of PM?

The EPA produces a daily air quality index which comprises both the ozone and PM concentrations. In regions where there are no direct measurements of particulate matter, satellite measurements of AOD can be used to estimate PM.

Application Readiness Level: *3*
Applied Sciences Category: *Public Health and Air Quality*
Potential Host Agency: *EPA (James Szykman)*

Mission Data Product: Aerosol Optical Depth

Spatial resolution: <1 km

Latencies: <1 hour

Projected Mission Performance: AOD within +/- 0.02 at a horizontal resolution of 1 km

Ancillary Measurements: Aerosol vertical distributions, Surface PM concentrations (at a few locations)

What is the volcanic ash concentration during and after a volcanic eruption? Is there an impact on air quality as a result of a volcanic material deposited in coastal/populated regions?

Measurements collected to support PACE atmospheric corrections in coastal regions may be used to quantify the concentration of material associated with volcanic eruptions. These data may be useful in enabling prudent ash-related aviation hazard mitigation policies and advisories.

Application Readiness Level: *3*
Applied Sciences Category: *Disaster Mitigation, Public Health and Air Quality*
Potential Host Agency*: FAA, EPA, NOAA, International Civil Aviation Organization, Volcanic Ash Advisory Centers (Shobha Kondragunta, NOAA)*

Mission Data Product: Aerosol Optical Depth

Spatial resolution: <1 km

Latencies: <1 hour

Projected Mission Performance: AOD within +/- 0.02 at a horizontal resolution of 1 km

Ancillary Measurements: Aerosol vertical distributions, Sulfur dioxide concentrations

How do exchanges across the land-ocean interface influence carbon and nutrient loadings, water quality, and ecosystem dynamics in coastal waters?

The EPA Safe and Sustainable Water Resources Research Program aims at developing core indicators of water resource integrity and sustainability as well as indicators of key drivers and pressures across a range of spatial and temporal scales for use in integrated assessments. Integration of satellite observations with field measurements and modeling tools is needed to demonstrate assessment of sustainability and integrity of water resources.

Application Readiness Level: *3*
Applied Sciences Category: *Water Resources, Oceans, Coasts, Great Lakes, Ecosystems and Human Health*
Potential Host Agency: *EPA (Blake Schaeffer)*

Mission Data Products: Chl-*a*, K_D, CDOM, DOC, POC

Spatial resolution: Estuaries: ≤250 m; Coastal and Continental Shelf Waters: ≤1 km

Coverage: Minimum distance: 5.5 km; Maximum distance: 22 km

Latencies: 0.5-12 hours

Projected Mission Performance: 2-day global coverage at 1-km spatial resolution, hyperspectral radiometry from the the ultraviolet (350 nm) to NIR (885 nm) with complete downlink of 5 nanometer resolution data, 6-12 hour data latency.

Ancillary Measurements: Aerosols (e.g., spectral shape, particle size distribution, vertical distribution) for improved atmospheric correction

How are the productivity and biodiversity of coastal ecosystems changing, and how do these changes relate to natural and anthropogenic forcing, including local to regional impacts of climate variability?

PACE satellite-derived optics and biogeochemical variables may be assimilated into operational seasonal-to-interannual computer models. As a result, PACE data may improve model skills and forecasting capabilities of the Global Ocean Data Assimilation System / Coupled Forecast System (GODAS/CFS) and Real-Time Ocean Forecast System (RTOFS).

Application Readiness Level: *3*
Applied Sciences Category: *Ecological Forecasting*
Potential Host Agency: *NOAA (Paul DiGiacomo, Cara Wilson)*

Mission Data Products: Chl-*a*, K_{PAR}, K_{490}

Spatial resolution: 1 km

Temporal resolution: Daily

Coverage: Global

Latencies: 12 hours

Projected Mission Performance: 2-day global coverage at 1-km spatial resolution, hyperspectral radiometry from the the ultraviolet (350 nm) to NIR (885 nm) with complete downlink of 5 nanometer resolution data, 6-12 hour data latency.

Ancillary Measurements: Aerosols (e.g., spectral shape, particle size distribution, vertical distribution) for improved atmospheric correction

How can PACE help with oil spill monitoring and response?

NOAA's subsurface oil monitoring program uses various modeling and observational approaches (airborne, shipborne, ground-based, space-based measurements) to track oil spills (where the oil is going on the surface and under the sea) and assess impacts of major oil spill disasters to local communities, wildlife and the marine environment (e.g., Deepwater Horizon/BP Oil Spill).

Application Readiness Level: *3*
Applied Sciences Category: *Disasters, Water Resources*
Potential Host Agency: *NOAA (Paul DiGiacomo, Cara Wilson)*

Mission Data Product: Visible/true color imagery

Spatial resolution: <1 km

Coverage: Coastal waters: <185 km; 50N - 10N; 106 W- 60W

Latencies: < 6 hours

Projected Mission Performance: 2-day global coverage at 1-km spatial resolution, hyperspectral radiometry from the the ultraviolet (350 nm) to NIR (885 nm) with complete downlink of 5 nanometer resolution data, 6-12 hour data latency.

Ancillary Measurements: Aerosols (e.g., spectral shape, particle size distribution, vertical distribution) for improved atmospheric correction

ARL 3: **Proof of Application Concept (Viability Established)** - Feasibility studies to assess the potential viability of and provide a proof-of-concept for the application have been conducted

Figure 3. PACE "Application Question and Concepts" document.

Table 4. Example PACE mission applications.

Climate System
Carbon cycle research, mapping/assessment of carbon sources and fluxes, improved understanding of the biogeochemistry of elements involved in impacts and feedbacks of the climate system, improvement of climate models skills/forecasting capabilities, support of assessments, policy analyses, and design approaches to planning adaptation and responses to impacts of climate change.
Oceans, Coasts, Great Lakes - Ecosystems and Human Health
Fisheries and ecosystem health management, mapping of suspended sediment plumes, monitoring of water quality including transparency, eutrophication, hypoxic conditions, sediment resuspension and transport, impacts of river plumes on adjacent environments, patterns of connectivity, monitoring of oil spills and seeps, detection of harmful algal blooms (HABs), improved models of abundances of toxic pollutants, pathogens, bacteria that affect human and ecosystem health, monitoring of sea ice extent and passages, mapping of currents (applications to shipping industry, scheduling/fuel economy strategies).
Ecological Forecasting
Forecasting and early warnings of HABs, endangered species, vertebrate diversity and distribution, biodiversity, fisheries; PACE data assimilation into ocean models for improving model skills and forecasting capabilities.
Water Resources
Water quality and management of water resources in lakes, coastal areas and open oceans.
Disasters
Effects of hurricanes on ecosystems, oil-spills and seeps, tracking of volcanic ash, fires and impacts on ecosystems and human health.
Air Quality and Human Health
Air quality monitoring, forecasting, management, climate change effects on public health and air quality, aerosols, clouds, volcanic ash/aviation hazard applications

4.3 Coordination with PACE validation and other field activities

The PACE AWG will provide input on PACE validation activities. Tasks will include providing recommendations on the field campaign sites and applications-related input to the design of field campaigns. In doing so, the AWG will maximize the relevance of validation activities for particular applications. The AWG can also provide a forum for publicizing planned field campaigns and attracting more involvement from groups interested in PACE applications.

4.4 Communication and engagement strategies

The PACE Applications Team, AWG, and Early Adopters will function as a PACE Community of Support. Outreach activities will be coordinated with the activities of the PACE Applications Program, to ensure a clear path for interested users from first contact to Early Adopter, and then seek to maintain relationships after launch. A broad program is planned to engage and maintain continuity with users including:

- **Regular applications meetings and events** to foster communication between the project Science Team and the Community of Practice will be organized by the PACE Applications Team and leverage resources from the Applied Sciences Program, whenever possible.

These meetings will include participants from potential users across potential thematic applications, as well as smaller disciplinary events hosted at other meetings or sites as the opportunities arise. These meetings and events will be subdivided into three categories based on the focus and objectives of the meetings, as follows.

- **PACE Applications Workshops**: provide an update of the overall mission objectives and priorities to the community of interest and set up to exchange information about PACE ocean color/polarimetry products on a broad scale. Workshops are organized annually or every two years and provide feedback to the PACE mission about PACE product applications and the thematic areas in which their products may be applied.

- **PACE Applications Focus Sessions:** are concentrated events focused on a thematic topic or applications focus area (Figure 3, Table 4). These events provide a forum for a user group to receive specific support and information on the utility of PACE OCI and polarimetry products for related mission objectives. The focus sessions are organized by the Community of Practice with the assistance of the PACE Applications Team. Project personnel will participate in the focus sessions to guide the specific thematic applications needs of the community.

- **PACE Applications Tutorials:** online and offline PACE applications tutorials will be developed by the PACE Applications Team and will be available to the Community of Practice, to provide detailed information on a particular topic such as introduction on specific tools and utilities for working with PACE data. Tutorials define project product application opportunities and leverage innovation for how to best combine data sets, models, and expertise.

- **Event Reports** will provide a comprehensive description of the events described above. These reports will form the basis for future work, provide a reference for those who could not attend, enable new communities to understand the objectives of the applications program, capture knowledge and best practices, and provide ways to get involved.

- **PACE science and applications organized sessions, town halls, breakout sessions** in widely attended remote sensing and environmental science meetings will be organized by the PACE Applications Team. Outreach materials, including PACE Applications brochures and PACE product posters will be distributed during conferences and meetings by Applications and Science Team members throughout the life of the PACE mission.

- **Data workshops and short courses** designed to prepare the Community of Practice and provide hands-on instruction on data access and use of mission data products. PACE simulated datasets and scripts for processing and analyzing data that are customarily available to the wider science community will be disseminated at the data workshops and short courses. The PACE Applications Team will encourage the development of additional tools specific to the Applications community by the Early Adopters, Community of Practice, Science Team members and Federal partners. These tools will be distributed by a suitable DAAC for use by the wider community. Online tools, user services and data access will be well advertised and presented to the user community during the pre-launch phase so familiarity with these services will be well established by Phase E of the mission.

- **Articles in peer reviewed journals and the popular press**, press-releases, announcements or descriptions of the mission in newsletters, user forums, or other venues frequented by the user community will be provided to the science communications team for single point dissemination to the public.

- The **PACE Applications web page** (http://pace.oceansciences.org/applications.htm), accessible from the main PACE website (https://pace.gsfc.nasa.gov), highlights the applications value of PACE products, integrates and highlights all ongoing activities from the applications programs, and includes articles, presentations and posters from meetings and planning documents. The PACE website and PACE Applications link will be routinely updated and will provide a comprehensive overview of applications and potential methods of incorporating PACE data. The website will have clear contact information and provide ways to get data, organize new projects, and receive information materials for each application activity listed above.

- The PACE Applications Team will target **key international user groups** that are mature, have solid missions and budgets, and can ensure that investments are made in new ways of using OCI/polarimetry information from the PACE mission.

- The PACE Applications Team will conduct a study to estimate of the value of PACE data to society (cf. Macauley, 2007: Ascribing societal benefit to applied remote sensing data products: an examination of methodologies based on the Multi-angle Imaging SpectroRadiometer experience, *J. Appl. Rem. Sens*, *1*(1), 013538-013538-013520).

- The PACE Applications Team will write a **"Lessons Learned" report** on the PACE applications efforts. This report will capture feedback from users and Early Adopters as well as describe how user feedback was implemented by the PACE mission prior to launch. This report will serve as a historical document for the mission as well as a template for other mission applications programs.

4.5 Performance evaluation

The main goal of the PACE Applications Plan is to describe the applications program for the PACE mission and the communication strategies and outreach activities that will be developed to engage PACE research and operational users and build broad support for PACE applications. Our activities will focus on developing and encouraging both PACE Community of Practice members as well as Community of Potential members, in accordance with the ESD Directive on Project Applications Program. The PACE mission will use the process developed by more mature NASA Earth Science missions to explore the best ways to assess interaction and integration of PACE data within the user community. To evaluate the success of the Applications Plan, the PACE Project and Applications Team will:

- Review the composition of the PACE Applications Working Group 2 years before launch, and 1 year after launch;
- Assess the results of pre-launch application investigations;
- Assess how PACE data are used for applications post-launch; and
- Quantify the societal benefit realized due to the PACE data products through socio-economic studies and applied research presented in peer-reviewed journal articles, press releases and articles in the popular press.

This evaluation will be accomplished through qualitative and quantitative assessments of different levels of the data users:

- Community of Practice, focusing on participants who have previous experience with NASA products and have a clearly defined need for mission data products;
- Community of Potential, consisting of members who are unfamiliar with NASA mission capabilities but have the potential to benefit from the PACE products in their applications;
- PACE Applications Working Group; and
- PACE Early Adopters and PACE Science Teams.

Appendix A Abbreviations and acronyms

AOD	Aerosol Optical Depth
ASDC	Atmospheric Science Data Center
AWG	Applications Working Group
CCB	Configuration Control Board
CMO	Configuration Management Office
DAAC	Distributed Active Archive Centers
DPA Lead	Deputy Program Applications Lead
EA	Early Adopters
ESD	Earth Science Division
HAB	Harmful Algal Bloom
IOP	Inherent Optical Properties
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NPR	NASA Procedural Requirement
OCI	Ocean Color Instrument
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PARASOL	Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
SDT	Science Definition Team
SeaWiFS	Sea-viewing Wide Field-of-view Sensor (SeaWiFS)