



Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission

Paula S. Bontempi, Program Scientist
Betsy Edwards, Program Executive
Hal Maring, Deputy Program Scientist
Woody Turner, Program Applications Lead

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Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) Mission

Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) is an ocean color, aerosol, and cloud mission identified in the 2010 report “Responding to the Challenge of Climate and Environmental Change: NASA’s Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space Science”.

Science Objectives

- **Primary:** Understand and quantify global ocean biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change: **ocean color sensor**
- Extend key Earth system data records on global ocean ecology, biogeochemistry, clouds, and aerosols (expanded ocean color sensor similar to MODIS)
- **Secondary:** Understand and resolve/quantify the role of aerosols and clouds in physical climate (the largest uncertainty): **polarimeter**

Risk	• 8705.4 Payload Risk Class C
Launch	• 2022/2023, budget and profile driven
Orbit	• 97° inclination; ~650 km altitude; sun synchronous
Duration	• 3 years
Payload	• Ocean color instrument; potential for a polarimeter
LCC	• \$805M Cost Cap



Direction Memo

Intro

To: Distribution

From: Earth Science Division

Subject: Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission Direction

On December 5, 2014, a pre-Acquisition Strategy Meeting (ASM) was held at NASA Headquarters, with participation from the Centers via teleconference. The purpose of the meeting was to discuss the path forward for the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission. This memo serves to document the results of the meeting and to provide guidance to begin formulation for PACE. The charts presented by SMD at the meeting are enclosed.

The goal of PACE is to deliver a scientifically relevant mission that will make high-quality, global measurements of ocean color and atmospheric aerosol properties to advance Earth system science and applications, **while also setting a precedent for cost control and capability maximization for directed missions.** Sustained attention and dedication on the parts of the implementation teams, with continual involvement of senior levels of management at Centers and NASA HQ, will be necessary to ensure that the decisions and direction documented herein are maintained over the lifetime of the mission.

- Statement of facts
- Introduction of the idea of cost control and capability maximization
- Success will require sustained communications and involvement among *all* orgs.



Direction Memo Decisions (1)

The decisions reached during the December 5, 2014 pre-ASM meeting for PACE include:

1. The overall PACE mission is directed to the Goddard Space Flight Center (GSFC).
2. Full Life Cycle Cost (LCC) for the mission is capped at \$805M, inclusive of project labor, spacecraft, all payload instruments, launch vehicle, mission operations, ground data processing, and science. The ground data processing and science activities including post-launch geophysical calibration/validation will be directed by the Earth Science Division (ESD) at NASA Headquarters.
3. A design-to-cost approach will be employed. It is expected that the LCC cap will enable development and flight of PACE with a payload including both the primary ocean color instrument and the secondary polarimeter instrument, with appropriate capabilities and risk. Successful passage through the KDP-B and KDP-C gates will require explicit demonstration of the iterative design-to-cost approaches utilized during formulation.
4. An Acquisition Strategy Meeting (ASM) will be held at NASA HQ during Phase A to consider PACE Project recommendations for (1) the spacecraft procurement approach and (2) the approach for providing the secondary polarimeter instrument under the cost cap. Options for the polarimeter are:
 - a. No polarimeter (hopefully unlikely recommendation);
 - b. The polarimeter directed to the Jet Propulsion Laboratory (JPL);
 - c. The polarimeter competed (GSFC excluded).

- Cost cap includes two instruments, LV, science, processing
- Science, processing are directed by HQ ESD
- Design-to-cost approach
- Iterative approach to maximize capabilities within cost cap to be used in Phases A and B
- ASM in Phase-A to cover procurement approach for:
 - Spacecraft bus
 - Polarimeter

\$100M for science; \$705M for mission/project implementation and baseline operations



Direction Memo Decisions (2)

5. The Science Definition Team (SDT) report of October 2012 will be used as the basis for the science to be accomplished by PACE, with the understanding that this report documents science *objectives*, not mission requirements. Indeed, the design-to-cost approach directed by the pre-ASM meeting involves explicit iteration and balancing of mission capabilities, risk, schedule, and costs.
6. As reflected in the to-be-developed success criteria for the KDP-A and KDP-B gate reviews, formulation phases A and B must involve significant design-to-cost iterations of capability/risk/cost among all parties – the Project, the Center, the Program Office, and NASA ESD representing the communities. These trades will aim to maximize capability and minimize risk in balanced ways within the overall LCC cost cap.
7. In recognition of the additional analyses and iterations involved in the design-to-cost approach, the Phase A and Phase B durations will each be 18 months.

- SDT report describes the PACE science objectives
- Design-to-cost approach dictates iteration on capabilities and design to achieve balanced mission within constraints
- Phases A & B will be 18 months *each* to allow time for these iterations of capability/risk/cost
- KDP-A and KDP-B are ***not*** pro-forma

MCR, KDP-A to be held as soon as appropriate



Direction Memo

Directions (1)

Taking these decisions into consideration, the following formal direction is given:

1. The Earth Systematic Missions (ESM) Program Office shall be the program office of record.
2. A PACE project team shall be established at GSFC.
3. The ESD at NASA Headquarters, in conjunction with the ESM Program Office and the PACE Project Manager, shall establish the additional success criteria for KDP-A and KDP-B to specifically address cost/capability compatibility.
The additional study and analysis deliverables for each phase (beyond those defined in NPR 7120.5E) shall be established prior to the official start of that phase.

- Formal direction of PACE mission and Ocean Color instrument to GSFC
- Additional success criteria, related to the design-to-cost approach, will be developed prior to the beginning of formulation phase in order to successfully navigate through the key decision point reviews



Direction Memo

Directions (2)

4. A **kick-off meeting for PACE**, to include HQ/ESD, ESM Program Office, and GSFC Center (project and management) personnel and their invitees (to include non-GSFC personnel at the discretion of the GSFC Project) **shall be held as soon as possible but no later than January 17, 2015**. Discussion topics for this meeting include:
 - a. Approaches for defining the project elements within the firm cost cap;
 - b. Preliminary allocations for the overall costs of all HQ-directed PACE activities (including Science Teams, processing and analysis activities to be carried out by the Ocean Biology Processing Group at GSFC, and mission post-launch calibration and validation activities);
 - c. Approaches and expectations for implementing design-to-cost;
 - d. The approach for conducting an Acquisition Strategy Meeting (ASM) during Phase A to make recommendations for:
 - i. The procurement approach for the spacecraft
 - ii. The procurement approach for the polarimeter
 - e. Immediate and near-term funding levels and mechanisms from HQ to allow planning and other PACE activities to be initiated;
 - f. Plans for HQ production of the PACE Formulation Authorization Document, and the Project's Formulation Agreement response;
 - g. Planning dates, necessary preparatory activities, and tailored requirements for the KDP-A that will allow PACE to enter Formulation.
 5. The **ESD at NASA Headquarters shall direct the approach for ground data processing, the science team, and post-launch geophysical calibration/validation**.
- 13 January 2015 kick-off meeting addressed the topics identified in this list
 - PACE Science Team has been formed (first face-to-face meeting 14-16 January 2015)
 - Cal/Val approach being developed
 - Ground data processing to be performed by OBPG at GSFC



Vicarious Cal/Val

- Vicarious Cal/Val
 - FY15 – 17: ROSES 2014 A.3
 - Issued jointly between OBB and ESTO
 - Allows lead time for concepts to mature prior to launch
 - Identifies technical development needs/risks for the approaches selected
 - FY18 – 21: ROSES 2017 (4 years)
 - Selects best approach and hardware (pre-launch) for:
 - Vicarious calibration of ocean color
 - Validation of data products
 - Calibration/validation of polarimetry
 - FY22 – 25: ROSES 2021 (4 years)
 - Perform cal/val during mission operations
 - Includes airborne and in situ measurements
 - Continues every year during mission extensions



Science Teams

Pre-launch and Post-launch

- Pre-launch Science Teams
 - FY15 – 17: ROSES 2013 A.25
 - Achieves consensus and develops community-endorsed paths forward for the sensors for the full spectrum of components within a given measurement suits
 - Covers IOPs and Atmospheric Correction
 - FY18 – 21: ROSES 2017 (4 years)
 - Allows lead time for scientific algorithm development prior to launch
 - Initiates interface between instrument developers and OBPG
 - FY22 – 25: ROSES 2021 (5 years)
 - Pre-launch algorithms and post-launch competed science for both polarimeter and ocean color sensor
- Post-launch Competed Science
 - Competed through ROSES 2025
 - Joint funding between R&A and PACE mission budget
 - Mission contribution ~\$3.0M/year
 - Continues every year during mission extensions

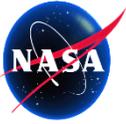


NRC DS Lessons Learned from a PS Perspective

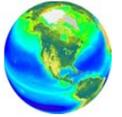
- State of Science & Mission Laundry List
 - How will the study be organized? Panels/sub-panels, (oceans were “missing” last time.....), NRC Boards...
 - DS-2 needs to convey that any recommendations are just that, recommendations and not requirements
 - Assessment of the state of the science (disciplinary and interdisciplinary) helpful – science needs/questions should drive ideas for measurements and instrument/mission capabilities
 - You don’t need to go so far as mode of observation
 - The committee needs to be careful if and when doing the “state of the science” that it does not look like one or a few people are driving the bus as to what is written – it really does need to reflect the larger communities’ thought processes.
 - Can the DS-2 address implementation costs without constructing mission concepts?
 - “Realistic Budget Scenarios” - can the DS-2 do that? The number of permutations for implementation is great and the engineering unknown – current pre-formulation studies prove this
 - Basis of instrument/mission cost estimate hard to determine (given the DS-2 timeline), or change (refine) once published – perhaps an assessment of past/current performance on accuracy of DS-1 estimates vs. NASA planning estimates?
 - How will DS-2 address synergies such as multi-application sensors and satellite formation flying?
 - What about airborne and *in situ* observations needed to do the ESD science?



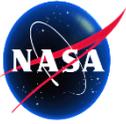
Back-Up



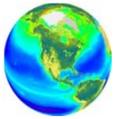
A.25: The PACE Science Team – Scope



- The Pre-Aerosol, Cloud, ocean Ecosystem (PACE) mission is a strategic **Climate Continuity mission** included in NASA's 2010 plan: Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space (Climate Initiative - <http://science.nasa.gov/earth-science/>). The Climate Initiative complements National Research Council's (NRC) Decadal Survey of Earth Science at NASA, NOAA, and USGS, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" (the NRC's Earth Science Decadal Survey - http://www.nap.edu/catalog.php?record_id=11820).
- In **2011**, NASA issued a Dear Colleague Letter to compete a **PACE Science Definition Team (SDT)** to develop the scientific foundation of the mission following the guidance given in the **Climate Initiative**. The PACE SDT has completed a report regarding science priorities of the PACE mission. The report has undergone public comment and been finalized; the final version of the report is on the PACE web site (<http://dsm.gsfc.nasa.gov/PACE.html>).



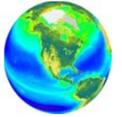
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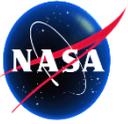
- PACE will be a polar-orbiting mission with an ocean color sensor and possibly an aerosol-cloud polarimeter. The mission will be capable of performing radiometric and possibly polarimetric ocean and atmosphere surveys, returning a range of geophysical data from which properties of the ocean and atmosphere can be produced to add to other critical climate and Earth system variables. The PACE mission has multiple scientific goals: making climate-quality global ocean color measurements that are essential for understanding the carbon cycle and global ocean ecology and determining how the ocean's role in global biogeochemical (carbon) cycling and ocean ecology both affects and is affected by climate change.
- Under consideration is the expansion of the ocean color instrument capabilities to include bands for aerosols and clouds, and, therefore, extend a number of observations of aerosols and clouds, focusing on reducing the largest uncertainty in radiative forcing of the Earth System. The ocean color radiometer will extend the ocean and (some) of the atmosphere data records from Sea-viewing Wide Field-of-view Sensor and Moderate Resolution Imaging Spectroradiometer (MODIS). Some ocean color data products may be continued with JPSS or Sentinel-3.
- Polarimetry measurements would complement the aforementioned observations, providing better quantitative estimates of aerosol type and height, improving our understanding of atmospheric dynamics and radiative sciences, and improve the atmospheric correction for ocean color remote sensing. If a polarimeter flies, those measurements would provide extended data records on clouds and aerosols, focusing on reducing largest uncertainty in radiative forcing of the earth system. The President's FY 2015 budget request allows for a PACE Launch Readiness Date as early as 2018 to enable these critical climate measurements.



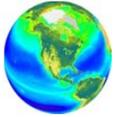
A.25: The PACE Science Team – Science Team



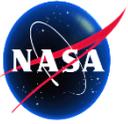
- The purpose of this solicitation is to formulate a PACE Science Team (ST) for a **three-year period**.
- Welcomes proposals from prospective Science Team members to pursue **theoretical and analytical studies** associated with one of two sets of measurements, one for **Inherent Optical Properties** and the other for **Atmospheric Correction**.
- The ST is expected to be composed of a diverse group of investigators who cumulatively bring end-to-end knowledge of different aspects of these two sets of measurements to the Science Team activities. **End-to-end knowledge encompasses laboratory and field measurement protocols and quality assurance, radiative transfer modeling, remote sensing theory in the UV-to-SWIR spectral range, and ocean color, aerosol, and cloud algorithms**, such as those currently applied in standard MODIS ocean color data processing.
- The two measurement suites where there is opportunity to do risk reduction and further clarify measurement requirements for future collaborative atmosphere and ocean science and applications on the PACE mission are: (1) **Inherent Optical Properties (IOPs) of the ocean, specifically the spectral absorption and scattering properties of phytoplankton, nonalgal particles, dissolved organic matter, and seawater itself, and the relationship of these properties to biogeochemical stocks**; and (2) **Atmospheric Correction of ocean color radiometry, including but not limited to hyperspectral methods, modeling of bidirectional effects and non-negligible radiances in the near-infrared, absorbing aerosols detection, and studies that focus on aerosol and cloud retrievals**.
- Proposers interested in focusing on **aerosol and cloud retrievals** in support of the PACE ocean color instrument (with a possible expanded bandset for aerosol and cloud retrievals) **or a possible PACE polarimeter should propose to the Atmospheric Correction group**. Team members for both measurement sets may consider the potential for planned domestic and international sensors to maintain key observations that the PACE mission would provide for IOPs and the Atmospheric Correction.



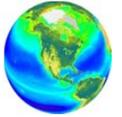
A.25: The PACE Science Team – Science Team



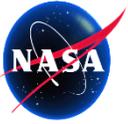
- NASA welcomes proposals for a **Principal Investigator** who wishes to be the **Science Team (ST) Leader**. NASA will select **one ST lead to oversee and coordinate activities for both measurement set groups**. A desire to serve as the PACE ST Leader should be **clearly identified in a separate section of the proposal**. The ST Leader will **organize, plan, and chair any needed team meetings, coordinating both measurement groups, integrate the input of the various team members within the individual groups, and work to achieve consensus on the overall science objective and requirements of each group as well as the integrated Team**.
- **NASA reserves the right to appoint a Deputy Team Leader** to assist the PACE ST Leader to ensure the breadth of scientific expertise is well represented. The PACE ST Leader (and possible Deputy Team Leader) will act in close association with the NASA Earth Systematic Mission Office, if needed, and Program Scientists to achieve the team goals. PIs interested in being the PACE ST Leader **should budget accordingly and keep the budget for the Team Leader role and requirements separate from any proposed measurement suite research activities**.



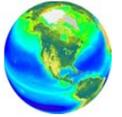
A.25: The PACE Science Team – Science Team



- Each "team" (IOPs and Atmospheric Correction) will be expected to collaboratively produce a final report that details recommended approaches for PACE for their respective measurement suite.
- The ultimate goal for each of the two measurement suite teams is to achieve *consensus* and develop community-endorsed paths forward for the PACE sensor(s) for the full spectrum of components within the measurement suite. The goal is to replace individual ST member recommendations for measurement, algorithm, and retrieval approaches (historically based on the individual expertise and interests of ST members) with consensus recommendations toward common goals.
- Proposers to either of the two measurement suite areas can include analysis of existing laboratory or field data (although MINOR laboratory and field data collection activities to support specific science and applications questions may be entertained) and must detail the science and applications questions to be addressed by the proposal, what theoretical or analytical analyses will be undertaken by the proposed activities (and how these analyses will be used to quantify and reduce uncertainties), what the expected scientific and applications outcomes of the proposed activities will be, the measurement risk to be reduced as a result of the proposed activities, and how the risk reduction will be assessed. The two Science Team measurement suite leads should propose the methods or approaches by which they anticipate bringing the measurement suite groups of the Science Team to consensus.
- All proposers, in particular measurement suite leads, should outline methods for implementing their proposed work (as appropriate) into the standard data processing capabilities of the NASA Ocean Biology Processing Group at Goddard Space Flight Center.

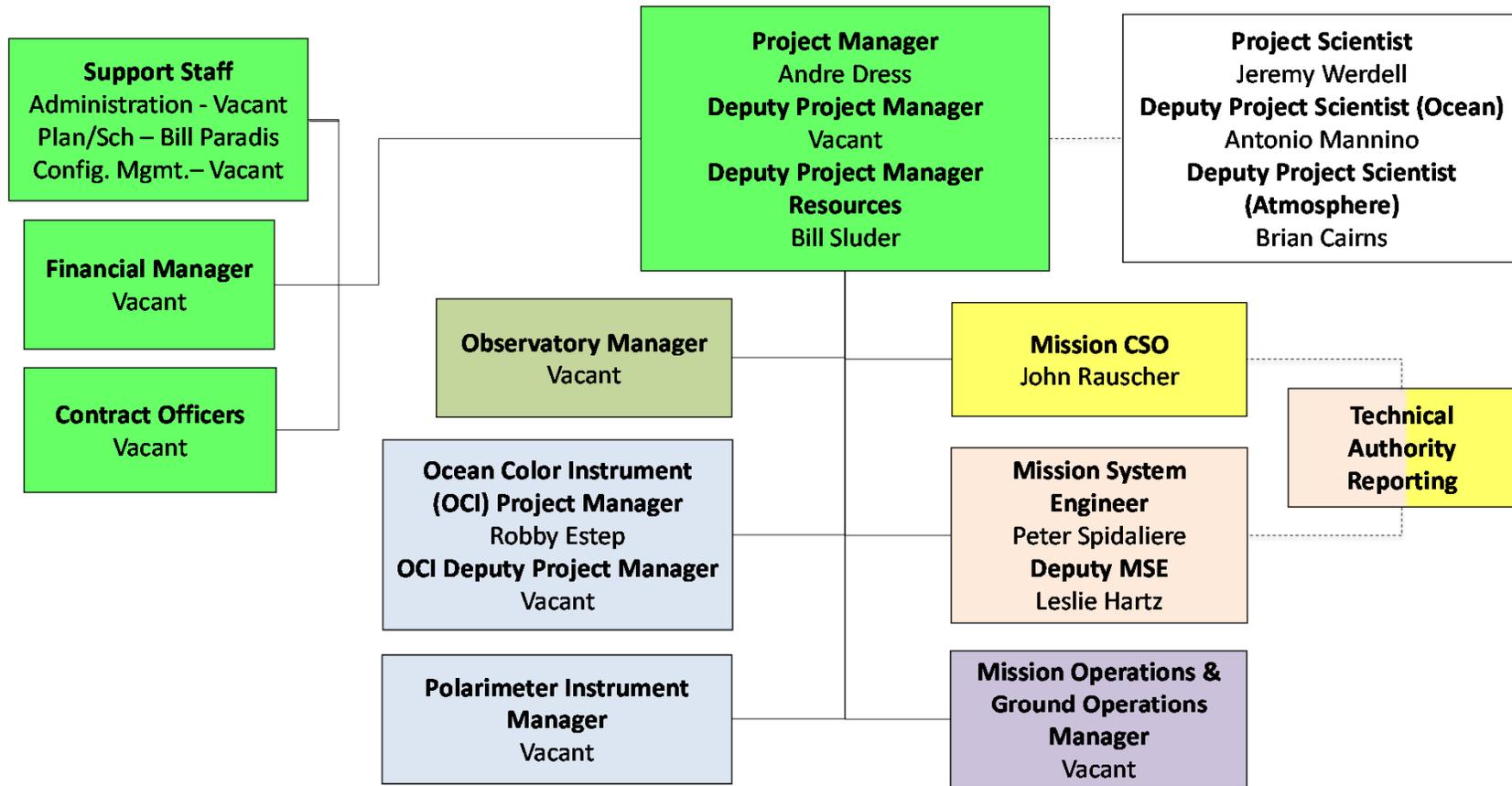


A.25: The PACE Science Team – Science Team



- There will be two staff members from NASA's Goddard Space Flight Center's Ocean Biology Processing Group and one staff member from NASA's Langley Research Center designated by the cognizant NASA Headquarters PACE program staff as points of contact for the PACE Science Team activities. Although these are noncompeted positions, the three designated people will be full members of the ST, charged to function as the liaison between the ST and the NASA centers that currently handle the data processing and data distribution for aerosol, cloud, and ocean color missions at NASA, respectively. These three designees will participate in all ST activities, including scientific discussions, measurement discussions, algorithm development and retrieval activities, and associated algorithm/retrieval testing and implementation activities (as appropriate). This will be done as a prototyping activity to examine one potential mission data processing approach.
- International PIs from institutions in countries outside the U.S. are free to propose to this solicitation on a no-exchange-of-funds basis. PIs from institutions outside the U.S., as interested, should indicate to the Points-of-Contact below their desire for participation.
- Prototypical algorithm or retrieval development activities using Hyperspectral Imager for the Coastal Ocean (HICO) data are welcome. The HICO instrument is currently on orbit aboard the International Space Station. Authorized users will have sponsorship of NASA.

PACE Pre-Phase A Project Organization Chart



Concept Studies

