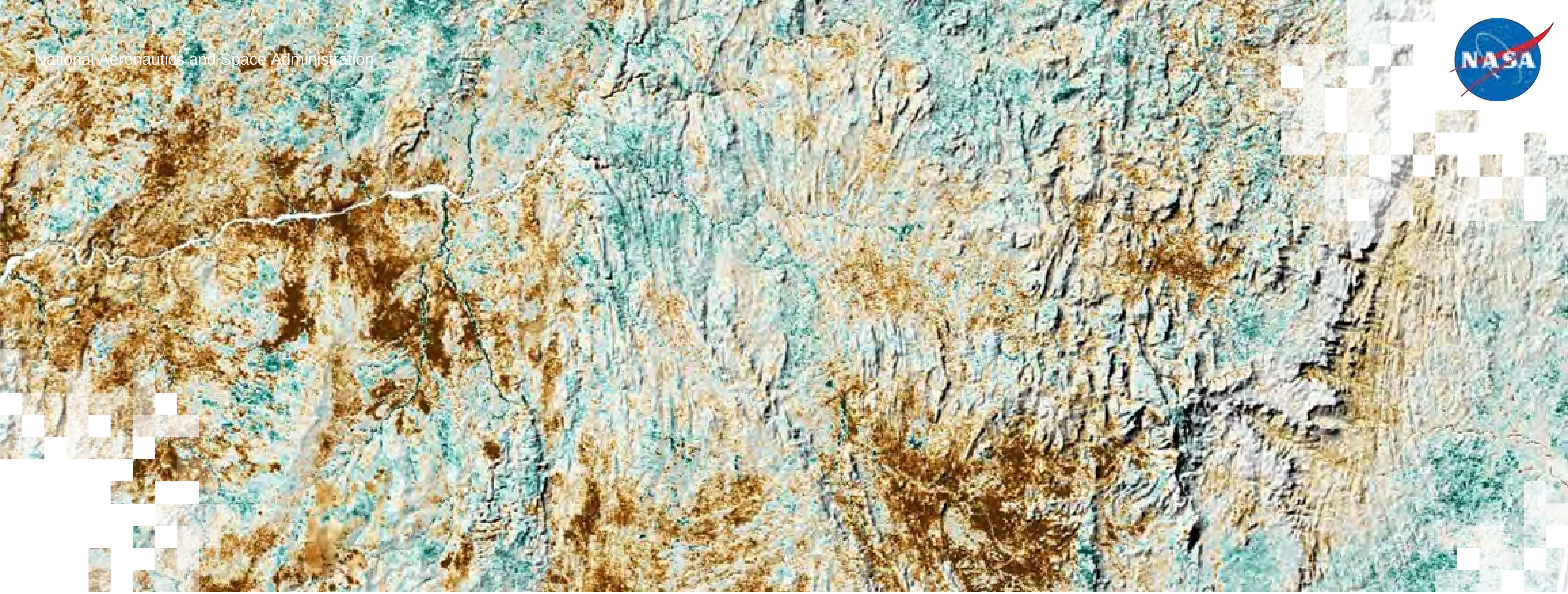


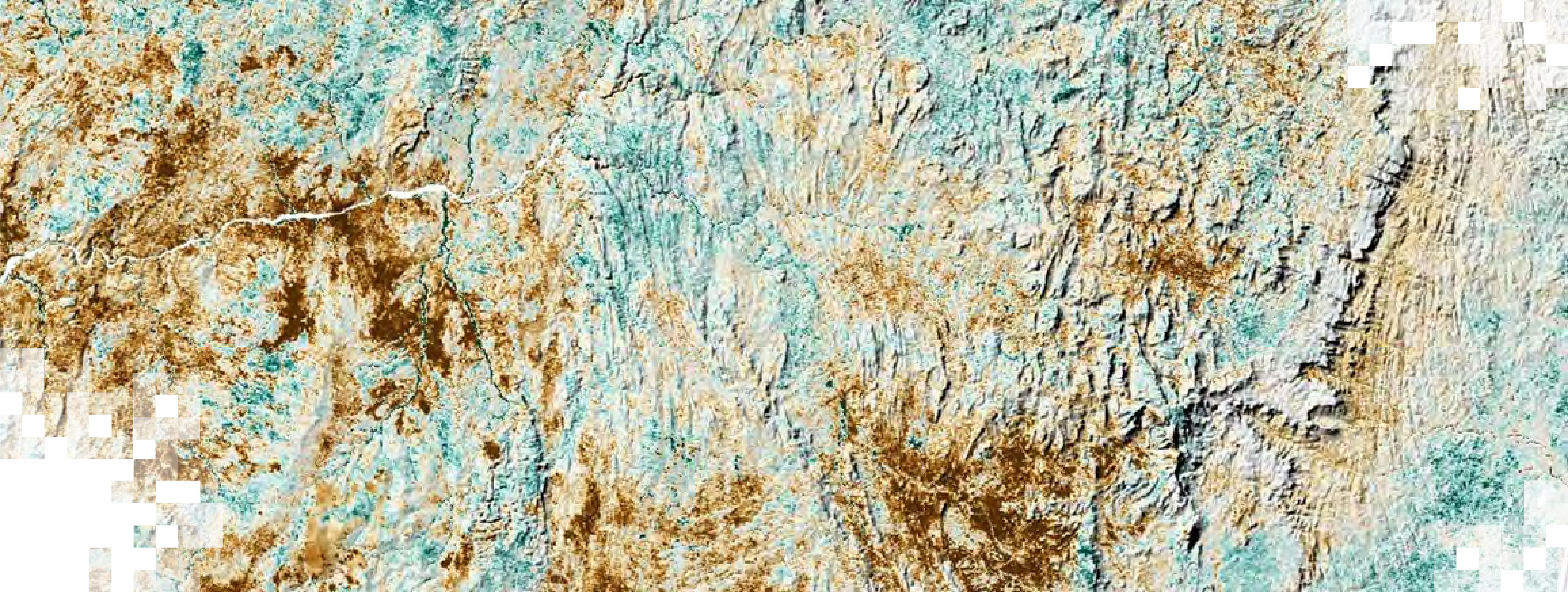
National Aeronautics and Space Administration

Calculating Spectral Indices for Land and Aquatic Applications Using QGIS

Part 1: Spectral Indices in QGIS

Justin Fain (BAERI), Sativa Cruz (BAERI), & Juan Torres-Perez (NASA)

February 27, 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.

AGRICULTURE

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About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
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- Only use open-source software and data
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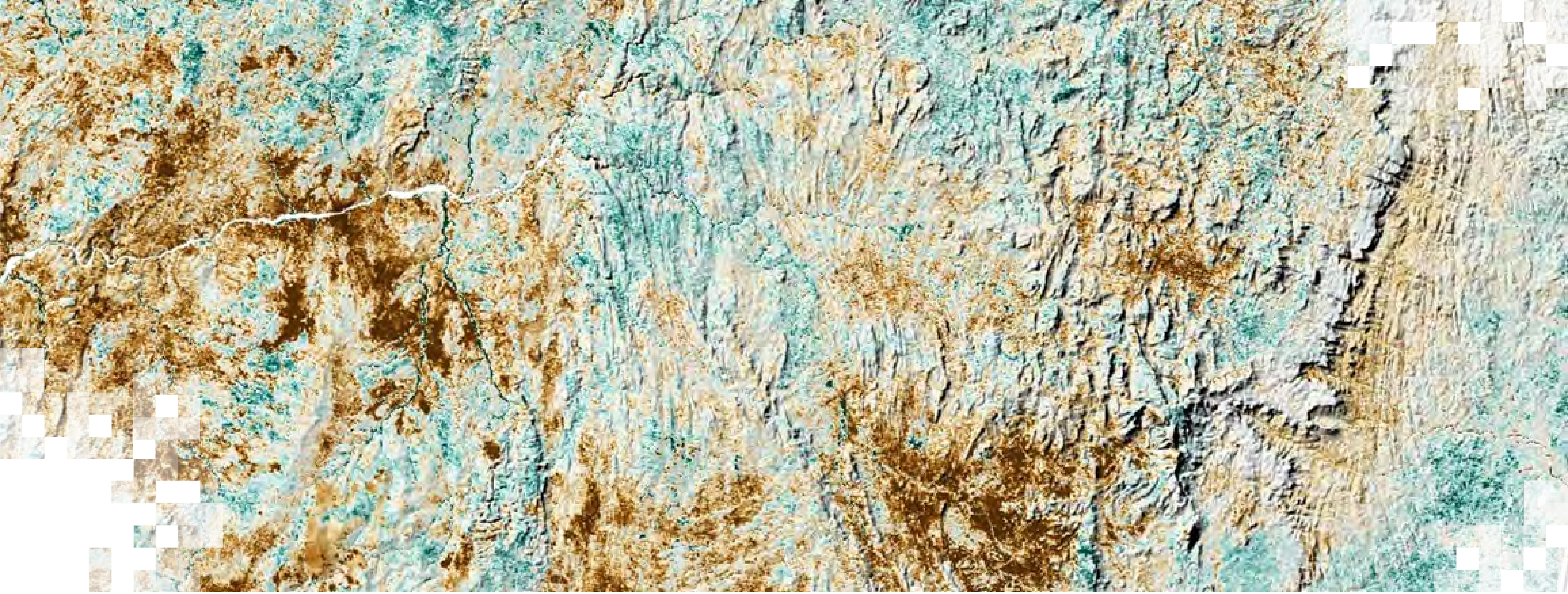


Calculating Spectral Indices for Land and Aquatic Applications Using QGIS

Overview

What are spectral indices?

- Spectral indices give us simple metrics to understand certain qualities of land and aquatic environments.
- Derived directly from spectral information recorded by remote sensing platforms.
- Relatively simple calculations which make use of differences in the reflection/absorption properties of the target, such as high IR reflectance in healthy vegetation or the high rate of IR absorption seen in water bodies.

Training Learning Objectives

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

1. Describe data sources, data processing, and applications for indices related to land and aquatic environments.
2. Calculate indices related to environmental monitoring in both land and aquatic systems using the QGIS raster calculator tool..
3. Identify which indices are appropriate for land versus aquatic monitoring.

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

Spectral Indices in QGIS

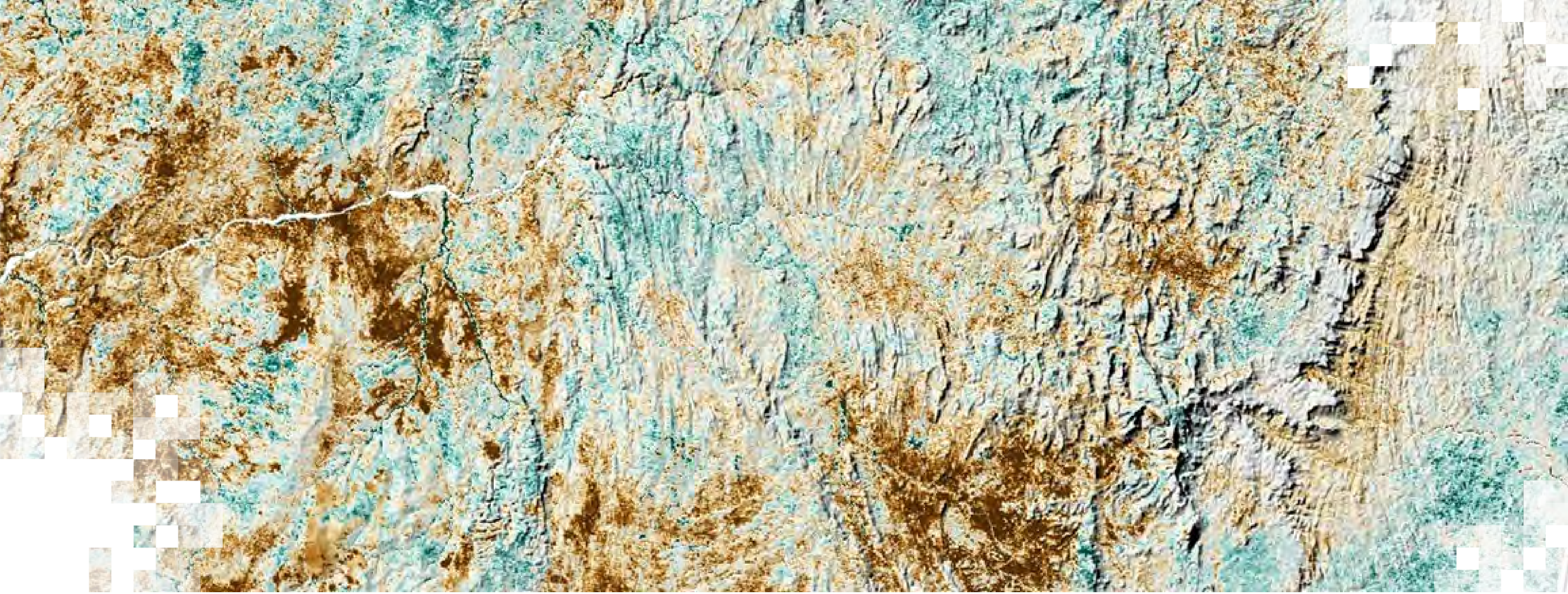
February 27, 2025

8:00 - 9:30 am PT
(11:00 am - 12:30 ET)
pm

Homework

Opens February 27, 2025 – Due March 13, 2025 – 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.



Calculating Spectral Indices for Land and Aquatic Applications Using QGIS

Part 1: Spectral Indices in QGIS

Part X – Trainers

Justin Fain

Research Scientist

BAERI/NASA Ames

Sativa Cruz

Research Scientist

BAERI/NASA Ames

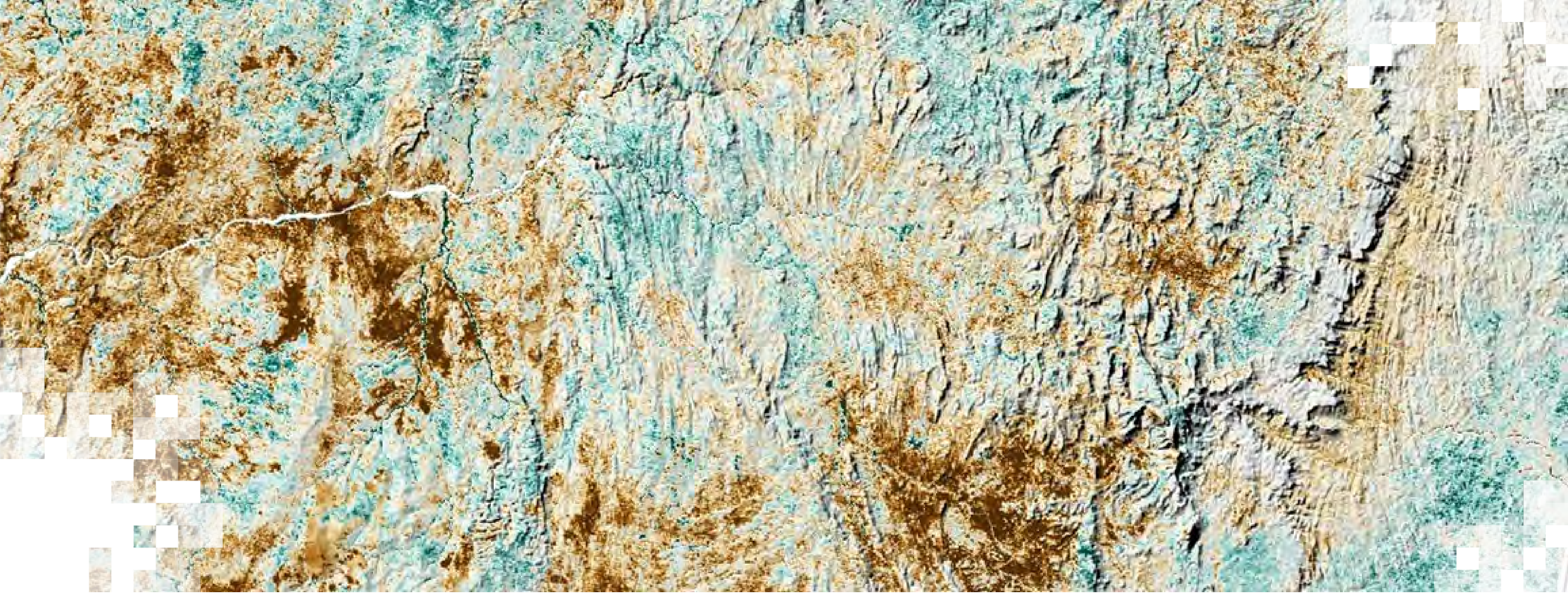
Juan Torres-Perez

Research Scientist

NASA Ames

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 of 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.

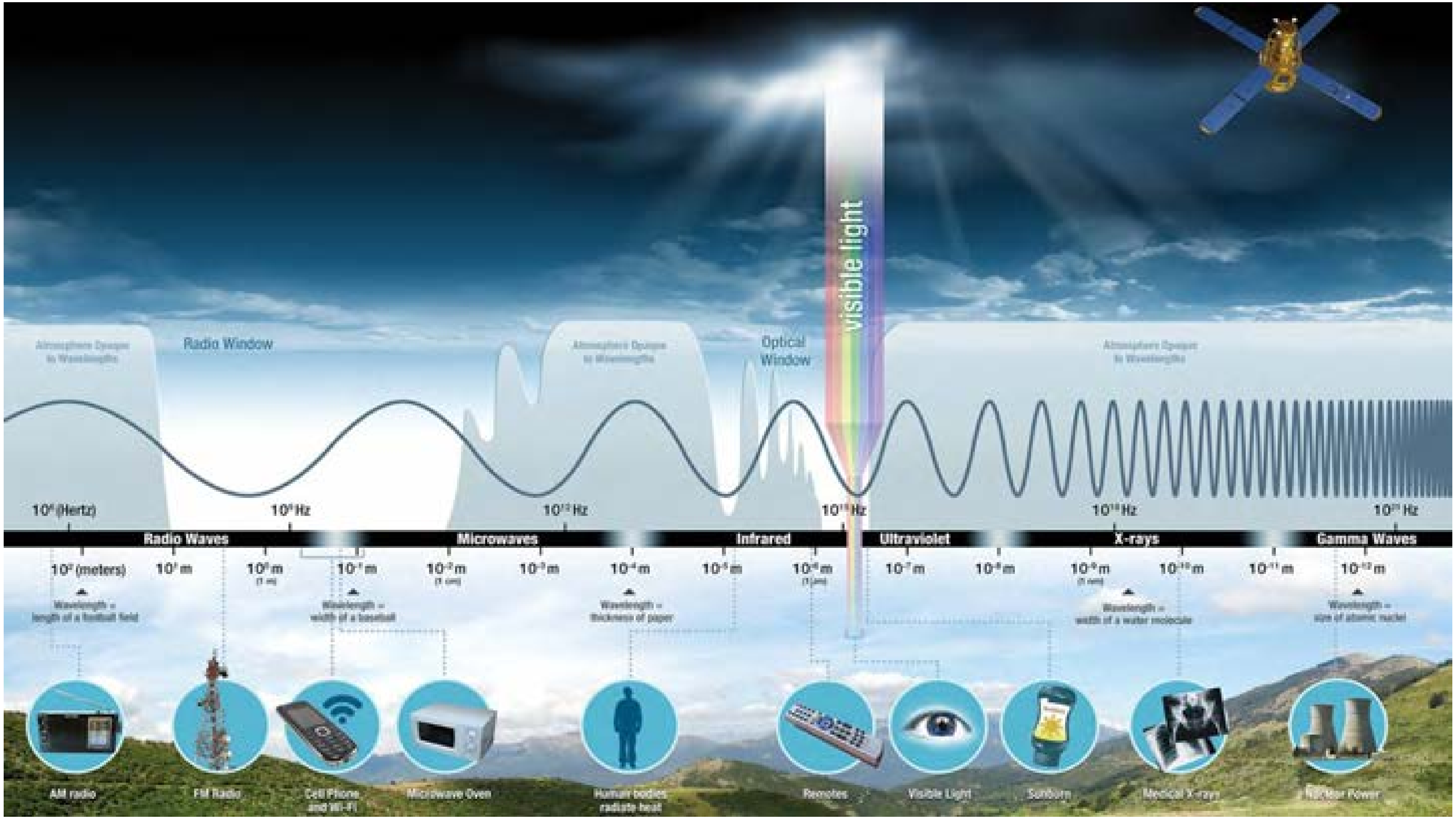


Review of Remote Sensing Concepts

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.

Electromagnetic Spectrum



What is measured with passive remote sensing instruments?

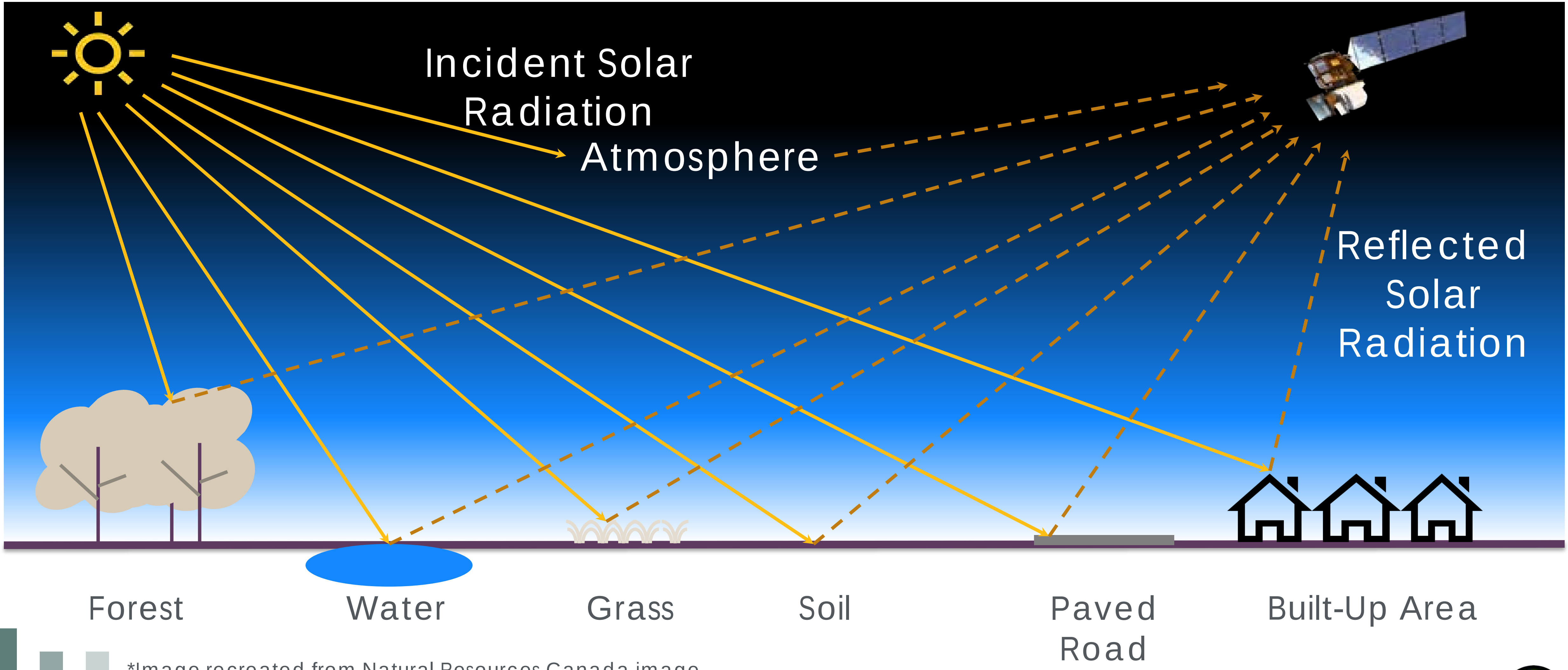


*Image recreated from Natural Resources Canada image.

Interaction with Earth's Surface: Vegetation

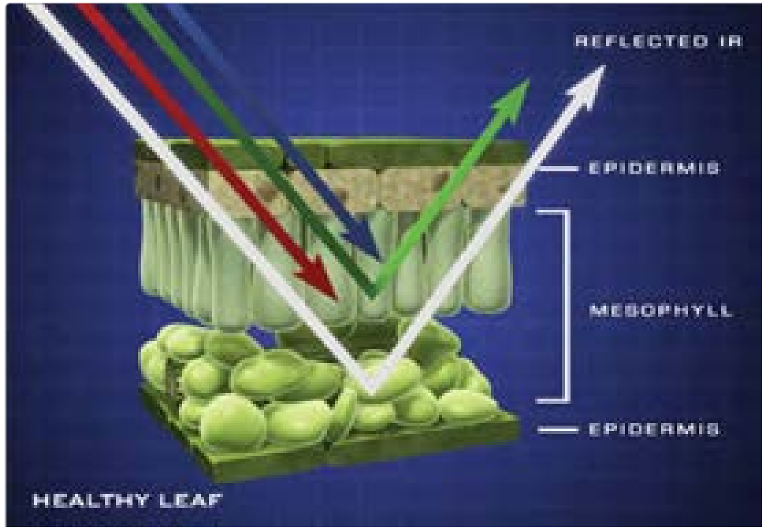
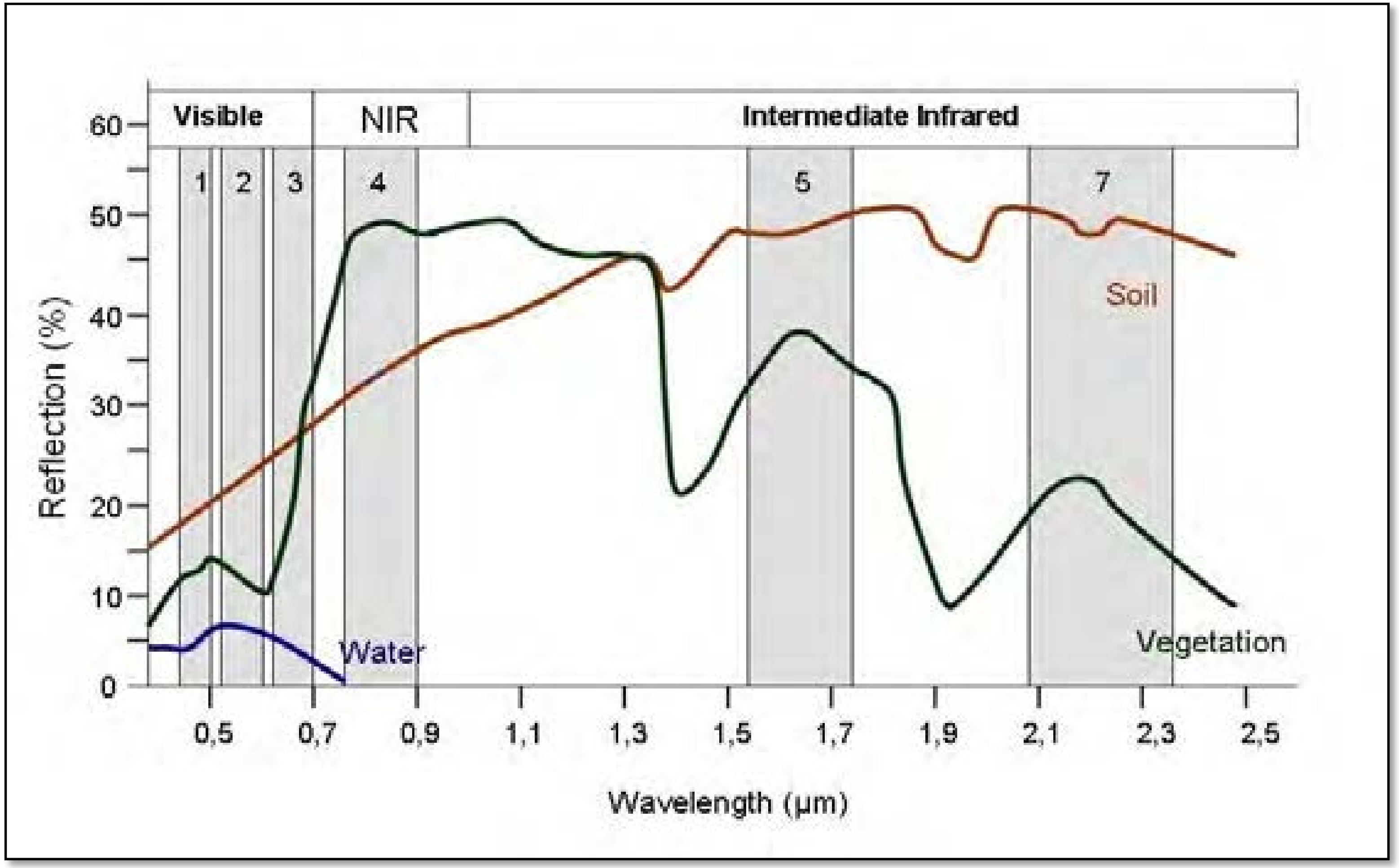


Image Credits: NASA/Jeff Carns & Ginger Butcher

- **Example:** Healthy, green vegetation **absorbs Blue** and **Red** wavelengths (used by chlorophyll for photosynthesis) and **reflects Green** and **Infrared**.
- Since we cannot see infrared radiation, we see healthy vegetation as green.
- The amount of reflected energy is dependent on the health of the vegetation, water content, and phenological stage.

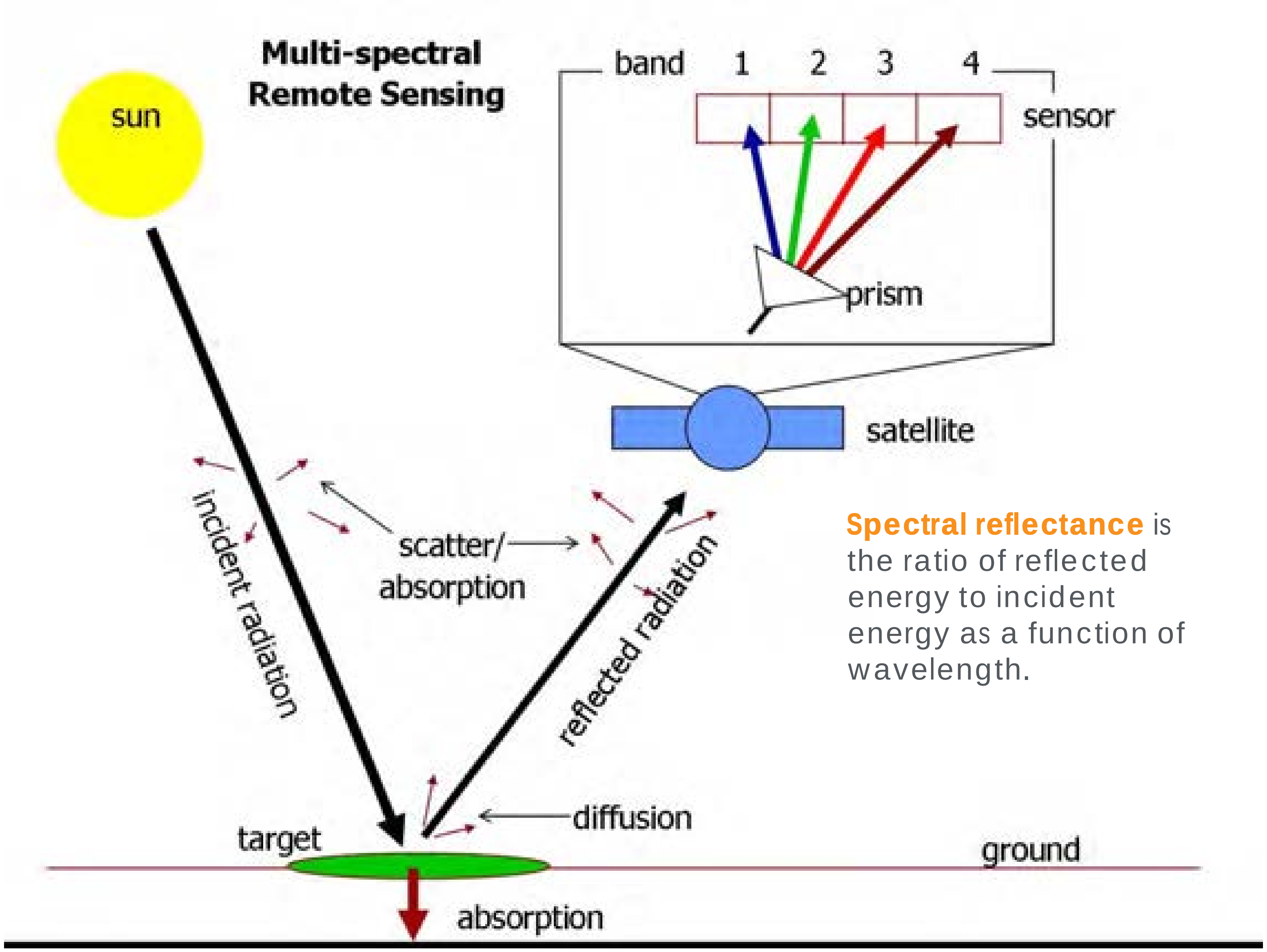
Spectral Signatures

- Every surface on Earth reflects and absorbs energy in different ways.
- Different surfaces have different spectral signatures.
- In this example, you can see the differences between water, vegetation, and soil signatures.



Spectral Resolution

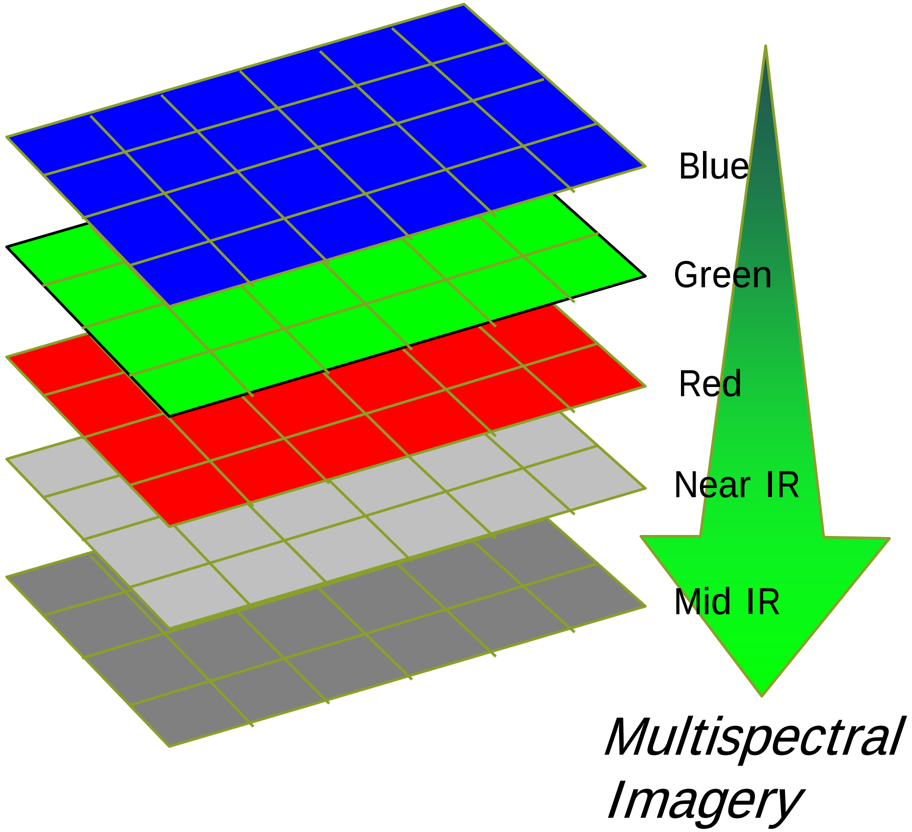
- The ability of a sensor to define wavelength intervals.
- Each "band" represents a different part of the electromagnetic spectrum.



Spectral reflectance is the ratio of reflected energy to incident energy as a function of wavelength.

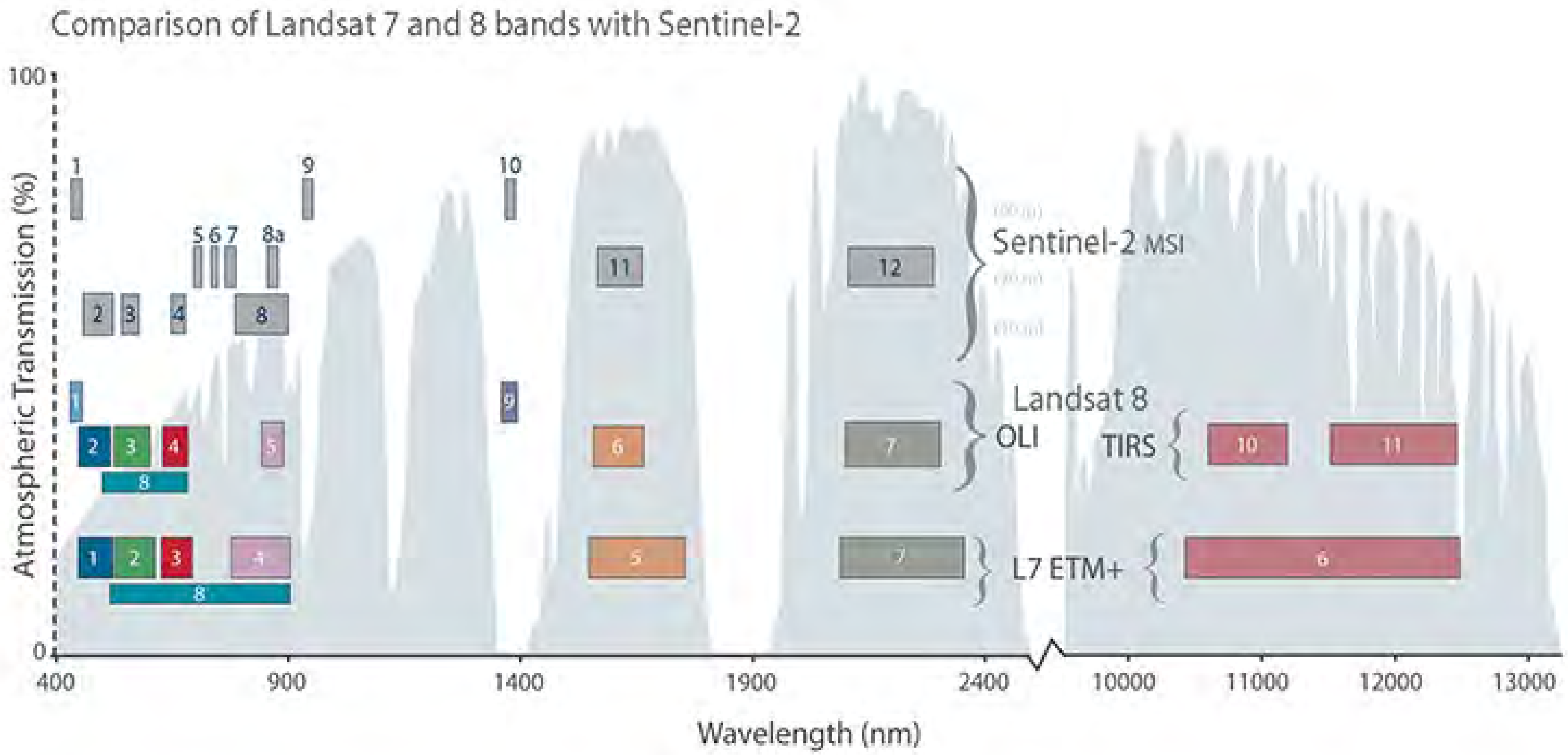
Spectral Resolution: Image Bands

Each image band is a different layer in an image.



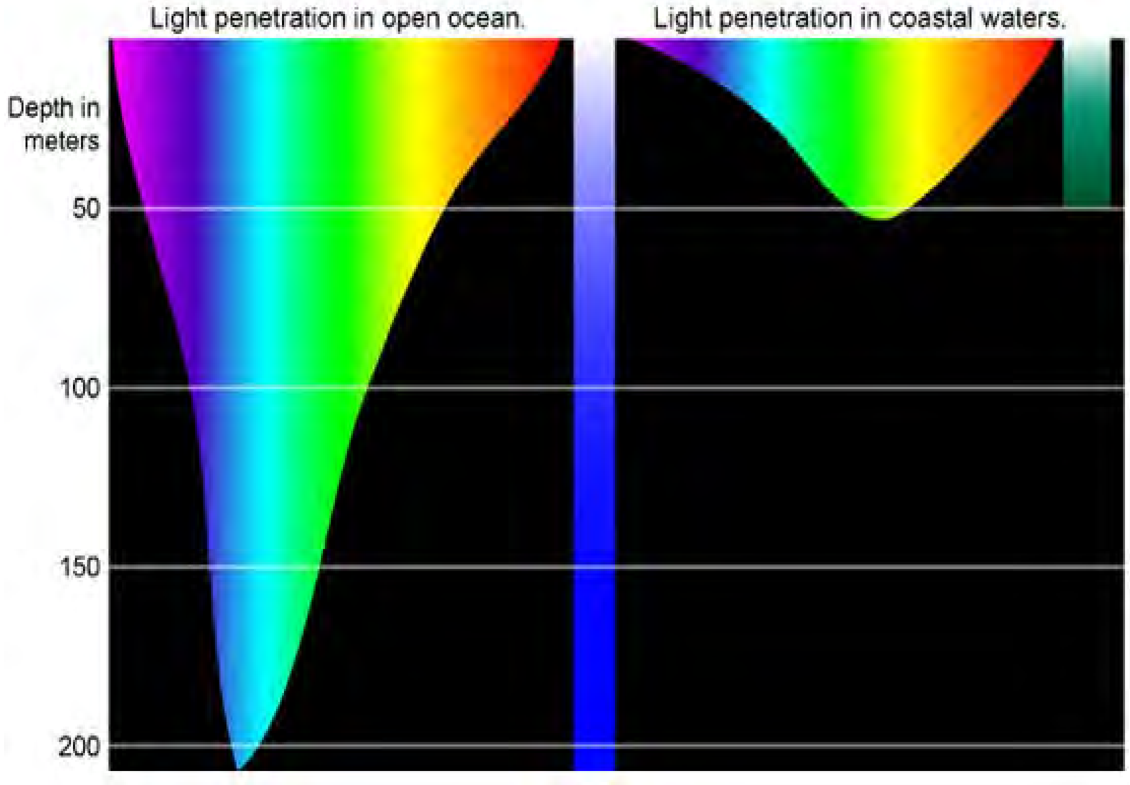
Spectral Characteristics of Landsat and Sentinel-2

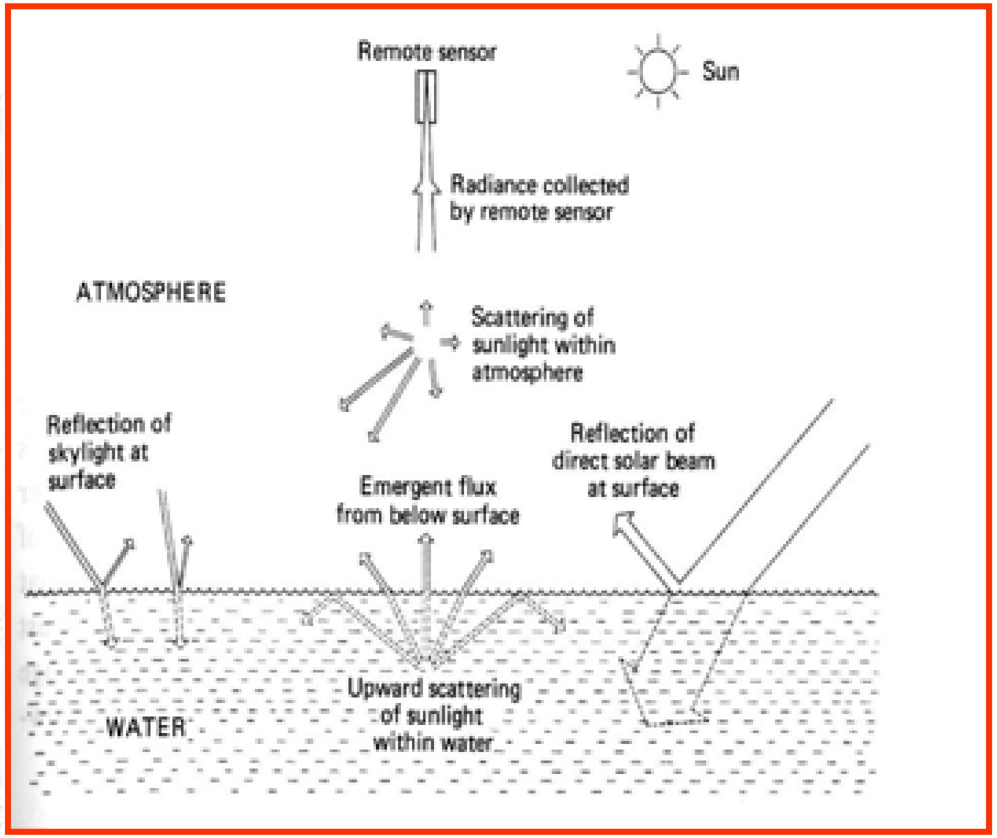
- Landsat instruments primarily measure light that is **reflected** from Earth’s surface (with one exception).
- Landsat instruments are designed to detect visible and infrared (near and mid) wavelengths.



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:

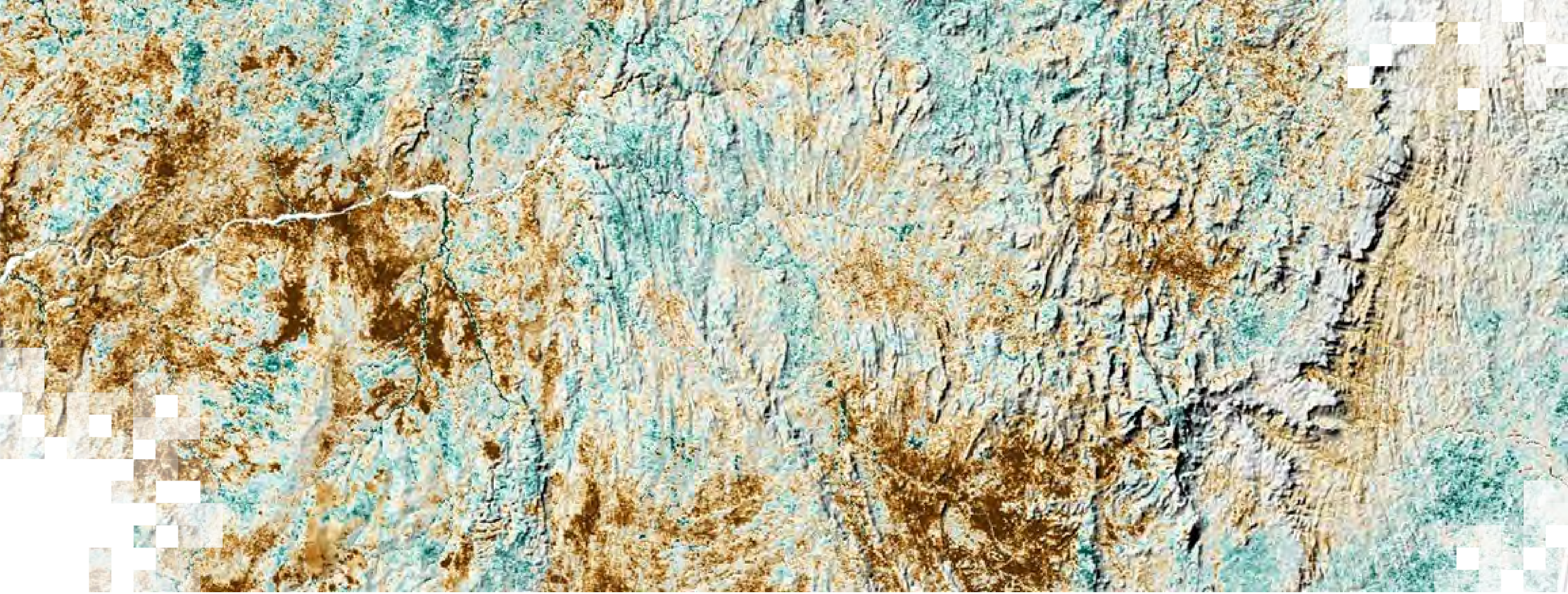
$$Rrs(\lambda,0^+) \cong C\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)} = \frac{L_W(\lambda)}{E_d(\lambda,0^+)}$$

Inherent Optical Properties:

- *a* = Absorption 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:

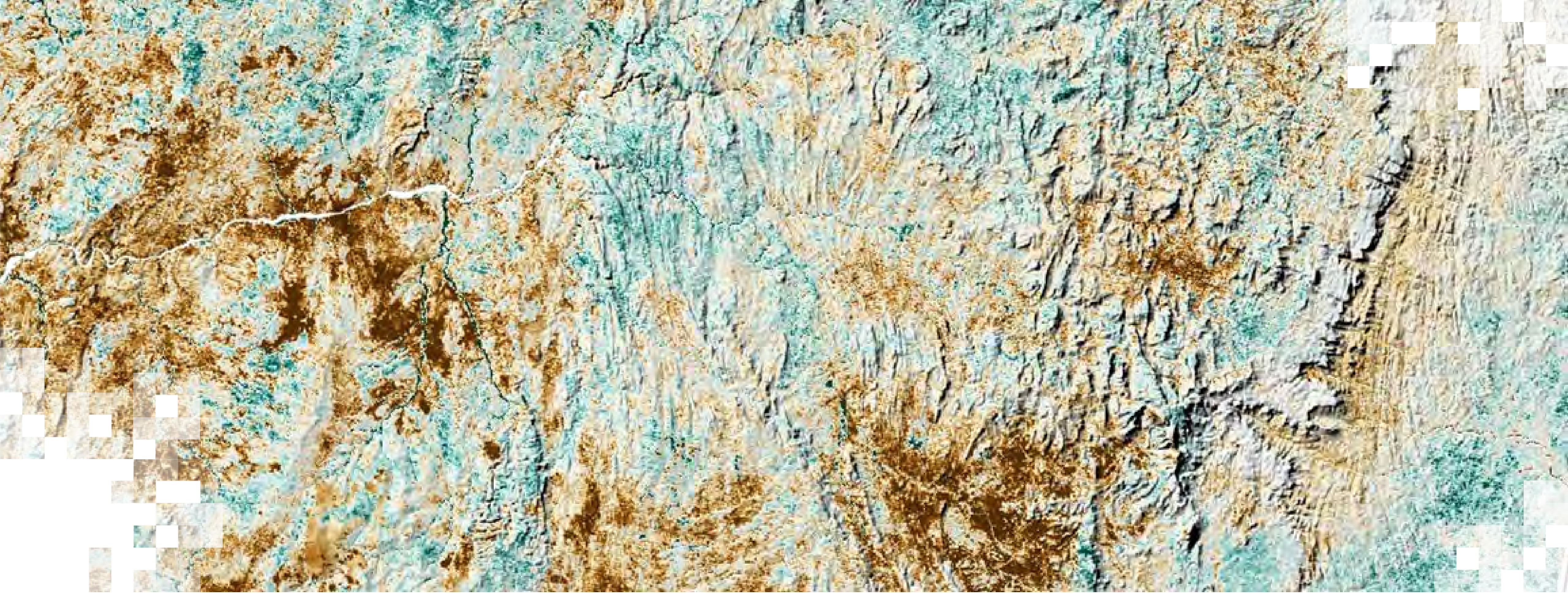
- L_w = Water Leaving Radiance
- L_u = Upwelling Radiance
- E_d = Downwelling Irradiance
- R_{rs} = Remote Sensing (rs) Reflectance



Spectral Indices

Overview of Selected Spectral Indices

Index	Name	Purpose
NDVI	Normalized Difference Vegetation Index	Vegetation Health
EVI	Enhanced Vegetation Index	Vegetation Health (Dense)
SAVI	Soil Adjusted Vegetation Index	Vegetation Health (Sparse)
NBR	Normalized Burn Ratio	Fire Impacts
NDCI	Normalized Difference Chlorophyll Index	Aquatic Chlorophyll
NDAVI	Normalized Difference Aquatic Vegetation Index	Aquatic Vegetation
FAI	Floating Algal Index	Free-floating Algae
NDTI	Normalized Difference Turbidity Index	Aquatic Turbidity



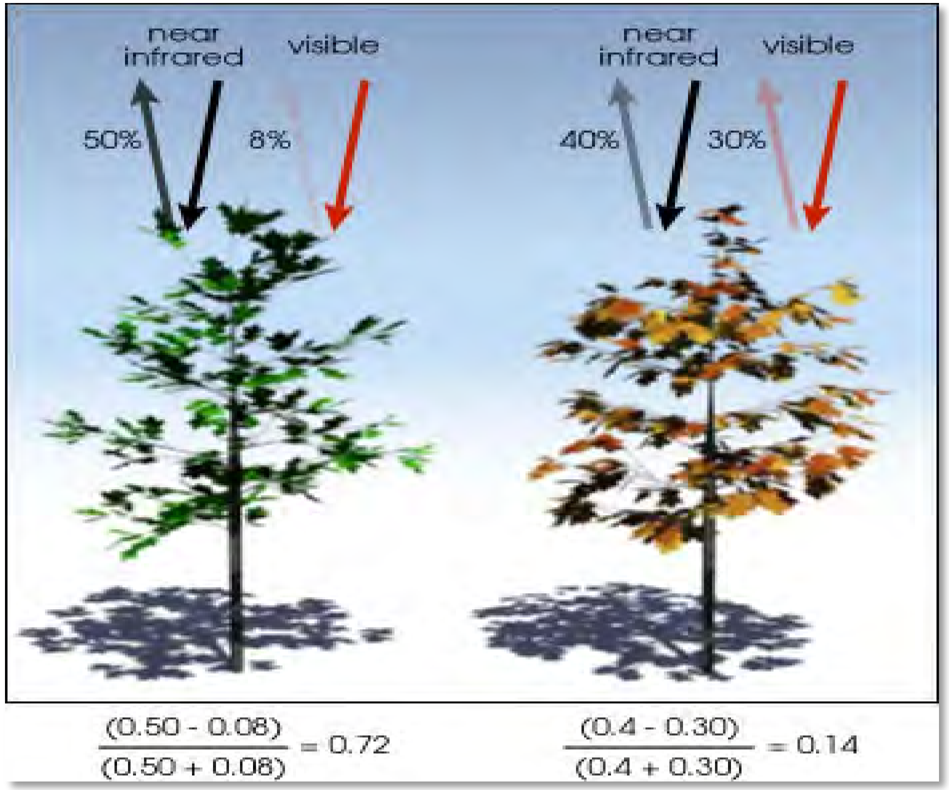
Normalized Difference Vegetation Index (NDVI)

NDVI: Overview

- NDVI Formula:

$$\frac{\text{Near-Infrared} - \text{Red}}{\text{Near-Infrared} + \text{Red}}$$

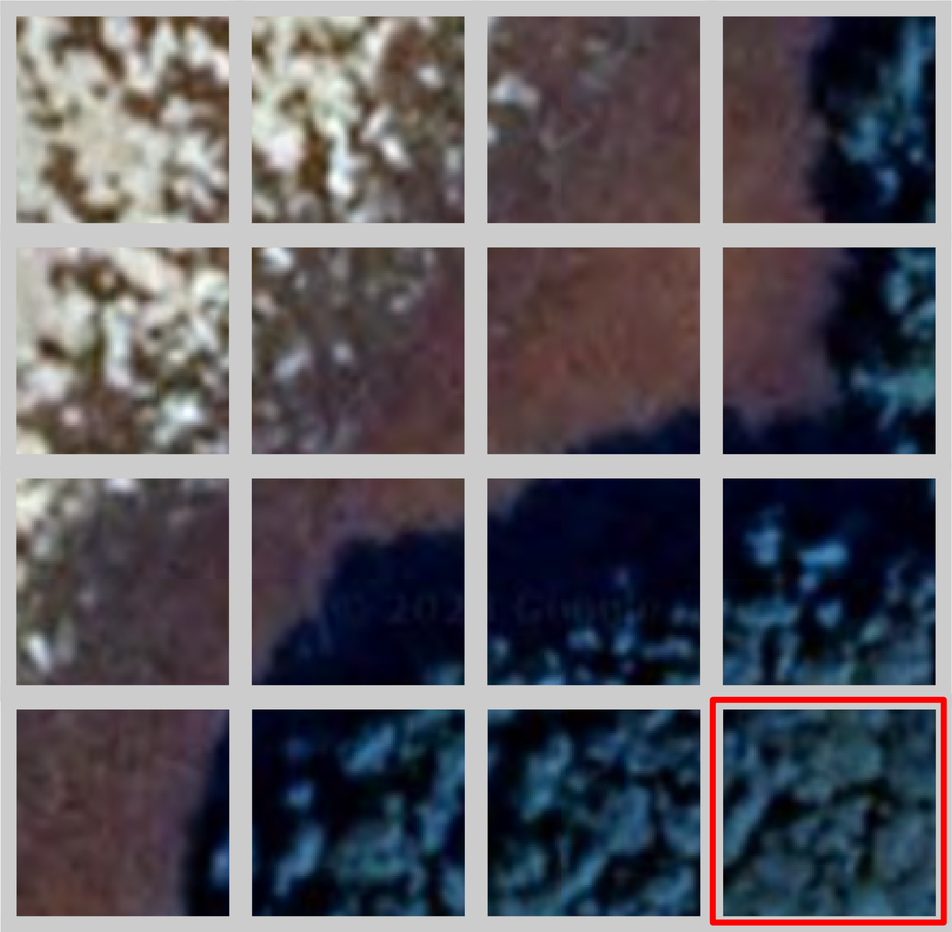
- Values range from **-1.0 to 1.0**.
  - Negative values to 0 mean **no green leaves**.
  - Values close to 1 indicate the **highest possible density of green leaves**.



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Image Credit: Robert Simmon

NDVI Example Calculation

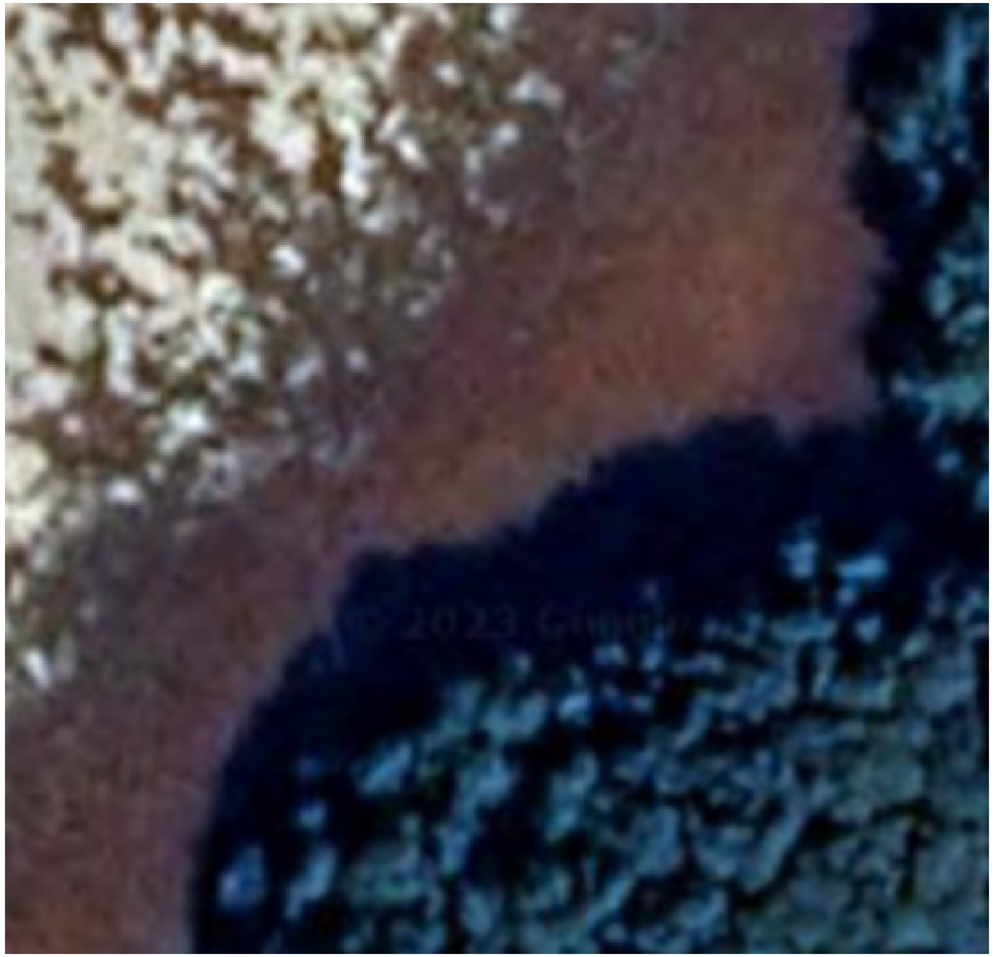


Near Infrared
(Landsat 9 Band 5)

.1144

Red
(Landsat 9 Band 4)

.0344



Near Infrared, Red, NDVI

$$\frac{\boxed{.1144} - \boxed{.0344}}{\boxed{.1144} + \boxed{.0344}} = \boxed{\mathbf{.538}}$$

Near Infrared

.0214	.0313
.0031	.1144

−

Red

.0473	.0444
.0415	.0344

.0214	.0313
.0031	.1144

+

.0473	.0444
.0415	.0344

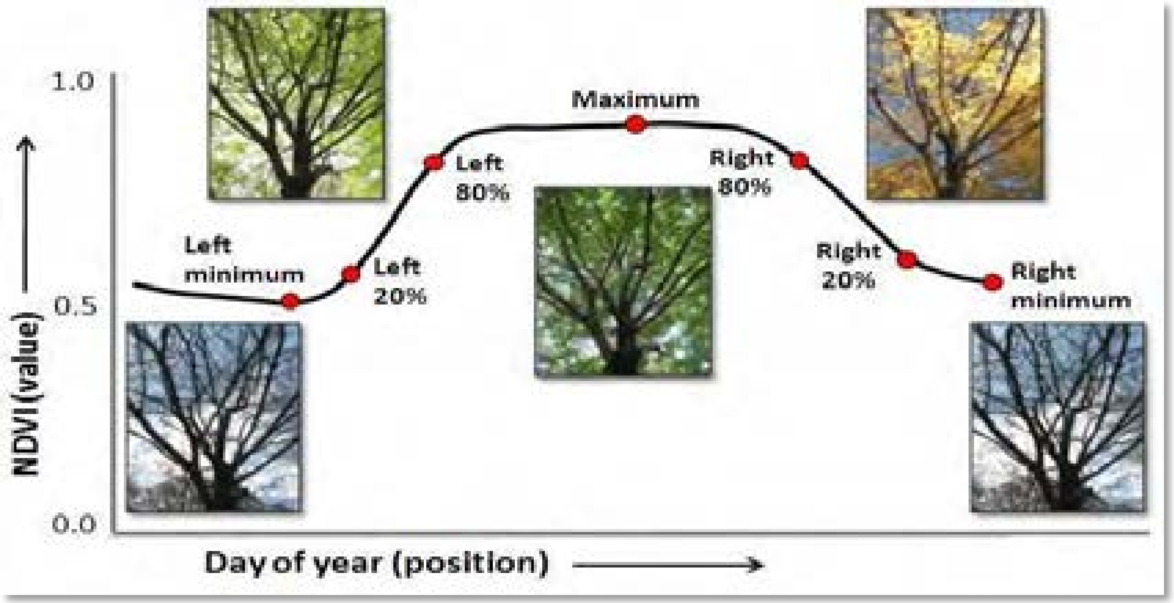
=

NDVI

-.377	-.174
-.862	.538

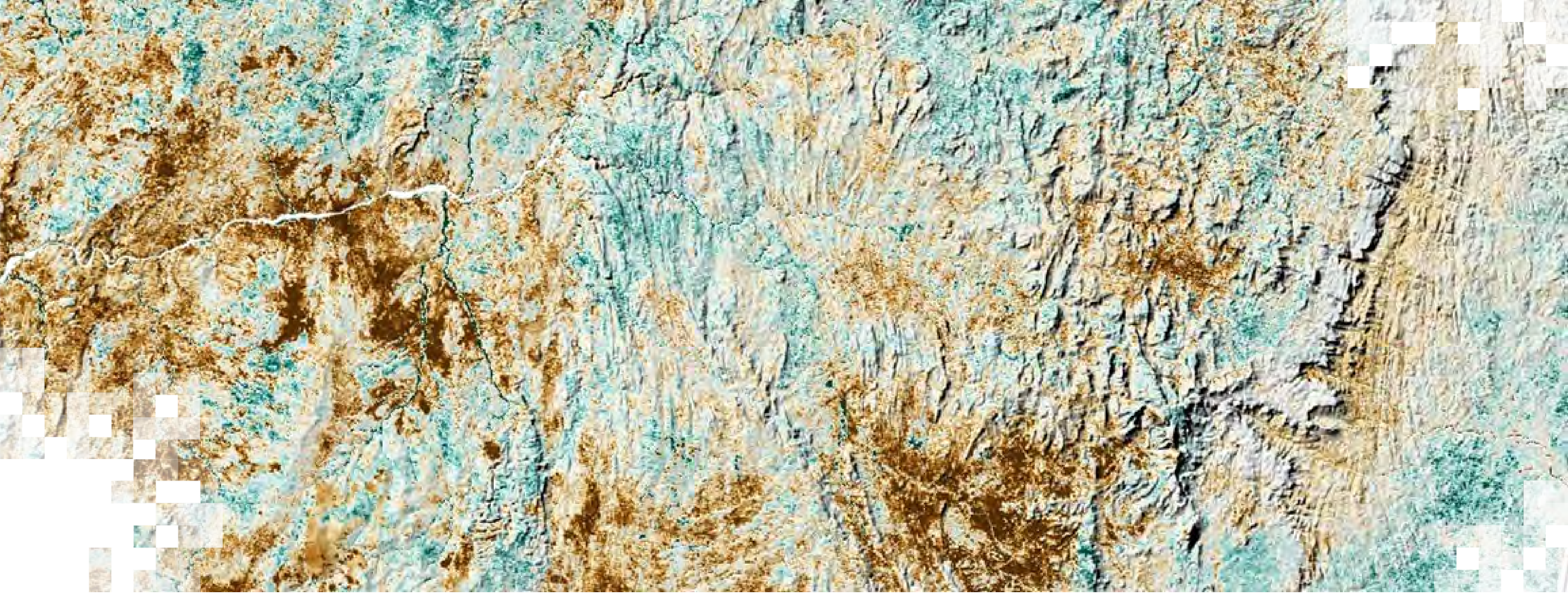
NDVI and Seasonality

- Remote sensing is used to track the seasonal changes in vegetation.
- Monthly NDVI images from MODIS or Landsat can be used to monitor phenology.



NDVI Images of North America in Winter and Summer

Credit: spacegrant.montana.edu



Enhanced Vegetation Index (EVI)

Enhanced Vegetation Index (EVI)

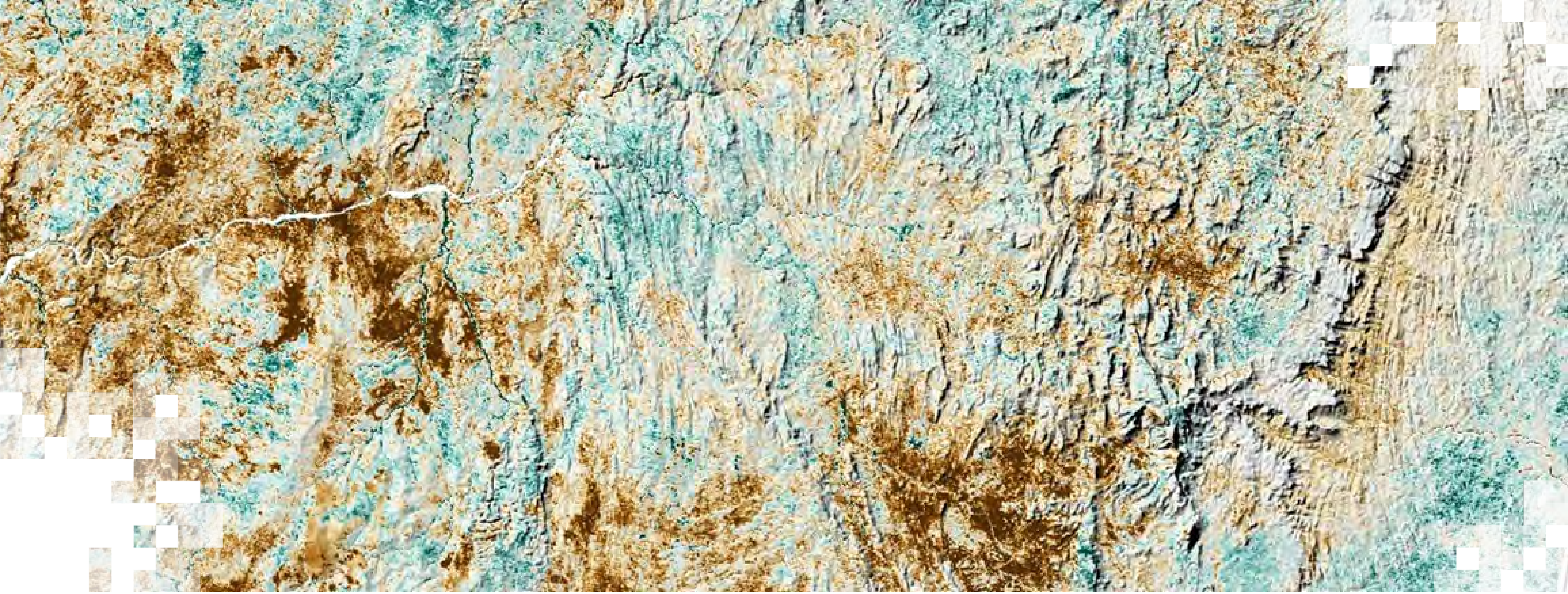
- Can be used in place of NDVI to examine vegetation greenness
  - More sensitive in areas with dense vegetation
- Adjusts for canopy background and some atmospheric conditions

$$EVI = G * \left(\frac{(NIR - R)}{(NIR + C1 * R - C2 * B + L)}\right)$$

Constants

$G = 2.5$
$C1 = 6$
$C2 = 7.5$
$L = 1$

- Does not saturate over high biomass regions
- L = Adjustment for canopy background
- C = Atmospheric adjustment
- Use of the blue band

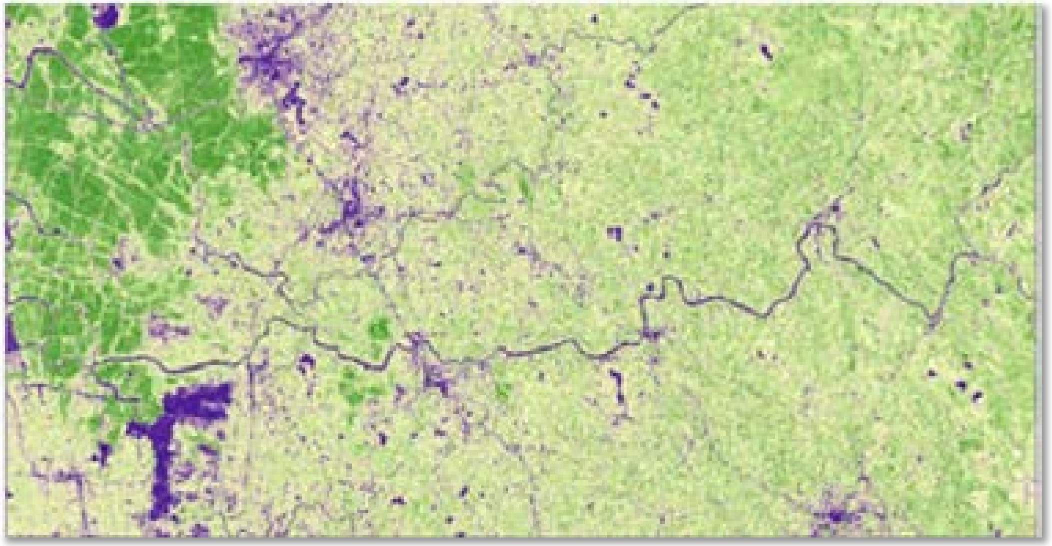


Soil Adjusted Vegetation Index (SAVI)

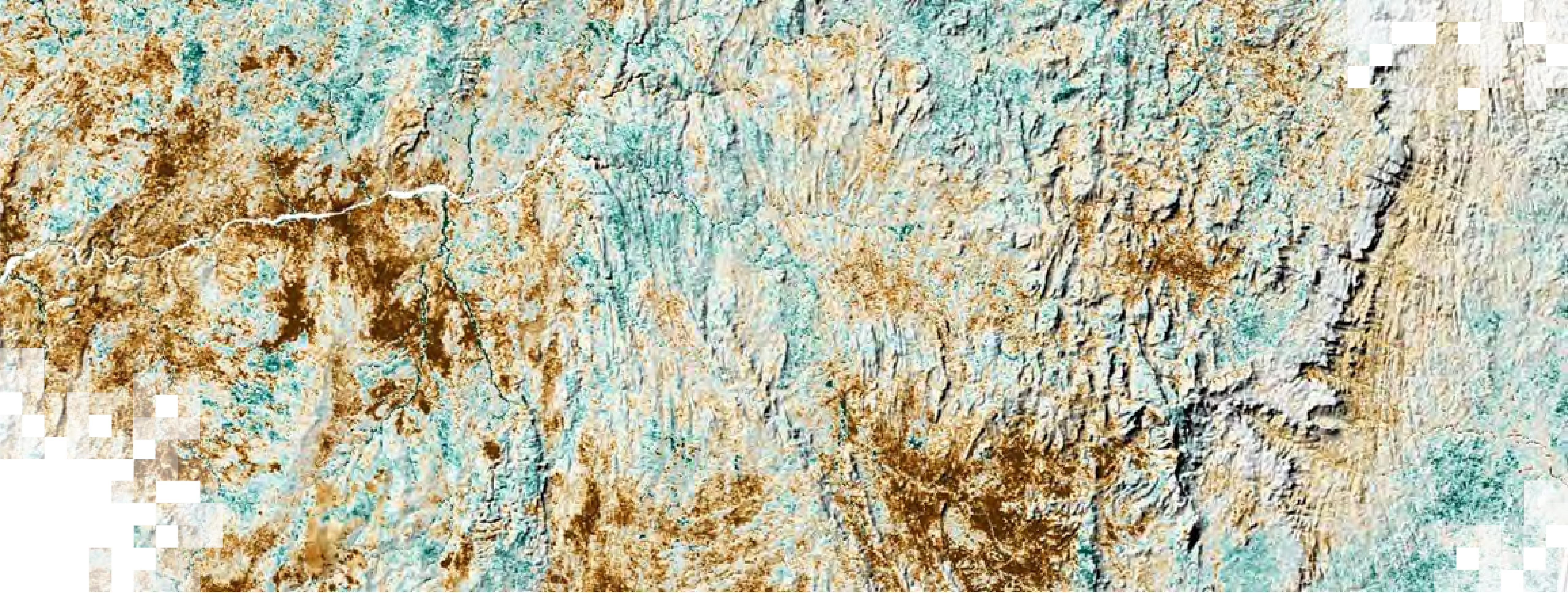
Soil Adjusted Vegetation Index (SAVI)

- Minimizes the influence of soil brightness
- Useful in areas with greater soil cover
  - Contains a soil brightness correction factor (L)
    - 0.5 typically used
    - Lower for areas with greater canopy cover
    - Higher for areas with less canopy cover

$$SAVI = \left(\frac{(NIR - R)}{(NIR + R + L)}\right) * (1 + L)$$



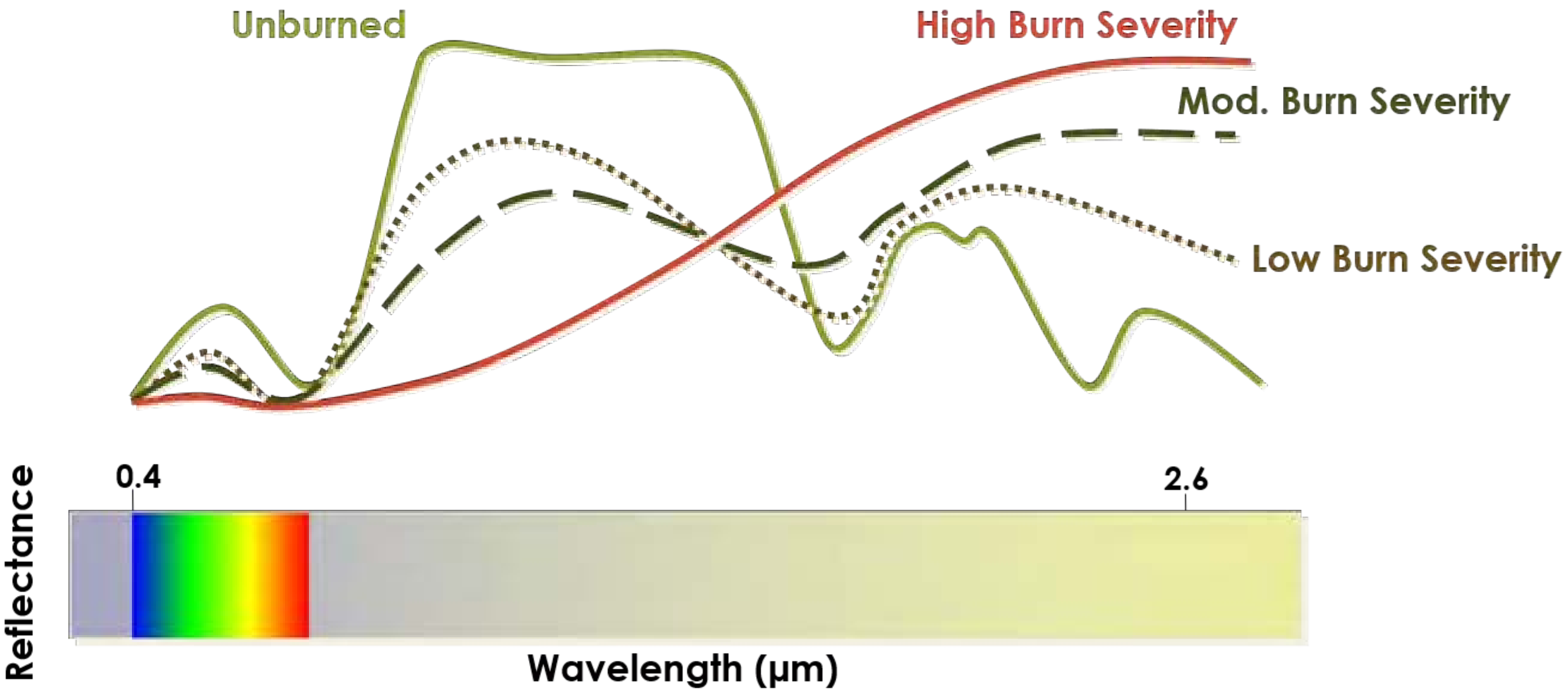
SAVI: Image Credit: Grind GIS



Normalized Burn Ratio (NBR)

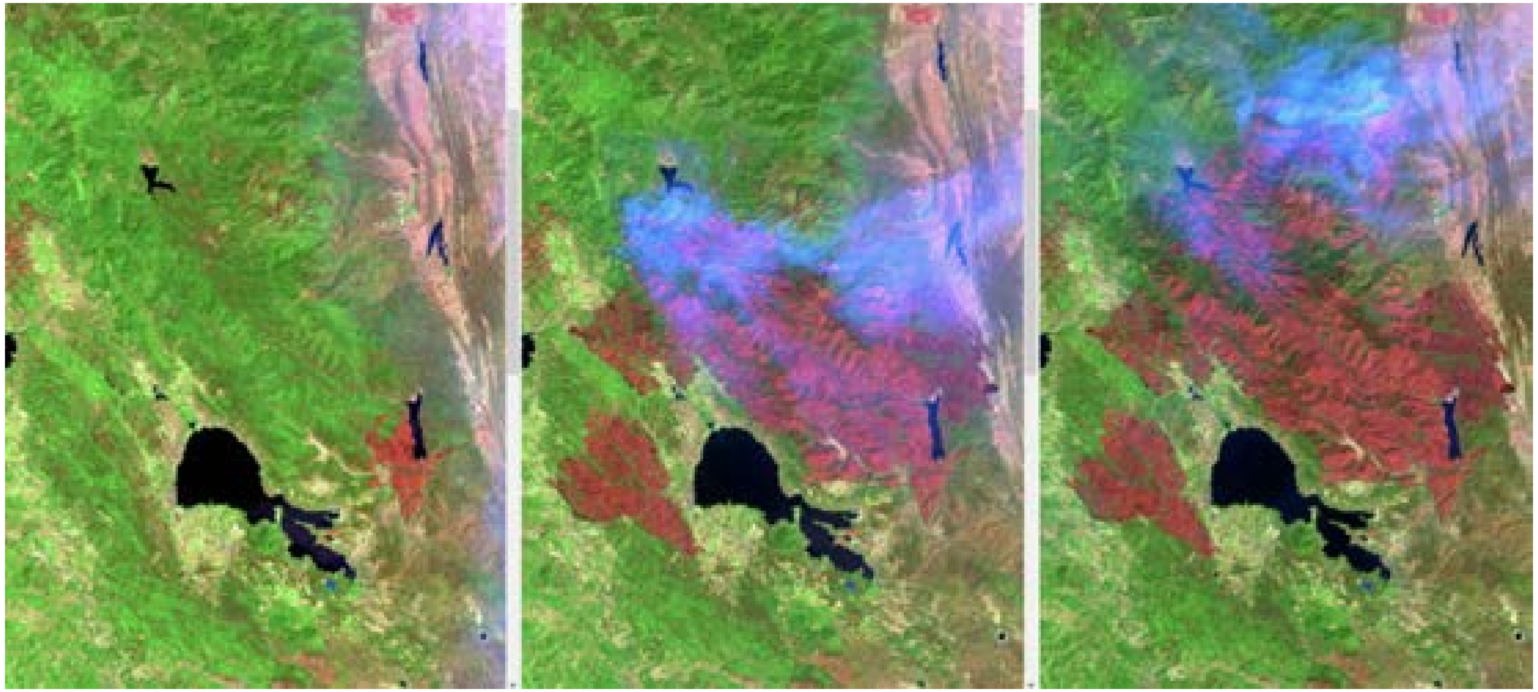
Healthy Vegetation vs. Burned Areas

Exploiting Spectral Response Curves



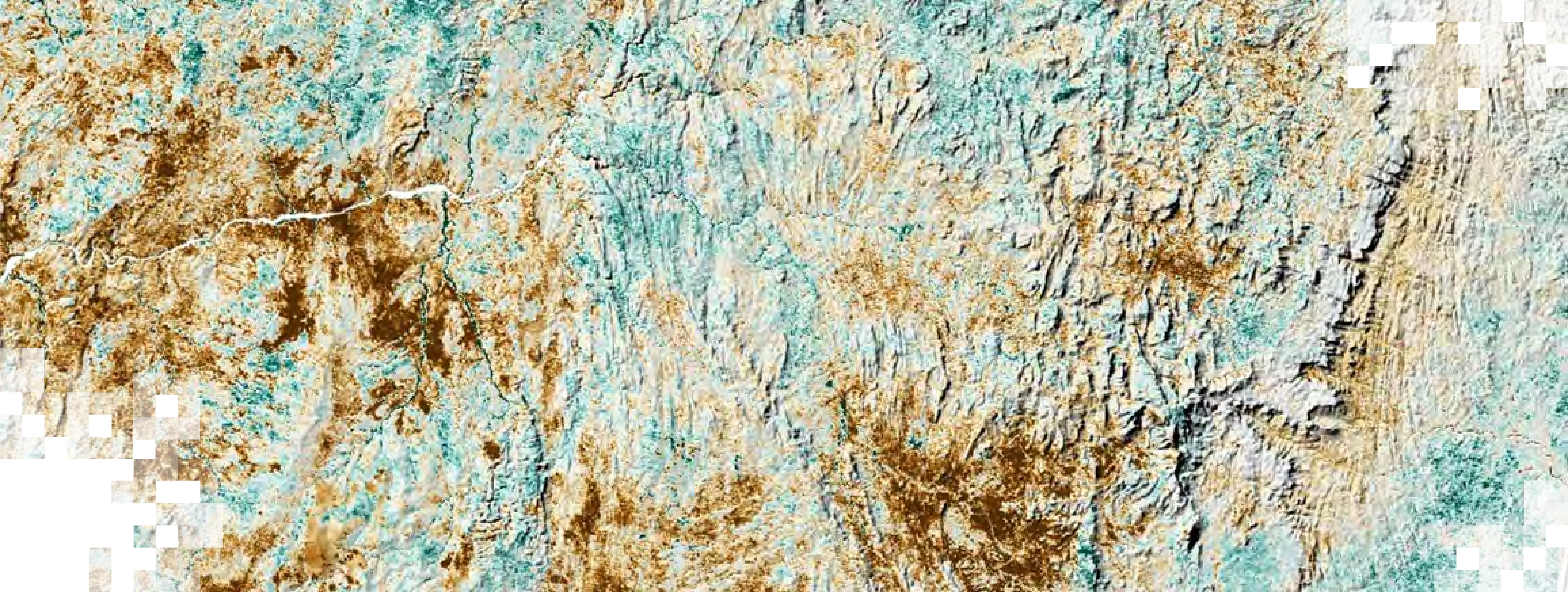
Burned Area: Normalized Burn Ratio (NBR)

- Used to identify burned areas
- Compare pre- and post-burn to identify burn extent and severity


July 26 Aug 11 Aug 27

Mendocino Complex Fires, 2018

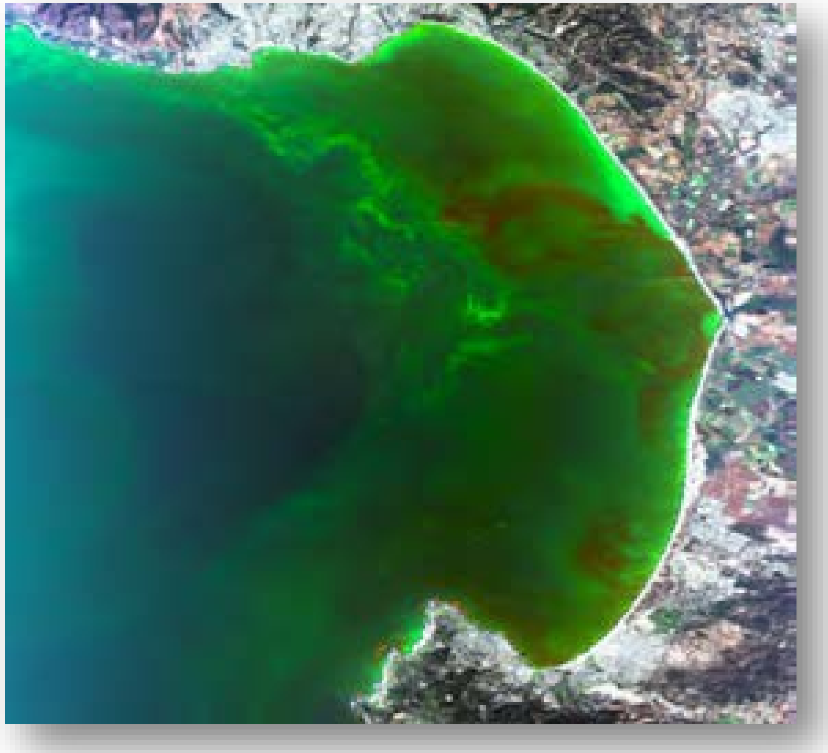
$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

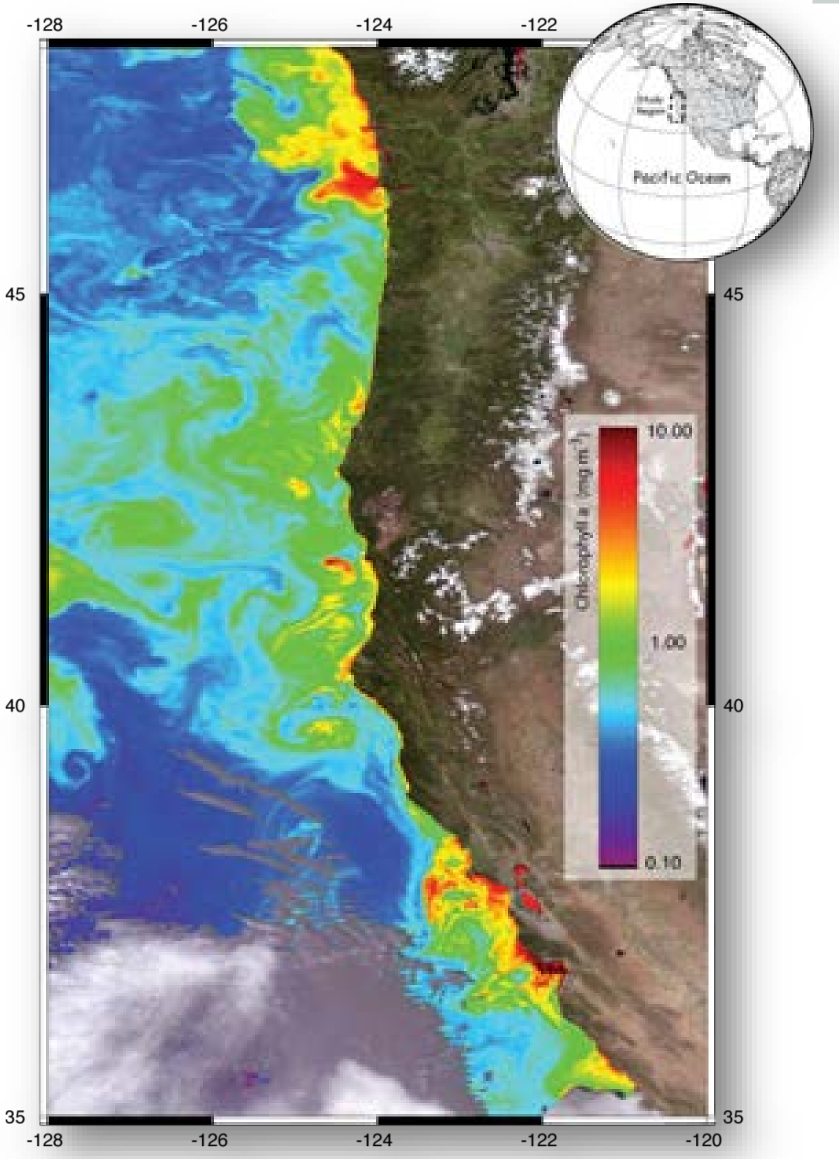


Normalized Difference Chlorophyll Index (NDCI)

Chlorophyll a

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



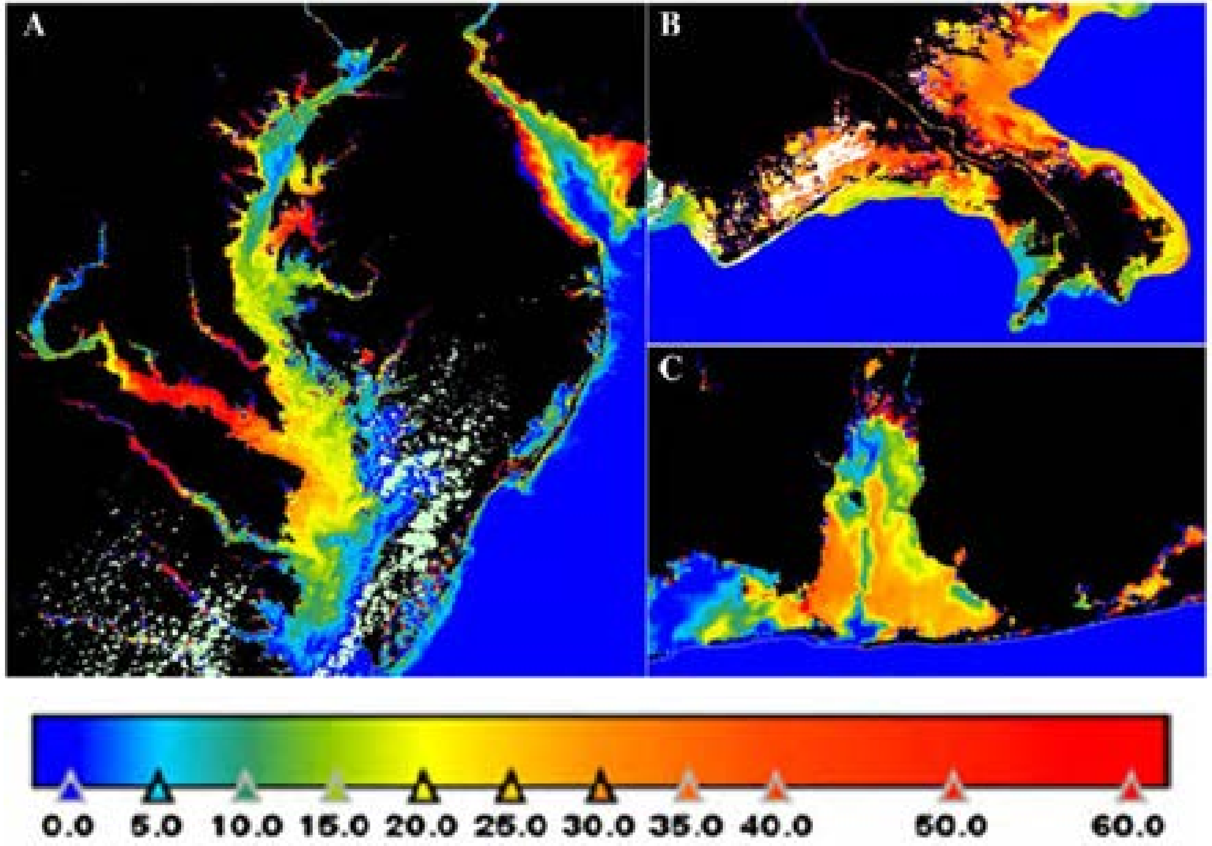


Credit: Liane Guild (NASA), Raphe Kudela (UC Santa Cruz)

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%.

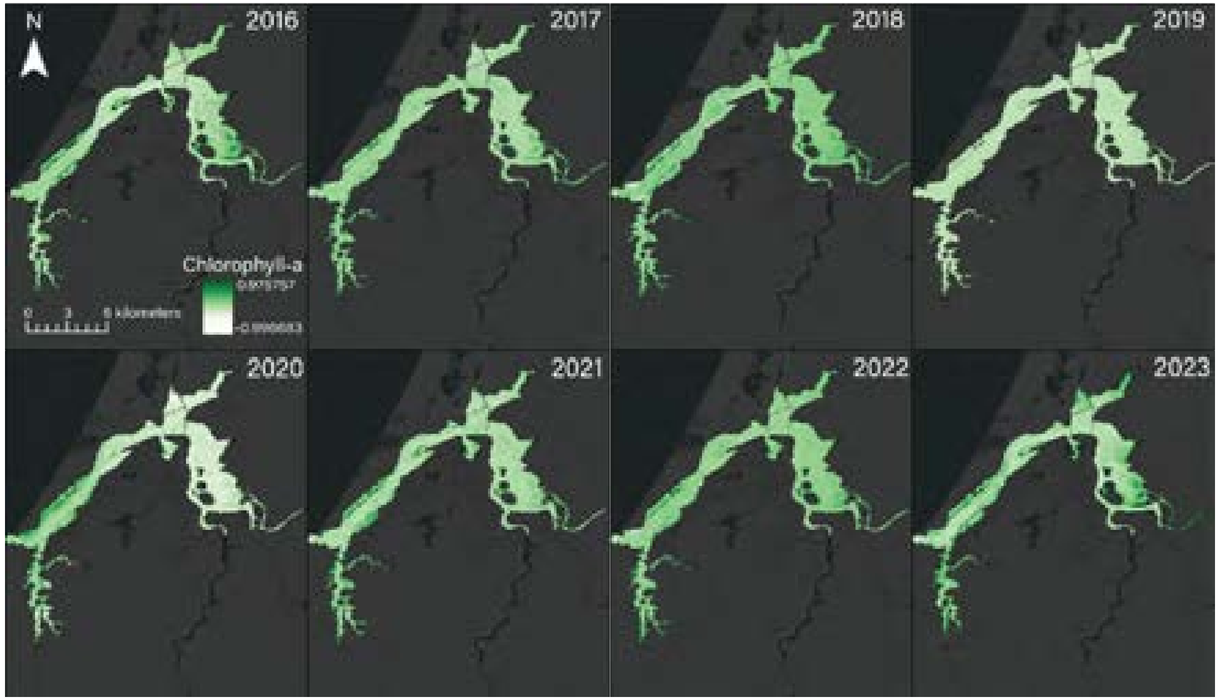
$$C_{chl-a} \propto \frac{[R_{rs}(708) - R_{rs}(665)]}{[R_{rs}(708) + R_{rs}(665)]}$$



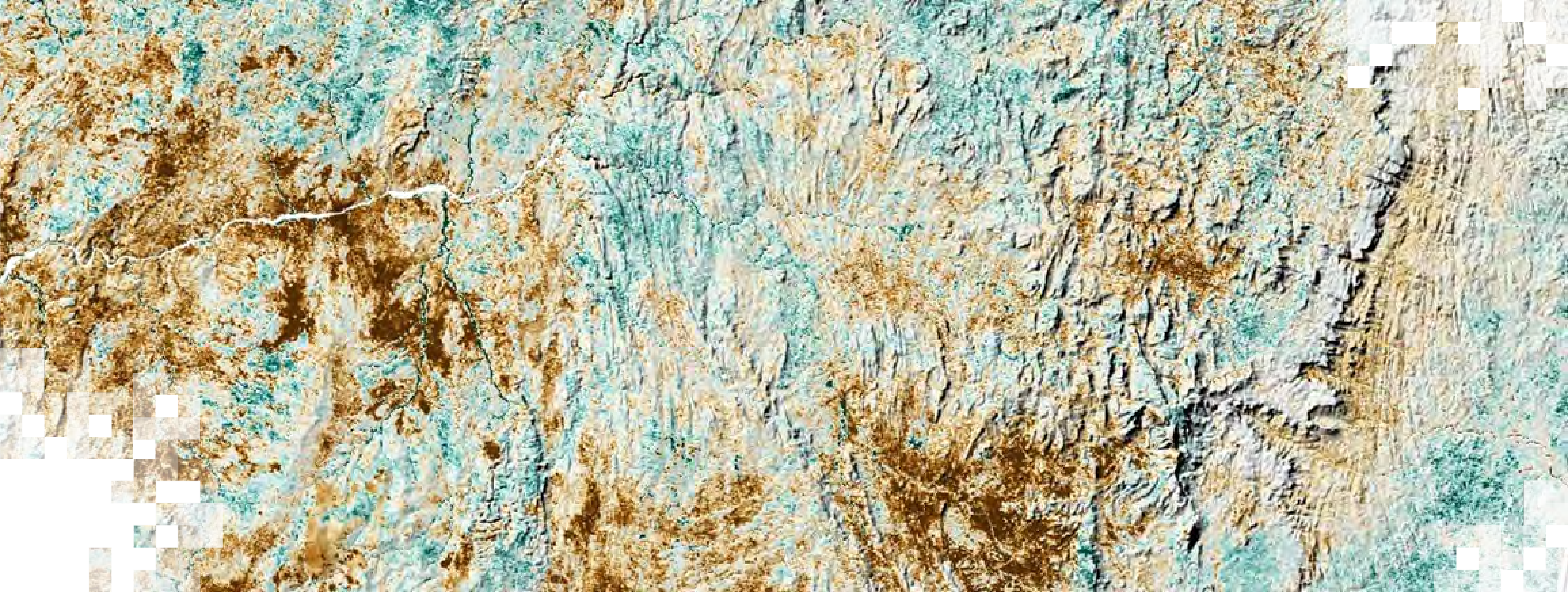
Mishra & Mishra (2012). Normalized difference chlorophyll index: A novel model for remote estimation of chlorophyll-a concentration in turbid productive waters. Remote Sensing of Environment, 117, 394-406.

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



Normalized Difference Aquatic Vegetation Index (NDAVI)

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)

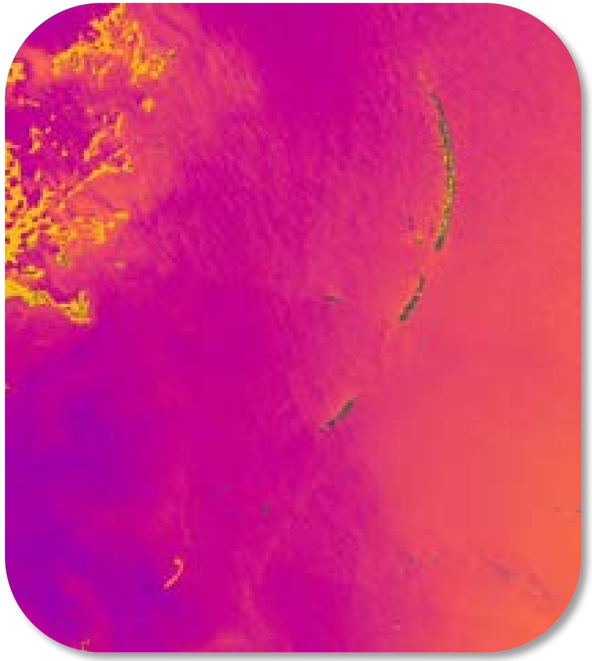
$$NDAVI = \frac{\rho NIR(0.76 - 0.90\mu m) - \rho BLUE(0.45 - 0.52\mu m)}{\rho NIR(0.76 - 0.90\mu m) + \rho BLUE(0.45 - 0.52\mu m)}$$

- 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.

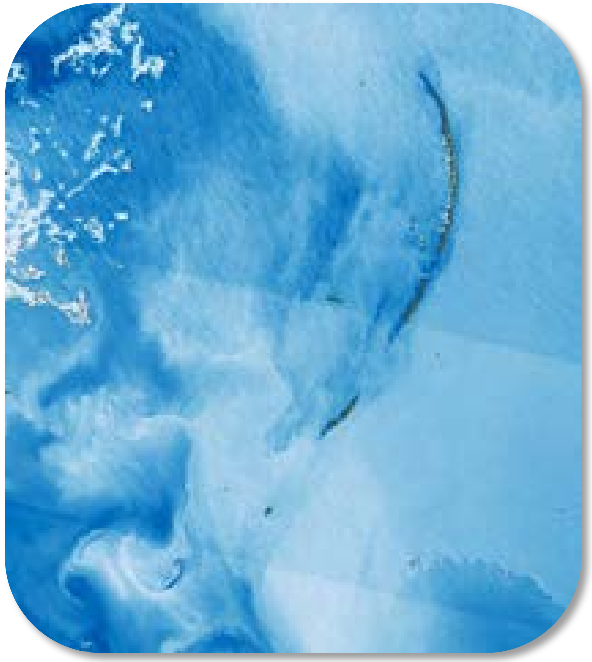
NDAVI – A Spectral Index Useful for Seagrass Monitoring

Near Infrared Band



&

Blue Band



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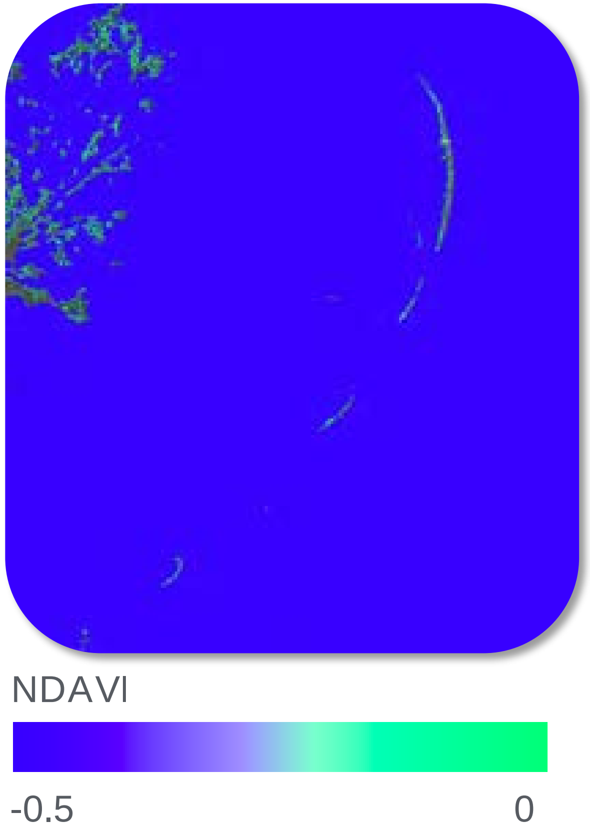
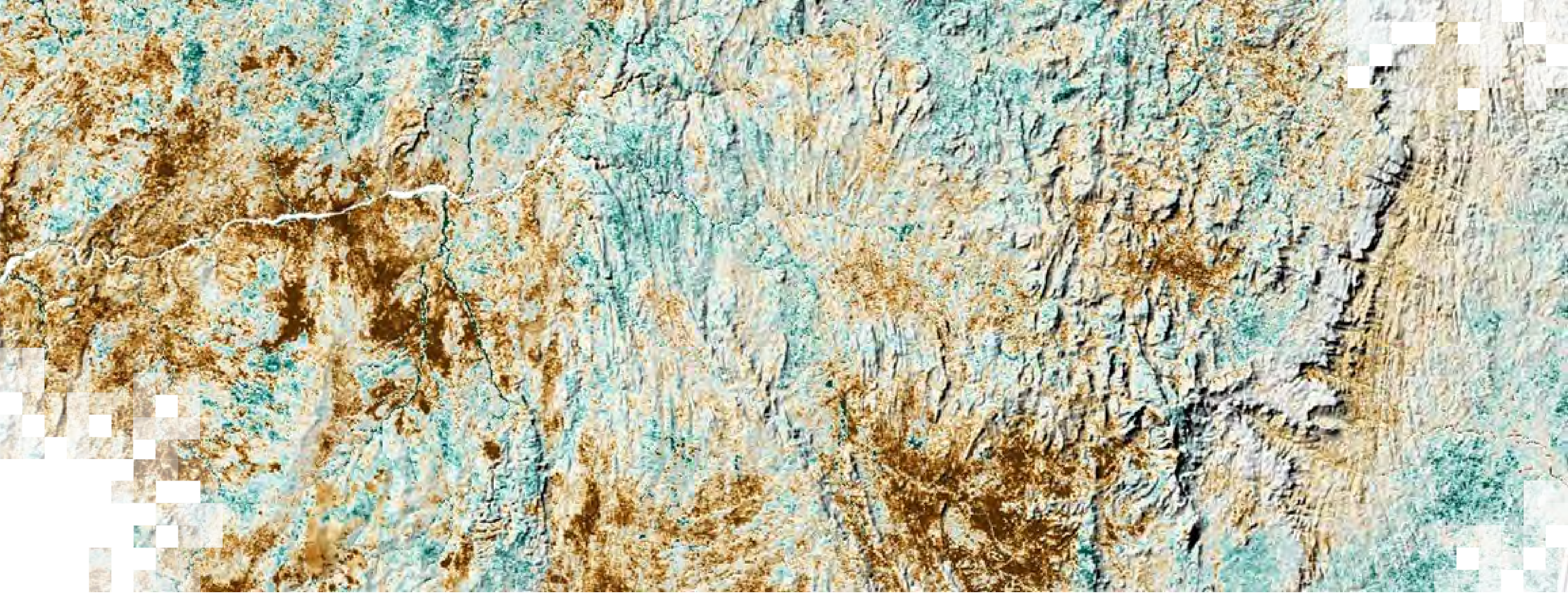
Aquatic Vegetation



Spring 2019 over the Chandeleur Sound

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

Credit: NASA DEVELOP ARC Summer 2021 Louisiana Water Resources



Floating Algae Index (FAI)

Floating Algae Index (FAI)

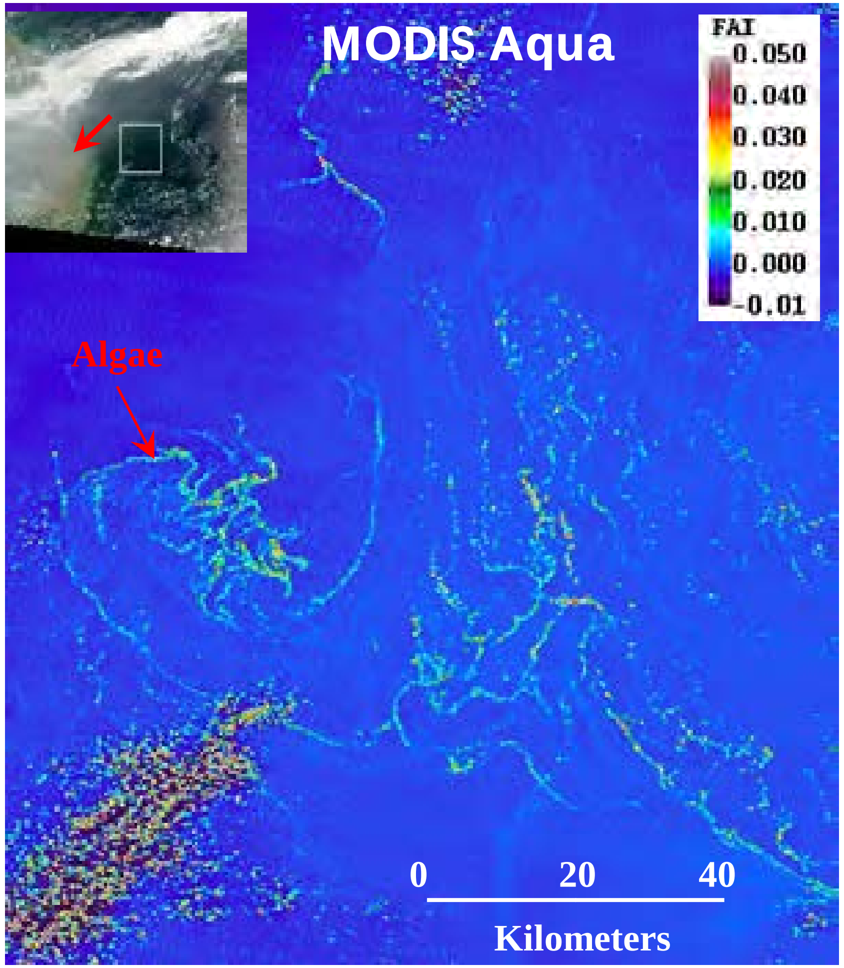
- $R_{rc\ (RED,\ NIR,\ SWIR)}$ = Molecular (Rayleigh) scattering-corrected reflectance in the red, near infrared, and shortwave infrared regions
- $R'_{rc,NIR}$ = Baseline reflectance in the NIR derived from a linear interpolation between the red and SWIR bands
- λ_{RED} = 645nm
- λ_{NIR} = 859nm
- λ_{SWIR}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

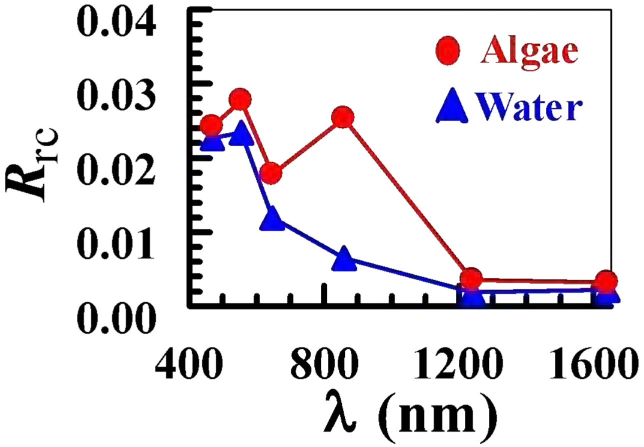
$$FAI = R_{rc,NIR} - R'_{rc,NIR},$$

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

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.

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

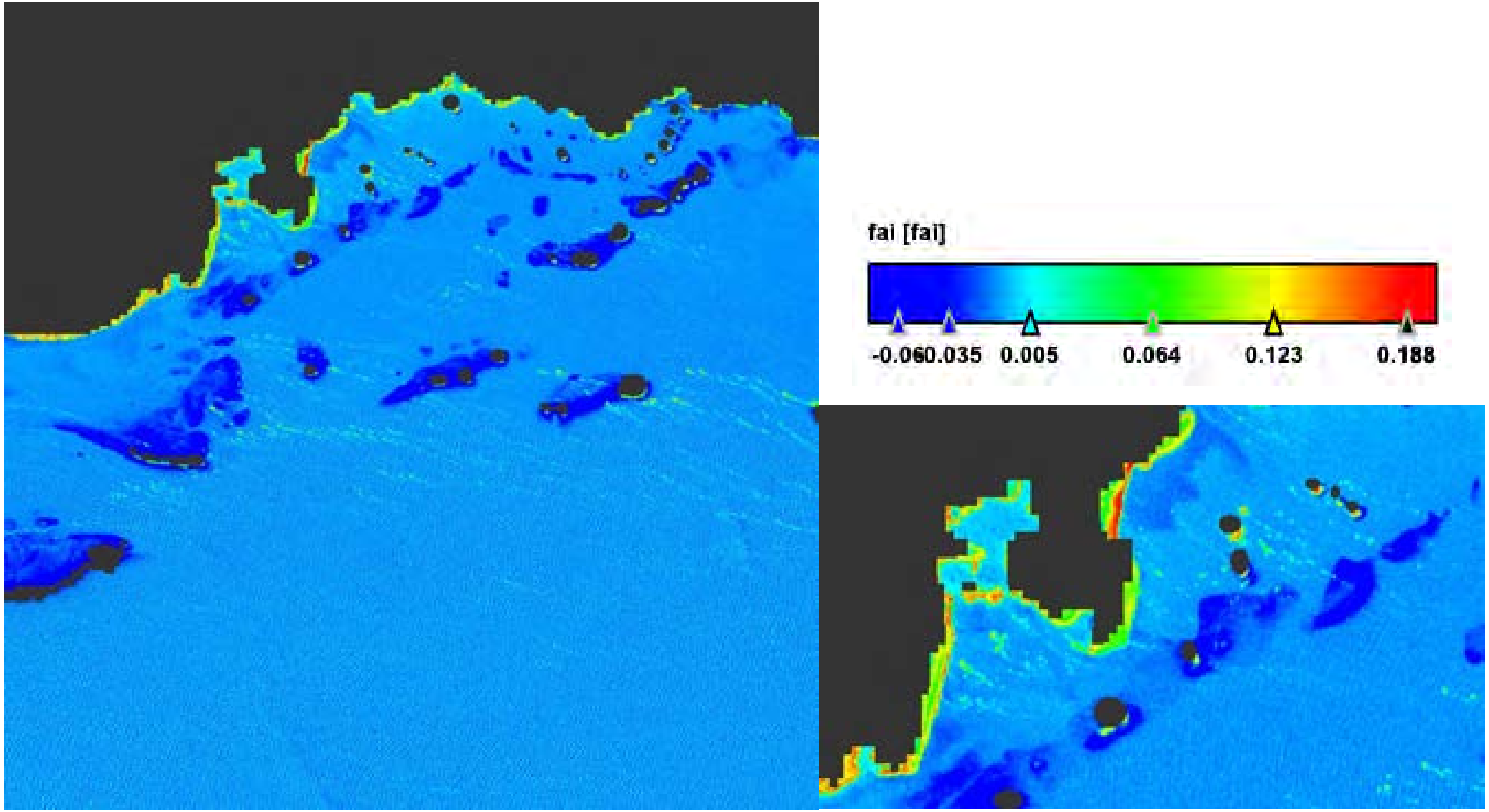


Image Credit: Jennifer Perez Univ of PR-Mayaguez Campus

Inherent Optical Properties (IOPs) and the ‘Color’ of Water

Chlorophyll

Water

Non-Algal Particle/ Sediments

CDOM

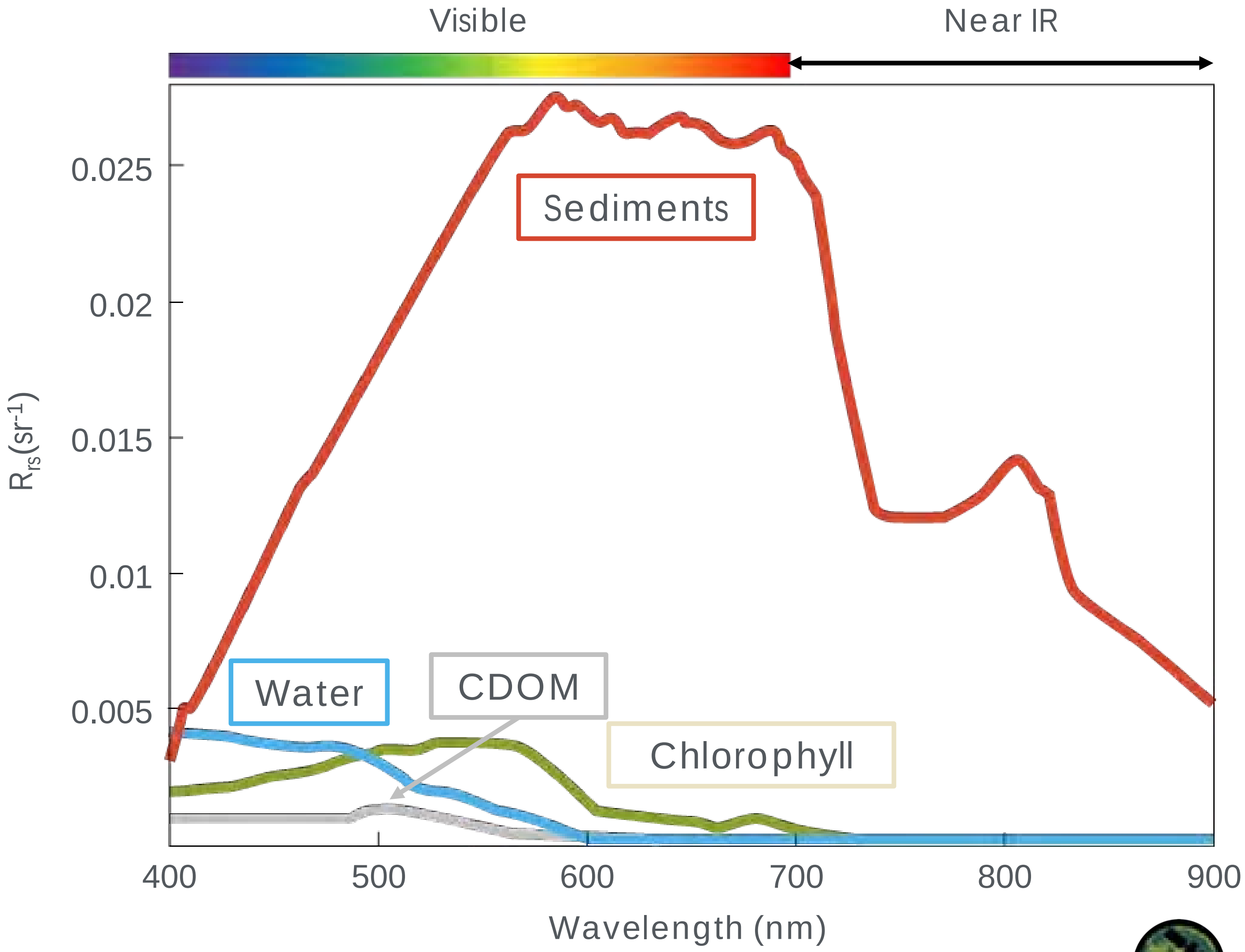
Inherent Optical Properties (IOPs) and the ‘Color’ of Water

Chlorophyll

Water

Non-Algal Particle/ Sediments

CDOM



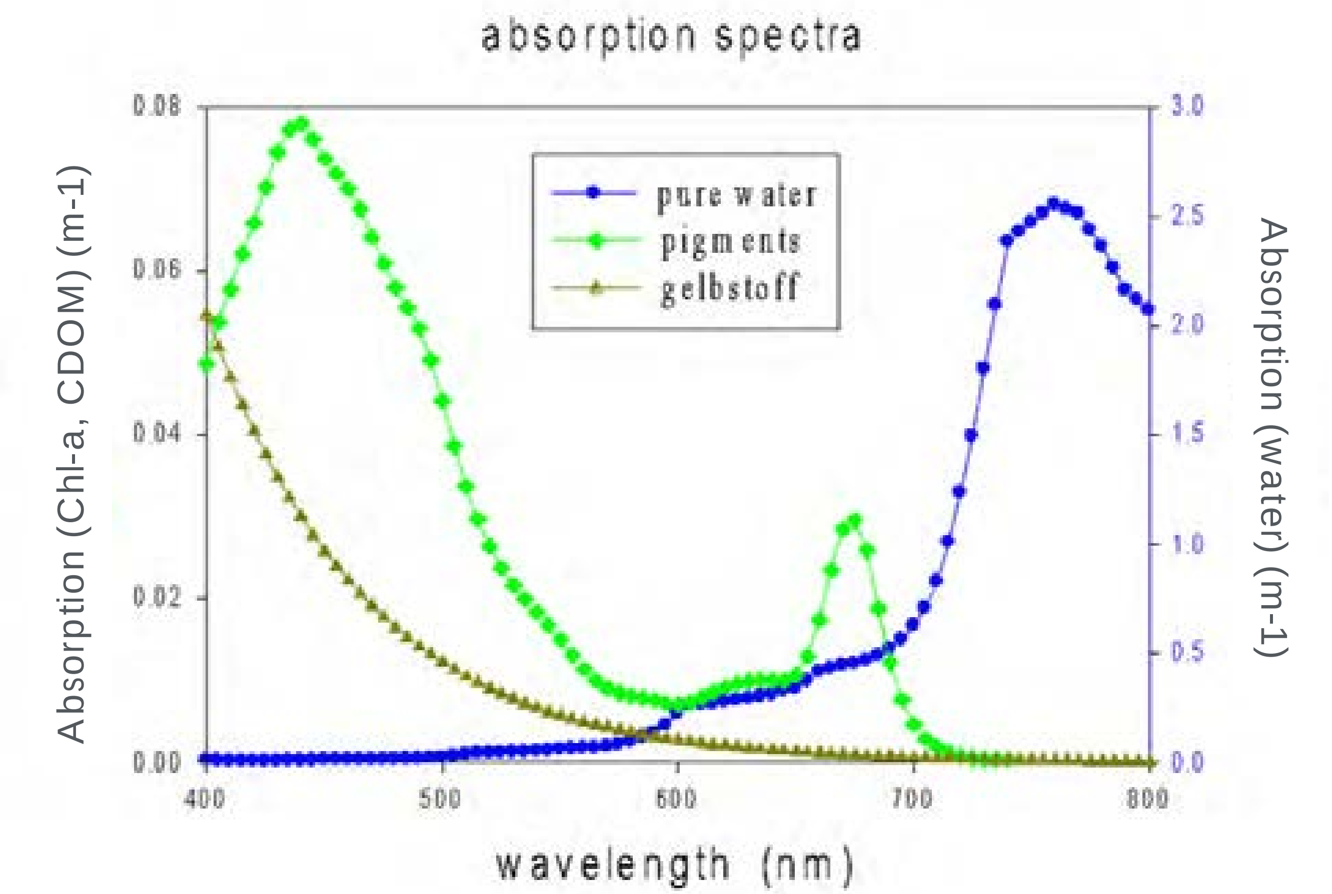
Some Water Quality Indicators Satellites Can Observe

- 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

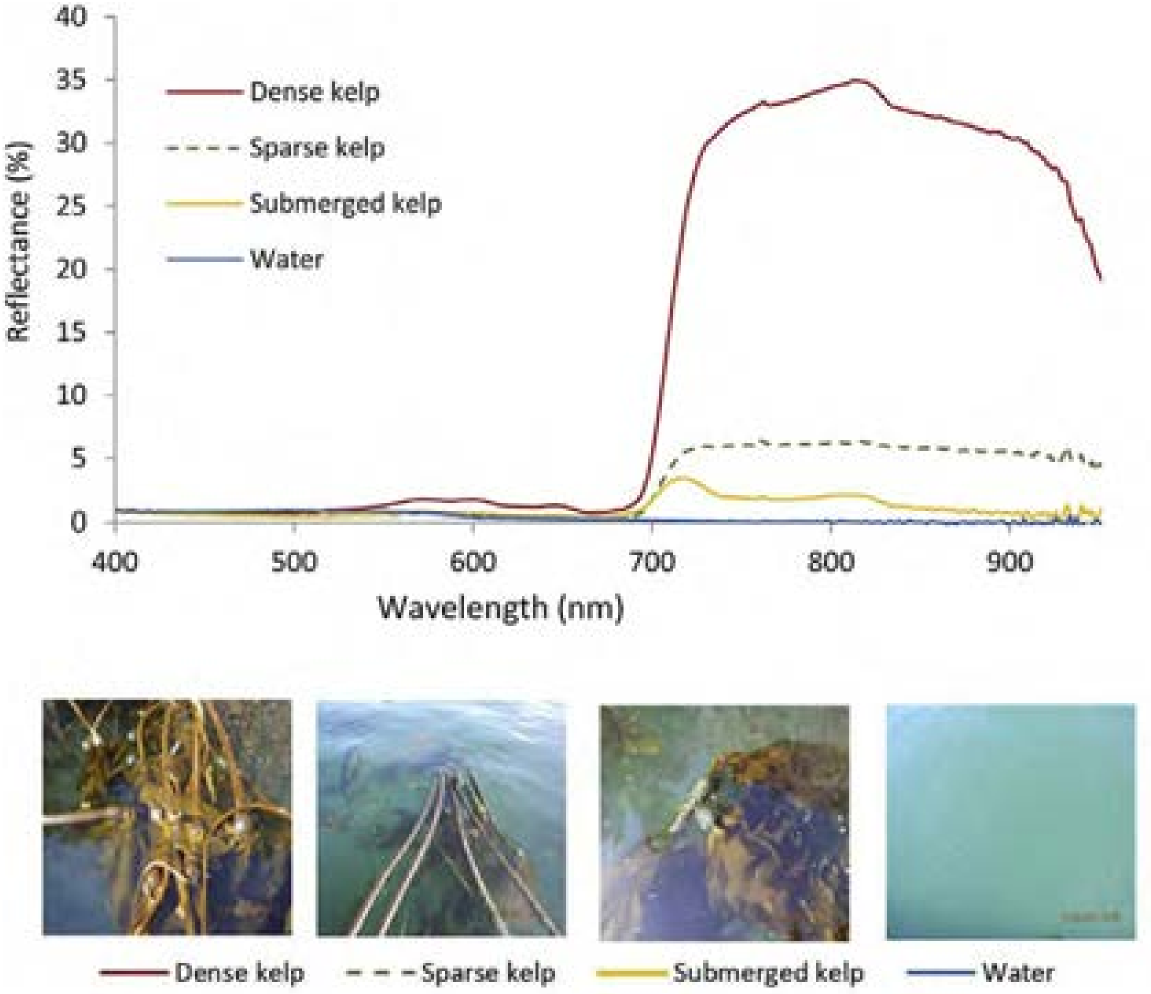
- Water absorbs strongly in the red, NIR, and SWIR.
- CDOM absorbs strongly in the blue region.
- Phytoplankton (Chl a) absorbs strongly in the blue and red regions of the spectrum.



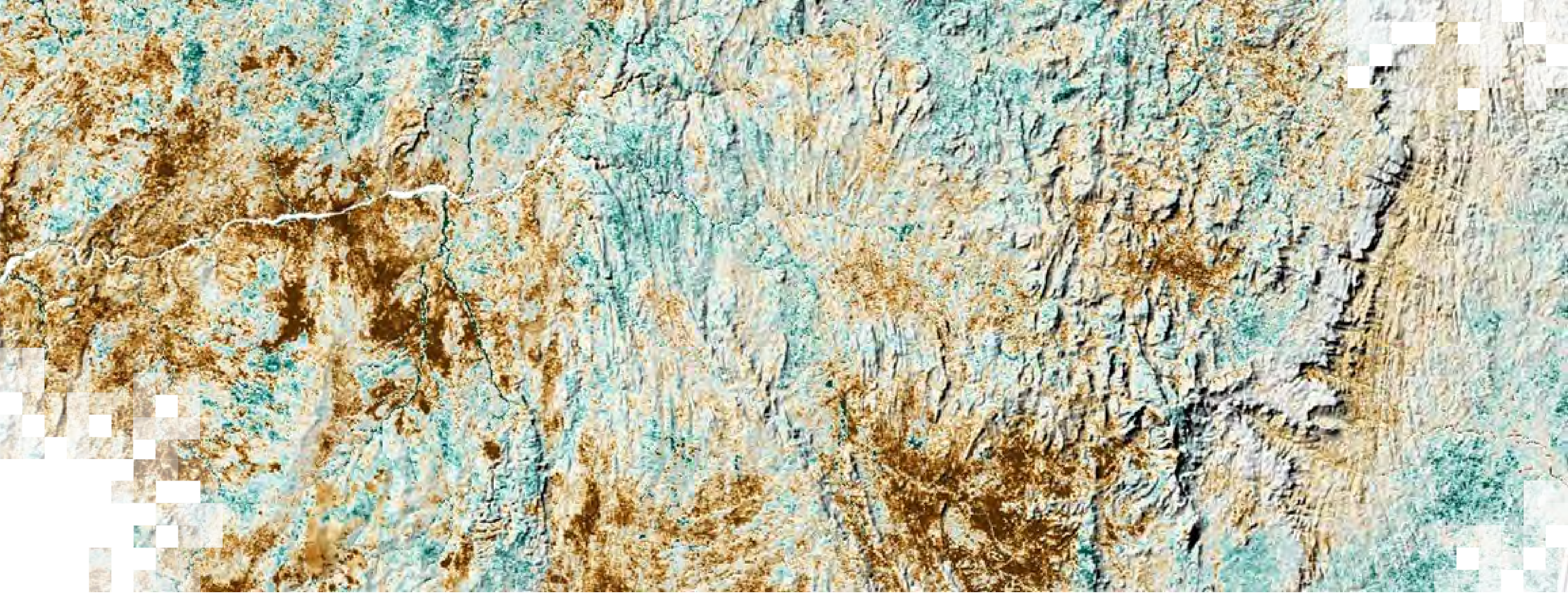
Credit: Univ. PR Bio-optical Oceanography Lab

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.

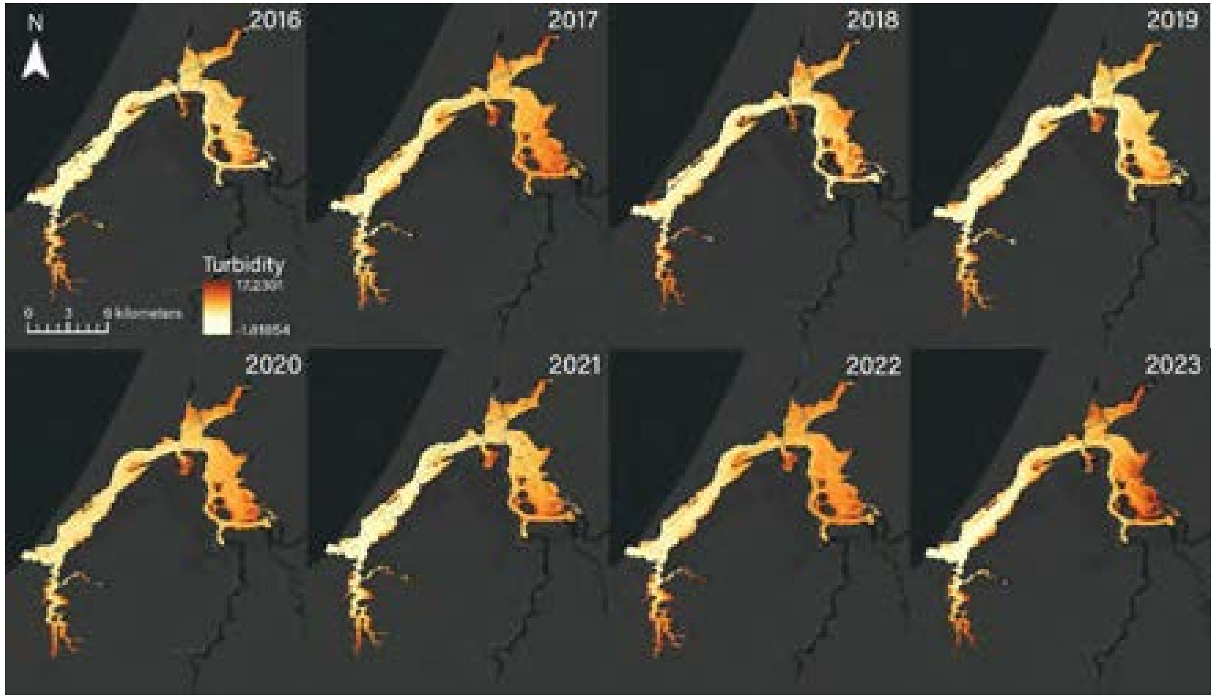


Normalized Difference Turbidity Index (NDTI)

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)

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

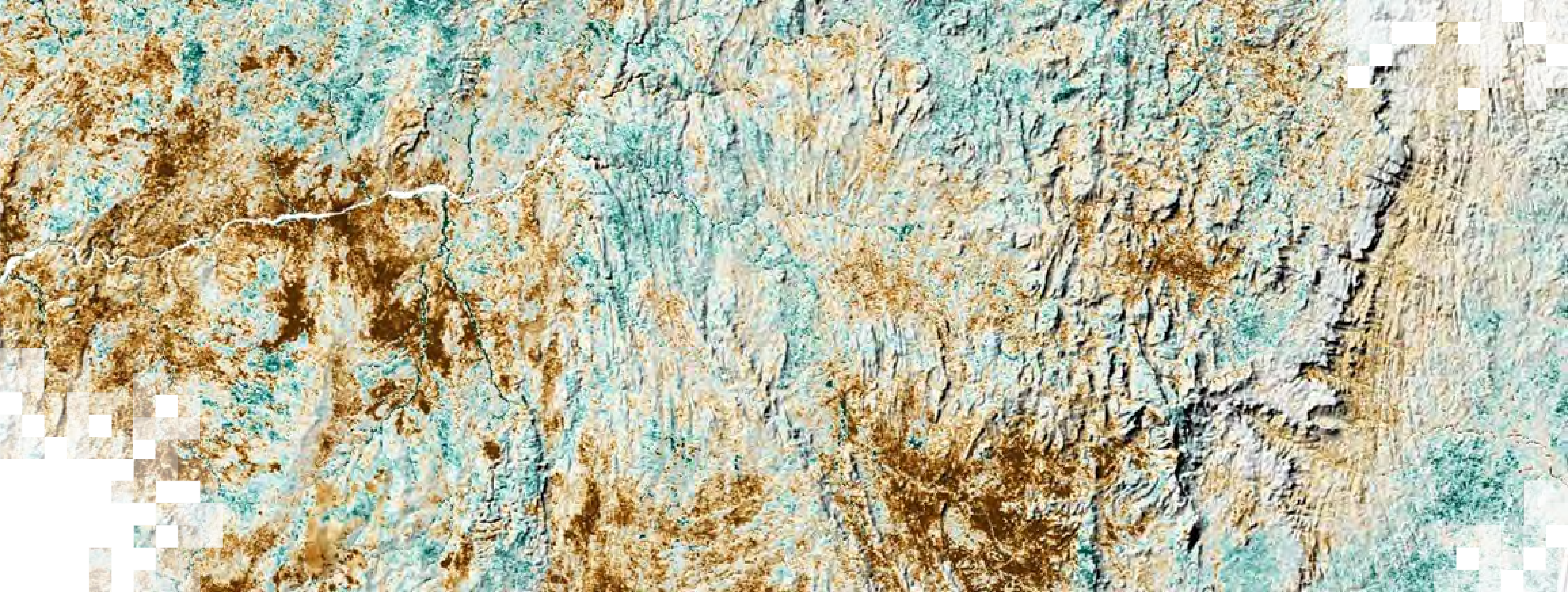


Credit: NASA DEVELOP Program Summer 2023 South Slough Water Resources Project

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.

Summary

- The spectral index you choose to use will depend on the nature of the phenomena you wish to observe.
- Some spectral indices are better than others when dealing with particular conditions, such as the influence of bare soils or turbid waters.
- Spectral indices provide quantifiable metrics that are useful in tracking the ways in which certain phenomena are distributed across space and time.



Calculating Spectral Indices for Land and Aquatic Applications Using QGIS

Demonstration

Training Summary

- Today we learned about the benefits of using spectral indices to study vegetation and aquatic targets.
- We talked about the most used spectral indices for land and aquatic targets.
- Demonstrated how to use QGIS to do simple calculations of spectral indices for land and aquatic applications.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 27/2/2025
  - Access from the [training webpage]
  - Answers must be submitted via Google Forms
  - **Due by 13/3/2025**

- **Certificate of Completion:**
  - Attend this live webinar (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.

Contact Information

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Thank You!