National Aeronautics and Space Administration

Monitoring Coastal and Estuarine Water Quality: Transitioning from MODIS to VIIRS

Overview of Remote Sensing Observations for Water Quality Monitoring in Estuaries

Amita Mehta, Juan Torres-Pérez, Sean McCartney

September 14, 2021

Training Objectives

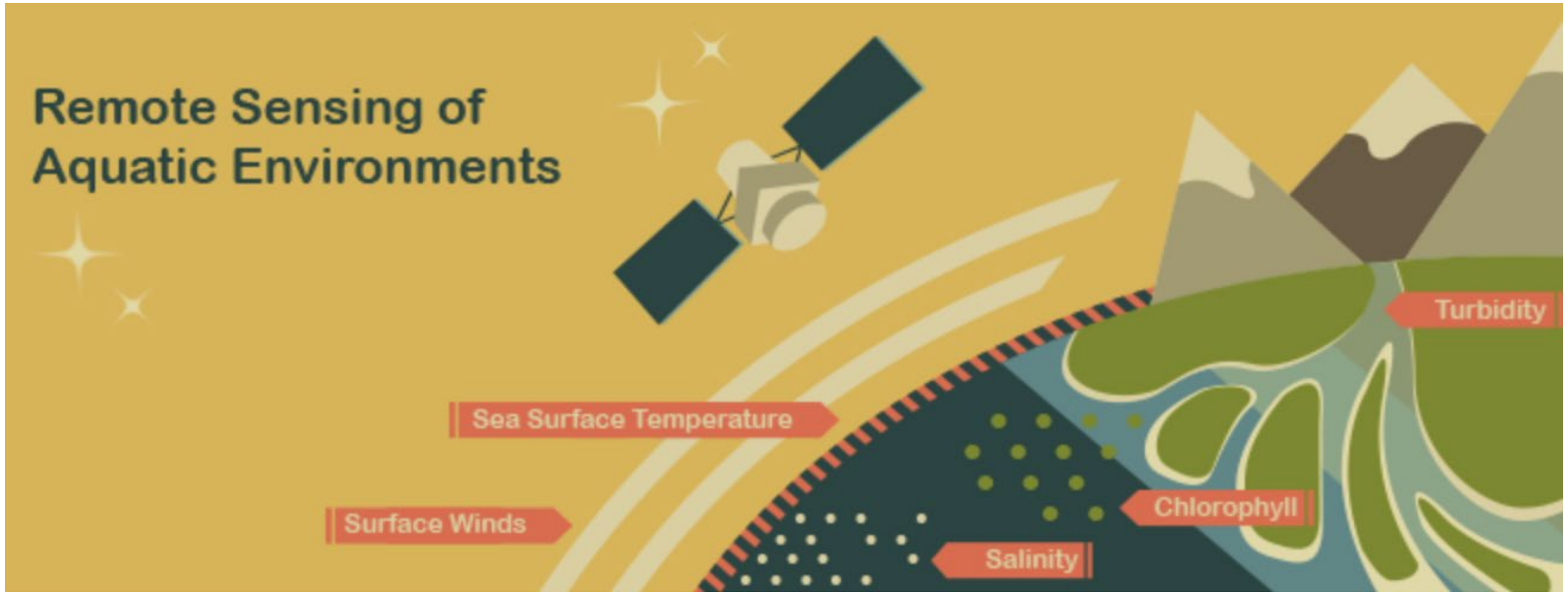
After participating in the training, attendees will be able to:

- Recognize the importance of coastal and estuarine waters and why they should be monitored for water quality
- Give examples of water quality indicators that satellites can observe
- Identify current satellite data that is useful for water quality monitoring
- Process MODIS[1] and VIIRS[2] imagery using SeaDAS[3] to obtain water quality parameters
- Apply the techniques for water quality monitoring in coastal and estuarine regions

[1]MODIS: Moderate Resolution Imaging Spectroradiometer
[2]VIIRS: Visible Infrared Imaging Radiometer Suite
[3]SeaDAS: SeaWiFS Data Analysis System

Prerequisites

- Fundamentals of Remote Sensing, Session 2C: *Fundamentals of Aquatic Remote Sensing*
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-fundamentals-remote-sensing



Training Outline

Three 1.5-hour sessions offered in both English and Spanish

Overview of Remote Sensing Observations for Water Quality Monitoring in Estuaries

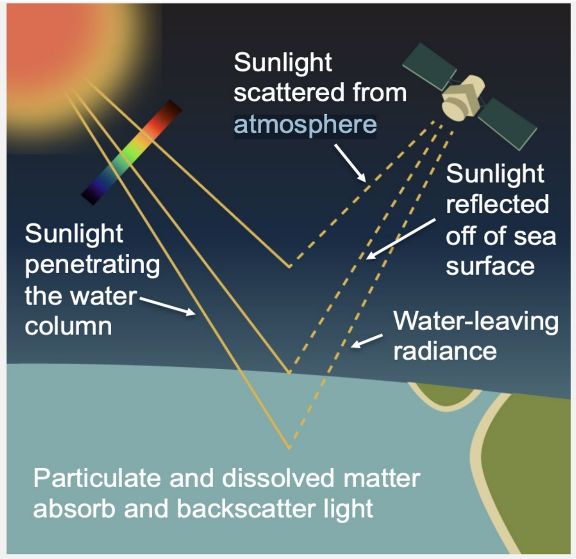


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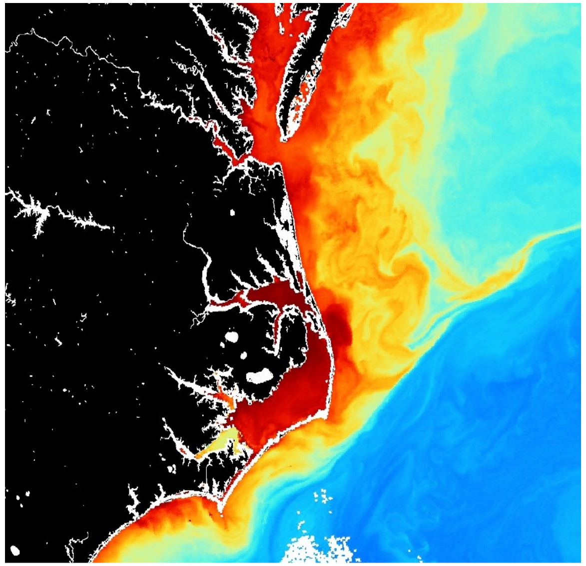
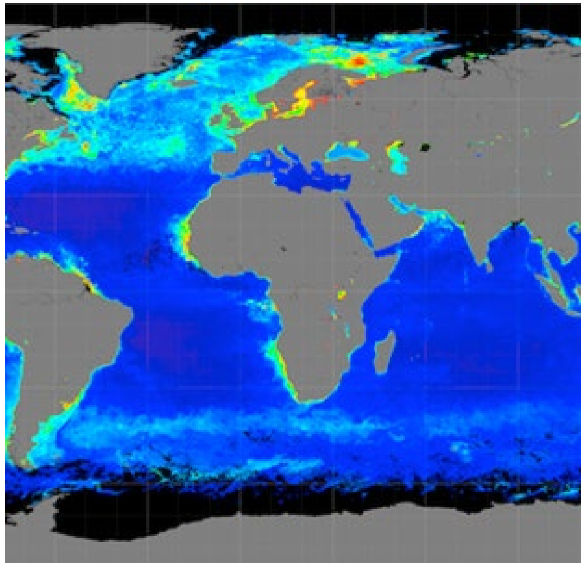
Image Processing using SeaDAS



September 16, 2021

Monitoring MODIS- and VIIRS-Based Water Quality



September 21, 2021

ARSET Water Quality Trainings

- Remote Sensing of Coastal Ecosystems:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-remote-sensing-coastal-ecosystems
- Integrating Remote Sensing into a Water Quality Monitoring Program:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-integrating-remote-sensing-water-quality-monitoring-program
- Introduction to Remote Sensing of Harmful Algal Blooms:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-remote-sensing-harmful-algal-blooms
- Introduction to Remote Sensing for Coastal and Ocean Applications:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-remote-sensing-coastal-and-ocean-applications

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Homework will be made available on September 21, 2021.
  - Due date for homework: October 5, 2021.
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Outline for Session 1

- About ARSET
- Background: Coastal and Estuarine Water Quality
- Remote Sensing of Water Quality
- Current Satellites and Sensors Relevant for Monitoring Water Quality
- Demonstration of MODIS and VIIRS Data Acquisition

Credit: NASA

About ARSET

- *ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.*
- Our trainings are:
  - Online and *in-person
  - Open to anyone
  - Live, instructor-led or self-guided
  - Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

*ARSET is not currently offering in-person trainings due to the COVID-19 pandemic.

- ARSET offers trainings for:
  - Disasters
  - Health & Air Quality
  - Land Management
  - Water Resources

For more information, visit appliedsciences.nasa.gov/arset

APPLIED REMOTE SENSING TRAINING PROGRAM
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Background: Coastal and Estuarine Water Quality

Coastal Waters

- The interface between terrestrial environments and open oceans
- Connected to terrestrial waters – estuaries and bays, sounds, harbors, rivers, and inlets
- Not classified as freshwater or open water
- Includes upwelling areas

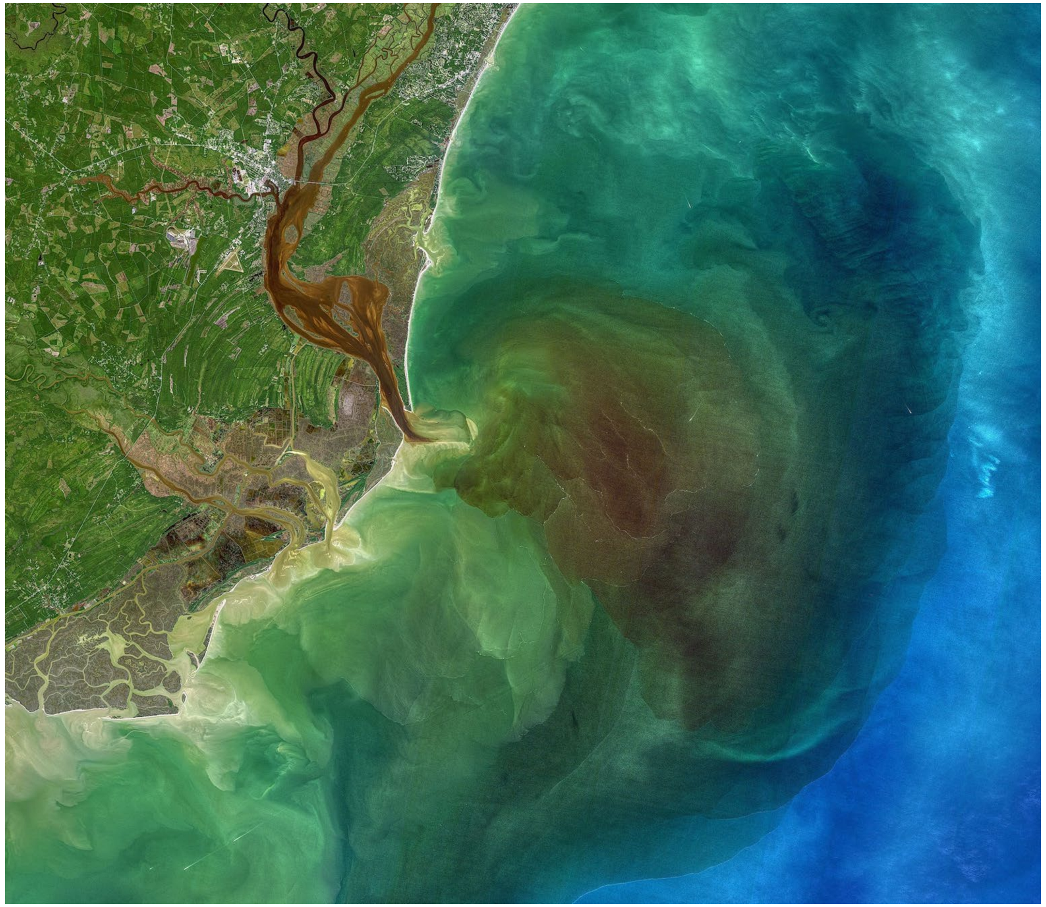
Credit: UGA

https://www.epa.gov/report-environment/coastal-waters

https://www.lawinsider.com/dictionary/coastal-waters

Estuaries

- A partially enclosed, coastal water body where freshwater from rivers and streams mixes with salt water from the ocean.
- A transition from land to sea, influenced by the tides but protected from the full force of ocean waves, winds, and storms by landforms.



Credit: NASA

Coastal and Estuarine Regions

- Support a variety of habitats, including:
  - Shallow, open waters, river deltas, tidal pools
  - Freshwater & saltwater marshes and swamps
  - Sandy beaches and rocky shores
  - Mud and sand flats
  - Seagrass meadows
  - Mangrove forests
  - Coastal wetlands
  - Kelp forests
  - Coral reefs
  - Oyster reefs

A unique mix of marine and terrestrial species lives in mangal ecosystems. (Photo: Jobos Bay National Estuarine Research Reserve. Credit: NOAA)

Global Coastal and Estuarine Regions

- Canada has the longest coastline in the world.
- There are about 1,300 estuaries globally (UNEP-WCMC).
- These regions play a very important role in the global economy.

Rank	Country	Coastline (Kilometers)
1	Canada	202,080
2	Indonesia	99,083
3	Norway	58,133
4	Russia	37,653
5	Philippines	36,289
6	Japan	29,751
7	Australia	25,760
8	United States	19,924
9	New Zealand	15,134
10	China	14,500

Rank	Country	Coastline (Kilometers)
11	Greece	13,676
12	United Kingdom	12,429
13	Mexico	9,330
14	Italy	7,782
15	India	7,516
16	Brazil	7,491
17	Denmark	7,314
18	Turkey	7,200
19	Chile	6,435
20	Federated States of Micronesia	6,112

https://www.worldatlas.com/articles/countries-with-the-most-coastline.html

Importance of Coastal and Estuarine Regions

- Provide a habitat and breeding ground for thousands of species, including commercially important ones
- Provide coastal protection against wave action
- Provide sustenance for millions of people worldwide
- Conservation/cultural heritage
- Recreational areas

Image Credit: Juan Torres-Pérez, NASA

Why Monitor Estuarine Water Quality (WQ)?

- Estuarine ecosystems are sensitive to a delicate balance between freshwater and saltwater.
- The physical, chemical, and biological indicators of estuarine water quality are constantly in flux.
- Degrading water quality (WQ) endangers aquatic plants, animals, and marine organisms.
- Monitoring WQ allows us to understand how to mitigate the impacts of land use change, eutrophication, and contamination in estuarine systems.

https://nerrssciencecollaborative.org/water-quality

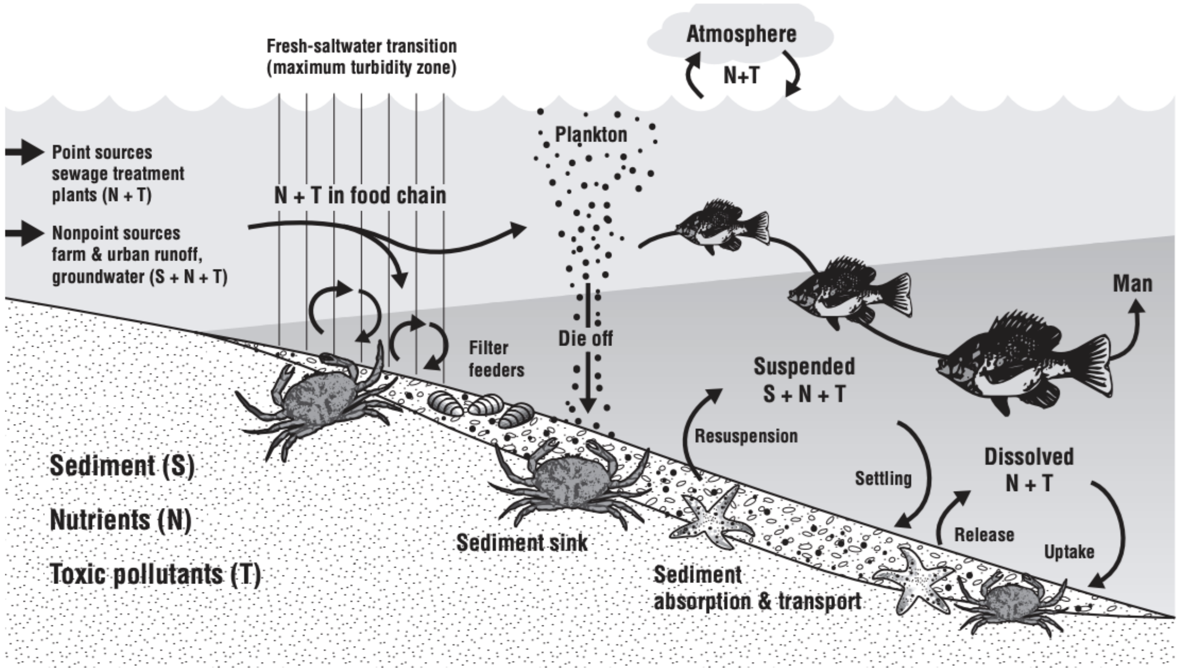


Figure 2-4. Schematic diagram of physical, chemical, and biological processes interacting in estuaries *(redrawn from USEPA, 1987).*

https://www.epa.gov/sites/default/files/2015-09/documents/2009_03_13_estuaries_monitor_chap2.pdf

Monitoring Water Quality in Coastal/Estuarine Regions

- Increasing nutrients and sediments in coastal water is a major concern, as it leads to low dissolved oxygen in the water – hypoxia – a major cause of destruction of benthic organisms and fish.
- Estuarine WQ indicators include:
  - Water Temperature and Salinity (pH)
  - Dissolved Oxygen
  - Nitrogen and Phosphorus
  - Chlorophyll-a Concentration
  - Turbidity

Coastal Hypoxia and Eutrophication

https://gulfhypoxia.net/about-hypoxia/

https://gwri.gatech.edu/sites/default/files/files/docs/2011/5.1.2Sheldon.pdf

Major Factors Affecting Coastal/Estuarine Water Quality

Local Factors:

- Coastal Runoff
- Mechanical Damage
- Illegal Dumping of Waste
- Plastics and Chemicals
- Introduction of Invasive Species

Image Credit: (Left) Juan L. Torres-Pérez, NASA; (Right) Tom Moore, NOAA

Major Factors Affecting Coastal/Estuarine Water Quality

Climate:

- Occurrence of extreme events
- Sea level rise
- Ocean acidification
- Sea surface and global temperatures
- Changes in ocean currents
- New and/or increased diseases

Bleached Coral; Credit: Juan L. Torres-Pérez, NASA

Pollution resulting from Hurricane Florence in North Carolina (September 2018)

https://www.newsweek.com/pollution-hurricane-florence-so-bad-you-can-see-it-space-1137656

Examples of Some *In Situ* Water Quality Observations

- Water Temperature
- Salinity
- Dissolved Oxygen
- Alkalinity
- pH
- Color
- Nutrients (e.g., Nitrogen)
- Tests for Specific Pollutants (e.g., Industrial Organic Compounds)
- Heavy Metals
- Colored Dissolved Organic Matter (CDOM)
- Suspended Solids - Turbidity
- Bacteria (e.g., *E. Coli*)
- Water Clarity
- Cyanobacteria
- Pathogens and Pathogen Indicators
- Algae-Produced Toxins
- Plastic Microbeads
- Chlorophyll
- Chlorophyll Anomaly
- Algal Pigments

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Remote Sensing of Water Quality

Why Use Satellite Remote Sensing for Monitoring Water Quality?

- Regular and consistent observations over a large area
- Consistent revisit rate for well-structured time series analyses
- Large number of data products available
- Complements *in situ* sampling
- Mostly free and open access

Sampling Sites

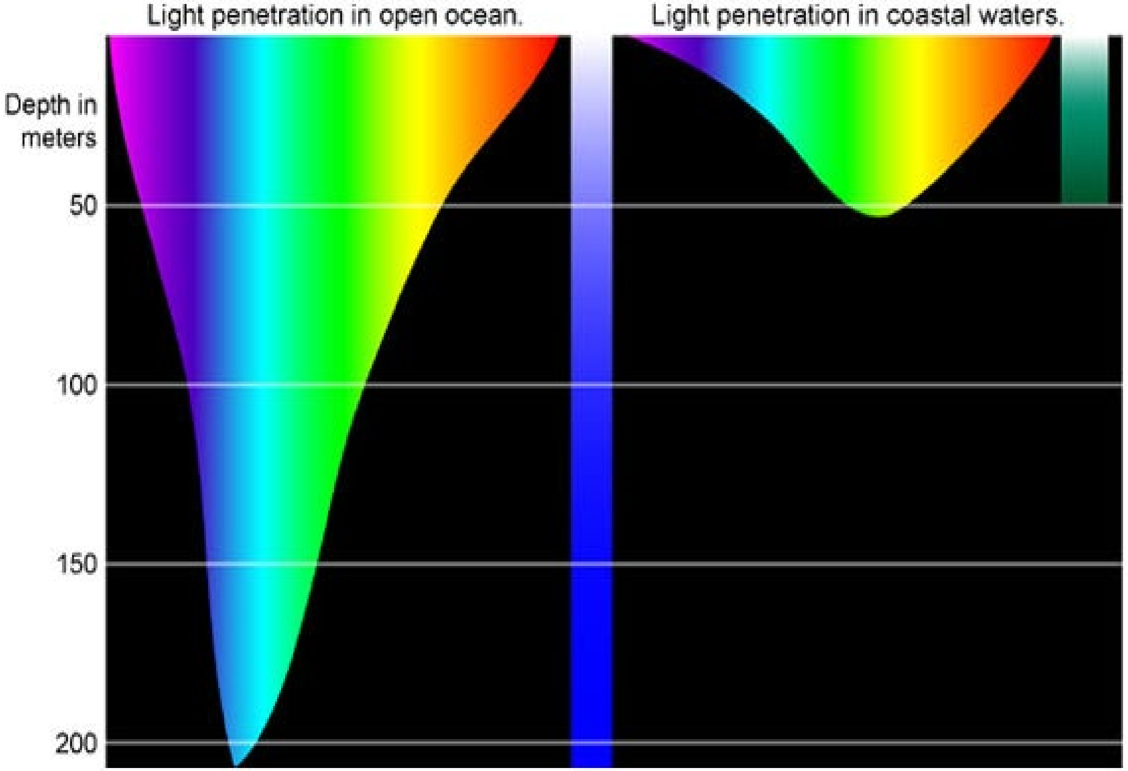
NASA Earth Observatory

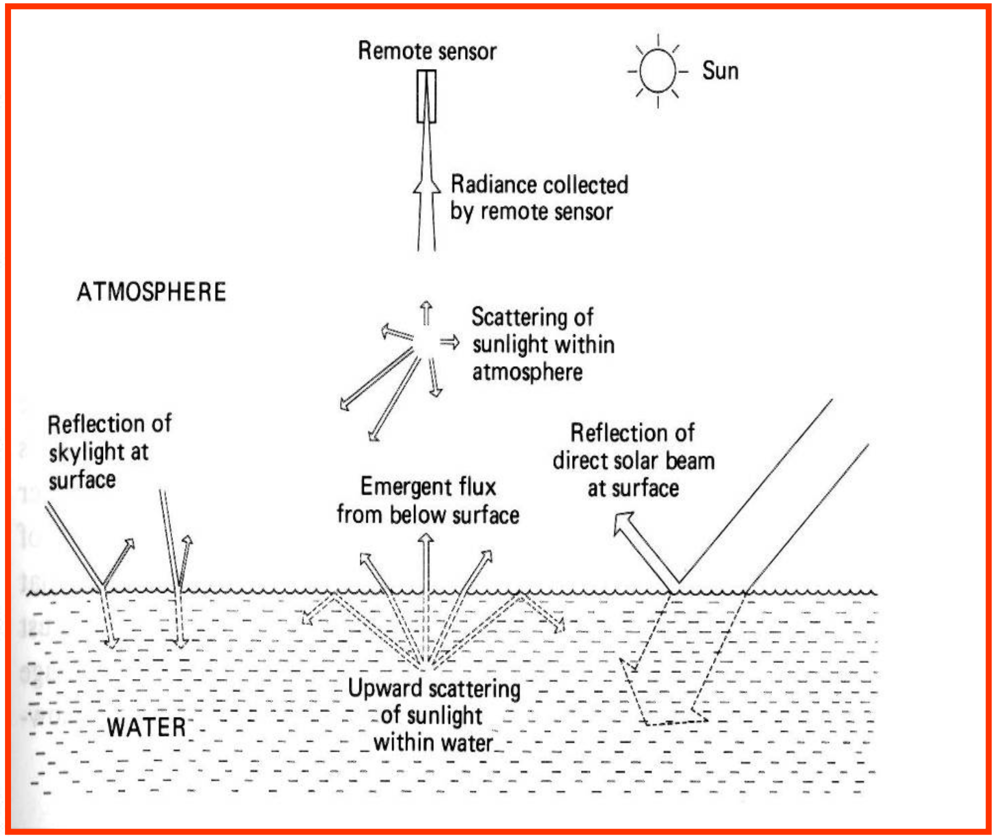
How *In Situ* and Satellite Observations Roughly Correspond

In Situ	Satellite
Water Temperature	Sea Surface Temperature (SST)
Colored Dissolved Organic Matter (CDOM)	Absorption by CDOM (a_{dg})
Suspended Solids – Turbidity	Diffuse Attenuation of Light at 490 nm (K_d)
Water Clarity	Chlorophyll-a, Normalized Fluorescence Line Height (nFLH)
Cyanobacteria	Cyanobacteria Index (CI)
Algal Pigments	Euphotic Zone Depth (Z_{eu}) Experimental Phytoplankton Functional Type Algorithms

Water Quality Affects Water Optical Properties

Natural water contains material that is optically active. Monitoring light reflectance from the water surface with remote sensing can indicate the quality of the water.





How Light Interacts with Water

Remote Sensing Reflectance (Rrs) or Ocean Color

$$\mathrm{Rrs}\left(\lambda,0^{+}\right) \cong C\,\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)} = \frac{L_w(\lambda)}{E_d\left(\lambda,0^{+}\right)}$$

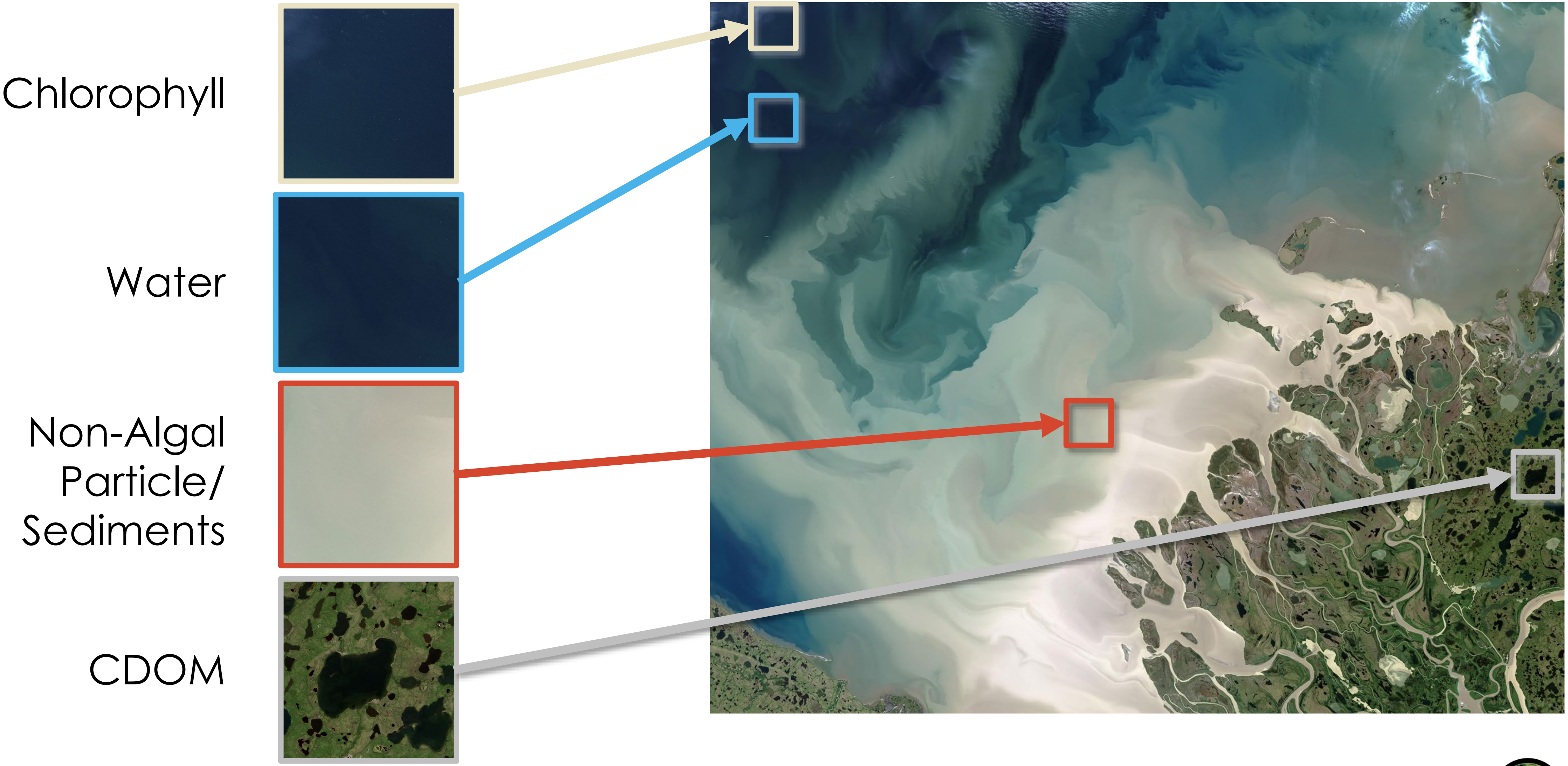
Inherent Optical Properties:

- *a* = Absorption by…
  - Phytoplankton (ph)
  - Non-Algal Particles (nap)
  - Colored Dissolved Organic Matter (CDOM)
  - Water (w)
- *b* = Scattering in forward (f) and backward (b) directions

Apparent Optical Properties:

- L_w = Water Leaving Radiance
- L_u = Upwelling Radiance
- E_d = Downwelling Irradiance
- R_{rs} = Remote Sensing (rs) Reflectance

Inherent Optical Properties (IOPs) and the 'Color' of Water



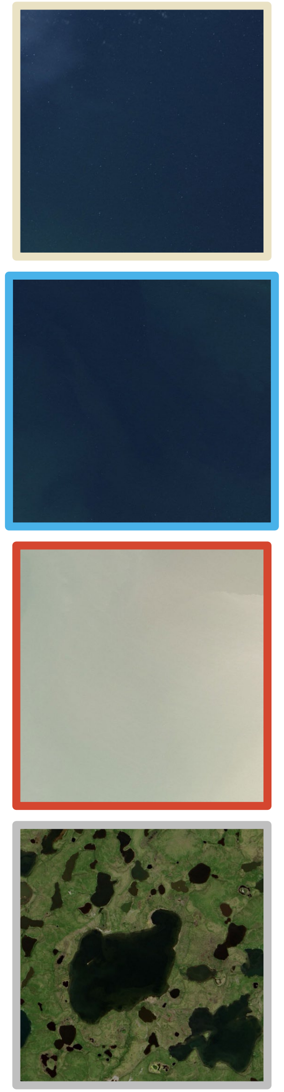
Inherent Optical Properties (IOPs) and the 'Color' of Water

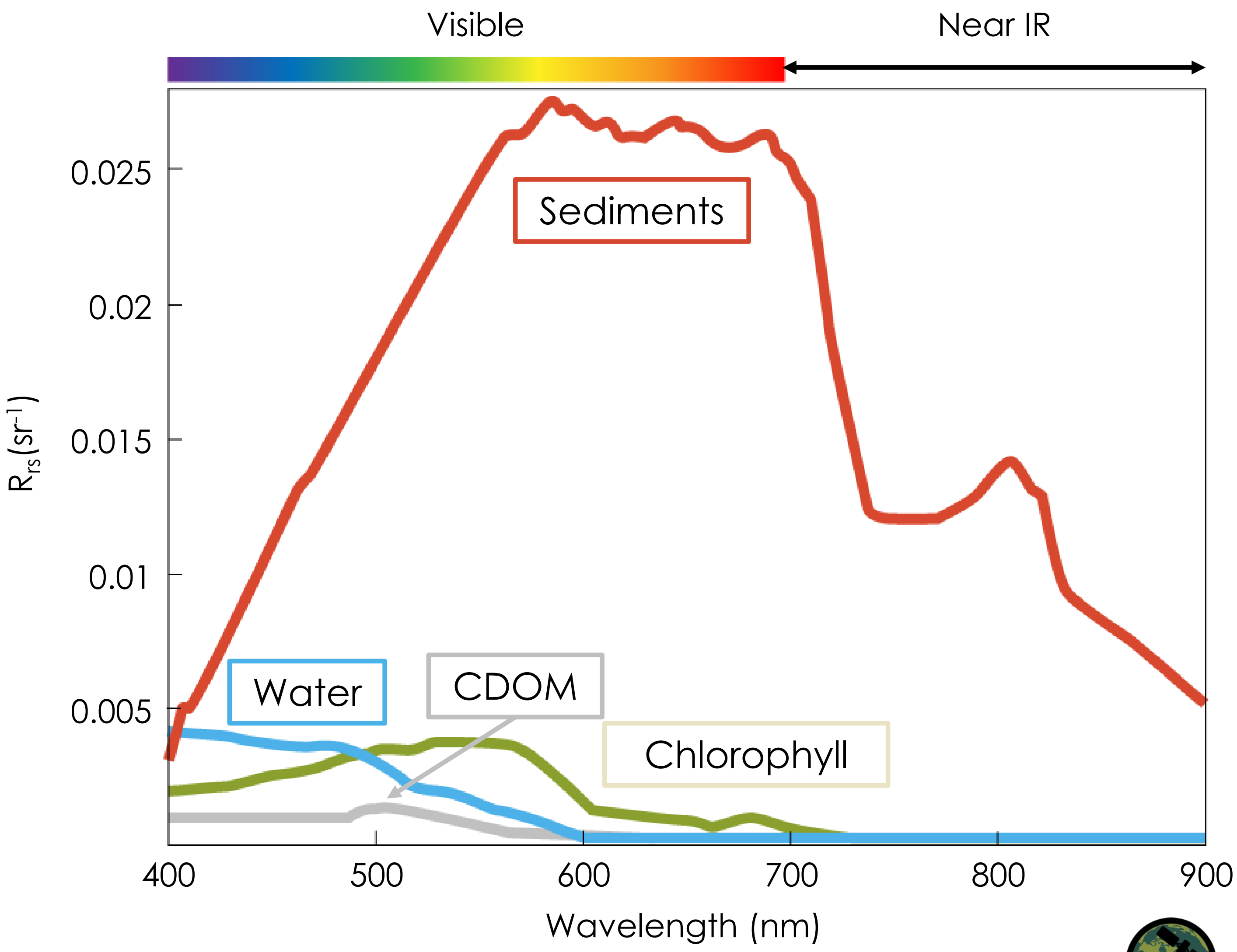
Chlorophyll

Water

Non-Algal Particle/ Sediments

CDOM





Some Water Quality Indicators Satellites Can Observe

- Colored Dissolved Organic Matter (CDOM)
- Sea Surface Temperature (SST)
- Chlorophyll-a (Phytoplankton)
- Salinity
- Total Suspended Solids (TSS)
- Fluorescence Line Height
- Euphotic Depth
- Diffuse Attenuation of Light

Image Credit: A blackwater river meets the sea [Text.Article]. (2018, October 27). Source: NASA Earth Observatory

National Aeronautics and Space Administration

Current Satellites and Sensors Relevant for Monitoring Water Quality

Satellites & Sensors for Water Quality Monitoring

Satellites	Sensors	Resolution
Landsat 7	Enhanced Thematic Mapper (ETM+)	185 km Swath; 15 m, 30 m, 60 m; 16-Day Revisit
Landsat 8	Operational Land Imager (OLI)	185 km Swath; 15 m, 30 m, 60 m; 16-Day Revisit
Terra & Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	2330 km Swath; 250 m, 500 m, 1 km; 1–2-Day Revisit
SNPP[1] and JPSS[2]	Visible Infrared Imaging Radiometer Suite (VIIRS)	3040 km Swath; 375 m – 750 m; 1–2-Day Revisit
Sentinel 2A and 2B	Multi Spectral Imager (MSI)	290 km Swath; 10 m, 20 m, 60 m; 5-Day Revisit
Sentinel 3A and 3B	Ocean and Land Color Instrument (OLCI)	1270 km Swath; 300 m; 27-Day Revisit

[1]SNPP: Suomi National Polar-orbiting Partnership
[2]JPSS: Joint Polar Satellite System

Current Satellite Missions for Water Quality Monitoring

- Landsat 7 (4/15/1999 – Present)
- Landsat 8 (2/1/2013 – Present)
- Terra (12/18/1999 – Present)
- Aqua (5/4/2002 – Present)
- SNPP (11/21/2011 – Present)
- JPSS (11/18/2017 – Present)
- Sentinel-2A (6/23/2015 – Present)
- Sentinel-2B (3/7/2017 – Present)
- Sentinel-3A (2/16/2016 – Present)
- Sentinel-3B (4/25/2018 – Present)

Future Satellite Missions for Water Quality Monitoring

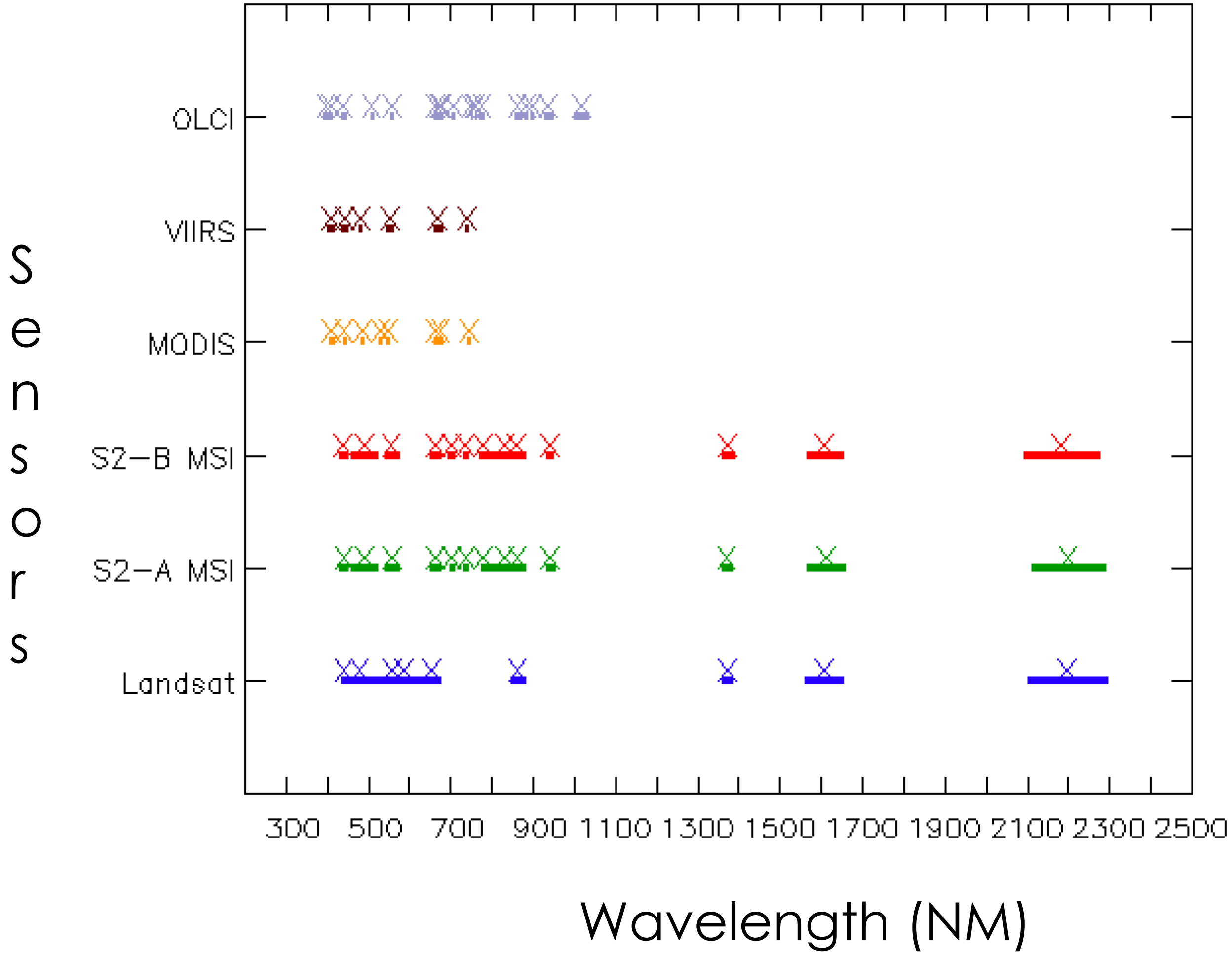
PACE: Plankton, Aerosol, Cloud, ocean Ecosystem
https://pace.oceansciences.org/mission.htm

- Planned for launch in 2023
- Advanced optical spectrometer, Ocean Color Instrument (OCI)
  - Hyperspectral measurements for water quality products (ultraviolet to near-infrared range)

SBG: Surface Biology and Geology
https://sbg.jpl.nasa.gov/

- In the initial phase of development
  - Hyperspectral imagery in the visible and shortwave infrared; multi-or hyperspectral imagery in the thermal IR

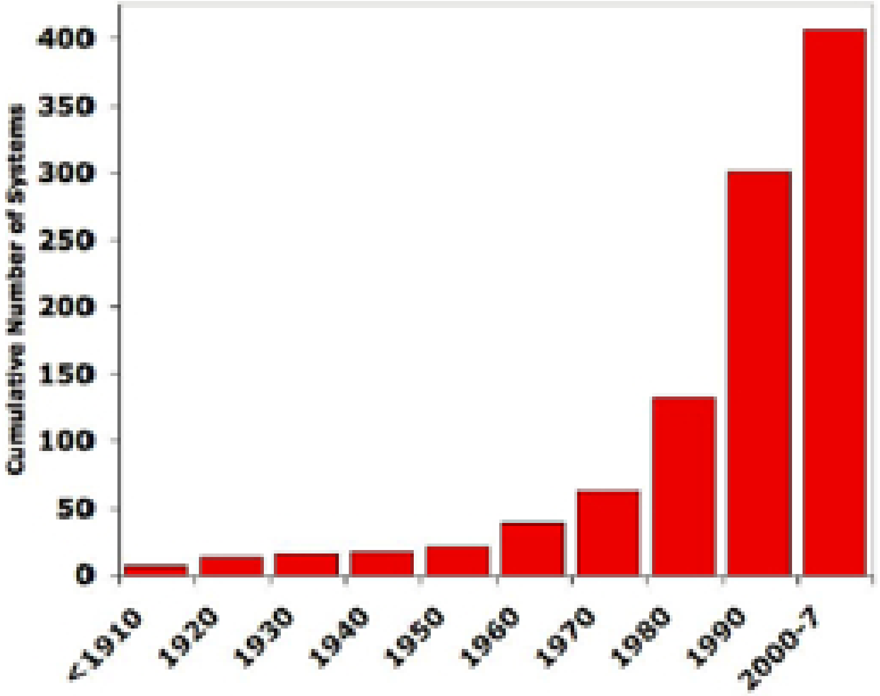
Sensor Spectral Bands



Monitoring Water Quality Changes over Time

- It is important to monitor estuaries on multiple time scales:
  - Short term (days to week) to understand and mitigate WQ variations due to weather events (e.g., storm runoff) and anthropogenic causes (e.g., industrial runoff, septic tank leakage).
  - Multi-year monitoring to understand and mitigate WQ changes related to climate impacts (e.g., sea level rise, increase in temperature) and land use changes (e.g., urbanization).

Dead Zones per Decade in Coastal and Estuarine Waters Worldwide

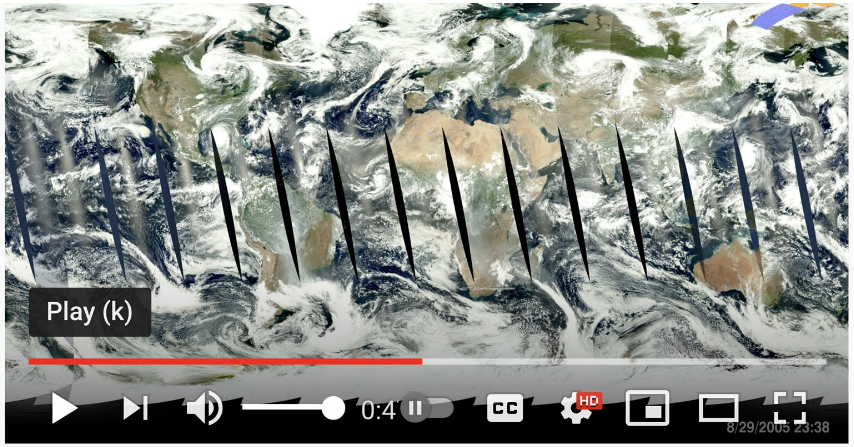


https://www.vims.edu/research/topics/dead_zones/trends/index.php

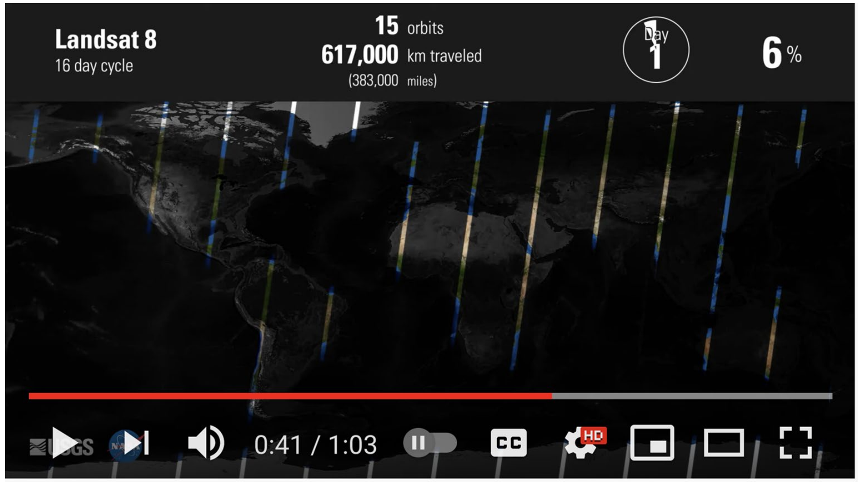
Long-term Satellite Missions for Monitoring WQ

- Landsat (~50 years) and MODIS (~20 years) are long-term missions.
- Landsat has higher spatial resolution (30 m), but narrow swaths (185 km) and lower temporal resolution (16 days).
- MODIS has moderate spatial resolution (250 m to 1 km) but wider swaths (2330 km) and higher temporal resolution (1-2 times per day).
- Both have moderate spectral resolution.

Aqua MODIS



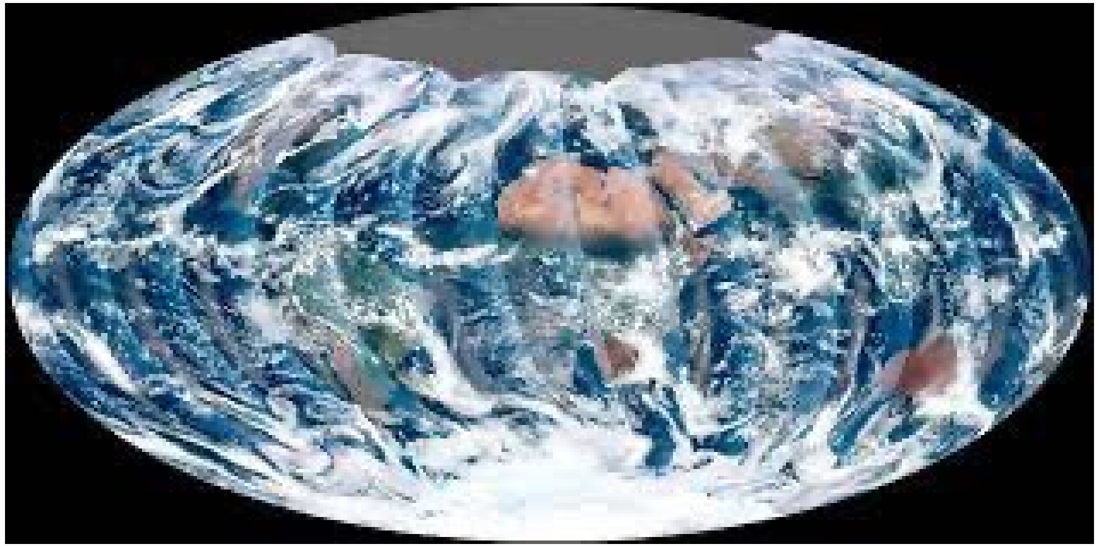
Landsat 8



Long-term Satellite Missions for Monitoring WQ

- Landsat 9 is scheduled to be launched in September 2021, continuing the time series.
- The MODIS time series is extended by VIIRS, a similar sensor flying on SNPP and JPSS.
- VIIRS has a wider swath width (3,040 km), moderate resolution (375 to 750 m), and frequent coverage (1-2 times per day), comparable to MODIS.

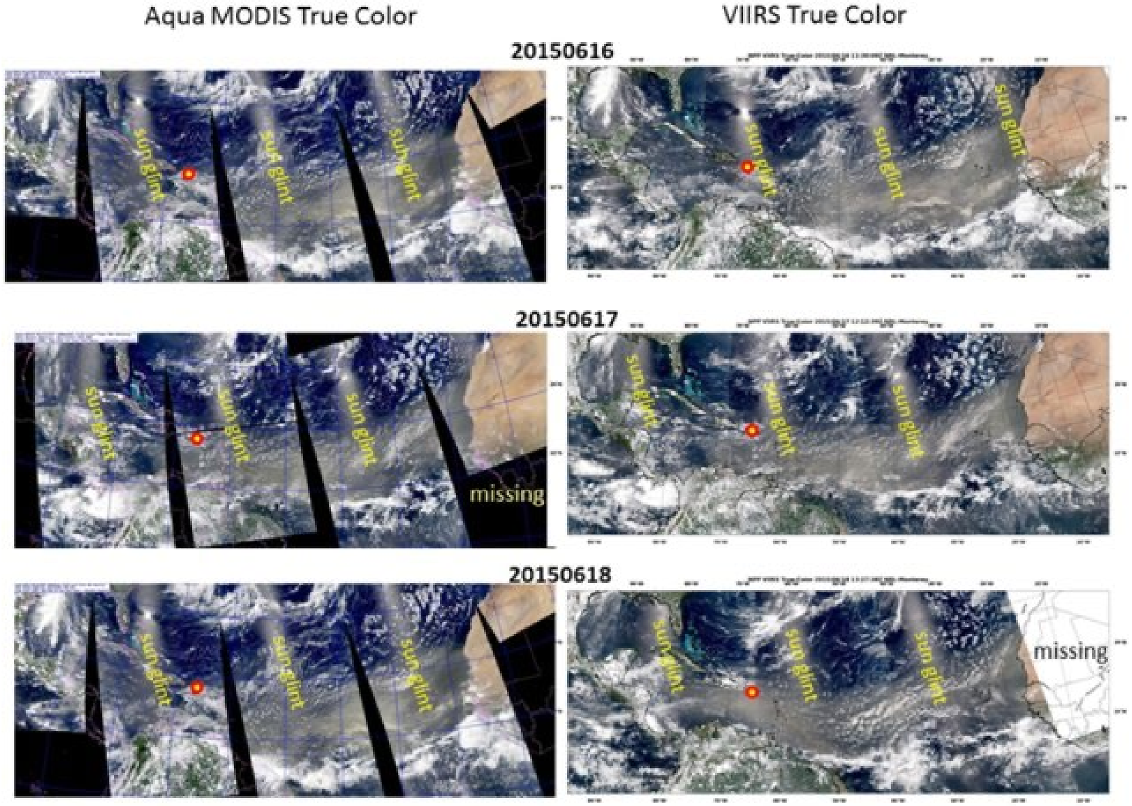
Global Image from VIIRS



https://earthobservatory.nasa.gov/images/76674/first-global-image-from-viirs

MODIS and VIIRS Comparison

- VIIRS has wider swaths and produces higher-resolution and more accurate measurements of sea surface temperature. It also has an operational capability for ocean-color observations and products.
- Several studies have compared MODIS and VIIRS products for continuity (e.g., Hu, 2014; Lander, et al. 2014; Levy et al. 2015; Li et al., 2015; Cao et al., 2018).



Levy et al. 2015 (DOI)
Li et al. 2015 (DOI)

https://www.jpss.noaa.gov/viirs.html

MODIS and VIIRS Comparison

- Lander et al. (2018) compared MODIS and VIIRS products with *in situ* data in the Gulf of Mexico and conclude that the VIIRS products will provide an adequate follow-on and replacement to MODIS for ocean color monitoring.
- Uncertainties in the intercomparison result from atmospheric corrections, sampling errors (pixel to point matchups and sea surface variations), and errors in coastal bio-optical algorithms.

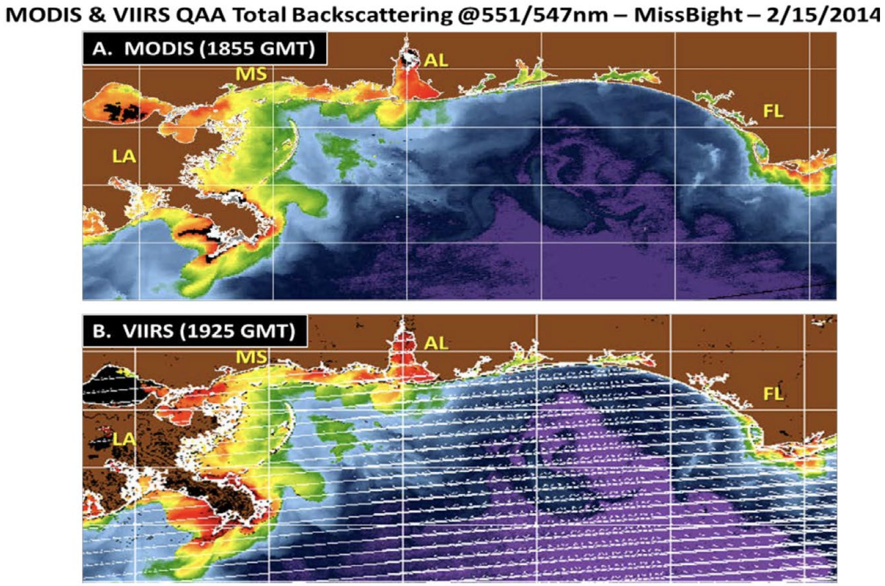


Figure 1 shows a comparison between VIIRS and MODIS Aqua derived total backscatter QAA @ 551nm (VIIRS) and 547nm (MODIS Aqua) product for November 20, 2013 covering the Mississippi Sound in the Northern Gulf of Mexico. Note that the derived total backscattering for both sensors is very similar and a small resolution improvement for VIIRS at 750m as compared to MODIS Aqua is at 1 kilometer. Blue dots represent flowthru data sample locations and red dots above water rrs.

Learn to Use MODIS and VIIRS Data for WQ Monitoring

Case Studies:

- Study Regions:
  - Chesapeake Bay
  - Río de la Plata
- Search and obtain MODIS and VIIRS Level-1 data from NASA Ocean Color Web
- Derive MODIS and VIIRS Level-2 data
  - Spectral Reflectance
  - Geophysical Parameters (e.g., sea surface temperature, chlorophyll-a concentration, attenuation coefficient)

Chesapeake Bay

Río de la Plata

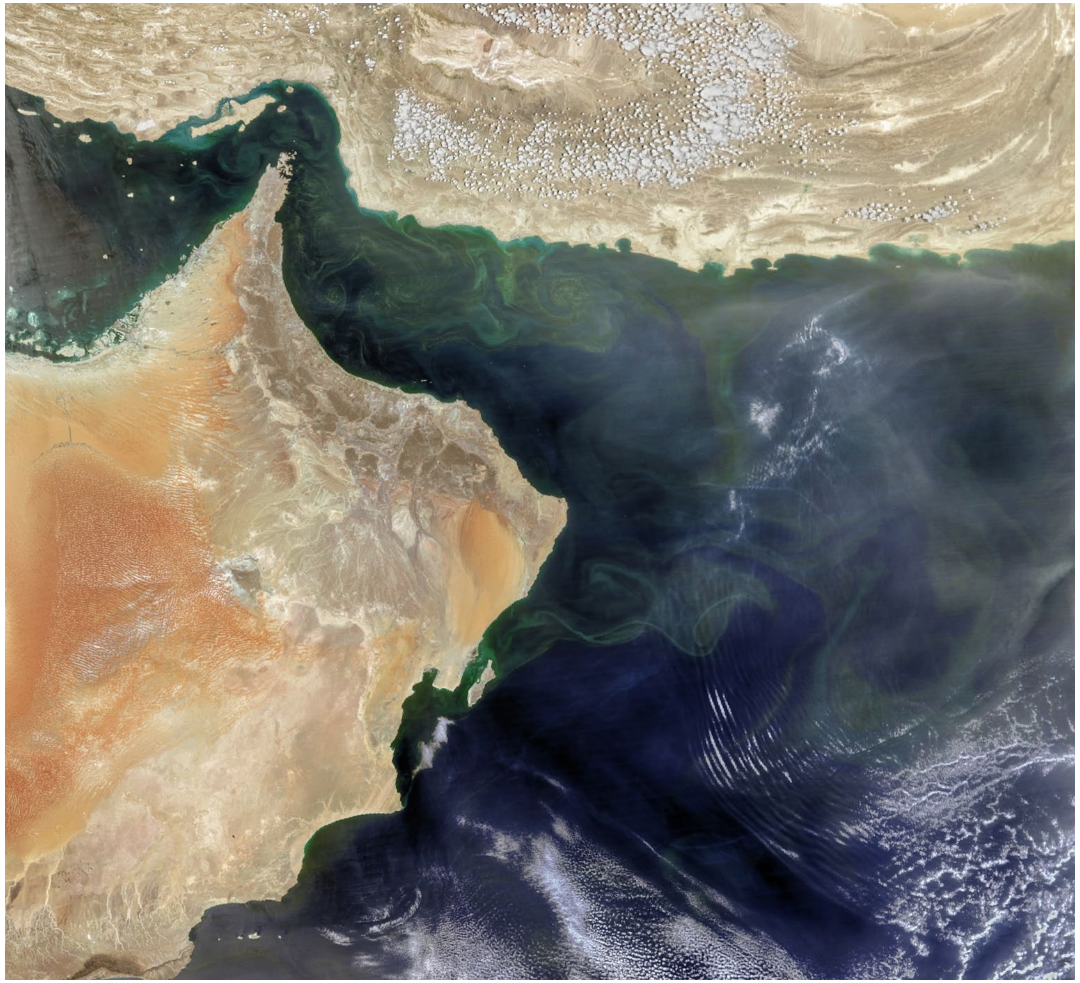
Credit: NASA

National Aeronautics and Space Administration

Demonstration of MODIS and VIIRS Data Acquisition

Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



Credit: NASA

Contacts

- Trainers:
  - Amita Mehta: amita.v.mehta@nasa.gov
  - Juan Torres-Pérez: juan.l.torresperez@nasa.gov
  - Sean McCartney: sean.mccartney@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-monitoring-coastal-and-estuarine-water-quality-transitioning
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Thank You!

Sensor Spectral Bands Wavelength (Band Widths) in Nanometers

Landsat 8 OLI	Sentinel 2A MSI	Sentinel 2B MSI	Sentinel 3A/3B OLCI	Terra/Aqua MODIS	SNPP/JPSS VIIRS
443.0 (20)	442.7 (21)	442.3 (21)	400. (15)	412.5 (15)	412.0 (20)
482.0 (65)	492.4 (66)	492.1 (66)	412.5 (10)	443.0 (10)	445.0 (18)
561.0 (75)	559.8 (36)	559.0 (36)	442.5(10)	488.0 (10)	483.0 (10)
655.0 (50)	664.6 (31)	665.0 (31)	442.0 (10)	531.0 (10)	555.0 (20)
865.0 (40)	704.1 (16)	703.8 (16)	510.0(10)	551.0 (10)	672.0 (20)
1609.0 (100)	740.5 (15)	739.1 (15)	560.0 (10)	667.0 (10)	742.0 (6)
2201.0 (200)	782.8 (20)	779.7 (20)	665.0 (10)	678.0 (10)	
590 (180)	832.8 (106)	833.0 (106)	674.5 (7.5)	748.0 (10)	
1375 (30)	864.7 (22)	864.0 (22)	681.25 (7.5)		
10800 (1000)	945.1 (21)	943.2 (21)	708.75 (10)		
12000 (1000)	1373.5 (30)	1376.9(30)	753.75 (7.5)		
	1613.7 (94)	1610.4 (94)	761.25 (2.5)		
	2202.4 (185)	2185.7(185)	764.38 (3.5)		
			764.5 (2.5)		
			778.75 (15)		
			865.0 (20)		
			885.0 (10)		
			900.0 (10)		
			940.0 (20)		
			1020.0 (40)		