Curriculum for the Bioregion[1]

Modeling Atmospheric CO_2 Data

John B. VanLeer
Cascadia Community College, Jvanleer@cascadia.edu
Rebecca Burke
Cascadia Community College, rburke@cascadia.edu

A teaching-and-learning activity that uses actual CO_2 data for graphing, regression analysis, and prediction.

Summary

The buildup of carbon dioxide in Earth's atmosphere as a result of human industrial and agricultural activities is amplifying the planet's natural greenhouse effect and producing global climate change. Data on global atmospheric CO_2 has been collected since 1958 when Charles Keeling began sampling and recording the data from the Mauna Loa Observatory in Hawaii. The data show a variety of cyclical features, but the most profound is the consistent rise in concentrations. From a mathematical point of view, the question arises as to how well the data can be matched to a particular function. From both a mathematical and a scientific point of view, regression analysis of the data could suggest how the future of CO_2 concentrations may appear. In this activity, students will use actual CO_2 data from the Mauna Loa Observatory in Hawaii to create their own "Keeling Curve"; conduct an analysis of the data; and, attempt to match it to a mathematical function. They will then use the function to predict increases in CO_2, both historical and future.

Short Description

In this activity, students will use actual CO_2 data from the Mauna Loa Observatory in Hawaii to create their own "Keeling Curve"; conduct an analysis of the data; and, attempt to match it to a mathematical function. They will then use the function to predict increases in CO_2, both historical and future.

Learning Goals and Big Ideas

In this activity, students will use actual CO_2 data to create their own "Keeling Curve"; conduct an analysis of the data; and, attempt to match it to a mathematical function. They will then use the function to predict increases in CO_2, both historical and future.

1″ *The Curriculum for the Bioregion is an initiative of the Washington Center for Improving the Quality of Undergraduate Education at The Evergreen State College. This "teaching and learning activity" is one of several developed by a faculty learning community in math in February, 2010.*

Keywords: greenhouse effect; global warming; global climate change; keeling curve; graphing and spreadsheets; regression analysis

Context for Use

This activity, depending on what class it is taught in and how much time is available, is designed for either an earth or environmental science course or a pre-calculus course. It is easily contextualized as either a mathematical tool to study a scientific phenomenon or as an application of a mathematical concept to a real-world problem.

Depending on how the exercise is used, it could be a 20 minute demonstration (with little hands-on experience) or a complete 90 minute laboratory. The length of time can be adjusted by varying the amount of work students actually do in discovering the issues and working with the data. The activity could take place any time during the quarter depending on in which class it is used.

Description and Teaching Materials

In this assignment, students download actual CO_2 data from a Scripps Institution website and manipulate it using a spreadsheet. The notion of global climate change could be introduced as background and an impetus for the assignment; or, it could be introduced subsequent to the assignment as part of an ongoing discovery of the issue. Again, this would depend on which course it is used. After some initial analysis of the basic graphs, students attempt to fit various functions to the curves using the spreadsheet functions. In its unmodified form, this activity first directs students to use only data from 1960-1990. From this data, students make predictions from the various regression models, and then analyze those predictions logically. It becomes clear that one regression model matches the data best. Then students add the remaining 1991-2009 data and determine how well the function predicted the changes. Lastly, students predict the rise of CO_2 through the year 2060. In the end, students discuss and evaluate the insights such analysis provides as well as the limitations. In particular, it should be emphasized that this analysis is simply a piece of a larger ensemble of evidence to demonstrate an enhanced greenhouse effect and global climate change.

How to introduce this activity depends heavily on the specific course in which it is used. In a mathematics course this activity (or demonstration) can be used as a legitimate real-world example, presuming that the idea of functions has been introduced. In this case, it will be useful if there has been some level of discussion or pre-reading on the subject of climate change so that students understood the context. Examples of such readings can be found below under “Resources”. If this activity is to be used in a science course, the teacher may decide to have little background in place, and use this activity in a series that has students discover climate change for themselves. In this case, the only prerequisite is having some working knowledge of spreadsheets; a deep understanding of functions and regression is not necessary to complete the activity. However, such knowledge will permit deeper analysis of both the data and the activity as a whole. Ideally, this activity could be used within a joint integrated course, such as a learning community combining math and science.

Procedure:

1. Go to http://scrippsco2.ucsd.edu
2. Click Data
3. Select Atmospheric CO_2 Data
4. Click Mauna Loa Observatory, Hawaii
5. Select Monthly

6. This is the data we are working with
7. Discuss the cyclic nature
8. Graph the data for 1960-1990 inclusive (CO_2 vs. Date) can compare to published graph (see attached pdf file) “Mauna Loa Observatory_Monthly Average CO_2 Concentration”
9. Fit linear, exponential, quadratic for 1960-1990 inclusive (CO_2 vs. Date)
10. Look at the R2 value
11. Discuss making the cut either a month per year or average the averages for each year
12. Re-run regressions for the cut(s) (January Data for each year used in the completed (see attached Excel spreadsheet – “Modeling CO_2 Data_raw”), but many other cuts possible, depending upon time you may wish to try and compare various cuts) 1960-1990 inclusive CO_2 (CO_2 vs. Yr)
13. Look at the R2 values
14. Make prediction for 2009 for each model
15. Discuss the dangers of extrapolation
16. Notice that the prediction for the quadratic makes no sense (exponential should really not be below linear value either, discuss), value BELOW where is should be. Need to have the coefficients of the exponential and quadratic models to more decimal places
17. Right click the equation for the quadratic model -> Select Format Trendline Label -> Change the Category to Number -> Change Decimal Places to 8
18. Modify the quadratic predictions, change the decimal places for the other models to 8 and see how this changes (or does not change) their predictions.
19. Discuss which coefficients need to be most accurate, discuss is 8 good enough for our model? Try 12 and compare the differences in the predictions. Discuss why using number of years since first year versus keeping the year in the thousands could have avoided this issues altogether.
20. Re-run regression adding the rest of the data. Observe the changes that occurred in each of the three models.
21. Calculate the prediction for 2060 for each revised model. Make sure to change the number of decimal places in the model coefficients to 8
22. Discuss

Attachments

There are documents attached to this teaching-and-learning activity:

- **Modeling CO_2 Data_raw** - the rawest data that was downloaded directly from the website. (Excel File)
- **Modeling CO_2 Data_2nd**” - includes that same data as a tab, but two additional tabs, one with some unknown data removed (since it’s not useful) and a third that simply has the year and the concentrations. (Excel File)
- **Instructor Key Modeling CO_2 Data_lab_step by step_completed_year and concentrations** - is sort of an answer key or instructor copy. It has the data, the completed graphs, and predictions. (Excel File)
- **Mauna Loa Observatory_Monthly Average CO_2 Concentration** (Adobe Acrobat pdf)

Teaching Notes and Tips

Students are instructed to make predictions through 2009 for each model because 2009 is the most recent annualized data available at the time this activity was created; later in the activity they will look at the actual data from 1991-2009 and compare it to their forecast. Instructors may choose to revise the year 2009 end point as later years' data becomes available.

There are three Excel spreadsheets attached to this teaching-and-learning activity. One, "Modeling CO_2 Data_raw", is the rawest data that was downloaded directly from the website. When an instructor does this activity, she may choose to have the students download the data from the Scripps site themselves, or, to save time, she may just hand them this file.

The second attached file, "Modeling CO_2 Data_2nd", includes that same data as a tab, but two additional tabs, one with some unknown data removed (since it's not useful) and a third that simply has the year and the concentrations. Again, depending on the instructor, one could give any of these to students depending on how much work and time was expected.

The third, "Instructor Key Modeling CO_2 Data_lab_step by step_completed_year and concentrations", is sort of an answer key or instructor copy. It has the data, the completed graphs, and predictions. We presented them in these different forms so as to allow for flexibility on the part of the instructor.

Assessment

How this activity is assessed is as potentially varied as its incorporation. If it is used only as a teacher-led demonstration, perhaps the only assessment will be questions on a test. However, if students are conducting the activity, then any number of the various elements can be assessed, including the completed graphs, written analysis, and written conclusions i.e. a lab report). It is recommended that students complete this activity in small groups, where they can discuss the data and brainstorm both analyses and conclusions. Monitoring these conversations can be a portion of the overall assessment. Alternatively, 1) students could present their findings to an audience charged with challenging their analysis and conclusions; 2) students could provide only the conclusions and reflection of the process; 3) students could write or openly discuss the value and limitations of this method; and/or 4+) students could write or openly discuss what other methodologies, data and analysis would be needed to make a stronger and more complete argument for their findings.

References and Resources

Attached Documents

- Modeling CO_2 Data_raw (Excel File)
- Modeling CO_2 Data_2nd (Excel File)
- Instructor Key Modeling CO_2 Data_lab_step by step_completed_year and concentrations (Excel File)
- Mauna Loa Observatory_Monthly Average CO_2 Concentration

Additional

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- Real Climate: http://www.realclimate.org/index.php/archives/2004/12/michael-mann/
- Scripps' CO_2 site: http://scrippsco2.ucsd.edu/
- Excel Document: "A History of Atmospheric CO_2 and its effects on Plants, Animals and Ecosystems" editors, Ehleringer, J.R.,

T.E. Cerling, M.D. Dearing, Springer Verlag, New York, 2005.

- MEDIA: NOVA's "What's Up with the Weather." Dated, but useful for this activity and as an example of changing perspectives. http://www.pbs.org/wgbh/warming/
- MEDIA: PBS Frontline's "HEAT." Streaming video. http://www.pbs.org/wgbh/pages/frontline/heat/