

Modeling: How is the CO₂ Level Changing?

TEACHER NOTES

Lesson Overview

This activity uses data on monthly carbon dioxide (CO₂) levels collected from the Mauna Loa Observatory in Hawaii. It provides an opportunity to engage students with data that are relevant to contemporary discussions of climate change. Evident in the data are at least two change patterns: one reflecting cyclic variation across the seasons of the year, and another reflecting an overall general increase in average CO₂ levels for each year. This affords a variety of interesting questions the teacher can pose aimed at sorting out these two patterns.

About the Lesson and Possible Course Connections:

The activity can be used with middle school students who could plot certain subsets of the data using dot plots or box plots. The activity can be used with high school students comparing multiple box plots of the data across years, analyzing scatter plots, or fitting models to the data.

Learning Goals

Students will be able to:

1. Model a contextual situation mathematically and use the model to answer a question.
2. Summarize numerical data in relation to their context.
3. Represent and interpret graphical representations of data.
4. Use functions to model relationships between quantities.

CCSS Standards

Statistics and Probability Standards:

- 6.SP.B.4
- 6.SP.B.5

Interpreting Data Standards:

- S-ID.A, S-ID.B

Function Standards

- 8.F.B.4

Mathematical Practice Standards

- SMP.4

Lesson Materials

- Compatible TI Technologies:



TI-Nspire CX Graphing Calculators,



TI-Nspire Apps for iPad®,



TI-Nspire Software

- Modeling CO₂_Levels_Student.doc
- Modeling CO₂_Levels_Student.pdf
- Modeling CO₂_Levels_Data.tns
- Modeling CO₂_Levels_Teacher.doc
- Modeling CO₂_Levels_Teacher.pdf

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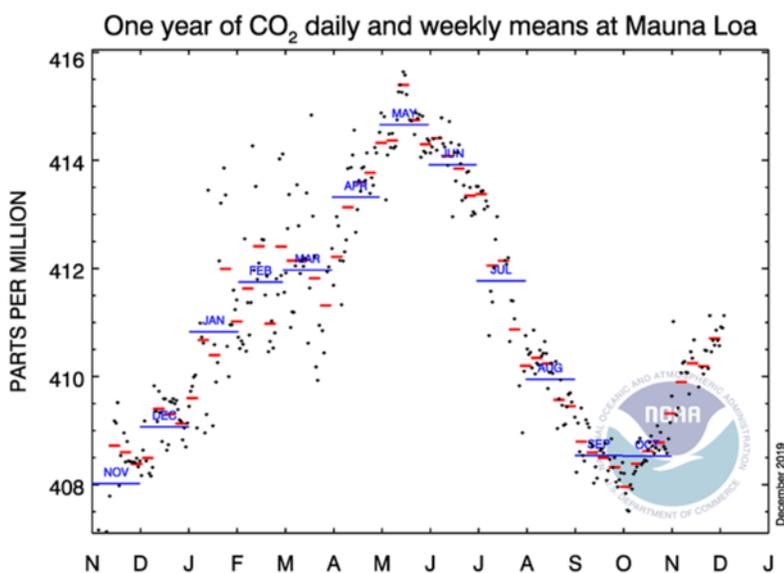
Background

One aspect of climate change is the level of carbon dioxide (CO₂) in the atmosphere. CO₂ emissions, measured in parts per million (ppm), are largely caused by burning fossil fuels like coal, oil and natural gas. This CO₂ keeps heat that would normally disappear into space, trapped on Earth. This results in an increase in the temperature of the earth.

Scientists compute daily averages from selected hourly values at stations around the world. Daily means are used to calculate weekly and monthly averages. Two independent CO₂ monitoring programs produce a daily CO₂ report at CO₂.Earth using data collected at the Mauna Loa Observatory in Hawaii. The daily averages are based on local time in Hawaii.

As an introduction to the work, students might write a paragraph describing what they see in the graph below of the daily and weekly mean CO₂ levels over a year, including what the different components of the graph mean.

This NOAA graphic shows daily CO₂ averages with black dots, **weekly CO₂ averages with red lines** (Sunday to Saturday) and **monthly CO₂ averages with blue lines**.



NOAA reports daily averages based on local time in Boulder, Colorado.

Teacher Tip: Students should open the .tns file containing the data. If they enter the data by hand, they are likely to make errors, but it is an option.



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Facilitating the Lesson

There are several ways this lesson can be implemented in the classroom:

Introduction: Present the class with the data – either projected or paper copies (See Appendix). Begin the discussion by having each student write down the answers to the following questions.

1. What do you notice?
2. What do you wonder about?
3. Students may note the cyclic pattern to the numbers in each column in contrast to a steady increasing pattern to the numbers in each row of the table. These patterns become much more evident in the graphs students create from the data.

1) Open-Ended Approach:

First, have students think alone for a few minutes and then write down how they would start to answer the question: How is the CO₂ level changing? Depending on the class, they might work individually or in randomly selected pairs.

The goal is to use the data in some way to describe the change, if any, in the CO₂ levels reported at Mauna Loa, Hawaii.

Student Instructions: In your groups,

- Exchange your ideas.
- Decide as a group how you will begin to analyze the data. Give each member of the group a job to do that will help you in the work.
- Decide whether your approach seems reasonable for the data. Explain why you think your model is good. What are the drawbacks, if any, to your model?

2) More-Structured Approach to Finding a Model:

Put students in teams and ask the following questions in a whole group discussion (after teams have had a chance to do some brainstorming):

1. What do you notice about the data?

Possible responses:

- Each year the levels seem to be higher in the winter and fall and lower in the summer;
- For most years the level in January is higher than the level from the previous January;
- The pattern seems almost cyclic;

2. What do you wonder about?

Possible responses:

- Is the change consistent over the years?
- If we stop burning fossil fuels, will the trend reverse?

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3. What kind of a graph might help?

Possible responses:

- A plot of the levels per month for each year;
- A dot plot of the mean levels per year;

(Note to teacher: figuring out how to plot such a large amount of data with repeating labels may take some creative thinking.)

4. Can you create a formula(s)?

What to Expect: Example Student Approaches

EX 1: Plotting monthly averages

Plotting the monthly averages for every year (or every other year as in Figure 1) shows the average level of CO₂ in ppm for each month has consistently increased since 2006. The pattern each year is cyclic, increasing from January to May, decreasing from May to September, and then increasing again, and is consistent from year to year.

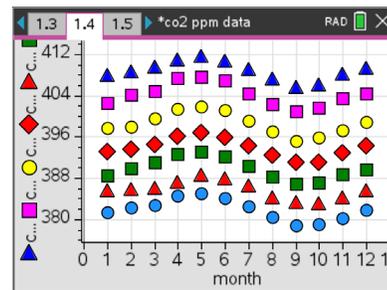


Figure 1. Mauna Loa average CO₂ levels in ppm for '06, '08, '10, '12, '14, '16, and '18 with the bottom circles representing data from '06 up to the triangles representing data from '18

Students may investigate the monthly averages of the first two years and the last two years in the data set. One way to plot the average CO₂ levels per month for 2006 and 2007 against the levels for 2017, 2018 is to use the year coded as 601, 602, ... 1811, 1812 (where 601 represents the first month, January, in 2006 and 1812 represents the last month, December, in 2018) plotted against the CO₂ levels for the particular month in that year. The plot shows the great jump in the years from 2007 to 2017.

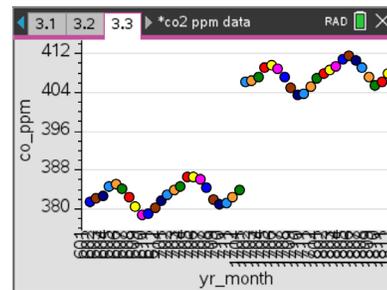


Figure 2. Average CO₂ levels for 2006, 2007 and 2017, 2018

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Figure 3 shows one student's attempt at this plot. You might want to ask students: What do you notice? What do you wonder? (Student reversed the last two years of data in the plot.)

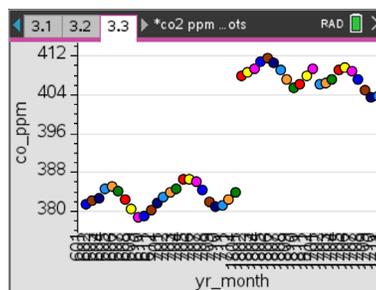


Figure 3. Student attempt at CO₂ levels vs. years

EX #2: Plotting Yearly means

Looking at a scatter plot of the mean levels per year (Figure 4) shows a linear pattern with a steady increase per year. The slope of the least squares regression line is 2.26, which indicates that each year the predicted increase in the average level of CO₂ is about 2.26 ppm. However, the residuals have a pattern suggesting that the model over predicts for the earlier and later years and under predicts for the years in the middle. Students may want to try transforming the data and look for other possible models.

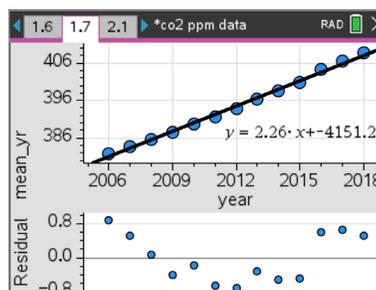


Figure 4. Regression line for mean CO₂ levels per year and corresponding residual plot.

EX #3: Exploring Variability

The variability in the data per year shows no pattern in the standard deviations for each year (Figure 5), with the largest variation occurring in 2016 and the smallest in 2008 and 2011.

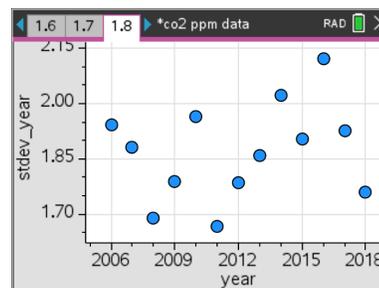


Figure 5. Standard deviation for mean CO₂ levels per month vs. year

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The box plots in Figure 6 show about the same interquartile range over the years, with 2011 and 2012 having slightly smaller IQRs. The medians of the monthly averages over the years steadily increased.

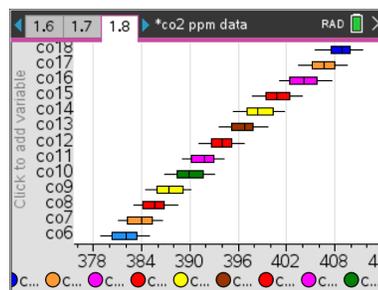


Figure 6. Box plots of average monthly CO₂ levels by year

EX #4: Sinusoidal Regressions

Because the data appear cyclic, fitting a sine curve might be a way to write an equation that captures the relationship between the months each year and the CO₂ levels. Students may note how similar the functions are among the different years with the only significant difference being the constant. For example, note the amplitude, period and phase shift are quite similar, but the constant in '06 is lower (382.04) than the constant in '18 (408.77).

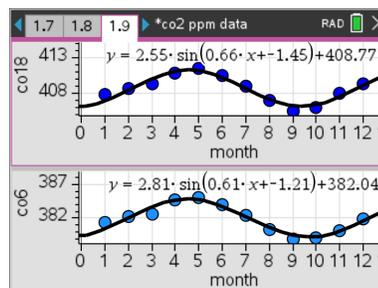


Figure 7. Using a sine function to model CO₂ levels



Validating the Models

Students should validate their models either by asking whether the models make sense in different scenarios related to the context or by finding other information to reflect against the model. One strategy might be to have each group consider whether the models created by other groups make sense.

Some questions are suggested below that might be useful in helping students think about whether their model was reasonable:

- Students might find data from other sites and see if the same trend was apparent (e.g., <http://www.exploratorium.edu/sites/default/files/snacks/SouthPoleCO2data.pdf>);
- They might look for data from before 2006 to see how that data fit into the pattern.
- They could check their model and thinking against the 2019 data and consider what might have caused any notable changes.

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Extension

1. Support or refute each of the newspaper headlines:

a. “CO₂ levels in atmosphere higher than any point since evolution of humans,”

U.S. & WORLD, Tuesday, May 14, 2019 <https://abc7chicago.com/science/co2-levels-rise-to-highest-point-since-human-existence-/5300197/>

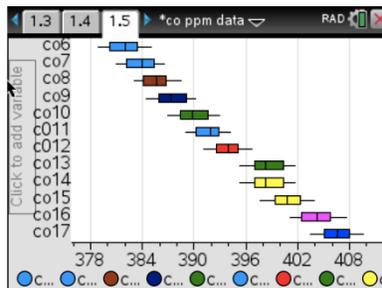
b. “Throughout the last decade, the average rate of increase has been around 2.3 parts per million per year”

Chelsea Harvey, March 13, 2017. Carbon dioxide in the atmosphere is rising at the fastest rate ever recorded https://www.washingtonpost.com/news/energy-environment/wp/2017/03/13/carbon-dioxide-in-the-atmosphere-is-rising-at-the-fastest-rate-ever-recorded/?noredirect=on&utm_term=.054caae660ee

c. “The rate of CO₂ growth over the last decade is 100 to 200 times faster than what the Earth experienced during the transition from the last Ice Age.”

<https://e360.yale.edu/digest/co2-levels-continue-to-increase-at-record-rate>

2. Notice in the plots below, the box plot for 2013 seemed to be slightly off the pattern. What might be an explanation? (Note that 2013 is identical to 2014 except for the color; the same data were entered twice by mistake. This illustrates the need to pay careful attention to deviations from a pattern and look for possible explanations.)



3. Explore a data set on the National Centers for Environmental Information National Oceanic and Atmospheric Administration (<https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/ice-core>).

Resources

<https://www.co2.earth/daily-co2>

<https://www.popsci.com/record-breaking-co2-graph-climate>

<https://serc.carleton.edu/eslabs/carbon/3c.html>

<https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections>



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Appendix: Data Set for Lesson

Table 1: shows the monthly average levels of carbon dioxide in ppm measured at Mauna Loa, Hawaii, since 2006.

	<i>Mean monthly CO₂ levels (ppm)</i>							
<i>Month /year</i>	<i>2006</i>	<i>2007</i>	<i>2008</i>	<i>2009</i>	<i>2010</i>	<i>2011</i>	<i>2012</i>	<i>2013</i>
1	381.38	382.89	385.44	386.94	388.50	391.25	393.12	395.51
2	382.19	383.90	385.73	387.42	389.94	391.82	393.60	396.79
3	382.67	384.58	385.97	388.77	391.09	392.49	394.45	397.31
4	384.61	386.50	387.16	389.44	392.53	393.34	396.18	398.35
5	385.03	386.56	388.50	390.19	393.04	394.21	396.78	399.76
6	384.05	386.10	387.88	389.45	392.15	393.72	395.83	398.58
7	382.46	384.50	386.43	387.78	390.22	392.42	394.30	397.20
8	380.41	381.99	384.15	385.92	388.26	390.19	392.41	395.15
9	378.85	380.96	383.09	384.79	386.83	389.04	391.06	393.51
10	379.13	381.12	382.99	384.39	387.20	388.96	391.01	393.66
11	380.15	382.45	384.13	386.00	388.65	390.24	392.81	395.11
12	381.82	383.95	385.56	387.31	389.73	391.83	394.28	396.81
	2014	2015	2016	2017	2018			
1	397.80	399.96	402.52	406.13	407.88			
2	397.91	400.26	404.04	406.42	408.61			
3	399.58	401.52	404.83	407.18	409.35			
4	401.29	403.26	407.42	409.00	410.80			
5	401.77	403.96	407.70	409.65	411.48			



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6	401.15	402.80	406.81	408.84	410.8			
7	399.00	401.30	404.39	407.07	409.05			
8	397.01	398.82	402.25	405.07	407.07			
9	395.26	397.64	401.03	403.38	405.48			
10	395.93	398.29	401.57	403.64	406.00			
11	397.13	400.16	403.53	405.14	407.98			
12	398.78	401.85	404.42	406.82	409.27			

Resources

Our Changing Atmosphere www.exploratorium.edu/snacks/our-changing-atmosphere

<https://www.exploratorium.edu/snacks/our-changing-atmosphere>