Sea to Sky:

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

Jeremy Werdell
PACE Project Scientist
NASA Goddard Space Flight Center

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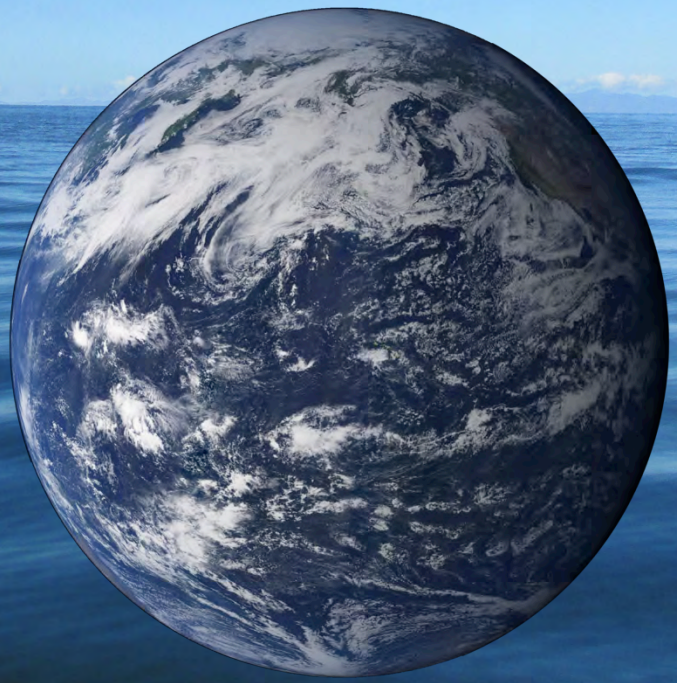
"How inappropriate to call this planet Earth, when it is quite clearly Ocean"

Arthur C. Clarke

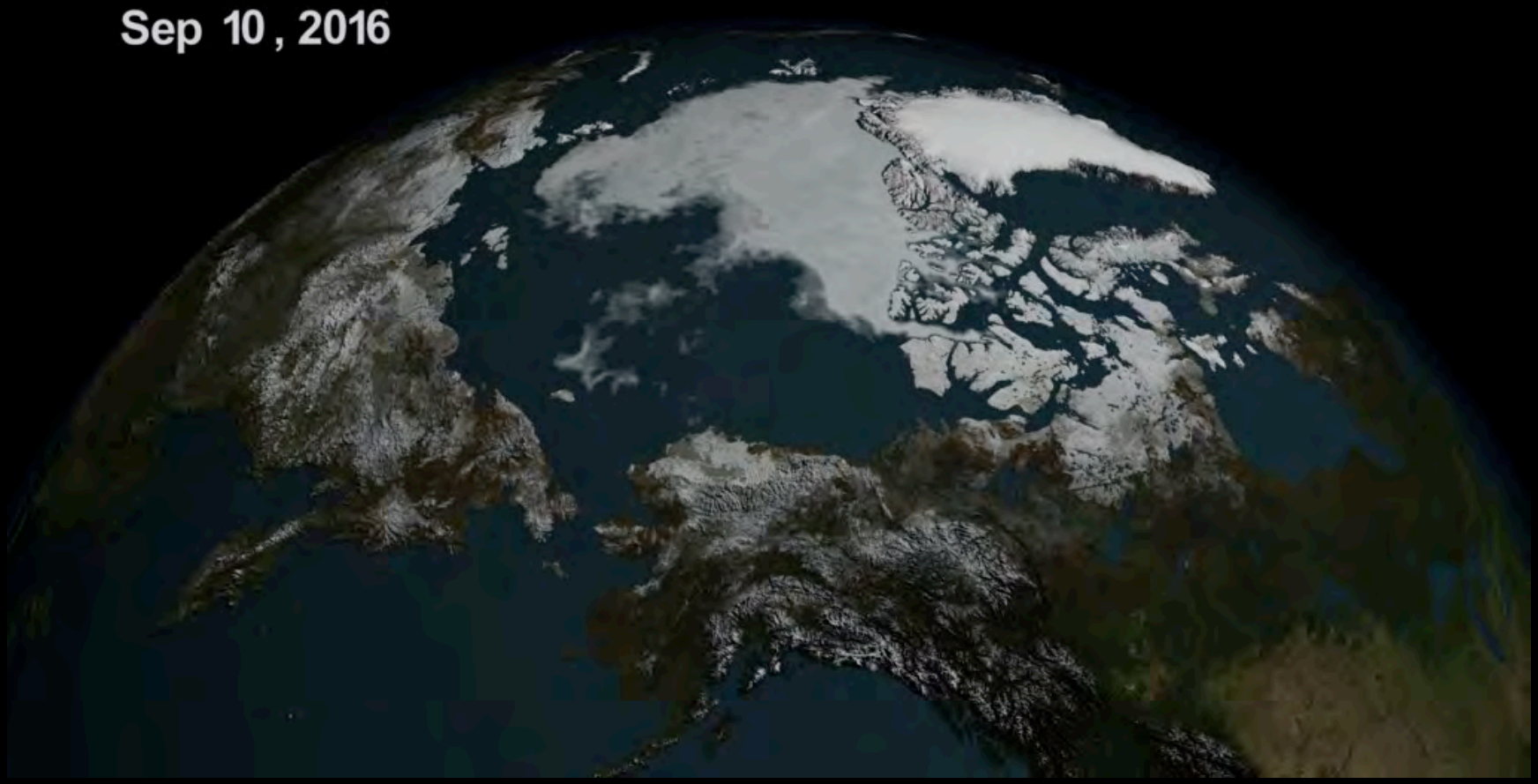
PACE




Earth's atmosphere moderates the Sun's radiation, creating a climate, enabling our planet to support life.

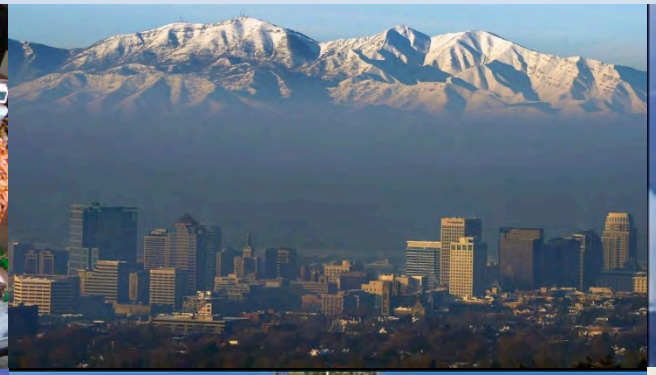

From jobs to food to recreation to regulating climate, the ocean is vital to all life on Earth.

But, due to natural & human drivers, our planet is changing.

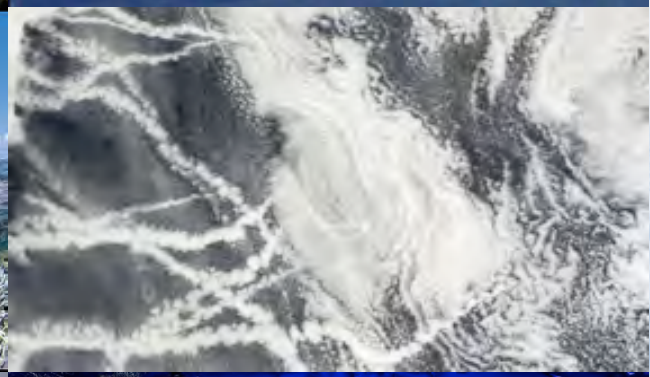


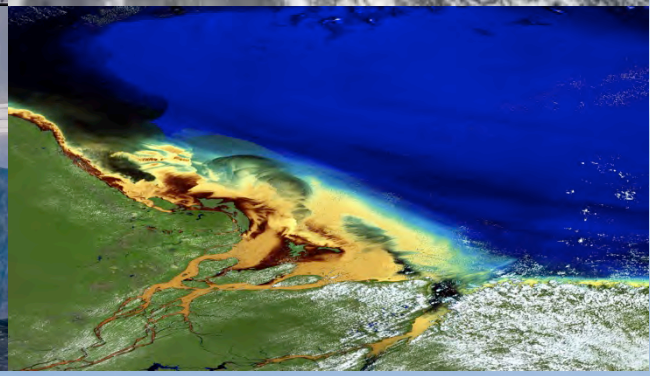
These changes impact Earth's weather, climate, & biology in our oceans, and thus, life on Earth.

Understanding & protecting our ecosystems is key to sustaining the Earth's economy

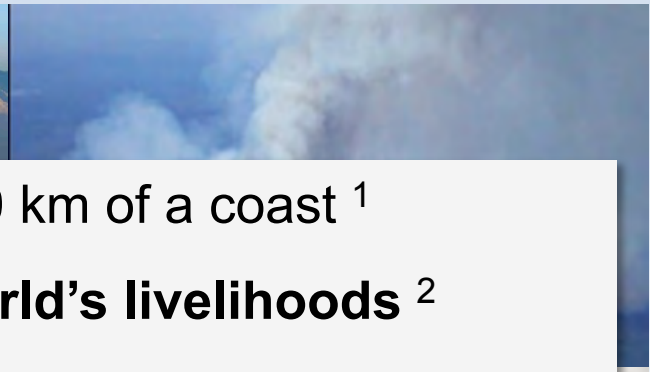




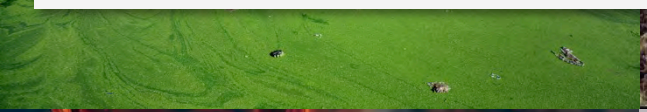



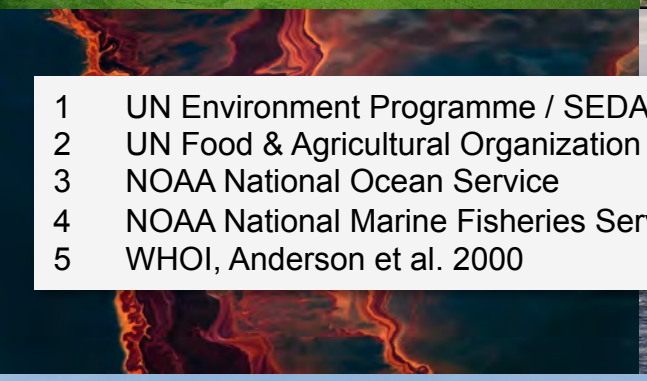
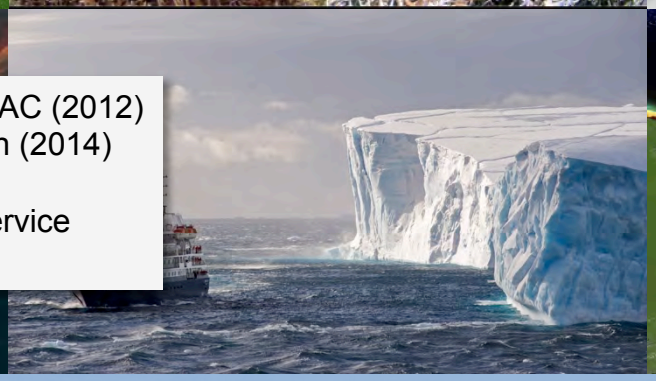
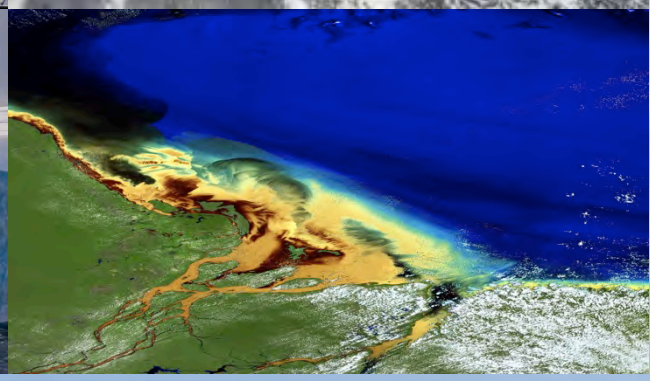
Ocean & atmospheric data benefit the public from tribal to international data users to policy-makers, managers, industry & economists.





- **~40% of the world's population** lives within 100 km of a coast [1]
- Fisheries & aquaculture support **~12% of the world's livelihoods** [2]
- Ocean economy contributed >**$282B to US GDP** & provided **>2.8M jobs** [3]
- Commercial value of US fisheries from coral reefs exceeds **$100M** [4]
- US harmful algal bloom events have average impact of **$50M each year** [5]



1 UN Environment Programme / SEDAC (2012)
2 UN Food & Agricultural Organization (2014)
3 NOAA National Ocean Service
4 NOAA National Marine Fisheries Service
5 WHOI, Anderson et al. 2000

PACE mission architecture

Mission Characteristics

- Hyperspectral ocean color instrument & possible multi-angle polarimeter
- 2-day global coverage to solar & sensor zenith angles of 75^{o} & 60^{o}
- Sun-synchronous, polar orbit with a local Equatorial crossing time of ~13:00
- 675-km altitude & 98^{o} inclination
- Class C (limited redundancy) for 3-years of operations & 10-years of fuel

Mission Elements

Mission Management:	Goddard Space Flight Center
Hyperspectral Ocean Color Instrument:	Goddard Space Flight Center
Multi-angle Polarimeter (optional):	To be procured or contributed
Spacecraft/Mission Operations:	Goddard Space Flight Center
Science Data Processing:	Goddard Space Flight Center
Competed Science Teams:	NASA Earth Sciences Division

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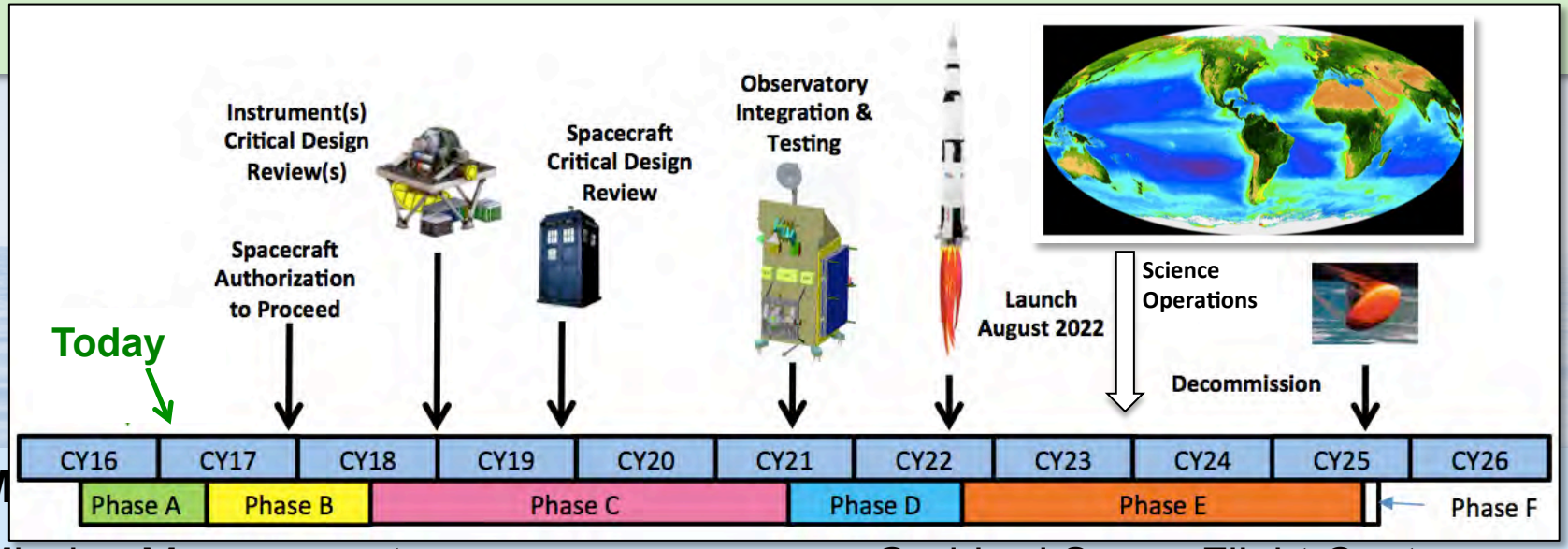

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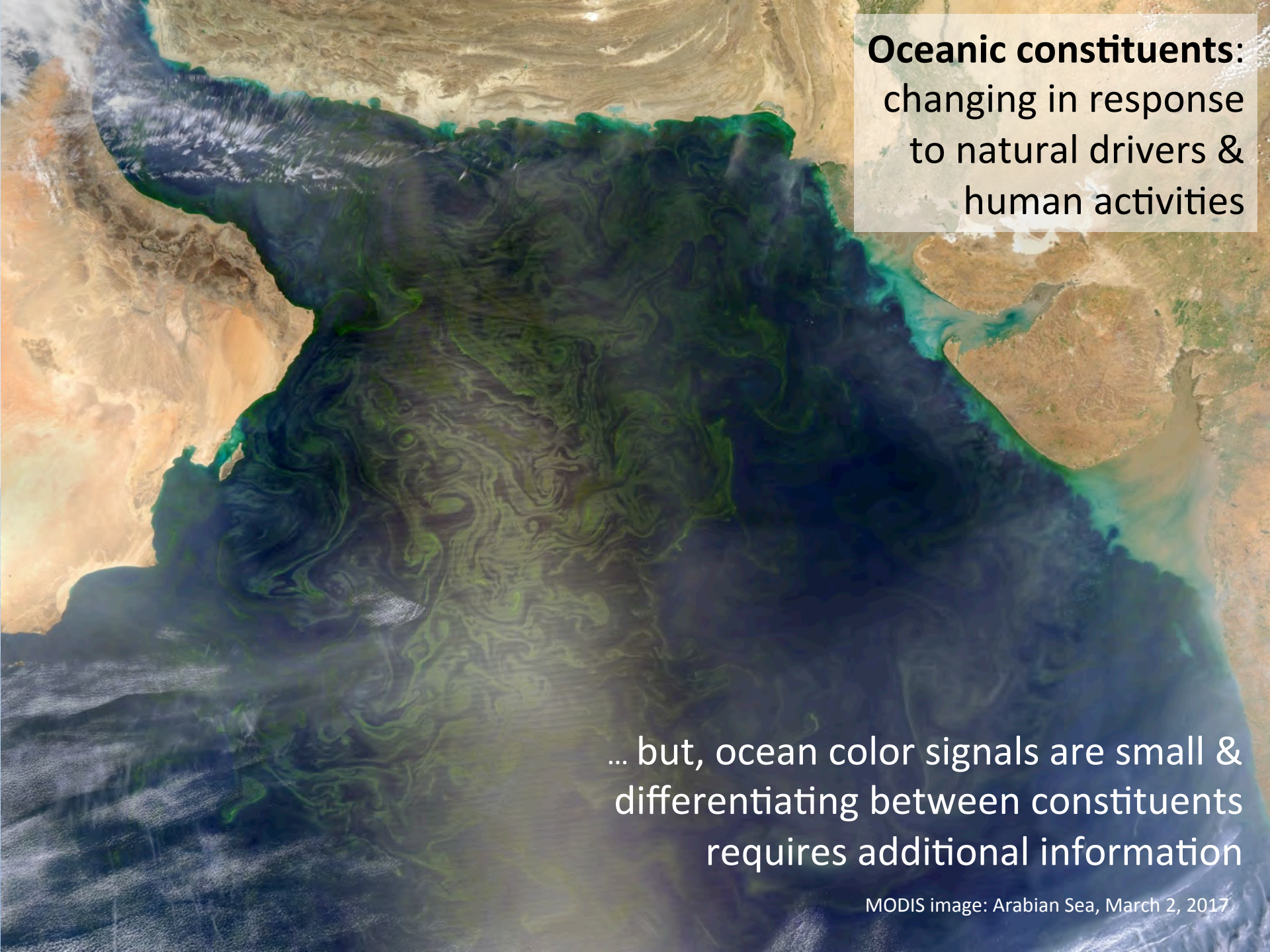
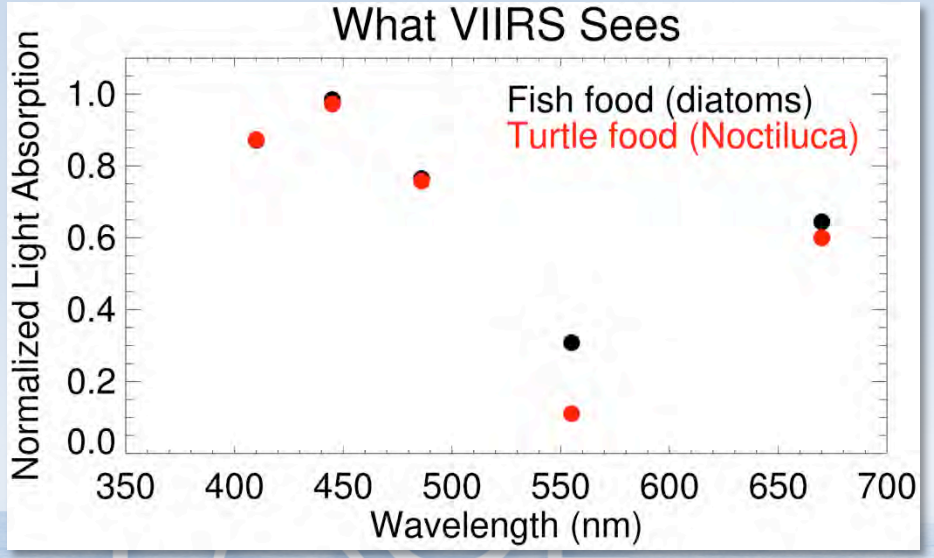


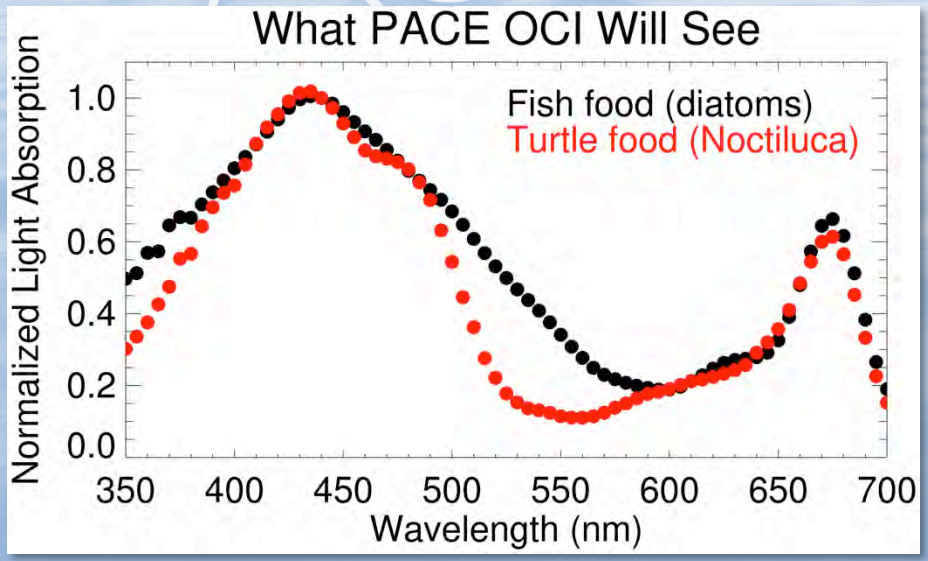
Oceanic constituents: changing in response to natural drivers & human activities

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

MODIS image: Arabian Sea, March 2, 2017

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





Why is making this step important?

A **metaphor** using land plants, which are similar to phytoplankton:

Today we can count the leaves, but have no idea if we're looking at a forest, orchard, meadow or cropland

With OCI we will *finally* distinguish between pine needles, apple trees, grasses, and corn stalks

All living creatures are tied to their food source; if their food disappears or moves, so do they & the ecosystem in which they live changes accordingly

With heritage multi-spectral satellite radiometers we get hints that change is happening, *but are completely blind to what is actually changing!*

jeremy.werdell@nasa.gov

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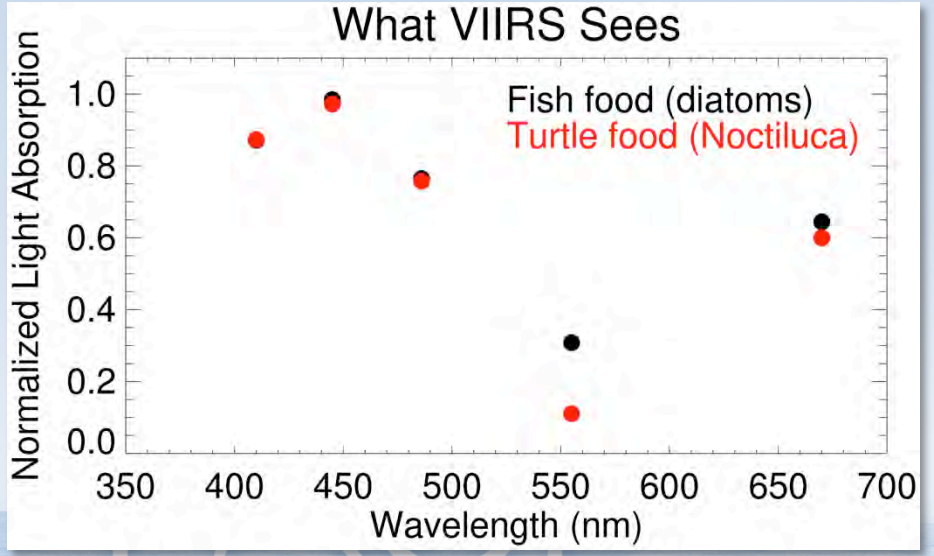
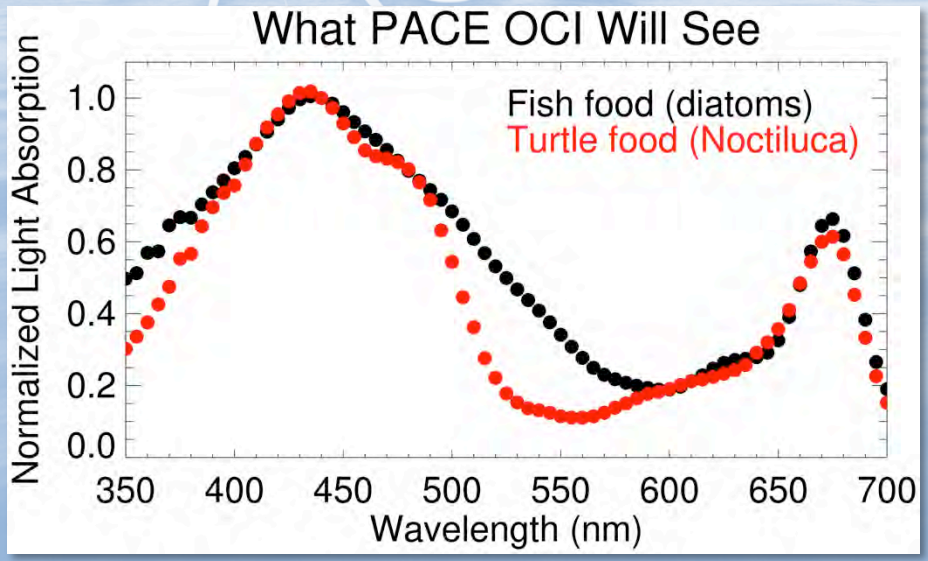
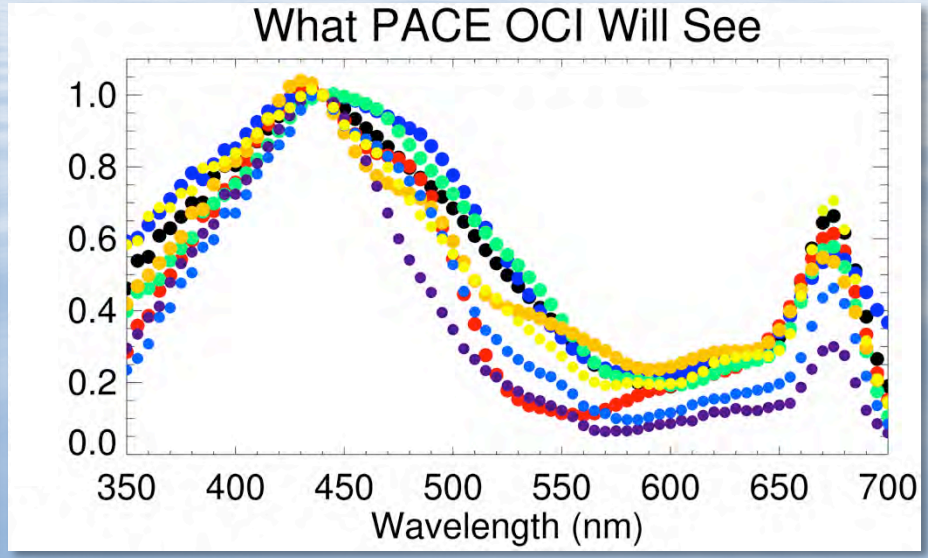
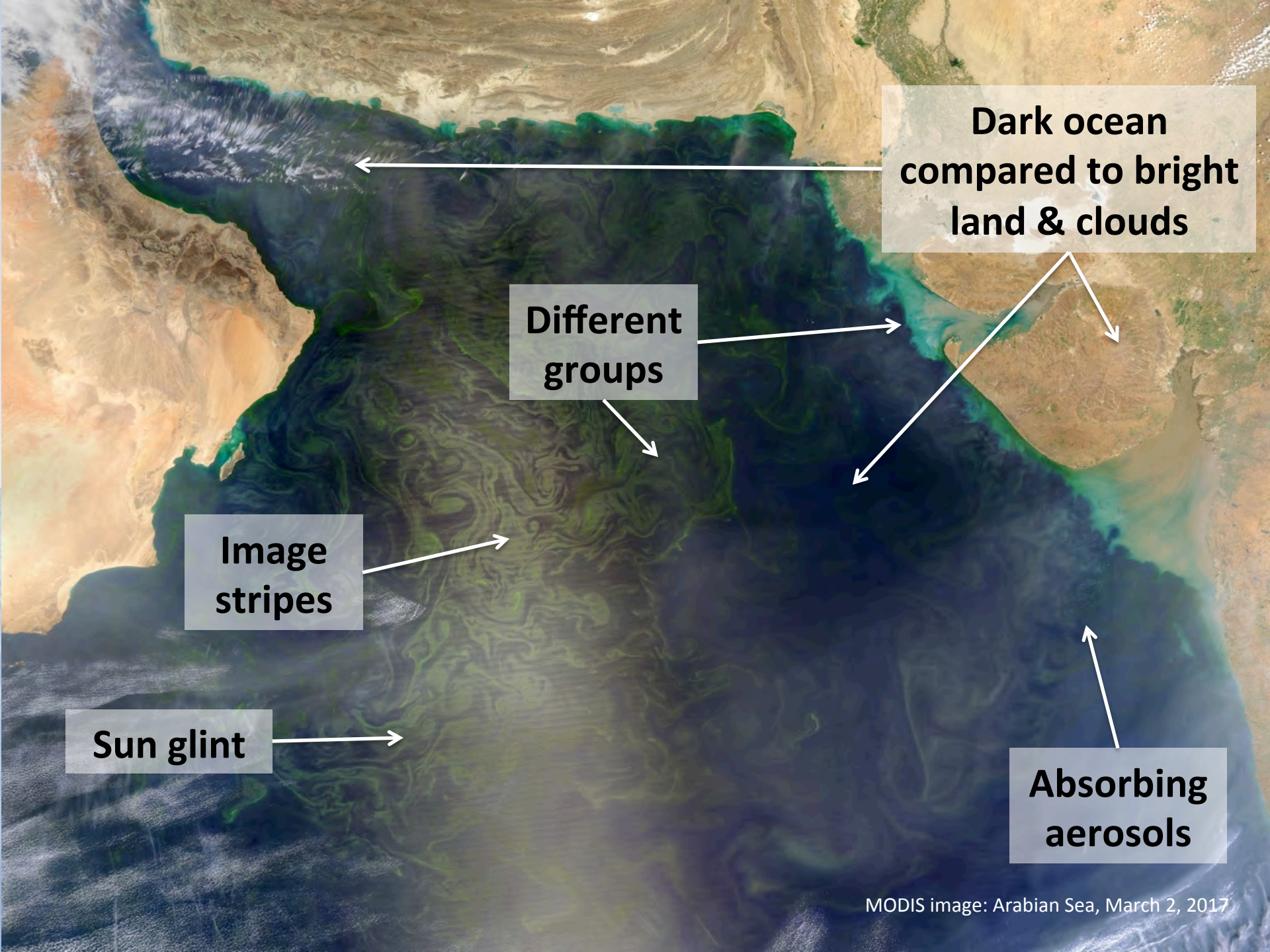


Why not just add more bands to a conventional instrument design?

Just as there are 1000s of kinds of land plants, there are 1000s of kinds of phytoplankton, all with different colors; **only an instrument that sees all colors** offers an opportunity to truly monitor fisheries, identify harmful algal blooms, & understand the land-ocean-atmosphere carbon cycle







MODIS image: Arabian Sea, March 2, 2017

PACE: *a quantum leap*

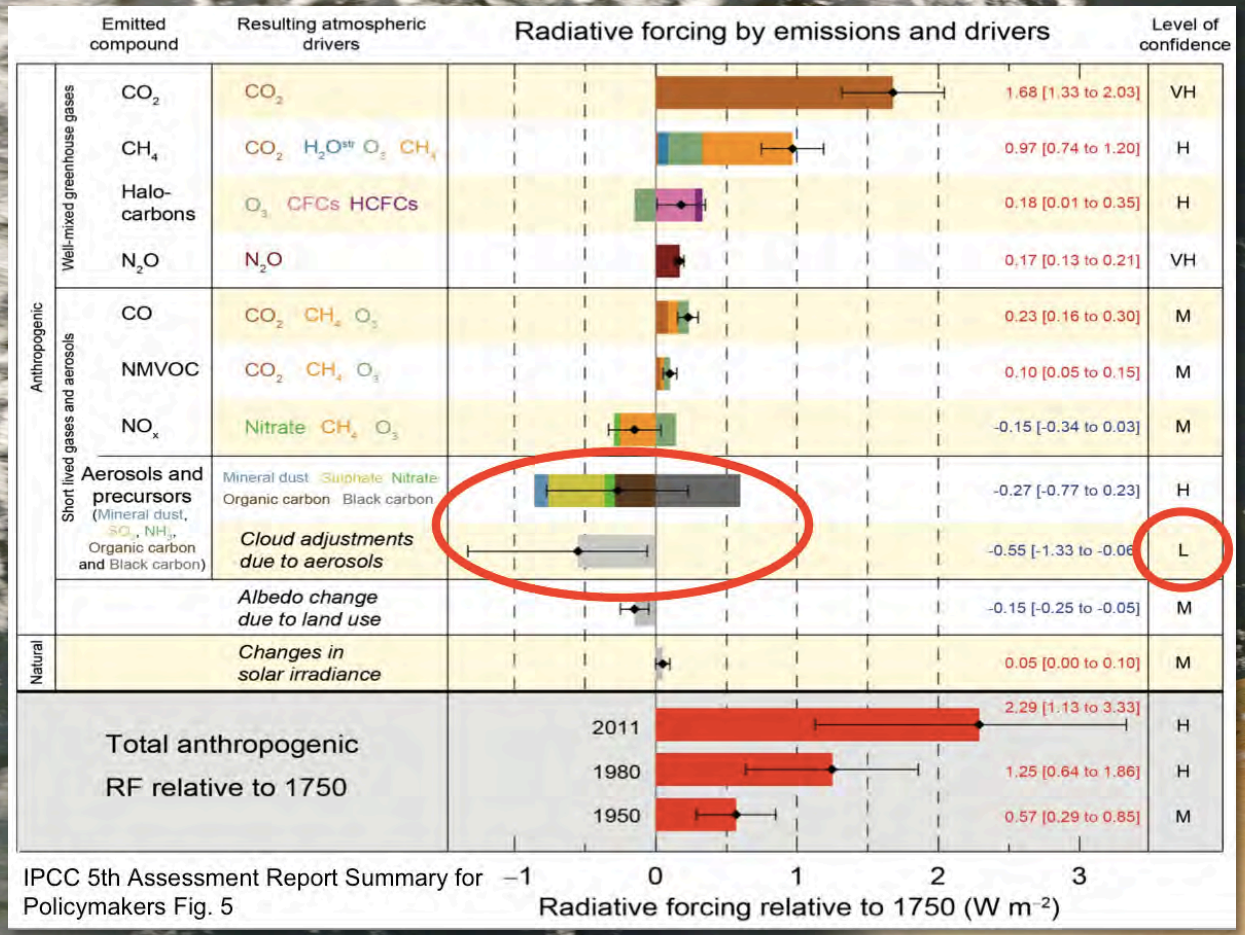
What makes PACE so advanced relative to other ocean color instruments?

*The PACE ocean color instrument will be the **first ever** to include all of the following:*

- **2-day global coverage** at 1-km
- **hyperspectral radiometry** from the ultraviolet (350 nm) to near-infrared (885 nm)
- **SWIR bands** (0.94, 1.25, 1.38, 1.61, 2.13, 2.26 μm)
- a single science detector to **inhibit image striping**
- **SNRs that rival or exceed** anything built previously
- Total calibrated instrument **artifacts < 0.5%** at top-of-atmosphere
- **fore / aft tilt** to avoid Sun glint
- semi-monthly **lunar calibration** + on-board solar diffusor mechanisms

	Spatial	Spectral *	Temporal	Detectors
VIIRS	750 m global	7 bands from 412 – 865 nm 1.24, 1.61, 2.25 μm	2-day nadir view	multiple 16 – rotating telescope
OLCI / Sentinel-3	300 m global	21 programmable bands from 400 – 1020 nm	3-day nadir view	multiple pushbroom
OLI / Landsat-8/9 MSI / Sentinel-2	10 - 60 m coastal	5-9 bands from 443 – 865 nm 1.60, 2.20 μm	16-day nadir view	multiple pushbroom
PACE	*1000 m* *global*	***115** bands from **350** – 885 nm* *1.25, 1.61, 2.13, 2.26 μm*	*2-day* ***±20° tilt***	***single*** ***1** – rotating telescope*

* only bands used for ocean color shown

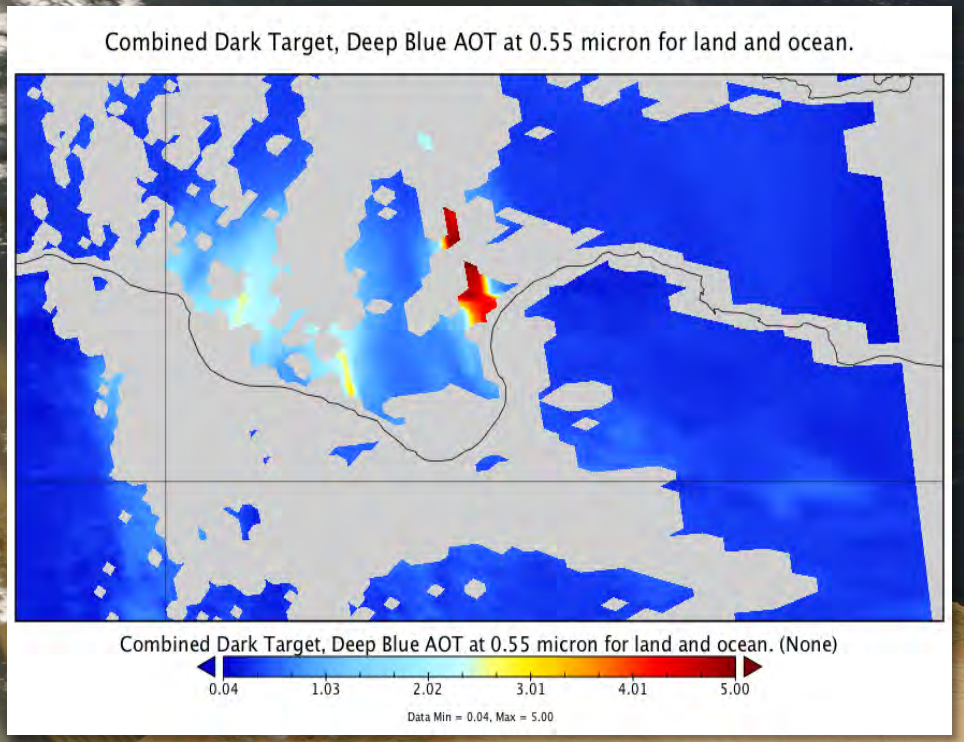


IPCC 5th Assessment Report Summary for Policymakers Fig. 5

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



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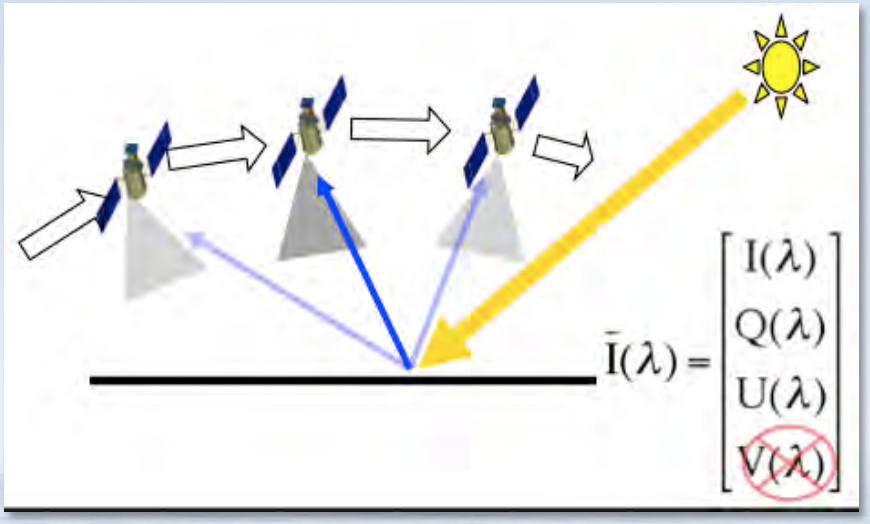
MODIS image: Libya coast, October 26, 2007

Multi-angle polarimetry adds two extra dimensions of information to study the (oceans &) atmosphere

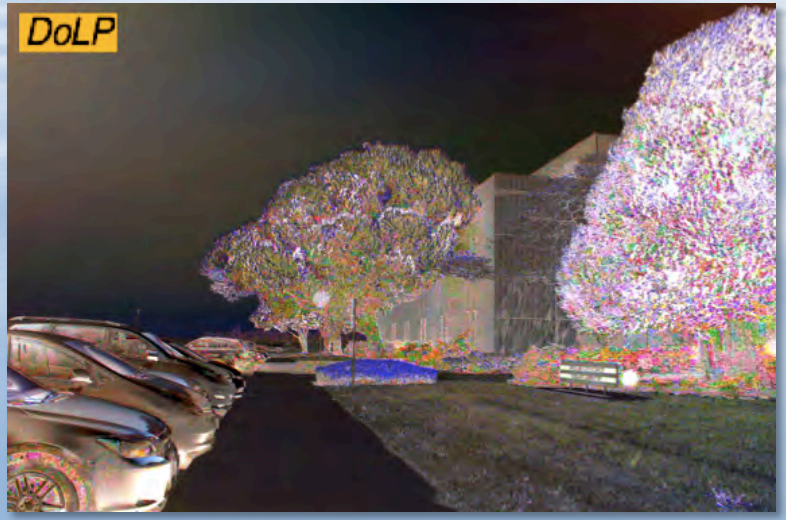
Reflectance

Multiple view angles



Polarized Reflectance

Degree of Linear Polarization

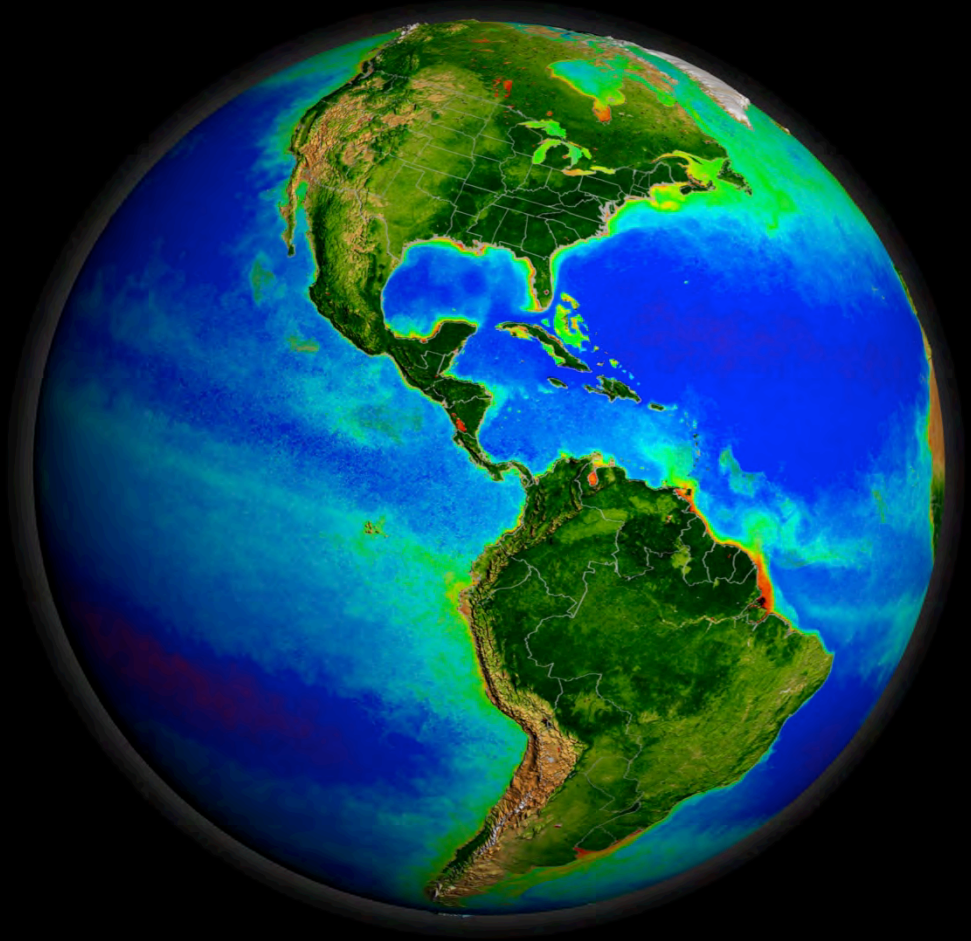


PACE Science Summary

PACE is unlike any other ocean color mission planned to be flown in the 2020's by any agency; it fills a substantial void

The current ocean color instrument concept provides a major leap forward in capabilities for the ocean color community; by itself, it will provide a wealth of information not currently available or planned to become available to this community

A polarimeter provides a leap forward in capabilities for the atmospheric community – it also provides a benefit to the ocean color community, making the combination of instruments a major contribution to science



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