Remote sensing of water clarity in the Chesapeake Bay: Advantages and disadvantages

STAC Workshop, April 22, 2022

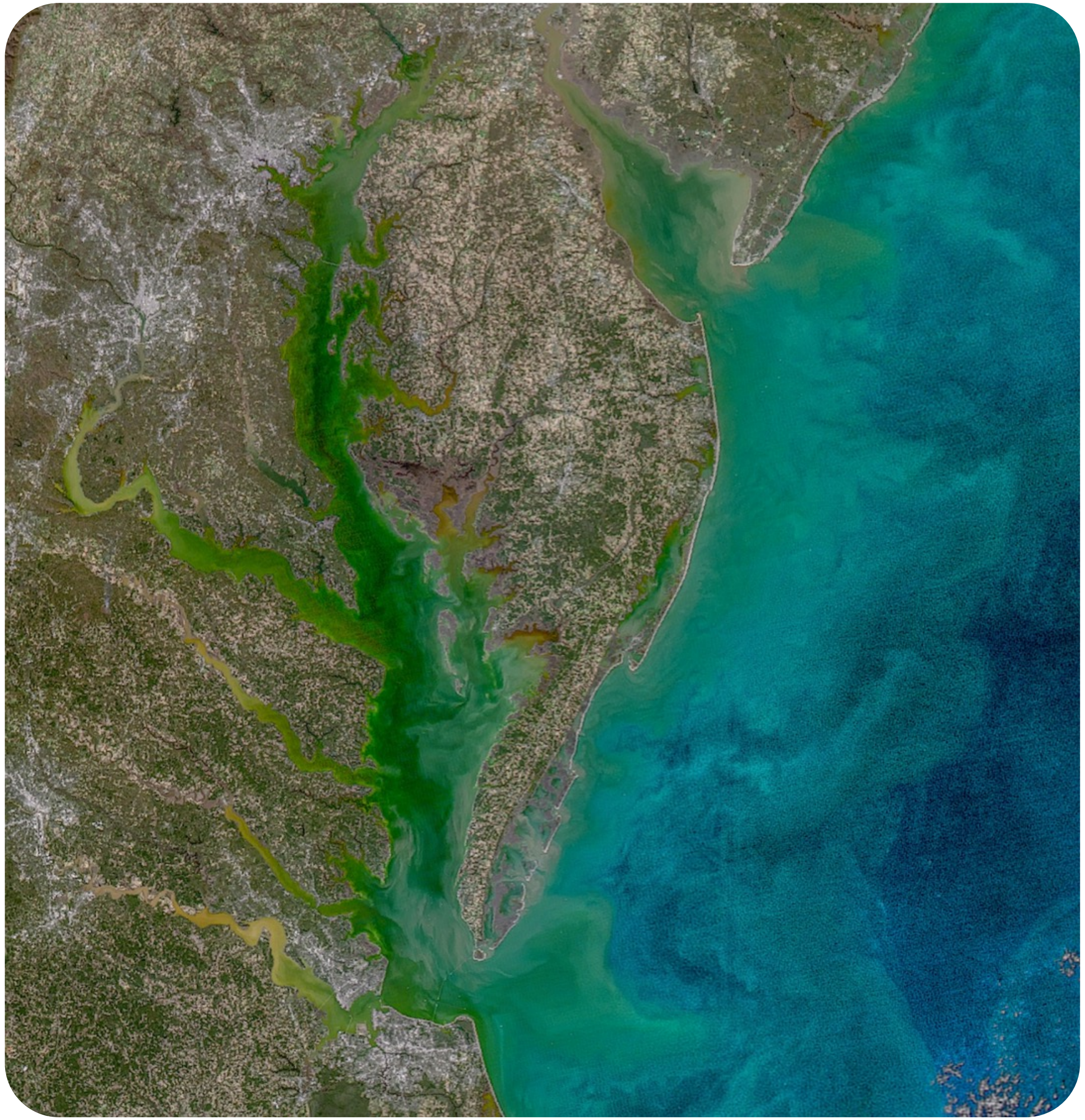
Advancing Monitoring Approaches to Enhance Tidal Chesapeake Bay Habitat Assessment on Monitoring Water Clarity and Chl-a

Jessie Turner

Postdoctoral Research Associate
University of Connecticut

Visiting Postdoc
Virginia Institute of Marine Science

Contact: jturner@uconn.edu



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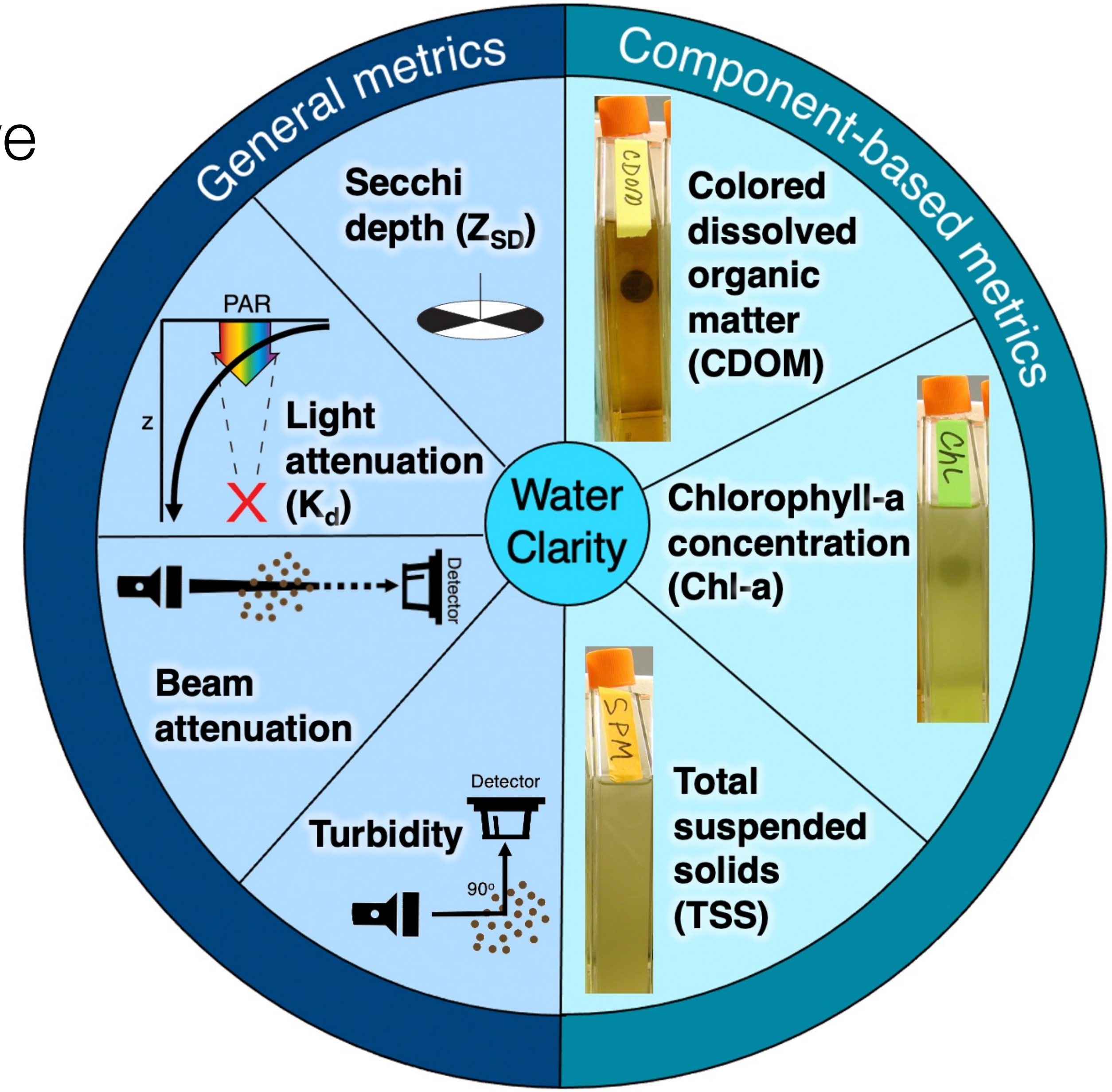
UCONN

Water Clarity

Water Clarity

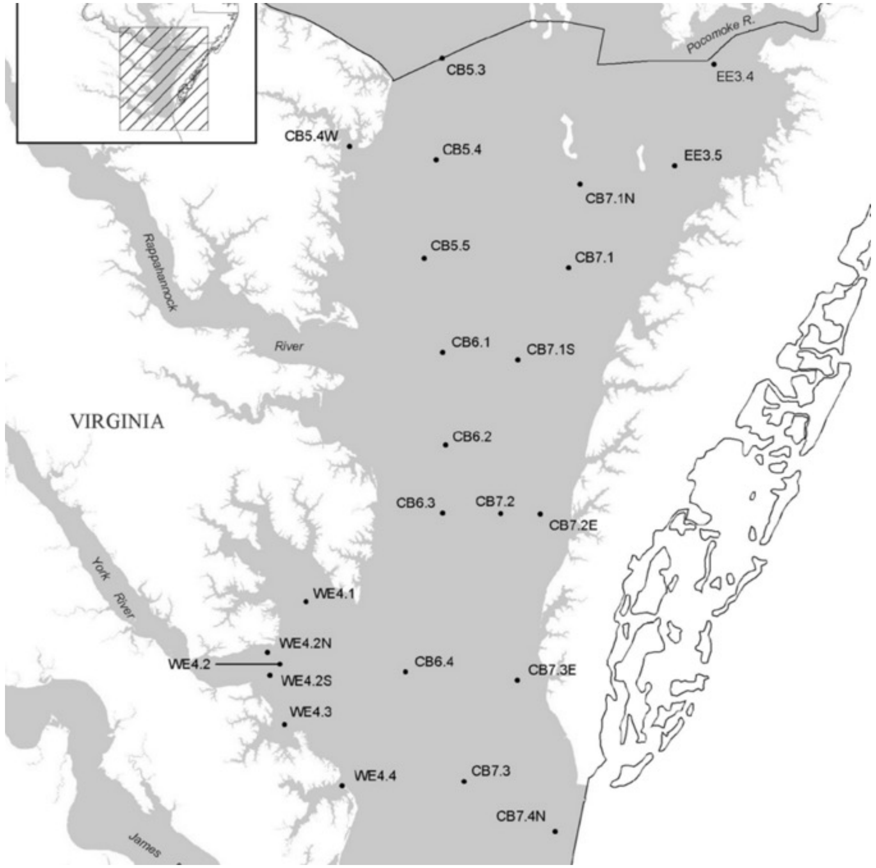
Defined by how we measure clarity in the field…



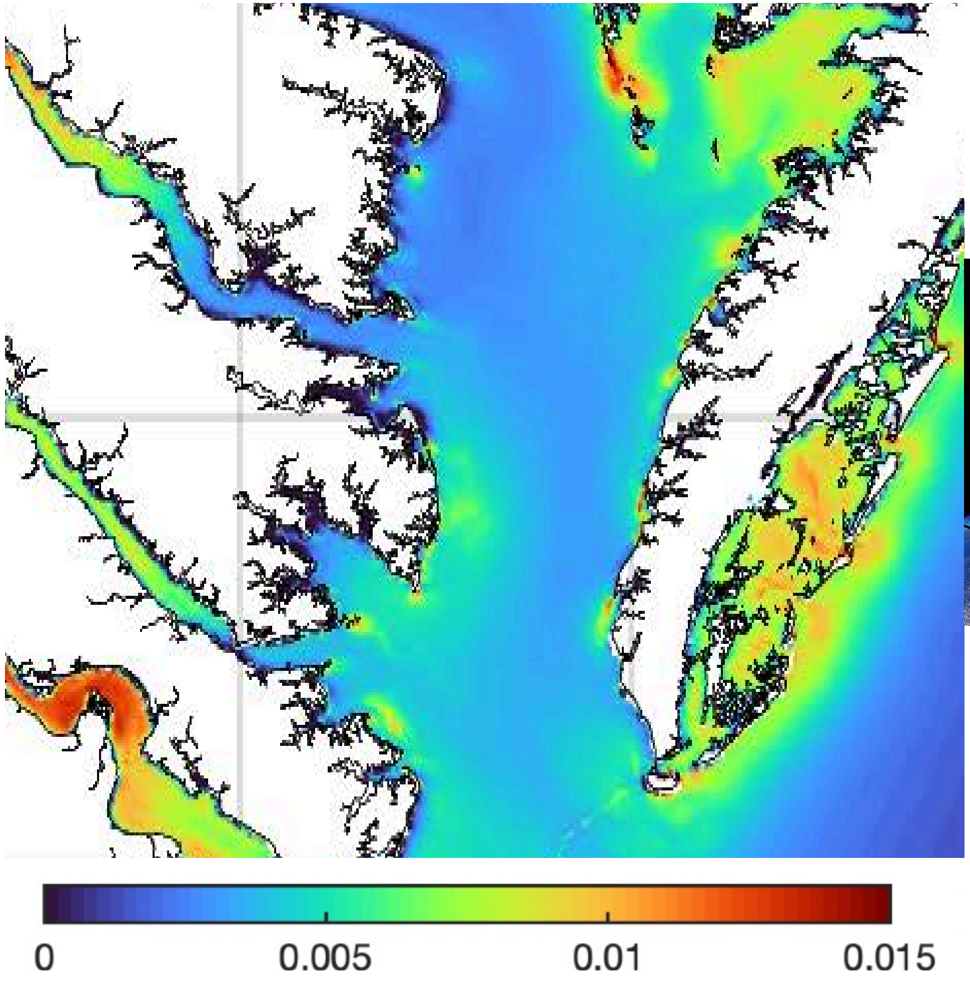
…and by which components block the light.

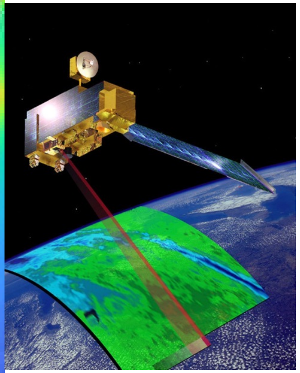
Satellite remote sensing adds coverage

Mainstem cruise stations



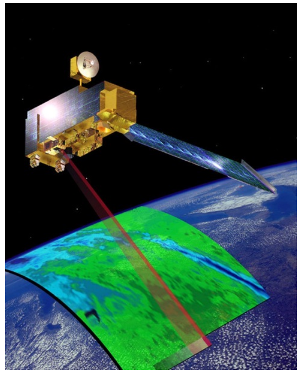
Satellite red reflectance



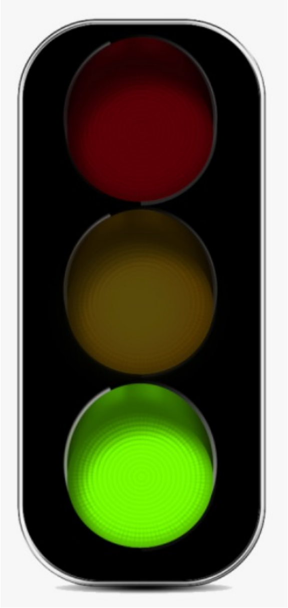


Long-term mean red reflectance at 645 nm (sr^{-1})
MODIS-Aqua Rrs (645) at 250m spatial resolution

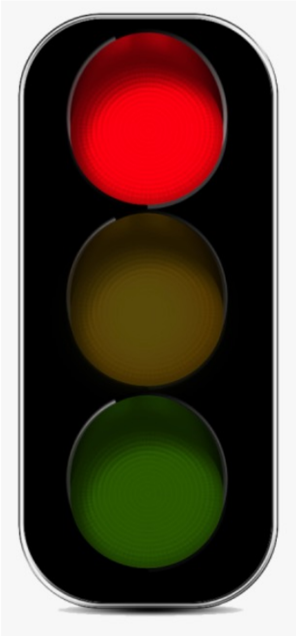
Conflicting Opinions



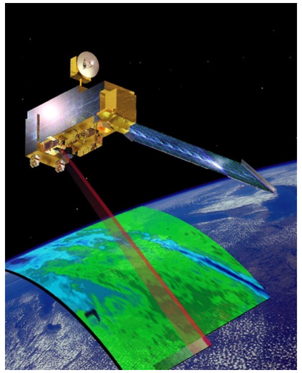
You should use satellite data! Great coverage! Long time series! Freely available!



You can't use satellite data for the Bay, it's optically complex!



Conflicting Opinions

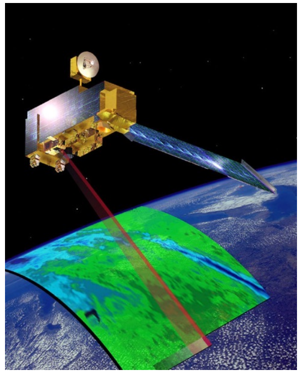


You should use satellite data!
Great coverage! Long time series!
Freely a

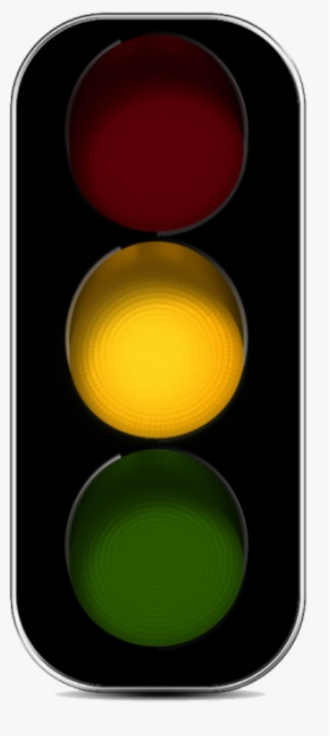
You can't use satellite data for the Bay, it's optically complex!

> > 1 component blocks out light:
> CDOM, phytoplankton, and sediments all make the water appear greener and/or browner from space

Conflicting Opinions

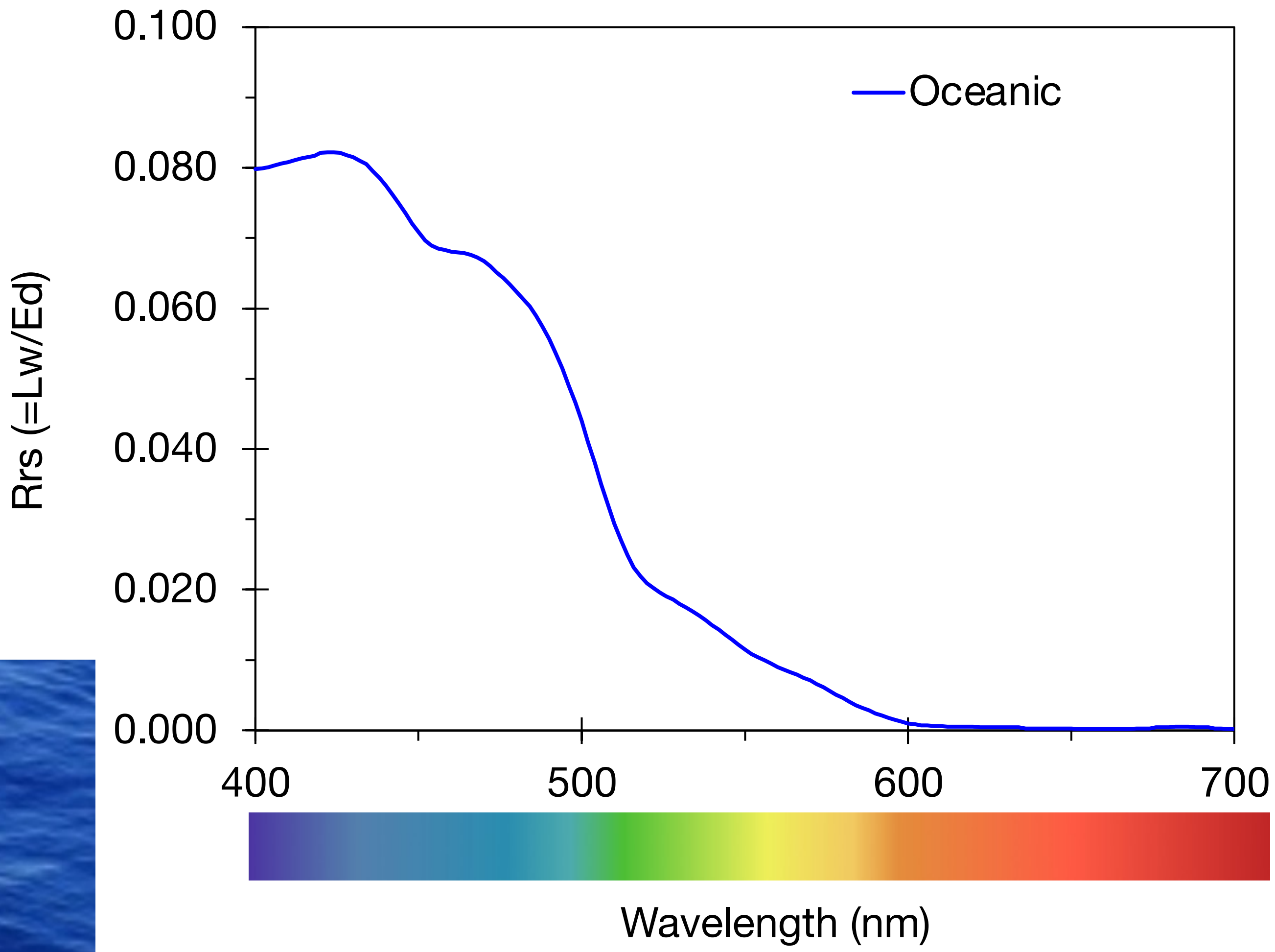


Use satellite data, but know the pros and cons of what you're using.

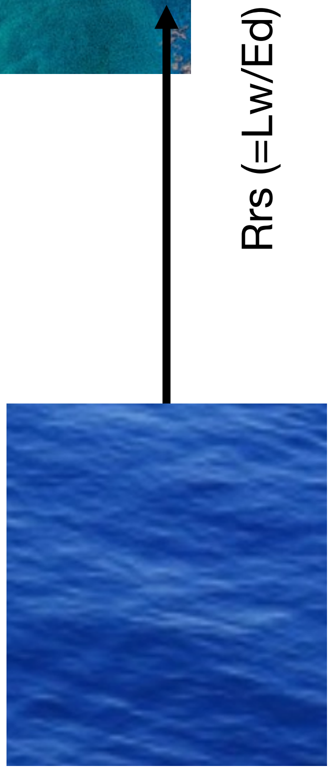


Which products to choose?
What does it all mean?

Remote Sensing Reflectance (Rrs)



Satellites see COLOR, in terms of Reflectance at different wavelengths



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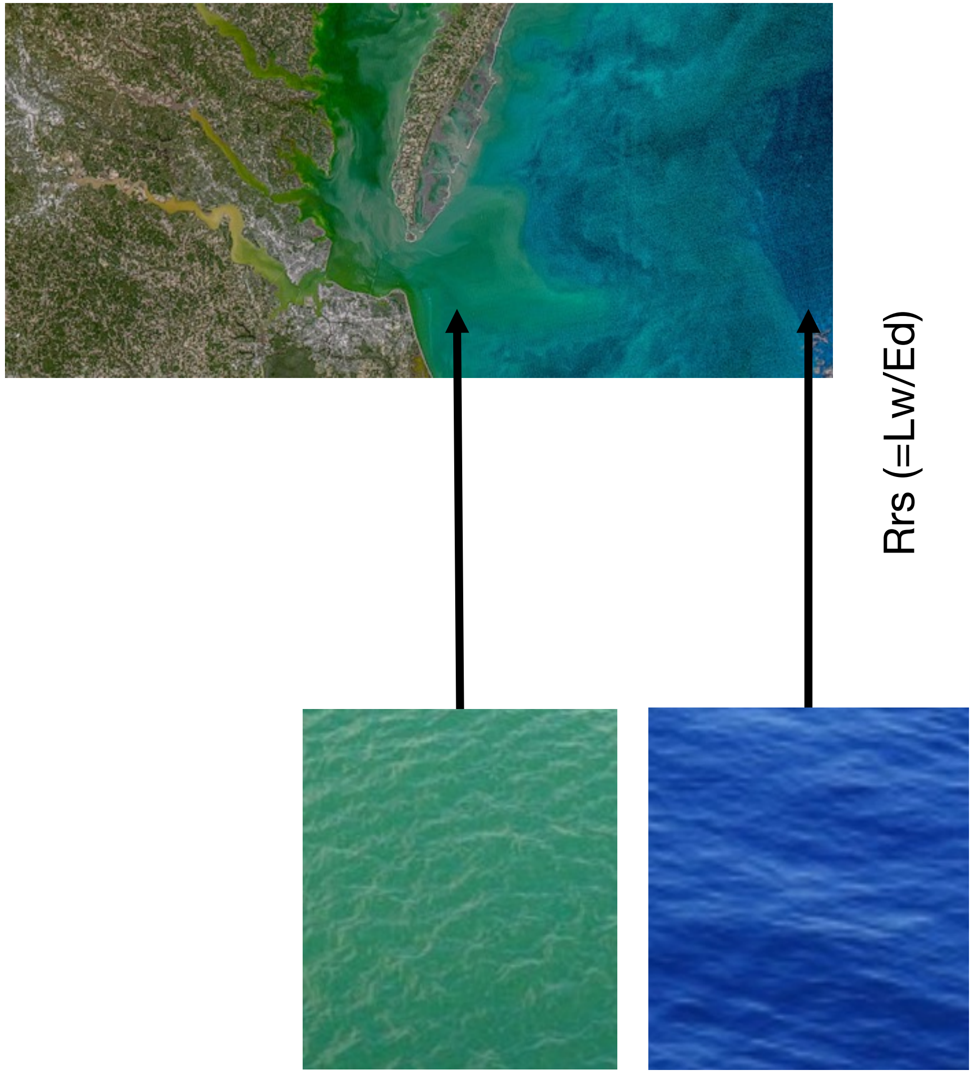

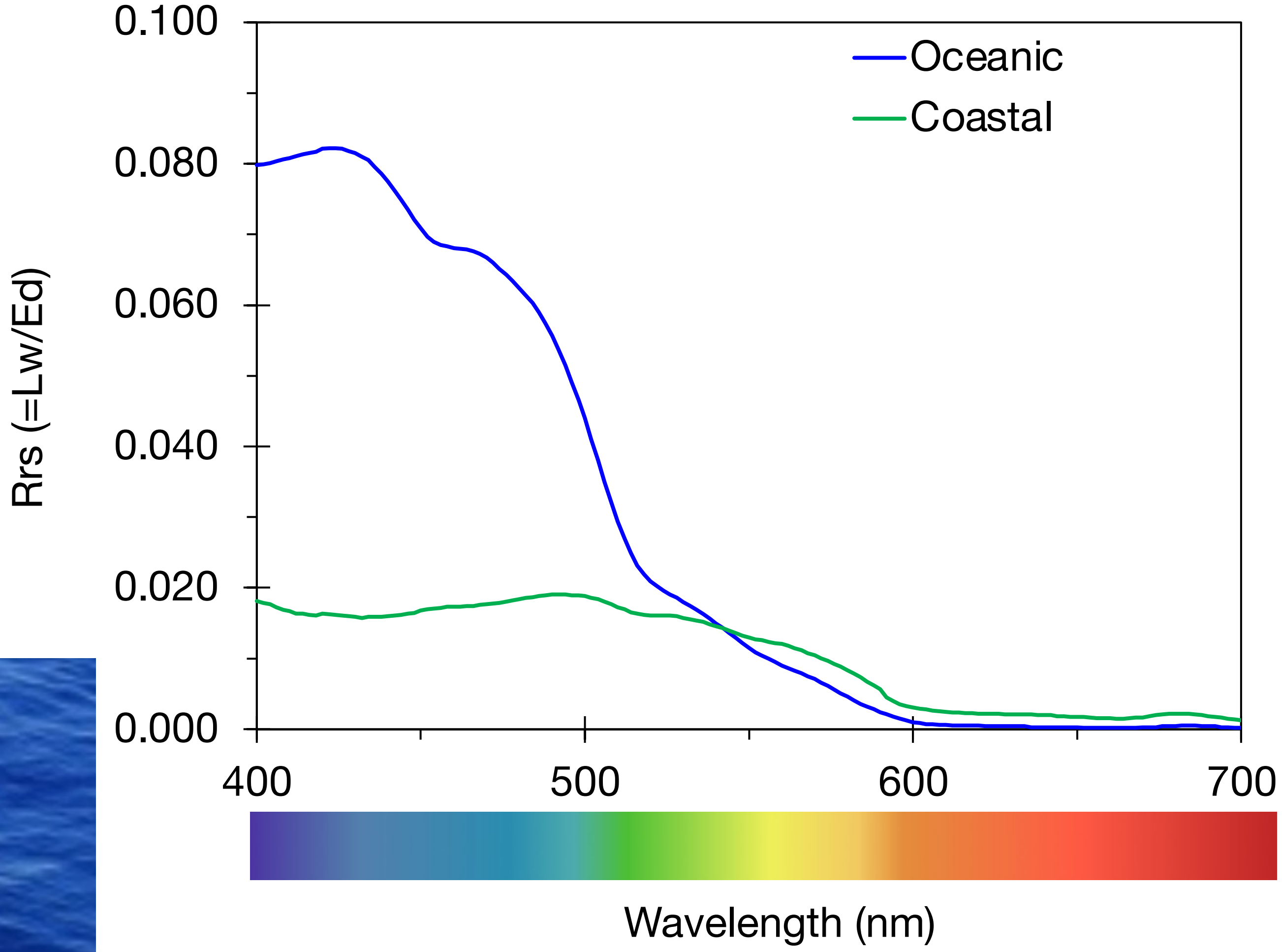

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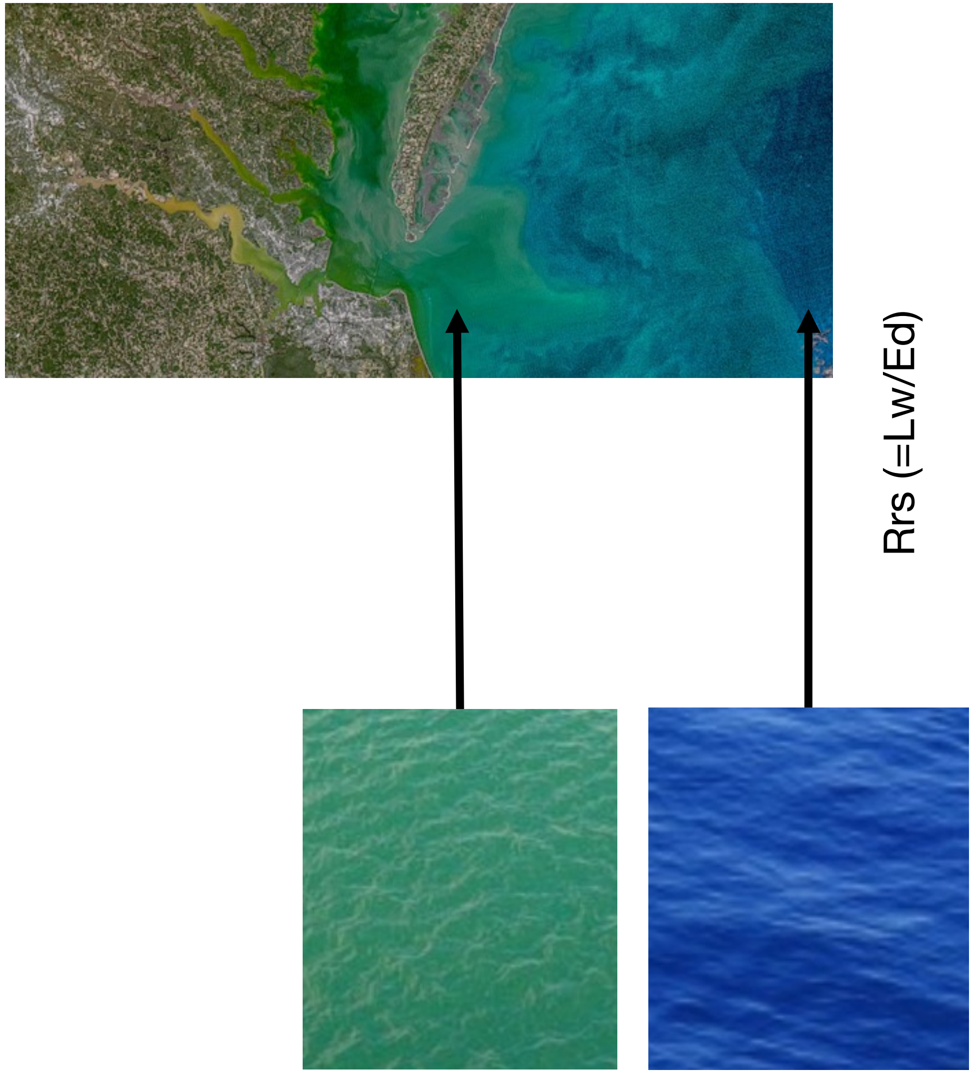

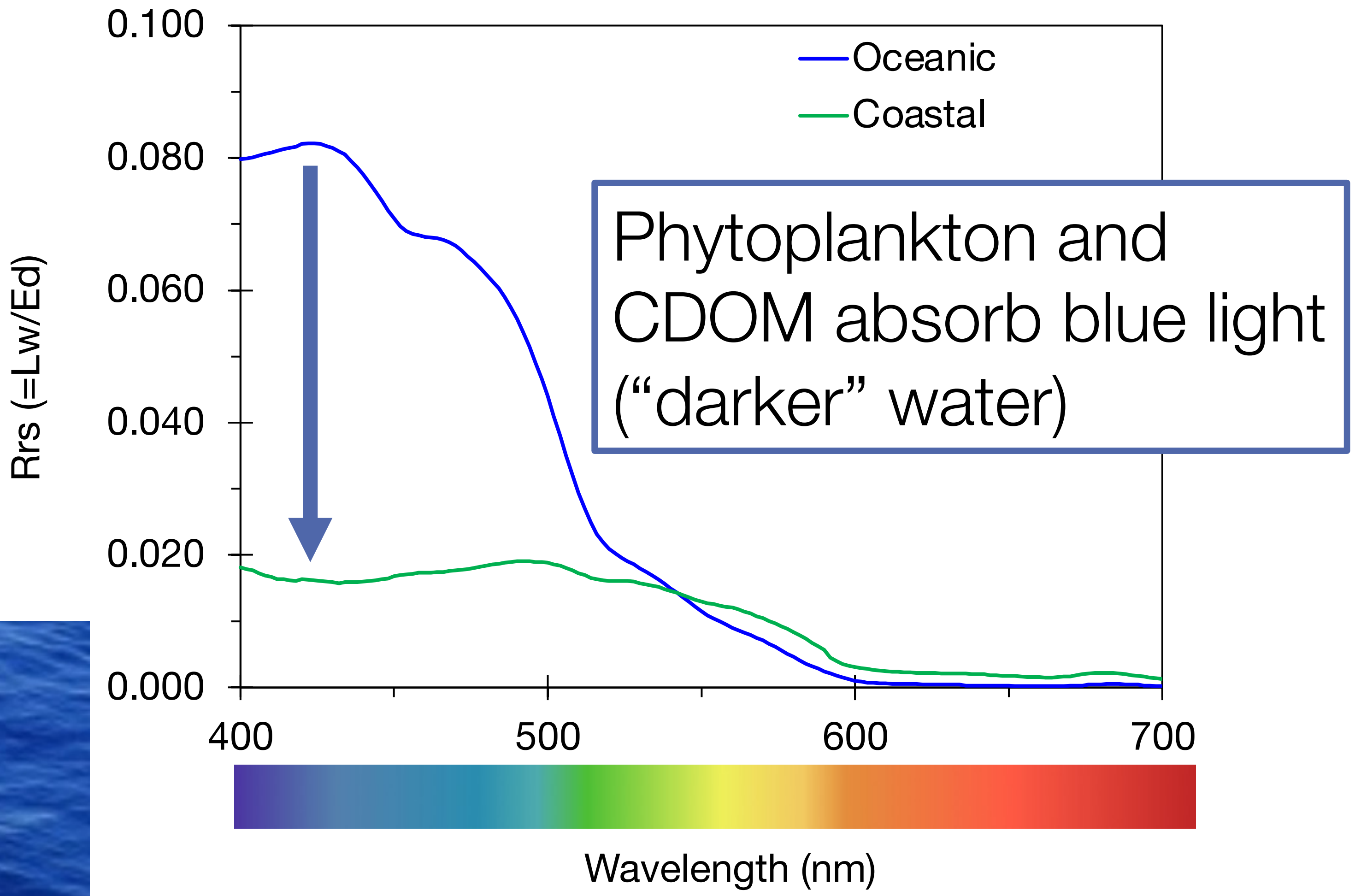

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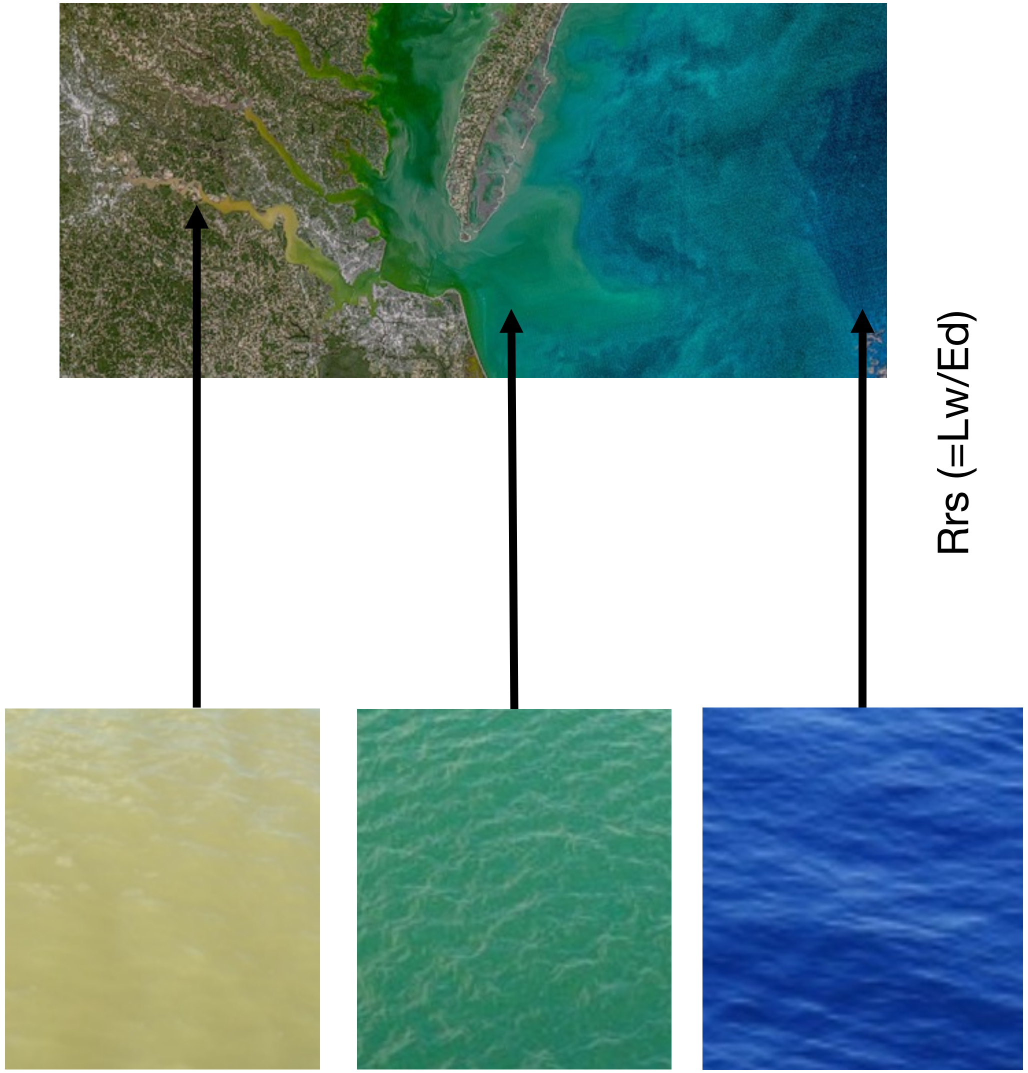

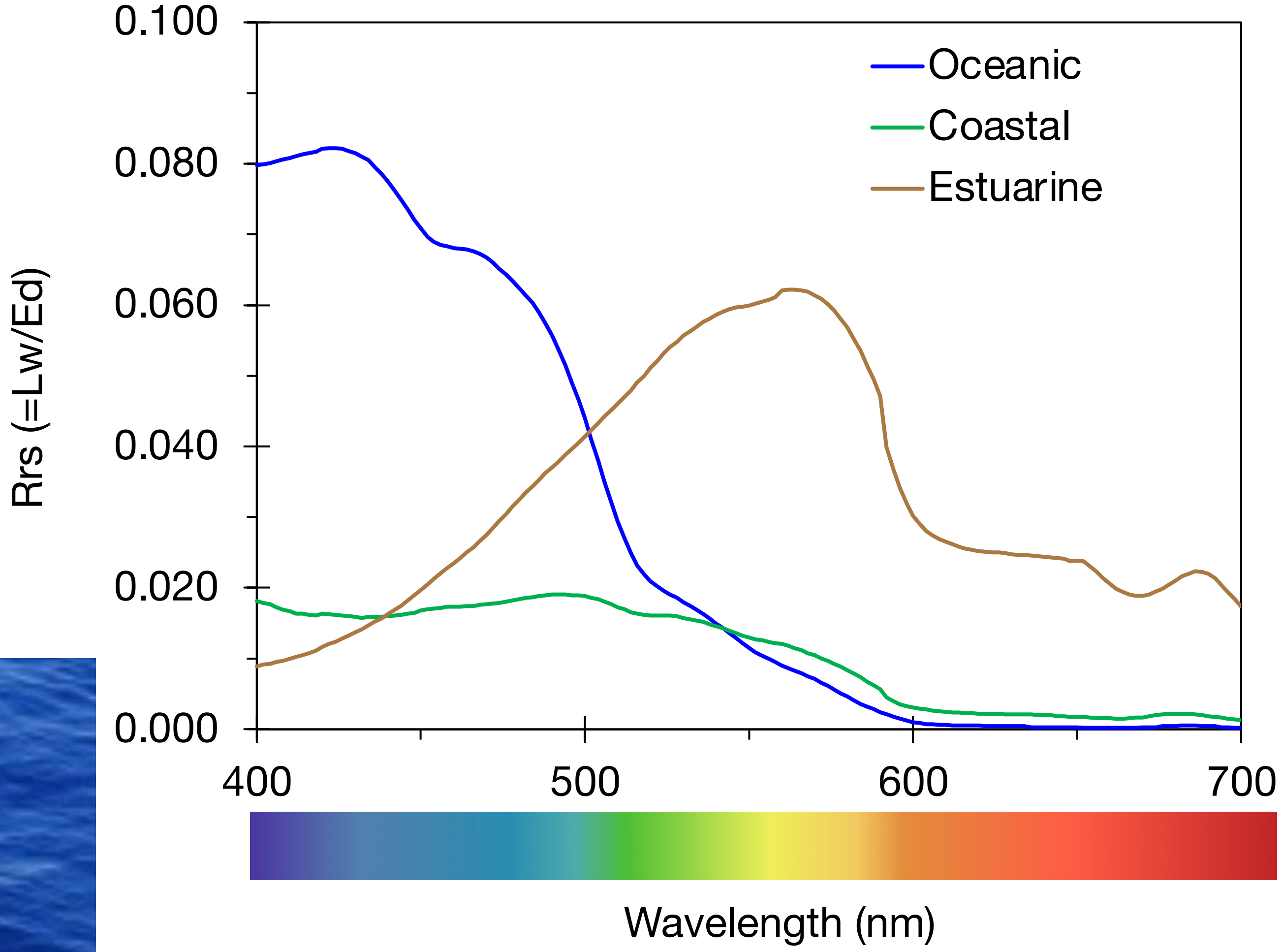

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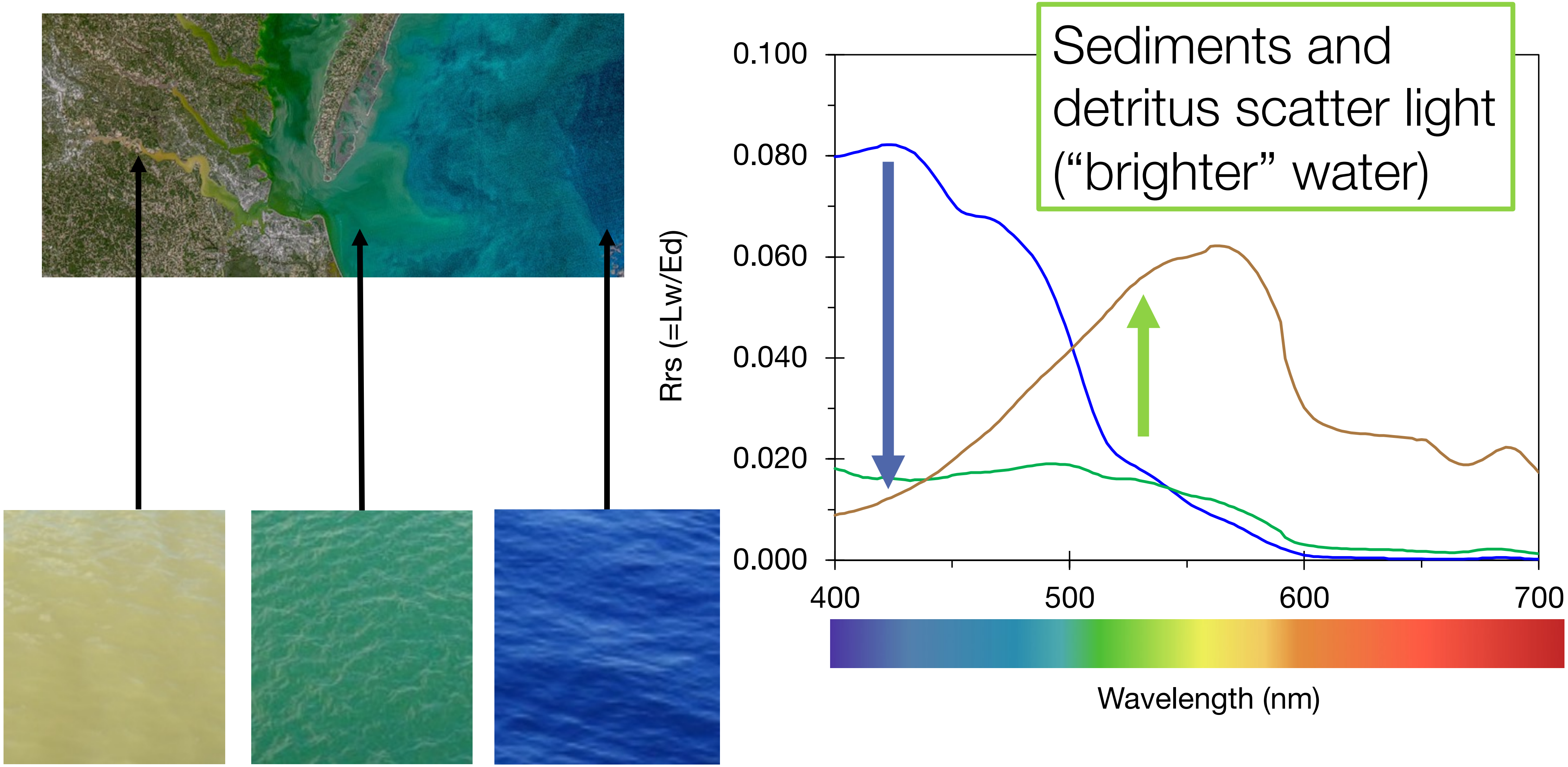

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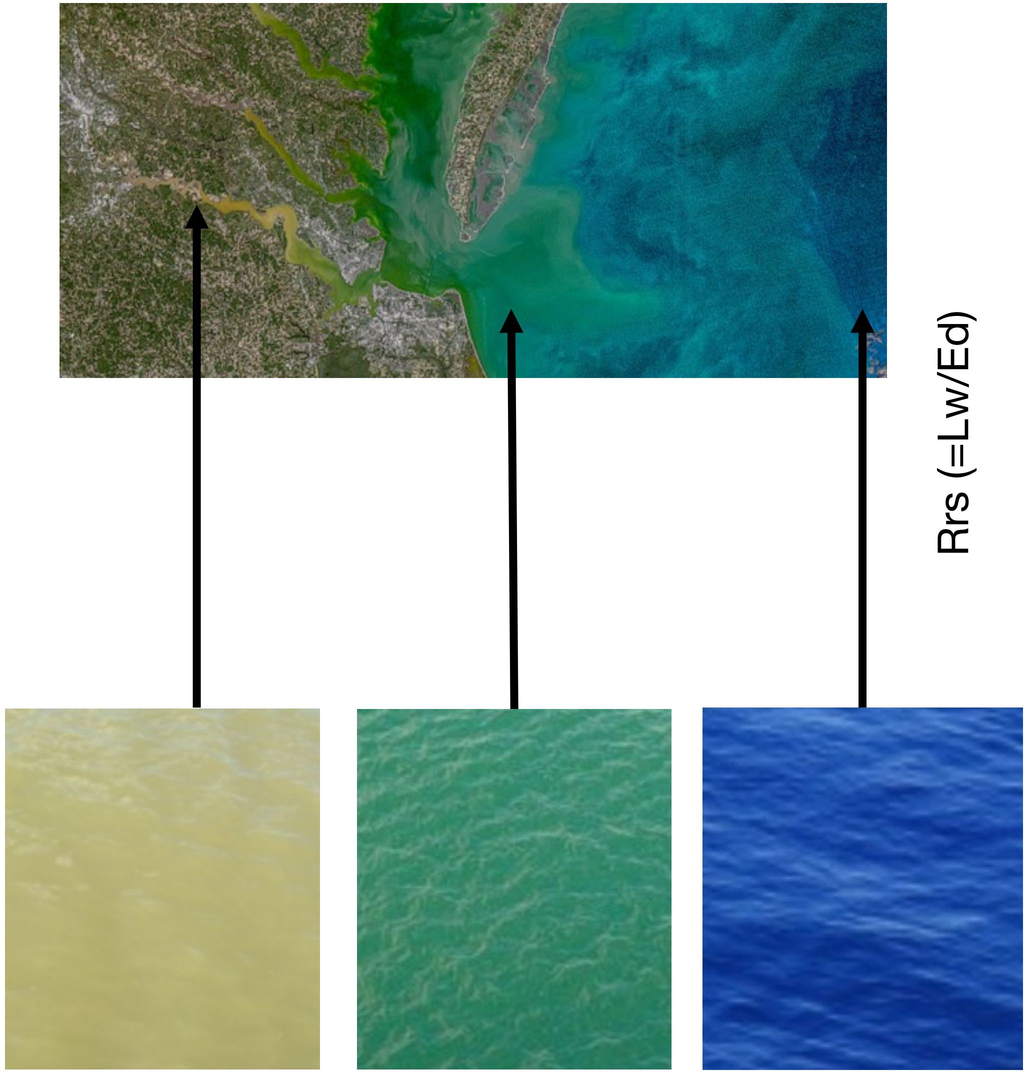

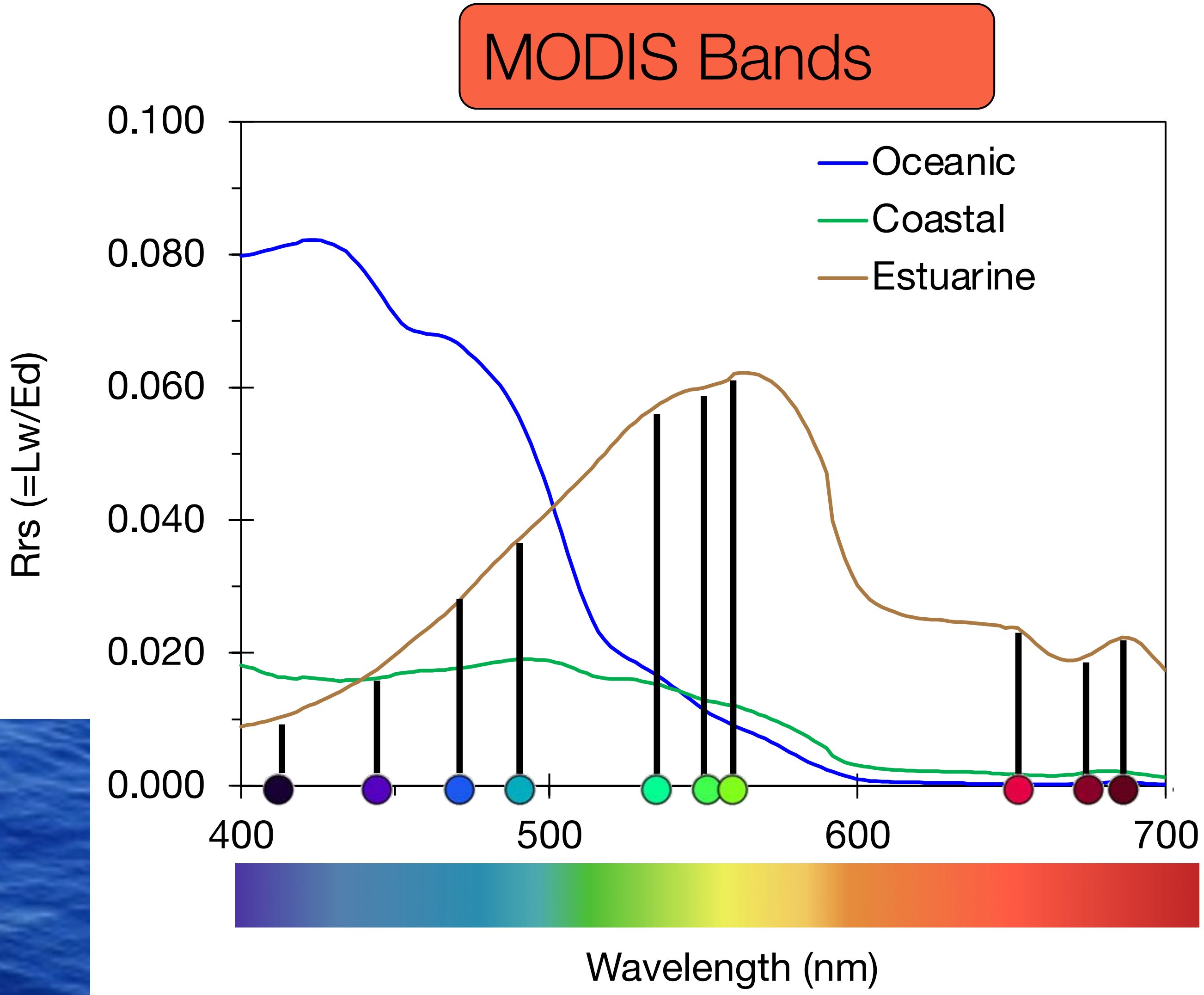

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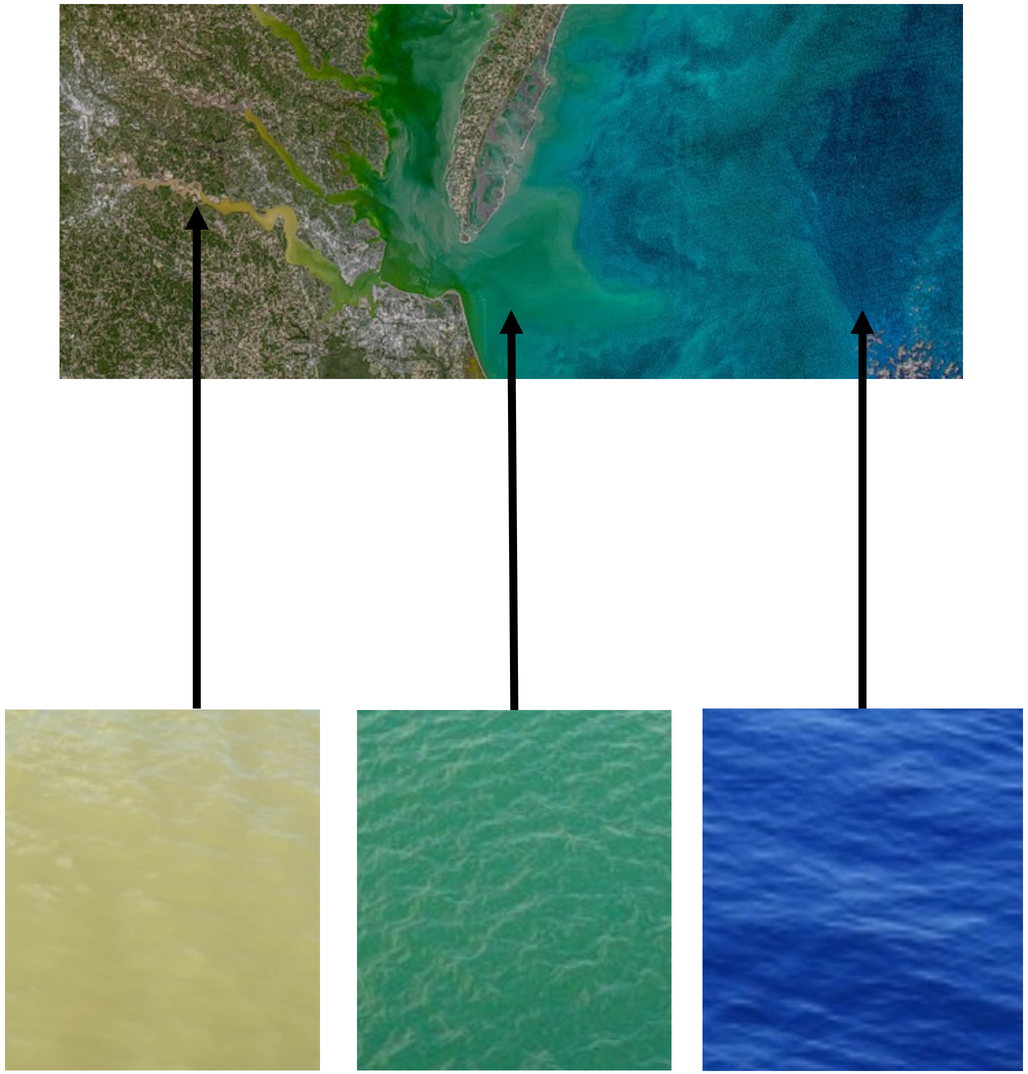

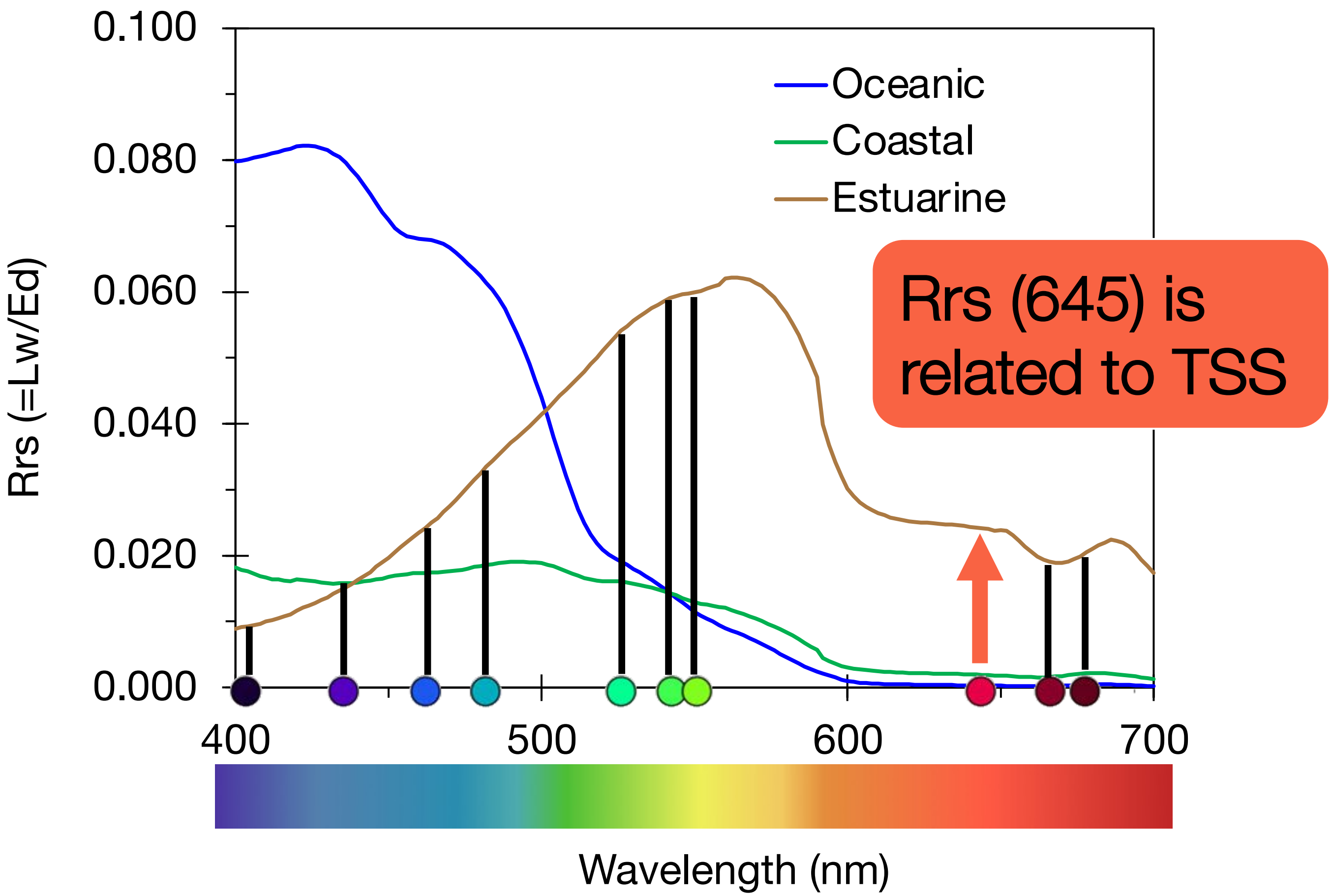

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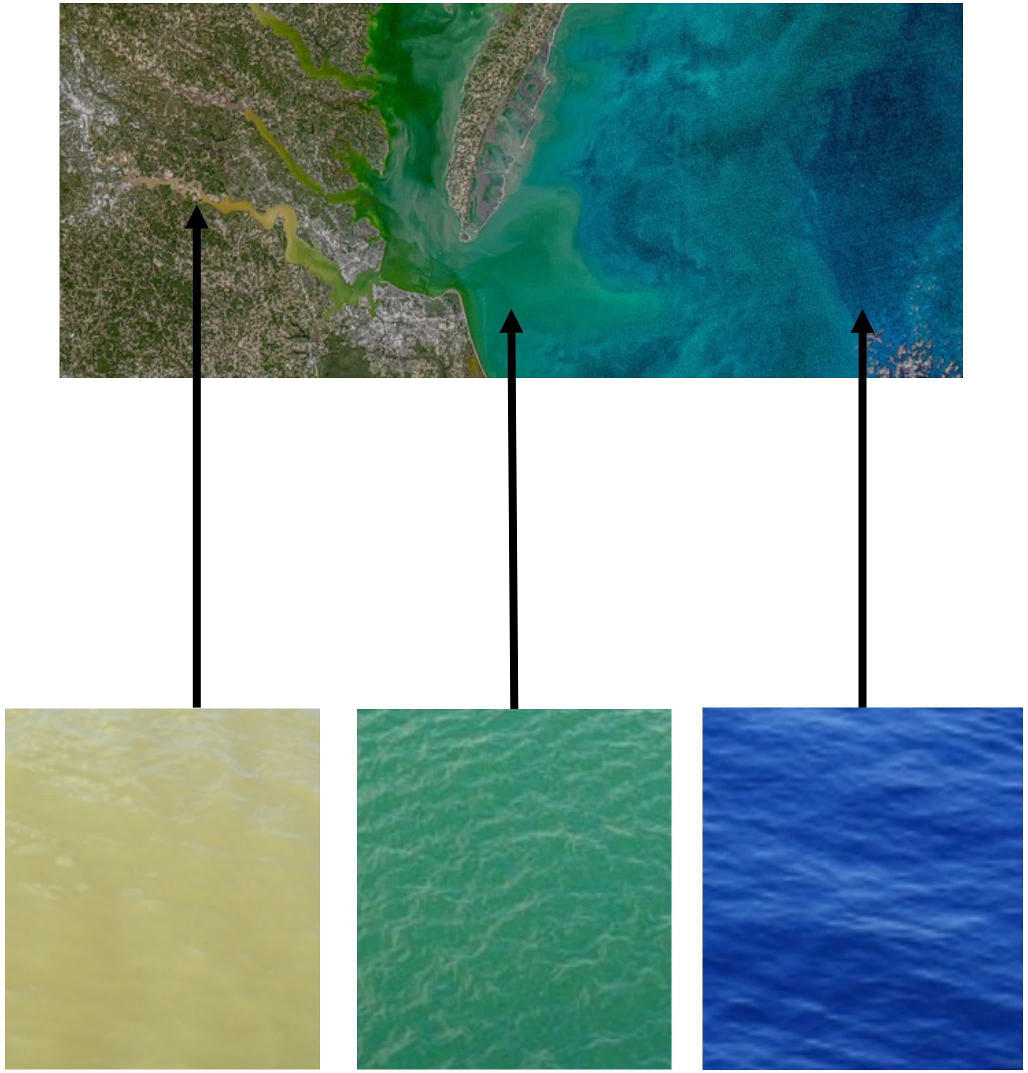
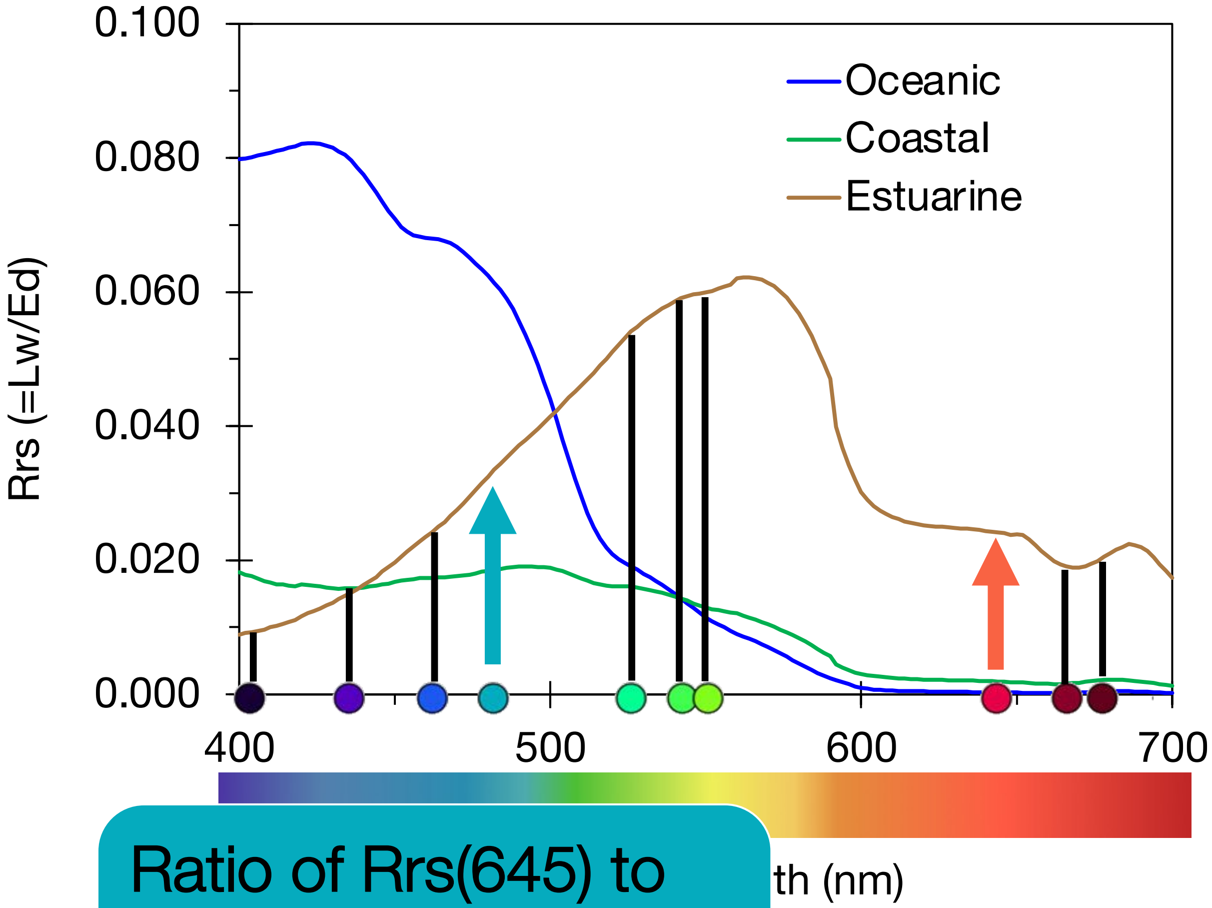
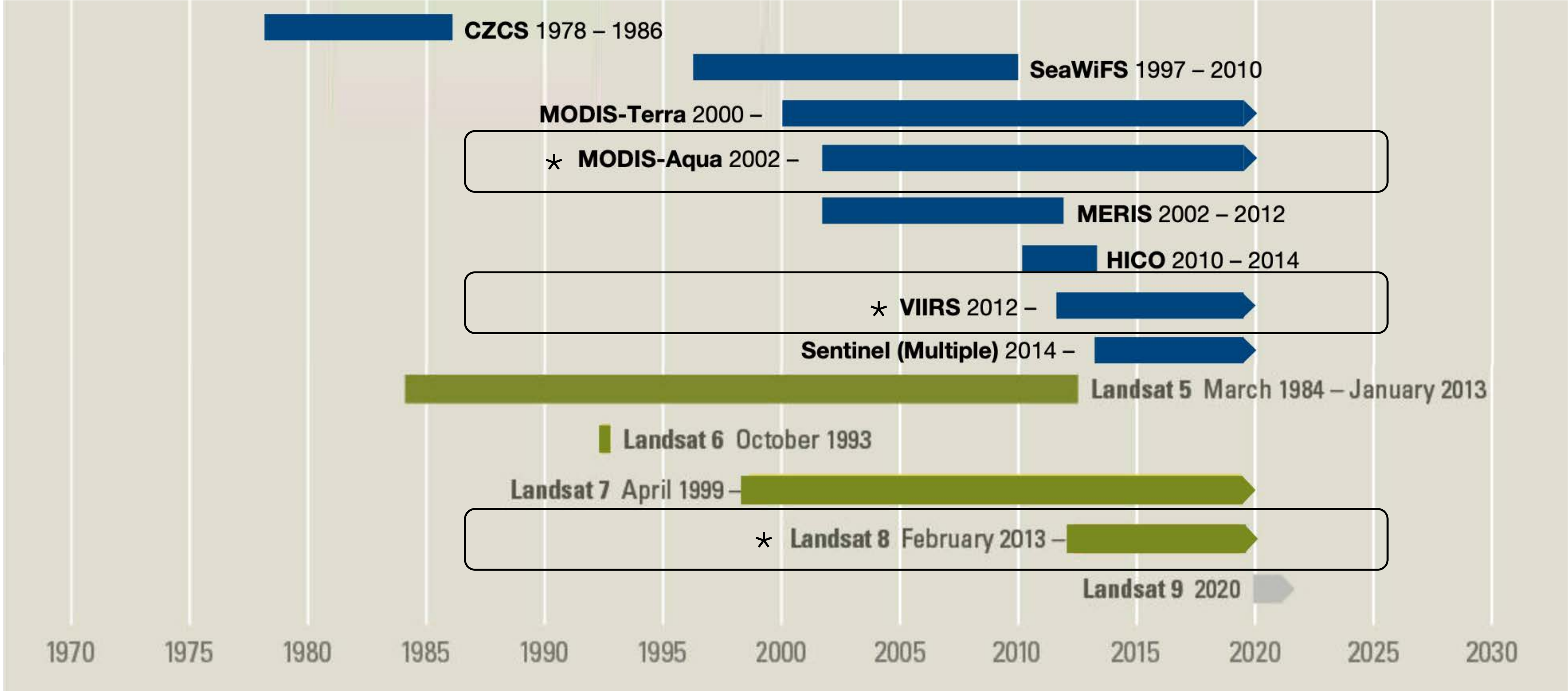




Ratio of Rrs(645) to Rrs(488) is related to Light attenuation (Kd)

Satellite missions for water clarity



Ocean color mission by NASA/NOAA/ESA

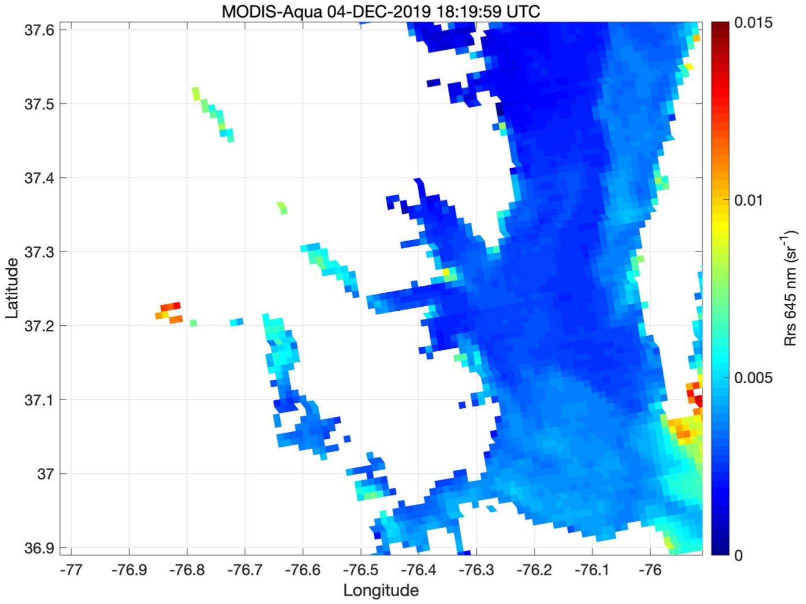
USGS mission primarily for land applications

* Shown in following slides

Satellite missions for water clarity: 3 example sensors

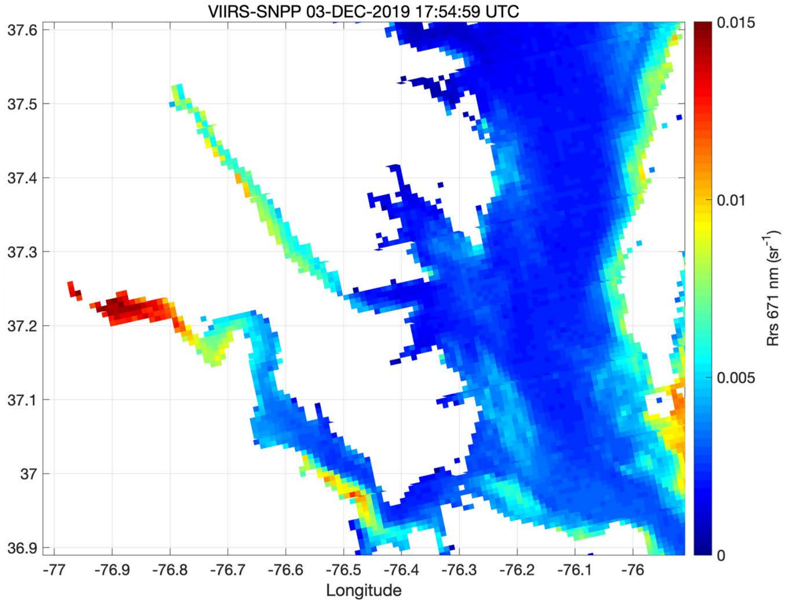
Atmospheric correction: NASA SeaDAS
Level-2 images (ready for science, but not spatially binned to a map projection)

MODIS
1 km spatial resolution – shown
(500m and 250 m for some bands, not shown)
Daily overpass



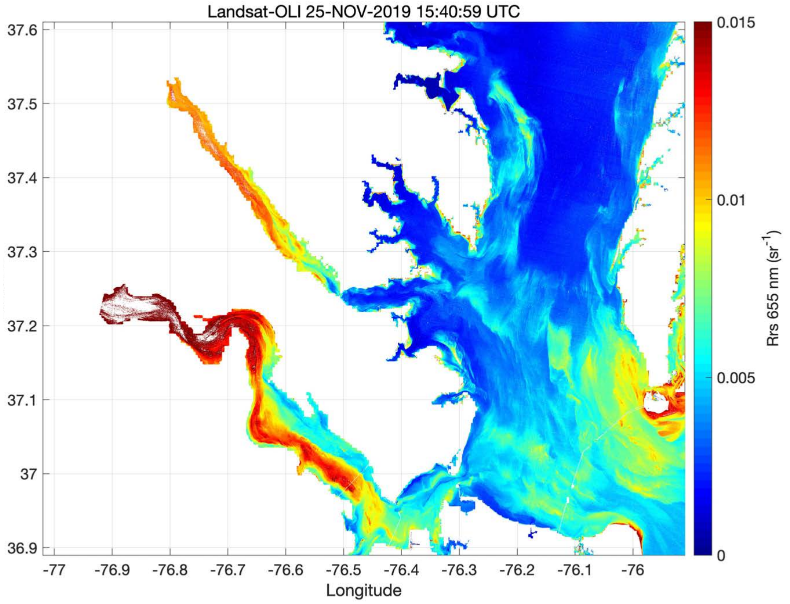
Available 1997-present
(counting SeaWiFS and MODIS)

VIIRS
675 m spatial resolution – shown
(375 m for I-bands, not shown)
Daily overpass

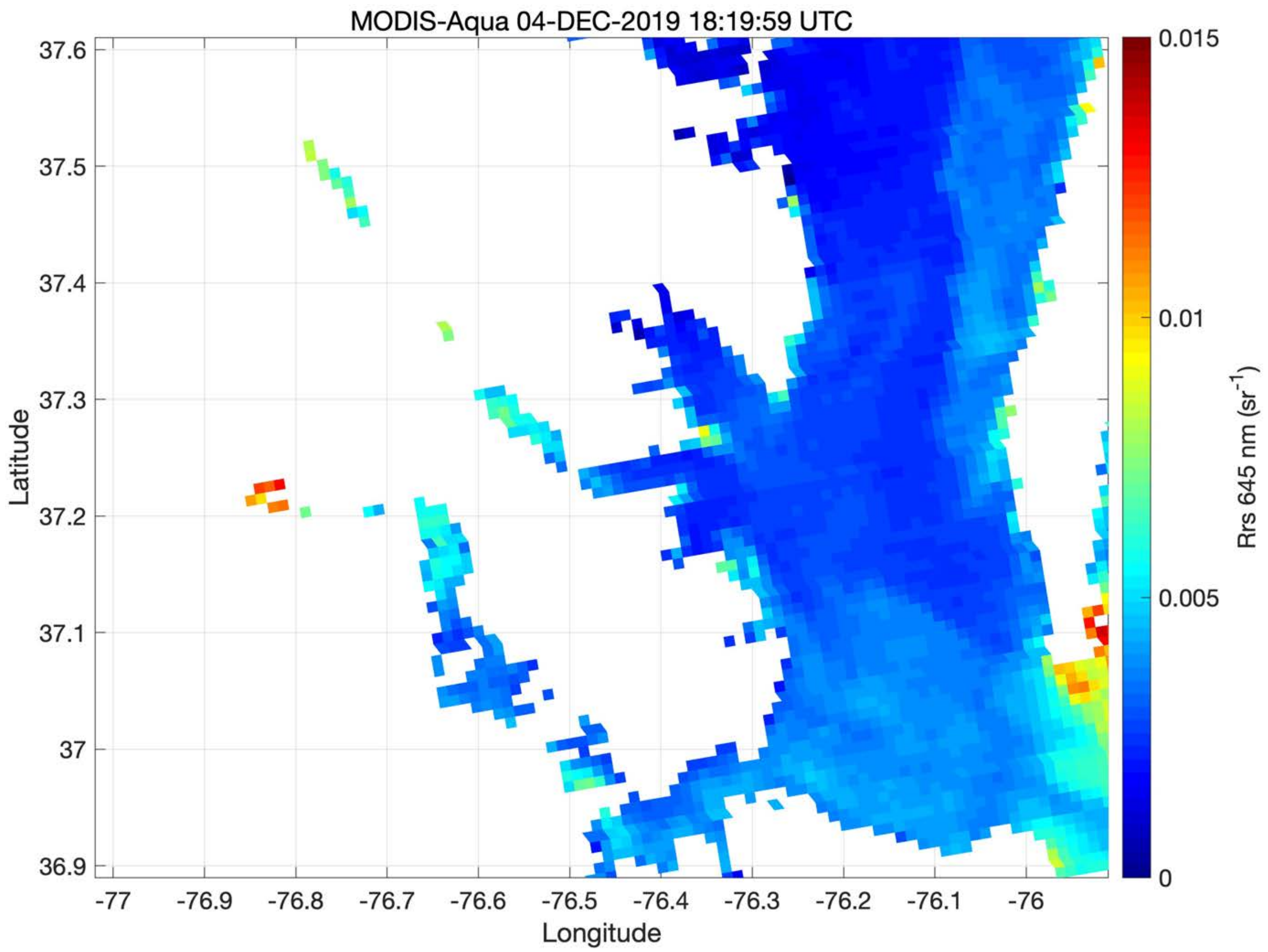


Available 2012-present

Landsat
30 m spatial resolution
Overpass every 16 days



Available 1984-present
(counting Landsat 5, 7, and 8)

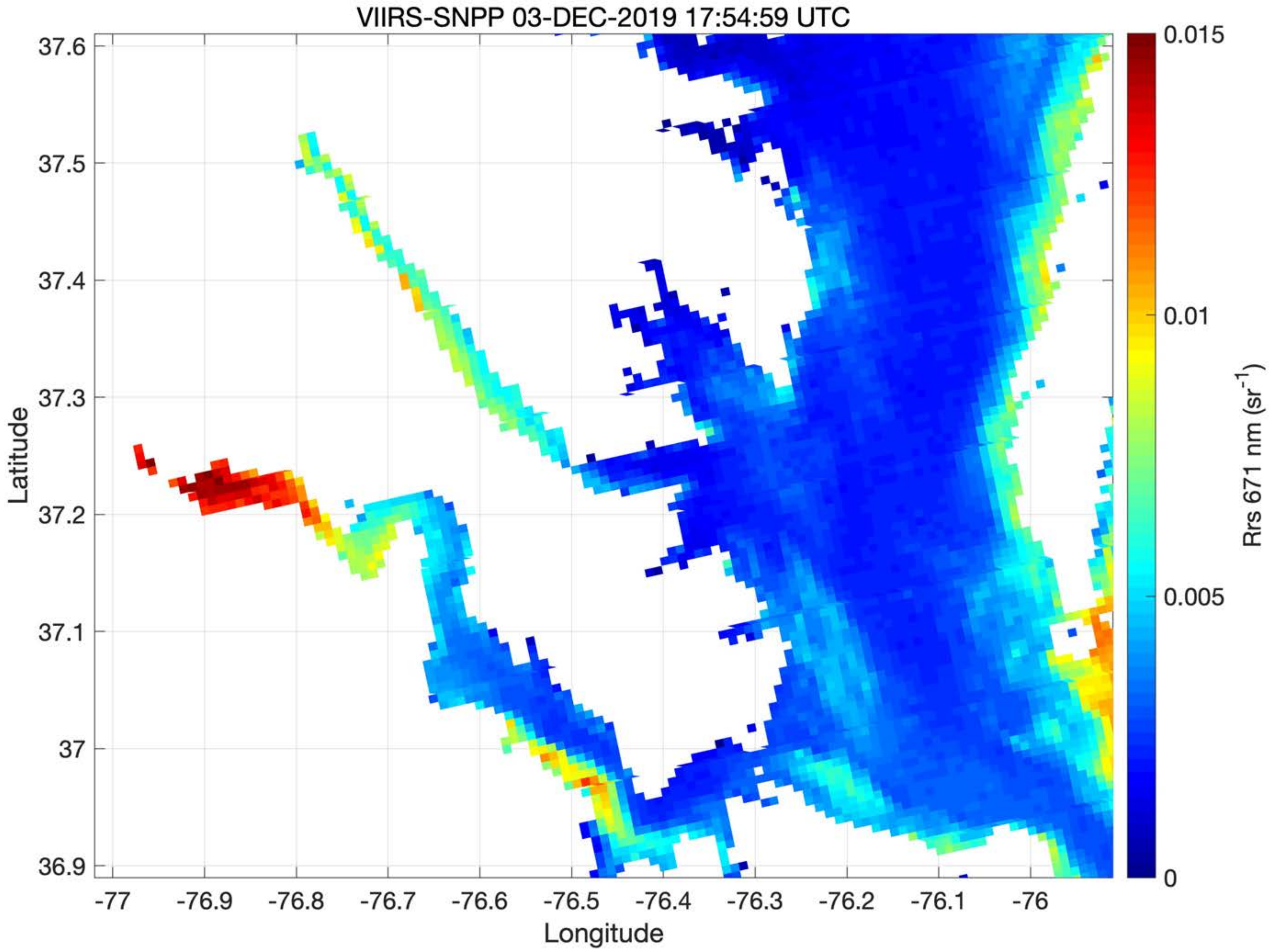


Pros:

- Daily overpass
- With SeaWiFS combined, can go back to 1997

Cons:

- Has been studied "to death" for Chesapeake Bay in the past
- Low spatial resolution, could not analyze tributaries or small creeks

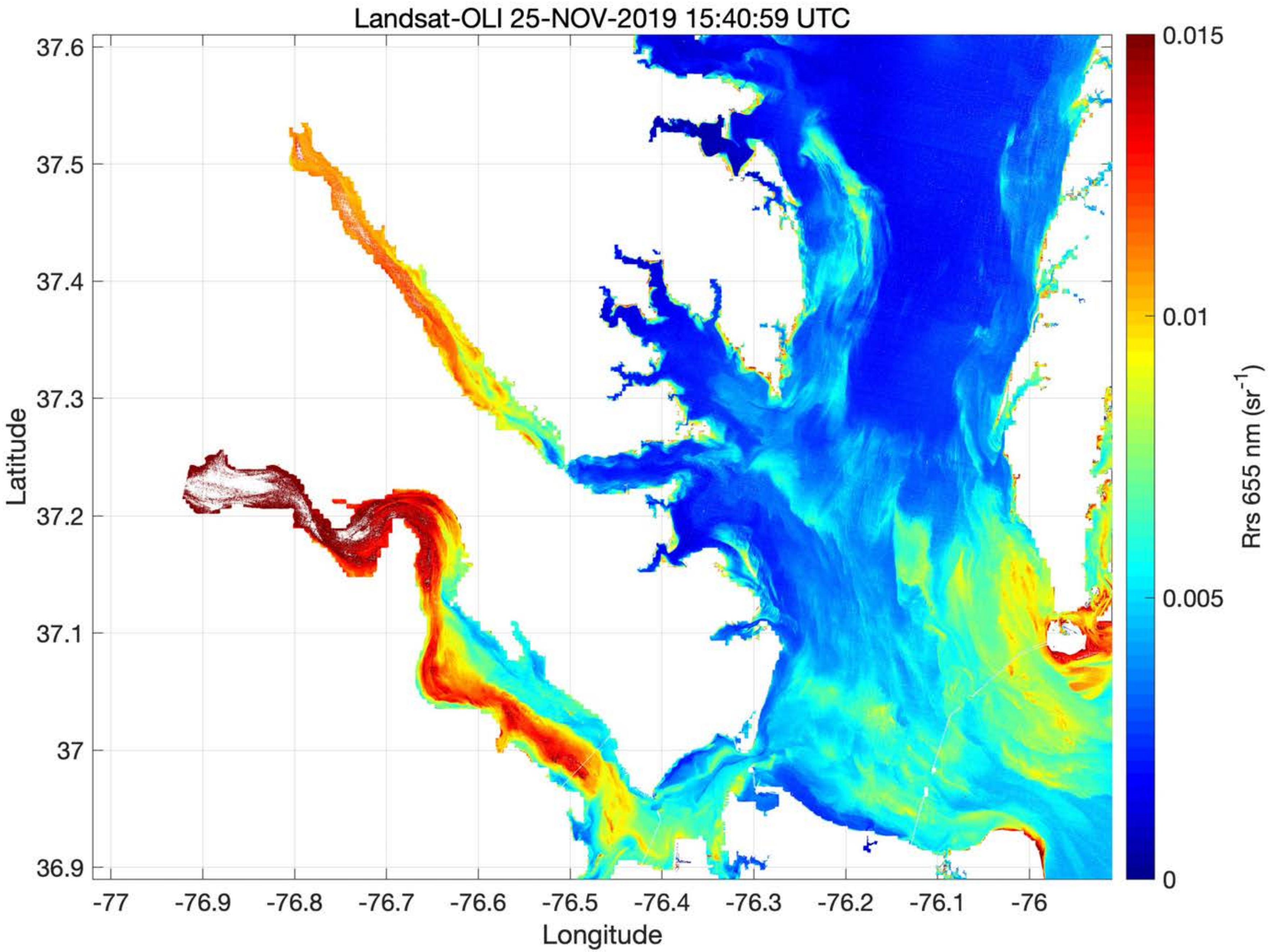


Pros:

- Daily overpass
- Moderately-good spatial resolution
- I-bands (near infrared) even better spatial res, could be used for TSS or Turbidity only

Cons

- Only goes back to 2012, so cannot really show any long-term change
- Issues with glint, angle, etc… Bruce Monger calls this the “troubled teenager” if SeaWiFS was the “perfect child”



Pros:

- Excellent spatial resolution, can resolve tributaries, small tidal creeks
- Landsat 5, 7 and 8 provide a continuous record back to 1984
- Untapped resource!

Cons:

- Need to add a bathymetry mask for optically-shallow water (sandbars)
- Landsat 5 and 8 are different sensors, different spectrally
- Requires more data processing because from USGS, not NASA

Satellite missions for water clarity: 3 example sensors

Atmospheric correction: NASA SeaDAS
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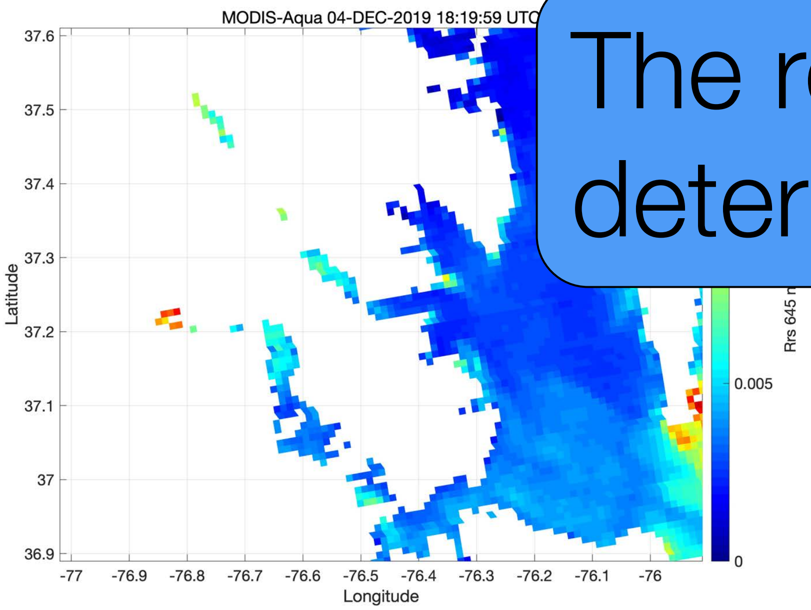

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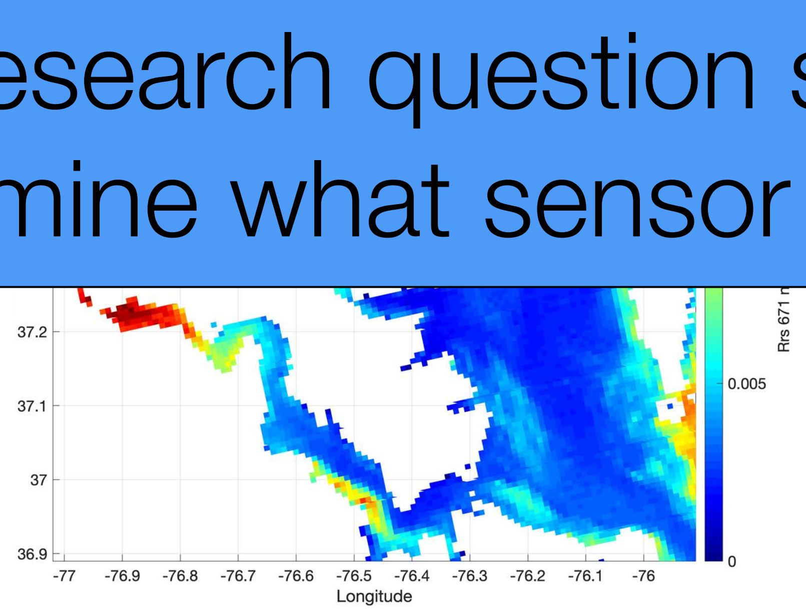

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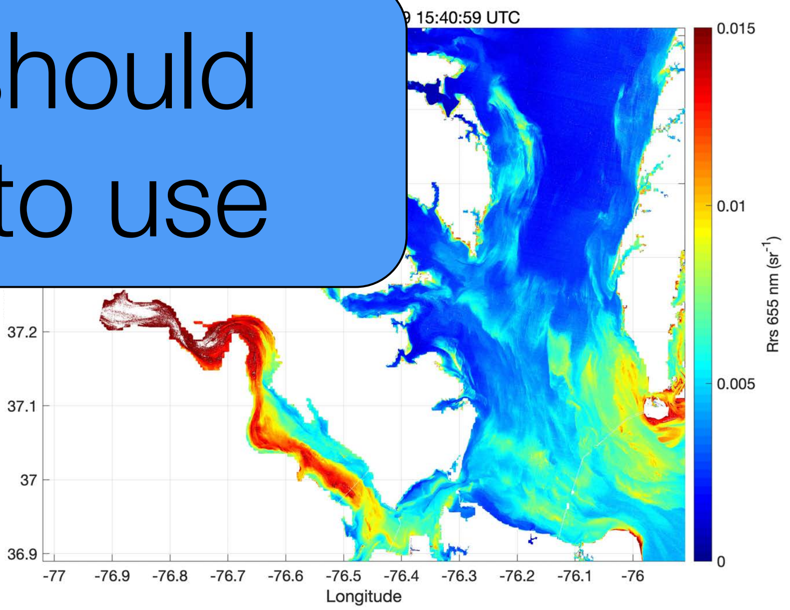
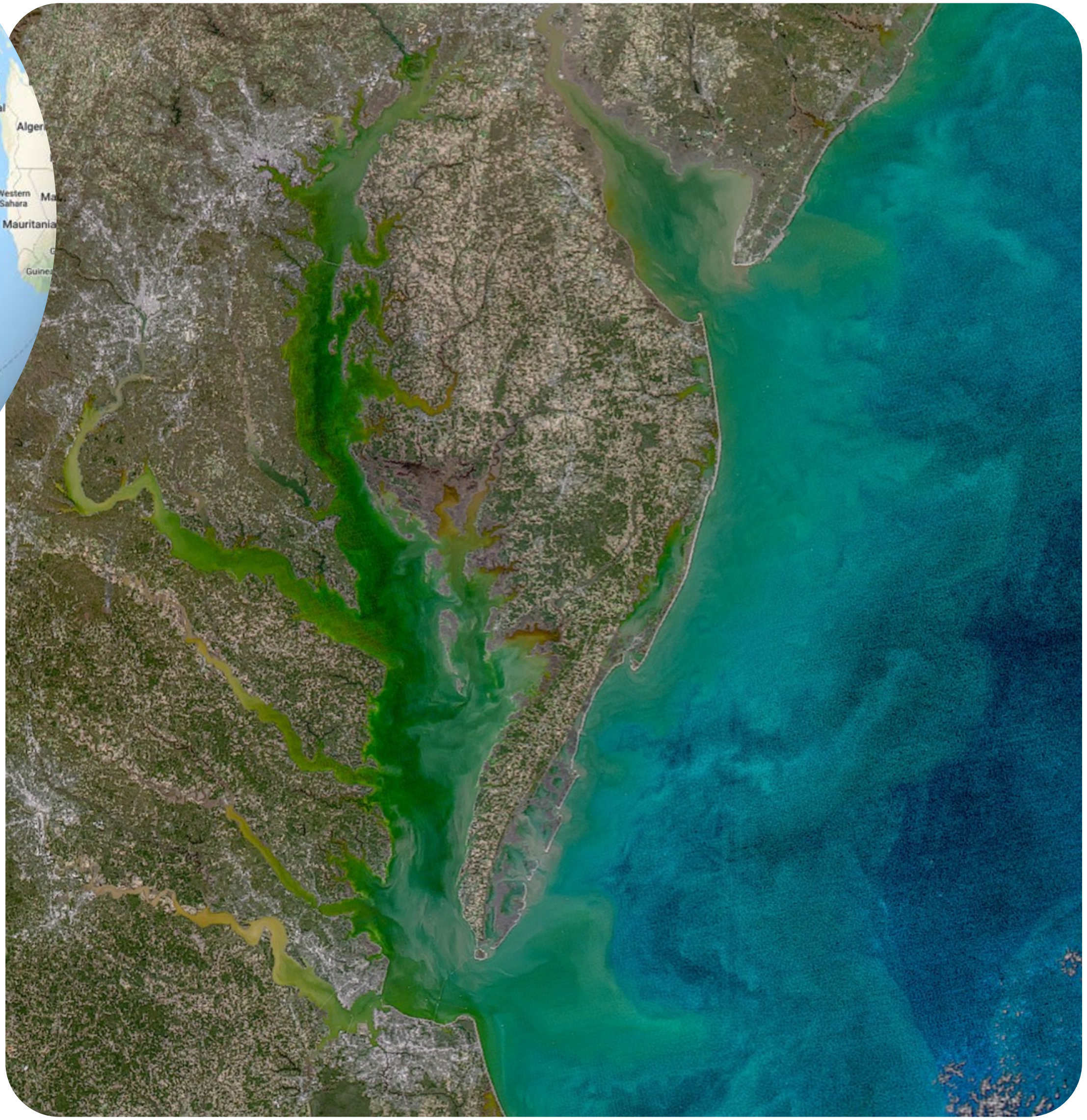


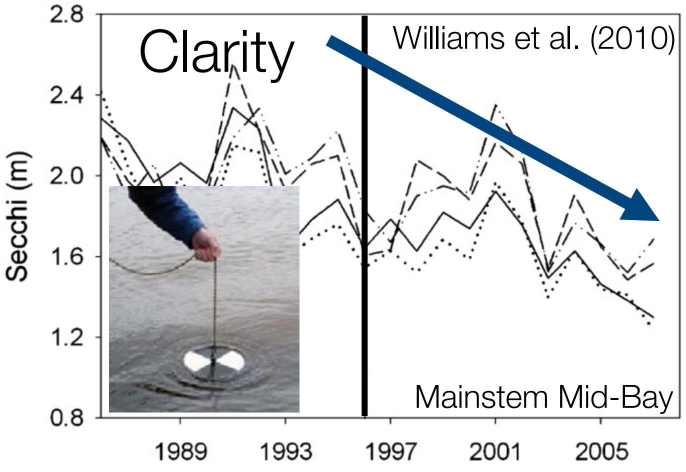
Available 1984-present
(counting Landsat 5, 7, and 8)

The research question should determine what sensor to use

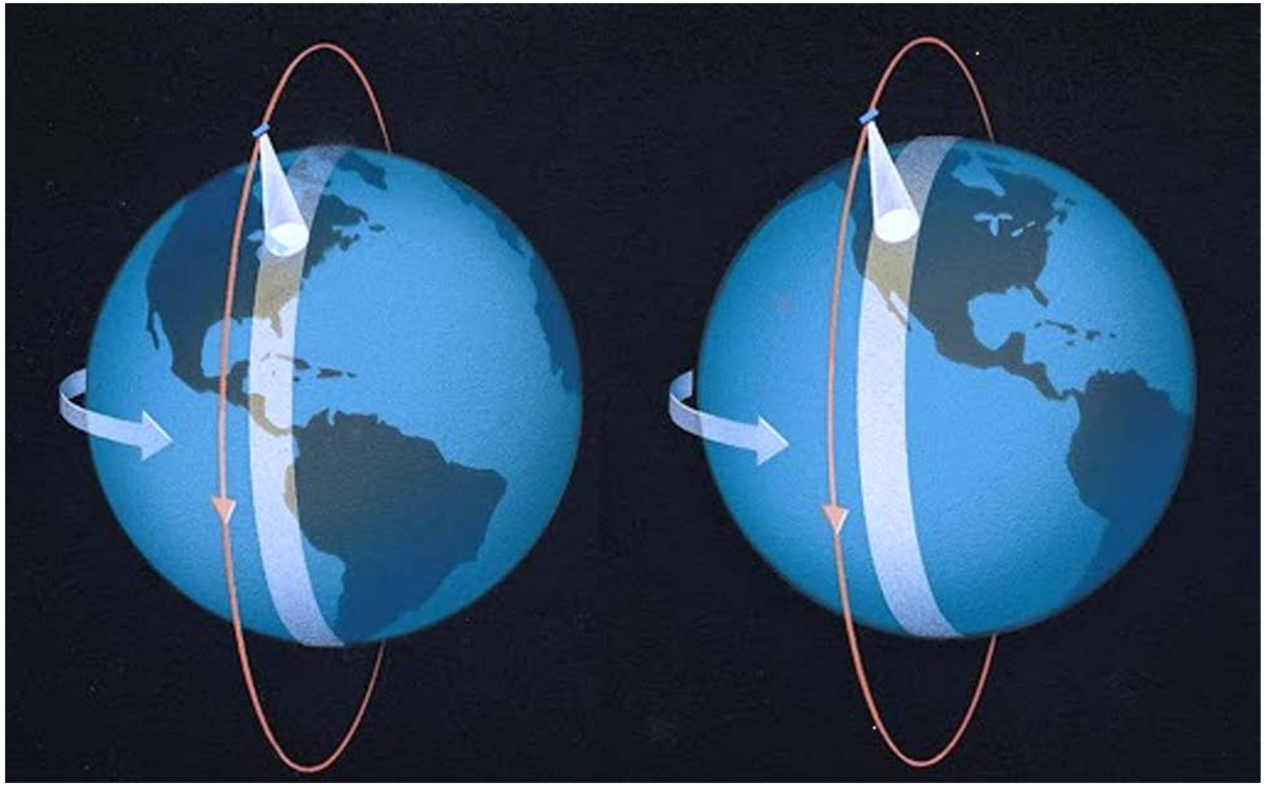
Example: Long-term trends

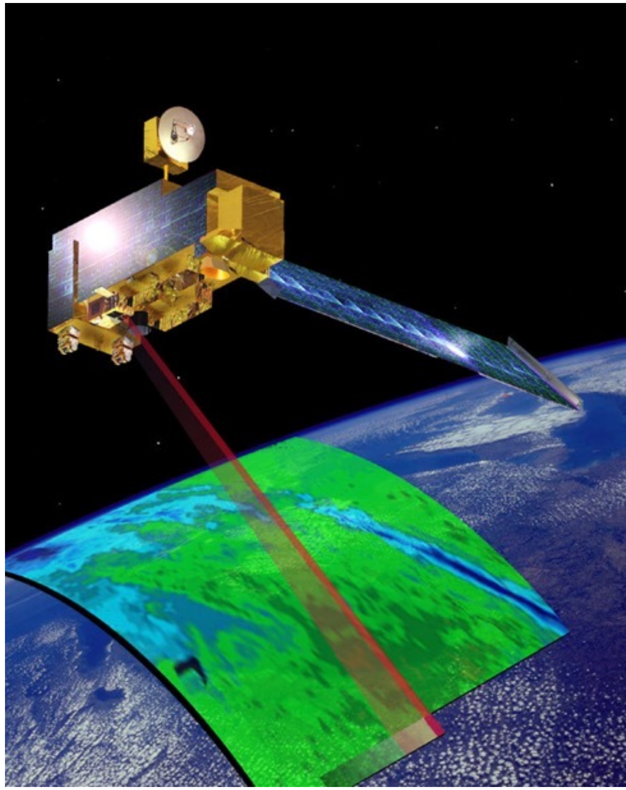
Figure 1. MODIS-Aqua true color composite image of the Chesapeake Bay and Mid-Atlantic Bight collected November 11, 2020.





Example: Long-term trends



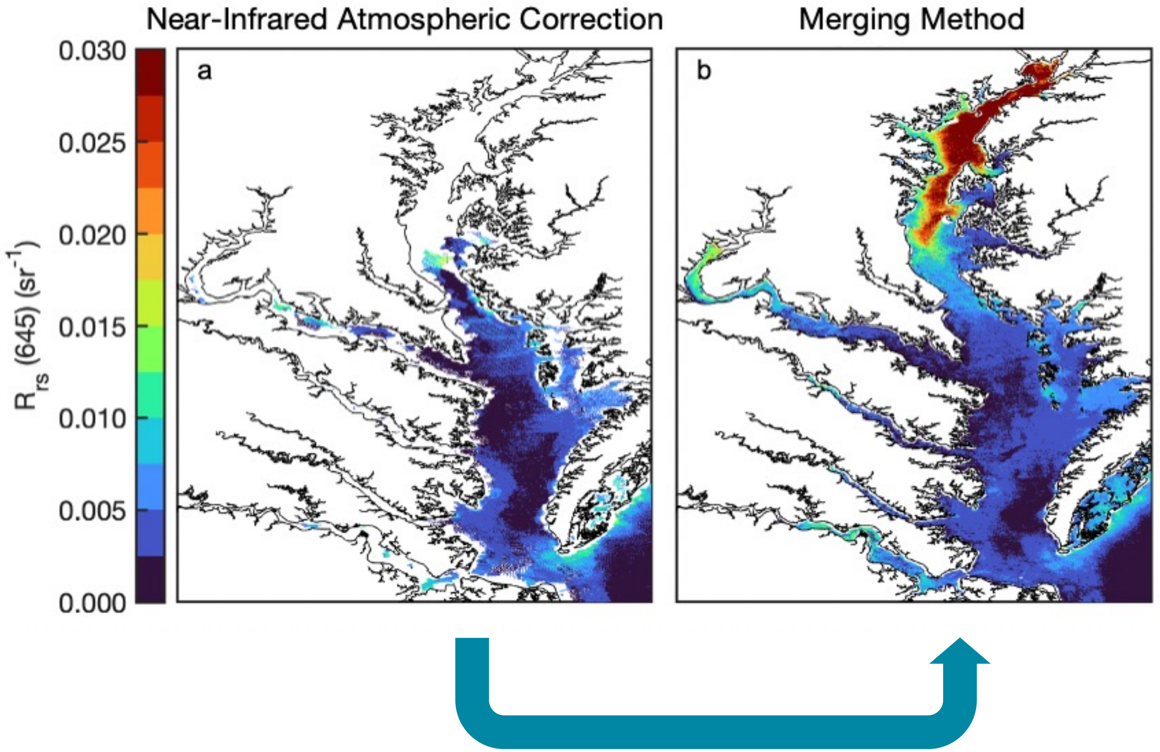


- MODIS-Aqua 2003-2020
- Daily overpass
- 250-m spatial resolution pixels in the red band
- 500-m and 1-km resolution in other bands

Example: Long-term trends

- Merged atmospheric correction method used to retain data during high-turbidity conditions

Example: September 2011 (Lots of storms)

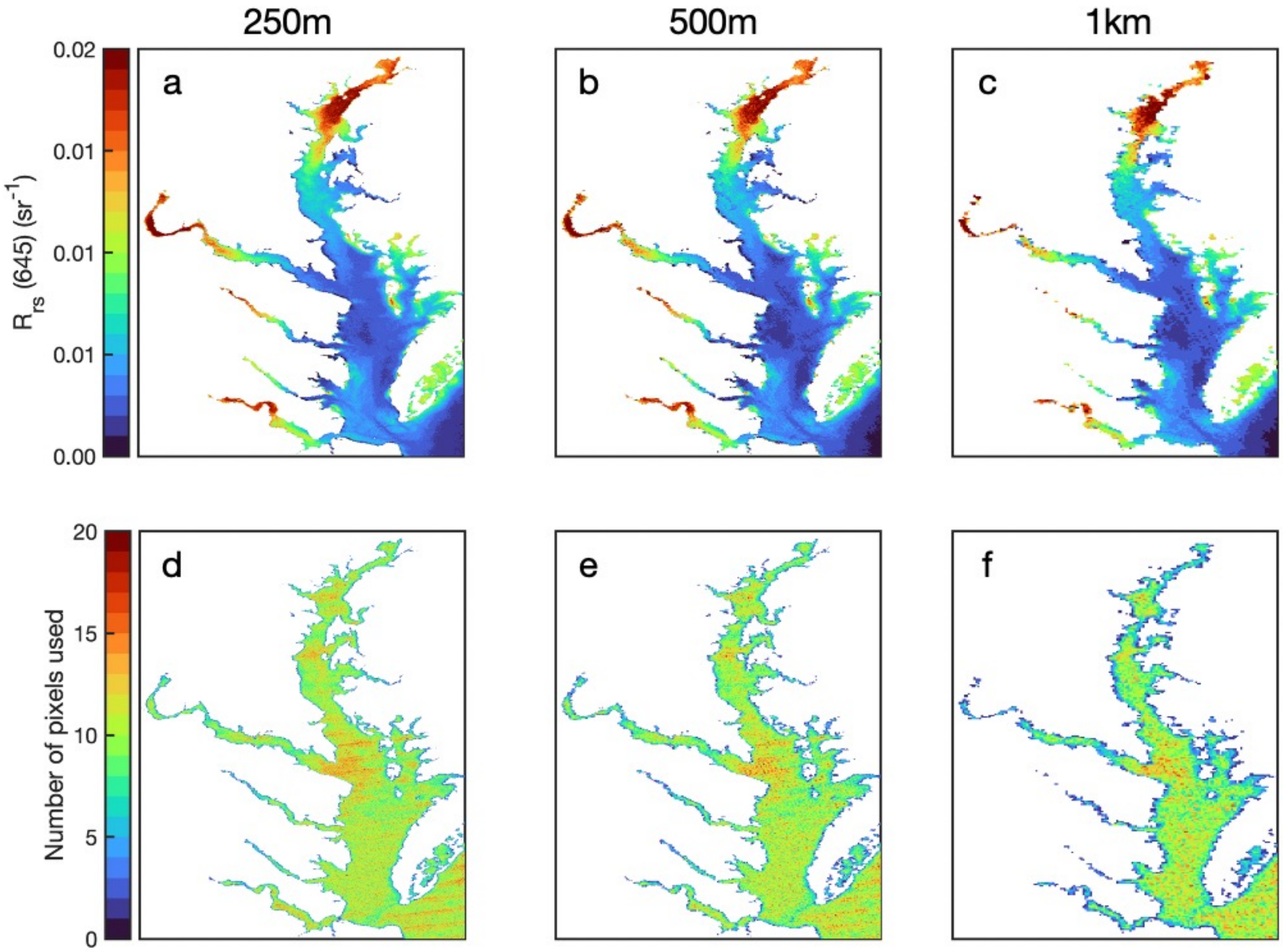


Following Aurin et al. (2013)

Up to 2x more scenes used in monthly composite

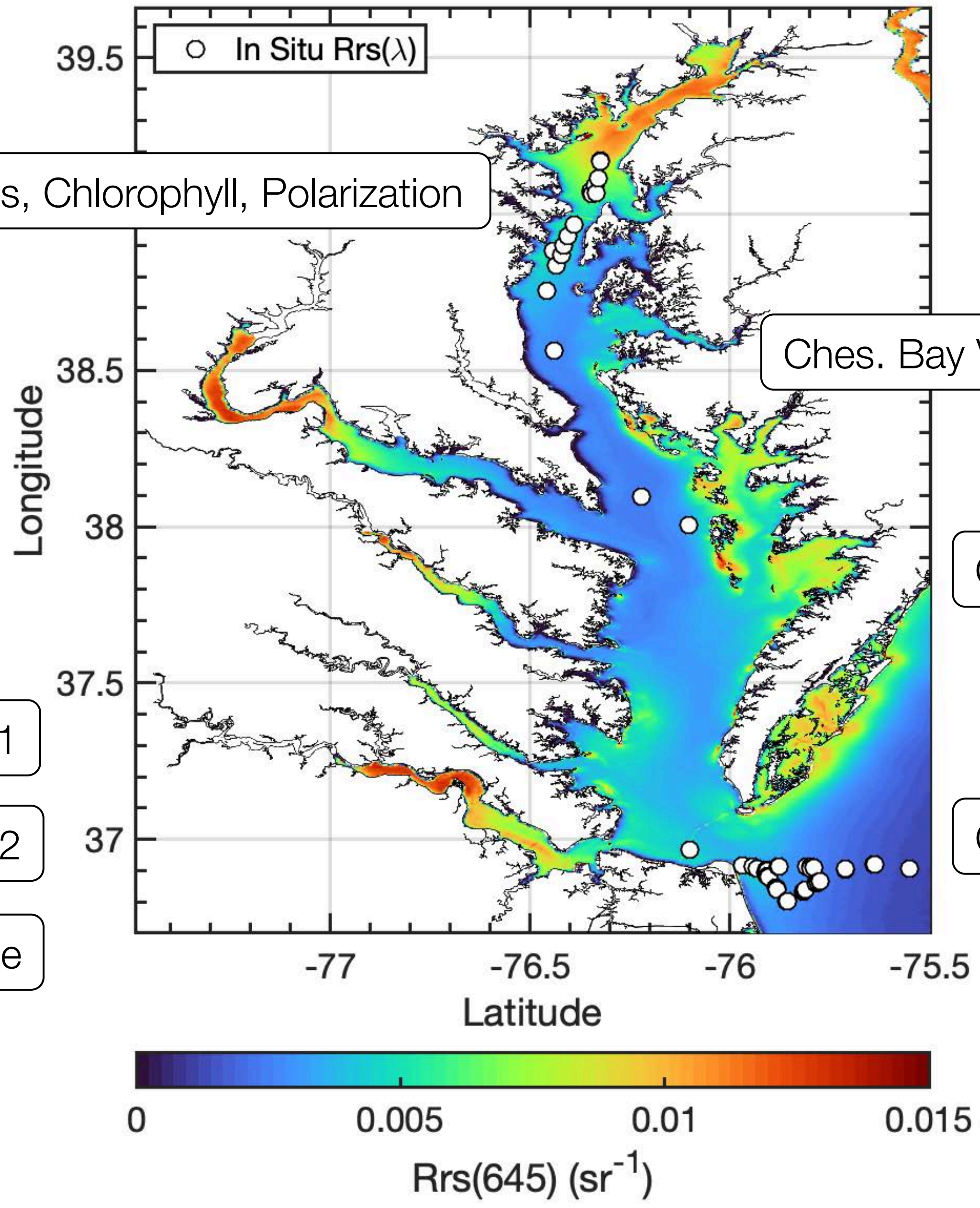
MODIS-Aqua spatial resolutions

One month:
March 2011



Validation

- NASA SeaBASS repository
- 8 field campaigns
- 2005 to 2014
- Different seasons
- Many salinities, water types



Bio-optics, Chlorophyll, Polarization

Ches. Bay Validation Cruise

GEO-CAPE

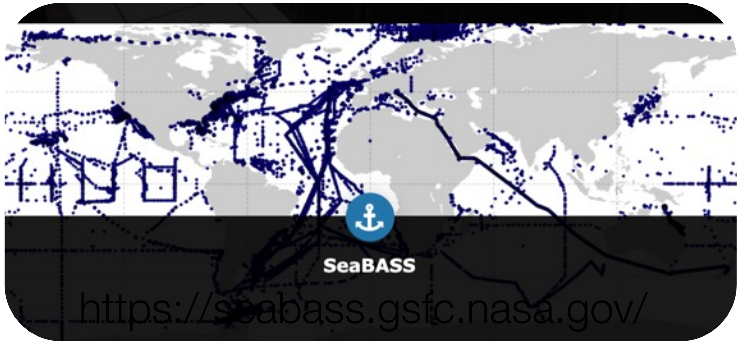
Ches. Light Tower

SABOR

Ches. Bay Plume 01

Ches. Bay Plume 02

Biome



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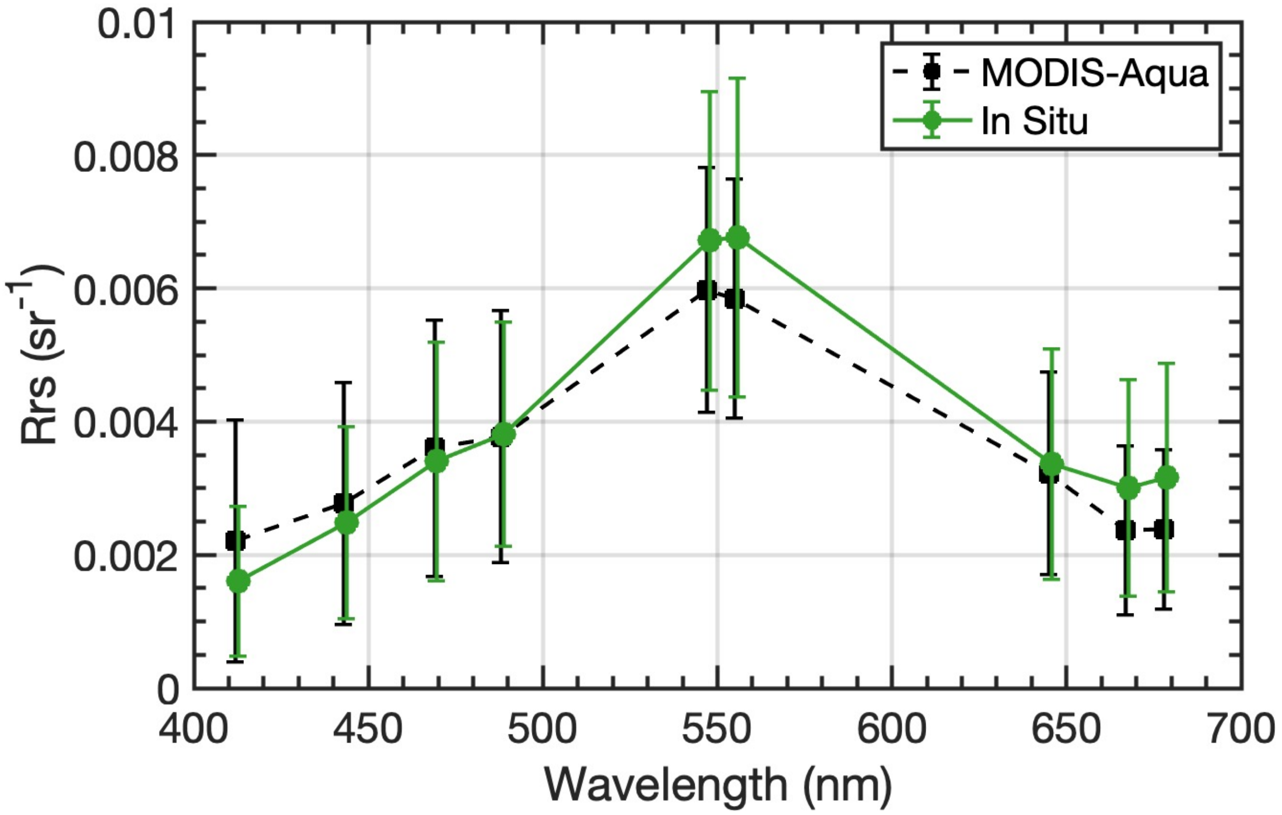
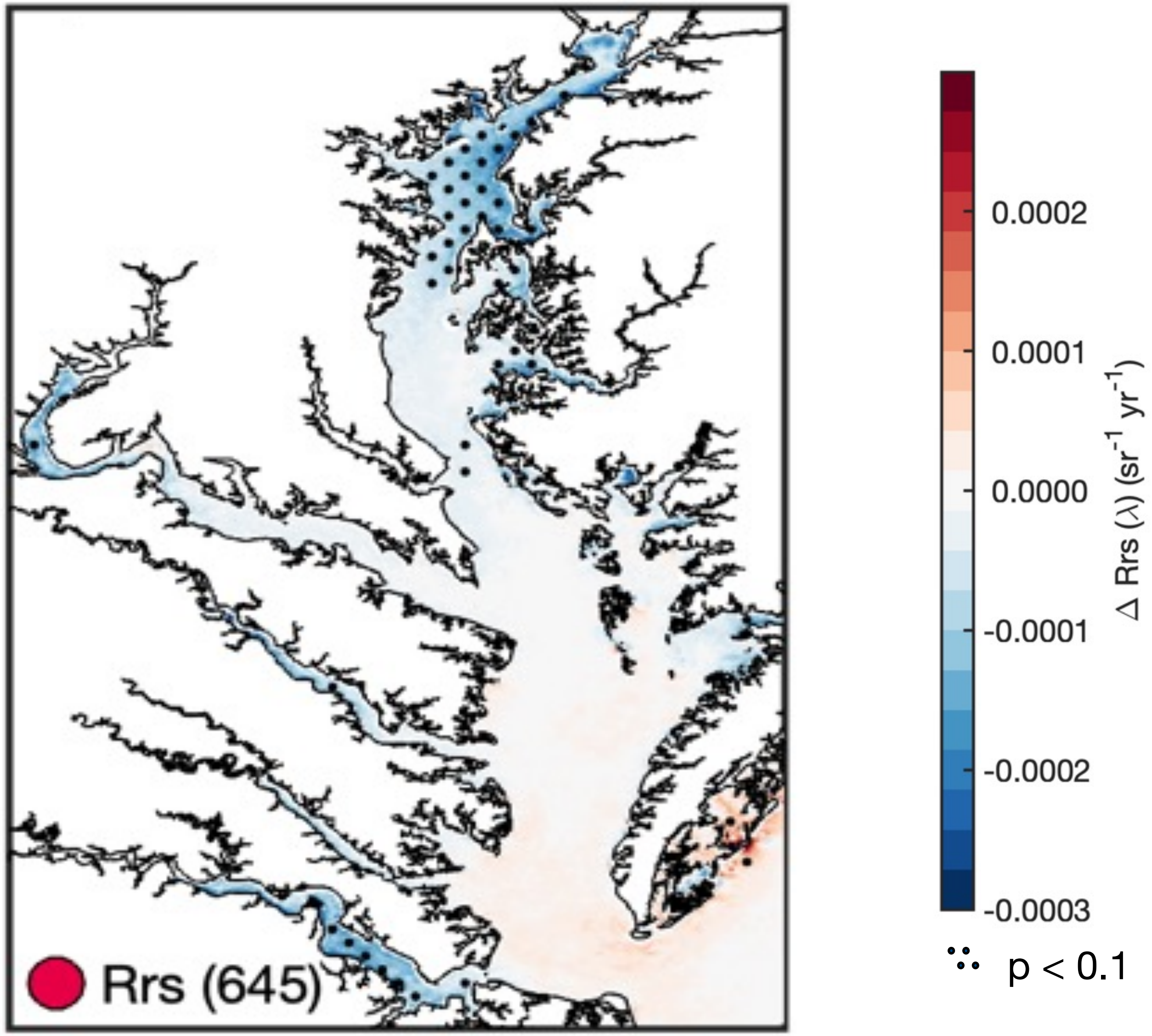


- Satellite overestimates blue Rrs
- Satellite underestimates green Rrs
- Variability satellite ~ variability in situ

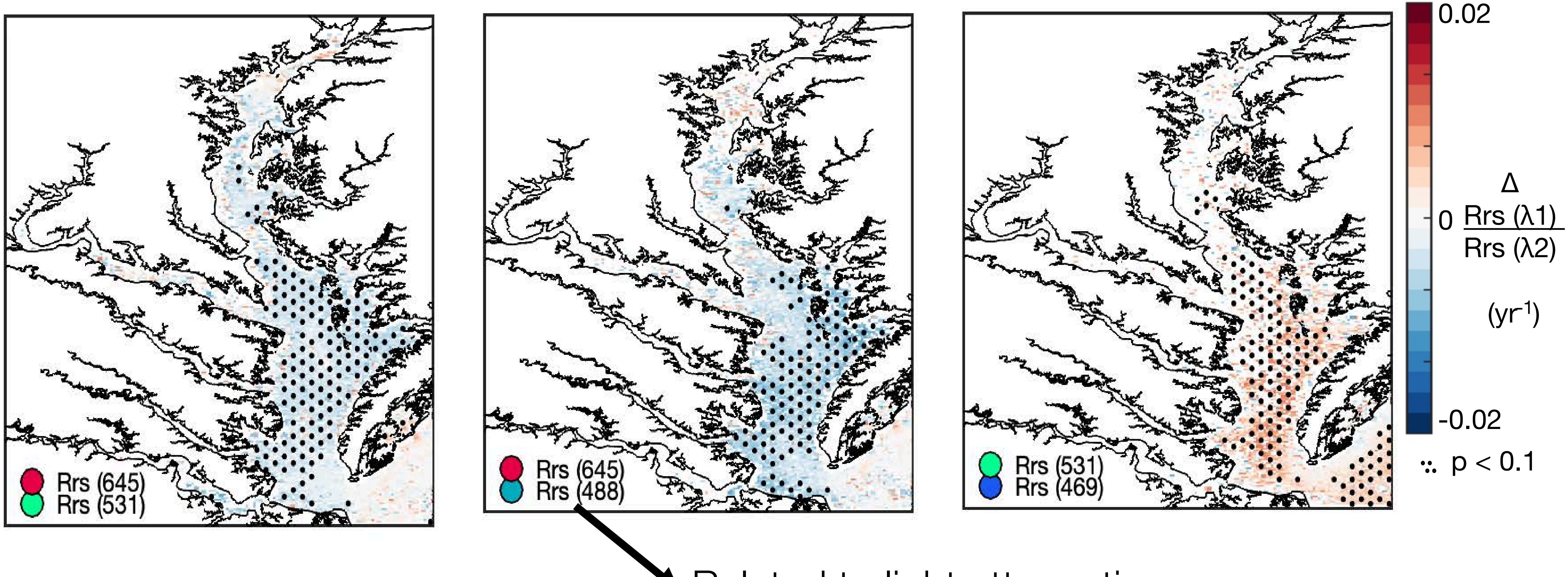
Single Bands Trend Results

Red Rrs:
Decreasing in upper Bay
No Trend in lower Bay



Band Ratio Trend Results

Red-to-green ratios　　Red-to-blue ratios　　Green-to-blue ratios



Related to light attenuation, turbidity, and suspended solids

What do these trends suggest?

Variable	Related in situ measurements	Trends
Red-band Rrs	Suspended solids, Turbidity	Decreasing in upper Bay, no trend in lower Bay
Red-to-green ratios	Suspended solids, Turbidity	Decreasing in mainstem Bay
Red-to-blue ratios	Light attenuation, Suspended solids, Turbidity	Decreasing in mainstem Bay
Green-to-blue ratios	Chlorophyll, CDOM	Increasing in mainstem Bay

What do these trends suggest?

Suggest **improving water clarity**
in mainstem and lower Bay

Variable		
Red-band		rend in
Red-to-green ratios	Suspended solids, Turbidity	Decreasing in mainstem Bay
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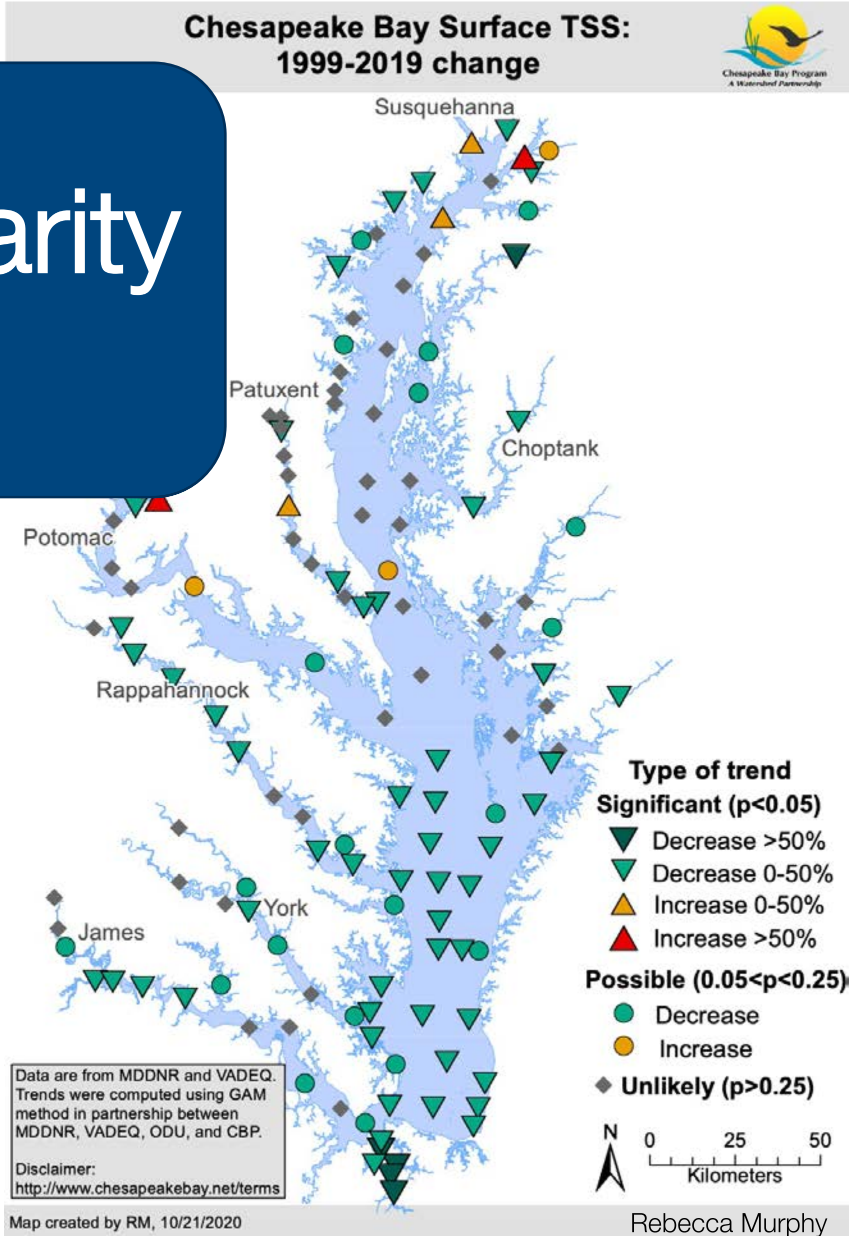
Red-to-blue rat	Turbidity	
Green-to-blue ratios	Chlorophyll, CDOM	Increasing in mainstem Bay

Suggest **increasing contribution of phytoplankton** to reflectance

Interpretations of long-term change

Suggest **improving water clarity**
in mainstem and lower Bay

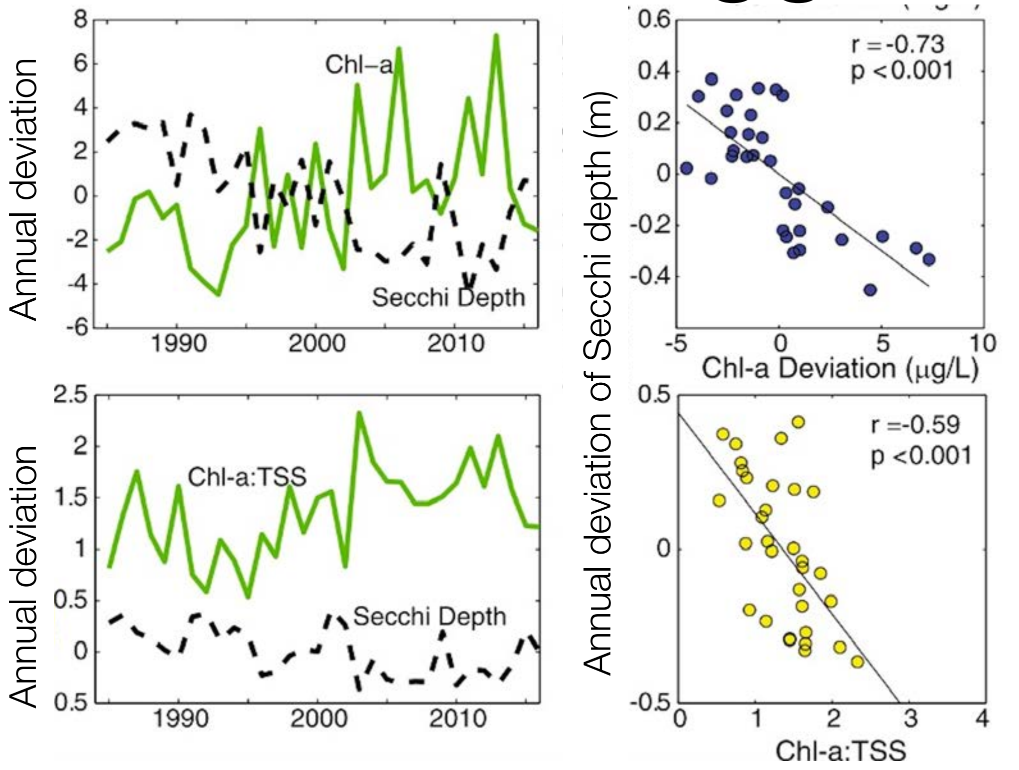
- In situ data 1999-2019 shows water becoming clearer in terms of Kd, TSS



What do these trends suggest?

Mid-Bay

Lower Bay



Testa et al. 2019

Suggest **increasing contribution of phytoplankton** to reflectance

Example: Florida “Virtual Buoy System”

https://optics.marine.usf.edu/projects/vbs.html

Optical Engineering 53(5), 051402 (May 2014)

Satellite-based virtual buoy system to monitor coastal water quality

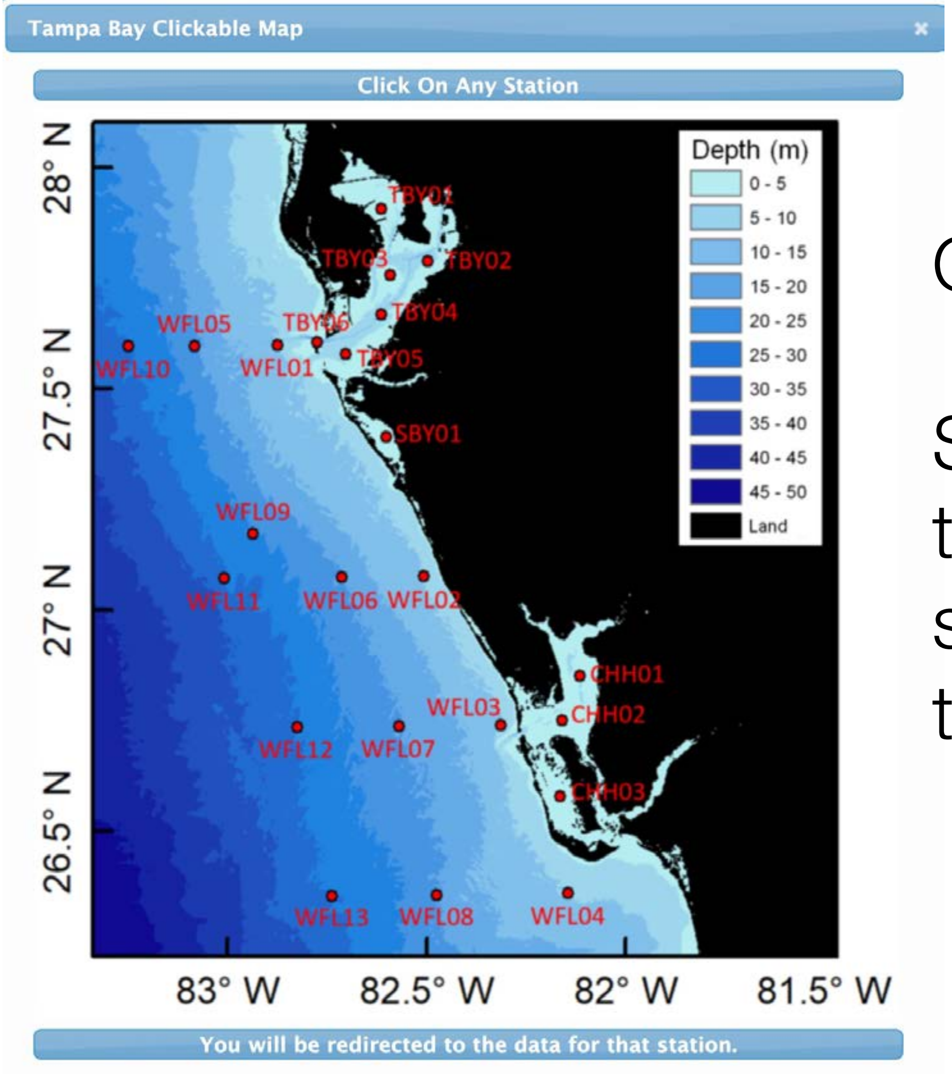
Chuanmin Hu
Brian B. Barnes
Brock Murch
University of South Florida
College of Marine Science
140 Seventh Avenue, South
St. Petersburg, Florida 33701
E-mail: huc@usf.edu

Paul Carlson
Florida Fish and Wildlife Conservation Commission
100 Eighth Avenue, SE
St. Petersburg, Florida 33701

Abstract. There is a pressing need to assess coastal and estuarine water quality state and anomaly events to facilitate coastal management, but such a need is hindered by lack of resources to conduct frequent ship-based or buoy-based measurements. Here, we established a virtual buoy system (VBS) to facilitate satellite data visualization and interpretation of water quality assessment. The VBS is based on a virtual antenna system (VAS) that obtains low-level satellite data and generates higher-level data products using both National Aeronautics and Space Administration standard algorithms and regionally customized algorithms in near real time. The VB stations are predefined and carefully chosen to cover water quality gradients in estuaries and coastal waters, where multiyear time series at monthly and weekly intervals are extracted for the following parameters: sea surface temperature (°C), chlorophyll-a concentration (mg m^{-3}), turbidity (NTU), diffuse light attenuation at 490 nm [$K_d(490)$, m^{-1}] or secchi disk depth (m), absorption coefficient of colored dissolved organic matter (m^{-1}), and bottom available light (%). The time-

Example: Florida “Virtual Buoy System”

https://optics.marine.usf.edu/projects/vbs.html



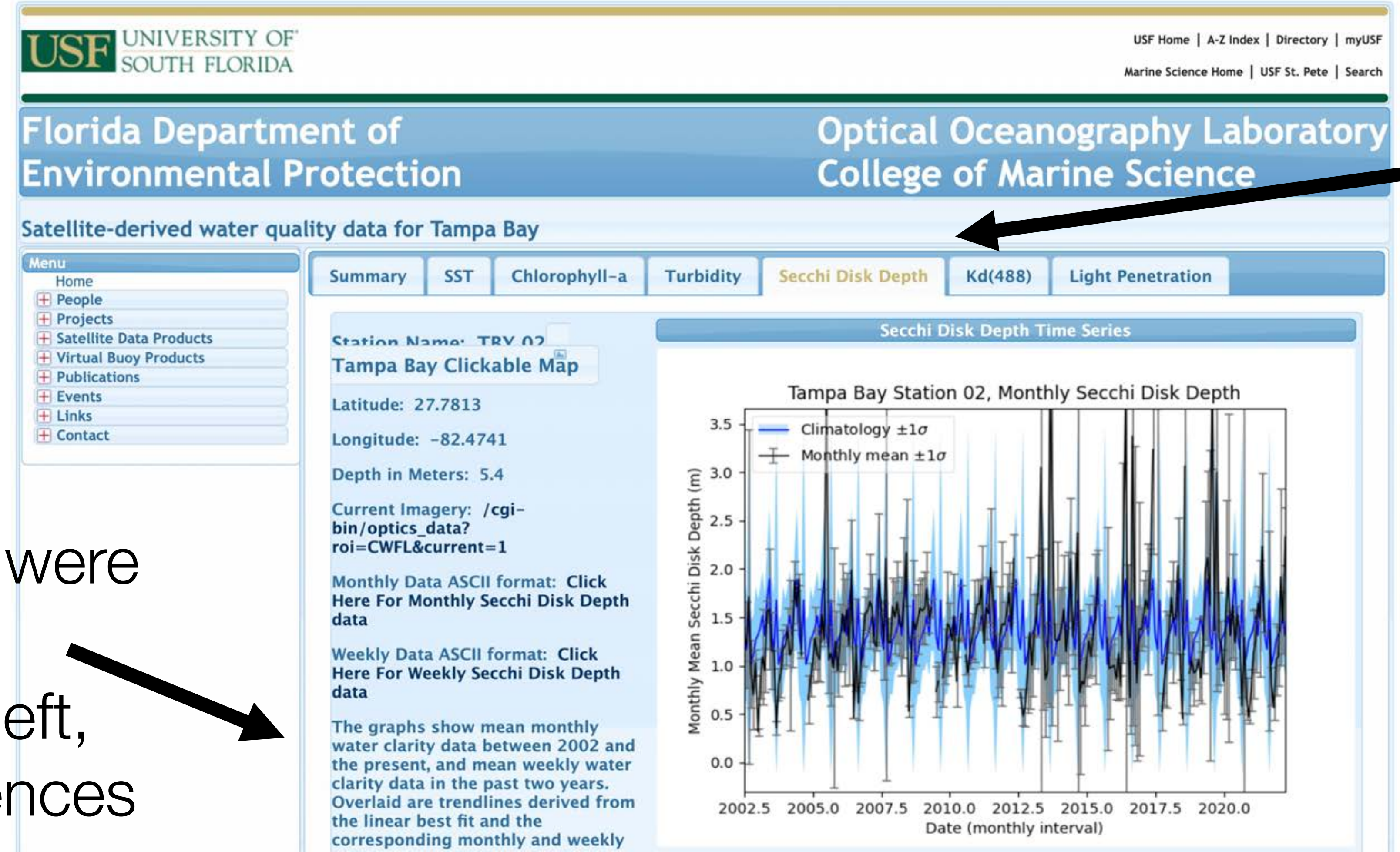
Click on a point

Software loads a time series of satellite data from that location

Example: Florida “Virtual Buoy System”

https://optics.marine.usf.edu/projects/vbs.html

Mostly from MODIS-Aqua



Products

How data were calculated written at left, with references

Florida methods may not work for the Bay

Florida coastal waters

- Fewer rivers
- Karst geology
- Groundwater inputs
- Carbonate sands
- Everglades/cypress
- Generally clearer waters

Chesapeake Bay

- More rivers and more diverse river inputs
- More sediment inputs
- Large watershed with mountains and wetlands
- “Incubator”
- Sink, not source, of sediments to/from ocean

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Different components blocking light, affecting ocean color

The "4-H" Resolution Compromise

Satellite Comparison for bloom applications

Example: Goal here is Chl-a fluorescence (red and near-infrared) to monitor phytoplankton blooms.

Applies somewhat to water clarity as well.

Satellite	Spatial	Temporal	Key Spectral
MERIS 2002-12 OLCI Sentinel-3a 2016-	300 m *OK*	2 day *good*	10 (5 on red edge) *good*
MODIS high res Terra 1999; Aqua 2002	250/500 m *OK*	1-2 day *good*	4 (1 red, 1 NIR) *marginal*
MODIS low res	1 km *poor*	1-2 day *good*	7-8 (2 in red edge) *OK*
Landsat	30 m *good*	8 or 16 day *poor*	4 (1 red, 1 NIR) *marginal*
Sentinel-2 (2015)	20 m *good*	10 day (5 day with 2nd satellite, launch in 2017) *Potential with 2*	5 (1 red; 2 NIR, 1 in red edge) *potential*

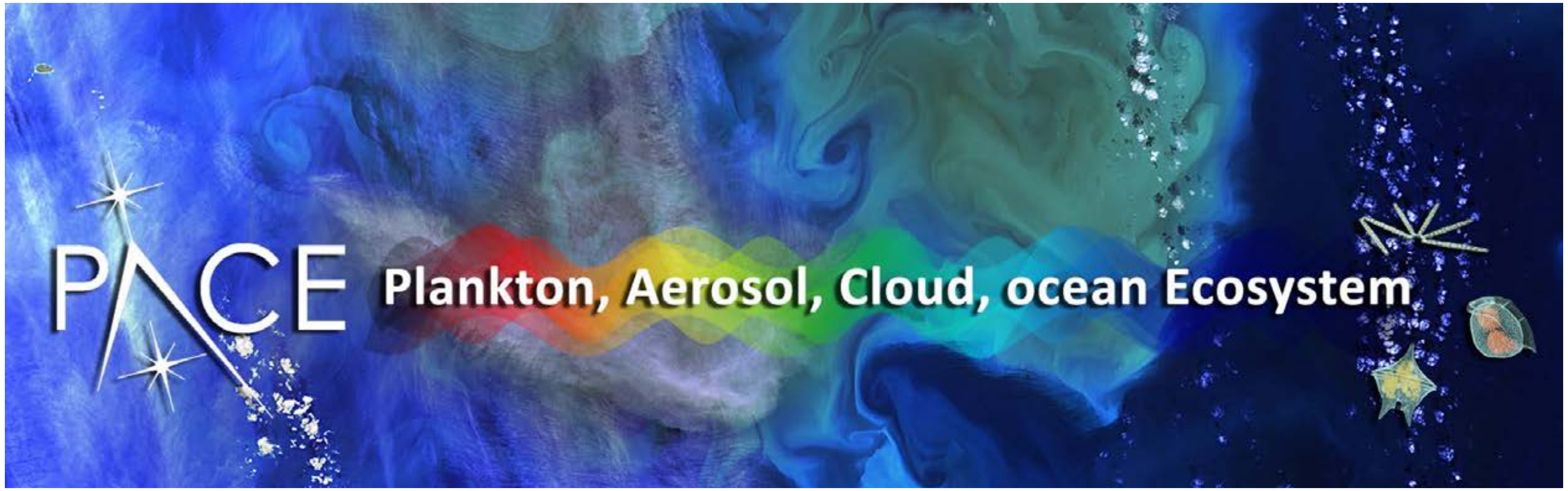
Clouds take out 1/2 to 2/3 of imagery

Some sunglint is not a problem for our algorithms

Minimum resolution, 3 pixels across (2 mixed land/water)

Powerpoint Slide by Richard Stumpf, 2017

Future satellite missions for water clarity



1km spatial res.
~Daily overpass
Hyperspectral
Polarization
"SeaWiFS-like"

~100m spatial res.
~Daily overpass
Hyperspectral
"Landsat-like"

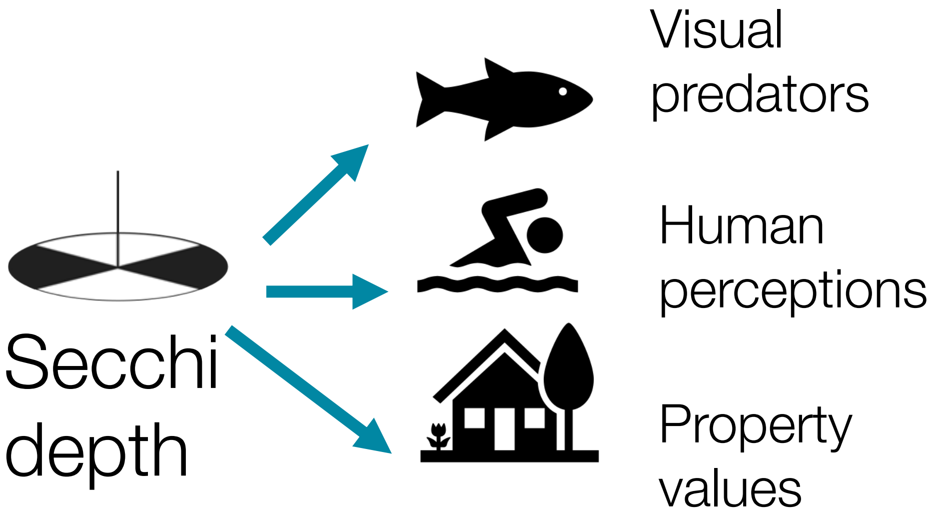
I am involved in: PACE Science and Applications Team
PACE Early Adopters

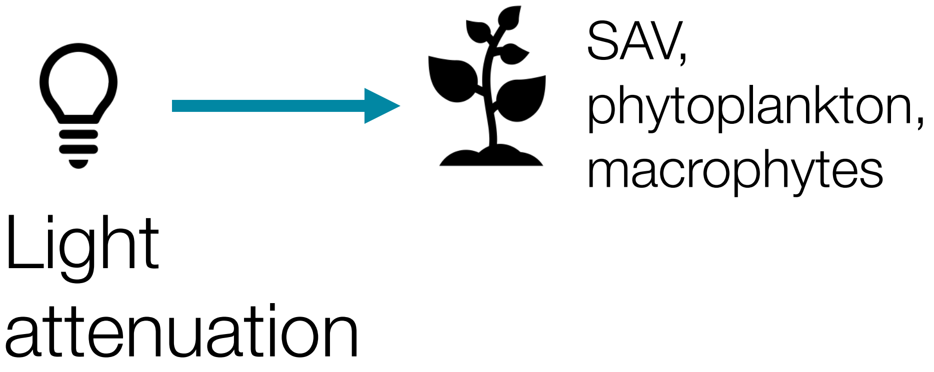
A note on “Water Clarity”

→ Use the best measurement for the specific research or management needs/goals.

Applying this to satellite data…

→VALIDATE with the measurement that is ultimately most needed.





Summary

Advantages

- Synoptic coverage
- Already in orbit, low cost, freely available
- High temporal, spatial resolution
- Estimates possible

Disadvantages

- Clarity in the Bay is complicated *in situ,* things like Kd, Secchi are decoupled
- Optically complex, Chl-a looks like CDOM
- Lower accuracy

Ask me about: Bibliography of water clarity algorithms for Chesapeake Bay

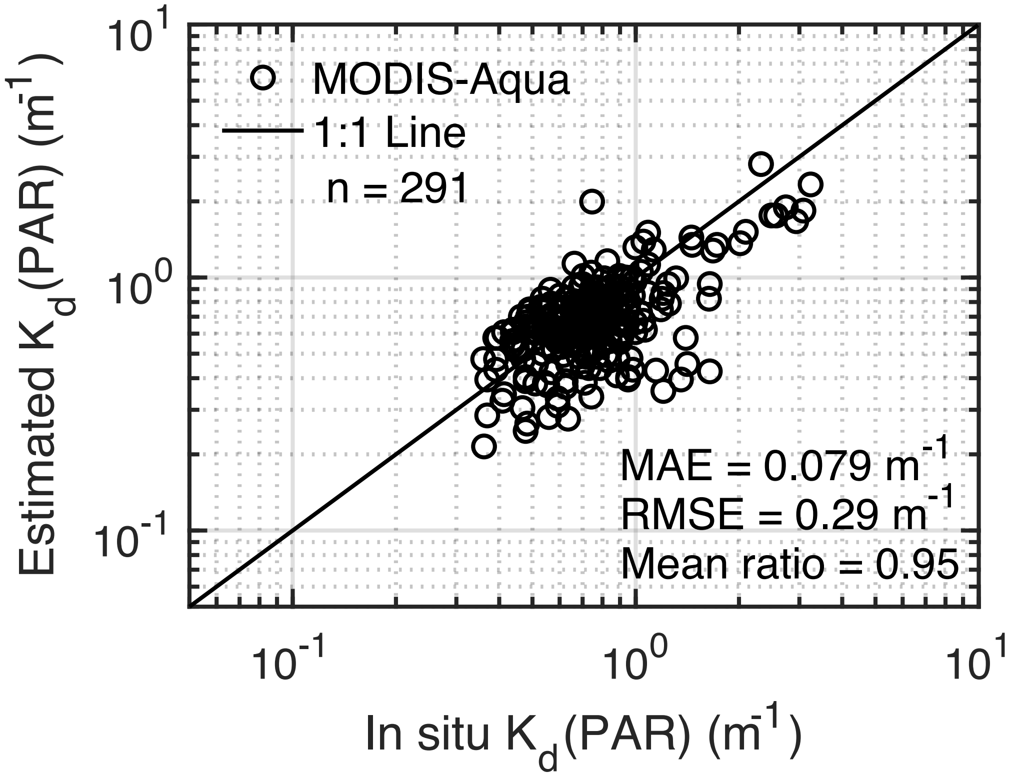
Thank you.
Questions?

MODIS-Aqua April 20, 2022

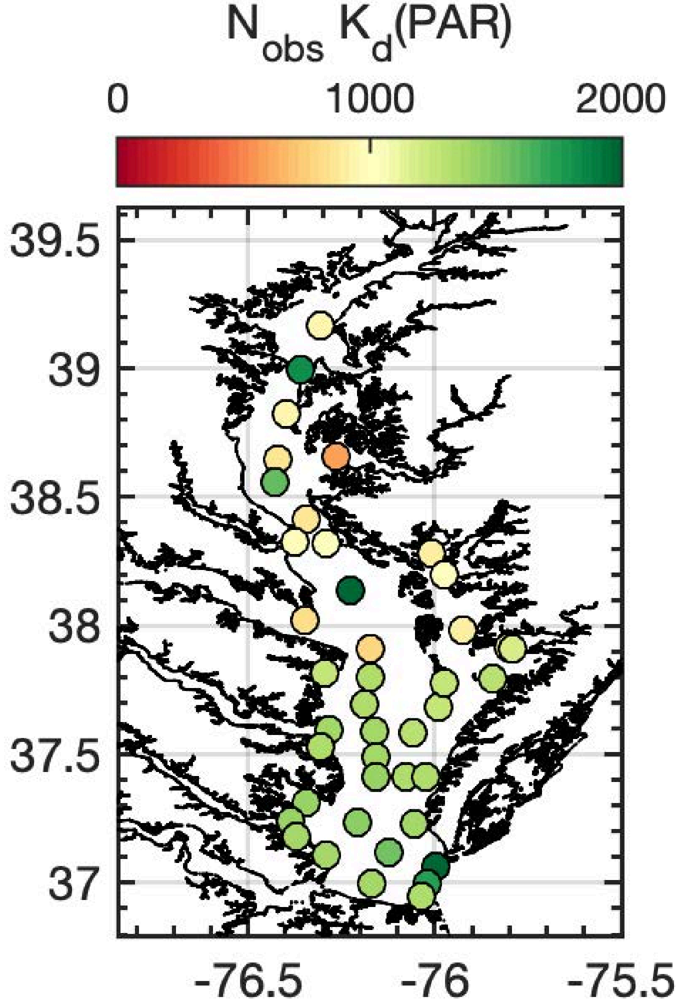
Contact: jturner@uconn.edu

Extra slides

Validation



Chesapeake Bay K_d(PAR) skill of MODIS-Aqua retrievals 2002-2007 compared to in situ CBP measurements. Adapted from Wang et al. (2009).



Number of in situ K_d(PAR) CBP observations 1984-2019 at 42 stations. N = 12,022 observations between 1984 and 2019.

Even in situ data has its issues with defining what is “clarity”

- Make sure to validate over multiple tides, seasons, dry/wet years to be sure the algorithm works for the answer you want.