CLIMATE CHANGE TOOLKIT
The Carbon Cycle: Calculating the rate of change of atmospheric CO₂

Standards
NGSS ESS3.C Human Impacts in Earth Systems
NGSS ESS3.D Global climate change
Grade Level: Middle School

Equipment
Spreadsheet/data table of CO₂ data from NOAA
Mauna Loa Atmospheric Observatory
Graph paper & ruler or computer spread sheet

Overview
The National Oceanographic and Atmospheric Administration (NOAA) has been making measurements of the composition of Earth’s atmosphere for more than 60 years. While there are many observatories around the world that make these measurements, the longest record comes from the observatory at Mauna Loa Hawaii (small photo).

Figure 1: The Global Carbon Cycle (https://earthobservatory.nasa.gov/features/CarbonCycle)
Examination of the global carbon cycle (Figure 1) shows that carbon moves into the atmosphere by a variety of natural processes, and by the actions of humans. There are also natural processes, such as photosynthesis, that remove carbon in the form of CO₂ from the atmosphere. In Figure 1 the natural flows are shown with yellow numbers while the human-caused flows are shown in red. Notice that the natural flows into and out of the atmosphere balance each other.

Photosynthesis by land plants is responsible for the largest flow of CO₂ out of the atmosphere. This large, seasonal change in CO₂ is evident in the measurements made at atmospheric observatories (Figure 2).

![Carbon dioxide concentration at Mauna Loa Observatory](image)

*Figure 2: Measured atmospheric CO₂ concentration, 1958-2019*

There are two important features of the CO₂ data recorded at the Mauna Loa Observatory.

First is the seasonal variation – the up & down, sawtooth pattern. Each spring and summer when land plants in the northern hemisphere leaf out and grow they remove CO₂ from the atmosphere and store it as biomass. In the fall and winter, respiration returns CO₂ back to the atmosphere, raising the measured CO₂ concentration.

The other important aspect of these data is the upward trend with time. This is due to human emissions of CO₂ to the atmosphere, principally through fossil fuel burning and deforestation. Because there is no process that balances the human emissions – nothing that removes CO₂ – the concentration of CO₂ in the atmosphere increases with time.
Procedure
We can calculate the rate of change of the atmospheric CO₂ concentration to learn how fast CO₂ is increasing in the atmosphere. We can find the overall average for the whole period of the record, and we can examine shorter intervals to see if the rate is increasing, decreasing, or remaining constant over time.

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On any graph with time on the horizontal axis, the slope of a line defined by the data is the rate of change with time of the quantity plotted on the vertical axis. So the slope of a line drawn through the CO₂ data in Figure 2 will be the annual rate of increase of CO₂. Since the CO₂ concentration varies seasonally, we can simplify the wiggles in the data by selecting a single month and use measurements from that same month across different years to calculate the rate of increase. Table 1 contains measurements for the month of May for each year of the CO₂ record.

Method 1: Calculate the average rate of change for the entire 62-year period using the difference between the initial and final CO₂ concentrations.

\[
\text{Slope} = \frac{(Y_2 - Y_1)}{(X_2 - X_1)}
\]

\[
\begin{array}{cc}
X & Y \\
1958 & 317.83 \\
2019 & 414.83 \\
\end{array}
\]

\[
\text{Rate} = \frac{(414.83 - 317.51)}{(2019 - 1958)} = 1.6 \text{ ppmCO₂/year}
\]

Method 2: Draw a line through the data that best represents the slope of the data points. Calculate the slope of the line by choosing any two points that fall on the line. With this method students can draw a “best fit” line, by eye, through the CO₂ data, and compare the result with the result from Method 1 (Figure 3).
In Figure 3 the slope of the line is \(84\text{ppm}/54\text{years} = 1.6\text{ppmCO}_2/\text{year}\), as above. Drawing a line and finding its slope is a good numeracy skill, and additionally, it shows an interesting feature of the data that might be missed by the 2-point difference technique of Method 1. The best-fit line well-represents the data in the middle part of the range (~1968-2008). In the early years, however, the rate of increase in \(\text{CO}_2\) is less than the slope of the line, and in the later years the rate of change is much greater. If we look back at Figure 2 we may also notice the concave-up shape of the data, but it is much more apparent when we draw a straight line – and – by working with the actual data in Table 1 we can show how much the rate of \(\text{CO}_2\) increase has changed over the last 60 years (Figure 4).

![May CO\(_2\) concentration, 1958-2019](image.png)

*Figure 3: Atmospheric \(\text{CO}_2\) measurements from the month of May, 1958-2019, NOAA-MLO*
Figure 4: Atmospheric CO₂ measurements from the month of May, 1958-1967 and 2010-2019.

Analysis: Figure 4 shows data for the first decade of the CO₂ record (1958-1967) and for the last decade of the record (2010-2019). The rate change in CO₂ concentration increase goes from 0.76ppm/yr to 2.4ppm/yr. Thus the current rate of CO₂ increase in the atmosphere is more than three times greater than what it was six decades ago.

Resources
Atmospheric CO₂ Data: https://scripps.ucsd.edu/programs/keelingcurve/

Contact Info
Dr. Alexandra Moore
Paleontological Research Institution
moore@priweb.org
Figure 5: Blank graph for hand-plotting MLO CO2 data.