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TELLUS

In memory of Charles David Keeling

Charles David Keeling passed away unexpectedly on 20 June 2005, at the age of 77, after suffering a heart attack. Dave Keeling's name will always be associated with the time series record of atmospheric carbon dioxide at Mauna Loa, which is often called the 'Keeling curve'. It has achieved iconic status as the foremost record of human influence on the earth's climate. He made the first and most important contribution to the now universal acceptance that atmospheric CO_2 is building up globally because of human activities, and beyond that, to the developing recognition that our species has become a force for change on earth of geological proportions.

Dave Keeling was the first to make very accurate measurements of atmospheric CO_2, starting in 1955. Before he announced his early results, it had appeared, largely from measurements in Scandinavia by a wet chemical method and published in Tellus, that CO_2 varied regionally from 250 to more than 350 ppm. If correct, that would have made it difficult to detect a slowly increasing trend. There was also no convincing evidence of an annual cycle in the Scandinavian data. As one of the outcomes of the International Geophysical Year, Keeling was able to start in 1958 continuous measurements of CO_2 at the Mauna Loa Observatory, at an altitude of 3400 m, a site that he guessed might be representative for much of the globe. His method of choice of the measurements was infrared absorption, backed by a system of very careful calibrations and independent flask samples.

He had already observed in air samples he had taken along the west coast of North America and in samples of oceanic air that there appeared to be a global background concentration with a quite narrow range. After the start of the Mauna Loa measurements, he later confessed to some anxiety, when the measured mole fraction was going down in July. Could there be a problem with the instrument? By the second year, he was confident that he had seen the annual cycle of carbon dioxide produced by photosynthesis and respiration, as well as an increase from one year to the next. No statistics were necessary to pull a tenuous signal out of the noise; it was there in plain view for all to see. Due to the high quality of the observations, other discoveries followed, such as the gradient in CO_2 mole fraction from north to south and its development over time, the relationship of the growth rate of CO_2 to the El Nino–Southern Oscillation, the changing seasonal cycle of CO_2, relationships between the $^{13}C/^{12}C$ isotopic ratio and CO_2 itself, and major features of the pattern of the partial pressure of CO_2 in surface ocean waters.

What makes Dave Keeling's measurements so convincing are his close attention to measurement protocol in order to avoid biases, his careful and continuing calibration procedures, and his deployment of independent methods, such as flask samples analyzed at the Scripps Institution of Oceanography that could be compared with the instrument operating on Mauna Loa. His measurements have

been built to last, and they set the standard for all of us to follow. Indeed, the basic elements of his approach are all incorporated in other programs measuring long-lived greenhouse gases in the atmosphere and oceans.

But Dave Keeling's contributions to the geosciences go far beyond the initiation of accurate and reliable series of measurements. His deep understanding of the physical, chemical and biological processes that govern the distribution of carbon between the rapidly exchanging natural reservoirs, the atmosphere, the oceans and the terrestrial systems, the flows between them and the human-induced changes that we now observe made him into one of the most important discoverers of the architecture of the global carbon cycle that is so fundamental to life on earth. A key aspect of this effort was of course the simultaneous consideration of the cycles of a number of fundamental elements that interact in the global geochemical web of the environment. And he was obviously delighted and rightfully so, when his son Ralph followed him in addressing the tough task of measuring accurately the variations of atmospheric oxygen in order to provide another independent and most essential piece of evidence for the ongoing human-induced change of our environment.

Dave was meticulous in this analytical work and naturally so also in writing scientific papers. We both remember the long series of revisions that each of our joint papers went through before submission for publication. His overarching goal was always to arrive at a best possible presentation of available information and their interpretation.

Dave Keeling did not practice science in an ivory tower. He was keenly aware of the grave implications of his findings for society, which was all the more reason for maintaining the highest possible standards of evidence.

We will sorely miss him, but his ideas and his fundamental contributions to the geosciences and geochemistry in particular will live on. And we will also remember him as a kind, generous and very much caring colleague, his love for music and his unsparing hospitality and friendship that he extended together with his wife and lifelong companion, Louise.

Pieter Tans and Bert Bolin