Global Change Today and Lessons from the PETM

The impact of human activity on global climate reached scientific consensus with the release of the report by the Intergovernmental Panel on Climate Change (February 2007):

> *"Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."*

While many people have long suspected this outcome, the scientific method is inherently conservative and it literally took decades of observation, data collection and analysis, debate, and testing of the results to reach this profound and sobering conclusion: human activity has unequivocally altered the composition of our atmosphere and is responsible for the recent record of global warming, primarily through the burning of fossil fuels.

The PETM occurred 55 million years ago and records an abrupt change in the ocean-climate system related to global warming. How does this ancient example of global change compare with present conditions of increasing concentrations of atmospheric carbon dioxide and rising global temperatures?

50-Year Record of Increasing Atmospheric Carbon Dioxide

Figure 1 shows the instrument record of increasing atmospheric carbon dioxide (CO_2) as measured near the summit of Manua Loa, Hawaii since 1957.

1. How much has atmospheric CO_2 increased since 1957? What was the concentration of CO_2 in 2006?
2. Has the rate of rising been constant during the past 50 years? Explain.
3. Why does the CO_2 curve display a saw-tooth pattern?

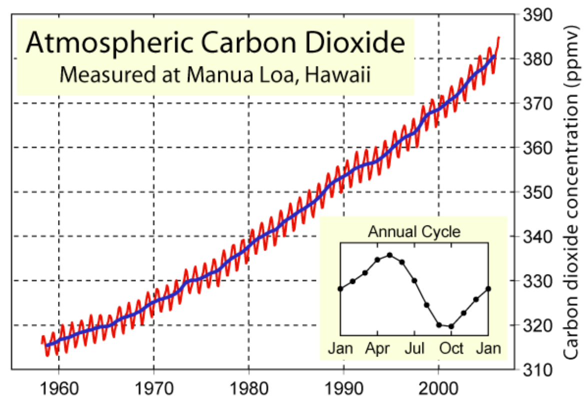

Figure 1. *This figure shows the history of atmospheric carbon dioxide (CO_2) concentrations as directly measured at Mauna Loa, Hawaii. This curve is known as the Keeling curve, and is an essential piece of evidence of the man-made increases in greenhouse gases that are believed to be the cause of global warming. The longest such record exists at Mauna Loa, but these measurements have been independently confirmed at many other sites around the world. The annual fluctuation in carbon dioxide is caused by seasonal variations in carbon dioxide uptake by land plants. Since many more forests are concentrated in the Northern Hemisphere, more carbon dioxide is removed from the atmosphere during Northern Hemisphere summer than Southern Hemisphere summer. This annual cycle is shown in the inset figure by taking the average concentration for each month across all measured years. The red curve shows the average monthly concentrations, and blue curve is a moving 12-month average. This figure was created by Robert A. Rohde from published data and is incorporated into the Global Warming Art project (http://en.wikipedia.org/wiki/Image:Mauna_Loa_Carbon_Dioxide.png).*

Global Temperature Trends of the Past 150 Years

Figure 2 shows the instrumental record of average global temperatures since the mid-1800s.

1. What are the key features of this plot?
2. How does the trend in global average temperatures compare with the concentration of atmospheric CO_2 during the past 50 years (~1957-2007)?
3. What is the rate of global temperature rise for the 50 years between 1957 and 2007 (i.e., the interval for which we also have an instrument record of CO_2)? Report your results in degrees Celsius (°C) per century.

Ice Core Records of Ancient Carbon Dioxide Concentrations

As we've seen, instrument records of changing atmospheric CO_2 are available dating back to 1957 (Figure 1). To determine pre-1957 concentrations of CO_2 we must rely on "proxy" records (i.e., indirect evidence). Ice cores collected in Greenland and Antarctica have provided a record of CO_2 for the past 400,000 years (Figure 3). The snow that accumulates in the high latitudes becomes progressively compacted and recrystallized by subsequent years of snow accumulation to form firn and eventually ice. Tiny bubbles of air become trapped in the firn and ice. These bubbles can be sampled and measured for the concentration of CO_2 and other gases. The ice core record shown in Figure 3 spans the past 4 glacial-interglacial cycles, which have repeated with a cyclicity of ~100,000 years. Such periodicity corresponds with predicted Milankovitch climate forcing related to the eccentricity of Earth's orbit around the Sun.

1. What is the natural range of variability of atmospheric CO_2 before the Industrial Revolution (~1800)?
2. The present concentration of CO_2 exceeds 380 ppmv (parts per million by volume). What can we conclude from these data?
3. How does the inset of Figure 3 (trends in atmospheric CO_2 over the past 1000 years) compare with the "hockey stick" trend of global temperatures over the past 1000 years (Figure 4)?

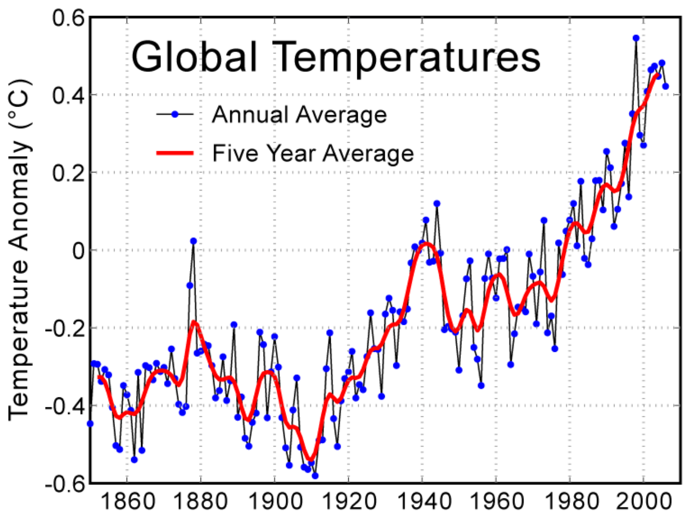

Figure 2. *This image shows the instrumental record of global average temperatures as compiled by the Climatic Research Unit of the University of East Anglia and the Hadley Centre of the UK Meteorological Office. Data set HadCRUT3 was used. HadCRUT3 is a record of surface temperatures collected from land and ocean-based stations. The most recent documentation for this data set is Brohan, P., J.J. Kennedy, I. Haris, S.F.B. Tett and P.D. Jones (2006). "Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850". J. Geophysical Research 111: D12106. DOI:10.1029/2005JD006548. Following the common practice of the IPCC, the zero on this figure is the mean temperature from 1961-1990. This figure was originally prepared by Robert A. Rohde from publicly available data and is part of the Global Warming Art project (http://en.wikipedia.org/wiki/Image:Instrumental_Temperature_Record.png).*

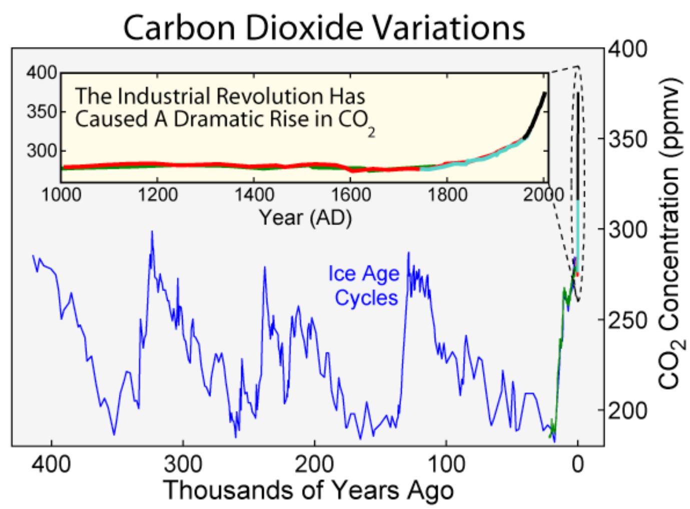

Figure 3. *This figure shows the variations in concentration of carbon dioxide (CO_2) in the atmosphere during the last 400,000 years. Throughout most of the record, the largest changes can be related to glacial/interglacial cycles within the current ice age. Although the glacial cycles are most directly caused by changes in the Earth's orbit (i.e., Milankovitch cycles), these changes also influence the carbon cycle, which in turn feeds back into the glacial system. Since the Industrial Revolution, circa 1800, the burning of fossil fuels has caused a dramatic increase of CO_2 in the atmosphere, reaching levels unprecedented in the last 400,000 years. This increase has been implicated as a primary cause of global warming. This figure was originally prepared by Robert A. Rohde from publicly available data and is incorporated into the Global Warming Art project (http://en.wikipedia.org/wiki/Image:Carbon_Dioxide_400kyr-2.png).*

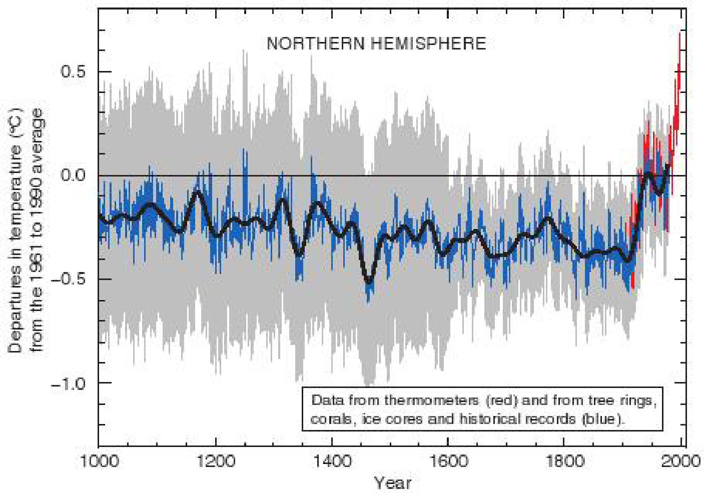

Figure 4. *"Hockey stick" trend of Northern Hemisphere temperature over the past 1000 years. This chart is from the Intergovernmental Panel on Climate Change Third Assessment Report (2001). It is the IPCC's reproduction of the work of Mann, Bradley, and Hughes (1998, Nature; 1999, Geophysical Research Letters). The colored lines are the reconstructed temperatures (blue = proxy data; red = instrument data), and the gray shaded region represents estimated error bars. http://en.wikipedia.org/wiki/Image:Hockey_stick_chart_ipcc.jpg*

How Does the PETM Compare with Modern Global Warming?

The PETM is an ancient example of how the Earth's ocean-climate system responded to very rapid global warming, probably triggered by the sudden release of greenhouse gases from sedimentary deposits. While the PETM was not related to human activity, it was a global event whose outcomes may foreshadow similar patterns of change in the near future.

1. How much did atmospheric temperatures increase during the PETM?
2. How long did it take for this rapid rise of temperatures?
3. Knowing the magnitude of temperature increase and the amount of time required to increase global temperature, estimate a range of possible rates of temperature change in degrees Celsius (°C) per century?
4. How does the PETM compare to the modern rate of temperature change?
5. What lessons can we learn from the PETM?

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