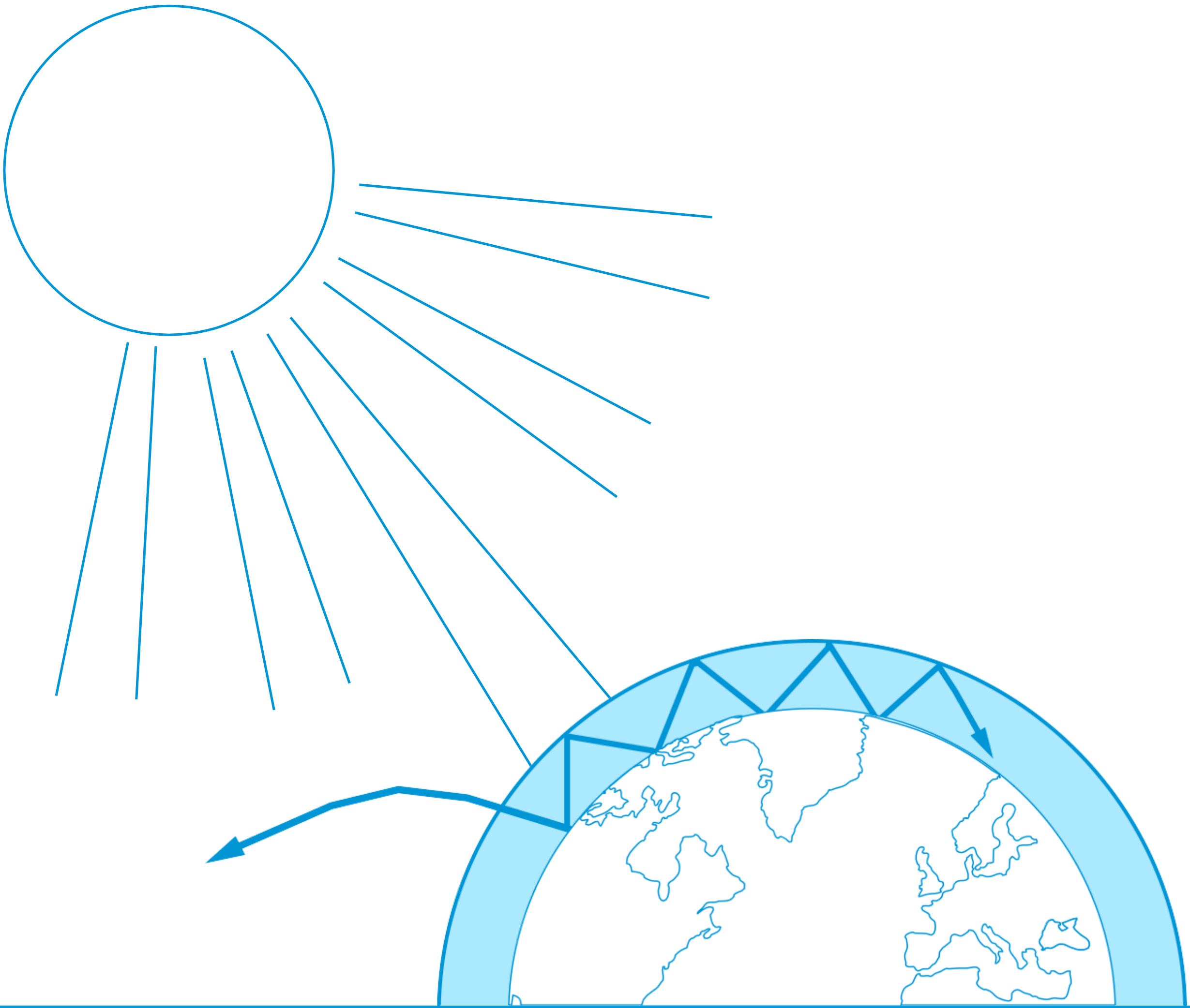
Geography | G04

Teach with space

→ CLIMATE CHANGE IMPACT ON LUXEMBOURG, USING SATELLITES DATA

Causes & consequences in Luxembourg



European Space Agency

Teach with space – Climate change impact on Luxembourg, using satellites data | G04
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→ CLIMATE CHANGE IMPACT ON LUXEMBOURG, USING SATELLITES DATAS

Investigating global warming in Luxembourg

Fast facts

Subject: Geography, Physics, Science

Age range: 15-19 years old

Type: hands-on student's activity

Complexity: easy

Lesson time required: 45 minutes per activity

Cost: low

Includes the use of: computer, internet

Keywords: Greenhouse effect, Global warming, satellite images, Climate, Geography, Physics, Science

Brief description

Using the Luxembourgish context, this set of activities includes activities on the interpretation of satellite images for better understanding the overall effects of global warming in, the country's main greenhouse gases sources.

Learning objectives

- Propose classroom activities to investigate climate related issues in Luxembourg using Sentinel satellite data
- Explain the current biggest contributions of Luxembourg to Climate Change
- Explain current Luxembourg actions to reduce greenhouse gases emissions

→ Introduction

2019 was the second warmest year on record and the end of the warmest decade (2010- 2019) ever recorded.

Carbon dioxide (CO2) levels and other greenhouse gases in the atmosphere rose to new records in 2019.

Climate change is affecting every country on every continent. It is disrupting national economies and affecting lives. Weather patterns are changing, sea levels are rising, and weather events are becoming more extreme.

Furthermore, it's impacting our children's mental health: climate anxiety among young people and their beliefs about government responses to climate change is an increasingly studied topic.

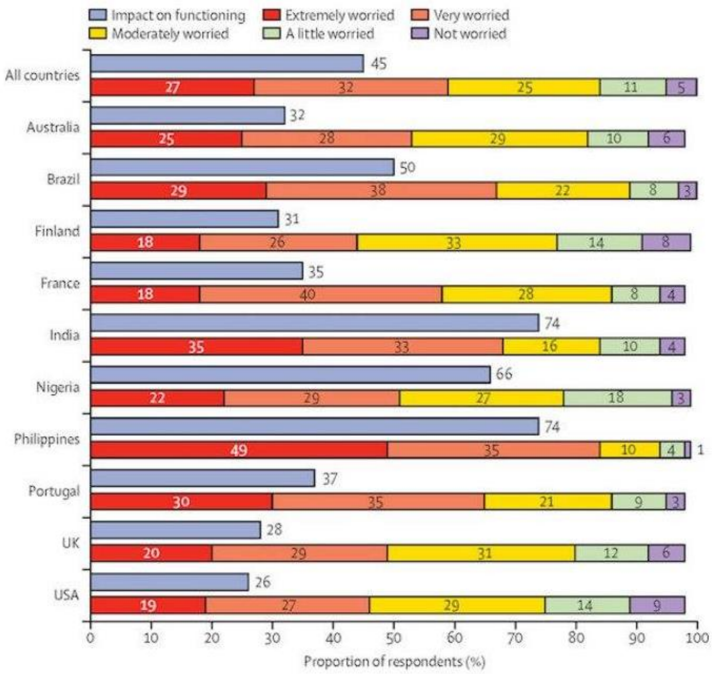
A December 2021 study [published in The Lancet Planetary Health](#) surveyed 10,000 young people aged 16 to 25 in ten countries.

The study collected participants' thoughts and feelings about climate change, as well as about government responses to climate change.

Respondents in all countries were concerned about climate change: 59% were very or extremely concerned and 84% were at least moderately concerned.
More than 50% reported each of the following emotions: sadness, anxiety, anger, helplessness, powerlessness, and guilt.

More than 45% of respondents reported that their feelings about climate change were negatively impacting their daily lives and functioning, and many reported a high number of negative thoughts about climate change.

It's the responsibility of the education community to talk objectively with the new generation about climate change, to increase their knowledge about the problem itself and better understand the most efficient solutions to stop global warming.



→ Worldwide perspective

Past and current climate

The IPCC (Intergovernmental Panel on Climate Change) is an organisation of 195 UN member states whose objective is to regularly assess the most advanced scientific knowledge on climate without bias. It brings together thousands of volunteer experts from around the world to assess, analyse and synthesise the many scientific studies on the subject.

The latest IPCC report describes our best knowledge of past and future climate evolution.

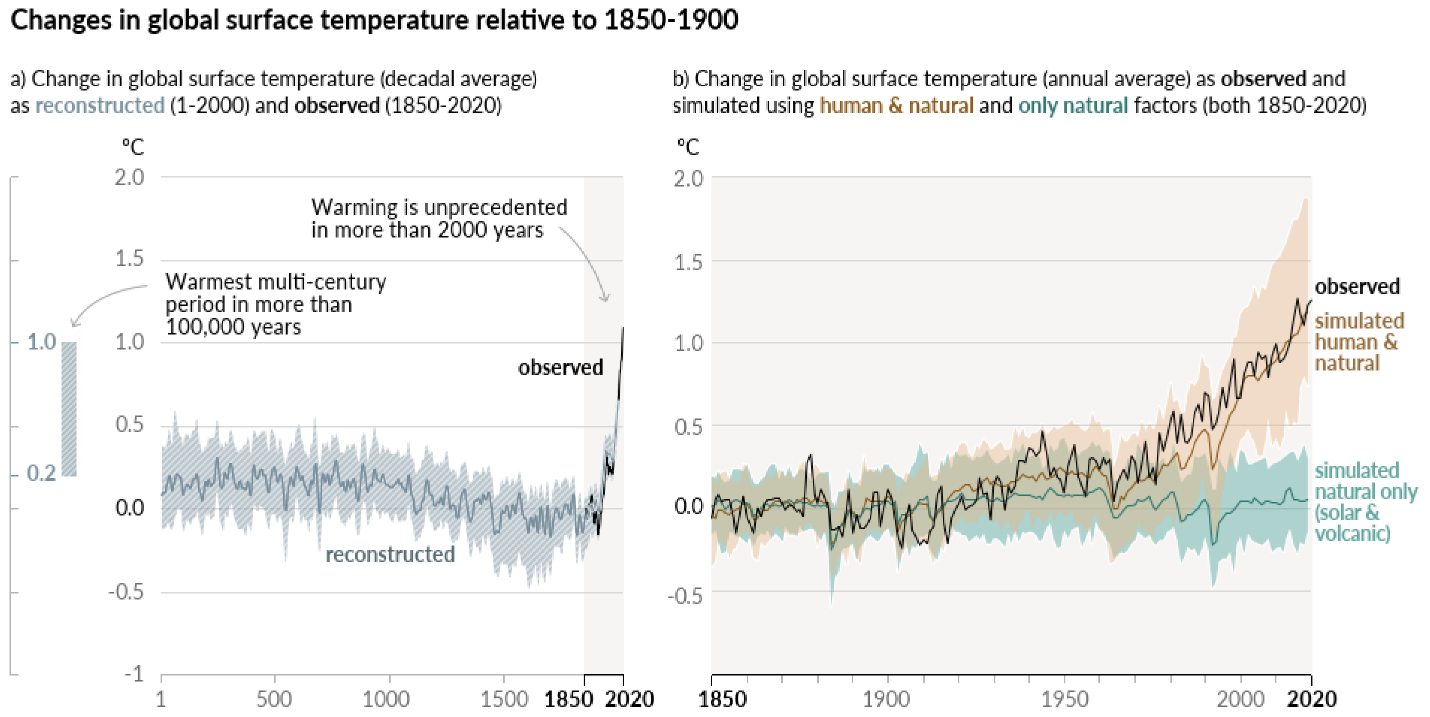


Figure 1 - Surface temperature compared to the average for the period 1850-1900.

The influence of humans on the warming of the atmosphere, oceans and continents is unambiguous. By emitting greenhouse gases (GHGs), humanity has caused rapid and widespread changes in the atmosphere, cryosphere (land and sea ice), biosphere (living things) and oceans.

The main GHGs emitted by humans are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
Some of the human emissions are captured by the ocean and on the surface of the continents. The rest is stored in the atmosphere, increasing its concentration. This concentration is expressed in parts per million (ppm) or parts per billion (ppb).

From 1750 to 2019, atmospheric concentrations have increased for each greenhouse gases:

Gas	Atmospheric concentration (1750)	Atmospheric concentration (1750)
CO2	280	410
CH4	800	1866
N2O	270	322

Although the atmospheric concentration of CH_4 is about 220 times lower than that of CO_2, CH_4 is responsible for more than a quarter of the warming due to its greater warming power. The magnitude of these variations for CO_2 and CH_4 far exceeds the natural variations between ice ages and interglacial periods over the past 800,000 years. The current CO_2 concentration is the highest in at least 2 million years.

This increase in the concentration of GHGs is causing a significant accumulation of energy in the form of heat at the surface of the globe. Of this energy, 91% is found in the oceans, 5% on continental surfaces, 3% in the ice (causing it to melt), and only 1% in the atmosphere.

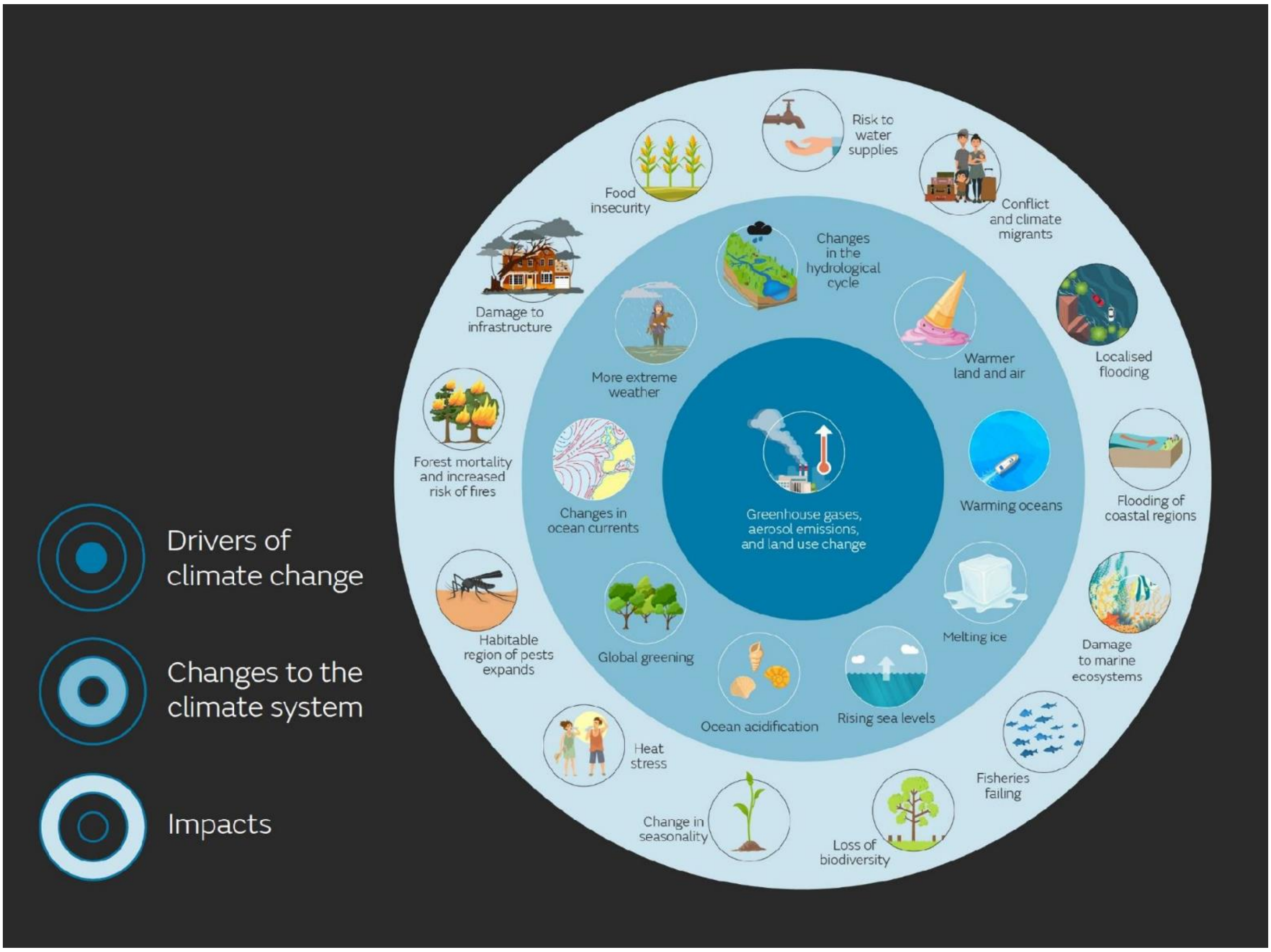


Figure 3 – drivers and effects of climate change

However, this tiny proportion (1%) of heat trapped in the atmosphere is the main cause of the warming: the global surface temperature over the period 2011-2020 was 1.09°C warmer than that over the period 1850-1900, with a greater warming over the continents (+1.59°C) than over the oceans (+0.88°C).

The rate of warming over the past 50 years is unprecedented for at least 2000 years. Current temperatures exceed the maximum of the last warm period 6500 years ago, and are likely to exceed the previous maximum of 125 000 years ago (FIGURE 1).

The accumulation of heat in the ice, in turn, has led to a retreat of the glaciers and the Arctic ice pack. Between the periods 1979-1988 and 2010-2019, the surface of the Arctic ice pack has decreased by 40% at the end of summer, its lowest value since at least 1850. The near-simultaneous retreat of most of the world's glaciers is also unprecedented in at least the last 1000 years. Similarly, the influence of humans on climate is most likely responsible for the melting of the Greenland ice sheet over the last two decades, which was 4 times faster over the decade 2010-2019 than over the period 1992-1999.
The melting of continental ice (mountain glaciers, Greenland ice cap) is also responsible for 42% of the rise in sea level over the period 1971-2018. In addition, there is the thermal expansion effect: the volume of a given body of water increases when its temperature rises. This effect is responsible for half of the sea level rise.

Sea level rose by 20 cm between 1901 and 2018. From a rate of 1.3 mm/year between 1901 and 1971, the rise accelerated to +3.7 mm/year over the period 2006- 2018. As a result, the sea level has risen faster since 1900 than in any century in the last 3000 years. Over the same period, the ocean has also warmed faster than it has since the end of the last deglaciation, about 11,000 years ago. In addition to affecting temperature and sea level, the dissolution of some of the man-made CO_2 into surface waters is increasing the acidity of the oceans.

By disrupting the climate, humanity has also caused changes in the frequency of extreme weather and climate events, which have become more frequent and intense overall since 1950. This is the case for extreme heat, the frequency of which has doubled since the 1980s, heavy precipitation (particularly in northern Europe), forest fires and floods.
In addition, there are soil droughts in some regions, particularly around the Mediterranean basin, in southern and western Africa, and in western North America.

According to the Global Warming Index from Oxford University, the current global warming since 1860 is +1.24°C.

The global annual temperature has increased at an average rate of 0.08°C per decade since 1880 but that rate has doubled since 1981 at +0.18°C per decade.
The 2020 Northern Hemisphere land and ocean surface temperature was the highest in the 141-year record at +1.28°C above average.

Possible future climate

As a result of past and future GHG emissions, the changes in the climate system observed in recent decades will continue throughout the 21st century and beyond. But **the extent of these changes depends mainly on future GHG emissions.**

If we continue at this rate of GHG emissions, temperatures will continue to rise globally - on average 1.4 to 1.7 times more on land than at sea, and at least twice as much at the North Pole as elsewhere (FIGURE 2). Sea level rise and ocean acidification will continue. Heat waves, extreme rainfall and severe hurricanes will become more frequent and intense, while cold snaps will become less frequent. Extreme events of unprecedented magnitude are certain to occur. Land ice and permafrost will continue to melt, and Arctic Sea ice will retreat, particularly in summer. An almost ice-free summer in the Arctic is likely before 2050, whatever we do.

Rainfall will be generally more abundant, especially in the high latitudes, the tropics, and most monsoon regions, but more variable, both within a season and from year to year. Some areas will receive less rain in the future, however, such as the Mediterranean and several subtropical regions. On average, rainfall events - particularly those associated with monsoons - as well as droughts will be more intense, although again significant regional variations are expected.

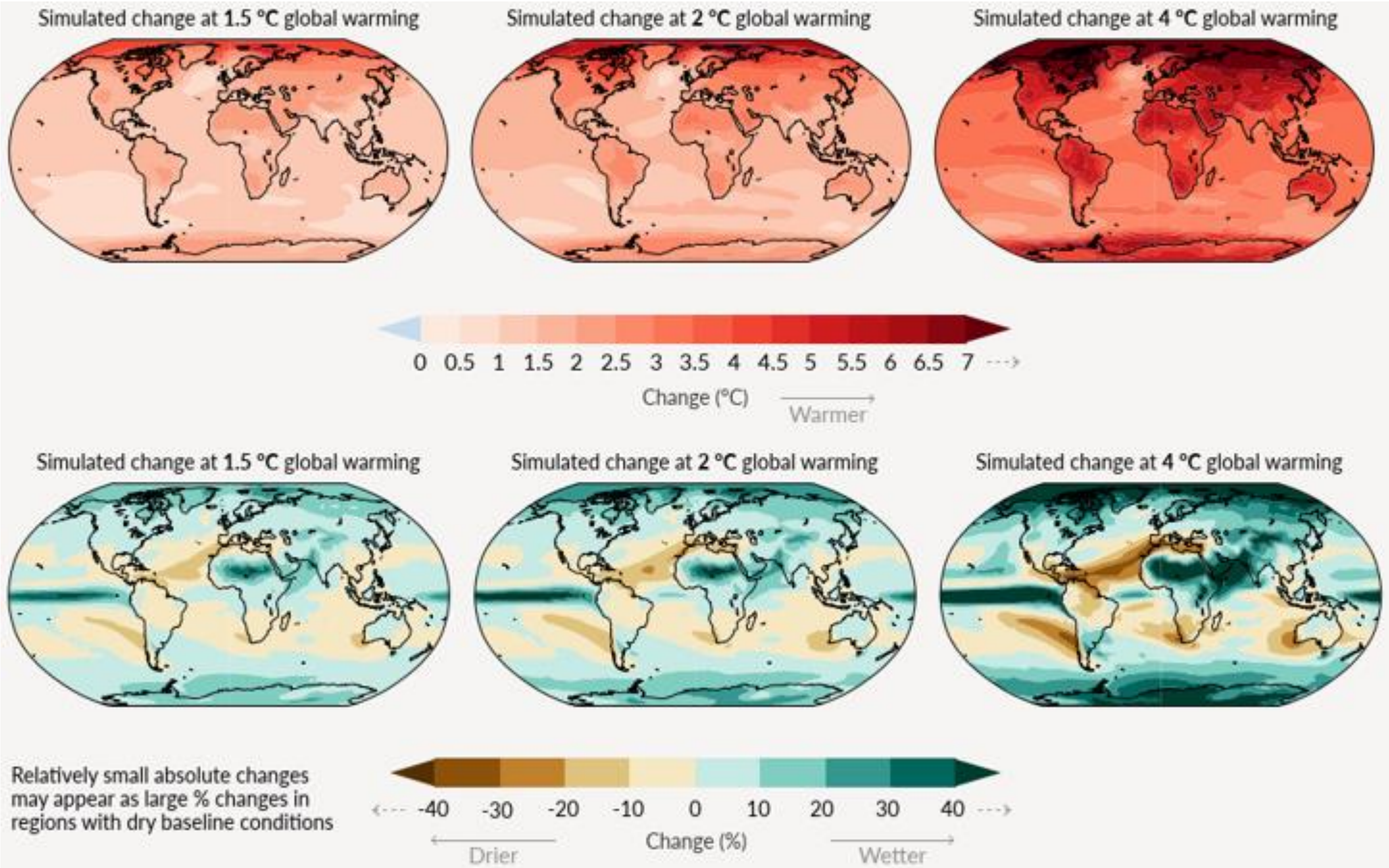


Figure 3 - Simulated change in temperature (°C) and precipitation (%) (annual average) relative to the period 1850-1900 for different levels of global warming

With CO_2 remaining in the atmosphere for an average of a century, the global temperature will continue to rise until at least 2050, no matter what we do over the next few decades.
Even with immediate reductions in GHG emissions, the +1.5°C mark will be reached, and has a 50/50 chance of being exceeded by 2040 - in less than 20 years!
Note that these figures represent 20-year averages - so it is likely that +1.5°C will be reached in some cases well before 2040, perhaps even by 2025.
A rapid reduction in emissions would nevertheless make it possible to significantly limit global warming by 2100, to between 1.4 and 1.8°C, while it would reach 2.7 to 3.6°C in the intermediate scenarios and 4.4°C in the worst case scenario.
The +2°C mark would thus be largely passed before 2060, except in the optimistic scenarios.

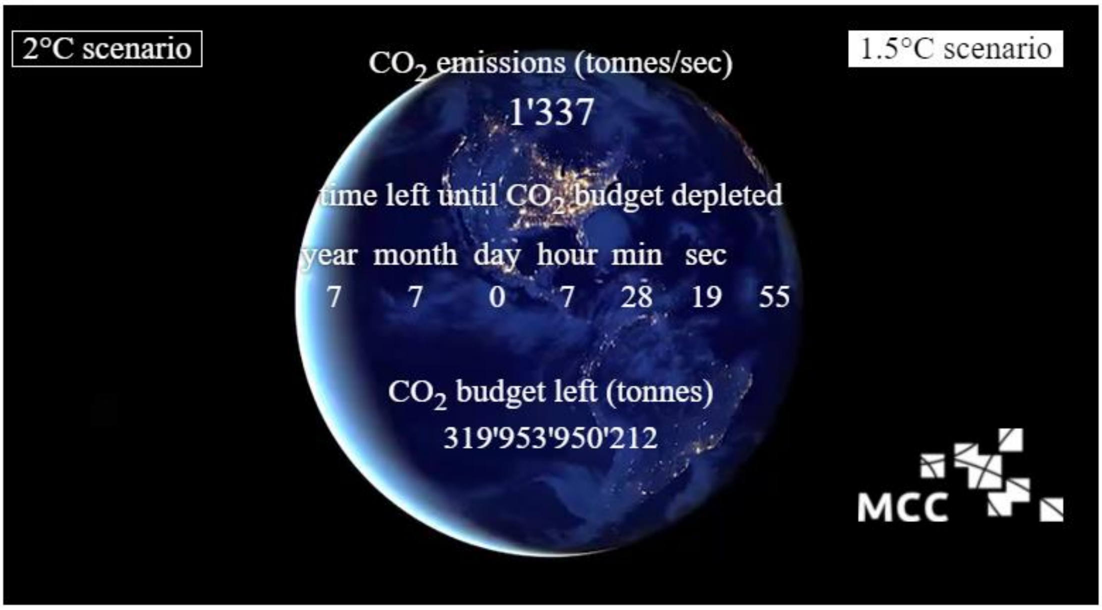
Although it may seem insignificant, a 0.5°C difference in global warming has major consequences, especially for extreme events. A heat peak that occurred once every 50 years a century ago is already 5 times more frequent today, while the global temperature has increased by 'only' 1°C. With 1.5°C warming, it would be almost 9 times more frequent, and almost 14 times more frequent at +2°C, while at +4°C it would occur almost every year. Any increase in warming also reduces the effectiveness of natural carbon sinks (oceans, soils, vegetation).
Even if we manage to limit the temperature increase to 1.5°C by 2100, three major changes are irreversible on a human lifetime scale: ocean warming and acidification, melting of glaciers and polar ice caps, and sea level rise. Future reductions in GHG emissions will only slow down but not stop these phenomena, even if surface temperatures no longer rise. This is because the inertia of the oceans and land ice is much greater than that of the atmosphere.

By 2050, sea level is projected to rise by at least 18 cm compared to the 1995-2014 average regardless of GHG emissions. By 2100, sea level is projected to rise by 38 cm in the most optimistic scenarios. Beyond that, the level will continue to rise as the deep ocean warms and land ice melts. These figures are consistent with what we know about warmer climates in the past.

1.5°C threshold date

According to the latest IPCC report SPM2 table on the 1.5 degree Celsius target, the atmosphere can absorb, calculated from the beginning of 2020, no more than 400 gigatons (Gt) of CO_2 if we are to stay below the 1.5°C threshold.

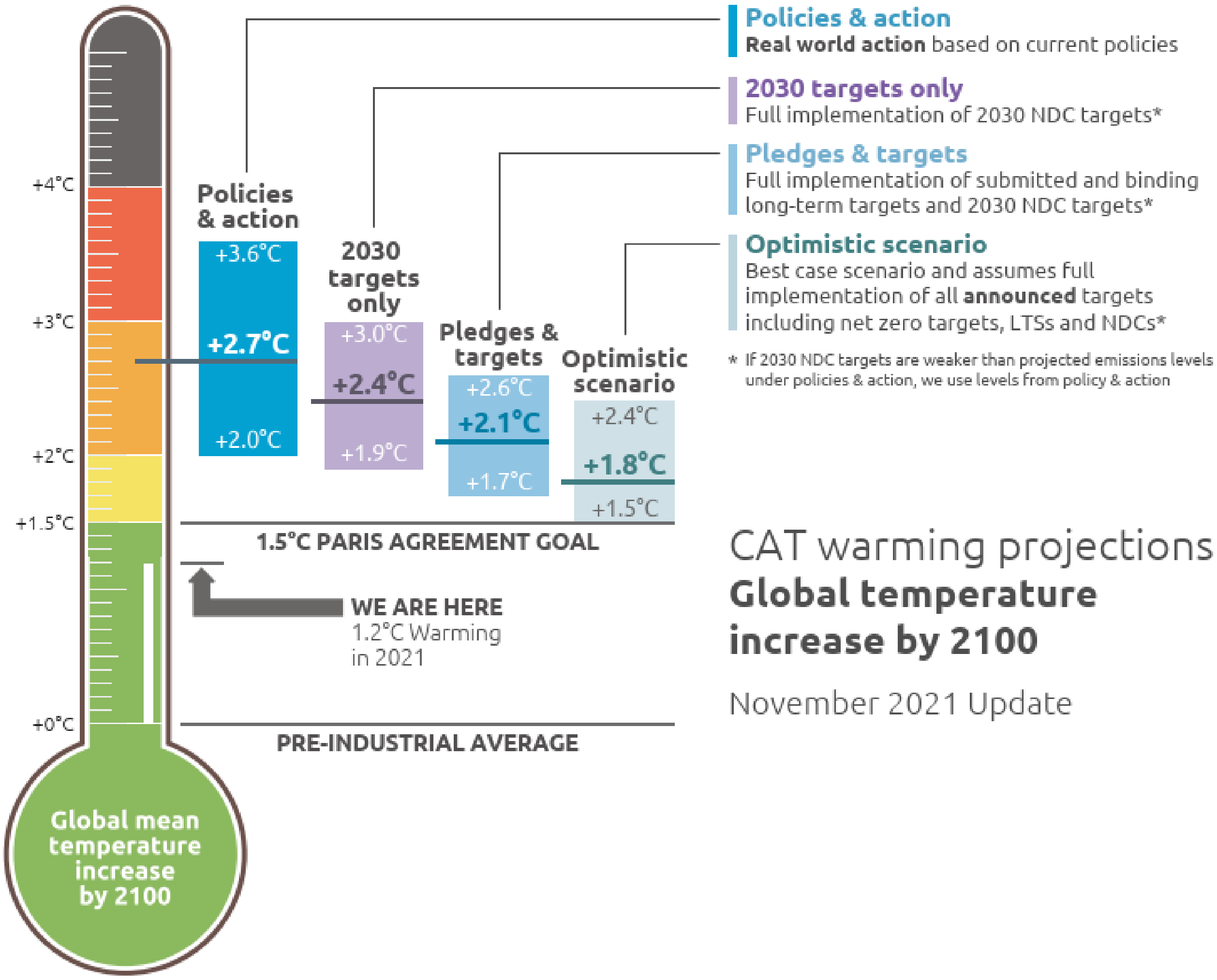
Annual emissions of CO_2 from burning fossil fuels, industrial processes and land-use change are estimated to be 42.2 Gt per year. With emissions at a constant level, the budget to stay below the 1.5°C threshold is expected to be used up in less than eight years from now.



2100 warming estimation

Since the Paris Agreement, each country is required to establish an Nationally Determined Contribution (NDC) and update it every five years. A NDC is a climate action plan to cut emissions and adapt to climate impacts

According to the UN Emissions Gap report and Climate Action Tracker, if promised greenhouse reduction are set in place, we may limit the warming in 2100 from 1.8°C to 2.7°C with a maximum of 3.6°C in the worst case.



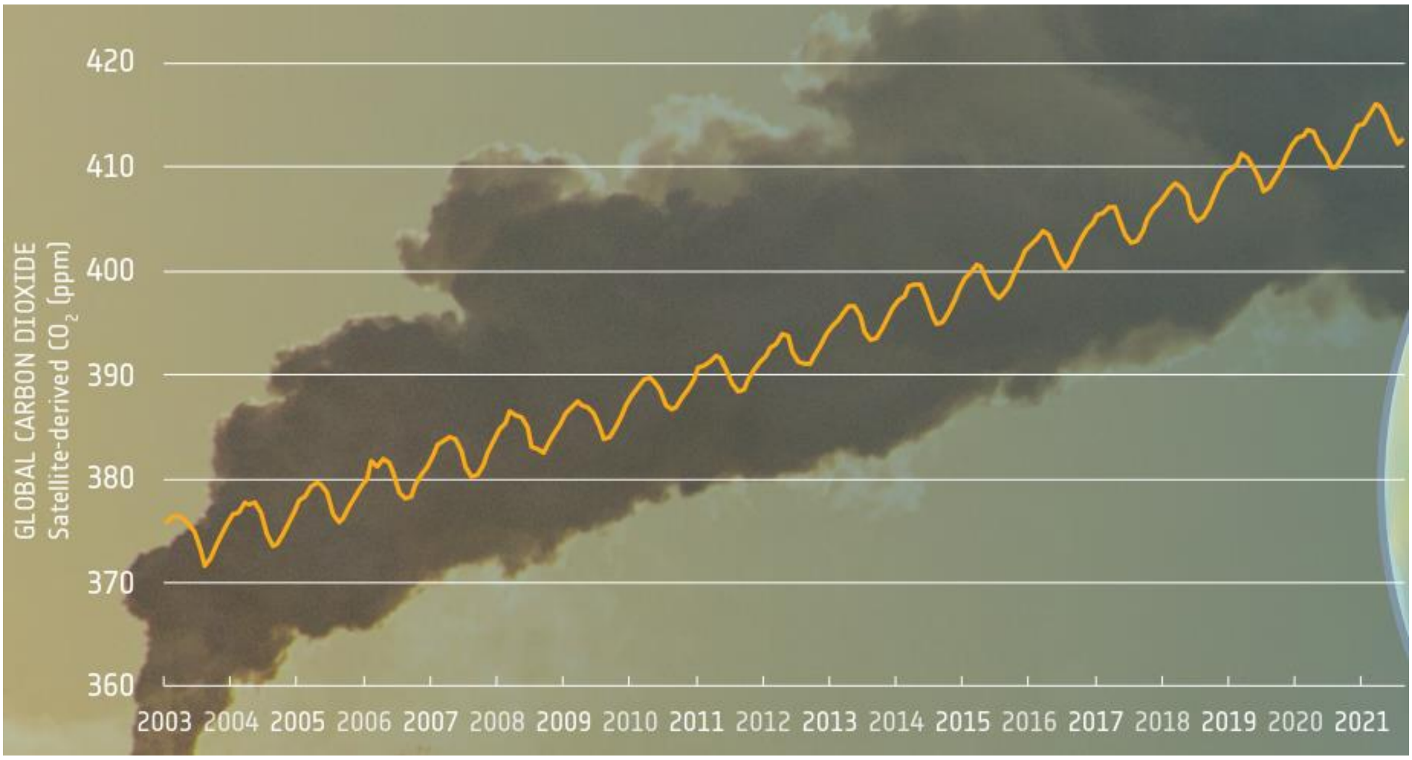
→ Earth Observation satellites

Satellites observing Earth from space provide the crucial lines of evidence to understand our changing climate. They measure and monitor our vast oceans, land, atmosphere, and inhospitable difficult to reach areas such as the polar regions.
Satellite observations provide early warnings of change, improve climate predictions and deliver the hard facts needed for effective international climate action.
To produce data suitable for climate research, information from multiple satellite missions need to be combined to produce datasets that span decades.

Earth Observation is [ESA's biggest space program budget]() with more than 1.5 billion euros in 2020.

The ESA Climate Change Initiative generates robust, long-term global satellite datasets for over 21 key components of the Earth system. Observations from ESA's 40-year satellite archive as well as current Copernicus Sentinels contribute to these datasets.

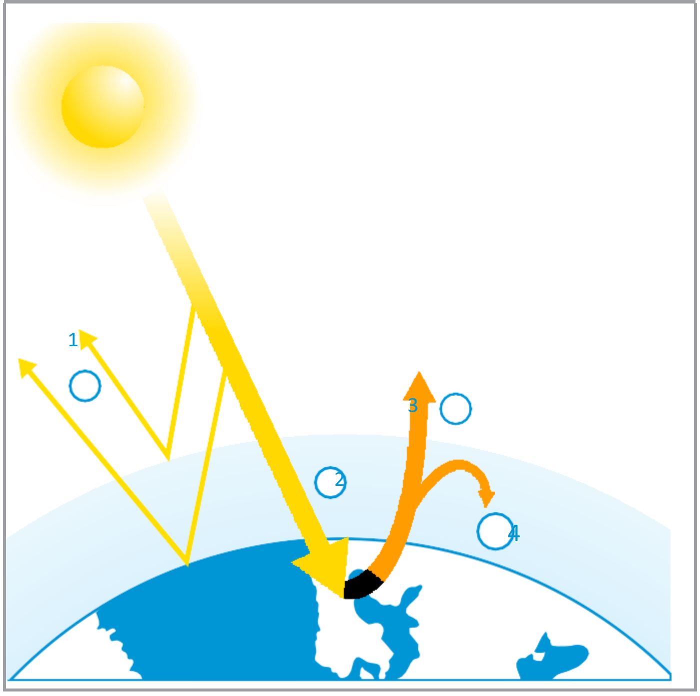
This body of evidence offers
* an accurate and impartial yardstick to study climate drivers, feedbacks, Earth system cycles
* provides the scientific basis for robust climate modelling.
* contribute to the scientific knowledge underpinning Intergovernmental Panel on Climate Change (IPCC) Reports.



→ Background

Most of the energy the Sun radiates is visible and near infrared light that consists of short wavelength radiation. This radiation easily passes the particles found in the atmosphere. When this short-wave radiation hits the Earth a large proportion of it is converted into heat. Earth's temperature does not infinitely rise because the surface and the atmosphere are also radiating heat back to space. This net flow of radiation into and out of the Earth system is called Earth's radiation budget (Figure A2). Heat is long-wave radiation that individually contains less energy than the short-wave radiation. This means it interacts with the atmosphere in a different way. The Earth radiates heat back into the atmosphere during the day and night, which helps to cool the surface. However, not all of this heat escapes to space, some remains trapped by the greenhouse gases in the atmosphere. The result is that the Earth's atmosphere is warmer than it would be without this 'greenhouse effect'.

Figure A2



↑ Earth's radiation budget.
1 - Some radiation is reflected by the atmosphere, clouds and Earth's surface.
2 - Some radiation is absorbed by the atmosphere, clouds and most of it is absorbed by the land and oceans, heating the Earth. 3 - Infrared radiation is emitted by Earth's surface. Some of this radiation escapes to space.
4 - Some is trapped by the greenhouse gases in the atmosphere.

If greenhouse gases were not present in Earth's atmosphere, life as we know it would be almost impossible because the average surface temperature would be 18 Celsius below zero. The primary greenhouse gas in Earth's atmosphere is water vapour. It traps the largest amount of heat coming from the ground. However, the greenhouse gases that climate scientists are more concerned about are CO_2 and methane (CH_4) because these are the major greenhouse gases emitted by human activities and have been increasing in the atmosphere since the beginning of the industrial revolution.

→ Luxembourg perspective

Past and current climate

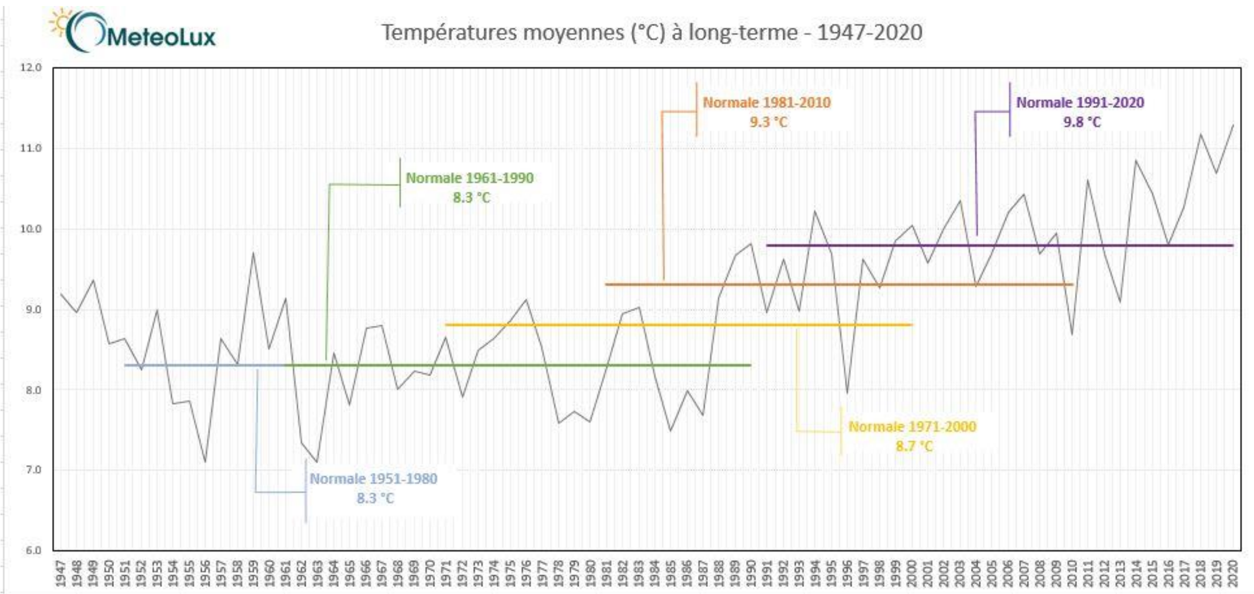
Water reflects much of the sun’s energy back into the atmosphere, while land absorbs much more of that energy. That means it takes more added heat to raise ocean temperatures than land temperatures. This is why most of the warming we see today is happening on continents rather than over the ocean.

The effect is even stronger near the poles where rising temperatures have melted large amounts of snow and ice—white surfaces that normally reflect the sun's rays back into the atmosphere and keep the areas they cover cool.

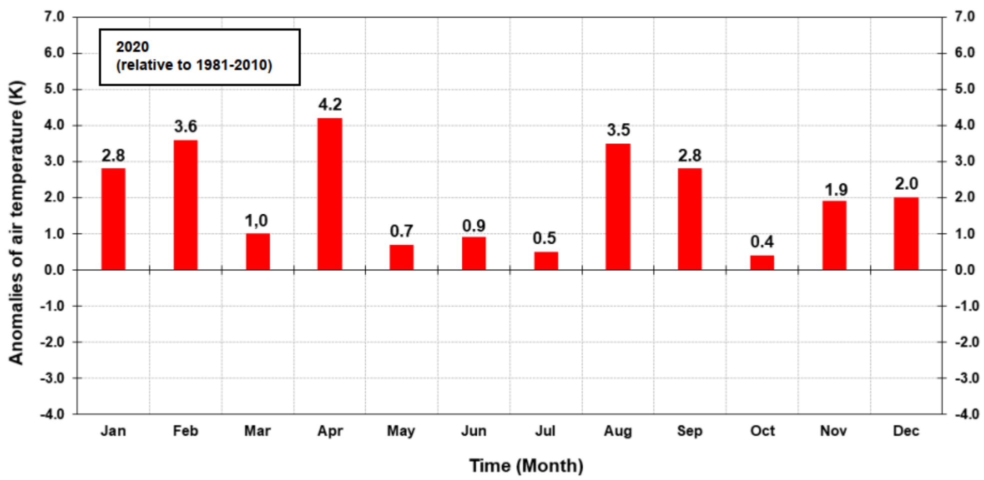
In Luxembourg it has been measured that the local warming is about twice faster than the worldwide average.

MeteoLux has a meteorological park located in the Findel-Luxembourg airport, with an observation station that has been continuously measuring various atmospheric parameters since January 1st 1947.

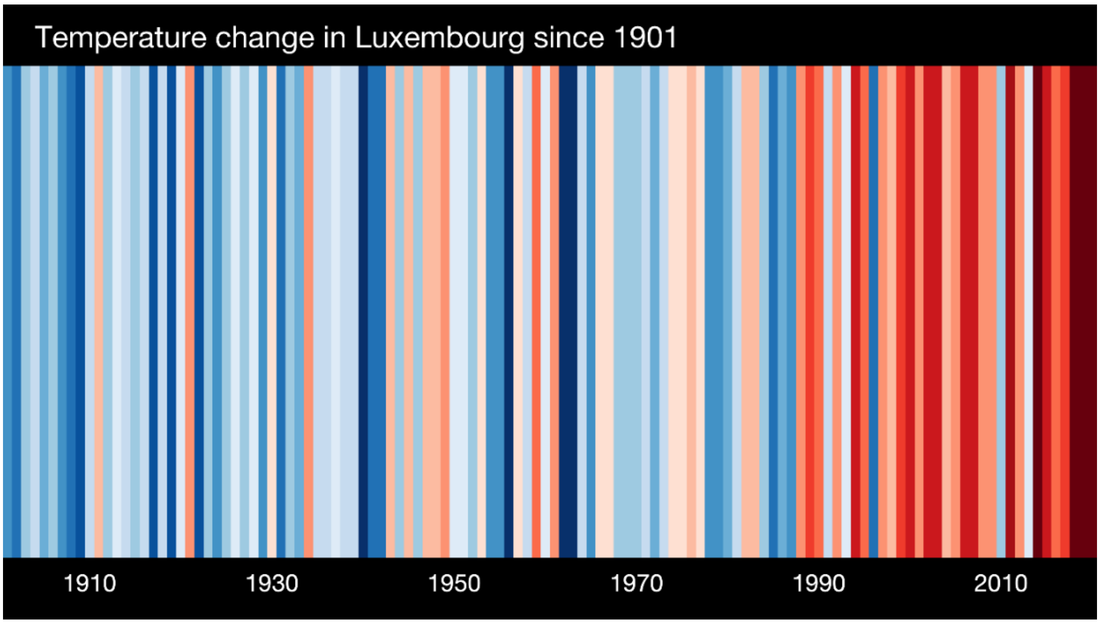
Since 1950 the average temperature has increased from +1.5°C in Luxembourg
Since 1850 the average temperature has increased from +2.2°C in Luxembourg



In its 2020 climate report, MeteoLux shows that every months in 2020 exceeded the 1981–2010 average temperature.



The following “warming stripes” graphic is a visual representation of the change in temperature as measured in Luxembourg over at least the past 100 years. Each stripe represents the temperature averaged over a year.
The stripes turn from mainly blue to mainly red in more recent years, illustrating the rise in average temperatures and the warming acceleration over the last 30 years.

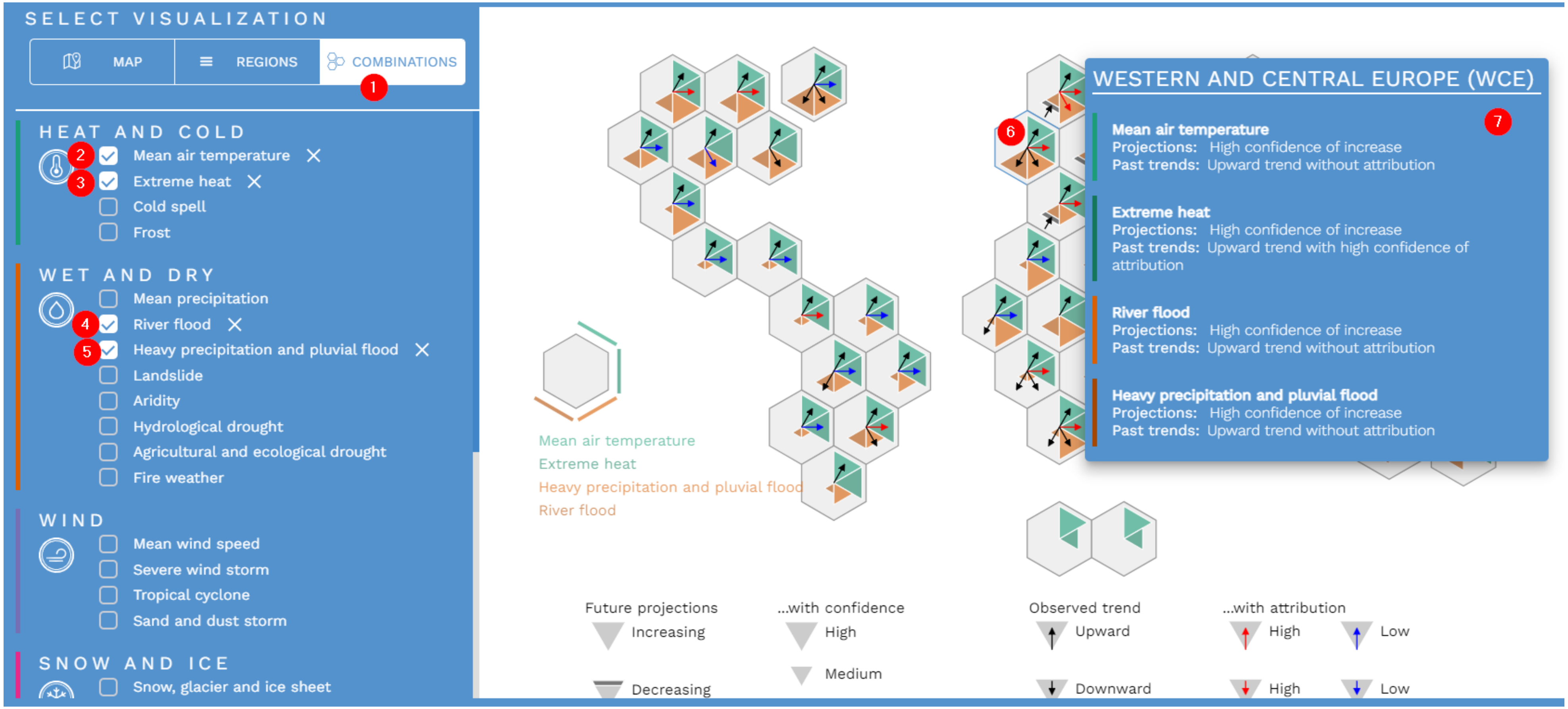


Climate change impact in Luxembourg

The IPCC has released an Interactive Atlas regional synthesis that explain changes in climatic impact-drivers (CIDs) in several categories such as heat and cold, wet and dry, snow and ice. Climatic impact-drivers (CIDs) are defined as physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.

In this activity, students will use the IPCC Interactive Atlas to learn about the most important current and future climate change impacts in Luxembourg: https://interactive-atlas.ipcc.ch/regional-synthesis

The goal is to select variables on the left where projections have "High confidence of increase".
Note that Luxembourg is part of the "Western and Central Europe (WCE) region.



Climate change satellite observations in Luxembourg with EOBrowser

EO Browser is an online tool that provides easy and free access to satellite images from different EO missions. You can choose your area of interest and your desired time. With the EO Browser, it is not necessary to process any data, it provides ready to use satelliteimages and pre-configured visualizations. It has never been easier. Have a look and try for yourself!

In this activity, we will practice our skills with EO Browser through case studies looking at:

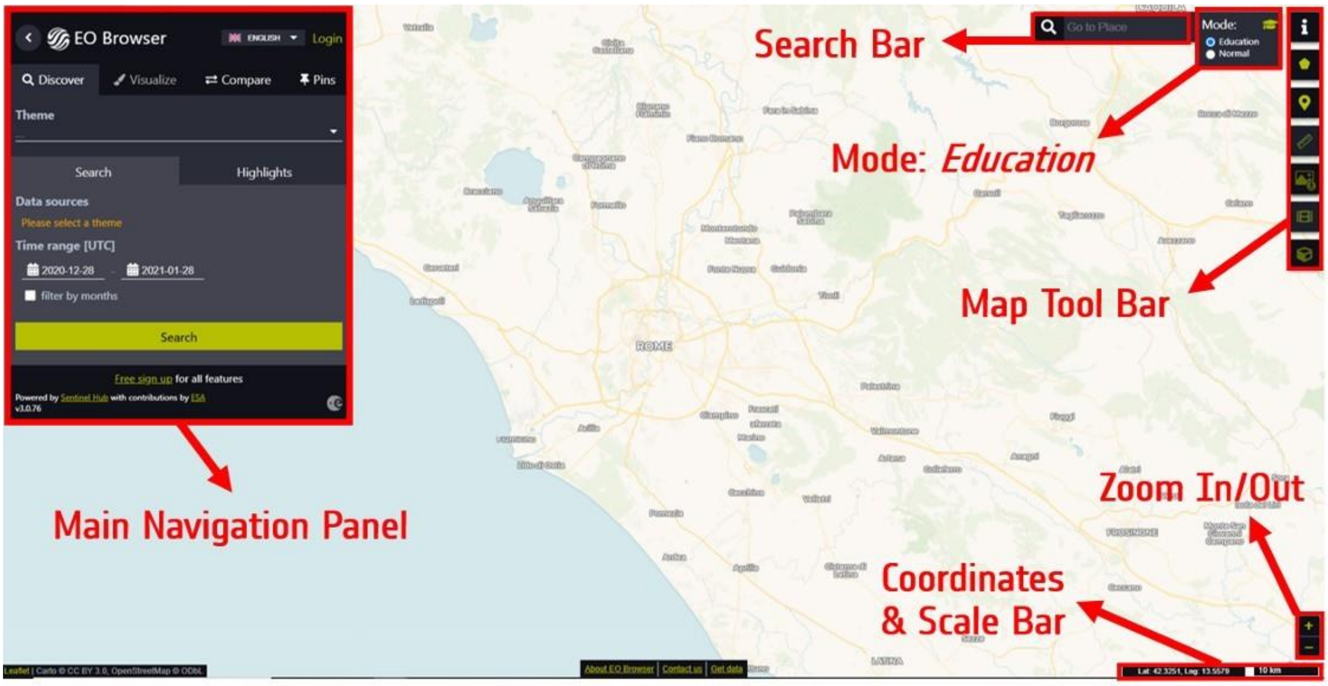
- The impact of heatwaves on the ecosystem and how they change the landscape appearance.
- The impact of floods on river banks and city infrastructure

Part A: Introduction to EO Browser Workspace

Activity A1: Getting to know the EO Browser: Education layout

1. We will be making use of EO Browser in **Education mode**: **https://apps.sentinel-hub.com/eo-browser/**

2. On the top right corner of your EO Browser screen, click on and choose *Mode: Education*



Activity A2: Creating an EO Browser account (Optional)

On the top left of the Main Navigation Panel, click on 

NOTE: You can still use EO Browser and download satellite images without an account. However, to use some of the Map Tool Bar functions for later parts of the mini lab (i.e. measure and timelapse), you need to be logged in!

Create your own EO Browser user account.

Activity A3: How to visualize images

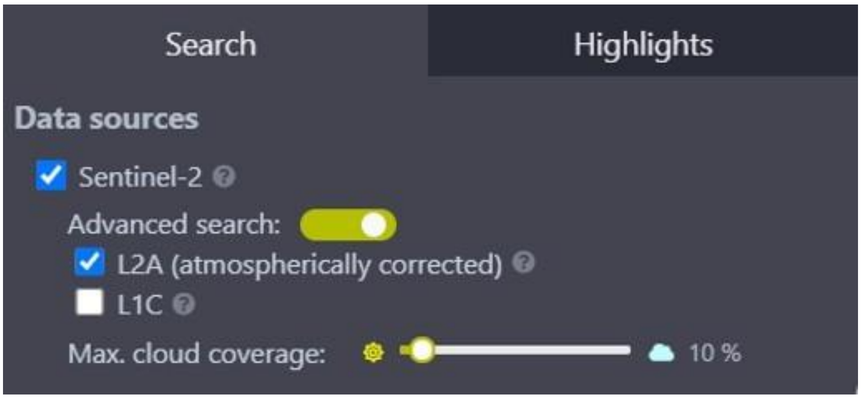
1. On the top right corner of your EO Browser screen, on the Search Bar, type in "Luxembourg"

2. Then go to the Main Navigation Panel and select the Theme: Change Detection through Time

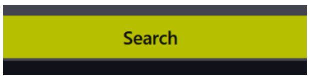
3. Now, we want to find the ideal satellite image that will show us a cloudless and clear image. For this, under Data sources on the Main Navigation Panel, you will select Sentinel-2 > Advanced search > L2A (atmospherically corrected) > Max. cloud coverage (10%)

4. Now, we want to find the ideal satellite image that will show us a cloudless and clear image. For this, under Data sources on the Main Navigation Panel, you will select Sentinel-2 > Advanced search > L2A (atmospherically corrected) > Max. cloud coverage (10%)

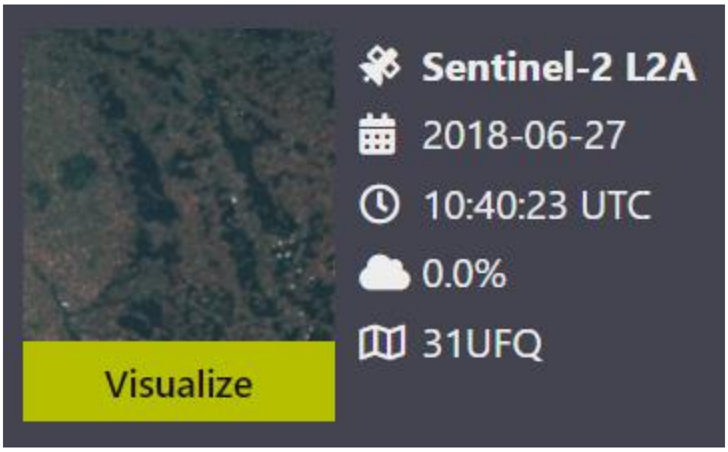
5. Then, set the *Time Range* from 2018-06-01 - 2018-07-31.



6. Then, please set the *Time Range* to 2017-01-01 - 2017-03-31.

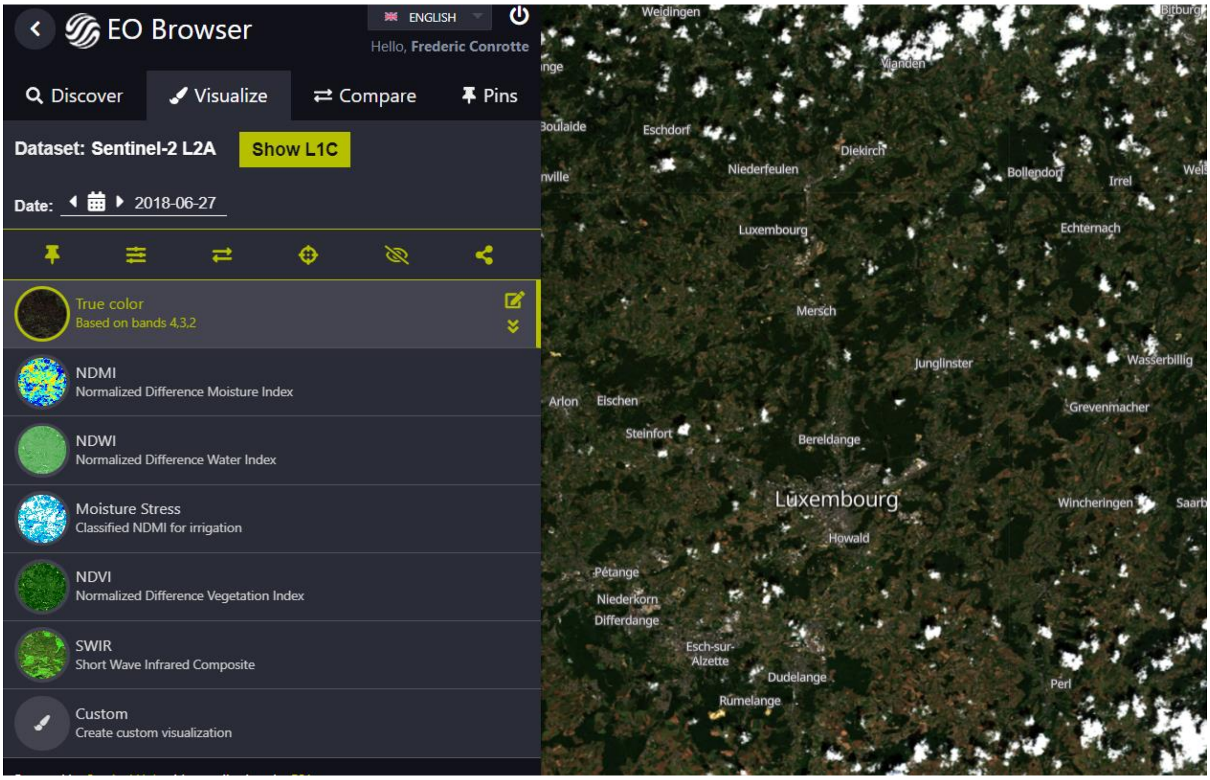
7. Click *Search*. 

8. Choose the satellite image taken on 2018-06-27



9. Click *Visualize* and wait a few moments as this may take some time to load.

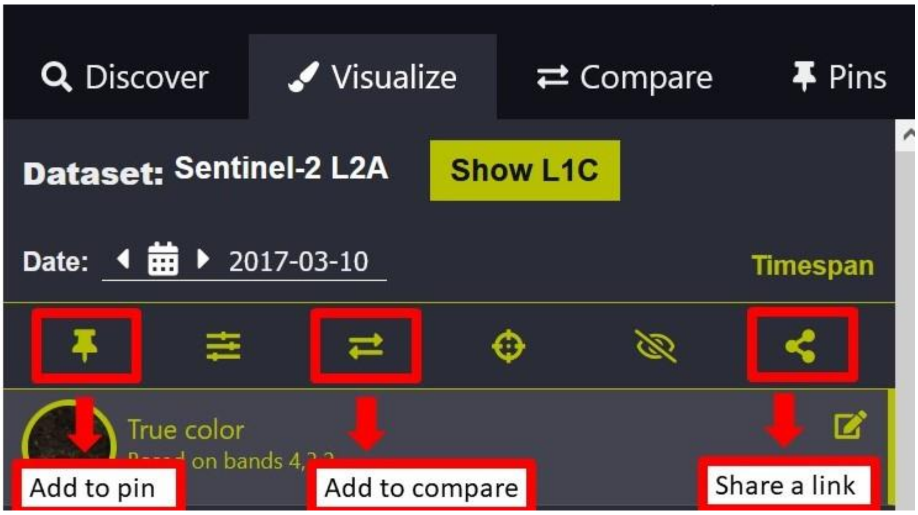
10. After a few moments, you should now be able to see a high-resolution image of Luxembourg in True Colour. Feel free to zoom in/out and look around!



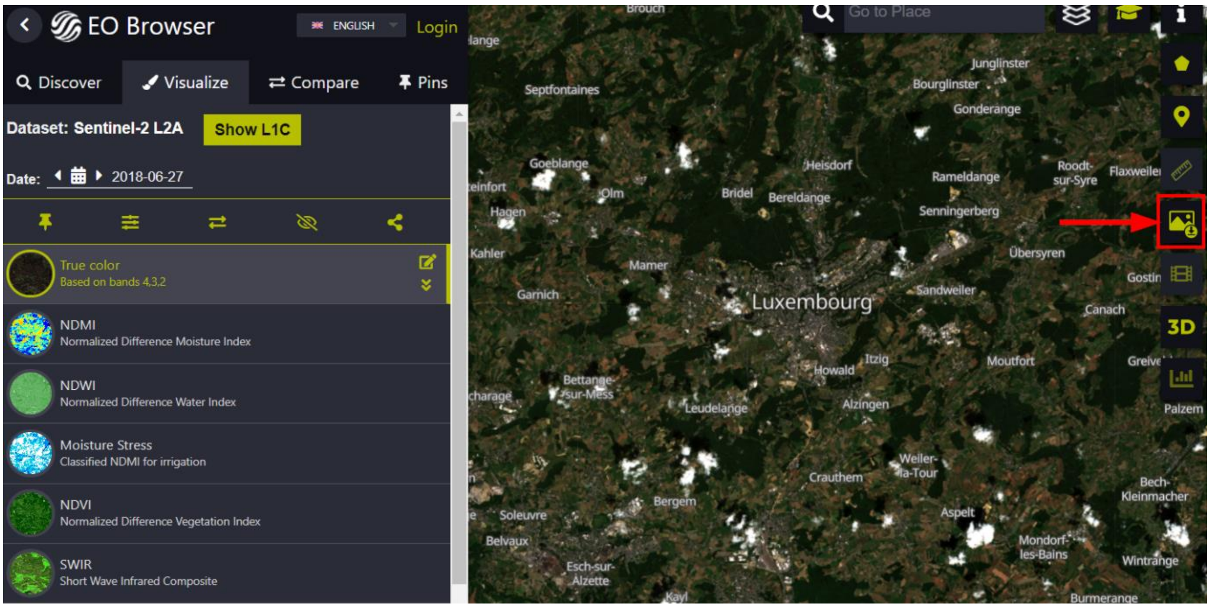
Activity A4: How to share a link or download an image

1. SHARE: After an image is loaded, you are able to share the exact satellite image with the exact same view/zoom by clicking the Share button on the Main Navigation panel.

This is the exact link to the image above: https://sentinelshare.page.link/XFX1



2. DOWNLOAD: To download the image in JPG or PNG format, go to the Map Tool Bar (on the right of your screen) and click on Download Image .

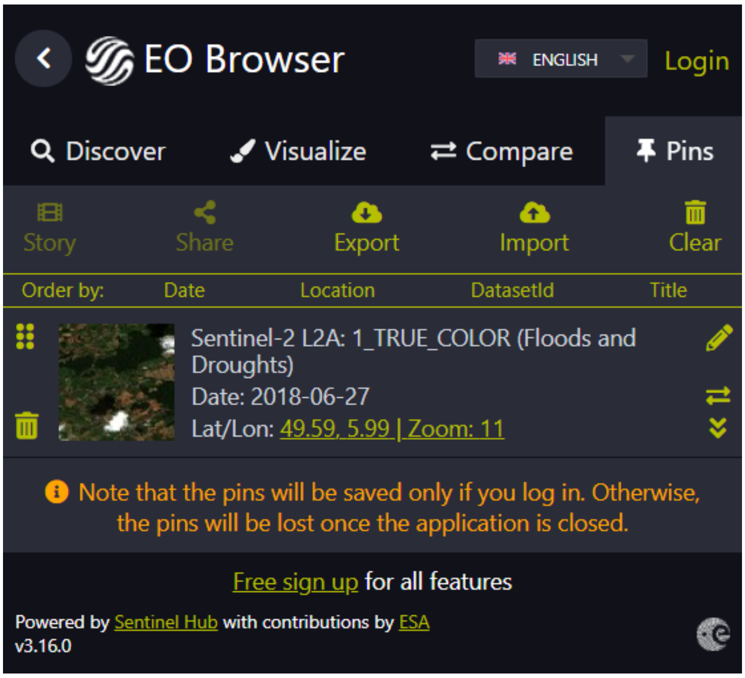


Activity A5: How to pin or save image(s)

1. Now, we will save our image so that we can view it for later. For this, we will click on the Add to pins button on the Main Navigation Panel. 

2. To check if you have correctly saved/pinned it, click on the Pins section 

. If it is pinned/ saved correctly, it should appear like below:



Part B: Observing drought using satellite images

Soil moisture is impacted by droughts, and it is our goal in this exercise to evaluate it.

The 2018 summer was particularly dry with a heat wave all over Europe as well as in Luxembourg.

The first heat waves occurred between 13 and 27 July (making this the fifth longest heat wave in history) and the second one from 29 July until 7 August: at least 5 days with maximum temperatures of 25 °C or higher, of which 3 days of 30 °C or more

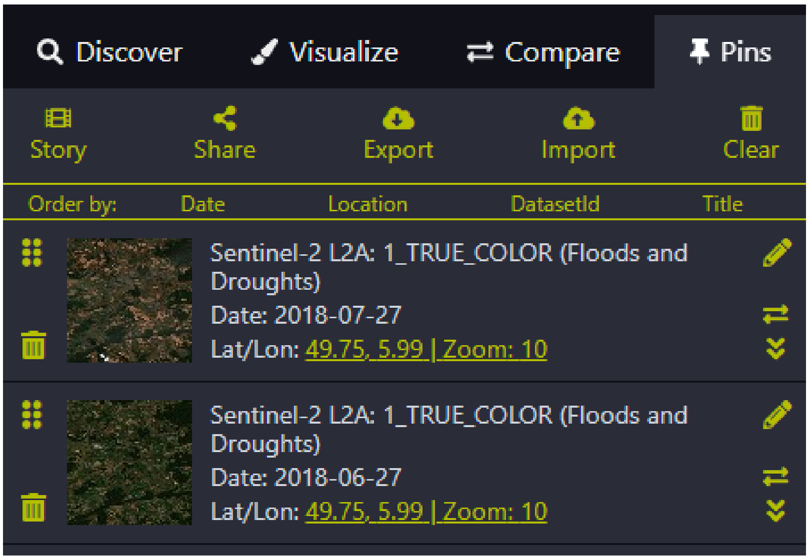
Activity B1: Compare drought satellite images side-by-side in True Color

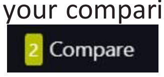
1. In adding to the image pinned in activity A5, we have to find a second drought satellite image.

2. Repeat activity A3 to search for a picture from July 2018

3. Choose the picture 2018-07-27, click visualize.

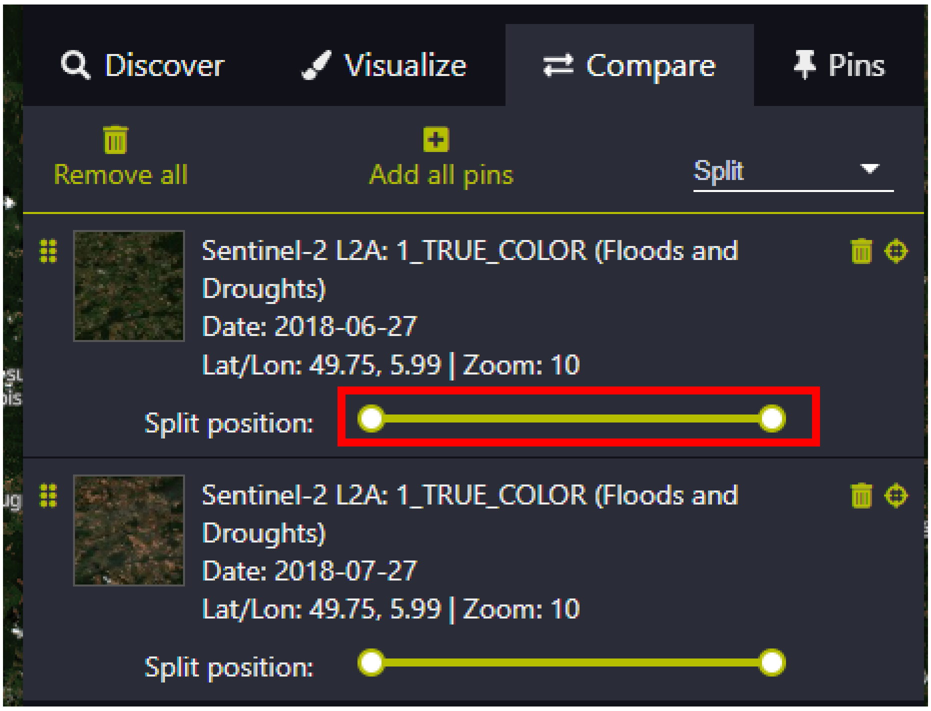
4. Pin your second satellite image to your Pins section. You should now have 2 pinned satellite images. One from 2018-06-27 and one with the date 2018-07-27.



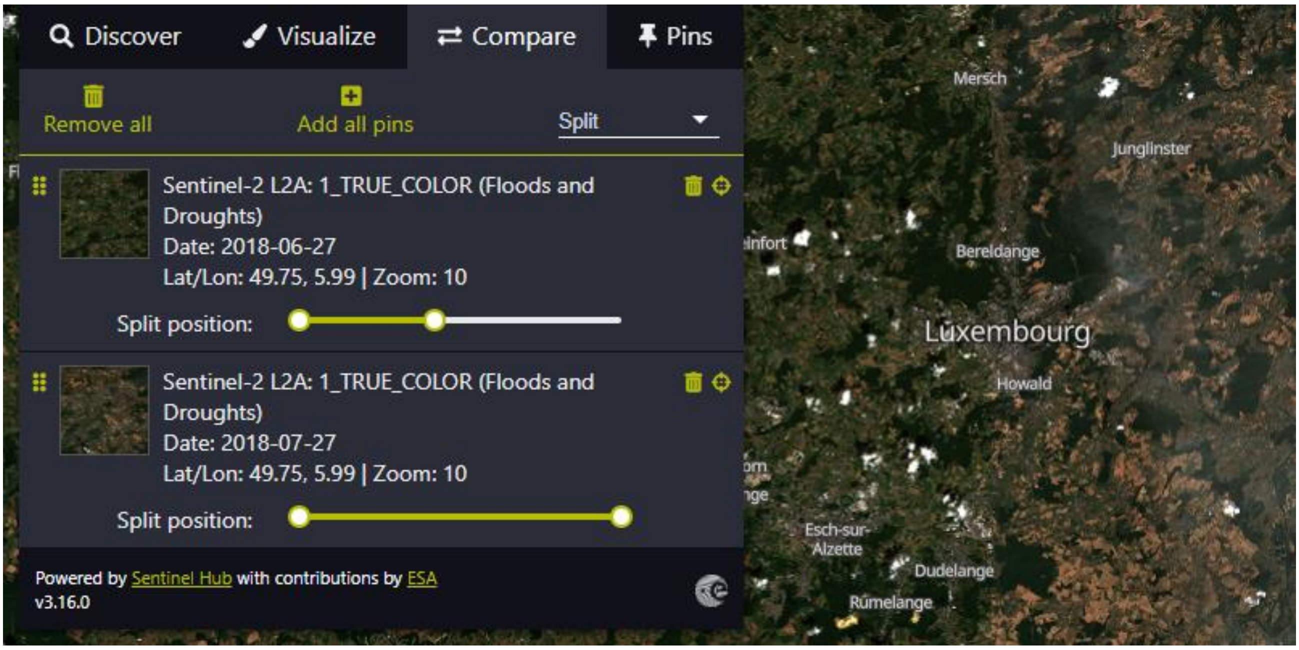
5. Click now on the compare button on the right site . Click on the compare button for every picture you want to choose for your comparison. Choose the two images. You can check the number of chosen images next to the *Compare* field 

6. Now go to the Compare section and adjust the “Split position” toggle bar to compare your two images side-by-side.

7. Analyze differences between the image with the date 2018-06-27 vs the one from 2018-07-27 using the slider



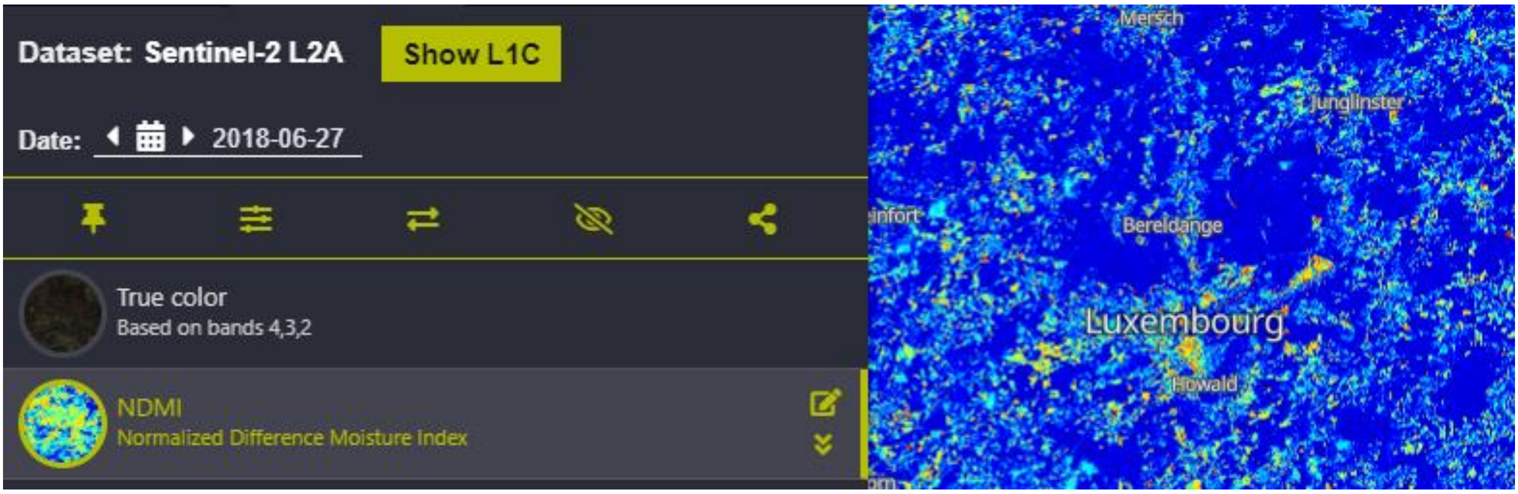
You will see the ground much dryer on the July image



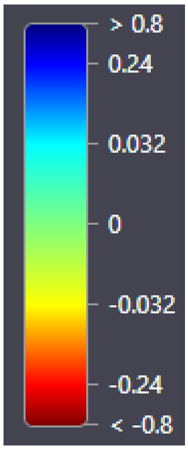
Activity B5: Compare drought satellite images side-by-side using NDMI

Comparing images using true colour is interesting but it’s not precise enough to measure the scale of the drought.

In this exercise, you will observe satellite image but this time, selecting NDMI in the “Visualize” tab, just before pinning the image



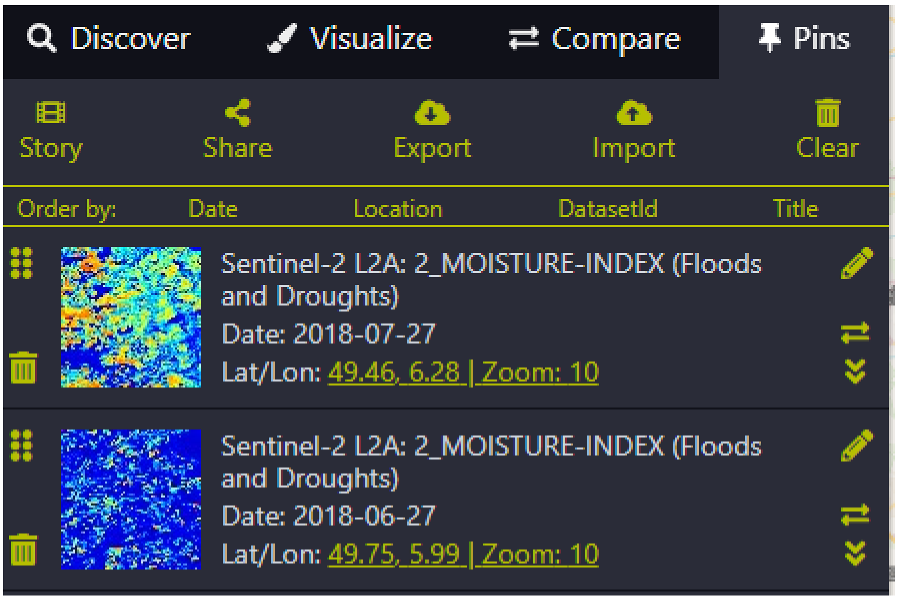
NDMI



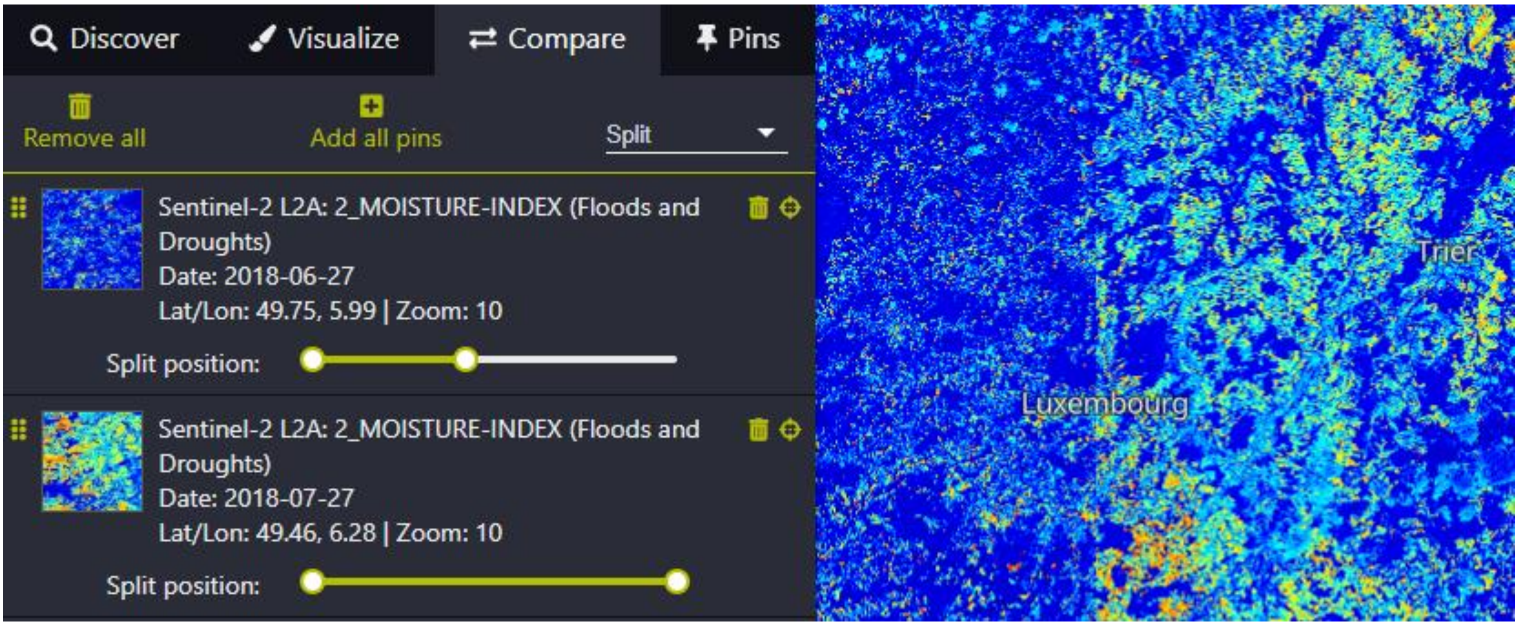
The normalized difference moisture Index (NDMI) uses visible and near-infrared images to determine vegetation water content and monitor droughts. The value range of the NDMI is -1 to 1.

Negative values of NDMI (values approaching -1) correspond to barren soil.
Values around zero (-0.2 to 0.4) generally correspond to water stress.
High, positive values represent high canopy without water stress (approximately 0.4 to 1).

You should then have the images pinned like this



This comparison provides better drought details and granularity.

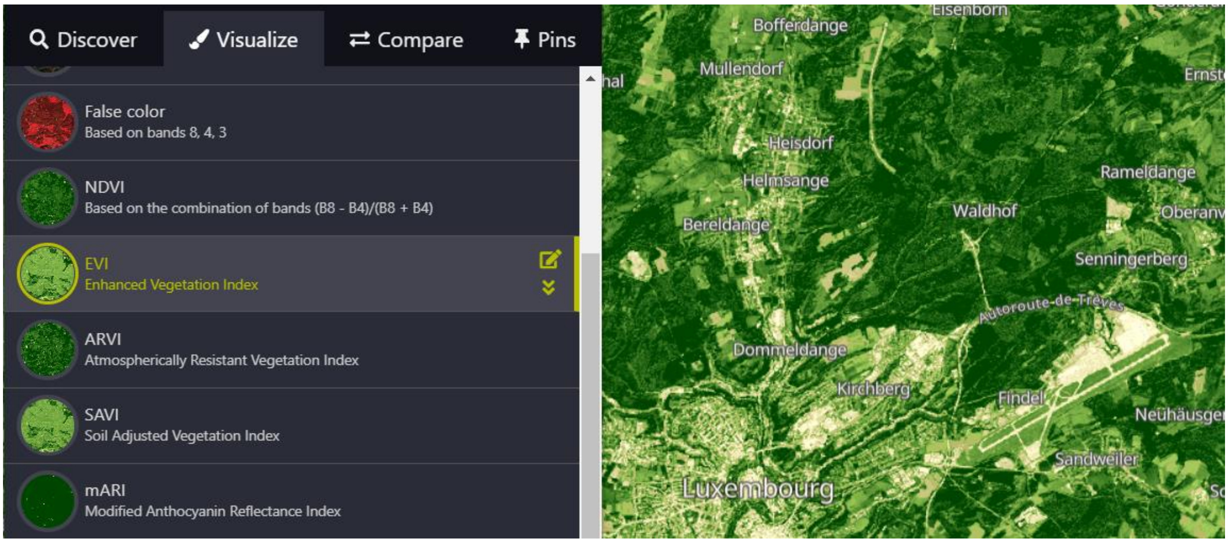


Activity B6: Compare drought impact on forest using EVI

From MeteoLux data, we know that July 2017 saw a rainfall record in Luxembourg while July 2020 saw one of the most severe drought in history.

The biggest continuous forest area in Luxembourg is the forest north-east of Luxembourg, near the Findel Airport

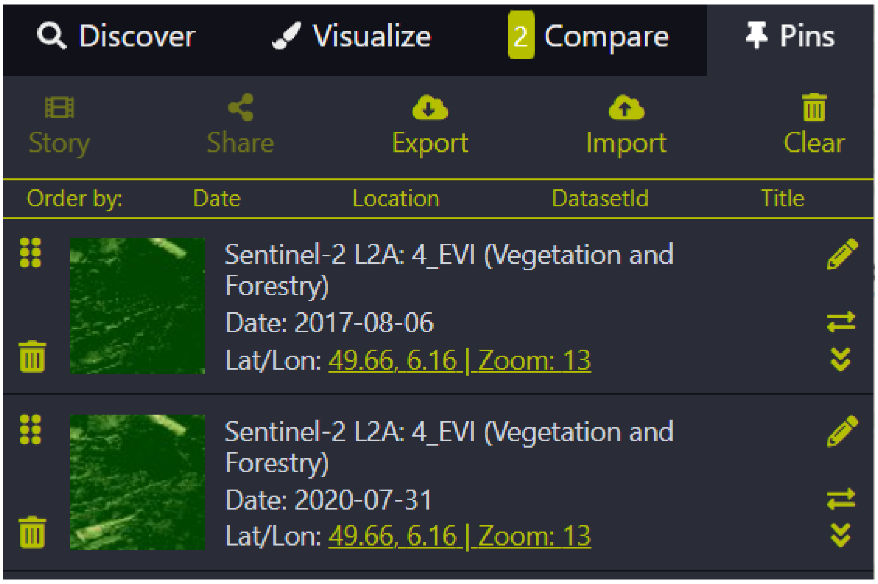
In this exercise, you have to repeat activities B1 to B4 using the same satellite image but this time, selecting EVI index in the "Visualize" tab, just before pinning the image



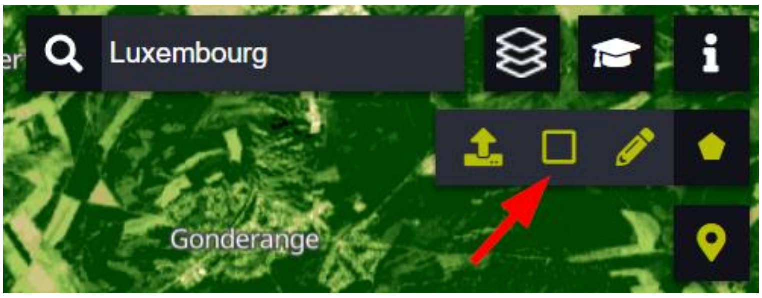
EVI

The enhanced vegetation index (EVI) is an 'optimized' vegetation index as it corrects for soil background signals and atmospheric influences. It is very useful in areas of dense forest cover. The range of values for EVI is -1 to 1, with healthy vegetation generally around 0.20 to 0.80.

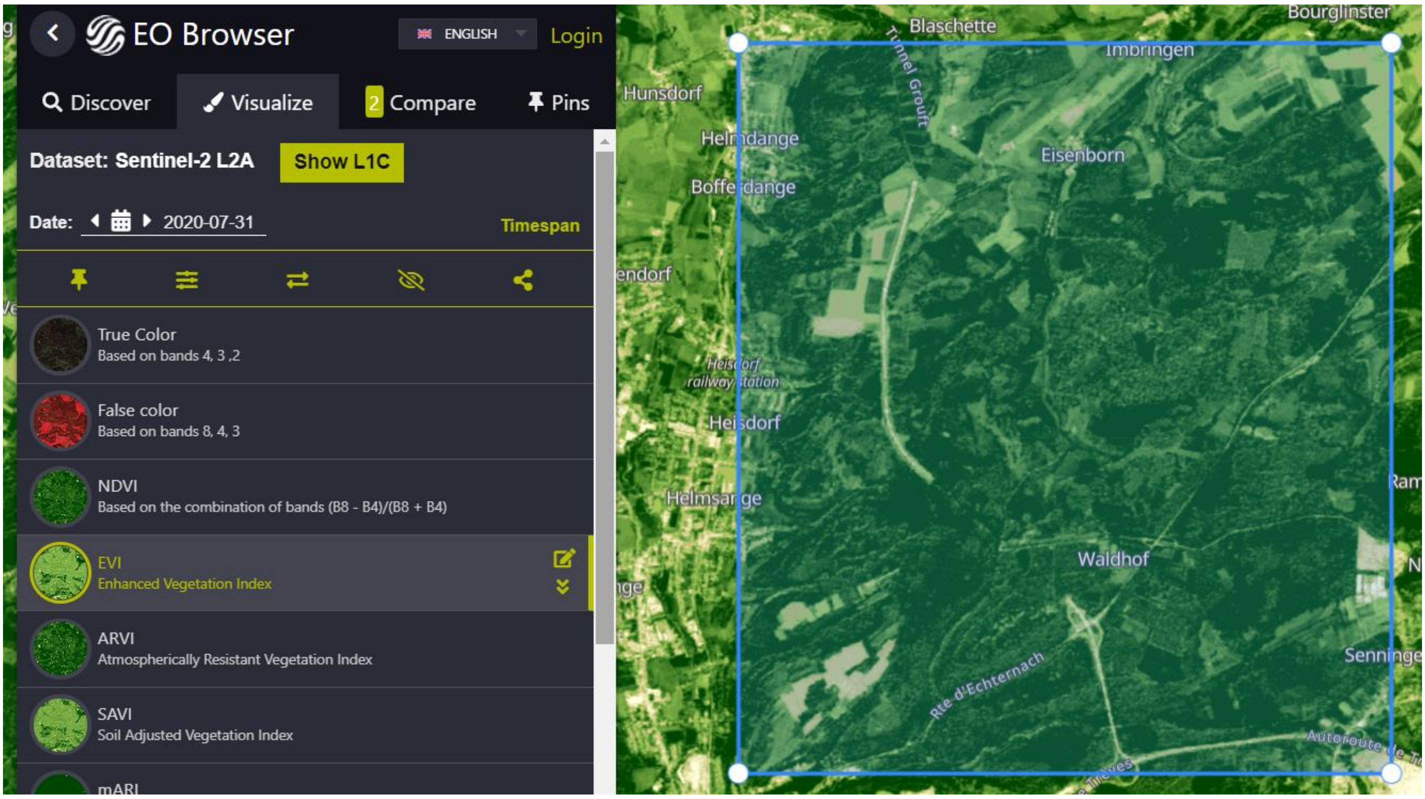
You should pin 2 satellite images of this area. One from 2017-07-31 and one with the date 2020-07-31.



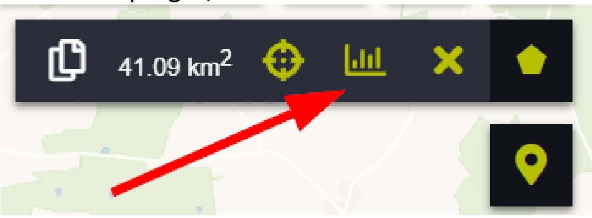
Then click on the first image and then draw a rectangle around the forest using the “restangle tool” on to the right



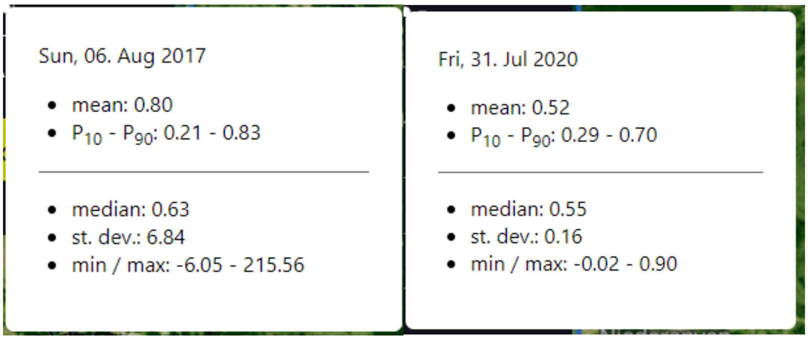
You should obtain a setup like the following picture:



One the top right, click on the “Statistics” button to obtain mean values of the EVI index over this area



You can then see that the mean EVI value at the end of July 2020 is lower than the value end of July 2017, signaling a forest suffering from the drought.



This effect is visible since this area is close to the main Luxembourg city where the temperature is even higher than average because of urban heat islands phenomena.

Urban heat islands is an urban area significantly warmer than its surrounding rural areas due to human activities and land surfaces artificialization. Concrete for instance can hold roughly 2,000 times as much heat as an equivalent volume of air.

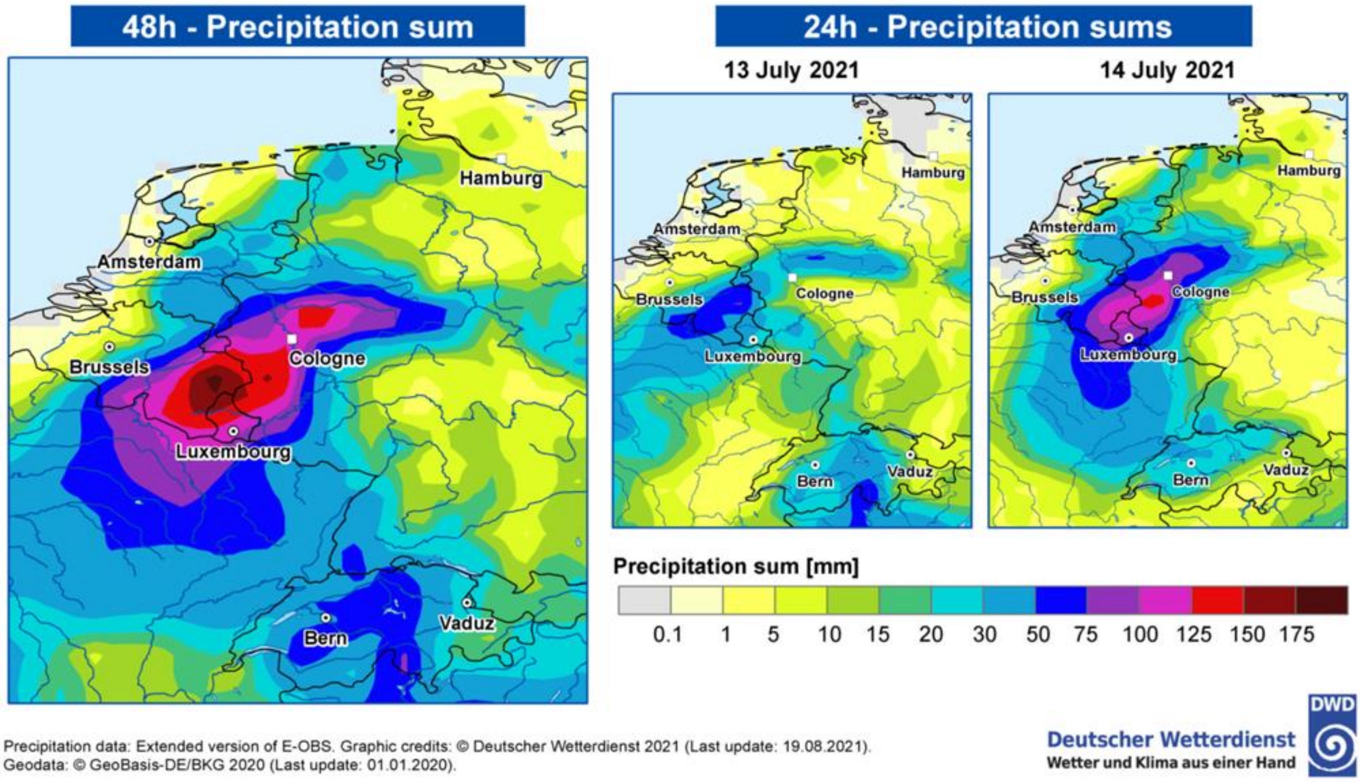
Part C: Observing floods using satellite images

From the 12th to the 15th of July 2021, heavy rainfall associated with cut-off low-pressure system led to severe flooding in Germany, Luxembourg, Belgium and the Netherlands.

The flooding resulted in at least 184 fatalities in Germany and 38 in Belgium and considerable damage to infrastructure, including houses, motorways and railway lines and bridges and key income sources. Road closures left some places inaccessible for days, cutting off some villages from evacuation routes and emergency response.

In Luxembourg, Echternach was particularly impacted.

Human-induced climate change has increased the likelihood and intensity of such an event to occur and these changes will continue in a rapidly warming climate.



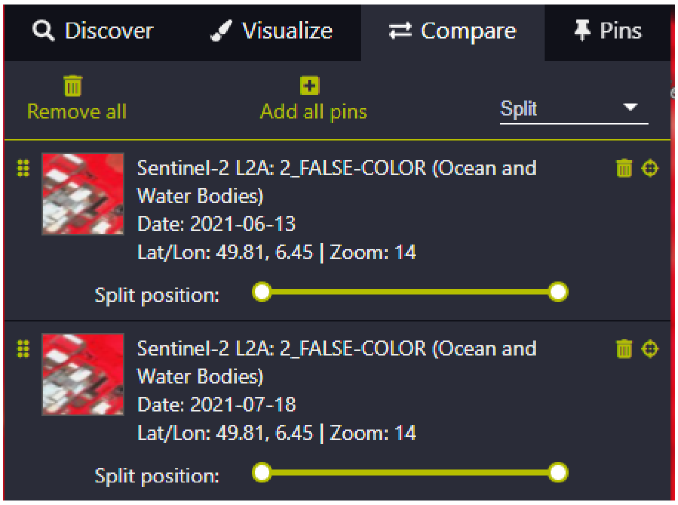
A satellite sensor can image Earth in different bands. A band is a region of the electromagnetic spectrum.
A **false color image** uses near infrared, red and green bands is commonly used to assess plant density and health, since plants reflect near infrared and green light, while they absorb red.
Cities and exposed ground are grey or tan, and water appears blue or black.

Activity C1: Compare floods satellite images side-by-side in False Color

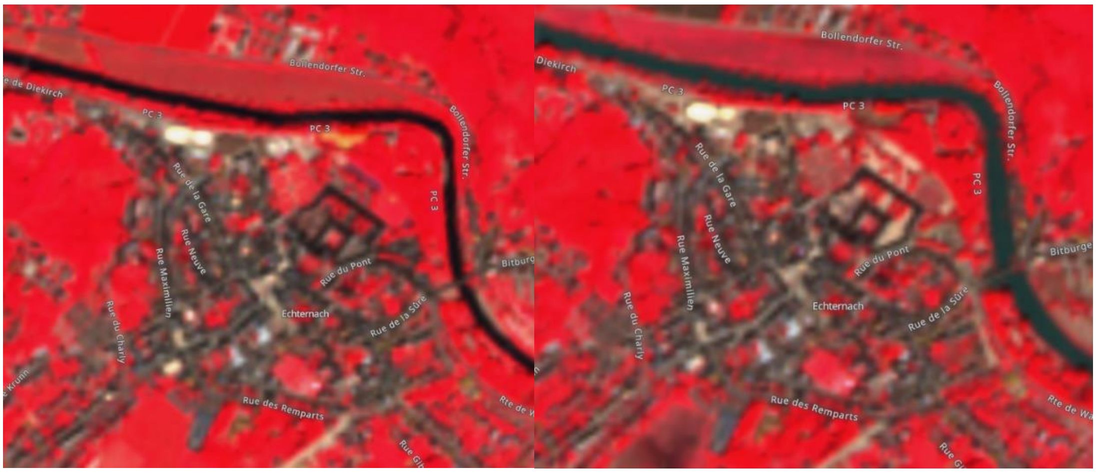
1. Select the Theme “Ocean and Water Bodies” in the “Discover” tab

2. Still using Satellite 2 and cloud coverage lower than 10%, search for images around Echternach from beginning of June until end of July 2021

3. Pin images from 2021-06-13 and 2021-07-18 in False Color and add them to the Comparison tab



4. Compare the 2 images: before and after 3 days after the flooding



→ Links

ESA resources

ESA Education Climate Change classroom resources
esa.int/Education/Climate_detectives/Classroom_resources_for_Climate_Detectives

Climate Change from Space" kit which summarize decades of Earth observations:
esamultimedia.esa.int/docs/EarthObservation/CLIMATE_KIT.pdf

ESA mobile app "Climate from Space"
esa.int/Our_Activities/Observing_the_Earth/Space_for_our_climate/Climate_at_your_fingertips

ESA Climate Change videos
esa.int/ESA_Multimedia/Keywords/Description/Climate_Change/(result_type)/videos

ESA space projects

ESA Climate Change Initiative (CCI)
http://cci.esa.int

ESA CCI greenhouse gases
http://www.esa-ghg-cci.org

ESA Earth Observation satellites
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions