

EduS4EL © - Worksheet

CO₂ in 400,000 years of Earth's history

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Source: <https://www.pexels.com/de-de/foto/fotografie-der-fabrik-929385/>

In a recent Future of Humanity survey of over 10,000 young people in 22 countries aged 18-25 (also known as Generation Z), climate change was the most frequently cited issue facing the world¹. From King Charles² to Pope Francis³ to Antonio Guterres⁴ and many other prominent figures or heads of state, the consensus is that climate change is the biggest threat to our planet. Scientists have been warning for decades about the global threat that global warming and climate change pose to planet Earth. Environmental impacts such as loss of sea ice, accelerated sea level rise and longer and more intense heat waves are already being observed. Extreme weather events are being observed with increasing frequency. In addition, glaciers have shrunk, ice on rivers and lakes is breaking up earlier, the ranges of plants and animals have shifted, and trees are flowering earlier. (see, for example, the sixth assessment report of the Intergovernmental Panel on Climate Change IPCC, <https://www.de-ipcc.de/358.php>).

¹ <https://www.amnesty.org/en/latest/news/2019/12/climate-change-ranks-highest-as-vital-issue-of-our-time/>

² <https://www.reuters.com/article/us-davos-meeting-prince-charles/uks-prince-charles-says-climate-change-is-humanitys-greatest-threat-idUSKBN1ZL26F>

³ <https://catholicclimatecovenant.org/encyclical>

⁴ <https://www.un.org/sg/en/content/sg/statement/2018-09-10/secretary-generals-remarks-climate-change-delivered>



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Carbon dioxide (CO₂) is an important gas in the earth's atmosphere that ensures that the sun's heat radiation is not completely reflected back into space, but is instead reflected back to earth. As a result, CO₂, together with other gases, ensures that the Earth's surface maintains a vital temperature of around 16° Celsius on average. However, if the amount of CO₂ in the atmosphere increases, the temperature on the Earth's surface also rises as a result. Both CO₂ as a driver of climate change and human activities as a cause for the increase of its concentration in the atmosphere are clearly proven from a scientific point of view. Nevertheless, sceptical voices expressing doubts about either or both aspects have not completely disappeared. The emission of the greenhouse gas CO₂ is one of the main driving forces of climate change. At climate conferences, the reduction of these emissions is an important subject of negotiation at the meetings of state representatives. Time and again, however, the human role in increasing the atmospheric CO₂ concentration is doubted and reference is made to regular fluctuations in the course of the Earth's history. Can these doubts be refuted by data?

Further background information

Detailed information (including didactic material) and illustrations in the form of explanations, tables, graphics, animations and videos are very abundant on the internet. We found the following websites particularly informative:

- NASA: <https://climate.nasa.gov/>
<https://data.giss.nasa.gov/gistemp/>
- Copernicus Climate Change Service <https://climate.copernicus.eu>
- CO2earth: numbers for living on earth <https://www.co2.earth/co2-ice-core-data>

A scientific report in NATURE on the data from the Vostok ice core

- <https://www.nature.com/articles/20859>

and a report in SCIENCE on how ice age cycles have affected CO₂ levels

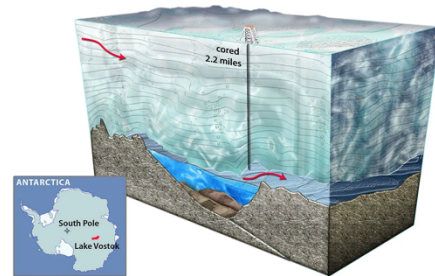
- <https://www.science.org/doi/10.1126/science.abd2115>

Internet sources with teaching/learning materials

- The Climate Literacy and Energy Awareness Network
<https://cleanet.org/clean/literacy/index.html>
- National Centers for Environmental Information
<https://www.ncei.noaa.gov/news/how-can-ice-teach-us-about-climate>

Data sources

CO₂ concentrations obtained from Antarctic ice cores (Vostok ice core, https://en.wikipedia.org/wiki/Vostok_Station, see figure) or directly in the atmosphere (Keeling curve, https://en.wikipedia.org/wiki/Keeling_Curve) serve as the data basis.



These data are suitable for analysing the CO₂ concentration over time because ice cores in places of perpetual frost are regarded as archives for climate data. Snow accumulates there very slowly, and an ice core composed of many layers of snow contains a long, accurate record of temperature and atmospheric composition over many millennia because the air bubbles trapped in the ice are small samples of the ancient atmosphere. By analysing air bubbles in the ice, it is possible to reconstruct the atmospheric composition at different times, including CO₂ content, methane content and other greenhouse gases. These air bubbles are trapped in the ice when it formed and give an indication of the atmospheric CO₂ concentration at that time.

Between 1970 and 1995, Russian and French teams drilled to a depth of 3623 metres at Vostok Station in Antarctica, generating data that reconstructed the CO₂ concentration in the atmosphere and the temperature at Vostok for the last 420,000 years. CO₂ is measured in parts per million by volume (ppm), which is the number of CO₂ molecules per million molecules of dry air. The Vostok ice core data consists of two time series: CO₂ and temperature, with the temperature given as a deviation from the modern surface temperature average of -55.5 degrees Celsius at Vostok

In order to be able to adequately assess the current fluctuations in temperature and CO₂ content with regard to the last few millennia, it is necessary to look at current data from our time. Another well-known dataset relating to the CO₂ concentration in the atmosphere serves this purpose. In 1958, Charles David Keeling began CO₂ measurements on the mountain Mauna Loa, Hawaii, which have been carried out regularly ever since. The Mauna Loa Observatory is located at an altitude of 3397 metres above sea level and is one of the most important atmospheric research facilities due to the strong marine inversion layer at this location. Measuring at this altitude not only minimises the influence of vegetation and human activity on the measurements, but also allows a clear separation between the polluted, lower parts of the atmosphere and the much cleaner troposphere (see <https://gml.noaa.gov/obop/mlo/>).

List of variables

Vostok_temperature

Variable name	Possible characteristics	Explanation
Age ice	From 0 to 422 766 years of earth history	Age of the ice
Temp	From -9.39°C to +3.14°C	Temperature deviation from the modern age value

Vostok_co2

Variable name	Possible characteristics	Explanation
Age ice	From 5600 to 419 328 years of earth history	Age of the ice
co2	182 to 298	Content of CO ₂ in the earth's atmosphere, measured in ppmv (parts per million)

The data is available via ESS-DIVE, a freely accessible online platform for storing, sharing and discovering data from the Environmental Systems Science (ESS) programme funded by the United States Department of Energy, <https://ess-dive.lbl.gov/>

MaunaLoa

Variable name	Possible characteristics	Explanation
year	1958 until 2022	Year
month	1-12	Month
decimal date	1958.2 until 2022.8	Date as decimal number
co2	310 to 425	Content of CO ₂ in the earth's atmosphere, measured in ppmv (parts per million)

Source: NOAA/ESRL and Scripps Institution of Oceanography.
<https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html>

For data exploration we work with the software Common Online Data Analysis Platform CODAP.

CODAP is a free educational software for data analysis. This web-based data science tool is designed as a platform for developers and an application for students in grades 6-14.



Discover and analyse:

Now it is up to you to explore the data. By clicking on the following link, you can view and analyse the data using the CODAP programme,

<https://codap.concord.org/app/static/dg/en/cert/#shared=https%3A%2F%2Fcfm-shared.concord.org%2FsKjZcdL00PGLmHjyLZws%2Ffile.json>

Tasks:

The key question here is: ***Is there a connection between the CO₂ content in the Earth's atmosphere and temperature? How are CO₂ values measured in the Earth's atmosphere in recent times and their fluctuations to be understood against the background of CO₂ data from the Earth's history?*** Try to come to conclusions through suitable graphical representations and statistical calculations.

1. Create a graph that shows the temperature over time for 420,000 years of human history. Describe in words what you see. It may be helpful if you click on "connecting lines" in the graph menu (to the right of the graph). How many degrees of temperature has climate varied in the past, as indicated in these data? Over what time scale can a shift from minimum to maximum temperature occur?
2. Similarly, create a graph showing the CO₂ content over time for 420,000 years. Comment in the graph! What is the unit of measurement for CO₂? Within what range do the CO₂ measurements vary over time? Unfortunately, it is not possible to show CO₂ content and temperature in *one graph*. But if you place the two graphs directly below each other, you can observe parallel developments of both progressions. By clicking on the icon Brush select the option "transparent" and change the color of the graph. Now you can place the two graphs directly on top of each other. Comment!
3. Paleoclimatologists - scientists who study the climate during the different geological eras of the Earth - see the cause for the fluctuations in temperature and CO₂ in various orbital changes. Do some research on the internet to find out more about the interaction between temperature, CO₂ levels and orbital changes. What questions come to mind? What are your conclusions?
4. Create a graph from the Mauna Loa dataset that shows the time course of the CO₂ content in the Earth's atmosphere between 1958 and 2022. Set the variable "decimal date" to the horizontal axis. For a better view, select "connecting lines" again and pull the graph apart a little with the mouse. Describe what you see. Is there a trend? What could cause the wavy fluctuations?
5. The curve created in 4) is called the Keeling Curve. Who was Charles David Keeling?



6. Compare the fluctuations of CO₂ in the 400 000 years before our time with the changes in the Keeling curve today.
7. What conclusions do you draw from your analyses with regard to the guiding questions? How sure are you about this? What are possible limitations?

Extension (for advanced climate researchers):

8. it may seem problematic to compare the Vostok data so directly with the Mauna Loa data. After all, the data was collected using very different methods and the first CO₂ data from Vostok dates back 5000 years while the Mauna Loa data starts in 1956. Research this topic on the internet, e.g. on the website of the Scripps Institute of Oceanography at the University of California in San Diego <https://keelingcurve.ucsd.edu/2014/03/20/how-are-ice-core-data-and-mauna-loa-atmospheric-data-made-comparable/> or <https://www.co2.earth/co2-ice-core-data>
9. Further information is provided by data from another ice core, the Law Dome ice core. It contains CO₂ data between the years 1010 and 1975, each at 5-year intervals. Click on the following link and you will receive a CODAP worksheet that also contains the Law Dome data.

<https://codap.concord.org/app/static/dg/en/cert/#shared=https%3A%2F%2Fcfm-shared.concord.org%2Fbe3QAwpduOycgLvv8o6S%2Ffile.json>

Create a graph that represents the time course of the law dome data. What do you find?

10. We now look at the CO₂ data of all three data sets, the data from Vostok, Law Dome and Mauna Loa together in one graph. Use the data table ALLco2. The monthly Mauna Loa data were aggregated to annual averages. From the ALL_CO₂ data table, drag the year variable onto the horizontal axis, the co₂ variable onto the vertical axis and drop the source variable into the centre of the graph. Now the three data sources are also differentiated by colour.
11. Is this visualisation too confusing because of the large time scale? Then click on the symbol  in the graph menu and select "Show parent visibility toggles". A line now appears at the top of the graph, with which the data sources can then be selected individually or in any combination. Clicking on the symbol  rescales the axes so that the data fits clearly into a graph.
What conclusions can you draw from the graphs created in this way?