TEACHER PAGE – *Trial Version*

** After completion of the lesson, please take a moment to fill out the feedback form on our web site (https://www.cresis.ku.edu/education/k-12/online-data-portal)**

Lesson Title: Data Series – An Historical Record of CO_2
Grade: 9-12

Question: How has the atmospheric CO_2 concentration changed throughout history?

Time:
Two 45 minute class periods plus additional time for instruction on Excel if necessary. Lesson can be structured to 20-30 minute segments or as stand-alone activities.

Scope of the Lesson:
This lesson contains basic graphing components, interpretation of information and communication to others of findings depicted on their graph. You may choose to use either the total lesson or bits and pieces depending on student abilities and time constraints. The lesson is also designed so that it can be expanded for advanced students and used as an enrichment activity or a remedial activity.

Use of Microsoft Excel or another computerized graphing program will speed the activity and allow for more than one set of data to be examined. Graph paper and calculator can also be used by the students to get the same results.

If groups are given different data sets, the graphs can be printed or displayed so that the entire class or several groups can merge their information to come up with findings.

Objectives:
Given a set of data students will be able to:

- Create, using Microsoft Excel or another graphing program, an appropriate graph.
- Determine the mean, median, mode and range of the data.
- Using the graph they construct, be able to answer questions related to the data.
- Interpret the information found on the graph, and present their findings either orally or in a written format.

Standards:

- National 9-12: A1, 2; D1, 2; E2; F4, 5, 6; G1, 2, 3

Vocabulary:

- anthropogenic: an effect or object resulting from human activity
- ice core: a core sample typically removed from an ice sheet, most commonly the polar ice caps of Antarctica and Greenland, or from glaciers
- residence time: the length of time a substance remains in an absorbed or suspended state
- sintering: process of sealing off and trapping air bubbles in ice

Background:
Although past and present changes in climate can be related and traced back to several different sources, scientists wishing to determine the past and present state of the climate, as well as future estimates of climate change, often analyze the amount, or concentration, of carbon dioxide (CO_2) present in our planet's atmosphere. Current concentrations are relatively easy to measure, requiring only a small sample of the air. To obtain older concentrations from the past, however, scientists must be able to analyze previous states of the atmosphere through pristine air samples located in **ice cores**. By studying air trapped in these cores, an accurate picture of past CO_2 levels can be reconstructed and compared to current levels, helping to establish a link between atmospheric CO_2 variance and climate change.

The trapping of air within an ice sheet is a relatively slow process that occurs when air is allowed to circulate between the layers of snow which accumulate at the high elevations of an ice sheet. As additional snow accumulates on the ice sheet annually, the underlying layers from previous years are gradually buried and compressed, slowly shutting off the flow of air to subsurface layers. Increased pressure from the weight of the overlying layers eventually turns the snow into layers of ice, and at about 50 meters (165 feet) air from the outside atmosphere is no longer able to circulate among these layers. This lack of circulation, combined with increased compression, causes air which had been slowly diffusing to subsurface layers to be sealed off and trapped as small bubbles in a process known as **sintering**. The small amount of air contained within each bubble is never again exposed to the outside environment, thus forming a permanent record of the atmosphere at the time in which sintering occurred. Over time, each layer of ice and its associated air bubbles are buried deeper and deeper within the sheet. Scientists are then able to "reclaim" the air for study by drilling from the highest point of the ice dome and extracting a core of ice which can contain numerous annual layers of ice, some dating back hundreds of thousands of years. Sintered air within each layer can then be extracted and concentrations of key atmospheric constituents, such as CO_2, can be measured and determined. By studying such concentrations, scientists can re-create past climatic aspects, such as global temperature, while determining the impact that natural and human factors have had on global climate.

Repeated evaluation of various ice cores shows, with high confidence, that CO_2 levels reached a concentration of 280 parts per million (ppm) following the last glacial maximum and remained at this level for thousands of years. Around the turn of the 19th Century, however, concentrations began an accelerated increase, reaching 365 ppm by the end of the millennium, with nearly 70% of this increase occurring after 1950. This phenomenon, which has been labeled as the **anthropogenic CO_2 increase**, can be linked to two major sources: the burning of fossil fuels and clearing of forested land. In this manner, carbon dioxide is being added to the atmosphere at a much greater rate than occurs naturally, causing an increase in global temperature and changing of global climate through the enhanced greenhouse effect.

Current Research:

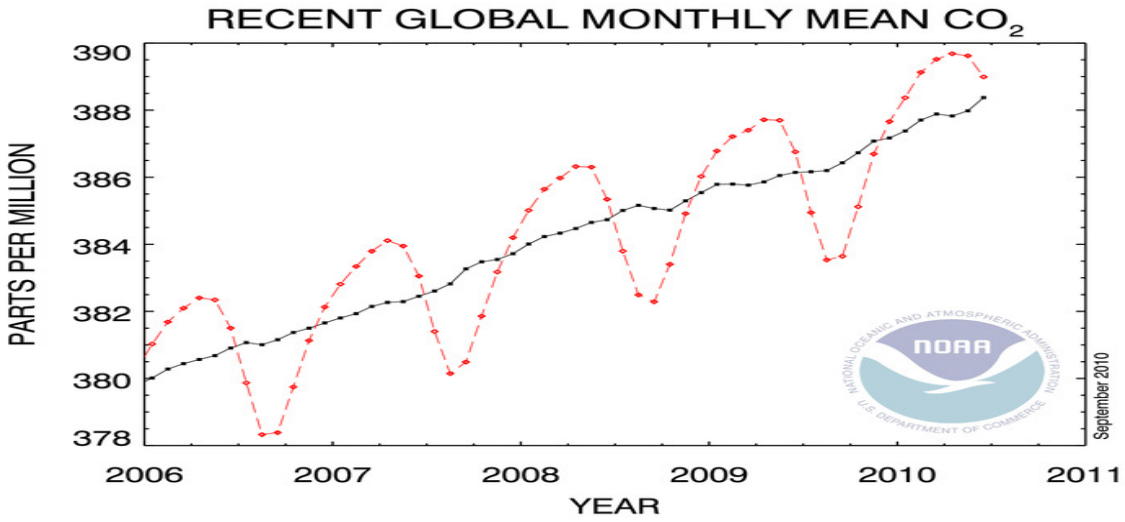
During 2007-2011, CReSIS scientists collaborated with researchers from the University of Coppehagen to help with the North Greenland Eemian Ice Drilling - NEEM project, - an international ice core research project aimed at retrieving an ice core from North-West Greenland reaching back through the previous interglacial, the Eemian. To learn more about the NEEM project and drilling for ice cores – check out this link - http://neem.dk/about_neem/.

In this activity, students will examine two different carbon dioxide sources: recent measurements from air samples collected at the Mauna Loa Observatory in Hawaii and older concentrations from an actual ice core drilled in 1975 at the Law Ice Dome in Antarctica. Analysis of both types of values will allow students to re-create concentrations of CO_2 since 1010, determine the rate at which CO_2 concentrations have changed since the 18th Century, and estimate future concentrations.

Materials:

- Computer w/Microsoft Excel (or other graphing software)
- Data Set – Historical CO_2 Record from the Law Dome, Antarctica (1010-1975)
    - http://cdiac.ornl.gov/ftp/trends/co2/lawdome.combined.dat
        - Last data set at bottom of the page
- Data Set – Scripps Institution of Oceanography, CO_2 Concentrations from Mauna Loa Observatory, Hawaii (1959-2009)
    - ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt
- Student Worksheet

Engage:



In the above figure, the dashed red line with diamond symbols represents the monthly mean values, centered on the middle of each month. The black line with the square symbols represents the same, after correction for the average seasonal cycle.

Q1) What environmental factors might be responsible for the annual up and down nature of the red line?

Explore:

- Download the data set "Historical CO_2 Record from the Law Dome, Antarctica (1010-1975)" (see materials section, last data set at bottom of the page). Follow instructions from 'How to Import Data into Microsoft Excel' if necessary.

Q2) Find the following statistical information for CO_2 concentration (years 1010-1975). Mean. Median.

Q3) Find the mean CO_2 concentration for each century.

Explore:

- Using Microsoft Excel, plot a graph of CO2 concentration versus time, treating each century as a separate series.
    - Add a trend line to the data for each century (series).

Q4) Discuss what trends you can interpret from these averages.

Q5) Based on the rate of increase from 1900-1975, predict what the CO_2 levels will be in 2005. 2010.

Q6) How do these levels compare with the actual level of 387.4ppm in 2009?

Q7) What does this tell you about CO_2 concentrations?

Q8) Using the graph, determine, on average, the amount that CO2 concentrations have increased during each century (1700s, 1800s, and 1900s).

Q9) Based on the graph and your calculations in questions 2-8, what predictions can you make about future CO_2 concentrations? Provide support for your prediction.

Elaborate:
Consider the more recent CO_2 data collected at Mauna Loa Observatory in Hawaii.

- Download the data set "Scripps Institution of Oceanography, CO_2 Concentrations from Mauna Loa Observatory, Hawaii (1959-2009)."
- Construct a graph of the actual measured CO_2 concentration versus time.

Q10) What trends are noticeable with this data?

Q11) Are these similar to those from the Law Dome, Antarctica data?

Elaborate:

- Construct a combined graph using the averageCO_2 concentration at the Mauna Loa site and the concentrations from the Law Dome site. Place each set of data on the same graph.

Q12) Describe the relationship between the data from Mauna Loa and Law Dome.

Q13) What conclusions can you draw about the accuracy of each collection method?

Q14) Refer to question 5, what should the CO_2 levels be in 2007?

Q15) How do these levels compare with the actual CO_2 levels measured at Mauna Loa?

Q16) What does this information tell you about the rate of increase of CO_2 concentrations?

Explain:
CO2 remains in the atmosphere for more than 400 years (IPCC, 2007), a process referred to as **residence time**. Greenhouse gas emissions are thus still in the atmosphere, meaning there is already a certain amount of CO2 concentration increase locked in for the next several decades.

Evaluate:
Q17) Write a short description of the activity you have just completed. Consider the following topics in your discussion:

- How have CO_2 concentrations changed in the past?

- How will CO_2 concentrations continue to change into the future?
- How would CO_2 concentrations change if society were to shift entirely too renewable and sustainable energy resources tomorrow?

References:

- D.M. Etheridge, L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola and V.I. Morgan. 1998. Historical CO_2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
- Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends)
- IPCC, Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon et al., Eds. (Cambridge Univ. Press, Cambridge, 2007).

STUDENT PAGE

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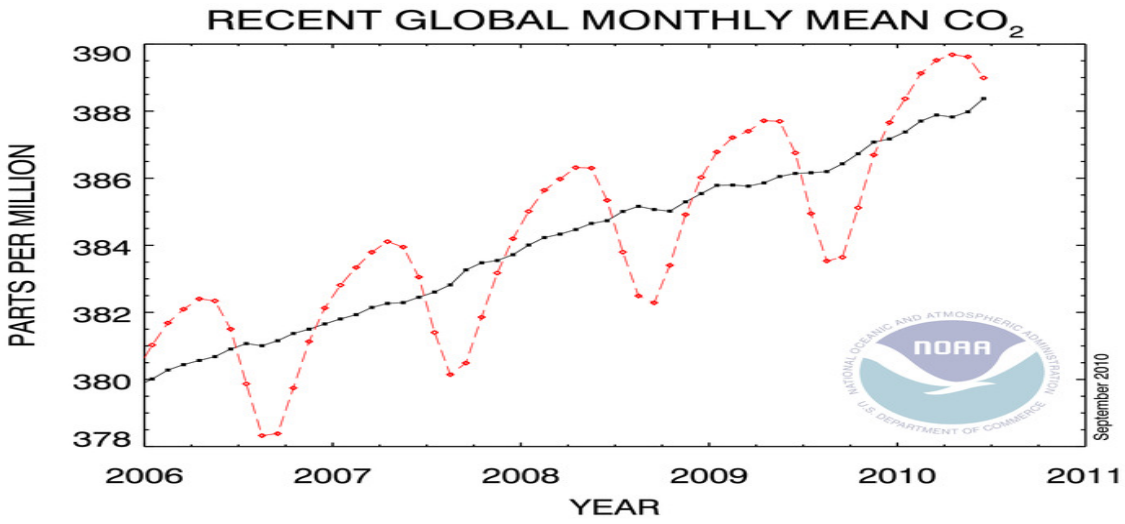

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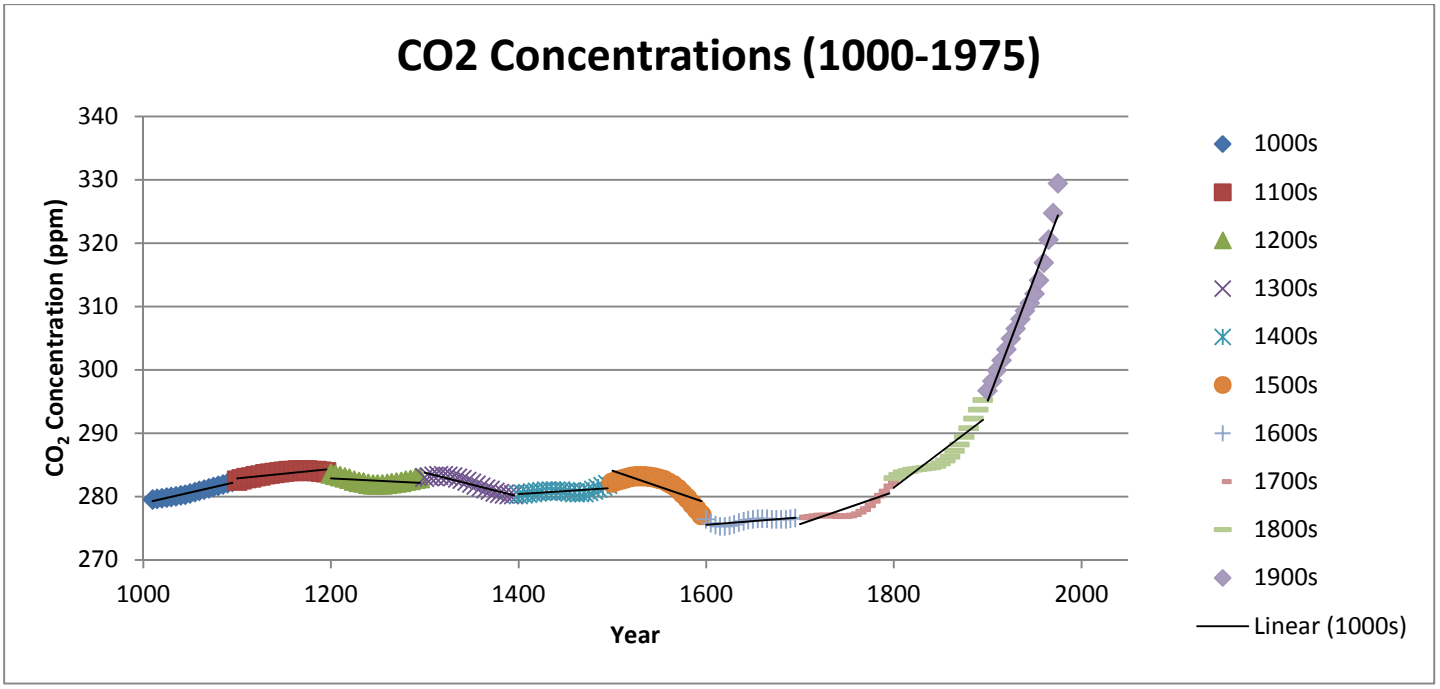
- IPCC, Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon et al., Eds. (Cambridge Univ. Press, Cambridge, 2007).

ANSWER KEY

Q1) Seasonal changes when trees are growing or are dormant are responsible for the up and down nature of the graph. More CO_2 is absorbed during times when there are more leaves on the trees (spring and summer) resulting in lower CO_2 concentrations. During the autumn and winter months when there are few to no leaves, CO_2 concentrations are seen to increase.

Q2) Mean – 283.7; Median – 281.75

Q3) 1000s – 280.7; 1100s – 283.6; 1200s – 282.5; 1300s – 282.0; 1400s – 280.8; 1500s – 281.7; 1600s – 276.1; 1700s – 278.1; 1800s – 286.8; 1900s – 309.8 ppm/year



Q4) Before 1700, trends were slightly up or slightly down. After 1700, there is a dramatic increase in CO_2 concentration averages from century to century, especially from the 19th to 20th Centuries. On average, concentrations increased by about 8 ppm from the 1700s to the 1800s, and by about 23 ppm from the 1800s to 1900s. This implies that a significant increase in concentrations occurred over this 100 year period.

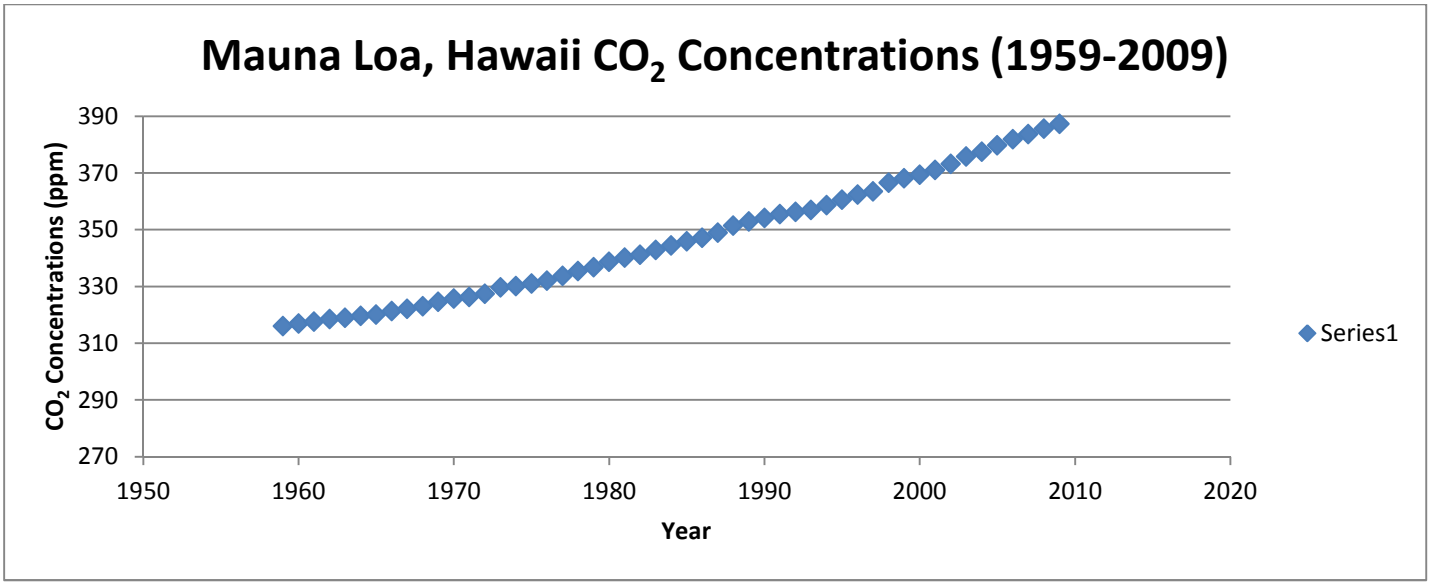
Q5) 2005 – around 340 ppm; 2010 – around 345 ppm

Q6) The predictions from question 5 are much lower than the observed 387.4 ppm in 2009.

Q7) CO_2 concentrations are continuing to increase over time.

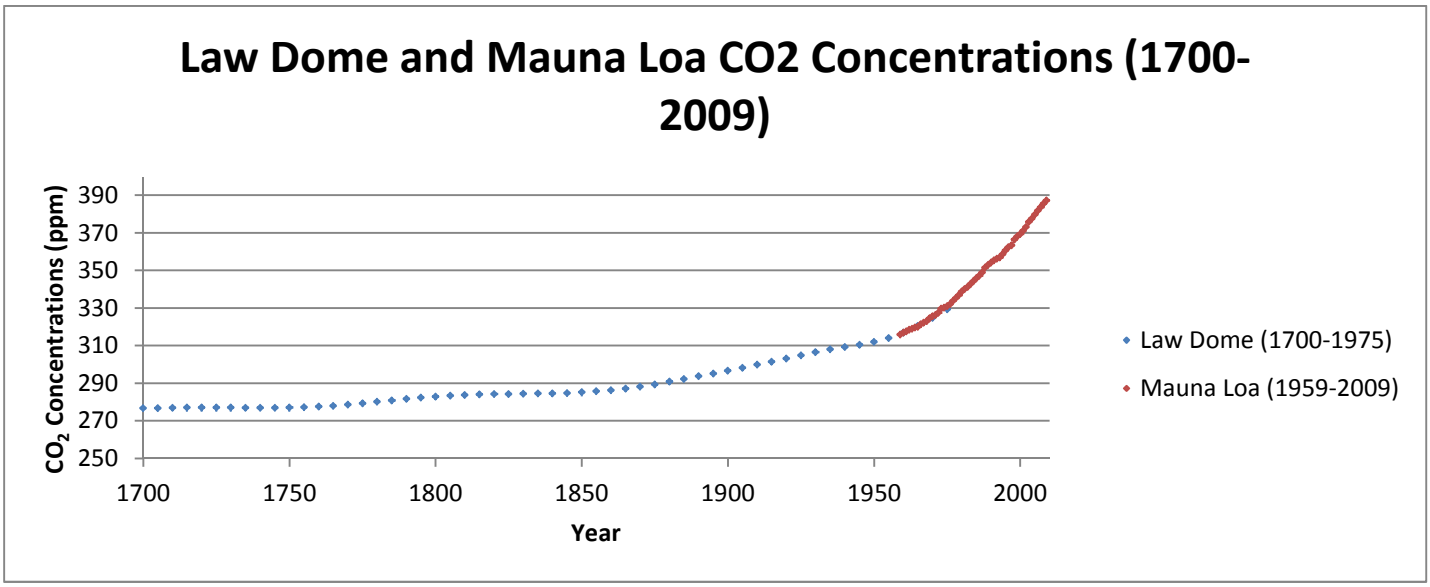
Q8) 1700s – 0.050 ppm/year; 1800s – 0.112 ppm/year; 1900s – 0.390 ppm/year

Q9) There is a fairly consistent trend in CO_2 concentrations in the 1700s and early 1800s before levels begin to drastically increase around 1850 (shortly after the industrial revolution). Concentrations then continue rising at a relatively rapid rate through the 20th Century. If trends continue, CO_2 levels will continue to increase at increasing rates.



Q10) There is still an upward trend.

Q11) The increasing trend from Mauna Loa is not as dramatic as the increases seen from Law Dome.



Q12) Both sets of data are extremely similar and, therefore, show very good alignment over the time period in which they overlap.

Q13) This coincidence of values implies that each set of data has a certain degree of accuracy associated with its collection and analysis methods, and that each "paint" an accurate picture of past and current CO_2 concentrations.

Q14) If CO_2 concentrations had continued to increase at an average rate of 0.390 ppm, a value of 341.8 ppm would be expected for 2007. However, this extrapolated value is about 42 ppm lower than the actual value measured at Mauna Loa, suggesting the rate of CO_2 release to the atmosphere has increased since 1975.

Q15) According to the data from Mauna Loa, the 2007 value was 383.7 ppm, well above the predicted values from the Law Dome data.

Q16) This extrapolated value (383.7) is about 42 ppm lower than the actual value measured at Mauna Loa, suggesting the rate of CO_2 release to the atmosphere has increased since 1975.

Q17) Concentrations will continue to increase in the future due to the rising rate at which CO_2 is being added to the atmosphere. This upward trend can be seen graphically in the exponential increase shown in the mid and late 20th Century and by comparing both the average concentration and average rate of increase values for each century. Should our society move to more renewable and sustainable energy, our levels of CO_2 would continue to increase into the future because of the long residence time of CO_2. It would be several hundred years before we start to see and negative rate of CO_2 concentration change.