OBITUARY

Charles David Keeling 1928–2005

Pioneer in the modern science of climate change.

SCRIPPS INST. OCEANOGR./UCSD

Numerous records now show how we humans are altering the planet, with potentially global consequences for climate. But the first and now iconic examples of documenting global climate change were the precise measurements of the concentration of carbon dioxide in the atmosphere made at the mountain station on Mauna Loa, Hawaii, by Charles David Keeling. If the world today realizes that it has a problem and needs to curb emissions of greenhouse gases, it in large part owes this knowledge to Keeling's painstaking efforts.

Keeling was born in Pennsylvania in 1928, and studied chemistry and isotope geochemistry in Chicago. After completing his PhD, in 1953 he moved to the California Institute of Technology, and became interested in the problem of measuring levels of CO_2 in the atmosphere. Before that time, the prospect that levels of atmospheric CO_2 could be altered on a global scale because of the burning of coal, gas and oil was largely theoretical. At the end of the nineteenth century, Svante Arrhenius and Arvid Högbom had suggested that temperature might be affected by greenhouse gases. But the possibility of increasing atmospheric CO_2 was of no concern because the ocean was believed to absorb most of any increase.

In the 1950s, however, Roger Revelle and Hans Suess at the Scripps Institution of Oceanography in California realized that the sink capacity of the ocean is limited because of the slow mixing with deeper waters. Measurement of atmospheric CO_2 thus became a compelling topic of scientific interest. A job offer from Revelle brought Keeling to Scripps, where he remained for his entire career.

Keeling looked for alternatives to the existing, questionable methods of determining variations in CO_2, and eventually resorted to using an infrared analyser. As this is a relative measurement, he had to devise a clever system of calibration to make the measurements accurate and comparable between different sites and over long time spans. In conjunction with the International Geophysical Year 1957, a series of global geophysical activities spanning 1957–58, systems were set up on Mauna Loa and in Antarctica, supplemented by lab measurements on air flasks regularly sampled at the South Pole. The choice of such remote places was to ensure that they were as far away from local sources of CO_2 as possible, thus allowing reliable detection of changes in the background atmosphere.

Only two years later, Keeling produced a classic paper showing that the atmospheric CO_2 concentration was rising at the South Pole at a rate consistent with estimates of fossil-fuel emissions and ocean uptake. He also showed that the concentration at Mauna Loa exhibits a characteristic seasonal variation. Using concurrent measurements of the $^{13}C/^{12}C$ isotope ratio in CO_2, which differs according to the exchange processes with the land and the ocean, Keeling was able to demonstrate that this seasonal variation is probably driven by the annual cycle of vegetation in the northern extratropics.

Many would have left it at that and moved on to other scientific investigations. Keeling, however, anticipated the power of long-term observations and, despite many funding crises, relentlessly pursued the measurements. Thanks to this work, we now have two highly accurate records of atmospheric CO_2 spanning almost half a century; between the late 1950s and today, levels of CO_2 have risen from about 315 parts per million to more than 375 parts per million.

The information content in these long records is truly amazing. Keeling and his co-workers showed that the changes in total atmospheric CO_2 content can be estimated quite accurately. And by combining this with estimates of fossil-fuel emissions, we can tell how much CO_2 is being absorbed jointly by the ocean and terrestrial biosphere. Close analysis of the seasonal cycle in CO_2 concentrations at Mauna Loa revealed an increase in amplitude of up to 20% over the 40 years, indicating a strengthening 'breathing' of the vegetation in the Northern Hemisphere. The records also show interannual variations, which can be related to climate fluctuations such as those of the El Niño–Southern Oscillation. And using concurrent $^{13}C/^{12}C$ isotope measurements, Keeling's group could estimate the relative contributions of land and ocean to these phenomena.

The records from Mauna Loa and the South Pole were soon complemented by measurements made elsewhere to produce a global picture of CO_2 distribution. Keeling was aware that these data could be used with a model of atmospheric transport to determine the regional patterns of CO_2 sources and sinks. During a sabbatical stay in Stockholm in the early 1960s, he and the meteorologist Bert Bolin performed the first such 'inversion' of atmospheric CO_2 measurements and demonstrated that fossil-fuel emissions indeed contribute significantly to the global distribution of the gas. As increasing numbers of atmospheric monitoring stations became established by other groups, this pioneering work was refined with better numerical models. Today it constitutes a key method for monitoring the carbon cycle on larger scales.

Keeling was not always an easy colleague to work with. He was meticulous and demanded the same standards from his co-workers. But it is thanks to this attention to detail that we now have such beautiful documents depicting the changes in atmospheric composition. His work was recognized by numerous awards, such as the Blue Planet Prize from the Science Council of Japan and the Tyler Prize for Environmental Achievement.

Outside science, Keeling led an active life. Supported by his lovely family, he was involved in the political life of his home town; he also conducted a choir, and after a hard day at work he enjoyed playing the grand piano (and did so with considerable proficiency). He took great interest in foreign cultures — I fondly remember how, during a sabbatical stay in Switzerland, he even took on the challenge of taking lessons in the Bernese Swiss–German language with considerable success. But his major love was nature, and especially the mountains. Keeling died on 20 June. Appropriately, his final resting place is near his summer house in the wilderness of Montana. ■

Martin Heimann

Martin Heimann is at the Max Planck Institute for Biogeochemistry, PF 100164, 07701 Jena, Germany.
e-mail: martin.heimann@bgc-jena.mpg.de