Remote sensing – Cities and agriculture

GLOBE		Related SDGs:	Type of activity
Sphere	**Protocols**		
Atmosphere	Air temperature. Surface temperature. Wind direction and speed. Rainfall. Relative humidity	11 (Sustainable cities and communities) 13 (Climate action) 15 (Life on land)	Exploratory
Biosphere	Land cover. Biometrics. Phenology		
Pedosphere	Soil characterization. Fertility. Humidity. pH. Temperature		
Package	Agriculture ENSO Soils Towns Meteorology		

Overview

The basic concepts of remote sensing are explained to analyze cities and crops with satellite images. Satellite images processed with a combination of bands and indices are used. In addition, students can try different combinations of bands and apply other specific indices to highlight some features.

Time

4 or 5 lessons

Prerequisites

Ability to interpret satellite images and maps. Ability to locate points using latitude and longitude.

School level

High school and college students

Purpose

Understand the application of wave properties, use satellite sensors and satellite images to obtain information from the Earth and process it 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 assigning the colors Red (R), Green (G), and Blue (B) to identify specific features in the field.
- Apply specific indexes to analyze information from satellite images.
- Analyze changes in land cover due to the growth of cities and crops.
- Analyze seasonal changes in cities and crops.

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.

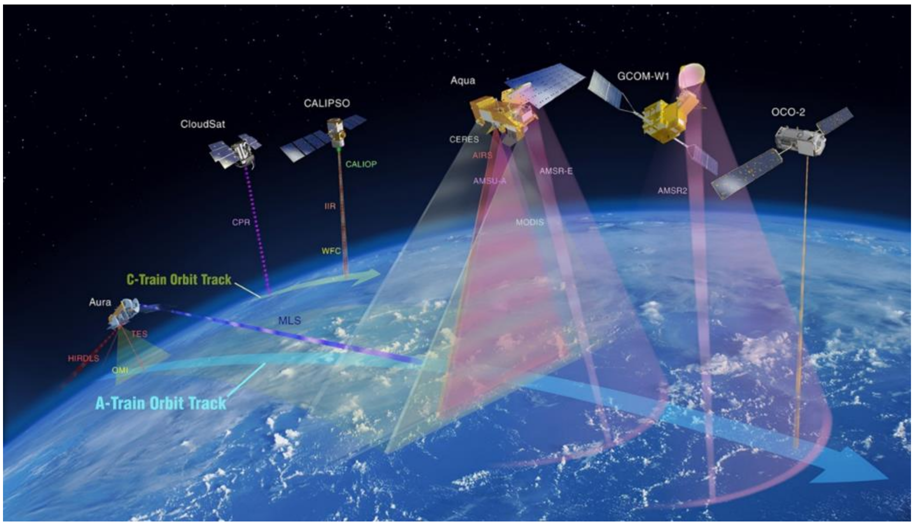

Fig. 2. International Afternoon Constellation. Source: https://atrain.nasa.gov/

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 reflects, 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.

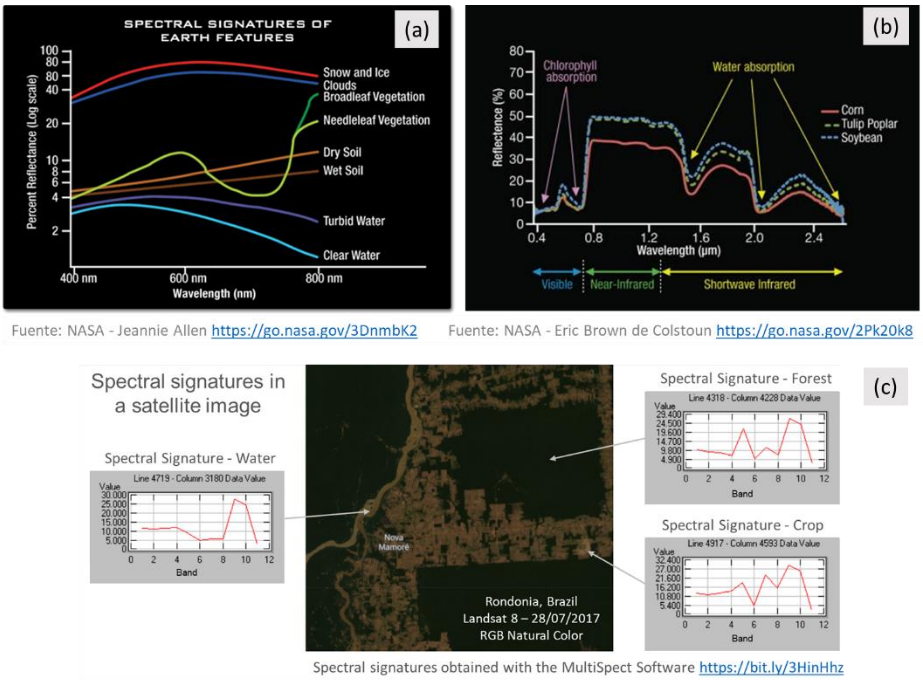

Fig. 3. Spectral signatures: (a) of different Earth features. (b) of vegetation. (c) Examples of spectral signatures in different pixels of the satellite image of Rondônia, taken by the Landsat 8 satellite on 27/07/17.

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).

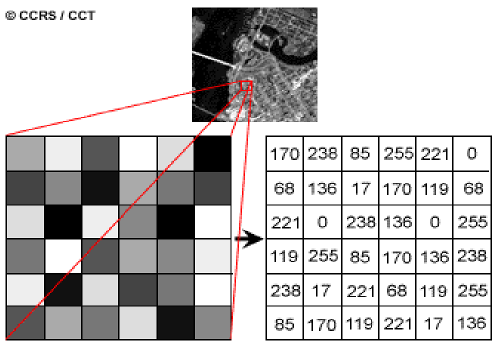

Fig. 4. Satellite image and numerical matrix of a Landsat 7 satellite image band. Each pixel (or square) represents a land area of 30m x 30m and a specific brightness color. Source: https://www.nrcan.gc.ca/

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)

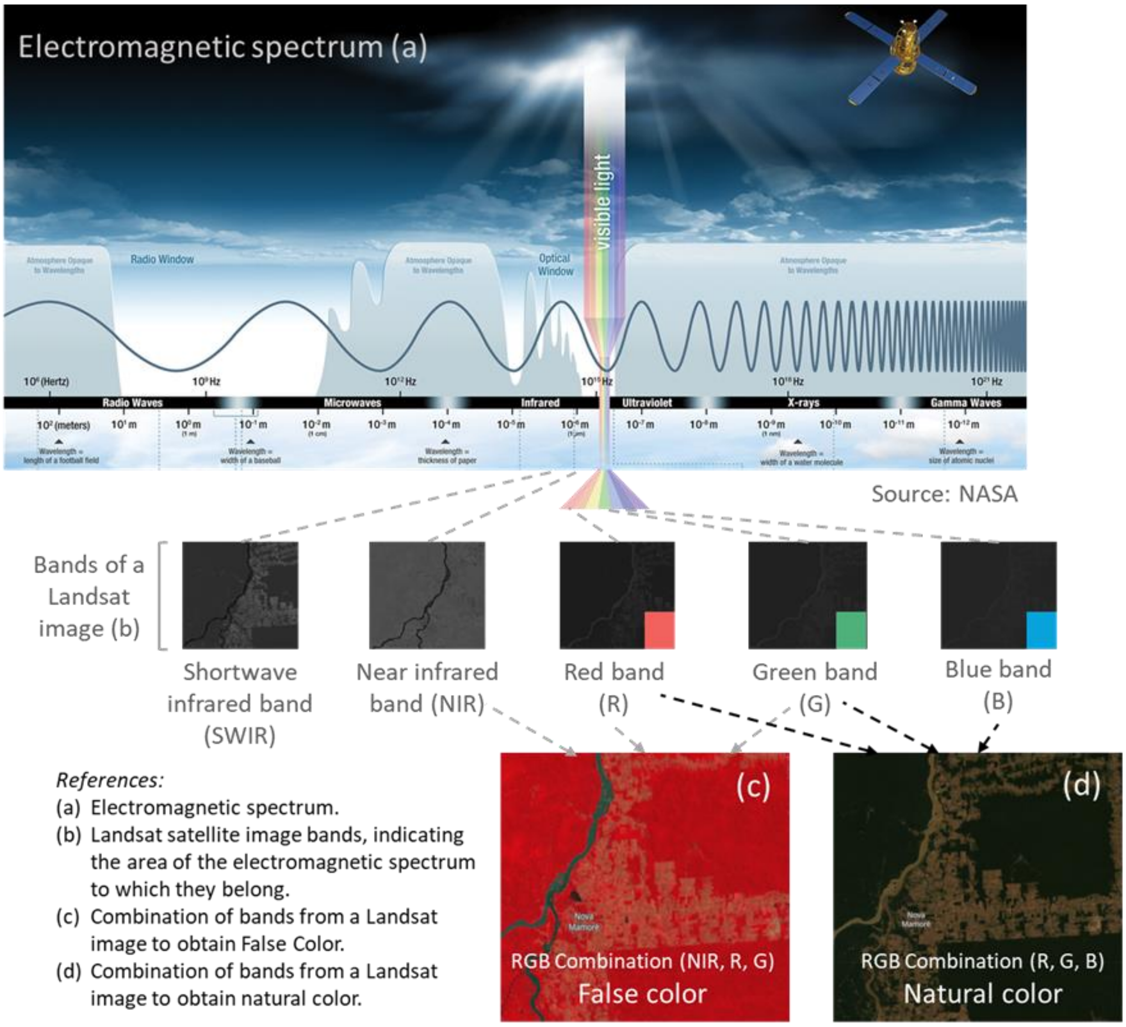

Fig. 5. Combination of Landsat satellite image bands to visualize various aspects. Sources: NASA and Landsat.

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.

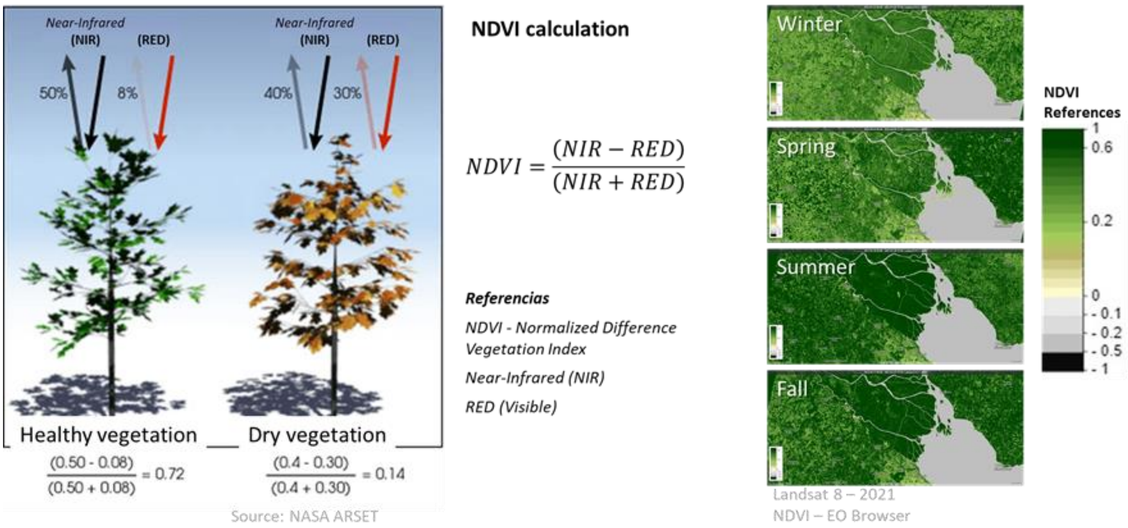

Fig. 6. Calculation and satellite images of the Paraná River Delta processed with the NDVI index. Seasonal changes in vegetation are detected with different color intensities.

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

- How has land cover changed due to the expansion of cities and crops?
- How can the proportion of green spaces in cities be analyzed through satellite images?
- What aspects of seasonal changes are easily identifiable through satellite imagery?
- How valid are band combinations and indices for analyzing satellite information?

Scientific concepts

- Ecosystems. Forests. Meadows. Deserts. Crops.
- Land cover
- Waves and the electromagnetic spectrum.
- Graphics. 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/

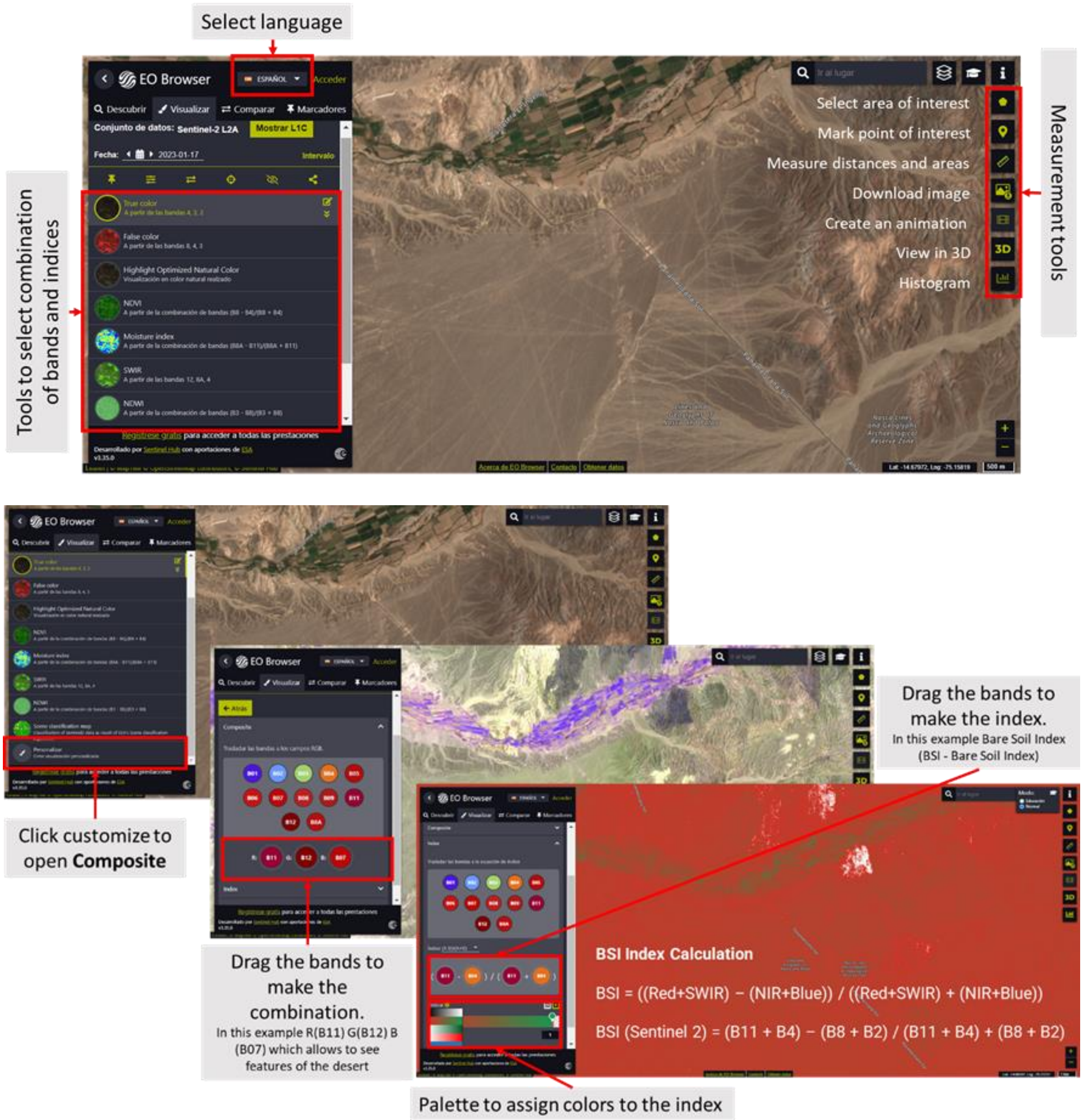

Fig. 7. Infographic of EO Browser App tools.

Case analysis:

Case 1: Urban growth. Cities of Asunción, Paraguay, and Clorinda, Argentina.

- Google Map - Location
- Climate graph Weather by Month of the average temperatures and rainfall.

Worldview

- Compare the growth of the cities of Asunción and Clorinda (between 1988 and 2022). Use the ruler (right, below the screen) to measure each city's distances and areas on different dates.
- Analyze the extent of both cities in 2022 (with night lights) and population density. Measure the areas with the highest population density.

- Download the most representative images of the data consulted.

EO Browser (see tools in Fig. 7):

1. Image Sentinel (1/12/2022): True Color, False color, False Color (Urban) ,
2. Sentinel Image (2022-06-12): True Color, False color, False Color (Urban)
   - Use the ruler (on the right of the screen) to measure distances and areas.

In EO Browser images, do the following:

1. See the images in actual color (True Color), and false color (False color) and False Color (Urban), and note the differences between the cities of Asunción and Clorinda. Compare both images (summer and winter)
2. Select the NDVI index (on the left of the screen) and then the histogram (on the right of the screen). Compare the results of the images. Measure the area of the cities, reselect the histogram, and compare the results.
   1. Do the same for NDMI (Moisture Index) and SWIR (to know the water present in vegetation and soil).
   2. Check the **histogram** (on the right of the screen), and open the menu of the index you are looking at (on the left) to see the reference of the colors. Analyze the histogram by comparing the values with those in the reference.
3. To make a new **combination of bands,** go to customize (left below) and select **composite**.
   1. Drag the bands to the circles to make the RGB combination: (R) 11, (G) 8, and (B) 3. Also, try the RGB combination: (R) 12, (G) 11, and (B) 4.
   2. Compare the sharpness with which you see vegetation cover concerning previous visualizations.
4. **Generate an index.** It is difficult to differentiate between urban areas, farmland, or bare soil, particularly in arid areas. For this reason, several indices have been developed. The Normalized Difference Tillage Index (**NDTI**) is sensitive to differences between buildings and farmland. Also, the indices of Normalized Built Difference - **NDBI** and the urban **UI.**
   1. Go to Customize (left below) and select **Index**. The formula for placing the bands appears.

      For NDTI at site A (locate band B11) and site B (locate band B12) corresponding to the following calculation:

      NDTI = (SWIR 1 – SWIR 2) / (SWIR 1 + SWIR 2)

      NDTI (Sentinel 2) = (B11 – B12) / (B11 + B12)

      For NDBI at site A (locate band B12) and site B (locate band B8) corresponding to the following calculation:

      NDBI = ((SWIR2-NIR) / (SWIR2+NIR))

      NDBI (Sentinel 2) = ((B12-8) / (B12+B8))

      For UI, at site A (locate band B11) and site B (locate band B8) corresponding to the following calculation:

(IU) = ((SWIR1-NIR) / (SWIR1 + NIR))

UI (Sentinel 2) = ((B11-B8) / (B11+B8))

1. In each index, go to the **threshold** and select a color palette to color the image.
2. Refer to the histogram on each index to compare the different indices.
3. Analyze which color scheme or index you can best visualize cities with.

5. Make a presentation comparing the results obtained in summer and winter for both cities.

<u>Case 2:</u> Analysis of agricultural fields in central Argentina.

- Google Map - Location
- Climate graph Weather by Month of the average temperatures and rainfall.

Worldview:

- Compare Landsat images (years 2001 and 2022). Use the ruler (right, below the screen) to measure each city's distances and areas on different dates.
- Analyze the sizes and shapes of the plots between the different years. Record the changes they observe.
- Download the most representative images of the data consulted.

EO Browser (see tools in Fig. 7):

1. Sentinel Image (2022-07-20): True Color and False color
2. Sentinel image (2022-12-02): True Color and False color
    - Use the ruler (on the right of the screen) to measure distances and areas.

In the images in EO Browser, do the following:

1. See images in True and False colors. Analyze changes between winter and summer.
2. Select the NDVI index (on the left of the screen) and then the histogram (on the right of the screen). Compare the results of the images. If you want to measure a specific area, you can draw the area and then select the histogram.
    1. Do the same for NDMI (Moisture Index), NDWI (to detect water bodies), and SWIR (to know the water present in vegetation and soil).
    2. Check the **histogram** (on the right of the screen), and open the menu of the index you are looking at (on the left) to see the reference of the colors. Analyze the histogram by comparing the values with those in the reference.
    3. You can draw an area and do the same analysis for that particular sector.

3. To do the **band combination,** go to customize (left below) and select **composite**.
    a. Drag the bands to the circles to make the merge to make the RGB combination: (R) 8A, (G) 11, and (B) 2.
    b. Compare the sharpness with which you observe the urban area and the vegetation for the previous visualizations.

4. **Generate an index**. There are many vegetation indices, some with greater complexity in the calculation. The best known and used is the NDVI, but other indices are also used to know other aspects of the crop (e.g., GNDVI has greater sensitivity to detect different chlorophyll concentration rates). Select the

NDVI index, the Green Normalized Difference Vegetation Index (**GNDVI**). Also, the indices: Modified Normalized Difference Water Index - **MNDWI (Normalized** Difference Water Index) and Normalized Burn Ratio - **NBR** (Calcination Index).

a. Go to Customize (left below) and select Index. The formula for placing the bands appears.
For GNDVI at site A (locate band B8) and site B (locate band B3) corresponding to the following calculation:

GNDVI = (NIR-GREEN) /(NIR+GREEN)

GNDVI (Sentinel 2) = (B8 – B3) / (B8 + B3)

For MNDWI at site A (locate band B3) and site B (locate band B11) corresponding to the following calculation:

MNDWI = (Green - SWIR) / (Green + SWIR)

MNDWI (Sentinel 2) = (B3 – B11) / (B3 + B11)

For NBR at site A (locate band B8) and site B (locate band B11) corresponding to the following calculation:

NBR = (NIR – SWIR) / (NIR + SWIR)

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

b. In each index, go to the **threshold** and select a color palette to color the image.
c. Refer to the histogram on each index to compare the different indices.
d. Analyze with which color combination or index you can best visualize the cities.

5. Make a presentation comparing the results of winter and summer in the crops. Also, compare the visualizations you get with the different indexes.

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 using different waves of the electromagnetic spectrum to obtain information about cities, crops, and other features of 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 expand the information or clarify aspects if necessary).*
2. Divide the class into groups and assign a case to each group for analysis.
   a. Look at the current satellite image on Google Maps. What do you see in that image (forest, desert, crops, cities, roads, rivers, etc.)?
   b. Analyze the climograph of the average rainfall and temperatures of that place.
   c. See the differences between old and 2022 images in Worldview. Measure distances and areas to establish differences.
      Note: In WorldView, you can change month and year, bottom left
   d. Check out EO Browser images from different seasons. Discuss band combinations and indexes. Use the combinations and indexes listed (you can try different bands and analyze the visualization if you wish).
3. Ask your students to give a presentation about the case under discussion. They can make a story with maps (ArcGIS StoryMaps), a slide show, or a video.
4. Gather all the groups 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 create a story with maps (Story Map), a video, or flyers to post on social networks summarizing the cases analyzed.

Frequently asked questions

- Where do I find satellite images? – Worldview – Google Earth – Google Map
- Where do I find information on global environmental conditions and population? ResourceWatch gathers information from different sources.

Suggested resources

As an extension of this activity, students can consult satellite images of different dates and places to explore other places 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 other people. You can also perform environmental measurements to complement research based on satellite images.

Websites

- UN-Habitat (2023) Earth Observations Toolkit for Sustainable Cities and Human Settlements. https://eotoolkit.unhabitat.org/
- NASA. (2023) Eyes on the Earth. https://eyes.nasa.gov/apps/earth/#/ (satellites that take images of Earth)
- USGS (2021) Common Landsat Band Combinations. https://on.doi.gov/3wAKJvd (Band combinations with Landsat images)

- USGS (2022) What are the best Landsat spectral bands for use in my research? https://on.doi.gov/3HEMdLf
- GISGeography (2022) Sentinel 2 Bands and Combinations. https://gisgeography.com/sentinel-2-bands-combinations/ (Band Combinations with Sentinel Imagery)

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=QlSVr_NmynXoqWQm
- NASA Climate Change. (2021) *NASA's Earth Minute: Mission to Earth?.* Youtube: https://youtu.be/R8hh_I3I9Ao?si=WBOWIpw23UkhyREB
- NASA Climate Change. (2021) *NASA's Earth Minute: Gas Problem.* Youtube: https://youtu.be/K9kga9c0u2I?si=cRSJ8nkzkBaWvRSW
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- ScienceAtNASA (2011) *Tour of the Electromagnetic Spectrum 5. Visible Light Waves*. Youtube: https://youtu.be/PMtC34pzKGc [Español. Traducido por: Dpto Electricidad Electrónica (2017) *El espectro electromagnético 5. Luz visible*. Youtube: https://youtu.be/BVbbkzygf94]
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Other resources:

- Data and maps of environmental conditions and crops by countries and agricultural production districts - NASA HARVEST – Earth data for informed agricultural decisions. https://cropmonitor.org/tools/agmet/
- Global expansion of cropland in the 21st century - Global Land Analysis & Discovery (GLAD) (2000 to 2019) https://bit.ly/3eKcooe
- Crop Explorer – Crop Explorer https://ipad.fas.usda.gov/cropexplorer/
- FAO Earth Observation Map (Environmental conditions and crops: Global and by country) https://www.fao.org/giews/earthobservation/index.jsp?lang=es
- Global Agricultural & Disaster Assessment System (GADAS) Map https://geo.fas.usda.gov/GADAS/
- Tutorials: Worldview (short video, Complete video, Website, ideas for the classroom) EO Browser (Website o video, infographic), Story Map
- Automatic translation: Videos, Website

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