Remote Sensing – Hydrosphere

GLOBE		**SDG Partner/s**	**Type of Activity/s**
Sphere	**Protocols**		
Atmosphere	Air temperature. Surface temperature. Wind direction and speed. Rainfall. Relative humidity	11 (Sustainable cities and communities) 13 (Climate action) 14 (Life below water) 15 (Life on land)	Exploratory
Biosphere	Land cover. Biometrics. Phenology		
Pedosphere	Soil characterization. Fertility. Humidity. pH. Temperature		
Hydrosphere	Water temperature. pH. Alkalinity. Electrical conductivity. Transparency. Salinity. Nitrates.		
Package	Agriculture Oceans Rivers and Lakes Soils Towns Water quality		

Overview

The basic concepts of remote sensing are explained to analyze satellite images of two cases: the turbidity of the water of the Río de La Plata at its mouth in the sea and the melting of the HPS-12 glacier in Chile. 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 indices to analyze different features in satellite images.
- Analyze the variations of turbidity of the water at the mouth of the La Plata River.
- Analyze the rate of melting of the HPS-12 glacier in Chile.

Background

Remote Sensors

Remote sensing is acquiring information remotely using remote sensors. A camera is a sensor that allows us to obtain information from objects at a distance. Our eyes are sensors that enable us to obtain information from our environment. To study the Earth, sensors are placed on satellites, the International Space Station, airplanes, drones, etc. Fig. 1.

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

Remote sensors provide a global perspective and a large amount of data from the atmosphere, hydrosphere, pedosphere, and biosphere that allow us to know the current state, study trends with historical information (e.g., Record of 20 years 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 collaborative group of satellites from different countries that travel 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 Evening Constellation). This constellation of satellites makes almost simultaneous observations with a wide variety of sensors that are very useful for conducting research, issuing alerts, making decisions, etc. Fig. 2.

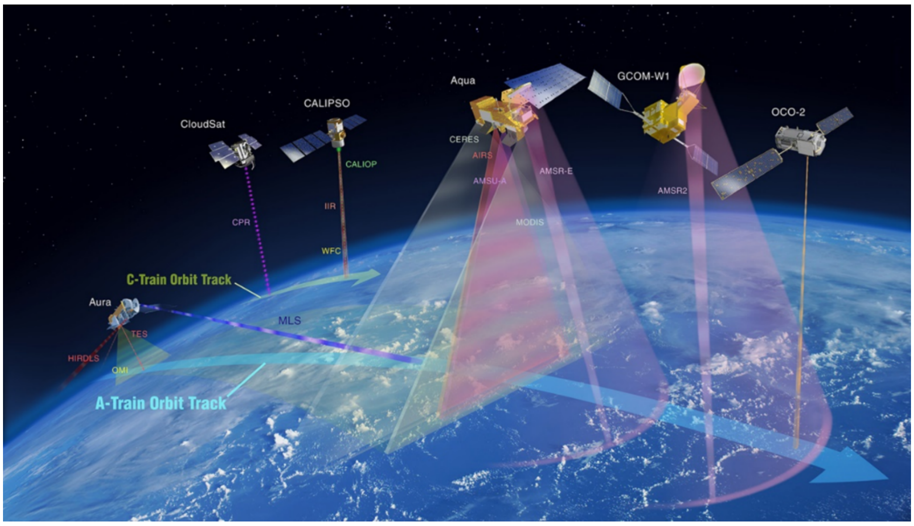

Fig. 2. International Afternoon Constellation. Source: https://atrain.nasa.gov/

Some sensors are passive; that is, they detect the electromagnetic waves reflected by the earth's surface when illuminated by the sun or when it emits light (e.g., the night lights of cities). Most passive sensors operate in the electromagnetic spectrum's visible, infrared, and microwave portions. Passive sensors measure land and sea surface temperature, vegetation properties, clouds, 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 vertical aerosol 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. Albedo is the property of anybody to reflect incident radiation. For example, snow is a transparent 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, absorb, or transmit varies depending on the wavelength.

Spectral bands and signatures

As the reflected energy varies 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, state of vegetation, etc.). Fig. 3.

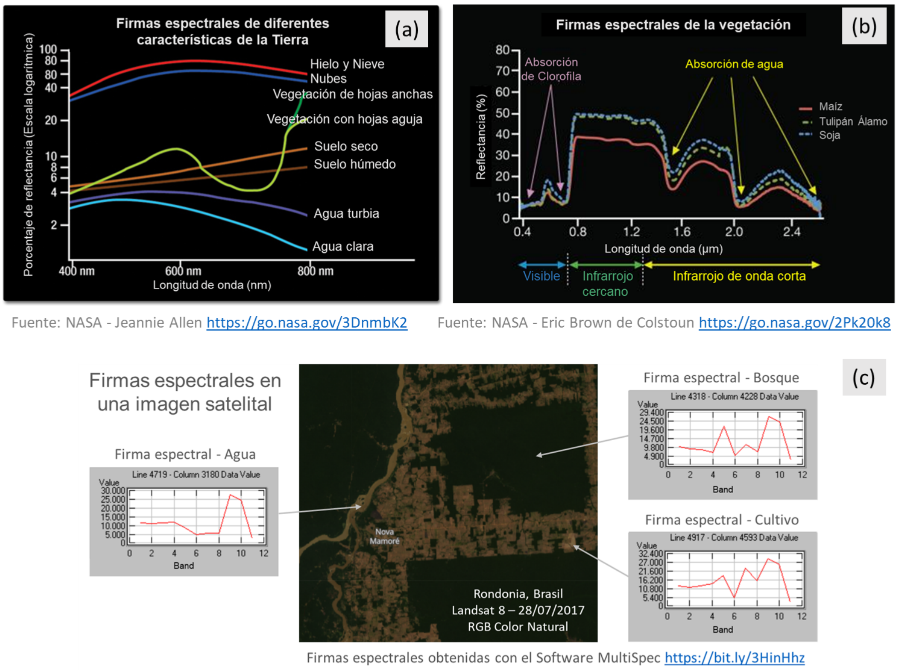

Fig. 3. Spectral signatures: (a) of different characteristics of the Earth. (b) vegetation. (c) Examples of spectral signatures in different pixels of the satellite image of Rondônia, taken by the Landsat 8 satellite on 07/27/17.

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

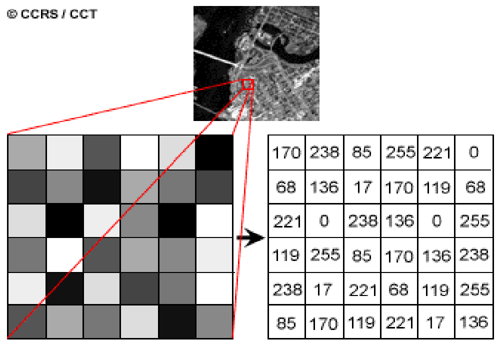

Fig. 4. Satellite image and numerical matrix of a Landsat 7 satellite image band. Each pixel (or frame) represents a terrain area of 30m x 30m and a certain brightness color. Source: https://www.nrcan.gc.ca/

Each satellite image has multiple bands representing different electromagnetic spectrum wavelengths [Fig. 5 (a)]. The sensors on most satellites use everything from infrared to ultraviolet, including visible light. The bands represent data from visible regions and infrared (shortwave infrared, near-infrared, and mid-infrared). [Fig. 5 (b)] When We combine the bands in an RGB image to obtain a color similar to the natural one, we are working with three matrices, one per color channel: Red (Red), Green (Green), and Blue (Blue). [Fig. 5

(d)] As with grayscale images, 0 represents the absolute absence of color, and 255 represents the total presence of hue for 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 others in wavelengths that our eyes do not perceive. [Fig. 5 (c)]

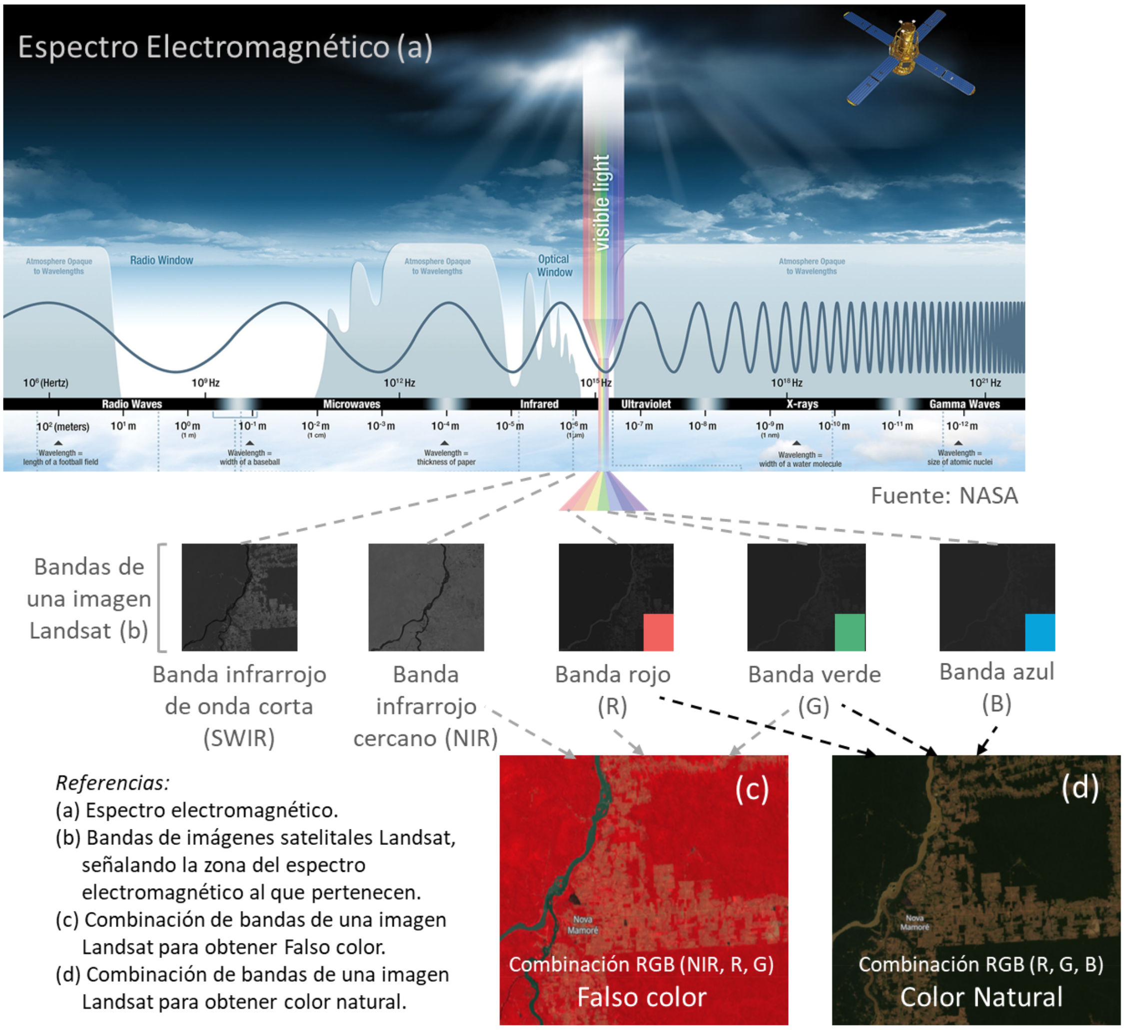

Fig. 5. Combination of bands of Landsat satellite imagery to visualize different aspects. Sources: NASA and Landsat.

Indexes

As satellite images are matrices, it is possible to perform calculations with them to detect other elements not visible with the color scheme. The indices are obtained from calculations with the matrices that form each band of the satellite images. This calculation is performed using some specific software, and as a result, a new image is obtained where the pixels related to the parameter we are measuring are graphically highlighted. The vegetation indices emphasize vegetation cover parameters: 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 widely used, but several similar indices exist. The NDVI allows estimating vegetation quantity, quality, and development based on measuring the intensity of radiation from some bands of the electromagnetic spectrum that vegetation emits or reflects. The bands vary according to the type of satellite. Some viewers automatically generate the most common indexes. High NDVI values indicate healthy vegetation; low values indicate that vegetation is drying out (may be due to water stress, disease, fire, etc.). Fig. 6.

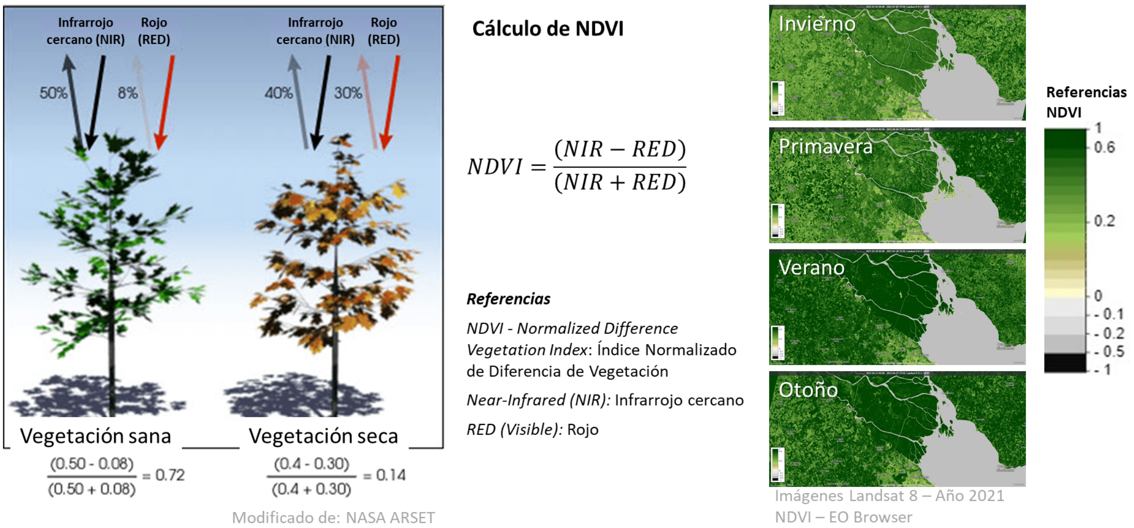

Fig. 6. Calculation and satellite images of the Paraná River Delta processed with the NDVI index. Seasonal changes in vegetation are detected with different color intensities.

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

Guiding Research Questions

- Why does water turbidity vary throughout the year? Is it related to rainfall and temperature?
- What are the causes of glacier melt? What are the consequences?
- Why do you use different combinations of bands and specific indices to visualize some land cover characteristics?

Scientific concepts

- Ecosystems. Rivers. Lakes. Glaciers
- Land coverage.
- 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/

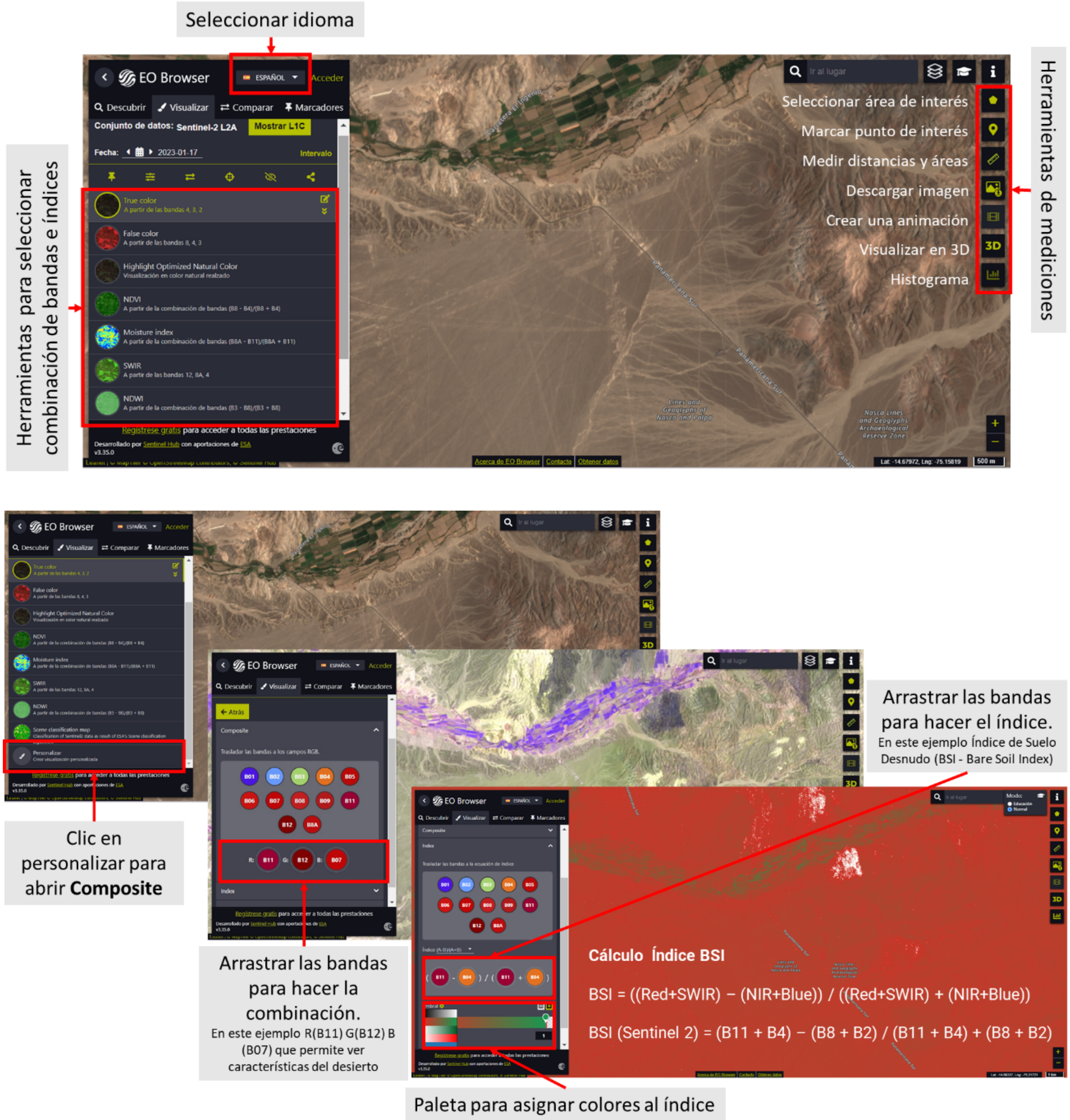

Fig. 7. Infographic of EO Browser App tools.

Case analysis:

<u>Case 1</u>: Turbidity at the mouth [of the Río de la Plata](#).

- Google Map - [Location](#)

Worldview

- Compare images from 2000 and 2022
- Seasonal turbidity (July and December)
- Environmental conditions. a) Average monthly rainfall, b) Temperature of the earth's surface, and c) Water temperature
- . Generate a video in Worldview with each data group queried.

EO Browser (see tools in Fig. 7):

1. Sentinel image 13/08/22: False color, True color
2. Sentinel Image 06/12/22: False color, True color
    - Use the ruler (on the right of the screen) to measure the dispersion of sediments from the mouth to the sea. Also, measure the area of sediment in the sea.

In EO Browser images, do the following:

1. See false-color images and analyze seasonal changes.
2. Select Highlight Optimized Natural Color (on the left of the screen) and compare with false color images. (Consider that sedum. ent albedo is higher at visible wavelengths.)
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) 3, (G) 4, and (B) 8.
    2. Compare the sharpness with which you observe the discharge of sediment from the river concerning previous visualizations.
4. **Generate an index.** To improve the analysis, use the Normalized Difference Turbidity Index (NDTI), which is sensitive to changes in the turbidity of water bodies.
    1. Go to Customize (left below) and select **Index**. The formula for placing the bands appears. At site A (locate band B4) and site B (locate band B3), corresponding to the following calculation:

    $$NDTI = (RED – GREEN) / (RED + GREEN)$$

    $$NDTI\ (Sentinel\ 2) = (B4 – B3) / (B4 + B3)$$

    b. Then go to the **threshold** and select a color palette for the image.
    c. Refer to 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.
    d. You can draw an area and do the same analysis for that particular sector.
    e. Go to the ruler and measure the area with sediment in each image.
5. Make a presentation by comparing the results of both images

Case 2: HPS-12 Glacier Melting Analysis

- Google Map - Location
- Climate graph // Weather by Month of the average temperatures and rainfall. (Optional: Map of the World's glaciers and watersheds)

Worldview:

1. Compare images from 1985 and 2021.
    - Select the ruler (bottom right) and measure the distance the glacier retreated in the 2021 image.
    - Select the area (bottom right) and measure the melted ice surface.
    - They can change year and month to measure melting in other periods.
2. Download the most representative images or generate a video in Worldview with the analyzed data.

EO Browser (see tools in Fig. 7)

1. Sentinel-2 Image: February 2020 - True Color and False Color
2. Sentinel-2 Image: February 2021 - True Color and False Color
3. Sentinel-2 Image: February 2022 - True Color and False Color

In EO Browser images do the following:

1. See images from different years and analyze changes.
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**.
    1. Drag the bands to the circles to make the merge to make the RGB combination: (R) 11, (G) 8, and (B) 4.
    2. Compare the sharpness with which you observe the vegetated area for previous visualizations.
4. **Generate an index**. It is difficult to differentiate between clouds, snow, and ice. Indexes have been developed to visualize the different coverages; in this case, they are of interest (**NDGI**) Normalized Difference Glacier Index and **(NDSII)** Normalized Difference Snow Ice Index. Both indices are used to detect glaciers and monitor their changes.
    1. Go to Customize (left below) and select **Index**. The formula for placing the bands appears.

        For the NDGI (Normalized Difference Glacier Index), at site A (locate band B3) and at site B (locate band B4) corresponding to the following calculation:

        NDGI = (GREEN – RED) / (GREEN + RED)

        NDGI (Sentinel 2) = (B3 – B4) / (B3 + B4)

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

For NDSII (Normalized Difference Snow Ice Index), at site A (locate band B3) and at site B (locate band B8) corresponding to the following calculation:

NDSII = (GREEN – NIR) / (GREEN + NIR)

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

c. Then go to the **threshold** and select a color palette for the image.
d. For both indices, refer to the histogram (on the right of the screen), and open the menu of the index you are looking at (on the left of the screen) to see the reference of the colors. Analyze the histogram by comparing the values with those in the reference.
e. You can draw an area and do the same analysis for that particular sector.

5. Make a presentation comparing the results of the visualizations generated for the different years analyzed.

What to do and how to do it

- ***Beginning***

Show your students the following videos: a) NASA: Mission to Earth, b) NASA shows two decades of snow and rain, and c) The electromagnetic spectrum. Introduction. Brainstorm how satellite technology studies the Earth and monitors its changes.

- ***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, glacial lakes, ice fields, etc.)?
   b. Analyze the rainfall and temperatures of that place.
   c. Analyze the event in Worldview and make a video or download the most representative images.
      Note: In WorldView, you can change month and year, bottom left
   d. Consult the EO Browser images, and analyze the banding combinations and indexes. Use the combinations and indexes indicated (if you wish, you can try different bands and analyze the visualization).
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 important 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 sites of interest and even different events. You can use GLOBE Program protocols to perform manual measurements in your environment or download data from measurements made by others. It can also perform environmental measurements to complement research based on satellite imagery.

Websites

- NASA. (2023) Eyes on the Earth. https://eyes.nasa.gov/apps/earth/#/ (satellites that take images of the 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 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 images)

Videos:

- NASA Climate Change (2021) *How NASA Satellites Help Model the Future of Climate*. Youtube: https://youtu.be/iAUFVUzZIhI
- NASA Climate Change. (2021) *NASA: La humedad de la Tierra.* Youtube: https://youtu.be/YPgmdRYrvjU
- NASA Climate Change. (2021) *NASA: La Tierra tiene fiebre.* Youtube: https://youtu.be/R5RcCc3qWMY
- NASA Climate Change. (2021) *NASA: Las nubes.* Youtube: https://youtu.be/R5YYdEATivg
- NASA Climate Change. (2021) *NASA: Los vientos oceánicos.* Youtube: https://youtu.be/MJSaIFY0CsE
- NASA Climate Change. (2021) *NASA: Me llamo Aerosol.* Youtube: https://youtu.be/Dr4Dkm1Ud1E
- NASA Climate Change. (2021) *NASA: Misión a la Tierra.* Youtube: https://youtu.be/M0HHZ9vRlpk
- NASA Climate Change. (2021) *NASA: Problema de gas.* Youtube: https://youtu.be/4ZvAEQLWDTs

- NASA en Español (2020) *La NASA muestra dos décadas de nieve y lluvia*. Youtube: https://youtu.be/HVxosovHInw
- ScienceAtNASA (2011) *Tour of the Electromagnetic Spectrum 3. Microwaves*. Youtube: https://youtu.be/UZeBzTI5Omk [Español. Traducido por: Antenas y Salud (2015) *El espectro electromagnético 3. Microondas*. Youtube: https://youtu.be/OCxFv_KDdZE]
- ScienceAtNASA (2011) *Tour of the Electromagnetic Spectrum 4. Infrared Waves*. Youtube: https://youtu.be/i8caGm9Fmh0 [Español. Traducido por: Dpto. Electricidad Electrónica (2017) *El espectro electromagnético 4. Infrarrojo*. Youtube: https://youtu.be/DgZKWfRRxKw]
- 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]
- ScienceAtNASA (2011) *Tour of the Electromagnetic Spectrum 6. Ultraviolet Waves*. Youtube: https://youtu.be/QW5zeVy8aE0 [Español. Traducido por: Eldador (2011) *El espectro electromagnético 6. Luz ultravioleta*. Youtube: https://youtu.be/IOKEbZgB2lI]
- 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 (video corto, video completo, sitio web, ideas para el aula) EO Browser (sitio web o video, infografía) , Story Map

Traducción automática: Videos, Sitios web

Bibliography

Brown, C. & Harder, C. (Ed.). (2016). *The ArcGIS® Imagery Book: New View, New Vision*. Esri Press. https://bit.ly/3YocWRP

Carvalho Resende, T., Stepanov, M., Bosson, J. B., Emslie-Smith, M., Farinotti, D., Hugonnet, R., ... & Berthier, E. (2022). *World Heritage Glaciers: Sentinels of Climate Change*. ETH Zurich. https://unesdoc.unesco.org/ark:/48223/pf0000383551

CIC (2022) *Comité Intergubernamental Coordinador de los Países de la Cuenca del Plata*. https://cicplata.org/es/

di Natale, J. (2022) *Todo tiene un porqué, en el Río de la Plata.* Centro de Investigaciones del Mar y la Atmósfera. CIMA, CONICET, UBA. http://www.cima.fcen.uba.ar/reportaje.php?n=15

Dogliotti, A. I., Ruddick, K., & Guerrero, R. (2016). Seasonal and inter-annual turbidity variability in the Río de la Plata from 15 years of MODIS: El Niño dilution effect. *Estuarine, Coastal and Shelf Science*, *182*, 27-39. https://www.sciencedirect.com/science/article/pii/S0272771416303729

Esri. (2023) *Galería de índices.* ArcGIS Pro 3.0 https://bit.ly/3DCLg3W

Gibbens, S. (2017) *One of Earth's driest places experiences rare flower boom.* National Geographic. https://on.natgeo.com/40hF0rO

GIS en territorio (2023) *Cuencas hidrográficas*. https://bit.ly/3jlOi5u

GISGeography (2022) *100 Earth Shattering Remote Sensing Applications & Uses*. https://gisgeography.com/remote-sensing-applications/

GISGeography (2022) *Spectral Signature Cheatsheet – Spectral Bands in Remote Sensing*. https://gisgeography.com/spectral-signature/

GISGeography (2023) *What is Remote Sensing? The Definitive Guide*. https://gisgeography.com/remote-sensing-earth-observation-guide/

GLIMS and NSIDC (2005, updated 2018): *Global Land Ice Measurements from Space glacier database.* Compiled and made available by the international GLIMS community and the National Snow and Ice Data Center, Boulder CO, U.S.A. https://www.glims.org/ - https://www.glims.org/maps/glims

Harder, C., & Brown, C. (2017). *The ArcGIS book: 10 big ideas about applying the science of where*. Esri Press. https://bit.ly/3HWGrF7

INA (2022) *Sedimentos en la Cuenca del Plata. Dinámica de Sedimentos en la Cuenca del Plata en el contexto de Cambio Climático.* Proyecto Claris. https://www.ina.gov.ar/lha/index.php?seccion=16

Mehta, A., Schmidt, C. Kuss, A. and Palacios, S. L. (2022) *Fundamentals of Remote Sensing.* NASA Applied Remote Sensing Training Program (ARSET). https://go.nasa.gov/3WLt12K

Morales, A. (2017) *16 programas gratuitos para trabajar con imágenes de satélite.* MappingGIS https://bit.ly/3XLGJUL

NASA Earth Observatory (2000 to 2022) *Snow Cover*. Global Maps. https://go.nasa.gov/3JGtjoN

NASA Earth Observatory (2012) *Sediment in the Río de La Plata*. https://go.nasa.gov/3Dzy5AC

NASA Earth Observatory (2014) *Why is that Forest Red and that Cloud Blue? How to Interpret a False-Color Satellite Image*. https://go.nasa.gov/3Hfov75

NASA Earth Observatory (2018) *Melting Beauty: The Icefields of Patagonia*. https://go.nasa.gov/3EsBfaL

NASA Earth Observatory (2019) *Is HPS-12 the Fastest Thinning Glacier?* https://go.nasa.gov/3ejpdWq

NASA EarthData (2023) *Data Pathfinders.* https://go.nasa.gov/3HFmnGW

NASA Science (2023) *Tour of the Electromagnetic Spectrum*. https://science.nasa.gov/ems/

NASA, Science Mission Directorate. (2010). *Anatomy of an Electromagnetic Wave*. NASA Science website: http://science.nasa.gov/ems/02_anatomy

NASA, Science Mission Directorate. (2010). *Infrared Waves*. NASA Science website: http://science.nasa.gov/ems/07_infraredwaves

NASA, Science Mission Directorate. (2010). *Introduction to the Electromagnetic Spectrum*. NASA Science website: http://science.nasa.gov/ems/01_intro

NASA, Science Mission Directorate. (2010). *Reflected Near-Infrared Waves.* NASA Science website: http://science.nasa.gov/ems/08_nearinfraredwaves

NASA, Science Mission Directorate. (2010). *Reflected Near-Infrared Waves.* NASA Science website: http://science.nasa.gov/ems/08_nearinfraredwaves

NASA, Science Mission Directorate. (2010). *The Earth's Radiation Budget.* NASA Science website: http://science.nasa.gov/ems/13_radiationbudget

NASA, Science Mission Directorate. (2010). *Ultraviolet Waves.* NASA Science website: http://science.nasa.gov/ems/10_ultravioletwaves

NASA, Science Mission Directorate. (2010). *Visible Light.* NASA Science website: http://science.nasa.gov/ems/09_visiblelight

NASA, Science Mission Directorate. (2010). *Visualizations: From Energy to Image*. NASA Science website: http://science.nasa.gov/ems/04_energytoimage

NASA, Science Mission Directorate. (2010). *Wave Behaviors*. NASA Science website: http://science.nasa.gov/ems/03_behaviors

NASA. Earth Data. (2023) *What is Remote Sensing?* https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing

Odenwald, S. (2012) *Remote Sensing Math*. NASA Goddard Spaceflight Center. https://www.nasa.gov/pdf/637834main_Remote_Sensing_Math.pdf

Odenwald, S. (2015) *Earth Math.* Space Math. NASA Goddard Spaceflight Center. https://www.nasa.gov/sites/default/files/files/Earth_Math_2015.pdf

Palacios, S. (2020) *Fundamentals of Aquatic Remote Sensing.* NASA Applied Remote Sensing Training Program (ARSET). https://go.nasa.gov/3RkRUBe

Pelto, M. (2017) *HPS-12, Chile Spectacular 13 km retreat 1985-2017.* AGU Blogosphere. https://bit.ly/3YkpJVk

Schoolmeester, T., Johansen, K.S., Alfthan, B., Baker, E., Hesping, M. y Verbist, K. (2018). *Atlas de Glaciares y Aguas Andinos. El impacto del retroceso de los glaciares sobre los recursos hídricos.* UNESCO y GRID-Arendal. https://unesdoc.unesco.org/ark:/48223/pf0000266209

The GLOBE Program (2022) *GLOBE Protocol Bundles.* https://www.globe.gov/es/web/earth-systems/

The IDB Project (2023) *List of available Indices*. Index DataBase. A database for remote sensing índices. https://www.indexdatabase.de/db/i.php?&order=-rcount

WGMS (2021). *Global Glacier Change Bulletin No. 4 (2018–2019).* Zemp, M., Nussbaumer, S.U., Gärtner-Roer, I., Bannwart, J., Paul, F., and Hoelzle, M. (eds.), ISC(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland. https://wgms.ch/downloads/WGMS_GGCB_04.pdf