Exercise with EO Browser: Vulcanology (Sentinel-2, Sentinel -5P)

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Learning goals

- Define suitable search criteria (time range, area, satellite, satellite product, visualization type) in EO Browser for a case study in vulcanology
- Get a basic introduction to the concepts of satellite revisit and coverage
- Understand the different levels of processing for Sentinel-2 products (L1C and L2A)
- Interpret Sentinel-5P SO_2 maps
- Understand the concepts of RGB visualizations, and customize them in EO Browser
- Export images in EO Browser
- Compare images from different dates in EO Browser
- Create a timelapse in EO Browser

Overview

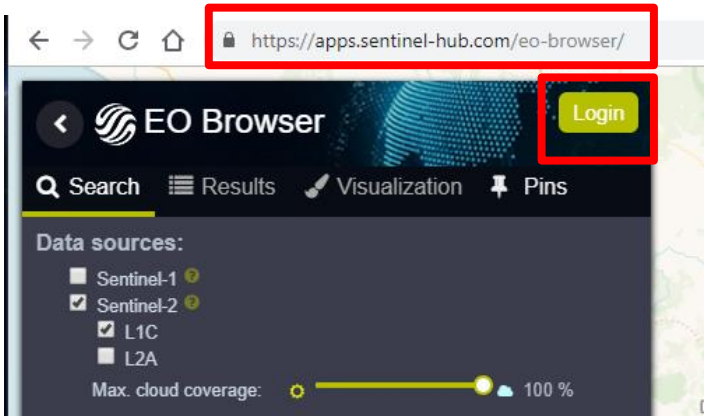
1. **Exercise 1: Sentinel-2 for Etna lava flow**
    - Image search
    - Note 1- Sentinel-2 processing levels (L1C and L2A)
    - RGB visualization for lava flow
    - Note 2- basics of remote sensing: atmospheric interference
    - Custom rendering with different RGBs
    - Export visualization
    - Compare images
    - Create Timelapse
    - Note 3- Sentinel-2 revisit and coverage

2. Exercise 2: Sentinel-5P for Etna atmospheric emissions
    - Image search
    - Image interpretation
    - Additional materials

1. Exercise 1: Sentinel-2 for Etna lava flow

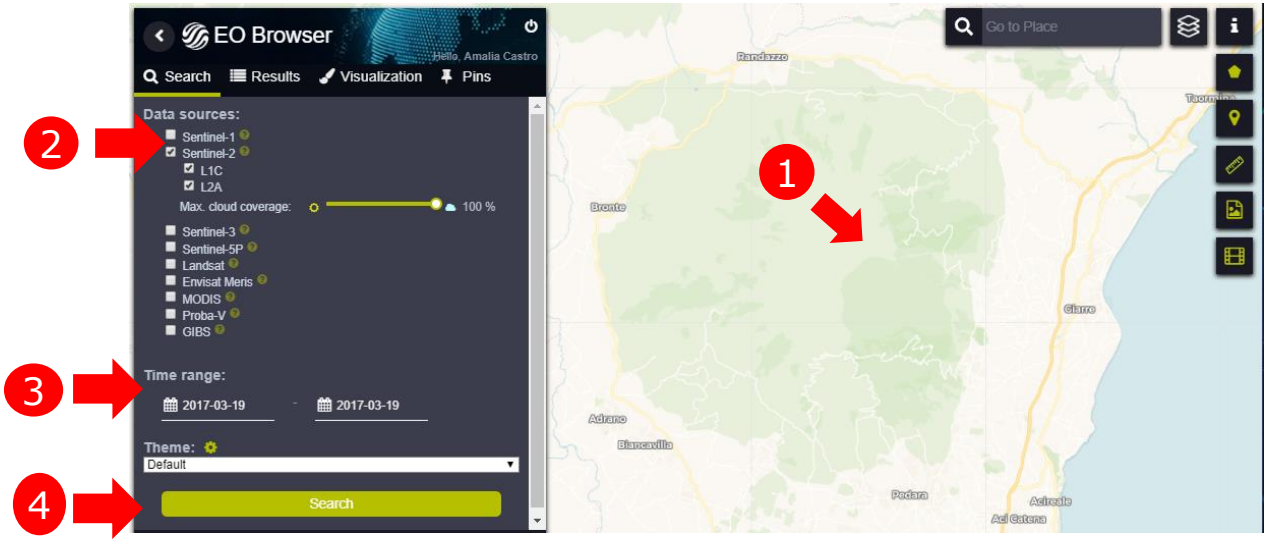
http://apps.sentinel-hub.com/eo-browser/

Register **for free** with an email address, to have full access to all the tools.



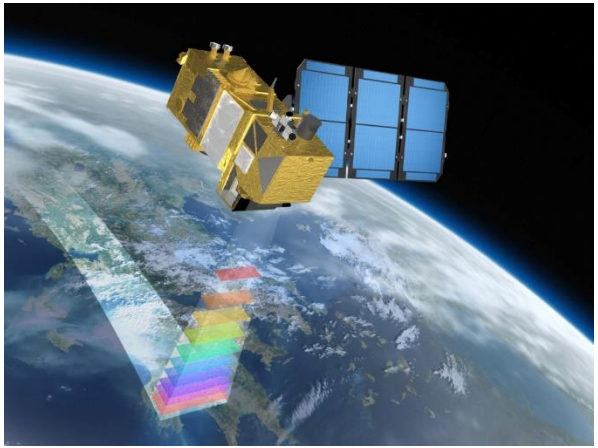
1. Exercise 1: Sentinel-2 for Etna lava flow

1. **Where to search?** Navigate to the Etna area (simply use your mouse to move the display as seen below. There is no need to upload polygons or enter coordinates)
2. **Which sensor?** Select **Sentinel-2 (both L1C and L2A)* See Note 1 in next slide**
3. **When to search?** Define Time range: **2017-03-19 to 2017-03-19 (yes, the same day for both!)**
4. Click Search



1. Exercise 1: Sentinel-2 for Etna lava flow– **NOTE 1**

When the satellite acquires the image, it sends it to a **ground station**. But the image is **not yet ready to be used** because its quality is not yet good enough!



A simple explanation of this is that the image has **geometric distortions** (e.g. due to the rotation of the earth) and the values recorded are influenced by the fact that the **atmosphere absorbs** part of the radiation.

1. Exercise 1: Sentinel-2 for Etna lava flow– **NOTE 1**

But what does L1C and L2A mean?

As we just said, Sentinel-2 acquires an image **over a certain area**, and then sends it to a **ground station in Earth**. This image is called **Level 0**, because **no corrections** have been applied to it yet: the image still presents **distortions** that affect its geometry and the values recorded. Corrections are applied **gradually** (not all of them at once). Every time a correction is applied, we say the **level of the image increases** (e.g. Level 1-A, then Level 1-B, etc).

Level 1C (L1C) images have had **all the corrections done except for the atmospheric correction**: the distortion of the atmosphere is still present. The values represent what the satellite measures at the **top of the atmosphere** (not at the bottom of the atmosphere!).

After the algorithm that makes this last correction is applied, the outcome is called a **Level-2A product (L2A)**. L2A products therefore represent the measurement at the **BOTTOM of the atmosphere**, i.e. at the **level of the ground.**

1. Exercise 1: Sentinel-2 for Etna lava flow– **NOTE 1**

Ideally we would only use L2A products, but when Sentinel-2 started acquiring images, **the algorithm that creates L2A products was not applied to L1C images in an automatic way**. This means L2A images of that period do not show in EO Browser.

Users needed to apply the algorithm themselves (by downloading the L1C image, opening it in the ESA SNAP software, and using the Sen2Cor plugin in that software to create the L2A product).

It was only later on that the algorithm started being **applied automatically** to L1C products: L2A products became available **as routine** and could therefore **appear in EO Browser**.

This is the reason we prefer to select **L1C AND L2A:** to be sure that, whenever we search for an image in EO Browser, we will be able to find one. Otherwise, if we only selected L2A and we were looking for older dates (e.g. end of 2015), we may not find L2A results in EO Browser…

More info at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/processing-levels and https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/product-types/level-2a

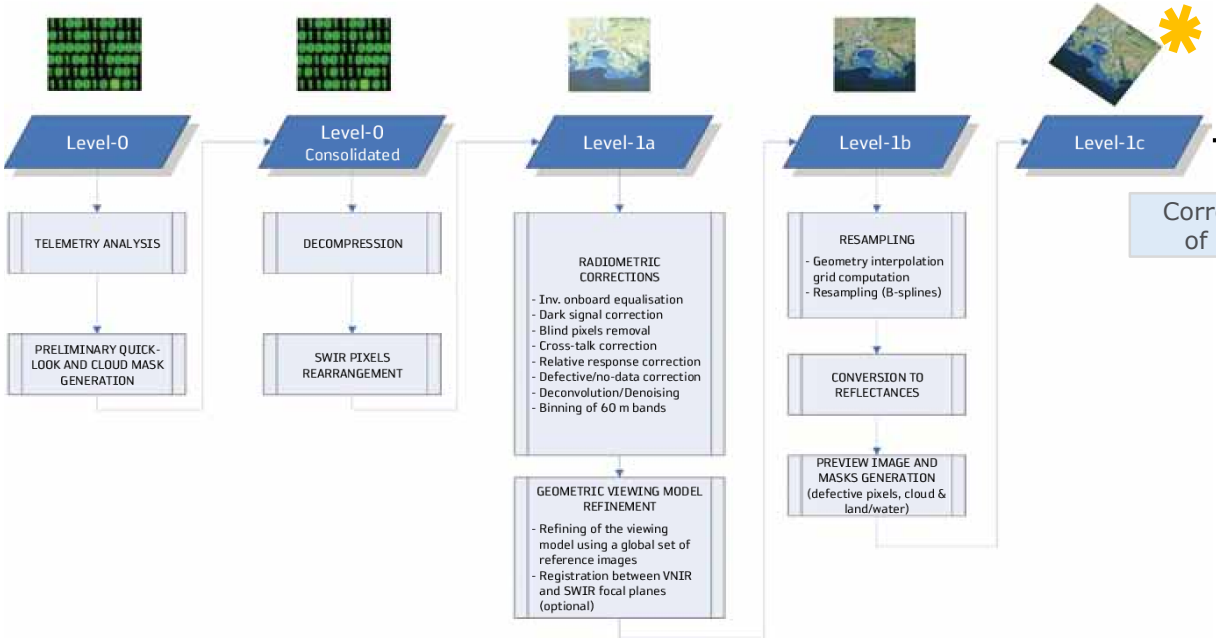
ESA SNAP Software: https://step.esa.int/main/toolboxes/snap/

Sen2Cor plugin: https://step.esa.int/main/third-party-plugins-2/sen2cor/

1. Exercise 1: Sentinel-2 for Etna lava flow– **NOTE 1**

As we said, the original image received by the ground station is called a Level-0 image.

After each correction, the level increases.



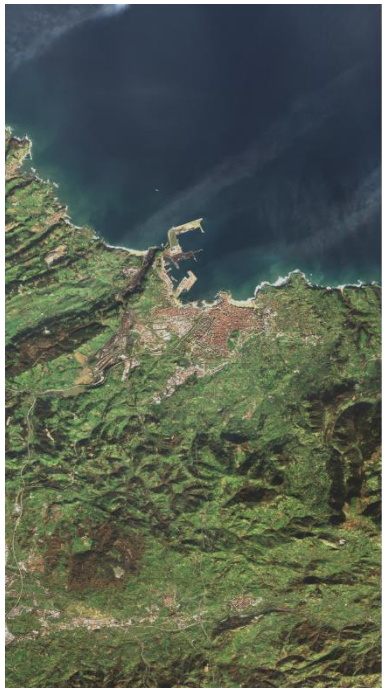
Subset of Level-1C

Subset of Level-2A

Note the image used as example (✱) for L1A to L1C is different than the image whose **subset** illustrates L1C and L2A (✱): since it is a subset, its geometry is different. And since it is taken over a different area, the coastline and features look different.

1. Exercise 1: Sentinel-2 for Etna lava flow– **NOTE 1**

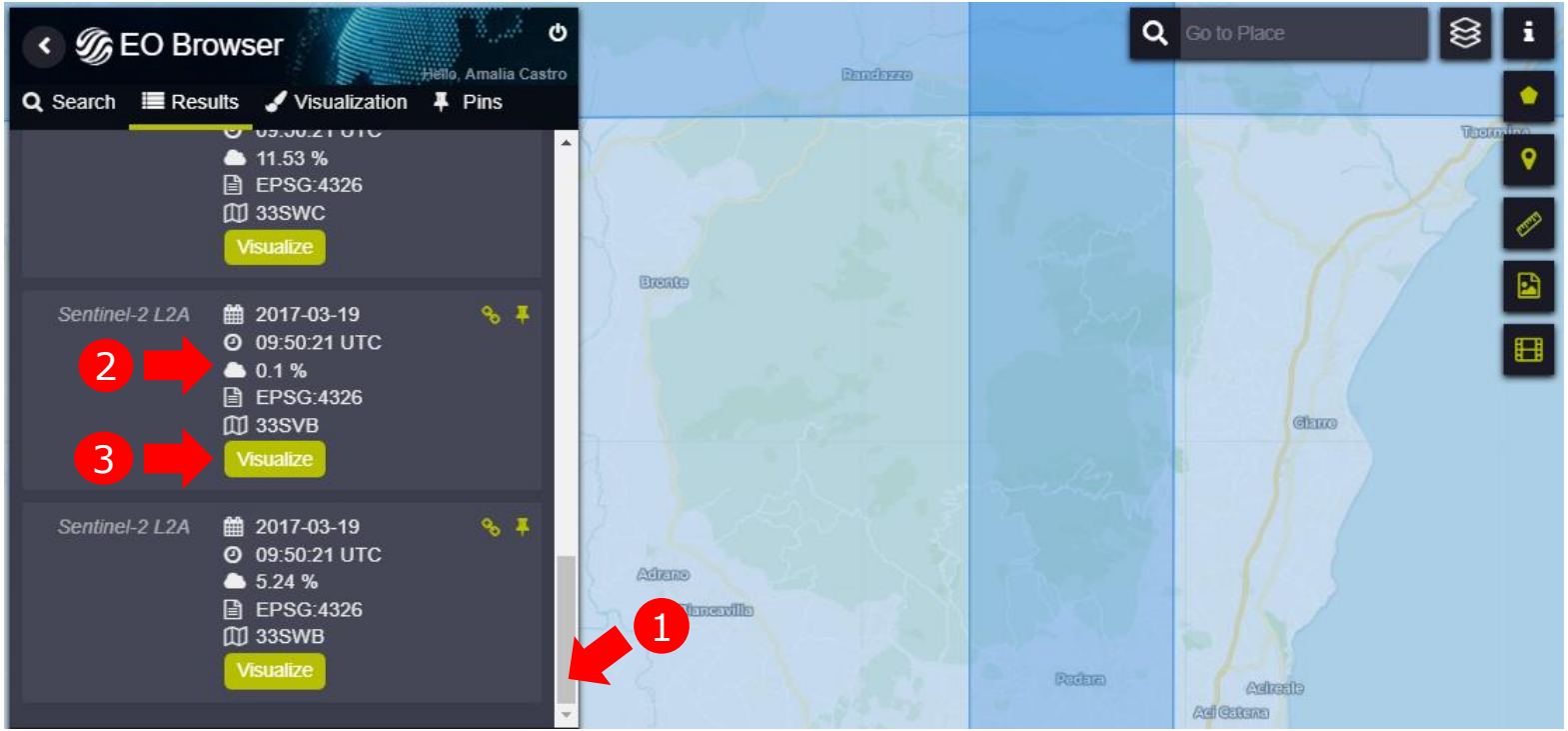
Subset of a Level-1C image (**before** correcting for the effects of the atmosphere)



Subset of a Level-2A image(**after** correcting for the effects of the atmosphere)

1. Exercise 1: Sentinel-2 for Etna lava flow

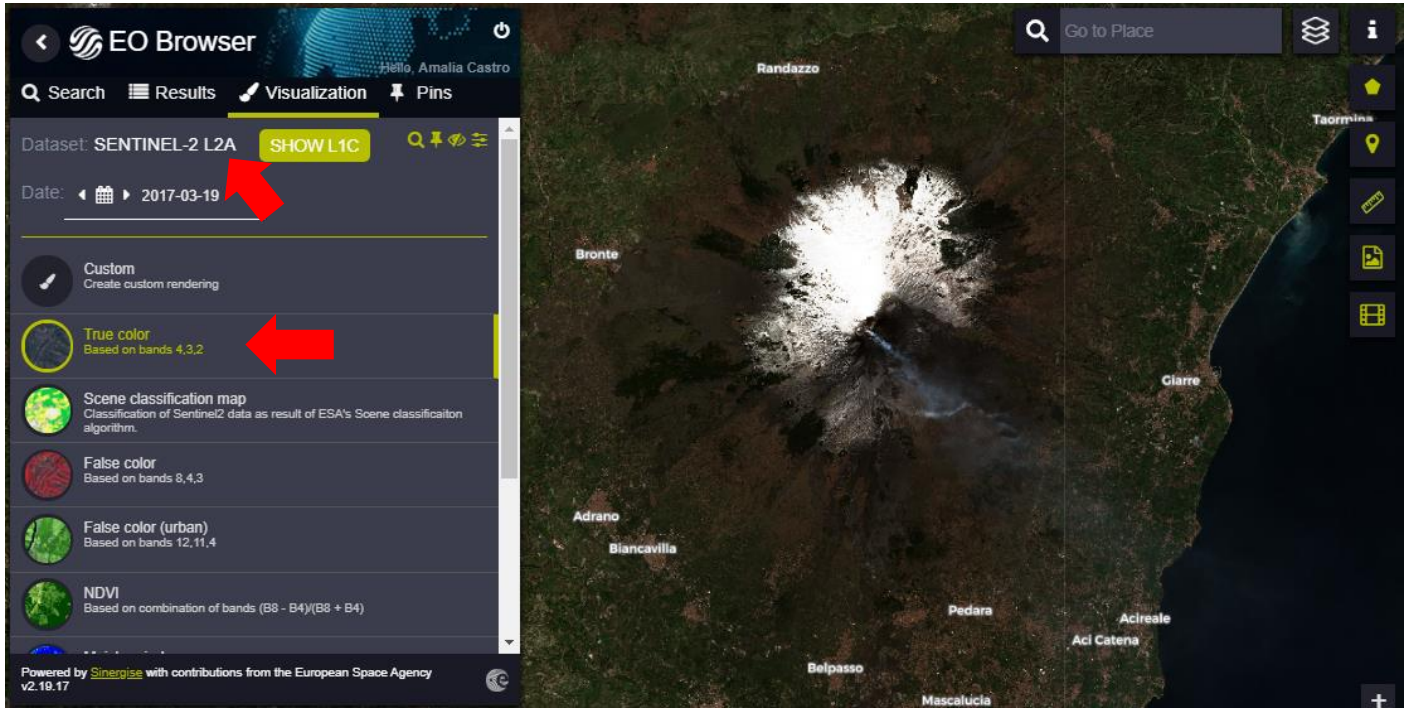
1. Scroll down
2. Select the image with the **lowest cloud cover (0.1%)**
3. Click Visualize



1. Exercise 1: Sentinel-2 for Etna lava flow

Note this image is a **Level-2A** product (the distortions due to the atmosphere have been **removed**).

Try seeing the **lava flow** with the visualizations that are available by default (**True Colour**, False colour, False colour (urban)) or in the maps (NDVI, Soil Moisture…). Do you manage to see it?



1. Exercise 1: Sentinel-2 for Etna lava flow

True Colour is **a way of combining the bands of the satellite** that creates an **image which resembles what our eyes naturally see**. This is useful because it is **easier to interpret!**

However, remember that satellite images are **different from pictures** because they **record the radiation that our eyes cannot see!** Therefore other visualizations (other combinations of bands) can give us **additional information**, even if they look “strange”.

For example, the **False Colour** visualization is a way of displaying bands that creates an image where any areas with vegetation appear very clearly and in colour red. This is handy when you need to know where there is vegetation, because it is clearly visible.

The **False Colour (urban)** and the **SWIR** visualizations allow you to see the lava flow.

1. Exercise 1: Sentinel-2 for Etna lava flow

But how are band combinations created? What does “Based on bands 4,3,2” mean?

When we ask the software to display an image, the computer gives a colour for each pixel, and **that colour is a combination** of **different proportions** of red, green and blue.

The computer decides the proportions for each colour **based on the value of the pixel** in the **band that is assigned** to the colour channel.

RED channel = Band 4

GREEN channel = Band 3

BLUE channel = Band 2

For example:

If a pixel shows green → there are higher values in the band that we assigned to **GREEN** (in this example, vegetation).

If a pixel shows brown → there is a combination **in some proportions** of the values in the bands assigned to **RED**, **GREEN** and **BLUE.** This combination creates a brown colour (in this example, bare soil areas).

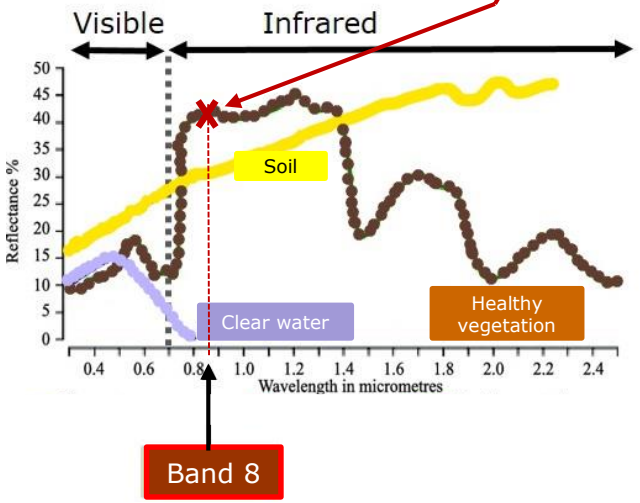
The fact that those different proportions exist is what allows for a wide range of colours in the display!

1. Exercise 1: Sentinel-2 for Etna lava flow

Choosing a different combination of bands, we create what is called a **False Colour** display. The image looks different than how our eyes see the world, and it is a way to highlight vegetation.

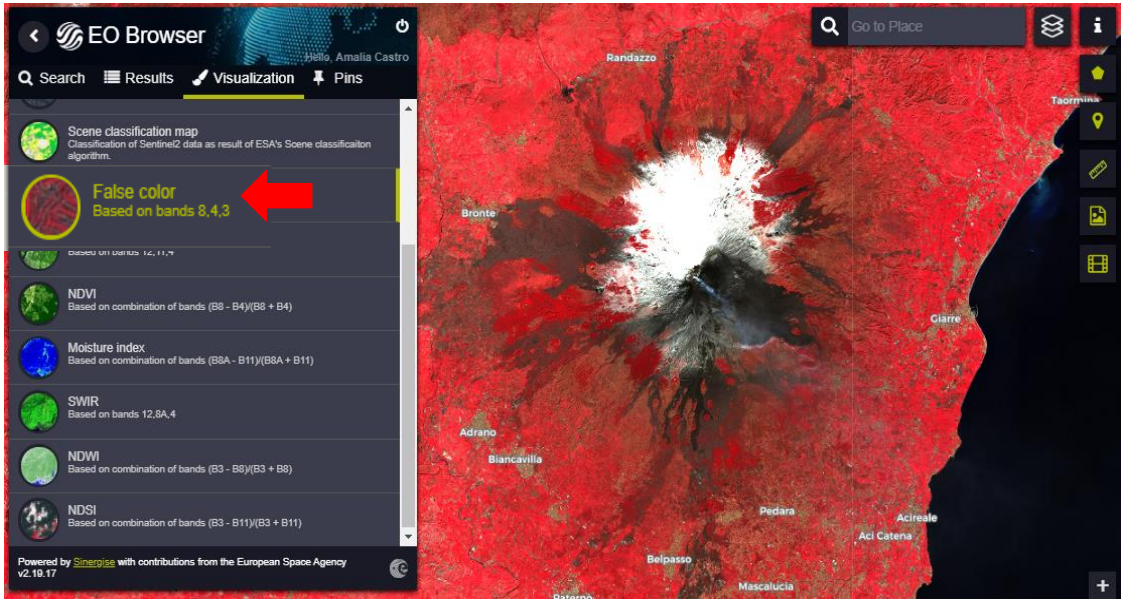
Pixels that look red are those that have **higher values** in Band 8, because in False Colour, Band 8 is the one assigned to the **RED** channel.

But **we don't see the lava flow….**



Graph modified from Kumar, D Nagesh & Tv, Reshmidevi. (2013). Remote Sensing Applications in Water Resources. Journal of the Indian Institute of Science. 93. 163-188. Available at https://www.researchgate.net/figure/Spectral-reflectance-curves-of-different-land-cover-types-Modified-from_fig4_245538996

RED = Band 8, **GREEN** = Band 4, **BLUE** = Band 3



1. Exercise 1: Sentinel-2 for Etna lava flow

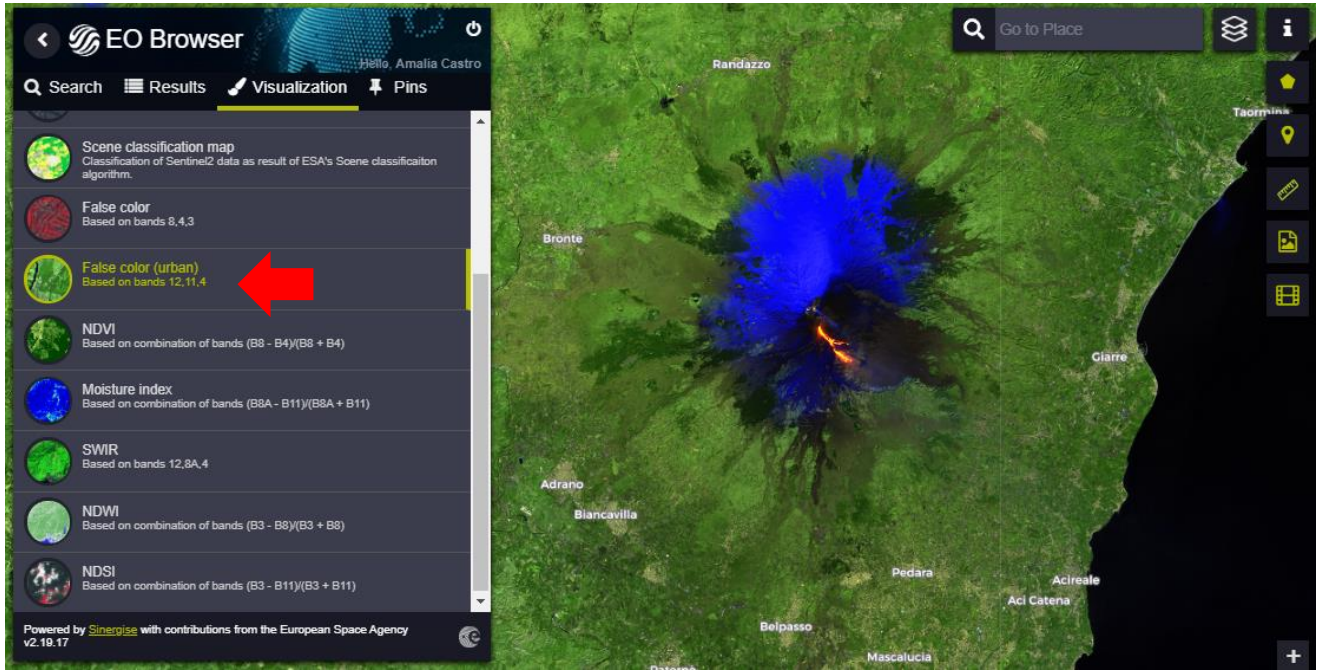
The visualization called **False Colour (urban)** shows the lava flow nicely in red. Why? Because the pixels in the area of the lava flow had higher values in Band 12, which is the one assigned to **RED**.

RED = Band 12

GREEN = Band 11

BLUE = Band 4

But why Band 12?



1. Exercise 1: Sentinel-2 for Etna lava flow

- When first ejected from a volcano, the **temperature of lava** can vary between 700 and 1200°C.

- At these temperatures, the **main radiant emissions** are in the Thermal Infrared (TIR), middle Infrared (MIR) and Short Wave Infrared (SWIR) parts of the Electromagnetic spectrum.

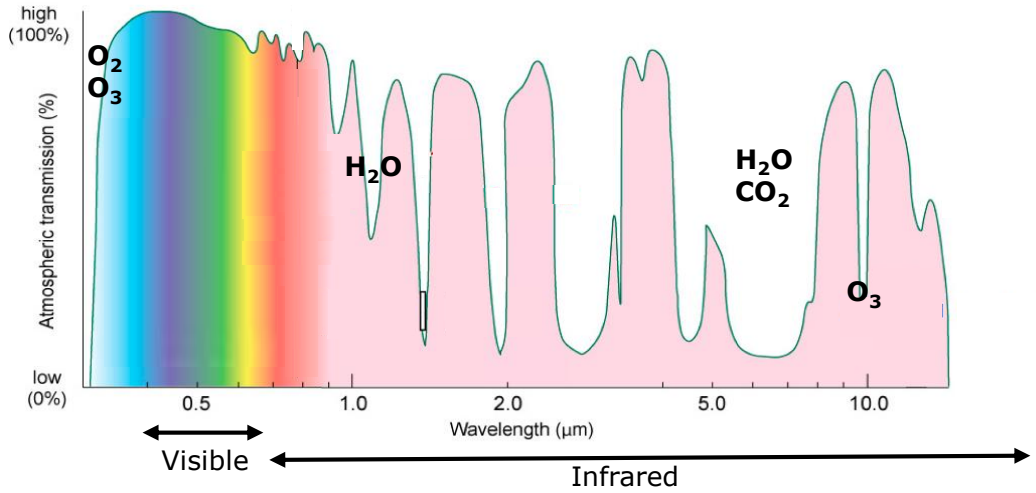
- Band 12 is situated in the Short Wave Infrared part of the Electromagnetic spectrum, at 2190 nm.

- Therefore, as long as the lava is incandescent, **Band 12 will be able to show it** to us.

- And since we have assigned **Band 12 to the RED channel**, the (very hot) lava will look red.

NOTE 2 - Basics of Remote Sensing: Atmospheric interference

Reminder of the basics of Remote Sensing: **atmospheric windows**.

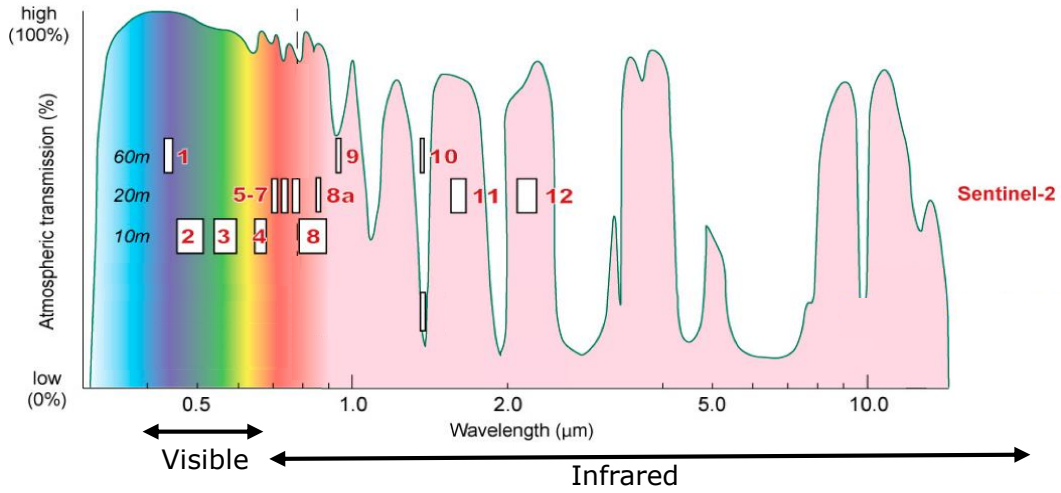


Original image from Kääb, A.; Winsvold, S.H.; Altena, B.; Nuth, C.; Nagler, T.; Wuite, J. Glacier Remote Sensing Using Sentinel-2. Part I: Radiometric and Geometric Performance, and Application to Ice Velocity. Remote Sens. 2016, 8, 598, available at https://www.mdpi.com/2072-4292/8/7/598/pdf/1

NOTE 2 - Basics of Remote Sensing: Atmospheric interference

Sentinel-2 takes measurements in **different parts of the spectrum** with different bands. Observe that bands are located where the **atmosphere transmits more radiation**!

In the **False Colour (urban)**, Bands 12, 11 and 4 are used.



- Band 1 = 443 nm
- Band 2 = 490 nm
- Band 3 = 560 nm
- **Band 4 = 665 nm**
- Band 5 = 705 nm
- Band 6 = 740 nm
- Band 7 = 783 nm
- Band 8 = 842 nm
- Band 8A = 865 nm
- Band 9 = 940 nm
- Band 10 = 1375 nm
- **Band 11 = 1610 nm**
- **Band 12 = 2190 nm**

Original image from Kääb, A.; Winsvold, S.H.; Altena, B.; Nuth, C.; Nagler, T.; Wuite, J. Glacier Remote Sensing Using Sentinel-2. Part I: Radiometric and Geometric Performance, and Application to Ice Velocity. Remote Sens. 2016, 8, 598, available at https://www.mdpi.com/2072-4292/8/7/598/pdf/1

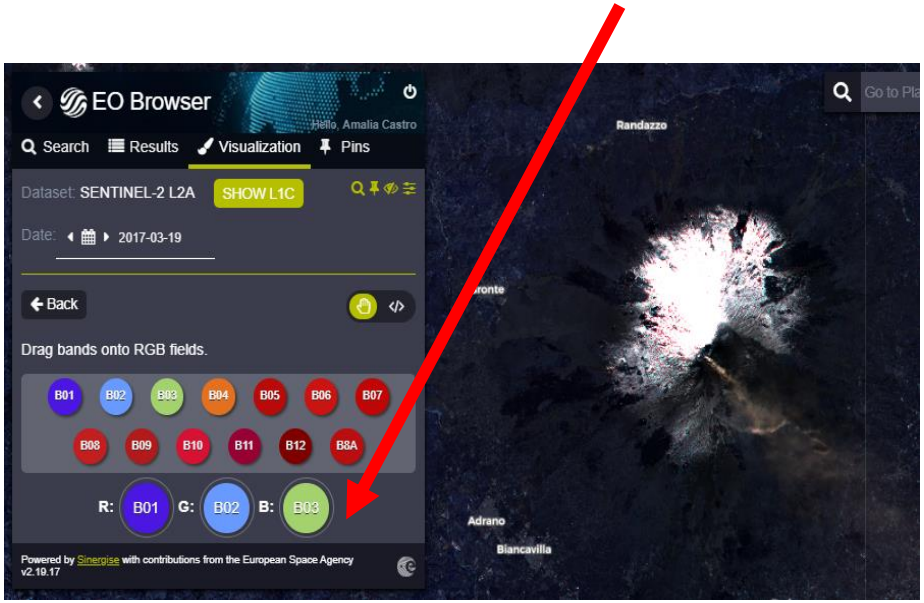
1. Exercise 1: Sentinel-2 for Etna lava flow

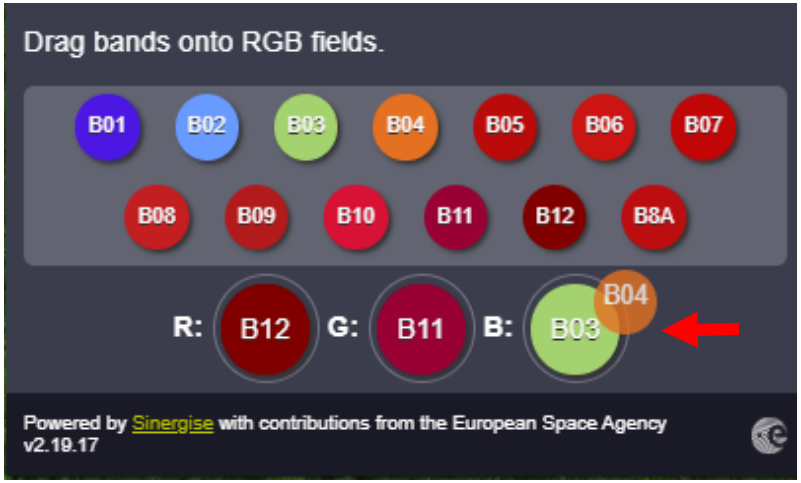
The visualization **False Colour (urban)** gives you this pre-defined combination of bands. But you can also **re-create it manually**, or even explore by **creating your own combinations!**

1. Exercise 1: Sentinel-2 for Etna lava flow

Select **Custom rendering.** You will see the default selection of bands (**R**=B01, **G**=B02, **B**=B03), which does not look very useful in our case. We want to have **R=B12, G=B11, B=B04.**

Click on the circles containing each band (B12, B11 and B04), and drag them to the R, G or B circles correspondingly.



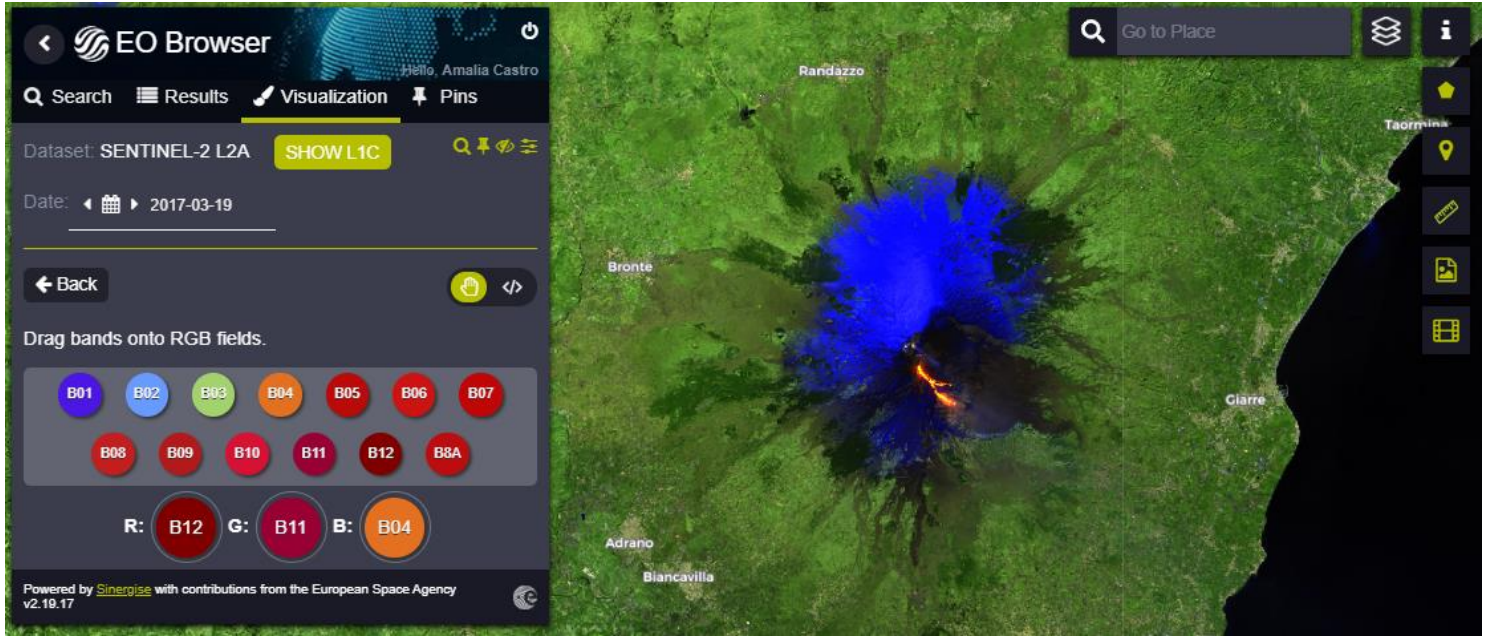


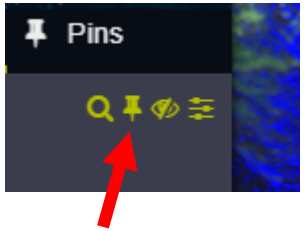
1. Exercise 1: Sentinel-2 for Etna lava flow

This is how you have **manually** created the same as the **False Colour (urban)** visualization.

Snow can now be differentiated from smoke & clouds.

Pin the image in order to save it.

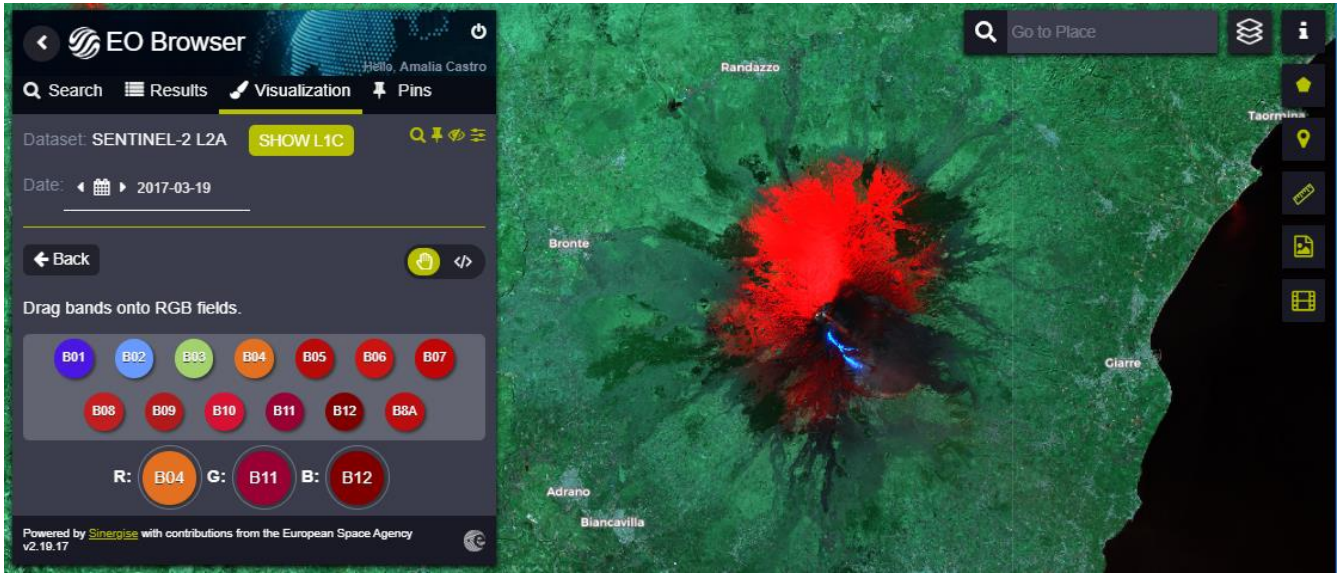




1. Exercise 1: Sentinel-2 for Etna lava flow

You can **explore using other bands combinations**, to make sure you understand how **RGB** displays work.

For example, if you use this combination below, why does the **snow look red** and **the lava blue**? **R=B04, G=B11, B=B12.**



1. Exercise 1: Sentinel-2 for Etna lava flow

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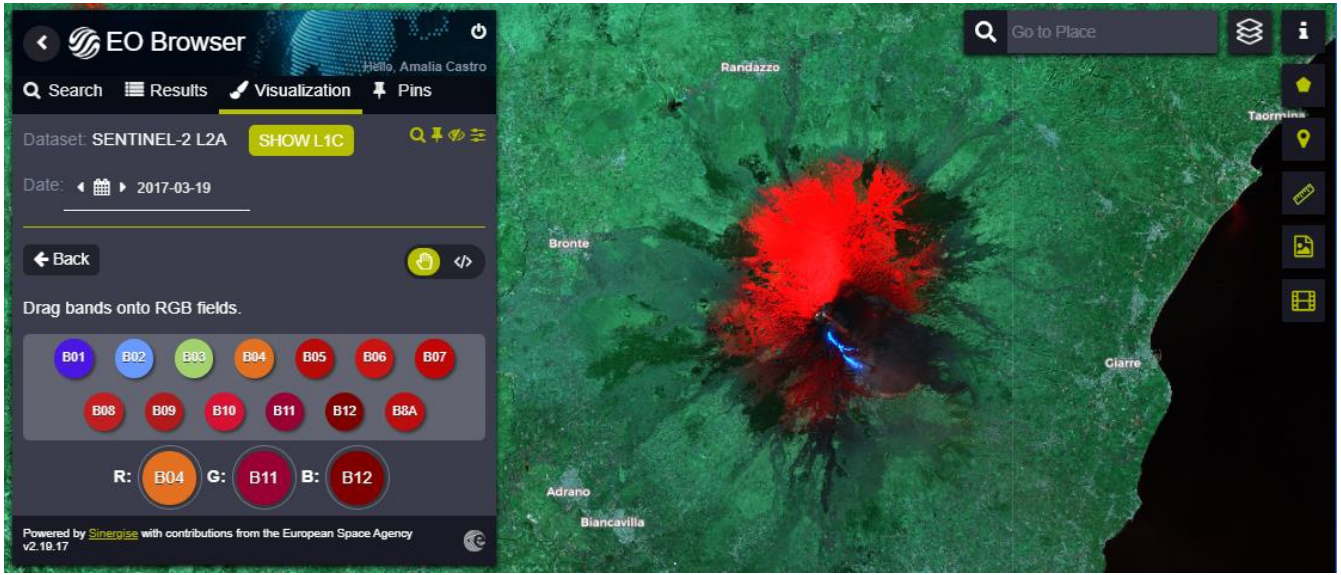


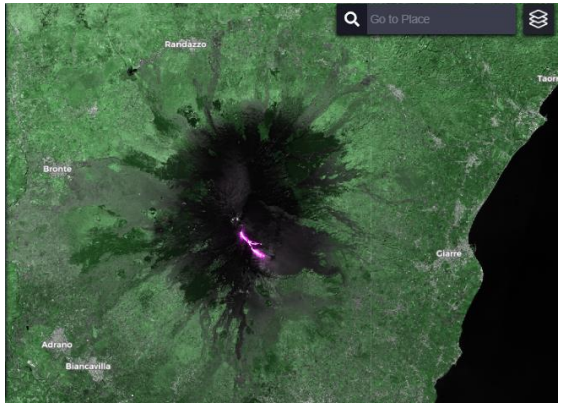
Answer: because the lava has higher values in B12, and B12 is assigned to the **BLUE** colour.

1. Exercise 1: Sentinel-2 for Etna lava flow

IMPORTANT TO KNOW: when you want to **visualize hot lava flows**, you should always use the **bands in the Short Wave Infrared** part of the Electromagnetic spectrum (like **B12**).

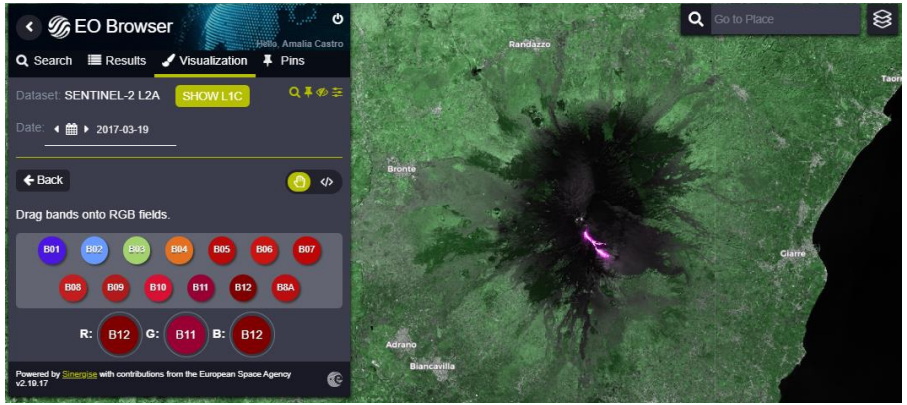
But you **do not need to assign it to the RED colour** of the display if you don't want to! For us, fire or hot lava is usually thought of as red, that is why a display with red lava is **more intuitively understood**. But it is **not wrong** to show it in a different colour, as long as you **understand** the mechanism behind!

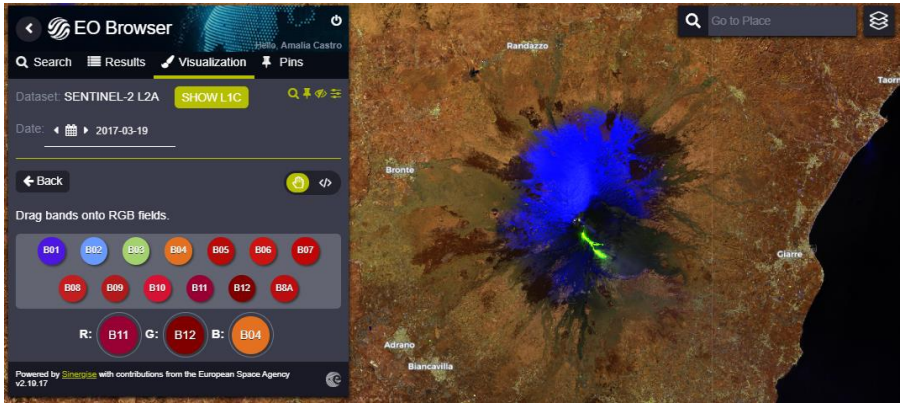
- **A small game:** Can you try to recreate those beautiful displays?



1. Exercise 1: Sentinel-2 for Etna lava flow

Answer:

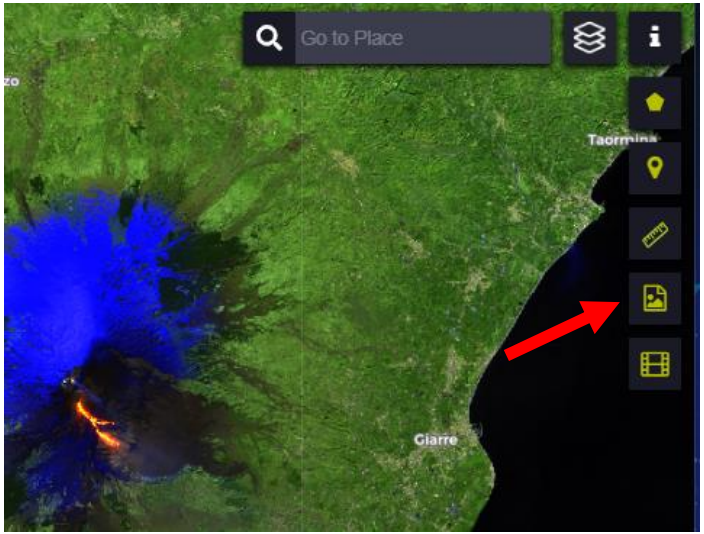


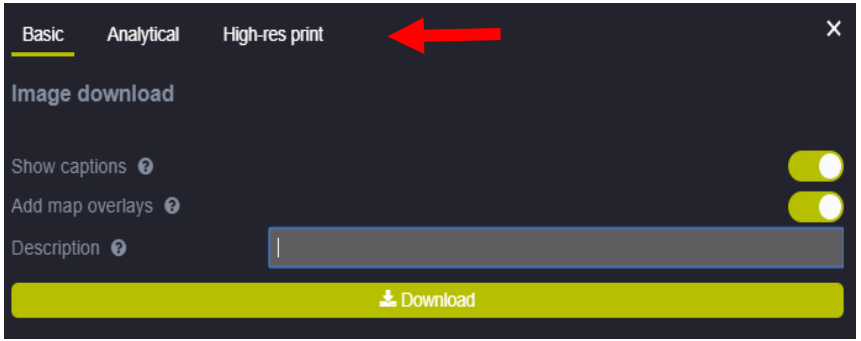


1. Exercise 1: Sentinel-2 for Etna lava flow

In EO Browser you can also **export** images. When you have a **display that you like** and that you understand, export it by clicking on the **Save icon** (right side of the screen). Then select the **format and resolution** you want (in Basic, Analytical or High-res print).

Note you will **need to be logged in EO Browser** to have this functionality! Otherwise it will not appear.





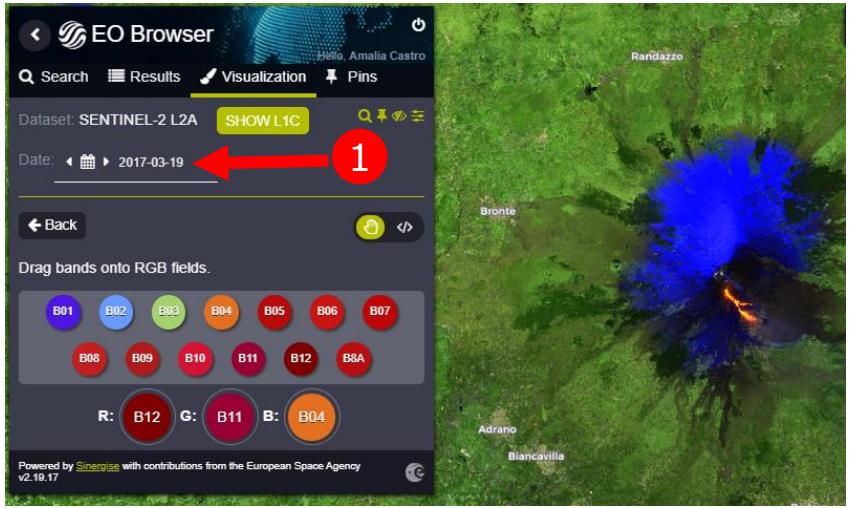
1. Exercise 1: Sentinel-2 for Etna lava flow

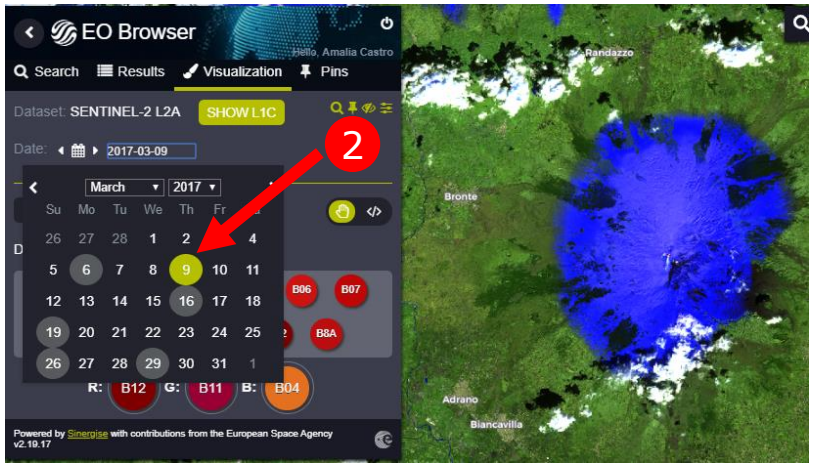
Next let’s find out **how to compare two images**, to see the start of the eruption.

1. Exercise 1: Sentinel-2 for Etna lava flow

This is a shortcut to search for images:

1. **Click the calendar next to "Date"** (You **don't** need to go back to Search like we did to find the image from 2017-03-19 and repeat all the steps)
2. Select the **2017-03-09** and the image will display with the same band combination.
3. Notice the clouds and…the absence of lava flow. The **eruption had not started yet** that day.

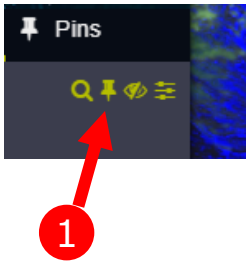


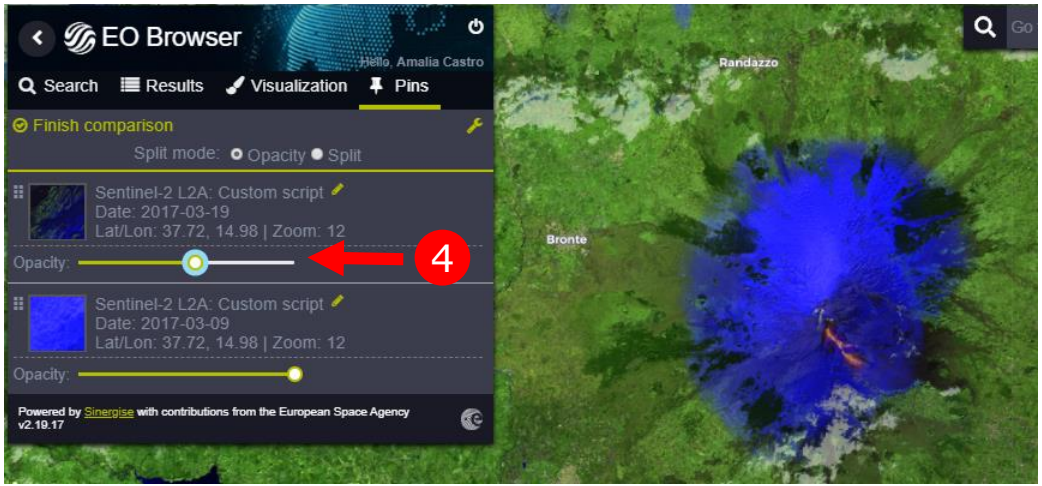


1. Exercise 1: Sentinel-2 for Etna lava flow

To compare both images we will **overlay them** (put one on top of the other) and play with the **transparency** to visualize the change:

1. Pin this image from **2017-03-09**
2. Go to Pins: the images you have saved by “pinning” them earlier are stored here
3. Click Compare
4. **Play with the transparency sliders**

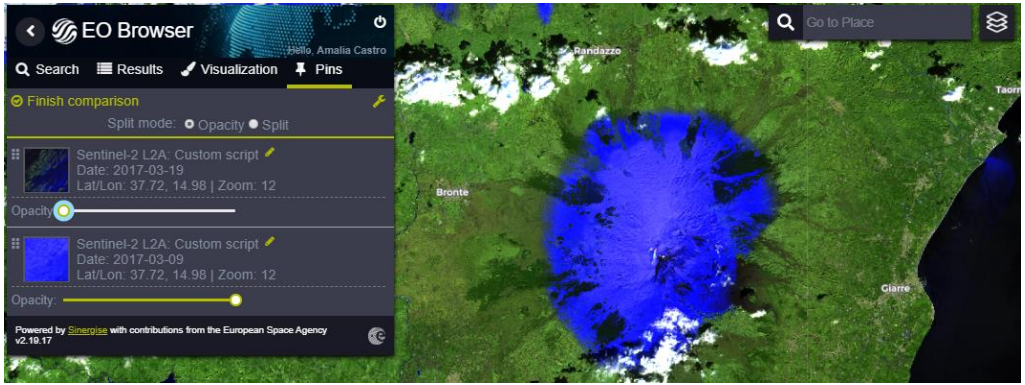




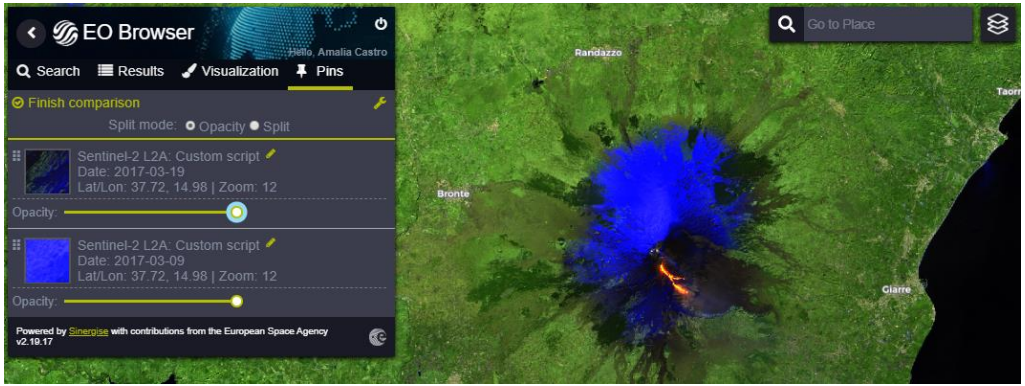
1. Exercise 1: Sentinel-2 for Etna lava flow

What has **changed** between the two dates?

2017-03-09



2017-03-19



1. Exercise 1: Sentinel-2 for Etna lava flow

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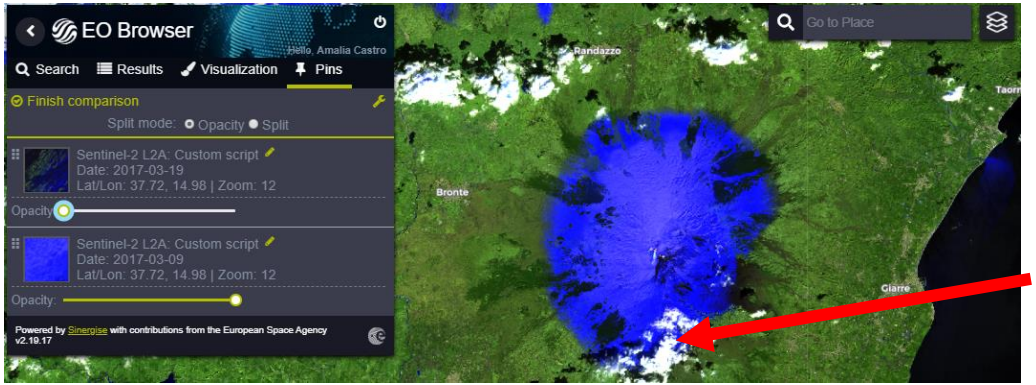
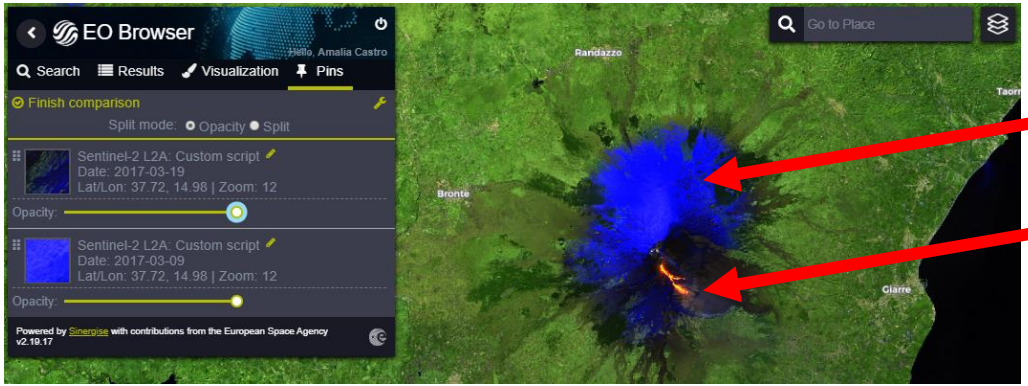
2017-03-09



Clouds moved away

2017-03-19

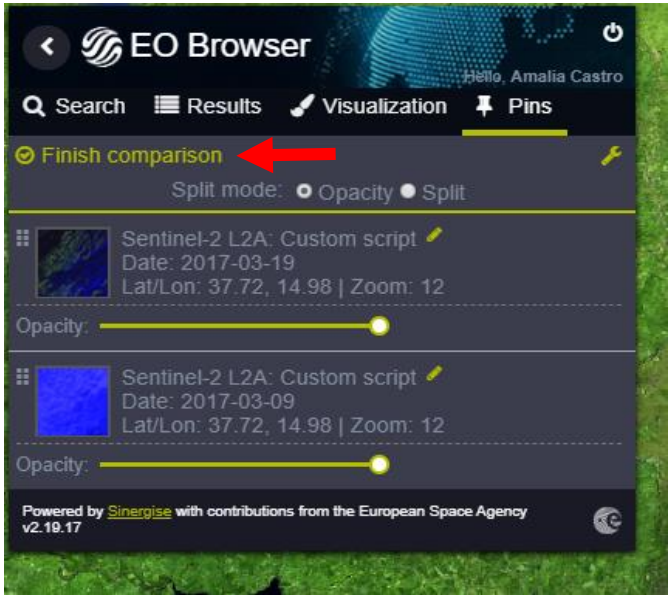


Snow melted

Lava flow appeared

1. Exercise 1: Sentinel-2 for Etna lava flow

Click “**Finish Comparison**” when you are finished.



1. Exercise 1: Sentinel-2 for Etna lava flow

A nice way to visualize the evolution of the volcano is by doing a **Timelapse gif**:

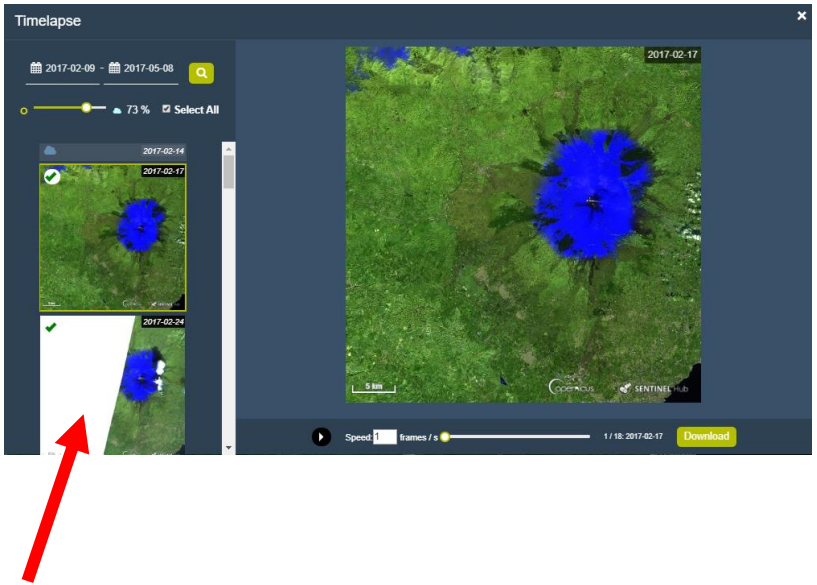
(Make sure you have something displaying: a band combination, for example. Otherwise the tool is not active).

1. Put the **start date** and **end date** of the period of time you are interested in (for example **2017-02-09** to **2017-05-08)**
2. Search for the images. The small visualizations on the left side will be updated
3. Adjust the **percent of clouds** you accept in your images (e.g. 73%)
4. Scroll down the images, and leave ticked the ones you like
5. Click play to preview your gif
6. Adjust the **speed** to make it slower or faster
7. **Download it** Sentinel-2_L2A-timelapse
8. You can show it to your friends and family!

1. Exercise 1: Sentinel-2 for Etna lava flow – NOTE 3

Did you notice some of the images do not show the whole area?

The video below (right) will give you a hint….

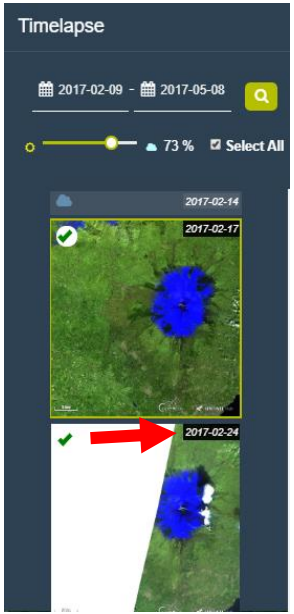


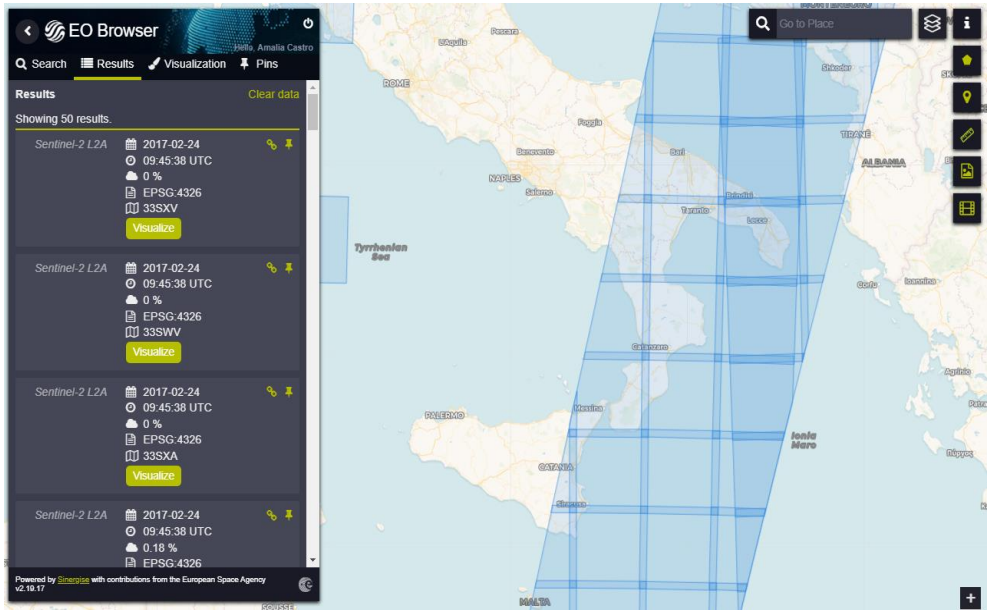
http://www.esa.int/spaceinvideos/Videos/2016/08/Sentinel-2_global_coverage?source=post_page

1. Exercise 1: Sentinel-2 for Etna lava flow – NOTE 3

Another hint…..

1. Go back to search and zoom out to see **the whole south of Italy**
2. Select **Sentinel-2** (**L2A** only, for simplicity)
3. Keep a single day in the Time range: **2017-02-24** (same date as the image in the Timelapse that appears “cut”)
4. Click Search

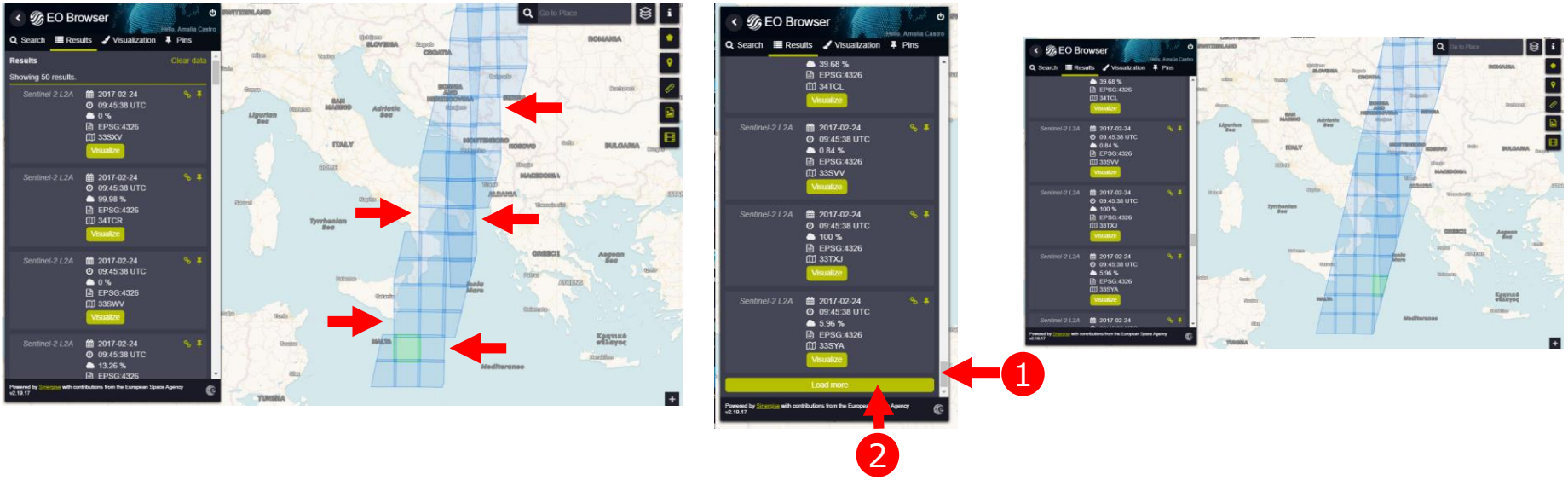




1. Exercise 1: Sentinel-2 for Etna lava flow – NOTE 3

Note that sometimes, there are **more data** than the Results tab of the EO Browser **shows by default**. It could be that you see an image like the one below, with “gaps” on the sides.

In that case, **scroll down**, click **Load more**, and **all** the results should be displayed.



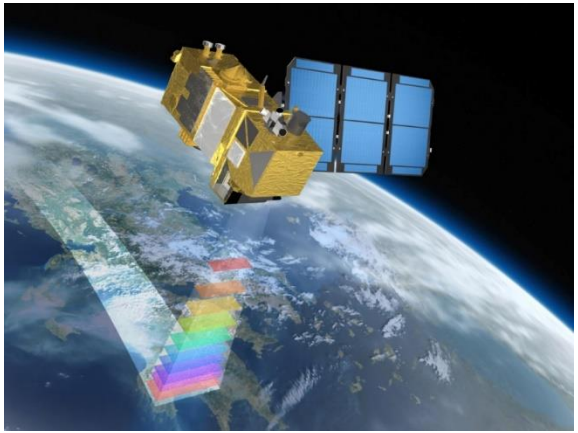
1. Exercise 1: Sentinel-2 for Etna lava flow – NOTE 3

Answer: the image is not cut, it is simply that the Etna volcano was **on the edge of the image** that was acquired that day. Every day the satellite Sentinel-2 orbits over a **different area** of the world, it does **not cover the same areas every day**!

Game: can you find other days when the Etna volcano appears on the edge of the image?

1. Exercise 1: Sentinel-2 for Etna lava flow

We have now finished the exercise with **Sentinel-2.**



We will have a look at what **Sentinel-5P** can offer.

Overview

1. Exercise 1: Sentinel-2 for Etna lava flow
    - Image search
    - Note 1- Sentinel-2 processing levels (L1C and L2A)
    - RGB visualization for lava flow
    - Note 2- basics of remote sensing: atmospheric interference
    - Custom rendering with different RGBs
    - Export visualization
    - Compare images
    - Create Timelapse
    - Note 3- Sentinel-2 revisit and coverage

2. **Exercise 2: Sentinel-5P for Etna atmospheric emissions**
    - Image search
    - Image interpretation
    - Additional materials

2. Exercise 2: Sentinel-5P for Etna atmospheric emissions

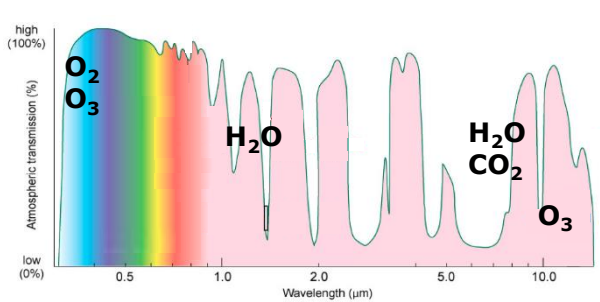
http://www.tropomi.eu

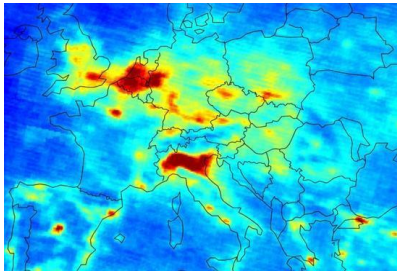
Sentinel-5 Precursor (S-5P) is the satellite developed in preparation for the Sentinel-5 mission that will be launched in the future. It carries only **one sensor**, called **TROPOMI**, which is the most advanced **multispectral imaging spectrometer** to date.

TROPOMI observes the **sunlight that is scattered** back to space by the surface of the Earth and by the atmosphere, and it detects the **unique fingerprints of gases** in **different parts of the electromagnetic spectrum**.

It can detect a wide range of pollutants, because it measures in the Ultra Violet, Visible, Near Infrared and Short Wave Infrared parts of the electromagnetic spectrum.

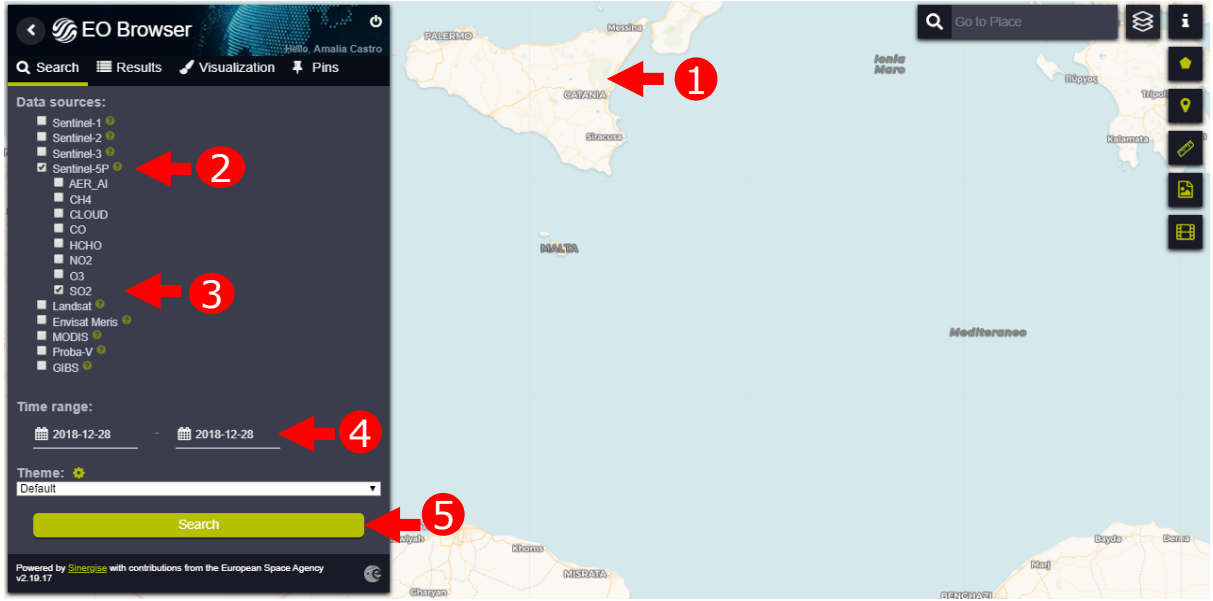
For example NO_2, O_3, formaldehyde, SO_2, CH_4, CO can be measured.





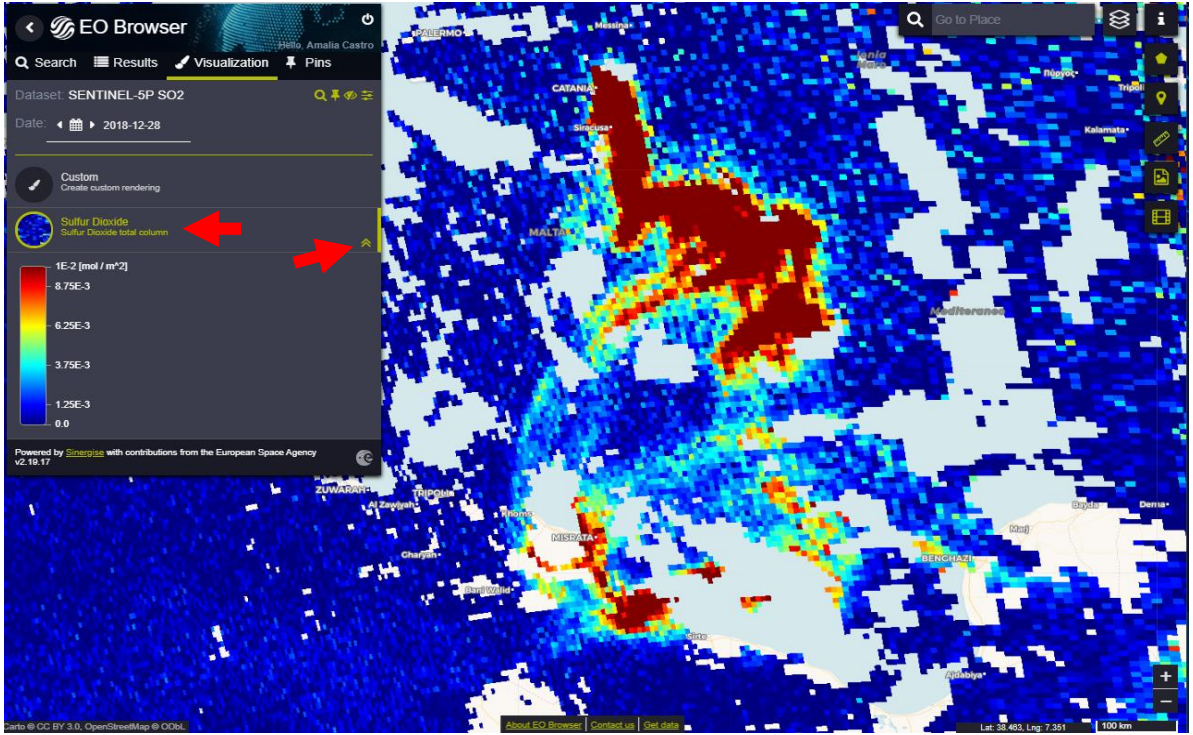
2. Exercise 2: Sentinel-5P for Etna atmospheric emissions

1. **Zoom out** to see Sicily and the southern part of the Mediterranean sea around it. Zooming out is important because Sentinel-5P is designed to look at events that occur over **large areas** (that is why its **pixels are much bigger** than those from Sentinel-2!)
2. Select **Sentinel-5P**
3. In particular the map of **Sulfur Dioxide (SO_2)**
4. Select **2018-12-28** (as **both** start and end date)
5. Click Search



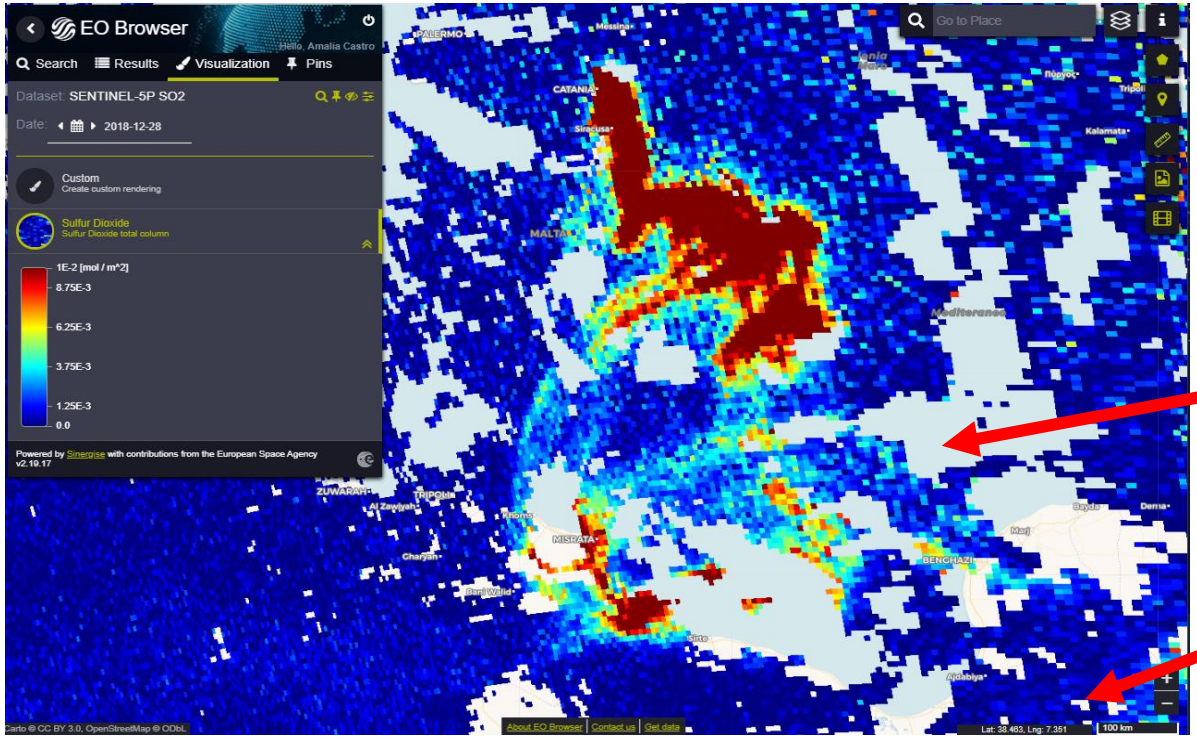
2. Exercise 2: Sentinel-5P for Etna atmospheric emissions

In the two results, select any of the images and click on **Sulfur Dioxide (SO_2).** You can see the plume of SO_2 on that day and its dispersion.



2. Exercise 2: Sentinel-5P for Etna atmospheric emissions

The **gaps** are **empty pixels**, and they are empty because there was a **cloud** or because the **measurement in the pixel did not pass the quality controls**.



Empty pixels, probably due to clouds (because of the shape of the gap)

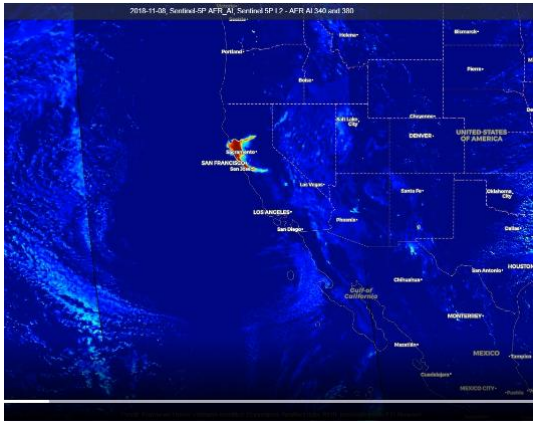
Isolated empty pixels, probably due to quality issues

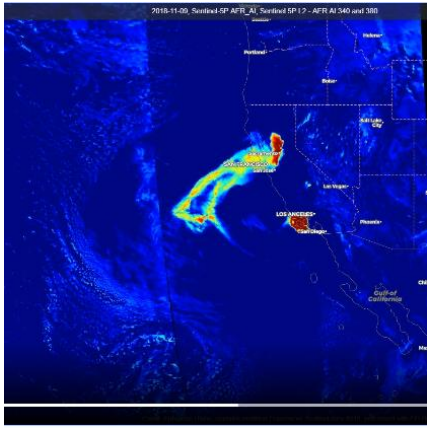
2. Exercise 2: Sentinel-5P for Etna atmospheric emissions

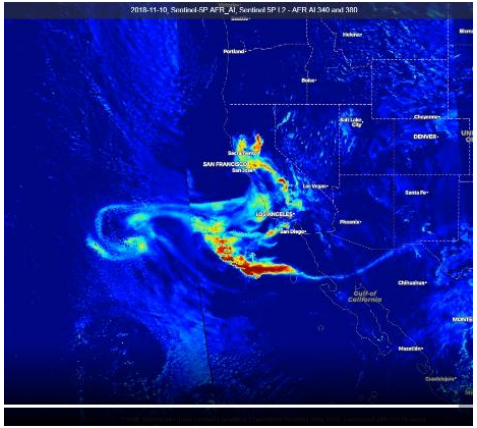
https://www.sentinel-hub.com/explore/education

Additional material:

The **EO Browser case study on Air Pollution** uses **Sentinel-5P** and has beautiful visualizations of the spread of **aerosols from wildfires**, for example. We invite you to have a look at it as well !







Learning goals

- ✓ Define suitable search criteria (time range, area, satellite, satellite product, visualization type) in EO Browser for a case study in volcanology
- ✓ Get a basic introduction to the concepts of satellite revisit and coverage
- ✓ Understand the different levels of processing for Sentinel-2 products (L1C and L2A)
- ✓ Interpret Sentinel-5P SO_2 maps
- ✓ Understand the concepts of RGB visualizations, and customize them in EO Browser
- ✓ Export images in EO Browser
- ✓ Compare images from different dates in EO Browser
- ✓ Create a timelapse in EO Browser

Thank you for your attention!

www.esa.int