Climate Engine Virtual Workshop

Jan 25, 2023

Supporting South Florida Water Management District

Google Cloud   Climate Engine®

Contents

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1. Workshop Agenda

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Climate Engine Workshop Agenda

January 25, 2023

Time (in ET)	Wednesday, Jan 25	Section Lead
Introduction (1:00-1:05)	Workshop Introduction + Overview	Caleb White
Session 1 (1:05-1:50)	Remote Sensing & Earth Science, Level 1	Ankur Shah
Break (1:50-2:00)	Break	
Session 2 (2:00-2:45)	Remote Sensing & Earth Science, Level 1	Ankur Shah / Kristen O'Shea
Break (2:45-3:00)	Break	
Session 3 (3:00-3:45)	Remote Sensing & Earth Science, Level 1	Kristen O'Shea
Wrap Up (3:45-4:00)	Wrap Up	Caleb White

Workshops Overview

Workshop #1: January 2023

This 3-hour workshop will focus on level 1 remote sensing topics, such as an introduction to remote sensing and remote sensing of algal blooms. It will then overview the example visualization app created by Climate Engine, walking through the datasets and functionalities utilized. This session will specific to algal bloom use case(s), however there will be elements of all tracks/levels of the Climate Engine Training Hub (following slides).

Workshop #2: February 2023

This 3-hour workshop will focus on on level 1 data science topics, with a focus on Climate Engine APIs. It will dive into background on APIs and resources available (documentation, swagger page, etc). It will then focus on walking users through an example workflow utilizing Google Colab notebooks. Users are encouraged to come prepared with use cases, questions and/or applications where remote sensing could be employed in their operating environment.

Workshop #3: April 2023

This 3-hour workshop will focus on level 2 & 3 remote sensing topics that will enable attendees to explore using different remotely sensed data and derived indices for various use cases. This will include a deeper dive into the example visualization apps and hosting your own creations. Users are encouraged to come prepared with use cases, questions and/or applications where remote sensing could be employed in their operating environment.

Workshop #4: June 2023

This 3-hour workshop will focus on level 2 & 3 data science topics that will enable attendees to streamline their workflows and leverage the power of cloud computing for their analysis, modeling, and visualization efforts. Users are encouraged to come prepared with use cases, questions and/or applications where remote sensing could be employed in their operating environment.

2. Purpose

Purpose

This Climate Engine virtual workshop will enable users at the South Florida Water Management District to better understand foundational knowledge of remote sensing and potential ways integrate this data into their workflows and decision making.

We will showcase the power of bringing different types of datasets together via advanced cloud pipelines, with example visualization apps created using Earth Engine Apps. We will break down the structure of apps and how users can implement various pre-built components to suit their use cases.

3. Instructor Introduction

Kristen O'Shea

Kristen O'Shea is a Geospatial Data Scientist that has worked on a wide-variety of environmental projects domestically & abroad. A generalist at heart, she has mapped wild rice in the midwest US, developed restoration prioritization tools for coffee-landscapes in South America and Southeast Asia, explored biodiversity and ecosystem health in fashion commodity sourcing regions world-wide. She specializes in spatial analysis, modeling, and creating visualizations that enable decision makers to make informed management and organizational decisions.

Ankur Shah

Ankur is a Geospatial Data Scientist at Climate Engine who assists the team with product development and environmental research. Before joining Climate Engine, he worked with a team of NASA on Earth observation projects such as detecting floating marine debris and identifying aircraft contrails using satellite imagery. Ankur holds a BSc in physics and Earth science from the University of Alabama in Huntsville. He frequently produces informative videos on environmental topics on his YouTube channel. He is passionate about natural climate solutions, sustainable urban design, and environmental education.

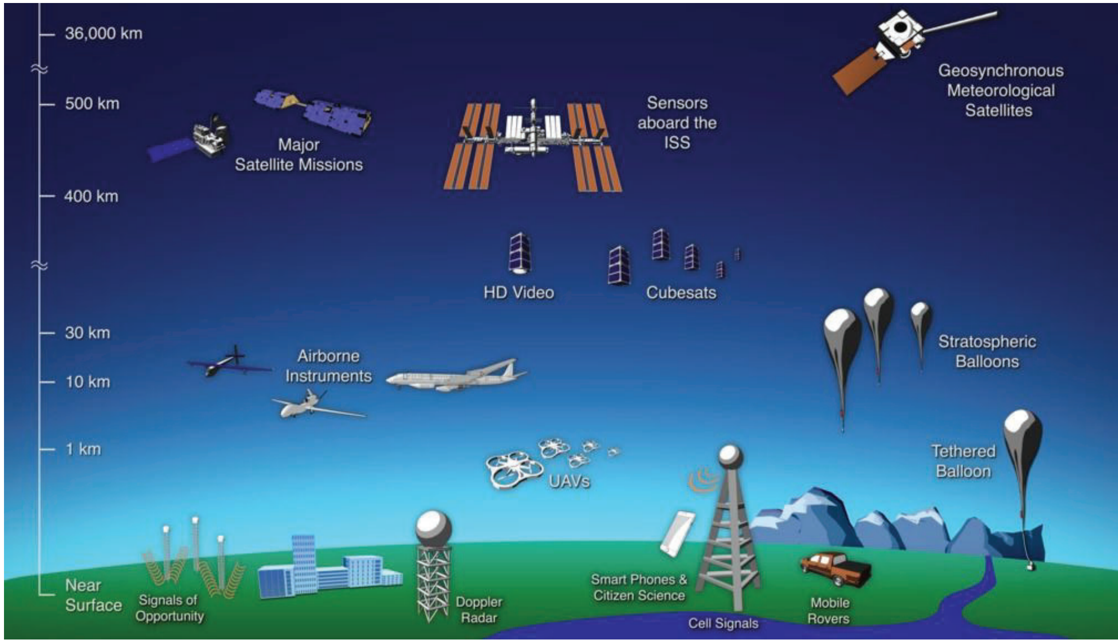
4. Workshop Materials

Section 1: Leveraging Remote Sensing for Environmental Applications (~45 min)

Introduction to Remote Sensing

Remote sensing is the science and process of the measurement of a object **without** physical contact.

This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be identified and categorized by class/type, substance, and spatial distribution.

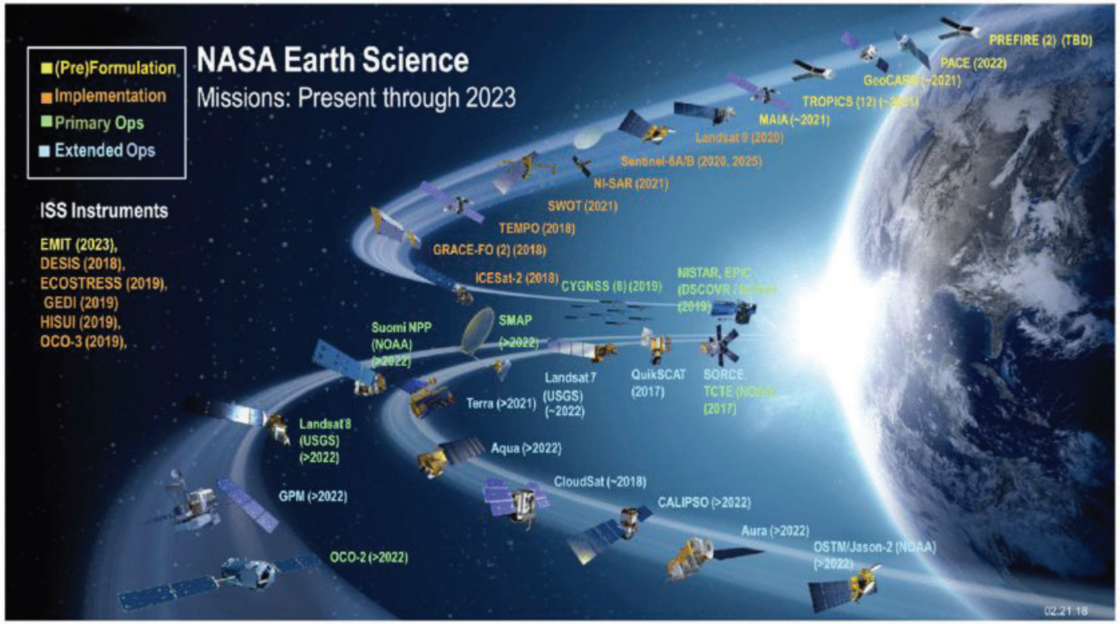


Remote Sensing, Credit: *Amy Moran, Matthew Rodell, NASA's Goddard Space Flight Center*

NASA Satellites for Earth Observation (EO)

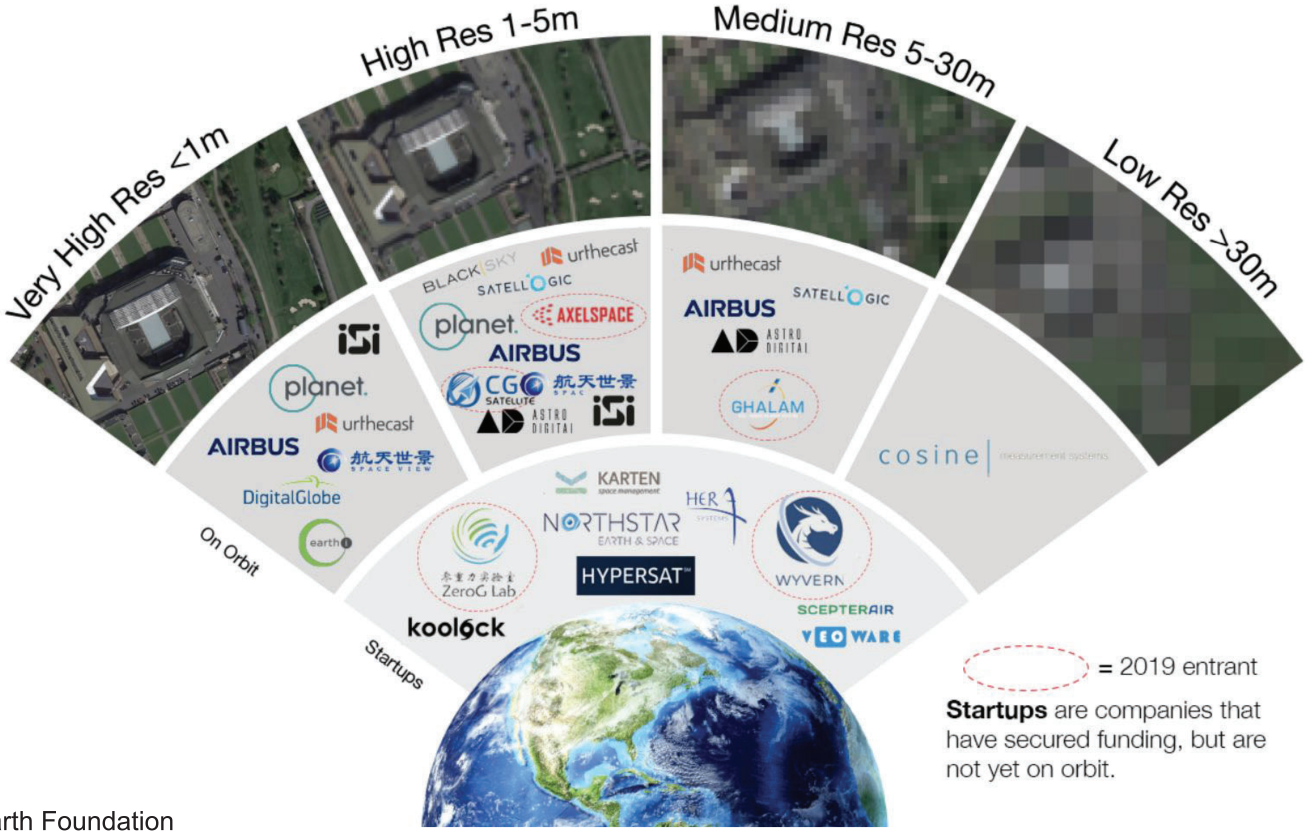
Platforms for live tracking of satellites:

- NASA Eyes platform for live NASA satellites
- Astria Graph for Real Time Space Objects Map
- Low Earth Orbit Tracking by LeoLabs

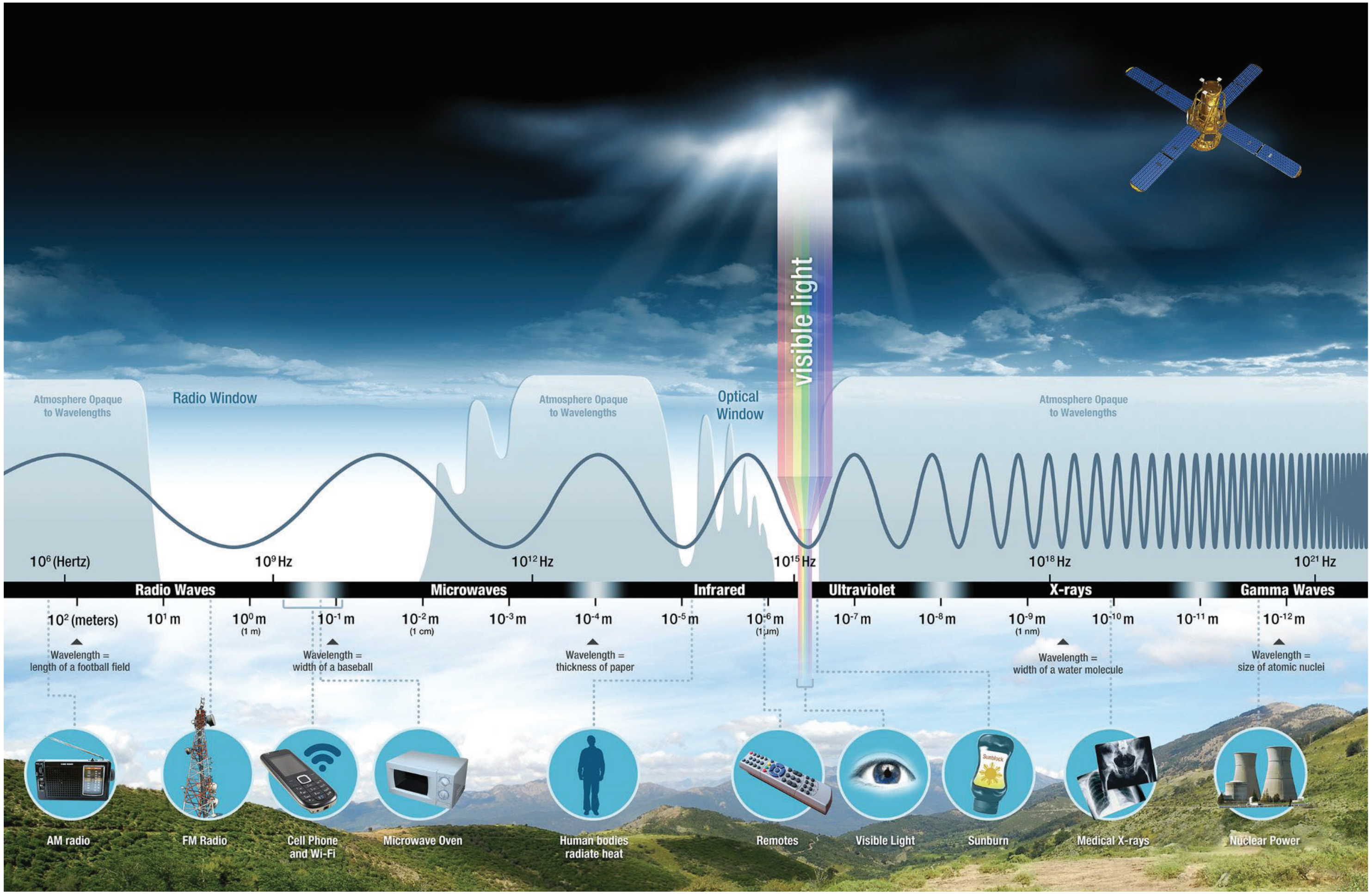


Remote Sensing, Credit: *NASA's Goddard Space Flight Center*

Commercial Satellites for EO



Credit: Radiant Earth Foundation

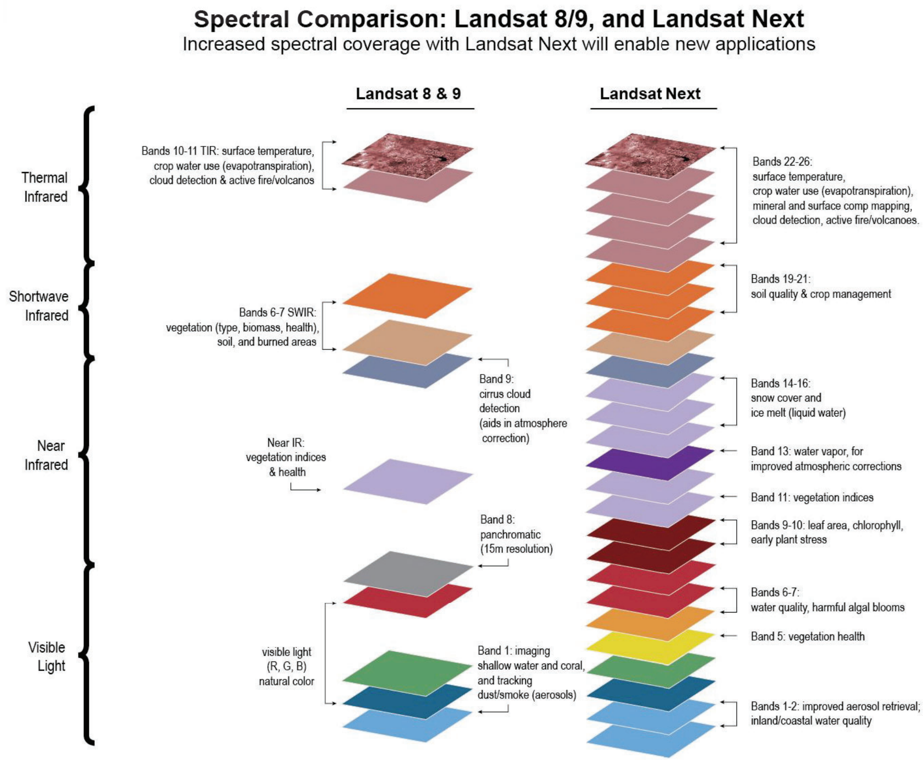


Electromagnetic Spectrum, Credit: *NASA Science*

Introduction to Remote Sensing

The primary wavelengths of interest for Earth science are microwaves, infrared, and visible light.

Satellites use **bands** which are wavelength ranges for observing specific features.



Credit: *NASA Landsat*

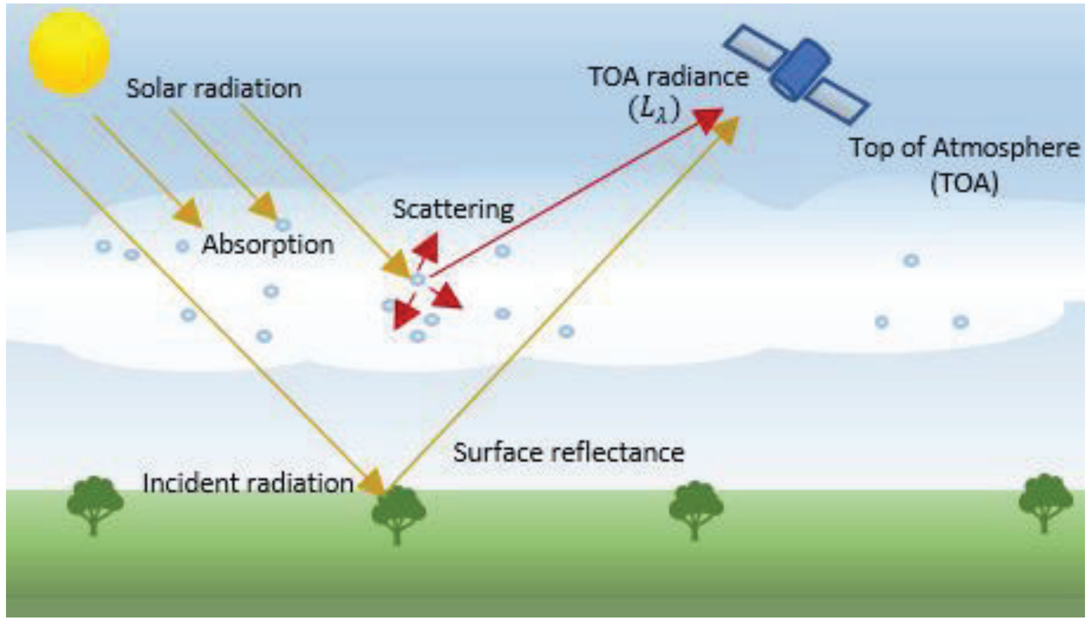
Physical Quantities in Remote Sensing

Radiance - the radiation emitted or reflected by an object

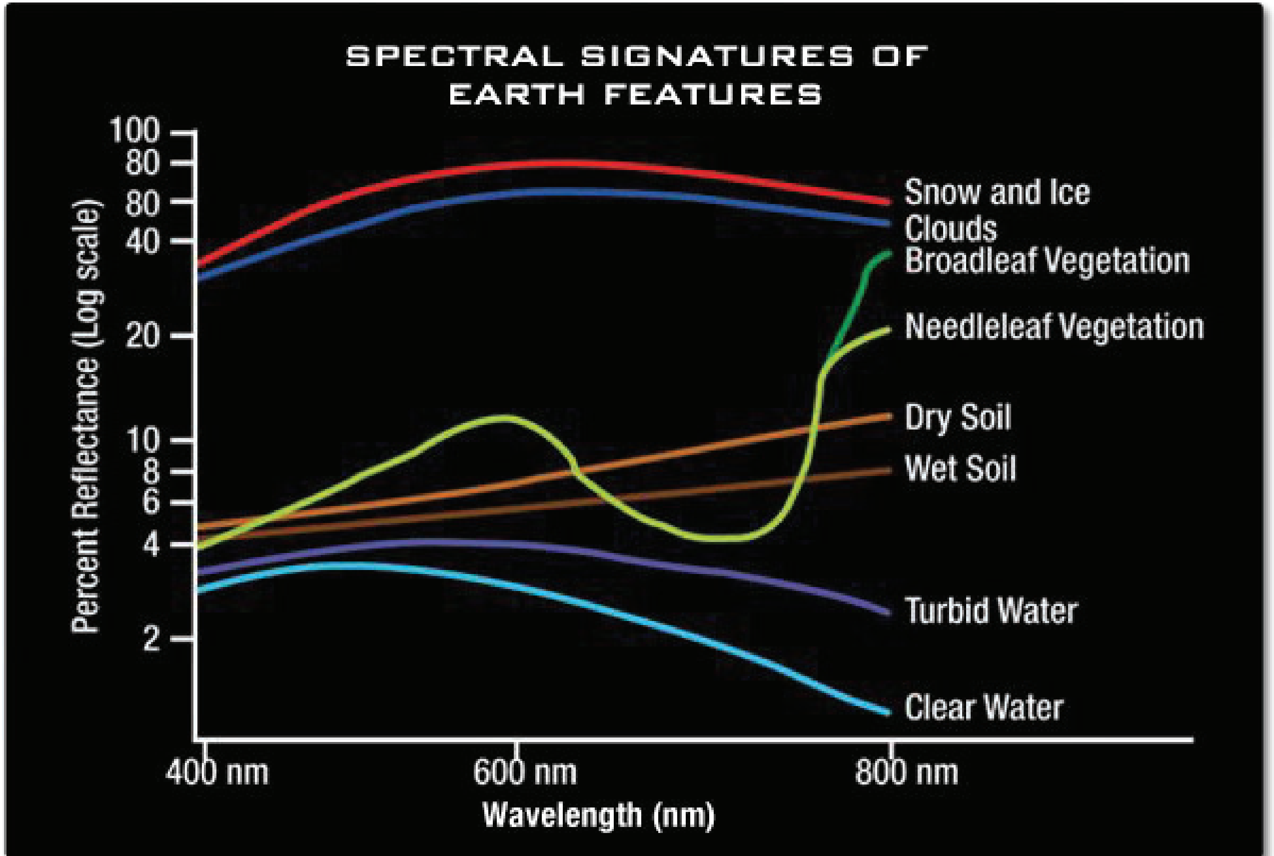
TOA Reflectance - the reflected radiation reaching the sensor from the Top of Atmosphere (TOA)

Surface Reflectance - the incident radiation reflected by the surface

Read more on the physics of remote sensing [here](#).



Physical Path of Radiation, Credit: Mathworks



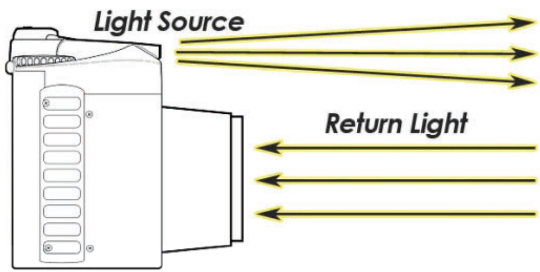
Credit: Jeanie Allen, *NASA Science*

Active vs. Passive Remote Sensing

Active Sensors

- Active sensors have their own source of radiation or illumination
- Sends a pulse and measures the reflected backscatter

Examples include camera with flash, SAR

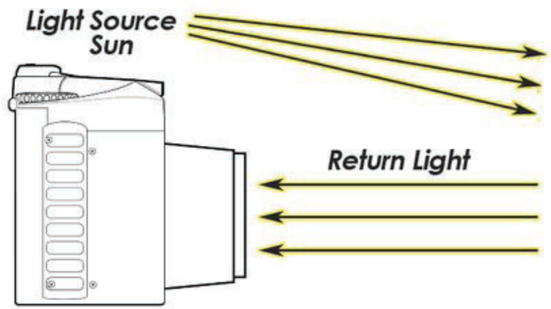


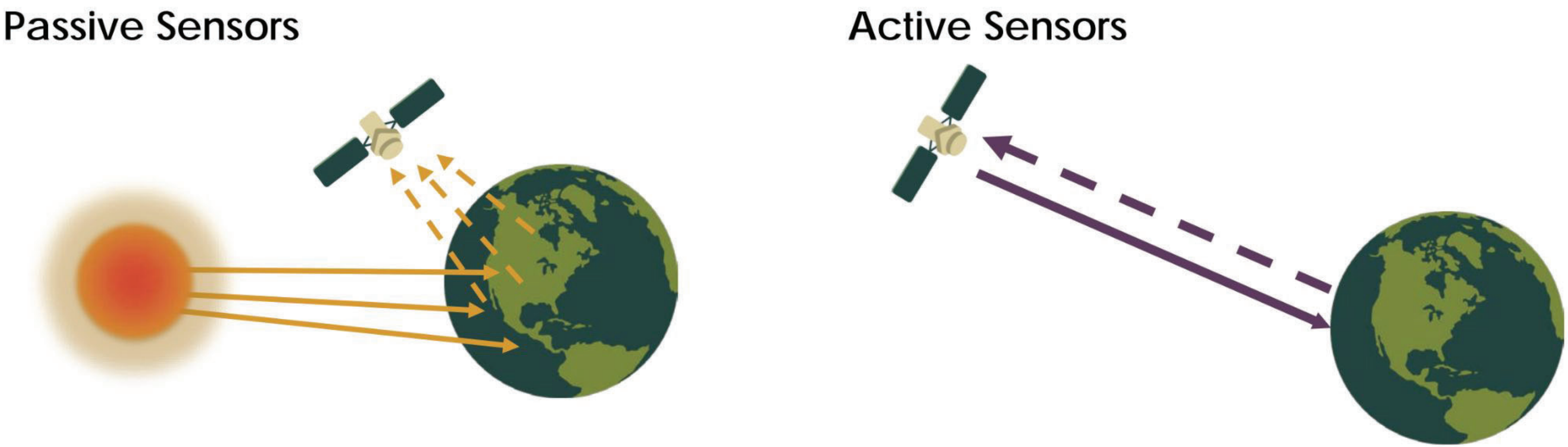
Credit: GISGeography

Passive Sensors

- Passive sensors use reflected or emitted radiation from the object as they do not have a source of illumination
- Use light from other sources (sun)

Examples include MODIS, LANDSAT, Optical sensors





Credit: *NASA Applied Sciences Remote Sensing Training Program (ARSET)*

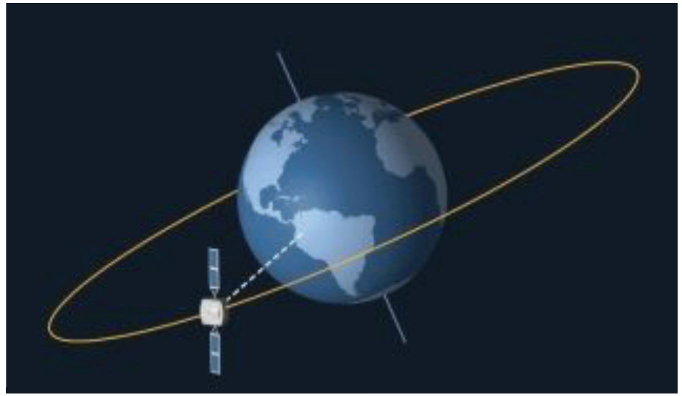
Resource for fundamentals of remote sensing by NASA ARSET

What is Resolution?

Resolution plays a role in how data from a sensor can be used. It primarily refers to the level of detail the imagery can provide. Resolution can vary depending on the satellite's orbit and sensor design.

There are four types of resolution to consider for any dataset:

1. Radiometric
2. Spatial
3. Spectral
4. Temporal

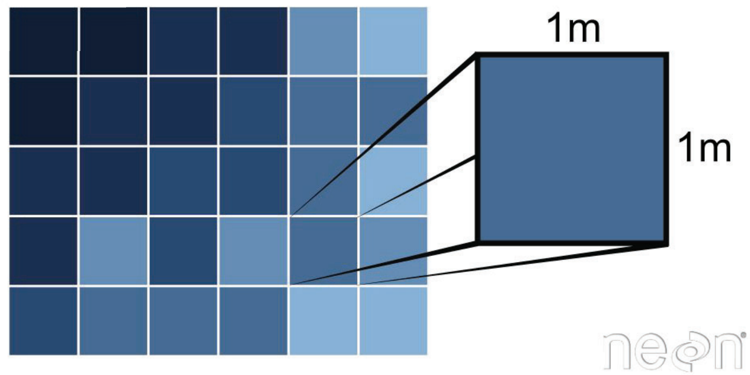


Credit: *NASA Science*

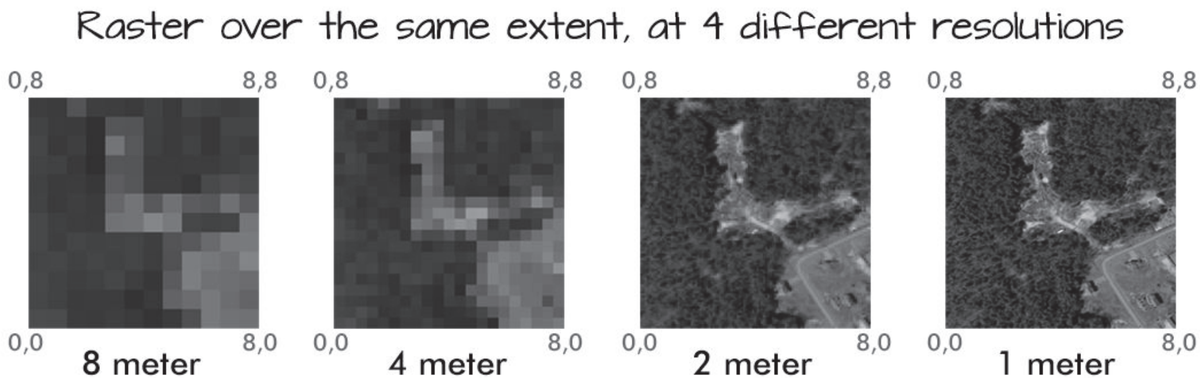
Spatial Resolution

Spatial resolution is the **size** of each pixel in units of distance. It represents the spatial extent of a pixel. In other words, it is the size of the smallest feature that can be detected by a satellite.

The lower the resolution, the coarser the image and higher the value of the resolution + vice versa.



Credit: National Ecological Observation Network (NEON)

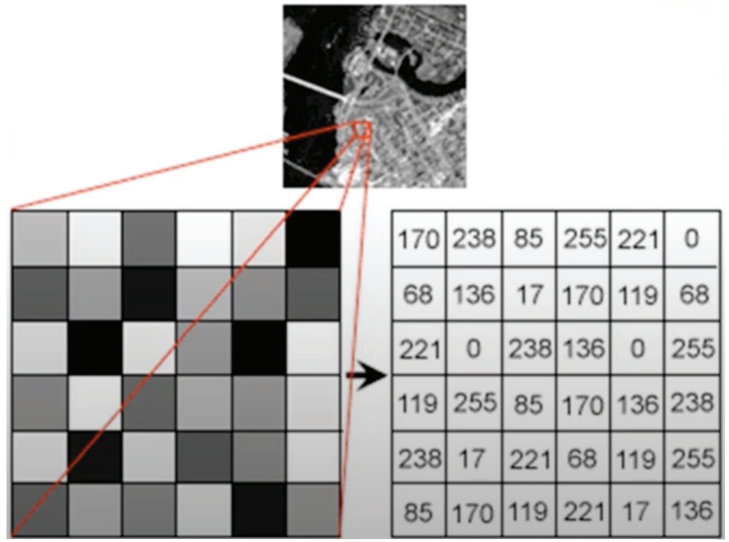


Landsat 8 image of Reykjavik, Iceland, acquired July 7, 2019, illustrating the difference in pixel resolution. Credit: NASA Earth Observatory.

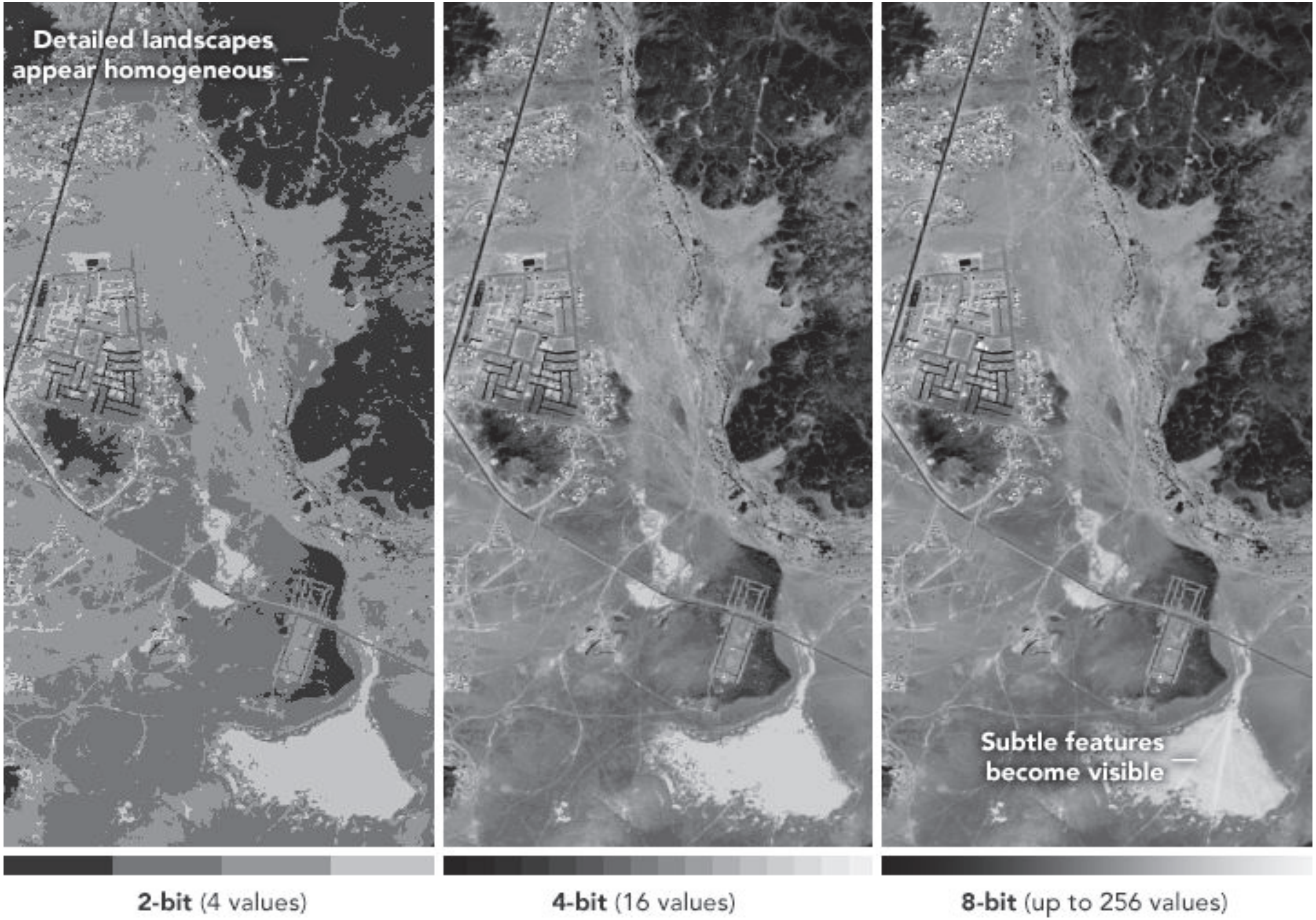
Radiometric Resolution

Radiometric resolution is the **amount of information** in the image, that is, the number of bits representing the energy recorded. Pixel values are stored as Digital Numbers (DN) and then converted to radiance. The higher the radiometric resolution, the larger the range of DNs.

For x bits, there are 2^x values which can be stored in a pixel. For instance, an 8-bit image will have 2^8 or 256 values ranging from 0 to 255.



Credit: *Remote Sensing Basics Presentation* by Crooked Contours



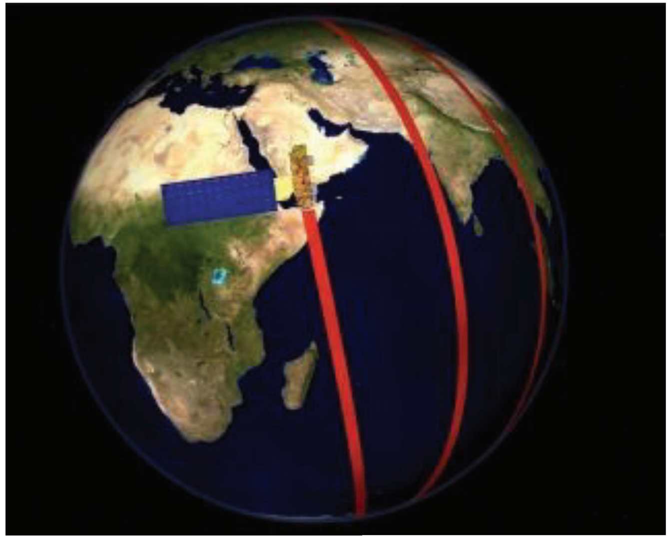
Landsat 8 image of Reykjavik, Iceland, acquired July 7, 2019, illustrating the difference in pixel resolution. Credit: NASA Earth Observatory.

Temporal Resolution

Temporal resolution is the measure of frequency or repeat cycle where the sensor returns to the same part of Earth's surface.

If temporal resolution is 3 days then object revisits or recaptures same region after 3 days. Satellites can also be in constellations (eg. Sentinel-2, Sentinel-3) which can reduce revisit time depending on the number of satellites.

Aligning revisit time with field sampling will enable robust validation and combination of in-situ and remote data collection.



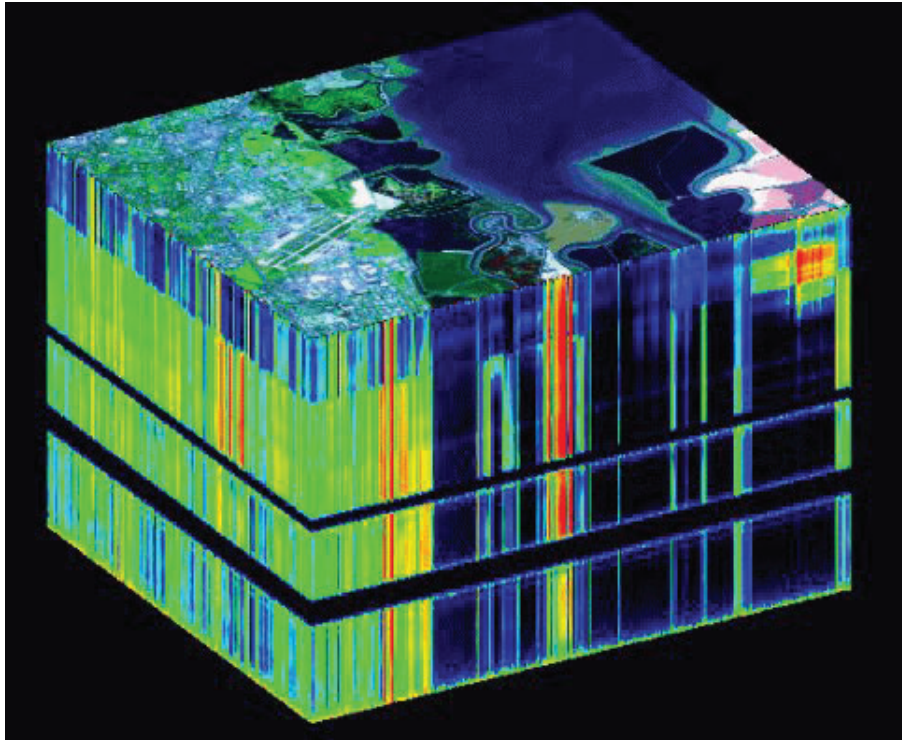
Credit: *NASA Aqua*

Spectral Resolution

The spectral resolution refers to the number of spectral bands in a sensor. The higher the spectral resolution, the more bands the sensor possesses.

There are two main types of sensors based on their spectral resolution:

1. Multispectral - generally 3-10 bands
2. Hyperspectral - hundreds to thousands of bands



AVIRIS spectral channels in a cube Credit: *NASA JPL*

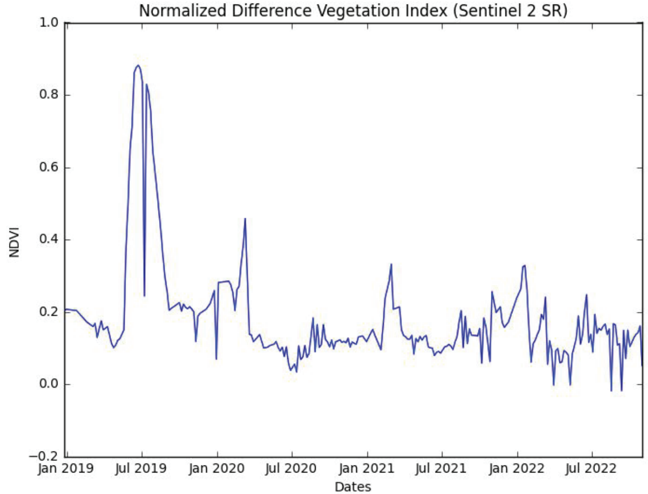
Resolution Tradeoffs for Sensor Selection

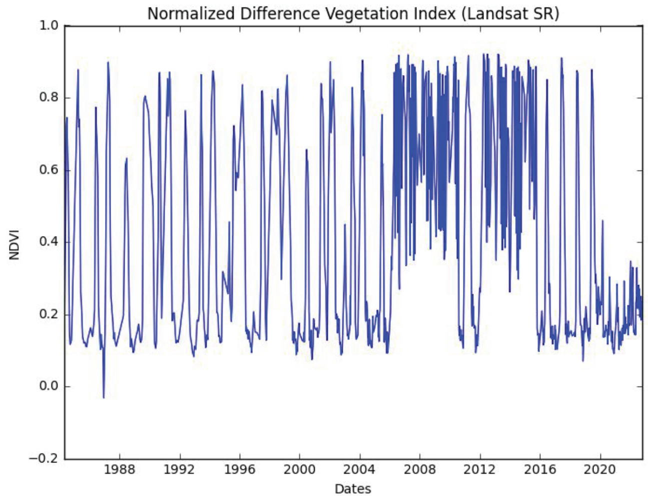
1. Higher spatial and radiometric resolution consume more memory/storage presenting logistical challenges for large areas + high costs

2. Low spatial resolution is fine for large-scale and global analyses or monitoring

3. High temporal resolution is favorable for capturing fast changing dynamics

4. Higher spectral resolution is ideal for distinguishing between species of algae since the band widths are smaller and more exacting, whereas current lower spectral resolution sensors have higher spatial coverage





Sensors | Landsat

Specifications:

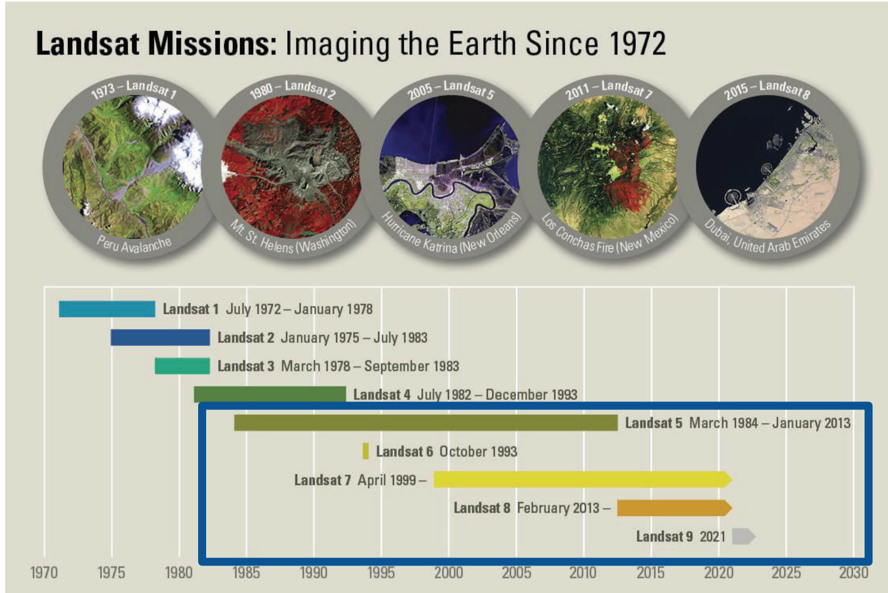
Spatial resolution: 30 meters

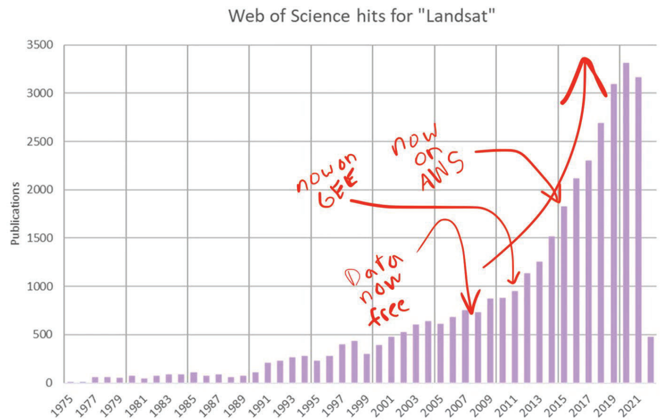
Temporal resolution: 16 days

Period of record: 1984–present

Details:

- NASA/USGS mission
- Longest continuous space-based record of Earth's surface
- Trade-off between spatial and temporal resolution—common to all sensors.
  - Cloud cover can be a challenge
- Temporal resolution higher when multiple satellites are active
- There is increasing interest in Landsat 1, 2, 3, 4, but it is challenging to work with





Credit: Joe Morrison, Umbra

Sensors | MODIS

Specifications:

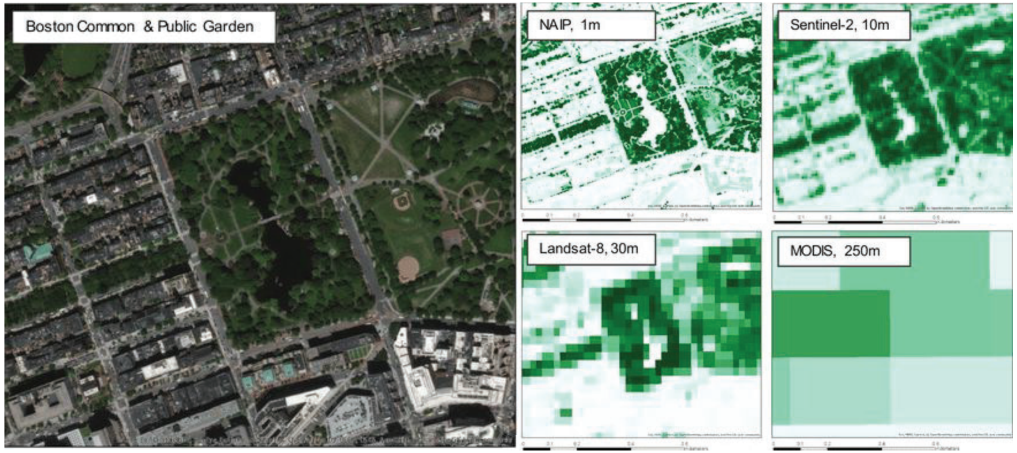
Spatial resolution: 250-1000 meters

Temporal resolution: 1-2 days

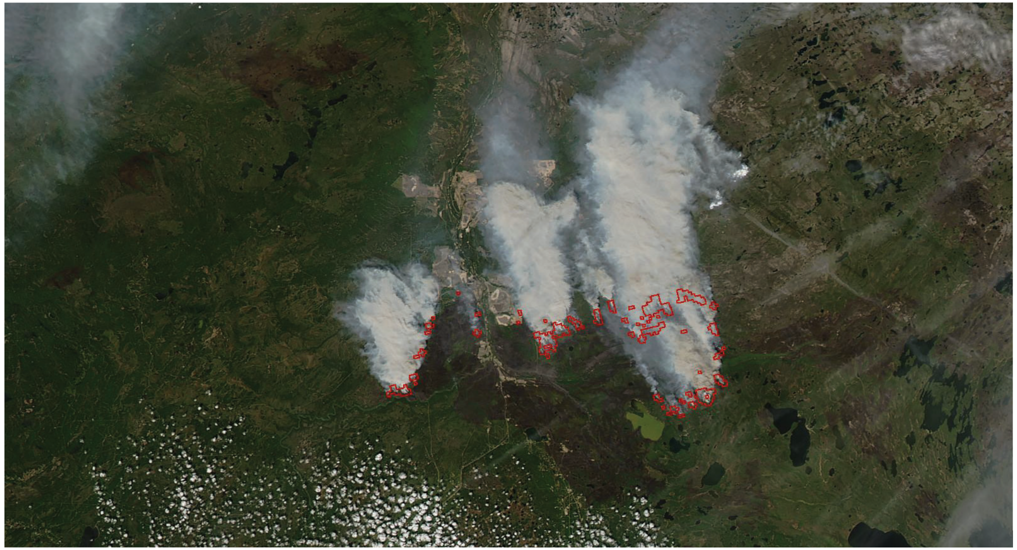
Period of record: 2000–present

Details:

- NASA
- Coarser resolution than Landsat, but captures more of the EM spectrum—36 bands
- Frequent revisit time makes it useful to:
  - Fuse with Landsat
  - Monitor in near-real time (fire, agriculture, etc.)



Credit: Raquel B. Jimenez, Boston University



Credit: Joe Schmaltz, NASA

Sensors | Sentinel-2

Specifications:

Spatial resolution: 10-20 meters

Temporal resolution: 5 days

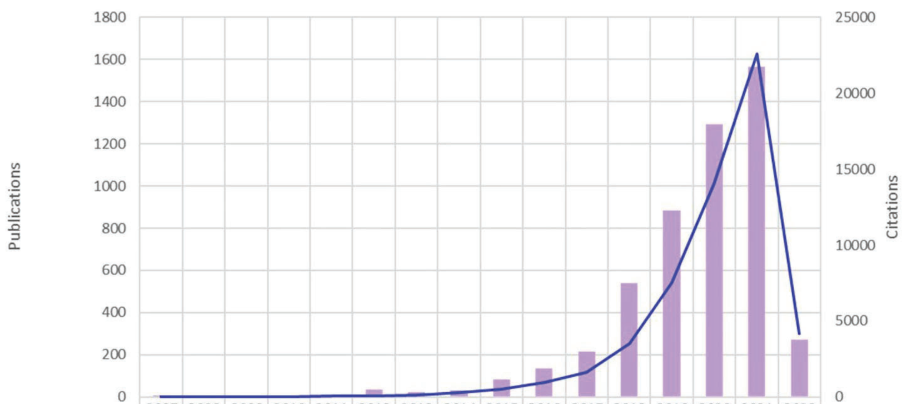
Period of record: 2015–present

Details:

- European Space Agency (ESA) mission
- Compatible with and similar to Landsat, in many ways
    - 13 bands
- Two satellites (Sentinel-2A and B) in orbit
- Other Sentinel satellites collect thermal data and synthetic aperture radar (SAR)

Credit: Freie Universität Berlin

Web of Science hits for "Sentinel-2"



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Publications	5	3	7	6	8	35	24	30	83	134	216	538	885	1294	1563	272
Citations	2	2	13	28	40	80	136	280	521	933	1626	3543	7541	14049	22594	4196

Credit: Joe Morrison, Umbra

Sensors | Sentinel-3

Specifications:

Spatial resolution: 300 meters

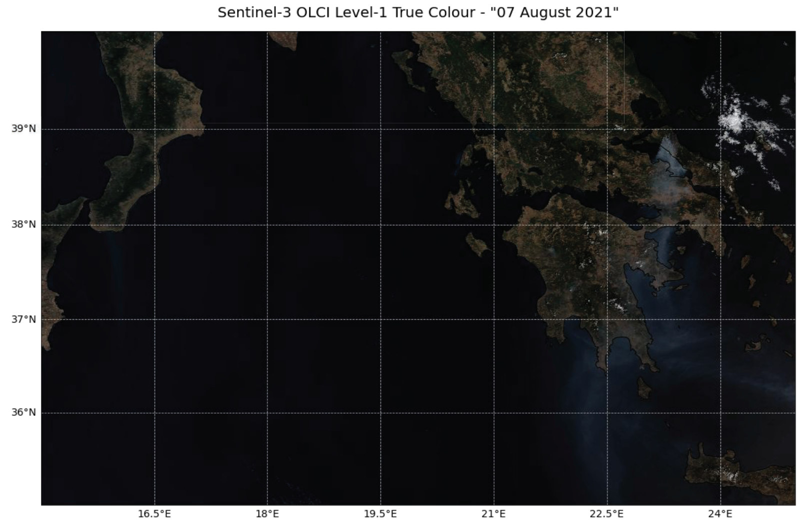
Temporal resolution: 2-3 days (Sub-cycle)

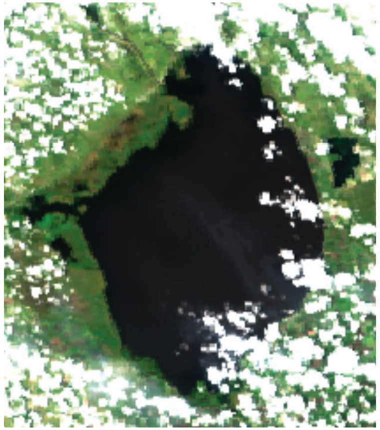
[More information here]

Period of record: 2016–present

Details:

- European Space Agency (ESA) mission
- Made for measuring land and ocean surface temperature, color, water quality
- Two satellites (Sentinel-3A and B) in orbit
- Other Sentinel satellites collect thermal data and synthetic aperture radar (SAR)





Use Cases of Each Satellite

Landsat	MODIS	Sentinel-2	Sentinel-3
• Long-term monitoring • Seasonal Vegetation health • LST trends • Trend analyses	• Daily Monitoring • Fire monitoring • LST • Longer-term monitoring • Air quality • Cloud cover • Climate variables	• Red Edge for vegetation/vegetative stress • Crop monitoring on shorter time-scales • Coastal/Lake pollution	• Monitoring Water Quality • Phenology of Marine and Terrestrial Biomass • Aerosols Characterization

Interactive Session

Q & A

- NASA CSDA list/ use cases, NASA Earthdata and Worldview explorer, ESA explorer
-

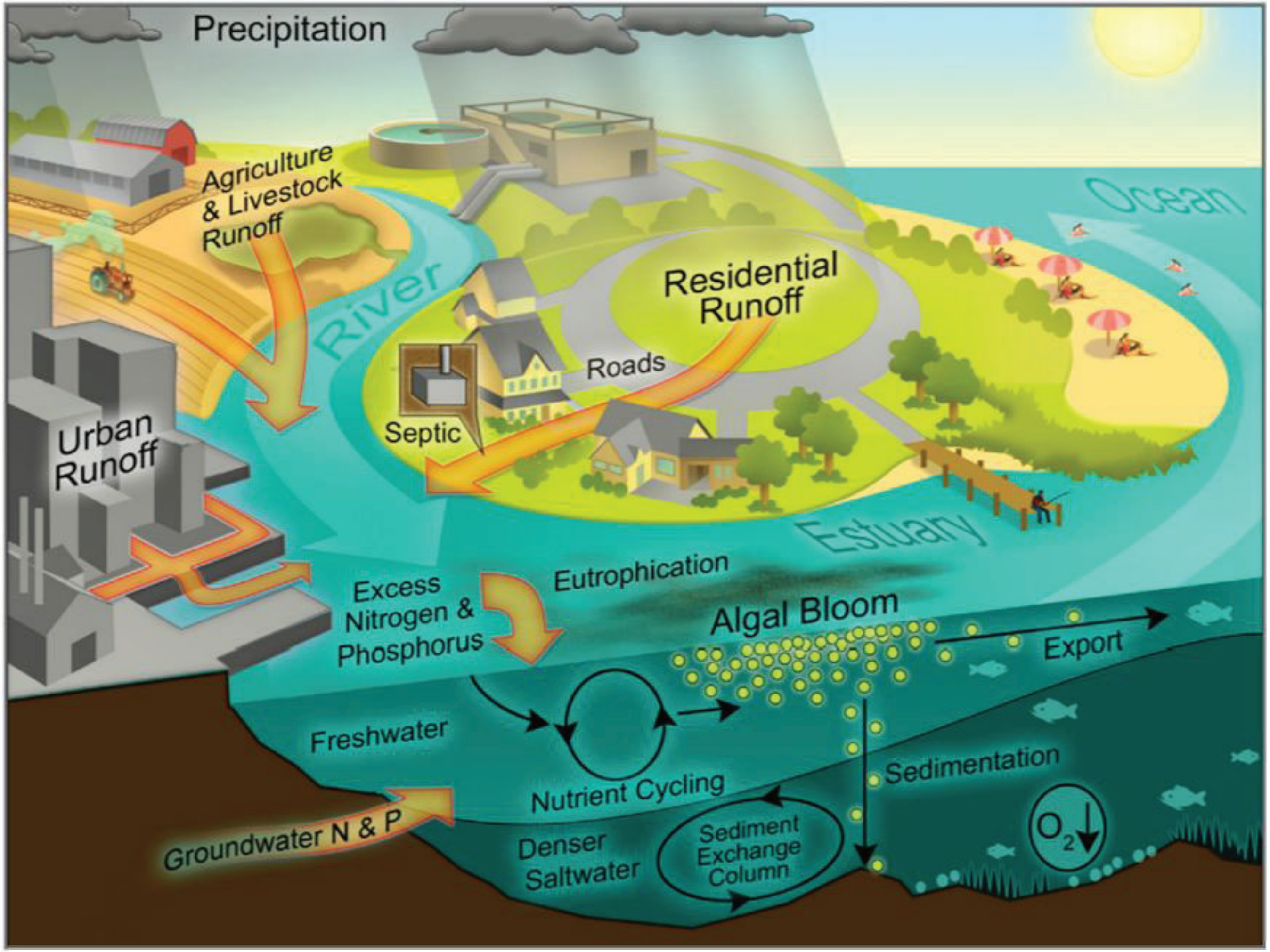
Section 2: Remote Sensing of Algal Blooms (~45 min)

Brief Overview of Algal Blooms and Causes

Harmful algal blooms are excessive growth of macroalgae and cyanobacteria on water bodies. They occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds.

HABs occur naturally, but human activities which disturb or damage ecosystems seem to play a role in their more frequent occurrence and intensity. Primary causes include:

1. Increased nutrient loadings and pollution (increased phosphorus+nitrogen)
2. Food web alterations
3. Increase in water temperature - blooms more likely to occur in summers/fall
4. Water flow modifications - lower flow enables growth of algae
5. Changes in water conditions such as pH and turbidity



Credit: A. Joyner UNC-CH Institute of Marine Sciences

Impact of Algal Blooms

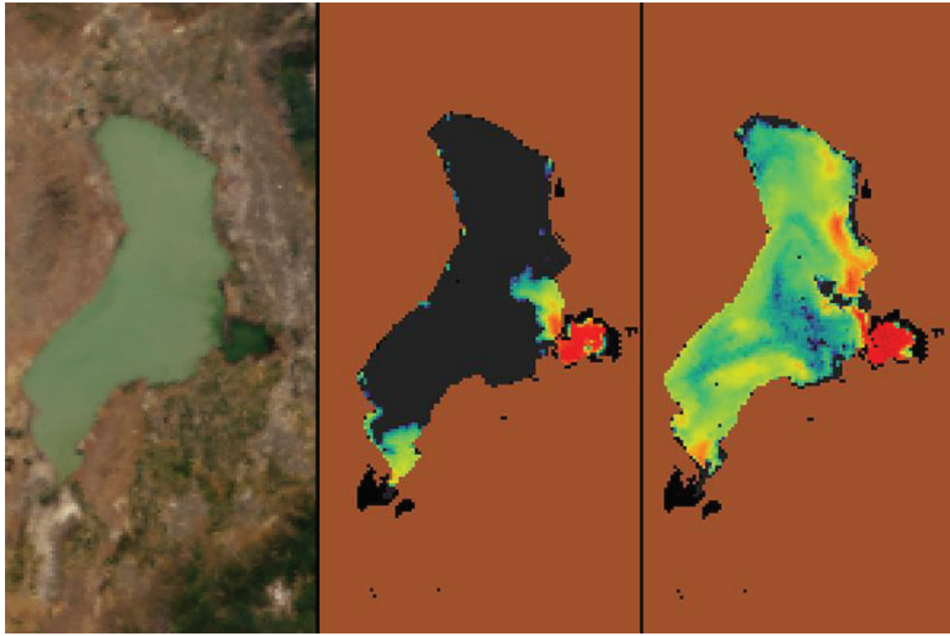
Blooms have the following impacts:

- Produce toxins which can harm health
- Contaminate drinking water
- Deplete oxygen causing hypoxia
- Impede visual predators leading to food web disruptions
- Attenuate light to benthic submerged aquatic vegetation or corals
- Cause economic losses by inhibiting transportation, tourism, health impacts on the local population

Remote Sensing of Algal Blooms

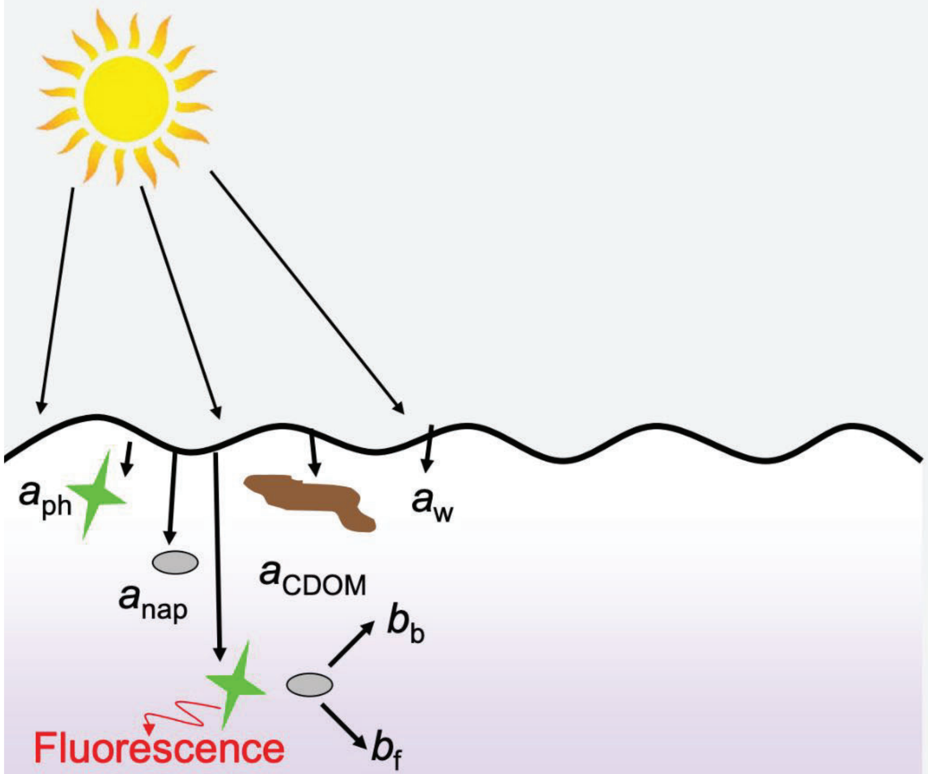
Algal blooms can be remotely sensed using chlorophyll, chlorophyll-a anomalies and inherent optical properties of algae and cyanobacteria.

Using specific wavelengths, indices can assist in visualization and monitoring of algae blooms.



Utah Lake, as seen by satellite in true color (left) and with satellite-derived data of cyanobacteria concentrations from the Copernicus Ocean and Land Colour Instrument on Sentinel-3A taken 21 June (middle) and 3 July 2017 (right). Cyanobacteria concentrations are represented using a color scale ranging from blue (low concentrations) to red (high concentrations).
Credit: Cyanobacteria Assessment Network

Physical Path of Radiation



$$R_{rs}(\lambda,0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Inherent Optical Properties

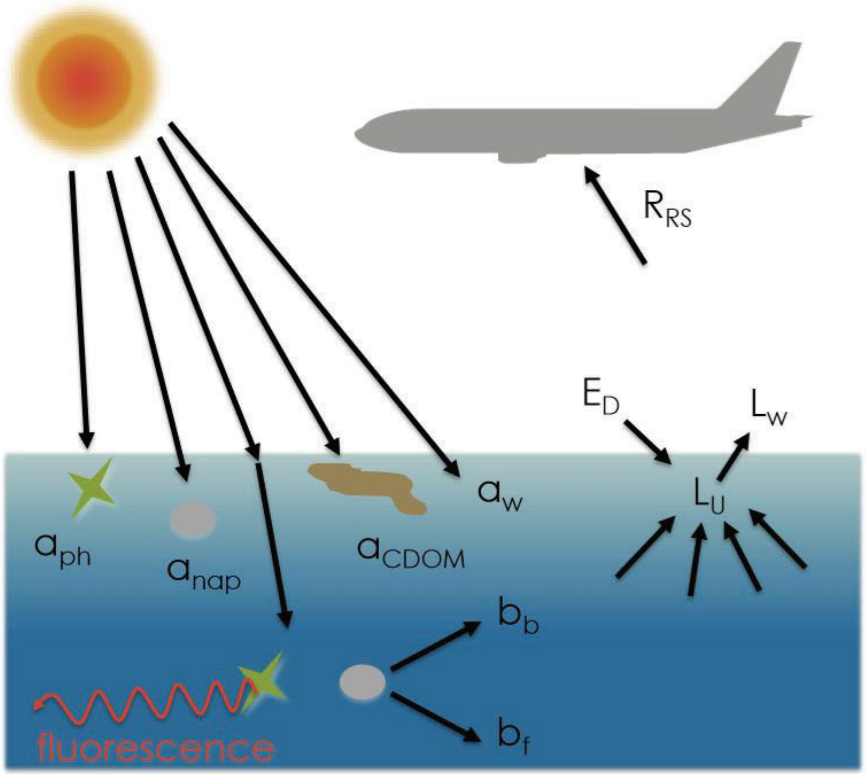
a = absorption by…

- phytoplankton (ph)
- non-algal particles (nap)
- colored dissolved organic matter (CDOM)
- water (w)

b = scattering in forward (f) and backward (b) directions

Credit: NASA ARSET

How Light Interacts with Water

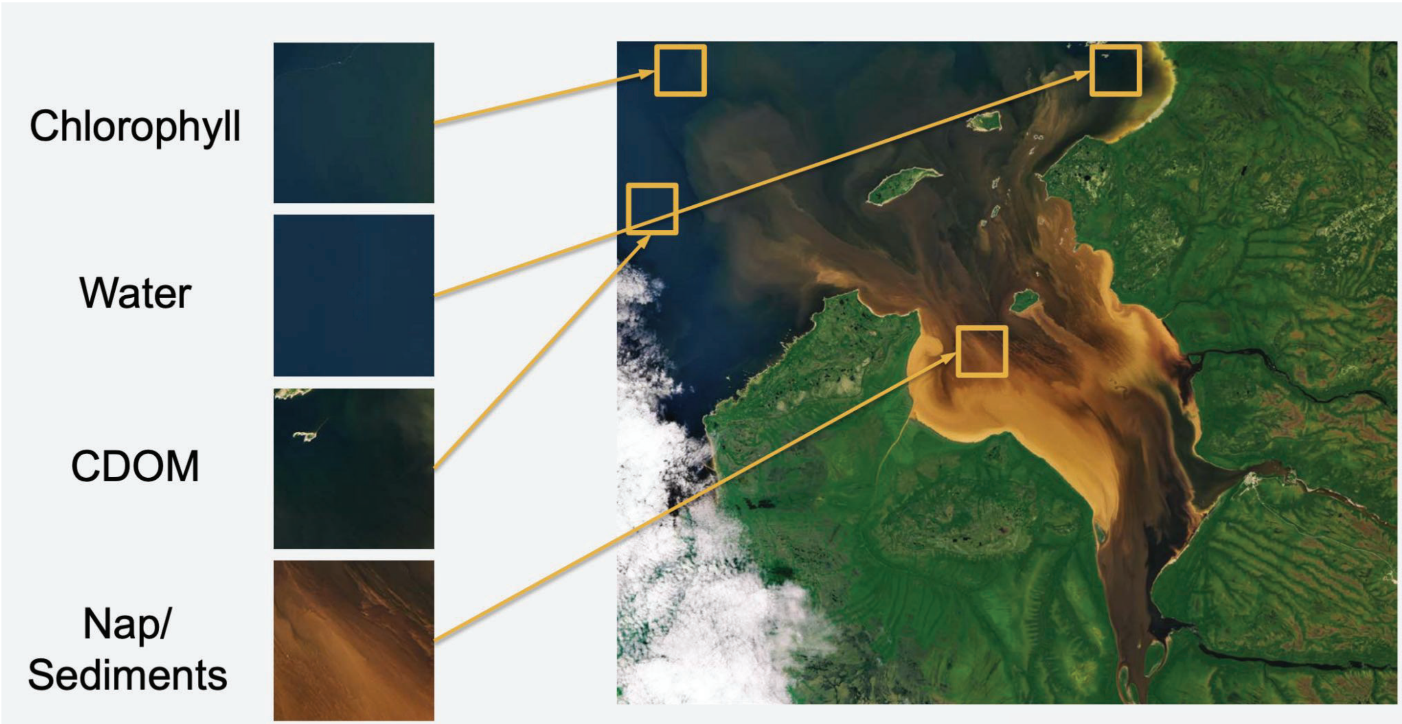


$$R_{rs}(\lambda,0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} = \frac{L_w(\lambda)}{E_d(\lambda,0^+)}$$

Inherent Optical Properties
a = absorption
b = scattering

Apparent Optical Properties
L_W = water leaving radiance
L_U = upwelling radiance
E_d = downwelling irradiance
R_{rs} = remote sensing (rs) reflectance

Parameters & Optical Properties of Algal Blooms

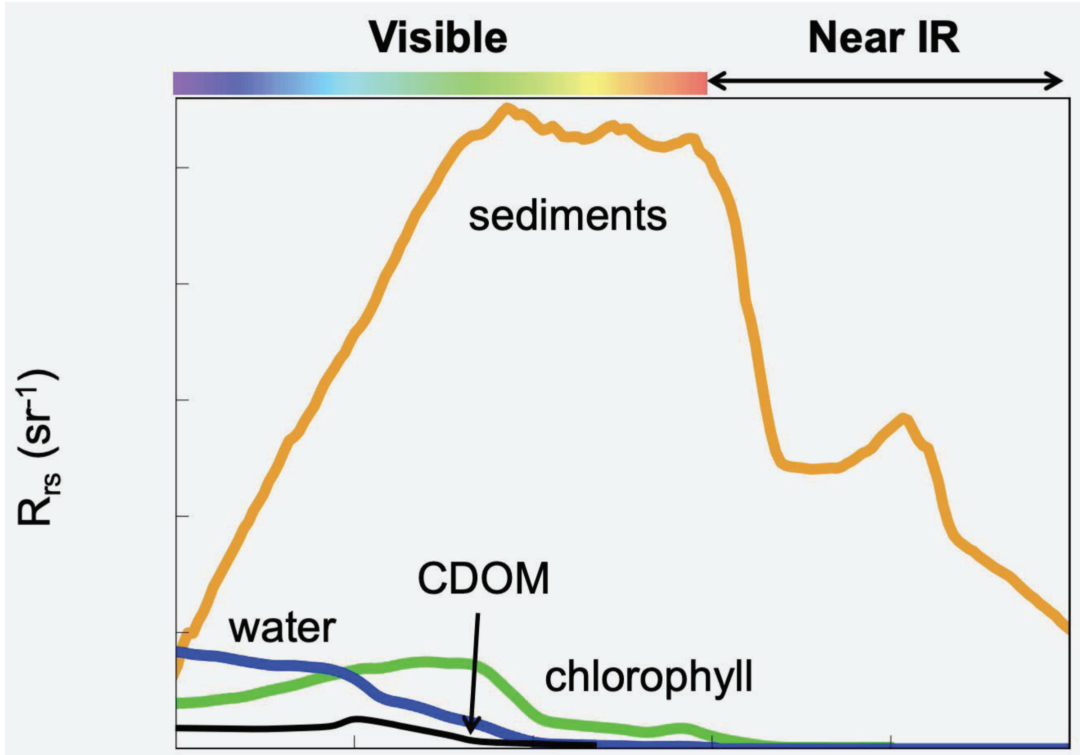


Credit: NASA ARSET

Parameters & Optical Properties of Algal Blooms

The remote sensing reflectance of the constituents of blooms is plotted against wavelengths ranging from the visible to the near IR range.

Sediments have the highest overall reflectance whereas CDOM and water have the lowest. Chlorophyll reflects in the green wavelength range.



Credit: NASA ARSET

Parameters & Optical Properties of Algal Blooms

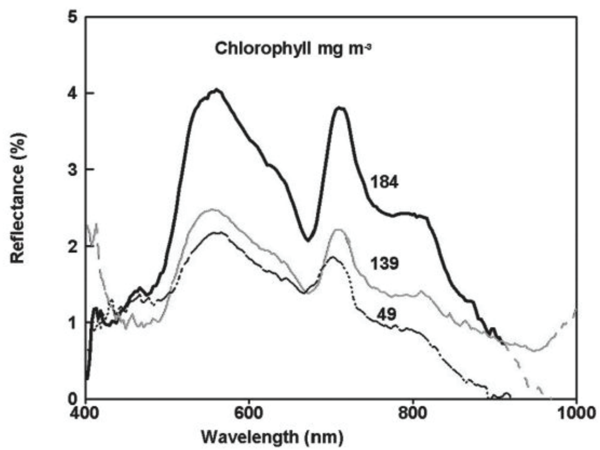
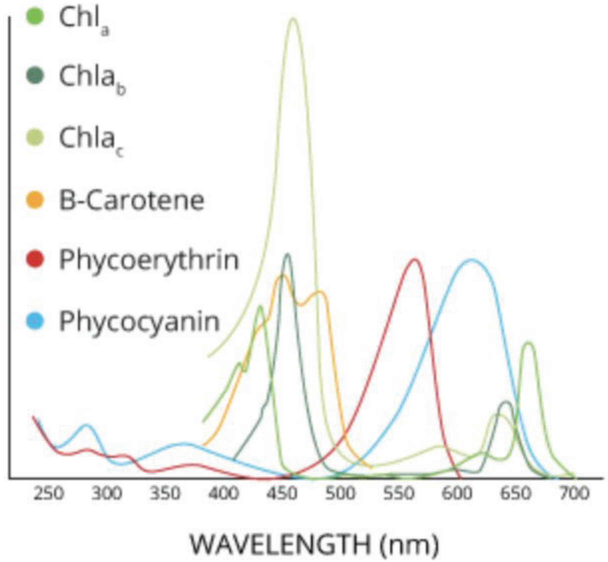


Figure 2. Relationship between reflectance and wavelength for different chlorophyll concentrations. Based on measurement made *in situ* with a high spectral resolution (1-nm) spectroradiometer at 1 meter over a large tank (Schalles *et al.*, 1997).



Credit: *Fondriest Environmental Inc.*

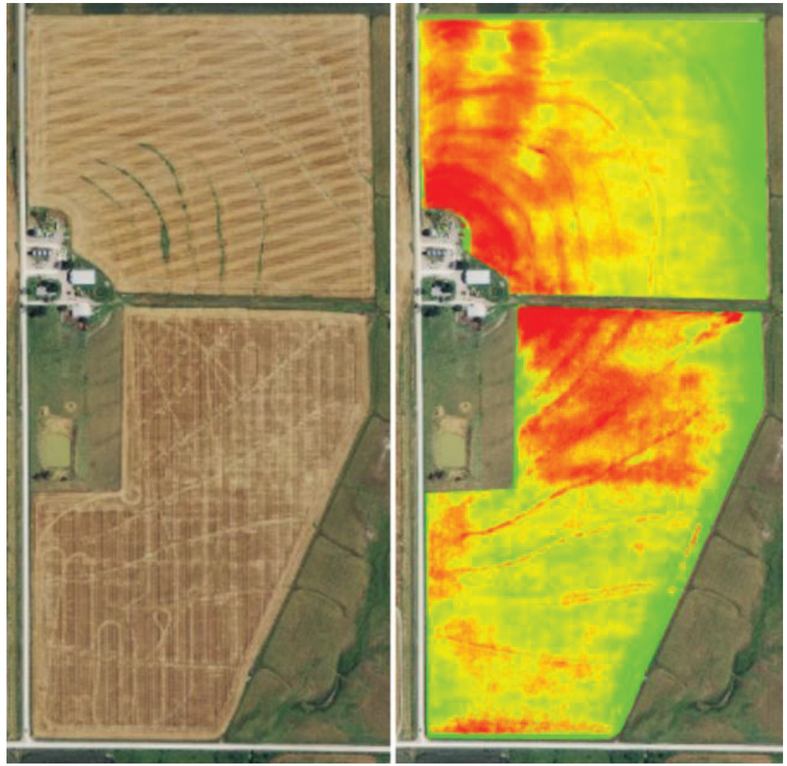
Color	Wavelength (nm)
Violet	380-450
Blue	450-475
Cyan	476-495
Green	495-570
Yellow	570-590
Orange	590-620
Red	620-750

Chlorophyll-a concentration algorithm by NASA GSFC

Satellite Bands & Indices to Observe Blooms

Spectral indices are **combinations of spectral reflectance**, generally mathematical formulas, using two or more wavelengths that indicate the relative abundance of features of interest.

Examples include Normalized Difference Vegetation Index (**NDVI**), Enhanced Vegetation Index (**EVI**), Normalized Difference Chlorophyll Index (**NDCI**), etc.



Credit: Botlink

Satellite Bands & Indices to Observe Blooms

Indices are specific combinations of bands to observe/visualize certain parameters. For visualizing algal blooms, the following indices are commonly used.

1. Chlorophyll monitoring indices
    a. Chlorophyll-a
    b. CiCyano $SS = \rho_{\lambda 2} - \rho_{\lambda 1} + (\rho_{\lambda 3} - \rho_{\lambda 1}) \times \left(\frac{\lambda_2 - \lambda_1}{\lambda_3 - \lambda_1}\right)$ 1 = 620 nm, 2= 665 nm and 3= 681 nm
    c. NDCI - Red edge 1 − Red/Red edge 1 + Red
2. Vegetation indices
    a. NDVI
    b. Blue NDVI

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad BNDVI = \frac{NIR - blue}{NIR + blue}$$

3. Floating Algae Index
4. Surface Algal Bloom Index

Read more about algal bloom indices here.

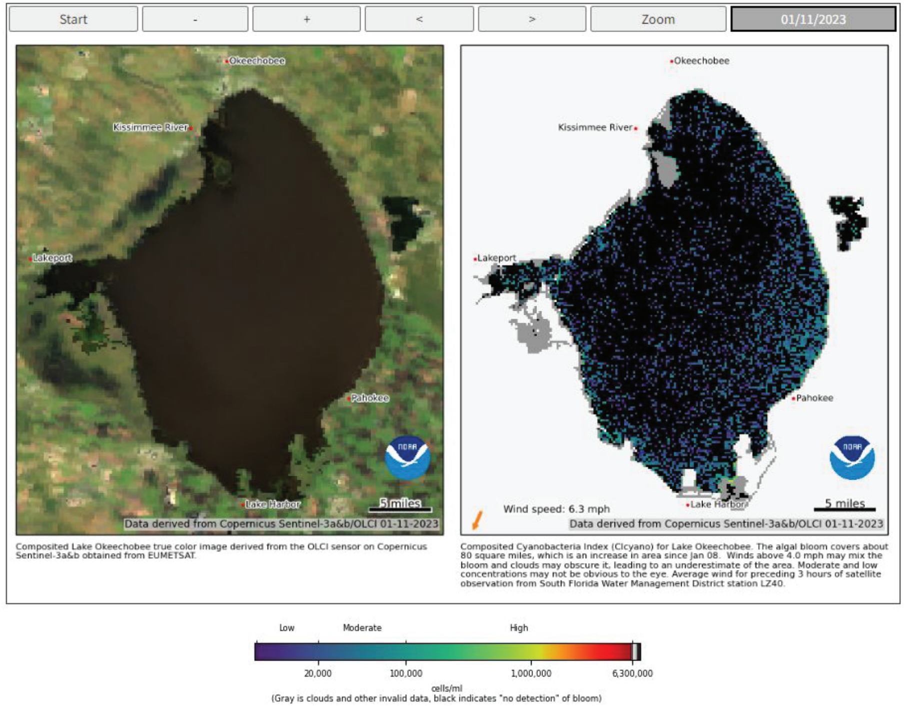
Limitations of Remote Sensing for Algal Blooms

1. Can only use proxies to estimate and visualize algal bloom extent without actual measurement of toxins
2. Cannot infer species without in-situ data collection or high resolution hyperspectral sensors
3. Additionally, the following issues are common to aquatic remote sensing:
    a. Clouds
    b. Sun angle/glint
    c. Speckled pixels
    d. Mixed Pixels (trouble identifying algae along shorelines)

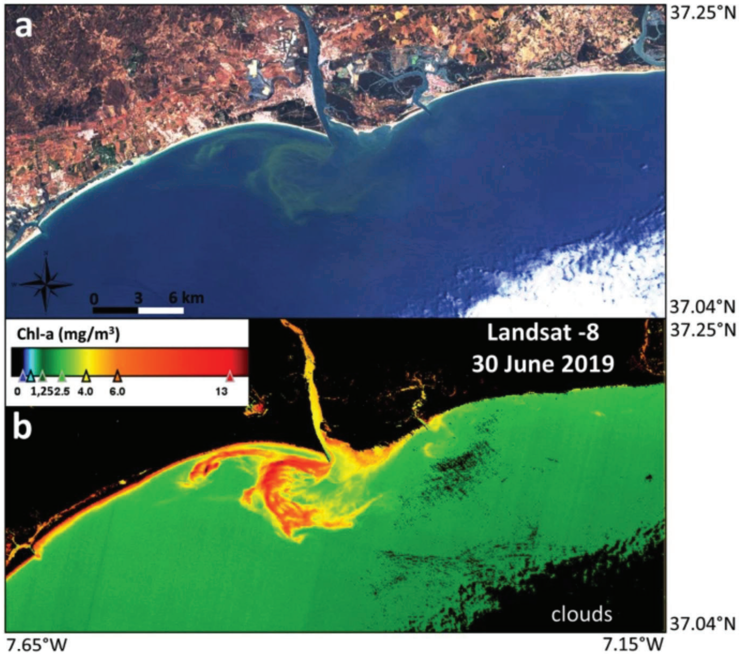
Existing Tools for HAB Monitoring

NOAA HAB Monitoring System uses Sentinel-3 CICyano index measuring algae in cells/ml to monitor specific lakes in the US for HABs.

More specific regional monitoring systems can be found here.

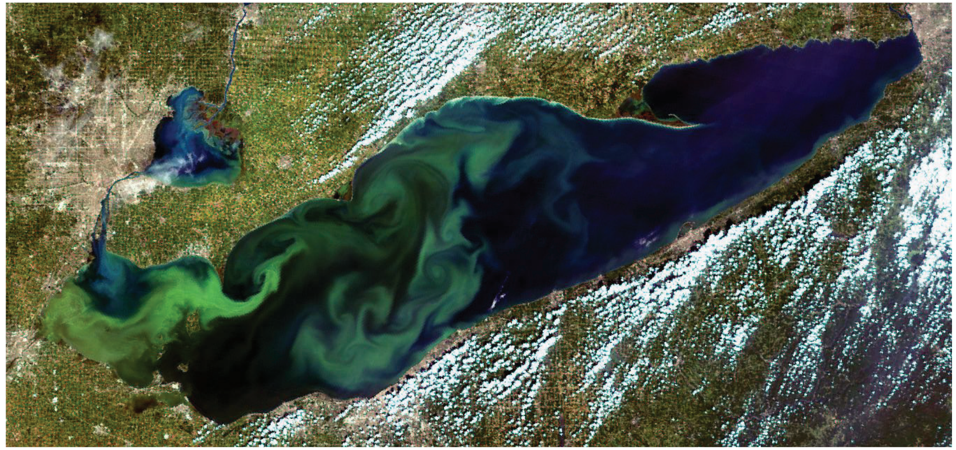


Example Use Cases

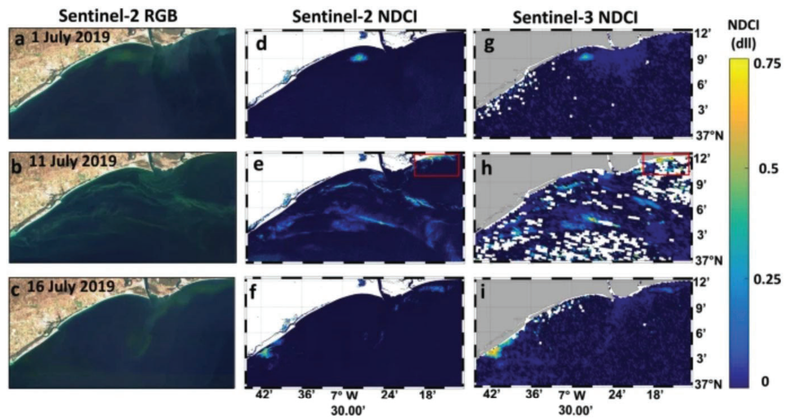


Caballero et al., 2020

MODIS Terra, Lake Erie 2015



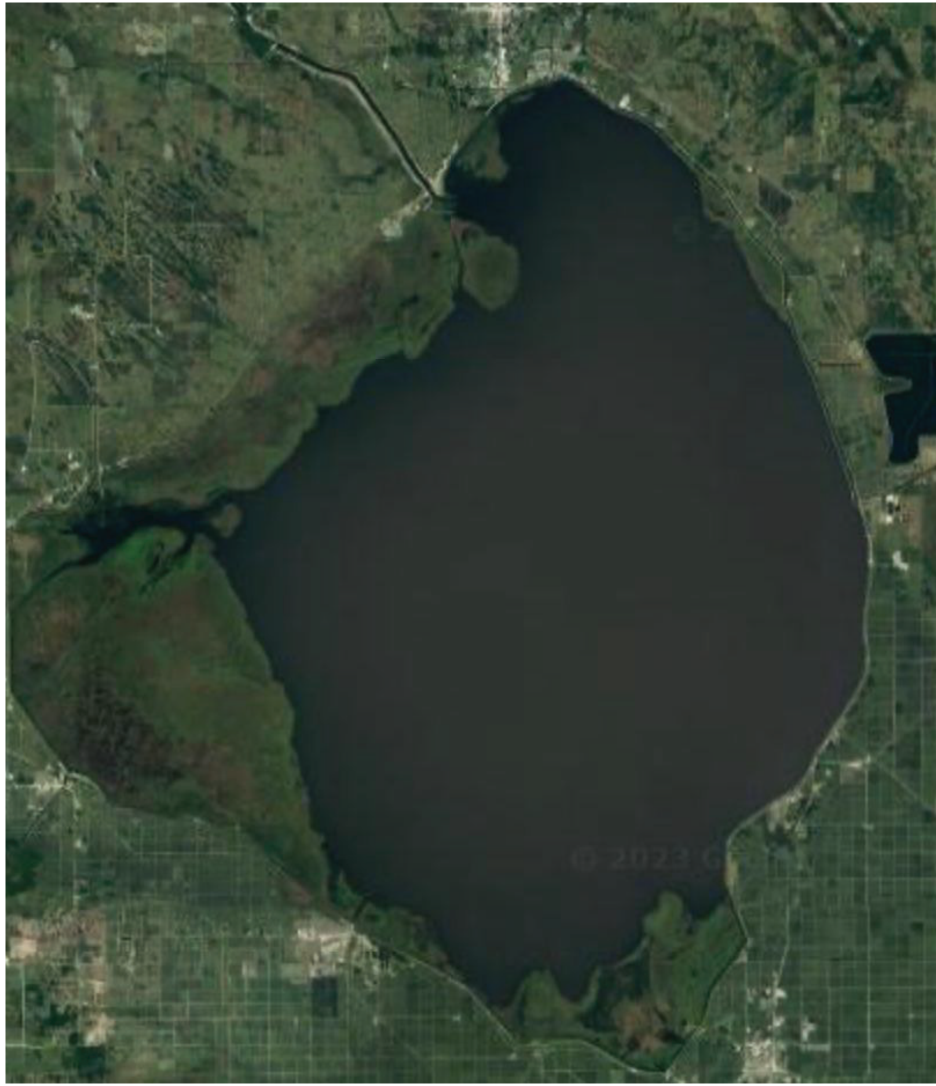
NOAA, Sea Grant



Caballero et al., 2020

Algal Bloom Pilot

- Lake Okeechobee in Florida experiences algal blooms yearly that impact water quality, recreation, public health, etc.
- Identified need to bring together datasets from multiple sources for more streamlined reporting, analysis, and decision making.
- Reliable remote sensing products for harmful algal blooms could provide additional spatial and temporal information about blooms in between in-situ sampling efforts.
- Incorporating meteorological data can help scientist better understand the role of climate in environmental management.



Cloud Pipeline

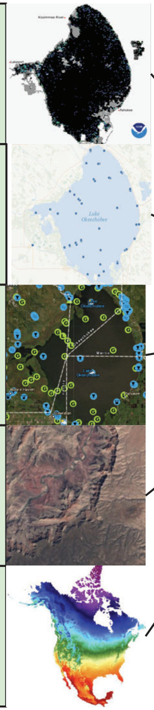
NOAA Harmful HARMFUL ALGAL BLOOM MONITORING SYSTEM DATA

Florida Department of Environmental Protection (FDEP) Algal Bloom Site Visits

South Florida Water Management District's DbHydro Data

Landsat 8|9 Water Quality Indices and Sentinel-2 Water Quality Indices

Meteorological Data

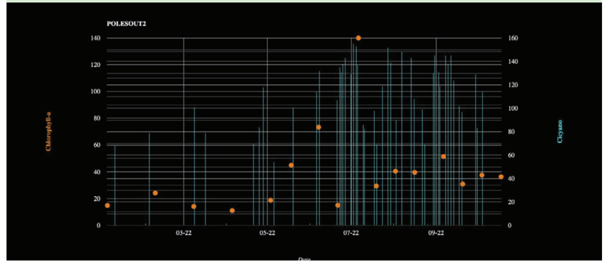


Climate Engine

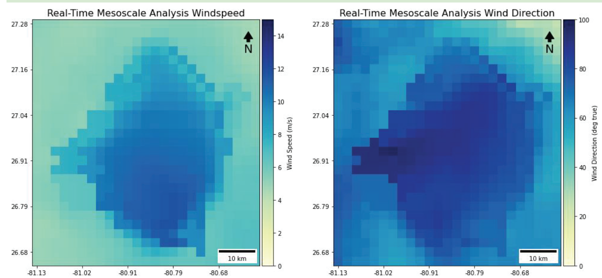
Google Cloud

Google Earth Engine

Earth Engine App



Climate Engine API



Interactive Session

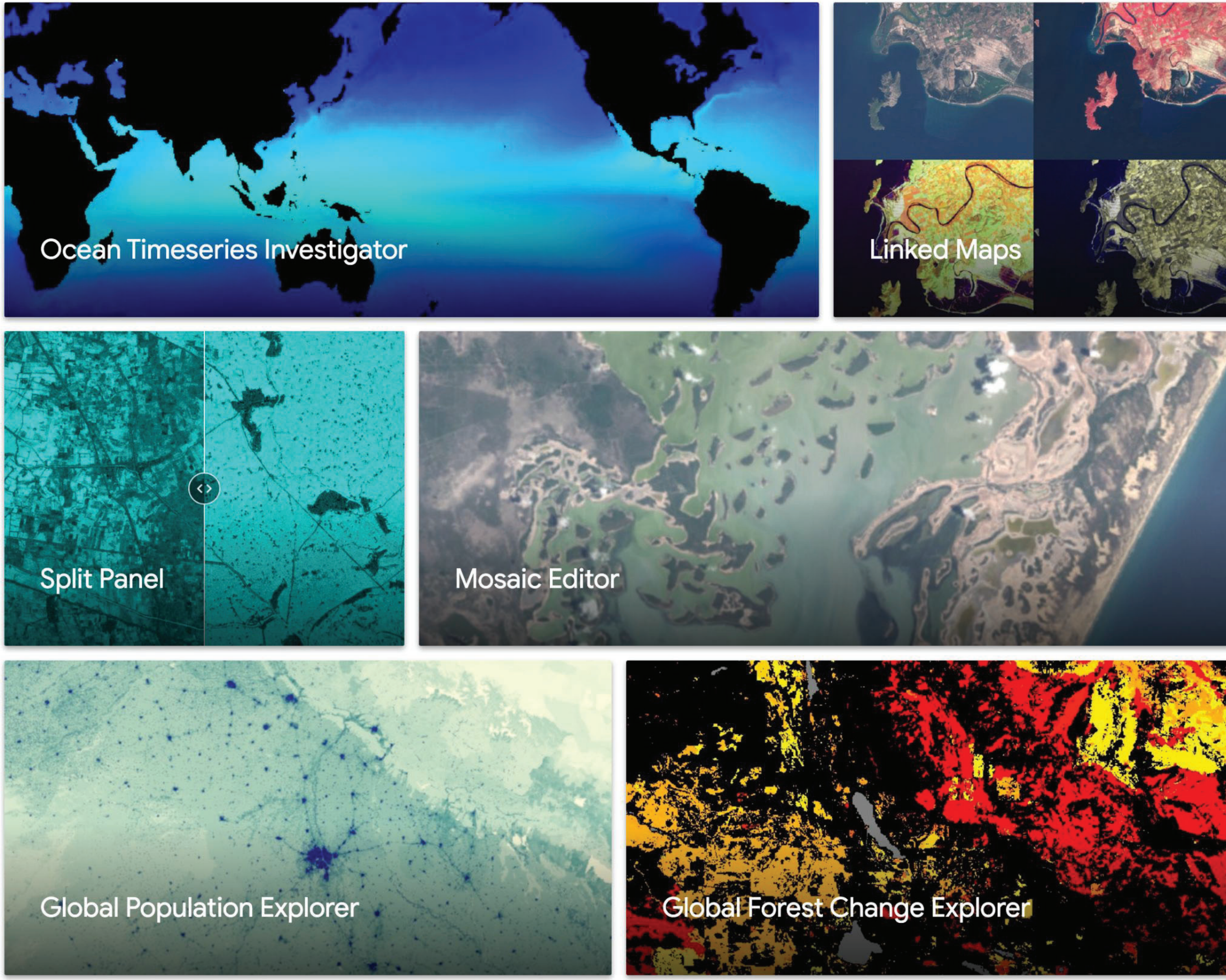
Q & A

- Solving cloud cover for bloom monitoring
- How to create Indices viz
- Detecting various plant pigments with RS
- Publications for indices, relationships, accuracy
- Hydrology incorporation into the app? -> modeling use case

Section 3: Google Earth Engine Applications & Climate Engine API Introduction (~45 min)

Google Earth Engine Apps

- Built right in the Earth Engine code editor
- Don't need to be a developer to create and share
- Variety of functionality pre-built to analyze and visualize your data
- Well-documented examples that you can use to guide your app design



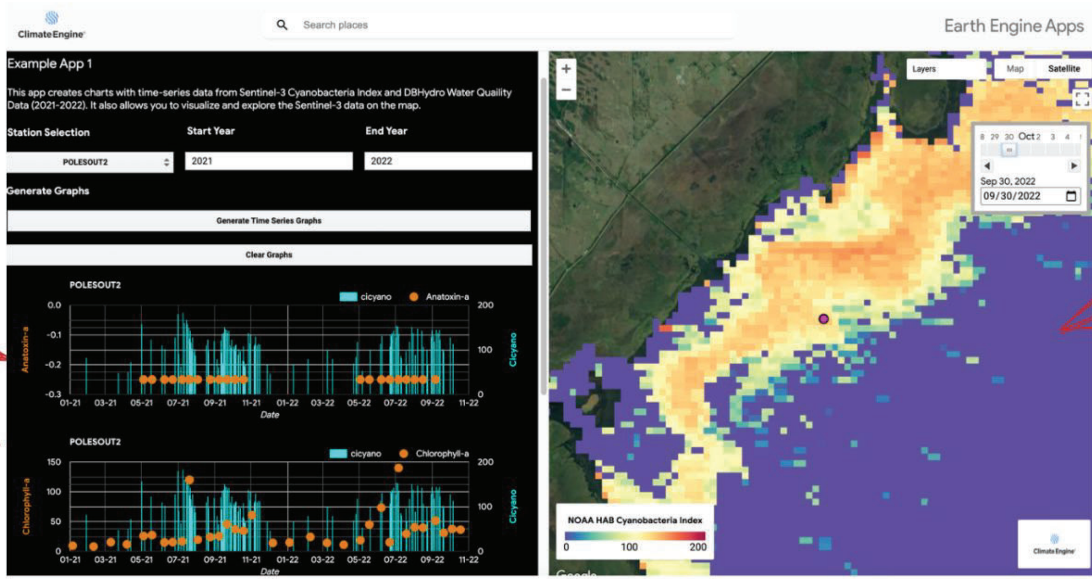
Structure of Google Earth Engine Apps

Panel

A ui.Panel is an upper-level UI container in which to arrange widgets

Widgets

There are a variety of widgets you can use to build your UIs. These widgets include buttons, checkboxes, sliders, textboxes and selection menus.

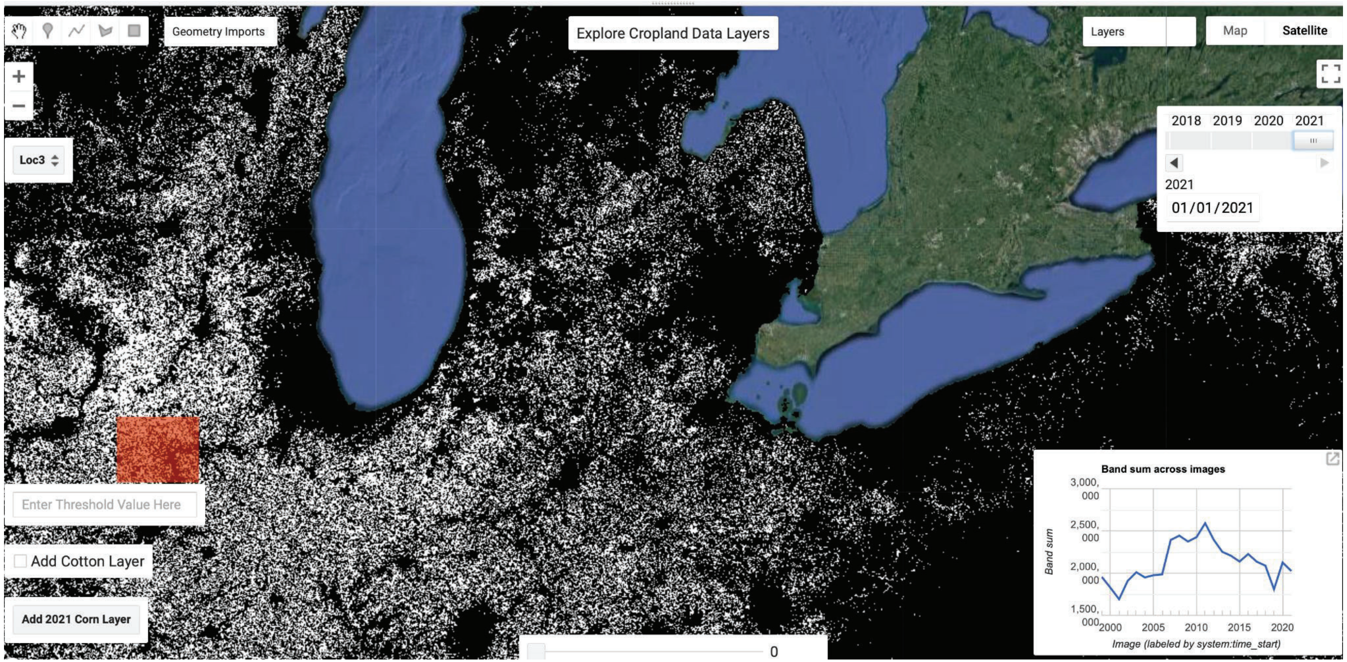


Map

Like other widgets, you can print a map to the console. Manipulate the content of the map by clearing, getting or setting individual layers.

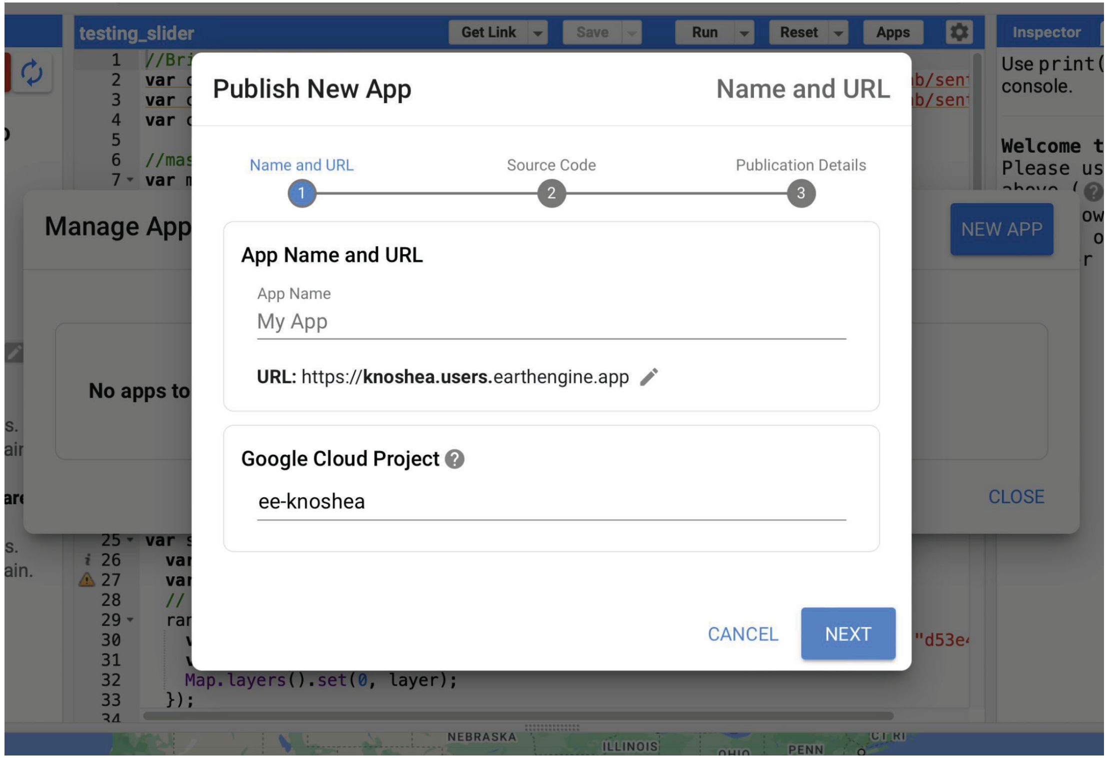
Widgets Introduction (Demos)

- ui.Label
- ui.Button
- ui.Checkbox
- ui.Slider
- ui.DateSlider
- ui.Textbox
- ui.Select
- ui.Chart
- ui.Map



How to Host, Publish, and Share Apps

1. Complete Script
2. Click Create New App
3. Fill out Name and Cloud Project
4. Select App Code
5. Select Publication Details
    a. Set thumbnail/description
    b. Select Restrictions
    c. Add a Logo



App 1 Code Walk Through

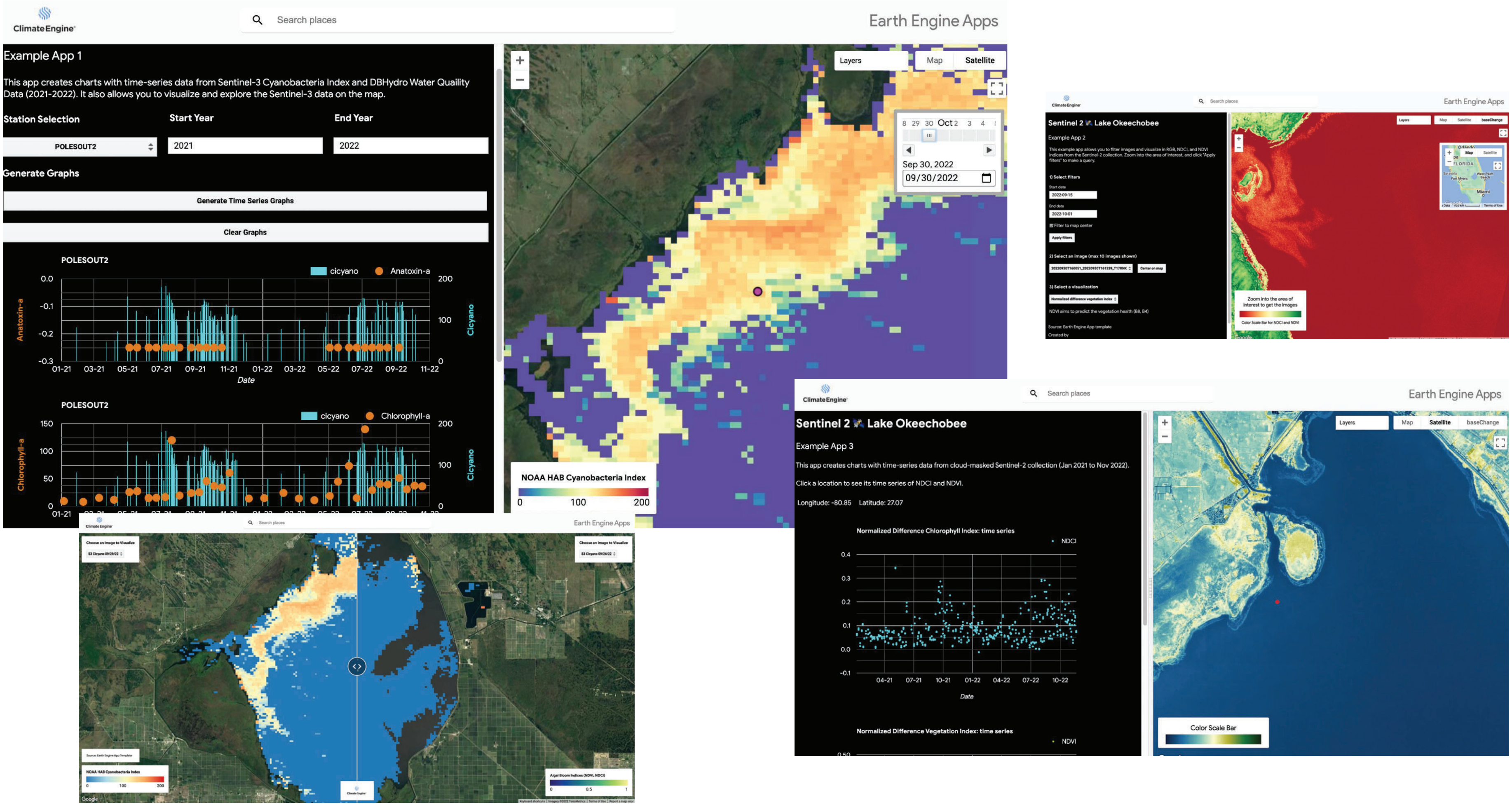
```
//===============Set Color Scheme=========
// Colour scheme
var font_c = 'white';
var back_c = 'black';

//Map
var map= ui.Map();
map.setCenter(-80.7921270781557,26.951862176828445, 10);
map.setOptions("SATELLITE")
map.setControlVisibility(true)

//==========Bring in HAB Dataset=========
var col_a = ee.ImageCollection('projects/ce-datasets/assets/ce-noaa-nccos-hab/sentinel-3a');
var col_b = ee.ImageCollection('projects/ce-datasets/assets/ce-noaa-nccos-hab/sentinel-3b');
var col = col_a.merge(col_b);
print(col, 'col')

//=========Masking Function==============
var mask = function (img) {
    var m = img.select('cicyano');
    var mask = m.lt(250);
    return img.mask(mask).copyProperties(img);
};
//=====Generate Visualization Parameters===
//viz
var viz_rgb = {bands: ['red', 'green', 'blue'], min: 0, max: 255};
var viz_c = {
    bands: 'cicyano',
    min: 0,
    max: 249,
    palette: ["9e0142", "d53e4f", "f46d43", "fdae61", "fee08b", "ffffbf", "e6f598", "abdda4", "66c2a5", "3288bd", "5e4fa2"].reverse()
};
//============Map Date Slider=============
// Use a DateSlider to create annual composites of this collection.
var collection = ee.ImageCollection(col);
// Use the start of the collection and now to bound the slider.
var start = ee.Image(collection.first()).date().get('year').format();
print(start)
var now = Date.now();
var end = ee.Date.fromYMD(2022, 11, 16).format();
print(end)
```

Explore Apps



Thank you!

Support: support-sfwmd@climateengine.com

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