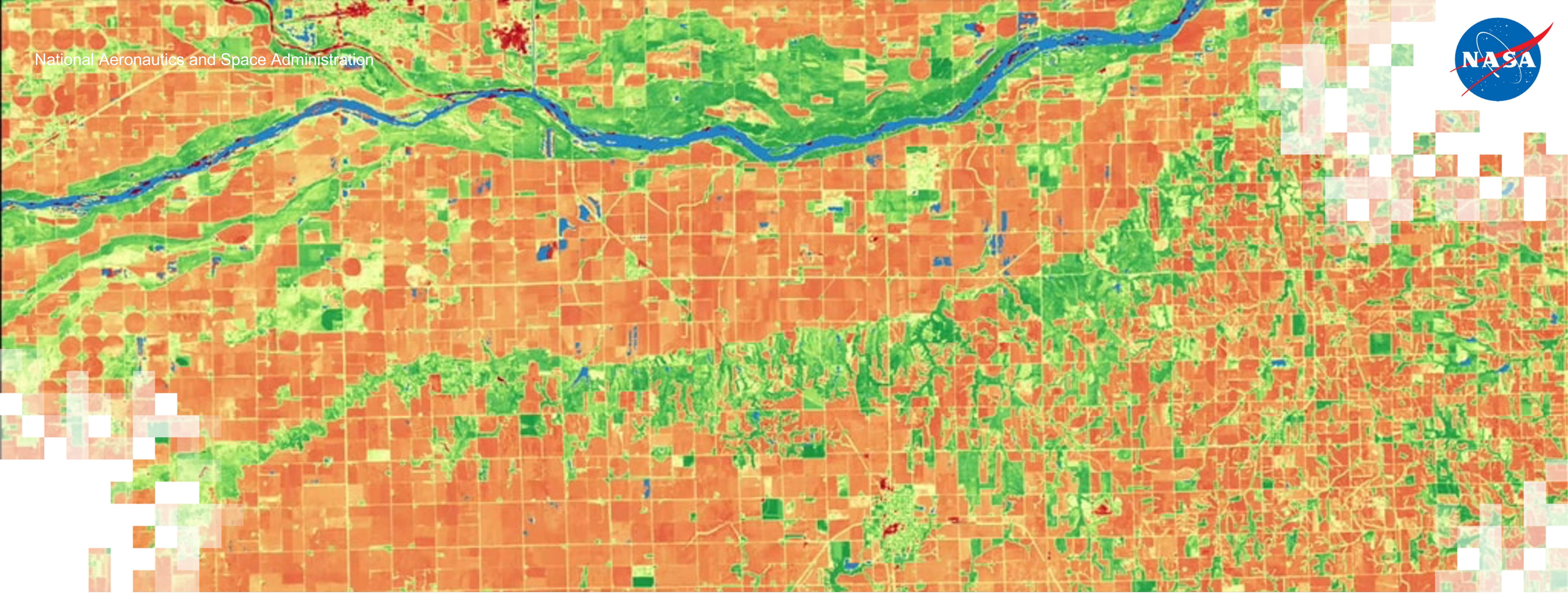


Spectral Indices for Land and Aquatic Applications

Part 2: Spectral Indices Used for Aquatic Applications

Juan L. Torres-Pérez (NASA ARC), Amber McCullum (BAERI), Britnay Beaudry (BAERI), & Sativa Cruz (BAERI)

November 2, 2023

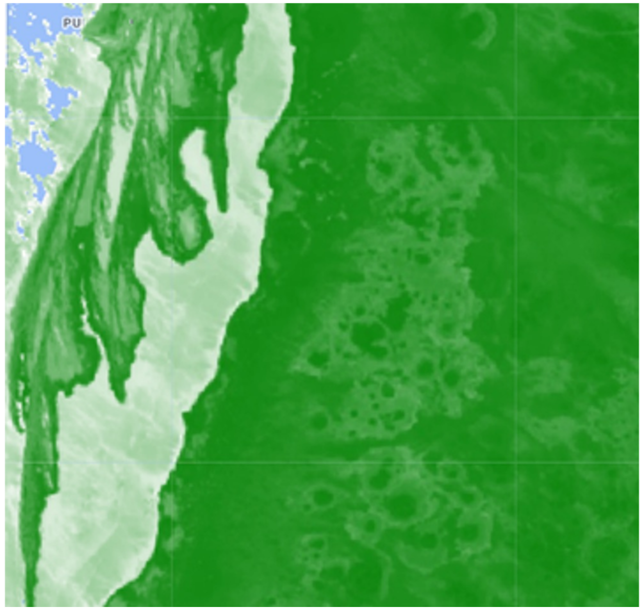
Purpose of this Training

- To provide an overview of commonly used spectral indices for aquatic and land applications.
- Learners will see examples of spectral index calculations with diverse sensors including Landsat 9 (OLI-2), Sentinel-2 MSI, and the Harmonized Landsat Sentinel-2 datasets.
- Demos using Google Earth Engine will be shown for both aquatic and land applications.

Training Learning Objectives

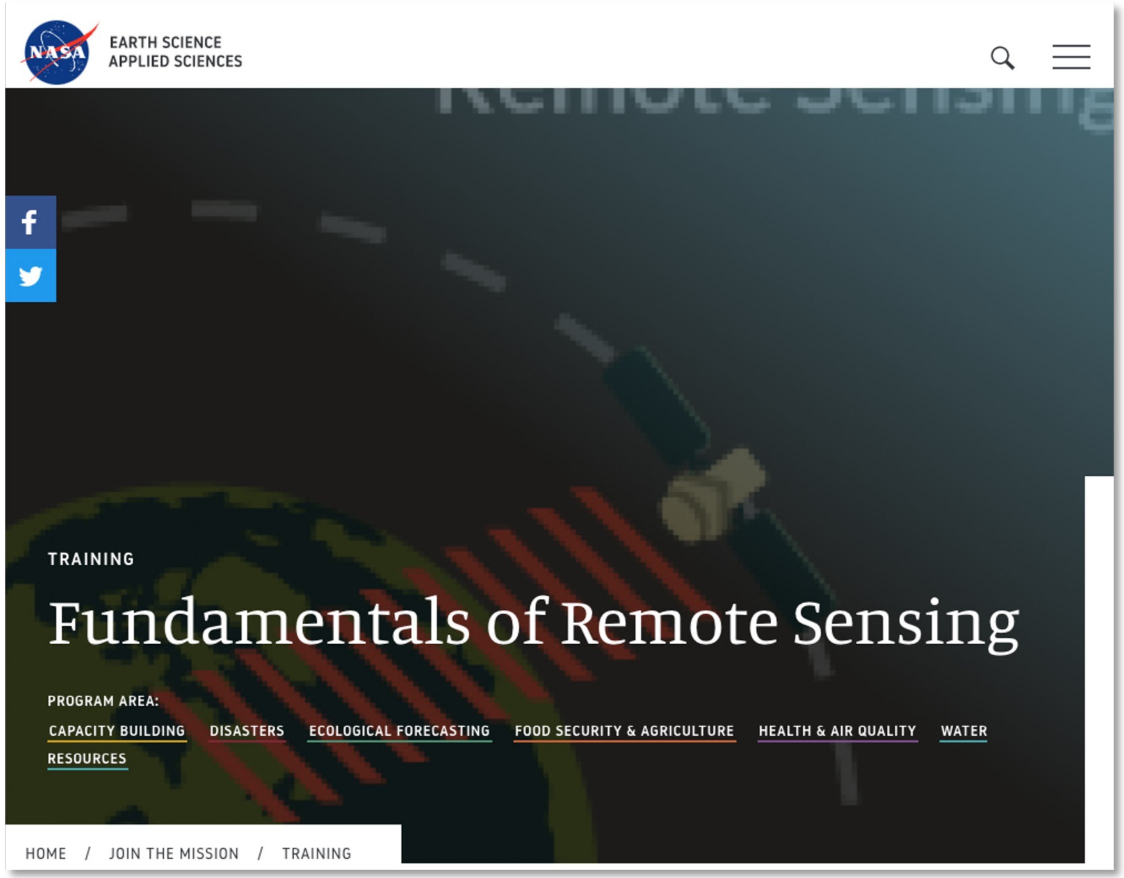
By the end of this training series, participants will be able to:

- Recognize commonly used spectral indices in land and aquatic environments
- Distinguish between spectral indices to select those best suited for a given land or aquatic system of interest
- Compute spectral index calculations over appropriate areas of interest
- Acquire spectral index products from a variety of sources



Prerequisites

- Fundamentals of Remote Sensing
  - Or equivalent experience



Training Outline

Part 1
Overview of Spectral Indices
October 26, 2023
11-12 and 15-16 ET

Part 2
Spectral Indices for Aquatic Applications
November 2, 2023
11-12 and 15-16 ET

Part 3
Spectral Indices for Land Applications
November 9, 2023
11-12 and 15-16 ET

Homework
Opens November 9 – Due November 23 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Part 2 – Trainers

Britnay Beaudry

Instructor

Ecological Conservation

Amber Jean McCullum

Team Lead

Ecological Conservation

Juan Torres-Pérez

Instructor

Ecological Conservation

Sativa Cruz

Instructor

Ecological Conservation

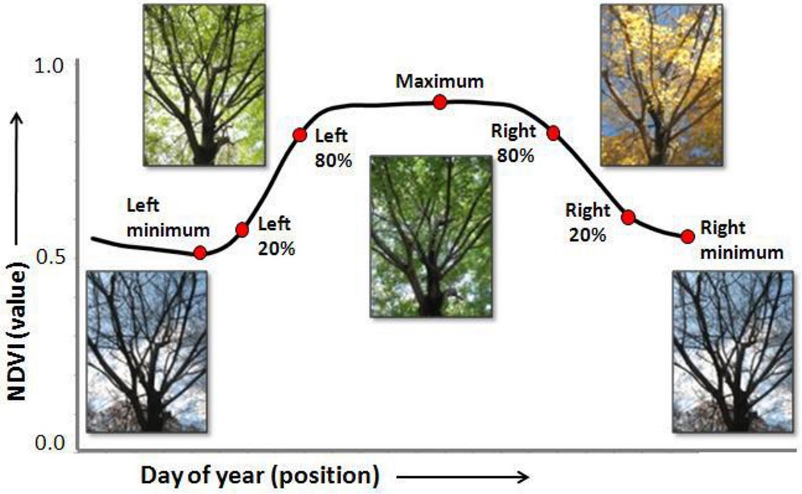
Part 2 Objectives

By the end of Part 2, participants will be able to:

- Recognize common spectral indices for aquatic applications
- Distinguish some basic differences between spectral indices developed for aquatic applications and those developed for land applications
- Recognize the main regions of the electromagnetic spectrum useful for aquatic applications
- Review some recent examples on the use of spectral indices for coastal and ocean applications

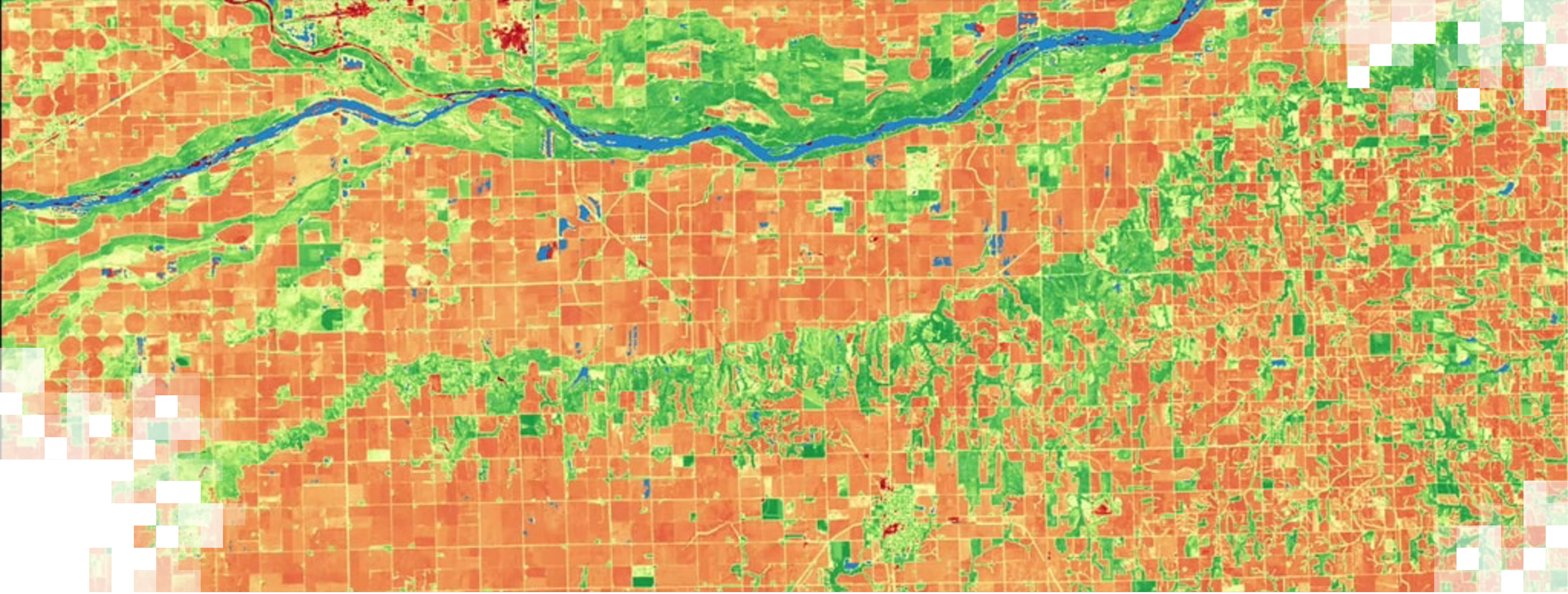
Review of Prior Knowledge

- Every surface on Earth reflects and absorbs energy in different ways.
  - Plants, for example, absorb in the blue and red and reflect in the green and NIR.
- Different surfaces have different spectral signatures.
- Spectral indices are simple band ratios that highlight a specific process or property on the land or aquatic surface.
- The Normalized Difference Vegetation Index (NDVI) is one of the most used indices for analyzing vegetation health.
  - It is a simple relationship between the Red and NIR regions of the spectrum.



How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

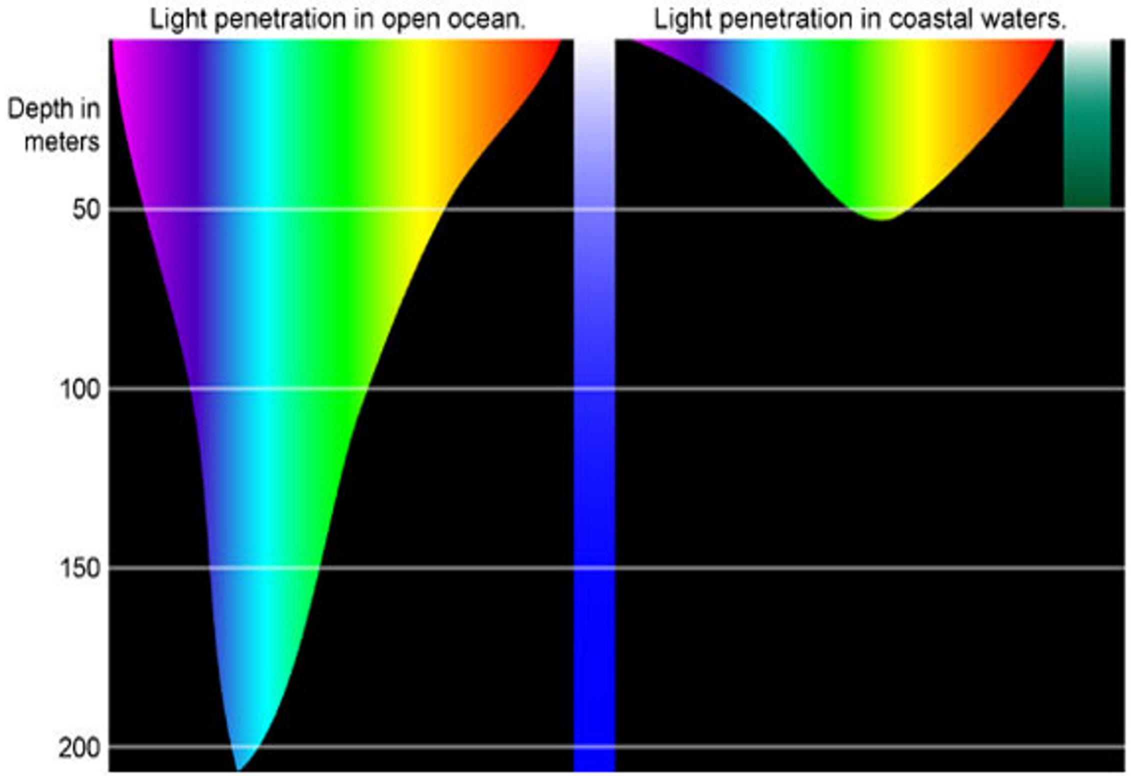


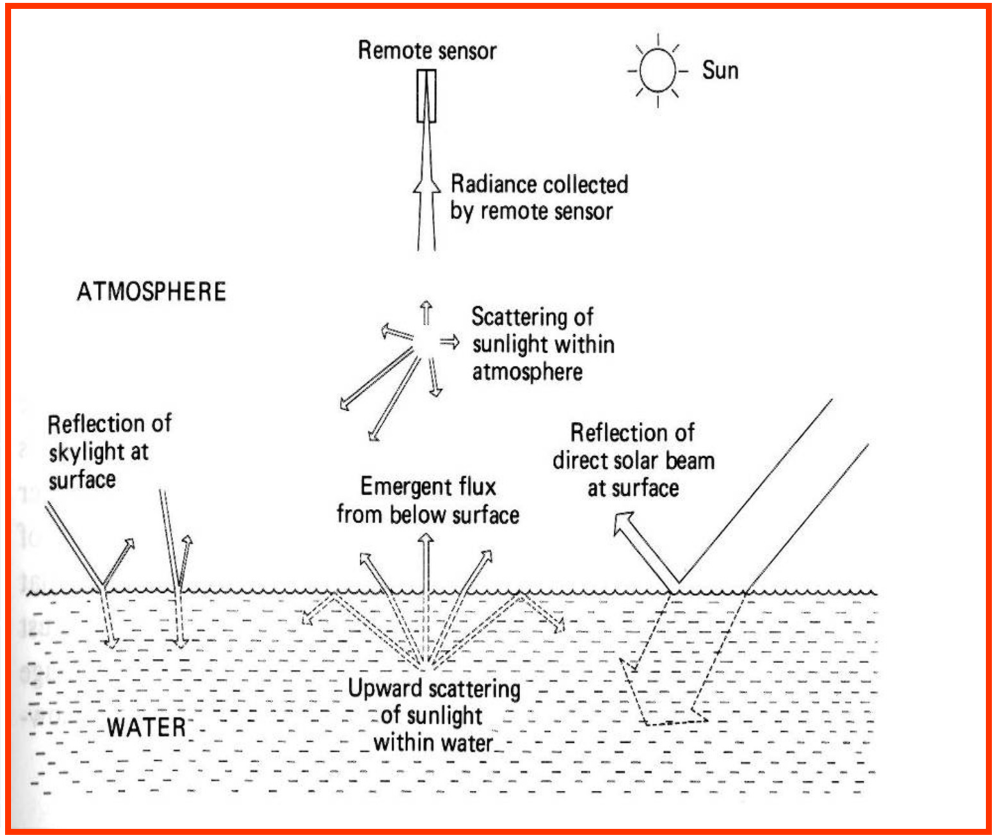
Part 2:

Spectral Indices for Aquatic Applications

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

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

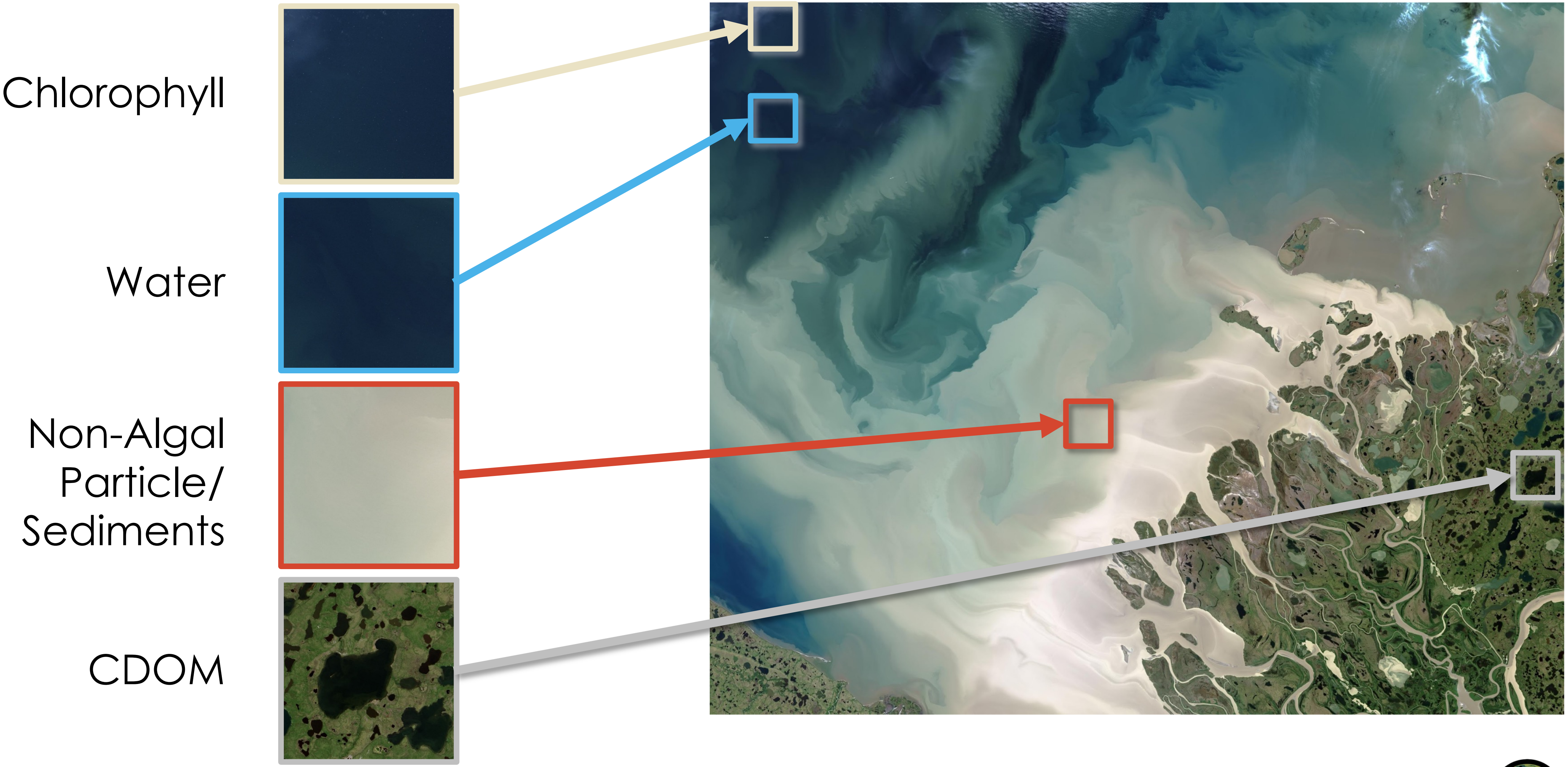
Inherent Optical Properties:

- *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



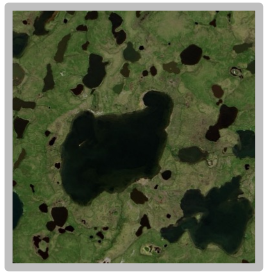
Inherent Optical Properties (IOPs) and the 'Color' of Water

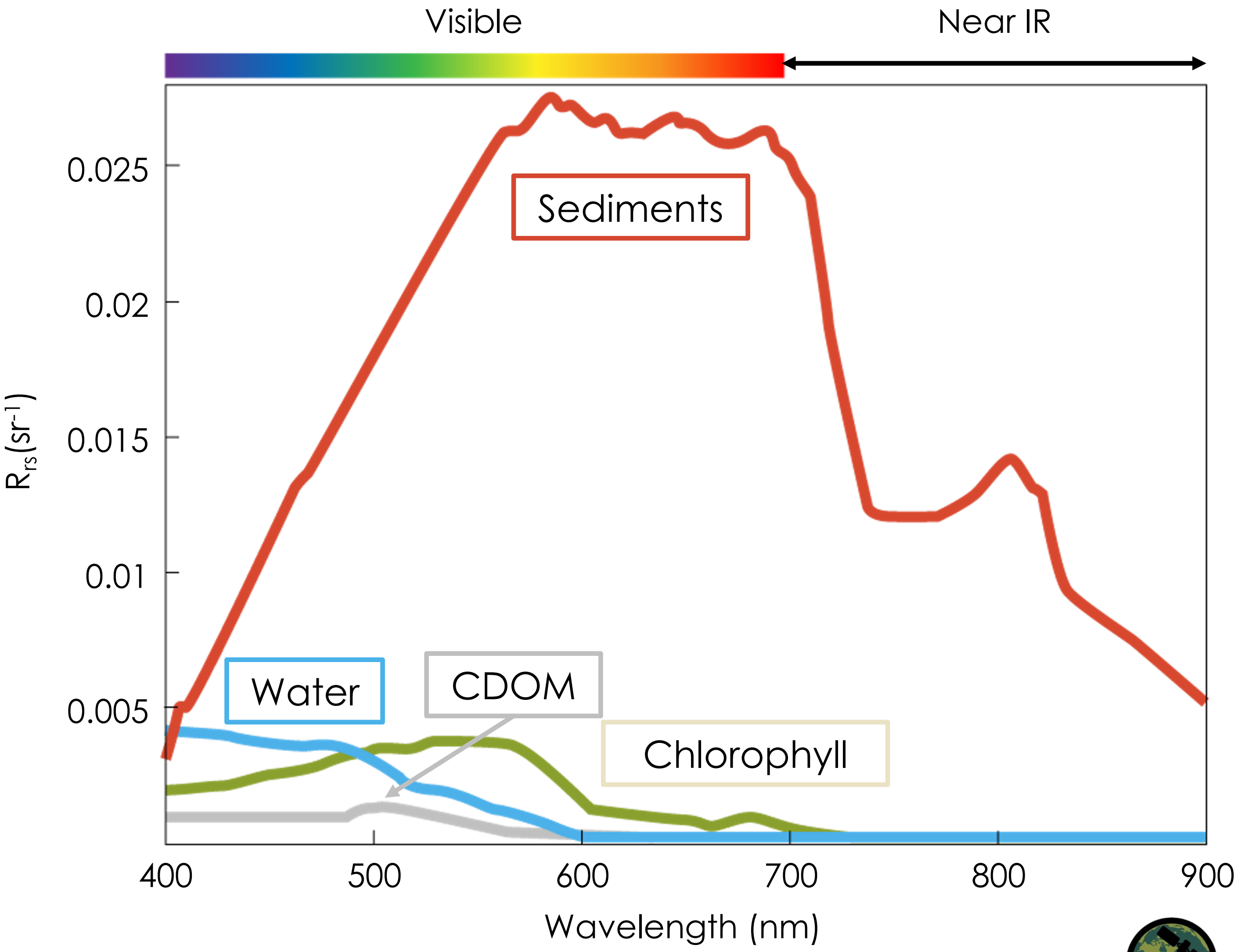
Chlorophyll

Water

Non-Algal Particle/ Sediments

CDOM





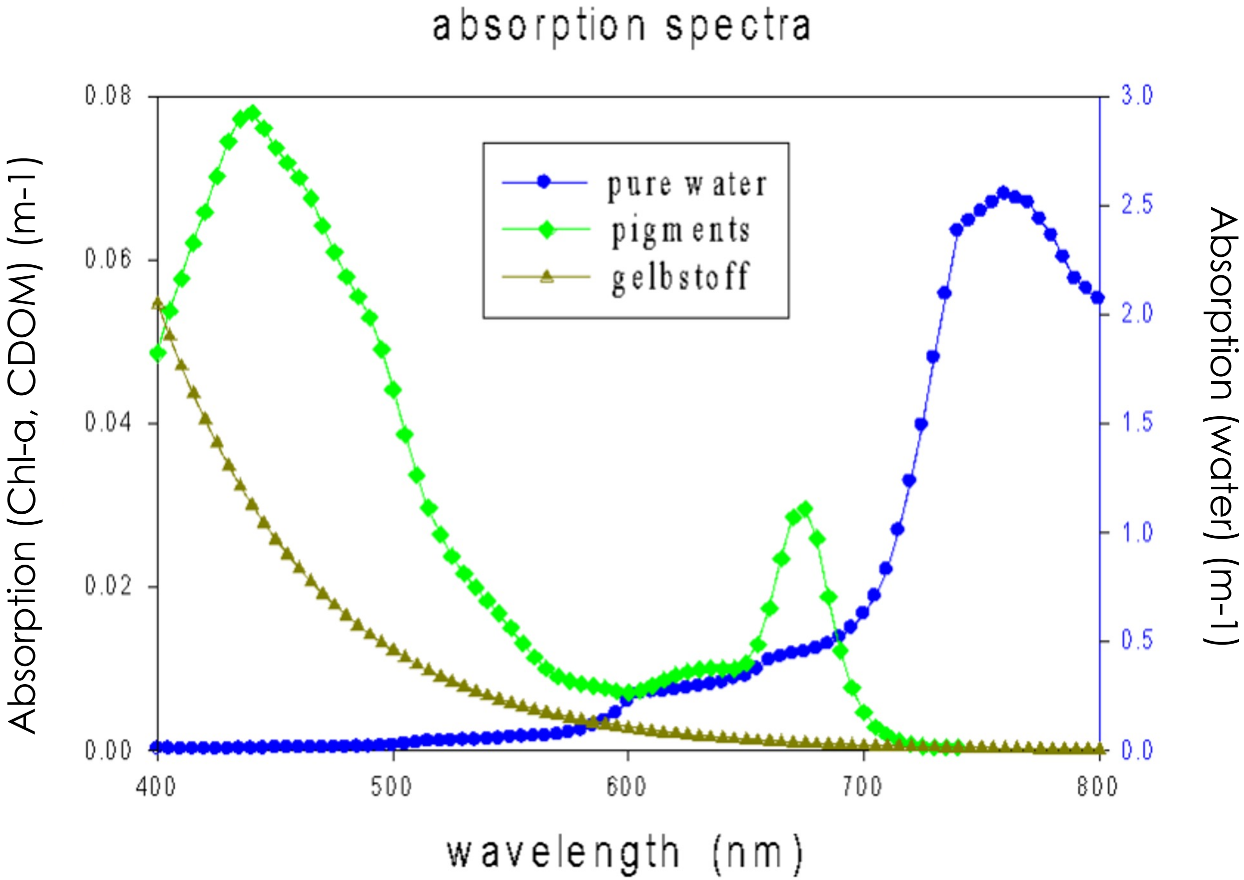
Some Water Quality Indicators Satellites Can Observe

- 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

Absorption of Water, CDOM, and Phytoplankton

- Water absorbs strongly in the red, NIR, and SWIR.
- CDOM absorbs strongly in the blue region.
- Phytoplankton (Chl a) absorbs strongly in the blue and red regions of the spectrum.



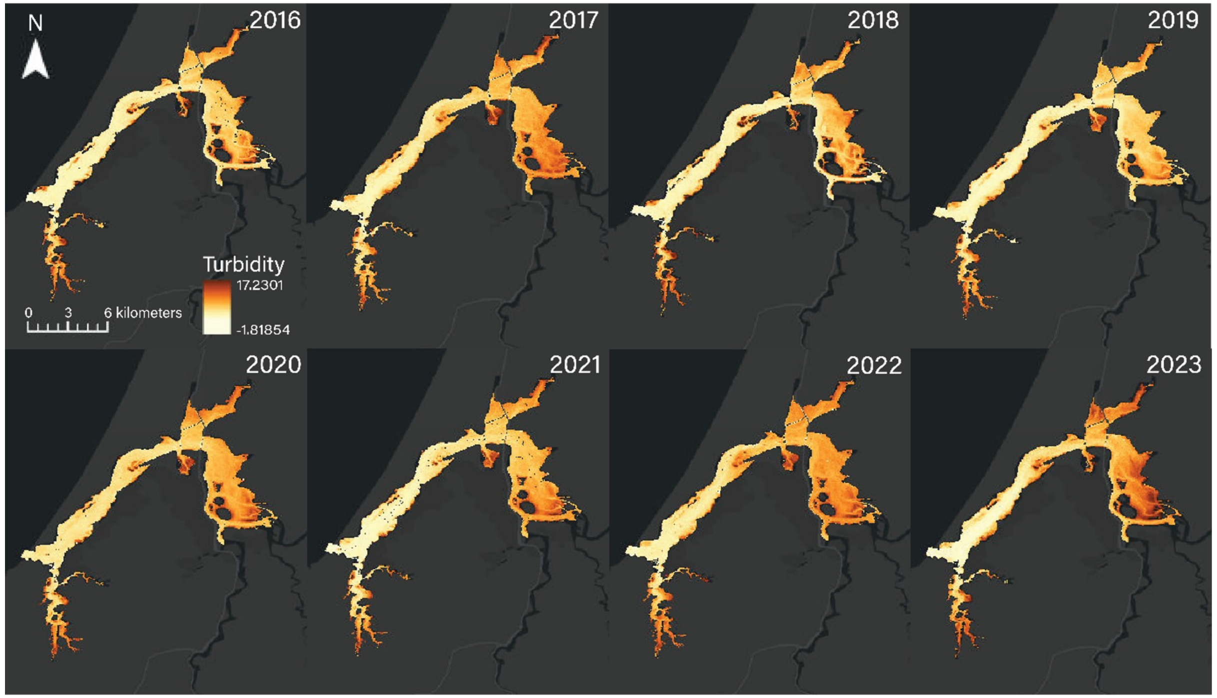
Credit: Univ. PR Bio-optical Oceanography Lab

Normalized Difference Turbidity Index (NDTI)

- Originally developed by Lacaux et al (2007) for water quality assessment in ponds and small inland water bodies
- Used the SPOT-5 Level 2 images (10m spatial resolution)
- Has been applied with some success to other water bodies using other sensors (Landsat 8 OLI; Sentinel-2 MSI)

$$NDTI = \frac{(Red - Green)}{(Red + Green)}$$

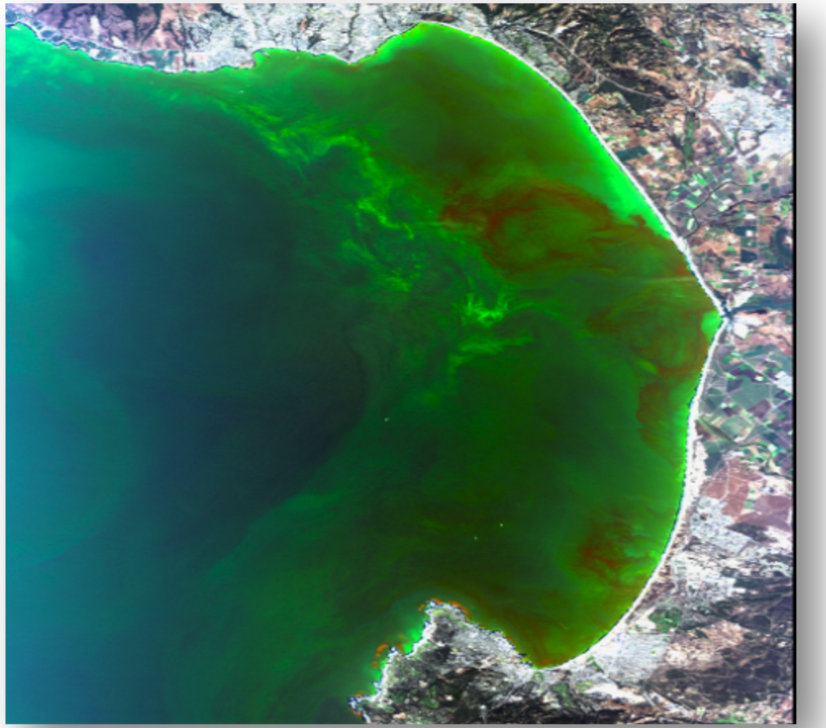
Lacaux et al (2007), Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal, Remote Sensing of Environment, 106, 66-74.

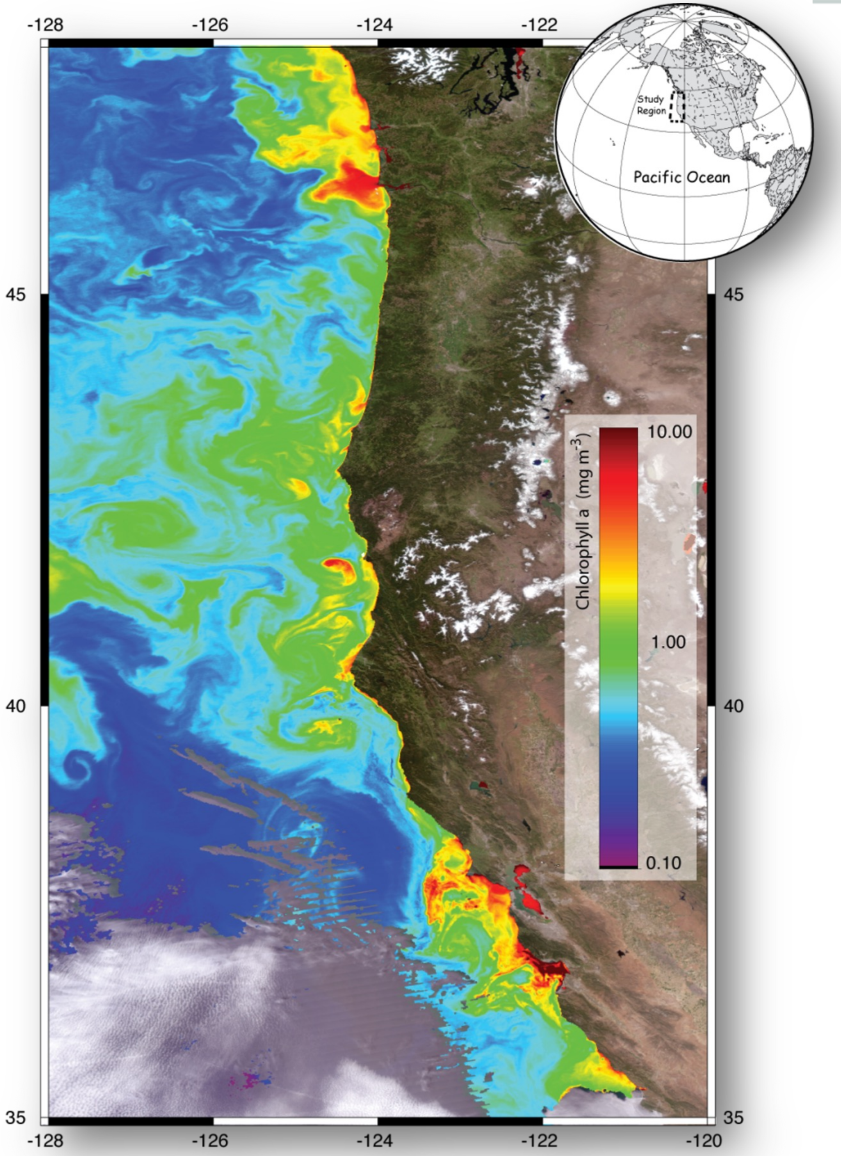


Credit: NASA DEVELOP Program Summer 2023 South Slough Water Resources Project

Chlorophyll a

- Indicator of phytoplankton biomass and blooms
- Indirect indicator of nutrients



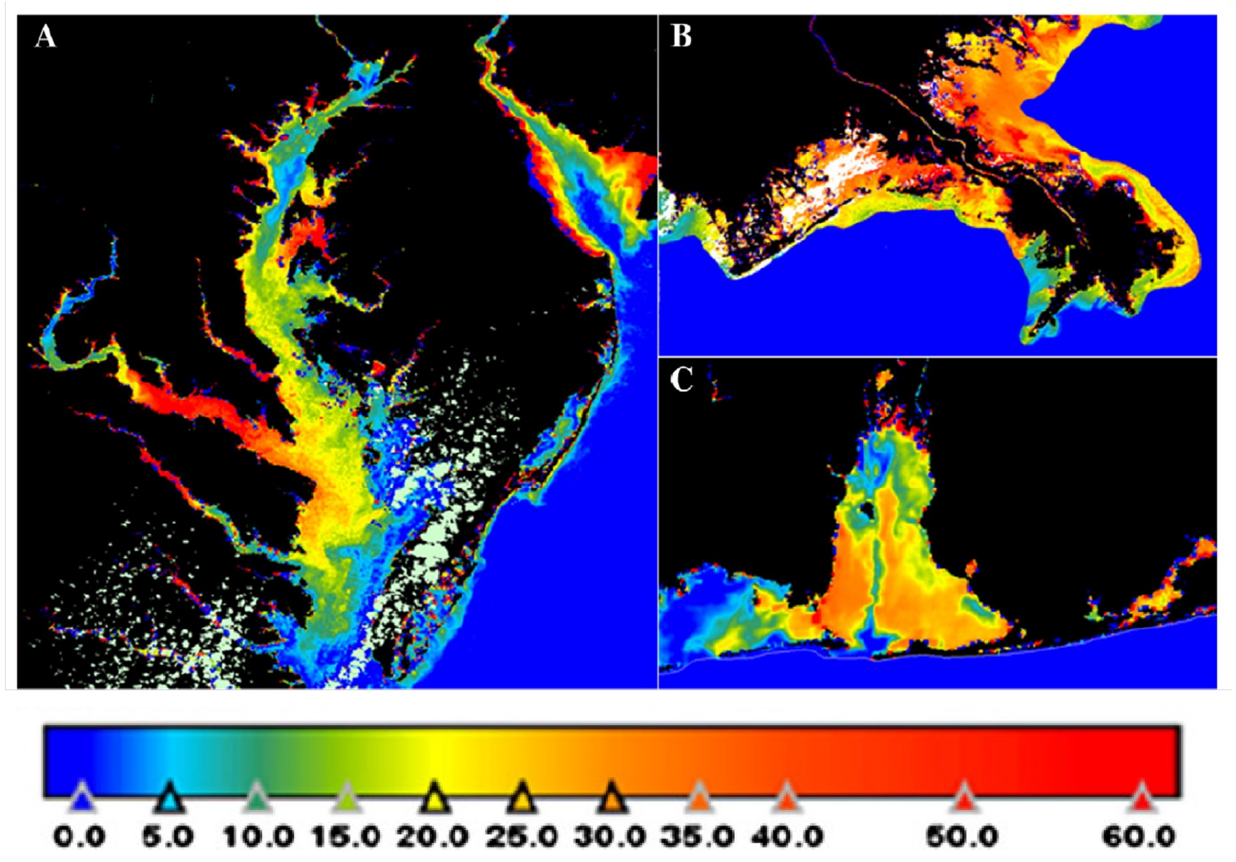


Credit: Liane Guild (NASA), Raphe Kudela (UC Santa Cruz)

Normalized Difference Chlorophyll Index (NDCI)

- Proposed by Mishra & Mishra in 2012 to predict Chl-a concentrations in turbid (Case 2) waters in coastal and estuarine areas with MERIS datasets.
- Tested the algorithm with data from several study regions in the US (Delaware Bay, Chesapeake Bay, Mississippi River Delta, Mobile Bay) with an average bias of 12%.

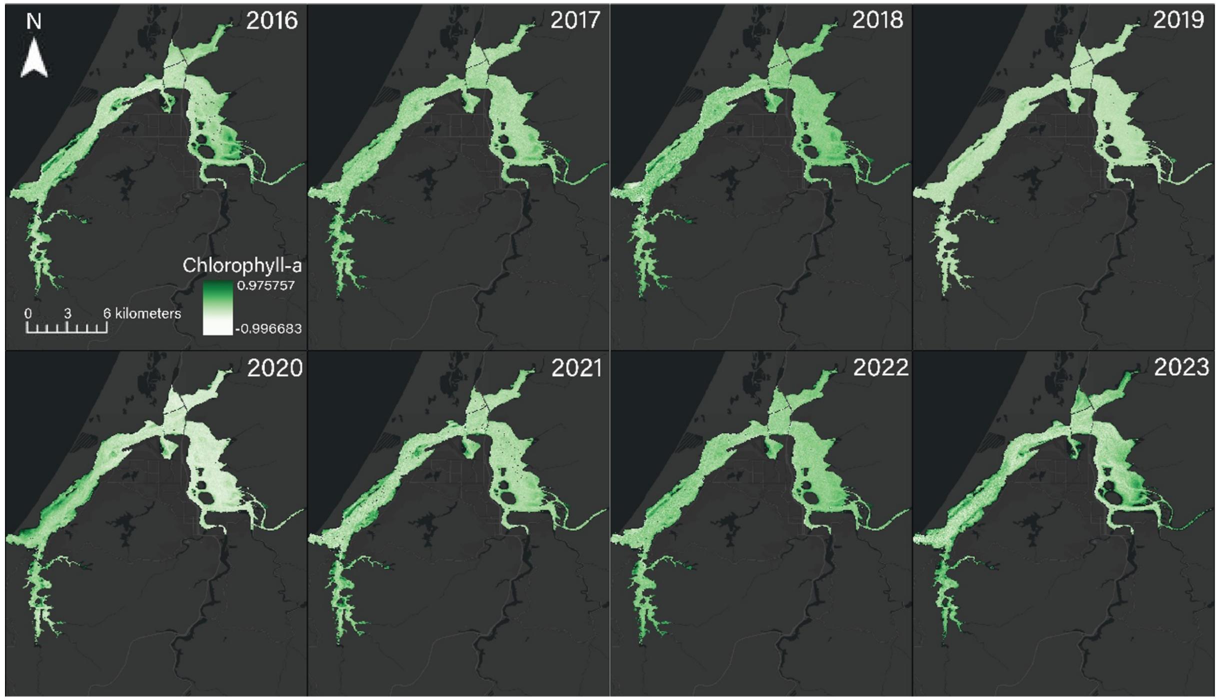
$$C_{chl-a} \propto \frac{[R_{rs}(708) - R_{rs}(665)]}{[R_{rs}(708) + R_{rs}(665)]}$$



Mishra & Mishra (2012). Normalized difference chlorophyll index: A novel model for remote estimation of chlorophyll-a concentration in turbid productive waters. Remote Sensing of Environment, 117, 394-406.

Application of NDCI to Estuarine Waters in Western US

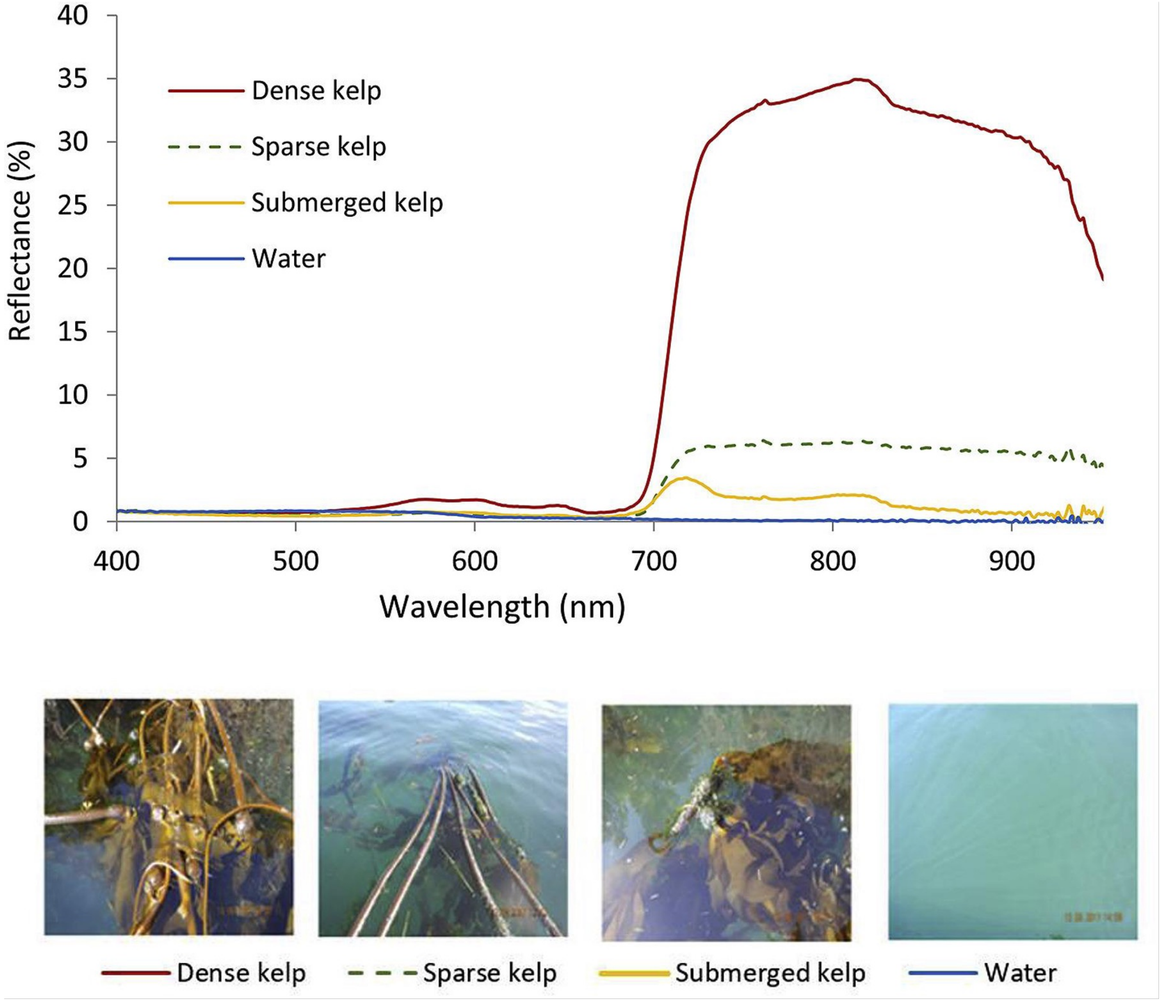
- High NDCI values can be indicative of regions impacted by nutrient enrichment.
- In general, NDCI will give an idea of the concentration of phytoplankton communities in the water column.
- But… in relatively clear and shallow waters, it may be influenced by the presence of benthic vegetation such as seagrass or green algae.



Credit: NASA DEVELOP Program Summer 2023 South Slough Water Resources Project

Discrimination of Floating Kelps at the Water Surface

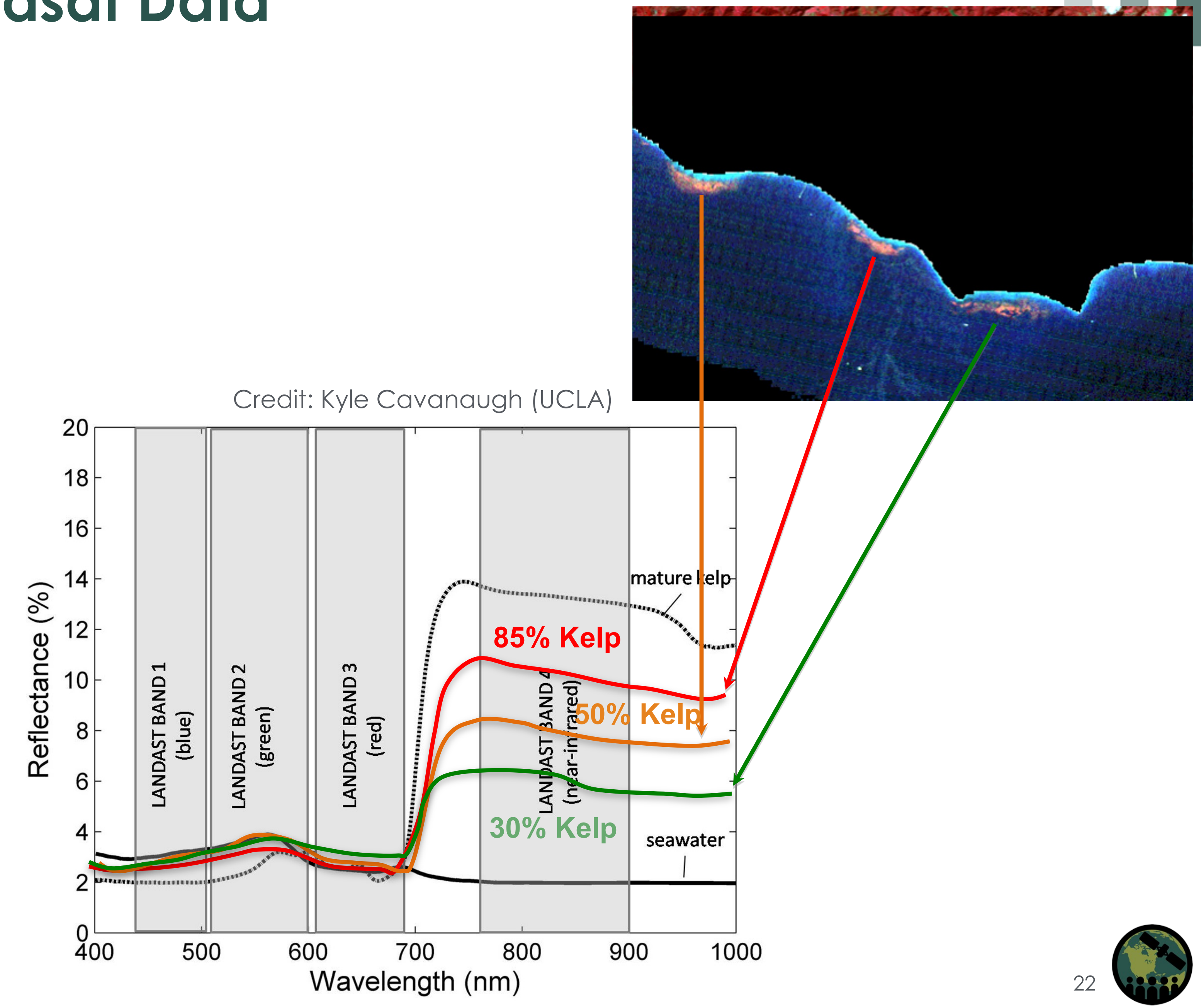
- Dense kelp at the water surface reflects strongly in the NIR.
- Sparse and submerged kelp signals reflect the high influence of the water absorption of NIR even in the first centimeters of the water column.
- Signals are also influenced by the presence of phytoplankton, suspended sediments, and Colored Dissolved Organic Matter (CDOM).



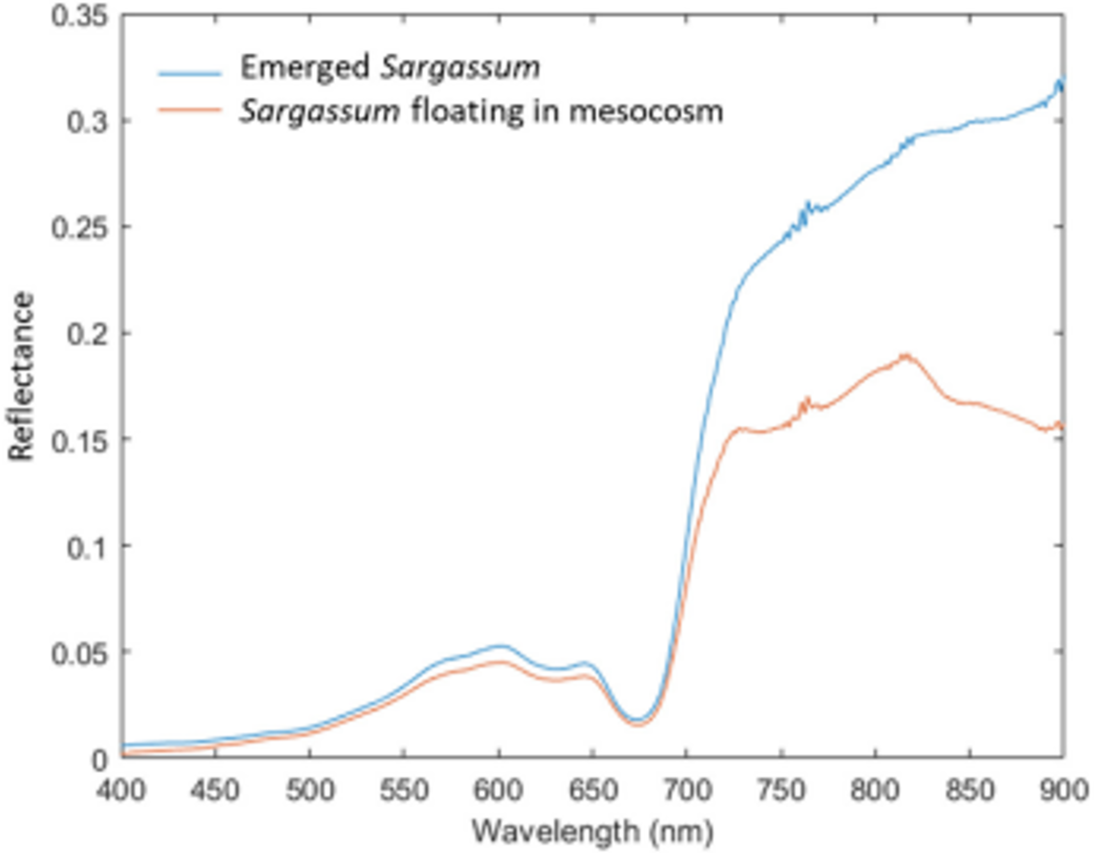
Schroeder et al (2019) Global Ecol. Cons.

Spectral Unmixing of Landsat Data

- Every pixel needs to be modeled as a combination of water and kelp endmembers.
- Due to Landsat pixel size (30m) and heterogeneous canopy cover at water surface.



Exploiting Vegetation Spectral Signature to Detect *Sargassum*



From: Descloitres et al. (2021)

Moderate Resolution Sensors for *Sargassum*

	MODIS (A & T)	VIIRS
Spatial Resolution	1 km	750 m
Temporal Resolution	1 day	1 day
Cross Track	2 330 km	3 040 km
Algae Index	AFAI[1]	AFAI[1]
Radiometric data*	Rayleigh-corrected reflectance**	Rayleigh-corrected reflectance**
Wavebands	λ_1 = 667 nm	λ_1 = 671 nm
	λ_2 = 748 nm	λ_2 = 745 nm
	λ_3 = 869 nm	λ_3 = 862 nm

From: Ody et al. (2019)

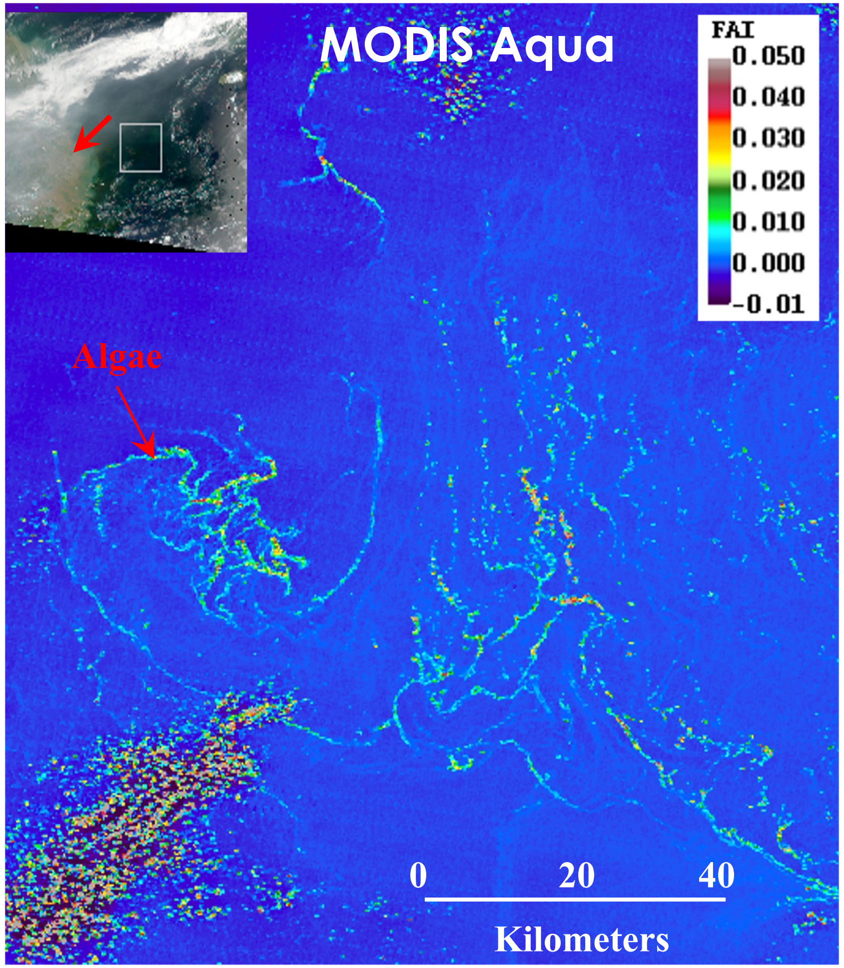
Floating Algae Index (FAI)

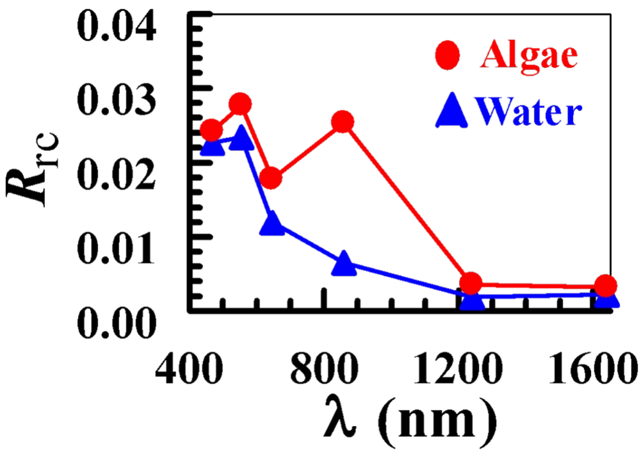
- $R_{rc\ (RED,\ NIR,\ SWIR)}$ = Molecular (Rayleigh) scattering-corrected reflectance in the red, near infrared, and shortwave infrared regions
- $R'_{rc,NIR}$ = Baseline reflectance in the NIR derived from a linear interpolation between the red and SWIR bands
- λ_{RED} = 645nm
- λ_{NIR} = 859nm
- λ_{SWIR} = 1240nm

$$\mathrm{FAI} = R_{\mathrm{rc,NIR}} - R'_{\mathrm{rc,NIR}},$$
$$R'_{\mathrm{rc,NIR}} = R_{\mathrm{rc,RED}} + \left(R_{\mathrm{rc,SWIR}} - R_{\mathrm{rc,RED}}\right) \times (\lambda_{\mathrm{NIR}} - \lambda_{\mathrm{RED}}) / (\lambda_{\mathrm{SWIR}} - \lambda_{\mathrm{RED}})$$

Hu, C. (2009). A novel ocean color index to detect floating algae in the global oceans. Remote Sensing of Environment, 113, 2118–2129.

Floating Algae Index (FAI)





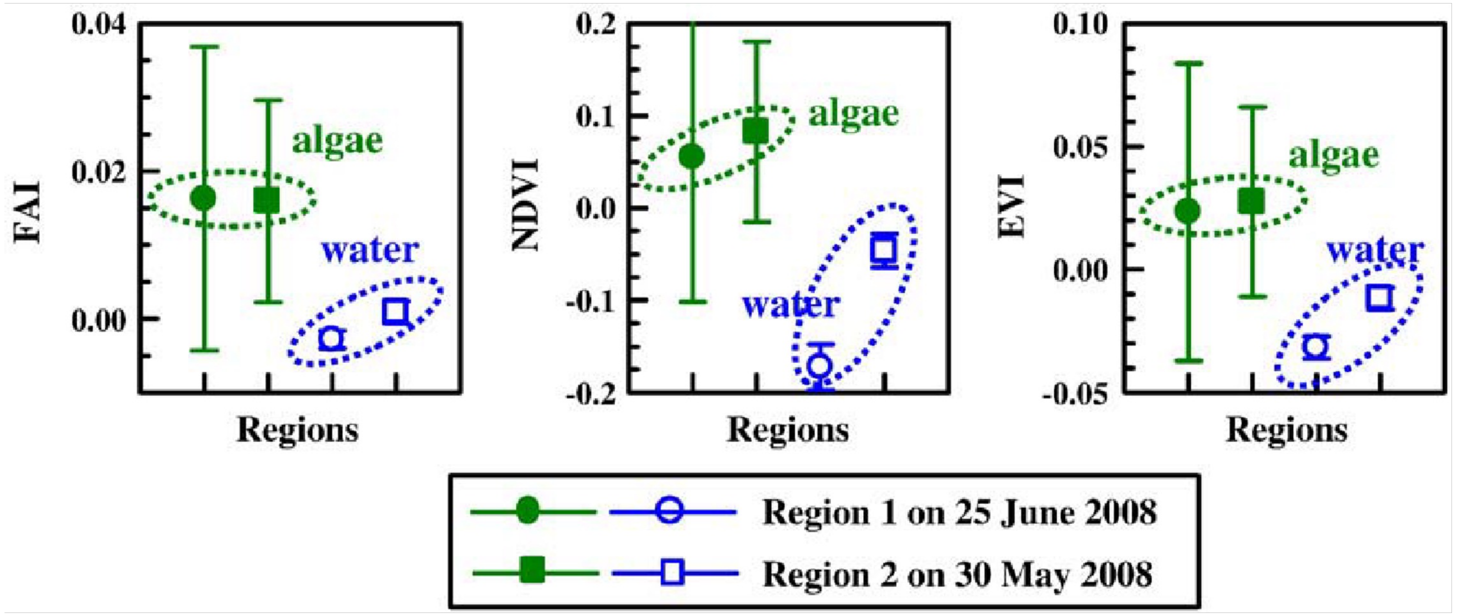
From: Hu (2009)

FAI Spectral Bands: λRED =645nm, λNIR =859nm, λSWIR =1240nm

Hu, C. (2009). A novel ocean color index to detect floating algae in the global oceans. Remote Sensing of Environment, 113, 2118–2129.

FAI Compared to NDVI and EVI Applied to Algae Detection

- Hu (2009) also applied the MODIS-based Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) to the same algal bloom in China.
- In both study regions, the FAI values appeared more stable than those of NDVI and EVI over "algae" and "water" pixels.



Hu, C. (2009). A novel ocean color index to detect floating algae in the global oceans. Remote Sensing of Environment, 113, 2118–2129.

Sentinel 2 MSI (10m) FAI, La Parguera, SWPR

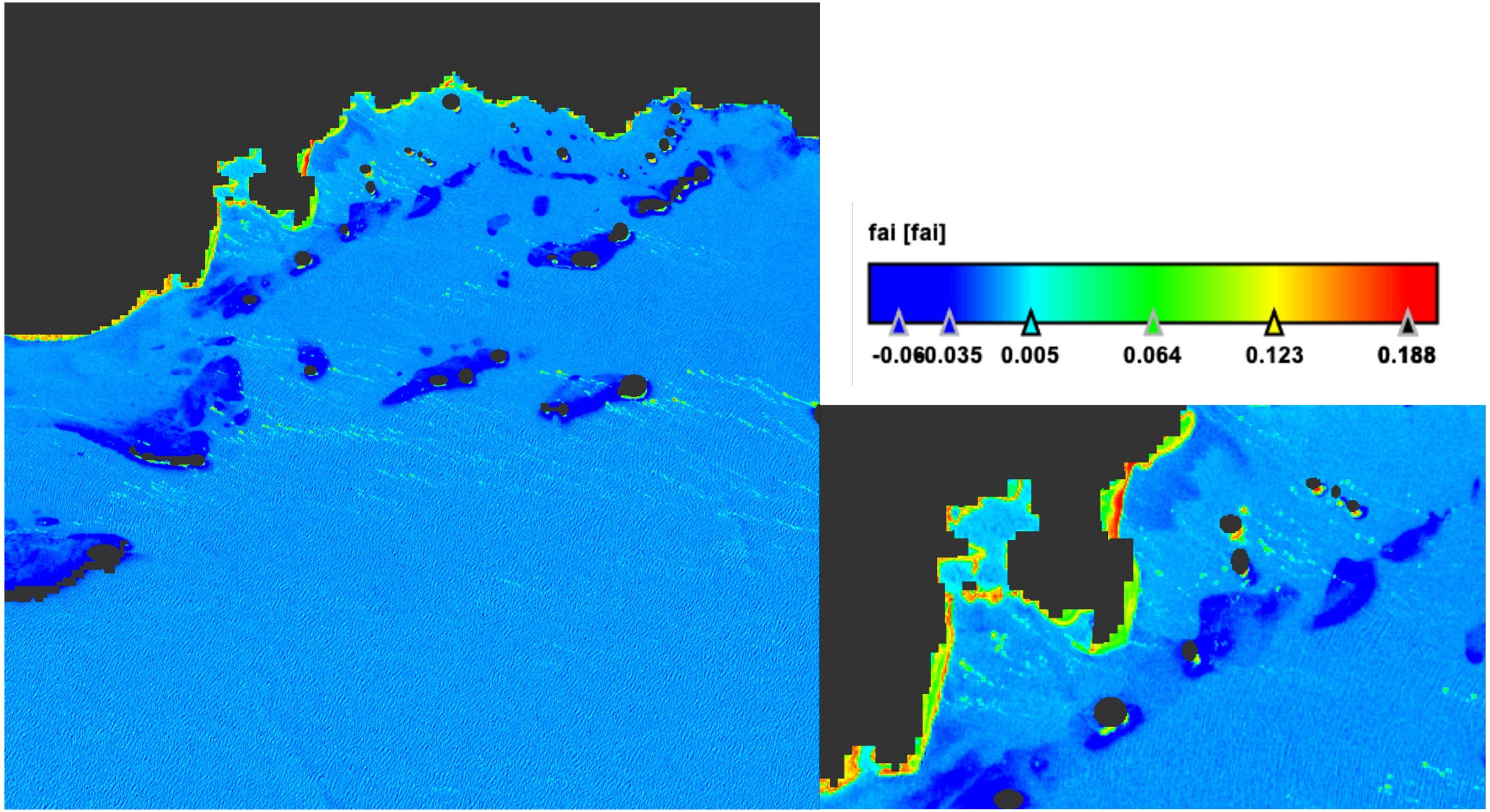
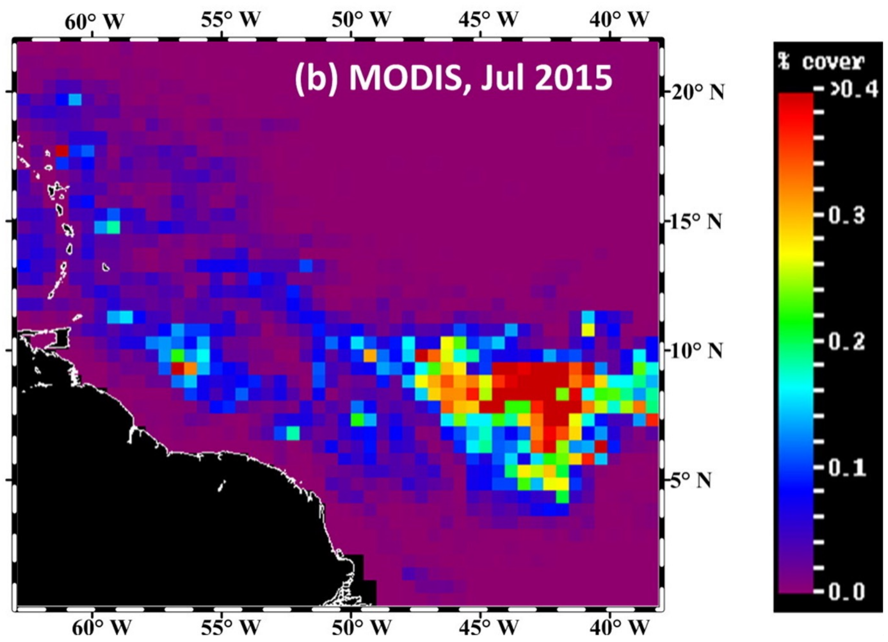
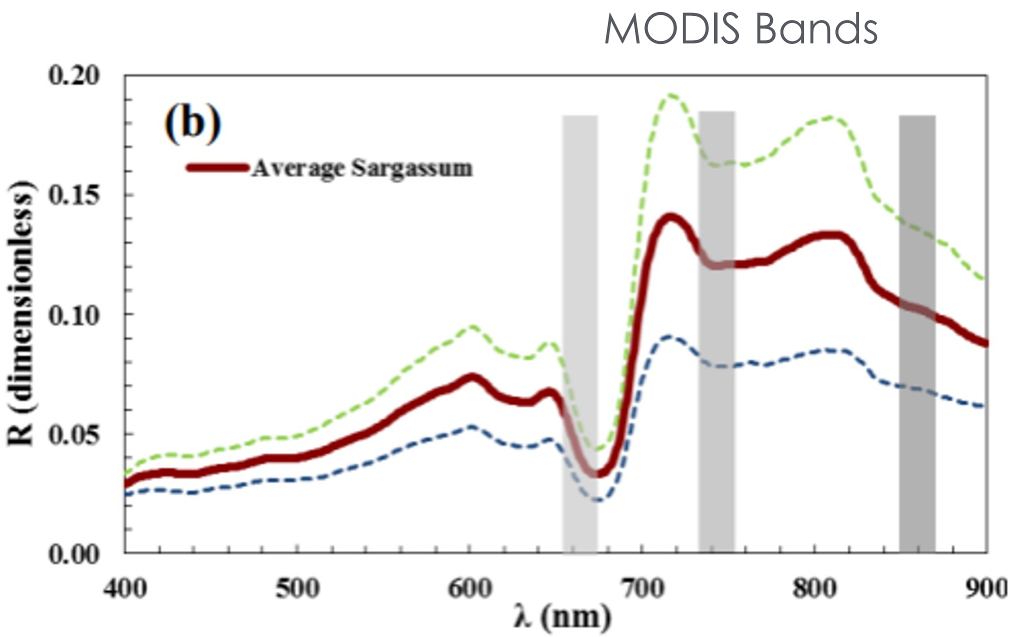


Image Credit: Jennifer Perez Univ of PR-Mayaguez Campus

Alternate Floating Algae Index (AFAI)



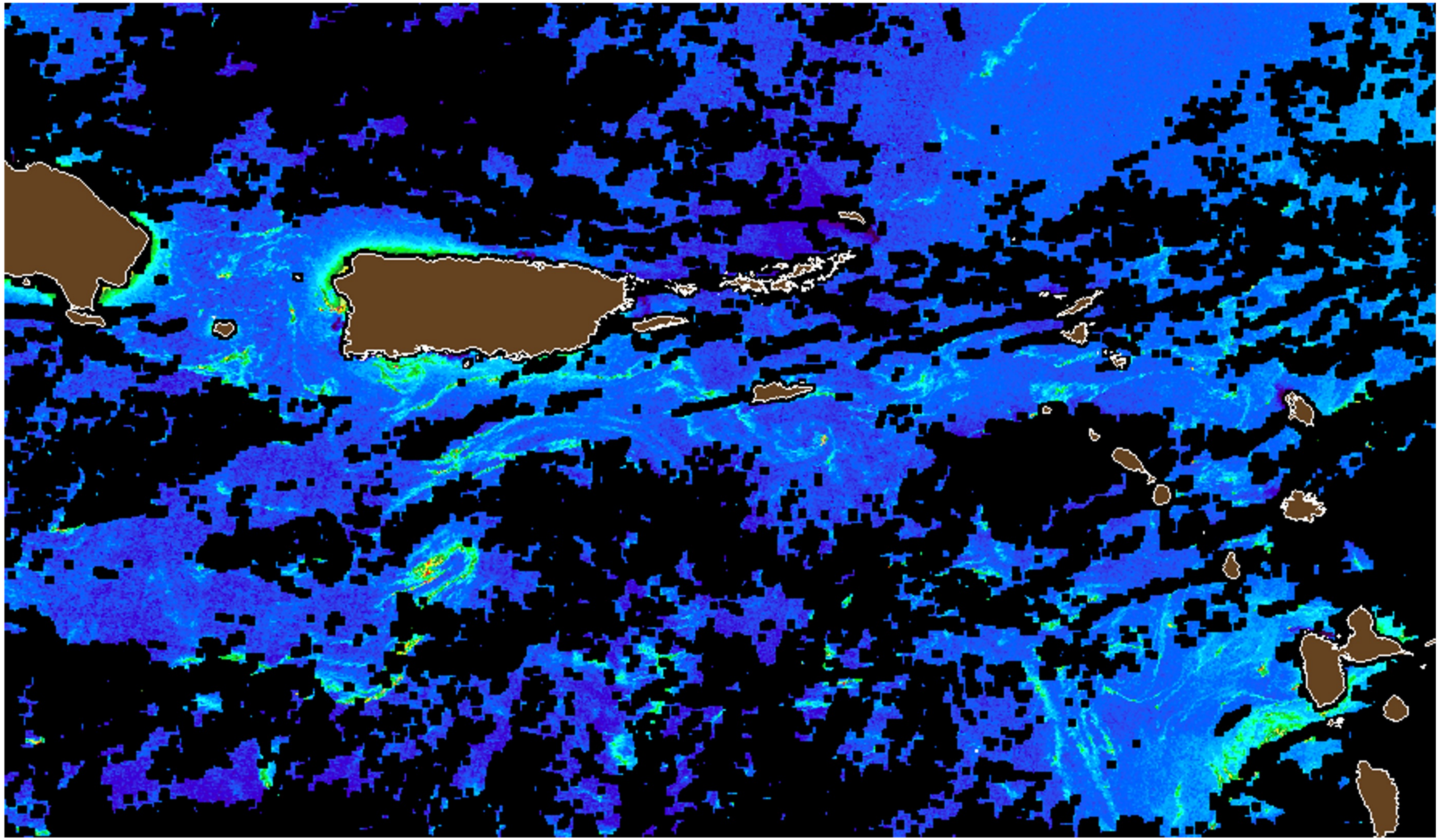


Adapted from Wang & Hu 2016

AFAI Spectral Bands: (λRED=667nm, λNIR=748nm, λSWIR=869nm)

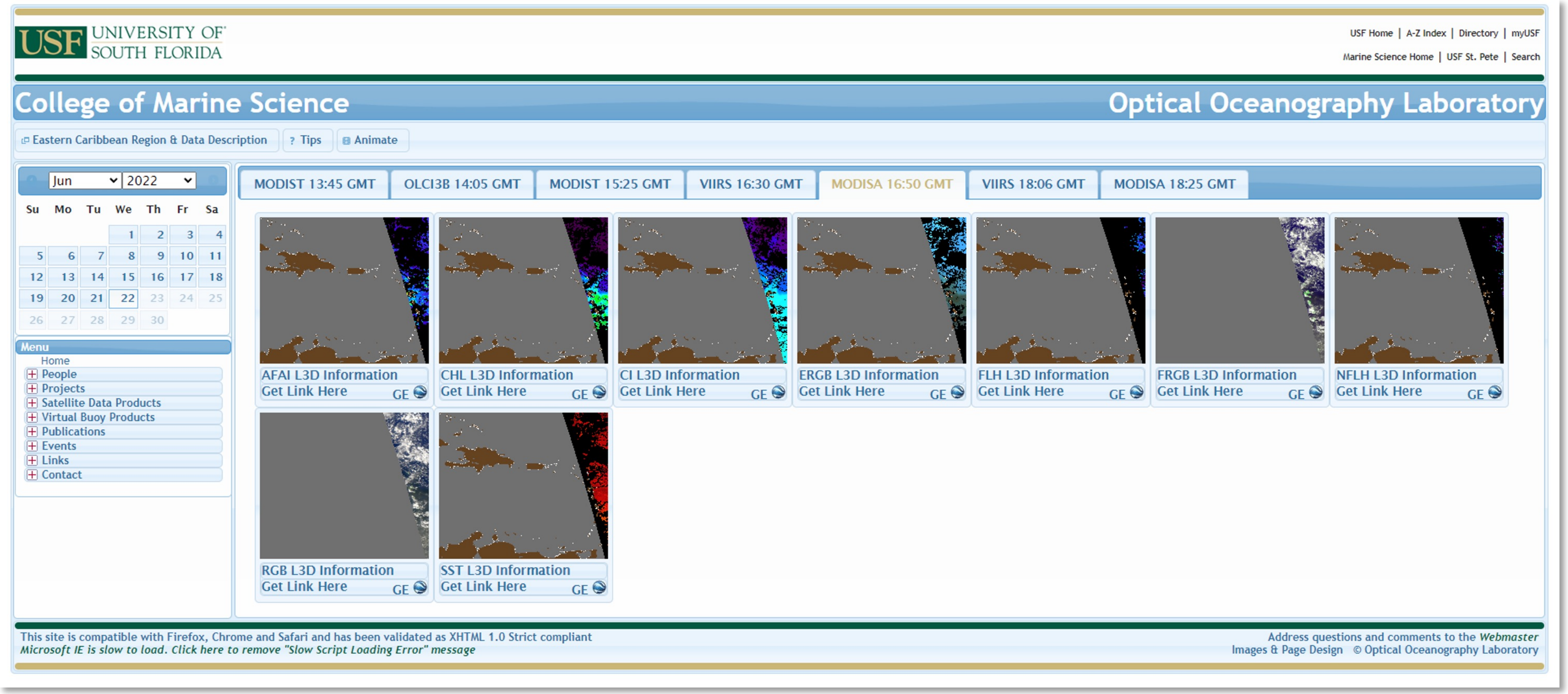
Wang, M and Hu, C. Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations, Remote Sensing of Environment, Volume 183, 2016, Pages 350-367, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2016.04.019.

Alternate Floating Algae Index (AFAI)



May 4, 2022, Courtesy of: https://optics.marine.usf.edu/projects/SaWS.html

Sargassum Watch System (SaWS)



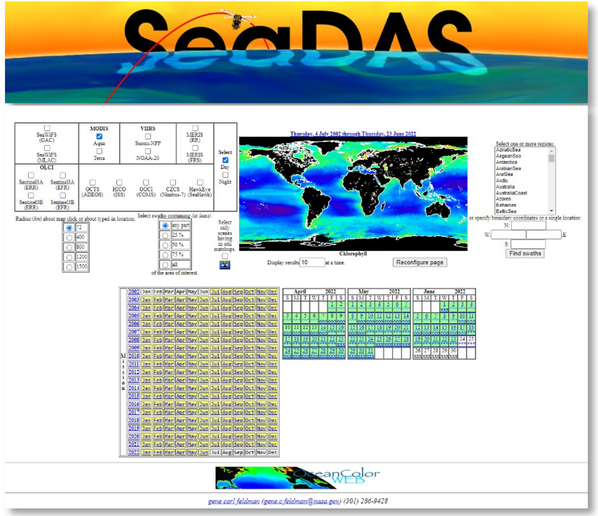
https://optics.marine.usf.edu/projects/SaWS.html

Additional Data Sources

- MODIS/VIIRS
  - NASA's Ocean Color Web Level 2 Browser
  - Processed with SEADAS using L2 gen
  - https://oceancolor.gsfc.nasa.gov/
- Sentinel-3 OLCI
  - Level-2 Products
  - Processed with SNAP Processing Software
  - https://scihub.copernicus.eu/

[ARSET Monitoring Coastal Estuarine Water Quality: MODIS to VIIRS Transition]()

[ARSET Monitoring Coastal Estuarine Water Quality with Remote Sensing and In Situ Data]()



Normalized Difference Aquatic Vegetation Index (NDAVI)

- Introduced by Villa et al (2014)
- Designed to use the Landsat TM/ETM+ Bands 1 (blue; centered at 480nm) and 4 (NIR; centered at 830nm)

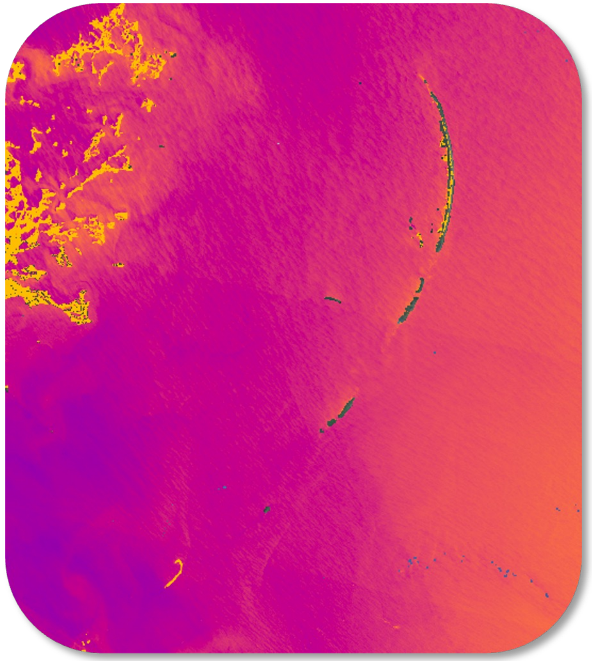
$$\text{NDAVI} = \frac{\rho_{\text{NIR}(0.76-0.90\,\mu\text{m})} - \rho_{\text{BLUE}(0.45-0.52\,\mu\text{m})}}{\rho_{\text{NIR}(0.76-0.90\,\mu\text{m})} + \rho_{\text{BLUE}(0.45-0.52\,\mu\text{m})}}$$

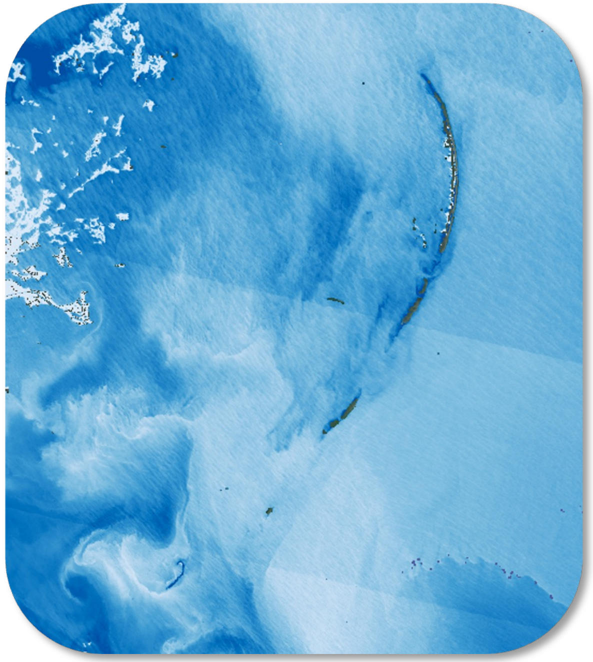
- Where ρ = surface reflectance

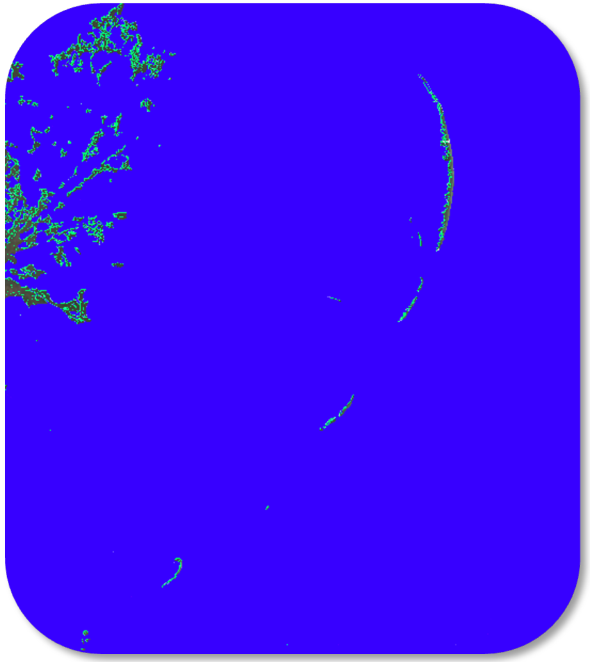
Villa et al (2014), Aquatic vegetation indices assessment through radiative transfer modeling and linear mixture simulation. Int. J. Appl. Earth Obs. And Geoinformation, 30, 113-127.

NDAVI – A Spectral Index Useful for Seagrass Monitoring

Near Infrared Band & **Blue Band** = **Aquatic Vegetation**







NDAVI

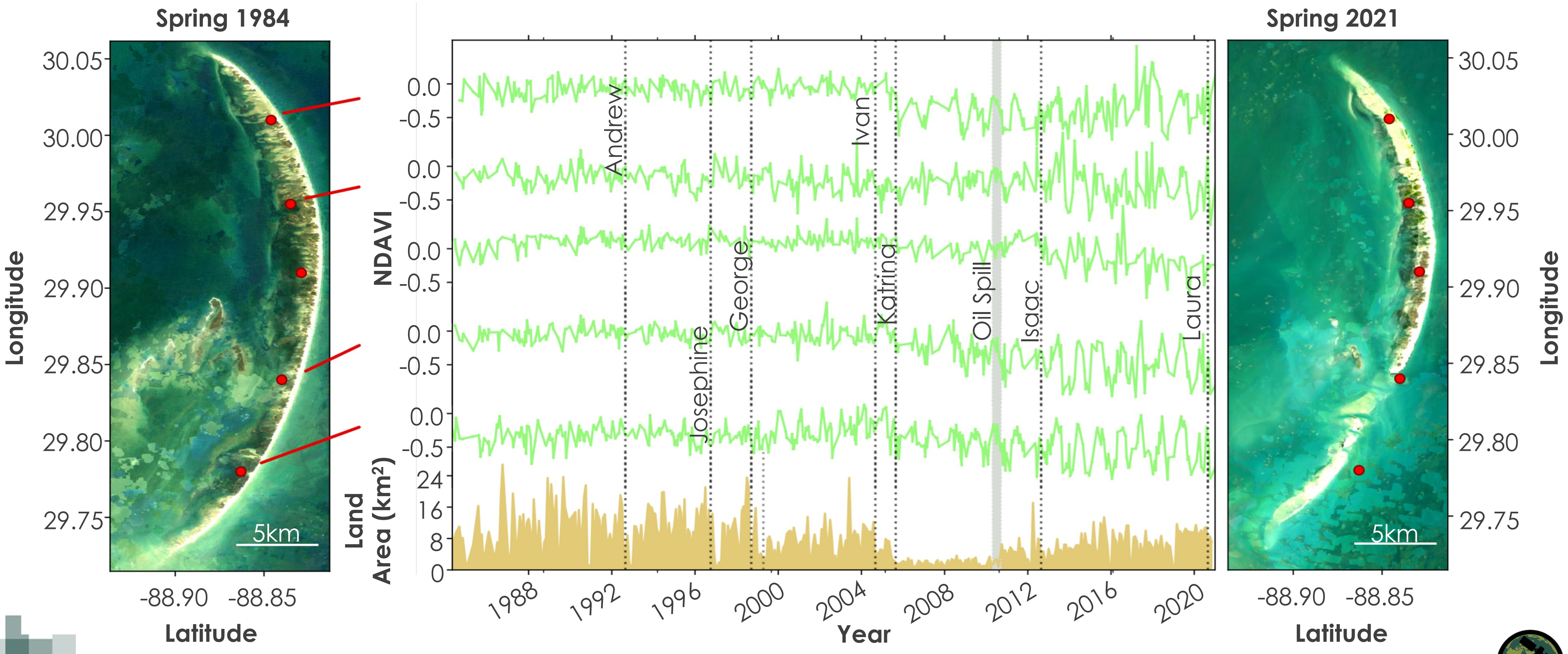
Spring 2019 over the Chandeleur Sound

Normalized Difference Aquatic Vegetation Index = (**NIR** – **Blue**)/(**NIR** + **Blue**)

Credit: NASA DEVELOP ARC Summer 2021 Louisiana Water Resources

NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses

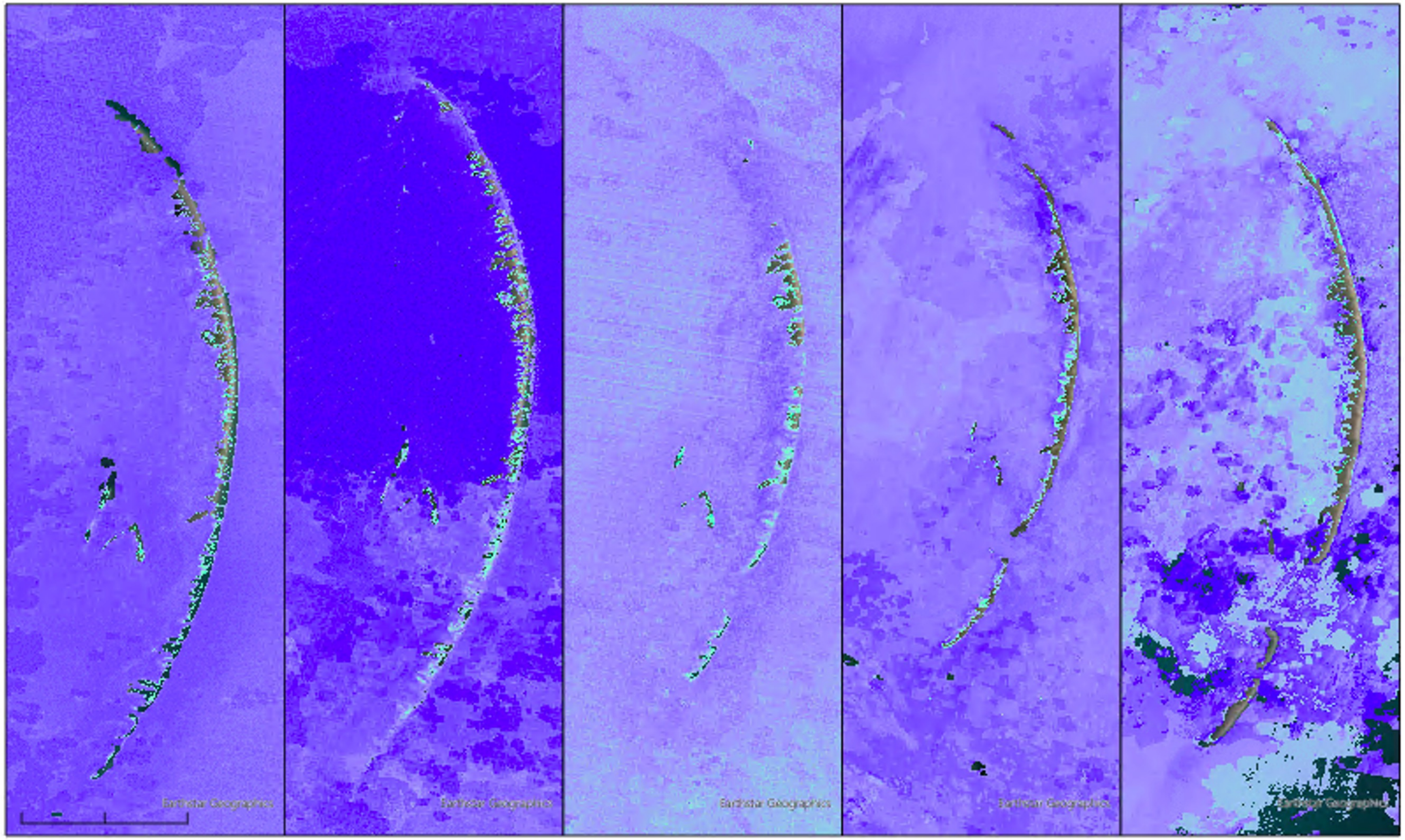
NDAVI and land area from 1984 to 2021 at five locations along the islands.



Credit: NASA DEVELOP ARC Summer 2021 Louisiana Water Resources

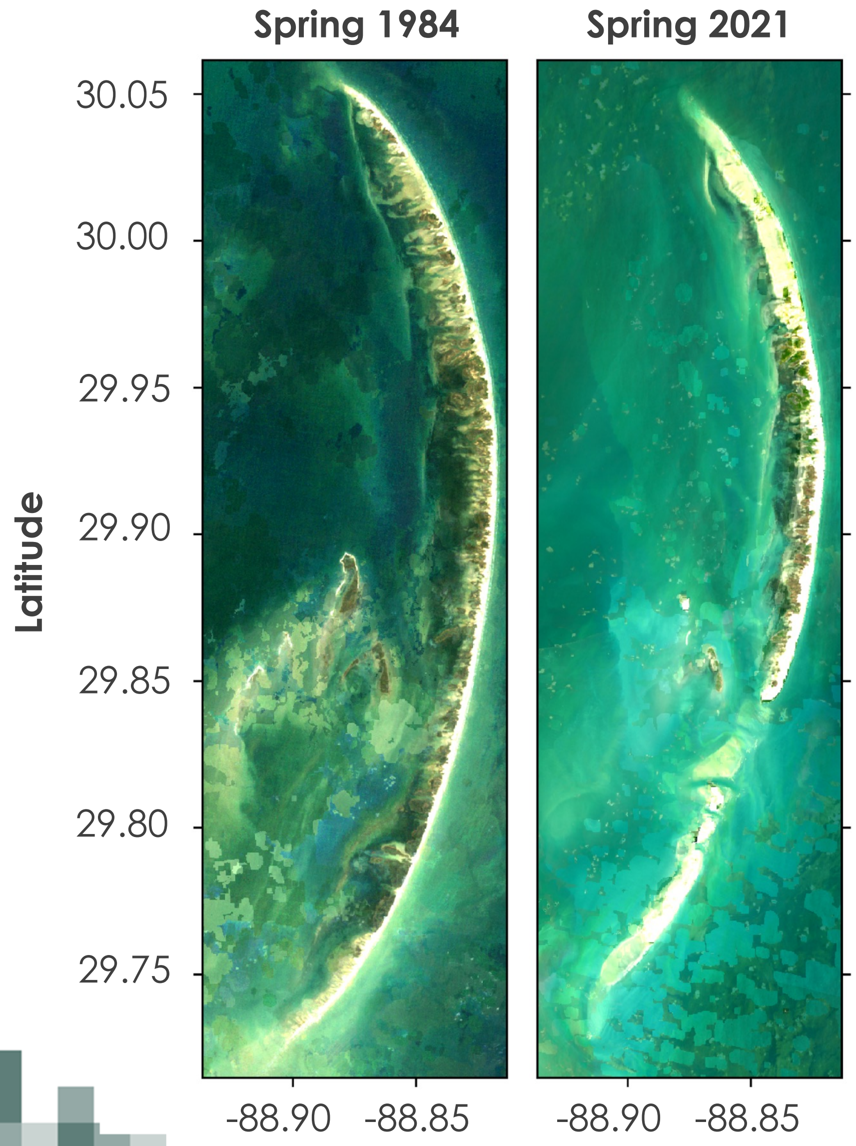
NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses

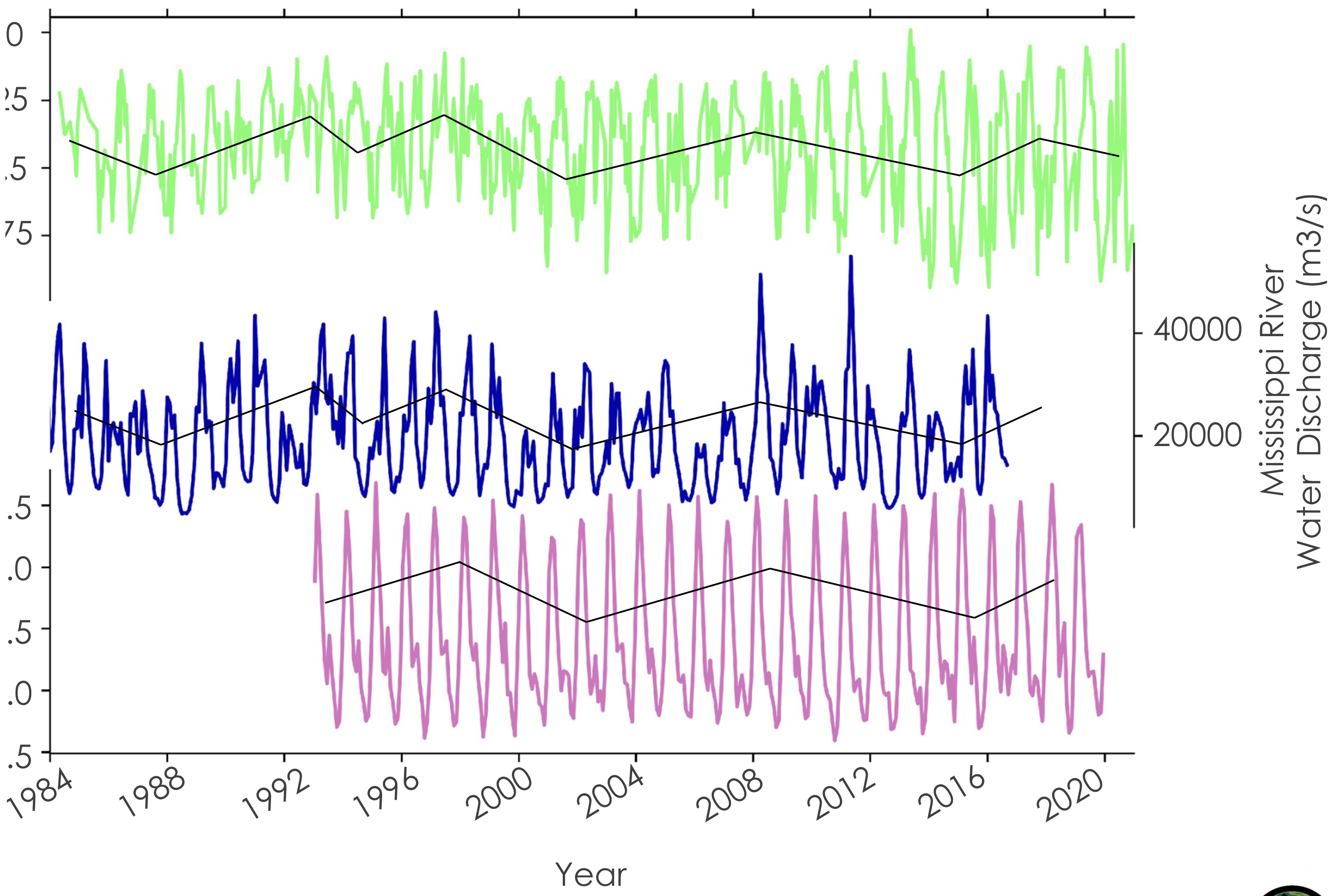
NDAVI around the Chandeleur Islands from Summer 2000 – Summer 2020



Credit: NASA DEVELOP ARC Summer 2021 Louisiana Water Resources

NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses





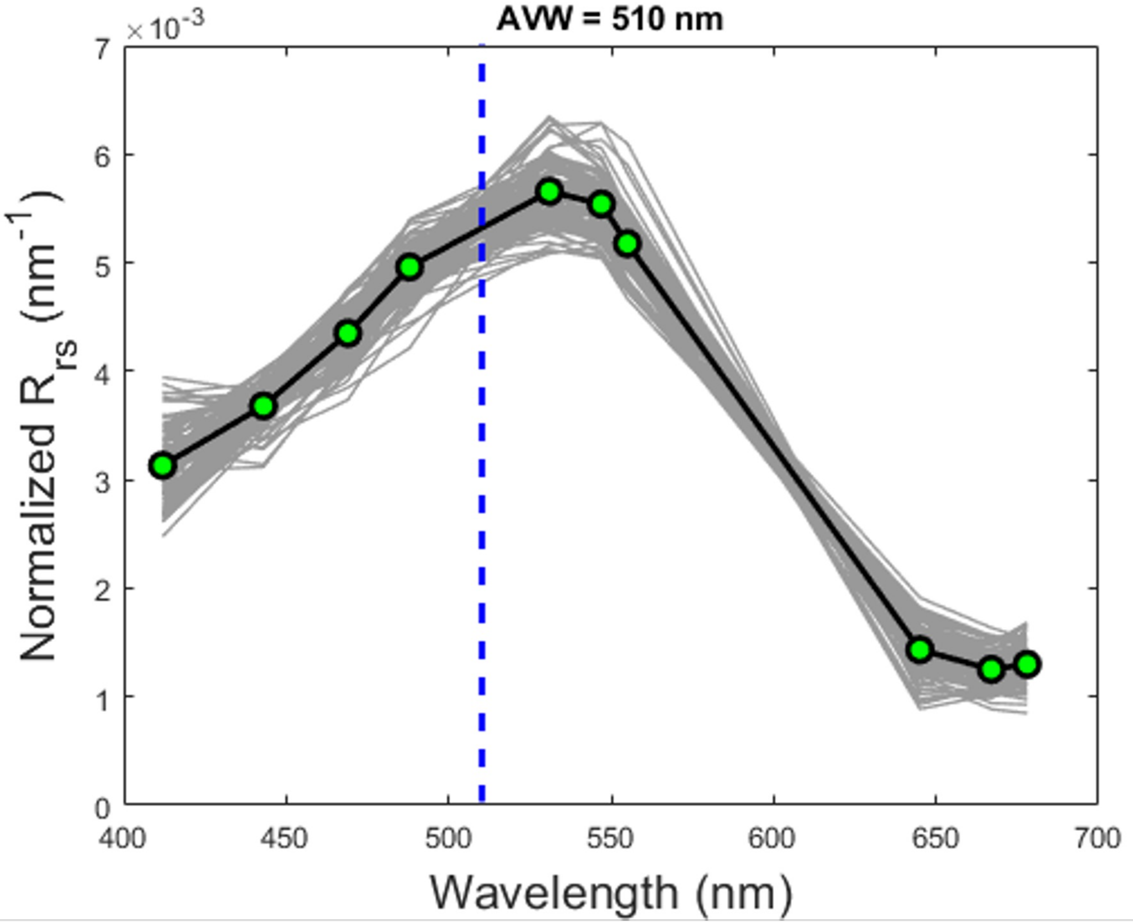
Credit: NASA DEVELOP ARC Summer 2021 Louisiana Water Resources

Apparent Visible Wavelength (AVW)

Additional Information At: NASA Ocean Color

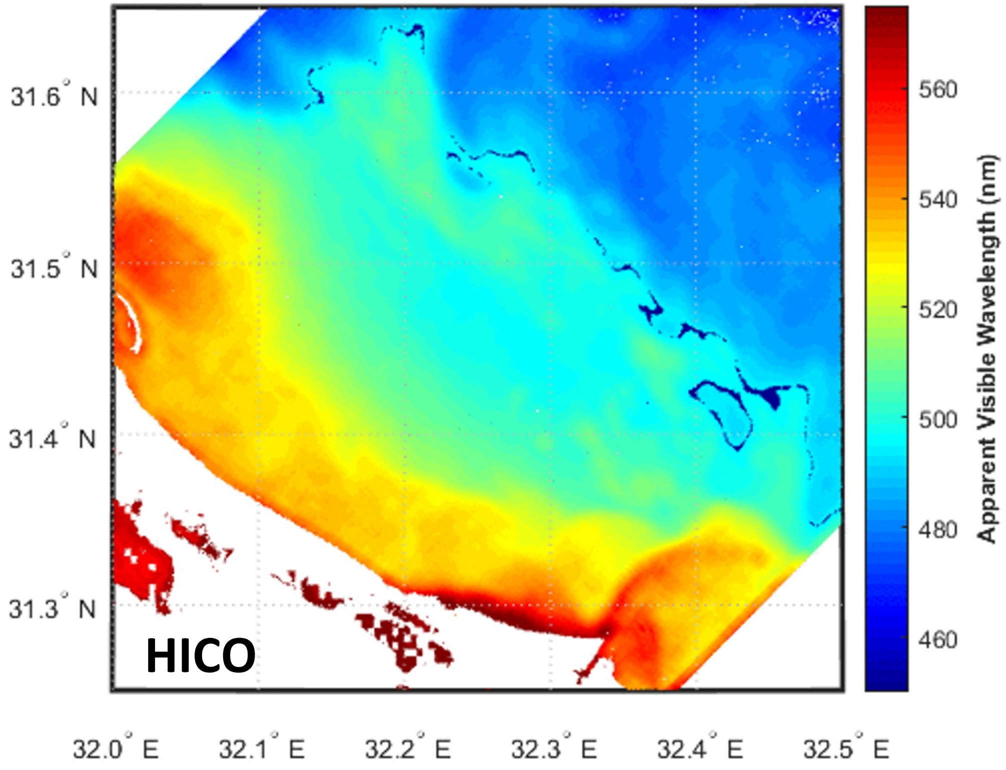
$$AVW = \frac{\sum_{i=\lambda_1}^{\lambda_n} R_{RS}(\lambda_i)}{\sum_{i=\lambda_1}^{\lambda_n} \frac{R_{RS}(\lambda_i)}{\lambda_i}} = \left(\frac{\sum_{i=\lambda_1}^{\lambda_n} \lambda_i^{-1} R_{RS}(\lambda_i)}{\sum_{i=\lambda_1}^{\lambda_n} R_{RS}(\lambda_i)} \right)^{-1}$$

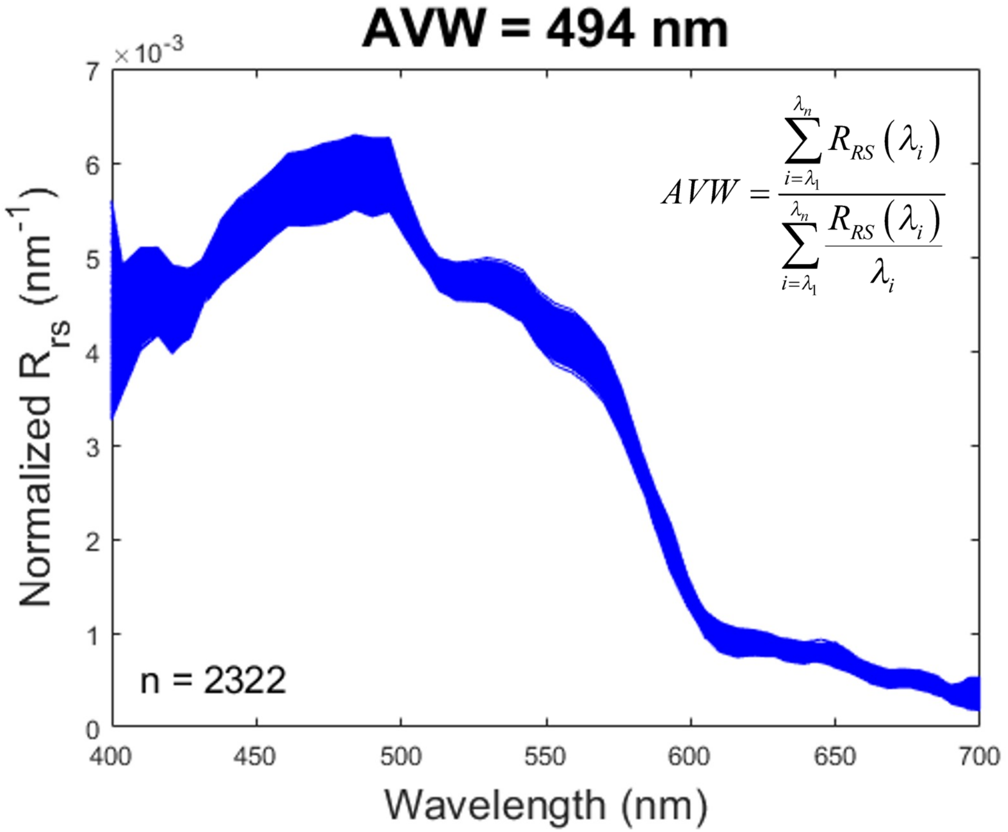
*The weighted harmonic mean of the R_{RS} wavelengths, outputs an **Apparent Visible Wavelength, AVW** (in nm). The derivation of the AVW is simply a first-order measure of the dominant color of the water, as determined by the weight that each measured channel contributes to the reflectance in the visible range of the spectrum.*



Vandermeulen et al. (2020). 150 Shades of Green: Using the full spectrum of remote sensing reflectance to elucidate color shifts in the ocean. Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2020.111900

Apparent Visible Wavelength (AVW)

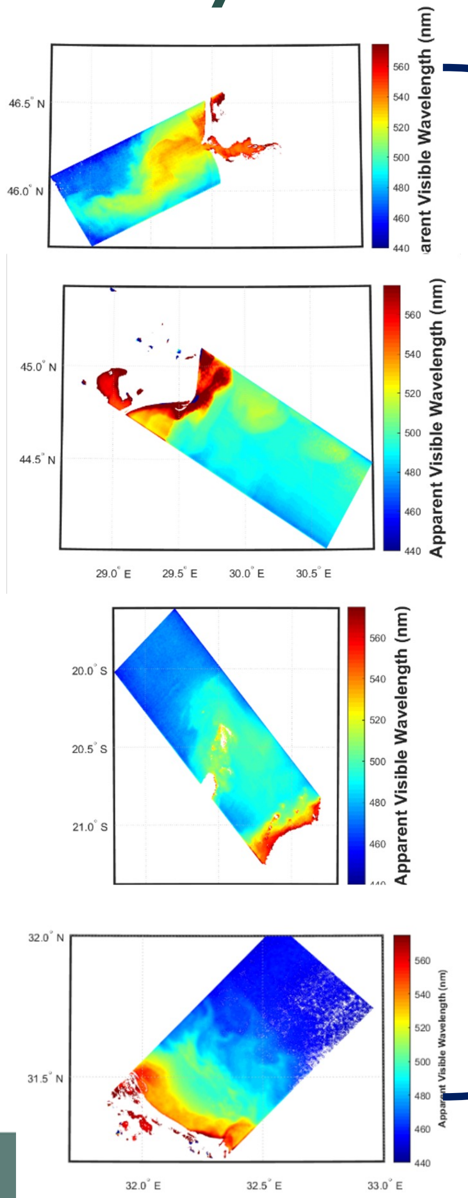




Using full spectral information represents a more holistic approach to unraveling spectral variability, ensuring that any diagnostic signals present are considered, and thus can help maximize the potential of spectral information embedded in remote sensing data.

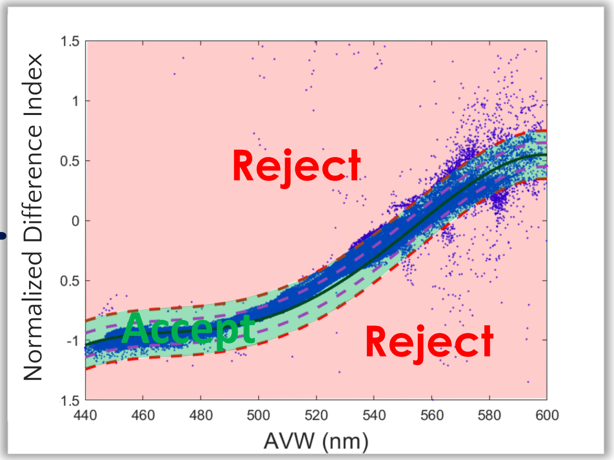
Credit: Ryan Vandermeulen (NOAA Fisheries)

Quality Water Index Polynomial (QWIP)

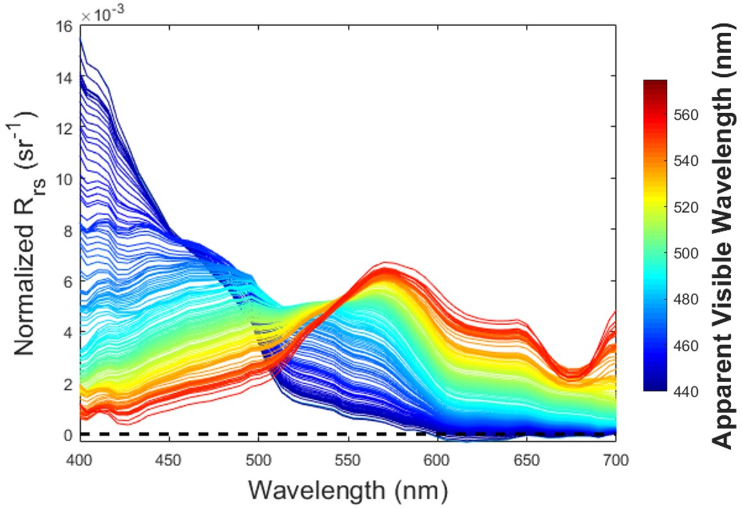


HICO Images

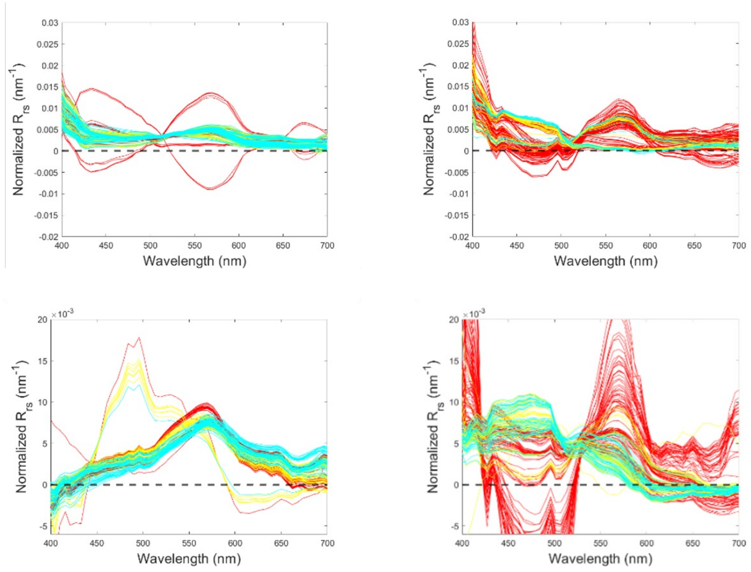
Automated Quality Control of Hyperspectral Satellite Imagery



Accept



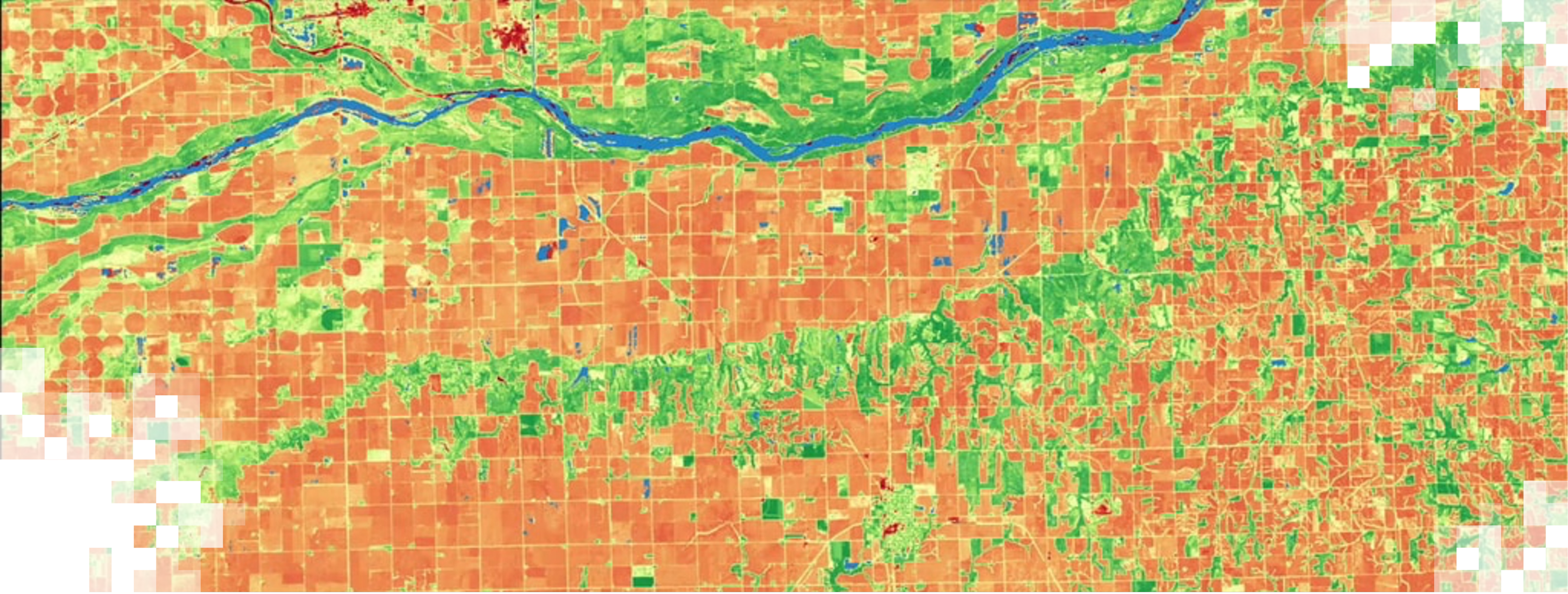
Reject



Dierssen et al (2022), QWIP: A quantitative metric for quality control of aquatic reflectance spectral shape using the apparent visible wavelength, Frontiers in Remote Sensing, 3, 869611.

QWIP Deviation Score: 0.2 – 0.25 | 0.25 – 0.35 | > 0.35

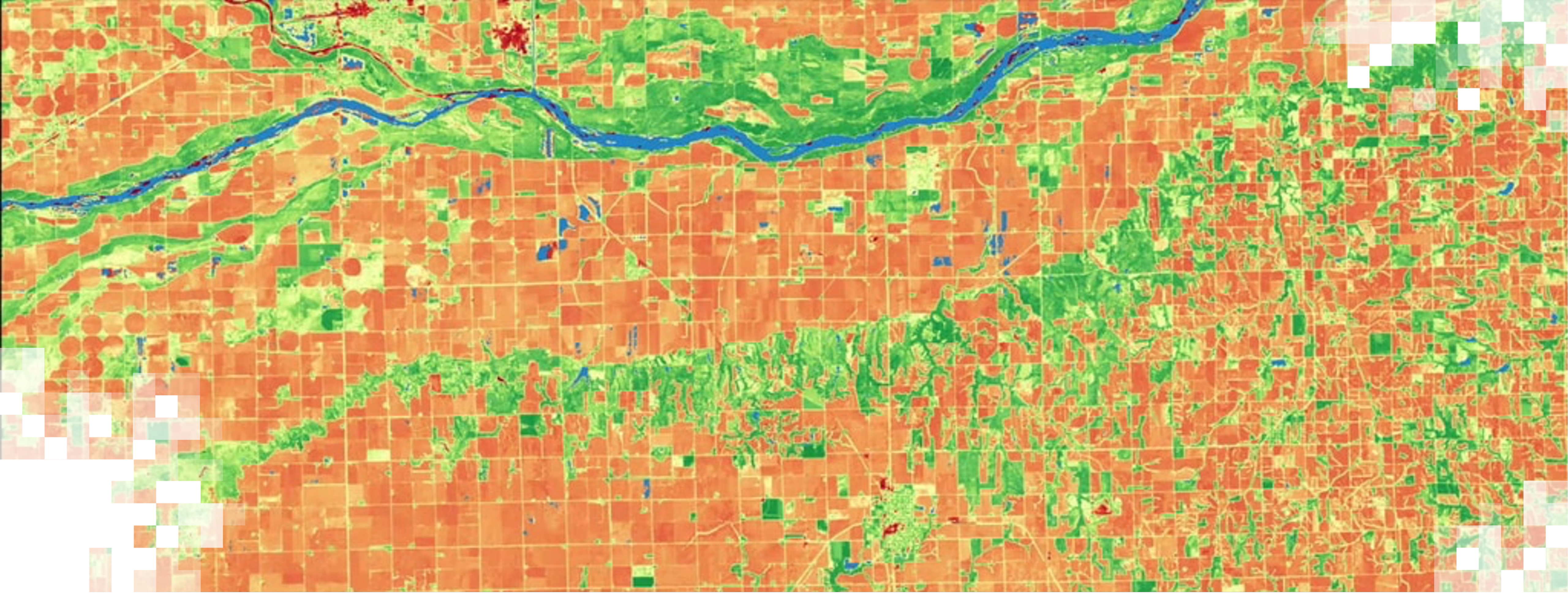
Credit: Ryan Vandermeulen (NOAA Fisheries)



Index Calculation in Google Earth Engine

CODE LINK:

https://code.earthengine.google.com/9a316de7092e6af4a9f2fde33baea8c4



Part 2:
Summary

Summary

- A number of simple spectral indices have been developed in the past decades, mostly for multispectral datasets.
- Particular wavelengths (such as NIR or SWIR) do not penetrate much into the water column and influence the specific index to use.
- It is important to make sure the appropriate atmospheric correction algorithm has been applied to the imagery during pre-processing before applying a spectral index. This is particularly important with aquatic targets.
- Some indices are specific to particular sensors whereas others can be applied to multiple sensors.
- New algorithms (or indices) may be applicable to both multispectral and hyperspectral datasets.

Looking Ahead to Part 3

- As a reminder, in Part 3 of this webinar series, we will concentrate on land-based spectral indices including the Enhanced Vegetation Index (EVI), the Soil-Adjusted Vegetation Index (SAVI), and the Normalized Burn Ratio (NBR).
- Like in today’s session, short demos will be presented on how to apply some of these indices in Google Earth Engine.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 9/Nov/2023
  - Access from: Spectral Indices for Land and Aquatic Applications
  - Answers must be submitted via Google Forms
  - **Due by 23/Nov/2023**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

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Thank You!