

The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission:

Ushering in an era of daily, global hyperspectral
satellite radiometry and polarimetry



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Living Planet Symposium, 23-27 May 2022



PACE will support studies of:

- ocean biology, ecology, & biogeochemistry
- atmospheric aerosols
- clouds
- land

Primary hyperspectral radiometer:

- Ocean Color Instrument (OCI) (GSFC)

2 contributed multi-angle polarimeters:

- HARP2 (UMBC)
- SPEXone (SRON/Airbus)

History:

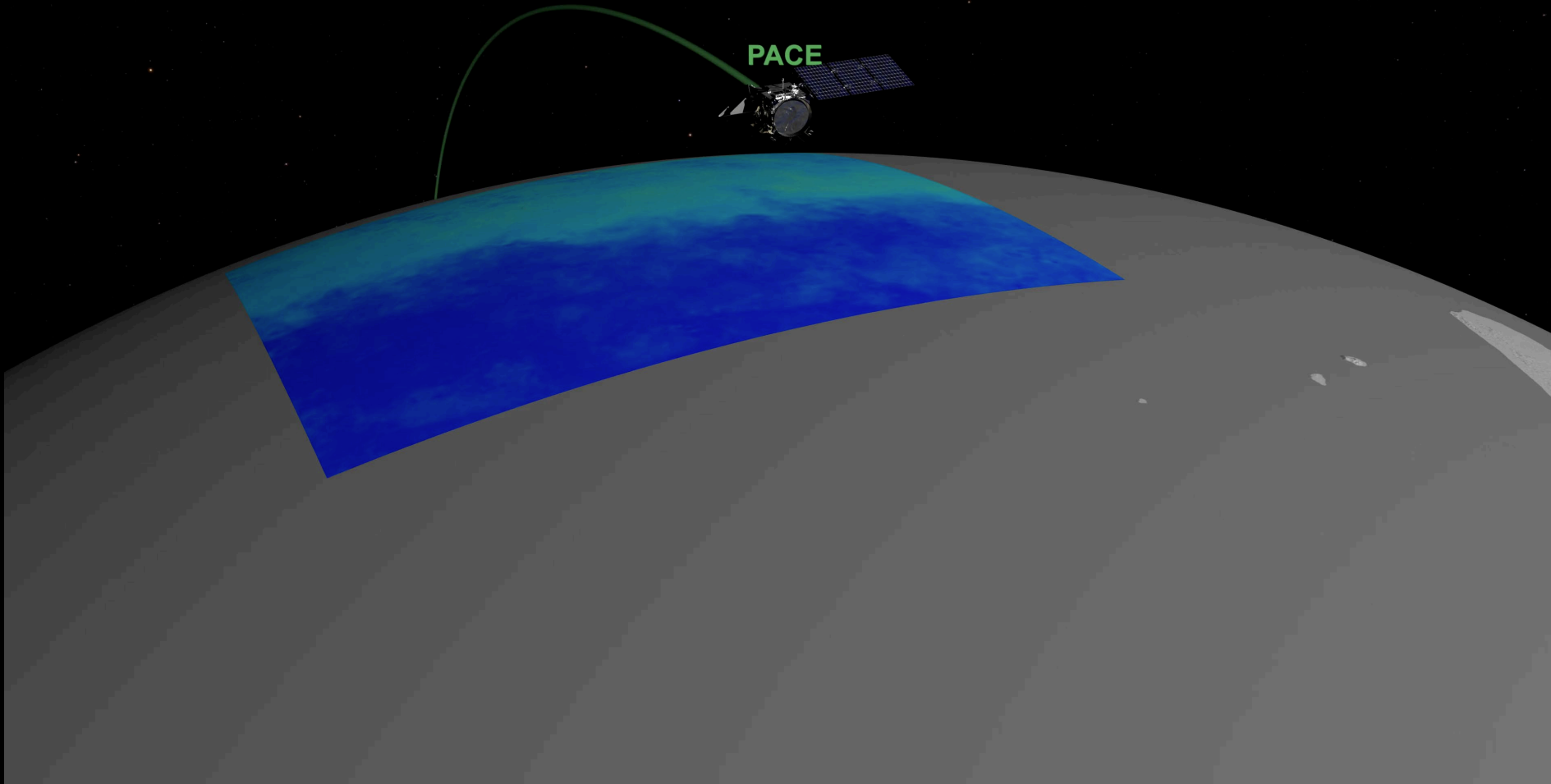
- 2003-ish preliminary concept studies
- 2011 NASA Climate Change Initiative
- 2012 Science Definition Team
- 2014 first PACE science team
- 2015 mission directed to GSFC

Legacies:

- SeaWiFS, MODIS, VIIRS
- POLDER, MISR

Key characteristics:

- January 2024 launch
- Falcon 9 from KSC/Cape Canaveral, Florida
- 676.5 km altitude
- polar, ascending, Sun synchronous orbit; 98° inclination
- 13:00 local Equatorial crossing
- 6-9 hour average data latency (24 hr max.)



Extend key systematic ocean biological, ecological, & biogeochemical essential climate variables records, as well as cloud & aerosol essential climate variables

Make new global measurements of ocean color that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate

Collect global observations of aerosol & cloud properties, focusing on reducing the largest uncertainties in climate & radiative forcing models of the Earth system

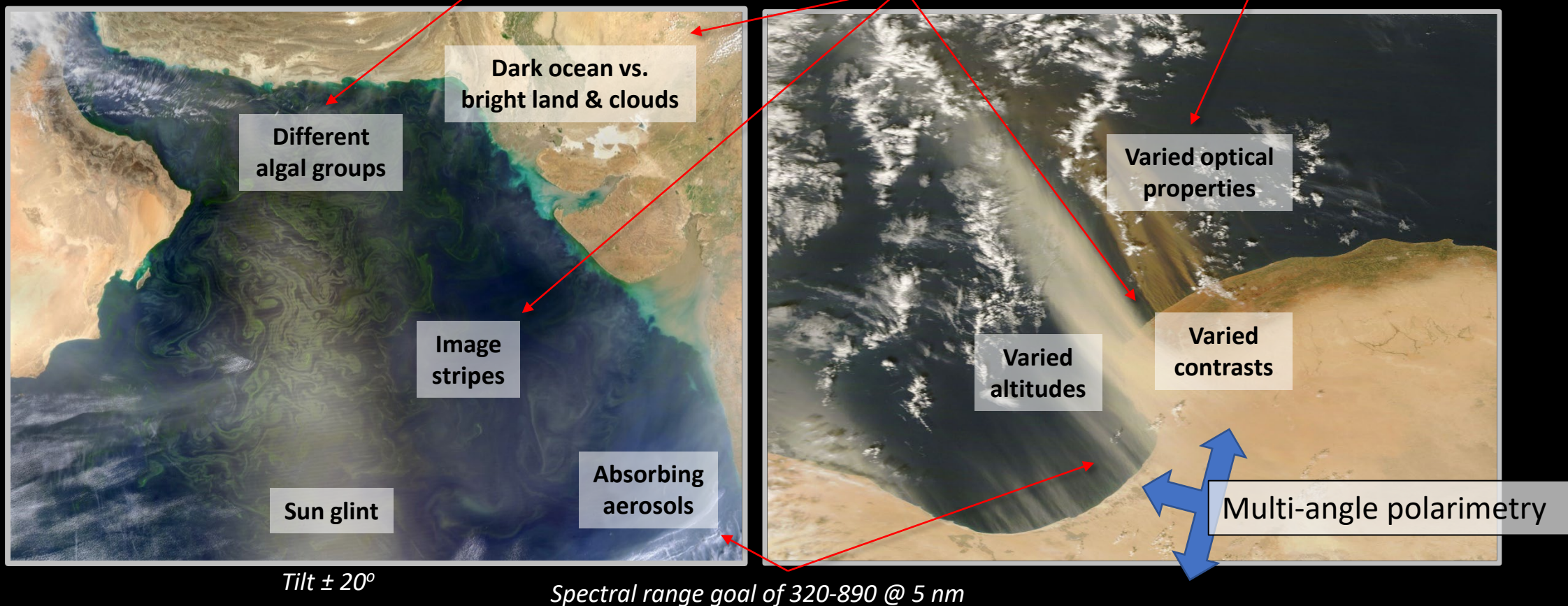
GSD of $1 \pm 0.1 \text{ km}^2$ at nadir

Twice-monthly lunar calibration & onboard solar calibration (daily, monthly, dim)

Spectral range from 340-890 @ 5 nm

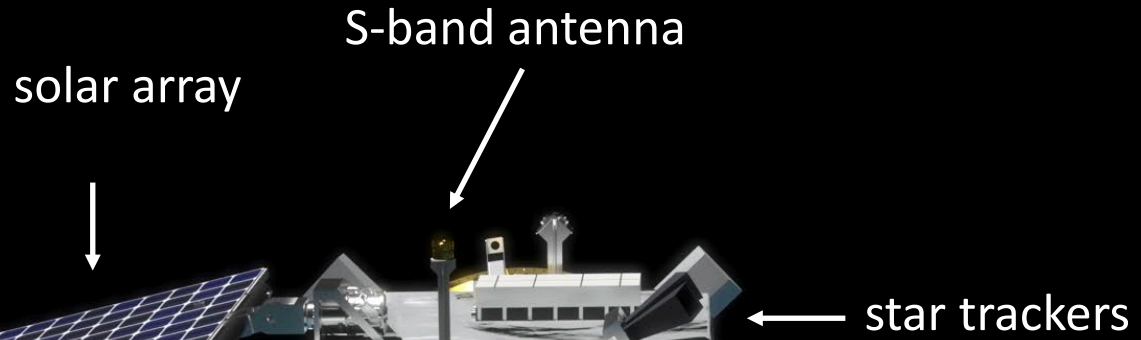
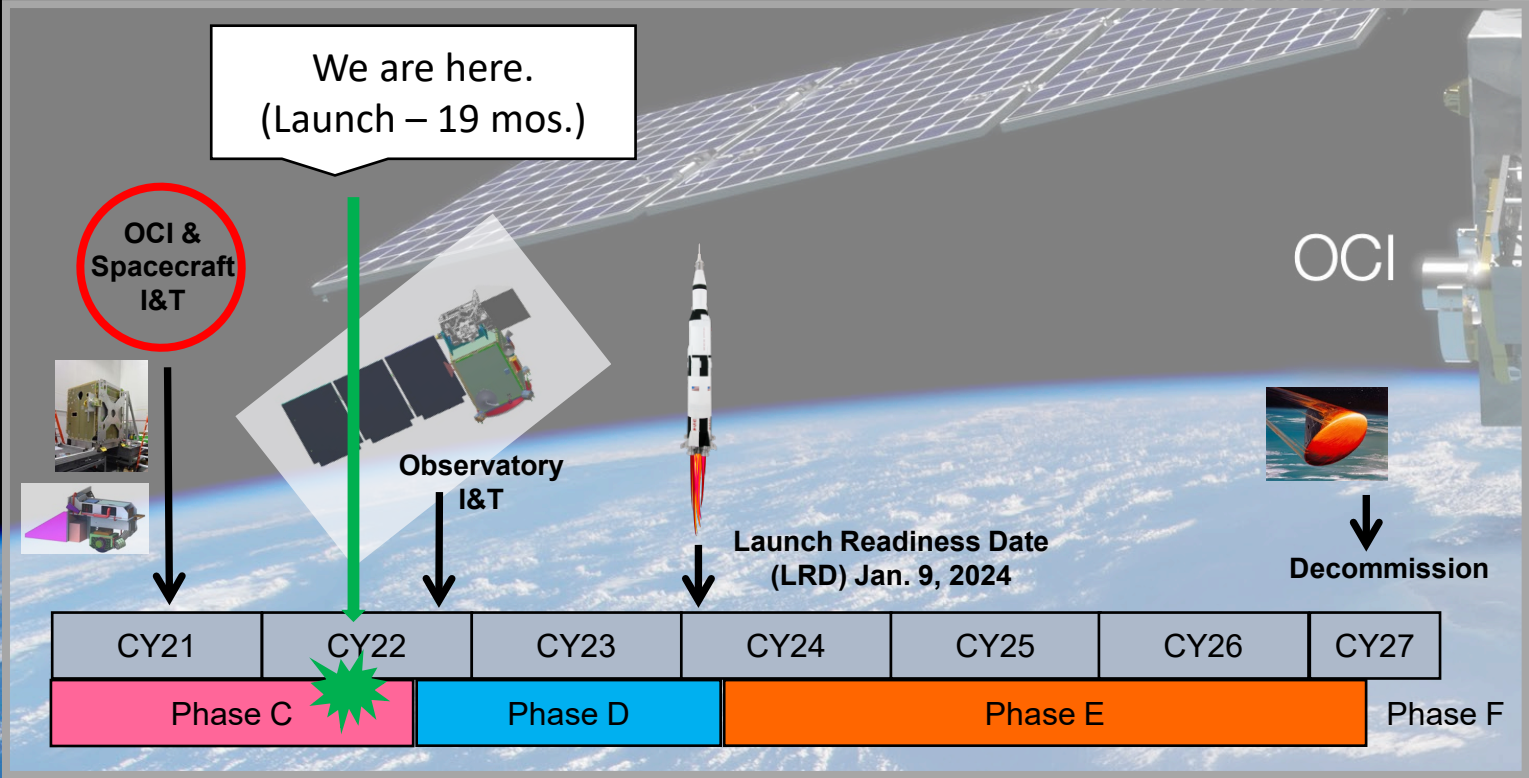
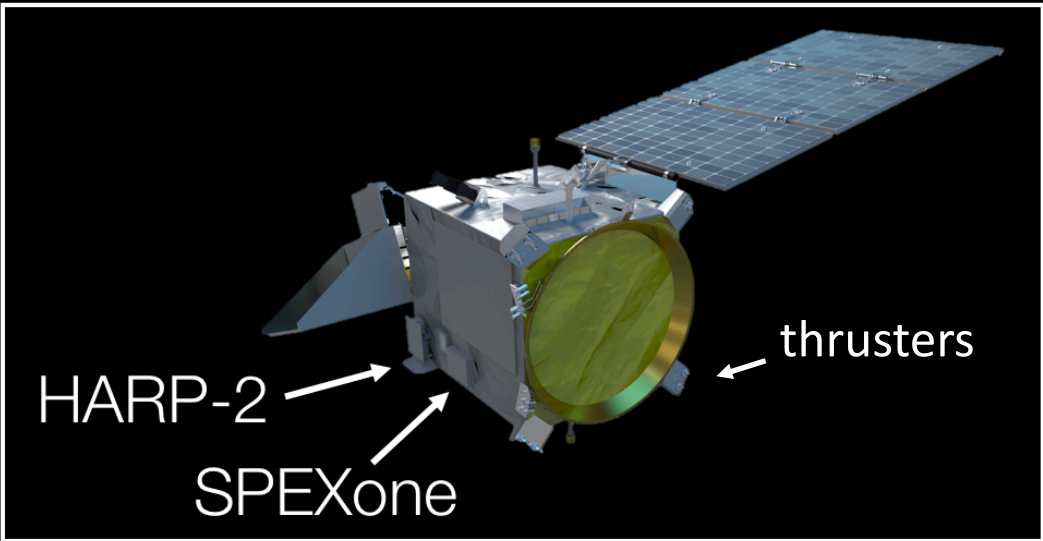
940, 1038, 1250, 1378, 1615, 2130, 2260 nm

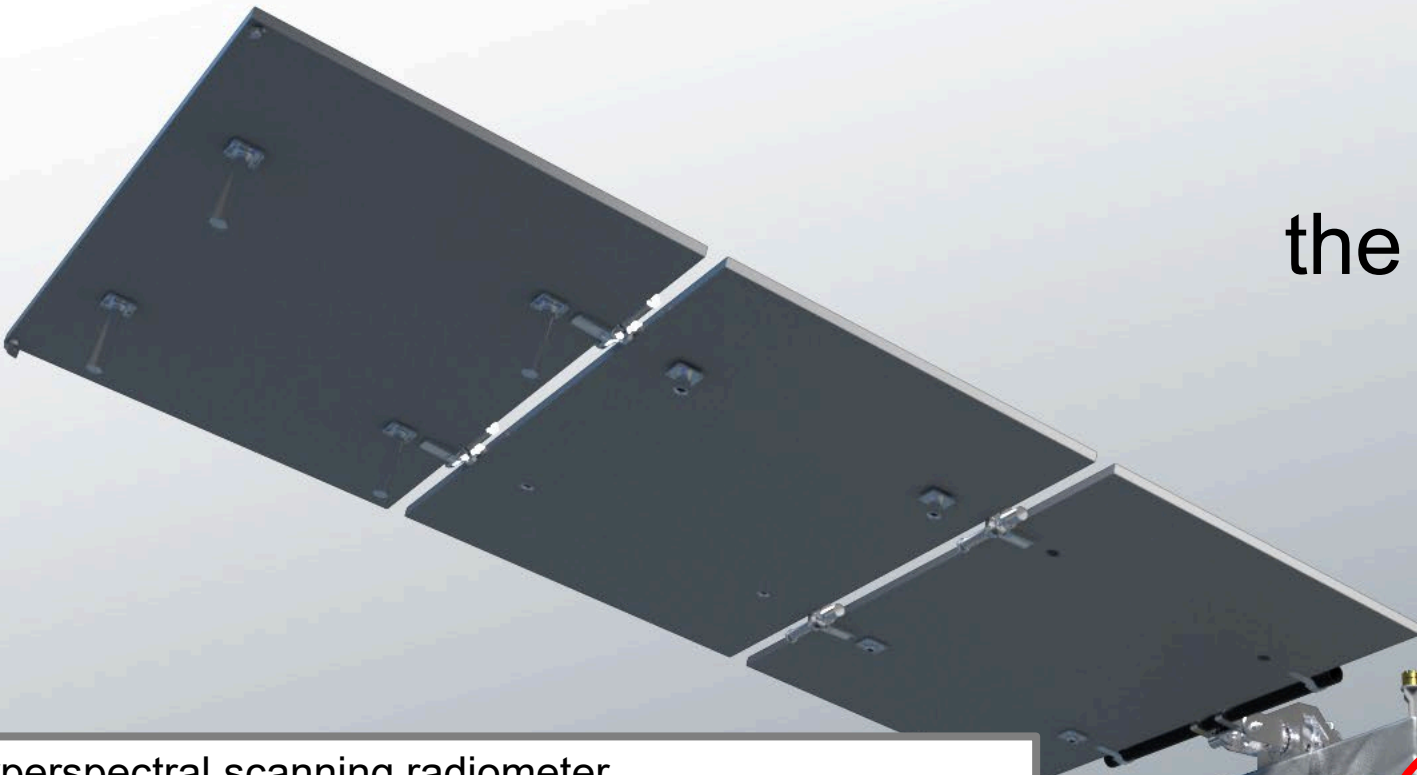
Instrument performance requirements



Improve our understanding of how aerosols influence ocean ecosystems & biogeochemical cycles and how ocean biological & photochemical processes affect the atmosphere

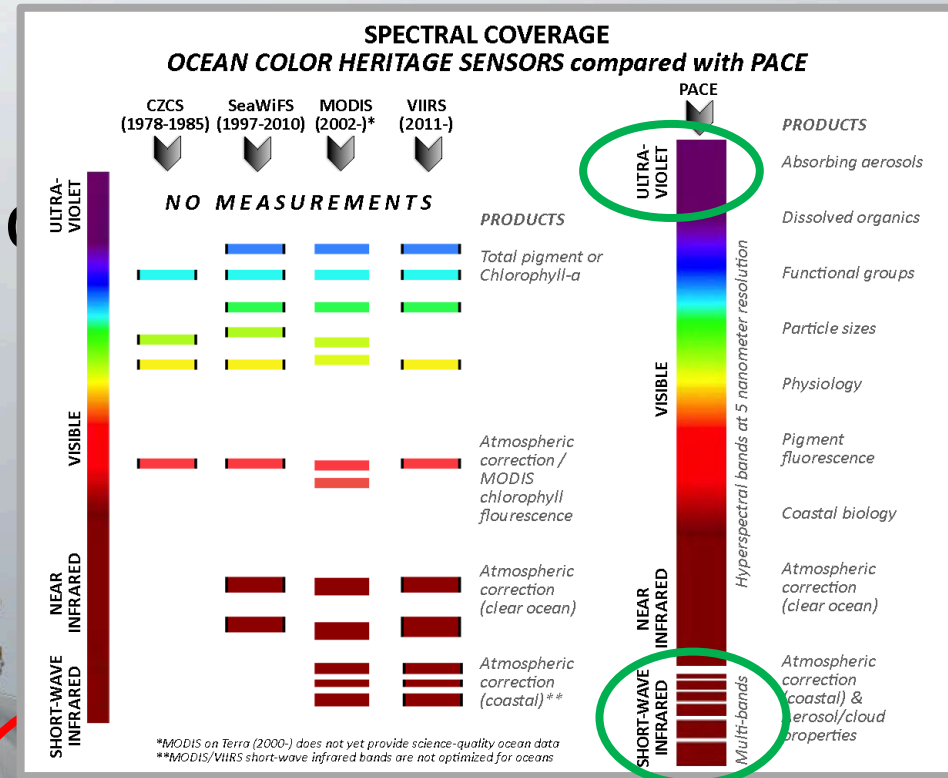
Additional beauty shots of the PACE observatory can be found at: <https://svs.gsfc.nasa.gov/12469>





the c

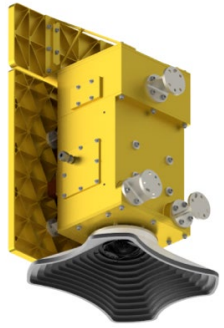
- hyperspectral scanning radiometer
- (320) 340 – 890 nm, 5 nm resolution, 2.5 nm steps⁺
- plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- *single science pixel to mitigate image striping*
- 1 – 2 day global coverage
- ground pixel size of 1 km² at nadir
- ± 20° fore/aft tilt to avoid Sun glint
- 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**



intent / goal is migration to advanced spectral matching and anomaly/derivative methods

+ 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 preparing for environmental testing
- Delivery to GSFC for I&T in Fall 2022

- Excellent for cloud droplet size and ice particle shape/roughness retrievals
- *Provides cloud capabilities beyond those required of OCI*
- *Wide swath matches OCI, offering potentially improved atmos. correction*

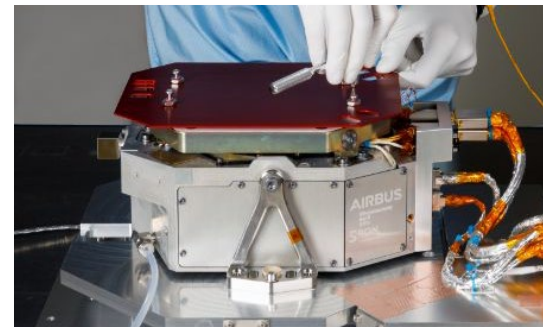
	HARP-2	SPEXone
UV-NIR range	440, 550, 670, 870 nm	Continuous from 385-770 nm in 5 nm steps
SWIR range	None	None
Polarized bands	All	Continuous from 385-770 nm in 15-45 nm steps
Number of viewing angles [degrees]	10 for 440, 550, 870 nm; 60 for 670 nm [spaced over 114°]	5 [-57°, -20°, 0°, 20°, 57°]
Swath width	±47° [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

- Excellent for aerosol characterization
- *Addresses aerosol climate objectives beyond those required of OCI*

OCI + SPEXone + HARP2

- Greater information content than any current instrument suite for ocean color, aerosol, & cloud observations
- New data products: ocean color from multi-angle polarimetry, wind speed, etc.

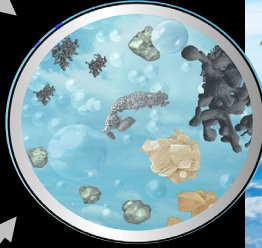
SRON/Airbus Spectro-polarimeter for Planetary Exploration (SPEXone)



Update

- SPEXone flight unit delivered to GSFC, with midpoint testing complete
- 16 orbits of simulated data available online

concentrations of brown/black carbon



aerosol absorption
aerosol optical depth
aerosol size distributions
aerosol heights & layers

ocean reflectance
whitecap fraction
angular light distributions

Top-of-atmosphere radiance

What satellites see while orbiting hundreds of miles above Earth's surface

Atmospheric contribution

Optical signature of the atmosphere itself, such as clouds and tiny particles known as aerosols

Water-leaving radiance

Light exiting the ocean that gives it its color

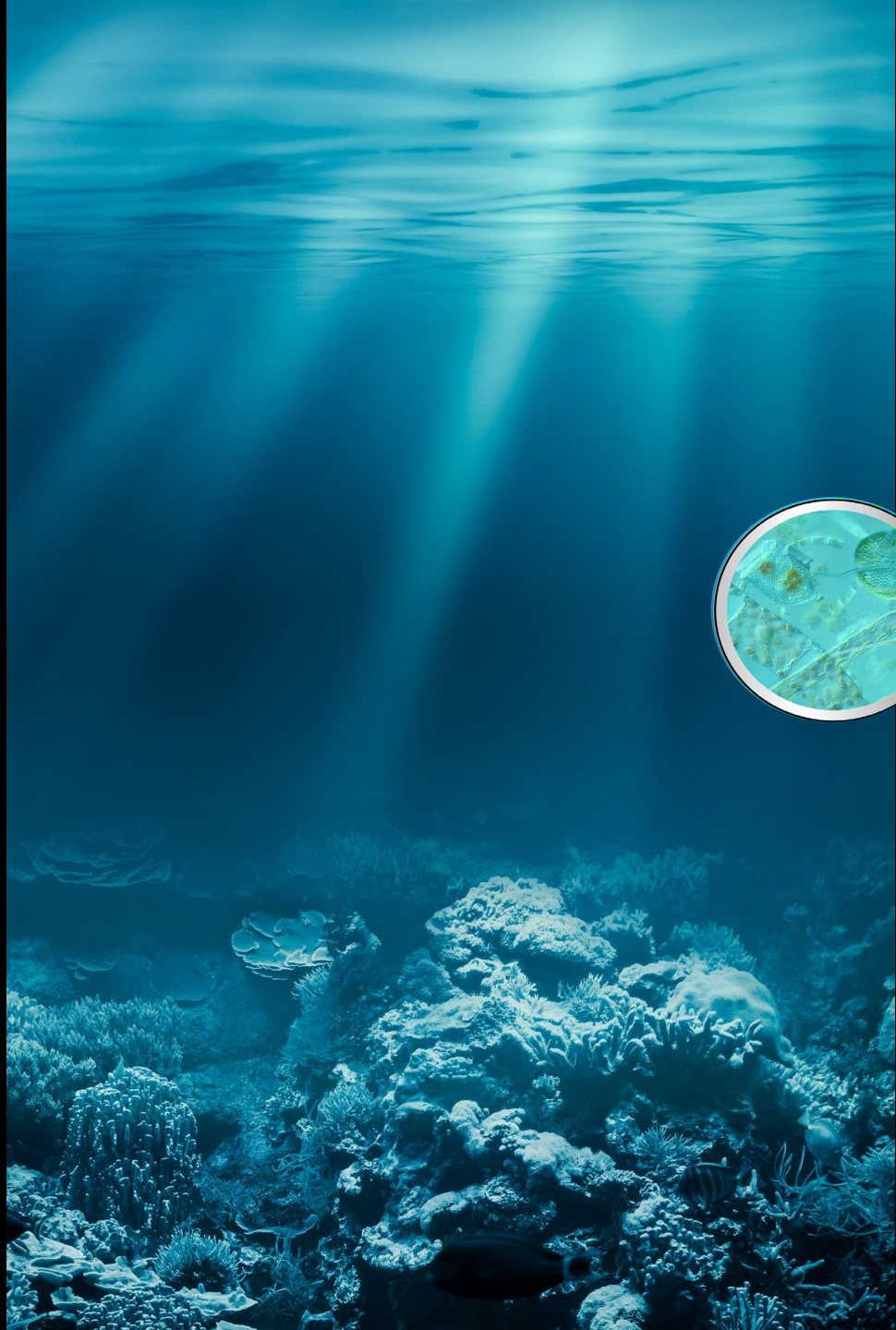
Oceanic contribution

How light is scattered and absorbed by seawater and the "stuff" contained in it

planned data products (1)

cloud optical depth
cloud height
cloud thickness
cloud phase (liquid/ice)
droplet size distributions
ice crystal shapes

oil slick detection



light penetration
angular light distributions
index of refraction

light transmission
absorption properties
scattering properties

PAR: photosynthetically
available radiation

bathymetry
classifications

planned data products (2)

photosynthetic pigments
fluorescence
plankton communities

concentrations of
particulate carbon &
suspended matter

land albedo
vegetation indices

science community engagement

Current Science & Applications Team (SAT#2) intact through mid-2023

Next team (SAT#3) expected to be competed via NASA ROSES-23

PACE Validation Science Team (PVST) to be assembled ~6 months prior to launch (as of today, this would be ~mid-2023) via late ROSES-22 amendment

- Preliminary focus on validation of threshold products (ocean color radiometry, AOT, clouds)
- Evolution into validation of derived/advanced products, including polarimetry, & closure experiments
- **Separate but complementary PACE Post-launch Airborne eXperiment (PACE-PAX)**
- **International partnerships & synergies welcome!**

Two System Vicarious Calibration teams in the middle of their second year

- Third year funded; down-select to one still possible

Applications Program, Early Adopters, & Community of Practice

- Join and get involved @ <https://pace.oceansciences.org/applications.htm> !

resources & useful info

data product descriptions + access to simulated data & characterizations

PACE technical memos & other documents

Data Products Overview

Ocean Properties to be Produced by OCI
Bio-optical and biogeochemical properties of seawater constituents in the sunlit upper ocean.



Products >

NASA/TM-2018-219027/ Vol. 7
PACE Technical Report Series
Volume 7
June 2018, Charles R. McClun, and P. Anne Werdell, Editors

Ocean Color Instrument (OCI) Concept Design Studies

Shankar Abhinav, Robert Arnone, Michael J. Behrenfeld, Bruce Barnes, James Cullen, Robert E. Egle, Bruce France, David Hagopian, Anne Brewster, Annette Menzies, Luchian L. W. McKinley, Clifford Hickey, James Neale, Steve Robinson, Frederick S. P. Paik, Wayne Robinson, Sergio R. Signorini, Ryan Underwood, Tully Wainright, and Jeremy Wordell

Extended UV Capability for Ozone Retrieval
Chlorophyll Fluorescence Requirements
Estimates for Optimal Sensing of Coastal Features
Analysis 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

[Dec-18] Ocean Color Instrument (OCI) Concept Design Studies [MORE >](#)

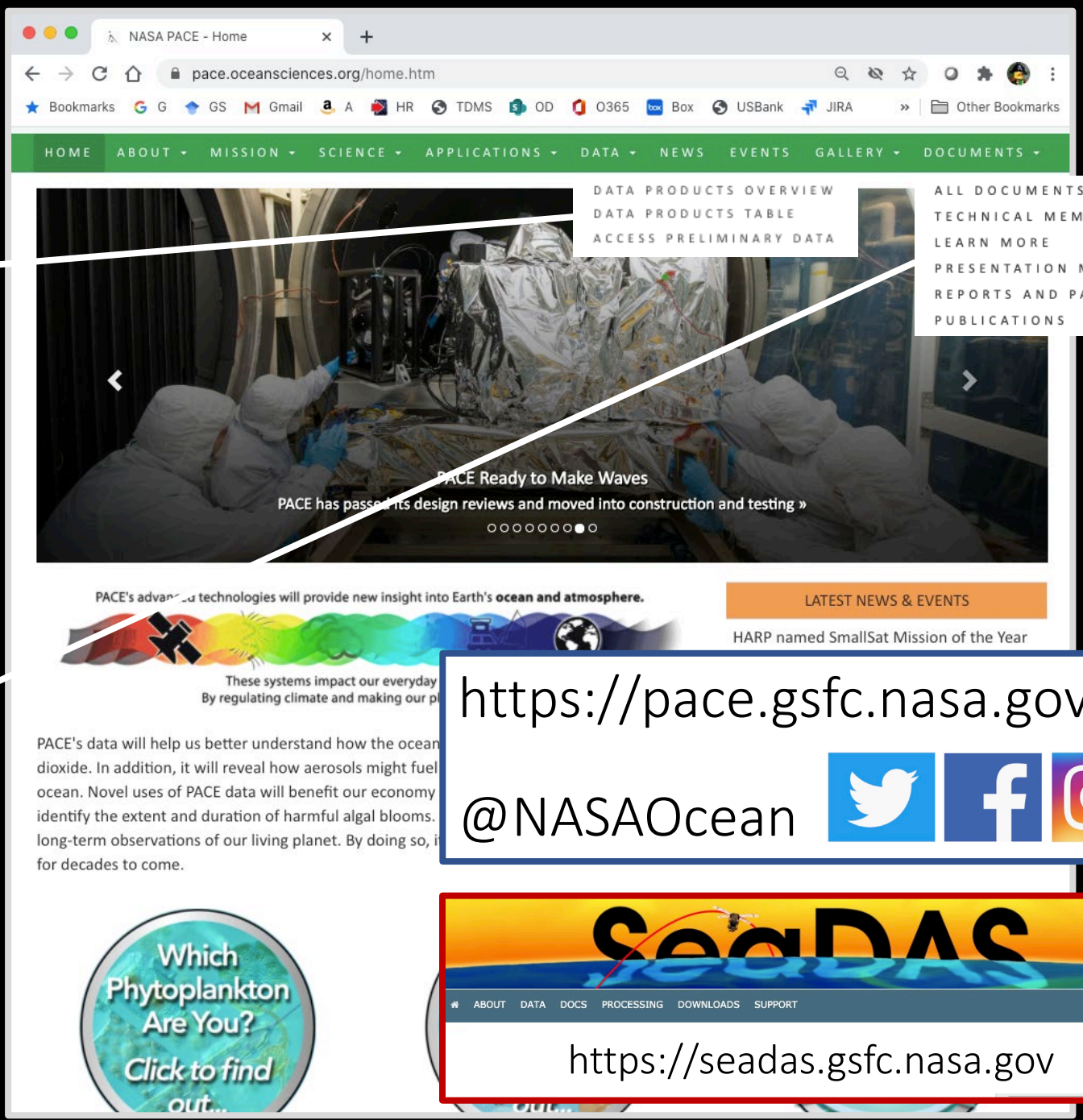
NASA/TM-2018-219027/ Vol. 6
PACE Technical Report Series
Volume 6
June 2018, Charles R. McClun, and P. Anne Werdell, Editors

Data Product Requirements and Error Budgets Consensus Document

Franklin Ahmad, James Cullen, Bryan A. Franz, Endre M. Karolyhosi, Luchian L. W. McKinley, Frederick S. Paik, and Jeremy Wordell

Ocean Color Science Data Product Requirements
OCI Pointing Knowledge & Control Requirements
SNR Requirement: Assessment & Verification
Derivation of OCI Systematic Error Approach
Uncertainty in Ocean Color Observations
Uncertainty in Aerosol Model Characterization

[Dec-18] Data Product Requirements and Error Budgets Consensus Document [MORE >](#)



NASA PACE - Home
pace.oceansciences.org/home.htm

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DATA PRODUCTS OVERVIEW
DATA PRODUCTS TABLE
ACCESS PRELIMINARY DATA

ALL DOCUMENTS
TECHNICAL MEMOS
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PRESENTATION MATERIALS
REPORTS AND PAPERS
PUBLICATIONS

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.

LATEST NEWS & EVENTS
HARP named SmallSat Mission of the Year




These systems impact our everyday life
By regulating climate and making our planet more habitable

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

Which Phytoplankton Are You?
Click to find out...

<https://pace.gsfc.nasa.gov>

@NASAOcean



<https://seadas.gsfc.nasa.gov>

<https://pace.gsfc.nasa.gov>

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SeaDAS

ABOUT DATA DOCS PROCESSING DOWNLOADS SUPPORT

<https://seadas.gsfc.nasa.gov>

Thanks to my co-authors and colleagues: Antonio Mannino

Brian Cairns

Heidi Dierssen

Lorraine Remer

Laura Lorenzoni



PACE

Plankton, Aerosol, Cloud, ocean Ecosystem

PACE data availability, formats & software

Data Level	Description	Format
Level 0	Lowest level science data (Raw Data; Consultative Committee for Space Data Systems (CCSDS) packets - https://public.ccsds.org/Pubs/133x0b2.pdf)	CCSDS
Level 1A	Uncalibrated science data in self-describing archive format	netCDF4
Level 1B	Calibrated radiances, geo-located science data as observed	netCDF4
Level 1C	Calibrated radiances, geo-located, co-registered (resampled) science data	netCDF4
Level 2	Science products derived from Level-1B/C	netCDF4
Level 3	Temporally and spatially composited science products	netCDF4

<https://oceancolor.gsfc.nasa.gov>

The screenshot shows the OceanColor WEB website with the 'DATA' menu open. The menu items are: Overview, Search & Download Methods, Find Data, Direct Data Access, Data File Search, OPeNDAP, SeaBASS, Search, Browse, Submit, Projects, and PRISM-CORAL Data. The 'Find Data' and 'SeaBASS' options are circled in red. A red arrow points from the 'Level 2' row in the table above to the 'Find Data' option, and another red arrow points from the 'netCDF4' column in the table to the 'SeaBASS' option.

The screenshot shows the OceanColor WEB website with the 'DATA' menu open. The 'Data Access' section is circled in red and contains the following items: PACE Simulated and Proxy Data, Prelaunch Instrument Characterization Data, and Ancillary Data for PACE Processing. A red arrow points from the 'netCDF4' column in the table above to this section. Another red arrow points from the 'Level 2' row in the table above to the 'Data Access' section.

<https://seadas.gsfc.nasa.gov>

The screenshot shows the Seadas website with the title 'The Official NASA/OB.DAAC Data Analysis Software'. The website includes a navigation menu with 'ABOUT', 'DATA', 'DOCS', 'PROCESSING', 'DOWNLOADS', and 'SUPPORT'. A 'Features' button is visible in the bottom right corner. A red arrow points from the 'SeaBASS' option in the OceanColor WEB menu to the Seadas website.