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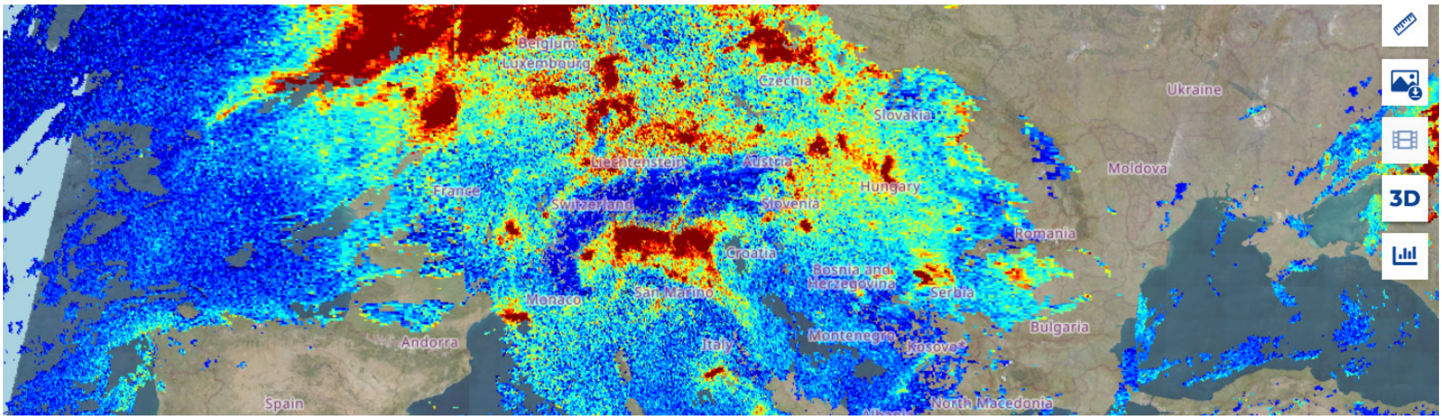

Eyes in the sky: tracking air pollution with satellites

ESA Education

What can the colours on a satellite map actually tell us about the air we breathe? Join us as we explore how the Copernicus Sentinel satellites detect gases such as nitrogen dioxide, and how chemistry helps us understand what's happening in the atmosphere above us.

Have you ever wondered how scientists track invisible gases and emissions like nitrogen dioxide (NO_2) and carbon dioxide (CO_2) across the planet? Satellites from the European Space Agency (ESA) and from other national space agencies, such as the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), allow us to observe the fluxes of air pollution and greenhouse gases around the Earth, and to see how these emissions are linked to human activity. Before satellites, data came only from ground stations or airborne measurements like balloons. Today, satellite observations monitor continuously the entire globe, including very remote and usually inaccessible places, and are validated with ground measurements. Since the 1990s, ESA has been involved in tracing gases and emissions from space, although initially with research-oriented missions such as ERS-2 and Envisat. Measuring atmospheric gases from space for operational purposes and with high precision has only become possible in recent decades, thanks to technological advances. Nowadays, the Copernicus programme, operated by ESA and the European Commission, provides an operational, continuous flow of data from different satellites, which is freely accessible to all citizens and supports policy, regulation and enforcement on a scale that is unmatched globally. This article invites students and teachers to explore the chemistry behind these gases and work with real satellite data through hands-on classroom activities.

Background information

The ESA uses satellites to monitor air pollution and greenhouse gases from space. Even the smallest changes in atmospheric gas concentrations can be detected by the Copernicus Sentinel satellites. By measuring variations as small as one part per million for carbon dioxide, satellite data enable scientists to improve climate models and provide policymakers with more accurate predictions of the impacts of rising greenhouse gas levels.[1]

Sentinel-5 Precursor (Sentinel-5P) is the first Copernicus mission specifically dedicated to monitoring the Earth's atmosphere (figure 1). It carries the TROPOMI instrument, which maps trace gases such as nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3) and methane (CH_4) – all of which affect air quality, human health and climate.[2]

Exploring data with Copernicus Browser

The Copernicus Browser is a free online tool that makes it possible to browse and download full-resolution images from all Copernicus missions. Through this interactive tool, you can access data from satellites such as Sentinel-5P, which monitors gases like nitrogen dioxide, and Sentinel-1, which uses radar to reveal urban areas, flooding, and land changes. You can zoom in on any location, adjust the date to see how conditions evolve over time, and compare different satellite layers side by side. For this activity, you'll use the Copernicus Browser to observe NO_2 hotspots over cities and link them to combustion sources like traffic, power plants and industrial zones.

Nitrogen dioxide (NO_2) is a reddish-brown gas primarily produced by burning fossil fuels in vehicles, power plants and industrial processes. As air contains 80% nitrogen, some of this nitrogen also reacts with oxygen during combustion, forming NO2. In the atmosphere, nitrogen dioxide contributes to smog, acid rain and ground-level ozone, all of which can harm human health, damage vegetation and disrupt ecosystems.

The TROPOMI instrument, on board the Sentinel-5P satellite, detects nitrogen dioxide by measuring how sunlight is absorbed and scattered as it passes through the Earth's atmosphere. Since each gas absorbs specific wavelengths of sunlight, TROPOMI can precisely identify and map NO_2 concentrations around the globe every day, with spatial resolution of about 3.5 km × 5.5 km per pixel.

Carbon dioxide (CO_2) is naturally present in the atmosphere through processes such as respiration, volcanic activity, and the carbon cycle. However, human activities, such as fossil fuel combustion, have caused a dramatic increase in CO_2 levels. Since the Industrial Revolution, atmospheric CO_2 has risen by about 50% – an unprecedented increase in hundreds of thousands of years. Satellite observations clearly show this steady upward trend, confirming the link between human activity and climate change.

Figure 1: Sentinel-5P

How can we measure CO_2 from space?

While Sentinel-5P does not directly measure CO_2, it can infer CO_2 emissions with limited accuracy by detecting combustion-related gases such as CO and NO_2 by using ratios of these two emitted gases.[3] Therefore, this method is mainly used for rough estimates and to locate places where gases are emitted. Using these indirect measures to estimate CO_2 emissions requires careful modelling to minimise uncertainties.[4]

NASA's OCO2 and OCO3 missions measure CO_2 directly. One of the first dedicated CO_2 measuring satellites was JAXA's GOSAT. Europe's upcoming CO_2 Monitoring Mission (CO_2M), launching in 2027 as part of the Copernicus Expansion Programme, will provide high precision, direct CO_2 observations to better track human-driven emissions. Worldwide, space agencies and industry continue to develop new technologies to improve the accuracy and validation of atmospheric measurements and data.

Activity 1: NO_2 and CO_2 comparison exercise

Begin the lesson by exploring air pollution, the factors that drive climate change and how satellite data helps us monitor them. Then ask students answer yes or no to a series of statements to assess what they already know (Activity worksheet 1):

Statement	NO_2 (air pollutant)	CO_2 (greenhouse gas)
Contributes to breathing problems and smog		
Is one of the main gases driving climate change and ocean acidification		
Is produced by combustion		
Can stay in the atmosphere for hundreds or even thousands of years		

Activity 2: Mapping NO_2 emissions with Copernicus Browser

Materials

- Computer
- Internet connection
- Activity 2 worksheet

Procedure

1. Open Copernicus Browser: https://browser.dataspace.copernicus.eu

Note: For background information on how to use Copernicus Broswer, check the Copernicus Browser teacher guide.

2. Under "DATA COLLECTIONS", select "Sentinel-5P" (figure 2).
3. Choose "NO_2 (Nitrogen dioxide)".

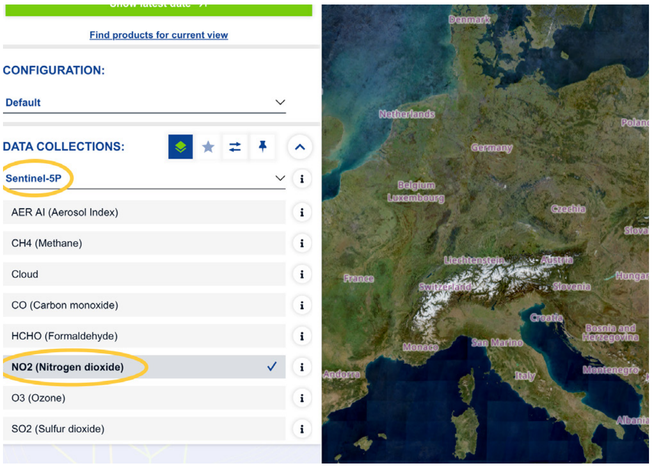

Figure 2: Copernicus Browser view
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4. Check the data legend by clicking the nitrogen dioxide label (figure 3).

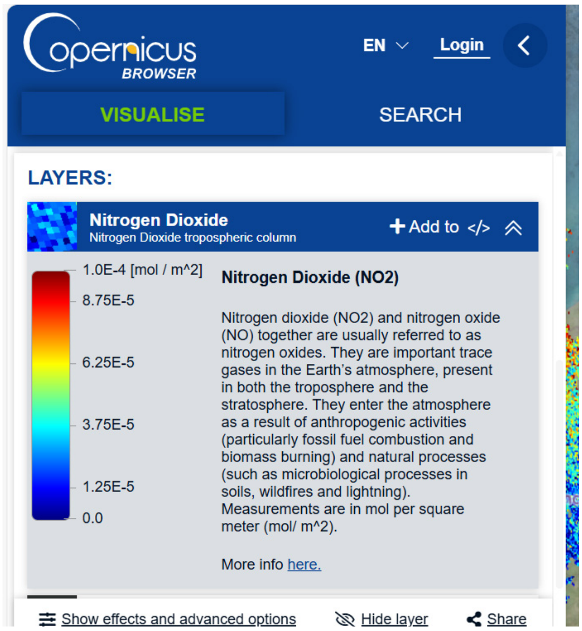

Figure 3: Nitrogen dioxide data legend
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5. Select a date (e.g. 03/03/2025) and observe how NO_2 concentrations vary.

Discussion

Ask your students the following questions:

Note: These questions are aimed to spark a debate. Encourage your students to discuss what they think between each other and to access the internet if it can be useful.

- Where are the main European NO_2 hotspots? Did you expect these results?
- What type of human activity generates NO_2?
- Use the Copernicus Browser to check NO_2 maps for different days over the same region. Do you notice changes? Why might this happen?
- Why do some areas (e.g. Spain) appear blank on the NO_2 map?
- Satellites show where NO_2 is in the atmosphere, but ground stations also measure it. Why do scientists use both?

Answers to the questions are provided in the activity 2 answers sheet.

Activity 3: Mapping out air pollution sources

Select a different map (excluding NO_2) to investigate the factors that may contribute to higher emissions in these areas of Europe.
Hint: Urban and industrial areas often coincide with NO_2 hotspots.

Note: Encourage students to explore different datasets and notice which types of landscapes or human-made structures, such as cities, industrial areas or highways, correspond with pollution hotspots.

Materials

- Computer
- Internet connection
- Activity 3 worksheet (answers provided in the activity 3 answers sheet)

Procedure

To access these maps:

1. Select "Sentinel-1 Mosaics" (Sentinel-1 IW Monthly Mosaics) under the configuration "Default".
2. Use the comparison tool to view NO_2 with Sentinel-5P and SAR Urban with Sentinel-1 Mosaics side by side.
3. Slide between the maps to compare pollution with built-up areas.

Activity 4: From combustion to the atmosphere – inorganic chemistry activity extension

Are there any chemical reactions involved in the production of NO_2 and of CO_2? Fill in the blanks in activity worksheet 4.

Formation of nitrogen dioxide:
____ + ____→ 2 NO
2 NO +____→ 2 NO_2

Formation of carbon dioxide:
CH_4 + ____→ CO_2 + 2 H_2O

Answers:
When we look at Sentinel-5P NO_2 maps, we're seeing the chemical footprints of combustion: the burning of fuels in cars, factories, and power plants.
At high temperatures, nitrogen (N_2) and oxygen (O_2) react to form nitric oxide (NO), which then reacts further to form nitrogen dioxide (NO_2):

$$N_2 + O_2 \rightarrow 2\,NO$$

$$2\,NO + O_2 \rightarrow 2\,NO_2$$

That's why Sentinel-5P often detects NO_2 hotspots over busy cities and industrial regions, which mark areas of intense fuel burning and traffic activity.
But NO_2 isn't the only gas formed during combustion. When carbon-containing fuels, like methane (CH_4), petrol, gas or coal, burn, the carbon (C) reacts with oxygen to form carbon dioxide (CO_2) and water vapour (H_2O):

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

This process releases energy but also contributes to greenhouse gas emissions, playing a major role in climate change. So, every bright NO_2 region in a Sentinel-5P map tells a larger story: the chemistry of combustion connects the air we breathe with the climate we share, and satellites help us see and better understand that link from space.

Discussion

- Which gases formed during combustion can be detected by satellites like Sentinel-5P?

- Which of these gases have the biggest impact on human health?
- How could switching to cleaner energy sources help both people and the planet?

These questions encourage students to connect the science of combustion and atmospheric chemistry with real-world environmental and health issues, using satellite data as a tool to understand and visualise the impacts. «

References

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[2] The Sentinel-5P Mssion: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P

[3] Chen J, Balamurugan V (2025) Assessing the Capability of Sentinel-5P (TROPOMI) NO_2 Measurements to Monitor Point Source CO_2 Emissions. *EGU General Assembly 2025*. doi: 10.5194/egusphere-egu25-18869

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Resources

- Read the Copernicus Browser teacher guide.
- Get an overview of ESA's Earth observation-related educational resources.
- Check out ESA's teaching resources on urban hotspots, the greenhouse effect and its consequences, and the carbon cycle, all of which include a teacher guide and student worksheets.
- Let your students take on the role of Climate Detectives, investigating local air pollution problems.
- Take a look at ESA's Air Quality Platform, which measures different characteristics of ambient air in various locations around the world.
- Learn about how ocean acidification affects sea life: Ribeiro CI, Ahlgren O (2021) An ocean in the school lab: carbon dioxide at sea. *Science in School* **55**.
- Investigate the effect of fireworks on air quality with your class: Shallcross D, Harrison T (2011) Smoke is in the air: how fireworks affect air quality. *Science in School* **21**: 47–51.
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