On belief and reason

Why we should trust the projections of global warming by climate models

Tom Anderson

Many people accept that the threat of climate change is real and, furthermore, take an interest in the underlying science. There are, however, those who remain unconvinced by the projections of climate warming to the end of this century, as made by the big Earth System Models (ESMs) run on supercomputers. I am referring here to the general public, noting that the doubters also include a small number of out and out sceptics who specialise in trying to find ways to discredit the evidence. Along with co-authors Ed Hawkins and Phil Jones, I have recently published an open-access article in the journal *Endeavour,* that describes the scientific case as to why we should trust the projections of warming by climate models, written for a general audience. I will come back to the article later.

First, I would like to take the opportunity to ponder how we form and maintain beliefs (here, I mean beliefs as in general knowledge about the ways of the world rather than, for example, religious beliefs) and thereby show how easy it is, based on our world view and natural instincts, to be sceptical of global warming. I will argue that scepticism about climate science can arise from a number of sources including inability to directly experience or sense long-term warming, prejudice based on a world view that does not welcome bad news, and intuition which tells us that complex systems, such as global climate, should be inherently unpredictable. I should emphasise from the outset that, although over the years I have done a good deal of reading about general science and how science progresses, I am an ocean scientist and not a psychologist. The ideas I present are therefore entirely my own personal opinions.

The importance of experience

A scholar might tell us that we form and maintain beliefs by achieving understanding about how the world works, in which case it is the reasons, or explanations, for things being and happening that provide the foundation of knowledge. While scientists certainly think like this, I doubt whether this is how everyday beliefs are generated. Consider a simple example: caffeine is disruptive to sleep. The scientific explanation as to why this is so is that caffeine increases adrenaline production and blocks sleep-inducing chemicals such as adenosine and melatonin. This is not, I would say, the reason why we believe that caffeine impairs sleep. I myself have not consumed coffee or tea for more than ten years because of developing an allergy to caffeine. Has my sleep improved during this time? Yes. The simple reason I believe that caffeine disrupts sleep is that it accords with my own experiences: I sleep better without it. Beliefs are thus primarily shaped by experience, without recourse to reason, despite the fact that much of our knowledge comes from things we have been told by other people, read in books, etc.

Let me relate another example, that of weather forecasts, which are the result of simulations run on supercomputers. When the ever-smiling weather lady tells us that it is 'probably' going to rain tomorrow, we will likely cancel that picnic to the beach. The forecast is accepted as trustworthy even if we have little understanding of the processes of weather, how they are represented in computer simulations, and the resulting sources of error. Why? We find by experience that, time and time again, the weather forecast is more or less accurate and does not let us down. When it comes to climate models, however, there is no such experience. We might frazzle on the beach during our summer holiday and be told by meteorologists that 2016 is the hottest year on record, but for many of us it is just another hot day. We do not directly sense, or experience, long-term climate change in our daily lives. The scientists can, of course, show us graphs of rising CO_2 and global temperature but, again, these can only be accepted as meaningful information by appealing to reason.

Advertisers know how to convince us ...

Our world view of beliefs

The second factor that shapes beliefs, I suggest, is our world view, in other words our beliefs as a united whole, such as what we think is good and bad, right and wrong, etc. We live our lives within a world view that leads, usually unconsciously, to prejudice on many fronts. For example, I generally trust the medical profession, and if doctors tell me that caffeine disrupts sleep, or dentists tell me that drinking sugary drinks causes tooth decay, I am inclined to believe them. I am likewise inclined to believe that any number of drugs may have therapeutic effects although, again based on experience, I am suspicious of possible side-effects.

What would we do without modern medicines, electricity, cars, computers and smart phones? Science has provided us with many benefits and so, based on our experience of these developments, surely we should trust scientists and believe their messages about global warming. Many people do, of course, but others think otherwise. The source of information is important. Advertising agencies can entice you to buy any number of products, providing they are made sufficiently appealing in context of our world view of 'likes'. How about, for example, the prospect of a little 'pep and vigour' from eating vitamin donuts: 'each ... fortified with a minimum of 25 units [!] of vitamin B1'. When it comes to articles about health in the newspapers, any number of conflicting stories may be found. For example, the benefits and dangers of consuming alcohol may be presented interchangeably from one week to another. The media struggle to accurately communicate climate science. Sceptical arguments may be introduced to achieve 'balance' but the result is often, as I wrote in the *Endeavour* article, 'an emphasis on confusion and uncertainty when presenting the climate change debate'.

There are two other factors, that again relate to our world view, which exacerbate the situation: the bad news mindset and intuition. Starting with the former, nobody likes to hear bad news. It is curious that the pain of losses is usually greater than the joy of equivalent gains, a phenomenon known as 'loss aversion', as demonstrated by the renowned psychologist Daniel Kahneman. The distress caused by having to pay an extra thousand pounds in tax is, for example, more extreme than the joy experienced when winning the same amount on the lottery. The same idea is often seen in the sporting arena. The 'golden goal' was introduced into association football in the 1990s as a means of increasing the drama in matches that end up in extra time. The first goal scored after the regulation 90 minutes would provide a golden moment of ecstasy as the opposing team was eliminated in an instant. At least that was the idea. A more apt term for golden goal might be 'sudden death', with obvious negative connotations. Instead of playing for glory and going all out for the golden goal, most teams mired themselves in defence, terrified of a swift exit. The golden goal was abandoned in 2004.

An unfolding disaster is only reluctantly included as a belief within our world view, and then only if it is readily experienced, or if there are simple remedies at hand (in which case it is no longer bad news). We believe, for example, in the deadly consequences of cancer because most of us have met people who have suffered and died, as well as because of the images seen on TV. Climate change is bad news, but news that may be conveniently disregarded in day-to-day life. We can't experience it and, anyway, it is all too easy to adopt a mindset that it does not matter because it will not affect us any time soon. The people most likely to believe in climate change are, I suggest, those who have experienced disasters such as hurricanes or floods, the frequency of which may be increasing with global warming.

Simplicity within complexity

Intuition is subtle, oblique knowledge that aids in problem solving. We use intuition to try and know or understand something without recourse to rational explanation. It is hunches and gut feelings, again based on world view. Even Einstein once said, 'The really valuable thing is intuition'. For most people, I suggest, intuition tells us that it is hard to make predictions about complex systems because there are so many interacting parts. The climate system is one such example. How is it possible to make projections of global warming when there are a myriad of processes in the ocean, on land and in the atmosphere, including the water cycle, ice, vegetation growth, cloud formation, etc., and all

Termites are driven by simple cues, but what they build is far from simple

acting in concert with human influences, notably atmospheric emissions of CO_2? In order to answer this question, I will briefly delve into complexity science, a discipline that arose to prominence in the 1980s. Complex systems are defined as those with many parts whose interactions lead to emergent outcomes that cannot necessarily be envisaged straightforwardly from a knowledge of the parts in isolation. A classic example is provided by termite colonies which build mound-like nests that can reach 20 feet or more tall (*see above*), encasing an intricate network of tunnels and chambers. This sophisticated architecture is the result of the collective behaviour of millions of termites, behaviour which is driven by apparently simple rules but which may actually be rather subtle involving, for example, reactions to various pheromones (chemical messengers) that are excreted by the termites as they go about their business. Mathematical models of termite mounds have been developed, with some degree of success. I would nevertheless say that this is an example of a complex system where it is difficult to make reliable predictions on the basis of mathematics as a consequence of the subtlety of the rules involved – a common characteristic of biological systems. So why should modelling climate be any different?

Complexity does not, I argue, necessarily mean unpredictability. There is the paradox that despite the complexity of the world, the rules of nature are simple. Well, maybe not for biology (especially behavioural biology, as with the termites), but for physics and chemistry, yes. Physical laws mean that we are able to achieve remarkable feats such as the European Space Agency mission in which the *Rosetta* probe made a successful rendezvous with comet '67P/Churyumov-Gerasimenko', a journey of ten years and four billion miles. It is the case, I argue, that simple physics is present at the heart of the climate system. Whereas weather is unpredictable beyond a few days or weeks because of its chaotic nature, we can reliably predict that summer will be warmer than winter, a consequence of the tilt of the Earth on its axis and the resulting geographical changes in radiation balance as the seasons pass by. Projections of climate warming are, in similar fashion, influenced by CO_2 in the atmosphere and its influence on radiative transfer. As the Intergovernmental Panel on Climate Change (IPCC) stated in its 2007 report:

Projections of future climate are shaped by fundamental changes in heat energy in the Earth system, in particular the increasing intensity of the greenhouse effect that traps heat near the Earth's surface, determined by the amount of carbon dioxide and other greenhouse gases in the atmosphere. Projecting changes in climate due to changes in greenhouse gases 50 years from now is a very different and much more easily solved problem than forecasting weather patterns just weeks from now.

I return to this theme, namely simplicity at the core of the climate system, later.

Prejudice and probability

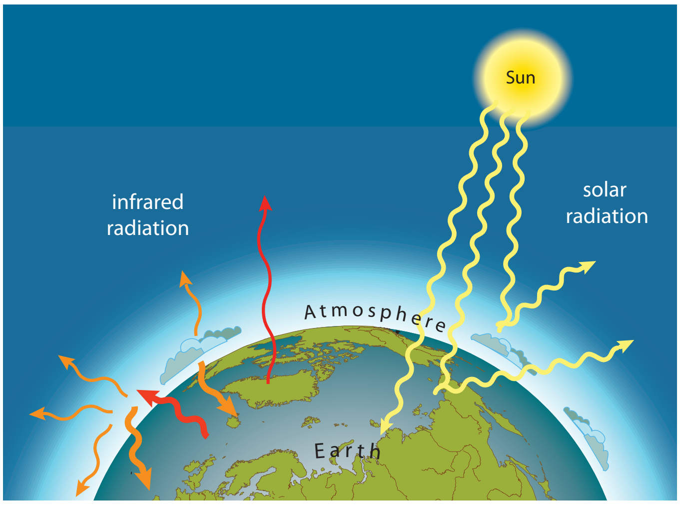
Before coming to the *Endeavour* article, I would like to illustrate just how easily we are prejudiced by our world view by comparing three uses of the word 'probably'. First, think back to the weather lady saying that it will 'probably' rain tomorrow, and how readily we believe this. Compare this with the statement made by the IPCC in their 2007 report that temperatures are 'probably' going to increase by between 1.8 and 4 °C by the end of the century. A similar statement is made in the 2013 IPCC report, namely that temperature increase will 'likely' exceed 1.5 °C. Yet, in complete contrast to our acceptance of the weather forecast, many apparently play down 'probably' and 'likely' in these instances and say it is not enough to warrant belief. Simple negative prejudice.

My final example is colloquial (rather than statistical) in nature and involves the unfortunate death of Mr Alexander Litvinenko by poisoning with radioactive polonium. On 20 January last year, Sir Robert Owen remarked: 'I have further concluded that the FSB operation to kill Mr Litvinenko was probably approved by Mr Patrushev, then head of the FSB, and also by President Putin.' That word 'probably' again, implying that the conclusion is consistent with the evidence, but without definite proof. While not wanting to make any judgement here, I reckon that many in the UK think it almost certainly the case that the statement is true, while doubtless the Russian public have no such belief given that the Russian media turned on the word 'probably' to discredit the statement as having insufficient basis in fact. This example again serves to show just how easily the communication of information is distorted by our world view of beliefs.

Why we should trust the projections of climate models

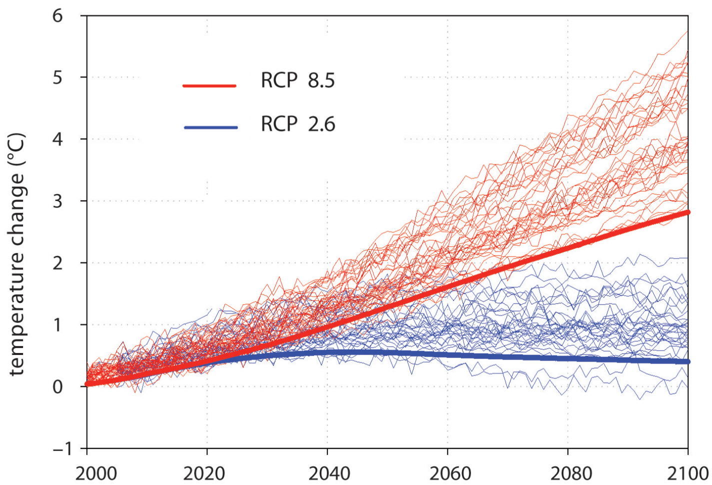
Thus, I arrive at the finale: a summary of my thesis, as presented in the *Endeavour* article, as to why we should trust the projections of 21st century global warming by climate models. I am left with no alternative but to present the case by appealing to reason. Let me start by describing the well-known 'greenhouse effect'. Solar radiation passes through the atmosphere largely unhindered, warming the surface of the Earth. Energy is in turn re-emitted as infrared radiation (heat) which is absorbed by, and warms, the atmosphere. Most gases in the atmosphere, including oxygen and nitrogen, do not absorb infrared, but carbon dioxide (CO_2) does, as well as water vapour. Carbon dioxide is of course produced by the burning of oil, coal and gas and is increasing year-on-year in the atmosphere. And so the atmosphere traps more infrared radiation and, acting like a blanket, causes the Earth to heat up. This connection between CO_2 and anthropogenic warming was first made by Guy Stewart Callendar, a British steam engineer working in the 1930s. Callendar constructed a simple model of the radiation balance of the Earth and how it is influenced by atmospheric CO_2. The model might appear complex in that it had to take account of the seasonal variations in sunlight, pathways of radiation at different latitudes, reflectance of sunlight from clouds and ice, and heating within the atmosphere. In fact, however, this is all relatively straightforward physics and chemistry. I along with my co-authors formulated an empirical (mathematical) approximation of Callendar's model and, using observations of atmospheric CO_2, showed that the model successfully predicts the warming that was observed during the 20th century. Why is it successful? Because, as I argue above, simplicity exists within the complexity of the climate system, namely the physics of the greenhouse effect, as influenced by the concentration of CO_2 in the atmosphere.

Ah, I hear the doubters say, but what about the climate feedbacks? These include melting of snow and ice, water vapour, changes in ocean stratification and changes in clouds. Climate feedbacks were not included in Callendar's model, with the exception of water vapour, and it would therefore appear that they were relatively unimportant during the 20th century given the successful prediction of warming using Callendar's model. This need not, however, be the case in future. We used the empirical approximation to Callendar's model again, but this time making projections of warming to the end of the 21st century (*see left*). Results are shown for two different CO_2 emissions scenarios, Representative Concentration Pathways (RCPs) 2.6 (low CO_2 emissions) and 8.5 (high CO_2 emissions), and are compared with the projections of an ensemble of climate models. These Earth System Models include not only the radiative transfer of the greenhouse effect, as in Callendar's model, but also a suite of climate feedbacks. The outcome: the projections of Callendar's model (the thick lines in the plot) are at the lower end of those of the ESMs. The explanation is straightforward. The simple physics and chemistry of the greenhouse effect, as represented in Callendar's model, give rise to quantitatively reliable baseline warming. The feedbacks add extra warming. There is uncertainty in the magnitude of the extra warming, but not in the sign:



The 'greenhouse effect'
The radiative balance between incoming solar radiation (yellow arrows) and the absorption of re-emitted infrared radiation by the atmosphere (orange and red arrows) drive surface heating

Intercomparison of 21st century projections of Earth temperature from an ensemble of Earth System Models, for Representative Concentration Pathways (RCPs) 2.6 (low CO_2 emissions; blue) and 8.5 (high CO_2 emissions; red) scenarios (thin lines), with projections based on Callendar's model superimposed (thick lines). The RCP numbers correspond to radiative forcings in 2100 relative to the pre-industrial state, i.e. +2.6, +8.5 W m^{-2}.



Reproduced with permission from Anderson et al. (2016). See Further Reading positive, namely amplification of warming. Why should we believe that the feedbacks are positive? Heating causes melting of snow and ice meaning less sunlight is reflected back to space (if you've ever been out in the mountains in snow, you will know how bright that reflection is), thereby warming the Earth's surface. A warmer atmosphere holds more water vapour (it is why condensation appears when warm air is cooled on your car windscreen) and the water vapour in turn absorbs and re-emits infrared radiation, causing warming. You can see I am trying to promote reason by appealing to your experiences. Warming increases ocean stratification, resulting in less exchange between surface and deep waters and less uptake of CO_2 from the atmosphere. The stratification also reduces nutrient supply to the ocean surface, decreasing the 'biological pump' whereby phytoplankton growth leads to the production of particulate organic carbon that sinks into the deep ocean. Well, all I can say about our knowledge of these ocean feedbacks is that it is based on fundamentally sound principles accruing from decades of high quality research. At some point, we have to trust the scientists, at least in part, because science has been so successful in the past. There are other feedbacks also, notably those associated with clouds, that can act in either direction, positive or negative. There are uncertainties. Overall, however, the case that the combined action of climate feedbacks will be to amplify warming (over the baseline warming, as projected by Callendar's model) is overwhelming.

I finish by quoting directly from the *Endeavour* article:

The projections of end-of-century global warming by ESMs are fundamentally trustworthy: quantitatively robust baseline warming based on the well understood physics of radiative transfer, with extra warming due to climate feedbacks. These projections thus provide a compelling case that global climate will continue to undergo significant warming in response to ongoing emissions of CO_2 and other greenhouse gases to the atmosphere.

Further reading

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Another telling of the inconvenient truth

'Before the Flood' is a documentary directed by Fisher Stevens and starring Leonardo DiCaprio. It was released in October 2016 and is available online.* In the film, Leonardo DiCaprio rings the alarm bell on climate change, using Hieronymus Bosch's allegorical painting, *The Garden of Earthly Delights*. The issue of climate change is one we've been aware of for some time now, but can a film by a Hollywood movie star cause a dramatic change in how we address this challenge?

A decade or so on from Al Gore's 'An Inconvenient Truth', this movie similarly aims to increase public engagement in the subject. To paraphrase DiCaprio, if you give people the data, you empower them. The narrative is clear, and highlights climate change as the global challenge it is – a challenge greater than individuals and countries can address independently, and impacting most on those who contributed the least to the problem. This is, however, where similarities between the two movies end: 'Before the Flood' is a fast-paced, high-drama movie. As might be considered typical of visual media today, it races along with flashing images, spectacular scenery and suspenseful music, but the 1½ hour run-time still made it feel a little too long.

Exploiting his role as UN Messenger of Peace, Leonardo DiCaprio calls in a stream of A-list friends to help deliver his message, including Barrack Obama, Elon Musk and Pope Francis. The movie is packed with information on issues and potential solutions, from the impact of cattle-rearing and what we eat, to our electricity-hungry society and 'gigafactories', and latency in policy making and who we choose as our political leaders. Only the narrative on the palm oil industry felt like distraction from these main issues, and came to what seemed a dead end. Honouring its by-line, *'The science is clear. The future is not',* the film does not spend a great amount of time presenting the scientific evidence or details. As a scientist, I still found it interesting viewing, particularly the socio-economic and political aspects of the climate change challenge. Personal highlights included the amazing demo of the NASA 'Hyperwall' (if you find the opportunity to see it in real life, do – It is even more brilliant), and the insight provided by Michael E. Mann on how a single graph could change your career and have a dramatic influence on your personal life.

As scientists, we can fall in the trap of 'doom and gloom thinking', and the movie's overall message remains hopeful. It suggests both small changes individuals can make to their life styles (eat less red meat, for example), and larger ones which will require buy-in at all levels of society across the globe, and a great political drive (including implementing carbon taxes). We are 'humankind before the flood', and this is a renewed call to action.

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Marine Scotland Science

Find out more about 'Before the Flood', including how to stream online, by visiting https://www.beforetheflood.com/