TEN THINGS EVERYONE SHOULD KNOW ABOUT CLIMATE MODELS

Andrew Montford

With a foreword by Steve Baker MP

The Global Warming Policy Foundation
Note 32

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About the author

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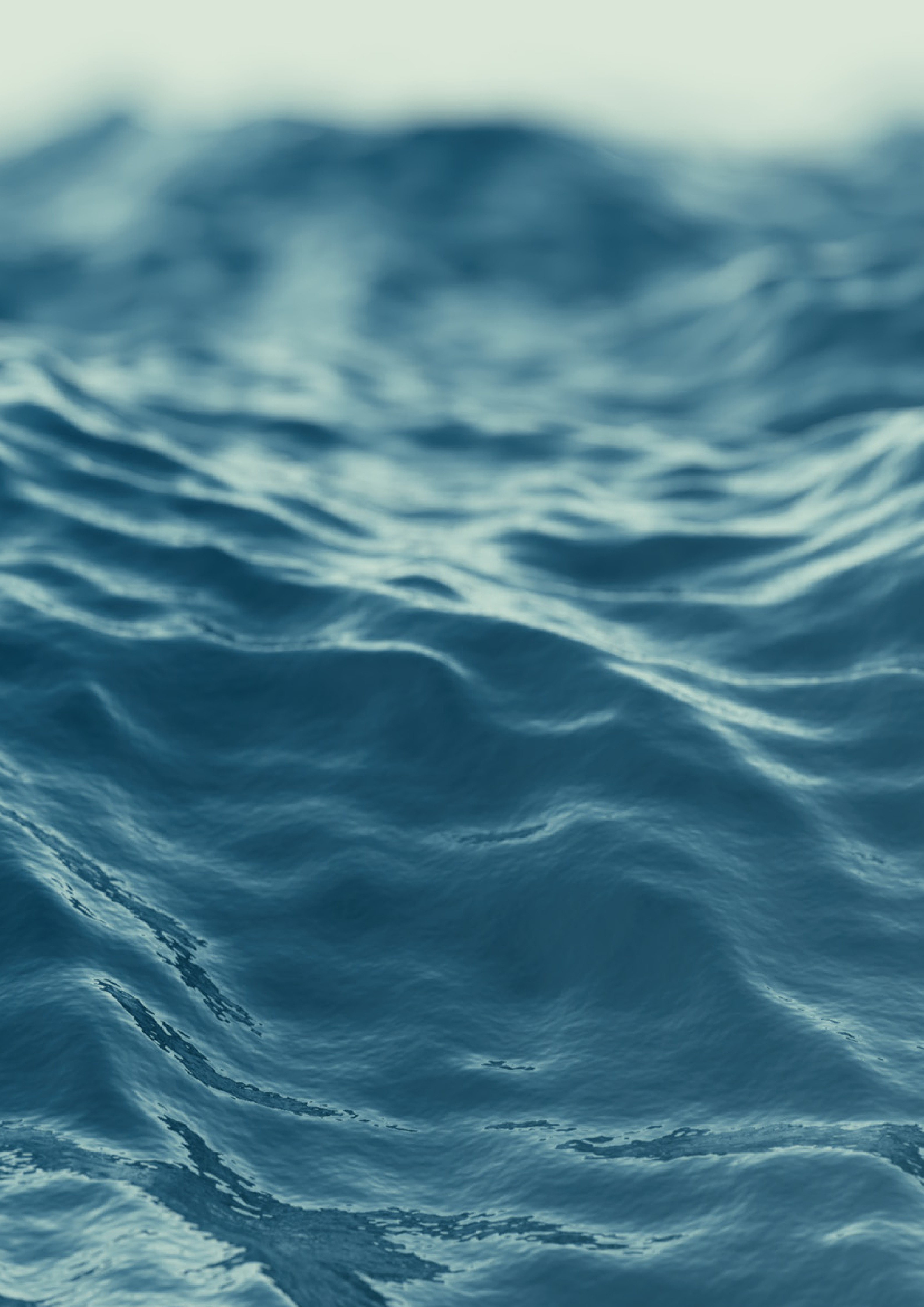

Foreword

By Steve Baker MP

Before I became an MP, I was a Royal Air Force engineer officer, working on airworthiness. Following that, I completed an MSc in computer science and had a career in software engineering. As a result, I have a keen interest in software, critical systems and risk management: that is, how we decide what to do when in jeopardy.

Airworthiness engineering is a serious business, and safety critical software engineering is exceptionally rigorous. However, there's a growing awareness that things are often rather different in academia. What goes on in university laboratories may often be of little interest outside the ivory tower, so it's perhaps unsurprising that the approach of scientists to software engineering is a little different to what happens in wider world. Why go to the trouble of documenting your computer code if nobody is ever going to look at it? Why use unit testing or a comprehensive version control system to manage development? Coding standards? Pah! An experimental approach is often taken, with code written and rewritten in a voyage of discovery, usually with little or no documentation, and no validation, rigorous or otherwise. Huge blocks of code may be found commented out without explanation. It is not software engineering; it is hacking, unfit for a good hobbyist.

Hacking may be fine if computer code genuinely has no impact beyond the laboratory, but with ministers increasingly looking to university researchers to provide support and justification for their policies – or even to substantially direct policy – with the most profound impact on our liberty and prosperity, such unprofessional standards can no longer be tolerated.

We have seen the implications during the Covid pandemic. The computer simulations offered by the Government's scientific advisers have been widely criticised, both for the poor quality of their code and the wild divergence of their predictions from subsequent reality. We are still assessing the full collateral cost of inaccurate models deployed to inspire and justify lockdowns.

In the long-term, climate models may be even more impactful. The Net Zero target in place, largely following from climate model predictions about what the future may hold, has implications for every human being on the planet alive today and for billions as yet unborn. If we get this wrong, humanity as a whole, now and in the future, will suffer the consequences. The situation could scarcely be more serious.

Yet there is every sign that climate models are just as error strewn and just as badly coded as many of the Covid models. There have long been signs that climate model predictions are diverging from reality and things don't seem to be getting better. A recent article in *Nature* suggests that many of the most up-to-date models are entirely incompatible with observational records. But it also points out that they are being used to inform impact studies and environmental policy regardless.

Andrew Montford's paper is therefore timely. It sets out, in an accessible way, some of the issues that afflict climate modelling, giving the public a sense of where we might be going wrong. It is hard to read it without concluding we need to think again, with exceptional care, before accepting computer simulations – of climate, or of anything else – as a guide to good policy.

Demand for climate policy rests largely on climate models

It is widely thought that the climate is changing in a significant way. Views like this are commonly expressed as the idea that the weather has been unusual, often alongside some reference to extreme weather events. However, the climate changes all the time and so it is difficult to say with any confidence that any recent trends are anything out of the ordinary.

Because of this, climatologists have to rely on computer simulations in order to try to understand whether human carbon dioxide emissions are having a discernable effect and to predict what might happen in the future.

These simulations, with names like global climate models or Earth system models,[1] hereafter 'climate models', are therefore central to the policymaking process. All claims that the climate is doing something out of the ordinary and that it will do bad things in the future are only as reliable as the climate models behind them. It is therefore important that policymakers understand climate models' weaknesses, as well as their much-trumpeted strengths.

Climate models are very complex

Since the first simulations of the climate were developed, climate models have become vastly more sophisticated, incorporating more and more aspects of the ocean–atmosphere system. They are now immensely complex, typically incorporating of the order of a million lines of computer code. They bring in what scientists understand to be the key components of the climate system: the continents, the oceans, the atmosphere, heat from the sun and so on. The surface of the virtual Earth of the computer model is divided into a grid, above which a column of the atmosphere rises and, for ocean squares, below which a column of seawater descends. In each of these columns, the changing climate has to be calculated using complex mathematics, with each of the components of the climate system and their interactions worked out.

This is no simple task, and it is a remarkable scientific achievement to have brought the computer models to the stage at which their output looks approximately like the real climate: in the virtual planets inside the climate models, cyclones form in the tropics and move polewards just as in the real Earth. However, although there are, say, monsoons in climate models, they can still get nitty-gritty details – say the direction of the winds that bring the short rains to East Africa (!)[2] – back to front.

1 These are distinct concepts. Earth system models incorporate interactions between the ocean-atmosphere system and the biosphere, whereas global climate models do not.

2 Hirons L and Turner A (2018). 'The impact of Indian Ocean mean-state biases in climate models on the representation of the East African short rains'. *Journal of Climate*, 31(16): 6611--6631.

This superficial resemblance to the real Earth does not, however, demonstrate that the models are valid representations of the real climate. Indeed, it is generally accepted by those who study simulation that a simple model is preferable to a complex one. As some have observed, the choice of the correct level of complexity depends on a detailed understanding of the system,[3] which climate modellers do not have.

Climate models are not complex enough

Despite their extraordinary complexity, climate models may not be complex enough. The grid squares on a climate model might be 50 km across. It is possible to calculate some aspects of the climate system at this scale from basic physical principles and, indeed, prominent scientists are keen to state that climate models are derived from basic physics. However, for some components of the climate system the physics involved takes place at scales that are too small to deal with in this way. For example, the greenhouse effect takes place at atomic scales; clouds, plants and many features of the landscape are more likely to be measured in metres or centimetres rather than kilometres. The Met Office's HadCM3 model's grid size essentially misses most of the Andes because that mountain range is too narrow to be represented,[4] raising obvious question marks over the validity of its predictions for South America's climate. For many parts of the climate system it is therefore only possible to work with an average figure for the grid square. This introduces major uncertainties, since it is impossible to know whether these so-called "parameterisations" remain valid as the climate changes. One recent paper found that if you altered the order in which the parameterisations were calculated in a climate model, you ended up with profoundly different answers.[5] Which order is right is anyone's guess.

In addition, there are numerous factors that scientists have identified as potential influences upon the climate but where the magnitude of the effect, if any, has yet to be determined. There are many examples, but to consider just one, a 2013 NASA workshop heard how some types of ultraviolet radiation from the sun could vary in intensity by an order of magnitude over time. Ultraviolet affects the chemistry and hence the physics of the atmosphere,[6] but what, if anything, this variation means for the climate is unclear and we are similarly ignorant of what any of these 'known unknowns' might mean. The

3 Chwif L and Paul RJ. On simulation model complexity. http://www.simul8.com/support/newsletter/chwif.pdf.

4 Smith L, The user made me do it: Seamless forecasts, higher hemlines and credible computation. Available at: http://www.eas.gatech.edu/sites/default/files/SmithTalkGT.pdf. Smith notes that the Andes land surface in the simulation is as much as two kilometres lower than in the real mountains.

5 Donahue A and Caldwell M (2018) Impact of physics parameterization ordering in a global atmosphere model. *Journal of Advances in Modeling Earth Systems;* 10: 481–499.

6 The discussion referred to 'extreme ultraviolet radiation', rather than UV per se. See 'Solar variability and terrestrial climate'. NASA Science News, 8 January 2013. http://science.nasa.gov/science-news/science-at-nasa/2013/08jan_sunclimate/.

point that there are almost certainly also 'unknown unknowns' need hardly be made.

These gaps and simplifications in the climate model mean that it is not possible to accept them as valid representations of the climate system that can provide robust predictions about how the Earth will respond to anthropogenic carbon emissions.

Climate models are tuned, climate models are fudged

Perhaps it is because of the complexity, or perhaps because of our relative lack of knowledge of the climate system, but when climate models are put together they rarely perform in a realistic manner, with too much or too little heat being retained by the virtual atmosphere. This results in the virtual temperatures rapidly drifting away from the observed ones.

In order to address this problem, climate models are 'tuned' – in other words some of the parameterisations are arbitrarily adjusted – so as to make the model warm at a more realistic rate.[7,8] An example would be to adjust the way clouds are represented in the model. Clouds are one of the great areas of uncertainty in the climate system, so many of the possible parameterisations are plausible. Different combinations of input values could give a virtual global temperature record similar to the real one, but completely different estimates of future warming.[9] Which climate future is the real one is, again, anyone's guess, and is therefore possible to simply pick the one that gives a desired answer.

The ability to tune the output in this way gives climatologists a 'fudge factor' and makes claims that climate models are 'based on fundamental physics' rather hollow. At best they are 'largely' based on physics.

Another fudge factor is the cooling effect of atmospheric pollution – so-called 'aerosols'. It has been noted that climate models that have high temperature sensitivity to carbon dioxide also have high estimates of the cooling effects of aerosols. Estimates for low-sensitivity models are lower. This means that both high- and low-sensitivity models can reproduce recent temperature history, but it is clear that the pollution estimates are being determined by the required answer rather than being derived from observations or from physics.

Climate models get the temperature of the Earth wrong

Although climatologists are able to fudge their way to the correct rate of warming, they get the temperature of the Earth wrong. This is

7 Mauritsen T, et al. "Tuning the climate of a global model." Journal of Advances in Modeling Earth Systems 4.3 (2012).

8 Voosen P (2016) "Climate scientists open up their black boxes to scrutiny". *Science*; 354(6311): 401--402.

9 Zhao M, et al. (2106) "Uncertainty in model climate sensitivity traced to representations of cumulus precipitation microphysics". Journal of Climate, 29, 543–560.

perhaps unsurprising, because, among other things, they get the amount of solar energy hitting the Earth's surface badly wrong.[10]

The global surface temperature records and the climate model outputs are expressed as anomalies from a long-term average rather than as the simple temperature. However, this manner of presentation hides the important fact that the virtual temperature in climate model outputs varies considerably – by as much as 3°C.[11] Clearly they cannot all be right, and the impact for those that are wrong is significant because many important climate processes are temperature dependent. One example is the amount of heat reflected from the polar ice caps, which depends on the area of ice, something that will vary significantly if temperature changes by 3°C.

It is often argued that despite such difficulties, climate models have still been able to reproduce the twentieth century temperature history. However, many of the latest generation of models produce climate histories that are entirely incompatible with the observations.[12] Moreover, as noted above, because of the availability of various 'fudge factors' even when they appear to perform well, it may be misleading. The true test of a computer model's reliability is its predictive ability and here the climate models do badly, with the observed surface temperatures frequently on the cusp of falling outside the range of temperature predictions deemed 'likely' by the IPCC, and predictions for higher levels of the atmosphere performing even worse.

Climate models get many other things wrong too

Climate models haven't just got the surface temperatures wrong. There are many other features of the climate system that are incorrectly simulated. Some climatologists have suggested that the failure to get the surface temperatures correct is because the real-world climate is transporting heat to the deep oceans, an explanation which, even if correct, suggests that a major climate subsystem is not being correctly captured.

Climate models predict that the stratosphere should cool as the surface warms, but in fact the only cooling observed has been in the wake of volcanic eruptions. Between times, the stratosphere has been warming. The situation is just as bad in the troposphere, where climate models predict a rapid warming that has in practice not materialised.

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10 The average error is about 7 Wm^{-2}, while the energy imbalance that is said to be causing global warming is only 0.5–1 Wm^{-2}. See Wild M, et al. (2015) 'The energy balance over land and oceans: an assessment based on direct observations and CMIP5 climate models'. *Climate Dynamics*, 44: 3393–3429, who say that this is a 'long-standing issue in climate modeling'.

11 See IPPC WGI, AR5 Chapter 9, Figure 9.8.

12 Z Hausfather et al. (2022) 'Climate simulations: recognize the "hot model" problem'. *Nature*, 4 May.

If climate models are bad at temperature predictions, they are even worse at rainfall. Even the IPCC describes their ability as only 'modest', while others have said they are 'useless', noting that their predictive abilities are even worse than a naive forecast based on extrapolating the long-term mean.

Because climate models tend to be tuned to a global average of some kind, they appear able to 'hindcast' recent temperature history. However, when their output is compared at a more detailed level it becomes clear that the use of an average is disguising many biases and errors. No climate model has proven able to provide skillful predictions of climate at a regional level.

Climate models do not conserve energy

It is a fundamental physical principle that energy should be conserved – in other words that the total energy of a system should remain constant. So once a climate model has reached equilibrium, the heat arriving from the virtual sun into the virtual atmosphere should equal the heat leaving. However, it has been observed that the most up-to-date climate models tend to reach equilibrium when the two figures are not equal. In most of these virtual worlds the heat arriving at equilibrium is greater than the heat leaving, indicating that some of this heat is being 'lost' and thus a fundamental physical principle is being breached.[13] This raises enormous doubts over the validity of climate model predictions.

Climate models can't predict the future

The problems noted in earlier parts of this paper should convince the reader that, for the moment at least, computer models are incapable of saying much about the future climate. The IPCC acknowledges this in part, noting that predicting the future state of the climate at any point in the future is not possible even in theory because the climate is a chaotic system. They suggest that the focus should instead be on predicting a range of possible future climates and assigning probabilities to each. However, the experience of the last two decades suggests that even the wide range of possibilities predicted by the climate models is not wide enough and tends to incorporate far too much global warming and not nearly enough natural variability.

Everyone knows that climate models are failing, but no-one will say

The inadequacies of climate models are well-recognised within the field. But as Leonard Smith, a prominent (mainstream) researcher noted, their output is nevertheless being sold to

13 Mauritzen T et al. (2012) 'Tuning the climate of a global model'. *Journal of Advances in Modeling Earth Systems*; 4: M00A01.

policymakers as if it were adequate to support decision-making, with the contents expressed in terms that allow for 'plausible deniability'.[14] Moreover, according to Smith, a joint statement of support for climate models by a group of learned societies was cancelled once those involved in its drafting learned of how systematic errors were being hidden by the presentation of the results as anomalies.[15]

In the famous words of the statistician George Box, all models are wrong, but some are useful. This saying, frequently repeated by climatologists, is undoubtedly true, but does rather beg the question of what precisely they are useful for. Climatologists have no choice except to use computer models to try to understand the way the Earth works, so for this purpose they are not only useful, but in fact essential. Their relevance to the policy arena however is far from clear. Policymakers are often misled into thinking that climate models are providing robust predictions about the future. The less reputable scientists, often in positions of responsibility, point to the match between twentieth century temperatures and the climate models to emphasise their case.

It is only once the degree of tuning and fudging and the simultaneous failure to match other climate indicators and the wholesale failure out of sample is seen that it is possible to understand just how misleading this is.

Climate models are causing harm

Despite the many failings of climate models, their predictions continue to be accepted as valid by politicians. Policymakers are using climate model output as a justification for decisions that have immediate and appalling consequences for the developing world and can only be justified as necessary evils; unfortunate steps that are necessary as a way to avoid the still greater evil of climate change. One example is the decision in 2007 to divert a significant proportion of the world's crops to biofuels, which caused widespread hunger in poor countries and was, in the words of one UN official 'a crime against humanity'. Another is the decisions by the UK and US to end overseas aid for projects to develop fossil-fuelled power stations, depriving some of the world's poorest of access to energy and condemning them to cook on open hearths, something that is known to cause widespread premature death.

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14 Smith L, 'The user made me do it: Seamless forecasts, higher hemlines and credible computation'. Available at: http://www.eas.gatech.edu/sites/default/files/SmithTalkGT.pdf. 'Information we are supplying which is not 'adequate for purpose' is being interpreted as if it was. "Plausibile Deniability" [sic] seems a poor aim to me.'

15 The source is Smith's talk again. 'At least one united (multi-society) statement of support are failed to appear due to learning the systematic errors "masked" when anomalies are plotted.'

About the Global Warming Policy Foundation

People are naturally concerned about the environment, and want to see policies that protect it, while enhancing human wellbeing; policies that don't hurt, but help.

The Global Warming Policy Foundation (GWPF) is committed to the search for practical policies. Our aim is to raise standards in learning and understanding through rigorous research and analysis, to help inform a balanced debate amongst the interested public and decision-makers. We aim to create an educational platform on which common ground can be established, helping to overcome polarisation and partisanship. We aim to promote a culture of debate, respect, and a hunger for knowledge.

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