NASA Sets the PACE for Advanced Studies of Earth's Changing Climate

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PACE provides a strategic climate continuity mission that will collect many global measurements essential for understanding marine and terrestrial biology, biogeochemistry, ecology, and cloud and aerosol dynamics.

Introduction

Spend any amount of time observing Earth's oceans and one thing becomes readily apparent: Ocean water is anything but clear; its color varies immensely, depending on exactly where one is looking (e.g., coastal waters are very different than the open ocean) and what happens to be dissolved or suspended in the water beneath its surface at that location. Such variations provide the basis for ocean color science. Many particulate and dissolved constituents of the near-surface water column absorb and scatter light differently in the ultraviolet (UV) and visible (VIS) regions of the electromagnetic spectrum. So at its most fundamental level, ocean color science is about relating the spectral variations in the UV-VIS marine light field (i.e., differences in the ocean's color) to the concentrations of the various constituents residing in the sunlit, near-surface water column—see *How Ocean Color Measurements Are Made* on the next page.

To continue a multidecade record of ocean color measurements, NASA recently approved the Pre-Aerosols, Clouds, and ocean Ecosystems (PACE) mission to enter *Pre-Phase A*—mission preformulation and conceptual studies. First presented in the 2010 NASA 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*[1], PACE provides a strategic climate continuity mission that will collect many global measurements essential for understanding marine and terrestrial biology, biogeochemistry, ecology, and cloud and aerosol dynamics.

PACE, the primary sensor for which is currently called the Ocean Color Instrument (OCI), is an ocean color mission but, as its name implies, it will also be used to study important aspects of atmospheric science. Since the mission's primary focus is ocean color, this article begins with some background on that topic. The origins of the mission, its objectives and scientific questions, its organizational structure, and benefits to society are also addressed.

In the coming months, *pace.gsfc.nasa.gov* will be developed and populated with news, updates, educational materials, and oceanic and atmospheric information for interested community members.

Contributions to Ocean Color

In addition to dissolved and inorganic material such as salts, ocean water contains a variety of microscopic living organisms, each with their own unique impact on the optical properties of water. In fact, one of the most important components found in ocean water are phytoplankton. These microscopic marine algae form the base of the marine food chain and produce over half of the oxygen we breathe. Phytoplankton also play an important role in converting inorganic carbon in carbon dioxide (CO_2) to organic compounds, fueling global ocean ecosystems and driving the oceanic biogeochemical cycles through grazing (i.e., they provide a food source for zooplankton) and through their degradation products and the *microbial loop*—where bacteria reintroduce dissolved organic carbon (DOC) and nutrients to the trophic system, effectively recycling both back into the food chain. Phytoplankton are therefore a critical part of the ocean's biological carbon pump, whereby atmospheric CO_2 gets sequestered to the deep ocean, and are responsible for roughly half of Earth's net *primary production*—the difference

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[1] To view the report, visit *science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf*.

between the rate of plant production of useful chemical energy and the rate of their use of that energy in respiration. However, phytoplankton growth is highly sensitive to variations in ocean and atmospheric physical properties, such as upper-ocean stratification and light availability within this mixed layer. Phytoplankton also vary greatly in their size, function, response to ecosystem changes or stresses, and nutritional value for species higher in the food web. Hence, measurements of phytoplankton community composition and their distributions remains essential for understanding global carbon cycles and how living marine resources are responding to Earth's changing climate. All these inorganic and organic substances combine to form the actual optical properties of the ocean, which ultimately give it its color.

Ocean Color: An Important Climate Data Record

A key step toward helping scientists understand how the Earth has responded to its changing climate over time—and how it may respond in the future—is through the establishment of high-quality, long-term, global time series of various geophysical parameters. Given the nature of the phenomena and the timescales needed to distinguish trends, such measurements will require combining data from several missions. These climate-quality time series are called climate data records (CDRs[2]), and are being generated for a variety of geophysical parameters, including ocean color.

Beginning with the launch of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS[3]) in 1997, NASA has generated a continuous record of global ocean color measurements—although the proof-of-concept ocean color satellite observations date back to 1978—see *OCI Builds on NASA's Ocean Color Heritage* on page 7. This time series of remotely sensed quantities provides a valuable data record for studying long-term changes in ocean ecosystems. Observations of spectral marine inherent optical properties (IOPs), the spectral absorption and scattering properties of seawater, and the particulate and dissolved constituents it contains, can be used to infer the contents of the upper ocean, including phytoplankton community composition—see **Figure 1.** This information is critical for advancing our understanding of biogeochemical oceanic processes

How Ocean Color Measurements Are Made

In simplified terms, here's how an ocean color measurement works: An instrument in space, such as the PACE Ocean Color Instrument (OCI) described on page 8, measures the spectral radiance exiting the top of the atmosphere. Of the total amount of radiance seen by the satellite instrument, only a small portion is actually coming from the ocean; by far the dominant portion comes from the atmosphere, and this "noise" effectively hides the desired signal. To retrieve the portion of the signal exiting the water, scientists and programmers apply atmospheric correction algorithms that remove the radiance contribution from the atmosphere; what remains is the small portion passing through the ocean surface—the component of interest for ocean color measurements. That radiance is then converted to spectral remote-sensing reflectances, which are essentially the ratio of the light coming from the ocean normalized to the light from the sun entering the ocean. Once these reflectances are known, then bio-optical algorithms are used to produce estimates of geophysical and optical properties, such as the near-surface concentration of the phytoplankton pigment chlorophyll-*a* and spectral marine inherent optical properties (IOPs).

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[2] The U.S. National Research Council (NRC) defines a CDR as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.
[3] SeaWiFS flew onboard the Orbview spacecraft, and operated until 2010.

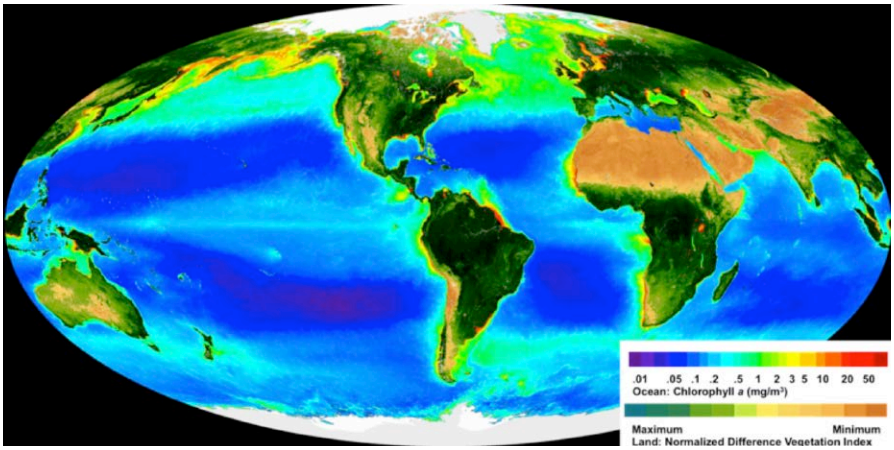

Figure 1. Global image of the Earth's biosphere as seen by SeaWiFS. For the ocean, the colors indicate the abundances of chlorophyll-*a*, with purple-blue showing low abundances and green-yellow-red showing high abundance. For land, the colors show the normalized difference vegetation index (NDVI), with brown and green indicating arid and lush regions, respectively. **Image credit:** GSFC Ocean Biology Processing Group

—e.g., carbon exchanges and fluxes, phytoplankton community dynamics, and ecosystem responses to disturbances.

PACE Science Targets

The PACE science objectives have been described in the *PACE Science Definition Team Report*[4]. They are the result of decades of experience with requirements developed by the ocean color and cloud and aerosol communities. The advanced capabilities of the PACE OCI over heritage instruments will extend the current time series of high-quality CDRs and answer the science questions listed here, grouped by topic:

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PACE Science Questions

Global ocean ecosystems and climate

- What are the standing stocks and compositions of ocean ecosystems? How and why are they changing?
- How and why are ocean biogeochemical cycles changing? How do they influence the Earth system?
- What are the material exchanges between land and ocean? How do they influence coastal ecosystems and biogeochemistry? How are they changing?
- How do aerosols influence ocean ecosystems and biogeochemical cycles? How do ocean biological and photochemical processes affect the atmosphere?
- How do physical ocean processes affect ocean ecosystems and biogeochemistry? How do ocean biological processes influence ocean physics?
- What is the distribution of both harmful and beneficial algal blooms and how is their appearance and demise related to environmental forcings? How are these events changing?
- How do changes in critical ocean ecosystem services affect human health and welfare? How do human activities affect ocean ecosystems and the services they provide? What science-based management strategies need to be implemented to sustain our health and well being?

Coastal ocean ecosystems

- What are the distributions of habitats and ecosystems and the variability of biogeochemical parameters at moderate scales and what is the impact on coastal (e.g., estuarine, tidal wetlands, lakes) biodiversity and other coastal ecosystem services?
- What is the connectivity between coastal, shelf, and offshore environments?
- How does the export of terrestrial material affect the composition of phytoplankton communities in coastal waters, and how do these in turn affect the cycling of organic matter?
- How do moderate scale processes (e.g., sedimentation, photodegradation, respiration) affect the cycling of terrigenous organic material in the coastal environment?

Aerosols and clouds

- What are the long-term changes in aerosol and cloud properties and how are these properties correlated with inter-annual climate oscillations?
- What are the magnitudes and trends of direct aerosol radiative forcing (DARF) and the anthropogenic component of DARF?
- How do aerosols influence ocean ecosystems and biogeochemical cycles?

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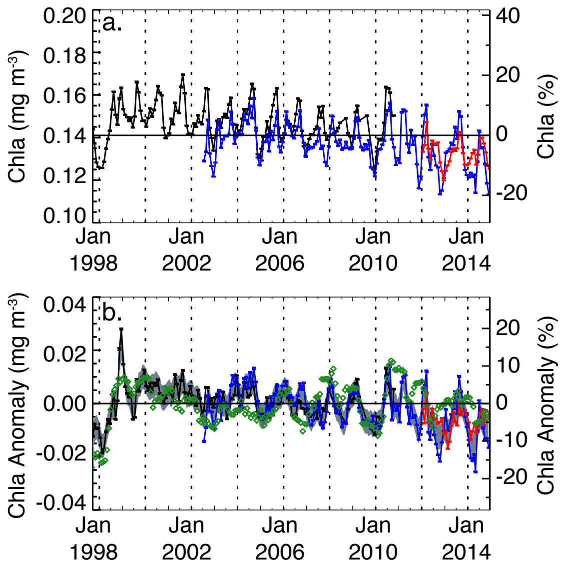
[4] To view the report, visit *decadal.gsfc.nasa.gov/PACE/PACE_SDT_Report_final.pdf.*

OCI Builds on NASA's Ocean Color Heritage

The PACE Ocean Color Instrument (OCI) builds on a firm foundation of ocean color observations at NASA that includes a 17-year continuous record of satellite ocean color observations, and many more years of experience (see graphs below). The Coastal Zone Color Scanner (CZCS), launched in 1978 onboard Nimbus-7, was the first instrument that measured ocean color from space. Intended to be a "proof-of-concept" mission, CZCS did that—and much more. CZCS observations ceased in 1986, but research continued for many years thereafter that laid the groundwork for the missions that followed*.

While some climate data records (CDRs) (e.g., ozone) are continuous from the Nimbus era to the present, such is not the case with ocean color. There was an 11-year gap between the end of CZCS observations and the next NASA ocean color mission**: the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), launched in 1997 onboard the SeaStar (later renamed Orbview-2) satellite. Despite a challenging start—SeaStar was initially deployed upside down!—SeaWiFS proved itself resilient and went on to provide quality global ocean-color observations for over a decade.

Ocean color measurements continued into the NASA Earth Observing System (EOS) era. Two of the flagship EOS missions carried the Moderate Resolution Imaging Spectroradiometer (MODIS): Terra, launched in 1999, and Aqua, launched in 2002. More recently, the Visible Infrared Imaging Radiometer Suite (VIIRS), launched in 2012 onboard the Suomi National Polar-orbiting Partnership (NPP), also obtains ocean-color measurements. VIIRS will also fly on upcoming Joint Polar Satellite System missions, the first of which (JPSS-1) is scheduled for launch in late 2016.



These graphs illustrate the seventeen-year, multimission record of chlorophyll-*a* averaged globally for the latitudinal band 40° S to 40° N for SeaWiFS (black), MODIS onboard Aqua (blue), and VIIRS (red). The top graph plots the independent record from each mission, with the multi-mission mean chlorophyll-*a* concentration for the region (horizontal black line). The bottom graph plots monthly anomalies after subtraction of the monthly climatological mean (SeaWiFS relative to the SeaWiFS climatology, and MODIS and VIIRS relative to their respective climatologies), with the average difference between SeaWiFS and MODIS-Aqua over the common mission lifetime (grey). The multivariate El Niño Southern Oscillation index is inverted and scaled (green diamonds) to match the range of the chlorophyll-*a* anomalies. **Image credit**: Bryan Franz, NASA's Goddard Space Flight Center

* To learn more about the ocean-color instruments that followed, click on the Missions & Sensors tab on the left menu bar at *oceancolor.gsfc.nasa.gov.*

**This story is told in Chapter 5 of *The Color of the Atmosphere with the Ocean Below: A History of NASA's Ocean Color Missions,* by Jim Acker. The book provides a summary of the development of NASA's ocean color missions with many references to "source" material.

PACE Mission Requirements

Responding to mission objectives and finding ways to answer the scientific questions is what drives mission requirements. NASA will incorporate many of the features and "lessons learned" from heritage spectrometers flown by NASA as well as those flown by international partners[5] into the OCI instrument design. A lesson learned from the

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[5] Examples would include the European Space Agency's Medium Resolution Imaging Spectrometer (MERIS) instrument that flew onboard Envisat and the Japanese Aerospace Exploration Agency's Ocean Color and Temperature Scanner (OCTS), and Global Imager (GLI) instruments that flew onboard the Advanced Earth Observation Satellite (ADEOS) and ADEOS II, respectively.

SeaWiFS era, for example, is the benefit of an ocean color instrument that can view the full Moon each month from its Earth view port. The reflectance of the Moon can be accurately modeled, providing an invaluable temporal calibration source for the ocean color instrument. As of this early stage in the project, the key minimum threshold mission and OCI instrument characteristics and capabilities are:

- Earth surface spatial resolution at nadir of 1 km^2 (~0.4 mi^2) for all science bands.
- Sun-synchronous polar orbit with an equatorial crossing time near local noon (1100-1300).
- Two-day global coverage of science measurements to a solar zenith angle of 75° and sensor view zenith angles not exceeding 60°—with mitigation of sun glint.
- A spectral range from 350 to 800 nm at 5-nm resolution, plus near-infrared bands at 865 and 940 nm and four or more shortwave infrared bands spanning 1240, 1378, 1640, 1880, 2130, and/or 2250 nm.
- Downlink and storage of the complete 5-nm resolution data from spacecraft to ground.
- Monthly characterization of instrument detector and optical component changes using lunar observations through the Earth-viewing port that illuminate all science detector elements.

While PACE is predominantly an "ocean color" mission, it will also have secondary objectives—and possibly a secondary instrument. An additional overarching goal for the mission is to help determine the roles of the ocean and atmosphere in global biogeochemical cycling and how perturbations to Earth's energy balance both affect and are affected by rising atmospheric CO$_2$ levels and Earth's changing climate.

Organizational Requirements and Responsibilities

PACE is being implemented as a NASA *Class C*[6] mission with a notional launch date in the 2022–2023 timeframe and minimum mission duration of three years, with orbit maintenance capabilities for 10 years. PACE is designated as a design-to-cost mission, meaning that it has a fixed budget cap of $805 million. Under this funding framework, science returns from the mission will need to be optimized through a series of trade and feasibility studies that encompass the OCI, a potential polarimeter (see PACE: Measuring More than Ocean Color below), the spacecraft and launch vehicle, the ground and science data processing segments, pre- and post-launch, science and calibration/validation programs, and all other components of system integration and mission management.

Full responsibility for the PACE mission was directed to NASA's Goddard Space Flight Center (GSFC) in December 2014. GSFC will design and build the OCI, as well as maintain responsibility for project management, safety and mission assurance, mission operations and ground systems, launch vehicle/spacecraft/instrument payload integration and testing, and OCI calibration, validation, and science data processing.

PACE: Measuring More than Ocean Color

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The PACE mission will contribute to the continuation of atmospheric CDRs as well as those for ocean color. The OCI will allow continuation of "heritage" aerosol measurements made using the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua and the Ozone Monitoring Instrument (OMI) onboard Aura. It will also provide additional

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[6] To learn more about the classifications used to categorize NASA missions, see *Appendix B* of "NASA Procedural Requirements (NPR) 8705.4," which can be found at *nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_0004_/N_PR_8705_0004_.pdf*.

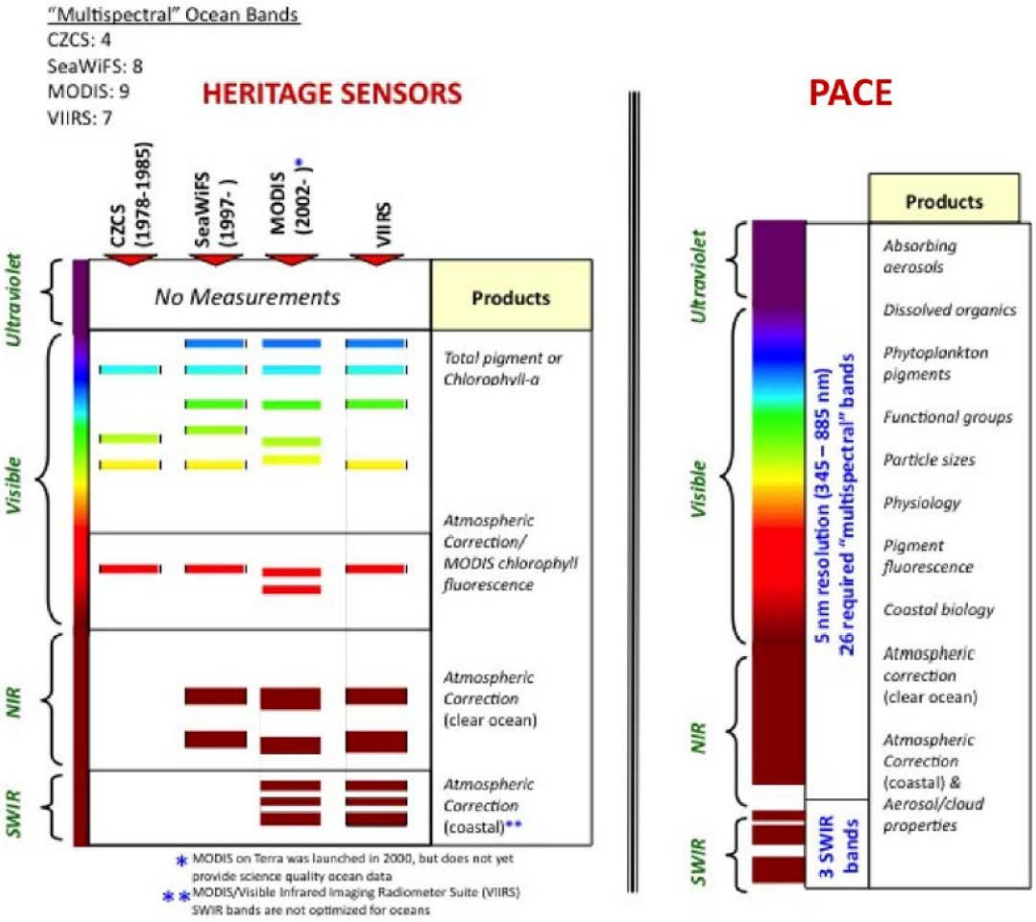

Figure 2. Comparison of PACE spectral coverage with heritage U.S. ocean color sensors. The PACE instrument will provide continuous high-spectral-resolution observations (5 nm) from the UV to NIR (350 – 800 nm), plus several short-wave infrared (SWIR) bands to support cloud and aerosol science and ocean color atmospheric correction. **Image credit**: PACE Science Definition Team Report (*see Footnote 4 for access information)*

characterization of aerosol particles because its spectral range will include short-wave infrared wavelengths—see **Figure 2**. This will enable continuation of MODIS-like and OMI-like characterization of aerosol properties, and MODIS-like measurements of water vapor and retrievals of cloud optical properties. These are the key atmospheric components affecting our ability to predict climate change as they contribute the largest uncertainties in our understanding of climate forcings and cloud feedbacks for an increasingly warmer planet. The interactions between these species are key to such understanding, as aerosols, water vapor, and clouds remain intertwined within the hydrologic cycle because most cloud droplets are seeded by small aerosol particles called cloud condensation nuclei. Changes in the amount, type, and distribution of aerosols, therefore, can alter the micro- and macro-physical characteristics of clouds. Furthermore, natural and anthropogenic changes to the aerosol system may affect clouds and precipitation, which can alter where, when, and how much precipitation may fall.

Possible Enhancements to OCI

A number of possible enhancements to the base PACE mission have been proposed. While all of these enhancements would make the mission more scientifically robust, they come with possible technical tradeoffs: Enhancements might result in delays in launch schedule; decreasing the mission's technology readiness level[7] (which implies more risk of failure); increased payload mass leading to increased power requirements;

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[7] Technology readiness levels are a means to classify how "ready" a given system component or instrument is. For more on how the Earth Science Technology Office defines them in the context of NASA missions, see *esto.nasa.gov/technologists_trl.html.*

changes in data rates, data volume, signal-to-noise ratios, spectral resolution, and/or spatial resolution; higher probability of image artifacts (e.g., striping); and more extensive pre- and post-launch calibration efforts. All of these might have an impact on the cost of the mission.

OCI Upgrades

The possible enhancements to the PACE OCI that are under consideration would push beyond the minimum mission requirements and enable the mission to address some of the more advanced science questions. Possibilities include reducing ground spatial resolution of OCI to 50, 100, or 250 m (~164, 328, or 820 ft, respectively) to enable fine-scale coastal and inland water retrievals; extending the spectral range of the instrument down to 300 nm to better discriminate between color contributions from dissolved organic matter and absorbing aerosols; and, reducing spectral resolution to less than 5 nm and/or enabling spectral subsampling between 1 and 2 nm in particular regions of the spectrum (e.g., over the chlorophyll fluorescence peak to reveal additional information on phytoplankton physiology and health).

Polarimeter Options

PACE may optionally carry a multiangle polarimeter as a secondary instrument, which would add significant capabilities to the atmospheric science components of the mission. While still in the exploratory stages, early results suggest that polarimetry has the potential to make significant contributions to the retrieval of atmospheric characteristics and selection of aerosols as part of ocean-color atmospheric correction.

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With regards to retrieving atmospheric characteristics, a polarimeter allows quantitative retrieval of aerosol scattering optical properties, absorption, size, and particle shape, in addition to the MODIS-OMI heritage of aerosol optical depth, and a less exact measure of size and absorption. For clouds, polarimetry provides a more exact measure of cloud droplet size distributions, including the width of the distribution. Retrievals of cloud top height and ice cloud phase function are also possible with appropriate choices of wavelength bands and angular sampling.

The second area that the addition of a polarimeter would help feeds into the mission's primary objective: ocean color. A PACE polarimeter would provide an unprecedented opportunity to develop novel joint ocean-atmosphere retrievals that may improve upon or enhance traditional ocean color atmospheric correction and provide information on ocean biologic and atmospheric components from a simultaneous inversion. Furthermore, polarimetric measurements of the ocean surface may enable estimation of the angular distribution of the underwater light field, which could additionally shed light on the optical properties of near-surface marine particles.

Several polarimeter options exist as of this writing: no polarimeter; a polarimeter development directed to the NASA/Jet Propulsion Laboratory (JPL); and an open-competed (or contributed) polarimeter, with GSFC excluded. Under these options, the Project is exploring several measurement concepts—temporal modulation, spectral modulation, amplitude splitting, and sequential measurement strategies can all be used to provide imaging of both the total and polarized intensity of light. Assuming that a polarimeter is added to PACE, it will certainly constitute a significant enhancement to the base mission—but it will also increase the technical complexity of the mission.

PACE Mission Organization

Successful implementation of any mission requires close coordination at several organizational levels, and PACE is no different. The main responsibility at the project level is the responsibility of the PACE Project Science Team (listed in sidebar on page 11), with scientific and other responsibilities allocated to the Science Team, the Calibration and Validation Team, and the Science Data Processing Team.

PACE Science Team

The first competed PACE Science Team was awarded and assembled in July 2014[8]. This science team will serve three years and is led by **Emmanuel Boss** [University of Maine—*PACE Science Team Lead*] and **Lorraine Remer** [University of Maryland, Baltimore County—*Deputy PACE Science Team Lead*]. Team members received funding to complete a variety of individual science inquiries. Team members have also been working collaboratively in a variety of subgroups to address the science of IOPs and their retrieval from space and of atmospheric characterization as it pertains to PACE, including ocean color atmospheric correction.

The specific goals of the PACE Science Team are to achieve consensus and develop community-endorsed paths forward for the PACE instrument(s) for the full spectrum of IOP and atmospheric measurements, algorithms and retrievals; and to identify gaps in knowledge, research, and technologies that should be filled (such that they could be addressed in future ROSES calls). PACE Science Team members have been conducting new and novel studies and evaluating previous studies to assess the merits associated with various radiometer and polarimeter features. In addition, the PACE Science Team has provided input on radiometer and polarimeter specifications. For example, the Science Team hosted a series of webinars where community experts described new and available technologies, their attributes, and the science they will facilitate.

PACE Calibration and Validation Team

Under a separate solicitation, three proposals were funded in the same time frame to develop prototype, advanced hyperspectral radiometer systems to perform vicarious calibration for PACE. This post-launch, on-orbit calibration removes any remaining absolute bias in the instrument (and, atmospheric correction algorithm, in the case of ocean color). Vicarious calibration remains a critical component of every ocean color mission as no satellite radiometer system can be sufficiently well characterized on Earth to provide the accuracy required to derive geophysical products from measured radiances once on orbit.

PACE Science Data Processing Team

Building on a legacy of ocean color data processing spanning decades, the Ocean Biology Processing Group within the GSFC Ocean Ecology Laboratory (*oceancolor.gsfc.nasa.gov*) will maintain responsibility for all science data processing of ocean color data products, and their distribution and storage. Similar support for atmospheric science data products from the OCI and potential polarimeter will be determined pending the development of an acquisition strategy for the polarimeter.

Societal Benefits

Science for its own sake is not enough to provide the needed support to perform such activities. Particularly in a resource-limited environment, benefits to society at large—most commonly through applications of the data—must be demonstrated, and PACE will amply address this requirement. Specifically, the advanced capabilities of the PACE OCI over heritage instruments will enable improvement in the following categories of science applications:

*Climate***:** PACE will allow improved mapping, assessment, and understanding of climate-relevant biogeochemical concentrations and fluxes; enhanced climate model skill and forecasting capabilities; improved support for policy analyses and

PACE Project Science Team

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Hal Maring [NASA HQ—*PACE Deputy Program Scientist – Atmospheres*]

Woody Turner [NASA HQ—*PACE Applied Sciences*]

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[8] The team resulted from a NASA Research Announcement (NRA), titled *Research Opportunities in Space and Earth Sciences (ROSES)–2013*, implemented by the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES).

assessments; and refined design of planning adaptation and response approaches to impacts of climate change.

Oceans, coasts, Great Lakes: PACE will support enhanced fisheries and ecosystem management; improved monitoring of water quality, hypoxic conditions, eutrophication, and oil spills/seeps; refined detection of harmful algal blooms (HABs); improved models of abundances of toxic pollutants, pathogens, and bacteria that affect human and ecosystem health; refined monitoring of sea ice extent and passages; and enhanced mapping of ocean currents with relevance to fuel economy strategies for the shipping industry.

Ecological forecasting: PACE will support improved models for forecasting and early warning detection of HABs, identification of endangered species, and assessment of biodiversity; and refined data assimilation into ocean models to improve model skill and forecasting capabilities.

Water resources: PACE will allow improved assessment of water quality and management of water resources in lakes, estuaries, coastal areas, and over the open ocean.

Disasters: PACE will enable refined detection, tracking, and assessment of the effects of hurricanes, oil spills and seeps, volcanic ash plumes, and fires, and improve evaluation of the impact of these disasters on marine and terrestrial ecosystems and human health.

Human health and air quality: PACE will support improved air quality monitoring, forecasting, and management, and refined assessment of climate change impacts on air quality and public health.

With the PACE mission now moving forward, NASA anticipates extending its ocean color data record into a third decade with continuous measurements of biogeochemical and cloud and aerosol properties from specialized space-borne radiometers such as OCI.

Looking Forward

With the PACE mission now moving forward, NASA anticipates extending its ocean color data record into a third decade with continuous measurements of biogeochemical and cloud and aerosol properties from specialized spaceborne radiometers such as OCI. These data records will enable the continued development of CDRs of oceanic and atmospheric properties that will further our scientific understanding of Earth's responses to its changing climate and the subsequent impacts of these responses on living marine resources. Furthermore, the large-scale views of the biosphere and atmosphere that PACE provides will help reveal the roles of the ocean and atmosphere in global biogeochemical cycling and how Earth's changing energy balance both affect and are affected by rising atmospheric CO_2 levels and changing climate. The PACE mission will also complement two additional missions recommended in the 2007 decadal survey,[9] that will support ocean color, land, and cloud and aerosols science: the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission, which will maintain a geostationary orbit that provides continuous views of the Earth's Western Hemisphere, and the Hyperspectral Infrared Imager (HyspIRI) mission, a polar orbiter like PACE, but with very small ground pixel sizes (60 m) and reduced temporal coverage for studying land-ocean ecosystems. For more information about GEO-CAPE and HyspIRI, visit *geo-cape.larc.nasa.gov* and *hyspiri.jpl.nasa.gov*, respectively. ■

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[9] To learn more about NASA's decadal survey, visit *science.nasa.gov/earth-science/decadal-surveys*.