

A 50 YEAR RECORD OF THE EVOLUTION OF THE MERIDIONAL GRADIENT IN ATMOSPHERIC CO₂ AND ITS RELATION TO FOSSIL FUEL EMISSIONS

C.D. Keeling, S.C. Piper, and T.P. Whorf

Scripps Institution of Oceanography, Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0244

NOTE: Charles David (“Dave”) Keeling passed away unexpectedly on June 20, 2005. He led a distinguished career in carbon cycle research that began in 1955. Up to the day of his passing, Dave actively carried on research with his group of 9 members and he had planned to present a part of that research at the 7th International CO₂ Conference. In his place, Stephen Piper, a co-author and a member of Dave’s group since 1984, will present this paper.

Measurements of atmospheric CO₂ began in 1957-1958 at a wide range of locations, including at fixed stations, on ice floes, on oceanic expeditions, and on aircraft flights, with logistical and financial support provided by the International Geophysical Year (IGY) program. Although the measurement effort was reduced in scope immediately following the IGY, today, measurements are made at more than 100 locations. Over this same time interval, emissions of CO₂ from fossil fuel combustion increased from 2.3 thousand million metric tons per year (GtC/yr) in 1958 to 7.1 GtC/yr in 2003 [Marland *et al.*, 2005, and personal communication]. More than 90% of this CO₂ was released into the northern hemisphere where it lingered before mixing fully world-wide. The atmospheric CO₂ concentration, in response, rose faster in the northern hemisphere than in the southern, the interhemispheric difference increasing from near zero during the IGY to about 3 parts per million (ppm) in 2003. For all northern hemisphere stations where our program has measured CO₂, the gradient changes relative to the South Pole are generally proportional to the rate of fossil fuel CO₂ emissions, disregarding seasonal and short term interannual variability in the CO₂ data. Here, we use this fact to diagnose how the carbon cycle has evolved over the past half century.

To determine a relationship of atmospheric CO₂ gradients with the magnitude of industrial CO₂ emissions, we perform a linear regression on industrial emissions of the difference between observed concentration difference, in ppm, between the South Pole and each other station of our network. Measurements used here are as reported by Keeling *et al.* (2005). Our most precise record of latitudinal gradient in atmospheric CO₂ is for the station pair, Mauna Loa Observatory Hawaii (MLO) and the South Pole (SPO), graphed versus time in Fig. 1. Latitudinal profiles of fitted CO₂ over time contributed by all stations of our study are shown in Fig. 2. The profile designated “residual” represents fitted CO₂ for zero industrial emissions and represents CO₂ gradients associated both with natural, *ie.*, non-anthropogenic, fluxes and anthropogenic fluxes that have not varied in time proportionally to fossil emissions. Early in the record period, *e.g.* curves labeled “residual” and “1956”, the profiles show a nearly symmetrical shape with a peak in the tropics. Later, the profiles show a clearly progressive buildup of CO₂ in the northern hemisphere. A similarity of patterns in fitted CO₂ and ¹³C/¹²C north of the equator (not shown) is a strong indication that the build-up in the gradients are terrestrial in origin – some combination of changing industrial emissions and CO₂ exchange with the terrestrial biosphere. The lack of a tropical peak in ¹³C/¹²C, however, is strong evidence that the peak in CO₂ is caused by an oceanic source.

To gain further insight into the specific sources and sinks of atmospheric CO₂ that contribute to these patterns, we use a regional inverse model with the atmospheric tracer transport model TM2 [Piper *et al.*, 2001]. The atmospheric transport model TM2 predicts, on average, 37% greater increases in gradients with respect to the South Pole owing to fossil fuel emissions than observed for gradient changes at three stations in our program with long records (Mauna Loa and Cape Kumukahi, Hawaii, and La Jolla, California). If the TM2 model predictions are correct, a significant compensating sink for atmospheric CO₂ in the northern hemisphere is indicated. Given that fossil fuel emissions rose from 2.3 to 7.1 GtC/yr between 1958 and 2003, a compensating northern hemisphere sink of about 0.8 GtC/yr in 1956 increased to about 2.6 GtC/yr today. Because of uncertainty in transport model predictions such a sink cannot be proven to exist, but such a sink is likely to be suggested by any model with similar transport characteristics to the TM2 model, if used to predict the meridional gradient in CO₂ from fossil fuel emissions. Measurements of the ¹³C/¹²C isotopic ratio of atmospheric CO₂ for the stations of our program made since 1980, suggest that this sink, if real, is owing to progressively greater removal of CO₂ by land plants, at least since 1980.

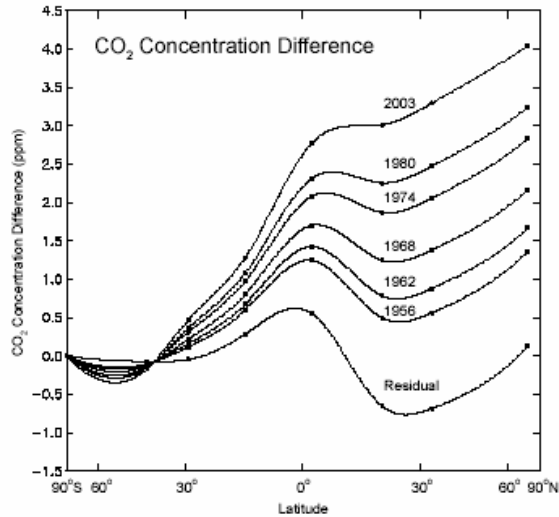


Fig. 1. Differences versus time in the seasonally adjusted concentration of atmospheric CO₂ between Mauna Loa, Hawaii and the South Pole (monthly dots) and its linear regression on the rate of industrial CO₂ emissions.

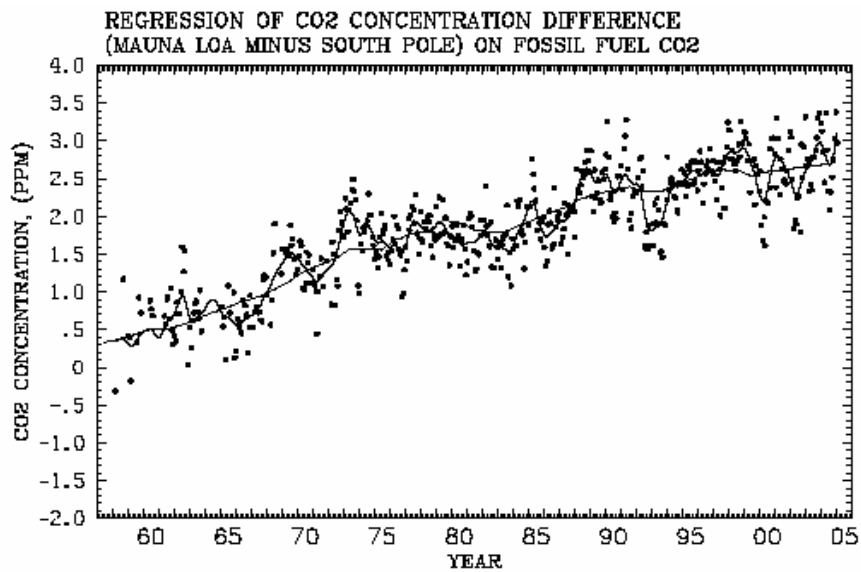


Fig. 2. Latitudinal profiles of the regression concentration differences for selected years from 1956 to 2003 and of the residual difference associated with zero industrial emissions (labeled “residual”).

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