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50 years on: The Keeling Curve legacy

By Helen Briggs

Science reporter, BBC News

It is a scientific icon, which belongs, some claim, alongside $E=mc^2$ and the double helix.

Its name - the Keeling Curve - may be scarcely known outside scientific circles, but the jagged upward slope showing rising carbon dioxide (CO₂) levels in the atmosphere has become one of the most famous graphs in science, and a potent symbol of our times.

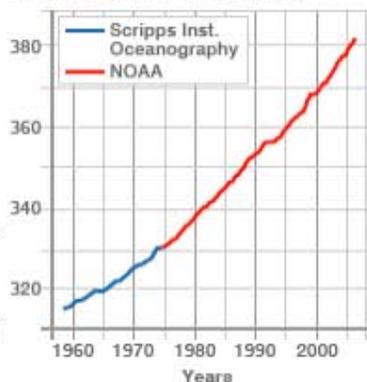
It was 50 years ago that a young American scientist, Charles David Keeling, began tracking CO₂ in the Earth's atmosphere at two of the world's last wildernesses - the South Pole and the summit of the Mauna Loa volcano in Hawaii.

His very precise measurements produced a remarkable data set, which first sounded alarm bells over the build-up of the gas in the atmosphere, and eventually led to the tracking of greenhouse gases worldwide.

The curve set the scene for the debate over climate change, and policies, sometimes controversial, that address the human contribution to the greenhouse effect.

"It wasn't until Keeling came along and started measuring CO₂ that we got the evidence that CO₂ was increasing from human activities," says Professor Andrew Watkinson, director of the Tyndall Centre for Climate Change Research at

ATMOSPHERIC CO₂ AT MAUNA LOA OBSERVATORY
Concentration (parts per million)



SOURCE: NOAA

“ Without this curve, and Professor Keeling's tireless work, there is no question that our understanding and acceptance of human-induced global warming would be 10-20 years less advanced than it is today ”

Dr Andrew Manning, UEA

the University of East Anglia (UEA), UK.

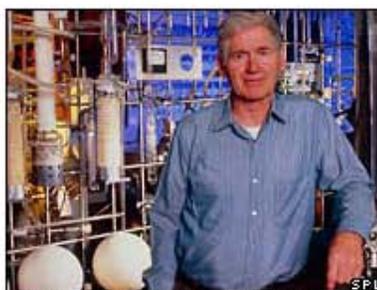
"The graph is iconic from a climate perspective."

Dr Alistair Manning of the UK Met Office agrees. "It was the first real indication that CO₂ levels were rising," he says. "That therefore started scientists thinking about the impact such a change would have on the climate."

'Tireless work'

Back in the 1950s, when Keeling began his experiments, no-one knew whether the CO₂ released from the burning of fossil fuels (coal, oil/petroleum and natural gas) would end up in the atmosphere or be fully absorbed by oceans and forests.

"The goal behind starting the measurements was to see if it was possible to track what at that time was only a suspicion: that atmospheric CO₂ levels might be increasing owing to the burning of fossil fuels," explains biogeochemist Dr Andrew Manning, also from the UEA, who worked with Professor Keeling in the 1990s.



Keeling had to work hard to justify his work

"To do this, a location was needed very far removed from the contamination and pollution of local emissions from cities; therefore Mauna Loa, high on a volcano in the middle of the Pacific Ocean was chosen.

"Without this curve, and Professor Keeling's tireless work, there is no question that our understanding and acceptance of human-induced global warming would be 10-20 years less advanced than it is today," adds Dr Manning.

Sleepless nights

Professor Keeling discovered that carbon dioxide was rising continuously and that there were annual fluctuations in carbon in the atmosphere (the little squiggles on the line), caused by seasonal variations in plant growth and decay.

When he started his measurements in 1958, CO₂ levels were around 315 ppmv (parts per million by volume - that is 315 molecules of CO₂ for every one million molecules in the air); by the year 2005 they had risen to about 378 ppmv.

Yet despite the importance we place on climate change research today, Professor Keeling, known as Dave to friends and colleagues, struggled to secure funding for his monitoring efforts.

"Dave Keeling suffered many sleepless nights, even as late



as in the 1990s, being forced again and again to justify continued funding of his programme," recalls Dr Manning.

"The fact that we are celebrating 50 years now is due purely to his incredible perseverance, courage and optimism."

He says the technical, analytical and logistical challenges of the work are enormous.

"To measure such tiny changes in the composition of the air, high on a remote mountain top in the middle of the Pacific Ocean is extremely challenging even today in the 21st Century," he explains.

"That Dave Keeling was able to successfully begin and continue such highly demanding measurements in the 1950s is a tribute to his brilliance."

Detailed monitoring

Today, carbon dioxide levels are sampled weekly at about 100 sites around the world.

Flasks filled with air are taken to a laboratory, where they are analysed for carbon dioxide, other greenhouse gases and pollutants.

Aircraft collect similar samples at higher altitude, while space-borne sensors detect some gases remotely throughout the atmosphere.

"Without the fifty-year carbon dioxide record, we wouldn't understand the cause of the climate change we are observing today," says James Butler, deputy director of The National Oceanic and Atmospheric Administration (Noaa) Earth System Research Laboratory.



Monitoring efforts continue atop the Mauna Loa volcano

"The carbon dioxide record has allowed us to connect the dots between increasing fossil fuel emissions and a warmer world."

Charles Keeling died in 2005, aged 77. He continued his research into carbon dioxide at the Scripps Institution of Oceanography in San Diego, US, until his final day.

By then he had authored nearly 100 research articles and had received the National Medal of Science - the US's highest award for lifetime achievement in scientific research.

His son, Professor Ralph Keeling, also a geochemist at Scripps, continues his work.

TIMELINE: carbon monitoring

1957: Charles David Keeling starts work monitoring CO₂ at the South Pole and Mauna Loa Observatory, Hawaii

1958: Keeling starts first direct continuous atmospheric measurements of CO₂

Early 1970s: NOAA, the US federal agency, starts monitoring CO₂ worldwide

1995-2003: NOAA's Earth System Research Laboratory (ESRL) at Boulder, Colorado, develops and maintains the world's standard references for CO₂ and other greenhouse gases