Why We Disagree About Climate Change

UNDERSTANDING CONTROVERSY, INACTION AND OPPORTUNITY

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TWO

The Discovery of Climate Change

2.1 Introduction

In the spring of 1845, Sir John Franklin set sail from England on a naval expedition charged by the British Government with identifying and mapping an ocean channel through the Northwest Passage. This fabled trade route, linking the Atlantic and Pacific Oceans through the sea-ice of the Canadian archipelago, had been central to much of Britain's maritime exploration of the North American continent since as far back as the sixteenth century, but no-one had yet been successful in opening the Passage. Neither was Franklin. He and all his men perished in their search, prompting an upwelling of national mourning, and adding another chapter to the mythology of heroic British explorers.

Over 160 years later, changes in Arctic climate are doing what hundreds of years of exploration could not achieve – opening a clear sea passage between the two oceans. In August 2007, the Norwegian Polar Institute announced that the Northwest Passage – the sea route – was open to routine traffic, and several ships navigated the passage before it was again closed by the growing winter sea-ice. Canada has instigated new naval patrols in the region to demonstrate her territorial claims and is contemplating a new military base in the Arctic. Russia has staked its claim to 460,000 square miles of resource-rich Arctic waters by planting its flag on the North Pole's sea floor. And the prospect of new shipping routes connecting northern Canada with eastern Asia is offering new economic opportunities in the Canadian north. The small settlement of Churchill on Hudson Bay could find itself at the centre of a new network of international shipping routes.[1] The melting Arctic is just one example – a dramatic and visual one – of how changes in physical climate alter both the natural and human worlds: changing the geometry of land and ice and the tone of our political discourses, but also changing our imagination by making us rethink the significance of our narratives of the past.

It may have been unthinkable to the commissioners of Britain's nineteenth-century maritime explorations that changes in climate could bring about their long-desired goal of extending the reach of the country's imperial trading power. Yet we now believe – we now know – that, far from being constant, the essential character of physical climate is its inconstancy. The great Ice Ages in the Earth's past, only dimly apprehended by the explorers of 1845, are now an established part of our natural history. The large-scale modification of the land surface wrought by humans over long centuries, or short decades, alters the climatic properties of regions, and now a new agent of climate change – humanity itself – seems to be at work, evidenced through shrinking Arctic sea-ice, retreating Himalayan glaciers, and rising sea levels.

This chapter tells the story of how we 'discovered' that physical climates could change and, more importantly, how we 'discovered' that humans have become an active agent in these changes. Section 2.2 constructs a simple genealogy of the idea of climate change, a crucial part of which was the revolutionary proposition of the early nineteenth

[1] 'Canada's climate change boomtown', see http://news.bbc.co.uk/1/hi/business/7155494.stm [accessed 28 May 2008] extracted from the radio programme 'The great game in a cold climate' broadcast on BBC Radio 4 on 1 January 2008.

century that huge planetary-scale changes in climate had occurred in the distant past (Section 2.3). The bulk of the chapter (Section 2.4) then traces the growing realisation through the twentieth century that the collective impact on the atmosphere of human actions was also sufficient to change the way the climate system worked; to change the nature of weather not just locally, but globally. Rather than going into great detail here – the story has been told in much greater depth elsewhere[2] – we focus on six individuals and the contribution to knowledge they made and, with the benefit of hindsight, the significance of these contributions. These six scientists are: John Tyndall, Svante Arrhenius, Guy Callendar, Charles Keeling, Syukoro Manabe and Wally Broecker. The cultural contexts in which their science was practised becomes as important a part of the climate change story as their substantive contribution to new ways of understanding climate. The chapter concludes (Section 2.5) by reflecting briefly on how – and why – the idea of anthropogenic climate change has currently achieved such prominence in scientific, political and popular discourse.

2.2 The Genealogy of Climate Change

In Chapter 1: *The Social Meanings of Climate*, we traced the etymology of the word 'climate' back to Classical Greek culture. Cultural discourses around climate *change* also have a history, a genealogy that can again be followed back to the Greeks. Aristotle's student Theophrastus, in the third century BC, first observed and documented local changes in climate induced by human agency: the draining of marshes cooled the climate around Thessaly in Greece, while the clearing of forests around Philippi warmed the climate.[3] Not only

[2] See, for example, Fleming, J. R. (2005) *Historical perspectives on climate change*. Oxford University Press; and Weart, S. R. (2003) *The discovery of global warming*. Harvard University Press: Cambridge, MA.

[3] Glacken, C. (1967) *Traces on a Rhodian shore: nature and culture in Western thought from ancient times to the end of the eighteenth century*. University of California Press: Berkeley, CA, pp. 129–30.

could climates change, but human interventions in the natural world could act as the agent of change. A later Greek discourse of climate change was also constructed around changes in climate, but changes experienced through mobility – for example, the widely held view of the Classical era that Mediterranean travellers would turn black at the Equator, or else die. The experience of encountering forbidding climates through journeys into unexplored territories, and the anxieties of such climatic encounters, is a human idea that has resurfaced many times since these fearful tales were first told.

Enlightenment discourses about climate change from the seventeenth century onwards frequently concentrated around the effects of deforestation. The eighteenth-century historian Edward Gibbon could see the beneficial warming effects of tree-clearing both in changes of climate through time – the 'improvement' in European climate since Classical times, he claimed, was due to the clearing of 'immense woods'; and in the differences in climate caused by geography – the contemporary forests in Canada, he believed, subjected that land to a climate as fierce as that of ancient Germany.

Other projects were also afoot through which Enlightenment thinkers began to believe that regional climates could be subject to the will of Man. The eighteenth-century French philosopher Comte de Buffon reflected the growing ideology of human mastery when he remarked that, 'the addition or removal of a single forest in a country [by Man] is sufficient to change its temperature … [so] … modifying the influences of the climate he lives under … to the point that it suits him'.[4] This philosophising was put to the test in the New World as early American colonists cleared large swathes of forest along the eastern seaboard. Hugh Williamson, an American doctor, was therefore able to remark in 1760, in front of his American Philosophical

[4] pp. 236–244 in Buffon (1778) *Les époques de la Nature*. Paris; cited in Boia, L. (2005) *The weather in the imagination* (trans. R. Leverdier). Reaktion Books: London, p. 65.

Society colleagues, that the climate had changed within the last forty to fifty years; the winters being less harsh, the summers cooler.[5]

Climates elsewhere in the world were also under suspicion of changing and deforestation was again to blame, but this time introduced by European settlers in the tropics. This tropical manifestation of climate change had different effects compared with its temperate cousin, since destruction of tropical forests was believed here to exacerbate the droughts that many early colonists in the eighteenth century found endemic in sub-tropical regimes. According to this view, climate change threatened not only the economics and well-being of a colony, but posed hazards to the integrity and health of the settler populations in plantation colonies.[6]

By the middle of the nineteenth century, the combined work of geologists and physicists had revealed a new dimension to climate change completely unrelated to the activities of Man: the huge swings in global climate implied by massive and ancient glaciations, a story that is told in more detail in the next section. Alongside these emerging radical ideas of climatic instability occurring over previously unimagined time-scales, observers were still grappling with the extent to which human activities could alter contemporary regional climates. Such changes appeared to be trivial when set against the large changes in climate induced by the newly found Ice Ages, and increasing volumes of meteorological data were beginning to cast doubt on the extent of substantial human influence on climate via forest clearing.

Evidence for recent changes in climate was, nevertheless, offered by some. For example, Monsieur Arago of the French Institute in Paris wrote in 1834 that, based on the evidence of grape-ripening dates, the summers in several parts of France were 'colder than they had been formerly',[7] a line of reasoning he also applied to England and her

[5] Cited in Glacken, *Traces on a Rhodian shore*, p. 659.

[6] p. 8 in Grove, R. H. (1998) *Ecology, climate and empire: the Indian legacy in global environmental history, 1400–1940*. Oxford University Press: Delhi.

[7] *The Times*, 18 February 1834.

apparent decline in viticulture since the days of the 'old chronicles'. Eduard Brückner, a prominent Austrian geographer, was another of this small band of climate change believers in the late nineteenth/early twentieth century, who maintained that statistical evidence *could* be found for contemporaneous changes in regional climates. Brückner demonstrated that average temperature and precipitation for areas of central Europe and Russia when measured over successive thirty-five-year periods differed substantially, claiming that such changes in climate would have implications for rivers, lakes and agriculture. His insistence that such changes were real and were related to deforestation led him to advocate in the Prussian House of Representatives what was probably the first climate change policy: a proposed law to preserve the forests of Prussia to protect the rainfall and river levels of the state.[8]

Despite the work of Brückner and a few others, the dominant mindset during the first half of the twentieth century was that physical climate was basically constant on time-scales that mattered to human thought and planning. In the context of the ever-lengthening appreciation of the deep past, however, beliefs about climate change had changed radically.

2.3 Natural Climate Change

A crucial part of the story of climate change was the dawning realisation of the multiple glaciations which the Earth has experienced over its history. That the world's climate had changed sufficiently to induce such massive glacial advances and retreats was an idea that did not emerge until the early decades of the nineteenth century. The prevailing view at the time was that of a young Earth and a stable climate,

[8] Brückner, E. (1890) *Klimaschwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit*. Wien and Olmütz; quoted in von Storch, H. and Stehr, N. (2006) Anthropogenic climate change: a reason for concern since the 18th century and earlier. *Geografika Annaler* 88A(2), 107–13.

punctuated by occasional natural catastrophes – earthquakes, floods, volcanic eruptions – which between them could account for all of the geological and fossil evidence of a dynamic Earth that was then being discovered. While eighteenth-century natural philosophers were constructing the notion that Man might alter regional climates through the force of his own development and technology, no-one was contemplating powerful natural forces that could radically destabilise global climate.

Not until Jean Louis Rodolphe Agassiz in the 1830s. The evidence that persuaded this 30-year-old Swiss naturalist that the world's climate *could* change in such substantial ways was presented to him and his colleagues by Alpine glaciers. A small number of Swiss scientists and engineers, partly concerned with the hazards of bursting ice-dammed lakes, had become convinced that glaciers had once extended well beyond their then known limits. It was Agassiz's older colleagues Ignace Venetz and Jean de Charpentier who convinced the ambitious young naturalist of the plausibility of such a hypothesis, but it was Agassiz alone who in July 1837 first presented a coherent Ice Age theory to the Swiss Society of Natural Sciences meeting in Neuchâtel. The idea of Ice Age climates affecting an ancient Earth became even more firmly associated with Agassiz after he subsequently published his book *Etudes sur les Glaciers* in 1840.

The idea that the Earth's climate was susceptible to such large changes in climate, and over such long time-scales, was not an easy one for mid nineteenth-century Europe to accept. It sat uneasily alongside traditional Biblical interpretations of a (fixed) created world and of the supposed beneficent hand of God preserving climatic conditions suitable for human habitation. Yet Agassiz began to find scientific converts, first in Europe and then in the United States of America after he moved there in the 1840s. By the 1860s, Agassiz's glacial theory of climatic change was firmly established on both sides of the Atlantic. At this early stage of understanding it was the glacial period(s) within the past few hundred thousand years that was under consideration; the existence of even more ancient Ice Ages remained as yet unsuspected.

The question of causation, however, remained very much in dispute. It was obvious that the Ice Age was unrelated to human influence on climate, and various naturalistic causes were proposed to displace lingering ideas of divine manipulation of the climate system. Sunspot activity, volcanic eruptions, atmospheric dust, movements in the Earth's crust and changes in the orbital characteristics of the Earth were all put forward as candidates. James Croll's astronomical theory of Ice Ages began to find favour following the publication of his 1875 book *Climate and Time*, but alternative hypotheses continued to circulate. The idea that reductions in atmospheric carbon dioxide could induce such a climatic change was also considered by John Tyndall and others (see section on John Tyndall and greenhouse gases), and prompted Svante Arrhenius to undertake the first calculations of the sensitivity of world temperature to carbon dioxide in the 1890s (see section on Svante August Arrhenius and climate sensitivity). Croll's astronomical theory found its eventual champion in the Serbian mathematician Milutin Milanković, whose 1924 elaboration of Croll's ideas thereafter became canonical as the explanation for glacial climates.

It was within this nineteenth-century world of changing views on the stability of climates that the early scientific foundations were laid for what has now become the anthropogenic theory of climate change.

2.4 Anthropogenic Climate Change

The pedigree of our scientific understanding of how humans are today altering global climate can be traced back to 1824, when the French physicist Jean-Baptiste Joseph Fourier presented an essay to the Académie Royale des Sciences in Paris on the regulation of planetary temperatures. In this essay, published later that same year, Fourier correctly understood that the atmosphere is asymmetrical with respect to the transmission of incoming solar energy and outgoing terrestrial energy – the constituent gases of the atmosphere are more opaque to outgoing thermal energy than they are to incoming short-wave solar energy. This phenomenon was later christened the 'greenhouse effect'. The story of the last 180 years of scientific thought, research and scholarship with respect to this idea is too long and convoluted to recount here. In laying the ground for later chapters, however, this scientific journey is illuminated by telling the story of six individual scientists whose contributions to the overall body of scientific knowledge about anthropogenic climate change are seminal. Each vignette describes the contributions to knowledge that were made, the context in which they were made and in which they were received, and a comment on the contemporary significance of the work of these individuals. In telling these stories, we see at work the peculiarities of science: how context, funding, patronage, technology and personality each add texture and serendipity to the production of knowledge.

1859: John Tyndall and greenhouse gases

On Wednesday 18 May 1859, after a full day's work in the basement laboratory at the Royal Institution in central London, the 38-year-old Irish scientist John Tyndall wrote in his diary, 'Experimented all day; the subject is completely in my hands!'[9] Tyndall had been experimenting with the absorptive properties of gases with a view to testing the idea that different gases, commonly found in the atmosphere, absorbed differing amounts of short-wave and long-wave radiation. This was the idea that Joseph Fourier had articulated thirty years earlier and, if true, could help to explain how the temperature of the planet was regulated. Tyndall's experiments in May 1859, which he further advanced for several years afterwards, established for the first time that the molecules of water vapour, carbon dioxide, nitrous

[9] pp. 36–55 in: Tyndall, J. (1855–1872) *Journals of John Tyndall Vol. 3, 1855–1872* Unpublished Tyndall Collection, Royal Institution, London.

oxide, methane and ozone each exhibit unique absorptive properties when radiant (infra-red) heat is passed through them; thus, for example, water vapour is 16,000 times more effective at absorbing infra-red radiation, molecule-for-molecule, than is oxygen.

John Tyndall's discoveries became central for understanding the heat budget of the atmosphere. By demonstrating that this group of gases – later collectively named 'greenhouse gases' – possessed distinctive radiative properties, his work opened up the possibility that, by altering the concentrations of these gases in the atmosphere, human activities could alter the temperature regulation of the planet. Although Tyndall could foresee such a possibility in the 1860s – changes in the amount of any of the radiatively active constituents of the atmosphere 'could have produced all the mutations of climate which the researches of geologists reveal'[10] – he was a long way from developing a coherent account of how human actions could induce significant changes in climate on the relevant time-scales.

Tyndall's research was published at the beginning of the intellectually tumultuous decade of the 1860s. On Thursday 24 November 1859, just six months after Tyndall's initial experimental results, Charles Darwin's book *On the Origin of Species* was published in London. Along with this challenge to the prevailing orthodoxy of a fixed biological creation, scientists were also grappling with the equally revolutionary implications of Louis Agassiz's new 'Ice Age theory' (see Section 2.2). Trying to understand the causes of these great Ice Age fluctuations in climate was one of the issues of the time. The ideas of Darwin and Agassiz were assaulting fundamental conceptions of time and stability in, respectively, biological and climatic history. John Tyndall was intimately connected with these debates. He became a close friend of Thomas Huxley and other scientists in Darwin's circle and he was consulted by Charles Lyell – who was trying to evaluate Croll's newly published orbital theory – about

[10] pp. 276–277 in Tyndall, J. (1861) On the absorption and radiation of heat by gases and vapours. *Philosophical Magazine* (Ser. 4) 22.

whether Tyndall's new radiative theory of climatic change could help unravel the causal mystery of the Ice Ages. On 1 June 1866, Tyndall replied to Lyell saying that changes in radiative properties alone were unlikely to be the root causes of glacial epochs, thus contradicting his earlier supposition of 1861 quoted above. These exchanges about theories of climatic change presaged much later arguments about the interplay between natural and human factors in the modification of global climate.

John Tyndall was one of the outstanding scientific personalities of the Victorian age and a passionate defender of the scientific naturalism which flowered in later Victorian Britain. He had a typically eclectic education, moving from school into railway surveying during the railway boom years of the 1840s, before teaching school mathematics and earning his doctorate in experimental chemistry at Marburg in Germany. His professional career was finally established when Michael Faraday invited him, in 1853, to give a series of discourses at the Royal Institution in London. Under Faraday's patronage, Tyndall was able to develop and display his talent for experimental science across an astonishing variety of subjects.

Tyndall is deservedly credited with establishing the experimental basis for Fourier's 'greenhouse effect'. Tyndall was also correct in identifying the fundamental role of water vapour in atmospheric dynamics which, he claimed, 'must form one of the chief foundation-stones of the science of meteorology'.[11] Now, about 150 years later, the differential absorptive properties of the suite of greenhouse gases he investigated – now expanded to include a range of artificial gases unknown to Tyndall, the halocarbons – still remain central to the idea of anthropogenic climate change. Subsequent work has established the global warming potentials of each of these gases with some level of precision, calculations that are pivotal in efforts to quantify the extent of human influence on the world's temperature.

[11] p. 54 in Tyndall, J. (1863) On the passage of radiant heat through dry and humid air. *Philosophical Magazine* (Ser. 4) 26.

1896: Svante August Arrhenius and climate sensitivity

By the 1890s there was widespread agreement about the nature and extent of previous glaciations on Earth (see Section 2.2), but significant disagreement about the cause of these large climatic oscillations. Croll's hypothesis of astronomical variations 'enjoyed a certain favour with English geologists',[12] but others preferred the idea that it was 'changes in the trapping of heat by vapours and gases in the atmosphere'[13] which controlled the Earth's climatic history. No-one, however, had performed the calculations to show just how sensitive the Earth's climate was to changes in atmospheric composition; a concept that has now become known as 'climate sensitivity'.

The first calculations of this parameter were performed by a 36-year-old Swedish physicist, Svante August Arrhenius, and his results were presented before the Stockholm Physical Society in 1895. Arrhenius was familiar with the conceptual 'greenhouse' thinking of Fourier, the experimental results of Tyndall from the 1860s and his later, modified, calculations of the absorption coefficients for water vapour and carbon dioxide. In a classic exercise of scientific synthesis, Arrhenius drew these ideas and data together to show that halving or doubling the concentration of carbon dioxide in the global atmosphere would lead to changes in average surface air temperature of the Earth of between about 4° and 5°C.

Arrhenius's calculations were performed by hand, not computer, and communicated by written and spoken word, not by the internet. Yet his network of scientific correspondents was considerable and his calculations – which showed that changes in atmospheric composition *could* in principle lead to glacial climates – were well

[12] p. 274 in Arrhenius, S. (1896) On the influence of carbonic acid in the air upon the temperature of the ground. *London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 41, 237–76.

[13] Manson, M., cited p. 15 in Mudge, F. B. (1997) The development of the greenhouse theory of global climate change from Victorian times. *Weather* 52, 13–17.

received by Italian, Swedish and American scientists. The continuing resistance to Croll's astronomical theory of Ice Ages meant that, by the turn of the century, 'the theory of global climate change [caused] by changes in atmospheric carbon dioxide levels was widely accepted'.[14]

But what caused the rise and fall of atmospheric carbon dioxide in the distant past? And could changes in atmospheric concentrations of this gas also be a contemporary phenomenon? Arrhenius was rather less interested in these questions and left it to his geologist colleagues, Arvid Högbom and Thomas Chamberlin, to argue over the carbon cycle. Although it was known that nearly a billion tons of coal worldwide was being combusted annually at the turn of the century, the belief was that little of the released carbon dioxide would remain in the atmosphere. Arrhenius, when pushed, conceded that such combustion might induce 'a noticeable increase' in atmospheric carbon dioxide over the course of a few centuries. Such warming, he deduced, might be beneficial for humanity by staving off the next glacial cycle.

Svante Arrhenius is a significant figure in the story of climate change. As so often with new scientific insights, there were things he got right and things he got wrong. He was well ahead of his time in making the first estimates of climate sensitivity – a temperature value which describes how much the world would eventually warm if the concentration of greenhouse gases in the atmosphere were doubled. Over a hundred years later and the judgement of the world's scientists is that its value probably lies somewhere between 2° and 4.5°C, although slightly lower or much higher values cannot be ruled out. The laborious manual calculations made by Arrhenius were not significantly in error, even though he couldn't have known how problematic determining this quantity was going to prove for later scientists. On the other hand, the cycling of carbon through the atmosphere, biosphere and oceans

[14] *Ibid.*, p. 15.

was poorly known in 1900, and Arrhenius grossly underestimated the rate at which carbon dioxide could accumulate in the atmosphere. Rather than taking several centuries to effect a noticeable increase, the concentration of this greenhouse gas has increased by about 40 per cent in not much more than a century, and may well have doubled before the present century is seen out.

Further understanding of the mechanisms of climate change did not proceed smoothly from Arrhenius' insights. As the twentieth century developed, the carbon dioxide theory of Ice Ages and of climate change largely disappeared from scientific discourse. The Swedish physicist Knut Ångström had suggested that the absorption power of carbon dioxide was limited by the overlapping spectral bands of water vapour, there was little agreement among geologists about what could cause carbon dioxide concentrations in the atmosphere to rise and fall in cyclical fashion, and the calculations by Milanković in the 1920s gave new credibility to Croll's astronomical theory.

But the world's temperature was now rising and a few meteorologists had begun to notice.

1938: Guy Stewart Callendar and global temperature

Many of the winters during the period from the 1910s to the 1930s were generally mild over Europe and North America, the two regions in the world where meteorological observations had their longest historical reach. These formal records lent themselves to statistical analysis, enabling the popular perception of a warming climate to be placed into a longer-term perspective. James Kincer of the US Weather Bureau had proposed in the mid-1930s that the data suggested that an 'apparent longer-term change' towards a warmer climate was taking place,[15] but he used his analysis primarily to corroborate intuitive

[15] Kincer, J. B. (1933) Is our climate changing? A study of long-time temperature trends. *Monthly Weather Review* 61(9), 251–9.

statements commonly being heard from the elderly that 'winters were colder and the snows deeper when I was a youngster'.

It took an idiosyncratic British mechanical engineer to put together a coherent argument as to *why* the regions around the North Atlantic were warming. Guy Stewart Callendar had an enquiring mind, trained under the influence of his father, a physics professor in London. Although his professional duties as a steam engineer at Imperial College required him to contribute to the international efforts to standardise steam tables, as a personal pursuit Callendar had become interested in Arrhenius's carbon dioxide theory of climate change, which in the 1930s lay largely dormant. Perhaps prompted by his own perceptions of mild British winters he began collecting long series of meteorological observations from stations around the world. He also made his own set of calculations about the net absorption effect of carbon dioxide in the atmosphere, following in Arrhenius's footsteps but using more recent coefficients. His hunch was simple: 'As man is now changing the composition of the atmosphere at a rate which must be very exceptional on the geological time-scale, it is natural to seek for the probable effects of such a change.'[16] Callendar believed these effects to be a warming climate which could be detected in the observations.

Callendar completed his work during the mild English winter of 1936/7. Although no meteorologist, he first presented his findings to a London meeting of the Royal Meteorological Society in February 1938, a few weeks before Hitler's annexation of Austria. With hindsight, this study can be seen as the first attempt at detecting and attributing large-scale climate change to human-induced emissions of greenhouse gases (see Box 2.1).

[16] p. 38 in Callendar, G. S. (1939) The composition of the atmosphere through the ages. *Meteorological Magazine* 74, 33–9.

Box 2.1: Detecting and Attributing Anthropogenic Climate Change

The paper that Guy Stewart Callendar read to the Royal Meteorological Society on Wednesday 16 February 1938 was the first systematic attempt to link together the three pillars of the idea of anthropogenic climate change: the physical theory of carbon dioxide and the greenhouse effect, the rising concentration of carbon dioxide in the atmosphere, and the increase in world temperature. His was the first study of what has now become known as the detection and attribution of anthropogenic climate change. We can compare Callendar's pioneering effort with the more recent considered assessments about detection and attribution contained in the four reports of the Intergovernmental Panel on Climate Change (IPCC) published between 1990 and 2007.

Callendar calculated that the expected increase in world temperature on the basis of physical theory and his carbon dioxide concentration estimates, 'to be at the rate of 0.3°C per century at the present time'. He followed this by stating baldly that 'world temperatures have actually increased at an average rate of 0.5°C per century during the past half-century.'[17] Although Callendar was clear in his own mind that he had found strong evidence for anthropogenic global warming, many of his listeners that day in London were sceptical. Sir George Simpson, then director of the British Meteorological Office, thought that 'his results must be taken as rather a coincidence'.[18] The five other discussants in the Reading Room of the Society that day also expressed considerable scepticism over Callendar's claims.

[17] p. 223 in Callendar, G. S. (1938) The artificial production of carbon dioxide and its influence on temperature. *Quarterly Journal of the Royal Meteorological Society* 64(2), 223–40.

[18] *Ibid.*, p. 237.

Just over fifty years later, in September 1990, the First Assessment Report of the IPCC was announced in front of a rather larger audience of the world's media gathered together in Bracknell near the headquarters of the UK Meteorological Office. This report, published under the auspices of the United Nations, contained a considered statement about the question of detection and attribution: 'Our judgement is that global-mean surface air temperature has increased by between 0.3° and 0.6°C over the last hundred years ... the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability.' This guarded conclusion was more cautious than Callendar's in 1938, yet it initiated what was to become the central scientific question about climate change over the next two decades: the detection and attribution of anthropogenic climate change.

Successive reports from the IPCC reveal the incremental way in which these scientific assessments extended the belief that formal detection and attribution of human influence on global climate had been attained. Thus, in 1996, the Second Assessment Report stated that 'the balance of evidence suggests that there is a discernible human influence on global climate', while the Third Assessment Report in 2001 concluded that 'most of the observed warming over the last fifty years is likely[19] to have been due to the increase in greenhouse gas emissions'. In the Fourth Assessment Report, published in February 2007, the statement had hardened into a more bullish: 'Most of the observed increase in global average temperatures since the mid twentieth century is very likely[20] due to the observed increase in anthropogenic greenhouse gas concentrations.'

[19] According to IPCC conventions, 'likely' implies a chance of between 66 and 90 per cent that the statement is correct.

[20] According to IPCC conventions, 'very likely' implies a greater than 90 per cent chance of the statement being correct.

These five statements, spread over seventy years of scientific endeavour, reveal two important things about science. They reflect a conventionally assumed attribute of science as being a cumulative enterprise, in which knowledge is shaped and influenced by previous claims and propositions, often building and consolidating confidence in what is already known. Thus one follows the transition from ignorance (before 1938), through informed speculation (Callendar in 1938), to increasing levels of confidence (IPCC between 1990 and 2007) about the detection of human influence on world climate. But these sequential statements challenge another attribute commonly associated with science – an adjudicator of objective and certain truth. These statements are constituted in the language of belief and probability. At each stage of the process, substantial judgement on the part of the scientist(s) is required; a judgement formed through dialogue, dispute and compromise rather than through detached and disinterested truth-seeking. Knowledge about climate change is being communicated in conditional terms. This is a theme to which we will return in Chapter 3: *The Performance of Science.*

Callendar's work was not well received. Apart from scepticism from the meteorological professionals, there were others who questioned his estimates of carbon dioxide in the atmosphere and his absorption calculations. His cause was not helped by the perception, and later quantification through the 1950s and 1960s, that temperatures in Europe and North America had begun to fall. Callendar himself had proposed a verification of his ideas by stating at the end of his 1938 paper that 'the course of world temperatures during the next twenty years should afford valuable evidence as to the accuracy of the calculated effect of atmospheric carbon dioxide'.[21] At face value, and on his own terms, the evidence seemed to contradict his theory.

[21] Callendar, The artificial production of carbon dioxide, p. 236

Many years later, in November 1960, Callendar wrote in his personal papers of the continuing unpopularity of the carbon dioxide theory of climate change, citing four reasons why people didn't accept it:

- The idea of a single factor causing worldwide climatic change seems impossible to those familiar with the vast complex of forces on which any and every climate depends.
- The idea that man's actions could influence so vast a complex is very repugnant to some.
- The meteorological authorities of the past have pronounced against it, mainly on the basis of faulty observation of water vapour absorption.
- Last, but not least, they did not think of it themselves![22]

Callendar died in 1964, long before his 1938 ideas became common scientific currency. It was another twenty-two years after his death before the first truly global – land and marine – temperature series was published, and another forty-three years before the IPCC announced what Callendar had argued in 1938: that the rise in world temperature was very likely to be a result of the rise in carbon dioxide. A deeper irony was that, whereas Callendar's physical reasoning from the 1930s has proved broadly correct, his interpretation of the *significance* of what he claimed is not the way in which climate change is now viewed. 'The combustion of fossil fuel ... is likely to prove beneficial to mankind in several ways ... for instance, the increases in mean temperature would be important at the northern margins of cultivation, and the growth of favourably situated plants is directly proportional to the carbon dioxide pressure. In any case, the return of the deadly glaciers should be delayed indefinitely.'[23]

[22] Guy Stewart Callendar papers, CRU/CAL/L/LE2a, University of East Anglia, Norwich, UK.

[23] Callendar, The artificial production of carbon dioxide, p. 236

1957: Charles David Keeling and the carbon cycle

Callendar's pioneering research efforts in the late 1930s had required no external funding; he undertook his calculations in the evenings and weekends while working for Imperial College. For many scientific innovations, however, funding the research to test ideas can be more difficult than conceiving the ideas in the first place. This is certainly true in the case of large-scale and continuous field measurements.

By the mid-1950s there were a small number of geophysicists who clearly understood that, without knowing the fate of carbon dioxide molecules emitted into the atmosphere, the arguments over Arrhenius's and Callendar's ideas could not be settled. How much of the carbon dioxide emitted from fossil fuel combustion could the oceans absorb? How fast was carbon accumulating in the atmosphere? No accurate or universal measurements of carbon dioxide concentrations existed, and there were certainly no standardised historical data with which to monitor change over time. Colleagues Roger Revelle at Scripps Institution of Oceanography in California and Hans Suess at the University of Chicago saw a great opportunity on the back of the 1957/8 International Geophysical Year (IGY) to get the funding needed to set up new monitoring sites. The IGY was a major international scientific collaboration aimed at quantifying the state of the global environment, while doubling up for the USA and the USSR as a convenient front for extending the reach of military surveillance and as an exercise in strategic geopolitical posturing.

Revelle and Suess, however, and the young post-doctoral scientist they hired to run these new carbon dioxide measuring sites – Charles David Keeling – were simply grateful to acquire the funding to pursue their scientific goal: 'To establish a reliable "baseline" carbon dioxide level which could be checked ten or twenty years later.'[24] Keeling established two sites at which he initiated a routine series of

[24] Keeling, C.D. cited p. 439 in Weart, S.R. (2007) Money for Keeling: monitoring CO_2 levels. *Historical Studies in the Physical and Biological Sciences* 37(2), 435–52.

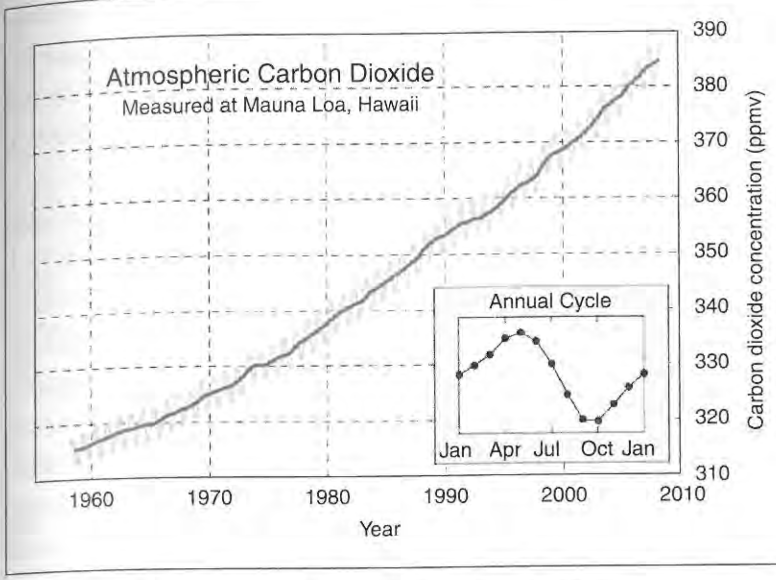

FIGURE 2.1: *Measurements of atmospheric carbon dioxide concentration (ppmv) at Mauna Loa Observatory, Hawaii. The concentration has risen by about 25 per cent since Charles Keeling started these measurements in 1957/8. Source: NOAA/Wikipedia.*

measurements using a new infra-red analyser technique which he had perfected: one site was at the Mauna Loa Observatory in Hawaii, on top of the world's largest volcano, and the other was at the American scientific base at the South Pole. He started these measurements of atmospheric carbon dioxide concentrations in September 1957 at the South Pole and in March 1958 at Mauna Loa – measurements that are still made routinely today, more than fifty years later (see Figure 2.1).

Keeling's measurements were more successful than either he or Revelle had anticipated. Within eighteen months of starting, Keeling had revealed that the carbon dioxide concentration was rising at both sites, by between 0.5 and 1.3 parts per million (ppm) per year. This was the first incontrovertible evidence for the contemporary increase of this greenhouse gas in the atmosphere that Callendar had estimated and upon which Arrhenius had earlier speculated. Keeling offered caveats about his findings, wondering, for example, about the varying roles of oceans and land biota in modulating these increases year by year; yet these pioneering measurements laid the foundation for all subsequent work on understanding the carbon cycle and the human role in modifying it.

But the importance of these measurements was realised at the time by only a few. Throughout the 1960s, Revelle, Suess and Keeling, and then later in the 1970s Keeling alone, were engaged in frequent negotiations to secure funding to keep the routine measurements going. They ceased altogether for several months in the first half of 1964 as US Weather Bureau support was withdrawn, and even as late as 1979, officials at the US National Science Foundation told Keeling that they would not support routine monitoring indefinitely. Throughout these decades, and right up until his death in June 2005, Keeling maintained a belief in the importance of the measurements he was taking or supervising, well before their significance became apparent to others, or even fully to himself.

1975: Syukuro Manabe and climate models

Keeling's carbon dioxide curve from Mauna Loa continued rising through the 1960s and 1970s, from 314 ppm in 1957 to 331 ppm in 1975. Although Northern Hemisphere land temperatures were not keeping track with this increase, new developments in atmospheric science all pointed towards Callendar's (1938) proposition being correct. The question Arrhenius had provided one answer to in 1896 became increasingly important: exactly how sensitive was the Earth's climate to a doubling of atmospheric carbon dioxide? Calculations made using one-dimensional radiative–convective models in the 1960s and early 1970s had suggested that climate sensitivity was in the range 1.9°–10°C or more. This wide range of published values reflected different modelling approaches and, in particular, different representations of the feedback processes associated with an enhanced greenhouse effect. The role of water vapour, the importance of which Tyndall had recognised back in the 1860s, was particularly problematic. In 1967, atmospheric scientists Syukuro Manabe and Richard Wetherald at Princeton University, New Jersey, had undertaken one such calculation that suggested a climate sensitivity of 2.3°C, but there clearly was no consensus about this value nor about the most appropriate modelling approach through which it could be estimated.

Developments in computer technology and in the numerical weather prediction models used for short-range weather forecasting had, by the early 1970s, spawned the development of new general circulation models of the global atmosphere with which climate could be simulated. Manabe had developed one of these models at the Geophysical Fluid Dynamics Laboratory at Princeton and, together with his colleague Wetherald, used it to conduct the first model experiment which explicitly simulated the three-dimensional response of global climate to a doubling of atmospheric carbon dioxide concentration. Such a model, used for this purpose, represented an advance over previous work in a number of ways. Heat transport by large-scale eddies in the atmosphere were explicitly represented, the water vapour feedback was simulated, and the effect of the ice–albedo feedback was quantified for the first time.

The results of this emblematic model experiment have withstood remarkably well the subsequent advancements in understanding of the physics of the climate system and the capacity to model it. Manabe's model computed a climate sensitivity of 2.9°C; higher than many of the values derived from the best radiative–convective models of earlier years, and well within the range now cited by the IPCC. Their model also allowed them to determine, for the first time, the vertical and latitudinal gradients of the air temperature response to carbon dioxide doubling: greater warming at the poles was revealed, more moderate warming in the tropics, and cooling in the stratosphere; features of the climate system response to elevated greenhouse gas concentrations that remain central to studies directed to the detection of the human fingerprint on global climate change.

Manabe and Wetherald were acutely aware of the limitations of their model and therefore of the limitations to their results.[25] The horizontal spatial resolution of their model was about 500 km (meaning that islands as large as Iceland were invisible to the model), the model had no ocean (simply a 'wet surface' covering 70 per cent of the Earth's surface with infinite water available for evaporation), and there were no interactive clouds. This latter deficiency meant that one important feedback process – cloud cover changes – could not be simulated by their model. In comparison with later Earth system models their early version was undoubtedly crude, and Manabe did not exaggerate the importance of their findings, stating that 'it is not advisable to take too seriously the quantitative aspect of the results obtained in this study'.[26]

Despite these limitations, Manabe's pioneering experiment using the emerging technology of supercomputing opened the way for many more such models to be developed in climate modelling laboratories. Such models are now widely used for exploring the effect of rising greenhouse gas concentrations on global climate. Looking back from the twenty-first century and from the perspective of our artificially warmed Earth, Manabe and Wetherald's study represents a significant achievement and a notable milestone in the scientific study of anthropogenic climate change. Yet Manabe's warning about not taking the results of such a study 'too seriously' remains to be examined. In

[25] Their paper gives a full account of the 'mistake' they made when fixing the boundary between permanent and temporary sea-ice. They mistakenly programmed the boundary to occur at −25°C rather than at −10°C, their intended value. Manabe's scrupulous adherence to the principles of scientific practice meant that since they were unable to re-run the model with the correct value – presumably because of limited computer resources – they fully acknowledged their mistake in the published paper. Indeed, they turned it to their advantage by arguing that given the similarity between satellite-derived and their modelled surface albedo at high latitudes, −25°C may anyway have been a more appropriate value to have used!

[26] p. 13 in Manabe, S. and Wetherald, R. T. (1975) The effects of doubling the CO_2 concentration on the climate of a general circulation model. *Journal of the Atmospheric Sciences* 32, 3–15.

what sense are computer models predicting reality? Are they 'truth machines', to be believed in by all, or do they act more like metaphors to help us to think about the future? The nature of climate models and their uses in policy making will be examined in Chapter 3: *The Performance of Science*.

1987: *Wallace S. Broecker and abrupt climate change*

In the 1830s, the surface geological evidence of past glaciations in Switzerland extending well beyond existing glacier limits convinced Louis Agassiz that climates must have changed massively in prehistoric times. About 130 years later, in the 1960s, the first cores drilled through the Greenland Ice Sheet to bed-rock began to yield evidence offering a different perspective on the Earth's climatic history. The first of these ice cores was at Camp Century, a US military air base in northwest Greenland, and extended through nearly 1.4 km of ice, capturing indictors of climatic behaviour from nearly 100,000 years of Earth history. Later ice cores followed in the 1970s and 1980s, in Antarctica as well as in Greenland, and their evidence suggested that transitions between glacial and inter-glacial climates were not necessarily smooth oscillations extending over thousands of years. The Earth's climate was perhaps capable of substantial changes on much shorter time-scales, perhaps just a few hundred years, or even less than a century.

American oceanographer Wallace S. ('Wally') Broecker was one of the most outspoken of the group of scientists who exploited this new evidence for developing a new conception of climate change. In 1987 he wrote an article in the journal *Nature* in which he connected the evidence of relatively rapid changes in climate in the past to the possibility that anthropogenic climate change in the future might also trigger abrupt changes in aspects of the Earth's climate. The article was titled 'Unpleasant surprises in the greenhouse?' and his argument was that, 'We have been lulled into complacency by model simulations that suggest a gradual warming over a period of about

100 years … these [ice-core] records indicate that the Earth's climate responds in sharp jumps which involve large-scale re-organisations of Earth's system … I fear that the effects of [global warming] will come largely as surprises.'[27]

Broecker drew attention, in particular, to the possibility that a large-scale feature of the ocean circulation known as the thermohaline circulation, which yields the Gulf Stream in the North Atlantic, might be one such mechanism in the Earth's system that could be destabilised by rising greenhouse gas concentrations. If the thermohaline circulation weakened substantially over a short period of time, or even collapsed entirely, then the climates of the North Atlantic Basin could be quite radically altered.

This new thinking about climate change in the late 1980s was to lead scientists to find new ways of conceiving, representing and modelling climate change. The Earth's climate system needed to be understood as a whole – atmosphere (including the stratosphere), oceans, ice sheets, forests, lakes, land cover – and the interactions between all of these components were fundamental for understanding the way that the system as a whole behaved. Humans, however, were not accommodated in these models. Ideas such as thresholds, abrupt and non-linear changes, and 'tipping points' became part of the new paradigm of Earth system science. These ideas do not, however, present themselves to us, unambiguously, through observed evidence. As with the Greek idea of *klimata*, the metaphor of Gaia for the Earth system and the idea of 'tipping points' in the climate system are ways of seeing the world; ways of believing. The Greek notion of *klimata* lasted for nearly 2,000 years. It remains to be seen how durable and powerful these new conceptions of climate change, pioneered by Broecker and like-minded colleagues, will prove to be.

[27] p. 123 in Broecker, W. S. (1987) Unpleasant surprises in the greenhouse? *Nature* 328, 123–6.

2.5 Climate Change Today

In the 160 years since explorer John Franklin perished in the Canadian Arctic, the enterprise of science has succeeded in overturning the old, yet persistent, Greek idea of climate as a stable property of the natural world. 'Climate is what you expect, weather is what you get' is no longer an adequate aphorism because we have come to believe that climate, just like weather, is constantly changing. Our expectations of climate have changed. This is the insight that Louis Agassiz applied over the very longest of time-scales. This too is the more recent insight offered us by Tyndall, Callendar, Broecker and colleagues.

The view, dominant over the first half of the twentieth century, which led Hubert Lamb to remark, in 1959, 'not so very long ago … climate was widely considered as something static, except on geological time-scale[s], and authoritative works on the climates of various regions were written without allusion to the possibility of change',[28] is as anachronistic to us today as the notion of a flat Earth. Physical climates change, they change on all time-scales, and we humans have become an active agent of change. But this alteration in perspective did not happen instantly, and it was not driven purely by science. This chapter concludes by reflecting briefly on how and why the idea of anthropogenic climate change has today achieved such prominence in scientific, political and popular discourse. We do so by considering four inflection points in recent decades – four moments in wider political or cultural history when the idea of climate change took on new significance: the 1960s environmental awakening, the 1972 Stockholm Conference on the Environment, the 'greenhouse summer' of 1988, and the singularity of the events of 11 September ('9/11') in 2001.

The early suggestions of human-induced climate change from Arrhenius in the 1900s and Callendar in the 1930s were generally

[28] p. 299 in Lamb, H. H. (1959) Our changing climate, past and present. *Weather* 14, 299–318.

associated with relatively benign, or even positive, consequences for society. This contrasts sharply with the tone of the current discourse about climate change, which is predominantly one of danger and catastrophe (see Chapter 7). The origins of discourses about dangerous climate change can be traced back to the environmental awakening of the early 1960s in Europe and North America, prompted in part by Rachel Carson's book *Silent Spring*, published in September 1962. One of the first associations of anthropogenic climate warming with notions of danger was in a 1963 conference of scientists convened by the Conservation Foundation of New York, which warned of a 'potentially dangerous atmospheric increase of carbon dioxide'.[29] The idea of a human-induced change in world climate found sympathy in the broader currents of intellectual thought in the 1960s and the emergence of a new environmentalism.

The first governmental and international assessments of the prospects of climate change were conducted during this period. In the USA, the President's Scientific Advisory Committee published a report on *Restoring the Quality of our Environment* in 1965, which included a specific section on climate change, and in 1971 an international *Study of Man's Impact on Climate* was published under the auspices of the Swedish Academy of Science. But it was the first United Nations Conference on the Environment in Stockholm in 1972 which was seminal in establishing more popular awareness about the potential extent of human influence on the world's environment, including its climate. The mood of concern was further heightened by the report *Limits to Growth*, published by the Club of Rome in 1972, and by the 1973 world oil crisis. This anxious mood allowed a new genre of popular climate science books to emerge during the mid-1970s – for example, Lowell Ponte's *The Cooling* (1976), Steve Schneider's *The Genesis Strategy: Climate and Global Survival* (1976) and John Gribbin's *Forecasts, Famines and Freezes* (1977). Although there was significant contention about whether the direction of human influence was for global warming or global cooling, the idea that humans were now a climatic force on the planet was firmly established.

A decade later, by the mid-to-late 1980s, the dominant scientific opinion had settled firmly on the prognosis of future warming. The emergence of anthropogenic global climate change as a significant public policy issue induced a heightening of anxiety. The term 'climate catastrophe' in the context of anthropogenic climate change first appeared in the German language in the cultural magazine *Der Spiegel* in April 1986 and, following the 'greenhouse summer' of 1988 (see Box 2.2), the idea of climate change penetrated more deeply into popular culture in the West, although more superficially – or not at all – in other parts of the world. The wider geopolitical resonance of climate change was linked with the collapse of the Soviet Union in 1989. Fears of Cold War destruction were displaced by those associated with climate change, prompting the observation at the time from cultural theorist Andrew Ross that, 'apocalyptic fears about widespread droughts and melting ice caps have displaced the nuclear threat as the dominant feared meteorological disaster'.[30]

Box 2.2: What Happened to Climate Change in 1988?

Unlike the hole in the ozone layer revealed by atmospheric chemist Joe Farman in 1985 or the steady rise in atmospheric carbon dioxide shown by Charles Keeling in 1960, there was no major new scientific discovery about climate change in 1988. Yet something happened in that year to bring the idea of anthropogenic climate change into the foreground of public consciousness. What happened was a

[29] Cited p. 353 in Weart, S. R. (1997) Global warming, cold war and the evolution of research plans. *Historical Studies in Physical Biological Sciences*, 27(2), 319–56.

[30] p. 8 in Ross, A. (1991) Is global culture warming up? *Social Text* 28, 3–30.

convergence of events, politics, institutional innovations, and the intervention of prominent public and charismatic individuals.

The year started with a claim, in January, that 1987 had been the warmest year ever recorded in the 130-year global temperature series published by the University of East Anglia in the UK. The five warmest years recorded at that time were all registered in the 1980s. At the end of May, and taking inspiration from the previous year's meeting in Montreal about the protection of the ozone layer, the first major intergovernmental conference on climate change was held in Toronto with representatives from forty-eight nations. The conference statement on 'The Changing Atmosphere: Implications for Global Security' called for a 20 per cent reduction in carbon emissions from 1988 levels among the industrialised nations by 2005. And it was in 1988 that the World Meteorological Organization formally approved, at its 40th Executive Council, the establishment of a new international scientific assessment panel, to be called the Intergovernmental Panel on Climate Change (IPCC), a decision subsequently backed by the UN Environment Programme. In November the IPCC held its first working session in Geneva, leading eventually to the publication of its First Assessment Report in 1990.

Events too, contributed by the climate system, added to the momentum. As a significant drought developed across the US Midwest, a Senate hearing in Washington on Thursday 23 June took evidence from Jim Hansen, a NASA scientist from New York, in which he famously said: 'It is time to stop waffling so much and say that the evidence is pretty strong that the greenhouse effect is here.' From 1988 onwards the number of annual Congressional hearings in Washington on climate change averaged about ten per year compared with fewer than two previously (see Figure 2.2). Not only did George Bush (Senior) and Michael Dukakis take note – Bush later claiming, in the race for the White House, that he would be remembered as the 'environmental President' – but Soviet President Mikhail Gorbachev

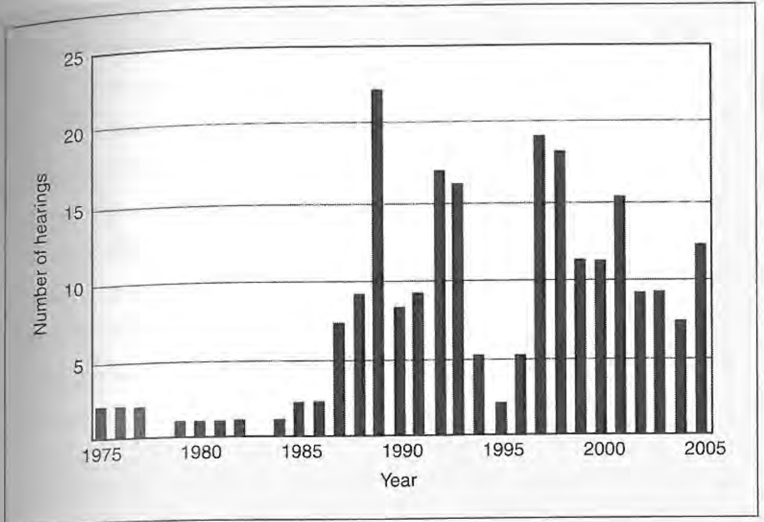

FIGURE 2.2: *Annual frequency of US Congressional hearings on climate change between 1975 and 2005.*
Source: Anon. (2006).

added a Soviet voice to the green debate for the first time. In the UK, Prime Minister Margaret Thatcher made a speech to the Royal Society in London in September which drew attention to the urgency of tackling climate change: 'It is possible that ... we have unwittingly begun a massive experiment with the system of this planet itself. We need to ... consider the wider implications for policy for energy production, for fuel efficiency, for reforestation.'[31]

By the end of the year *Time* magazine had picked up the mood of public concern in the Western world and offered its readers a front cover nominating 'Endangered Earth' as 'Planet of the Year', depicting the globe wrapped in polythene and tied with rope, highlighting the Earth's precarious situation and our casual treatment of it. The idea that humans not only could, but really were, warming the planet's climate had firmly embedded itself well beyond the confines

[31] Margaret Thatcher's speech to Royal Society, London, 27 September 1988.

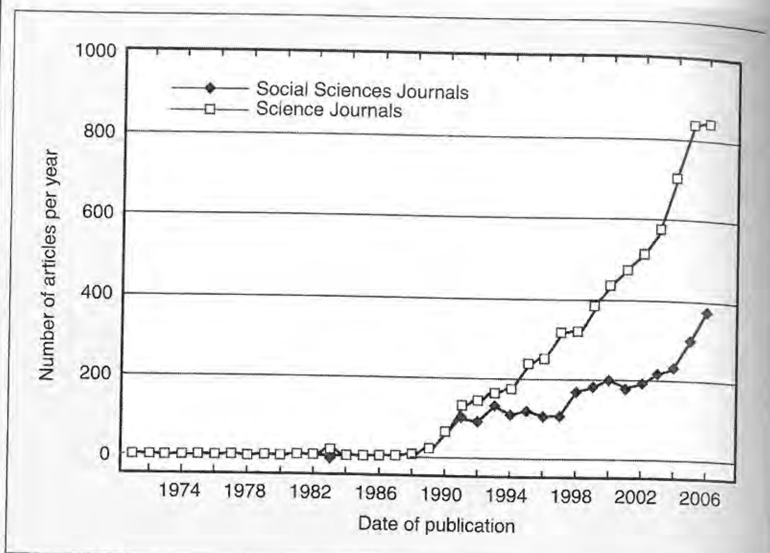

FIGURE 2.3: *Number of articles published annually in science journals (white squares) and social science journals (black diamonds) between 1970 and 2006 mentioning 'climate change' or 'global warming' (but not 'pollution') as found in the ISI Web of Knowledge. Mentions are in title, abstract or keywords.*
Source: Goodall (2008).

of science, among world leaders, national politicians and the media. For the international research community, 1988 was undoubtedly the year when climate change 'took off' (see Figure 2.3). Yet this was still a very geographically skewed penetration of the idea of climate change. Few citizens in India, China or Africa, for example, were talking about it and, in these and other nations, climate change had certainly not yet emerged as a public policy issue.

The language and metaphorical constructions of fear and catastrophe regarding climate change have been embellished substantially in the period following 9/11. The 'war on terror' provided a new benchmark against which the dangers of future climate change

could be referenced, while new linguistic and metaphorical repertoires have been developed. Commenting on an extensive 2006/7 study of climate change discourses found in the British media, and in the pronouncements of senior politicians and leading public commentators, Simon Retallack of the Institute for Public Policy Research in London reflected on the significance of this language: 'The alarmist repertoire uses an inflated language, with terms such as "catastrophe", "chaos" and "havoc", and its tone is often urgent. It employs a quasi-religious register of doom, death, judgement, heaven and hell. It also uses the language of acceleration, increase, intractability, irreversibility and momentum.'[32]

At the same time, enhanced Earth system modelling capabilities have opened up new scenarios of the climatic future, simulating our alleged rapidly impending approach to triggering major alterations to large-scale functions of the Earth system, for example the melting of the Greenland Ice Sheet, the massive release of methane hydrates in the tundra, or a redirection of the thermohaline circulation of the world's oceans. These prospective futures, given virtual reality through computer modelling, have been grouped together and communicated widely using Malcolm Gladwell's 'tipping point' metaphor, further nourishing the discourse of global climate catastrophe. Not only does this discourse find saliency in the media, but also through a new cohort of popular science books – for example, Fred Pearce's *With Speed and Violence: Why scientists fear tipping points in climate change* (2007) or Mayer Hillman's *The Suicidal Planet: How to prevent global climate catastrophe* (2007).

This contemporary climate discourse of fear, constructed around looming and apocalyptic changes in future climate, resonates with discourses of the past. As we saw in Chapter 1: *The Social Meanings of Climate*, human cultures have always been capable of constructing

[32] p. 55 in Retallack, S. and Lawrence, T. (2007) *Positive energy: harnessing people power to prevent climate change*. Institute of Public Policy Research: London.

narratives of fear around their direct or vicarious experience of 'strange', unknown or portended climates. Yet these discourses of fear are always situated – geographically, historically and culturally. They are not imposed by Nature, they are created through Culture.

2.6 Summary

This chapter has helped us understand the places where the idea of anthropogenic climate change first emerged and when and how the idea achieved wider prominence. Some of the roles played by key individual scientists in this story, and their contributions to scientific thinking, have been revealed. But this story about the idea of climate change is not a simple one of science progressing purposefully in a straight line from blissful ignorance to a state of confident knowledge. We have shown how the idea of climate change meant different things in different places and at different times in the past, especially how understanding the causes of climate change, and the implications of these causes, has been fluid and contested. The six years in which we briefly stopped – 1859, 1896, 1938, 1957, 1975 and 1987 – and the contributions to knowledge made by the six scientists investigated, also tell us something about the contexts and contingencies that affect and shape the scientific process.

John Tyndall's work in his underground laboratory in the late 1850s captured the experimental dimension of science, the controlled conditions in which Nature can be made to perform and, as Tyndall said at the time, 'to reveal all of her secrets'. A generation later, these 'secrets' were being used by another scientist who wanted to demonstrate a particular idea: that variations in atmospheric carbon dioxide could be a credible explanation for the newly discovered Ice Ages of Earth's prehistory. Arrhenius synthesised available knowledge but applied it to the wrong problem, largely missing the significance that we now attach to his calculations of climate sensitivity. Science has not always required large investments of public money, and Guy Callendar's solitary work in the late 1930s demonstrates that an outsider to the disciplinary establishments within science – but an outsider determined to follow a hunch – could make a seminal contribution to knowledge. In 1938, he published what was, in effect, the earliest detection and attribution study of anthropogenic global climate change, a conceptual framework which has been refined and exploited, particularly over the last twenty-five years. While Callendar's 'expert judgement' was called into question in the following two decades, the process of making judgements or collective assessments of knowledge and uncertainty remains an essential foundation of knowledge claims about climate change.

When significant amounts of funding *are* required to mount large-scale field measurements, opportunism often plays a part. Exploiting opportunities afforded by the Cold War and the 1957 International Geophysical Year, Roger Revelle and Charles Keeling were able to initiate (and then sustain), routine and accurate measurements of atmospheric carbon dioxide – measurements which have become a central piece of evidence for anthropogenic climate change. Developments in technology are also integrally bound up in the enterprise of science – for example, computational power and ice-coring techniques – and these have been especially important in explaining the emergent knowledge about climate change in recent years. Syukuro Manabe, for example, exploited new supercomputing technology in the mid-1970s to pioneer what has become a hegemonic role of models in the study of climate change; while Wally Broecker, in the late 1980s, used new evidence from deep ice cores to introduce a new conceptual paradigm for how we think about climate change.

The story told thus far leaves out the contributions to discourses about climate change which have come from the social sciences and humanities; it has focused largely on the privileged position that the natural sciences have acquired in shaping this story. We will see in later chapters why the economic, ethical, psychological and political dimensions of climate change are so challenging but, given the pre-eminent position that natural science still retains in climate change debates, we first need to enquire into the nature of such knowledge. How stable is scientific knowledge about climate change? How is such natural science research funded, and how is this research received by society? Do these knowledge claims travel well across disciplinary boundaries and between cultures? We need to investigate the idea that one of the reasons we disagree about climate change is because we disagree about the nature of scientific knowledge and its role in policy making.

FURTHER READING FOR CHAPTER 2

Flannery, T. (2006) **The weather makers: our changing climate and what it means for life on Earth.** Penguin: London.

Tim Flannery's book presents a racy, populist account of the emergence of climate change and the roles of various scientists and their ideas (as well as much else about the consequences of climate change and his preferred solutions). A good easy read, as long as you recognise the polemical nature of his writing.

Fleming, J.R. (1998) **Historical perspectives on climate change.** Oxford University Press: Oxford and New York.

The finest single account yet published of the various stages in the 'discovery' of the idea of anthropogenic climate change, starting with the Enlightenment and ending in the 1970s. There is a second 2005 edition in paperback.

Fleming, J.R. (2007) **The Callendar effect: the life and work of Guy Stewart Callendar (1898–1964).** American Meteorological Society: Boston, MA.

This is the first published biography of Guy Callendar and is a very readable account of his life and work, notably his prescient contributions to the ideas behind global warming: rising world temperature, rising concentrations of carbon dioxide, and infra-red sky radiation. It is also meticulously sourced and cites all of Callendar's published works.

Imbrie, J. and Imbrie, K.P. (1979) **Ice Ages: solving the mystery.** MacMillan: London.

A good introduction to the early nineteenth-century discovery and debates around the idea of Ice Age climates, although this would need supplementing with a more recent account of how our ideas about the Ice Ages have changed in the last thirty years.

Schneider, S.H. (1989) **Global warming: are we entering the greenhouse century?** Sierra Club Books: San Francisco, CA.

Steve Schneider has had one of the longest scientific careers in the field of climate change. This book is an interesting read, since it captures how the science and policy of anthropogenic climate change were understood in the late 1980s, just at the time that serious politicians first started taking an interest in the questions raised. The book covers science, politics and the media, written by someone who was at the centre of these debates then, as indeed he remains today.

Von Storch, H. and Stehr, N. (2006) Anthropogenic climate change: a reason for concern since the 18th century and earlier. **Geografiska Annaler** 88A(2), 107–13.

A reminder, if one were needed, that climate change did not start with the IPCC and the Kyoto Protocol. This short article makes the point crystal clear by citing briefly a variety of discourses about climate change from the seventeenth century through to the 1960s. The nineteenth-century Austrian geographer Eduard Brückner is used as an illustrative character in this story.

Weart, S.R. (2003) **The discovery of global warming.** Harvard University Press: Cambridge, MA.

Another careful account of the 'discovery' of the idea of anthropogenic climate change, with greater attention paid to the American contributions of the 1950s and 1960s. This is rather less assured than the account by Fleming, but has the added advantage of being accompanied by an extensive website – www.aip.org/history/climate/ – hosted by the American Institute of Physics, which allows more interactive investigation, and also a mammoth bibliography. There is a second, expanded, 2008 edition in paperback.

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Bailey, I. (2007) Neoliberalism, climate governance and the scalar politics of EU emissions trading. *Area* 39(4), 431–42.

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Index