Ocean Color

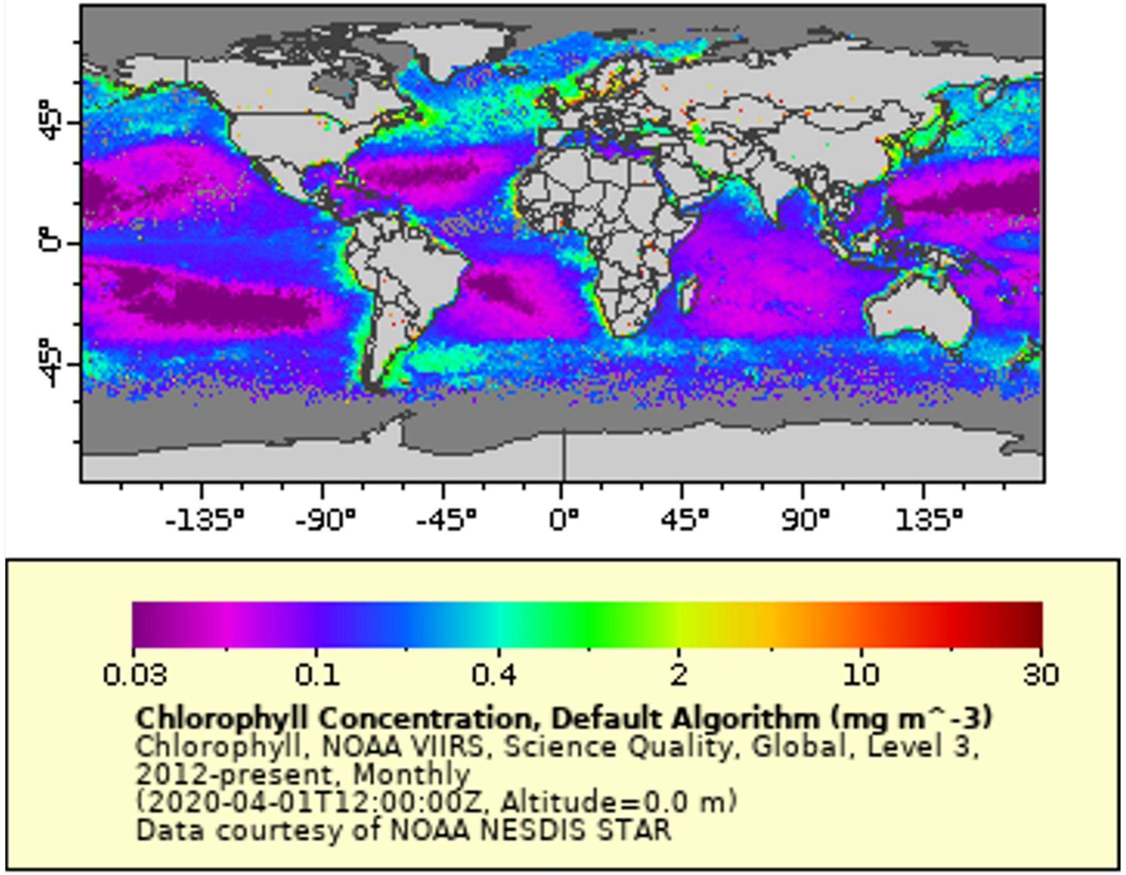
NOAA CoastWatch Satellite Course

Last Updated 10/7/2020

Ocean Color

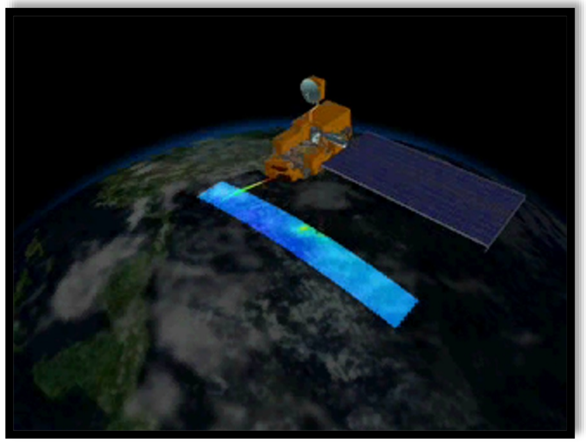
- Ocean color measurements from space have revolutionized our understanding of the ocean on every scale, from local to global and from days to decades.

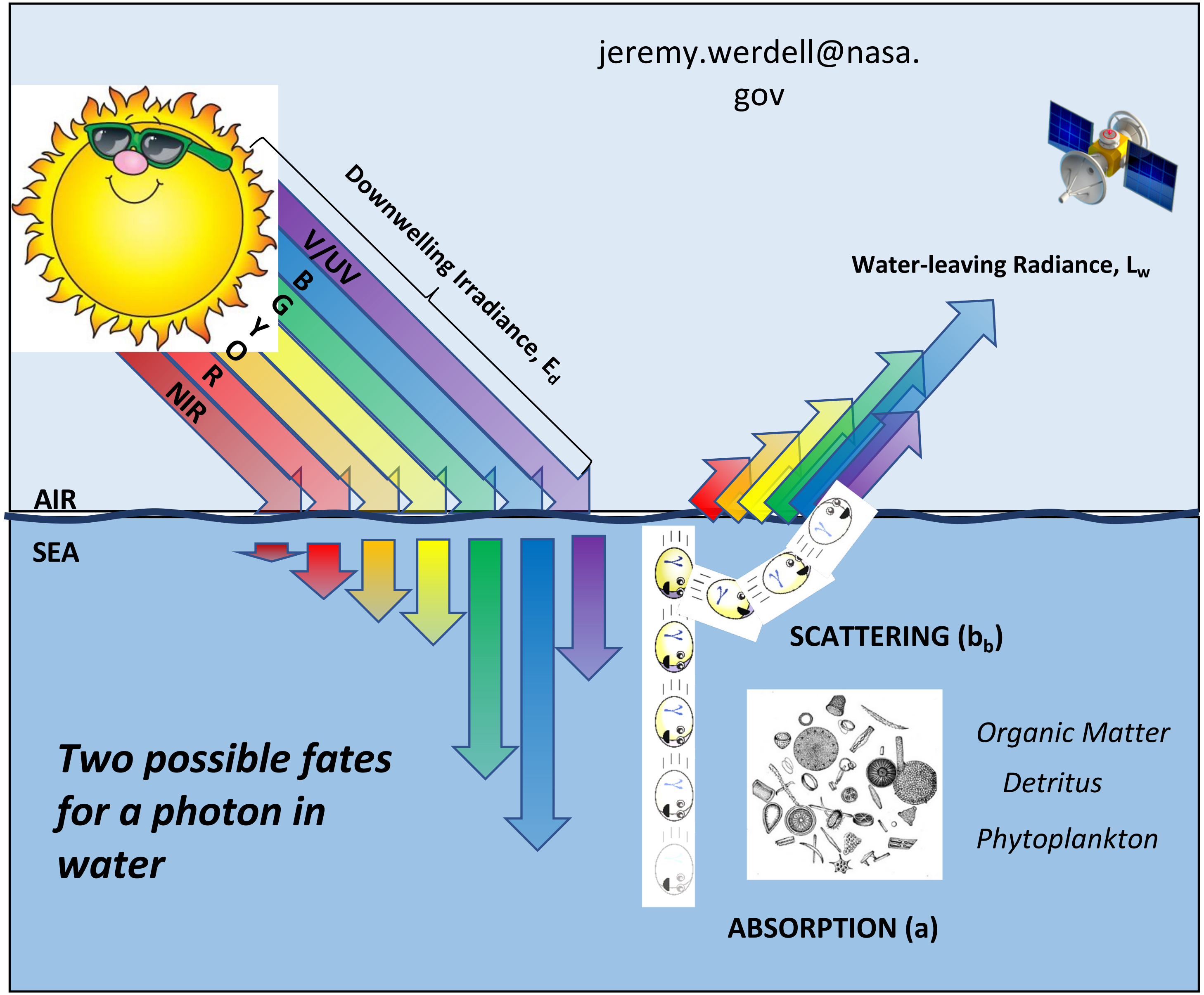
- Ocean color measurements reveal a wealth of ecologically important characteristics including:
  - chlorophyll concentration
  - phytoplankton bloom monitoring
  - primary productivity
  - sediment transport
  - dispersion of pollutants
  - responses of oceanic biota to long-term climate changes
  - water clarity and quality



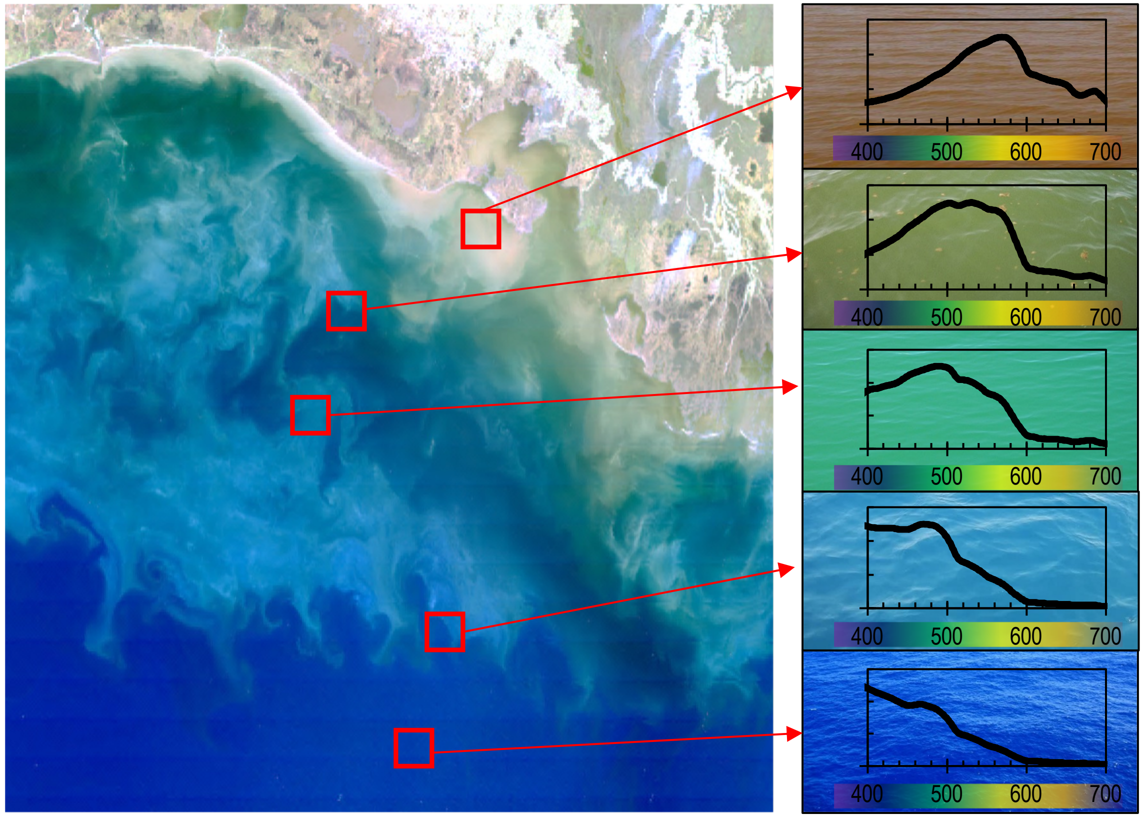
IOCCG, 2008

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





What causes variation in the color of the ocean?



Water-leaving Radiance

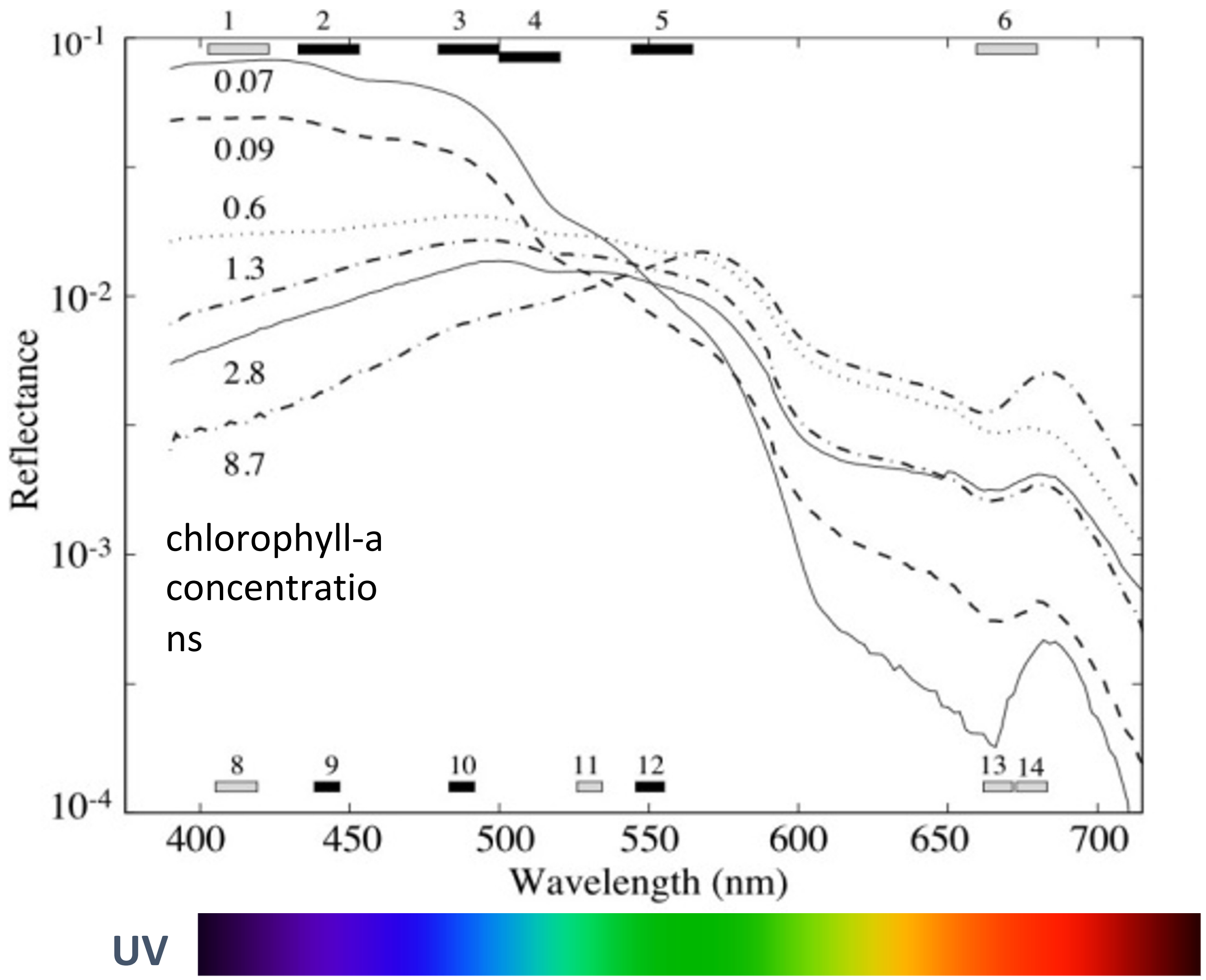
The color of the ocean is a function of light that is absorbed or scattered as a result of constituents in the water.

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

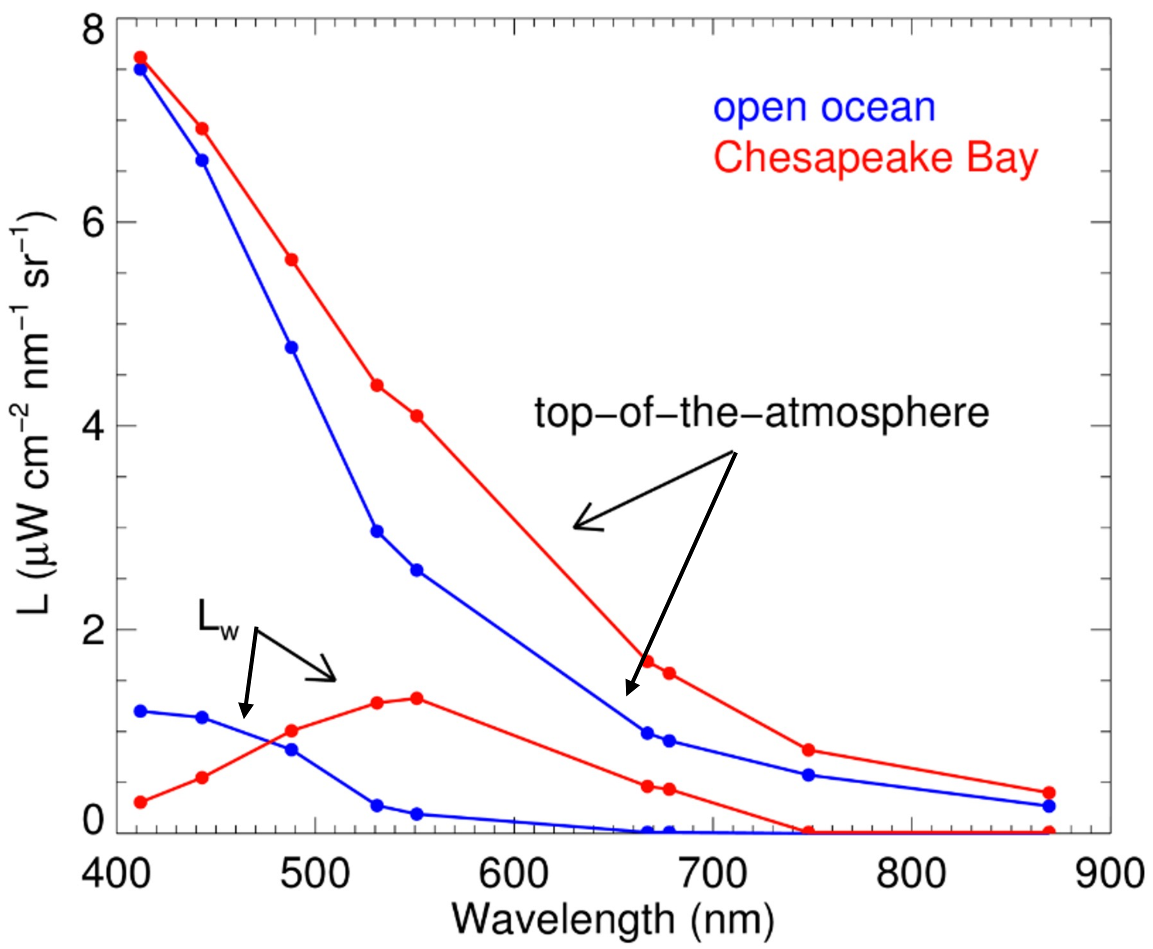
jeremy.werdell@nasa.gov

Chlorophyll Concentration and Reflectance

Reflectance is affected by the concentration of pigments in the water



Atmospheric correction



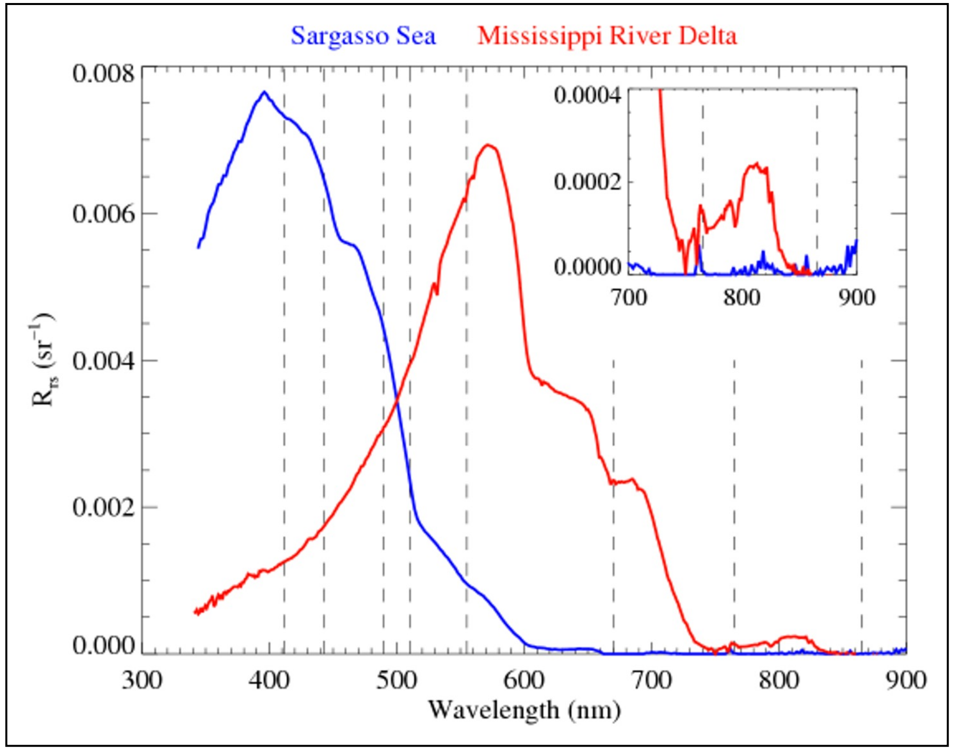
The radiance from the water signal (L_w) is often less than 10% of the total signal measured by the sensor (L)

Good atmospheric correction is critical.

jeremy.werdell@nasa.gov

Case-1 versus Case-2 waters

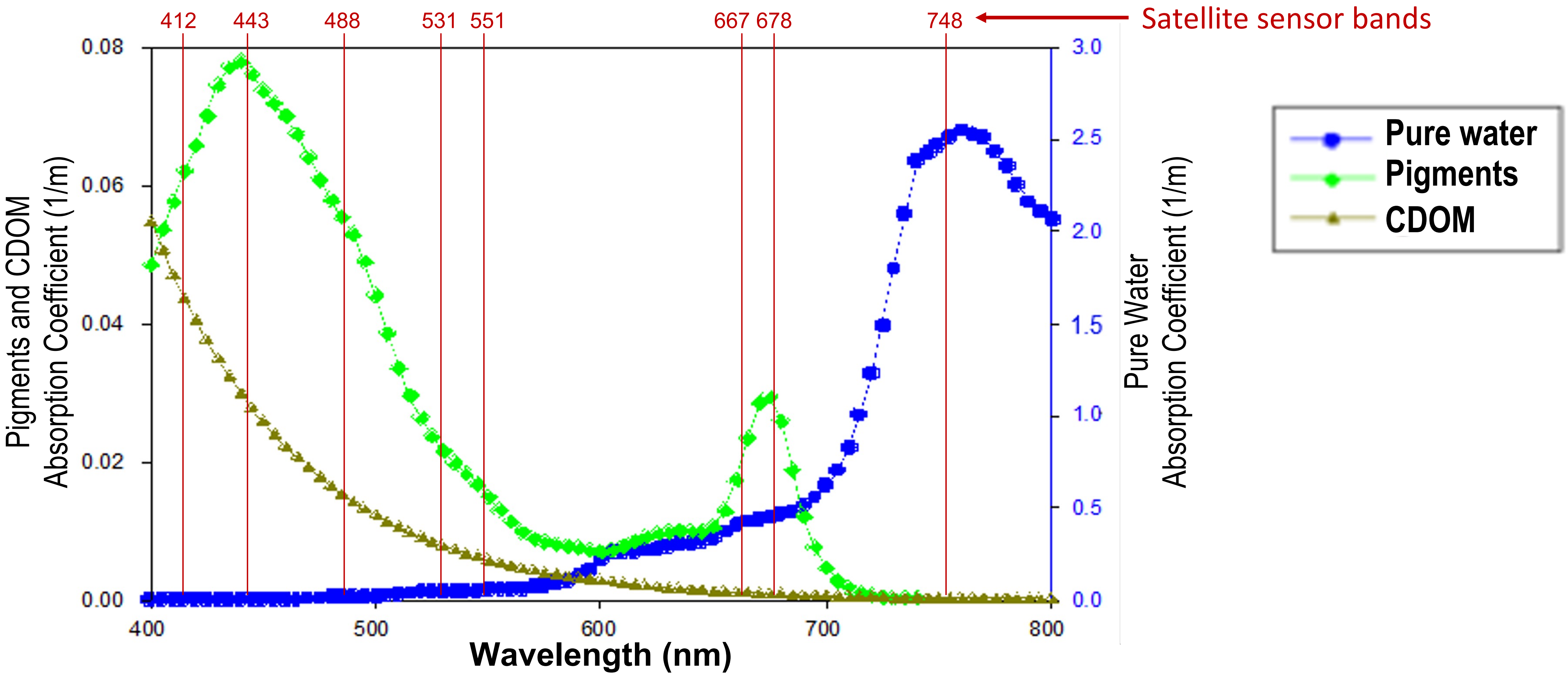
Case 1 - Open Ocean
Water where the optical properties are determined primarily by phytoplankton and their derivative products



Case 2 - Everything Else
Namely water where the optical properties are significantly influenced by other constituents, such as mineral particles, Colored Dissolved Organic Matter (CDOM), or microbubbles, whose concentrations do not covary with the phytoplankton concentration

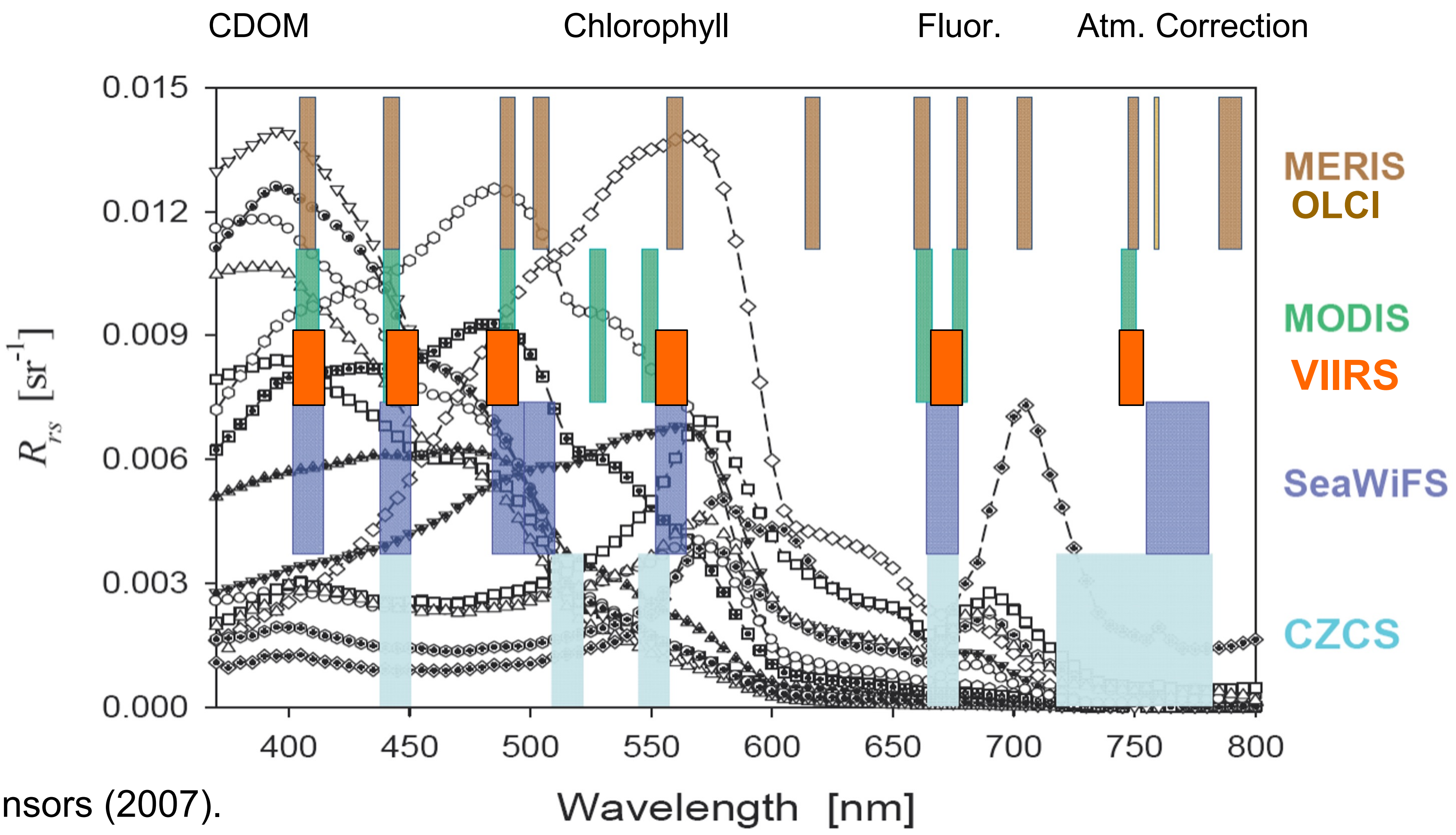
Absorption Spectra and MODIS reflectance bands

SENSOR BANDS ARE CHOSEN TO TARGET SPECIFIC PEAKS IN ABSORPTION SPECTRA



Sensor band comparison

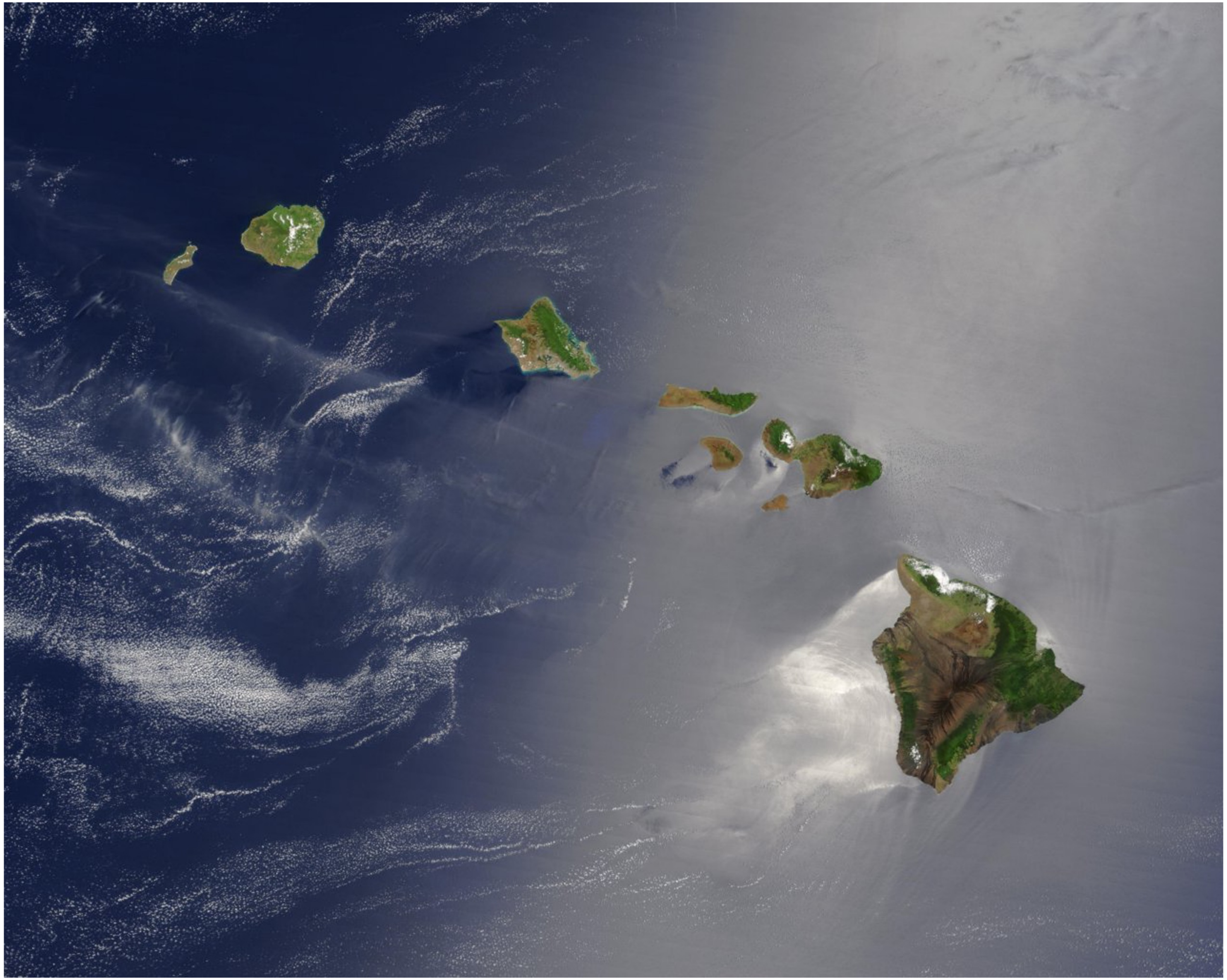
Examples of different measured spectral remote-sensing reflectance, overlain wit different sensor bands.



Modified from Lee et al., Sensors (2007).

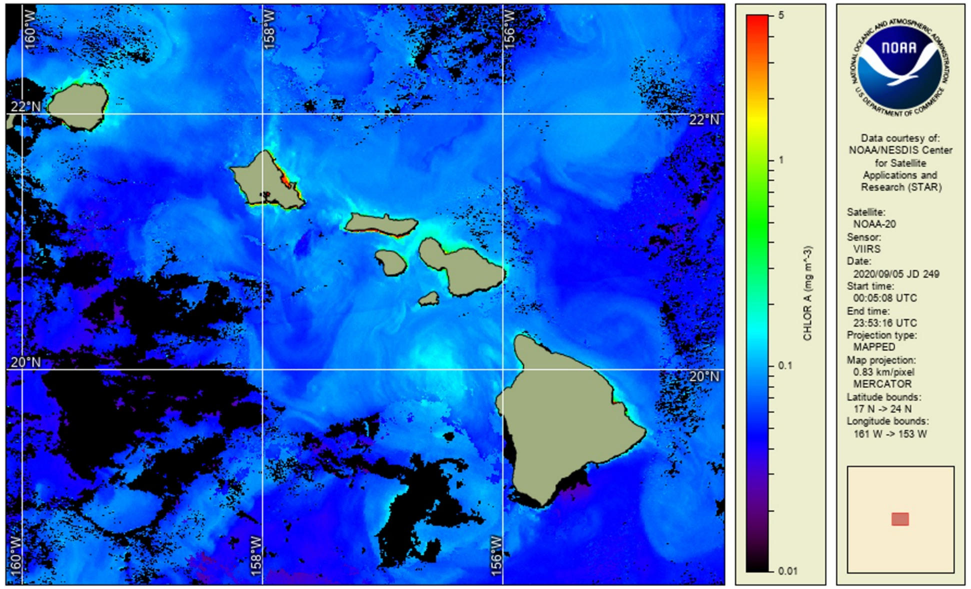
Sunglint

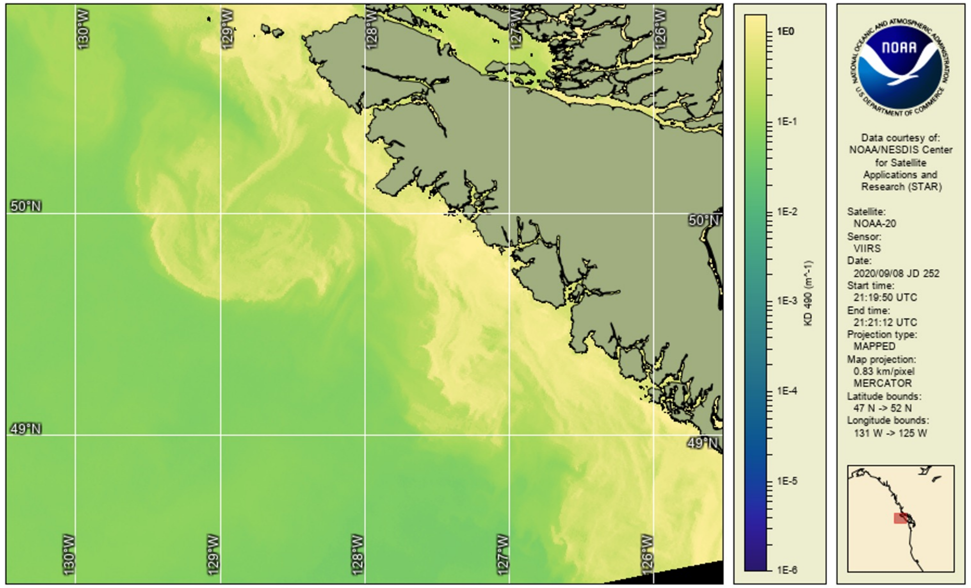
- Sunglint is the mirror reflection of sunlight off the sea surface.
- With strong sunglint the OC measurement can severely compromised, often impossible.
- However sunglint is very effective for detecting oil spills



Ocean color data products

- Normalized water-leaving (nLw) radiance at visible bands
- Chlorophyll-*a* concentration (single sensor, merged, gap-filled)
- Diffuse attenuation coefficient at 490 nm (Kd490)
- Diffuse attenuation coefficient of photosynthetically active radiation (KdPAR)
- QA score (an empirical product quality assessment available in Level-2 datasets)
- Various regional products (HAB, sediment, phytoplankton composition, primary productivity, etc)



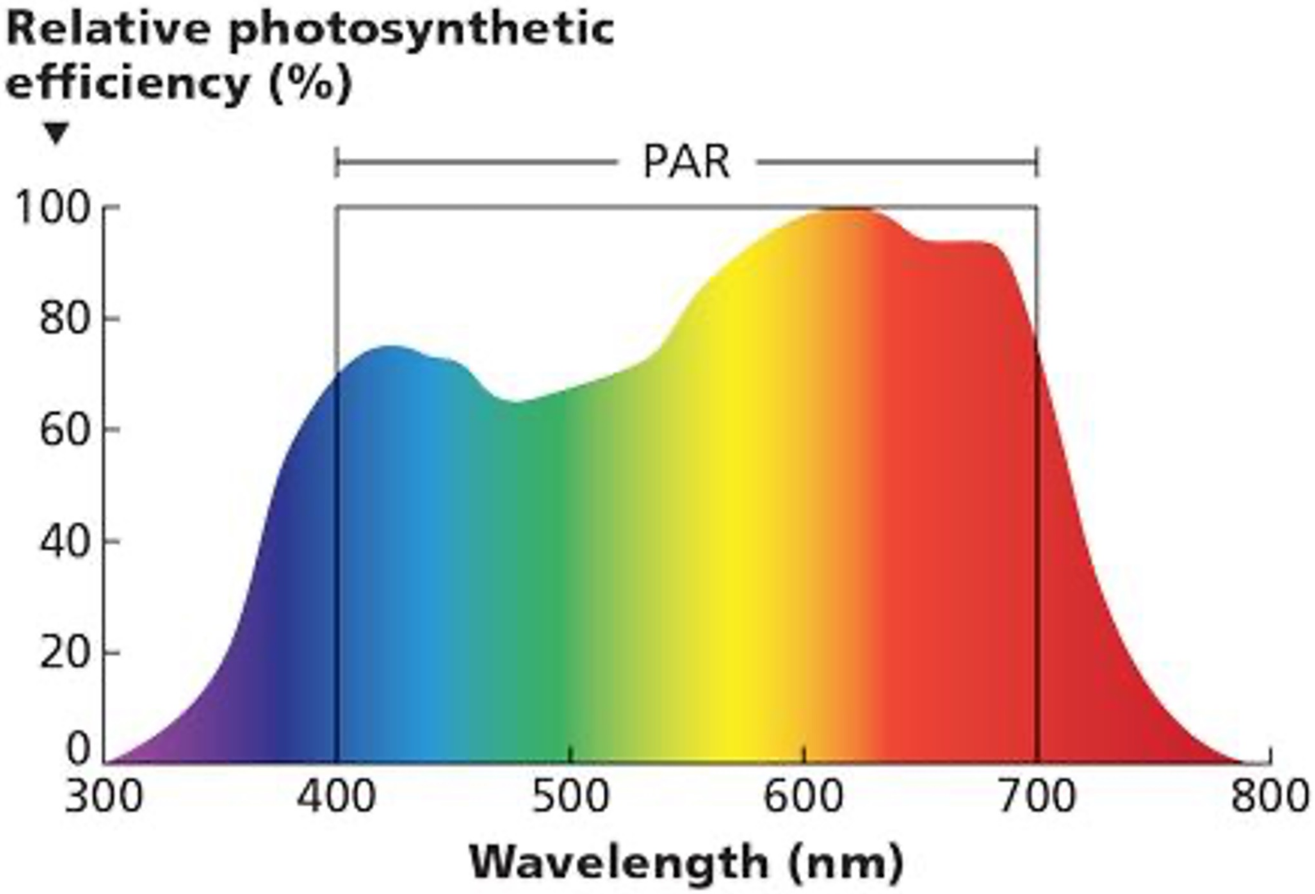


Kd490

- The diffuse attenuation coefficient is a measure of the attenuation of light in the water column.
- Kd490 is an indicator of water clarity. Particles absorb in the blue, so when there are a lot of absorbing particles in the water the attenuation at 490 nm is greater.
- Higher Kd value means smaller attenuation depth, and lower clarity of ocean water.

KdPAR

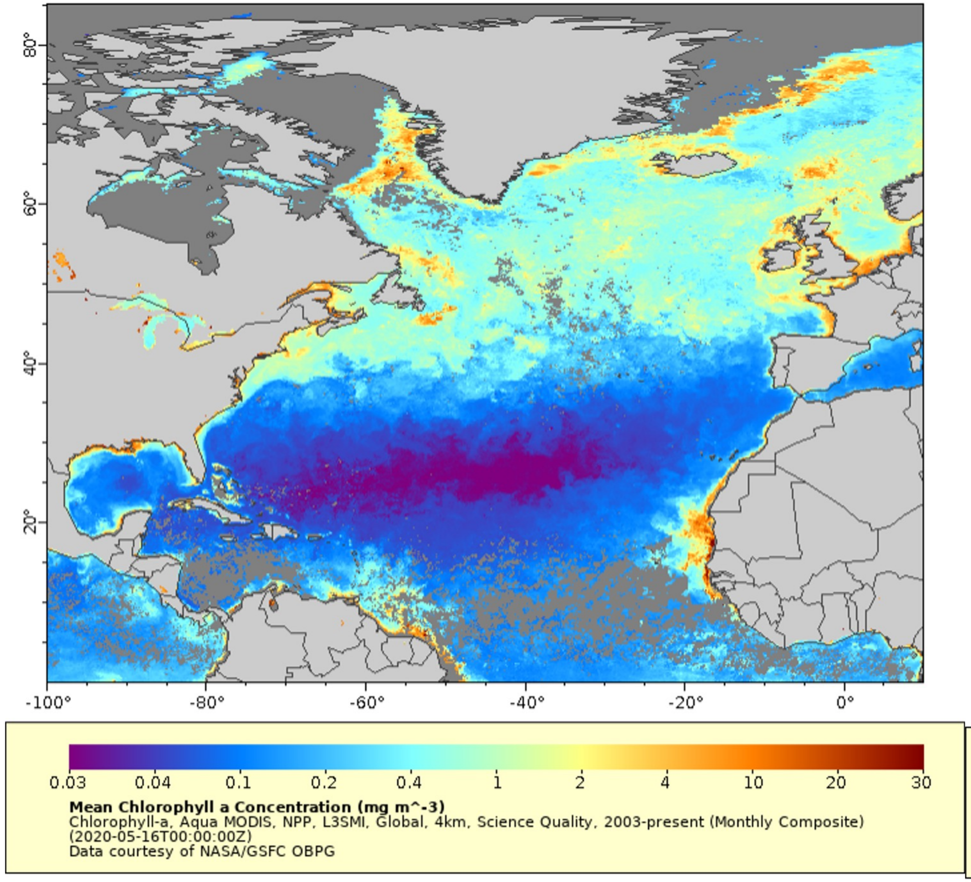
- Photosynthetically Active Radiation (PAR), is light from 400 to 700 nm, the range of wavelengths used in photosynthesis.
- With Kd490, surface PAR from satellites, and some assumptions, we can calculate PAR at depth
- PAR is a common input used in modeling marine primary productivity.
- As with Kd490, a higher KdPAR value means the visible light is attenuated more strongly as it travels through the water column, making less light available for photosynthesis.



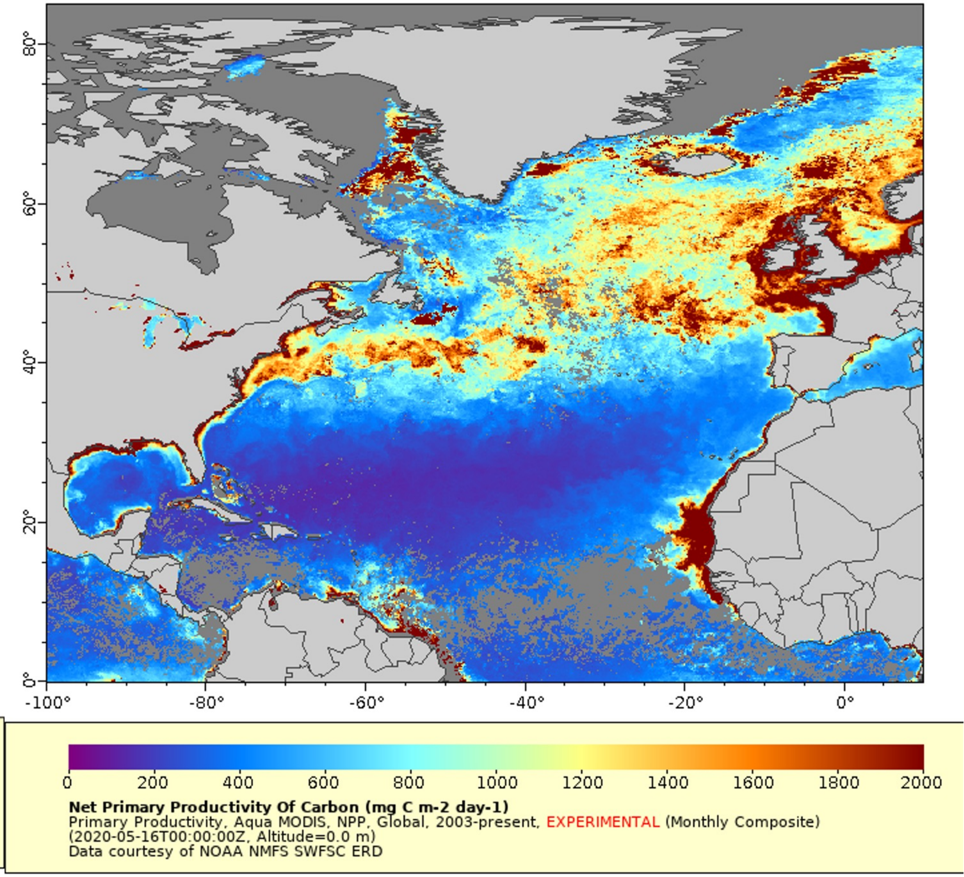
Primary Productivity (PP)

- Primary productivity is the rate of carbon fixation by the phytoplankton during photosynthesis.
- PP can be estimated globally from satellite data using chlorophyll, PAR, SST and daylength.

Chlorophyll, May 2020

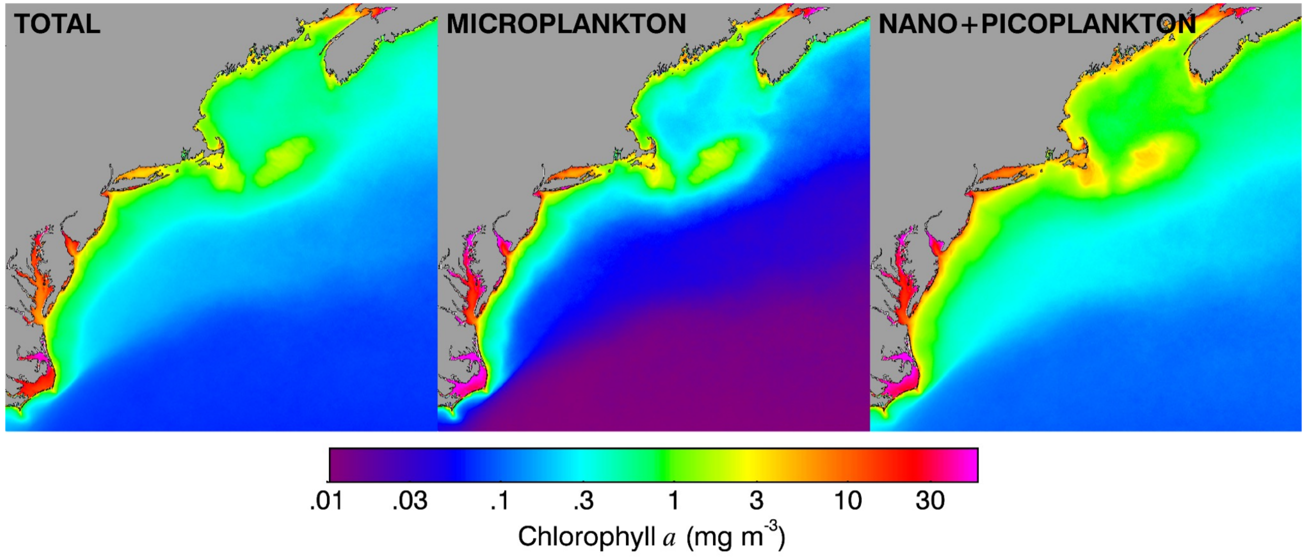


Primary Productivity, May 2020



Phytoplankton Composition

Satellite ocean color data is used to derive phytoplankton functional groups using a series of Remote Sensing Reflectance (R_{RS}) band ratio algorithms at 490, 555 and 670 nm.

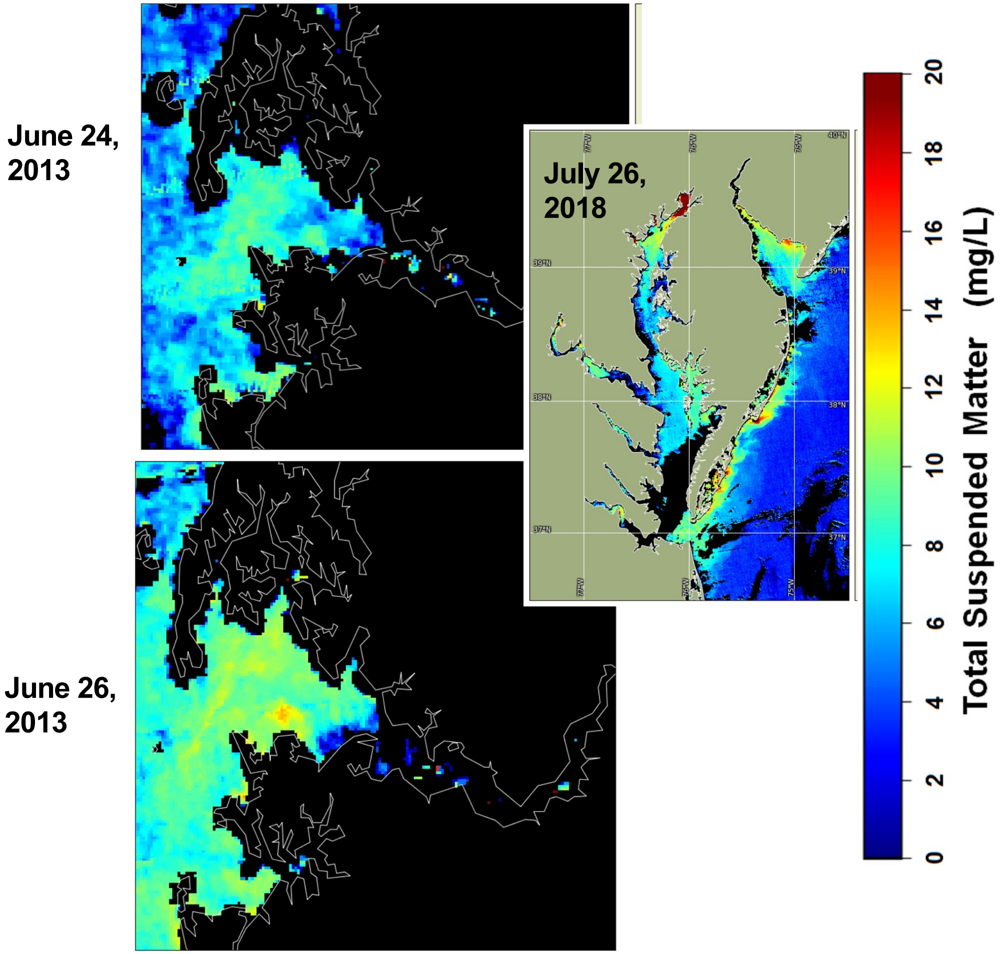


(Pan 2010 & 2011)

Kim Hyde and colleagues

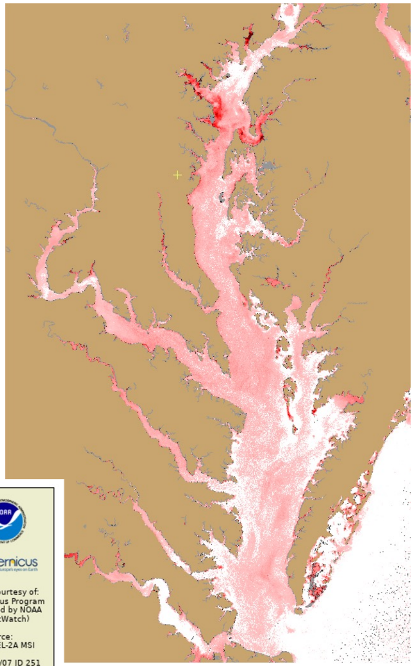
Total Suspended Matter (TSM)

- Sediment concentration (mg/L) in surface water (top 1m)
- TSM algorithm specifically developed by NOAA for Chesapeake Bay (Ondrusek et al., 2012)
- Once daily observation (from a single satellite)
  - Clouds cause missing data
- Provides spatial overview
  - Detect spatial patterns
- Monitor change over time
- 250 m spatial resolution
- Data from NASA's Aqua satellite, MODIS instrument

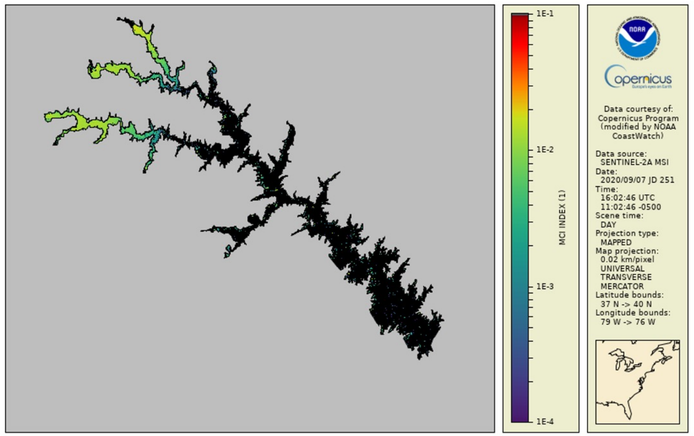


Custom Satellite-derived products for algal bloom monitoring

Relative Chlorophyll

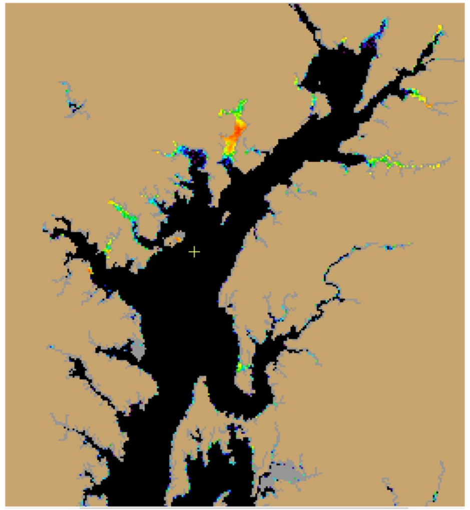


Hi-res MCI for cyanobacteria

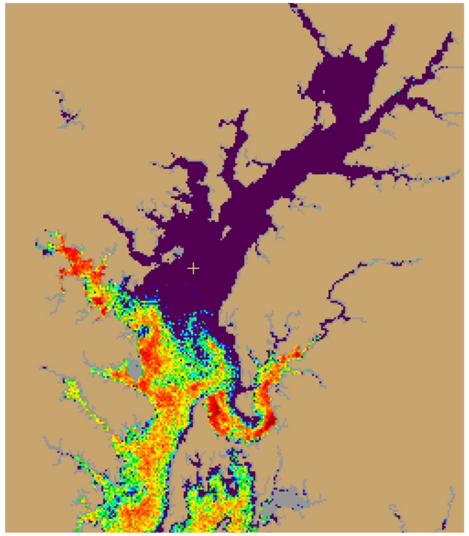


True Color

Non-Cyano Index
(chl-a with negligible
fluorescence)

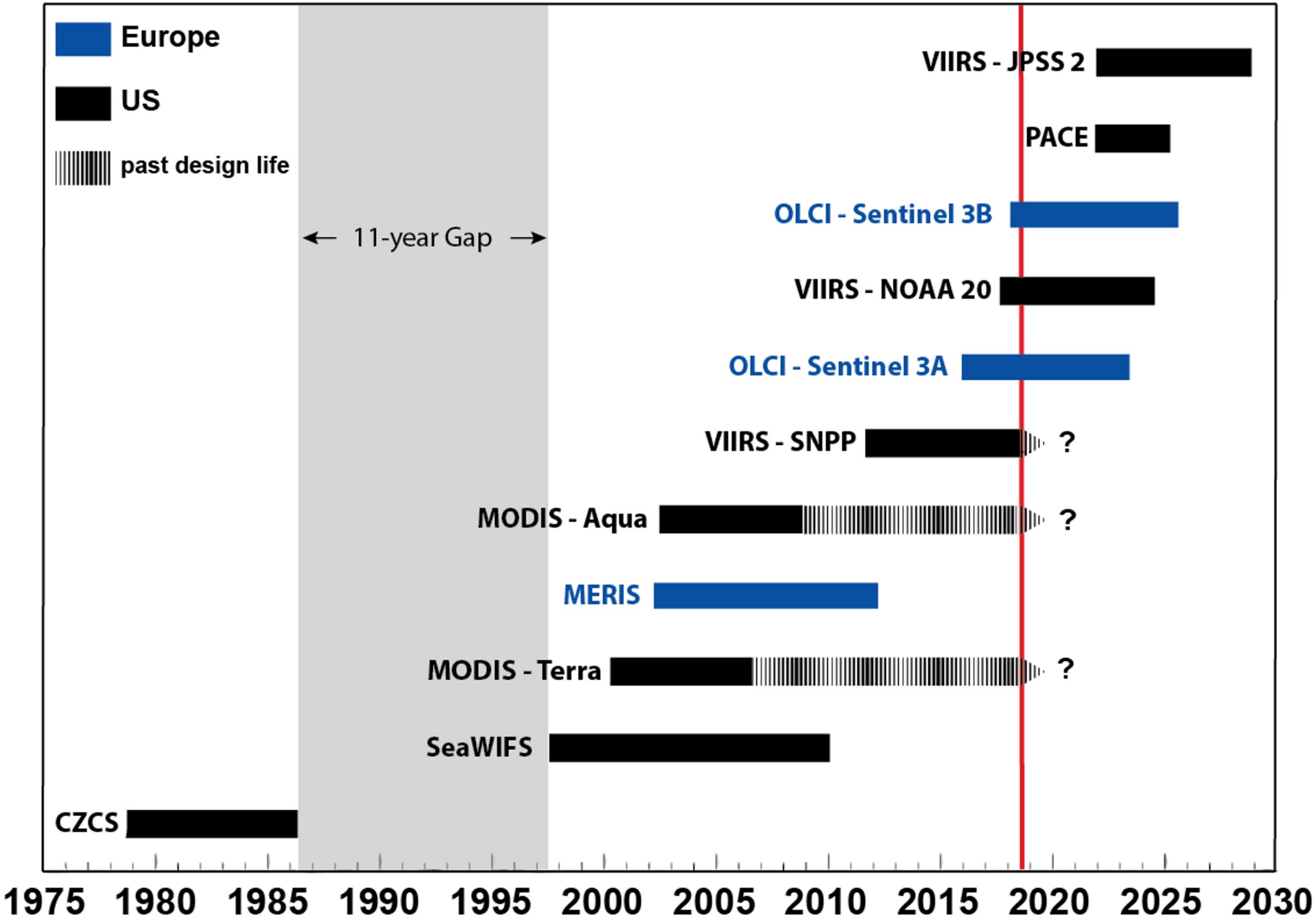


RBD
Fluorescence



Note: Imagery derived from Copernicus Sentinel data from EUMETSAT
Available from Chesapeake Bay at https://coastwatch.noaa.gov/cw_html/NCCOS.html

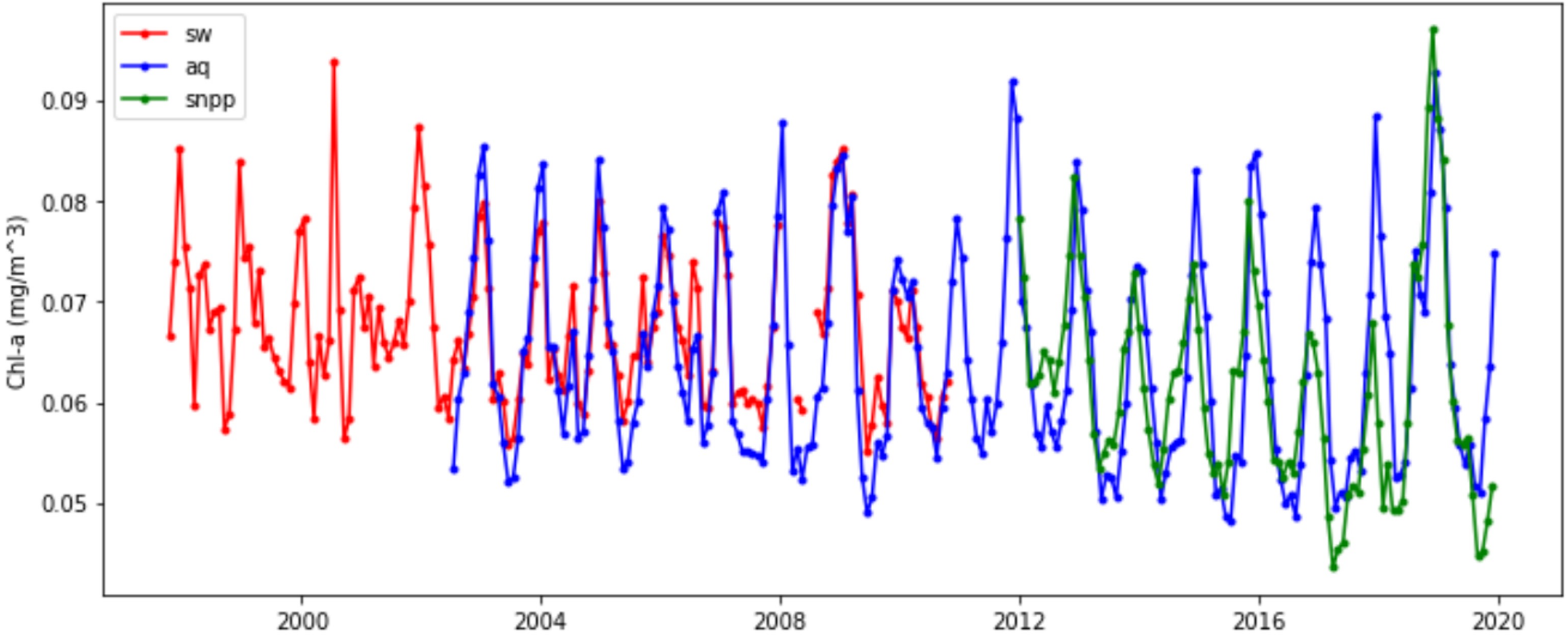
Global Ocean Color Sensors

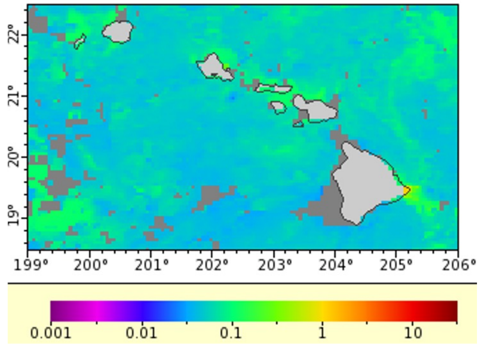


Blended Ocean Color dataset: ESA CCI dataset

- European Space Agency's Climate Change Initiative (CCI) produces merged satellite products for assessing long-term trends.
- Merged MERIS, Aqua-MODIS, SeaWiFS and VIIRS data with associated per-pixel uncertainties
- Date from 1997 through 2018.
- Daily, weekly & monthly data are available the West Coast and Central Pacific Node data servers

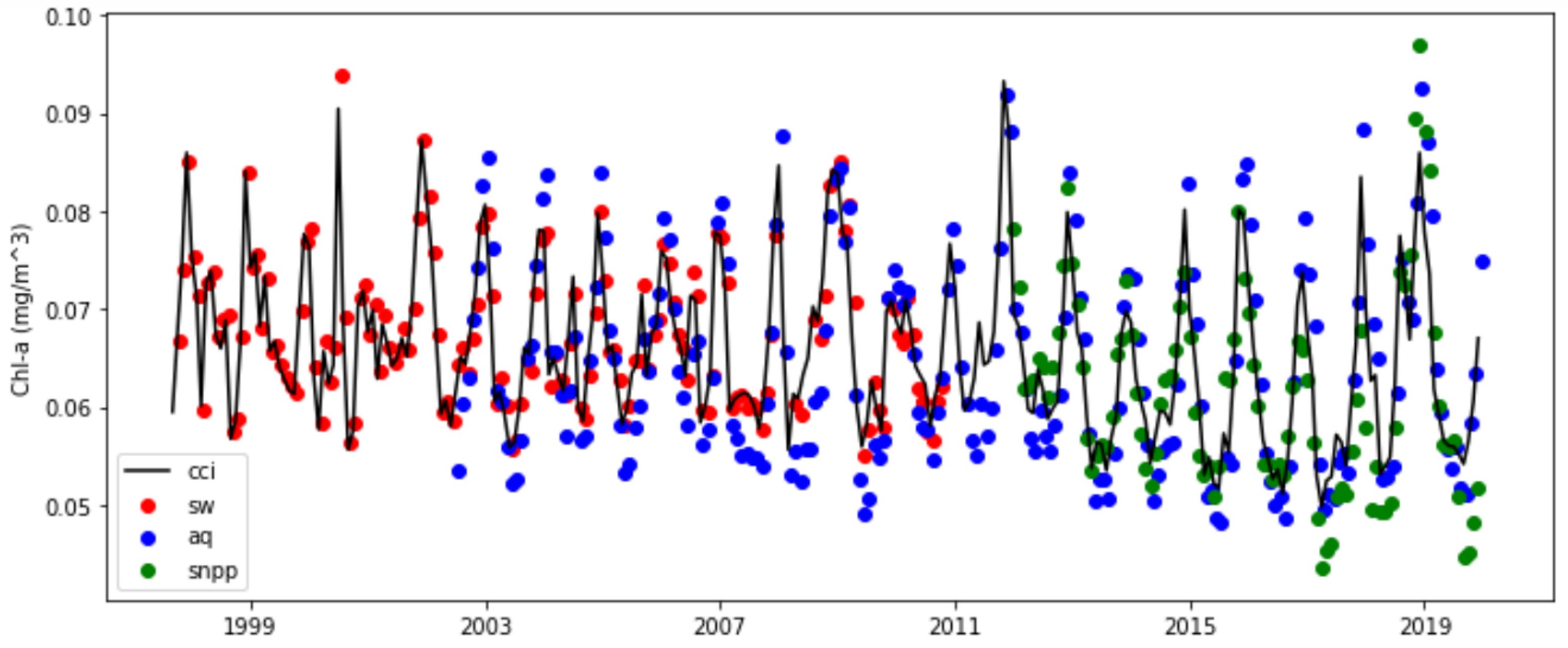
Looking at OC time-series

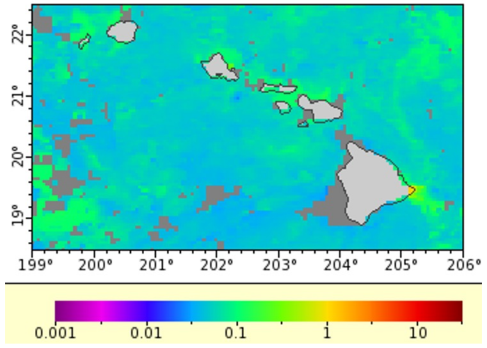




Measurements from different sensors are not always in close agreement during periods of overlap, making it challenging to study long-term trends.

Time-series of ESA CCI Dataset



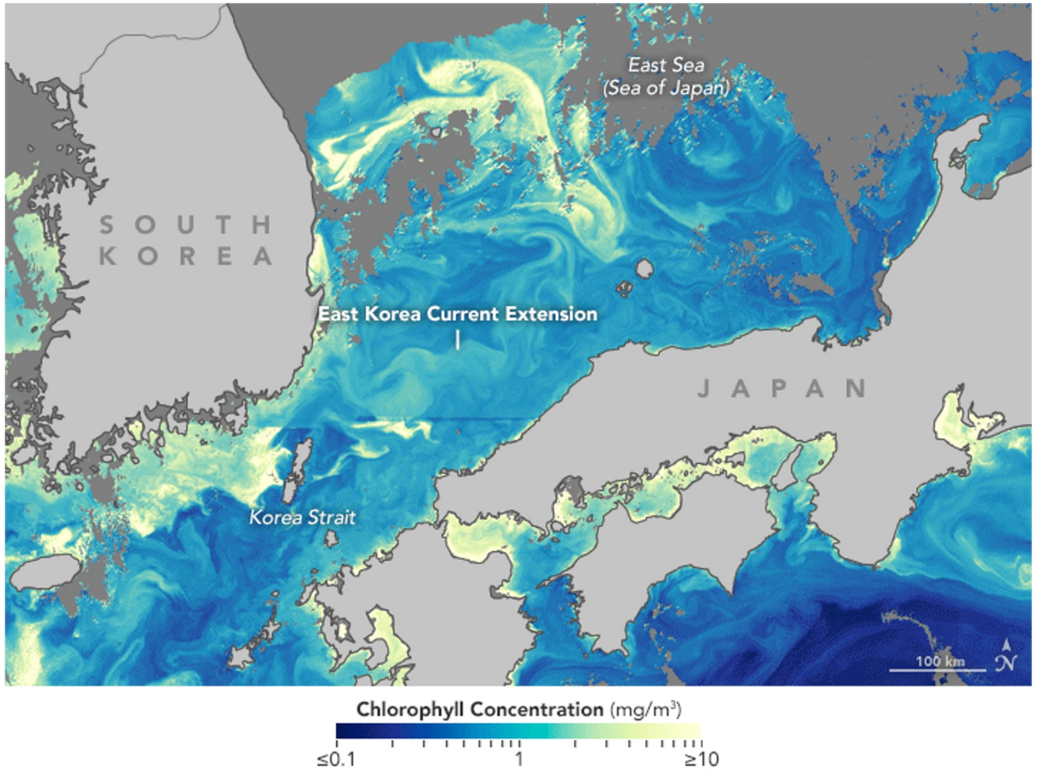


With the ESA CCI dataset overlain

Geostationary Ocean Color Sensors

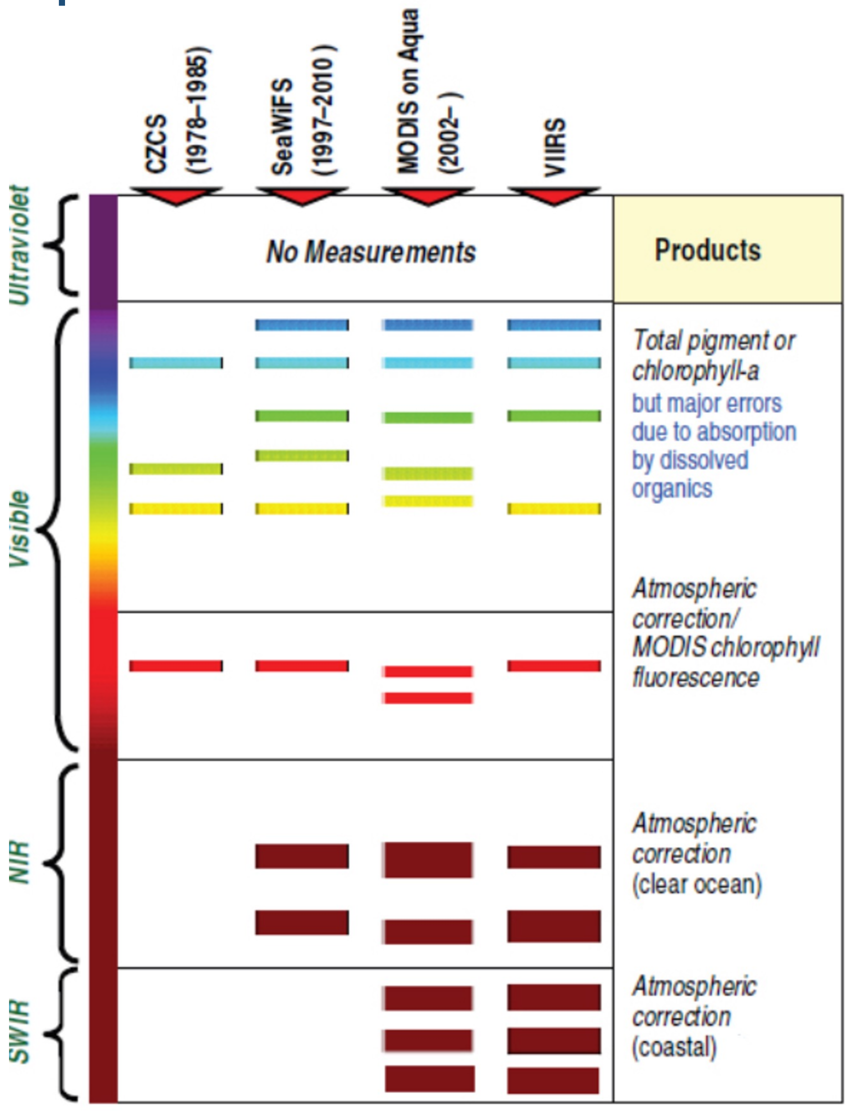
- Almost all of the OC sensors are on polar-orbiting satellites, providing one observation per day, if there are no clouds.
- GOCI is the only geo-stationary OC sensor operating. S. Korea launched it in 2010, and it only observes the region around S. Korea.
- In the US, GLIMR (Geosynchronous Littoral Imaging and Monitoring Radiometer) is planned for 2027.

A Day in the East Korea Current, from GOCI

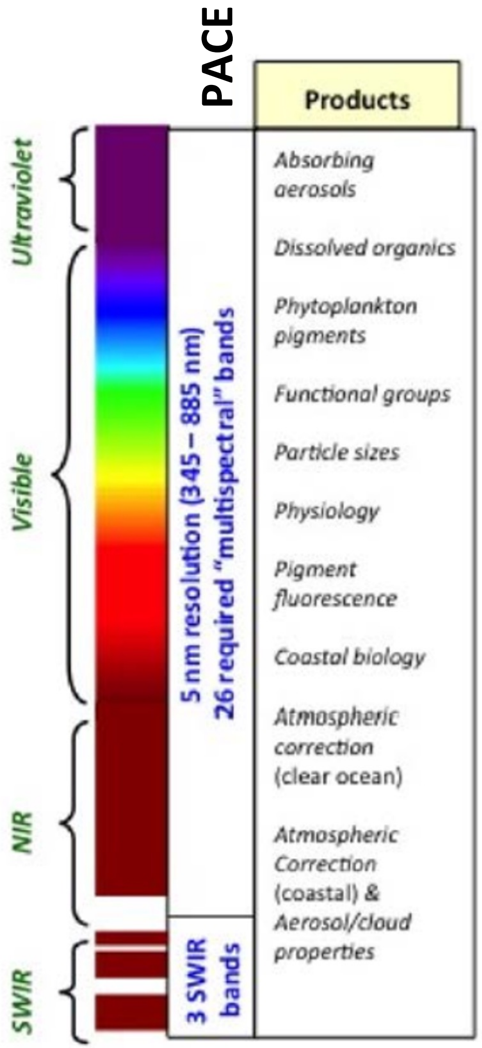


May 12, 2016
https://earthobservatory.nasa.gov

Towards hyperspectral sensors



https://pace.gsfc.nasa.gov/



Currently, Dec 2022 launch

Ocean Color Summary

Measurements are made in the visible wavelegths and can not be made through clouds or at night.

Atmospheric correction is extremely important!

There are a suite of products measured by "ocean color" satellites:

- Chlorophyll (most commonly used)
- Primary Productivity
- Water Clarity
- Photosynthetically Available Radiation (PAR)
- CDOM (Colored Dissolved Organic Matter)
- Fluorescence,
- and more

Algorithms were developed for Case-1 (open ocean) waters.

- Care must be taken when using data from Case-2 (coastal) waters.

The most recently launched U.S. OC sensors are VIIRS

- Joint NASA/NOAA missions were launched Oct. 2011 (SNPP) and Nov 2017 (NOAA-20)

Primary US satellites: • SeaWiFS 1997-2010 • MODIS/Aqua 2002- 2016-present • VIIRS 2011- 2016-present

European satellites: • MERIS 2002-2012 • OLCI April 2016-present

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
- Introduction to ERDDAP
- What Dataset to Choose?
- Bringing Satellite Data into ARCGIS