Spectral Signatures and Indices

https://gis4schools.readthedocs.io/en/latest/credits.html

February 18, 2026

Outline

Plan

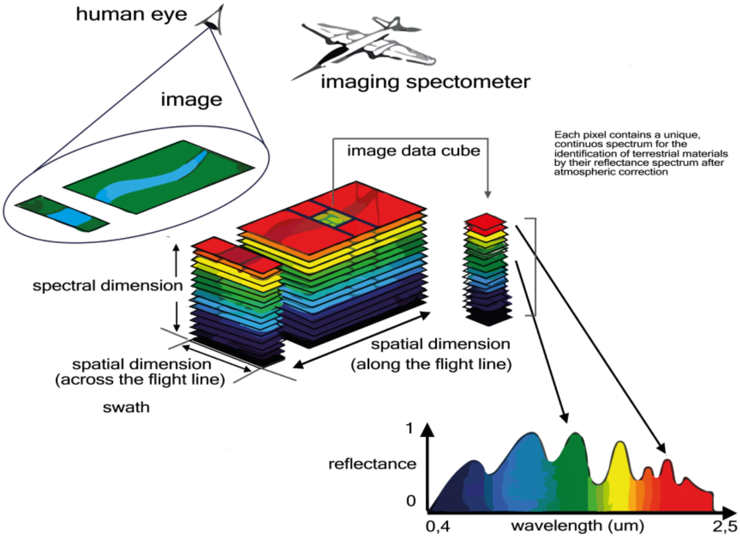
What is a Spectral Signature?

- Every material (natural or manmade) reflects sunlight uniquely.
- Reflection depends on:
  - Chemical composition and physical properties.
  - Texture and surface roughness.
  - Moisture and degradation state.
- This reflected sunlight is called **reflectance** (ρ).

Defining the “Fingerprint”

- Properties define the brightness (reflectance) of “colors” (wavelengths) in different “lights” (spectral bands).
- **Spectral Signature:** The variation of reflectance across different wavelengths.
- Because these are unique, they act like a **fingerprint** for material identification.

Spectral Signature Concept



Why do we use Spectral Signatures?

1. Monitoring Health/Status

   If the material is known, signatures reveal degradation or health (e.g., crop monitoring).

2. Identification

   If the material is unknown, the signature allows for automatic land cover mapping.

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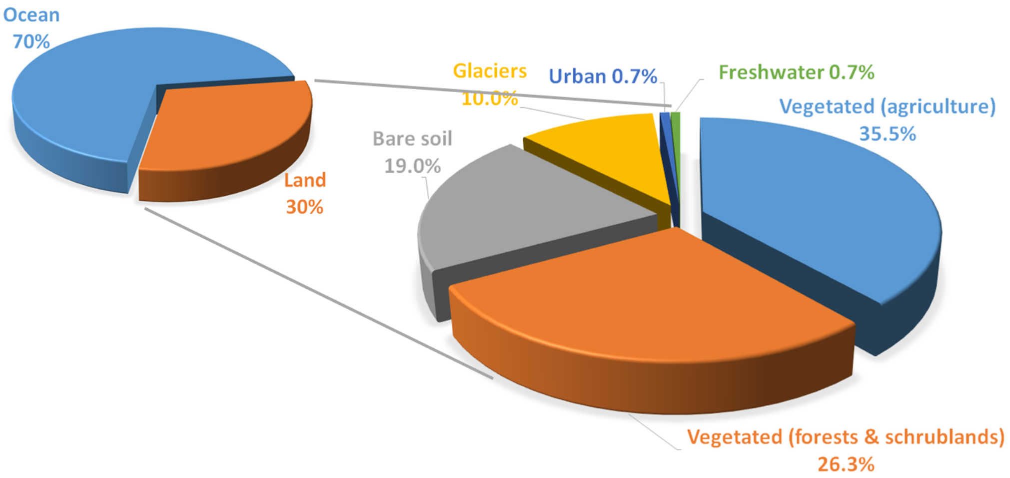
Distribution of main land covers on Earth



Land Cover

- Describes the **physical coverage** of the Earth's surface.
- **Examples:**
  - Farmlands, Glaciers, Forests, Lakes.
- Satellite imagery is a highly efficient method for determining land cover.

Land Use

- Describes **how humans use** the land and the activities performed there.
- **Examples:**
  - Recreational, Residential, Commercial, Industrial.
- **Warning:** Remote sensing systems provide info *only* on physical coverage. Land use **cannot** be directly determined by satellite images alone.

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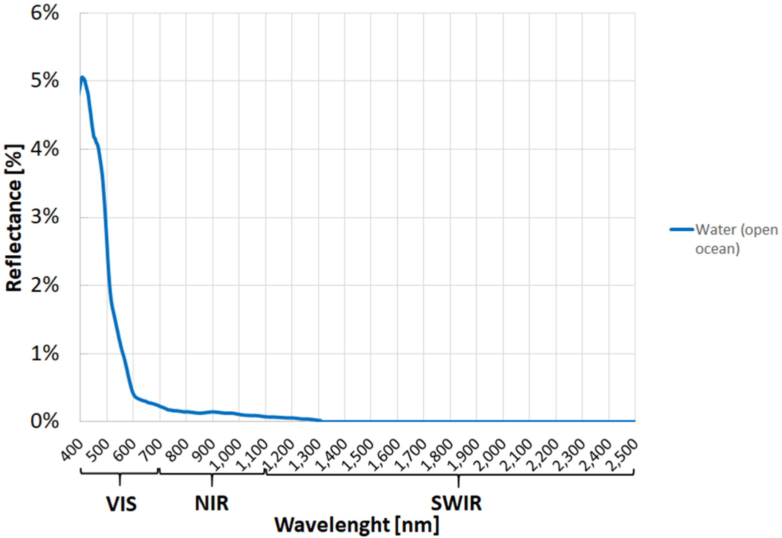
Monitoring Global Ecosystems

- Satellites track how land cover signatures change over time to monitor planetary health.
- We focus on "Macro" classes that dominate the Earth's surface.

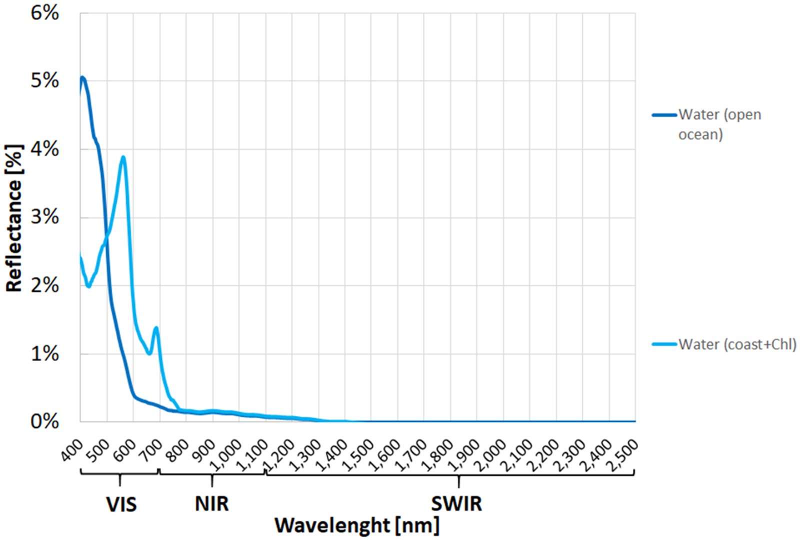
Spectral Signature: Water

- **Clear Water:** High absorption in the NIR/SWIR; reflects primarily in blue-green visible light.
- **Polluted Water:** Presence of chlorophyll or sediment shifts the signature, increasing reflectance in specific bands.

Spectral Signature: Water



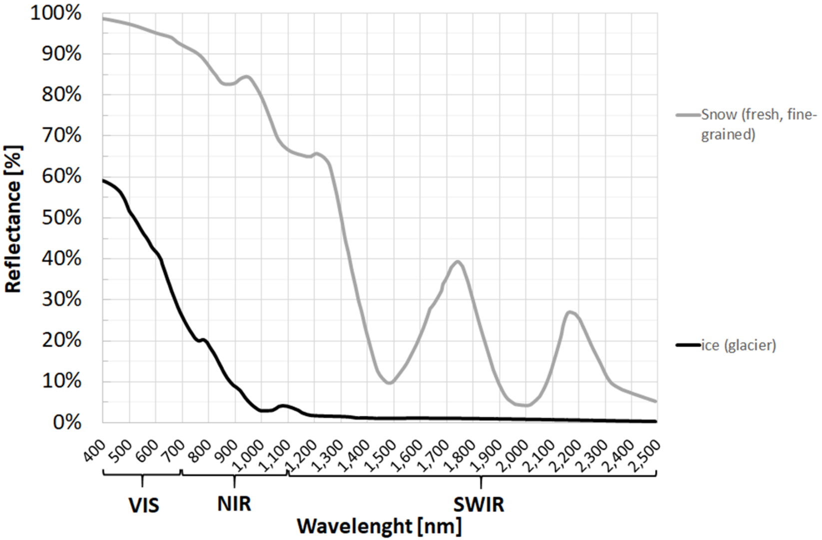
Spectral Signature: Water



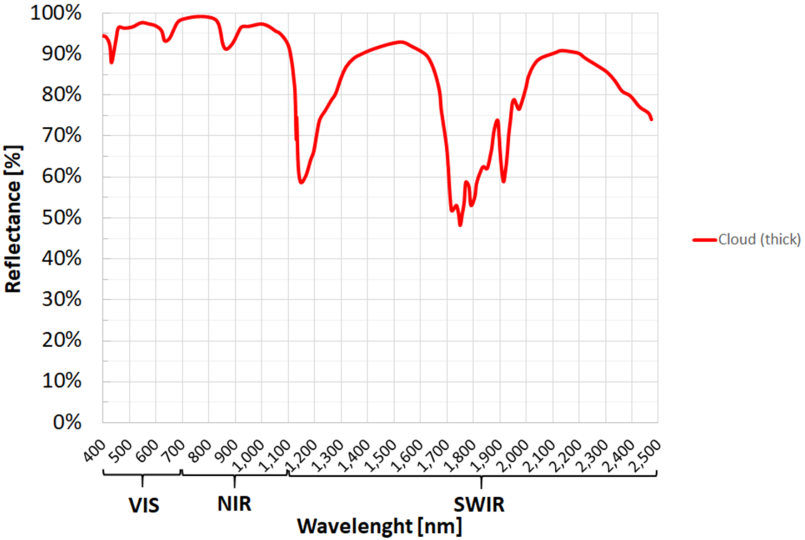
Spectral Signature: Snow vs. Clouds

- **Snow/Ice:** High visible reflectance, but very low reflectance in Short-Wave Infrared (SWIR).
- **Clouds:** High reflectance across both visible and SWIR bands.
- This difference is key for cloud masking in satellite imagery.

Spectral Signature: Snow vs. Clouds



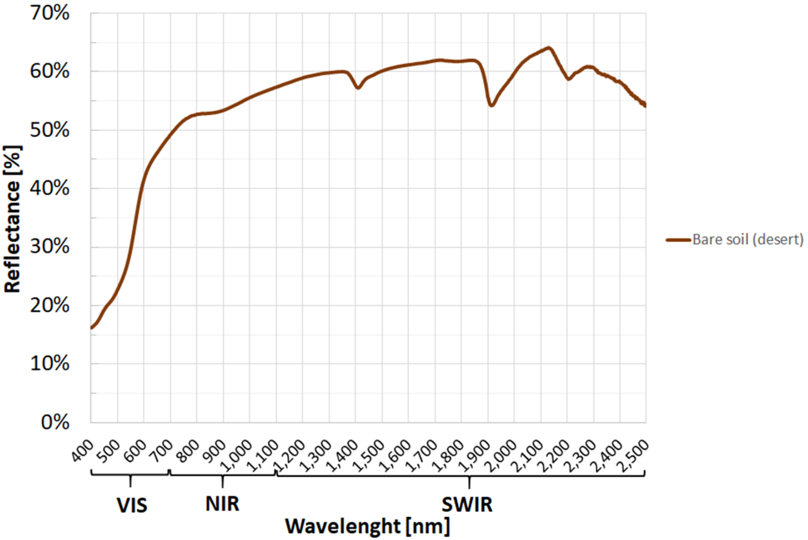
Spectral Signature: Snow vs. Clouds



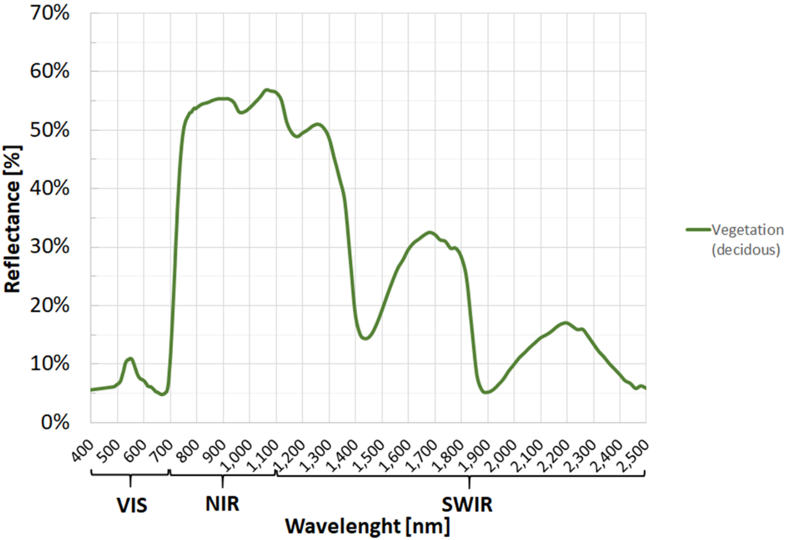
Spectral Signature: Soil and Vegetation

- **Bare Soil:** Generally shows a steady increase in reflectance as wavelength increases.
- **Healthy Vegetation:** Low red reflectance (chlorophyll absorption) and very high NIR reflectance (leaf structure).

Spectral Signature: Soil and Vegetation



Spectral Signature: Soil and Vegetation



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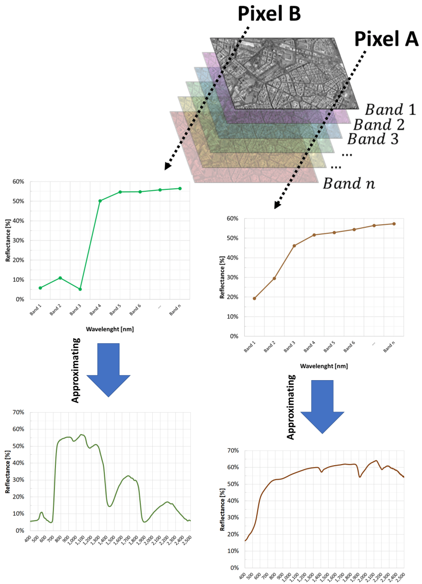
Satellite Measurements

- Satellites record reflectance in discrete **spectral bands**.
- They produce multiband grayscale images.
- We approximate the continuous signature curve by plotting values as a **polyline**.

Satellite Measurements



The Necessity of Atmospheric Correction

Warning

Use ONLY atmospherically corrected images!

- Satellites capture both surface reflectance and atmospheric scattering (noise).
- Scattering must be removed to analyze the true signal of the Earth's surface.

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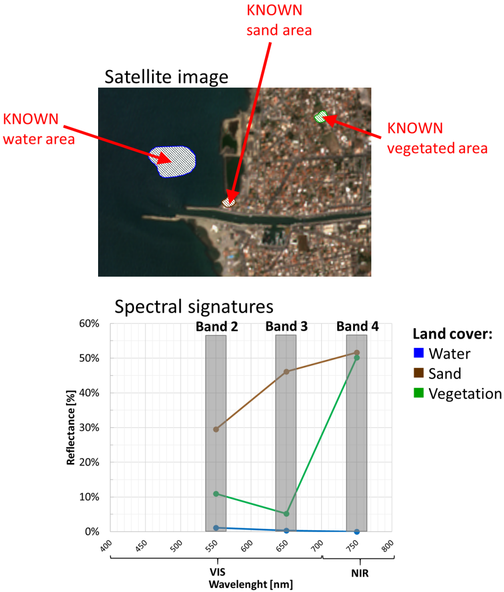
The Feature Space

- Comparing “curves” visually is difficult.
- We use a reference system of orthogonal axes where **each axis is a spectral band**.
- In this space, a spectral signature becomes a single **point**.

The Feature Space



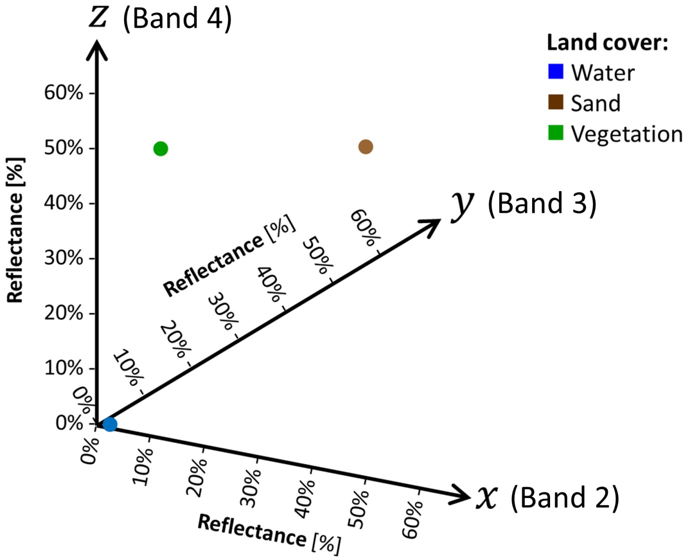
Similarity via Euclidean Distance

Similarity is determined by how close points are in the feature space.

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \tag{1}$$

- x, y, z represent reflectances in different bands.
- Closer points = More similar materials.

Similarity via Euclidean Distance



Spectral Classes

- Points that group together in the feature space form a **cluster**.
- These clusters are referred to as **spectral classes**.
- This is the mathematical basis for automatic land cover mapping.

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What is a Spectral Index?

- A mathematical expression applied to a multispectral image.
- **Goal:** Highlight specific properties (health, moisture, mineral abundance).
- Transforms qualitative images into **quantitative numerical tools**.

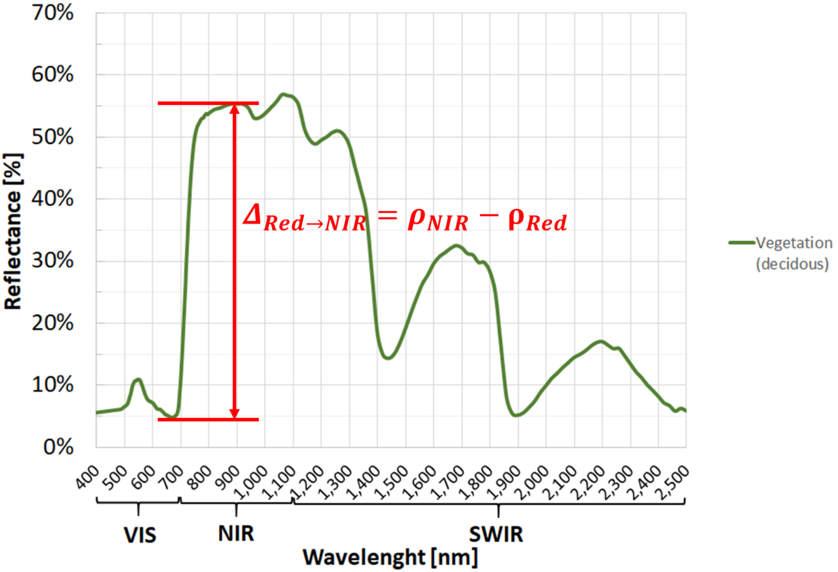
Mathematical Families of Indices

Family	**Example**	**Pros**
Difference	CRI	Simple calculation
Ratio	RVI	Reduces atmospheric effects
Normalized	NDVI	Bounded range (-1 to 1)
Complex	EVI	Highly accurate mapping

Designing Indices: The Vegetation Gap

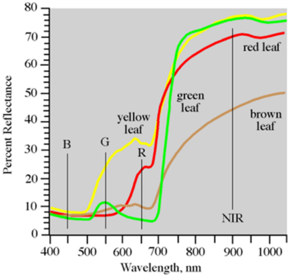
- Healthy leaves have a massive gap between **Red** (absorption) and **NIR** (reflectance).
- As vigor or biomass increases, this gap widens.
- Most vegetation indices use the relationship between these two bands.

Designing Indices: The Vegetation Gap



Designing Indices: The Vegetation Gap

Healthy (green leaf) | Becoming sick (yellow leaf) | More sick (red leaf) | Dead (brown leaf)



Spectral signatures

Ratio Vegetation Index (RVI)

The simplest greenness index:

$$RVI = \frac{NIR}{Red} \tag{2}$$

- Always positive ($RVI \geq 0$).
- Larger ratio = healthier/denser vegetation.
- **Limitation:** Not bounded from above, making comparisons difficult.

RVI Typical Values

- **4 to 10:** General healthy vegetation.
- **Up to 30:** Very dense, very healthy vegetation.
- **Below 4:** Sparse or “sick” vegetation.

Normalized Difference Vegetation Index (NDVI)

The most widely used index in remote sensing:

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{3}$$

- Normalized range: **-1 to 1**.
- For vegetated land, values are always positive.

NDVI Thresholds for Land Cover

- **NDVI $<$ 0.2:** Bare ground / Soil.
- **0.2 to 0.6:** Shrubs, grass, and crops.
- **NDVI $>$ 0.6:** Dense forests.

NDVI: Interpreting the Signal

- **For Mixed Pixels (Amount):**
  - Low (0.2 - 0.4): Sparse veg.
  - High (> 0.6): High-density veg.
- **For Full Cover (Health):**
  - Low (0 - 0.2): Very sick veg.
  - High (> 0.6): Very healthy veg.

NDVI Beyond Vegetation

- **Close to -1:** Clear water.
- **-1 to 0:** Polluted water, snow, or ice.
- **Close to 0:** Clouds.
- **0 to 0.2:** Bare soil.

Normalized Difference Water Index (NDWI)

Designed to highlight water bodies:

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{4}$$

- Positive for water.
- **Threshold 0.3:** Often used to separate flooded from non-flooded areas.

NDWI for Water Stress

Caution

A different index, also called NDWI, is used for vegetation.

$$NDWI_{stress} = \frac{NIR - SWIR}{NIR + SWIR} \tag{5}$$

- Used to detect drought or water stress in plants.

Normalized Difference Snow Index (NDSI)

Differentiates snow from clouds using the SWIR band:

$$NDSI = \frac{Green - SWIR}{Green + SWIR} \tag{6}$$

- **Snow:** High Green, Low SWIR.
- **Clouds:** High Green, High SWIR.
- **Threshold 0.4:** Differentiates snow cover.

Applications

- **Agriculture:** Monitoring crop health and yield prediction.
- **Biodiversity:** Mapping tropical forest cover and detecting deforestation.
- **Geology:** Identifying mineral compositions through SWIR absorption bands.

Build Your Own Spectral Index

1. Identify the spectral signature of the standard state.
2. Determine how your target phenomenon affects reflectance.
3. Create a math expression using specific bands.
4. Ensure the output is proportional to the observed phenomenon.

Summary

- Spectral signatures are the “fingerprints” of the Earth’s surface.
- Indices (NDVI, NDWI, NDSI) turn raw imagery into quantitative data.
- Understanding these principles is essential for environmental monitoring, agriculture, and climate change studies.