The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere

Keeling, C. D. (1960), The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere. Tellus, 12: 200–203. doi: 10.1111/j.2153-3490.1960.tb01300.x

The National Oceanographic and Atmospheric Administration (NOAA) recently reported that on May 9, 2013 the daily mean concentration of carbon dioxide in the atmosphere of Mauna Loa, Hawaii surpassed 400 parts per million (ppm) for the first time since measurements began in 1958. This is an important milestone because, as the oldest continuous CO_2 measurement station in the world, Mauna Loa serves as the primary global benchmark site for measurement of this potent greenhouse gas.

Charles D Keeling was a pioneer in climate science, and developed a method of producing precise measurements of CO_2, which he implemented at several locations. It is his record of the increase in atmospheric CO_2 at Mauna Loa Hawaii, as well at other "pristine air" sites, which represents the most important time-series data set for the study of global change in atmospheric CO_2. The data set is known as the "Keeling Curve" and the curve has documented a steady rise in atmospheric CO_2.

In recognition of the crossing of the 400 ppm threshold at Mauna Loa, we revisit one of the seminal papers in CO_2 dynamics.

Objectives:

- The study's primary objective was to analyze CO_2 concentrations over time in various locations.
- Gas analyzers equipped with strip chart recorders were used to measure CO_2 concentrations in Antarctica, Hawaii and Florida and a fourth analyzer was set up in the laboratory.
- Samples were also collected from aircraft flying 5 – 6 km over the Pacific Ocean and from surface stations at the South Pole and Arctic ice flows.

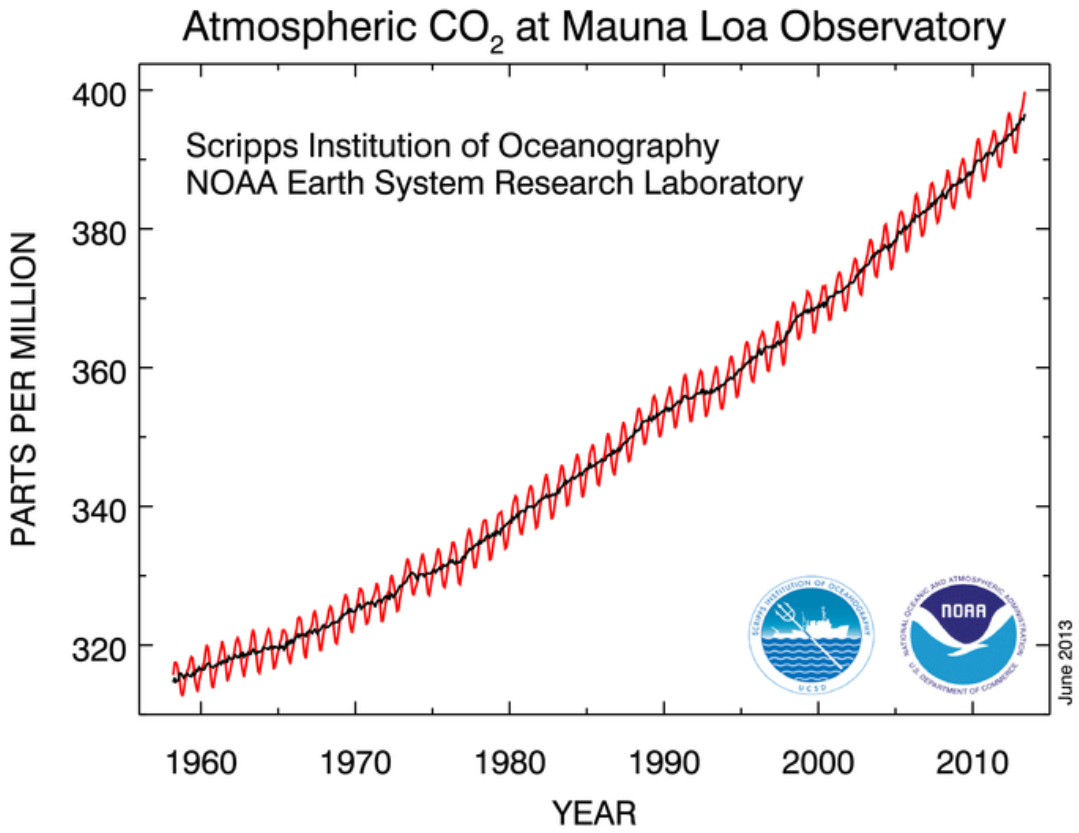
New Science:

- The study identified and characterized, for the first time, a systematic variation with season and latitude in the concentration and isotopic abundance of atmospheric CO_2 in the northern hemisphere.
  - A clearly defined seasonal variation was found in all samples from the northern hemisphere.
  - Maximal CO_2 concentrations were found at the beginning of the spring growing season, and minimum concentrations found in the fall, near the end of the growing season.
  - The isotopic composition of CO_2 associated with the seasonable variability was found to be in good agreement with the value for air found associated with forests and vegetation.
- Local contamination was found to occur at all three continuous recording stations:
  - In Little America, Antarctica, the contamination was determined to be due to combustion of the fuel in the immediate vicinity of the station.

    - At Mauna Loa a less prominent variability was found in less than half the samples, and was attributed to carbon released from volcanic vents, anthropogenic combustion, and effect of upslope wind.
    - The concentration La Jolla, California, site was highly variable, with CO_2 highest when the wind blew from the direction of Los Angeles, and lowest when winds were from the west or southwest.
- In the southern hemisphere, there was no seasonal variability in CO_2 concentrations, but a small but persistent increase in atmospheric CO_2 over time was found in Antarctica.
- At the South Pole, the increase was about 1.3 ppm per year and this was determined to be nearly that to be expected by the combustion of fossil fuel (1.4 ppm) if no removal from the atmosphere takes place.
- In each location where multi-year measurements were available, the concentration of CO_2 was found to be increasing steadily.

<u>Significance:</u>

- Before this paper was published, atmospheric CO2 was considered to be highly variable, in contrast to oxygen, nitrogen and the rare gasses, and this variation was unexplained.
- The correlation of atmospheric CO_2 with the seasonal cycle, especially in the regions with vegetative land cover (northern temperate zones), was a milestone in understanding the role vegetation plays in the carbon cycle.
- While a seasonal variability in CO_2 could be attributed to vegetative cycles, and short-term variability could be attributed to point sources, both natural (i.e. volcanoes) and anthropogenic, a steady long-term increase in CO_2 was shown to be near to, and consistent with, the combustion of fossil fuel (i.e. anthropogenic).
- The study implied that atmospheric CO_2 would continue to rise incrementally over time, due to the combustion of fossil fuel.
- In June, 2013, the CO_2 concentration at Mauna Loa briefly exceeded 400 ppm. In 1960, the mean monthly average CO2 concentration was 317 ppm (rounded numbers). This indicates an average gain of 1.56 ppm per year – higher than the increase found in this study.



Monthly average atmospheric carbon dioxide concentration versus time at Mauna Loa Observatory, Hawaii (20°N, 156°W) where CO_2 concentration is in parts per million in the mole fraction (ppm). The curve is a fit to the data based on a stiff spline plus a 4 harmonic fit to the seasonal cycle with a linear gain factor.

Data from Scripps CO_2 Program.

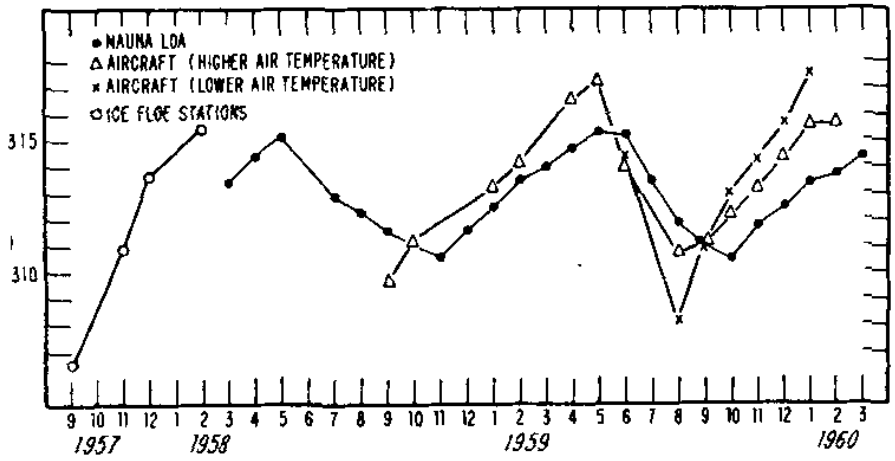


Figure 1: Variation in concentration of atmospheric carbon dioxide in the Northern Hemisphere.

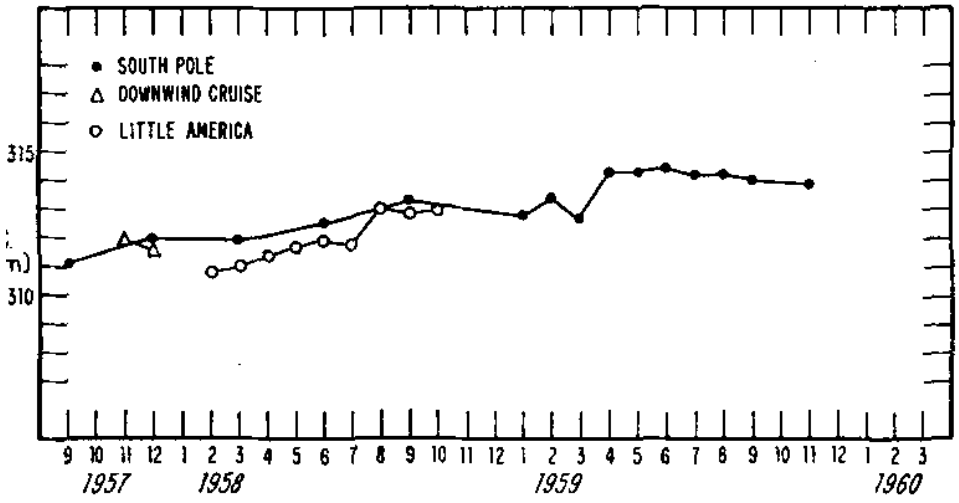


Figure 2: Variation in concentration of atmospheric carbon dioxide in the Southern Hemisphere.