The slow discovery of human-induced climate change

"Few of those familiar with the natural heat exchanges of the atmosphere, which go into the making of our climates and weather, would be prepared to admit that the activities of man could have any influence upon phenomena of so vast a scale."

Weren't it for the old-fashioned language, climate sceptics, who believe there is no scientific consensus on human-made climate change, would readily place this sentence in a 2013 paper. However, the statement belongs to a landmark study published by Guy Stewart Callendar in 1938. He carries on with: "In the following paper, I hope to show that such influence is not only possible, but is actually occurring at the present time."

Seventy-five years later, the world's biggest carbon emitters are now taking action. China, who alone emits nearly a quarter of man-made emissions, agreed to implement emission caps earlier this year. The US, the second largest CO_2 emitter, followed suit with US President Obama issuing regulations to limit carbon-dioxide emissions from power plants in the country. The European Union also considers preventing dangerous climate change a strategic priority, and has recently committed to spend at least 20% of its 2014–2020 budget on climate action.

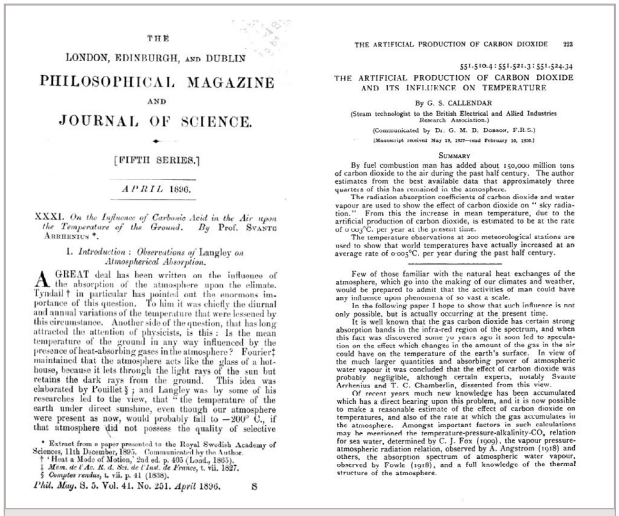
These measures follow a long-standing consensus by the climate-science community who now overwhelmingly agree that climate change is real and that greenhouse gases emitted by human activities are the main cause. The recently released report on the physical science basis of climate change by the Intergovernmental Panel on Climate Change (IPCC) summarises this agreement by stating: "It is *extremely likely* that human activities caused more than half of the observed increase in global average surface temperature from 1951 to 2010."

The consensus of the scientific community on climate change and its severe consequences is now clear, and is pushing policymakers to finally take action. But the history of climate change science tells us that wasn't always the case.

The deadly glaciers and the relation between CO_2 and temperature

Callendar's 1938 paper was ground-breaking: it was the first to demonstrate the warming of the Earth's surface and to suggest this warming was related to fossil-fuel burning. But it was not without errors. Fearing "the return of the deadly glaciers", Callendar believed that a human-generated temperature increase would be beneficial. The 'deadly glaciers' were a reference to the ice ages of the Earth's past, when glaciers had covered Europe and much of North America.

In the late 19th century, Svante Arrhenius calculated the influence of atmospheric carbon on ground temperatures in an attempt to explain the Earth's ice ages. Physicist John Tyndall had earlier found out that water vapour, methane and carbon dioxide strongly



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XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

1. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

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THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE 223

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THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE AND ITS INFLUENCE ON TEMPERATURE

By G. S. CALLENDAR
(Steam technologist to the British Electrical and Allied Industries Research Association.)
(Communicated by Dr. G. M. D. Dobson, F.R.S.)
[Manuscript received May 19, 1937—read February 10, 1938.]

SUMMARY

By fuel combustion man has added about 150,000 million tons of carbon dioxide to the air during the past half century. The author estimates from the best available data that approximately three quarters of this has remained in the atmosphere.

The radiation absorption coefficients of carbon dioxide and water vapour are used to show the effect of carbon dioxide on "sky radiation." From this the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0·003°C. per year at the present time.

The temperature observations at 200 meteorological stations are used to show that world temperatures have actually increased at an average rate of 0·005°C. per year during the past half century.

Few of those familiar with the natural heat exchanges of the atmosphere, which go into the making of our climates and weather, would be prepared to admit that the activities of man could have any influence upon phenomena of so vast a scale.

In the following paper I hope to show that such influence is not only possible, but is actually occurring at the present time.

It is well known that the gas carbon dioxide has certain strong absorption bands in the infra-red region of the spectrum, and when this fact was discovered some 70 years ago it soon led to speculation on the effect which changes in the amount of the gas in the air could have on the temperature of the earth's surface. In view of the much larger quantities and absorbing power of atmospheric water vapour it was concluded that the effect of carbon dioxide was probably negligible, although certain writers, notably Svante Arrhenius and T. C. Chamberlin, dissented from this view.

Of recent years much new knowledge has been accumulated which has a direct bearing upon this problem, and it is now possible to make a reasonable estimate of the effect of carbon dioxide on temperatures, and also of the rate at which the gas accumulates in the atmosphere. Amongst important factors in such calculations may be mentioned the temperature-pressure-alkalinity-CO_2 relation for sea water, determined by C. J. Fox (1909), the vapour pressure-atmospheric radiation relation, observed by A. Angstrom (1918) and others, the absorption spectrum of atmospheric water vapour, observed by Fowle (1918), and a full knowledge of the thermal structure of the atmosphere.

First pages of Arrhenius's 1896 (left) and Callendar's 1938 (right) seminal papers.

block radiation coming from the Sun. Inspired by this, Arrhenius calculated that cutting atmospheric carbon dioxide by about half would return the Earth to the ice ages. Using the same crude atmospheric model, he estimated that by doubling the CO_2 in the atmosphere, the global temperature would increase 5 to 6 °C. But at a time when the industry was burning fossil fuels at a negligible rate, he thought it would take thousands of years for that much CO_2 to be added to the atmosphere.

Early 20th century scientists criticised Arrhenius' calculations and ignored that variations in atmospheric CO_2 – those of human origin in particular – could alter the climate. Callendar's paper was met with similar scepticism. It took another few decades for consensus to start forming around the idea that human-made climate change was real.

The Keeling Curve and ice cores

Following the Second World War and well into the Cold War, there was a sharp increase in research funding from US military and other government agencies, giving many American scientists – including Charles David Keeling of Keeling Curve fame – the chance to make detailed measurements of carbon-dioxide levels in the atmosphere. These showed CO_2 concentrations were increasing steadily each year. Now, over 50 years later, the levels approach 400 parts per million (ppm), an increase of over 40% since the industrial revolution. While it was clear that atmospheric CO_2 was rising, it was still hard for some scientists to accept that the Earth's climate – a complex system influenced by many variables – could be dangerously warmed by this.

The 1980s brought fresh and critical discoveries from ice-core research, yielding information on local temperatures and atmospheric composition in the past few thousand years. Researchers, such as Hans Oeschger and Willi Dansgaard, discovered that the

Earth's temperature had abruptly changed various times in the past and that the changes in temperature and CO_2 had mostly moved in lockstep.

The scientific consensus had begun to form: the rapid concentration of atmospheric CO_2 prompted by fossil-fuel burning could drastically change the climate.

Climate change gets political

In the hot year of 1988 the consensus was strong enough for the discussion on human-induced climate change to enter the realm of politics. In June that year, climatologist James Hansen (then of the NASA Goddard Institute for Space Studies) testified before the US Congress, alerting decision-makers and the public to the dangers of climate change:

"I would like to draw three main conclusions. Number one, the earth is warmer in 1988 than at any time in the history of instrumental measurements. Number two, the global warming is now large enough that we can ascribe with a high degree of confidence a cause and effect relationship to the greenhouse effect. And number three, our computer climate simulations indicate that the greenhouse effect is already large enough to begin to [a]ffect the probability of extreme events such as summer heat waves."

In the same year, the World Meteorological Organization and the United Nations Environment Programme established the IPCC "to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts."

Twenty-five years, and five Assessment Reports later, the "[w]arming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased," as stated in the latest IPCC's report's summary for policymakers.

Climate change is in our hands. (Credit: Stephanie Flude)

If the discovery of human-induced climate change was slow, slower still – at a time of urgency – has been the implementation of concrete and efficient measures to fight it.

As University of East Anglia's Corinne Le Quéré wrote in The Guardian following the release of the IPCC summary for policymakers, "[the scientists'] job is done now and it is time to let the policymakers do theirs." The scientific community, and the world, waits to see how political leaders will respond.

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