Science Policy and the History of Climate Change

Martin Carr, 24 November 2006

Introduction

Societies exist because of the stories we tell. The earliest societies passed on stories from one generation to the next by telling and retelling them, and in the process the stories developed and changed. From the time of the Babylonian empire stories were written down and housed in libraries, and so libraries became places where stories could be found, read and interpreted. The Royal Society's science policy collections are one such resource for the telling of stories which shape the world we live in. Of the many stories we could have heard today I could have told the story of genetics, from Gregor Mendel's pea plants grown in the garden of an Augustinian friary to the latest personalised medicines. We could have heard the story of the emerging field of nanotechnology, and its perceived risks, or that of energy, from Michael Faraday's researches to current debates on renewable energy. But the story I have decided to tell is perhaps the most important of all, and one of especial interest to the British, because it is the story of the weather, and in particular climate change.

History of Climate Change - Methods

The first question to ask is about methodology - how do we come to understand the climate and climate change? I'm going to suggest that there are three approaches:

1. The appeal to authority, such as references to historical literature, or the writings of explorers, or the experiences of older generations.
2. A second was the gathering of vast sets of observed data over large areas and extended time periods in order to discern patterns.
3. The third, and perhaps most subtle, is to ask from first principles what the climate ought to be, and here the work of Fourier, Tyndall, Arrhenius and others, to whom we shall return, is notable.

Climate Change – the Early Days

Discussion of climate and climate change is no new discipline. In ancient times, climate was believed to be a function of latitude.

Aristotle believed it related to the character of a nation, Hippocrates related it to health. During the Enlightenment, Abbe Du Bos, writing in his 'Critical reflections' believed that the rise and fall of cultures was linked to changes in climate, and that climate change since ancient times had led to the artistic, moral and scientific decline of certain nations. Du Bos believed climate change was brought about by emanations of vapours from the earth. Baron Montesquieu, perhaps the most influential environmental determinist of the Enlightenment, also speculated on the role of climate on cultures, though for him latitude was of greater significance, and he allowed a greater role for the moral climate. Both cautioned that moving to new climates, such as the colonisation of America, was potentially bad for people. David Hume, following Du Bos and in turn influencing Montesquieu, believed that the advances in European culture were due to climate change, and that cultivation of the land was the determining factor in causing it to warm up. He believed the same was happening in America, only faster.

So it is to the Americas we turn for the first great climate change debate …

The American Climate Change Debate

Early colonists were disappointed the climate was so bad there, finding that despite being at similar latitudes to Europe, the climate was more violent. This anomaly needed explanation, and in 1694 Edmond Halley proposed that a comet had recently tilted the earth and that the Americas had until recently been more northerly and were still warming up. In a similar vein, Buffon, the notable Parisian naturalist, believed the flora and fauna of the Americas to be so degenerate because they had remained longer under the waters of the great deluge.

The colonials were rather defensive about these opinions and patriotically argued that the climate was clearly improving. Cotton Mather believed it was getting warmer as settlers cultivated the land and cleared the forests; Benjamin Franklin agreed, but thought it would be take many years of observations to prove it. Hugh Williamson of Harvard wrote in 1771 "It is generally remarked by people who have resided long in Pennsylvania and neighbouring colonies, that within the last forty or fifty years there has been a very great observable change of climate, that our winters are not so intensely cold, not our summers so disagreeably warm as they have been". He believed, as had other Enlightenment philosophers, that this warming was good for settlers and bad for natives. In time the Americas would have a climate as favourable for the flourishing of the arts and sciences as had ancient Greece.

What accounted for this change? John Evelyn, writing in 'Silva' believed moisture was the chief agent; moisture was bad for health and that by clearing forests both health and climate could be improved. This view was echoed by John Woodward in his 1695 publication, 'An essay toward a natural history of the Earth'. Edward Holyoke, an American physician, believed trees absorbed phlogiston and thereby produced air capable of extreme cold. Deforestation was able to moderate this, as he believed had happened in the US.

However, the theory had its critics, including Noah Webster, who cited a number of cold winters in his defence. A new approach was needed, and that was to be experimental observation.

Early Climate Observations

Following Franklin's suggestion, early observations were pioneered by Jefferson, who thought that environmental improvement could be shown by detailed observations. The first uniform meteorological observations had started in Italy at the Academia del Cimento in Florence in 1654. In 1667 Robert Hooke and Robert Moray, following a request by Wren, suggested to the Royal Society that records should be made, with little success, though Boyle and Locke followed Hooke's suggestion. In 1732, James Jurin, writing in the Philosophical Transactions, issued another plea for records to be kept and sent to the Society. A third appeal was issued in 1744, but again there was little response. Further efforts continued in the nineteenth century by the Meteorological Society, later the Met Office.

The situation was replicated in various other countries, with varying rates of success. The first call for international collaboration to make climate measurements came from the American Matthew Maury, director of the US Naval Observatory, in 1851. He sent letters worldwide, but as state systems were not yet fully operational, his plan failed. In 1872 however things were more favourable, and the International Meteorological Organisation (now the WMO) traces its origins back to a conference in that year in Leipzig, driven by

American action. From 1875, the Bulletin of International Simultaneous Observations was produced, including worldwide charts of observations.

Theories of American climate change due to settlement were rebutted on two fronts. In the literary sphere, Noah Webster showed citations from ancient authors were selective and misleading. His critique was blunted however by his later belief that cultivation did make weather more variable. The chief means of settling the argument however rested on climate data. Samuel Forry, an army surgeon, in 1842 used data from over 60 stations gathered by the Army Medical Department to rebut the climate change theory. Du Bos, Montesquieu, Hume, Evelyn, Buffon, Jefferson, Holyoke and the rest he believed had simply cited each other with no evidence. Forry concluded that climates are stable, that they are susceptible to human changes, but these changes are small compared to the influence of latitude, elevation and proximity to water. Humboldt agreed, and sets out a similar view in his popular work 'Views of Nature'.

Other pioneer climatologists took the same opinion, including William Ferrel, the most mathematically astute geophysicist in North America at the time. It is interesting to note that Ferrel understood in general terms the greenhouse effect, and in an 1884 essay on radiation from a diathermanous envelope writes, "It is seen, therefore, of what great advantage the atmosphere is in raising the mean temperature of the earth's surface. This effect is similar to that of the glass covering of a conservatory of plants, which is a diathermanous medium with permits the heart of the sun to pass through with facility, but is almost completely impenetrable by the heat radiated from the air and all bodies within". By 1889 in a notable essay 'Is our climate changing?', Cleveland Abbe, chief scientist at the Army Signal Office, agreed with Ferrel that the debate was now settled. In a memorable quote from his essay he says this: "It will be seen that rational climatology gives no basis for the much-talked-of influence upon the climate of a country produced by the growth or destruction of forests, the building of railroads or telegraphs, and the cultivation of crops over a wide extent of prairie. Any opinion as to the meteorological effects of man's activity must be based either upon the records of observations or on a priori theoretical reasoning … The true problem for the climatologist to settle during the present century is not whether the climate has lately changed, but what our present climate is, what its well-defined features are, and how they can be most clearly expressed in numbers." Where are we? We've moved from the literary and historical understanding of climate to an empirical one, and a recognisably modern climatology. Abbe anticipates the next phase in the climate change debate, the understanding of the physical basis of climate. To understand the emergence of this field, we turn our attention to three scientists in particular – Fourier, Tyndall and Arrhenius.

The birth of climatology

Joseph Fourier, a French physicist, published an article in 1824 identifying three factors contributing to terrestrial temperature – heat from the Sun, heat from space and other celestial bodies, and heat from inside the earth. During his comments on the atmosphere, he alludes to the greenhouse effect, though for Fourier this was not the major factor, the 'temperature of space' was.

In 1859, John Tyndall, one of the greatest British 19^{th} century scientists, began work with early spectrophotometers to understand the radiation of heat from gases. He wrote in Philosophical Magazine, "The atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet". Tyndall believed the major gas trapping heat was water vapour, a view set out in his essay 'Radiation through the earth's atmosphere'. It seemed conclusive from Tyndall's research that water vapour was the major factor in absorbing and radiating heat, and he was supported by Herschel and Stokes who declared the results 'quite beyond doubt'. If Fourier had hinted at the greenhouse effect, Tyndall had given it experimental backing.

But for our story, and the role of carbon dioxide in particular, we turn at last to the Swedish electrochemist Svante Arrhenius, who in modern times is seen by many as the founding father of climate change science. Relying mainly on the experimental work of others, he presented a paper in 1895 to the Stockholm Physical Society which argued that changes in carbon dioxide concentrations of about 40 percent would trigger feedback mechanisms to account for glacial formation and retreat. His work was published the following year in a memoir, 'On the influence of carbonic acid in the air upon the temperature of the ground'. The real focus for Arrhenius was explaining ice ages. Arrhenius however accepted the work of another scientist Hogbom, whose carbon cycle paid little attention to industrial processes and deforestation, and focused on crustal processes, notably volcanic eruptions and limestone formation, in regulating CO_2 concentrations during various geological periods.

In his 1908 book 'Worlds in the making' Arrhenius reviews the history of the 'hot-house' theory: "That the atmospheric envelopes limit the heat losses from the planets had been suggested about 1800 by the great French physicist Fourier. His ideas were further developed afterwards by Pouillet and Tyndall. Their theory has been styled the hot-house theory, because they thought that the atmosphere acted after the manner of the glass panes of hot-houses". Arrhenius' own estimates of the temperature increases likely to be caused by rising CO_2 concentrations are remarkably similar to modern computer simulations of climate change, though the coincidence is entirely fortuitous.

By 1904 Arrhenius was taking anthropogenic carbon dioxide emissions seriously. He believed the effects of a new ice age could be ameliorated by them, and the earth could even enter a new carboniferous age of tremendous plant growth.

At the same time T.C. Chamberlin, an American, began to investigate in greater depth the link between geology and study of the atmosphere. In 1896 he outlined a theory of glaciation based on variation in CO_2 levels and subsequent water vapour feedbacks. However, he was dismissive of Arrhenius and Hogbom's theories that CO_2 variation was largely due to volcanism. Chamberlin expanded knowledge of the carbon cycle and instead saw the key factor as being inorganic processes such as crustal uplift and weathering of rocks, which triggered changes in CO_2 concentration and hence feedback mechanisms. This would lead to cycles of glaciation and warming.

In 1913 however Chamberlin renounced the CO_2 theory of climate change saying 'I greatly regret that I was among the early victims of Arrhenius' views'.

In the 1923 Carnegie yearbook Chamberlin published his mature view of the effects of water vapour and climate. Though he rejected the carbon dioxide theory, his legacy to us is an appreciation of the interconnectedness of the earth's systems.

I now want to talk about another American, Ellsworth Huntington. Huntington was a bad scientist, a eugenicist and by all accounts a racist, so why would we want to consider him at all? His views of climatic determinism, returning to the era of Du Bos and Montesquieu, led him to studies on the effects of climate on civilisations and the efficiency of workers. However his idea that climate change was caused by variations in solar activity has had a lasting effect. Huntington's legacy was to impede the development of climatology in the early 20th century, and shows us that not all science is progress

So in the early 20th century, climate science was in a time of flux and controversy. Most scientists didn't believe increased CO2 would have any effect on temperature, as existing concentrations would already absorb all the radiation, and other factors were seen as more important. The exception was G.S. Callendar, to whose paper read to the Royal Meteorological Society in 1938 we shall return. Overall, there was no universal agreement.

In 1950 C.E.P. Brooks presented a summary of climate change theories. The possibilities were numerous: changes in the Earth's orbit, changes of solar radiation, lunar-solar tidal influences, elevation of land masses and mountain building, changes in atmospheric circulation, changes in oceanic circulation, changes in continent-ocean distribution, changes in atmospheric composition, including the CO2 theory, volcanic dust in the atmosphere, cosmic dust theory, sunspot theory and polar migration and continental drift theory. Each theory had its supporters and opponents. The respected meteorologist Hans Panofsky attempted to synthesise a variety of influences, with a preference for the orbital and mountain building theories, but which theory any scientist preferred was very much down to personal preference.

Many opposed the CO2 theory. Humphreys, using results obtained by Angstrom, argued against it, and the tone of his 1940 edition of 'Physics of the Air' was echoed in the USDA Yearbook for 1941:
"Much has been written about varying amounts of carbon dioxide in the atmosphere as a possible cause of glacial climates. The theory received a fatal blow when it was realized that carbon dioxide is very

selective as to the wavelengths of radiant energy it will absorb, filtering out only such waves as even very minute quantities of water vapour dispose of anyway. No possible increase in atmospheric carbon dioxide could materially affect either the amount of insolation reaching the surface or the amount of terrestrial radiation lost to space". G. C. Simpson reinforced the view that the CO2 theory had had its day, and C.E.P. Brooks dismissed it similarly and said that Callendar's results were coincidence.

So let's look at bit more closely at Callendar's work. Callendar followed the lead of Eckholm (a colleague of Arrhenius) and extensively investigated CO2 concentrations and its possible effects. He was active in the mid 20th century, and his first significant contribution was his 1938 article, which detailed a quarter degree rise in average global temperatures over the preceding 50 years. Callendar's model for the future predicted a 2 degree rise in mean global temperatures with a doubling of CO2, though he cautioned that the effect of CO2 might be 'considerably greater than supposed'. His 1939 article 'The composition of the atmosphere through the ages' is significant for an early statement that humanity was conducting a 'grand experiment' and had become an 'agent of global change'. However, for Callendar, as for Arrhenius, warmer was still better, with increased plant growth and the indefinite delay of the ice age supposed. For the first time he began to accurately plot CO2 concentrations, and showed they had risen by 10 percent in the last 50 years.

By the late '40s and '50s climate change was on the public's mind, and a proliferation of articles appeared. In the 50s Gilbert Plass used his interdisciplinary background to bridge gaps between the physics of infrared absorption and the geochemistry of the carbon cycle and between geophysics and computer modelling. Plass supported Callendar's view that humanity was conducting an experiment with the atmosphere.

The science of climate change was boosted by the International Geophysical Year in 1957-58 in which one of the main players was Roger Revelle.

Revelle was the self-declared 'grandfather of the greenhouse effect'. His reputation has been exaggerated partly because of his influential position, and partly I think because of his own ego. In 1957 he and

Hans Suess published a notable article on the exchange of CO2 between the oceans and the atmosphere. They cited the work of Plass and Callendar, and like Chamberlin believed positive feedbacks would exacerbate the effects.

In this article they said, "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years. This experiment, if adequately documented, may yield a far-reaching insight into the processes determining weather and climate."

Following the IGY, Revelle and Harry Wexler of the US Weather Bureau agreed to set up continuous CO2 monitoring on Mauna Loa, under the direction of Charles Keeling. The result was the famous Keeling curve, a saw-toothed graph of inexorably rising CO2 concentrations. Though Keeling's work was influential we should however take care to note that CO2 measurements actually date back to John Dalton and others in the 19th century. Callendar's curve also fits closely with Keeling's. Revelle's overall contribution was more as an advocate of climate change than as a scientist.

Global cooling or global warming?

After the '50s computer modelling began to offer new insights into climate. At the same time the debate switched to global cooling and a possible new ice age, stimulated by an article by Maurice Ewing and William Donn in 1958. By the '70s global cooling was an observable trend, and speculation centred on an anthropogenic increase in the Earth's albedo.

But by the 1980s however warming was back on the agenda. James Hansen of Nasa, who has recently been awarded the WWF's conservation medal, announced to Congress and the world in 1988, 'global warming has begun'. He predicted a possible runaway greenhouse effect. Though later he revised his view, it was a starting point for further concern. This coincided with concerns about the ozone layer, which culminated in the internationally binding, and effective, Montreal protocol, proving that international action on the environment could work. The IPCC report of 1995 seemed on balance to suggest that human influence on the climate could be detected. The next landmark was the Kyoto protocol, which was agreed in 1997 and came into force in 2005. Politicians today are discussing what the next steps are. Another notable recent trend is that the debate has spread across disciplines, into sociology and politics, economics (such as the recent Stern report) and religion. A debate has also begun about whether we should adapt to climate change, or try to prevent it altogether. And new theories of how to prevent warming have been suggested, such as Paul Krutzen's suggestion of altering the composition of the upper atmosphere.

And that I think brings us more or less to where we are now. I hope I have convinced you of the importance of the historical dimension in any future discussion of climate change science, and how stories of the past can inform future thinking. We can only hope that the ending to the climate change story will be a happy one.