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Keeling Curve: Result, Interpretation & Global Monitoring

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Abstract

The Keeling Curve is a graph of the accumulation of carbon dioxide in the Earth's atmosphere based on continuous measurements taken at the Mauna Loa Observatory on the island of Hawaii from 1958 to the present day. The curve is named for the scientist Charles David Keeling, who started the monitoring program and supervised it until his death in 2005.

Keywords: Mauna Loa Measurements; Results and Interpretation; Global Monitoring; Ralph Keeling.

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1. Introduction

Keeling's measurements showed the first significant evidence of rapidly increasing carbon dioxide levels in the atmosphere. According to Dr Naomi Oreskes, Professor of History of Science at Harvard University, the Keeling curve is one of the most important scientific works of the 20th century. Many scientists credit the Keeling curve with first bringing the world's attention to the current increase of carbon dioxide in the atmosphere.

Prior to the 1950s, measurements of atmospheric carbon dioxide concentrations had been taken on an ad hoc basis at a variety of locations. In 1938, engineer and amateur meteorologist Guy Stewart Callendar compared datasets of atmospheric carbon dioxide from Kew in 1898-1901, which averaged 274 parts per million by volume (ppm), and from the eastern United States in 1936-1938, which averaged 310 ppmv, and concluded that carbon dioxide concentrations were rising due to anthropogenic emissions. However, Callendar's findings were not widely accepted by the scientific community due to the patchy nature of the measurements.

2. Mauna Loa Measurements

In 1957-1958, the International Geophysical Year, Keeling obtained funding from the Weather Bureau to install infrared gas analyzers at remote locations, including the South Pole and on the volcano of Mauna Loa on the island of Hawaii. Mauna Loa was chosen as a long-term monitoring site due to its remote location far from continents and its lack of vegetation. Keeling and his collaborators measured the incoming ocean breeze above the thermal inversion layer to minimize local contamination from volcanic vents. The data were normalized to remove any influence from local contamination. Due to funding cuts in the mid-1960s, Keeling was forced to abandon continuous monitoring efforts at the South Pole, but he scraped together enough money to maintain operations at the Mauna Loa Observatory, which have continued to the present day.

Keeling published the first "Keeling Curve" of monthly carbon dioxide records from Mauna Loa from 1958 to 1960 in the journal Tellus in 1960, and reported that the year-to-year increase in carbon dioxide roughly matched the amount of fossil fuels burned per year. By 1976, it was well established that the rising carbon dioxide in the curve was due to anthropogenic emissions.

Carbon dioxide measurements at the Mauna Loa Observatory in Hawaii are made with a type of infrared spectrophotometer, now known as a non-dispersive infrared sensor that is calibrated using World Meteorological Organization standards. This type of instrument, originally called a capno graph, was first invented by John Tyndall in 1864, and recorded by pen traces on a strip chart recorder. Currently, several laser-based sensors are being added to run concurrently with the infrared spectrophotometer at Scripps Institute of Oceanography, while NOAA measurements at Mauna Loa still use the non-dispersive infrared sensor.

3. Results and Interpretation

The measurements collected at Mauna Loa Observatory show a steady increase in mean atmospheric carbon dioxide concentration from 313 parts per million by volume (ppm) in March 1958 to 406 ppm in August 2017, with an increase of ~2 ppmv carbon dioxide per year. This increase in atmospheric carbon dioxide is due to the combustion of fossil fuels, and has been accelerating in recent years. Since carbon dioxide is a greenhouse gas, this has significant implications for global warming. Measurements of carbon dioxide concentration in ancient air bubbles trapped in polar ice cores show that mean atmospheric carbon dioxide concentration was between 275 and 285 ppmv during the Holocene epoch (9,000 BCE onwards), but started rising sharply at the beginning of the nineteenth century.

The Keeling Curve also shows a cyclic variation of about 5 ppmv each year corresponding to the seasonal change in uptake of carbon dioxide by the world's land vegetation. Most of this vegetation is in the Northern hemisphere where most of the land is located. From a maximum in May, the level decreases during the northern spring and summer as new plant growth takes carbon dioxide out of the atmosphere through photosynthesis. After reaching a minimum in September, the level rises again in the northern fall and winter as plants and leaves die off and decay, releasing carbon dioxide back into the atmosphere.

4. Global Monitoring

Due in part to the significance of Keeling's findings, NOAA began monitoring carbon dioxide levels worldwide in the 1970s. Today, atmospheric carbon dioxide levels are monitored at about 100 sites around the globe through the Global Greenhouse Gas Reference Network. Measurements at many other isolated sites have confirmed the long-term trend shown by the Keeling Curve, although no sites have as long a record as Mauna Loa.

5. Ralph Keeling

Since Charles David Keeling's death in 2005, responsibility and oversight of the project was transferred to Keeling's son, Ralph Keeling. On the fiftieth anniversary of the beginning of the project, the younger Keeling wrote an article in Science magazine describing his father's life and work, along with how the project has grown and evolved over time. Along with more precise measurement materials and funds for the project of monitoring of the Earth's carbon dioxide levels, Keeling wrote his pride for his father's work and how he has continued it in his memory.

6. Recognition

In 2015, the Keeling Curve was designated a National Historic Chemical Landmark by the American Chemical Society. Commemorative plaques were installed at Mauna Loa Observatory and at the Scripps Institution of Oceanography at the University of California, San Diego.

On May 9, 2013, the daily mean concentration of carbon dioxide in the atmosphere measured at Mauna Loa surpassed 400 parts per million (ppm). Estimates of carbon dioxide during previous geologic eras suggest that carbon dioxide has not reached this level since the mid-Pliocene.

7. Conclusion

Charles David Keeling, of Scripps Institution of Oceanography at UC San Diego, was the first person to make frequent regular measurements of atmospheric carbon dioxide (CO2) concentrations at the South Pole and on Mauna Loa, Hawaii from March 1958 onwards. Keeling had optimized the measurement techniques at three locations: Big Sur near Monterey, rain forests of the Olympic Peninsula in Washington State, and high mountain forests in Arizona. He observed strong diurnal behavior of carbon dioxide, with excess carbon dioxide at night due to respiration by plants and soils, and afternoon values representative of the "free atmosphere" over the Northern hemisphere.

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