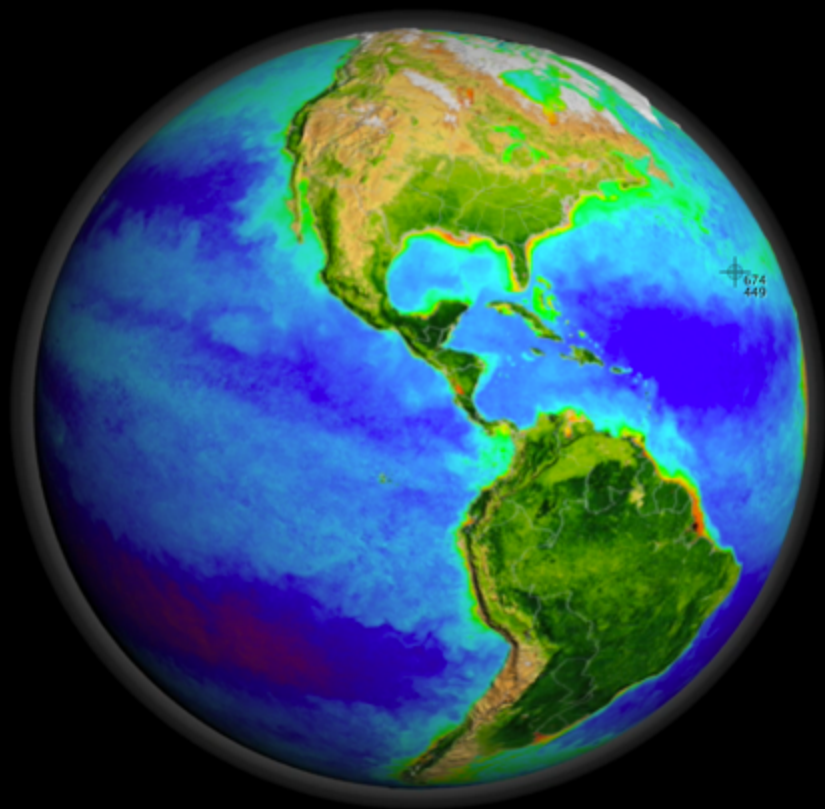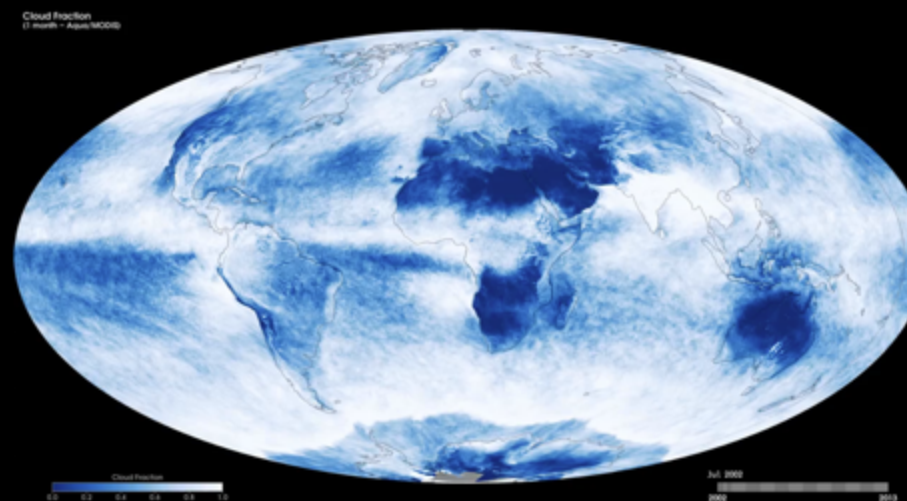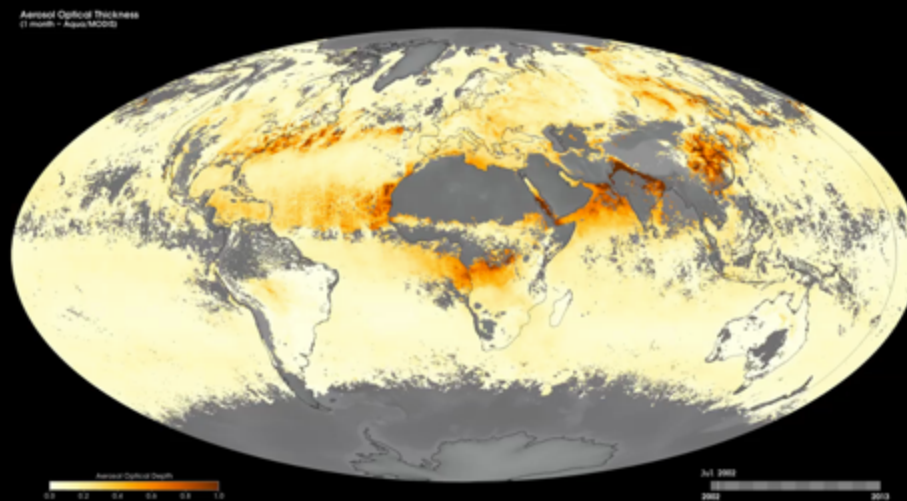# PACE Town Hall

Dr. Jeremy Werdell, Project Scientist

Dr. Paula Bontempi, Program Scientist

14 February 2018

AGU-ASLO-TOS Ocean Sciences Meeting

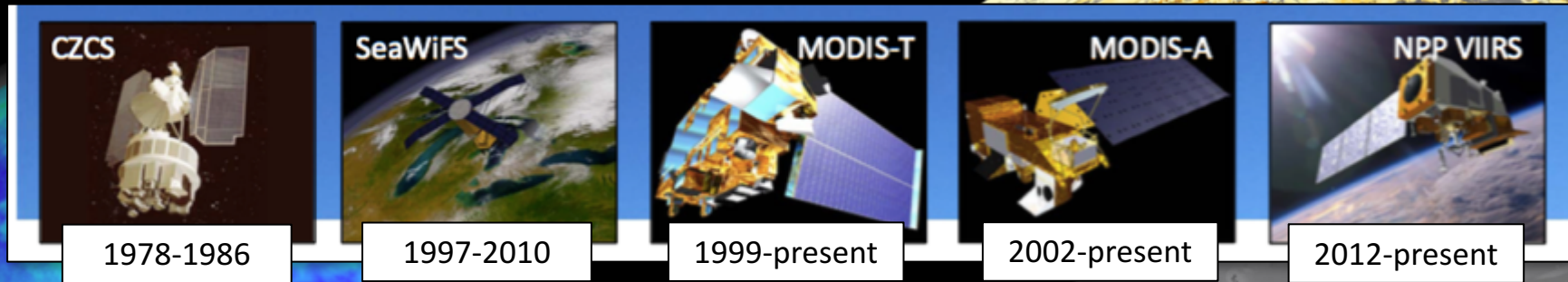ocean chlorophyll
normalized land vegetation index

aerosol optical thickness

cloud fraction

ocean chlorophyll
normalized land vegetation index

aerosol optical thickness

| CZCS | SeaWiFS | MODIS-T | MODIS-A | NPP VIIRS |
| 1978-1986 | 1997-2010 | 1999-present | 2002-present | 2012-present |

Broadly speaking, PACE has two fundamental science goals:

(1) Extend key systematic ocean color, aerosol, & cloud climate data records

(2) Address new & emerging science questions using its advanced capabilities

cloud fraction

Core, overarching science goals

Extending key systematic ocean biological, ecological, & biogeochemical climate data records and cloud & aerosol climate data records;
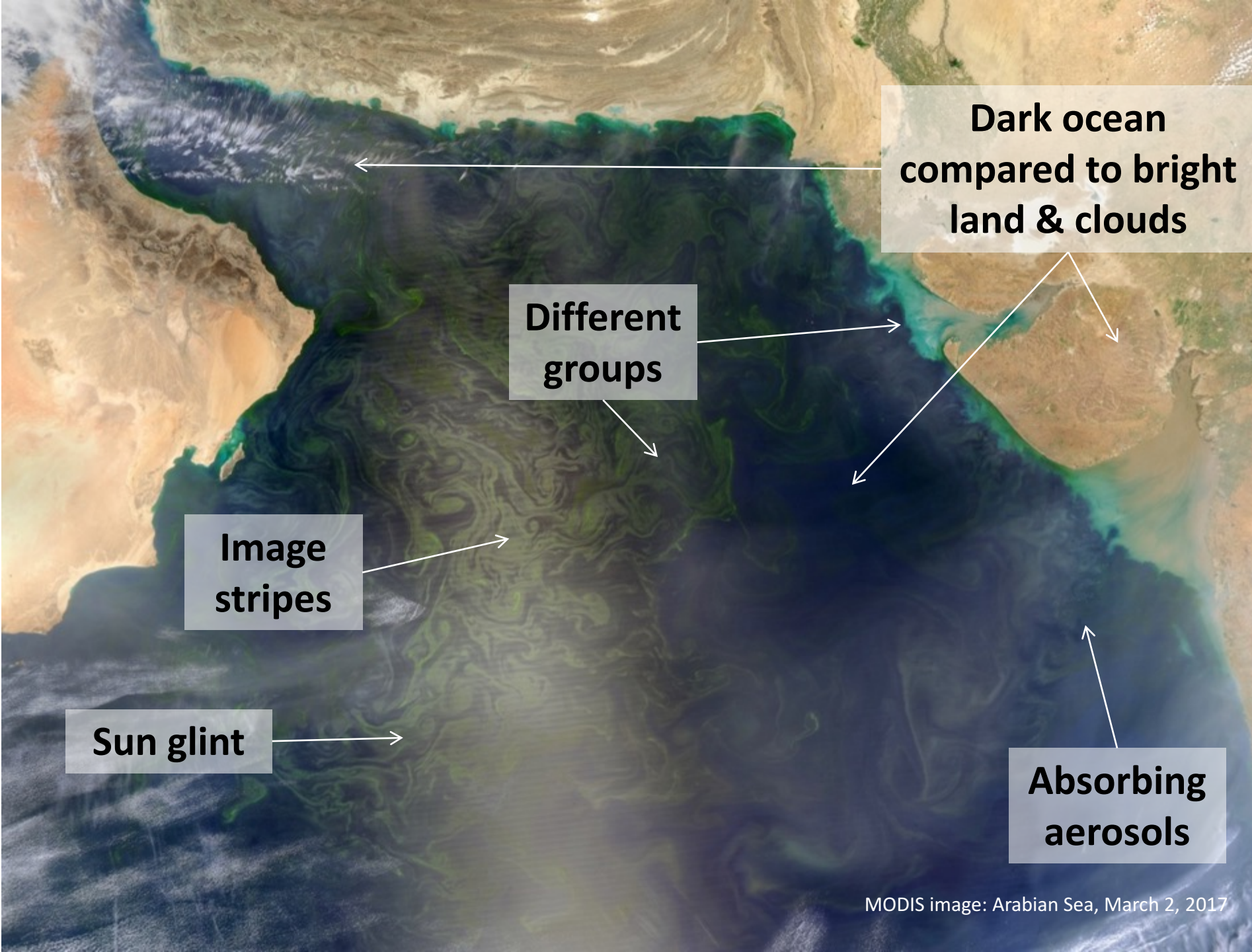
Making new global measurements of ocean color data products that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate;

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

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

Challenges

signals from the ocean are small & differentiating between constituents requires additional information relative to what we have today

Dark ocean compared to bright land & clouds

Different groups

Image stripes

Sun glint

Absorbing aerosols

MODIS image: Arabian Sea, March 2, 2017

What VIIRS Sees
(diatoms) (Noctiluca)

What PACE OCI Will See
(diatoms) (Noctiluca)

5
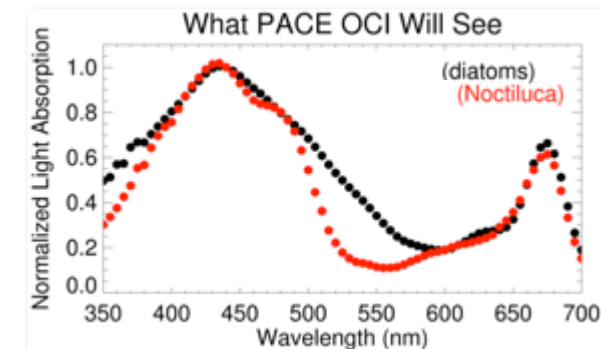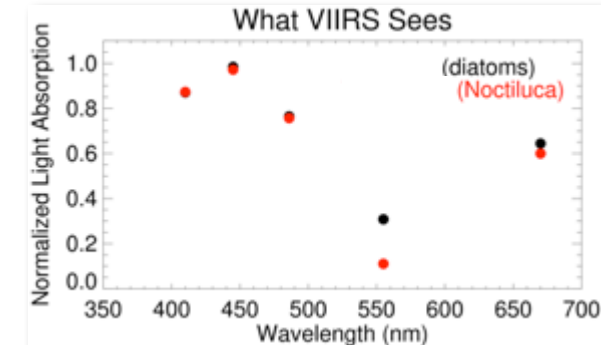
Aerosols & clouds: largest uncertainty terms in climate radiative models

Varied optical properties

Varied contrasts

Varied altitudes

MODIS image: Libya coast, October 26, 2007

Challenges

aerosol, cloud, climate interactions are complicated and difficult to observe
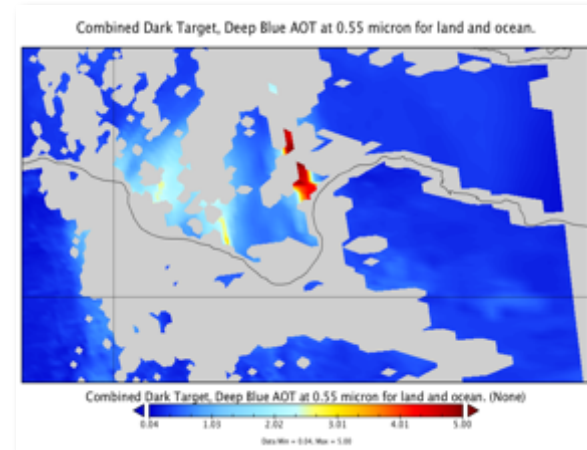
PACE will have:

- an OCI with UV bands to 350 nm (320 nm goal) & two 2 μm bands
- multi-angle polarimetry
- (no thermal bands)

Mission characteristics

Key Mission Elements

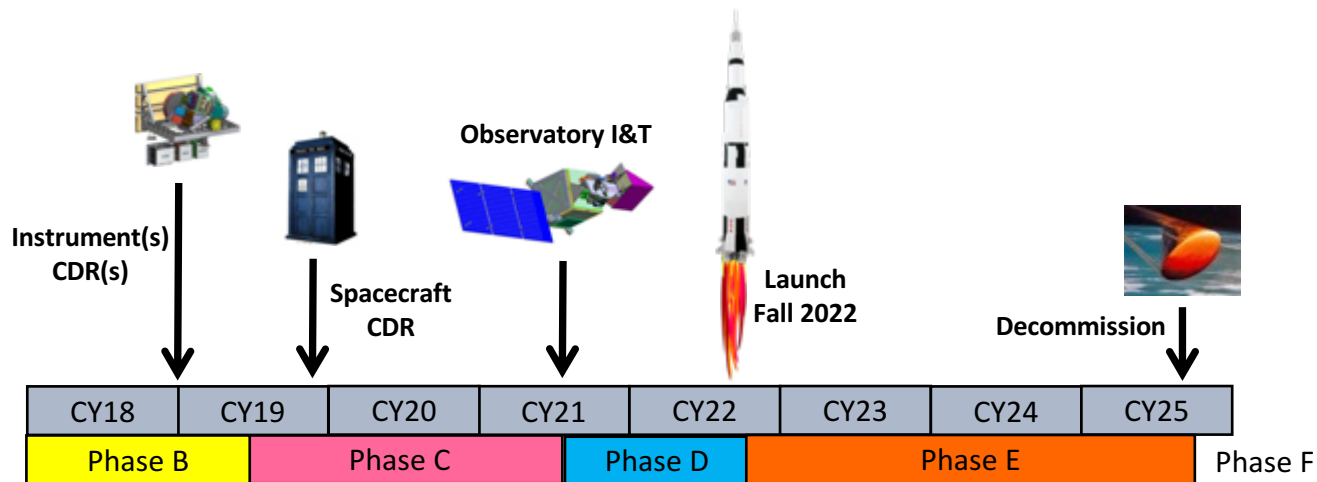|	
Mission management	NASA Goddard SFC
Ocean Color Instrument	NASA Goddard SFC
HARP2 polarimeter	U. Maryland Baltimore County
SPEXone polarimeter	SRON (Netherlands)
Spacecraft/Mission Ops	NASA Goddard SFC
Science data processing	Ocean Biology Processing Group
Competed science teams	NASA Earth Sciences Division

Key Mission Features

Cost	Directed, DTC, $805M
Life	3-yr, Class C, 10-yr fuel
Orbit	676.5 km, Sun sync, 1-pm MLT AN
Coverage (OCI)	2-day global
RF Communication	Ka direct to ground, 600Mbps

Key Mission Science Requirements

Ground sample distance of 1 ± 0.1 km^2 at nadir

Sun glint mitigation (OCI tilt $\pm 20^o$)

OCI spectral range from (320) 350-865 nm @ 5 nm resolution

OCI with 940, 1038, 1250, 1378, 1615, 2130, 2260 nm bands

Twice-monthly lunar calibration

Onboard solar calibration (daily, monthly, dim)

A vicarious calibration system

Core data products, uncertainties, & a validation program

Instrument(s) CDR(s)

Spacecraft CDR

Observatory I&T

Launch Fall 2022

Decommission

CY18	CY19	CY20	CY21	CY22	CY23	CY24	CY25
Phase B		Phase C		Phase D	Phase E			Phase F

Who's working on PACE (as of early Feb 2018)?

Netherlands
SRON [SPEXone]
TNO [Primary Mirror]

France
Airbus [SPEXone]

California
Irvine Electronics [Avionics]
Semiconductor Technology Associates Inc [CCDs]
Teledyne [CCDs]

Colorado
Avior Control Technologies Inc [OCI Rotation Motors]
Cobham [Avionics]

Minnesota
4th Access Machining [Avionics]

New Hampshire
Corning [Primary Mirror]
[Back End Optics]

Utah
Space Dynamics Laboratory
[SWIR AOB]

Maryland
Support Contracts
Alcyon Technical Services
ARES Technical Services
ATA Aerospace
Business Integra INC
KBRwyle Technology Solution LLC
Trident Vantage Systems LLC

Genesis [Avionics]
University of Maryland, Baltimore County [HARP2]

Virginia
Moog Inc [Bearings]
Science Applications International Corp [Support]
TRAX International Corp [Support]

Arizona
Advanced Circuits [Avionics]

Texas
Southwest Research [Avionics]

Alaska
Artic Slope Regional Corporation [Support]

Arkansas
BEI Precision Systems and Space Company
[Encoders]

the first PACE science team (2014-2017)

Ocean Color Instrument – physical assembly

Concept follows the heritage of the SeaWiFS, MODIS, and VIIRS

Data, control, & interface units
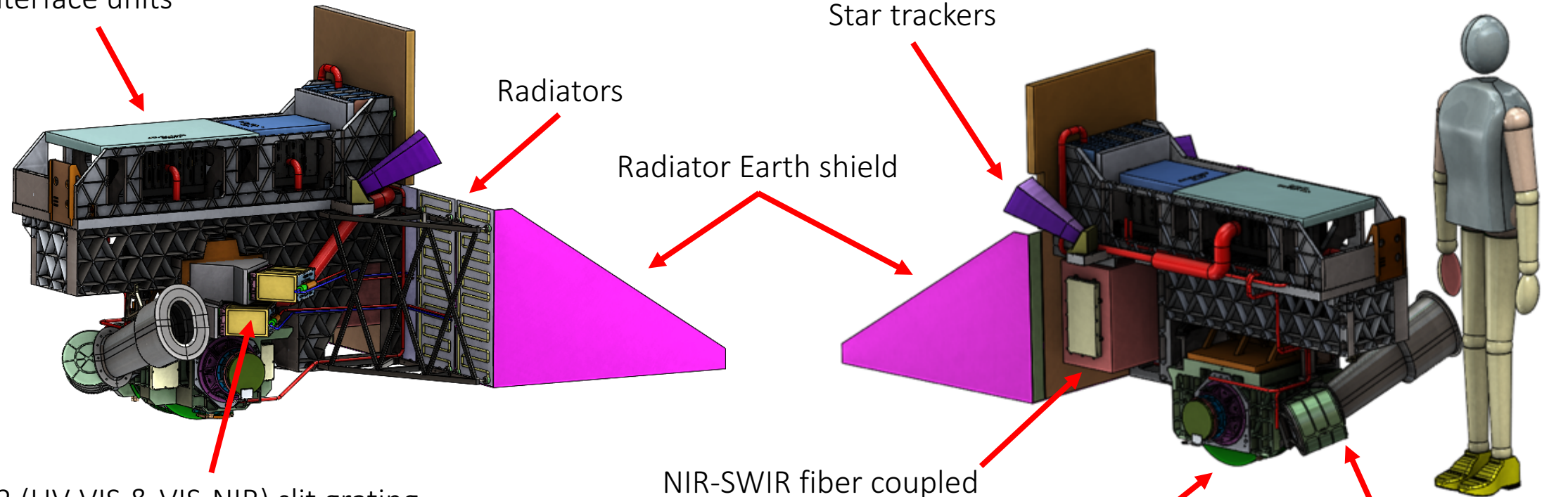
Radiators

Radiator Earth shield

Star trackers

2 (UV-VIS & VIS-NIR) slit grating hyperspectral spectrographs

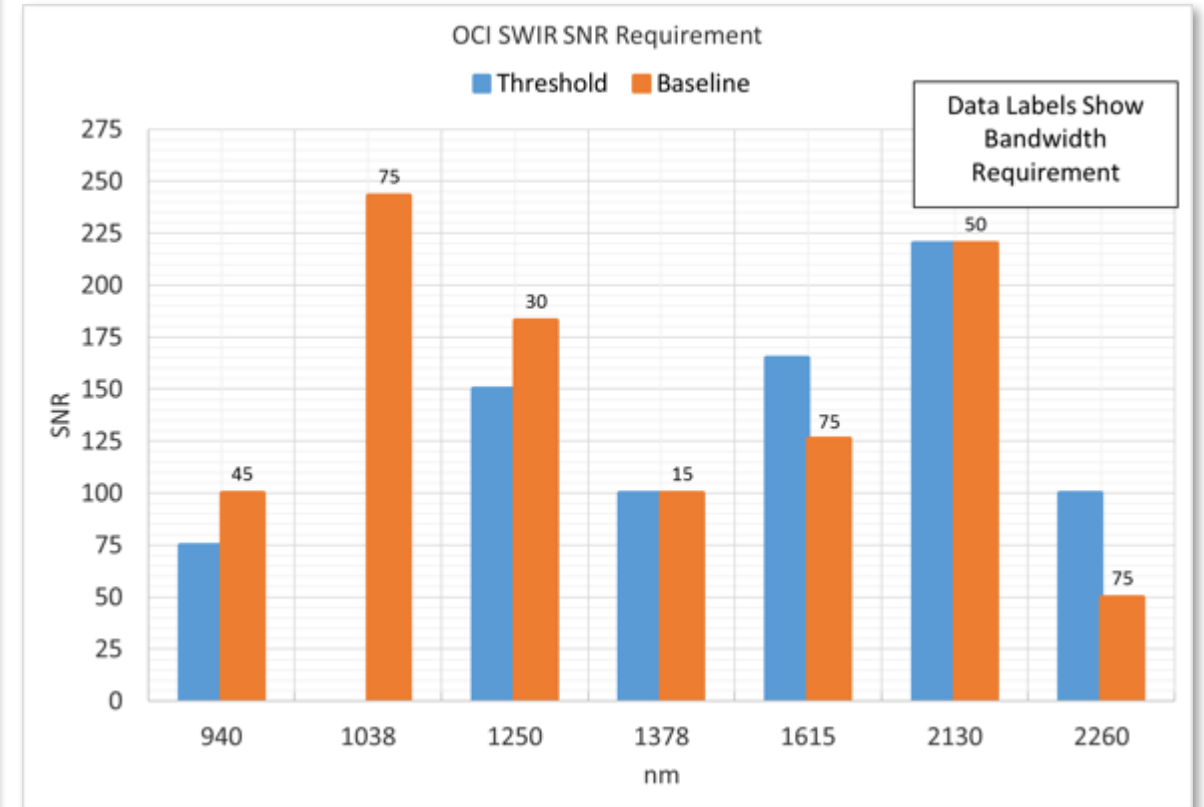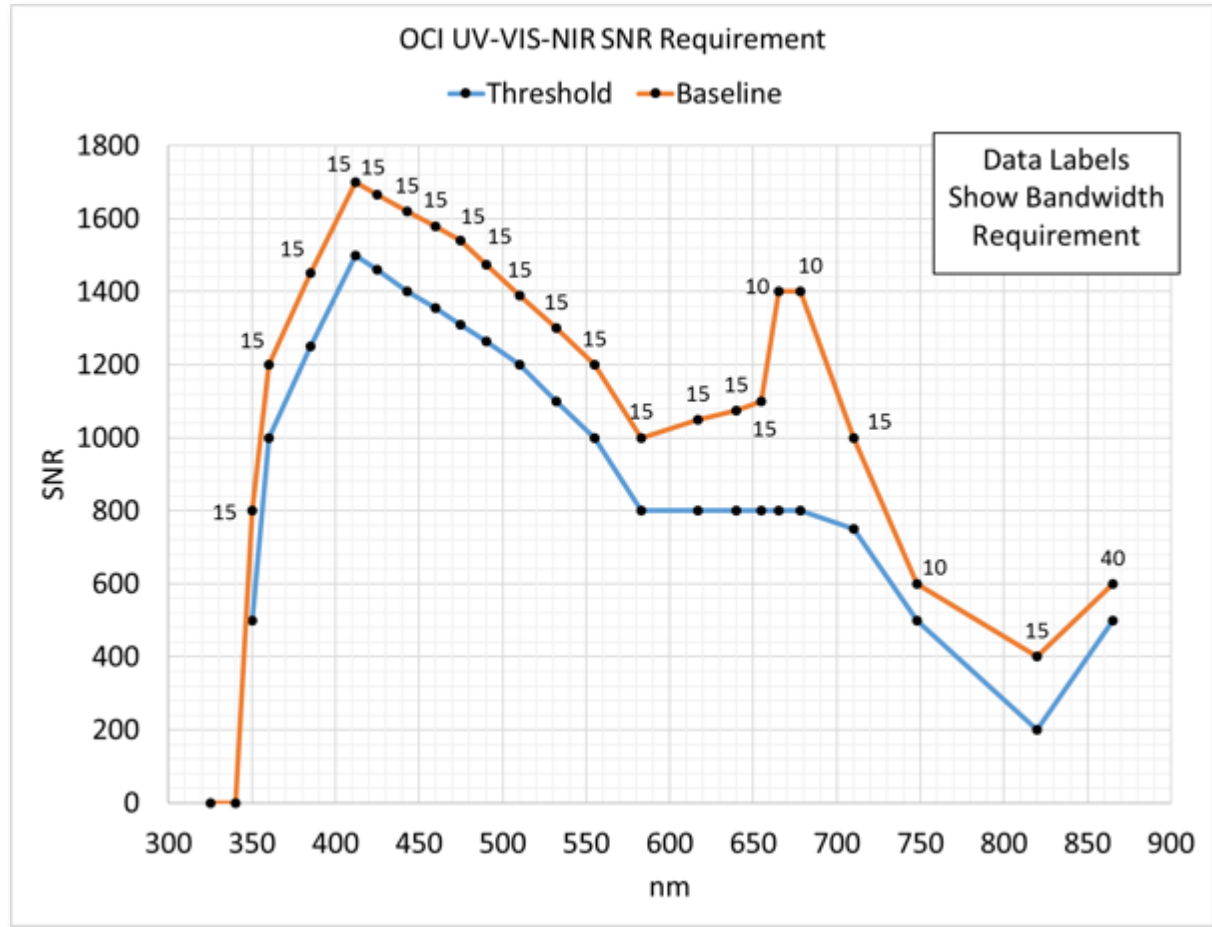NIR-SWIR fiber coupled multiband filter spectrographs

Cross-track rotating telescope with ± 56.5° field of regard

Solar calibration assembly

270 kg, 315 W, 13 Mbps up to 40 Mbps (CBEs)

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

OCI UV-VIS-NIR SNR Requirement

OCI SWIR SNR Requirement

Required science data products (OCI)

Required data products & additional expected data products:

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 ($\tau < 0.3$)
Diffuse attenuation	Cloud top pressure ($\tau > 3$)
Fluorescence line height	Shortwave radiation effect

Building capabilities to produce this full suite of OCI products from proxy data using preliminary/heritage algorithms by the end of 2018

Advanced & evaluation science data products

Required data products & additional expected data products:

Incomplete list of advanced (~baseline) products

Carbon stocks & fluxes	Liquid / ice cloud water path
Phytoplankton pigments	Polarimeter-specific products
Phytoplankton physiology	Applied sciences-specific products
Community structure (PFTs)	Land data products (TBD)
Productivity	Your very favorite data product that
PAR, light attenuation, water quality	I forgot to list (*so plz don't ask*)

General expectations for future PACE science teams:

- *Novel* methods for required products (exploit spectral capabilities)
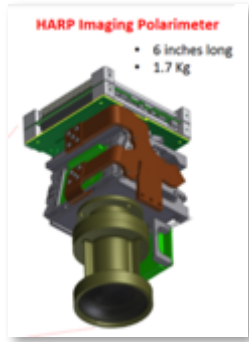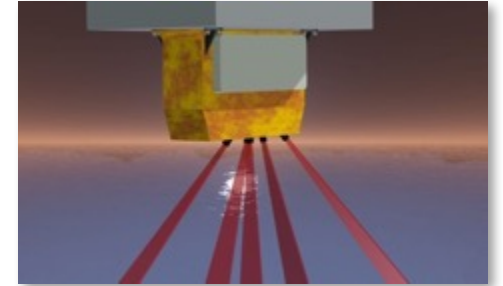- Methods for advanced products + scientific applications

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 Hasekamp

HARP Imaging Polarimeter
- 6 inches long
- 1.7 Kg

Hyper Angular Rainbow Polarimeter (HARP-2)

Contribution from University of Maryland Baltimore County

POC: Vanderlei Martins
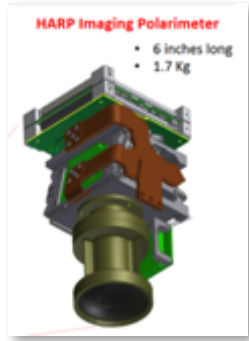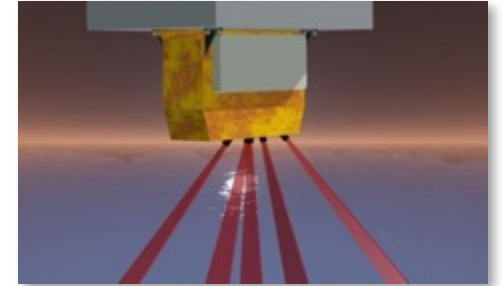
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Hyperspectral (UV) + narrow swath

HARP Imaging Polarimeter
- 6 inches long
- 1.7 Kg

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 (hyperspectral 2 nm)	440, 550, 670 nm (10) + 870 nm (40 nm)
# viewing angles	5 (-52°, -20°, 0°, 20°, 52°)	20 for 440, 550, 870 nm + 60 for 670 nm (114°)
Swath width	9° (100 km)	94° (1550 km)
Ground sample distance	2.5 km^2	3 km^2
Heritage	AirSPEX	AirHARP, cubesat HARP for ISS

OCI-polarimetry synergy

Spectro-Polarimeter for Planetary Exploration (SPEXone)

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

Hyper Angular Rainbow Polarimeter (HARP-2)

- 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 atmospheric correction

OCI + SPEXone + HARP-2

- Hyperspectral + hyperangular + highly accurate radiometric & polarimetric observations = far 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.

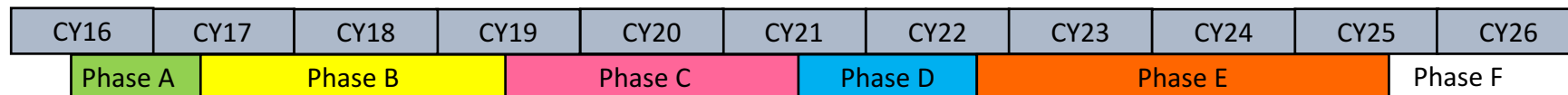# Looking forward: the mission's coming year(s)

Phase B – preliminary design & technology completion

- July 2017 – Q2 2019
- All mission elements must pass Preliminary Design Reviews (PDR)
- 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)
  - build science capabilities (plans for cal, val, algs, processing, documentation, etc.)

Phase C – final design & fabrication

Phase D – system assembly, integration & testing, & launch

Phase E – science operations

CY16	CY17	CY18	CY19	CY20	CY21	CY22	CY23	CY24	CY25	CY26
Phase A	Phase B		Phase C		Phase D		Phase E			Phase F

Looking forward: noteworthy mentions

Budget Status: FY18 and beyond (as of early Feb 2018)

- "The President's 2018 Budget requests $19.1 billion for NASA, a 0.8 percent decrease from the 2017 annualized CR level…for ESD: $1.8B, down $102M, or ca 5% cut from 2017 annualized CR level."

- FY18 President's Budget identified termination of five missions: OCO-3, DISCOVR, PACE, CLARREO Pathfinder, RBI, NASA's Office of Education, and a reduction to ESD research (first step in budget process)

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

- Free download: http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm

- Briefing slides available, as is webinar – Town Hall tonight, 6:30-7:30pm, D135-136

- 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-launch & post-launch schedule

Pre-launch Science Teams

- FY15 – 17: ROSES 2013 A.25
  - Achieved consensus and develops community-endorsed paths forward for IOPs and Atmospheric Correction
- FY19 – 22: ROSES 2019 (4 years)
  - Allow lead time for scientific algorithm development & applications development prior to launch
  - Initiates interface between instrument developers and OBPG; OBPG/OB DAAC and algorithm developers; possible LaRC DAAC for polarimetry (not yet decided)
- FY23 – 25: ROSES 2022 (3 years)
  - Pre-launch algorithms and post-launch competed science/applications for ocean color instrument's aerosol, cloud, ocean science, plus aerosol and clouds from polarimeters

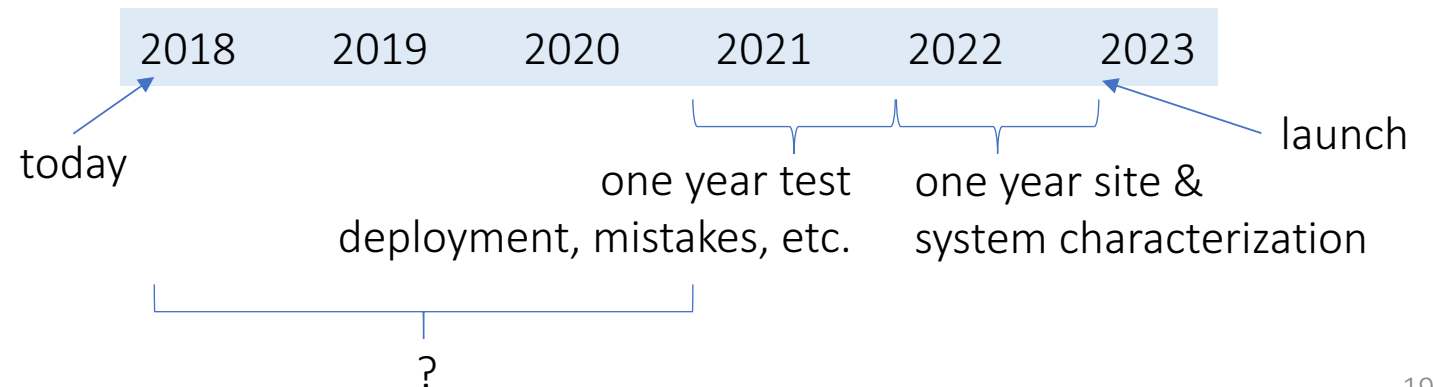**Post-launch Competed Science - options**

- Competed through ROSES 2025
- After launch, joint funding between EOS project, R&A, and PACE mission budget, exploring additional funding from Applied Sciences
- Mission contributions (many TBDs)
- Continue during mission extensions

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 are completing analysis and testing of hardware:

  - Hyperspectral radiometric device for accurate measurements of water leaving radiance from autonomous platforms for satellite vicarious calibrations - PI – Andrew Barnard, SeaBird Scientific

  - Hybrid-spectral Alternative for Remote Profiling of Optical Observations for NASA Satellites (HARPOONS) - PI – Carlos DelCastillo, NASA GSFC

  - Developing a MOBY-NET instrument, suitable for a federation network for Vicarious Calibration of Ocean Color Satellites Perform cal/val during mission operations - PI – Ken Voss, University of Miami

- ROSES 2018 or 2019 - Select best approach and hardware (pre-launch) or further risk reduction on instrumentation, if needed, for vicarious calibration of ocean color data products.

options: systems in development, expected external assets (e.g., MOBY, BOUSSOLE), FRM4SOC, other in situ sources, models
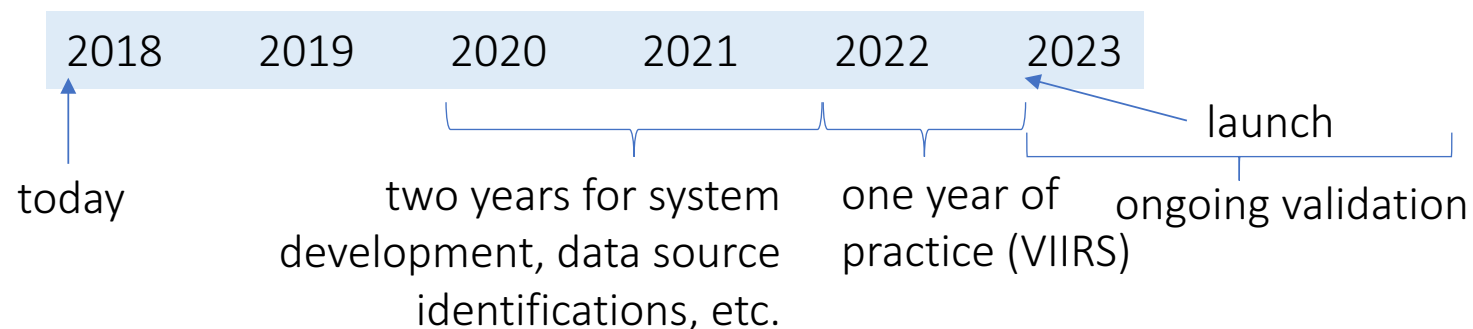
2018	2019	2020	2021	2022	2023

today

one year test deployment, mistakes, etc.

one year site & system characterization

launch

?

Looking forward: a validation program

FY19 – 21: ROSES 2018 or 2019 (3-4 years)

- Selects best approach and hardware (pre-launch) or further risk reduction on instrumentation, if needed, for validation of all data products (aerosol, cloud, ocean color) – *in situ*; Calibration/validation of polarimetry data products (TBD)

FY22 – 25: ROSES 2021 or 2022 (4 years)

- Perform cal/val during mission ops; Includes airborne and *in situ* measurements; Continue every year during mission extension(s)
- International community (EUMETSAT, ESA, and the Copernicus Program) are investing in Fiducial Reference Measurements for Sentinel and coordination is critical

2018	2019	2020	2021	2022	2023

today

two years for system development, data source identifications, etc.

one year of practice (VIIRS)

launch

ongoing validation

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 ($\tau < 0.3$)
Diffuse attenuation	Cloud top pressure ($\tau > 3$)
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)

Looking forward: applied sciences

New agency directive on Applied Sciences within missions

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 white papers developed and posted to the website. • Applications Traceability Matrices developed and posted to the website. • Applications Working 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 Adopters Program established.
Phase C/D	• Annual workshop focused on results from Early Adopters. • Description of validation datasets to the community of practice. • Conference presentations and papers; newsletters and journal articles on user interaction to expand the community of potential. • Data workshops, short courses, focus sessions, tutorials. • Interaction with NASA HQ Applied Sciences to prepare 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 Benefit Value Assessment. • Information for Senior Review Submissions.

PACE

Applications Plan
Ver. 1.0

October 2017

Edited by:
Maria Tzortziou [1], Ali Omar [2], Woody Turner [3], Jeremy Werdell [4], Antonio Mannino [4], and Annette de Charon [5]

[1] NASA HQs PACE Deputy Program Applications Lead - Oceans, [2] NASA HQs PACE Deputy Program Applications Lead - Atmosphere, [3] NASA HQs PACE Program Applications Lead, [4] NASA PACE Project Scientist, [5] NASA PACE Deputy Project Scientist - Oceans, [6] PACE Project Communications Team.

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Looking forward: applied sciences

Understanding Earth Together

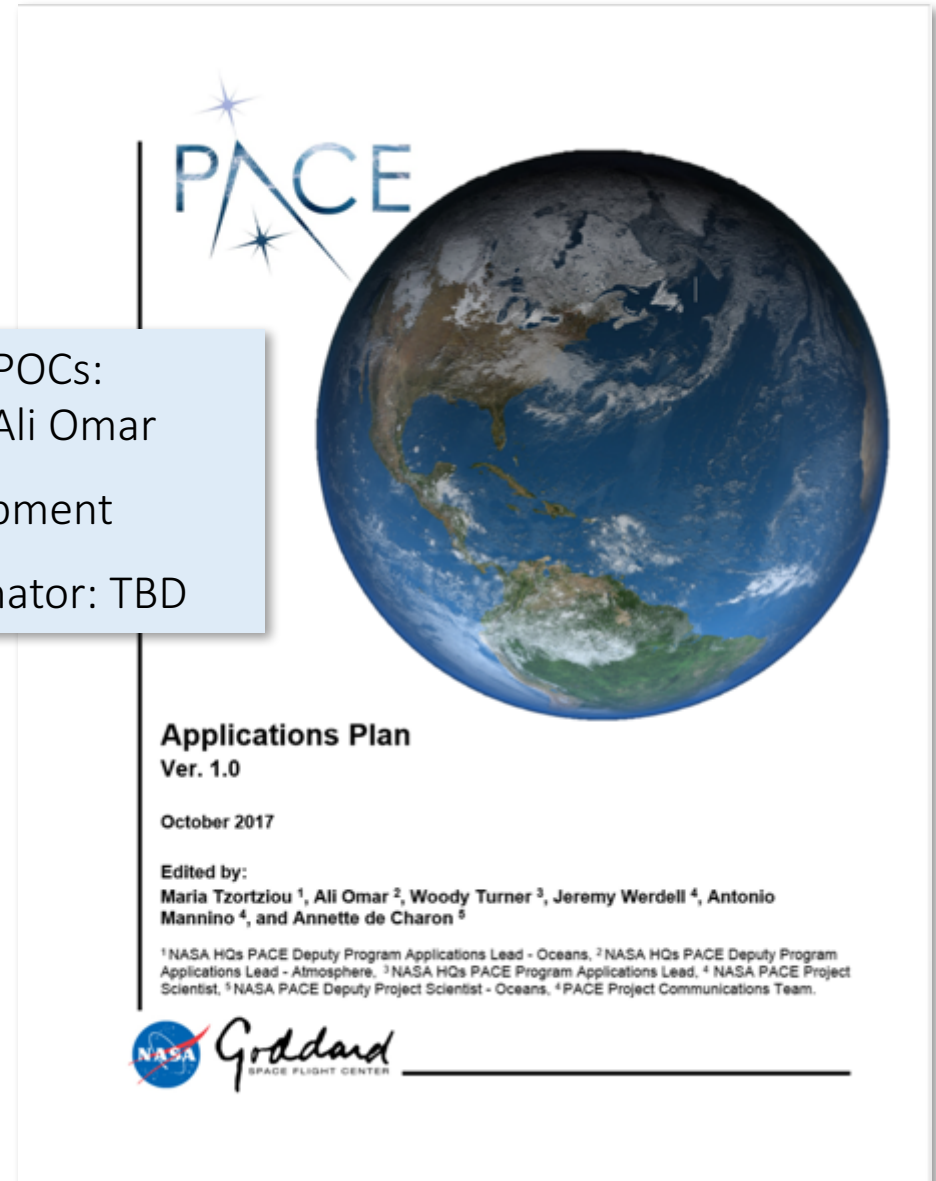GET INVOLVED WITH APPLICATIONS OF NASA OCEAN & ATMOSPHERE DATA

NASA's Applied Sciences Program is designed to discover and demonstrate innovative uses and practical benefits of Earth science data, scientific knowledge, and technology.

Launching in 2022, NASA's PACE mission provides a unique opportunity for early involvement by the user community.

Consider joining the PACE Early Adopter Program!

PACE Applied Sciences program POCs:
Woody Turner, Maria Tzortziou, Ali Omar

A/S Program currently in development

Project Applied Sciences Coordinator: TBD

PACE

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Take home messages

- **Possibilities for next competed science team**
  - new approaches for existing data products (e.g., OCI spectral range!)
  - advanced & merged data products & science and interdisciplinary science
- **Vicarious calibration system**
  - System(s) in field 2+ years prior to launch
  - Calibration needs for cloud & aerosol communities?
  - OSSEs or needs for site(s) characterization?
- **Field data - Validation**
  - What do we need (field campaigns, communities, instruments, timing)? *How do we ensure collection & availability of resources such as ships/aircraft?*
  - Existing resources, docs, & partners of which to be aware?
- **Algorithms**
  - Heritage approaches being identified & implemented
  - Open process for new products & methods/approaches for existing products

Learn more about PACE

https://pace.gsfc.nasa.gov
@NASAOcean (Twitter)
@NASA.Ocean (Facebook)
Technical Memo. series
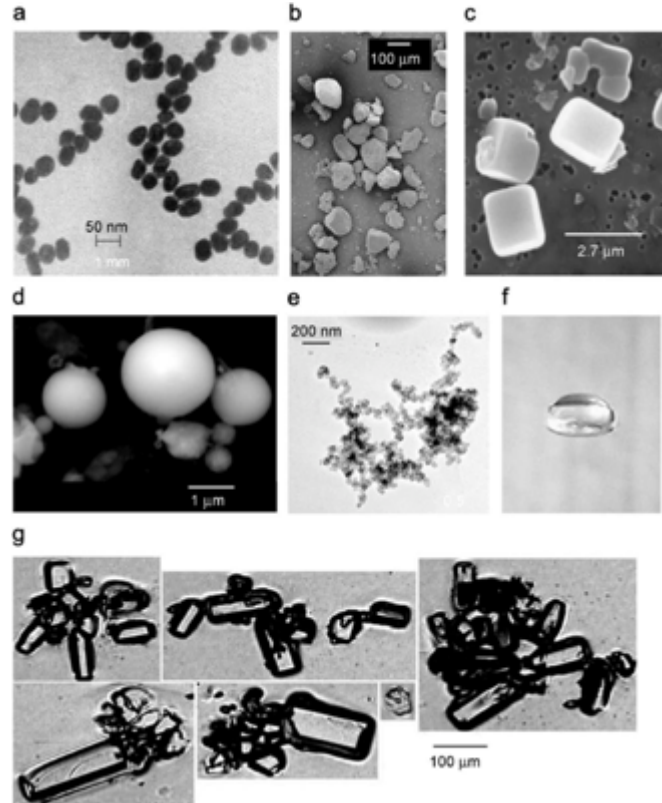
Thank you.
Questions?

PACE

Plankton, Aerosol, Cloud, ocean Ecosystem

Multi-angle polarimeter(s) on PACE

For multi-angle polarimetric observations to be beneficial for aerosol and cloud characterization and atmospheric correction they need the following capabilities:

Example atmospheric aerosols, particles that have a wide range of sizes, shapes and chemical compositions.

Spectral range

- While the total intensity reflected by land surfaces has considerable spectral variation, polarized intensity does not. A wide spectral baseline is needed to perform accurate aerosol retrievals over land.
- UV to characterize aerosol absorption would compliment OCI's UV sensitivity.

Swath width

- A broad, OCI-matching swath is needed to provide atmospheric correction for the entirety of the OCI observation.

Angular range

- A wide view angle range observes scattering angles essential for aerosol size and complex refractive index retrieval.

Polarimetric accuracy

- High accuracy needed for best aerosol and cloud retrievals

Number of viewing angles

- Roughly 5 angles needed for accurate aerosol retrievals
- Characterization of ice cloud crystal shape (Aspect Ratio - AR) and roughness requires ~10 angles. Determination of liquid cloud droplet size requires 40-60 view angles.