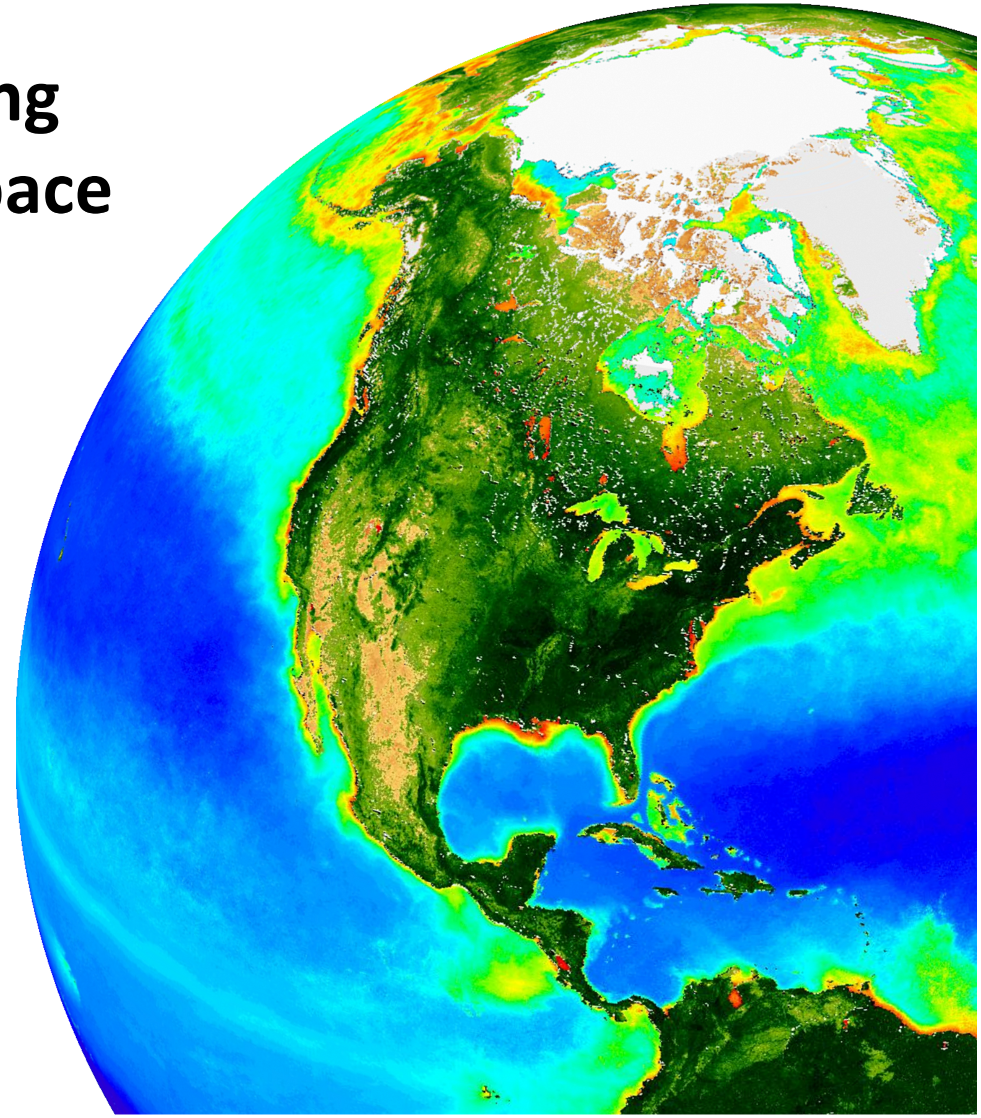
Observing the microscopic living (and non-living) ocean from space

Jeremy Werdell
NASA Goddard Space Flight Center
Ocean Ecology Laboratory
PACE mission

Contributors: Joel Scott, Bridget Seegers, and Ryan Vandermuelen

National Water Quality Monitoring Council
7 February 2018



PACE

Plankton, Aerosol, Cloud, ocean Ecosystem

Advanced Measurements of Sea & Sky

NASA • Goddard Space Flight Center

oceanographer @ NASA Goddard Space Flight Center since 1999

PACE Project Scientist since 2015


PACE
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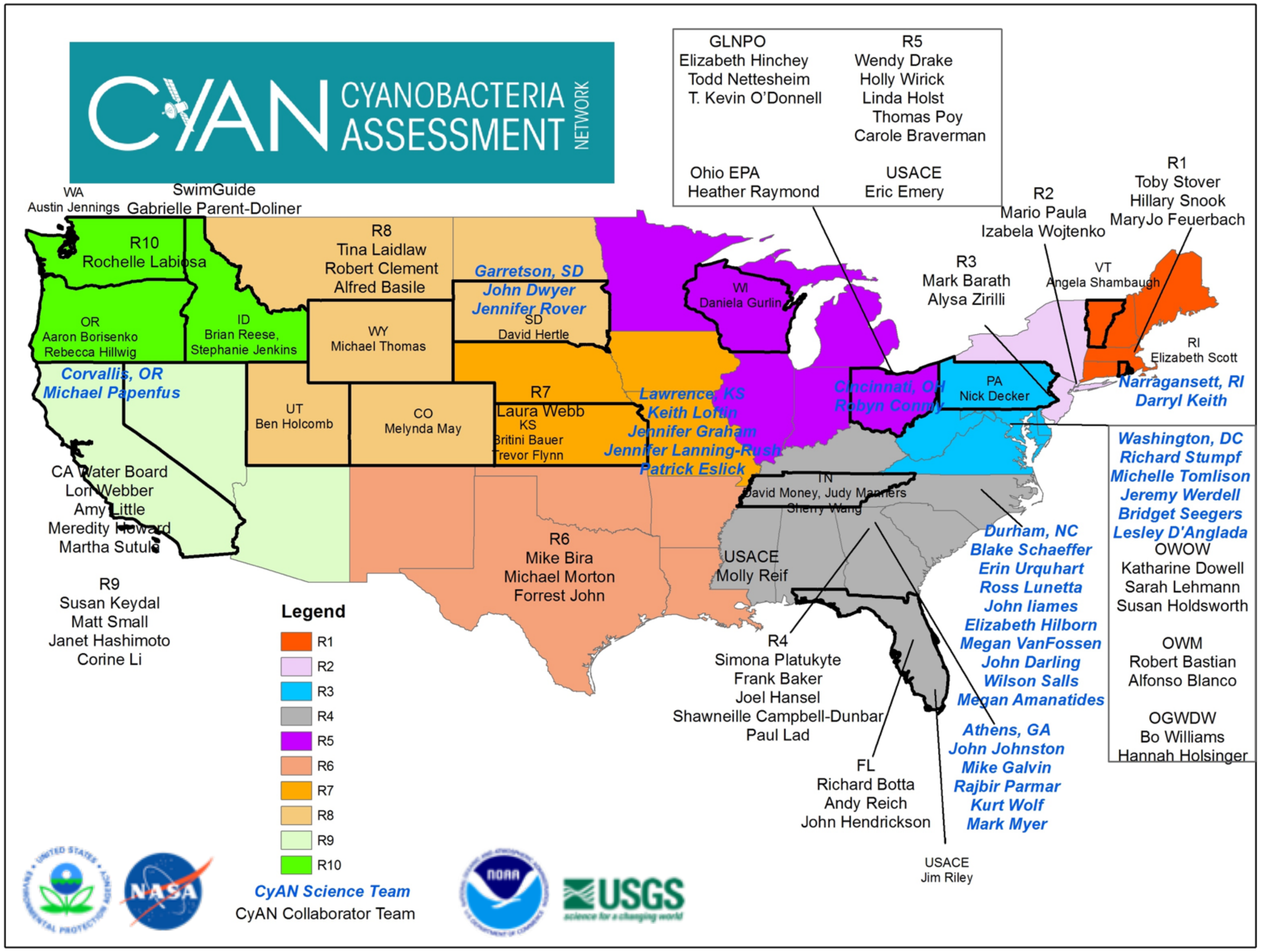
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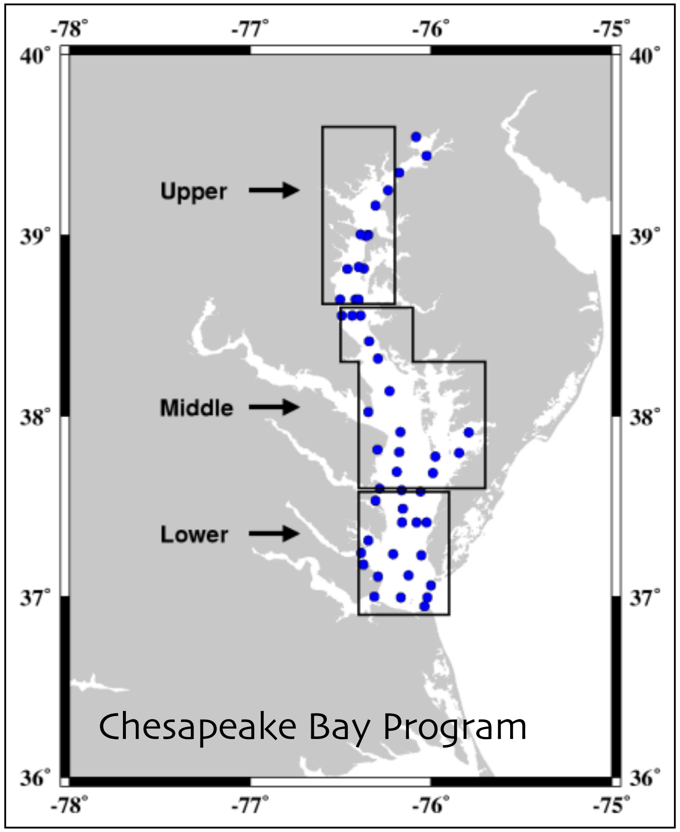
Why NASA? Why satellites?



Chesapeake Bay Program
A Watershed Partnership

http://www.chesapeakebay.net

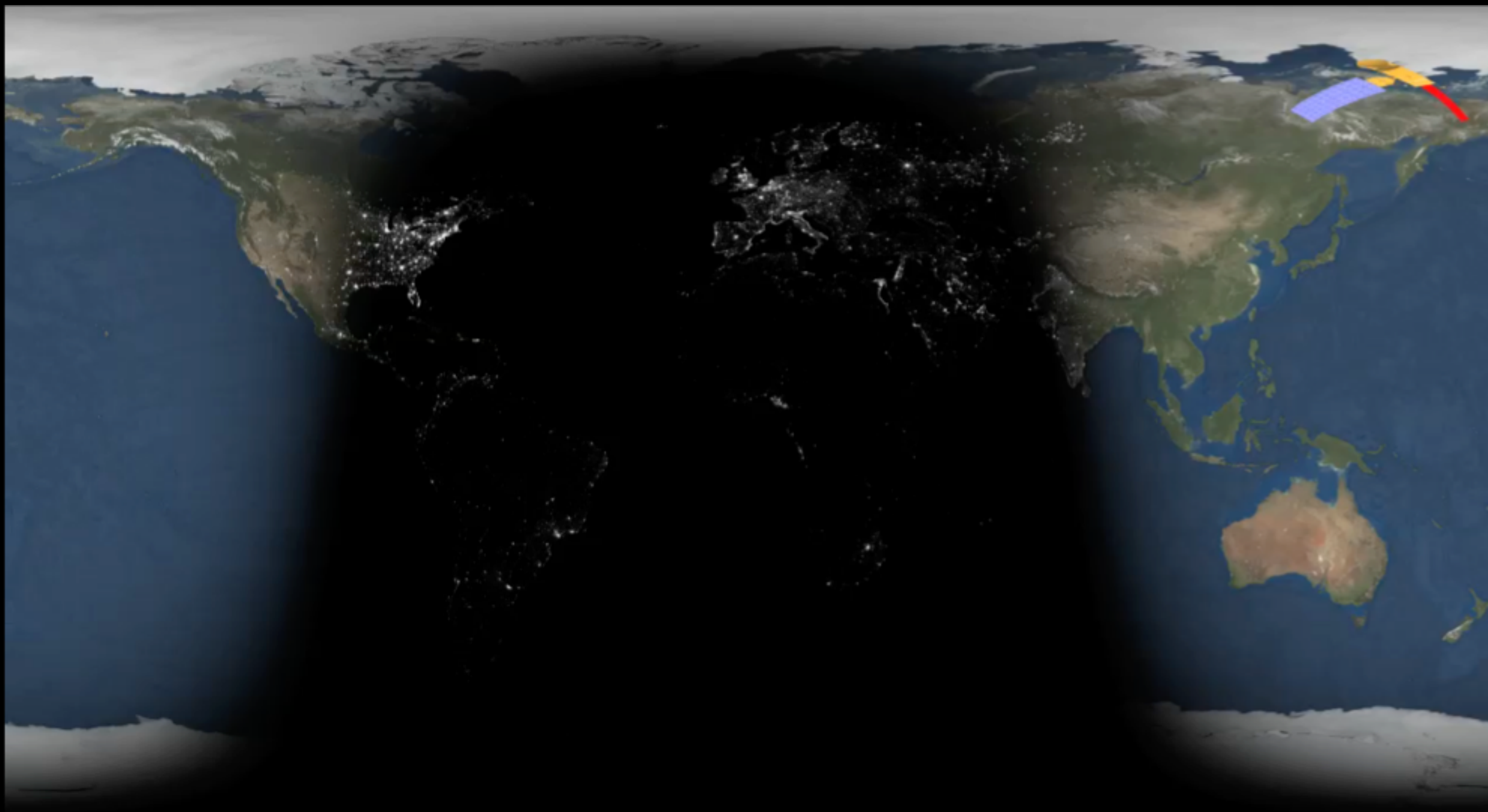
routine data collection since 1984
12-16 cruises / year

49 stations
19 hydrographic measurements

algal biomass
water clarity
dissolved oxygen

satellites complement in situ sampling with routine, synoptic, & consistent views of our critical marine ecosystems

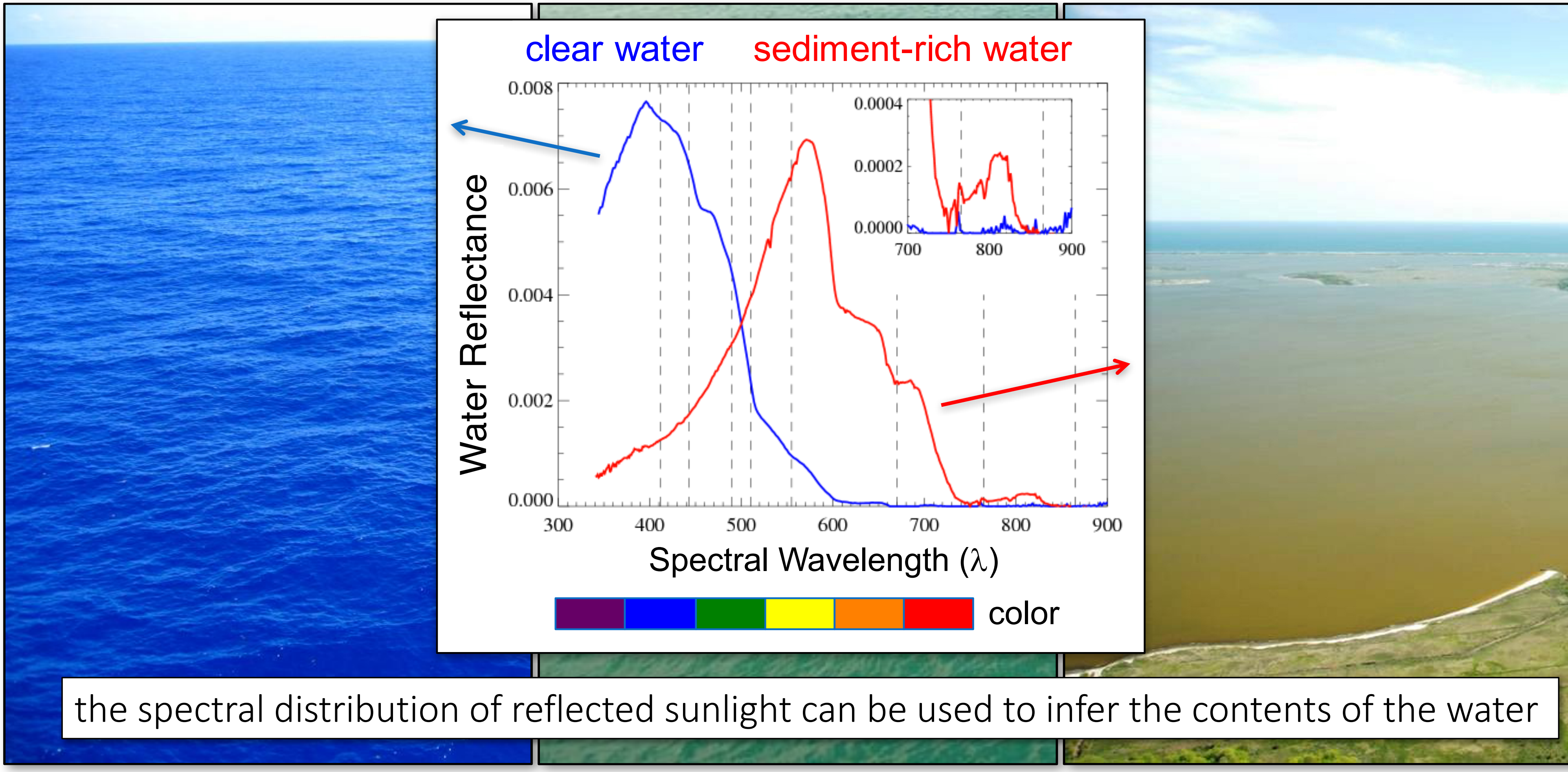
This talk focuses on polar orbiting satellites



"And as your tour guide, I'd now like to point out that we're **completely** lost."

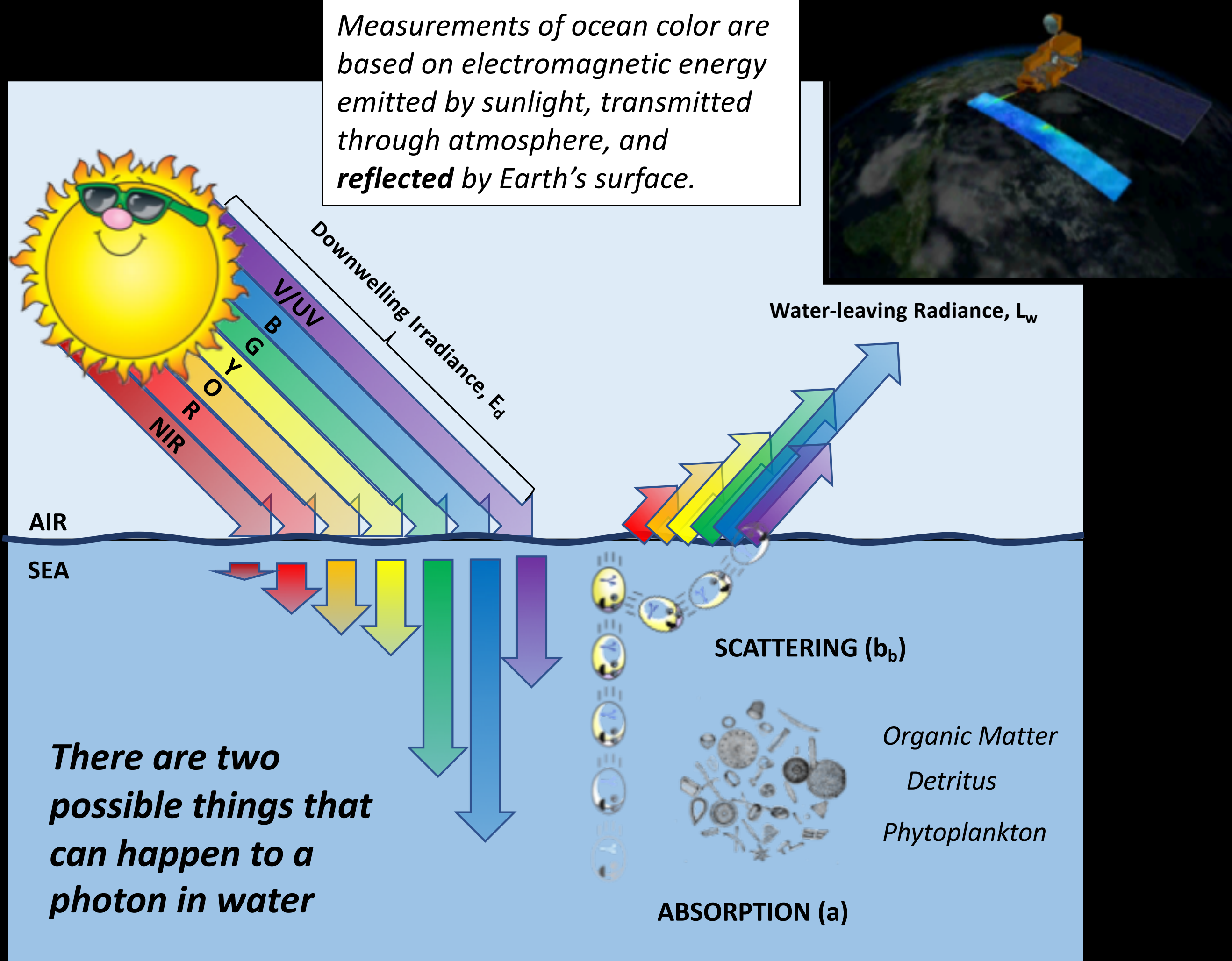
What is ocean color?
Challenges!
Applied sciences examples
Demystifying the use of ocean color

Chapter 1: What is "ocean color"?



the spectral distribution of reflected sunlight can be used to infer the contents of the water

Measurements of ocean color are based on electromagnetic energy emitted by sunlight, transmitted through atmosphere, and ***reflected*** *by Earth's surface.*

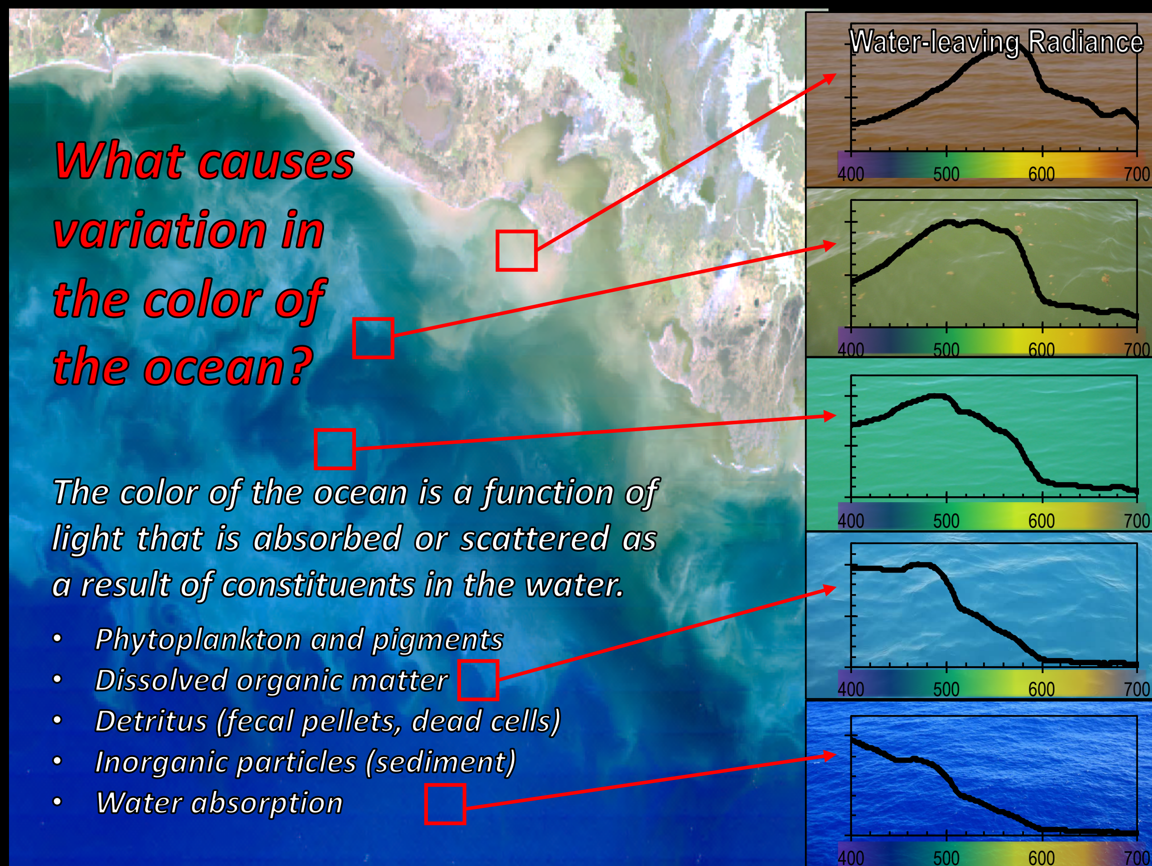


There are two possible things that can happen to a photon in water

What causes variation in the color of the ocean?

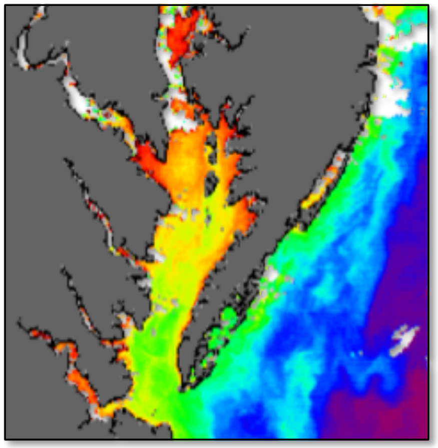
The color of the ocean is a function of light that is absorbed or scattered as a result of constituents in the water.

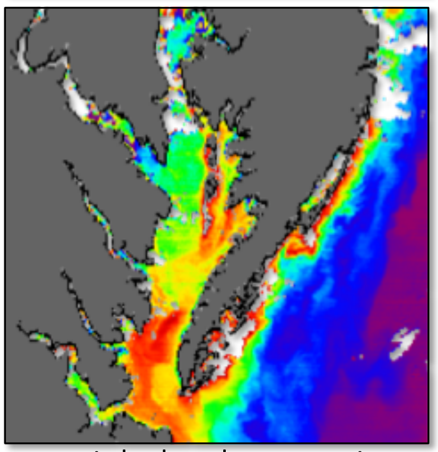
- Phytoplankton and pigments
- Dissolved organic matter
- Detritus (fecal pellets, dead cells)
- Inorganic particles (sediment)
- Water absorption



Ocean color data products

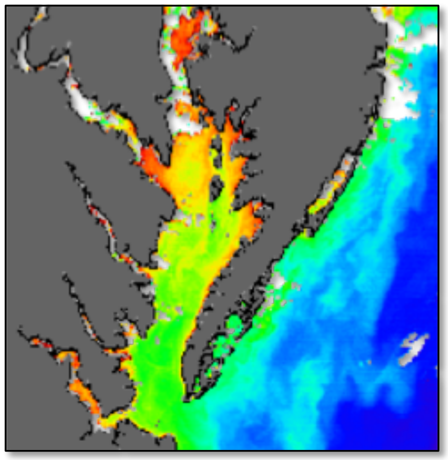
chlorophyll-a (*algal biomass*)



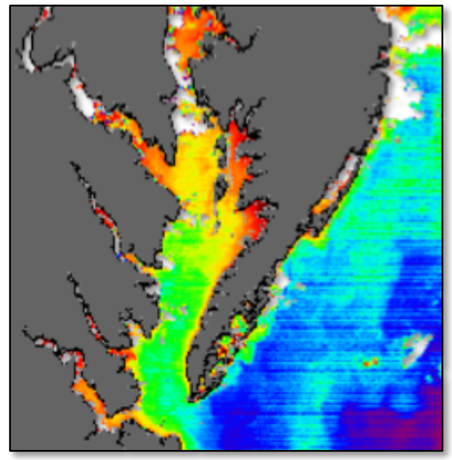


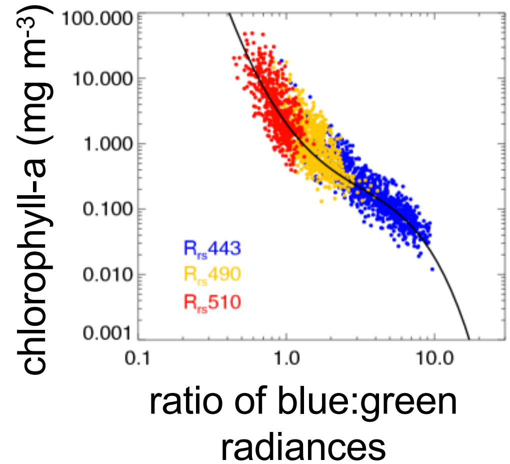
particle backscattering (*sediment load*)

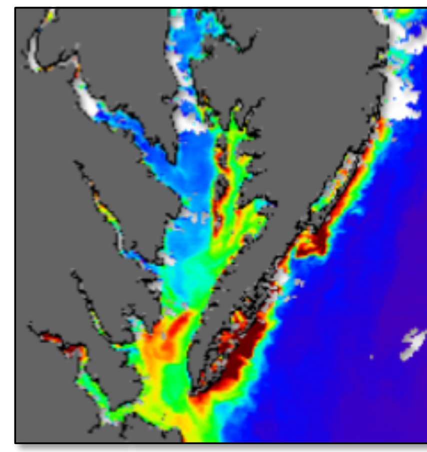
diffuse light attenuation (*water clarity, turbidity*)



dissolved organic matter absorption (*runoff*)







red light reflectance (*sediment load*)

and, many others, including:

phytoplankton community composition (*including HABs*)
particle size distributions (*water composition*)
particulate (in)organic carbon (*productivity*)
euphotic depth (*visibility, water clarity*)
water temperature (MODIS, VIIRS)

Applications for water quality monitoring

Applications for ocean health & fisheries

Reports and Monographs of the International Ocean-Colour Coordinating Group

An Affiliated Program of the Scientific Committee on Oceanic Research (SCOR)
An Associated Member of the (CEOS)

IOCCG Report Number 15, 2014

Phytoplankton Functional Types from Space

Edited by:
Shubha Sathyendranath (Plymouth Marine Laboratory)

Report of an IOCCG working group on Phytoplankton Functional Types, chaired by Shubha Sathyendranath and based on contributions from (in alphabetical order):

Jim Aiken, Séverine Alvain, Ray Barlow, Heather Bouman, Astrid Bracher, Robert J. W. Brewin, Annick Bricaud, Christopher W. Brown, Aurea M. Ciotti, Lesley Clementson, Susanne E. Craig, Emmanuel Devred, Nick Hardman-Mountford, Takafumi Hirata, Chuanmin Hu, Tihomir S. Kostadinov, Samantha Lavender, Hubert Loisel, Tim S. Moore, Jesus Morales, Cyril Moulin, Colleen B. Mouw, Anitha Nair, Dionysios Raitsos, Collin Roesler, Shubha Sathyendranath, Jamie D. Shutler, Heidi M. Sosik, Inia Soto, Venetia Stuart, Ajit Subramaniam and Julia Uitz.

http://www.ioccg.org/groups/PFT.html

NASA/TM–2015-217528

Report on IOCCG Workshop

Phytoplankton Composition from Space: Towards a validation strategy for satellite algorithms

Astrid Bracher, Nick Hardman-Mountford, Takafumi Hirata, Stewart Bernard, Emmanuel Boss, Robert Brewin, Annick Bricaud, Vanda Brotas, Alison Chase, Aurea Ciotti, Jong-Kuk Choi, Lesley Clementson, Emmanuel Devred, Paul DiGiacomo, Cécile Dupouy, Toru Hirawake, Wonkook Kim, Tihomir Kostadinov, Ewa Kwiatkowska, Samantha Lavender, Tiffany Moisan, Colleen Mouw, Seunghyun Son, Heidi Sosik, Julia Uitz, Jeremy Werdell, and Guangming Zheng

The International Ocean-Colour Coordinating Group (IOCCG)
25–26 October 2014
Portland, Maine, USA

http://ioccg.org/groups/PFT-TM_2015-217528_01-22-15.pdf

frontiers in Marine Science

REVIEW

A Consumer's Guide to Satellite Remote Sensing of Multiple Phytoplankton Groups in the Global Ocean

Colleen B. Mouw, Nick J. Hardman-Mountford, Séverine Alvain, Astrid Bracher, Robert J. W. Brewin, Annick Bricaud, Aurea M. Ciotti, Emmanuel Devred, Amane Fujiwara, Takafumi Hirata, Toru Hirawake, Tihomir S. Kostadinov, Shovonlal Roy and Julia Uitz

frontiers in Marine Science

REVIEW

Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development

Astrid Bracher, Heather A. Bouman, Robert J. W. Brewin, Annick Bricaud, Vanda Brotas, Aurea M. Ciotti, Lesley Clementson, Emmanuel Devred, Annalisa Di Cicco, Stephanie Dutkiewicz, Nick J. Hardman-Mountford, Anna E. Hickman, Martin Hieronymi, Takafumi Hirata, Svetlana N. Losa, Colleen B. Mouw, Emanuele Organelli, Dionysios E. Raitsos, Julia Uitz, Meike Vogt and Aleksandra Wolanin

https://www.frontiersin.org/research-topics/5253/colour-and-light-in-the-ocean

Heritage & future missions – It's a consumer's market

		2017	2018	2019	2020	2021	2022	2023	Number of O/C Bands	Spectral Range	O/C GSD (m)	Global Capability
MODIS	Terra		?						36	VIS-SWIR	1000	GLOBAL
MODIS	Aqua		?						36	VIS-SWIR	1000	GLOBAL
OCM-2	OceanSat-2								8	VIS-NIR	1000	GLOBAL
GOCI	COMS								8	VIS-NIR	500	GEO
VIIRS	S-NPP								22	VIS-SWIR	750	GLOBAL
OLI	Landsat-8								8	VIS-SWIR	30	LIMITED
MSI	Sentinel-2A								13	VIS-SWIR	10/20/60	LIMITED
OLCI	Sentinel-3A								21	VIS-NIR	300	GLOBAL
SGLI	GCOM-C								19	UV-SWIR	250/1000	GLOBAL
	SABIA-MAR								13	VIS-NIR	200/1000	GLOBAL
VIIRS	JPSS-1								22	VIS-SWIR	750	GLOBAL
MSI	Sentinel-2B								13	VIS-SWIR	10/20/60	LIMITED
OLCI	Sentinel-3B								21	VIS-NIR	300	GLOBAL
GOCI-II	GeoKompsat-2B								13	VIS-NIR	300	GEO
HSI	EnMap								HYPER	VIS-SWIR	30	LIMITED
OCM-3	OceanSat-3								12	VIS-NIR	360	GLOBAL
OLCI	Sentinel-3C								21	VIS-NIR	300	GLOBAL
VIIRS	JPSS-2								22	VIS-SWIR	750	GLOBAL
OLI	Landsat-9								8	VIS-SWIR	30	LIMITED
OCI	PACE								HYPER	UV-SWIR	1000	GLOBAL

color legend: LAUNCHED PLANNED; 2017? PLANNED


How to choose?
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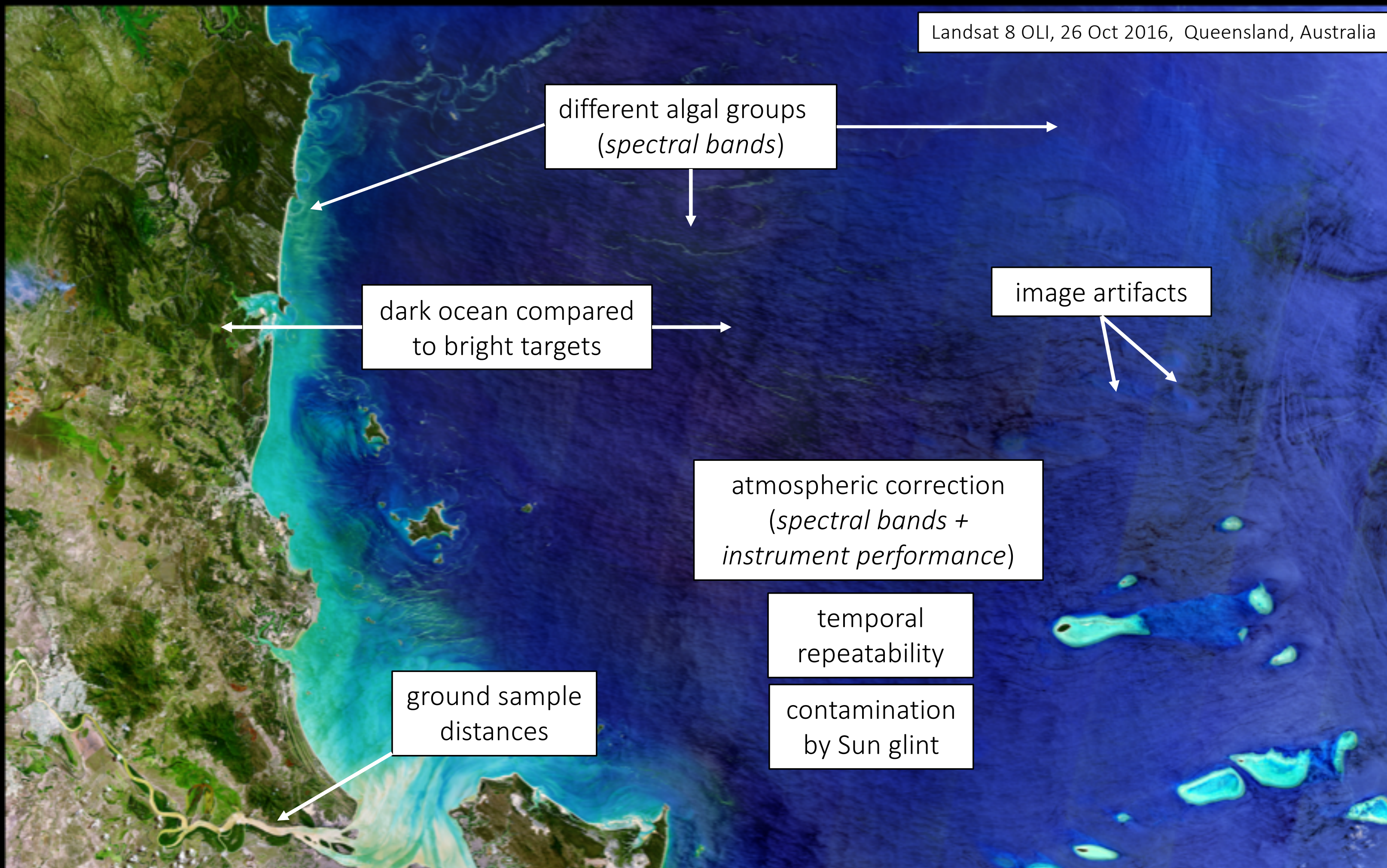
Plankton, Aerosol, Cloud, ocean Ecosystem

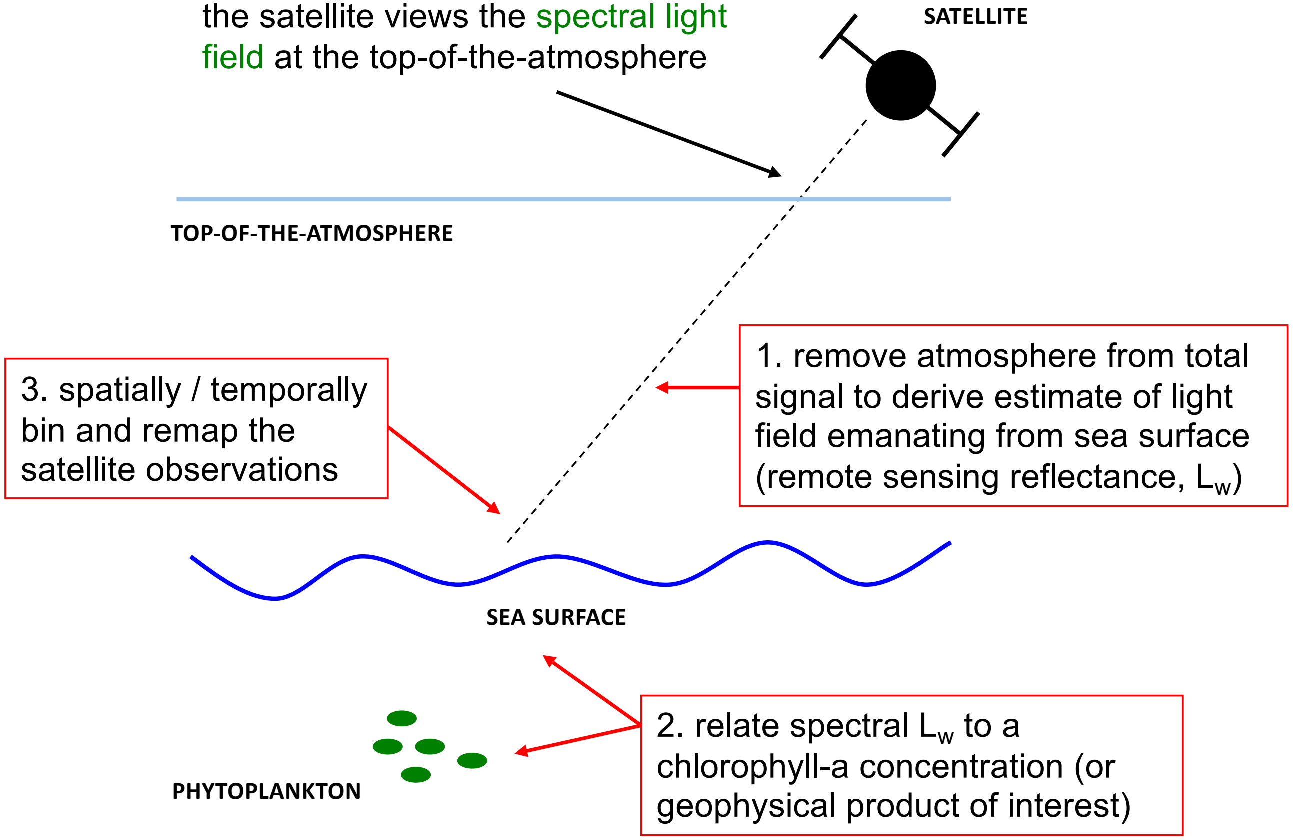
Different instruments & missions offer different capabilities

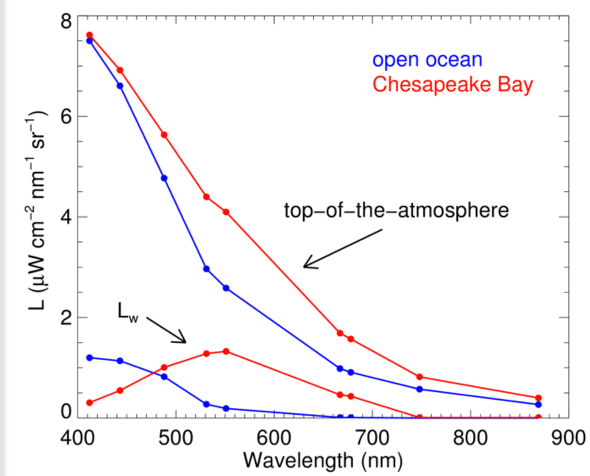


Chapter 2: Challenges

Atmospheric correction
Sun glint
Image artifacts
Spectral resolution

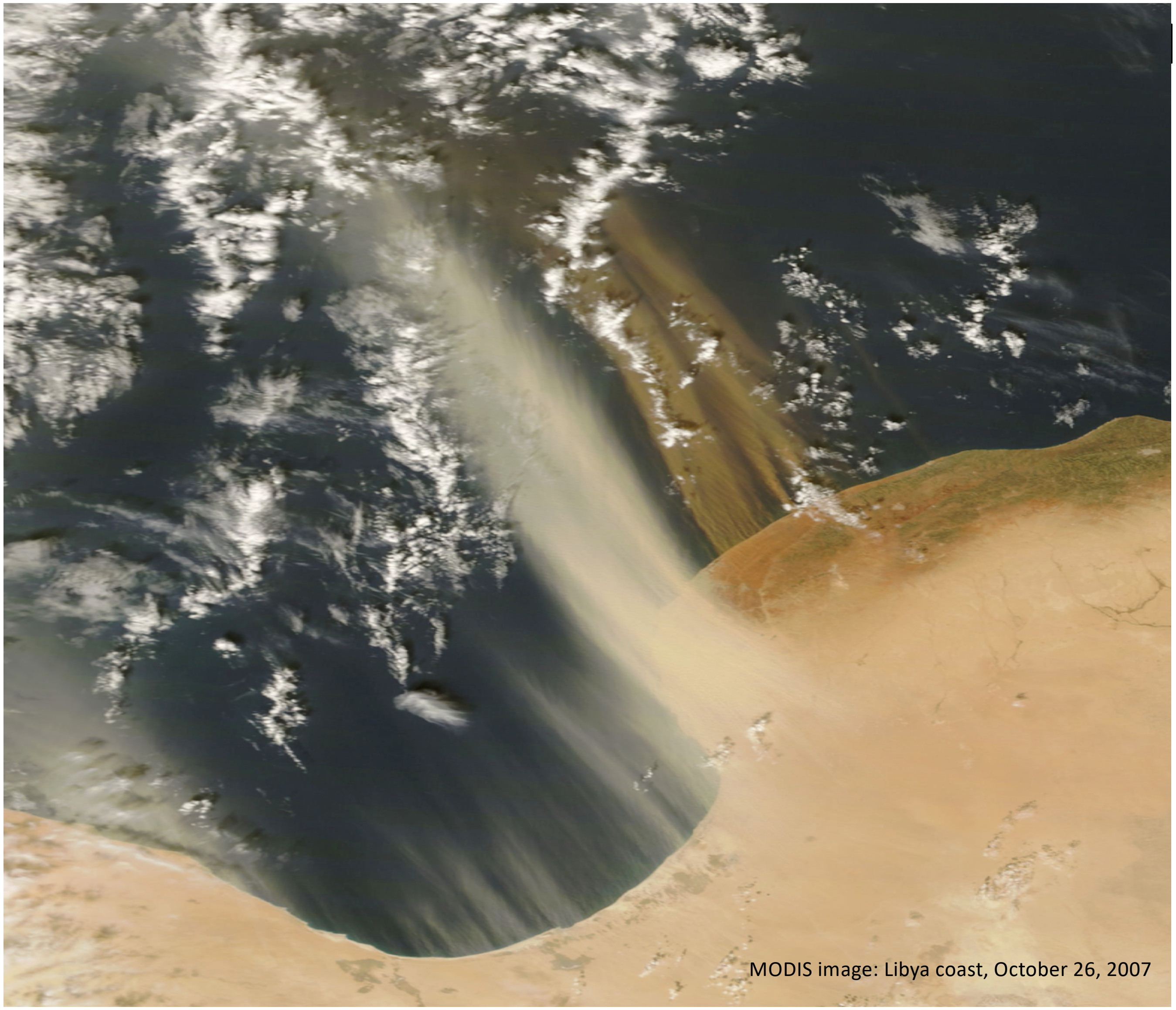
Steps for deriving ocean color data products from space



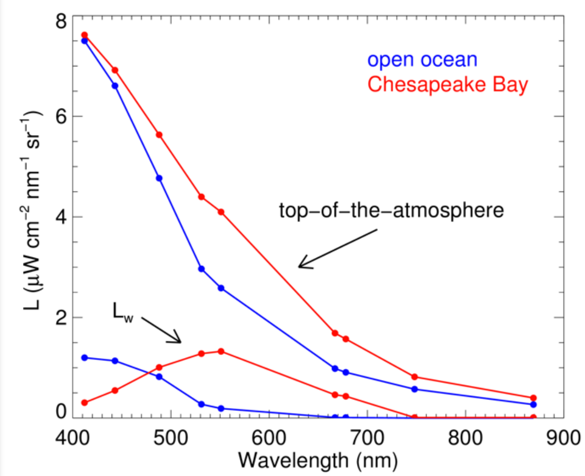


the water signal is often less than 10% of the total signal measured by the satellite

lucts from space



MODIS image: Libya coast, October 26, 2007



the water signal is often less than 10% of the total signal measured by the satellite

We cannot see "ocean color" through Sun glint

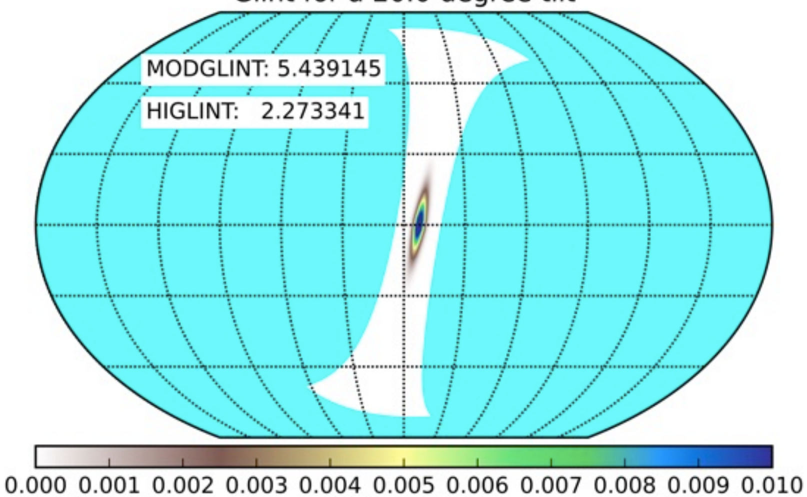
Courtesy NASA Earth Observatory

Ground to Space: A Glittering Path of San Francisco Sunglint

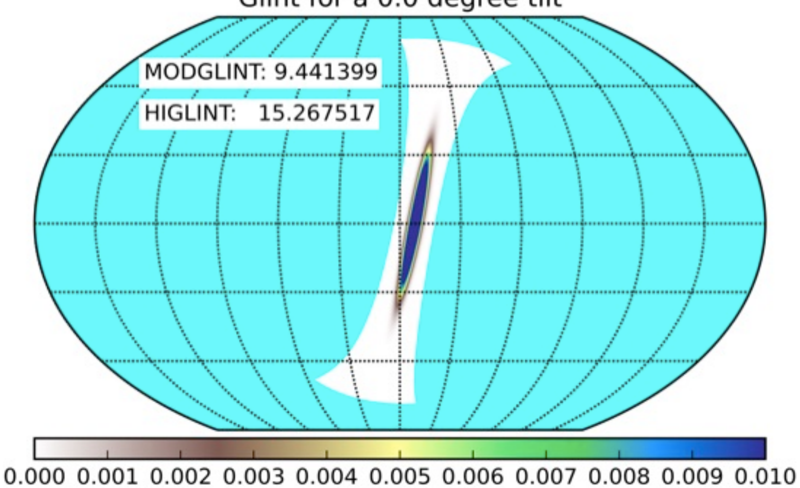
https://earthobservatory.nasa.gov/blogs/earthmatters/2016/11/09/ground-to-space-a-glittering-path-of-san-francisco-sunglint/

What to do? Tilt the instrument fore/aft.

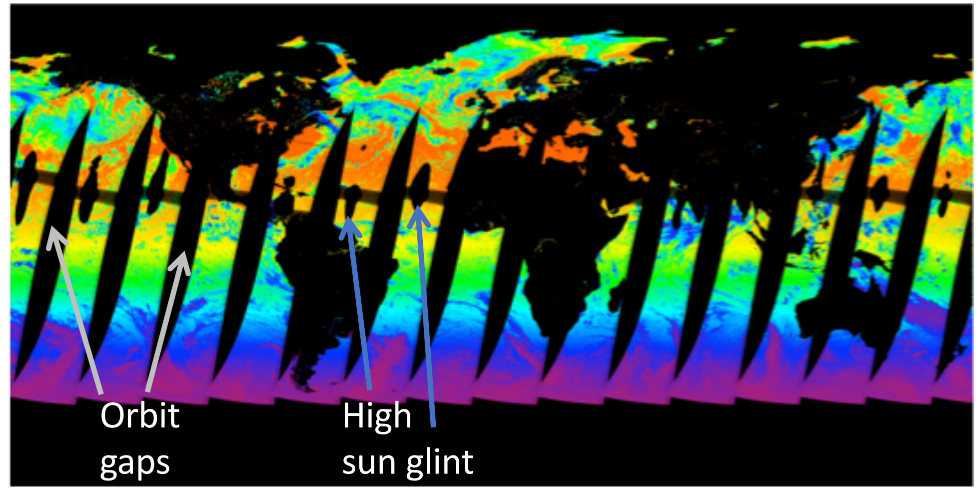
Glint for a 20.0 degree tilt



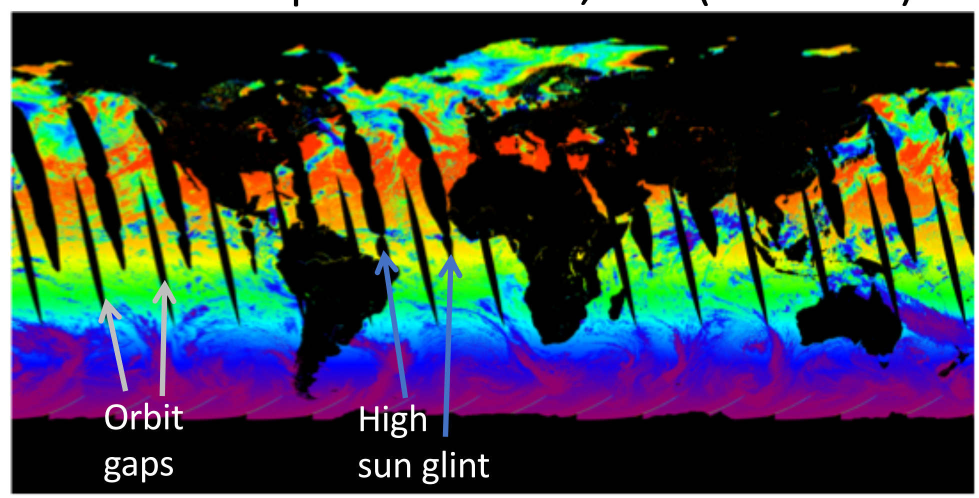
Glint for a 0.0 degree tilt



SeaWiFS PAR - June 21, 2007 (with tilt)



MODIS-Aqua PAR - June 21, 2007 (without tilt)

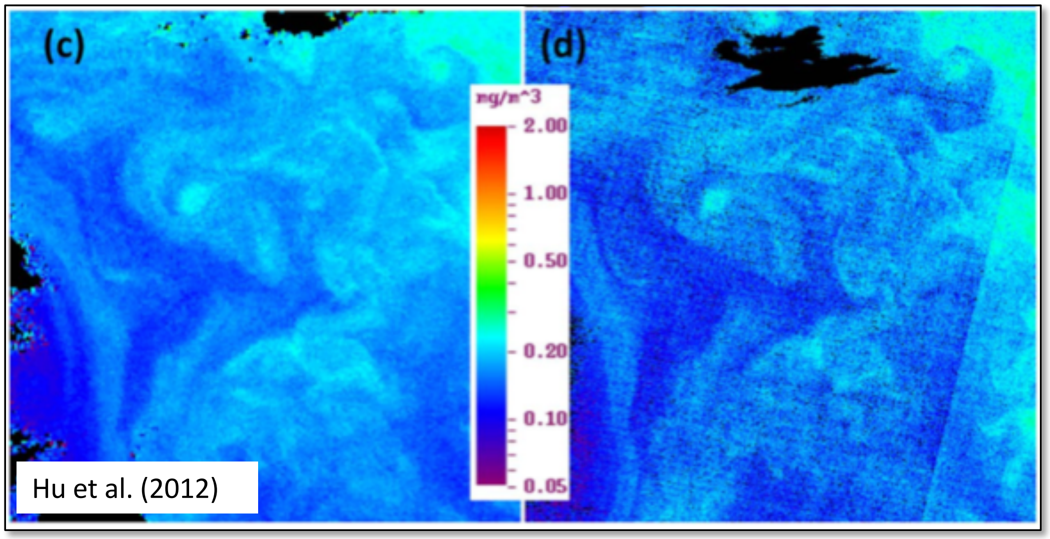


PAR = Photosynthetically Available Radiation (Einstein m^{-2} d^{-1})

Image artifacts & instrument design

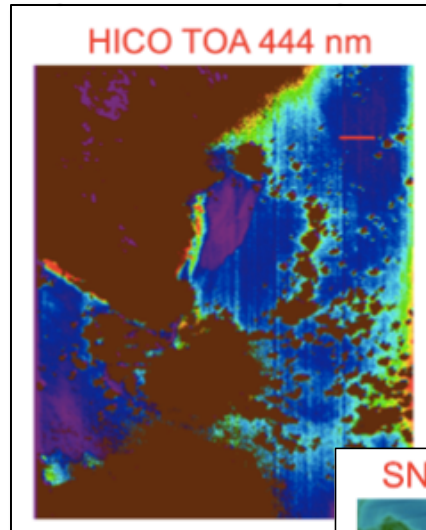
SeaWIFS (rotating telescope)
1 science detector

MERIS (pushbroom)
multiple science detectors

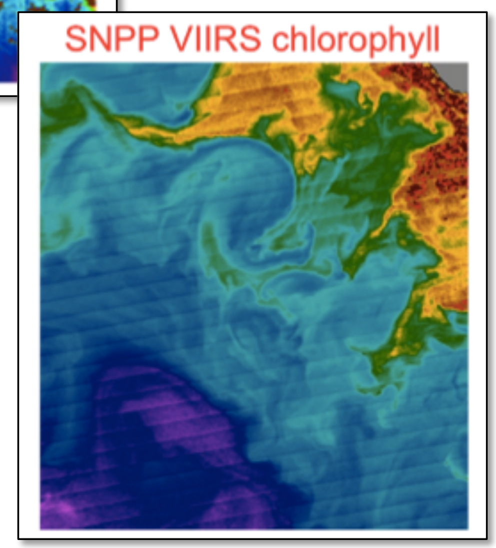


often larger science pixels
(1 km)

often smaller science pixels
(30-300 m)



All multiple detector instruments show stripes in ocean color imagery (more detectors to calibrate)



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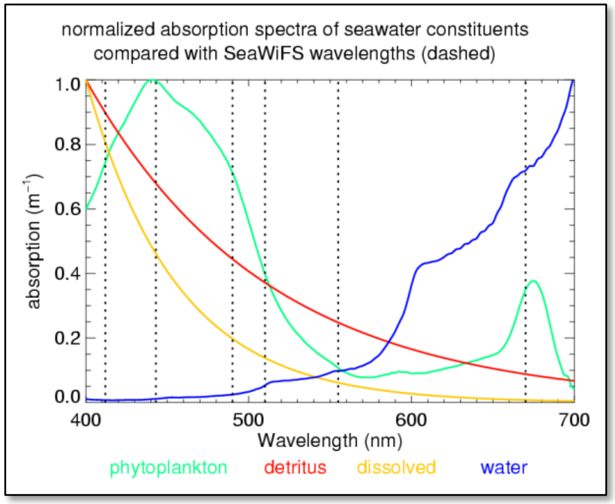
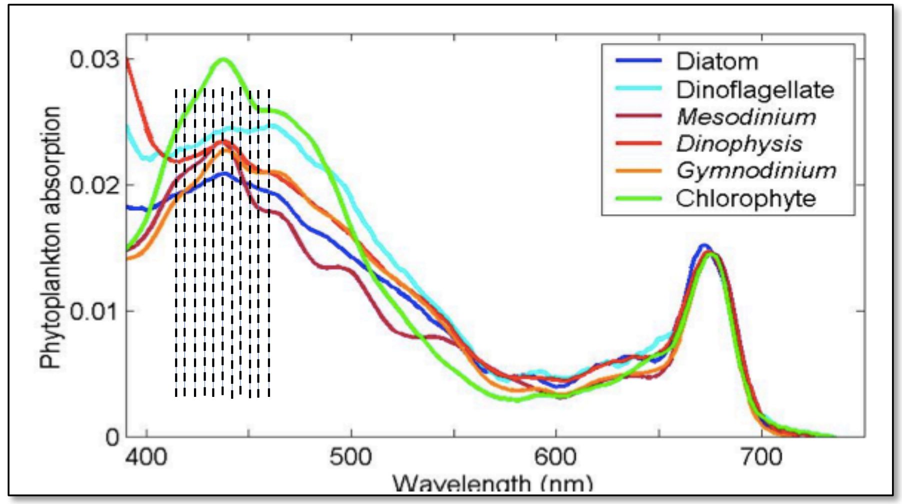
Spectral resolution

Heritage





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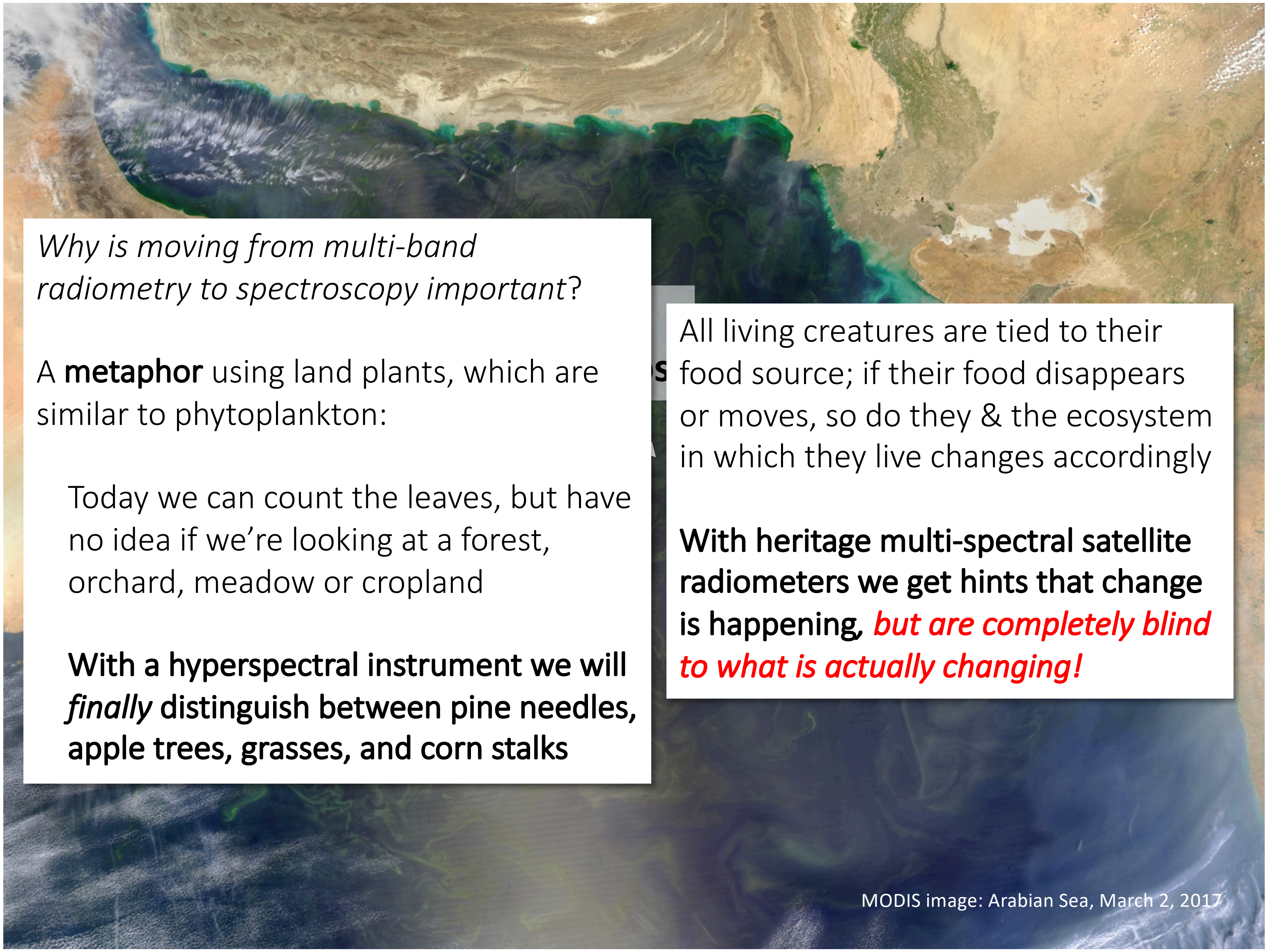
Challenges

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



Why is moving from multi-band radiometry to spectroscopy important?

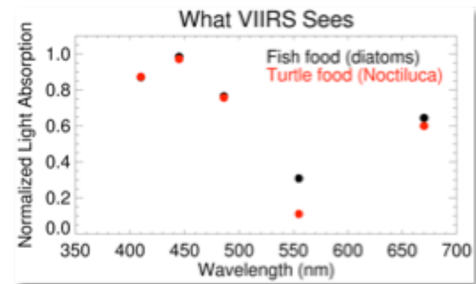
A **metaphor** using land plants, which are similar to phytoplankton:

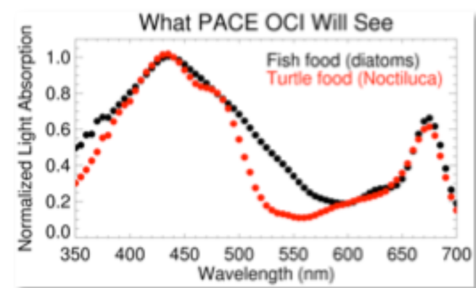
> Today we can count the leaves, but have no idea if we're looking at a forest, orchard, meadow or cropland
>
> **With a hyperspectral instrument we will *finally* distinguish between pine needles, apple trees, grasses, and corn stalks**

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!*

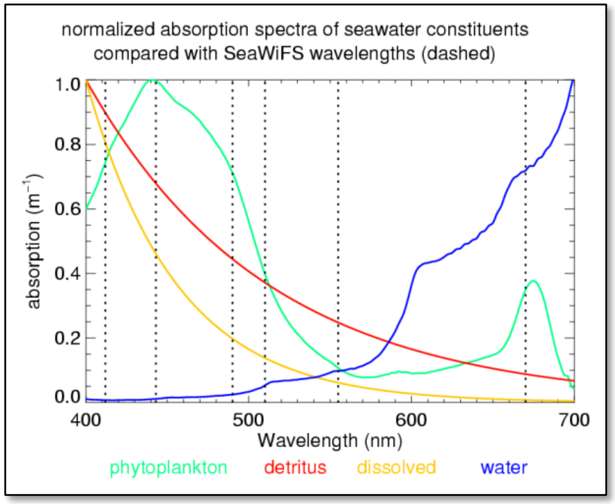
MODIS image: Arabian Sea, March 2, 2017

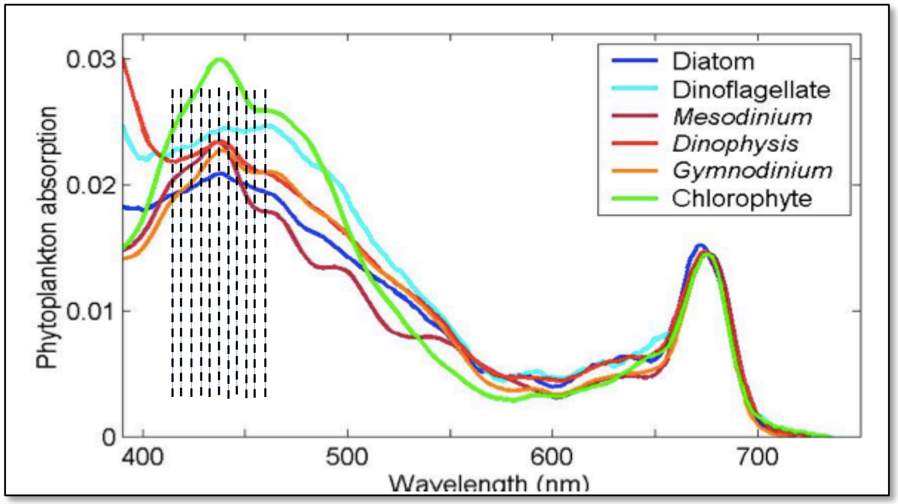




Spectral resolution

Heritage





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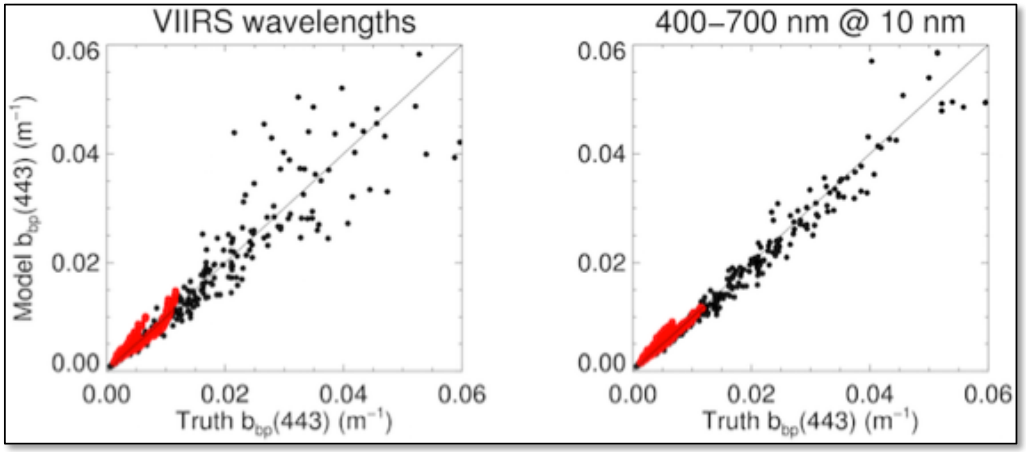
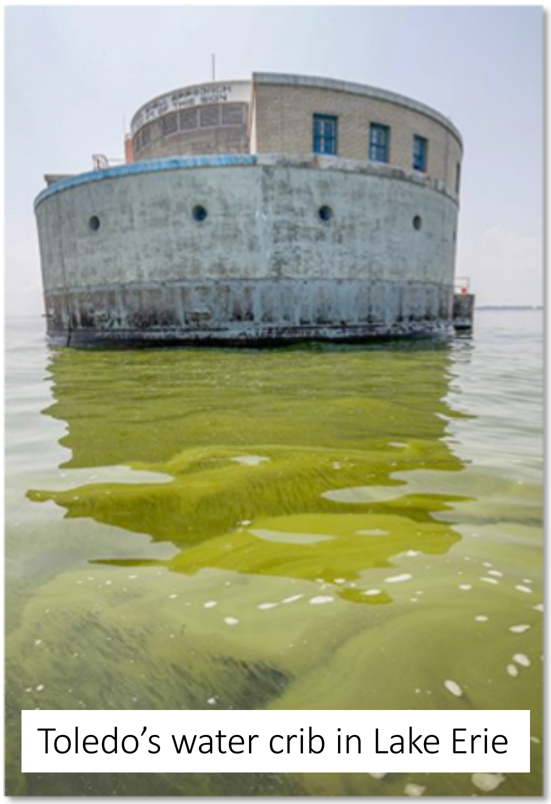


Particle backscattering retrievals improve when using "hyperspectral" retrievals compared to using only VIIRS wavelengths

Chapter 3: Applied sciences examples

Detection of harmful cyanobacteria blooms



Toledo's water crib in Lake Erie

A satellite image from NOAA shows an aerial view of Lake Erie's massive 2011 algae bloom.

PHOTOGRAPH BY NASA/EARTH OBSERVATORY

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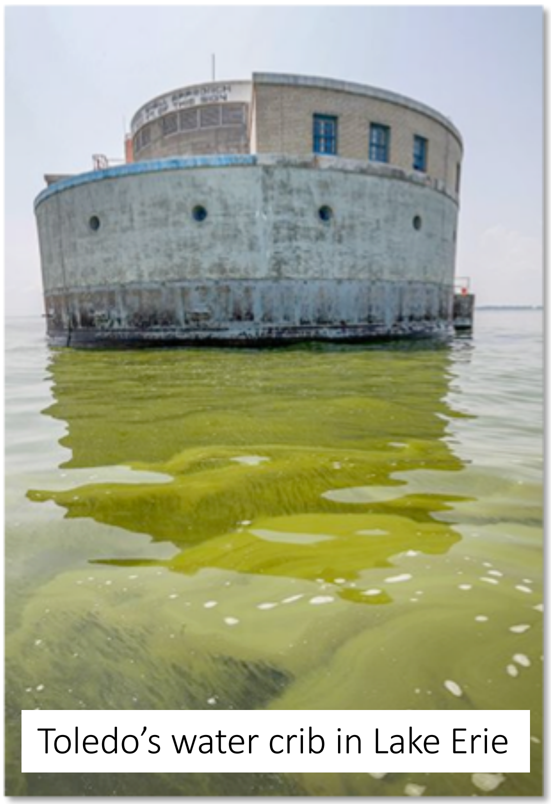
Chapter 3: Applied sciences examples

Detection of harmful cyanobacteria blooms



Toledo’s water crib in Lake Erie

Lake Erie Harmful Algal Bloom Bulletin

10 August, 2017, Bulletin 09

The *Microcystis* cyanobacteria bloom continues in the western basin along- and offshore the Ohio and Michigan coast from Maumee Bay north past Stony Point and east towards Middle Sister Island. Observed winds this week (8/7-10) reduced mixing, increasing surface concentrations from earlier. Scums have been reported. Measured toxin concentrations are below the recreational thresholds throughout most of the bloom extent, but concentrations can exceed the threshold where the bloom is most dense (which would look green from a boat).

Forecast winds (5-12kn) today through Saturday (8/10-12) may promote mixing, reducing surface concentrations of *Microcystis*. Winds will promote easterly transport of *Microcystis* today through Sunday (8/10-13) towards the Ontario Coast.

Please check Ohio EPA's site on harmful algal blooms for safety information. http://epa.ohio.gov/habalgae.aspx. Keep your pets and yourself out of the water in areas where scum is forming. The persistent cyanobacteria bloom of *Planktothrix* continues in Sandusky Bay and extends into Lake Erie. NOAA's GLERL provides additional HAB data: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia.

-Davis, Lalime

The images below are "GeoPDF". To see the longitude and latitude under your cursor, select "Tools > Analyze > Geospatial Location Tool".

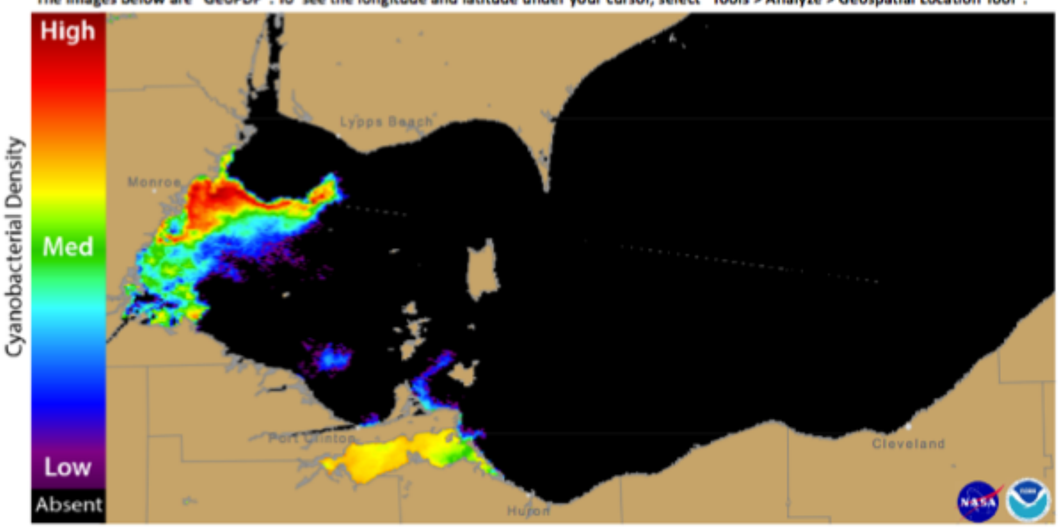


Figure 1. Cyanobacterial Index from modified Copernicus Sentinel 3 data collected 08 August, 2017 at 11:26 EST. Grey indicates clouds or missing data. The estimated threshold for cyanobacteria detection is 20,000 cells/mL.

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Support environmental management and public use of U.S. lakes by providing a capability of detecting and quantifying algal blooms and related water quality using satellite data records.

CyAN Work Packages

Remote sensing	• Uniform and systematic approach for identifying cyanobacteria blooms.
	• Strategy for evaluation and refinement of algorithms across platforms.
Environment	• Identify landscape linkages causes of chlorophyll a and cyanobacteria
Health	• Exposure and human health effects in drinking and recreational waters.
Economics	• Behavioral responses and economic value of the early warning system.
Information distribution	• Bring the technology to EPA, states and tribal partners.
	• Provide notifications and decision support

Full mission-long MERIS & OLCI (300-m) time-series of cyanobacteria abundance generated for ~1,800 resolvable inland continental U.S. lakes

CYAN

Harmful Algae 67 (2017) 144–152

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

A method for examining temporal changes in cyanobacterial harmful algal bloom spatial extent using satellite remote sensing

Erin A. Urquhart[a,*], Blake A. Schaeffer[b], Richard P. Stumpf[c], Keith A. Loftin[d], P. Jeremy Werdell[e]

Ecological Indicators 80 (2017) 84–95

Contents lists available at ScienceDirect

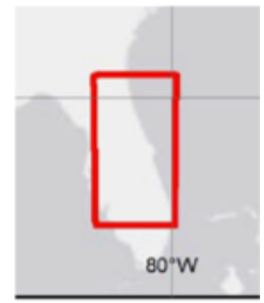
Ecological Indicators

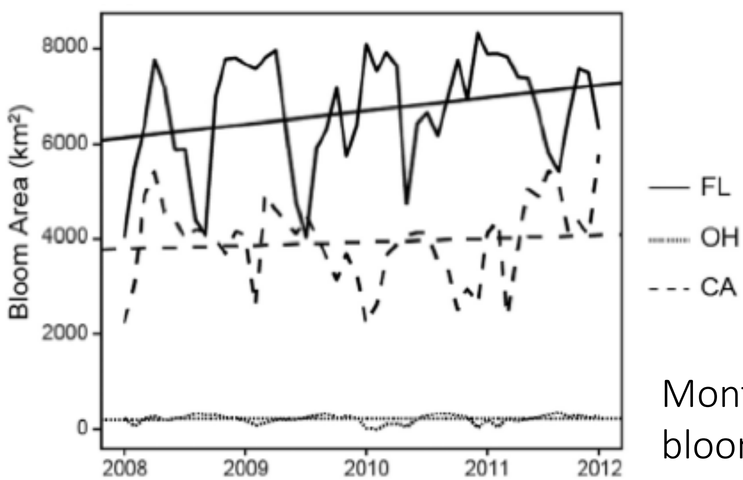
journal homepage: www.elsevier.com/locate/ecolind

Original Articles

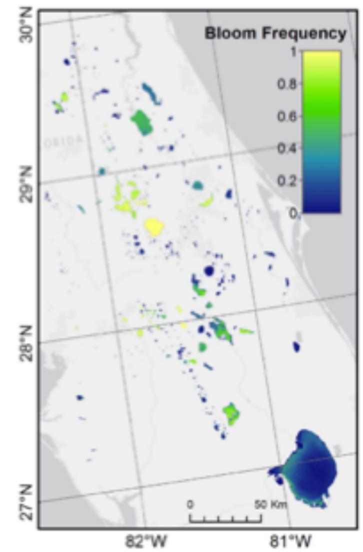
Satellite monitoring of cyanobacterial harmful algal bloom frequency in recreational waters and drinking water sources

John M. Clark[a], Blake A. Schaeffer[b,*], John A. Darling[b], Erin A. Urquhart[a], John M. Johnston[b], Amber R. Ignatius[a], Mark H. Myer[a], Keith A. Loftin[c], P. Jeremy Werdell[d], Richard P. Stumpf[e]



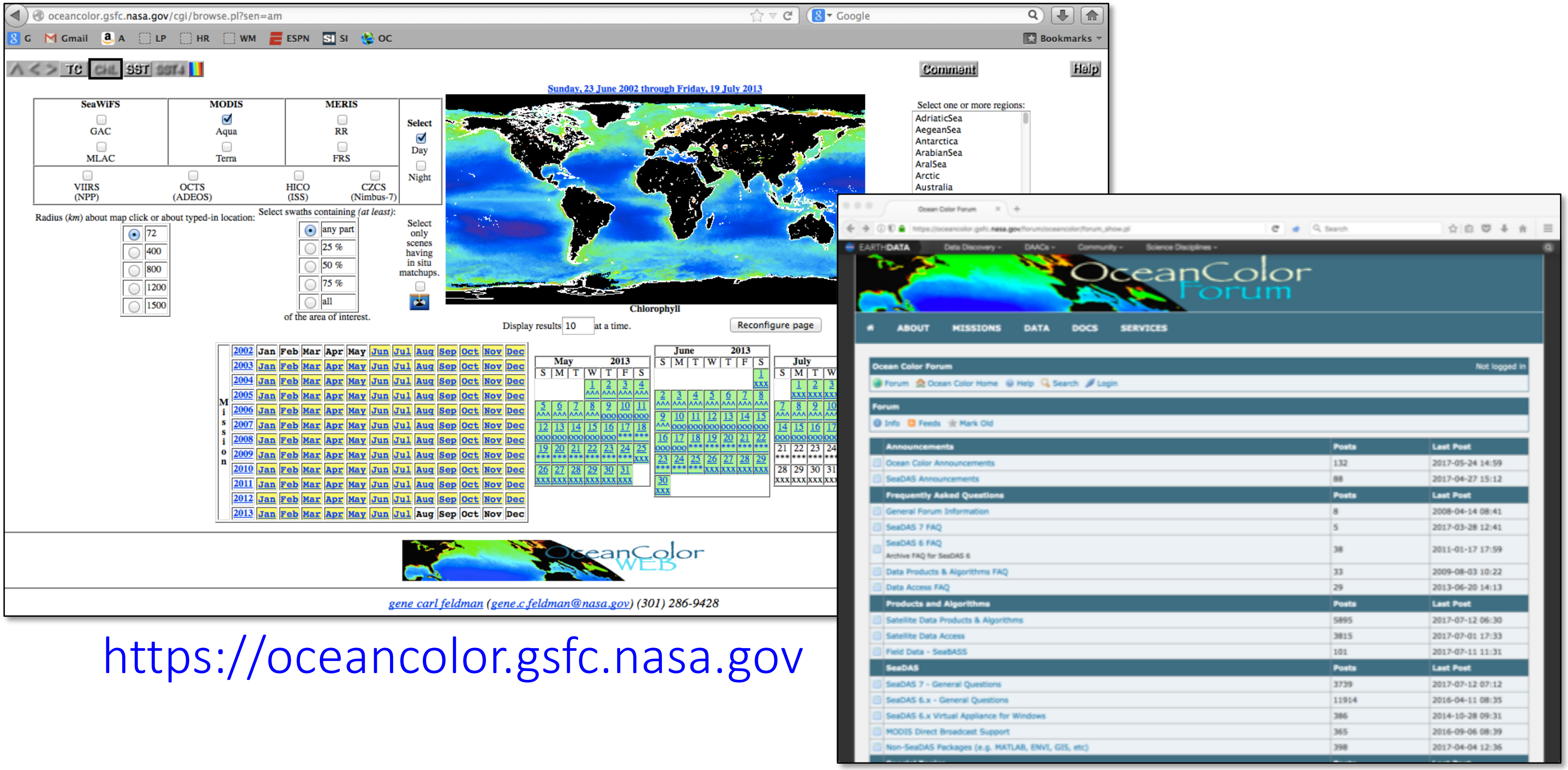


Frequency of observed cyanoHAB occurrence above WHO high threshold (100,000 cells mL^{-1}) from 2008-2011 at the pixel level.



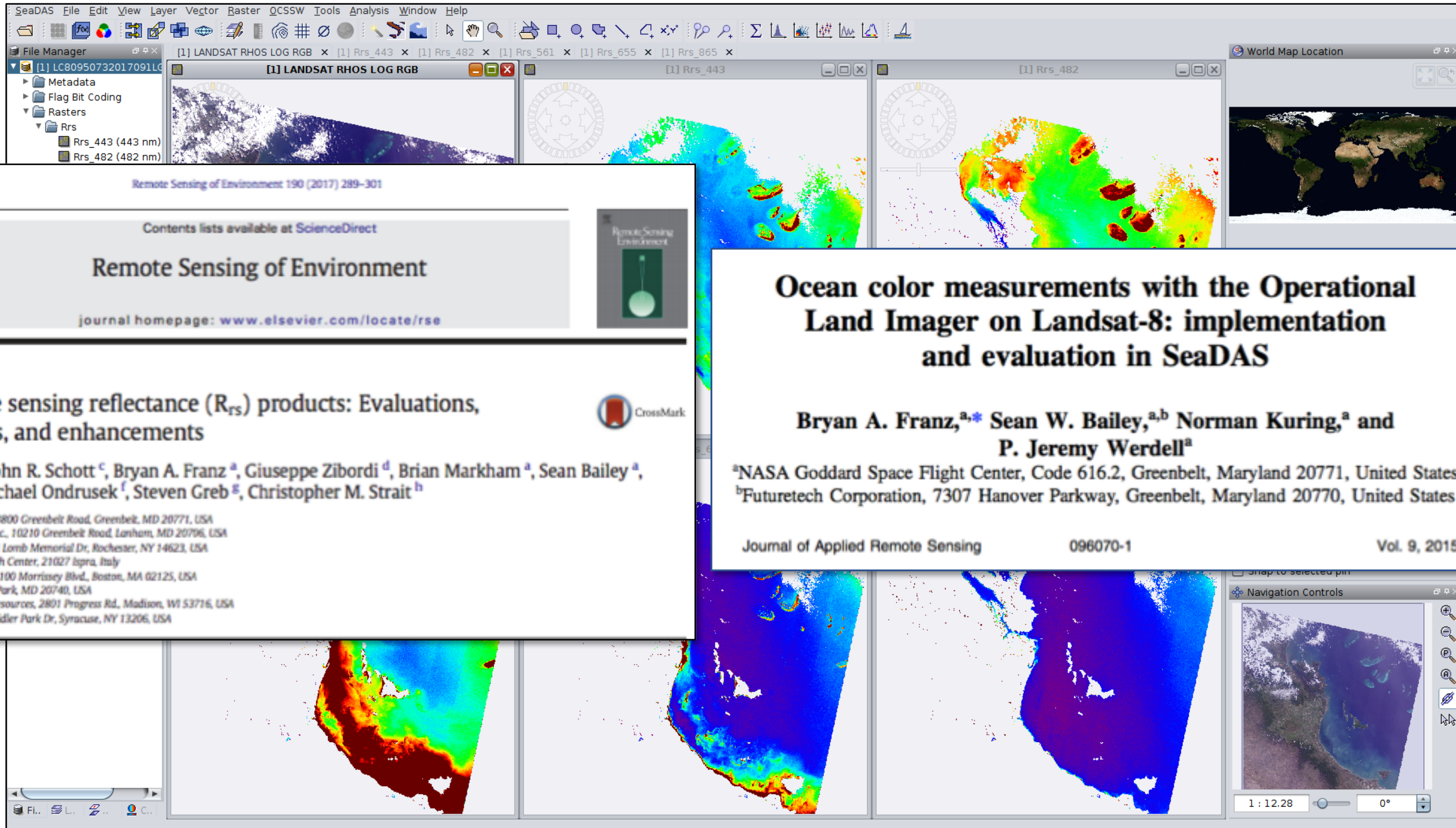
Monthly temporal assessment of total bloom area (km²) for FL, OH, & CA.

Chapter 4: Demystifying the use of satellite ocean color data



https://oceancolor.gsfc.nasa.gov

Further demystifying the use of satellite ocean color data



Remote Sensing of Environment 190 (2017) 289–301

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Landsat 8 remote sensing reflectance (R_{rs}) products: Evaluations, intercomparisons, and enhancements

Nima Pahlevan [a,b,*], John R. Schott [c], Bryan A. Franz [a], Giuseppe Zibordi [d], Brian Markham [a], Sean Bailey [a], Crystal B. Schaaf [e], Michael Ondrusek [f], Steven Greb [g], Christopher M. Strait [h]

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[e] University of Massachusetts Boston, 100 Morrissey Blvd., Boston, MA 02125, USA
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Ocean color measurements with the Operational Land Imager on Landsat-8: implementation and evaluation in SeaDAS

Bryan A. Franz,[a,*] Sean W. Bailey,[a,b] Norman Kuring,[a] and P. Jeremy Werdell[a]

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Journal of Applied Remote Sensing 096070-1 Vol. 9, 2015

Citizen science!

Research Article Vol. 25, No. 8 | 17 Apr 2017 | OPTICS EXPRESS A361
Optics EXPRESS

From toes to top-of-atmosphere: Fowler's Sneaker Depth index of water clarity for the Chesapeake Bay

BENJAMIN CROOKE,[1,2] LACHLAN I. W. MCKINNA,[1,3,*] AND IVONA CETINIC[1,4]
[1]NASA Goddard Space Flight Center, Code 616, Greenbelt, MD 20771, USA
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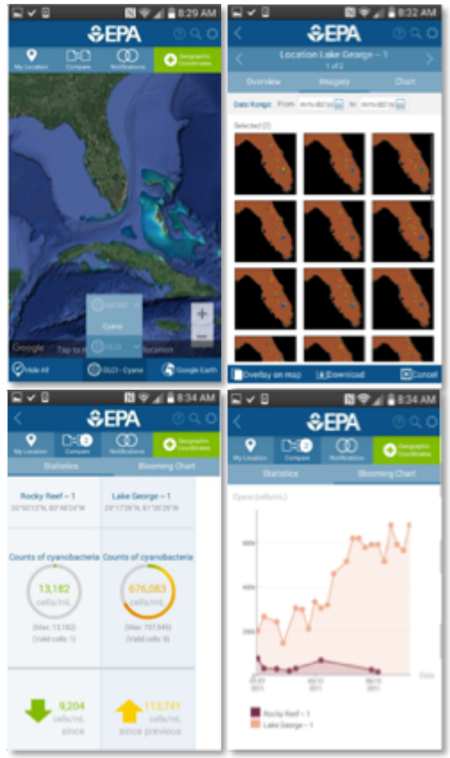
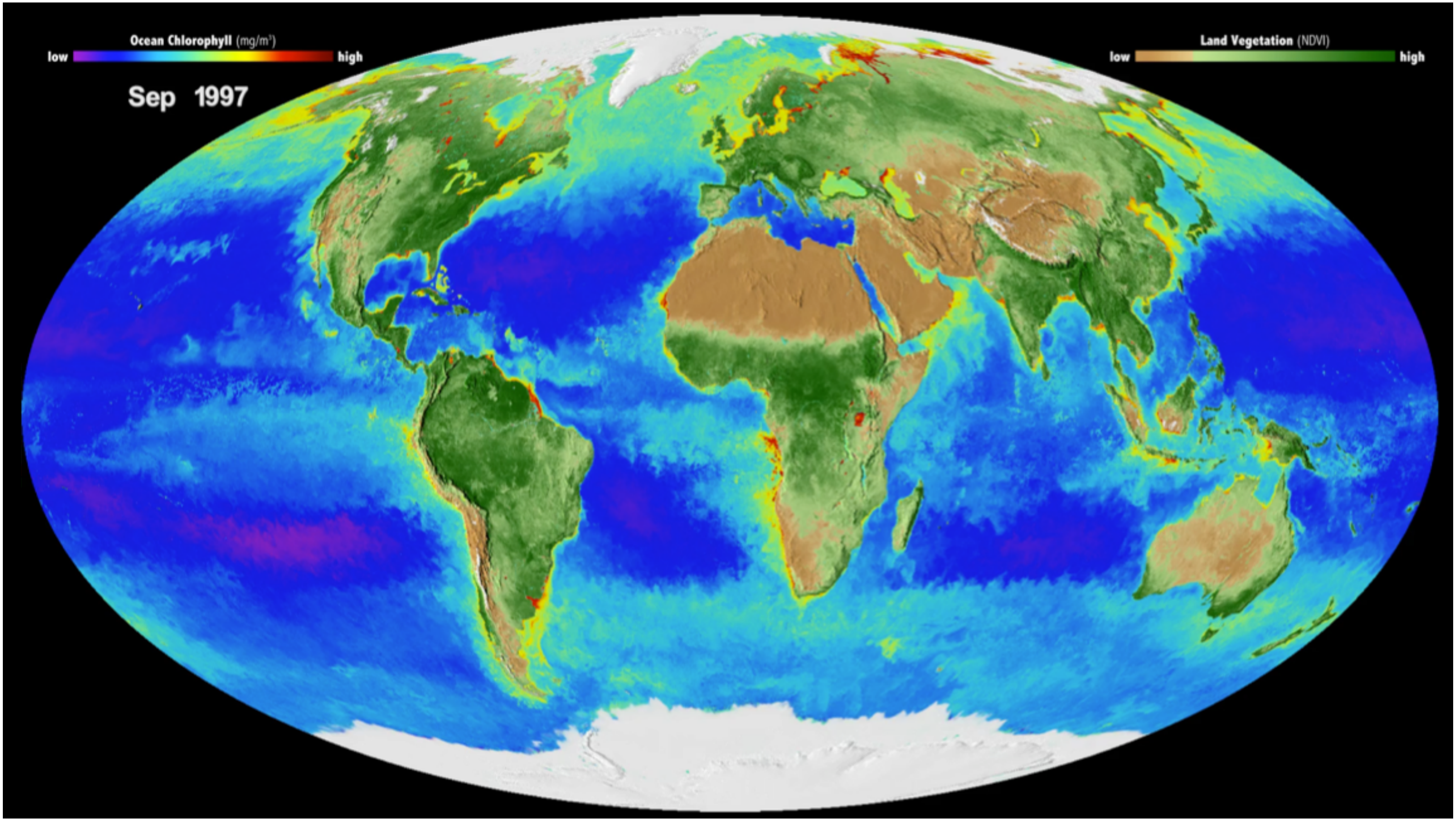
[4]GESTAR/Universities Space Research Association, Columbia, MD 21046, USA
*lachlan.i.mckinna@nasa.gov




Ocean Chlorophyll (mg/m³)
low
high
Sep 1997
Land Vegetation (NDVI)
low
high

Thank you! Questions?

PACE Mission Features

Cost	Directed, DTC, $805M
Life	3-yr, Class C, 10-yr fuel
Launch	Fall 2022
Orbit	676.5 km, Sun sync, 1-pm MLT AN
Coverage (OCI)	2-day global
RF Communication	Ka direct to ground, 600Mbps

PACE Key Mission Science Requirements

Ground sample distance of 1 ± 0.1 km^2 at nadir
Sun glint mitigation (OCI tilt ± 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


Backup
PACE
Plankton, Aerosol, Cloud, ocean Ecosystem

Learn more about PACE

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

PACE 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

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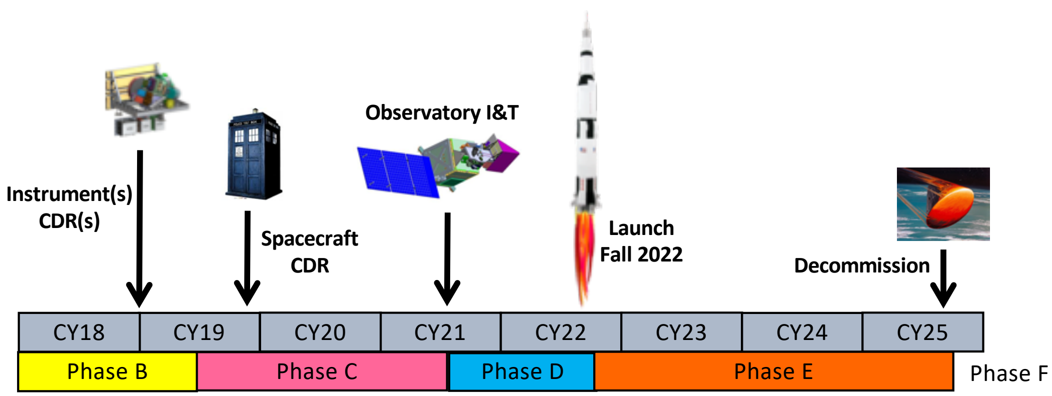

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