
# Monitoring Harmful Algal Bloom Indicators for Aquaculture using NASA Remote Sensing Observations Aquaculture 2025 Meeting

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March 08, 2025

# About ARSET

# About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

# About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

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ARSET Trainings Reach a Global Audience

# Monitoring Harmful Algal Bloom Indicators for Aquaculture using NASA Remote Sensing Observations

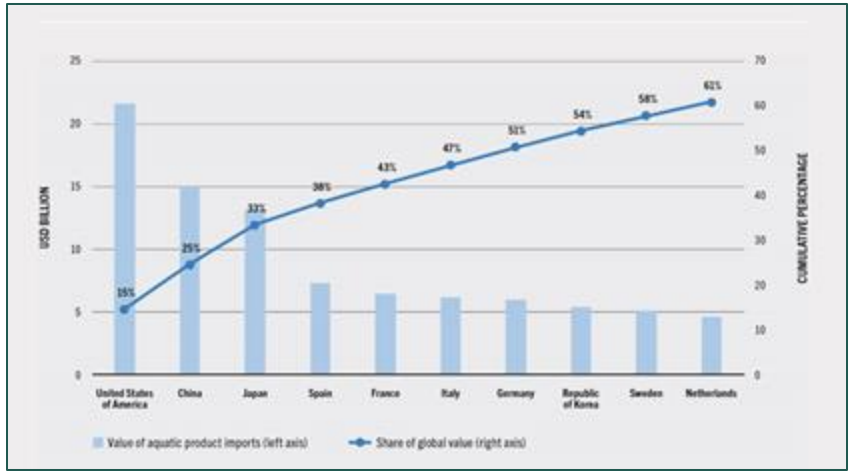
# Impact of Aquaculture

- Improves food security and nutrition for humans
- Boosts economic growth
- Can help keep waterways clean

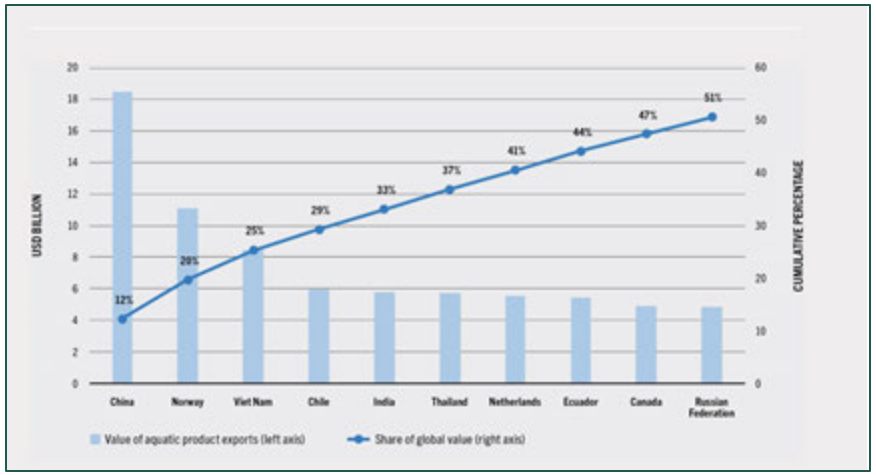
**In the US:**

- 5,961 aquaculture farms
- About 1,500 aquatic species
- 22,000 jobs in aquaculture activities
- Economic Impact: $4,000,000,000
- Value of Seafood Imports: $29,682,165,000

TOP TEN IMPORTING COUNTRIES OF AQUATIC PRODUCTS, 2020




TOP TEN EXPORTING COUNTRIES OF AQUATIC PRODUCTS 2020




NOAA Fisheries
National Aquaculture Association

Food and Agriculture Association

# Harmful Algal Bloom Impact on Aquaculture

**Harmful Algal Bloom (HAB) in Water:**

- Produces toxins
- Reduces dissolved oxygen
- Contaminates or kills fish & shellfish – directly by toxins or clogging gills

**HAB Events and Aquaculture:**

- Contaminated fish consumption can affect human health
- Result in delay or closure of harvest
- Supply and demand chain disruption & food insecurity
- Prevent the growing of new cohorts
- Cause economic losses of millions of dollars

NOAA Fisheries

NOAA Ocean Service

**Monitoring water quality and HAB benefit aquaculture productivity and management**

# Workshop Objectives

By the end of this workshop participants will be able to:

- Recognize basic concepts about satellite remote sensing for monitoring water quality in coastal and inland waters.
- Identify satellites, sensors, and data products relevant for monitoring algal bloom in coastal and inland waters.
- Gain hands-on experience in using selected NASA webtools for data search, access, and visualization for improved water quality monitoring.

# Workshop Schedule

## Part 1 [8:40 to 9:30 AM]

### Presentations

- Fundamentals of Remote Sensing
- Overview of Satellites and Sensors for Water Quality Monitoring, Specifically Algal Bloom and Sediments

### Demonstrations

- **NASA Worldview**: Access and Visualize Satellite Images, Sea Surface Temperature (SST), & Chlorophyll-a, Land Cover, Rainfall
- **CyAN**: Cyanobacteria Assessment Network

### Hands-On Exercise

- Monitor Chlorophyll-a and SST using Worldview

## Part 2 [9:40 to 10:30 AM]

### Presentation

- Introduction to Satellite-based analysis Tool for Rapid Evaluation of Aquatic environMents (STREAM)

### Demonstration

- **STREAM**: Monitor Chlorophyll-a concentration, Total Suspended Solids (TSS), and Secchi Disk Depth (SDD)

### Hands-On Exercise

Monitor Chlorophyll-a, TSS and SDD

### Workshop Summary & Q/A

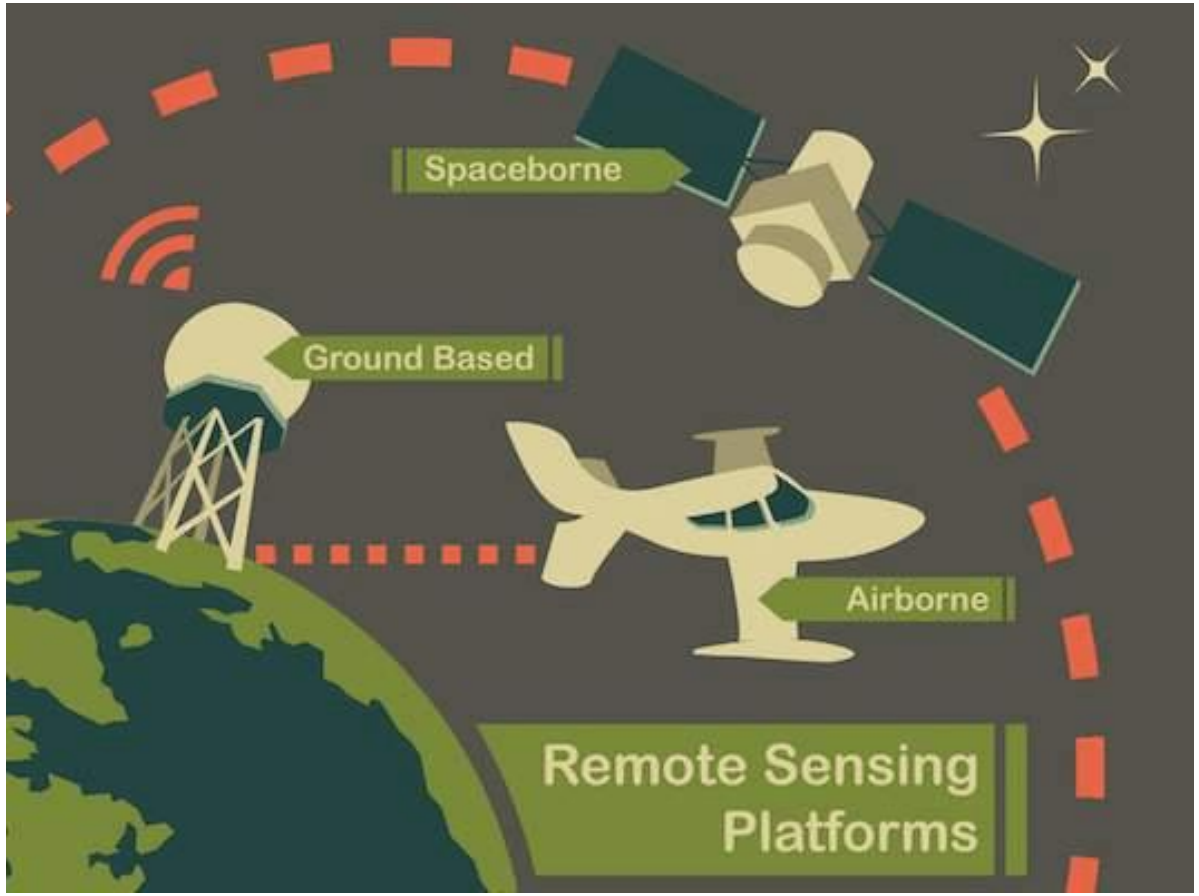
# Monitoring Harmful Algal Bloom Indicators for Aquaculture using NASA Remote Sensing Observations

**Part 1**

# Fundamentals of Remote Sensing

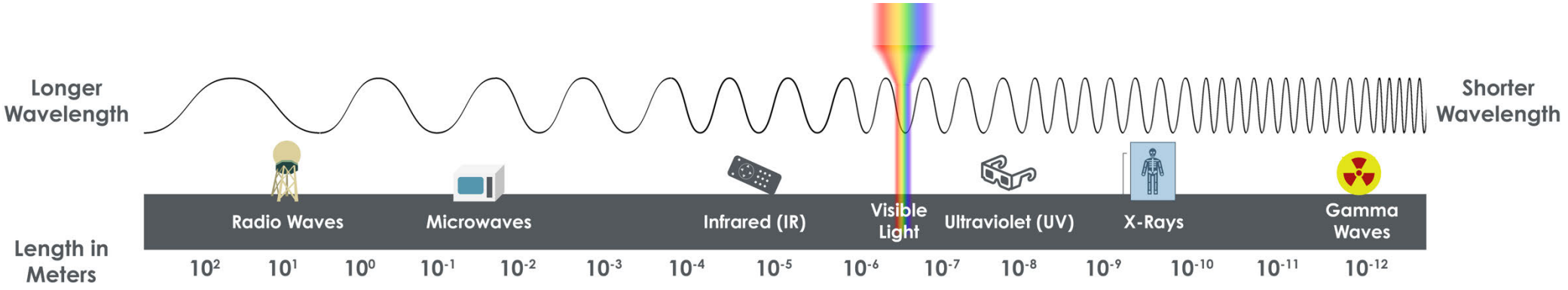
# What is Remote Sensing?

- **Remote sensing** is obtaining information about an object from a distance.
- Photography is a very common form of remote sensing.
- There are different ways to collect data, and different sensors are used depending on the application.
- Some methods collect ground-based data, others airborne or spaceborne.



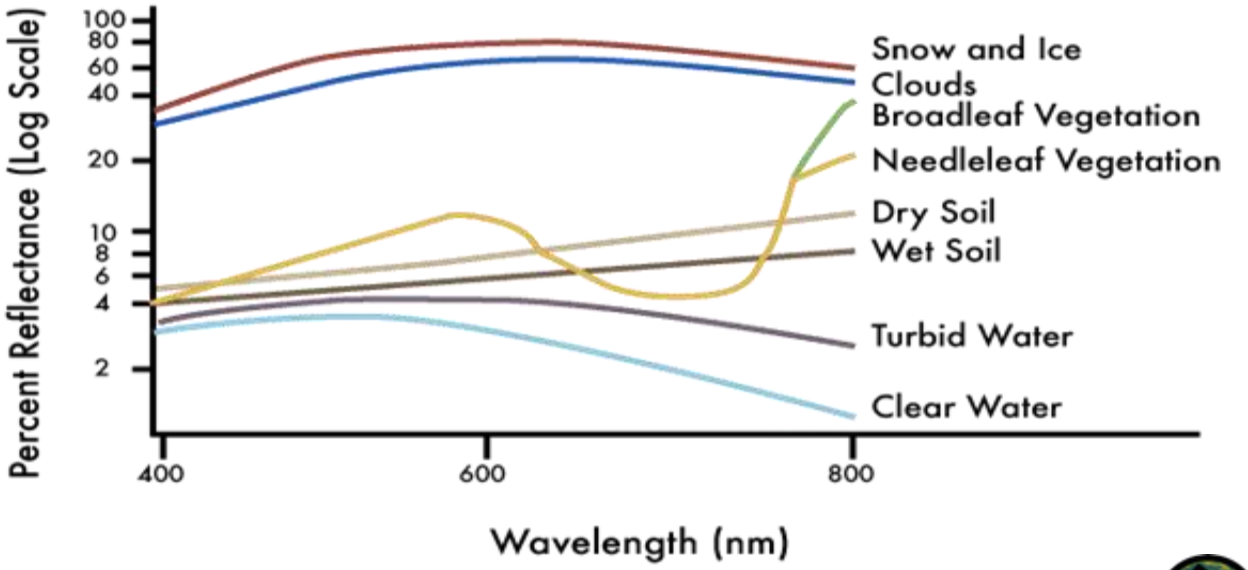

ARSET – Fundamentals of Remote Sensing

# Electromagnetic Spectrum




- Different substances reflect, absorb, and emit different wavelengths of radiation across the electromagnetic spectrum.
- We infer what a material is by looking at what wavelengths have (and have not) been affected by it: the **spectral signature**.

## Spectral Signatures of Common Materials

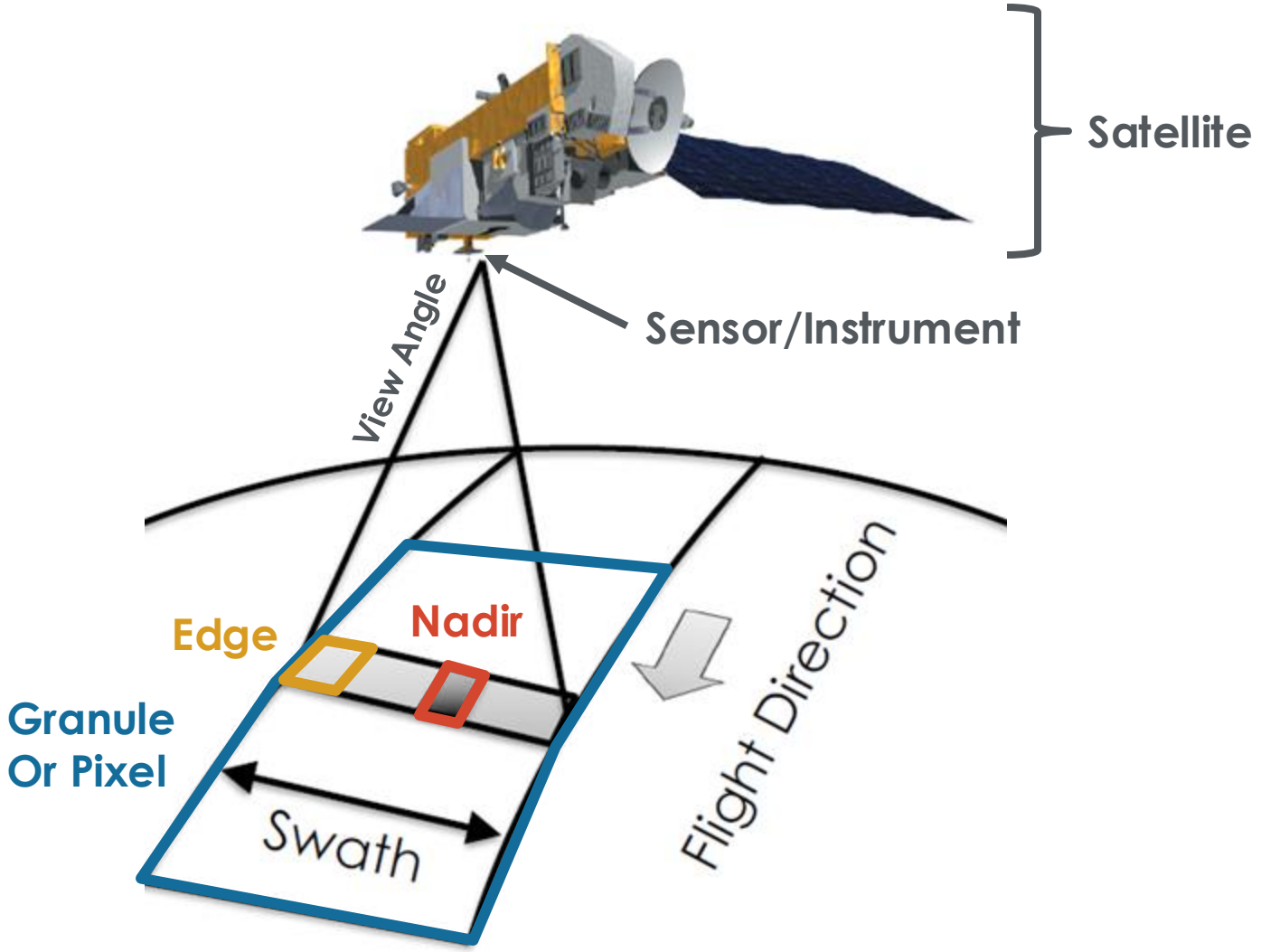


# Passive and Active Remote Sensing

- **Passive** sensors measure radiant energy reflected or emitted by the Earth-atmosphere system or changes in gravity from the Earth.
- Radiant energy is converted to **bio-geophysical quantities** such as temperature, precipitation, and soil moisture.

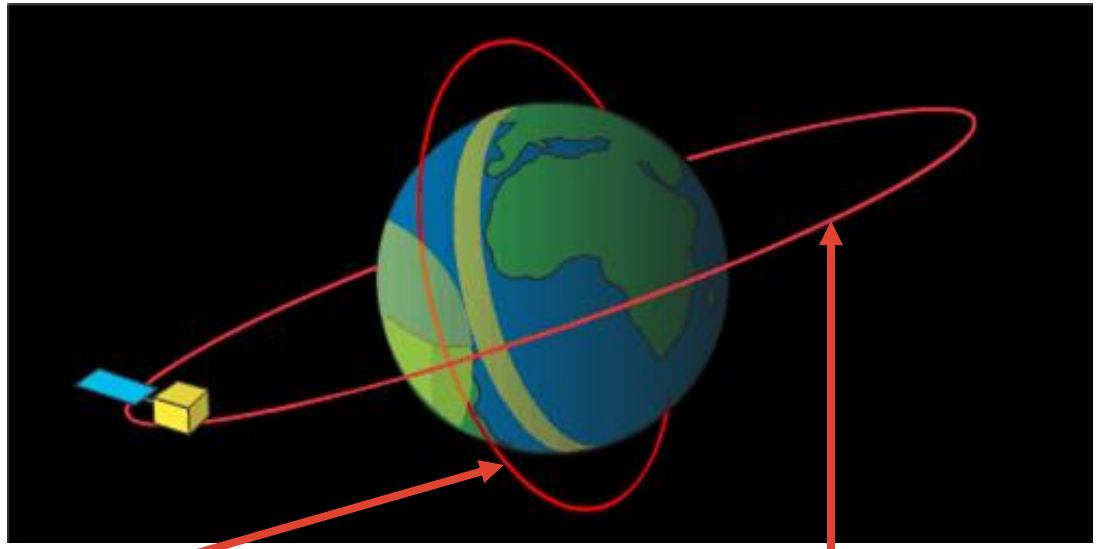
- **Active** sensors provide their own energy source for illumination.
- Most active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions and can be used day or night.

# Satellites and Sensors



# Orbits

Image Credit: scijinks.gov/orbit



## Low Earth Orbit (LEO)

- Polar orbits are common; inclined orbits also have specific uses
- Less frequent measurements
- Global (or near-global) spatial coverage over multiple orbits

## Geostationary Orbit (GEO)

- ~36,000 km over the equator with the same rotation period as Earth
- Multiple observations/day possible
- Limited spatial coverage; observations are always of the same area

**Orbit impacts temporal resolution and spatial coverage.**

# Spatial Resolution

**Spatial Resolution** signifies the ground surface area that forms one pixel in the image.

- Typically refers to the nadir resolution directly below the instrument.
- Sub-pixel objects can sometimes be resolved.

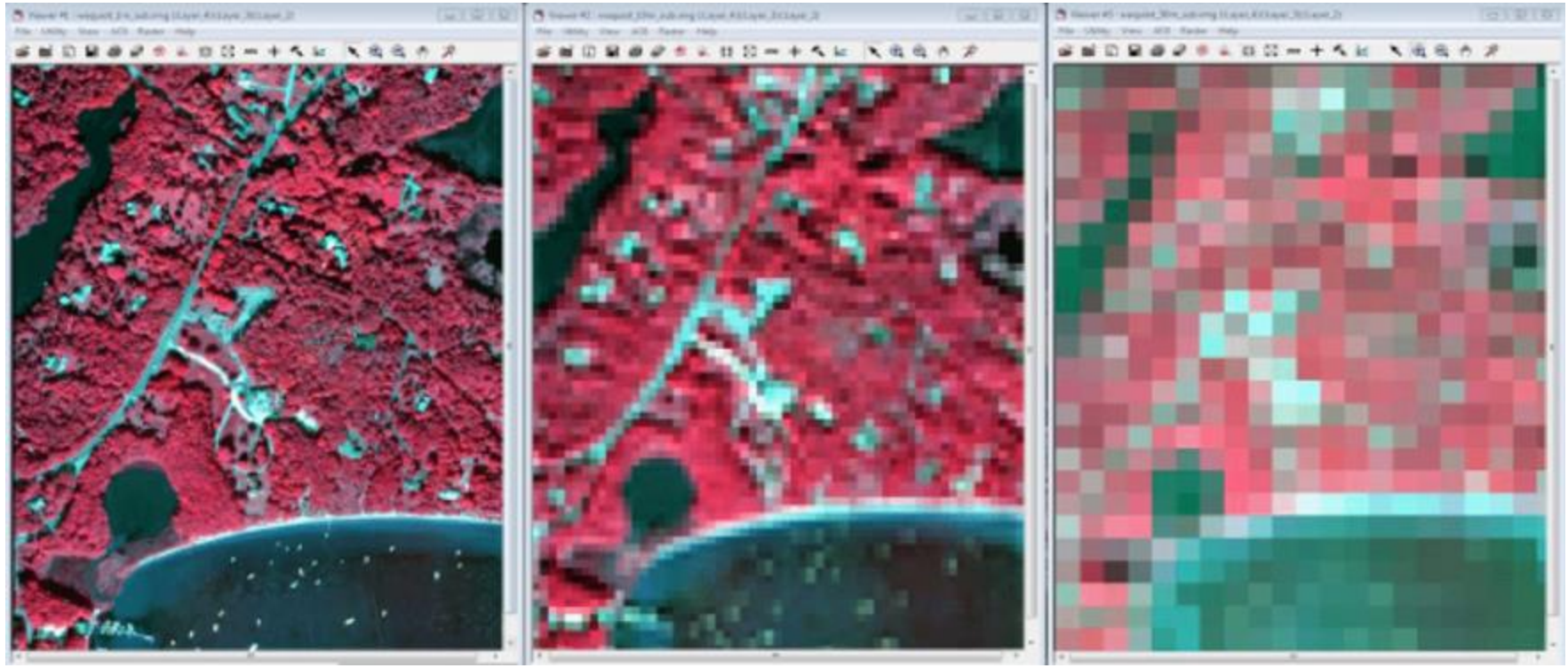
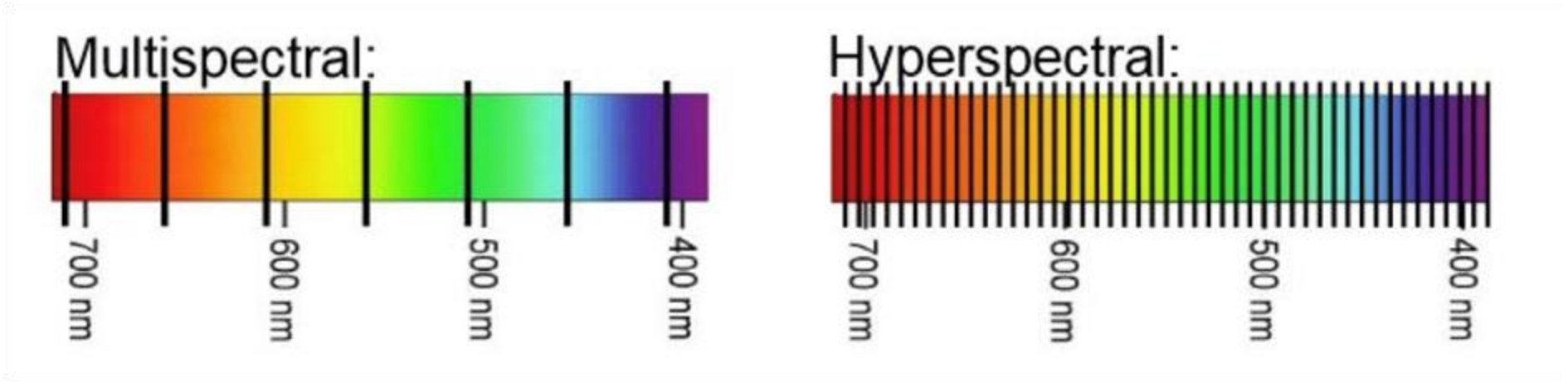


Image Credit: csc.noaa.gov

# Spectral & Radiometric Resolution

- **Spectral Resolution** signifies the number and width of spectral bands of the sensor. The higher the spectral resolution, the narrower the wavelength range for a band; think of it as the size of an array of numbers.




- **Radiometric Resolution** describes a sensor's ability to discriminate differences in energy (or radiance); think of it as more precision or "bits" for each number.
- More and finer **spectral bands** and **radiometric resolution** provide more detailed data, capable of representing different kinds of bio-geophysical properties.

# Satellite Data Processing Levels

NASA categorizes data products according to the level of processing used to produce them.

- **Level 0 & 1**
- **Level 2**
- **Level 3**
- **Level 4**

# Satellite Data Processing Levels: Levels 0 and 1

- **Level 0 & 1** is the raw instrument data that may be time-referenced. It is the most difficult to use.
- **Level 2**
- **Level 3**
- **Level 4**

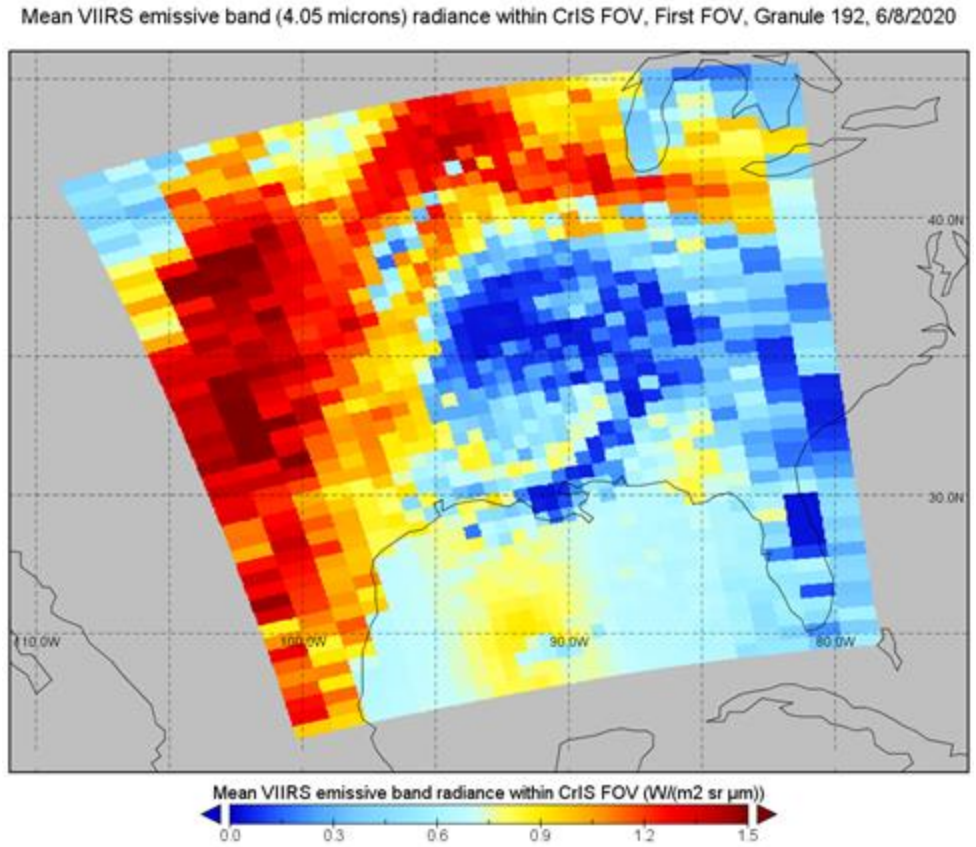



Image Credit: NASA GES DISC

# Satellite Data Processing Levels: Level 2

- **Level 0 & 1**
- **Level 2** is Level 1 data that has been converted into a bio-geophysical quantity through a computer algorithm (known as retrieval). These data are geo-referenced and calibrated.
- **Level 3**
- **Level 4**

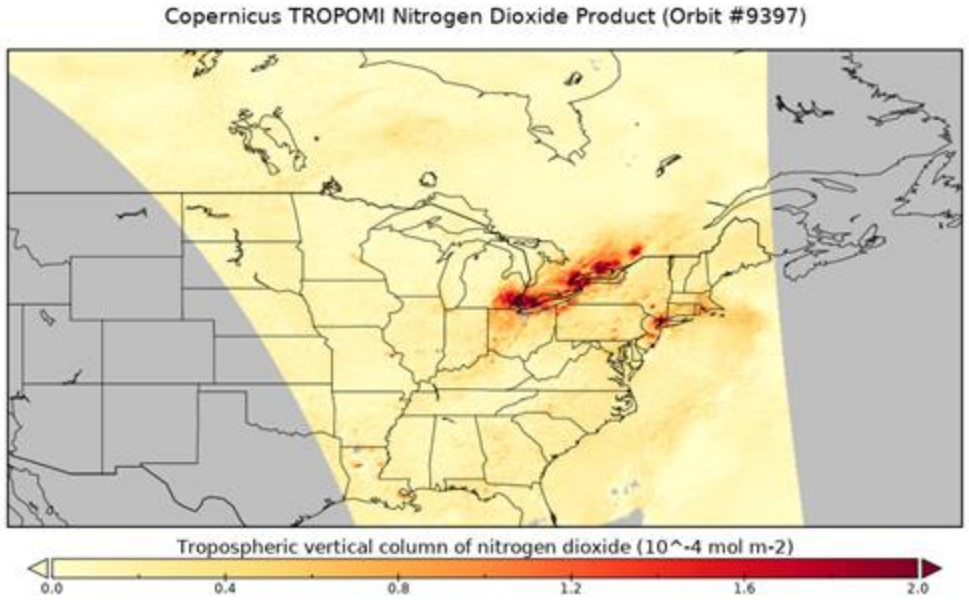



Image Credit: NASA GES DISC

# Satellite Data Processing Levels: Levels 3 & 4

- **Level 0 & 1**
- **Level 2**
- **Level 3** is Level 2 data that has been mapped onto a uniform space-time grid and quality controlled.
- **Level 4** is Level 3 data that has been combined with models or other instrument data to fill gaps and gain additional insight.

**Level 3 & 4 data are the easiest to use.**

MODIS Level-3 Sea Surface Temperature

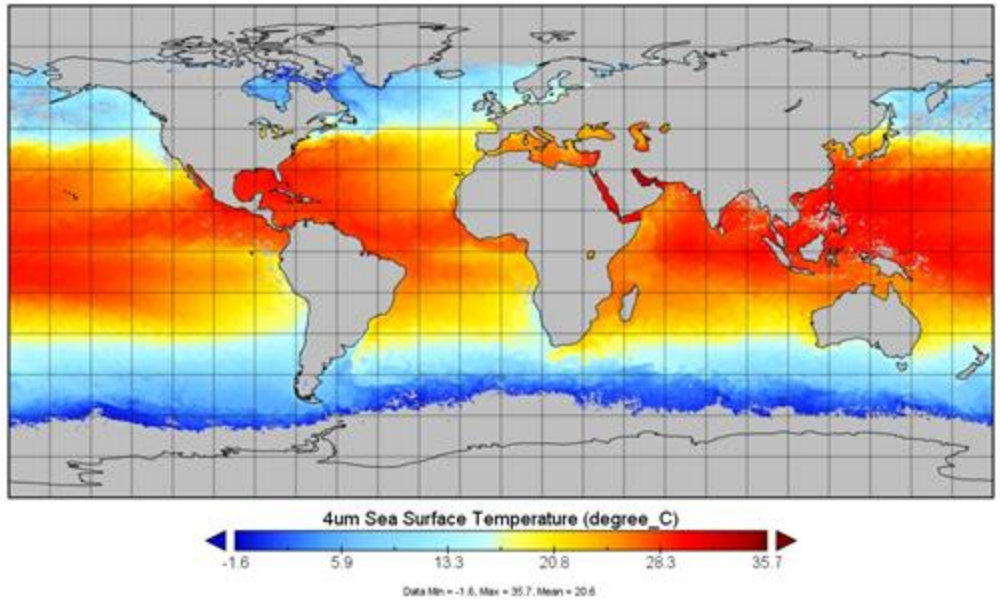



Image Credit: NASA JPL PODAAC

# Satellite Data Processing Levels: Levels 0-4

- **Level 0 & 1** is the raw instrument data that may be time-referenced. It is the most difficult to use.
- **Level 2** is Level 1 data that has been converted into a bio-geophysical quantity through a computer algorithm (known as retrieval). These data are geo-referenced and calibrated.
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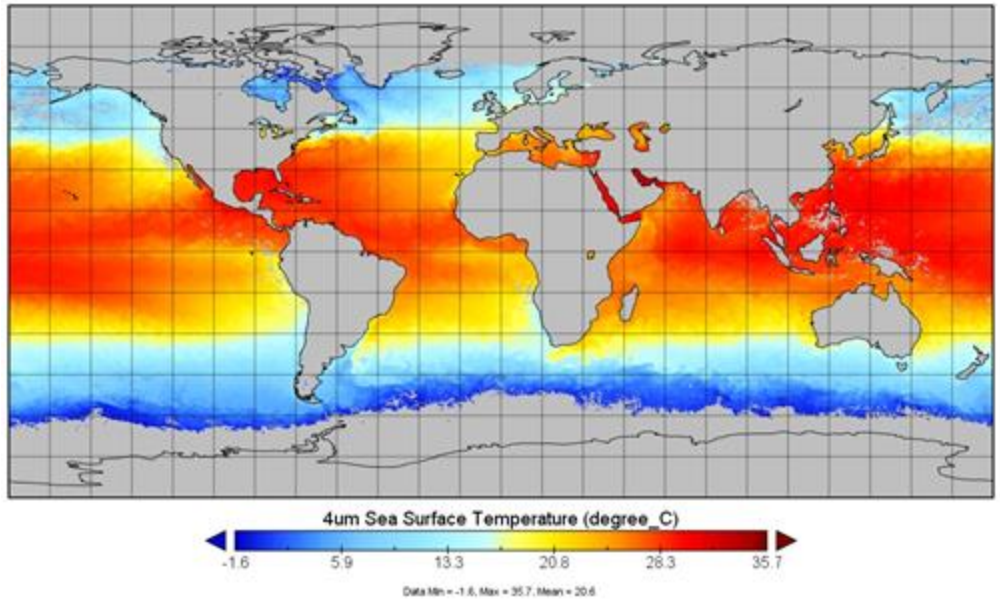



Image Credit: NASA JPL PODAAC

# Advantages of Remote Sensing

- Provides information where there are no ground-based measurements.
- Provides **globally consistent** observations.
- Provides **continuous monitoring** of our planet.
- Earth systems models integrate surface-based and remote sensing observations and provide uniformly gridded, frequent information of bio-geophysical parameters.
- Data are **freely available** and there are web-based tools for data analysis.

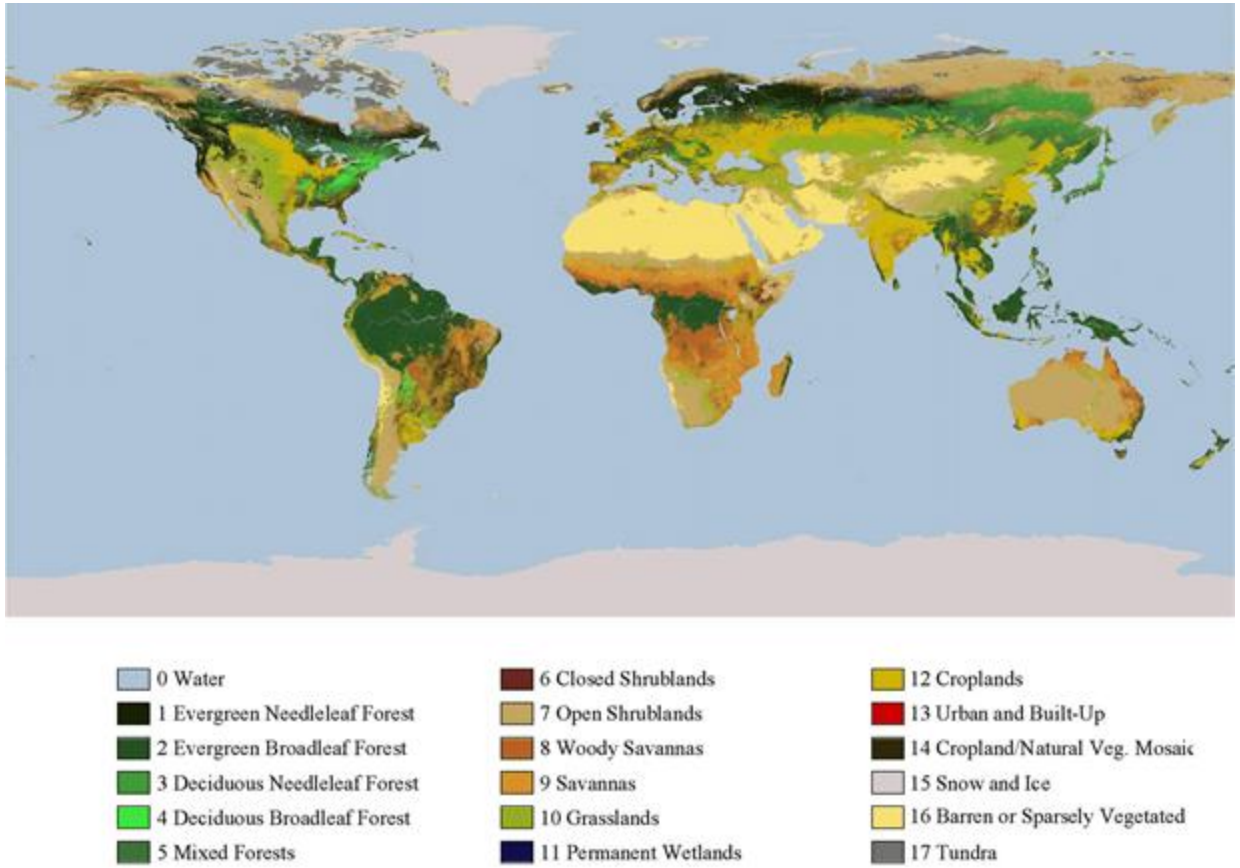



Image Credit: NASA GSFC

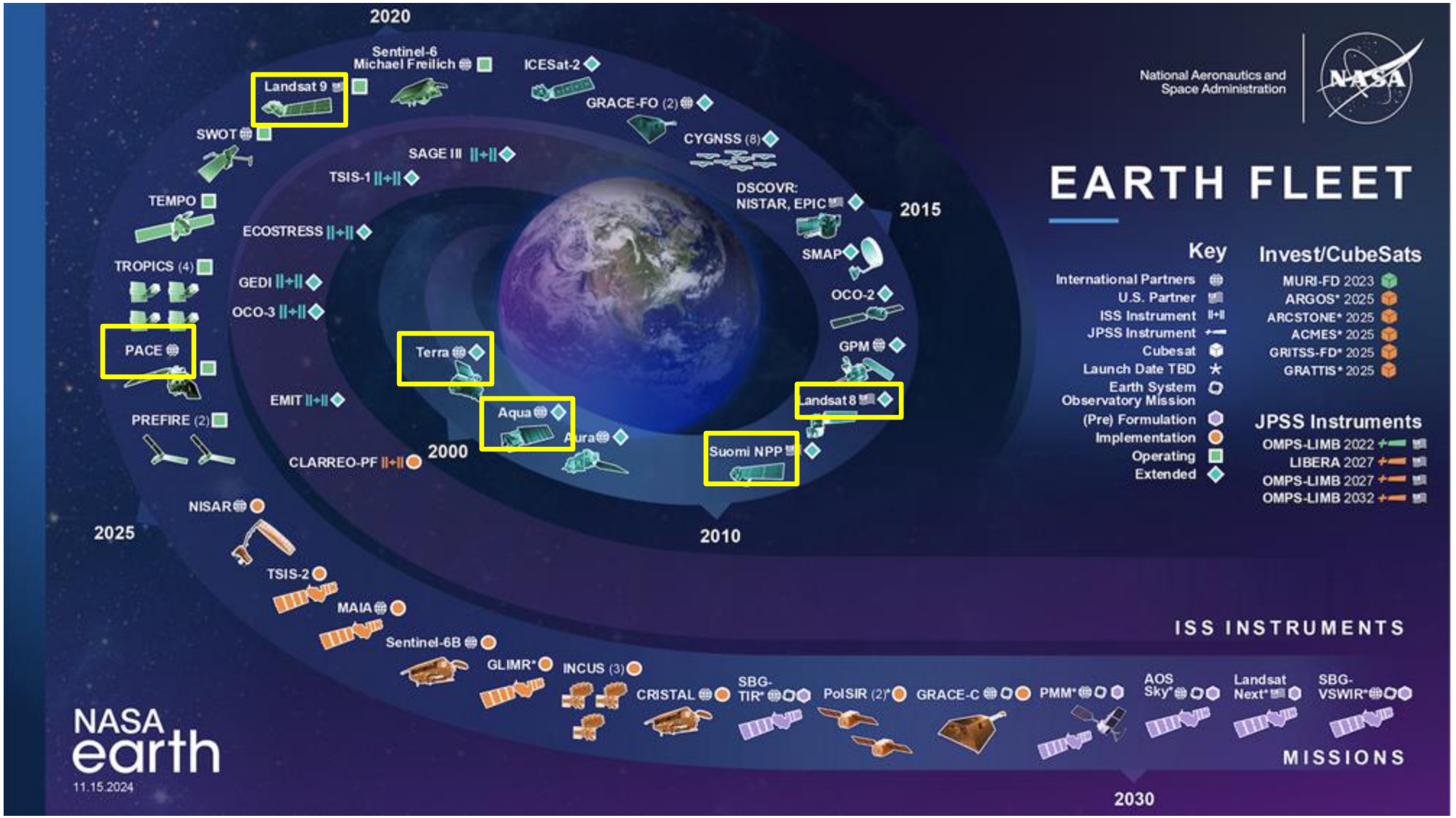
# Limitations of Remote Sensing

- **Tradeoffs:** Spectral, spatial, temporal, and radiometric resolution are competing priorities.
- **Interference** from clouds, sun glint, and other sources can cause missing data.
- **Large amounts of data** in a variety of formats can require specialized processing and visualization tools.
- **Data Validation:** While the data are generally validated with selected surface measurements, **local assessment is recommended** to ensure that the data are relevant for any particular use case.

Image Credit: NOAA

# Overview of Satellites and Sensors Relevant for Water Quality Monitoring

# NASA's Earth Observing Satellites

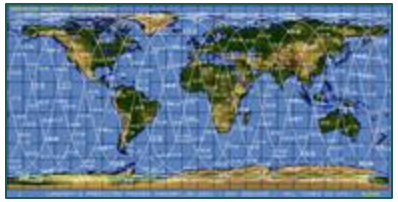



NASA SVS

# Current Satellite Missions Relevant for Monitoring Water Quality

- GPM is in a low inclination orbit.
- All other satellites are in polar orbit.
- All satellites have multiple sensors and different swarth widths and spatial/temporal resolutions.

Landsat 8 & 9

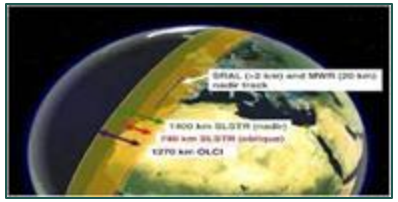


Aqua & Terra

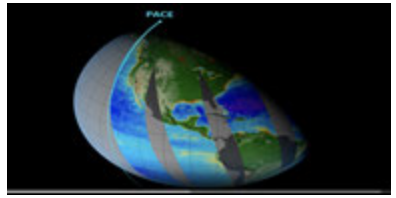
SNPP, JPSS 1 & 2

Sentinel-2

Senitnel-3 OLCI



PACE




The acronyms are defined on the next two slides.

| Satellites | Launch Dates |
|---|---|
| Landsat 8: | 02/2013 |
| Landsat 9: | 09/2021 |
| Terra: | 12/1999 |
| Aqua: | 05/2002 |
| SNPP: | 10/2011 |
| JPSS 1 (NOAA 20): | 11/2017 |
| JPSS 2 (NOAA 21): | 11/2022 |
| SSentinel 2A*: | 06/2015 |
| Sentinel 2B*: | 03/2017 |
| Sentinel 3A*: | 02/2016 |
| Sentinel 3B*: | 04/2018 |
| PACE: | 02/2024 |

* European Space Agency Missions

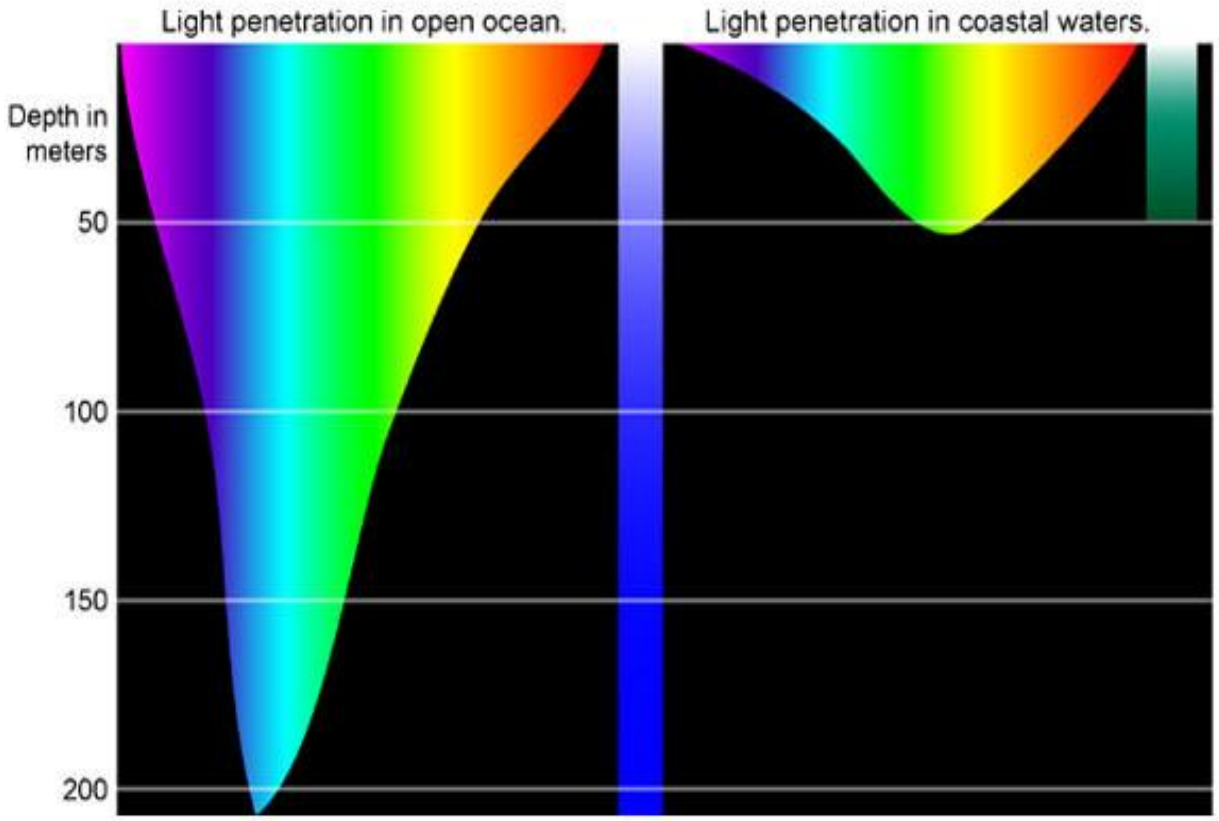
# Satellites and Sensors for Monitoring Waterbody Parameters & Landcover

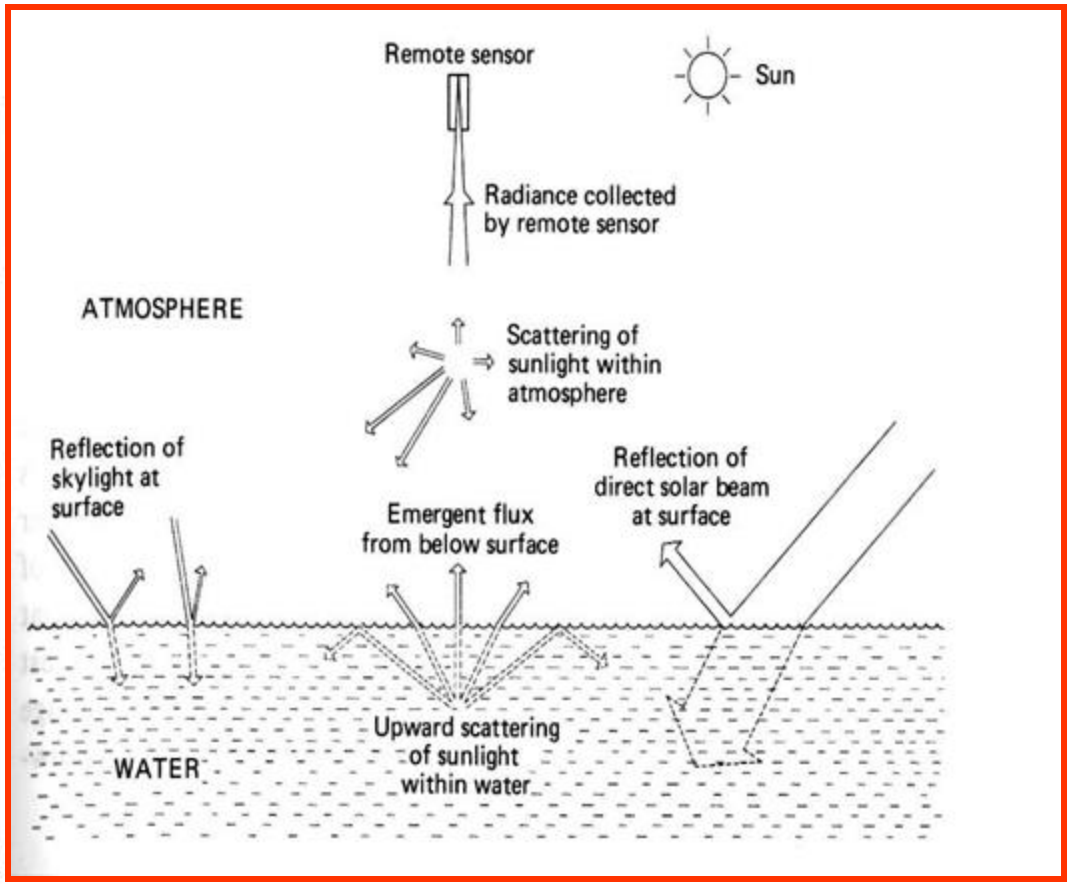
| Parameters | Satellites & Sensors | Resolutions |
|---|---|---|
| **Water:** Temperature, Chlorophyll-a, Sediments, CDOM<br>**Land:** Land Cover | **Landsat 8 & 9**<br>Operational Land Imager (OLI & OLI2) – Optical<br>Thermal Infrared Sensor (TIRS1 & TIRS2) – Thermal IR | 185 km Swath; 15 m, 30 m, 60 m;<br>16-Day |
| **Water:** Temperature, Chlorophyll-a, Total Suspended Matter, CDOM.<br>**Land:** Land Cover and Vegetation Indices | **Terra & Aqua**<br>MODerate Resolution Imaging Spectroradiometer (MODIS) – Optical and Thermal IR | 2,330 km Swath; 250 m, 500 m, 1 km; 1–2-Day |
| **Water:** Temperature, Chlorophyll-a, Total Suspended Matter, CDOM.<br>**Land:** Land Cover | **SNPP and JPSS**<br>Visible Infrared Imaging Radiometer Suite (VIIRS) – Optical and Thermal IR | 3,040 km Swath; 375 m – 750 m;<br>1–2-Day |
| **Water:** Temperature, Chlorophyll-a, Total Suspended Matter | **Sentinel-3A and -3B**<br>Ocean and Land Color Instrument (OLCI) – Optical<br>Sea and Land Surface Temperature Radiometer (SLSTR) – Optical and Thermal | 1,270 km Swath; 300 m;<br>1–2-Day |
| **Water:** Chlorophyll-a, Turbidity, CDOM, Cyanobacteria<br>**Land:** Landcover | **Sentinel-2A and -2B**<br>Multi Spectral Imager (MSI) – Optical | 290 km Swath; 10 m, 20 m, 60 m;<br>5-Day |
| **Water:** Chlorophyll-a, Suspended Particulate Matter, CDOM, Phytoplankton Constituents | **PACE**<br>Ocean Color Instrument (OCI) – Optical<br>Hyperspectral Measurements | 2,500 km Swath, 1 km,<br>1–2-Day |

SNPP: Suomi National Polar-orbiting Partnership JPSS: Joint Polar Satellite System PACE: Plankton Aerosol, Cloud, ocean, Ecosystem

# 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.



# Remote Sensing of Water Quality

- Satellite sensors measure top-of-atmosphere (TOA) radiances.
- The TOA radiances result from a combination of surface and atmospheric conditions, including the effects of clouds and aerosol particles.
- Water-leaving reflectance depends on backscattering and absorption of radiation due to water, sediments, phytoplankton, and colored dissolved organic matter (CDOM).

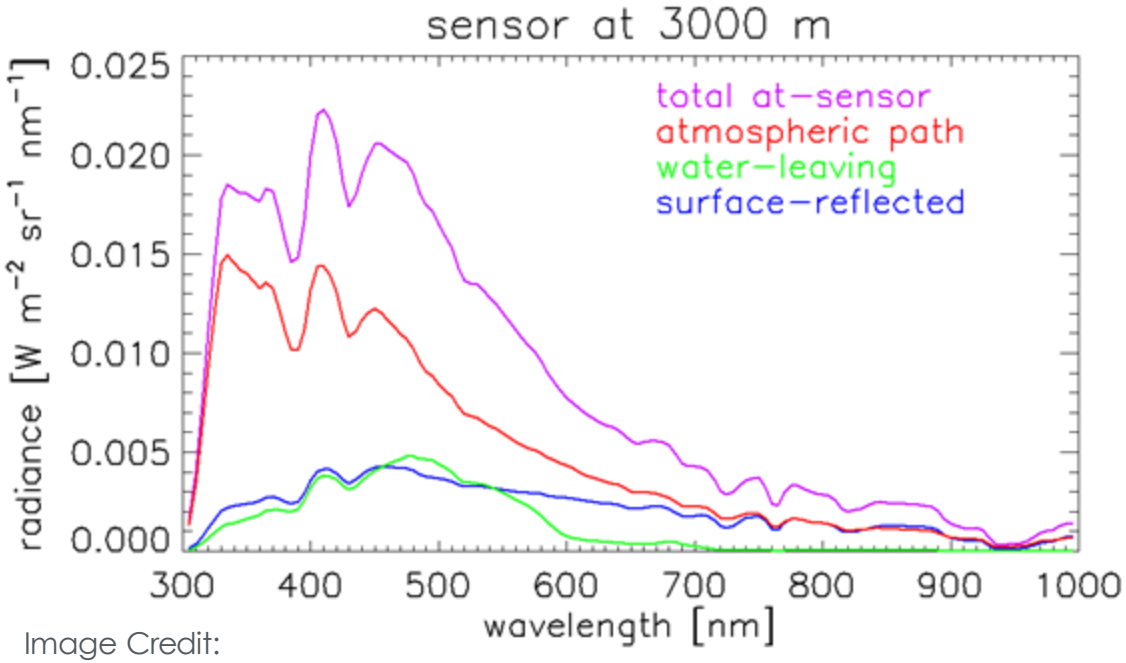
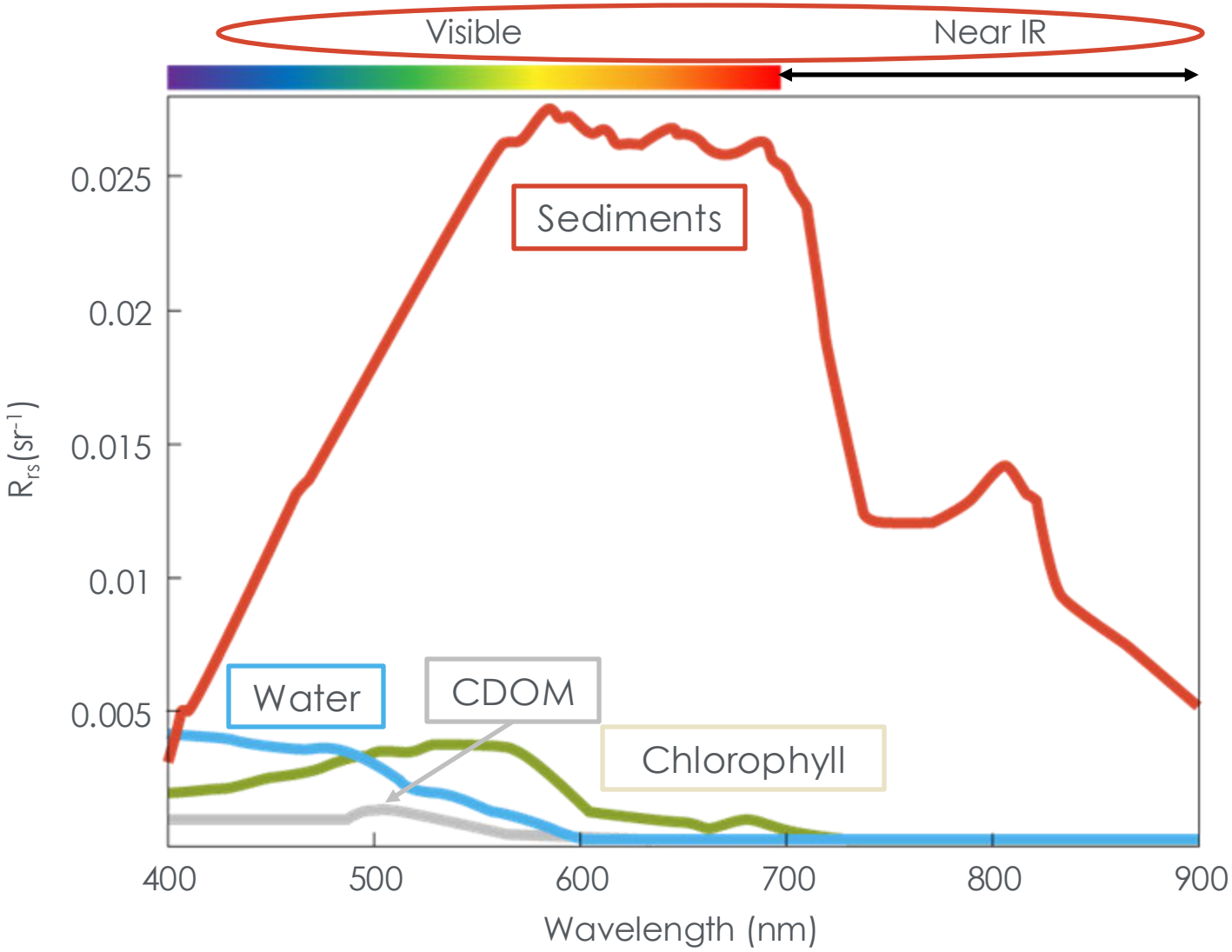



Image Credit: http://www.oceanopticsbook.info/view/remote_sensing/the_atmospheric_correction_problem

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

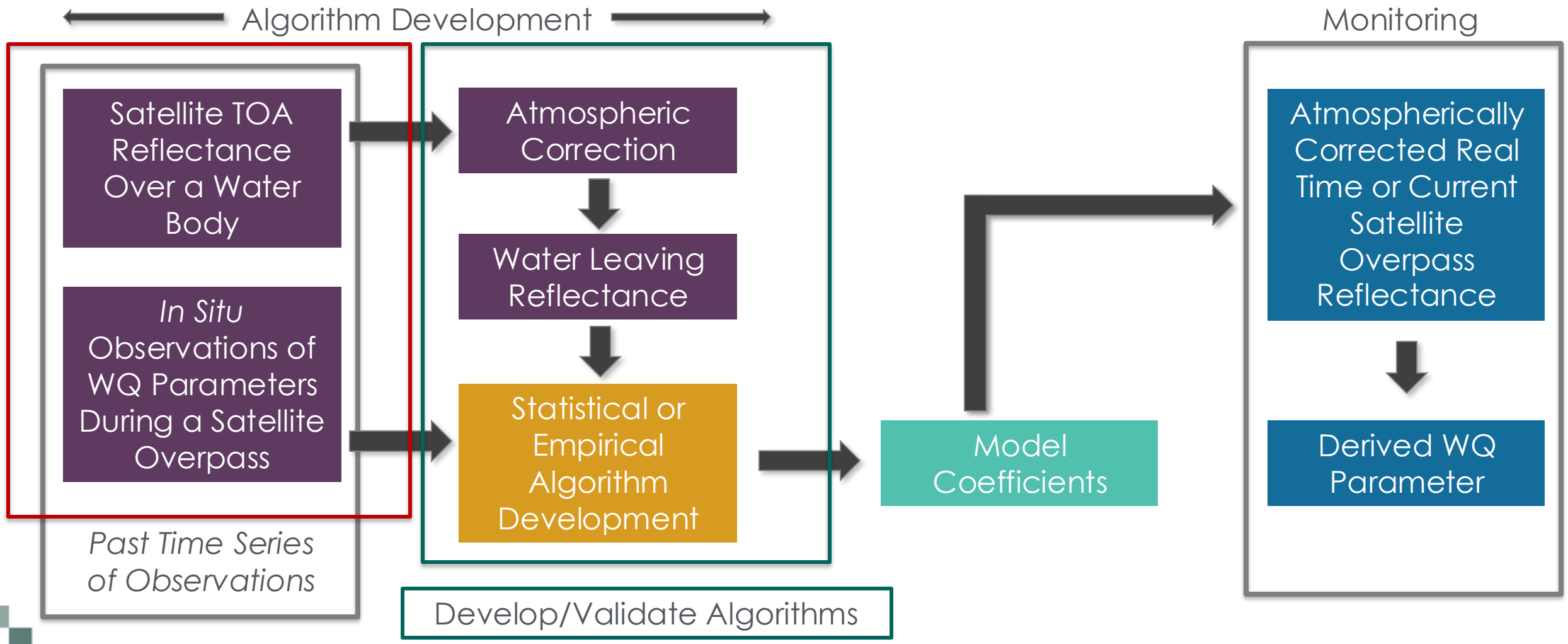
Inherent Optical Properties:

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



# Water Quality Parameters from Remote Sensing Observations

## Quantitative Technique

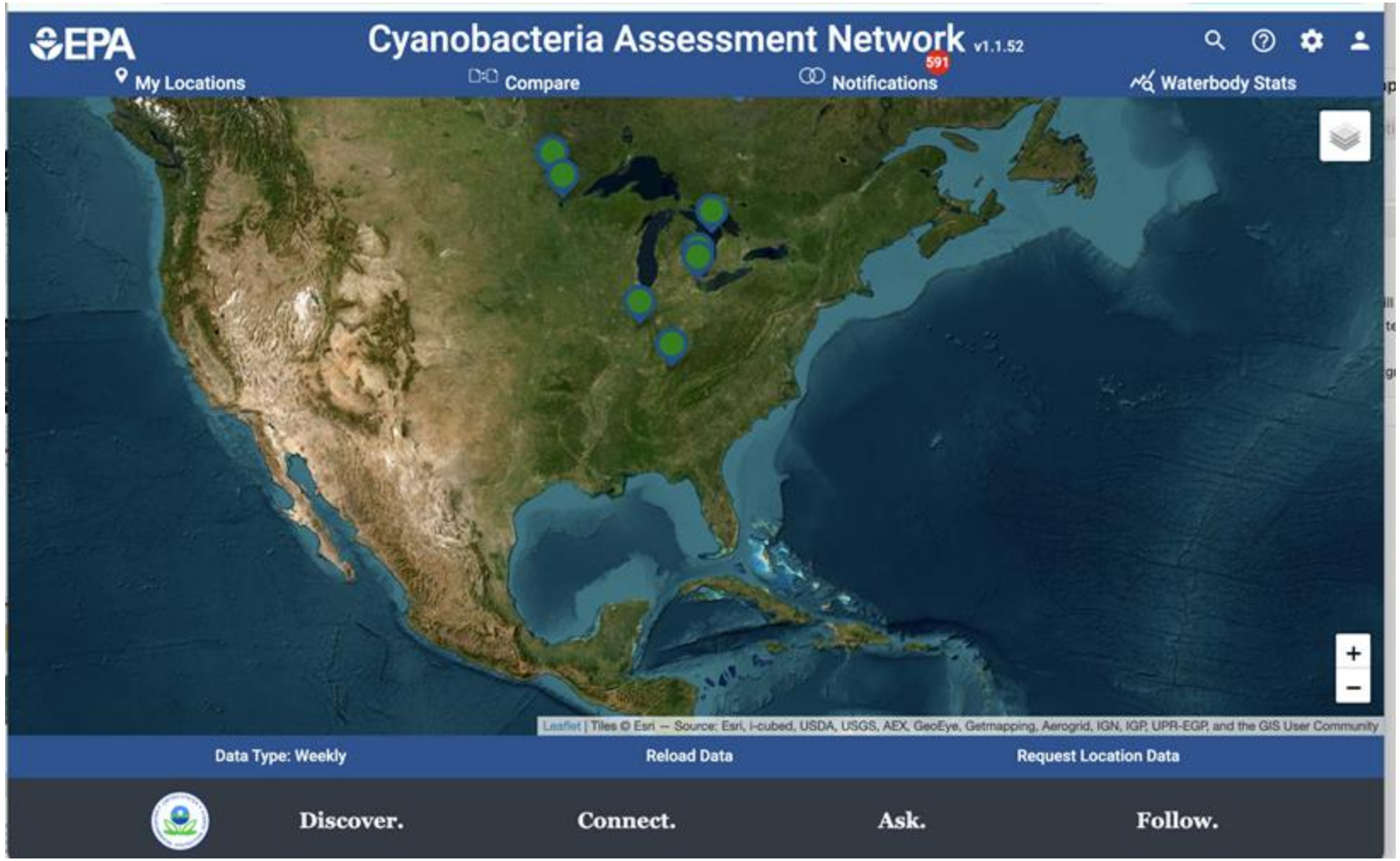


# Demonstration: NASA Worldview

- Worldview

# Demonstration: Cyanobacteria Assessment Network

- CYaN




ARSET CyAN Training

# Monitoring Harmful Algal Bloom Indicators for Aquaculture using NASA Remote Sensing Observations

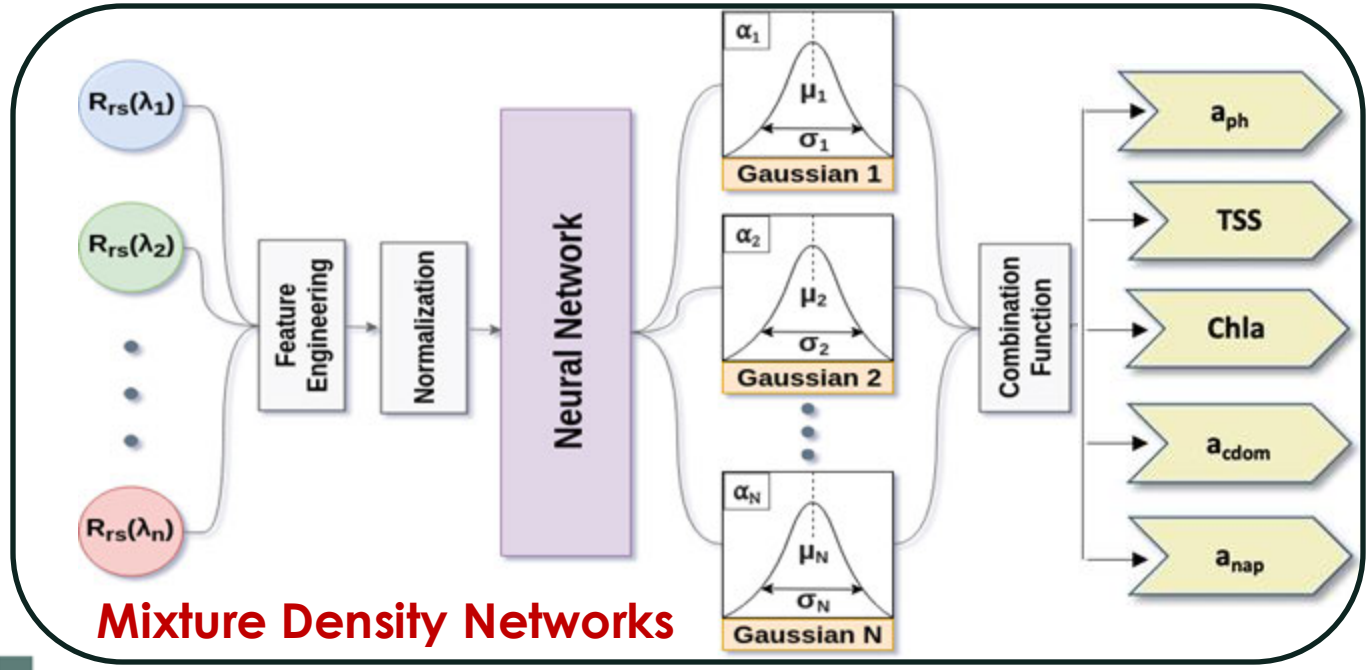
**Part 2**

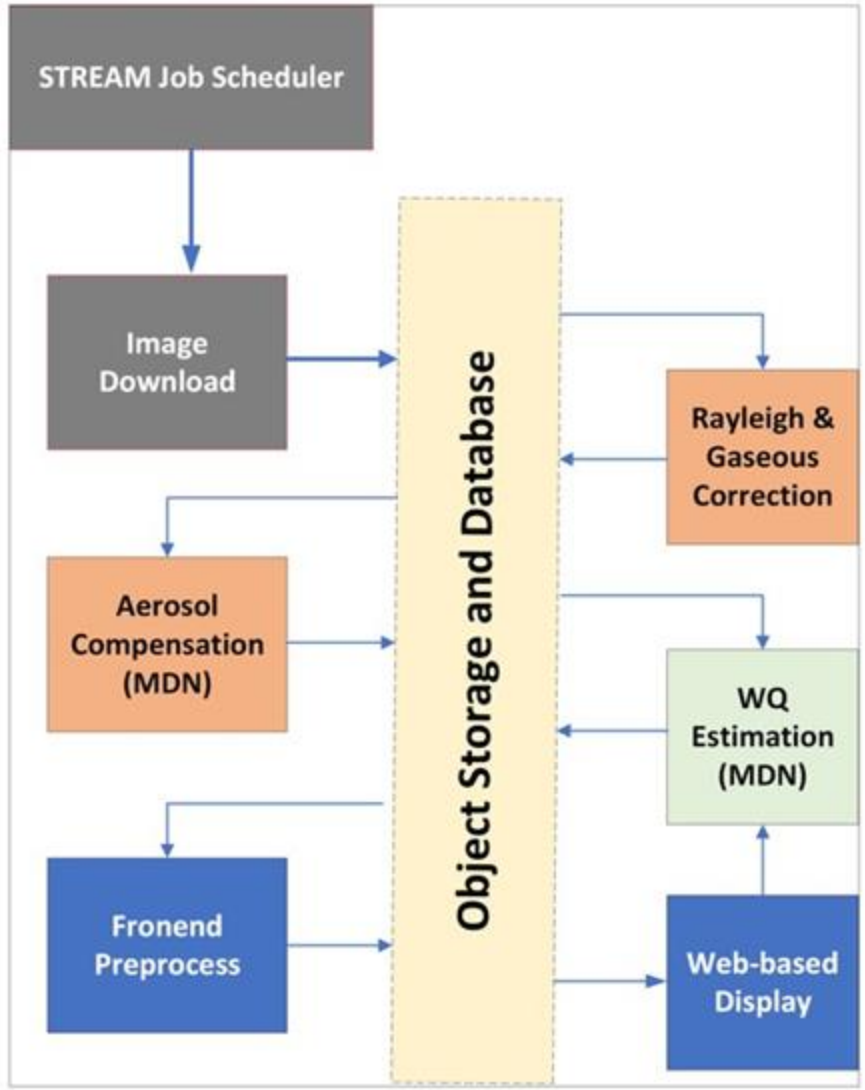
# Introduction to Satellite-based analysis Tool for Rapid Evaluation of Aquatic environMents (STREAM)

# STREAM's Processing Framework

**AQUAVERSE**: A machine-learning-centered model

- Remove Rayleigh scattering & gaseous absorption
- Compensate for aerosol
- Retrieve Chla, TSS, and Zsd



# Validation – GLORIA

- Over 7,500 Hyperspectral RRS
  - 1nm Intervals from 350-900nm
- Coastal and Inland Water Bodies
- Co-Located In-Situ Water Quality Indicators
  - Chlorophyll-a, TSS, Secchi Depth, CDOM
- Over 25 Years of Temporal Coverage

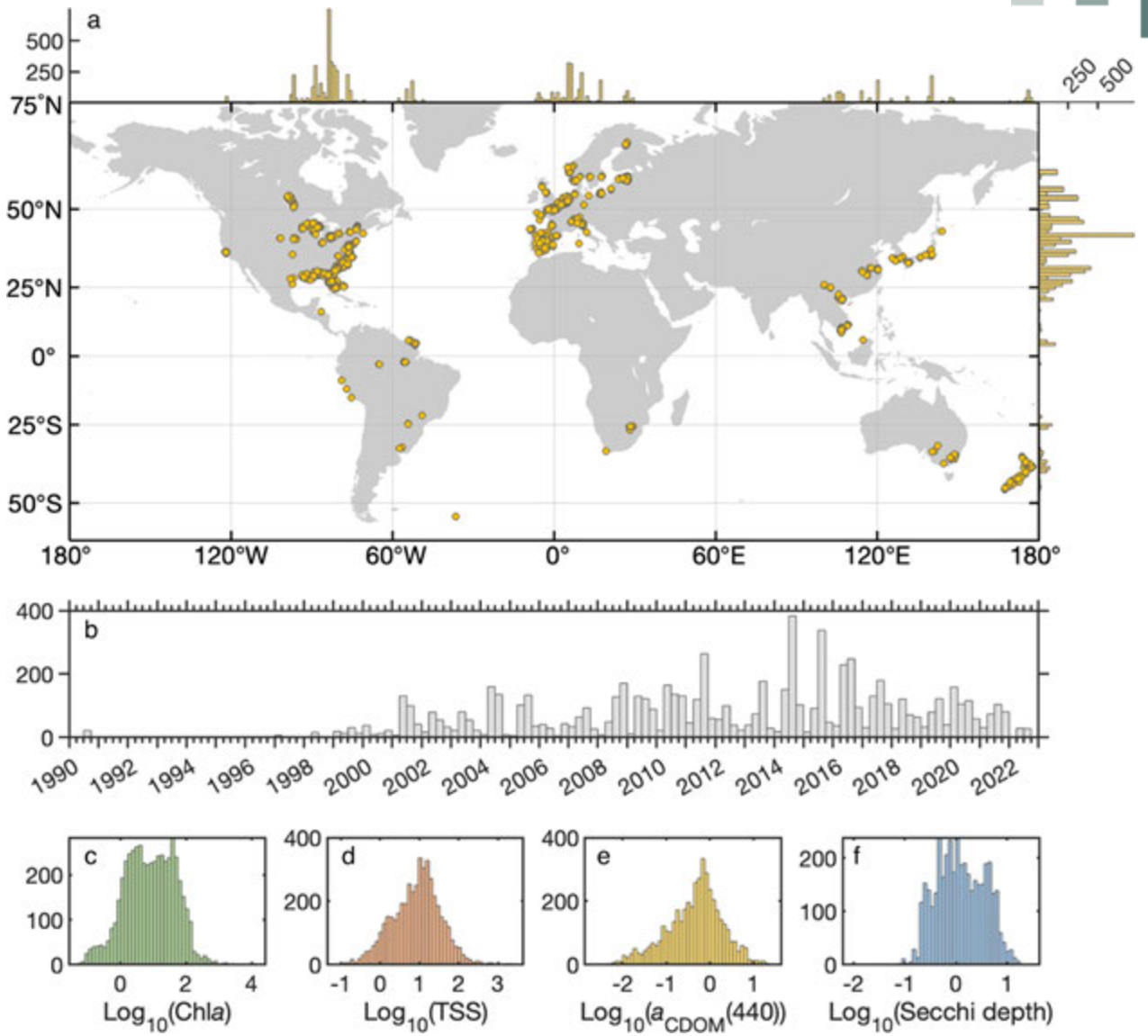
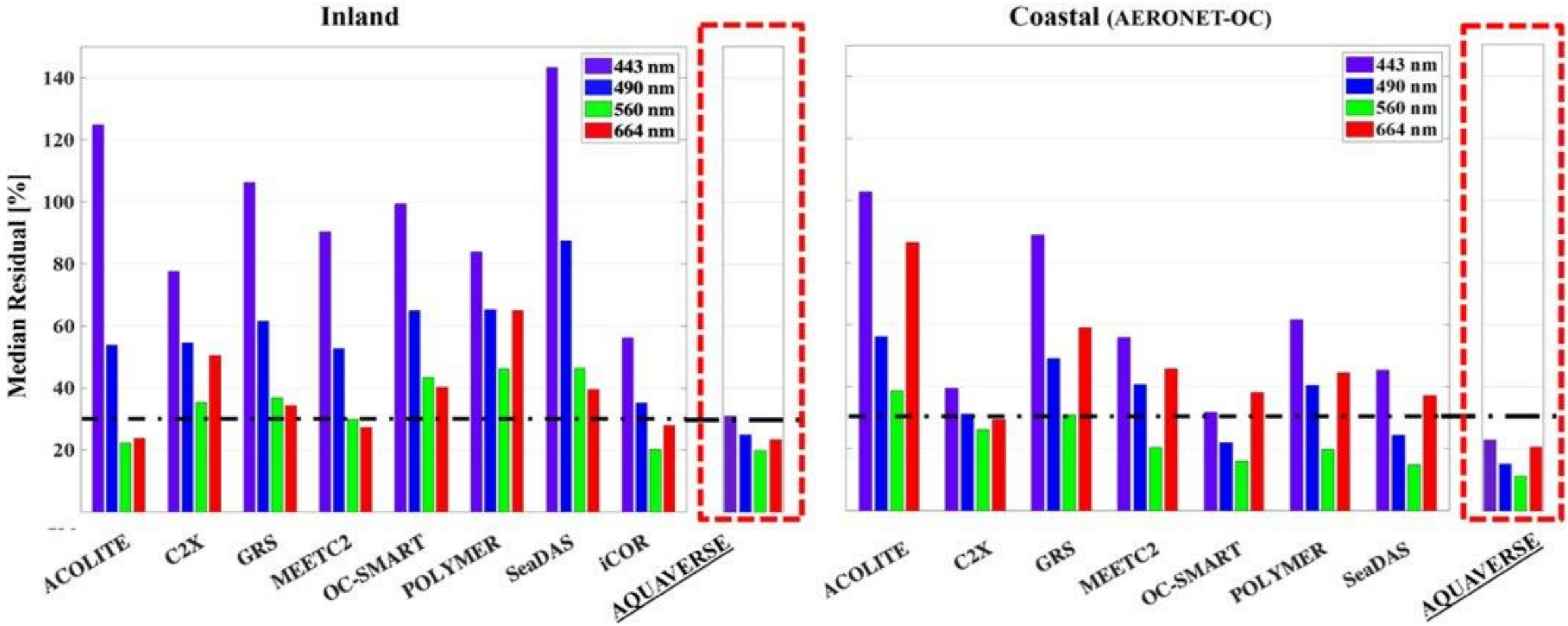


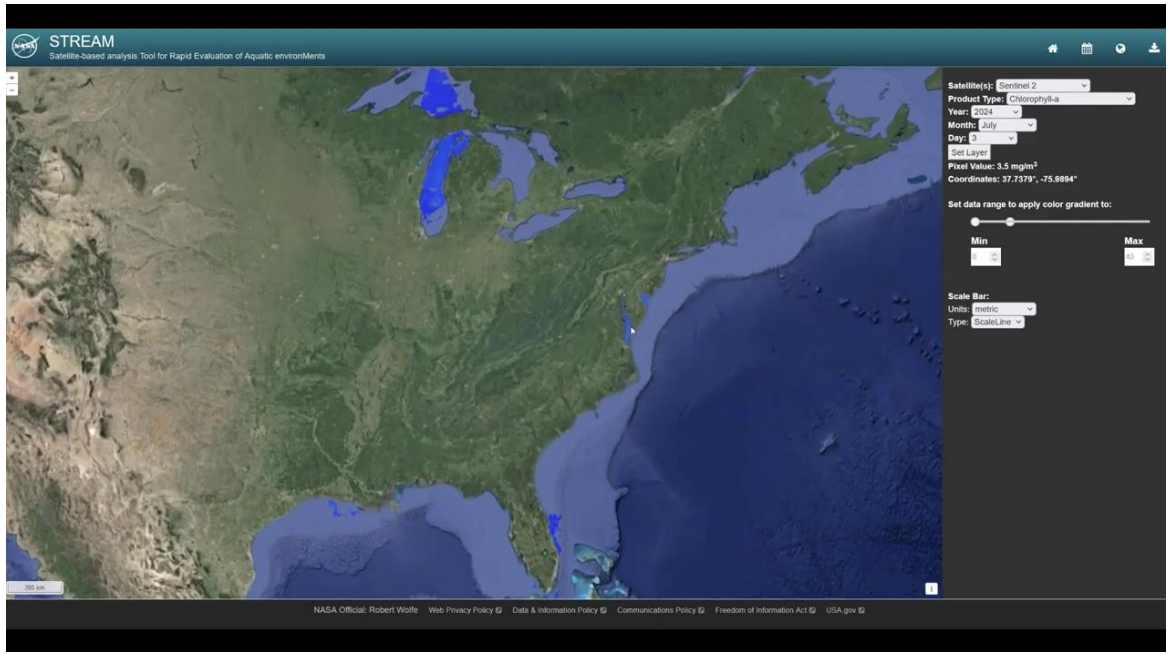

Fig. 2 – Lehmann, M.K., Gurlin, D., Pahlevan, N. et al. https://doi.org/10.1038/s41597-023-01973-y

# Performance Assessment

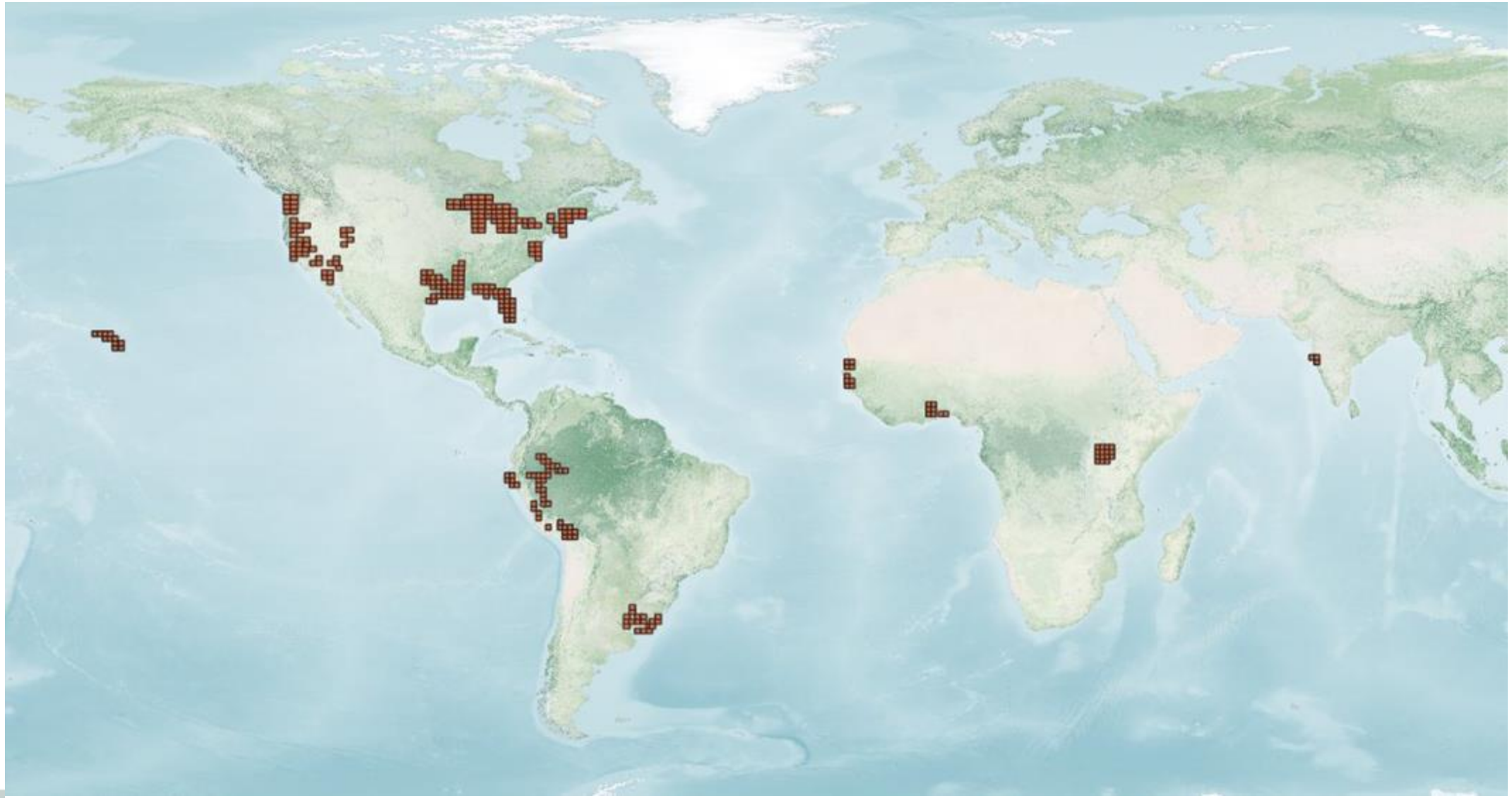


# STREAM Features

- Near-Real-Time Image Processing
  - Latency of 2-6 Hours
- Satellite Missions: Landsat 8/9 and Sentinel-2 (10–30 meters)
- Products: Chlorophyll-a, Total Suspended Solids (TSS), and Secchi Disk Depth
- Downloadable Maps (GeoTIFF)
  - Archive & Freely Available RESTful API
- Visualization
  - Interactive OpenLayers Map
- Daily Processing Since June 2024



# Spatial Coverage

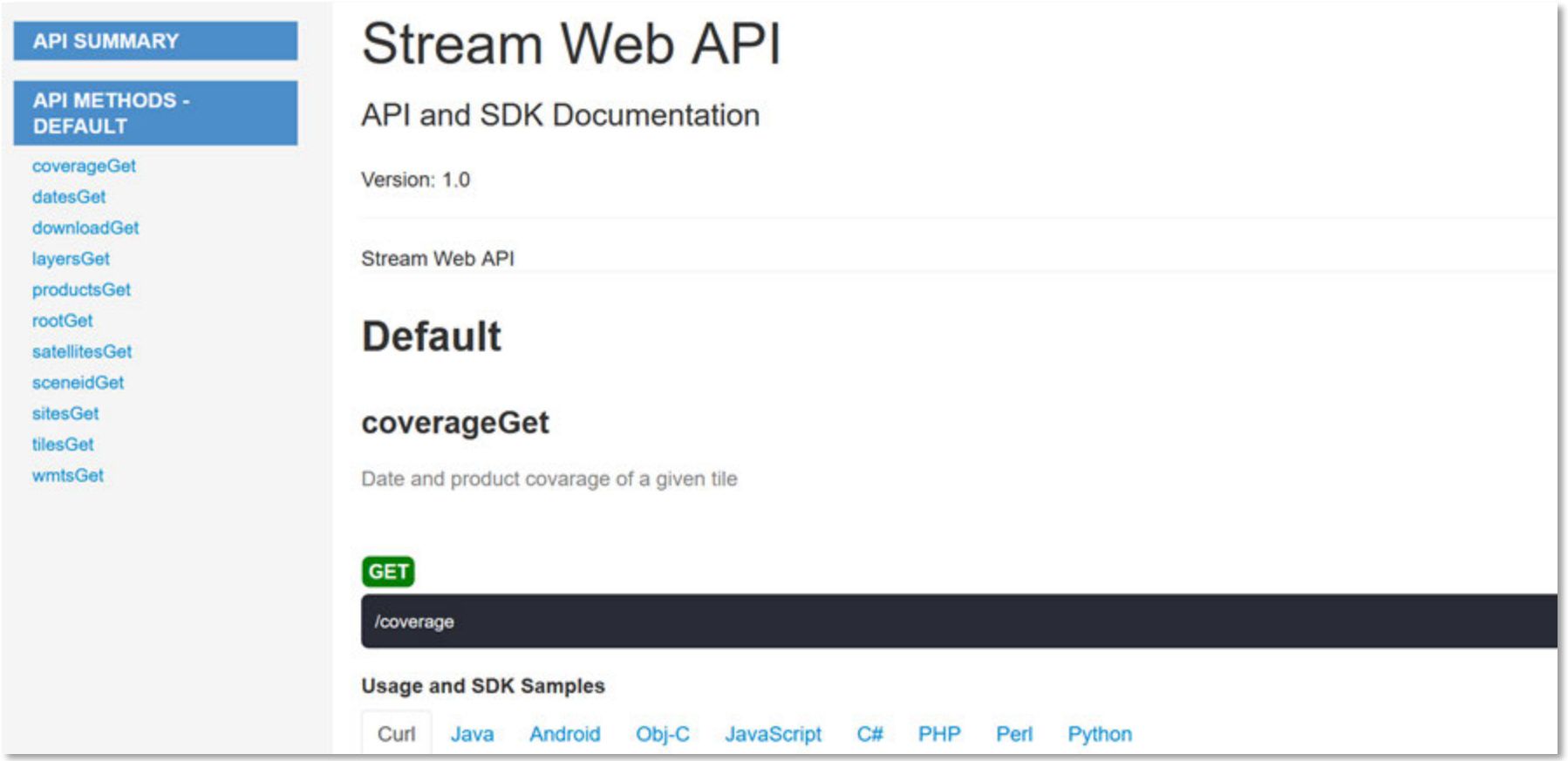


# Demonstration: STREAM Website

https://ladsweb.modaps.eosdis.nasa.gov/stream/

# Demonstration: STREAM API

https://ladsweb.modaps.eosdis.nasa.gov/stream/api



# Summary

# Recap

- Fundamentals of Remote Sensing
- Overview of Satellites and Sensors for Water Quality Monitoring, Specifically Algal Bloom and Sediments
- Introduction to Satellite-based analysis Tool for Rapid Evaluation of Aquatic environMents (STREAM)
- **NASA Worldview**: Access and Visualize Satellite Images, Sea Surface Temperature (SST), & Chlorophyll-a, Land Cover, Rainfall
- **CyAN**: Cyanobacteria Assessment Network
- **STREAM**: Monitor Chlorophyll-a Concentration, Total Suspended Solids (TSS), and Secchi Disk Depth (SDD)

# Summary: Monitoring Algal Bloom Using NASA Remote Sensing Observations

- Multiple satellites are in orbit observing costal and open oceans and inland waterbodies.
- Provide data for monitoring selected water quality parameters.
- Complement in situ measurements.
- Large amounts of data in a variety of formats, spatial & temporal resolutions, and data gaps, require specialized processing.
- Webtools and software available for easy data access, analysis, and visualization.
- ARSET provides online and in-person trainings for data access and applications.
- NASA remote sensing data, webtools, and trainings are **cost-free**.

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- ARSET Website
- Follow us on X!
  - @NASAARSET
- ARSET YouTube

# Resources

- ARSET – Fundamentals of Remote Sensing
- NASA Earthdata: Remote Sensing
- NASA Ocean Color
- NASA Sea Earth Data Analysis System (SEADAS)


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

# Thank You!