Remote Sensing – Atmosphere: Precipitations

GLOBE		Related SDGs:	Type of activity
Sphere	**Protocols**		
Atmosphere	Air temperature. Surface temperature. Wind direction and speed. Precipitation. Relative humidity	11 (Sustainable Cities and Communities) 13 (Climate action) 15 (Life of Terrestrial Ecosystems)	Exploratory
Biosphere	Terrestrial coverage. Biometry. Phenology		
Pedosphere	Soil characterization. Fertility. Humidity. pH. Temperature		
Bundle	Agriculture Air Quality Soils Cities Meteorology		

Overview

Basic remote sensing concepts are explained to analyze satellite images of a mega forest fire in Chile and the Atacama Desert blooming after extraordinary rains. Satellite images processed with a combination of bands and indices are used. In addition, students can try different band combinations and apply other specific indices to highlight some features.

Time

4 or 5 classes

Prerequisites

Basic knowledge of ecosystems, photosynthesis, meteorology, waves, electromagnetic spectrum, and ICT. Analysis of bar charts, line graphs, and histograms. Ability to interpret satellite images and maps. Ability to locate points using latitude and longitude.

School Level

High school and university students

Purpose:

To understand the application of wave properties, satellite sensors, and satellite images to obtain information about the Earth's process to observe changes, trends, and interrelationships between the biosphere, atmosphere, hydrosphere, and pedosphere.

Student outcomes

- Know the types of electromagnetic waves satellite sensors use to obtain information from the Earth system.
- Identify changes and trends in satellite imagery.
- Apply combinations of the bands by assigning the colors Red (R), Green (G), and Blue (B) to identify specific features on the ground.
- Apply specific indices to analyze satellite image information.
- Analyze land cover impacts caused by wildfires.
- Analyze the relationship between temperature, rainfall, and flowering in the Atacama Desert.

Introduction

Remote Sensing

Remote sensing is acquiring information from a distance using remote sensors. For example, a camera is a sensor that allows us to obtain information about an object from space (when we take a photograph), and our eyes are sensors that enable us to get information about our surroundings when we look at something. To study the Earth, sensors placed on satellites, the international space station, airplanes, drones, balloons, and others are used to detect and record reflected or emitted energy—fig. 1.

Fig. 1. Different types of remote sensors that obtain information from the Earth. Source: https://svs.gsfc.nasa.gov/30892

Remote sensors provide a global perspective and a large amount of atmospheric, hydrosphere, pedosphere, and biosphere data that allow us to know the current state, study trends with historical information (e.g., 20-year record of rain and snow), and use them for data-driven decision making. NASA has its fleet of satellites orbiting the Earth, and some satellites operate in consortium with other countries (several of them belong to the Latin

American and Caribbean region). An example of this is the International Afternoon Constellation, formed by a coordinated group of satellites from different countries that travel in a synchronized orbit with the sun, passing at approximately 13:30 local solar time, with a difference of seconds to minutes between them (for this reason it is called the Afternoon Constellation). This constellation of satellites performs near-simultaneous observations with a wide variety of sensors that are of great utility for conducting research, issuing warnings, making decisions, etc. Fig. 2.

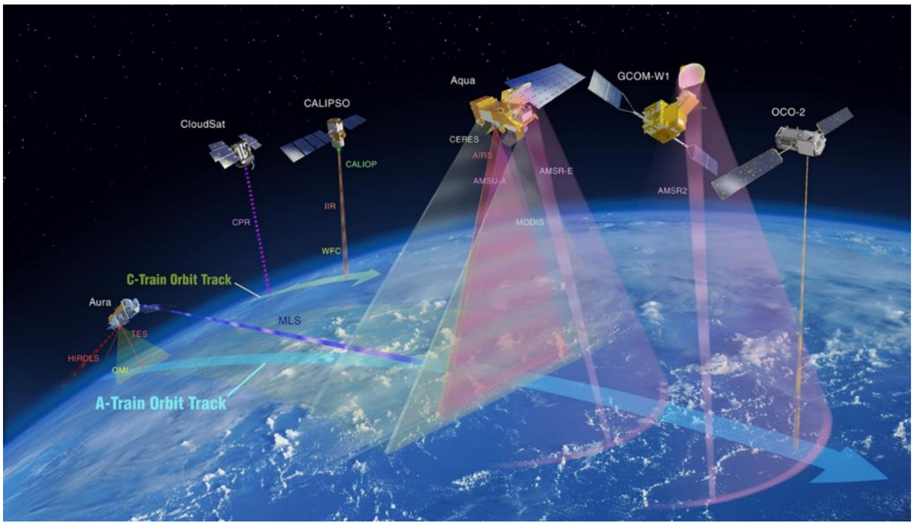

Fig. 2. International Afternoon Constellation. Source: https://atrain.nasa.gov/

Some sensors are passive, i.e., they detect electromagnetic waves reflected from the earth's surface when illuminated by the sun or when it emits light (e.g., city lights at night). Most passive sensors operate in the electromagnetic spectrum's visible, infrared, and microwave portions. Passive sensors measure land and sea surface temperature, vegetation properties, cloud properties, aerosols, and soil moisture. However, they have limitations because they cannot penetrate the dense cloud cover that regularly covers the tropics. Active sensors emit waves that bounce off the Earth's surface and return. Most operate in the microwave band of the electromagnetic spectrum, allowing them to penetrate the atmosphere (e.g., radar). These sensors measure aerosol vertical profiles, forest structure, precipitation and winds, sea surface topography, and ice.

The Sun is the primary source of energy observed by satellites. Different types of surfaces reflect different amounts of solar energy. The albedo is the property of anybody to reflect incident radiation. For example, snow is a light surface and has a high albedo (it reflects up to 90% of incoming solar radiation). The ocean is dark, with low albedo (it reflects only about 6% of incoming solar radiation and absorbs the rest). When energy is absorbed, it is re-emitted, usually at longer wavelengths. In the case of the ocean, the absorbed energy is re-emitted as infrared radiation. The amount of energy surfaces reflect, sponge, or transmit varies with wavelength.

Spectral bands and signatures

As the reflected energy goes according to the surface type, it can be used to identify different characteristics of the Earth; it works just like our fingerprints and is called a spectral signature. Thanks to the spectral signature, it is possible to identify different types of rocks and minerals, clear and turbid water, soil moisture, different types of vegetation, vegetation conditions, etc.). Fig. 3.

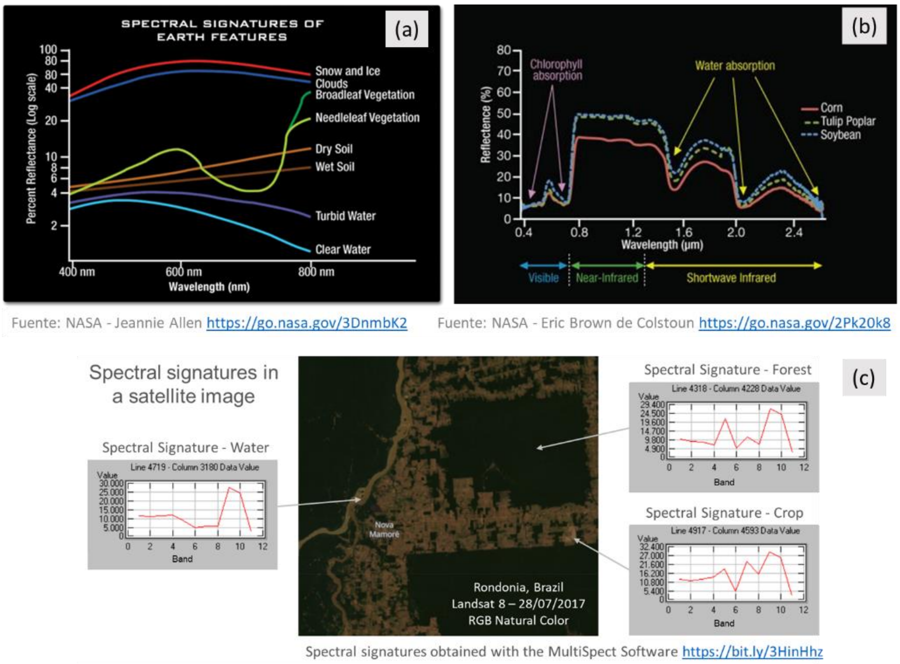

Fig. 3. Spectral signatures: (a) of different Earth features. (b) of vegetation. (c) Examples of spectral signatures in different pixels of the satellite image of Rondônia, taken by the Landsat 8 satellite on 27/07/17.

A digital image comprises pixels (or squares) whose color represents a number each. Thus, a picture is a matrix of grayscale numbers ranging from 0 (white) to 255 (black). Any other value within that range is a variation of gray (Fig. 4).

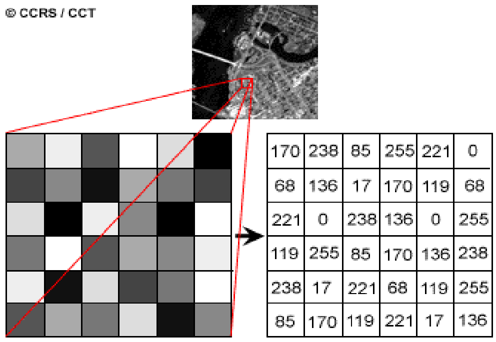

Fig. 4. Satellite image and numerical matrix of a Landsat 7 satellite image band. Each pixel (or square) represents a land area of 30m x 30m and a specific brightness color. Source: https://www.nrcan.gc.ca/

Each satellite image has multiple bands representing different electromagnetic spectrum wavelengths [Fig. 5 (a)]. Sensors on most satellites use infrared to ultraviolet, including visible light. The bands represent data from the visible and infrared (shortwave infrared, near-infrared, and mid-infrared) regions. [Fig. 5 (b)] When we combine the bands in an RGB image to obtain a color similar to natural color, we work with three matrices, one per color channel: Red, Green, and Blue. [Fig. 5 (d)] As in the grayscale images, 0 represents the absolute absence of color, and 255 is the total presence of the hue corresponding to a particular channel. One of the RGB colors is assigned, and the false color is obtained to observe other aspects reflected in infrared bands or different wavelengths that are not perceived by our eyes. [Fig. 5 (c)

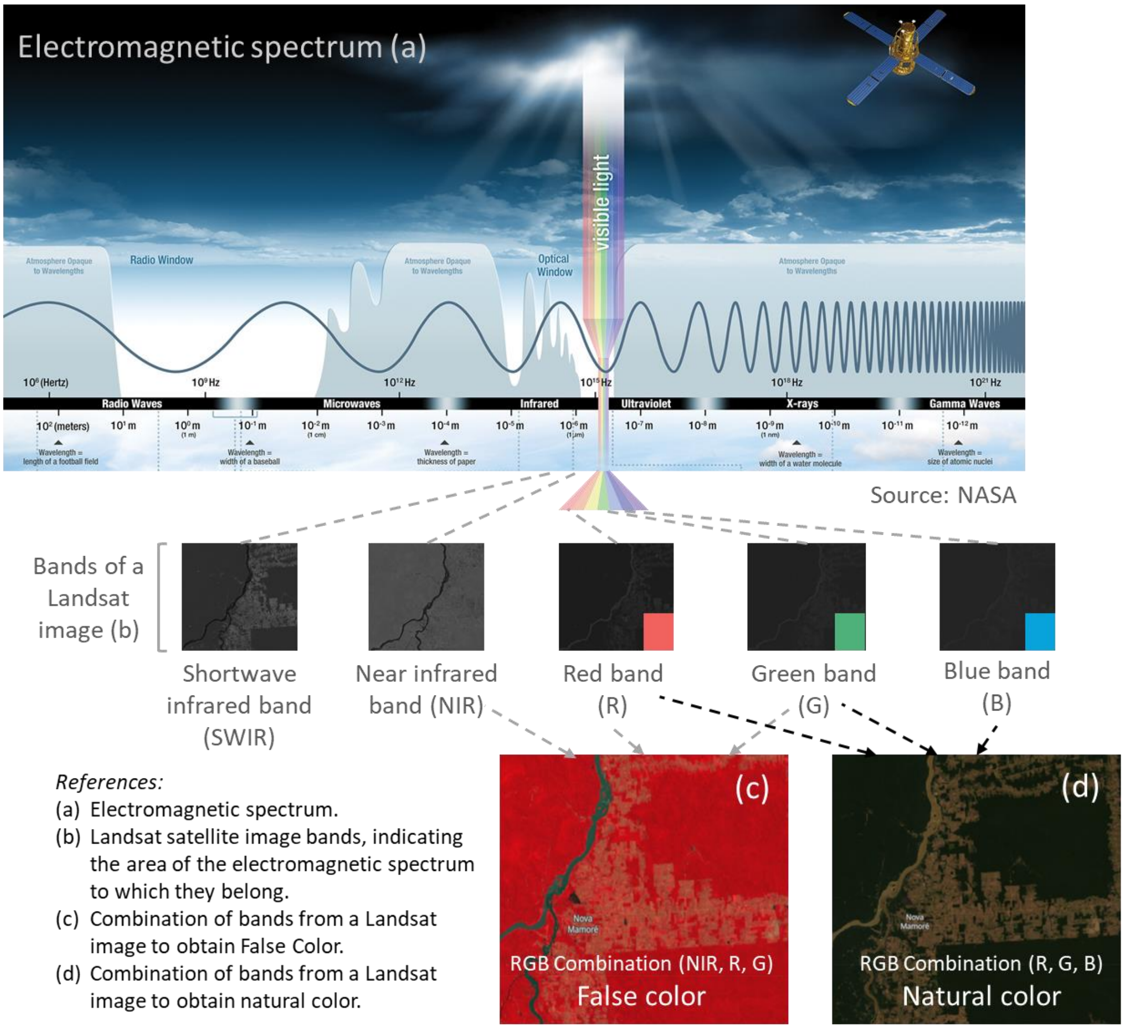

Fig. 5. Combination of Landsat satellite image bands to visualize various aspects. Sources: NASA and Landsat.

As the satellite images are matrices, it is possible to perform calculations to detect other elements not visible with the color combination. The indexes are obtained from calculations with the matrices that form each band of the satellite images. This calculation is performed using specific software, and as a result, a new image is obtained where the pixels related to the parameter, we are measuring are graphically highlighted. E.g., vegetation indices emphasize parameters of vegetation cover: density, leaf area index, chlorophyll activity, and others. For example, details of changes in vegetation cover are easily analyzed by applying indices. The Normalized Difference Vegetation Index (NDVI) is the most commonly used, but several similar indices exist. The NDVI allows estimating vegetation quantity, quality, and development based on measuring the radiation intensity of some bands of the electromagnetic spectrum that foliage emits or reflects. The bands vary according to the type of satellite. Some images automatically generate the most common indices. High NDVI values indicate healthy vegetation; low values indicate that the vegetation is drying out (may be due to water stress, disease, fire, etc.) - Fig. 6.

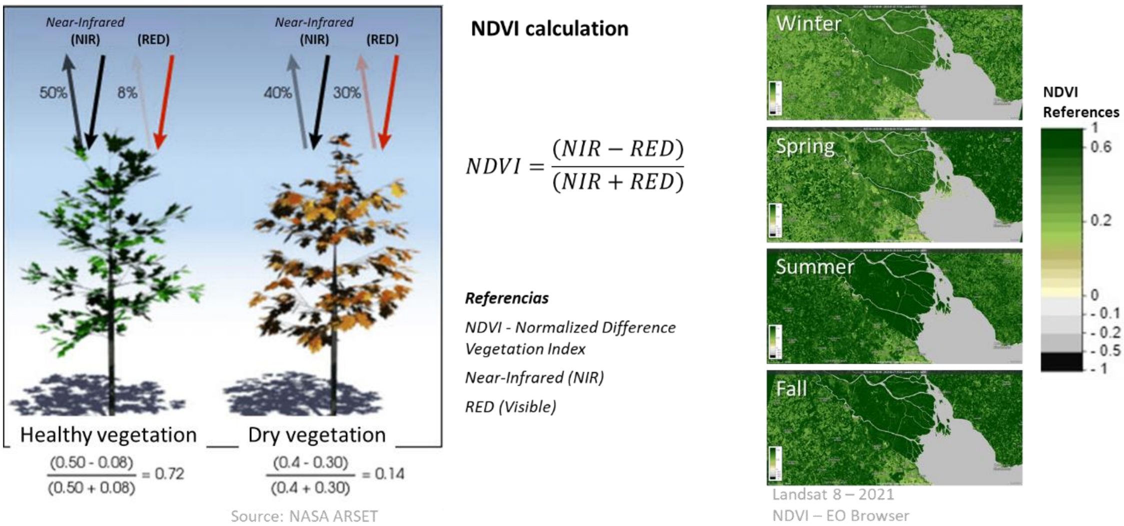

Fig. 6. Calculation and satellite images of the Paraná River Delta processed with the NDVI index. Seasonal changes in vegetation are detected with different color intensities.

Spectral indices have been developed to analyze various aspects of satellite images that have applications in ecology, agriculture, disasters (floods, fires, etc.), aquatic resources, geology, etc. All of them use calculations using different bands of satellite images.

Guiding Research Questions

- Why do some areas catch fire more often than others?
- What is the relationship between precipitation and vegetation type? What vegetation type is in my local environment, and how is precipitation distributed throughout the year?
- What happens when precipitation patterns change in my environment? Are there any known local/regional consequences related to the ENSO phenomenon?
- What conditions allow a massive flowering of plants in the desert? Where do desert blooms occur besides the Atacama?

Scientific concepts

- Ecosystems. Forests. Grasslands. Deserts.
- Land cover.
- Waves and electromagnetic spectrum.
- Graphs. Histograms
- Satellite images

Materials and Tools

1. ArcGIS StoryMaps https://storymaps.arcgis.com/
2. Worldview https://worldview.earthdata.nasa.gov/
3. EO Browser App https://apps.sentinel-hub.com/eo-browser/

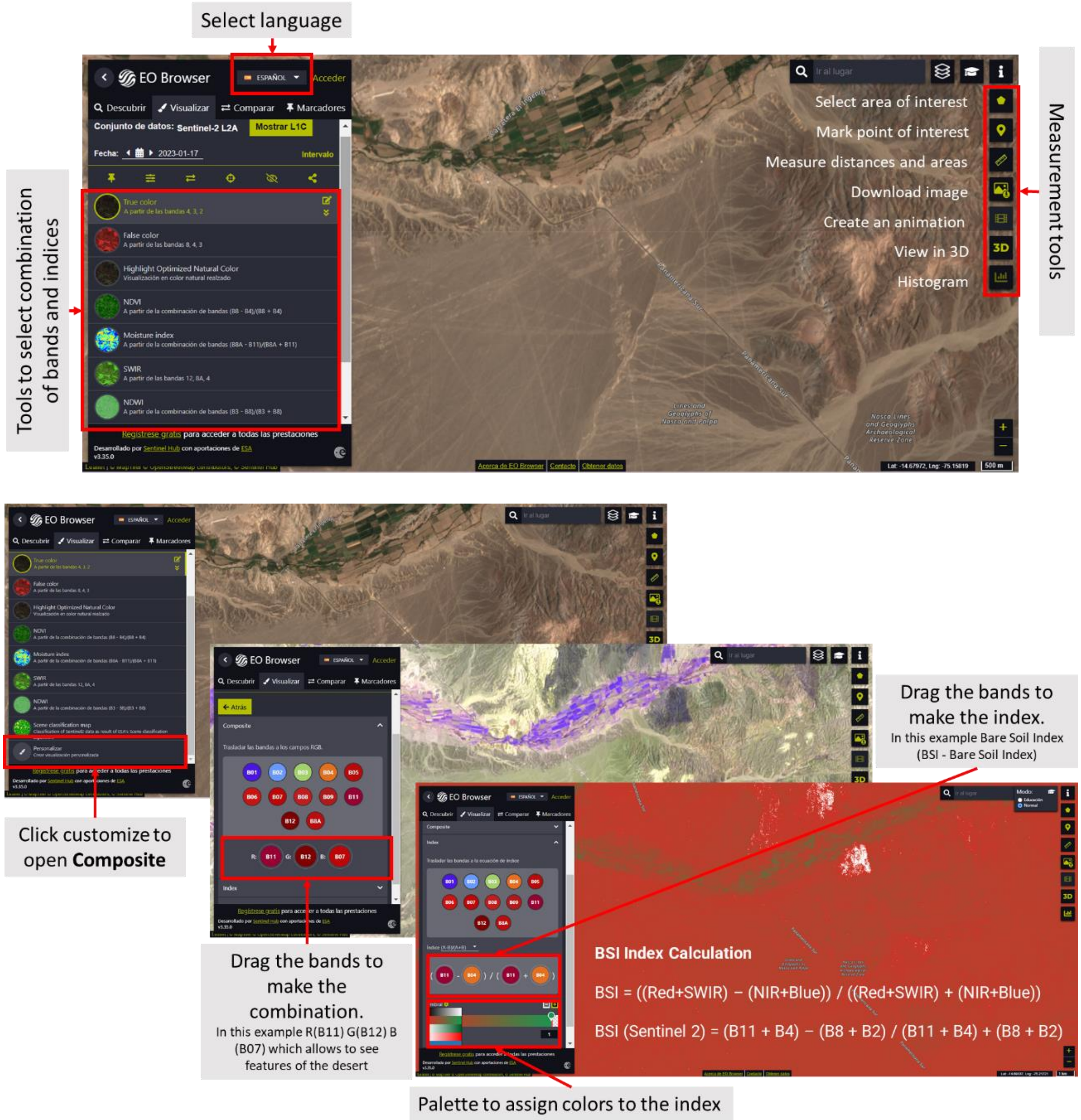

Fig. 7. EO Browser App tools infographic. Source: Own elaboration based on screenshots of the app.

Case analysis:

***Case 1**: Analysis of burned areas (forest and the city of Villa Santa Olga) Chile. January 2017.*

- Google Map - Location
- Climogram of average temperature and precipitation.
- Tree cover. Gain and loss.

Worldview

- Hot spots, smoke, and fire lights at night (consider that city lights also appear; change dates to differentiate with fire lights). City fire 01/26/17: Check days before and after the fire. Observe fires near the city and use the ruler (right, below the screen) to measure distances to hot spots.

- Environmental conditions: a) Precipitation, b) Temperature.
- Generate a video in Worldview with each data set queried.

EO Browser (see tools in Fig. 7):
Sentinel image False color before the fire 19/01/2017 2.
2. Sentinel image False color after the fire 20/03/2017 3.
● Use the ruler (on the right of the screen) to measure the burned area and distances from nearby cities to the boundary of the burned area.
3. Sentinel Image False color after six years 01/28/2023.

On the EO Browser images, perform the following:

1. View the false color images and analyze the changes.
2. Select the NDVI index (on the left side of the screen) and then the histogram (on the right side of the screen). Compare the results of the images. You can draw the site and then select the histogram to measure a specific area.
   a. Do the same for NDMI (Soil Moisture Index) and SWIR (for water present in vegetation and soil).
   b. Refer to the **histogram** (on the right side of the screen), open the menu of the index you are observing (on the left side) to see the color reference. Analyze the histogram by comparing the values with those of the reference.
   c. You can draw an area and do the same analysis for that particular sector.
3. To make a new **band combination,** go to customize (left below) and select **composite**.
   a. Drag the bands to the circles to make the RGB combination: (R) 11, (G) 8 and (B) 3.
   b. Compare the sharpness with which you observe the burned area concerning previous visualizations.
4. **Generate an index.** To improve the analysis, use the Normalized Burned Ratio Index (NBRI), which is sensitive to changes in vegetation and is used to detect burned areas and subsequently monitor ecosystem recovery.
   a. Go to Customize (bottom left) and select **Index**. The formula for placing the bands will appear. Place A lace band B8) and in place B (place band B12) correspond to the following calculation:

$$NBRI = (NIR – SWIR) / (NIR + SWIR)$$

$$NBRI\ (Sentinel\ 2) = (B8 – B12) / (B8 + B12)$$

   b. Then, go to **Threshold** and select a color palette to colorize the image.
5. Make a presentation comparing the results obtained before and after the fire to analyze the impact and after six years to evaluate if it has recovered.

Case 2: Analysis of the "flowering desert". Rapid flowering after rains in the Atacama Desert.

- Google Map - Location
- Climogram of average temperatures and rainfall.

1. Flowering 2017. Worldview:

   - NDVI - Flowering from June to November (maximum in August).
   - Environmental conditions: a) Precipitation, b) Temperature.

- Generate a video in Worldview with each dataset queried.
- EO Browser (see tools in Fig. 7):
- False color, NDVI, Moisture Index (NDWI - Soil Moisture), SWIR (Short Wave InfraRed - amount of water present in vegetation and soil).

EO Browser (see tools in Fig. 7):
o: False color, NDVI, Moisture Index (NDWI - Soil Moisture), SWIR (Short Wave InfraRed - amount of water present in vegetation and soil).

2. *Flowering 2021*
   Worldview:
   - NDVI - Flowering from August to October (maximum in August - September).
   - Environmental conditions: a) Precipitation, b) Temperature,
   - Generate a video in Worldview with each dataset queried.

   EO Browser (see tools in Fig. 7):
   o: False color, NDVI, Moisture Index (NDWI - Soil Moisture), SWIR (Short Wave InfraRed - amount of water present in vegetation and soil).

3. Desert without flowers:
   Worldview:
   - NDVI - Desert without flowers
   - Environmental conditions: a) Precipitation, b) Temperature,
   - Generate a video in Worldview with each data set queried.

   EO Browser (see tools in Fig. 7):
   - False color, NDVI, Moisture Index (NDWI - Soil Moisture), SWIR (Short Wave InfraRed - the amount of water present in the vegetation and in the soil).

On the images in the EO Browser of the blooms (2017 and 2021) and the desert without blooms, perform the following:

1. View the false-color images and analyze the changes.
2. Select the NDVI index (on the left side of the screen) and then the histogram (on the right side of the screen). Compare the results of the images. You can draw the site and then select the histogram to measure a specific area.
   a. Do the same for NDMI (Soil Moisture Index) and SWIR (to know the water in vegetation and soil).
   b. Refer to the **histogram** (on the right side of the screen), open the menu of the index you are observing (on the left side) to see the color reference. Analyze the histogram by comparing the values with those of the reference.
   c. You can draw an area and do the same analysis for that particular sector.
3. To make the **combination of bands,** go to customize (left below) and select **composite**.
   a. Drag the bands to the circles to make the RGB combination: (R) 8A, (G) 11, and (B) 12. Also, try with the combination of RGB bands: (R) 8, (G) 4, and (B) 3.
   b. Compare the sharpness with which you observe the vegetated area concerning the previous visualizations.
4. **Generate an index.** Indices have been developed to visualize flowers (for application to canola crops and their yellow flowers), but they do not apply to this type of flowers. Instead, the Normalized Difference Infrared Index (NDII) measures

the water content of vegetation canopies and is more precise for detecting the area with plants in the desert.

a. Go to Customize (bottom left) and select **Index**. The formula for placing the bands will appear. Site A (place band B8) and at site B (place band B11) correspond to the following calculation:

NDII = (NIR – SWIR 1) / (NIR+ SWIR 1)

NDII (Sentinel 2) = (B8 – B11) / (B8 + B11)

b. Then, go to the **threshold** and select a color palette to colorize the image.

5. Make a presentation comparing the results in both blooms and of the desert without flowers.

What to do and how to do it

- ***Beginning***

Show your students the following videos: a) NASA Remasters Nearly 20 Years of Global Rain, b) *Climate Change Could Affect Global Agriculture Within 10 Years y c) Introduction to the Electromagnetic Spectrum* Also, the websites: a) Eyes on the Earth, b) Sentinel 2 Bands and Combinations

Then share ideas about the usefulness of satellite information for making decisions in daily life. Also, about the use of different waves of the electromagnetic spectrum to obtain information about the Earth.

- ***Development***

1. Ask students to read the introduction to this activity and make a concept map with the information. *(The introduction provides the basic fundamentals of remote sensing with links to further information or clarification.)*
2. Divide the class into groups and assign a case to each group to analyze.
   a. Look at the current satellite image on Google Maps. What do they see in that image (forest, desert, cities, roads, rivers, etc.)?
   b. Analyze the climogram of rainfall and temperature averages for that location.
   c. Look up the environmental conditions during the events analyzed and make a video in Worldview.
      i. *Note*: In WorldView, you can change the month and year at the lower left.
   d. Consult the EO Browser images and analyze the band combinations and indices. Use the combinations and indexes shown (if you wish, you can try different bands and analyze the display).
3. Ask your students to prepare a presentation on the analyzed case. They can make a story with maps (using ArcGIS StoryMaps), a slide presentation, or a video.
4. Bring all the groups together and ask them to explain the cases analyzed.
5. Complete the concept map with the main characteristics of each case analyzed.

- ***Closing***

Due to the relevance of both events, it is essential to develop dissemination materials. Students can elaborate a story with maps (Story Map), a video, or flyers to post on social networks summarizing the cases analyzed.

Frequently asked questions:

Where can I find satellite images? - Worldview - Google Earth - Google Map

Where do I find forest cover information? Global Forest Watch (GFW) has a wealth of information on forests.

Where do I find information on global environmental conditions and population? ResourceWatch brings together information from different sources.

Suggested Resources

As an extension of this activity, students can consult satellite images from different dates and locations to explore other sites of interest and even different events. You can use the GLOBE Program protocols to make manual measurements in your environment or download data from measurements made by others. You can also make environmental measurements to complement your research based on satellite imagery.

Websites:

- Esri. (2023) *Indices gallery.* ArcGIS Pro 3.0 https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/indices-gallery.htm
- GISGeography (2022) *Sentinel 2 Bands and Combinations.* https://gisgeography.com/sentinel-2-bands-combinations/
- NASA. (2023) Eyes on the Earth. https://eyes.nasa.gov/apps/earth/#/
- USGS (2021) *Common Landsat Band Combinations.* https://on.doi.gov/3wAKJvd
- USGS (2022) *What are the best Landsat spectral bands for use in my research?* https://on.doi.gov/3HEMdLf

Videos:

- NASA Climate Change (2021) *How NASA Satellites Help Model the Future of Climate*. Youtube: https://youtu.be/iAUFVUzZIhI
- NASA Climate Change. (2021) *NASA's Earth Minute: Dishing the Dirt.* Youtube: https://youtu.be/hgsIFyITvJE?si=zBZXPyvjRbi5wIvy
- NASA Climate Change. (2021) *NASA's Earth Minute: Earth Has a Fever.* Youtube: https://youtu.be/nAuv1R34BHA?si=AJHU9ZxNf6qDu2pj
- NASA Climate Change. (2021) *NASA's Earth Minute: Cloudy Forecast.* Youtube: https://youtu.be/UCVn_IODeys?si=jyecSHoKZHf-w0WK
- NASA Climate Change. (2021) *NASA's Earth Minute: Blowin' in the Wind.* Youtube: https://youtu.be/UCVn_IODeys?si=jyecSHoKZHf-w0WK
- NASA Climate Change. (2021) *NASA's Earth Minute: My Name is Aerosol.* Youtube: https://youtu.be/4eh6IKahbok?si=QISVr_NmynXoqWQm
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- NASA Climate Change. (2021) *NASA's Earth Minute: Gas Problem.* Youtube: https://youtu.be/K9kga9c0u2I?si=cRSJ8nkzkBaWvRSW

- NASA (2019) *Two Decades of Rain, Snowfall from NASA's Precipitation Missions*. https://youtu.be/qNlRQgACTFg?si=c95YgYXQ3yXQDb-P
- NASA en Español (2021) *Climate Change Could Affect Global Agriculture Within 10 Years*. Youtube: https://youtu.be/-NZIvvhGlR0?si=av2opPTE48KSuwCT
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- ScienceAtNASA (2011) *Tour of the Electromagnetic Spectrum. Introduction 1*. Youtube: https://youtu.be/lwfJPc-rSXw [Español. Traducido por: Antenas y Salud (2015) *El espectro electromagnético. Introducción 1*. Youtube: https://youtu.be/K-up0o96Vhw]

Other resources:

Tutoriales de: Worldview (short video, Complete video, Website, ideas for the classroom)
EO Browser (Website o video, infographic), Story Map

Traducción automática: Videos, Website

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