Glacier Retreat

GLOBE		Associated SDG	Type of Activity
Spheres	**Associated Protocols**		
Atmosphere	Air temperature. Surface Temperature. Clouds. Precipitation.	6 (Clean Water and Sanitation) 13 (Climate Action) 14 (Life Below Water) 15 (Life on Land)	Exploratory
Biosphere	Land Cover.		
Pedosphere	Soil Moisture. Soil temperature. Frost Tube		
Hydrosphere	Water temperature. pH. Alkalinity. Electrical conductivity. Water Transparency. Salinity. Nitrates.		
Bundle	Water Cycle. Water Quality. Rivers and Lakes.		

Overview

Satellite images and maps are analyzed to determine glacier fluctuations over the last 20 years or more. Glaciers and fluctuations are located, and the impacts of temperature increase on glacier extent and new lake formation are compared.

Time

4 or 5 classes

Prerequisites

Basic knowledge of ecosystems, meteorology and ICT. Ability to interpret satellite images and maps. Ability to locate points using latitude and longitude.

School Level

Upper Primary School, High School and University students

Purpose

To understand the impact of ice loss on glaciers and the changes in the interrelationship among the spheres of the Earth System

Student Outcomes

LEARNING ACTIVITY

- To compare satellite data on snow cover, net radiation, Earth's surface temperature and cloud fraction to establish relationships.
- To analyze cases of glacier cover changes, the formation of new water bodies due to ice melting and their impact on ecosystems and human activities.
- To consider the impact of human activities on climate change and glacier retreat.
- To outline hypotheses of possible consequences on human activities from the disappearance of glaciers in some regions.

Background

Low temperatures and snow precipitations are essential for the formation and maintenance of glaciers. The largest ice sheets are located in the poles and are important for their influence on climate regulation and their contribution to changes in sea level. In the Andes, glaciers are found above the snow line, where cold temperatures maintain the ice all year round. Glaciers are considered sensitive indicators of climate change because they respond quickly to changes in temperature and precipitation. The WMO (World Meteorological Organization) report on the "2021 *State of the Climate in Latin America and the Caribbean*" notes that warming is accelerating in the region and precipitation patterns are changing. As a result, The Andes glaciers have lost much of their mass and are in retreat. The WGMS (World Glacier Monitoring Service) monitors some of the world's benchmark glaciers and documents the fluctuations. The rapid retreat of tropical glaciers is considered one of the most visible indicators of global warming. The degree of glacier retreat varies, but small glaciers are more vulnerable. Many of the Andean glaciers have already disappeared and this situation increases the risk of water scarcity for populations, production, hydroelectricity generation and ecosystems.

The formation of glaciers depends on latitude, altitude and annual precipitation. As snow accumulates, it compresses the snow already deposited and creates a dense layer, called firn. If snow continues to accumulate, the pressure increases and the firn becomes more compact until it becomes solid glacier ice that begins to flow by the effect of the force of gravity on its own mass, or by sliding or internal deformation. Glaciers have an upper accumulation zone, where the snow mass is deposited, and a lower ablation zone, where the glacier mass is lost. The ablation process can occur by melting, erosion, wind, and frontal sliding. The area between the zones where accumulation equals ablation is called the equilibrium line, the area that marks the boundary between new snow and old snow that is exposed after melting. When periods of greater ablation or greater snow accumulation occur, this equilibrium disappears and the glacier can advance or retreat.

The albedo is the ability of surfaces to reflect solar radiation. Glaciers influence the global climate because their reflective capacity of ice and snow is important for regulating the temperature in the atmosphere. Dark surfaces have a low albedo, absorb more energy and warm up. White surfaces, such as snow, have a higher albedo and reflect much of the sun's energy back into space.

The high albedo of the snow keeps the surfaces cold, but as the glaciers shrink, the dark ground that absorbs radiation is exposed, causing warming and further enhancing the melting of the surrounding snow. Soot particles, also known as black carbon, travel long distances and are often deposited on glaciers, darkening their surface and causing further melting. This phenomenon is more frequent in glaciers that are relatively close to large cities.

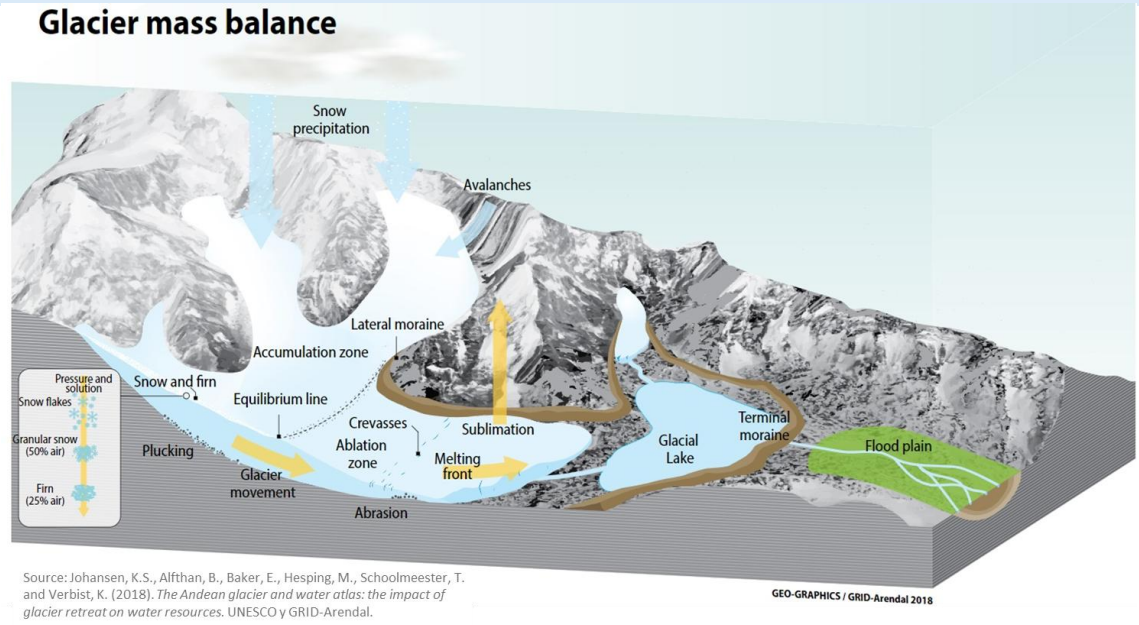

Fig. 1. Snow accumulation and ablation zones on a glacier.

Glaciers provide water to most of the large rivers in South America. The headwaters of the great basins in the high areas of the Andes usually receive more precipitation than the plains. In addition, glaciers and snow-covered areas constitute a significant reserve of water that is released during snowmelt and are particularly important in regions with large seasonal variations and low levels of precipitation.

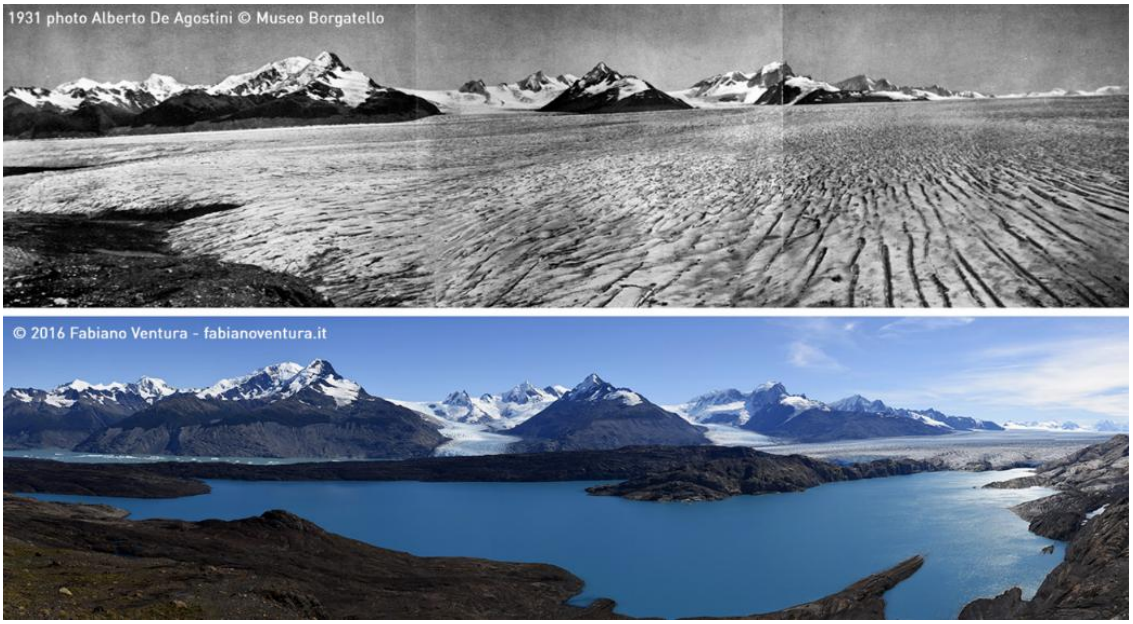

Fig. 2. Comparison of photographs of Upsala Glacier, Argentina taken in 1931 and 2016.

Glacier retreat can be quantified by comparing old photographs with current ones as in Figure 2, and also by satellite imagery, as shown in Figure 3.

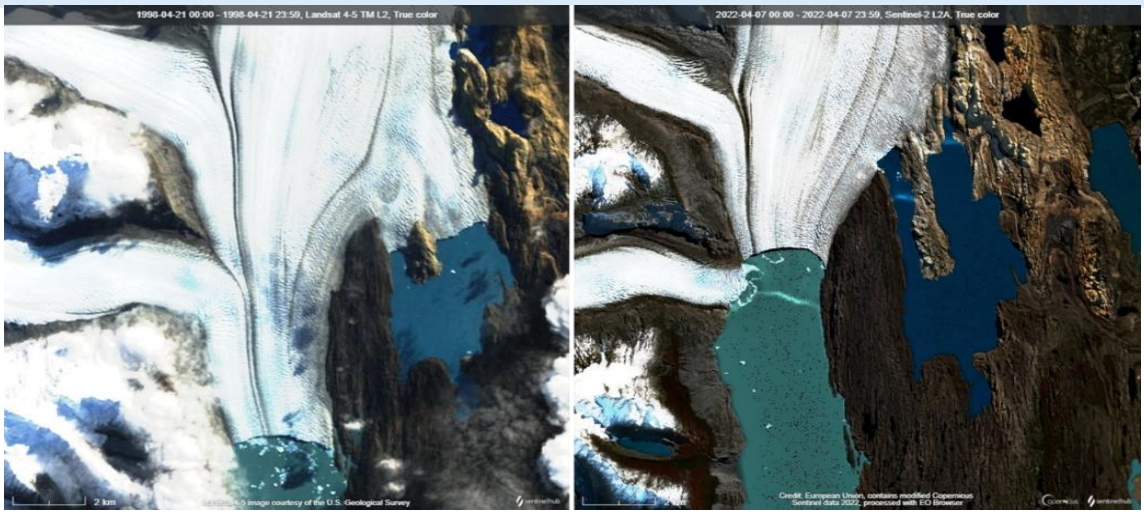

Fig. 3. Satellite images of the Upsala Glacier in Argentina. The recent Sentinel-2 L2A image from April 2022 (right) shows ice loss at the glacier front and edges when compared to the Landsat 4-5 TM L2 image from April 1998 (left).

The loss of ice causes river levels to decrease and increases the risk of drought. Where river flows have been documented over long periods of time, these trends can be observed.

To assess the condition of a glacier, glaciologists measure the annual mass balance which is the result of the snow accumulation (mass gain) and melting (mass loss) during a given year. The mass balance reflects the atmospheric conditions during a hydrological year. By measuring the mass balance over a long period, it is possible to observe trends.

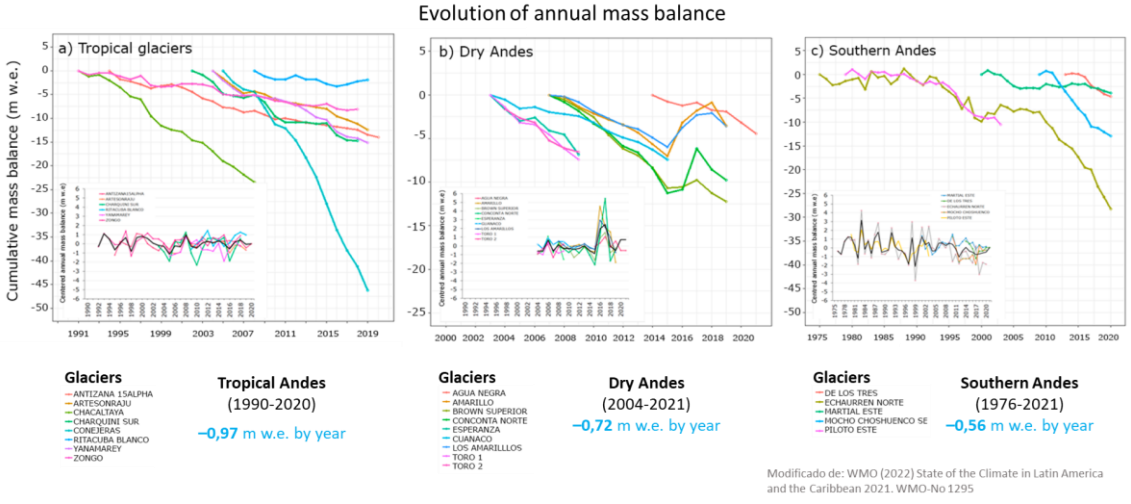

Fig. 4. Decrease in the annual mass balance of Andean glaciers.

Figure 4 shows the ice mass trends in recent years in the Andes region by the World Glacier Monitoring Service (WGMS). Glaciers in the tropical Andes have lost -0.97 (meters of water equivalent) between 1990 and 2020. Analyses using satellite imagery show significant reductions in glacier area in recent decades. The Dry Andes and the Southern Andes also show the same trend of retreat. In the future, glaciers throughout the Andes are expected to continue to retreat and the resulting hydrological changes will impact communities and ecosystems. Therefore, knowing and monitoring changes in ice cover is the first step in understanding and designing mitigation measures for impacts.

Guiding Research Questions

- How does the extent of glaciers change?
- What kind of changes are observed?
- Are there new lakes around the glaciers?
- To which watersheds do the glaciers you are studying contribute water?
- What is the relationship among temperature, precipitation and the formation of an ice cover?
- What is the impact of changes in ice cover on ecosystems and people's lives?
- What human activities impact glaciers on a large scale?
- How can changes in the cryosphere be measured?

Scientific Concepts

- Ecosystems
- Cryosphere
- Land Cover
- Electromagnetic Spectrum
- Satellite Images - False Color Composite

Materials and Tools

- ArcGIS StoryMaps https://storymaps.arcgis.com/
- Global maps - Records of the last few years:
    1. Snow cover - https://go.nasa.gov/3fYZPFQ
    2. Net radiation received by the Earth's surface - https://go.nasa.gov/2T2EwDJ
    3. Earth's surface temperature - https://go.nasa.gov/3rQKN7T
    4. Fraction of clouds that regulate the Earth's temperature - https://go.nasa.gov/2JavOOV
- Cases of changes in some glaciers:

Case 1. Glaciers of the Sierra Nevada del Cocuy, Colombia:

1. Google Map - Location
2. Google Earth (Sequence 1985 to 2020)
3. Wordview (comparison 1986 and 2021)
4. EO Browser - (seasonal changes): January - August

Case 2. Quelccaya Glacier, Peru:

5. Google Map - Location
6. Google Earth (Sequence 1985 to 2020)
7. Wordview (comparison 1985 and 2022)
8. EO Browser - (seasonal changes): April - September

Case 3. Glaciers in Ancohuma (Cordillera Real), Bolivia:

1. Google Map - Location
2. Google Earth (Sequence 1985 to 2020)
3. Wordview (comparison 1986 and 2022)
4. EO Browser - (seasonal changes): May - September

Case 4. Upsala Glacier, Argentina:

1. Google Map - Location

2. Google Earth (Sequence 1985 to 2020)
3. Wordview (comparison 1985 and 2022)
4. EO Browser - (seasonal changes): April - September

Case 5. Southern Patagonian Ice Glacier (HPS-12), Chile:

1. Google Map - Location
2. Google Earth (Sequence 1985 to 2020)
3. Wordview (comparison 1985 and 2021)
4. EO Browser - (seasonal changes):): Febrero- September

Case 6. Several glaciers in Sierra de Sangra, on the Chile-Argentina border:

1. Google Map - Location
2. Google Earth (Sequence 1985 a 2020)
3. Wordview (comparison 1985 y 2022)
4. EO Browser - (seasonal changes): February - September

Supplementary material to analyze all the cases locating each glacier in:

1. Glacier Inventory - GLIMS and it records nearby glaciers
2. Glacier Fluctuations - WGMS for ice fluctuations in recent years
3. Drought Atlas - to know the variation of humidity over long periods of time. SADA [In Spanish] to know the variation of humidity over long periods of time. (Data is currently available for some countries).

What to Do and How to Do It

- ***Beginning***

  Show your students the Global Snow Cover Map and note the changes for different months of the year around the world. Compare the same month in different years.

  Compare snow cover with: a) Net Radiation, b) Land Surface Temperature and c) Cloud Fraction. Look again at the changes in different months of the year and the same month in different years to see how they match.

  Have your students record the years with the highest and lowest ice cover. Also have them record the overlaps of these years with net radiation, surface temperature, and cloud fraction.

  Ask students to develop some hypotheses about possible causes of changes in snow cover.

- ***Development***

  1. Divide the class into groups and assign one case to each group to discuss.
     a. Look at the current satellite image on Google Map. What do you see in that image (glaciers, forest, rivers, lakes, plantations, cities, roads, etc.)? What type of cover do they correspond to (Urban, Suburban, Roads, Forest, Prairie, Crops, Ice, Rocks, Water, etc)?
     b. Open the Google Earth sequence and observe the changes in each year. Record the major changes (e.g., changes in ice extent, glacial lake formation, changes in vegetation cover, etc.).

   c. Compare Landsat images (old) and Sentinel images (current). Record the observed changes.
   d. Compare recent Sentinel images in EO Browser with the combined bands for false color composite. What seasonal changes are seen in the images? (Consider this combination of bands that highlights vegetation in red and allows for clearer visualization of snow on the ground.)
2. Ask your students to create a presentation about the case study. They can make a story with maps (using ArcGIS StoryMaps), or a slide presentation.
3. Bring all the groups together, ask them to explain the cases they discussed and compare the similarities among the cases.
4. If you have glaciers nearby or are in a watershed where water availability depends on glacier ice, you can use the same tools to analyze their status and changes in recent years. You can also supplement with field measurements. If you do not have glaciers nearby you can analyze other cases and compare them. Resources:
   a. Location of glaciers in the world - GLIMS https://www.glims.org/maps/glims (See bibliography for glacier inventories and specific reports in different countries)
   b. WGMS ´s Glacier Fluctuations - https://wgms.ch/fogbrowser/
   c. SADA ´s Drought Atlas - https://sada.cr2.cl/ [In Spanish] (This atlas has information for some countries, but it is being updated to be extended to other regions.)

- ***Ending***

  Because of the relevance of this issue, it is important to develop outreach information materials. Students can make a story with maps (Story Map), a video, or flyers to post on social networks summarizing the cases they analyzed and highlighting the importance of glaciers for ecosystems and communities.

Frequently Asked Questions

Where do I find satellite images? - Worldview – Copernicus Browser - Google Earth - Google Map

Where do I find glaciers? - GLIMS is a database of the world's glaciers. You can download glacier contours and place them in Google Earth.

Where do I find glacier retreat information? WGMS is a database of glacier fluctuations around the world. It has information on some reference glaciers.

Suggested Resources for Further Information

As an extension of this activity students can consult satellite images from different dates and locations to explore other glaciers. The GLIMS and WGMS databases have specific information. There are also national glacier inventories (see link of interest). Worldview and Google Earth have stored images since the 1980s.

Other Resources:

Drought Atlas https://sada.cr2.cl [In Spanish]

Snow Cover and Sea Ice Cycle at the Poles https://svs.gsfc.nasa.gov/4995

WGMS Fluctuation of Glaciers - https://wgms.ch/fogbrowser/

GLIMS Glacier Inventory - https://www.glims.org/maps/glims

Global maps:

1. Snow cover since the year 2000 - https://go.nasa.gov/3fYZPFQ
2. Land temperature since the year 2000 - https://go.nasa.gov/3rQKN7T

Links of interest:

National Water Authority - ANA. Peru. Glaciers. https://tinyurl.com/3pc2w8fm

Chilean Glaciers Foundation https://www.glaciareschilenos.org/

Institute of Hydrology, Meteorology and Environmental Studies - IDEAM. Colombia. Glaciers in Colombia. https://www.ideam.gov.co/

National Glacier Inventory. IANIGLA. Argentina. https://www.glaciaresargentinos.gob.ar/

Glaciology Laboratory. Chile. https://glaciologia.cl/

Videos:

NASA Climate Change (2021). *Global Warming from 1880 to 2021.* Youtube: https://youtu.be/haBG2IIbwbA

NASA Climate Change (2021). *NASA: Sea level rise.* List: Earth Minute. Youtube: https://youtu.be/msnOHuPep9I

NASA Climate Change (2021). *NASA: Earth has a fever.* List: Earth Minute. Youtube: https://youtu.be/nAuv1R34BHA

NASA Climate Change (2021). *NASA: Usual suspects.* List: Earth Minute. Youtube: https://youtu.be/dLGbqjp78lE

NASA Climate Change (2022). *Climate Spiral*. Youtube: https://youtu.be/jWoCXLuTIkI

NASA Climate Change (2022). *Global Warming Broken Down by Latitude Zone: 1880-2021*. Youtube: https://youtu.be/f6FMS7mJatM

NASA Climate Change (2022). *Watching the Land Temperature Bell Curve Heat Up (1950-2020)*. Youtube: https://youtu.be/1YigIVWMPHM

Tutorials by: Worldview, Copernicus Browser, Story Map

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NASA Earth Observatory (2016) *Glacier Change Threatens Andes Communities.* https://go.nasa.gov/3Vd2nAo

NASA Earth Observatory (2016) *Retreat of the Sierra de Sangra Glaciers.* https://go.nasa.gov/3EpS1qX

NASA Earth Observatory (2017) *Ice on the Move in Patagonia.* https://go.nasa.gov/3yqxcrx

NASA Earth Observatory (2017) *North Patagonian Icefield.* https://go.nasa.gov/3RUW0Pu

NASA Earth Observatory (2017) *South Patagonian Icefield.* https://go.nasa.gov/3rIKxri

NASA Earth Observatory (2018) *Glacial Retreat at a Non-glacial Pace.* https://go.nasa.gov/3rGgC37

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 Earth Observatory (2022) *Chilean Volcano Low on Snow.* https://go.nasa.gov/3CkYd0y

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