There and back again: PACE version

Jeremy Werdell

PACE class @ UMBC
1-5 Aug 2022
2000-2001 had:
• SeaWiFS
• MODIS-Terra
• MISR
• several others (MOS ...)

2000-2001 did not yet have:
• MODIS-Aqua
• VIIRS
• POLDER-2
• MERIS, OLCI
• Landsat for oceans
The PACE ‘Family Tree’


2002-2004: PhyLM (Physiology Lidar Multispectral) mission development

2006: GOCECP (Global Ocean Carbon, Ecosystems, and Coastal Processes) instrument study

2006: OCEaNS concept submitted to Decadal Survey

2007: ACE (Aerosol, Clouds, and Ecosystems) mission recommended in NRC Decadal Survey Report

2008-2011: ACE Ocean Science Team defines approach and measurement requirements

2012: PACE SDT (Science Definition Team) defines mission approach and measurement recommendations

2010: PACE (Pre-ACE) mission recommended in NASA Plan for Earth Observations recommends

Science and Observation Recommendations for Future NASA Carbon Cycle Research


National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
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Earth’s Living Ocean: ‘The Unseen World’
An advanced plan for NASA’s Ocean Biology and Biogeochemistry Research
2006
DRAFT
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NASA Earth Science Decadal Survey Missions

Tier I: The Near Term Missions
- CLARREO
- SMAP
- ICESat-II
- DESDynl

Tier II: The Mid-Term Missions
- HypiRIR
- ASCENDS
- SWOT
- GEOCAPE
- ACE

Tier III: The Far-Term Missions
- LIST
- PATH
- GRACE-II
- SC8P
- 3D-Winds
- GACM

These fifteen missions, and the observations they collect, will help us better understand and protect the Earth system and respond more confidently to natural and human-induced changes.

AEROSOL-CLOUD-Ecosystems (ACE)

Launch: 2015-2016
Mission Size: Large

- Cloud and aerosol height
- Improved climate models
- Prediction of local climate change
- Improved climate models

- Organics material in surface ocean layers
- Ocean productivity
- Ocean health

- Aerosol and cloud types and properties
- Air-quality models and forecasts
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OC039
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1. To address threshold PACE ocean science questions the PACE mission must include:

- An accurately calibrated and well characterized ocean color instrument covering a spectral range of 350 to 800 nm at ~5 nm resolution, and including a short wavelength near-UV band (approximately centered around 350 nm), two NIR bands (one of which should be centered at 865 nm), and three SWIR bands (1240 nm, 1640 nm, and 2130 nm) for atmospheric corrections. All measurement bands must have a spatial resolution of 1 km² (square pixel at nadir) with two-day global coverage. This instrument option is called OCI.
- A mission architecture that includes continual post-launch calibration (including lunar and vicarious calibration), frequent reprocessing of the entire data set, development and maintenance of algorithms, field validation, and process studies. The mission architecture should also include a| product and data management system and algorithm inter-comparison.

b.3. Threshold Atmosphere Science Questions

This threshold atmosphere science question (ASQ) is addressed with the OCI+

ASQ-1 - In combination with data records that were begun with heritage/existing imagers, what are the long-term changes in aerosol and cloud properties that can be continued with PACE and how are these properties correlated with inter-annual climate oscillations?

b.4. Goal Atmosphere Science Questions

b.4.1 Goal Atmosphere (Ocean-Aerosol) Science Questions

These science questions are addressed by the OCI-3M:

ASQ-4 - What are the magnitudes and trends of Direct Aerosol Radiative Forcing (DARF), and the anthropogenic component of DARF?

ASQ-5 - How do aerosols influence ocean ecosystems and biogeochemical cycles?
Early 2014 ...

The 1st PACE Science Team

A Novel Approach to a Satellite Mission’s Science Team

NASA’s Plankton, Aerosol, Cloud, Ocean Ecosystem satellite mission, still in planning stages, operates with a framework that could serve as an example for science support of future missions.

By E. Bess and L. A. Remer  12 February 2018

An artist’s rendering of the proposed NASA PACE satellite. PACE is expected to significantly contribute to better understanding of the functioning of the atmosphere and oceans. Credit: E. V. Edens, PACE Project, NASA GSFC
Late 2014 ... PACE becomes a real mission

Early 2015 ... The fun begins

New mission to study ocean color, airborne particles and clouds

By Steve Cole, NASA Headquarters, and Rani Gran, NASA's Goddard Space Flight Center
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).
Mission Formulation Studies

PACE Mission Formulation and Architecture
OCI Coverage Loss from Glint and Tilt Change
Case Study on Data Completeness Requirement
Hyperspectral Pushbroom Image Striping Artifacts
Analysis of Potential PACE Altitude Reduction
PACE OCI Proxy Data Development
PACE Instrument Design Lab Studies
Case for the Addition of a Coastal Color Imager
Analysis of a Pushbroom OCI Lunar Calibration

Ocean Color Instrument (OCI) Concept Design Studies

Extended UV Capability for Ozone Retrieval
Chlorophyll Fluorescence Requirements
Estimates for Optimal Sensing of Coastal Features
Analyses Supporting an OCI 1038 nm Band
Analysis of OCI SWIR Bands
Strategy & Requirements: Solar & Lunar Calibrations
Ltyp and Lmax Calculations for the OCI
Analysis of OCI Spectral Resolution Considerations

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

December 2018
From: Oceanographer and Navigator of the Navy (OPNAV N2N6E)
To: Director, Launch Enterprise Directorate, Space and Missile Systems Center

Subj: PLANKTON, AEROSAL, CLOUD, OCEAN ECOSYSTEM MISSION ADVOCACY

1. The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission proposed by the National Aeronautics and Space Administration (NASA) will collect data useful for characterizing the oceanographic and atmospheric battlespace, providing opportunities for asymmetric warfarefighting advantages for joint forces.

2. The PACE mission would extend and enhance the current constellation of spaceborne ocean color satellite sensors, which provide optical conditions for operational products supporting multiple warfare areas. Optical products from PACE will help assess the ocean and atmospheric impact to diver operations, communications, mine and target detection, and will offer new prospects for examining bioluminescence potential, and assessing the performance of hyperspectral systems. PACE will simultaneously collect integrated global observations of coupled aerosol and cloud properties, connecting sea state, radiation budgets, aerosols and dust storms, water vapor, storm formation and clouds coverage. These efforts will reduce the largest uncertainties in climate and radiative forcing models of the Earth system and improve the operational picture of environmental conditions across the battlespace.

3. The PACE mission’s characterization of cloud coverage and ocean surface wind speed magnitudes will partially address two Department of Defense meteorological and oceanographic collection gaps, as defined in the Joint Requirements Oversight Council Memorandum 092-14.

4. My point of contact is CDR Jeff Dixon, OPNAV N2N6EL who can be reached at commercial: (703) 695-6308, or by email at: jeffrey.c.dixon1@navy.mil.

C. R. EKSTROM
By direction

Copy to: HQ USAF/ILWX
ocean color &
the ocean color instrument

ocean color retrievals drive OCI’s
design & performance requirements

- hyperspectral scanning radiometer
- (320) 340 – 890 nm, 5 nm resolution, 2.5 nm steps+
- plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- single science pixel to mitigate image striping
- 1 – 2 day global coverage
- ground pixel size of 1 km² at nadir
- ± 20° fore/aft tilt to avoid Sun glint
- twice monthly lunar calibration
- daily on-board solar calibration
- <0.5% total system error for VIS-NIR
- SNRs optimized for ocean color science
- simulated top-of-atmosphere data available

+ with 1.25 nm steps in several spectral regions
* developed primarily for mechanical processing assessments
UMBC Hyper Angular Rainbow Polarimeter (HARP-2)

**Update**
- Flight unit rebuild underway at UMBC
- Delivery to GSFC for I&T in Fall 2022

SRON/Airbus Spectro-polarimeter for Planetary Exploration (SPEXOne)

**Update**
- SPEXOne fully integrated onto the spacecraft in June 2022
- 16 orbits of simulated data available online

<table>
<thead>
<tr>
<th></th>
<th>HARP-2</th>
<th>SPEXone</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-NIR range</td>
<td>440, 550, 670, 870 nm</td>
<td>Continuous from 385-770 nm in 5 nm steps</td>
</tr>
<tr>
<td>SWIR range</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Polarized bands</td>
<td>All</td>
<td>Continuous from 385-770 nm in 15-45 nm steps</td>
</tr>
<tr>
<td>Number of viewing angles [degrees]</td>
<td>10 for 440, 550, 870 nm; 60 for 670 nm [spaced over 114°]</td>
<td>5 [-57°, -20°, 0°, 20°, 57°]</td>
</tr>
<tr>
<td>Swath width</td>
<td>±47° [1556 km at nadir]</td>
<td>±4.5° [106 km at nadir]</td>
</tr>
<tr>
<td>Global coverage</td>
<td>2 days</td>
<td>30+ days</td>
</tr>
<tr>
<td>Ground pixel</td>
<td>3 km</td>
<td>2.5 km</td>
</tr>
<tr>
<td>Heritage</td>
<td>AirHARP, Cubesat</td>
<td>AirSPEX</td>
</tr>
</tbody>
</table>
Phase C – final design & fabrication
- all mission elements have passed Critical Design Reviews (CDRs)
- all mission elements will have System Integration Reviews (SIRs)
- engineering test units characterized; flight builds nearing completion
- Project & HQ science implementing science capabilities

PACE mission update: where are we?

We are here. (Launch – 17 mos.)
science community engagement:

- Science & Applications Team #2 (competed; Jun 2020)
- System Vicarious Calibration teams (competed; Jul 2020)
- Post-launch validation team (to be competed; TBD)
- Applications Program
Science & Applications Team #2 ("the SAT")

3 year competitive award that began in July 2020

24 teams (>100 people) with researchers spanning U.S. & international collaborations

contribute algorithms & approaches for OCI & polarimeter science products
resources & useful info

data product descriptions + access to simulated data & characterizations

PACE technical memos & other documents

https://pace.gsfc.nasa.gov

@NASAOcean

PACE Ready to Make Waves
PACE has passed its design reviews and moved into construction and testing.

PACE’s advanced technologies will provide new insight into Earth’s ocean and atmosphere.

These systems impact our everyday lives. How?

By regulating climate and making our world a better place.

PACE’s data will help us better understand how the ocean interacts with carbon dioxide. In addition, it will reveal how aerosols might fuel the ocean. Novel uses of PACE data will benefit our economy, help us identify the extent and duration of harmful algal blooms, and provide long-term observations of our living planet. By doing so, we can prepare for decades to come.

Which Phytoplankton Are You? Click to find out.

What in the World are Aerosols? Click to find out.

Which Phytoplankton Are You? Quarantine Edition

Which Phytoplankton Are You? Click to find out.
THE PLANKTON, AEROSOL, CLOUD, OCEAN ECOSYSTEM MISSION

Status, Science, Advances

P. JEREMY WENDT, MICHAEL J. BERNER, PAULA S. BONTEMPI, EMANUEL BOSS, BRYAN CAINE, GARY T. DAVIS, BRYAN A. FRANZ, ULRIC B. GIES, ERIC T. GOHRMAN, OTTO HASEMANN, KIRK D. KOELSCH, ANTONIO MANNINO, J. VANDERLIND MARTINES, CHARLES R. MCCLEAN, GERHARD MESTER, AND LORRAINE A. RYER

The PACE mission represents NASA's next investment in ocean, cloud, and aerosol data records to enable continued and advanced insight into oceanographic and atmospheric responses to Earth's changing climate.

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission represents the National Aeronautics and Space Administration's (NASA) next advance in satellite ocean color and polarimetry for the combined study of Earth's ocean-atmosphere-land system. Its multidisciplinary observations will serve the oceanographic, atmospheric, and terrestrial science communities, building upon a recognition that significant synergies exist between measurement requirements for atmospheric and oceanic systems remote sensing retrievals of geophysical properties. PACE observations will enable continuation of climate research-quality long-term data records established by a diversity of heritage U.S. and international Earth-observing satellite missions. The underlying motivation for the mission, however, has long been to provide advanced observational capabilities enabling a leap forward in capabilities for remote observations.


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The abstract for this article can be found in this issue, following the table of contents.

OPEN ACCESS

Introduction

This article was submitted at the request of the guest editor of this special issue of Frontiers in Remote Sensing, Dr. Robert Frey, who thought it would be useful for the community for use to document our experiences and perspectives on using observations in NASA's ocean color missions beginning with the Nimbus-7/Coastal Zone Color Scanner (CZCS) launched in October 1978 and extending through the upcoming PACE, Cloud, ocean Ecosystem (PACE) mission scheduled to launch in January 2024. Thus, our account will be limited primarily to activities conducted at NASA Goddard Space Flight Center, e.g., experiences with the sea-viewing Wide Field-View Sensor (SeaWiFS) and preparations for PACE, and intentionally reach much less of a “review” nature. Over the past 40 years, there have been numerous advances and refinements in the fields of technology, methodologies, and algorithms and we will highlight many. Acknowledgments also provide a detailed description of the NASA ocean color program through the initial phases of the National Polar-orbiting Environmental System (NPOESS) Preparatory Project (NPP) [NPP] that incorporated the First Visible Infrared Imaging Radiometer Suite (VIIRS). In addition, the basic concepts of ocean color are discussed by a number of chapter authors in Zibordi et al. (2014), as well as in Wendt and McClain (2018). Of course, this article provides a useful accompanying reference for the atmospheric correction process and terminology we will discuss. Finally, there have been comprehensive and authoritative sessions that we will not discuss, but one of note is the Airborne Oceans (AOL, see, e.g., Hoge, 1976) that operated out of the NASA Wallops Flight Facility (WFF) for many years. We will endeavor to recount the realistic advances in ocean science that have resulted from these missions. In our reflections, being somewhat personal, we will refer to ourselves as in the text as CM, RR, and JW, for Charles “Chuck” McClain, Bryan Frame, and Jeremy Wendt.
persevere ...
persevere ...

... and collaborate