Water Quality

NOAA Coastwatch Satellite Course

Last Updated: 1/20/2022

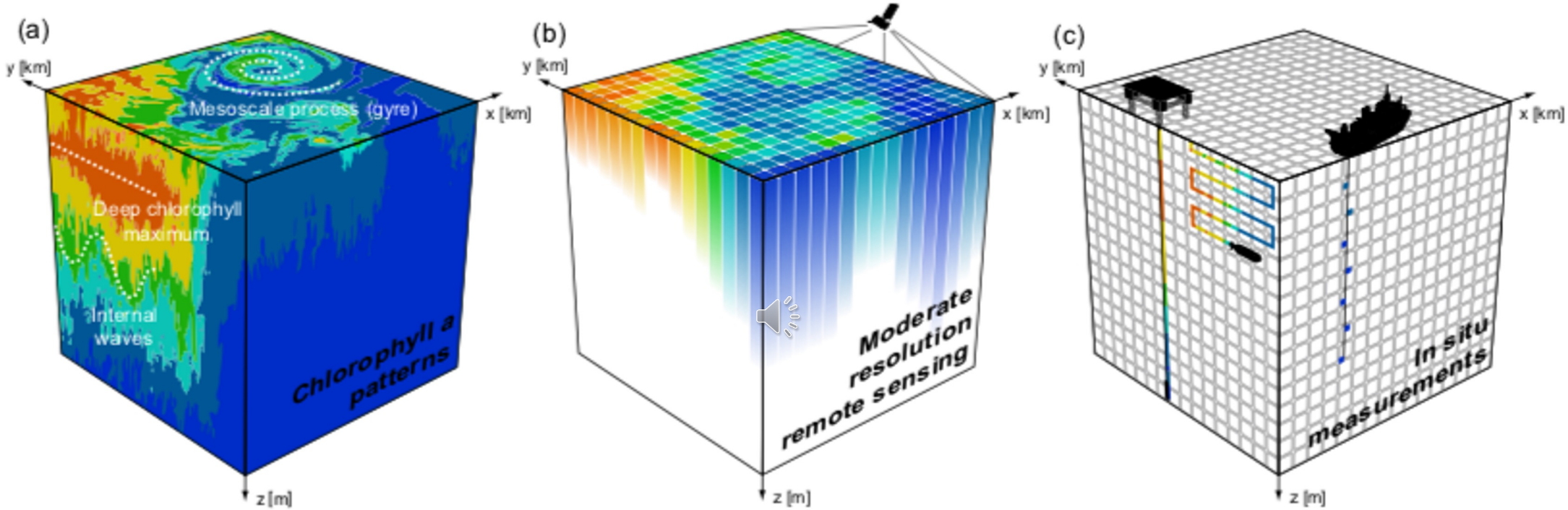
Satellite-derived Parameters

- Chlorophyll-*a*
- Sea/lake surface temperature
- Algal blooms/Harmful Algal Blooms (HABs)
- Turbidity/Water clarity
- Suspended sediments
- Colored dissolved organic matter (CDOM)
- Submerged, emergent and floating aquatic vegetation
- Surface oil slicks

How *In-Situ* and Satellite observations roughly correspond

In-Situ	Satellite
Water Temperature	Sea Surface Temperature (SST)
Chlorophyll Concentration and Algal Pigments	Chlorophyll-a Absorption Chlorophyll Fluorescence Phytoplankton Community Composition Spectral characteristic algorithms
Colored Dissolved Organic Matter (CDOM)	Absorption by CDOM (α_{dg})
Turbidity, Water Clarity	Diffuse Attenuation of Light at 490 nm (K_d) Diffuse Attenuation for Photosynthetically Active Radiation (K_dPAR) Euphotic Zone Depth
Total Suspended Solids (Total Suspended Matter, Suspended Particulate Matter)	Total Suspended Solids (Total Suspended Matter, Suspended Particulate Matter)
Salinity	Sea Surface Salinity (open ocean only, not available for coastal areas)

Measurement Scales



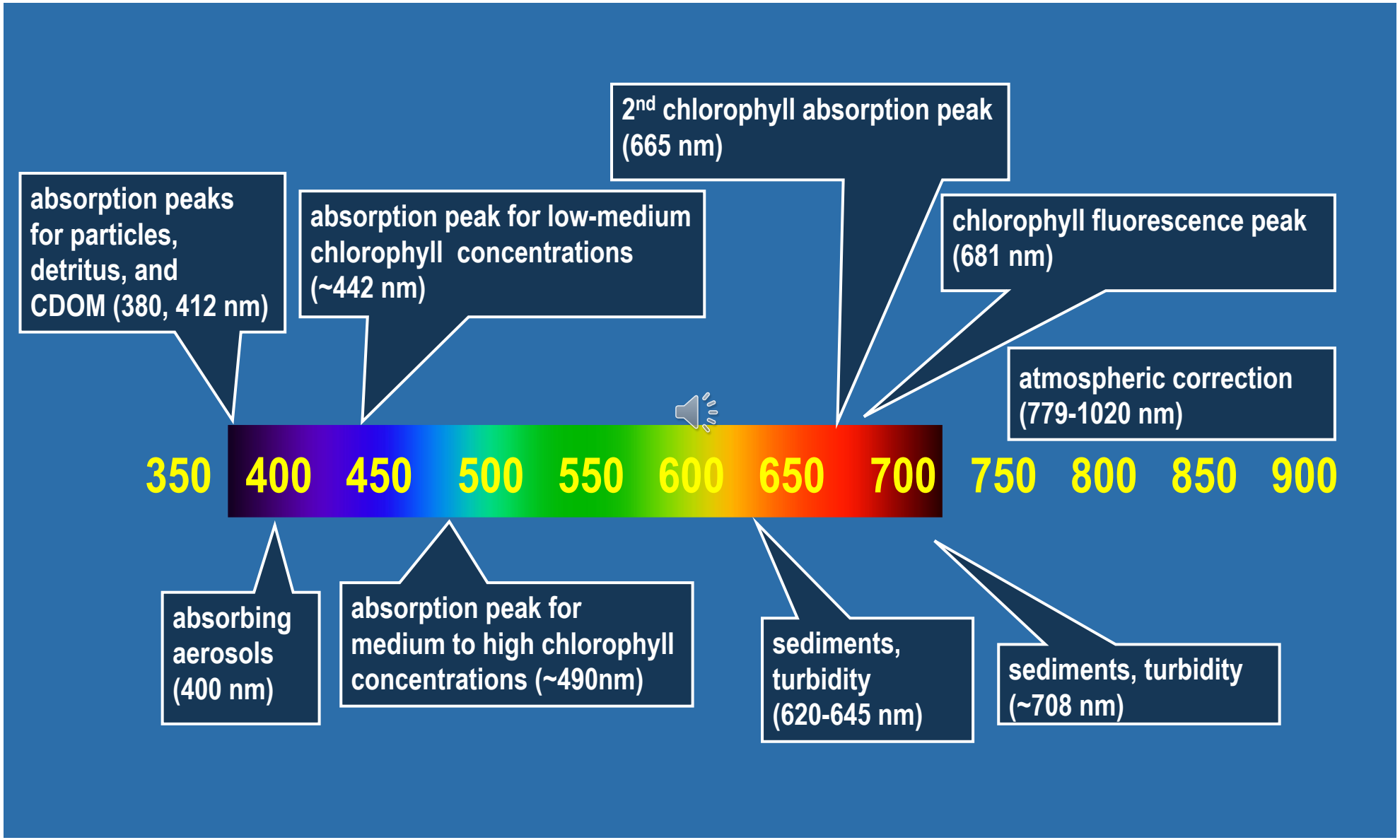
Comparison of how typical chl-a distribution patterns (a) are resolved with moderate-resolution satellite sensors (b) and in situ measurements (c).

Odermatt et al., Earth Syst. Sci. Data, 2018

Other parameters associated with, but NOT measured by satellite data

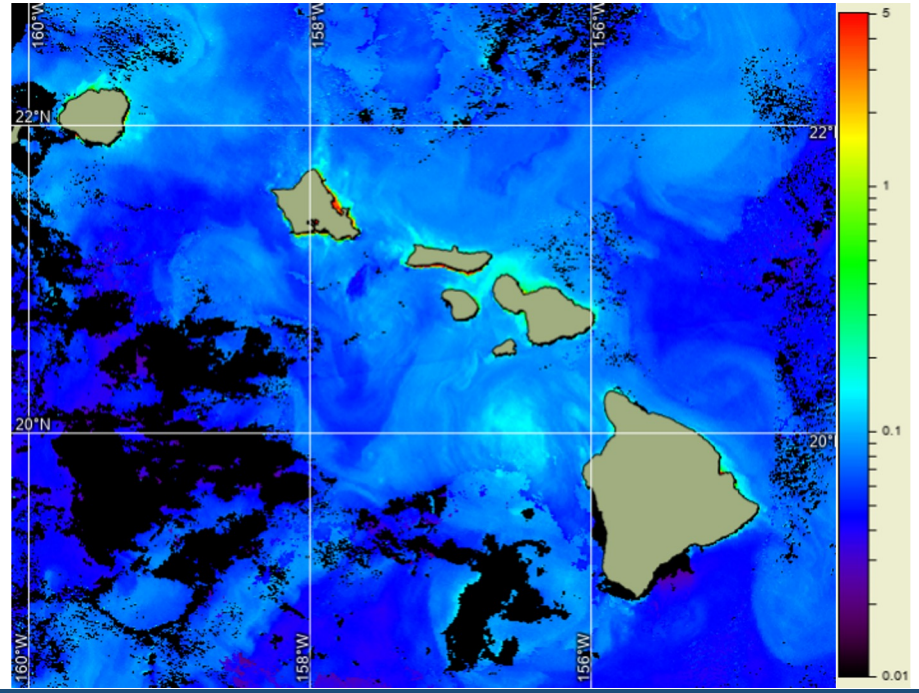
- **Algal toxins**
  - Most toxins are colorless and so are not directly measurable from ocean color remote sensing.
  - The relationship between pigments or cell densities and cyanotoxins is highly variable and remains a challenge for satellite remote sensing of algal bloom toxicity.
- **Nutrients**
  - Do not contribute directly to water spectral signature but contribute to ocean color indirectly through promotion of algal growth.
  - Statistical relationships are often based on an increase in chlorophyll with nutrients, as long as nutrients are the limiting growth factor.
- **Dissolved oxygen**
  - Remote sensing of chlorophyll-*a*, algal blooms and/or temperature may provide valuable information to understand hypoxia events.
- **Pollutants/metals/microbial contamination**
  - Not measurable directly with remote sensing.
  - May be inferred indirectly through their association with particulate and/or dissolved organic matter in plumes or resuspension events.

Spectral characteristics of oceanic waters

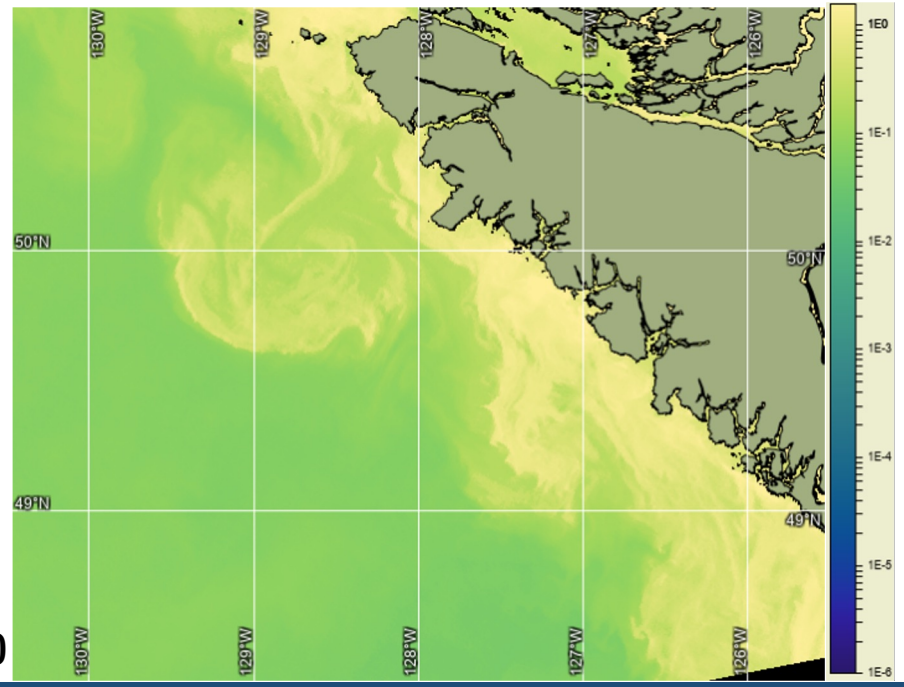


Ocean color data products

- Chlorophyll-*a* concentration (single sensor, merged, gap-filled)
- Diffuse attenuation coefficient at 490 nm (Kd490)
- Diffuse attenuation coefficient of photosynthetically active radiation (KdPAR)
- Various regional products (HAB, sediment, phytoplankton composition, primary productivity, etc)



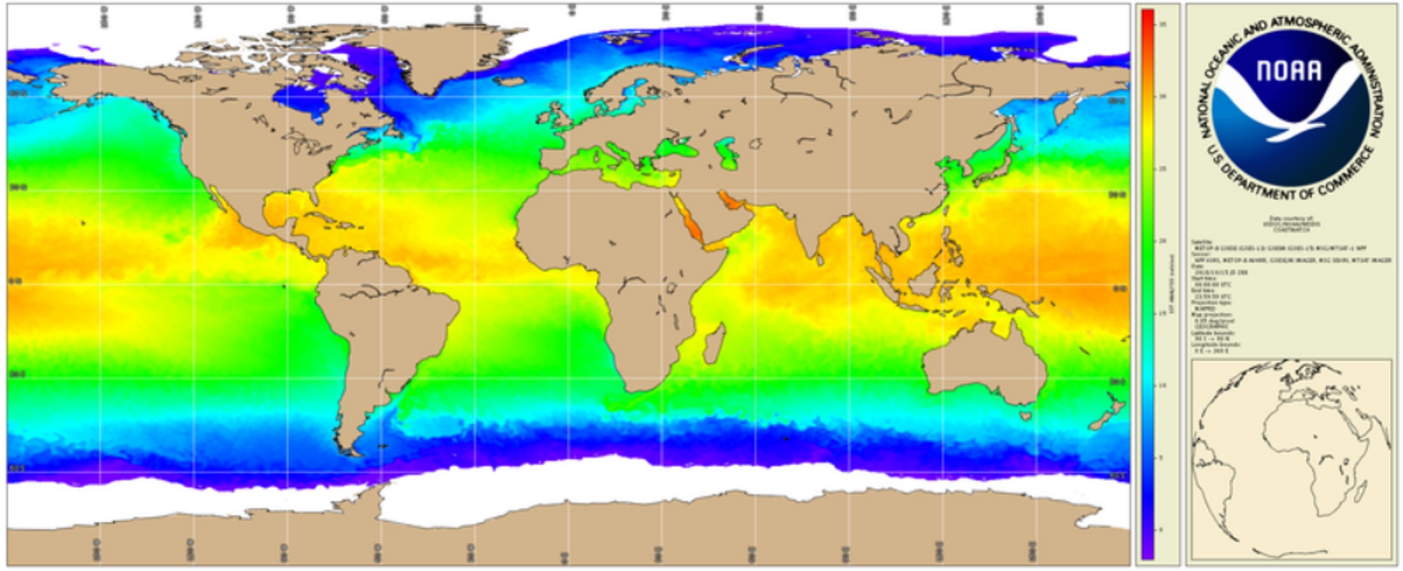
Chl-a

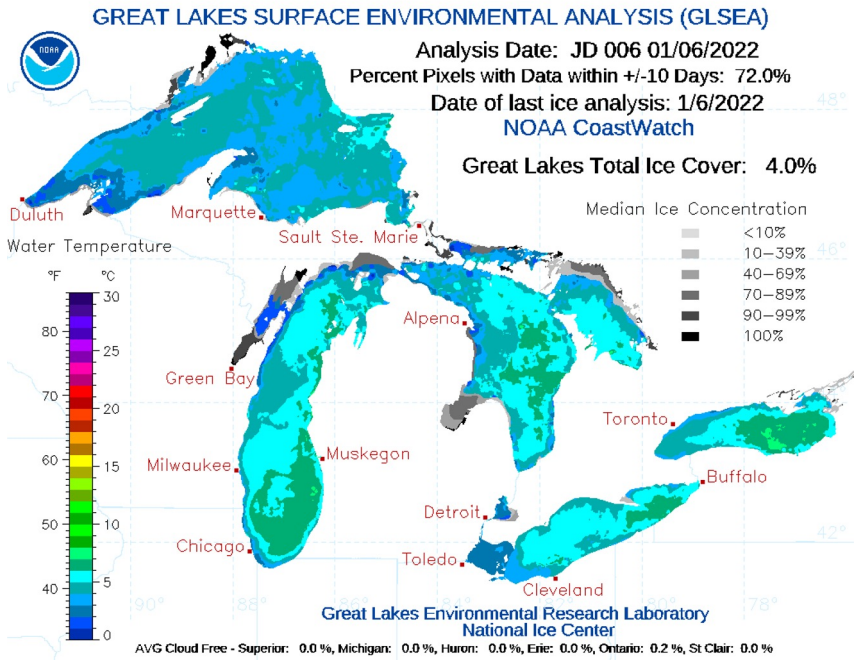


Kd490

Sea Surface Temperature (SST)

- SST is well-established remote sensing capability using thermal infrared or passive microwave remote sensing.
- These sensors are in both polar and geostationary orbit, making SST the oceanographic parameter with the most comprehensive satellite measurements.
- More information on SST can be found in the “Fundamentals of SST” presentation.



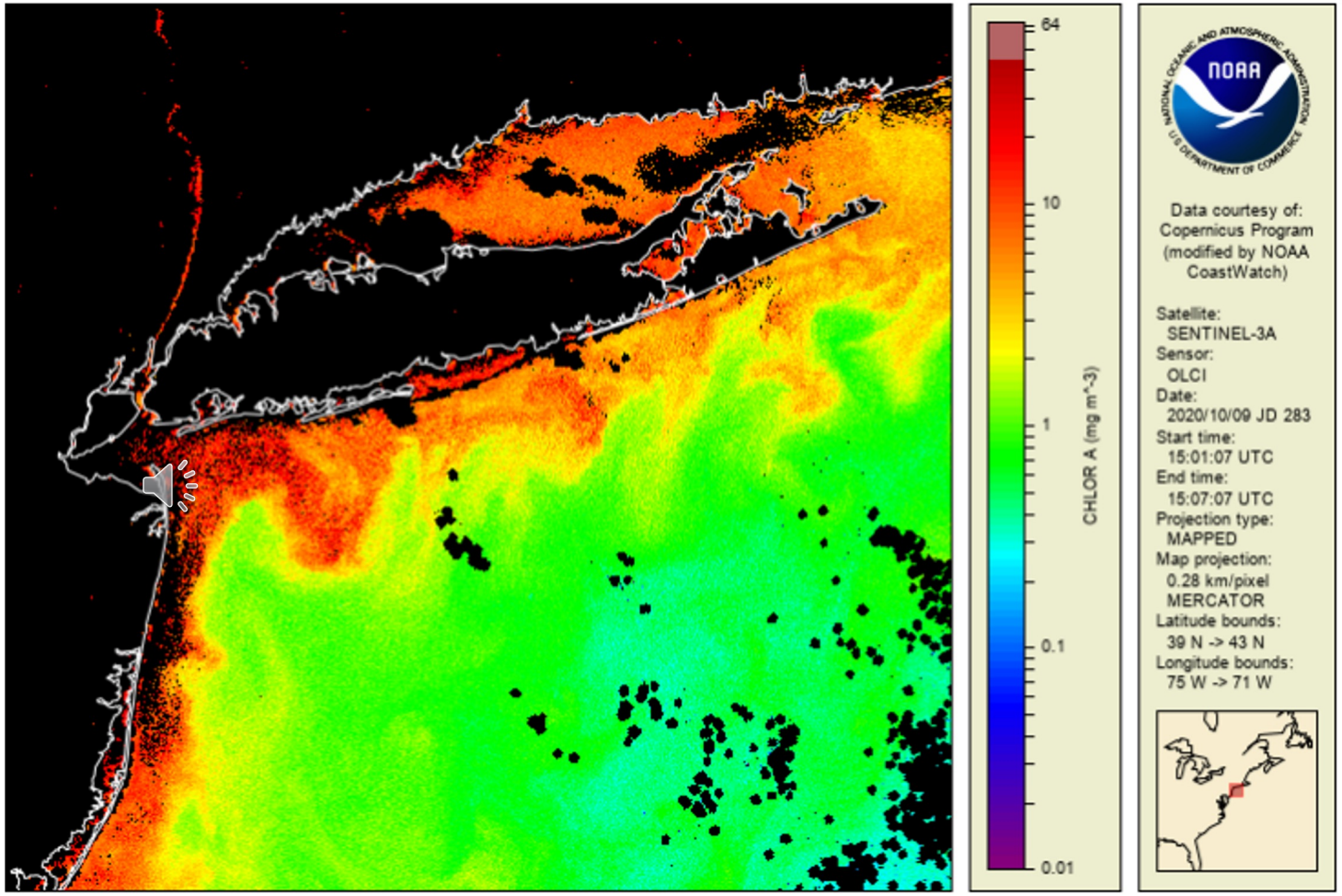


Great Lakes Surface Environmental Analysis (GLSEA)

Data Product Availability:
SST data are available in a variety of resolutions from all CW nodes.
SST averaged product called Great Lakes Surface Environmental Analysis (GLSEA) that includes ice-cover at CW-GLN

Chlorophyll

- Chlorophyll a is an indicator of total phytoplankton biomass.
- In remote sensing, water is classified by optical attenuation properties. Case 1 is clear open ocean. Case 2 is everything else.
- A variety of algorithms suitable for wide-ranging coastal and inland water conditions are available and are in routine use.
- More information on chl-a can be found in the “Fundamentals of Ocean Color” presentation.

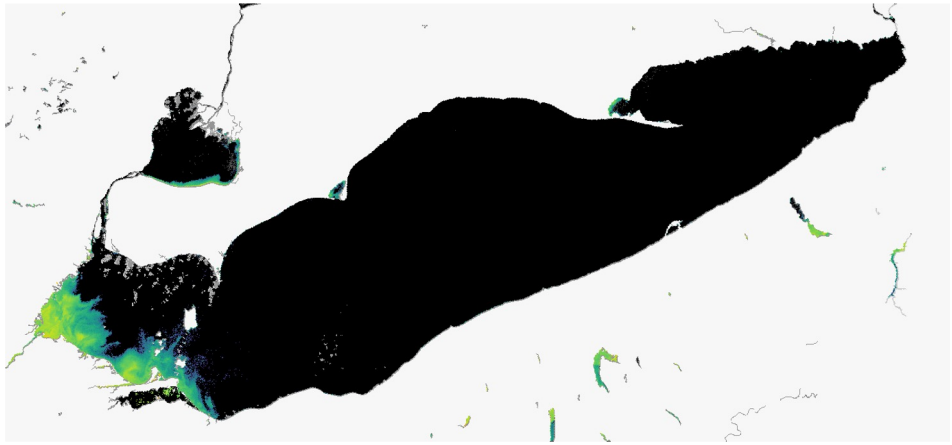


Data Product Availability:
Chlorophyll data are available in a variety of resolutions from all CW nodes.

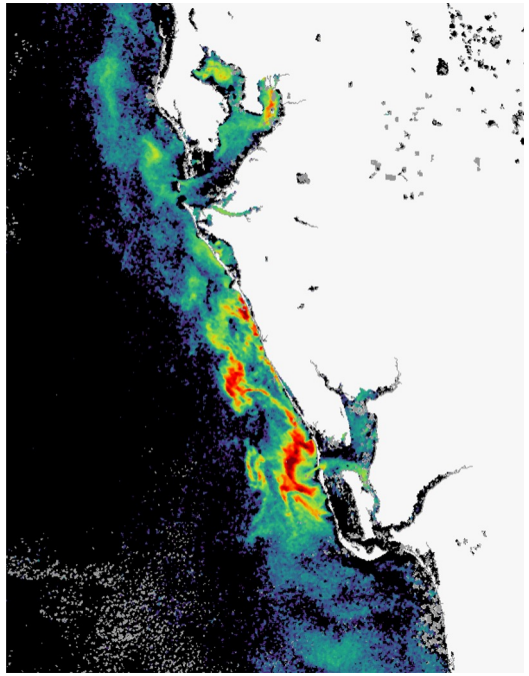
Algal Blooms

- Algal blooms are rapid increases in phytoplankton concentration or biomass, and some can contain toxic species known as Harmful Algal Blooms (HABs)
- Standard satellite chlorophyll products are not accurate in many coastal waters, due to interference from colored organic dissolved material.
- Alternative products to measure biomass are used in coastal waters.
  - Most are regional and may need tuning for other locations
  - Some are quantitative based on chlorophyll concentration or fluorescence. Increases in abundance can indicate new blooms

Cyanobacteria Index - Lake Erie 09/02/2021



Relative Fluorescence- Eastern Gulf of Mexico 08/11/2021



Data Product Availability

NOAA National Centers for Coastal Ocean Science (distributed by CoastWatch)
https://coastwatch.noaa.gov/cw_html/NCCOS.html
NOAA's HAB Monitoring System
https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system

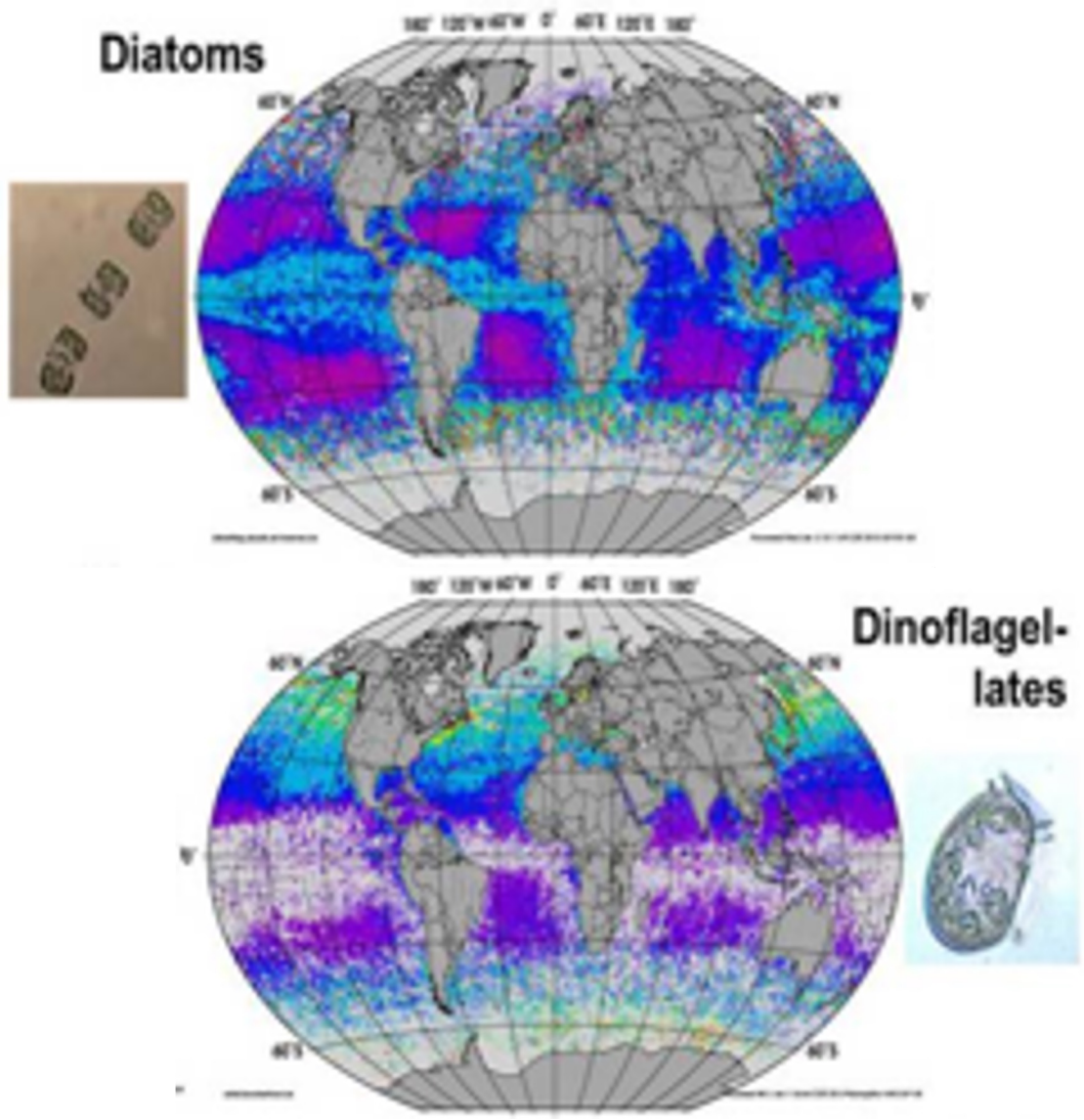
Phytoplankton Community Composition

- Satellite ocean color data is used to derive phytoplankton community with algorithms for:

  1. Phytoplankton taxonomic class
  2. Phytoplankton size class
  3. Particle size distribution

- These are based on abundance, radiance, absorption, and scattering parameters.

- Formerly known as “Phytoplankton Functional Types”

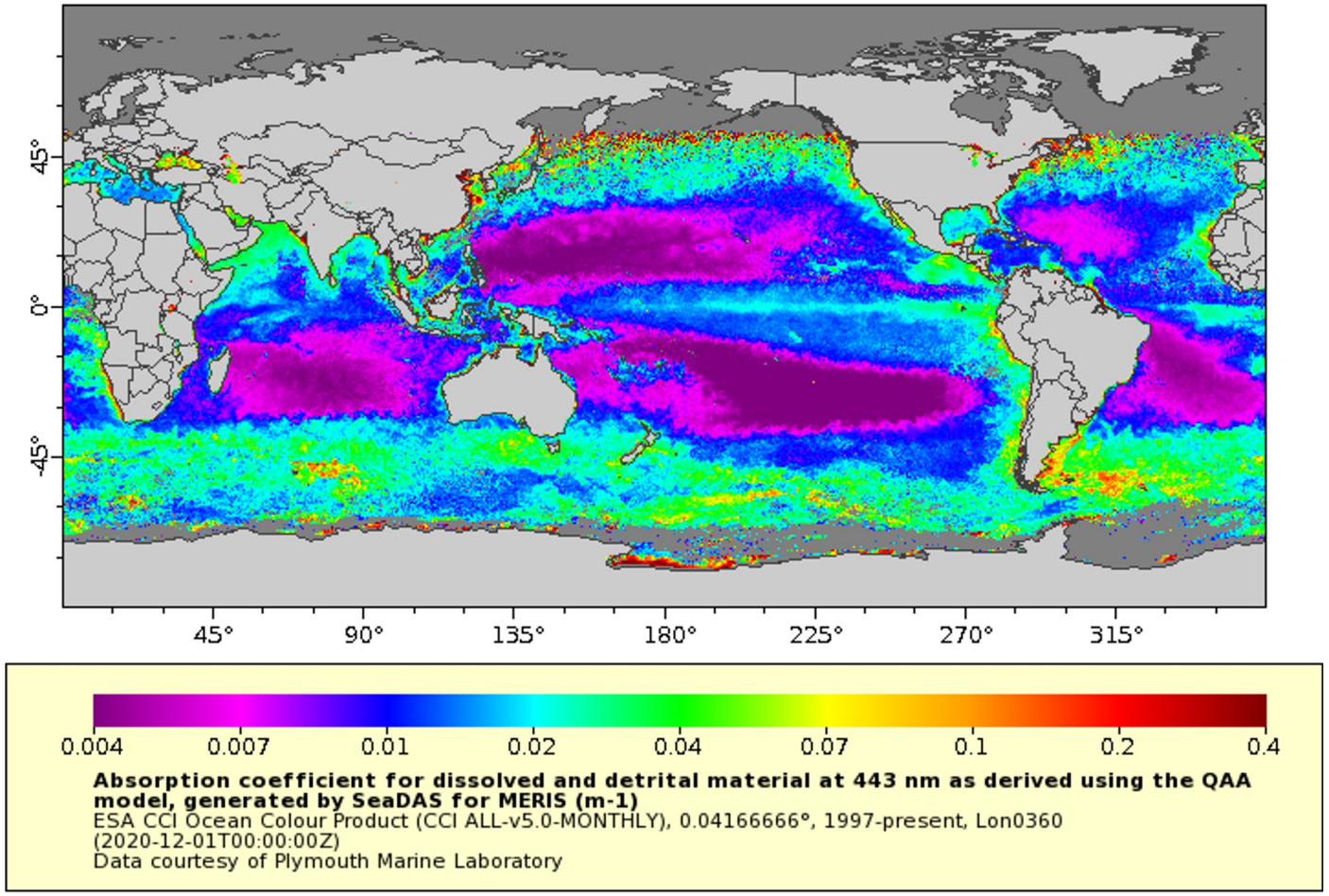


https://www.awi.de/en/science/climate-sciences/physical-oceanography/main-research-focus/ocean-optics.html

Data Product Availability:
Some experimental products exist, but most are not publically available

CDOM (Colored Dissolved Organic Material)

- CDOM is most prevalent in coastal waters and highly reduces valid retrievals of chlorophyll values from satellite data
- CDOM dominates the blue and UV spectrum and also controls UV and blue light depth penetration in the open ocean
- Often satellite products for CDOM are called adg_443 which represents the absorption due to gelbstoff at the 443 nm wavelength



Data Product Availability:
Global, daily, weekly, and monthly composites from ESA's OC-CCI product served by CW-WCN
Global, daily, weekly, and monthly composites for all US OC sensors served by NASA
Monthly, daily for the Great Lakes on the CW-GLN

Turbidity vs. Light Attenuation

Turbidity (units are NTUs, FTUs)

- Turbidity indicates the amount of scattering of light by particles
- Measured *in-situ* using nephelometers, turbidometers and similar instruments
- Turbidity is usually measured in Red-NIR
- Turbidity can be a better indicator for assessing visibility than light attenuation

Light Attenuation (Kd) units m^{-1}

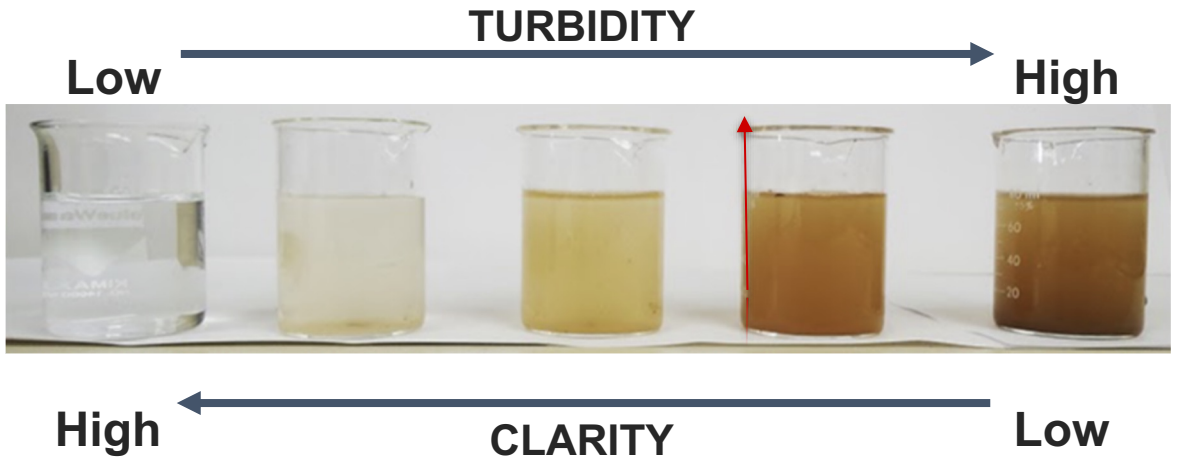
- How rapidly sunlight is lost with depth in the water
- Caused by both absorption and scattering
- Estimated for diffuse light at a specific wavelength: e.g., 490 nm for Kd490
- How deep light penetrates matters for benthic plants and for photosynthesis

In places with a lot of sediment in the water, turbidity and Kd are closely correlated.
Both are correlated to the inverse of Secchi depth (SD), and Kd ~ 1/SD

Turbidity is also used in conjunction with Water Clarity

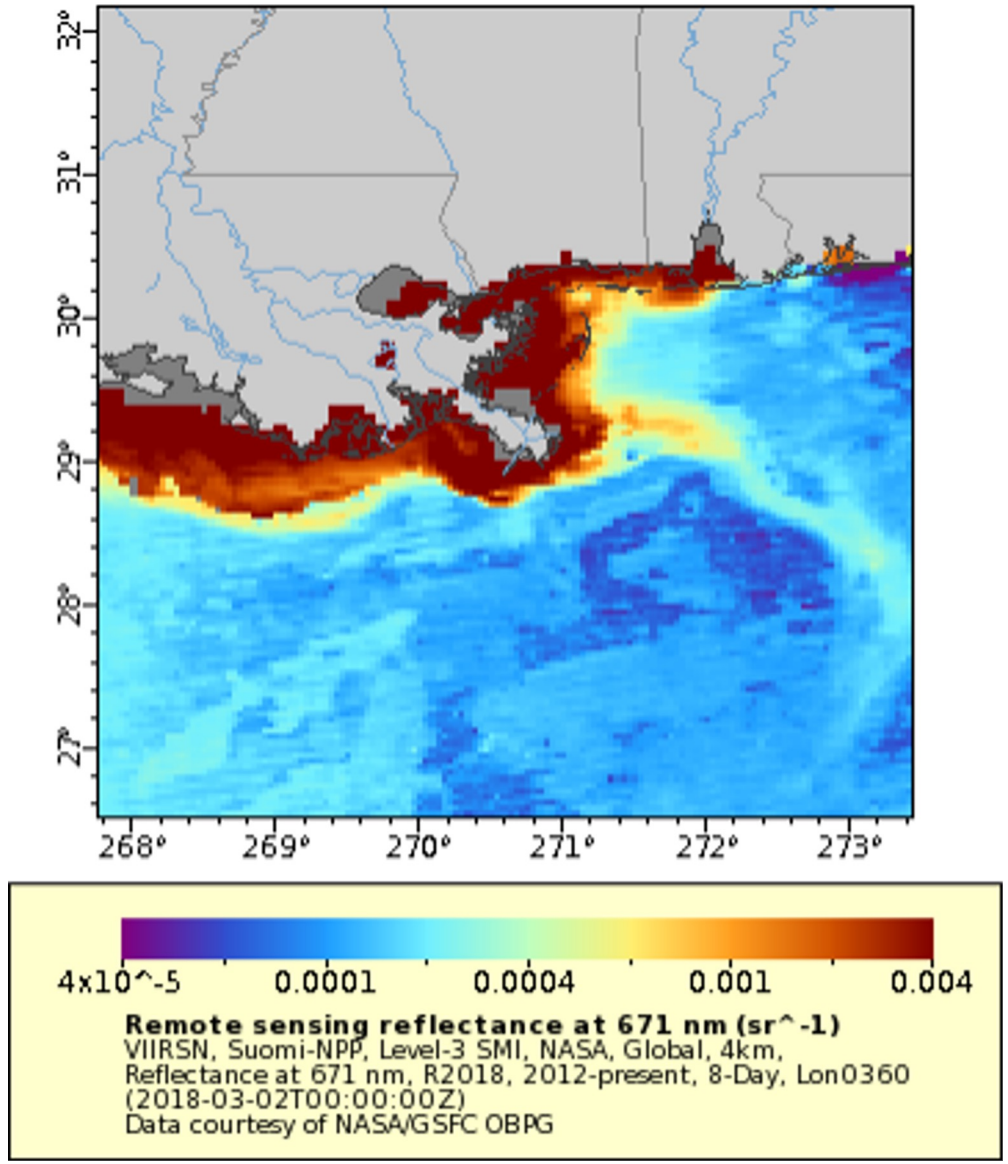
Water Clarity can be a catch-all term related to:

- Light attenuation (absorption & scattering)
- *In-situ* measured turbidity
- Visibility
- Other assessments of particles in the water (e.g. detritus, sediment, organic particles)



Sediment Index

- Remote Sensing Reflectance at 667 (MODIS) or 671 (VIIRS) nm
- It is an index of relative amount of sediment and not an estimation of sediment concentration



Data Product Availability:

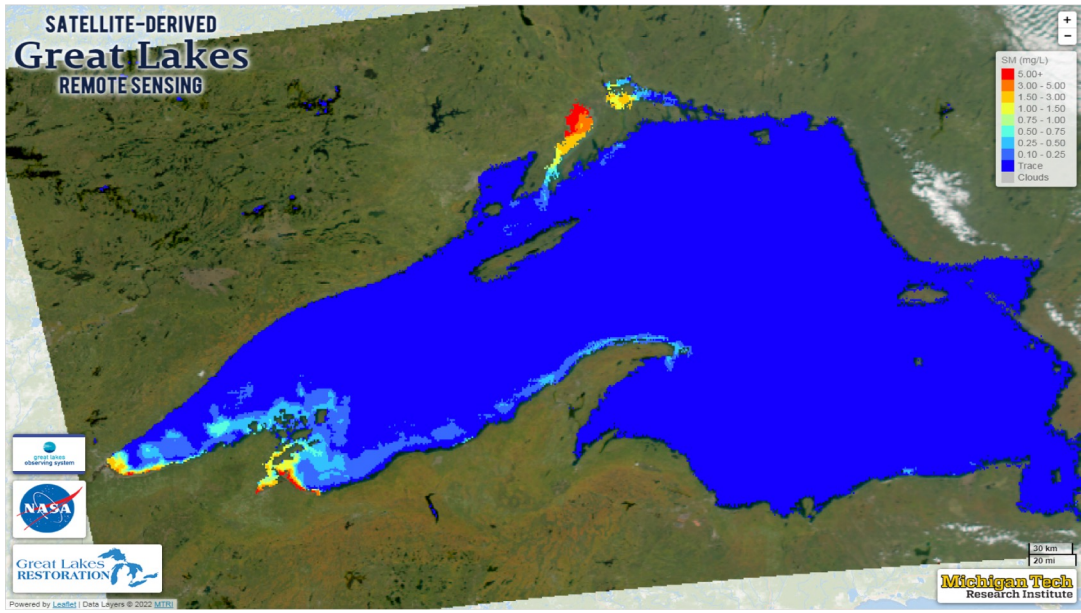
- Global fields from VIIRS and OC-CCI available on CW-WCN ERDDAP
- Regional fields are available from CW-ECN

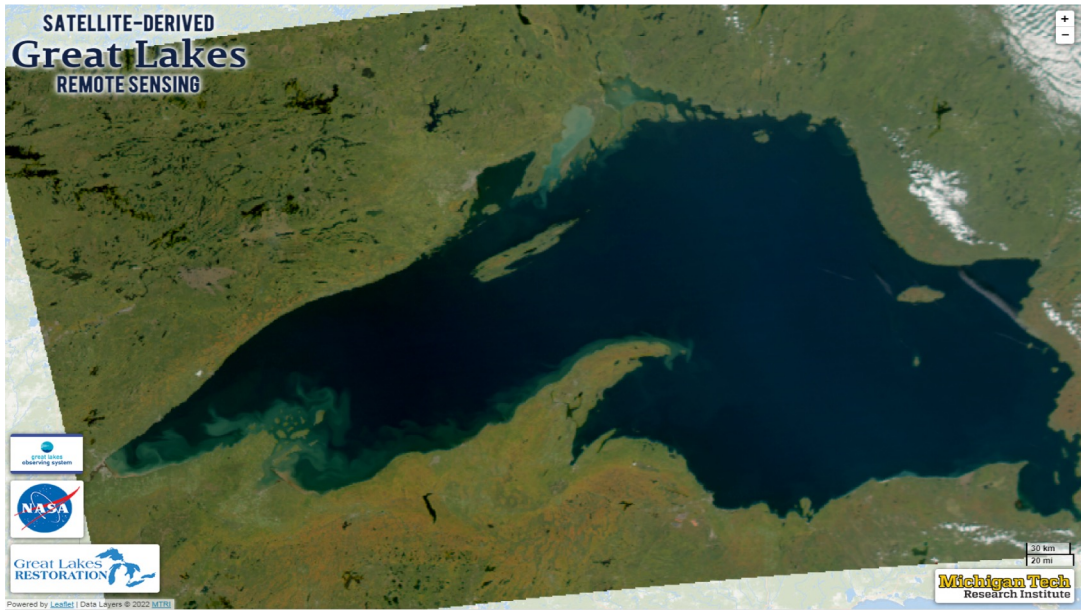
Total Suspended Matter (TSM)

Satellite-derived **total suspended matter (TSM)** is a measure of the concentration of particulate material in the surface water.

Also referred to as:

- Suspended Particulate Matter
- Total Suspended Solids



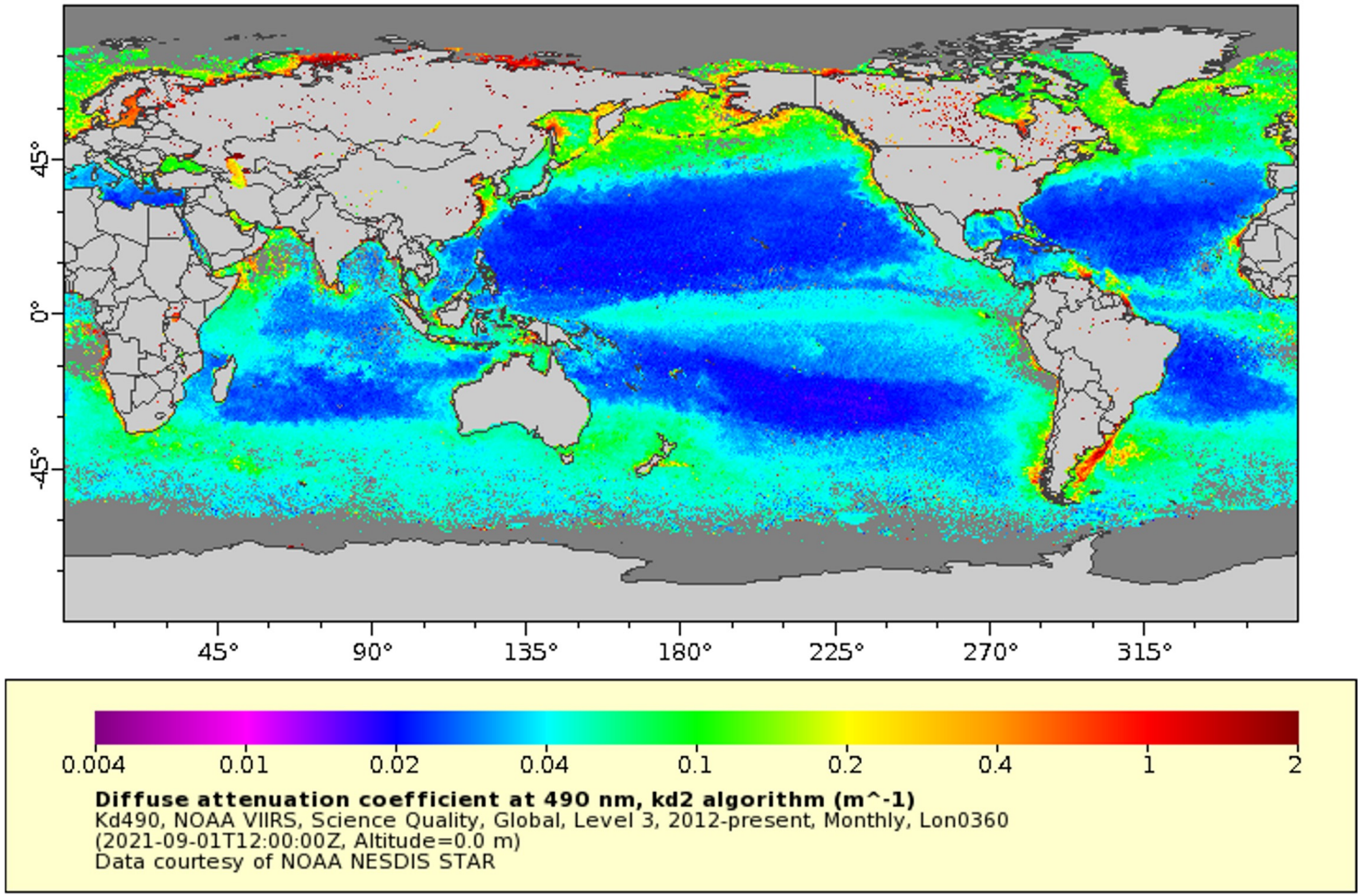


Lake Superior

Data Product Availability:
Regional fields are available from CW-ECN, CW-GLN

Kd490 - Light attenuation

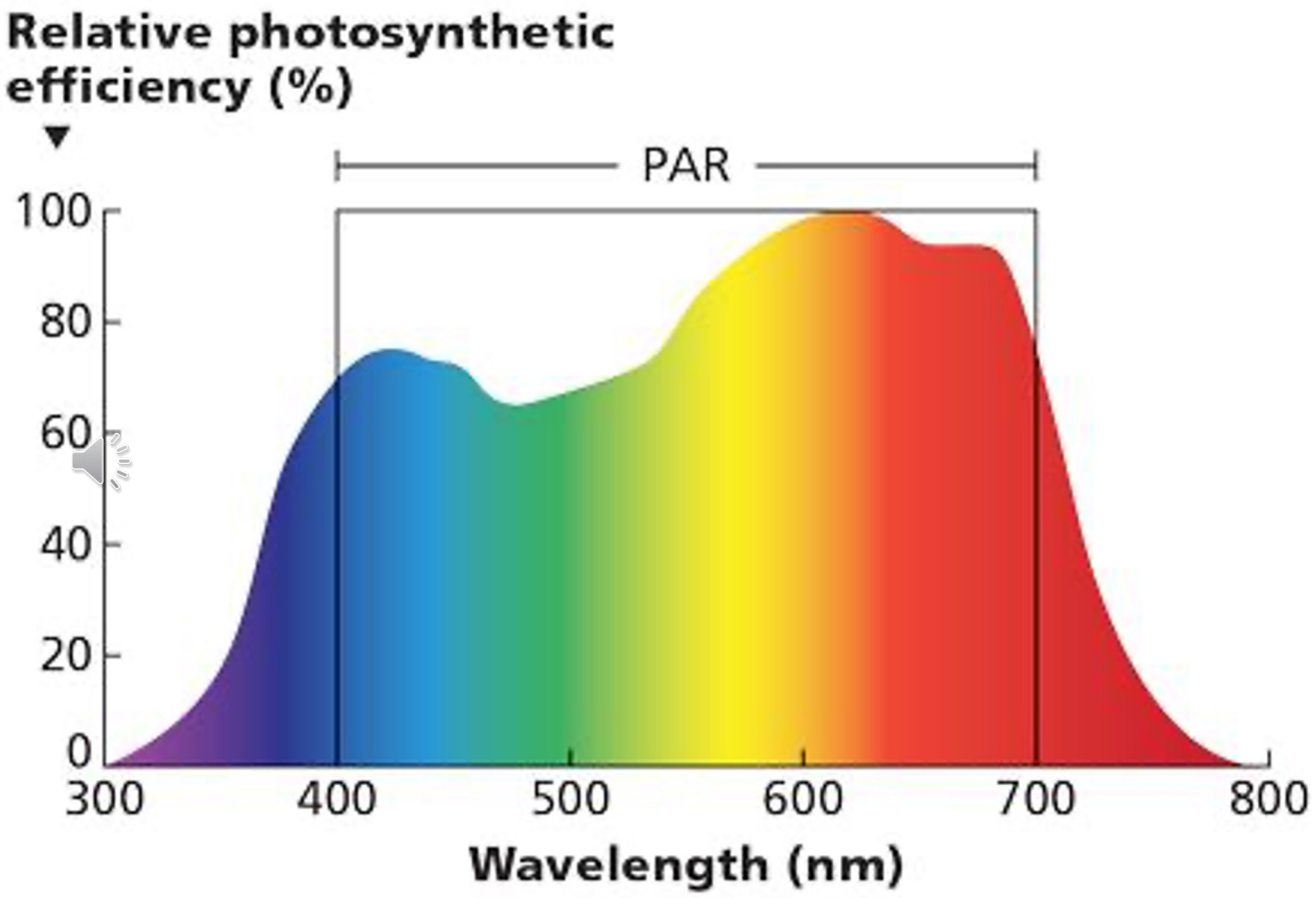
- The value of Kd490 represents the rate at which light at 490 nm (blue-green portion of the spectrum) is reduced with depth
- The blue-green portion of the spectrum corresponds to the peak of Chl-a absorption.
- Higher Kd490 values relate to a lower secchi depth due to the absorption and scattering properties of the water sample.



Data Product Availability:
Global fields of daily, weekly and monthly Kd490 are available on ERDDAP

KdPAR

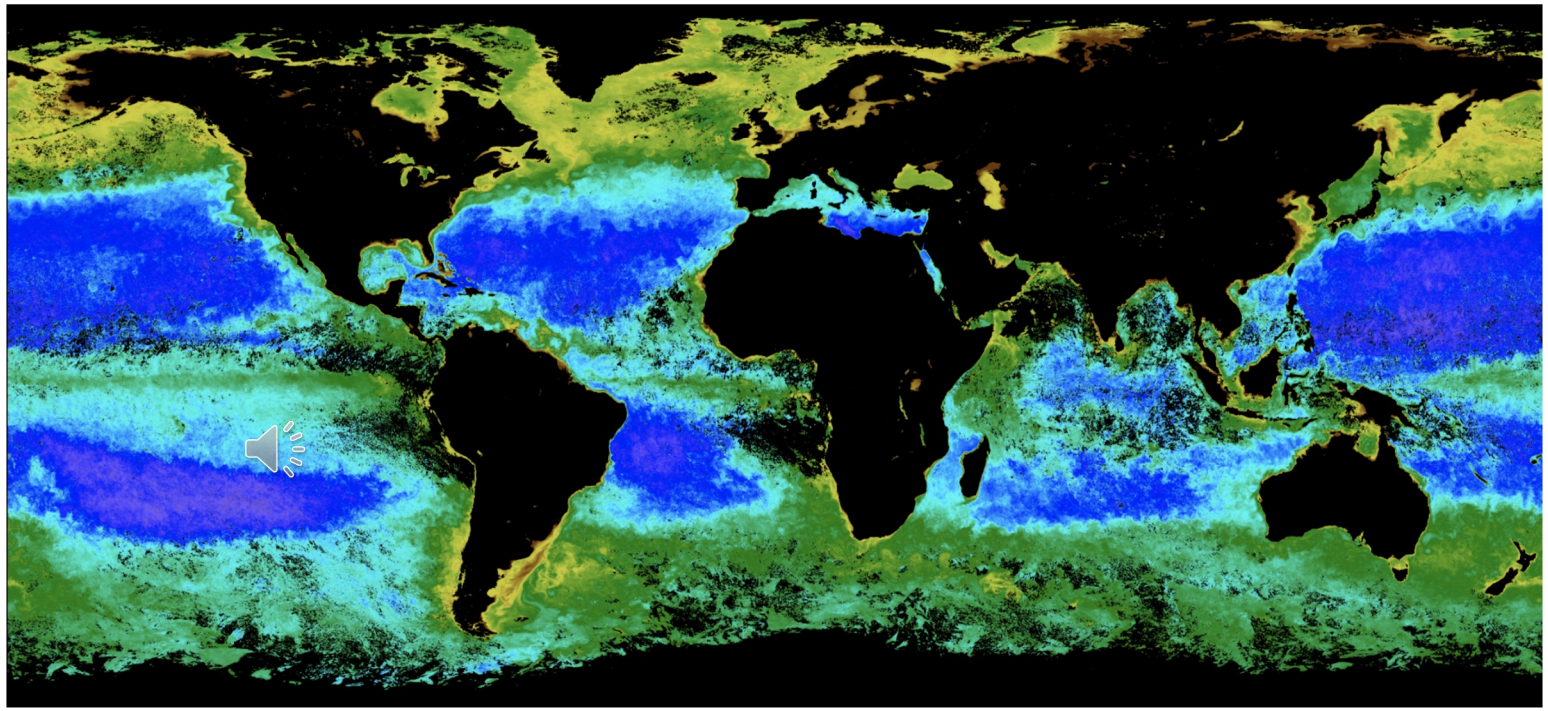
- Photosynthetically Active Radiation (PAR), is light from 400 to 700 nm, the range of wavelengths used in photosynthesis.
- PAR is a common input used in modeling marine primary productivity.
- KdPAR is the attenuation of the PAR wavelengths, estimated from Kd490
- As with Kd490, a higher KdPAR value means the visible light is attenuated more, providing less light for photosynthesis.



Data Product Availability:
Global fields of daily, weekly and monthly KdPAR are available on ERDDAP

Euphotic Zone Depth

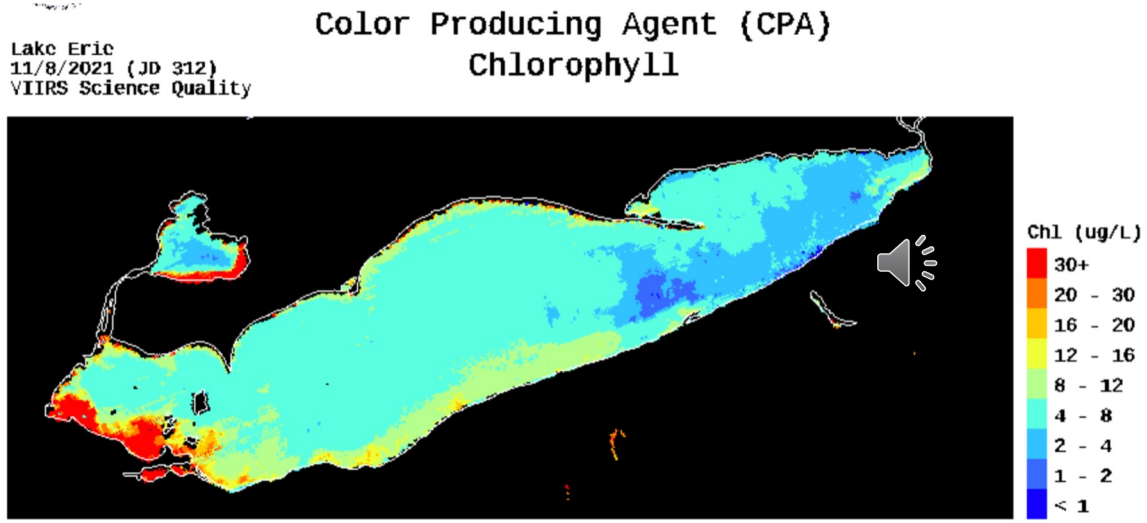
- The Euphotic Zone Depth is the depth where 1% of surface PAR remains
- Euphotic Zone Depth and turbidity are related quantities - both measure light limitation in the water-column
- Euphotic Zone Depth is a depth measurement (m), whereas Kd490 is an attenuation measurement (light reduction over distance m^{-1})

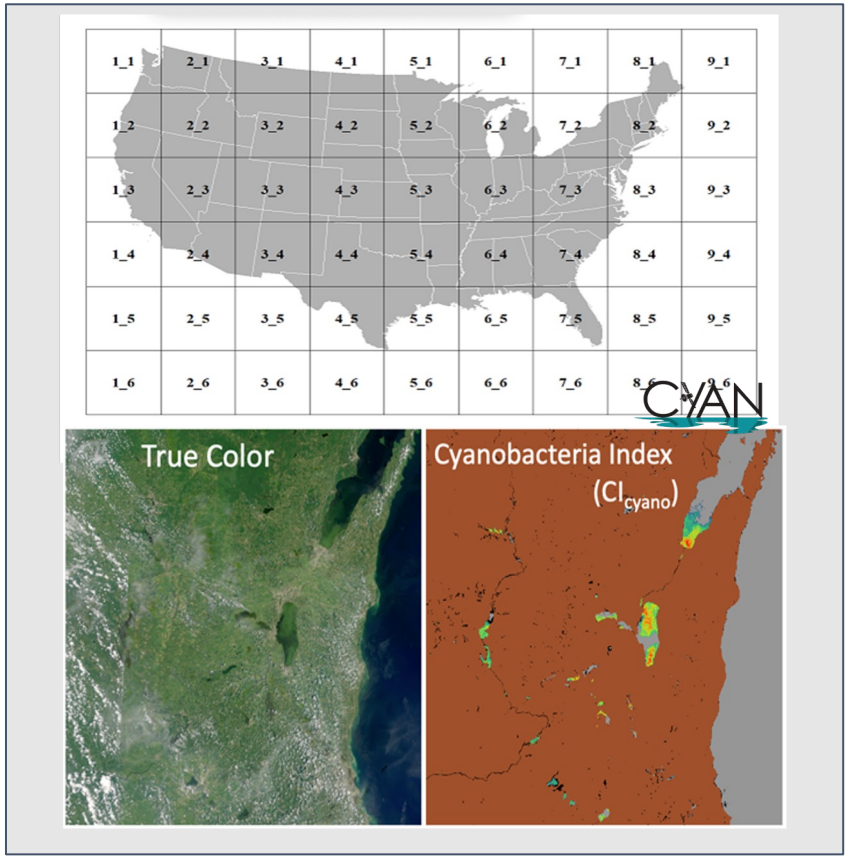


Data Product Availability:
NASA's ocean color page provides global fields of Euphotic Zone Depth (under the Product Status of 'Special' https://oceancolor.gsfc.nasa.gov/)

Inland Lakes

- Great Lakes CoastWatch Node hosts a suite of ocean color products including chlorophyll, CDOM, suspended minerals, as well as primary productivity and water clarity
- Inland Lakes imagery extends beyond the Great Lakes with examples such as the CyAN Project



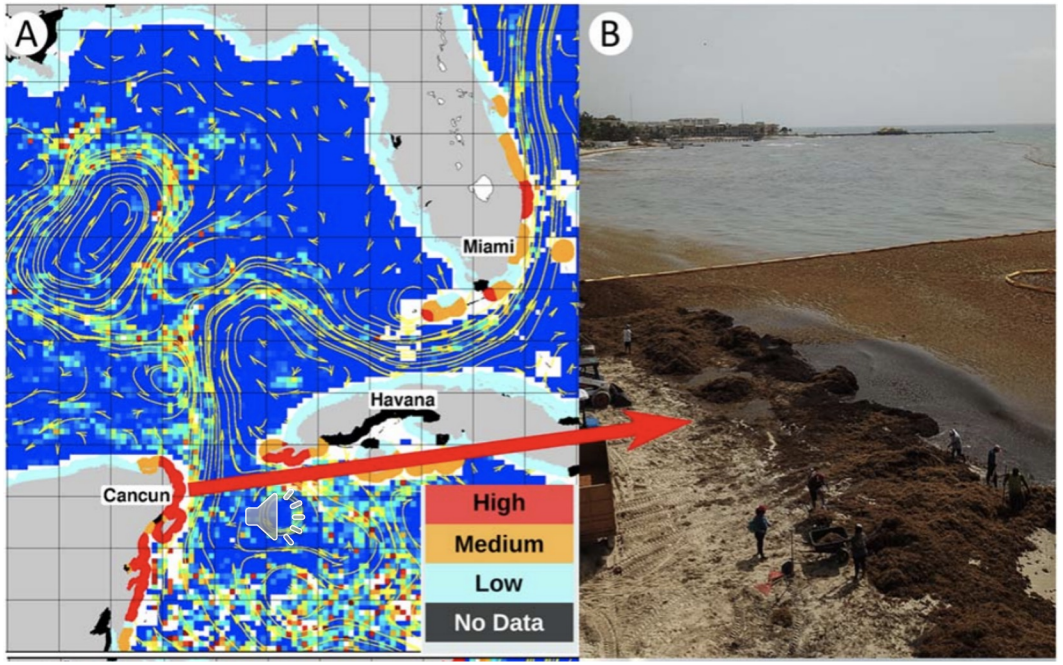


Data Product Availability:

CW-GLN, NCCOS regional products: https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/
GLERL: https://coastwatch.glerl.noaa.gov/ocean-color/ocean-color.html
NCCOS Lake Erie HAB Forecast: https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/lake-erie/
CyAN Data Products: https://oceancolor.gsfc.nasa.gov/projects/cyan/
Lake temperatures: https://climate.esa.int/en/projects/lakes/data

Floating Vegetation and Submerged Aquatic Vegetation (SAV)

- The spatial scale of floating vegetation and submerged aquatic vegetation (i.e. Landsat) requires the use of high resolution data
- Available products are regional



A CoastWatch (Caribbean/GoM Node) project

Great Lakes SAV (Glase, 2015)

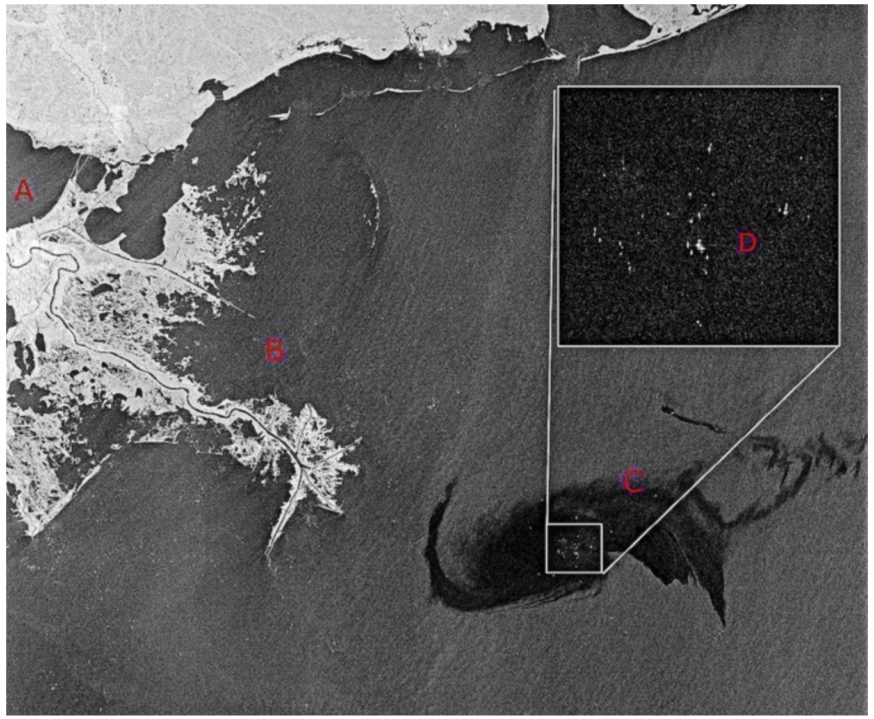
Data Product Availability:
Caribbean/GoM CoastWatch has regional fields of the USF Alternative Floating Algal Index (AFAI) in 1, 3 and 7 day composites
https://cwcgom.aoml.noaa.gov/erddap/search/index.html?&searchFor=afa

EPA Great Lakes Restoration Initiative (GLRI) with CoastWatch Partners:
https://geodjango.mtri.org/static/sav/

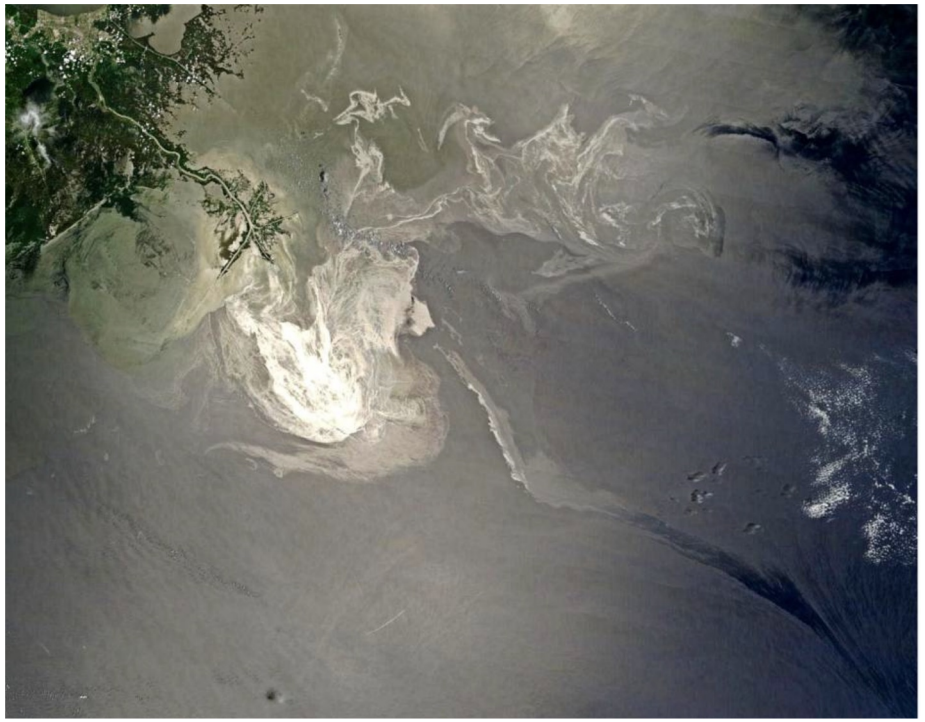
Trinanes et al., Monitoring pelagic Sargassum inundation potential for coastal communities, Journal of Operational Oceanography, 2021

Oil Slicks

Oil slicks are typically detected using active microwave sensors like Synthetic Aperture Radar (SAR) but optical imagery offers some additional benefits such as discriminating surface oil slicks from algae.



Radarsat imagery of the DWH spill. The bright dots in the insert are ships working to control the spill.



A visible image of the DWH spill from the NASA Terra satellite taken on 24 May 2010.

Data Product Availability:
No “off the shelf” products available.

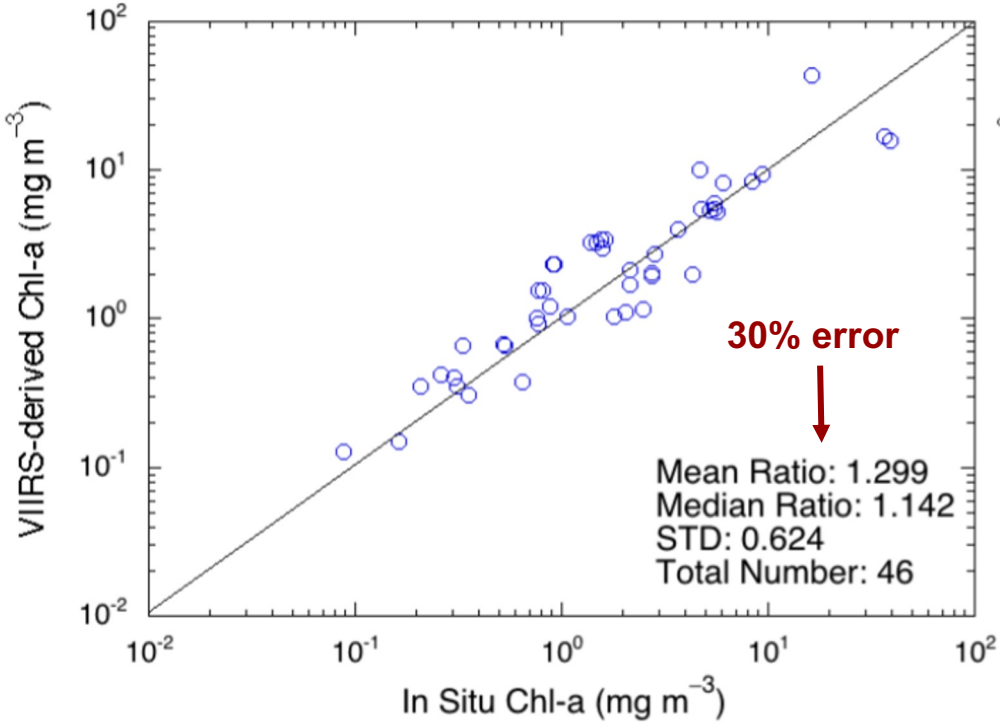
Fingas & Brown, A Review of Oil Spill Remote Sensing, Sensors, 2017

Satellite Data Accuracy

Data products are released after validation studies

- Satellite data are validated against *in-situ* data
- Comparison must be temporally & spatially representative
- Results are presented as comparison statistics (e.g. ratio, bias, standard deviation, RMS)
- Experimental products may not have been validated
- Validation studies are published
  - In the scientific literature
  - As Algorithm Theoretical Basis Documents (ATBD) maintained by the producing agency (e.g. NASA, NOAA)
  - Usually with the algorithm description

Chl-a Measurements: VIIRS-SNPP vs. In-situ



➔ *In-situ* data from the NASA SeaBASS database

➔ Satellite data ±3 hours of *in-situ* sampling time

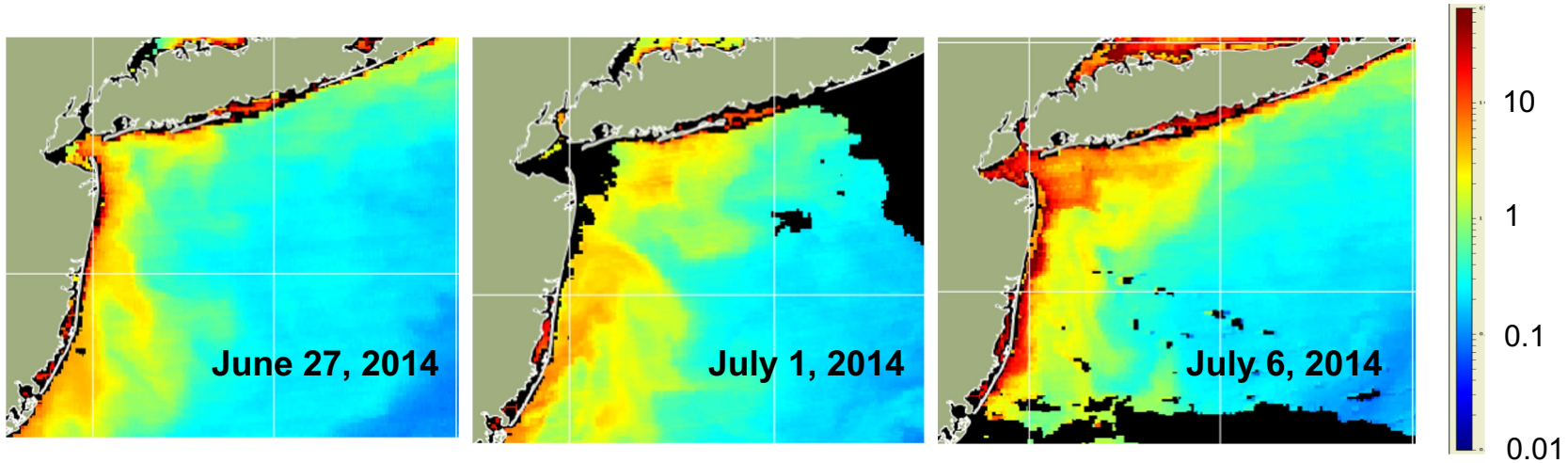
➔ Satellite value is mean of 3X3 pixel box centered on *in-situ* sampling location

➔ NOAA VIIRS Ocean Color ATBD, Wang et al., 2017

Satellite Data Accuracy, continued

- The validation study describes the degree of accuracy. It *does not* mean the data are accurate!
- Your application defines what level of accuracy you can accept.
  - **Low accuracy applications:** detecting spatial patterns, averaged trend over time. Absolute data value is less important than detecting features or trends.
  - **High accuracy applications:** model input, environmental studies at single point locations. Absolute data value is important.

Example of low accuracy application: Imagery detects location and changes in plume, without needing to know absolute chlorophyll value. (Chlorophyll values are not accurate for coasts unless specially tuned for a location.)



Other Resources

U.S. EPA Watershed Academy

Training modules and webcasts about a range of watershed management topics
http://www.epa.gov/watertrain

U.S. National Water Quality Monitoring Council

Resources on all aspects of water quality monitoring
https://acwi.gov/monitoring/

NASA ARSET

Three-part on-line training session on water quality
https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

International Ocean-Colour Coordinating Group (IOCCG)

Report on water quality monitoring
https://ioccg.org/wp-content/uploads/2018/09/ioccg_report_17-wq-rr.pdf

AquaWatch

Established to improve the coordination, delivery and utilization of water quality information.
https://www.geoaquawatch.org/

NOAA CoastWatch Satellite Course - Narrated Presentations

- Satellite 101 – Part 1
- Satellite 101 – Part 2
- Fundamentals of Ocean Color
- Fundamentals of Sea-Surface Temperature
- Fundamentals of Altimetry, Wind and Salinity
- Sea Ice
- **Water Quality**
- Introduction to ERDDAP
- Bringing Satellite Data into ArcGIS