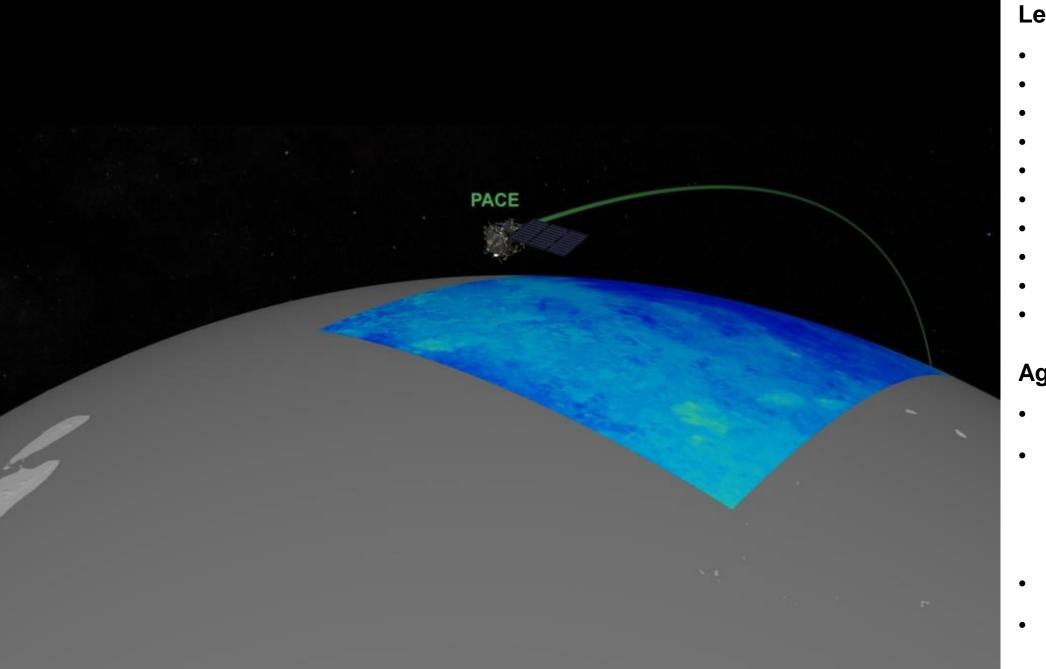
PACE update – IOCS & OCRT 8 April 2019, Busan, South Korea,

Jeremy Werdell, Paula Bontempi NASA GSFC, NASA HQ

Plankton, Aerosol, Cloud, ocean Ecosystem



Legacies:

- CZCS
- SeaWiFS
- POLDER
- MODIS
- MISR
- MERIS
- VIIRS
- OLCI
- SGLI
- others

Agenda:

- mission update
- programmatic update, cal/val, & future community opportunities
- instrument updates
- Q&A

Mission update

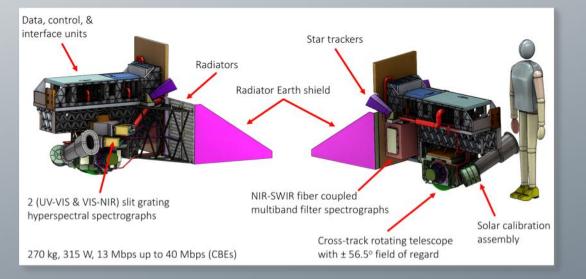
Cost, Schedule, Lifespan

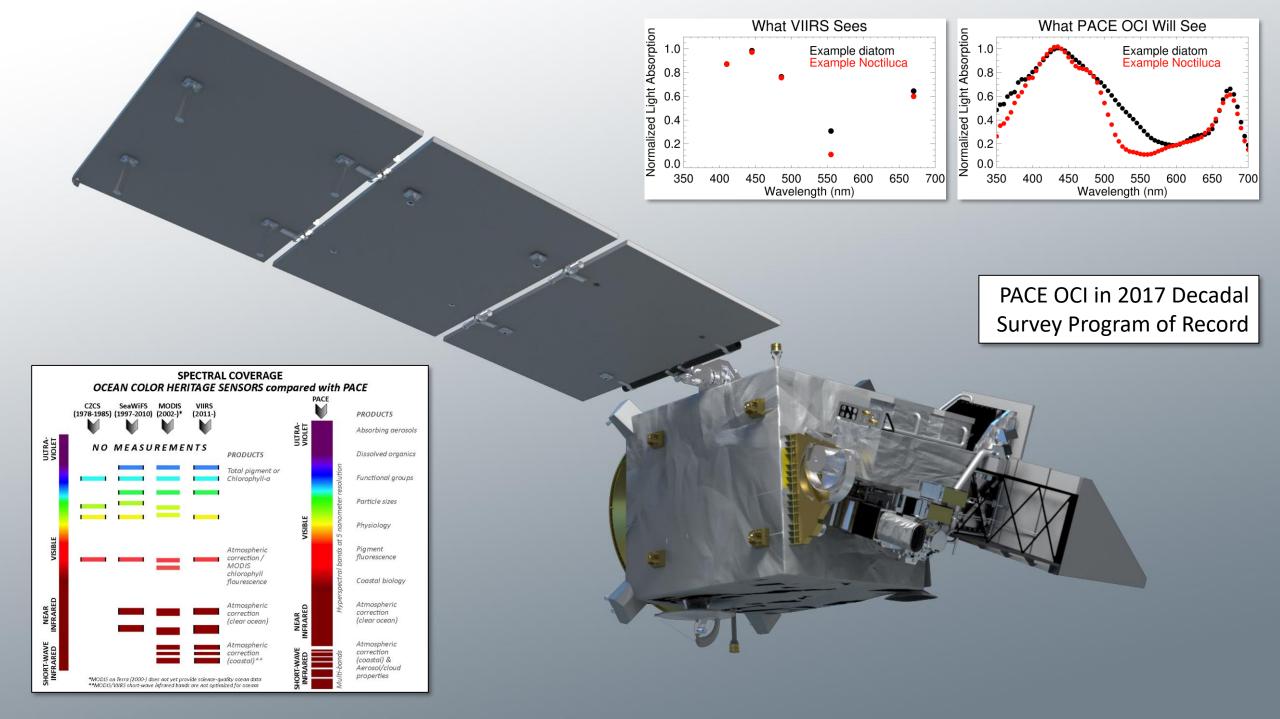
- \$805M Design-to-Cost
- Category 2, Class C
- ~Dec 2022 launch
- 3-year design life
- 10-years of propellant

Orbit

- 675.5 km altitude
- Polar, ascending orbit
- Sun synchronous
- 98° inclination
- 13:00 local Equatorial crossing

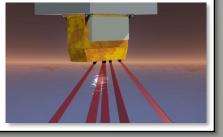
- 340 890 nm at 5 nm resolution
- Plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- 1 2 day global coverage
- Ground pixel size of 1 km² at nadir
- ± 20° fore/aft tilt to avoid Sun glint
- Twice monthly lunar calibration
- Daily on-board solar calibration
- Performance that meets or exceeds heritage
- Built at NASA Goddard Space Flight Center





UMBC Hyper Angular Rainbow Polarimeter (HARP-2) HARP Imaging Polarimeter • 6 inches long • 1.7 Kg

SRON Spectropolarimeter for Planetary Exploration (SPEXone)



PACE polarimeters *NOT* in 2017 Decadal Survey Program of Record

	HARP-2	SPEXone
UV-NIR range	440, 550, 670, 870 nm	Continuous from 385-770 nm in 5 nm steps
SWIR range	None	None
Polarized bands	All	Continuous from 385-770 nm in 15-45 nm steps
Number of viewing angles [degrees]	10 for 440, 550, 870 nm; 60 for 670 nm [spaced over 114°]	5 [-57°, -20°, 0°, 20°, 57°]
Swath width	±47º [1556 km at nadir]	±4.5° [106 km at nadir]
Global coverage	2 days	30+ days
Ground pixel	3 km	2.5 km
Heritage	AirHARP, Cubesat	AirSPEX

Looking forward: the mission's coming year(s)

Phase B – preliminary design & technology completion (mission PDR in Jun 2019) Phase C – final design & fabrication (Aug 2019)

- All mission elements must pass Critical Design Reviews (CDR) (~Dec 2019)
- Preceded by series of sub-element Engineering Peer Reviews (EPRs)
- Project & HQ Science + OBPG Science Data Processing:
 - respond to element issues (study, charge/retreat, provide therapy)
 - implement science capabilities (plans for cal, val, algs, processing, documentation, etc.)
 - Interact with newly formed Science Teams

Phase D – system assembly, integration & testing, & launch (~Sep 2021)

Phase E – science operations (~Dec 2022)

C	Y16	CY17	CY18	CY	19	CY20	CY2	21	CY22		CY23	CY24	CY25		CY26
	Phase	A	Phase B		Phase C F		Pl	nase D	Phase E		Phase F		iase F		
							_		4	-					

Programmatic update & future science teams

Looking forward: noteworthy mentions

Budget Status: FY20 and beyond (as of early Mar 2019)

- The Budget requests a total of \$21 billion for NASA, \$1.7798 billion for Earth Science
- FY20 President's Budget maintains the Administration's previous termination of two Earth Science missions—PACE and CLARREO Pathfinder—lower priority science. Terminates NASA's Office of STEM Engagement.

2017-2027 Decadal Survey for Earth Science and Applications from Space

- Free download: http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm
- Program of Record "The series of existing or previously planned observations, which should be completed as planned. Execution of the ESAS 2017 recommendation requires that the total cost to NASA of the Program of Record flight missions from FY18-FY27 be capped at \$3.6B."

Looking Forward: PACE Science Team pre- & post-launch schedule

Pre-launch Science Teams

- FY15 17: ROSES 2013 A.25
 - Pursued consensus and community-endorsed paths forward for IOPs & atmospheric correction
 - Final reports are being submitted and will be compiled into a NASA Technical Memo.

• FY20 – 22: ROSES 2019 A.38 (3 years)

- Allow lead time for pre-launch scientific algorithm & applications development prior to launch
- Initiates interface between algorithm developers and OBPG/OB.DAAC
- FY23 25: ROSES 2022 [TBD] (~3 years)
 - At-launch algorithms and post-launch competed science/applications for OCI's aerosol, cloud, & ocean science, plus aerosol & clouds (& oceans?) from SPEXone & HARP-2

Post-launch competed sciences teams (TBD)

- Most likely competed through ROSES 2025
- To continue during mission extension(s)

Looking forward: vicarious calibration

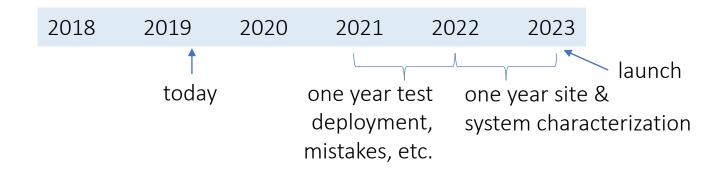
ROSES 2014 A.3 OBB (FY15-17) - written and competed before PACE was a real mission

- Issued under OBB, managed jointly between OBB and ESTO
- Allowed lead time for concepts to mature prior to launch & Identified technical development needs/risks for the approaches selected
- Three projects funded that have completed analysis and tests of hardware

ROSES 2018 A.49 (amendment 22 Feb 2019)

- Select best approach and hardware for further risk reduction on instrumentation for OCI ocean color vicarious calibration
- Two selections with a down-select after 12 months
- 4 year horizon
- NOIs were due 26 March, proposal 23 May
- Completely open competition (US-based PI's); international collaborators welcome

options: systems in development, expected external assets (BOUSSOLE, MOBY), FRM4SOC (Copernicus/EUM), other *in situ* sources, models



Looking forward: a validation program

FY22 – FY25 (TBD): ROSES 2021 & FY26 – FY28 (TBD): ROSES 2025

- Perform validation experiments during mission ops for all data products (aerosol, cloud, ocean color), including validation of polarimetry data products as possible
- Include airborne (as possible) and *in situ* measurements

International community (e.g., ESA, EUMETSAT, and the Copernicus Program) are investing in Fiducial Reference Measurements for Sentinel and **coordination is critical**



Level 1 required (~threshold) products

Water-leaving reflectance	Aerosol optical thickness
Chlorophyll-a	Aerosol fine mode fraction
Phytoplankton absorption	Liquid / ice cloud optical thickness
NAP+CDOM absorption	Liquid / ice cloud effective radius
Particulate backscattering	Cloud layer detection ($ au$ < 0.3)
Diffuse attenuation	Cloud top pressure (τ > 3)
Fluorescence line height	Shortwave radiation effect

Uncertainty requirements accompany all L1 req'd data products (i.e., we need quantitative validation of all of these products)

PACE will provide insight into systems that affect our everyday lives

With advanced global remote sensing capabilities, PACE will provide a combination of **atmosphere and ocean observation** to benefit society in the areas of water resources, disaster impacts, ecological forecasting, human health, and air quality.

Users at local, state, federal and international agencies as well as the general public will be able to apply data from PACE to make more informed and robust decisions about their activities.

Applications Community Building Activities

Mission Applications Plan

ce Flight Center



Describes the elements of the applications program for the project, its management, and deliverables from all Phases of the mission

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 written papers developed and posted to the website. Applications Traceability Matrices developed and posted to the website. Applications Twinking Group established.
Phase B	Workshop conducted with targeted science communities to communicate key model, observation and Applied Sciences opportunities and requirements. Newsletters, articles, posters, and other communications developed to expand the community of potential. Early Adocters Program estabilished.
Phase C/D	Annual workshop focused on results from Early Adopters. Description of validation datasets to the community of practice. Conference presentations and papers; newsitetters and journal articles on user interaction to expand the community of potential. Data workshops, short courses, focus sessions, tutorials. Interaction with NASA HO Applied Sciences to provere funding opportunities.
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 Banefit Value Assessment. Information for Senior Review Sumissions.

Applications Traceability Matrix

developed with input from the user community

'	Application Concept	Regul	Measurement	Applied Sciences Category	Potential Host Agency	Product	Projected Missi Performance		Anoillary Measurements		
5 8 2 8 4 5 8 4	The Environmental Protection Agency produces a daily air quality index which comprises both the occure and particulate matter concentrations. In regions where there are no direct measurements of PM, satellite even the second accurate the second second second second accurate the second	Observations of in resolutions of less latencies of less	ACD at spatial othern film and than 6 hours	Public Health and Air Quality	Environmental Protection Agency (James Szyliman - EPA)	Aerorol Optical Depth	ADD within ± 0.02 a horizontal resolutio 11m	eta naf 3 :	Associverical distributions Surface PM concentrations at a few locations		
itho ng n yasa in	measurements of ACE conclusionation Can ve quartifying concernation using measurements collected to import PACE amonghetic corrections in coastallargoals." Can ve provide useful data to enable prodent aviation velocianic anhibitated intigation poloy and advisories?	Observations of a resolutions of less latencies of less	s than 1 km and	Disaster Misgarion Health and Ar Quality	Federal Aviation Administration (FAA), US EPA, NOAA, International Civil Aviation Diganization, Volcanic Ash Advisory Centers (Shokhia Kondragueta- NOAA)	Depth	ADD within ± 0.02 a holizontal resolutio Tilen		Aerosol vertical dombusions Sultur dioxide concentrations		
	The EPR Sole and Source-able Value - Observation- and a developing user existing and - Space - Developing and - Space - Developing and - Space - Developing and		Can be used to estimate PM. Account of the end of CC. Account of particular matter, satellite measurements of ACD and the satellite measurements o						E measurements of the ts of PM? t: Projected Mission Performen ACD within +/-0.02 at a hore of 1 km	cec ontal resolut Surface PM	
ges d ing.	Assimilation System / Coupled Forecast System ICF31, Real-Time Ocean Forecast System, RTOF51 for improving model skills and forecasting capabilities.	Latency: 121	Potential Host What is th quality as	Agency: EPA (James) ne volcanic ash a result of a vi	concentration olcanic materia	during and al deposited	in coastal/p	populated regio			
	NDAA's subsurface of monitoring program uses various modeling and observational approaches (above, thipbone, ground-based, gause- based measurement) to track of split where the of is going on the surface of under the sea, and what the consequences are to coastal communities, wildle and the matter	Vinblehuero Spatial < 16 Temposat 11 Coverage: o (<100 nmit S Uncertainty: Latency: 0.5	coastal regis associated v prudent ash Application Re Applied Science Potential Host	Measurements collected is support PACE atmospheric connections in costal regions may be used to quarkit the concentration of material associated with valcance entrations. These data may be useful in establication pulcets ash-related aviation haardt mitigation policies and advicories. Applications Institutes Land. Applications Institutes Land. Applications Control (Sandar March 1996). Patient Rev Applications (March 1996). Reveal the Applications (March 1996).					 Projected Milssion Performans AGD within +/- 0.02 at a horize resolution of 1 km Andilary Measurements: Aerosol vertical distributions, Suffar disxide concentrations 	AGD within +/- 0.02 at a horizontal resolution of 1 km Andilary Measurements: Among vertical distributions.	
	enstenment (s.g. Despusse Horizont®P 0.15g4)		water qua The EPA Saf at developin sustainabilit range of spa Integration modeling to and integrit Application Re Application Re	ality, ond ecosy e and Sustainable ag core indicators y as well as indica- tial and temporal of satellite observ rols is needed to d y of water resource rediress Level: 3	Istem dynamic Water Resources of water resource itors of key drivers i scales for use in i attions with field n fernonstrate asses res.	s in coastal Research Pro Integrity and and pressure negrated ass neasurements isment of sust	waters? gram alms of constants is across a signature of constants and signature of constants ainability of constants ainability of constants	arbon and nutri fission Data Product hi-o. K., CODM, DOI patial resolution: stuaries 250 m oastal and Continem- helf Waters: s1 km owrage: finimum distance: 2 datencies: 0.5-32 hou	 Projected Mission Performan- POC 2-day global coverage at 3-km resolution, hyperpectral radii the utraviole (350 nm) to NR data, 6-32 Nour data latency. Aerosolo (e.g., spectral shape, aerosolo (e.g., spectral shape, atomotypenc correction amonghenic correction 	ometry from I (885 nm) w neter resolut particle size	
			PACE satelli assimilated As a result, capabilities Forecast Sys (RTOFS). Application Re Applied Science	natural and an te derived optics a into operationals NACE data may im of the Global Oce atem (GODAS/CFS edimess Levels 3 es Generaly Ecologic	thropogenic fo and biogeochemic easonal-to-interan prove model skills an Data Assimilati and Real-Time O	rrcing, inclu cal variables m nnual comput s and forecast ion System / C locan Forecast	ding local to ray be M er models. Or ing Sp oupled Te System Co	ns changing, an regional impac Ission Data Product I-a, K _{ind} K _{ell} antial resolution: 1 k imporal resolution: 1 prenge: Global tencies: 12 hours	2-day global coverage at 1-km : resolution, hyperspectral radio the ultraviolet (350 nm) to NIR	metry from t (BBS nm) wi eter resoluti	
			NOAA's sub observation space-based the surface disasters to (e.g., Deepw Application Ra Appled Scient	surface oil monito al approaches (air i measurements) and under the sea local communities rater Horizon/BP (soffness Levet: 3 ses Category: Oxoster		s various mod , ground-base where the oil acts of major of marine enviro	eling and M d, Vis is going on Sp all spill onment So 10	ission Data Product: able/true color imag natial resolution: <1 iverage: astal waters: <185 k stal waters: <185 k N - 10N 6 W - 60W tencies: <6 hours	pery 2-day global coverage at 1-km in resolution, hyperspectral radius km the ultraviolet (350 mm) to NIR	patial metry from t (885 nm) wit eter resoluti sarticle size	
			ARL 3: Proof o	Application Conc	ept (Viability Establ	lished) - Feasb	lity studies to as	sess the potential vi	ability of and provide a proof-of-co	incept for t	

PACE Community Survey

PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) Mission User Survey 💦

What is this survey

This survey is designed to characterize the NASA PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission user community in terms of its composition, activities, remote sensing needs, and research interests. We will use this to plan outreach and applications before PACE launches in order to tailor them to <u>your</u> needs as part of the future PACE user community.

ny are we asking you to complete this questionnaire?

s a professional in the field, you have been identified as someone with insight into how PACE ata can be used and applied. We are interested in how you plan to use PACE data in your vork. Your answers will help NASA anticipate the scope of PACE science and applications as rell as the socioeconomic impact of future PACE products.

If you would like further information about this questionnaire, please contact Maria Tzort; by e-mail at maria.a.tzortziou@nasa.gov, or Ali Omar at ali.h.omar@nasa.gov.

2. INSTRUCTIO

- For open-ended questions, please constrain your thoughts to 1000 characters.
 Unless otherwise indicated, make only one choice per multiple-choice item. Please
- choose the answer that most closely matches your situation. • The response "NA" means "not applicable" or "not appropriate." Please choose this response only in cases where you feel that the subject matter of the question is
- unrelated to your work. Some questions do not have a "not applicable" alternative.
 When you provide an 'other' answer, we will categorize this answer in the analysis of the result.
- Thank you for your time and attention in helping NASA improve how we engage with the mission user community!

Applications White Papers



PACE Mission Applications - Contact Us: Maria Tzortziou maria.a.tzortziou@nasa.gov Ali Omar Woody Turner woody.turner@nasa.gov 212-650-5769 Maria Tzortziou Ali Omar Woody Turner woody.turner@nasa.gov 212-650-5769 Maria Tzortziou Maria Tzortziou Ali Omar Yoody Turner Woody.turner@nasa.gov 202-358-1662



Instrument updates

Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) Instruments

(Primary) Ocean Color Instrument (OCI)

Wide swath, UV-VIS imaging spectrometer with SWIR channels designed for ocean color applications, useful for aerosols and clouds

- Preliminary design review (PDR): Mar 2018
- Critical design review (CDR): Dec 2019

Hyper Angular Rainbow Polarimeter 2 (HARP2)

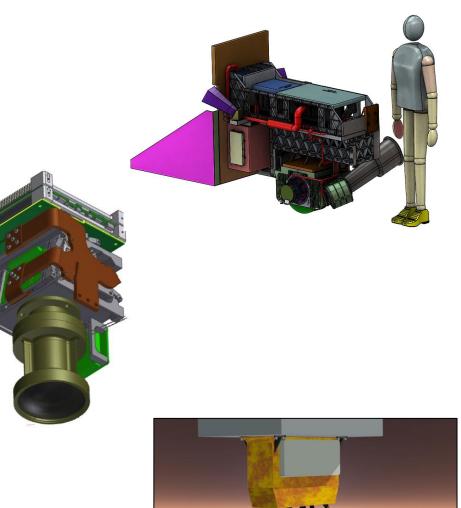
wide-swath multi-angle polarimeter, hyper-angle capability

- PDR: Aug 2018
- CDR: Apr 2019

Spectro-Polarimeter for Planetary Exploration (SPEXone)

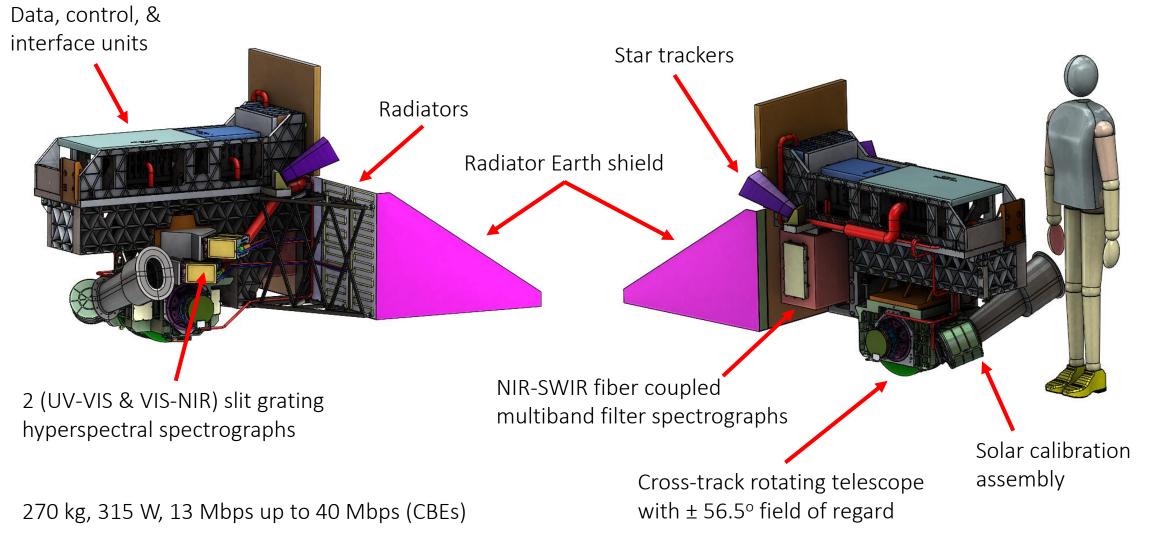
narrow-swath multi-angle polarimetric spectrometer

- PDR: Jul 2018
- CDR: Feb 2019



Ocean Color Instrument – physical assembly

Scanning concept follows SeaWiFS and VIIRS heritage



OCI is tilted by ±20° to avoid sun glint

SPEXone and HARP-2 are 'contributed' instruments

Requirements derive from **do no harm** philosophy alone

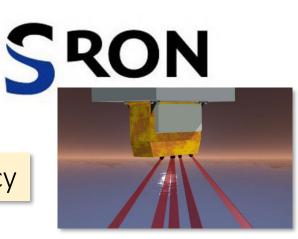
No requirements for successful data collection or science

Both originally designed as cubesat scale instruments

And, they will provide an excellent proof of concept for atmospheric correction, aerosol, & cloud retrievals

Polarimetry on PACE Two cubesat-sized *contributed* instruments

Spectro-Polarimeter for Planetary Exploration (SPEXone)Contribution from the Netherlands (SRON, NSO, Airbus; TNO optics)POC: Otto HasekampHyperspectral (UV) + narrow swath + high accuracy





Hyper Angular Rainbow Polarimeter (HARP-2)

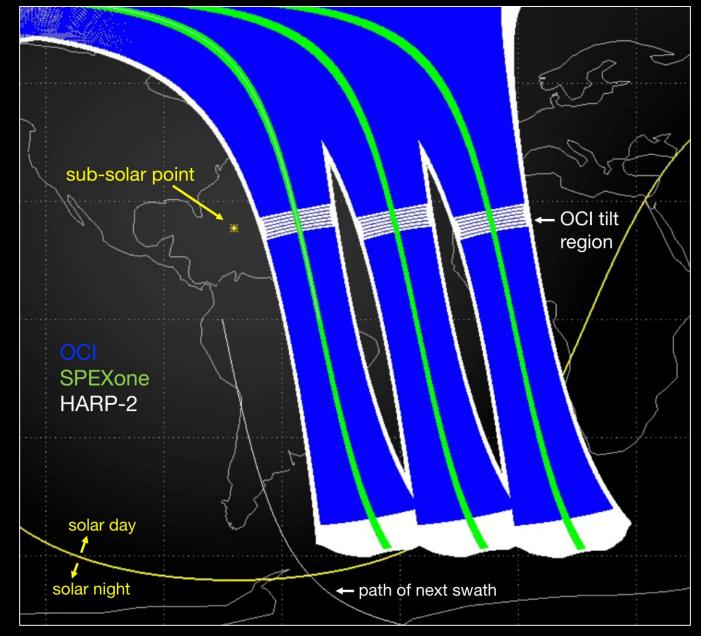
Contribution from University of Maryland Baltimore County

POC: Vanderlei Martins

Hyperangular + wide swath

	SPEXone	HARP-2
Spectral range (resolution)	385-770 nm (continuous @ 5 nm)	440, 550, 670 nm (10) + 870 nm (40 nm)
Polarized bands	385-770 nm (continuous @ 15-45 nm)	All
Polarimetric accuracy (DoLP)	0.002	< 0.01
# viewing angles	5 (-57°, -20°, 0°, 20°, 57°)	10 for 440, 550, 870 nm + 60 for 670 nm (114°)
Swath width	9° (106 km at nadir); 30+ day global cov.	94º (1556 km at nadir); 2 day global coverage
Ground sample distance	2.5 km ²	3.0 km ²
Heritage	AirSPEX, SPEX/ASPIM	AirHARP, cubesat HARP for ISS

Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) Instruments



Learn more about PACE



PACE's advanced technologies will provide upprecedented insight into Earth's ocean and atmosphere, which impact our everyday lives by regulating climate and making our planet habitable. Our oceans teem with Mice, upporting many of Earth's execonomies. Yeve discoveries in Earth's living ocean will be revealed with Mice, global observations, such as the diversity of organisms funding marine food webs and how eosystems respond to environmental change. RECK will observe our atmosphere to study clouds along with the truy althorne particles known as aerosoli. Looking at the ocean, clouds, and aerosols together will improve our howeking of the roles explays in our change planet.

PACE's data will reveal Interactions between the ocean and atmosphere, including how they sechange carbon dioxide and how atmospheric areasois might fuel physiciation growth the two face ocean Nevel uses of PACE data – from lisentRying the extent and duration of harmful algal blooms to improving our understanding of an quality – will result in direct economic and societab lenetRy. By extending and expanding NASA's long record of satellite observations of our living planet, we will take Earth's pube in new wave for decates to come.



PACE will show all chlorophyll is not created equa

Why Do We Need PACE?

ology Aerosols & Clouds Carbon Applied Sciences Economy & Society Science Questions

Our occan has teem, with life and many of its most vial appears are invisible to us. Like on hand, the occan has deterts, forestar, meadows, and jungies, providing habitats for many form of Ifs. The tops of life in these habitats is determined by microscopic alges that float in our occase. Known as "physophiathsat", these thys oparations come in many different habes, sizes, and colors. The diversity of physophiathsat hypes determines the roles they pay in occan habitats. It als determines how well they capture energy from the suar and cohors from the tamosphere.



National Aeronautics and Space Administration

Goddard Space Flight Center Greenbelt, Maryland 20771

NASA/TM-2018-219027/ Vol. 3



PACE Technical Report Series, Volume 3

Ivona Cetinić, Charles R. McClain, and P. Jeremy Werdell, Editors

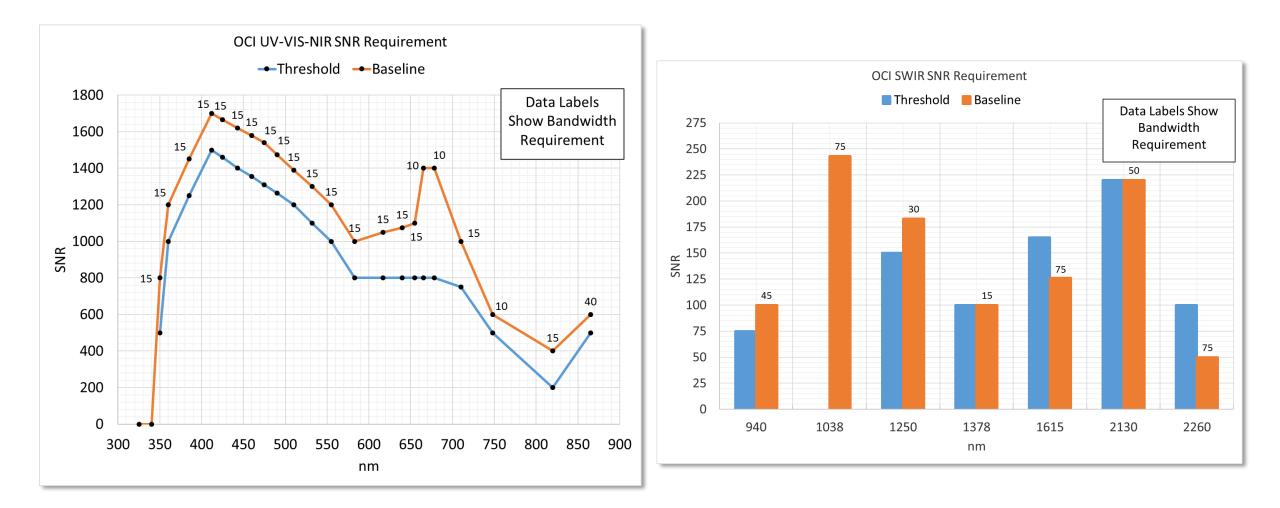
Polarimetry in the PACE Mission: Science Team Consensus Document

PACE Science team

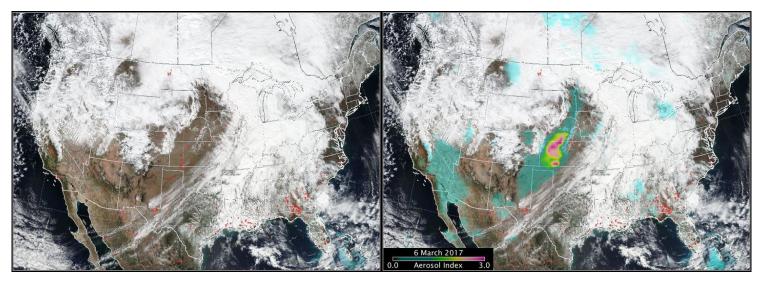
https://pace.gsfc.nasa.gov @NASAOcean (Twitter) @NASAOcean (Facebook) Technical Memo. series

backup

Ocean Color Instrument (OCI) – signal-to-noise (SNR)



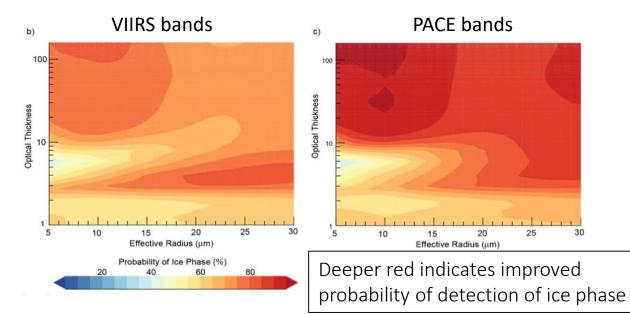
OCI atmospheric improvements over heritage



1 km resolution at nadir from UV to SWIR

UV + oxygen-A and B-bands provide opportunities for aerosol algorithms beyond heritage

VIIRS RGB + OMPS Aerosol Index



Two 2- μ m bands (VIIRS + MODIS) improve retrievals of cloud thermodynamic phase

@AGUPUBLICATIONS



Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE 10.1002/2017JD026493 Characterizing the information content of cloud thermodynamic phase retrievals from the notional PACE OCI shortwave reflectance measurements

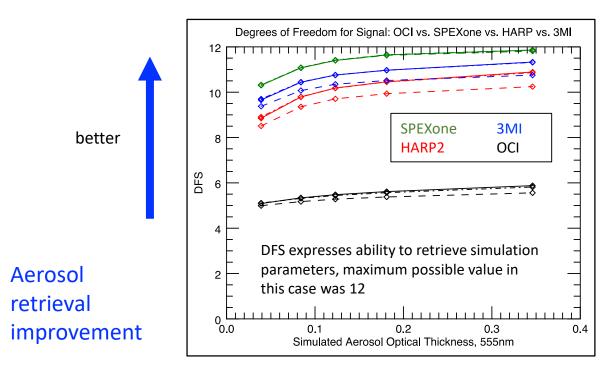
O. M. Coddington¹ (0), T. Vukicevic², K. S. Schmidt^{1,3} (0), and S. Platnick⁴ (0)

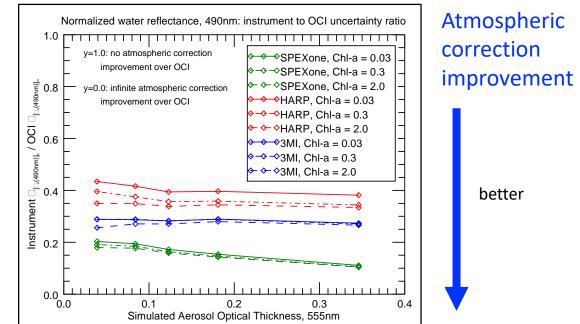
How will PACE polarimeters perform?

Radiative transfer simulations + information content analysis (Knobelspiesse et al. 2012)

Right – atmospheric correction improvement: ratio of SPEXone/HARP2 water leaving reflectance uncertainty to OCI uncertainty. EUMETSAT 3MI for reference.

Below – aerosol retrieval improvement: degrees of freedom for signal for a simultaneous aerosol & ocean retrieval





Both offer dramatic improvement, comparable to 3MI

Other characteristics must also be considered, e.g.

considerable swath width difference (SPEXone: 9°, HARP2: 94°).

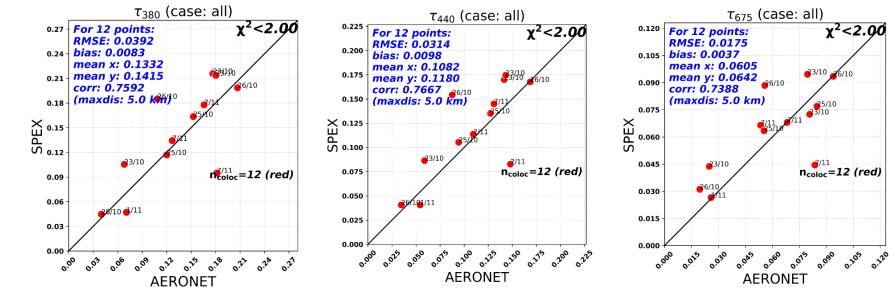
Cloud property retrieval

Hyperangular capability of HARP2 can be used to retrieve droplet size distributions and to characterize ice particle roughness and aspect ratio, which reduces the uncertainty in ice particle size retrievals from OCI.

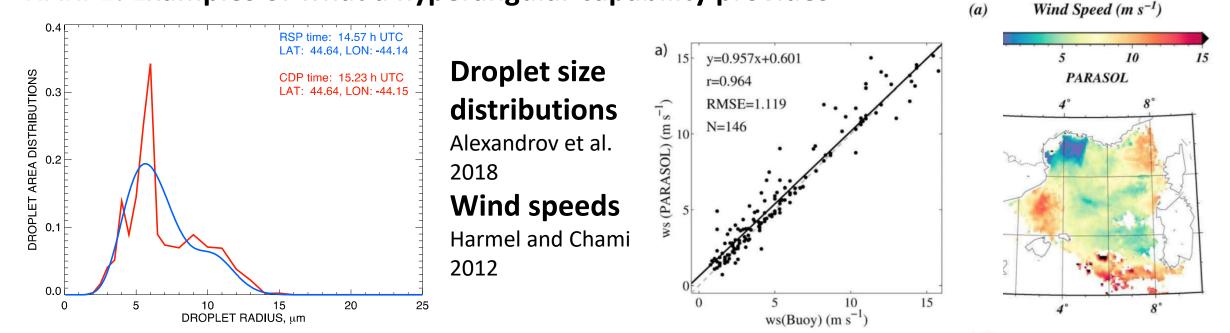
Operational algorithms must be created to exploit this information.

How will PACE polarimeters perform?

SPEXone: Example aerosol retrievals from SPEXAirborne during ACEPOL Hasekamp et al. AGU 2018



HARP2: Examples of what a hyperangular capability provides



How will PACE polarimeters perform?

0.3

0.2

0.1

-0.1

0.3

0.2

0.

0.0

-0

0

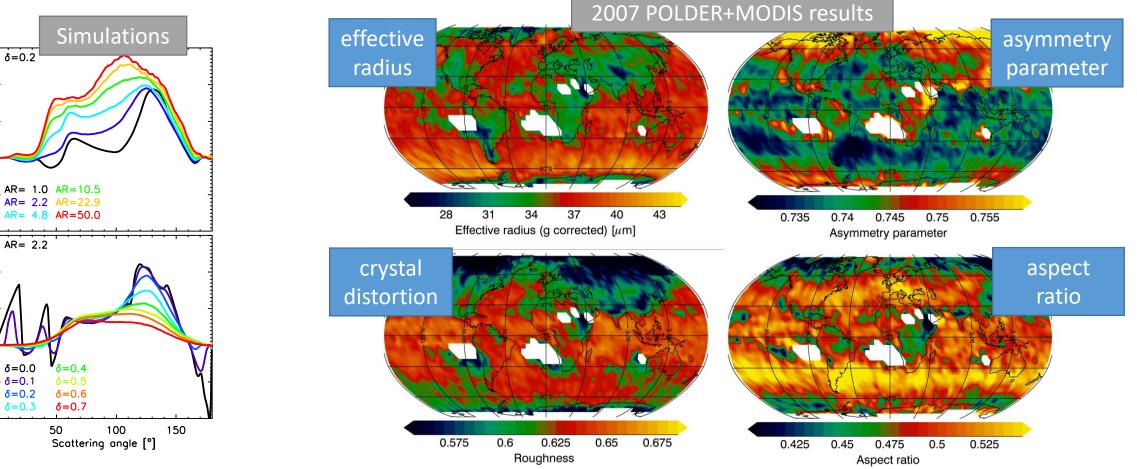
Degree of linear polarization

Degree of linear polarization

 $\delta = 0.2$

SPEXone + HARP2 + OCI: Polarimetric observations compliment OCI ice cloud retrievals

- Polarimetry allows retrieval of ice crystal aspect ratio and crystal distortion, which are fundamental • properties determining the scattering asymmetry parameter
- Retrieving asymmetry parameter avoids the need to assume an ice optical model for optical • thickness and effective radius retrievals from VIS/SWIR bands



van Diedenhoven et al

(AMT 2012, JGR 2014)