An Analysis of the Differences in Annual Carbon Dioxide Levels Measured at the Mauna Loa Observatory

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Abstract

The differences in the annual carbon dioxide concentrations appear to have increased from about 5.3 ppm to about 6.2 ppm during the period from 1958 to 2001, potentially reflecting increased photosynthetic activity, as the gas concentrations increased from about 315 ppm to about 370 ppm. A global response to the increase in carbon dioxide levels during the latter half of the twentieth century is addressed through this research. Global mechanisms for decreasing carbon dioxide levels apparently are not keeping pace with the rate of increase in CO_2 production, which would indicate a need to decrease anthropogenic production of this gas.

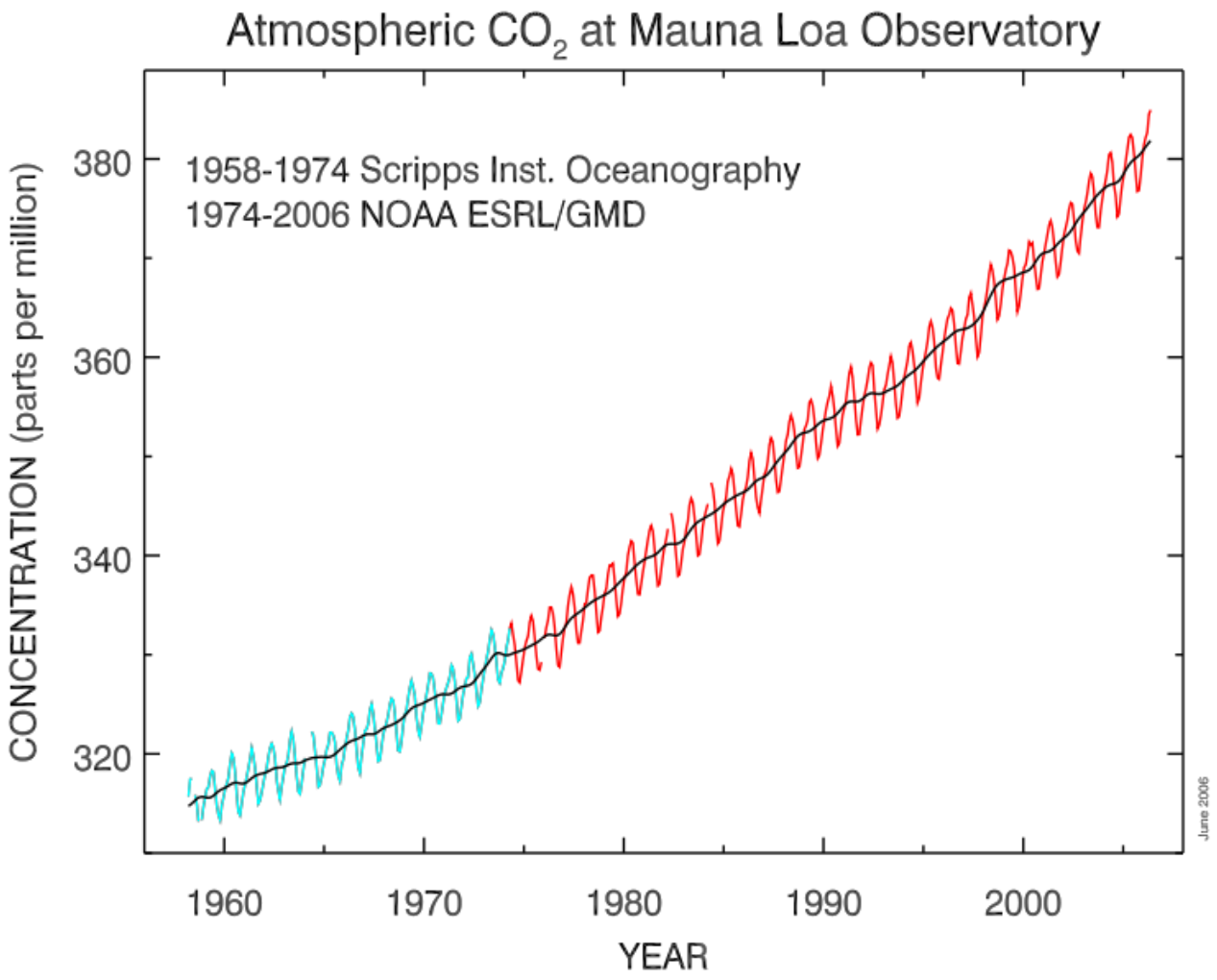
Introduction

Carbon Dioxide (CO_2), a gaseous product of the decomposition or combustion of organic substances, is a minor constituent of the

Earth's atmosphere (about 0.4 parts per thousand, or about 400 parts per million). As a part of the carbon cycle, it participates in the recycling of carbon from solid and aqueous sources (biota, rocks and oceans) into and out of the atmosphere. A major route from gaseous to condensed forms is photosynthesis. Combustion and microbial decomposition offer major routes from the condensed and dissolved states back to the gaseous state.

Carbon dioxide levels historically have shown several ~100,000 year cycles between about 180 ppm and 280 ppm [11]. Recently, however, the rise of the Industrial Age has increased the per capita rate of combustion of carbon sources above these historical levels, which combined with a rising human population level have resulted in a rise in the global concentration of CO_2, beginning in the latter half of the eighteenth century, to levels higher than any concentrations that have been measured or estimated over the previous four hundred thousand years.

More recently, CO_2 measurements taken at a single location (Mauna Loa, HI) clearly show a rise in gas levels from about 315 ppm in 1958 to about 397 ppm in 2012.



http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.pdf
Fig. 1 Atmospheric carbon dioxide levels measured at Mauna Loa Observatory.

We wondered whether the increase in carbon dioxide concentration might result in an increase in photosynthetic CO_2 absorption. There appears to be some agreement that increased carbon dioxide concentrations may increase plant production [2]. However, the results of laboratory studies and farm-scale field studies often appear to show inconsistent plant response to

increases in atmospheric CO_2 concentrations [3, 12, 15]. In contrast, we were not interested in measuring plant growth; rather, our focus was directed toward the overall global effect of rising carbon dioxide concentrations on the absorption of this gas.

The Mauna Loa data appear to offer some insight into this question. The data are recorded frequently enough to see the annual change in the carbon dioxide concentration. In effect, we can see the Earth “breathe” once a year as the spring and summer plant growth in the northern hemisphere (where the land masses predominate) absorbs a measurable portion of the global atmospheric CO_2. Dave Keeling, who established this body of carbon dioxide measurement data, immediately recognized this annual phenomenon when he wrote "We were witnessing for the first time nature's withdrawing CO_2 from the air for plant growth during summer and returning it each succeeding winter" (as quoted in [7]).

Over the fifty-plus year span of the data, the carbon dioxide levels have risen from low-300 ppm to high-300 ppm levels. If plants were able to absorb more CO_2 at higher gas concentrations, we might expect to see larger differences between the annual high and low gas concentrations in recent years, when the CO_2 levels

have been higher, compared with the earlier years. If, on the other hand, higher carbon dioxide concentrations resulted in no greater absorption, then we would expect to see no change in the annual gas differences over time. The expected change in the differences might amount to about one-quarter to one-third of the difference, and thus should be observable.

Experimental Setup

We estimated the annual high and low carbon dioxide concentrations for selected years from the Mauna Loa graphed data. We chose three seven-year periods at the beginning, the middle, and the end (2001) of the graphed data.

We calculated annual differences in the concentrations and averaged the differences for each of the three periods. We then compared the differences among the periods to determine any trends over time.

Experimental Results

Our estimated carbon dioxide levels for the selected years were:

Mauna Loa Carbon Dioxide

Year	Estimated (+/- 0.5 ppm) CO_2 Max	CO_2 Min
1958	317.5	312.0
1959	318.0	313.0
1960	320.0	314.0
1961	320.5	315.0
1962	321.0	315.5
1963	322.0	318.0
1964	322.5	317.0
1977	337.0	331.0
1978	338.0	333.0
1979	339.0	334.0
1980	341.0	336.0
1981	342.5	336.5
1982	344.0	338.0
1983	345.5	339.5
1995	364.0	357.5
1996	365.5	359.5
1997	367.0	360.0
1998	369.0	364.0
1999	371.0	364.0
2000	372.0	366.5
2001	374.0	367.5

The averages and average differences for the three periods were:

Period	Average CO_2 (ppm)	Average Difference (ppm)	Avg. Diff. Average (percent)
1958 - 1964	318	5.3	1.67
1977 - 1983	338	5.6	1.65
1995 - 2001	366	6.2	1.70

Interestingly, the difference in the annual concentration of CO_2 (annual maximum - annual minimum) increased from the earliest period to the latest period, as the carbon dioxide concentration increased – more CO_2 was absorbed when the concentration was higher. This increase in the absorption resulted in a constant rate of absorption – each year, the spring growth absorbs about 1.7 percent of the atmosphere's carbon dioxide. It appears that the photosynthetic carbon dioxide fixing system does respond to changes in atmospheric carbon dioxide levels. This response is seen clearly in the following graph of average carbon dioxide concentration difference against average carbon dioxide concentration:

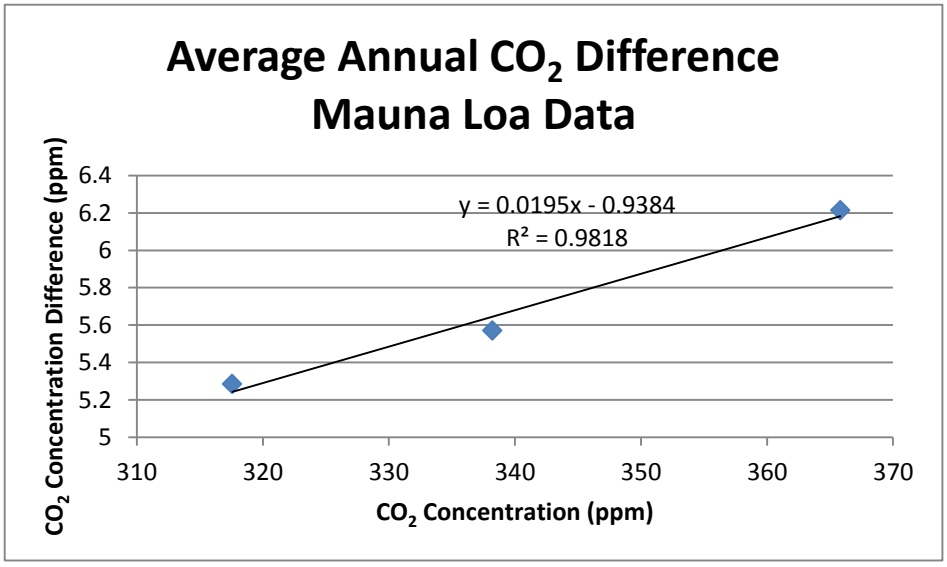


Fig. 2 Graph of average annual carbon dioxide differences vs. carbon dioxide concentration

A linear fit of the data returned a correlation coefficient of 0.98.

Linear regression analysis of the individual annual differences vs. carbon dioxide concentration yielded a positive slope (m = 0.019) that is statistically non-zero (t-test) at the 95% confidence level:

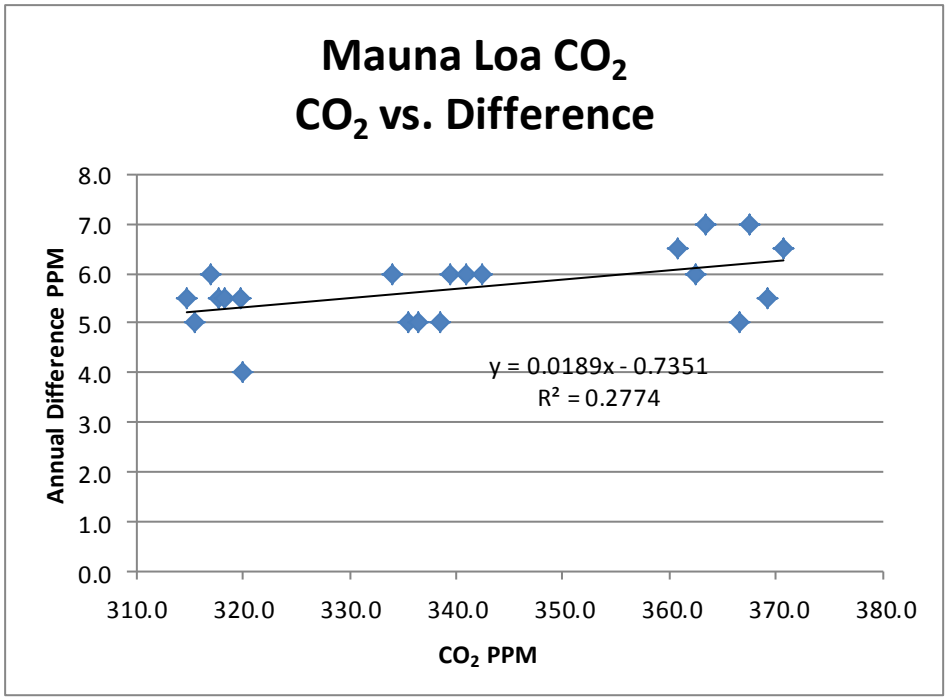


Fig. 3 Graph of carbon dioxide differences vs. carbon dioxide concentration: all data

Conclusions

As the atmospheric carbon dioxide concentration increased during the latter half of the twentieth century, the difference between the annual highest and lowest carbon dioxide levels also increased, maintaining a relatively constant net rate of annual absorption of about 1.7 percent, and suggesting that annual photosynthetic activity increased in the presence of higher gas concentrations.

Although the absorption of carbon dioxide apparently increased, the rate of this increase has not matched the increase in the rate of

CO_2 emission, resulting in exponentially rising levels (an increasing rate at which the concentration rises), from about 0.6 ppm per year at the beginning of the Mauna Loa measurement (1960's) to about 1.9 ppm per year at the turn of the millennium, and averaging about 1.2 ppm per year [14].

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