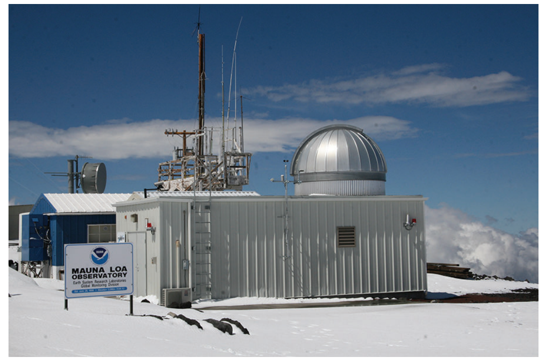
CLIMATE CHANGE TOOLKIT

The Carbon Cycle: Calculating the rate of change of atmospheric CO_2



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

Equipment
Spreadsheet/data table of CO_2 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).

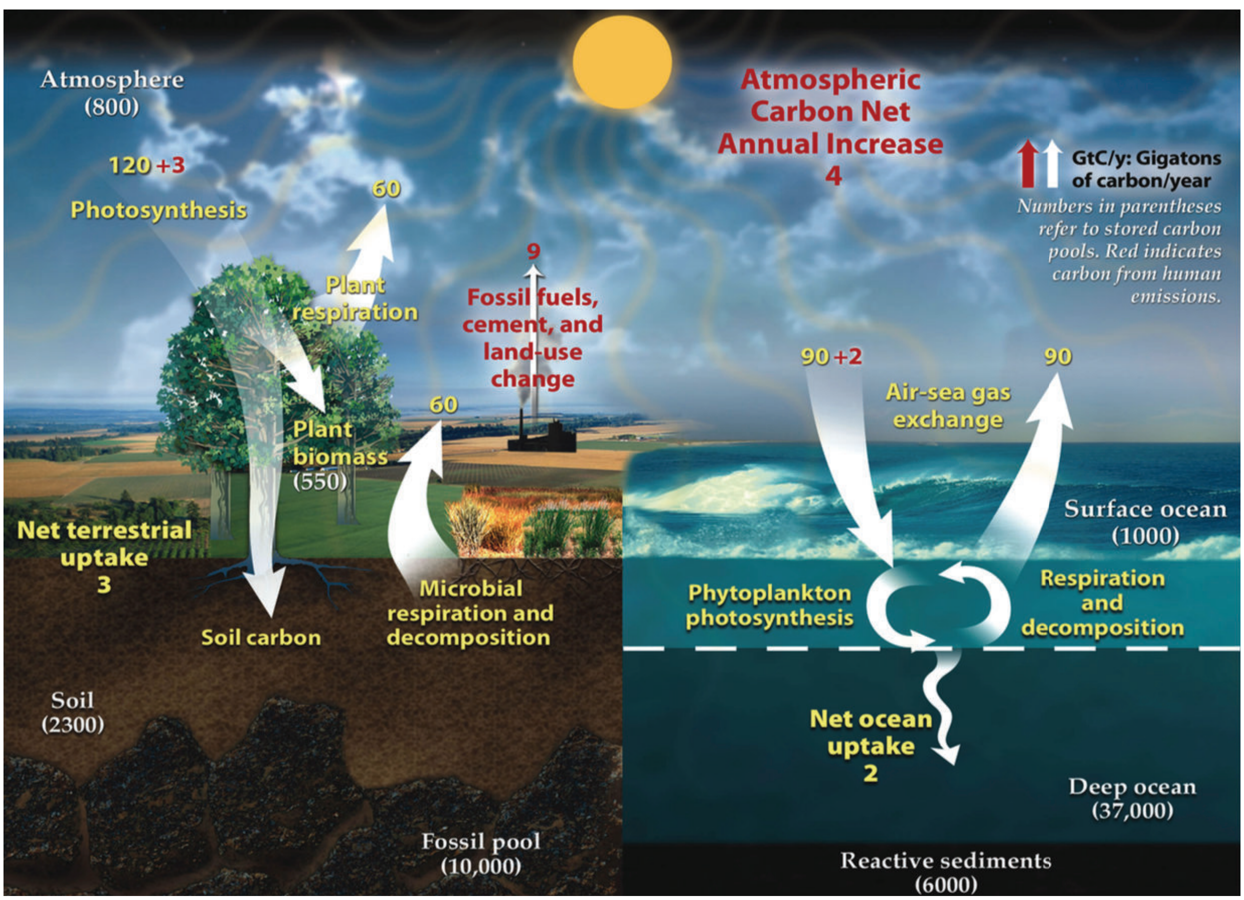


Figure 1: The Global Carbon Cycle (https://earthobservatory.nasa.gov/features/CarbonCycle)

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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 CO_2 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 CO_2 out of the atmosphere. This large, seasonal change in CO_2 is evident in the measurements made at atmospheric observatories (Figure 2).

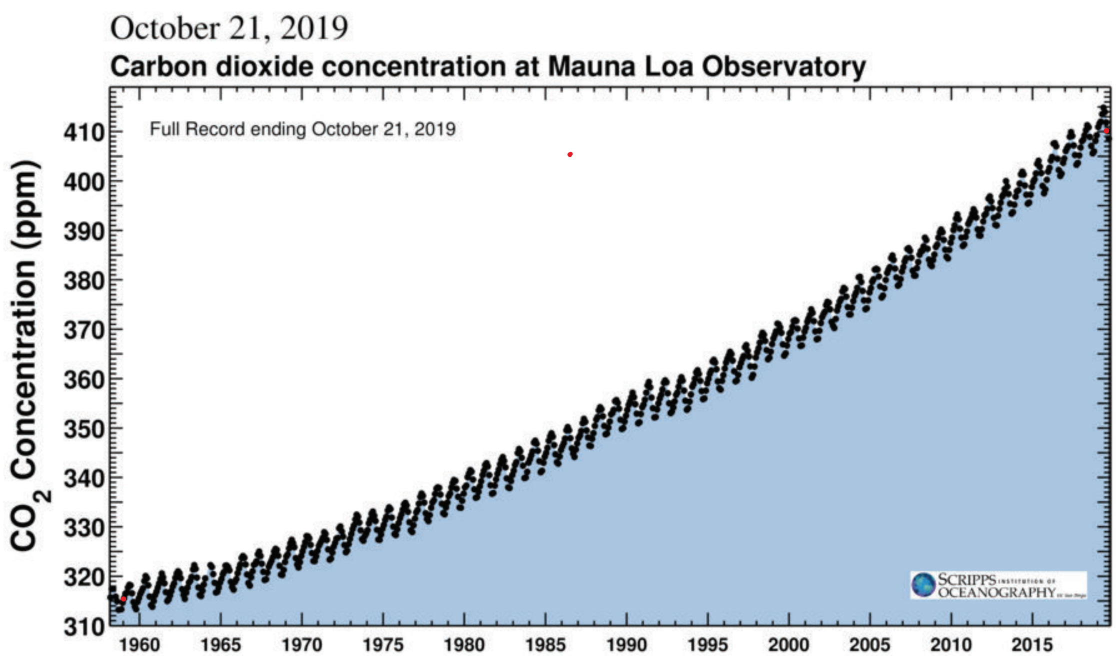

Figure 2: Measured atmospheric CO_2 concentration, 1958-2019

There are two important features of the CO_2 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 CO_2 from the atmosphere and store it as biomass. In the fall and winter, respiration returns CO_2 back to the atmosphere, raising the measured CO_2 concentration.

The other important aspect of these data is the upward trend with time. This is due to human emissions of CO_2 to the atmosphere, principally through fossil fuel burning and deforestation. Because there is no process that balances the human emissions – nothing that removes CO_2 – the concentration of CO_2 in the atmosphere increases with time.

Procedure

We can calculate the rate of change of the atmospheric CO_2 concentration to learn how fast CO_2 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.

Table 1: Atmospheric CO_2 measurements from the month of May, 1958-2019, NOAA-MLO

Year	CO2 (ppmv)	Year	CO2 (ppmv)	Year	CO2 (ppmv)	Year	CO2 (ppmv)	Year	CO2 (ppmv)	Year	CO2 (ppmv)
1958	317.51	*1968*	325.57	*1978*	338.01	*1988*	354.22	*1998*	369.3	*2008*	388.51
1959	318.29	*1969*	327.38	*1979*	339.47	*1989*	355.67	*1999*	371	*2009*	390.17
1960	320.04	*1970*	328.08	*1980*	341.47	*1990*	357.16	*2000*	371.83	*2010*	393.22
1961	320.58	*1971*	328.92	*1981*	342.91	*1991*	359.34	*2001*	374.02	*2011*	394.28
1962	321.02	*1972*	330.07	*1982*	344.14	*1992*	359.66	*2002*	375.55	*2012*	396.87
1963	322.25	*1973*	332.48	*1983*	345.76	*1993*	360.28	*2003*	378.35	*2013*	399.98
1964	322.26	*1974*	333.09	*1984*	347.43	*1994*	361.69	*2004*	380.62	*2014*	401.88
1965	322.17	*1975*	333.97	*1985*	348.93	*1995*	363.8	*2005*	382.24	*2015*	404.1
1966	324.08	*1976*	334.88	*1986*	350.22	*1996*	365.41	*2006*	384.92	*2016*	407.66
1967	325	*1977*	336.75	*1987*	351.85	*1997*	366.8	*2007*	386.41	*2017*	409.91
										2018	411.3
										2019	414.83

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 CO_2 data in Figure 2 will be the annual rate of increase of CO_2. Since the CO_2 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 CO_2 record.

Method 1: Calculate the average rate of change for the entire 62-year period using the difference between the initial and final CO_2 concentrations.

Slope = $(Y_2-Y_1)/(X_2-X_1)$

X	Y
1958	317.83
2019	414.83

Rate = (414.83-317.51)/(2019-1958) = 1.6 ppmCO_2/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 CO_2 data, and compare the result with the result from Method 1 (Figure 3).

In Figure 3 the slope of the line is 84ppm/54years = 1.6ppmCO_2/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 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 CO_2 increase has changed over the last 60 years (Figure 4).

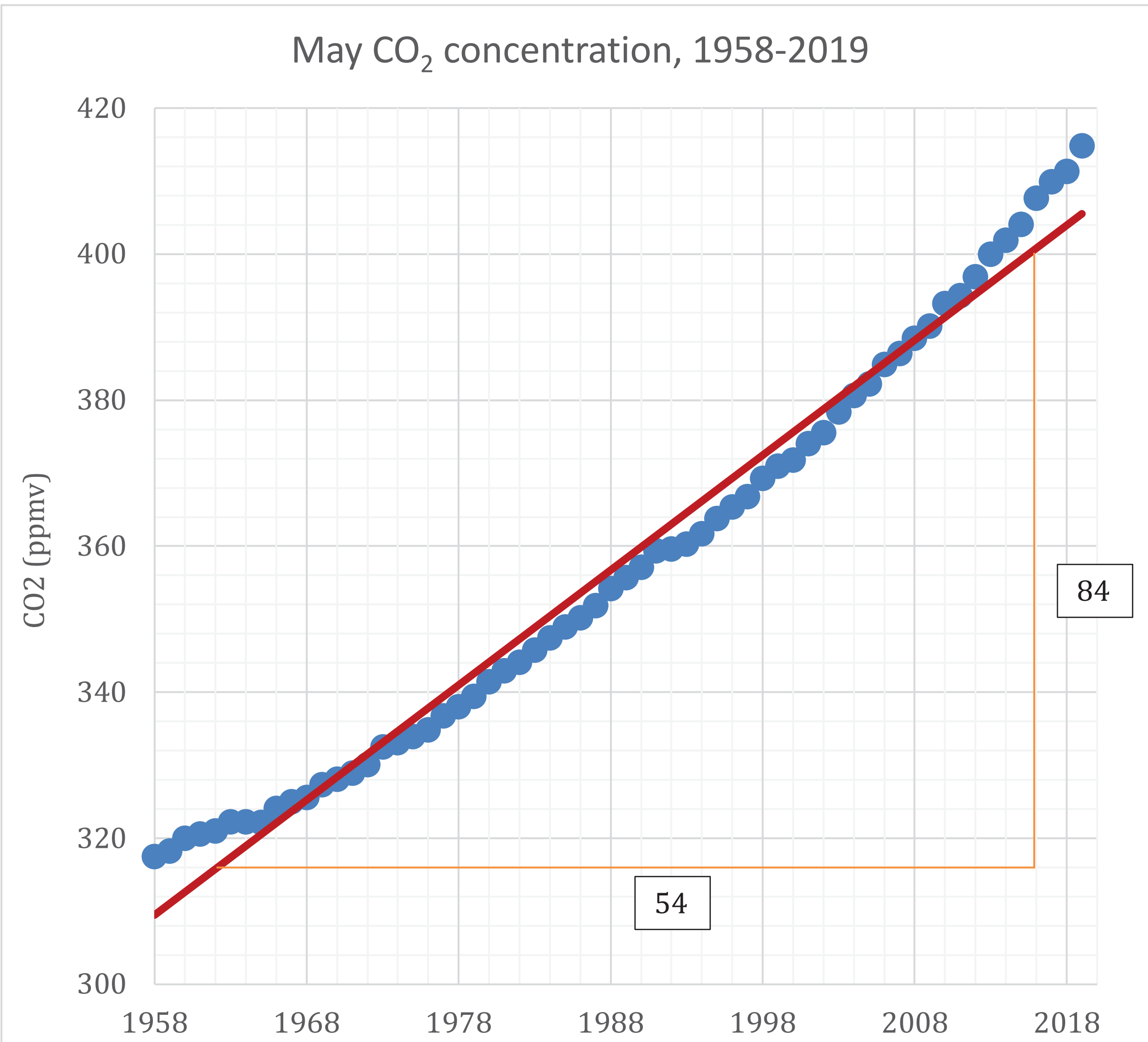

Figure 3: Atmospheric CO_2 measurements from the month of May, 1958-2019, NOAA-MLO

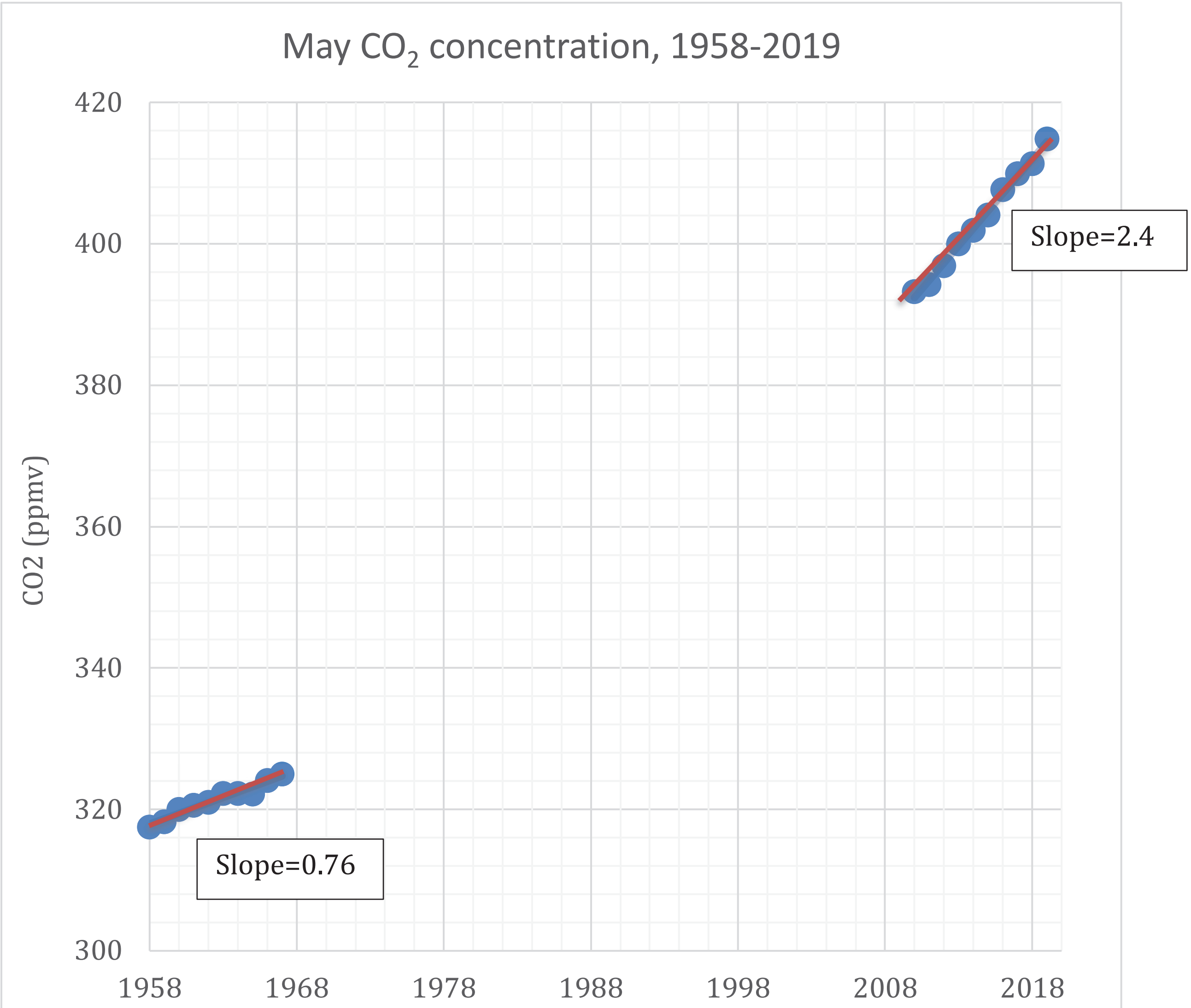

Figure 4: Atmospheric CO_2 measurements from the month of May, 1958-1967 and 2010-2019.

Analysis: Figure 4 shows data for the first decade of the CO_2 record (1958-1967) and for the last decade of the record (2010-2019). The rate change in CO_2 concentration increase goes from 0.76ppm/yr to 2.4ppm/yr. Thus the current rate of CO_2 increase in the atmosphere is more than three times greater than what it was six decades ago.

Resources
Atmospheric CO_2 Data: https://scripps.ucsd.edu/programs/keelingcurve/

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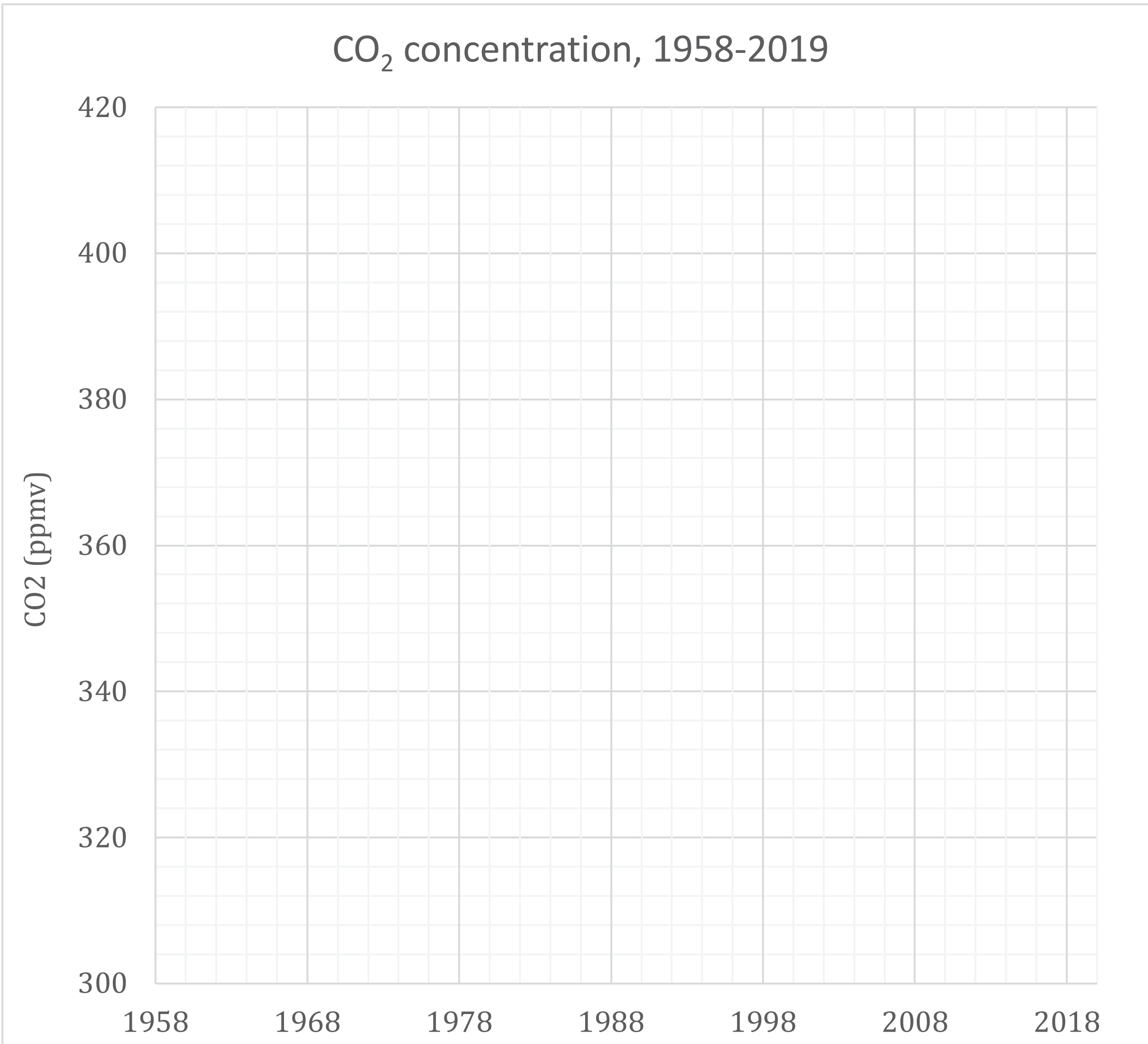

Figure 5: Blank graph for hand-plotting MLO CO2 data.