OCRT update on the **P**re-**A**erosols, **C**louds, & ocean **E**cosystems Mission

NASA Ocean Color Research Team Meeting

Silver Spring, MD ~ 2 May 2016

The Mission

PACE began in Dec 2014 per a HQ/ESD letter of direction

- Mission management directed to NASA GSFC
- Ocean color instrument (OCI) to be built at GSFC
- Polarimeter (optional) to be contributed, procured, or directed to JPL
- Science data processing directed to GSFC Ocean Biology Processing Group

Mission characteristics

- $805M “design-to-cost” capped mission at 65% cost confidence
    - project team, spacecraft, launch vehicle, instruments, 3 years of mission ops, calibration/validation, science data processing, mission science
- Class C (short duration, minimum risk)
- 3 year mission; 10 years of fuel
- Sun synchronous polar orbit with *2-day global coverage*
- *Equatorial crossing time between local 11:00 and 13:00*
- *OCI tilt to avoid Sun glint*
- *OCI monthly lunar calibration*

Schedule

Mar 2016: Mission Concept Review

Jun 2016: KDP-A (entry in the Phase A)

Jul 2016: Acquisition Strategy Meeting

Fall 2016: Systems Requirements Review

Aug 2022: Launch

Independent panel reviews overall mission architecture

HQ decides how the polarimeter & spacecraft are acquired or built

Independent panel reviews all (top level) mission requirements

Ocean Color Instrument (OCI)

OCI will be a scanner (rotating telescope, e.g., SeaWiFS):

- **Ground sample distance ≤ 1 km^2 at nadir**
- **5 nm resolution between 350 & 890 nm, plus SWIR bands centered on 940, 1240, 1380, 1640, 2130, & 2250 nm (all downloaded from S/C)**
- **Image artifacts < 0.5% at calibrated, top of atmosphere radiances**
- **Water-leaving reflectance uncertainties better than 20%/0.004 for 350-395 nm, 5%/0.001 for 400-695 nm, & 10%/0.002 for 700-890 nm**

Ocean Color Instrument (OCI)

OCI will be a scanner (rotating telescope, e.g., SeaWiFS):

- **Ground sample distance ≤ 1 km^2 at nadir**
  - Evaluating costs, SNR, technical aspects of 500, *750, 1000*, & 1250 m
  - Variable spatial aggregation at the edge-of-scan (a la VIIRS)
- **5 nm resolution between 350 & 890 nm, plus SWIR bands centered on 940, 1240, 1380, 1640, 2130, & 2250 nm (all downloaded from S/C)**
  - Extending spectral range to ~315 nm
  - Variable spectral super-sampling (@ 1.25 nm) for specific spectral ranges
  - Defining band centers & ideal blue-red spectrograph transition range
- **Image artifacts < 0.5% at calibrated, top of atmosphere radiances**
  - (Level-2) instrument threshold & baseline performance requirements
- **Water-leaving reflectance uncertainties better than 20%/0.004 for 350-395 nm, 5%/0.001 for 400-695 nm, & 10%/0.002 for 700-890 nm**
  - Defining more robust performance requirements for the red region (e.g., precision req. to retrieve lowest FLH of interest, SNR impacts to bio-optical inversion/derivative approaches & retrieval of gaseous transmittances in this region)

Spacecraft Altitude

- **Nominal spacecraft altitude is 675 km**
  - OCI 2-day global coverage at 60º instrument view angle
  - Polarimeter 3-day global coverage
- **Project exploring reducing the altitude to ~425 km**
  - Supports constellation flying with active instruments, e.g. LIDAR & radar, that perform better at lower altitudes
- Preliminary results indicate the OCI concept can be modified to support 425 km with a GSD of ~800 m & without reducing its SNRs
  - **Many TBDs** & questions … (lower mass, higher telescope rotation rate) … requires several additional weeks of study

Why A Polarimeter?

- **Atmospheric Correction is difficult to accurately perform without a polarimeter when absorbing aerosols are present** (e.g. dust and biomass burning are widely prevalent types of concern & are mitigated with a polarimeter)
- **Aerosol Science on the radiative forcing of climate that can be done with a polarimeter is complementary to ocean color objectives** (i.e. identification of aerosol types & sizes so that fertilization effects can be identified & estimated)
- **Cloud Science associated with cloud feedbacks is facilitated by the combined payload of an ocean color instrument & polarimeter** (while ocean color is the focus of the mission 70% of the globe is cloud covered on average)
- **Hydrosol Characterization is improved by observations of the polarization of scattered light** (based on theoretical & observational studies)

Why A Polarimeter?

The PACE Science Definition Team (SDT) determined a polarimeter flown on PACE would complement the Ocean Color Imager (OCI), but only evaluated the 3MI instrument

The ROSES Science Team prepared a consensus document on capabilities & utilities of a polarimeter for PACE

- **Cloud Science associated with cloud feedbacks is facilitated by the**

Minimum & enhanced polarimeter capabilities were identified against which to evaluate polarimeters using a range of polarization analysis techniques (sequential, temporal modulation, spectral modulation & amplitude splitting)

Coastal Sensor Trade Study

Why Study a High Spatial Resolution Ocean Color Camera for PACE?

- To respond to the breadth of science identified in the SDT Report
- HQ requested a trade feasibility study for including a coastal sensor

Project conducted a trade study for a coastal ocean color sensor

- RFI released July 2015 for minimum science capability (Low Cost)
- Project Science refined sensor capabilities (minimum to preferred)

Project assessed 13 coastal sensor candidates for cost, science capability, heritage & OCI independence

- Industry, federal, & academic institutions, plus GSFC IDL

Viable instruments need to be independent of spacecraft / OCI

- 5 of 13 candidates met this objective & preferred science capabilities

Project is exploring a new option proposed by the Canadian Space Agency that would be in part contribution & with a partnership with NRL

Coastal Sensor Trade Study

Why Study a High Spatial Resolution Ocean Color Camera for PACE?

- To respond to the breadth of science identified in the SDT Report
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A coastal sensor is not currently part of the PACE mission concept. The Project will need additional funding to support the inclusion of this (tertiary) instrument.

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- Industry, federal, & academic institutions, plus GSFC IDL

Viable instruments need to be independent of spacecraft / OCI

- 5 of 13 candidates met this objective & preferred science capabilities

Project is exploring a new option proposed by the Canadian Space Agency that would be in part contribution & with a partnership with NRL

CSA-NRL Coastal Camera (Preliminary) Basics

- Canadian-built pushbroom camera
- Hyperspectral VIS-NIR (~400-1000 nm)
- Spectral Resolution of ~8 nm (<2 nm sampling)
- ~100 m GSD at nadir
- SNR range from ~400 to 750 (for 10 nm bandwidths)
- ~240 km swath
- TBD gimbal/targeted pointing capability
- Targeting decision by NASA/CSA/NRL
- Open Data Policy
- **Many TBDs …**

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- Hyperspectral VIS-NIR (~400-1000 nm)
- Spectral Resolution of ~8 nm (<2 nm sampling)

Project is requesting overguide funding from NASA to implement a contributed coastal ocean sensor

- ~240 km swath
- TBD gimbal/targeted pointing capability
- Targeting decision by NASA/CSA/NRL
- Open Data Policy
- **Many TBDs …**

Applied Sciences

- → Working closely with HQ, GSFC, the Project, & ROSES Science Team
- → Monthly telecons with **PACE Project Team** to coordinate activities
- → Coordination on development of **PACE Mission Applied Science Plan** (deadline: KDP-B, the entry point into Phase B, circa Spring 2017)
- → Engagement of **User Communities** (presentations, workshops, Web material
- → Development of **cross mission activities** to establish connections between PACE & other NASA missions & ocean-atmosphere-terrestrial communities.

HQ POCs: Maria Tzortziou (Ocean), Ali Omar (Atmosphere), Woody Turner
Project POC: TBD
For more information, see: http://pace.gsfc.nasa.gov

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- → Development of **White-Papers** on PACE Mission Applied Science foci areas
- → Development of the **Applications Traceability Matrix (ATM)** for PACE

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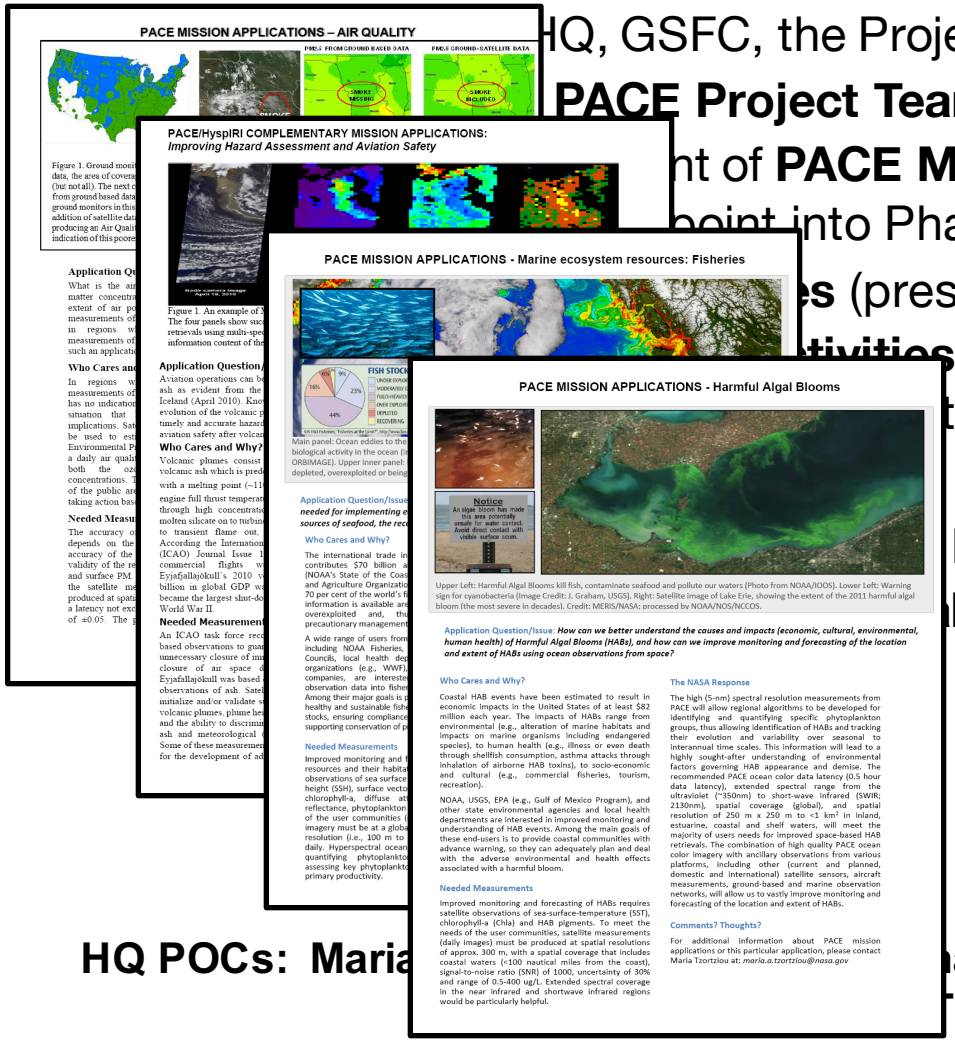
Applied Sciences

PACE Applied Science White Papers



HQ, GSFC, the Project, & ROSES Science Team

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Mission Applied Science foci areas

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PACE Applications Traceability Matrix

developed with input from the user community

PACE Application Questions & Concepts

What is the air quality forecast of particulate matter (PM) predicted from PACE measurements of the aerosol optical depth (AOD) in regions where there are no direct measurements of PM?

The EPA produces a daily air quality index which comprises both the ozone and PM concentrations. In regions where there are no direct measurements of particulate matter, satellite measurements of AOD can be used to estimate PM.

Application Readiness Level: *3*
Applied Sciences Category: *Public Health and Air Quality*
Potential Host Agency: *EPA (James Szykman)*

Mission Data Product: Aerosol Optical Depth
Spatial resolution: <1 km
Latencies: <1 hour

Projected Mission Performance: AOD within +/- 0.02 at a horizontal resolution of 250 m
Ancillary Measurements: Aerosol vertical distributions, Surface PM concentrations (at a few locations)

What is the volcanic ash concentration during and after a volcanic eruption? Is there an impact on air quality as a result of a volcanic material deposited in coastal/populated regions?

Measurements collected to support PACE atmospheric corrections in coastal regions may be used to quantify the concentration of material associated with volcanic eruptions. These data may be useful in enabling prudent ash-related aviation hazard mitigation policies and advisories.

Application Readiness Level: *3*
Applied Sciences Category: *Disaster Mitigation, Public Health and Air Quality*
Potential Host Agency: *FAA, EPA, NOAA, International Civil Aviation Organization, Volcanic Ash Advisory Centers (Shobha Kondragunta, NOAA)*

Mission Data Product: Aerosol Optical Depth
Spatial resolution: <1 km
Latencies: <1 hour

Projected Mission Performance: AOD within +/- 0.02 at a horizontal resolution of 250 m
Ancillary Measurements: Aerosol vertical distributions, Sulfur dioxide concentrations

How do exchanges across the land-ocean interface influence carbon and nutrient loadings, water quality, and ecosystem dynamics in coastal waters?

The EPA Safe and Sustainable Water Resources Research Program aims at developing core indicators of water resource integrity and sustainability as well as indicators of key drivers and pressures across a range of spatial and temporal scales for use in integrated assessments. Integration of satellite observations with field measurements and modeling tools is needed to demonstrate assessment of sustainability and integrity of water resources.

Application Readiness Level: *3*
Applied Sciences Category: *Water Resources, Oceans, Coasts, Great Lakes, Ecosystems and Human Health*
Potential Host Agency: *EPA (Blake Schaeffer)*

Mission Data Products: Chl-*a*, K_d (water quality)
Spatial resolution: Estuaries: ≤250 m; Coastal Waters: ≤500 m
Coverage: Minimum distance: 5.5 km; Maximum distance: 22 km
Latencies: 0.5-12 hours

Projected Mission Performance: 0.5 hour data latency, direct broadcast of 5 nanometer resolution data, spatial resolution of 1 km²(+/-10%) at all angles across track. Along track spatial resolution of 250 m² to <1 km² for inland, estuarine, coastal and shelf area retrievals for all bands or a subset of bands.
Ancillary Measurements: Aerosols (spectral shape, vertical distribution), NO_2, O_3 concentrations for atmospheric correction

How are the productivity and biodiversity of coastal ecosystems changing, and how do these changes relate to natural and anthropogenic forcing, including local to regional impacts of climate variability?

PACE satellite-derived optics and biogeochemical variables may be assimilated into operational seasonal-to-interannual computer models. As a result, PACE data may improve model skills and forecasting capabilities of the Global Ocean Data Assimilation System / Coupled Forecast System (GODAS/CFS) and Real-Time Ocean Forecast System (RTOFS).

Application Readiness Level: *3*
Applied Sciences Category: *Ecological Forecasting*
Potential Host Agency: *NOAA (Paul DiGiacomo, Cara Wilson)*

Mission Data Products: Chl-*a*, K_{PAR}, K_{490}
Spatial resolution: 1 km
Temporal resolution: Daily
Coverage: Global
Latencies: 12 hours

Projected Mission Performance: 0.5 hour data latency, direct broadcast of 5 nanometer resolution data, spatial resolution of 1 km²(+/-10%) at all angles across track. Along track spatial resolution of 250 m² to <1 km² for inland, estuarine, coastal and shelf area retrievals for all bands or a subset of bands.
Ancillary Measurements: Aerosols (spectral shape, vertical distribution), NO_2, O_3 concentrations for atmospheric correction

How can PACE help with oil spill monitoring and response?

NOAA's subsurface oil monitoring program uses various modeling and observational approaches (airborne, shipborne, ground-based, space-based measurements) to track oil spills: where the oil is going on the surface and under the sea, and what the consequences are to local communities, wildlife and the marine environment (e.g., Deepwater Horizon/BP Oil Spill).

Application Readiness Level: *3*
Applied Sciences Category: *Disasters, Water Resources*
Potential Host Agency: *NOAA (Paul DiGiacomo, Cara Wilson)*

Mission Data Product: Visible/true color imagery
Spatial resolution: <300 m
Temporal resolution: 1 hr
Coverage: Coastal waters: <185 km 50N - 10N 106 W- 60W
Latencies: 0.5-1 hours

Projected Mission Performance: 0.5 hour data latency, direct broadcast of 5 nanometer resolution data, spatial resolution of 1 km²(+/-10%) at all angles across track. Along track spatial resolution of 250 m² to <1 km² for inland, estuarine, coastal and shelf area retrievals for all bands or a subset of bands.
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ARL 3: **Proof of Application Concept (Viability Established)** - Feasibility studies to assess the potential viability of and provide a proof-of-concept for the application have been conducted

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- → Development of **White-Papers** on PACE Mission Applied Science foci areas
- → Development of the **Applications Traceability Matrix (ATM)** for PACE

- → Development of an **Early Adopters Program** to demonstrate applications of proposed data products for societal benefits (when mission goes to Phase A)

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Communications

- Responsible for news releases, features, mission status reports, products
- Working closely with HQ, GSFC, Project, NASA Earth, other missions, science team
- Cross-cutting efforts: NASA-wide Earth Right Now Communications Campaign (e.g. Earth 24Seven, Earth Expeditions campaigns: NAAMES, KORUS-OC, CORAL)
- Web: http://pace.gsfc.nasa.gov
- Social media team:


facebook.com/NASA.Oceans


@NASAOceans


nasaoceans

- Public engagement: participation by NASA GSFC Ocean Ecology Lab
- Education & Public Outreach no longer within missions – now farmed out under CAN

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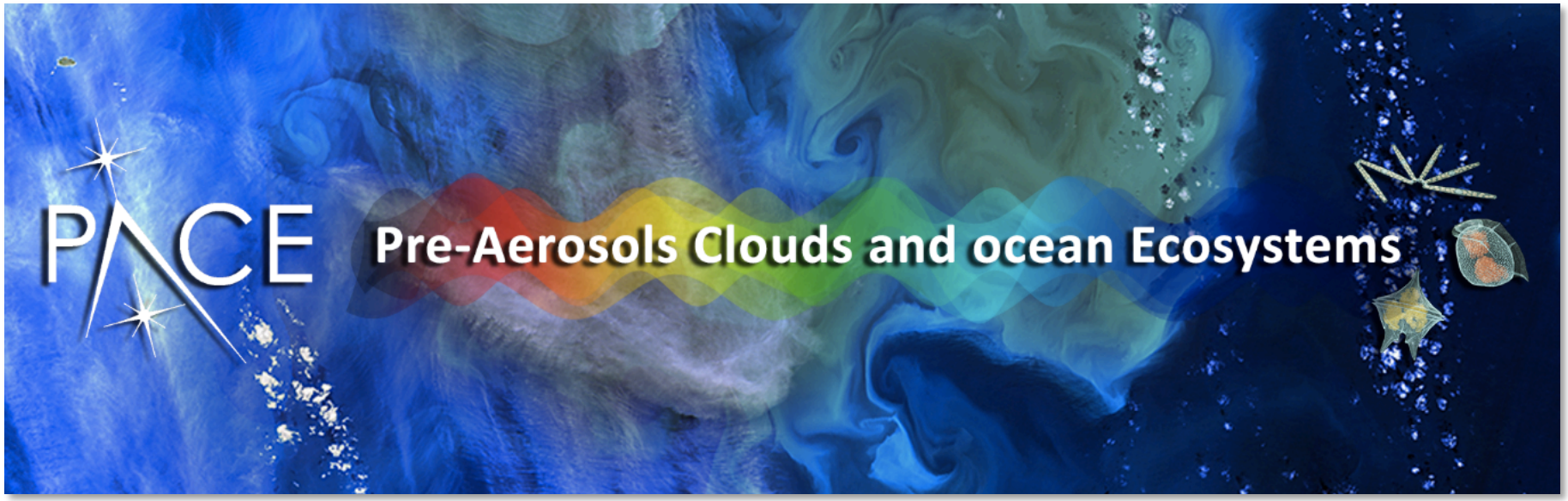
  - May 6 – NAAMES field campaign feature
  - May 10 – NAAMES NASA Social in Woods Hole
  - May 12-23 – NAAMES C-130 field campaign with PACE Communications team producer
  - May 20 – KORUS-OC field campaign feature: http://nasa.gov/earthexpeditions
  - Jun 4 – World Ocean Day, Smithsonian Museum of Natural History in Washington, DC
  - Jul 27 – NASA GSFC Science Jamboree



QUESTIONS?

BACKUP

Mission Threshold Req's

	Mission Threshold Req.	Rationale
Earth spatial resolution	1 km^2 at nadir	Provides adequate spatial resolution for global oceanographic & atmospheric climate-related studies
Orbit	Sun synchronous, polar orbit w/ local 11:00-13:00 Equatorial crossing time	Maximizes the illumination of the ocean & minimizes the optical pathlength of the atmosphere to be removed through the ocean color atmospheric correction process
Global coverage	2-day to solar zenith ≤ 75° & sensor zenith ≤ 60°	Yields an adequate fraction of clear-sky scenes to allow global-scale computations at monthly, seasonal, & annual timescales
Instrument tilt	±20° to avoid Sun glint	Maximizes spatial coverage given that ocean color data products cannot be reliably acquired in the presence of Sun glint
Lunar calibration	Monthly through Earth view port w/ illumination of all science detectors	Required to achieve radiometric stability of 0.1% at the top of the atmosphere, which is necessary to detect trends in geophysical variables that vary on the order of 1-5% per decade
Image artifacts	Striping artifacts ≤ 0.5% and correctable to noise levels	Spatial & temporal analyses of geophysical data products cannot tolerate image artifacts; 0.5% mis-calibration at the top-of-the atmosphere leads to 5% uncertainty in water-leaving reflectances
Accuracy / precision of water-leaving reflectances (unitless)	20% or 0.004 for 350-395 nm 5% or 0.001 for 400-700 nm 10% or 0.002 for 700-900 nm	The spectral matching & spectral derivative analyses to be made possible by PACE to address advanced science questions require high absolute accuracies
Mission duration	3 years w/ 10 years of fuel	Longest time-series possible is desired to detect climate trends
UV-VIS-NIR capabilities	350-890 nm @ 5 nm	Required to reveal oceanographic constituents that cannot currently be resolved by heritage instruments
SWIR capabilities	940, 1240, 1380, 1640, 2130, and 2250 nm	Required to continue time-series of heritage cloud & aerosol products from MODIS & VIIRS, and to enhance the ocean color atmospheric correction process

Desired Polarimetric Capabilities

Rationale for prioritization	Priority	Minimum Capability	Enhanced Capability
PACE is a climate-science mission. Global polarimetry will: (1) Reduce uncertainties in aerosol characterizations for input into global climate forcing (e.g., IPCC) models; and (2) Improve ocean color atmospheric correction, thus improving understanding of global ocean ecosystems and carbon cycles	1a	**% ground coverage of OCI Swath** Not specified *Target: 50%*	**% ground coverage of OCI Swath** Not specified *Target 90%*
	1b	**Swath width** ±15-25°	**Swath width** ±30°
The utility of the measurements degrades when uncertainties exceed 1%	2	**DOLP uncertainty** <0.01	**DOLP uncertainty** <0.005
Spectral resolution, number of polarized bands, and angular range (# of scattering angles) all dictate what derived products can be produced	3a	**Spectral channels** >4 over 400-1600 nm + 2200 nm only if sparse angular sampling	**Spectral channels** Minimum + 940 nm or O2 A-band and 1378 or 1880 nm
	3b	**Angular range** ±50° at satellite in all bands	**Angular range** ±55° at satellite in all bands
Multiangular capabilities enhance the ability to estimate many cloud and aerosol properties	4a	**Number of angles** 5-6 for clouds	**Number of angles** ~50 for cloud bows
	4b	**Number of angles** 4 for aerosols	**Number of angles** 10 for aerosols
4 km is adequate for climate science		**Pixel size / Spatial resolution** 5 km	**Pixel size / Spatial resolution** 1 km
All concepts meet the radiometric and SNR requirements		**Radiometric uncertainty** 5%	**Radiometric uncertainty** 3%
		SNR Not specified	**SNR** Not specified

Enhanced capabilities identified based on recent work in the peer reviewed literature.
The minimum capability follows those for 3MI, which was featured in the PACE SDT Report.

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	1b	**Swath width** ±15-25°	**Swath width** ±30°
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In collaboration with HQ/ESD, the Project is exploring several acquisition strategies, including instrument concepts from JPL, Netherlands SRON, ESA/SELEX, others

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