What's behind the curtain of the NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission?

A proposal for an OCB Training Activity

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Summary

We seek to host a one-week graduate-level course on the upcoming NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission and passive satellite remote sensing, with foci on both oceans and atmospheres. Our target audience is Early Career Scientists (specifically graduate students and post-doctoral fellows), with the goal of imprinting this next generation on the mission by offering unique access to all elements of a major NASA flight project. We will construct the class with a combination of lectures and activities that relate to OCB core objectives and host it at the University of Maryland Baltimore County, a minority serving institution in the greater Baltimore area. Students will receive behind the scenes access to all aspects of the mission, including members of PACE with responsibilities for building the instruments and observatory. Qualified individuals from underrepresented groups in STEM will be prioritized to promote the diversity and inclusion aims of OCB and NASA. We are targeting the week of 8-12 August 2022, roughly 30 students, and a budget of $70,000 and will make all course material available for online dissemination at the conclusion of the class.

Background and rationale

In 2015, NASA directed the PACE mission to Goddard Space Flight Center following recommendations from the 2010 NASA document *Responding to the Challenge of Climate and Environmental Change: NASA's plan for Climate-Centric Architecture for Earth Observations and Applications from Space*[1]. This direction ultimately realized the research communities' decade-plus push for a future Earth-observing satellite mission to meet growing needs for scientific discovery. A central objective of PACE is enabling new insights on the sensitivity of global aquatic ecology and biogeochemistry to environmental change. While heritage ocean color missions have provided desperately needed platforms for observing grossly under-sampled ocean ecosystems since 1997, the oceanographic community quickly recognized needs for enhanced satellite measurement capabilities to address the additional issues of changing phytoplankton distributions, ecosystem and habitat health, and carbon fluxes in the global oceans. A second driving objective of PACE is the retrieval of advanced atmospheric data products with the goals of reducing uncertainties in global climate models and improving our interdisciplinary understanding of the ocean-atmosphere system. Despite the substantial achievements of heritage satellite missions, better constraining aerosol and cloud properties and improving our understanding of effective radiative forcing requires significant advances in measurement capabilities. Phrased simply, PACE represents NASA's next great investment in ocean, clouds, and atmospheric data records to enable continued and advanced insight into oceanographic and atmospheric responses to Earth's changing climate.

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[1] https://science.nasa.gov/files/science-pink/s3fs-public/atoms/files/Climate_Architecture_Final.pdf

Today, the PACE mission is part of the Program of Record in the National Academies of Science, Engineering, and Medicine 2018 Decadal Survey *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space*[2]. It supports a three-instrument payload: a global, hyperspectral (ultraviolet-to-shortwave infrared) scanning spectrometer (named OCI) focused on measurements of ocean color (aquatic biogeochemical products, such as phytoplankton community composition, and bio-optical properties) together with aerosols and clouds; and two small multi-angle polarimeters (named HARP2 and SPEXone) for measurements of detailed aerosol and cloud microphysical properties. All instruments are first-of-their-kind and, while they have heritage space-borne pedigrees, they offer highly advanced measurement systems for retrieving ocean-atmosphere properties relative to what's available today and to what is being planned elsewhere at NASA or international space agencies. The scanning spectrometer will enable never-before-seen observations of phytoplankton community dynamics, the polarimeters will provide unique observations of aerosol-cloud interactions (which are tied to the largest uncertainties in climate models), and the combination of the instruments offers a quantum leap forward in global Earth observations, yielding unprecedented insights to further humanity's understanding of our home planet and the climate stressors and ecosystem responses and feedbacks already occurring.

In summary, the PACE mission emerged from a near two-decade-long science community effort aimed at **not only bringing satellite ocean color measurement capability *up to speed* with science capabilities and needs, but also providing data records of the Earth System that the next generation of scientist can *grow into***. And while it encompasses capabilities for both oceans and atmosphere, it also envisions synergistic opportunities between these science communities. The combination of hyperspectral, broad swath radiometric measurements from OCI (ranging from the UV to SWIR), hyperangular measurements from HARP2, and hyperspectral measurements from SPEXone substantially increase science value of the mission beyond what could be available from any one measurement or a single-sensor mission and offer never-before-seen looks at the Earth System. PACE is slated to launch in January 2024 and is currently in its final design and fabrication phase, with system assembly, integration, and testing to begin in fall 2021. Given this relatively late stage in mission development life, **we believe the time is right to engage the next generation of Early Career Scientist in PACE, with the goal of empowering this next generation with detailed expertise in global Earth System passive remote sensing**.

Objectives

Our deliverable will be a one-week graduate-level course in PACE and passive satellite remote sensing, with foci on both oceans and atmospheres. The objective for doing so is simple: host a PACE-specific training course for Early Career Scientists (specifically graduate students and post-doctoral fellows) with the goal of imprinting the next generation of scientist on the mission by offering unique access to all elements of a major NASA flight project. This will encompass not just lectures on Earth science, but also details on instruments' performance and how they relate to derived geophysical products, uncertainties, and ultimately, Earth system models. We will have PACE systems engineering staff involved to provide

[2] https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

insight into details that are often not readily available to the research community (e.g., design choices that impact products, agency hurdles that dictate the mission lifecycle, and rationales for certain instrument concepts). We also plan to offer a software laboratory (e.g., SeaDAS) and, if possible pending center access restrictions, field trips to the PACE Project itself at Goddard Space Flight Center (GSFC).

Expected outputs

Our expected outputs are three-fold, with two tangible and one intangible outcome(s). First, we will conduct a one-week graduate-level course for ~30 students (potentially more if the budget and logistics allow) on PACE and passive remote sensing. Second, we will make all training materials available (as possible pending possible ITAR[3] restrictions) to be publicly posted online at the conclusion of the course (if OCB wishes to collaborate on and host a Web site for the training event). Third, and perhaps most important, we will unleash over two dozen empowered Early Career Scientists with newfound expertise in global Earth System passive remote sensing and novel insight into the PACE mission on the world. While intangible, we believe the latter will not only assist the students with future career endeavors, but also increase the use of data from the highly unique and advanced PACE observatory, which should ultimately improve our scientific understanding of our home planet.

Support for OCB priorities

Our proposed training activity directly address two core objectives of the OCB program:

- *"… explore the ocean's role in the global carbon cycle and the response of marine ecosystems to environmental changes of the past (paleo), present, and future (prediction)*": The primary promise of PACE is an advanced scanning spectrometer to substantially improve capabilities for the remote retrieval of phytoplankton community composition and carbon stocks. Its two multiangle polarimeters will offer additional potential for retrieving microphysical hydrosol properties (e.g., aquatic particle size distributions and refractive indices) as well as offer a remarkable opportunity to better understand the coupled atmosphere-ocean system, which significantly influences the global carbon cycle. In summary, the course content is in direct alignment with this core objective of OCB.
- *"… train the next generation of ocean scientists and engage early career scientists in OCB and partner program meetings and training courses by providing travel and tuition support, networking, and mentoring opportunities"*: The core objective of this proposed class is to train the next generation of Early Career Scientists in passive remote sensing of the Earth System. In addition, the class will offer opportunities for the students to meet, be mentored by and forge relationships with NASA scientists and associated university experts, as well as for students to network amongst themselves. Lessons learned by the proposers, who also participate in the NASA/UMaine Ocean Optics Summer course, indicate that student peer-to-peer networking offers substantial future professional (and social) opportunities. In summary, the course *raison d'être* is in direct alignment with this core objective of OCB.

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[3] International Traffic in Arms Regulations

Participation

Students: We envision accepting applications for roughly 30 student enrollments. As a course tailored for graduate students and post-docs, the class will be held in the summer and we expect to start accepting applications early in 2022. We expect the application package to include: (1) student CV; (2) student personal statement; (3) graduate school transcript; and (4) a letter of support from the student's current advisor. This could include both U.S. and international students. One unfortunate limitation of the latter might be restricted access to GSFC for foreign nationals. To promote the diversity and inclusion aims of OCB and NASA, we will prioritize qualified individuals from underrepresented groups in STEM for acceptance into the course and utilize NASA's MUREP[4] (and similar) mailing lists for recruitment.

Instructors: We envision a dynamic array of participation in this category, inclusive of the mission Project Scientists and their team leads, local experts in Earth System science and radiative transfer theory, instrument providers and their teams, and PACE systems engineers and managers, to name only a few. A tentative skeleton agenda is provided in Appendix A. A list of potential instructors is provided in Appendix B. Note that availability of PACE Project members, particularly systems engineers and managers, will be subject to mission availability at the time of the course. We will construct the agenda to be as flexible as possible to accommodate evolving schedules.

Logistics and budget

We request a $70,000 to host this class at the University of Maryland Baltimore County (UMBC), a minority serving institution in Baltimore, Maryland. UMBC has the facilities and infrastructure to host the training event's classes and laboratories, lodge and house the students, and provide meals. As a bonus, UMBC is also contributing the HARP2 multi-angle polarimeter that will fly on the PACE observatory, which will provide additional insider knowledge on its development and science capabilities. Scoping costs based on current UMBC rates are used here for preliminary budgeting:

UMBC facilities costs	$14,250
Instructor food & catering (~10 revolving people x 5 days x $55/day)	$2,750
Van rentals for field trips	~$2,000
Travel & hotel for 2 non-local instructors	$2,200
Student accommodations (30 students x ~$1,465)	$43,950
Draft total for 30 students and ~10 instructors	$65,150

The per student cost of ~$1,465 breaks down as follows: $390 for 6 days of single room dorm housing, $275 for 5 days of food and catering, $600 for airfare, and $200 for ground transportation. Note that any remaining funds from the requested $70,000K can be used to enlist additional students, support student incidentals or meals during travel days, provide additional local experiences or facilities field trips, recruit

[4] Minority University Research and Education Project; https://www.nasa.gov/stem/murep/home/index.html

additional non-local instructors, and otherwise be used to maximize the student and class experience. Funds are not requested to support local instructors beyond the costs of their meals at UMBC.

If UMBC as hosts cannot be realized, a backup venue will be the Welcome Center at GSFC in Greenbelt, Maryland, which includes classrooms and offers reasonable access to local hotels and restaurants and the DC Metro train and bus system. We plan to tentatively host this class from 8-12 August 2022, subject of course to current COVID-19 safety guidelines and related UMBC/GSFC procedures. Given student schedules, the class could likely proceed one week later, but would otherwise need to slip to a winter/semester break timeframe, e.g., January 2023, to ensure desired attendance.

Appendix A: Skeleton list of class topics and activities

We will develop an agenda that provides lectures, labs, field trips, and special events. The following provides a conceptual list of lectures, course content, and activities to be offered.

<u>Topics</u>

History of ocean color / atmospheric observations from satellites
How does it work? Spectroscopy
How does it work? Radiative transfer through the atmosphere and ocean
How does it work? Polarimetry
PACE ocean color science (biogeochemical and bio-optical retrievals)
PACE atmospheric science (aerosols and clouds retrievals)
PACE modeling and applications
Using PACE in a consumer's market
OCI behind the scenes

- Why doesn't every satellite measure hyperspectral radiances at 1 m^2?
- Design choices and trade spaces
- Relating requirements to engineering reality
- How does it work?

HARP2 behind the scenes
SPEXone behind the scenes
Flight projects behind the scenes
How to take an idea to orbit
Using PACE data

- netCDF, metadata, data processing levels, standard products, and you
- Learning from simulated data
- SeaDAS (and equivalent) lab

Validating ocean and atmospheric data products
Uncertainties for performance assessments

<u>Activities</u>

General tour of GSFC

General tour of UMBC instrument development facilities
Behind the scenes tour of the PACE Project
National Air and Space Museum
Fireside chat: career paths in Earth science (gov't vs academics vs non-profit vs …)
Fireside chat: communicating Earth science (hosted by NASA Earth communication team member)
Fireside chat: navigating NASA funding (hosted by NASA Program Manager if available)
Shark tank exercise: student groups brainstorm a mission and pitch it
Local Maryland dinner (if budget allows for it)

Appendix B. Potential list of instructors / lecturers

Lecturers will ultimately be defined as the agenda is crafted. The following provides a list of potential participants with a focus on those available from the PACE mission. Those marked with an asterisk (*) will participate in all/most aspects of the course and work with OCB on its organization and execution.

* Brian Cairns (GISS; PACE Deputy Project Scientist – Atmospheres)
* Ivona Cetinić (GSFC; PACE Project Science Lead for Biogeochemistry)
Gary Davis (GSFC; PACE Mission Systems Engineer)
André Dress (GSFC; PACE Project Manager)
Ulrik Gliese (GSFC; OCI Instrument Science and Technology Manager)
Eric Gorman (GSFC; OCI Instrument Systems Engineer)
Kirk Knobelspiesse (GSFC; PACE Project Science Lead for Polarimetry)
Corina Koca (GSFC; OCI Deputy Project Manager)
Noosha Haghani (GSFC; PACE Deputy Mission Systems Engineer)
Otto Hasekamp (SRON; SPEXone Project Scientist)
Amir Ibrahim (GSFC; PACE Project Science Lead for Atmospheric Correction)
Laura Lorenzoni (NASA HQ; PACE Program Scientist)
* Antonio Mannino (GSFC; PACE Deputy Project Scientist – Oceans)
* Vanderlei Martins (UMBC; HARP2 Project Scientist)
Lachlan McKinna (Go2Q; PACE Project Science Lead for Bio-optics)
Gerhard Meister (GSFC; OCI Instrument Scientist)
Veronica Pinnick (GSFC; PACE Integration and Testing Manager)
* Lorraine Remer (UMBC; HARP2 Project Manager, Science & Applications Team Deputy Lead)
Andrew Sayer (GSFC; PACE Project Science Lead for OCI Atmospheres)
Beth Weinstein (GSFC; PACE Observatory Manager)
* Jeremy Werdell (GSFC; PACE Project Scientist)
* Pengwang Zhai (UMBC; Science & Applications Team Project lead)

Plus, PACE Element Design Leads, GSFC/UMBC Earth Scientists, and other special guests.