NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission update

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Acknowledgments: PACE Team

https://pace.gsfc.nasa.gov

Outline

- What is PACE?
- Current Status
- Challenges and solution for accomplishing heritage and advanced science
- What Multi-Angle Polarimetry adds to PACE?
- High spatial resolution capability
- Why PACE OCI is a quantum leap for OC?
- OCI SNR
- Data Products

What is PACE?

aerosol optical thickness

ocean chlorophyll
normalized land vegetation index

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

And so much more …

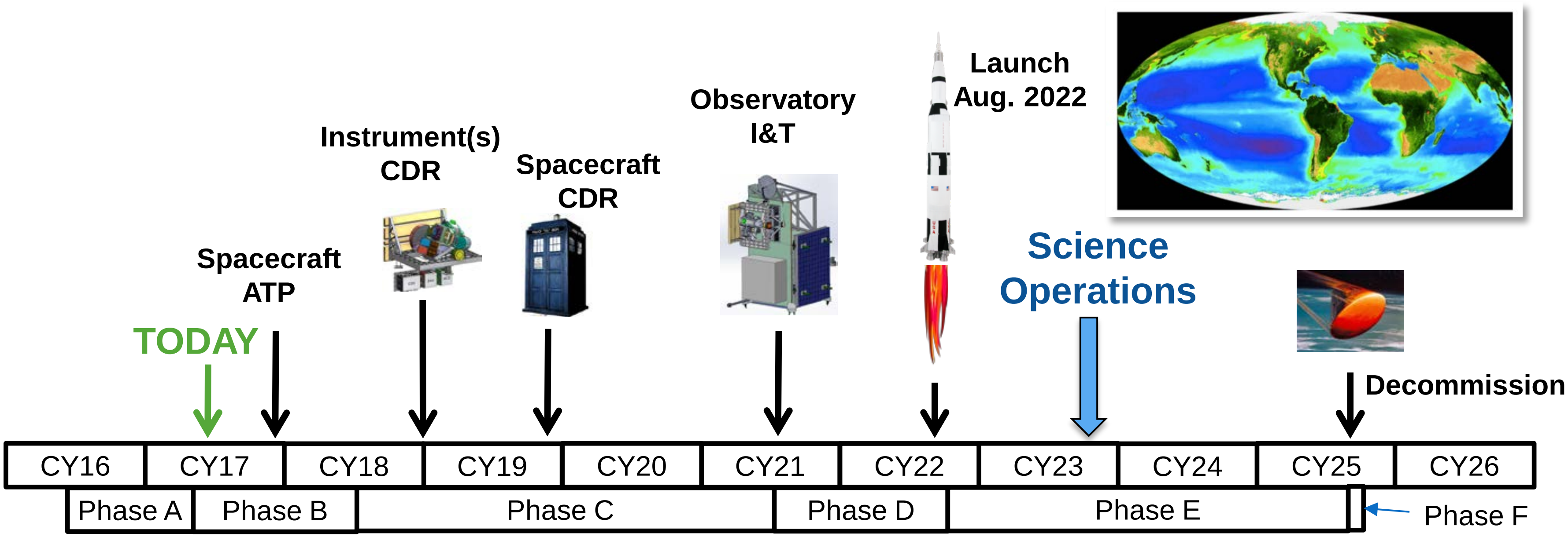
PACE science objectives are defined in the PACE SDT Report (2012)

cloud fraction

Mission Architecture, Cost, and Schedule

Mission Characteristics

- Hyperspectral UV-Vis-NIR ocean color instrument with discrete SWIR bands & a possible multi-angle polarimeter
- 2-day global coverage to solar & sensor zenith angles of 75^{o} & 60^{o}
- Sun-synchronous, polar orbit with local Equatorial crossing of ~13:00
- 675-km altitude and 98^{o} inclination
- Class C (limited redundancy) for 3-yrs of operations & 10-yrs of fuel
- $805M Design-to-Cost (cost-capped)



Current Status of PACE

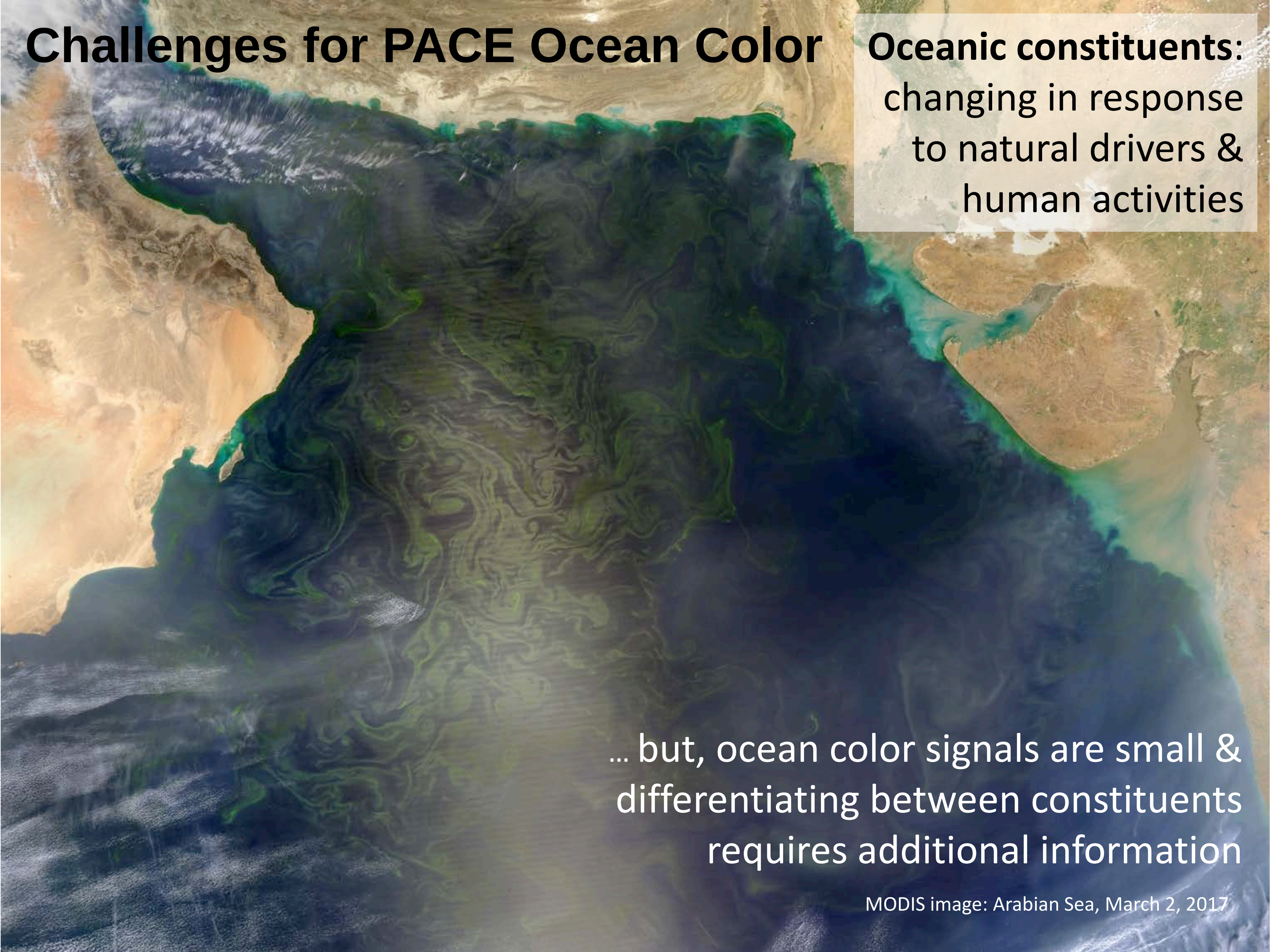
President's "Skinny Budget" for FY 2018 recommended cancelling PACE and several other Earth Science Missions

- Congress still to act on the FY 2018 budget
- Direction from Goddard and NASA Mngmt has been consistent: *PACE Project should proceed as planned*
- 2017 budget approved in early May provides $90M for PACE through Sept. 30th.
- PACE is on track with all Phase B activities
- Official KDP-B review is scheduled for June 1st
- PACE Applications Plan almost finished
- PACE project remains optimistic
  - Continued support from the community and public helps immensely – THANK YOU!!!

Challenges for PACE Ocean Color

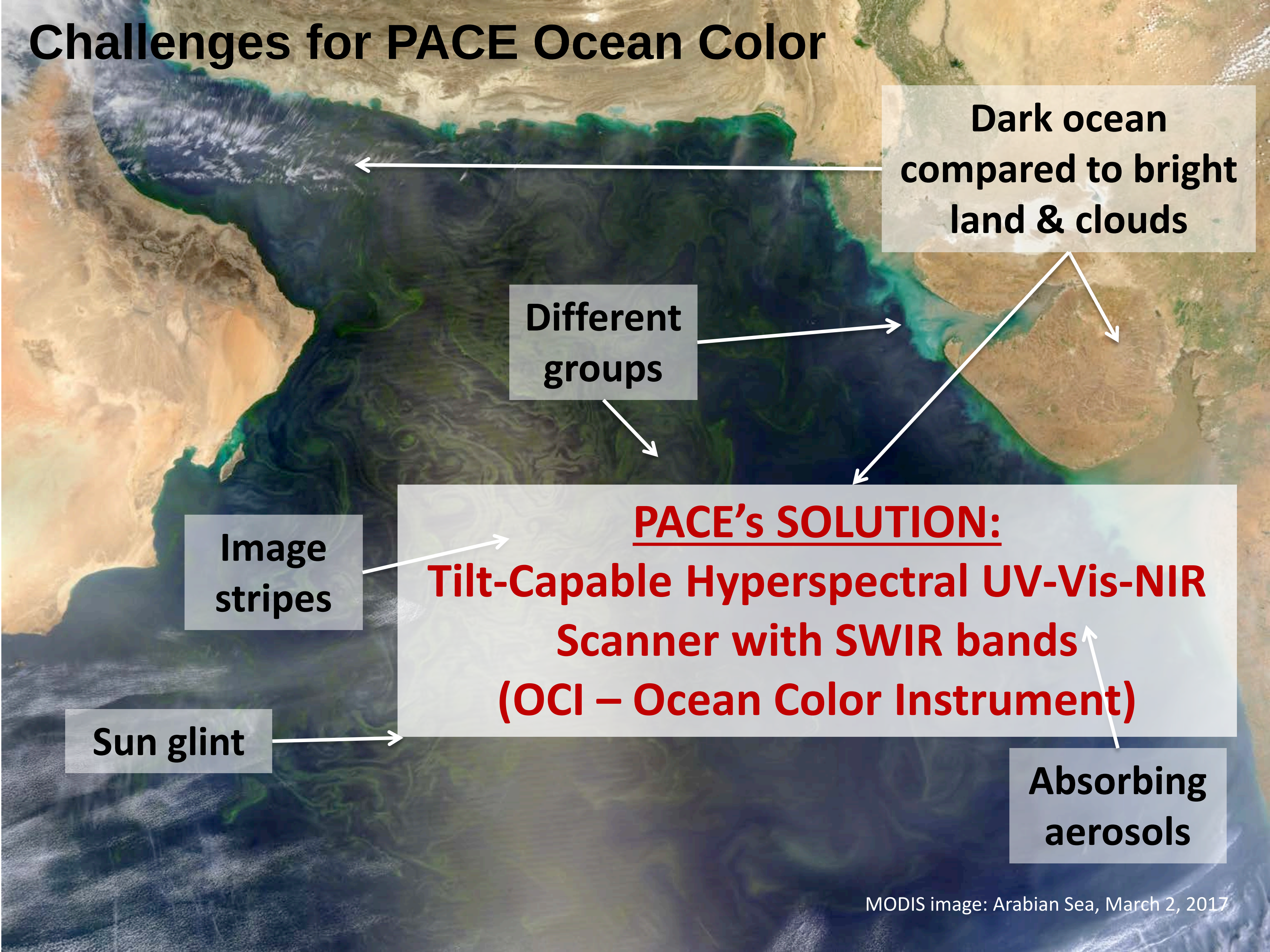
Oceanic constituents: changing in response to natural drivers & human activities

… but, ocean color signals are small & differentiating between constituents requires additional information



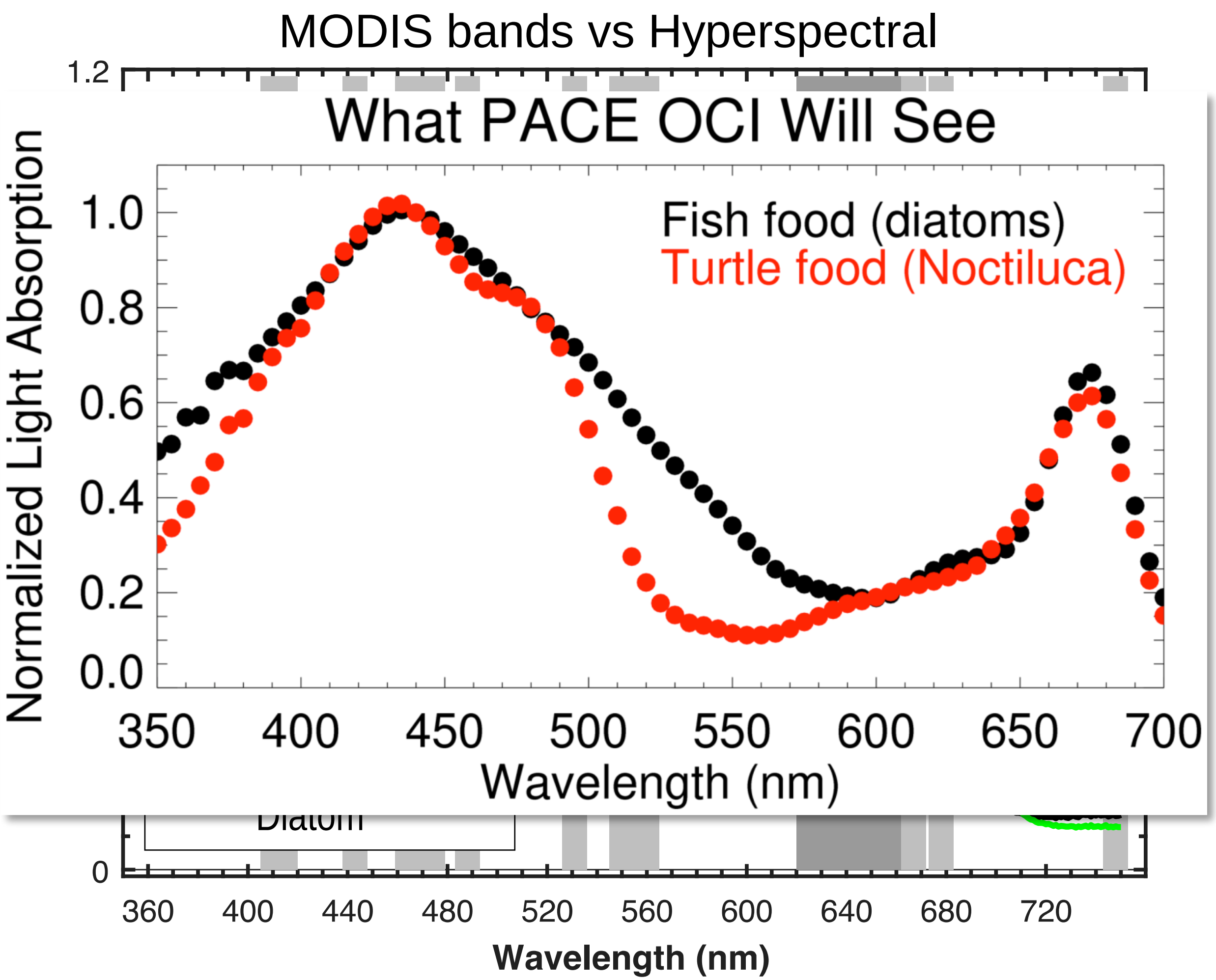
MODIS image: Arabian Sea, March 2, 2017

Challenges for PACE Ocean Color



The step from multi-spectral radiometry to spectroscopy is not an incremental one – it's a *quantum leap*

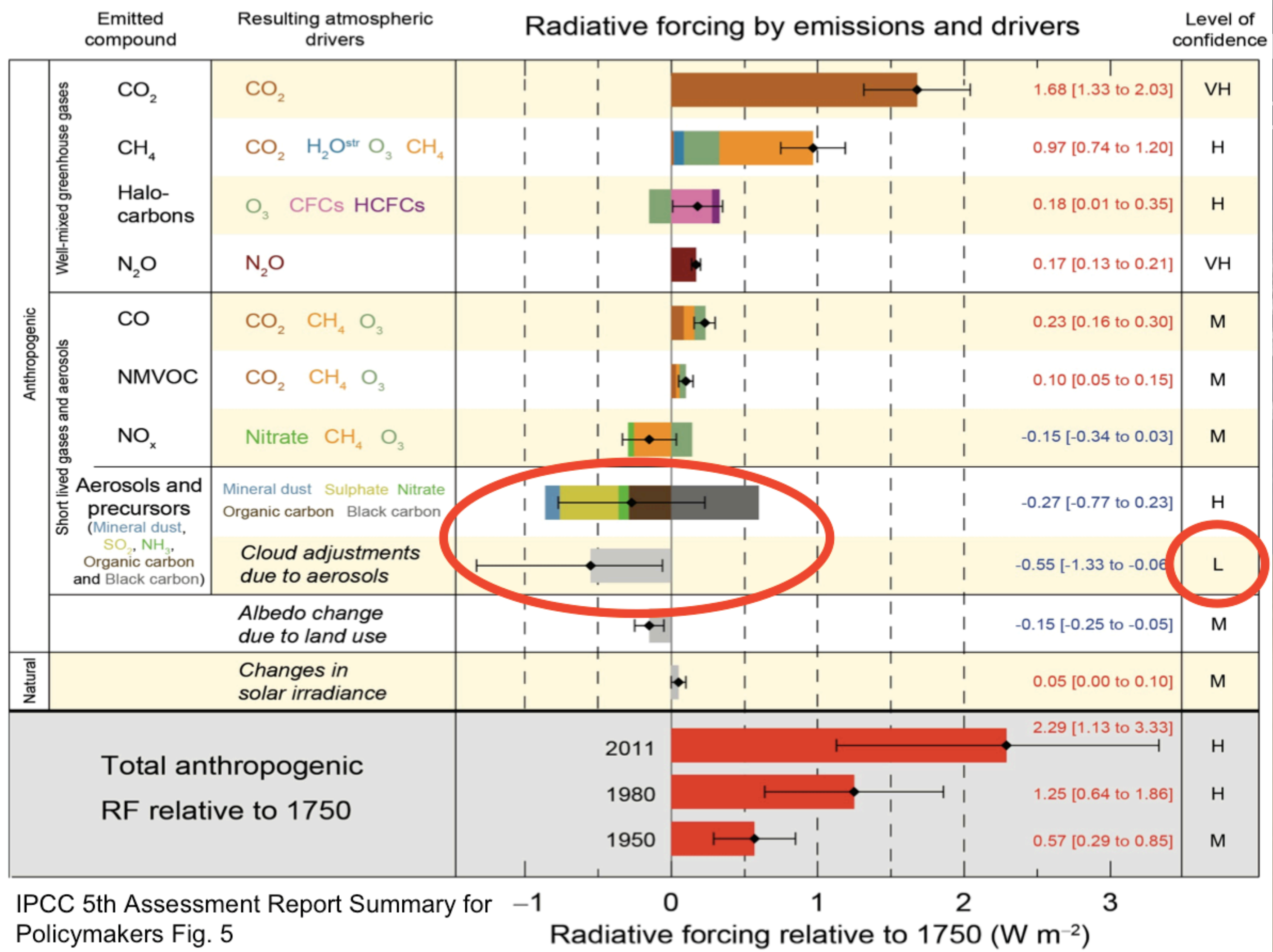
- **Cannot distinguish phytoplankton community composition with a small number of bands**



Why not just add more bands to a conventional instrument design?

There are 1000s of phytoplankton, each with different absorption spectra; **only an instrument that sees all wavelengths** offers an opportunity to truly **monitor ecosystems, manage fisheries, identify and quantify HABs, and understand the global carbon cycle**

erosols & clouds: certainty terms in radiative models



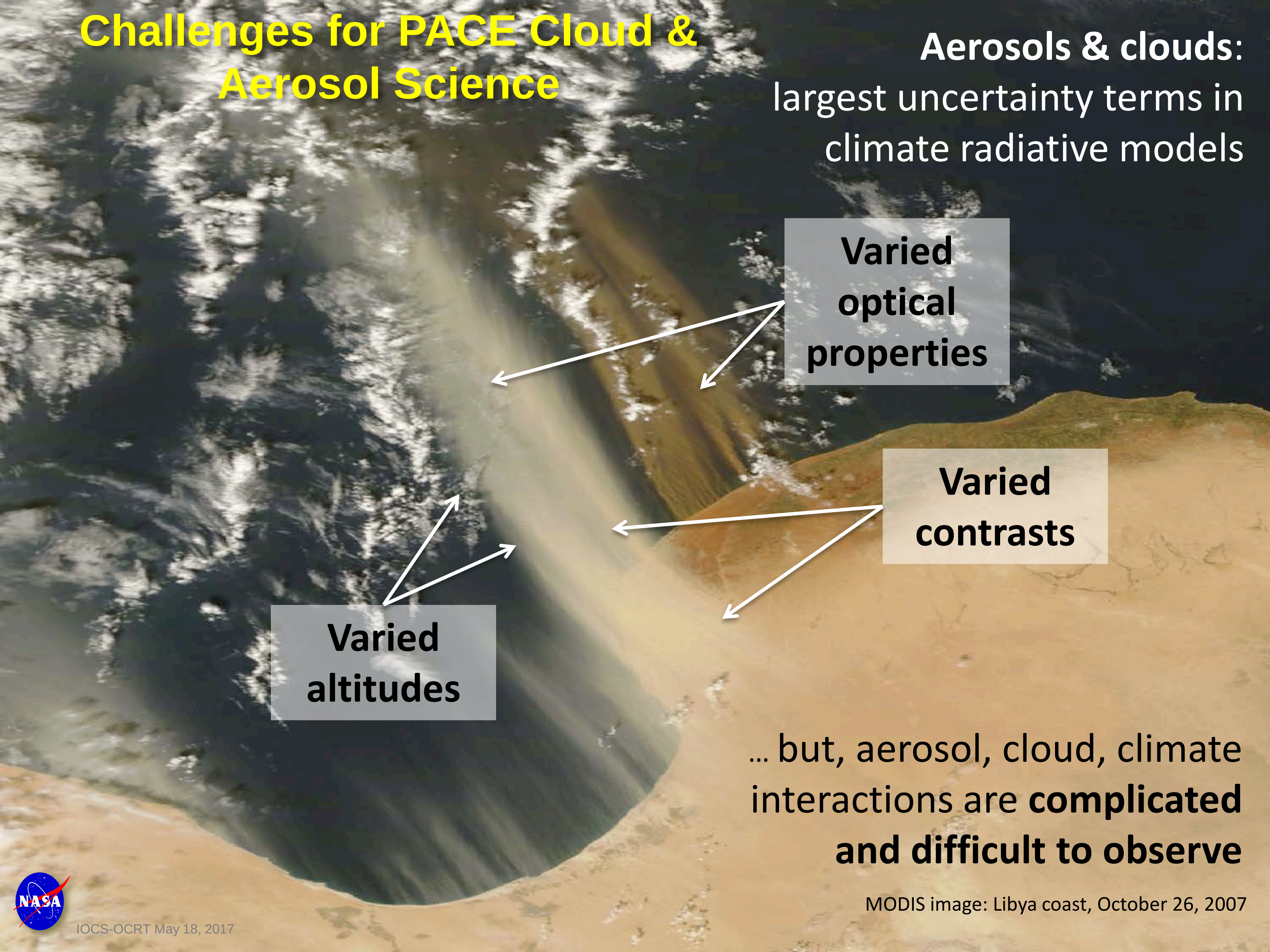
IPCC 5th Assessment Report Summary for Policymakers Fig. 5

… but, aerosol, cloud, climate interactions are **complicated and difficult to observe**

MODIS image: Libya coast, October 26, 2007

Challenges for PACE Cloud & Aerosol Science

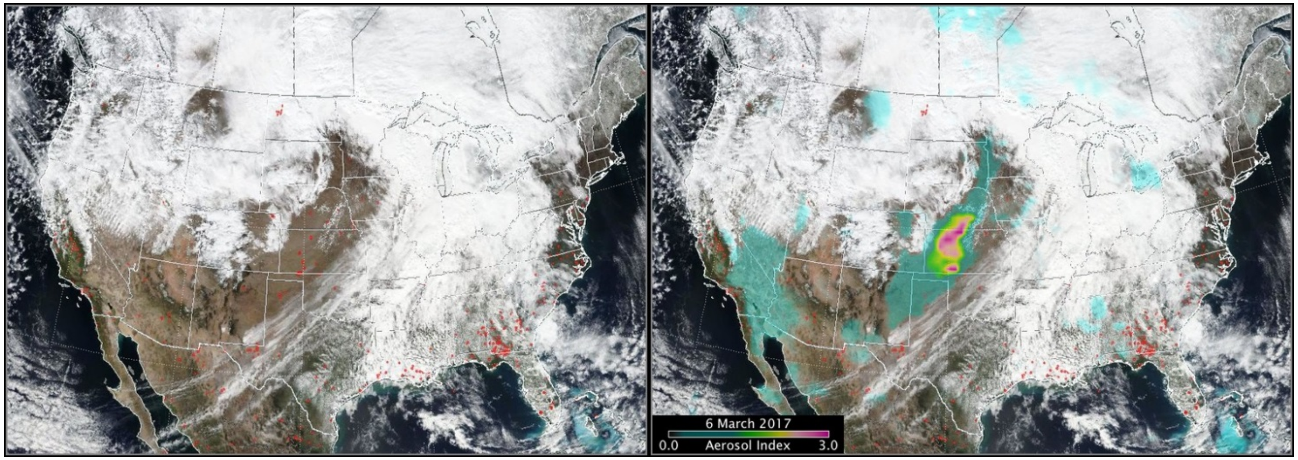
Aerosols & clouds: largest uncertainty terms in climate radiative models



… but, aerosol, cloud, climate interactions are **complicated and difficult to observe**

MODIS image: Libya coast, October 26, 2007

OCI atmospheric improvements over heritage

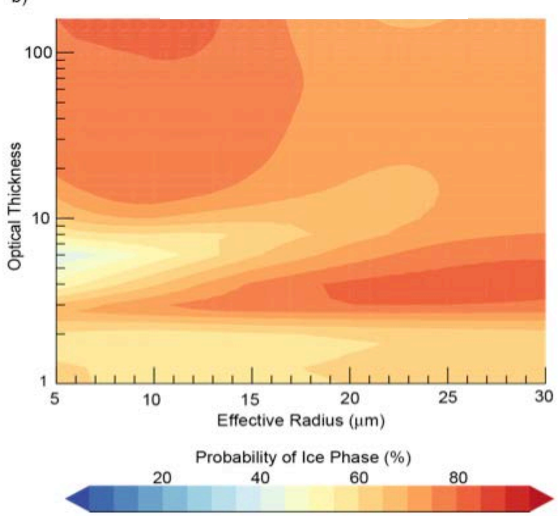


VIIRS RGB + OMPS Aerosol Index

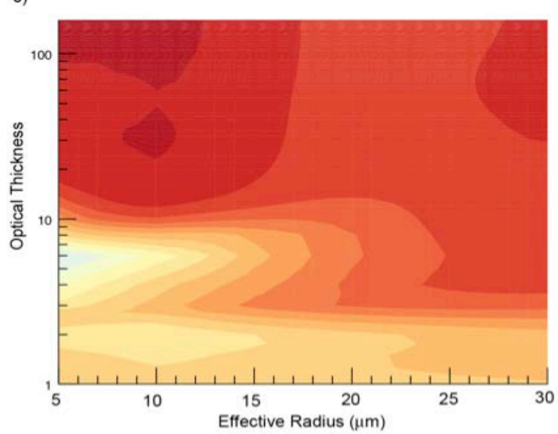
Higher spatial resolution than many heritage products

UV + oxygen-A bands to estimate aerosol concentrations & absorption magnitudes, not just an index

VIIRS bands



PACE bands



Deeper red indicates improved probability of detection of ice phase

Two 2-μm bands improve retrievals of cloud thermodynamic phase

From Coddington et al. 2016, in preparation.

What would a multi-angle polarimeter add to PACE?

- Unsurpassed aerosol and cloud measurements, including aerosol characterization **to climate-relevant accuracy**
- Improved characterization of aerosol absorption and vertical profile, which will also benefit ocean color atmospheric correction
- Additional data products (e.g. wind speed) for use in ocean color data product generation
- New and advanced polarization-based ocean color data products (e.g., marine particle sizes)

Usefulness of planned 3MI on ESA missions to assist with OCI atmospheric correction/retrievals is limited because of differences in spatial and temporal sampling.

- *Planned 3MI instruments will fly on a polar orbiter with a 09:30 equator crossing time with 824 km orbital altitude… PACE will have an equator crossing time close to 13:00 and a 675 km orbital altitude.*

What about High Spatial Resolution Capability?

- **PACE Project investigated ~50 m to 500 m spatial capability**
  - Finer spatial resolution on OCI – Not Technically Feasible
  - Purchase/build a coastal camera – Too expensive under cost-cap
- **CSA (with NRL) offered to contribute COCI to PACE**
  - ~100 m spatial resolution; 240 km swath; 3-day revisit capable
  - Hyperspectral UV-Vis-NIR; 5 nm bands; high SNR; 3 SWIR bands
- **PACE Project worked with CSA and NRL to enable this**
  - Identified an "ad hoc science team" and convened a workshop in June 2016 with CSA and NRL Users and Science Team; conferred with PACE ST; developed a white paper describing science and application benefits
  - Shared technical specifications to determine feasibility
  - Provided NASA HQ with the white paper and cost estimate for accommodating COCI on PACE (2-axis gimbal, I&T, SDS, science …)

- *NASA HQ did not approve funding to accommodate COCI*
- *CSA continues to seek a host for COCI*
  - *CSA continues COCI instrument development*

PACE OCI: *a quantum leap*

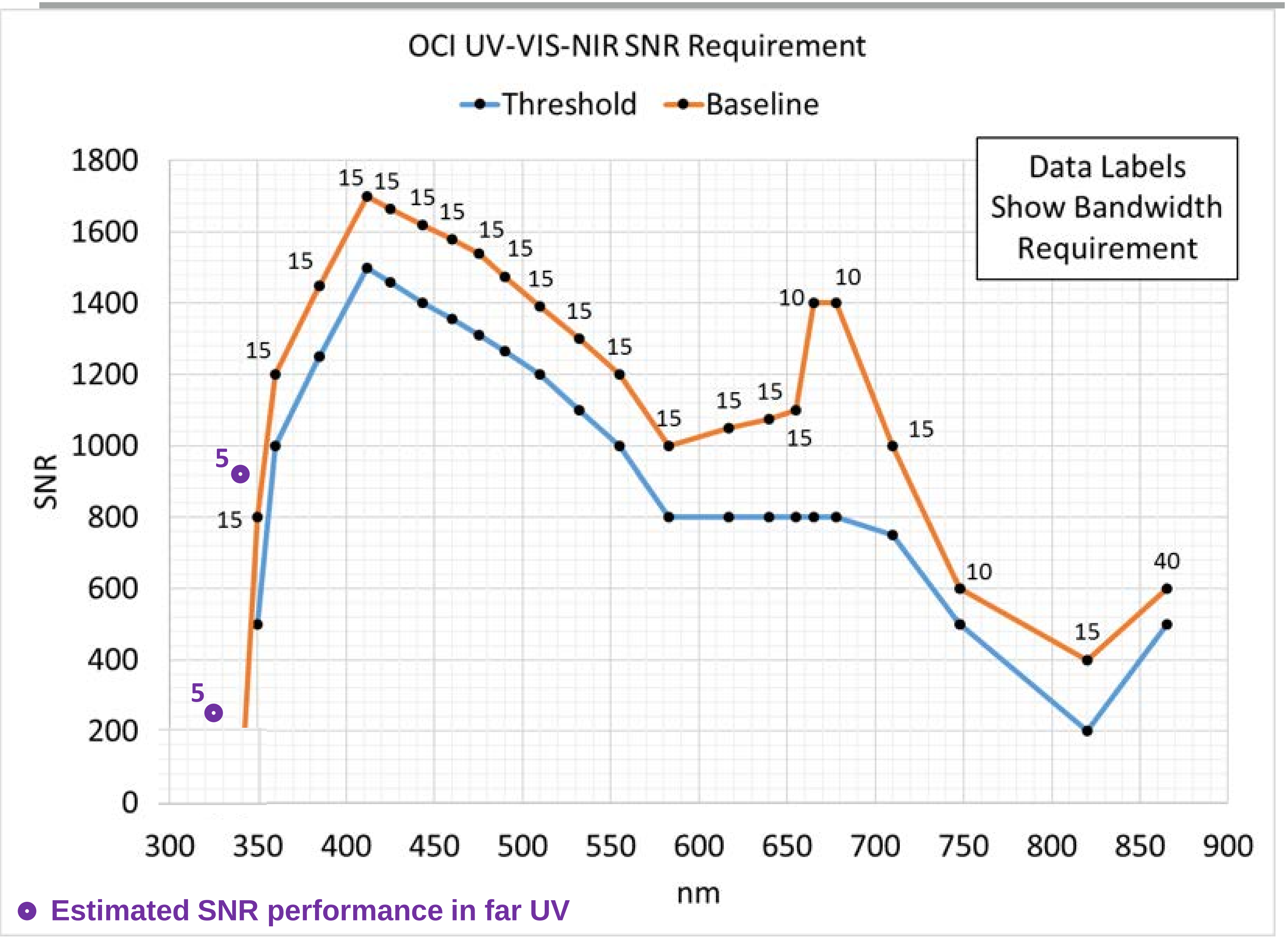
What makes OCI more advanced relative to prior ocean color instruments?

PACE OCI will be the ***first ever to include all*** *of the following:*

- **2-day global coverage** at 1-km
- **hyperspectral radiometry** from the ultraviolet to near-infrared (350-885 nm); complete downlink of **5 nm spectral resolution** data
  - **Spectral oversampling** - overlapping 5 nm bands (1.25 nm steps)
  - Goal to **extend to 320 nm** (ozone)
- **6 SWIR bands** (0.94, 1.25, 1.38, 1.61, 2.13, 2.26 μm)
  - **considering a 1040 nm band**
- **>115 discrete spectral bands**
- High SNRs **(esp. UV-Blue region)**
- a single science detector to **inhibit image striping**
- Total calibrated instrument **artifacts < 0.5%** at top-of-atmosphere
- semi-monthly **lunar calibration** + on-board solar diffuser mechanisms
- **fore / aft tilt** to avoid Sun glint

Ocean Leaving Reflectance Accuracy	**20% or 0.004: 350-395 nm** **5% or 0.001: 400-600 nm** **10% or 0.0005: 600-800 nm**

OCI UV-VIS-NIR Radiometric Precision Requirement



PACE Data Products

Standard OCI Ocean data products

- Spectral ocean water-leaving reflectances
- Chlorophyll-a
- Inherent Optical Properties (a's & b's)
- PAR
- Diffuse attenuation coefficient
- Particulate Organic Carbon
- Particulate Inorganic Carbon
- Fluorescence Line Height

OCI Atmospheric data products

- Spectral aerosol optical depth
- Cloud layer detection
- Cloud top pressure
- Liquid & ice cloud optical depth
- Liquid & ice cloud effective radius
- Shortwave radiation effect

Baseline Advanced OCI data products

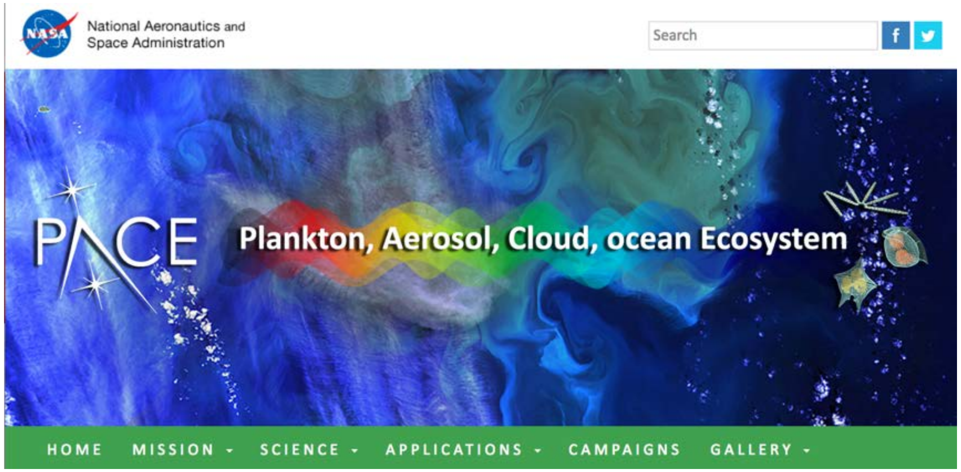
- Phytoplankton community structure
- Phytoplankton physiology parameters
- Photosynthetic pigments
- Primary/community production
- Dissolved Organic Carbon
- Particle abundances
- Particle size distributions
- Carbon fluxes & export

Polarimeter data products

- Aerosol particle size distributions
- Aerosol optical depth
- Aerosol refractive index
- Aerosol single scattering albedo
- Aerosol shape & non-spherical fraction
- Aerosol layer height
- Cloud optical depth
- Cloud liquid particle size distributions
- Cloud ice particle shape & roughness
- Cloud top & base height

and many other data products … (land)

PACE Website – Applications White Papers



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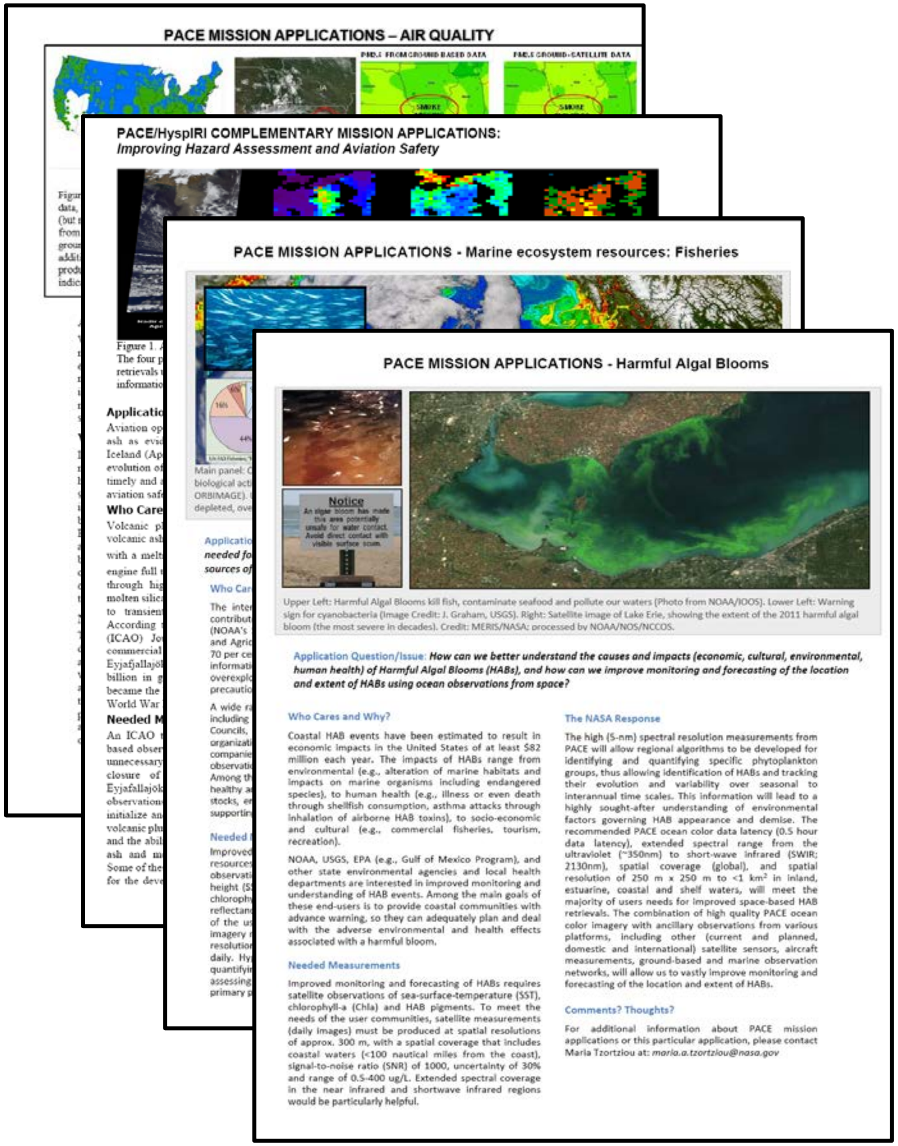

PACE MISSION APPLICATIONS - Harmful Algal Blooms

Upper Left: Harmful Algal Blooms kill fish, contaminate seafood and pollute our waters (Photo from NOAA/IOOS). Lower Left: Warning sign for cyanobacteria (Image Credit: J. Graham, USGS). Right: Satellite image of Lake Erie, showing the extent of the 2011 harmful algal bloom (the most severe in decades). Credit: MERIS/NASA; processed by NOAA/NOS/NCCOS.

Application Question/Issue: ***How can we better understand the causes and impacts (economic, cultural, environmental, human health) of Harmful Algal Blooms (HABs), and how can we improve monitoring and forecasting of the location and extent of HABs using ocean observations from space?***

Who Cares and Why?

Coastal HAB events have been estimated to result in economic impacts in the United States of at least $82 million each year. The impacts of HABs range from environmental (e.g., alteration of marine habitats and impacts on marine organisms including endangered species), to human health (e.g., illness or even death through shellfish consumption, asthma attacks through inhalation of airborne HAB toxins), to socio-economic and cultural (e.g., commercial fisheries, tourism, recreation).

NOAA, USGS, EPA (e.g., Gulf of Mexico Program), and other state environmental agencies and local health departments are interested in improved monitoring and understanding of HAB events. Among the main goals of these end-users is to provide coastal communities with advance warning, so they can adequately plan and deal with the adverse environmental and health effects associated with a harmful bloom.

Needed Measurements

Improved monitoring and forecasting of HABs requires satellite observations of sea-surface-temperature (SST), chlorophyll-a (Chla) and HAB pigments. To meet the needs of the user communities, satellite measurements (daily images) must be produced at spatial resolutions of approx. 300 m, with a spatial coverage that includes coastal waters (<100 nautical miles from the coast), signal-to-noise ratio (SNR) of 1000, uncertainty of 30% and range of 0.5-400 ug/L. Extended spectral coverage in the near infrared and shortwave infrared regions would be particularly helpful.

The NASA Response

The high (5-nm) spectral resolution measurements from PACE will allow regional algorithms to be developed for identifying and quantifying specific phytoplankton groups, thus allowing identification of HABs and tracking their evolution and variability over seasonal to interannual time scales. This information will lead to a highly sought-after understanding of environmental factors governing HAB appearance and demise. The recommended PACE ocean color data latency (0.5 hour data latency), extended spectral range from the ultraviolet (~350nm) to short-wave infrared (SWIR; 2130nm), spatial coverage (global), and spatial resolution of 250 m x 250 m to <1 km^2 in inland, estuarine, coastal and shelf waters, will meet the majority of users needs for improved space-based HAB retrievals. The combination of high quality PACE ocean color imagery with ancillary observations from various platforms, including other (current and planned, domestic and international) satellite sensors, aircraft measurements, ground-based and marine observation networks, will allow us to vastly improve monitoring and forecasting of the location and extent of HABs.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Maria Tzortziou at: *maria.a.tzortziou@nasa.gov*